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OBSERVATIONS OF THE VERTICAL STRUCTURE OF STRATOCUMULUS WITH LIDAR AND AN S-BAND RADAR

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1. Introduction

The vertical cloud structure is a key element in the energy budget of the atmosphere. On a global scale, however, too little experimental data is available. To meet this deficit, the European Space Agency is considering to operate the Earth Radiation Mission: a space-based combination of radar and lidar to monitor the clouds. To study the benefit of this combination, ground-based experiments were done in The Netherlands during the Clouds and Radiation-campaigns in 1996 [Van Lammeren et al, 1997].

In this paper, an example of observation of stratocumulus will be discussed. The radar measurements will be compared with in situ measurements of the cloud droplet size spectra. Based on the observations, some preliminary remarks concerning space-based observations will be made.

2. The instruments

The Delft Atmospheric Research Radar DARR is an S-band FM-CW Doppler radar. It operates at 3.315 GHz, whereas other cloud radars operate at frequencies above 35 GHz. The radar can observe scattering due to cloud particles and clear-air phenomena. Gaseous absorption as well attenuation due to hydrometeors is negligible. The cloud measurements were done with a range resolution of 15 or 30 meter, depending on the meteorological situation. The temporal resolution is 5.12 seconds. The sensitivity of the radar is -30 dBZ at 2 km.

The lidar system for the measurements in this paper is a Vaisala CT75. It has a range resolution of 30 meter, and a temporal resolution of 30 seconds. To cross-check the range accuracy of the Vaisala-lidar and the radar an experiment was performed by pointing them at a chimney at a distance of approximately 1100 meter from the radar site.

For cloud observations, the radar and lidar were pointed towards the zenith. The systems were collocated at the Faculty of Electrical Engineering in Delft, near the coast of the North Sea.

3. Measurements

Figure 1 shows the radar reflectivity and the lidar backscatter as function of time. Throughout the measurement, a cloud layer is observed between 1500 and 1700 meter. In the second half of the measurement, the convective activity in the boundary layer is increasing as can be recognized in the enhanced speckle patterns in the radar plot. The cloud layer breaks up in separate cumuli. The lidar backscatter varies has a maximum backscatter of 3000 [1000 srad km]^-1; the radar reflectivity varies between -15 and -30 dBZ. To some extent the radar signal may be due to scattering by spatial inhomogeneities of the refractive index (caused by for instance turbulent mixing at the cloud top); the quantification of this phenomenon is still subject to research.

The differences between the radar and lidar are intriguing. They give different cloud heights. The radar sees a cloud that is approximately 75 meter higher than that the lidar sees. A small cloud layer at approximately 1200 m is observed by the lidar between 8 and 9 utc; this cloud is optically too thick for the lidar to penetrate: the layer at 1600 m is not seen anymore. The radar did not measure the lower cloud.

It is not shown in this paper, but further analysis of this measurement revealed that the temporal correlation between the maximum received power from the lidar and the radar was quite significant, even though the two instruments did not observe the peak reflections at the same heights. Details can be found in [Russchenberg et al, 1997].

