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Meteorological

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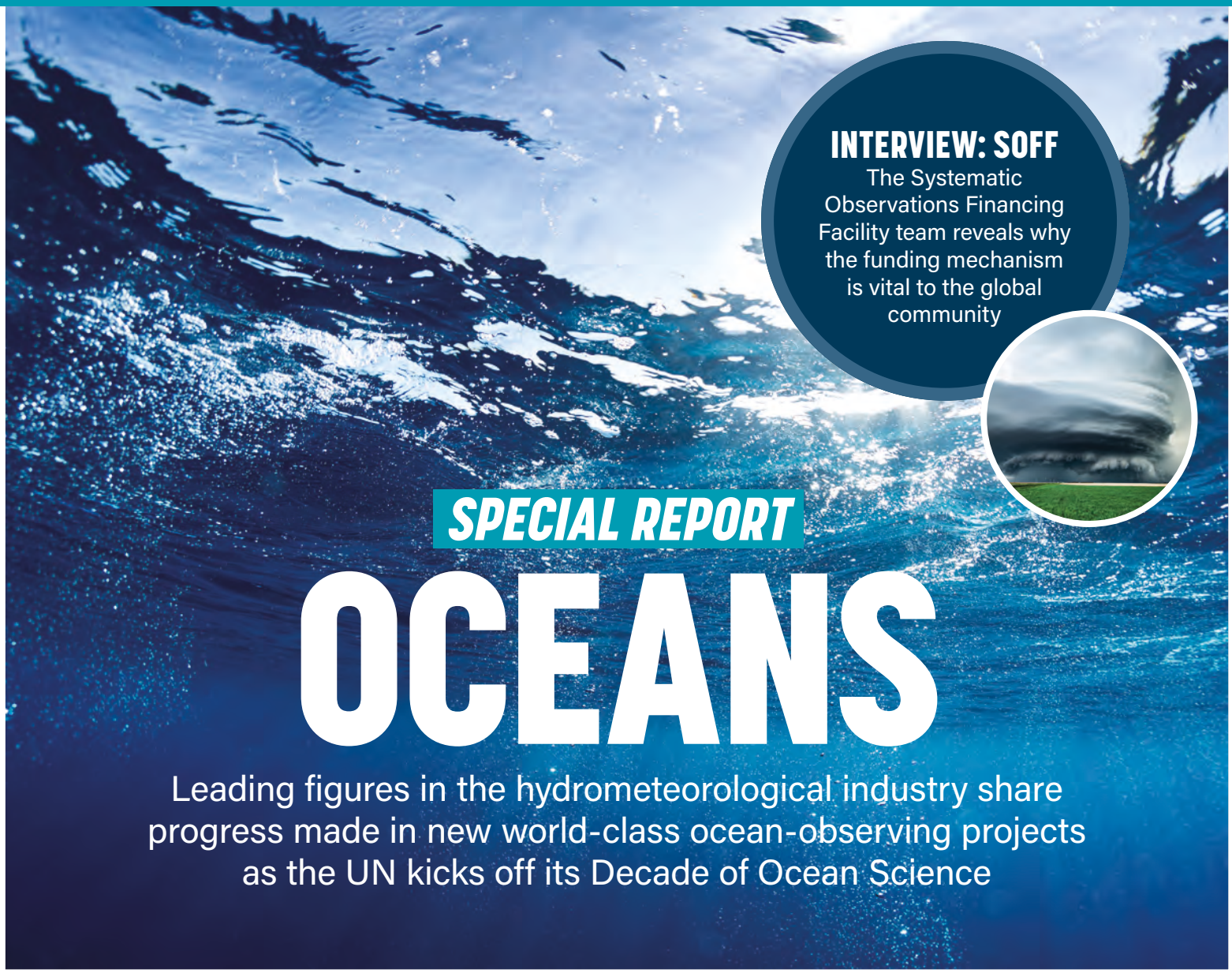
TECHNOLOGY INTERNATIONAL



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SPECIAL REPORT: OCEANS

Meteorological Technology International speaks to some of the leading figures in the hydrometeorological industry involved in ocean observing projects as the UN kicks off its Decade of Ocean Science for Sustainable Development

Helen Norman

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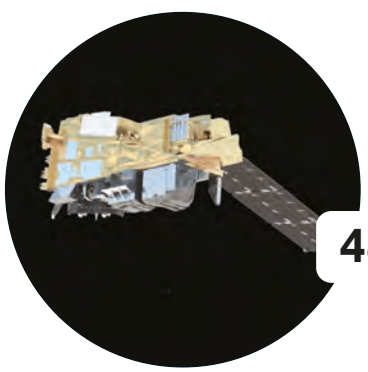

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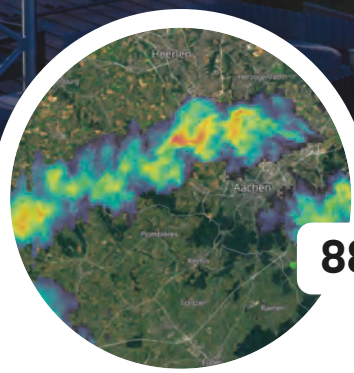

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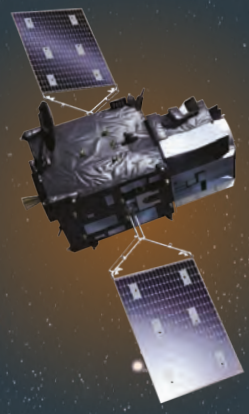
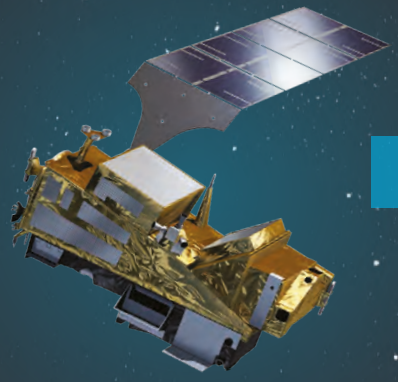


Meteosat Third Generation, carrying the Sentinel-4 instrument



Metop Second Generation, carrying the Sentinel-5 instrument

The Sentinels are funded by the European Union's Copernicus programme.

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The Forecast

The blue economy, which relates to the exploitation, preservation and regeneration of the marine environment, is estimated to be worth around US$1.5tn globally per year. It accounts for more than three-quarters of world trade and provides livelihoods for more than six billion people. These figures highlight the importance of the oceans, but unfortunately, despite improved management and conservation actions, the UN's First World Ocean Assessment found that much of the ocean is now seriously degraded.

In June, the UN officially kicked off the Decade of Ocean Science for Sustainable Development, which aims to strengthen the management of our oceans and coasts for the benefit of humanity. The Ocean Decade will provide the international cooperation needed to develop the scientific research and innovative technologies that can connect ocean science with the needs of society.

The success of the Ocean Decade relies on the contributions of many stakeholders, including scientists, policymakers, civil society, funders and the private sector. The hydrometeorological sector is playing a key role here, as it seeks to increase the quantity and quality of ocean observations and the analysis of the data.

In this issue of *Meteorological Technology International* I spoke with some of the leading scientists working on projects to better monitor the oceans (see *All At Sea*, page 34). One of those scientists is Mathieu Belbéoch, who leads OceanOPS – the international center of excellence for coordination and monitoring of meteo-oceanographic observing systems that are part of the Global Ocean Observing System (GOOS).

Belbéoch highlights the key projects being undertaken by OceanOPS currently and outlines some of the main aims from its newly released strategic plan. He also speaks about some of the main challenges faced by his team and by the ocean monitoring community globally, the biggest one being funding. "We need to stabilize more funding as currently the limited resources not only impact OceanOPS development, but also limit the achievement of an integrated global ocean observing system," he says. "I look forward to seeing the development of a funding mechanism within the WMO to help some new countries contribute to the system with floats, drifters, weather stations, etc."

The funding mechanism that Belbéoch is referring to is the new Systematic Observations Financing Facility (SOFF), which aims to support countries to generate and exchange basic observational data critical for improved weather forecasts and climate services (see *Value for Money*, page 26). Spearheaded by the WMO, SOFF is a commitment and priority of the Alliance for Hydromet Development, which is a coalition of major climate and development finance institutions. The launch is planned for the UN Climate Change Conference (COP26) in November 2021.

"At the moment there are severe gaps in the observing system, especially in Africa, the Caribbean, Pacific Islands and in some parts of Latin America. This means that the quality of the early warning services is poorer and has a negative impact on weather forecasts worldwide," says Professor Petteri Taalas, secretary-general of the WMO.

The better provision of early warning systems is also a key aim of the meteorological community as part of the UN's Ocean Decade. Around 40% of the global population live within 100km of the coast, according to the WMO, so there is a dire need to protect communities from coastal hazards, such as waves, storm surge and sea level rise, through improved multi-hazard early warning systems and impact-based forecasts.

While work begins on the plethora of projects being undertaken as part of the UN Ocean Decade, Meteorological Technology World Expo has begun work on a new project of its own – Meteorological Technology World Expo North America. This event will be held in Chicago on May 4 and 5, 2022 and will build on the European show, which has been held annually for the past 10 years. Visit www.meteorologicaltechnologyworldexpo.com/usa/ to find out more. We hope to see you there!

Helen Norman, editor-in-chief

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Tara Craig

RIGHT: The UK Met Office currently has three Cray XC40 supercomputing systems capable of more than 14,000 trillion arithmetic operations per second

BELOW: Supercomputing power has advanced greatly over the years. The Met Office's English Electric KDF9 computer installed in 1965 had a speed of 60,000 arithmetic operations per second

SUPER POWER

The supercomputer will have over **6PB** of memory and is built in four quadrants to maximize operational resilience

The UK Met Office's new supercomputer aims to provide more accurate weather forecasting and a better understanding of climate change

The UK's Met Office has signed a multimillion-pound agreement with Microsoft for the provision of a world-leading supercomputing capability. Expected to be the world's most advanced supercomputer dedicated to weather and climate, it will be in the top 25 supercomputers on the planet and, once at full capacity, will be twice as powerful as any other in the UK.

A £1.2bn (US$1.7bn) UK government grant will fund the supercomputer's lifespan, covering not just the technology but also the wider costs associated with the work required to migrate to the new machine and run the program.

The supercomputer contract is for a decade rather than the five years usually associated with machines of this type. A refresh point halfway through will enable the Met Office to review the supercomputer's performance to date and decide what is required from the second-generation machine.

According to Nic Bellingham, supercomputing technology lead at the Met Office, the functions of the new supercomputer can be broken down into two areas. She explains, "We have our operational forecast models, the things that we run day in, day out, 24/7 – those are the models that we use to

provide all of the forecasts that we carry out for the public, for industry, the things that we use to drive our weather warning decisions, and the commercial products that we sell to customers.

"Alongside that is the research that we do, undertaken both by our own scientists and by people that we collaborate with, such as our academic and industry partners."

> "We would describe the supercomputer as 'the Ferrari rather than the Ford Focus' of the computing world"
>
> Nic Bellingham, supercomputing technology lead, UK Met Office

The Ferrari of computing

Bellingham explains that the Met Office tends to run its machines "very full", to get the best possible use out of the technology that it is paying for. According to Bellingham, this also has implications for longevity.

"We would describe the supercomputer as 'the Ferrari rather than the Ford Focus' of the computing world – particularly ours. We do work them hard. We have high availability requirements for our supercomputer. Their lifespan is a combination of the length of time that they last and the time it takes us to outgrow them," she says.

As the Met Office improves its forecast models, they become bigger, requiring greater compute capacity. For the first five years of the contract, the new supercomputer will provide six times the compute capacity of the met's current machines. "At the refresh point we will grow it again by another three times, so for the second five years we will effectively have 18 times our current capacity," says Bellingham.

"This lets us run much bigger models. It enables us to run models at greater levels of granularity, so we can run city-scale models, for example, on demand. It will allow us, for example, to look more closely at storms or fog or intense heat or rainfall in greater detail than we can do currently.

"A large chunk of it is about being able to do more of what we currently do at greater levels of detail – to reduce the gap between datapoints in the model. The higher resolution means we can take account of more local variations, for example in geography, buildings and land surfaces."

The greater capacity of the new supercomputer will also enable the UK Met Office to develop its work with other national met services and academic partners, collaborating through the provision of data.

£13bn

(US$18.2bn) of financial benefit for the UK is expected over the supercomputer's 10-year lifespan – that's £9 of profit for every £1 spent

Why Microsoft?

The Met Office followed a standard procurement process before choosing Microsoft. "We had our set of requirements and our evaluation model. We went through a competitive dialog process before reaching the final decision," says Bellingham.

"It is important to state that these are HPE Cray dedicated machines, certainly for the first generation," she continues. "They will be very similar to the machines we have installed at the moment. They just happen to be hosted in Microsoft data centers. They are plugged directly into Microsoft's Azure cloud.

"That gives us opportunities for different ways of working. It gives us potential to think about what that second five years will look like – they may be very different to what we have currently in terms of the technology."

By the five-year refresh point, Bellingham expects that the Met Office will understand its requirements for the second half of the contract. The team will feed its requirements back to Microsoft and then begin what she describes as "very much a collaborative 'this is what we need and what does that need to look like?'" process.

In addition to the technology itself, the contract – a managed supercomputing service – includes maintenance and cybersecurity measures. Microsoft will also host the Met Office's new supercomputer, at its UK South Region data center. The Met Office has three data centers of its own, two on-site at its Exeter HQ and one at the nearby Exeter Science Park, but no longer has the capacity to host the size of supercomputer and the amount of power required. ▮

MICROSOFT AND METS

The Met Office's new supercomputer is not Microsoft's only work within the meteorological sector. Chris Perkins, general manager of public sector at Microsoft UK, explains, "In the field of weather and climate modeling, the US Navy's Fleet Numerical Meteorology and Oceanography Center (FNMOC) announced in 2020 that it had demonstrated a developmental 21-member Coupled Ocean/Atmosphere Mesoscale Prediction Systems-Tropical Cyclone (COAMPS-TC) ensemble for a number of tropical cyclones, using Microsoft Azure high-performance computing capabilities.

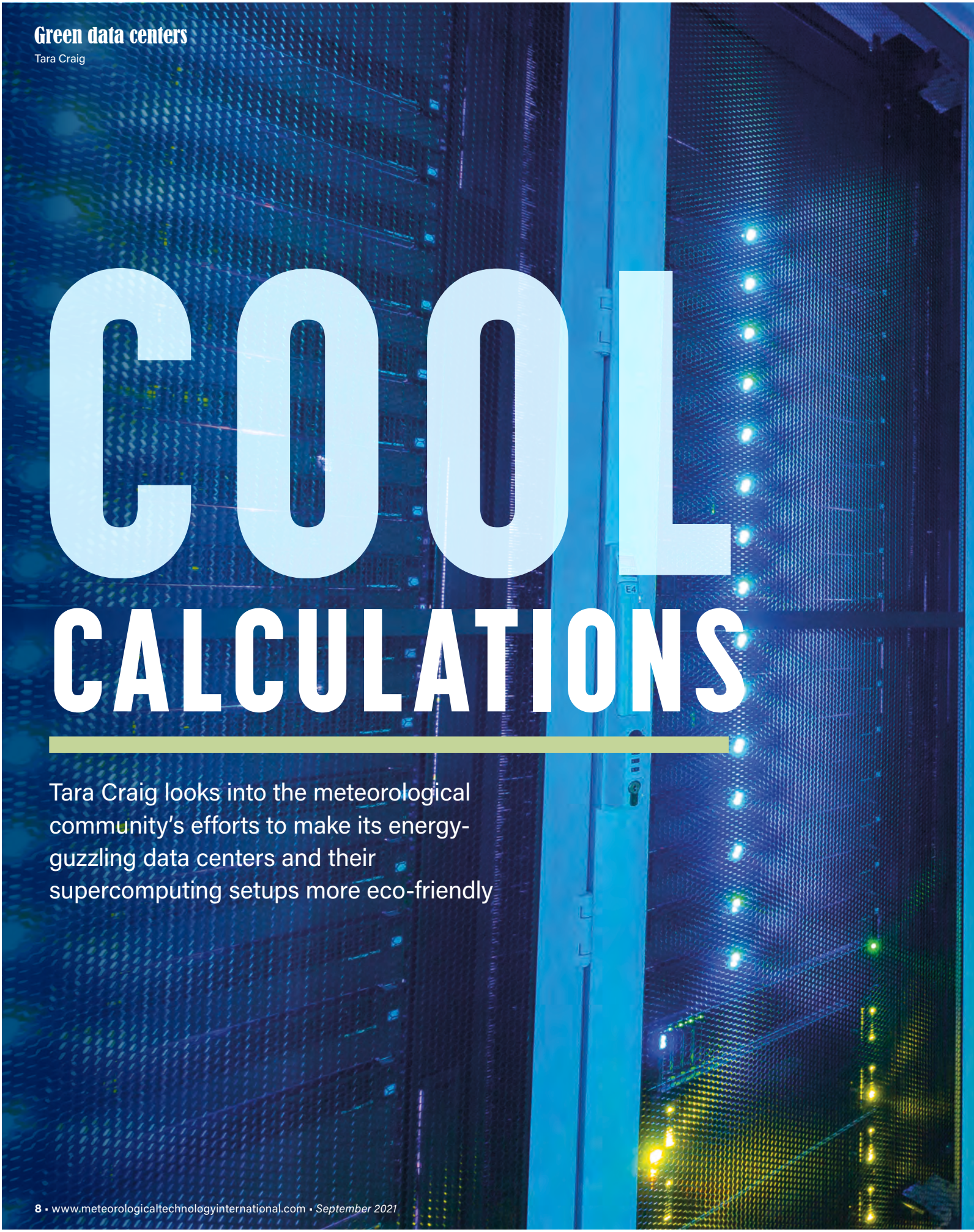
"The FNMOC said that deploying this technology will ensure fleet safety by improving forecasting of tropical cyclone paths and intensity," he adds.

According to a statement from the Naval Meteorology and Oceanography Command, the new system has already proved its worth: "During Hurricane Sally [September 11-18, 2020], COAMPS-TC accurately predicted landfall along the Alabama/Florida border while many other global models predicted a direct strike in New Orleans."

Tara Craig

COOL CALCULATIONS

Tara Craig looks into the meteorological community's efforts to make its energy-guzzling data centers and their supercomputing setups more eco-friendly



Verne Global's Icelandic data center campus is built on a former NATO base near Keflavik

Data centers play a vital role in meteorology today, with supercomputers relied upon to run increasingly detailed weather models, better predict severe weather, provide an ever-wider range of potential weather scenarios, and deliver more and more localized forecasts. This efficiency and scope does not come without a cost, however.

Carbon emissions from tech infrastructure and the data servers that enable cloud computing now exceed those of pre-Covid-19 air travel, according to a report released by French think-tank The Shift Project in March 2021. Enormous amounts of energy are required not only to power around-the-clock computing, but to cool the data centers.

Location, location, location

Met service providers are under growing pressure to make their computing capabilities more environmentally friendly, many of them subject to regional or national requirements to produce zero carbon emissions within the coming decades.

The Danish government's climate policy, for instance, is subject to EU targets of reducing greenhouse gas emissions for 2020 and 2030. The long-term objective of the government is for Denmark to reduce its greenhouse gas emissions by 70% in 2030 compared with 1990 levels and to be a net zero emission society in 2050.

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ABOVE: Verne Global has used the natural climate in Iceland to keep data center cooling costs and energy output low

BELOW: A new data center using renewable tidal power in Scotland could be built by 2024

> "The highly predictable nature of tidal power means that potentially 100% of power requirement for a data center could be provided from renewable sources in a very resilient form"
>
> **Sam Mackilligin, director – zero carbon energy systems, AECOM**

One way of reducing energy consumption is to choose a cooler location for the data center, so that less energy is required to keep the computers at an optimal temperature

"Our supercomputer is located in Iceland," explains Thomas Kjellberg Christensen, CIO and CFO of the Danish Meteorological Institute (DMI). "Due to the colder climate there, the energy requirement for cooling is significantly lower than it would be in Denmark. To reduce our environmental impact, we use free natural cooling as much as possible."

Locating a supercomputer in Iceland is something of a win-win situation. Not only does the climate mean that less cooling is required, but the island has access to plentiful supplies of green energy, from both hydropower and geothermal sources. DMI uses these to cool its supercomputer.

Also benefiting from Iceland's energy and climate is Milan-based meteorological and climatological research organization Meteo Expert, which chose data center specialist Verne Global's Icelandic data center to house its compute-intensive applications.

"Iceland is the only country in Europe that generates 100% of its power from renewable sources, so having the data center there makes our campus environmentally friendly from the start," explains Nick Dale, EVP of business development at Verne Global. He stresses that however eco-friendly the design of a data center, if it is powered by fossil fuels, it will continue to generate carbon emissions.

Like DMI, Verne Global and Meteo Expert are making the most of the Icelandic climate for cooling purposes, benefiting from not only environmental but financial advantages.

"The year-round temperate climate enables natural air cooling of the data center – saving a significant amount of energy, given that on average, cooling IT equipment makes up 40% of a data center's total energy consumed.

HARNESSING TIDAL POWER

The Pentland Firth between the Scottish mainland and the Orkney Islands is considered the best tidal stream site in the world, with currents reaching up to 5m/sec (18km/h).

In 2019, renewable energy project developer SIMEC Atlantis commissioned engineering consultants AECOM to undertake a pre-feasibility study of the potential for a data center at its MeyGen site in the Pentland Firth.

"The study found that all the fundamentals for a data center are present. Indeed, the highly predictable nature of tidal power means that potentially 100% of power requirement for a data center could be provided from renewable sources in a very resilient form," says Sam Mackilligin, director – zero carbon energy systems, AECOM.

According to Mackilligin, while the data center element of MeyGen was deemed feasible in 2019, it was taken no further at that point. "But the environment in 2021 is very different, with data center owners grappling with the challenge of moving to net zero emissions, so the idea of delivering a data center at MeyGen has re-emerged," he says.

MeyGen is the largest tidal-powered plant in the world, and the proposed facility would be the world's first tidal-powered data center. "SIMEC Atlantis has a lease and a grid connection for a further 237MW of generating capacity at MeyGen. If a first data center is built, then more would likely follow if adequate data cable connectivity can be provided," Mackilligin adds.

There are several other sites in the UK suitable for tidal-powered projects. An application for a site off Anglesey is pending, with the potential to provide 240MW of power. According to Mackilligin, this would work well for a data center.

STFC

40%

The amount of total energy consumed cooling IT equipment in a data center

ABOVE: Atos's BullSequana XH2000 supercomputer

RIGHT: The heat exchangers in the integrated control room underneath the high-performance-computing data center at NREL's Energy Systems Integration Facility

"We're able to leverage ambient-air cooling through a system of venting that allows colder outside air to come in, passing through filters and laser monitoring systems, and then into server rooms. The warm air from inside is then vented outside," says Dale.

"A number of our customers have chosen to move their supercomputers to fully green energy data centers that have low cost of energy," says Andy Grant, group VP of large strategic HPC projects at French multinational Atos. "For example, one customer who had a 2MW requirement reduced the annual carbon intensity of their supercomputers from over 11 million kilograms of CO_2 to 0kg simply by moving to a data center in the Nordics that uses geothermal energy to power the machines and by recycling the heat. This saving is equivalent to the energy usage of over 10,000 households."

Tactical choice of location for a data center may not require an international move, however. The UK Met Office's recently announced new supercomputer (see *Super Power*, page 6) will be one of the world's most environmentally sustainable. Powered by 100% renewable energy, it will reduce CO_2 emissions by 7,415 metric tons in its first year of operational service alone, compared with current annual emissions.

Furthermore, having it hosted by Microsoft rather than in a UK Met Office data center will lead to a significant improvement in its power usage effectiveness (PUE), a ratio that describes how efficiently a computer data center uses energy; specifically, how much energy is used by the computing equipment.

Nic Bellingham, supercomputing technology lead at the Met Office, explains, "The best PUE number you can get is 1, which means all of that power is used for running the IT equipment. That's never really going to happen, because there are always going to be things like lighting, and ventilation of the building itself. A figure of 1.1, which we will have at the Microsoft data center, is very good – we're very pleased with that." The Met Office aims to be net zero carbon by 2030.

Keeping it cool

Rather than relying on the local climate, Chinese multinational tech firm Lenovo uses direct water-cooled systems for its supercomputers. These are used by the likes of the Malaysian Meteorological Department, China's Zhejiang Provincial Meteorological Bureau, Germany's Potsdam Institute for Climate Impact Research, and SciNet Canada, the supercomputer center at the University of Toronto.

Zaphiris Christidis, meteorological segment leader at Lenovo Infrastructure Solutions Group, explains, "Traditionally, supercomputers have used air as a cooling agent, but liquid is much more efficient, removing up to 90% of the heat generated by system components."

This saves energy in two ways, according to Christidis. "Firstly, our direct water-cooled systems require no fans, which are typically the largest consumer of energy in this situation.

"Secondly, data centers that use our direct water-cooled technology require less air-conditioning. This is because our system

Dennis Schroeder / NREL

REUSE OF EXCESS HEAT

There are both environmental and financial benefits to reusing the excess heat generated by data centers as a by-product of cooling computers, rather than releasing it into the atmosphere. In environmental terms, these include avoiding, for instance, burning natural gas for heat, as well as potential reduction in water usage (with less need for cooling towers when rejecting heat into the atmosphere).

In financial terms, the ideal solution is to reuse waste heat at the data center. The next best option is to tie it into a campus loop, followed by using it for district heating, although this has the potential to add complexity, according to Otto Van Geet and David Sickinger of the USA's National Renewable Energy Laboratory (NREL).

The NREL uses a heat exchanger to tie in its data center hydronic facility loop with the building/campus hydronic loops, its Energy Systems Integration Facility (ESIF) having been designed to use low-temperature heat. The heat captured from the data center meets 100% of the ESIF's heating needs, including heating outside walkways in the winter for snow melt and preconditioning make-up air for labs. In summer, unused heat is rejected via low-cost evaporative cooling towers.

Like the NREL, NCAR-Wyoming Supercomputing Center (NWSC) uses its waste heat to melt snow and ice and to heat office spaces, but a number of non-meteorological organizations have come up with more imaginative uses. Among them are Facebook, which is heating more than 7,000 local homes with waste heat from its data center in Odense, Denmark, and Dutch data center operator NorthC, which has set up a district heating system in Aalsmeer just south of Amsterdam. Developed with the help of the municipality, the Aalsmeer Energy Hub transports hot water from the NorthC data center to local customers including a swimming pool, a school and a plant nursery.

Otto Van Geet is a principal engineer at Applied Engineering Group, and David Sickinger is responsible for high-performance-computing projects oversight at the NREL.

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THE WORLD OF WEATHER DATA

avoids the need for a cold aisle/hot aisle cycle concept (whereby cold air is blown into the front of the rack, sucked through the system to cool the components, then expelled to the hot aisle to be recooled). In addition, we have announced a new liquid-cooled power supply for a completely fanless server too."

Launched in 2018, Lenovo Neptune features several aspects of liquid cooling, including: direct liquid cooling, where liquid is pumped through a loop in the system to remove all of the heat from the components; thermal transfer modules (TTM) and liquid to air (L2A) heat exchangers, which deliver liquid cooling benefits without having to install plumbing. It also features rear-door heat exchangers that act like a radiator in a car, absorbing heat before it hits the hot aisle, and energy-aware runtime software that enables users to govern the system resources according to the job being run.

Earlier this year Atos signed a new four-year contract worth more than €80m (US$95m) with the European Centre for Medium-Range Weather Forecasts (ECMWF) to supply its BullSequana XH2000 supercomputer, one of the most powerful meteorological supercomputers in the world. The new solution is direct liquid cooled (DLC) using warm water up to 40°C.

Atos's Grant explains, "The DLC technology is even used to cool the power supplies and interconnect switches in the system, meaning there are no requirements for fans. Around 95% of the heat generated is extracted to water, making the systems extremely energy efficient.

"The Atos system includes additional technologies to minimize energy use, under the umbrella Smart Energy Management Suite. The first of these is Bull Energy Optimizer (BEO), which gathers energy and temperature metrics from all components of the supercomputer and links them with the job execution information to provide per-job information. The Dynamic Power Optimizer controls energy consumption through a power capping policy, keeping the system under predefined constraints. It also enables application behavior profiling, to minimize its energy footprint, without any application modification."

Finally, the Atos Performance Engineering team has tuned the ECMWF system's parameters to reduce runtimes, helping minimize the carbon intensity of a given workload.

BELOW: Lenovo powers the supercomputer at the Barcelona Supercomputing Center in Spain

> "It's estimated that by next year, central processing units will consume 175% more power than they did in 2014"
>
> **Zaphiris Christidis, meteorological segment leader, Lenovo Infrastructure Solutions Group**

€80m

The value of Atos's new four-year contract with ECMWF to supply its BullSequana XH2000 supercomputer

What next?

Verne Global's Dale predicts that as organizations focus on sustainable computing solutions, the data center market will continue to expand beyond the traditional FLAP markets (Frankfurt, London, Amsterdam, Paris) to places such as the Nordics, which offer good connectivity, natural cooling and lower carbon footprint. Enhanced connectivity through new subsea cables, like the IRIS cable from Iceland to Ireland, will make green computing all the more accessible.

Dale adds that although IT equipment is becoming smaller and more energy efficient, as silicon and chip design becomes more and more compact, the number of enterprises and research organizations using AI and high-intensity compute is on the rise, and power density – the amount of power a server rack draws – is also increasing.

"Cooling technologies – like embedding tiny, liquid-filled channels in the microchips themselves – will continue to evolve, and finding ways to meet these cooling requirements while minimizing carbon emissions will be a top priority," Dale predicts.

Christidis of Lenovo welcomes his customers' growing demand for green and sustainable computing systems. He comments, "It's estimated that by next year, central processing units will consume 175% more power than they did in 2014. More power into the system means more power will be required to cool those components, and clearly, alternative energy sources and cooling methods will need to be deployed."

Atos's Grant, meanwhile, predicts an increasing shift toward energy awareness in supercomputing. "This means programmers and systems teams will not just optimize for time and throughput, but also for energy consumption. I believe AI models such as machine learning will increasingly be used to dynamically change systems to help with this," he says.

Whether the focus is on optimizing computer performance, reducing the need for cooling or even shifting to cleaner energy sources, it is clear that the environment is front and center of meteorological organizations' supercomputing plans – exactly where it should be. ▮

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MAY 4 & 5, 2022

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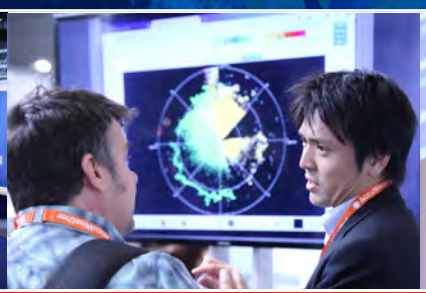

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Jack Roper

There's only one way to ensure weather satellites and their instruments can withstand the harsh conditions of launch and orbiting in space, and that's by employing rigorous testing methods

PUT TO THE TEST

The MetOp-SG Scatterometer Antenna in the spherical antenna test range at the Danish Technical University in Copenhagen. Image: European Space Agency

Weather satellites with finely calibrated instruments are fired into space, exposed to thunderous vibration and noise, followed by the explosive shock of separation. For years, they work in a vacuum, between searing heat and frigid planetary shade, continually providing accurate data to weather models and climate science. But first, they must demonstrate robustness in pre-flight test regimes fundamentally unchanged by geography or time.

MetOp Second Generation (MetOp-SG) satellites will supersede the MetOp series now in service. "MetOp quickly became the single most important weather satellite, providing nearly 50% of satellite observation impact on weather forecasts," says European Space Agency (ESA) MetOp programs manager Dr Graeme Mason. "MetOp-SG will collect those essential measurements at better spatial or spectral resolution while adding new instruments."

Six satellites across two series will provide observations until 2043. In 2024, the first will launch from French Guiana and enter sun-synchronous orbit at 831km mean altitude. It will circle Earth 14 times daily (or every 100 minutes), downloading data as it overpasses Svalbard, Norway.

GOES-T is the third GOES (Geostationary Operational Environmental Satellite) R-Series spacecraft built by NASA for NOAA. Destined for geostationary orbit 35,785km above Earth, it is scheduled to launch in December 2021.

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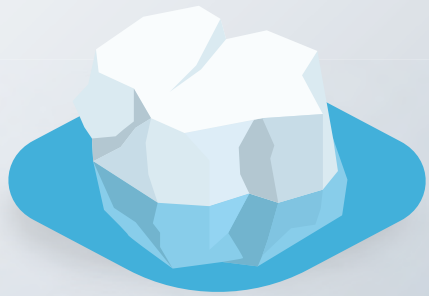
* Snow depth
* Snow Water Equivalent (SWE)
* Liquid Water Content (LWC)
* Snow Drift

Snow melt
* Liquid Water Content (LWC)
* Snow Melt

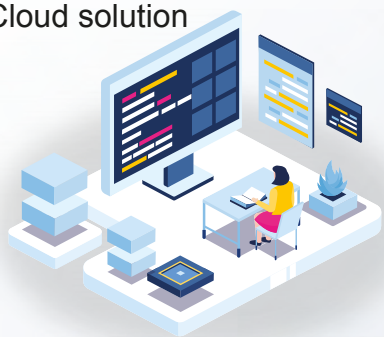


Precipitation
* Rain
* Hail

Surface Water
* Radar Water level
* Radar Surface velocity
* Radar Discharge meter

Industry Process
* Radar Water level
* Radar Surface velocity
* Radar Flow meter

Data collection
* Data loggers
* Cloud solution



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LEFT: NOAA's GOES-T satellite in the thermal vacuum chamber

BELOW: During acoustic testing, GOES-T endured extremely high sound pressure of 138.4dB from high-intensity horns

"GOES-R and GOES-S are called GOES-16 and GOES-17 now they're on orbit," explains NASA GOES-R flight project manager Candace Carlisle. Once aloft, GOES-T will become GOES-18. Following NASA on-orbit checkout, it may enter on-orbit storage or immediately replace GOES-17 in operational service.

GOES-T preflight testing by Lockheed Martin in Littleton, Colorado, mirrored the program that MetOp-SG will undergo at ESA's European Space Research and Technology Centre (ESTEC) in the Netherlands. "We have several environmental tests," says Mason. "In our terminology, we shake it and bake it! We demonstrate that satellites will survive the launch, which is a rough affair, by simulating the vibration and loads they will experience."

Testing methods

Satellites are mounted on vibration tables and shaken in three axes, then the results are mathematically combined. "We shake it beyond the level expected to ensure it survives," says Mason. "We do sine vibration, sweeping through from 2Hz to 100Hz to identify structural resonances that match anything on the launcher."

These are large test objects (GOES-T measures 6.1 x 5.6 x 3.9m, MetOp-SG 6.6 x 3 x 3.3m) but ESTEC has Europe's largest shaker table: the Hydra. "Satellites must fit into fairings of rockets – in our case, the Soyuz Launcher," explains Mason. "They're clamped to a ring at the base, and that's how we mount them on vibration tables."

For acoustic tests, satellites are placed in fairing-like chambers and horns inject sound at launch-equivalent levels: GOES-T was subjected to 138.4dB. "For another spacecraft, Maryland Sound International provided the sound system, but they also do rock concerts," says Carlisle. "We're launching on Atlas, so the Atlas user's guide determines our acoustic testing level."

Shock tests simulate the trauma of launch-vehicle separation. "The rocket provider provides a payload attach fitting to the spacecraft contractor," she continues. "We fire pyros, which explosively trigger the release in space, to provide the shock."

Thermal vacuum tests ensure satellites can operate in the stark thermal vicissitudes of space. Lockheed Martin exposed GOES-T to temperatures from 87°C to -55°C in an 8.8 x 19.8m vacuum chamber. "First, we go to hot," says Carlisle. "That's the bake-out."

Key tests are common to NASA and ESA. "We do a thermal balance test to demonstrate it works at hot and cold temperatures and validate our thermal mathematical models," says Mason. "Then we do thermal vacuum cycling.

