P2.2 ATMOSPHERIC BOUNDARY LAYER OBSERVATIONS AT CABAUW THE NETHERLANDS

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1. INTRODUCTION

The KNMI site Cabauw in the Netherlands with its 213 m meteorological tower has been a focus of experimental boundary layer research already since the 1970's. Over the years the site has expanded its scope of work to land atmosphere interaction and clouds and its interaction with radiation. Recent interest in climate change and environmental issues have stimulated new research at Cabauw. Since 2003 six national institutes, organized in the consortium CESAR (Cabauw Experimental Site for Atmospheric Research), join their experimental atmospheric research on the Cabauw site (http://www.cesar-observatory.nl). This means that the scope of work is even further expanded to aerosols and its interaction with clouds and radiation, green house gases and soil hydrology. Moreover the combination of instruments at the site gives a large range of research possibilities (Russchenberg et al, 2005). Here we highlight research on the atmospheric boundary layer and its interaction with the land surface. We give an overview of the current observational program and its related research activities.

2. RESEARCH PROGRAMS

The atmospheric boundary layer (ABL) forms the transporting interfacial layer between the surface and the free atmosphere for momentum, heat, water vapour and trace gasses. The vertical transport is modulated interactively by the formation of boundary layer clouds. Radiative properties of these clouds are influenced by the properties and density of specific aerosols (CCN). Detailed observations in the boundary layer and at the surface are of importance for atmospheric model development and for the validation of specific satellite based products. Accurate representation of the ABL and its interaction with the land surface in atmospheric models is of great importance for weather forecast, climate prediction and for inverse modelling techniques to estimate greenhouse gas (GHG) sources and sinks.

Figure1. The 213 m meteorological tower at Cabauw, The Netherlands.

From an observational point, challenges are: 1) The issue of horizontal scale; 2) closure of the surface energy budget and its possible

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implication for surface gas flux observations (see Figure 2); 3) closure of the water budget; 4) cloud formation and its relation with aerosols and 5) the influence of transport on ABL budgets.

Uncertainty in the representation of the stable boundary layer (SBL) over land in climate models results in large discrepancies between simulated and observed winter time land surface climate in high latitudes. Within the context of GEWEX Atmospheric Boundary Layer Studies (GABLS) studies are performed which uses Cabauw observations, among others, to improve SBL model parameterizations. As an example Bosveld and Beyrich (2004) produced statistical results on the structure of the stable boundary layer which were demonstrated to be useful for model evaluation. Baas et al. (2006, **J1.7**) analyse the occurrence and characteristics of Low level Jets at Cabauw.

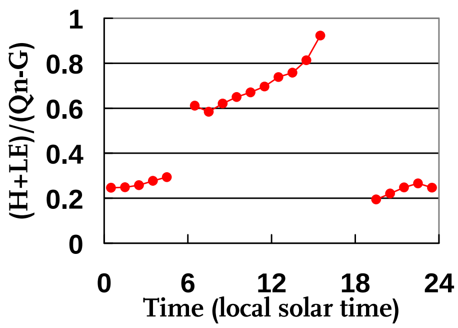

Figure 2. Composite over 1.5 year of diurnal change of the ratio between total turbulent surface heat flux (H+LE) divided by available energy (Qn-G). Night time relative imbalance is large, day time relative imbalance gets smaller during the day.

Other research is carried out under the flag of the Dutch research program Climate for Space (a.k.a. BSIK KvR). Among them is a project on the interpretation of boundary layer observations with respect to horizontal scale and the assessment of their mutual consistency. This is a site specific study which combines all relevant observations with a state of the art single column boundary layer model tuned for the specific situation at Cabauw and fed with the influence of transport from a 3D atmospheric model. The outcome aims at consistent time series of surface fluxes and ABL structure and dynamics. As a preliminary study Ronda and Bosveld (2006, **J5.9**) use adjoint techniques to assimilate soil thermal observations in a model.

As an important input for this project scintillometer observations are taken over a 10 km path to obtain regional scale sensible heat fluxes. Moene et al, (2006, **J7.1**) analyse the quality of these observations by comparing with airborne flux observations.

A second project under the same program aims at determining the water budget of the polder in which Cabauw resides. This gives water flux information on the scale of a model grid point. The water table in the ditches around Cabauw is managed by the local water board. Water balances can be made up by measuring polder in- and outflow of water, together with rain, soil water storage and evapo-transpiration. Uncertainties arise due to the unknown magnitude of seepage into the polder

The interpretation of accurate GHG concentrations at high towers of which Cabauw is one (http://www.chiotto.org), in terms of sources and sinks involves inverse modelling. When going from the global scale via continental scale to sub-continental scale the correct representation of boundary layer processes becomes more and more important. The project involves the high precision monitoring of GHG concentration along the tower together with observations of the transport capacity of the ABL.

The Cabauw grassland site is one of the sites in the Netherlands that monitor surface fluxes of GHG. It is part of the CarboEurope-IP network. Together with the other sites the information is used to access the GHG exchange for typical eco-systems in the Netherlands. Werner et al. (2006, **JP5.3**) analyse CO_2-flux observations at various heights in the tower to explore the possibilities of making up atmospheric CO2 budgets over the flat land around Cabauw.

