THE INTERNATIONAL REVIEW OF WEATHER, CLIMATE AND HYDROLOGY TECHNOLOGIES AND SERVICES

Meteorological TECHNOLOGY INTERNATIONAL

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CUBESATS

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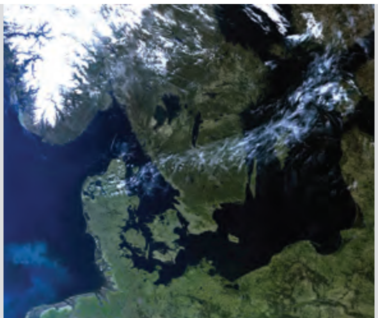
DROUGHT

How modern rainfall prediction and measurement technologies can help minimize the global impact of drought



EUMETSAT

The intergovernmental organization looks to the future following the successful launch of its final Copernicus Sentinel satellite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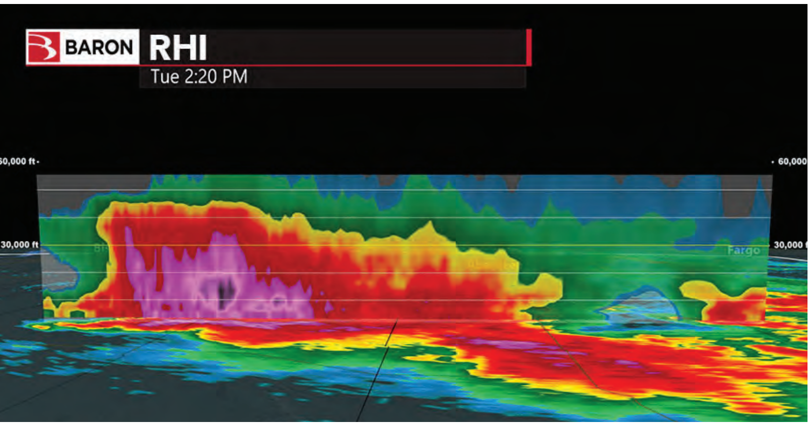
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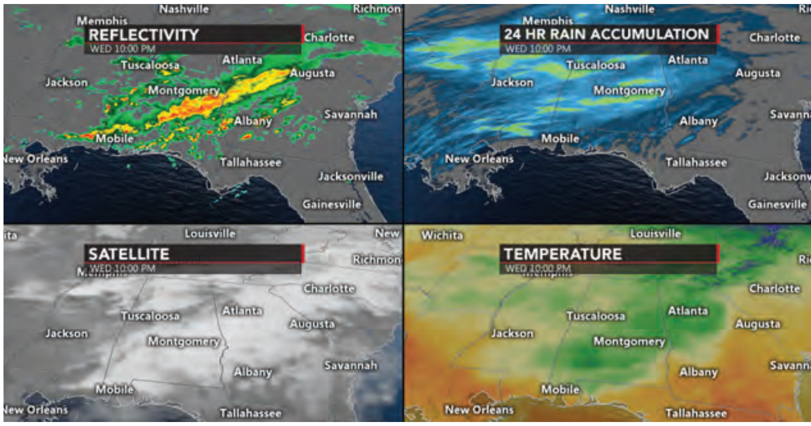
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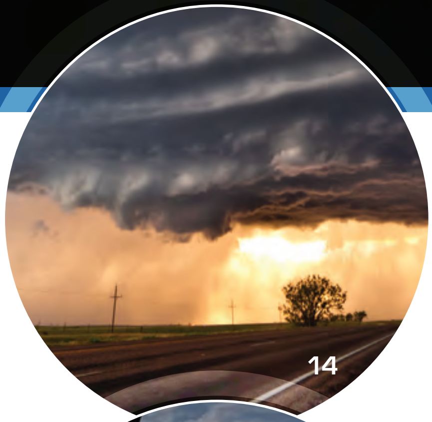

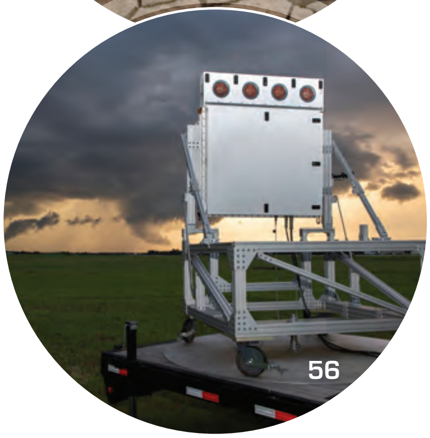


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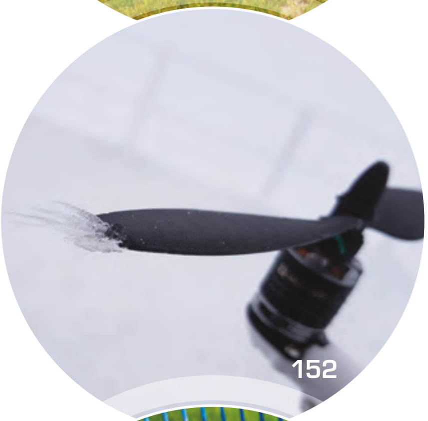
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Welcome to *Meteorological Technology International*, the only review of weather, oceanic prediction, measurement and analysis technology

Putting together the content for this year's Meteorological Technology World Expo preview was no easy task. This was not because it was hard to track down information. It was purely because there are so many different aspects to this year's event, which is being held on October 9-11 in Amsterdam, Netherlands. The show really is crammed full of exciting stuff to get stuck into.

The exhibition alone will host around 200 exhibitors, each displaying the latest in meteorological forecasting instrumentation. Alongside this, the show will host the hugely popular and insightful CIMO TECO-2018 conference, which has around 50 key presentations and a further 170+ papers available for attendees to read. Discussions will cover everything from the evaluation of existing weather sensors in the Netherlands and remote measurements of volcanic plume electrification using a sparse network technique, to operational early warning systems in Brazil and crowdsourced data in Norway.

And that's just the start of what's going on. The event is also hosting a workshop by the Global Weather Enterprise on how to ensure that everybody has access to high-quality weather information, and the International Forum of Users of Satellite Data Telecommunication will host Satcom 2018. There will be technology-led workshops from some of the industry's leading suppliers, including Leosphere, Metek and Stevens Water. There will also be two drinks receptions to give visitors the chance to network and take stock of everything they have learned during the day.

To help you plan for this year's event, *Meteorological Technology International* has put together a comprehensive event preview, which includes information on product launches, first-time exhibitors, dates for the must-attend conference sessions and workshops, and those all-important drinks receptions! Turn to page 66 to start planning your time at the event.

As this year's expo is being held in Amsterdam, we took the opportunity to speak with the director general of the Royal Netherlands Meteorological Institute (KNMI), Dr Gerard van der Steenhoven. Experts from KNMI will be discussing a number of the institute's key projects during CIMO TECO-2018, including the specification and evaluation of present weather sensors, experiences with quality evaluation of AMDAR observations, and operational use of aircraft-derived data for meteorology and other applications. Turn to page 20 to find out more about these presentations and current developments being undertaken at KNMI.

Van der Steenhoven believes that one of the main challenges facing the industry at the moment is data collection and integration. "Nowadays, data is emerging everywhere. Every car and smartphone can be a source of meteorological data. To serve society, we need to get access to all this data and bring it to advanced computing clusters," he says.

Data integration is one of the key issues being addressed at this year's CIMO TECO-2018 event, along with how the public and private sector can work better together to improve weather prediction. To find out more about other issues and trends being discussed at the conference, visit www.wmocimo.net and click on the program tab to view the agenda. I look forward to seeing you in Amsterdam in October!

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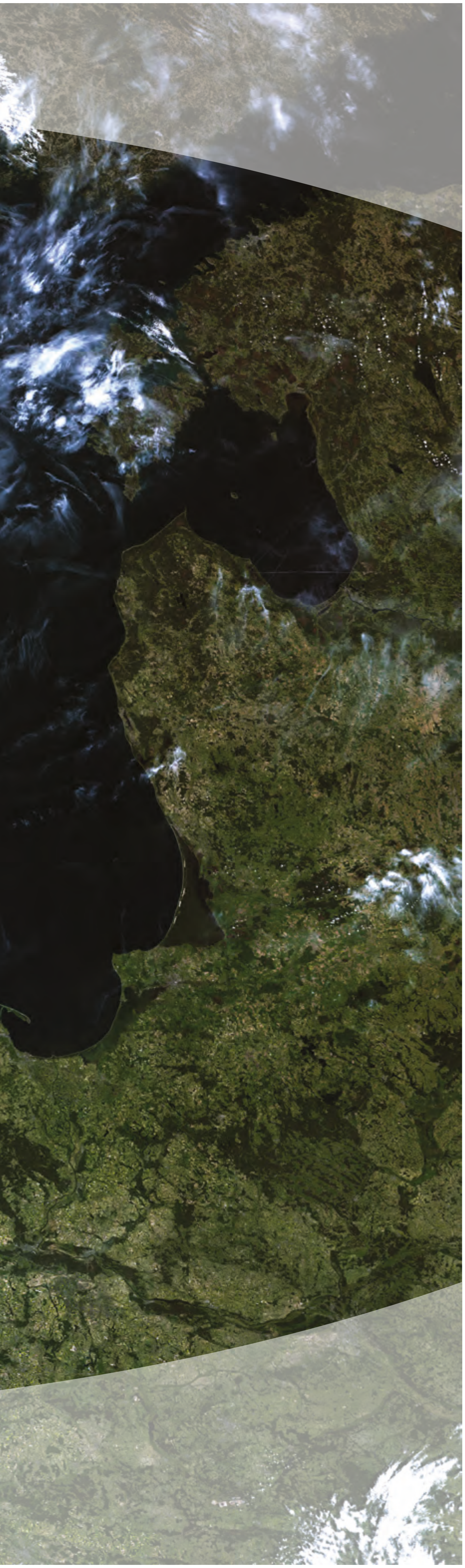
Sean Burns, head, Real-time Services and Systems Operations Division, EUMETSAT

VIEW FROM ABOVE

EUMETSAT looks to the future of European meteorological satellite systems



One of the first images after the launch of Sentinel-3B. The Ocean and Land Colour Instrument captures a rare, cloud-free day over Northern Europe. Features over the land and water can be clearly seen, including differing types of land cover, such as snow cover, and phytoplankton in the North Sea

EUMETSAT operates a complex network of meteorological satellite systems around the clock and delivers real-time data streams to users. As the organization enters a crucial phase in advancing its operational capabilities, Sean Burns, head of the Real-time Services and Systems Operations Division at EUMETSAT, discusses the challenges of integrating new satellites into operational systems and disseminating the data as quickly and efficiently as possible.

WHAT IS EUMETSAT WORKING ON?

Last year, we completed the re-positioning of all of our Meteosat Second Generation (MSG) satellites after the launch and commissioning of the final MSG spacecraft in 2015. We have Meteosat-11 at 0º; Meteosat-10 at 9.5º East, which is performing what we call rapid scanning over Europe; then Meteosat-8 over the Indian Ocean at 41.5º East; and Meteosat-9 is in orbit but spare. So now the second generation is complete, we're waiting for the third generation (MTG), with the first satellite set to be launched in 2021.

We also have the Sentinel program, with the recent launch of Sentinel-3B to join the existing Sentinel-3A satellite. It's just reached the tandem phase, so it's flying 30 seconds behind Sentinel-3A to calibrate the instrumentation. The satellites will then move so that they are half an orbit apart, and that will provide full coverage of Earth, twice as often as you'd have with Sentinel-3A.

HAS SENTINEL-3B MET EXPECTATIONS?

Everything's looking good and we haven't discovered any problems so far. We're just checking the instruments, performing the calibrations, and starting the production of what we call the Level 1 and 2 products.

HOW ARE THE SATELLITES IMPROVING WEATHER OBSERVATIONS?

Meteosats, which take images every 15 minutes, and in the case of the rapid scanning service, every five minutes, are really used for nowcasting. From these images, our systems can derive atmospheric motion vectors products providing information on local windspeed, direction and altitude, which are used by global weather models for real-time forecasting.

Our polar-orbiting Metop satellites have brought meteorological observations to a new standard and have significantly improved numerical weather forecasts and climate monitoring.

Studies show that Metop-A and -B, the two Metops currently in orbit, contribute 27% of the error reduction in weather forecasts attributed to all sources of real-time observations. This will increase further after the launch of Metop-C later this year.

The dual-satellite Sentinel-3 mission will provide full and frequent global coverage of ocean color, sea surface temperature and altimetry measurements.

HOW HAVE YOU IMPROVED THE DARMSTADT HQ CONTROL ROOM?

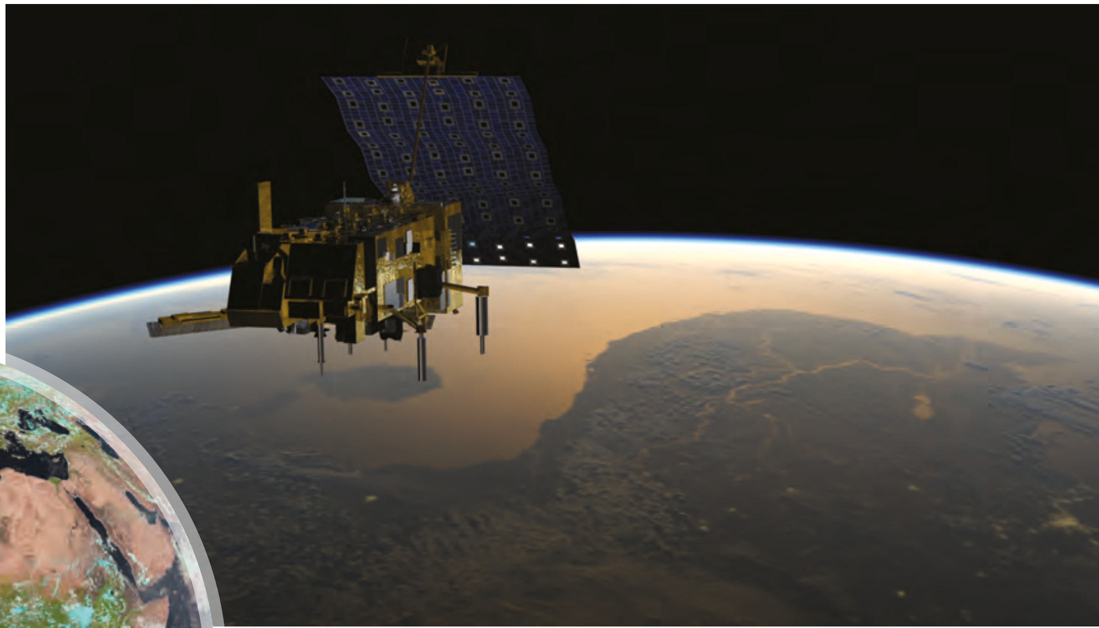
We took a step back and imagined what the control center should look like, taking into account the latest technologies and ergonomics, examining how controllers are best served by the control room layout.

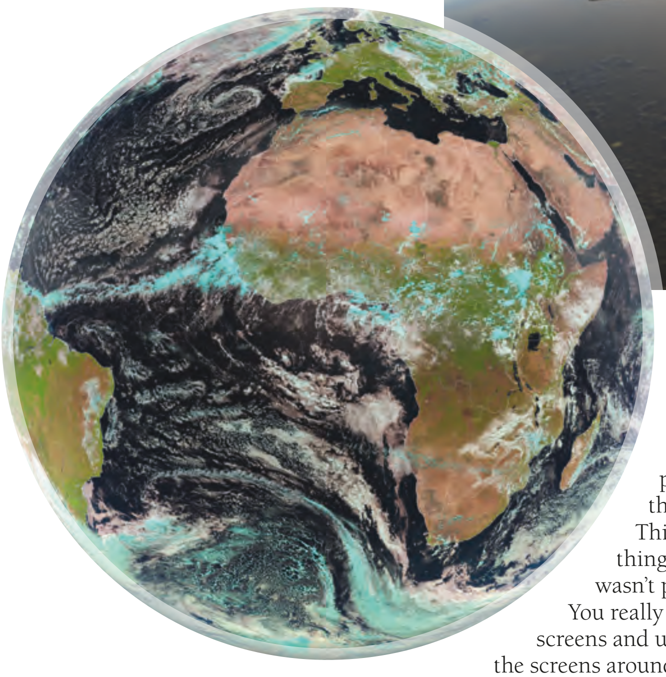
The aim is to continue to control our current-generation satellites and prepare for the next generations – MTG and EUMETSAT Polar System, Second Generation – and our current and future Copernicus Sentinel missions.

The screens are arranged as single rows in islands looking after the different satellites

An artist's impression of a polar-orbiting Metop satellite in orbit

An image of the full disc from zero degrees





and their systems. So, one would be taking care of MSG, a second would be looking after EPS, and another, Sentinel-3. We also look after the multimission systems that are used by all the missions, such as the dissemination of products.

You have big screens on the wall where you can monitor what's going on, literally the big picture of the services we provide, and then you have screens in front of you, where you can control the spacecraft and the ground segment. If you spot anything on the big screen, you can bring it down and put it on the screen next to you, to have a better view of what's going on; you can drill down to isolate and fix problems. It's very flexible in that respect.

You can also attach these screens to any of our programs. If you wanted to dedicate more screens to commissioning a spacecraft, then that's possible. It's also very secure. We've put in place security mechanisms for displaying the data and keeping it protected.

WHAT MAKES IT SO ADVANCED?

The video technology has improved enormously over the last few years. This means that all the switching between the screens, being able to move screens from one place to another, and programing the setup of the screens, is much easier. This has been the main thing we've improved – it wasn't possible several years ago. You really had to have dedicated screens and use patch panels to move the screens around. Now it's fully flexible.

WHAT IS THE ROLE OF YOUR DEPARTMENT?

I head up the Real-time Services and System Operations Division. We look after the systems and data from when it is received by the remote ground stations, the central processing of the raw data to create images and products, and then the dissemination of that data to all our end users.

COPERNICUS SENTINEL-3B WAS LAUNCHED FROM RUSSIA IN APRIL 2018

We also take care of the dissemination of data we receive from organizations all over the world, which complements the data we produce ourselves. Partners such as NOAA in the USA, and many national meteorological agencies in countries such as China, India and Japan, send us data and we make it available to users via EUMETCast, our satellite broadcast system, which is a relatively simple and cheap way of getting lots of data to our users.

Our division also looks after everybody's technical training, all the planning and scheduling of operations, the control center setup, information security, business continuity, and the preparation of operations for future systems.

Copernicus Sentinel-3B

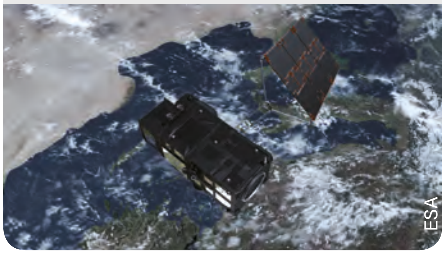
The successful launch of the Copernicus Sentinel-3B satellite in April 2018 established the European backbone for a space-based, global ocean monitoring system for operational oceanography.

The dual-satellite Sentinel-3 mission is one of six Sentinel missions deployed and exploited by the European Space Agency (ESA) and EUMETSAT as the space component of the European Union's flagship Copernicus Earth observation program.

Once it has finished contributing to the new satellite's commissioning, led by ESA, EUMETSAT will take over the control of Sentinel-3B to perform flight operations for the Sentinel-3 two-satellite configuration from its Darmstadt headquarters and provide two Sentinel-3 marine data streams.

Alain Ratier, director general, EUMETSAT, said, "After the commissioning of Sentinel-3B, during which the two Sentinel-3 satellites fly in tandem, 30 seconds apart, for cross-calibration, the satellites will be moved 140° apart, as requested by the marine user community.

"This will provide full and frequent global coverage of ocean color and sea surface temperature measurements and the best sampling of the ocean surface topography achievable by altimeter measurements from two Sentinel-3 satellites and one Jason satellite."



ESA

> "We took a step back and imagined what the control center should look like"
> **Sean Burns, head of the Real-time Services and Systems Operations Division, EUMETSAT**

WHAT ARE THE CHALLENGES OF OPERATING A SATELLITE NETWORK?

The first challenge is setting up the interfaces, getting all this data flowing around the system, from the satellite to the user, and ensuring that what is delivered to the user is what they need in terms of availability and quality. On top of that, you have lots of upgrades to all the systems happening all the time, from obsolescence, new functionality and new products. You have to bring in new programs and coordinate all this while taking into account the security environment we find ourselves in. This is a complex environment to manage while maintaining high availability for users.

HOW ARE THINGS PROGRESSING WITH THE COPERNICUS DATA AND INFORMATION ACCESS SERVICES (DIAS) INITIATIVE?

We're now working on the first version of a new system and have partnered with two other organizations – ECMWF, located in the UK; and Mercator Ocean in Toulouse, France. They operate the Copernicus marine environment, atmosphere monitoring and climate change services. Our system, called WEkEO, enables Copernicus data to be downloaded for free, including all data from Sentinel satellites, contributing missions and the Copernicus marine, land, atmosphere and climate services. The group is basically trying to collect lots of data, not only the Sentinel data, but also data from the different providers involved in producing ocean products, and making this available to the users.

WEkEO also features cloud-based hosted processing and tools, enabling users to transform the data and services to meet their specific needs. WEkEO's strength relies on its distributed and federated infrastructure providing users with the most up-to-date Copernicus data and a continually expanding offer in the future.

HOW DO SAFS BENEFIT THE METEOROLOGICAL COMMUNITY?

Each Satellite Application Facility (SAF) is hosted in one of the member states, but often involves several member states. They are dedicated centers of excellence providing users with operational data and software products, each one for a dedicated user community and application area.

We'll work together on a particular application facility, where the SAF takes our data and so-called Level 1 and Level 2 products, and produces further products, for example taking data from more than one source to produce what is called a Level 3 product. EUMETCast is typically used to disseminate these SAF products.

WHAT DOES EUMETSAT HAVE PLANNED FOR THE FUTURE?

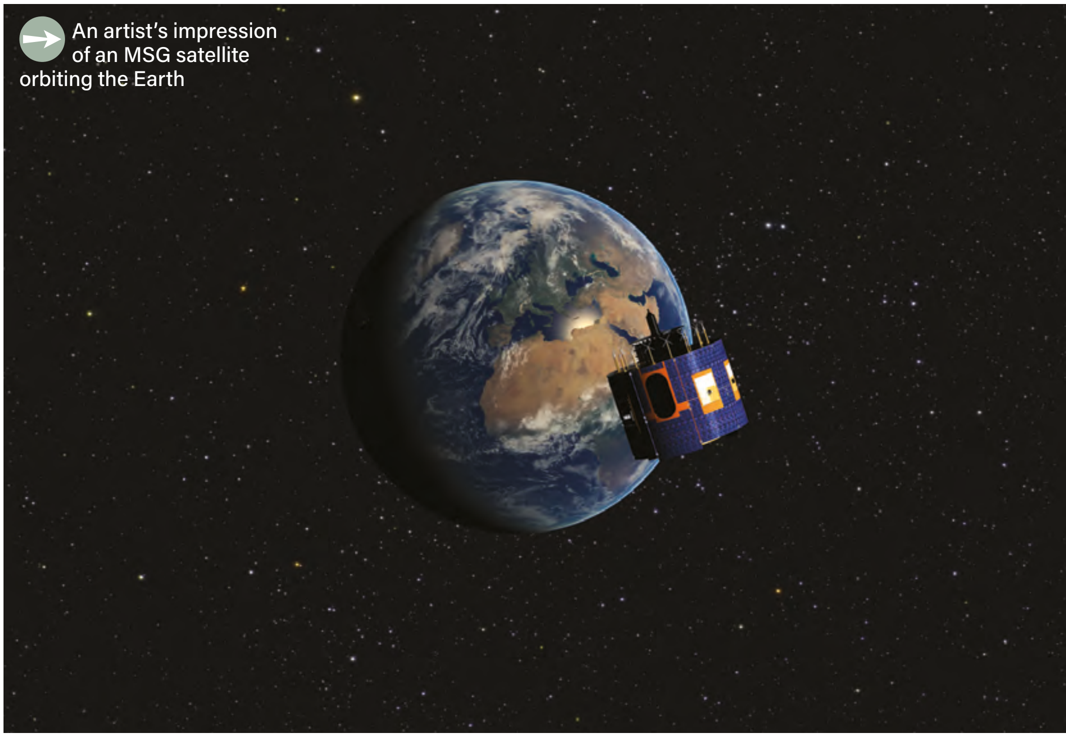
Later this year, we plan to launch Metop-C, the third EUMETSAT Polar System (EPS) satellite, which will mean three Metop satellites in orbit. Then we'll turn our attention to the second generation of polar orbiting satellites, the third generation of Meteosat satellites, and finally the Jason-CS program (Continuity of Service) – three new programs and new systems that are going to come online in 2020, 2021 and 2022 respectively.

It is going to be an enormous amount of work to integrate these into our operational systems, and then provide this data to the users, because it's a huge amount of data, even compared with what we send out now. That's going to be a big challenge.

JOIN THE SATCOM FORUM AT CIMO TECO-2018, OCTOBER 9-11

WHAT ARE YOU DOING AT METEOROLOGICAL TECHNOLOGY WORLD EXPO?

EUMETSAT is involved in two things: the SatCom forum and the DCS workshop. The DCS workshop will be integrated with the SatCom forum and is intended to provide individuals and companies who produce *in situ* data transmitters and weather stations with the opportunity to describe what they want in terms of new standards, and what they actually want to see, whether it's data transmission or accessing data. We're going to have presentations about different potential standards that we plan to implement and new standards we've already implemented, then gain feedback from users. ∎



An artist's impression of an MSG satellite orbiting the Earth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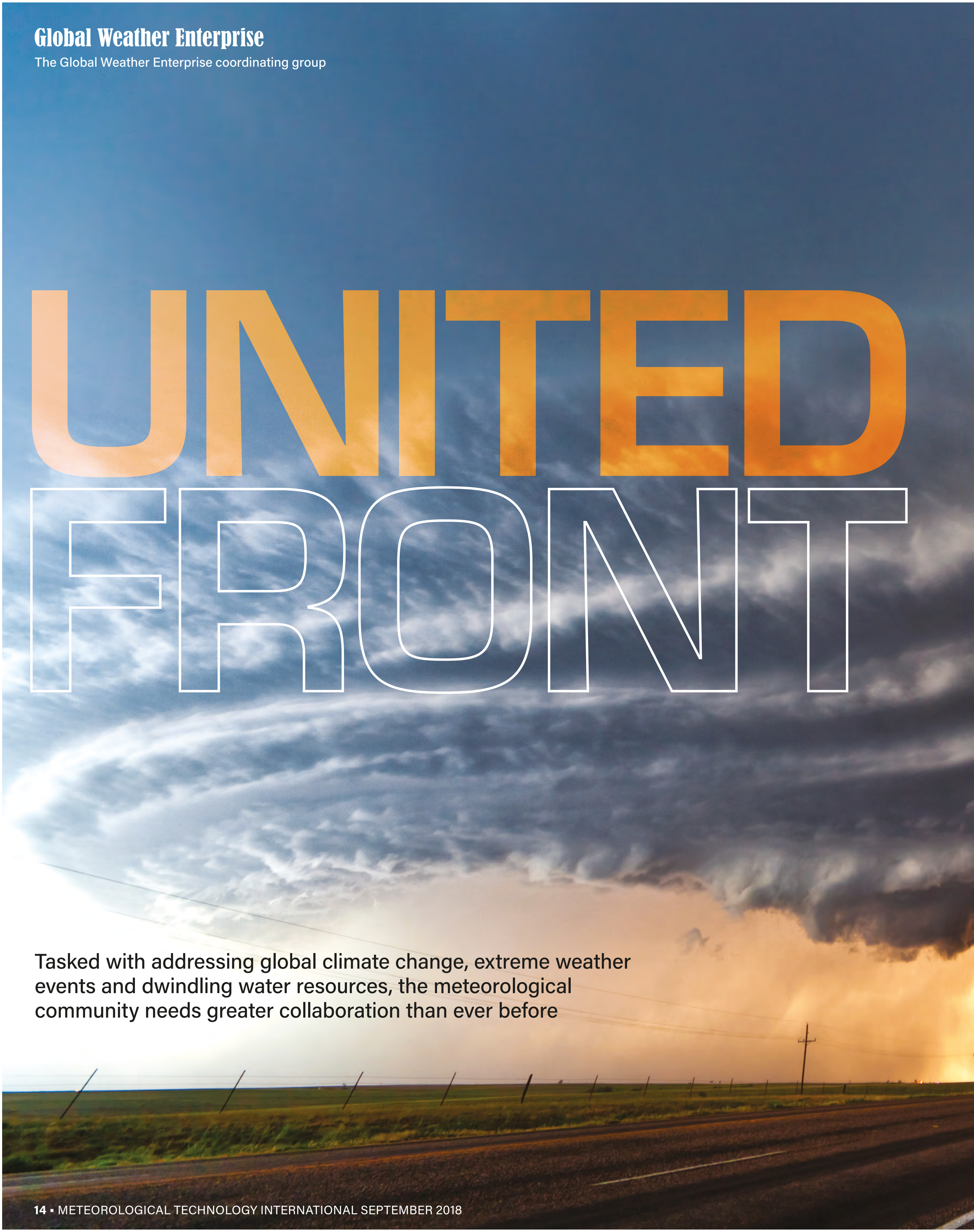


UNITED FRONT

Tasked with addressing global climate change, extreme weather events and dwindling water resources, the meteorological community needs greater collaboration than ever before

Meteorology and its related fields, such as climatology, hydrology and environmental sciences, have been a global interest for more than 150 years. By the mid-1950s, almost every country had established a national agency to deal with the collection of data, and later, the provision of forecasts and life-saving weather warnings.

Although the early years of the meteorological sector had shown some elements of enterprise, the various participants, such as publicly funded government agencies (national meteorological and hydrological services), academic institutions and private manufacturing industries, were not regarded as a single enterprise. The connections between the various stakeholders were not considered to be close, at national or international level.

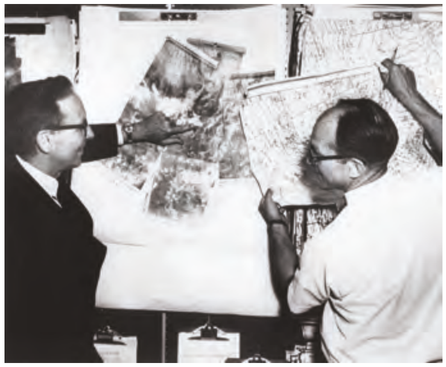
It wasn't until the establishment of the World Meteorological Organization (WMO) as an intergovernmental organization and UN specialized agency in 1951 that the weather sector became globalized. The private weather sector grew substantially at the same time – combined, the two evolved into what we today call the Global Weather Enterprise (GWE).

MOVING WITH THE TIMES

Today, there is growing recognition that in order to meet the societal needs of the 21st century for decision-support information, the main stakeholders of the GWE should collaborate more closely to reshape the meteorological sector and promote innovative, efficient and sustainable operational and business solutions. Weather-informed decision making has become a mainstream activity at all levels, building demand for highly accurate localized information in support of disaster risk management; long-term climate projections for strategic planning by governments and international bodies; tailor-made products to mitigate weather and climate sensitivity of industrial sectors; hydrometeorological information to help water management; and reliable, accurate, easily accessible information for people in their daily activities.

Observations support growth in many economic sectors, including agriculture

In years past, the analysis of weather charts was time-consuming and manual



Forum objectives

The GWE Forum's terms of reference include:

a) Helping to identify and exploit opportunities and to mitigate risks associated with the growth and development of the GWE. In doing so, the Forum builds upon existing capacity and capabilities across the weather enterprise to identify the potential for further development;

b) Contributing to the establishment of a common understanding of the GWE landscape and related roles and responsibilities of its stakeholders. It will work on developing agreed principles of mutually beneficial partnerships and code of ethics in the GWE context;

c) Keeping in focus the need of the developing and least-developed countries and making proposals that engage the public and private sectors to create solutions to improve their capacity and engagement in the GWE;

d) Providing input to the WMO Executive Council, HMEI Council, and to relevant global practices and groups within the World Bank Group on matters related to the GWE;

e) Recommending studies and evidential reports on the status and progress of the GWE;

f) Coordinating the publication of position papers and other communication materials regarding the growth and development of the GWE;

g) Promoting a series of dialog opportunities for the three sectors of the GWE to meet and discuss developments;

h) Exploring ways to engage and involve the community as widely as possible.

The GWE, however, is undergoing major structural change.[1] Private sector organizations now have the capability to do far more than in the past, from providing observations and undertaking global modeling, to providing value-added services such as cloud-based high-performance computing. The science and technology of the GWE is also advancing rapidly, with more accurate predictions over longer timescales. These changes need to be reflected in corresponding shifts in infrastructure investments, education and training. Therefore, it is highly necessary to engage in a constructive dialog between all partners.

For decades, the GWE has comprised of intertwined contributions from the public and private sectors, with support from academia, and greater engagement between all parties would only lead to further growth and prosperity for the whole enterprise. Failure to manage the latest structural changes may have a detrimental impact on inter-industry collaboration and could even have significant consequences for the goals set forth by the UN Agenda 2030,[2] the Sendai Framework[3] and Paris Agreement[4].

ANNUAL LOSSES FROM DISASTERS AVERAGE US$300bn

THE CHALLENGE

The World Economic Forum's (WEF) *Global Risks Perception Survey 2017-2018* lists weapons of mass destruction, extreme weather events, natural disasters, failure of climate change mitigation and adaptation, and water crises, as the top-five risks that will have the biggest impact in the next 10 years. The four environmental risks all have a higher than average likelihood of occurrence and are tangibly affecting human well-being, including health and economic prosperity.

WEF 2018 highlighted the need to build a shared future that better predicts extreme risks and fosters the resilience required to mitigate these risks. More than one billion people have lifted themselves out of poverty in the past 15 years, but climate and disaster risks threaten these achievements.[5]

Global asset losses from disasters are now reaching an average of more than US$300bn per year. A recent World Bank report found that the impacts of disasters on well-being are equivalent to a US$520bn drop in consumption (60% more than the asset losses usually reported) and force some 26 million people into poverty every year.

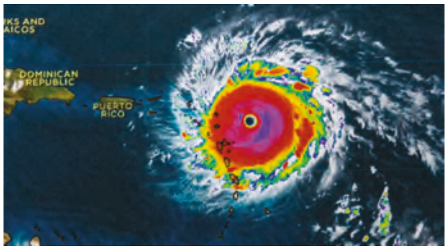
Marshalling the combined resources of the GWE is an essential step in providing society with the means to increase their resilience to the increasing risks associated with more extreme weather events. In *The future of the Global Weather Enterprise: Opportunities and risks*, Thorpe and Rogers highlight the need for the GWE to grow if it is to fulfill the requirements of today's society for weather information, and that this growth will be best achieved by improved and more frequent dialog and co-designed initiatives between the various actors in the public, private and academic sectors.

GWE FORUM

The WMO, the Association of Hydro-Meteorological Equipment Industry (HMEI), and the Global Facility for Disaster Reduction and Recovery (GFDRR) of the World Bank Group, created the GWE Forum

Real-time satellite imaging enhances our understanding of, preparation for and response to weather events

Hurricane Maria ravaged the Caribbean islands in 2017, causing an estimated US$95bn in damages and 146 fatalities



First meeting of the Global Weather Enterprise Forum held in April 2018 at the InterMET Asia Conference, Singapore

to facilitate dialog among the public, private and academic sectors. The Forum is an independent consultative platform to assist the sectors in considering the necessary coordinated actions to address the growth of the GWE, and to make recommendations for consideration by relevant bodies, including the WMO and development partners.

As Thorpe and Rogers demonstrate, the GWE is facing increasing challenges, which may, among other things, require deliberated guidance from the Forum. Such challenges include, but are not limited to: the growing demand for weather and climate information; technical innovation; the public support for fundamental research; the integrity and sustainability of the global observing system; the growth of private sector capabilities; the structure of international financing; the roles of the private and public sectors; the growth of a service-based approach toward the provision of data; weather information standards and access; and support for low- and middle-income countries. The GWE must also address education and training, with greater focus on communication programming, big data statistics, and machine learning.

Thanks to the technological advances of modern society, the GWE also has more opportunity to combine its resources and propose innovative ways of working together to maximize the overall benefit to society. A variety of relationships between national and international players in the public, private and academic sectors are possible all along the meteorological, climatological and hydrological value chain, which has the potential to produce better, more sustainable, cost-effective services to society if they are mutually beneficial, properly funded, ethical and respectful of sovereignty.

Consequently, the GWE Forum activities will focus on: identifying the attributes of, and ways to remove, the barriers to 21st century meteorological and hydrological information services; and fostering the emergence of partnerships within the GWE to maximize socio-economic benefit of meteorological and hydrological information worldwide.

In that context, the areas of consultations in the Forum include: incentivizing the creation of fit-for-purpose data by all sectors; making all relevant information flow more freely; developing and maintaining the GWE workforce; strengthening application and basic research, and speeding the deployment of proven applied science; uptake of innovation in service delivery; and advancing work on sustainable business models, especially through rational public-private partnerships.

The GWE has reached a turning point where it has the opportunity to evolve and maximize its support of the UN's Sustainable Development Goals. The GWE Forum is fostering dialog inside the GWE in this respect, taking into account the important guiding principle that everybody should have access to high-quality weather information and that no one should be left behind, especially those in low- and middle-income countries that are highly vulnerable to weather and climate extremes. ▮

Authors
Michael Staudinger, ZAMG, Austria; Patrick Benichou, Meteo France International; David B Parsons, University of Oklahoma, USA; Alan Thorpe, David Rogers, Vladimir Tsirkunov, Makoto Suwa, and Anna-Maria Bogdanova, GFDRR/WBG; Brian Day and Bryce Ford, HMEI; and Dimitar Ivanov and John Hirst, WMO

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Find out more...

The Global Weather Enterprise will be hosting a two-day Weather Enterprise conference in parallel with this year's CIMO TECO-2018, which is being held alongside Meteorological Technology World Expo 2018 on October 9-11, in Amsterdam. The conference, which will be held on October 11-12, has been organized by the WMO in cooperation with the World Bank GFDRR and the Association of Hydro-Meteorological Equipment Industry (HMEI). It will focus on two key themes: data and business models. To read more about the event, turn to page 66.


Better Data –
Accurate Forecasts
WEATHER SOLUTIONS FOR ALL METEOROLOGICAL NEEDS
Stroke Density Map - 20 km grid
Average: 2012-2016
GLD360 v2.0 data: 7,828,464,140 strokes
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Interview: Royal Netherlands Meteorological Institute

Helen Norman

Jannes Wiersema

TREND SETTING

With Meteorological Technology World Expo traveling to Amsterdam on October 9-11, *MTI* speaks to director-general Dr Gerard van der Steenhoven, from the Royal Netherlands Meteorological Institute, about the investments, projects and future trends that are set to change the industry

Jannes Wiersema

"We have an ambition to gradually change our institute and its traditional weather room into a multihazard early warning center in order to better serve the Dutch society in the years to come"

Dr Gerard van der Steenhoven, director-general, KNMI

ESA, KNMI

The TROPOspheric Monitoring Instrument (TROPOMI) is the UV-VIS-NIR-SWIR spectrometer on the Copernicus Sentinel 5 Precursor platform

Tineke Dijkstra

The KNMI weather room in its current setup. It is foreseen that the weather room will develop into a multihazard early warning center

TELL US ABOUT KNMI AND THE WORK IT CARRIES OUT IN GENERAL

KNMI, the Royal Netherlands Meteorological Institute, is the national meteorological service provider in the Netherlands, including three small Dutch islands in the Caribbean. It provides information and, if needed, warnings, to society at large on weather, climate, seismology and Earth observation. In particular, KNMI is the designated operational provider of weather information and advises Dutch aviation authorities and KLM Royal Dutch Airlines. Moreover, it maintains and develops the national network of weather stations; it runs a local-area numerical weather prediction model (eight times a day); it is the focal point for the Intergovernmental Panel on Climate Change (IPCC); it has the largest weather and climate research group of the country; it is the Principal Investigator of the leading air-quality satellite instruments OMI and TROPOMI (which was recently launched on the ESA Sentinel 5P mission); and it operates the national seismological network to inform the general public about natural and induced earthquakes.

WHAT IS KNMI WORKING ON AT THE MOMENT?

Among the many projects that KNMI carries out every year, I would like to single out two: a project to transform the IT infrastructure at our main location in De Bilt; and the project to renew, rethink and redesign our network of weather stations. Both projects are aimed at addressing the legacy problems that most meteorological service providers throughout the world are suffering from today. I am pleased to tell you that KNMI recently received the financial means from the Dutch Ministry of Infrastructure and Water Management to commence and implement these projects.

Furthermore, in the near future we hope to develop an early warning center. We have the ambition to gradually change our institute and its traditional weather room into a multihazard early warning center to better serve Dutch society in the years to come. This trend is motivated by the increased occurrence of extreme weather events due to climate change. To reduce the associated risk to life and property, KNMI feels obliged to use the latest developments in meteorology, climatology, data science and IT to inform and warn the public earlier and more precisely. This is an international trend that was already mentioned in the 2015 Paris Agreement on climate change.

Wind turbines are appearing at many places on the flat Dutch landscape, so it is becoming increasingly important to monitor wind vectors up to 300–400m above the ground

WHAT NEW TECHNOLOGIES HAS KNMI INVESTED IN?

In the Netherlands two new dual-polarization radars were installed in 2016-2017. In the same period all our automatic weather stations were equipped with new ceilometers. Both renewal projects provide great opportunities to improve our services. At the institute itself, a new high-performance computer was installed in late 2017. It is six times more powerful than the previous one, while its energy consumption per teraflop is five times lower.

In space, the most important development is the previously mentioned launch of the TROPOMI instrument, which provides us, and the rest of the world, with air-quality data of unprecedented resolution (3.5 x 7km^2). This data allows us to identify specific sources of air pollution. Furthermore, later this year several satellites will be launched which are equipped with scatterometers and laser instruments that will provide us with 3D wind information. Together, all these instruments, once assimilated in the numerical weather prediction models, are expected to yield substantial improvements in weather forecasts.

On the ground, in collaboration with the Dutch atmospheric research community, at our Cabauw facility we are installing the observational infrastructure needed to support weather and air-quality models of the future that will provide forecasts at much higher resolution than is currently possible. These instruments will include new remote-sensing instruments to measure air pollution, clouds and radiation at a very fine scale.

HOW ARE YOU USING DATA TO IMPROVE OPERATIONS AT KNMI?

We are working on improving user tools by developing a web-based meteorological workstation. This project, called GeoWeb, provides forecasters with any combination of data sets (from anywhere in the world) tailored to the task at hand to better analyze and interpret available information. In addition to that, we are taking first steps in cloud computing and data science. One example of how we are achieving this is through the Weather Observations Website project, which was developed by the Met Office. In this project, individual citizens with a weather station in their garden can share data among themselves and with us on the WOW website. The main challenge is to assess the quality of this data and integrate it and other IoT information to improve our day-to-day operations.

CIMO TECO-2018

The Royal Netherlands Meteorological Institute will be showcasing a number of its key projects at this year's CIMO TECO-2018 conference, which will be held on October 8-11 in Amsterdam, Netherlands, alongside Meteorological Technology World Expo. To register to attend the conference visit www.wmocimo.net. Here are four of the key KNMI presentations...

Specification and evaluation of present weather sensors

Dr Wiel Wauben, KNMI

Topic: Characterization and standardization of environmental measurements – traceability assurance

KNMI has recently completed testing and evaluation of present weather sensors (PWS), following its issue of a European tender for a new solution. The tender consisted of mandatory requirements and desirable features that had to be met by the PWS manufacturers, including maintainability, implementation and costs. Three solutions were chosen and then tested in the field and laboratory over a period of one year. This presentation will provide attendees with details of the three PWS solutions and will present and discuss the results of the one-year evaluation period.

Operational use of aircraft-derived data for meteorology and other applications

Dr Paul Mark Alexander de Jong, KNMI

Topic: Emerging measurement technologies: From development to operation

Nowadays thousands of aircraft equipped with many sensors fill the skies. These sensors measure various meteorological properties, such as pressure, wind speed and temperature, which are then broadcast to air traffic management. To make full use of this data, the European Meteorological Aircraft Derived Data Center (EMADDC) has been established to receive, process, distribute and improve the quality of the information. The current status and foreseen improvements of EMADDC will be revealed during this presentation.

Experiences with quality evaluation of AMDAR observations

Dr Jitze van der Meulen, KNMI

Topic: Ensuring sustainability of measurements

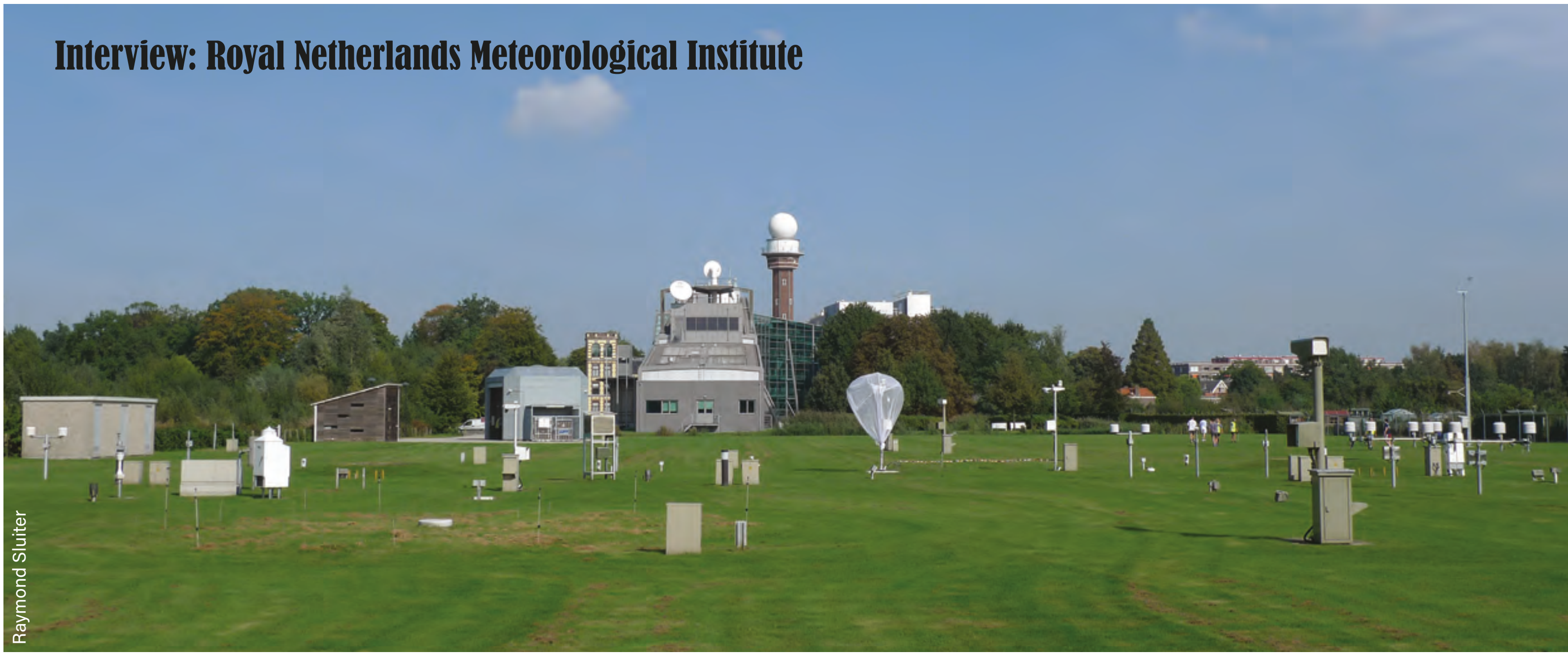
This presentation will look at how Aircraft Meteorological Data Relay (AMDAR) is being evaluated and results will be presented and discussed. The evaluation of AMDAR data has been performed since 1999. The methods used over the years will be discussed and evaluation reports revealing short- and long-term trends in the quality of the aircraft-based observations will be showcased to attendees. The evaluation reports advise AMDAR operators on possible improvements to working processes. Moreover, archived reports support data analyses of the upper-air for climate applications.

Neural network approach to automatic fog detection using traffic camera images

Andrea Pagani Giuliano, KNMI

Topic: Measurement and integration challenges in the next 20 years

Nowadays dense networks of surveillance cameras along roads and waterways generate large amounts of image data that can be used for better fog detection. With this in mind, KNMI has developed an automated fog detection system that makes use of these existing cameras. In order to successfully recognize fog conditions from many different sceneries, it has employed a deep neural network. The results for the new system are promising. This presentation will present details of the deep neural network and results of the detection system using traffic camera images.



Raymond Sluiter

The KNMI office building in De Bilt, close to Utrecht. The test field, in front of the building, contains many setups to develop and evaluate new measurement techniques

HOW ARE YOU IMPROVING DATA COLLECTION AND EVALUATION?

One very interesting project that helps illustrate this is how we are trying to develop a novel way of combining data from various precipitation products, including radars, satellites, automatic and manual rain gauges (of which more than 300 are spread around the Netherlands), gauges that are being used by regional water and harbor authorities, etc. However, there are considerable challenges associated with this and we are working to overcome them at the moment. As well as the technical challenges, such as data quality control, that such projects are faced with, there are considerable legal hurdles that need to be overcome. Data ownership and limits imposed by laws regulating the relationship between the public and private sectors, make such projects highly complex. Nevertheless the need to improve our knowledge of regional and urban weather situations provides us with strong motivation to carry out such projects.

We are also looking at making better use of the data from the attenuation of radio signals emitted by mobile telephone masts, which can help us identify information on precipitation patterns. Such data is particularly useful in countries with poor radar coverage and provides supplementary information in other countries. Also, we developed a special product for the national road authority to report on the status of roads. By combining information derived from road temperatures and numerical weather forecast, a good assessment of the probability of the occurrence of slippery roads has been obtained (in collaboration with our colleagues in Finland). It is being used to decide whether salt or sand needs to be scattered on the roads.

WHAT ARE THE KEY CHALLENGES FACING KNMI AT THE MOMENT?

I would like to mention one challenge in particular. Because of the growing importance of IT and data science, we need more experts in those domains. However, many public and private organizations are faced with the same challenge. Hence, it is not easy to recruit such specialists in sufficient numbers. For that reason, we are also looking at training our own employees. Whether this is sufficient remains to be seen.

In terms of general challenges, we see that more data will become available to us. In the past, data collected by national meteorological institutes was largely based on standalone hardware equipment; nowadays data is emerging everywhere. Every car and smartphone can be a source of meteorological data. To serve society we need to get access to all this data and bring it to advanced computing clusters. These will no longer be single mainframes, but cloud based. As a result, the national meteorological services of the future can be regarded as massive data services with a meteo license. This trend represents a major disruptive change for all of us. As long as we keep our main goal – reducing the societal risks associated with weather extremes and climate change – clearly in focus, it should be possible to meet this challenge. ▮

What's next?

Dr Gerard van der Steenhoven provides his key predictions for the future of the meteorological industry

Data everywhere
I see the industry moving from gathering centralized well-calibrated data, to gathering and receiving data from anyone, anywhere. This data will be less controlled, and this will trigger another trend, which will see more investment in software to ensure this less controlled data is evaluated in an adequate way.

Collaboration
The industry will begin to adopt a more collaborative approach between national meteorological institutes where neighboring countries work more closely together, especially in Europe. Institutes will collaborate with other national weather providers to share both technology and data. We will also see the industry move from using local computing to cloud computing.

Public and private
There will also be closer collaboration with the private sector and we will see new ways of working. This may require the development of entirely new, and largely unknown, legal frameworks for international data-sharing that go beyond the WMO's Resolution 40 – the principle of free and unrestricted exchange of meteorological and related data and products.

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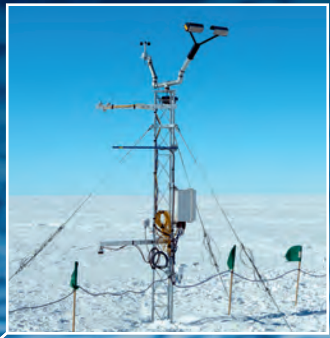

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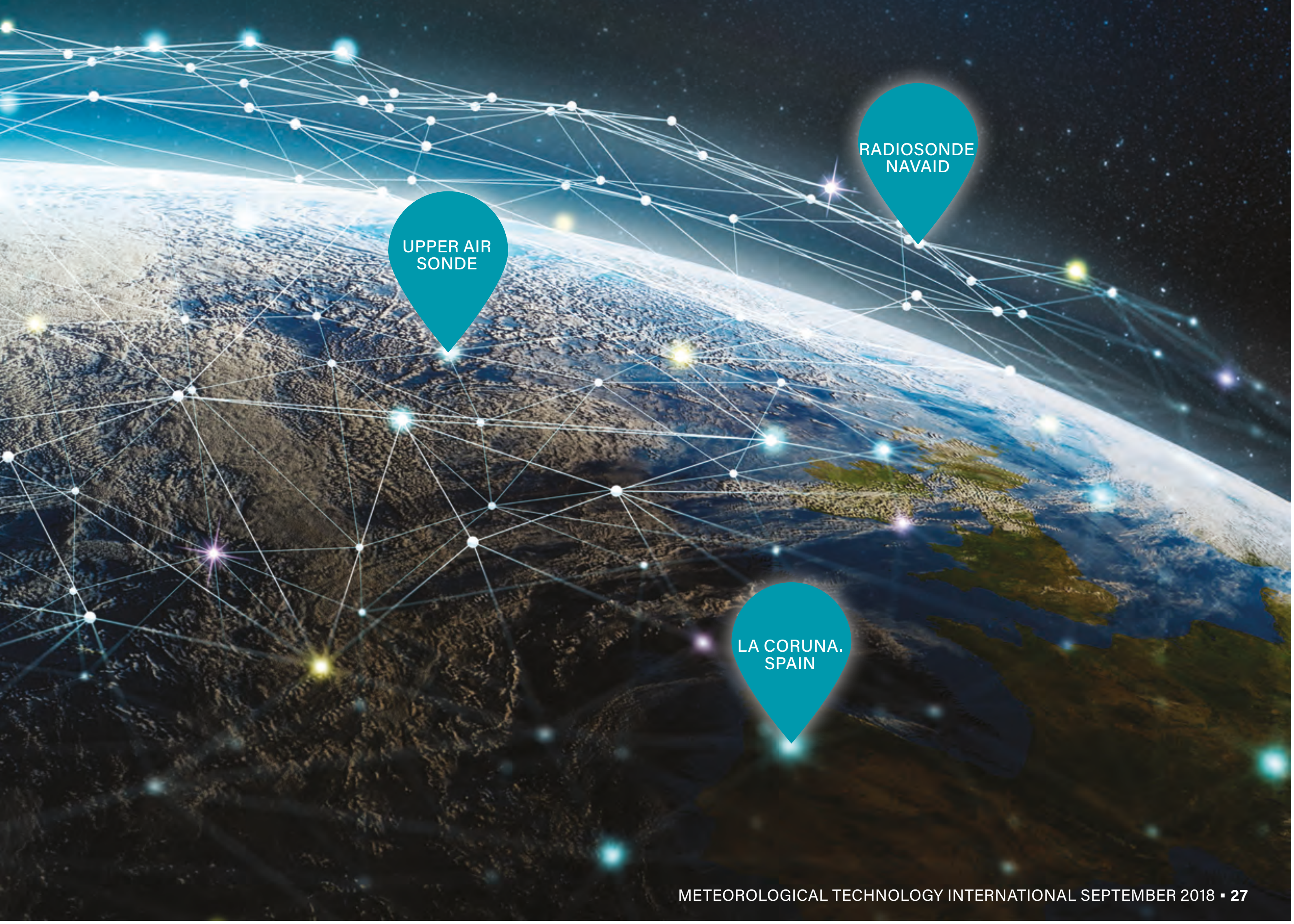
Jörg Klausen, Federal Office for Meteorology and Climatology MeteoSwiss, Switzerland

METADATA MANAG

Use of the Observing Systems Capability Analysis and Review (OSCAR) solution for the management of metadata helps to optimize investments in observational infrastructure

GEMENT



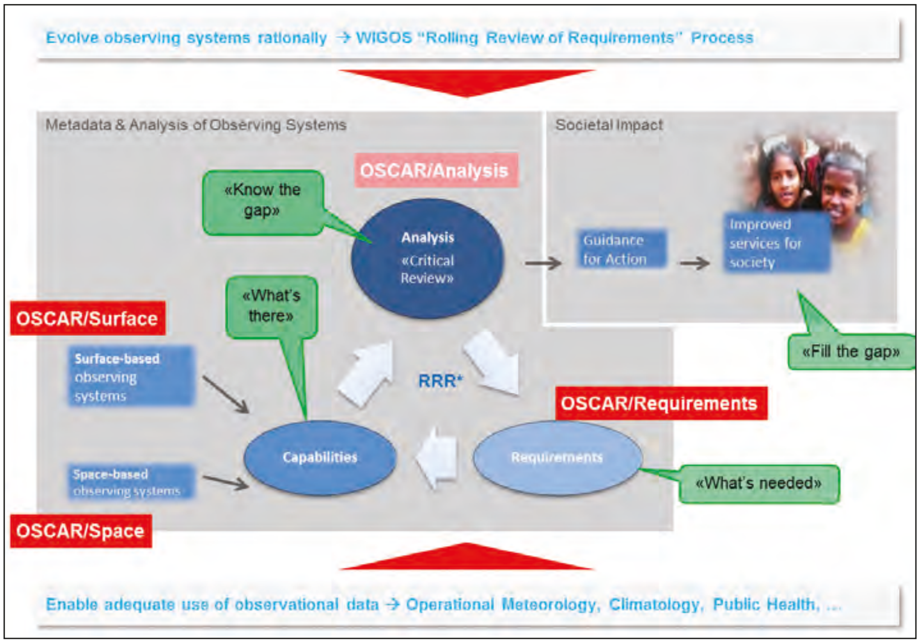


Figure 1: Schematic of the WIGOS rolling review of requirements process supported by the web-based Observing Systems Capability Analysis and Review (OSCAR) tools

The Swiss Federal Office for Meteorology and Climatology (MeteoSwiss) was approached by the WMO in 2013, with a request to build a system for the management of observation metadata. At the time MeteoSwiss had already supported the development of a similar system called Global Atmosphere Watch Station Information System (GAWSIS), focusing on atmospheric composition monitoring in the context of the WMO Global Atmosphere Watch (GAW) program for about 10 years. The time was ripe for a technical upgrade of that system, and extending it to include all sorts of other meteorological and climatological observations seemed worthwhile.

Many national meteorological and hydrological services (NMHS), in particular smaller services and those in less industrialized countries, were struggling with proper documentation of their observing systems. Moreover the traditional *WMO Publication No. 9, Volume A, Observing Stations* and the *WMO Catalogue of Radiosondes* were outdated and no longer met requirements. WMO was pushing a new framework called the WMO Integrated Global Observing System (WIGOS) to align observations coordinated or co-coordinated by the organization on a global scale. In 2014 a joint venture between the WMO and MeteoSwiss, with financial support from the Federal Department of Foreign Affairs (FDFA) in Switzerland, laid the ground for the development of Observing Systems Capability Analysis and Review (OSCAR)/Surface, an immensely successful collaboration with ever-increasing global reach.

The OSCAR tools were initially conceived as a set of web-based catalogs in support of a rolling review of requirements (RRR) process, whereby technology-free observational requirements (statements of 'what's needed') are compared with observational capabilities (documentation of 'what's there') on a global scale in a rational process of gap analysis (Figure 1). These gap analyses are the basis for statements of guidance (SoG) informing decision makers about needs and opportunities for the evolution of the observing systems in support of better services to society.

Currently three web-based components of OSCAR exist:
• OSCAR/Requirements (catalog of observational requirements);
• OSCAR/Space (catalog of space-based observing capabilities);
• OSCAR/Surface (catalog of surface-based observing capabilities).

TO DATE OSCAR/ SURFACE HAS RECEIVED MORE THAN 290,000 PAGE VIEWS

The fourth component, OSCAR/Analysis (a collection of tools and services to support the gap analysis), is still in its infancy. OSCAR/Space and OSCAR/Requirements have existed for quite some time and are regularly used. OSCAR/Surface was launched as an operational platform on May 2, 2016.

