CO_2 FROM SPACE: CONFRONTING FIRST RETRIEVALS FROM ECMWF USING AIRS RADIANCE DATA WITH FORWARD SIMULATIONS

Y. Tiwari[1], M. Gloor [1,2], R. Engelen [3], C. Rödenbeck[1], F. Chevallier[4], P. Peylin[4], M. Heimann[1]

[1] *Max-Planck Institute for Biogeochemistry, Jena, Germany; ktiwari@bgc-jena.mpg.de*
[2] *Princeton University, Princeton, New Jersey, U.S.; emg@Princeton.EDU*
[3] *ECMWF, Reading, U.K.;* [4]*LSCE, Paris, France*

ABSTRACT
In the present study atmospheric CO_2 retrievals based on Aqua satellite AIRS (Atmospheric Infrared Sounder) instrument observations are compared with forward model predictions. There is quite good agreement in seasonal cycles as well as North-South gradients when averaged over large scales. At smaller scales there are contrasts between upper troposphere CO_2 above continents versus oceans in the retrievals and there are signatures off Africa which seem likely artifacts caused by aerosols. As a consequence retrievals cannot be used at this stage to constrain surface sources and sinks without causing large biases. Interestingly there is good agreement in the shape of the N-S gradient at low-to-mid latitudes in the Northern hemisphere between simulations based on one transport model (LMDZ) and retrievals, but disagreement when comparing with simulations based on a second transport model (TM3). This raises questions about lower to upper troposphere transport and their representation in these models.

INTRODUCTION
One approach to estimate carbon sources and sinks is inverse modeling of atmospheric tracer transport combined using atmospheric CO_2 concentration data. For example recently Rödenbeck et al. 2003 used 20 years of NOAA/CMDL CO_2 data and the TM3 global atmospheric tracer transport model to estimate interannual variation and spatial patterns of surface CO_2 fluxes using this technique. While these studies give important insights on flux variability, the estimates have large uncertainties because the observations are carried out at a quite sparse network. There is a lack of data both in the lower and upper troposphere particularly over land. A potentially promising measurement method for closing some of these data gaps is the retrieval of CO_2 from space. Recently Richard Engelen from ECMWF (Reading, U.K) has developed methods for atmospheric CO_2 retrieval and started to estimate atmospheric CO_2 using data from the AIRS instrument on the recently launched Aqua satellite. As the retrieval method is not yet mature it is important to identify biases and uncertainties. The present study attempts this by a comparison of forward atmospheric transport model predictions with the retrievals. For the forward modeling CO_2 flux estimates of Rödenbeck et al. 2003 are used as boundary conditions in the TM3 [*Heimann 1996*] and LMDZ models as well as in the LMDZ model from IPSL, France.

SATELLITE RETRIEVALS
Aqua, a polar orbiting satellite, was launched on May 4, 2002. It crosses the equator at 1:30 am and 1:30 pm. AIRS covers the 3.7µm to 15.4µm region with spectral resolution of $\lambda/\Delta\lambda = 1200$ recording 2378 channels [*Aumann et al.* 2005]. As retrievals are sensitive to water vapor, only emission signals from regions above clouds are used for the ECMWF retrieval method. The cloud detection scheme for AIRS is described in *McNally and Watts* [2003]. The AIRS retrievals for the year 2003 used in this study have been obtained by a 4D-var data assimilation approach developed and implemented in the ECMWF weather forecast model by R. Engelen [*Engelen et al. 2004*]. 18 channels mainly sensitive to the upper troposphere are used. The vertical distribution of the sensitivity of the radiances measured at the 18 frequencies to CO_2 is given in Fig. 1 which is reproduced from Engelen and McNally 2005. The retrieval algorithm over land and over oceans is identical.

MODEL SIMULATIONS
Both atmospheric transport models solve the continuity equation for an arbitrary number of atmospheric tracers on a regular grid spanning the entire globe. The horizontal resolution of TM3 is 4^0 (latitudes) x 5^0 (longitudes) with 19 sigma-pressures layers in the vertical. The TM3 model is driven by meteorological fields derived from the NCEP [National Center for Environmental Prediction] reanalysis [*Kalnay et al.*, 1996]. The horizontal resolution of LMDZ model is 2.5^0(latitudes)x3.75^0(longitudes) with 19 sigma-pressure layers in the vertical coordinate. The calculated winds (u,v) are relaxed to ECMWF analyzed meteorology with a relaxation time of 2.5 hrs(nudging) in order to realistically account for large scale advection [*Bousquet et al.*, 2005]. Model simulations are extracted from the simulations for comparison with AIRS retrievals by applying time and space synchronous sampling and then by weighting the above cloud portion of the simulated profile data with the AIRS weighting function (Fig. 1).

