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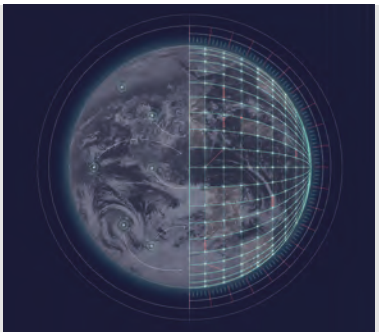

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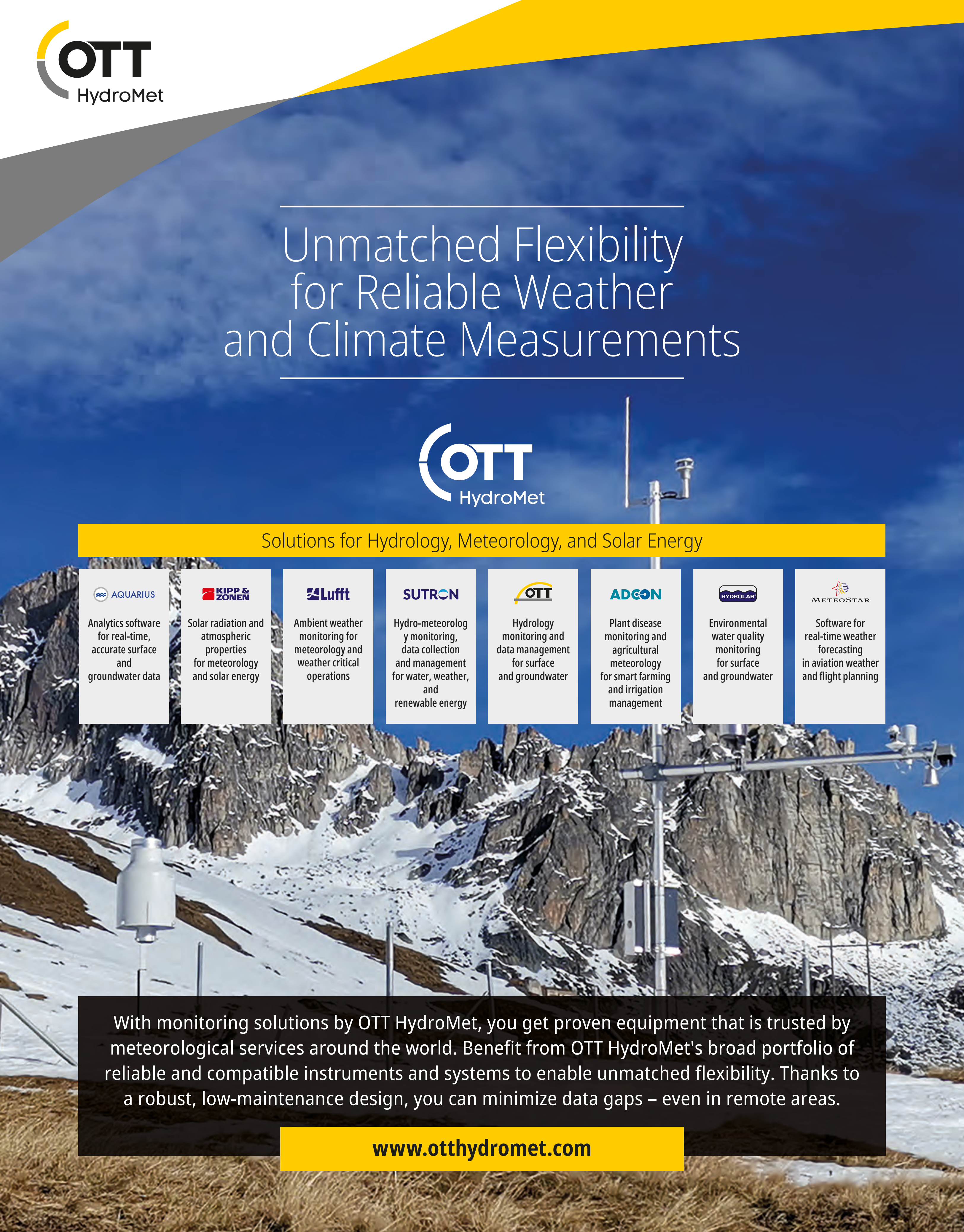
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The Forecast

On Sunday, April 4, 2021, Tropical Cyclone Seroja hit Indonesia and Timor-Leste, causing widespread flooding and landslides. Thousands were left homeless and, at time of going to press, an estimated 182 had been killed – a number that is expected to rise, as dozens more are missing.

Events like Tropical Cyclone Seroja highlight the vulnerability of communities to extreme weather in developing and least developed countries (LDCs) such as Timor-Leste. The World Meteorological Organization is currently working with Timor-Leste and the UN Green Climate Fund to develop an early warning system for the country to help it safeguard rural communities and their physical assets from climate-induced disasters.

According to a report published by the World Bank in March, in collaboration with the WMO and the UK Met Office, there is an urgent need to invest in basic ground-based weather stations to enhance the capacity of LDCs to mitigate climate risks, such as storms, flooding, drought, heatwaves, forest fires and sand/dust storms. The report, *The gaps in the Global Basic Observing Network (GBON)*, states that improving the collection and international exchange of surface-based observational data could deliver socioeconomic benefits worth more than US$5bn each year.

In the report, lead author Daniel Kull, who is a senior disaster risk management specialist at the World Bank, said, "In view of the growing climate- and weather-related challenges facing humanity...surface-based observations should be treated as a critical public good."

According to some media reports, one of the reasons the flooding was so bad in Timor-Leste was a faulty sewerage system, which resulted in contaminated water flooding homes – a significant health threat.

One project that is helping communities in countries like Timor-Leste is DARAJA – which stands for Developing Risk Awareness through Joint Action (see *Bridge the gap*, page 8). DARAJA is an initiative to bring timely weather reports to vulnerable populations living in informal settlements. The project has been rolled out in settlements in Kenya and Tanzania, and uses local weather leaders to connect national meteorological hydrological service providers with communities. DARAJA has helped communities prepare for flooding by, for example, encouraging them to clear trash from the streets and from the settlements' rudimentary drainage systems. James Kirika, a weather leader in Kibera, Kenya, said, "In earlier years people did not prepare themselves and when the rains came, shops and houses would flood."

Mark Harvey, CEO of Resurgence, co-founder of DARAJA, hopes to replicate the project in informal settlements throughout the world.

Meanwhile, the WMO is pushing ahead with its Systematic Observations Financing Facility (SOFF) project, which seeks to provide technical and financial assistance to enable countries to generate and exchange basic observational data. As a priority, SOFF will support LDCs and Small Island Developing States, which face the most serious shortfalls in observations.

Extreme weather events like those in Timor-Leste and Indonesia will undoubtedly occur again, but with the support of the WMO and with projects like DARAJA there is hope that nations can be better prepared to save both lives and livelihoods.

Helen Norman, editor-in-chief

> "Events like this highlight the vulnerability of communities to extreme weather in developing and least developed countries such as Timor-Leste"

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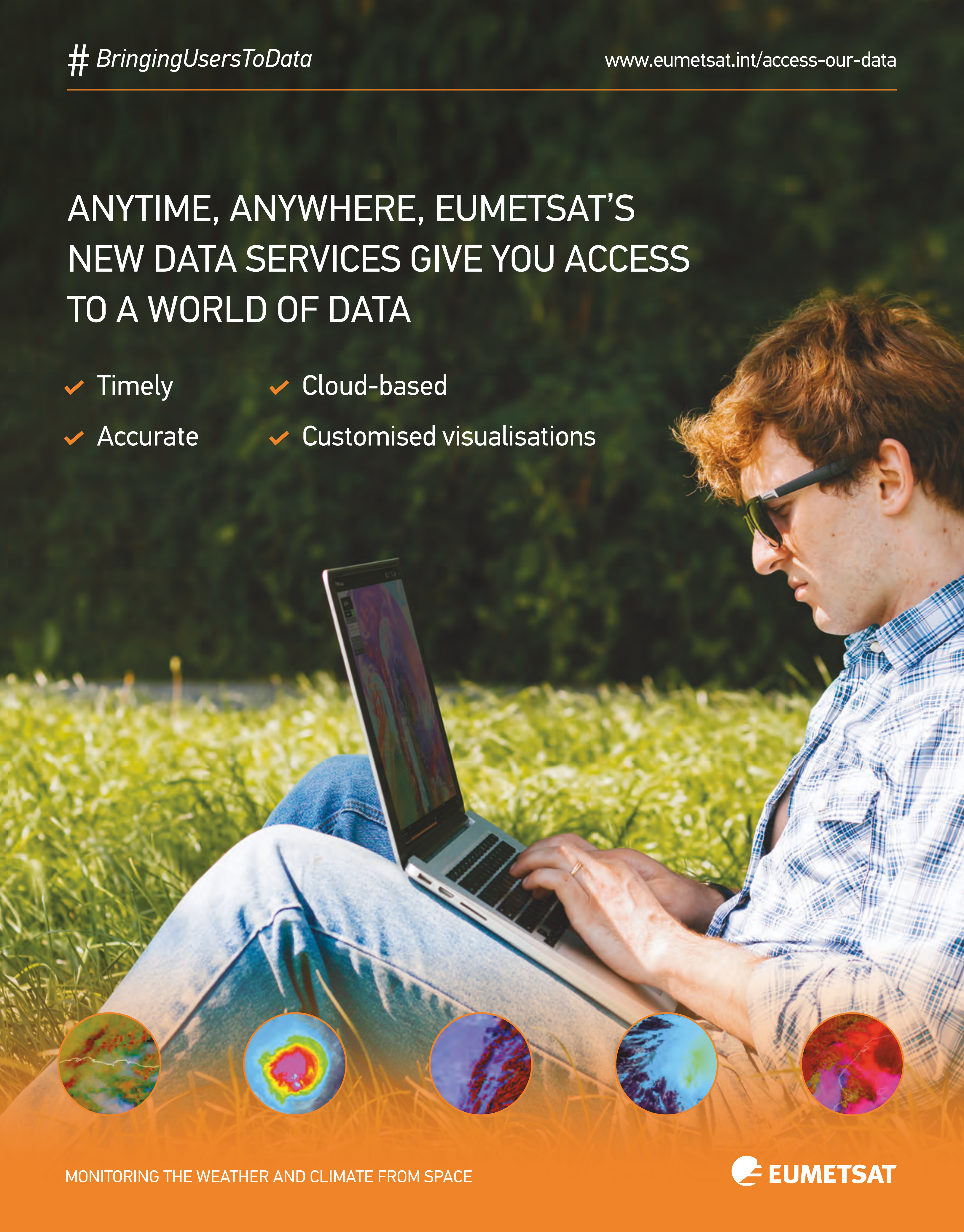
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Helen Norman

ON THE JOB

EUMETSAT's new director general, Phil Evans, talks next-generation satellites and embracing a balanced approach to innovation

On January 1, 2021, EUMETSAT welcomed the new year with a new face in the top seat. Phil Evans, who was previously the director of Physics Programs for the Institute of Physics, took over the role of director general from Alain Ratier. For Evans, his main aim is to build on the legacy of past EUMETSAT DGs and to ensure the organization continues to embrace agility to drive innovation.

"I am lucky to have arrived at EUMETSAT at a very crucial moment in the history of the organization," Evans says. "Weather and climate predictions are more important than ever, and the development of 'new space' is accelerating. These are challenging, and thus also interesting, times. I am looking forward to shaping EUMETSAT's new strategy and guiding its implementation so the organization can thrive in this fast-evolving environment."

Evans, who spent more than three decades in several senior positions at the UK Met Office before moving to the Institute of Physics, has joined EUMETSAT during turbulent times, both for the climate and for human societies. He is, however, proud to be joining an organization that can help tackle global challenges. "I could not think of a more socially relevant organization to work for right now," he adds.

Next-gen satellites

Looking at some of the key milestones on the horizon for EUMETSAT, Evans continues, "In 2020 we saw the launch of the Sentinel-6 Michael

EVANS' THREE KEY AIMS FOR 2021

1. "My first goal is to listen! To really understand the organization, its staff and stakeholders to ensure I understand rigorously what makes it tick, what challenges it faces and how to make it an even better organization than it is today."

2. "I also want to ensure that we are well prepared for the challenging and busy times ahead of us, and that we have the best possible basis for delivering MTG and EPS-SG."

3. "Last, but not least, the current societal challenges are too broad and the solutions too global to solve them alone, without strong partnerships. EUMETSAT must ensure that its partnerships in Europe and beyond are as strong and mutually beneficial as possible. Despite the limitations as a result of Covid-19, my final priority for this year is to ensure that we keep building on our current partnerships."

ABOVE LEFT: Phil Evans became director general of EUMETSAT on January 1, 2021

ABOVE RIGHT: Artist's impression of the Meteosat Third Generation satellites in orbit

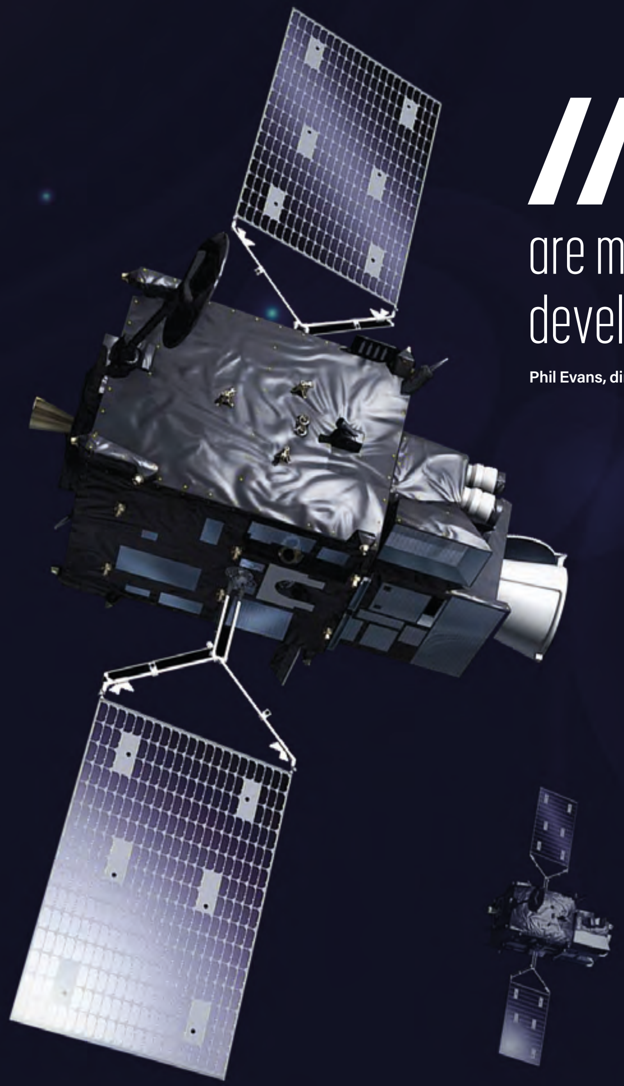


Image: ESA and EUMETSAT

> Weather and climate predictions are more important than ever, and the development of 'new space' is accelerating"
>
> **Phil Evans, director general, EUMETSAT**

Freilich satellite, the first of a new generation of ocean monitoring satellites to be launched into space in the coming decade. Sentinel-6 is doing well so far and we are furthering its integration with our data delivery platforms. The first data will be made available to our users in June – this is an important milestone, and one that will have broad implications far beyond EUMETSAT.

"We are also working on the next generation of satellites – the third generation of geostationary satellites Meteosat (MTG,) and the second generation of polar-orbiting satellites Metop (EPS-SG)," he continues. "These new generations of satellites are essential to ensure that we keep delivering the most accurate data to our users. The first of the MTG satellites will launch at the end of 2022, and the first EPS-SG at the end of 2023."

According to Evans, the future generations of satellites to be launched after MTG and EPS-SG may have quite different specifications. "The current development of private satellite fleets and of micro satellites raises interesting questions for agencies like EUMETSAT," he comments. "We need to find a way to 'stretch our thinking' and find a balance between innovation and the benefits of the larger reference satellites that we have implemented previously and which will remain essential. I have taken an interest in what constellations of micro sats might offer for a long time but believe we should take a 'system of systems' approach where we maximize the benefits of the total satellite observing infrastructure," Evans adds.

Improving agility

Aside from preparing for new approaches in Earth observation, such as small satellite constellations, Evans also hopes to contribute to further strengthening EUMETSAT's workforce. "One of my key aims is to continue to develop the organization and its employees and improve our agility and the way in which we innovate and incorporate innovation," he says.

"I believe the main challenge for us and our member states at the moment is to have a measured approach and decide rationally what we want to do differently. In any case, such developments are an opportunity for us to do a better job and contribute to our member states and society in general in a more significant way."

And it is this contribution to society that motivates Evans to continue working tirelessly in the meteorological sector. "The meteorological and climate communities are endlessly fascinating," he enthuses. "The reliable operational exchange of Earth observation data must be one of the greatest achievements in international cooperation. It requires the integration of science, technology, computing, and human expertise, and it is an endeavor that touches on almost every aspect of our lives, often in profound ways," Evans concludes. ∎

EUMETSAT'S NEW DATA SERVICES

On page 40, Yves Buhler, director of the technical and scientific support department (TSS) at EUMETSAT, shares details of the organization's new data services, which sit at the heart of the organization's long-term big data strategy

Case study: DARAJA

Paul Willis

BRIDGE

DARAJA project leaders share how they are addressing the vulnerability of rapidly growing informal urban settlements to extreme weather to protect livelihoods in Kenya and Tanzania

Kounkuey Design Initiative (KDI)

Residents in the Sokomoko settlement in Nairobi are particularly at risk of flooding. DARAJA is now helping them to be better prepared

THE GAP

James Kirika was born and raised in Kibera, an informal settlement in the Kenyan capital of Nairobi and one of the largest urban slums in Africa. The softly spoken Kenyan has become something of a minor celebrity among Kibera residents, with his own nickname, after he organized a community clean-up operation in Kibera ahead of a forecast of heavy rainfall. "People came out in large numbers," says Kirika. "In earlier years people did not prepare themselves and when the rains came, shops and houses flooded."

He organized the clean-up, which included clearing trash from the streets and from the settlement's rudimentary drainage system, as part of his role as a community leader for the DARAJA project, primarily funded by the UK Met Office's Weather and Climate Service for Africa (WISER) program, to bring weather reports to vulnerable populations living in informal settlements.

So far, DARAJA – a Swahili word (see *Closing the gap between weather forecasting and world's poor*, below) that stands for Developing Risk Awareness Through Joint Action – has been rolled out in Nairobi and also in Kigogo, an informal settlement in the Tanzanian city of Dar es Salaam, but there are plans to expand it worldwide.

Speaking about the community clean-up operation, Kirika adds, "The next day when the heavy rains came, water did not enter the shops and houses, and everybody was so happy that from that day on people started calling me The Weather Man."

Understanding the forecast

Direct actions such as this have had a major impact in changing attitudes toward weather forecasting, which Kibera residents have traditionally viewed with skepticism. Even Kirika admits that, prior to his role with DARAJA, he didn't understand the forecast.

"It was too hard to understand the icons and the technical terms that were used in the forecast," says Kirika, who is one of 24 community leaders working on behalf of the project in Kibera.

Patricia Nying'uro, a principal meteorologist at the Kenya Meteorological Department (KMD), says that before the DARAJA project, the agency's forecasts were couched in "very scientific language" and were "too wordy" to be understood by most Kibera residents.

As well as the esoteric language, the residents' misunderstanding also stemmed from a lack of knowledge concerning forecasting, notes Nying'uro. "We did not communicate probabilities so well," she says. "Because of this, people had the idea that forecasting was an exact science. So if there was a forecast of rain, they expected rain."

Through DARAJA, KMD has worked with other stakeholders including community groups and non-profits working in Kibera, and other informal settlements in Nairobi, to create forecasts that are both intelligible and accessible. Nairobi's informal settlements are estimated to host 60-70% of the city's population.

Community leaders like Kirika, who are also responsible for translating KMD's weekly forecasts into SMS bulletins tailored to Kibera residents, are a vital part of this process, according to Nying'uro, not least because they have helped to personalize the forecasts by giving them a human face.

"The forecaster used to feel like someone remote and far away, someone the people couldn't relate to," says Nying'uro. "But with the local community leaders, this is someone you see all the time. So it enhances the confidence people have in the forecast."

The dangers of wet and dry season

Before the project got underway in late 2018, the DARAJA organizers surveyed Kibera residents to find out their level of engagement with weather

CLOSING THE GAP BETWEEN WEATHER FORECASTING AND THE WORLD'S POOR

When Mark Harvey, CEO of Resurgence and the co-creator of DARAJA, first got all of the partners in the project together for a meeting in London, he gave them an ultimatum. "I told them I wasn't going to let them out of the room until we had found an improvement on the instantly forgettable project name, which at the time was called Supporting Urban Intermediaries for Better Forecasting," he says.

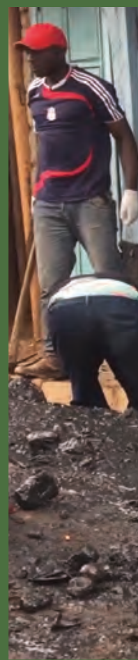
"I told them we needed a Swahili name – the most commonly spoken language across East Africa – that resonates and gives this project some heart and soul," he adds.

Harvey and his partners eventually came up with the word 'daraja', which means 'bridge' in Swahili. The name speaks to the project's aim of creating a bridge between forecasting and the vulnerable residents of informal settlements.

While the project and its name are rooted in the culture and environment of East Africa, according to Harvey the fundamental problems that gave rise to it are common in many places throughout the world: "We're actually solving a problem that is much bigger than we first realized. It's endemic across Sub-Saharan Africa, South Asia and many parts of Latin America and the Caribbean."

Defining the problem, Harvey continues, "Many national weather agencies in these regions have not kept up with urbanization. Firstly, because they don't currently see serving the sector as being critically important to their operating models, and secondly, their sole focus on scientific accuracy means that they produce technically literate forecasts that are unintelligible for many users."

Harvey's vision is to replicate the DARAJA project in informal settlements throughout the world. As well as Nairobi and Dar es Salaam, Resurgence has received financing to expand the project into Kingston, Jamaica, he notes. They have also had interest from cities in West Africa, the Sudan and India. Replicating the project is relatively straightforward, according to Harvey. "To get a new DARAJA deployment off the ground we just need a national meteorological agency and a community development organization based in the informal settlement," he says. "Then we have to worry about the financing model that drives it."



Kounkuey Design Initiative (KDI)

"We did not communicate probabilities so well. Because of this, people had the idea that forecasting was an exact science"

Patricia Nying'uro, principal meteorologist, Kenya Meteorological Department (KMD)

ABOVE & BELOW: Weather Mtaani leaders help organize clean-up activities, and inform their communities about the rainy season, their initiative and how to take preventive action

forecasting. It found that nearly half – 44% – received no weather or climate information at all.

This lack of engagement can have dire consequences in a place like Kibera, where missing an extreme weather alert can mean the difference between life and death. Torrential rain is particularly dangerous in the settlement, according to Kirika.

"Here in Kibera, the drainage system is unplanned," he says. "Most of the houses are made with mud walls and iron sheet roofs, and due to lack of space people also build on top of drains, especially near the roads. So a lot of people are affected by floods when it rains."

Many of the dwellings are also built near the river, which is frequently clogged with trash dumped there by residents due to the lack of proper waste disposal services. In heavy downpours the rainwater has nowhere to drain and the water backs up into the settlement, with sometimes deadly results. "In the floods, people have lost their properties and also their lives," comments Kirika.

Another common danger in the rainy season is electrocution as rising flood waters come into contact with the exposed wires that residents use to tap electricity illegally from the power grid.

Kounkuey Design Initiative (KDI)

Centre for Community Initiatives (CCI)

Students in Dar es Salaam, Tanzania, learning about the climate and weather as part of the DARAJA project

Although Nairobi's high elevation, 1,800m above sea level, means it experiences less severe heat than other cities in East Africa, temperatures in informal settlements like Kibera are usually a few degrees hotter than elsewhere in the city. This is because of the urban heat island effect, notes Sabrina Ohler, a senior planning coordinator at the Kounkuey Design Initiative (KDI), an international non-profit working in Nairobi and the implementing partner of the DARAJA project in Kenya. "In the dry season you can have fire outbreaks because everything is so hot and dry it's easier for fire to spread," says Ohler. In hot spells the corrugated roofing causes dwellings to overheat, leading to cases of heat exhaustion among the residents, she notes.

Community engagement

To protect residents against these weather impacts, the DARAJA project leaders realized they needed to improve engagement with the weather forecast. The first step in doing this was to persuade KMD to produce city-specific forecasts for Nairobi and Dar es Salaam, according to Mark Harvey, CEO of Resurgence, a UK-based social enterprise specializing in climate resilience and co-founder of the DARAJA project.

The next step was to find the most effective ways of getting these forecasts out to residents. "Part of our baseline research work was to map how information flowed between the national weather agency and the local communities, and then within the communities themselves," comments Harvey. "We asked residents how they received weather reports, but also how they received other information, such as celebrity gossip and sports results."

RIGHT: DARAJA community leaders are known locally as Weather Mtaani leaders

THE CHANGING STATUS OF FORECASTING IN AFRICA

One reason national weather agencies in Kenya and Tanzania had neglected communities in informal settlements was because of a failure of resourcing to allow them to keep up with the times and provide services to emerging user groups in the urban space, notes Resurgence's Mark Harvey. This low resourcing is in part because of the unrecognized importance of national weather agencies in these two countries and across Africa in general, he notes.

"They just don't have the prestige attached to them of, say, the Met Office in the UK or NOAA in the US," he says. "These agencies are largely overlooked, and their status needs to be urgently improved."

However, as African weather agencies seek to make themselves more visible, there are signs that attitudes toward them are changing, according to Patricia Nying'uro, of the Kenya Meteorological Department (KMD).

"We certainly carry some of the blame for the way we have been perceived," comments Nying'uro. "We have tended to sit in our departments and produce these wonderful forecasts but without really disseminating them in a way that the end user can fully appreciate." In recent years, however, KMD has worked more closely with key customers such as the agricultural and energy sectors "to co-produce weather information specific to their needs", says Nying'uro. The result, she says, is that "the impression that people have of us has improved over the years".

As well as these attempts to modernize, the other factor that may help to elevate the status of weather agencies in Africa is climate change. The impact of climate change is being felt throughout the continent in rising temperatures, more extreme weather and changes to seasonal weather patterns.

While the science behind the phenomenon is not understood among many residents in informal settlements like Kibera, they are aware of the changes, notes Sabrina Ohler, of the Kounkuey Design Initiative (KDI).

"Many residents have come to Kibera from rural areas or maintain strong links with their ancestral villages and some go back there at certain times of year," says Ohler. "So they're aware of how excess rainfall has impacted farming especially in western Kenya, and the effect this has on food prices."