OSCAR/Surface (Figure 2) presents itself as a modern, robust web-based application providing search and reporting features that are open to the public. It also has an elaborate management console that allows WMO Members to document their observing systems, including their histories, with a level of detail previously unheard of. During its first two months of operation, OSCAR/Surface received more than 12,000 page views from users all over the world. Currently approximately 290,000 page views by more than 13,000 users have been registered.

INTEGRATING INFORMATION

When the new GAWSIS-OSCAR/Surface applications were launched, users were presented with information collected from various sources. This included all the land-based stations reported in the former Volume A, as well as the ocean platforms coordinated by JCOMMOPS and the weather radars documented in the WMO radar database. Moreover metadata collected in GAWSIS from several of the GAW world data centers and a number of regional and/or program-specific data centers was included (Figure 3). Today GAWSIS is directly linked to the OSCAR platform, thereby providing information on the capabilities for observing the chemical composition of the atmosphere.

While GAWSIS and OSCAR offer robust management consoles for people to make changes to existing information, what was really missing at the time of launch was a machine-to-machine interface, enabling members to upload WIGOS metadata in bulk. To facilitate such automatic interaction with the platform, an XML application scheme had to be agreed by the WMO community, following the recently developed WIGOS Metadata Standard (WMO-No.1192). This formally defines how metadata can be encoded for upload to GAWSIS-OSCAR/Surface. The scheme has been thoroughly reviewed and was published as an experimental release in *WMO 306 Manual on Codes Part D Vol. I.3 as FM-241-16 WMDR-XML WIGOS Metadata Data Representation*. Since then, the scheme has

Figure 3: OSCAR/Surface combines various data sources, namely of the WMO land-based observing systems GOS and GAW, as well as the WMO co-sponsored GOOS

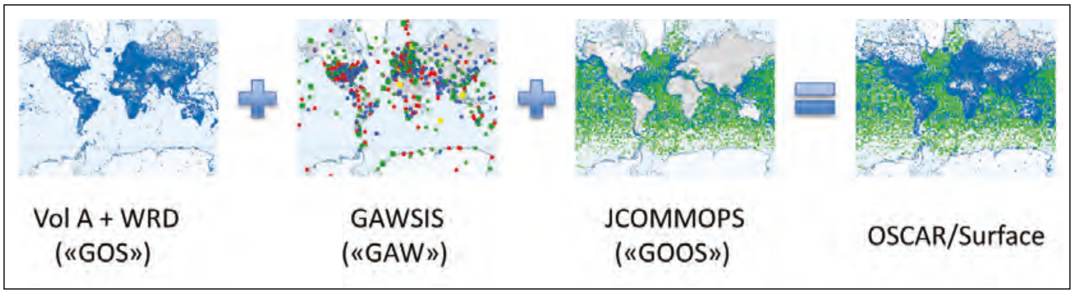
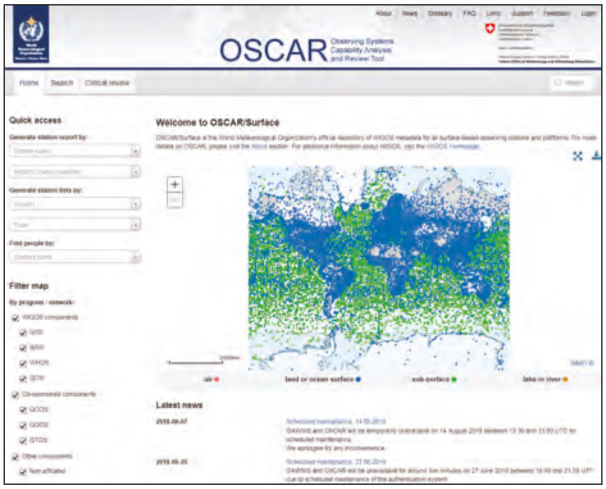


Figure 2: Screenshot of the OSCAR/Surface application (https://oscar.wmo.int/surface)



further matured and is currently available as release candidate 1.0RC9. The OSCAR/Surface application has been updated to be able to cope with metadata delivered in this format, and the first members are getting ready to provide their metadata to OSCAR/Surface in this common format.

INDUSTRY PARTNERSHIP

Any description of observations obviously needs to document the instrumentation in use. When OSCAR/Surface was designed, it was recognized that the tool holds great potential not only for the WMO and its members, but also for the meteorological industry. A call to the members of the Association of Hydro-Meteorological Equipment Industry (HMEI) in 2015 yielded responses from a number of leading manufacturers that are now listed in OSCAR/Surface. For the users of OSCAR/Surface, the instrument catalog is of great importance as a unified list from which to choose instruments during the process of documenting meteorological observations.

For industry players, OSCAR/Surface may be seen as a platform to showcase their products and from which to gain insight into their market penetration and the geographical distribution of their instruments. Optimally used, OSCAR/Surface can support business analysis and also provide a historical perspective.

It is still early days, and many manufacturers are not yet present at all, or only with a subset of the instrumentation they produce or have produced in the past. Moreover many observations are still insufficiently documented. The instrument catalog is relatively simple at present, but the most important attributes of instrumentation can be easily recorded. Manufacturers are invited to take control of this part of OSCAR/Surface. The application features the role of instrument expert, which gives full access to the instrument catalog. Manufacturers with a small portfolio will best use the web interface directly; those with a larger range of instrument types and models are invited to update their listing using the machine-to-machine interface. The OSCAR/Surface support team at MeteoSwiss is ready to assist.

EMBRACING THE FUTURE

The WMO and MeteoSwiss are active in promoting the OSCAR tools and in training NMHS in how to use the applications to their advantage. The machine-to-machine interface will enable well-resourced members to document their assets more easily and quickly while the applications' management consoles facilitate changes on a smaller scale. Both will be evolved in response to change or new user requirements. For smaller NMHS, in particular those who may not want to invest in developing their own national metadata repository, OSCAR/Surface represents a robust solution, accessible from anywhere, anytime. In combination with the WIGOS Data Quality Monitoring System (WDQMS), and with links to some of the data centers archiving observations, OSCAR/Surface will soon also report on the current state of observing systems.

Before long the only limitation to comprehensive documentation of the global meteorological, climatological, hydrological, cryospheric and atmospheric composition observing systems will be the willingness and capacity of members and partners to collect and share all this information. As a web-based application running on laptops as well as tablets, OSCAR/Surface may even be used by technical staff servicing assets for real-time documentation while in the field.

The ultimate goal of the various OSCAR components, and of OSCAR/Surface in particular, is to enable adequate use of observations to support network management, to facilitate global assessments of the observing capabilities of members, and to guide their rational evolution based on clear requirements. A close collaboration between the hydro-meteorological equipment industry and WMO members can benefit both those who develop and sell equipment and those who operate it in their observing networks. Both need documentation, and OSCAR/Surface is the place to collect it. Be prepared for a lot of metadata coming to a web browser/database near you! ∎

Contributors
• Bertrand Calpini, Lucia Cappelletti, Léa Freydier and Nina Horat, Federal Office for Meteorology and Climatology, MeteoSwiss, Switzerland
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• Luís Nunes, Timo Pröscholdt and Lars Peter Riishojgaard, WMO, Geneva, Switzerland
• TT-WMD, WMO ICG-WIGOS Task Team on WIGOS Metadata

Find out more...

At this year's CIMO TECO-2018 conference, which is being held alongside Meteorological Technology World Expo on October 9-11 in Amsterdam, Jörg Klausen from MeteoSwiss, the Federal Office for Meteorology and Climatology, will provide an in-depth presentation on OSCAR and its capabilities. The presentation, called 'WIGOS and OSCAR: Where observational requirements meet observational capabilities', will also discuss how the tool can be improved in the future. To register to attend visit www.wmocimo.net.

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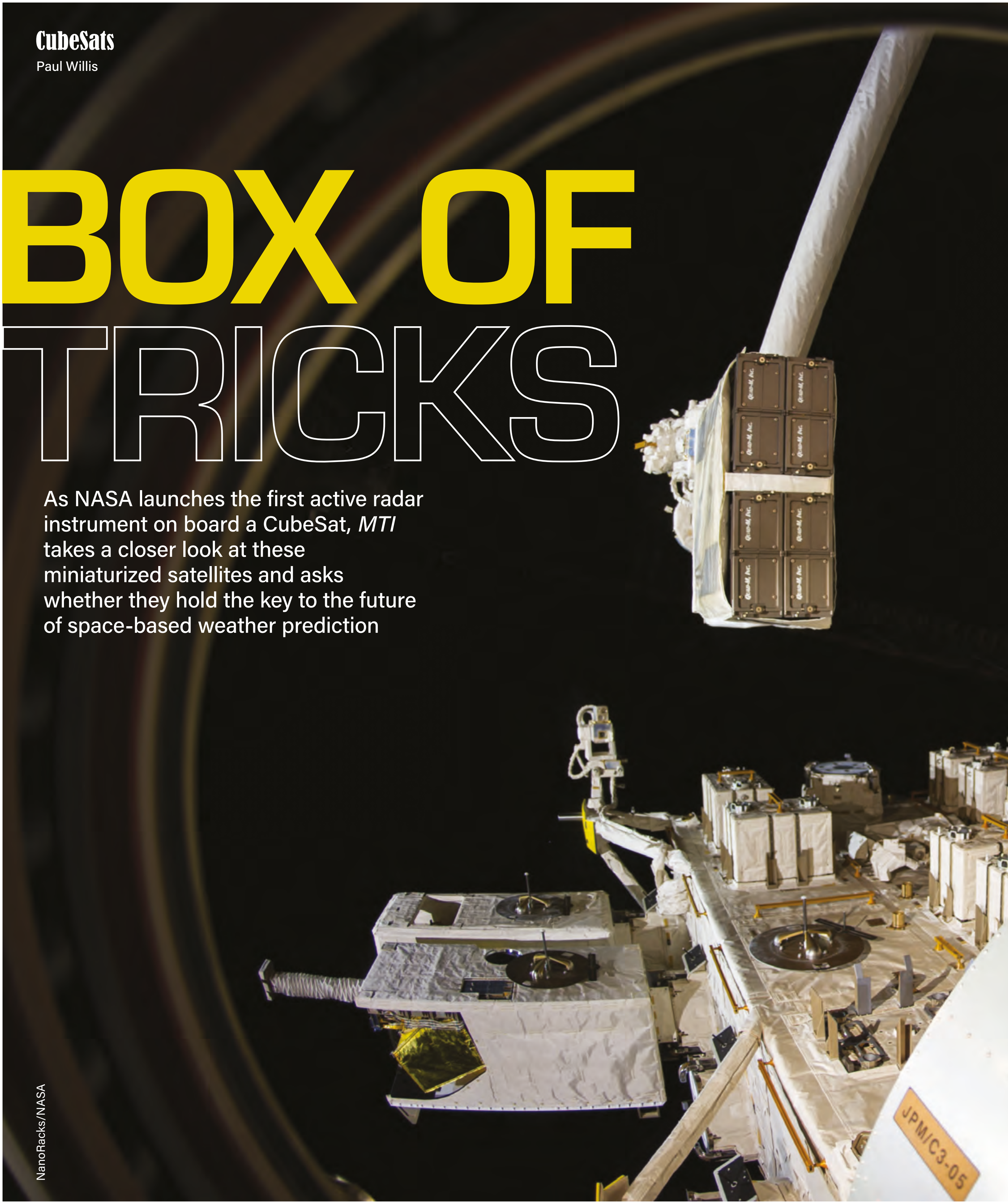
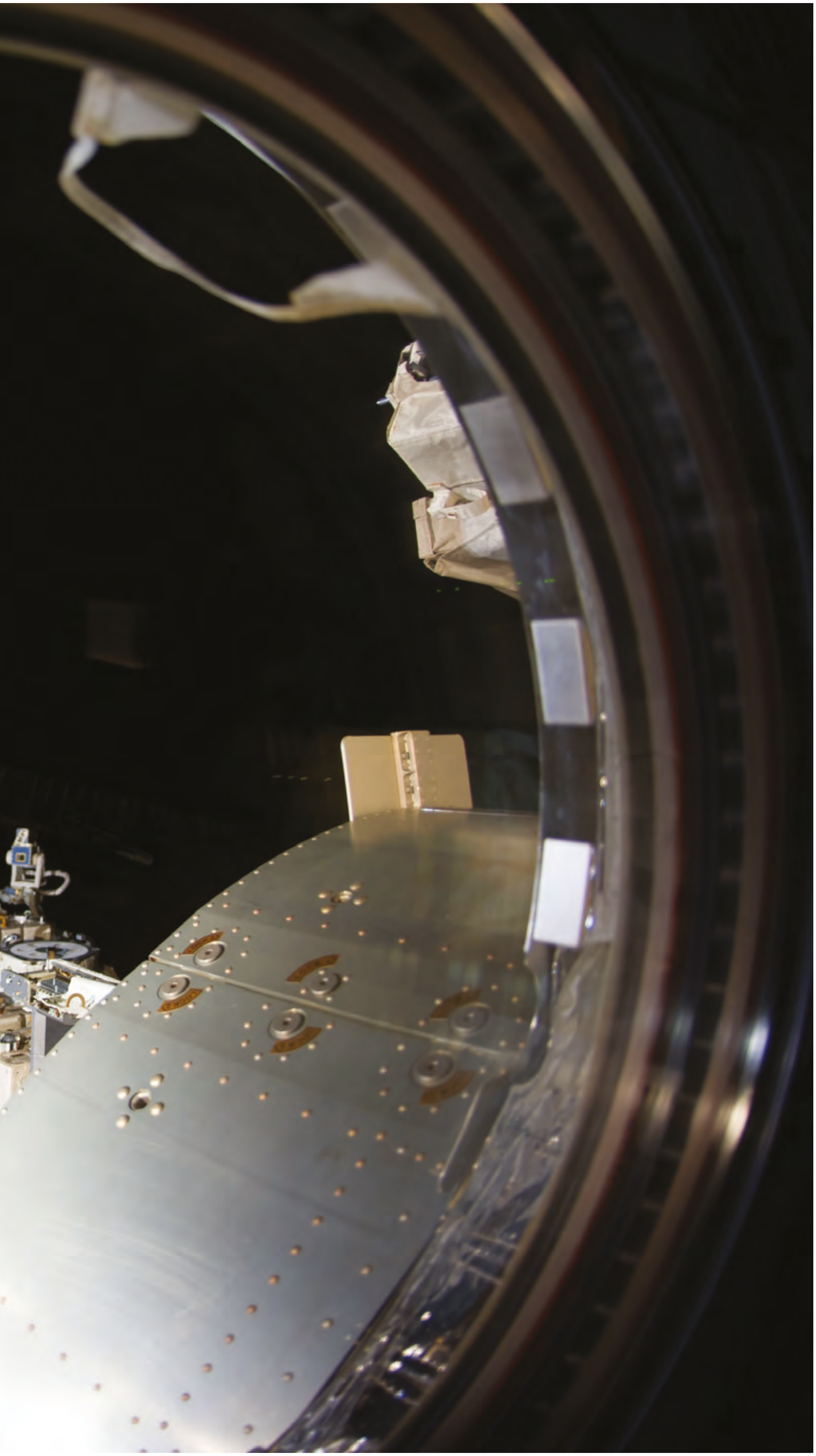
Paul Willis

BOX OF TRICKS

As NASA launches the first active radar instrument on board a CubeSat, *MTI* takes a closer look at these miniaturized satellites and asks whether they hold the key to the future of space-based weather prediction



NanoRacks/NASA



A CubeSat being deployed from the ISS using Nanoracks technology

In May 2018 a rocket blasted off from NASA's Wallops Flight Facility in Virginia, USA, on a commercial resupply mission to the International Space Station (ISS). Among the cargo on board Orbital ATK's Cygnus spacecraft were 15 CubeSats – microsatellites often no larger than a cereal box.

The CubeSats' journey into space was overseen by Nanoracks, a space launch service provider that works with NASA to offer access to the ISS on the various resupply vehicles that fly there. "We are a turnkey provider for these launch services," says Conor Brown, Nanoracks' external payloads manager. "So if a customer wants to launch a CubeSat, we offer the ISS commercially as a way to do that."

As well as being Nanoracks' partner, NASA is also one of its main clients and one of the 15 CubeSats on the Cygnus spacecraft was RainCube, a microsatellite carrying a precipitation-studying radar developed by NASA. RainCube, which was launched into orbit from the ISS in mid-July, marks a potential new milestone in the use of CubeSats as it is the first time one has been fitted with an active radar instrument.

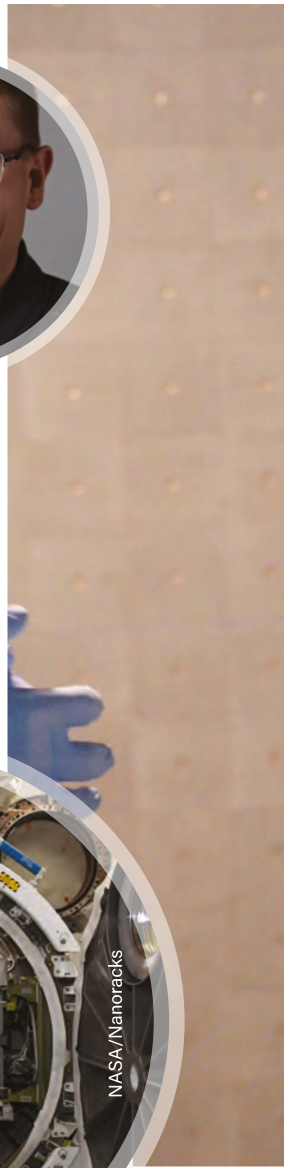
CUBESAT PROLIFERATION

CubeSats have existed since the late 1990s, when they were developed by university research departments as a cheap alternative to conventional satellites. But it's only in the past five years that NASA has taken a close interest in the technology, according to RainCube's principal investigator, Eva Peral, of NASA's Jet Propulsion Laboratory in Pasadena, California.

"Before then there was the concern that such a small satellite would only be useful as an educational tool but not for real scientific work," explains Peral. "What we're trying to prove with RainCube is that they can be used for real science."

"Spire is going to be providing data at an accuracy and in volumes of perhaps 10 times greater than they are used to now"

Nick Allain, director of PR and brand, Spire



Nick Allain, director of brand and PR at Spire

CubeSats' small solar panels means power must be used carefully

RemoveDEBRIS was launched from the ISS to address the problem of space debris

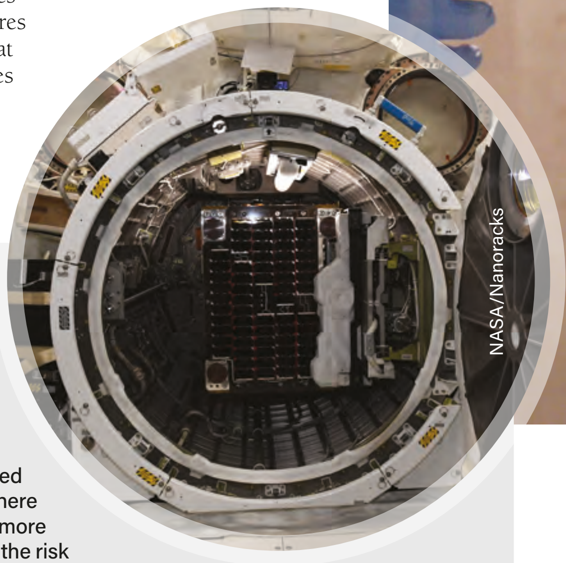
RainCube is scheduled to begin collecting atmospheric weather data in August 2018. If the trial proves successful, it could pave the way for a flood of CubeSats fitted with weather-tracking instrumentation to be launched into Earth's orbit.

"This is going to be the renaissance of weather data," says Nick Allain, director of PR and brand at Spire, a CubeSat manufacturer with offices in Glasgow and San Francisco. "The weather modeling community has been looking for better data sets since it started. And Spire, and companies like us, are going to be providing data at an accuracy and in volumes perhaps 10 times greater than they are used to now. The downstream effect will be very interesting."

The main reason for this expected proliferation is CubeSats' small size, which makes them much cheaper to put into orbit – around a million dollars or less versus the hundreds of millions it costs to get a traditional satellite into space. This, coupled with the fact that CubeSats can be developed relatively quickly, means that dozens of them can be flown into orbit in a single launch.

Nanoracks, for example, has put 208 CubeSats into orbit since it began deploying them in 2013, with its highest recorded payload standing at 33 in a single mission. Brown says, "If you look at the current ecosystem you have geostationary satellites that take daily images of entire hemispheres and you have low Earth orbit satellites that orbit at around 600km (370 mile) altitudes for higher resolutions. CubeSats could potentially replace or augment the work of those low Earth orbit satellites."

"We're very aware of CubeSats and the potential they have to help us with



NASA/Nanoracks

Are CubeSats making space unsafe?

According to the online Nanosatellite Database, as of May 2018, a total of 875 CubeSats have been launched. This quiet revolution in space technology brings with it one overwhelming danger, according to Dr Hugh Lewis, a senior lecturer in aerospace engineering at the UK's Southampton University: space debris. "Even though many CubeSats are deployed into relatively low altitude orbits, the sheer number of them could cause problems," Lewis says.

He points to a 2014 analysis he carried out that found that CubeSats had accounted for one in 20 of all close approaches with other objects – with a close approach defined as coming within 5km (3 miles) of one another. "Some CubeSats had accumulated more than 15,000 close approach events in just two or three years," he says, adding that in most cases the other object was a bigger satellite.

The risk is made worse because, typically, CubeSats lack any kind of propulsion mechanism, meaning the burden for maneuvering out of the way to avoid a collusion is placed on other space users. Lewis also worries that since most CubeSat companies are "relative newcomers to the space sector" they may be ignorant of their responsibilities for "conducting their operations in a safe and sustainable manner".

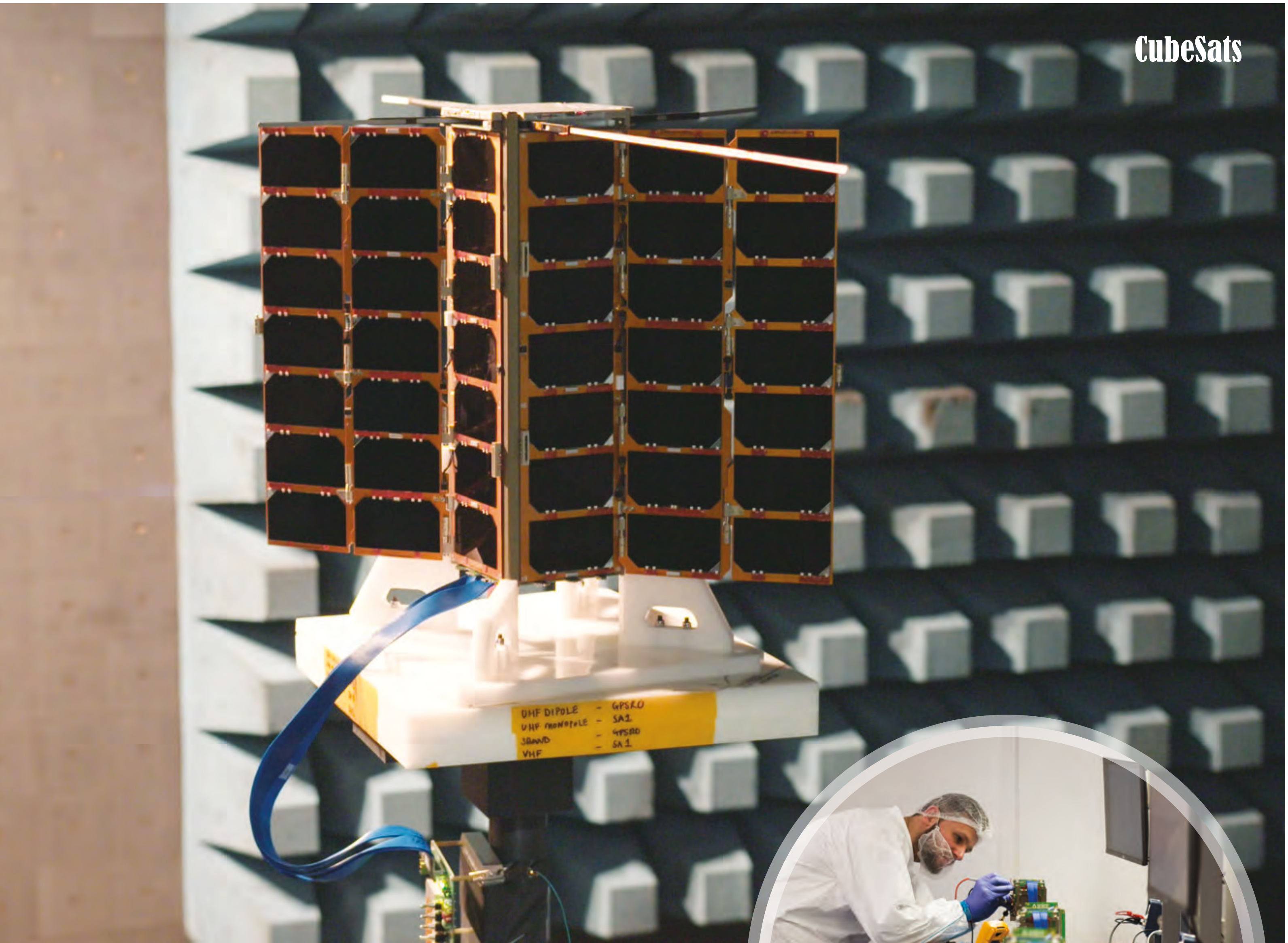
CubeSat companies deny that they are creating a hazard. Nick Allain of CubeSat maker Spire claims that because CubeSats degrade quickly and are small enough to burn up completely on re-entry, they pose less of a risk than conventional satellites. "From the point of view of space debris, we have a hard limit on how much junk is up there," explains Allain. He compares this with conventional satellites, which he says are often operated so late into their lives that there is no guarantee that the propulsion systems designed to fire them into so-called 'graveyard orbits' will work.

Lewis dismisses Allain's claims, noting that one in five CubeSats are now being deployed in higher orbits where they will degrade more slowly and where the risk of collision is greater.

A collision between a large satellite and a CubeSat would likely destroy both, according to Lewis. This is because the orbital speeds of CubeSats mean they carry "huge amounts of energy" despite their small size.

Lewis says Allain's response is "a sign that we need to do better with education and raising awareness of the space debris problem in the CubeSat community." He continues, "If things continue as they are, I would not be surprised if we see a collision involving a CubeSat in the years ahead. This would undoubtedly lead to questions about liability and, perhaps, increased regulation. I'm fairly sure that the CubeSat community does not want either of those things."

Projects to attempt to clean up are underway, however. In June RemoveDEBRIS, which attempts to address the build-up of dangerous space debris orbiting Earth, was deployed from the ISS. The mission, which is led by the Surrey Space Centre at the University of Surrey in the UK, will perform four experiments, including the first harpoon capture in orbit and a net that will be used on a deployed target. The team will test a vision-based navigation system that uses cameras and lidar technology to observe CubeSats that will be released from the main spacecraft.



Commercial manufacturing of CubeSats has made them more affordable than larger satellites

the numerical modeling we use to support our forecasting," says Dr Jim Yoe, chief administrative officer at the US National Weather Service (NWS), part of the US National Oceanic and Atmospheric Administration (NOAA).

AUGMENTING DATA

According to Yoe, the NWS's current forecasting models "rely very heavily" on polar orbiting observation satellites fitted with a number of weather-tracking instruments including sounding systems that listen for variations in microwave and infrared frequencies. These systems can be used to plot the distribution of temperature and moisture around the globe. "One of the neat things about CubeSats is that potentially we could have more of these sounders cheaply and quickly to augment the sounding data we already collect."

He believes that CubeSats would mitigate risk in the event of the loss of one of its conventional satellites. "Right now, we have a lot of satellites in our ecosystem, which means that we're not at the mercy of a single point of failure," he comments. "But with CubeSats we would have an extra layer of insurance."

Another advantage of being able to put so many of these microsatellites into space at once is that they can be constellated. In other words, a train of them can be lined up in the same orbit, short distances apart. "Constellating them opens up the possibility of being able to take continuous snapshots of these weather systems," explains Peral. "This could vastly improve our understanding of how these systems evolve over time."

COMMERCIAL INPUT

The relatively low cost of CubeSats has increased the involvement of the commercial sector in the collection of satellite weather forecasting data. NASA's RainCube might be the first CubeSat to carry active weather-tracking instrumentation, but Spire's current fleet of nearly 60 CubeSats has already been monitoring Earth's weather

NanoRacks/NASA

Nanoracks' CubeSat Deployer mechanically and electrically isolates CubeSats from the ISS

CubeSats have a lifespan of just two to three years

for several years thanks to the passive weather-tracking technology they carry – known as radio occultation.

"The technology works by listening for GPS satellite signals that have missed Earth," says Allain. "Because our CubeSats are on a different orbit from GPS satellites, we get a moment several times in each orbit when a GPS signal from a satellite on the other side of the planet actually cuts through the atmosphere instead of going down to Earth. We measure how much that signal bends and the bending angle gives us temperature, pressure and humidity readings from the ground all the way up to the ionosphere."

Spire has just completed the first stage of a NOAA trial of its radio occultation data, with the next phase set to begin at the end of the year. Yoe welcomes the growth of private sector data sources, saying that "it calls for an open mind on both sides – from both users and providers.

"We, the users, might have to be more flexible about our sources and in return the providers might have to be more flexible about getting the data in time – because operational weather models have to run on very precise schedules."

SIZE LIMITATIONS

While the small size of CubeSats is a major selling point, it also creates a number of challenges, not least of which is the problem of miniaturizing the measuring devices and communications equipment to a small enough scale that they can be fit on board the microsatellite. To circumvent the problem of miniaturization, recent generations of CubeSats have been developed to be several orders of magnitude bigger than the 10 x 10 x 10cm standard size, known in the industry as 1U. For example, the radar used in NASA's RainCube mission is fitted on a satellite six times larger than the standard – 6U in other words.

CubeSats for weather forecasting

IceCube
One of the most successful meteorological CubeSat missions to date is IceCube, a NASA microsatellite deployed from the ISS in May 2017. The bread loaf-sized satellite was outfitted with a radiometer to sense cloud ice in Earth's atmosphere. Scientists pioneered the use of submillimeter wavelength bands, a technology that already existed but had never been used in space. The mission produced the first map of global atmospheric ice distribution.

MiRaTA
The Microwave Radiometer Technology Acceleration (MiRaTA) satellite is another CubeSat mission with potential major implications for meteorology. Developed by researchers at MIT and launched in November 2017, the mission's aim is to prove that CubeSats can carry instrument technology capable of routinely collecting reliable weather data. On board the MiRaTA is a miniaturized microwave radiometer. A key component of modern weather satellites, microwave radiometers are used to measure radio frequency signals related to the thermal radiation emitted by atmospheric gases and can be used to track storms and other weather events.

ExoCube
The ExoCube, a space weather satellite developed by California Polytechnic State University, was launched into orbit in 2015 from the Vandenberg Air Force Base in California. Its mission was to measure the density of various gases in Earth's exosphere, the last layer of the atmosphere before space. However, the attempt was beset by technical problems. In the first instance, the ExoCube's antenna failed to deploy. The mission ended in failure when, after six months, radio contact was lost.

RainCube
Launched in May this year, NASA's RainCube satellite carries a precipitation-profiling radar to measure rain clouds. It is the first time a CubeSat has been fitted with an active instrument. "There have been passive instruments like radiometers, telescopes and GPS receivers, but this is the first one carrying an instrument that transmits a signal," says RainCube principal investigator Eva Peral. Also on board is a high-frequency, compact antenna. "It's going to enable not just weather applications, but also communications applications," Peral says.

NanoRacks/NASA

"When the CubeSats reach the ISS they are unpacked by crew along with the rest of the cargo"

Conor Brown, senior mission manager, Nanoracks

How to put a CubeSat into orbit

While CubeSats may be minuscule, getting them into space requires the use of some seriously big hardware – a 40m-high rocket weighing 300 tons and a spacecraft weighing another 1.6 tons, according to Conor Brown, senior mission manager at Nanoracks. Nanoracks' payload of CubeSats goes aboard one of the various commercial resupply vehicles flying to the ISS. The two most frequently used are the Cygnus spacecraft on board the Antares rocket and the SpaceX Dragon spacecraft on board the Falcon 9 rocket.

Until recently Nanoracks only launched its CubeSats as pressurized cargo inside the spacecraft. While this still goes on, Nanoracks can now also launch unpressurized thanks to a CubeSats deployer that is bolted externally to the spacecraft. "When the CubeSats reach the ISS they are unpacked by crew along with the rest of the cargo," comments Brown.

When the time comes for deployment, ISS crew members put the deployers (spring-loaded boxes designed and built by Nanoracks and used for dispensing the CubeSats into space) onto a slide table inside one of the ISS airlocks. "The airlock is opened and the slide table is extended out into space. From there, a robotic arm moves the deployer to a safe position, where we individually command the deployment," adds Brown.

Nanoracks takes charge of everything from launch until deployment, according to Brown. "We shepherd the payload through the space process so that the customer never needs to interact directly with NASA themselves."

↑ CubeSats can be maneuvered using their solar panels

However, even this has proved too small for the mission's needs, according to Peral. "The antenna is not as large as we would like," she says. "It's 0.5m, which doesn't give us the resolution we would like. We're now working with a developer to create a 1m antenna on a 12U CubeSat."

CubeSats' small size also limits their power-generation capabilities. The solar panels on conventional satellites are large enough to be able to have all their instruments switched on all the time. The much smaller panels on CubeSats means that power use must be carefully budgeted.

Allain explains, "We use a smart power management system. Since we know when we're going to be seeing GPS satellites, we can power down components when we know they are going to be using power uselessly."

The solar panels on CubeSats are not only used for energy generation, however. When the satellites are first deployed, the panels act like sails, enabling the CubeSat operator to maneuver the satellites and place them at safe intervals to avoid bunching.

This is made possible because CubeSats are deployed at low enough orbits to pick up drag from Earth's atmosphere. However, the drag also makes them more subject to wear and tear than satellites in higher orbits.

This is one of the reasons why CubeSats have such relatively short lifespans, orbiting for just two or three years before they burn up in Earth's atmosphere. In comparison, some conventional satellites stay in orbit for several decades.

CUBESAT LIFESPANS

Allain, however, believes the short lifespan works in the technology's favor, since it fosters constant updating. "The three-year timeframe is as long or longer than we need," he comments. "We look at CubeSats in the same way as you might look at your smartphone. We are up to about 15 generations of hardware design on our satellites. It changes so quickly and they get so much better so much faster. When you compare our satellites today with what we launched 12 months ago, for example, you're talking about data generation that in some cases is 10 times higher."

Nanoracks' senior mission manager, Conor Brown, agrees with this estimate: "The refresh rate is really the selling point of these CubeSats." To cope with the fast turnover rate, Nanoracks is currently developing its own commercial airlock that will be carried into space on an upcoming resupply mission and bolted onto the ISS. Brown anticipates that the company's CubeSat deployments will soon rise to 50 per year.

"Every NASA center has a microsatellites office and they're putting serious money into demonstrating the viability of these new generations of CubeSats," says Brown. "I think we are at a tipping point." ∎

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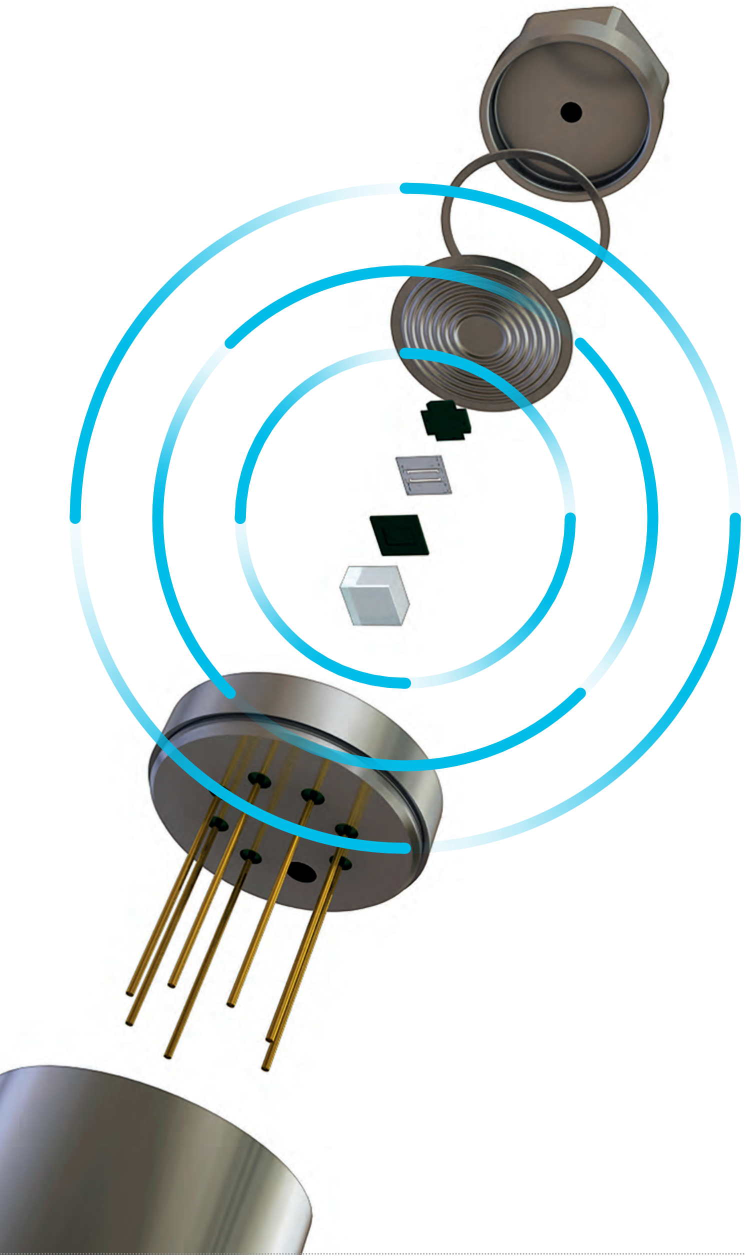

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TEST OF CONCEN

The examination of ice nuclei in the atmosphere could hold the key to more accurate snow forecasting at future Winter Olympic events

TRATION

PyeongChang cloud physics observation site

Severe weather events often affect the Winter Olympics in many unforeseen ways, with intense snow storms and extreme wind chill resulting in the cancellation or postponement of events. Weather forecasting and nowcasting in such complex circumstances often require Herculean effort.

This year's Winter Olympics traveled to PyeongChang, South Korea, with the opening ceremony taking place on February 9. This was followed by the Paralympic Winter Games, running from March 9-18.

To support the 2018 Winter Games with accurate weather predictions, the Korea Meteorological Administration (KMA) initiated the International Collaborative Experiments for PyeongChang Olympic and Paralympic winter games (ICE-POP 2018) project.

ICE-POP 2018 is a component of the WMO's World Weather Research Program (WWRP) Research and Development and Forecast Demonstration Projects (RDP/FDP) and involves observation, nowcasting, numerical weather prediction, and verification activities.

An array of radars, lidars, precipitation and cloud physics sensors were deployed around the venues in support of experimental nowcasting and very short-range forecasting products. In addition a mobile observation system, research ship and research aircraft were deployed to fill observation gaps. All experimental products were used and evaluated in various scenarios during the Winter Games and will undergo careful verification in the months and years to come.

PREDICTING SNOW SEVERITY

One of the major uncertainties in the prediction of winter weather is the amount and type of snow. Forecasting freezing precipitation during the winter months is often a difficult problem for operational models. The cloud physics process that converts supercooled water to ice and snow involves ice nucleation. This process is described in models through simple parameterizations. Several types of parameterization of ice nucleation for cloud models have been developed in the past decades, ranging from empirically derived expressions to parameterizations of ice crystal nucleation rates derived from theory. These parameterizations are put to the test by measuring the concentration of ice nuclei as a function of temperature and relative humidity.

THE 2022 WINTER OLYMPICS WILL TAKE PLACE IN BEIJING

During the ICE-POP experiment, instrumentation manufacturer Droplet Measurement Technologies (DMT) deployed its Spectrometer for Ice Nuclei (SPIN) at a site in PyeongChang adjacent to the venue of the Olympic alpine events. For the first time in South Korea, the DMT SPIN instrument obtained measurements of ice nuclei concentrations over temperature and water/ice saturation conditions typically found in precipitating cold clouds.

The work started by conducting a site survey to determine the best location for the SPIN instrument. The most suitable site was found to be the KMA Cloud Physics Observation Site (CPOS) in Daegwallyeong. The site is heavily instrumented as it is a prime location for studying winter orographic clouds that are thought to produce heavy

Dr Duncan Axisa reviewing SPIN data in PyeongChang

Spectrometer for Ice Nuclei (SPIN) manufactured by DMT

snow events. CPOS was equipped with many cloud physics sensors, including the DMT Cloud Condensation Nuclei spectrometer, DMT Fog Monitor and the DMT Meteorological Particle Spectrometer. SPIN was shipped to the site and deployed in an instrumented trailer at CPOS.

Several challenges were encountered during the deployment, including accessing the site during extreme snow events and conducting an experiment in the Olympic village. Nevertheless ice nuclei measurements were recorded during the entirety of the Olympic and Paralympic games. That data has now been collected and is being used to study the mechanisms of ice formation in clouds and the formation of snow.

So far the data analysis has revealed that ice nuclei concentrations vary from 1 to 7,000 per liter of air at temperatures from -23°C (-9.4°F) to -40°C/F and relative humidity with respect to ice of 122% to 161%. The fraction of particles activated as ice nuclei form 10^{-6} to 10^{-2} of the total aerosol population. These measurements have been compared with temperature-only parameterizations to analyze model accuracy and relevance to PyeongChang. A more accurate parametrization derived from measurements will be developed going forward, and will improve the accuracy of snow forecasts in the region.

MORE RESEARCH REQUIRED

According to the Intergovernmental Panel on Climate Change (IPCC), the level of confidence for understanding the impacts of atmospheric particles on clouds remains low. In particular the formation and lifetime of ice phase and mixed-phase clouds remain among the most uncertain. To understand and model the pathways that describe the processes of ice nucleation and formation of precipitation, more measurements are needed.

Measurements of ice nuclei concentration are challenging. The concentration of natural ice nucleating particles in the atmosphere typically range from 0.1 to 1,000 per liter of air. That is equivalent to 10^{-6} to 10^{-4} ice nuclei

Past collaborations

As was the case for ICE-POP 2018, meteorological experts combined resources to improve weather forecasting models at the 2014 games in Sochi, Russia, and the 2010 games in Vancouver, Canada:

- Science of Nowcasting Olympic Weather for Vancouver 2010 (SNOW-V10) was carried out for the observation, monitoring and demonstration of nowcasting systems with the goal of developing a winter nowcasting system over complex terrain;
- Forecast and Research: the Olympic Sochi Testbed 2014 (FROST-2014) project, applied a mesoscale ensemble prediction technique to winter weather over complex terrain and demonstrated winter nowcasting and high-resolution numerical weather prediction.

According to NASA, which contributed observational and modeling data sets for SNOW-V10 and FROST-2014, these projects made certain discoveries but also encountered several issues:

- High spatial and temporal observation is essential to obtain good measurements and prediction of severe weather elements over complex terrain;
- The development or decay of precipitation due to terrain influences needs to be considered to improve the predictability of a winter nowcasting system based on radar echo extrapolation;
- There were difficulties verifying non-traditional variables (visibility and precipitation type) despite advances in the forecasting of these variables from high-resolution models over complex terrain;
- Some verification results showed that high-resolution was better than lower-resolution but in other cases it was shown to be worse.

Over the coming months the results from ICE-POP 2018 will be used to strengthen the findings from the previous games and will contribute to a stronger weather prediction strategy for the 2022 Winter Olympics in Beijing, China.

→ DMT Fog Monitor and DMT Meteorological Particle Spectrometer

↓ Access road to physics observation site

fraction of the total particle concentration. In addition, differentiating between droplets and ice crystals using particle discrimination techniques is experimentally complex. Several mechanisms are involved in the ice nucleation process and accurate measurements have to be sensitive to each of these mechanisms.

SPECTROMETER FOR ICE NUCLEI

SPIN is the first commercially available online ice nucleating particle counter manufactured by DMT. It is a low-temperature continuous flow diffusion chamber (CFDC), which exposes particles to controlled temperature and humidity conditions. Also referred to as a parallel plate CFDC, SPIN is designed to detect and size individual ice nuclei that grow in the range of 0.5-15µm. This design is the result of a partnership between researchers at the Massachusetts Institute of Technology (MIT) and engineers at DMT.

The chamber walls are two parallel plates coated with a thin layer of ice. A temperature gradient is maintained between the two plates and water vapor and heat diffuse from the warmer to the colder wall. A laminar airstream laden with atmospheric particles flows between the plates and each of the particles is exposed to linear profiles of water vapor and temperature. Aerosol particles are surrounded by filtered sheath air restricting the aerosol flow to a narrow range across the temperature and water vapor profile between the walls.

For example, at an aerosol temperature of -24°C (-11.2°F), 134% relative humidity with respect to ice and 106% relative humidity with respect to water, the 'warm' wall temperature is set and controlled at -13°C (8.6°F) and the 'cold' wall temperature at -30°C (-22°F). In this case supercooled droplets, in addition to ice, can nucleate on the aerosol particles. Particles that nucleate grow to detectable sizes. Those that grow to form droplets can be identified using a depolarization optical particle counter, which increases the accuracy of detecting the individual ice nuclei that grow to form ice. SPIN can be operated at temperatures ranging from -5°C (23°F) to -60°C (-76°F), at relative humidity conditions that are supersaturated with respect to ice and supersaturated or subsaturated with respect to water.

SPIN can be programmed by the user to scan a number of temperatures and relative humidity settings to simulate the thermodynamic conditions that are present in cold clouds. A typical measurement consists of raising the chamber relative humidity isothermally or stepping through different chamber temperatures and relative humidities. This generates spectra of ice nuclei concentrations as a function of temperature and relative humidity with respect to ice and water. These measurements are used to construct cloud microphysical parameterizations for use in both weather prediction models and global climate models, where the precipitation produced by these models is sensitive to these parameterizations.

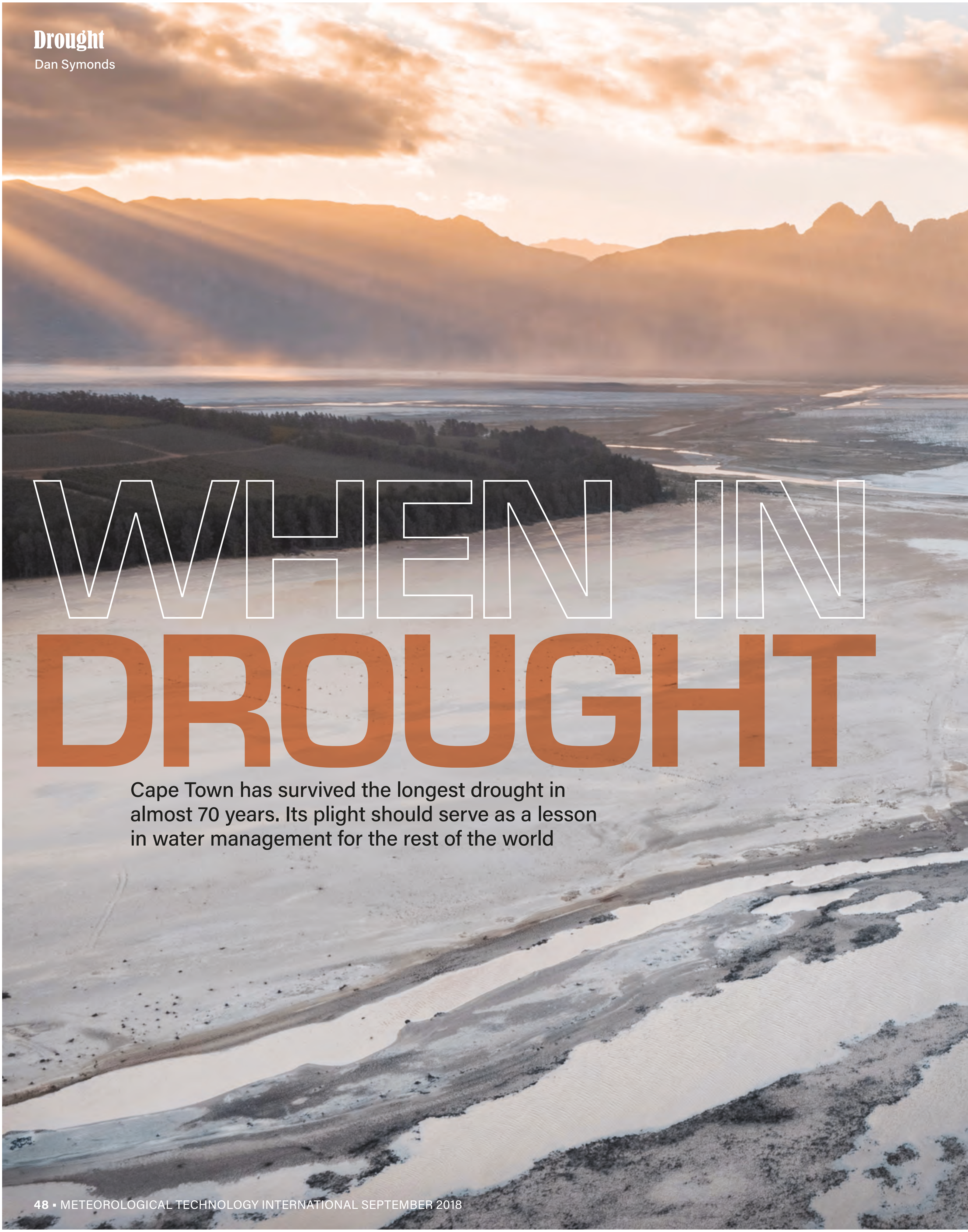
SPIN IDENTIFIES ICE NUCLEI IN THE RANGE OF 0.5-15µm

TRIED AND TESTED

In September 2015 SPIN was put to the test at the Leipzig Ice Nucleation chamber Comparison (LINC) hosted by Leibniz Institute for Tropospheric Research (TROPOS) in Leipzig, Germany. A side-by-side simultaneous comparison between SPIN and another non-commercial CFDC instrument was performed to investigate instrument specific differences. Results showed qualitative agreement. It was found that SPIN detected a higher number of ice nuclei at low temperatures and lower relative humidity. This higher sensitivity was attributed to SPIN's long parallel-plate design, which increases the residence time of the particles in the chamber, increasing the probability that a particle grows into an ice particle.

The introduction of SPIN as a commercially available ice nucleus counter is analogous to the development and commercialization of the DMT Cloud Condensation Nuclei (CCN) spectrometer. The CCN instrument is now widely used on field experiments and measurements are made with higher temporal and spatial coverage, contributing to the body of knowledge of aerosol impacts on warm clouds and precipitation. SPIN is positioned to establish a similar impact, in closing gaps in our understanding of the effect of aerosols on ice phase and mixed-phase clouds, and in understanding the chain of events that describe the processes of ice nucleation and formation of precipitation. ■

Dan Symonds



WHEN IN DROUGHT

Cape Town has survived the longest drought in almost 70 years. Its plight should serve as a lesson in water management for the rest of the world

After experiencing one of the longest droughts in living memory, running from 2015 to early 2018, Cape Town, on South Africa's southwest coast, finally received some respite after a sustained period of winter rains. Indeed, the situation had become so dire – with the driest three consecutive years on record since 1951 – that the country was only a few months away from Day Zero, a national state of emergency where the main water supply would be halted and then rationed at collection points throughout the city. Had it not been for the water conservation efforts of the port city's inhabitants, Day Zero would have arrived.

During the drought, city residents managed to cut water consumption by 60% in three years by using just 50 liters (11 gallons) or less a day per person. In July 2018, the city's water usage hit a record low of 481 million liters (106 million gallons) per day, with an ongoing target of 450 million liters (99 million gallons) per day. Self-enforced measures such as having 90-second showers instead of baths, flushing the toilet only when necessary, and washing outer garments less frequently, all contributed to a reduction in water usage. Thanks to this year's rains, water supply levels have now reached around 50%, staving off Day Zero for at least another 18 months.

Although the outlook for South Africa's water situation has vastly improved since the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Water in Cape Town's Theewaterskloof Dam fell to under 20% of its normal levels

Cape Town was within months of Day Zero

Maximizing the collection of rainfall and fresh water

According to the WMO, national meteorological and hydrological services can play a major role in ensuring that water harvesting and retention techniques are placed in the most appropriate locations. By ensuring their observation network is well distributed and maintained, meteorological agencies can gather data on typical weather variables such as precipitation and temperature, but also make observations on rivers, streams and groundwater, providing the climatological analysis needed to select the best locations. Water harvesting and retention techniques include:

- Restoration and maintenance of rivers, lakes, aquifers and connected wetlands;
- Reconnection and restoration of floodplains and disconnected meanders, elimination of riverbank protection;
- Restoration and maintenance of meadows, pastures, buffer strips and shelter belts;
- Soil conservation practices (crop rotation, intercropping, conservation tillage), green cover, mulching;
- Afforestation of upstream catchments;
- Targeted planting in order to 'catch' precipitation;
- Green roofs, rainwater harvesting, permeable paving, infiltration trenches, rain gardens, detention basins, retention ponds, urban channel restoration.

winter rains, the South African Weather Service (SAWS) remains cautious as forecasts for mid- and late-winter are uncertain. For the southern coastal regions, early indicators show below-normal rainfall conditions for late winter and early spring, meaning further challenges could lie around the corner.

UNDERLYING CAUSES

Quite simply, drought occurs when more water evaporates from the soil than precipitation falls over a prolonged period of time. For Cape Town, a three-year period of dryness resulted in combined fresh water levels reaching less than 20% at the drought's peak.

"It should be noted, however, that these low rainfall totals are not necessarily indicative of a long-term drying trend in the Cape Town area," explains Robert Stefanski, chief of WMO's Agricultural Meteorology Division. "In 2013, 1,112mm [44in] was recorded, making 2013 the sixth-wettest year since 1921, while 853mm [34in] of rainfall, which is above the average, was also recorded in 2014."

CAPE TOWN RESIDENTS WERE ASKED TO LIMIT WATER USAGE TO 50 LITERS A DAY

South Africa, with its unique geographical location, is under the influence of the subtropical ridge (also known as the high-pressure belt), which under certain conditions may cause extensive drought or, under different conditions, extensive flooding. The geographical extent and position of the subtropical high-pressure belt are affected by large-scale circulation in the tropics. Relatively minor shifts could prevent the regular influx of moisture from the tropics and southern Indian Ocean for the summer-rainfall areas and also prevent the much needed cold fronts from reaching the winter-rainfall regions. For the southwestern parts of the country – the winter-rainfall region – there is another factor called the Antarctic Oscillation (AAO), also known as the Southern Annular Mode (SAM), that comes into play.

"SAM dictates the geographical position of mid-latitude cyclones, of which cold fronts are part," says Cobus Olivier, scientist – prediction research, SAWS. "The interaction between the subtropical ridge and the AAO makes for an extremely complex system that influences the weather over the southwestern parts of the country, and hence seasonal forecasts for this tend to be quite unreliable."

The long drought may be the prevailing reason behind Cape Town's water shortage, but it is by no means the only factor. The population of Cape Town has doubled in the past 20 years, whereas the water supply capacity has not increased proportionately, leading to the accelerated depletion of water levels.

"Although it is projected that some regions in South Africa will become drier in future, it is not possible to say whether the recent drought can mostly be attributed to climate

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change," says Dr Andries Kruger, chief scientist: climate data analysis and research, SAWS. "Drought itself is a meteorological issue, but it should be recognized that proper planning for population growth is necessary."

This is a notion shared by Stefanski, who refers to the combination of such factors as a region's vulnerability to drought: "Drought is a complex natural hazard and the impacts associated with it are the result of numerous weather and climate factors, and many societal factors define the level of resilience of the society. Population growth and redistribution, as well as changing consumption and production patterns, are two of the factors that define the vulnerability of a region, economic sector or population group. Many other factors, such as poverty and rural vulnerability, weak or ineffective governance, changes in land use, environmental degradation, environmental awareness and regulations, and outdated or ineffective government policies, also contribute to changing vulnerability."

LESSONS LEARNED

Globally speaking, South Africa can be considered a relatively dry country with total rainfall averaging 500mm (20in) each year. This figure is 820mm (32in) for Cape Town. For this reason, drought always poses a greater ongoing concern for inhabitants compared with other countries around the world. Therefore, it is essential to prepare as well as possible and provide suitable infrastructure to help cope with the expected conditions. In the Gauteng region of South Africa, for example, cities are less vulnerable to drought as they are fed by the Vaal Dam and secondary Katse Dam in Lesotho, both of which are much bigger than Cape Town's current water reserves.

"The best action that cities and countries can undertake is to bring together all of the stakeholders to develop drought polices and make an integrated plan," says Stefanski. "There are three aspects to this: drought monitoring and early warning; vulnerability and impact assessment; and mitigation, preparedness and response."

Now that the rains have arrived, there is a high probability that areas of farmland will experience difficulties with erosion following the extended dry period.

"As in other countries, South Africa has numerous alien plant species," says Stephanie Landman, lead scientist: post-processing, weather research, SAWS. "These species prevent the capturing of excess run-off and contribute to large-scale erosion leading to destruction of farmland and forestry (vineyards in Western Cape). To combat this, natural fauna and flora might prevent or at least limit the impact of periods of low rainfall."

This is a concern also shared by the WMO, which has set out a series of guidelines on how to maximize the collection of rainwater and mitigate some of the damage caused by flooding (see *Maximizing the collection of rainfall and fresh water*, previous page).

FUTURE PREPARATION

South Africa possesses a comprehensive rainfall measurement network, but the majority of SAWS-operated rainfall stations are manual, with an observer taking readings on a daily basis. The conversion of these stations to automatic stations would increase the reliability of SAWS' measurement network and would also make the data available sooner.

"Efforts should always be made to increase the spatial density and reliability of the observational network," says Kruger. "In this regard, the latest automatic rainfall station technology is important, as these stations can be situated in places where the daily physical measurement of rainfall is not possible. In addition, the temporal frequency of measurements is greatly improved (every five minutes versus daily for manual stations). Furthermore, the crowd-sourcing of rainfall

The Integrated Drought Management Programme

WMO and Global Water Partnership established the Integrated Drought Management Programme (IDMP) to support stakeholders at all levels by providing policy and management guidance and by sharing scientific information knowledge and best practices for integrated drought management.

There are currently more than 35 partner organizations in IDMP, including the United Nations Food and Agriculture Organization and the United Nations Convention to Combat Desertification (UNCCD). The main role of meteorological organizations is to provide the weather and climate observations and to monitor drought by means of indices that use rainfall, soil moisture and other physical variables.

Residents conserved water by taking short showers rather than baths

Locals waiting to collect natural spring water

The Theewaterskloof Dam is Cape Town's primary water supply

Automatic weather stations would help improve network coverage

measurements from volunteer observers could supplement the official observation network in future."

For developing countries such as South Africa, the biggest challenge in building these observational networks is securing adequate funding. The maintenance of a network is costly, having to support regular visits to the stations, maintaining quality control of the measurements and acquiring and maintaining the technology needed to store and disseminate large amounts of data. According to Stefanski, this is where organizations like the WMO can contribute with initiatives such as the Integrated Drought Management Programme (see previous page).

"The world's national meteorological and hydrological services can make a difference by ensuring that their observation network covers the most sensitive drought-prone areas," he says. "Increased monitoring capabilities, including the expansion of automated weather station networks, satellites and the internet, are contributing to better monitoring systems. The internet enables improved access to critical data and information to assist in climate and drought assessments, while also facilitating the delivery of this information through a wide range of tools or decision-support products to users in many sectors."

While first-world nations benefit from more accurate prediction models afforded by such networks, it is worth bearing in mind that drought is now considered a global issue. Although direct links with global warming may yet be unsubstantiated, there is no doubt that large parts of Europe, Asia and the USA have experienced a prolonged heatwave this summer, with agricultural concerns and water restrictions in Dublin, Ireland, and Olso, Norway. In the USA, areas of southern California and Arizona are also experiencing severe drought, while Japan has endured a prolonged period of record-breaking temperatures.

