Annual report 2007. Regional Component.

Executive summary

The main effort in 2007 was spend on executing two short campaigns in April and September. These were successfully executed and we now have, with the 2005 campaign data, a full dataset of surface fluxes, atmospheric concentration data and aircraft flux data available, with which to study both experimentally and with models the spatial representation of carbon dioxide in the regional domain. In 2007 we operated two tall towers. These showed that the amplitude of the diurnal cycle near the coast at Biscarosse is higher in September compared to April (13 ppm vs 8 ppm), whereas at Bellegarde, near Toulouse, the diurnal cycle is much more pronounced in April (22 ppm vs 10 ppm). The Dimona concentration flights in April near the western part revealed an east–west CO_2 gradient with higher values at low levels over the crops and les Landes forest than near the ocean coast. Most of the flights showed this gradient during the whole day, although the regional differences are reduced during the afternoon because of the boundary layer vertical mixing. Higher values of CO_2 concentrations over land at this time of the year are probably related to a relatively high value of soil respiration (wet conditions), low values of CO_2 uptake and reduced vertical mixing in the atmospheric boundary layer in early spring Our modelling shows that a high resolution mesoscale model, the WRF model, model can capture the variability of CO_2 concentrations in the afternoon due to the sea breeze that is not captured by the coarser LMDZ. A study using the mesosccale model RAMS showed the variability of representation errors during the day and how these are dependant also on the sea breeze, emphasizing again the need for high reolution studies that resolve the vicinity of the observation sites. This suggest that global models can be strongly biased when they are assimilating coastal station data for inversion studies at a too coarse resolution.

Introduction

In 2007 the main emphasis of this component was on executing two short (max 4 weeks) campaigns in the les landes region, following the successful 2005 campaign. The objective of these additional campaigns was to document contrasted climatic conditions (early spring and autumn), as a complement of the May-June 2005 campaign. In fact, in April and September 2007, the soil moisture, as well as the fraction of vegetation offered different conditions for surface-atmosphere CO_2 exchanges. The experimental area was extended toward the Toulouse area, dominated by croplands (mainly winter crops), with not only aircraft measurements (as displayed on Figure 1) but also high accuracy atmospheric CO_2 measurements observed at a tall tower.

(a) (b)

Figure 1 : Sky Arrow Alterra trajectory : (a) : North track, over les Landes forest; (b) South track, near Toulouse

The experimental set-up is shown on Figure 2. Eight surface stations were measuring continuously the CO_2 and energy surface fluxes, at representative ecosystems of the region (pine forest,

maize, sunflowers and wheat). The CERES 2005 measurements have been completed by an eastern CO_2 concentration tower of 60 m height (Bellegarde-Saint-Marie's tower), added to the Biscarosse and Marmande towers. Radio-soundings were launched during IOP days in Toulouse in April and at La Cape Sud (the central site in les Landes forest, already installed in 2005) and Toulouse in September.

Three aircrafts, the Dimona (from MetAir) and two Sky Arrows (from IBIMET and ALTERRA) were flying over les Landes forest or near Toulouse during IOP days when the meteorological conditions were favourable.

Summary of the measurements and Intensive Observing Period (IOP)

6 IOP days in April (from the 18th to the 23rd) and 8 days in September (7-8 and from the 10th to the 15th) were sampled intensively. During the experimental week of April, anticyclonic conditions prevailed with a weak wind (5 to 10 kts). The mornings were often cloudy (with low level clouds that rapidly dissipated) but the sky was clear during the afternoon, allowing warm temperatures (25 to 29°C) and sea breeze development, especially on the 20,21 and 22nd of April.
The 7th and 8th of September were rather warm with clear sky, whereas the other September IOP days were more cloudy. Nevertheless, warm temperatures were observed in the experimental area. The wind was weak all the time with variables directions (for instance, from North-East on the 12th and from South-East on the 13th). The daily operations are further detailed on the Tables 1 and 2.

