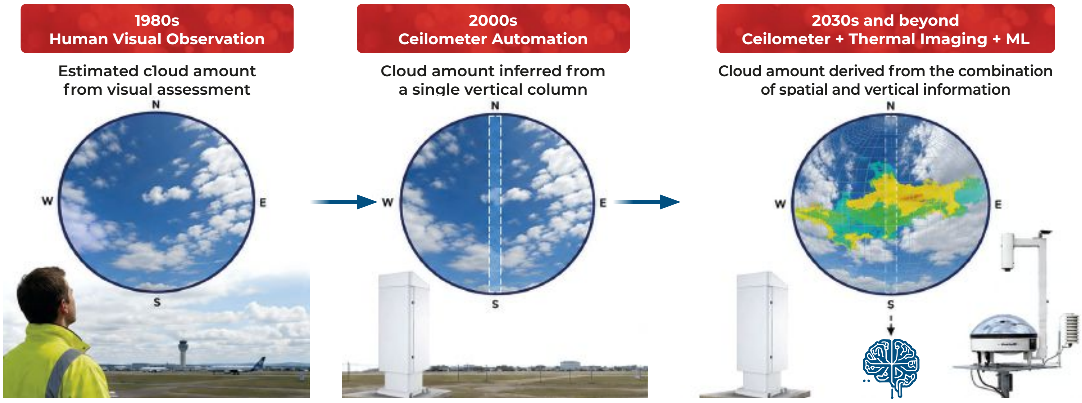
Dr Laurent Sauvage, senior advisor, meteorology and aviation safety, Reuniwatt



Beyond the vertical

Reuniwatt explores how thermal hemispheric imaging, sensor fusion and machine learning are shaping the next generation of airport weather observation systems

Airport weather observation has been evolving toward automation for more than four decades. Nowadays, automatic weather stations assist human observers, with laser ceilometers as the reference for cloud-base measurements, and automated METAR generation maturing worldwide (Figure 1).

The operational context has also changed. Air traffic continues to grow, but environmental constraints and infrastructure costs make new runways difficult. The challenge is no longer to expand infrastructure but to increase existing airport capacity. In parallel, digital and automated ATM systems are turning airports into data-driven ecosystems.

Meteorological observations no longer only produce routine reports. They provide continuous environmental awareness for operational decision-making. As movements become more frequent and margins decrease, representativeness becomes as important as accuracy. But can tomorrow's airport weather systems continue to rely on instruments that observe only a tiny fraction of the sky?

ABOVE: Figure 1 – Evolution of cloud amount observation. The thermal hemispherical imagery brings the missing spatial information to single point measurement of ceilometers

A cloud is not a point

Among aviation weather parameters, cloud amount remains difficult to automate. Cloud-base height and cloud amount appear together in every METAR, yet they are fundamentally different: cloud-base height is measured; cloud amount is observed or inferred from point measurement.

A laser ceilometer determines cloud-base altitude with exceptional precision by analyzing the atmospheric column above the instrument. ICAO-compliant systems rightly rely on this reference. Cloud amount, however, is a spatial quantity. The METAR descriptors FEW, SCT, BKN and OVC refer to the fraction of sky covered by clouds over an airport.

Current auto METAR systems estimate this spatial quantity from successive measurements along a single vertical laser beam as clouds drift overhead. This has demonstrated useful operational performance but remains a statistical point-observation interpretation of a rapidly changing spatial phenomenon. The challenge is therefore no longer sensor accuracy – it is observation geometry.

Adding more necessary dimensions

Hemispheric imagers provide information that no vertical profiler can measure directly: the spatial distribution of clouds across the entire sky, with resolved information at each elevation and azimuth.

Visible-light all-sky cameras have shown their value, but performance is constrained by illumination changes, solar glare, twilight transitions and reduced night capability. Thermal infrared imaging changes this paradigm. Instead of observing reflected sunlight, calibrated thermal imagers measure infrared radiance emitted by clouds and the atmosphere, providing continuous day and night observations.

More importantly, a calibrated thermal imager, such as the Sky InSight thermal all-sky imager developed by Reuniwatt (Figure 2), should not simply be regarded as a camera. It is a passive hemispheric radiometer. Each pixel corresponds to a quantitative radiance measurement.

Beyond imaging: a radiometric measurement

Radiometric calibration unlocks one of the least appreciated capabilities of thermal imaging. Because atmospheric temperature generally decreases with altitude, cloud brightness temperatures indicate the approximate altitude of different cloud layers, enabling first-order estimation of cloud-layer altitude across the complete hemisphere.