AVERAGE ANNUAL RAINFALL FOR CAPE TOWN IS 820mm

Although water levels may not reach the same critical levels as in Cape Town, the experience should serve as a stark reminder to city planners to adjust water infrastructure in line with population growth. Nothing can be done to prevent drought, but efforts can certainly be made to better prepare against water scarcity and to help improve the reliability of seasonal forecasting methods.

"Many cities suffer from some form of water scarcity," concludes WMO's Stefanski. "Naturally occurring drought will only exacerbate already-present water scarcity issues." ▮

How they did it

- Cape Town hotels removed bath plugs so guests could only shower;
- Some restaurants refused to serve tap water to customers;
- Several car hire firms stopped washing their vehicles;
- A prestigious restaurant launched a pop-up kitchen that served food only on paper plates;
- Hair salons gave discounts to customers who washed their hair at home;
- Some car washes used only non-potable water;
- Residents used biodegradable, eco-friendly detergents to wash clothes so that water could be recycled in the garden;
- Residents prepared food in big batches and opted for steaming over boiling;
- Buckets were left in the shower to collect run-off water for use elsewhere;
- Residents were asked to use water-free home cleaning products;
- Ninety-second military-style showers were taken, rather than baths;
- Locals and visitors were asked to avoid flushing the toilet unnecessarily.

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T H E W O R L D O F W E A T H E R D A T A

David J McLaughlin, professor of electrical and computer engineering, University of Massachusetts, USA

DOWN TO EARTH

Short-range X-band radar has emerged over the past decade as a valuable supplement – perhaps even a future alternative – to today's long-range weather radars

Long-range microwave radars are an important part of the weather forecasting and warning infrastructure used by many nations. After decades of technological improvement, today's weather radars have unprecedented capability to map storm motion and structure. Yet a fundamental limitation of long-range weather radars is the inability to observe the lower part of the troposphere due to Earth's curvature and terrain blockage.

Taking the USA as an example, the radars of the WSR-88D or NEXRAD network are spaced more than 230km (143 miles) apart. Earth's curvature prevents this network from observing more than 70% of the troposphere below 1km (0.6 miles), as shown in Figure 1. Detection and forecasting of weather near ground level relies on extrapolation of observations aloft. This leads to high false alarm rates, missed detection of hazards, and large errors in estimation of precipitation near ground level, where people live.

The radars in the WSR-88D network, like those in other operational civil infrastructure radar networks around the world, are physically large, high-power systems. Designed for long-range (100km+ [60 miles+]) coverage through heavy precipitation, these radars must operate at S- and C-band wavelengths not subject to

Raytheon's low power phased array radar (Image: Raytheon Company)

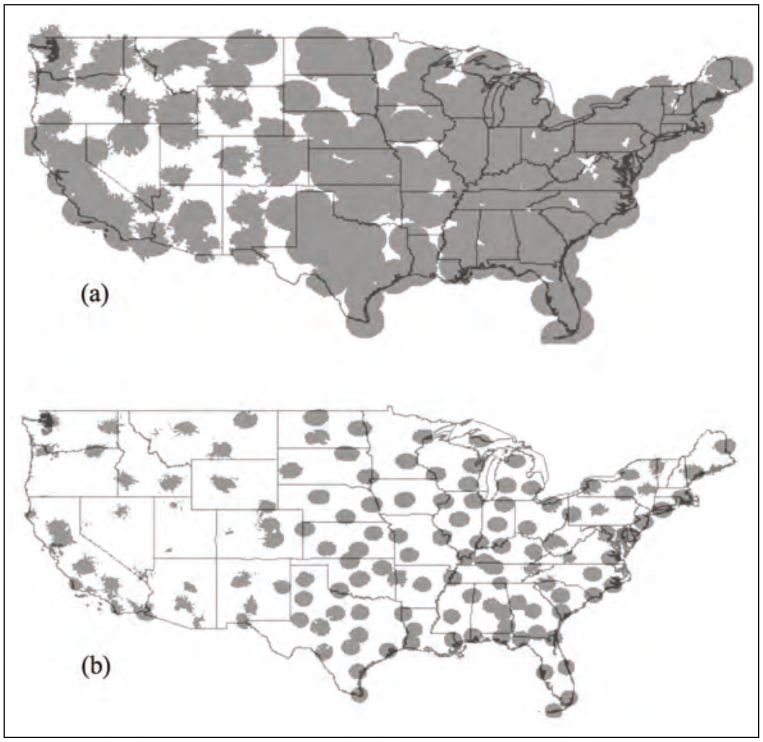


Figure 1: NEXRAD radar coverage in the USA is nearly complete at 3km (1.9 miles) altitude (top). Coverage at 1km (0.6 miles) altitude (bottom) is limited to regions in close proximity to the radar sites, owing to Earth's curvature

> "This technology is based on smaller, lower-cost, shorter-range radars"
>
> David J McLaughlin, University of Massachusetts, USA

substantial attenuation. This requires large antennas to achieve narrow antenna beams and kilometer-scale spatial resolution throughout the coverage region. High-power transmitters are needed to meet minimum sensitivity requirements, and large mechanically scanned antennas require dedicated land, towers and other support infrastructure. The acquisition cost for each site – including radar equipment, land and other installation costs – is several million dollars per radar, and the annual per-radar operating and maintenance cost of the USA radars has been estimated to be US$500,000.

The large size of these systems, combined with potential environmental effects, limits the availability of potential installation sites. The strategy for deploying national radar networks such as this is to site radars where low-altitude coverage is most needed, while minimizing the number of radars in the network as a means of controlling the costs of the system.

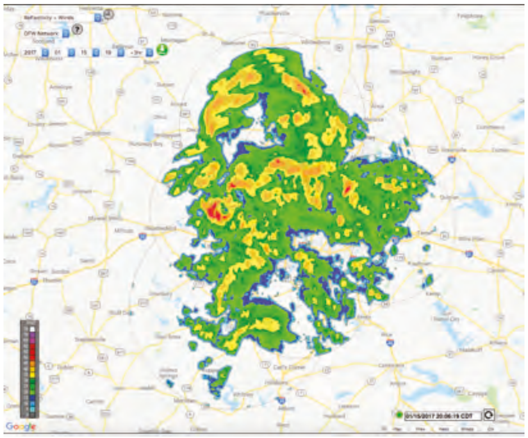
The increasing need for improved coverage at low altitudes, particularly in the planetary boundary layer, is associated with numerous applications, including improved hazardous weather forecasting and warning, wind mapping for firefighting and tracking airborne toxic release, more accurate precipitation estimation for flood alerts and sewer management, monitoring bird migration, and enhanced roadway weather.

Beyond weather, a USA report on Homeland Defense and Civil Support noted: "The nation will need to develop an advanced capability to replace the current generation of radars to improve tracking and identification of low-altitude threats." Such needs cannot be met with networks composed of long-range radars because of the fundamental inability of such systems to provide comprehensive low-altitude coverage.

THE EMERGENCE OF X-BAND WEATHER RADAR

X-band weather radar has emerged over the past decade as a new tool for weather hazard forecasting and warning. This technology is based on smaller, lower-cost, shorter-range radars. The radars are typically configured in 'dense networks' with radars communicating with one another and adjusting their sensing strategies in direct response to the evolving weather and to changing user needs. In contrast to the larger C- and S-band radars, X-band antennas are as small as 1m (3.3ft) in length and radars are spaced tens of kilometers apart.

To investigate the storm-mapping capability of this technology, the participants in the Collaborative Adaptive Sensing of the Atmosphere (CASA) project fabricated and deployed a set of four small radars in southwest Oklahoma in 2006. The radars, shown in Figure 4, use 1.2m (3.9ft) antennas and 10kW transmitters (the peak power level of a small magnetron transmitter or 100W solid-state transmitter with 20dB pulse-compression gain). Although the



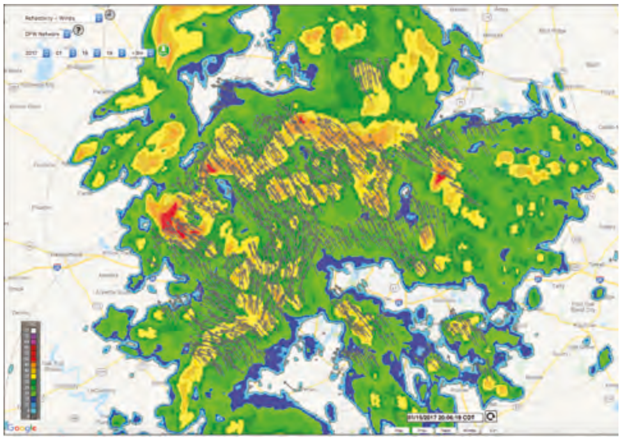


Figure 2: (Left) Seven-node CASA network comprising X-band radars from four vendors (Image: Brenda Philips, University of Massachusetts)

Figure 3: (Right) Wind vector field derived from overlapping coverage in CASA's Texas network (Image: Brenda Philips, University of Massachusetts)

radars are much smaller and transmit much less power than C- and S-band radars, they are capable of mapping storms in fine detail, even during very light precipitation, when range is limited to tens of kilometers.

Figure 5 shows the single-pulse signal-to-noise ratio (SNR) for these radars when observing very light precipitation characterized by a radar reflectivity factor Z of 6.5dBZ. The left-hand image of Figure 5 shows that a single radar is capable of observing light precipitation (SNR >0dB) to 30km (18.6 miles). The right-hand image shows gap-free coverage obtained via a network of such radars spaced 30km apart.

X-band radars are being deployed today in applications including gap-filling in operational radar networks, drainage basins for active water management, tactical deployments for military troops, mobile deployments for firefighting, and in numerous research networks around the globe. The generally small size of X-band radars allows them to be placed on existing infrastructure elements such as modest-sized towers, rooftops and mobile platforms. The limited range of individual radars defeats the Earth curvature blocking problem suffered by long-range radars, and when arranged in networks comprising multiple radars, X-band technology can comprehensively map damaging winds and heavy rainfall from the tops of storms down to the boundary layer, beneath the view of today's networks.

X-BAND ANTENNAS ARE AS SMALL AS 1M (3.3FT)

CASA operates an experimental network of X-band radars in the Dallas/Fort Worth metroplex in Texas, USA. The seven radars in this network have been supplied by four different market-leading vendors. Figure 2 shows a high-resolution reflectivity mosaic produced by this heterogeneous mix of radars. V Chandrasekar from Colorado State University reports that Quantitative Precipitation Estimates (QPE) derived from this network are comparable to, or better than, QPE derived from rain gauges in the region. The overlapping coverage of the radars enables multi-Doppler retrievals of the wind vector field, as illustrated in Figure 3. Images such as this provide better characterization of severe storms as well as wind hazards to aviation, such as downbursts and windshear events.

Figure 4: Prepping the CASA radars prior to installation (Image: Apoorva Bajaj, University of Massachusetts)

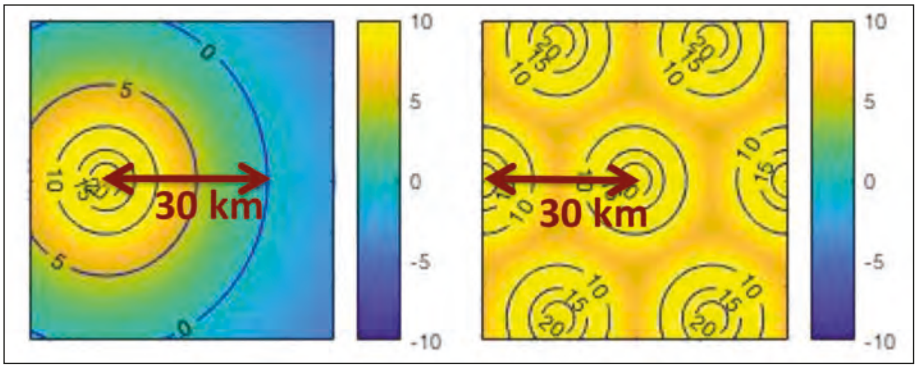


Figure 5: Signal-to-noise (SNR, in dB) plots for a single small X-band radar (left) and a network of radars spaced 30km (18.6 miles) apart (right)

INTERNATIONAL DEPLOYMENTS

Japan's Ministry of Land, Infrastructure, Transport and Tourism has deployed a network of 38 dual-polarization X-band

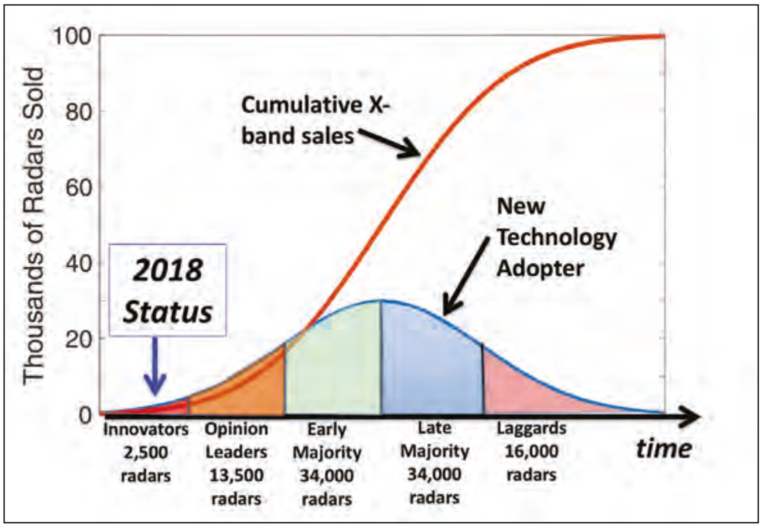


Figure 6: Technology diffusion roadmap illustrating adoption of X-band weather as 100,000 radars are purchased and deployed over time

radars that spans the entire country and operates in conjunction with the national C-band radar network. The composite system is providing better precipitation estimation than would be achieved by the C-band network alone.

Blanket deployment of many small radar nodes across an entire country is but one of several possible future deployment strategies for this technology. Additional strategies include selective deployment of smaller networks in heavily populated areas, geographic regions particularly prone to wind hazards or flash floods, valleys within mountainous regions, and in specific regions where it is particularly important to improve observation of low-level meteorological phenomena.

MeteoFrance has deployed X-band radars in its operational weather radar network to cover specific regions where the long-range radars have problematic gaps. The results of these early deployments, and the many research papers stemming from the research trials, will undoubtedly improve our understanding of the capability and the potential for dense X-band radar networks. These early trials will likely impact future adoption of the technology.

COST-EFFECTIVE PHASED ARRAY RADAR ON THE HORIZON

Electronically scanned phased array antennas are a key technology in radars produced for defense applications and can be an enabling technology for the dense X-band radar networks described here. Phased arrays permit flexibility in beam steering without requiring rotating antenna pedestals. As such, they do not require maintenance of moving parts and are more robust with respect to component failure. Moreover, phased arrays can potentially be mounted on the sides of towers and buildings, giving greater flexibility in the selection of installation sites.

Figure 7 is a conceptual design of a three-face phased array weather radar developed by FIRST RF Corp. The 1m (3.3ft) diameter structure is shown attached to a lightweight telescoping mast to support transportable, rapid deployment.

This phased array radar is envisioned for deployment in both monostatic (co-located transmitter and receiver) and bistatic (transmitter and receiver spaced tens of kilometers apart) configurations, as well as operation as part of a dense network.

Raytheon Company has reported on its development of low-power phased array radar based on a 1m^2 (10.8ft^2) active electronically scanned array (AESA) technology. The company's dual polarization phased array radar, now in its third design iteration, is capable of precise tracking of drones and other low-flying aircraft in addition to simultaneously performing high-resolution weather mapping. The technology is envisioned for deployment of single units near airports as well as in dense networks with multiple interacting radars spaced 30km apart. The company reports it has done a low-rate initial production run of the radars for testing and development purposes and will be ready for deployment of the technology as early as 2019-2020, with large-scale production thereafter. ∎

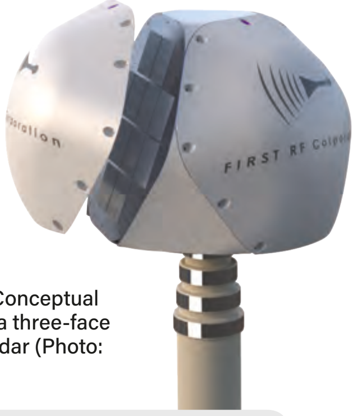


Figure 7: Conceptual design of a three-face phased array radar (Photo: FIRST RF Corp)

Mass deployment of X-band technology

Where any new disruptive technology is concerned, it is difficult to forecast the future with accuracy. There are some 2,000 large radars (S-band and C-band) deployed globally today. At 30km spacing, and depending on lay-down topology, 50 short-range X-band radars would be needed to cover the range of a single large radar. This represents a global deployment of roughly 100,000 X-band radars. Figure 6, based on Gaussian technology diffusion theory, is a speculative roadmap for adoption and deployment of 100,000 X-band radars.

Diffusion of new technology, such as smartphones, into the market has been characterized by a sequence of various customer groups, having different interests and characteristics, adopting the new technology over time. A Gaussian – or bell – curve characterizes the number of units purchased and deployed by the various adopter groups, with 'Innovators' representing the first adopters and making the first 2.5% of all eventual purchases. Next, 'Opinion Leaders' make 13.5% of total purchases, followed by the 'Early Majority' (34%), 'Late Majority' (34%) and eventually 'Laggards' (remaining 16% of purchases), all of whom together represent 100% adoption and all purchases and deployments of the technology.

There are, perhaps, around 300 X-band radars deployed today. Based on the assumption that 100,000 X-band radars will eventually be deployed, Figure 6 indicates that adoption is currently within the Innovators category. Innovators tend to be those who are technology-oriented, have immediate problems to solve, and have some willingness to take risks with new technology.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Volker Wulfmeyer, Andreas Behrendt, and Diego Lange, Institute of Physics and Meteorology, University of Hohenheim

HIGH PROFILES

A highly accurate Raman lidar is combining operational water vapor and temperature profiling with high temporal and range resolutions to achieve a breakthrough in weather forecasting and climate research

The observation of atmospheric moisture and temperature profiles is essential for the understanding and prediction of Earth system processes. The 3D fields of temperature (T) and water vapor (WV) are fundamental components of global and regional energy and water cycles. They determine the radiative transfer through the atmosphere and are critical for the initiation of convection, as well as the formation of clouds and precipitation. Therefore it is expected that the assimilation of high-quality, lower tropospheric WV and T profiles will result in a considerable improvement in the quality of weather forecast models particularly with respect to forecasting extreme events.

However, there is a severe lack of techniques to provide T and WV profiles, so the lower troposphere must be considered *terra incognita* with respect to its moisture and temperature distributions. This critical gap in data is severely limiting advances in weather forecasting, as well as climate and Earth system research (Wulfmeyer et al. 2015).

The required accuracy and resolution of T and WV profilers was determined by WMO working groups as a 5 to 10 minute averaging time, as well as 0.5-1K and 2-5% relative error for humidity, in combination with a vertical resolution of 100-300m in the lower troposphere. Passive infrared and microwave remote sensing systems cannot fulfill these requirements due to their strong degradation of independent vertical information, e.g., resulting in a vertical resolution of only 500-1,000m at a height of 1,000m above ground (Turner and Löhnert 2014, Wulfmeyer et al. 2015).

Fortunately, over recent years, active remote sensing techniques such as WV and T rotational Raman lidar (WVTRL) have considerably advanced, so it is now possible to measure these profiles operationally in all climate regions with extraordinary resolution and accuracy (Hammann et al. 2015, Behrendt et al. 2015). A first data assimilation study using TRL profiles demonstrated a huge positive impact on the analysis of temperature fields in a mesoscale weather forecast model (Adam et al. 2016).

Accurate, high-resolution measurements can be realized in all climate regions. This has been confirmed by simulations of WVTRL with end-to-end performance models, which is straightforward and credible, as the lidar equation uniquely depends on atmospheric and system parameters. Figure 1 (overleaf) demonstrates corresponding simulations. Excellent daytime performance can be achieved in all climate zones with errors considerably less than the WMO breakthrough requirements for nowcasting, very short-range forecasting, and high-resolution NWP from the surface to approximately 3,000m for WV and even higher into the lower troposphere for T.

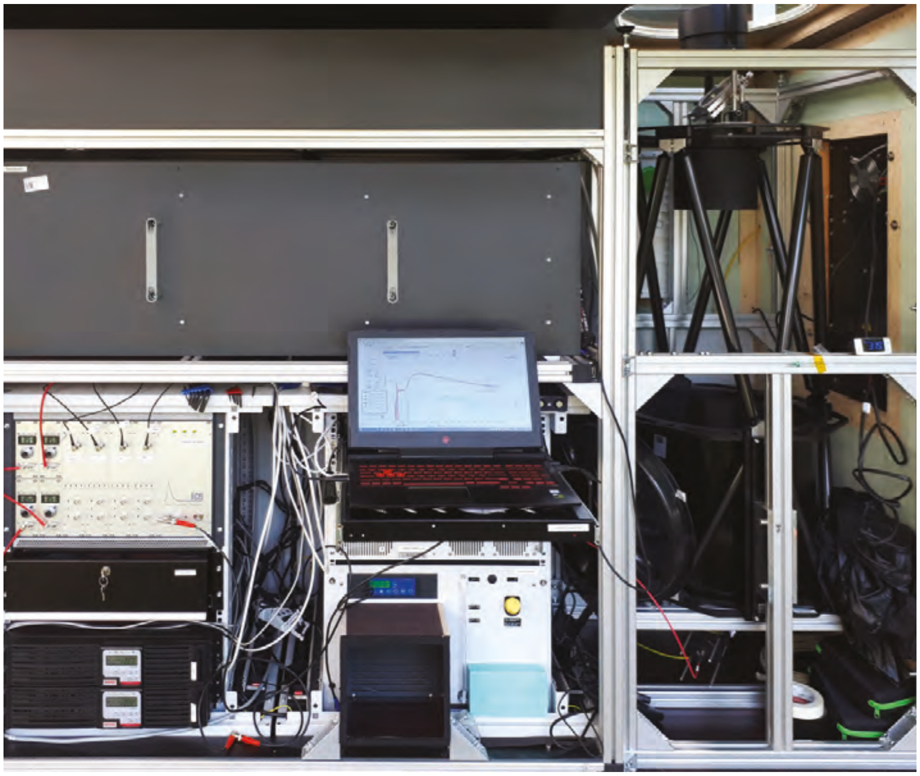
During the night, this performance is even better and also permits routine profiling of WV and T to the upper troposphere. Note that the performance demonstrated in Figure 1 must not be fixed to the corresponding resolutions, but trade-offs are possible to adapt them to users' needs, such as increasing the temporal resolution for turbulence measurements and for the 2D or 3D scanning of WV and T fields.

RAMAN LIDAR METHODOLOGY

A lidar measures backscatter signals from laser pulses that are transmitted to the atmosphere. The backscattered radiation is collected by a receiver consisting of a telescope, a series of filters for selecting signals of interest and for daylight background suppression, detectors and a data acquisition system. Due to the considerably higher frequency of the electromagnetic radiation employed by a lidar compared to a radar, molecular and particle backscatter can

Compact automatic T and WV Raman lidar. Image: Industrial Design by Weinberg & Ruf

Interior setup of the lidar system



be detected in clear air, which is generally not possible with cloud or weather radar. Therefore lidar systems provide unique information about the pre-convective environment, as well as the environment around clouds and precipitation which is so critical for advanced weather forecasting.

The special feature of a Raman lidar (RL) is the measurement of inelastic frequency-shifted signals due to Raman scattering of WV, oxygen and nitrogen. These signals are directly proportional to the number densities of the corresponding molecules. Furthermore, the pure rotational Raman signals depend on ambient temperature. Therefore the RL technique can be used to measure WV and T profiles simultaneously with a combination of these different signals.

In the case of WV Raman lidar (WVRL), the WV Raman backscatter signal $P_{R,WV}$ is divided by a temperature-independent combination of two rotational Raman signals P_{R,O_2,N_2} detected close to the elastic signal (Behrendt et al. 2002). The WV mixing ratio can be determined in dependence of range by taking their ratios according to:

$$m(r) = K_m \frac{P_{R,WV}(r)}{P_{R,O_2,N_2}(r)}$$

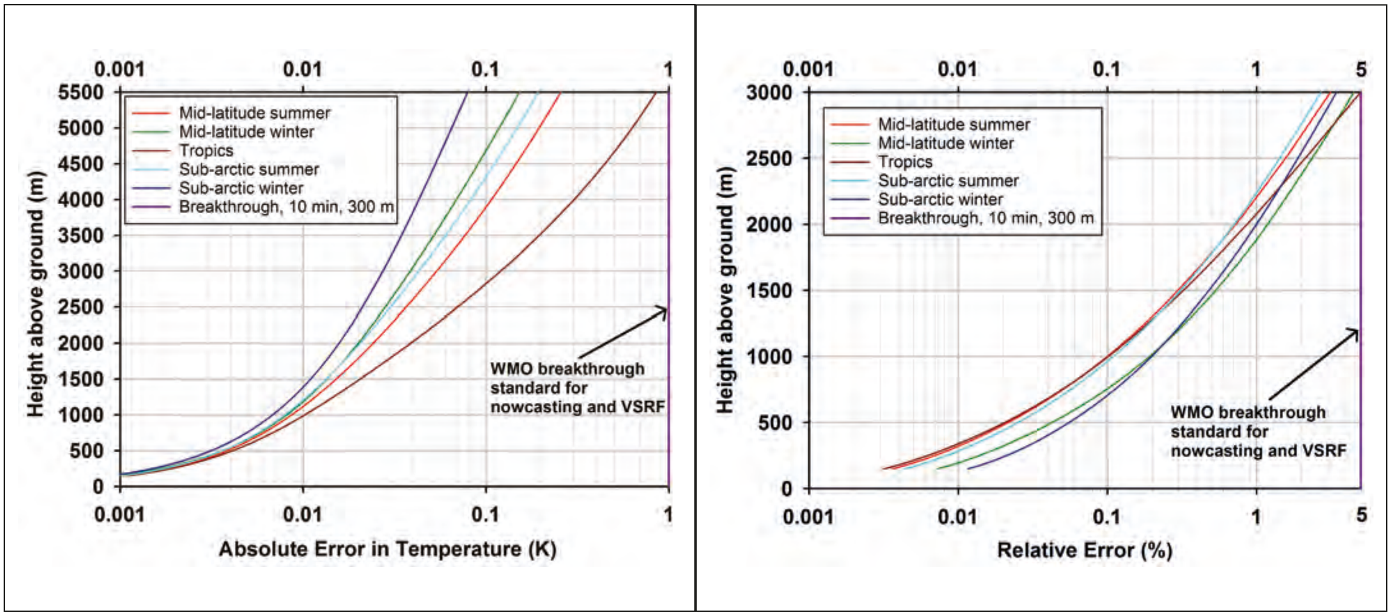


Figure 1: Analysis of state-of-the-art WVTRL in different climate regions. The expected errors during daytime are shown for resolutions of 300m and 10 minutes, respectively. Left panel: absolute error of temperature measurements. The breakthrough requirements of WMO for WV and T profiling with respect to nowcasting and very-short range weather forecasting (VSRF) are also shown. Right panel: relative error of mixing-ratio measurement

The system constant K_m can be determined by comparison with other sensors such as narrowband WV differential absorption lidar (WVDIAL), radio soundings, other *in situ* sensors, or a theoretical analysis of the receiver transmission functions. In a variety of publications it has been confirmed that the system constant K_m of a well-engineered WVRL is very stable in time, so that very good long-term stability and accuracy of the WV profiles can be achieved (Turner et al. 2002).

In the case of TRL, two signals of the rotational Raman spectrum close to the elastic signal are received with two interference filters. One filter detects the signal at high rotational quantum numbers (P_{RRH}) and another at low rotational quantum numbers (P_{RRL}). As the temperature sensitivities of these signals are different and all other range-dependent influences cancel out, the ratio Q of the signals becomes merely a function of temperature, hence:

$$Q(r) = \frac{P_{RRH}(r)}{P_{RRL}(r)} = f[T(r)]$$

This equation can easily be inverted so that a temperature profile in dependence of range can be measured. Similar to WV profiling also for T profiling, a calibration is necessary, in this case using three time-independent calibration constants *a, b,* and *c* (Behrendt 2005) so that:

$$T(r) = F[Q(r), a, b, c]$$

A huge advantage of WVTRL is that both T and WV profiles are measured using one laser transmitter and a single receiver that detects the three Raman backscatter signals as described above. The result is a very compact, reliable and robust active remote sensing system. Furthermore, several variables can be derived such as relative humidity, virtual temperature, and buoyancy, from the signal intensities, not only WV and T profiles but also their uncertainty profiles are provided by error propagation in near real time (Wulfmeyer et al. 2016).

The unique performance of TRL with respect to accuracy as well as vertical and temporal resolutions is confirmed in Figure 2. Now it is not only possible to perform routine temperature profiling in the lower troposphere during daytime, but also to detect turbulent fluctuations. Figure 2 reveals an interesting evolution of the temperature field as well as the location and the strength of the inversion layer. This is likely due to a combination of horizontal advection and vertical turbulent transport of heat.

If an averaging time of just five minutes is used, the temperature profile presented in Figure 3 can be derived. An example around 21:23 UTC is shown, which was daytime at the site. The result confirms the outstanding performance of TRL to resolve the vertical structure of temperature with extraordinary vertical resolution, enabling inversion layers and lids to be detected and quantified. This is very important for process studies and data assimilation. The same resolution and performance with respect to water vapor profiling has already been demonstrated in various publications (see Wulfmeyer et al. 2010, Turner et al. 2014).

KEY SYSTEM COMPONENTS

The performance of a WVTRL depends on several system components. A key component is the laser transmitter, which should provide high single-shot pulse energy, high repetition rate and good pointing stability. This laser transmitter should operate in the UV region, as this ensures eye-safe operation and increases the Raman scattering cross-section.

In recent years a breakthrough has been achieved in the development of diode-laser pumped, compact Nd:YAG lasers. These lasers are nearly maintenance-free for long periods of continuous operation (over two years) and can be frequency-tripled to the UV. It is clear that this advance is highly beneficial for the routine and operational application as well as the commercialization of WVTRL. Nowadays these lasers can be delivered with a pulse energy of >100mJ and a repetition rate of >200Hz at a wavelength of 355nm, which ensures excellent daytime performance while still being compatible with eye-safety requirements.

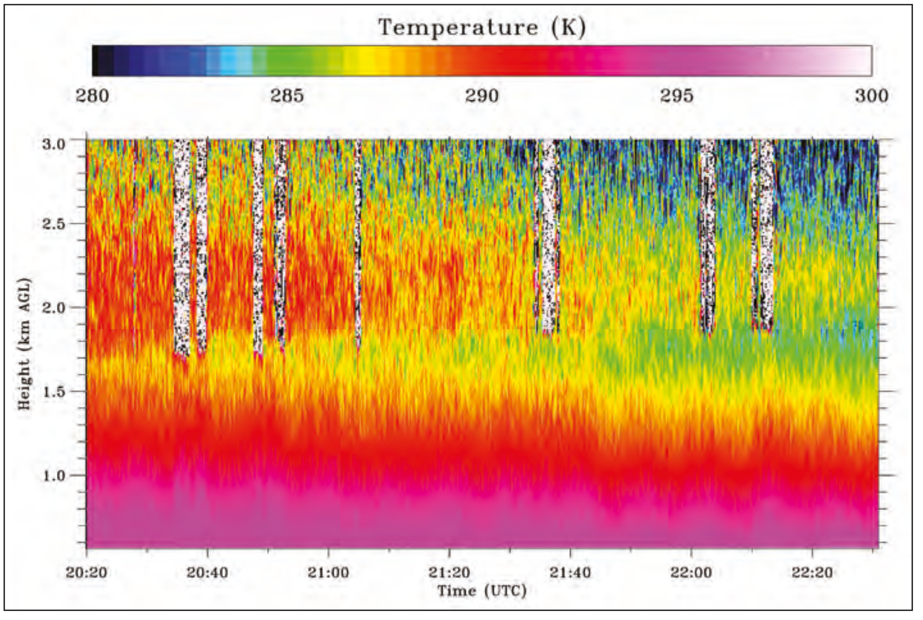


Figure 2: Time-height cross-section of a temperature measurement performed with TRL during the Land-Atmosphere Feedback Experiment for the Atmospheric Radiation Measurement program.[1] The accuracy of the profiles is approximately 0.2K and the resolutions are 10sec and 100m, respectively. The black and white areas are due to clouds. The cloud base is approx. 100m below these areas, as the lidar can even penetrate a part of the clouds

The other key component is the receiver for the detection of the Raman signals. A medium-sized telescope with a primary mirror diameter of 30-40cm is sufficient to collect large enough backscatter signals. Due to recent advances in filter technology it is possible to produce stable narrowband, interference filters in the UV region with high transmission and excellent side-band suppression. These filters allow for a strong reduction of the daylight background and avoid any leakage of the elastic signal in the Raman channels even in the presence of boundary layer clouds, which eliminates systematic errors.

SUMMARY AND OUTLOOK

We demonstrated a breakthrough of the Raman lidar technique for daytime and night-time WV and T profiling with high resolution and accuracy from the surface to the lower troposphere. A comprehensive methodological analysis of WVTRL confirms excellent performance in all climate regions exceeding the WMO breakthrough requirements for nowcasting, VSRF, and high-resolution NWP in the lower troposphere. Typically, range-resolved measurements of WV mixing ratio can be performed with an error of less than 5% up to 3km using a temporal resolution of 10 minutes and a vertical resolution of 300m under all climate conditions.

Vertical measurements of T can be performed with an error of less than 0.5K and the same temporal and vertical resolutions up to 4.5km. In the daytime convective boundary layer, measurements of both WV mixing ratio and T are possible with turbulence resolution (10s) and enabling scanning applications (Behrendt et al. 2015). The night-time performance, e.g., for studying the nocturnal planetary boundary layer, is even much better due the absence of daylight background.

Due to the relatively low power requirement and the compact setup of the new generation of WVTRL systems, ground-based stations and networks can be applied for:

- Climate monitoring;
- Verification of weather, climate, and earth system models;
- Data assimilation for improving weather forecasts;
- Process studies;
- Calibration of passive remote sensing systems such as microwave radiometers, Fourier transform infrared spectrometers as well as radio soundings.

A very short latency of the delivery of data within minutes, including all error profiles and the error covariance matrix, is possible. This performance serves the next generation of very fast rapid-update-cycle data assimilation systems for nowcasting and short-range weather forecasting very well.

It is important to note that the assimilation of these thermodynamic profiles will also considerably advance the impact of radar data assimilation. Currently the assimilation of radar data suffers from the missing knowledge of the thermodynamic environment around clouds and precipitation, resulting in severe model imbalance problems. A new synergy of WVTRL and radar networks would reduce these imbalances considerably increasing the benefit of radar observations. Additionally, in the future it is possible to operate corresponding lidar networks not only over land but also over the ocean on ships or buoys, enhancing the coverage of thermodynamic lidar networks.

By improving the average power of the laser transmitter, its pulse energy, and the efficiency of the receiver, the accuracy and resolution of the measurements can further be increased. Therefore this new measurement capability should be strongly considered as part of the future ground-based observing system. Furthermore, airborne and space-borne operation of WVTRL has been demonstrated (Whiteman et al. 2010) or is being considered in upcoming satellite missions such as the next ESA Earth Explorer mission (Di Girolamo et al. 2018). ∎

1. www.arm.gov/research/campaigns/sgp2017lafe

Note from author: The funding of the ACROSS project (see http://across-project.de) by BMBF and HGF in Germany is highly appreciated

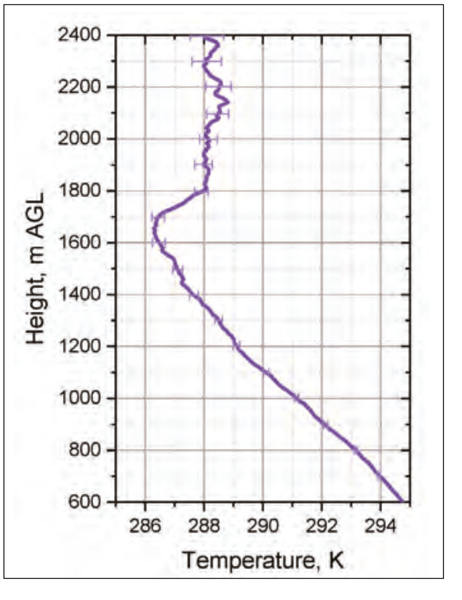


Figure 3: Temperature profile extracted from Figure 2 at 21:23 UTC averaged over 5 min. The vertical resolution is 100m. The inversion layer and its strength of approximately 2K/300m are revealed

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Meteorological Technology World Expo 2018, taking place in Amsterdam, Netherlands, is set to be the biggest weather forecasting and observation event ever!

Meteorological Technology World Expo 2018, taking place in Amsterdam, Netherlands, on October 9-11, is the must-attend event for any company or organization looking for next-generation weather forecasting and climate change measurement technologies and services. Now in its eighth year, this truly global exhibition is expected to attract 200 exhibitors and 4,000+ attendees from over 100 countries. This year's event will host the WMO's prestigious CIMO TECO-2018 conference, which will be followed by CIMO-17 from October 12-16.

Graham Johnson, managing director of UKi Media & Events, the company behind Meteorological Technology World Expo, says, "I'm particularly proud of the fact that the World Expo will this year host the WMO's CIMO TECO-2018. We know that its addition will attract more visitors to the event than ever before, but also that it will help attract some of the most senior industry figures from around the world."

On the exhibition floor there will be more new product launches for next-generation forecasting technologies than ever before. This includes radiometers from Davos Instruments (p68); solar spectral sensors from Spectrafy (p68); sonic wind sensors from LCJ Capteurs (p71); 3D-printed automatic weather stations by COMET/UCAR (p74); hydrogen generators from Nel Hydrogen (p76); the Modbus meteorological sensor suite from Lambrecht (p83); infrasound sensors from Seismo Wave (p81); scalable dataloggers from CAE (p81), and much more.

The event will also host three technology workshops on the expo floor, hosted by Leosphere, Metek and Stevens Water.

This guide looks at the best technologies on show, highlights key conference sessions and identifies important networking opportunities at the three-day event, including the free-to-attend drinks reception, sponsored by Earth Networks, being held in the exhibition hall at 5:30pm on Wednesday, October 10. Alongside the CIMO TECO conference, MeteoSwiss and the WMO will be hosting a special workshop on October 11 looking at how the OSCAR tool can benefit the entire industry.

The International Forum of Users of Satellite Data Telecommunication Systems (Satcom Forum) will be holding its Satcom 2018 workshop on October 9-11, and the recently launched Global Weather Enterprise will hold a two-day session about better data sharing on October 11-12.

"The whole event this year adds up to be the place for debate, discussion and partnerships to be formed," comments Johnson. "Meteorological Technology World Expo was conceived with one purpose in mind: to find ways to improve weather forecasting and make climate-change measurement more accurate. The 2018 show, which features more exhibitors than ever before, is yet another huge step to that becoming a reality."

To register for the free-to-attend event in Amsterdam, visit www.meteorologicaltechnologyworldexpo.com.

EXHIBITOR NEWS...

FLEXIBLE AND RUGGED SENSING SOLUTION

FIRST-TIME EXHIBITOR

Introducing a new line of solar spectral sensors at this year's event, first-time exhibitor **Spectrafy**'s SolarSIM combines simple, rugged hardware and advanced analytics to provide data about broadband solar irradiance (GHI, DNI), spectral solar irradiance, UV-A and UV-B radiation, PAR, aerosols, water vapor and the ozone layer.

The sensors have been evaluated at WRC events such as IPC XII and FRC IV and were calibrated to NIST standards. Spectrafy claims a highly stable design and unparalleled resolution.

SolarSIM also boasts a flexible and versatile architecture, integrating functionalities that would previously have required two or more instruments. The pricing structure is designed so that customers only pay for the features they use, as functionalities can be easily added later, as and when required.

▸ **SPECTRAFY BOOTH 6030**

SOLAR RADIOMETRY

Reference radiometers from **Davos Instruments** are precise representations of the WRR standard, guaranteeing long-term stability and low uncertainties. They are intended for outdoor calibrations of solar sensors where low uncertainties are crucial. The instruments are used by national and regional radiation centers and leading calibration laboratories.

At Meteorological Technology World Expo, the company is launching its new radiometer control unit for high-precision solar irradiance measurements. The unit is compatible with the PMO6cc absolute solar radiometer sensor. It can provide higher measurement cadences, more reliable measurements and comes with a state-of-the-art user interface that has been specifically designed to facilitate installation, operation and calibration.

With the new radiometer control unit, existing PMO6 radiometers can also be upgraded. The control unit is ready to operate the next-generation (PMO8) sensors that are currently under development at Davos Instruments.

To collect precise solar irradiance data, a proper traceability chain and high-quality instrument calibration are crucial. Situated in Davos, Switzerland, Davos Instruments is a spin-off company of the World Radiation Centre (PMOD/WRC), which hosts the World Radiometric Reference (WRR) for solar irradiance. With this in mind, the company is an ideal partner for high-precision solar irradiance measurements and calibrations.

Visitors to Davos Instruments' booth are encouraged to try the new radiometer control unit and user interface at Davos's booth using their own smartphone or tablet.

FIRST-TIME EXHIBITOR

▸ **DAVOS INSTRUMENTS BOOTH 9070**

The event is expected to attract around 200 exhibitors and 4,000+ attendees from over 100 countries

CIMO TECO-2018

OCTOBER 8-11

The World Meteorological Organization (WMO), under the auspices of the Commission for Instruments and Methods of Observation (CIMO), will host the 2018 Technical Conference on Meteorological and Environmental Instruments and Methods of Observation (CIMO TECO-2018) at this year's Meteorological Technology World Expo in Amsterdam, Netherlands.

Instrument experts from national meteorological and hydrological services, research institutes and the private sector will address four key topics at CIMO TECO-2018: characterization and standardization of environmental measurements – traceability assurance; emerging measurement technologies: from development to operation; ensuring sustainability of measurements; and measurement and integration challenges in the next 20 years.

This year, the WMO had an outstanding response to its call for papers for the conference, with more than 220 high-quality abstracts submitted from all WMO regions. For an insight into some of this year's presentations see *Top Picks* on page 86.

To learn more about CIMO TECO-2018, view the preliminary program and to register to attend, visit: www.wmocimo.net

Hukseflux Thermal Sensors

THE CHEESE AND WINE WMO POSTER SESSION

Tuesday, October 9
5:30pm

Sponsored by Hukseflux Thermal Sensors

ROAD CONDITION SCANNING

Environmental sensor developer, **Teconer**, has recently supplied mobile units for road condition and surface temperature monitoring to several maintenance companies and to the Meteorological Service of New Zealand (MetService).

MetService selected Teconer's devices for specific deployments in the road-weather data acquisition network after a pilot sensor-assessment process and a data acquisition trial. The trial aimed to expand road-weather observation assets by evaluating the meteorological integrity and potential utility of a range of very precise vehicle-mounted sensors for monitoring road-weather conditions across a network.

The Teconer mobile monitoring system reports winter road surface conditions, friction, surface temperature, dew point temperature and water layer thickness. Information is presented on a user-friendly interface called the Road Condition Map (roadweather.online), where data can be viewed on the map or as graphs. Photographs can be taken by mobile devices in vehicles and are then integrated into the same interface.

Teconer develops and markets mobile road measurement systems based on optical sensor technology. The collected data is very useful to winter maintenance operators for planning their activities effectively and to forecast providers for the enhancement of the quality and precision of their services. Furthermore, the monitoring system provides valuable assistance to airport operators in using runway capacity to its full potential.

▸ TECONER BOOTH 9050


Visit us at MTWE 2018 Stand #10028
MPL
MPL
Delivering fast, reliable, high-resolution aerosol and cloud measurements from the ground to the troposphere

TECHNOLOGY WORKSHOPS

Key suppliers will be taking to the exhibition floor to showcase their latest solutions for the meteorological sector. **Workshops confirmed so far include:**

LEOSPHERE
Wednesday, October 10
10:30am-12:30pm

METEK
Wednesday, October 10
2:00pm-4:00pm

STEVENS WATER
Thursday, October 11
10:30am-12:30pm

PRODUCT LAUNCH

CUSTOM CREATIONS

Boasting its own integrated research and development facility, **LCJ Capteurs** has the flexibility to design and produce sensor units tailored to the customer's specifications. This can be a custom variation of an existing product or a specific unit built from scratch. All sensors are factory tested with data logged against each serial number.

LCJ Capteurs has introduced a new ultrasonic wind sensor at every Meteorological Technology World Expo since 2014, and this year is no exception. The company will present the latest member of its CV7 range with a model powered by its own solar panel, making it extremely well-suited for remote installations.

All sonic wind sensors can be directly run by a PC or any other equipment with normalized 0-10V, 4-20mA, SDI-12, NMEA or potentiometer inputs, making them particularly useful for integration with autonomous weather stations (AWS).

The first CV7 sensor was launched on the market 10 years ago, with more than 14,000 ultrasonic wind sensors delivered since 1999 on every continent. LCJ Capteurs' sensors have proved their build quality, reliability and accuracy in the harsh marine environment and are now widely used in other fields for applications such as smart buildings, smart city installations, amusement parks, public fountains, sport installations, air quality stations, agriculture and the IoT.

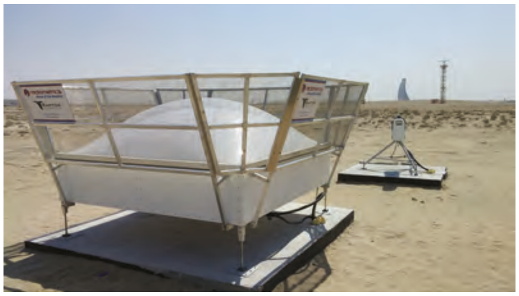
▸ LCJ CAPTEURS
BOOTH 11072

DISCOVER AN EXPECTED
200 EXHIBITORS!

THERMODYNAMIC PROFILING

Radiometrics, a developer of remote sensing systems, will introduce the MP-AQ100 at Meteorological Technology World Expo. The MP-AQ100 is a low-cost thermodynamic profiler optimized for air quality managers and researchers. The company will also present the SkyCast wind and thermodynamic profiling system, which provides continuous, real-time profiles of boundary layer wind, temperature and humidity. SkyCast systems for aviation weather support utilize VizAir software to deliver alerts and other weather decision support tools optimized for airports. Radiometrics has installed SkyCast systems at Abu Dhabi International Airport, and on Dongsha Island, Taiwan. A SkyCast system typically incorporates a boundary layer or tropospheric radar wind profiler, an MP-3000A thermodynamic microwave profiler, and optionally an AWP-4000 acoustic wind profiler (sodar) for high-vertical resolution low-level winds.

▸ RADIOMETRICS
BOOTH 3025



NEW PRODUCT

USER-FRIENDLY WEATHER RADAR

Expanding on its X-band weather radar line with the company's most affordable weather radar for rainfall and Doppler monitoring to date, **Furuno** is excited to introduce its WR110 single-polarity model.

The WR110's compact dimensions and self-contained design make it easy to transport in most standard vans. Setup is uncomplicated, as it uses a normal household power supply. Once up and running, the system boasts low power consumption and requires very little routine maintenance, thanks to the design of its solid-state core. The WR110 joins the dual polarimetric WR-2100, which is one of the smallest and lightest dual polarimetric weather radars available. Multiple WR-2100 radars can be networked to extend the total range, and the WR110 fits into existing networks.

▸ **FURUNO ELECTRIC BOOTH 8020**

SOIL MOISTURE SENSORS

▸ **DELTA-T DEVICES BOOTH 3000**

Delegates in search of the latest developments in soil moisture sensing technology should stop by **Delta-T Devices**' booth, since the company will be demonstrating its range of soil sensors for different applications. The SM150T, which is positioned as a more cost-effective solution, boasts ±3% moisture accuracy; the ML3 ThetaProbe improves that accuracy to ±1%. For monitoring soil moisture profiles down to 1m (3.3ft), Delta-T offers the PR2 Profile Probe, which is available in both analog and SDI-12 versions.

In addition to its soil moisture sensors, Delta-T will present its sunshine pyranometer. The SPN1 measures global and diffuse radiation in addition to sunshine state. It gathers all these function into one compact instrument with no moving parts. Output from an SPN1 enables the calculation of direct normal irradiance.

Attendees can see technology in action during the vendor technology workshops, which will be held on the exhibition floor

PRODUCT UPDATE

ENVIRONMENTAL SENSORS

The UK division of **Campbell Scientific** will exhibit the most recent versions of its digital sensors, dataloggers and solutions for environmental monitoring. Products on display this year include Campbell's CS136 optical sensor for cloud height and the CS216 temperature and relative humidity probe. The CS136 improves on its CS135 predecessor with a more compact, lightweight design. It uses lidar to determine the height of clouds and aerosols above the instrument.

The company will also feature its Konect cloud-based data-collection software, WxPRO weather station, ClimaVUE 50 compact digital weather sensor, SoilVUE digital profiler, CS320 digital thermopile pyranometer and the CR1000X datalogger.

▸ **CAMPBELL SCIENTIFIC UK BOOTH 6005**

NEW SOLUTION

LOW-COST WEATHER STATION

Promoting its initiative to develop and deploy low-cost weather instrumentation globally, the **University Corporation for Atmospheric Research** (UCAR) will be at Meteorological Technology World Expo to demonstrate its 3D-printed automatic weather station (3D-PAWS), which can be used as a low-cost surface observation solution for less developed, data-sparse regions of the world. The current design consists of a three-cup anemometer, wind vane, tipping bucket rain gauge and sensors for temperature, relative humidity, light and pressure.

The system is designed to be adapted and installed using locally sourced materials. Sensor operation, communication and data archiving are controlled using a low-cost Raspberry Pi computer, which is installed in a waterproof housing on the instrumentation frame. Power can be supplied using a 5V input or through a battery with solar power backup.

Communications with the 3D-PAWS system are achieved with a direct network connection, wirelessly or through an adapter or GSM cell.

▸ **COMET/UCAR BOOTH 6070**

NEW PRODUCT

ATMOSPHERIC MEASUREMENTS

The newly launched r-weather atmospheric multisensor from **Boschung Mecatronic** is a compact instrument that measures air temperature, relative humidity, dew point and air pressure, as well as precipitation intensity, type and quantity in a single enclosure. When combined with a mechanical or ultrasonic wind-speed and wind-direction sensor, the r-weather forms one of the most comprehensive atmospheric measuring instruments available.

This new generation of atmospheric sensors, kicked-off by the r-weather, will focus on maximum reduction of maintenance during operations. The self-cleaning process of the r-weather avoids the presence of dust, spider webs or any other obstruction in the optics and an integrated heating system further reduces complications.

Due to its sturdy design, measurements can be conducted in harsh meteorological conditions, including next to motorways for road weather information systems (RWIS), airport runways for airport weather observation systems (AWOS), and on the coast for coastal navigation systems.

▸ **BOSCHUNG MECATRONIC BOOTH 8030**

WHERE TO EAT IN AMSTERDAM

RIJKS CUISINE: DUTCH

The restaurant belongs to the Rijksmuseum – a national gallery dedicated to the art and history of Amsterdam – and serves up Michelin-starred food from executive chef Joris Bijdendijk that takes its inspiration from ingredients grown and raised on Dutch soil.

Address: Museumstraat 2, 1071 XX Amsterdam
Distance from exhibition center: 4.7km (2.9 miles)
Opening hours: Mon-Sat 11:30am-3:00pm, 5:00-10:00pm, Sun 11:30am-3:00pm

DAALDER CUISINE: EUROPEAN

Two Michelin-starred Daalder combines high-quality food with a relaxed and cheerful atmosphere. Diners choose from a three-, four-, five- or seven-course meal with dishes decided by Chef Dennis Huwaë.

Address: Lindengracht 90, 1015 KK Amsterdam
Distance from exhibition center: 15.5km (9.7 miles)
Opening hours: Lunch Fri-Mon 12:00-2:30pm; Dinner Thu, Fri, Sun & Mon 6:00-10:00pm, Sat 7:00-10:00pm

YAMAZATO CUISINE: JAPANESE

Michelin-starred authentic Japanese kaizeki cuisine is served by kimono-clad waitresses in minimalistic surroundings with views over a Japanese garden. Dishes include seasonal menus, à la carte dishes, sushi and the restaurant's trademark bento box.

Address: Ferdinand Bolstraat 333, 1072 LH Amsterdam
Distance from exhibition center: 2.6km (1.6 miles)
Opening hours: Lunch Sat & Sun 12:00-2:00pm; Dinner Mon-Sun 6:00-9:30pm

FOODHALLEN CUISINE: MIXED

Foodhallen is the first indoor foodmarket in the Netherlands, offering a variety of local food stalls, restaurants and cafés. Visitors can enjoy live music, nine art-deco cinema screens, and specially brewed blond beer, Gleuvenglijder.

Address: Bellamyplein 51, 1053 AT Amsterdam
Distance from exhibition center: 5.4km (3.4 miles)
Opening hours: Sun-Thu 11:00am-11:30pm, Fri & Sat 11:00am-1:00am

YERBA CUISINE: INTERNATIONAL

Yerba opened in February 2018 and offers sustainable plant-based dishes using local produce. The restaurant offers a seasonally changing à la carte tasting menu, or the chef can create a meal for you. All dishes are available as vegan, vegetarian or omnivore.

Address: Ruysdaelstraat 48, 1071 XE Amsterdam
Distance from exhibition center: 3.7km (2.3 miles)
Opening hours: Thu-Mon 6:00pm-close, Sat & Sun 11:00am-3:30pm (brunch), 6:00pm-close

SERVICE PROVIDER

SATELLITE SERVICES

Founded in 1986 to supply weather and climate-related satellite data, images and products for member and cooperating states, the **European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)** is an intergovernmental organization whose goal is to improve the daily lives of European citizens and to ensure their safety.

EUMETSAT achieves its goals by operating a system of meteorological satellites that continuously observe the atmosphere and the ocean and land surfaces. They aid meteorologists in identifying and monitoring the development of potentially dangerous weather situations and in issuing timely forecasts and warnings to emergency services and local authorities. This way, the effects of severe weather can be mitigated, and people's lives and property can be protected as much as possible. This information is also critical to ensuring the safety of air travel, shipping and road traffic, and for the daily business of farming, construction and a number of other industries.

▸ EUMETSAT BOOTH 13045

EARTH OBSERVATION

A renowned producer of integrated solutions for Earth observation and remote sensing systems, **Scisys** has improved its 2met! product line-up with a number of features that enable it to deal with all current and future satellite technology and data.

2met! is Scisys' range of components, systems and applications for a variety of Earth observation satellites (MSG, GOES, NOAA, METOP, FengYun, TERRA/AQUA, NPP, JPSS, Himawari, Sentinels) operating in various frequency bands (L-, C-, X- and Ku-band). The 2met! products also support telemetry standards in line with the CCSDS standards.

The new generation provides platform-independent solutions focusing on future mission requirements from EUMETSAT's Meteosat third generation (MTG), EUMETSAT's Polar System second generation (EPS) and the European Space Agency's Sentinel satellites. There are new front-end features, new processing algorithms, and 2met! supports GOES-16 satellite data via EUMETCast.

Scisys will also showcase Pleniter, its integrated software suite for the planning, implementation and operation of complete satellite missions. It builds on the extensive ground segment experience Scisys has gained from supporting more than 50 space missions.

PRODUCT DEBUT

▸ SCISYS BOOTH 6025

The CIMO TECO-2018 conference will be held October 8-11, followed by CIMO-17 from October 12-16

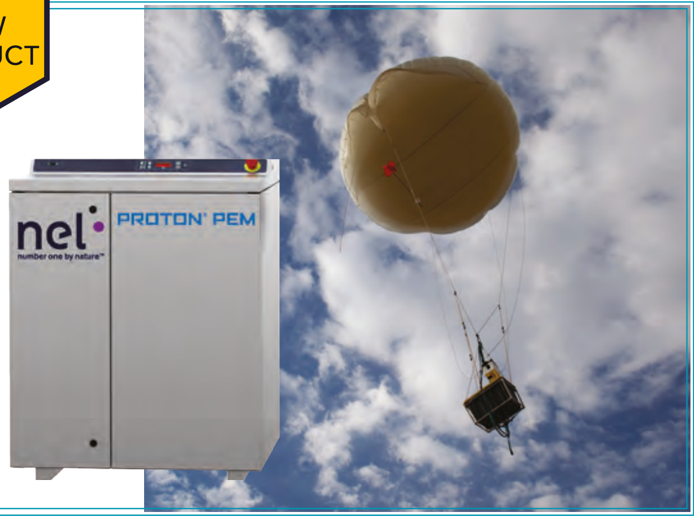
NEW PRODUCT

ON-SITE HYDROGEN GENERATORS

Launched this summer, Proton on Site and **Nel Hydrogen** will present the third generation of the S series proton PEM hydrogen generator.

Rugged and compact, it can be deployed even in remote locations where delivering a gas supply may be problematic. Using just electricity and water, the third-generation hydrogen generator can produce hydrogen wherever and whenever it is needed, at volumes of 0.26Nm^3/hr to 1.05 Nm^3/hr. Nel Hydrogen's on-site generators boast a compact build, no hazardous chemicals and minimal maintenance requirements.

▸ NEL HYDROGEN BOOTH 6000



EXTREME WEATHER DRONES

Unexpected extreme weather events such as thunderstorms, hail and fog cause extensive damage at great commercial cost. It is acknowledged by weather experts that in order to improve forecasting accuracy, and to provide greater visibility of the likelihood of such extreme weather events, there is the need to deal with a massive data gap in meteorological observations in the planet's boundary layer.

To overcome this problem, **Meteomatics** developed a range of high-quality purpose-built Meteodrones. The data that is currently missing from the global weather models becomes available by flying Meteodrone missions from ground level up to 3,000m (9,840ft) every 15 minutes while continuously recording temperature, humidity, pressure and wind data. These measurements can then be processed in Meteomatics' own high-resolution weather model, which has already been proved to provide more accurate forecasts for Switzerland.

Fast acquisition and computation of data is the key element for many business processes, whether it's dealing with data from weather stations and forecasting, or even satellite and radar images. The customized Meteomatics Weather API supports users with their weather-based processes with a fast way to access Meteomatics' extensive weather database.

▸ METEOMATICS BOOTH 8035

INTEGRATED WEATHER INFORMATION SOLUTION

Combitech, which is part of the Saab group, will showcase i-MET, its concept of integrated weather products for aviation, road, sea and military applications.

Visitors to Meteorological Technology World Expo will be able to experience demos of AWOS7 and ATIS7, two parts of the solution.

The i-MET concept includes a number of systems for weather information, but integrates them seamlessly, ensuring reliability and ease of use. i-MET interfaces and integrates sensors and systems, and all can be monitored and controlled through the now improved admin tool, available both locally and through remote support. Technical and maintenance personnel will also benefit from the integrated status and fault analysis tool, which features both physical and logical views.

AWOS7 (Automatic Weather Observation System) and ATIS7 (Automatic Terminal Information Service) have been expanded with a digital runway incursion warning system (DRIWS) and improved integration with airfield condition reports and breaking action measurements. In addition, the functionality for interfacing and integrating sensors and systems from various suppliers has been enhanced, as has the remote support feature.

▸ COMBITECH BOOTH 9040

PRODUCT UPDATE

SERVICE PROVIDER

CRITICAL DATA TRANSFER

With a track record of providing comprehensive information management services to the aviation, rail and critical infrastructure sectors, **Rockwell Collins** is a trusted partner for sending critical, secure messages and content over its ARINC Global Network, as well as providing a wide range of value-added applications, meeting the needs of the aviation industry. At this year's Meteorological Technology World Expo, Rockwell will demonstrate how this network supports its comprehensive weather services including winds, turbulence and icing, and tools to meet the challenges of global convective weather.

▸ ROCKWELL COLLINS
BOOTH 4008

Meteorological Technology World Expo will host Satcom 2018 on October 9-11, and the GWE Weather Enterprise Conference on October 11-12

SENSOR MONITORING

Darrera's booth will feature live demos of the firm's new Weathercloud monitoring platforms for roads, harbors, heliports, solar farms and air quality in smart cities. Weathercloud aids the monitoring and managing of all sensor data through a versatile and fully customizable application. Since the application is web-based, it is directly compatible with any device.

