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DISCOVER THE SKY

A thermal infrared imager enables airports to obtain automatic 3D cloud mapping 24/7, improving the capacity of short-term forecasting

Observing clouds at night and getting their variability above a site is a challenge, whether it's for aviation, laser communication or meteorological purposes. The Sky InSight thermal infrared ground imager from French company Reuniwatt has been developed to fulfill these requirements.

Sky InSight was created by Reuniwatt to provide short-term irradiation forecasts of up to 30 minutes for solar energy applications. Indeed, clouds passing over a photovoltaic installation represent a threat as they can lead to an 80% drop in production levels in seconds. This is a serious issue for off-grid projects, which depend on solar energy.

Reuniwatt's engineers had first started to use visible imagers to detect passing clouds, but these instruments had limitations as they were blinded by sun glare (circumsolar effect) (Figure 4). Therefore, they designed and manufactured their own thermal infrared imager, which is impervious to such occurrences. This was necessary to initiate their nowcasting statistical models and to provide accurate states of the sky and of the solar plant's capacity up to half an hour in advance. In addition to the luminance retrieval, Sky InSight also provides a precise state of the clouds and their motion in the sky.

COMPLETE OBSERVATION PLATFORM

Sky InSight is composed of a thermal long-wave infrared (LWIR) camera core with a 640 x 480p spatial resolution. The radiation coming from the sky is reflected on a hemispherical mirror that provides a 360/180° view of the sky. Its chrome-coated surface ensures an optimal reflection of LWIR radiations. This mirror has been chosen for cost-reduction purposes as well as for a better calibration due to a lower curvature of the dome than that of a small germanium upward-looking fish-eye camera.

Humidity and temperature sensors, installed in a ventilated casing located near the camera, provide *in situ* meteorological information improving the estimation of clear atmosphere radiance. An embedded computer is used to acquire and upload the data on a server for measurement processing (Figure 2).

The LWIR atmospheric window from 8µm to 13µm is well suited for cloud observation. Cloud emission is high to present a strong contrast with a clear sky radiometric signature. A thermal infrared imager has the advantage of directly

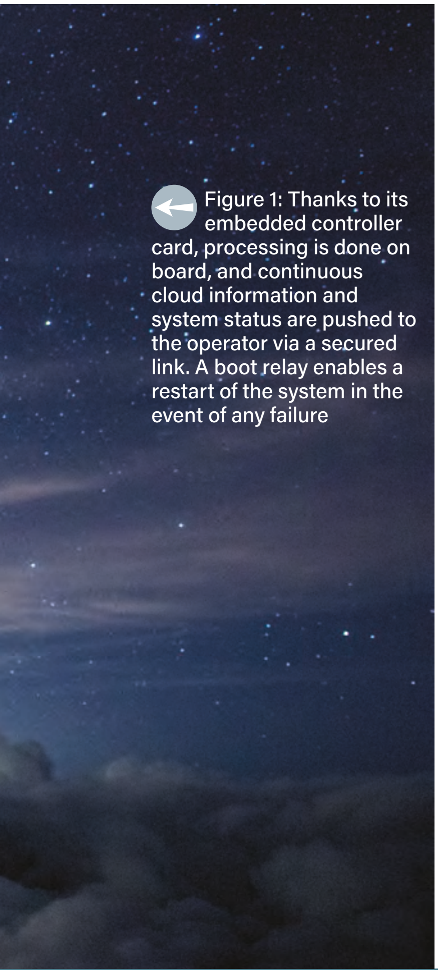


Figure 1: Thanks to its embedded controller card, processing is done on board, and continuous cloud information and system status are pushed to the operator via a secured link. A boot relay enables a restart of the system in the event of any failure

