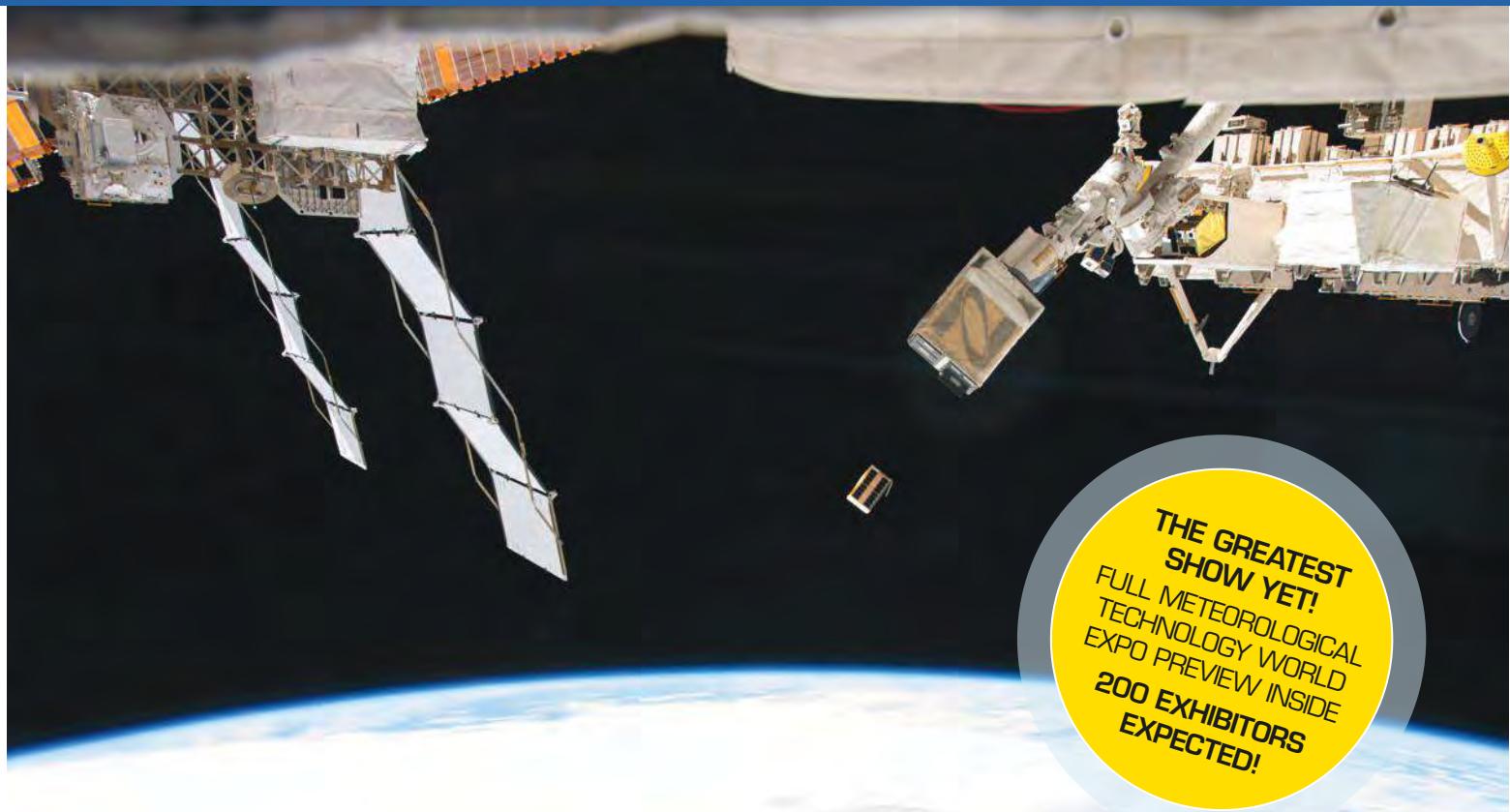


Meteorological

TECHNOLOGY INTERNATIONAL



CUBESATS

Do these miniaturized satellites hold the key to the future of space-based weather prediction?



