Integrated global carbon cycle modeling system for atmospheric CO_2 data assimilation

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CITES-2013, Sep 3, 2013, Petrozavodsk

Objective

Global carbon cycle is an important process to watch.

- Do predictions of the carbon emissions and CO_2 growth match IPCC scenarios?

- Relatively frequent extreme events, such as 1998 El Nino – Indonesia fires, 2003 European heat wave, 2010 E. Russian fires, 1998, 2002 Siberian forest fires, require quantification of the impact on carbon emissions and sinks.

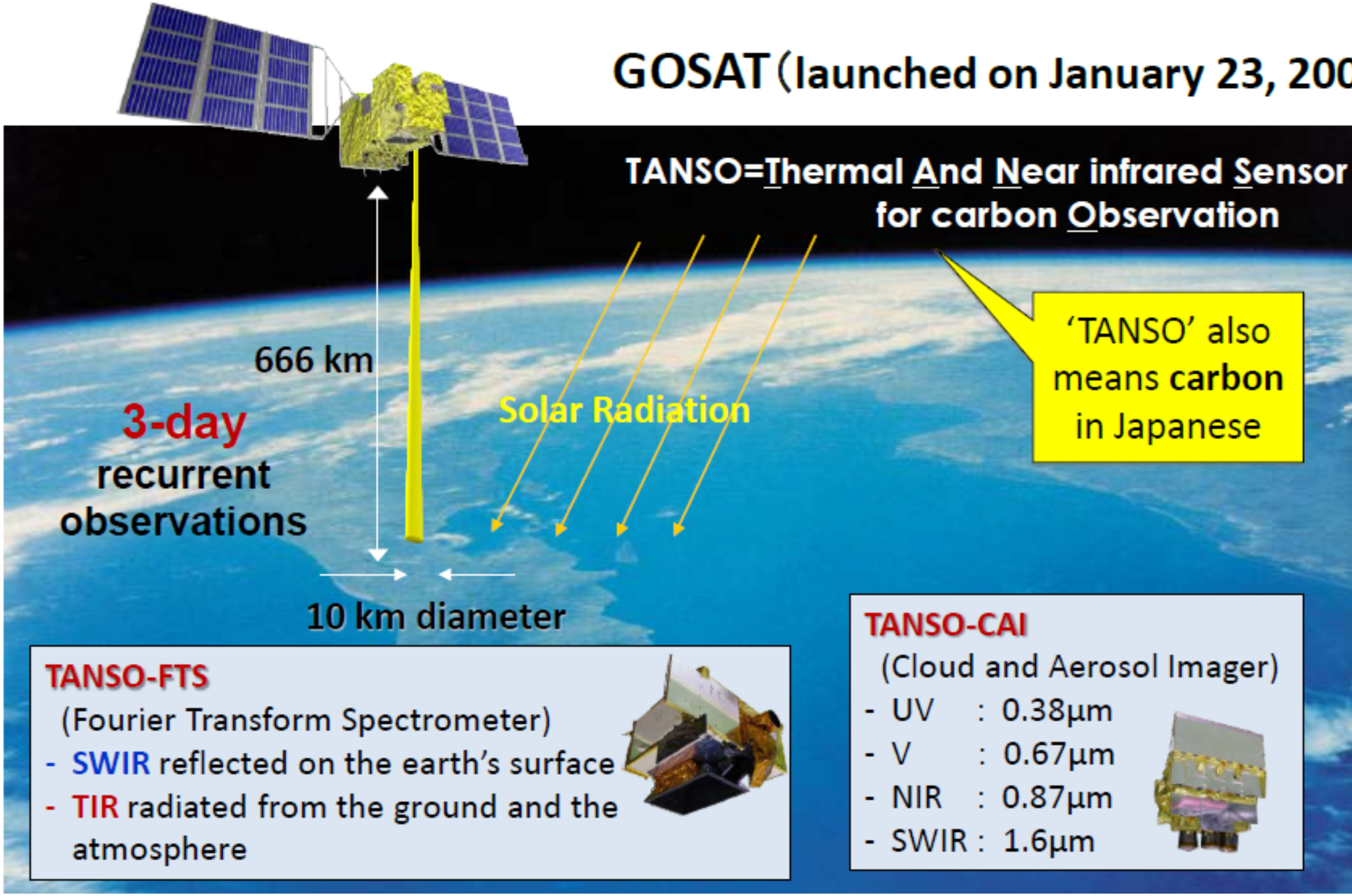
- Fate of the global terrestrial and oceanic carbon sink need to be checked periodically.

