Land Use Change in the Alps and its Effect on CO_2 and Water Exchange between a Composite Ecosystem and the Atmosphere

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Abstract First results of the European project "ECOMONT" are presented. In a field campaign on Monte Bondone near Trento, Italy, fluxes of H_2O and CO_2 over a composite ecosystem area were measured with scintillation anemometers and an instrumented aircraft. The turbulent fluxes from the aircraft data are discussed and compared to the advective fluxes. The budget of the fluxes from the aircraft data is evaluated and compared to the scintillation mass fluxes. After a correction of the advective term, H_2O and CO_2 exchange rates with the vegetation could be estimated.

1. INTRODUCTION

The European project "ECOMONT" (Ecological Effects of Land Use Changes on European Terrestrial Mountain Ecosystems) deals with investigating land-use changes in Alpine areas. It is embedded in the context of the Framework IV of the European Comunity: The functioning of ecosystems, see Cernusca 1995.

Alpine ecosystems are known to be particularly sensitive to pertubations, due to short vegetation periods or natural stresses such as windfall, sudden temperature decrease, drought and frost.

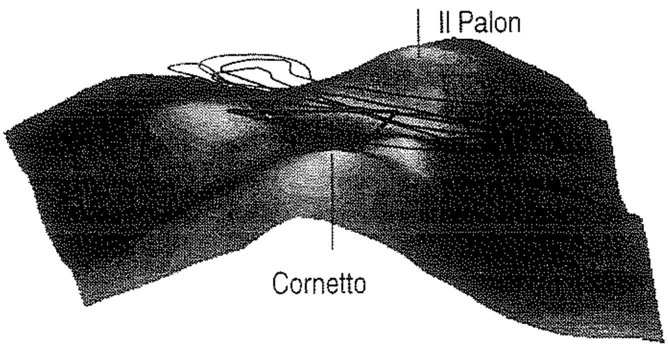

Figure 1: The experimental site on Monte Bondone West of Trento, Italy. Part of the aircraft flight track and underneath the triangel of scintillation anemometers is shown.

Consequently, the threshold value for harmful impacts such as anthropogenic air, water and soil pollutants is much lower compared to the ecosystems in less elevated areas. Furthermore, the decreasing interest in cultivating Alpine meadows and pastures gives rise to a change in the composition of ecosystems. It is the aim of ECOMONT to study mainly this changes due to abandoned high elevated agricultural sites. Three pilot experimental sites from the Northern Tirol, Austria, down to the Trentino, Italy, are evaluated for investigating the connections between land-use change and the transport of water vapour, CO_2, sensible heat and pollutants. This paper will focus on the pilot site on Monte Bondone, a mountain West of Trento, Italy. This mountain is located in the middle of the Trentino valley, reaching a height of 2100 m sea level. The valley bottom at Trento is of about 200 m sea level. As shown in Figure 1, the mountain is dominated by two peaks, the "Il Palon" in the North and the "Cornetto" in the South. In between these two peaks, a flat area of about 3 km^2 in form of an elevated Plateau on 1700 m sea level is the main area under consideration.

2. EXPERIMENTAL SETUP

Meteorological data are recorded with a 12 m tower on the East side of the Plateau. Parameters and averaging times are chosen according to the WMO (World Meteorological Orginasation) standards.

The fluxes of trace gases through vertical planes surrounding a triangel over the Plateau (see Figure 2) are determined by a combination of concentration and total air flux measurements. Concentrations of trace gases are measured with differential optical absorption spectroscopy (DOAS, see Graber et al. 1997) over open paths through the atmosphere. The integral air fluxes are measured with scintillometers (see Poggio et al. 1996) in parallel light beams. The combination of both instruments allows for the measurement of the advective flux perpendicular to the beams. Consequently, it is possible to evaluate the divergence or convergence of air masses within the triangel.

The flux of CO_2 and H_2O over the Plateau is further investigated with an instrumented motorglider. Theses two gases are measured with an open path, fast responding infrared absorption gas analyzer (see Auble and Meyers 1992) with 10 Hz temporal resolution, corresponding to 5 m spatial resolution for the instrumented aircraft used. In order to determine the turbulent fluxes due to large scale eddies, a fast responding wind measurement is established on the aircraft.