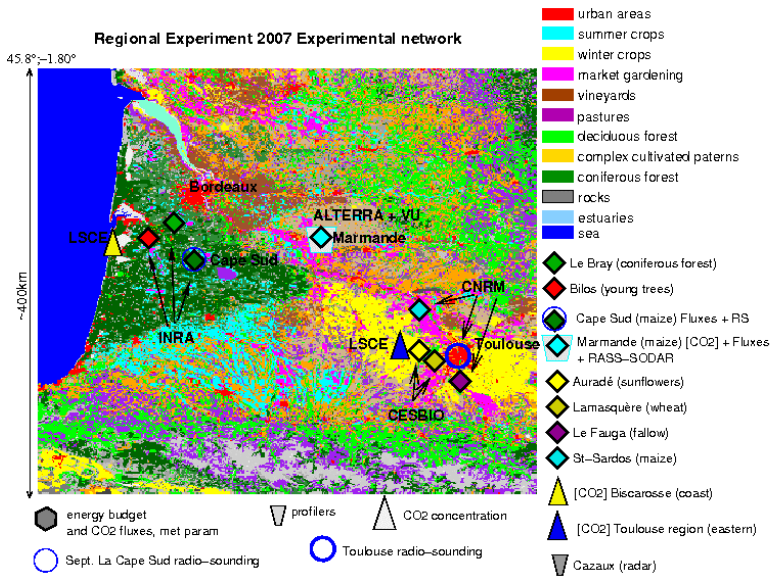

Figure 2 : CERES 2007 experimental set-up

In April, the soil water content (W) is nearly at the field capacity (Wfc) in the CERES area, except near Toulouse where the soil is dryer. The Figure 3 displays the Soil Water Index (SWI) corresponding to the ratio SWI = $\frac{W - Wwilt}{Wfc - Wwilt}$, where Wwilt is the wilting point. In September the soil is dryer (SWI ranging from 0.3 to 0.6 in the experimental zone) than in April but remains normal accordingly to the 1996-2006 mean (not shown here). Preliminary analysis also shows a large difference of observed BL height between April and September, possibly as a response of the reduction of soil moisture availability (not shown).

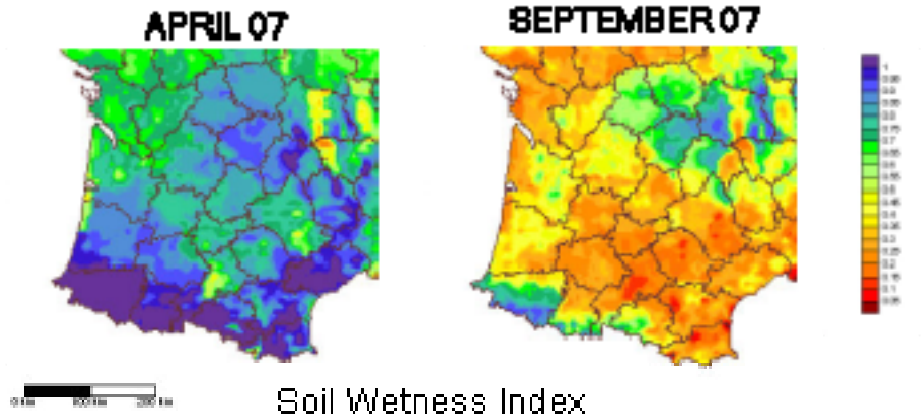

Figure 3 : The Soil Wetness Index (SWI) computed from the SIM hydrometeorological model (Habets et al., 2008)

High precision tower observations

Two high precision CO_2 instruments have been set up in South West France as part of the CarboEurope Regional Experiment. The first instrument, installed at Biscarosse (BIS, fig 1a) 2km from the sea shore, is sampling air at 47m above the ground (~120m asl). The analyser, called CARIBOU, is based on a Licor-6252 which is very precisely regulated in temperature, pressures and flowrates. Calibration is maintained using 6 calibration gases (used every 8 days), one reference gas (used every hour) and one target gas (used every 7 hr). The second instrument is located at Bellegarde Sainte Marie (BSM) about 30km NorthWest from Toulouse and 200km from Biscarosse (Fig.1). The instrument installed at BSM was developed by B. Stephens, NCSR, and is based on a Licor-820. Four calibration gases are analyzed every

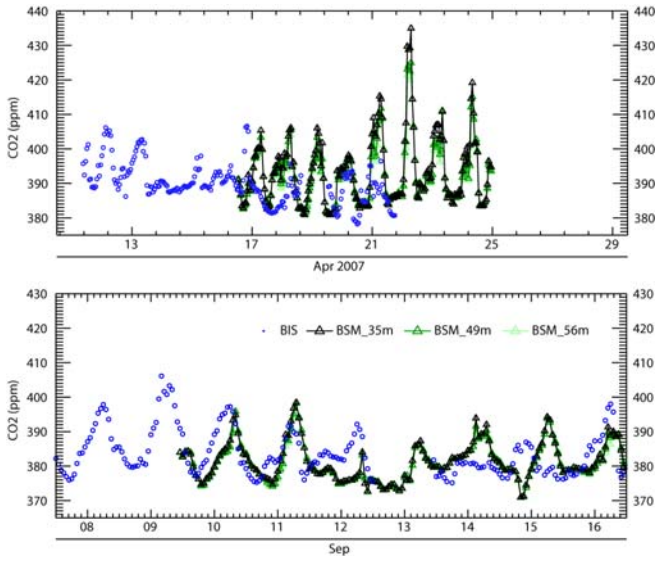

Figure 4. Atmospheric CO_2 concentration measurements at Biscarosse (BIS) and Bellegarde (BSM) in April (above) and September (below).

