climate changes
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Climate scenarios

Monitoring and profiling with CESAR Observatory

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About this report

This report gives a helicopter view of the CESAR Observatory project. It briefly describes the highlights, the CESAR data base, the new technologies added throughout the project period, and the first steps in joining models and observations. Most of the work has been reported in more detail in the open literature. Contents of the report:

Introduction

1. Introduction

The climate system is complex. Although it is understood in qualitative terms, there are still many physical processes of which the impact on climate change is far from quantifiable. A well-known example of such a process is the interaction between cloud and rainfall formation, aerosols, radiation and the land-atmosphere energy exchange. It is one of the sources of large uncertainty in climate models.

The uncertainty is largely due to a lack of reliable observations of the processes. In this project we aimed at the development of the required observation methodologies to study these processes. We explored and enhanced the capacity of CESAR Observatory, in the heart of The Netherlands, in order to make it one of the leading atmospheric observatories in the world. In particular, we defined:

- New technologies: advanced radar and lidar systems were developed and installed at the observatory.
- Quality improving enhancements of the observatory.
- New retrieval techniques to derive the relevant atmospheric parameters.
- The data base infrastructure of CESAR Observatory.
- Evaluation studies to assess the quality and consistency of the observations.
- Studies to assess the potential impact of new observations on model output.

The major outcome of the project is the observatory itself. We now have a world class observatory for atmospheric studies. It is one of the few stations worldwide with which one can study climate-relevant processes in the context of atmospheric chemistry, physics, hydrology and meteorology. The CESAR database is easily accessible to the scientific community.

CESAR Observatory is one of the major research facilities in The Netherlands. It serves the atmospheric community at seven research institutes and agencies: the universities of Delft, Wageningen and Utrecht, ECN Energy Research Centre of The Netherlands, TNO Applied Scientific Research, RIVM National Institute for Public Health and the Environment, and KNMI Royal Netherlands Meteorological Institute. Furthermore, the observatory is also supported by European Space Agency. The observatory is hosted and operated by the KNMI. CESAR data are used for a wide range of applications, e.g.:

- Monitoring of long term tendencies of climate variables in the atmosphere
- Validation of space-borne observations and retrieval products
- Studies of atmospheric and land surface processes for climate and air quality modelling
- Evaluation of weather, climate and air quality models
- The development, implementation and assessment of new measurement techniques
- Training of young scientists at post-doc, PhD and master level.

An important advantage of the site is its location: both close to the sea and to some of the major European industrial and populated areas. This location leads to a large variety of air mass types at the site. Other advantages are its long term dataset of advanced parameters, the coinciding location of the different instruments, and the area around the site, which is flat and has suffered only minor landscape developments since 1972.

Where now lies the future of CESAR Observatory? Several areas are distinguished:

1. **Process studies.** The observatory is well-equipped for detailed studies of atmospheric processes that should lead to a better understanding of these processes in the climate system. The observatory has already hosted several international observation campaigns to study cloud-aerosol-radiation interaction, rainfall, land-atmosphere exchange processes and atmospheric

chemistry, and will continue to do so. The quality of the observatory attracts many international scientists to participate in observation campaigns and add their own instrument to CESAR's arsenal.

2. **Climate monitoring.** Climate changes over long time scales. Apparent trends in climate change can therefore only be traced within long time records of quality observations. CESAR Observatory is well-equipped to this task. Many essential climate variables can be measured routinely and stored in the CESAR data base. Not only can we monitor local variations of climate drivers– like solar radiation and greenhouse gases – in relation to the temperature, but also in the context of climate feedbacks, like cloud formation and water vapour.
3. **Model evaluation.** Climate models are based on laws of physics, but the climate system is too complex to model without assumptions and approximations, especially concerning physical phenomena that occur on scales smaller than the model's resolution grid. High quality observations are necessary to test the validity of these assumptions, to improve the model output via data assimilation and to develop better parameterizations of these small scale processes.
4. **Satellite synergy.** Observations from space are of the utmost importance to get a global overview of the climate system. However, the spatial and temporal accuracy of satellite observations is often limited. This can be improved significantly by combining space observations with measurements from the ground. The detailed information from ground observations can be incorporated in satellite retrievals and used for quantitatively and qualitatively enhancements. CESAR Observatory is well-suited for this work.
5. **New technologies.** CESAR is not only an observatory. It is also a field laboratory for new technologies. Prototypes of new instruments and technologies can be tested and validated. A good example is the weather radar installed on top of the CESAR observation tower: this radar is seen as a prototype of regional radar for the detection of extreme rainfall in urban areas.

2. Highlights

2.1 Clouds and radiation

Ground-based radiation instruments are important to evaluate the accuracy of atmospheric retrievals (e.g. cloud and aerosol properties), radiative transfer models and measurement techniques. Especially cloudy atmospheres are a challenge for measurements and modelling. We focused on the shortwave closure analysis for the clear-sky cases and the overcast water cloud cases at Cabauw. The shortwave broadband irradiances were simulated with a broadband model[1] using different atmospheric states and aerosol, cloud properties as input parameters.

Clear sky evaluation

The clear-sky evaluation is based on an exceptional period of fine weather during the first half of May 2008, resulting in a selection of 72 comparisons, on 6 days, between radiation measurements[2] and the simulations of direct, diffuse, and global irradiances. The data span a wide range of aerosol properties, water vapor columns, and solar zenith angles. The model input consisted of aerosol

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[1] Doubling-Adding KNMI (DAK) radiation model.
[2] With the Baseline Surface Radiation Network BSRN.

products[3] and radiosonde data. The wavelength dependence of the aerosol optical thickness, single scattering albedo, and asymmetry parameter was taken into account. On the basis of these data, excellent closure was obtained (see Figure 1).

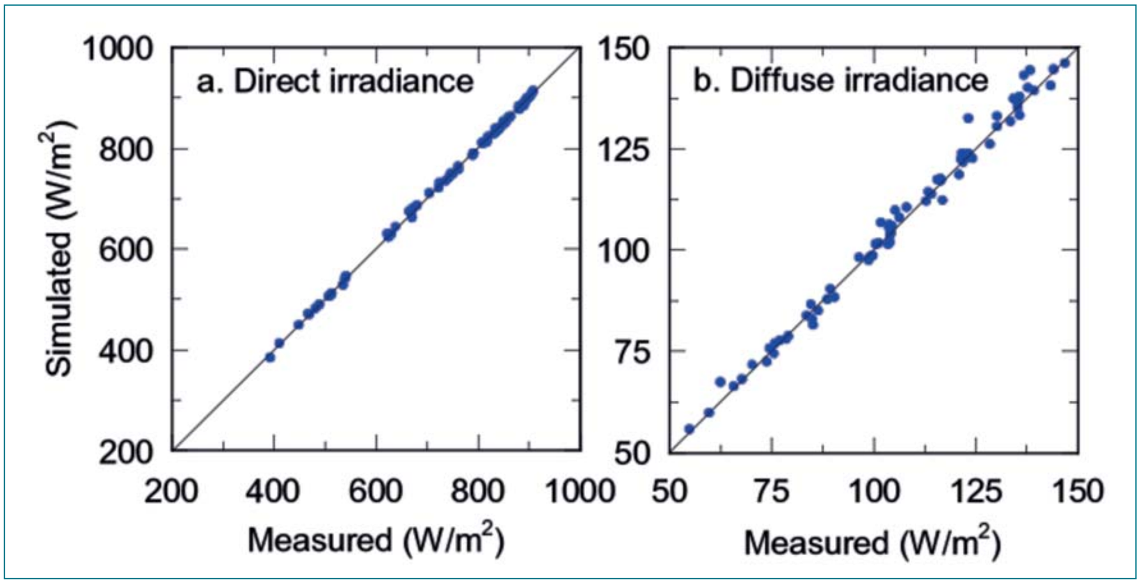

Figure 1.
Scatter plots of DAK simulations versus BSRN measurements (Cabauw, the Netherlands) of (a) direct, (b) diffuse irradiance for 72 clear-sky cases. The mean differences between model calculations and measurements are 2 W/m² (+0.2%) for direct irradiance, 1 W/m² (+0.8%) for diffuse irradiance.

Cloudy sky evaluation

The evaluation study for the cloudy cases is restricted to overcast, single-layer, homogeneous, non-precipitating water clouds. In total we selected 639 cases on 9 days between May 2008 and May 2009 and on 30 January 2007. To select proper cases we used the Cloudnet target categorization product derived from lidar and radar measurements, rain gauge data, cloud fraction data derived from the NubiScope and the total sky imager. The selection process is automatic and objective. The cloud optical thickness is derived from the cloud liquid water path from ground-based microwave radiometer measurements and satellite-retrieved cloud effective radius, MODIS level 2 product. Figure 2 shows the results. The correlation coefficient between the measured and simulated global irradiances is 0.95.

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3 Standard products of the Aerosol Robotic Network (AERONET).

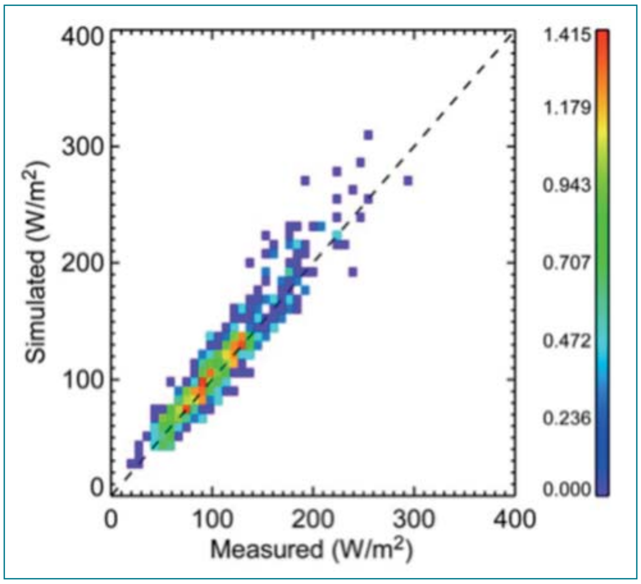


Figure 2.

Density plot (with logarithmic color scale) of DAK simulations versus BSRN measurements (Cabauw, the Netherlands) of global irradiance for 639 cloudy-sky cases. The mean difference between simulated global irradiances and BSRN measurements is 6 W/m^2 (5%), with a standard deviation of 14 W/m^2 (13%). The cloudy cases cover a large range of liquid water path (30-400 g/m^2), water vapour column (0.7-3.1 cm) and solar zenith angle (41-75°). The colour bar indicates number of occurences.

To refine the cloud model in radiative transfer models, a retrieval technique has been developed which combines a vertical cloud model with cloud radar, microwave radiometer and lidar observations to infer the cloud liquid water content, droplet concentration, effective radius) and the cloud optical depth. Ideally the cloud parameters are validated with simultaneous ground-based and aircraft in-situ measurements. While this type of information is vital to evaluate the cloud retrievals, aircraft flights are expensive and not practical to use in in-situ sampling to obtain representative statistics of the cloud microphysical and optical properties. Therefore an alternative evaluation study is applied. The liquid water cloud retrievals are evaluated by means of a radiation closure experiment Since different atmospheric instruments with different viewing angles are involved, the impact of the cloud vertically and horizontally inhomogeneity on radiation closure experiment is considered. On the basis of a single-layer water cloud case study a good closure at the surface was obtained with a mean difference of ~ -0.6 W/m^2. The retrieved optical depth and effective radii are in a realistic range. In this case the impact of the horizontal inhomogeneities of the cloud layer on radiation closure is rather small. The effect of the vertical distribution of the cloud properties on the surface fluxes is even smaller, but a sensitivity analysis revealed that the *vertical inhomogeneity has a significant impact on the top of atmosphere fluxes*, in dependence on the solar zenith angle and cloud optical depth.