Related projects involve the observation and study of boundary layer cloud formation with its interaction between aerosols and radiation and the fine scale spatial distribution of rain around Cabauw. In the near future the site will be augmented with a high resolution rain radar at the top of the tower. A Raman lidar will become operational with the possibility of continuous water vapour profiling. Other techniques for measuring atmospheric water like slanted path GPS and micro wave radiometry will be implemented. The CO2 observations form an interesting addition to wind, temperature and humidity observations to study the processes in the convective boundary layer (Vila de Arellano et al., 2004) .

z (m)	meteo	gasses	fluxes
200	F,D,TA,TD	CO_2, CH_4, N_2O, SF_6, CO, ^{222}Rn	
180			τ,H,λE,F_{CO2}
160			
140	F,D,TA,TD		
120		CO_2, CH_4, N_2O, SF_6, CO, ^{222}Rn	
100			τ,H,λE,F_{CO2}
80	F,D,TA,TD		
60		CO_2, CH_4, N_2O, SF_6, CO	τ,H,λE,F_{CO2}
40	F,D,TA,TD		
20	F,D,TA,TD	CO_2,CH_4, N_2O, SF_6, CO	
10	F,D,TA,TD	CO_2	
5		CO_2	τ,H,λE,F_{CO2}
2	TA,TD	CO_2	
1		CO_2	F_{CH4} F_{N2O}

Table 1 Instrumentation of the 213 m tower. Meteo of Wind speed (F), wind direction (D), air temperature(TA) and dew point temperature(TD). Concentrations of Carbon dioxide (CO_2), Methane (CH_4), Dinitrogenoxide (N_2O), Sulphurhexafloride (SF_6), Carbonmonoxide (CO) and Radon 222 (^{222}Rn). Fluxes of Momentum (τ), Sensible heat (H), Latent heat (λE), Carbondioxide (F_{CO2}), Methane (F_{CH4}) and Dinitrogenoxide (F_{N2O}).

3. OBSERVATIONS

3.1 *Basic meteorology*

The basic meteorological observations include precipitation amount and duration, short wave incoming radiation and surface pressure. Surface wind speed, wind direction, air temperature and dew point temperature are observed at standard heights. Radio soundings are available two times a day at the nearby (25 km) synoptical station De Bilt. At De Bilt also a weather radar is operated. Four synoptical weather stations are available each within a distance of less then 50 km from Cabauw.

3.2 *Tower profiles*

Detailed observations of meteorological parameters and of trace gas concentrations are made along the 213 m tower. Table 1 lists the observed parameters and their heights. The non-GHG concentrations like CO, ^{222}Rn and SF_6 are of particular importance since the sources are relatively well known which makes them suitable for the evaluation of atmospheric transport models.

3.3 *Soil Hydrology*

Observations of the polder in- and outflow are performed by the water board. In- and outflow observations at smaller catchments within the polder are also performed. Soil water storage is measured with vertical profiles of TDR sensors and with ground water level sensors in a row perpendicular to the ditches. Calibration of the TDR sensors needs special attention due to the electrical conductivity of the clay soil. Precipitation is measured with a number of rain gauges.

3.4 *Soil Thermodynamics*

Soil thermal characteristics are measured at a special plot. It includes a soil temperature profile, soil heat flux plates at two depths and at three positions to account for local soil heterogeneity and infrared surface radiation temperature. Various methods are used to derive surface soil heat flux from these observation.

3.5 *Surface Radiation*

Short wave downward and upward radiation is measured as well as long wave downward and upward radiation. From these four components the net radiation is calculated. Also net radiation is measured directly. Photo active radiation both upward and downward is measured. Since 2005 a BSRN station is operational at Cabauw.

3.6 *Surface fluxes*

Turbulent fluxes of momentum, sensible heat, latent heat and Carbon Dioxide are measured at 5 m height. In the previous years maize was grown to the West of the instrument location well within the footprint of the turbulence equipment. The instruments will be moved to the North of the main tower at a height of 3m so that the footprint is dominated by grass for most conditions. Local exchange fluxes of CH_4 and N_2O are monitored using an alternating box measurement technique.

3.7 *Regional fluxes*

To derive regional scale fluxes an Extra Large Aperture Scintillometer (XLAS) has been operated over a path of 10 km between the Cabauw tower and a Nearby TV-mast This instrument will be reinstalled. In the main tower turbulence equipment for wind temperature, humidity and Carbon dioxide is operated at the 60, 100 and 180 m level.

3.8 *Atmospheric Boundary Layer structure*

Boundary layer structure is observed by various remote sensing instruments. A windprofiler/RASS system gives continuous observations of the wind profile (up to 4 km) and hourly observations of the (sonical) temperature (up to 1 km). A boundary Lidar system is available that traces the boundary layer height. A Cloud Radar is available that measures among other boundary layer clouds and it gives continuously boundary layer profiles of C_n^2 with high vertical resolution.

4. CONCLUSIONS

With the foundation of the Dutch consortium CESAR the Cabauw site has grown to one of the better instrumented atmospheric profiling sites in the world. The observations related to the atmospheric boundary layer and the interaction with the land surface serve as the basis for a number of interesting boundary layer research projects. Dominating themes in these projects are the improvement and evaluation of parameterizations in atmospheric models and evaluation of satellite based algorithms for accessing land characteristics like surface evapo-transpiration, carbon flux and soil moisture. The studies relate to weather forecast and climate prediction and to the study of sources and sinks of GHG at the national and international level.

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