Multiyear regional CO_2 flux products

	Carbontracker	Rodenbeck et al 2003 Chevallier 2011	Rayner 1999, Baker 2007, Patra 2005, Bousquet 2000, etc	GOSAT Level 4 product
method	Ensemble Kalman Filter	Iterative, with adjoint and CG	Direct matrix solver	Direct matrix solver
resolution time&space	22 regions+ ecosystems (~400 unknowns),weekly	grid based, monthly, weekly	22+ regions, monthly	64 regions monthly
period	2000-2011	1993-2011	15-20 years	2009-2011
flux correlation	region, ecosystem type	proximate grid cell	No*	No
update	annual	annual	no	annual from 2011

GOSAT observation and sensors

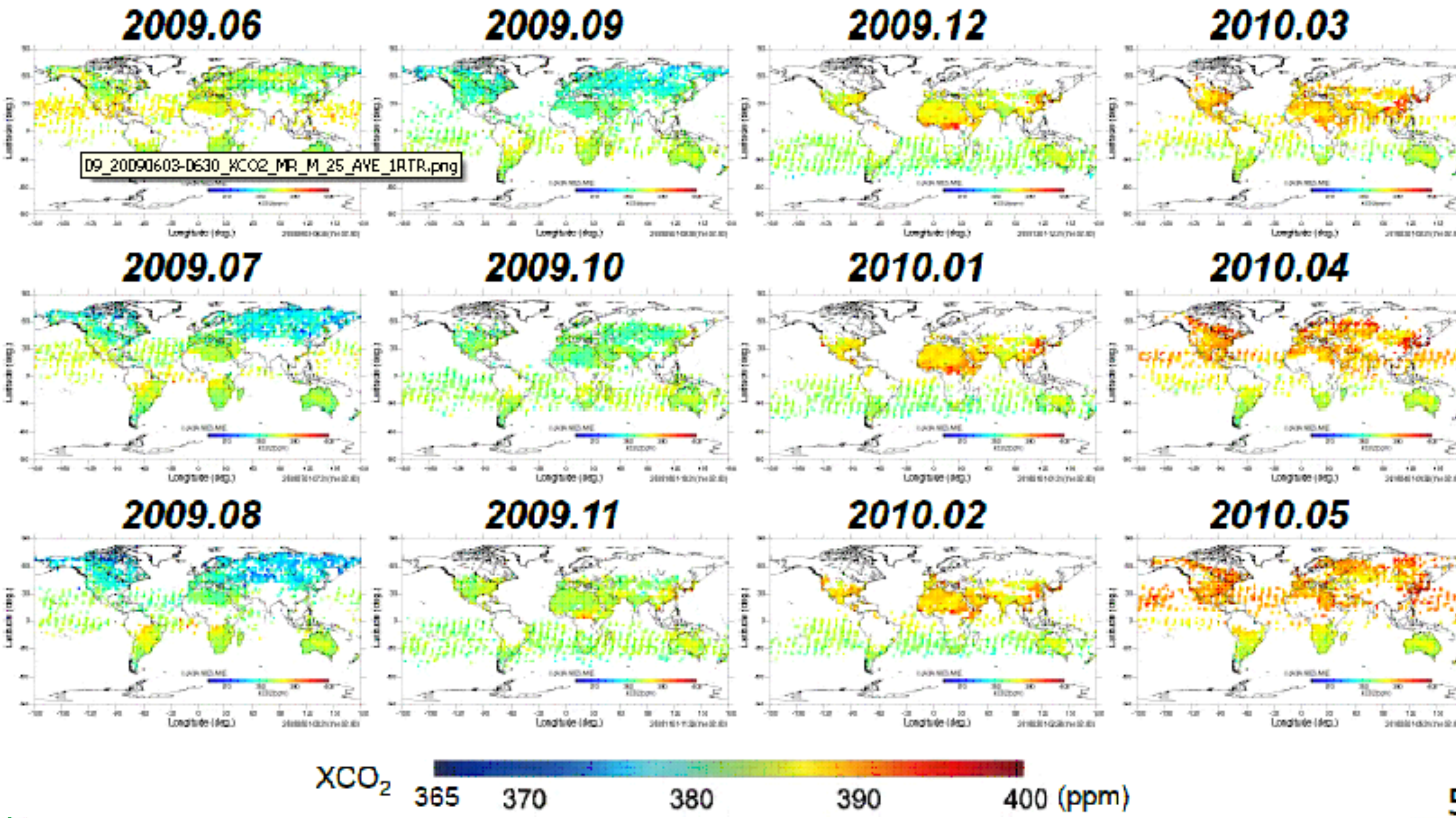
GOSAT (launched on January 23, 2009)