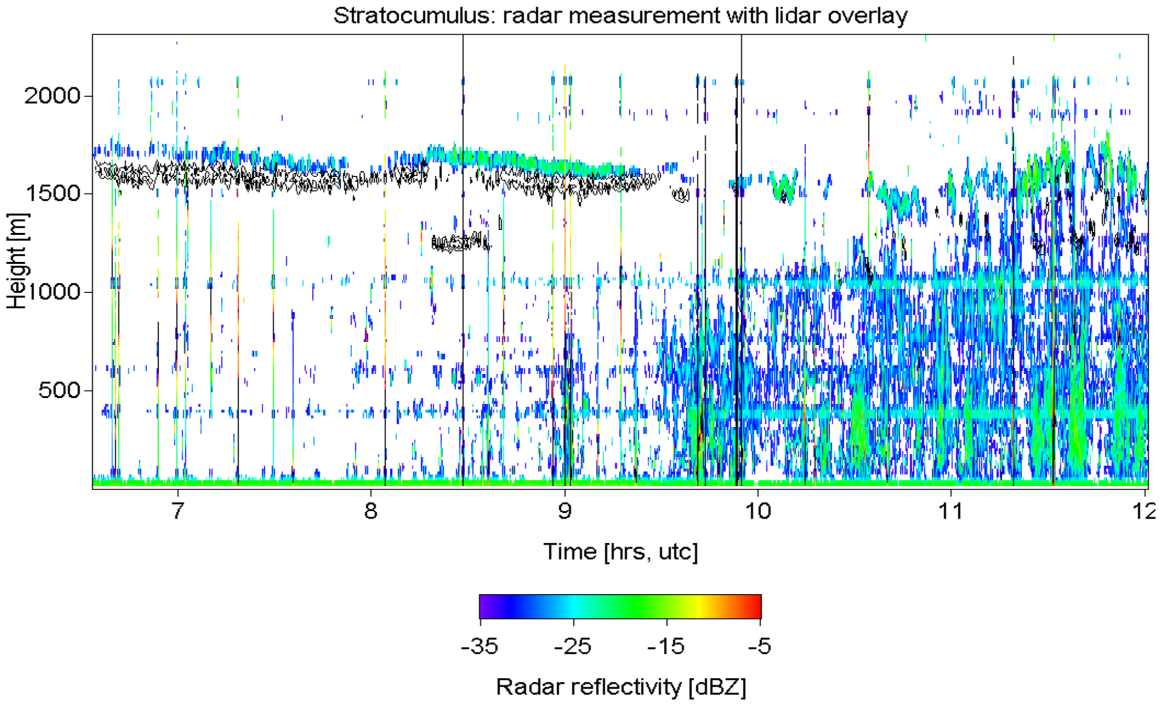

Figure 1 Height-time diagram of the radar reflectivity with contours of the lidar backscatter on April 19, 1996; Stratocumulus breaking in to cumuli after 10 utc. The lidar backscatter has a maximum backscatter of 3000 [1000 srad km]^-1. Radar resolution: 15 meter, 5.12 seconds.

4. Comparison with in situ measurements

During the observations section of section 3, the cloud droplet size distribution was measured with an FSSP. From the in situ data, the averaged radar reflectivity and lidar return were calculated. The results are given in Figure 2; the simulations are in agreement with the actual observations of Figure 1: the lidar gets a peak reflection from the cloud base, whereas the radar receives the maximum power from the cloud top. The sensitivity of the radar in this particular case is probably not good enough to observe the cloud base.

The aircraft was flying along horizontal tracks in the cloud field at different heights, not always close to the radar. The sampling volumes of the radar, lidar and FSSP were not coinciding, which means that the comparison of the in situ measuerments with the radar/lidar observation can only be made qualitatively.

The observations of Figure 2 can to some extent be generalized. In stratocumulus the liquid water content as well as the mean dropsize is often seen to increase with height [Martin et al, 1994] [Gerber, 1996] [Slingo et al, 1982]. This will have an impact on the vertical profiles of the lidar and radar signals, due to differences in the scattering mechanisms in the microwave and optical range. In the absence of attenuation, the radar will receive its maximum power from the top of the cloud. The lidar signal, however, will have a peak in the lower part of the cloud: the extinction prevents the lidar from penetrating into the cloud towards the top. From space, however, the situation will be different: both the radar and the lidar will see a maximum near the cloud top.

The actual situation is of course more complex than these idealized clouds. The concentration is not constant and the height dependence of the liquid water content is never truly linear, but the idealization clearly shows a trend.