Weathercloud provides management tools including custom-designed dashboards, dynamic plots, advanced reports, and configurable alarms and notifications. In addition, it is also a publicly accessible platform that shows the real-time data from over 10,000 stations around the world.

▸ DARRERA
BOOTH 7014

TECH WORKSHOP SPOTLIGHT:

STEVENS WATER

Soil physics workshop

▸ Thursday, October 11, 10:30am-12:30pm

Knowledge of soil moisture and the measurement of soil moisture help society answer some important questions about drought, flood forecasting, greenhouse gas emissions, food security and crop production. This course will focus on the science of the analytical measurements of soil water content and water potential. From an applications-in-the-field perspective to a more theoretical approach, this course provides tools, information and insight for users of soil moisture sensors and soil moisture data.

▸ STEVENS WATER
BOOTH 6045

DURABLE WEATHER SENSORS

UPDATED PRODUCT

Exhibiting since 2011, **Optical Scientific** (OSi) has further improved its DSP-WIVIS family of sensors, which combine present weather, precipitation and visibility measurements. It reports that all of its 1,100 first-generation LEDWI present weather sensors that were fielded during the 1990s are still in operation today.

In addition, the company has recently expanded its AWOS weather systems business. It is now fielding FAA-certified AWOS-AV systems for domestic small airports, along with its modular AWOS (MAWOS) system. The latter can be configured for a wide range of applications, from small weather stations to large international airports. New on the MAWOS system for this year are the ATIS-like features.

▸ **OPTICAL SCIENTIFIC BOOTH 5035**

DISCOVER AN EXPECTED 200 EXHIBITORS!

WMO

WORKSHOP SPOTLIGHT: METEOSWISS

in association with the WMO

OSCAR/Surface instrument catalog

▸ **Thursday, October 11**

This workshop will look at the Observing Systems Capability Analysis and Review Tool (OSCAR), which is being jointly developed by the WMO and MeteoSwiss. OSCAR is a web-enabled catalog of environmental observing systems worldwide. The workshop will introduce OSCAR/Surface and will demonstrate how instrument manufacturers can raise their profile by contributing to the instrument catalog. It will also give manufacturers a chance to provide input on the tool in order to better serve their needs. To read more about OSCAR, see *Metadata Management* on page 26.

DATALOGGING INNOVATION

Building a remote wireless sensor network with datalogging capabilities requires a suitable channel of communication, and with LoRa (long range), the right technology has arrived. LoRa uses unlicensed bands of the radio frequency spectrum below 1GHz. Smart modulation makes it possible to cover large frequency ranges without the need for hopping and repeaters, while using very little power.

With this in mind, **Your Data Our Care (YDOC)** has developed its own LoRa-based wireless sensor network (WSN) for efficient data transmission and control of sensors.

In YDOC's network, a datalogger acts as network master, dictating the network rhythm and servicing up to 60 WSN motes (sensor nodes). When a datalogger wakes up to take samples, it will in turn wake up all the motes in its network and instruct them to take samples and transmit their measured values.

Because there is no need for a continuously powered gateway, the whole wireless network uses low power. Logger and sensor motes are available with several power provisions (such as a compact integrated solar panel) as it is not practicable to power a serious sensor with batteries.

At regular intervals, the logged data will be transferred over the cellular network in common data formats by FTP, HTTP or MQTT. This way, data does not pile up in an impractical proprietary cloud server and it can be easily downloaded and processed through a user-specific application.

▸ **YOUR DATA OUR CARE BOOTH 10055**

SPEAKER INTERVIEW

SATCOM 2018

Featuring the EUMETSAT Satellite Data Collection Systems workshop

▸ October 9-11

The chair of the International Forum of Users of Satellite Data Telecommunications (Satcom Forum), Mike Prior-Jones, talks to *MTI* ahead of this year's Satcom 2018 conference

What is Satcom Forum?

Satcom Forum is an international group for those interested in the use of satellite communications within environmental sciences. It had its first formal meeting in 2016, and is jointly managed by the WMO and the Intergovernmental Oceanographic Commission (IOC).

What is the main aim of Satcom Forum?

We're a sort of information clearing-house. We aim to bring together scientists, engineers and officials who make use of satellite communications to collect data from the field within the satellite industry. We provide a handbook and website with details of all the systems currently on the market, so that users can choose the system that best suits their needs. We also advocate back to industry on behalf of users, so that new products and services can be developed that meet the needs of the environmental science sector. This includes marine and polar science, as well as meteorology and hydrology.

What key trends will be addressed during Satcom 2018?

After a long period where the market has been relatively static, we now have a number of exciting new developments. For example, Iridium has its new Next constellation due to enter commercial service very soon, and is offering new types of data service that take advantage of its new satellites. We also have new entrants to the market in the shape of companies like Kepler, OneWeb and Hiber, who are launching new satellites and aiming to bring the cost of satellite communications down. There's been a lot of industry interest in the Internet of Things, which is just old-fashioned telemetry and telecommand given a new name, but that's led to a lot more sensors, data management platforms, and radio and satellite networks being launched. Several of these new satellite companies have polar orbiting satellites, which give complete global coverage including both poles. This is great for polar science.

Who will be speaking at Satcom 2018?

We have a number of confirmed talks. Orbcomm, which operates a satellite network designed explicitly for data services, will be talking about its latest service offerings. Rock Seven, a UK-based specialist manufacturer of Iridium terminals and reseller of airtime, will be talking about how to manage a large 'fleet' of remote sensors using a web platform, as well as the benefits of prepayment tariffs for scientific use. And Kepler, a Canadian startup that has one satellite in orbit, will be talking about how it will be launching a service that can do store-and-forward communications for large volumes of data at low cost. More speakers will be announced shortly and I hope to have representatives from across the sector, both industrial and scientific.

Why should visitors attend this forum?

It's a great opportunity to learn about how satellite communications can help you with your data collection needs. Historically, satellite was expensive, and so a lot of scientists have simply ruled it out in the past. But things have moved on, and it's becoming accessible to everyone. For those already using satellite, it's a chance to learn about new developments and feed your experiences back to industry.

We'll also be launching the new *Satcom Handbook* at the event. The new book aims to be an authoritative and unbiased guide to all the satcom systems on the market. It'll be published in two forms: first as a website (in English only), kept up-to-date regularly as new systems are launched; and second as a formal document, published by the WMO and translated into all the organization's official languages: English, Arabic, Chinese, French, Russian and Spanish.

RADIATION SENSORS

Based in the Netherlands, **Hukseflux Thermal Sensors** produces a range of solar and long-wave radiation sensors, compliant with the latest ISO, IEC and WMO standards.

The SR15 digital pyranometer series, introduced by Hukseflux this summer, is a range of high-accuracy digital solar radiation sensors. The range is first class according to the WMO guide and ISO 9060:1990 standard and Spectrally Flat Class B in the 2018 revision.

Version SR15-D1, equipped with an onboard heater, is compliant in its standard configuration with the requirements for Class B photovoltaic (PV) monitoring systems of the IEC 61724-1:2017 standard.

Hukseflux Thermal Sensors' SR15 digital pyranometer series offers the best measurement accuracy in its class and is suitable for application in meteorological networks.

▸ **HUKSEFLUX THERMAL SENSORS**
BOOTH 9020

INFRASOUND MONITORING SYSTEMS

For the past four years, **Seismo Wave** has manufactured and sold microbarometers under license of the French Atomic Energy Commission. Initially created for nuclear test detection and installed all over the world, the MB3 is one of the most accurate and reliable infrasound sensors on the market.

Infrasound (sometimes referred to as low-frequency sound) is sound that is lower in frequency than 20Hz and is undetectable to the human ear. The frequency is also generated by natural events such as severe weather, frontal passages, earthquakes, volcanic eruption, tornadoes and auroras.

The use of infrasound to monitor the atmosphere has been largely unheard of through the years, but times are changing and new research has demonstrated that infrasound will soon have several new applications for operational weather and climate prediction.

At this year's Meteorological Technology World Expo, Seismo Wave will present its new Time 1 Infrasound Sensor Portable Station – a field-ready backpack embedding a digital microbarometer, GPS antenna, battery and solar panel. Easy to install, its 1GB memory can retrieve three months' worth of data at 50Hz, providing continuous and up-to-date monitoring of natural hazards.

▸ **SEISMO WAVE**
BOOTH 6065

FIRST-TIME EXHIBITOR

NEW PRODUCT

SCALABLE DATALOGGER

Presenting the latest versions of its turnkey multi-hazard monitoring and early warning systems, **CAE** is proud to introduce its powerful and scalable datalogger, featuring an embedded Linux operating system and an onboard interactive web server. Highly configurable, it is designed for alert management and low power consumption.

Another highlight on CAE's booth will be a rain intensity sensor that can endure low temperatures and can operate remotely without mains power. Finally, CAE will showcase its 3D web platform, a tool to support emergency decision making. It is compatible with a number of different technologies and will accept and integrate data from a wide range of sources.

▸ **CAE**
BOOTH 5030

PRODUCT LAUNCH

SENSING SNOW DEPTH

With more than 30 years' experience in manufacturing environmental measurement sensors, Austrian firm **Sommer Messtechnik** is set to launch its new Ultrasonic Snow Depth Sensor, which the company claims will revolutionize the snow depth market with new levels of stability, accuracy and reliability.

In addition to its measurement qualities, the new snow depth sensor can be easily integrated with existing systems, making it ideally suited to replace older and less-accurate snow depth sensors. Thanks to its low energy requirements, it is the ideal sensor for remote, solar-powered sites. Furthermore its maintenance-free ultrasonic membrane seal promises to heavily reduce the total cost of ownership.

As well as its snow depth sensor, Sommer will also launch a datalogger that boasts a variety of user communication options. It features simultaneous and automatic selection modes and offers internal calculation and conversion features. These innovative features will help customers realize new and versatile applications very easily, making it the ideal companion for emergency and remote applications such as in the hydrology market and hydromet stations.

▸ SOMMER
BOOTH 4030

TECH WORKSHOP SPOTLIGHT:

METEK

Innovation in low-cost remote sensors – micro rain radar and Doppler lidar

▸ Wednesday, October 10, 2:00-4:00pm

Metek will present two innovative remote sensing techniques during its workshop, and will provide the opportunity for hands-on demonstrations of each. First, its Micro Rain Radar MRR-PRO allows for precise measurements of the Doppler spectra caused by hydrometeors and yields the rain rate, liquid water content, and drop size distribution for the liquid phase. The system has been evolved to be a powerful standalone profiler for investigations of precipitation and cloud dynamics with very low installation and logistics effort.

Second, the CW Doppler Lidar Wind Scout enables users to set up accurate wind and turbulence measurements at any site within minutes. Due to its compact design, the system can be integrated easily into mobile instrumentations, as well as in housings. The Wind Scout can, for example, deliver valuable data for the determination of pollution dispersion parameters for air quality studies in urban and industrial sites.

▸ METEK
BOOTH 9015

INTERNATIONAL EXPERTISE

Created in 2002 against a backdrop of growing concerns related to climate change and its socioeconomic impact, **Meteo France International (MFI)**, a subsidiary of the French national meteorological service Météo-France, is tasked with designing and implementing turnkey modernization projects for national meteorological services, exporting Météo-France's expertise throughout the world.

The organization also provides integrated solutions for other weather-sensitive entities such as the armed forces, aviation or air-quality authorities.

During Meteorological Technology World Expo 2018, MFI will conduct live demonstrations of its new forecasting system, Synergie-Web, co-developed with Météo-France. It will also discuss a series of recent projects such as strengthening the Iranian met service, the development of an integrated METOC decision-aid solution for the French Armed Forces, and the supply of a state-of-the-art climate data management system for the Singaporean National Environment Agency.

▸ METEO FRANCE INTERNATIONAL
BOOTH 11025

PRODUCT DEBUT

SENSOR SUITE

Long-time exhibitor **Lambrecht Meteo** has expanded its product portfolio with the new Modbus series, which includes sensors for all key meteorological parameters, including wind direction and speed, precipitation, humidity, temperature, air pressure and global radiation. The company is thriving and plans to expand its international distribution network. As well as presenting the new Modbus series at the expo, Lambrecht Meteo will be looking for partners who understand their local markets and want to offer their customers the best-possible products and services.

▸ LAMBRECHT
BOOTH 8060

BISTATIC WEATHER RADAR

The QX weather radar family from **MetaSensing** is a fully polarimetric weather radar system that uses X-band frequencies for the high-resolution monitoring of precipitation.

The radars use solid-state technology for reliability, high performance and maintaining a compact size. In addition they feature quad-pol acquisitions to improve the suppression of unwanted echoes and refine hydrometeor classification.

MetaSensing has developed oscillator boards that enable bistatic radar to be combined with full polarimetry (quad-pol), making it the instrument of choice for atmospheric science research and weather service operations.

Versions with frequency-modulated continuous wave (FMCW) and pulse are available, as is a portable single-antenna model. All can be deployed as an individual unit or as part of a network of radars.

Visit MetaSensing's booth to find out more about the QX weather radar range and how it can be used to speed up scientific discoveries and their implementation.

▸ METASENSING
BOOTH 12022

PRODUCT DEBUT

GWE WEATHER ENTERPRISE CONFERENCE

▸ October 11-12

The Global Weather Enterprise (GWE) was formed following a series of successful dialog events, which gathered representatives from the public, private and academic sectors. GWE is an independent platform developed to foster dialog between different stakeholders in the meteorological sector. The two-day GWE Weather Enterprise Conference (WEC), which has been organized by the WMO in cooperation with the World Bank GFDRR and the Association of Hydro-Meteorological Equipment Industry (HMEI), will focus on two key themes: data and business models.

In terms of data, the WEC will look at how observational data can be better shared throughout the industry, including in the public and private sectors. For business models, the forum will look at the provision of meteorological, hydrological and climatological services, and how the public, private and academic sectors can improve their cooperation to develop sustainable, mutually beneficial business models.

The conference will give experts from various fields an opportunity to present case studies and to continue the cross-sector dialog during the event, which is needed for the improvement of services to citizens, particularly in the developing parts of the world. To find out more about GWE see *United Front*, page 14.

MICRO-WEATHER STATIONS

PRODUCT LAUNCH

The new WMO-compliant MeteoHelix micro-weather stations from **Barani Design Technologies** combine the reliability of naturally ventilated shields with the accuracy of fan-aspirated shields.

Set to be priced below €500 (US$580), the new MeteoHelix line will be one of the most economical WMO-compliant wireless weather station ranges on the market.

The most distinguishing feature of the MeteoHelix micro-weather station is its outer helical design, which enables it to achieve air temperature accuracy in all weather conditions. The helix is purely functional and is complemented by a second black internal helix, which blocks contaminants from fouling the internal sensors.

Designed to last six to eight months without sun, these ultra-low power micro-weather stations feature a built-in solar cell that gives 20 days of sunless operation for every day of sunshine. The wireless stations measure rainfall, sunshine hours and solar irradiation, air temperature, relative humidity and atmospheric pressure.

The MeteoHelix is suited for cost-conscious applications such as urban climate measurement, where high data density and accuracy are needed.

▸ BARANI DESIGN TECHNOLOGIES
BOOTH 10005

PARTICLE IDENTIFICATION

NEW EXHIBITOR

The Swisens Poleno, from Swiss sensor manufacturer **Swisens**, is a new sensor designed to identify and count airborne particles and aerosols in real time. The instrument is optimized for the identification of pollen taxa in real-time and for the long-term monitoring of pollen concentration in the air, making it ideally suited for automatic pollen monitoring and prediction modeling.

The Swisens Poleno is an air-flow cytometer that relies on the analysis of light scattering and induced fluorescence. The device is able to measure the fluorescence lifetime in the nanosecond range of a single particle in flight and 3D images of each particle taken in flight. With these measurement methods, many independent features of individual particles in flight can be determined, enabling it to provide the most independent characteristic values per particle available on the market. By combing this rich data set with state-of-the-art classification algorithms, the Swisens Poleno is able to achieve high-quality classification results. In addition, the integrated unique aerosol concentrator enables unprecedented time resolution.

▸ SWISENS
BOOTH 9060

NEW PRODUCT

WIND SENSORS FOR DRONES

Made from a graphite and nylon composite, and weighing only 100g (0.2lb), the FT205 ultrasonic wind sensor from **FT Technologies** has been specifically designed for use on drones and unmanned aerial vehicles (UAVs) engaged in environmental monitoring.

Powered by the company's unique Acu-Res Technology, the FT205 is the first in a new generation of lightweight sensors that use ultrasound to derive air speed, direction and temperature. It also features a built-in compass.

Although light, the compact size and shape of the FT205 make it physically very strong. Resistant to vibration, shock and electrical interference, it is also fully sealed and water resistant. It can operate at altitudes up to 4,000m (13,120ft) and at temperatures between -20°C and +70°C (-4°F to 158°F).

With low power requirements, and reading wind speeds up to 75m/s (168mph), the FT205 sensor is ideal for UAV flight control systems and atmospheric observation from remotely piloted aircraft.

▸ FT TECHNOLOGIES
BOOTH 11040

TECH WORKSHOP SPOTLIGHT: LEOSPHERE

Lidar as a working tour: operational use cases

▸ Wednesday, October 10, 10:30am-12:30pm

Pulsed coherent Doppler lidar adoption is growing fast. Meteorological services, air-quality management offices, airports, wind-farm developers and wind-turbine manufacturers are all taking advantage of Doppler lidar's atmospheric measurement capabilities. Today more than 1,200 Doppler lidars are in operation globally. Last year marked the beginning of a new phase in lidar use as ISO published ISO 28902-2, which standardized the Windcube heterodyne pulsed Doppler lidar technology for atmospheric measurements. In previous year's Leosphere's workshops have focused on hands-on experiences of the scanning Windcube hardware, and how to remotely control, process, display and manage lidar data with the scanning Windcube software. This year the company's technical workshop will focus on practical experiences and operational use cases of the technology.

▸ LEOSPHERE
BOOTH 8010

TOP PICKS

An insight into eight not-to-be-missed conference presentations ahead of this year's CIMO TECO-2018 event

CIMO TECO-2018 will host four busy days of conference sessions between October 8-11, with industry experts discussing all the latest trends, challenges and breakthroughs in meteorological measurements and instrument technologies. The conference, which will be held alongside Meteorological Technology World Expo in Amsterdam, will host presentations as well as more than 150 white papers for attendees to peruse in their spare time. Here, Helen Norman, editor of *Meteorological Technology International*, picks eight key presentations at this year's event. To register to attend and for more information on all the conference abstracts visit www.wmocimo.net. To register to attend Meteorological Technology World Expo visit www.meteorologicaltechnologyworldexpo.com.

1

WEATHER RADAR DATA REPRESENTATION SUPPORTING THE EMERGENCE OF WEATHER RADAR AS A GLOBAL RESOURCE

Topic: Characterization and standardization of environmental measurements – traceability assurance

Dr Daniel Michelson et al, Environment and Climate Change Canada

The WMO Inter-Programme Expert Team on Operational Weather Radars (IPET-OWR) has collected activities and experts from the Commission for Instruments and Methods of Observation (CIMO) and Commission for Basic Systems (CBS). IPET-OWR's work plan responds to the emergence of weather radar as a global resource. A key element of successfully supporting this resource is standardized data representation.

In recent years, two weather radar data representation formats have emerged. In Europe and Australia, the OPERA Data Information Model ODIM_H5 has become an operational HDF5-based standard. In North America, Europe and elsewhere, CfRadial based on netCDF and Climate and Forecasting (CF) Conventions supports data representation research. IPET-OWR has successfully converged ODIM_H5 and CfRadial and leveraged the advantages of each to recommend CfRadial 2.0 as a single global standard.

This presentation showcases CfRadial 2.0 and provides examples of applications where such improved weather radar data representation has positive impact.

2

COMPARING DEVG AND EDR AIRCRAFT TURBULENCE METRICS

Topic: Characterization and standardization of environmental measurements – traceability assurance

Dr Douglas Body, Australian Bureau of Meteorology

There are two different metrics for aircraft turbulence in current use – Derived Equivalent Vertical Gust (DEVG) and Eddy Dissipation Rate (EDR). DEVG uses vertical accelerometer measurements to determine the instantaneous vertical gust velocity, which, superimposed on a steady horizontal wind, would produce the measured acceleration of an aircraft. In contrast, the eddy dissipation rate is a parameter that quantifies the turbulence intensity within a fluid, making it an aircraft-independent measure of the atmospheric turbulence intensity.

The onboard AMDAR software for 23 Airbus 330-200/300 aircraft has been configured to provide DEVG and EDR simultaneously, enabling the rare opportunity for two turbulence metrics to be directly compared for both "normal" flight and severe turbulence events. Results from this study will be revealed during this presentation.

3

A FIELD ASSESSMENT OF A NOVEL RAIN MEASUREMENT SYSTEM BASED ON EARTH-TO-SATELLITE MICROWAVE LINKS

Topic: Emerging measurement technologies – from development to operation

Dr Matteo Colli et al, DITEN, University of Genova, Italy

This presentation will look at the performance of an innovative environmental monitoring system, the Smart Rainfall System (SRS), which estimates rainfall in real time by analyzing the attenuation of satellite signals (DVB-S in the microwave Ku-band). SRS is made up of a set of peripheral microwave sensors placed on the field of interest, and connected to a central processing and analysis node. It has been developed jointly by the University of Genoa, its departments DITEN and DICCA, and environmental monitoring startup Artys.

The rainfall intensity measurements, accuracy and sensitivity performance of SRS will be discussed during this presentation, based on preliminary results from a field comparison experiment undertaken in Genoa.

4

REMOTE MEASUREMENTS OF VOLCANIC PLUME ELECTRIFICATION USING A SPARSE NETWORK TECHNIQUE

Topic: Emerging measurement technologies: from development to operation

Dr Jeff L Lapierre et al, Earth Networks, USA

Ash from explosive volcanic eruptions can severely affect our environment by disrupting airline flights and marine traffic, reducing air quality, and impacting downwind communities. Understanding the processes occurring during eruptions can help mitigate these hazards by giving early warning of the eruption onset and improving the forecasts of ash dispersal.

An emerging tool in this approach is detecting the electrification of volcanic ash clouds. Volcanic lightning is a new field of research, with recent field campaigns focusing on how to link electrification to eruption dynamics such as mass flux, water content, and microphysical processes, for instance volcanic hail formation. However, many volcanoes are remote and lack local monitoring equipment, making fine-scale electrical measurements particularly challenging. This presentation will reveal a new technique to detect volcanic electrification that requires only two wideband radio frequency sensors located within approximately 1,000km (620 miles) of the volcano.

5

FORECAST SENSITIVITY TO OBSERVATIONAL IMPACT AS AN EVALUATION TOOL FOR GLOBAL OBSERVING NETWORKS

Topic: Ensuring sustainability of measurements

Dr Lawrence Morgan, Met Office, UK

Forecast Sensitivity to Observational Impact (FSOI) is an analytical method used to assess the impact of observations on a granular basis, down to the level of individual measurements. The outcome of FSOI analyses ranks observations in order of impact on NWP sensitivity – these results can be, and have been, used to make funding decisions for observing networks. With an operational cost far lower than commonly used data-denial experiments, FSOI analyses are becoming the standard in the numerical weather prediction (NWP) community. However, accurately assessing the impact of observations through FSOI requires understanding subtle differences in the way that data-denial experiments work and the influences of other observation types. Using examples from radiosonde networks and aircraft, this presentation will include a summary of FSOI results in the context of observational impacts and draw comparisons between these results and data-denial experiments.

6

LESSONS FROM THE MODERNIZATION OF NATIONAL METEOROLOGICAL AND HYDROLOGICAL SERVICES (NMHSs): A CASE STUDY OF THE ZAMBIA METEOROLOGICAL DEPARTMENT

Topic: Ensuring sustainability of measurements

Oliver Mudenda, Zambia Meteorological Department

The Zambia Meteorological Department has recently undertaken a modernization project funded by the World Bank. The main aim of the project was to bring its national meteorological and hydrological services into the 21st century. The key part of the project was the installation of 68 automatic weather observation stations (AWOS). The hope is that these new stations will help to continuously increase the geographical coverage of the meteorological observation network and in turn improve the communication of severe weather warnings in the country.

During this presentation the Zambia Meteorological Department will share its experiences on the modernization project and exchange best practices among other national meteorological and hydrological service providers, especially considering the advent of the Global Weather Enterprise (GWE) concept.

7

DATA COLLECTION NETWORK MODERNIZATION: WHAT YOU NEED TO KNOW

Topic: Measurement and integration challenges in the next 20 years

Bruce Hartley, Meteorological Service of New Zealand

Operating a high-quality automated network is one of the important objectives for any organization providing critical weather forecasts and data products. If your organization is considering converting a network of manual observations to an automated network, or considering significant technology upgrades to an existing automated network, the management processes are for the most part the same. The main differences are that for automating a network of manual observations there will be additional steps associated with provision of infrastructure (equipment siting, power and communications), and redeployment and retraining of observing staff. This paper will present the management considerations and processes needed to perform a successful transition to, or upgrade of, an automated data collection network.

8

MEGACITIES EXPERIMENT ON INTEGRATED METEOROLOGICAL OBSERVATION IN CHINA (MEMO)

Topic: Measurement and integration challenges in the next 20 years

Dr Bai Li et al, Meteorological Observation Center, China Meteorological Association

MEMO has been initiated by the China Meteorological Administration (CMA) and organized by CMA Meteorological Observation Centre (MOC). It is a large-scale integrated meteorological observation experiment. MEMO attempts to establish ground-based remote-sensing integrated observation stations, which consist of the dual polarization weather radar, Ka-band cloud radar, L-band wind profile radar, microwave radiometer and lidar. The stations will obtain the high-precision vertical structure information of temperature, humidity, wind, hydrometeor (precipitation and cloud), and aerosol in the range of a megacity. It will effectively improve the overall quality of meteorological observation data and model assimilation rates, and establish the interaction mechanism of observation and forecast and also solve the key technical problems in the short term forecasting, nowcasting and the environmental weather service.

Ludovic Thobois, scientific partnership and animation manager for meteorology and aviation, Leosphere

FLYING HIGH

Obtaining detailed insights into upper air wind behavior above airports is now possible thanks to remote sensing technologies

Windcube 400S-AT monitoring windshear at Dubrovnik Airport for Croatia Control

Airports may be interested in the same characteristics of wind as other industries, but the significance of these factors to the air traffic management (ATM) sector is crucial. Wind speed and direction are principal factors, helping to determine the landing and take-off configurations as well as the procedures for approach and take-off, such as the choice of the runway.

Windshear, for instance, refers to a change lasting several seconds in the direction and/or speed of the wind. A decreased lift will cause the aircraft to drop below its intended flight path, while an increased lift will of course have the opposite effect. A sustained change to the headwind or tailwind of 15kts is classed as significant windshear. It can make planes on approach or departure much more difficult to control, and much more susceptible to the need for rapid corrective action. According to the International Civil Aviation Organization (ICAO), windshear phenomena have caused more than 1,400 deaths in aviation. Its unpredictability is also responsible for the disruption of air traffic management, which can have a substantial business impact on airport operations.

Turbulence is another consideration, referring to the rapid irregular motion of air. It brings about rapid bumps or jolts, but only occasionally does it have a significant influence on an aircraft's intended flight path. However, in severe instances, abrupt changes in the altitude and attitude of the aircraft may occur, the pilot may suffer a momentary loss of control, and passengers may be injured.

Finally, wake vortex is a form of turbulence generated by all aircraft when flying. Wake vortices vary in relation to a number of conditions, including the size of the aircraft creating it and the airport's own local wind and turbulence conditions.

As you'd expect, wind conditions are a major concern for ICAO. At present, however, its current meteorological guidelines mention only conventional surface wind measurements, measured at 33ft above the ground. They fail to address wind conditions in the upper air, especially along the initial take-off and final approach landing corridors (up to 1,640ft). If air traffic management is to operate at its most efficient levels, and if safety precautions are to be at their best, other measurement methods clearly need to be employed. While landing and take-off represent just 6% of flight time, it's a sad fact that 57% of accidents occur then – which is why winds during these phases are the most important to measure and forecast.

INTRODUCING WEATHER RADAR... AND LIDAR

At Hong Kong International Airport (HKIA), China, the wind sensor data gathered from anemometers and weather buoys is analyzed by the anemometer-based Windshear Alerting Rules – Enhanced (AWARE) system to issue windshear alerts.

HKIA also employs a Terminal Doppler Weather Radar (TDWR) system, which continuously scans the high runway corridors to detect windshear and microbursts (intense small-scale downdrafts produced by a thunderstorm or rain shower). Being radar-based, TDWR works only when rain occurs. So, what can be done to measure wind at altitude on dry days?

At HKIA, the answer came in the form of a Doppler lidar system, capable of detecting airborne particles as small as 1.5μm and providing real-time detection of windshear at up to 10km (6.2 miles) in the glide slope. HKIA was the first airport in the world to deploy a lidar sensor for wind shear measurement.

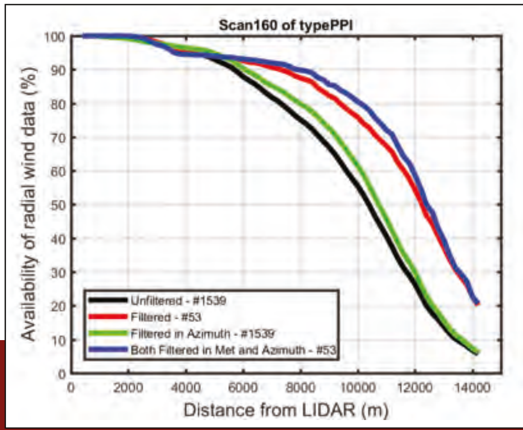
Over the past 20 years, significant improvements have been made in lidar techniques, largely as a result of the introduction of optical fiber technology. The low cost and high reliability of its components, which have led to their widespread use in the mainstream telecommunications industry, are now being appreciated in ATM. Examples of compact, reliable and accurate atmospheric lidar sensors that have been developed and industrialized include those from ONERA, the French aerospace lab, and Leosphere, in the form of the Windcube product series. Further improvements in power, range and reliability are being made all the time.

Working in conjunction with TDWR and ground-based measurement systems, Doppler lidar enables airports to create and sustain an all-weather 3D monitoring solution.

DUBROVNIK: A CASE IN POINT

Dubrovnik has one of Croatia's busiest airports, handling more than two million passengers in 2016. The airport is around 15km (9.3 miles) from the city center, near

Schematic view of Bora winds on the Adriatic Coast



Windcube 400S-AT averaged data availability measured at Dubrovnik Airport

the shore of the Adriatic Sea, about 160m (525ft) above sea level. The Dinaric Alps, a mountain range rising to 1,000m (3,280ft), run closely parallel to the coastline, and slope down to the airport and to the sea beyond.

The prevailing winds are generally low, but in winter the airport is particularly susceptible to what is known as the Bora wind. This is a northern to northeastern katabatic (or down-slope) wind on the lee side of the Dinaric Alps and down to the Adriatic Sea. Bora events can last from a couple of hours to several days, and can induce strong crosswinds of up to 70kts.

These wind events have a major impact on air traffic control at Dubrovnik Airport and also at other airports on the Adriatic coast, causing many delays. They can sometimes cause the airport at Dubrovnik to close, necessitating the rerouting of all incoming flights. Even more importantly, Bora winds have huge implications for flight safety, and need to be fully forecast and mitigated.

The meteorological department of Croatia Control is interested in better characterizing the Bora winds and in improving forecasts at Dubrovnik Airport. It is currently working on a four-year project to develop a Bora event decision support system. As a result, last winter it launched a wind measurement campaign as part of its activities in the SESAR 2020 (Single European Sky ATM Research) Research and Innovation (R&I) program, including a scanning Doppler Windcube 400S-AT lidar system from Leosphere that could characterize the winds in three dimensions.

This equipment provides remote measurements of winds and aerosols/clouds inside the planetary boundary layer (PBL) with a resolution from 75m (246ft) to 200m (656ft) under clear air conditions, and with a wind accuracy of better than 0.3m/s (0.7mph).

The Dubrovnik Windcube installation measures the crosswind created by the Bora, especially on the approach of Runway 12, on which it has the greatest impact. It was deployed 1.35km (0.8 miles) away from the runway and close to its threshold. The maximum range exceeds 10km (6 miles) and enables large scale monitoring around the airport.

During the trial, 14 Bora events were logged and measured at speeds of up to 60kts. One of them lasted 1.5 days, with the wind veering from the north to the northeast and strengthening from 8 to 23kts – and gusting up to 35kts. Strong turbulence and fluctuations along the vertical were recorded, and on the RHI vertical slice, a strong wind was measured as well as a great deal of flow separation (turbulence) 2km (1.2 miles) away from the equipment, and thus close to the airport itself.

Croatia Control is still analyzing the data gathered during the exercise, and is comparing the findings with measurements from on-site anemometers. It is working with the Department of Geophysics in the Faculty of Science at the University of Zagreb. It will also be making a submission to the European Commission as a contribution to the SESAR2020 R&I program.

In addition to the submission, Croatia Control is also working at a national level with airports, airlines and academia on the Bora Dubrovnik Project. Due to start in 2019, it's a four-year program aimed at developing a Bora event decision support system.

"It's good to see the spatial data that lidar obtains," says Alen Sajko, director of the MET Division at Croatia Control. "It's something you simply don't get with anemometers. We were never able to see patterns like these before. It's very useful. For example, we discovered that one part of the skies above the airport is much more affected by Bora events. The positioning of the anemometers meant we couldn't have picked this up in any other way.

"Lidar has also confirmed that when an aircraft is subjected to these events, its vertical speed can change dramatically in just 20 seconds," he continues. "It is vital information that we can pass on to pilots and to air traffic control, and that we can also use to produce better forecasts."

WEATHER SYSTEM INTEGRATION

Lidar information can be readily integrated into weather systems. For example, Windcube data can be combined with IRIS software from

Air traffic management: lidar benefits

Safety

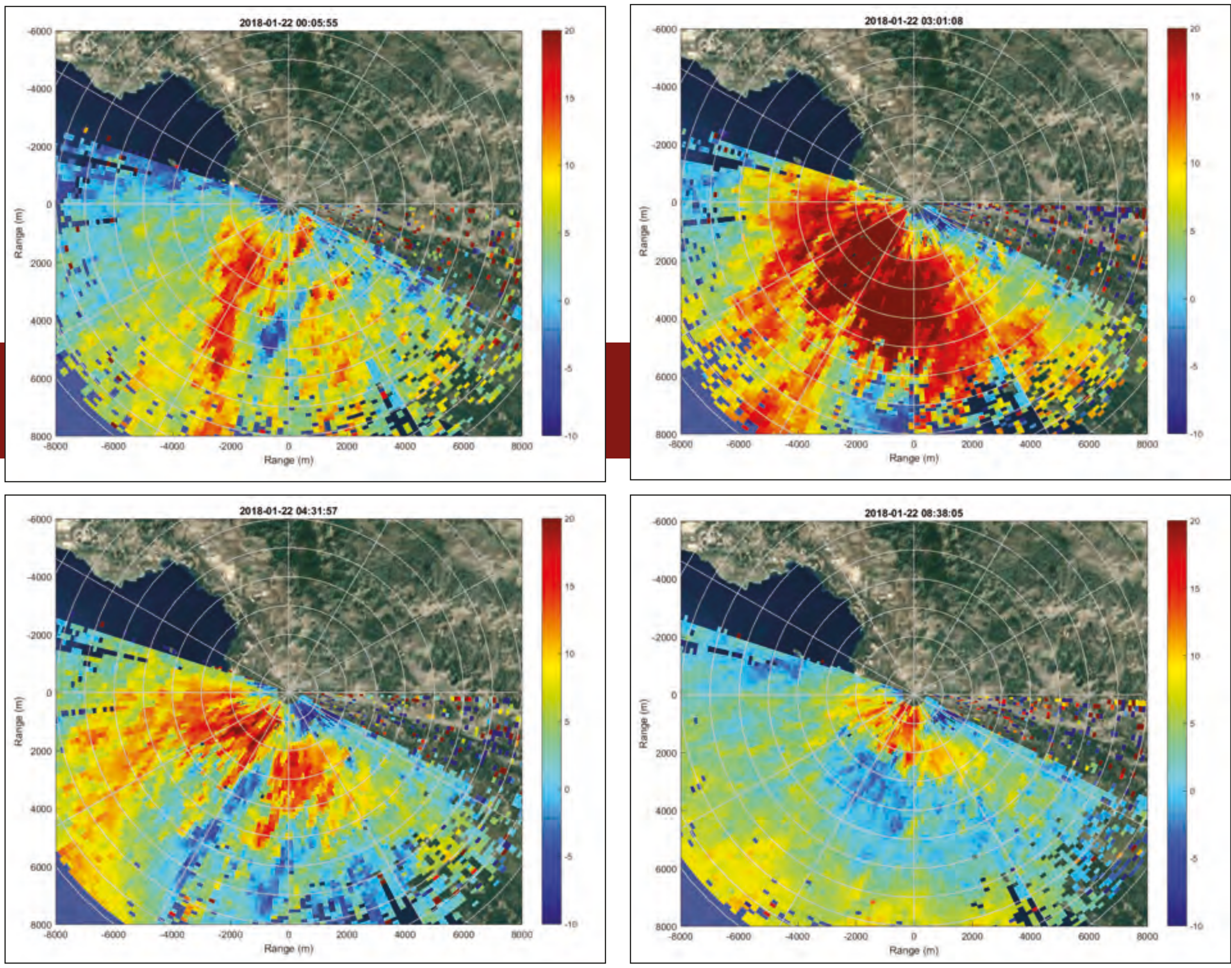
Detailed data gathered at flying heights to show real-time and trending conditions of:
- Windspeed and direction
- Windshear
- Turbulence
- Wake vortices
- Air traffic management awareness of unmanned aerial vehicles (UAVs, also known as drones) in the air near airports

General conditions

- Weather forecasts – including fog prediction (currently at proof-of-concept stage)
- Cloud base measurement
- Volcanic ash detection

Performance optimization

- Better runway management
- Better air traffic control management of distance between aircraft on approach and take-off
- Better noise reduction procedures



Samples of Bora wind measurement by the Windcube 400S-AT

Vaisala and Rainbow 5 software from Selex to display relevant and operational meteorological products such as windshear alerts.

ADDRESSING WAKE TURBULENCE

Airports are interested in Doppler lidar for another reason. Around 40 years ago, ICAO standards defined wake turbulence categories and their separation distance minima to prevent the risk of wake vortex encounters. Larger aircraft both create and can tolerate larger wake vortices – so minimum safe distances will depend on the size of the leading and following aircraft in the pattern.

For more than 10 years, Eurocontrol, an intergovernmental organization working to build pan-European ATM performance, has worked with ICAO and others to develop a new, optimized categorization of aircraft. Approved by the European Aviation Safety Agency (EASA), RECAT-EU aims to increase airport capacity safely by redefining wake turbulence categories and the minimum safe distances between aircraft.

To implement these new regulations, wake vortex data must be collected by a lidar sensor: in dry weather and at flying height, there is simply no alternative. Lidar is used for designing new wake turbulence regulations, performing the safety assessment to validate the potential implementation of an existing wake turbulence regulation, and for performing the risk monitoring.

Eurocontrol is also making use of lidar to develop a separate, time-based separation model. “Headwinds affect flight times and distance and so have a bearing on the intervals needed between aircraft,” explains Vincent Treve, runway throughput and wake project manager at Eurocontrol. “We have an implementation at Heathrow, and another is in progress in Vienna.”

In addition to trends calculated from the offline analysis of data, many airports like to cross-check wake data after deployment – so Eurocontrol has developed a lidar-based platform for the continuous monitoring of risk. In addition, the organization is merging databases of data gathered from several sites across Europe – it expects new concepts to emerge from this initiative.

For Treve, lidar’s two principal ATM roles of monitoring risk and measuring wind will in time be joined by a third application: defining the separation of aircraft as a function of wake behavior captured in the previous 10 minutes. The application is still in development but it is on its way.

LIDAR MOMENTUM

The interest international airports are showing in Doppler lidar is growing rapidly. By the end of this year there will be four times as many airports permanently equipped with the technology as six years ago, and several more trials are taking place worldwide. It’s likely that as air traffic volumes grow, so too will interest in the detailed measurement of wind in general.

In addition, many other tasks can be performed by Doppler lidars developed originally for wind: cloud base measurement and the characterization of aerosol hazards such as ash plumes. Doppler lidars are also expected to become the super ceilometer, with numerous functions for better mitigating adverse wind and aerosol hazards, and for enhancing the weather resilience of ATM. Combined with its benefits in terms of safety, ATM efficiency, and increased insight, it’s clear why lidar is about to take off. ∎

Laura Alku, software product owner, Vaisala

The design quality of Vaisala's weather radars helps provide a seamless user experience

STAY IN FOCUS

How meteorologists and forecasters can make the most out of their weather radar systems

There are four components to obtaining high-quality meaningful data from a weather radar system: an optimized radar system, excellent data acquisition, advanced signal processing and application-based data quality control.

COMPONENT BREAKDOWN

Optimized radar system: To reap the benefits of the latest dual polarization technology, a robust and optimized hardware design is required to ensure the accuracy and precision of the measurements. The system should allow fast scanning to be performed, uphold the pointing accuracy and guarantee matching beams of the dual polarization antenna so that the measurements from both polarizations correspond to the same observed volume of the atmosphere. A proper configuration of the system is also required. The needs of monitoring incoming weather are different from monitoring windshear phenomena. Therefore the tasks in the scanning strategies need to have different configurations to ensure the detection of the different weather phenomena.

Data acquisition: Having the data is not enough. The system should have stable acquisition hardware to guarantee collection of the correct data and its proper interpretation. It should also contain basic signal processing techniques, including but not limited to pulse corrections, interference and ground clutter filtering. A good data acquisition system guarantees a solid base line for successful data post-processing.

Advanced signal processing: Understanding the measured environment is the first step in making good interpretations of the data and improving the quality of observations. Weather radar, as with any remote sensing technology, will always experience challenges such as attenuation, low power and non-meteorological echoes, when measuring weather phenomena. The important aspect is to understand these challenges and use the physics involved in a smart way to reduce their impact over the weather radar observations.

Application-based data quality control: After acquiring reliable data from a set of hardware and a signal processing system, it is important to understand what the data is going to be used for. Observing bird migrations requires a different set of quality measurements than monitoring the amount of precipitation in a catchment area, for example. Therefore quality parameters play a vital role in obtaining meaningful information from a weather radar system.

DATA PRESENTATION

These four components and the relationship between them ensure meaningful data. However, meaningful information without a way to present it does you no good. Having reliable, flexible and secure application software is just as important as having each of the components to produce the data. A way of accessing and interacting with data from any source is a necessity. Information technology and software have become a key factor in practically every device, and weather radar is no exception.

On those grounds, and to fulfill the demanding needs of the weather radar users, Vaisala Oyj introduced its Interactive Radar Information System (IRIS) Focus weather radar software in 2015. It is the first step in a renewal program of the original IRIS software that has been sold for decades. From its beginning, IRIS has been a reliable source of information and Vaisala is taking that reliability to a completely different level by adding accessibility and interaction. For this reason, the core of IRIS Focus is improving usability, reducing complexity and allowing easy access to the data from anywhere.

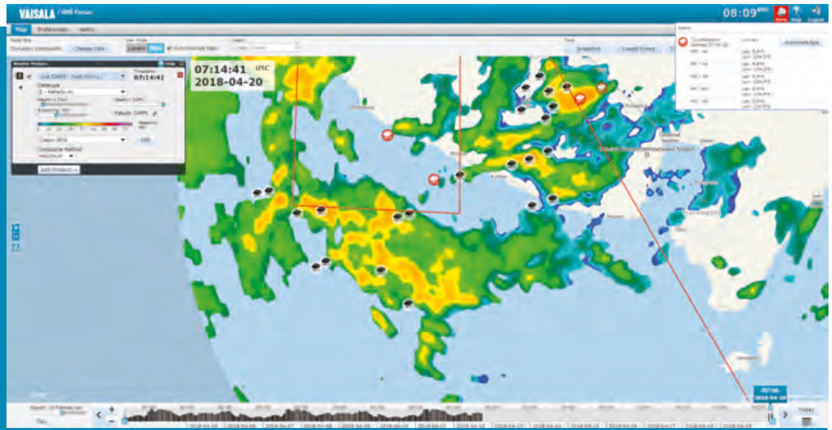
Meteorologists and forecasters are turning to IRIS Focus application software to analyze current and past atmospheric conditions. It provides a modern way of making weather radar products and a rich set of tools for viewing and analyzing weather radar data like never before. It displays the data in maps using the latest geographic information system (GIS) datasets, with the possibility of adding lightning information from Vaisala Oyj global lighting detection data (GLD2360) to extend radar coverage.

Meteorologists and forecasters have the critical task of providing accurate weather predictions based on data and models for different purposes, such as early warning systems. The acquisition of information from several sources is necessary for ensuring good initial conditions and more accurate predictions. Weather radar data has increased its use and credibility for this purpose. With the growth in the use of radar data, the need for easy access and usability become vital requirements for the application software. IRIS Focus is answering these needs, offering personal user settings and on-demand storm analysis of current or past atmospheric events at any location using a web browser. It enables users to access, visualize, analyze and share data like never before.

Forecasters, for example, want to make better use of their time. Saving time and getting straight to their duties as fast as

Vaisala weather radar site located in Colombia

IRIS Focus expands radar coverage by adding lightning information



IRIS Focus boosts alert functionality and helps forecasters, meteorologists and decision makers to better respond in hazardous situations

possible, without the laborious setup of data display systems, gives them the ability to concentrate on assessing the current weather situation in the country or area of responsibility. IRIS Focus's saved-view feature allows them to quickly change between their most frequently used views by recreating products, zoom levels and tools settings using their preferences.

A successful early warning system needs data accuracy, correct interpretation, stable processes and excellent communication. IRIS Focus weather radar software aims to contribute to the accuracy of the data and to its interpretation.

There are three vital components when considering data accuracy of an early warning system: historical data information, an automatic alert system and a short-term weather prediction, or Nowcast. Historical data provides an understanding of the trends in climatological changes; the automated alert system gives the first glance into a dangerous situation; and the Nowcast provides a good first indication of how the incoming weather could look. IRIS Focus is helping early warning systems by providing tools and features that aim to tackle these components.

HISTORICAL DATA VISUALIZATION

Finding trends and patterns present in weather radar data can be challenging. Localizing relevant events in real time or reading specific event data should be easy and not a time-consuming task, so that the user's attention is on data analysis. IRIS Focus allows the user to import historical radar data for visualization and analysis. With the zoomable timeline, checking significant weather becomes simple. It uses histograms to map the presence of weather events and quickly identify if there are significant weather events, reducing the time used to search through large amounts of weather radar data.

NOWCASTING

Hazardous atmospheric conditions might develop quickly, affecting the vulnerable population. Automated short-term forecasting tools based on different types of data provide information on the potential development of dangerous conditions. IRIS Focus's Nowcasting feature uses weather radar data to predict precipitation movement based on the motion vector field, and performs advection over the different data types. It does not use any numerical weather prediction model or try to replace them, but it could provide good initial conditions and the first indication for forecasters to investigate relevant events in more detail.

AUTOMATIC ALERT SYSTEM

Attracting the attention of forecasters and meteorologists in possible hazard situations is important for successful early warning systems. A visual indication of potential events developing in monitored areas allows users to respond quickly, make deeper analysis of the situation and follow the event evolution in real time. IRIS Focus's alerting functionality enables the user to set up event criteria and draw the areas of interest for issuing visual alerts, which are the first real signs of a possible event. Additionally IRIS Focus provides a list of logged events and issued alerts as a tool for decision support.

After issuing an event alert, it is important to corroborate the event's existence and make deeper data analysis. This might consist of checking other data sources, such as overlapping radars in a network, lightning sensor, rain gauges, etc, or making an in-depth study of the weather radar data available. IRIS Focus provides different tools for making this analysis possible. On-demand product generation, data integration, and curved or straight cross sections, are tools that improve the interpretation of the 3D area, the event evolution in real time and provide more information to assess the impact of the different weather events.

In this data information era, successful communication translates to fewer lives lost, less ignorance and more awareness. Sharing weather radar information with the public will enormously contribute to educating them and improving their awareness of the impact that preparation for weather events might have on people's daily lives. IRIS Focus's image export functionality makes sharing the information easy. It enhances the snapshots and makes it possible to share views directly on to a website, creating a direct channel between the experts and the public.

Vaisala wants to contribute to the development of early warning systems by providing reliable measurement devices, outstanding data processing, and application software that provides the necessary tools for data analysis and process simplification. Even though IRIS Focus weather radar software is already a powerful tool for meteorologists and forecasters, it is just the beginning. ∎

Daniel Betz, chief product officer, nowcast

ALL CLEAR

What is the quickest and safest method to reopen an area of interest after a thunderstorm?

Lightning research and safety specialist nowcast develops and operates a lightning-detection system for the precise detection of lightning. The system stems from intense and prolonged research in Munich, Germany, and has led to multiple installations across the globe under the LINET lightning detection network brand name. LINET is demonstrably one of the most precise lightning detection systems in the world. There has yet to be a study in which another commercial network reaches the levels of accuracy and reliability offered by LINET.

In the pursuit of developing the most efficient, reliable and effective lightning safety system on the market, nowcast conducted cutting-edge research into combining the LINET system with locally installed electrostatic field mills.

WHAT ARE FIELD MILLS?

Electrostatic field mills are often used to detect local thunderstorm cells above, or in the close vicinity of, an area of interest such as an airport, mine or sports venue. The risk of lightning can also be estimated through the measurement of electric field strength/variation.

When a field mill detects voltage with less than 100V/m of a fair field weather situation, we can safely assume that there is no chance of a lightning flash in the vicinity. As voltage increases, so does the chance of a lightning flash. However, it is not a simple case of setting a defined voltage limit or threshold and activating an action sequence according to this, as is currently the standard procedure with field mills. Multiple variables from numerous data sources plus a robust algorithm are required to properly forecast a developing thunderstorm.

With a standalone field mill system, it is only possible to predict the probability of a lightning flash occurring in the next few minutes. This is vital information for keeping the area of interest safe, but does not offer sufficient efficiency gains. The greatest such

Lightning strikes pose a significant danger to airport staff and passengers on the airfield

gains are realized when a field mill system is used as a basis for an 'all clear – area safe' process. To maximize these gains, the field mill system needs to work alongside a precision lightning detection network. The combined data from the two systems needs to be processed in real time, with an appropriate algorithm and actionable data made available via an online solution. This was the most challenging aspect nowcast faced in developing a true total lightning safety system.

IN PRACTICE

Since developing its unique system, nowcast has identified two practical applications for the implementation of field mills to increase operational efficiency during a thunderstorm. For providing warnings about a developing storm, the field mills provide limited operational efficiency gains but achieve maximum safety levels. For determining when a thunderstorm has passed, the mills provide maximum operational efficiency gains and maximum safety levels.

Using a standalone field mill warning system with no other data inputs offers minimal efficiency gains, as only thunderstorms encroaching/developing over the immediate vicinity can be taken into consideration. However, an opportunity does exist to gain an extra few operational minutes. This is because a lightning detection network activates a warning when a (lightning) flash has been recorded within a designated boundary. This warning does not represent the most accurate actual risk calculation of the area. The lightning flash might be on the edge of the boundary and the voltage below dangerous levels. A more accurate calculation would include an algorithm that factors in the voltage and changes thereof. Such a warning system would provide maximum safety levels and increase efficacy. However, this system still cannot be completely certain that a lightning flash will happen or not, even if the optimal conditions are recorded.

When it comes to maximizing efficacy, determining when it is safe to resume operations presents the greatest opportunity. The best practice thus far has been the countdown method. This involves using a highly accurate lightning detection network to record every lightning flash within a

The Weather Cockpit combines all available sources of weather data and creates automatic reports designated boundary. A countdown timer is activated and reset each time a flash is detected. Once the timer reaches zero, the area is deemed safe and outdoor activities can resume. There are no set thunderstorm safety standards; boundary sizes and countdown periods vary from industry to industry and from institution to institution. An example of a guideline safety standard can be noted in the aviation industry. The industry often (but not unilaterally) uses an inner core boundary of five nautical miles, an intermediate boundary of eight nautical miles and an outer boundary of 15 nautical miles. This method is effective in improving safety, but at the cost of operational efficiency, depending on the timers.

A field mill can minimize the amount of unnecessary waiting time by determining when voltage has been reduced to a safe level within the area of interest. The voltage monitoring based system poses a significant advantage over the countdown-based system in that when there is no voltage recorded there is no threat of a lightning flash. However, residual voltage might still exist in the vicinity, even when a thunderstorm has passed. For this reason, a combination system is considered the safest and the most efficient method available. If residual voltage exists then a time-out safety buffer based on the lightning detection network will be activated.

This combined approach was the basis of nowcast's research into a number of thunderstorm events at an international airport during 2017. The airport employed the LINET countdown system to optimize its thunderstorm stoppages procedures. The system was considered successful and helped to keep interruptions to a known minimum.

The local installation of at least one field mill per airport is necessary to measure the local electrostatic field

However, could stoppages be reduced even further by combining a field mill with LINET? Upon reviewing the data, it was discovered that during those select events a conservative total of 96 minutes could have been saved.

TECHNICAL REQUIREMENTS

There are a number of prerequisites for installing and operating an effective field mill thunderstorm warning system:

- A number of field mills must be installed locally. The absolute minimum is two, but one at every boundary extremity is considered best practice;
- A local nowcast LINET field mill processor is required for on-site data processing, formatting and transfer to a database in real time for further off-site analysis;
- The thunderstorm warning system can only be combined with the LINET network, therefore the combined system is only available to LINET customers;
- A unique algorithm combining many combinations of parameters, not just absolute limits, is required to transform the recorded data into actionable insights;
- An online platform such as LINET view or the UBIMET Weather Cockpit is required to set buffer areas/boundaries, alarms and to review the real-time data to assess the meteorological situation.

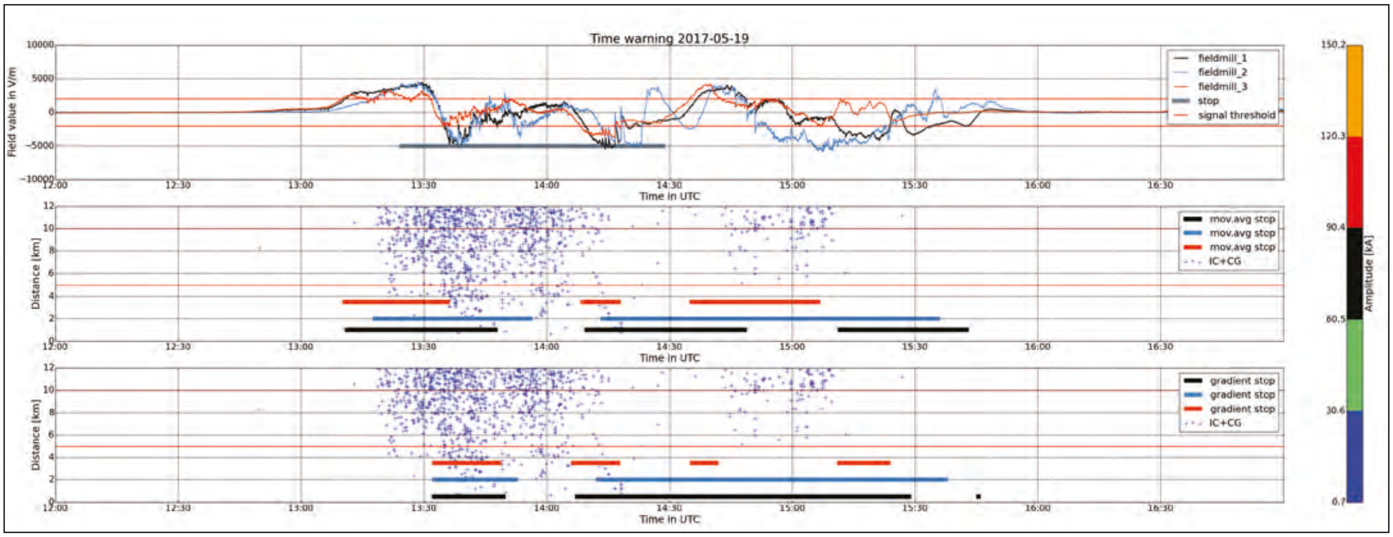
BENEFITS OF NOWCAST SYSTEM

The process developed by nowcast offers a number of unique advantages:

- Data is immediately available in a secure online platform – no more walking up to each field mill to access the current readings;
- The guesswork has been removed from making a decision. The unique algorithm triggers a traffic light warning system with no room for false interpretation;
- The algorithm is based on a transparent use of data, creating a decision base void of any inherent bias.

OUTCOME

The nowcast method provides a very accurate, technology-based decision support system for multiple industries. The combination of the LINET lightning detection system with electrostatic field mills provides a superior decision basis and the highest safety level for thunderstorm management. As all parameters are considered, the system ultimately offers the maximum efficiency and best management of a thunderstorm situation. ∎



Clearly, the electrostatic field alone can't serve as reliable source for thunderstorm warnings. Additional data is crucial to develop a valuable algorithm for professional operational needs

David Hammond, business development manager, Campbell Scientific

ROUTE TO SUCCESS

Gap-filling sensors provide a low cost alternative to road outstations and help strengthen the temporal and spatial resolution of route-based road weather forecasts

Adverse weather conditions affect the safety and capacity of a nation's roadways, affecting driving behavior, vehicle performance, surface conditions and the roadway infrastructure. Wherever you are in the world, the weather can impact your road network in many ways, at any time of the year. Snow and ice, flooding, fog and high winds are some of the common weather-related hazards that can affect commuters.

In countries that experience cold winter climates, snow and ice is the biggest hazard affecting motorists. To ensure optimum mobility and safety during the winter months, transportation authorities depend on reliable and accurate weather information provided by road weather information systems (RWIS).

In an RWIS, strategically located road weather stations (commonly referred to as road outstations) provide measurements of key meteorological and road surface parameters. Typical measurements include road surface temperature, subsurface temperature, air temperature, dew point, precipitation, and wind speed and direction.

Road weather models combine this site-specific data with meteorological data from numerical weather prediction models to predict future road surface conditions for the upcoming day and night. These road forecasts, which are typically either domain- or route-based, are issued by forecasting agencies to winter maintenance decision makers in a timely manner, from which treatment decisions for a given road network can be made.

ROUTE-BASED FORECASTING

The main aim of an RWIS has always been to reduce costs (economic and environmental) without compromising commuter safety. Prior to route-based forecasting, transportation authorities would typically treat all routes in a specific climatic domain if the forecast for that domain indicated the need. This domain-based forecasting relied on thermal interpolation between road outstations, using thermal maps to determine the likely road conditions along a stretch of road between outstations.

Route-based forecasting was originally devised from the assumption that if the regional climate is constant, any variation in climate and road surface temperature across the climate zone is controlled by the variation in geographical and road infrastructure parameters around a route.

By surveying the local variations in geography and modeling their impact on road surface temperature, virtual forecasts can be created away from the road outstation, enabling route-based forecasts to be produced. Such an approach enables the thermal projection of road surface temperature across a road network entirely by model predictions, removing the need for thermal mapping, which is subject to a number of errors that are well documented.

REDUCED COSTS

From research to date, the biggest cost savings in route-based forecasting are found in countries that experience a high

Campbell Scientific's SDMS40 multipoint scanning snowfall sensor, which detects the onset of snowfall and snowmelt

CS136 lidar ceilometer

Designed to complement Campbell Scientific's optical sensor range, the new CS136 is a compact, low-weight ceilometer for meteorological and aviation applications. It provides information on cloud height, sky condition (up to five layers) and vertical visibility.

The single lens design enables a high signal-to-noise ratio and maximized detector sensitivity, resulting in better performance at low and high altitudes. This provides a powerful and stable platform from which to measure cloud height and vertical visibility with high accuracy, stability and repeatability.

CS125 infrared visibility and present weather sensor

The CCFC Field Camera for intelligent road-weather information systems

A road-weather information system from Campbell Scientific in use at a Eurotunnel entrance

proportion of marginal winter nights, where highway authorities are responsible for the precautionary treatment of the road network.