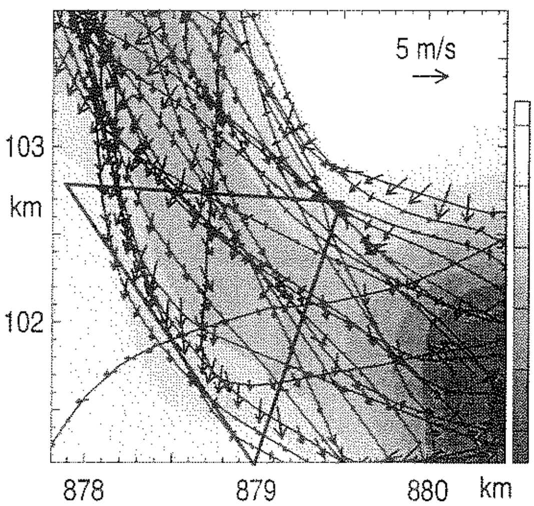

Figure 2: The flight path over the Plateau with the triangel of scintillometers. Along the flight path the horizontal wind is shown.

These wind measurements consist of a five hole pressure sonde (see Crawford and Dobosy, 1992) and a fast GPS (satellite based global positioning system): The wind is calculated as the difference of the motion of the aircraft relative to the wind and relative to the earth. Additionally, ozone, temperature and NO_2 are measured.

The flight patterns are in accordance with an optimal density of information on a local scale with the following focal questions: 1. Perpendicular to the valley axis vertical planes are investigated to estimate the total influx of water and CO_2 with the valley wind. 2. Horizontal planes with a meandering flight pattern coveres the Plateau with extended low-level aircraft flux transects. An example is shown in Figure 2. 3. Stacks of flight lines along the upwind and downwind borders of the Plateau are investigated to get data for budget analysis. To exhibit the method applied to the data, the present study focusses on the horizontal flights over the Plateau. An example of 1100 sec duration of the flight of 18 June 1997 from 09:30 to 12:00 CET is shown in Figure 1.

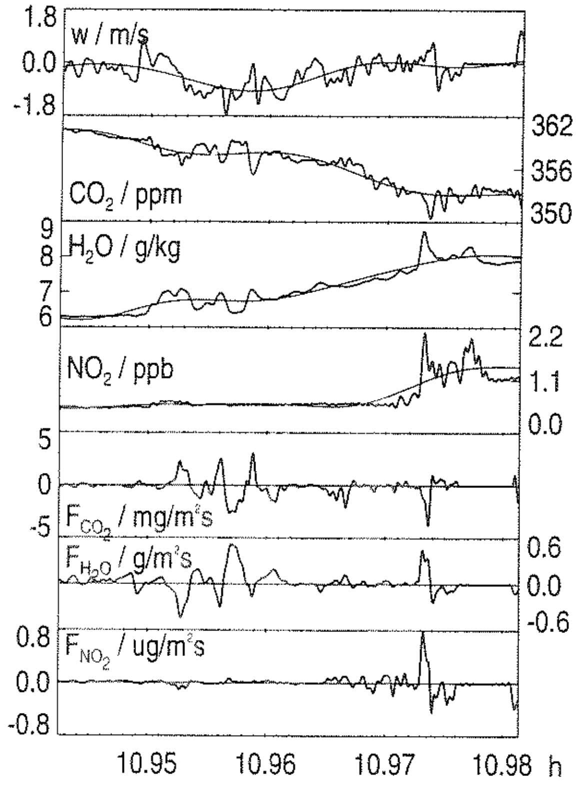

Figure 3: Time sequence of aircraft data with vertical wind w, CO_2, H_2O and NO_2 concentrations and fluxes.

3. AIRCRAFT DATA EVALUATION

This chapter deals with the evaluation of a dataset of approximately 1 hour from the flight of 18 June 1997. The topography along with the horizontal projection of the flight path over the Plateau is shown in Figure 2. The arrows indicate the horizontal wind measured with the aircraft: The wind is plotted every 4 sec along the flight path. The overall situation of the corresponding horizontal flow pattern with respect to the triangel shows an advective influx into the area of this triangel at the Northern border and an outflux at the South-Western border. Also a slight outflux at the Eastern border can be suggested.