DROUGHT

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



EUMETSAT

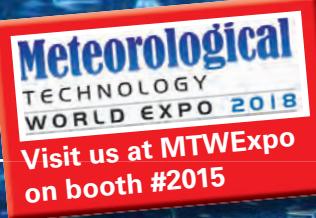
The intergovernmental organization looks to the future following the successful launch of its final Copernicus Sentinel satellite

The Right Measuring Principle for Every Requirement

The OTT HydroMet Precipitation Sensors



a passion for precision · passion pour la précision · pasión por la precisión · passione per la precisione · a



Lufft WS100

- Maintenance-free, non-catching and life-time calibrated Radar Precipitation Sensor
- Hydrometeor velocity measurement and size correlation for Precipitation intensity, type and Drop Size Distribution
- Real time measurement for intensity range from 0.01 to 200 mm/h for liquid and solid precipitation



OTT WAD

- Self-emptying weighing Precipitation Sensor based on tipping bucket method
- Catching instrument with 200 and 314 cm² orifice for precipitation intensity and amount
- High accuracy of ±3% on measurements with linear and real-time characteristics for intensity range from 0.001 to 720 mm/h for liquid precipitation in subtropics and tropical climate zones



OTT Pluvio²

- Weighing precipitation sensor with collecting bucket
- Used as a worldwide standard by national weather services and Environment Agencies in countries of Northern hemisphere for liquid and solid precipitation monitoring
- Life-time calibrated and low total costs of ownership to provide 99% data availability
- High sensitivity and accuracy of ±1% on measurements over the entire intensity range of 0.05 to 3,000 mm/h with linear and real-time characteristics



OTT Parsivel²

- Laser-based premium Disdrometer for simultaneous measurement of hydrometeor sizes and velocities
- Power-saving, maintenance-free and non-catching
- Provides completely processed real-time information on liquid and solid precipitation in terms of intensity, amount, type, kinetic precipitation energy, radar reflectivity, visibility and drop size distribution (32 classes)
- High accuracy of ±5% for liquid precipitation over the entire intensity range of 0.001 to 1,200 mm/h

Precipitation sensors

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

 Antarctic precipitation system, including a particle size measurement sensor and an elevated, screen-protected Pluvio[®] precipitation gauge



SENSOR EVOLUTION

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

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

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

Operating on a different system, the OTT Pluvio² series, launched in 2007, weighs collected precipitation and records the data. This provides

a solution that is precise at a comparably high resolution, has a low total cost of ownership and consumes little power, especially when using an anti-freeze agent instead of a heater. The OTT Pluvio² series has been selected by numerous national weather services in countries in the northern hemisphere as the standard instrument for liquid and solid precipitation monitoring. There are no losses from evaporation, as can happen with heated TBRG systems, and the system is linear with specified accuracy for the entire intensity range up to 3,000mm/h.

Because of its advantages, the OTT Pluvio² series was particularly well suited for deployment at the McMurdo Station in Antarctica, where researchers from the University of Colorado Boulder, and the US National Center for Atmospheric Research are investigating methods to measure accumulating snowfall. These measurements are important to better understand the potential for rising sea levels caused by climate change. Measuring snowfall in the Antarctic is particularly challenging due to the difficulty of distinguishing between falling and blowing snow.

To help achieve their objectives, the team deployed a tailor-made Antarctic precipitation system (APS), which includes a particle size measurement sensor and an elevated (3.5m [11.5ft]) screen-protected OTT Pluvio² precipitation gauge. The APS also recorded measurements for temperature, windspeed and accumulating snow height. Four APS stations have been set up in Antarctica in a project lasting two years.

OPTICAL SENSORS

Optical non-catching sensors such as the laser-based OTT Parsivel² approach new levels of liquid and solid precipitation monitoring by providing the complete scope of measurements in real time within a measuring range of 0.001mm/h to 1,200mm/h. Launched in 2006, the OTT Parsivel² simultaneously measures the amount,

size and speed of particles and distinguishes precipitation types.

Its outstanding measuring performance and accuracy of $\pm 5\%$ for liquid precipitation make the Parsivel² an ideal accompaniment for weather radars. It is maintenance-free, WMO compliant and now available with heated screens. Its high spatial and temporal resolution helps to improve quantitative precipitation estimation (QPE). It is highly suitable for weather radar calibration, delivering complete information about a precipitation event and processing it as a drop size distribution (DSD) matrix. Moreover it issues calculated parameters as comprehensive statistical DSD data and informs about radar reflectivity. A network of 12 Parsivel² sensors and OTT dataloggers, was recently deployed for the Space Applications Centre in Ahmedabad, India.