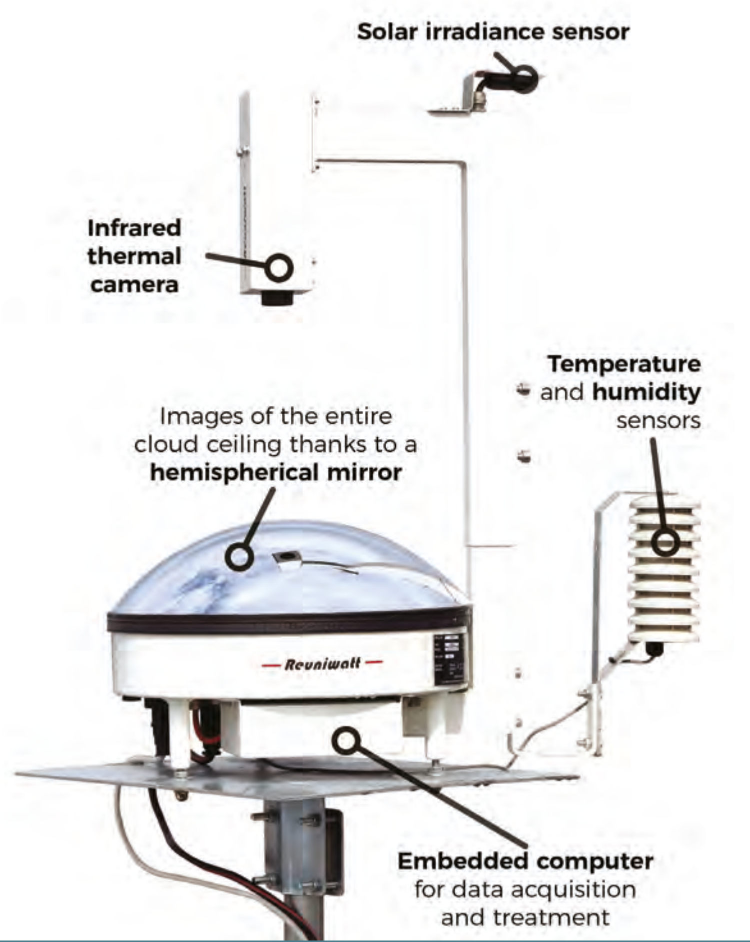
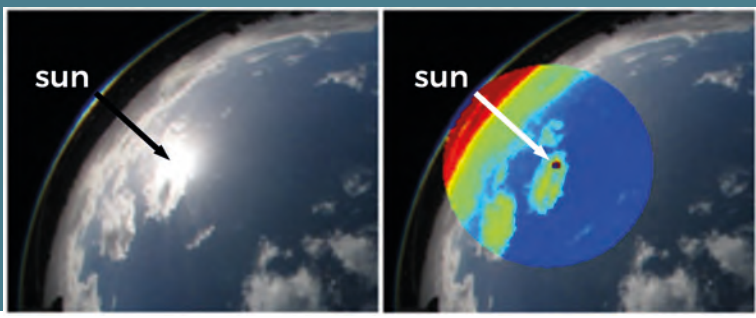


Figure 2: Reuniwatt's Sky InSight

Figure 3: The sky is reflected on the coated mirror (a). The camera measures the cloud and clear sky radiance for the entire sky (b). For further analysis, the image is carefully corrected from the mirror distortion using a precise known positioning of the sun for each pixel (c)



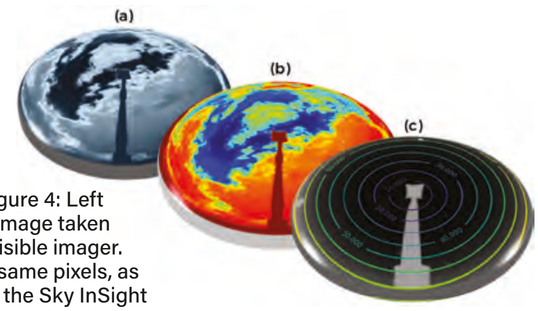


Figure 4: Left – image taken with a visible imager. Right – same pixels, as seen by the Sky InSight

detecting cloud emission rather than relying on reflected and scattered sunlight in the case of visible or near-infrared observation systems. Thus, cloud detection performance does not depend on the illumination of the cloud cover by the sun, enabling continuous night and day observation.

Benefits of using a thermal camera are particularly obvious when you look in the sun's direction. As shown in Figure 4, the pixels of visible cameras tend to be saturated, which distorts any relevant information regarding cloud presence. In contrast, Sky InSight shows a very limited saturated region.

CLOUD SEGMENTATION

Once geometrically calibrated, another challenge arises when looking at the sky with a thermal camera: atmospheric emission in the 8µm to 13µm window is sensitive to water vapor presence (Figure 3). Thus, the determination of cloud-free atmospheric emissions must be determined to consistently detect clouds with varying water vapor contents. However, the clear sky radiance is strongly correlated with the dew point at ground level and therefore can be retrieved thanks to Sky InSight's humidity and temperature sensors.

Once the clear sky radiance has been retrieved, it can be removed from the global radiance to get a residual radiance that can reveal some interesting cloud properties. The first one is cloud presence. A simple threshold on the residual radiance can detect if a cloud is on the pixel's field-of-view. Reuniwatt has validated the performance of its cloud detection algorithm with a co-located visible high-resolution sky camera where more than 2,000 pixels have been manually annotated as 'cloudy' or 'clear'. Some of the results are shown in Figure 5.

The accompanying software, working in SaaS mode and married with Sky InSight, provides a cloud image every 30 seconds (a higher rate is also possible) as well as the result of the automatic and real-time cloud fraction calculation in okta. This parameter may be pushed in the meteorological terminal air report (METAR/SPECI).

3D CLOUD MAPPING AND TRACKING

The imager's capacity for retrieving the clouds' temperature from the thermal measurements enables the Sky InSight to determine the clouds' altitude due to the