2.2 Cloud studies

Processes driving cloud formation and development are complex and, at present, still poorly understood. This leads to an inaccurate representation of clouds in climate and weather forecast models. Progress in understanding cloud processes is tightly coupled with the observation techniques available nowadays; it is worth noting that while the observation of large scale cloud properties is properly achieved, an accurate retrieval of the cloud micro-physical properties, i.e. cloud particle sizes and number concentrations, is still missing. Especially our ability to characterize

mixed-phase clouds, composed of a mixture of water and ice particles, is hampered by limitations of our observational capacity.
In atmospheric research, ground-based radar systems are often employed to study ice/mixed-phase cloud properties. These techniques convert the radar signal backscattered by a volume of cloud particles to cloud's microphysical characteristics. However, the size of a radar resolution volume is often too large, compared to the microphysical and thermodynamical variability of the atmosphere. The microphysical information contained in the radar signal is then complex and difficult to retrieve. Therefore, the ground-based observations of the cloud's particles microphysical characteristics are a real challenge in atmospheric science.

We have used the 3 GHz transportable atmospheric radar TARA to characterize the microphysical properties of the ice crystals present in ice/mixed-phase clouds, through a combination of Doppler and polarization measurements. On the one hand, the polarimetric response of an atmospheric target is related to the shape of the particles, and when spheroidal particles are assumed, to the axial ratio. On the other hand, particle motion induces the Doppler shift, which, when measured by the radar, can be converted to the particle radial velocity. We have developed a new retrieval technique, where the microphysical characteristics of ice / mixed-phase clouds are obtained from the radar spectral polarimetric measurements.

High data quality is required for the reliability of spectral polarimetric parameters. A microphysical model for the study of the conversion of ice crystals into raindrops was improved by relating the ice crystals properties of ice/mixed-phase cloud regions to spectral polarimetric data. The model is based on different relations between the particle habit and orientation (assuming a spheroidal shape), the ice crystals' maximum size and their size distribution. The model was enriched with the inclusion of column-like pristine ice, and the orientation of ice particles.

The major breakthrough of this work is the development of a new microphysical retrieval technique, which for the first time, could provide a detailed microphysical analysis of ice crystals present in ice and mixed-phase clouds from the sole use of radar Doppler-polarimetric measurements. The spectral polarimetric parameters were first used to determine the type of ice particles present in the radar resolution volume, related to their main orientation, main size and habit. The microphysical model (previously mentioned) was then applied to the retrieval technique, as a forward model, in order to determine the mean ambient radial wind velocity and the parameters of the particle size distribution.

The retrieval technique was tested for a specific meteorological condition during the COPS (Convective and Orographically-induced Precipitation Study) measurement campaign, in Summer 2007. The microphysical results and the interpretation of the cloud processes obtained so far, within a convective nimbostratus cloud, showed good spatial and time regularity as well as good correlation with the precipitation pattern found below the cloud (see Figure 3 for example). The retrieval results were compared and validated with other collocated sensors on board of an aircraft, flying over the ground-based site; the mean ice water content, the mean number concentration and the particle size distribution were in good agreement.

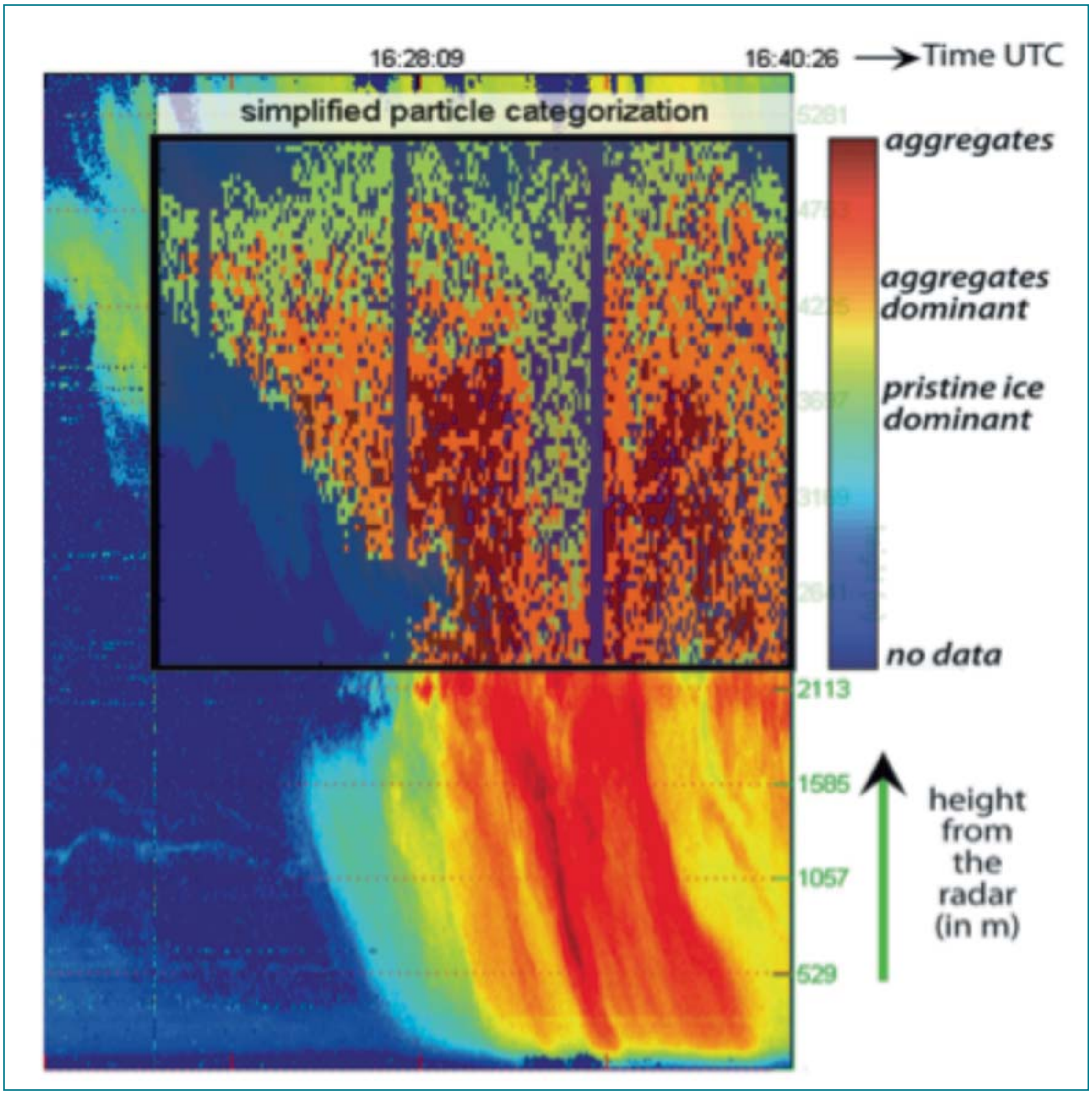


Figure 3.
Reflectivity profile connected to microphysical properties. The background shows a typical radar observation of stratiform rain. The inset shows the classification of ice particles in the clouds. A good correlation is observed between the microphysical properties retrieved within the ice/mixed-phase cloud and the precipitation pattern below: strong aggregation leads to strong rainfall.

2.3 Aerosol monitoring: physical, optical and chemical aerosol properties with lidar and tower-based in situ instruments

Aerosol data have been collected since the installation of the instruments in Cabauw. This has resulted in a multi-year database for aerosol micro-physical and optical properties which are publicly available ((http://ebas.nilu.no/). For specific campaigns dedicated databases have been constructed. The Dutch Aerosol and Nitrogen Dioxide Experiments for Validation of OMI and SCIAMACHY (DANDELIONS) was a project that encompassed validation of spaceborne measurements of NO_2 and aerosol. The extensive data set of ground-based, balloon, and satellite data on NO_2, aerosols, and ozone obtained from two campaigns within the project, held during May–June 2005 and September 2006 are stored in the CESAR database (http://www.cesar-database.nl/). The main aerosol-related result of the project was that observations of the aerosol optical depth derived with three ground-based instruments correspond well with each other, and with space-based aerosol optical depth observed by OMI.

EUCAARI (European Integrated project on Aerosol Cloud Climate and Air Quality Interactions) studies the role of aerosol on climate and air quality. In this framework the Intensive Observation Period IMPACT took place in May 2008 with the overall objective to perform observations of boundary layer, cloud and aerosol processes in order to quantify the effect indirect aerosol effect. For EUCAARI several sophisticated instruments were installed at Cabauw (HTDMA, wet neph, MAX-DOAS, AIS) some of which continued to measure during more than a year and covered the CINDI (http://www.knmi.nl/samenw/cindi/index.php) campaign. A recent development is the application of these instruments for measurements of aerosols.

A case study of atmospheric aerosol measurements exploring the impact of the vertical distribution of aerosol chemical composition upon the radiative budget in North-Western Europe was performed in May 2008. Ammonium nitrate and organic matter were observed to increase with altitude within a well-mixed boundary layer. This increase was attributed to partitioning of semi-volatile gas phase species to the particle phase at reduced temperature and enhanced relative humidity.

North-Western Europe can be viewed as an analogue for the possible future air quality over other polluted regions of the Northern Hemisphere, where substantial reductions in sulphur-dioxide emissions have yet to occur. Anticipated reductions in sulphur-dioxide in polluted regions will result in an increase in the availability of ammonia to form ammonium nitrate as opposed to ammonium sulphate.

Our observations over North-Western Europe, a region where sulphur-dioxide emissions have already been reduced, indicate that failure to include the semi-volatile behaviour of ammonium nitrate will result in significant errors in predicted aerosol direct radiative forcing. Models that do include secondary aerosols, e.g. LOTOS-EUROS, do not always treat the partitioning between gas-aerosol phases correctly.

During 2008 observations have been performed using the MARGA-Sizer aerosol sampler. This instrument has been developed for semi-continuous measurement of the size-distribution of submicron nitrate, ammonium, sulphate and chloride. Novel in the instrumentation is the size-classification. The average observed concentration of nitrate was 5.1 $\mu g/m^3$, which was very similar to the value interpolated from data in the national network. The mass concentration of submicron nitrate was 3.8 $\mu g/m^3$ of which 35% was in particles smaller than 0.32 mm. To put this in perspective: the concentration of sulphate and submicron sulphate was lower than that of nitrate (2.57 resp. 2.04 $\mu g/m^3$), while about the same percentage (38%) was in particles smaller than 0.32 mm. The ion-balance showed that the compounds were present as fully neutralized salts. Figure 4 and 5 show that quite large diurnal variations were observed for nitrate and sulphate, with a surprising sharp maximum in the summer afternoon for sulphate and an afternoon minimum for nitrate in summer and spring. The size-distribution of the semi-volatile nitrate and sulphate was rather constant over the daily cycle. Nitrate levels are higher in winter than spring and summer, while sulphate concentrations are highest in summer.