The picture that emerged both in Nairobi and Dar es Salaam was a "preference for radio and SMS", according to Harvey. Armed with this data, regular weather bulletins were set up on local radio stations such as Nairobi's Pamoja FM, a community radio station set up in the wake of ethnic violence that erupted in the city following a disputed election result in 2007.

In Dar es Salaam the awareness campaign also reached into schools. "This was through the formation and training of school clubs that were trained to educate fellow students and share daily forecasts through school parades, announcements in class or by using the school notice board," says Stella Stephen of the Centre for Community Initiatives (CCI), one of the non-profits charged with running the Dar es Salaam DARAJA project.

Meanwhile, community leaders in both cities were trained to produce the SMS bulletins. To simplify the forecast, icons were used wherever possible. The meteorological jargon was ditched and, in the case of Kibera, the forecast was translated from English into both Swahili and Sheng, a mixture of Swahili, other local languages, and English. The forecast was also altered to be more impact-based, according to Kirika.

"The charts are created daily and there is also a weekly one, which is the one we usually translate," he says. "In it we give relevant advice based on what is being forecast, such as to wear light clothes if it's going to be hot, or to check on electric wiring if rain is expected."

> "In the dry season you can have fire outbreaks because everything is so hot and dry it's easier for fire to spread"
>
> **Sabrina Ohler, senior planning coordinator, Kounkuey Design Initiative (KDI)**

The community leaders were also called upon to use their social media influence to help ensure the translated forecast summary reached as wide an audience as possible, notes Ohler.

Taking action

Through this word-of-mouth approach the SMS bulletins that Kirika and his colleagues compile in Kibera now reach a growing audience of engaged residents. As a result, 20 months after the project first launched, community access to weather forecasts has risen from 56% to 93% in the surveyed areas in Nairobi and from 74% to 93% in Dar es Salaam, according to surveys of residents conducted in both cities.

Even more important than the issue of access, however, have been the behavioral changes resulting from this new information source. In both Dar es Salaam and Nairobi, far more residents have reported taking actions, such as cleaning drains, making repairs to their homes, moving valuable possessions out of harm's way and changing their travel arrangements in response to weather alerts. There has also been an increase in the number of residents reporting that the actions they took had saved them money.

Although the resident surveys conducted in the two cities do not offer any direct evidence that the DARAJA project has saved lives, they do show the myriad small ways in which consistent access to weather information can make life just a little bit better.

In Kibera, for example, by far the most common behavioral change reported by residents was being able to dress appropriately for the weather. As Kirika puts it: "Weather plays a major role in the lives of people and businesses in Kibera. The motorcycle taxis known as boda bodas need to know whether they should carry umbrellas with them in the rainy season. Parents who want to send their children to school need to know if the roads they travel on are going to be flooded. So many people here depend on good weather information." ∎

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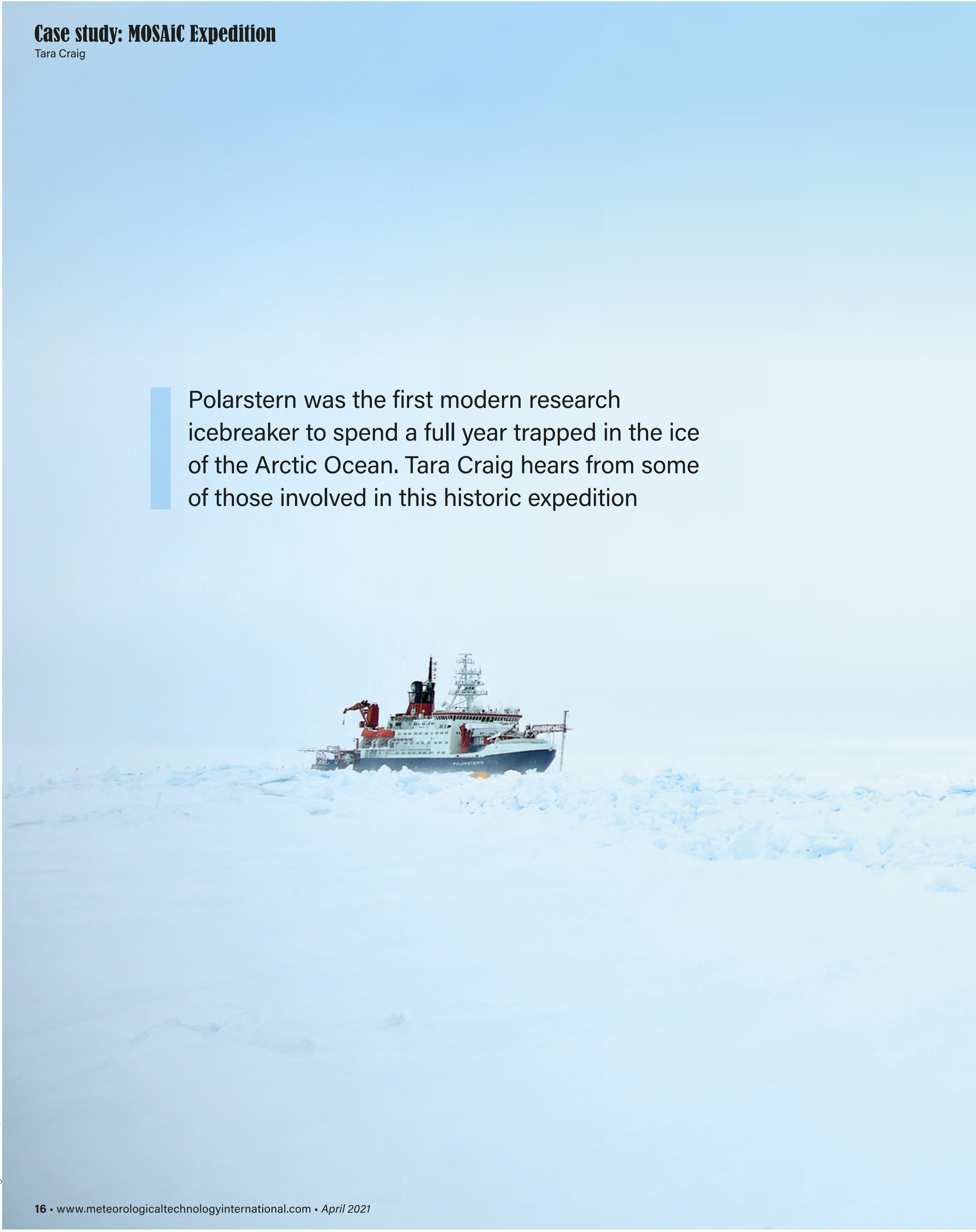


Alfred-Wegener-Institut/Michael Gutsche

> Polarstern was the first modern research icebreaker to spend a full year trapped in the ice of the Arctic Ocean. Tara Craig hears from some of those involved in this historic expedition

A YEAR IN THE ICE

Case study: MOSAiC Expedition

Packing up instruments at 'Met City' – a dedicated site for recording changes in the atmosphere surrounding the ice floe

Alfred-Wegener-Institut/Lianna Nixon

The Multidisciplinary drifting Observatory for the Study of Arctic Climate – MOSAiC – is a fittingly long and complicated name for the largest polar expedition in history. At its heart was Polarstern, which set sail from Tromsø, Norway, in September 2019. Fitted with a double-walled steel hull and 20,000hp engines, the Polarstern ship could easily break through 1.5m-thick ice and was fully-equipped for sustained operations at temperatures as low as -50°C.

The goal of the expedition was to take the closest look yet at the Arctic as the epicenter of global warming. Over the course of the year, experts observed what MOSAiC calls 'all the pieces of the Arctic climate puzzle – the atmosphere, sea ice, ocean, ecosystem, biogeochemical processes, and more', before putting the elements together to ascertain how they interact and respond to change.

The €150m (US$179m) expedition's findings will enable researchers to gain deeper insights into the relationship between the Arctic climate and the lower latitudes around the globe where most people live.

Improved climate forecasts are also important for the Arctic itself, since the overall warming and the loss of sea ice are changing the face of the region. Clear research findings can offer a sound scientific basis for future political decisions regarding environmental protection and global cooperation around the Arctic.

Furthermore, according to MOSAiC, the thawing ice is making the Arctic increasingly interesting from an economic perspective. New shipping routes are opening up. Raw materials previously buried under the ice are being exposed, and new fishing grounds will become accessible. This means that a clear framework is needed to ensure the Arctic is developed sustainably.

THE EXPEDITION IN NUMBERS

The coldest temperature recorded on the expedition was **-42°C**, on March 10, 2020

20 nations took part in MOSAiC, among them Germany, South Korea and the USA

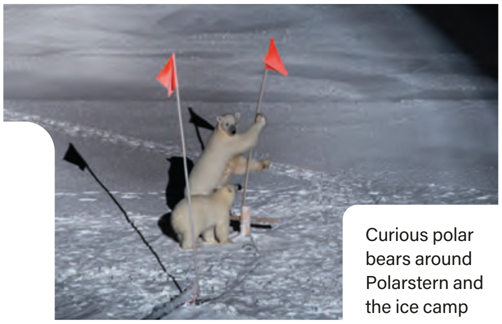
The average age of the participating researchers was **39**

More than **60** polar bears were sighted near the Polarstern

300+ people worked in the background to make the expedition possible

Polarstern was up to **1,500km** from the nearest human settlement

Polarstern drifted **3,400km** on a zigzagging course



Curious polar bears around Polarstern and the ice camp

Alfred-Wegener-Institut/Esther Horvath

A huge undertaking

MOSAiC is the work of an international consortium of polar research institutions, under the umbrella of the International Arctic Science Committee (IASC), and led by the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI), the Arctic and Antarctic Research Institute (AARI) and the University of Colorado Cooperative Institute for Research in Environmental Sciences (CIRES).

According to MOSAiC project manager Dr Anja Sommerfeld, the consortium grew rapidly and ultimately involved more than 80 institutes from 20 different countries. The primary logistical partner, she notes, was Russia, which provided several research icebreakers to support the main vessel, Polarstern.

Sommerfeld says, "At the beginning of the expedition, a Russian vessel joined Polarstern to assist the search for an ice floe and to set up a distributed network of satellite stations with autonomous working instruments up to 50km away from Polarstern."

Russia also provided an icebreaker to resupply Polarstern and to perform the exchange of scientists and crew members. Germany was

> "All team participants had been intensively trained in labs and on training expeditions at an Arctic station"
>
> **Dr Alexander Schulz, Alfred Wegener Institute**

responsible for the largest portion of the research, followed by the USA, one of the earliest investors in the expedition. China, the UK, Norway and Sweden were also important scientific partners.

It's all in the planning

Dr Alexander Schulz of the Alfred Wegener Institute was a member of the expedition's Team Ice. He explains that planning involved learning from previous Arctic expeditions. Furthermore, many of those on board Polarstern were hugely experienced, and "all team participants had been intensively trained in labs and on training expeditions at an Arctic station".

Selecting appropriate equipment was crucial. Polarstern had some very heavy kit on board, not least helicopters, snowmobiles and PistenBully snow groomers. There was also an enormous variety of scientific instruments. For Schulz alone, these included "a Campbell Scientific CSAT3B ultrasonic anemometer to measure turbulent wind and temperature fluctuations in the atmosphere; a LI-COR Biosciences LI-7500RS infrared gas analyzer to measure turbulent fluctuations of CO_2 and H_2O concentrations in the atmosphere; and a Silixa XT-DTS distributed temperature sensing instrument to measure temperature profiles along a fiber-optic cable in the atmosphere and the upper ocean".

Schulz also packed a Thies CLIMA Hygro-Thermo Transmitter compact air temperature and humidity sensor and a Vaisala tethered balloon system, which included a winch TTW111, tethersonde TTS111, receiver SPS220 and tethered balloon TTB327.

Most of the equipment and instruments had already been used to take measurements under Arctic conditions. "New or prototype measurement concepts and equipment were tested in proof-of-concept field campaigns and cold chamber tests," Schulz adds.

Extreme conditions

Equipment was adapted to operate under extreme conditions. Heavy, repeated icing of instruments was the main challenge, followed by the need to use small adjustment tools such as knobs, screws and connectors while wearing gloves. Other measurements required software adjustments in the field, with complex software interfaces posing problems in dark, cold, windy conditions.

Non-waterproof equipment was packed in waterproof reusable universal Zarges boxes, and

Alfred-Wegener-Institut/Esther Horvath

Markus Rex, expedition lead and head of MOSAiC, with the 'Miss Piggy' tethered balloon in Ny-Alesund, Norway, during MOSAiC field training

STORIES FROM THE ARCTIC

The five legs of the Polarstern expedition called on the skills, knowledge and fortitude of a massive, 442-strong contingent. Here, two participants look back on the experience

Team Ice and Ocean researcher Dr Julia Regnery says that the expedition changed her, teaching her greater awareness not only of nature and the environment, but also of her own work and even her decisions in life. Of course, MOSAiC was not without difficulties. "Polar night was particularly challenging, when temperatures dropped below -30°C," recounts Regnery. "It feels like working in slow motion in those temperatures and a lot of instruments stop operating. You need to be patient but also capable of suffering, as your feet and hands get cold really quickly."

Steffen Graupner, of Team Logistics and Safety, took part in Legs 2 and 5 of the expedition. For him, the hardest day was March 6, 2020, when he and fellow Leg 2 participants left Polarstern, traveling home on the icebreaker Kapitan Dranitsyn.

He comments, "Decades of exploration and travel in the Arctic had taught me to work and survive in the cold, the darkness, the remote solitude and with continuous polar bear encounters. AWI supplemented that with courses and all the latest technical survival equipment. But nobody had prepared us for saying goodbye to 'our' ship and 'our' floe, which had become much more than a home for us during three long winter months in the ice."

Regnery has many MOSAiC memories but considers her greatest takeaway to be teamwork. She recalls a particularly rewarding day when the ongoing absence of flying weather prompted the team to roll up their sleeves: "We managed to get one of our heavy infrastructure installation huts back to the ship – mainly by manpower. Normally it would be sling-loaded with the helicopter."

One of Graupner's most memorable days was in late February 2020. "The sun, missing for months, had climbed to only a few degrees below the horizon, forming nautical twilight, and pouring all shades of blue around the sky and over Polarstern," he reminisces. "After dinner, a group of us known as the North Pole Skiing Society skied a few miles into the void, plunging into that Arctic blue hour. It was a perfect day!"

Logistics and atmosphere team members move instruments on the ice

Alfred-Wegener-Institut/Lianna Nixon

other pieces of equipment were operated in heated tents, to increase the ambient operating temperature.

On the whole, the equipment performed well, says Schulz. "One instrument showed minor issues during the startup/boot process under extreme cold temperature (<-25°C), but slight pre-warming resolved this issue."

Filling the gaps

For MOSAiC co-coordinator Dr Matthew Shupe, of CIRES/University of Colorado Boulder and NOAA, the MOSAiC expedition's findings, rather than being unexpected, filled in "some substantial gaps" in scientific understanding.

"For example, we have started to understand the variability (and causes of variability) in the partitioning of surface energy budget terms at the surface of the sea ice," he explains. "This will enable us

> "We also observed remarkably low aerosol concentrations in the atmosphere"
>
> **Dr Matthew Shupe, CIRES/University of Colorado Boulder and NOAA**

to better understand the evolution of the sea-ice thermodynamic state, with important implications for sea-ice growth and melt.

"We also observed remarkably low aerosol concentrations in the atmosphere, sometimes less than 10 particles per cubic centimeter. At these levels, which are only really observed in frozen polar regions, cloud formation can be limited in spite of available moisture.

"Both of these processes have been observed to some degree in the past, but MOSAiC provides a much more complete story that gives a detailed view into the processes responsible."

Data collection and transmission

Data was collected and transmitted in many ways, according to Shupe. "For one of my projects, most of the equipment was on board the Polarstern, with a very sophisticated data system comprising many computers, arrays of hard disks and a complex network that enabled centralized control of nearly 60 instruments collecting many terabytes of data," he says. "Transmission of data in this case had to occur via physical transport of hard drives."

One of Schulz's projects involved remote stations deployed in the MOSAiC distributed network. These collected data locally with a specialized set of datalogging and management hardware. Data was sent back to Polarstern via radio LANs, and a subset of the data was automatically sent out via satellite communications using the Iridium network.

The benefit of hindsight

Preparations for MOSAiC included building a set of semi-autonomous atmospheric surface flux stations (ASFS) capable of functioning in remote locations away from Polarstern for long periods, with little maintenance. The operational challenges came from ice dynamics (which crushed one of the systems entirely), occasional damage caused by curious polar bears, and the need to maintain a methanol fuel cell power supply in the harshest mid-winter conditions. Not much can be done in terms of ice dynamics, but the team has tweaked its system to better protect it against polar bears and the impact of the weather on fuel cell operations.

Shupe admits that doing several things differently would have improved the team's ability

MOSAiC's Jakob Belter and Cristina Sans winch up the EM Bird electromagnetic-induction (EM) system in the Polar 6 airplane while Thomas Krumpen watches

Alfred-Wegener-Institut/Esther Horvath

Matthew Shupe drives a snowmobile over a bridge toward MOSAiC's 'Met City'

Alfred-Wegener-Institut/Lianna Nixon

to conduct basic science. The main power distribution system for the ice camp near Polarstern, for example, was "too heavy, too complicated and not adaptable enough for the very dynamic ice conditions encountered". This led to power outages in major installations at critical moments.

"In retrospect, there are ways to develop a power system better suited to the conditions. Such a system would be more readily repositioned and more modular in nature, enabling rapid adaptation, and have a robust system for backup power generation," says Shupe.

"Crucially, individual groups need to find ways to consume less power, and to make systems that are more autonomous. As the Arctic sea-ice system continues to evolve, power systems that are tethered to a main supply, like a ship, will be increasingly less feasible."

> MOSAiC has given fantastic new insights into sea ice over the course of one year"
>
> Dr Matthew Shupe, CIRES/University of Colorado Boulder and NOAA

What happens next?

Following this phase of the experiment, Shupe expects to see MOSAiC-specific analysis using the data collected in the Arctic. In time, this will be shared with other scientists to help evaluate how the expedition's models represent changes within the Arctic sea ice.

The expedition's findings will also feed into longer-term exploration of the Arctic. "MOSAiC has given fantastic new insights into sea ice over the course of one year. But many of these developments in the sea ice vary from year to year, or from location to location.

"Thus, we will continue the journey to unlock Arctic mysteries and continue to plan new observational activities in Greenland, over Arctic land surfaces and over different parts of the sea ice," he concludes. ∎

David Clemens-Sewall (left) and Steven Fons from the MOSAiC team during field work in the Arctic ice

Alfred-Wegener-Institut/Michael Gutsche

AN EIGHTFOLD FOCUS

The complexity of the preparations for MOSAiC was reflected in that of the research undertaken. Spending a full year in the Arctic presented such a unique opportunity that there were eight distinct strands to the scientists' work.

SEA ICE AND SNOW

For the first time, scientists could continually monitor changes in the ice through all four seasons. Their key questions concerned the exchange of energy, stimuli and chemical compounds between the atmosphere, snow, sea ice and ocean. They looked at the impact of today's thinner, more dynamic ice and at the sea as a habitat.

OCEAN

MOSAiC scientists focused on ocean circulation in the upper water layers, looking at the large-scale circulation of ocean currents, including their temperature, salinity and speeds.

ATMOSPHERE

The complex measurements focused on the entire range of the atmosphere, from the ice's surface to the upper reaches of the stratosphere at an altitude of 35km. Researchers examined very small-scale local processes on the surface of the ice and ocean, the characteristics of Arctic clouds and how different types of clouds affect sunlight.

ENERGY, MOMENTUM AND HUMIDITY FLUXES

A 2m-thick layer of sea ice insulates the Arctic ocean from the cold atmosphere. However, when it cracks open and the two come into contact, enormous upward currents are generated. MOSAiC experts examined what happens and how much energy is released into the atmosphere.

ECOSYSTEM

The Ecosystem team hoped that year-round sampling would provide unique insights into the entire food web and the importance of its members, including how species prepare for the months of darkness and how they respond to the return of the light.

BIOGEOCHEMISTRY FLUXES

MOSAiC's biogeochemistry (BGC) team members looked into the complex interactions between the ice and seawater, including the impact of the freezing and – especially in light of climate change – melting of the Arctic ice on these gas exchanges.

CHEMISTRY

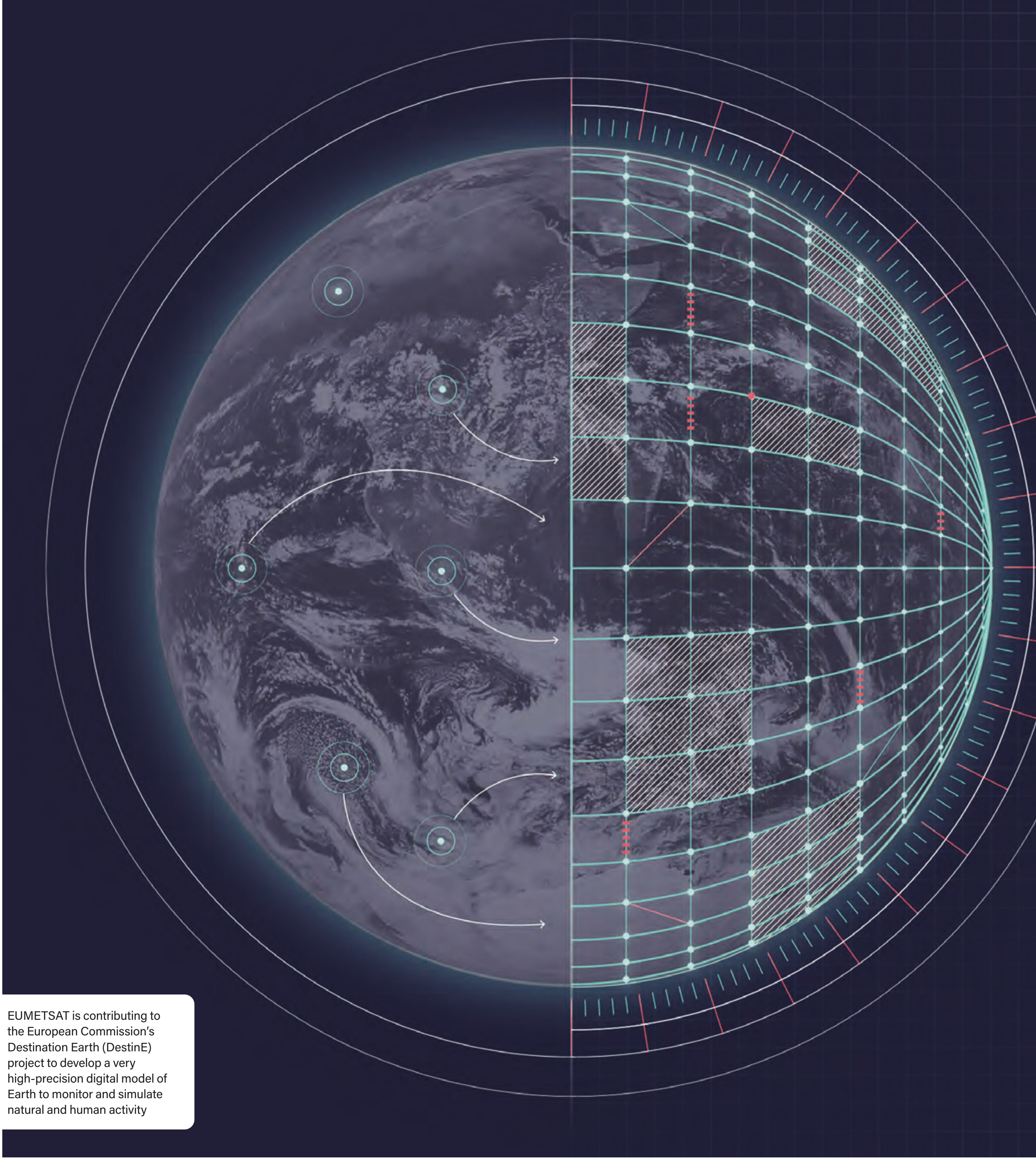
The BGC experts also focused on understanding the role that microorganisms and algae play in these chemical processes.

DYNAMICAL COUPLING

MOSAiC scientists studied dynamic coupling via atmospheric waves with the ozone layer above, and the changes in the ozone layer caused by anthropogenic activity.

ECMWF 2021-2030 strategy

Keri Allan



EUMETSAT is contributing to the European Commission's Destination Earth (DestinE) project to develop a very high-precision digital model of Earth to monitor and simulate natural and human activity

ACTION PLAN

ECMWF's director of research, Andy Brown, reveals how the organization's new 10-year strategy will explore the use of digital twins, AI and machine learning, along with making better use of data, to provide more accurate forecasts for the planet

In January, the European Centre for Medium-range Weather Forecasts (ECMWF) launched its 2021-2030 strategy. Developed to guide the center's activities over the next decade, the approach is updated every five years through a process of consultation and final approval by ECMWF's Council of Member States.

Organized around three pillars – science and technology, impact, and organization and people – the cornerstone of this strategy is ECMWF's mission to deliver cutting-edge global medium-range numerical weather predictions and monitoring of the Earth system to its member states.

The organization aims to achieve this by making the most of what technology has to offer, as highlighted by the strategy's areas of focus (see *Key actions from ECMWF's strategy 2021-2030*, page 28). This includes developing digital twins and using artificial intelligence (AI) across the numerical prediction chain, through to harnessing cloud computing to enable efficient use of data.

THE GROWING IMPORTANCE OF MACHINE LEARNING

In conjunction with the launch of its 2021-2030 strategy, ECMWF published a roadmap for machine learning (ML) activities at the organization. According to author Peter Dueben, the report's ambition is to show how ML fits into, benefits or replaces existing developments to improve numerical weather prediction (NWP) and climate services.

Work has been underway for several years, with the center introducing a new role of AI and ML learning coordinator, and undertaking several collaborative projects to explore the potential of ML throughout the NWP workflow. This includes investing in GPU hardware suitable for ML projects such as the HPC and European Weather Cloud. Research is also underway in the area of data assimilation, where ML tools and techniques are learning to estimate model errors for specific weather situations.

"We see that there could be applications for ML throughout our processes, but one good example is in the area of quality control," says ECMWF's Andy Brown. "Can ML help us decide if an outlying observation is a bad one, or if there really is a storm developing that we should know about? We're looking at whether ML can help us better distinguish between what's good and flawed data. We're also actively researching how ML techniques can improve the way we blend the previous model forecast with new observations."

Not only can ML be used to improve forecasts, it can also speed up computations, which in turn will save time and money. "We'll then be able to reinvest in something to make our forecasts even more accurate," Brown points out.

However, adopting and using ML effectively doesn't come without its challenges. For example, many applications will require customized solutions, and Earth science and ML scientists often follow different schools of thought.

The roadmap acknowledges these challenges and discusses the way ECMWF plans to overcome them, from improving collaboration between the two sectors through to developing customized ML solutions for domain-specific problems.