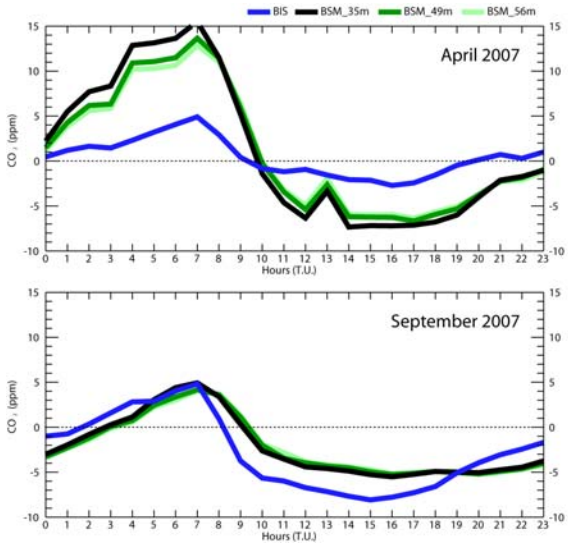

Figure 5. Mean diurnal cycles of atmospheric CO_2 at Biscarosse (BIS) and Bellegarde (BSM) in April (above) and September (below).

3.5 hours, and one reference gas is analyzed every 30mn. Air is sampled at three elevations: 35m, 49m and 56m above the ground.

Figure 4 shows the hourly means of atmospheric CO_2 measured at Biscarosse and Bellegarde (3 levels) in April and September 2007. The signal is characterized by the diurnal cycles, with CO_2 maximum observed during the night due to the accumulation of CO_2 in the shallow night time boundary layer as a result of anthropogenic and biospheric emissions, and reduced concentrations during the day due to photosynthesis. The amplitude of the diurnal cycle averaged over the observation periods of april or september (Fig.5) at Biscarosse is higher in September compared to April (13 ppm vs 8 ppm), whereas at Bellegarde the diurnal cycle is much more pronounced in April (22 ppm vs 10 ppm). Figure 6 gives another representation of the diurnal cycle at Bellegarde, showing the mean vertical profiles as a function of time. It appears that the night time CO_2 accumulation at the surface is at BSM higher in April compared to September. On the other hand, at BIS the main difference between April and September is the strength of the daytime depletion. *Daytime concentrations indicate a small CO_2 depletion in both seasons.* Those data will give a good opportunity to validate the vertical diffusion simulated by the atmospheric transport models.

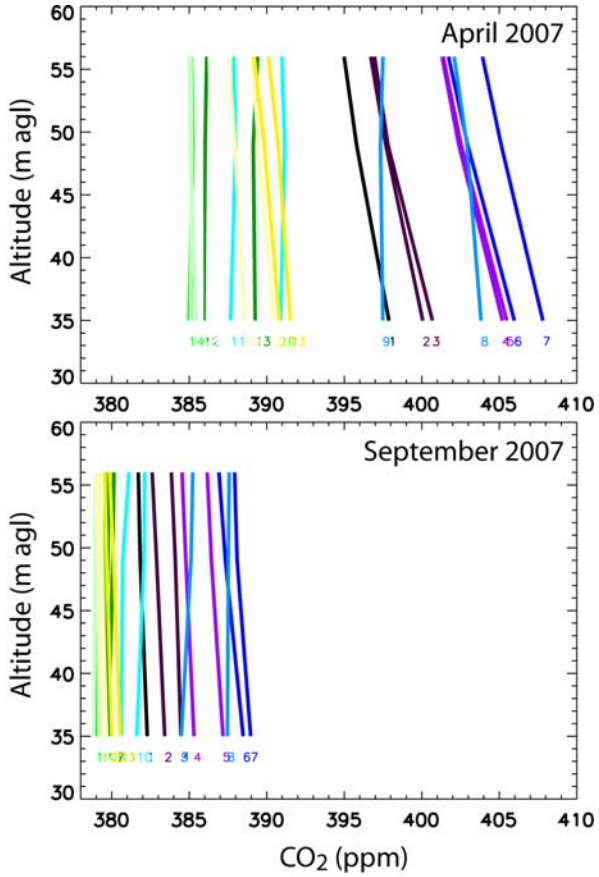

Figure 6. Vertical profiles averaged over the observation periods of atmospheric CO_2 at Bellegarde (BSM) in April (above) and September (below) as a function of time (Hr UTC).