"Polar-orbiting satellites spend just over half their orbits in the sun and the rest in shade," he continues. Spacecraft are cycled four times between hot and cold. GOES-T instruments underwent 12 hot-cold cycles in total: eight individually, then four in spacecraft-level tests.

"We test spares to 12 cycles," says Carlisle. "When we found an S-band transponder problem, it meant we had a fully cycled spare." Tests are not just about survival but also reliable operation. "We do performance tests at different plateaus," says Mason. "We may find a circuit doesn't start at cold temperatures due to tolerances on resistances or capacitances."

Electromagnetic compatibility (EMC) tests ensure components work together without interference. They take place in anechoic chambers – otherworldly caverns with bristled walls of radio frequency-absorbing (RF) foam – such as ESTEC's Compact Antenna Test Range.

"MetOp-SG has sensitive RF instruments," explains Mason. "We don't want to transmit unwanted signal in the bandwidth they measure. We have radiated tests, then conducted emission and susceptibility tests to ensure electronic signals don't disturb anything else."

> "We do a thermal balance test to demonstrate it works at hot and cold temperatures and validate our thermal mathematical models"
>
> **Dr Graeme Mason, MetOp programs manager, European Space Agency**

End-to-end tests and mission rehearsal

End-to-end functional tests establish that every system works as it should. For example, MetOp-SG's attitude and orbit control subsystem (AOCS), including thrusters, GPS/Galileo position sensors, star trackers and reaction wheels, is tested end-to-end with hardware-in-the-loop.

"We trigger and command things to ensure it's all wired correctly and the wheels spin in the direction we want them to," says Mason. End-to-end tests can identify problems with overflowing buffers. "When you're producing data, you don't want to fall over after a day because something runs out of memory."

Satellite validation tests connect the satellite to its post-launch control center. For most ESA missions this will be the European Space Operations Centre (ESOC), but MetOp-SG will be controlled by EUMETSAT's Mission Control Centre (MCC). Both are in Darmstadt, Germany. "Our spacecraft are operated through NOAA's Satellite Operations Facility in Maryland," says Carlisle. "The satellite is in Colorado rather than orbit, but all the data flows to the operations facility and we ensure they can control the spacecraft."

Finally, NASA is ready for a full mission rehearsal. Prior to a dress rehearsal, actors seldom rehearse a

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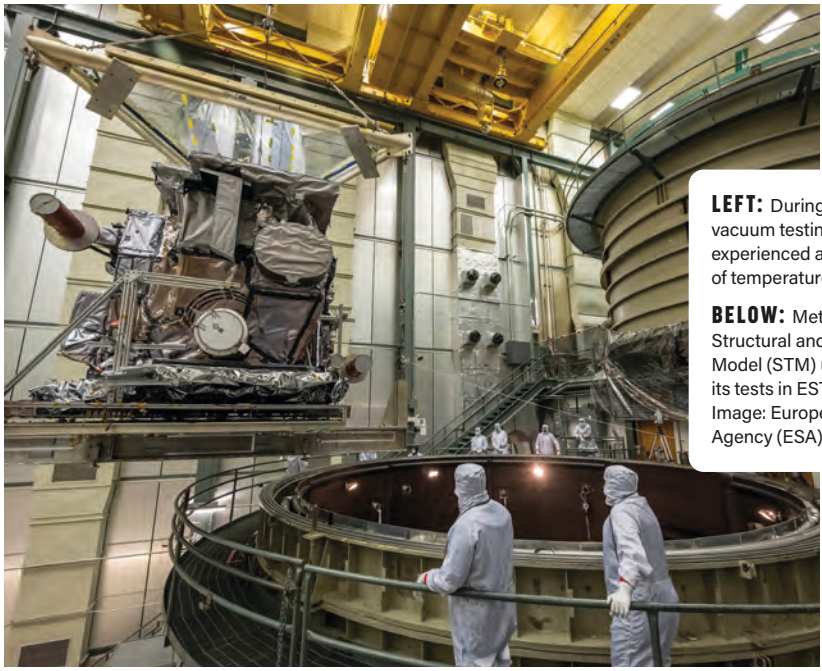


LEFT: During thermal vacuum testing GOES-T experienced a vast range of temperatures

BELOW: MetOp-SG Structural and Thermal Model (STM) undergoing its tests in ESTEC in 2019. Image: European Space Agency (ESA)

play in the correct order, but instead choose scenes based on which cast members are present. Similarly, end-to-end functional tests are ordered for efficiency rather than the real operational sequences of orbit.

"But mission rehearsal is a full dress rehearsal," says Carlisle. "We run through our scripts without stopping, just like the night of the show." This takes five days, ending with a lessons-learned debrief. "For GOES-T, our ground system built a new remote access capability with communication paths for home working," she adds. "We've just finished our second rehearsal and it went surprisingly well."

> "Preflight calibration means showing the satellite a scene or signal representative of what it will see on the ground"
>
> **Nigel Fox, NPL fellow and chief scientist in optical radiometry, Earth observation and climate**

Instrument calibration

MetOp-SG will carry an array of state-of-the-art instrumentation (see *MetOp-SG: the next generation of polar-orbiting satellites*, page 23). GOES-T has two Earth-pointing instruments (an advanced baseline imager and geostationary lightning mapper), three sun-pointing instruments and an in-situ instrument suite. Each completes environmental testing before delivery; Lockheed Martin conducted vibration, thermal vacuum and EMC tests on the lightning mapper in Sunnyvale, California. But instruments still require calibration to provide accuracy traceable to the primary standards of metrology institutes such as the UK National Physical Laboratory (NPL).

"Effectively, satellites measure light or electromagnetic energy at different frequencies," explains NPL climate and Earth observation science area leader Paul Green. "Specific wavelengths reveal certain processes. One infrared channel shows liquid water, another is all about ice."

Clouds are characterized by ratios between these channels: lower clouds contain more water, higher ones more ice. Radiometric calibration tunes instruments to measure electromagnetic radiation from known sources, while geometric calibration tunes their perception of shapes. "Does a square of light come out square?" asks Green. "Or as a rhombus or trapezoid? It's like back in the day, playing with optical settings on cathode-ray-tube TVs."

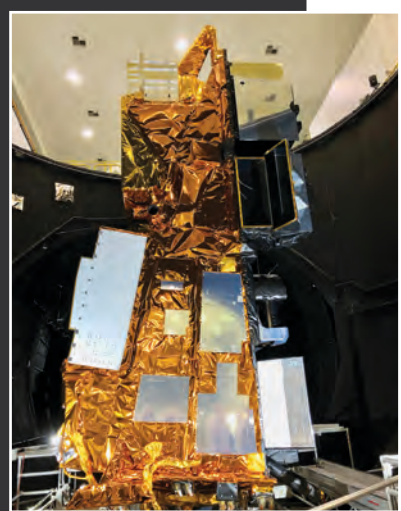
"Preflight calibration means showing the satellite a scene or signal representative of what it will see on the ground," says NPL fellow and chief scientist in optical radiometry, Earth observation and climate, Nigel Fox.

METOP-SG: THE NEXT GENERATION OF POLAR-ORBITING SATELLITES

The ESA/EUMETSAT MetOp-SG mission splits a 15-instrument payload across two three-satellite series (MetOp-SG-A and MetOp-SG-B). "They measure the atmosphere at wavelengths from ultraviolet, through visible and infrared, to microwave," says ESA's Graeme Mason. "That data is processed into calibrated radiances then assimilated into numerical weather models."

MetOp-SG-A's largest payload items are METimage, a visible and infrared imager with 20 channels at 500m media resolution, and IASI-NG, an infrared atmospheric sounder. "A microwave sounder (MWS) combines three boxes on the previous MetOp generation in one," says Mason "We have a multi-channel, multi-viewing, multi-polarization imager (3MI) to measure aerosols and particles in the visible and shortwave infrared, then the Copernicus Sentinel-5 atmospheric chemistry instrument to measure trace gases and air quality."

On both MetOp-SG series, radio occultation will track GPS or Galileo satellites rising or falling in orbit. "Radio-frequency signals from those satellites get refracted," Mason explains. "The amount of bending depends on the different atmospheric conditions. By measuring the phase differences between signals, you can retrieve temperature and humidity profiles that produce the observed bending," he adds.



MetOp-SG-B features an active microwave scatterometer. "It works in C-band at 5.3GHz," Mason continues. "It emits and receives back a radar signal at three angles: forward, sideways and backward. One angle gives us windspeed, but with three we are also able to determine wind direction."

Two conical scanning instruments – a microwave imager (MWI) for clouds and precipitation and an ice-cloud imager – will scrutinize adjacent bandwidths: the MWI 18-183GHz, the ice-cloud imager 183-664GHz. "They scan in opposite rotational directions to cancel each other's momentum," Mason explains. "Otherwise, the satellite would spin up like a gyroscope." MetOp-SG-B's payload also includes the Argos-4 data collection system.

"MetOp-SG is the next big thing in numerical weather prediction," says Mason. "We produce satellites affordably, making several copies of each generation. Launching at seven-year intervals, each series will provide 21 years of observation."

LEFT: MetOp-SG 3MI instrument in its calibration chamber at the test facility at the Centre Spatial de Liege in Belgium

BELOW: Raymetrics' eVe lidar – a novel mobile ground-based lidar for the enhancement and validation of ESA products

INFLIGHT CALIBRATION OF EARTH OBSERVATION SATELLITES

Detecting and understanding climatic changes within shorter timescales means reducing the uncertainties of space-based observations beyond levels currently enabled by preflight calibration.

"We do a wonderful job at calibrating instruments on the ground," says Nigel Fox of the National Physical Laboratory (NPL). "Then we stick them on rockets, shake them to high heaven and bounce them into a thermal vacuum environment. Unsurprisingly, they change in ways we can't really predict."

But the ESA TRUTHS mission will use a cryogenic radiometer to calibrate its instrument – a hyperspectral imaging spectrometer – in space.

"The Cryogenic Radiometer is the NPL primary standard, an instrument to which all optical radiation is referenced," Fox explains. Developed at NPL in the 1980s, it is the primary standard of national metrology institutes worldwide. "It uses the principle of electrical substitution radiometry to compare the heating effect of electrical and optical power," he continues. "Cooling that concept to cryogenic -250°C temperatures dramatically reduces sources of uncertainty."

The TRUTHS payload incorporates NPL STAR-equivalent technology with a cryogenic radiometer. Besides calibrating its own instrument, a novel orbit will enable TRUTHS to regularly compare notes with other Earth observation satellites.

"Because its instrument is well calibrated, it can underpass other satellites and view the same desert or snowfield," says Fox. "The other satellite can take the calibration it puts on that target. Calibration in orbit, directly traceable to a cryogenic radiometer, will solve the problem of degrading satellites."

TRUTHS is a UK-led ESA Earth Watch mission involving the Czech Republic, Greece, Romania and Switzerland. Currently in the prototyping phase, it awaits a decision to enter build mode in late 2022 with a probable 2026 or 2028 launch timeline.

"TRUTHS will revolutionize climate observation, improving accuracies by a factor of 10," says Fox. "Whereas now it takes 30 years to detect a climate signal over natural variability, we will do it in 15."

"If an optical satellite measures reflectance, we use a bright, uniform, sun-type source."

Politicians mostly accept the reality of climate change, but models differ in predicting its extent. Better understanding depends on reducing uncertainties in space-based observation of changes only detectable over 30-year timescales.

"Constraining uncertainty means policymakers can make better-informed decisions," explains Fox. "When do we build the next Thames Barrier? Do we sacrifice Norfolk because it's too hard to defend?"

Confidence is needed to distinguish anthropogenic climate trends from the noise of natural variability. "We had the Maunder Minimum 300 years ago," says Fox. "For 50 years, the northern hemisphere was 2°C colder due to perhaps a 0.2% change in the sun's output. We need to measure those parameters, if only to eliminate them."

"We calibrate microwave and infrared instruments as they measure the temperature of calibration targets in front of their apertures," says Mason. Correct target temperatures are ascertained with platinum resistance thermometers calibrated against a secondary standard, calibrated in turn against a primary standard such as the Cryogenic Radiometer (see *Inflight calibration of Earth observation satellites*, above).

"It provides traceable accuracy down to maybe 0.05K," he adds. "We stimulate visible instruments with an integrating sphere, which produces a uniform light beam whose intensity we can vary. We map the instrument's sensitivity by moving a spot across the field-of-view."

Satellite-based lidar observation may soon become indispensable to weather prediction. "The Aeolus mission showed that wind lidar measurements are possible from space," says Raymetrics' CEO, Nikos Kontos. "Space lidars could provide climate data and be used for water-vapor profiling."

The Raymetrics QOMA II laser, developed in an ESA-funded project, could be ripe for orbital deployment. "Lidar satellite instruments are tested in vacuum conditions and on airplanes to simulate vibration during launch," continues Kontos. "Fiducial reference systems, like our prototype eVe lidar, are used to calibrate and validate satellite missions."

Reducing calibration costs

Calibration is laborious and costly. Instruments travel to different facilities for radiometric and geometric calibration, each done in a vacuum chamber at eye-watering expense. But STAR-cc-OGSE (Spectroscopically Tunable Absolute Radiometric, calibration and characterization, Optical Ground Support Equipment) may change all that. Developed by NPL and M Squared Lasers, STAR combines calibration equipment including a collimator, large radiance sphere and polarizer with tunable lasers, creating a one-stop calibration shop that fits in the back of a truck.

"STAR pulls all the kit for calibration and characterization into one portable facility," says Green. "The tunable laser means you can consider satellites wavelength by wavelength and provides a powerful tool for understanding spectral stray light."

Full calibration is accomplished in one thermal vacuum test. "STAR shines light through a window into the chamber," Green explains. "We effectively move equipment in and out of a single beam."

STAR is highly automated and more accurate than existing systems. Its first customer is the MicroCarb microsatellite, intended to detect greenhouse gas fluxes with elusive spectral signatures.

Carlisle recalls Space Technology 5, launched in 2006. "At a high level, the testing is basically the same," she says. "Over time, the main difference is increased formality and documentation." She anticipates future polar-orbiting missions using smaller spacecraft forms. Mason expects to see publicly funded reference satellites complemented by smaller satellites that plug the gaps. "We could have constellations of small microwave or infrared instruments, built cheaply with shorter lifetimes. We would do the same tests but use smaller facilities, of which many more are available," he concludes. ▮

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Systematic Observations Financing Facility

Paul Willis

The team behind the Systematic Observations Financing Facility reveals how it is learning from past mistakes and failures to assist developing countries generate and exchange basic observational data critical for improved weather forecasts

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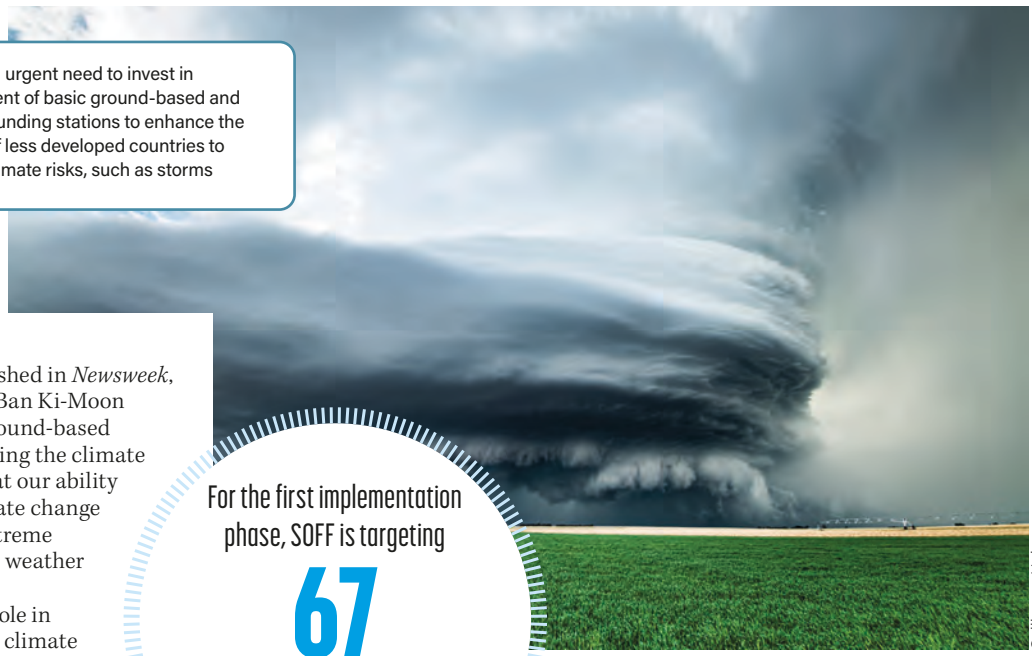

Guillaume Hobam

There is an urgent need to invest in improvement of basic ground-based and balloon sounding stations to enhance the capacity of less developed countries to mitigate climate risks, such as storms

In a recent opinion piece published in *Newsweek*, former UN secretary-general Ban Ki-Moon stressed the importance of ground-based weather observations in tackling the climate crisis. "We must not forget that our ability to shape policy, adapt to climate change and protect millions of lives from extreme weather events begins at the humble weather station," Moon commented.

Ground-based data plays a vital role in meteorology, not least because some climate metrics such as atmospheric pressure can only be measured from the ground.

"Surface-based observations have a value on their own for metrics that cannot be measured by satellites and they also have a value to validate data coming from space," says Markus Repnik, director for development partnerships at the WMO.

Despite their key role, the availability of ground-based observations across the globe is disproportionately distributed. As the former UN head points out in his opinion piece, the presence of weather stations corresponds very closely with a satellite image of the planet at night, with the lit-up regions of the world – Asia, Europe, North America and Australasia – also the places where ground-based data is more or less readily available.

For the first implementation phase, SOFF is targeting **67** countries (LDCs and SIDS) to bring to GBON compliance over 5 years

Identifying the data gaps

While the data gap in the blacked-out regions – which includes Africa, parts of Latin America and many small island nations – doesn't necessarily mean that ground-based observations are not being collected, some of them are not being shared internationally. A World Bank study published this year found that thousands of new or refurbished 'silent' stations that have stopped transmitting data, are needed. This data gap can be catastrophic for the countries themselves – most of which fall into the categories of Least Developed Countries (LDC) and Small Island Developing States (SIDS).

Data gaps are a problem for forecasting everywhere in the world. The accuracy of local forecasts depends to a large degree on real-time and continuous access to global observations. To address this need, the World Meteorological Congress in 2019 agreed to establish the Global Basic Observing Network (GBON), to acquire and internationally exchange the most important surface-based observational data at a minimum resolution and timeframe level.

But it was going to prove very challenging to achieve GBON compliance in the poorest countries unless a new way to finance ground-based observations was found. "Already during Congress we started thinking about what that might look like," explains Repnik.

The birth of SOFF

The result of these deliberations is the Systematic Observations Financing Facility (SOFF), a financing initiative to help in particular LDCs and SIDS meet their commitments to GBON.

SOFF, which is spearheaded by the WMO in collaboration with a number of international organizations, including the members of the Alliance

WMO SECRETARY-GENERAL PETTERI TAALAS ON THE IMPORTANCE OF SOFF

"In the face of climate change, LDCs and SIDS are paying the highest price. 2020 was one of the three warmest years on record and the threat of unprecedented climatic change has demonstrated how important it is, now more than ever, to act quickly and build a more resilient world.

"SOFF is so vitally important now because it will improve the availability of basic weather observations leading to better weather forecasts and climate prediction. This is crucial to saving lives, protecting the livelihoods of the most vulnerable and will bring benefits in overall global productivity. SOFF will strengthen global and local weather forecasting and climate prediction capabilities, which are essential to manage risks effectively, understand adaptation needs and act proactively with systematic early action.

"SOFF has one main outcome: significantly increasing the collection and international exchange of basic surface-based observations. This will lead to a major strengthening of the global observing capabilities and the availability of better model guidance for weather and climate monitoring and prediction at all spatial scales. This will enable the provision of vastly improved and enhanced weather and climate services at global, regional, national and local levels to all WMO members. The improvement in service delivery capabilities will be especially large in the areas where the current coverage of observations is poor.

"For the first implementation phase, SOFF is targeting 67 countries (LDCs and SIDS) to bring to GBON compliance over five years. This is expected to lead to at least a 20-fold increase of exchanged observations from surface stations and at least a 10-fold increase of exchanged observations from upper air.

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for Hydromet Development, is expected to be launched at the upcoming UN Climate Change Conference (COP26) in Glasgow this November.

It's not the first attempt to address the coverage gap in poorer countries, according to Repnik. And it hopes to succeed by paying close attention to where those previous attempts largely failed. There are three main reasons for those past failures.

He says, "The first is the wrong financing model, whereby even the poorest countries are expected to cover the full costs of maintaining and operating basic observations. This is quite unrealistic given the socioeconomic circumstances in these countries and the mismatch between national resources and the global public good of basic observations."

To prove what he is saying, he points to recent World Bank figures that show that for every US$1 invested in basic observations in developing countries US$25 will be generated for the world economy because of the improvements to forecasting obtained from increased observations. The same report estimated that improving the collection and international exchange of surface-based observational data could deliver additional socioeconomic benefits worth more than US$5bn a year.

The second problem Repnik notes is too much fragmentation. "A complete hodgepodge of projects and technologies that even the most developed countries would find almost impossible to maintain," he comments. The final problem he identifies as "the short-term focus of the investment financing instead of long-term international data exchange". To illustrate this, he points to ECMWF and WMO figures showing a drop of nearly 50% in international exchange of radiosonde data in Africa since 2015 despite significant funding for observations allocated to the region during that time.

ABOVE LEFT: While satellites are becoming increasingly important, there is still a need for reliable and accessible surface-based observations

ABOVE RIGHT: The HIGHWAY project is one example of effective funding and helped develop an early warning system for East Africa

> "Surface-based observations have a value on their own for metrics that cannot be measured by satellites and they also have a value to validate data coming from space"
>
> **Markus Repnik, director for development partnerships at the WMO**

Learning from past failures

There's a cliché story within development of how not to do things. It tells of a donor who buys a brand new 4x4 for a community but as soon as the car breaks down, they can't fix it because there are no spare parts for that model in the region. The 4x4 ends up rusting to pieces in the corner of the village.

Similar stories have happened in the meteorological sector, where donors financed observation infrastructure that never transmitted any data – in a sector where sustainability of investments is confronted with the additional complexity of weather systems and technologies.

For hydromet you need consistent standards, you need the systems to be interoperable and you need them to be able to exchange with the global weather system. That makes it all the more complicated to get things right.

SOFF aims to avoid earlier pitfalls by adopting an approach that recognizes the excessive financial burden on the poorest countries to operate and maintain observing systems that in addition to local benefits, provide a critical global public good. Consequently, all the funding will be in the form of grants, not loans. To address the issue of fragmentation, SOFF will only fund projects that are in line with the goal of GBON compliance.

"In the past there hasn't been a lot of coordination," says Laura Tuck, former World Bank vice president for sustainable development and SOFF global facilitator. "You have a lot of programs or projects that aren't connected to the basic metrics and operate in parallel. So the idea was, can we put together a program that's driven by global design while locally being embedded in larger hydromet development or climate projects so it's consistent with the country's strategies."

Creation of the SOFF is a commitment of the Alliance for Hydromet Development, a coalition between WMO and major development and climate

Šime Barešić

Highly weather-sensitive sectors such as agriculture, energy, transportation, construction and disaster risk management can benefit by over US$160bn per year from potential improvements in weather forecasting capabilities

> "So many of the donors and countries spend a lot of money, get the equipment and then it never delivers the data"
>
> **Laura Tuck, SOFF global facilitator**

finance partners, including the Green Climate Fund, multilateral development banks and UN organizations. "Part of the motivation for the Alliance in the first place was for these institutions to agree to coordinate at the local level and not be inconsistent," adds Tuck. But the Alliance also realized that in order to close the basic observations gap, a new financing model is needed – the SOFF. A key aspect of SOFF is that it will fund both the initial investment as well as ongoing maintenance costs, on a long-term and predictable basis.

But, notes Tuck, the availability of this second level of funding will be contingent on data being shared. "WMO has the capacity in real time to verify each station as it shares the GBON-compliant data, and when they do they get a money transfer to the met service for a specified amount to contribute to operations and maintenance," she explains. "Because that's the piece we see fall down in the past. So many of the donors and countries spend a lot of money, get the equipment and then it never delivers the data."

Mobilizing funding

The SOFF team estimate that with US$400m they can support 67 LDCs and SIDS to meet their commitments to GBON within five years. Thereafter they will need US$50m a year to contribute to the operating and maintenance costs.

In order to come up with these numbers the WMO, in collaboration with its alliance members, calculated global average unit costs for renovating weather stations or for building them from scratch, as well as their operation and maintenance, including the costs to cover 'human and institutional capacity'.

The source of this funding will be the developed countries, mainly from governments, according to Johannes Linn, the other SOFF global facilitator and a non-resident senior fellow at the US public policy think-tank the Brookings Institution and a former executive at the World Bank. "Our main contacts are the met agencies of these countries, but because we know that these agencies traditionally don't have resources for international funding of this type, we are reaching out – with their help – to other government agencies, often development ministries or climate-funding ministries. But it could also be the environment ministry or the foreign affairs ministry."

The SOFF team has been holding a number of intra-agency briefings where representatives from different ministries within a country are brought together to learn about SOFF. It has also already organized two Funders Forums. And at the recent UN High-Level Political Forum in early July, the Alliance for Hydromet launched its first Hydromet Gap Report and presented the SOFF as its priority to close the most foundational gap, the basic observations gap.

UN secretary-general Antonio Guterres, on the occasion of this Political Forum, emphasized that, "for accurate forecasts, we need reliable weather and climate data. Today, large gaps remain in basic weather data, particularly in SIDS and LDCs. One of the priority solutions featured in the Hydromet Gap Report is the creation of the Systematic Observations Financing Facility."

To find out more about the Alliance for Hydromet Development, visit: https://alliancehydromet.org/about/. And for more information on SOFF, visit: https://alliancehydromet.org/systematic-observations-financing-facility/soff-support-statements/. SOFF has also recently released a video highlighting the importance of the project. View here: https://www.youtube.com/watch?v=nM-OIgBq2Eg. ▮

GACS

Meteorology, Air Quality, VOCs, Noise & Vibration Monitoring Fence line monitoring solutions

Saudi Arabia Installed Fenceline monitoring station with renewable energy power source

Saudi Arabia Installed
100 meter MET MASTS

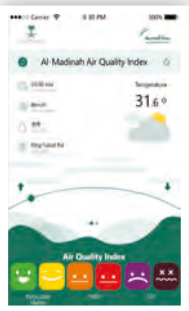
Gulf Advanced Control Systems (GACS Arabia), based out of Saudi Arabia serves the GCC region for environmental monitoring & compliance monitoring solutions, from supply of instruments to data validation & reporting on all of GCC environmental regulatory requirements.

Air quality stations

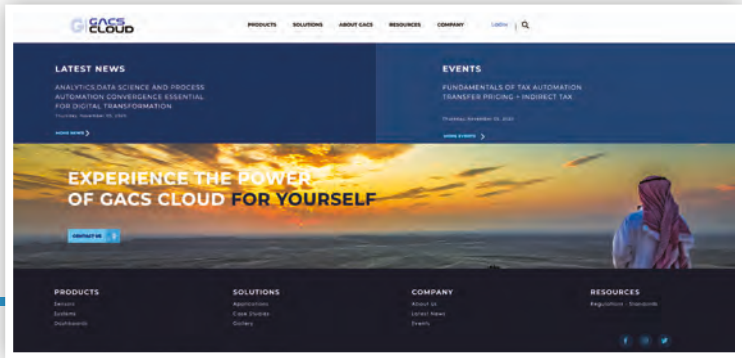
Air quality cabinets

Vehicle based monitoring

Meteorological & Air Quality Data Dashboards
for executive displays



Mobile Apps
for public



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Helen Norman

ALL AT SEA

As the UN kicks off its Decade of Ocean Science for Sustainable Development, *Meteorological Technology International* speaks to some of the leading figures in the hydrometeorological industry who are involved in world-class ocean observation projects

In June the UN officially launched its Decade of Ocean Science for Sustainable Development, which will run until 2030. The vision of the initiative is 'the science we need for the ocean we want'. According to the UN, the decade will provide a once-in-a-lifetime opportunity for nations around the world to work together to generate the ocean science needed to support the sustainable development of our shared oceans.

The work, projects, collaboration and frameworks involved in the ocean decade go beyond anything ever achieved within ocean science, and numerous hydrometeorological organizations – both public and private – are involved in a plethora of projects. In this special report, *Meteorological Technology International* speaks to some of the key people pushing for better ocean observations and data sharing, and provides insight into what the decade holds for them.

The current estimated economic value of the global ocean economy is **US$1.5tn** annually. By 2030, this is expected to double to **US$3tn**

Pierre Bahurel

Mathieu Belbéoch

John Trowbridge

Dr Toste Tanhua

PIERRE BAHUREL

CEO, MERCATOR OCEAN INTERNATIONAL AND CHAIR OF THE GLOBAL OCEAN OBSERVING SYSTEM EXPERT TEAM ON OPERATIONAL OCEAN FORECASTING

What is Mercator Ocean International's key role?

MOi is committed to providing real-time forecasts and multi-year reanalyses of the ocean environment, based on advanced ocean modeling and data assimilation. MOi maintains an operational digital description of the marine environment worldwide and helps organizations implement community and institutional programs, projects and initiatives for ocean monitoring.

We provide users with scientifically qualified and regularly updated data such as temperature, the intensity and direction of currents, ice cover, salinity, oxygen and chlorophyll content, acidity, etc. Covering the global ocean, from surface to bottom, we can forecast the ocean's state for the next 10 days or determine what it was 20 years ago.

What is MOi working on currently?

MOi hosts the Copernicus Marine Service, which we designed and have been running since 2015 on behalf of the European Union (EU). This serves to increase global ocean knowledge and boost the blue economy [sustainable use of ocean resources for economic growth, improved livelihoods and ocean ecosystem health] across all maritime sectors by providing free-of-charge state-of-the-art ocean data and information.

Furthermore, in November, MOi took on the responsibility of hosting the EU4OceanObs project, an EU Foreign Policy Action on international ocean governance that includes the EU Coordination Centre of the G7 Future of the Seas and Oceans Initiative (FSOI) and the EU office of the Group on Earth Observations (GEO) through the GEO Blue Planet Initiative.

EU4OceanObs brings together marine scientists and representatives from government agencies and ministries across the G7 to enhance the Global Ocean Observing System (GOOS) under the auspices of the UN. The EU Office works with the Copernicus Marine Service, EuroGOOS, the European Ocean Observing System, the European Research Infrastructure Consortium, and other programs and institutions of the EU to respond to EU needs and priorities for global in-situ ocean observations.

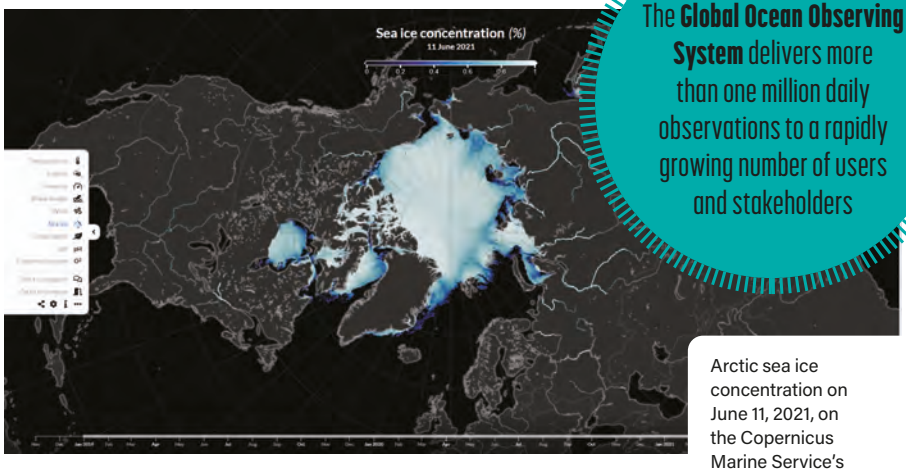
Tell us more about FSOI.

Supported by EU4OceanObs, the G7 FSOI brings together scientists and representatives from government agencies and ministries to address implementation priorities for the observing system, to review progress and to highlight gaps in system development. The G7 FSOI also provides scientific and technical support to the GOOS and its expert panels to catalyze the development of observing strategies and implementation required to advance the system, particularly for biogeochemistry, biology and ecosystem monitoring.

The EU Coordination Centre at MOi is leading G7 activities to complete and sustain the Biogeochemical Argo Array, and working with GOOS to develop strategies for surface ocean CO_2 monitoring, marine life observing and forecasting, and developing a global ocean monitoring indices framework.

What other organizations does Mercator work with to improve ocean monitoring?

MOi is one of the patron agencies of the international global OceanPredict program and a member of the International Global Ocean Data Assimilation Experiment (GODAE) steering team. The Mercator system is one of the OceanPredict's pilot systems. OceanPredict represents the third phase of GODAE, which will see full integration of previous achievements and expertise, and deepening of the partnerships with GOOS, the Expert Team on Operational Ocean Forecast Systems (ETOOFS) and GEO Blue Planet, to contribute to a value chain from observations, data and information



The **Global Ocean Observing System** delivers more than one million daily observations to a rapidly growing number of users and stakeholders

Arctic sea ice concentration on June 11, 2021, on the Copernicus Marine Service's MyOcean Light tool

"MOi is developing a science-based digital twin of the ocean to support the conservation and sustainable use of our oceans and seas"

Pierre Bahurel, Mercator Ocean International

systems, predictions and scientific assessments, to end users, with the aim of promoting the use and impact of observations and ocean predictions for societal benefit, and to increase the visibility of operational oceanography advances.

I also chair the ETOOFS of the GOOS under the auspices of the Intergovernmental Oceanographic Commission (IOC) of UNESCO. The role of ETOOFS is to create guidelines for how to develop and operate ocean forecast systems, and to improve the capacity, quality and interoperability of ocean forecast systems and products worldwide. ETOOFS will contribute to the three GOOS UN Ocean Decade 2021-2030 programs (Ocean Observing Co-Design, Observing Together and CoastPredict).

Moreover, ETOOFS is currently writing a comprehensive scientific guide about operational ocean forecasting systems, which will be published by the end of 2021. This guide aims to provide guidelines to improve the capacity, quality and interoperability of ocean forecast products to support climate, operational maritime services, biodiversity and the blue economy.

What are some of the new ways the oceans are being monitored?

For in-situ ocean observations, the GOOS is based on global networks that include research vessels, commercial vessels, profiling (Argo) floats, gliders, drifting buoys, moored buoys and arrays, animal-borne instruments, sea-level monitoring stations and global high-frequency radar networks. These networks are being expanded with new technologies including e-DNA and omics [the study of bio-sciences the names of which end in '-omics'] techniques to monitor biodiversity, and the observing community is developing multi-platform strategies to study the deep ocean, ocean acidification and ice-covered high-latitude seas.

MOi and the Copernicus Marine Service use data from the global observing system and the European observing networks, and also establish data collection partnerships in areas where data is limited. For example, most fishing activity takes place precisely where we lack – and need – oceanographic data, often in coastal and shelf seas. Fishing vessels offer an innovative way to expand our coverage of the ocean in areas where existing infrastructure or data-sharing networks are lacking. Fishing-net sensors, for example, provide an effective means to collect data across the entire water column, by gathering information first on their way down to the seafloor and then on their way back up to the sea surface.

The Copernicus Marine Service recently established a data flow from fishing vessels in the North Sea in collaboration with Berring Data Collective (BDC), a startup dedicated to ocean observation and oceanographic data collection. These data products are made available by the Copernicus Marine In Situ Thematic Assembly Centre (INS TAC), a core European marine data producer that draws from a wider network of producers to provide high-quality, multi-source data so that users – including the Copernicus Marine Monitoring and Forecasting Centres (MFCs) – can validate their studies, optimize their models and gain greater knowledge of the marine environment.

In 2020, the annual **Arctic sea ice** minimum was one of the lowest on record, exposing polar communities to abnormal coastal flooding

How can machine learning and AI help with ocean observations?

