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INTEGRATING SURFACE AND BOUNDARY LAYER OBSERVATIONS OF CO2 EXCHANGE IN HETEROGENEOUS LANDSCAPES: EXPERIENCES FROM THE RECAB CAMPAIGN IN THE NETHERLANDS

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1. INTRODUCTION

The EU funded project “Regional Assessment and monitoring of the Carbon balance within Europe”, RECAB, aims to understand the main controlling factors determining carbon dioxide content in the atmospheric boundary layer at the mesoscale within representative areas in Europe, using a combination of experimental, forward and inverse modeling tools.

The project aims to develop a monitoring / validation methodology for carbon dioxide exchange between land and atmosphere at the scale in between that of stand scale flux towers (FLUXNET) and continental scale atmospheric sampling/inverse modeling. The project focuses on six regions in Europe, each centered on an existing permanent flux tower: Valencia (towersite: Albufera), Spain; Uppsala (Norunda), Sweden; Eisenach (Hainich), Germany; Ede (Loobos), Netherlands; Bordeaux (La Bray) France; Viterbo (Castelporziano), Italy. Here we present first analysis of results from a winter campaign (14 January-8 February 2002) in the center of the Netherlands. Where appropriate also results form the other campaigns will be presented.

2. EXPERIMENTAL STRATEGY

The experimental region measures about 70 km diagonally with the endpoints of the diagonal formed by the permanent flux tower at Loobos and the permanent tall tower at Cabauw.

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The area is located in the center of the Netherlands and basically comprises four major landscape units:

- hilly glacial deposits covered by various forest types (evergreen needle leaf, deciduous broadleaf and mixed), heath lands and bare dune areas
- agricultural land dominated by a mixture of grassland and maize crops on mostly sandy soils
- very low lying, wet grassland on clay and or peat soils
- urban areas

At the time of the conference a second, summer campaign is being executed in the same area.

Campaign wise observations have been made of:

- exchange fluxes of CO_2 between land and atmosphere deploying a number of permanent and mobile eddy-correlation flux towers, as well as an low-flying eddy-correlation flux aircraft
- CBL concentrations of CO_2 and other greenhouse gases, deploying flask-sampling from aircraft, and continuous sampling from tall towers
- general ABL dynamics using RASS-SODAR and tall tower observations

2.1 Airborne measurements

Airborne measurement of surface fluxes of CO_2 at very low altitude have been made by a Sky Arrow ERA (Environmental Research Aircraft) equipped with the NOAA/ARA Mobile Flux Platform (MFP), and a commercial open-path infrared gas analyzer (LiCor 7500). The plane typically operates at very low altitude (100-500 ft) and is able to measure turbulent fluxes of heat, water vapor and CO_2, radiative fluxes of net all-wave and PAR, radiative surface temperature, air temperature and dew point. GPS and onboard video camera provide accurate flight track registration. On- and off-line processing software has been developed to calculate and analyze fluxes.

Airborne measurement have been made, using a Piper Cherokee, of continuous concentration profiles of temperature, humidity, CO2, and flask sampling at discrete altitudes within and just above the Convective Boundary Layer. Flasks have been analyzed with high precision for concentrations of CO_2, CH_4 and N_2O, plus isotopic rations of δ^{13} C and δ^{18} O in CO_2. GPS provides accurate flight track registration. On- and off-line processing software has been/will be developed to calculate and analyze profiles and CBL budgets.

2.2 Tower measurements

In the region two permanent flux towers are being operated.

At the Loobos site (5.7439 E, 52.1667 N) fluxes of energy water and CO_2 have been measured continuously since 1995 above Scotts Pine. The annual sink strength of the forest varies between years between 2.3 and 3.7 tonnes Carbon.ha^{-1}.yr^{-1}. In addition radiation components, in and above canopy profiles of temperature, humidity and CO2 and soil moisture and heat flux are monitored.

At the Cabauw site (4.927 E, 51.971 N) turbulent fluxes have been measured intermittently for several years. In addition radiation components, and soil moisture and heat flux are monitored.

Another flux tower is in operation at a fully instrumented meteorological site at the Haarweg (5.628 E, 51.977 N) on grassland.

Finally a mobile flux tower was operated for the duration of the campaign on bare soil (Maize in summer). In winter this site (5.7157 E, 52.1491 N) was always a source of CO_2.

2.3 Auxiliary measurements

At the Cabauw site CBL profiles of CO_2 are monitored continuously at (4 or) 20, 60, 120, 200 m. Temperature, humidity and wind are monitored continuously at 4, 10, 20, 40, 80, 140 and 200 m. In addition at the site a wind profiler, ceilometer and (non-)scanning LIDAR are operated.

