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Forward and inverse modeling of CO_2

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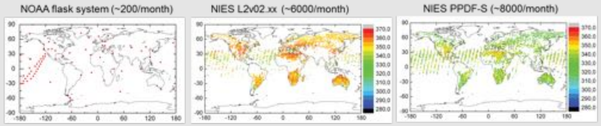
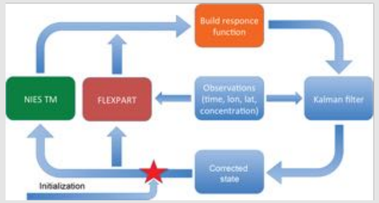
CO_2 flux inversion

Observations

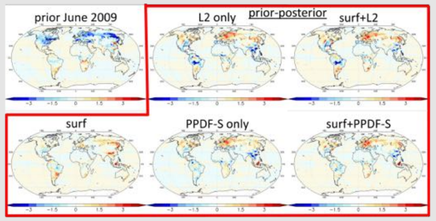


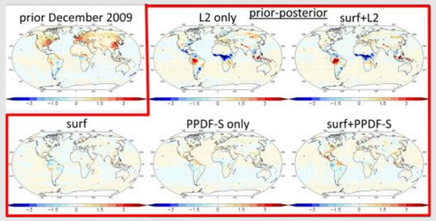
GELCA model



GELCA model:
NIES TM calculates responses for:
- EOF
- priory fluxes
- background
FLEXPART calculates responses from observations to 2D and 3D grid
Problem setup:
- GELCA model
- 170 EOF coefficients
- Fix-Lag Kalman smoother (step=1 month, lag=6 month)

Monthly global CO_2 fluxes and anomalies: prior - posterior ($g/m^2/day$)





Particle dispersion model

4-th order Runge-Kutta method with linear interpolation in time and space of reanalysis data (ECMWF, NCEP, JCDAS)

$$\lambda(t+\Delta t) = \lambda(t) + \frac{1}{a}\int_t^{t+\Delta t} \frac{u(\lambda,\varphi,t)}{\cos\varphi}dt,$$

$$\varphi(t+\Delta t) = \varphi(t) + \frac{1}{a}\int_t^{t+\Delta t} v(\lambda,\varphi,t)dt$$

λ,φ - longitude and latitude, u,v – zonal and meridional winds, dt – time step, a – Earth's radius.

$$\Delta\lambda = r_\lambda L/(a\cos(\varphi))$$

$$\Delta\varphi = r_\varphi L/a$$

$\Delta\lambda$ – turbulent particle displacement in zonal direction, and $\Delta\varphi$ – in meridional direction

r_λ, r_φ randomly sampled values from the range [-0.5,+0.5], generated from a uniform distribution..

Following Saltbones et al., (1998) a horizontal length scale L for the turbulent motion is defined as:

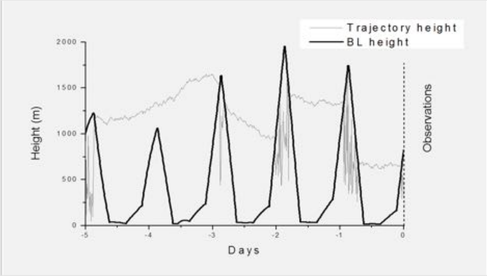
$$L = aX^b$$

X=Vdt, b=0.875, a= 0.5 within BL and 0.25 above.

In the vertical direction the air parcel location is determined according to a uniform probability distribution within BL. Above the BL the vertical dispersion is determined as:

$$\Delta p = g r_z \sqrt{2dtK_z}$$

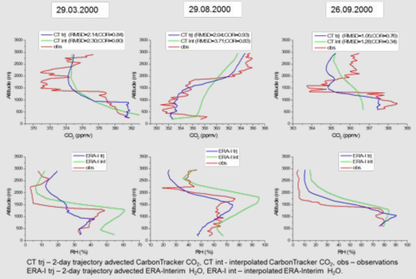
Δp - turbulent particle displacement in vertical direction; g – acceleration of gravity; ρ - air density; r_z - randomly sampled value from the range [-0.5,+0.5]; Kz – vertical diffusivity coefficient.