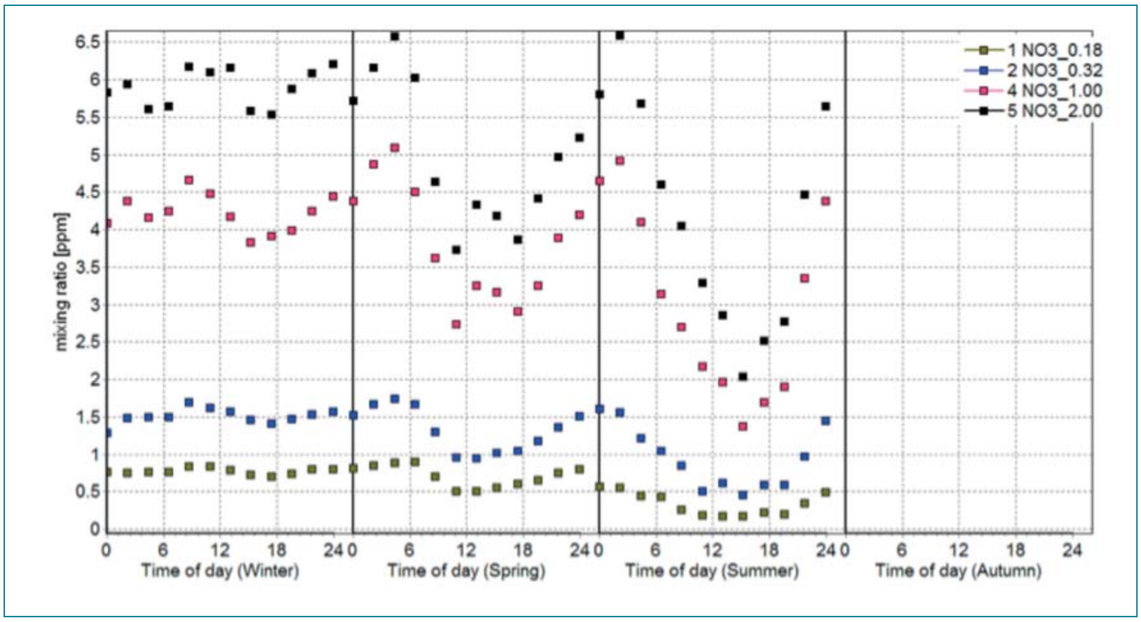


Figure 4.
Size resolved diurnal nitrate concentration patterns of aerosol measured at Cabauw during 2008 as a function of season. Due to malfunction no observations are available in the period Sept-Nov 2008.

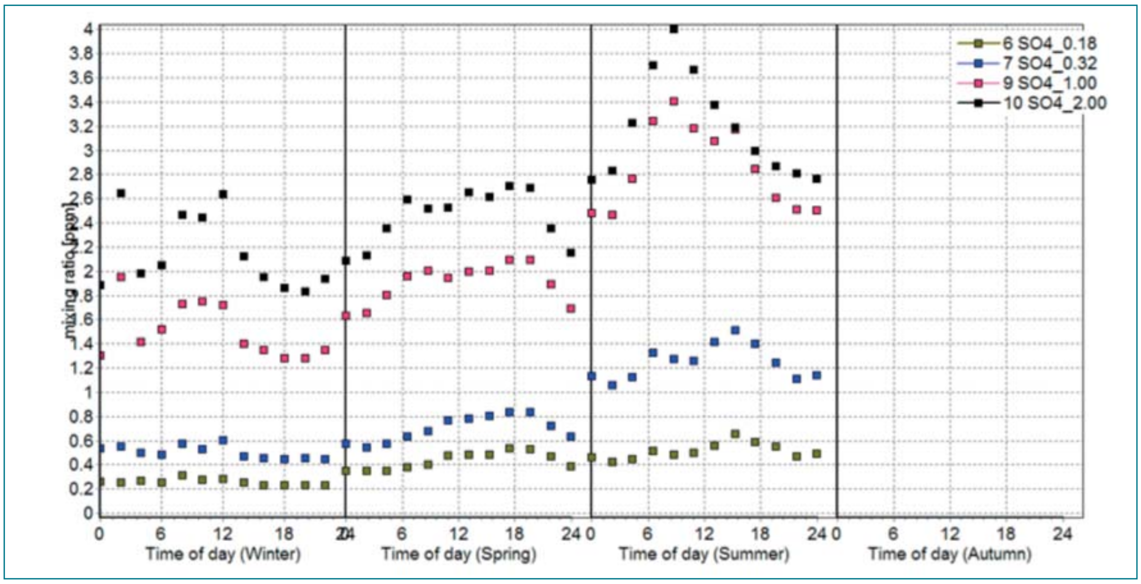


Figure 5.
Size resolved diurnal sulphate concentration patterns of aerosol measured at Cabauw during 2008 as a function of season.

2.4 Observing regional scale energy fluxes and profiles

The estimation of actual regional scale fluxes is of importance when evaluating atmospheric models and satellite retrieval algorithms which both have horizontal resolution much coarser then typical near surface flux observations. The 200 m meteorological tower gives a unique opportunity to measure regional scale fluxes by measuring at higher levels above the surface than is normally done. To this end turbulent instruments are installed at 60, 100 and 180m from which fluxes of momentum, sensible and latent heat and CO2 are derived. Moreover, a scintillometer over a path of 10 km is installed from which regional scale estimates of sensible heat flux can be derived. This complemented the already existing measurement program on land surface atmosphere interaction. Figure 6 shows that the regional scale total heat flux does not deviate significantly from the local observed values. This sheds some new light on the long standing issue in micro-meteorology of surface energy budget imbalance.

Part of the already existing observations has been improved in quality during the course of the project. These are surface turbulent flux observations, the surface radiation observations and the soil heat flux system. For the more traditional observations well established automatic quality control procedures are implemented. For the turbulent observations, however, such procedures are still lacking. Within the project one of the procedures described in the literature has been implemented and evaluated. The results until now are not satisfactory, and a quite laborious on-eye inspection is still needed. Gap filling methods are implemented based on physical modeling of the land surface atmosphere system.

To arrive at a best-estimate of the state of the atmospheric boundary layer, a data-assimilation system has been set-up, which combines the observations with a state-of-the-art atmospheric model. A Regional Atmospheric Climate Model (RACMO) is run in forecast mode on a continuous basis. From this a single column model is derived. From the 3D operational RACMO runs we derive dynamical forcings for the Cabauw column. In search of an appropriate data-assimilation method for the complex full atmosphere-soil model, the method of ensemble Kalman filter (enKF) was found to be a convenient technique.

Climate monitoring

Climate monitoring calls for long term systematic observations of essential parameters with an adequate and well defined accuracy and quality. We discriminate between operational observations and research observations. Operational observations have a high standard in availability, maintenance and quality control and instruments are controlled to meet well prescribed specifications. This is at the moment the closest we get to what may be called climate monitoring. An important piece that is still missing is accuracy specification for the specific purpose of climate monitoring. Current specifications are based on WMO standards which has an emphasis on application in weather forecasting and less so in climate monitoring.

The operational observations at Cabauw include the automatic weather station, the tower profiles of wind, temperature and humidity as well as the four components of the surface radiation budget, soil heat flux and soil temperature, cloud properties and turbulent fluxes.

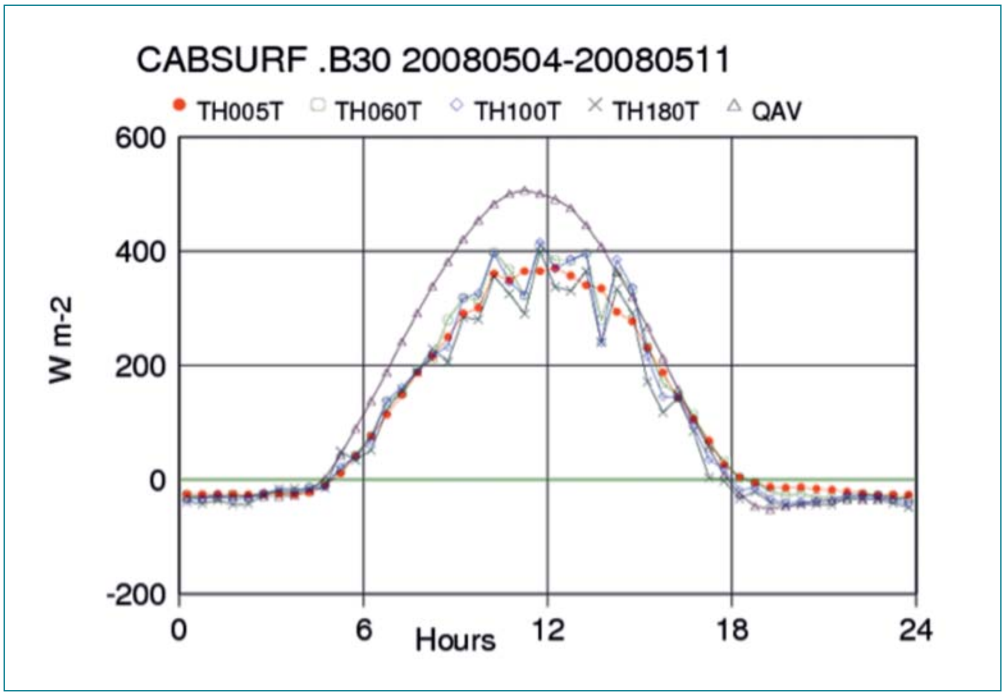


Figure 6.
An eight days composite of total heat flux for the four turbulent flux levels at Cabauw together with available heat flux (net radiation minus soil heat flux). A clear heat flux imbalance is found especially in the morning time. In most surface energy balance studies only a comparison is made with turbulent instruments close to the surface. Here we see that when going to higher levels no improvement in surface energy budget closure is obtain

2.5 The water balance terms

Complex exchange processes occur at the land surface. Uncertainty in water and energy fluxes across the land-atmosphere model boundaries is a source of model errors. Understanding and quantifying these flux processes through observation can help to improve both meteorological and hydrological models. The CESAR test “catchment” is approximately 0.5 km^2. It is part of a polder area, and drained by small, man-made channels. The soil consists of heavy clay on peat and is mainly covered with grass or cultivated for maize. The area is flat and at an elevation of approximately one meter below mean sea level. It is possible that there is seepage from the nearby river Lek, of which the water level is variable and on average approximately 2 m higher than the water levels in the catchment.

In theory the water balance should close, but in practice it never closes completely. This can mainly be attributed to (1) measurement errors or (2) water balance terms that have been omitted, such as upward seepage from the river Lek or other (small) inlets through which water flows into the catchment. At CESAR Observatory the discharge, soil moisture, precipitation and evapotranspiration are measured to determine the water balance:

1. *Discharge*
   Downstream of the inlet to the observatory a V-notch weir has been installed. The outlets of the first and second sub-catchment are monitored by Rossby-weirs. Upstream of the weirs pressure-based Keller water level sensors have been placed. Discharges are derived from the recorded water levels (15-minute interval) and stage-discharge relationships obtained from

calibration in the laboratory. In April 2009 an additional linear magneto-strictive sensor was installed upstream of the V-notch weir to measure water levels directly. Accurate discharge data are available since May 2007.

2. *Soil moisture*
   In 2003 a TDR-system has been installed in the field. This system consists of 6 vertical arrays (in a circle with a diameter of 7 m) of 6 sensors at 5, 15, 30, 45, 60 and 72.5 cm depth. It measures 36 volumetric water content values on a daily base. Soil moisture data are available since November 2003, but few data are available for June and July 2007 and for July and August 2008 due to system collapses. It should be stressed that these soil moisture sensors represent one location in the catchment and that moisture content can be highly variable in space.
3. *Precipitation and evapotranspiration*
   Daily precipitation sums have been collected by a rain gauge network and by the Royal Netherlands Meteorological Institute, KNMI, at the automatic weather station in the catchment. Daily actual evapotranspiration rates have been estimated by the KNMI. With an eddy covariance set-up first estimates of latent and sensible heat fluxes are made and subsequently their Bowen ratio is computed. Finally this ratio is used to divide the available energy (net radiation minus soil heat flux) between latent and sensible heat flux.