Figure 3 shows the result of the measurements of one flight leg over the Plateau (approximately from North-West to South-East at 11:00 CET) with a duration of 140 sec. The data are treated with an FFT (fast Fourier transformation) in order to avoid the influence of noise on the high frequency side. Figure 3 shows the data after low pass filtering with a cutoff frequency of 0.5 Hz. The eddy covariance method is used to evaluate the turbulent vertical flux through a horizontal plane given by the aircraft flight pattern in a layer over the Plateau. The flux is calculated from the detrended measurements of the vertical wind component and the CO_2- or H_2O-concentration respectively. The detrending is achieved by evaluating the trend of the data with an FFT low pass filtering with a cutoff frequency of 0.02 Hz (thin lines in the upper 4 frames of Figure 3). This corresponds approximately to the time needed for crossing the Plateau twice. Therefore, this detrending takes out the topographically induced effects. The overall bandpass between 0.02 and 0.5 Hz is therefore well suited to take care of the main eddies leading to vertical fluxes (see Mitic et al. 1995). Consequently, for the flux calculation the trend is subtracted from the 0.5 Hz low pass filtered data, resulting in the turbulent component w' for the vertical wind and the turbulent concentrations CO_2', H_2O' and NO_2'. In the upper 4 frames of Figure 3 these turbulent components appear as the differences between the thick lines (0.5 Hz low pass filtered data) and thin lines (trend).

The bulk pattern of the CO_2 concentration in Figure 3 over the Plateau shows a decrease from North-West to South-East, for H_2O the opposite is true. The fine structure of the data also show a clear anticorrelation. This feature reflects the fact, that the vegetation is a sink of CO_2 and a source of H_2O. Therefore, the concentrations of CO_2 and H_2O are predominantly controlled by the vegetation. In comparison with the detrended pattern of the vertical wind it becomes obvious, that often dry air with higher concentration of CO_2 moves upwards, while wet air with lower CO_2 moves downwards.

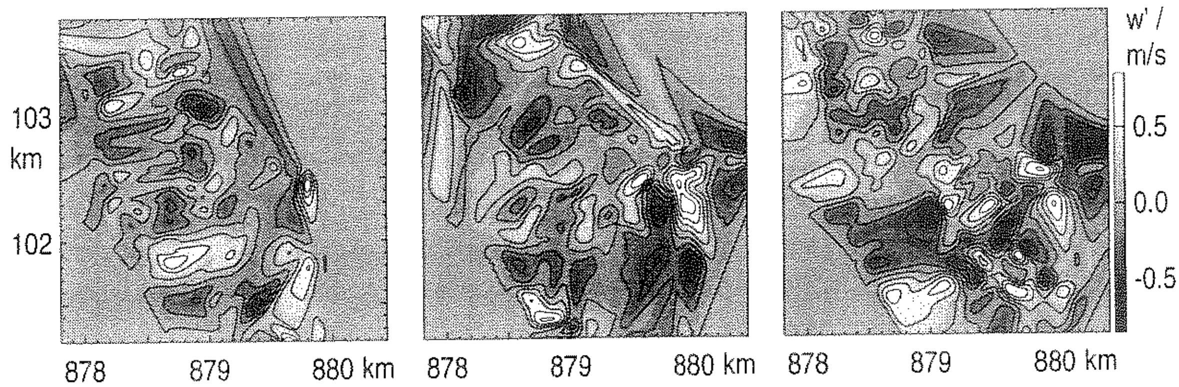

Figure 4: Turbulent component of the vertical wind w' (upwind positive) in three layers over the Plateau: 40 - 100 m, 100 - 120 m, 120 - 180 m (from left to right).

The turbulent vertical fluxes in the lower 3 frames of Figure 3 is calculated according to the following equation

$$F_{CO_2} = \rho\, CO_2'\, w' \,\frac{M_{CO_2}}{M_{air}} \qquad (1)$$

with density of air (ρ), molecular weight of CO_2 (M_{CO_2}) and air (M_{air}). The fluxes of H_2O' and NO_2' are calculated in a similar way. Following this eddy covariance approach, upwards moving wet air with low CO_2 leads to negative fluxes of CO_2 and positive water fluxes. This reflects the fact, that a turbulent exchange of CO_2 takes place, where an air parcel of low concentration is brought up into a higher layer with originally higher concentration. Thus, this turbulent upward transport process leads to a decrease of the CO_2 concentration in the higher layer and mass continuity demands replacing the origin of the air parcel in the lower layer with higher CO_2 concentration.