The center has defined 13 milestones for advancement over the next five years, including the establishment of a dedicated ML team distributed across the organization by Q4 2021 and a minimum of five ML applications integrated into the operational workflow by the latter half of 2023. The end goal is that ML technology will be fully integrated into NWP and climate services by 2031, and will have improved predictions and the use of predictions in many areas of the workflow.

From September 20-24, 2021, ECMWF will host a virtual workshop on the use of high-performance computing in meteorology. The theme is 'Towards Exascale Computing in Numerical Weather Prediction'

ECMWF aims to deliver

3-4km

convection-permitting ensemble forecasts before 2030

"We've given ourselves the challenge of producing the most cutting-edge forecasts, so have been looking at what's going to help us best deliver that over the next 10 years," says Andy Brown, director of research at ECMWF. "In some areas that means doing more of the same, but better. But as science and technology move on, we've made some changes to priorities in our strategy. For example, there's an enhanced emphasis on computational science; really pushing high resolution. There's also a big thrust on the observations side and maximizing the value we get from them."

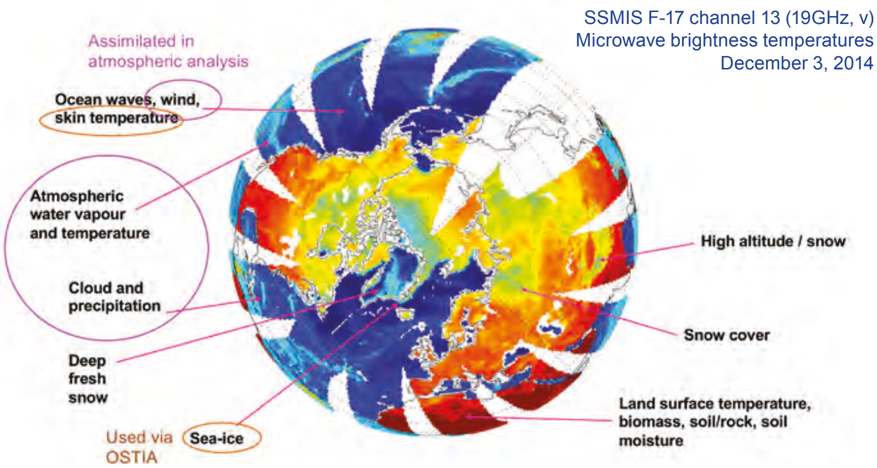
Improving use of observations

In the field of observations, goals include a step change in the information extracted from satellite data over land, snow and sea ice, and the enhanced use of observations linked to physical processes such as clouds, rain and lightning. Long-term research and development in this area will lead to a move from an 'all-sky' use of satellite data to an 'all-sky and all-surface' approach. This will be achieved by making the best use of new and existing data from satellites including EUMETSAT's MTGs, EPS-SG and Copernicus Expansion High Priority Candidate Missions (HPCM) and ESA's Sentinels.

"There's an enhanced emphasis on computational science; really pushing high resolution"

Andy Brown, director of research, ECMWF

BELOW: ECMWF has pioneered the use of satellite observations of microwave radiances affected by clouds and precipitation. Today, such all-sky observations are routinely used at ECMWF and make a great contribution to the quality of weather forecasts



"There are a lot of exciting new observations coming from our partners that we use to improve our forecast models. But the real science is in how we use those observations, particularly over difficult surfaces like snow or sea ice. We know that's a hugely valuable source of data for our systems, but we're not as good at utilizing it as other conditions," Brown continues.

"In the past we made a 10-year investment in learning how best to use data from cloudy conditions. We're now undertaking a similar research thrust in this area, which will improve how broadly we're able to use the data from these surfaces," he adds.

High-resolution ensemble forecasts

Introducing the strategy, Silvio Cau, ECMWF Council president, noted that ensemble forecasts with increasingly improved resolution and longer ranges are at the core of the center's vision.

Currently, operational forecasts are 18km ensembles, but ECMWF aims to deliver 3-4km convection-permitting ensemble forecasts – addressing gray-zone physics, initialization and a non-hydrostatic dynamical core – before 2030. It is even exploring 1km-scale resolution which, as Brown points out, "is a mind-boggling computational challenge".

The strategy states that such predictions will require fundamental predictability research, developments in the use of new observations, advances in (coupled) data assimilation and model improvements, with the reduction in systematic model errors being crucial to increasing predictive skill in the extended range.

This is the area that excites Brown the most because it encapsulates a variety of different challenges. "To achieve this goal requires a fundamental change in the type of weather forecasting model you use, and crossing that threshold gives us new science challenges," he comments. "Just think of the number of grid points and the amount of data we'll need to handle. On one level it's intimidating, but if this stuff was easy, it'd be dull. This is cutting edge, both scientifically and computationally, and will open up a whole new world."

Digital twins of Earth

This links to another of the strategy's areas of focus: developing next-generation models to produce high-resolution digital twins of Earth.

ECMWF is working with ESA and EUMETSAT on the Destination Earth (DestinE) initiative, which aims to develop a high-precision digital model of Earth to monitor and simulate natural and human activity using computing, data and AI methodologies.

This will be used to continuously monitor the health of the planet, study the effects of climate change and the state of the oceans and cryosphere, and improve modeling and predictive capacities around hurricanes and other extreme weather events.

> "It's the skilled people working on this science and technology that are essential to enabling us to deliver better forecasts"
>
> **Andy Brown, director of research, ECMWF**

"This is where we began thinking about the concept of 1km-resolution forecasting," says Brown. "It's all about breaking down an enormous problem into real steps that can be reached over time. Each time we move supercomputers, our ensemble system changes. We moved from 25-18km last time, and on our current supercomputer we'll move to somewhere in the region of 9-11km. Each of these steps provides a worthwhile improvement in forecast quality, but going to a kilometer scale is a different sort of step entirely. We've done a single kilometer run for a season, but this is going to take us on the next step of starting to do a weather forecast every day at that resolution."

High-performance computing for numerical weather prediction

High-performance computing (HPC) plays an essential role in optimizing numerical weather prediction (NWP), and together with member states, ECMWF is investigating the potential of upcoming disruptive HPC technologies.

"Evolving GPU and FPGA technologies offer exciting opportunities. For example, we want to find ways to become more energy efficient, as running these big models uses a lot of electricity and there's a huge opportunity for us to boost time-to-solution and energy-to-solution," says Brown. As part of its strategy, ECMWF has developed a portable, performant code base for its prediction system, and is investigating different scientific choices to understand which will maximize its performance.

Things are changing, according to Brown, who notes that ECMWF is moving away from the paradigm where you decide what science you'll use and then put the code on the computer, to one where understanding what will run efficiently on the computer is a design consideration from the start. The organization is looking at fairly radical redesign of the dynamical core, as it has effectively been using the same technology for more than 20 years.

"Although our current core is actually more cost-efficient than the new one would be right now – we've spent years honing it to run super efficiently – as you get to new architectures, inefficiencies mean that a different design is better," he says. "We've only got one supercomputer, but we wanted to start practicing with some of the different technologies out there, so we put in a bid for the IBM-developed supercomputer Summit, which uses CPUs and GPUs. This was where we did our global first of a 1km-resolution run for a whole season. We started just using the CPUs, but in the past few months we've adapted the spectral transform part of our dynamical core to run on GPUs.

"We've got an internal project called Hybrid 2024, which is looking to move beyond just having spectral transforms onto GPUs, adding our representations of turbulence or the drag caused by mountains, for example.

"We anticipate that our next supercomputer will be a hybrid of CPUs and GPUs. So we're already doing these projects to test and learn how to move different parts of the modeling system core to GPUs to ensure we're ready for when that time arrives," Brown adds.

People power

ECMWF understands that it cannot achieve the goals of its strategy on its own. Therefore it will continue to enhance its partnerships and collaborations as part of the EMI, in addition to building on those with the WMO, ESA and European Commission. "It's the skilled people working on this science and technology that are essential to enabling us to deliver better forecasts," says Brown.

ECMWF understands that building closer partnerships with the computing industry is key to tailoring supercomputing to the needs of NWP, particularly as it is focusing on what machine learning (ML) can bring to the table (see *The growing importance of machine learning* on page 26). In response to this need, the organization has been working to bring together experts from its traditional community of physical sciences and those from the data science world.

"Over the past five years many of ECMWF's weather model development projects have involved computing vendors and manufacturers, which is helping to build important links to this area, and members of our traditional community have been invited to speak at a number of AI conferences," Brown notes.

"The technology is crucial, but it's the people behind the clever techniques, better models and more elegant data assimilation systems that have contributed the most. People and partnerships are really important, which is why we put them right up there alongside science and technology in the strategy," he concludes. ■

KEY ACTIONS FROM ECMWF'S STRATEGY 2021-2030

- Overcoming computational and scientific challenges to achieve ensemble forecasts at 3-4km resolution
- Extracting maximum value from observations to produce accurate analysis of the Earth system, consistent across its components
- Developing next-gen models to produce high-resolution digital twins of Earth
- Increasing the use of cloud technology to enable efficient use of data
- Integrating global reanalysis and reforecasts of weather and environmental hazards from 1950 onward
- Estimation and monitoring of CO_2 emissions
- Contributing to the optimization of the global observing system
- Moving toward open data
- Harnessing artificial intelligence (AI) and machine learning (ML) to enhance performance and uncertainty formulation
- Optimizing system design and two-way transfer between research and operations

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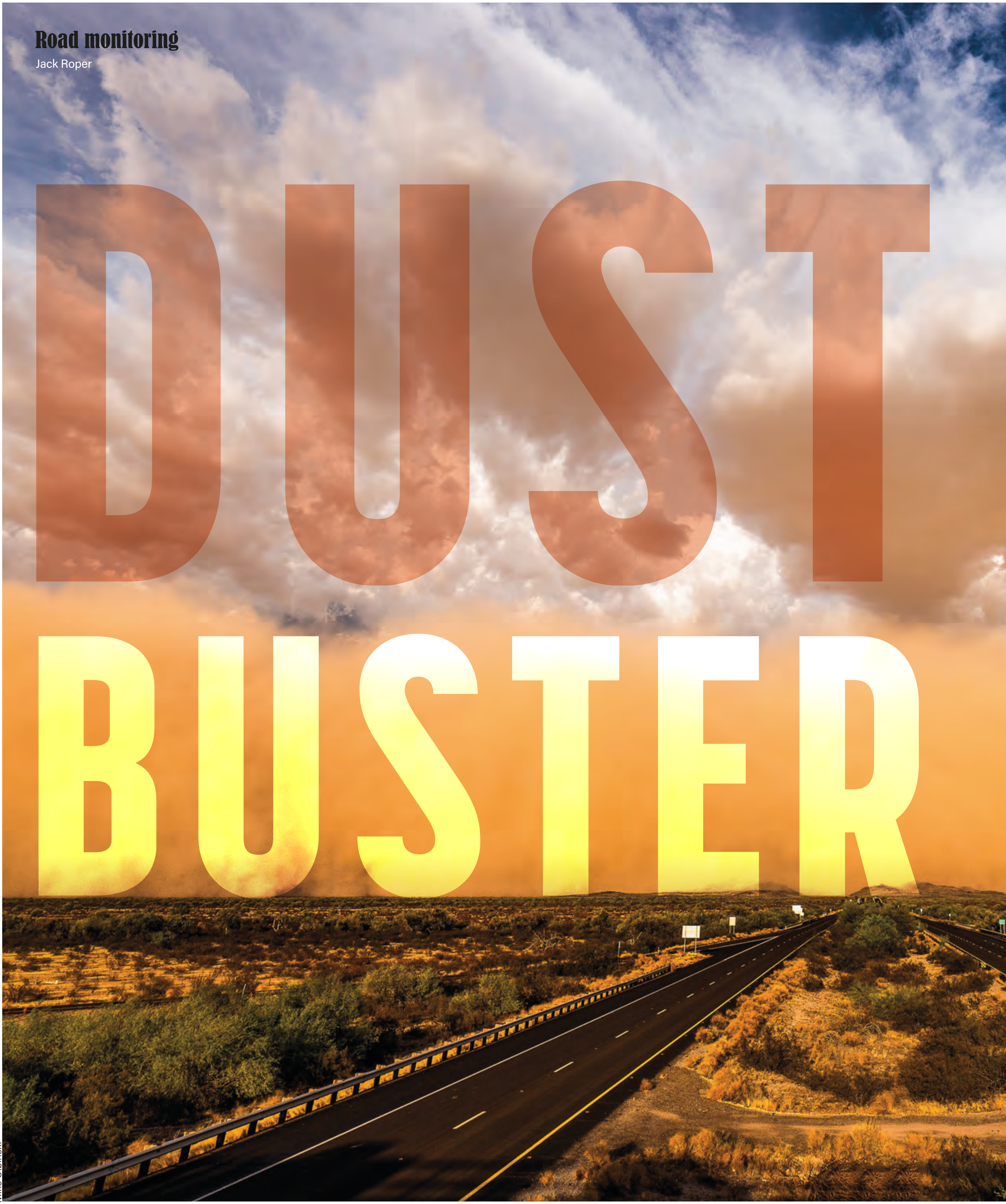
Jack Roper

DUST BUSTER



Mike Olbinski

A first-of-its-kind automated highway dust detection system has been developed by the Arizona Department of Transportation to keep citizens safe on the interstate during the North American monsoon season – the peak time for severe storms that create hazardous driving conditions

Between Phoenix and Tucson in Arizona, Interstate 10 (I-10) crosses 160km of wide-open desert. On a 16km stretch between Eloy and Picacho Peak, Arizona Department of Transportation (ADOT) has created an automated highway dust detection system that dynamically adapts the enforceable speed limit in response to roadside visibility data.

It includes a 6m Doppler radar tower that will enhance National Weather Service (NWS) coverage of the area. The US$6.5m system went live on June 15, 2020 – the start of monsoon season, when titanic dust storms roll across the desert.

"Dust storms are usually affiliated with the convective thunderstorms of the North American monsoon," explains NWS Phoenix lead meteorologist Jaret Rogers. "As rain falls, the cloud begins to collapse and produces a huge outflow of wind."

Horizontal 80km/h gusts billow outward, disturbing loose soil desiccated by months of aridity. "Outflow boundaries can travel 100 miles [160km], kicking up dust," Rogers continues. "Eventually, that becomes a wall of dust." Sometimes, that wall can be 96km wide and tower 305m above the desert. Suddenly, driving south from Phoenix seems like driving on Mars, enveloped by planet-wide dust storms.

"Visibility is reduced and traffic slows to a crawl," says ADOT systems maintenance manager, David Locher. "I've had trouble seeing the end of the hood on my truck." ADOT advises motorists to pull over, kill their lights and disengage the brake pedal. "That way, people won't follow you," Locher explains. "We've had commercial vehicles drive into dust without stopping and rear-end passenger vehicles."

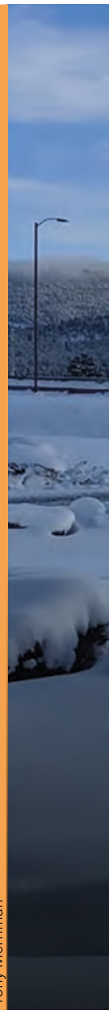
A study of incidents on I-10 provided the impetus for dust detection. "Of 80-odd accidents on a 100-mile stretch, 43 occurred within one half-mile [0.8km]," Locher comments. Backed by a supportive governor and federal FASTLANE funds, ADOT set about building its system.

Informed decisions

Thirteen roadside Vaisala PWD10 visibility sensors are positioned at driver's-eye level. "Airports use PWD sensors for applications including fog warning systems," says Vaisala's ground transportation application manager, Rose Parisi. "They determine visibility and meteorological optical range by measuring scattered light from particles between two sensor heads." As visibility deteriorates, an algorithm decreases the enforceable speed limit displayed on variable LED signs.

Arizona Department of Transportation

The system's weather radar is mounted on a 6m tower and works with 13 sensors on posts next to the freeway



Tony Merriman

"The dust detection system correlates airborne particles to a visibility sight distance," Locher comments. "Once visibility drops below 1,800ft [548m], it reduces the speed limit from 75mph [120km/h] down to 35mph [56km/h] in 10mph [16km/h] increments."

Staff at ADOT's Phoenix Traffic Operations Center can verify the dust alert via CCTV; variable message boards forewarn motorists leaving Phoenix and Tucson. "We're fine-tuning our ability to populate messages automatically," says Locher. "We can tell people there's a likelihood of dust 50 miles [80km] from the corridor, enabling them to make informed decisions.

"What's new isn't the hardware, but the integration itself," Locher continues. "It's a fully automated system that doesn't require human activation or approval. It sees reduced visibility, automatically reduces speed limits, then automatically returns to normal by itself."

ADOT conducted a 30-day pilot before operations commenced. "We ran everything on a test server with real data coming in from the road," Locher says. Finally, the system went live. But days passed, then weeks... and no dust came to test it. "We had some activations when maybe a farmer was plowing, but those events are generally short-lived."

Dust sources adjacent to I-10 are partly the result of past agricultural practices. "Drive past Picacho and Eloy today and there's nothing out there, but several uses have cycled through," says University of Arizona distinguished professor Eric Betterton. "In the West, farmers can access vast range lands for little or no charge. Once there were pistachio orchards, which mitigated the wind speed. There was cotton farming, so the land was irrigated and planted." If once-cultivated land is left neglected, it becomes a potent dust source, as does finely ground rock from mine tailings if they are not kept damp, as per best practice.

"Ultimately, if you control the source of dust, all the other problems go away,"

The weather radar can detect storms

64

kilometers away

"We can tell people there's a likelihood of dust 50 miles from the corridor, enabling them to make informed decisions"

David Locher, systems maintenance manager, ADOT

Arizona Department of Transportation

Blowing dust regularly reduces visibility on Interstate 10 in Arizona

PREDICTING ICY CONDITIONS IN FLAGSTAFF

Arizona Department of Transportation's automated system already detects dust and dynamically adapts speed limits on I-10 south of Phoenix. Now, ADOT will apply the same technology to entirely different road-weather phenomena in the icy north of the state. "People are surprised at Arizona's diversity," says ADOT's David Locher. "The dust is down south at 1,300ft [396m] elevation. But Flagstaff is at 7,000ft [2,133m] with pine trees, and 30°F [17°C] cooler. In summertime, it's a hideaway where Phoenix people can escape the heat."

Flagstaff stands on the old US Route 66, a stop on the road to California in *The Grapes of Wrath*. Today, Interstate 40 (I-40) is a major transcontinental trucking route rising sharply into mountains west of Flagstaff. "When it freezes, trucks get jackknifed on that hill climb," says Locher. "The road gets closed and snowplows can't get through. We recently lost I-40 for half a day in snow season."

ADOT is looking for a contractor to deliver a similar system to that on I-10, along with 160km of conduit and fiber-optic cable.

"We'll have the same variable signs and a similar algorithm to reduce the limit in 10mph [16km/h] increments," continues Locher. "But instead of visibility sensors, embedded pavement temperature sensors will predict the roadway icing over."

"There are two main types of pavement sensors," says Vaisala's Rose Parisi. "In-pavement sensors use passive technology and are embedded flush in the roadway. But recent years have seen a shift to roadside-mounted non-invasive sensors that use optical spectroscopic measuring principles."

Getting automated ice detection operational for next winter presents a new level of algorithmic challenge. "For dust, we just needed a formula to correlate visibility distance into a speed limit," says Locher. "But now we have to figure out what the road surface is doing. Is it frozen – or is it going to freeze? That makes the algorithm a little more difficult."

Betterton adds. He advocates soil treatment in parallel with detection and forecasting efforts. Arizona Department of Environmental Quality (ADEQ) used this strategy further east near San Simon, when ill-advised plowing led to dust-related road fatalities.

"ADEQ made the farmer spray the land with water then apply a soil amendment," says Betterton. "A thin adhesive bonds soil particles together, providing a temporary protective skin." Planting vegetation and limiting access to land would suppress dust further. "The state could intercede to treat these well-known dust sources," Betterton concludes.

Capturing dust storms

Close collaboration with NWS led ADOT to install a 6m Doppler radar tower on I-10, supplementing close-vicinity detection with the capability to see dust storms 64km away. It fills in the blanks in formerly imperfect NWS coverage from weather radars in Phoenix and Tucson.

"For detecting thunderstorms, there's no real gap," explains Rogers. "But dust storms happen near the ground, whereas radars look upward at an angle. Fortunately, ADOT had funding for a radar. It's another tool that enables us to capture and characterize dust storms moving through that area."

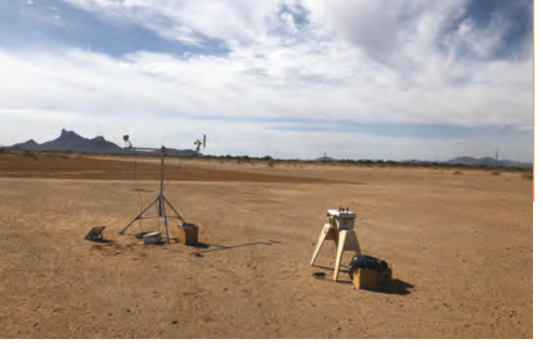
Generally, Arizonans are aware of a major dust storm on the move. "There's a dramatic media display," says Rogers. "They send up helicopters to film it coming." Plus, NWS Phoenix triggers the multichannel US Emergency Alert System, which sends push notifications to cell phones within a geofenced area.

"We have high confidence when we issue a warning, and people take them seriously," says Rogers. Yet the typical lead time is an hour at most, and dust remains hard to predict on longer timescales with any certainty. "There's no direct way to forecast specific dust storms," Rogers explains. "Obviously, you need potential for thunderstorms – and weather-model resolution is continually improving. But you also need to know the state of the soils, which is beyond our expertise as meteorologists."

Nevertheless, NWS Phoenix has correctly identified days of enhanced risk for several consecutive years. "Really it's just knowing, historically and climatologically, that storms in certain spots have potential to kick up dust," says Rogers. "Observationally, our ability to characterize soils could still improve."

Dust only becomes airborne when wind velocity exceeds the threshold necessary for saltation to occur. "Electrostatic forces make small soil particles adhere to larger ones, but a sufficiently strong wind lifts medium-size particles from the surface," Betterton explains. "They bombard and dislodge the finer particles, which become suspended in the wind."

LEFT & BELOW: The Iron King Mine (left) and Picacho (below) in Arizona have both been used by the University of Arizona to characterize dust sources and test meteorological instruments



> "The soil surface really matters. If it rained yesterday and shut down dust production, you need to know"
>
> **Eric Betterton, distinguished professor, University of Arizona**

Dust doesn't increase gradually with wind speed, but appears suddenly once a threshold is passed. "We've been in the desert with a portable wind tunnel, varying wind speed to determine that minimum velocity," Betterton adds.

Improving accuracy

If localized sources were characterized and saltation wind-velocity thresholds integrated in weather models, dust might be forecast with greater certainty. But that integration is no trivial task. "The soil surface really matters," says Betterton. "If it rained yesterday and shut down dust production, you need to know. But that's asking a model, which looks forward, to look back in time and change itself as a result."

ADOT's system also features a Vaisala WXT536 Weather Transmitter. "The WXT536 is a multiparameter sensor providing wind, temperature, relative humidity, precipitation and barometric pressure observations," says Parisi. "Humidity measurements help factor out false readings from fog or rain, because high humidity makes dust unlikely." Dust-storm data can be hard to come by and ADOT expects the additional measurements to feed future University of Arizona research. "Vaisala has participated in applications that dynamically adjust speed limits based on road condition, road friction, wind and precipitation data," Parisi adds.

In a state of contrasting extremes, ADOT periodically contends with wildfires. "One fire took out 10 miles [16km] of wooden freeway guardrail," Locher recalls. "Rain on burnt areas then causes flash floods, sometimes with sad results."

Flagstaff, three hours north of Phoenix, enjoys an alpine climate of mild summers and snowy winters (see *Predicting icy conditions in Flagstaff*, previous page). Here, ADOT will adapt its algorithm and use different sensors for automated safety on icy mountain roads. For now, the ADOT system has yet to encounter a major dust storm after 2020 proved a 'nonsoon' year. "The monsoon season was a total dud," says Locher. "That's a blessing, because they wreak havoc, but we wanted one to test the system!"