AI is being used, for example, in new types of algorithms called artificial neural networks and applied to the in-situ data. Inspired by the neural networks in our own brains, these consist of a series of algorithms that seek to recognize underlying relationships in a set of data. For example, within some of the products of the Copernicus Marine Service, neural networks infer information about three different nutrients (nitrate, phosphate and silicate) – for which there are very few direct observations – from a set of input in-situ parameters (temperature, salinity, pressure and oxygen) – for which there are more observations. The neural network is trained to find a statistical relationship between the input parameters and the nutrients using historical data collected over the past 30 years.

Meanwhile, MOi is developing a science-based digital twin of the ocean to support the conservation and sustainable use of our oceans and seas. MOi is also working with the EU and international partners in the UN Decade of Ocean Science for Sustainable Development to develop a comprehensive digital representation of the ocean, including a dynamic ocean map, which provides free and open access for exploring, discovering and visualizing past, current and future ocean conditions in a manner relevant to diverse stakeholders.

OCEAN DATA ASSIMILATION AT ECMWF

In May 2021, ECMWF and OceanPredict held a virtual workshop to discuss ocean data assimilation. The workshop gathered experts from different domains to address the interactions in the ocean, atmosphere, sea ice and biogeochemistry system and to look at the exploitation of novel observations.

Magdalena Alonso Balmaseda, head of the Earth Predictability Section at ECMWF, reveals what went on during the workshop: "Discussions during the workshop addressed common questions including the treatment of model error, the specification of short-range forecast and observation errors, the balancing of resolution and ensemble configurations, and the exploitation of machine learning. The discussions also covered the infrastructure needed to share developments among different domains, and between operations and research."

There were a number of key recommendations, including advancing the scientific foundations underpinning the coupling among Earth system components, better exploration of machine learning solutions and the use of target observations. "Other recommendations included making use of emerging observations with the ability to sample the ocean at finer spatial/temporal scales, further developing methods for representing multi-scale flow-dependent background errors, which include the time dimension, balancing resolution/ensemble needs, and developing stronger links between the data assimilation and modeling communities to benefit the scientific and infrastructure developments in both domains," Balmaseda adds.

"Training and recruitment are also extremely important," Balmaseda continues. "It is essential that the industry invests in the next generation of data assimilation scientists through specific training programs on the use of modern software development and collaboration techniques. Beyond training, sustained research funding for data assimilation in the research community is also required to maintain a sufficient pool of talent and expertise to exploit new computer architectures and observing systems."

MATHIEU BELBÉOCH

OCEANOPS LEAD

What is OceanOPS?

OceanOPS is the international center of excellence for coordination and monitoring of meteo-oceanographic observing systems that are part of the GOOS. OceanOPS coordinates and optimizes the performance of a network of 10,000 weather-oceanographic observing devices including international Argo deployment, drifting and fixed buoys, OceanGliders piloted profilers, weather-oceanographic and research vessels, marine animals equipped with oceanographic sensors and tide gauges.

Tell us about Sailing for Science.

You don't always need an expensive research vessel to deploy observing devices in the ocean. Sometimes a mariner or sailor can do the job just as well. This is why we teamed up with the Vendée Globe around-the-world yacht race, which happens every four years. During the 2020-2021 event, 10 skippers took with them scientific instruments including either drifting buoys that gather climatological information or Argo floats that analyze sea water. During the race they deployed all the drifting buoys and almost all the Argo floats at agreed coordinates in the Atlantic Ocean.

Four skippers also carried onboard equipment to measure essential ocean variables such as sea surface salinity, temperature, CO_2 and atmospheric pressure, as well measuring the microplastics pollution at sea. The data collected was shared in real time with international open-source databases. One of the main benefits of this project is that these racing yachts can reach remote and not yet well-sampled areas of the ocean, filling critical observational gaps.

Another key benefit was the media attention the project received. The skippers helped us to humanize the work we are doing with the GOOS and illustrate the importance of ocean monitoring for the climate.

Do you plan to continue running projects like this?

We are working with sailing boats, fishing vessels and merchant ships that operate outside of science on a regular basis. Our plan, now that we have gathered extensive experience with this approach, is to regroup and federate all these contributions as part of a UN Ocean Decade project called Odyssey. This project plans to partner with citizen science and private-sector initiatives to complement existing GOOS networks with third-party contributors.

We believe there is a growing appetite in the society outside of science to contribute to ocean observations, so we want to better unlock the data potential. Every single vessel from the big commercial ships down to the paddleboard has the capacity to put sensors on board, so we would like to make it a standard approach either through regulation or best practice.

What other projects do you have coming up?

Our main role is coordination and monitoring, but sometimes we do support the platform operators to fill some ocean gaps by deploying buoys. We are doing this this year with a project we are running in the South Atlantic Ocean. This is to help fill the gaps following Covid-19, which saw some projects postponed or cancelled altogether.

> "We believe there is a growing appetite in the society outside of science to contribute to ocean observations"
>
> **Mathieu Belbéoch, OceanOPS**

IMOCA skipper deploying a weather buoy during Vendée Globe

We are chartering a 25m shipping vessel, which is low cost and has a low carbon footprint. The vessel is currently in the bay of Brest in France. In October/November it will leave to go across the Atlantic Ocean and down to Cape Town to deploy floats. It will be equipped with about 100 profiling robots and surface drifters, and it will also take measurements itself as it travels. The ship is a former racing vessel, so we are also giving a second life to those ships.

Where are some of the big data gaps?

One of the largest is in the Southern Ocean. We have hardly any ships operating there. The shipping vessels don't go there and the research vessels very rarely travel there. We are in discussions with some tourist vessels and racing vessels to see if they can deploy buoys and gather data. There are also some marine animals, such elephant seals, equipped with sensors that enable us to gather data from below the ice.

Tell us about your new strategic plan.

Our new strategic plan for 2021-2025 provides guidance for OceanOPS activities to continue the center's success toward a more efficient and integrated system that delivers data and information necessary for an increased range of services and research.

It is based on five key aims: monitor the improvement of global ocean observing system performance; lead metadata standardization and integration across the global ocean observing networks; support and enhance the operations of the global ocean observing system; shape OceanOPS infrastructure for the future; and enable new data streams and networks.

We really want to encourage our community to deploy buoys where needed, so we need to illustrate where the gaps are and where they need to develop. We also want to help other countries to get involved in ocean observing. There is a lot of margin for progress with regard to international cooperation in this area.

What key challenges are you facing?

Funding is a big issue. We need to stabilize more funding as currently the limited resources not only affect OceanOPS development but also limit the achievement of an integrated global ocean observing system. I look forward to seeing the development of a funding mechanism with the WMO to help some new countries contribute to the system with floats, drifters, weather stations, etc.

Another of our key challenges is political. A third of the ocean is an exclusive economic zone (EEZ), which means it is under the sovereignty of a nation; to deploy an instrument there, you need their authorization. Some countries will just say no, and there is nothing we can do about that. We need some political support to unlock new ocean data in some of the EEZ areas.

What do you hope to achieve by the end of the decade?

I hope that in 10 years' time we will have the capacity to process data from any instrument from anywhere in the world, and there will be more standardization with regard to data flow and the instruments used. For the latter, we need the support of industry because this is where standards are typically born. Today there is a lot of energy spent processing data that comes from instruments that are not standardized or calibrated. If we can improve our dialogue with the industry then maybe in 10 years' time we can have more efficient data flow for today's applications and for future generations.

The **Sentinel-6 Michael Freilich satellite** collects measurements for about 90% of the world's oceans

MONITORING THE OCEANS FROM SPACE

There is a lot of work still to be done to improve in-situ measurements of the ocean, according to OceanOPS lead Mathieu Belbéoch. He believes that a lot can be learned from the framework adopted for satellite observations. "In-situ measurement observations need a clear implementation plan like the space agencies have created for launching weather and ocean monitoring satellites," he explains.

There are a number of satellites that monitor the ocean. One of the most recent ones to be launched is the Sentinel-6 Michael Freilich satellite – US-European collaboration collecting measurements for about 90% of the world's oceans. It measures sea surface height and other key ocean features, such as ocean surface windspeed and wave height. The satellite, which was launched in November 2020, began to provide its first scientific measurements in June. Sentinel-6B is slated for launch in 2025.

These are the latest in a series of spacecraft starting with TOPEX/Poseidon in 1992 and continuing with the Jason series of satellites that have been gathering precise ocean height measurements for nearly 30 years.

NASA is set to launch its Surface Water and Ocean Topography (SWOT) satellite in late 2022. This will help researchers understand and track the volume and location of water around the world, making NASA's the first truly global survey of the planet's surface water.

JOHN TROWBRIDGE

SENIOR SCIENTIST, DEPARTMENT OF APPLIED OCEAN PHYSICS AND ENGINEERING, WOODS HOLE OCEANOGRAPHIC INSTITUTION AND PRINCIPAL INVESTIGATOR ON THE OCEAN OBSERVATORIES INITIATIVE (OOI)

What is the OOI project?

The Ocean Observatories Initiative is a science-driven ocean observing network that delivers real-time data from more than 800 instruments to address critical science questions regarding the world's oceans. OOI data is freely available online.

The observatory consists of five arrays continuously collecting ocean data. Two coastal arrays expand existing observations off both US coasts. A cabled array 'wires' a region in the Northeast Pacific Ocean with high-speed optical cables and a high-power grid that powers data gathering and observation. Global components address planetary-scale changes using moored open-ocean infrastructure linked to shore via satellite.

The OOI's network of interactive, globally distributed sensors provides access to real-time ocean data, enhancing our capability to address critical issues such as climate change, ecosystem variability, ocean acidification and carbon cycling.

At what stage is the project currently?

The network was commissioned in 2016 and has so far provided 36TB of data in response to 189 million download requests. Scientists have used this data to produce numerous peer-reviewed publications that are advancing our understanding of ocean processes and changing ocean conditions. The National Science Foundation has recognized the value of the data, with an investment of US$52.5m, supporting 92 research projects that use OOI data or infrastructure.

The observatory is managed by a program management office at the Woods Hole Oceanographic Institution (WHOI). WHOI, the University of Washington, Oregon State University and Rutgers University are responsible for operating and maintaining specific parts of the infrastructure. The current period of performance began on October 1, 2018 and will end on October 1, 2023. The envisioned lifetime of the project is 25 years, extending into the 2040s. Anticipated execution will be through a continuing series of five-year periods of performance.

What recent developments have been made as part of OOI?

An exciting development is a series of workshops that brought together members of the OOI community to determine the location and conceptual design of the Pioneer Array, currently located 75 nautical miles south of Martha's Vineyard in Massachusetts. In the original OOI concept, the Pioneer Array was envisioned as a moveable coastal array that would occupy a new location every five to seven years for continuous data collection applicable to the most important coastal oceanographic science questions.

The community input at the workshops has determined that the new location will be in the southern Mid-Atlantic Bight, over the shelf and slope just north of Cape Hatteras [North Carolina, USA]. The most recent workshop in the series resulted in a high-level plan for locating the Pioneer Array infrastructure and for the addition of new sensors to address a wide range of interdisciplinary scientific questions. The next steps, to be undertaken by the WHOI team, include detailed site characterization, engineering design, permitting, testing and logistical planning, all to support deployment at the new location in 2024.

What insights have you gained from the data so far?

OOI data serves as the backbone of new scientific insights. These include a new understanding of undersea volcanos, based on detailed observations by the OOI Regional Cabled Array of the 2015 eruption

NOAA Ship Okeanos Explorer at sea

Art Howard/NOAA Ocean Exploration

UNDERWATER ROBOTS ON TEST

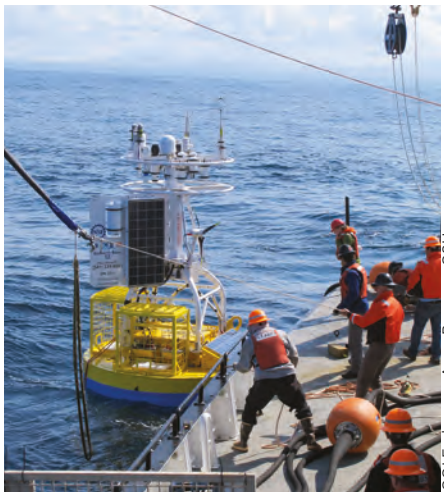
In May, NOAA's ship Okeanos Explorer departed Port Canaveral in Florida on an expedition led by NOAA Ocean Exploration and featuring the technology demonstration of an autonomous underwater vehicle. Called Orpheus, the new class of submersible robot will showcase a system that will help it find its way and identify interesting scientific features on the seafloor.

By utilizing a low-power system of cameras and lights, along with advanced software, Orpheus is an order of magnitude lighter than most deep-sea submersibles. Smaller than a quad bike and weighing about 250kg, Orpheus is designed to be nimble, easy to operate and rugged while exploring depths inaccessible to most vehicles.

Designed by Woods Hole Oceanographic Institution in collaboration with NASA's Jet Propulsion Laboratory, Orpheus can work untethered almost anywhere in the ocean. Ultimately, the project team hopes to see a swarm of these underwater robots working as a team to build 3D maps of the vast regions of unexplored ocean floor in the hadal zone – regions deeper than 6,000m.

UW/NSF-OOI-CSSF

Oceans have taken up more than **90%** of the excess heat in the climate system. By 2100, they will have taken up two to four times more heat than they have in the past 50 years if global warming is limited to 2°C, and up to four to seven times more if emissions are higher



OOI Endurance Array Program, OSU

ABOVE: OOI's Regional Cabled Array powers a digital still camera, which lights up the active hydrothermal vent, called El Gordo in the International District Hydrothermal Field, at the summit of Axial Seamount and nearly a mile beneath the ocean's surface

RIGHT: OOI's Coastal Endurance Array's Oregon shelf surface mooring is released from a crane into the water

at Axial Seamount, off Oregon, which have enhanced the ability to predict future eruptions. OOI data has enabled the discovery of previously unknown and rapidly evolving processes by which nutrients are exchanged between the deep ocean and the continental shelf off New England, supporting a productive coastal ecosystem and one of the nation's most productive but fast-changing fishing grounds. Scientists, for example, are sharing real-time data with New England fishers, who can then adapt where, when and how they fish. The OOI has provided the first year-round observations of air-sea heat transfer, deep convection and the biological carbon pump in the Irminger Sea off Greenland, one of the few sites worldwide of the deep-water formation that feeds the global thermohaline circulation, which mediates the climate for the entire Earth.

What data products have been developed?

The primary purpose of the OOI is to deliver processed data from individual sensors for analysis and synthesis by the oceanographic and earth science communities. However, several data products have been developed from raw measurements from individual instruments on the various arrays. An example is direct measurements by the Direct Covariance Flux sensor of the so-called sensible heat flux – how much and how fast heat is transferred between the atmosphere and the ocean. This sensor obtains velocity and temperature measurements at some 20Hz and then processes and analyzes these measurements to produce heat and momentum transfer rates on an hourly averaged basis, suitable for use in scientific analyses and numerical simulations of ocean processes.

What technology and instruments are used as part of the OOI?

The basic OOI infrastructure is chock full of notable technology. The submarine cable and the supporting technology in the Regional Cabled Array provide unprecedented power and bandwidth for undersea measurements. In essence, it serves as a power source and internet connection for two-way communication to more than 140 scientific sensors on the seafloor and throughout the water column. It has vast expansion capabilities. Other notable technology includes oceanographic moorings that survive and transmit data in year-long deployments at remote, hostile locations such as the Irminger Sea off Greenland, and the Southern Ocean off the tip of South America.

New designs for coastal moorings support interdisciplinary sensor suites and real-time communications in harsh conditions over continental shelves and slopes. Meanwhile, newly developed gliders provide measurements and communications during unprecedented year-long deployments at remote locations, and autonomous underwater vehicles provide rapid sampling of coastal regions with advanced sensor payloads.

The cyber infrastructure used to collect and relay all of this data is perhaps the crown jewel. It successfully ingests measurements from over 800 individual instruments, processes the data and performs QA/QC, and then serves the data in near real-time to anyone with an internet connection.

Are there any big data gaps for ocean forecasting?

A major data gap is the Southern Ocean, which plays a major role in the climate system and is greatly under-sampled because of remoteness and extreme conditions. The OOI array in the Southern Ocean operated and provided unique measurements of water-column processes and air-sea transfer for several years but was discontinued in 2020 because of funding limitations. Restoration of this capability would be a significant step forward.

> "Newly developed gliders provide measurements and communications during unprecedented year-long deployments at remote locations"
>
> **John Trowbridge, Woods Hole Oceanographic Institution**

DR TOSTE TANHUA

SCIENTIST, GEOMAR HELMHOLTZ CENTRE FOR OCEAN RESEARCH KIEL

Geomar and German adventurer Arved Fuchs have teamed up for an expedition to gather measurements in the northern North Atlantic

S Kaehlert, Geomar

What is Geomar's key role?

Geomar Helmholtz Centre for Ocean Research Kiel is a leading marine research institute. We investigate chemical, physical, biological and geological processes of the seafloor, oceans and ocean margins and their interactions with the atmosphere. The institute operates three research vessels, state-of-the-art equipment such as the manned submersible JAGO, the deep-sea robots ROV KIEL 6000, PHOCA and ABYSS, and several major laboratories.

How does Geomar support GOOS?

Ocean observing programs in which Geomar is active include the repeat hydrography program GO-SHIP, the Argo and BGC-Argo programs, ocean gliders, OceanSITES that coordinate fixed observing platforms such as moorings, and many more. Geomar is very active in the OSNAP array of current moorings in the North Atlantic that is monitoring the strength and variability of the Atlantic Meridional Overturning Circulation (AMOC).

Geomar is also a long-standing member of POGO (Partnership for Observation of the Global Ocean), an organization for oceanographic institutes around the world.

What is Geomar working on currently?

Geomar is currently coordinating a large EU Horizon 2020-funded research program called EuroSea. This project with 55 partners aims to improve and integrate the European Ocean Observing and Forecasting System. Geomar also coordinated a past, but very influential, H2020 program, AtlantOS, with objectives similar to EuroSea's but with a slightly wider scope of the whole Atlantic Ocean. The AtlantOS project is now established as a program to support coordination of ocean observations in the Atlantic Ocean, and as such has been approved as a GOOS project.

In what unique ways are you gathering data?

In Geomar we are at the forefront of developing and integrating well-established and novel ocean observing systems and platforms. This is often done in cooperation with private and industrial partners. One example is the use of instrumentation on racing yachts to observe surface ocean carbon dioxide concentrations and the abundance of microplastic. Geomar is also exploring the use of autonomous surface vehicles such as sail drones and wave gliders that can be sent on unmanned missions for months at a time to observe the oceans.

About **2,000 autonomous instruments**, such as profiling floats and drifting buoys, must be deployed every year to sustain the Global Ocean Observing System.

Have you made any new findings about the ocean recently?

Geomar led a large 12-year, recently closed, research project on climate-biogeochemistry interactions in the tropical ocean. Key findings there are about the rate of loss of oxygen in the tropical ocean's oxygen minimum zones (OMZ) and a much better understanding of the processes that are governing these changes. Major scientific findings of the project include the identification and detailed quantitative understanding of oxygen supply by small-scale physical processes, in particular temporally varying zonal current bands that transport oxygen to the tropical OMZs. Also, novel biogeochemical processes for cycling nutrients in the sediments and in the water column were identified.

What data gaps still exist?

There are many gaps in ocean observing, unfortunately. The Argo program of profiling floats has been very successful in constraining the ocean heat content (OHC) in the top 2,000m of the ocean. However, 48% of the ocean volume is below 2,000m depth, and although the heat content in the upper ocean is changing faster than the deep ocean, it is a gap that can decrease uncertainties in OHC significantly. Therefore, deep Argo floats (4,000-6,000m capacity) are being developed and deployed to fill that gap. This is complementary to the repeat hydrography program GO-SHIP, which is the only other program systematically addressing this. ▮

GEOMAR'S NEW AUV POSEIDON

The research vessel Poseidon served marine research at Geomar for more than 40 years before it was decommissioned and sold at the end of 2019. Geomar is now using the €1.2m (US$1.4m) from the sale to develop a new autonomous underwater vehicle (AUV) that will undertake research missions also under the name Poseidon.

The project is in its early stages but the first details have been defined. For example, the AUV Poseidon will be able to dive autonomously to a depth of 6,000m for several hours and collect a variety of data. Various measuring instruments and sensors will be integrated on the AUV, such as multibeam echo sounders, side-scan sonars, turbidity and fluorescence sensors and a CTD (conductivity, temperature and depth device) that measures standard values such as salinity, water temperatures and depth.

Marcel Rothenbeck, team leader of the AUV team at Geomar, says, "AUV Poseidon will be designed as a standard torpedo-shaped AUV and prepared for about 3kts. The main purpose is for acoustical and visual mapping but there are a lot of other tasks possible.

"We are currently working on the electrics and data exchange between the central system and the subcomponents. The mechanical construction is in the second phase. The chassis is structurally prepared so that strength tests can be done. The first water test is planned for spring 2023."

Externally, the new AUV POSEIDON will resemble the AUV ABYSS already operated at Geomar

Janna Sprenger, Christoph Kersten/GEOMAR

ESRI OCEAN, WEATHER, AND CLIMATE GIS FORUM

How and Why Mapping Is Vital to Making Your Data Actionable

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Extreme changes in the ocean, weather, and climate wreak havoc on our global society. People are increasingly looking for information that is easy to understand and will help them make critical decisions that protect lives and property, create opportunities for economic growth, and enable societal advancement.

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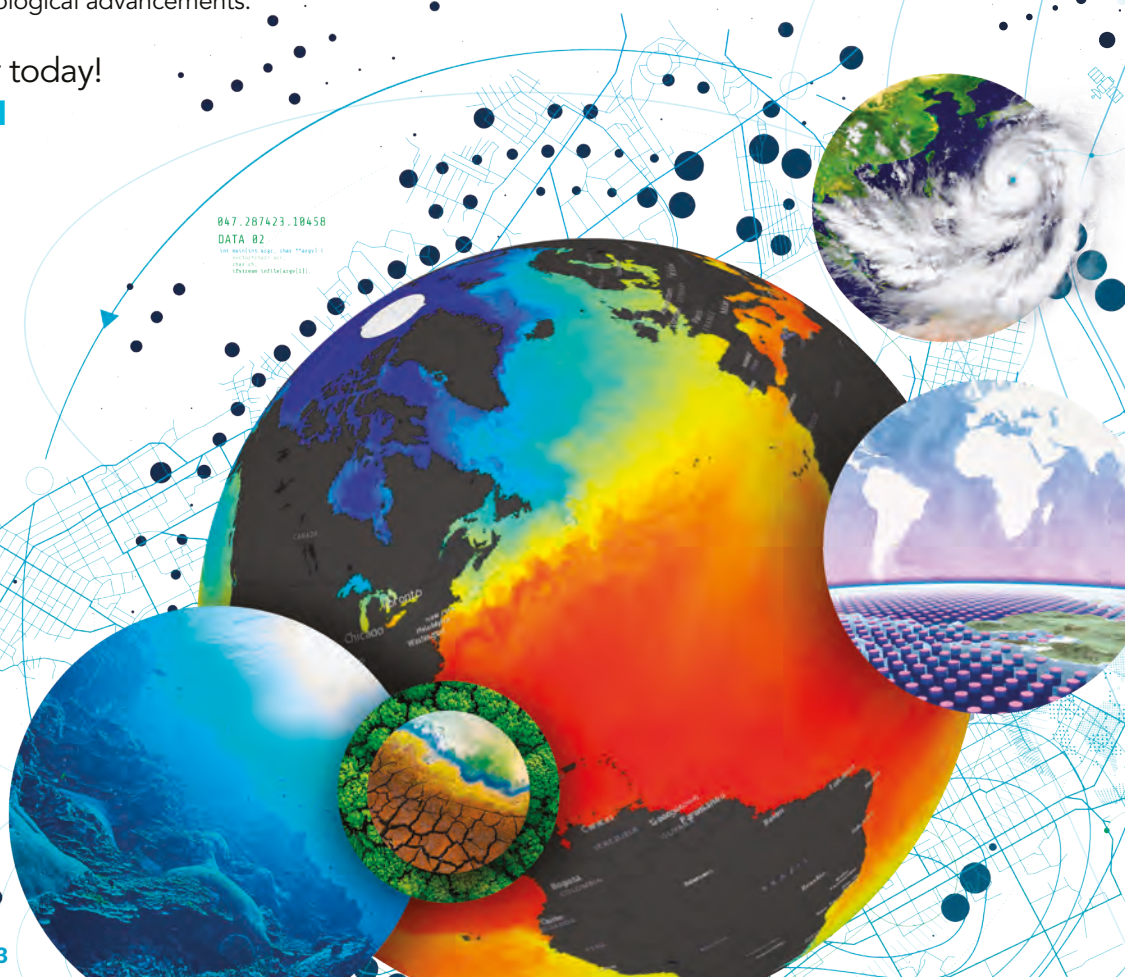

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Helen Norman

MAP IT OUT

Esri's chief scientist, Dawn Wright, talks about the importance of the UN Decade of Ocean Science and how her company is supporting a number of actions to improve ocean science

Why is the UN Decade of Ocean Science important?

The ocean is under massive threat from climate change and it desperately needs more of our attention. Hence, the United Nations Decade of Ocean Science for Sustainable Development is a once-in-a-lifetime global cooperative program to expand scientific and industry partnerships that will support groundbreaking science, management, conservation and sustainable development of the ocean.

The overall mission for the Ocean Decade, which officially began in June and runs until 2030, is to bring to bear transformative ocean science solutions for sustainable development, connecting people and our ocean.

For the US specifically, the Ocean Decade presents a tremendous opportunity to play a leadership role in helping to shape the future of ocean and coastal science, along with the future of technology and sustainable development. This is our chance to set the course for ocean science over the next 10 years and beyond. Advancing all these capabilities through domestic and international partnerships enables the US to achieve its goals of safeguarding human health, tackling climate change, ensuring coastal resilience and promoting economic prosperity.

How is Esri supporting it?

The Ocean Decade Executive Committee issued a call last year for Decade Actions, where partners all over the world were invited to submit proposals requesting endorsement of their programs. After a thorough review process against the endorsement criteria contained in the Ocean Decade's Implementation Plan,

more than 60 programs and contributions have been endorsed. Esri is a participating partner in five of them: Deep Ocean Observing Strategy (DOOS), led by the Scripps Institution of Oceanography; Digital Twins of the Ocean (DITTO), led by the GEOMAR Helmholtz Center for Ocean Research Kiel and Kiel University; Early Career Ocean Professionals (ECOP), led by the Ocean Decade Informal Working Group for Early Career Ocean Professionals; Seabed 2030, led by the Nippon Foundation and the General Bathymetric Chart of the Oceans (GEBCO); and Promote Seabed 2030 and Ocean Mapping, led by NOAA.

Furthermore, Esri is also a member of the Ocean Decade US Nexus – a program of the US National Ocean Decade Committee of the National Academy of Sciences, to help the committee share, promote and communicate news about US efforts related to the Ocean Decade.

How will DITTO help with ocean monitoring?

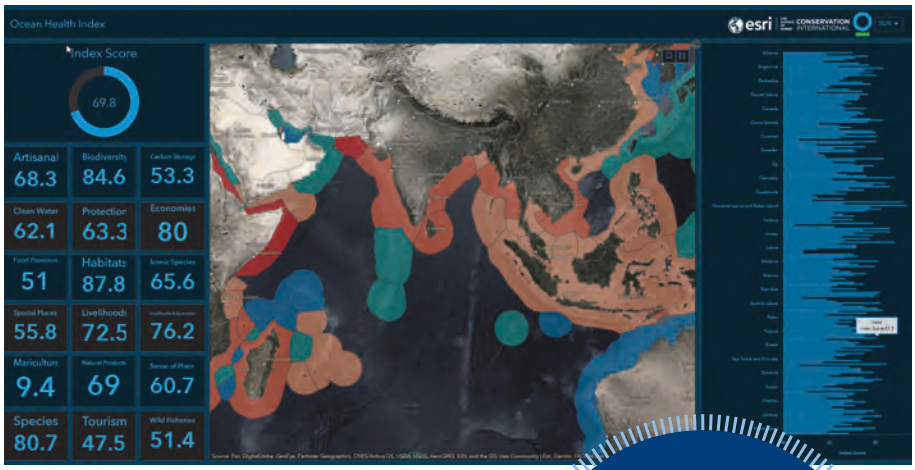
Digital twins will be powerful for natural environments such as the ocean, especially as a way to provide more intuitive access to the existing vast stores of ocean data, models and simulations, including those of air-sea interactions that affect weather and climate. The current ecosystem of ocean-observing platforms, buoys, robots, ships and satellites allows us to answer the questions, What is the state of the ocean today? How will it change tomorrow?

But a well-constructed digital twin of the ocean will enable a wider range of users to not only interact with these digital assets but also explore future scenarios, especially related to human interactions with the ocean.

High-value application areas include fisheries and mariculture, marine protected areas, ocean-based tourism, ecological forecasting, weather forecasting, marine infrastructure development and the interactions between all of these with an ever-growing collection of data streams.

The prototypes that we'll be building as part of the DITTO program will help to answer many questions, including: What is the most cost-effective option to mitigate the long-term coastal impact of sea-level rise and the short-term impacts from hurricanes and coastal storms? What is the future of tropical Atlantic upwelling regimes and the implications for coastal commercial fisheries?

Esri is one of 40 global DITTO program partners that will be collaborating on a series of digital twin prototypes for various settings. The prototypes and frameworks that the partners – representing universities, national oceanographic centers, the private



LEFT: The Ocean Health Index dashboard monitors ocean conditions

ABOVE: In November 2020, Esri held the Ocean, Weather and Climate GIS Forum to share advances in data collection, analysis and understanding of met-ocean interactions

sector and governments – will be building depend on several core elements for their technical infrastructure. Esri specializes in many of these and thus will be contributing expertise and solutions to the tools that are planned for data ingestion, discovery and management; tools for spatial analyzing data with classical or AI-based functions, creating what-if scenarios, and visualizing the result in effective 3D and a user-friendly environment. Esri is also contributing the existing 3D digital ocean known as the Ecological Marine Units, which includes 50-year volumetric averages of ocean temperature, salinity, dissolved oxygen and nutrients.

Please can you tell us about any new solutions you have recently developed for ocean monitoring.

The Ecological Marine Units' 3D digital ocean is moving into a new phase with the incorporation of the latest version of NOAA's World Ocean Atlas data. We have also developed a new High Tide Flooding web application in cooperation with NOAA that promotes the understanding of different sea-level rise scenarios for locations throughout the USA.

Another important web app is the new US Vessel Traffic app, which helps marine spatial planners better understand the uses of ocean space and identify potential space-use conflicts. This app enables the user to explore maritime activity, look for patterns and download manageable subsets of massive AIS (automatic identification system) data feeds.

Understanding the characteristics and metrics for a healthy ocean can go a long way toward promoting sustainable practices and policies by national governments, so we have produced a global dashboard that draws from the Ocean Health Index project of the National Center for Ecological Analysis and Synthesis (NCEAS) and its partners. This dashboard allows for the viewing of country-level statistics about how coastal oceans are changing over time.

Another ocean monitoring dashboard comes from our collaboration with OceanOPS, which makes it possible to view the status of 3,775 Argo floats globally. This network of global sensors helps us better understand the current met-ocean state of our ocean from the air-sea interface down to ~2,000m depth.

Esri has also created the Sea Ice Aware app based on data and analyses of the National Snow and Ice Data Center. The app displays the monthly mean sea-ice extent for both the Arctic and the Antarctic, along with the historical median extent. Additionally, there are dynamic graphs that visualize the minimum and maximum extent for each year and the monthly time series for each year.

Read the full interview with Esri's chief scientist, **Dawn Wright**, at www.MeteorologicalTechnologyInternational.com

> "We need more ocean observations to better inform our daily, weekly and seasonal weather forecasts"
>
> **Dawn Wright, chief scientist, Esri**

What are the main data gaps in terms of the oceans?

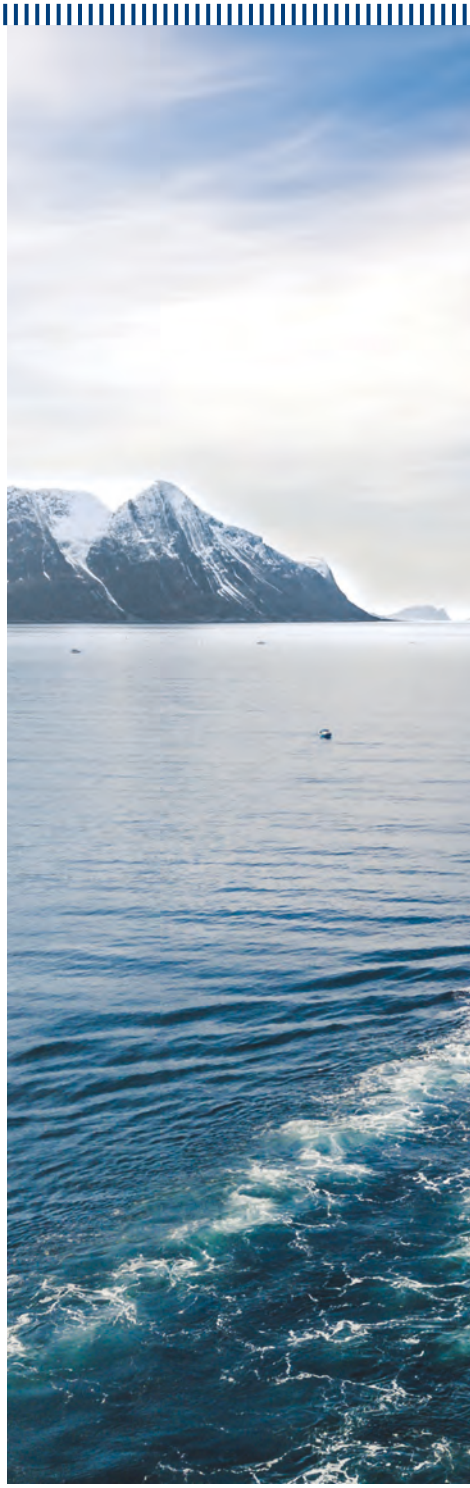
One of the reasons why Seabed 2030 was endorsed as a UN Ocean Decade Action is that we still have only 20.6% of the global ocean floor mapped in detail similar to maps that we have on land. As a case in point, the USA has the second largest exclusive economic zone (EEZ) in the world, yet 53% of US waters, including the Great Lakes, remain unmapped by our current technology. The US does have a National Ocean Mapping, Exploration and Characterization (NOMEC) Strategy to eventually remedy this.

Similarly, we need more ocean observations to better inform our daily, weekly and seasonal weather forecasts. They are key to improvements in these forecasts, especially for high-impact events such as El Niño, sea-ice minima, hurricanes and other storms, drought, marine heat waves, land heat waves, ocean acidification, ocean deoxygenation and regional weather. Ocean observations, including at depth, are important for initializing the state of the ocean for hurricane prediction (especially intensity) and global sub-seasonal to seasonal (and longer) timescales. ▮

Shaijan Baby, Director, MicroStep-MIS FZCO

ALL ABOARD

A look at the design and development of an Eddy Covariance Flux System on board a research vessel to study the exchange of water vapor and carbon dioxide between the ocean surfaces and atmosphere



Over the past several millennia, greenhouse gases have played a vital role in keeping temperatures at sustainable levels to support life on Earth. Greenhouse gas molecules and clouds absorb most of the infrared radiation from the sun and re-emit this radiation in all directions, effectively warming the Earth's surface and the lower atmosphere (troposphere). Without the natural greenhouse effect, the heat emitted by Earth would just pass outward into space and the planet would have an average temperature of about -20°C.

Water vapor is the largest contributor to Earth's greenhouse effect, followed by non-condensable gases, of which carbon dioxide is the other dominant contributor. Over the past two centuries, the levels of carbon dioxide in the atmosphere have unceasingly increased due to human activities such as the increased use of fossil fuels and large-scale deforestation. This has led to increasing global temperatures due to the continuous increase of carbon dioxide in the atmosphere, causing more water vapor to enter the atmosphere.