Aircraft observations

The Dimona flights in April over the western part revealed an east–west CO_2 gradient at low levels, with higher values over the crops and les Landes forest than near the coast. Most of the flights showed this gradient during the whole day, although the regional differences are reduced during the afternoon because of the boundary layer vertical mixing. The higher values of CO_2 concentrations over land at this time of the year is probably related to relatively high rate of soil respiration (wet conditions), low value of CO_2 uptake and reduced vertical mixing in the atmospheric boundary layer.

The Dimona aircraft measurements near Toulouse show very high concentration of CO_2 in the boundary layer in the morning (up to 430 ppm and more than 400 ppm at 1100 UTC near the surface). These are correlated to the low Boundary Layer (BL) development of around 500m at 1100 UTC at Toulouse on 22 April. A significant decrease of CO_2 concentrations occurred in the afternoon related to the development of the boundary layer as well as the winter crop assimilation.

In April, the Sky Arrow IBIMET flew horizontal transects in the western part of the domain, while the Alterra Sky Arrow flew the eastern transect. Systematically higher values of CO_2 uptake by the vineyards were observed compared to the relative weak CO_2 fluxes over the forest. The evapotranspiration was high, probably because of a high contribution of the soil evaporation in the total latent heat.

Apart from the regular transect flight, the two aircraft also performed 'diurnal flights', in close collaboration with a second aircraft from IBIMET, sampling a few representative land cover types in the centre of the domain at high temporal evolution. The two aircraft proved to be well intercalibrated and together a very good diurnal cycle for four land cover types (deciduous forest (oak), evergreen forest (pine), maize and mixed agriculture) could be obtained (fig 8).