In the UK, for example, which experiences an average marginal night ratio of 1:3 (70 nights per winter), rock salt is predominately used to treat roads during the winter months. At a cost of around €45 (US$52) per ton, a typical road authority in the UK will outlay approximately €565 (US$654) per salting route (assuming 4-5 tons of salt per route), with salt and labor costs accounting for approximately 40% of this cost.

Based on these figures, a road authority using route-based forecasting can expect to save on average €340 (US$390) when no treatment is required for a single route.

ARE MORE OUTSTATIONS NEEDED?

Over the past two decades, route-based forecasting has become widely accepted by forecast providers and winter road maintenance operators globally as a great improvement over traditional domain-based forecasts. However, despite the financial savings, there remains the challenge of how to verify a route-based forecast at the full spatial and temporal resolution.

With modern computing power and high-resolution Geographical Information Systems (GIS), there is no defined upper limit for the spatial and temporal resolution of a route-based forecast. Operationally, it is reasonable to think that a forecast should be able to account for thermal singularities around a route (bridge decks, frost hollows, areas prone to katabatic drainage), requiring a spatial resolution of sub-100m (328ft). Temporally, model re-runs every 15 to 30 minutes would align forecast data with the typical resolution of *in situ* roadside measurements. With maintenance budgets continually under pressure, and given the typical cost of a road outstation is in excess of €20,000 (US$23,000), it simply isn't practical to install road outstations at this type of spatial resolution, or even every 1km (0.6 miles). In response to this, some manufacturers have developed mobile sensors designed to be vehicle mounted. These sensors can provide the spatial resolution required to verify a route-based forecast along an entire route, but they lack the continual temporal resolution obtained from a road outstation.

An alternative concept of gap-filling sensors that provide a better balance of spatial and temporal resolution than mobile sensors, and at much lower cost than traditional road outstations, is now an option for the road weather industry.

GAP-FILLING SENSORS

Gap-filling sensors are intended to provide decision makers and forecasters with a higher-resolution view of the temperature differences across a transportation network. These sensors provide data using non-invasive technology at a lower cost than a traditional road outstation. This enables transportation authorities that use route-based forecasting to deploy more temperature sensors around their network, providing decision makers with additional real-time road temperature data to help them make more informed decisions.

A network operator also needs to have accurate, high-quality data on-demand to ensure any changes in treatment strategy are taken proactively, based on real-time data.

Accuracy, reliability, high quality, flexibility, interoperability, longevity and low cost of ownership are key features of Campbell Scientific's road weather stations. These stations operate continually around the world in some of the most hostile environments.

With Campbell Scientific road weather systems, the Campbell datalogger is at the heart of the monitoring network. All systems are sensor and platform agnostic, meaning they can interface with any sensor or protocol and provide data in any format to forecasters.

The Campbell road weather systems can also flex and scale to suit any number of potential installations, be it a national road network incorporating thousands of sensors, or a local installation with only a few monitoring stations. As a result, highway authorities are increasingly using Campbell systems to provide trusted, reliable data to aid in their winter maintenance decisions.

CAMPBELL SYSTEMS IN ACTION

Utah Department of Transportation (UDOT) maintains a network of road weather information system weather stations across the state. The network includes 85 Campbell Scientific road weather systems with CS125 present-weather sensors. They are used to provide real-time data for the UDOT snow and ice performance measure, providing critical information to snowplow crews.

Present weather data from CS125 sensors is used to estimate snowfall rates, which are combined with other meteorological parameters such as road temperature, wind speed and wet-bulb temperature to create a real-time storm intensity index. This real-time index informs UDOT meteorologists of how much weather the snowplows are facing on a given road at that time.

Comparisons against road conditions enable UDOT meteorologists to determine if the storm intensity index is meeting their level of expectations. Snowfall rates calculated from CS125 sensors are analyzed alongside real-time data from 45cm (18in) soil temperature probes, enabling meteorologists to establish the snowfall rate needed to overcome the road, and mobilize snowplow crews accordingly. ∎

Gerhard Peters, head of R&D, Metek

RELIABLE DATA

Continuous wave lidars can provide more accurate wind measurements with high resolution at short distances

The first reports on lidar-based wind measurements appeared half a century ago, and Doppler wind retrieval by lidar began in the 1980s. Rapid progress of laser technologies, along with the diversity of user requests, has led to a wide range of commercial lidar products being developed, from containerized systems with a greater than 10km (6 mile) range, to portable boxes with ranges of some tens of meters.

PULSED DOPPLER LIDARS

The most widespread method for wind measurement is to transmit pulses and assign a range to the propagation time of the echo signal. The shorter the pulse length, the broader the transmitted frequency band and the finer the range resolution. While there is a lot of competition for radar frequency bands, there is no such issue for optical frequencies. Therefore lidars could be built with extremely short pulses and correspondingly fine range resolution. Unfortunately this freedom cannot be exploited for Doppler measurements due to a fundamental difference from radar signal analysis.

Typical pulse repetition rates of radars are in the range of 10kHz or more. Therefore the change of position of atmospheric scattering centers between subsequent pulses is small compared with typical radar wavelengths (millimeter to meter), and consequently the pulse-to-pulse phase shift of echoes from a given range gate is small ($<<\pi$).

In the left-hand panel of Figure 1, the radar pulses (thick red lines) and echo signals (thin red lines) from range r_1 are depicted in a range-versus-time diagram. The phase of the received signal is indicated by the angle of the black arrows below the time axis. The pulse-to-pulse phase shift is associated with the Doppler shift. The more pulses available for the phase measurement, the better the Doppler resolution.

The assumption of small phase shift between subsequent pulses does not hold for lidars with wavelengths in the µm-range. Therefore the Doppler shift must be extracted from the echo of one pulse.

For the Doppler retrieval it is essential that the transmitted pulse has some spatial extension so that echo signals are received from overlapping ranges during a finite time interval. During this time interval the change of position of scattering centers in the overlapping range slices causes a phase change of the echo signal, which translates into Doppler shift. The finite pulse and the receiving time window for echoes from a range interval centered at r_1 is shown in the right-hand panel of Figure 1.

For better Doppler resolution, the transmitted pulse and the receiving time window must be extended, leading to poorer range resolution. Typical trade-offs for pulsed Doppler lidars are 20m (66ft) range resolution and 2m/s (6.6ft/s) Doppler resolution. Another limitation of pulsed lidars is the smallest observable range, which is about twice the pulse length. The final velocity resolution can be improved by averaging over many pulses. Nevertheless the quest for small minimum range and fine range resolution can lead to unacceptable Doppler resolution.

CONTINUOUS WAVE LIDAR

An alternative ranging method uses focusing the lidar beam at a certain distance. Scattered light is mainly received from the focal point. Since the receiving time is unlimited any Doppler resolution can be achieved. Multiple ranges can be scanned sequentially by varying the focal distance.

With increasing range, the range resolution rapidly becomes worse (Figure 2). Beyond a certain range – depending on the beam diameter at the lidar – the focusing effect vanishes completely. A typical range limit is 200m (660ft). Consequently the preferred use of continuous wave (CW) lidars is measurement at small ranges with fine resolution. Even here certain shortcomings must be kept in mind:

• In the simplest CW lidar realization the observed frequency shift is equal to the absolute value of the Doppler shift. The sign of the wind component is obtained using a ground-based wind vane. Although its output doesn't need to be precise, the method is not

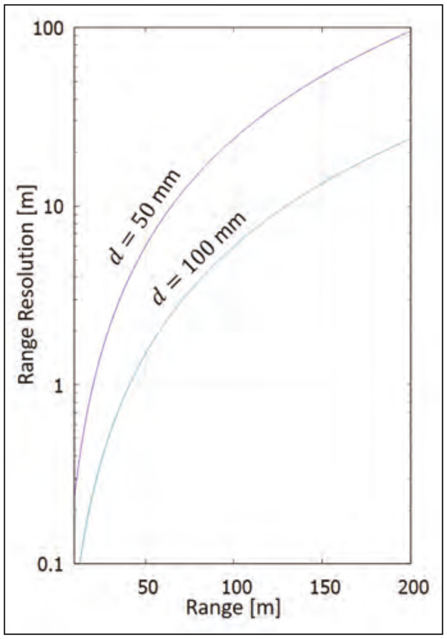


Figure 2: Range resolution of a CW lidar for two telescope lens diameters

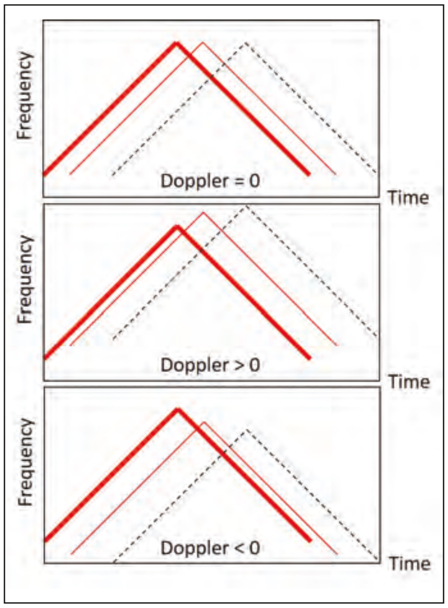


Figure 3: Triangular frequency modulation

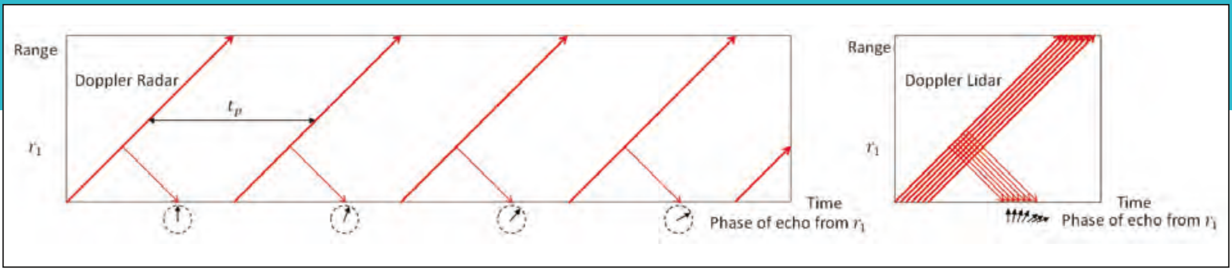


Figure 1: Doppler analysis for pulsed radar (left) and pulsed lidar (right)

reliable for all lidar operation sites, including street canyons, where the surface wind is decoupled from the wind at sounding height.

• Strong returns from a cloud base may dominate the signal, even if the cloud base is distant from the nominal range.

• There is a 'blind frequency range' close to zero. Therefore the basic CW concept is not applicable below certain minimum windspeeds.

There is an extension of the CW concept that avoids these shortcomings. If the frequency is modulated with a triangular pattern, the frequency of the echo signal is not only shifted due to the Doppler effect but also due to the time delay between the transmitted and received signals (Figure 3).

PRACTICALITIES

The sign of the Doppler shift is derived from comparing the modulus of the frequency shifts $|f_+|$ and $|f_-|$ on the rising and falling branch of the triangle. In the top panel on Figure 3, non-moving targets are assumed. Here $|f_+|$ and $|f_-|$ are determined only by the range term, which is equal on both branches. In the middle and lower panels, positive and negative Doppler terms contribute to the frequency shift in addition to the range term. In the first case $|f_+|$ is smaller than $|f_-|$, and vice versa in the second case. Thus $D = |f_+| - |f_-|$, indicates the Doppler shift including its sign.

Signals from outside the focus cause 'wrong' frequency shifts. The frequency of such signals is indicated in Figure 3 by the black dashed lines. If they are strong, they can show up in the Doppler spectra as secondary peaks. They can be recognized as spurious because the sum of the frequency shifts $S = |f_+| + |f_-|$ depends only on the range. Since the nominal range is known due to the chosen focal distance, the associated value of S_n is also known. Comparison with the observed value, S_o, reveals if spectral peaks are spurious.

For zero windspeed there remains a finite frequency shift. So, there is no low wind limitation.

WIND SCOUT AND WIND RANGER

Metek has developed a compact near-range FMCW lidar with fixed or steerable focus distance (Wind Scout, Wind Ranger). For retrieving the wind, vector conical scans are performed around a vertical axis (Figure 4).

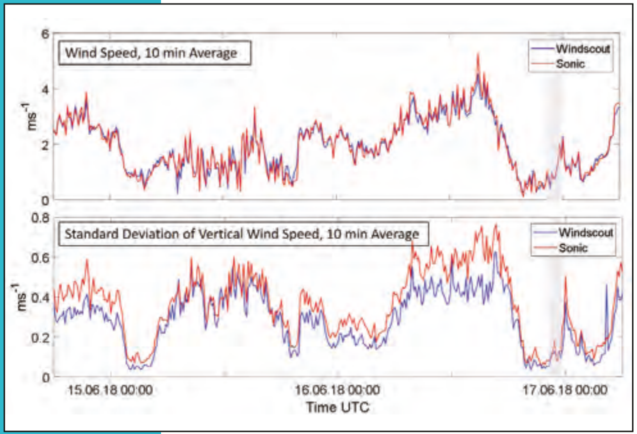


Figure 6: Comparison with sonic anemometer

Figure 4: Wind Scout/ Wind Ranger

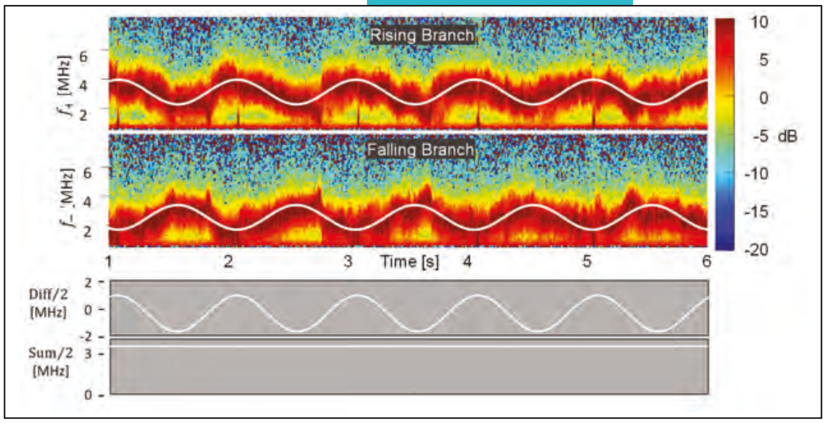


Figure 5: Colored panels – Doppler spectra during five revolutions of the scanner. Gray panels – (top) difference in peak frequencies; (bottom) sum of peak frequencies

The scanner rotates once per second with a 10° zenith angle.

Figure 5 shows spectra obtained on the rising and falling modulation branches for five scanner revolutions. The *y*-axis is the frequency shift (absolute value) and the color shows the relative spectral power averaged over 0.01s. Time is running on the *x*-axis. One recognizes the periodic undulation of the frequency shift with opposite phase for the rising and falling branches, as expected according to the discussion of Figure 3. The white lines represent sinusoidal fits of $|f_+|$ and $|f_-|$. In the lower gray panels, the D and S of the fitted peak frequencies are shown.

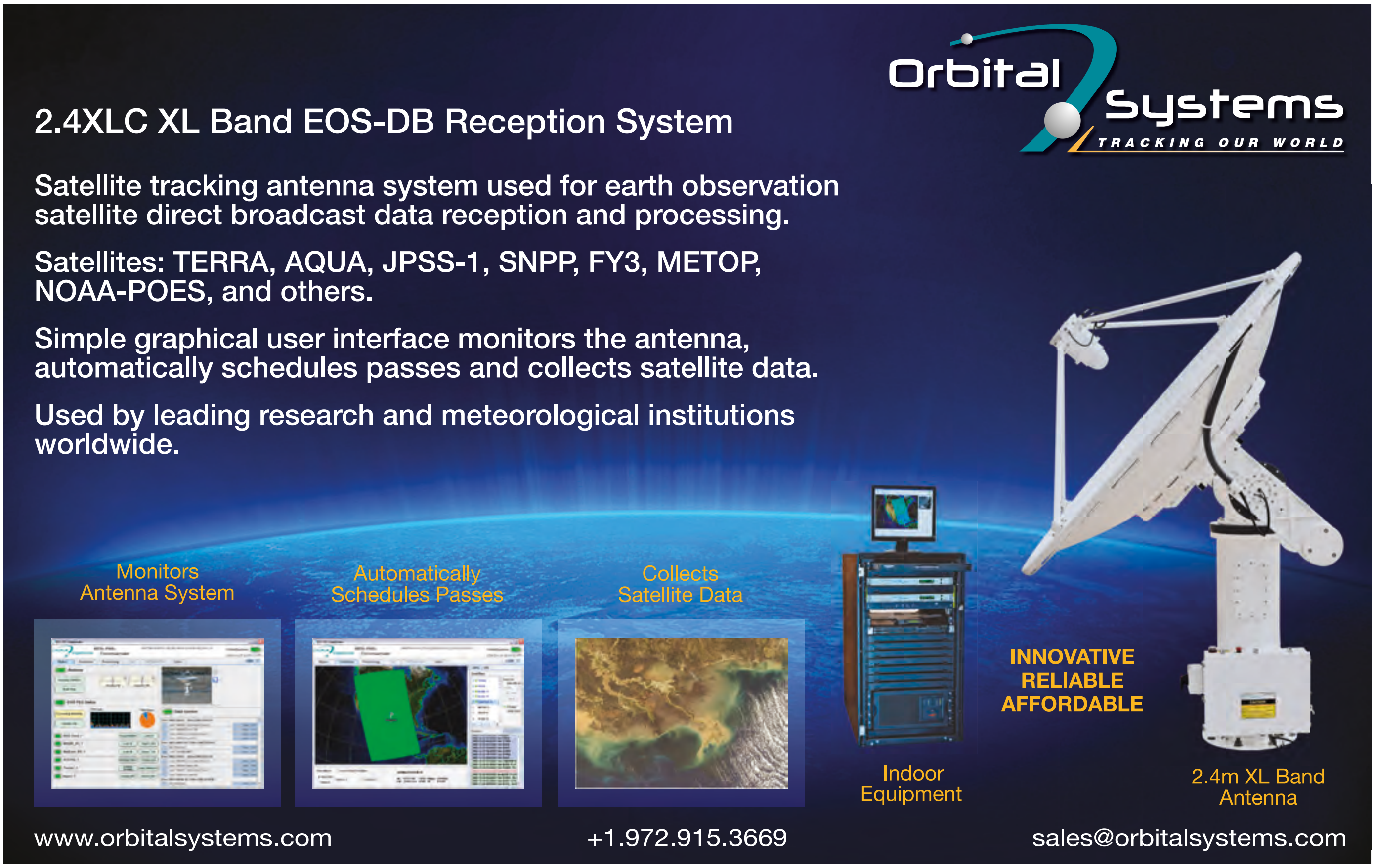
As discussed above, D indicates the Doppler shift. The windspeed and direction is derived from the amplitude and phase of the sinusoidal variation of $D(\alpha)$, where α = scan angle. The sum $S_o(\alpha)$ in the lower gray panel is constant. It is not affected by the Doppler shift but depends only on the focus distance. From the modulation parameters it can be inferred that $S_o = S_n$. Therefore spurious spectral peaks originating from outside the focus can be excluded.

PROPERTIES AND FIELD EXPERIENCE

The system can be deployed by a single person and starts running after power-up using either the internal data storage or by transmitting data in real time via the network port. A web-based control interface is available. The system complies with laser safety classification 1M according to IEC 60825-1:2014/EN 60825-1.

Comparisons with ultrasonic measurements are shown in Figure 6 for the windspeed (upper panel) and the standard deviation of the vertical wind component (lower panel). The low bias of the latter is to be expected because the lidar data represents spatial-temporal averages over the full scan circle, with corresponding attenuation of small-scale and high-frequency contributions to the turbulence. The nocturnal minima of the standard deviation provide an estimate of the measurement noise, which is less than 5cm/s.

The gray band in Figure 6 indicates a rain event with rain rates up to 3mm/h. This event obviously did not impair the quality of the lidar wind measurement. ∎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William Cottay, director of cloud services, Penguin Computing

COMPUTING POWER

EarthCast Technologies expands its product offering with high-performance cloud computing

Until recently, only the wealthy could afford the high-performance computing (HPC) resources needed to support complex forecasting capabilities, combining real-time data feeds from global observations with numerical modeling prediction technology. The ability to create precise monitoring and prediction products, outlining local hazardous weather and environmental impacts around the globe, was out of reach for many people. Dr Greg Wilson, Earth system scientist and president and founder of EarthCast Technologies, knew that the potential market for his products was limited by the costs of computing resources required to create such complex models.

EarthCast combines global observations and cutting-edge prediction technology, with the goal of monitoring and predicting data for the entire Earth system. This data is then offered to commercial clients. For EarthCast, acquiring these traditional on-site computing systems would have cost a significant amount of money and required the addition of dedicated staff to support them.

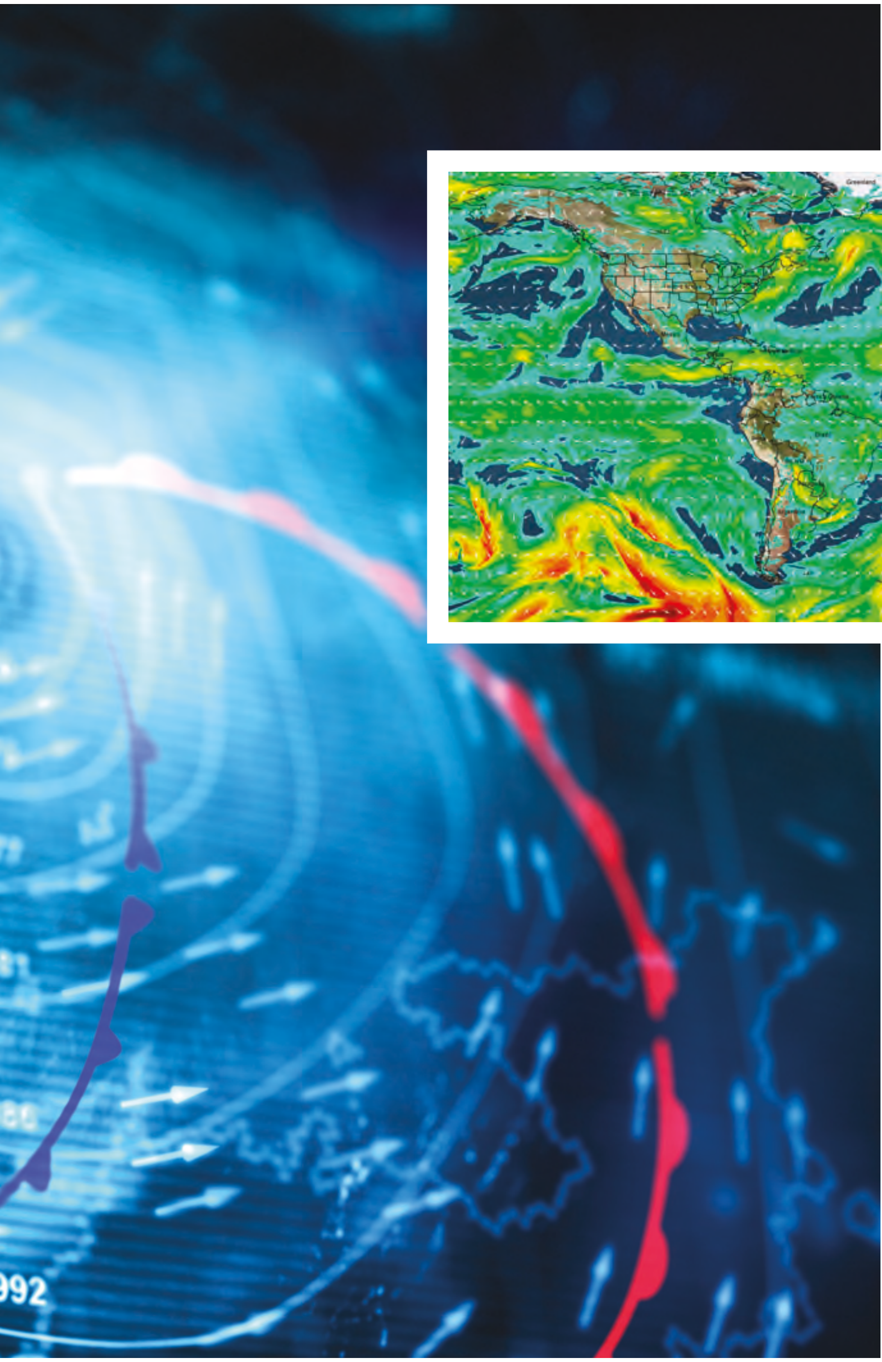
The company would also have paid for 100% of the system, but would only use it 20% of the time, such as during peak hurricane monitoring season. That meant that it would lie unused 80% of the time – not a reasonable proposal for any business.

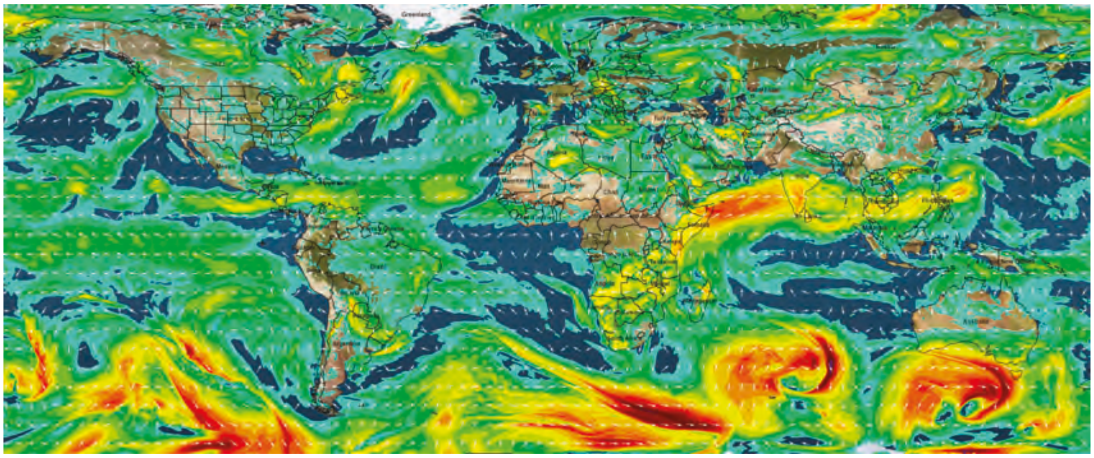
As an alternative strategy, EarthCast turned its attention to a solution being adopted with growing frequency by weather modeling businesses – cloud-based HPC.

EarthCast had previously attempted to run its forecasts on traditional cloud providers but, like many others, realized that those resources would not support the tightly coupled code necessary to produce the company's products. However, with the Penguin Computing On-Demand (POD) platform, EarthCast finally had a solution to meet its needs.

PENGUIN POD PLATFORM

Built on bare metal with no performance-reducing virtualized servers, the POD platform is housed at multiple Penguin Computing data centers and accessible via secure command line interface (CLI) or browser access to remote desktops. EarthCast was able to choose from a variety of POD clusters, with different configurations, depending on computing and storage needs and budget.





EarthCast

A global wind and direction forecast created by EarthCast on the Penguin Computing On-Demand platform

EarthCast chose to use the Penguin Computing On-Demand solution to generate global forecasts

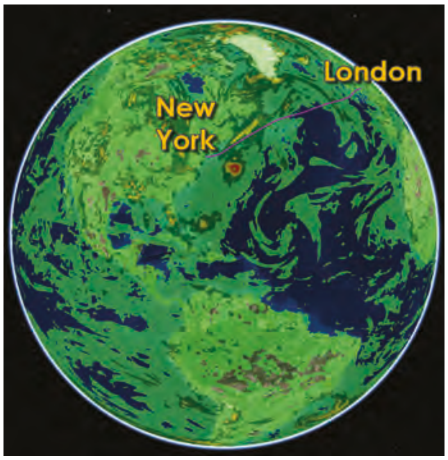
A global turbulence flight pattern from London to New York, which EarthCast created on Penguin Computing On-Demand to predict flight patterns

The cost for each cluster is defined by cost per second, so the overall cost is predictable and transparent – critical for growing businesses such as EarthCast that need both powerful computing and expense control.

With traditional HPC clusters for computing with high-speed, low-latency interconnects available via the cloud whenever they needed, EarthCast was able to expand from twice daily forecasts to five-minute forecasts.

The company now models the full Earth system and was able to run a five-day forecast for Hurricane Harvey in 2017 on the cloud. EarthCast was also able to begin offering its products to commercial clients and expand its overall market and, thus, its business.

This process was relatively painless because, unlike some other vendors, Penguin Computing provides clients with free access to highly experienced support engineers in the weather computing field, who can manage all data remotely and have optimized the POD clusters to run the Weather Research and Forecasting (WRF) model.



EarthCast

Commenting on the partnership, Dr Wilson of EarthCast says, "Our team of Earth scientists, meteorologists and IT geospatial experts works with Penguin Computing to ensure use of the latest technologies in data handling and high-performance computing. This relationship allows us to both control and predict our costs and frees us to concentrate on our core business."

While the POD infrastructure provides the technical resources for numerical weather forecasting, creating a true production environment required more than just the hardware and software. This is where Penguin Computing's experts were able to help.

"Penguin Computing's HPC experience and first-class support lets us focus on our business and enables us to confidently promise results to our customers," adds Wilson. "Combined with POD, we can provide immediate cost-effective environmental modeling at any scale, from local to global."

Team members working with EarthCast, including Linux experts, PhD level environmental and chemical engineers, network architects, business solution specialists, and highly skilled support staff, came in at different points, as and when EarthCast needed them.

The POD team's networking and Linux experts provided specialized data servers and redundant networking to ensure access to satellite data used to create forecasts and deliver products to customers. Networking experts worked with EarthCast customers to create site-to-site virtual private network solutions so they could access EarthCast predictions and other products. Business solution specialists worked with EarthCast to create a robust, geographically distributed computing environment to support EarthCast's service-level agreements. ∎

Christine Boomer, senior marketing manager, Micro Pulse LiDAR, part of Hexagon

FINGER ON THE PULSE

Icing is a very serious problem for smaller fixed wing aircraft, helicopters and drones. A new method of supercooled water detection may provide an answer

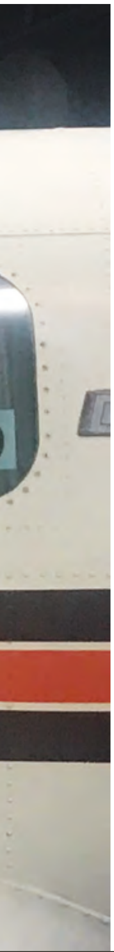
Miles above Earth, aircraft encounter a variety of challenging weather conditions, including wind, rain, snow, clouds, lightning and extreme cold. A particularly dangerous situation occurs when supercooled liquid water (SLW) freezes onto the wings and bottom of an airplane. This accumulation of ice changes the airflow, reduces lift and increases drag and weight, making flying difficult and dangerous. Although de-icing before take-off is a standard procedure when icing conditions are forecast, once a plane is in the air there is no effective method to directly detect SLW and avoid icing en route.

For fixed wing aircraft alone, the US National Transportation Safety Board (NTSB) reported that from 2010 to 2014 there were 52 inflight icing accidents resulting in 78 fatalities. For rotary wing aircraft, where there is much less wing surface area and the aerodynamics of the equipment is more sensitive, the icing threat is even more pronounced. In lieu of a foolproof method of de-icing in the air, more accurate real-time measurements of cloud characteristics and identification of icing potential using remote sensing techniques would help pilots avoid threats before an aircraft encounters a problem.

CLOUD EXPERTISE COMBINED WITH LIDAR TECHNOLOGY

An investigation into combining data from existing sensors to successfully identify ice clouds is being pursued by Richard Stone, owner of RHS Consulting, and Justin Fisher, director, Micro Pulse LiDAR, part of Hexagon. Stone is a weather modification expert who flies in icing conditions routinely and has been studying and interacting with clouds for over 30 years. RHS Consulting provides operational cloud seeding and weather research services, which are in demand on a global scale to meet agricultural needs in increasingly dry regions.

"Cloud seeding and ice cloud avoidance are both applications that rely on measuring the size of water droplets – one to find water and one to avoid it," says Fisher. "By using our



Mini Micro Pulse lidar installed on an RHS cloud seeding aircraft

"Even a low SLW content cloud can create hazardous conditions if you fly through it for long enough"

Richard Stone, owner, RHS Consulting

Mini Micro Pulse Lidar technology (MiniMPL), we felt there was a great opportunity to reach a new level of understanding about the SLW content of clouds based on Stone's experience in searching for cloud moisture."

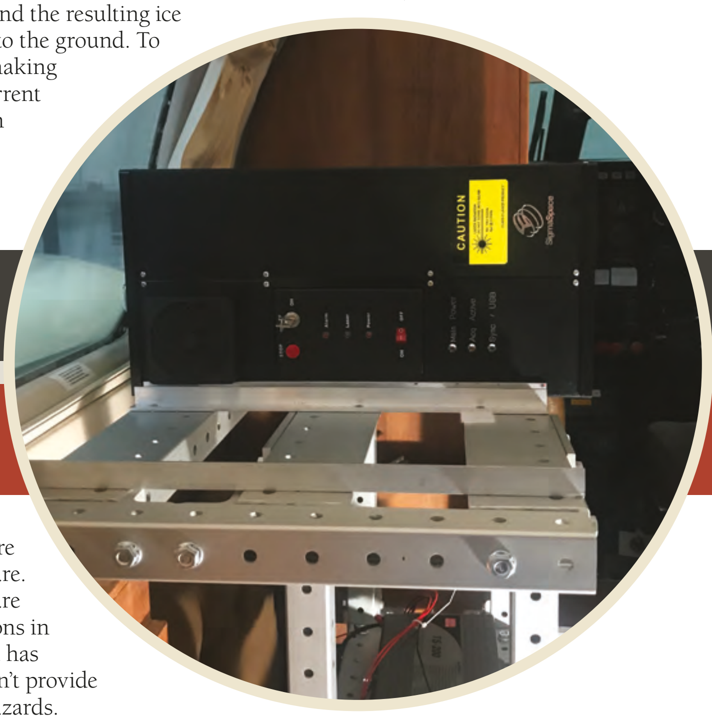
Cloud seeding involves locating excess moisture in clouds. When silver iodide particles are introduced into a cloud, the available moisture condenses and freezes around the particles, and the resulting ice crystals grow and fall to the ground. To identify the best rainmaking opportunities with current methods, pilots rely on weather forecasts and sensors mounted on seeding aircraft to measure cloud moisture content and temperature. These measurements are restricted to thin ribbons in the sky that an aircraft has already passed and don't provide advance warning of hazards.

Remote sensing offers a huge advantage for detecting icing before an aircraft passes through icing conditions, and provides an opportunity to avoid the conditions altogether. The MiniMPL specializes in identifying cloud particles as ice crystals or water droplets and quantifying these particles in the cloud from a distance. This hasn't been possible using current methods. Ice crystals by themselves don't present a hazard to aviation, so being able to detect the difference between SLW drops and ice crystals is crucial.

"Even a low SLW content cloud can create hazardous conditions if you fly through it for long enough, so you really need to identify all the types of particles, and their sizes and density, to improve your chances of successful rainmaking or avoid icing conditions for general aviation," explains Stone. "The MiniMPL offers that opportunity."

WHAT CAUSES DANGEROUS ICING?

Along with seeking better cloud seeding methods, aviation safety is a major concern. Clouds are composed of water droplets that can stay in a liquid state at below normal



The Mini Micro Pulse lidar fixed to a custom bracket for test flights

freezing temperatures. If an airplane runs into these SLW droplets, they freeze to the surface of the aircraft. Larger droplets don't freeze immediately and will bleed back from the leading contact edges and freeze on the underside of wings and airframe.

Specifically, supercooled water droplets larger than 30µm create the biggest hazard for aircraft. Smaller droplets can also stick to the leading edges of wings, but wing de-icing systems are designed to shed the moisture. Large droplets present a much more dangerous situation because they can accumulate all over the aircraft, where there are no systems in place to remove the ice. Accumulated ice makes flying much more difficult. Aircraft are particularly vulnerable when flying slowly, at less than 300mph (483km/h), which is the situation when they are preparing to land. Avoiding these icing conditions entirely is the best option.

"Icing is a very serious problem, especially for smaller fixed wing aircraft, and even worse for rotorcraft," says Stone. "Drones also are negatively impacted in icing conditions, particularly because a remote operator cannot actually feel how the aircraft is flying or see icing on the wings. If ice accumulates rapidly, an operator can lose control with no indication of a problem."

Current onboard systems available for aircraft only detect icing once it has already formed on the hull or wings. Weather charts, pre-flight planning and briefings from meteorologists are used to predict where there might be problems during a flight, but often the pilot resorts to looking out the window to assess the situation. This tactic is not especially helpful at night.

MINI MICRO PULSE LIDAR DELIVERS REAL-TIME UPDATES

To provide a solution to the vulnerability of aircraft to icing, a sensor is needed on the aircraft that identifies cloud content and measures droplet size in the air space far enough ahead of the plane that the pilot can alter course to avoid potential ice hazards. For several years Sigma Space (now part of Hexagon) has been experimenting with different wavelengths on the MiniMPL and flying lidar and other instruments to feed data into algorithms. By adding RHS Consulting to the effort, the research team reaps the benefits of Stone's many years of studying clouds in search of better ways to deliver moisture to the ground.

In late March 2018, Stone tracked a fast-moving set of medium-sized vorticity centers passing over the Sierra Nevada

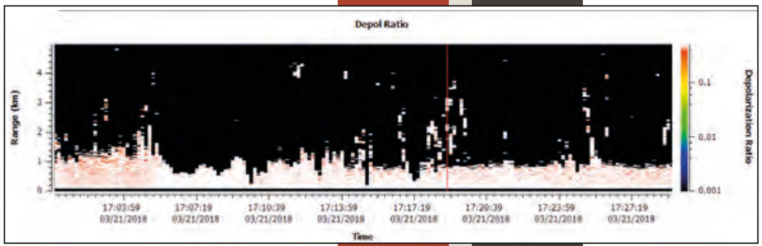


Figure 1: Depol ratio from test flight #1 still able to detect ice droplets up to 5km (3 miles), even with bias from plastic window

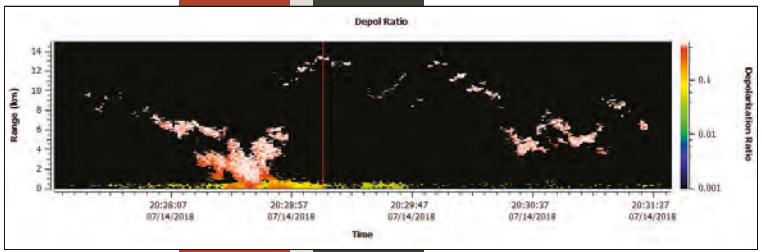


Figure 2: Test flight #2 data showing greatly improved resolution and cloud detection

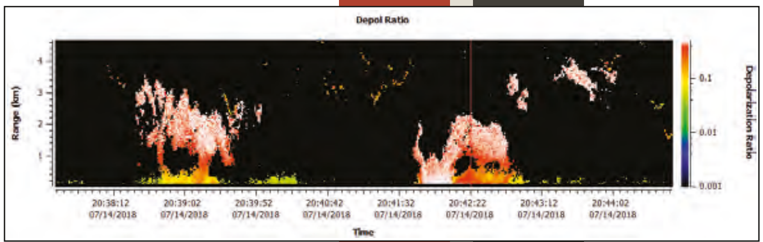


Figure 3: Test flight #2 data showing multiple cells

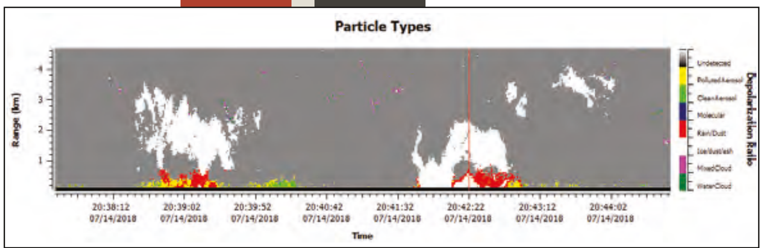


Figure 4: Cells classified. Future advances will enhance range and mixed phase detection limits

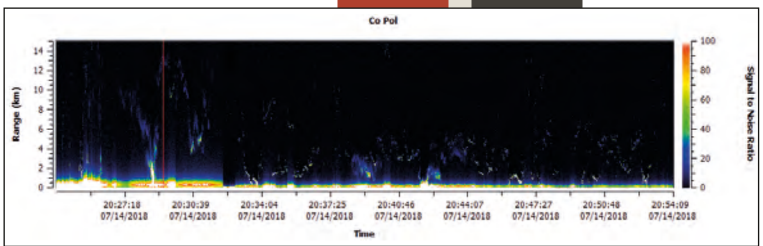


Figure 5: Glass window solved CoPol signal issues and greatly improved the range of detection

mountains near Minden, Nevada. Moist southwesterly flow continued across the Minden area as a ridge strengthened over the Rockies and a deep trough rotated eastward across the California coast as the storm came on shore. The storm looked suitable for a test flight, so Stone took off with a variety of sensors, including a MiniMPL and a G-band radiometer that provides data complementary to lidar and senses moisture at longer ranges.

Raw data from the MiniMPL viewed onboard showed it was detecting ice and water droplets up to 5km (3 miles) from the aircraft (Figure 1). This compared with a 15km (9-mile) range when the unit was operated at the hangar, viewing wave clouds from the surface instead of through a plastic window. To improve the sensor's viewing range in the air, and remove potential depol bias, the plastic viewing port on the aircraft was replaced with optical glass. With the addition of a suitable glass view port, a detection range of 15km (9 miles) is reached and has significantly improved depolarization measurements (Figures 2-5).

The depolarization ratio provided by MiniMPL is used to characterize hydrometeor type, such as droplets, raindrops and ice crystals, as a function of time and range. The dual polarization backscatter measurements enable very high accuracy – better than 0.7%. The data enables operators to discriminate between the occurrence of pure water clouds and the presence of dirt/water cloud mixtures, with measurements and analyses completed and reported in seconds.

The initial test flight data was collected with a 10-second sample integration time and 15m (49ft) range bin size (Figure 1). After replacing the window, subsequent data was collected at one-second sample integration times and 5m (16ft) range bins to improve resolution, and enable more detailed analysis. As testing continues, results from different wavelengths and multiple sensors mounted on various parts of the plane will be investigated.

"Future designs of an ice cloud detector could include multiple wavelengths in a MiniMPL sensor on a pivoting gimbal that is able to point straight ahead for flight, then switch to nadir and zenith for landing and take-off, respectively," explains Fisher.

ENCOURAGING RESULTS

Several key factors that influence icing on aircraft – particle concentration and particle size – are measurable with the MiniMPL to a high degree of accuracy. In addition the MiniMPL has a range of up to 15km and the data can be processed within seconds – both valuable features for a remote sensing solution that will help pilots detect and avoid ice clouds.

The detailed analysis of the first trial flights by RHS Consulting shows that most of the cloud was classified as ice with some mixed phase and SLW droplets interspersed throughout. Understanding the characteristics of each cloud, along with wind speed, temperature and other measurements, supports good decision making and maintains safety standards.

"The MiniMPL technology is showing a lot of potential on board aircraft for improving remote sensing to provide early warning for icing hazards," says Stone. "I also find the level of detail the data provides, used in conjunction with other sensors, to be very useful for our cloud-seeding activities." ∎

Alessandro Rossi, chief innovation officer, Sunto

IRRADIATION MONITORING

Collecting better information on sun irradiance allows photovoltaic operators to ensure optimal control of solar exploitation

With two-thirds of global greenhouse gas emissions stemming from energy production and use, it is important that a cleaner, more efficient source is optimized. Solar power plays a pivotal role in this area: in 2016, photovoltaic (PV) production grew faster than any other fuel, and in 2018 solar capacity installations worldwide are exceeding 100GW for the first time.

One of the major challenges to meet this rising demand is increasing the efficiency and profitability of producing energy from the sun. If the sun's energy is harnessed efficiently, it is estimated that solar power can potentially deliver more than 2,500TW of energy globally.

While rooftop installations are the most visible part of this solar revolution, utility-scale solar farms are the major driver of its breathtaking growth. According to the latest data, in 2016 large installations represented 200GW – 65% of total installed capacity worldwide. Such huge farms present relevant operational and financial challenges though, for their magnitude requires special efforts to maximize performance and energy yield and keep costs for operations and maintenance (O&M) in line with the budget.

FACTORS AFFECTING PERFORMANCE

But how can we know if a PV plant is performing at its maximum efficiency? Is the plant exploiting the full amount of irradiation available from the sun? Monitoring the amount of available sunlight is of the utmost importance to this aim, because solar irradiation is the key environmental factor determining the production of the solar array. However, it is also highly variable both in space and in time, and the output of PV systems changes as these variables fluctuate.

Key factors affecting a PV system performance include total sunlight, its type (direct or diffuse, and their ratio), spectral shifts of irradiance, and the angle of incidence between the sun and the modules. If the total usable incident irradiance (fuel in) can be monitored, it can be determined if the PV system is generating electricity per expectations (energy out). For this reason, monitoring the amount and type of available sunlight is of paramount importance to maximize the performance of PV plants: it allows operators to effectively assess the performance ratio (PR); to quickly identify production drops; manage diagnostics; schedule maintenance; and to take timely corrective actions to couple with system failures or inefficiencies, which translates into an overall increase of production – and of revenues.

Besides production, monitoring the amount of solar irradiation is also important when considering the integration of large PV plants to the grid, because variable weather conditions strongly affect the amount of energy being produced and consumed. For this reason, detailed high-resolution solar forecasting is extremely valuable, as it allows operators to optimize the management of the supply. While on a daily basis solar forecasting is carried out with satellite data, when it comes to intra-hour variations, fine-grained information is necessary with regard to actual irradiation on the ground, to predict the system output under various sky conditions.

The CaptPro sensor mounted on its sun-fuelled Wireless Docking Station (WDS)

Previously, several devices were used for on-site measurement of the different types of irradiance necessary for measuring a plant's performance: pyranometers for measuring global irradiation, pyrheliometers pointed by sun trackers for direct irradiation, and pyranometers shaded by sun trackers for diffuse irradiation. All these instruments were typically assembled in bulky and expensive solar monitoring stations that require a professional workforce and demanding maintenance.

Due to their high cost, fixed installation mode and expensive maintenance needs, only very few stations, or more frequently only pyranometers, are typically used for monitoring large installations. As a result, plant managers don't have the most accurate data on the performance of their installations, as reality is dynamic. This is a difficulty: minor errors in irradiation measurements, with unnoticed slight under-performance, easily translate in loss of annual revenues ranging from tens of thousands of euros for a 5MW installation, up to €1m (US$1.2m) for a 250MW plant. Plus, since inaccurate monitoring causes the performance ratio to drop below a contracted value, errors can also result in financial penalties.

COST-EFFECTIVE SOLUTION

To enable effective and efficient solar irradiation monitoring, Sunto has come up with a breakthrough technology. CaptPro is a robust and portable irradiation sensor that performs simultaneous measurements of global, diffuse, direct and ground-reflected solar irradiation with no need for sun tracking systems or moving parts. CaptPro offers comprehensive, cost-effective monitoring capabilities to make irradiation monitoring simpler, more accurate and more affordable.

Thanks to its design and proprietary algorithm, it summarizes in a single self-standing device the output of pyranometers and pyrheliometers, and eliminates the need for extra equipment such as solar trackers. Additionally, it provides information about sun positioning and the spectral bands (infrared, visible and ultraviolet) of all four types of irradiation measured. Extremely easy to install and to maintain, CaptPro is tilt-plane independent and does not need routine adjustment or polar alignment.

When powered by its sun-fueled docking station, CaptPro can be configured to work within a wireless sensing network, monitoring irradiance in a seamless, cable-free way on a fine-grained, distributed scale.

By boosting the fine-grained localization of system failures, inefficiencies and production drops, CaptPro enables plant managers to take prompt, real-time actions to fix system failures and inefficiencies, and quickly restore optimal production levels, thus maximizing energy production, reducing O&M costs, and increasing profitability for investors, developers, owners and managers of PV plants.

CaptPro has been calibrated by the World Radiation Centre and successfully tested by Enel Green Power. ∎

Thanks to the WDS, irradiation measurements can be complemented by wind, temperature and humidity monitoring

Kurt Nemeth, program manager, and Helena Wingert, content specialist, OTT Hydromet

SENSOR EVOLUTION

There are many ways to measure precipitation, so it is important to weigh the strengths and weaknesses of each method against the intended application

Antarctic precipitation system, including a particle size measurement sensor and an elevated, screen-protected Pluvio^2 precipitation gauge

Sir Christopher Wren, the renowned English designer, astronomer, geometer and architect, invented the world's first tipping bucket rain gauge (TBRG) as long ago as the 17th century. The solution was considered revolutionary at the time as it enabled a clockwork chart to automatically record rainfall. Precipitation is collected in one of two buckets, which tips once it reaches a certain level (typically 0.1mm). At each tip, the data is recorded.

Elements of the early TBRG live on in the OTT WAD automatic weighing rain gauge, which combines a tipping bucket with a load cell so that it collects and weighs every rain drop and issues the data in real time. Launched in May 2018, it has the added benefit of taking weight gain into account and ignoring evaporation and emptying effects. The result is a precipitation sensor that combines the advantages of weighing sensors with those of classic tipping buckets. Thus it has a maximum uncertainty of ±3%, fulfilling WMO guidelines over the entire intensity range. The WAD issues values on precipitation intensity in the range of 0.001mm/h to 720mm/h and is especially suitable for subtropical and tropical zones. These climates are characterized by extreme rain events with up to 10,000mm of annual rainfall and severe weather conditions, including regular hurricanes and typhoons.

Operating on a different system, the OTT Pluvio^2 series, launched in 2007, weighs collected precipitation and records the data. This provides a solution that is precise at a comparably high resolution, has a low total cost of ownership and consumes little power, especially when using an anti-freeze agent instead of a heater. The OTT Pluvio^2 series has been selected by numerous national weather services in countries in the northern hemisphere as the standard instrument for liquid and solid precipitation monitoring. There are no losses from evaporation, as can happen with heated TBRG systems, and the system is linear with specified accuracy for the entire intensity range up to 3,000mm/h.

Because of its advantages, the OTT Pluvio^2 series was particularly well suited for deployment at the McMurdo Station in Antarctica, where researchers from the University of Colorado Boulder, and the US National Center for Atmospheric Research are investigating methods to measure accumulating snowfall. These measurements are important to better understand the potential for rising sea levels caused by climate change. Measuring snowfall in the Antarctic is particularly challenging due to the difficulty of distinguishing between falling and blowing snow.

To help achieve their objectives, the team deployed a tailor-made Antarctic precipitation system (APS), which includes a particle size measurement sensor and an elevated (3.5m [11.5ft]) screen-protected OTT Pluvio^2 precipitation gauge. The APS also recorded measurements for temperature, windspeed and accumulating snow height. Four APS stations have been set up in Antarctica in a project lasting two years.

OPTICAL SENSORS

Optical non-catching sensors such as the laser-based OTT Parsivel^2 approach new levels of liquid and solid precipitation monitoring by providing the complete scope of measurements in real time within a measuring range of 0.001mm/h to 1,200mm/h. Launched in 2006, the OTT Parsivel^2 simultaneously measures the amount, size and speed of particles and distinguishes precipitation types.

Its outstanding measuring performance and accuracy of ±5% for liquid precipitation make the Parsivel^2 an ideal accompaniment for weather radars. It is maintenance-free, WMO compliant and now available with heated screens. Its high spatial and temporal resolution helps to improve quantitative precipitation estimation (QPE). It is highly suitable for weather radar calibration, delivering complete information about a precipitation event and processing it as a drop size distribution (DSD) matrix. Moreover it issues calculated parameters as comprehensive statistical DSD data and informs about radar reflectivity. A network of 12 Parsivel^2 sensors and OTT dataloggers, was recently deployed for the Space Applications Centre in Ahmedabad, India.

RADAR PRECIPITATION SENSORS

Radar-based precipitation sensors, such as the Lufft WS100, launched in 2017, measure hydrometeor velocities by means of the Doppler effect and correlate them to drop sizes with the help of the Gunn-Kinzer relationship function. Moreover they can derive precipitation intensity and amount, and can distinguish precipitation types (drizzle, rain, snow, hail). Such radar precipitation sensors are therefore usually more suitable for the observation of precipitation intensity rather than the precipitation amount, which makes them most suitable for urban observation networks and road weather monitoring systems. Their greatest advantage is that they offer maintenance-free operation.

Most recently a heavy rainfall alerting system was installed in Bavaria, in which precipitation, air pressure and water levels are monitored. The network includes Lufft all-in-one weather sensors with integrated radar precipitation sensor, as well as the WS100. The installation was completed in June 2018 and connected with an updated website where citizens can track recent weather conditions and flood hazard levels. ∎

Left to right: The Parsivel^2 optical disdrometer, Pluvio^2 S weighing precipitation gauge, OTT WAD 200, and the WS100 radar precipitation sensor

Shantel Perez, business development supervisor, Intellisense Systems

WHATEVER THE WEATHER

New weather sensing technology supports humanitarian missions and the local community alike

An MWS unit installed at an Army Airborne facility in the USA

Intellisense Systems, Inc. (ISI), located in Torrance, California, provided two micro weather sensor (MWS) systems to the US Air National Guard (ANG) in support of disaster response and humanitarian relief operations in the US Virgin Islands (USVI) and Puerto Rico following hurricanes Irma and Maria in 2017.

Immediately following the devastating effects of the hurricanes, the ANG deployed the 146th Airlift Control Flight to the areas that had experienced catastrophic damage. The lack of local weather data and observations associated with collapsed power grids and damaged equipment resulted in airfield and resupply operations coming to a grinding halt. This missing and critical information was needed as ANG crew rely on weather data and observations to safely complete air resupply operations.

As a global innovation company that delivers highly engineered, critical, functional products and services for defense customers, including cutting-edge sensor, information processing, optoelectronic, augmented intelligence and visualization technologies, ISI saw an opportunity to help the ANG with technology initially developed for the US Department of Defense (DoD). The meteorologist associated with the 146th Airlift Control Flight accepted assistance in the form of ISI's MWS to fill the critical weather data and observation information gap. The MWS is a lightweight, ruggedized, highly integrated unattended ground sensor capable of being deployed globally in remote or denied locations for meteorological monitoring and increased situational awareness. Its 3.5 lb (1.6kg) lightweight construction is ideal for helping military personnel monitor the operational environment.

ESSENTIAL DATA

ANG's contingency response team immediately deployed ISI's two sensor systems to various strategic locations surrounding the active airfields to assist them in monitoring the weather conditions. One of those sensors was installed in the Mercedita Airport in Puerto Rico and the other at the Cyril E King International Airport in St Thomas, USVI. The MWS provided critical environmental information and panoramic imagery to ANG leadership, whose decisions were needed promptly to assist urgent resupply and medical evacuation missions.

ISI's rapid response and assistance enabled ANG personnel to establish 24-hour weather reporting operations in support of ongoing US disaster relief efforts and resume airfield and resupply operations. The technology provided essential weather data such as windspeed and direction, barometric pressure, temperature, cloud ceiling and visibility to air traffic controllers on the ground as well as to incoming pilots. The MWS also supplied ANG meteorologists with visual imagery, which proved to be a useful tool for providing military personnel with present weather conditions as aircraft arrived at the MWS deployment locations. Imagery was being provided through the MWS 360° camera on top of the unit. This real-time information ensured steady sequencing of aircraft into and out of the active airfields in the area of operations.

Staff sergeant Jerry Rodriguez, meteorologist with the ANG, described the MWS as "an extremely useful technology during our contingency response missions". He added, "It is well packaged for mobility and provides our team flexibility in any environment, unlike the stationary weather sensors at some airfields. Additionally the built-in satellite communications proved to be critical during situations where communications were limited or non-existent."

FUTURE MISSIONS

ISI continues to employ these units to assist ANG personnel. The intent for future operations is to have these remote sensors permanently available and rapidly installed by Total Force (active duty and ANG) personnel to allow an increased level of prediction and monitoring in data sparse areas. The lead time that the MWS can provide to humanitarian relief and other time-sensitive missions will be essential for future disaster response and mitigation. The active-duty force across all services, including Air Force, Army, Navy and Marine Corps, is now fielding the MWS. One thing that Total Force can agree on is the critical role weather plays in mission success; often it is the deciding factor in whether a mission will be conducted or stood down altogether. History has shown that weather can cause complete mission failure when not taken into account or mitigated through present weather observations. The MWS technology seeks to prevent these disasters from occurring in the future and ensuring mission success.

REMOTE MONITORING

Not only has the MWS assisted during humanitarian missions, but it has also been sent to monitor weather conditions around the world. It is currently supporting activity in areas where weather sensing was previously unavailable due to power and communication restrictions, such as remote regions in North Africa and Alaska.

In Alaska, the National Forestry Service is currently testing units to monitor weather patterns in areas that are environmentally challenging at certain times of the year. Recreational activities in these areas – such as skiing and kayaking – where weather can be next to impossible to predict, can quickly become life threatening.

The Forestry Service's concept of operations for the MWS is to strategically place these sensors throughout known recreational areas to create a sensor network that will provide early warning and continuous monitoring to residents and visitors to Alaska's frontier. Information of this kind can alert residents and visitors to dangerous upcoming weather. This can ultimately allow people to take cautionary action when outside.

LOCAL SUPPORT

ISI, a wholly owned subsidiary of Physical Optics Corporation (POC), also recently partnered with local officials in Torrance, California, who were pleased to assist its efforts in supporting agencies close to home. ISI has volunteered to enhance local airfield operations by placing the MWS at Zamperini Field in the City of Torrance. The system will supplement existing equipment and provide an additional source of weather data for the airfield. It will also provide panoramic imagery for incoming pilots to have a true 'eyes on the ground' approach. Some of the information provided includes temperature, windspeed, wind direction, precipitation, humidity, cloud measurements and visibility.

This is just the beginning of ISI's support of the community. The company plans to continue its efforts to support local law enforcement and other agencies throughout Torrance and southern California. The myriad technologies developed at ISI will undoubtedly provide cutting-edge solutions to the challenges faced by local communities. Whether through sensor systems, augmented intelligence, wearable technology or high-definition displays, ISI remains laser focused on being at the forefront of innovation.

ISI's chief operating officer, Frank Willis, is "proud that ISI is able to answer the call and know that our technology is making a difference. Our goal is to enhance the capability of the men and women serving our country and responding at home and abroad to these disastrous events. ISI will continue to explore opportunities to assist the men and women defending our country and supporting worldwide efforts with cutting-edge technology that provides solutions to the challenges they face. We are also committed to our local community and the place we have called home for more than 30 years. Our friends and family in Torrance will always have our support through any means we can provide." ∎

MWS installed at Cyril E King International Airport, US Virgin Islands

MWS being installed in a remote area of a United States Army facility

Ian Abbott, senior product manager, Baker Hughes, a GE company

ACCURACY UNDER PRESSURE

Baker Hughes's barometric pressure sensors now feature Trench Etched Resonant Pressure Sensor (TERPS) technology, a new silicon sensing technology designed to give the highest performance available from a pressure sensor

Meteorologists can ensure high accuracy and stability of pressure measurements using a new range of technologically advanced electronic instruments

TERPS technology has been designed for applications where ultimate accuracy and stability are required

Pressure measurement using electronic instruments has been possible for many years. However, for compliance with WMO and FAA standards, there are a number of technical challenges to overcome. Barometric pressure measurement uses an absolute reference – the reading is compared with zero pressure, or a hard vacuum. This means that many of the simpler designs of electronic pressure sensors are not suitable. Accuracy is also an issue – the desired 0.1Pa is 0.0001% of 1,000hPa and is an order of magnitude greater than the capability of most pressure sensors. For high-performance industrial-grade pressure sensors with digital compensation in a temperature range of -20°C to +80°C (-4°F to +176°F), 0.1% accuracy is considered to be good.