So far, ADOT has had only praise, both from locals and those passing through what is a major coast-to-coast corridor. Minor dust events have twice reduced the speed limit to 56km/h, and embedded loops revealed average driver speeds of 72km/h. "That's pretty good," says Locher. "People were slowing – either because they respected the system, or because they couldn't see." ∎

Standalone Hydrological Station:

- LX-80 radar level sensor
- RSS-2-300 W surface velocity radar
- HydroCam for visual site inspection
- HydroTemp water temperature probe
- SmartObserver datalogger with integrated MPPT battery charger and GPRS/3G/4G/NB-IoT connectivity
- SDI-12 and Modbus communication support for 3rd party sensor integration
- Connects to HydroView cloud-based hydrological data management and analysis software

*Sensors also sold separately

Water Level

Surface Velocity

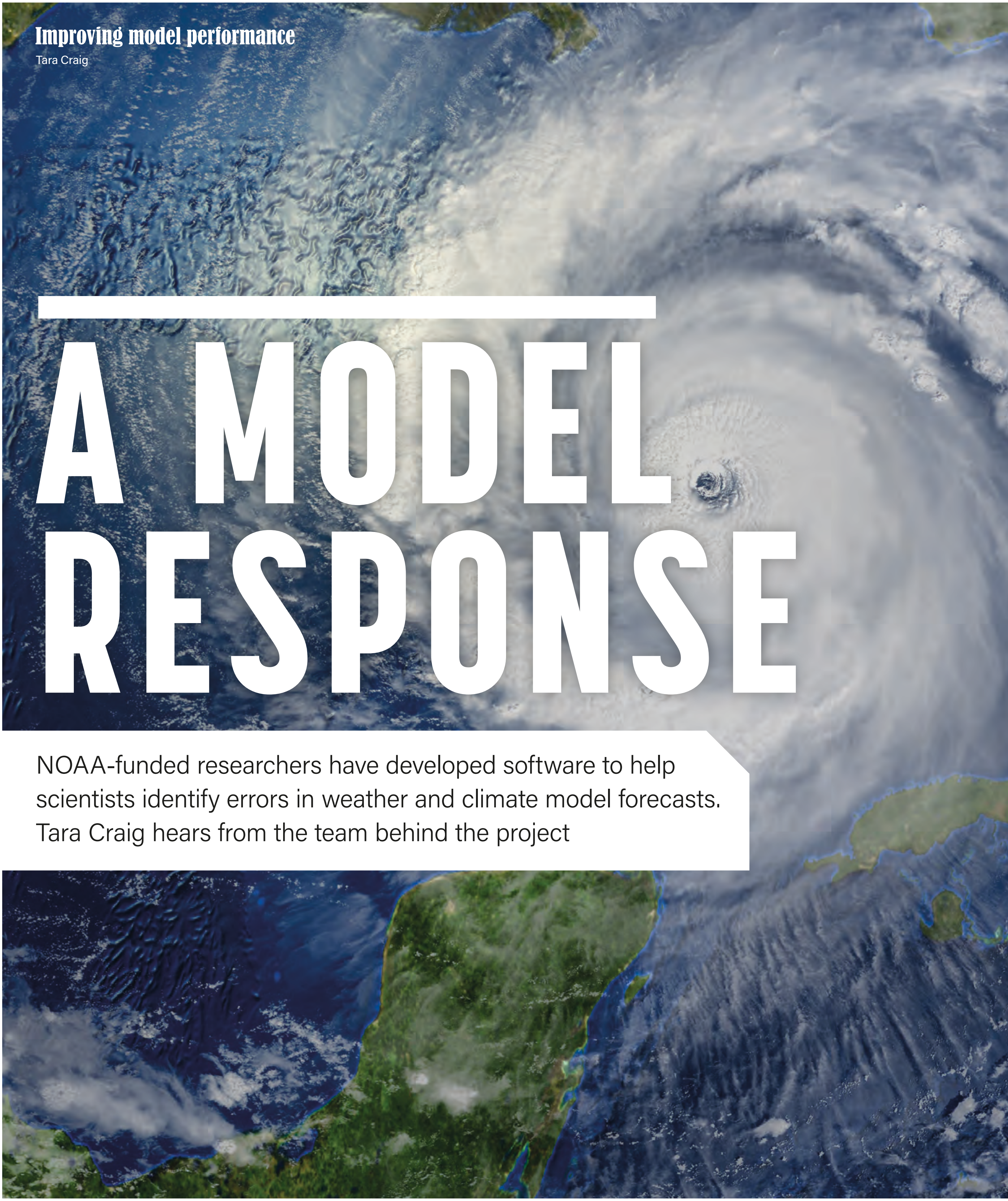
Total Discharge

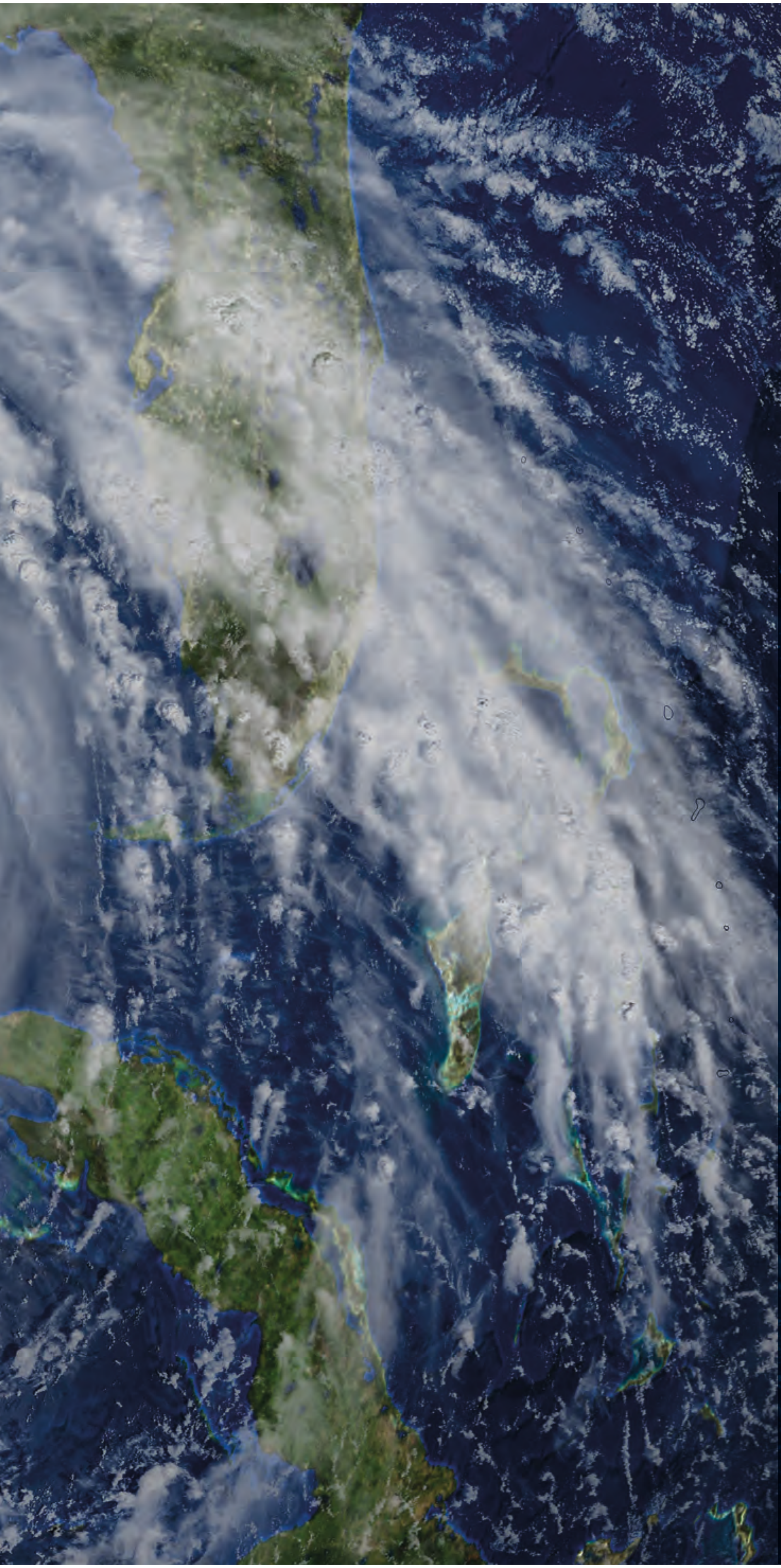
Water Temperature

Tara Craig

A MODEL RESPONSE

NOAA-funded researchers have developed software to help scientists identify errors in weather and climate model forecasts. Tara Craig hears from the team behind the project





According to the USA's National Oceanic and Atmospheric Administration (NOAA), Americans are increasingly demanding more accurate and detailed weather and climate forecasts. As a result, weather and climate models are becoming more complex and moving to higher resolutions.

Although there is a wealth of process-level expertise across the US weather and climate community, for it to be truly effective it needs to be tapped into and brought closer to the model development activities led by NOAA and at the National Center for Atmospheric Research (NCAR).

The Model Diagnostics Task Force (MDTF) funded by NOAA's Modeling, Analysis, Predictions and Projections (MAPP) program created new diagnostics software to capture that information in the community and make it available as and when required for the development of new weather and climate models.

One of the project's main goals is to compile community-developed tools to analyze weather and climate data in a simple-to-run, flexible framework so that users can focus more on science and less on (re)writing code for similar analyses performed by the weather and climate science community.

Experts in the community submit proposals to write a process-oriented diagnostic (POD). If their proposal is selected, they work with the framework development team to develop the POD and ensure it runs on model output from NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) and NCAR.

What does the software do?

The new software provides detailed analyses, maps and figures of how well models are performing and whether or not the underlying model dynamics and physics are behaving as they should. John Krasting, physical scientist at GFDL's Ocean and Cryosphere Division, is overseeing its development. "We feed model output into the diagnostic framework driver; the software package determines what analyses to run and presents the results as a web page for a researcher or model developer to review," he explains.

"We have diagnostics that look at different parts of the Earth system, including the atmosphere, ocean, land and sea ice," Krasting continues. "The diagnostics look at very fast processes occurring on hourly timescales all the way up to decadal-to-centennial-scale processes."

The software runs PODs written in Python and NCAR Command Language (NCL) on model output. Each POD script targets a specific physical process or emergent behavior, with the goals of determining how accurately the model represents that process, ensuring that models produce the right answers for the right reasons, and identifying gaps in the understanding of phenomena.

PODs span the climate realm (atmosphere, land surface, ocean, ice) in both time (diurnal-to-interannual) and space (point-to-planetary). They target a variety of physical processes including cyclone lifetimes, warm rain microphysics, Atlantic Meridional Overturning Circulation 3D structures, radiative feedbacks of climate forcings, radiative changes under Arctic sea-ice loss, mixed layer depths and sea-ice concentrations. Also covered are tropical cyclone rain rate characteristics, sea level rise, Madden-Julian Oscillation (MJO) propagation, MJO teleconnections, tropical wave amplitude and variability, soil moisture-evapotranspiration and its diurnal cycle, and precipitation-moisture relationships.

> "We have diagnostics that look at different parts of the Earth system, including the atmosphere, ocean, land and sea ice"
>
> **John Krasting, physical scientist, Geophysical Fluid Dynamics Laboratory, Ocean and Cryosphere Division, NOAA**

An essential aspect of the software is the distributed and communal way in which it has been developed. It is housed in a government laboratory (GFDL), which is working with another federally funded laboratory (NCAR, funded by the National Science Foundation), and the diagnostic components of the software are developed by the broad community, both federal and non-federal.

The competitive process through which contributors are selected ensures that the best minds are working on the most useful contributions to the software. Furthermore, the way in which development is structured solves significant incentive issues. For example, to be deemed successful, academics need to carry out research and have it published, and the software and model development process calls for coding, product development and testing.

47
The number of different diagnostics solutions set to be implemented by MDTF by 2024

The broad academic community can contribute hugely to model development, but they do not get credit for writing code in their incentive systems. This effort enables a bridging of those incentive structures and requirements: the laboratory benefits from valuable code, while the non-federal partners get to work on a range of interesting science questions.

Close collaboration

Software development was very much a team project. Members of the scientific community affiliated with government labs, academic institutions and the private sector all helped develop the framework and/or have contributed PODs.

The MDTF, led by David Neelin, professor of atmospheric and oceanic sciences at UCLA, coordinates the individual diagnostic developers at institutions across the USA with the framework development team.

The primary framework software development takes place at NOAA-GFDL and is led by Krasting, Princeton University's Aparna Radhakrishnan, Thomas Jackson and Jessica Liptak from Science Applications International Corporation, and Wenhao Dong of the University Corporation for Atmospheric Research

WHAT NEXT FOR THE TASK FORCE?

In the current phase of the project, the team is anticipating PODs that explore the lifetimes of extra-tropical cyclones, rain rates in tropical cyclones, warm rain microphysics, distributions of surface-air temperature extremes and precipitation, thermodynamic-precipitation relationships, and radiative feedbacks of climate forcings. The MDTF diagnostics package also includes ocean PODs that target comparatively slower processes such as tropical Pacific sea-level trends and variability, and the impacts of sea-ice loss on radiative budgets.

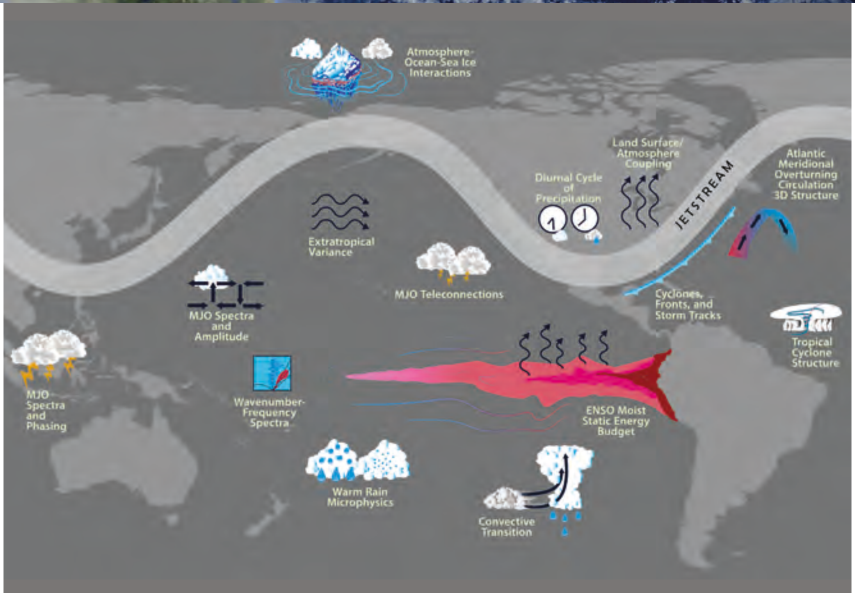
The package is evolving. It has eight different diagnostics implemented, 11 under development to be included by 2022 and 28 proposed, which may be implemented by 2024. Proposed areas of focus include precipitation-buoyancy diagnostics, surface-flux diagnostics and the moist static energy variance budget of tropical cyclones.

The current set of diagnostics is weighted toward the atmosphere, and the task force hopes to expand it to incorporate more components of the Earth system. This will involve new challenges as it encounters different model grids and data structures.

"We are working toward integrating the MDTF diagnostics package into the modeling center workflows at GFDL and NCAR to enable the package to run on more model experiments and configurations. We are also looking at ways of analyzing multiple simulations at the same time," explains GFDL's John Krasting.

On the software engineering side, the task force is exploring the use of container management software to easily and securely deploy the software on workstations and high-performance computing cluster- and cloud-based systems. Developers are also implementing continuous integration testing using GitHub Actions so that every pull request triggers end-to-end testing before the framework team reviews the code.

When asked what other meteorology-related projects its members are working on, the task force response is: "The sky is the limit."



(UCAR). The framework development team is also supported by NCAR's Dani Coleman, and Yi-Hung Kuo and Fiaz Ahmed of UCLA.

Other members of the MDTF leads team include Andrew Gettelman (NCAR), Eric Maloney of Colorado State University, Yi Ming (NOAA-GFDL) and Florida State University's Allison Wing. The framework team and project leads work together to resolve issues with the code, brainstorm ideas for new features and draft plans for future releases of the MDTF diagnostics package.

The entire task force, including POD developers, meets monthly to answer questions, present analyses from PODs and share information about upcoming changes to the code.

ABOVE: This image illustrates multiple weather climate and model process areas included in the new Model Diagnostic Task Force software package

The benefits

Uncovering what is working well in models and what can be improved is an important part of making better weather predictions and climate projections. By building stronger connections between the major modeling centers at government labs and the academic and private-sector, the MDTF aims to involve more people in the model development process. The task force hopes that this will ultimately lead to better models and better understanding of how to use the output from them.

> "Many long-standing model biases have been cut roughly by half"
>
> David Neelin, lead, Model Diagnostics Task Force

The community development approach has enabled the MDTF to cooperatively target processes spanning the entire climate realm, including the atmosphere, land surface, ocean and sea ice.

Availability of the software

The MDTF diagnostics package is available to download from GitHub, a platform designed to coordinate work among programmers who are collaboratively developing source code during software development. Furthermore, the package can be run on a Linux or MacOS desktop or laptop; it does not require access to high-performance computer (HPC) systems or privately hosted data.

Users can run the existing PODs on model output data in NetCDF (network common data form) format, or on sample model output and observational data from public servers. New PODs are added as they are delivered by task force members. The developers say the MDTF diagnostics package is geared toward weather and climate scientists from all sectors.

As with most open-source software, development is never finished. "The MDTF diagnostics package continues to grow and evolve as we incorporate more diagnostics and probe different parts of the weather and climate models," says Krasting.

The end-user and diagnostic-developer bases are new to Git version-control software. The framework team adapts documentation to meet this type of need from the community, with the task force facilitating the two-way communication between the leads team and POD developers.

In addition to downloading the code from GitHub, installation of the software requires users to download supporting observational data and (optionally) sample model data, currently available via anonymous FTP (file transfer protocol) from UCAR. It also involves using an included script to install required version-controlled third-party libraries and dependencies via the Conda package manager, configuring paths to this data in a settings file and (optionally) conducting a test run of the framework on the sample data to verify the installation. The diagnostics and evaluations team also maintains an up-to-date, site-wide installation of the package for GFDL users, accessible from the post-processing/analysis cluster and workstations.

According to NOAA, the software package has already led to significant advances in model performance, including forecasts of regional precipitation and extreme events such as monsoons. "Many long-standing model biases have been cut roughly by half," says MDTF lead David Neelin. "These improvements are critical for advancing a number of NOAA priorities," he concludes. ▮

Helen Norman

INSIDE INFORMATION

Yves Buhler, director of the Technical and Scientific Support department (TSS) at EUMETSAT, shares details of the organization's new data services, which sit at the heart of its long-term big data strategy

What new services has EUMETSAT launched recently?

We have a number of services that are currently pre-operational and will become fully operational in June 2021. First, Data Store provides a single point of access to the growing catalog of EUMETSAT data.

Eventually, this service will offer the full data catalog, including near-real-time and historical data, as well as climate data records.

Second, the Data Tailor service will allow users to customize EUMETSAT data to their needs by applying, for example, format conversions, region of interest subsettings and many other options.

Third, the EUMETView data visualization service will allow users to create visualizations, maps and animations using EUMETSAT data. The evolution of weather phenomena can be seen by creating animations through EUMETView. EUMETView is a genuine web map service on EUMETSAT data.

In addition to these new data services, we are regularly enhancing our portfolio of data by adding new data products derived from our own satellites, and use our international cooperation with other satellite operators worldwide to offer our users a complete set of meteorological data for a variety of different applications.

"We are regularly enhancing our portfolio of data by adding new data products derived from our own satellites"

What do you hope to achieve with these new services?

The expectations of the users of EUMETSAT have fundamentally changed with the emergence of new technologies in the big data era. Users today expect a variety of flexible services using cloud technologies. Empowering the user is a key aspect here.

With these new services we will offer access to vastly more data as new satellite systems come on stream. The EUMETSAT archive contained 6PB of data at the end of 2020. That will increase to about 50PB by 2025. As the volume of data increases, it is important for us to ensure that its delivery remains easy and reliable for our users.

Copernicus Sentinel-6 satellite data (see *Monitoring the global ocean*, right) will start to become operationally available from mid-year and will be fully operational by the end of the year. The upcoming launches of the next generations of our geostationary and polar-orbiting satellites, starting in 2023, will also contribute additional data sets to make weather and climate predictions and modeling more accurate and pertinent.

Not only will the quantity of data increase, but the quality of the data from these new instruments will be among the best in the world. Hopefully, enhanced by state-of-the-art scientific processing, the EUMETSAT new data services will become a worldwide reference for meteorological data and derived products.

Finally, EUMETSAT data will become available to more users in a variety of formats that will encourage a broader range of uses. EUMETView will allow for easier and more pertinent data visualization, and Data Tailor will allow users to select the format of choice.

Another aim is to increase the number of people using the data, whether for applications in weather-sensitive sectors of the economy or for scientists and researchers.

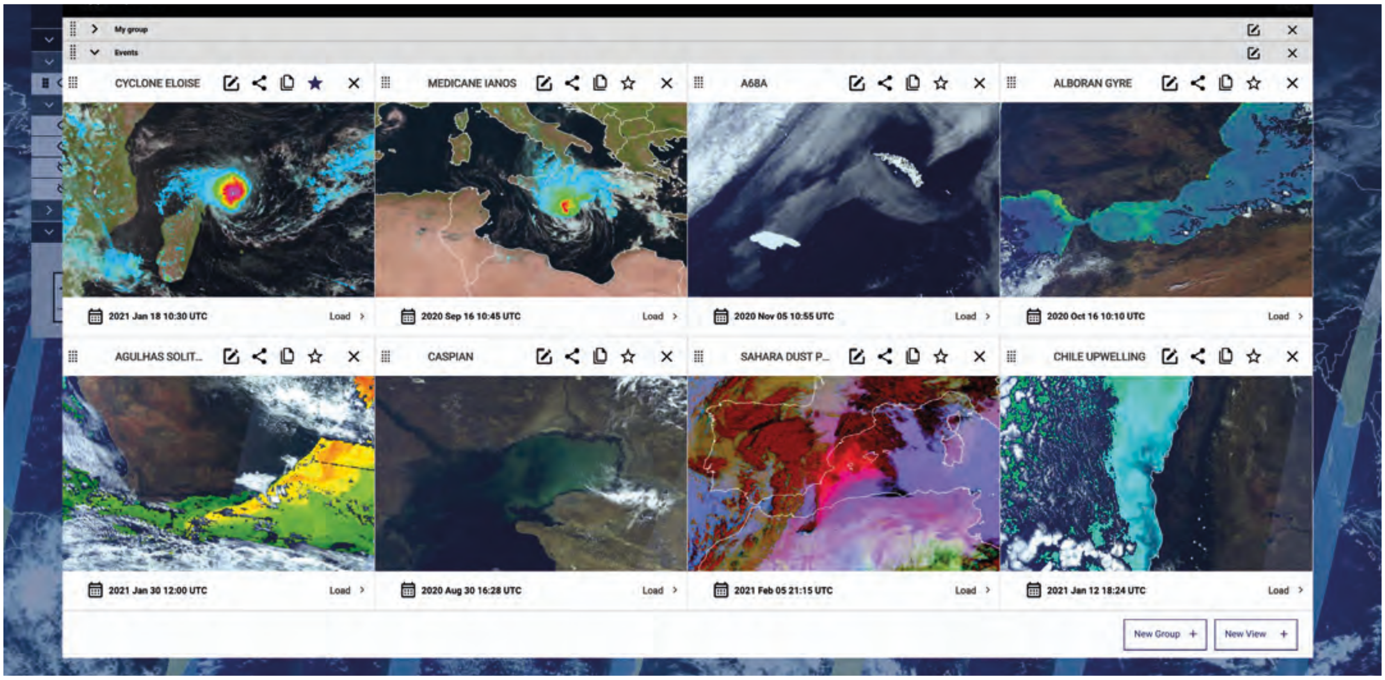
Allowing for easy access and processing on the cloud ensures that all users, even those with less powerful computers, can use the EUMETSAT data and generate their value-added products from the available data sets. Clearly this greater flexibility has the purpose of maximizing the usage and user impact of our data and products for our users.

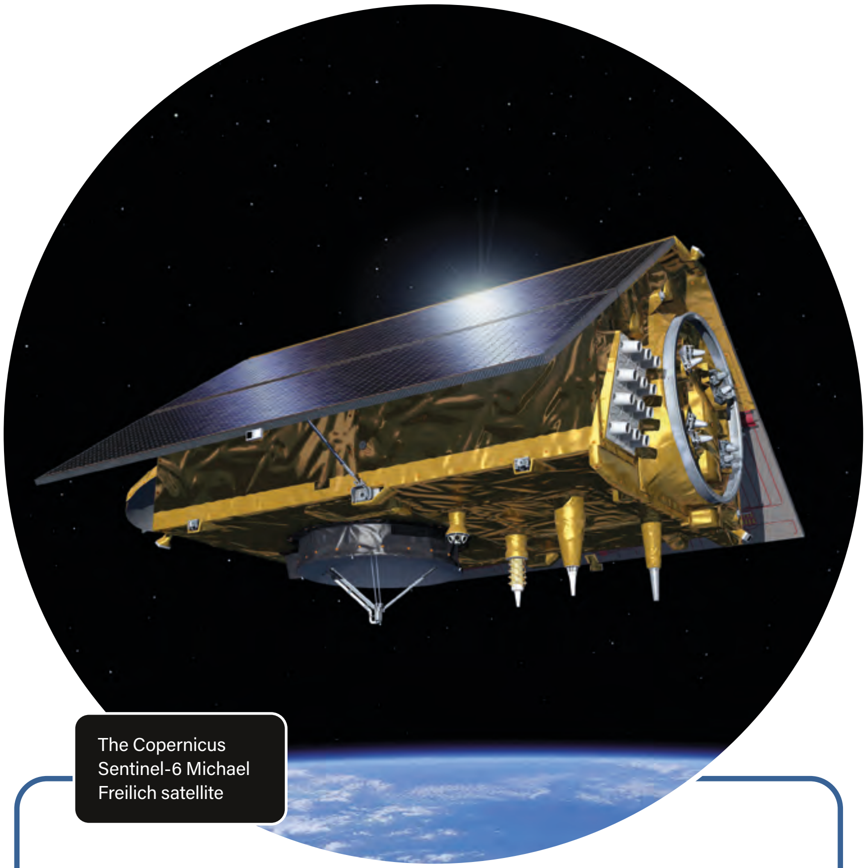
These new data services will also strengthen the participation of EUMETSAT in wider European and international projects, such as the development of WEkEO as part of the Copernicus program, or of the European Weather Cloud, in the context of the European Meteorological Infrastructure. The new data services are also an important support, both technologically and scientifically, to the EU's Digital Agenda and the Green Deal. In that context, EUMETSAT will be a core partner for the Destination Earth project launched by the European Commission, providing the knowledge and infrastructure to manage the immense quantity of data necessary to create digital twins of the Earth.

What information is provided in the new data services?

The data from EUMETSAT's meteorological satellite fleet and the Copernicus spacecraft it operates on behalf of the European Commission are available through these new

BELOW: This image shows eight separate events saved for later use via the EUMETView My Views capability. Top row, from left: Cyclone Eloise on January 18, 2021, the day before it made landfall in Madagascar, comprising the multisensor precipitation estimate and natural color imagery from Meteosat Second Generation (MSG) Indian Ocean service; Medicane Ianos, pictured on September 16, 2020, killed four people and caused flooding and severe agricultural damage in Greece. Layers are similar to those used in the first panel; iceberg A68A as seen on November 5, 2020, using top-of-atmosphere, natural color data from Copernicus Sentinel-3's Ocean and Land Colour Instrument (OLCI); the Alboran Gyre on October 16, 2020, shows concentrations of chlorophyll-a as captured by OLCI. Bottom row, from left: global Metop sea surface temperature data from EUMETSAT's Ocean and Sea Ice Satellite Applications Facility (OSI-SAF) (with Sentinel-3 OLCI natural color data), capturing western boundary current variability through a solitary meander in the Agulhas Current off the eastern tip of South Africa on January 30, 2021; OLCI true color image of the Caspian Sea on August 30, 2020, shows the turbidity of the northern part of the water body; the pink plume shown on this image from February 5, 2021, shows dust from the Sahara spreading into Europe on this false color MSG RGB imagery; the upwelling of cold water on the western coastline of Chile comprises layers of sea surface temperature and ocean color data from Copernicus Sentinel-3





The Copernicus Sentinel-6 Michael Freilich satellite

MONITORING THE GLOBAL OCEAN

On November 21, 2020, the Copernicus Sentinel-6 Michael Freilich ocean-monitoring satellite was launched from Vandenberg Air Force Base, California. Its primary role is high-precision ocean altimetry, providing information about sea surface topography including sea level and significant wave height. Its secondary mission is radio occultation, which is an essential input for climate monitoring and weather forecasting.

EUMETSAT worked on the mission with the European Commission, the European Space Agency, NASA and NOAA, with the support of the French Space Agency (CNES). "EUMETSAT is now fully responsible for the operation of the entire mission as a Copernicus Sentinel mission," says Yves Buhler. "This is under the delegation of the European Commission in collaboration with NASA/JPL for the US instruments, the NOAA ground station services from Fairbanks, the support of CNES for the altimetry processing and the in-orbit support from ESA and industry.

"The next steps will be the formal close-out of the satellite in-orbit verification phase, with detailed reports from industry becoming available, final onboard software updates capturing improvements identified so far and the deployment of a further improved version of the Sentinel-6 processing, allowing us to benefit from improved calibration data early in the process," he adds.

