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CLOUDS are coming

Reuniwatt's new thermal all-sky imager has demonstrated its capacity for accurate weather and cloud cover analysis at airports, helping to improve aviation safety

The multiplication of severe weather events is no small challenge for air traffic management. Some meteorological conditions, such as condensation clouds, wind, fog, rain, extremely cold temperatures and lightning, can have a huge impact on airport operations. For controllers to exercise their expertise, they must maintain awareness of the adverse weather location and its evolution (laterally and vertically).

Detecting and characterizing clouds is an essential step toward taking the right decisions in traditional air traffic scenarios, particularly during the critical phases of taking off and landing, and also for the application of unmanned aircraft such as maintenance drones on the airport premises. Furthermore, small and medium-size airports do not always have continuous staffing to make observations, especially at night. Some cannot even afford to have an automated weather observing system (AWOS) on-site.

Therefore, the use of thermal all-sky imagers is key to improving the potential of remote towers and the creation of autoMETAR – automated meteorological aerodrome reports – in the near future. At a reasonable price, they could greatly enhance the capacity to mitigate risks.

Typical observation and forecasting instruments for aviation include ceilometers, pyrgeometers and pyranometers. They offer improved and continuous capacity compared with human observers, deliver valuable information and are indispensable for the implementation of remote and virtual towers.

However, infrared all-sky imagers such as Reuniwatt's Sky InSight can provide more spatially resolved descriptions of the cloud cover, both day and night, and will improve the capabilities of airport weather stations.

Comparing cloud cover measurement techniques

Several candidates for cloud cover retrieval are available: zenith pointing ceilometers, all-sky imagers, radiometers and scanning lidars.

Ceilometers accurately measure the ceiling or base height of cloud layers, and leverage pulsed-diode lidar technology and single-lens optics. They are engineered to deliver highly accurate data on the altitude of multiple cloud layers, right above their location. They are also used to estimate a cloud amount for each layer

Figure 1: Reuniwatt's full-sky thermal imager Sky InSight deployed in Boulder, Colorado, next to a ceilometer and other radiometric instruments operated by NOAA's SURFRAD Network

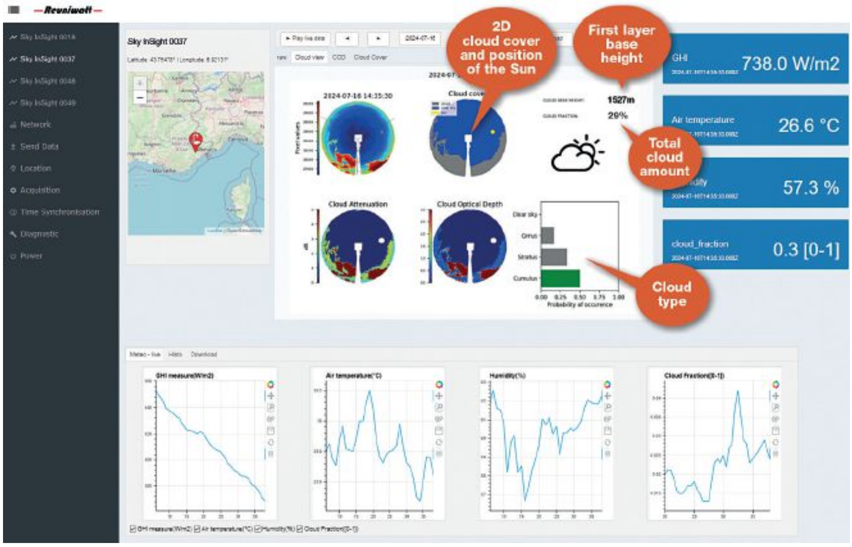


Figure 2: Web portal for an access to multiple Sky InSight imagers, providing the necessary cloud information every 30 seconds: 2D cloud position; total cloud amount; cloud type; 2D optical depth; and local temperature, humidity and irradiance data

detected by the instrument using a 30-minute time-weighted average method. This measurement, used at airports, is limited by partial clouds passing just above the instrument and do not represent the full cloud amount that must be reported from the observation site.

Precision infrared radiometers are intended for the measurement of down- and up-welling longwave irradiance. It has been demonstrated that they may provide cloud cover information from their global integrated measurement of the full-sky irradiance, even though some limitations can appear, as described later.