The greenhouse gases that we emit into the atmosphere don't remain there indefinitely. For example, the amount of carbon dioxide in the atmosphere and the amount of carbon dioxide dissolved in the surface waters of the oceans stay in equilibrium. This is because the air and water mix well at the sea surface. When we add more carbon dioxide to the atmosphere, a proportion of it dissolves into the oceans, which makes seawater more acidic.

Ocean acidification is already affecting many marine species, such as corals and oysters that make shells and skeletons by combining calcium and carbonate from seawater. It is widely agreed that the exchange of water vapor and carbon dioxide between the ocean surfaces and atmosphere has far-reaching implications for life on Earth. Therefore, understanding this process is an active area of interest for climate scientists and marine researchers.

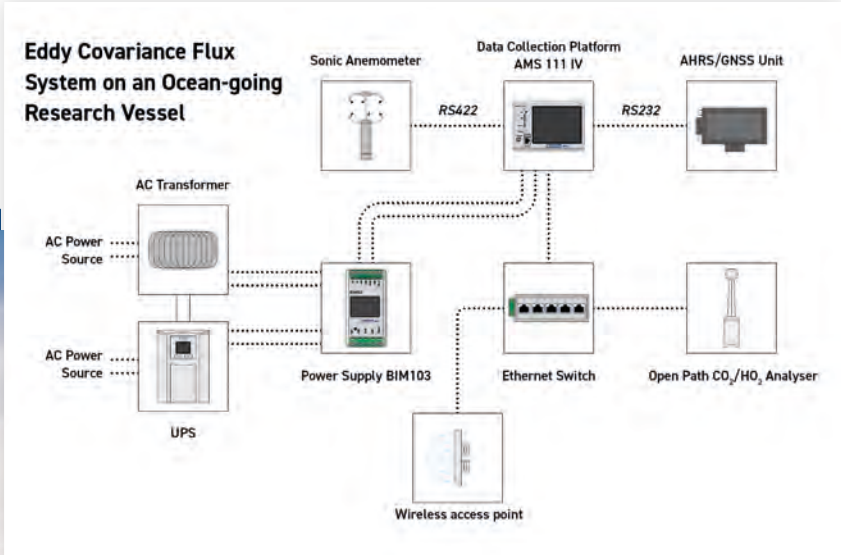
The eddy covariance technique

The eddy covariance method (also known as eddy correlation and eddy flux) is a key technique that provides direct measurement of vertical turbulent fluxes within atmospheric boundary layers. The technique has been employed for various applications to determine the exchange rates of trace gases over natural ecosystems and agricultural fields to quantify gas emission rates. The micrometeorological technique is particularly well suited for examining differences in fluxes due to temporal changes (e.g. seasonal), geographical area, ecosystem types and surface conditions. Short-term field stations have been successfully used to measure turbulent momentum, heat fluxes and trace gas flux using the Eddy Covariance Flux System (ECFS).

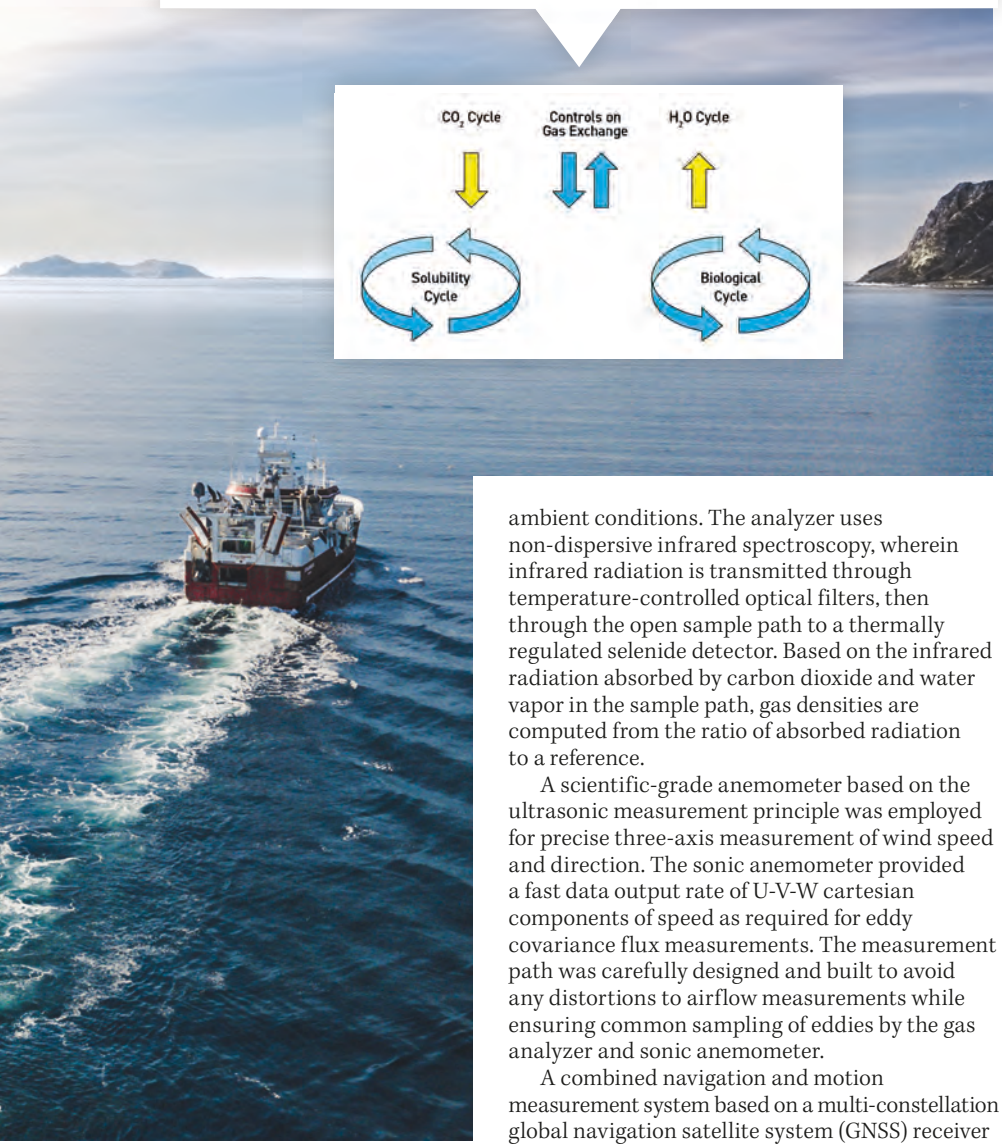
A complementary strategy is to deploy ECFS on research vessels to sample the wide range of ocean environments and study the exchange of water vapor and carbon dioxide between the ocean surfaces and atmosphere. The feasibility of this approach depends on the development of the ECFS being sufficiently robust to overcome the technical and logistical challenges of measuring air-sea fluxes in harsh environments from a moving platform.

The solution for a shipboard ECFS consists of an integrated system with various components including a fast-response infrared gas analyzer, a sonic anemometer, a position and velocity measurement system and a motion measurement system along with a high-speed data collection platform (DCP) with interfaces to a central system with data validation and mapping capability.

An infrared gas analyzer based on an open-path analyzer was employed for high-speed measurements of carbon dioxide and water vapor



LEFT: MicroStep-MIS's eddy covariance method was used on a research vessel to sample the wide range of ocean environments



ambient conditions. The analyzer uses non-dispersive infrared spectroscopy, wherein infrared radiation is transmitted through temperature-controlled optical filters, then through the open sample path to a thermally regulated selenide detector. Based on the infrared radiation absorbed by carbon dioxide and water vapor in the sample path, gas densities are computed from the ratio of absorbed radiation to a reference.

A scientific-grade anemometer based on the ultrasonic measurement principle was employed for precise three-axis measurement of wind speed and direction. The sonic anemometer provided a fast data output rate of U-V-W cartesian components of speed as required for eddy covariance flux measurements. The measurement path was carefully designed and built to avoid any distortions to airflow measurements while ensuring common sampling of eddies by the gas analyzer and sonic anemometer.

A combined navigation and motion measurement system based on a multi-constellation global navigation satellite system (GNSS) receiver and attitude heading reference system (AHRS) with low-noise, low-drift gyros and accelerometers was selected for accurate and robust outputs of position, velocity and attitude. Sensor measurements are fully calibrated, temperature compensated and mathematically aligned to an orthogonal coordinate system for highly accurate outputs.

Data collection

Datalogging based on MicroStep-MIS's latest AMS 111 IV software platform provided integrated data collection and management from all the sensor packages. The modular platform based on the Linux operating system, with software features such as data validation and real-time quality control, ensured the accuracy of the measured data.

The data collection platform based on a 32-bit A5 core main processor plus a 32-bit M3 slave processor was configured for high-speed data collection up to 30Hz. A built-in touchscreen graphic display provided a user interface for previewing measured values, adjusting system time and setting system variables directly on the data collection platform. The system supported autonomous operation and included a battery-backed rechargeable uninterrupted power system.

The ECFS was designed, developed and delivered as a turnkey solution for a leading marine research institute for commissioning on an ocean-going, ice-class multidisciplinary research vessel with blue-water capability ranges of up to 10,000 nautical miles and for voyages lasting up to 45 days. This system, integrated with custom-built data processing plus visualization software, vessel tracking and mapping functionalities, was successfully tested for the design conditions by the marine research institute in January 2021 to support the mapping of greenhouse gases from a moving platform.

In conclusion, an innovative solution of deploying an ECFS with built-in tracking and mapping capabilities will support studies of the exchange of carbon dioxide and water vapor in large areas over ocean surfaces. The system is expected to play a crucial role in the larger quest and combined responsibility toward studying and understanding the multiplicity of areas vital for human civilization, such as climate change, disruption of the water cycle, global warming and ocean acidification. ▮

Isabelle Kling, head of communications, EUMETSAT

THE ROAD AHEAD

EUMETSAT has launched a new long-term strategy focusing on innovation, quality and ensuring social benefits

Metop-SG is a series of six meteorological satellites developed by the European Space Agency and EUMETSAT to be launched from 2023

In June 2021, the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) celebrated its 35th year of delivering Earth observations as critical inputs for forecasting and warnings of high-impact weather events. In the same month, the intergovernmental organization released a new strategy that aims to advance its capabilities and develop the next generation of climate monitoring systems.

"EUMETSAT stands on the cusp of a new era that will bring about significant change and improvement to what we do and how we do it," says Phil Evans, director general of EUMETSAT. "We will be providing more, and higher-quality, data via new platforms, to our member states, the European Centre for Medium-Range Weather Forecasts [ECMWF], European Union member states, partners and users around the world. This will bring tangible benefits to those users and the communities they serve.

"Our new strategy will help us fulfill our mission in the long term, going beyond the development and operation of fleets of satellites to enabling us to lead the innovations that will drive our sector forward."

Focus on innovation

In particular, EUMETSAT will examine innovations in the space sector, including the potential role of micro- and nanosatellites and the private sector, to determine what they mean for the organization and how best to engage with those approaches. This will mean striking an appropriate balance between traditional and new approaches.

According to Evans, in addition to advancing capabilities and knowledge in modeling and prediction, EUMETSAT aims to deliver relevant data to a wider variety of users, and to give policy and decision makers access to highly accurate and timely information about weather and climate issues.

"This calls for the delivery of seamless observations of weather, aerosols and atmospheric chemistry, the oceans, sea ice, the cryosphere and land parameters by EUMETSAT," he explains. "It also requires combining the frequent observations from geostationary orbits with the less frequent but global observations from our polar-orbiting systems."

The next generation

EUMETSAT aims to launch its next generation of Earth- and climate-monitoring satellite systems, low-Earth orbiting (EUMETSAT Polar System – Second Generation) and geostationary (Meteosat Third Generation), over the next five years.

They will carry new, state-of-the-art instruments, some of which will be the first of their kind. By 2030, EUMETSAT will have totally renewed its fleets in both orbits.

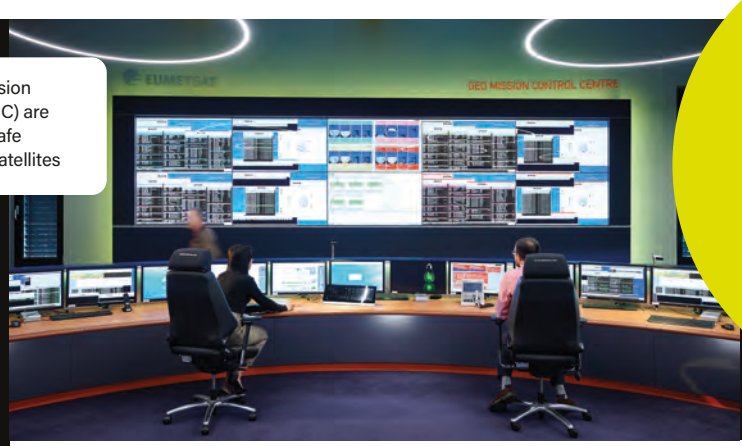
"These new systems will provide the national meteorological services and scientists in EUMETSAT and EU member states with the most accurate, timely and relevant data for modeling and simulations," Evans says. "They will extend our existing data sets that already go back 35 years.

"The Meteosat program is a European success story and a recognized asset for the European Space Strategy. Meteosat Third Generation [MTG] will provide an unprecedented four-dimensional weather monitoring capability through an evolution of the imaging service, a new lightning imaging service and a new atmospheric sounding service providing measurements in the infrared and ultraviolet spectra.

"The MTG fleet is expected to greatly improve the timeliness and accuracy of very short-range weather predictions issued by the national meteorological and hydrological services in our member states and our other users. The system will literally save lives."

EUMETSAT will have launched **11 SATELLITES** between 2020 and the end of 2030 – the complete renewal of its Earth observation fleet

> "EUMETSAT stands on the cusp of a new era that will bring about significant change and improvement to what we do and how we do it"
>
> **Phil Evans, director general, EUMETSAT**



The EUMETSAT Mission Control Centres (MCC) are responsible for the safe operations of all its satellites

The first of the MTG satellites will be launched at the end of 2022, and the first

EPS-SG SPACECRAFT

at the end of 2023

EUMETSAT'S NEW STRATEGIC OBJECTIVES

- Deploy the new MTG and EPS-SG satellite systems and maximize their benefits to member states and users
- Deliver operational services responding to evolving user requirements, based on the continuous infusion of science and cost-effective infrastructures and operations
- Establish and exploit a federative European Weather Cloud infrastructure in partnership with the ECMWF and European national meteorological and hydrological services
- Consolidate EUMETSAT's contribution to the realization of Vision 2040 of the WMO Integrated Global Observing System (WIGOS) and plan future satellite systems
- As a partner of the Space Strategy for Europe, deliver Copernicus ocean and atmospheric composition monitoring missions and contribute to collaborative research and innovation projects for the common benefit of EUMETSAT and EU member states
- Cooperate with other satellite operators and contribute to global partnerships for monitoring weather, climate and greenhouse gases from space to meet additional needs of member states
- Expand the user base for EUMETSAT-provided data, products and services
- Continuously improve management and risk management processes
- Remain an attractive employer for diverse, skilled, talented and engaged people

The EUMETSAT Polar System – Second Generation (EPS-SG) will continue meteorological observations from the polar orbit from 2023-2043. It will bring Earth observations to a new standard through the suite of innovative European instruments flown on the Metop – Second Generation spacecraft.

Looking further into the future

The generations of satellites that will be launched after Meteosat Third Generation (MTG) and EPS-SG could be quite different from their predecessors, notes Evans. "The current development of private satellite fleets and microsatellites raises interesting questions for agencies like EUMETSAT," he says.

"We must innovate but our larger reference satellites will remain essential. What is important is that we maximize the benefits of the total satellite observing infrastructure through a system-of-systems approach. However, we have to recognize that what we need is more information of quality rather than just more information.

"What is crucial is that each observation acquired by EUMETSAT satellites has a direct and positive impact on the activities of our member states' meteorological and hydrological services; that is, a positive impact on the models that forecast the weather. To achieve this, the quality of the observation is absolutely key, and this is why we need to be very careful when considering new approaches.

"There are potentially very promising avenues currently considered by new space companies, but they should be carefully assessed and their impact demonstrated. I also believe that it is time in Europe to invest in innovative Earth observation instrument technology and new instrument concepts providing the highest possible measurement performances within the constraints imposed by small spacecraft.

"This is an area where Europe can make a difference and it is crucial to prepare now for future EUMETSAT satellite systems, planned for deployment from 2040," Evans concludes.

Ensuring accessibility

The MTG and EPS-SG systems will generate many times more data than the current systems. To remain at the forefront in terms of data management and ease of access to data for users, EUMETSAT has adopted a big data approach, one aspect of which is the development and launch of new, cloud-based services.

"Let me put this into perspective," Evans says. "At the end of 2020 there were 6PB of data in EUMETSAT's archive. By the end of 2025, we expect to have about 50PB of data in the archive. The exponential growth of data makes providing cloud-based services crucial in order to remain fast, competitive and reliable."

EUMETSAT's new big data services became fully operational this year. "They represent a revolution in terms of ease of access to our data," Evans says. "EUMETSAT currently has about 8,000 users, of whom 3,000 are private users.

"However, our new EUMETView data visualization service attracts about 54,000 unique users per month. We expect that our new services will vastly increase the variety and the number of people who will use our data, including those who wish to develop various weather data-based apps and other applications," he concludes. ▮

> "EUMETSAT currently has about 8,000 users, of whom 3,000 are private users"
>
> **Phil Evans, director general, EUMETSAT**

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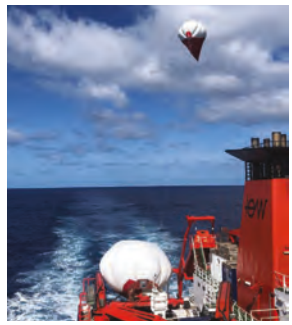

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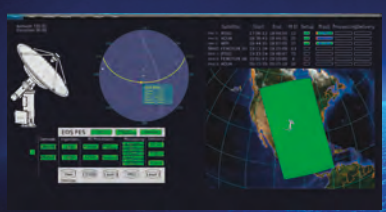
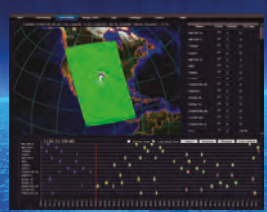


Satellite Pass Scheduling Screen



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Meteorological TECHNOLOGY WORLD EXPO

TECHNOLOGY SHOWCASE

A look at some of the tech innovations that were set for their Paris debut in 2021

DATES FOR YOUR DIARY!

Meteorological Technology World Expo 2022 will be held on **October 11, 12, 13,** at Porte de Versailles in Paris, France. The event will be held in the same exhibition venue and hall as was planned for 2021 and attendees can once again expect to see 200+ exhibitors. Furthermore, the WMO's TECO will run alongside Meteorological Technology World Expo 2022.

New US show will launch in Chicago in 2022

Meteorological TECHNOLOGY WORLD EXPO NORTH AMERICA 2022

MAY 4 & 5, 2022
CHICAGO, USA

NEW C-BAND SOLID-STATE RADAR

▸ METEOPRESS

Meteopress's fully solid-state GaN C-band radar product line features dual polarization, Doppler and 3D volumetric scanning – in an affordable, reliable and easy-to-install package. All of the radar components are incorporated within the radar body, reducing the requirement for heavy infrastructure.

In operation for over 15 years and boasting the second-largest network of weather radars in Europe, Meteopress claims to offer the most affordable X-band radars. The company supplies national meteorological offices with reliable equipment with very attractive business models, like 50:50 partnerships or Radar as a Service deals.

Meteopress has used the latest general and specialized developments in AI and neural networks to create a state-of-the-art neural network nowcasting system that is easy to deploy on any existing radar data. It provides retraining on a data set and then provides a stable light system running on basic off-the-shelf computers.

After successful trials in the Czech Republic and a case study with the Danish meteorological office, the Meteopress AI radar nowcasting system is one of the best-performing neural-network-based automatic nowcasting systems on the market. Currently it is deployed by ZAMG, the Austrian meteorological office, and is available to new customers. Meteopress has increased the accuracy of the Danish meteorological office's nowcasting system by an impressive 43% (CSI and MAE metrics).

DETECTION, NOWCASTING AND FORECASTING FOR AIRPORTS

► MICROSTEP-MIS

MicroStep-MIS, in cooperation with SESAR (Single European Sky ATM Research Joint Undertaking) on the PJ04 TAM project, has developed the Advanced Aviation Weather Decision Support System (AAWDSS).

The AAWDSS is used for detection, nowcasting and forecasting of phenomena affecting airport operation. It includes detection and nowcasting algorithms and forecasting models, such as thunderstorms, low-level windshear and microburst, gust fronts, turbulence, fog and NWP models.

The solution integrates all available meteorological observations and forecasts with progressively finer steps and evaluates them against airport-specific configurable thresholds.

Enhanced common situational awareness is enriched by alerting functionalities based on intensity, duration, probability and related impact assessment. AAWDSS is an advisory tool that provides local procedures related to the alert, to minimize human-factor failure. It informs the user about the current state of significant meteorological phenomena, and provides forecasts (nowcasting) as well as a short history of them to see the trend. Current data, as well as the history of the phenomena, are gathered from a standard AWOS (automated weather observation system) and METAR/SPECI messages. Input data used for nowcast generation are configured to the customer's specifications.

A regional weather prediction model can be deployed as standalone or integrated with AAWDSS. Furthermore, other models, such as fog prediction or radar-based thunderstorm nowcasting, can be deployed together with radar or integrated with AAWDSS.

The Advanced Aviation Weather Decision Support System can integrate data from multiple sources. It comes with an integrated monitoring system IMS4 that integrates and collects the data from the other IMS4 products. IMS4 is an application software, now its fourth generation since 1993. It is designed for 24/7 unattended operation, in compliance with regulations.

AUTOMATED WEATHER STATIONS

► OTT HYDROMET

In recent years, OTT HydroMet has focused on setting up complete automated weather stations. The company tailors a solution combining sensors, dataloggers and communication modules from its brands including Lufft, Kipp & Zonen, OTT, SUTRON and ADCON.

Robust, maintenance-free systems are essential to keep weather stations running in remote areas that are difficult to access, for example in the Alps or at remote solar energy plants. Take the Lufft Ventus bird-proof ultrasonic wind sensor, which is built to resist extreme cold and aggressive sea water, or the proven OTT Pluvio² weighing rain gauge, which combines extreme sensitivity with very low maintenance needs.

Adequate communication systems are essential for every meteorological station – especially for remote ones. OTT HydroMet provides appropriate telemetry solutions based on mobile networks and satellite technology.

For atmospheric scientists, OTT HydroMet presents its ceilometer Lufft CHM 8k with an impressively low false alarm rate below 2% under all weather conditions for clouds below 1km and close to 0% in clear sky conditions.

The latest addition to the OTT HydroMet portfolio is the new Kipp & Zonen SMP15X, the industry's first Class A pyranometer. It delivers integrated heating with zero moving parts (solid-state technology) and best-in-class surge protection.

NEW MOBILE INFRASOUND STATION

► SEISMO WAVE

Seismo Wave specializes in infrasound sensors for the research community and for civil and military security. At this year's expo, the company will introduce its new mobile infrasound stations specially designed for temporary monitoring campaigns.

These sensors enable the detection of extreme atmospheric events with frequencies between 0.01Hz and 20Hz. Both models are characterized by their low self-noise (approximately 10dB under the low-noise model at 1Hz) and their remote calibration capability. Known as reliable and robust, the MB3 sensors are all in-lab calibrated on the Seismo Wave premises.

Installed at locations worldwide, Seismo Wave micro-barometers serve in many scientific observation and prevention applications: meteorology, volcanology, earthquakes, tsunamis, tornadoes, landslides and avalanches.

NEW TECHNOLOGY FOR COMPREHENSIVE PRECIPITATION MEASUREMENT

▸ ADOLF THIES

The 3D Stereo Disdrometer for precipitation characterization will overcome previous shortcomings of instrumentation. The system detects the size, shape and optical properties of meteors as well as their vectorial velocity. This enables superior type detection of hydrometeors as well as non-hydro meteors. The instrument has the high accuracy of accumulation gauges while surpassing the typification of the current disdrometers. Further strengths are the clear identification of solid precipitation and the detection of fog.

The 3D Stereo Disdrometer was field tested for several years in various climatic regions. The integrated heating is characterized by its particularly effective heating management. Furthermore, a newly developed and proved algorithm minimizes the well-known wind influence that is observed in most of the common precipitation measurement systems.

Taking pictures of falling particles provides a huge number of analysis options. One of the 3D Stereo Disdrometer's main advantages is that it indicates the share of each meteor type for mixed precipitation. Another advantage is the unambiguous detection of non-hydro meteors such as insects, spider webs or blowing sand and dust.

The new, field-proven 3D Stereo Disdrometer is designed for and proven in 24/7 operation with nearly no maintenance needs. It is suitable for everyday use primarily in critical applications where not only are robustness and uptime vital but also minimum failure alarm ratio and highest probability of detection.

The device is manufactured in a series production and its price-performance ratio makes it an excellent choice for highly reliable, fully automated weather station networks, and also for single applications in meteorology, climatology and hydrological measurement tasks.

HYDROGEN PRODUCTION UNITS

▸ SAGIM

Sagim has manufactured and supplied hydrogen production units using electrolysis and chemical processes for over 95 years. The company has supplied more than 250 electrolysis hydrogen generators and 5,000 chemical systems to more than 100 countries worldwide.

The company's hydrogen generators are mainly used for meteorology and industry. According to customer needs, Sagim can offer a range of units from 0.25Nm³/hr to 5Nm³/hr.

Sagim designs technical assemblies to meet the specific needs of its meteorology clients but also those in the field of energy, such as alternator cooling in power plants or within renewable energies for fuel cells.

All services are ISO 9001:2015 quality certified. Furthermore, due to concerns about environmental issues and impacts that its products may cause, Sagim has set up an environmental management system and now has ISO 14001:2015 certification.

WEATHER SENSORS

▸ THETA

The Theta MP700 sensor is designed for combined measurement of solar radiation and rainfall in addition to measurements for wind speed and direction, temperature, relative humidity and air pressure.

The sensor has a compact design and is made with aluminum alloy with Teflon coating. Rainfall measurements are conducted using photoelectric or piezoelectric techniques. It has a built-in data pre-processing capability and a universal interface with selectable output protocols. It is easy to use, install and integrate into third-party systems.

ULTRA-LOW-POWER ULTRASONIC WIND METERS

▸ CALYPSO

As a manufacturer of wired and portable ultra-low-power ultrasonic wind meters for professional applications, Calypso continues to expand its product portfolio, with a number of exciting recent additions in particular catching the eye..

Take its latest wind sensor protocols. On top of the existing RS485, RS485 poll, UART, NMEA183 and NMEA2000, Calypso has worked on achieving a more versatile wind sensor that covers the needs of many, different industries. As a result, the new SDI12, MODBUS, the Davis and the ISOBUS protocols have helped the company enter new markets.

Calypso's technology is also going wireless. The company is making all its products wi-fi and Bluetooth connected using the new NMEA Connect Plus gateway. Its wireless edge is compatible with many apps and systems, such as WeatherFile cloud.

Also on display, the company's unique solar portable system, together with its robust, improved rain performance, ultra-low-power wind sensor, is the smallest, lightest, portable ultrasonic wind meter on the market.

WATER-LEVEL PRESSURE SENSORS

▸ **DUALBASE**

Extreme events and hostile environments such as the Amazon jungle, Antarctica and offshore operations require equipment with great quality, reliability and robustness. Monitoring the environment has strategic importance for decision making by public and private managers to mitigate the harmful effects of critical hydrometeorological events, for the management of industrial and agro-industrial activities, for transport and for urban distribution of water.

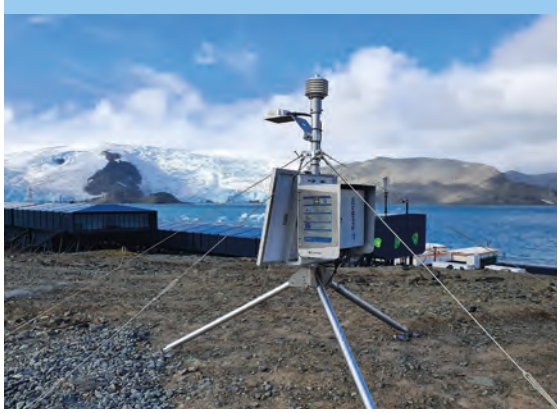
Dualbase's LimniDB water level sensors, especially the LimniDB-CAP capacitive ceramic pressure sensor, are state-of-the-art water-level pressure sensors for harsh environments. LimniDB-CAP is easy to use and maintain, and has excellent temperature-compensated accuracy.

The LimniDB-Borbulha Bubbler water-level sensor is designed for applications where it is too difficult to instal a conventional pressure sensor, or the characteristics of the river are too dangerous for the sensor. The LimniDB-Borbulha Bubbler has an air compressor that is strong enough to maintain a clean system, with low energy consumption.

These sensors are designed to offer reliable data and operation in any kind of environment. Providing excellent accuracy, they have already been installed, tested and approved by the Brazilian National Water Agency monitoring network. More than 4,500 hydrometeorological stations are currently in operation.

Dualbase develops special solutions for specific purposes, such as enclosures for IP68 protection of equipment, which can be installed underground or in places that can be flooded for many hours, protecting the electronic equipment inside the enclosure.

Dualbase also develops new technologies for reliable telemetry. In a partnership with the Brazilian Aerospace Agency and the National Institute for Space Research, the company is developing new systems for reliable, low-cost satellite telemetry for worldwide coverage in geostationary and low-orbit satellites, such as Meteosat, GOES, SCD and ARGOS.



CLASS-LEADING PYRANOMETERS

▸ **EKO INSTRUMENTS**

Designed for meteorological applications, scientific research and photovoltaic system performance monitoring, the S-Series range of pyranometers from Eko Instruments delivers industry and ISO 9060:2018 performance. From the elite MS-80S Class A, through the cost-effective MS-60S Class B and MS-40S Class C options, every S-Series pyranometer comes with a five-year warranty and the same unique four-channel digital and analog interface with SDI-12, plus internal diagnostics with tilt, roll and humidity sensors. Compatible with 95% of dataloggers, DAQ and SCADA systems, the S-Series also includes electromagnetic compatibility and surge protection, making it an accurate, reliable and robust family of pyranometers.

The company also offers the next-generation MS-21 pyrgeometer, featuring a revolutionary design that delivers thermal consistency, accuracy and reliability.

REAL-TIME POLLEN MONITORING

▸ **SWISENS**

Digitalization has enabled the automation of pollen measuring stations. As with modern meteorological technology, a data connection to the existing data network is possible. Pollen warnings based on measured values and improved forecasts will be possible. Model-based forecasts without current measured values and delayed evaluations by previous manual measurement methods have been overcome.

Swisens offers a comprehensive monitoring system tailored for meteorological services. SwisensEcosystem Pollen Monitoring provides full support in handling measurement technology and paves the way for real-time pollen monitoring. The intelligent measuring system identifies pollen types within seconds. Within minutes and in continuous operation, local evident concentrations are available. With the reliable SwisensPoleno Mars measuring system and a data framework, the company ensures seamless integration of pollen data into the existing network.

NEW RADIOSONDE

▸ **METEOMODEM**

Meteomodem has developed a brand-new M20 radiosonde, which it says represents a revolution in the field of in-situ upper air measurements, allowing enhanced PTU and wind quality data. It boasts a low cost thanks to its small size and weight (only 36g).

Meteomodem also offers an automatic radiosonde launcher, the Robotsonde system. The Robotsonde is fully compatible with the new M20 radiosonde. Able to perform 12 or 24 soundings without human intervention, this system provides many benefits to users by making the operators' tasks easier, cutting the running costs of sounding stations, reducing the possibility of error and wrong handling during preparation and launching phases, and guaranteeing safety when using hydrogen gas.

NEW MICROWAVE TEMPERATURE PROFILER

▸ IFU GMBH AND RPO ATTEX

IFU and RPO Attex have collaborated on a new version of the microwave temperature profiler family – the MTP-5i. Users receive vertical temperature profiles in the atmospheric boundary layer (ABL) from 0-1km 20-30 minutes after installation for any part of the world; they do not need any additional measurements, calibration or data collection.

According to both companies, the advantage of the MTP-5 single-frequency, angular scanning microwave radiometer is its technical simplicity and operational reliability. The measurement results are error-free due to the manual calibration because MTP-5 is a self-calibrated unit.

The recovery algorithm has been successfully tested in comparisons with radio-sounding data in Russia, Europe and the USA. MTP-5 devices are widely used as maintenance-free, all-weather, self-calibrating and consumable-free tools.

In the MTP-5i device, the companies have used their experience of application in urban heat islands, ecology of cities, mining companies and industrial zones. Numerous international comparisons show sufficient resolution in accuracy in the first few hundred meters, which allows objective characteristics of dynamic and statistical distribution of the temperature in ABL to be obtained. MTP-5i data provides information about the mixing layer height, the stability class and temperature inversions.

The data is used for several tasks: operational forecast refinement, forecasting fog conditions at airports and assimilation into numerical forecast models. The mobile version of the MTP-5i device has been successfully tested and can be used, for example, on a car roof for researching the complex terrain of mountain-valley ABLs to improve the quality of forecast models.

The new device is available in the EU (Italy and Spain – special conditions). IFU provides assembly, testing, training, technical support and warranty for the MTP-5i.

HAIL SENSOR

▸ EIGENBRODT

The Hail Harp sensor was developed in a partnership between the German Meteorological Service (DWD) and Eigenbrodt. The patented measuring principle allows the reliable detection of small and large hailstones and effectively distinguishes these hail events from all other forms of precipitation. The Hail Harp can be used in a standalone configuration, when only the hail information is relevant. It is also useful as an add-on for plausibility checks of present weather sensors, which often provide erroneous hail information.

In contrast to other known hail sensors, the Hail Harp's unique detection surface is composed of parallel metal strings instead of a closed surface. Only hail stones of 4mm diameter or larger have enough momentum to move the strings. These movements are picked up by a contactless transducer and the output signal allows a distinction between large and small hail.

MOBILE ROAD CONDITION MONITOR

▸ TECONER

An enhanced version of Teconer's mobile road condition monitor will be introduced this autumn. The new design of the mobile sensor features improved analysis and a smaller physical size. Installation and relocation of mobile road sensors becomes easier than ever before.

The mobile and fixed-point road weather measurements provide an excellent tool for winter maintenance operations on roads and at airports. Continuous measurements by mobile sensors effectively complement the data gaps in road sections between fixed road weather station sites, and improve the understanding of road surface conditions all over the network. All measurement data is available for reviewing and retrieving on the Teconer server.

NEW SCALABLE DATALOGGER

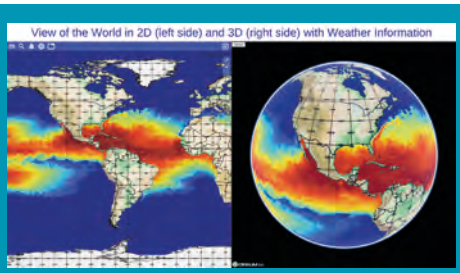
▸ CAE SPA

CAE's new scalable Datalogger Compact packs quit a punch, featuring an embedded Linux operating system and an interactive web server on board. It boasts a high degree of flexibility at different levels: hardware, software, installation and data management. Its modularity allows tailoring of each remote station architecture to the client's needs. CAE has also developed IoT protocols on it, such as CoAP and MQTT.

The company has also developed the only standalone rain gauge on the market allowing accurate measurement of cumulated rain and intensity with integrated datalogger and GPRS modem. The PG4i is a professional all-in-one rain measurement system.

In addition, CAE also offers its wildfire monitoring and early warning system for the calculation of ignition risk indexes, the detection of the ignition of a fire hot spot and dissemination of alarms, and the integration of forecast models displaying the probable propagation of the fire front.

Meteorologists will also be familiar with CAE's AEGIS, a powerful web-based platform and decision-making support tool. This software from CAE allows the geospatial display of information in real time. The platform is developed on an open-source architecture and is particularly suited for interoperability.



