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CLOUD-NET

Deliverable: 12

Recommendations for industry.

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RECOMMENDATION FOR INDUSTRY: DELIVERABLE 12.

1. THE OPTIMUM MIX AND SPECIFICATION OF THE INSTRUMENTS FOR A CLOUD OBSERVING STATION.

The recommended GCOS Cloud Remote Sensing Station defined in Deliverable 14 comprises three fundamental instruments:

a) A vertically pointing Dopplerised Cloud radar.
b) A vertically pointing lidar ceilometer.
c) A vertically pointing dual frequency microwave radiometer.

As shown in deliverable 10 with this combination of instruments it is possible to derive a vertical profile of cloud fraction, liquid water content and ice content, which can then be compared with the values for these three variables which are held in operational forecast models.

In the next sections we consider the specifications required for these three instruments and how these specifications can be satisfied by products supplied by European industry. One particular aspect of importance is the cost of the Cloud Remote Sensing Station if it is to be widely deployed. Current costs restrict these stations to just a few locations where they are used exclusively for research. If stations are available at reduced cost then the market would be much larger, and one can envisage each European country establishing several such stations, rather in the manner that they have stations for launching radio sondes.

2. A VERTICALLY POINTING DOPPLERISED CLOUD RADAR.

The specification for this cloud radar (deliverable 14) is that it should have a sensitivity of –55 dBZ at a range of 1 km for a 60 m gate length and a dwell time of 30 seconds. This is sufficient to detect radiatively significant ice clouds up to an altitude of 10 km. It should be able to detect Doppler velocities with an accuracy of 0.1 m/s.

Currently systems are commercially available at 35 and 94 GHz. These frequencies are not ideal because there is significant attenuation by atmospheric gases, by liquid water within clouds, and considerable loss (up to 10dB) of signal power during periods of rainfall because of a thin layer of water on the radome. The attenuation is less at 35 GHz, and at this frequency reliable transmitters are available. At 94 GHz there is some concern over the cost and the lifetime of the present generation of extended interaction amplifiers. Cloudnet experience is that such amplifiers which could be obtained during the first few years of the project can lose up to 10 dB of transmitted power during one year of continuous operation. One of the advantages of operating at 94 GHz is that the return from insects is less; although in practice insects can be recognised by their Doppler return and rejected. However, when there are many insects in the boundary layer the presence of insects may make the detection of clouds difficult within the layer. One way of avoiding the present technological problems associated with a pulsed radar at 94 GHz, would be to develop a frequency modulated continuous wave radar (FM/CW) to operate at 94 GHz. Designs suggest that the required sensitivity can be obtained while transmitting a peak power much lower than the present pulsed systems. This should lead to a transmitter which is less expensive, more reliable, and with a much longer lifetime.

An alternative approach would be to explore the development of an X-band (3 cm) vertically pointing Doppler cloud radar. This is a well established frequency for meteorological radars and is widely used for sensing precipitation, so components are reliable and relatively inexpensive, but the difficulty which arises for this application is that there is appreciable attenuation in very heavy rainfall. However, for the detection of clouds at vertical incidence, the attenuation due to clouds, atmospheric gases, and water on the radome is negligible. In addition, it should be possible to construct a simple pulsed radar with high transmitted power at low cost, and, with a reasonable sized antenna of size up to 2 m, such a system should be able to reach the required specification.
Recommendation.

Accordingly, the following two systems are worthy of development and have the potential to fulfil the current specification but at a much reduced cost when compared to the conventional pulsed mm-wave cloud radars currently available:

a) A 94 GHz (3.2 mm) Dopplerised cloud radar using frequency modulated continuous wave technique. Because of the lower peak power the transmitter should be much cheaper, more economical and with longer life time than the current 94 GHz pulsed radars. At this frequency insect returns are reduced, but operating during rainfall is still difficult.

b) An X-band (3 cm) Dopplerised cloud radar using a conventional high power pulse. At X-band the technology is mature and reliable high power pulsed transmitters with long lifetime are available. The advantage of this frequency is the lack of attenuation by atmospheric gases, liquid clouds, and water on the radome. Such a radar would operate in periods of precipitation, thus avoiding the sub-sampling of current cloud radars which do not operate reliably during rainfall. This avoidance of sampling problems facilitates comparison of observations with models.

3. A LIDAR CEILOMETER.

The function of the lidar ceilometer is to detect the presence of liquid clouds and to measure the height of their base. Because liquid clouds are composed of small droplets, they have a very low radar reflectivity and cannot be detected by the radar unless there are drizzle droplets within the clouds. Indeed if drizzle is present then it is most likely to be both within the clouds and below then, so the radar echo does not identify cloud base. The lidar ceilometer is needed to detect such water clouds, and also to detect the presence of aerosols particles. The aerosol particles have a moderate backscatter and small attenuation. Water clouds can be recognised by their high backscatter (above 10^{-4} /m/sr) and because water clouds rapidly attenuate the signal, the lidar backscatter signal should be rapidly attenuated within 100 m of its peak return at cloud base. Ceilometers with this specification are commercially available at low costs. Indeed many National Met Services already have networks of ceilometers to provide information on cloud base.

Recommendation to industry.
Ceilometers which are currently commercially available are satisfactory, inexpensive, reliable and have a specification adequate for a cloud remote sensing station and no further development is necessary.

4. A DUAL FREQUENCY MICROWAVE RADIOMETER.

The purpose of this instrument is to provide accurate liquid water path, so that when combined with the cloud-base of the water clouds derived from the lidar and cloud-top detected with the radar, it is possible to compute the liquid water content of the cloud.

Conventionally the liquid water path is derived from the microwave radiometers, by firstly converting the brightness temperatures measured at the two frequencies into two optical depths, and then solving the two equations for the optical depths for the two unknowns, the liquid water path and the water vapour path. However, because of uncertainties in the absorption coefficients and instrument offsets, liquid water paths derived can be error prone and even negative, so a calibration offset is introduced into the two equations to represent these effects. During periods when the ceilometer indicates the liquid water path is zero, the equations are overdetermined, and the approach optimises the choice of calibration offset to yield a zero liquid water path.

Recommendations to Industry.
Current designs of microwave radiometers aim to achieve a highly stabilised system with calibration sources which are either internal or use labour intensive tip-curves to achieve an absolute accuracy of 0.5K in the measured brightness temperature in the two channels. The Cloudnet retrieval of liquid water content uses the lidar to identify periods where no liquid cloud is present, and to adjust the calibration offsets to force zero liquid water path to be retrieved during such periods. During periods when liquid water clouds are present, interpolating the offsets before and after the cloudy period derives the calibration offset. This technique is tolerant of changes in the absolute value of the brightness temperatures of up to 5K, provided that drifts of this offset are slow during the cloudy period. Industry should explore how this relaxation in the specification of the brightness temperature accuracy can lead to a simpler and more economical design of instrument.