Other challenges include stability and robustness. In many applications, units can have their zero set every day, but with absolute devices this is much harder. In addition weather stations are often sited in remote areas, with calibration only once a year. This demands high levels of stability to maintain the validity of data. Equipment also needs to survive the rigors of its site.

There are a limited number of technologies capable of meeting the above requirements. In addition, meeting them at a cost-effective price and offering realistic delivery times presents further challenges to the instrumentation manufacturer. Baker Hughes, a GE Company, designs and manufactures the RPS/DPS 8100 series, which exceeds all the requirements set by the WMO and FAA and meets the needs of meteorologists. The RPS/DPS 8100 series of barometric pressure sensors is the first to incorporate the company's Trench Etched Resonant Pressure Sensor (TERPS) technology, developed to deliver enhanced accuracy and stability. According to the company, the unique properties of the TERPS technology make it the ideal solution for barometric pressure measurement in meteorology applications.

TERPS technology was developed by GE's Druck business, which has been manufacturing high-performance piezo-resistive pressure sensors since 1972. The business has developed expertise in high-performance, high-stability, fast-responding, high-quality pressure sensors. With a state-of-the-art clean room in Leicester, UK, and a global manufacturing footprint, the company has developed manufacturing processes that serve a wide range of applications, from aerospace to subsea and from process engineering and metrology to industrial instrumentation.

TERPS

The TERPS technology in the RPS/DPS 8100 series uses three major manufacturing and packaging techniques. Deep reactive ion etching (DRIE) enables the creation of complex and arbitrary geometries within the resonating structure. This optimizes the design and performance of the resonator to enable higher pressure and wider temperature ranges. The use of silicon fusion bonding (SFB) enables the machining of individual components of the sensor to be processed separately and then fused together, thus retaining the properties of single-crystal silicon. This provides greater flexibility in the design of the sensor element, giving higher pressure and temperature ranges.

The new sensors operate in essentially he same way as any silicon-based resonant sensor. The silicon structure is driven into resonance by the application of an electrostatic field and when pressure is applied to a diaphragm, the silicon resonator is stretched, changing the frequency, much like a guitar string. This change in frequency relates directly to the applied pressure.

The new manufacturing techniques have enabled performance improvements over the older resonant silicon pressure transducer (RPT) designs. The bulk micromachining of the silicon, a technology that has been migrated from GE's Advanced Sensors business, improves product delivery times.

In terms of performance, the new manufacturing and packaging of the TERPS technology in the RPS/DPS 8100 series offers accuracy up to 0.01% full scale over a compensated temperature range of -40°C/F to +85°C (185°F), and stability of ±0.01 full scale/annum. What's more, the use of optimized resonator geometry offers the flexibility to extend the sensor's operation to even harsher environments and wider temperature ranges.

IMPROVED PERFORMANCE SENSORS

WMO and the FAA standards for automated weather observing systems (AWOS) have become the core standards that all weather stations need to meet. The RPS/DPS 8100 series has been specifically designed to meet or exceed these standards, not just in lab tests but also in harsh and remote environments. Combined with improved stability, the TERPS technology means less calibration and a lower overall cost of ownership.

The 8100 series barometers are available in a number of options to best suit different applications. A USB output gives easy connection to laptops, desktop PCs and mobile devices. A simple app is available to create a handheld instrument. RS485 is available for more traditional connections to process instrumentation and component parts can be supplied to allow integration into OEM systems.

In addition to providing the performance and packaging improvements available with TERPS, the RPS/DPS 8100 product line takes advantage of best practices to offer a wide range of pressure and electrical connections, thus enabling a level of customization for specific application requirements never before available in a sensor of this class.

The combination of the power of TERPS technology with the quality, reliability and flexibility of the RPS8100 series offers a unique solution for the high-accuracy and high-stability pressure measurement required for meteorological applications. ∎

Alec Bennett, meteorological products manager, Biral

FIRST STRIKE

How can airports predict if the first lightning strike will occur overhead? The on-site monitoring of charged raindrops may hold the answer

Figure 1: Biral BTD-300 thunderstorm detector

Thunderstorms and their associated lightning flashes can pose a major threat to life if people are caught in the open. In the aviation industry, staff and passengers can find themselves on an exposed site with little or no protection. In such circumstances, the early detection of thunderstorm activity is critical.

A common method of thunderstorm warning is the detection and tracking of lightning flashes surrounding the site, allowing the proximity of the thunderstorm to be monitored in real time. Lightning location networks, single-site detectors and even optical detection from space are used to get information about lightning activity, with kilometer-accurate locations available across most of the world within minutes – and sometimes even seconds.

While detection technology, sensitivity and global coverage have advanced considerably over the past few decades, challenges in thunderstorm warning still remain. One of these is the ability to warn of the potential for lightning activity in an area before the first lightning flash is detected. Clearly a thunderstorm has to begin somewhere and although in the majority of cases adequate warning is provided by the detection of distant lightning from an approaching storm, occasionally the first lightning strike will be uncomfortably near to your site.

METHODS OF PREDICTION

How likely is it that a thunderstorm will develop overhead without warning from the detection of previous flashes occurring a safe distance away? The answer to this question will vary according to the site and even the time of year, with some locations more favorable to overhead thunderstorm generation than others. For example, thunderstorms can be triggered when moist air is forced to rise above a mountain range, where it becomes unstable, rising higher into the atmosphere and producing persistent thunderstorms for the windward site of the range.

For sites with no systematic trigger of overhead thunderstorm activity, it is worth evaluating the probability that the first lightning flash of a storm will be nearby, compared with storms that are already producing lightning some distance away as they approach.

In one such case, archived data was analyzed from a Biral BTD-300 thunderstorm detector (Figure 1) near Bristol in southwest England during 2017. This mid-latitude coastal site has no nearby mountains or other likely triggers of thunderstorm activity. Like the rest of northwest Europe, the site is subject to strong extratropical cyclones during the autumn and winter months, which can produce thunderstorms near their center and along trailing cold and occluded fronts. Convection from polar air traveling over the relatively warm sea can also trigger thunderstorms during these seasons, which are blown over the western coasts of the UK. In summer, deep convection is initiated at the site by local heating of the land, with a key ingredient of the strongest thunderstorms being hot, moist air moving north from France and Spain.

In addition to lightning detection, the BTD-300 warns of the potential for overhead lightning by measuring the charge on individual raindrops and the variability of the atmospheric electric field. The latter indicates if the atmospheric electric field is sufficiently strong to produce ions as the air breaks down around tall, pointed objects below a developing thunderstorm. Charged rain and ions are both indications of increased lightning risk and can occur several minutes before the first lightning flash is produced by the storm. This enables the BTD-300 to alert the user before any warning is issued from a lightning-only detection technique.

With this in mind, the BTD-300 warnings issued during 2017 were analyzed in relation to thunderstorms that produced lightning within 10 nautical miles (18.5km) of the site. This distance was chosen since it is defined as "thunderstorm in the vicinity" for US METAR (aviation weather observation) codes. Lightning within this range is referred to as 'nearby' in this article. To assess whether nearby flashes were preceded by distant ones, a suitable definition for "distant" must be used. The lower limit must be 18.5 km (10 nautical miles), and since the maximum reporting range of the BTD-300 is 83km (45 nautical miles), this must be the upper limit. Distant lightning is therefore defined here as occurring between 18.5-83km (10-45 nautical miles) from the site. As an indication of the scale of these areas, a map showing the location of the BTD-300 and the nearby/distant lightning zones is shown in Figure 2.

FILTERING THE RESULTS

During 2017 a total of 16 thunderstorms produced 502 nearby lightning flashes, which is fairly typical of the region, equaling a flash density of 0.5 flashes per square kilometer (0.4 square miles) per year. Of

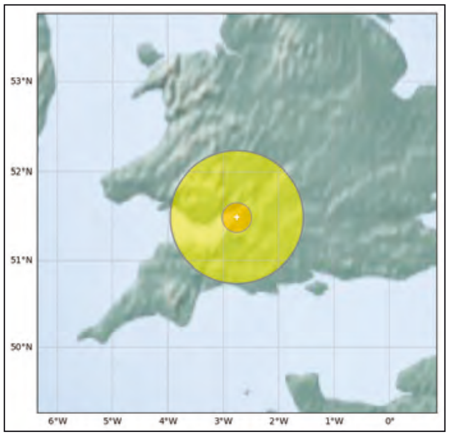


Figure 2: Location of BTD-300 in the UK (white cross). The orange and yellow circles identify regions defined as nearby and distant respectively, for lightning proximity classification

Table 1: Early warning times then the first flash of a storm was nearby, given by non-flash warning triggers (charged rain and corona ions)

Table 1

Date of storm	Early warning from non-flash triggers
06/06/2017	10 minutes
18/08/2017	12 minutes
15/09/2017	17 minutes
29/12/2017	14 minutes

those 16 storms, 10 produced distant lightning within 30 minutes of the first nearby flash. There were only four storms associated with a charged rain or corona warning and no distant lightning, which provided the only alert of increased risk to the site. Of the remaining two events, one had no warning and the other had charged rain followed by distant lightning ahead of the first nearby flash (Figure 3).

These results clearly demonstrate the benefit of using a combined lightning and non-lightning method to warn of the first nearby lightning flash, with 31% of storms producing their first flash nearby without any prior distant lightning to act as a warning. By including the non-lightning warning triggers of charged rain and ion detection, unexpected storms reduced to only 6%. The early warning times when the first flash of a storm occurred nearby is shown in Table 1. It can be seen that these vital non-flash triggers provided 10 to 17 minutes' early warning.

The warning activity before all nearby flashes was also assessed, since monitoring of a nearby storm is necessary to gauge when activities can resume after it leaves the area. The probability of detection and false alarm ratio of nearby lightning for each warning type is shown in Figure 4. In this figure, the three BTD-300 triggers of charged rain, corona ions and distant lightning are also compared with the occurrence of heavy rain, as a non-electrical comparison that a user may also use as a sign of potential nearby thunderstorm development.

This was measured using a Biral VPF-730 visibility and present weather sensor located approximately 2m (6.6ft) from the BTD-300. This instrument classifies hydrometeor type (rain, snow, etc) and intensity each minute using the forward scatter and backscatter of near-infrared radiation. While the official definition of heavy rain differs between countries, the WMO defines heavy rain as being >10mm/h. This definition is also used in the UK by the Civil Aviation Authority for heavy rain associated with cumuliform cloud.

From Figure 4 it can be seen that distant lightning has the greatest probability of detection, at 89%. This was followed by charged rain and corona, with heavy rain offering the lowest POD for nearby lightning. The false alarm ratio is used to assess whether the warning was likely to be followed by a nearby flash within 30 minutes. The lowest FAR was for corona, and the highest for heavy rain. This means that when a warning is activated by corona ions, it has an even greater chance of predicting a nearby lightning flash than distant lightning.

The false alarm ratio from distant lightning could, however, be improved by considering the direction of the lightning flashes in relation to the direction that the thunderstorms are moving (such as by ignoring distant flashes of retreating storms). The BTD-300 consequently has an optional lightning direction finder module to aid such discrimination. The existence of charge on the raindrops added substantial accuracy to the prediction compared with using rainfall intensity alone.

To summarize, there is growing evidence that while the detection of distant lightning is the best single method of warning, this method alone will miss the typically 25% of thunderstorms that develop nearby. Additional monitoring of atmospheric electrical precursors at the site itself is required to reliably ensure the safety of people and equipment from nearby lightning. ∎

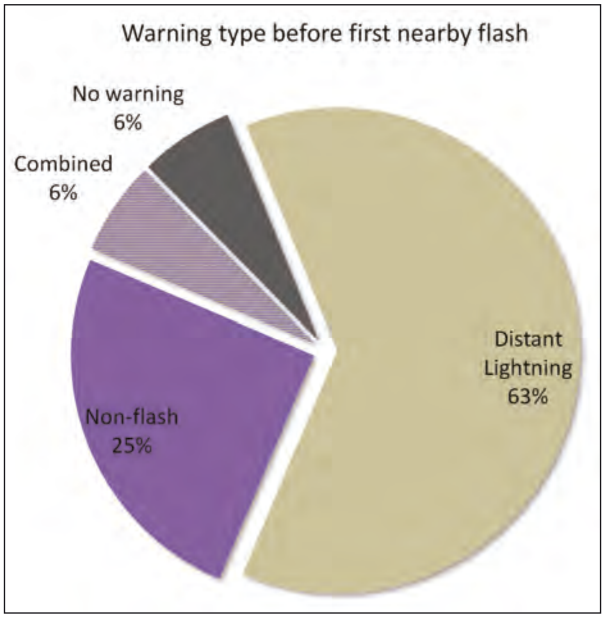


Figure 3: Occurrence of warning type within 30 minutes of the first nearby lightning flash during 2017, as reported by a BTD-300

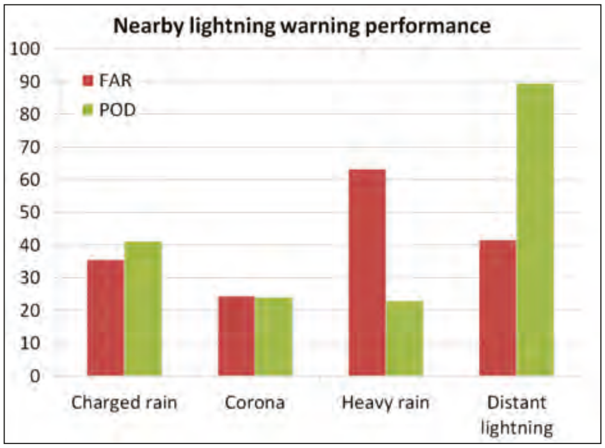
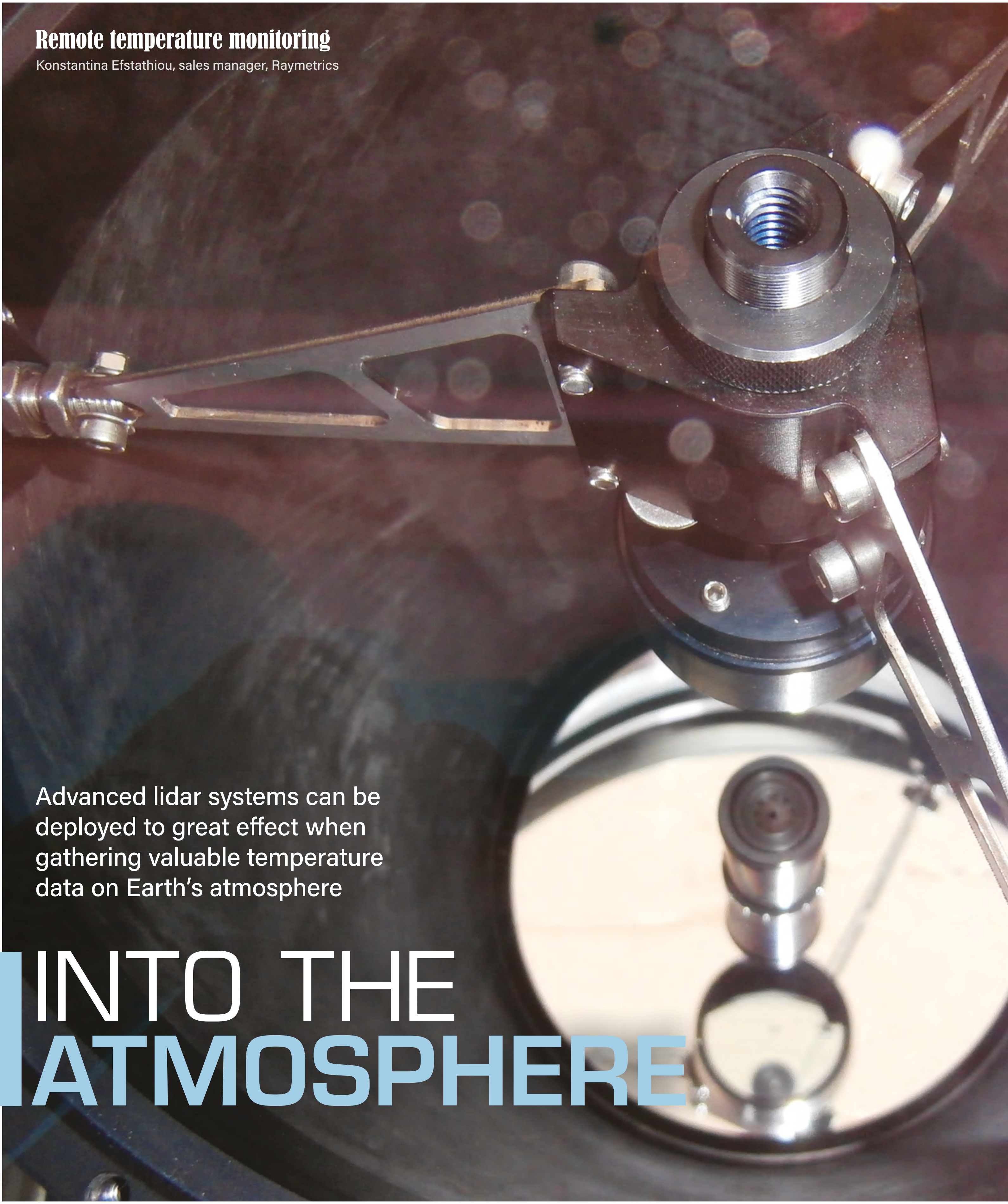


Figure 4: Probability of detection (POD) and false alarm ratio (FAR) for nearby lightning flashes according to warning type, during 2017

Konstantina Efstathiou, sales manager, Raymetrics



Advanced lidar systems can be deployed to great effect when gathering valuable temperature data on Earth's atmosphere

INTO THE ATMOSPHERE

Inner telescope overview

Raymetrics temperature and humidity lidar system

Vertical distribution of temperature is a key parameter of Earth's atmosphere. Accurate knowledge of temperature profiles can contribute significantly in fields such as meteorology, atmospheric dynamics, climatology and atmospheric chemistry. To be useful, such measurements should have high vertical and temporal resolution, to capture the complexity and variability of Earth's atmosphere.

Raymetrics, a leading manufacturer of advanced lidar systems, has developed a series of instruments that can measure temperature from near the ground to the top of the mesosphere, with accuracy that can satisfy even the most demanding research or operational requirements.

One of the techniques adopted by Raymetrics' lidar systems is based on the emission of short laser pulses in the atmosphere and the detection of the radiation scattered back toward the sensor. The spectral characteristics of the backscattered radiation allow the estimation of various atmospheric properties, while the time difference between the emission of the laser pulse and the detection gives information about the altitude that is being probed.

For example, by using a combination of emission and detection wavelengths, advanced lidars are able to measure the concentration and properties of atmospheric aerosols, the concentration of atmospheric gases, and retrieve temperature and relative humidity profiles.

Using its own light source, a lidar can operate both day and night. Measurements during daytime are naturally more challenging, as solar radiation can interfere with the measurements. However, this challenge can be overcome through a high-powered system, spectrally narrow detection channels and optimized optomechanical design. For many years such lidars have been confined to labs or advanced research facilities, but thanks to recent technological advantages they have reached the maturity necessary for the long-term unattended measurements required by operational and research agencies.

TEMPERATURE PROFILES

Two lidar techniques are particularly relevant for the operational monitoring of temperature profiles: the rotational Raman (RR) technique and the integration technique. The RR technique can be used to derive temperature profiles from the ground up to the lower stratosphere (~25km/16 miles) while the integration technique can be used to retrieve temperature information from stratosphere up to the top of the mesosphere (~90km/56 miles). For tropospheric measurements, the RR lidar is the method of choice.

The RR technique takes advantage of the fact that the intensities of RR lines change with ambient temperature. By measuring the appropriate regions of the RR signals backscattered from the atmosphere, the RR lidar can retrieve the temperature of ambient air at high accuracy and with minimum assumptions. As the technique is not influenced by the presence of aerosols and thin clouds, it is ideal for use in the lower atmosphere. However, the weak strength of the RR signals limits the effective range to 25km. This range can change depending on lidar power and atmospheric conditions.

On the other hand, the integration technique assumes that the elastically backscattered signal is proportional to the molecular number density of the atmosphere. This assumption limits the applicability of this technique at the higher stratosphere and mesosphere. The two techniques combined can cover almost a full 90km range, making them a powerful combination for most atmospheric applications.

PRODUCT DEVELOPMENT

With more than 17 years in the industry, Raymetrics designs new products that address major meteorological parameters. For temperature monitoring, the company develops systems based on both RR and integration techniques. The RR systems can be optimized either for planetary boundary layer studies or for studies in the free troposphere. The instruments integrate state-of-the-art technology, developed in research laboratories in Europe, with Raymetrics' experience in building robust, standalone systems that are able to operate 24/7 even in harsh environmental conditions.

Raymetrics' RR lidar system can provide aerosol backscatter and extinction profiles, as well as water vapor mixing ratio profiles, making it an ideal tool for meteorological services and research organizations. Furthermore, the integration technique can be used to extend the effective range of temperature profiling of the free troposphere. Finally it should be mentioned that Raymetrics, through strategic partnerships, provides solutions for temperature profiling in the stratosphere and mesosphere based on the Rayleigh lidar technique. All Raymetrics solutions can be remotely controlled and operate unattended, while a monitoring platform (cloud-based or installed on-site) provides early warning for required maintenance, thereby minimizing downtime and operational costs. ▮

Clive Lee, technical sales and service manager, Kipp & Zonen

STATE OF FLUX

Large aperture scintillometers provide a reliable alternative to the eddy covariance technique when conducting long-range heat flux observations from Earth's surface

Extra Large Aperture Scintillometer with GPS receiver

Limited natural resources and climate change are increasingly important topics. Fresh water, the hydrological cycle and the balance of energy play a large part in both, affecting the biosphere and Earth's climate. Water is vital for many aspects of our life, such as food production and processing, forestry, industry, transport and recreation. Effective management of this resource, and understanding where it is being lost or gained, is therefore crucial.

There are large temporal and spatial variations in the availability of water in a region. These variations depend on many factors, such as rainfall, hydraulic properties of the soil, water consumed and transpired by crops, surface water evaporation, agricultural irrigation and river run-off. However, the key process is the transport of energy between Earth's surface and its atmosphere.

Ground-based measurements of surface energy fluxes are beneficial to satellite data, hydrological models and energy balance in climate models, for validation and calibration. The basis for these models and remote sensing techniques is the 'energy balance' at Earth's surface. The driving force is the total energy available, the net radiation balance. This energy is divided among the surface energy fluxes (see Figure 1, page 134).

The total net radiation balance Rn is the result of the subtraction of all outgoing radiation fluxes from the incoming radiation fluxes, at Earth's surface. The incoming components are global solar radiation and long-wave thermal radiation received from the atmosphere and clouds. Solar radiation reflected by the surface and long-wave radiation emitted by the ground are the outgoing components.

H is the 'sensible' heat flux which changes the temperature of the air, and G_s is the energy flux into the soil which causes a ground temperature change. 'Latent' heat flux does not cause any detectable temperature changes – when added to water it causes a phase change from the liquid to gaseous state (evaporation) and is released again when the water changes back from gas to liquid (condensation). Latent heat flux, LvE, cannot be sensed or felt because the temperature of the water molecules is not changed.

Vegetation extracts large amounts of water from the soil and releases it into the atmosphere through a process called transpiration. Transpiration and surface water evaporation are the two main contributors to latent heat flux and often referred to jointly as evapotranspiration (ET). In many regions, this is the main source of outgoing fluxes of water.

Traditionally, the method for obtaining accurate surface heat fluxes has been the eddy covariance technique. H is derived from the vertical velocity of wind and temperature, representing a footprint extending around 100m (328ft) from the measurement location, but this is very different from the typical pixel size of satellite and model data, which is in the order of kilometers. This is most significant in areas where the terrain is not homogeneous in composition, elevation and vegetation.

LARGE APERTURE SCINTILLOMETER

An alternative method for continuously monitoring the surface energy balance is based on a Large Aperture Scintillometer (LAS). A transmitter and receiver are placed at opposite ends of a path ranging from 100m up to several kilometers. The transmitter emits a beam of pulsed near-infrared radiation, which is detected by the receiver. Heat fluxes cause variations of temperature and water vapor concentration that create turbulent eddies in the atmosphere, which refract and scatter the transmitted radiation. The receiver detects these intensity variations of the beam, which are proportional to small changes in the refractive index of air (Cn2). Such an instrument is the Kipp & Zonen LAS MkII.

To derive the sensible heat flux, H, the Monin-Obukhov Similarity Theory (MOST) is applied. This is done by combining the Cn2 measurement from the scintillometer with time-coherent local measurements of ambient temperature, pressure and windspeed and applying algorithms to process the data in real time.

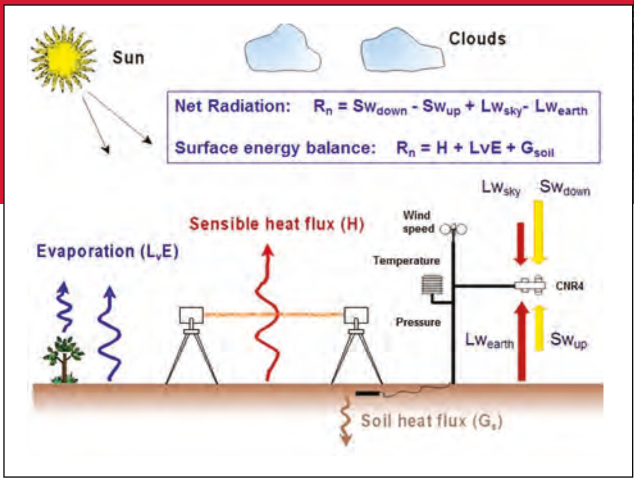
To calculate latent heat flux, LvE, and evapotranspiration, ET, additional data is required. Rn is provided by a net radiometer that measures all four components of the radiation balance, separately or combined in a single sensor. Heat flux plates measure the energy that flows into, or out of, the soil (Gs). Two very accurate, vertically separated, temperature sensors are required to determine the direction of the heat flow in the atmosphere.

Given these measurements we can calculate LvE as the unknown factor that completes the surface energy balance. This closure of the equation is often not achievable with the eddy covariance technique. A major advantage of an LAS system is that it yields the average fluxes over a large integrated footprint which matches the pixel sizes of hydrological models and satellite images. The LAS MkII covers paths up to 4.5km (2.8 miles) but, to improve the spatial match even further, a new Extra Large Aperture Scintillometer, the X-LAS MkII, has been developed to measure paths up to 12km (7.5 miles).

An optical scintillometer cannot measure over a path that is primarily open water

Extra Large Aperture Scintillometer and microwave scintillometer measuring over wetlands

Figure 1: Components of the surface energy balance



because the flux is too low. A microwave scintillometer, such as the MWSC-160 from Radiometer Physics of Germany, can measure LvE directly and over water, but it must be used together with an optical Large Aperture Scintillometer. The X-LAS MkII response to larger turbulent eddies closely matches that of the RPG microwave instrument and this combination provides direct measurements of both sensible heat and latent heat fluxes (evapotranspiration) averaged over a very large area

Scintillometer systems are often installed in remote areas and need to operate autonomously from simple solar powered batteries, storing data and communicating using wireless networks. Systems are installed in a wide range of climates; from arid deserts where the temperature can be +50°C (122°F) during the day and fall to -10°C (14°F) at night, to the hot and humid Amazon rainforest, or the aggressive conditions of coastal areas. Scintillometers are designed in such a way that they can cope with all these conditions.

Keeping the optical surfaces clear is important for good measurements and a built-in window heater system ensures proper operation under most weather conditions. It is critical that the internal optics and external beam stay optimally aligned, so the housings and adjustable mountings must remain stable after installation. The LAS MkII is all-aluminum and so was the larger X-LAS MkI, which as a result was heavy and difficult to handle. To reduce size and weight, while maintaining rigidity and optical alignment, the new X-LAS MkII has a unique tapered carbon-fiber enclosure.

Scintillometers are often moved during field campaigns and the Kipp & Zonen models pack into easily handled rugged transport cases. To make setup on site quick and easy they can be installed and configured using a built-in display and keypad, without the need for laptops or software. Internal digital processing automatically computes all the relevant parameters, such as Cn2 and H. Real-time data is available on the display, so you know the status of your experiment in seconds.

The built-in datalogger stores several months of measurements and results and a serial interface gives full remote control over the instrument operational settings and display of real-time or stored data. Analog outputs are also available, enabling easy integration into new or existing measurement networks.

TRIED AND TESTED

Users need to be able to trust the long-term reliable operation of the instruments as well as the data they provide. To ensure this, new scintillometers are thoroughly tested indoors and outdoors.

Inherent in the LAS and X-LAS design and measurement process is that there is no need for an absolute calibration. To ensure quality and consistency, however, a facility has been constructed that will compare new instruments against reference instruments over a clear path of 890m (2,920ft) between the 10m-high (33ft) roof of the Kipp & Zonen factory and the 90m (295ft) top of a building at the Technical University of Delft, Netherlands.

A reference LAS MkII transmitter on the TU Delft building has sufficient beam divergence to illuminate multiple reference and test LAS MkII and X-LAS MkII receivers on the factory roof, enabling them all to be relatively calibrated and to check the operation of the system through to the processed data. An additional receiver on the university roof, with an RF datalink back to the factory, enables alignment and testing of new transmitters.

A new carbon-fiber X-LAS MkII was compared with an original, all-aluminum X-LAS MkI, updated to the latest electronics and optics. The correlation of results was very good, demonstrating the stability of the new design.

In addition, two X-LAS MkI scintillometers updated to the latest optics and electronics were compared in the field at the CESAR observatory, in the west of the Netherlands, mounted at 60m (197ft) height on the 213m (699ft) Cabauw observation tower, to test the long-range performance at 9.8km (six miles).

One of the instruments belongs to the Royal Netherlands Meteorological Institute (KNMI) and is usually housed at this site; the other was a Kipp & Zonen reference unit.

The data collected over the autumn and winter of 2015/2016 showed excellent agreement between the two instruments and even recorded the New Year fireworks going off!

The new all-digital carbon-fiber X-LAS MkII is now proved and is the ideal basis for measurements of turbulence, sensible heat flux, latent heat flux and evapotranspiration over large path lengths up to 12km (7.4 miles).

This is particularly useful for validating satellite data and models and as the optical partner for a microwave scintillometer. ∎

Portable weather stations

Daniel Nelson, technical sales manager, and Karen Fox, marketing manager, Coastal Environmental Systems

RAPID RESPONSE

When called upon by emergency responders, portable weather stations need to provide a quick, rugged setup that's intuitive to use in all environments

Solar-powered Portable Tactical Weatherpak weather station

Intercept touch screen display for Weatherpak MTR emergency response weather stations

The Coastal Environmental Systems (CES) Weatherpak MTR is an all-in-one rugged weather station for emergency responders. The station is designed for portable use and can be set up in less than 60 seconds.

The Weatherpak MTR measures wind speed and direction (every second, with an ultrasonic wind sensor and automatic true-north alignment using the built-in compass), temperature, relative humidity, barometric pressure and – optionally – gamma radiation. The weather data is transmitted to the MTR display from a distance of up to five miles (line of sight) via radio. The data is then used to update a plume model. This information helps determine the placement of personnel, vehicles and evacuation of residents.

PURPOSE-BUILT DISPLAY

CES recently developed a new high-resolution touchscreen display, based on an embedded PC running CES Intercept software for data collection, storage and processing. The new version of the display is lighter, but has a larger touchscreen. With multiple mounting configurations and radio options, it can be placed anywhere (wall mount, heavy-duty desktop, panel mount). Intercept provides a clear interface for emergency responders to view all data from the HAZMAT station, as well as data from other Weatherpak weather stations in the vicinity.

Intercept software comes with built-in audio alarms. For example, if the Weatherpak station has the optional gamma radiation sensor, there is also a preconfigured gamma radiation alert. Users can also create additional alerts themselves. These alerts can be based on data from a single sensor or from multiple sensors.

INTERCEPT SOFTWARE

The Intercept display software starts up automatically when the display computer detects that a Weatherpak MTR is operating. If additional Weatherpaks are in the vicinity they will be automatically detected and the Intercept display will show their data in addition to that of the main Weatherpak MTR. The integrated GPS in both the MTR stations and the MTR display provide their locations relative to each other, and the distances between the Intercept system and the stations are calculated by the system.

Trend graphs of meteorological parameters are available, including temperature, barometric pressure, humidity, and wind direction and speed. Users can select a specific date or range to graph. The data on display is updated once a minute. Intercept also stores data as customizable log files that can be exported.

MILITARY DEPLOYMENT

Portable weather stations provide military and civil defense units with indispensable weather data for mission-critical operations. Coalition air bases in Afghanistan use portable automated weather observing systems (AWOS) with mobile air traffic control towers and as backup to fixed weather stations. Civil defense agencies in South America include portable weather stations in their mobile strategic communication centers and are deployed in the event of an earthquake or other natural disaster. Chemical, biological, radiological and nuclear (CBRN) response teams around the globe set up weather stations in the hot zone of a HAZMAT incident to model the spread of harmful airborne chemicals.

In both aviation and hazardous materials response, the field-tested reliability of the weather station is paramount. The Portable Tactical weather station, also called PTAC, is based on the CES Weatherpak and has met the needs of military operations for over two decades. Recently the PTAC station has provided support for natural disasters in Chile, helicopter operations in the jungles of Panama, remote desert deployments in Afghanistan and the Middle East, and as backup at air bases around the world.

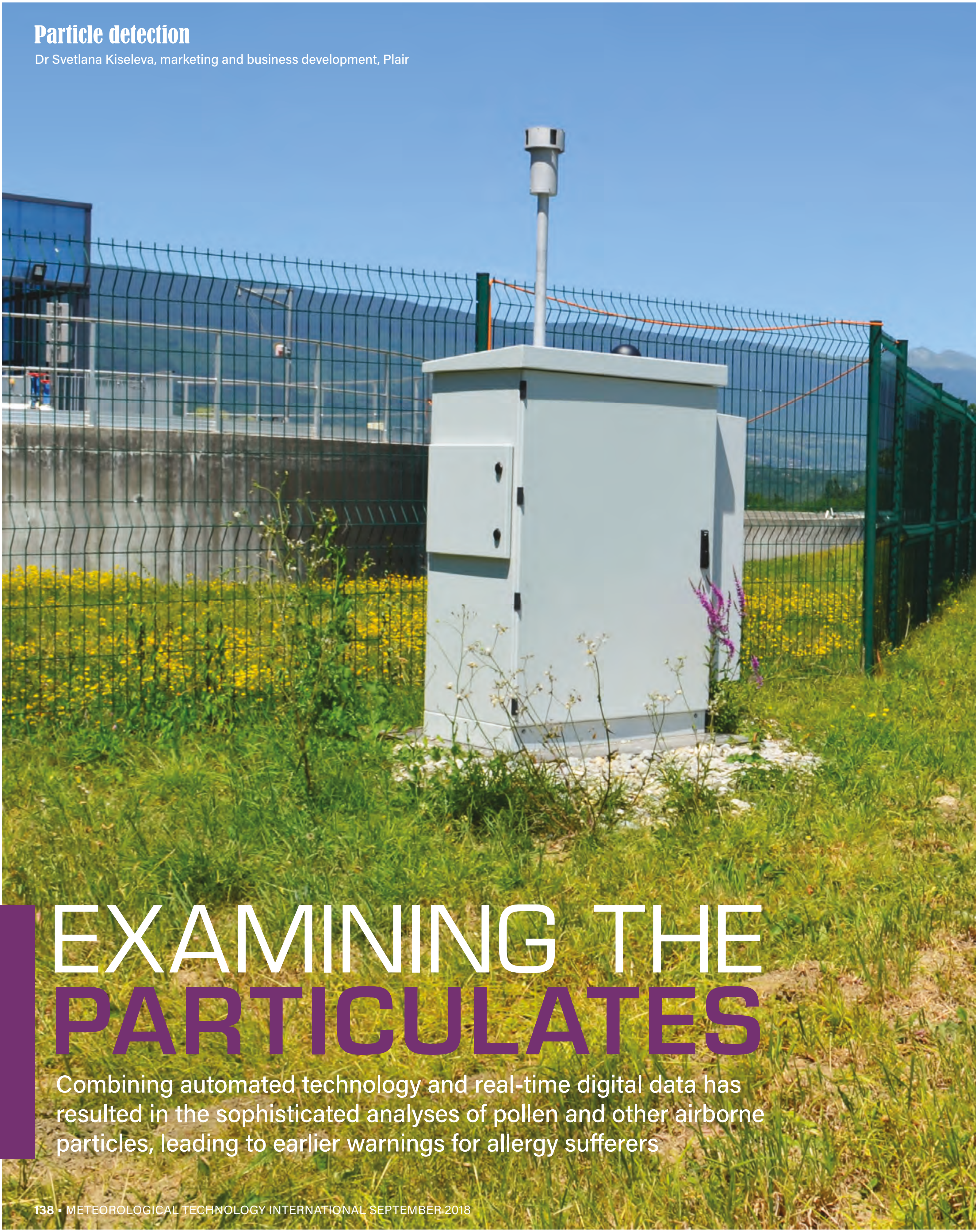
Rapid deployment in harsh conditions is a necessity for critical military aviation operations. Developed specifically for the CES PTAC station, the new CS136 ceilometer is made in the UK by Campbell Scientific. Weighing only 18kg (40lb), the compact sensor can be carried in one hand. An expandable leveling base provides secure operation on uneven terrain.

Reliable performance at low altitude is essential for aviation, achieved in the CS136 using a single-lens design that maximizes sensitivity for accurate performance at all altitudes. The CS136 ceilometer measures cloud base for up to four layers, including cloud cover for up to five layers. It can withstand winds up to 55m/s (123mph), has an altitude range of 0-8km (0-5 miles)and an operating range of -40°C to +60°C (-40°F to 140F).

Low power consumption is an important consideration for tactical operations, too. The CS136 ceilometer is DC powered, so the entire PTAC can be solar powered. The CS136 is easy to install and operate, and complies with or exceeds ICAO and WMO specifications for cloud measurements.

In addition to the standard meteorological instruments, PTAC systems can be completely solar powered and equipped with visibility/present weather measurements, lightning/thunderstorm detectors and rain gauges, to be operated as full-fledged AWOS. ∎

Dr Svetlana Kiseleva, marketing and business development, Plair



EXAMINING THE PARTICULATES

Combining automated technology and real-time digital data has resulted in the sophisticated analyses of pollen and other airborne particles, leading to earlier warnings for allergy sufferers

A network of Rapid-E instruments from Plair is currently performing successfully in Switzerland

Traditional methods of detecting aeroallergens are slow and labor-intensive, taking two to eight days to produce results. Automated methods, in contrast, can be sensitive, precise and quick. The increasing prevalence of allergies and asthma caused by pollen has led to a greater need for automated aeroallergen monitoring, to provide timely information and accurate predictions. Continuous monitoring and real-time reporting of pollen concentrations in the air can help susceptible individuals better prepare to avoid exposure.

Technological progress in hardware and software over the last 20 years has made pollen counting and classification more efficient. Despite global trends in automation, however, some industries are still reluctant to move to alternative methods. In fact, users often consider these methods as black boxes because of their complex technology. Companies developing solutions based on automated pollen monitoring need to adapt to these barriers while delivering reliable high-resolution data.

There are two common methods of automatic pollen monitoring: one based on automated imaging and the other based on flow cytometry using fluorescence. While other existing and emerging technologies for rapid identification, such as polymerase chain reaction or DNA analysis, provide accurate results, they cannot produce uninterrupted measurements and so are unsuitable. Moreover, they require a person to operate them and to replace saturated chips. Until now, image recognition methods have only been successful for detecting pollen, while flow cytometry can be applied to analyze numerous types of particles simultaneously. For example, it can measure fine and coarse particles together with airborne pollen. In addition, methods based on fluorescence flow cytometry can measure fungal spores and bacteria.

Rapid-E, or Real-Time Airborne Particle Identifier, which corresponds to an advanced fluorescence-based flow cytometer (Figure 1), is produced by biotechnology company Plair. The instrument's patented, proprietary technology relies on advanced laser analysis through scattering and fluorescence, and its machine learning algorithms classify pollen species automatically. The system has been tested on more than 15 species of tree pollen, including birch, alder, hazel, pine, cypress, oak, ash, plantain, plane, hornbeam and elm, and numerous weeds and grasses. New pollen types can be added through the calibration process.

Aside from producing real-time measurements, Rapid-E also collects samples which can be verified manually. The process is similar to how traditional microscopy is undertaken, using manual identification of samples under a microscope.

QUALITY CONTROL

Ever since the idea of using fluorescence-based flow cytometry to monitor pollen was first introduced, some users have raised a weakness – that these instruments were unable to provide backup images for subsequent quality control or analysis. To address this need, Plair has introduced a mechanism to perform on-demand sampling following online measurements of scattering and fluorescence.

Rapid-E can collect multiple samples of airborne particles intended for lab-based analysis at a later stage. Users can install up to 10 independent filters in Rapid-E's internal airflow, and collect microparticles during user-defined time spans. The filters can easily be used for further in vitro analysis and replaced afterwards. Glass slides used for traditional microscopy serve as impaction media in the sampling mechanism (Figure 2).

Examples of airborne particles captured by Rapid-E's sampling mechanism and analyzed under a microscope are shown in Figure 3. They reveal that Rapid-E can efficiently sample biological particles, from small fungal spores to large pollen grains. Large air pollutants of more than 5µm in diameter can also be observed.

PLAIRGRID DASHBOARD

Rapid-E's PlairGrid online dashboard enables users to activate and run the sampling module remotely. They can define the date and timespan to perform sampling for each

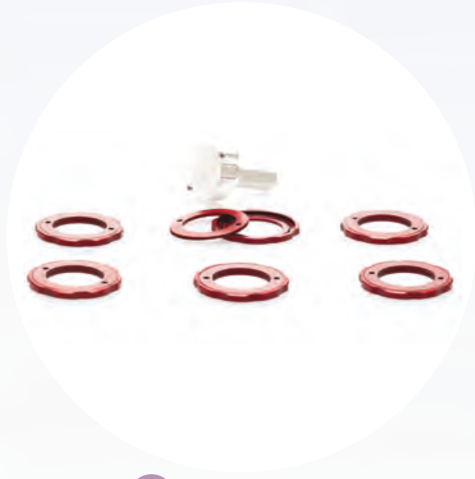


Figure 1: Rapid-E detects numerous airborne particles, including pollen, fungal spores and air pollution

Figure 2: Rapid-E's filter sampling mechanism uses glass slides to collect and sample airborne particles

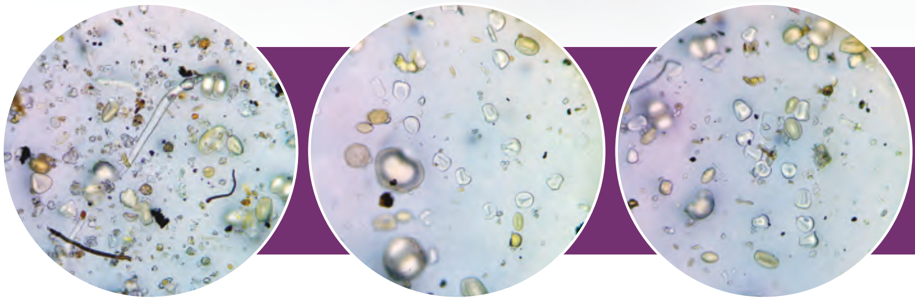


Figure 3: Typical images, obtained with Rapid-E's sampling mechanism, of tree pollen species, pollutants, and fungal spores on filters

filter. Up to 10 independent samplings can be launched automatically from a distance without intervention on the instrument.

Applications of on-demand sampling include quality control of calibrations on various pollen species, a posteriori analysis of pollutants with chemical methods, and identification of fungal spores using microscopy or molecular tools, among other research applications.

SIMULTANEOUS MEASUREMENT

Besides its use for sophisticated pollen analysis, fluorescence-based flow cytometry can also measure air pollutants, such as fine and coarse particles. Timely measurements of all airborne particles provide a better picture of atmospheric aerosol concentrations. Indeed, such measurements are in high demand for healthcare-related research, as the combination of pollen with other particulate matter (PM) can lead to more severe allergic reactions.

To answer this need, Plair recently implemented the functionality of PM measurements in Rapid-E, which runs in parallel with its sophisticated scattering and spectroscopic analysis. Four standard parameters are now reported to the instrument's dashboard and the online PlairGrid dashboard: PM1, PM2.5, PM10 and total particulate matter. Introducing this feature was a natural step, since Rapid-E can detect airborne particles down to 0.5µm. Performed independently, PM measurements consider all particles passing though the instrument whether or not fluorescence measurement is performed.

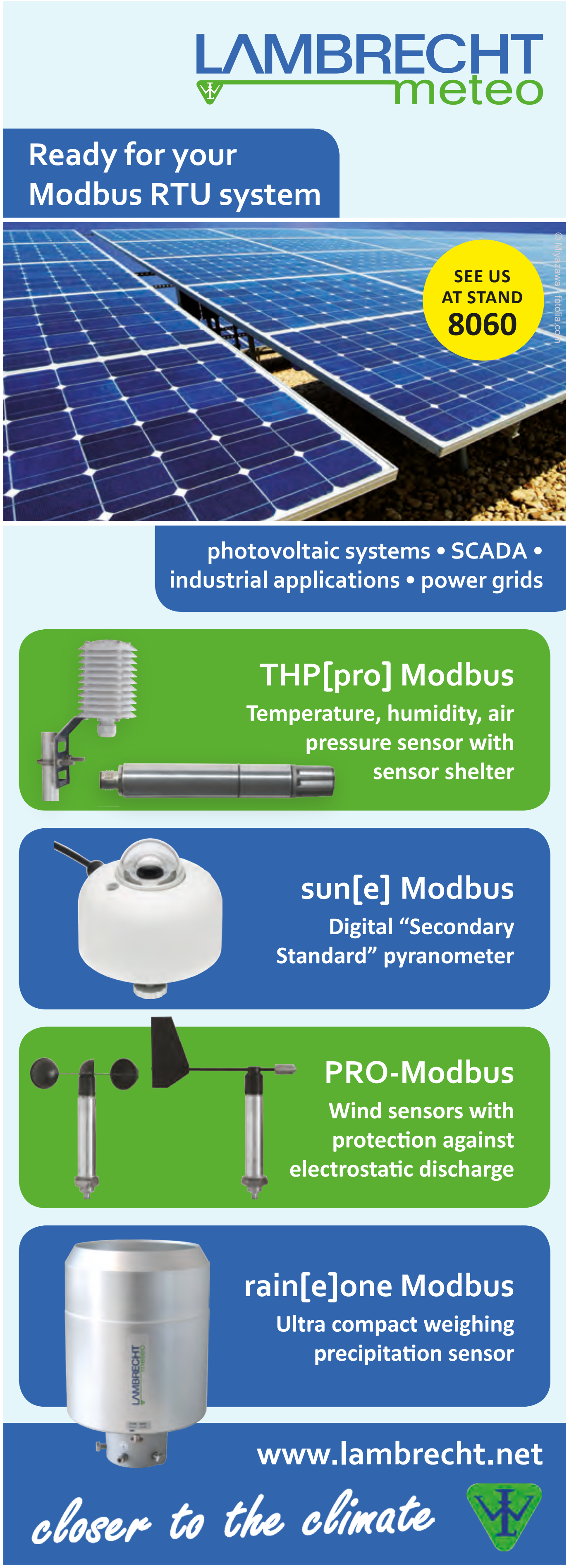
For online measurements, Rapid-E can be adjusted to execute full particle analysis only on a selected particle size, ranging from 0.5µm to 100µm. A good example is configuring the instrument to count pollen grains (full analysis of all particles larger than 5µm) as well as to measure PM. In this case, the volume of data and usage of sensitive ultraviolet components are optimized, allowing for long-period and consistent monitoring with Rapid-E.

OPPORTUNITIES FROM AUTOMATION

Automated technology leads to efficient and speedy airborne allergen analysis and enables the production of continuous and timely data. Rapid-E can count pollen in real time, and identify and classify multiple species while measuring other particulates. It delivers uniform digital data that can be stored, shared and disseminated further among users and the susceptible population. Such data helps to develop a common pollen database and global forecasting system. The data's real-time availability permits the identification of trends in pollen emission, which is still not possible through traditional sampling methods.

What's more, in addition to real-time observations, Rapid-E preserves the advantages of traditional sampling. The instrument can collect a wide range of airborne particles on filters, including pollen, spores and particulates. The filters can then be analyzed under a microscope and stored for later analysis. Such samples can be used for quality control to verify real-time analysis or to check calibrations.

The current and potential benefits of advanced pollen monitoring are wide-ranging and significant. Timely information assists allergy experts and patients in determining exposure levels, and helps pharmaceutical companies to optimize stock and advertisements, and even to develop targeted medication. Analysis over the long term could contribute to research on climate change's influence on flowering stages and pollen allergenicity. ∎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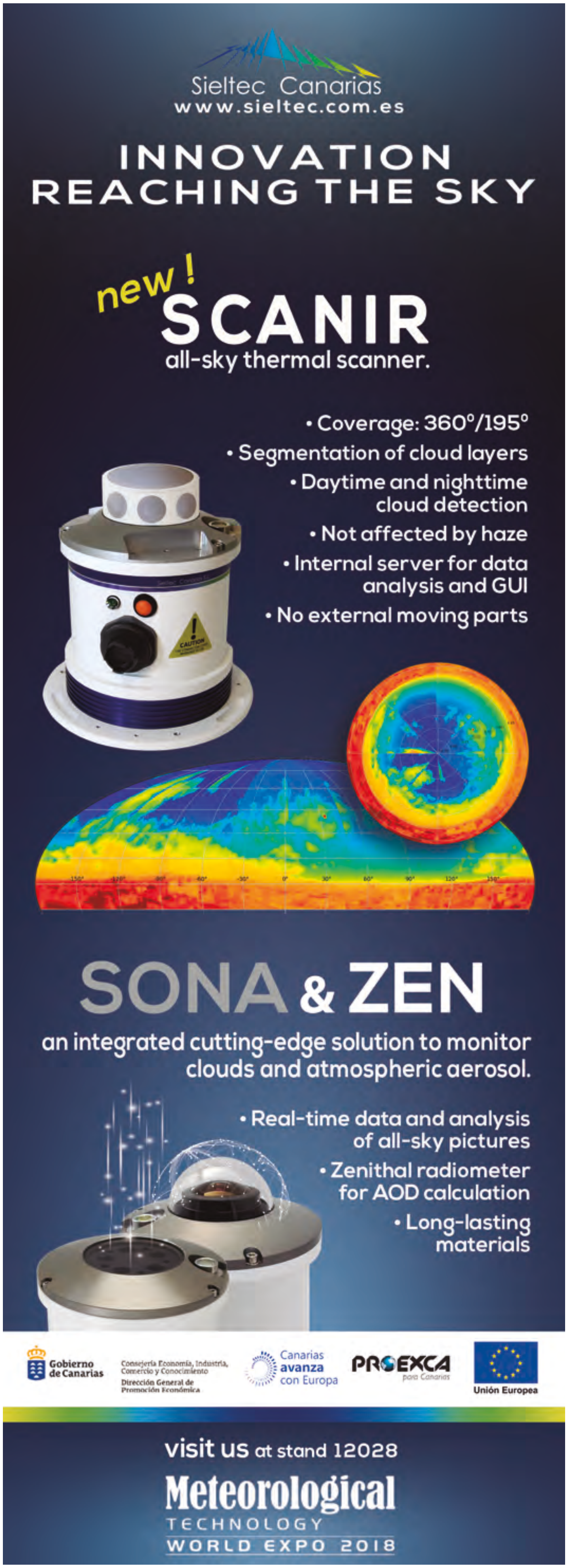
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Paul Willis

COMPLETE CONTROL

Maintaining a fully integrated research and development facility helps ensure the highest standards when producing durable precision instrumentation

The location of Delta OHM's headquarters in the leafy green environs of the medieval Italian city of Padua, Northern Italy, could not be more peaceful and picturesque. Yet appearances can be deceptive. For this is a company that deals in extremes.

Delta OHM is one of the world's most respected producers of environmental measuring devices, with its products built to measure and endure some of the most intense climatic conditions on the planet. Whether it is recording rainfall during the hurricane season in the Americas or the wind speeds of Antarctic ice storms, Delta OHM's devices are at the frontline of measuring extreme weather.

"We export to over 70 countries worldwide," says Heerco Walinga, Delta OHM's international business development manager. "You will find our devices throughout the world, including at the North and South Poles."

The technological know-how needed to produce such devices has been honed over 40 years at the company's Padua headquarters. Founded by research scientist Pietro Masut, the company has grown from a two-man operation run out of a garage, to a multimillion-dollar facility with more than 60 employees and an in-house calibration center composed of six testing labs. Two years ago the company was sold to the German conglomerate GHM.

The calibration center, which is accredited to ISO17025 standard, enables all the company's products to be researched, tested and produced in-house. The recommendations of the WMO are important guidelines in this process. The fact that the company has its own accredited labs gives it a distinct advantage over its competitors.

"We are not unique in what we do," says Walinga. "There are a lot of good companies with great instrumentation. However, the fact that we oversee our total production process

Dedicated lab for air speed calibration, complete with wind tunnel

ourselves, from R&D until final delivery, means we can ensure that product quality is always very high."

Controlling the entire production cycle also ensures faster deliveries. "We don't keep any products in stock, but produce everything on demand," he says. "Our average turnaround from order to shipment from the factory is two to three weeks."

The company produces an array of devices for a range of markets, including the construction industry, the alternative energy sector, the pharmaceutical sector, the food industry, transport infrastructure, agriculture, manufacturing and cultural services.

Many of the devices that serve these markets are unrelated to weather. For example, one device fitted to the seats of forklift trucks measures the impact of vibrations on the operator's body, to ascertain occupational hazard. Another is a wall-mounted climate-control device used by museums worldwide to ensure the conservation of their art collections.

In the area of meteorology, Delta OHM's most important customers are national weather service providers and their subsidiaries. The in-house R&D facilities mean Delta OHM is able to respond swiftly to the needs of this customer base, which is becoming more demanding in response to the effects of climate change.

"There's more demand for our products and there's more demand for devices that record greater extremes," says Walinga. "It used to be that wind measurement was a maximum of 60m/s (134mph), but the requested range is now creeping higher and higher."

HD51 ANEMOMETER

The company's newest product, the HD51 anemometer, is an example of this trend. Like earlier anemometer models, the HD51 uses ultrasound to measure windspeed. This eliminates the need for moving parts, which means that the anemometers can be installed without the need for maintenance, an important development given that they are often sited in remote locations such as offshore wind turbines.

Where the HD51 departs from its predecessors, however, is in its range and robustness. Capable of recording wind speeds of up to at least 85m/s (190mph), the HD51 is made from a durable anodized aluminum alloy and has an integrated heating system, which means it can be used in temperatures ranging from -40°C/F) to 60°C (140°F).

"About two years ago we decided we needed to create a more complete and robust solution, capable of reaching very high performance levels," says Delta OHM's R&D chief Fabrizio Minozzi.

Following the initial prototype, there has been an extensive testing phase, which has included calibration in in-house wind tunnels as well as external field tests. Minozzi expects the final product to be on the market in October 2018.

The HD51 is fitted with digital outputs to allow it to be hooked up to one of Delta OHM's range of IoT-capable datalogging devices. According to Minozzi, the remote devices upload meteorological data direct to the cloud, without risk of loss.

Weather station field test at Delta Ohm's headquarters

The development of the HD51 was a direct response to the demands of the market. As such, it reflects the company's care in paying close attention to the needs of its customers.

"Once we get an order we invest time talking to the customer to get a complete picture of their needs, the exact circumstances of where it will be used, and exactly what it needs to do, continues Walinga. "We take an extra step where others might simply take the specifications, give a quotation and jump into production." ∎

Padua R&D facility

Visitors to Delta OHM's Padua headquarters can see a product's development from concept through to full-scale manufacturing. The 7,500m² (80,700ft²) site comprises a manufacturing plant with 22 staff and an R&D center with 19 employees, 13 of whom are engineers.

The centerpiece of the R&D facility is the calibration center, with six ISO17025-accredited testing labs. The labs test for six physical measures: temperature, humidity, pressure, sound, air speed and photo-radiometry.

In these labs, Delta OHM's R&D staff benefit from access to two wind tunnels capable of generating speeds of up to 70m/s (157mph), dew point hygrometers for measuring humidity, and piston gauges and pressure calibration instrumentation for simulating and measuring pressure.

"Having these in-house testing facilities gives us an unlimited opportunity to retest prototypes until we reach the best performance," says Delta OHM's Fabrizio Minozzi.

The company's production operation is equally advanced. Electronic components are fitted to printed circuit boards via state-of-the-art pick-and-place machines. Elsewhere in the plant, components are assembled using ultrasonic and laser welding.

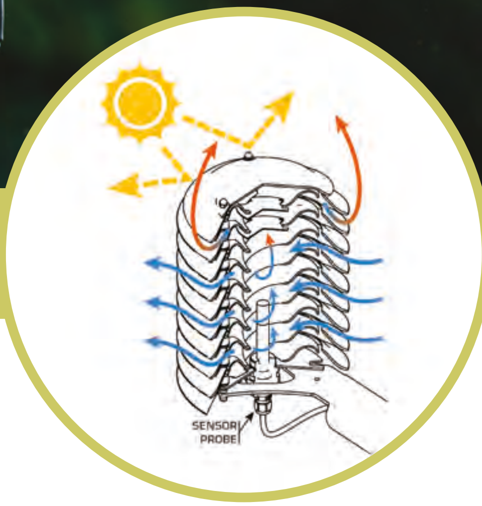
The R&D operation works with local business parks and maintains close ties with the agricultural technologies and electronics department at the nearby historic University of Padua, where Galileo created one of the first telescopes.

"For us, it is always a process of study," says Minozzi. "We study the market and how our customers are adapting to a changing world, and from our studies we try to create products that offer the best possible solution to their needs."

Jan Barani, CTO of Barani Design Technologies

HOT STUFF

What is real air temperature and how can technology be better used to measure it?



MeteoShield Professional illuminated by a sunset at the Slovak Hydrometeorological Institute

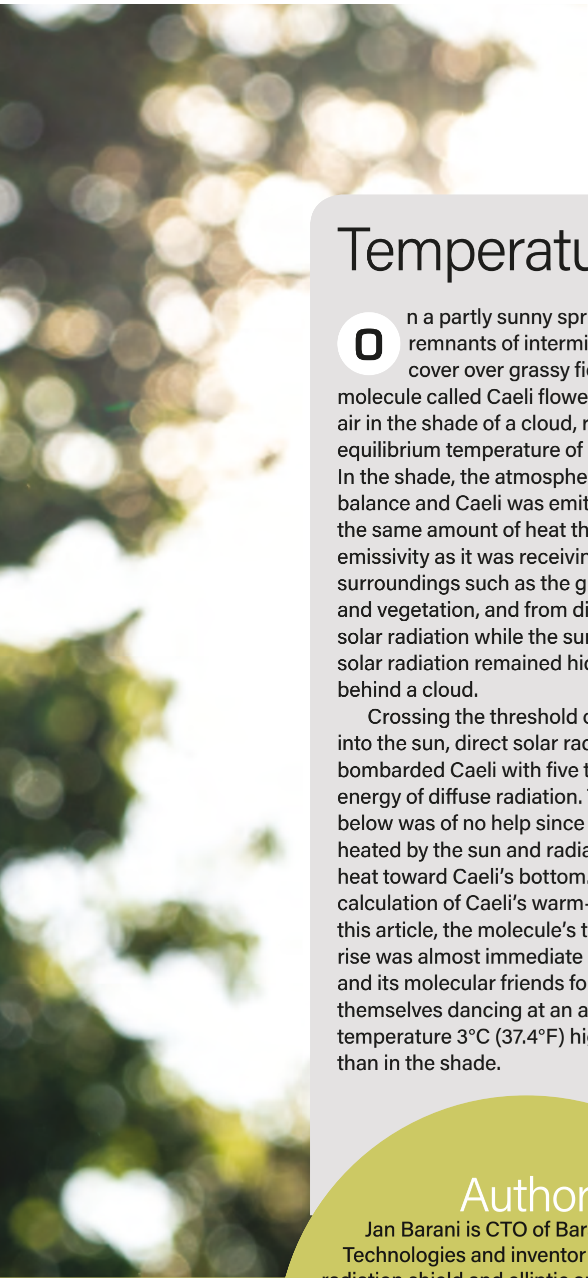
Figure 1: Airflow through the internal structure of the double-helix and double-louver design of the MeteoShield Professional

While temperature sensors are getting more and more accurate, uncertainty of air temperature measurement has remained mostly unchanged over the past few decades. Where once iconic Stevenson screen shelters dominated the professional meteorological landscape, they are now becoming rarer, slowly being replaced by smaller, cheaper, multi-plate radiation shields and fan-ventilated shelters. Are they still the benchmark of precision air temperature measurement or are upcoming technologies like the helical radiation shield from Barani Design Technologies ready to make them obsolete?