WEB- AND GIS-BASED WEATHER FORECASTING

▸ **IES**

Info-Electronics Systems (IES) is set to introduce its latest web-based weather information processing, rendering and display system, WebGIS. WebGIS is a state-of-the-art weather briefing/forecasting workstation, providing advanced functionality for weather information management. It is a latest-technology web-based system that runs on a central server; users work remotely through an internet connection using standard browsers and can customize their products.

The customized solution presents information in a completely geo-referenced format and allows users to access, process, display and manage numerous types of data, including GRIB, alphanumeric, satellite, radar imagery and lightning. Charts, graphs, animations and many other features are available for any custom-made areas of interest over the map. The newest modules – 3D-Globe and 3D-Volumetric – bring incredible perspectives to the visualization and analysis of all that data. Users can produce new products using the available calculator function and can also create tephigrams, hodographs, vertical and horizontal cross-sections and soundings.

NEW DIGITAL THERMOMETER RANGE

▸ **NAVIMET**

Navimet has a new range of digital thermometers, as well as a new digital hygrometer, all ideal for meteorological applications.

The new models available are: THN-01 thermometer for weather shelters; THN-07 above-the-soil thermometer; THN-08 thermometer for evaporation pan; THN-09 thermometer for temperature -10/-20/-50/-100cm below the soil surface; H64 hygrometer to measure humidity (% RH) and dew point temperature (Td in °C).

The THN digital thermometers are accurate to 0.1°C. They offer an extended range of 110°C (-39.9°C to 69.9°C). A quick reset of extrema values allows the weather shelter to stay open for a shorter time.

The H64 hygrometer displays minimum, maximum and instantaneous relative humidity (% RH) as well as minimum, maximum and instantaneous dew point temperature.

NEW ULTRASONIC WIND SENSOR

▸ **LCJ CAPTEURS**

LCJ Capteurs is excited to present its innovative SONIC-ANEMO-DLG ultrasonic wind sensor with incorporated datalogger, which will be available in wired and wireless versions.

The new SONIC-ANEMO-DLG, designed for integrators as well as for standalone weather monitoring stations, is an excellent sensor to record average wind speed and wind direction. The period and resolution of the samples will determine the number of records. The integrator can choose the measurement period and the number of records.

The sensor is available in an autonomous version with battery and photovoltaic cell or in an ultra-low-power (ULP) version, and the data can be collected by a low-power serial protocol as a source file.

French company LCJ Capteurs was established in 1999 with the aim of designing a static and robust wind measurement sensor that was marinized, lightweight (to be mounted at the head of the mast), compact and accurate with a low power consumption. Ultrasonic measurement technology has become essential to create a product without any moving parts, which are usually subject to wear and tear.

LAUNCH OF NEW WEATHER RADAR

▸ **IACIT**

One of the most modern ever produced having only been launched this July, IACIT's new RMT 0200 is a cutting-edge weather radar featuring double polarization with 100% solid-state transmission. An S-band weather radar developed for the detection of long-distance weather phenomena, the RMT 0200 is capable of monitoring and predicting intense weather that may cause natural disasters. It has a transceiver based on software defined radio (SDR) technology and uses nonlinear frequency modulation (NLFM).

The system has exclusive technologies including a 100% solid-state transmission system (modulator and amplifier) that allows the application of pulse compression technology in the signal processing, thus reducing energy consumption, noise and electromagnetic pollution. The system has software packages specific to each application, including SWIM-enabled service bus (system-wide information management) and specific products for SWAP (severe weather avoidance plan). It also has

software packages for myriad specific scenarios such as agriculture, hydrological analysis and civil defense.

CELLULAR MICROCLIMATE MONITORING WEATHER STATION

▸ **ONSET**

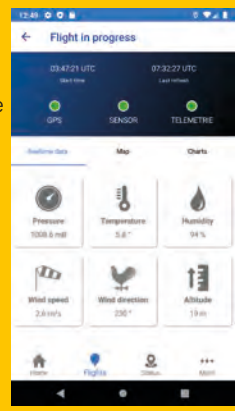
Onset's web-enabled HOBO MicroRX weather station is a compact, rugged, easy-to-deploy, low-cost cellular microclimate monitoring solution. With an integrated solar panel or a battery-powered option for shaded deployment locations, the HOBO MicroRX accepts a wide range of research-grade plug-and-play sensors to measure temperature, relative humidity, rainfall, PAR, solar radiation, wind speed and direction, soil moisture, and more. It is available with an optional water-level sensor input.

For remote access to accurate, reliable data, the MicroRX works with Onset's cloud-based HOBOlink software, where users can view and manage data, customize dashboards for instant visualization of current and historical data, and receive email and/or text alerts if conditions exceed set thresholds. HOBOlink also integrates with Google Maps for a quick view of all HOBO devices in a system.

When used as the core component of Onset's HOBOnet system, the MicroRX station accepts up to 50 wireless HOBOnet sensors for microclimate monitoring of environmental conditions. With its reliable sub-GHz wireless mesh networking and self-healing technology, and affordable wireless sensors communicating through a single gateway, the HOBOnet system provides a low-cost way to get multiple data points to the internet.

RADIOSONDE WITH HEATED HUMIDITY SENSOR

▸ **GRAW RADIOSONDES**



Graw has enhanced its DFM-17 radiosondes by adding an optional heated humidity sensor. This technology will be introduced at Meteorological Technology World Expo.

Graw will also demonstrate new features of its one-of-a-kind GRAWgo smartphone app, which is designed to quickly and securely provide real-time flight data and messages. GRAWgo provides enormous value to managers, supervisors, educators, military commands and anyone else looking for visibility and rapid visual overviews of an ongoing sounding. GRAWgo provides secure access to the status of ongoing flights, flight data graphics, messages, flight tracking and push notifications to all designated members of a flight team.

SODAR FOR WIND ENERGY

▸ **REMTECH**

For some years sodar instruments have had a limited altitude range, cumbersome dimensions and heavy weight. As these instruments reach the end of their useful life and support, an ideal new product for most applications, especially in the wind energy field, is Remtech's PA-XS sodar.

The PA-XS weighs only 20kg and its power consumption is only 10W. Its average range is 400m AGL, and data availability is more than 90% at 200m AGL. The squared correlation is higher than 0.97 compared with a certified meteorological tower.

VISIBILITY AND PRESENT WEATHER SENSORS

▸ **BIRAL**

Biral is able to boast an extensive meteorological sensor portfolio. This includes the visibility and present weather sensors from the VPF and SWS ranges, which are in use at national and international airports worldwide, and at many national meteorological services. Biral offers the most extensive range of these sensors to suit every application. One of their key features is their extended operating life, even in the harshest conditions. For example, even when installed on marine metocean buoys or at the base of offshore wind turbines in the splash zone, these hard-anodized sensors are supplied with a five-year warranty.

Also shown is the new range of thunderstorm detectors and lightning warning systems – the BTD range. These sensors are installed at civil and military airports, mining operations, golf courses, football stadiums and rocket launch sites. Their unique quasi-electrostatic measurement principle and traditional radio frequency direction sensing combines two measuring worlds. This allows them to accurately locate distant lightning storms, and offer advanced warning of the threat of an overhead storm before the first strike. The addition of this 'overhead' advanced warning adds another layer of highly relevant safety data for the end user. ▮

FROM THE PUBLISHER OF **METEOROLOGICAL TECHNOLOGY INTERNATIONAL**

OCTOBER 11, 12, 13, 2022

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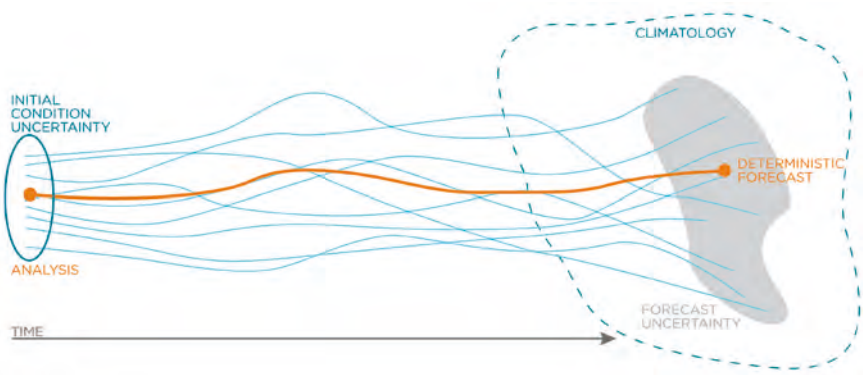
Aki Lilja, director of soundings, Vaisala

THE BEST is yet to come

Vaisala examines the key factors and challenges being worked on as part of the ongoing pursuit of perfect weather prediction



Ensemble forecasting is increasing accuracy in forecasts and modeling and compares predictions from multiple model forecasts or multiple runs from the same model. Plotting the results on a spaghetti diagram provides a strong indication of forecast reliability

For more than a century, weather forecasting has constantly evolved through the collaborative efforts of the international scientific and meteorological communities. A greater understanding of Earth's systems and the physics that go into weather modeling, better assimilation of observed conditions and the ever-expanding power of supercomputing all contribute to the ongoing transformation of weather and climate modeling.

As synoptic forecasting continues to become more detailed and its accuracy extends further out by days and even weeks, the observational data we collect must become more accurate and more immediate.

A critical component of modern weather forecasting is the use of numerical weather prediction (NWP) models. These complex mathematical models, including physics, thermodynamics and fluid dynamics, rely on an analysis of current weather as their starting points. This dependence of NWP models on the accuracy of present state observations creates an initial value problem in forecasting. Data assimilation and ensemble forecasting are two approaches forecasters use to address this concern. Advances in the technology used to gather observational data are another.

Comprehensive coverage can be achieved with fully integrated and optimized radar networks using both X- and C-band radars. Vaisala's X-band Weather Radar helps fill gaps in radar coverage and enhances data quality in strategic locations

Global forecasting meets the digital age

The complex mathematical equations used in weather forecasting require an interconnected assemblage of meteorological data that can differ drastically by region, terrain, human influences and other inputs. This is why so many national and international forecasting agencies exist. Each creates weather and climate models tailored for a specific regional or global use. All their models are available for use by nearly anyone as part of the ongoing open exchange of information within the weather forecasting industry.

For decades, the weather and climate models that these established agencies built were almost exclusively used for scientific and public forecasting purposes. Until recently, scientists, meteorologists and private weather providers relied on this flood of modeling and observational data made readily available by the major weather services. The explosion of digital technology, along with advances in sensors, computing and analytics, has enabled companies to build local, private networks that gather the precise data they need. They then use this data to generate business-specific forecasts tailored around specific real-world problems that balance operational efficiency and worker safety.

Private satellites, affordable supercomputing and the ability to harvest data from an endless number of internet-connected devices, wearables and vehicles have new arrivals leapfrogging the information-gathering capabilities of governmental agencies. This abundance of riches in terms of observational data can be connected to the models with the support of accurate, backbone weather observation networks managed typically by national meteorological institutes. All these new data sources provide dense local additional data (albeit with lower accuracy) and that helps the model to determine local features that cannot be captured by the accurate but less dense backbone networks.

REQUIREMENTS FOR MAKING NWP MORE ACCURATE

- Improve the accuracy of the numerical solution of the atmospheric thermodynamics and fluid dynamics equations
- Take into account sub-grid-scale physical processes
- Improve the evaluation of the initial state of the atmosphere
- Take account of the non-linear and chaotic properties of atmospheric processes

Advancing the future of NWP

A wide variety of observations are used to generate weather forecasts and Earth system models. While a drastic shift in the nature of this data won't be forthcoming any time soon, the ways we collect, process and analyze it will greatly impact the overall skill of NWP predictions in the coming years. Successfully addressing the inherent technological challenges faced by the forecasting community will rely on continued collaboration among public agencies, private industry and the scientific community to develop new approaches to data collection, distribution, analysis and application. Important developments include:

High-performance computing (HPC). Ever since the first NWP experiment was run on the ENIAC computer, processing power has been a limiting factor in meteorologists' ability to expand forecast areas, integrate new data and increase model resolution. Current HPC and supercomputing processing run in terms of petaflops (units of computing speed equal to one million billions [10 to the power of 15] of floating-point operations per second).

Today's laptops and workstation computing systems are sufficient to run localized forecasts; however, increasing the accuracy and resolution of global models and long-term forecasts will continue to require exponentially more powerful aggregated computing options, the power to run them and the space to store the data.

Data assimilation. Data assimilation is one of the primary approaches used to address the initial value problem in forecasting. Updating a previous forecast with current observations improves short- and long-term forecast accuracy. Thus, the better we describe the starting conditions with each run, the less weather forecasts will diverge from actual conditions over time.

A brief look at the history of modern weather forecasting

1896 — First documented use of weather balloons by Léon Teisserenc in France

1904 — Vilhelm Bjerknes derives a two-step procedure for model-based weather forecasting, which forms the basis for present-day weather models

1922 — Lewis Fry Richardson organizes the first numerical weather prediction experiment. A six-hour forecast for two points in central Europe takes at least six weeks to create

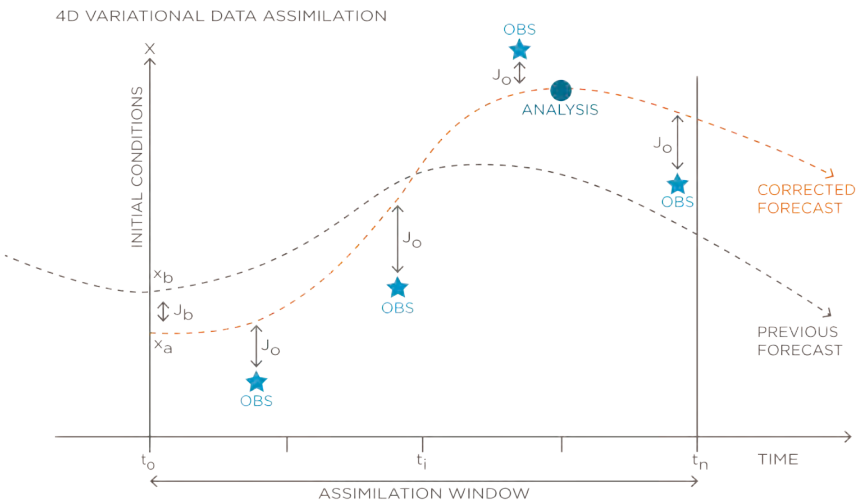
1925 — Carl-Gustaf Arvid Rossby identifies the jet stream by explaining the large-scale motions of the atmosphere in terms of fluid mechanics

1929 — Robert Bureau coins the name 'radiosonde' and flies the first radiosonde that sends precise encoded telemetry from weather sensors

1931 — Vilho Väisälä achieves his first successful sounding, which leads him to build a company, five years later, that provides commercially viable radiosondes

1941 — England implements the first pulsed radar network during World War II. Operators noticed echoes from weather elements such as rain and snow

1950 — A Princeton University team, led by American meteorologist Jule Charney, performs the first successful NWP experiment using the ENIAC digital computer. The first 24-hour forecast took nearly 24 hours to produce



Enhancing the accuracy of initial observations used in data assimilation will hinge on the increased ability of sensors to capture and transmit in-situ and remote sensing data in as close to near-real time as possible.

Ensemble forecasting. This more recent approach to increasing accuracy in forecasts and modeling compares predictions from multiple model forecasts or multiple runs from the same model. Plotting the results on a spaghetti diagram provides a strong indication of forecast reliability.

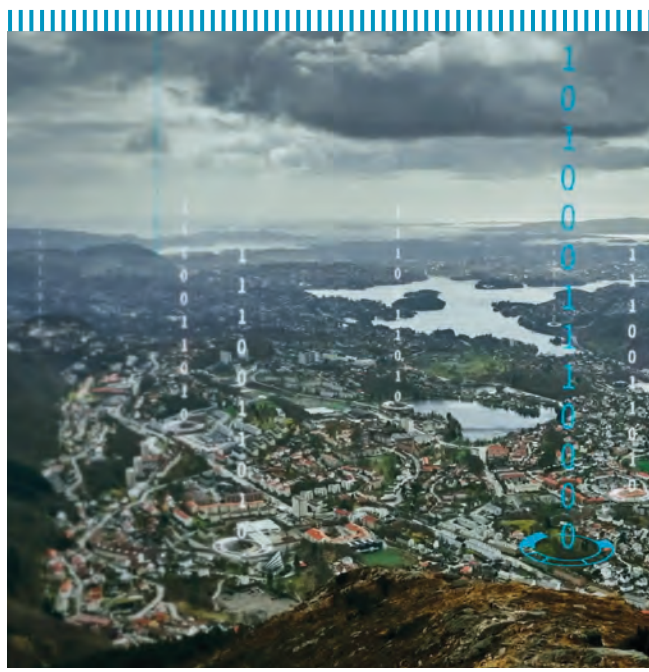
Ensemble forecasting is able to address Vilhelm Bjerknes' fundamental interaction between fluid dynamics and thermodynamics that make up the primitive equations used in climate models, and Edward Lorenz's idea of deterministic chaos, where small changes in initial conditions produce large changes in long-term outcome.

Whether applying a same-model or multi-model comparison, the continued improvement of ensemble forecasting starts with better observational data. This will result in cleaner data that computers with increased processing ability can transform into more accurate forecasting with increasingly accurate estimates of the forecast's uncertainty for each time and location; all the while the uncertainty varies depending on the weather pattern relevant to the location.

The Internet of Things. IoT makes it possible to connect devices through cloud services and use data in powerful new ways. Wearables, autonomous vehicles, smartphones and other IoT-connected devices all provide opportunities to capture localized observational data on a massive scale. IoT also offers whole new applications for the results of observational data analysis, such as feeding real-time road conditions to autonomous vehicles and pushing out highly targeted severe weather alerts to the public.

Use of these new sources of observational data is setting new requirements for processing and

ABOVE: Four-dimensional variational data assimilation (4D-Var) is an approach pioneered at the ECMWF that incorporates time in the model formulation. Rather than working with a fixed set of observations, the 4D-Var configuration exploits the near-continuous stream of incoming observations by introducing recently arrived observations at each outer loop iteration of the assimilation. This enables the analysis to benefit from more recent observations



1954 The Royal Swedish Air Force Weather Service creates the first routine real-time numerical weather forecast

1956 Norman A Phillips develops the first successful climate model, which can realistically depict monthly and seasonal patterns in the troposphere

1961 Edward Lorenz uses a simple digital computer to simulate weather patterns and discovers that small changes in initial conditions produce large changes in the long-term outcome

1974 Global models are first taken into use when the finite-difference model is introduced with a grid interval of 2.5 lat-long degrees and nine layers

1992 European Centre for Medium-Range Weather Forecasts (ECMWF), the Canadian Meteorological Centre and the National Centers for Environmental Prediction begin ensemble forecasting

1997 ECMWF implements 4D-Var, adding the element of time to the 3D-VAR forecasting it introduced just three years previously

2006 Operational weather radar improves with the addition of common precipitation classification such as freezing rain, rain and snow mixed, and snow

THE 2010s Theoretical advances in predictability, fluid dynamics and numerical methods; assimilation of diverse observations from Earth's surface and space; coupling of ocean models with the atmospheric models; and high-performance computing drive advances in NWP forecasting. Accurate 5-day and 10-day forecasts become standard

quality assurance of the data. For the best results, the connected devices will also need to be robust, compatible, easily integrated and cloud-ready.

Better observational data

The better the starting point, the better the results. It's the first – and arguably the most important – rule of weather forecasting and Earth system modeling, and it all starts with the quality of sensors. Weather observation sensors and systems help scientists, weather agencies and weather-affected industries quickly and accurately monitor, collect and process observational data with solutions built to meet their specific needs.

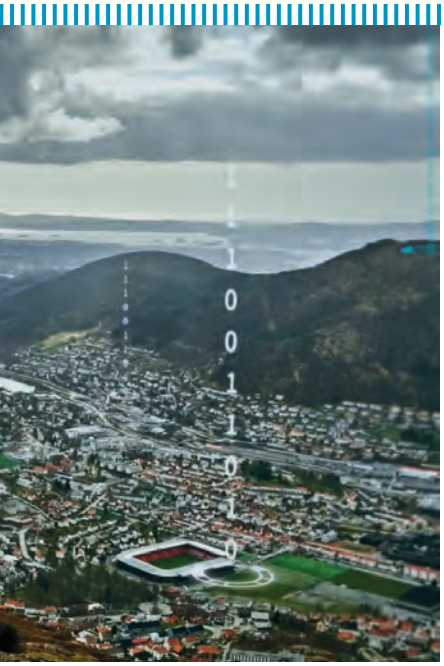
Ceilometers: redefining operational vertical profiling. Cloud height and high-quality vertical profiling data is crucial to create precise weather

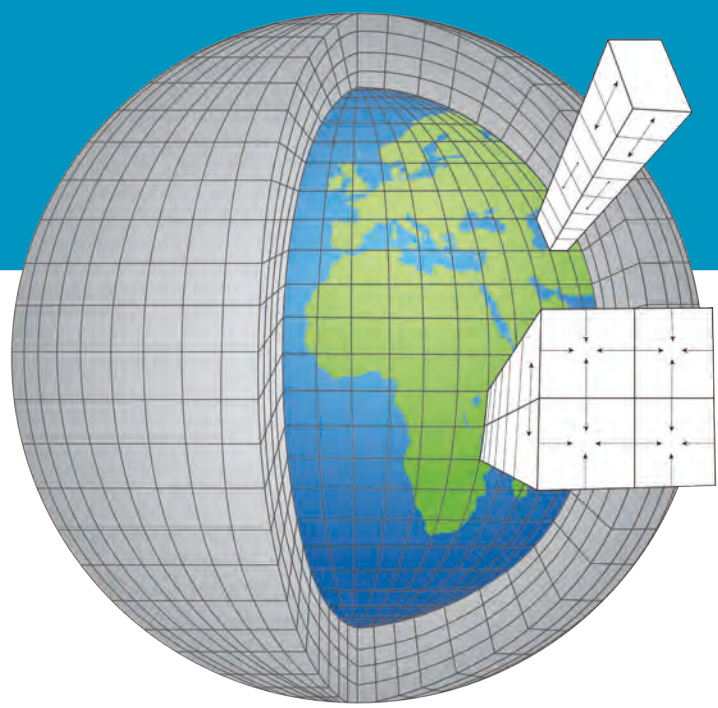
2021 AND BEYOND

The continued evolution of weather science, high-performance computing and observational system technology will be crucial factors driving the next transformation of NWP. With effective technological support, numerical forecasting will soon include all weather-sensitive components of the Earth system, including cloud, turbulence and land surface processes.

Global modeling should continue to see better observational integration and direct assimilation of disparate regional data, such as radar network data streams. An increase in local area modeling will be driven by increased data from private and commercial local observation networks and crowdsourced observations of opportunity from personal gadgets and vehicles for gathering localized observational data.

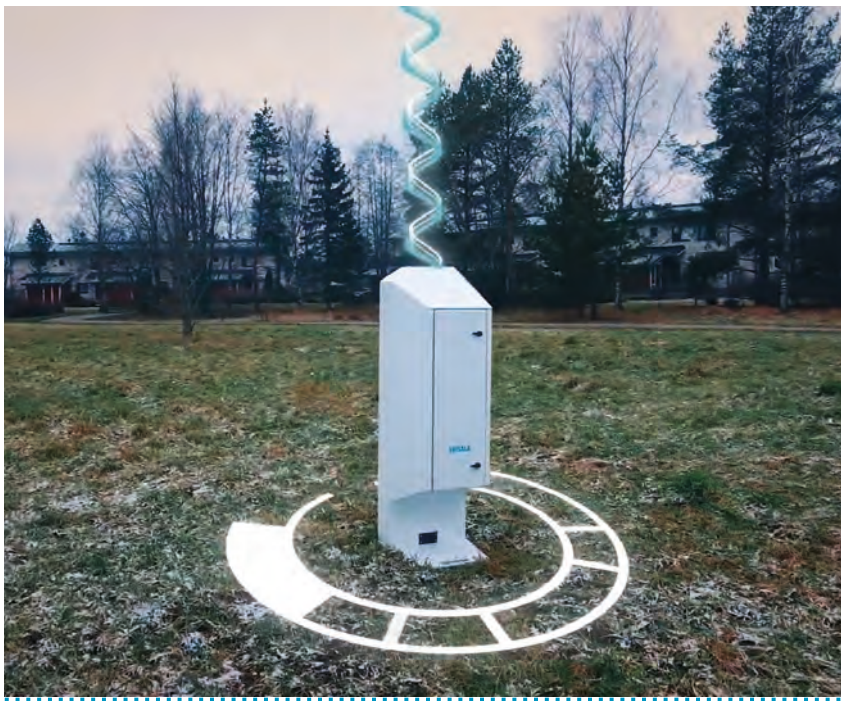
Within a couple of decades, we should see models with resolutions in the order of 1km and eventually down to sub-kilometer scale. Complex models should also be able to run fully coupled atmosphere-land-ocean-sea-ice models in the multiseasonal range for weather and the multidecadal range for the climate.





LEFT: As meteorological institutes look to improve and fill gaps in their weather observation networks, new challenges are emerging in connectivity, efficiency and simplicity. Today's networks demand technology that provides integration and data security without compromising accurate weather observation data

RIGHT: Example of a 3D global model grid illustrating the huge number of variables included in weather prediction models



ABOVE: More than just a ceilometer, the Vaisala CL61 uses first-of-its-kind technology to provide refined profiling data and detect liquid/frozen depolarization, dust and volcanic ash – in any weather, 24/7

forecasting, situational awareness and air quality reporting. Vaisala ceilometers are high-performance light detection and ranging (lidar) instruments capable of unattended operation in all conditions. In addition to providing basic cloud height information, the latest Vaisala ceilometer can provide depolarization measurement that enables accurate liquid and frozen differentiation as well as detection of dust and volcanic ash layers. The data from operational ceilometer networks can be used in multiple applications ranging from NWP modeling and verification to nowcasting for safer air travel and operation.

Sounding systems and radiosondes: accuracy matters. Radiosonde observations remain among the most important inputs for numerical weather forecast predictions. Their resolution, accuracy and full vertical coverage of the atmosphere are essential for model initialization. Professor Vilho Väisälä put the finishing touches on his first commercial radiosonde in 1936. Today, an abundance of atmospheric soundings around the world are performed with Vaisala sounding equipment, and the majority of soundings in the GCOS Reference Upper Air Network are reported from Vaisala Radiosonde RS41 measurements.

From high-resolution NWP input data for weather studies and climatology research to weather system modeling and storm tracking, Vaisala's sondes can help users understand the vertical distribution of clouds and thermodynamic energy in the atmosphere. Observing elevated inversions reliably helps in pollutant dispersion and urban climate modeling and forecasting. Radiosondes are also essential in establishing baselines and validating and calibrating satellite data. Whatever the application, Vaisala can provide sounding solutions that are accurate and durable with excellent observation quality and uncompromised data availability.

Wind profiling: filling the gap in weather forecasting. The ability to reliably monitor atmospheric parameters such as wind, turbulence, clouds and aerosols is a critical aspect of accurate weather forecasts, climate modeling and other atmospheric research.

Vaisala's wind lidar captures continuous, real-time atmospheric wind profiles for the needs of nowcasting and environmental applications. It accurately monitors the first vertical layers of the atmosphere, which aren't covered by standard ground- or satellite-based observations. Wind lidar is the ideal complement to satellites and other intermittent data sources and is a necessary piece for a complete ground-based integrated wind-profiling system.

Weather radar: the precipitation workhorse. Weather radar is best known for providing accurate real-time storm tracking and accurate hourly nowcasting. It can also deliver crucial observations on precipitation type and intensity and storm behavior for extended forecasting and long-term modeling purposes.

This technology can be the best tool for meteorologists and researchers to accurately identify and track precipitation, determine its motion and intensity, and identify the precipitation type such as rain, snow or hail. It can even distinguish between liquid and frozen precipitation within rain clouds and eliminate non-meteorological targets from radar data.

Perhaps its most important application is forecasting the intensity and severity of the approaching precipitation. This can include detailed storm system data that captures the exact path and precipitation levels, precipitation type and ground-level amounts, and ground-level disturbances such as microbursts and tornadoes.

Vaisala offers short- and long-range dual-polarization radar options that deliver unsurpassed detection that improves data quality by eliminating non-meteorological targets. These radar options can be easily integrated into radar networks to ensure complete detection coverage across wide expanses as well as in localized and mountainous areas.

Weather research, forecasting and modeling all rely on quality observations, which Vaisala strives to provide, even when the industry is rapidly changing.

Vaisala is one of the industry's trusted leaders, not just for its sensors and technologies. It is also known for the investments it makes in advancing the science and research required to deliver better observations for more accurate climate models, weather forecasts and storm tracking to the world. The company's deliveries, installation projects and lifetime customer support are designed to help customers achieve sustainable, long-term solutions for their weather information needs. ▮

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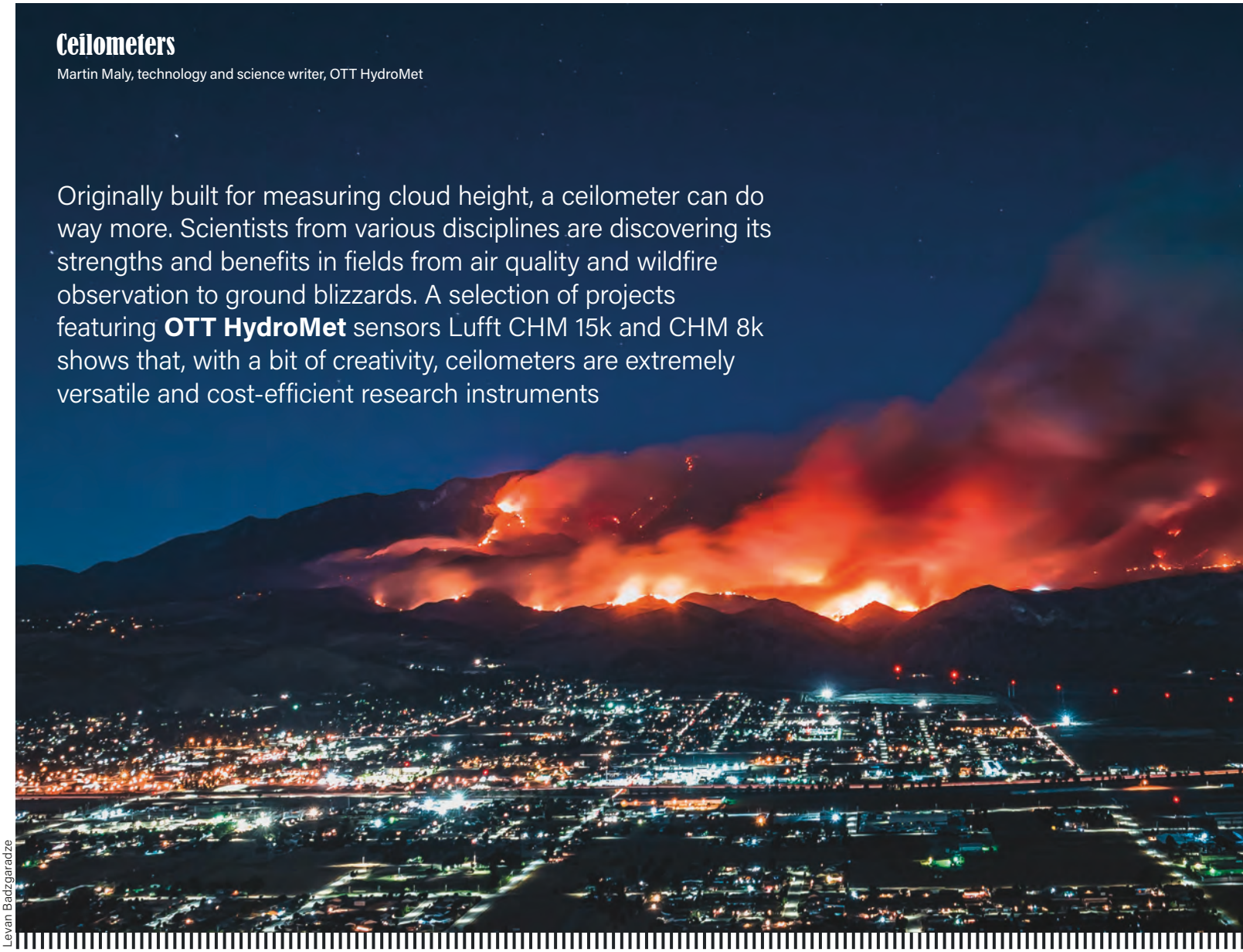
Martin Maly, technology and science writer, OTT HydroMet

Originally built for measuring cloud height, a ceilometer can do way more. Scientists from various disciplines are discovering its strengths and benefits in fields from air quality and wildfire observation to ground blizzards. A selection of projects featuring **OTT HydroMet** sensors Lufft CHM 15k and CHM 8k shows that, with a bit of creativity, ceilometers are extremely versatile and cost-efficient research instruments



Levan Badzgaradze

SCIENTIFIC all-rounders

ABOVE: In 2020, the west coast of the USA suffered from severe wildfires, some of them endangering villages and cities, as shown in this image taken in California

RIGHT: This image was taken during the Sahara dust outbreak at Heraklion Airport in Crete in 2018

ABOVE: The Lufft CHM 15k ceilometer is equipped with an Nd:YAG solid state laser, emitting light pulses with a wavelength of 1,064nm

The year 2020 went down in history not only as the first year of the Covid-19 pandemic, but also because of devastating wildfires. Burning forests and bushes left swaths of destruction in Australia, Siberia, Brazil and across the west coast of the USA.

Wildfires are and always have been an elemental part in nature's circle of life. However, with regard to rising temperatures and increasingly long droughts, they are becoming more severe, burning for longer periods of time and on wider areas.

However, it is not only the destruction that worries scientists. The flames cause massive releases of carbon and other harmful particles, many of them too small to be visible. Light as they are, they float around the globe, documented by ceilometers in various countries independently from each other.

Lidar experts confirm atmospheric simulations based on satellite photos

In mid-September 2020, the smoke from wildfires on the west coast of the USA reached Europe. This had been foreseen by the Copernicus Atmosphere Monitoring Service (CAMS), whose predictions are based on satellite images and simulations. Not long after, scientists in various countries proved CAMS' forecasts right, detecting smoke coming from the west coast. Many of them use lidar instruments such as the Lufft CHM 15k and CHM 8k. So did, and still does, Aaron Kennedy, associate professor at the University of North Dakota. He detected smoke particles on their way eastward across North America before they reached the Atlantic Ocean.

Kennedy works in the university's Department of Atmospheric Sciences. He has a CHM 15k as part of his versatile equipment. "The last summer was the first chance we had to collect ceilometer observations of the smoke. During the events, we shared data with our local national weather service office. This gave them an idea of how thick and how high the smoke was," Kennedy explains.

Wildfires have various impacts on the weather and air quality

Traditionally, the main purpose of ceilometers is to measure cloud base height. This is especially relevant for meteorologists and airports that need highest accuracy and reliability even in very low altitudes (under 1,000m) and under tough conditions. Two prominent users are the Royal Netherlands Meteorological Institute (KNMI), which added 50 Lufft CHM 15k ceilometers to its network in 2019, and the German Weather Service (DWD), which purchased almost 100 CHM 8k ceilometers for all international airports in Germany last year.

In addition to their typical use case – the detection of cloud base height and vertical visibility – ceilometers are able to detect tiny particles flowing in the air (aerosols). This makes them an important instrument for studies on pollution and air quality.

Severe fires make a significant impact on the environment and the atmosphere, as Kennedy explains: "First, wildfire smoke scatters energy from the sun and has a cooling impact during the day. Most weather models don't include smoke, so if a forecaster is unaware [of a wildfire], they can go wrong. While the wildfire smoke plumes are usually elevated, sometimes they can mix down to the surface. In this case it hurts air quality. Finally, they change the visual properties of the atmosphere, which results in intense sunsets and the absence of blue sky."