For the duration of the campaign an additional RASS-SODAR was operated at the Haarweg site.

3 RESULTS

Here we will present some example results of data collected as much of the analysis is still in progress. Airborne measurements were made twice daily on 5 days: 23, 25, 29, 30 and 31 jan and on 02 Feb., the last day being the ‘golden day’ of the campaign.

3.1 Tower based fluxes

In this period in winter most of the area is relatively wet. Figure 1 shows that latent heat fluxes can be considerable and for grasslands (‘Cabauw’) or bare soil (‘Maize’) often in excess of net radiation, thus leading to negative sensible heat fluxes (towards the surface). Over the ‘dark’ forest (‘Loobos’) net radiation is in excess of evaporation resulting in a postive sensible heat flux.

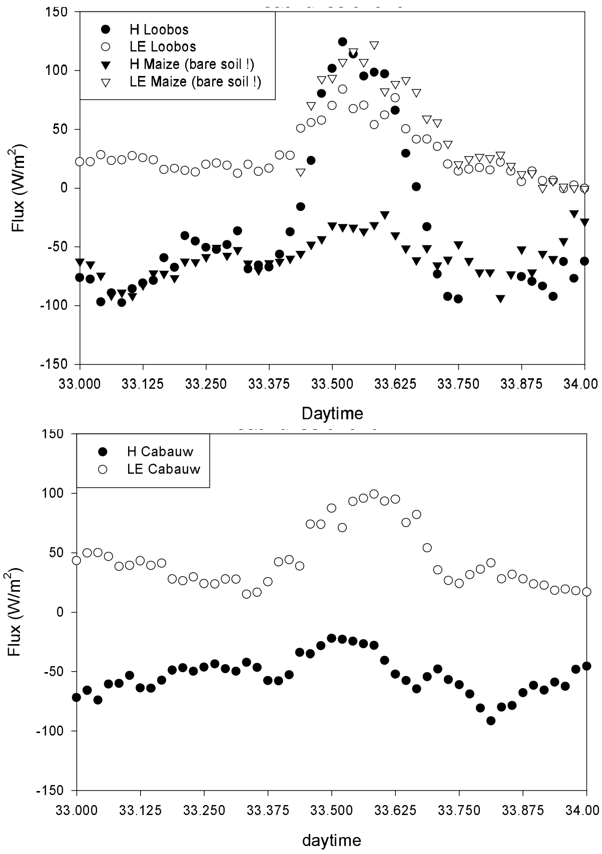

Figure 1. Heat fluxes on 02 february 2002 at three different sites.

Figure 2 shows that grasslands and bare soil are a source of carbon dioxide throughout the day in this season. On ‘nice’ days evergreen forest takes up CO_2; on more typical winter days the net CO_2 exchange of forest is minimal.

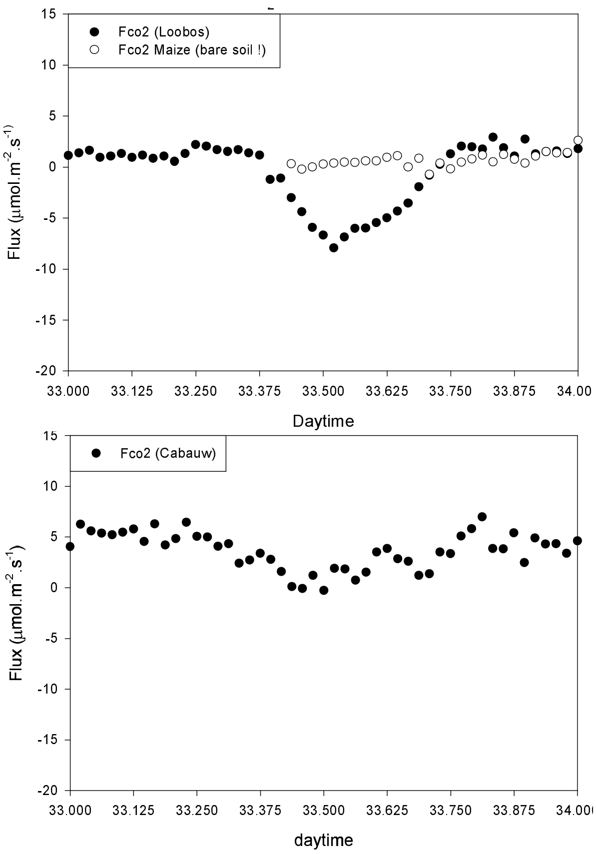

Figure 2. Carbon dioxide fluxes on 02 february 2002 at three different sites.