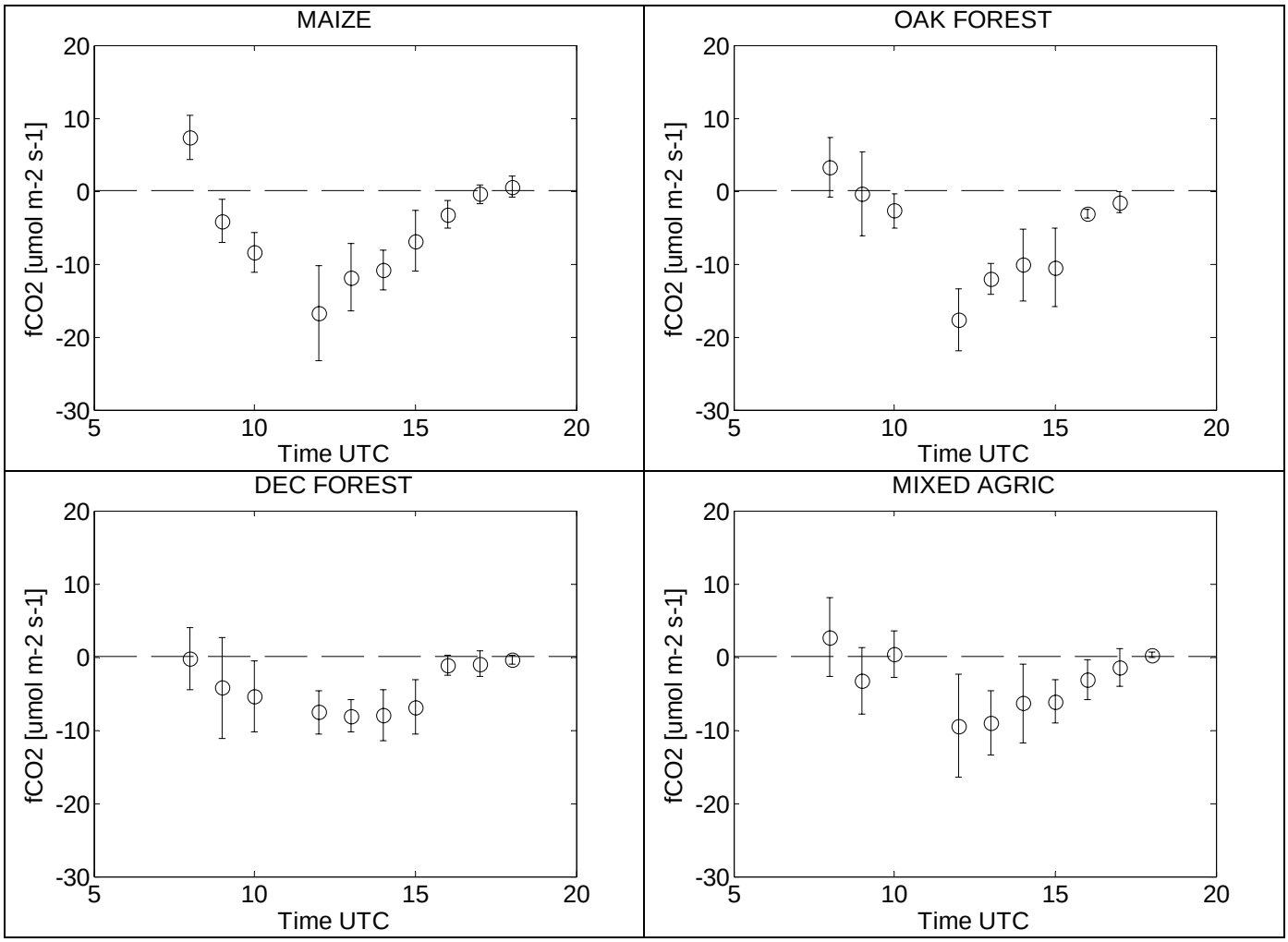

Figure 8 Diurnal cycle of CO_2 flux for 4 land cover types, obtained from two closely coordinated flux aircraft.

Modelling

The intercomparison paper was published this year in BioGeosciences [S*arrat, et al. 2007a*]. Two case studies were publiced [*Sarrat, et al. 2007b* and *Ahmadov, et al*., 2007]. Further work involved locating a major probem in RAMS and solving it, so that mass conservation was improved [*Meesters, et al. submitted*]. We further use the modelling to assess representation errors for the 2005 campaign, and to asses issues related to model resolution [*Tolk, et al. submitted*]. The first results of inversion studies at this scale were published in ACPD [*Lauvaux, et al. 2007*].

The high resolution (2km) simulations of the various groups demonstrate the significant influence of the mesoscale flows such as sea-land breeze on the CO_2 distribution over the region, especially close the coast. We have compared model output for CO_2 concentration and fluxes, and meteorological fields from different kind of the observation systems – surface stations, radio soundings, profilers and aircrafts. Especially the characterization by Met Air's Dimona aircraft measurements turned out to be crucial for the model evaluation.

The Max Planck Institute used the Weather Research and Forecasting (WRF) model [http://wrf-model.org], with the diagnostic biospheric model Vegetation Respiration and Respiration Model coupled to WRF as a module. The comprehensive description of the modelling system is given in the paper - [*Ahmadov, et al.*, 2007]. Some of the modelling results were presented in the paper [*Ahmadov, et al.*, 2007] and at several international conferences held in 2007. Here we have presented one of the interesting results of our modeling study. Fig. 9 shows the CO_2 concentration measured at the Biscarrose tower during the CERES. The observations are compared with simulated CO_2 from the mesoscale WRF

model and global LMDZ model. The Biscarosse station is under strong influence of sea-land breeze and this effect appears as a recirculation of the CO_2, which was respired during night time over land, back from the ocean during the daytime. Fig. 9 clearly exhibits that the WRF model, but not the coarser LMDZ model can capture the second maximum of CO_2 concentration in the afternoon due to the sea breeze. This allows us to stress that global models can be strongly biased when they are assimilating coastal station data for the inversion studies.

Our analysis shows that the WRF model runs still need to be improved in order to more accurately resolve the advection and mixing of CO_2 over the region. For this purpose currently we are validating different WRF model parameterization schemes, dynamics and physics options setup. In addition we are testing the meteorological input data for WRF initial and boundary conditions, especially soil moisture initialization. We will use WRF model runs to perform inversion runs by the lagrangian particle model – STILT to optimize the VPRM parameters constraining CO_2 fluxes for the different biome types.

