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

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HERE COME THE DRONES

UAVs are set to revolutionize observational capabilities as satellites did 40 years ago

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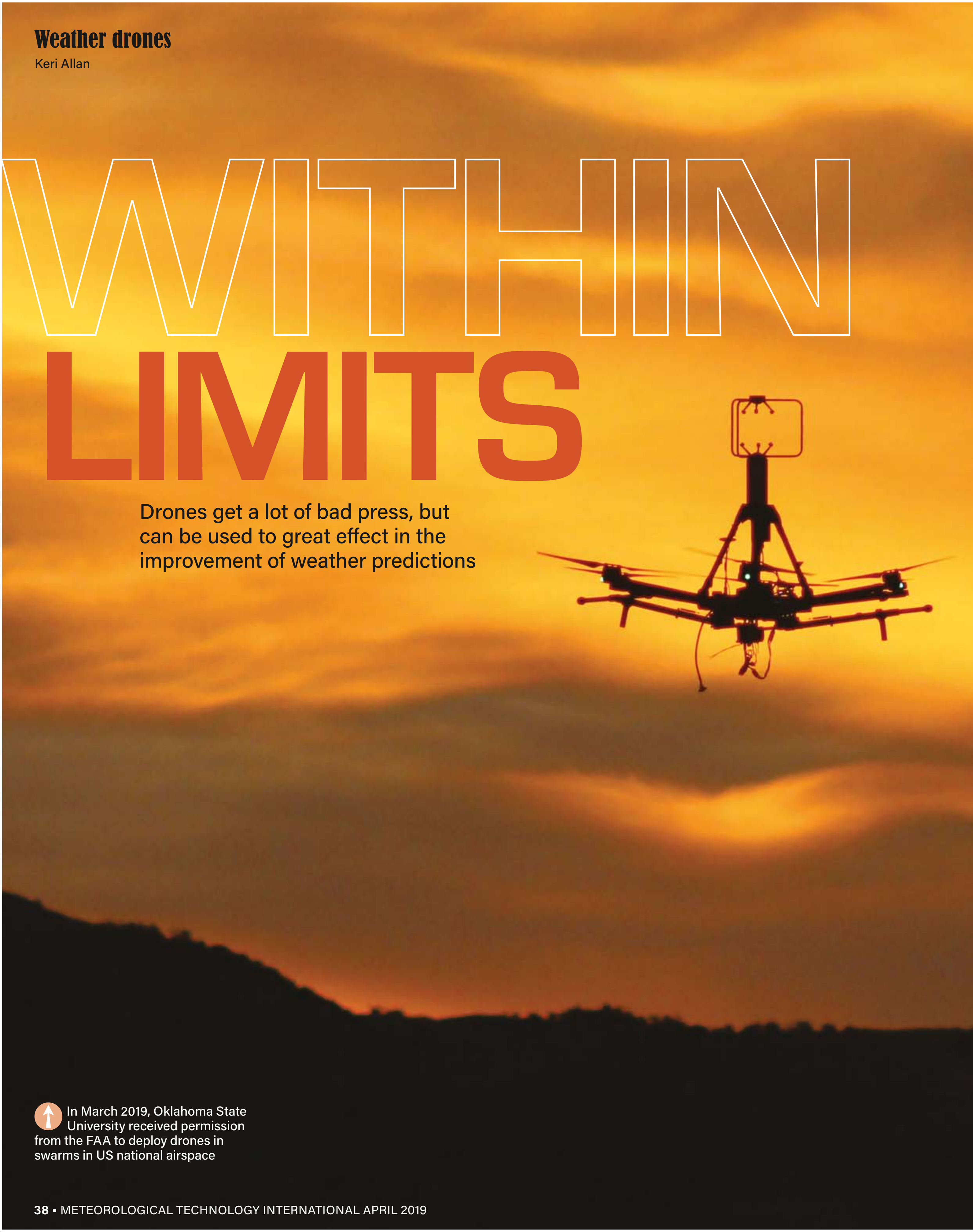
Keri Allan

WITHIN LIMITS

Drones get a lot of bad press, but can be used to great effect in the improvement of weather predictions



In March 2019, Oklahoma State University received permission from the FAA to deploy drones in swarms in US national airspace

The benefits of using unmanned aerial vehicles (UAVs) in meteorological research are numerous. Not only are they cheaper to use than traditional manned aircraft, they can also fly at extremely low altitudes and get to places that manned vehicles cannot safely reach – such as tornadoes, hurricanes or volcanic ash clouds.

Unlike weather balloons they can be reused, and sensors can be added that would be too expensive to use on a one-use balloon-based system. UAVs are also more flexible in the areas they can cover, unlike masts or towers.

"Meteorological masts are very inflexible things. With small unmanned aircraft you're not restricted to one location so can get a lot of insight into the underlying processes that are important to handle, describe and model correctly," says Prof. Joachim Reuder, deputy head of the University of Bergen's Geophysical Institute in Norway.