Comparing the fluxes of water and CO_2 in Figure 3, the anticorrelation of water and CO_2 is obvious again. The NO_2 behaves similar to H_2O, demonstrating that the ambient NO_2 level is below the compensation point. Thus, the vegetation on Monte Bondone acts as a *source* of NO_2.

4. VERTICAL TURBULENT FLUXES

From the flight legs over the Plateau the data during one hour are separated in 3 different layers: From 40 to 100 m above ground, from 100 to 120 m and from 120 to 180 m. The turbulent component of the vertical wind is analysed separately for each layer and interpolated to a regular grid over the area as shown in Figure 4. This analysis shows, that some of the up- or downwind areas penetrate over two or three levels, thus leading to coherent structures over the boundary layer. On the other hand, up- and downdrafts are observed, which are not persistent, neither in time nor in space. This short-lived eddies are a source of uncertainty in the flux estimate.

Figure 5 brings together all 3 layers and combines the vertical wind with the turbulent concentrations of CO_2 and H_2O to evaluate the flux over the Plateau. As already pointed out for Figure 3, the anticorrelation of the turbulent (detrended) concentrations of water (H_2O') and CO_2 and their corresponding turbulent fluxes is obvious. The area of the triangel is 1.225 km^2. Integrating the turbulent fluxes over this area leads to -48 g/s for $F_{CO_2'}$ and +6.1 kg/s for $F_{H_2O'}$.

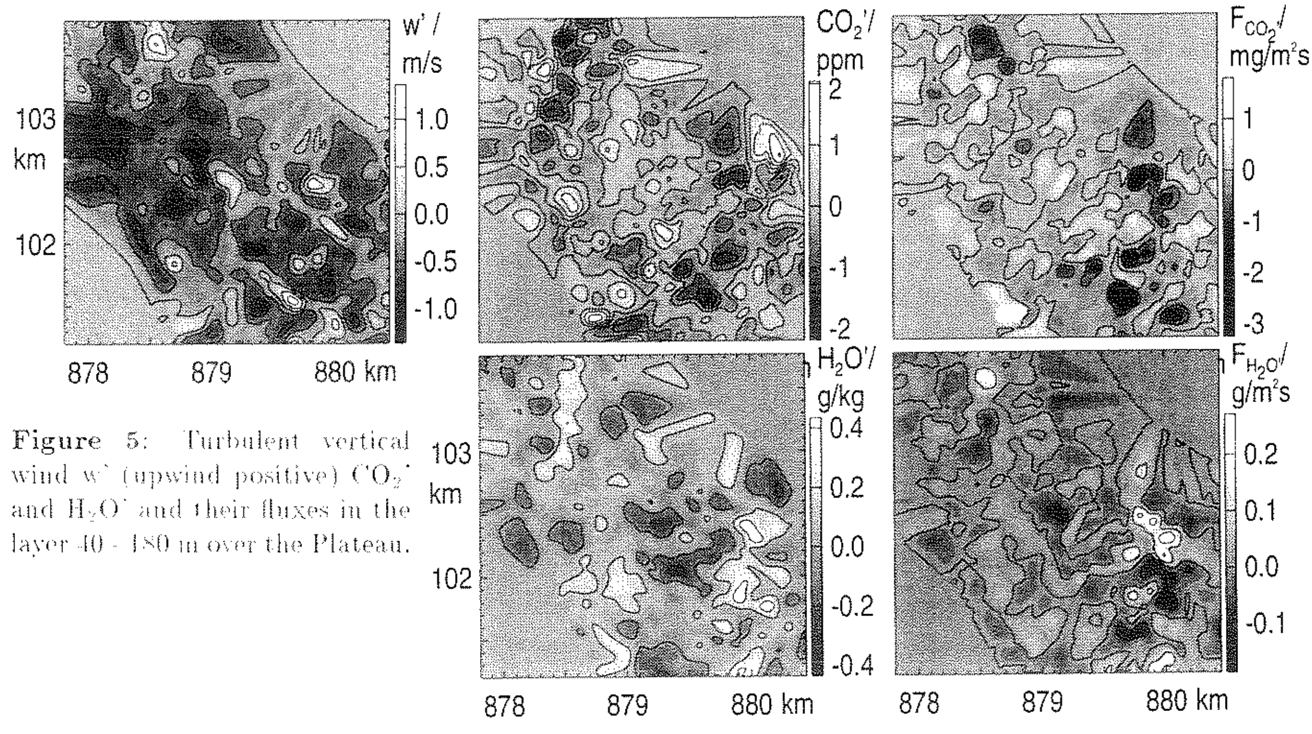

Figure 5: Turbulent vertical wind w' (upwind positive) CO_2' and H_2O' and their fluxes in the layer 40 - 180 m over the Plateau.