Water balance terms vary during the year. We selected 2-month winter and summer periods for which daily sums of water balance terms are shown in detail (Figure 7). From November 1st 2007 to January 1st 2008 all terms are smaller than 1 mm/day except the precipitation and the outflowing discharge. Evapotranspiration is small because temperature and radiation intensities are low in this period. The inflowing discharge is nearly zero because natural drainage maintains acceptable water quality in the polder area. Because evapotranspiration is also small in winter, outflowing discharge is strongly linked to the precipitation.

From May 1st 2008 to July 1st 2008 the evapotranspiration is the largest term in the water balance. No longer a strong link exists between precipitation and outflowing discharge. During this period the inflowing discharge is larger than the outflows, which means that water is episodically infiltrating out of the channels to replenish the soil moisture deficit. The lower graphs show the daily fluctuation in storage change, estimated from the daily change in soil moisture and the total balance. Ideally, changes in the water balance are compensated by soil moisture storage. In summertime the soil moisture content decreases. Although individual fluctuations of soil moisture, discharges, evapotranspiration and precipitation are different, the sums over the period are quite close together.

Water balances have also been set up for two years: from June 1st 2007 to June 1st 2008 and from June 1st 2008 to June 1st 2009. In contrast to the two two-month periods, the water balance does not close well for these years. The rest terms are large and negative, which means that the outflow terms and storage change are larger than the inflow terms. An explanation for the imbalance could be that there is indeed seepage from the river Lek. If this is the case, an input term is not taken into account, leading to negative rest terms. Another explanation could be that there are other (small) inlets through which water flows into the catchment.

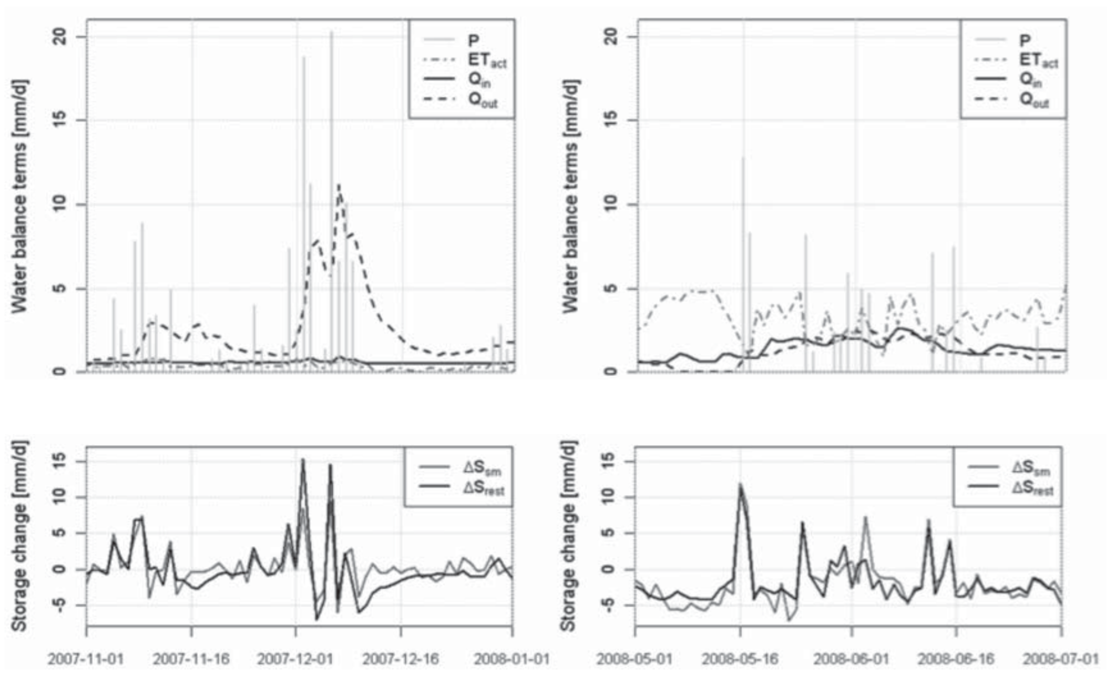


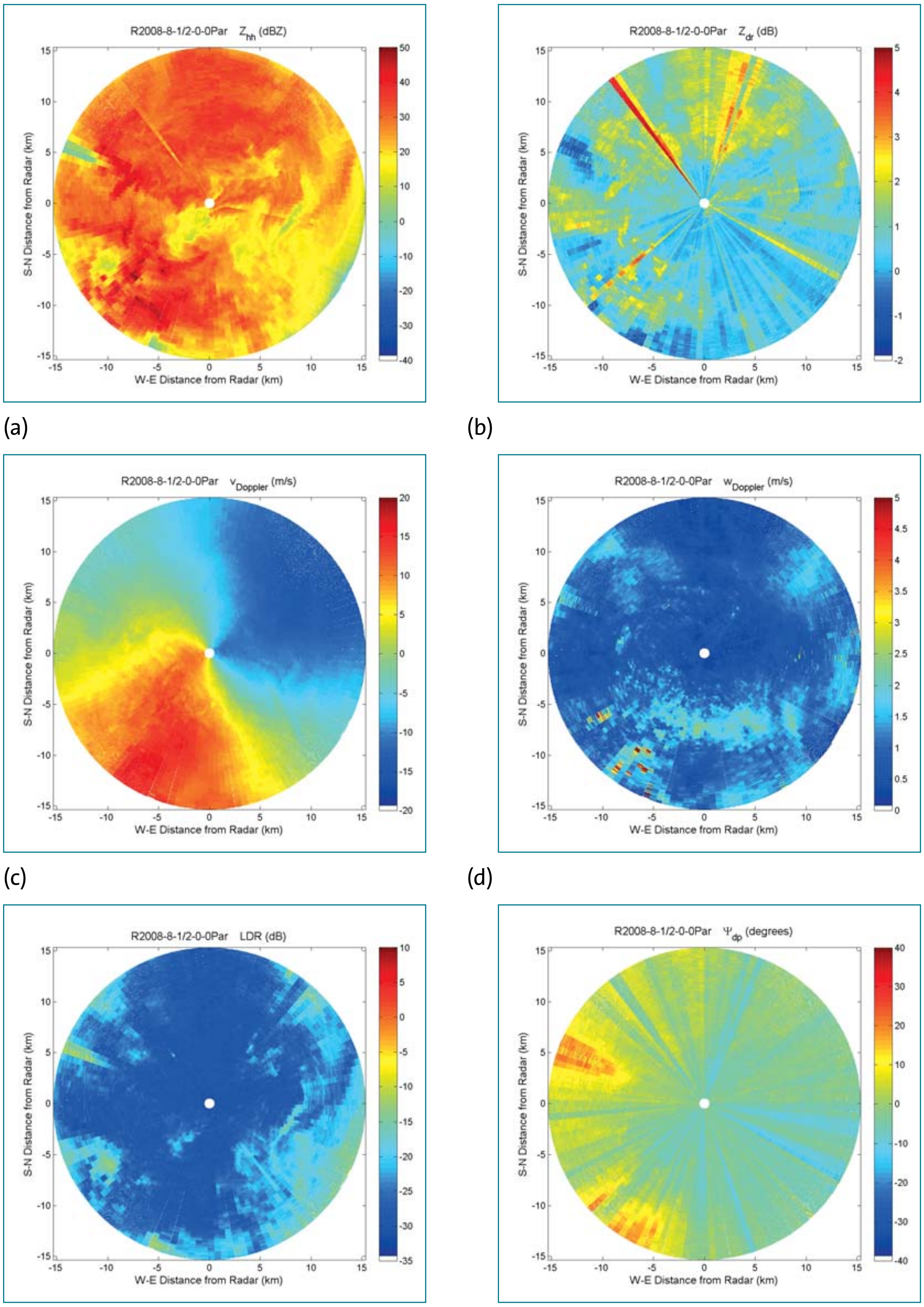
Figure 7.
Water balance terms in two two-month periods. P = precipitation [mm d^{-1}], ET_{act} = actual evapotranspiration [mm d^{-1}], Q_{in} = inflowing discharge [mm d^{-1}], Q_{out} = outflowing discharge [mm d^{-1}], ΔS_{rest} = residual change [mm d^{-1}], and ΔS_{sm} = change in soil moisture [mm d^{-1}].

2.6 IDRA, a new advanced high-resolution radar for drizzle observation

The radar was designed to observe the horizontal spatial distribution as well as the temporal evolution of rainfall. Its location on top of the 213 m high meteorological tower at CESAR Observatory ensures a reduced impact of ground clutter on the measurements. Furthermore, synergies between the radar and the large variety of measurements carried out by other instruments at CESAR are to be exploited. The radar is designed to have a good sensitivity and a large dynamic range which allows not only the observation of drizzle but also the observation of all other kinds of precipitation, even of heavy rainfall. It is a fully polarimetric radar system with Doppler capabilities and a high range resolution down to 3 m. By using polarimetry, clutter suppression is greatly improved such that a much cleaner atmospheric signal is obtained, which improves quantitative measurements. Drop-size distributions and drop-size to drop-shape relations can be established from polarimetric radar data, and hydrometeor classification is possible.

The following table summarises the specifications of the radar:

Parameter	Value
	
polarisation on transmit	linear horizontal and linear vertical
maximum range	15 km in standard mode
cross-polarisation isolation	< -30 dB
Minimum detectable reflectivity	-15 dBZ at 15 km in standard mode
central frequency	9.475 GHz (X-band)
Range resolution	3 – 30 meter
antenna half-power beam width	1.8° (0.031 rad)



(a) (b)

(c) (d)

(e) (f)

Figure 8.
Example of the IDRA radar showing a plan-position indicator measured at 2008-08-01, 2:00 UTC, with the antennae rotating at 1rpm. Shown are the weather radar observables (a) reflectivity Z_{hh} (dBZ), (b) differential reflectivity Z_{dr} (dB), (c) radial Doppler velocity v_r (ms^{-1}), (d) Doppler spectrum width w_r (ms^{-1}), (e) linear depolarization ratio *LDR* (dB), and (f) differential phase Ψ_{dp} (°).

In June 2008, the real-time data processing reached its operational status. Since then IDRA is regularly carrying out measurements. The radar can be remotely controlled. A near real-time display that is updated once a minute of the reflectivity measurement of the radar is available online at *http://ftp.tudelft.nl/TUDelft/irctr-rse/idra*. The data acquired by IDRA is made publicly available for scientific use. Via the CESAR database *http://www.cesar-database.nl* plan-position indicators (PPI) of reflectivity measurements can be obtained in five minute intervals. Additional IDRA observables such as Doppler velocity, Doppler spectrum width, polarimetric parameters and raw data are made publicly available via the 3TU.Datacentrum (http://dx.doi.org/doi:10.4121/uuid:5f3bcaa2-a456-4a66-a67b-1eec928cae6d). The data will be uploaded and archived regularly in the aforementioned publicly available databases such that the goal of a long-term observation of drizzle and precipitation properties by radar at CESAR can be achieved. A measurement example of one PPI acquired by IDRA is shown in Figure 8. Beside the reflectivity, the Doppler and the polarimetric parameters computer are shown.