4. COMPARISONS

The zonally and meridionally averaged CO_2 distribution (Fig.2) reveals overall qualitatively good agreement between retrieval and models. The amplitude of the seasonal variation of the signals is very similar. There is as phase shift in the timing of the increase of carbon just after the phase of decrease due to summer drawdown caused by photosynthesis on land. This may be an indication that the models exaggerate upward propagation of surface signatures during the winter season. Similarly amplitudes of the zonal mean seasonal signal averaged over 5 degree latitude bands (Fig. 3) and its decrease with decreasing latitude agrees well between AIRS retrievals and model simulations. Throughout all latitude bands the increase of atmospheric CO_2 in spring as estimated by AIRS lags the model simulations by approximately one month. This may be an indication that surface signals are communicated too fast from the surface to the upper troposphere in the models during spring in northern hemisphere mid-latitudes.

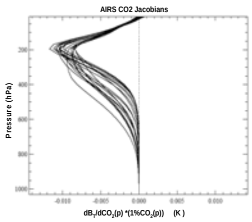

Fig.1. Weighting function for the 18 channels used in the assimilation. (Ref.- Engelen et al., 2005, JGR....in press)

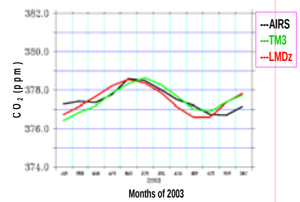

Fig.2. AIRS, TM3 and LMDz time series, CO2(ppm), (Zonal mean and 40S to 40N meridional mean)

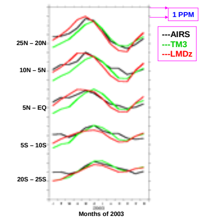

Fig.3. Comparison of time variation of AIRS, TM3 and LMDz monthly mean CO_2 (ppm) (5^0 zonal means)

Zonal mean fields as a function of time (Fig.4) reveal the expected North-south propagation of the N-hemisphere spring maximum CO_2 signal due to fossil fuel burning and absence of land photosynthesis. In AIRS retrievals and LMDZ simulations the maximum signal occurs instantaneously in the northern hemisphere during spring months whereas TM3 simulations show an upward trend already during winter. Finally spatial patterns for three seasons are compared in Fig. 5. The North-South gradient is similar between retrievals and simulations. Compared to retrievals and model predictions based on LMDZ, TM3 simulations show an elevated CO_2 signal in the northern Atlantic during May-June months. Also there are contrasts between CO_2 above oceans and land in the retrievals that are absent in the simulation results. Similarly there are features off Africa that are reminiscent of aerosols

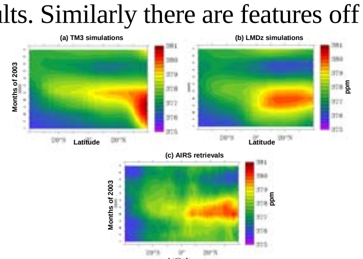

Fig.4. Column weighted zonal mean time series CO_2 (ppm), 2003 troposphere. **(a)** TM3 **(b)** LMDz **(c)** AIRS

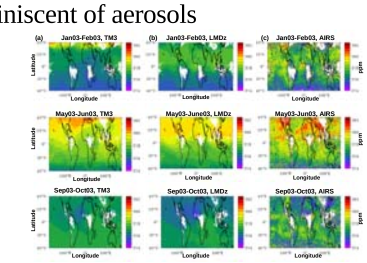

Fig.5. Column weighted atmospheric CO_2 (ppm), two monthly mean maps, 2003. **(a)** TM3 **(b)** LMDz **(c)** AIRS

5. SUMMARY AND OUTLOOK

The comparisons presented here convey a somewhat mixed message regarding the use of CO_2 from space to give new insights about the carbon cycle. On the one hand the good agreement of key signatures of atmospheric CO_2 like the seasonal cycle caused by the northern hemisphere land biosphere and decrease of magnitude with latitude is encouraging evidence that CO_2 from space may have potential to reveal new aspects of the carbon cycle. On the other hand biases over North America and Africa indicate problems in the retrievals that limit there use for constraining carbon sources and sinks with inverse methods at this stage. Discrepancies between simulations at northern hemisphere low-to-mid latitudes but agreement of one of the model simulations with retrievals indicates also limitations of lower troposphere to upper troposphere transport representation in the transport models.

REFERENCES

Aumann, H.H., et al.(2005),*Geophys.ResLett.*,32,L21802,doi:10.1029/2005GL022564.
Bousquet, P., et al. (2005),*Atmos.Chem.Phys.Discuss.*,5,1679-1737.
Engelen, R.J., et al.(2004),*J.Geophys.Res.*,*109*,D19309,doi:10.1029/2004JD004777.
Heimann, M.(1996), Tech. Rep. 10, Max-Planck Institute for Meteorology, Hamburg, Germany.
Indermühle, A., et al. (1999), *Science*, vol.286, Issue 5446, 1815
IPCC: Climate Change 2001, The Scientific Basis, Cambridge Univ. Press, Cambridge.
Kalnay, E., et al.(1996), *Bull. Am. Met. Soc.*, 77, 437-471.
McNally, A.P., and P. D. Watts(2003), *Quart. J. Roy. Meteorol. Soc.*, 129, 3411-3423, doi:10.1256/qj.02.208.
Rödenbeck, C., et al. (2003), *Atmos. Chem. Phys.*, 3, 1919-1964.