According to Buhler, with the calibration/validation activities leading to product validation and releases planned in stages as early as June this year, "the project will gradually hand over elements of the system from development into operations. This is planned to be completed by end of June this year, when Sentinel-6 Michael Freilich could be declared operational," he concludes.

services. This includes data from the geostationary satellites Meteosat-8, positioned over the Indian Ocean, and Meteosat-9, 10 and 11 with their views over Africa and Europe, as well as from the three polar-orbiting Metops, A, B and C.

In addition, data from the Copernicus spacecraft operated by EUMETSAT, Sentinel-3A and 3B, is available, as is data from the ocean altimetry spacecraft Jason-3. Data from the follow-on mission to Jason-3, Copernicus Sentinel-6, will start to become available from mid-year. The data from EUMETSAT's unique archive stretching back more than 40 years is also progressively being made available through the Data Store.

Why are these services being launched now?

The new services are elements of a long-term big data strategy at EUMETSAT. We deliver cost-efficient, operational services to our member states 24/7, on a high-availability basis. To do so, we need to use the latest technology. With the rapid development of the cloud and internet-based solutions, we also have to continuously adapt.

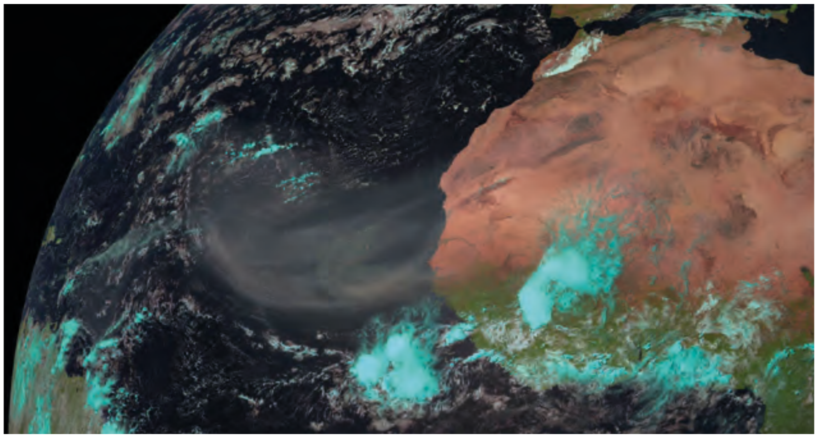
There are three overarching directions of our strategy. First, to provide a vast collection of data from our satellites and also from third-party satellite operators with whom we have cooperation agreements. This provides the diversity. Second, to establish a high quality standard, both for the accuracy of the measurements and for state-of-the-art processing on the ground to derive the best products from our satellites. We aim to remain world leading in this respect.

Third, to build up an infrastructure and services that make this access to EUMETSAT data quick and easy to use through fully integrated data services. Anyone with internet access will have access to EUMETSAT's data.

The new services will benefit existing users in the meteorological, climate and research communities. EUMETSAT has more than 8,000 users of our data, including almost 3,000 private users. Our open-view service attracts an average of more than 54,000 unique users per month. The new services can also be beneficial to other, new users, such as entrepreneurs looking to develop new applications based on Earth observation data; weather forecasters and presenters communicating about weather events and the climate; and weather- and climate-sensitive sectors of the economy, particularly through downstream processing of EUMETSAT data.

"The new services will benefit existing users in the meteorological, climate and research communities"

> "The EUMETView service provides new functionalities for displaying visualizations and creating maps from across the EUMETSAT product range"



ABOVE: Dust blow/transport from West Africa westward over the Atlantic Ocean, seen by the Meteosat-11, Natural Colour RGB product, June 18, 2020, at 14:00 UTC

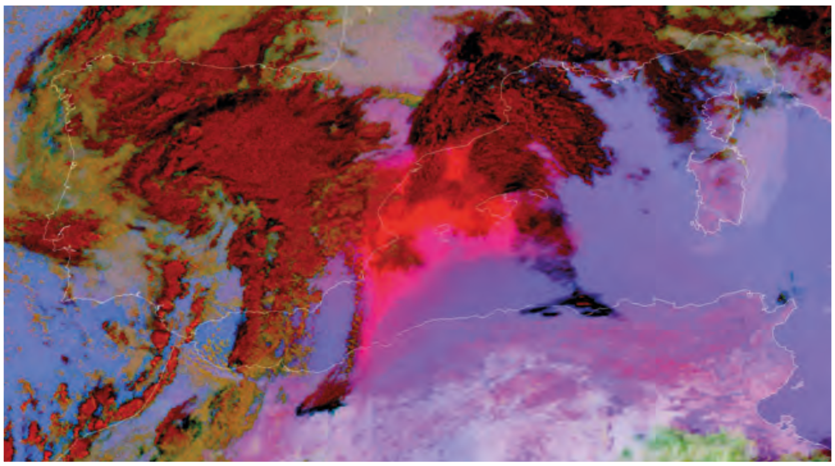
BELOW: Dust from the Sahara, seen as a hot pink color in the center of the image, over Europe, in February 2021. This image is taken from an animation made with EUMETView, using the Meteosat Second Generation Dust Red Green Blue product

How are the new services innovative?

EUMETSAT will provide an integrated and fully cloud-native service portfolio and a way of empowering the users of our data to choose and adapt the services to their needs. In this way, EUMETSAT is combining two concepts: the classic 'data to the users' with the modern 'users to the data'.

The EUMETView service provides new functionalities for displaying visualizations and creating maps from across the EUMETSAT product range. EUMETView is an online map service that provides these visualizations through a customizable web user interface and an enhanced set of Open Geospatial Consortium (OGC) standard application programming interfaces (APIs).

Data viewing can be personalized by adding layers by satellite or theme, and the settings can be saved for future use. Personalization allows users to change the area of interest, map projection, base maps and overlays. Maps can be animated and downloaded, as can the corresponding georeferenced products.



Further functionality allows users to view data as point-based information and as time series. Maps may be saved in either 'event mode', tying the view to a specific point in time for later recall, or 'live mode', in which the latest updated version of the map will be recalled when requested. The product navigator stays up to date with the latest data sets that are available for viewing.

The APIs allow users to integrate EUMETView into other applications and systematically download images and products without accessing the web user interface.

The EUMETSAT Data Store provides users with a single point of access to a growing catalog of EUMETSAT's meteorological, climate and ocean data. Eventually, it will offer the full data catalog, including near-real-time and historical data and climate data records.

Access to the store is through a web user interface or a series of APIs. Products identified in the store can be combined with the functionality provided by the Data Tailor API, allowing for product customization. The Data Store allows users immediate access to the data, reducing delays. The product navigator will stay up to date with the latest data sets that are available for download.

The Data Tailor software makes it possible for users to subset and aggregate our data products in space and time, filter layers, generate quick looks, project onto new coordinate reference systems, and reformat into common GIS formats (netCDF, GeoTIFF, etc). It offers a uniform way to transform both historical and near-real-time satellite data provided by EUMETSAT.

What are the costs?

The Data Store and EUMETView services do not cost the users anything, unless they are commercial users and want to have access to our Meteosat data with a latency of less than three hours. For this kind of license, two types of flat rates apply: one for end users at €4,000 (US$4,711) per year and one for broadcasters/service providers at €8,000 (US$9,422) per year. ∎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Airport operations are extremely sensitive to weather phenomena – safety is paramount.
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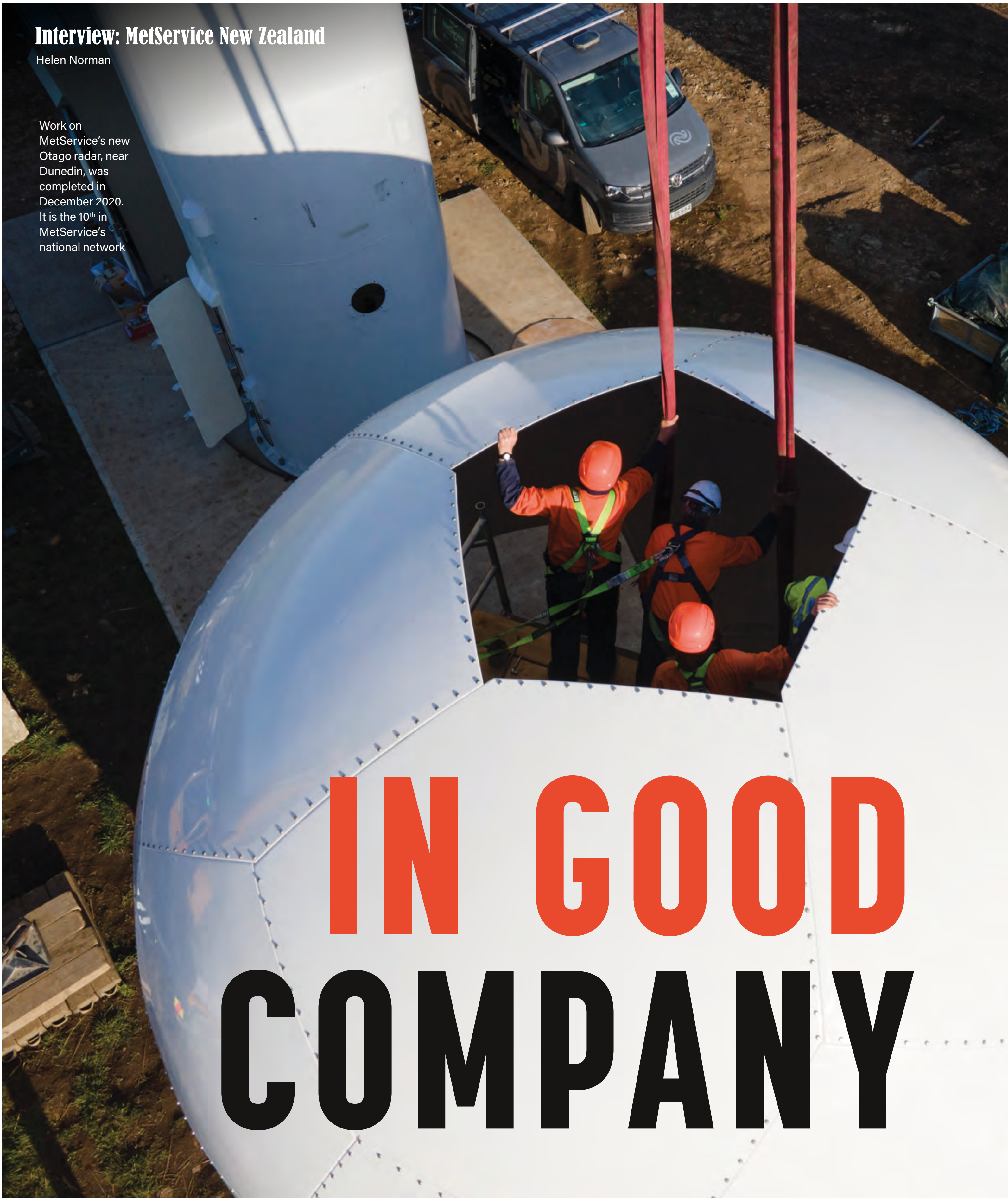
Inspired by the vision, curiosity and creativity of the great master inventor – Leonardo is designing the technology of tomorrow.

Helen Norman



Work on MetService's new Otago radar, near Dunedin, was completed in December 2020. It is the 10th in MetService's national network

IN GOOD COMPANY

Stephen Hunt, the new CEO of MetService New Zealand, talks to *Meteorological Technology International* about the unique challenges of balancing its commercial model with the requirements of its public-safety mandate

As a pilot and mountaineer, Stephen Hunt has been using high-end meteorological products in safety-critical environments for more than 35 years. As a result, the new CEO of New Zealand's MetService has been dependent on the science and technology of meteorology to stay safe and, on many occasions, to stay alive.

"From the Arctic to the Antarctic, tropics to deserts, aircraft carriers to ice runways, meteorological experts and weather intelligence have often been vital components providing a decisive factor," he says. "Managing threats and risks using weather products is deeply ingrained in the aviation industry. For airline flight operations, weather impacts safety and productivity, and can increase carbon emissions. Meteorological accuracy and data integrity have a clear impact on profitability and customer experience."

Hunt took over his new role in January 2021 after a career predominantly in military and civil aviation. "Over the years I have been extremely fortunate to have the opportunity to fly in many different, and often extreme, global environments," he says. "Originally from New Zealand, I flew for the Royal Air Force for 17 years before spending two years flying business jets in Australia. Since returning to New Zealand in 2005 I have completed an MBA and held a variety of roles with the Royal New Zealand Air Force, on the executive board at the Civil Aviation Authority and on the senior leadership team at Air New Zealand."

According to Hunt, all these roles have involved very close relationships with meteorology. "The precision, data integrity, accuracy and usability of meteorological products produced for aviation is the same as that needed by many other industries. Because of my aviation experience, I focus on the customer and user, the efficiency of our systems, and on the relevance, delivery channels and accessibility of weather information."

Leading the way

One of Hunt's key aims as the new CEO of MetService is to connect with the organization's workforce so they can build on existing success together. "MetService has wonderful and talented people devoted to science, public safety and to the success of our customers," Hunt comments. "Our purpose of helping New Zealanders stay safe and make informed decisions based on the weather forecast goes to the heart of our organization's collective commitment to the security and success of New Zealand."

For Hunt, this is an exciting and challenging time within the meteorological sector, and one that offers growth opportunities for MetService. "The global competitive landscape is changing quickly and there are plenty of opportunities to look at ways to integrate our systems more efficiently and manage our data in more structured and accessible ways," he says. "This approach will enable us to apply our science and R&D expertise to produce better services and products across more channels. A current example of improving our capabilities is the shift from owning our computing resources and data storage, to the migration into the cloud for both high-speed on-demand computing and data warehousing."

> The commercial imperative keeps us focused and lean, and provides competitive flexibility"
>
> **Stephen Hunt, CEO, MetService New Zealand**

CAREER HIGHLIGHT

Speaking about one of his fondest memories from his career to date, Stephen Hunt says, "I was privileged to fly the BAe Harrier with the RAF. It was always exhilarating to fly from remote locations around the world and in challenging environments. Without a doubt, my fondest memories are from sharing those experiences with incredible people – the fellow pilots and engineers of my squadron, and the meteorologists and other support staff who helped keep us safe. Of those experiences, flying low-level missions off ice runways in northern Norway in the permanent darkness and bitter cold of arctic mid-winter remain among my fondest memories. Those missions were flown on the very edge of safety, and the weather – blizzard, wind and cloud – was a constant threat."

The future will see MetService increase its capabilities in augmented reality, virtual reality, machine learning and AI. "How we shape the current role of forecasters and embrace these emerging technologies is an ongoing opportunity," Hunt continues. "The specter of climate change is the backdrop to these new technologies, and during my time with MetService we will face the real impacts of long-term climate trends on short-term weather."

Commercial opportunities

Back in 1992, New Zealand became the first country in the world to create a commercial company out of its national weather service. The idea was to commercialize its scientists' expertise and use the profits to help support operations and reduce the cost of weather services for the taxpayer. Today, MetService is a world leader in public weather forecasting and commercial weather information and has operations in New Zealand, Australia, Asia and Europe.

"Being a commercial company that generates sustained revenue and profit is extremely efficient for New Zealand," explains Hunt. "The commercial imperative keeps us focused and lean, and provides competitive flexibility. Our offshore work allows us to return revenue for investment into new products and services that benefit New Zealand.

"Today, we have some world-leading capabilities in visualization, media and marine services. Competing with the biggest weather companies in the world helps drive our innovation and responsiveness. In the media space, our Weatherscape platform is used by more than 30 broadcasters globally. Every Australian media outlet uses Weatherscape to present the weather, for example. Al Jazeera began using Weatherscape in 2019, and last year we were delighted to begin working with Sky News in Europe.

ABOVE: Stephen Hunt, MetService CEO, outside the Wellington HQ with his 1957 Land Rover

RIGHT: Weatherscape is an innovative weather graphics system developed by MetService and used by media broadcasters around the world

The Otago radar is estimated to cost NZ$2.8m (US$1.9m). All New Zealand radar imagery is updated every 7.5 minutes on metservice.com and MetService apps

TOP TECH

Stephen Hunt highlights the three technologies he believes will have the biggest impact on the meteorological sector in the next five years

ARTIFICIAL INTELLIGENCE
The application of AI methods will become essential to gain full benefit from meteorological data.

REMOTE SENSING
Space-based remote sensing systems will continue to revolutionize the way we understand the atmosphere, leading to greater forecast accuracy and lower uncertainty, while continually raising the bar in terms of the technical capability needed to use them.

MEDIA
New media, including social media, will continue to grow in importance – particularly in how we communicate safety-critical weather messages.

"The Weatherscape product has been operating internationally now for almost 20 years," Hunt continues. "We are currently scoping out significant improvements that will enhance the graphics and realism of this platform, that enable Weatherscape to be used across a wider range of industries."

Enhancing services

Hunt explains that to remain competitive and fulfill its public-safety purpose, MetService must continually evolve to become more efficient, effective and high-performing. "One way we are working on enhancing our offering is by liberating more of our high-value data through scalable, digital platforms and APIs across our oceanography and meteorology divisions. This will allow other organizations to better integrate our meteorological expertise into their own products and systems."

MetService also has a strong history of partnering with organizations to launch new products that support the work of other sectors. "A recent example is our work in Australasia with a UK-based company, which sees MetService provide in-depth weather data to support the cost-effective management of energy infrastructure," says Hunt. "Furthermore, MetOcean, our oceanography division, is conducting groundbreaking research into ocean climatology, and recently launched seven-day forecasts of sea surface temperatures that predict marine heatwaves. These conditions have profound impacts on ocean life, marine industries and aquaculture. Our work has also supported the development of a lightning detection network across 25 locations in the South Pacific."

MetService's forecast and research teams are also currently piloting some innovative projects that use global weather research and forecasting (WRF) data and high-resolution rainfall nowcasting in New Zealand. "And we are working with other New Zealand agencies and organizations to develop real-time forecasting models for volcanic ash fall to help New Zealand communities best manage the impact of future eruptions," Hunt adds.

Future plans

One of Hunt's and MetService's key aims is to ensure the organization makes best use of its data and that any data gaps are filled. "New Zealand is a mountainous country surrounded by water, synonymous with having four seasons in one day," Hunt explains. "Our extensive radar network is a critical asset and we continue to grow our national coverage. We added the 10th radar to our network in late 2020. We continuously work with the New Zealand government to address existing gaps in the radar coverage across New Zealand.

"We are also running a program of work to overhaul our data architecture. As the technology landscape changes, we anticipate an increasing need for data scientists to allow the extraction of valuable information from ever-increasing data volumes, with an emphasis on applications of AI to support our role," he adds.

Balancing the needs of its public-safety mandate with its commercial model as a state-owned enterprise will continue to present both a challenge and an opportunity for MetService. Currently, approximately 40% of the organization's income comes through a contract with the New Zealand government; the remainder is secured through commercial endeavors.

"We've successfully operated under this model for almost 30 years, and the need to innovate and diversify is paramount, especially in the current environment," explains Hunt. "Of course, 2020 saw a significant reduction in aviation revenue. As a result, we've diversified our offering, providing additional support to aeronautical projects, including embedding meteorologists who are specialized in aviation into organizations in this industry," he concludes. ∎

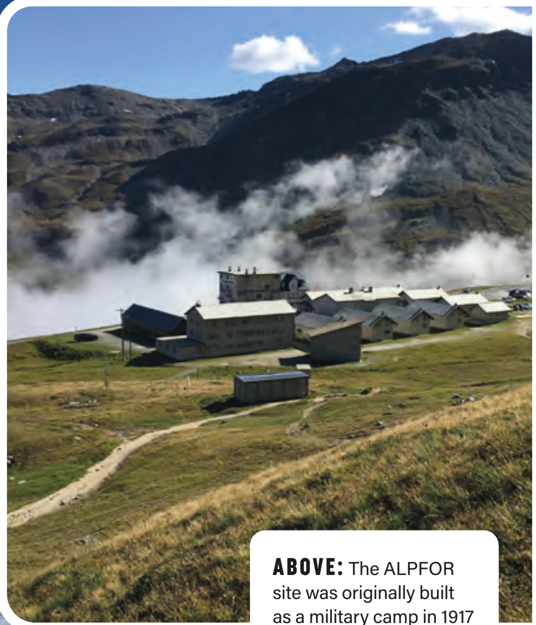
Weighing rain gauges

Martin Maly, science and technology writer, OTT HydroMet

ALPINE ecosystems

MAIN: In less than a century, the site at the Furka pass evolved from a military camp to an iconic movie setting and finally to a unique research station. Recently, an OTT Pluvio² has upgraded the scientists' equipment

RIGHT: Even in summer the landscape surrounding the research station is covered with snow



ABOVE: The ALPFOR site was originally built as a military camp in 1917

BELOW: Senior biologist Dr Erika Hiltbrunner and Christian Körner, professor emeritus for botany at the University of Basel, are working at the ALPFOR research station

At a unique research site in the Swiss Alps, ecologists are investigating the impact of civilization and climate change on the alpine world. A weighing rain gauge from **OTT HydroMet** is boosting data quality

Sean Connery introduced the Furka mountain pass to the world in 1964. Amid the Swiss Alps, where the Uri and Wallis cantons share a border, the late actor raced down the sinuous road in James Bond's legendary silver Aston Martin DB5 in the movie *Goldfinger*.

Decades later, ecologists from the University of Basel have repeopled a deserted military camp in the mountain pass and turned it into a unique research facility called the Alpine Research Station Furka (ALPFOR), sitting 2,440m above sea level. The scientists' mission is to investigate the impact of climate change and other anthropogenic influences on alpine ecosystems. In the past, plants and animals needed thousands of years to acclimatize in the lofty mountains. Today, they are exposed to changes in their environment within decades.

Reliable meteorological data is required to better understand the ecological processes and challenges that alpine life is facing. Beyond obviously relevant parameters such as temperature above and in the ground, wind speed and direction, relative humidity and solar irradiance, Swiss scientists, including Prof. Christian Körner and Dr Erika Hiltbrunner, execute more sophisticated measurements such as the deposition of atmospheric nitrogen compounds into the alpine vegetation.

OTT Pluvio² helps to understand the nitrogen cycle

Thanks to catalyzers in industrial facilities and in every car, nitrogen oxide (NO_X) emissions have been reduced. However, emissions of nitrogen in other forms, such as from agriculture, are unabatedly increasing. Fertilizers and intense livestock farming emit high amounts of ammonia nitrogen (NH_3) into the air. These gases return as nitrogen deposition onto the earth surface and the vegetation in forests, bogs or grassland.

In the mountains, these soluble nitrogen compounds are deposited mainly through rain and snow. They act as a unilateral fertilizer and harm biodiversity by boosting fast-growing plant species that supplant slow-growing, often rare, alpine plants. Even in remote areas of the higher Alps, nature is facing an estimated tenfold increase in nitrogen deposition compared with preindustrial times. Scientists are eager to better understand this ecological problem, which is where the OTT Pluvio² weighing rain gauge comes into play.

To evaluate the nitrogen pollution of alpine ecosystems, it is necessary to know the exact amount of nitrogen deposition, as well as alpine plants' reaction to it. Precise precipitation monitoring is essential for that. At ALPFOR, the non-profit organization of the same name runs an automated weather station. There, the majority of a year's precipitation falls as snow, often

WE MEET AGAIN, MR BOND

ALPFOR's researchers often show scenes from *Goldfinger* to visitors at the station. Instead of the Aston Martin, they focus on how land cover has changed in the area since 1964. Today, former grasslands have been fully encroached by green alder bushes due to reduced land use. Green alder bushes evaporate more water than grassland, again with consequences for the water cycle.

accompanied by strong winds. Therefore, ordinary tipping-bucket rain gauges with their small orifices lack reliability, even when heated. A weighing rain gauge with a heated ring is the instrument of choice at the weather station.

The precipitation's local nitrogen concentration is known from water and air samples gathered close to the pluviometer. The OTT Pluvio² provides the respective amount of precipitation. From both parameters, scientists can calculate the annual atmospheric nitrogen deposition. This research project is led by Dr Hiltbrunner.

Hosting a variety of ecological, hydrological and meteorological research

The institute's location in the Furka mountain pass combines multiple characteristics, making it an ideal place for research. On the one hand, its height 2,440m above sea level typifies areas in the higher Alps, which in many cases are remote and far from any human settlement. On the other hand, being housed in a former Swiss military camp next to a public road, the institute has good access to transportation – at least in summer.

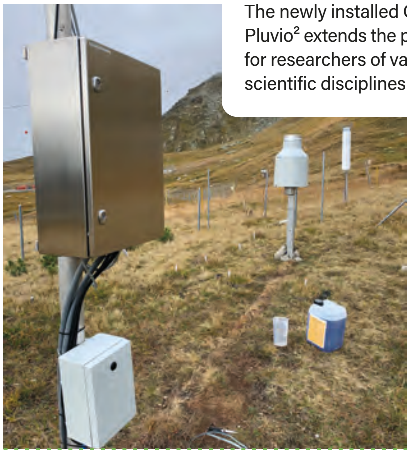
Power supply and mobile radio communication are also helpful with regard to the OTT Pluvio's heated orifice ring and data access. Remote operation is essential because the location is nearly inaccessible during winter due to the high risk of avalanches, which is why the mountain pass road is closed from mid-October to May. The OTT Pluvio² has proven its strengths in remote operation worldwide thanks to its robust and nearly maintenance-free design. The large-scale weighing principle is very sensitive to low amounts of precipitation, even when bird droppings or leaves are disposed to the bucket.

In winters with enormous amounts of precipitation, the bucket may need emptying. Then, the institute is only accessible on touring skis from the direction of the village Realp in the valley. The Pluvio's smart software identifies and immediately adapts to the emptying processes, therefore avoiding data gaps.

In the mountains, the amount of local precipitation can vary significantly, with up and down winds, even across small distances. The scientists placed their OTT Pluvio² at a point that represents the average precipitation amount in a radius of 2km, which is known from a previous study with 12 measuring points.

The OTT Pluvio² complements the scientists' equipment – they rely on OTT HydroMet sensors for other applications, too. They also measure solar radiation and reflection with two Kipp & Zonen CMP11 radiometers. For precise and reliable wind monitoring, the scientists use an ultrasonic anemometer, the Lufft Ventus. It is based on the same measurement principle as the popular Lufft WS series, but specially designed for ice-free operation in extreme conditions down to -40°C.

Depending on the specific project, the scientists investigate different parameters by applying different measurement methods. A few years ago, Dr Erika Hiltbrunner participated in a project to measure the fluxes of CO_2 in the region with help of the eddy covariance method. Extremely accurate measurements of windspeed and wind direction are essential here to collect solid data for plausible simulations.



The newly installed OTT Pluvio² extends the possibilities for researchers of various scientific disciplines

Reliable weather data is essential to outdoor research

For the scientists, reliable, ice-free operation even in harsh winter conditions is key to scientific success when analyzing the carbon balance of alpine grassland. Unfrozen soil lying under snow cover emits small quantities of carbon dioxide, as if it were breathing. During a long period of eight to nine months, this effect outweighs CO_2 taken up by plants during the growing season.