Ceilometers supporting research networks

The spatial distribution of aerosol particles is an important parameter for various scientific and technical applications, including monitoring of air quality. But traditional meteorological research equipment is expensive and static, thus providing only data limited to its measuring site. In a recent research project, a group of German meteorologists investigated the capability of conventional ceilometers to extend and strengthen the measurement network originally consisting of expensive research lidars. The Lufft CHM 15k has become their device of choice.

The Meteorological Institute Munich (MIM), based at the Ludwig-Maximilians-Universität (LMU), has a long tradition in working with lidar (light detection and ranging) systems. In a recent

project, a team of scientists led by the late meteorologist Matthias Wiegner investigated whether properties of the aerosol distribution observed by a ceilometer are valid only locally or representative for a whole area.

After 24 months of observations, they found that commercial ceilometers could fill gaps in the measurement network consisting of complex scientific equipment to determine spatial aerosol distribution. Because these instruments are stationary and expensive, the ability to work with commercial devices would be very welcome.

German meteorologists investigating the mixing layer height

It turns out that the mixing layer height (MLH) as a qualitative measure for the vertical distribution of aerosol particles is quite homogeneous for a wider area. The analysis of data from both testbeds (Munich and Berlin) provided results that show a strong correlation of the measurements, even despite their allocation with distances of up to 116.7km in the Munich area and 74.8km in the Berlin area.

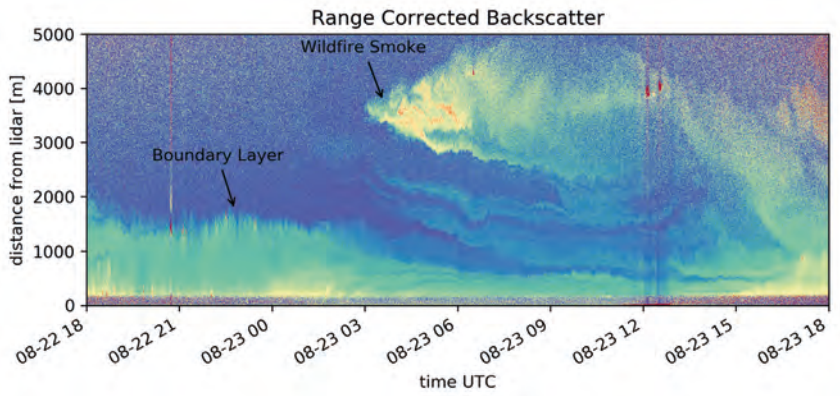
Contrary to the MLH, the integrated backscatter varies with growing distance. The scientists stated that differences between city, industrial areas and the countryside have been observed. They summarized in their publication *On the spatial variability of the regional aerosol distribution as determined from ceilometers*, published in *Atmospheric Chemistry and Physics* in 2020: "In view of (...) the representativeness of the spatial distribution of aerosols derived from data of a single ceilometer for a metropolitan area like Berlin or Munich, we conclude that the MLH can be considered as 'homogeneous'."

In contrast, the integrated backscatter is less homogeneous due to the spatiotemporal heterogeneity of aerosol properties and sources. Consequently, the exploitation of denser networks of particle measurements is required, and the deployment of a single ceilometer is not sufficient to characterize the distribution of integrated optical properties as the integrated backscatter. As a part of further research, the MIM has acquired a Lufft CHM 8k, too.

Sahara dust paralyzing Greece

The eruption of the Icelandic Eyjafjöll volcano in 2010 (Eyjafjallajökull is the glacier covering the volcano) demonstrated man's helplessness against the forces of nature. Thick layers of volcano ash paralyzed European and some transatlantic aviation for weeks. Monitoring volcano ash particles with ceilometers is a standard application for airport meteorological systems. Less apocalyptic but far more frequent are sandstorms. Strong winds can take sand and dust from the Sahara desert over great distances, even across the Mediterranean Sea to Europe.

Sand and dust outbreaks can have a severe impact on people's health and transportation safety, especially aviation. Additionally, they can endanger energy production by covering the PV modules of large solar power plants. It is with good reason that the WMO released a report on the impacts of sand and dust storms in June.



ABOVE: Wildfire smoke coming from the US west coast observed 2,000 km away at the University of North Dakota through a Lufft CHM 15k in September 2020

BELOW: A setup for mobile atmospheric research including a Lufft CHM 15k ceilometer and an OTT Parsivel² disdrometer is mounted on a truck

In March 2018, the southern part of Greece suffered from a severe Saharan dust outbreak. The dust had been driven across the Mediterranean due to strong south winds. Shortly after, the head of the Research Centre for Atmospheric Physics and Climatology at the Academy of Athens, Christos Zerefos, reported that the climate will become even more destabilized in the years to come and the fluctuation of extreme phenomena will become even more frequent. He was expecting more dust transfers from the African continent as a result.

In case of sand dust drifts such as those occurring in Greece, ceilometer measurement networks can detect and analyze the sand clouds and track their direction. This information helps to prepare motion prognoses and to estimate the risk for people in the affected area.

Monitoring ground blizzards in North Dakota

In the wide plains of North Dakota, it is not sand but snow that captures meteorologists' attention. Aaron Kennedy from the University of North Dakota investigates the dynamics and

distribution of blowing snow. In areas with a lot of snowfall and strong winds, blowing snow can cause severe snowstorms called ground blizzards. With help of a Lufft CHM 15k, Kennedy detects how high the wind takes up the snow.

Blowing snow is essentially shattered snow crystals. When they are taken up by the wind, they bounce around, get shattered and fall into smaller pieces. This is why blowing snow particles are smaller than falling snowflakes. Combining the ceilometer data with measurements from radars and an OTT Parsivel^2 disdrometer enables detection of the blowing snow layer height and even the snow particle size.

"The great thing about lidars is that they are useful for numerous fields," he says. "While the wildfire smoke has impacts on things such as visibility and air quality, the traditional use for ceilometers is to provide cloud heights for aviation. For winter weather, it provides information on the height of the blowing snow layer. In some cases, these observations can be combined with radar and we can even retrieve estimates of properties such as particle size."

From smoke to sand to snow – a selection of research projects involving OTT HydroMet ceilometers CHM 15k and 8k exemplifies a global trend in meteorology, climatology and atmospheric science. These disciplines are tied together, and scientists are increasingly investigating the mutual impacts. Lidar instruments such as the reliable and versatile Lufft ceilometers CHM 15k and CHM 8k help to monitor and better understand these phenomena. ▮

LUFFT CEILOMETER SERIES PROFILE

A ceilometer is a device that uses a laser or other light source to determine the height of a cloud ceiling or cloud base. They can also be used to measure the aerosol concentration within the atmosphere. Using the single-wavelength, backscatter lidar technology, Lufft ceilometers deliver cloud base heights, cloud penetration depths, aerosol layer heights like the boundary layer, vertical visibility and the sky condition index.

They have a double-walled housing combined with an integrated fan and automatic heating system and provide reliable protection against misting, precipitation, freezing or overheating. They deliver exact results due to high sensitivity. Reliable and accurate results at any time of the day or night are ensured by the use of long-life laser sources, filters with narrow bandwidth and highly sensitive photo detectors.

The CHM 8k and the CHM 15k are equipped with an integrated controller offering a fully embedded, real-time calculation of all target parameters. Moreover, Lufft offers comfortable user web interfaces for data monitoring.

The CHM 8k is the new ceilometer from Lufft and has a measuring range from 0m to 10km and a cloud detection range from 5m to 8km. The tried-and-tested Lufft CHM 15k has a measuring range of 15km.

An innovative testing device, the Lufft Cloud Height Simulator simulates different cloud heights to check the proper functioning of the device. It generates light pulses that correspond to well-defined clouds, thus enabling independent in-field quality check within 15 minutes.

ABOVE: The Lufft CHM 8k ceilometer focuses on the airspace relevant for aviation from ground level up to an altitude of 8km

RIGHT: The Lufft Cloud Height Simulator enables quick in-field tests to ensure a stable monitoring performance

Tibor Pavić, business development specialist, Geolux

DOWN stream

Neretva Delta is the river delta of the Neretva river, which flows through Bosnia and Herzegovina and Croatia, and empties into the Adriatic Sea

Geolux is working closely with the University of Zagreb's Faculty of Civil Engineering to carry out hydrological monitoring on the Neretva Delta

The valley of the river Neretva is located at the south of the Croatian Adriatic coast, where the river mouth forms a delta. The surface area of the delta is 12,000ha, and the surface of the drainage basin is approximately 10,500km^2. The total length of the Neretva River is around 225km.

In the past, the Neretva Delta consisted of 12 tributaries. More recently, the number of tributaries has been reduced to only four through numerous hydro-technical reclamation processes. By gradually draining out the swamp, the delta has been transformed into a fertile agricultural area that is abundant with great natural wealth and agriculture diversity.

The Neretva valley has been used to serve a dual function: during high-water levels, it is used as a relief channel, and in the dry season, it is used as a reservoir of fresh water for irrigation. Between 1968 and 1972 two dams with floodgates and ship locks were built on the Neretva: one upstream of the agricultural area in Opuzen, and the other at the delta. The dam in Opuzen controls the water inflow, while the other dam prevents the penetration of salty seawater into the Neretva. Salt intrusion represents a great threat to the whole Neretva ecosystem and can result in reduced crop yields.

State and local authorities, the national water management company Hrvatske vode and the academic community in Croatia are continuously working on improving flooding protection in the Neretva valley and its irrigation capacity, as well as preventing the intrusion of saltwater into the agricultural area. The University of Zagreb's Faculty of Civil Engineering is performing continuous hydrological monitoring of water level and flow in irrigation channels in the Neretva river valley.

The Faculty of Civil Engineering has procured Geolux instruments for continuous water level and flow monitoring at four selected locations on the delta. Geolux has provided the instruments and related equipment and has performed the equipment installation.

Non-contact radar

An important decision factor for the Faculty of Civil Engineering, when selecting Geolux instruments, was the fact that the instruments use non-contact radar technology for the measurement of both water level and water flow

ABOVE & BELOW: The Geolux HydroStation undertakes contactless hydrological monitoring enabling water-level and discharge monitoring from above the water surface

BELOW RIGHT: Preparing a foundation for the pole mount

(discharge). The instruments are installed above the water surface and are not in contact with the water itself. This makes the installation of equipment easier, and the maintenance is minimal. Water flow is calculated using the index velocity method by measuring the water level and surface velocity.

Non-contact radar instruments are commonly installed on an existing overhead structure, such as a bridge, over a water surface. As there are no such structures near locations chosen by the Faculty of Civil Engineering, Geolux had to propose a different solution for mounting the instruments above the water surface. Custom-designed aluminum poles with an extended arm were constructed and installed at the irrigation channel bank so that the arm that holds the radar instruments extends over the water.

All four stations were installed in two days. During the first day, an excavation was made in the ground of the channel bank for a concrete base, and concrete was poured to form a foundation for mounting the aluminum pole. A few days later, after the concrete had been cured, the external formwork was removed, and the aluminum pole was attached to the foundation. The instruments – radar level meter and surface velocity radar – were attached at the end of the extended arm, while the enclosure with datalogger, solar panel and backup battery were attached directly to the pole.

Gaining accurate measurements

To provide accurate and reliable measurements, it was important to ensure that the wind does not cause noticeable vibrations of the mounting pole and extended arm. The concrete foundation, the aluminum pole and the arm were designed to withstand the maximum expected wind at the installation sites with minimal vibrations, to ensure measurements are not affected.

In general, the accuracy of the radar level sensor is not greatly affected by the vibrations when the device is configured to use a longer averaging filter. The accuracy of the surface velocity radar can be decreased if the instrument vibrates while it makes the measurement. As a general rule, the arm with the surface velocity radar should not oscillate more than a few centimeters in each direction, with a period not shorter than half a second.

Aquatic vegetation at the monitoring sites poses another obstacle to measurement accuracy. The vegetation grows at the channel banks and also protrudes from the water surface near the banks and grows up to 2m in height above the water. If the vegetation is within the range of the radar beam, it can affect the radar measurements of both the water level and surface velocity.

Unlike most similar products on the market, the Geolux radar level sensor has a special operation mode where it can automatically detect the vegetation above the water and measure the true distance to the water. The surface velocity radar measurements are affected by the vegetation when the wind moves the vegetation back and forth. By configuring the surface velocity radar to use a longer averaging filter length, such problems can be minimized.

To achieve the most accurate measurement results, it is recommended to configure the instruments accordingly and to properly maintain the monitoring site by regularly cutting down the vegetation. To ease site maintenance, Geolux has installed a camera at each site. The camera, Geolux HydroCam, takes periodic snapshots of the monitoring site and delivers the images together with the measurements to the central server. By looking at the recent site photos from the camera, it is obvious when the vegetation is too high and needs to be cut down.

Strong results

The four monitoring stations were installed in the Neretva river valley nine months ago. The analysis of the measured data indicates that there is no decrease in measurement accuracy caused by the pole vibrations. The design of the concrete foundation and the aluminum pole with an extended arm has been proved to firmly keep the instruments above the water surface. The aquatic vegetation on sites requires both proper configuration of the devices and periodic site maintenance. The planning of maintenance is made simple by the availability of near-real-time photos from each monitoring site.

Geolux is dedicated to supporting its clients, from suggestions about site selection to instrument installation and configuration of operating parameters. This project from the Neretva river valley is an example of how Geolux has closely cooperated with its customer, from the planning stage and data analysis, to obtaining the best possible results. ▮

James Zog, James Sun and Ding Ling, Zoglab

ALL in hand

Zoglab reveals the key features of its new handheld weather solution, which has been developed to enable more people to benefit from daily weather forecasts

Handheld weather instruments lower the threshold for undertaking meteorological observations, allowing more companies and individuals to benefit from daily forecasts. This is also in line with the WMO's aim to improve the collection of observational weather data to deliver socioeconomic benefits.

Aiming to resolve the problems of size, network difficulties and high power consumption of traditional weather stations, Zoglab has proposed a design for a handheld weather meter based on microelectromechanical system (MEMS) technology. This weather meter, the HWS1000, can be directly put into a pocket and used on the go. It can measure seven meteorological parameters simultaneously, making it suitable for monitoring sub-local weather in real time. The handheld weather meter has shown good application value in outdoor activities, natural disasters, fire rescue, defense and military, sporting events, storm chasing, etc.

MEMS is an industrial technology that integrates microelectronic circuit technology and micromechanical systems. It has the characteristics of miniaturization, high integration, high efficiency and mass production. The application of MEMS sensors in meteorological equipment enables a variety of measurement parameters to be integrated into an instrument weighing less than 200g. The instrument also has a small volume.

The HWS1000 weather meter can undertake measurements of temperature, humidity, air pressure, wind speed, wind direction, illumination, ultraviolet rays, etc. It also has a built-in compass, flashlight, SOS distress signal, infrared temperature measurement, position tracking, altitude measurement and other auxiliary monitoring functions.

Even with all these functions, the weight and size of the HWS1000 are equivalent to a normal cell phone, and it is completely suitable for long-term handheld use or for simply putting in a backpack or pocket. Furthermore, the design accuracy and range of the HWS1000 handheld weather meter have been based on professional weather stations.

The handheld weather meter integrates various global navigation satellite system (GNSS) positioning functions including GPS, Beidou, GLONASS, QZSS and Galileo, to meet all-weather, high-precision and rapid positioning requirements, and it achieves centimeter-level global positioning. When a single meter is used, it can accurately obtain meteorological data of different locations, altitudes and latitudes, and analyze the dynamic change path of the climate according to the positioning track. When multiple meters are used, combined with high-precision

LEFT: The HWS1000 professional handheld weather station comes in a number of models, including professional and standard options

map matching and positioning, a weather observation shared data service network can be formed.

For specific uses such as in vehicles and in the field, HWS1000 can be connected to a cell phone application via Bluetooth and wi-fi communication. For example, by installing the meter on the roof of a vehicle, the observation data can be obtained in real time through the cell phone app inside the vehicle.

Static test analysis

In order to verify the accuracy and stability of the data measurement of the HWS1000 handheld weather meter, static tests on temperature, humidity, air pressure, wind speed and illumination were conducted with professional calibration equipment. In a laboratory with an ambient temperature of 20-25°C and humidity of 50-80% RH, multiple sets of verification points were selected to perform comparative test analyses on the meter.

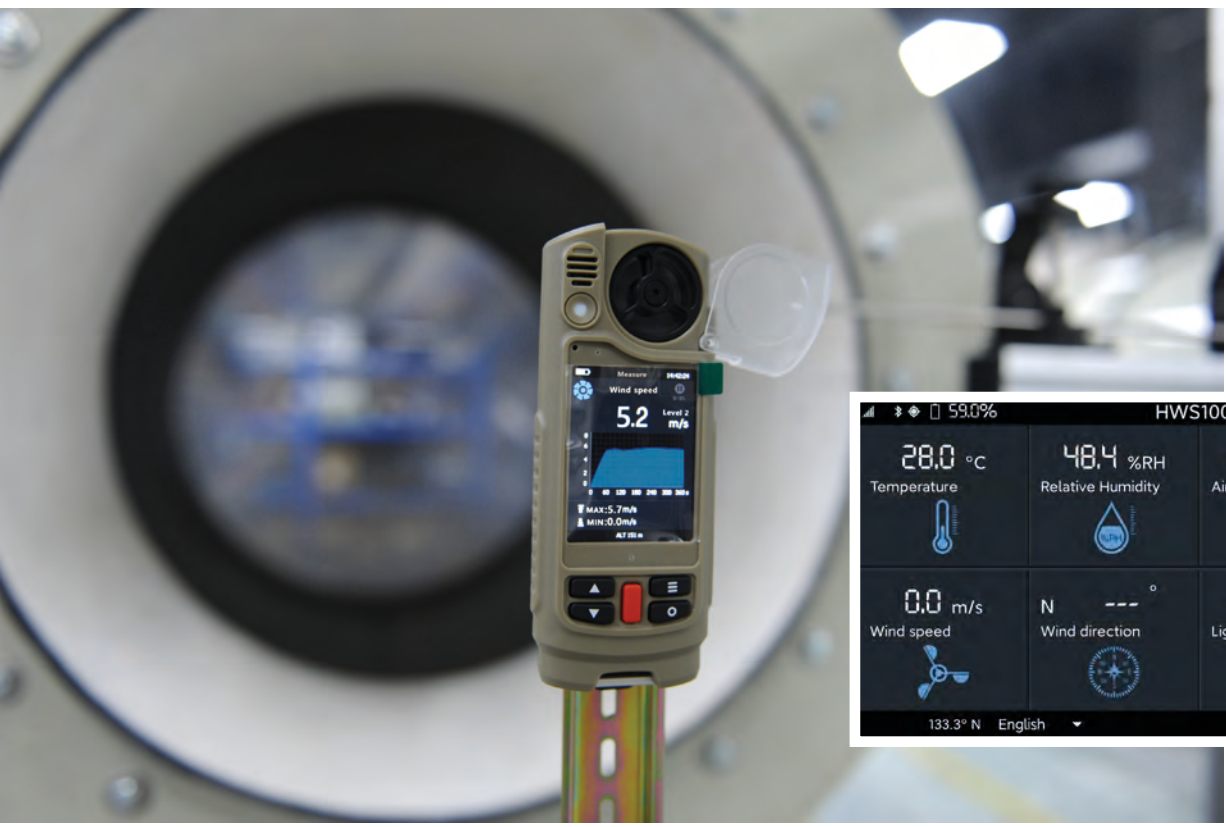
The temperature measurement differences between six HWS1000 units and a temperature reference meter were within 0-0.3°C. The humidity measurement differences between six HWS1000 units and a reference humidity meter were within 0.1-1.2% RH. The pressure measurement differences between six HWS1000 units and a pressure reference meter were within 0-0.3hPa. The wind speed measurement differences between two HWS1000 units and a wind tunnel reference meter were within 0.1-0.3m/s. And the illumination measurement differences between six HWS1000 units and the illumination reference meter were within 53-8,286lx.

From the comparison, it can be seen that the HWS1000 measurement data has a very small deviation from the standard instrument, but it is within a reasonable range and can meet the needs of conventional weather observation services.

In addition, HWS1000 supports third-party calibration for all parameters. If it is used for more than one year, the instrument can be sent to a lab to be recalibrated to ensure that the measurement data remains accurate.

Key applications

The HWS1000 handheld weather meter is designed for user needs in various industries such as natural disasters, fire rescue, outdoor activities, defense and military, weather enthusiasts, etc. In addition to measuring common weather parameters, it is equipped with more than 10 kinds of field safety protection and self-rescue



LEFT: The HWS1000 capturing wind speed and direction data

BELOW: Measurements, including data on air pressure and temperature, from the HWS1000 can be displayed on a mobile application

LEFT & BELOW: The HWS1000 can be used for various applications including fire monitoring, mountaineering, agriculture, track and field sports, polar scientific research, aviation and navigation

functions, including flashlight, compass, weather forecast, SOS distress signal, etc. It is not only a weather instrument, but also a tool to ensure personal safety in the outdoor environment.

Natural disasters. These events seriously threaten the safety of life, health and property. Meteorological monitoring can play an important role in the different stages of disaster warning, rescue and reconstruction. In addition to relying on disaster broadcasts released by media, handheld weather meters can provide companies or individuals with accurate monitoring services in real time and formulate personalized emergency plans.

Forest fires. These occur frequently every year, and firefighters face great risks in the rescue process. The handheld weather meter is light and compact and can be used as a portable firefighting tool to be distributed to disaster relief personnel. One benefit is to observe the weather changes at any time to ensure the safety of personnel; the second is to be able to predict the development trend of the disaster according to the weather changes and adjust the rescue plan in time to complete the rescue work more efficiently.

Defense and military. In military activities such as ammunition shooting and artillery launching, handheld weather instruments can provide environmental correction parameters for long-range shooting. They can also provide weather services for group parachuting, aviation flights, military situation reconnaissance and other activities.

Outdoor and sporting activities. The weather has a great impact on outdoor activities such as hunting, rowing, archery, shooting, fishing and golf. In competitive events in particular, subtle climate changes can alter the results of the game. With an ergonomic design, easy-to-use interface, infrared temperature measurement, weather forecasting and other special features, the functionally enhanced handheld weather meters can provide users with a competitive edge in sports and a confidence- and fun-building tool in the wild.

Meteorology. There are many weather enthusiasts around the world, and handheld weather meters can provide important support for the formation of weather community activities. They are also good teaching aids for meteorological science education for primary and middle school students, or introductory experimental instruments for students in colleges and universities. ▮

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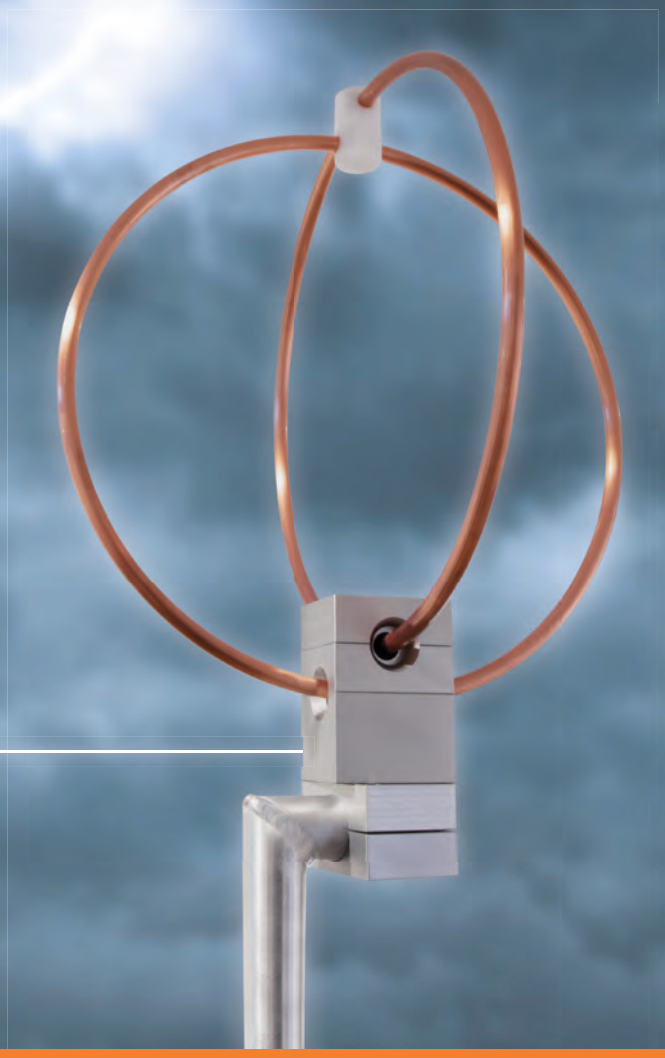

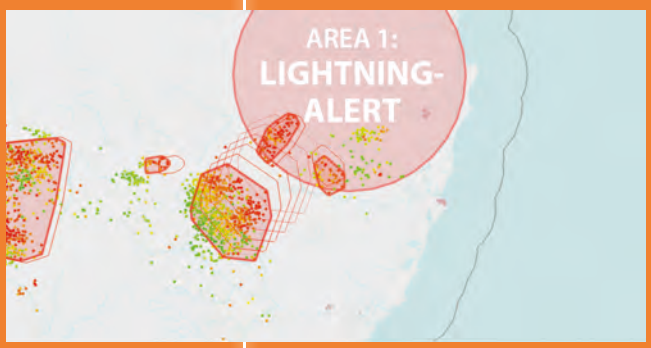

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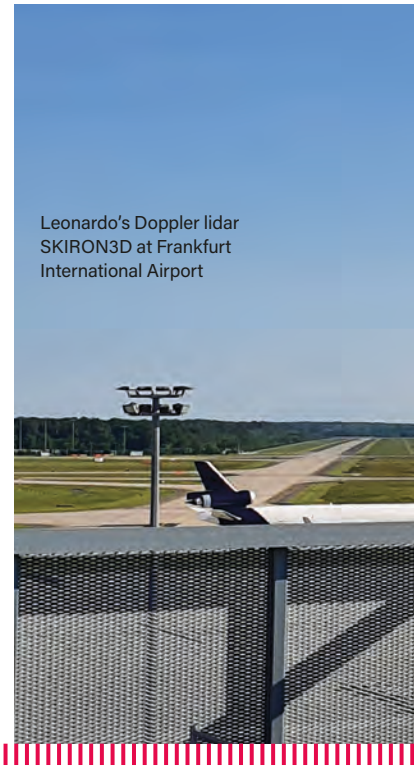
Dr René Grasselt, senior aviation MET expert, Dr Albert Töws, lead systems engineer lidar, and Dr Ronald Hannesen, senior meteorologist, Leonardo Germany

RANGE matters

Leonardo introduces multichannel technology for Doppler lidar to serve the community's requirements on time-critical, long-range detection



Leonardo's Doppler lidar SKIRON3D at Frankfurt International Airport

Today's challenge in designing a new meteorological sensor is to match a wide range of operational and technical requirements. The reasons are complex and may be economically driven, caused by global climate change or demands on interoperability to fit in smart system-of-systems technologies.

Based on many years of experience in the global lidar market and intensive R&D, in particular within the framework of the Single European Sky ATM Research (SESAR) program, Leonardo Germany considers the development of multichannel technology to be vital to achieve high-performance detection with Doppler lidars. This unique engineering approach is designed to serve the varied needs of the entire global meteorological community, and the specific demands of the global aviation community.[1]

ICAO is the key

From an aviation point of view, the major requirement for a high-power Doppler lidar is its capability to detect over a long range in the shortest time possible. The need is to capture small-scale turbulence and windshear phenomena at airfields and on the glide slopes.

ICAO Doc 9817[2] *Manual on Low-Level Wind Shear and Turbulence* provides the framework and recommends that windshear be calculated over the flight paths. ICAO Doc 9817 defines: "A headwind loss of more than 15kn but equal to, or less than, 30kn indicates a windshear with loss. A headwind loss of more than 30kn over 4km is indicated as microburst. A headwind gain of 15kn or more over 4km is indicated as windshear gain, representing areas of convergence (negative divergence) normally ahead of and along a gust front."

Moreover, as an operational requirement, ICAO states in Doc 9817 that information about significant changes in surface wind and along the take-off/final approach path up to 500m above runway level shall be provided to the pilot. An information update rate of every minute is recommended.

High-power pulsed coherent Doppler lidars such as Leonardo's SKIRON3D are predestinated sensors in this respect. ICAO Doc 9817 recommends Doppler lidar as a means to detect windshear in dry weather and near the surface, due to the absence of interference by ground clutter and side lobes compared with microwave radar.

Quantity counts

To fulfill ICAO recommendations with respect to range and update rate, a certain performance of the pulsed coherent Doppler lidar is required. The measurable range depends not only on system parameters but also strongly on atmospheric conditions. Therefore, it is difficult to verify the performance of a pulsed coherent Doppler lidar system on-site within a limited measuring time.

The aerosol concentration is highest within the boundary layer and reduces strongly above the boundary layer. Not only is the altitude dependence of the backscatter coefficient strong, but the coefficient may vary by one order of magnitude or more depending on weather, environment, time of day and season. Furthermore, the coherence of the signal is distorted by the refractive turbulence, which leads to strong range dependence.

Considering the strong dependence of the measurable range of the lidar system on atmospheric conditions, the expressiveness of the measurable range concerning system performance is unspecific. A sophisticated way to verify the performance of the system is the so-called figure of merit (FOM). This parameter consists of system properties that are measurable with standard measurement equipment and can therefore be verified practically even on-site.

Consequently, the practical verification of the performance of a Doppler lidar using the FOM proves to be paramount, as this parameter is measurable and does not depend on weather conditions like the measurable range.

The basic FOM

System properties of pulsed coherent lidar systems differ depending on the manufacturer's chosen system architecture. Typically, fiber-based lidar systems have a higher possible pulse repetition frequency (PRF) but a lower pulse energy than lidar systems realized in free-space optics.

As the returned scatter light from the atmosphere is very low, independent pulse echoes have to be averaged for a certain time, typically between 0.02 seconds and 1 second. The signal-to-noise ratio increases not only with higher transmitted pulse energy but also with the square root of independent pulse echoes. This is represented with the basic FOM definition as:

$$FOM=E\cdot\sqrt{PRF}$$

The FOM increases with the square root of the PRF and is proportional to the transmitted pulse energy. This FOM parameter enables a simple comparison of entirely different system architectures.

Two significant parameters contribute to the range performance of a lidar system and should be considered. First, the pulse length (actually also the shape of the transmitted pulse) directly influences the bandwidth of the received atmospheric signal, which is inversely proportional to the signal-to-noise ratio, following the lidar equation. This means that a longer transmitted pulse results in a higher signal-to-noise ratio and therefore in a higher measurable range.

Second, the system efficiency due to insertion loss of components, bad optics or misalignment could reduce the signal-to-noise ratio and therefore reduce the range performance.

Precise FOM

The more precise FOM can be found in ISO 28902-2,[3] where it is defined more comprehensively considering the pulse length, system efficiency and the telescope diameter. Telescope sizes do not differ greatly between the systems available on the market. However, pulse length and system efficiency are worth considering in some cases. The precise FOM defined in ISO serves a more detailed comparison between pulsed Doppler lidars, while the basic FOM suits a rougher comparison between different architectures.

For lidar systems with multiple channels, the number of available channels increases the effective PRF, which is the number of channels multiplied by the PRF. In the case of multiple channels, the FOM can be expressed as:

$$FOM=E\cdot\sqrt{(N\cdot PRF)}$$

The advantage of a multichannel lidar system is obvious, as it increases the FOM of a system through a higher effective PRF. However, as the channels are independent, the unambiguous range depends on the PRF of a single channel. As an example, a single-channel lidar works normally with a PRF of 10kHz, which corresponds to an unambiguous range of 15km, where second trip or even third inference from clouds are very likely to occur. A multichannel lidar system with four channels would work at 16kHz effective PRF but with 4kHz for each independent channel. This would result in an unambiguous range of over 30km, which significantly reduces the probability of second trip interference in the detected signal.

The observation

To prove that the technical capabilities of Leonardo's SKIRON3D lidar system are in line with ICAO recommendations, particularly with regard to the requirements defined by the FOM, a field measurement campaign was undertaken at Frankfurt International Airport in Germany.

The campaign started in September 2020 and is scheduled to continue until September 2021. A special focus was the detection range of SKIRON3D, which was observed for hundreds of thousands of PPI scans during the Frankfurt campaign.

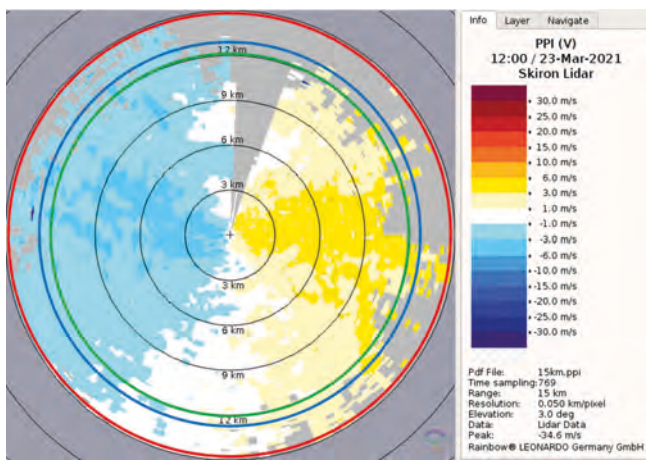
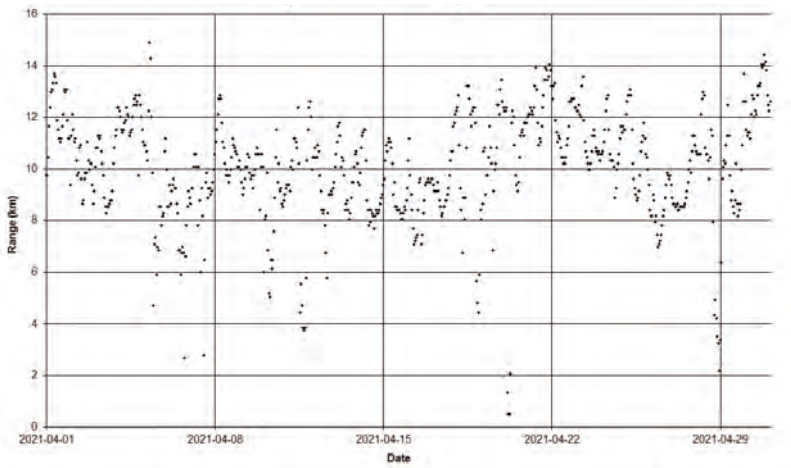


FIGURE 1: Median range detection with SKIRON3D at Frankfurt International Airport, Germany

Instead of using the most distant echo, which might result from a strong scatter such as clouds and thus give misleadingly large figures, the so-called median range was used as an appropriate measure to determine the range beyond. For a given PPI scan, this is the most distant range, for which at least half of the rays provide valid data.

For example, in Figure 1, at a range of 12km (green circle), more than half of the rays contain valid data. At the largest scanned range, at 15km (red circle), less than half of the



MONTH	MEDIAN RANGE SKIRON3D
November 2020	8.52km
December 2020	7.08km
January 2021	8.40km
February 2021	8.40km
March 2021	10.08km
April 2021	10.20km

FIGURE 2 (LEFT): Median range detection with SKIRON3D in April 2021 at Frankfurt International Airport

FIGURE 3 (ABOVE): Median range results from SKIRON3D during the measurement campaign at Frankfurt International Airport

rays contain valid data. The blue circle at a distance of 13.2km is the largest range for which one half or more of the rays contain valid data. This is the median range for this data set.

Median range was routinely calculated for all PPI scans, where PPI scans from one hour were used to get one median value (which is the median of all PPI median ranges). Figure 2 shows the data for April 2021. Except for cases with precipitation, the range is above 8km with peaks above 14km.

The monthly median was above 10km, which is typical for the Central European spring climate. During the Central European winter, range is often reduced due to fog or low-level clouds, as becomes evident in Figure 3.

Climate limits the lidar detection range in two ways: precipitation and fog reduce it significantly, and the aerosol concentration of dry air affects signal-to-noise ratio due to backscatter and attenuation. For the latter, very high concentration limits the range due to attenuation, and very clean air does not provide sufficiently strong backscatter.