2.7 A new Raman lidar for the diurnal observation of clouds, aerosol and water vapour profiles and boundary layer structures

The distribution and (optical) properties of aerosols and of clouds play a central role in atmospheric radiative transfer, as does the vertical distribution of water vapour. Over the past years, Raman lidar techniques have been developed that can provide this information. Several other profiling (lidar) techniques exist that can provide the same parameters as well, but the Raman lidar technique offers the possibility to provide all mentioned parameters with a single, robust system. The development of the Raman lidar for CESAR enables sensor synergy for the routinely retrieval of advanced data products for application in climate studies.

Based on a feasibility study the final configuration of the lidar was determined. It was decided to include the following parameters: water vapour to dry air mixing ratio, aerosol backscatter at 1064, 532 and 355 nm and aerosol extinction at 532 and 355 nm, and the depolarisation ratio at 532 nm. This configuration enables application of state-of-the-art retrieval algorithms for aerosol retrieval. The system is capable of performing around the clock measurements. The lidar system was built-up in a laboratory at the Dutch National Institute for Public Health and the Environment (RIVM). At first an experimental set-up was built, in order to test basic functionality and experiment with a number of different solutions for optical and mechanical design. After that, a final configuration was designed and built, re-using as much as possible parts from the pilot system. The complete system, called 'Caeli' (CESAR Water Vapour, Aerosol and Cloud Lidar), depicted in Figure 9 was put in a sea container to make the system transportable. The system was first deployed at the CESAR in May 2008.

The system validation for aerosol measurements took place during the EARLINET (European Aerosol Research Lidar Network) intercomparison campaign in May 2009 in Leipzig. Retrieval algorithms had been verified previously in a separate algorithm validation exercise also conducted under EARLINET. The performance of the water vapour profile measurements was routinely checked against regular radio soundings from the KNMI station in De Bilt. High-resolution water vapour measurements are possible, showing the capability of the system to observe highly dynamical boundary layer processes (Figure 10).

Since field deployment in May 2008, Caeli is performing regular measurements, according to the EARLINET schedule, i.e. two observations per week on fixed weekdays and preferably after twilight. Although EARLINET is aimed at aerosol profiling, all parameters are recorded simultaneously during measurement sessions, i.e. including water vapour and depolarisation. Caeli also participated in a correlative measurement programme for validation and representativeness of the space borne lidar CALIPSO. During night-time close proximity overpasses of the satellite, Raman lidar measurements were performed. Finally, Caeli took part in the intensive observation periods at CESAR during the international campaigns IMPACT (for aerosol modification studies) and CINDI (aimed at validation of air quality measurements from space borne platforms and from ground based remote sensing instruments). Quicklooks from the Raman lidar observations at Cabauw are available from http://cerberus.rivm.nl/lidar/Cabauw

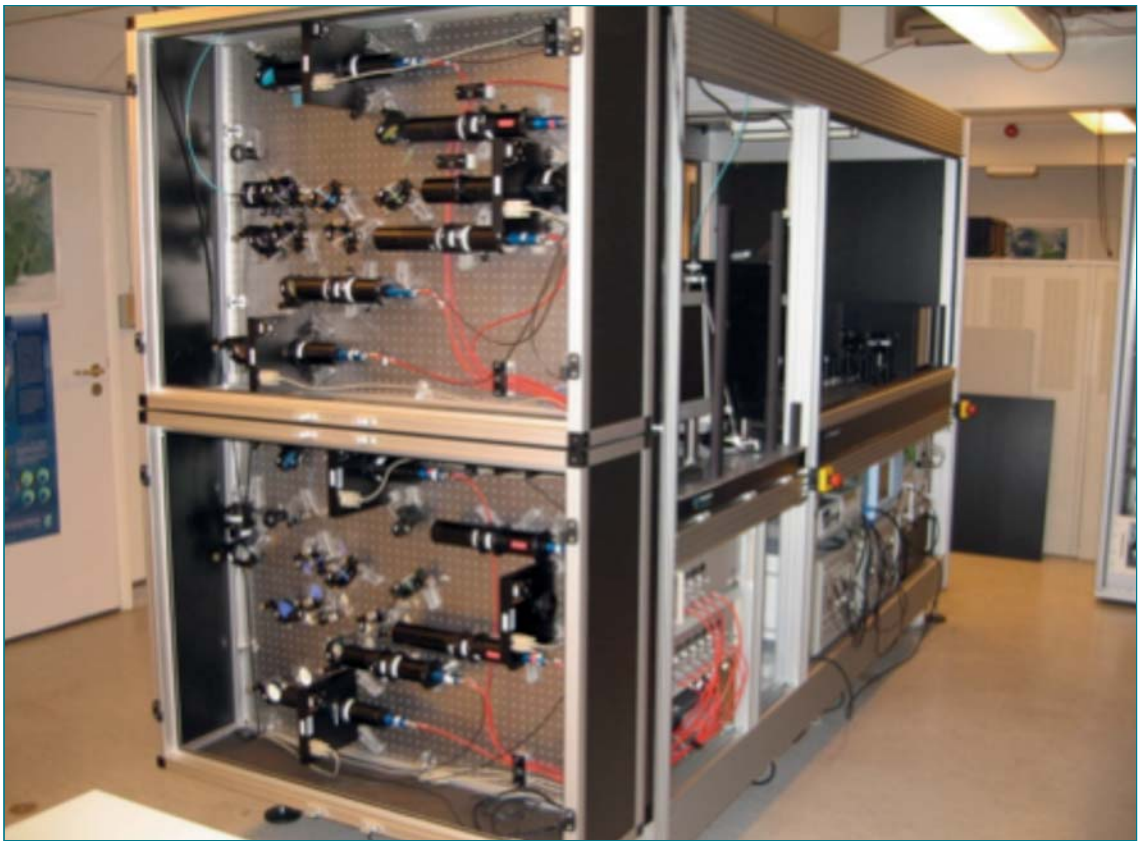


Figure 9.
Picture of the completed Raman lidar 'Caeli' in the laboratory.

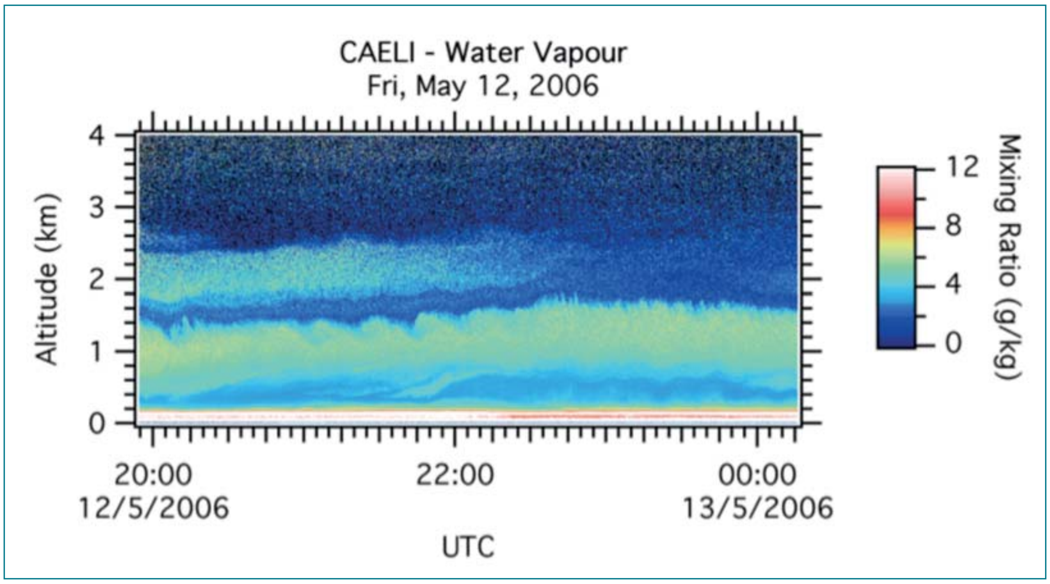


Figure 10.
Example of a high-resolution water vapour profiling measurement. Data are shown at 10 second integration and 7.5 meter vertical resolution.

3. The Cesar database portal

To utilize the CESAR data to its full potential it is important for the data users to be able to access, exchange and retrieve the data in an user friendly way with an acceptable response time and without any operator interference. A web based data management and distribution system is crucial to obtain this goal. Therefore KNMI developed in-house the CESAR database system CDS to address this need for CESAR data access and distribution. The frontend (i.e. the web portal) of the CDS comprises a self-registration, a limited search function and a download basket for ordering data files. Meta-data on the data set level is provided in the web portal, as well as an option to preview the data by quicklooks which are stored with the data files in the database. The data itself are all stored in netCDF format and comply with the Climate and Forecast Metadata Convention version 1.4. The backend of the system includes ftp-buffers for upload of the data by the data providers and for near real time distribution. The core of the backend is based on the Netherlands Atmospheric Data Centre (NADC) software, which handles all the ingestion, archiving, metadata extraction, and the generation and distribution of the logging and error reports. An offline facility has been implemented to generate statistics about user visits and download orders.

Cds General Description

The database is not developed as a full scale relational database but rather provides the user a search facility with a limited number of parameters. The data files and associated quicklooks are stored in a plain file system. The metadata of the data files are stored in a MySQL database. The datasets available in the CDS are free for non-commercial use under the restrictions described in the CESAR data policy document. However it is possible to restrict access to a limited user group but restricted access can be set only at the level of the dataset. All datasets, the public and the restricted, are delivered free of any charge. Therefore no accounting is implemented, only for creating user and download statistics a log of all access and downloads is maintained. The hardware of CDS is embedded in the ICT infrastructure of the KNMI. The input and output buffers are located on the main ftp-server of the KNMI, the hard disks for the storage of the data files and MySQL databases are part of KNMI's Central Data Storage system connected to the webserver via high speed optical fibre links. This set-up allows for easy extension of the hard disk capacity, and furthermore the system status monitoring is now fully incorporated in existing monitoring services. This set-up does ensure a high and long-term availability.

Metadata

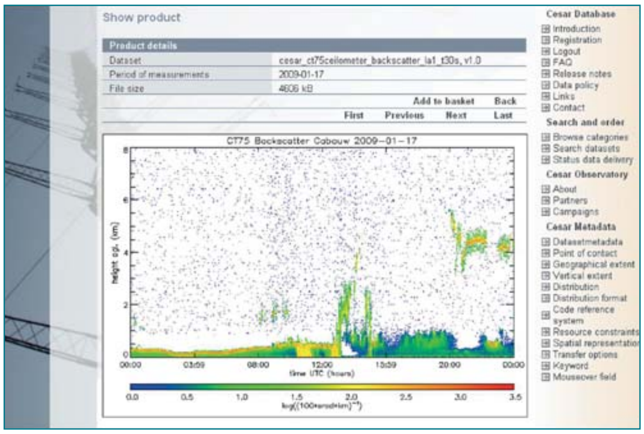
Meta data are data describing the data and are essential for the users either to find the required data and/or to assess the usefulness of the data (quality, origin, etc.). Meta data can apply to different levels of data, e.g. the whole dataset or to a single member of the dataset. All the data files stored in the file system of the CDS must comply with the CDS filename convention. The filename format allows the user to easy recognize the contents of the file from the filename itself. The time variable in the file is always in hours offset from midnight (UTC) from the day that follows from the filename. This is stricter than the CF convention prescribes.