Scanning Doppler lidars are primarily used to measure mean wind quantities, but ancillary information about cloud coverage and cloud base height can also be obtained using strong backscattering signal from clouds. However, these systems are rather expensive and need specific conditions for siting. Infrared all-sky imagers, such as the patented Sky InSight, can provide continuous two-dimensional tracking and forecasting of the cloud cover. The use of the IR technology enables unprecedented accuracy for day and night cloud detection. It catches additional information on the cloud ceiling and anticipates cloud cover from any direction. The information provided can include cloud fraction and cloud classification (Figure 2), as well as a full panoramic view in some cases.

Finally, sequences of images taken every 30≈seconds give the observers and controllers information on cloud towering at far distances and allow them to assess whether this will become hazardous for the airport. This ability to predict the arrival of a hazard enables local or remote forecasters and controllers to make reports and prepare effectively for a change in the traffic configuration at their airports.

Around-the-clock 360° cloud fraction

Reuniwatt has led an extensive study to compare the total cloud amount retrieved from different instruments during two case studies at a NOAA site in Boulder, Colorado. While ceilometers and pyrgeometers point only in an upward direction, the Sky InSight enables enhanced observation thanks to its 360° vision per image (Figure 3).

Based on a statistical analysis, Reuniwatt concluded that, overall, cross-instrument accuracies among all methods range between 70% and 75%, primarily due to the prevalence of clear sky or overcast conditions, which are the most beneficial situations for ceilometers and pyrgeometer techniques.

When we take a closer look at partial cloud cover cases (2-6 oktas), cross-instrument accuracies drop to 25-46%, with the ceilometer showing the largest divergence while the camera and radiometers tend to offer similar results more often. The camera emulation of a ceilometer significantly improves 'agreement' between the two instruments, suggesting that 33% of the ceilometer's variance is due to the reduced field-of-view and averaging window.

The analysis of several edge cases enables a better understanding of the discrepancies due to optical and radiative cloud properties (Figure 4). Both the ceilometer and the Sky InSight measure cloud blockage in a binary way, regardless of cloud microphysics properties. The pyrgeometer, however, produces a cloud cover estimate that is weighed by the average cloud thermal emissions relative to the clear sky.

This phenomenon is visible in Figure 4, Case 1 (*overleaf*), an overcast sky configuration where a significant portion of thin clouds is visible on the infrared camera image and on the laser signal. The pyrgeometer's retrieved measurements indicate a cloud cover of 4 oktas while the other instruments lean toward the reality of an almost fully overcast sky.

Case 2, a partially covered sky configuration, showcases the limitations of the ceilometer's restricted field-of-view and reliance on

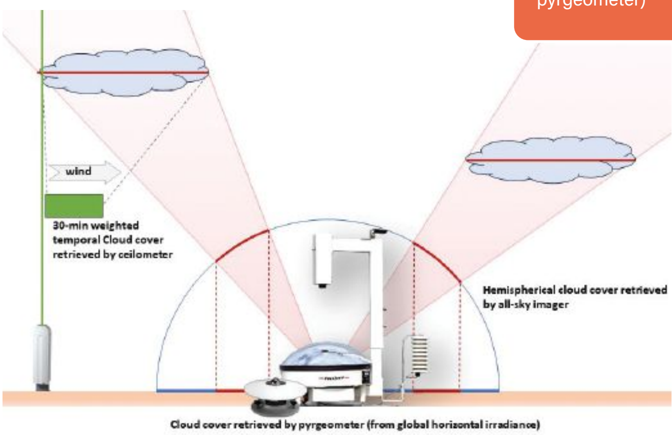
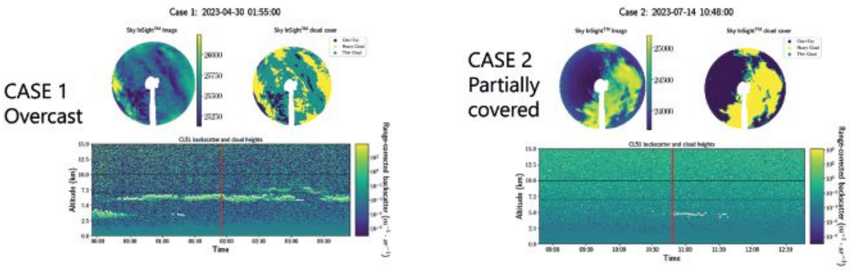


Figure 3: Sky conditions observed by various instruments (Sky InSight, ceilometer, pyrgeometer)