CO_2 observations by GOSAT

[2.5 deg. grid monthly means of XCO_2]

(TANSO-FTS SWIR Level 2 Ver.02.00)   *e.g.) June 2009 – May 2010 (12 months)*



Forward modeling tools

Fossil fuel emissions

CDIAC country level monthly and 1x1 degree resolution emissions (2 years delay)

EDGAR country level monthly and .1x.1 degree resolution emissions (about 2 years delay)

Terrestrial Ecosystem exchange

GFED 3.2 now includes CASA monthly fluxes

Oceanic fluxes

Takahashi et al 2009 climatology

CO2 flux models developed in GOSAT project

Fossil fuel emissions

ODIAC 1x1, .01x.01 degree resolution emissions (monthly)

Oda, T., and Maksyutov, S.: A very high-resolution (1km×1 km) global fossil fuel CO2 emission inventory derived using a point source database and satellite observations of nighttime lights, Atmos. Chem. Phys., 11, 543-556, 2011

Terrestrial Ecosystem exchange

VISIT daily ecosystem exchange, 0.5x0.5 degree

Saito, M., Ito, A., and Maksyutov, S.: Optimization of a prognostic biosphere model in atmospheric CO2 variability and terrestrial biomass, Geosci. Model Dev. Discuss., 6, 4243-4280, 2013

Oceanic fluxes

OTTM ocean pCO_2 4d-var assimilation system, 1x1 monthly fluxes

Valsala, V., and Maksyutov, S.: Simulation and assimilation of global ocean pCO2 and air-sea CO2 fluxes using ship observations of surface ocean pCO2 in a simplified biogeochemical offline model, Tellus-B, 62B, 821-840, 2010