Modeled concentration at observation point x_r and time t_r is calculated as:

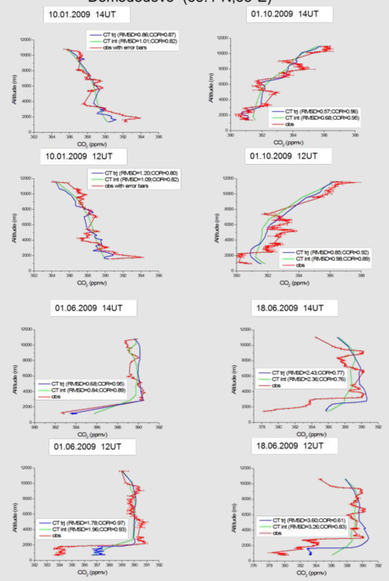
$$C(x_r,t_r) = \frac{Tm_{air}}{hNL\rho m_{CO_2}} \sum_{ij}^{IJ}\sum_{l=o}^{L} F_{ij}^{l} \sum_{n=1}^{N} f_{ij}^{ln} + \frac{1}{N}\sum_{ijk}^{IJK} C_{ijk}^{B} \sum_{n=1}^{N} f_{ijk}^{n}$$

Fyodorovskoe (56⁰N;33⁰E)



CT trj – 2-day trajectory advected CarbonTracker CO_2, CT int - interpolated CarbonTracker CO_2; obs – observations
ERA-I trj – 2-day trajectory advected ERA-Interim H_2O, ERA-I int – interpolated ERA-Interim H_2O.

CONTRAIL Project (Machida et. al., 2008)
Domodedovo (55.4⁰N;38⁰E)

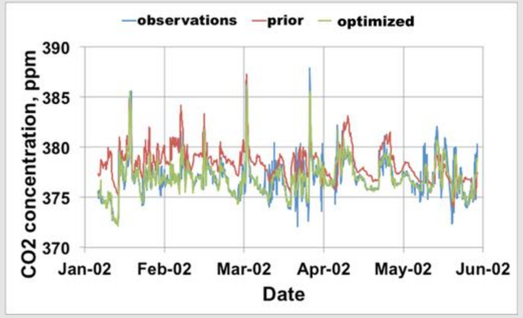


SUMMARY

- Coupled Eulerian/Lagrangian model (GELCA) was developed and applied for CO_2 flux inversion;
- Posterior global CO_2 fluxes were estimated based on NOAA flask surface observations and GOSAT NIES L2v02.xx and NIES PPDF-S data;
- Trajectory model with turbulence parameterization has been used to simulate the vertical CO_2 profiles;
- Comparisons of modeled profiles and aircraft observations demonstrate the ability of the model to reproduce the laminated structure in CO_2 vertical profiles especially gradients at the boundary layer top region;
- Example of ensemble meteorology application for CO2 concentration simulations at continuous observation sites was presented.

Ensemble meteorology

Ensemble meteorology was created by combining of JCDAS wind fields and ESRL/PSD GEFS Reforecast Version 2 dataset. JCDAS data were interpolated from original T106 Gaussian grid to regular 1.25°×1.25° grid, the vertical structure has 40 levels and was used without any modifications. ESRL/PSD GEFS Reforecast 2 includes 10 perturbed forecast members, ensemble mean and one control forecast with 1.0°×1.0° horizontal resolution; the vertical structure is described by 12 pressure levels, 4 hybrid levels near surface and 10m level. To create JCDAS ensemble meteorology ESRL/PSD GEFS Reforecast 2 winds were interpolated to 1.25°×1.25° grid. Flux footprints were simulated with Flexpart LPDM (Lagrangian Particle Dispersion Model) for each of the 10 ensemble members and the CO_2 concentrations were simulated using GELCA, footprints and surface carbon dioxide emissions. We have used these 10 different concentrations and applied Kalman filter to obtain the optimal weights of the linear combination for the ensemble members resulting in a best fit to the observations within a fixed size time window of several days. The results obtained with ensemble wind fields and optimized weights show better agreement with observations against the prior ensemble meteorology simulations and model results with original JCDAS dataset.



References:

Machida, T., H. Matsueda, Y. Sawa, et al., (2008), Worldwide measurements of atmospheric CO2 and other trace gas species using commercial airlines. J. Atmos. Oceanic. Technol. 25 (10), 1744-1754.

Acknowledgments

CarbonTracker 2010 results provided by NOAA ESRL, Boulder, Colorado, USA from the website at http://carbontracker.noaa.gov.

ECMWF ERA-Interim data used in this study have been obtained from the ECMWF Data Server (http://data-portal.ecmwf.int/data/d/interim_daily/).

The **CONTRAIL** (Comprehensive Observation Network for TRace gases by AirLiner) project is being jointly conducted by NIES (National Institute for Environmental Studies), the MRI (Meteorological Research Institute), JAL (Japan Airlines International), JAMCO (JAMCO Corporation) and JAL-F (JAL Foundation).

JRA-25 long-term reanalysis cooperative research project carried out by the JMA and CRIEPI.

NOAA's 2-nd generation global ensemble reforecast data set" *Bulletin of the American Meteorological Society* article as follows : Hamill, T. M., J. S. Whitaker, G. T. Bates, D. R. Murray, M. Fiorino, T. J. Galarneau, Jr., Y. Zhu, and W. Lapenta, 2013