ATMOSPHERIC BOUNDARY LAYER

Research into the atmospheric boundary layer (ABL) has particularly benefited from the use of UAVs. The ABL is usually in a turbulent state and reacts to changes in surface conditions quickly, making it difficult to characterize experimentally and model numerically. More detailed data is needed to lower degrees of uncertainty and provide better estimations of the processes taking place to improve weather models.

"We've always had problems describing what's happening near to the ground. With balloons, you're already 100m (330ft) up after just two seconds. The solution had always been to make taller towers, but this isn't something that's easy to put up, nor can you move it around," says Richard H Grant, professor of applied meteorology at Purdue University, in Indiana, USA.

"This is a great opportunity to use UAVs to get a handle on what's going on. For example, the work I've been involved in focuses on the transition from day to night – there's a lot of unknowns about the changes that occur between our daytime and night-time conditions," he says.

Many research projects are currently underway in this area, including work undertaken at the National Oceanic and

Scientists from the University of Oklahoma operating the CopterSonde UAS during the ISOBAR field campaign led by the University of Bergen. Image: Joachim Reuder, UiB

Atmospheric Administration (NOAA). Dr C Bruce Baker, director of the Atmospheric Turbulence and Diffusion Division of NOAA's Air Resources Laboratory, believes that this will help us get a much better snapshot of what our atmosphere is doing.

"We're missing this big gap as right now we're just releasing two weather balloons per day in certain areas and measuring data from static 10m [33ft] towers. Think of it like a movie – we're trying to work out what's going on by just looking at a couple of frames. With unmanned aerial systems [UASs] we can go up more frequently, say every hour, and figure out much more of what the movie's trying to tell us. We can see what's happening more frequently but also in multiple places, which will provide major improvements in weather forecasting," comments Baker.

A great example of this comes from the 2018 International Society for Atmospheric Research using Remotely piloted Aircraft (ISARRA) conference, where the world's largest unmanned aircraft campaign took place (see sidebar, *Introducing ISARRA*).

"During a post-conference flight week, around 70 different aircraft performed more than 200 flights to investigate boundary layer processes in an alpine valley in the Rocky Mountains," says the University of Bergen's Reuder. "This type of coordinated UAV operation, using swarms or flocks of UAVs, will be a very big thing in the future."

ARCTIC RESEARCH

ABL projects are taking place around the world. For example, the University of Bergen's ISOBAR project focuses on increasing our knowledge of the ABL in the arctic region by studying the physical processes governing the turbulent exchange under stable conditions. Today, these are not well presented in weather prediction models due to a lack of appropriate understanding and thus parameterization of the stable boundary layer and researchers have been using a suite of RPAS with different measurement systems to gather important meteorological information.

These included a multipurpose atmospheric sensor carrier that is being used for long-range horizontal turbulence measurements, an advanced mission and operation research multicopter for vertical profiles of the surface layer and fixed location measurements, and also a small unmanned

Prof. Joachim Reuder, deputy head of the University of Bergen's Geophysical Institute in Norway

The small unmanned meteorological observer (SUMO) measures profiles of temperature, humidity, wind and atmospheric turbulence. Image: UiB

meteorological observer (SUMO) for turbulence profiles and vertical profiles.

SUMO

Originally developed as a controllable and recoverable radiosonde for high-resolution measurements in the ABL, SUMO was developed by the University of Bergen's Geophysical Institute with the Paparazzi open-source hardware and software project for UAVs. It has become a new standard for researchers working in this field.

Based on Multiplex's Funjet model construction kit, the aircraft has a length and wingspan of 80cm (31in) and an overall take-off weight of approximately 600g (1.3 lb). It can measure air temperature, humidity and pressure, as well as the surface temperature based on IR emission, with a temporal resolution of 2Hz and windspeed and direction determined by a no-flow sensor algorithm based on the GPS speed given by the autopilot.

"The autopilot – Paparazzi – is freely available and hosted on the website of France's École Nationale de l'Aviation Civille. It's now being used by hundreds of researchers around the world and everything you need to know about building your own SUMO is available online," says Reuder.

The low-cost UAV used as part of the Cloud-Map project

Cloud-Map focuses on the development of UAVs and their integration with sensors for meteorology and atmospheric physics

STORM PREDICTION

Research is underway to improve predictions of where and when storms will develop. During the NOAA project Verification of the Origins of Rotation in Tornadoes EXperiment-Southeast (VORTEX-SE), Baker's team found UAVs useful.

"An infrared camera on the copter showed us how hot the surface was in a very specific region. We were able to start learning how the differential heating between the hot and cold spots would generate circulation, which could contribute to the generation of severe storms as a front went through," he explains.

The Cloud-Map project has seen researchers from the Universities of Oklahoma, Kentucky, Nebraska and Oklahoma State University incorporate sensing technologies they've developed into one low-cost UAV. Running for the past three years, the project is collecting data at low altitudes where severe storms begin their development through convective initiation.

"Data from these lower altitudes might provide insight into the formation of severe storms and allow us to create 3D weather forecasts at the mesoscale level with greater accuracy than currently," says Jamey D Jacob, director of Oklahoma State University's Unmanned Systems Research Institute. "Using both rotary-wing and fixed-wing systems, we've been able to collect data in

Introducing ISARRA

ISARRA – the International Society for Atmospheric Research using Remotely piloted Aircraft – is a member-based, non-profit society, developed to support collaboration and knowledge-sharing between scientists and academics working in the UAVs field.