Country totals by BP annual review

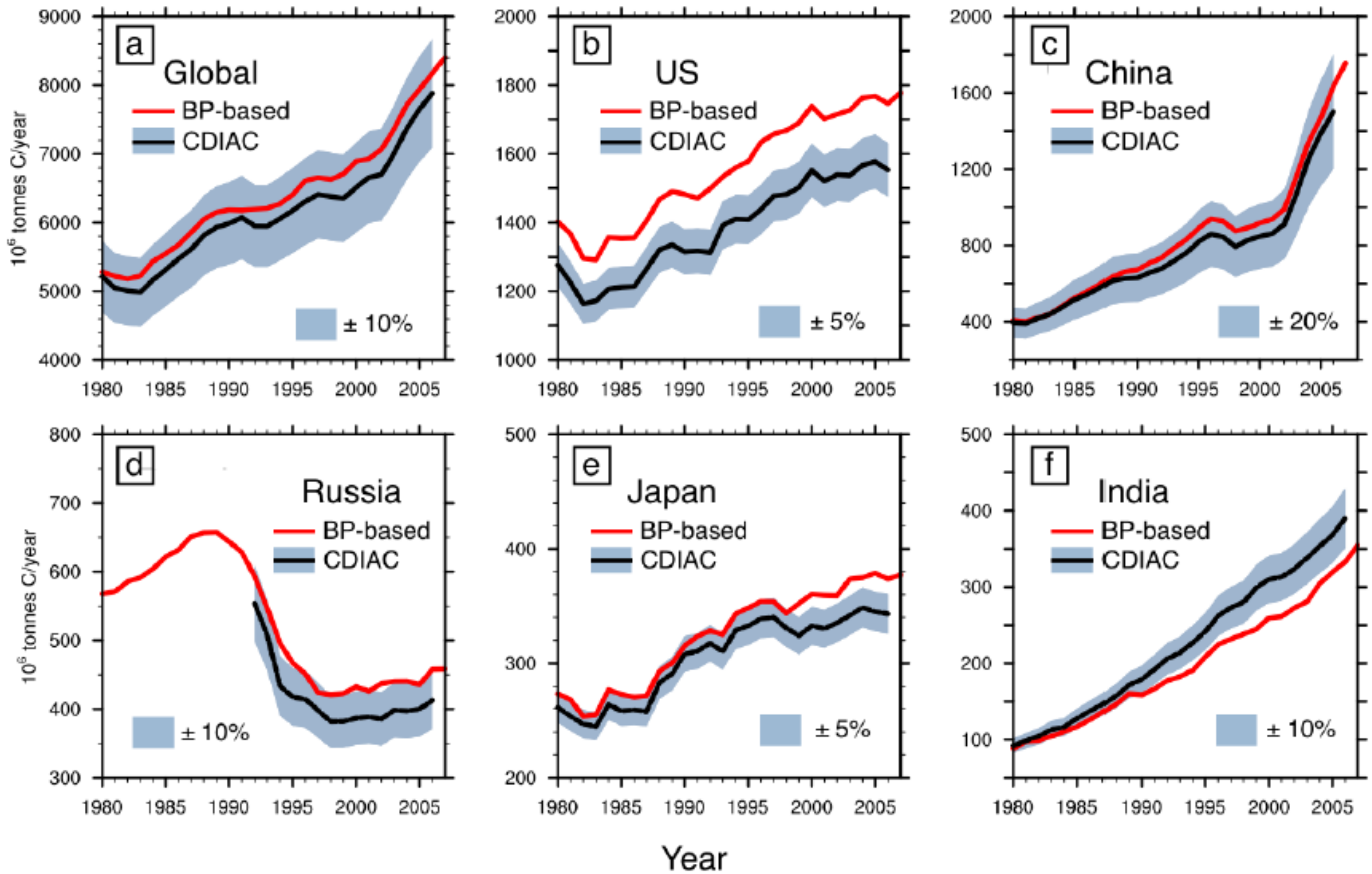


Figure 4.3: Comparison of the historical global and national CO_2 emission estimates for the years 1980–2007. The red line shows the estimates given using (BP, 2008) in this study and