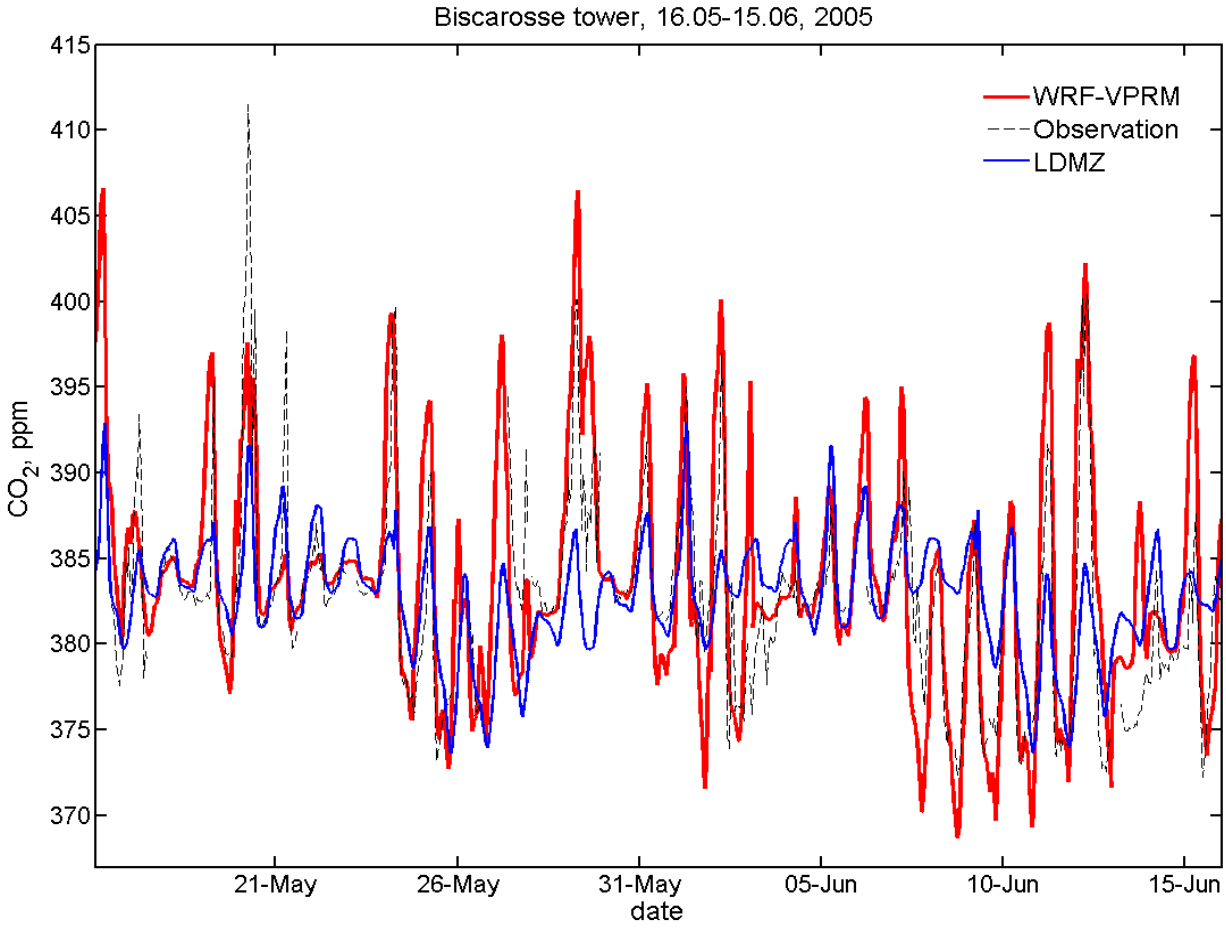

Fig.9. CO_2 time series (dashed black) measured from a 60 m tower at the coastal site Biscarosse (France). Simulations by WRF-VPRM (red) and LMDZ (blue) are also shown.

The VU University Amsterdam performed high resoltuion simulations with the Regional Atmospheric Modelling System (RAMS) [*Meesters et al., submitted and Tolk et al., submitted*]. From the simulated variations in the CO_2 concentration representation errors were derived for grid sizes of 10-100km. Inverse modeling requires an accurate estimate of the quality of the observations to get a realistic estimate of the inferred fluxes and their uncertainties. Representation errors, i.e. the mismatch between point observations and grid cell averages, may add substantial uncertainty to the interpretation of atmospheric CO_2 concentration data. Representation errors are found to vary spatially and temporally, both within one day as in between days (Fig. 10), due to differences in meteorology. Within the nocturnal boundary layer the representation errors are relatively large and mainly determined by topography. During the day, surface CO_2 flux variability, mesoscale circulations and self organized atmospheric structures are found to be the main sources of representation errors. Whether the circumstances favour the formation of mesoscale circulations is therefore of critical importance for the spatial distribution and the strength of the representation errors. Careful up-scaling of point observations may reduce the importance of the representation error substantially and the simulation results may serve as a handle to quantify the remaining uncertainty.