Nevertheless, the scientists consider the site to be a net carbon sink and not a source. However, the length of the growing season matters to the overall carbon balance, as the scientists point out in their research paper published in 2018 in the journal *Ecosystems*.

Ecology is a highly complex science, especially in the mountains, where multiple processes interact with each other and sometimes cause opposing effects. Understanding these in the alpine world and in the Arctic – both regions of melting glaciers and permafrost – is key to dealing with the challenges of climate change in other regions, too. "Reliable weather data is essential for any kind of outdoor ecological research," states Prof. Körner. "Accurate precipitation plays a central role in topics linked to the water cycle."

For those reasons, the OTT Pluvio² weighing rain gauge brings a significant improvement to the ecological research at ALPFOR. Being virtually maintenance-free and measuring with high accuracy even during remote operation, the proven technology contained in the OTT Pluvio² has given a significant boost to the precipitation data collected at the Furka mountain pass and at more than 10,000 sites worldwide. Not as spectacular as Sean Connery's Aston Martin DB5, perhaps, but surely as technically mature and reliable. ∎

MAIN: Despite being surrounded by mountains and far from the next village, the ALPFOR research station has access to a power supply and mobile communication

LEFT: The Furka pass is home to around 260 species, making it one of the floristically richest parts of the Alps

BELOW LEFT: Two Kipp & Zonen CMP11 radiometers and one Lufft Ventus ultrasonic anemometer are part of the OTT HydroMet portfolio, too

Dr Evan Ruzanski, senior scientist, Vaisala

RADAR observations

Vaisala reveals the benefits of using weather radar with dual-polarization capability to gather data on smoke and ash from the most destructive wildfire in Colorado's history

Wildfire smoke from the 2020 Cameron Peak fire in Rocky Mountain National Park

The Cameron Peak wildfire started on August 13, 2020, in Larimer County, west of the city of Fort Collins in Colorado. On December 2, 2020, the United States Forest Service declared the fire 100% contained. In the 112 days it burned, the fire became the largest wildfire in Colorado history, burning a total of 84,544ha and damaging or destroying 469 structures. According to a Larimer County assessor's report published in January 2021, the market value loss to the county was almost US$6.4m.

Even relatively small amounts of smoke and ash produced by wildfires can be detected by weather radars. The nature and operating characteristics of dual-polarization radars make them especially capable of detecting smoke and ash in a variety of conditions, from clear to cloudy skies, calm to windy and dry to wet conditions, and during the day or at night.

The data presented in Figures 1 and 2 (overleaf) shows the benefits of a weather radar with dual-polarization capability. Although the reflectivity values created by the wildfire smoke and ash are similar to those produced by precipitation, the correlation coefficient provides clear differentiation between the two different types of particles.

Reflectivity measures the density of particles in the atmosphere. This directly translates to the strength of precipitation and also the thickness of

WEATHER RADARS AND THEIR VALUE TO SOCIETY

Weather radars are critical for helping people prepare for dangerous weather conditions. These systems exist in all corners of the world — from the equator to the Arctic, the rainforest to the desert, and from coastlines to the mountains. The value of weather radars is both measurable and immeasurable. They provide high-quality real-time weather information to organizations and individuals. Severe convective weather, tropical storms and large-scale weather fronts make a significant societal impact and cause economic loss.

Through their large coverage areas, high resolution, fast updates and versatility, weather radars provide:
- Outstanding coverage and resolution;
- Severe weather analysis;
- Improved warnings;
- Accurate and quantitative precipitation estimation;
- Nowcasting and short-range weather forecasting.

Outperforming conventional rain gauge networks, weather radars excel in meteorological applications in both time and space. Fully integrated and optimized radar networks using both X- and C-band radars provide comprehensive coverage for meteorological surveillance.

Including X-band radars in the radar networks helps fill gaps in radar coverage – especially in mountainous terrain, at low altitudes and on wind farms.

The Vaisala weather radars are designed with the sensitivity to deliver exceptional accuracy for meteorological surveillance. Their innovative data processing and hardware design provide meteorological information to increase safety and improve operational efficiency.

With modern weather radars, weather services, airports and even maritime organizations that monitor conditions to protect life and property can significantly enhance data quality in strategic locations and deliver information at a higher resolution and with better precision.

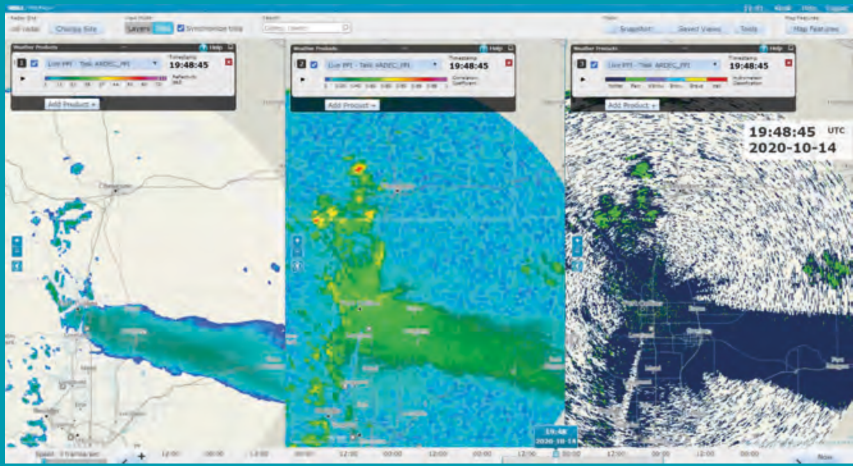


FIGURE 1: Data collected from the Cameron Peak wildfire and surrounding precipitation from 19:48:45 UTC on October 14, 2020, by a Vaisala WRM200 C-band dual-polarization weather radar displayed as Plan Position Indicators in IRIS Focus. The left panel shows reflectivity, the center panel shows the cross-correlation ratio (or correlation coefficient) between the horizontally and vertically polarized signals, and the right panel shows the classification of the hydrometeors using Vaisala's HydroClass. Here, the scattered precipitation patterns are outside the location of the smoke and ash produced by the wildfire

smoke and ash. Correlation coefficient measures the uniformity of the shape of particles in the atmosphere. Falling raindrops are oblate in shape and much more uniform than smoke and ash, which are random in shape and orientation as they fall or drift through the atmosphere. This difference is clearly seen in the correlation coefficient data, where the correlation coefficient values of smoke and ash are systematically lower than those of precipitation. This enables reliable type discrimination between wildfire smoke and ash and precipitation. Vaisala's HydroClass uses the correlation coefficient when determining the type of hydrometeor being observed.

These radar observations of wildfire smoke and ash also show the potential for emergency managers, firefighters, pilots of firefighting airplanes and residents in nearby areas to have new information about wildfire initiation and behavior, possibly resulting in improved firefighting and evacuation actions. More specifically, such data could be used to:

- Detect smoke and ash emission to assist in precisely locating a wildfire shortly after it has started;
- Forecast the evolution of the wildfire, including prevailing wind direction, speed and impacts of projected growth;
- Forecast the depth and location of the smoke and ash to create alerts for air traffic and/or degraded air quality;
- Forecast weather conditions above and around the fire for more effective and safer firefighting on the ground and in the air;
- Improve environmental modeling of fine particulate matter and black carbon for the impacted surrounding areas through better initial state estimation of the current location and concentration levels.

Future studies can be applied to other locations and weather radars, and eventually radar-assisted monitoring of wildfire smoke and ash could potentially save lives and property during wildfires around the world. ∎

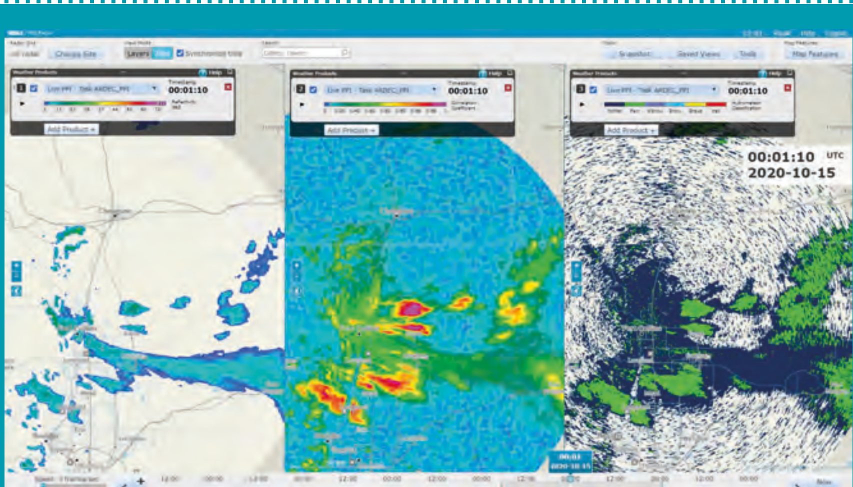


FIGURE 2: Data collected from the Cameron Peak wildfire and significant overlaid precipitation from 00:01:10 UTC on October 15, 2020, by a Vaisala WRM200 C-band dual-polarization weather radar displayed as Plan Position Indicators in IRIS Focus. The left panel shows reflectivity, the center panel shows the cross-correlation ratio (or correlation coefficient) between the horizontally and vertically polarized signals, and the right panel shows the classification of the hydrometeors using Vaisala's HydroClass. In this case, precipitation and the smoke and ash produced by the wildfire are co-located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Dr David Hammond, market development manager, surface transportation, Campbell Scientific

ROAD weather monitoring

Campbell Scientific provides insight into a practical application of new smart technology within the winter maintenance industry

The technological world we live in today is vastly different than it was even 15 years ago. If we think back to 2006, there were no smartphones – the original iPhone wasn't released until mid-2007, and the first Android device was still over a year away from launch. Microprocessor technology has come a long way during this time, influencing all areas of our lives, and the manufacturing industry has been a major beneficiary of these technological advances. Within the industry of environmental monitoring and data acquisition, technological advances are most evident in the shift occurring within the technology stack.

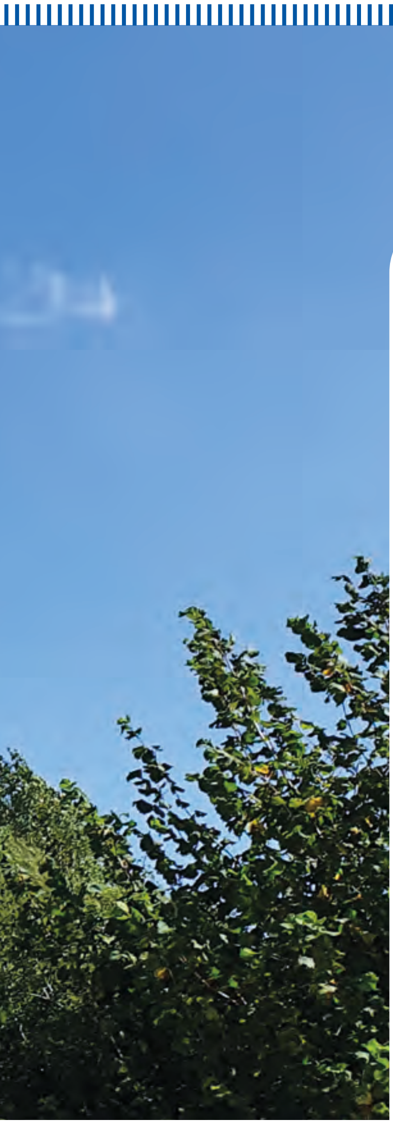
Traditionally, environmental data acquisition has consisted of a core data-acquisition unit (DAQ), such as a datalogger, connected to sensors that provide the raw measurement data that is processed by the DAQ. This processed data is then transmitted via a communications device (such as a cellular modem or RF radio) to desktop software – providing final database storage and data visualization, and analysis software – for data modeling, analysis and, in some cases, forecasting.

Over time, we have started to witness the streamlining of this technology stack. Many sensors now have storage capabilities, dataloggers have integrated communications, and desktop software has rapidly been replaced by cloud solutions capable of providing data storage, visualization, modeling, analysis and forecasting.

Many of these changes have occurred over the past 10 to 15 years. However, within the last three to five years we have started to witness a definite shift toward a future technology stack consisting of dense networks of smart sensors communicating directly to the cloud. In many ways, what we have seen to date can be considered a mere glimpse of what future environmental monitoring networks will look like.

Game-changing communications

The development of true, fully integrated smart sensors has been driven by recent technological advances with communications. A number of new low-power wide-area network (LPWAN)



communication technologies are becoming game-changers within the environmental monitoring industry. Sigfox, LoR Cat-M1 aWAN, NB-IoT and Cat-M1 are just some of the technologies to emerge over the last few years.

While each of these technologies has its pros and cons, low power is a common feature, which ultimately is the reason why such technologies are seen by many as game-changing. For many years, the power consumption of IP communications devices, such as cellular modems, has been the limiting factor in developing truly integrated, self-powered smart sensors. Now, with the ability to embed LPWAN communications directly into sensing devices, fully integrated, self-powered smart sensors provide an opportunity for densification of monitoring networks at a scale and cost that, until now, has not been economically feasible.

MAIN & BELOW: The newly launched Wintersense smart sensor (www.capbellsci.eu/wintersense) uses a cloud-hosted data solution to enable rapid densification of road weather networks. Wintersense is a completely integrated smart sensor, available in two configurations, R1 or R2. R1 sensors provide non-invasive surface temperature measurement in a compact, self-powered unit with integrated Sigfox communications. R2 provides the same features as R1 with the addition of air temperature, relative humidity and dew point measurements

In many countries, the network infrastructure to support this new breed of smart sensors is still in its infancy, largely because of the need for telecommunications providers to roll out upgrades to their existing cellular infrastructure to support these new technologies. As these networks increasingly come online, the applications that benefit from this new technology will continue to grow.

Smart sensors for winter road maintenance

One industry starting to benefit from such technology is the winter road maintenance industry. Alongside existing environmental sensor stations (ESS) and mobile sensor options, smart sensor technologies provide highway engineers with a wealth of observation options to assist in their winter maintenance decision making. While no single technique is perfect, a step change in observational capabilities is now available to the winter maintenance industry.

Traditionally, an ESS for winter maintenance consists of a number of sensors providing in-situ measurements of road surface temperature, road surface condition, subsurface road temperature, and a range of meteorological parameters including air temperature, dew point, wind speed and direction, rainfall, visibility and present weather. In particularly cold climates, snow- and frost-depth monitoring are also common measurements found on road ESS. The exact sensor set on a given station will vary depending on the specific climate, the client's available budget and utility availability (often power) in remote areas.

Specific measurement parameters from a road ESS can have greater or lesser significance for maintenance operations depending on the regional climate. In marginal winter climates, however – typically regions that experience many nights during winter with road surface temperatures close to 0°C – road surface temperature and dew point are particularly important parameters, as the primary goal of winter maintenance teams in these regions is to prevent ice formation on roads.

With many road authorities now making treatment decisions (whether or not to salt their road network) on a route-by-route basis with the aid of route-based forecasting services, smart road temperature sensors are playing an important role. Such technology provides the ability to easily monitor road surface temperature and dew point at a higher spatial resolution than

Using the latest-generation, low-power wide-area network (LPWAN) communications, Wintersense is a fully integrated smart sensor

was previously possible and provide forecast agencies with the additional route data necessary for validating and course-correcting their route-based forecast models.

In the modeling process, a numerical weather prediction (NWP) model typically takes inputs from nearby meteorological observation stations along with satellite data, rainfall radar and the site-specific ESS data. The model then exports what it thinks the weather will do on a land area grid, the resolution of which will vary based on the models being used. The UK Met Office, for example, used a 1.5km grid. This output is ingested into a road forecast model that typically applies adjustments for traffic, sky view factor, road construction depth, land-use type and other parameters. The actual road surface temperature data from the site is then compared against what is being forecast at that location, and the forecast model can then be gently adjusted (nudged) to the actual value.

With a route-based forecast, it will analyze points along the road in the near vicinity of the station and adjust these in the same direction. Importantly, though, any bias adjustments to road forecasts diminish rapidly away from the actual site, and beyond a set distance (e.g. 5km), bias adjustments will stop. The lack of bias adjustments beyond a set distance from an actual station is important as it provides the scientific basis for densification of road weather networks. Essentially, the further away you go from an observing site, the more chance that weather conditions will be different from that site. As you transition beyond a bias adjusted section of a road forecast, forecasters are essentially flying blind and have no in-situ data to nudge their models in these areas if necessary.

By densifying existing road ESS networks with lower cost, in-fill smart sensors to provide additional road surface temperature and dew point data, there is no longer a need to base treatment decisions on forecasts underpinned by data from a sparse number of ESSs. Smart road temperature sensors offer the potential to reduce the number of blind spots, improve forecast accuracy and ultimately help road authorities to minimize their expenses through smarter, route-based treatment decisions with the additional confidence that data from in-fill smart sensors provides.

Smart sensors in action

Delivering an efficient and effective winter maintenance service is often a fine balance between minimizing cost and environmental impact while maintaining optimum levels of service. Winter maintenance engineers are obliged to ensure that any money invested to improve winter services is done so based on a cost versus benefit analysis.

Using new IoT smart-sensor technology, coupled with a route-based forecasting service, a study is currently underway that will assess the cost-benefit of a new approach to delivering a winter service within the urban Metropolitan Borough of Wigan in northwest England, UK.

In the past, winter maintenance treatment decisions in Wigan were based on a single area-wide 'domain' forecast based on the worst-case scenario. To maximize efficiencies in its winter service, Wigan needed more granular information from its forecasts. Using data from a dense network of Wintersense smart sensors, high-resolution, route-specific forecast models are now being used that enable the testing of selective treatment across the borough, with a pathway toward realizing further efficiencies in the future.

The outcomes of this ongoing research will provide practical guidance for the industry on how to implement a dense sensor network and route-based approach, and a true cost-benefit analysis for densifying road weather networks with in-fill smart sensors. The research will also contribute to the wider discussion on mobile sensing versus densification using in-fill smart sensors, and the practicalities associated with using data from both methods in delivering a route-based forecasting service. ∎

Dr Lukas Hammerschmidt, head of drone development and operations, and Nadja Omanovic, meteorologist and sales specialist, Meteomatics

AIR support

Meteomatics' Meteodrones might become a real alternative for radiosondes as their capabilities continuously evolve to fly in inclement weather and at ever higher altitudes

Meteomatics is driven by its motivation to transform the world of weather information. The company innovates in the field of data distribution through the Weather API, but an in-house-developed technology might soon stir up traditional radio soundings as well.

Meteomatics' purpose-built weather drones, known as Meteodrones, already contribute operationally to the acquisition of weather data for assimilation into a 1km weather model for Switzerland (SWISS1k). The demonstrably successful application of drones for radio soundings and the recent advances in drone technology have left experts wondering where this field will develop.

Meteomatics is a global pioneer in the development and application of unmanned aerial vehicles (UAVs) to collect weather observations that can be directly assimilated into weather models. This data enables the company to create accurate, hyper-localized weather forecasts for anywhere on the planet. The company created its first Meteodrone back in 2012. Since then, it has assembled a leading team of drone and electrical engineers and undertaken more than 3,000 operational flight hours (>18,000 vertical flight profiles). Years of experience have resulted in the latest and most advanced Meteodrone ever created and built by Meteomatics.

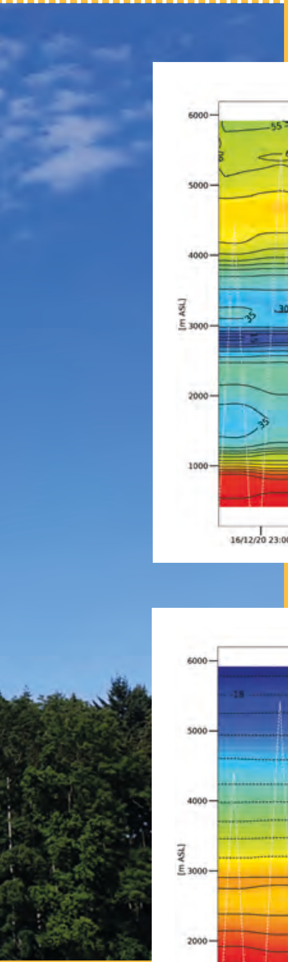
The latest version of the Meteodrone features enhanced capabilities that mean the equipment can be used in severe weather, with increased operational range. It also includes features that improve ease of use and safety. Is this enough to compete with the gold standard, the radiosonde?

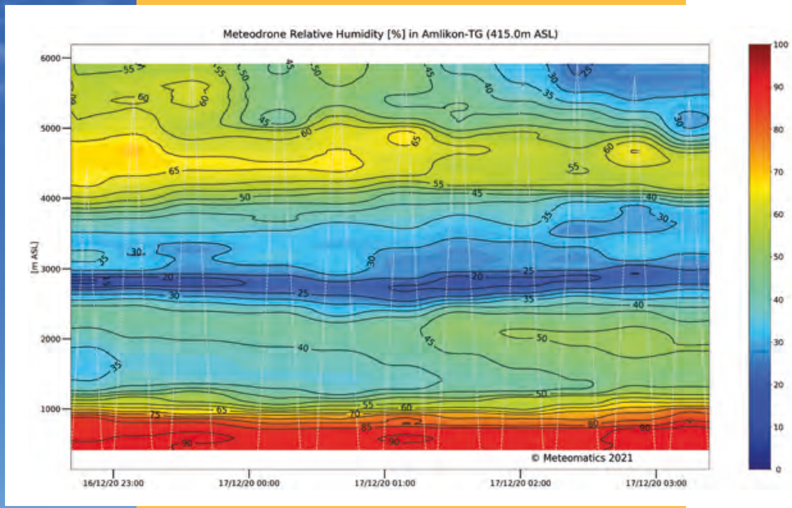
New flight level unlocked

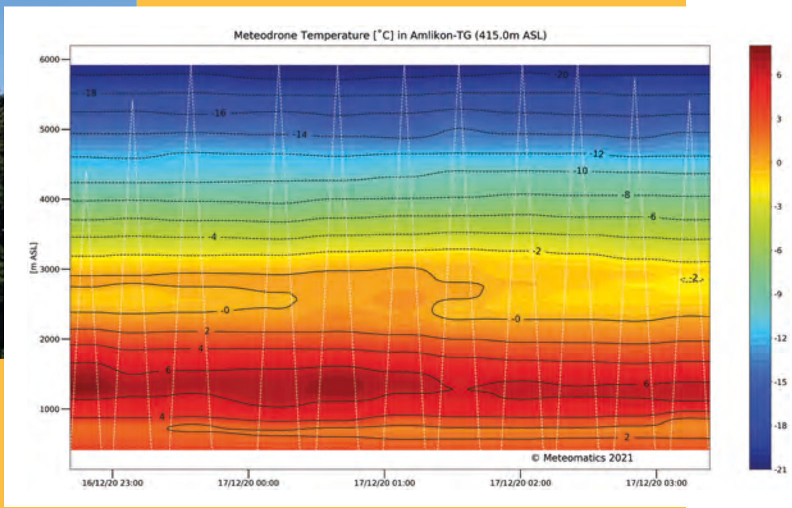
Meteomatics has continuously increased the accessible flight altitudes of its Meteodrones: 150m in 2012, 1,500m in 2014, 3,000m in 2018 and now flying to 6,000m. The company has been able to keep increasing the altitude by making improvements to the drones' airframe, reducing the weight of the components and applying state-of-the-art battery technology. Not only is the required power to reach these altitudes ensured, but there is also sufficient time to complete the mission to measure atmospheric conditions as the Meteodrones ascend and descend.

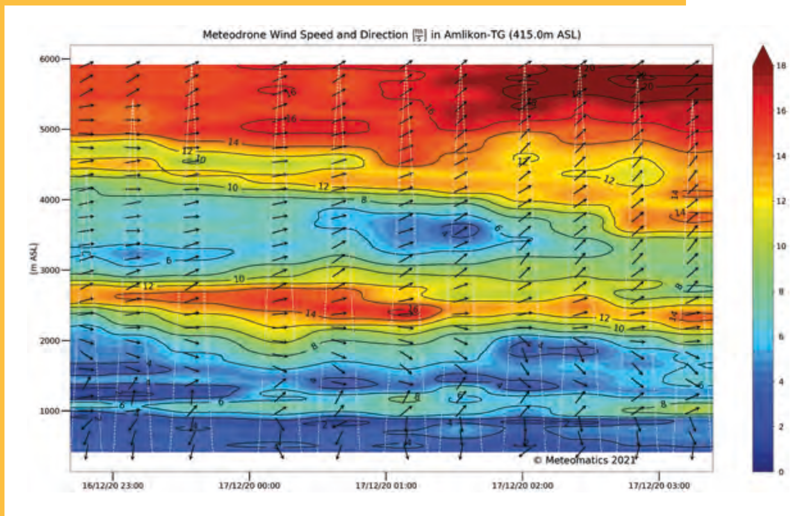
ABOVE: Meteomatics' Meteodrone can gather data in the mid and lower levels of the atmosphere

RIGHT: Temporal profiles of continuous Meteodrone flights during one night in Switzerland









Although weather satellites play a crucial role in capturing observations and have immensely improved weather forecasts, they cannot deliver accurate wind profiles of mid- and lower-atmosphere wind fields, which is essential for industrial applications and model initialization. Additionally, clouds pose a visible barrier as they prevent satellites from gathering measurements underneath them. Therefore, satellites have limited coverage of the planetary boundary layer, resulting in an observational data gap.

One solution to overcome this data gap is to use radiosondes. Many national meteorological and hydrological services (NMHS) use radiosondes, but there are several reasons why they are not the best solution: the equipment can be expensive to make; they are filled with helium, which is becoming a scarce natural resource; and they are commonly lost after deployment, as the wind carries them up to 250km from their starting position. However, the gathered data is still considered to be local.

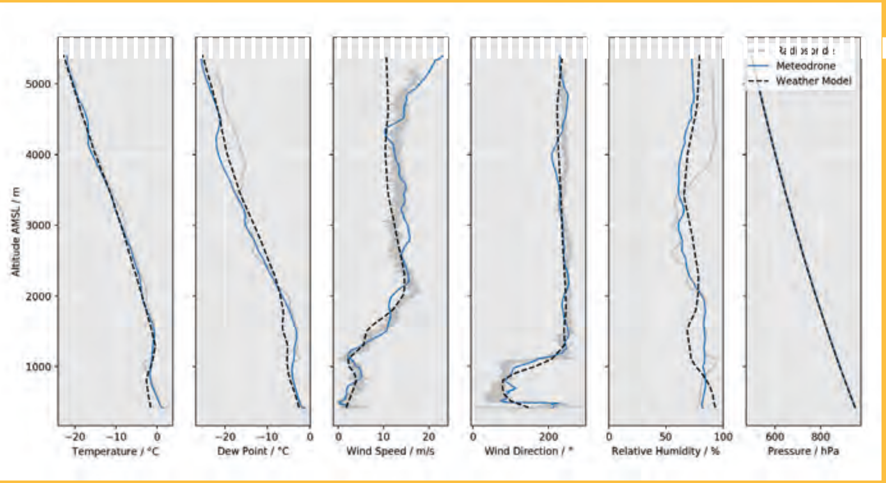
Meteomatics offers a more efficient, robust and reusable alternative to radiosondes and enables NMHS to initialize their own models with data collected from a drone mission as it flies through the mid and low atmosphere. Additionally, Meteodrones are a more sustainable and accurate method of gathering data throughout the atmosphere, as the drone can be reused. Furthermore, they are truly local because the Meteodrone system stays in the same location for the entire duration of the flight. Continuous temporal profiles are readily available since the Meteodrones' batteries can be exchanged and a new flight can be immediately started.