CARMA database

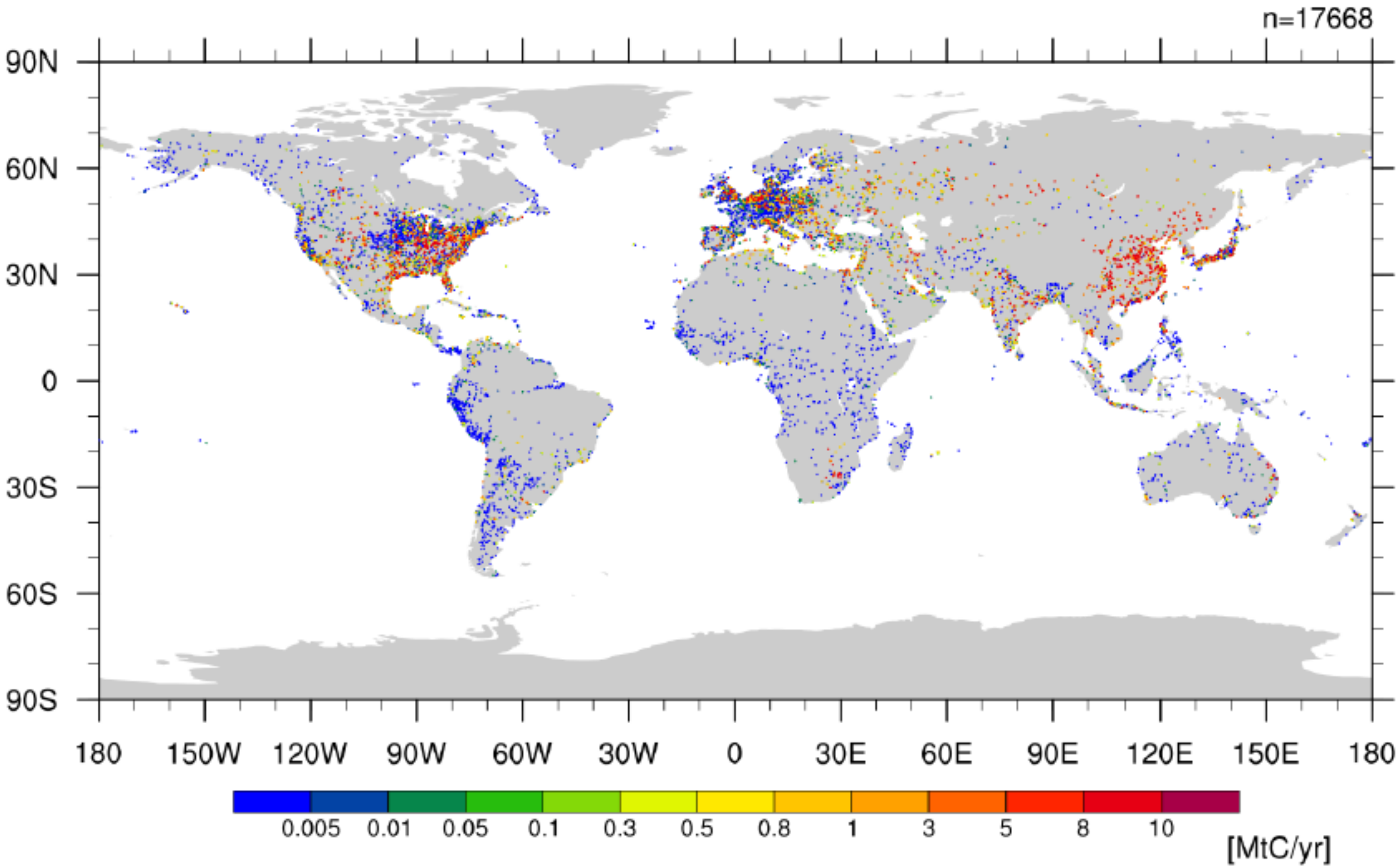