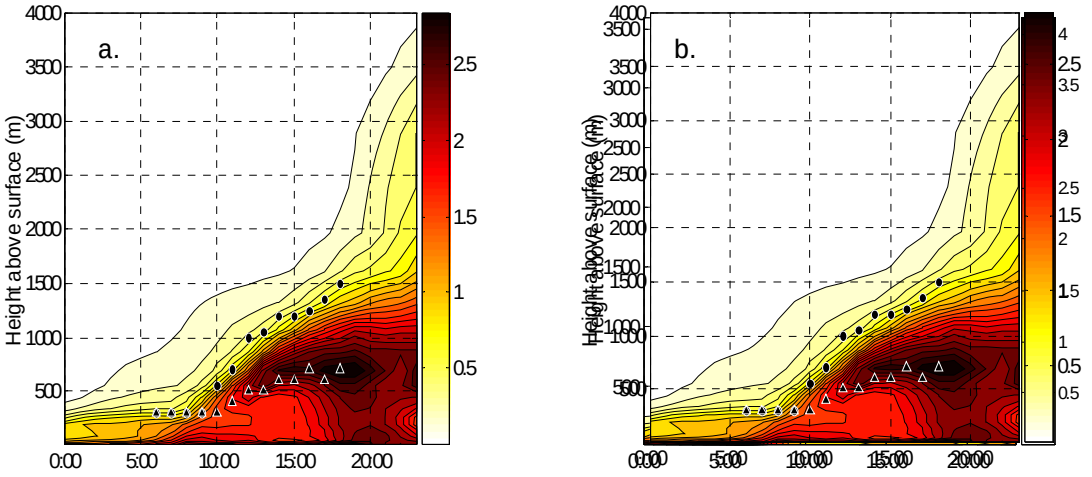

Figure 10 Figure 4, Variations of the representation errors at 27 May 2005 (a.) and 6 June 2005 (b.) with time and altitude. The representation errors are averaged over the area north of 44.16°N. The circles in a. indicate the height of the boundary layer in the convergence zone and the triangles the main boundary layer height over the rest of the land area at 27 May, in b. the circles represent the more homogeneous main boundary layer height over the land at 6 June.

We also examined the mass balance in calculations with RAMS. An error was found during the intercomparison concerning the surface fluxes on slopes. This error affects all the prognostic variables in RAMS to some extent, whenever sloping terrains are involved. We corrected this error in the code and performed some simulations to study the impact of the errors. Without correction, effective surface CO_2-fluxes on mountain slopes were found to be enlarged, under certain common conditions, to several times the parameterized fluxes. Neglecting this error can cause substantial errors in both forward and inverse model calculations. After the correction, a very good closure of the mass balance is obtained**.** This work was submitted as a technical note to J. Fluid. Mechan.

Further modelling efforts are aimed at extending the periods of simulation for the 2005 and 2007 campaign and improving the models at initialization of soil moisture and soil temperature, which are derived from the ECMWF database, and improved handling of the nudging of CO_2 mixing ratio. We also performed some tests to investigate the sensitivity of the model to various parameterizations of the planetary boundary layer (PBL) with RAMS. The various parametrizations were Mellor-Yamada level 2.5 closure, Smagorinsky deformation and the MRF scheme. As the PBL is essential for the transport of CO_2 more tests will be performed in the future including the PBL parametrization of Hong et al. (2006). Future

plans also include a complete simulation of the 2005 CERES campaign making use of the parametrizations and model set-up that was used in the simulation of the ‘golden' days.