5. BUDGET OF FLUXES

The overall budget for the triangel of Figure 2 can be estimated by calculating the vertical transport through the covering plane and the horizontal transport through three vertical planes along the triangel. In Figure 6 the data are mapped to the area under consideration. The vertical wind and the CO_2 concentration represent the low pass filtered data. The mapped CO_2 concentration shows the general trend of higher concentrations in the North-West and lower concentrations in the South-East. The "true flux" F_{CO_2} is calculated according to the equation given above, but without detrending the vertical wind and the concentration. This flux therefore includes vertical turbulent and vertical advective fluxes and is much higher than its turbulent counterpart: Integrating the CO_2 flux over the triangel leads to -159 kg/s, whereas the total vertical air mass transport through the triangel sums up to -295 t/s.

As an example of the horizontal advection through the vertical planes surrounding the triangel, the horizontal flux of CO_2 perpendicular to the plane along the Northern border is displayed in Figure 7. A predominant flux into the triangel is obvious in the Western part, while a slight influx is observed in the Eastern part. The horizontal CO_2 flux through the whole plane integrated up to 110 m above ground (the mean flight height) sums up to -170 kg/s, the negative sign representing the influx into the triangel. The horizontal air mass flux through this plane in tons per second is -310 t/s. The air mass flux through the vertical plane in the Southwest is integrated to +293 t/s and the flux through the Eastern border is +95 t/s. Taking into account the influx of -295 t/s via the horizontal plane above the triangel, the air mass abundance within the volume of 110 m above the triangel is 217 t/s. This discrepancy is due to the lack of data along the vertical planes. The horizontal outflow of this volume should be larger by a factor of 3.8.

From the scintillation anemometer, the winds through the three sides of the triangel in the same order averaged over the time period of 1 hour are -1.118 m/s, +0.147 m/s and +1.567 m/s respectively. With a mean height for the scintillation path of 10 m above ground and assuming a logarithmic wind profile, this values can be extrapolated up to 110 m. Assuming these winds to be representative for the vertical planes along the triangel, the fluxes through these planes sum up to -320 t/s, +254 t/s and +442 t/s. The air mass deficit in the volume over the triangel is therefore -173 t/s. The vertical flux -295 t/s as measured by the aircraft still overcompensates this flux by a factor of 1.7.

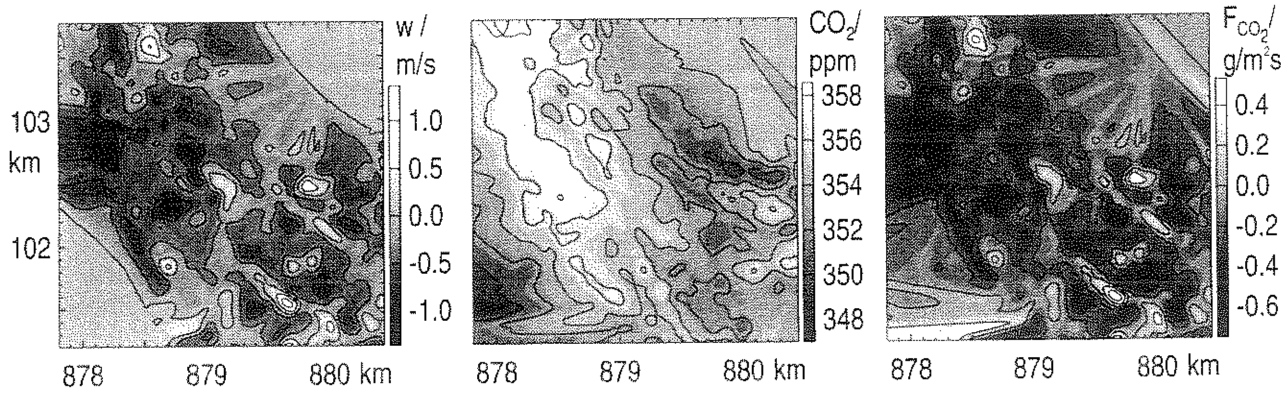

Figure 6: Vertical wind w, concentration of measured CO_2 and its total flux over the Plateau.