RADAR PRECIPITATION SENSORS

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

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



Left to right: The Parsivel² optical disdrometer, Pluvio² S weighing precipitation gauge, OTT WAD 200, and the WS100 radar precipitation sensor

New smart solution for UV measurement

- For every part of the UV spectrum
- State-of-the-art detector technology
- Improved performance at a lower price

The new SUV series offer a measurement solution for every part of the UV spectrum; UVA, UVB, UVE and total UV. The re-engineered design is smarter than alternatives thanks to its Modbus output, the latest detector technology and the corrected data option with UVIATOR software.



Visit booth 9005 at Meteorological Technology World Expo to get the latest information.

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Surface energy measurements

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

STATE OF FLUX

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





Extra Large Aperture
Scintillometer with
GPS receiver

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

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

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

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

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

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

Traditionally, the method for obtaining accurate surface heat fluxes has been the

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

LARGE APERTURE SCINTILLOMETER

An alternative method for continuously monitoring the surface energy balance is based on a Large Aperture Scintillometer (LAS). A transmitter and receiver are placed at opposite ends of a path ranging from 100m up to several kilometers. The transmitter emits a beam of pulsed near-infrared radiation, which is detected by the receiver. Heat fluxes cause variations of temperature and water vapor concentration that create turbulent eddies in the atmosphere, which refract and scatter the transmitted radiation. The receiver detects these intensity variations of the beam, which are proportional to small changes in the refractive index of air (C_n^2). Such an instrument is the Kipp & Zonen LAS MkII.

To derive the sensible heat flux, H , the Monin-Obukhov Similarity Theory (MOST) is applied. This is done by combining the C_n^2 measurement from the scintillometer with time-coherent local measurements of ambient temperature, pressure and windspeed and applying algorithms to process the data in real time.

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

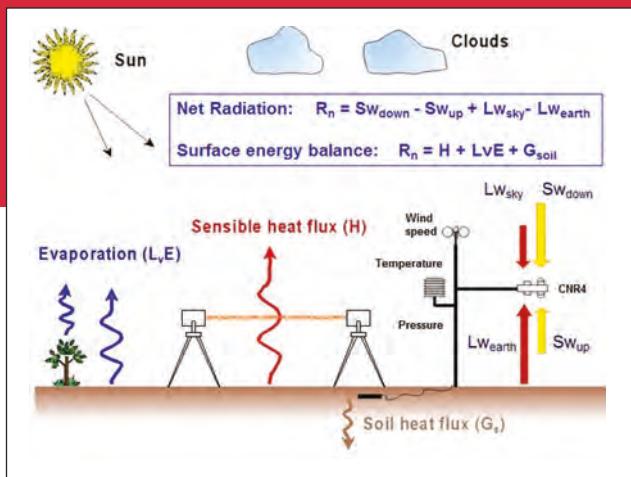
Given these measurements we can calculate LvE as the unknown factor that completes the surface energy balance. This closure of the equation is often not achievable with the eddy covariance technique. A major advantage of an LAS system is that it yields the average fluxes over a large integrated footprint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

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

Surface energy measurements

Extra Large Aperture Scintillometer and microwave scintillometer measuring over wetlands

Figure 1: Components of the surface energy balance



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

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

Keeping the optical surfaces clear is important for good measurements and a built-in window heater system ensures proper operation under most weather conditions. It is critical that the internal optics and external beam stay optimally aligned, so the housings and adjustable mountings must remain stable after installation. The LAS MkII is all-aluminum and so was the larger X-LAS

MkI, which as a result was heavy and difficult to handle. To reduce size and weight, while maintaining rigidity and optical alignment, the new X-LAS MkII has a unique tapered carbon-fiber enclosure. Scintillometers are often moved during field campaigns and the Kipp & Zonen models pack into easily handled rugged transport cases. To make setup on site quick and easy they can be installed and configured using a built-in display and keypad, without the need for laptops or software. Internal digital processing automatically computes all the relevant parameters, such as $Cn2$ and H . Real-time data is available on the display, so you know the status of your experiment in seconds.

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

TRIED AND TESTED

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

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

the Kipp & Zonen factory and the 90m (295ft) top of a building at the Technical University of Delft, Netherlands.

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

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

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

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

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

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

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