The CDS web portal

The CDS is developed to access the data without any operator interaction. A straightforward self-registration procedure is available in the web portal. On first sign-on users fill in a valid email address, their full name and affiliation. After successful registration a password is sent to this email address. On self-registration the user gets access to all public datasets. Access is regulated by a role; each user is assigned initially a public role which gives access to all public datasets. Access to restricted datasets can only be granted by the manager of the CDS by giving the user a different role.

Browsing datasets

The CDS provides two methods for browsing the datasets, i.e. 1) using the search facility with combined keyword, time and characteristic value queries, or 2) using the category tree. The latter provides a graphical representation of the CDS by category in the form of a collapsible tree view. Once a selection has been made the user can browse through the selection and preview the quicklooks of each data product. In the preview window there is an option to add the data product to the download basket. The search selection can also be modified by changing the parameters in the search option window. In order to make the CDS system not too complex it was decided not to implement 'on-the-fly' creation of quicklooks and use fixed sized prepared quicklooks only. One quicklook per data product can be shown, an example is shown in Figure 11.



Show product

Product details	
Dataset	cesar_ct75ceilometer_backscatter_la1_t30s_v1.0
Period of measurements	2009-01-17
File size	4606 kB

Figure 11.
Example of quicklook preview.

Ordering data products

If a selection is made and the user wants to order the selected data products he can add the selection to the download basket. As long as the basket is open, i.e. is not ordered, products can be added or deleted. The total size of the data products in the basket is limited to 5 GB uncompressed. Once a basket has been ordered the CDS will start a process of retrieving the files from the archive, compress the files using gzip, and make a single tarfile containing all the products requested in the order. Upon completion of this task the CDS will send an email to the user with a link to the "My Cesar" page of the user on which a clickable link to the order is available. The order will be available for download for a week, after this week the tar file is deleted from the disk. The status of the recent orders can be viewed in the "My Cesar" window.

4. New technologies at CESAR Observatory

Throughout the course of the project new instruments – in addition to requirements of the Climate changes Spatial Planning program – were installed at the observatory:

1. A scanning pyrometer for cloud detection

KNMI purchased a scanning pyrometer, the so-called NubiScope, in order to assess its usefulness for cloud observations with a better spatial representation than a ceilometer derived cloud cover. The NubiScope is a passive remote sensing instrument which consists of a pyrometer mounted on a pan and tilt unit. The pyrometer measures the brightness temperature in the atmospheric thermal infrared window (8-14 μm). The NubiScope operates fully automated and performs a scan of the entire hemisphere every 10 minutes. The observed temperatures are processed in order to derive the obscuration type (fog, precipitation, clouds) and cloud characteristics (cloud cover, layering and altitude). During a one year field experiment at the CESAR the stability and the sensitivity of the pyrometer to contamination has been monitored. The measurements of temperature and cloud cover have also been analyzed and compared with other measurements. The NubiScope cloud cover product has as well been evaluated by observers at Rotterdam airport (25 km distance) using a near real-time access to the 10-minute NubiScope scans. The evaluation showed that the observed differences between NubiScope and ceilometer could mostly be attributed to the better spatial representativeness of the NubiScope. Furthermore, the sensitivity of the NubiScope for high clouds is often better. Over a one year period the total cloud cover of NubiScope and ceilometer gave 44 % of the time identical results and 80 % and 87 % of the time they are within ±1 and ±2 okta, respectively. The averaged difference in total cloud cover is 0.07 okta and mean absolute deviation is 1.03 okta. These differences between NubiScope and ceilometer are similar to the differences between an observer and a ceilometer. Scanning enables the NubiScope to detect isolated clouds in clear sky situations or gaps in overcast situations. This reduces the number of occurrences of 0 and 8 okta for the NubiScope as compared to a ceilometer and is in better agreement with human observed distributions.

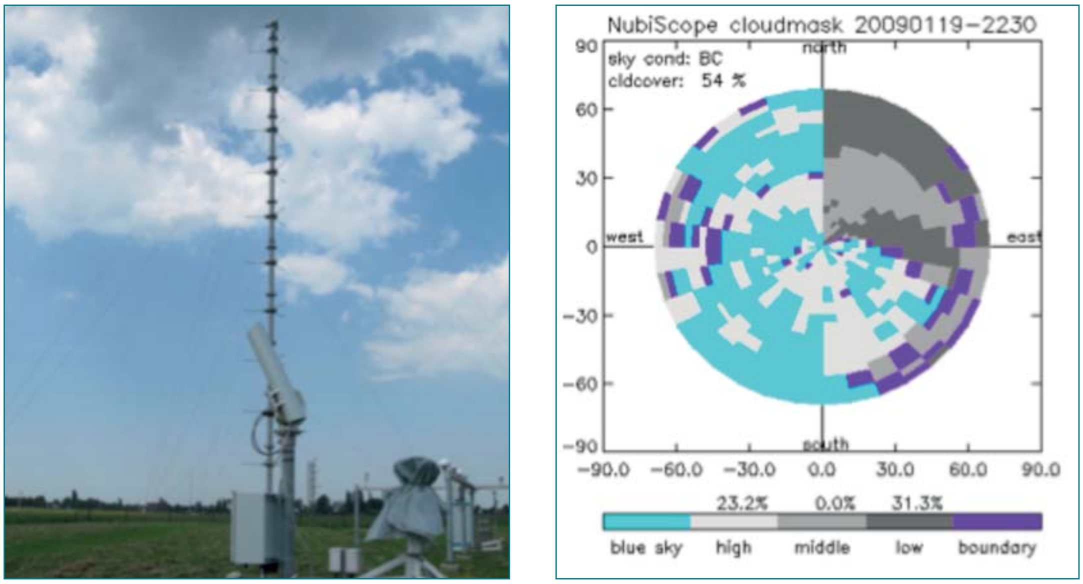


Figure 12:
The NubiScope installed at the BSRN site of CESAR (left) and derived cloud mask right during a situation with partial cloudiness.

2. Thermal desorption proton-transfer-reaction mass-spectrometry

Many of the aerosol climate effects are associated with uncertainties with respect to the organic fraction of fine aerosols. Standard filter based methods of measuring organic and elemental carbon are insufficient to constrain sources and sinks, or to elucidate the relevant physicochemical processes of organic aerosol formation. The introduction of aerosol mass spectrometry (AMS) has pushed forward the field and yielded many important insights. The advantages of AMS are that the major aerosol constituents (nitrate, sulfate, ammonia, and organics) are measured with high time- resolution and as a function of particle size. However, most of the chemical information of the organic fraction is lost due to extensive fragmentation during the electron ionization. Our goal was developing a technique yielding (i) reasonable temporal resolution (below 1 hour), (ii) detailed chemical information on constituent of organic aerosol, and (iii) a technique which is capable of quantifying the bulk of organic aerosol mass.

In 2007 we realized a first prototype of the thermal-desorption proton-transfer-reaction mass-spectrometer (TD-PTR-MS). The instrument is based on conventional PTR-MS technique which is enhanced by collection thermal desorption (CTD) aerosol inlet. Aerosols in the size range PM 0.9-2.5 are humidified and efficiently collected on a small spot in the CTD-cell. After the aerosol sampling cycle is completed the CTD-cell is gradually heated according to a pre-set temperature program. Evaporating organic and inorganic compounds are carried over to the PTR-MS for detection and quantification. Since summer 2009 a high mass resolution version of this instrument (hr-TD-PTR-MS, equipped with a time of flight mass spectrometer) is available which allows to determine the empirical formula rather than the nominal (integer) mass of the detected species. E.g. pinonaldehyde ($C_{10}H_{16}O_2$, mass: 168.115 Da) and Trimethoxybenzene ($C_9H_{12}O_3$, mass: 168.079 Da), both at nominal mass 168 Da, are separated by their fractional mass difference of 36.4 mDa. The concentration of hundreds of organic and inorganic aerosol compounds can be simultaneously monitored with this technique. A detection limit of a few pg/m^3 amounts of substance and a time resolution of 30 minutes have been achieved under field conditions. An example of first field data obtained with the instrument is given in Figure 13.

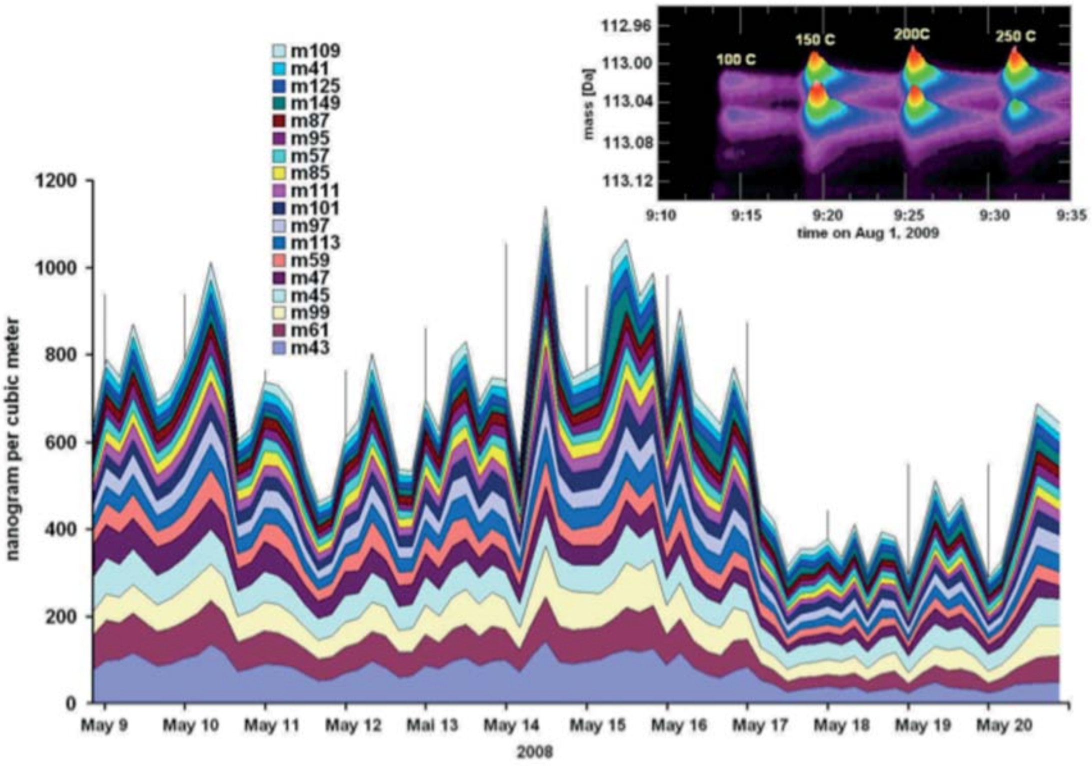


Figure 13.

Example TD-PTR-MS data during the EUCAARI-IOP campaign at the CESAR site. The Figure shows the timelines of the 18 most abundant ion signals detected with a quadrupole mass filter. The superior capabilities of the high-mass-resolution instrument reveal that the signals at nominal (integer) masses are usually due to several contributing species. The insert gives an example for mass 113: two major signals were observed at m113.023 and m113.060 attributed to $C_5H_4O_3H^+$ and $C_6H_8O_2H^+$, respectively. The 4 sequential peaks correspond to the signal from evaporating aerosol organics at CTD cell temperatures of 100, 150, 200, and 250 degrees Celsius, respectively.