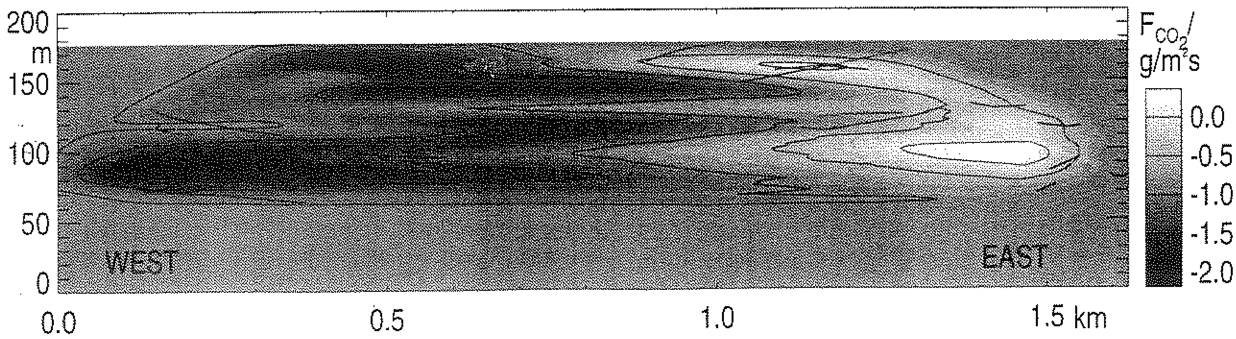

Figure 7: Total CO_2 flux through the vertical plane along the Northern border of the triangel (fluxes into the triangel are negative).

To get a complete budget over the volume of the triangel, it is assumed that the horizontal fluxes as measured with the aircraft are underestimated by a factor of 3.8. Under this assumption we find integrated air mass fluxes of -1178 t/s, +1113 t/s and +361 t/s through the vertical planes. The fluxes of CO_2 with the correction applied to the wind component perpendicular to the vertical planes only, result in
-650 kg/s, +610 kg/s, +198 kg/s. With the flux -159 kg/s through the vertical plane a CO2-deficit of 1.8 kg/s as the uptake by the vegetation can be suggested. The fluxes of H_2O through the vertical planes after correction of the horizontal wind sums up to -8548 kg/s, +8108 kg/s and +2687 kg/s. With the vertical flux of -2243 kg/s, a total flux of +4.3 kg/s out of the vegetation results.

6. CONCLUSIONS

The determiation of vertical fluxes of CO_2 and water was demonstrated for turbulent fluxes and "true" fluxes. The turbulent fluxes are determined with the eddy covariance technique and show consistent results by comparing water and CO_2 fluxes. The horizontal fluxes into a volume of air over complex terrain is burdened with uncertainties: On one hand the aircraft can not fly too close to the ground, on the other hand, the variation of the horizontal wind field in complex terrain varies very rapidly in space and time. The horizontal winds along the border of the triangel are assumed to compensate the vertical flux through the layer. The measured vertical wind is used to calculate a correction factor for the measured horizontal wind along this border. The result are a CO_2 uptake and an evaporation by the vegetation.

REFERENCES

Auble D., Meyers T.P.: An open path, fast response infrared absorption gas analyzer for H_2O and CO_2. *Bound.-layer Meteorol. 59*, 243-256, 1992.

Cernusca A.: proposal of the EU Project ECOMONT. Insbruck, 1995.

Crawford T.L. and R.J. Dobosy: A sensitive fast-responding probe to measure turbulence and heat flux from any airplane. *Bound.-layer Meteorol.,59*,257-278, 1992.

Graber W.K., Furger M., Poggio L.: DOAS and scintillation anemometry for the determination of trace gas fluxes and budgets. Proc. EnviroSense 97. Lidar and Atmospheric Sensing. European Symposium on Envrionmental Sensing III, 16-20 June 1997, Munich. 121-129, 1997.

Mitic C.M., Schuepp P.H., Desjardins R.L. and Macpherson I.J.: Spatial distribution and cooccurrence of surface-atmosphere energy and gas exchange processes over the Code Grid Site. *Atmos. Envir., 29*, 3169-3180, 1995.

Poggio L., M. Furger and W.K. Graber: A comparison of scintillation crosswind methods. *IGARSS 96 Digest. Vol I*, 399-401 (1996).