Measuring true air temperature is complicated. Automated weather observing system (AWOS) weather stations measure 'near-surface atmospheric air temperature' at a height of 2m (6.5ft), according to World Meteorological Organization (WMO) standards. They generally use sensors calibrated in a liquid bath in adiabatic conditions, while real measurement inside radiation shields and Stevenson screens takes place in anything but adiabatic conditions. In layman's terms, air temperature in the real world is never in balance with sensor temperature, thus measurement uncertainty due to varying sensor constructions and self-heating, along with radiative and convective heating and cooling, is not taken into consideration.

TRUE AIR TEMPERATURE

There is no clear definition of 'true near-surface atmospheric air temperature'.



Temperature from the viewpoint of air

On a partly sunny spring day with remnants of intermittent snow cover over grassy fields, an air molecule called Caeli flowed through the air in the shade of a cloud, reaching an equilibrium temperature of 15°C (59°F). In the shade, the atmosphere was in balance and Caeli was emitting exactly the same amount of heat through emissivity as it was receiving from surroundings such as the ground and vegetation, and from diffuse solar radiation while the sun's direct solar radiation remained hidden behind a cloud.

Crossing the threshold of shade into the sun, direct solar radiation bombarded Caeli with five times the energy of diffuse radiation. The ground below was of no help since it too was heated by the sun and radiating more heat toward Caeli's bottom. While exact calculation of Caeli's warm-up is beyond this article, the molecule's temperature rise was almost immediate and Caeli and its molecular friends found themselves dancing at an air temperature 3°C (37.4°F) higher than in the shade.

THE OBSERVER EFFECT

As Caeli's journey continued, it suddenly hit a white obstacle. Smacking directly into a Stevenson screen shelter, Caeli flipped upside down and slid through its slots into a chamber hidden from the sun. Attempting to shake off the heat from the sun, to its surprise, the molecule failed to reach equilibrium before sliding past a temperature probe. It remains a mystery what the molecule's exact temperature was. Did it cool off or heat up much like the inside of a white car on a sunny day, before squeezing through the back-side louvers into free air and into the sun?

A few meters later, Caeli's head started spinning again as it found itself skimming past a temperate probe. This time the molecule entered a helical solar shield and before realizing it was in the shade, it rubbed against its temperature probe. Did the shield's smaller size and easy air access to the sensor, while blocking solar radiation from 360°, mean that Caeli had less time to react to its presence, thereby minimizing the observer effect (where the measurement instrument alters the state of the property being measured)? Was the temperature measured in the helical shield therefore closer to the true air temperature of the air outside the shield?

During its short journey from the shade into the sun, through a Stevenson screen and finally the helical radiation shield, Caeli's temperature changed four times. Two of the later changes were due to the observer effect.

THE FUTURE OF AIR TEMPERATURE MEASUREMENT

What temperature did the sensors inside the Stevenson screen and helical shield measure? Which measurement was closer to the real atmospheric air temperature and what is the temperature that the numerical weather prediction models require?

"We aim to answer these important questions in the 2023-2027 road map of the Consultative Committee on Thermometry (CCT) of CIPM," says Andrea Merlone, chair of the CCT Working Group Environment, and coordinator of the MeteoMet project. Meanwhile, EURAMET is studying and preparing a European guide on calibration of thermometers in air, and the International Surface Temperature Initiative (ISTI) is promoting a joint action between metrologists and climatologists to identify all of the components of measurement uncertainty in near surface atmospheric air temperature records.

Author

Jan Barani is CTO of Barani Design Technologies and inventor of the helical radiation shield and elliptic anemometer. He graduated from Rensselaer Polytechnic Institute (RPI), New York, with a degree in aeronautical engineering and worked on numerous aerodynamic design projects at Boeing before entering the fields of meteorology and metrology, where his aeronautical experiences continue to influence the sensor and weather station designs he creates.

Before comparing various air temperature sensor systems, one must first understand what an instrument is trying to measure, to understand what 'true air temperature' is. Atmospheric air temperature has yet to be clearly defined.

Like any substance, air is prone to heating and cooling through well-known energy flows such as radiation, convection, conduction and emissivity. Other sensor-related influences include dew condensation; evaporative cooling from phase transitions; direct, diffuse and reflected solar radiation; self-heating; and calibration procedures.

WHAT AFFECTS TRUE AIR TEMPERATURE?

First, let's take a look at heating from radiative sources such as the sun and infrared heat radiating from the surroundings. These dominate atmospheric air temperature error and uncertainty. Even though air is mostly transparent, it is well documented that each of the gases composing it has a certain light sensitivity or absorbance spectrum and also emissivity (radiative cooling). The radiative heating of air from absorbed solar radiation accounts for the difference between incoming solar radiation from Earth's sun and the radiation actually reaching the ground, as shown in yellow in Figure 1. A familiar example is the absorbance of UV light in the upper atmosphere by ozone molecules. Just like every other substance, air also has the ability to cool itself by radiating heat away in the form of infrared radiation. This property, known as emissivity, is different for every material and color and contributes to the error that affects measurement quality inside every solar screen and solar radiation shield used to house meteorological air temperature sensors.

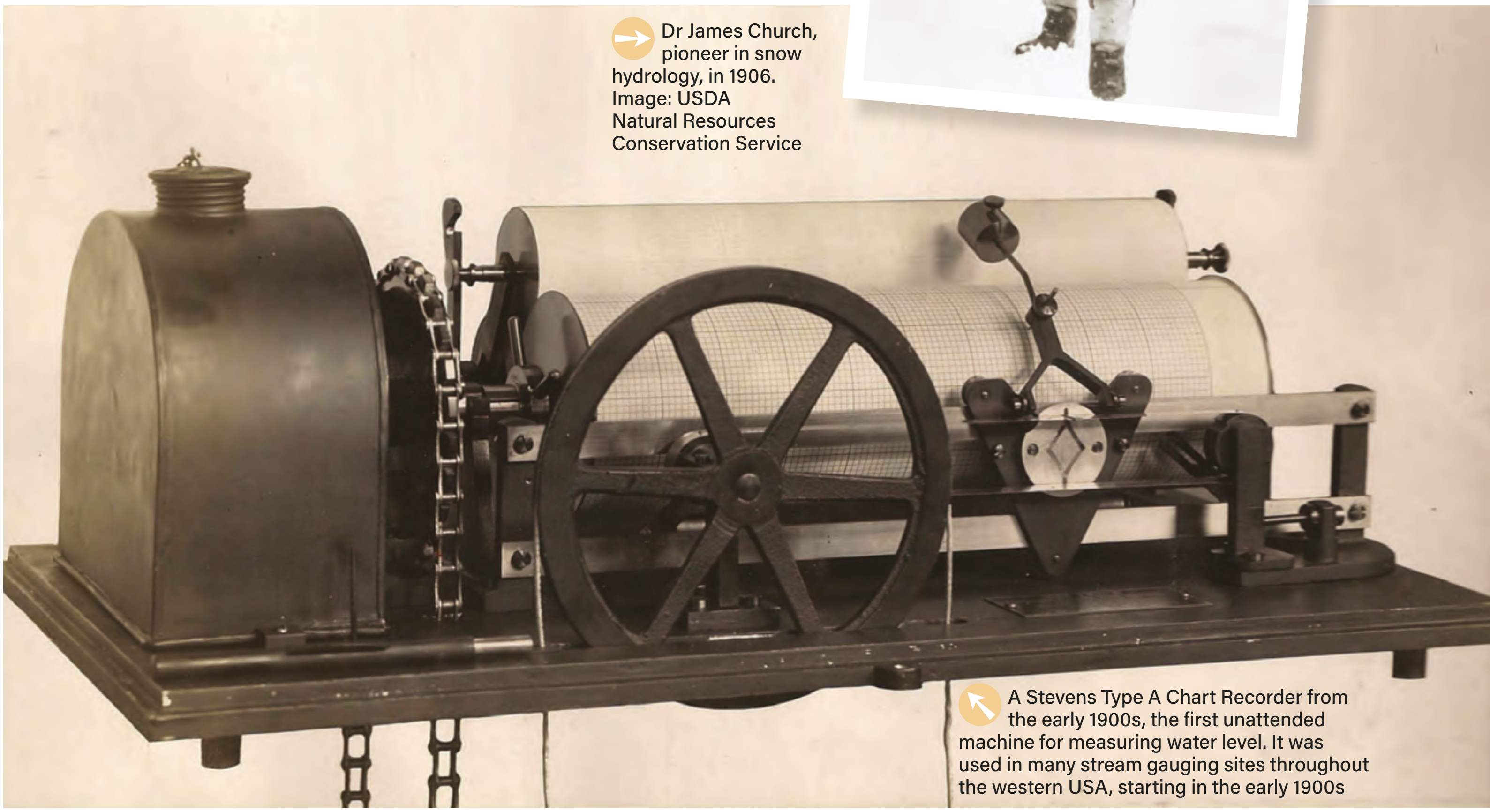
The energy balance of measurement systems affects the temperature the sensors read. In the professional community, it is widely believed that a larger solar screen is more accurate. Why some may think this, we will attempt to explain later, but first let's look at air temperature from the perspective of air molecules flowing in the wind at the WMO standard of 2m above ground. (For this illustration, it is not important whether our example molecule is N_2, O_2, Ar, CO_2, H_2O, O_3, NO, NO_2 or any other molecule or dust particle composing air.) ∎

Keith Bellingham, soil scientist, Stevens Water Monitoring Systems

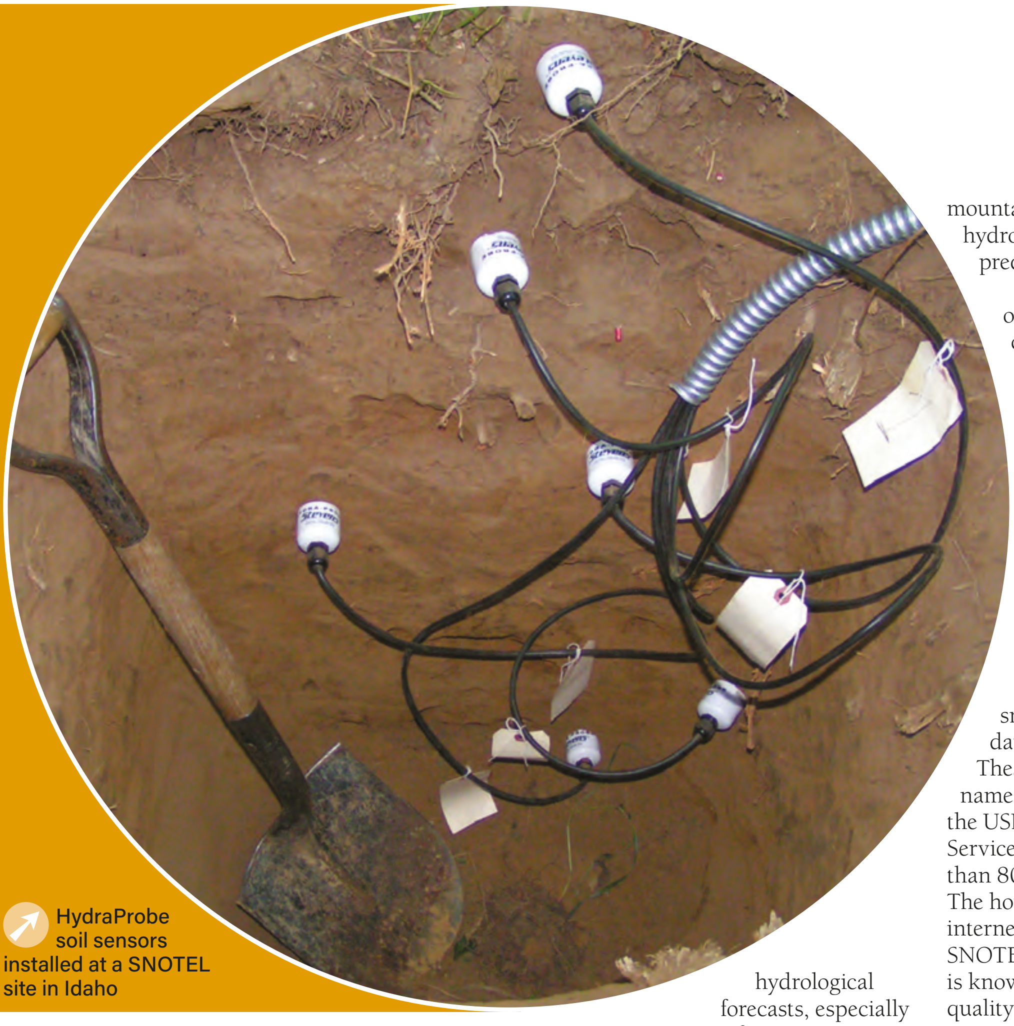
FLOW ANALYSIS

One of the world's largest meteorological networks, SNOTEL, is employing soil moisture sensors to monitor the impact of soil water content on stream flow forecasts

Dr James Church, pioneer in snow hydrology, in 1906. Image: USDA Natural Resources Conservation Service



A Stevens Type A Chart Recorder from the early 1900s, the first unattended machine for measuring water level. It was used in many stream gauging sites throughout the western USA, starting in the early 1900s



HydraProbe soil sensors installed at a SNOTEL site in Idaho

Many complex political, social, environmental and scientific challenges impact water resources. Snow telemetry (SNOTEL), one of the world's largest meteorological networks, working under the US Department of Agriculture (USDA), provides critical stream flow predictions for the understanding of hydrology in western USA.

For more than 100 years, predicting stream flow has been important for hydro-power generation, irrigation, water supply networks, and aquatic habitat protection. With more than 800 SNOTEL stations, along with hundreds of US Geological Survey (USGS) stream gauging stations, seasonal stream flow forecasts are published for most major watersheds in 12 US western states.

Policy decisions related to water management in the western US states depend on SNOTEL's stream flow forecasts. While the stream flow forecast models have traditionally relied on precipitation, snow pack and river flow data, new emerging models are starting to address the role soil moisture is having on streamflow.

Soil moisture is being recognized as an important measurement variable of a watershed's hydrological budget as research increasingly points to soil water content as strongly influencing the accuracy of hydrological forecasts, especially in areas of winter snow packs or heavy seasonal rains.

The analytical method for determining soil moisture in SNOTEL and many other networks is a unique impedance-based research-grade soil sensor technology with no sensor-to-sensor variations for a universal comparison on soil moisture across all locations, seasons, soil types or moisture ranges. SNOTEL has an innovative history and is a meteorology network leading the future of using soil moisture data in stream flow forecasting.

THE EVOLUTION OF SNOTEL

Much of the water in the western USA comes from the winter snowpack in the mountainous regions. The snowpack in the mountains of the western USA can range from nothing, or very little, up to 10m (33ft) or even 15m (49ft) deep of snow in the Cascade mountain range.

In 1906, a hydrologist at the University of Nevada, Dr James Church, began to document the relationship between winter snowpack in the mountains and stream flow throughout the year for certain watersheds. Church enhanced existing Russian technology for measuring snow water equivalent (SWE). Shortly after he developed these snow measurement techniques, the US Department of Agriculture began to construct 'snow courses' in the mountainous areas of the west so that hydrologists could make stream flow predictions from snow data.

These snow courses were areas free of trees, where the snow survey staff could take manual measurements of the snowpack. Around that same time, the USGS began installing stream gauging stations so that stream data could be compared with the snow data. In 1911, these USGS gauging stations began using mechanical chart recorders, an innovative new technology for automatically measuring water level developed by J C Stevens, one of the founders of Stevens Water Monitoring Systems.

Starting in the 1980s, the USDA's snow courses added weather sensors, dataloggers, and telemetry systems. These snow course telemetry sites were named SNOTEL or snow telemetry. Today, the USDA's Natural Resources Conservation Service (NRCS), manages and operates more than 800 (and growing) SNOTEL stations. The hourly data is now displayed on the internet for every station. The data from SNOTEL is of high quality, and SNOTEL is known worldwide for having the best quality-control protocols of any meteorological environmental network. Parameters measured at a SNOTEL site include solar radiation, total precipitation, snow depth, wind speed and direction, relative humidity, SWE and temperature. SNOTEL began adding soil moisture sensors in the late 1990s.

SIGNIFICANCE OF THE SWE PARAMETER

Traditional stream flow prediction models use SWE as a measurement variable. SWE is the amount of water contained within a core of snowpack that is manually measured by pushing a pre-weighed cylindrical tube into the snow. The tube is then weighed to get the weight of the snow, from which scientists are able to determine the amount of water in the snow. The density of snow can change with temperature and precipitation throughout the year. The same depth of snowpack can yield different water amounts depending on the density. The SWE measurement can provide universal comparisons for snow data across regions, locations and time for widely accepted stream flow forecasting models.

CALCULATING SNOTEL STREAM FLOW FORECASTS

The stream flow forecasts from the SNOTEL data are derived from the statistical relationship between the SWE on April 1 each year, precipitation, and the stream flow

Example of a typical SNOTEL site. Image: USDA Natural Resources Conservation Service

throughout the summer. Based on many years of historical data between the snow courses, SNOTEL and the USGS stream flow data, a mathematical algorithm can be generated from a matrix method to correlate the data so that a stream flow prediction can be generated. The comparison between the stream flow prediction and the actual flow is called 'skill'. The closer the skill is to 1.0, the closer the prediction was to the actual stream flow. While many stream flow forecasts provided by SNOTEL have a skill of 0.9 or greater, the need for more accuracy put an increased emphasis on a major part of the hydrological cycle that was previously ignored – the soil moisture.

SOIL MOISTURE INFLUENCE ON STREAM FLOW

Traditionally stream flow forecast models primarily used the antecedent SWE and precipitation values in their calculations. Soil represents a huge water reservoir and can introduce errors into the forecasts. Excluding run-off, water from snowmelt and precipitation will first percolate through the soil before entering the groundwater. Once the water is in the aquifer, it will travel down gradient and eventually discharge into a stream or lake. The vadose zone is the soil above the water table and represents a hydrological regime that can hold large amounts of water.

Once water enters the vadose zone, it will only move in one dimension – up and down. In unsaturated soils, water will migrate upward because of evaporation and the uptake of water by plants and trees. This upward movement of water is called evapotranspiration (ET). ET is the primary mechanism responsible for removing water from soil. During the winter months with a snowpack, ET is almost zero, and the soil moisture values stay relatively constant.

The downward movement of water in soil obeys an entirely different set of rules than it would in an aquifer. Water will suspend itself and adhere to soil particles. This attraction between water and soil particles is called capillary force. As the soil moisture increases, gravity will pull the water downward. The point at which the gravitational influence exceeds the capillary influence is called field capacity. Above field capacity, water will be conducted downward through the soil and will discharge into the water table. If the soil moisture stays below field capacity, water can only travel upward due to ET.

Because ET is negligible under snowpack, the soil moisture value just before the winter snow arrives will be the same soil moisture value in the spring when the snow begins to melt. If there is a dry autumn, and if winter arrives quickly, the soil moisture under the snowpack will be low. When the snow melts in the spring, much of the water will be retained by the soil, and not as much water will reach the streams. Accordingly, dry falls can result in below-average stream flow the next spring and summer even with an above-average winter snowpack. Conversely, if there is a rainy autumn, the soil will already be at field capacity when the snow melts in the spring, and all of the water from the snowpack will enter the water table, pushing an equal amount of water out into the streams. A wet fall can cause flooding in the spring, even if there is low snowpack.

Even though many SNOTEL sites have been equipped with HydraProbe soil sensors since the 1990s, not enough historical soil moisture data has been collected to be included as an input parameter in official stream flow forecasts. It takes at least 10 years of data to run a successful model forecast simulation. However, the new innovative SNOTEL models, which include soil moisture measurements, are showing more accurate stream flow forecasting results.

New SNOTEL forecasts are coming from sites where soil sensors have been installed for more than a decade, and they include evaluation of the soil moisture under snowpack. One possible input parameter to the forecast models based on soil moisture is called the 'soil moisture deficit index'. The soil moisture deficit is the difference between the current soil moisture and the soil's field capacity; it represents the amount of water that can enter into the soil before migrating downward to the water table. Thus, the soil moisture deficit index represents the amount of water the soil can hold based on the real-time water content and the soil properties. The deficit can then be used to adjust the chance of exceedance forecasts. This technique shows promise in improving forecasts by incorporating soil moisture data. As more SNOTEL sites are equipped with HydraProbe soil sensors, and as more historical data is accumulated, soil moisture will be incorporated into the forecast models.

CONCLUSION

SNOTEL, under the USDA, is leading the innovation in new stream flow and water supply forecasts that provide key insight for the management of hydropower generation, irrigation, and aquatic habitat protections. While once neglected and not well understood, soil moisture has been shown to improve the accuracy of the forecasts and USDA continues to instrument SNOTEL sites with HydraProbe soil sensors. As more historical data accumulates, soil moisture data will be incorporated into the stream flow models that will improve the accuracy of the water supply forecasts.

Companies such as Stevens Water Monitoring Systems, the manufacturer of the HydraProbe, continue to provide and develop advanced technology to help scientists and engineers solve the challenges facing water resources management. ∎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Andrea Costantini, sales technician and customer support specialist, Nesa

WEATHER AND WINE

Tradition and innovation are being combined to ensure the quality of Prosecco production in northeast Italy

↑ Agro-meteorological stations according to WMO

→ SigFox IoT sensors for leaf wetness and soil moisture

The Alta Marca Trevigiana region in northeast Italy, some 80km (50 miles) from Venice, is renowned for the production of Prosecco, a sparkling white wine popular all over the world.

The cultivation of vines in the region dates back to the Roman age; the medieval climate in particular was characterized by very mild conditions favorable to the development of agriculture and vines. Just after 1300 AD, climatic conditions began to worsen, at first sporadically and then more extensively, at a global level. This began with what climate historians call the Little Ice Age, which occurred within the post-glacial phase still in progress.

All types of crop were affected by the adverse climate, which manifested itself in varying degrees of intensity until the beginning of the 1800s, when there was extended damage and famine all over Europe, caused by icy winters, long rainy periods, and cold and cloudy summers. This restricted, and in some cases prevented, the growth of crops.

Since the mid-1800s, there has been a gradual softening of the climate, which has led to an improvement in the standard of crops. The current climate is characterized by global warming, caused by human activities and by the greenhouse effect, induced by climate-altering gas emissions. This causes extreme heat waves, long dry periods, hailstorms and high-intensity rainfall concentrated in a very short time.

Against this climactic backdrop, there is an evermore urgent need for crop cultivation for advanced technologies for climate monitoring, greater awareness of the importance of protecting the territory, and a reduction in the use of pesticides.

MONITORING PARTNERSHIP

This has led to the development of an important synergy between environmental monitoring company Nesa and the Consorzio Tutela del Vino Conegliano Valdobbiadene Prosecco DOCG, a private body made up of Prosecco industry stakeholders. The two have established a close relationship that involves the installation and long-term maintenance of an important network of WMO-compliant professional stations, equipped with sensors to measure temperature and air humidity, leaf wetness and precipitation.

Some specific sites are monitored to provide a full set of meteorological measurements including global solar radiation, atmospheric pressure and soil moisture. Integrated smart sensors are also equipped with an interface to a SigFox network. Therefore, fundamental data is acquired and transmitted in accordance with the WMO.

All the stations installed within the Prosecco wine producing area transmit the measured data in real time to a control and supervision center. From there the operators can extract the information regarding the short-term forecast needed to support targeted treatment against disease and to protect crops. The objective of the project is to improve, optimize and reduce the use of chemical products to preserve the local environment.

In addition, the automatic weather stations (AWS) enable the Consortium to comply with the EU Directive 2009/128/EC, which came into force in Italy on August 14, 2012, and requires the use of professional WMO-standard environmental monitoring stations to assist crop treatment choices. This kind of network is an excellent solution that can be easily adapted to any kind of crops worldwide (according to existing disease forecasting algorithms).

Moreover, Directive 2009/128/EC aims to achieve sustainable use of pesticides in the EU by reducing the risks and impacts of pesticide use on human health and the environment. It is also designed to promote the use of integrated pest management (IPM) and alternative approaches or techniques, such as non-chemical alternatives to pesticides. EU member states have drawn up national plans to implement the range of actions set out in the Directive.

The main actions relate to the training of users, advisors and distributors of pesticides; inspection of pesticide application equipment; the prohibition of aerial spraying; limitation of pesticide use in sensitive areas; and information and awareness raising about pesticide risks.

Nesa's experience, its presence in Alta Marca Trevigiana and its knowledge of the specific technologies of agro-meteorological monitoring make the company's technical solution ideal – and suitable for use in other public or private sectors.

ACCURATE MEASUREMENTS

The technology and its associated developments make it possible to carry out more accurate weather measurements. The use of sophisticated management and telemetry systems, the implementation of patented and sustainable solutions, the application of validation methods and the independent checks of final results allow the collection of data sets that can be used for the most varied post-processing (such as climate analysis, weather prediction models, air pollution dispersion simulations and so on).

The market is increasingly calling for precision sensors with smart electronics, the provision of which is one of the most interesting challenges for professional instrument manufacturers. Makers need to provide low-power products to enable the use of devices even in remote areas with low energy availability, while adapting with the increasingly strong push toward new IoT technologies.

Nesa is already active in the IoT market with its low-cost, high-efficiency and low-power sensors, which enable remote transmission using standalone small stations. The main use of such technology – which can be powered by autonomous batteries or supported by solar panel – is growing across markets such as agro-meteorology, geo and landslide supervision and alert, and hydrological critical measures for alarm and safety actions. Data retrieval requires only WMO-compliant sensors, small-packet supply battery and remote transmission modules, thus reducing hardware and software requirements.

The ever-increasing need to make IoT devices available with smart management, always connected to networks like SigFox, LoRaWAN, IEEE 802.15.4 and ZigBee, is a challenge that involves entire sections of Nesa R&D, and will certainly bring benefits to supranational organizations, Met Offices and any other institutional user looking for reliable, up-to-date and remote-collected data that can reduce technical, infrastructure and maintenance costs. ∎

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COOL CUSTOMER

Highly technical drones are helping to gather accurate weather data under the most extreme conditions

Different patterns of ice accumulation appeared in different heating systems

Meteodrone flying over Mount Säntis

Drones have become commonplace for a wide variety of professional control, monitoring and inspection tasks – including in the weather business. Meteomatics is a Swiss private weather service provider that offers drone technology, and is playing a vital role in accurate weather data collection at the VAKW, the Association of the Coordinated Weather Service in Switzerland.

PRODUCT RANGE

Meteomatics has developed three Meteodrones for distinct uses:

• The standard Meteodrone is optimized for daily operational flights and provides data for improved numerical weather forecasts. This drone collects important weather data between ground level and 3,000m (9,840ft) height every night.

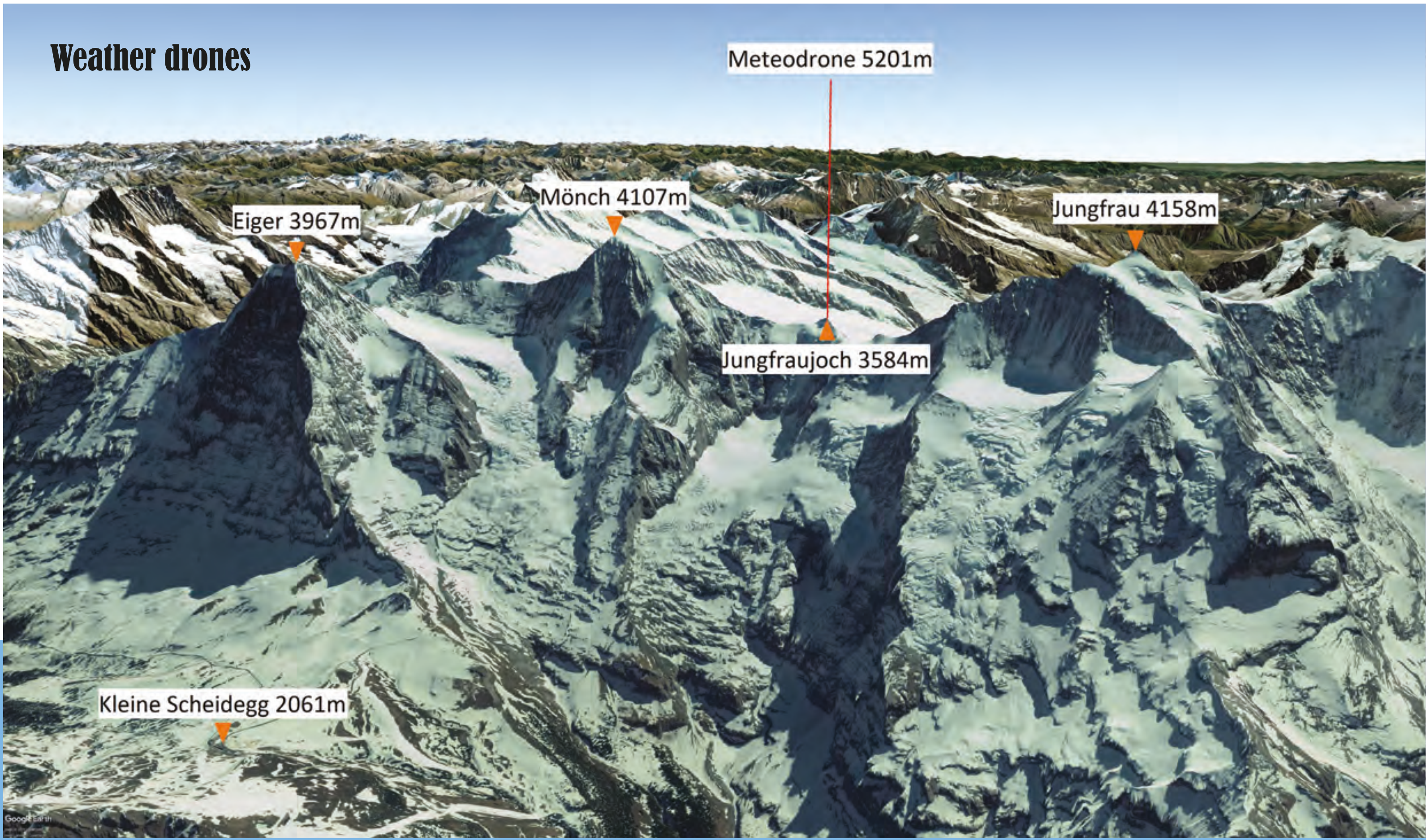
• The Meteodrone XL is the heaviest of the three drones at a weight of 5kg (11 lb). It is not the fastest drone in the range, but it can stay in the air for up to 40 minutes without charging the battery. In addition, it can be used for pollution measurement and the maximum payload is 1kg (2.2 lb).

• The smallest and fastest, the Meteodrone Severe Storms Edition (SSE), can withstand sustained windspeeds of up to 28m/s (63mph) with a maximum climb speed of 19m/s (62ft/s). A Meteodrone SSE was used during a project with the National Severe Storms Laboratory (part of NOAA) to improve tornado forecasts.

Meteomatics currently employs drone pilots to monitor all flights separately, but in the future one pilot could be responsible for about 10 drones. Meteodrones will be able to fly autonomously and launch from a so-called MeteoBase, which is the first step to installing a larger network of drones in one region and keeps costs attractive.

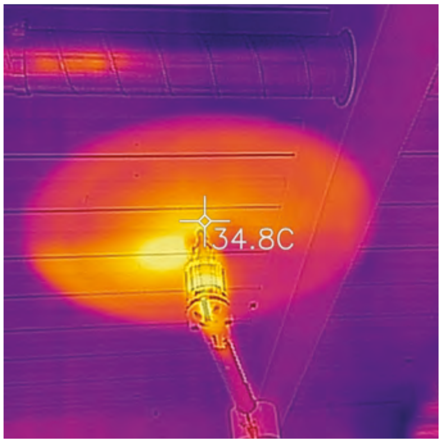
The advantages of a Meteodrone compared with a weather balloon are the high frequency of measurements and increased environmental compatibility. Drones can provide new measured data every five to eight minutes, instead of twice per day with a weather balloon. Drones and sensors can be used more than once, and due to a rescue system and GPS control system, the drones can't get lost.

In July 2017 Meteomatics obtained permission from the Swiss Federal Office of Civil Aviation (FOCA) to allow Meteodrones to fly to a height of 3km (9,850ft) above ground and gather data in higher air layers. This data helps improve



Swiss Alps, the starting point of the Meteodrones at the High Altitude Research Station Jungfraujoch, 3,584m (11,758ft) above sea level

Infrared image of the heated propeller



existing predictive models. Higher altitudes require longer flight times and increased wind stability. Propeller icing can also occur in these cold air layers, and the thinner air reduces system efficiency. Since then, solutions have been developed and tested to be able to operate safely at these higher deployment levels.

RESEARCH WORK

These challenges make one thing obvious: quickly tying a temperature sensor to any drone and collecting data is not an option. Therefore Meteomatics has its own research department and workshop where its drones can be developed and manufactured. Almost all parts of the drones and MeteoBase are designed on a computer and manufactured using the company's own machines.

Even though there are drones available in every electronics store, extreme weather conditions such as snowfall, rain, high humidity, stormy winds and icy temperatures increase demands on a drone and pose new challenges for development. Technical improvements to handle extreme weather are constantly being made.

To test new research results under extreme conditions, small teams from Meteomatics frequently go on measurement campaigns. In addition to tests in wind tunnels, the systems are tested in a real-world environment on the highest peaks in Switzerland – in storms, snowfall, icy fog and freezing temperatures. The conditions in the Swiss Alps are similar to those in the Arctic.

The propellers of the drone platforms can freeze at temperatures below 0°C (32°F) and high humidity, whereby the flow at the rotors can deteriorate so much that it leads to the drone crashing. In such a case, the rescue package is the last option available to prevent a total loss. Weather measurements must be terminated under such conditions.

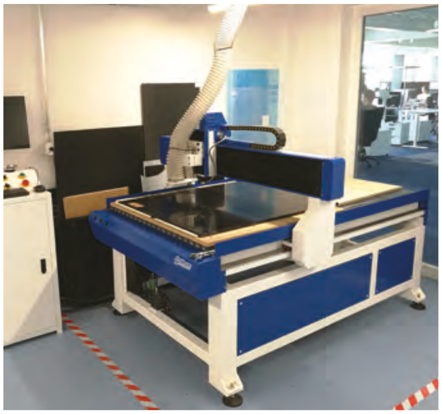
Meteomatics began testing its drones in March 2016 at a climate wind tunnel in Vienna, Austria, at which different atmospheric conditions can be simulated. In total, eight weather conditions were tested: two stratiform and six cumuliform clouds, during different freezing temperature conditions. The results showed that ice occurs more quickly in cumuliform clouds than in stratiform clouds. In addition, there were more ice deposits on propellers in 'warmer' freezing air.

ICE-FREE

A positive outcome from these tests was showing that the Meteodrone's electronics can withstand harsh icy conditions, and that all the meteorological sensors stayed ice-free at all times and the parachute cap frosted only below -20°C (-4°F).

But it became clear that the drone needed a heating option at the propellers. For more than a year, Meteomatics engineers worked on a solution. At the beginning of this year,

The Meteomatics team in front of the Sphinx observatory



The manufacturing rooms at Meteomatics' headquarters

heated rotor blades were tested on Mount Säntis in Switzerland; at 2,502m (8,208ft) above sea level it is the highest mountain in the Alpstein region. Under icy conditions (air temperature -9.2°C [15.4°F], humidity 95%, 20km/h [12mph] wind) the efficiency of various heating systems with different power classes was investigated. At the end of March, further tests were carried out in even more extreme weather conditions (-4°C, 100% humidity [dense fog] and windspeeds around 95km/h [59mph]). In these conditions, the entire experimental setup freezes in the wind in a very short time. However, by using a redeveloped heating system with increased heating power, the rotor blades could be kept almost completely ice-free. Thus, Meteomatics was able to record a milestone in the development of a drone anti-icing system.

THIN AIR CHALLENGES

The high altitudes at which Meteodrones fly bring new technical challenges. The first step in overcoming these was to investigate the efficiency of the rotors in these atmospheric conditions. For this purpose, in March 2018 engineers traveled to one of the highest mountains in Switzerland, the 3,584m (11,758ft) Jungfraujoch. From here, the drone ascended another 1,617m (5,305ft) to a final altitude of 5,201m (17,063ft).

On a separate propeller test bench, various engine/rotor combinations were tested and the results were compared with identical tests in denser air (at 700m [3,000ft] above sea level). This led to further refinements of the drone to increase performance at high altitudes.

NEW DEVELOPMENTS

It has been shown that Meteodrones operate well in adverse weather conditions. Thanks to the latest developments, however, the existing operational limits can be extended further. Thus, reliable operation is possible even in the most difficult weather conditions and consistently provide the highest quality weather readings.

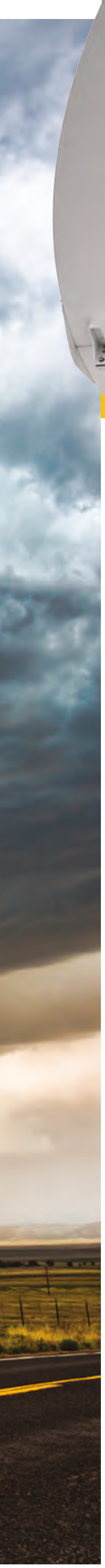
The new developments enable a range of applications: it is possible to use the drones for projects in the Arctic and Antarctic, or at the top of the highest mountains. The drones are also suitable for use at airports in the winter to measure cloud and fog conditions, saving airlines and airports money by reducing flight delays and cancellations. Better measurement data from difficult weather conditions allow more accurate forecasts, and two pilot projects took place at airports in Jersey, UK, and Zurich, Switzerland, last winter.

In April 2018, as part of the Aircraft Icing Technology Meeting in Florida, specialists from the FAA, NASA, the US Air Force, FOCA, Boeing, Airbus and many others explored the topic of icing in aviation. Meteomatics was a new member and the first with experience of ice affecting mini UAVs. ∎

Mrinal S Balaji, Darrin R Cartwright, James H Lee and John R Ellis, Baron Services Inc

GOLD STANDARD

The Baron Gen3 Radar Processor Suite is providing a new paradigm for weather radar data processing



Next-generation radar antenna from Baron

The world of weather forecasting is rapidly changing, driven by advances in radar signal and data processing technologies. Recent decades have seen the development of new ways of collecting, storing, manipulating and transmitting data that are transforming the way we conduct and organize weather science. This article is the second of a two-part series (for part one, see *Critical analysis*, April 2018, p76-78). It continues the conversation that began in the previous part by illustrating how Baron radar processor design addresses the diverse needs of weather application specialists by employing novel hybrid architectural concepts and effectively blending traditional signal processing techniques with innovative technologies such as CLEAN-AP for superior data quality.

PROCESSOR SUITE INTERNAL ARCHITECTURE

While on the surface the system configuration of the Baron Gen3 Processor Suite seems quite relatable to the existing processors in the radar industry, the method of execution of the various software philosophies within the processors sets them apart, raising the bar on big data processing standards to a new level.

With the continuously growing amount of data, the need for frameworks to store and process this data efficiently is increasing. The Baron Processor Suite employs Data Distribution Service (DDS), the first middleware standard that addresses challenging real-time requirements not satisfied by any other existing standard. It is capable of handling very high-performance communications and is currently used in applications like NASA's robotics, financial high-speed trading, advanced telescopes, medical imaging, air traffic control, smart grid management, and several other big data applications.

DDS outlines a data-centric publisher-subscriber architecture that connects the information providers with information consumers. As opposed to traditional message-oriented middleware, DDS understands and uses the context of the data to ensure that all interested subscribers have an accurate and consistent view of the data rather than simply focusing on the delivery of the message.

In addition, the architecture creates a global shared dataspace that streamlines integration. It transmits data directly from a publisher to all its subscribers with no intermediate servers. Publishers and subscribers can join or leave easily, be anywhere, publish at any time, and subscribe to any data they have permission to access.

DDS provides true auto-discovery of publishers and subscribers. There is no necessity to statically set IP addresses of nodes within the globally shared dataspace for the purpose of message routing. It also provides several mechanisms for filtering data on sending and receiving. Subscribers/publishers determine what messages they want to receive/transmit based upon the filter they define. Timing and flow are precisely controlled while the computer operating system platform and language differences are automatically translated. This allows flexibility in using different programming languages within different processors.

KEY BENEFITS OF DDS

The DDS standard allows processors to exchange messages internally and externally in an extremely efficient fashion. It can also provide the ability to perform R&D on an operational system. For example, one can develop and test an algorithm using multiple sets of setup parameters concurrently within an operational system, without interfering with the operational flow of data.

DDS employs a data-centric integration model to decouple applications. Applications communicate by publishing the data they produce and subscribing to the type of data they consume. They require no knowledge of each other, only of the data they exchange.

Creating redundant Radar Signal Processor (RSP), Radar Control Processor (RCP) or Radar Product Generator (RPG) processes is extremely straightforward using DDS as no additional hardware is needed. And it can provide internal process communications through shared memory, leading to extremely fast and efficient use of memory resources. It can also provide inter-node communication through multicast and unicast. Developers can choose to use multicast or unicast based upon the publisher and subscriber relationships.

Furthermore, the DDS server-less architecture has no single point of failure. Systems are self-healing when applications disconnect and reconnect. Automatic failover provides continuous availability when an application is no longer accessible.

CLEAN-AP

Developed by the University of Oklahoma, USA, and available through an exclusive licensing agreement with Baron, the Clutter Environment Analysis Using Adaptive Processing (CLEAN-AP) ground clutter filtering process allows for superior ground clutter suppression in addition to optimally and dynamically adapting the suppression process to the ground clutter environment. In development over the past several years, this new technology will be introduced within the US National Weather Service WSR-88D fleet soon.

KEY BENEFITS OF CLEAN-AP

CLEAN-AP performs automated clutter detection and suppression with no need for manual intervention. The need for clutter maps is eliminated through its real-time ground clutter detection capability. CLEAN-AP also uses adaptive data windowing that accomplishes a good compromise between clutter suppression and data quality. The technology is an integrated process providing a single algorithm for ground clutter detection and filtering on a bin-by-bin basis.

The unique clutter filtering ability of CLEAN-AP is vital when being used as part of an integrated network. By greatly improving the accuracy of base data, benefits occur throughout the entire system, from data collection and integration to forecast models, and this ultimately leads to more effective forecasts and alerting for the general public.

CLEAN-AP WITHIN THE RADAR PROCESSING SUITE

CLEAN-AP processing has been implemented in the RSP and with the help of the inventors, Dr Sebastián M Torres and David A Warde, the algorithm has been optimized to work at S-Band (2.7-3.0GHz), high-frequency S-Band (3.5-3.6GHz) and C-Band (5.3-5.8GHz) with all types of transmitters. Fielded currently at multiple operational radar sites, CLEAN-AP is the new golden standard for ground clutter filtering in the weather industry, says Baron.

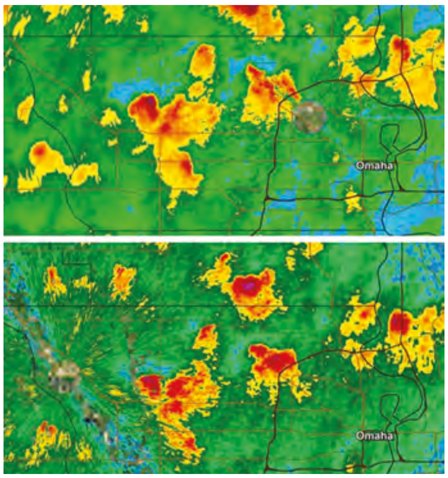


Figure 2: Operational radar with CLEAN-AP (upper) and without (lower)

Figure 1: Before (upper panel) and after (lower panel) CLEAN-AP application PPI scans

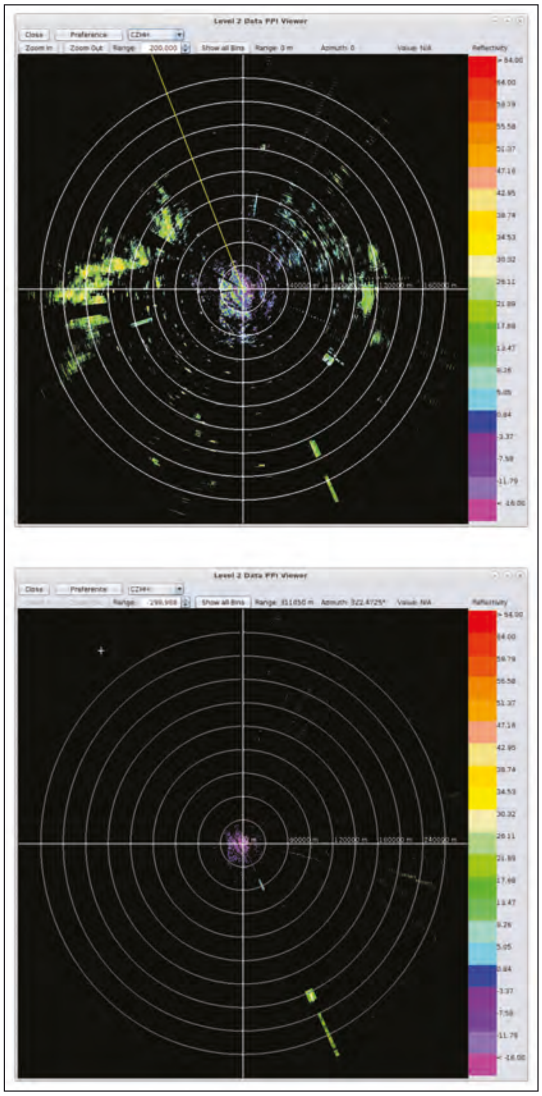


Figure 1 demonstrates radar reflectivity images along H-Polarization before (upper panel) and after (lower panel) CLEAN-AP was applied at an operational radar site. Anomalous propagation is seen all around the radar out to a range of approximately 200km (124 miles) and CLEAN-AP successfully and elegantly suppresses all of it in addition to the ground clutter around the radar.

Figure 2 illustrates the benefits provided by CLEAN-AP (upper panel) when compared with traditional ground clutter filtering (lower panel) at one of the operational sites:

- Superior ground clutter suppression while introducing less bias in the base data;
- Optimum amount of ground clutter removal while keeping the mixed-in weather signal intact;
- No deterioration of base data along the zero velocity isodop as opposed to noisy or missing base data with traditional ground clutter filtering schemes.

DATA CAPTURE

The versatile architecture within the various processors ensures they are able to provide base data in the following forms simultaneously: unclutter filtered, ground clutter filtered but point clutter preserved, point clutter filtered but ground clutter preserved, and ground and point clutter filtered.

In addition, the data can be requested in 8bit Integer, 16bit Integer, or 32bit IEEE Floating Point format. Another feature available as a result of the flexible internal architecture is the ability to capture data at various points within the processing chain. The data that can be captured includes, but is not limited to:

- 32bit IEEE floating point formatted digitized I/Q data from the IF Digitizer (IFD);
- 32bit IEEE floating point formatted base data from the RSP;
- 32bit IEEE floating point formatted base data from the RCP;
- 8bit Integer, 16bit Integer or 32bit IEEE floating point formatted base data from the RPG.

Data can additionally be captured at various internal points within the processors (for example inputs and outputs of the ground clutter filtering module; inputs and outputs of the point clutter filtering module).

CONCLUSION

The field of radar processing has always been open to innovation, supported by recent advancements in computing technology, improved architectural standards, and novel feature extraction and elimination algorithms like CLEAN-AP, resulting in the culmination of the Baron Gen3 Radar processing suite, which is currently operational at all Baron Gen3 operational sites.

Future work on the radar processing suite will continue to find ways to effectively blend physical models, prior knowledge, and traditional signal processing methods, to address applications of increasing complexity. Novel base data capable of filling in the gaps where better understanding of physical processes is needed will also be made available over time. ∎

Dr Alexander Myagkov, cloud radar specialist, Radiometer Physics

CLOUD CONTROL

Cloud radars are the instrument of choice for meteorologists looking for precise and detailed local observation of clouds and precipitation

The radar calibration at the FMI site, Finland. Image: Finnish Meteorological Institute

The radar setup at Ny-Ålesund, Svalbard, Norway. Image: University of Cologne

Back in 2015, Radiometer Physics (RPG) of Meckenheim, Germany, brought a novel product to the remote sensing meteorological equipment market – a 94GHz radar for cloud and precipitation observations. The instrument design has taken into account all the experience and needs of cloud radar users in the research sector.

The RPG radar features a number of innovative solutions that distinguish it from other meteorological radars. These improvements were achieved by using advanced technology that results in a more affordable solution for widespread use in research groups and large networks.

CURRENT STATE

Since 2015, RPG has delivered a number of cloud radars to European research customers. The first radars were installed at remote locations in cold environments where a considerable part of the clouds at environmental temperatures down to -38°C (-36°F) are mixed-phase, e.g. contain a mixture of tiny liquid drops and ice particles. Mixed-phase clouds are a hot topic in atmospheric sciences, especially in the Arctic region, where clouds of this type often persist for days and weeks. On the one hand, mixed-phase clouds efficiently scatter solar radiation back to space during the polar day, and on the other hand they sustain the greenhouse effect during the polar night. Currently, the meteorological community's understanding of the lifespan of mixed-phase clouds and their influence on the Arctic climate is very limited.

To address these topics, a ground-based and an airborne radar have been intensively used for vertical cloud profiling at Ny-Ålesund, Spitsbergen, Norway, within the German-funded Arctic Amplification project. In such conditions, it is desirable that the radar is operated remotely and does not require high levels of maintenance. The thermal insulation and active control keeps the temperature inside the radar housing balanced with an accuracy of ±0.5°C (±0.9°F) even at temperatures down to -40°C (-40°F). This is crucial for stabilizing the performance of high-frequency components. Hydrophobic radomes and the powerful blower protect the antennas from snow and melted water accumulation.

The Finnish Meteorological Institute (FMI) uses the RPG 94GHz cloud radar at Hyytiälä forestry field station in Finland in synergy with a number of active, passive and *in situ* instruments for characterizing the formation and development of snow particles. One of the key processes in the snow formation is riming. This process happens when a freshly formed ice particle passes through a layer of supercooled liquid drops. Often it accretes plenty of liquid particles on its surface. Riming increases the mass of ice particles that results in higher precipitation rates. The research group at FMI has already shown that passive observation of integrated liquid water is a proxy of the riming degree. To address and support such research applications, the RPG cloud radar has an embedded 89GHz radiometric channel measuring the integrated liquid water within the same field-of-view as the radar itself.

With long-term experience using centimeter wavelength weather radars, the environmental remote sensing group from the École polytechnique fédérale de Lausanne (EPFL) in Switzerland is now exploring the possibilities of the 94GHz radar. Typically, weather radars perform rapid azimuthal scans at low elevations to detect precipitation over large areas. Such operation regimes limit the applicability of advanced processing techniques for detailed cloud microphysics. In contrast, using Doppler capabilities, the RPG cloud radar can determine particles falling with different velocities within the same volume. The terminal velocity of particles is often related to their size. Thus, the cloud radar allows for tracking vertical changes of different particle populations.

The radar's compactness and low weight reduces efforts for packing, transportation and installation. The research group from EPFL is a good example of those taking advantage of the radar mobility. The radar was operated at a ski resort near Verbier, Switzerland, 2,370m (7,775ft) above sea level. Later on (and in collaboration with the Korean Meteorological Administration), EPFL brought the radar to PyeongChang in South Korea for snow observations during the 2018 Winter Olympic Games.

RPG cloud radars are also used in warmer places. One example is Granada in Spain. Located close to Africa, it experiences many dust plumes from the Sahara desert. It is known that dust has a great impact on global climate and it also drives cloud formation, especially in humid environments. To understand aerosol-cloud interactions,

The scanning dual-polarized radar at an RPG site in Meckenheim, Germany

The radar during the Winter Olympic Games in South Korea. Image: École polytechnique fédérale de Lausanne, Switzerland

in addition to active optical instruments that are widely used for aerosol detection, the University of Granada now operates the RPG radar. One of the requirements for this application is an ability to detect the smallest cloud particles at altitudes up to 15km (9 miles). The RPG radar features state-of-the-art components and advanced processing, easily fulfilling this requirement.

ONGOING DEVELOPMENT

In general, most cloud radars are used in atmospheric sciences. Nevertheless, RPG sees a great potential of cloud radars for civil services such as weather agencies and airports. To focus on their needs, RPG has designed and manufactured a scanning dual-polarization version of the radar. RPG is also working on the retrieval developments that will help users from non-scientific fields to easily use the radar for their own purposes.

The pointing system of the radar allows for elevation and azimuthal scanning. Observations at low elevation angles are beneficial for observations of fog layers, which are typically just a few hundred meters thick. Fog typically consists of a huge number of tiny liquid drops, which do not produce enough scattering for detection by centimeter wavelength weather radars. On the other hand, lidars (which are very sensitive to small particles) also experience problems with measurements in fog because of severe attenuation. Thus, cloud radars are the only instruments that can reliably profile fog layers. Moreover, Doppler cloud radars measure particles motions. Tiny drops are mainly driven by air motions and turbulence and therefore the radar can provide detailed dynamical properties in fog.

Another important product derived from scanning observations is wind profiling. Scanning Doppler lidars are a well-known tool for wind retrievals.

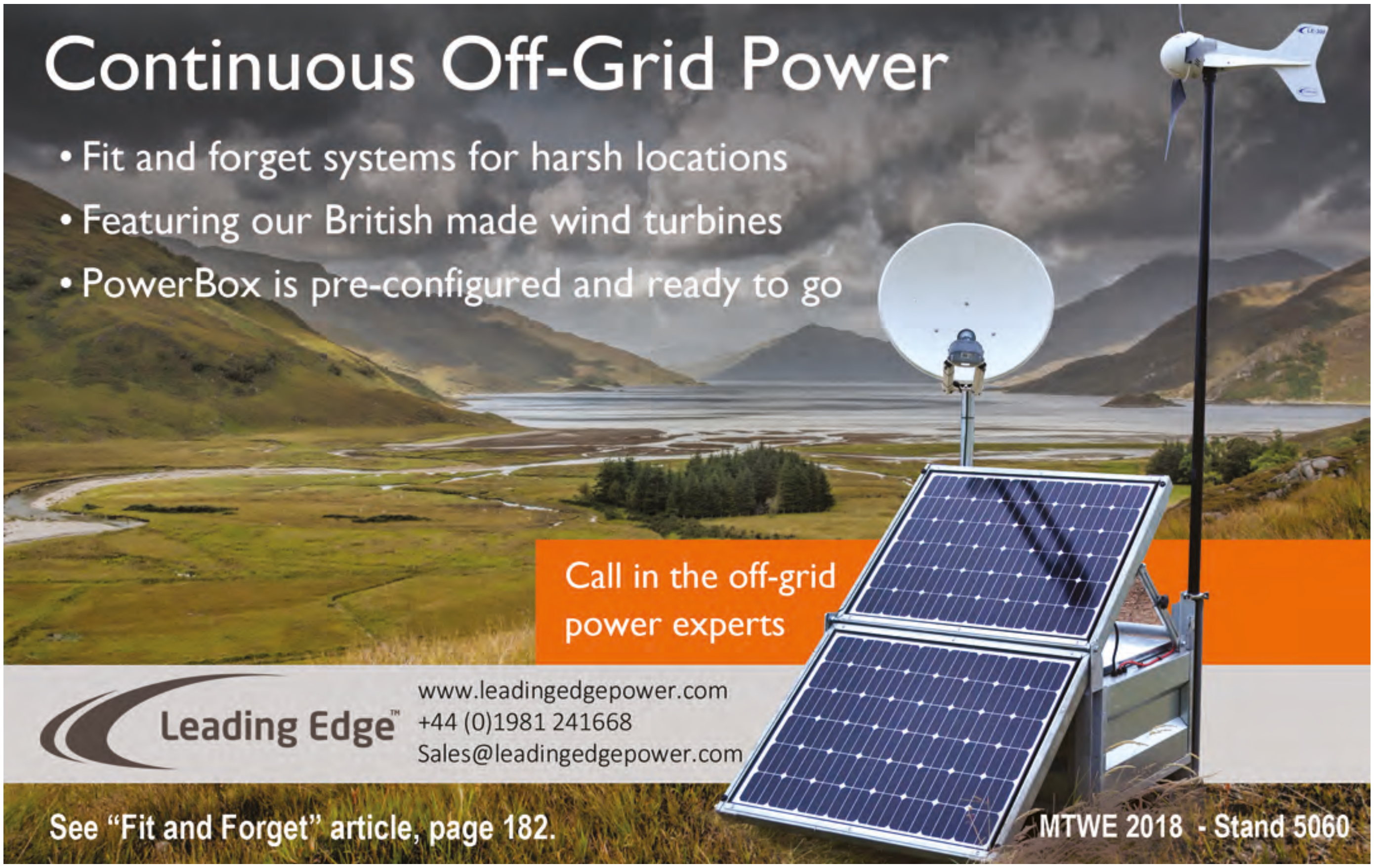
Nevertheless, while performing well during clear sky conditions, all Doppler lidars experience severe problems in the case of liquid clouds, precipitation and fog, due to the signal attenuation. In contrast, attenuation of a millimeter wavelength signal by liquid water is much smaller. However, its scattering during clear sky is almost negligible. Therefore, the RPG cloud radar should be considered an excellent complementary tool to a wind lidar. It can provide vertically resolved windspeed and direction inside clouds and precipitation with temporal resolution down to one minute.

Radar polarimetry has shown a high efficiency for meteorological applications. A set of polarimetric variables serves for detection, classification and quantitative characterization of precipitation. Measuring the same set of variables as weather radars, the RPG radar can be used for the discrimination between aggregates, plates and dendrites, ice columns, melting ice, hail and raindrops. It can also quantitatively characterize shape and orientation of cloud particles. Moreover, the RPG cloud radar is one of a few systems available on the market that can provide spectral polarimetric observations, meaning that the set of polarimetric variables is measured separately for particles moving with different velocities. This unique feature is a huge step toward development of qualitatively new retrievals.

Currently, RPG is developing a method of drop-size-distribution (DSD) profiling based on spectral polarimetry. Using characteristic backscattering properties of droplets with different sizes, this method can convert Doppler spectra to DSD. The obtained DSD have temporal resolution down to a few seconds. This retrieval uses observations at low elevation angles and therefore can provide much larger overlap with weather radars than a disdrometer or a micro-rain radar can. This approach is highly beneficial for the calibration of weather radars, which often uses observations from surface-based disdrometers with a small sampling area as a reference. Based on the measured DSD profiles, weather radar products can be simulated and used as a reference for the calibration purposes.