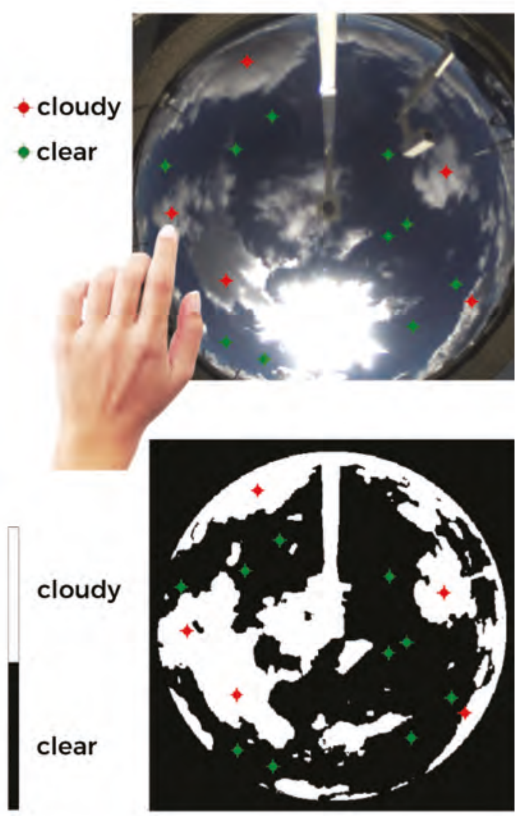


Figure 5: The Sky InSight cloud detection retrieval algorithm has been compared and validated to a standard visible camera during daylight with an atmospheric expert manual check

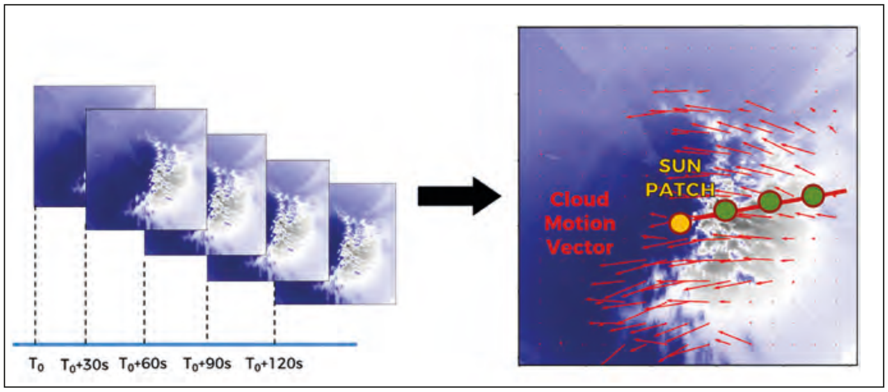


Figure 6: Using a sequence of successive images and a cloud motion vector algorithm, the Sky InSight's software is able to track the position of each cloud pixel and obtain their speed

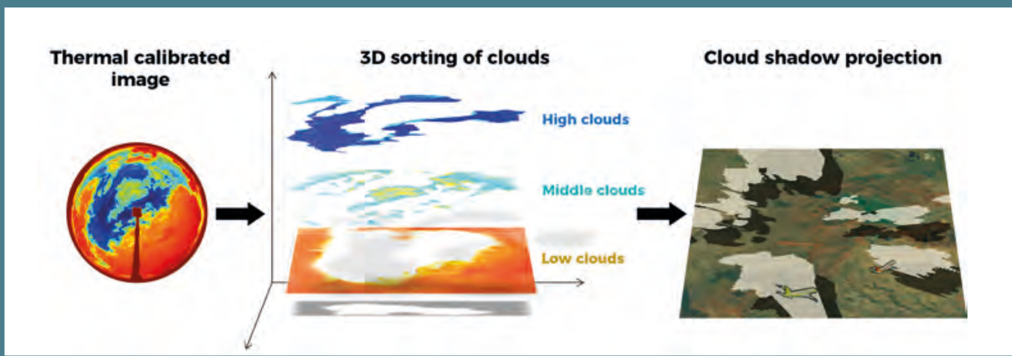


Figure 7: 3D cloud mapping processing using the Sky InSight's algorithm. The higher the clouds, the further we can detect them above the horizon, starting from a radius of a few kilometers around the site for fog and low cloud detection. Shadows can then be calculated by using the sun's known position

correlation between temperature and height. The colder the clouds, the higher they are (Figure 7). Sky InSight brings information that would require thousands of ceilometers within a 20km (12.4-mile) radius.

Reuniwatt uses the varying but well-known sun position angles during the year to calibrate them on every pixel of the image. Combined with the previously inferred cloud-base height, Reuniwatt scientists adapted a cloud motion vector algorithm (Figure 6) they had already mastered for satellite imagery and nowcasting information retrieval. This enables the system to retrieve the very small-scale motions of cloud patches and to obtain the speed of the clouds while forecasting their positions in the coming minutes. It is therefore possible to project the clouds and their cast shadows around the site of interest.

For a typical cloud-base height of 1,000m (3,300ft), Sky InSight can monitor a multi-kilometer radius region with an approximate resolution of 10m² (108ft²) at ground level. An example of cloud and shadow mapping around an aerodrome in Australia is shown in Figure 7.

On reflection, it quickly occurred to the Reuniwatt team that the Sky InSight thermal infrared ground imager could be extremely valuable for many other sectors beyond solar energy. Undeniably, clouds are not only an issue within solar projects: knowing their scope, optical depth, altitude, speed, and thus their current and future state, by day and by night, is as important for all weather, defense and space-bound applications.

Furthermore, coupling with satellite observations, even though their spatial resolution is less refined, may complete the required information. Reuniwatt is working on gathering data from both sides of the sky: below and above. ∎