5. Conclusions

The lidar signal from clouds is due to scattering in the resonance-region and the radar signal is due to Rayleigh-scattering, which makes the two instruments differently sensitive to the size of the cloud droplets, and consequently to the vertical distribution of water or ice inside the cloud. In case of clouds in which the water content increases with height, the radar receives its maximum from the upper half of the cloud. The extinction of the lidar signal will in these cases result in a peak somewhere at the bottom of the cloud. This has been illustrated with an example of observations of stratocumulus. From space the radar and lidar will both see a maximum at the cloud top, in that case.

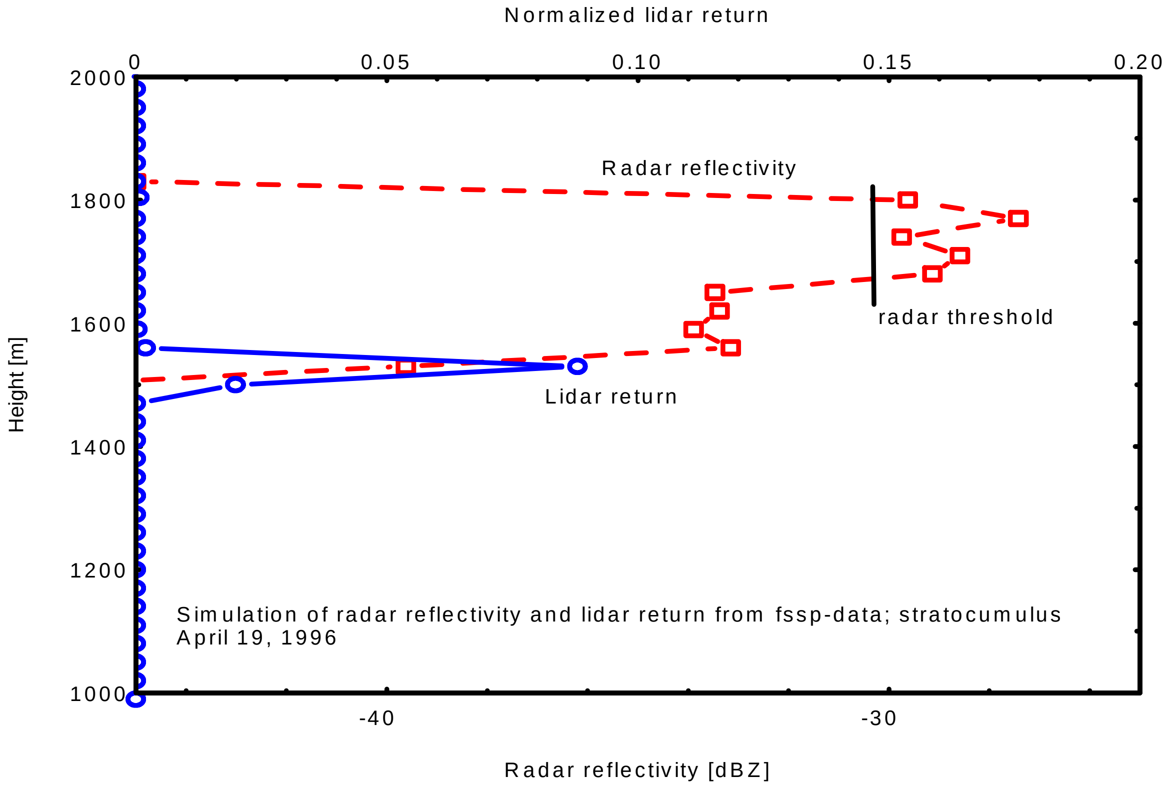

Figure 2 Simulated height profiles of the radar reflectivity and lidar return, based on in situ observations of the cloud droplet spectra. The lidar backscatter and extinction values were calculated using the optical approximation of scattering by spheres; applying exact Mie-calculations will not give significant changes. The radar reflectivity is calculated with the Rayleigh-approximation; at S-band the attenuation is negligible. Multiple scattering is ignored.

Acknowledgments

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