3. Aerosol MAX-DOAS

Multi-axis differential optical absorption spectroscopy (MAX-DOAS) is a technique to derive profiles of atmospheric constituents using spectral radiation measurements under different elevation angles. The DOAS method has been applied for three decades to measure a wide variety of gaseous species relevant to atmospheric chemistry, the application to aerosol retrieval is a new application the development of which was started in the last 5 years or so. Within EUSAAR a new MAX-DOAS method consisting of a cost-effective, very simple and mobile instrument that can be implemented at monitoring stations within EMEP is developed. The MAX-DOAS instrument was set up in Cabauw for testing and development from 02.05.2008 until 30.06.2008 and from 09.06.2009 until 12.04.2010. In the latter period a large number of MAXDOAS systems was brought together for two months during the CINDI campaign (Cabauw Intercomparison Campaign of Nitrogen Dioxide measuring Instruments). The designs of the MAX DOAS systems participating in CINDI covered a wide range of sophistication. For the retrieval algorithms the range was even larger, some groups had no retrieval algorithm at all, whereas other groups already combined several measurements in their algorithms. During the campaign the performance of the newly developed state-of-the-art MAXDOAS systems were tested and the systems were evaluated though inter-comparison of the aerosol products (ongoing). The first publications are expected spring 2011.

4. Wet Nephelometer

Aerosol in-situ measurements are performed under dry conditions. Ambient aerosol particles take up or release water depending on the ambient relative humidity. The hygroscopic growth at enhanced RH most notably impacts on the scattering coefficient. Accurate knowledge on the hygroscopic growth factor is crucial for calculations of the aerosol radiative effect (climate) and comparison to remote sensing products. To deal with this issue a new generation of standard, cost-effective humidity-controlled aerosol monitors for long-term monitoring activities has been developed within EUSAAR. This new generation of wet-nephelometers allows for scattering coefficient measurements at a range of controlled RH, from low to high. It serves as a basis to upgrade current nephelometers and as a standard instrument for future intercomparison. In the testing phase this new built instrument was operated in Cabauw during a four-months campaign in the summer of 2009. The results are published by Zieger et al., 2010 (ACPD, 2010)

5. Humidity Tandem Differential Mobility Analyzer

Aerosol particles change in size due to condensation or evaporation of water vapour, in response to changes in relative humidity. The actual response depends on the particle's chemical composition and is expressed by the hygroscopic growth factor. The hygroscopic growth factor of a certain aerosol particle can be defined as the ratio of wet and dry size of that particle. The hygroscopic growth factor can be determined by measuring particle size at different relative-humidity levels using a Humidity Tandem Differential Mobility Analyzer (H-TDMA). First the sample aerosol is dried and certain dry size class of particles is selected. Then the sample is humidified to known relative humidity and the size distribution of the wet sample is measured. Within EUSAAR a new generation of operational H-TDMAs is developed that can be used for long-term monitoring activities. An H-TDMA was operated at Cabauw starting during the EUCAARI campaign in May 2008 until the end of the summer of 2009.

6. Neutral Air Ion Spectrometer

The atmospheric nucleation and cluster activation take place at the mobility diameter range of about 1.2-2 nm. The Air Ion Spectrometer (AIS) is designed to measure mobility distributions of small atmospheric ions and charged particles (mobility diameters 0.8–40 nm in NTP) and is available since 2003. The last years an improved inlet section allows measurements of neutral particles as well (Neutral Air Ion Spectrometer NAIS). In case of parallel ion and neutral cluster measurements, the relative importance of ion-induced particle can be studied. From 15-04-2008 to 31-03-2009 (N) AIS were operated (partly also parallel) at Cabauw in the frame of EUCAARI. The spatial and temporal variation of the new particle formation events and parameters describing them are quantified and calculated estimates for three particle formation parameters are given: 1) particle formation rates and 2) growth rates, and 3) the contribution of ions to particle formation. At Cabauw, the number of nucleation events was observed to be highest in May-June and lowest in December-January. It was found that ion-induced nucleation starts earlier than neutral nucleation.

5. Observations for model evaluation

Atmospheric models are at the heart of weather forecasting, climate prediction and chemical transport studies. Confronting atmospheric models with relevant observations is key to assess the quality of the models and to improve the models. The increasing resolution of weather forecasting models and the interest for more detailed short-term forecasts calls for the assimilation of local observations. Here we describe a selection of model studies performed in the last few years in which CESAR observations have played a crucial role.

1. From process study to parameterization - ice cloud effective radius

Ice clouds play an important role in the energy balance of the atmosphere. They can either cause cooling or warming depending on their altitude, ice water content and microphysical properties like the particle effective radius. Describing the effective radius properly is important, as it determines, combined with the ice water content, the optical thickness and emissivity of ice clouds. In atmospheric models, the ice cloud effective radius commonly parameterized in terms of temperature and/or ice water content. Combined lidar and radar data was used estimate the effective radius of ice clouds above CESAR Observatory and compared to an earlier analysis performed using data from the ARM programs SGP site. It was found that the distribution of lidar-radar-derived effective radius with temperature was similar at Cabauw and at the ARM site. However, the mean dependence was found to be sufficiently different to warrant further investigation. Further investigation revealed that representing the cloud effective radius as a function of normalized depth from cloud top for different cloud thickness regimes yielded a parameterization that seemed equally valid for both the Cabauw data and the ARM data set.

The radiative effect of implementing this parameterization was then investigated by using radar-derived profiles of ice water content together with surface-based short wave transmissivity measurements. Here it was shown that the new parameterization yields the least bias compared to the default temperature dependent parameterization.

The new parameterization was implemented within the KNMI regional climate model (RACMO2) and forecast runs for an entire year (1995) in the domain in between 62W, 62E, 27N and 75N were performed. Maximum differences in planetary albedo and transmissivity due to the new parameterizations are found to be in the order of a few percent. Effects found in this study are relatively small compared to what the effects would look like for a climate run, as in such runs differences in the radiation flux profiles would impose a long-term feedback on the model dynamics. For the forecast runs presented here this effect is absent as the model is reset once a day.

2. The 3rd GABLS Single Column evaluation and intercomparison case

Correct representation of the stable boundary layer in models is of importance for applications ranging from weather forecast, climate studies, atmospheric transport, agriculture, wind engineering, aviation and public transport. Data from the long term CESAR archive to evaluate the atmospheric boundary layer as simulated by 19 models; we focus on the single column simulations. The study is performed in the context of the GEWEX Atmospheric Boundary-Layer Study (GABLS).

The specific characteristics of the CESAR site e.g. its flat topography and reasonable homogeneity makes it well suited to study decoupling around sunset, low level jet formation and the morning time transition. A suited case was found in the Cabauw long observational dataset: July 1st 2006 12 UTC to July 2nd 2006 12 UTC. This is an (almost) clear sky period with reasonable constant geostrophic wind over time of typically 7 m/s resulting in a turbulent stable boundary layer over night with a pronounced temperature drop and a well-developed low level jet at around 200 m height, caused by an inertial oscillation. The case setup is defined at www.knmi.nl/samenw/gabls.

Figure 14 shows time series of the 2 m temperature from the models together with the observations. The general signature of the temperature change is well captured by the models, e.g. a fast decrease during the first hours after sunset, followed by a more gradual decrease in the subsequent hours. Half of the models are within 1 K of the observations. The remaining models are up to 5 K colder then observed. Winds at the 200 m level are also shown in Figure 13. The 200 m level is interesting because in the observations it is well decoupled from the surface and it exhibits a substantial inertial oscillation after the onset of decoupling around sunset. All models peek at 11 hours after the start of the simulation but all of them at a lower value then observed. More than half of the models peek within 2 m/s from the observed values.

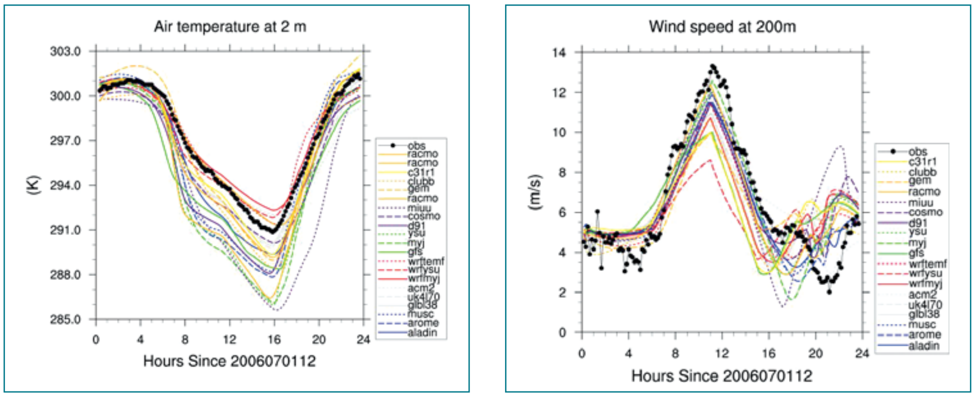


Figure 14.
Air temperature at 2 m for the models together with observations (left); wind speed at 200 m for the models together with observations (right)

3. Assimilation of local observations – Combining a Single Column Model with CESAR observations

To arrive at a best-estimate of the state of the atmospheric boundary layer, a data-assimilation system has been set-up, which combines the observations with a state-of-the-art atmospheric model. At KNMI, a Regional Atmospheric Climate Model (RACMO) is run in forecast mode on a continuous basis. A Single Column Model (SCM) is directly derived from RACMO. In search of an appropriate data-assimilation method first, a variational technique was pursued on the relatively simple problem of the thermodynamics of the soil in Cabauw. Implementing this technique on the much more complex full atmosphere-soil model proved to be too complicated.

Alternatively, the method of ensemble Kalman filter (enKF) was selected. Instead of using only one model realization, in an enKF system a collection of model realizations is used. Randomly disturbed initial conditions and large-scale forcings introduce small differences in the various model realizations. The spread among the ensemble members represents the uncertainty in the model forecast. By comparing this uncertainty with the estimated observation errors, an optimal estimate of the state of the atmosphere can be derived.

As an example, Figure 14 shows the impact of the data-assimilation system for one month of SCM forecasts. In this case, near-surface observations of temperature, specific humidity and both components of the wind vector were assimilated. Figure 15 compares model results for simulations with (enKF) and without (Empty) assimilation of observations with soundings from De Bilt at 12 UTC. It demonstrates that the assimilation of near-surface observations significantly reduces the root mean square error in a deep layer of 1000 to 1500 m above the surface. Combining model information with observations appears to provide a more accurate estimation of the state of the lower part of the atmosphere than can be obtained from both sources separately.

