The CLARA-Project: Intensive Experimental Study of Clouds and Radiation in The Netherlands

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Introduction

In 1996, intensive measurements campaigns were organized in The Netherlands with a multitude of instruments, aimed at a qualitative and quantitative description of clouds and their impact on atmospheric radiation. The campaigns were part of the Clouds and Radiation (CLARA) project: an intensive experimental study of clouds and radiation in The Netherlands. Originally, three specific objectives were defined:

- The creation of a data set on clouds and cloud-radiation interaction.
- Validation and calibration of the retrieval algorithms of ground-based and satellite remote sensing instruments.
- Validation of cloud and radiative transfer models and parameterizations thereof.

During the project, a new objective was added:

- Sensor synergy: how to combine different instruments to optimize the retrieval of cloud parameters.

The campaigns were organized in the coastal area of The Netherlands. Most of the ground-based instruments were installed on the campus of Delft University of Technology. Additional measurements were done with the KNMI cloud detection system, which is a network of ceilometers and infrared radiometers over the central part of The Netherlands. Additional studies were done in the ECN cloud chamber, some 70 km to the north of Delft. During selected days, an instrumented aircraft was flown through the clouds.

The CLARA-project is part of the Dutch National Research Programme (NRP) on Air Pollution and Global Change. More information concerning the CLARA-project can be found at: *www.knmi.nl/PROJECTS/CLARA/*.

Experimental Setup

Three measurement campaigns were organized: in spring, summer and autumn. Most of the ground-based equipment was operational continuously, thereby giving long time series of clouds and radiation data. During selected days with stratus, stratocumulus or cumulus, the cloud droplet size distribution was measured with an airborne forward scattering spectrometer probe (FSSP). Radiosondes were launched three times a day, with additional launches during aircraft flights. The cloud chamber was used to study the relationship between air pollution and cloud formation: the aerosol concentration of the air was correlated with the particle number concentration of clouds synthesized from ambient aerosols in the cloud chamber and with the real clouds outside. Table 1 gives information on most of the instruments that were used during the campaigns.

Table 1. The CLARA instruments, the derived physical parameters, and responsible institute.

Ground-Based Instrument	Physical Parameters	Institute
Radar, 3 GHz	Vertical cloud structure, microstructure, velocity	IRCTR
Lidar, 1064 nm, 532 nm	Vertical structure, optical thickness	RIVM
Ceilometers (2), 940 nm	Vertical structure, horizontal (in)homogeneity	KNMI
Radiometer, 20/30/50 GHz	Liquid water path, Water vapour path	EUT
Infra-red radiometer, 1 µm	Cloud emissivity, cloud base temperature	KNMI
Video camera	“Air truth”	KNMI
Cloud chamber	Aerosol-cloud droplet concentration	ECN
Radio sondes	Vertical profile of temperature, humidity, air speed	KNMI/IRCTR
Cloud detection system	Spatial cloud structures	KNMI
Space-Based Instruments		
METEOSAT [(a)]	Spatial cloud structure	KNMI
AVHRR [(b)]	Optical thickness	KNMI
ATSR [(c)]	Optical thickness	KNMI
Airborne Instruments		
FSSP	Drop size distributions of water clouds	ECN

(a) European Meteorological Satellites
(b) Advanced Very High Resolution Radiometer
(c) Along Track Scanning Radiometer

Scientific Issues

The data analysis focuses on several scientific issues:

Cloud geometry. The radar and the lidar were used to estimate the cloud geometry. It was found that sensor synergy is essential to measure the cloud base and top. The radar technique is very well suited to observe the top of water clouds, but may have some difficulty in identifying the cloud base. With the lidar, on the other hand, the cloud base can be estimated accurately, but the cloud top is difficult to observe due to extinction of the lidar signal. In the case of mixed-phase clouds, the lidar and radar signatures may be very different due to the size-dependence of scattering sensitivity: backscattering at the radar wavelength may be dominated by the ice crystals in the clouds, whereas the lidar signal can also be determined by the water droplets in the clouds.

Cloud variability. The radar and lidar observations are used to study the spatial cloud variability. The rationale for this study is dictated by possible future space missions with two satellites traversing the same location some time after each other: can sensor synergy then still be applied to extract microphysical cloud properties?

Retrieval of the liquid water path. The microwave radiometer is used to estimate to the path-integrated values of the liquid water content and that of the water vapour. The retrieval method requires the assumption of a vertical profile of the liquid water content, temperature and humidity. The profiles are obtained from the radiosondes, radar and lidar and 50-GHz radiometer observations.

Retrieval of number concentration of stratocumulus clouds. The liquid water path, derived from the radiometer, is combined with the radar and lidar derived cloud dimensions and with the extinction profile of the lidar to estimate the number concentration of cloud droplets in stratocumulus. This method is based on certain assumptions concerning the vertical cloud structure.