Flying at 6,000m enables customers to receive a continuous stream of high-quality observations from ground level into the free atmosphere (see images, left). Meteomatics flies operationally in Switzerland, gathering data, gaining meteorological insights and improving its SWISS1k high-resolution regional weather model. The images show an interesting case regarding night-time meteorological conditions. The white tracks indicate the flight tracks; the y-axis shows the height, and the x-axis shows the time. The low temperatures, high humidity and weak wind near the ground indicate the presence of fog up to 1,000m. Between 2,500m and 3,000m there is a strong nocturnal jet visible, bringing a dry layer of air into the atmosphere. At higher altitudes the wind is quite strong, up to ~40kts.

One-click soundings

Meteomatics has improved the usability of the Meteodrones by automating take-off, flight and landing, which makes handling easier. To enable this feature, customers simply have to push one button on the mobile ground control station and the Meteodrone starts its ascent while measuring temperature, pressure, humidity, wind velocity and direction.

The soundings are downloaded on the ground control station, analyzed and visualized before meteorological insights are created. This easy access is missing for radiosondes, which often require meteorological expertise and helium as a resource.



ABOVE: Comparison of radiosonde, Meteodrone, and weather model data. From left to right: temperature, dew point, wind speed, wind direction, relative humidity, and pressure

Operation in inclement weather

Any instrument flying into the atmosphere is subjected to severe weather and needs to be built to withstand the environmental conditions. Meteomatics has been working on tackling these challenges and has delivered a reliable product for the industry.

The company has recently added new de-icing capabilities to its Meteodrone, as propeller blades can accumulate ice at temperatures below 0°C and high humidity. The motor propulsion can deteriorate to the extent that the drone crashes. The Meteomatics drone development team has developed an anti-icing system that is triggered when an icing event is detected. It heats the rotor blades so that the Meteodrone can safely operate in icy conditions.

The customized propellers are vital safety components needed for improved flyability and reliable operation of the anti-icing mechanism, and also to endure high wind speeds. Therefore, Meteomatics has improved the airframe and powertrain composition of the Meteodrone to ensure that they can fly in wind speeds up to 50kts – a specific requirement to fly at high altitudes.

Meteomatics has also selected robust components to ensure that the Meteodrones can operate in low temperatures down to at least -50°C. Thanks to the optimized airframe design, the drone is waterproof and can operate in rain and snow.

Meteobase and convenient operation from the office

Meteorological drone operations require flights that are completely beyond visual line of sight (BVLOS) and preferably without any pilot directly present. Meteomatics achieves this by controlling the aircraft remotely using the Meteobase. It is the 'home' of the drone, providing a communication point so that the drone can be piloted either on-site or remotely from the operation center.

The operation center enables the simultaneous remote monitoring of multiple systems that can be scattered around the globe as long as an internet connection can be guaranteed. Plus, the Meteobase provides a platform for landing, charging and take-off, and protects the Meteodrone from the elements.

In 2020, Meteomatics completed a four-month project remotely operating Meteodrones and taking weather observations in the Illgraben region of Valais, Switzerland. The aim was to measure the topographical changes after a debris flow. Ten significant debris flows were seen over the previous summer – an unusually high number – and Meteomatics' Meteodrone was able to locate these flows and quantify the changes in the terrain. Thus, detailed observations could be made in hard-to-access, remote landscape, and without the need for risky physical observations.

METEOMATICS – PUBLIC-PRIVATE PARTNERSHIP

Meteomatics is proud to work in partnership with NMHS across the world to improve drone design and validate the exciting potential of Meteodrones to resolve the data gap. For example, the company has collaborated with MeteoSwiss and created a scientific paper titled *Improving High-Impact Numerical Weather Prediction with Lidar and Drone Observations*. In addition, it has worked with NOAA's severe storms laboratory to test the Meteodrones in high wind speeds (up to 100km/h) to help with tornado forecasting.

Meteomatics is also receiving interest from academia and research and commercial institutions, as more organizations become aware of the unique capabilities and data offered by Meteodrones.

Radiosonde comparison

To ensure a high quality of data, Meteomatics routinely compares its gathered measurements against model data and, most interestingly, against radiosonde data. The figures above show the data from the radiosonde, Meteodrone and weather model for different meteorological variables. The measurements were taken during the night and clearly depict almost stable stratification in the temperature profile.

Remarkably, there is a high agreement between all three data sources, which is also true for pressure and wind direction. The relative humidity is captured quite well: the Meteodrone agrees largely with the radiosonde up to 3,500m and then it is closer to the model data.

This deviation can be attributed to the spatial drift of the radiosonde, which gets stronger due to increasing wind speed (see third figure from the left, above). These differences can also be seen in the dew point, where again the non-locality plays a crucial role. The Meteodrone guarantees continuous local measurements.

Future outlook

For more than 100 years radiosondes have been delivering insights into the atmospheric structure. They are deployed at least daily all around the globe. These measurements are crucial for weather forecasts and understanding of weather phenomena, and are the gold standard in meteorological applications, reaching heights of up to 30km before being lost.

Even though they are carried away by the wind, their gathered weather data is used in weather forecast models as a single location input. Meteodrones offer an alternative that is truly local, with soundings readily available in high frequencies. Reaching the meteorologically relevant 500hPa level, they become increasingly important as an additional data source for weather prediction. They won't replace radiosondes today, but they already overcome the long-held limitations of conventional weather balloons, and will continue to reach higher altitudes, with Meteodrones expected to reach 10km in the next couple of years. ▮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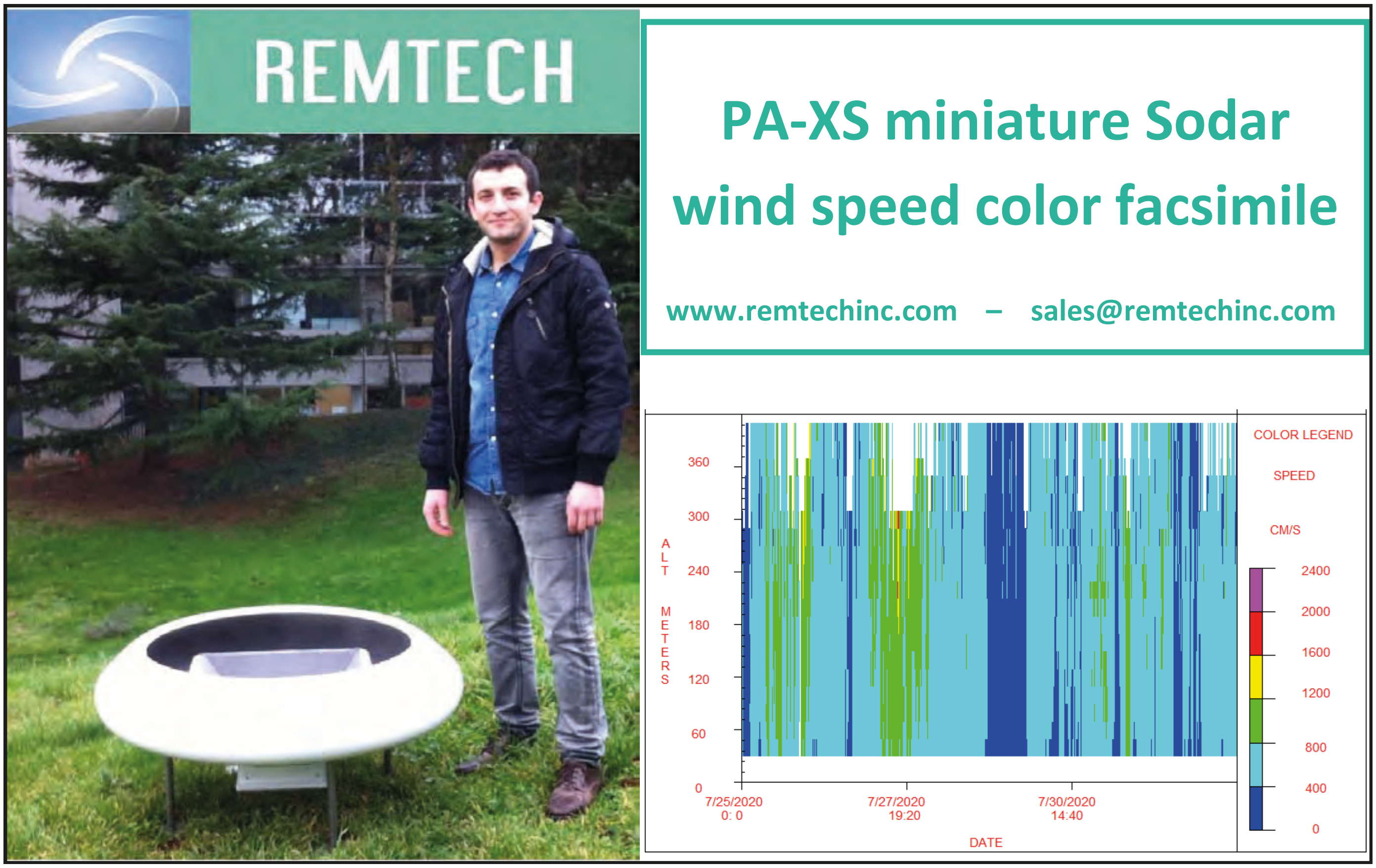
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Dr Arnaud Varé, head of sales mecatronic, Boschung

ALL-IN-ONE solution

Boschung presents a comprehensive atmospheric sensor for road weather information systems, with integrated visibility measurement and self-cleaning features

Launched at Meteorological Technology World Expo in September 2018, the Boschung r-weather has sprung up on roadsides all over the world. When traveling through countries such as Germany, Croatia, Switzerland, the USA and Russia, drivers may see this atmospheric sensor with its double protection shields.

The r-weather is a unique, compact atmospheric multisensor that measures air temperature, relative humidity, dew point and air pressure, as well as precipitation intensity, type and quantity. It also measures visibility in the same enclosure. With an integrated mechanical or ultrasonic windspeed and wind direction sensor, the r-weather is one of the most comprehensive atmospheric measuring instruments around.

Certified according to DIN EN 15518 (winter maintenance standard for road weather information systems), the device offers advanced technologies, such as optical backscattering for analyzing particle types and sizes.

Although it can combine a high number of measurements, the r-weather is also available as a modular system so that only the required parameters can be chosen. Therefore, it can be integrated, with high flexibility, into any larger weather information application. Furthermore, the physical and electronic integration has been made easier with common and open interfaces.

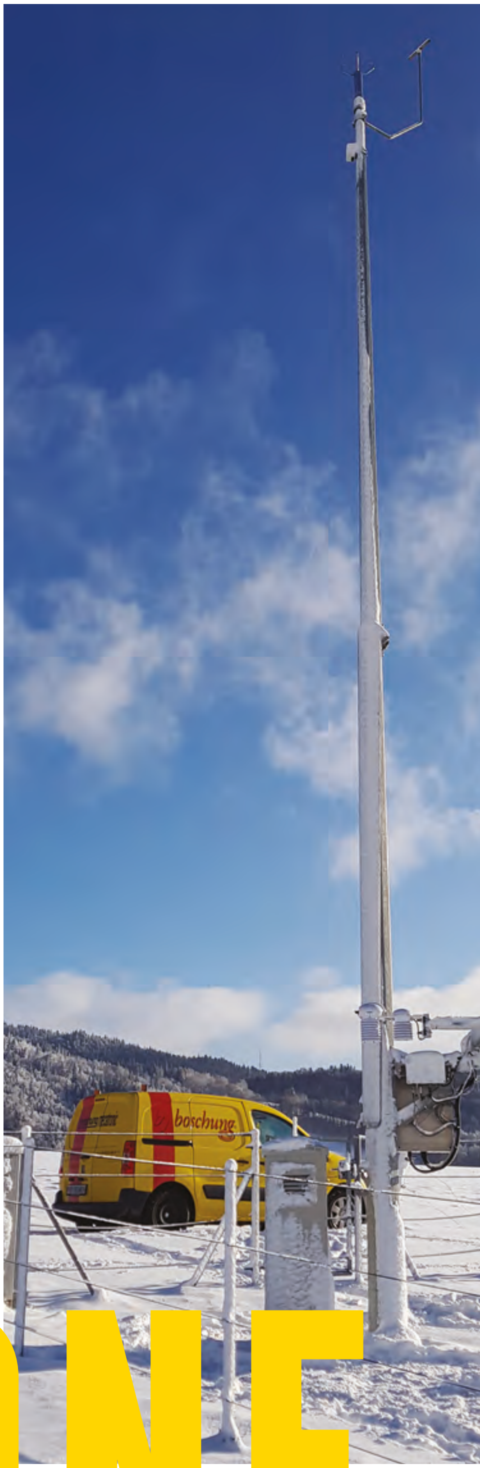
Visibility and freezing fog alarm

The integrated visibility sensor offers new possibilities in terms of security for road users. Combining visibility and other weather parameters enables the triggering of specific alarms. The r-weather has a freezing-fog alarm, for example.

When fog reaches a state of supersaturation (droplets of water suspended in the atmosphere settling on the roadway) and air or ground temperature is below 0°C, there is a risk that fog molecules will freeze on contact with the pavement. The denser the fog (the lower the visibility), the more dangerous freezing fog is for road users. A light fog with fairly good visibility at 200-300m is not icing, but a fog with a visibility lower than 100m increases the risk of frost on the roadway. Under such conditions (which can be set up by the integrator of the device), the freezing fog alarm is triggered by the r-weather.

Field-proven technology

Optical backscattering is the reflection of particles back in the direction from which they came. The different types of particles can be determined because each particle has a different reflection factor and a different size. For example, water reflects almost four times more than ice, although droplets are smaller than snowflakes. The r-weather is therefore able to distinguish



Célia Paccaud

between rain, snow, mixed rain/snow, hail, fog, mist and drizzle, as well as their quantities.

To test the sensor, Boschung was authorized by MeteoSwiss – the official Federal Office of Meteorology and Climatology in Switzerland – to install an r-weather on one of its measuring sites to compare it with the on-site reference meteorological instruments. Based on the analysis of data from nine consecutive days in December 2020, very accurate results were found.

Excellent average differences of 0.06°C were found for air temperature, 0.5% RH for relative humidity and 0.027hPa for air pressure. Despite a limited data set for comparing visibility measurements due to clear weather, fog detection was as good as an 89% match between the sensors. As for the detection of the precipitation types, in 80% of the cases the r-weather presented exactly the same types according to WMO codes.

Overall, after slight adjustments due to delay in measurements, the r-weather is accurate at 96% compared with the reference device. The remaining measurements were different states in the transition between light snow and rain, over an observation period including more than 50 hours of snowfall.

After using the r-weather on another project in the north of Finland, Ilkka Haapamäki, project manager for Suomen Kelitieto, said, "We installed one r-weather at Rovaniemi Airport and were impressed with the quality of the measurements. After comparison with reference stations from the Finnish Meteorological Institute, we analyzed that the types of precipitation are very accurate."

Solving the spider problem

The unique design of the instrument includes distinctive features to reduce the need for maintenance during operations, such as a self-cleaning concept for the optics, a lens heating system and shield protection.

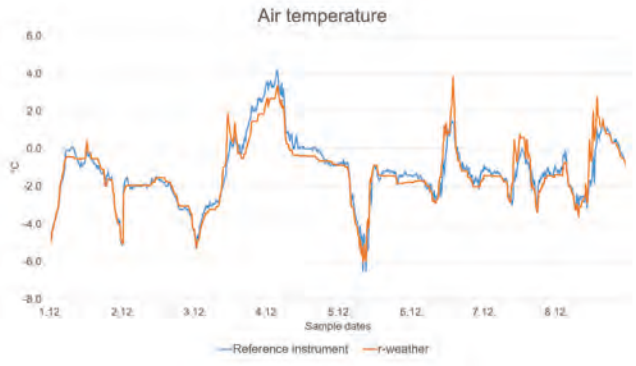
Thanks to an integrated compressor, the optical parts can be automatically cleaned by pressurized air in a very cost-effective way. Executed at predefined time intervals or after detection of debris, this cleaning process ensures that insects, dust, water and snowflakes are kept off the optics. This self-cleaning feature thus solves the common problem of spiders and spiderwebs on current weather sensors. This offers a financial advantage in terms of time saved by not sending maintenance technicians to clean the optics.

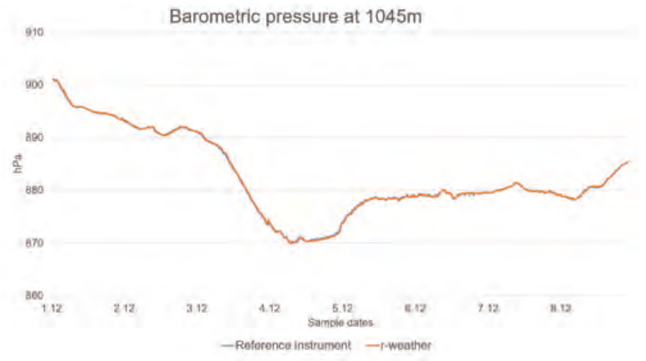
For winter environments, a heating system is available, which prevents the creation of ice and moisture on the lenses. This feature guarantees low maintenance and long-term reliability. "This is very important," highlights Haapamäki. "The sensor works when the outside temperature remains constantly under -15°C for several days."

Finally, although the measurement modules are combined in a single enclosure, they are all

ABOVE: MeteoSwiss's measuring site in Les Charbonnières, Switzerland

ABOVE RIGHT: The r-weather is a compact atmospheric multisensor, which measures air temperature, relative humidity, dew point, air pressure, and precipitation intensity type and quantity. Image: Boschung Group





ABOVE & LEFT: The results of a comparison of the r-weather sensor with MeteoSwiss's reference instruments

RIGHT: r-weather with heated lenses at Rovaniemi Airport in Finland

r-weather EFRO / Seppo Luhtasaajo

protected from one another. Barometric pressure, temperature and humidity are measured by sensing elements that are shielded from direct contact with precipitation and rays of sunlight.

Installation and integration

As a very compact instrument, the r-weather can be easily mounted. The installation effort has been considerably reduced as only one cable from the sensors, including wind measurement, has to be connected to the data processing unit. Furthermore, the device needs a very low power supply. As a result, new weather stations can be easily powered by alternative electricity sources such as solar panels.

The r-weather is used as an element of a weather station. Due to its proven design, measurements can be done in rough meteorological conditions, especially near highways, airports and coastal areas.

In addition to use with Boschung's comprehensive ice early warning systems, the r-weather can be integrated into any weather system. With standard RS232 and RS485 interfaces, as well as open protocols, measurements can be easily transferred to any preconfigured processing unit. Examples of r-weather integrated into third-party systems can be seen on Polish roads or at Milan Linate Airport.

Where does the name r-weather come from?

Boschung is headquartered in the middle of Switzerland, at the crossroads of many different cultures. In the case of the r-weather, the 'r' comes from the pronunciation of that letter with a French accent, recalling an atmospheric sensor installed in the 'air'.

The r-weather forms part of a series of Boschung sensors that also includes the r-condition, a contactless pavement surface condition sensor, and the r-snow, a snow depth measurement sensor. ▮

Acknowledgment

Boschung would like to thank MeteoSwiss for providing the data from the reference sensors of the measuring station in Les Charbonnières, Switzerland, where the r-weather was tested during one winter.

James Zog, James Sun, Ding Ling, Zoglab

DREAM machines

Zoglab highlights the key technological developments and recent applications of meteorological observation technology based on UAV platforms

Rotor-type weather observation UAV, take-off and landing platform and ground remote control station

The most common high-altitude weather observation methods are currently sounding balloons, weather planes, radiosondes, weather radar, weather rockets and weather satellites. Although each method successfully obtains quality data in daily weather observation, the traditional approaches still exhibit some shortcomings. For example, a sounding balloon is commonly used for vertical profiling, yet it suffers from a small carrying capacity, short observation times and an uncontrolled flying path.

As early as 1994, NASA tried to use a large unmanned aerial vehicle (Perseus B) to carry out earth science research, storm tracking and atmospheric sampling activities. The study proved that the UAV had excellent performance in terms of altitude, performance and payload capacity, making it an ideal platform for weather observation at various altitudes. With the advances in UAV technology, research institutions and enterprises from many countries have joined the exploration and application of UAVs in meteorological observations. UAVs equipped with meteorological equipment have become a new low-cost and highly flexible method of weather observation.

Meteorological UAV design

Based on flying heights and carrying capacity, different types of UAV platforms – such as rotary wing, hybrid wing and fixed wing – can be used to design meteorological observation systems. Large fixed-wing UAVs have excellent stability and carrying capacity, and are suitable for typhoon detection, plateau, uninhabited area and strong convective weather observation, artificial weather modification and boundary layer (aerosol, atmospheric vertical profile) detection, and drop-down sounding applications.

Hybrid-wing UAVs are suitable for low- and mid-level high temperature and humidity detection, artificial weather detection and regional radar calibration applications. Rotary-wing UAVs have low-cost and flexible applications, and are suitable for meteorological emergency support, observation services and image materials collection.

From the perspective of application and user acceptance, hybrid-wing and multirotor UAVs have broader prospects for low- and medium-altitude weather observation.

The multirotor meteorological detection UAV (UAV6000) is designed to observe multiple meteorological parameters up to a height of 500m. It comprises a meteorological module, atmospheric composition module, flight control platform, data processor and data analysis platform. The system is modularized and data is digitized. The design integrates the temperature,

humidity, pressure, wind speed and wind direction meteorological sensors with SO_2, NO_2, CO, O_3, CO_2, PM2.5, PM10 and other atmospheric composition sensors.

It uses GPS positioning to hover at the specified height to collect data, which it transmits to the ground remote control station in real time through a wireless transmission module. It is equipped with a high-definition aerial camera, meaning it can capture live images, sound and other auxiliary materials.

The UAV9000 hybrid-wing meteorological observation UAV is designed for observation of temperature, humidity and pressure at a height of 8,000m with wide area coverage and long observation time. It mainly comprises a weather cabin, UAV platform and ground remote control station. The flight route can be designed according to the target area, and the corresponding weather data can be collected in real time.

Calibration and verification

The UAV platform has a relatively complex structure. There are two major difficulties in the loading design of the weather module. One is that the structure of the platform affects air mobility and reduces the response speed of the sensor. The other is that the rotation of the rotor during flight affects the accuracy of the wind field data.

From 2018 to 2019, Zoglab carried out hundreds of comparison and calibration tests. Through data comparison with wind towers, lidars and tethered airships, key weather data from UAV has been verified as consistent with routine meteorological observation requirements.

ABOVE: Hybrid-wing weather observation UAV

BELOW: Comparison test between UAV and wind tower, lidar and tethered airship

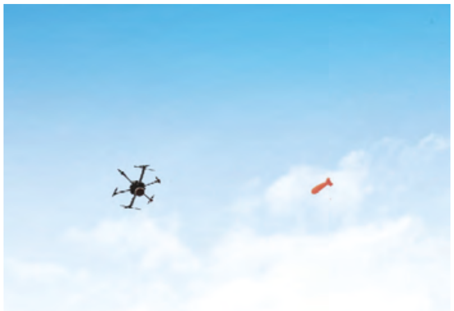
Meteorological UAV applications

From 2019 to 2020, the multirotor and hybrid-wing meteorological detection UAVs developed by Zoglab carried out numerous scientific research projects with partners including meteorological departments, universities and scientific research institutes. When traditional meteorological equipment cannot meet the observation requirements involving special environments such as rivers, deserts and forests, the low power consumption, high performance and high integration characteristics of weather observation drones have demonstrated their ability to obtain rich and comprehensive weather data.

PROJECT 1: **Research on wind effects on organic particles and chemical composition in the Amazon rainforest**
DATE: September-October 2019
EQUIPMENT: UAV6000 multirotor weather observation UAV

This project was initiated by Harvard University Massachusetts, USA, with the participation of University of California Irvine, Amazon State University and Zoglab. It mainly studied the impact of human activities on primitive rainforest climate and organic gas diffusion. The weather data, especially wind data, was used to study how organic particles and the chemical composition of particles are spreading in the prime rainforest environment, and how human pollution is affecting the local environment.

UAV6000 collected the wind data during the 30-day study. The data provided the crucial evidence that enabled the leading Harvard



ABOVE: An international team traveled to Manaus, Brazil, to carry out UAV research in the rainforest

BELOW: Wind speed and direction data from the UAV and lidar used in the Amazon rainforest project

ABOVE RIGHT: A UAV was deployed both day and night for vertical observation in the largest desert in China

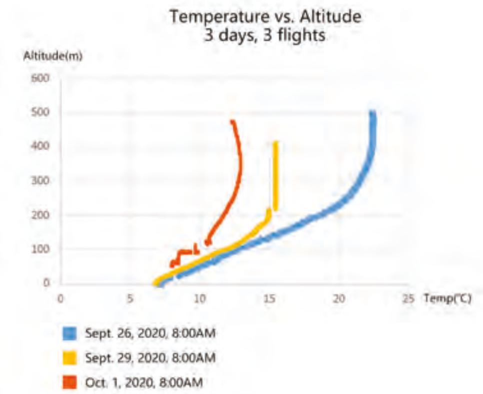
RIGHT: Temperature vertical profile under 500m

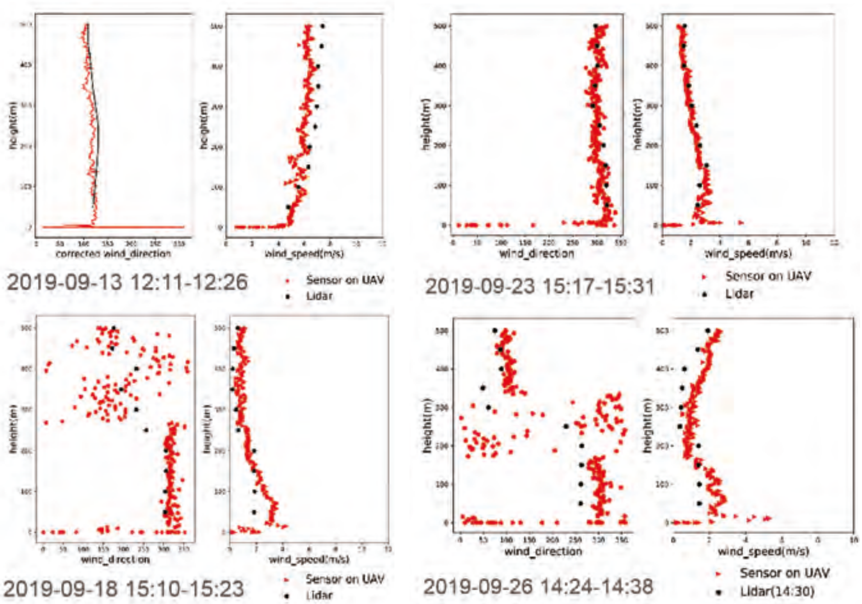
research group to build the gas diffusion model in the rainforest. Through analyzing the change trend of wind direction data from 200m to 500m in multiple periods on September 18 and September 26, 2019, the research group verified the existence of the local river breeze phenomenon that had long been theorized to exist.