3.2 Airborne measured fluxes

The top figures on the last page show a comparison of fluxes observed from the Loobos tower (forest) and those observed from the aircraft. For momentum flux and sensible heat flux (not shown) the match is very good. For latent heat (not shown) and carbon dioxide the match is reasonably good. For the Cabauw tower fluxes the match to aircraft fluxes is better for latent heat and carbon dioxide than for sensible heat and momentum.

Figure 4 shows an overlay of aircraft measured fluxes on the land cover map of the region. It shows that over the forest sensible heat flux is generally substantial and positive, while over the agricultural areas it is small and mostly negative. Similarly CO_2 fluxes are generally negative (sink) over the forest and positive (source) over the agricultural areas.

3.3 CBL profiles

Figure 5 shows a typical CO_2 concentration profile for this campaign, comparing flask samples and continuous system. From such profiles CBL budgets can be calculated. Results from another RECAB campaign (Germany, winter) have shown the potential of the method, while at the same time recognizing the importance of subsidence and advection components. Similarly isotopic ratios have been shown in other RECAB campaigns to be useful to discriminate between the different ecosystems in a region.

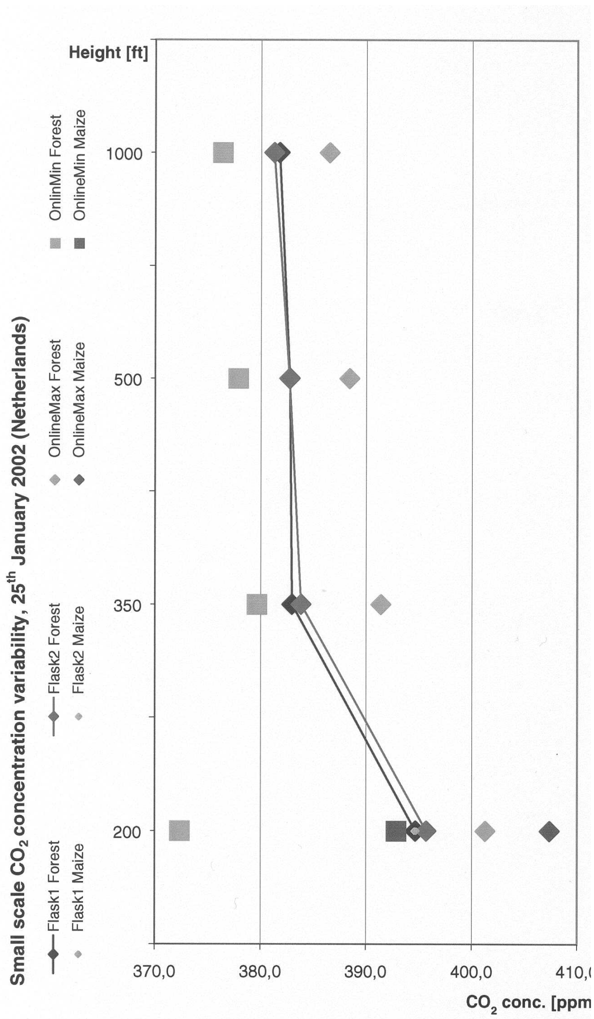

Figure 5. CBL profiles of CO_2 as measured by flasks (dots connected by lines) and by the continuous system (dots).

4 Conclusions

For most of the RECAB campaigns the match between tower based and aircraft based fluxes is rather good. Problems do arise in small scale landscapes with sharp contrasts (e.g. summer, Germany) possibly because of a mismatch between the spatial averaging window of aircraft data, and the underlying land surface heterogeneity. Work on better post-processing algorithms and footprint analysis of aircraft measurements is expected to improve this match. Measuring fluxes in this way appears to be a promising way to measures spatial patterns of heat and carbon dioxide fluxes, e.g. to validate spatially distributed models.

At the workshop more results will be shown and the general use of the RECAB strategy will be discussed.