This does not match the vertical precision of a laser ceilometer, but it restores the spatial dimension missing from point observations, naturally complementing the strengths of ceilometers.

Combining complementary observations

The future of airport cloud observation is unlikely to rely on a single breakthrough sensor. It will emerge from combining complementary observing geometries. The ceilometer provides accurate cloud-base measurements along its vertical beam. The thermal hemispheric radiometer maps cloud fraction while estimating cloud-layer altitude over the entire sky.

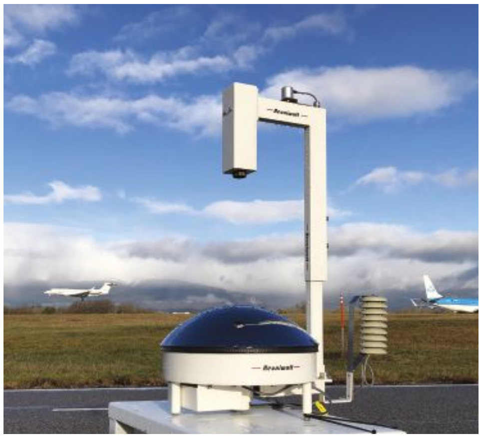
Machine-learning algorithms can associate hemispheric cloud structures with ceilometer cloud-base heights, reconstructing a more representative description of the atmosphere than either instrument can provide independently. This approach enhances existing observation chains, including regional airports with earlier generations of ceilometers, without changing their basic architecture.

Validation campaign at Geneva Airport

Sensor fusion offers an elegant solution to cloud representativeness. But does it deliver measurable real improvements? To answer this, Reuniwatt conducted an evaluation campaign at Geneva Airport between December 2019 and August 2020.

The team investigated whether hemispheric thermal observations could complement automatic METAR outputs from Ampycloud, a MeteoSwiss algorithm based on ceilometer data analysis.

They combined the calibrated thermal observations produced by the Sky InSight imager with the cloud-layer output generated by Ampycloud, using a physics-determined artificial neural network (ANN) specifically designed for the estimation of cloud amount. The operational METAR produced by certified human observers served as the reference dataset. The neural network learned the relationship between the hemispheric distribution of clouds, the vertical cloud-base measurements provided by the ceilometer and the cloud amount reported by experienced observers under a broad range of meteorological conditions.



ABOVE: Figure 2 – Sky InSight is the first all-sky imager to use an infrared camera for observing the atmosphere both day and night

BELOW: Figure 3 – Sequences of thermal images allow detection and tracking of clouds all around an airport. They enhance the capacity of weather observations from a reporting system into a predictive-support capability

The results demonstrated a significant improvement in automatic cloud amount estimation. Compared with the operational METAR reference, the fused sensor system achieved 97.7% agreement within ±1 okta, outperforming the ceilometer-only approach while preserving the robustness of the existing Ampycloud processing chain.

These results demonstrate that thermal hemispheric imaging contributes information that is genuinely complementary to point measurements. Its value lies in restoring the spatial representativeness required for reliable automated estimation of cloud amount in certain weather conditions.

From observation to prediction

Continuous hemispheric observations create opportunities extending well beyond automated generation of METAR. Because the complete sky is observed every 30 seconds, successive images naturally contain information on cloud displacement, growth and dissipation. Optical-flow techniques and machine-learning algorithms can derive cloud motion vectors and predict the future position of cloud fields several minutes ahead. Recent nowcasting tools, such as the ones used by Reuniwatt, illustrate how high-frequency thermal observations can be transformed into short-term forecasts of cloud evolution.

These forecasts usually cover only the next minutes, matching airport decision-making timescales. Knowing that a broken cloud layer will reach the approach path in five minutes is often more valuable than simply describing current conditions. Continuous hemispheric monitoring therefore transforms weather observation into tactical weather intelligence.

Toward airport weather intelligence

Future airport weather systems will not simply report atmospheric conditions – they will continuously reconstruct them. Laser ceilometers, calibrated thermal hemispheric radiometers, visibility sensors, numerical weather prediction, radar observations and machine learning will progressively contribute to a dynamic digital representation of the atmosphere above the airports.

Tomorrow's systems will not simply imitate human observers. They will observe the atmosphere in ways and at a frequency that humans never could. The future of airport weather will be defined by the intelligent fusion of complementary observations into a continuously updated digital twin of the airport sky. ∎