Method	Case 1	Case 2
Eppley PIR	4	7
CL51 (Ceilometer)	8	0
Sky InSight™ (Hemispherical)	7	4
Sky InSight™ (Ground Projected)	7	4
Sky InSight™ (Ceilometer mode)	7	1

Limitation of the ceilometer in cases of partially covered skies

Figure 4: Cloud fraction measurement comparison with a ceilometer, a pyrgeometer and a Sky InSight

time-averaged series. The cloud front has only just reached the zenith and cannot yet be fully seen by the ceilometer. As visible on the infrared image, the clouds are particularly thick and highly emitting – in this case, longwave downwelling irradiance is close to that of a fully overcast sky, as is shown by the pyrgeometer's measurement, which results in an estimate of 7 oktas.

The solid angle equivalent calculated from the infrared camera data, however, only classifies it in the 4-okta range for this particular case. In this sky configuration, many discrepancies may appear either from the ceilometer or the pyrgeometer measurements. Hence, sky camera and pyrgeometer measurements are sensitive to the full whole-sky dome but they also have some limitations. The latter may underestimate cloud cover for thin overcast skies (altostratus) while the former may miss some high-altitude thin clouds.

Choosing the right pixel

Various types of all-sky imagers have been deployed all around the globe and may be used for cloud cover retrieval. Each one possesses its own mechanical-optical design and orientation once deployed at a specific site. Accurately determining which part of the sky each pixel corresponds to in terms of azimuthal and zenithal angles is essential to calculate accurate cloud products.

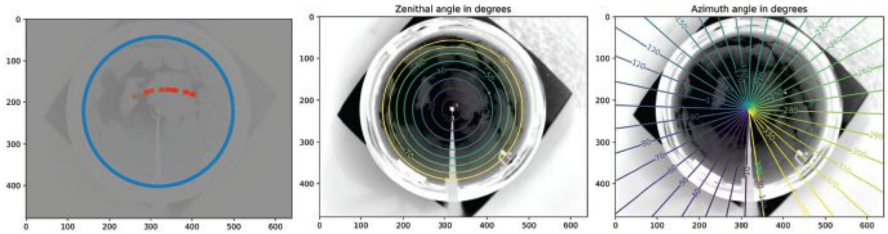


Figure 5: Reuniwatt's 2D cloud imager is tracking the sun to get an accurate position of each pixel on every single image

The imagers therefore require careful calibration to be reliable. Since 2012, Reuniwatt has made a tremendous research and development effort to develop and validate cloud detection and identification algorithms. One of the main lessons the company has learned is that precise camera calibration is key to a fine-tuned instrument.

Therefore, a geometric calibration is performed for each instrument and at each site to retrieve the optical intrinsic parameters of the sky imager. The process developed by Reuniwatt is fully automated and uses an algorithm based on the solar position captured during clear-sky days over full sun paths to adjust the pixels and provide a full calibration matrix in azimuth and elevation (Figure 5). This greatly facilitates the installation and maintenance process.

In addition to the geometric calibration, automated mask detection is performed to distinguish between informative and unusable pixels, usually due to obstructions in the field-of-view of the imager (typically obstacles or rain droplets).

Extending the coverage

A major advantage of the installation of a Sky InSight is its 360° view, covering the entire airport area. Statistical and case study analysis suggest that ceilometer cloud cover measurements tend to miss edge clouds or holes in the cloud cover because of their narrow spatial constraints – making partial cloud cover readings less likely.

The next generation of AWOS, which will integrate more remote and accurate observations, may benefit from improvements in the evaluation of the cloud cover and cloud amount. The Sky InSight thermal all-sky imager has demonstrated its capacity for this accurate observation compared with other techniques already deployed at airports. It is the key to providing a human observation equivalent with enhanced vision, ensuring air traffic safety through the deployment of automatic digital tools.

Reuniwatt has deployed a large worldwide fleet of all-sky imagers, leading to strong real-time data acquisition and post-processing experience. The company's value offer is evolving thanks to clients' valuable feedback, and it will soon be ready to offer Data as a Service (DaaS) solutions to interested parties. Deploying the thermal imagers at more airports and other sites may greatly enhance the capacity to deliver a large number of≈spatially resolved cloudy situations on a full territory. National met agencies that could assimilate part of this information and satellite validation approach may benefit from such literal ground truth. ■