It was created when a five-year EU-funded unmanned aerial systems in atmospheric research COST (European Cooperation in Science and Technology) project came to an end in 2013.

"The COST project gave us a certain amount of money each year to organize meetings, workshops and conferences in order to exchange information and define what would be necessary to move forward," says Prof. Joachim Reuder.

"When it came to an end, all of those involved – both individuals and institutions – realized it would be a shame to throw this away and so we looked into a way to keep it alive, and also expand out to include the USA, where a lot of work around UAVs in meteorological research was taking place. So, we created ISARRA, an international society with no membership fees."

ISARRA holds an annual conference that brings people together to discuss issues related to the field, everything from technical and regulatory issues through to new technologies and flight strategies, and of course a lot of interesting science. "It's an extremely collaborative and important environment," comments Reuder. "I believe that UAVs are useful tools for atmospheric science today and I foresee that they will revolutionize our observational capabilities as satellites did 30 to 40 years ago. Thanks to UAVs, we now have the opportunity to validate the operational weather forecast models that are now using a typical horizontal resolution of a few kilometers," he adds.

UAV flight testing using a rotocopter equipped with meteorological sensors as part of the Cloud-Map project

"Eventually I think all airborne measurements will be made using UAVs"

Jamey D Jacob, director, Unmanned Systems Research Institute, Oklahoma State University

conditions that are difficult or impossible for traditional systems, including high winds and ahead of storms. The goal is to provide the capability to improve timing and accuracy of severe storm predictions and 'warn-on-forecast'. We've flown higher and farther than we thought possible at this stage and in more drastic weather conditions. But we still have a long way to go to ensure the data we have is accurate and delivered in a timely fashion to forecasters," he adds.

The Cloud-Map project has also looked at the role of infrasound in storm prediction. Infrasound can be detected in excess of 100 miles (160km) and is focused at ground level downstream of a storm. In addition, infrasound from tornado-producing severe storms has been detected in excess of an hour before the tornado touches down. "This makes it a potentially valuable tool for directing UAVs to potential severe storm locations before they occur," Jacob notes.

PERMISSION TO FLY

Clearly, weather forecast models can benefit from research currently being undertaken by scientists using UAVs, but these projects face their own specific challenges, the biggest of which involves navigating flight permissions and restrictions. Reuder has experienced waits of between one month and a year and also points out that airspace regulations differ greatly from country to country.

"Disruptions like the ones that occurred at London Gatwick Airport negatively affect the relationship us scientists have built with our civil aviation authorities," he says. "It can be very challenging. On a few campaigns, obtaining permission was so difficult that we decided to use a manned aircraft instead, just so we could go ahead with the project."

Work, however, is underway to show that UASs can be operated safely beyond visual range in order to obtain approval to fly drones as high as 10,000ft.

This March, NOAA undertook a field study at Avon Park Air Force Range in Florida, USA. Inside military airspace, researchers were allowed to fly two UASs – a copter and fixed-wing aircraft – to their maximum flight altitudes of approximately 5,000ft. Knowing each aircraft's upper limit and the point at which the operator will lose visual line-of-sight will help improve future flight safety, plus NOAA used this opportunity to test UASs' detection systems and capabilities.

"One of the technological challenges is that UASs are currently unable to detect other things in the air," comments Capt. Philip Hall, director of NOAA's Unmanned Aircraft Systems Program. "Several ideas have been proposed to overcome this such as ground-based radar, and we're looking into a few different ideas, including a detection system installed on the 'bird' itself."

Much of the work around UAVs for weather prediction is still in the research phase – in terms of both the data gathered and airspace safety. Work may still be needed to ensure UAVs gain access to all airspace, and that systems are ready to be fully operational, but eventually, scientists are confident that UAVs will be the go-to devices for ABL and other upper-air meteorological research: "Eventually I think all airborne measurements will be made using UAVs," Jacob concludes. ∎

Wind power

UASs have an integral role to play for renewable wind energy, as data collected by them can help energy companies decide where best to place a wind farm and how turbines should be distributed.

A research collaboration between NORCE, the University of Stavanger, the Geophysical Institute at the University of Bergen and Equinor has been looking into the way that wind behaves offshore, deploying a triangle of three scanning lidar systems. However, the Geophysical Institute's Prof. Joachim Reuder believes that UAVs could also be very useful in collecting data in this area. "Turbines are getting larger and larger – the latest from GE has a blade length of 107m [351ft] so this turbine reaches 250m [820ft] into the atmosphere when installed.

"We have very few measurements at this altitude from a 250-300m high [820-980ft] meteorological mast, so, in these conditions, a UAV is perfect for looking at windshear and average windspeed – but also coherence. This is important information for the design and operation of wind turbines as the turbulence determines loads and fatigue on the turbine blades – and therefore the lifetime of a wind turbine.

"This is a area I'm seeing a lot of development in, especially in the field of direct turbulence measurements from multirotor UAVs," adds Reuder.

Image: Jesper Jensen