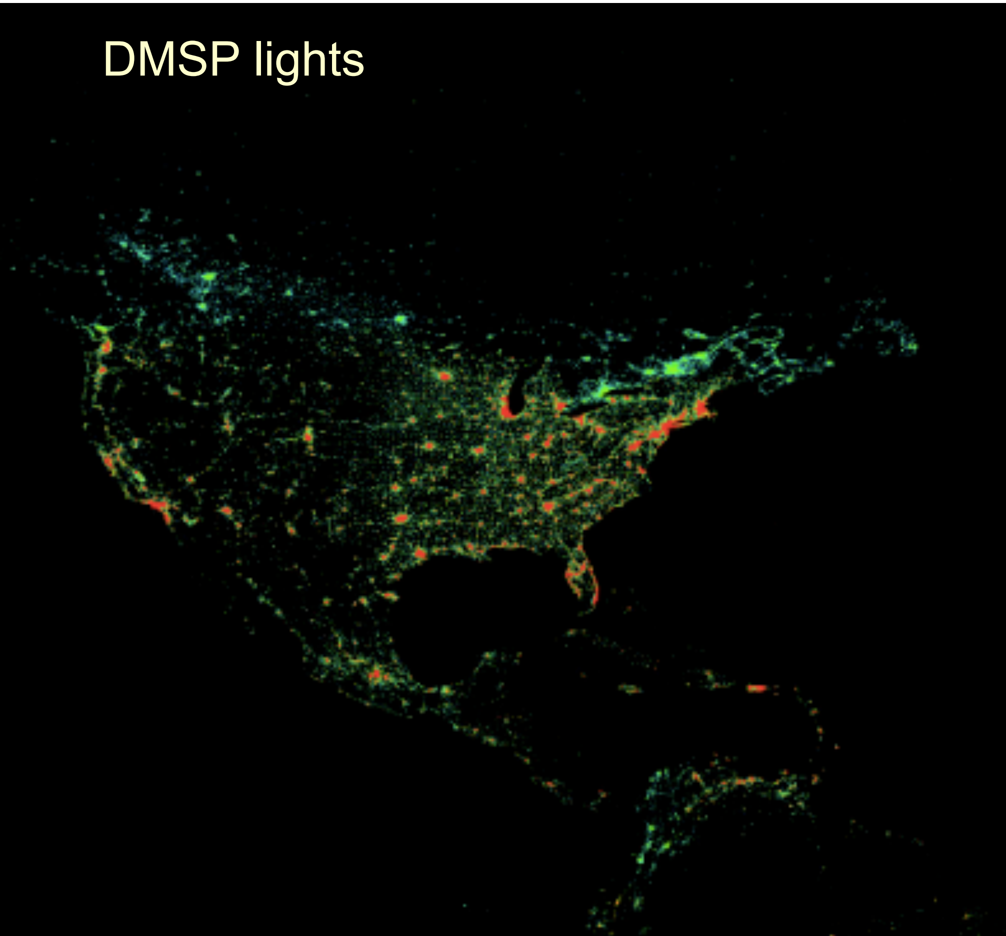
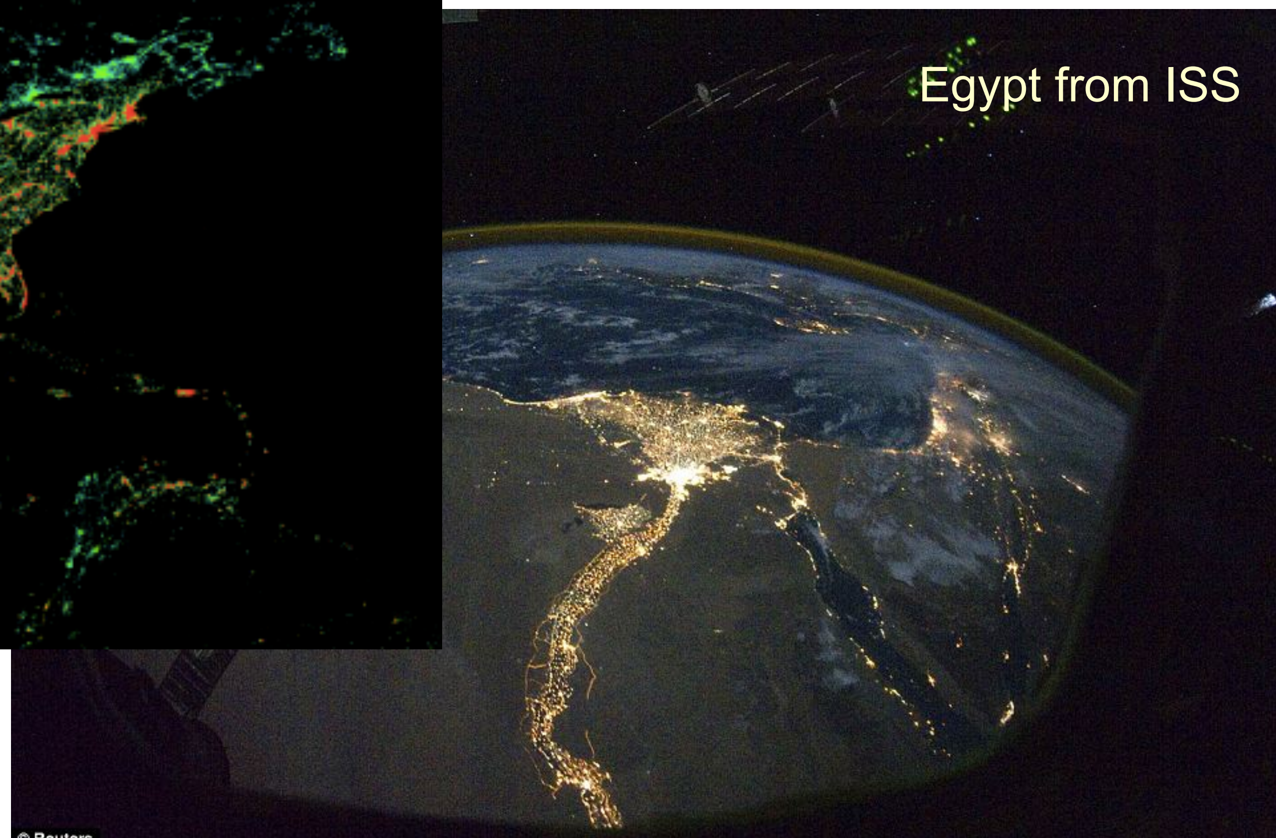