SUMMARY

RPG has been constantly pushing the limits of cloud radar technology by applying state-of-the-art techniques to maximize the information output for end users. The radar offers the best cost-efficiency on the market for precise and detailed local observations of clouds and precipitation. ∎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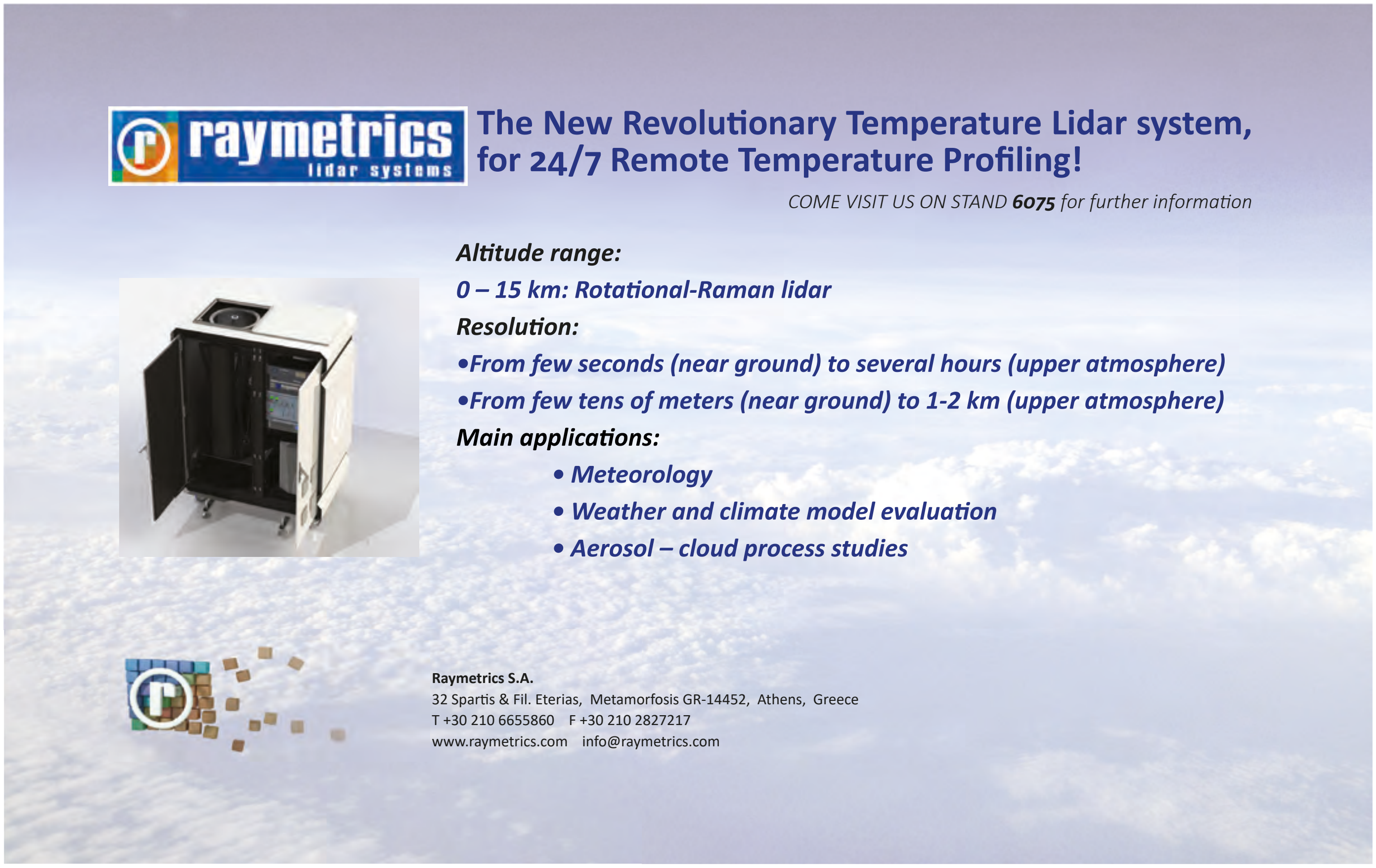
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Edgar Wetzel, business development manager, Kisters

MADE TO MEASURE

Vibration measurement technologies are helping to provide new levels of accuracy for hailstorm observations

According to the German Met Office (DWD), April 2018 was the country's warmest since records began in 1881. That same month, parts of the country experienced several major thunderstorms, with reports of large hailstones causing damage to windows, shutters, cars and crops. According to hail insurers, the total area of farmland reported as damaged during the last week of April amounted to more than 6,500ha (16,000 acres) with an insured sum of €17m (US$19.7m).

Hailstorms are a common meteorological phenomenon across Europe and regularly cause major economic and insured losses. Although the need to better understand hail events is evident, current measurement techniques often fall short.

HAIL MONITORING TECHNIQUES

Standard hail observation methods are based on passive technology, specifically hail pads that are exposed to the hail and analyzed manually after an event. The process is cumbersome and has limitations, as imprints can be difficult to see and evaluate. Passive systems also fail to generate alarms to warn of oncoming hailstorms.

In other cases, weather sensors and disdrometers measure hail size optically or by means of radar using a relatively small optical beam or radar conus. The larger the hailstones, the greater the distance between them and the higher the probability that they go undetected.

To combat these problems, HyQuest Solutions (Kisters Group) partnered with the University of Applied Sciences in Saarbrücken (htw saar) and Swiss-based inNET Monitoring to develop a sensor that relies on vibration measurements and a much larger sensing surface to collect data, thereby increasing the probability of detecting a statistically representative sample of hail pellets. After several years of research and field-testing, the

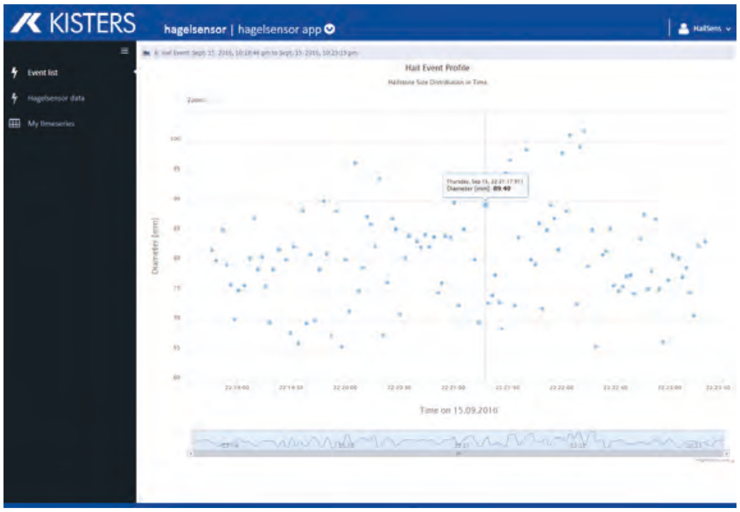


Figure 2: HailSens Model R&D/INS: Swiss HailSensor Network – typical flat roof installation. Image: inNET Monitoring

Figure 3: hailsens.online's cloud application visualization of a hail event. Image: Kisters

Figure 1: HailSens Model R&D/INS – industrial grade model. Image: HyQuest Solutions

HailSens is now able to provide automatic *in situ* hail measurements on the ground.

The solution's piezo microphones capture the energy of the hailstones at the moment of impact on the large measurement surface. An integrated micro-controller calculates the events in real time and provides data on the size of the hailstones and the intensity of the hailstorm. This data can be immediately transmitted to either a local data acquisition system or to a cloud-based server for further analysis and early warning alerts.

PURPOSE-BUILT MODELS

WMO SYNOP weather stations only record hail impacts when the diameter is greater than 5mm. However, weather model researchers and prognostic meteorologists require more detailed data to help improve their models and correlate detected events, including the magnitude in terms of number of impacts, pellet sizes and related kinetic energy. HailSens has been developed to serve both applications, with different models tailored for WMO SYNOP weather station use and for acquiring detailed data for research purposes.

The first model, HailSens SYNOP, is factory calibrated to report only impacts of pellets with a diameter greater than 5mm. Datagrams are sent over a serial cable to the data acquisition system of an automatic weather station, where the data is aggregated for reporting purposes.

For more detailed measurements, the HailSens R&D/INS model measures the energy of individual hailstones in real time and provides evidence on hailstone size, event duration and impact energy. All recorded data is transmitted to cloud-based servers using wireless communication, ensuring fast forwarding of data whenever an event is recorded. Thus, the damage potential of hail events can be assessed in real time.

Event-driven data transmission and alarm functionality ensure that early warning systems can be put in place, providing more time to react before excessive damage occurs.

HailSens sensor networks can also provide a means to optimize both the prediction models of insurance firms and the hail claims process. With this in mind, Swiss insurance company Mobiliar partnered with MeteoSwiss in June 2018 to begin installing a network of 80 sensors (Figure 2). The collected data is expected to improve the MeteoSwiss hailstorm weather models with better radar algorithms leading to more notification time for citizens.

DATA IN THE CLOUD

The HailSens Model R&D/INS is the first online monitoring system dedicated to the meteorological phenomenon of hail. To simplify the storage and management of the data collected, a cloud application, hailsens.online, has been developed using advanced NoSQL-type storage.

Data processing can be adapted to various purposes depending on the needs of the user. For example, raw data can be made available for researchers, while other users may prefer hail damage classification (using a variety of classification schemes), and others may want to see statistical evaluations of each single event. With a cloud-based solution (Figure 3), users do not need to download and install software and can benefit from a web-based user interface that enable users to access, view, assess and download the data on any tablet, laptop or desktop computer.

By leveraging detailed measurements provided by hail sensor networks over a longer period, conclusions can be drawn as to when, where and why hailstorms occur. Those potentially affected can be warned early of heavy hailstorms, and millions of euros worth of damage prevented. ∎

André Weipert, head of MET information systems and Hassan Al Sakka, senior MET expert, Selex

CLEAR MESSAGE

Improving the collection, processing and analysis of raw data from weather radar can help to improve the efficiency and quality of weather forecasting

Selex Meteor C band radar tower

Over the past 20 years weather radars (single or networked systems) have become one of the most relevant meteorological remote sensing systems. Being a fundamental pillar for many national meteorological and hydrological services (NMHSs), their success comes from their unique coverage, rapid atmospheric scanning and data update, resolution, ability to show real-time and online weather surveillance products for concise alerts on adverse weather conditions, and the ability to short-term forecast the measurement for a limited time of around one hour (depending on the coverage area, especially when using networked systems). In addition, weather radar enables the continuous monitoring of disruptive weather conditions needed for aerodrome operations to create meteorological services for aviation or to increase safety and efficiency for flight operations in general.

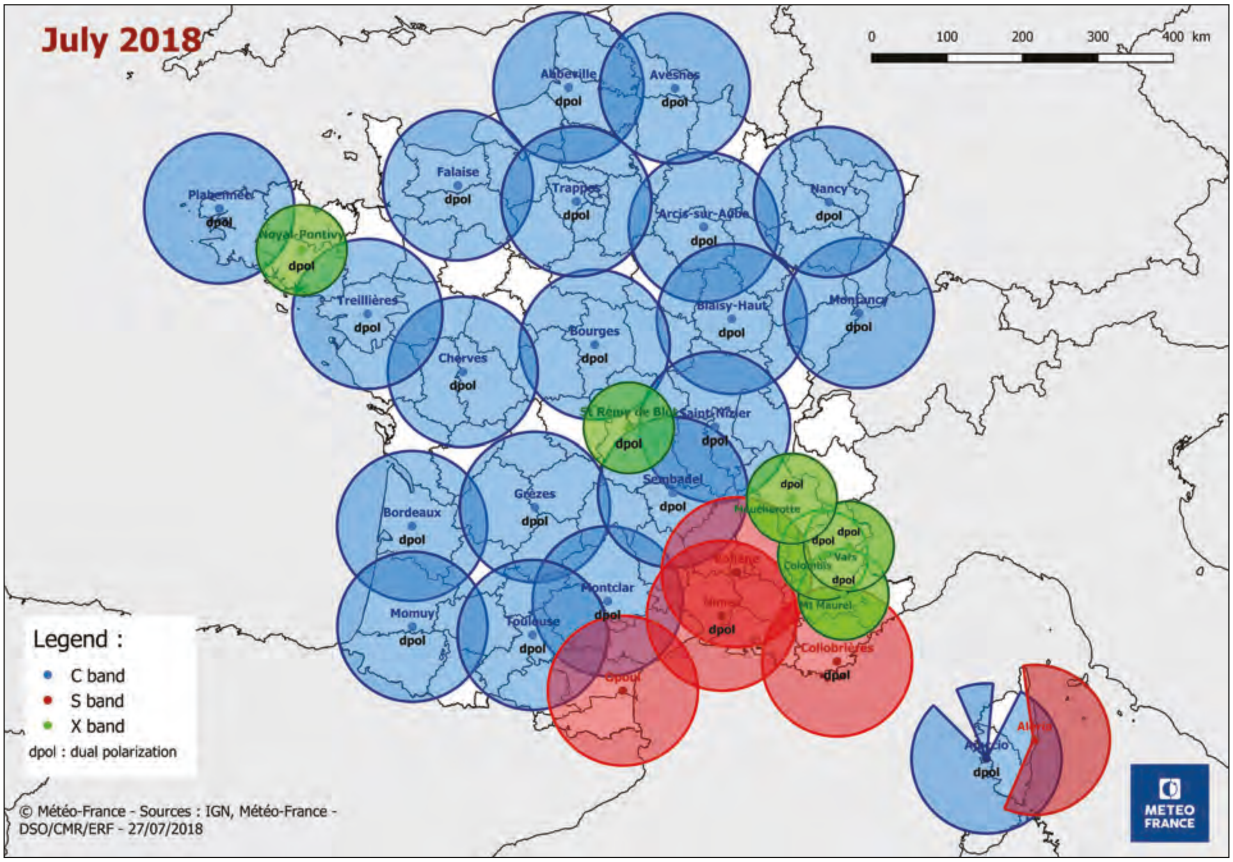
GATE-TO-GATE DATA QUALITY

In recent years, the need to put more attention on monitoring and improving radar data quality (gate-to-gate: from data acquisition to product/service provision) has continuously increased. This is for several reasons. First, weather radar data has become an input for numerical weather prediction (NWP) models, where only high-quality data is allowed, to reduce input errors as much as possible.

Second, weather radar data is often used for quantitative measurements such as quantitative precipitation estimation (QPE), which converts radar reflectivity to ground level rainfall rate, or the measurement of windspeed and direction and corresponding derived estimates (turbulence, windshear, crosswind). For example, the effect of variation of radar reflectivity by 1dBZ results in a variation in the estimate of QPE by ±15%.

Third, when the radar products interact with alert or decision-support systems, any reduced data quality may trigger false alarms that could create various impacts – for example, wrong and missing 'insect clutter' suppression impacts the velocity measurement needed for the correct derivation of alarms on windshear along the glide slope of landing aircraft for aviation applications.

Weather radar data starts to become readable once the signal processor has processed and filtered the signals and calculated the data moments. The data



The French radar network in 2018

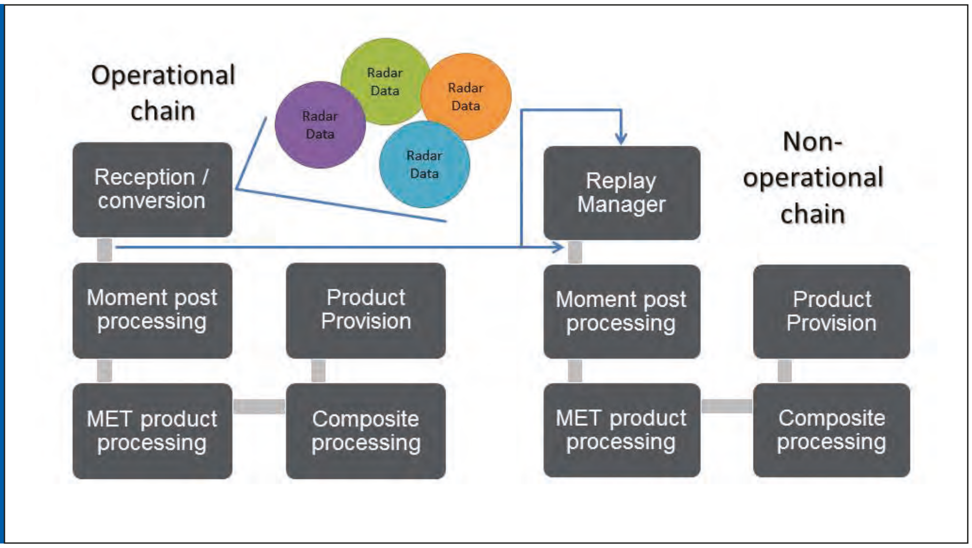
moment (or raw data) is the typical input for the meteorological data-processing software. The raw data is an ensemble of various data moments such as the radar reflectivity (Z_H), radial velocity (V) and spectral width (W) – Z, V and W can also be obtained before any filtering.

If the radar has dual polarization technology (transmitting and receiving simultaneously in the horizontal and vertical directions), more data is made available such as the differential reflectivity (Z_{DR}), differential phase (PHI_{DP}), specific phase (K_{DP}), cross polar correlation (RO_{HV}), linear depolarization ratio (L_{DR}) and so on. Dual polarization is very helpful to correct signal attenuation, to detect the shape of the targets, and by consequence to classify the measured entities into hydro-meteorological types (rain, wet snow, dry snow, hail, ice and mixtures) or to distinguish between meteorological and non-meteorological targets. Dual polarization also plays a major role in radar calibration and in the operational monitoring of radar performance in general.

LOWEST COMMON DENOMINATOR

Before they can be used, radar signals and raw data have to be processed. The steps for classic processing of the raw data are as follows: on the signal level, clutter removal, speckle and spatial filtering, and interference filtering. On the raw data level (the pre-processing scheme), calibration of Z_H and Z_{DR}, identification of non-meteorological echoes, bright band and vertical profile (of reflectivity) detection and correction, PHI_{DP} offset removal and filtering, K_{DP} estimation, attenuation correction, hydrometeor classification and QPE calculation.

After filtering and pre-processing, product generation takes place to convert the radar raw data into displayable entities, products and meteorological services. Raw data is the key for any analysis because, at any moment, products can be generated from raw data but not vice versa. For centralized heterogeneous radar networks (in terms of technology,



Parallel composite processing chains: operational and validation

product year or manufacturer), raw data is key as it represents the lowest common denominator that can be used for centralized harmonized data processing. Beyond that, raw data is the data type that is typically archived. For post-processing, each manufacturer and some meteorological services have their own data formats and compression schemes. Until now, there exists no single standardized international data format, but the most common are ODIM_H5, netCDF, Cf/Radial, Selex Rainbow format, Iris, Bufr and UF. Conversion between these data formats must be made available by the software system vendor, because without conversion or an open format, data cannot be exported and read outside the proprietary software framework. This is a major problem for researchers or radar composite processing centers that need to process radar data from the entire heterogeneous radar network into one common picture.

DATA INTER-COMPARISON

With all the radar benefits, many meteorological services installed radar networks to scan, as low as possible, the entire country. Reducing geometrical effects, beam blocking, and decreasing the distance (and as a consequence, decreasing the beam altitude) between targets and radars are the main advantages of a radar network. Modern radar networks offer a centralized data processing approach to make the raw data available, implement harmonized data corrections, and generate versatile radar composite products. But centralization opens the field to some challenges in microphysics (compositing radars at different wavelengths) and logistics (synchronization, connection speed, infrastructure and data quality).

To mitigate these problems, software tools have been developed that use the power of overlapping neighboring radars. Sophisticated graphical features are offered to compare raw radar data and to detect any mis-calibrations or data inhomogeneities. Basically it is done by identifying the overlapping areas of scanned volumes between two neighboring radars. The comparison is applied at the pixel (bin) level at the same altitude and size and, as a consequence, comparable distances.

Radar volume size increases according to the distance between the radar and the target, so to compare two volumes, a ratio threshold is set to remove any disproportion. Finally, the difference can be quantified, extracted and exported in terms of the distance, the altitude, time and biases. The result of the data analysis is then used to adjust the raw data before being processed to a meteorological product and composited or combined further on.

The extraction can be made via a graphical user interface where a cube, a vertical cut or a sector can be chosen. The extracted data is converted to a table where each bin is geographically specified, i.e. from which altitude, distance and direction it belongs. Such data tables can be easily read by any scientific software such as Matlab, Scilab, R and Python. The advantage of the data extraction is to study meteorological phenomena at different altitudes and to analyze the behavior of the different radar parameters regarding the phenomena themselves and between them. Such study can lead to quantifying and qualifying the observations in mathematical and statistical equations, which can be later used in meteorological models.

Currently the manual or automatic inter-comparison of overlapping radars is undervalued, but it should be a standard feature as raw data centralization is increasingly performed for large, heterogeneous radar networks. In addition, inter-comparison helps to better understand precipitation microphysics at different levels and how the radar parameters interact. Data inter-comparison offers a valuable method to elevate the quality of raw data and – as a consequence – of the resulting products.

The two main advantages of centralization are the collaborative monitoring of the entire network from one place – by studying the variation of various radar parameters over time – and having easy access to the raw data from the radar, especially for re-analysis. Re-analysis and data assessment means to work on the raw data using other (or the same) preprocessing schemes (attenuation correction and so on) to generate non-operational products in offline mode that can be used as exercises, simulations, validation or to re-study some specific meteorological situation.

REDUCING OPERATIONAL RISK

Some meteorological services duplicate their operational data processing framework for reasons of redundancy or to work in parallel on the same data without interrupting mainstream operations. The latter is particularly important. Usually any modification of operational data processing may need a lot of bureaucracy and validation. Operational means that the consolidated (quality controlled) meteorological product or alert will be published, with all consequences.

After raw data reception and conversion into standardized raw data entities, several data improvement steps are applied, such as correction for bright band, vertical profile, occultation, attenuation and sea clutter. Using the quality-improved raw data, the meteorological products are generated, combined and provided to the public. The non-operational data processing runs completely in parallel, receiving the various moments, applying data corrections and so on. The advantage is that data improvement steps in the overall data processing chain can be embedded in iterations, validated and only put into operation when the resulting data quality is achieved and accepted. This substantially minimizes operational risk and maximizes data quality in a sustainable fashion. ∎

James Zog, CEO and chief technical officer, Zoglab

TRIED AND TESTED

How do the latest laser wind radar and drone measurement technologies stack up against the ever-reliable wind mast?

The 100m (333ft) wind mast is located in the Hutian Mountain area of Lishui, Zhejiang Province, China

The drone rose at a rate of 1m/s (3.2ft/s)

The latest laser wind radar and meteorological drone observation technologies have the potential to provide highly precise wind observations, a continuous and intensive stream of data, and variable vertical measurement capabilities, which could make up for the poor flexibility of traditional observation methods such as wind masts and tethered airships.

In terms of observation and maintenance costs, laser wind radar and meteorological observation drones provide an economical alternative to tethered airships. When it comes to data analysis, the horizontal and vertical data distribution maps produced by these technologies can be combined with GPS and terrain data to calculate the 3D state of the atmosphere.

EQUIPMENT TEST

Since the working principle of each type of equipment is different, it needs to be verified and tested before it can be widely used. The working principle of the Zoglab LWR300/LWR2500 laser wind radar is to use 1,550nm laser multi-point scanning technology to send and collect the Mie scattering echo information of the aerosol particles in the air, and to analyze and calculate the high-resolution and highly accurate real-time 3D wind field data.

The Zoglab UAV6000 meteorological observation drone is a multi-element device that combines meteorological observation technology and an unmanned aerial vehicle (UAV). The wind field observation adopts an ultra-small resonant ultrasonic windspeed and direction sensor, and an ultrasonic time difference method is used to measure windspeed.

The radar and drone were tested against a 100m (330ft) wind mast, complete with a three-cup anemometer, located in the Hutian Mountain area of Lishui, Zhejiang Province, China. The altitude of the wind mast was set at 871.5m with 10m, 30m, 50m, 60m, 70m, 80m and 100m layers.

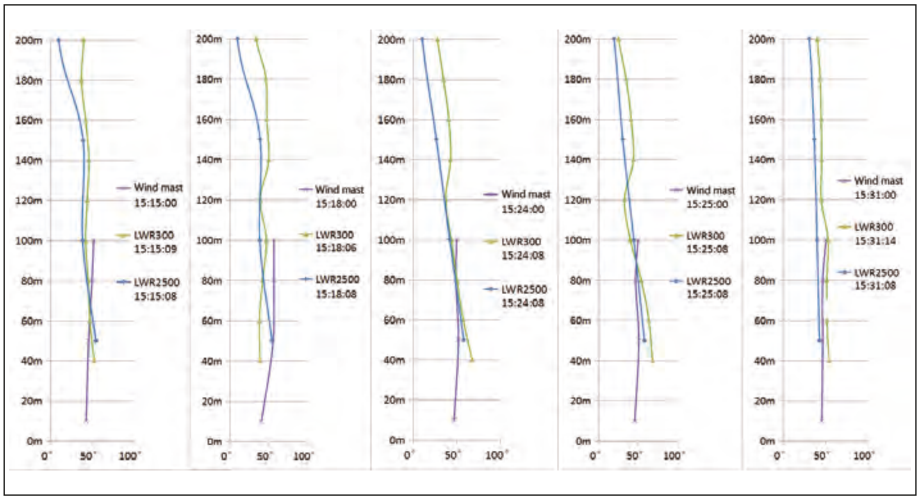
EXPERIMENTAL PROCESS

On April 25, 2018, a comparison test was performed between 12:00pm and 16:00pm. The test environment conditions were recorded as being a sunny-to-cloudy day, breezy, with the temperature varying from 26°C (79°F) to 12°C (54°F). Two laser wind radars were deployed within 10m (33ft) from the wind mast. After connecting the laptop, the laser wind radar observation connection software was turned on to ensure its normal operation and that data could be acquired from the radar. During the test, the laser wind radar and wind mast continually retrieved test data, while the meteorological observation drone rose at a speed of 1m/s (3.3ft/s) and hovered at different designated heights (consistent with the hierarchical height of the wind mast). It hovered for more than 30 seconds, retrieving data every four seconds.

LASER WIND RADAR VS MAST

The wind speed and wind direction recorded by the wind mast and the LWR300 and LWR2500 laser wind radar, averaged over two-minutes, were shown to be basically the same (see Figure 1).

Figure 1: wind direction comparison of LWR300, LWR2500 laser wind radar and 100m (330ft) wind mast



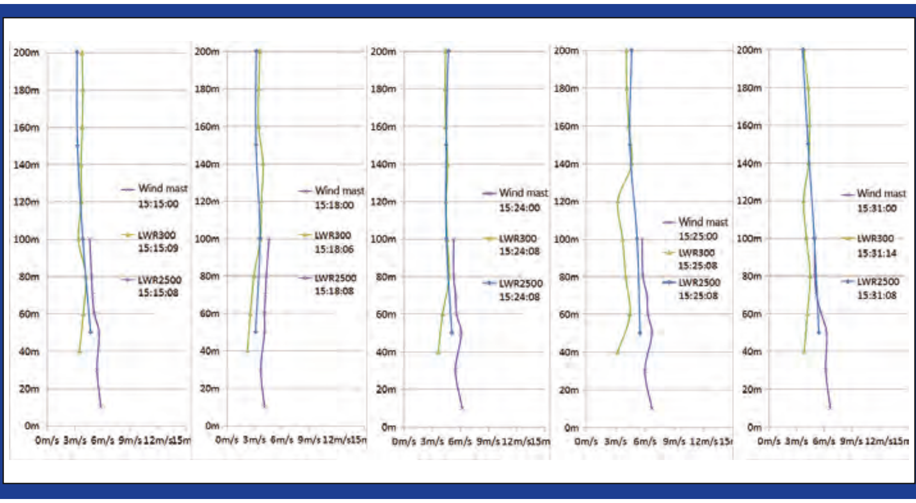


Figure 2: windspeed comparison of LWR300, LWR2500 laser wind radar and 100m (330ft) wind mast

UAV and wind mast sampling data

UAV6000

Height/m	Time	Instantaneous wind speed	Two-minutes average wind speed
10.4	12:41:42	2.9	2.6
29	12:46:24	1.9	3.7
75.2	12:50:18	4.4	4.3
96.3	12:53:42	3.7	4.7

Wind mast (Station number: TDF24)

Height/m	Time	Instantaneous wind speed	Two-minutes average wind speed
10	12:42:00	2.1	2.9
30	12:46:00	1.5	2.8
70	12:50:00	3.4	3.7
80	12:50:00	3.6	3.8
100	12:54:00	3.4	2.4

From the results in Figure 2, it can be seen that randomly selected windspeed and wind direction measurements from the LWR300, LWR2500 laser wind radar at 15:15, 15:18, 15:24, 15:25 and 15:31 are also consistent with the wind mast.

OBSERVATION DRONE VS MAST

During the test, the flying height of the drone and the height of the wind mast are deviated, and the similar height and time are selected as comparisons. Comparing the data of the drone and the wind mast, the maximum difference of the instantaneous windspeed is 0.9m/s (3ft/s), and the maximum difference of the two-minute average wind speed is 2.3m/s (7.5ft/s). The results showed that the test data of the UAV and the wind mast are basically the same.

CONCLUSION

Through the comparison analysis of the data obtained in this experiment, it is notable that the laser wind radar has a small deviation from the wind mast at the same height. The laser wind radar can display the wind field data of 48 different heights (LWR300 interval 20m-40m (66ft-132ft), LWR2500 interval 50m (164ft)), and the wide observation range can better restore the overall shape change of the wind field in the area.

It can also be seen from the comparison analysis that the observation data of the meteorological observation drone is not much different from the data of the wind mast and that it is within the tolerated margin for error. The meteorological observation drone has a high degree of flexibility, enabling data acquisition at any height, meticulously depicting trends in the wind field.

The reason for analyzing the data deviation is that the clock of the test equipment is not completely consistent – there is a deviation – and the clock signal of each experimental equipment can be solved by using GPS timing or GPRS timing. It is important to note that the laser wind radar, the observation drone and the wind mast are not exactly at the same position, with a distance of 10m between each of them. Due to the instantaneous change of the wind field and the non-uniform characteristics, certain data deviations are also caused. The meteorological observation drone is also not fully consistent with the wind mast at the same height.

The results show that the windspeed and wind direction data of the laser wind radar are basically consistent with the wind mast. The windspeed difference between the meteorological observation drone and the wind mast at 100m is less, and both can meet the requirements of the current wind field observation. ∎

Carlos Diaz, professional engineer, Sonoma County Water Agency, and Charles Yost, meteorologist, OneRain Incorporated

WILD AND WET

In California the race is on to protect life and property from the risk of flash flooding following wildfires

The US state of California is famous for its year-round favorable yet varying weather conditions. From surfing on the coast to skiing in the Sierras, Californian residents delight in weather patterns that are pleasant and highly predictable for most of the year. What makes the sunshine and desirable weather so predictable is a well-defined rainy season with little or no rainfall outside of that period. However, this pattern can also lead to deadly and powerful natural disasters in the form of wildfires and subsequent flash-flooding events.

THE SEASONAL MIX

Traditionally, California's rainy season starts as most of the country prepares for winter weather in the autumn. Most years start with several storms in the early months of the 'water year', which runs from October 1 to September 30 in the USA. The winter's rain events bring much-needed water for wildlife, vegetation and water supply. Just as seasonal grasses begin to grow and local vegetation springs again the rain stops, with little or no rain for the months of May to September. When the rains stop, the wildfire risk begins.

Wildfires are devastating forces that destroy everything in their path, leaving only the concrete slabs from houses and metal frames from cars. During the period of no rain, high temperatures, low humidity and abundant vegetation drying out, a strong wind event can turn a small brush fire into a roaring inferno that destroys hundreds of square kilometers of land. In the blink of an eye, a once-bustling neighborhood can be destroyed and transformed overnight into a desolate landscape that will be scarred for many years to come.

A CHANGED LANDSCAPE

As if the loss of lives and structures weren't bad enough, the burned area is now capable of producing life-threatening flash flooding locally and downstream. Post-fire changes in soil and vegetation cause any rainfall to run off faster and more completely, leading to larger volumes of faster-flowing water. Burn-scarred landscapes can generate swift currents within minutes of rain onset, causing flash floods, debris dams and mudslides. Because of the heightened flood risk, rainfall and stream monitoring networks are often installed for the first time or repaired and expanded in areas that recently burned.

The wildfire season of 2017 was the most widespread and most damaging in California's long history, even worse than the seasons during its most recent severe drought, that lasted from 2012 to early 2017. Two of the larger fires in 2017 occurred in Sonoma and Napa Counties just to the north of San Francisco in October 2017. The Tubbs Fire burned 148km^2 (57 square miles) in the northeast portion of Sonoma County, killing 22 people and destroying almost 6,000 structures. The Nuns Fire burned 228km^2 (88 square miles), resulting in three lives lost and more than 1,300 structures destroyed. A critical aspect of the fires was their timing: the fires started on October 8 and weren't completely contained until October 31, just in time for the start of the rainy season.

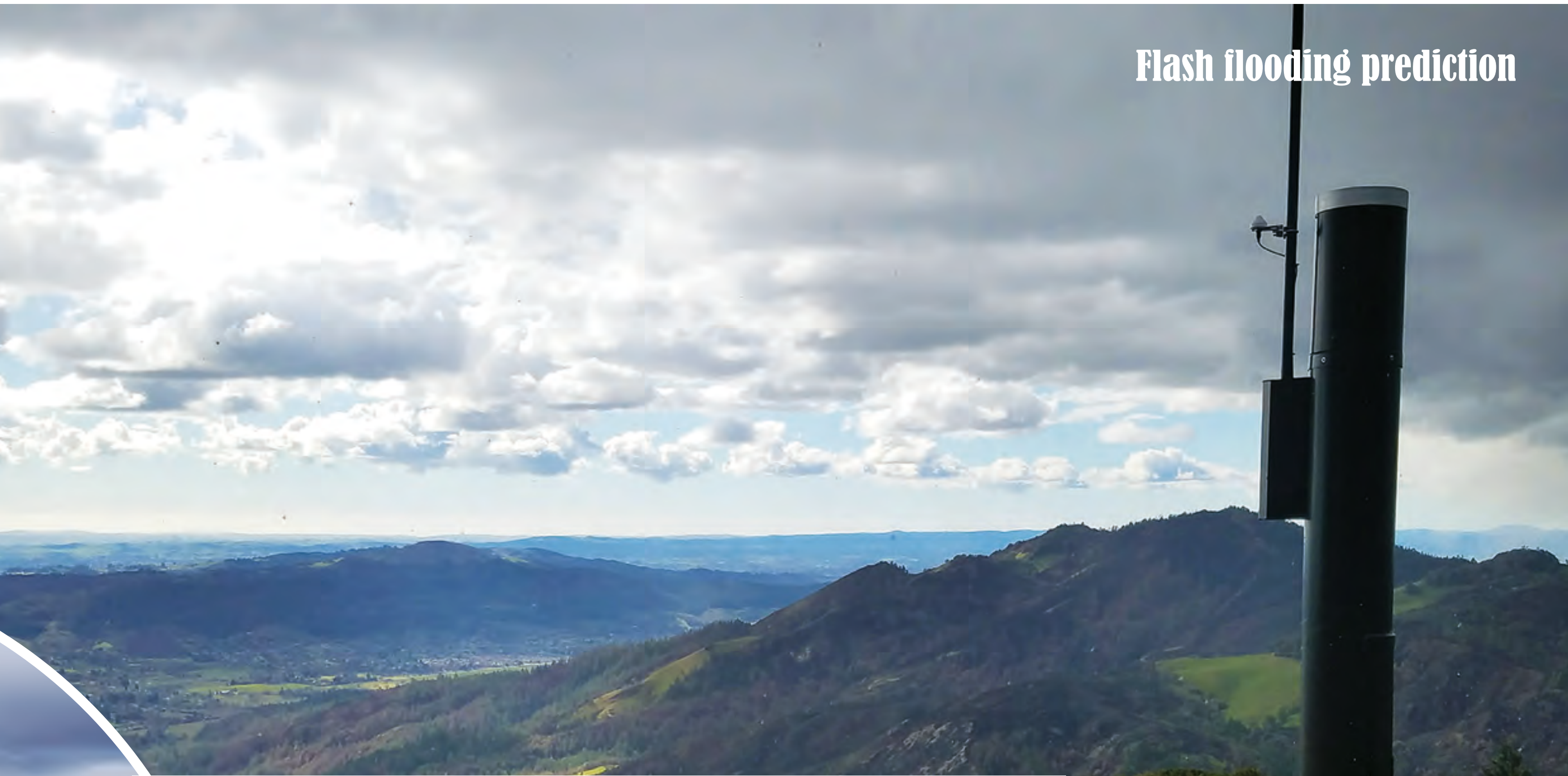
PARTNERING IN RISK RESPONSE

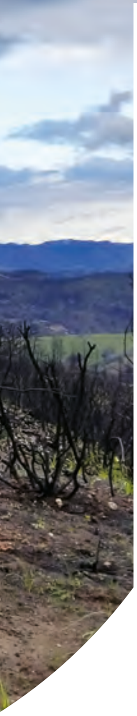
Sonoma County Water Agency (SCWA) is responsible for water supply, wastewater treatment and flood mitigation in the county. Even before the wildfires had stopped smoldering, it went to work to understand and plan ways to mitigate flash-flooding risk. Partnering with the National Weather Service (NWS) and the California Department of Forestry and Fire Protection, SCWA created a plan for a new environmental monitoring network

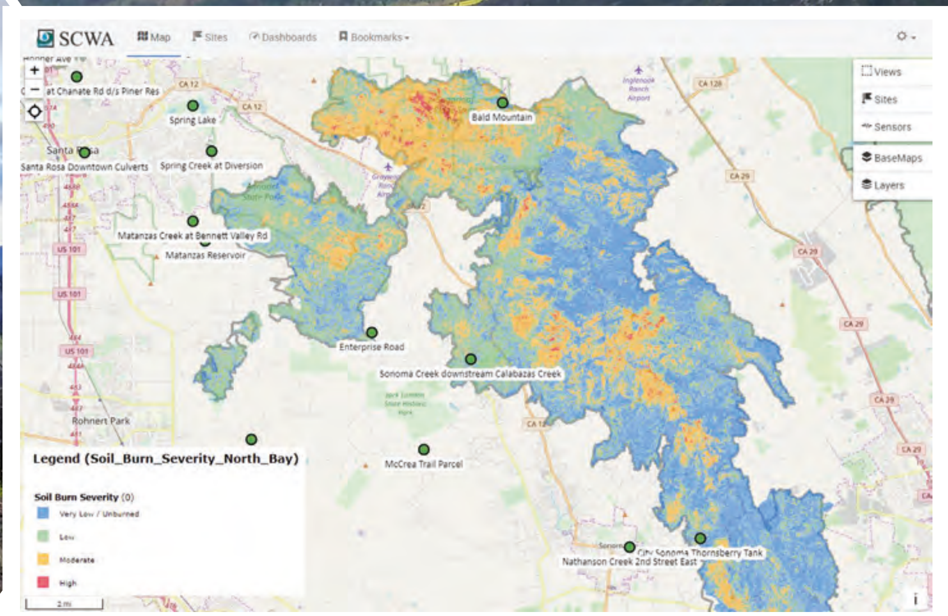
OneRain engineers install a new High Sierra Electronics automated rain gauge on a burned hillside

ALERT2

The technology chosen by the SCWA uses ALERT2, the next-generation, much improved version of ALERT, the NWS-originated, community-supported standard protocol that's provided flood warning globally for more than 40 years. ALERT2 sends much faster, more complete, virtually error-free environmental data and is supported by multiple hardware and software vendors. ALERT2 is trademarked by the US National Hydrologic Warning Council, a non-profit organization.







OneRain installed High Sierra Electronics' rainfall and stream gauges at 26 critical locations in California. Real-time data is delivered to Contrail base station software to support decision making

OneRain's Contrail data collection and monitoring software provides data feeds to the National Weather Service and a front-facing public website keeps the community informed

to measure rain and water levels at critical locations in and around the burn scars. This real-time network would provide advanced warning for flooding threats to communities trying to recover.

Their biggest challenge was the speed required for the network's installation. The system had to be extremely reliable and sustainable as it would be needed for years, but it had to be installed as quickly as possible with the rainy season having already started. Its mission-critical nature precluded using public cell networks due to incomplete geographic coverage and competition for bandwidth during weather events.

The SCWA selected a land-based radio system to deliver data from remote gauging sites to base station software. Based on the ALERT2 open standard protocol (see box), the approach is used by flood control and government agencies across the USA and the world for rainfall and flood monitoring. Although they considered satellite-based systems, compatibility with the flood warning networks in surrounding counties ultimately swayed their choice; SCWA was able to leverage Napa County's existing ALERT2 infrastructure and thus vastly speed up the installation time.

TECHNOLOGY SUCCESS

The NWS and SCWA chose 26 locations critical to providing effective advance warning. The selected sites included rain gauges placed throughout the burn scar to characterize rainfall over the most vulnerable areas, water level gauges in critical locations to detect flow and debris dams, and soil moisture sensors to track saturation and potential destabilization of slopes in areas vulnerable to debris flows. The system was completed in four months from conception to final implementation. Sensors can now report new information every minute with less than 1% data loss.

Today NWS and SCWA operations people have the data they need to create advance warnings and take appropriate action, wherever they are, using any web-enabled smart device. The consequences of rainfall over the next several years remain high-risk for their communities, but they will have early warning to protect themselves and their properties. Let it rain. ∎

Thomas Stadie, managing director, and Jörg Petereit, head of laboratory, Adolf Thies

SMART ANEMOMETER

A new generation of cup-star anemometers is setting a new standard in windspeed measurement

The new IEC61400-12-1 edition 2 standard has redefined and considerably increased the requirement for anemometer-based measurements, compared with the previous version. Among others, the requirements on the temperature range and the inclined flow (cosine) behavior have been redefined, and the effect of the air density on the wind measurement has been considered.

The special development of First Class Anemometer Advanced X by Thies Clima is the response to the redefined requirements of the IEC61400-12-1 edition 2. Thanks to additional integrated sensors, the anemometer is largely independent from affecting ambient parameters. By means of an internal air pressure sensor, the measured wind speeds can be corrected automatically to the alteration of air density. Based on this correction and the integrated sensor heating, the anemometer has been certified with the accuracy value 0.6 in class A.

Furthermore, the instrument comprises a tilt angle and acceleration sensor. The tilt angle sensor allows, for example, the monitoring of vertical installation. It facilitates the exact alignment of the anemometer, and enables operators to optimize the effect with inclined flow. A subsequent correction of the cosine behavior is possible together with a measured wind direction. At the same time, the sensor geometry has been improved even further to achieve an optimum cosine behavior already with the measuring value acquisition, with the aim of achieving the best results in rough terrain.

The vibrations at the installed sensor are measured by a three-axis acceleration sensor. The measuring values allow interferences on the vibration behavior of the complete mast system at different wind speeds and can be used to monitor the quality of the installation.

Another new feature is the ability to program calibration values into the sensor so that subsequent recalculation of the measured values can be dispensed with. The calibration is thus independent of downstream data recording systems and data integrity is substantially increased. The output telegram status indicates whether the stored calibration values were used in the calculation of the wind speed. As the sensor supports the traceability of the recorded measured values, even with multiple calibrations, it is possible to see, at any time, which calibration was used for individual measurement campaigns.

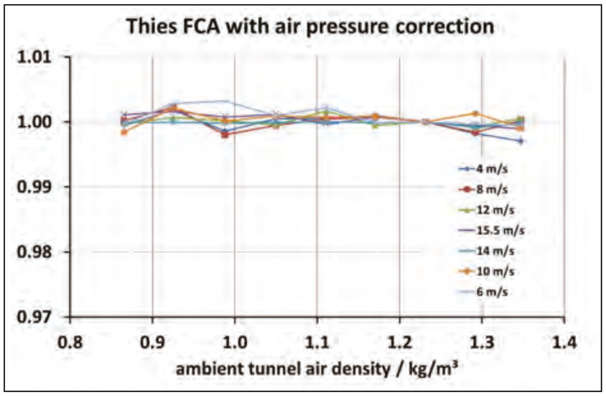
All measuring values are available using the integrated RS485 interface. The output occurs optionally via ASCII-telegrams or via data query in Modbus-RTU format. Various settings such as baud rate, protocol, or average time can be changed via several parameters. In addition to the mean values, gusts, standard deviation and turbulence intensity are also calculated directly in the anemometer.

The new First Class Anemometer Advanced X

A frequency output is still available and can be set so that the directly measured signals are provided as rectangular frequency signal, without further internal correction. A compatible data output to the previous model with frequency output is possible.

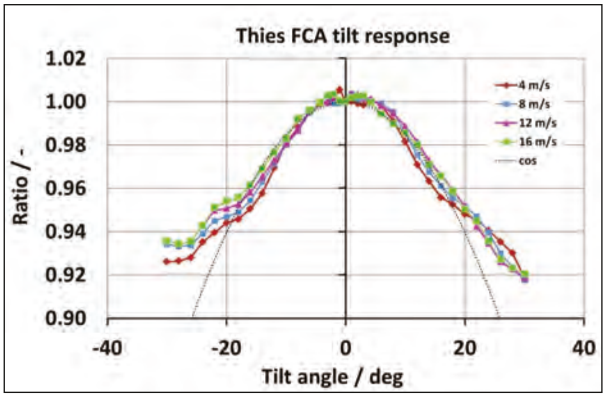
The Advanced X is operated with a voltage of 3.7V to 42V. Certain parameter settings allow for a low-power operation. A galvanically isolated 25W-shaft heating system guarantees that the anemometer performs its measuring tasks even in cold conditions.

With the integration of additional sensors for measuring the air pressure, tilt angle and acceleration, the new First Class Advanced X offers new possibilities to the user in the field of accuracy, traceability and quality with windspeed measurements. ∎



First Class Advanced X improves windspeed accuracy

First Class Advanced X demonstrates an improved cosine behavior



Silke Zollinger, press and events manager, Copernicus Communication

DATA POOL

Containing observations, reanalysis, seasonal forecasts, climate projections and climate indicators, the Copernicus Climate Data Store provides users with a wealth of trustworthy information about Earth's climate

Every day a huge amount of data on Earth's climate is collected from satellites, ground observations and many other sources. To help users deal with the complexity this entails, the Copernicus Climate Change Service (C3S), implemented by the European Centre for Medium-Range Weather Forecasts (ECMWF), has developed a one-stop shop for users to access and process trusted climate information.

Released this summer, the Climate Data Store (CDS) provides free and open access to climate information on global, continental and regional scales. Users can browse, search and download data and products, and perform data retrievals.

The CDS contains a variety of data types, including satellite observations, *in situ* measurements and climate projections, available as raw data and as processed maps and graphs. The datasets also include details on how accurate they are and how they have previously been used by scientists. The CDS is based on the Essential Climate Variables (ECVs) – a set of parameters that describe the overall state of the climate, including quantities such as temperature, sea level and atmospheric water vapor.

Dick Dee, deputy head of C3S, explains, "Eventually the CDS will contain datasets covering every ECV. This will enable users to analyze the impacts of climate change in a consistent and harmonized way."

To help users make the most of the data, the CDS also provides a set of software tools – the CDS Toolbox – that can be used to perform basic operations on datasets and even combine them. Multiple tools can be used together for more elaborate processing, and results can be presented visually on the CDS website.

"Users can generate graphs and maps from all available datasets," adds Dee. "These could be useful for many industries, including agriculture, insurance, energy, health, tourism and fisheries."

The CDS is a distributed system, meaning that users can request data and computations through its web portal. Requests are forwarded to the appropriate data repository and access is granted by individual data suppliers. To automate their interactions with the CDS, users can take advantage of the application programming interface (API). This provides batch access to all functions, including data retrievals and software tools.

ECMWF uses its forecast models and data assimilation systems to 'reanalyze' archived observations. Climate reanalysis gives a numerical description of the recent climate, produced by combining models with observations.

"Reanalysis creates global datasets describing the history of the atmosphere, land surface and oceans," says CDS manager Cédric Bergeron. "These datasets can be used for monitoring climate change, for research and education, and for commercial applications."

The CDS supports users with very different needs, from researchers that are interested in very large volumes of raw data, to decision makers looking for statistical analysis outputs.

Users with varying levels of expertise can interact with the CDS to transform data into information that is useful for them. And if a user runs into difficulties, the CDS user support team is always on hand to help.

"The store is continually being optimized and expanded through interaction with users," Bergeron continues. "We include their feedback in our development process to make sure that the system meets their requirements." ∎

↑ Enormous amounts of environmental data are stored in the computer hall's tape libraries

← Earth observation data is collected 24/7, analyzed and provided to all users for free through the Climate Data Store

Dave Hailes, managing director, Leading Edge Power

FIT AND FORGET

A hybrid approach to powering off-grid instrumentation provides the best chance of mission success

Figure 1: Wind and solar complement each other to provide constant power production

McMurdo Station

UNAVCO operates a GPS survey system at McMurdo Station, Antarctica. In this remote and hostile location, an array of scientific monitoring equipment is used to record a host of geophysical and meteorological data. A combination of solar and wind powers the telemetry equipment, with the LE-v50 Extreme wind turbine proving robust enough to cope with winds of 120mph (193km/h) for sustained periods.

"Our man at McMurdo reports that the turbine is holding up well, even through a recent storm with winds over 115mph," says Seth White, senior engineer at UNAVCO. "The blades are getting sandblasted, but the generator is fine."

Off-grid is a challenging environment for meteorological instrumentation, especially in locations where solar cannot be relied on to meet all the power requirements during the winter. While it's easy to plump for solar as the sole power provider, there are benefits in having a number of other power sources – wind, fuel cells or generators.

WHY HYBRID IS BEST

The closer an off-grid system is to Earth's poles, the greater the annual difference between summer and winter solar irradiation levels. At 55°N for example, solar output in the winter is just 30% of the summer value. Adding a second power source that complements solar and provides a more constant level of power production throughout the year is ideal (see Figure 1).

There are two main types of solar panels – monocrystalline and polycrystalline. Monos produce more power in low light conditions, such as cloudy days. Also consider them where space is limited, as they deliver the same power as polys but with a smaller footprint.

For mission-critical systems, methanol fuel cells are a useful backup, with solar and wind providing the bulk of the power and the fuel cells kicking-in infrequently. If systems are sized correctly, an annual visit is all that's required for refueling.

CONSTANT POWER

Off-grid power systems require deep-cycle batteries. Flooded lead-acid batteries are highly cost-effective compared with leak-proof sealed absorbent glass mat (AGM) or gel batteries. However, these sealed batteries are suitable for being transported over rough terrain and are maintenance-free, with no need to check electrolyte levels every few months.

The battery bank must be able to store enough power to keep the equipment operating should there be no input from the power generators. Autonomy is usually between three and five days, but can be more for mission-critical applications. It's advisable to have a low-voltage disconnect functionality to prevent the batteries going below 30-40% depth of discharge and reducing their operating life.

OVERCOMING THE ELEMENTS

Traditional horizontal axis wind turbines are unable to handle strong winds of more than 60mph (97km/h). In locations where such winds are likely, a special type of wind turbine is required – the vertical axis turbine.

The rotor blades on vertical axis turbines with a Savonius design, such as the Leading Edge LE-v50, rotate at the speed of the wind. Although this design is less efficient at capturing the energy in the wind, these turbines can survive wind speeds up to 120mph (193km/h), which destroy horizontal wind turbines.

Successful deployment of an off-grid system depends on carefully sizing the system to generate and store the power required by the equipment. The result is a fit-and-forget solution, delivering power 24/7. And for added peace of mind, there are some excellent web-based monitoring tools that allow the system to be checked remotely. ▮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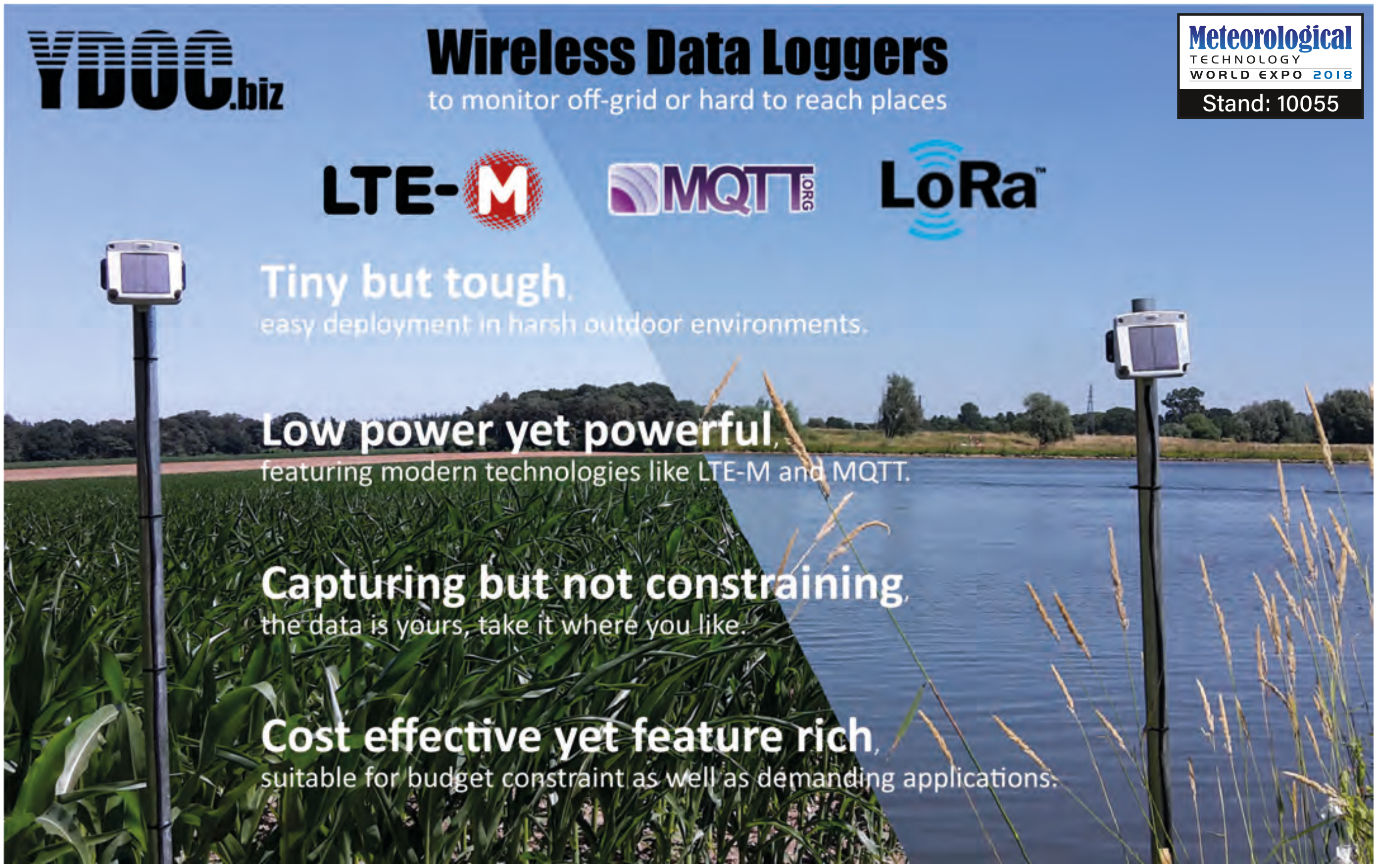
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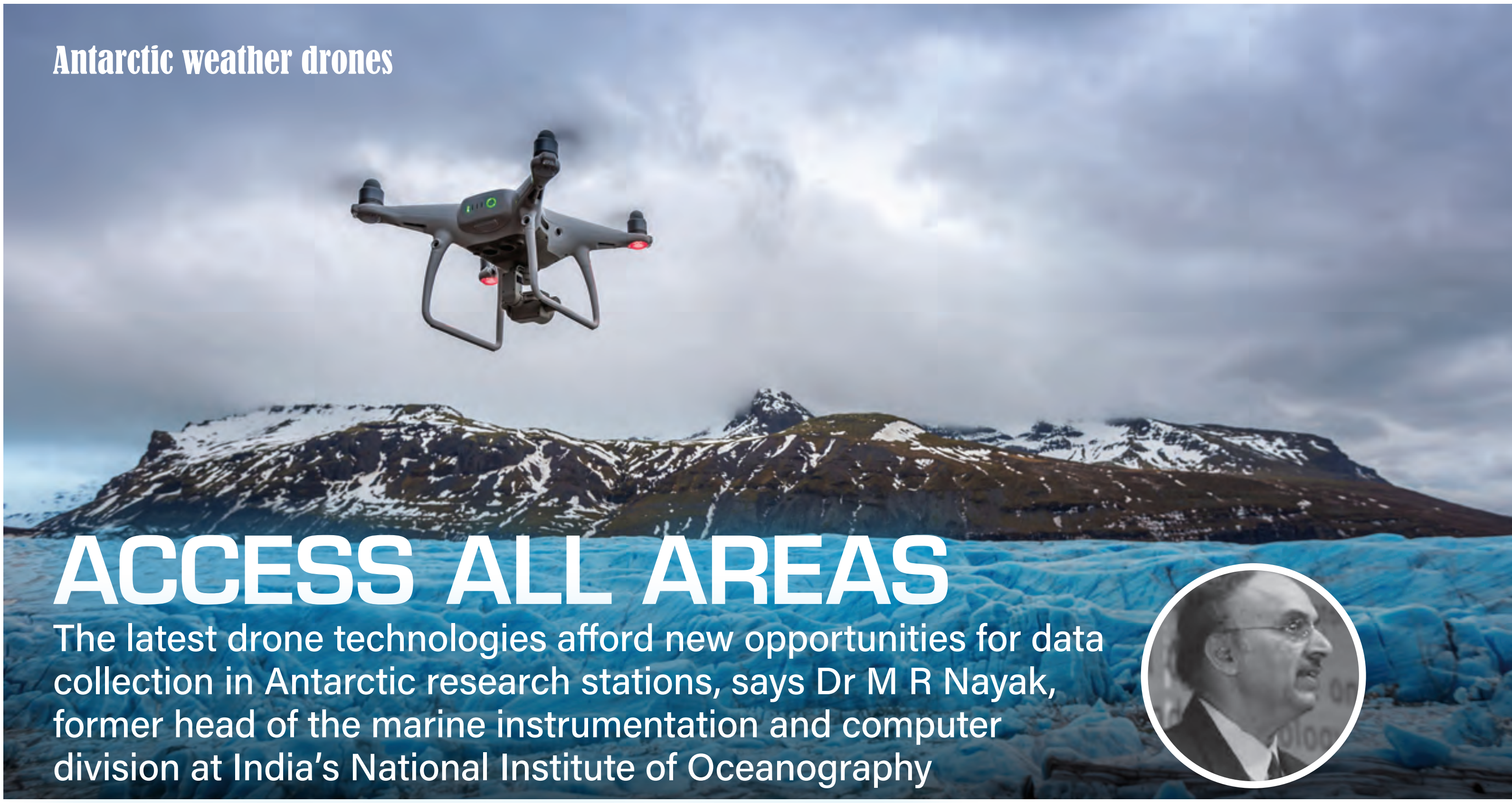

ACCESS ALL AREAS

The latest drone technologies afford new opportunities for data collection in Antarctic research stations, says Dr M R Nayak, former head of the marine instrumentation and computer division at India's National Institute of Oceanography

The study of Antarctica's climate is critically important as the region continues to experience changes that directly impact the global oceanic environment and atmosphere. Subjects of immediate interest include the forecasting of weather and understanding the impact of climate change. However, conducting research in Antarctica has always been a challenge.

The use of drones or unmanned aerial vehicles (UAVs) in the atmosphere and oceans may uncover meteorological secrets critical to improving weather forecasts. Potentially, they could collect samples from hard-to-reach remote locations where weather data is scarce. The data received could then be integrated into prediction models, improving their resolution and reliability.

Developments in artificial intelligence (AI) and robotics have made it possible to operate drone networks simultaneously with high efficiency, thus expanding the horizon of opportunities and capabilities. They can be fitted with a suite of meteorological sensors for the collection and transmission of weather data from remote locations in Antarctica to the operator's base stations. Key applications for such drone technologies include:

- Multidisciplinary studies of key processes to advance the understanding of complex ice, oceanic and atmospheric interactions;
- Systematic measurement of key drivers of changes in West Antarctica, for instance *in situ* observations of atmospheric and oceanic circulation, sea ice changes and influences, ice sheet flow and accumulation, and the sub-ice-shelf and grounding-line environment;
- Mapping the unknown terrains beneath the major ice shelves and the critical regions beneath the ice sheet, with technologies such as airborne radar, geophysical imaging, active seismic surveys, and sub-ice rovers, as well as traditional coastal and on-ice surveys.

Support for Antarctic and Southern Ocean research is vital for building an improved basis for understanding Earth's systems and for informing critical choices about how society might respond to major environmental changes over time.

While there is an endless reservoir of exciting and important questions that the deployment of drones in the Antarctic and Southern Ocean could address, limited budgets for research and logistical support mean that the need for prioritization and allocation of resources is real.

Many studies require observations of basic physical parameters (such as oceanic or atmospheric conditions), and efficiencies could be gained if this data was better shared among research teams or routinely obtained at key locations for shared use. An improved system for communicating data among researchers working in different locations and disciplines is therefore required. ∎

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