PROJECT 2: Climate research project in Taklamakan Desert, Xinjiang, China
DATE: September 22 to October 5, 2020
EQUIPMENT: UAV6000 multirotor meteorological UAV
The project was undertaken by the Urumqi Institute of Desert Meteorology, China Meteorological Administration, Institute of Atmospheric Physics, Chinese Academy of Sciences and Zoglab. Three meteorological observation UAVs were used to carry out a 15-day vertical observation in the desert in northwest China.

After selecting the 08:00hrs sample data from September 26, September 29 and October 1, 2020 UAV flights and performing analysis, it can be seen that the temperature is cooler near the surface than at a height of a few hundred meters in early morning hours. This trend is the opposite of what we observed for temperature vertical profile in the afternoons, validating the day and night temperature inversion for temperature in the desert areas.

PROJECT 3: Artificial weather modification project in Hainan Island, China
DATE: December 9-16, 2020
EQUIPMENT: UAV9000 hybrid-wing meteorological UAV
The project was implemented in Hainan, China, using a hybrid-wing meteorological observation UAV to observe the temperature and humidity changes of the target cloud. The weather data was used to predict whether there was a 'thunderstorm cloud' and provide a decision basis for man-induced weather modification.





Conclusion

As a new type of weather observation method, meteorological UAVs can provide diversified, localized and customized services in real time to make up for the shortcomings of traditional weather observations. After a large number of lab tests and field research projects, UAV6000 and UAV9000 meteorological observation UAVs meet the requirements of tropospheric meteorological observation under 8km.

The weather observation UAV has good maneuverability. Its applications can extend from general weather observation to other special applications such as artificial weather modification, weather radar calibration and emergency weather support. ■

Dr Dirk Brändlein, COO, nowcast

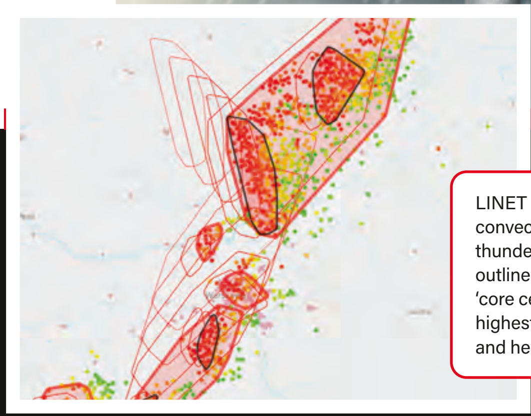
All HAIL

The LINET 3D total lightning detection technology from **Nowcast** offers a precise and sophisticated solution for high-precision lightning data. It also has the ability to measure the altitude of intra-cloud lightning, enabling it to provide useful and timely hail warnings

"Where there is lightning, there is hail too," says Dr Felix Keis, meteorologist and lightning detection network specialist at Nowcast in Munich. Water, ice particles, graupel and sometimes hail occur in every thunderstorm. But will hail form in a way that makes it dangerous when it hits the ground? The probability of dangerous hail reaching the ground is largely determined by the severity of the thunderstorm cell; for example, by the strength of the updraft winds and height of the cell. At the same time, these properties have a clear influence on the character of the lightning formation within the thunderstorm, such as the number and height of intra-cloud strokes. Thus, the severity and hail probability of a certain thunderstorm can be determined by using an appropriate lightning detection system, according to Dr Keis.

Nowcast's LINET is a large-area high-precision lightning detection system also used to determine the severity and hail probability of thunderstorms. It enables the determination of intra-cloud stroke altitudes without the need for separate VHF antennas, which are usually necessary for lightning detection systems that can deliver the emission height information of IC-strokes. VHF is expensive and only available for rather small areas around the sensor locations.

LINET classifies the severity of a thunderstorm and probability of hail by using different parameters. These could be the number of intra-cloud strokes and their ratio to cloud-to-ground strokes within a thunderstorm system, as well as the average altitude of the intra-cloud strokes.

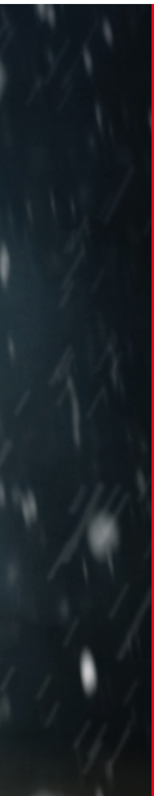


LINET is able to identify the convective core of a thunderstorm (see black outlined polygones). These 'core cells' represent the highest risk of hail, gusts, and heavy precipitation

The intra-cloud altitude parameter for sophisticated severity assessment is typically not available in other lightning detection systems for large areas. Compared with other technologies such as radar, LINET provides the lightning data and derived hail-probability information and warnings without delay and in real time.

These game-changing abilities not only enable an excellent severity assessment of thunderstorms, but also enable LINET's 'sub-cell identification'. A sub cell is the localized heavy convective core area within a thunderstorm and enables the separate detection, tracking and nowcasting of this most dangerous zone. This opens up new possibilities for associated warnings and actions.

The following case study is just one example of the high value of ultra-precise lightning detection data. Nowcast provides its LINET technology, as well as data and software services, to clients all over the globe. National weather services, energy providers, wind parks and insurance companies, as well as the scientific community, are part of nowcast's long-standing and ever-growing customer and partner portfolio.



A SPECIFIC USE CASE: AIOI/TOYOTA INSURANCE SERVICES GERMANY'S CAR DEALERSHIP HAIL WARNING SERVICE

AIOI/Toyota Insurance Services Germany insures its customers (car dealerships) against vehicle, building, liability and environmental damage. Since 2014, the company has been obtaining high-precision thunderstorm warnings from nowcast. AIOI is not concerned about lightning itself, but rather the hail risk and the added value for insured car dealerships through timely warnings.

Robert Lieb, right, who has been with AIOI/Toyota Insurance Services Germany for seven years, is the manager of the commercial unit, and is constantly looking at ways to optimize customer service and minimize hail damage. In an interview with nowcast, he explains how LINET enables this.

What is the focus of AIOI within the auto dealership sector?

Our multi-risk policies protect our customers against elementary and existential damage and thus cover a major risk for car dealerships. In addition to the actual settlement of claims, a special focus for us is placed on our loss prevention services.

Even if the insurance company could cover a concrete financial loss that has occurred, there are still portions of the loss that cannot be covered by the insurance company, such as image damage, loss of time or even simply value-reducing portions of a loss that a car dealership is left with. That's why we put a lot of effort into optimizing our prevention offerings. One important component is nowcast's hail warning service, because hail is very dangerous for car dealerships.

ABOVE & RIGHT: Nowcast provides thunderstorm and hail risk warning services to AIOI/Toyota Insurance Services Germany to help its clients protect their assets and reputation

How did the collaboration between AIOI and nowcast come about?

In 2013, the German insurance industry faced one of the worst hail years in a long time. As a direct consequence of this, we at AIOI put hail prevention at the top of our list of priorities.

We were already covered with a thunderstorm warning service from another vendor, but the accuracy and reliability of that service just weren't good enough. It quickly became clear that nowcast's sophisticated, patented technology would enable the accuracy and reliability needed so that hail warnings would not cause displeasure among car dealerships due to inflationary frequency, bringing a whole new level of credibility to this service offering.

How do you describe the objective of nowcast's hail warning service for your customers?

Our objective as an insurer is clear: we want to send our car dealers a precise hail warning that allows them to protect as many vehicles as possible. The added value for the dealers lies not only in a lower loss ratio, but also in higher

Nowcast's patented and ultra-precise lightning detection technology, LINET

customer satisfaction and image impact. Just think about how disappointed you would be if the delivery of your new car was announced for tomorrow and this joyful event gets spoiled by hail damage. Nowcast's hail warnings enable car dealerships to store and protect particularly expensive vehicles or those about to be delivered.

Can you also present the service from a numbers perspective?

Perhaps this is a good example: on average, hail damage with normal hail intensity costs the insurance company about €1,500-€2,500 [US$1,800-US$3,000] per car, not including the damage to the dealer, such as depreciation, etc.

If a medium-size dealership with around 50 vehicles manages to protect 20% of its vehicles in the event of hail due to our timely nowcast hail warning, this quickly results in approximately €15,000-€20,000 [US$18,000-US$24,000] savings for the insurance company due to the prevented hail damage. And the dealer saves about €250-€500 [US$300-US$600] depreciation per vehicle and also parts of the deductible. Thus, for the dealer, a four- to five-figure amount is saved in total. In addition, there is the excellent customer service and the avoided image damage, as well as saved trouble and time.

What makes nowcast's hail warning service so effective?

Our former provider of thunderstorm warnings was unable to offer warnings of the quality and accuracy required to reduce the damage to an absolute minimum. After all, if such an alert is transmitted too often without justification, such a service all too quickly turns into a burden and gets ignored, and this clearly misses the target.

With nowcast, trust could be brought back into the hail warning service and raised to a whole new level. Different warning levels provide the car dealership with an optimal basis for decision making without having to make meteorological assessments and interpretations itself. The service is fast, simple and precise.

How would you rate the cooperation with nowcast?

I can say without hesitation: excellent. From the beginning, we have had an extremely cooperative partnership with a direct line. Despite its global presence, nowcast is very close to the customer, takes care of customer requirements quickly and in a solution-oriented manner, and always tries to see things through our eyes.

In our daily business, the cooperation with nowcast is uncomplicated and pragmatic. This is also important for this service to run routinely and reliably. ∎

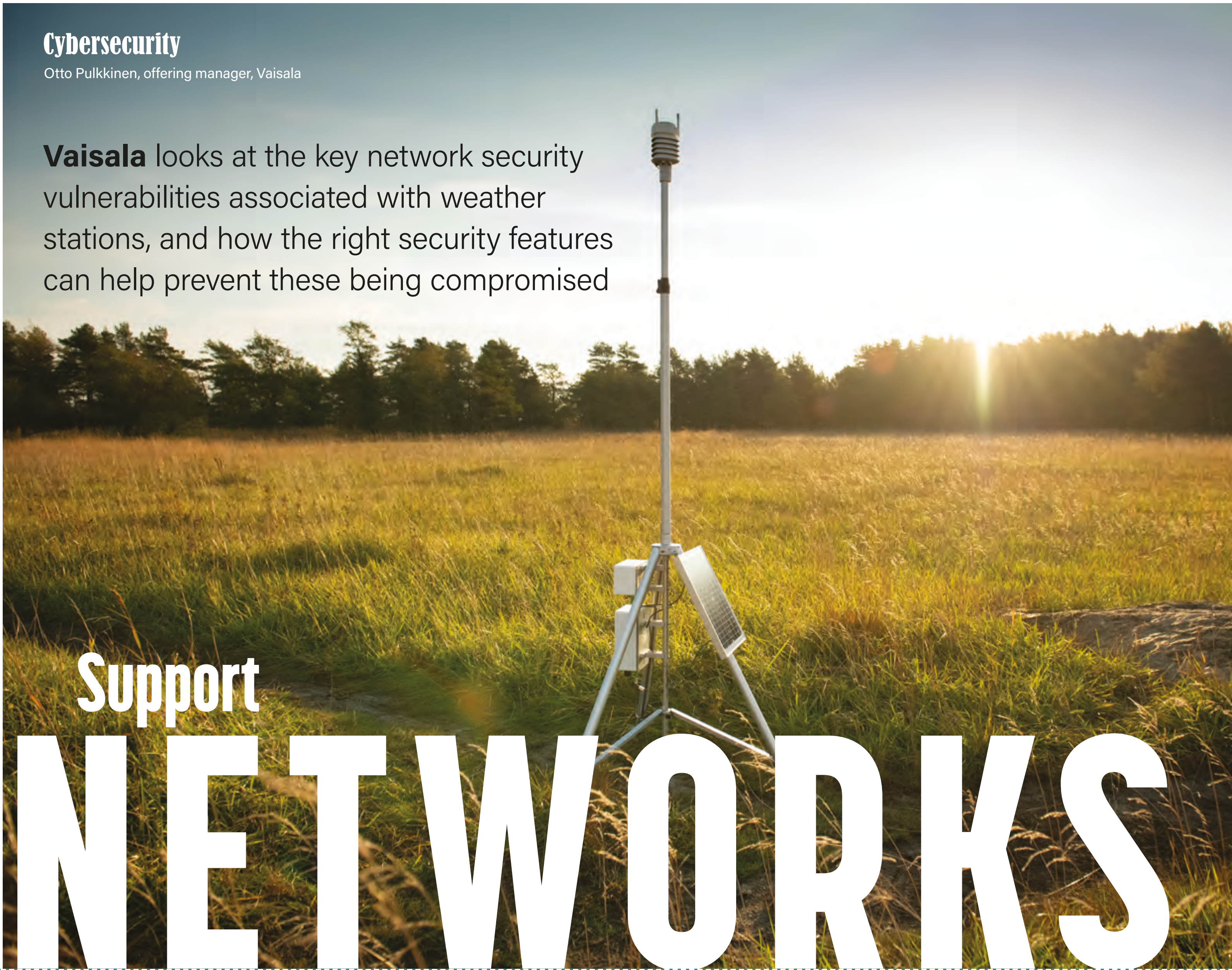
NOWCAST AT A GLANCE

- German company specialized in ultra-precise lightning detection (hardware and software)
- Patented 3D total lightning detection (CG and IC, including emission height)
- Accuracy of 75m on average; detection efficiency down to 2.5kA strokes
- Real-time operation, as well as historical lightning data
- Provides data services, complete autonomous networks and hybrid solutions
- Trusted by numerous customers around the world

> "Nowcast's hail warnings enable car dealerships to store and protect particularly expensive vehicles or those about to be delivered"

Robert Lieb, AIOI/Toyota Insurance Services Germany

Otto Pulkkinen, offering manager, Vaisala



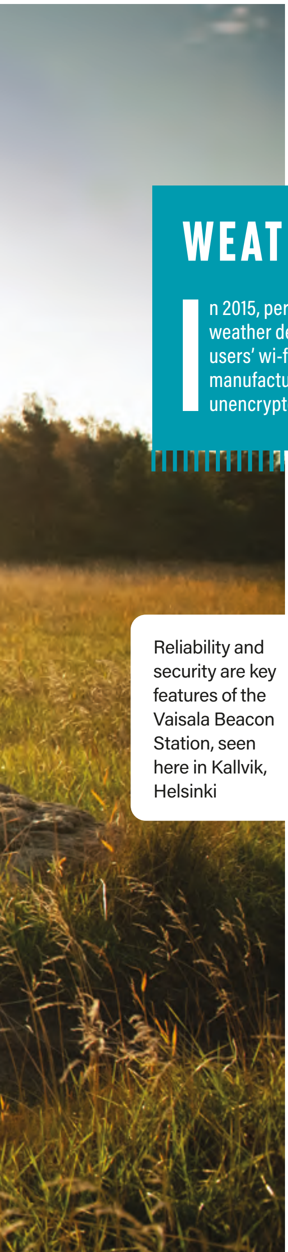
Vaisala looks at the key network security vulnerabilities associated with weather stations, and how the right security features can help prevent these being compromised

Support NETWORKS

Network security is a growing concern for businesses of all sizes. Internet of Things (IoT) systems are growing globally and have become specific targets for cyberattacks. Cyber threats can include ransomware, manipulation of measurement data in control applications and botnet attacks instigated with malware. The cost of successful attacks can be extreme: IBM estimates the average cost to a business is around US$3.86m for a data breach.

Because of this, businesses may be hesitant to integrate any additional devices that exchange data into their current networks. Furthermore, even if a device is necessary, businesses must compare the potential risk versus its benefits.

The Vaisala Beacon Station tracking weather conditions at Vuosaari Harbour in Helsinki, Finland



Reliability and security are key features of the Vaisala Beacon Station, seen here in Kallvik, Helsinki

WEATHER DEVICES IN THE NEWS

In 2015, personal, consumer-grade weather devices were sending users' wi-fi passwords back to the manufacturing company through unencrypted connections. This situation is one of a long list of basic security lapses discovered in smart home devices and other internet-connected appliances in the last decade.

In the meteorological sector, attention to cybersecurity should extend from IT infrastructures to weather and environmental observation networks and data. Weather stations can be classified according to how accurate, configurable and secure their inputs and outputs are. There are three key types of station: consumer, professional and reference.

Consumer-grade weather stations. These are advertised as a cost-effective option, simple to install and maintenance-free. They provide limited weather data, which usually includes cursory measurements taken at an outdoor station and transmitted to an indoor display. They can also connect to the internet to monitor weather conditions from anywhere.

Professional-grade commercial weather stations. These go beyond the basics and have vast capabilities. They are installed on-site and provide hyperlocal data that is vital for safety and planning. They are built to withstand all kinds of weather and work with a connectivity preference that suits users' needs.

Reference-grade weather stations. These are the most accurate, extensible and complex weather stations available and are typically used by meteorological institutes and associations for climatological observations.

Personal, consumer-grade stations can create security risks when connected to a public network, for example, by transmitting user credentials over an unsecured connection. Professional-grade systems are backed by much more security.

Security vulnerabilities

However, it is not easy to make the case that professional-grade instruments are always safer. When it comes to IoT, attacks can happen on any device. But it is critical to know that experts develop these devices with the right security measures in mind.

An attacker's motivation is not only about gaining access to an application; it is also about controlling the infrastructure. With that in mind, there are many areas of risk to consider. According to the Open Web Application Security Project (OWASP), there are 10 key things to avoid when building, deploying or managing IoT systems (see *OWASP's Internet of Things Top 10 Vulnerabilities*, right).

Security features in weather stations

With access to critical weather data, key individuals can use that information to forecast and guide the decision-making process. Businesses, industry and government agencies that want to add weather stations to their systems must thoroughly research the proper security parameters.

The Vaisala Beacon Station is designed with security in mind. When researching which weather station is right for you, consider these critical security features to ensure business safety.

System integrity – gateway certificate for device identity: The Beacon Station offers a secure identity based on a cryptographic certificate. Each gateway uses this certificate to provide proof of identity and maintain security from the device right through to the cloud software.

Systematic user management – secure management of user credentials: Data is accessed through the Wx Beacon Station application using secure credentials. The application does not store credentials or transmit unencrypted credentials at any time.

Unique access code: Users gain access to the Beacon Station through a local maintenance connection based on securely managed user credentials. A unique, one-time access code is generated to safeguard the creation of users' initial credentials.

Secure interfaces – TLS-encrypted web interfaces: Unlike some of its competitors, the Beacon Station uses encryption in all of its interfaces. This feature protects against eavesdropping, listening and inserting any data.

Secure software lifecycle – continuous updates: The Beacon Station provides continuous security improvements and patches when any vulnerabilities are discovered. A secure software lifecycle starts with an internal update process, tools and mechanisms.

Remote gateway software upgrades with encrypted installation packages: The Beacon Station's system software can be upgraded remotely through a secure process. Software packages are encrypted and signed, meaning that only secure upgrades provided by Vaisala are deployed.

The Vaisala Beacon Station

The Vaisala Beacon Station provides the reliability and security that users need. This compact weather station provides industry-leading system reliability and data security to keep information accessible and intact. Data security mechanisms and several built-in features deter unauthorized access and keep data safe. And with plug-and-play installation and accuracy, the Beacon Station gives users a simple, low-maintenance platform that provides high-quality measurements with efficiency and connectivity at every turn. ▮

OWASP'S INTERNET OF THINGS TOP 10 VULNERABILITIES

1. Weak, guessable or hardcoded passwords
2. Unsecured network services
3. Unsecured ecosystem interfaces
4. Lack of secure update mechanism
5. Use of unsecured or outdated components
6. Insufficient privacy protection
7. Unsecured data transfer and storage
8. Lack of data management
9. Unsecured default settings
10. Lack of physical hardening

MISSING LINKS?

Commercial microwave links from cellular telecoms networks offer potential for superior rainfall forecasting

ABOVE: Ruben Imhoff, Wageningen University & Research

LEFT: CMLs have proved useful for providing rainfall information close to the ground surface

Information on where, when and how much rain will fall in the coming hours is crucial for the infrastructure, agriculture and water management sectors. However, the most disruptive events are often the most challenging to forecast. These are generally high-intensity rain showers, which can develop and dissipate in a timeframe of half an hour.

One new approach to forecasting such rainfall events is through the use of commercial microwave links (CML) from cellular communication networks. Although the purpose of CMLs, which connect telephone towers, is not to measure rainfall, the signal from one tower to another is attenuated by, among other factors, rainfall. Mobile network operators keep track of this attenuation to gain insights into the reliability of their networks.

For meteorologists, the information about the signal attenuation of these CMLs can help determine the amount of rain that has fallen based on the attenuation in the signal. Thus, what may look like a burden for the telecoms industry actually provides a wealth of information for the meteorological sector.

Estimating rainfall and deriving country-wide rainfall maps from the CML data is an increasingly well-studied topic, but researchers from Wageningen University & Research, Deltares and Royal Netherlands Meteorological Institute (KNMI) have gone a step further and used the rainfall estimates from the commercial microwave links for rainfall nowcasting.

A test on 12 summer rainfall events in the Netherlands showed that these nowcasts have a performance that is comparable to rainfall nowcasts with weather radar data, particularly for high-intensity rainfall.

The study also showed some limitations in the short-term rainfall forecasts based on the CML data. Whereas radar gives observations for every square kilometer, including above bodies of water, CMLs are not homogeneously spread over a region and are even absent above large bodies of water. The CML network density is higher in urban areas than in rural areas. This means that rainfall estimates are generally more accurate in urban areas than in areas with a sparser CML network, which also affects the nowcasts.

The weather radar refreshes every five minutes, whereas the CML data was recorded every 15 minutes in this study. However, it is possible to increase the frequency to every five minutes, which could improve the nowcasts.

The way forward is to combine the data sources into a rainfall product that is then used as input for the nowcasting algorithm. A major advantage of the CML data is that the observations take place close to the ground, whereas other remote sensing techniques, such as radar, observe rainfall at higher altitudes. The CML data could complement the radar rainfall nowcasts when radars are present.

Furthermore, in regions where there are no radars or even rain gauges, but where there are cellular communication networks, the short-term rainfall forecasts with the CML data can offer an alternative. In these areas, the limitations of nowcasting with CML data could be overcome by using satellite data as a complementary data source.

The added value of these short-term rainfall forecasts lies in applications such as water management. These applications are already being investigated for radar rainfall nowcasting, but an important next step will be to test them with CML nowcasting.

The study is ongoing in Sri Lanka, Nigeria and Papua New Guinea. ∎

Author: Ruben Imhoff, a PhD candidate at research institute Deltares and Wageningen University & Research, Netherlands

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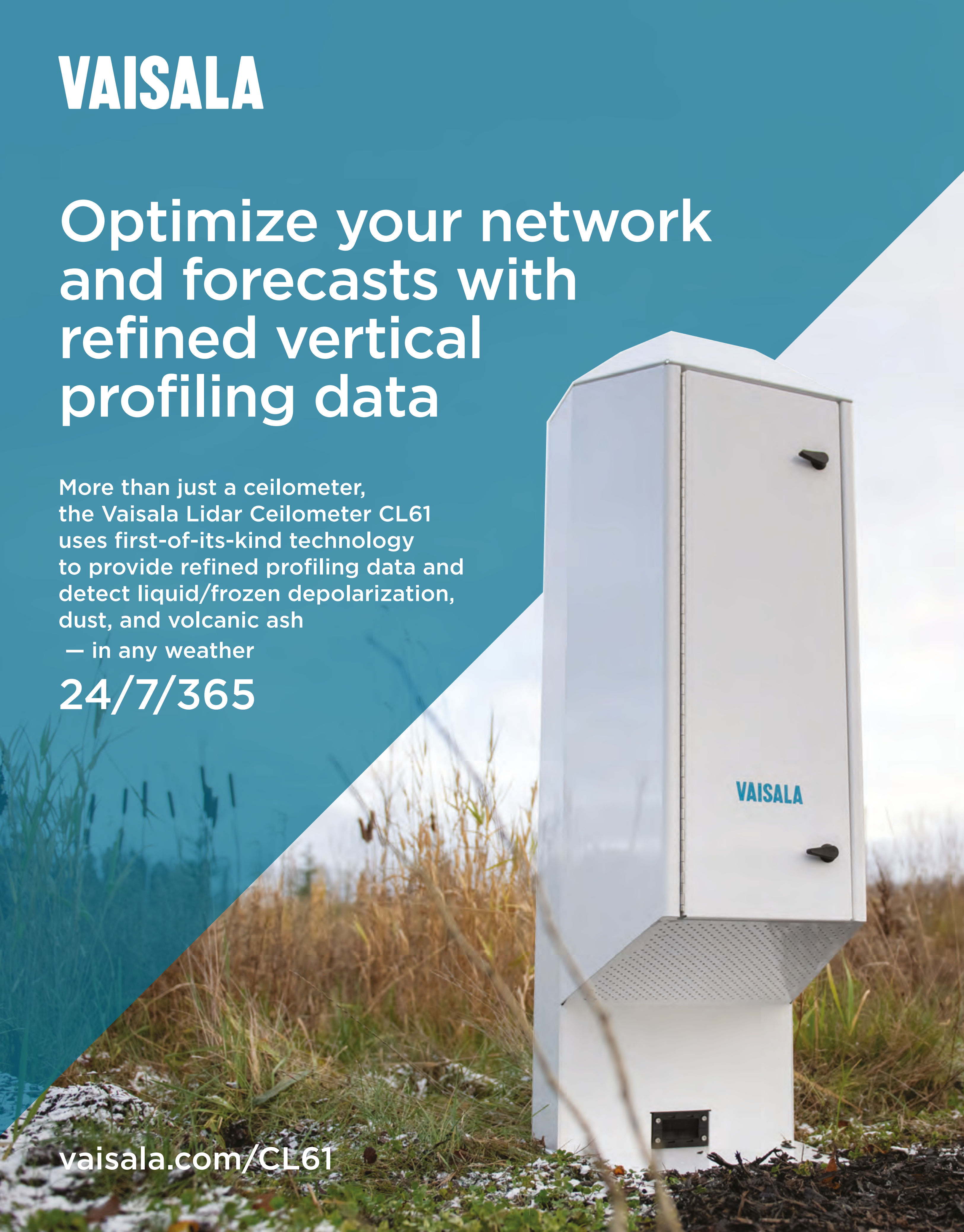
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