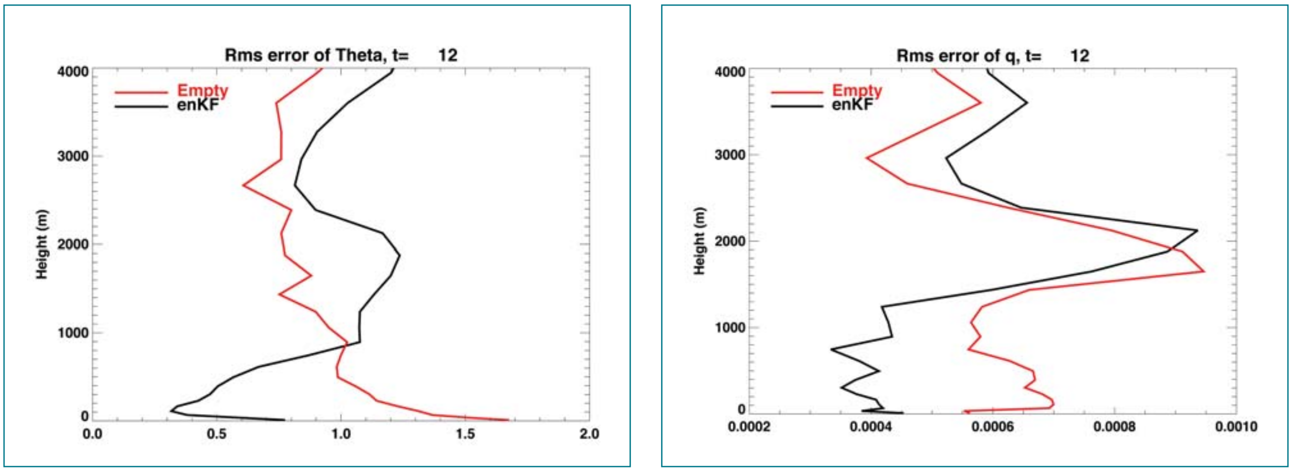


Figure 15.
RMS profiles of potential temperature (K) (left panel) and specific humidity (kg/kg) (right panel) at 12 UTC. Average values over 31 forecasts of the month of May 2008. The rms calculations are based on a comparison with soundings from De Bilt at 12 UTC. The black line presents the enKF results, the red line the Empty results.

4. The KNMI Parameterization Testbed (KPT) - A tool for process studies

Uncertainties in numerical predictions of weather and climate are often linked to the representation of unresolved processes that act relatively fast compared to the resolved general circulation. These processes include turbulence, convection, clouds and radiation. Single-column model simulation of idealized cases has become an often-used and relied-upon method to obtain insight at process-level into the behavior of such parameterization schemes; benefits are the enhanced model transparency and computational efficiency. Although having achieved demonstrable success, some shortcomings of this approach have been identified; i) the statistical significance and relevance of single idealized case studies might be questioned, and ii) the use of observational datasets has been relatively limited.

A recently initiated project at KNMI, named the KNMI Parameterization Testbed (KPT), is part of a general move towards a more statistically significant process-level evaluation. The aim of this project is to optimize the identification of problems in general circulation models that are related to parameterization schemes. The strategy of KPT is designed to address said shortcomings, as expressed by its two main targets:

1. To generate continuous series of single-column model simulations that cover long (i.e. multi-year) periods of time, in order to reproduce the same statistical level at which a general circulation model is typically evaluated;
2. To evaluate the complete parameterized system at multiple timescales against as many independent observational datasets as possible, for example as available at permanent meteorological super-sites.

Observational datastreams from various continuously operational meteorological sites are available in KPT, including most European CloudNet sites and the various sites of the Atmospheric Radiation Measurement (ARM) program of the Department of Energy of the United States government. However, the data coverage is most extensive for the Cabauw Experimental Site for Atmospheric Research (CESAR, http://www.cesar-observatory.nl/), the site for which KPT was originally developed. An interactive graphical user interface (GUI) has been developed for KPT that facilitates the visualization and inter-comparison of all types of datastreams at a range of different time-scales, ranging from high-frequency raw data at near-real time to long-term (multi-year) composites. The interface is directly coupled to the extensive CESAR archive that is maintained at KNMI. The participating single-column models represent most major operational European forecast and climate models, and currently includes ECMWF, ECHAM, HARMONIE, and WRF.

6. Future prospects of CESAR Observatory

The funding by the Climate spatial planning program was intended as an impulse to develop the observatory into its current state. Great challenges lie ahead of the scientific community to exploit CESAR Observatory to its full potential. Several areas are distinguished:

1. **Process studies.** The observatory is well-equipped for detailed studies of atmospheric processes that should lead to a better understanding of these processes in the climate system. The observatory has already hosted several international observation campaigns to study cloud-aerosol-radiation interaction, rainfall, land-atmosphere exchange processes and atmospheric chemistry, and will continue to do so. The quality of the observatory attracts many international scientists to participate in observation campaign and add their own instrument to CESAR's arsenal.
2. **Climate monitoring.** Climate changes over long time scales. Apparent trends in climate change can therefore only be traced within long time records of quality observations. CESAR Observatory is well-equipped to this task. Many essential climate variables can be measured routinely and stored in the CESAR data base. Not only can we monitor local variations of climate drivers– like solar radiation and greenhouse gases – in relation to the temperature, but also in the context of climate feedbacks, like cloud formation and water vapour.
3. **Model evaluation.** Climate models are based on laws of physics, but the climate system is too complex to model without assumptions and approximations, especially concerning physical phenomena that occur on scales smaller than the resolution grid of climate models. High quality observations are necessary to test the validity of these assumptions, to improve the model output via data assimilation and to develop better parameterizations of these small scale processes.
4. **Satellite synergy.** Observations from space are of the utmost importance to get a global overview of the climate system. However, the spatial and temporal accuracy of satellite observations is often limited. This can be improved significantly by combining space observations with measurements from the ground. The detailed information from ground observations can be incorporated in satellite retrievals and used for quantitatively and qualitatively enhancements. CESAR Observatory is well-suited for this work.
5. **New technologies.** CESAR is not only an observatory. It is also a field laboratory for new technologies. Prototypes of new instruments and technologies can be tested and validated. A good example is the weather radar installed on top of the CESAR observation tower: this radar is seen as a prototype of regional radar for the detection of extreme rainfall in urban areas.

7. Recommendations

Climate monitoring calls for long term systematic observations of essential parameters with an adequate and well defined accuracy and quality. This requires long term commitment of institutes that are able to perform observations on an operational basis. The project has shown that for some parameters these requirements are already fulfilled by the CESAR consortium. For other parameters it has been shown that it is in principle possible, but a significant investment is still needed to meet the requirements for climate monitoring in a cost effective way. Notably, systematic observations of cloud and aerosol properties and greenhouse gasses presently depend on insecure funding and continuity is at risk. Climate studies require a long span of attention, but the regular funding mechanisms do not offer the right backbone in support of such long term studies. In particular Climate monitoring is experiencing the drawbacks of the current system. It takes a long term commitment of the CESAR consortium and supporting institutions to meet the requirements for this.

Modellers and observationalists are serving the same purpose, but from different perspectives. In many programs these two communities do not collaborate as effective as possible. It is advised that in future programs joint activities are developed for observationalists to understand better what the needs of modellers are, and for modellers to understand better what the possibilities of new technologies and measurement techniques. Such a close cooperation will trigger a constant attention to the quality of the observations. Due to the nature of climate monitoring this cooperation would preferably be with an operational modelling group.

To allow optimal uptake of the data by the climate community a transparent data web portal is essential. This also encourages feedback of users to the data providers. This is to the benefit of data quality. It is advised to make the data availability and archiving an integral part of future projects, and not to distribute responsibilities over too many different parties.

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Selected overview of activities

Campaigns

Research groups aiming at targeted measurements campaigns are attracted by the complete set of observations continuously available at CESAR. In the past ten years the following campaigns were organized CESAR, or CESAR participated as a main station:

Acronym	Funded	Year	Description
CLARA	NRP	1996	Cloud macro- and microphysics
CaPRIX	KNMI	2000	Test of VHF/UHF boundary layer windprofiler
CNN-I	CLIWANET	2000	Cloud macro- and microphysics
CNN-II	CLIWANET	2001	Cloud macro- and microphysics
BBC	CLIWANET	2001	Cloud macro- and microphysics
CREX-02		2002	Small scale structure of rain
BBC2	4D-WOLKEN	2003	Cloud macro- and microphysics
DANDELIONS	SRON-GO	2005	Aerosol and Nitrogen Dioxide OMI and Sciamachy
SPE	NLR	2005	Sound Propagation experiment
DANDELIONS	SRON-GO	2006	Aerosol and Nitrogen Dioxide OMI and Sciamachy
EAGLE	EU	2006	Land surface remote sensing
SatLink	NIVR-GO2	2006	Linking Satellite Observations of Aerosol Optical Depth with Ground Level Observations of Particulate Matter (SATLINK)
EMEP	CLTAP	2006-2008	Highly time resolved measurements of inorganic gases and aerosols
GOP	Germany	2007	Quantitative Precipitation Forecasting
EUCAARI	EU	2008	Cloud aerosol interaction
ESA-CALIPSO	ESA	2008-2009	Long-term clouds-aerosols database from spaceborne lidar Measurements

Satellite missions

Advanced continuous operating atmospheric profiling sites like CESAR offer valuable, interesting datasets for validation of satellite based retrieval schemes. The partnership of ESA in CESAR emphasises this aspect. CESAR observations are used in the validation of products from the following missions:

Acronym	Purpose
AVHHR	Land surface and land surface flux characterisation
NASA Calipso/Cloudsat	Study of cloud abundance, distribution, structure, and radiative properties
NIVR/OMI	Ozone Monitoring Instrument: continue the TOMS record for total ozone and other atmospheric parameters related to ozone chemistry and climate, measurement of air quality components and aerosol characteristics at daily global coverage
MSG2	Meteorology
AATSR	Advanced Along-Track Scanning Radiometer
Galileo	Satellite Navigation systems
Bepi-Colombo	Radio-Science experiment MORE

CESAR observations are also used for testing of Satellite Communications Systems
CESAR partners are involved in the development of the following missions:

Acronym	Purpose
GPM	Precipitation satellite validation
ESA/ADM-Aeolus	Atmospheric profiling (wind, clouds, aerosols)
ESA-JAXA/EarthCare	Atmospheric profiling
GOSAT	Green House Gases
OCO	Green House Gases

Model evaluation

Numerous model studies are performed with CESAR observations, both for process studies as well as for statistical evaluation of models. Two times CESAR- observations were heavily involved in evaluation of a large suite of state-of-the-art atmospheric models, specifically chosen for an international model intercomparison:

PILPS (1997)	Land surface-Atmosphere interaction
GABLS (2008)	Stable Boundary Layers

CESAR is also involved in the following model studies:
TNO with Aerosol transport modelled in LOTOS-EUROS;
ECN gas transport modelled with TRANSCOM;
The networks in CarboEurope-IP, NitroEurope-IP use CESAR observations for several model evaluations;
ECN and JRC-Ispra validate emissions;
ECMWF, UK Met-Office and Meteo France/CNRS use Cabauw CO_2/CH_4 observations for evaluation;
WUR evaluates RAMS-HYPACT with CESAR observations;
ESA evaluates propagation models for Satellite Communication and Navigation systems.

Climate changes Spatial Planning

Climate change is one of the major environmental issues of this century. The Netherlands are expected to face climate change impacts on all land- and water related sectors. Therefore water management and spatial planning have to take climate change into account. The research programme 'Climate changes Spatial Planning', that ran from 2004 to 2011, aimed to create applied knowledge to support society to take the right decisions and measures to reduce the adverse impacts of climate change. It focused on enhancing joint learning between scientists and practitioners in the fields of spatial planning, nature, agriculture, and water- and flood risk management. Under the programme five themes were developed: climate scenarios; mitigation; adaptation; integration and communication. Of all scientific research projects synthesis reports were produced. This report is part of the Climate scenarios series.

Climate scenarios

The projects in this field are designed to obtain high quality climate information and scenarios relevant for the Netherlands. The projects both focus on an improved monitoring and modelling of regional climate variability, and at the construction of tailored climate change scenarios suitable for exploring spatial adaptation options, such as flood retention areas or coastal defense. In all fields special attention is devoted to extreme climate conditions. The climate scenarios are designed and developed jointly with a number of key stakeholders.

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