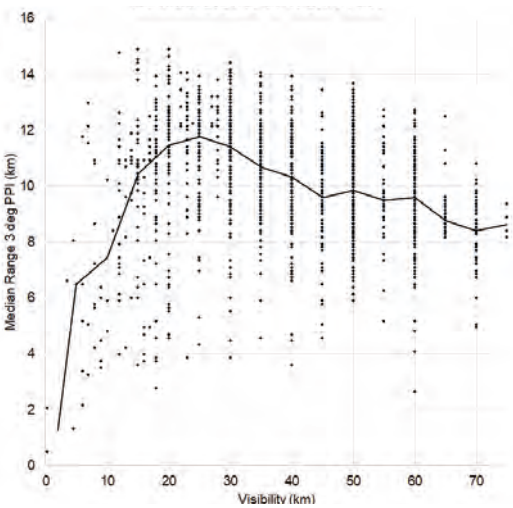
Figure 4 shows the dependency of hourly median range as a function of the visibility reported by the German Weather Service observatory at Frankfurt Airport (data source: opendata.dwd.de), covering March and April 2021. Detection is very good for most cases, except for very clean air and for heavily reduced visibility.

The observed dependency of detection range on visibility compares well with the information provided in ISO 28902-2. As a result of the measurement campaign, Leonardo's SKIRON3D proved to achieve the highest FOM stated in the ISO document.

Detection range depends greatly on the scan parameters. All the above data is from the PPI scans, which not only fulfill ICAO requirements in terms of update rate (one minute) but, taking only 27 seconds for a full-circle PPI, also allow for other scans, e.g. 3D data sampling or wake vortex detection scans. Also, the data is high resolution in space with 0.12km radial and 2.5° tangential resolution. With very high tangential resolution of 1°, the detection range is about 0.7km smaller than in the above figures. On the other hand, reducing scanner speed to one minute for a full PPI circle and lowering the tangential resolution to 6° increases the detection range by more than 4km. Such settings may be used by low-power systems to fulfill the ICAO requirements for update rate, but the resolution would be too coarse to enable reliable windshear measurements, and no other measurements would be possible. ▮

FIGURE 4 (BELOW LEFT): Hourly median range measured with SKIRON3D versus visibility at Frankfurt International Airport, 1 March to 30 April 2021

FIGURE 5 (BELOW): SKIRON3D scanner unit during measurement campaign at Frankfurt International Airport



References:

1) *Meteorological Technology International* magazine, September 2020, *Safe Air Travel*, p90
2) ICAO Doc 9817 *Manual on Low-Level Wind Shear and Turbulence*
3) ISO 28902-2 2017: Air quality – Environmental meteorology – Part 2: Ground-based remote sensing of wind by heterodyne pulsed Doppler lidar

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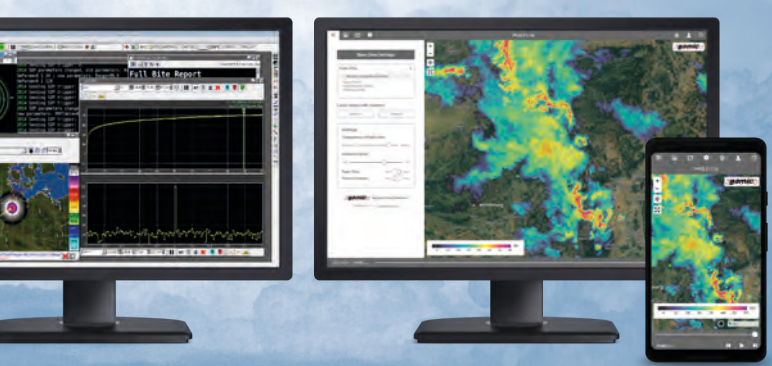

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Jacquelyn Heikel, brand manager, RainWise

ONE-STOP shop

RainWise's MK4-C cellular weather station has been developed to deliver maximum operational efficiency without the complexity of disjointed parts, power options and data storage

In the USA alone, weather volatility costs businesses more than US$500bn every year. From agriculture to renewable energy, the impact of severe weather is broad and unpredictable. With climate change accelerating this unpredictability, organizations need access to hyper-local weather conditions, patterns and alerts to make informed decisions that adjust to the current climate. Instead, most organizations rely on imprecise regional data, exposing them to the chaos of Mother Nature.

Weather-affected organizations task their operations leaders with creating stability from this volatility. They must deliver insights that ensure their organizations make the correct weather-related decisions. Only with precise meteorological data and state-of-the-art equipment can farmers know whether it's safe to spray their crops, for example, or solar installation operations gain insights into the efficiency and status of their systems.

Introducing the MK4-C

In times of increasing weather volatility, only a company built on years of ingenuity and experience can manufacture innovative, durable and connected solutions specific to industry needs across broad market segments. RainWise has poured four decades of weather-station experience into its design of the first rugged, all-in-one, self-powered and upgradeable cellular weather station.

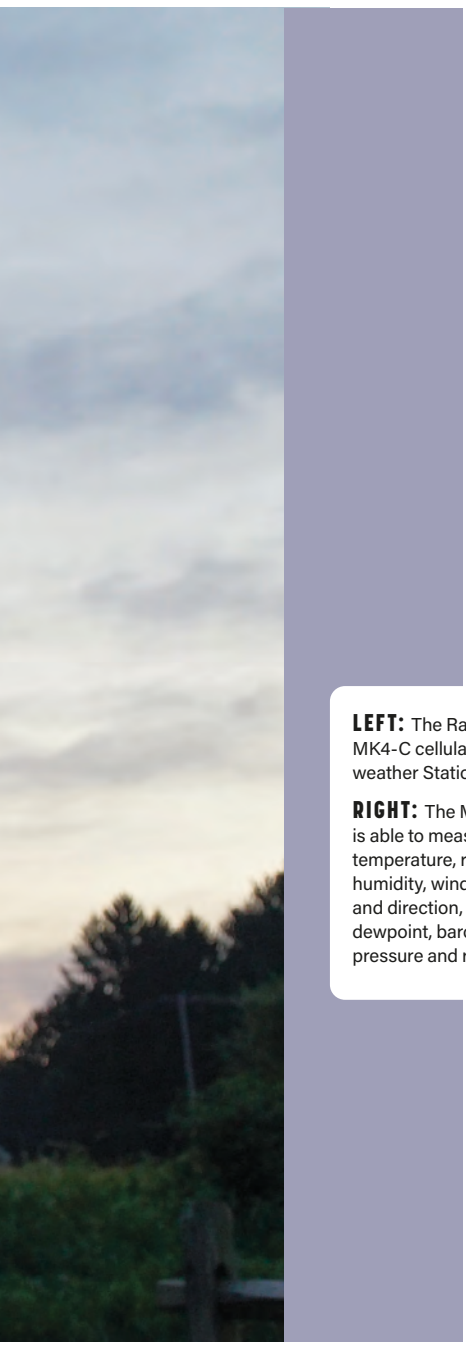
The RainWise MK4-C cellular weather station is highly versatile with multipoint monitoring, future upgradeable sensors and a built-in cellular modem. No wiring or electrical grid is required, making this station simple to install in any location. Highly customizable and built to last in extreme environments, the MK4-C is a safe long-term investment that will adapt to business needs and changing industry landscapes.

In addition to the integrated cellular modem, the MK4-C comes equipped with a high-power photovoltaic panel, battery and intelligent power management – no external power source or wi-fi connectivity are required. This all-in-one unit mounts in minutes on a single mast for the utmost functionality, convenience and reliability.

Unlike other cellular weather stations, the MK4-C features an aspirated fan built into the unit, increasing the accuracy of temperature and relative humidity (T/RH) by more than 50%. The integrated technology and self-powered management system enable someone with no prior experience to install the station with ease. Each station ships fully calibrated and takes less than 20 minutes to set up.

Customizable design and data plans

The MK4-C is a futureproof station that provides connectivity and reliability at every turn. Users can, for example, add high-quality plug-and-play sensor options at any time in the future without having to dismantle the station. Until now, the



LEFT: The RainWise MK4-C cellular weather Station

RIGHT: The MK4-C is able to measure temperature, relative humidity, wind speed and direction, dewpoint, barometric pressure and rainfall

ABOVE: The MK4-C offers an all-in-one design and can be set up in around 20 minutes

weather-station market represented complex decisions around integrations and sensor assembly, with cumbersome designs that required professional system integrators to install or upgrade.

RainWise has used its weather-station experience to develop an easy-to-customize modular architecture while still providing the reliability and accuracy that businesses require. Purpose-built to adapt to changing landscapes across industries and organizations, the MK4-C's upgradeable design provides solutions from one year to the next. Future expansion sensors include ultrasonic wind sensors and agricultural sensors.

Equipped with CAT/LTE-M and NB-IoT cellular connectivity, the MK4-C transports weather data to a personal dashboard on RainWise.net, where users can share data, view graphs, build reports and set up custom threshold alerts.

Other companies' cellular options often mean getting locked into expensive, inflexible data plans. RainWise gives users an integrated cellular modem with a cloud-connected data plan from Verizon or AT&T for under US$50/year, and the first year of data is free.

MK4-C for businesses

Operations leaders who trust RainWise can capture and monitor accurate microclimate data that informs high-stakes decisions – and know they're getting it right. RainWise understands that organizations can't stop due to changes in the weather. Being equipped with the right information delivers the stability and decision-making ability to create operational efficiencies, conserve resources and mitigate risk.

The MK4-C has enabled commercial customers such as Wallace Events to use real-time weather intelligence to make critical decisions on-site at events.

"The MK4-C is far superior to any other weather stations that I have seen," says Victor Chan, assistant manager at Wallace Events. "Just the fact that it is self-contained with its own solar power supply and cell phone modem is key. We can pretty much set it up anywhere, especially locations with no electrical power to plug into."

MK4-C weather stations provide businesses with a flexible network of real-time weather data that is adaptable and quickly deployable to multiple locations. Real-time measurements and alerts empower operations leaders to decide whether they can remain open or prepare for severe weather ahead.

"The main issue it solved for us was that it gave us real-time data on wind speed and direction at the location. Instead of looking at the news or other weather sites, we could just pull up the app to see what was going on," Chan adds.

Operations leaders in weather-affected organizations can't control the weather but they can control how they collect critical weather data. The MK4-C represents decades of research into sensor accuracy and a new meaning of functionality for the weather-station market, eliminating complex sensor, power and communication configuration decisions.

In our fast-changing world, accessible and accurate weather data is a must, particularly in highly regulated industries or any activity potentially affected by extreme conditions. When operations leaders rely on RainWise and the MK4-C, they can transform the uncertainty of weather conditions into confident decision processes that provide stability in the face of a volatile and changing climate. ▮

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- Based on a photon counting detector and a microchip laser at 1064 nm (micro pulse lidar)
- Data output in NetCDF format available
- Flexible communication via Ethernet and RS-485

Please visit www.lufft.com to find out more about the LIDAR Ceilometers.

Mike Thomas, senior product manager, industrial sensors, Druck, a Baker Hughes business

Pressure POINTS

Druck's pressure sensor technology, with its high levels of accuracy and reliability, is enabling customers to optimize performance across a wide range of applications

LEFT: Druck's ADROIT6200 is a high-performance, robust pressure measurement device

Barometric pressure measurement is fundamental to shaping the world around us. From weather forecasting and climate modeling to aircraft landing systems and digitally connected smart cities, barometric pressure measurement plays a critical role. In many of these demanding applications, obtaining an accurate measurement is only one of the requirements the barometric pressure sensor has to fulfill.

The sensor also needs to operate reliably and consistently despite extreme temperature variations or harsh environments. The electrical output needs to be suitable for the data acquisition system, which can be challenging in remote locations where power consumption is a key consideration. Finally, accuracy levels need to be sufficient to enable the data to be a benefit to the application, which is where the trade-off with sensor costs can be felt the most: higher accuracy costs more.

Druck technology

The most accurate digital pressure sensors use silicon or quartz measurement elements, and each technology has advantages and disadvantages. Since 1972, Druck, a Baker Hughes business, has developed its proprietary silicon technology in state-of-the-art facilities in Leicestershire, UK. TERPS (Trench Etched Resonant Pressure Sensor) uses groundbreaking resonant silicon technology to offer exceptional levels of accuracy (±0.1hPa) and stability (±0.005% FS typical) over a wide operating temperature range (-40°C to 85°C).

Druck piezoresistive silicon technology also offers exceptional levels of accuracy and stability due to the advances Druck has made in silicon design and manufacture. The digital signal processing and thermal compensation technologies offered by Druck enable highly accurate sensors (±0.6hPa) with a multitude of digital communication protocols coupled with low power consumption.

Druck's sensor product range enables accurate pressure measurement in harsh environments, such as during flight in the aviation sector

The use of digital processing has also enabled Druck to release the latest in a line of modular pressure sensors, the ADROIT6200. This product couples digital thermal compensation with an analog output to provide ±1hPA accuracy but with traditional voltage or 4-20mA output.

The small, robust package of this sensor makes it ideal for the most demanding harsh environments but at a price level that allows its adoption in many applications.

Landing aircraft safely

Airports, from the busiest international hubs to small private airfields, require accurate on-site barometric pressure measurement. This not only provides general weather data but also barometric pressure correction values for aircraft instrumentation. These corrections are critical to assist in the safe landing of incoming aircraft: an accurate altimeter adjusted to know exactly where the ground lies makes landing, particularly in bad weather, much safer.

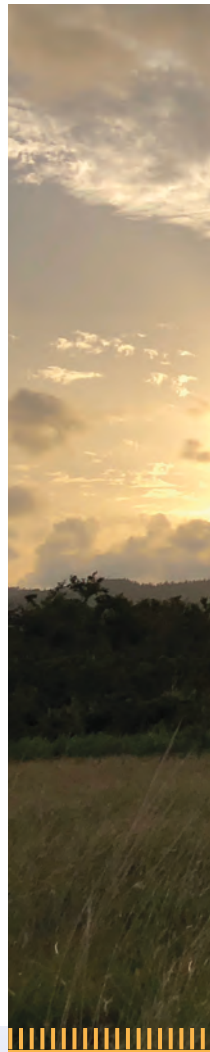
Druck TERPS meet the accuracy requirements of the WMO and hundreds of them are incorporated into airport weather stations across the globe to meet the International Civil Aviation Organization (ICAO) standards for such equipment.

Due to the rugged nature of the TERPS and their ability to operate over a wide ambient temperature range without affecting accuracy, they can be deployed in airports all over the world, from hot desert locations to high altitudes and even in freezing environments.

The high stability allows long service intervals and the design enables simple swap-outs for servicing without the need for local calibration and costly downtime.

The applications for barometric pressure measurement are more varied than ever and every application has specific requirements that need to be met. Choosing the right instrumentation for the task is a multidimensional problem where a trade-off between cost and performance will always need careful consideration. ▮

Jason Selzler, senior radar engineering consultant, and
Rebecca Williams, director of operations, EWR Radar Systems



RAPID RESPONSE

EWR Radar Systems has played a key role in helping storm-hit regions restore their weather forecast and early warning capabilities through the fast provision of portable doppler radars

In late September 2017, Hurricane Maria devastated Puerto Rico with more than 160km/h winds. The powerful Category 4 storm slammed into the island, rendering the country's two Doppler radars inoperable and leaving forecasters with a massive data gap that hindered weather forecasts and warning operations on Puerto Rico and the US Virgin Islands. With the radars down for an indefinite amount of time, a temporary solution was needed.

Through a collaboration with the Federal Emergency Management Agency (FEMA), National Oceanic and Atmospheric Administration (NOAA) and the US Department of Defense, the US Marine Corps was able to send two EWR Radar Systems portable Doppler radars to Puerto Rico for use while the other island radars were being repaired.

This mobile turnkey solution was selected due to its proven ruggedness and reliability; easy installation and setup, with the ability to have the radar fully functional within just 60 minutes; and minimal infrastructure requirements, needing only a power source and network connection.

The EWR X-band Doppler radars arrived in San Juan on October 21, 2017 – only a month after the hurricane. One system was installed at Roosevelt Roads to cover the eastern end of Puerto Rico, and a second was installed near Aguadilla to cover the western portion of the island. These systems restored the capability to serve 3.5 million people with early warnings and improved precipitation forecasts until the Federal Aviation Administration (FAA) radars were restored a full nine months later.

ABOVE: EWR's E700 Portable Doppler Radar deployed at Roosevelt Road, Puerto Rico, after Hurricane Maria in 2017

LEFT: EWR's Rapid Response Vehicle equipped with an E800 Dual Polarization Weather Radar

BELOW: The portable doppler radars can be field installed in one hour or less

Unfortunately, radar unavailability due to storm damage, as seen in Puerto Rico, is not an isolated event. In 2008, the radome of the US National Weather Service (NWS) radar in Reno, Nevada, was punctured by wind gusts up to 225km/h. Furthermore, super typhoon Yolanda damaged the Guiuan radar in the Philippines in 2013. This radar took more than two years to restore. More recently, Hurricane Laura destroyed the NWS radar in Lake Charles, Louisiana, in August 2020.

Minimizing downtime

Due to the aging of many national weather radar networks, radar downtime caused by component failure must also be considered. In late 2020, the Denver NWS radar was offline for about three weeks for the repair of the bull gear, a major mechanical component.

In October 2020, the Guam radar went down due to a broken motor and power amplifier. Although parts have been ordered, the US NWS Guam has announced that the radar will be down for the foreseeable future. Much like the US Marine Corps did with Hurricane Maria, the US Air Force is sending an EWR portable Doppler radar to Guam for interim use to provide critical weather information to the area forecasters.

When not being used as replacements for non-functioning network radars, mobile radars can be used to provide additional coverage for high-profile events. The Korean Meteorological Agency purchased three EWR E800 systems in preparation for the 2018 Winter Olympics. The temporary network was used to provide accurate weather predictions throughout the event. At the conclusion of the Olympics, the three radars were moved to different locations.

Mobile weather radars are an essential addition to any radar network. Portability and ruggedness are the key driving factors in the selection of a system. Solid-state amplifier technology and the elimination of tube amplifiers greatly enhance the reliability of the radars, particularly during rough transportation. They also require much lower voltages than the traditional magnetron or klystron, making them safer for field operation.

The arrival of such versatile technology enables more effective national weather radar networks. Furthermore, the addition of mobile radars can be used to prevent the data gap found when a network radar is going to be offline, either scheduled or unscheduled.

Today, mobile radars come in many forms. Single polarization or dual polarization, X-band and C-band options are available, mast, tripod, truck, trailer or container mounted. Like any other radar systems, they can be optimized to fit any mission. ▮

Johannes Vieten, meteorologist, GAMIC GmbH, Germany

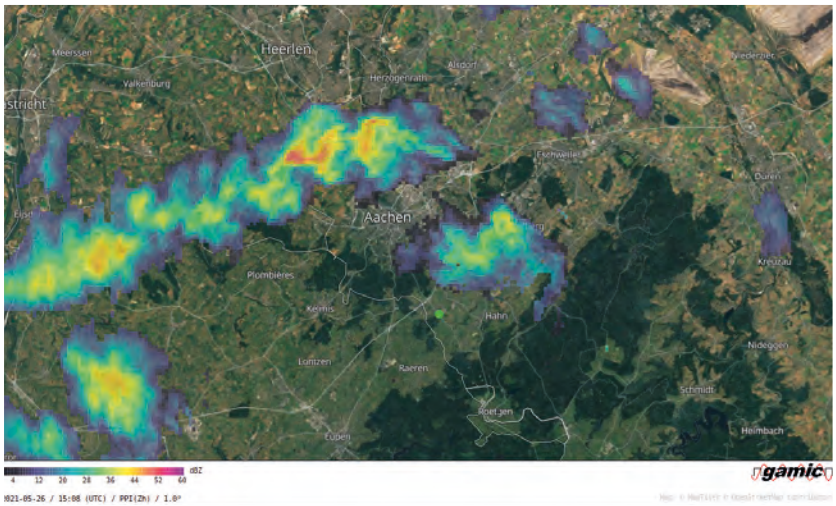
ADAPTING

to the inevitable

A high-precision weather radar system from **GAMIC** is set to improve flood control and water management in urban areas

On May 29, 2018, an intense thunderstorm cell passed over Aachen, a German city near the borders with Belgium and the Netherlands. Within minutes, parts of the city were flooded knee-high – the sewage system was not capable of holding the huge amount of water.

Due to climate change, scientists expect an increase in such small-scale but high-intensity convective precipitation events. Combined with more sealed surfaces and high population densities in urban areas, municipal authorities are challenged to reliably warn and protect people and assets and optimize water management systems for pluvial flood events. Therefore, there is an increased need for high-resolution precipitation measurement and data processing systems.



MAIN: The partly flooded city of Aachen in Germany after a heavy precipitation event on May 29, 2018[1]

ABOVE: An example visualization of precipitation data from the weather radar in Aachen

LEFT: GMWR X-band weather radar with dual polarization

Cooperation project

To address this challenge, in 2019 a collaborative urban lighthouse project[2] was initiated by GAMIC and KISTERS, two German companies with decades of experience in their fields of expertise.

GAMIC is a technological company manufacturing complete weather radar systems and developing meteorological signal processing hardware and software. Its product line comprises magnetron and solid-state X-band weather radars with Doppler functionality and dual polarization; the powerful ENIGMA signal processor, which has recently been updated to its fifth generation; and FROG-MURAN, a comprehensive weather radar software suite. GAMIC products are in operational use all over the world for meteorological, hydrological, air traffic and research purposes.

KISTERS, a medium-size company that was founded as an engineering office in 1963, develops software solutions for sustainable resource management of energy, water and air for environmental protection and safety, logistics and 3D viewing. It also produces measuring instruments for environmental monitoring. Furthermore, the company is active in the area of engineering services. KISTERS is a sought-after solution partner in an international context.

The aim of this cooperative project was to create a precipitation measurement, data processing and visualization system for the Aachen region. The system was to serve as a decision-making tool for establishing a water-sensitive urban planning concept, which is why the city of Aachen was closely involved from the very beginning.

The project was funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety as a measure to adapt to the impacts of climate change.

The radar system

One year after the start of the project, in summer 2020, GAMIC's GMWR X-band Doppler weather radar was installed on top of a new parking structure a few kilometers south of Aachen. The radar has a range of up to 100km so the city of Aachen and its urban and rural surroundings are covered very well and approaching precipitation systems can be detected with sufficient lead time.

With a high spatial resolution of only 100m and data processing capabilities down to 25m, precipitation can be observed on a very small scale. To be able to capture even very fast-developing storm cells, complete volume scans can be run every five minutes; single sweep scans are also possible with an even higher temporal resolution.

The radar's dual-polarization capability not only enables optimization of the data output but also the classification of hydrometeors. The possibility to distinguish hail from rain in heavy summer thunderstorms can lead to better warnings. Moreover, snow detection in the winter is a useful feature to optimize road maintenance, for example.

All in all, three main data products (reflectivity, rainfall rate and hydrometeor classification) are transmitted via a fiber-optics network directly to the KISTERS data center, where they are processed further. The KISTERS software system offers flexible visualization of the radar data and comprehensive hydrological analysis tools, as well as nowcasting features for meteorological and hydrological warnings.

Compared with the large-scale weather radar data of the major weather services, the GAMIC and KISTERS system provides precipitation data with higher spatial resolution and is much more

ABOVE: A GAMIC X-band weather radar installed on top of a parking structure south of Aachen, Germany

flexible, especially for urban regions and local users. However, both types of system have a right to exist alongside each other and they complement one another well.

Applications and users

There are two main applications for this weather radar hardware and software system. On the one hand, it is an early-alert warning system for torrential and flooding situations, which helps to protect people and assets. The system's high precision enables timely and targeted adaptation of measures for traffic control, sewer management and drinking water management.

On the other hand, the high-resolution short- and long-term precipitation data from the weather radar system can be used to optimize water management in the observed areas in general. Municipal authorities and service companies can improve the design of retention areas, ensure sewage capabilities and prepare waste, drinking and processing water management for heavy precipitation scenarios.

The main users of the system are municipal authorities, water management institutions and public transport and other infrastructure and service companies. These professional users have access to the radar data using KISTERS' HydroMaster platform dedicated to the management of risks related to storm and flooding events. Additionally, the precipitation data and short-term warnings can be provided to the public, especially to the citizens within the regions observed by the radar. The development of a mobile application for that purpose is currently being undertaken.

In a nutshell, GAMIC's high-precision X-band weather radar system provides a high-resolution data basis to reduce the impact of future flood events caused by heavy precipitation. Municipal authorities are thus provided with a tool that can improve the safety and quality of life of their citizens by optimizing urban water management. Such a system could likely reduce the impact of an event like the one that occurred in Aachen in May 2018. ▮

References:

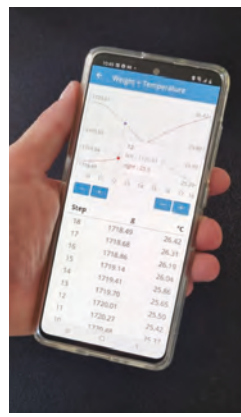
1. Hofmann, J; Schüttrumpf, H. *Risk-Based Early Warning System for Pluvial Flash Floods: Approaches and Foundations. Geosciences* 2019, 9, 127. https://doi.org/10.3390/geosciences9030127 8.
2. https://www.gamic.com/more/aachen-weather-radar-project

MPS systém

Since 1992 in Hydrology and Meteorology





Main features:

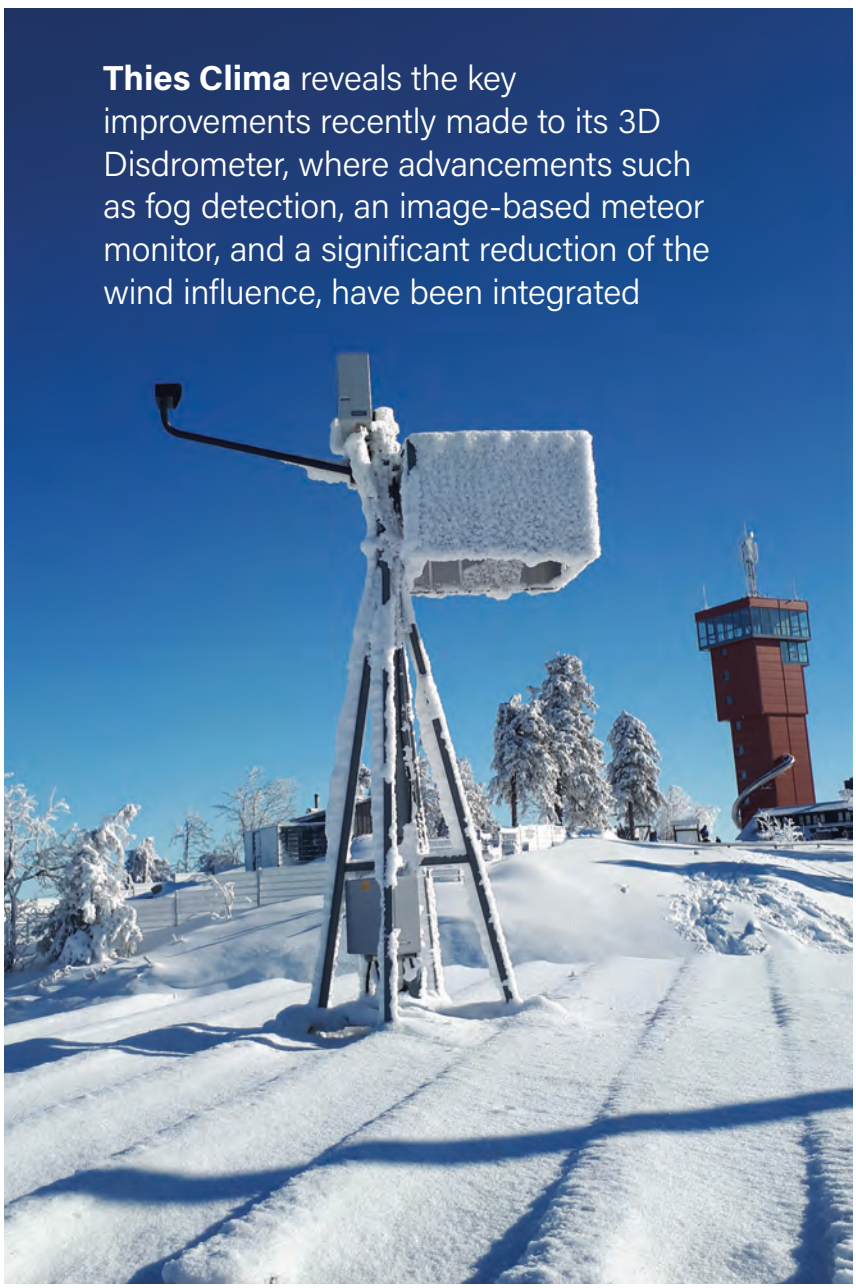
- All sensors are AiO – all in one solution
- Bluetooth communication for service and maintenance
- Very low power consumption
- Life time from battery min 10 years
- IoT communication – Sigfox, LoraWan,GPRS, Bluetooth
- Cloud and web solution

www.mps-system.sk

Parthkumar Gadhiya, development engineer, and Thomas Stadie, director of sales and marketing, Adolf Thies

SUPERIOR detection

Thies Clima reveals the key improvements recently made to its 3D Disdrometer, where advancements such as fog detection, an image-based meteor monitor, and a significant reduction of the wind influence, have been integrated



Adolf Thies, a provider of meteorological sensors and also well-known under the Thies Clima brand name, has recently optimized its 3D Stereo Disdrometer following evaluation of customer feedback and its own experiences with the solution. The company says that the device has evolved to become one of the most advanced commercial disdrometers on the market.

The system detects the size, shape and optical properties of meteors and their vectorial velocity. This enables superior detection of hydrometeors as well as non-hydrometeors. The instrument will achieve the high accuracy of any other collecting systems while keeping the high sensitivity and accuracy for low-intensity precipitation of optical gauges. According to Adolf Thies, when compared with the first version of the 3D Disdrometer, the latest version is significantly improved.

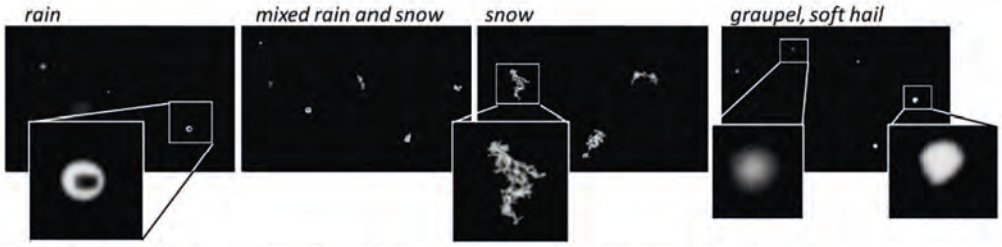
Generally, compared with collecting gauges, disdrometers offer far more options to determine the exact precipitation type. For example, the Thies laser precipitation monitor (LPM) identifies 20 types of precipitation event according to the weather code established by the WMO, based on the correlation between the size and speed of the detected hydrometeors.

The device has been continuously improved over the past 15 years and is manufactured in a series production line. Today's disdrometer generation comprises highly mature and robust devices. Because of those advantages, disdrometers are the preferred choice for precipitation measurement in fully automated, unmanned weather stations around the world.

Minimizing false observations

Despite those advantages, the detection capabilities of current weather sensors are limited by the underlying technology. Non-hydrometeors – such as blown dust and sand, birds and insects passing through the beam, swinging spider webs and also snow that is lifted by the wind – may cause false-positive detection of precipitation.

Furthermore, for current radar-based weather sensors, electromagnetic disturbances from surrounding industrial installations may be wrongly interpreted as Doppler signals and



While liquid precipitation appears as a donut, solid meteors do not exhibit such ring form

thus yield false observation of precipitation. In addition, due to their similar falling speed, drizzle and snow may be wrongly classified, yielding false intensity calculations.

To minimize the failure alarm ratio without compromising the detection probability, and depending on the required level of data consistency and accuracy, system providers and weather-station operators sometimes install backup weather devices and cross-checking routines. However, this approach is not only costly and time-consuming but also requires an in-depth understanding of the physical and meteorological effects.

The Thies 3D Stereo Disdrometer is designed to overcome those deficiencies. It consists of two cameras that take simultaneous high-speed pictures of meteors passing in front of an infrared-light-emitting screen.

In contrast to existing weather sensors where precipitation type and amount are determined either by a combination of Doppler effect and reflectivity (backward scatter) or by the duration of a shadow evolution when the meteor falls through an infrared beam (forward scatter), the new forward-scatter 3D Stereo Disdrometer analyzes the pictures of the meteors to determine their type, size and number. Like a human observer, the machine's software routines analyze the meteor's appearance and movement (such as size, shape, trajectory and speed) and derive the precipitation type and its intensity directly.

The 3D Stereo Disdrometer is based on stereoscopic imaging technology consisting of stereo cameras and a light source. This means it can precisely calculate the distance of a falling meteor from the two cameras; that is, the meteor's exact position within the measurement volume. Based on this information, not only can the size of the meteor be calculated, but valuable information on non-hydrometeors can be gathered. For example, if all the meteors are detected at a similar distance from the cameras, they will be classified as non-hydrometeors, thus reducing false-positive detections.

The stereo cameras work with 50fps. By comparing the movement of all particles per frame, the velocity distribution of the meteors is calculated. Based on the measured particle diameter and velocity, and by also taking ambient temperature into consideration, the precipitation type and intensity are derived. The 3D Stereo Disdrometer measures meteor speed up to 40m/s and presents the data in user-defined velocity classes. Similarly, measured diameters up to 40mm are presented in user-defined diameter classes.

New analysis opportunities

Taking pictures of falling particles provides a huge number of analysis options that currently available weather sensors and disdrometers for stationary use do not offer. First of all, this technology detects hydrometeors as small as 0.08mm, thus outperforming most of today's weather sensors. Second, picture recognition technology is inherently inert against vibrations as well as electromagnetic and magnetic disturbances, so the 3D Stereo Disdrometer can be used in industrial environments such as on a windmill nacelle or near photovoltaic installations.

Furthermore, liquid precipitation such as rain and drizzle is characterized by a donut shape where light passes with little extinction through the center of the droplet. On the other hand, crystallized particles show a high extinction all over the volume. Thus, the 3D Stereo Disdrometer detects undercooled (freezing) precipitation such as freezing rain and freezing drizzle when the instrument's outside air temperature sensor detects freezing temperatures while there is also liquid precipitation.

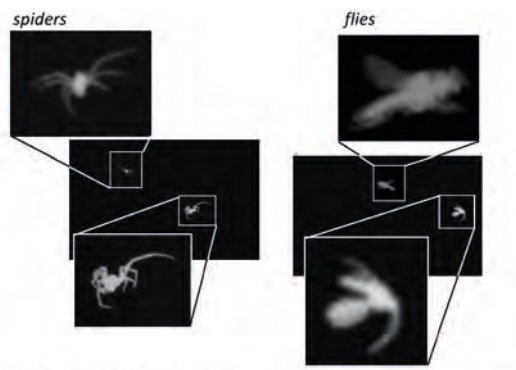
Solid precipitation can be categorized in high detail. For example, snow particles are characterized by an irregular outer contour, while graupel is characterized by its roundish shape, no donut appearance and low falling speed. For each precipitation type that Adolf Thies has observed over the years, a pattern recognition algorithm has been developed to identify and classify the meteors.