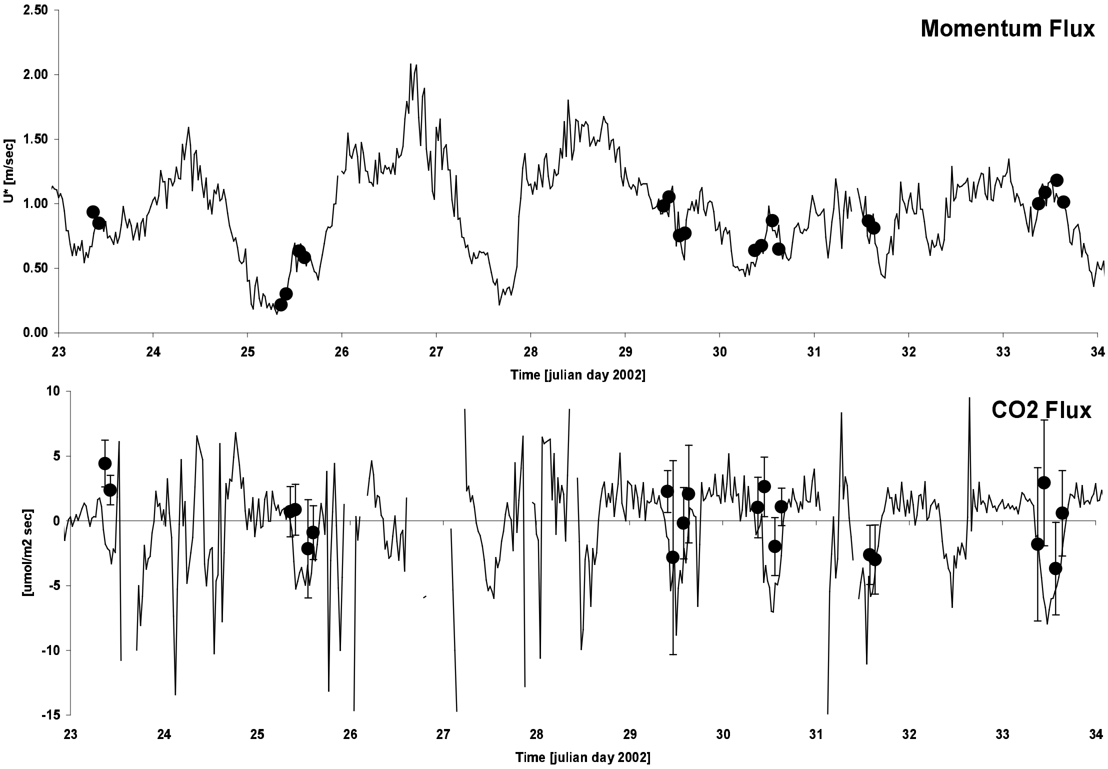

Figure 3. Comparison of tower based forest fluxes (line) and aircraft based fluxes (dots; averaged over entire flight track above forest). See text for explanation.

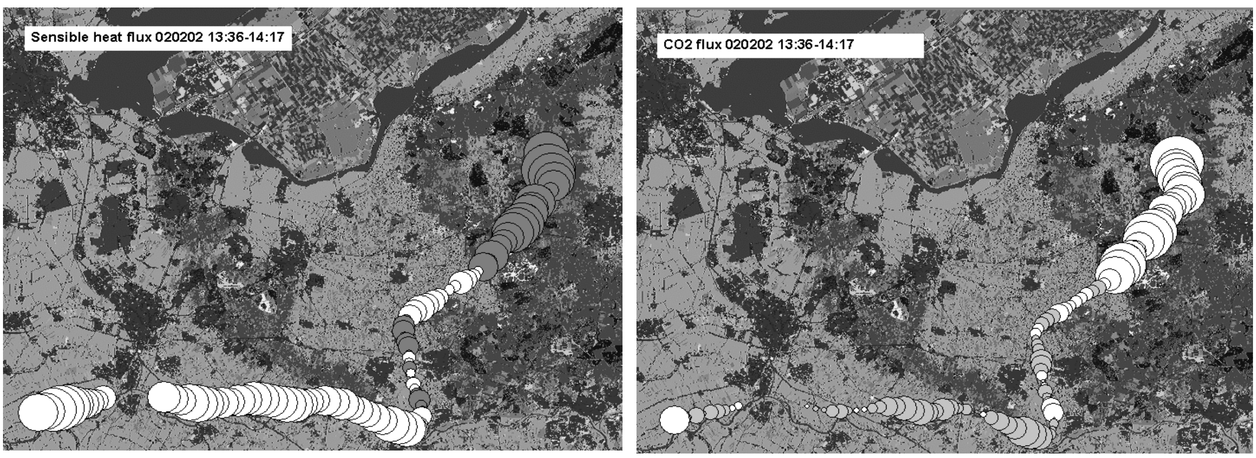

Figure 4. Aircraft measured fluxes (bubbles; left sensible heat; right CO_2) plotted on land cover map of the region. Bubble area relative to flux magnitude; colored bubbles positive, white bubbles negative fluxes.