Figure 4.1: Global spatial distributions of power plant emissions for the year 2007. The coordinate and emission data of power plants were taken from the CARMA database (CAR-

Fossil fuel fluxes: towards better accounting for spatial and temporal variability



Combine country/region totals with power plants data base, nightlights and seasonal energy demand model



ODIAC

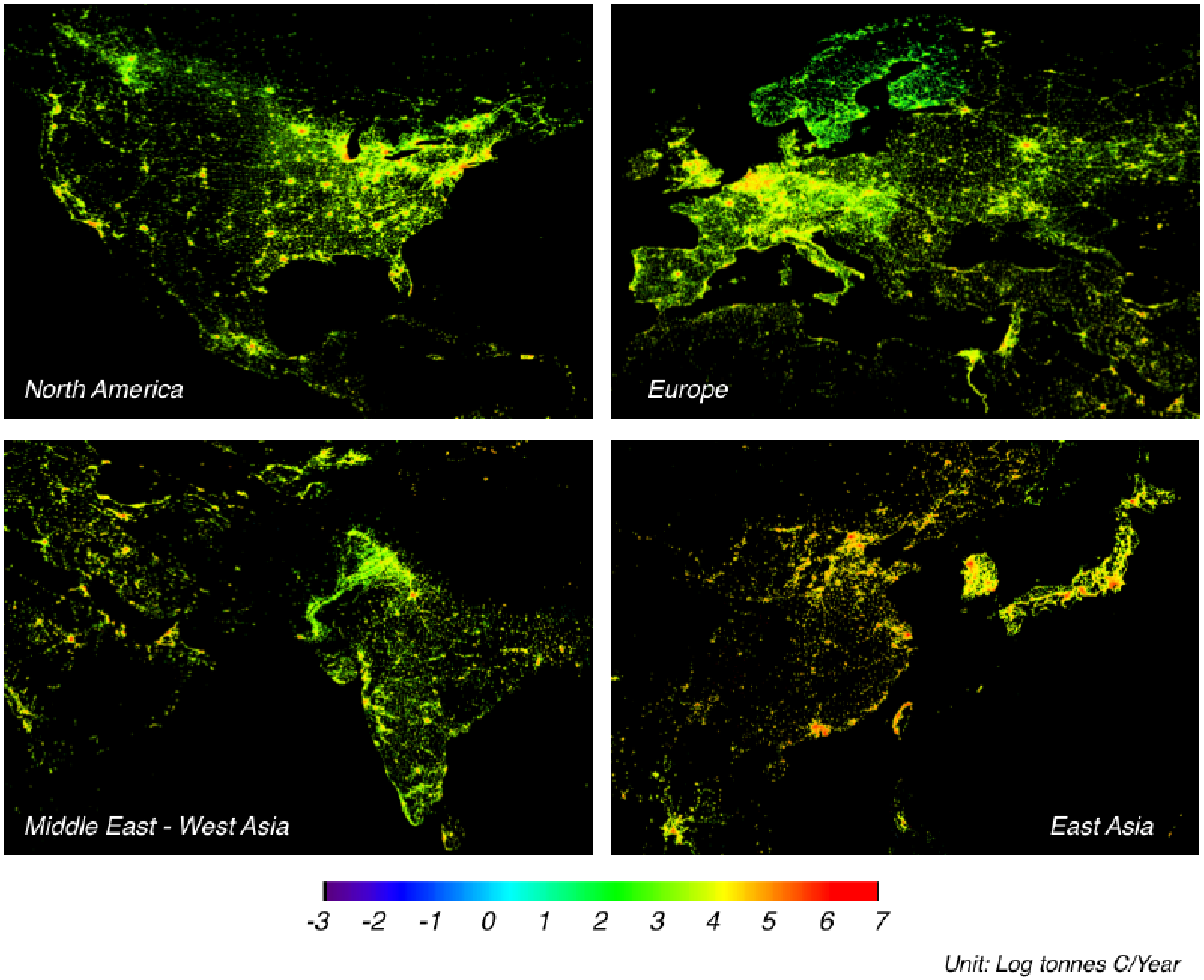
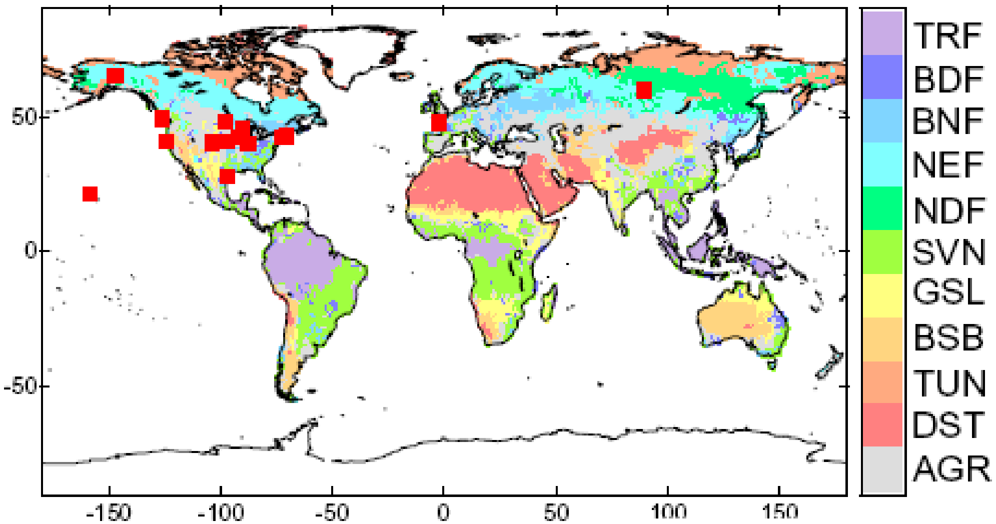