Determination of the optical thickness and liquid water content from AVHRR data. Radiative transfer calculations are used to retrieve the liquid water content and the optical thickness of stratocumulus from the AVHRR Channel 1 reflectivity values. Input from the lidar and radar is used to improve the method. The aircraft and the radiometer measurements are used for validation.

Analysis of FSSP data. The in situ data of drop size distribution are used to simulate height profiles of radar and lidar observations of stratocumulus, which are then compared with actual measurements. Using this approach, the differences between measurements with the two instruments can be clarified. Furthermore, the FSSP data is used to develop retrieval algorithms for the microphysical cloud parameters.

Radar-lidar synergy to estimate cloud particle sizes. The ratio of lidar and radar reflections is used to estimate the mean particle size in the clouds. This method assumes that scattering is either due to water or ice particles and can hence not be used in mixed-phase clouds.

Study of the melting zone in stratiform precipitation. The melting zone reveals itself on the radar screen as a bright band of reflection, although the intensity decreases when high-frequency radars are used. In the lidar data, however, the melting zone appears as a region of low reflection: it looks like a dark band. Several explanations for this dark band have been developed and are currently being further explored.

Multiple scattering of lidar waves in stratocumulus. A new model that predicts the multiple scattering for several configurations of ground-based and space-borne lidar systems is developed by estimating the ratio of incoherent and coherent parts of back-scattered signals (De Wolf et al. 1999). Future work in this field will comprise an experiment with a fast-scanning dual-beam lidar system.

Relationship between liquid water path and emissivity. The liquid water path that is derived from the microwave radiometer is correlated with the emissivity that can be derived from the infrared radiometer to qualify the radiative significance of water clouds.

Papers and reports dealing with these issues can be downloaded from *http://irctr.et.tudelft.nl/sector/rs/*.

Some Examples

Retrieval of the droplet number concentration in stratocumulus. The extinction of the lidar signal is determined by the liquid water path, the droplet number concentration, cloud thickness, and additional terms concerning the dropsize distribution and extinction efficiency.

The cloud thickness is estimated from the radar and lidar data. The liquid water path is derived from the microwave radiometer. Furthermore, the extinction profile is derived from vertical lidar profiles. With some reasonable assumptions regarding the dropsize distribution, one can now retrieve the particle number concentration. An example is given in Figure 1.

The parameter D gives the departure from adiabicity: $D = 0$ indicates an adiabatic cloud. A detailed description of the method is given in Boers et al. (1999).

Cloud base estimates. The radar and lidar are differently sensitive to the particle size and type and do not necessarily observe equal cloud structures. Figure 2 shows the estimated cloud base during the passage of a front. The cloud base of the front itself is estimated at the same height by the two instruments. The differences occur in the lower clouds between 2 UTC and 4 UTC. The IR-radiometer gives the path-integrated sky temperature. This temperature can be related to height by comparing it with radiosonde measurements. When this height is above the radar or lidar cloud base, the clouds are optically thin, as is the case in large parts of the frontal cloud cover. Just before 4 UTC the lidar detects a cloud layer at 1 km, that the radar does not see. The IR-radiometer indicates that this cloud layer is optically thick and probably radiatively significant.