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	IOP number	Weather conditions	Flight (numb, plan, H landing, take-off)				Remarks
			DIMONA (H LT)	Sky A IBIMET (H LT)	Sky A. ALTERRA (H LT)	RS Toulouse (H UTC)	
10-11-12 -april-07		"		Test flight on 12-april		12 HUTC every day	Checkup+download Marmande data
Sunday 15-april-07		"		Paired flight in Marmande with PHWUR	Paired flight in Marmande with IRAWH		LICOR calibration PHWUR against IBIMET bottles
Wednesday 18-april-07	IOP	Cloudy in the morning, better in the afternoon	1 flight over Clairac, Marm, Bisca (VP), Bellegarde	2 flights 11:00 and 15:00 Villen-Clerac-Marm-Mimiz VP Vill + Mim	1 flight : South track VP near Tlse VP near Vill	12, 18	
Thursday 19-april-07	IOP	Clear sky and weak SW wind Tmax=25°C	2 flights	2 flights 11:00 and 15:00 Villen-Clerac-Marm-Mimiz VP Vill + Mim	2 flights, south track Morning till Fronton vv Afternoon till Muret vv 2 VP Lasbordes	6, 12, 18	
Friday 20-april-07	IOP	Weak W wind and low level clouds in the morning. After dissipation, clear sky; 28°C and sea breeze.	2 flights	2 flights 11:00 and 15:00 Villen-Clerac-Marm-Mimiz VP Vill + Mim	2 flights, south track Morning till Fronton vv Afternoon till Muret vv 2 VP Lasbordes	6,12,18	
Saturday 21-april-07	IOP	W weak wind and low level clouds in the early morning, dissipated in the morning, then clear sky, 28°C. Sea breeze	2 flights	2 flights 07:00 and 11:00 Villen-Clerac-Marm-vineyard	2 flights, south track Morning till Fronton vv Afternoon till Muret vv 2 VP Lasbordes	6,12,18	
Sunday 22-april-07	IOP	W weak wind and low level clouds in the early morning, dissipated in the morning, then clear sky with few Cu, 27°C. Sea breeze	2 flights	2 flights 11:00 and 15:00 Villen-Clerac-Marm-Mimiz VP Mim	2 flights, south track Morning till Fronton vv Afternoon till Muret vv 2 VP Lasbordes	6, 12	
Monday 23-april-07	IOP	Clear sky, 29°C. South weak wind, no sea breeze	2 flights		2 Flux divergence flights: *morning: surface + 500 ft intervals upto 1500 ft *afternoon: surface + 1000 ft intervals upto 4000 ft *paired flight with Dimo Vill-Marm	12	Spanish plane arrival Intercalibration flights between the Dimona and the Alterra Sky Arrow LICOR calibration PHWUR against MPI-BGC bottles
TOTAL CERES	**1 IOP**	**Clear sky, warm temperature, sea breeze.**	**~11 flights 40 hours of flights**	**~11 flights**	**~ 11 flights**	**19 RS**	

Tab 1 : Summary of the April operations

	IOP number	Weather conditions	Flight (numb, plan, H landing, take-off)			Radiosoundings		Remarks
			DIMONA (H LT)	Sky A IBIMET (H LT)	Sky A. ALTERRA (H LT)	RS LACS (H UTC)	RSToulouse (H UTC)	
Friday 7-Sept -07	IOP1	Clear sky and warm			1 flight : S track		6,12,18	Bellegarde out of order since the 22nd of august
Saturday 8-Sept -07	IOP1	Clear sky and warm			1 flight : S track		6,12,18	Ibimet SA arrival Rass-Sodar KO
Sunday 9-Sept -07		Clear sky and warm, maritime entrance				12, 18		Dimona arrival Bellegarde repaired Rass-Sodar OK
Monday 10-Sept-07	IOP2	Maritimes entrances dissipated in the morning, then clear sky. N NW weak wind (5-10 kts) Sea breeze, 25-26°C	1 flight : Marm -Bellegarde - Tlse's flux stations - Agen – VP over Marm	Diurnal Course Experiment DAY1		6, 9, 12, 15, 18		
Tuesday 11-Sept -07	IOP2	Cloudy in the morning (7/8) in Les landes 2-3/8 in Toulouse NE wind 5-10 kts,	2 lagrangian flights : 9:30-12:30 MARM-LEBR-BISC-MARM 13:50-17:00 MARM-Mimizan	1 flight : North track (12-15 UTC)	1 flight : South track	0, 6, 9, 12, 15, 18		
Wednesday 12-Sept 07	IOP2	Clear sky, 2-3/8 Cu in the afternoon, weak NE wind, 5-10 kts 28-29°C	2 flights 10:20-14:50 MARM to La Cape Sud and the coast 16:00-18:00 flight	Diurnal Course Experiment DAY2		6, 9, 12, 15, 18		
Thursday 13-Sept -07	IOP2	Clear sky (AltoCu in the evening), warm 28-29°C. Sea breeze and SE wind in Toulouse	2 flights in les landes 10:00- LACS-BISC-Arcachon 15:00- LACS-Arcachon-MARM	Flux divergence flights		6, 12, 18		The Rass-Sodar has been turned off at 7:55 pm!
Friday 14-Sept -07	IOP2	All levels clouds everywhere dissipated around noon, but 5 octas of low level clouds in the West. T=28°C	2 flights 10:00 MARM- Agen- Francazal-Bellegarde- MARM 15:00 MARM- Agen- Francazal-Bellegarde- MARM	no flight	2 flights South Track	12, 18		
Saturday 15-Sept -07	IOP2	Low level clouds dissipated in the morning, variable weak wind (< 5 kts), warm temperature (28°C)	2 flights La Cap Sud – Biscarrosee (PBL characterization	no flight	no flight	6, 12, 18		Seneca (CEFLES) + CASA
TOTAL CERES	**2 IOPs**		**11 flights**	**4 days of observations**	**7 days of observations**	**22 RS**		

Tab 2 : Summary of the September operations