Picture recognition technology also enables precise determination of the water equivalent of solid

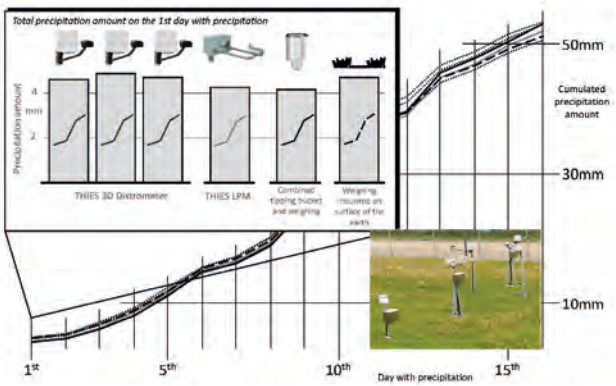
LEFT: Thies Clima reveals its upgraded 3D Disdrometer, where improvements such as fog detection, an image-based meteor monitor and a significant reduction of the wind influence have been integrated

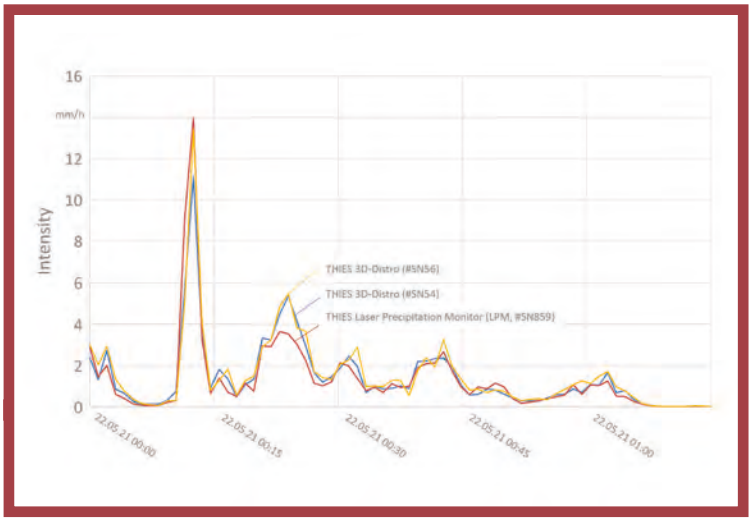
ABOVE: Various precipitation types identified

BELOW: Various non-hydrometeors identified



Identification of non-hydrometeors with picture recognition algorithms





meteors, thus outperforming radar- and laser-based disdrometers. One of the 3D Stereo Disdrometer's main advances, it indicates the share of each meteor type for mixed precipitation.

Another advantage is the unambiguous detection of non-hydrometeors such as insects. Currently, based on implemented picture analysis algorithms, around 97% of all non-hydrometeors are identified. This means that when there are insects within the measurement volume, they will not compromise the disdrometer's readiness to detect precipitation events.

Field testing

To meet operators' expectations of a mature and reliable disdrometer that can outperform existing instruments, the 3D Stereo Disdrometer was field-tested for several years in various climatic regions. Optimization routines have been implemented, such as a correction function so that the intensity data remains correct even if parts of the camera lenses are blurred when wet.

A long-term comparison with the Thies Laser Precipitation Monitor and alternative measuring principles yields excellent matching in terms of intensity, cumulated precipitation amount and precipitation type. The new device is offered with standard heating for moderate climate and extended heating for cold climate. The heating for cold climate is characterized by its particularly effective heating management. Furthermore, a newly developed and proved algorithm minimizes the well-known wind influence, which is observed in most of the common precipitation measurement systems.

The 3D Stereo Disdrometer offers an RS485/RS422 interface, Ethernet connection and SD card slot for communication. With the Ethernet (TCP/IP) connection, up to five users can operate the device at the same time. Data telegram transmission occurs every minute and consists of raw data, diameter and velocity group classification of every detected particle, accumulated amount, intensity, precipitation type and the device's internal data.

Another key feature is that the 3D Stereo Disdrometer transmits real-time particle images of the detected precipitation type, which helps the observer determine precipitation and current weather. The well-known Thies LPM View software has been extended to display additional data provided by the 3D Stereo Disdrometer. The meteor viewer shows actual meteors including their classification. Besides precise documentation for critical applications such as airport weather, it also supports human observers when determining METAR codes.

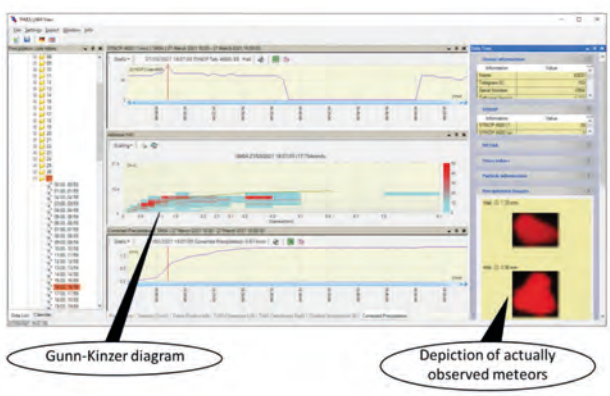
To receive representative and reproducible calibration results, the 3D Stereo Disdrometer's calibration procedure is carried out using a rotating glass disk containing engraved balls of different sizes. To acquire uncompromised results in the rating of diameter, 12 balls ranging from 0.2mm to 8.0mm are used. During this process, the engraved disk rotates in different positions inside the measurement volume to calculate the required parameter.

The new, field-proven 3D Stereo Disdrometer is designed for and proven in 24/7 operation with minimal maintenance needs that are comparable to today's weather sensors. In contrast to video camera installations that are offered for scientific investigations, the 3D Stereo Disdrometer is suitable for everyday use primarily in critical applications such as airport weather and environmental control on windmills, where robustness and uptime count, and minimum failure alarm ratio and highest probability of detection are also important. The device is manufactured in a series production and its price-performance ratio makes it a first choice for highly reliable, fully automated weather station networks, single applications in meteorology, climatology and for hydrological measurement tasks. ▮

ABOVE LEFT: A comparison of the measured precipitation amount with different methods

ABOVE RIGHT: Intensity measurement of different disdrometers during a typical rain shower, highlighting the reproducibility of the Thies 3D Disdrometer and comparability with data from the Thies Laser Precipitation Monitor (LPM)

BELOW: A snapshot of the user interface to operate Thies disdrometers



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

Geolux

Experts in contactless hydrology measurements

www.geolux-radars.com

Juraj Schwarz, CEO, MPS System

ACCURATE measurements

MPS System is helping to reduce negative influences, such as wind, temperature and inlet losses, to improve the quality of data from weighing precipitation gauges

The advantages of using weighing gauges for precipitation measurement are well known. They include no limits on rainfall intensity, inlets aren't blocked with particles or leaves, and they offer high accuracy. However, there are some disadvantages, including the requirement to manually empty the bucket, and the effect that negative temperatures and wind have on data accuracy. MPS System has been developing its TRwS family of weighing precipitation gauges for 15 years. Currently there are seven types of TRwS gauges in production. Two of them are stainless steel, and three are self-emptying, using unique weighing and self-emptying technology. The latter combine the advantages of the weighing and tipping principle.

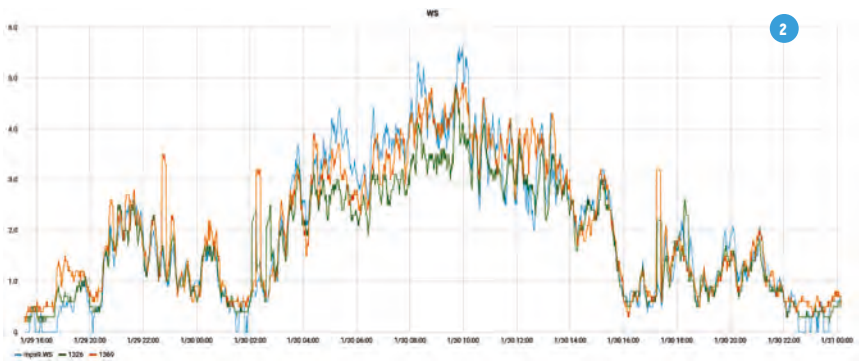
Reducing negative influences

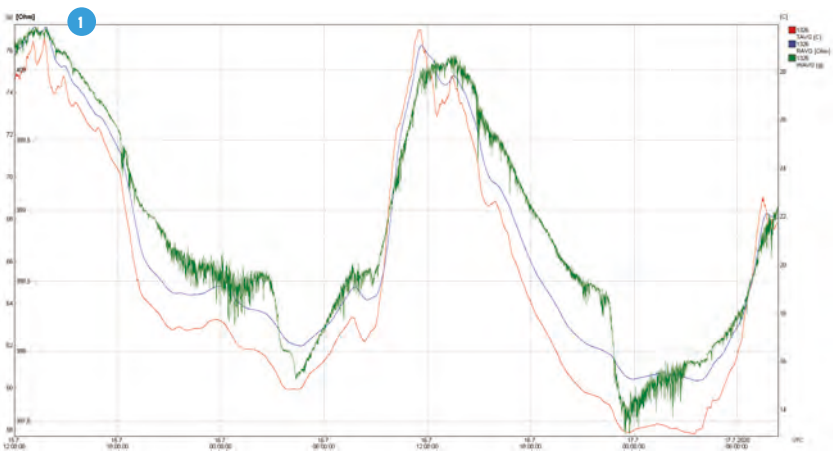
The TRwS gauges include load cells, which are analog sensors that change according to weight and temperature. The most difficult situation occurs when temperature changes rapidly, such as at sunrise and sunset, as this can generate false precipitation. Temperature compensation for the load cell is carried out, but this is often not enough for these rapid temperature changes, and false precipitation can be generated.

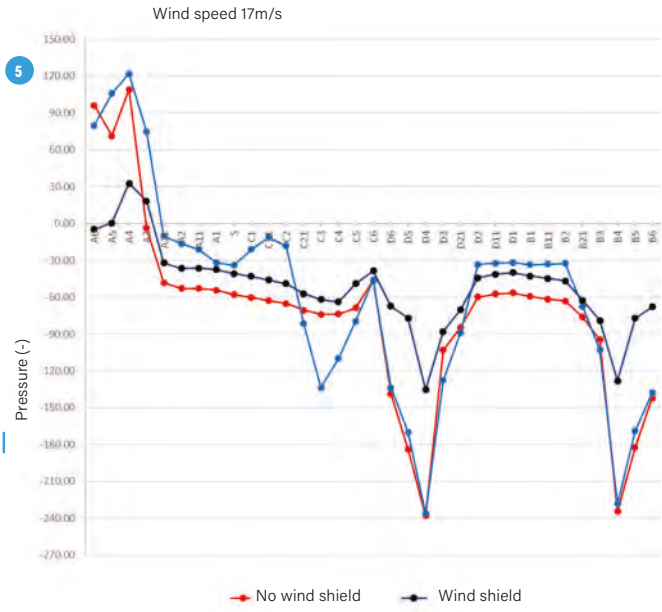
One approach to combat this is to put the load cell in an extra thermal box. However, this solution is complicated and often does not solve the problem. MPS System has developed an algorithm that can help overcome this challenge. It calculates the load cell value and temperature so that changes in temperature are taken into consideration when determining weight and, as a result, data is accurate. Years of development have resulted in stable firmware in this area.

FIGURE 1: The influence of wind and temperature on weight measurement. Green = weight, red = temperature, blue = wind speed

FIGURE 2: Correlations between wind speed measurement by wind sensor and extracted signals as a wind noise from weight measurements. Blue = wind speed, green = wind noise from 400cm², red = wind noise from 200cm²







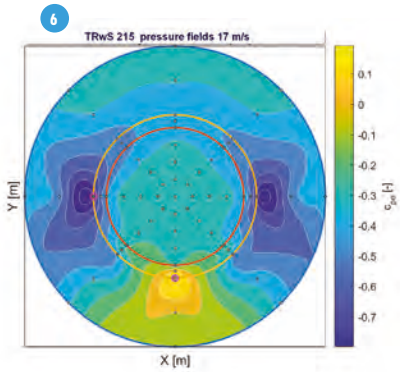


FIGURE 3: The wind tunnel at the Slovak University of Technology

FIGURE 4: The rain gauge with wind shield installed in wind tunnel

FIGURE 5: Measured pressure from 31 points during wind speed of 17m/s

FIGURE 6: Pressure fields

FIGURE 7: Installation of TRwS 4E25 with two MPS TB IOT modules for GPRS and Sigfox modems

Wind is another important factor that can affect the weighing precipitation gauge measurement. The signal from the load cell is modulated by wind in Figure 1. It is processed in a statistics module to eliminate 'wind noise' from the weight value. This separated 'wind noise' corresponds well with wind speed. The module can then provide a direct comparison with the wind sensor and wind noise from the rain gauges.

The correlation of this data can be seen in Figure 2. The value of the 'wind force' is available on the sensor output. It is well known that wind can have a negative influence on the data output of gauges, especially during light precipitation events.[1] However, thanks to the 'wind force' extracted from the measurement of weight, MPS implemented an algorithm that provides a direct measurement of precipitation and corrected data calculated with the adapted formula.

Weighing precipitation gauge measurements can also be improved by reducing the losses caused by drops coming from the orifice and inlet sleeve. The inlet surface keeps drops during a rain event and such losses are also defined by WMO and published in CIMO guides for manual and automatic observation.

MPS System carried out many tests with different types of surfaces, colors and nanolayers using the 'lotus' effect. Thanks to special treatment of the inlet surface, MPS reduced the amount of water by 80% without the need to use special layers that would need to be activated every two years. As a result, rainfall losses correspond to just 0.08mm. This value gauge adds to the several minute precipitations, and such value is available as a corrected precipitation.

Wind shields

MPS System has evaluated years of measurements from two gauges that have different orifice diameters: 200cm^2 and 400cm^2. The results show differences in the measured precipitation. During conditions with no wind and high rain intensity, these two gauges show the same value. The total capture content of water was 1-2mm. However, during wind conditions, the 200cm^2 gauge measured less water than the 400cm^2 one.

To test whether wind shields would help provide more accurate data, MPS System undertook laboratory testing in wind tunnels at the Slovak University of Technology in Bratislava (Figure 3). The dimensions of the tunnel were 2.6 x 1.6 x 26.4m. The discharge of air was 52m^3/s.

The two rain gauges (200cm^2 and 400cm^2) were tested, and they were adapted with 31 measurement points across the inlet and outside the cover. The same conditions were provided for both types, and tests were carried out both with and without wind shields. Figure 4 shows the position of the gauge with the wind shield in the tunnel. Tests were carried out with wind speeds of 5, 10, 15 and 17m/s. Figure 5 shows the measured pressure in each measurement point; Figure 6 shows pressure fields across the cover. The final data is available to the public[2] and further studies will be carried out.

MPS's new IoT module

MPS System's Tipping Bucket (TB) IoT module was developed primarily for precipitation sensors with pulse output, such as tipping bucket gauges. The most important advantages of the TB module include zero power consumption, a self-emptying system and competitive price.

The module features information on total precipitation, rain intensity, ambient temperature, calculation of mean, maximum and minimum values, and battery power. GPRS, Sigfox and LoRa networks are supported with corresponding modems to the plug-in module.

The module is powered by one primary battery and its lifetime is up to 15 years. Dimensions are such that the module can be installed in most of the tipping buckets on the market. Figure 7 illustrates the installation of MPS's self-emptying TRwS 4E25, with two modules for Sigfox and GPRS networks. ▮

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2) *Experimental measurement of pressure distribution on models of weight gauges*, Slovak University of Technology, Bratislava (2020)

Benedikt Burkhardt, head of project development, Nowcast

High-precision PARTNERS

The new ultra-precise lightning detection system in **South Africa** provides a great example of how **Nowcast** works closely with local partners to develop successful projects

The Blitz Detect team (L-R): Trevor Manas, Wilfried Wagner and Alexis Barwise

In addition to high-precision data services and complete autonomous lightning detection networks (LDN), German lightning expert Nowcast is known for its strong project partnership approach. In such partnerships, nowcast sets up ultra-precise, long-range lightning detection sensor networks in countries, or larger areas, together with local partners to jointly operate those networks. Key to such joint ventures is Nowcast's deep belief in true long-term partnerships. Acting like colleagues leads to the addition of great value to the region through technology. Celebrating mutual success as quality leaders in ultra-precise lightning detection, early thunderstorm warning and leading-edge short-term forecasting has proved to be an excellent driver for first-class services and outstanding customer satisfaction in the private and public segments.

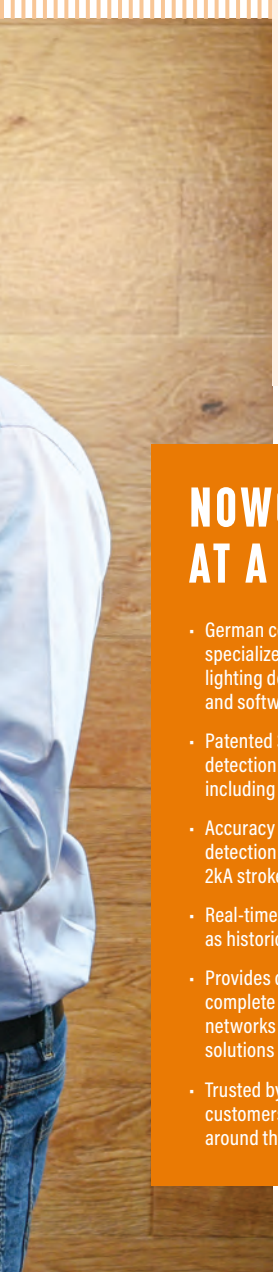
A trusted partner

When Nowcast deployed its first partnership lightning detection network together with a local company in Latin America many years ago, enthusiasm fueled the approach of engaging in long-lasting, professional, open-minded business partnerships across the globe. Qualified local partners that are working closely with Nowcast enable the success of best-in-class lightning-detection technology and thus also success in the defined market.

Today, Nowcast is proud to call numerous qualified and passionate private companies and national weather services its trusted partners and friends with one goal: to provide the most reliable and precise lightning data, particularly for lightning-prone countries/regions.

Maximum safety and efficiency for people, investments and processes have always been the clear objectives for Nowcast's partnership missions based on the Nowcast LINET (LIghtning detection NETwork) technology.

In May 2021, a brand-new partnership LINET system was installed in South Africa. Trevor Manas, managing director of Blitz Detect, and his business partners, Alexis Barwise, Wilfried Wagner and Etienne Gerber, are bringing their vast experience in lightning and lightning protection to this endeavor and form the local core team in South Africa. Here, they provide deeper insight into the partnership, as well as the benefits of ultra-precise lightning detection.



NOWCAST AT A GLANCE

- German company specialized in ultra-precise lighting detection (hardware and software)
- Patented 3D total lightning detection (CG and IC, including emission height)
- Accuracy of 75m on average, detection efficiency down to 2kA strokes
- Real-time operation as well as historical lightning data
- Provides data services, complete autonomous networks and hybrid solutions
- Trusted by numerous customers and partners around the world

What is Blitz Detect and who are the key personnel involved?

TM: Blitz Detect consists of a small team of highly experienced lightning protection specialists who are dedicated to providing precise lightning data to South Africa and sub-Saharan Africa.

Our team consists of me as managing director, with more than 26 years' experience in the lightning protection industry, and our chief technical officer, Alexis Barwise, who is an electrical and electronics engineer with 14 years' experience in the lightning protection industry. Barwise is also South Africa's representative on the IEC lightning protection technical committee.

We also have Etienne Gerber, Blitz Detect's sales director, who has been active as a lightning specialist for the past 12 years, and director Wilfried Wagner, who has vast experience in working in South Africa's energy sector, which is invaluable.

How would you describe the general lightning situation in South Africa?

AB: Many parts of South Africa have a high lightning stroke density and the country has one of the highest lightning fatality rates per capita in the world, with numerous deaths and injuries being reported each year.

At Blitz Detect, we are confident that the highly precise and reliable Nowcast lightning detection system can be instrumental in saving many lives and preventing thousands of lightning-induced injuries and damage.

We also aim to provide valuable lightning data to the insurance industry, aviation industry, energy suppliers and for lightning research in South Africa. At Blitz Detect, we strongly believe that the Nowcast system will make a substantial contribution to lightning safety and to the effective operation of essential services to the public in Southern Africa.

What is your mission for lightning detection?

WW: First and foremost, we want to save lives. South Africa has a very strong outdoor culture. The Nowcast system provides meticulous monitoring of all types of outdoor facilities, thereby making these operations and activities much safer for everybody.

Of course, lightning data is valuable in maintaining vital operations to many other types of industries such as the insurance, energy and aviation industry. Weather service providers as well as research facilities also benefit enormously from highly accurate lightning detection information.

Here at Blitz Detect we look forward to providing these customers with precise, easily accessible, cost-effective data-based lightning detection solutions.

> "The new LINET system plays a vital role in providing easy access for all our customers to an autonomous, independent and professional lightning detection solution"
>
> Wilfried Wagner, director, Blitz Detect

Before you partnered with Nowcast, you conducted a thorough investigation of the technical options and providers. What convinced you about Nowcast and its LINET technology?

TM: Working in the lightning protection industry for many years and having a deep understanding of the mechanisms of lightning, it was an easy decision to go with Nowcast and its LINET system. The unsurpassed accuracy, efficiency, reliability and speed without doubt make the Nowcast LINET systems the benchmark in lightning detection.

Blitz Detect chose to operate the new South African LINET lighting detection network together with Nowcast in a business partnership. What do you expect from a good business partnership?

AB: Nowcast operates its LINET lightning detection networks all around the world. Therefore, Nowcast has an enormous amount of experience and understanding of how these systems work and how to achieve the optimum output in all the different regions of the world. We at Blitz Detect clearly understand that by partnering with Nowcast, we will be able to utilize this knowledge to provide our customers with the highest levels of accuracy and efficiency. Thus, both parties can profit from a long-term business partnership, working together as colleagues for a great goal.

How did the setup of the new LINET lightning detection sensors go?

EG: The Nowcast team provided invaluable support throughout the entire network setup. It was only with their help that I am happy to report the rollout was seamlessly executed in only a few weeks and functioned properly without failure.

How important is the highest possible precision and reliability of such a service for your customers in South Africa?

EG: It is of utmost importance. Precision and reliability are key to the success of the South African network. Professional customers that require lightning data can normally only profit from this data if the highest standards of quality are fulfilled. Thunderstorms are sharply delineated events and should therefore be detected and forecast with the highest possible accuracy and reliability to achieve optimum benefit for decision making, etc.

Part of the new South African sensor network – a LINET lightning detection sensor on a local school building

What makes your overall business stand out in your market?

WW: Given the fact that the existing forms of lightning detection in South Africa are outdated, less accurate and more expensive than products and services that Blitz Detect can offer, we clearly stand out in our market. The new LINET system plays a vital role in providing easy access for all our customers to an autonomous, independent and professional lightning detection solution.

What can customers expect from Blitz Detect's new services?

TM: All of our customers, be it for early warnings/nowcasting or for historical lightning data, can expect the highest level of accuracy and reliability in the detection of lightning and severe storms. They can also expect to be provided with an accessible, real-time, easy-to-use interface that is also cost-effective. ▮

PARTNERSHIP OPPORTUNITIES

If you are interested in exploring the partnership opportunities with Nowcast in your country/region, regardless of whether you are a national weather service, a private weather service or a private company/investor interested in bringing such vital services/data to your country, we invite you to contact us at www.nowcast.de.

Ahead of the Weather

Airport operations are extremely sensitive to weather phenomena – safety is paramount.

Leonardo designs the SKIRON3D coherent pulsed lidar system, which detects wind hazards including shear, gusts, turbulence and microbursts.

Compact, cost-effective and modular by design; the SKIRON3D ensures flight safety and operational efficiency.

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Johannes Fritsche, R&D, and Christoph Sommer, managing director, Sommer

Let it SNOW

Sommer looks at the relevance of snow monitoring in sustainable water resource management

People living around the Atacama Desert in South America have been hit hard by climate change and warming temperatures, as their already precarious living conditions have been aggravated by a virtual absence of rain. The only water resource they have is snow in the heights of the Andean mountains and they have no choice but to rely on it.

Likewise, although on an entirely different scale, the Himalayas provide the basis of life for more than two billion people. The massive range with the world's highest peaks is not only an arena for the most ambitious mountaineers, but also constitutes an enormous reservoir of vital water in the form of snow and ice. The large populations on both sides of the Himalayas – China and India – are heavily dependent on this water source.

In regions where climate change is already affecting daily life, people have started to think of wise water usage and are taking a closer look into snow as the primary source of water. In this context, information about the abundance of snow and its characteristics is very important and supports the sustainable management of water resources.

TOP LEFT: SSG-2 snow scale is a fluid-free snow pillow for SWE measurement

TOP RIGHT: SPA-2 is a snow pack analyzer for SWE, LWC and snow depth measurement. In Poland (pictured) it supports the provision of flood management

BELOW: A typical measurement site for SWE, LWC and snow depth measurement

Snow monitoring for efficient water usage

The most basic quantity that needs to be determined for water management is snow depth. Seemingly simple, representative and accurate measurements require advanced instrumentation such as the Sommer USH-9. This instrument is a maintenance-free, ultrasonic snow depth sensor with a sealed ceramic membrane.

To ascertain the amount of water that is stored in a snowpack (snow water equivalent or SWE) the Sommer SSG-2 snow scale can be applied. With its large sensor surface and liquid-free operation it provides a robust instrument for continuous monitoring of SWE.

During spring, rapid snowmelt can lead to floods and impair or destroy vital infrastructure. With specialized instrumentation such as the Sommer SMA-2, the increase of liquid water content (LWC) within the snowpack can be monitored and the time until water release can be estimated.

As multiple variables determine the state of a snowpack and the quantity of bound water, an all-in-one device is called for and is provided by the Sommer SPA-2 sensor. It combines a snow depth with an SWE and LWC sensor to provide all key data that describe the snow. In conjunction with a data acquisition system, the device can be part of an entire monitoring network that supports the regional water resource management.

As a leading developer of snow monitoring equipment, Sommer is an important supplier and partner of government agencies, utilities and operators around the world. The sensors listed here are only part of Sommer's product portfolio, which extends to non-contact radar sensors and tracer-based measurement kits for water discharge measurements and fully equipped automatic weather stations. ▮

Johannes Fritsche, R&D, and Christoph Sommer, managing director, Sommer

Come on STREAM

Non-contact radars are transforming water flow monitoring, notes **Sommer**

Snow meltwater, which makes its journey toward the ocean during spring season, hardly ever poses a risk of flooding. However, if snowmelt coincides with heavy rain, massive water flows can be created that can eventually lead to extensive inundation, unusable infrastructure and destroyed agricultural land. To reduce the risk of flooding and the degree of the related damage, proper flood management by public authorities and contractors is of prime importance.

Measure flow with undefined cross-sections

Water management relies on accurate flow data of creeks and streams. This data should be collected far upstream to detect an emerging flood early on.

However, water monitoring in alpine and subalpine regions is often challenging due to the rough flow conditions. For such areas, tracer-based discharge measurement equipment, such as the Sommer TQ-Tracer kit, offers a reliable and economic tool to determine water flows of streams with undefined cross-sections.

Eventually, the streams leave the mountains and merge into large rivers. Flow monitoring of these water courses may be done in a traditional way by application of rating curves. These appear handy but they are costly and accuracy takes a long time – up to several years. Additionally, a rating curve is rendered invalid once the riverbed has been eroded or significant amounts of sediments have settled.

Non-contact radars

These drawbacks can be overcome with the use of non-contact radar sensors such as the Sommer RG and RQ instruments. As they are not in contact with water and operate autonomously, these devices provide continuous flow data from the time of installation. Even ungauged sites are easy to monitor and measure now.

While the RG, a single flow velocity sensor, can be combined with an existing water level meter, the RQ provides a complete level, velocity and flow monitoring device that returns flow data in real time. Both options record the water flow velocity, a quantity that gives valuable insight into the river's flow conditions.

A Sommer RQ radar sensor produces a rating curve in a short time and has the advantage that any change of the river cross-section is immediately visible. These unique features of Sommer sensors enhance reliability and minimize fieldwork and costs.

Over the past two decades it has become clear that flow monitoring with state-of-the-art radar technology is an enormous asset for single-site applications and modern monitoring networks. This is mirrored in Asia and the USA, where installations of new devices have multiplied. ▮

ABOVE: A typical TQ-Tracer measurement site in the German mountains. For undefined cross-sections, the TQ-Tracer is ideal to ensure accurate discharge

BELOW: ADMS is an Autonomous Discharge Measurement Station – an all-in-one station for simple and fast deployments that can also be used as a rapid deployment unit for storms and local flood events during periods of heavy rain. This RQ-ADMS installation is situated in the Austrian mountains

Michal Najman, chief executive officer, Meteopress

BREAK the mold

A recent **Meteopress** collaboration proves there are new ways to innovate business models in the weather market, enabling faster expansion of the weather network

For years, the weather industry has been a very stable environment dominated by large manufacturers on one side and large national meteorological offices on the other (customer) side. The business models were also a straightforward process: public procurement of large radar sets with maintenance package included.

The latest collaboration between Austrian meteorological office ZAMG and Meteopress, a Czech weather radar manufacturer, exemplifies a new way to approach business and partnerships.

In Austria, radar instruments have typically been owned and installed by Austro Control, the local aviation authority. ZAMG wanted to expand the network and add radars to places not already covered. A public-private partnership has therefore been established where both parties make an equal financial contribution to the project. They each retain the right to use the data and share the maintenance costs, and Meteopress provides regular upgrades and innovations within the contract.

Meteopress was responsible for the entire project implementation, including identifying possible sites for radars, land rental or purchase, licensing, radar deployment and calibration. ZAMG provided guidance, approved the locations and contributed financially.

Currently, the project consists of four X-band radars (two 2.4m antennas and two 1.8m antennas) covering the upper and lower Austria regions. It also enables flexibility. In two of the existing sites, X-band radars are only a temporary solution to test the locations and are in the process of being upgraded to Meteopress's new C-band solid-state dual-polarization radar systems. Most of the infrastructure – the tower, the radomes and connectivity – was prepared in the first phase, so the upgrade is a fairly easy three-day job.

ABOVE RIGHT: Meteopress radar deployment in Hochficht, Austria

ABOVE: Rendering of Meteopress's new C-band weather radar

"We are very satisfied with the project results and there are plans to continue and expand on it in near future," says the acting director of ZAMG, Andreas Schaffhauser.

Radar as a Service

In the software world, the most common business model is a Software as a Service approach. It is used, for instance, by Adobe with great success, enabling the company to provide its customers with all the updates, upgrades and the freshest versions of the software without the need to charge them extra fees or support old, obsolete software at a large internal cost.

Is such an approach possible in a weather equipment world? In this scenario, radar equipment would be provided not as hardware that is purchased and then depreciates, but as a service for a certain amount of time – five years, for example. During this time, the customer pays only a fraction of the full price. This approach also gives customers flexibility and enables them to specify the size and type of equipment necessary.

The Covid-19 pandemic has taught us to improvise, so this might be the time to test new solutions in the met sector. Public-private partnerships are now encouraged by the WMO, and the innovative online and software worlds can inspire us about how we can approach business deals and relationships in the future.

Have you had a business model in mind? Now it is time to explore it and get your radar network up and running in no time. ▮

Ishrath Abdulkhader, general manager, Gulf Advanced Control Systems

SECOND nature

Gulf Advanced Control Systems outlines its key instruments, service solutions and testing applications to carry out world-class environmental monitoring

ABOVE LEFT & RIGHT: Environmental compliance monitoring using renewable energy sources in Saudi Arabia

Gulf Advanced Control Systems (GACS-Arabia), based in Saudi Arabia, has been supplying environmental and laboratory products, services and systems integration solutions since 2004. The company operates mainly in the air quality, emissions, fugitive emissions, leak detections, particulates, noise, vibration, water and wastewater quality, and oil spill monitoring sectors, and provides instruments to undertake these tasks. GACS-Arabia also offers compliance and field-testing services, and operations and maintenance services, and has developed a GACS-Cloud solution and a mobile app, enabling users to view and analyze data from multiple sources in one place.

The company designs and engineers its own solutions for environmental monitoring and also acts as a distributor for some of the world's largest meteorological, ambient air, emissions and water monitoring instrument manufacturers, mainly from North America and Europe. GACS-Arabia can act as a unique service partner and systems integrator thanks to the experience it has gained working with world-renowned brands.

Within the hydrometeorological sector, GACS-Arabia offers weather monitoring stations, ambient air pollution monitoring stations, various sensors for air monitoring, construction compliance, fence line monitoring, indoor air quality, noise, vibration monitoring and other regulatory applications.

The company also offers site assessments, meteorological station inspections, validations and studies, and other services including emissions monitoring from various sources, such as fugitive emissions from industrial processes also known as LDAR or FEMs.

GACS-Arabia's services also cover water quality monitoring solutions, groundwater monitoring, oil spill monitoring, and flow monitoring for municipal and industrial applications such as discharge compliance. Its water quality services cover several applications such as agriculture, desalination, groundwater, ocean and coastal monitoring, stormwater and surface water. The company holds a considerable market share in ambient air quality systems and in environmental compliance services in Saudi Arabia, and serves the GCC region.

The company can provide extensive service support including installation, troubleshooting and maintenance for the products it sells and for products represented in the region. GACS-Arabia is among the very few companies in Saudi Arabia to offer complex integration solutions. Most of its systems integrations are undertaken locally in Saudi Arabia and delivered regionally to UAE, Bahrain, Yemen, Oman and Kuwait. ▮

DREAM TEAM

A new consortium aims to help citizens mitigate the impact of weather- and climate-related threats and support authorities to adapt services to climate change

At the end of 2020, 26 national hydrological and meteorological service (NHMS) providers from Europe and North Africa decided to join forces to improve short-range weather prediction. The move saw three regional consortia, ALADIN, LACE and HIRLAM, enter into a larger partnership called the ACCORD consortium, which stands for 'A Consortium for Convection-scale modelling Research and Development'. Dr Saji Varghese, head of research at Met Éireann, the Irish NHMS, and chair of ACCORD's science committee, explains more...

Why has ACCORD been set up?

ACCORD was set up to broaden and deepen the research collaboration on developing advanced high-resolution weather prediction capability for local areas. It will further advance and strengthen research in the complex science of weather prediction, develop new algorithms to take advantage of the opportunities from new computer architectures and tackle the challenge of massive data flows with our combined expertise and effort. We will enhance and evolve the development of our numerical weather prediction model code and cooperate on new components of the modeling system.

How will it work?

Prior to the formation of the ACCORD consortium, a five-year research and development strategy was jointly developed by the consortium members. Based on the strategy, a rolling work plan was devised and more than 100 scientists will contribute toward its implementation. The management structure consists of a program manager, who will have overall responsibility for implementation of the ACCORD work plan, area leaders for the different research areas and three leaders from the merged groups.

ACCORD aims for the efficient development of a world-leading operational NWP system

While the consortium will collaborate on science and development, the production and delivery of operational weather forecasts will continue to be the responsibility of the NHMS. The scientific and technical innovations of the consortium will be implemented in the regular upgrades of the operational numerical weather prediction systems.

ACCORD will also collaborate closely with other organizations, including EUMETSAT, EUMETNET and ECMWF, to provide the very best regional weather prediction capability for its members.

What key solutions will it focus on first?

With rapidly increasing resolution of global models, moving toward hectometric resolution of limited area models to maintain their added value is a primary focus of ACCORD. Further development of ensemble forecast capabilities would need immediate attention by many members. To achieve these goals, major scientific work is planned in the areas of dynamics, physics, surface, ensembles and verification. Development of nowcasting systems based on the NWP tools is also an important area.

How will national met agencies benefit from ACCORD?

With our joint effort, we will develop more integrated and efficient working methods, and minimize duplication of work by achieving a high degree of interoperability of the common codes. This will accelerate the improvement of weather forecasts. In this way, we will help our fellow citizens to reduce weather-related threats to life, health, economy and property, and support authorities to adapt their services to climate change. ▮

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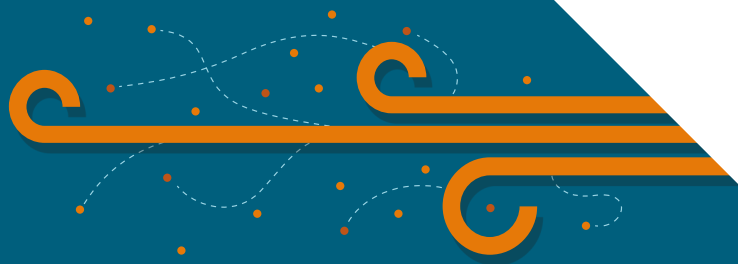

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