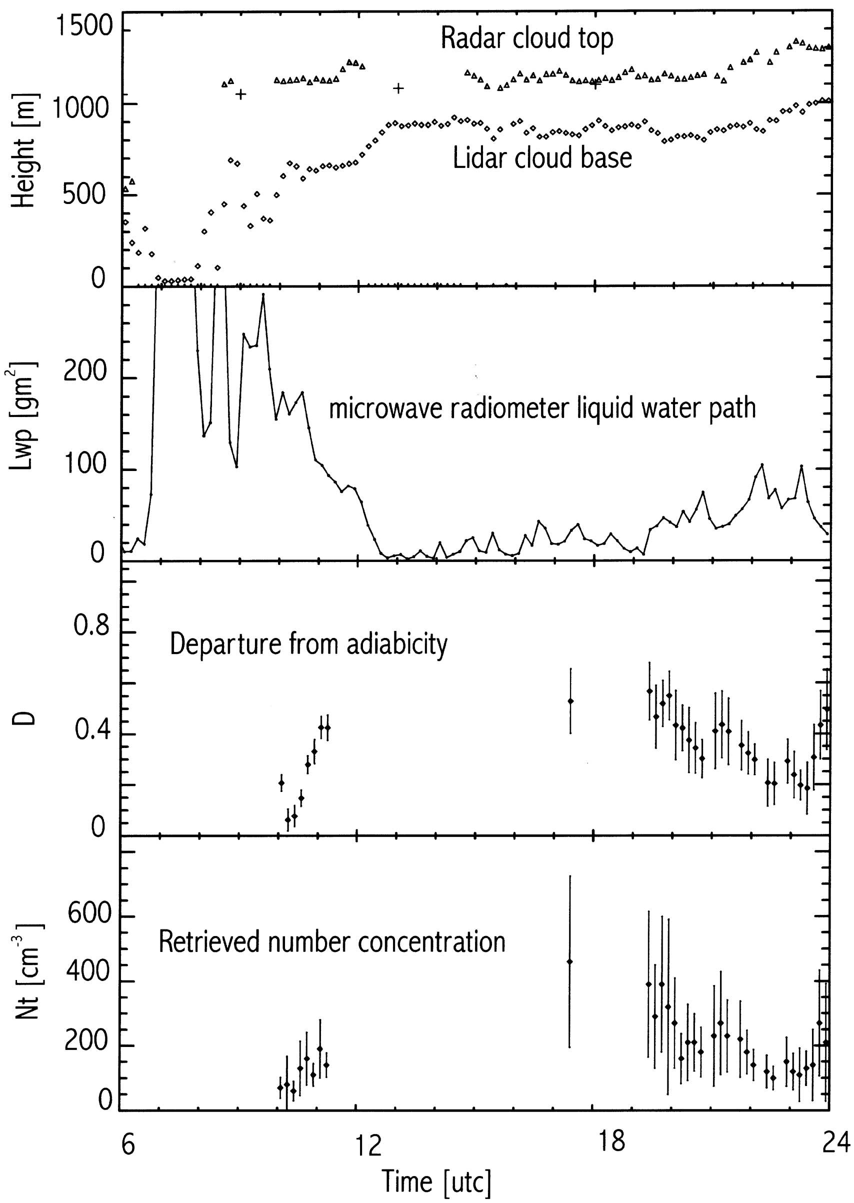

Figure 1. Time series of measured and retrieved cloud parameters. Individual points are 10-min. averages. Between 12 UTC and 18 UTC the cloud deck was broken, leading to unreliable results.

Concluding Remarks

The CLARA-project has resulted in a good data set that can be used to study many aspects of the cloud-radiation interaction. The data set is very useful for the development of retrieval methods of micro-physical cloud properties and macroscopic cloud structures.

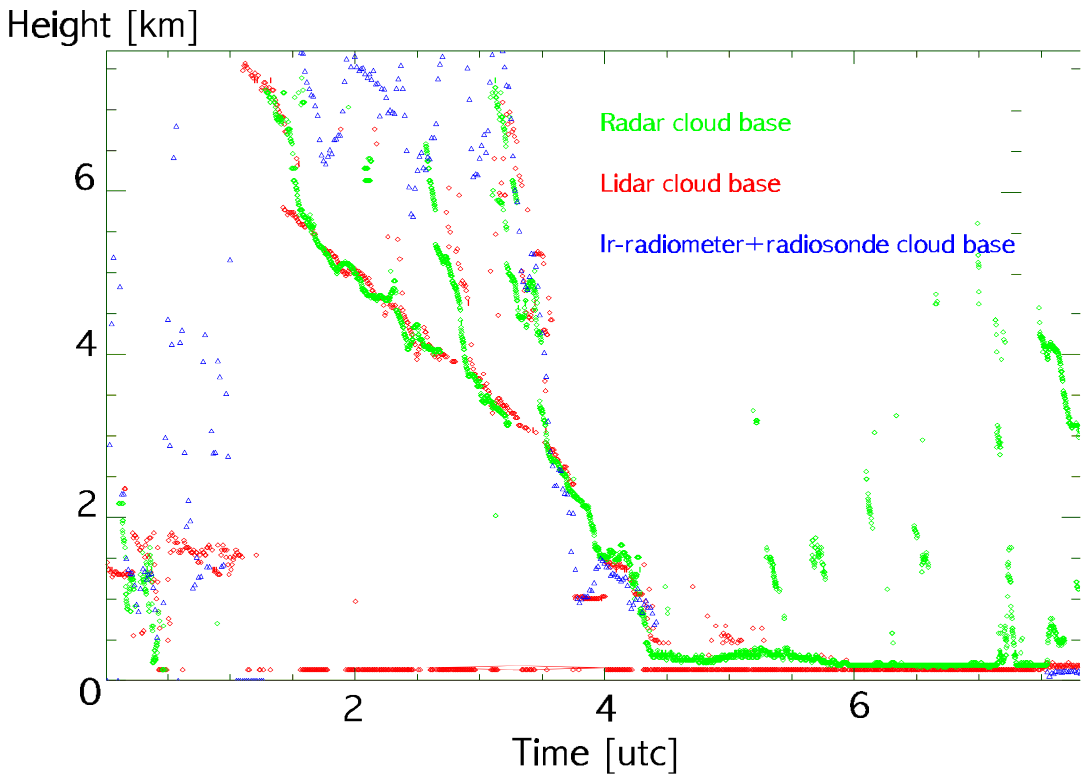

Figure 2. Estimated cloud base during passage of a front.

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