Figure 4.6: Regional spatial distributions of CO_2 emissions for the year 2006. From top left (clockwise): North America, Europe, East Asia, and the Middle East and West Asia. The

Land fluxes: improving simulation seasonal cycle in atmospheric CO2 partial column abundance



Initial values for each ecosystem
light use efficiency for NPP

E_{max}=0.55 gC/MJ PAR

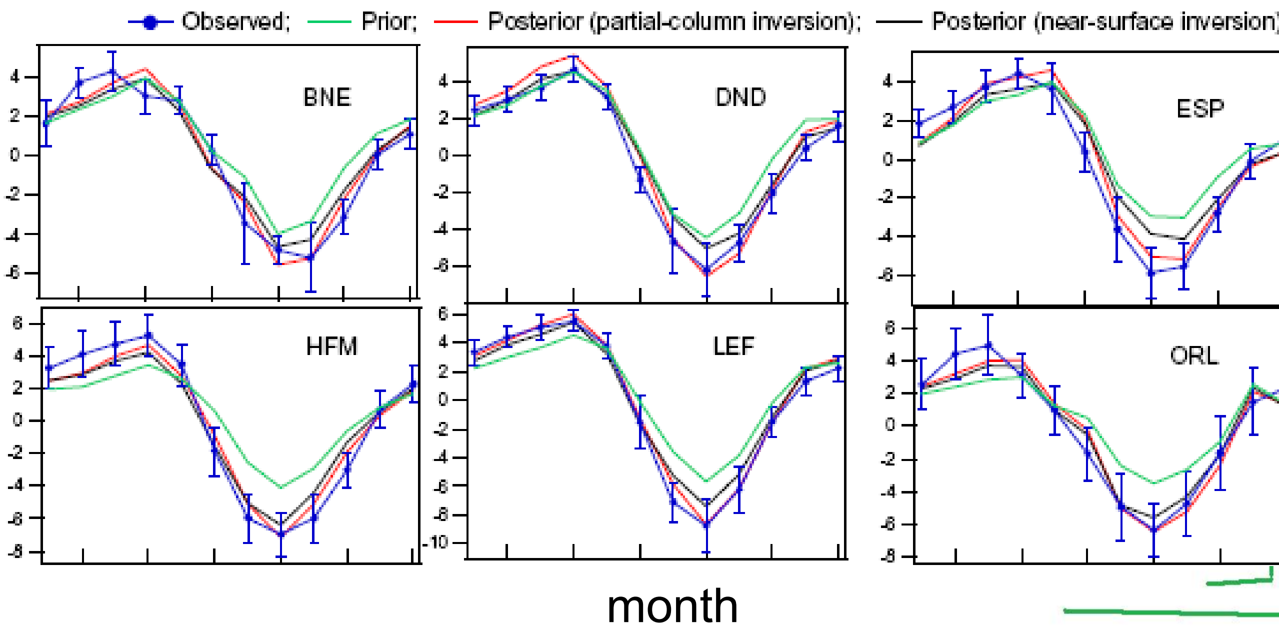
temperature coefficient of respiration

Q_{10}=1.50

Optimized independently for each vegetation type in CASA model

By Nakatsuka & Maksyutov, BG 2009

Seasonal variation of CO_2 partial column, with ecosystem model optimized with observations. Result: monthly CO2 flux maps at 1x1 deg res.



Next step optimization of the seasonal cycle separately for each biome.

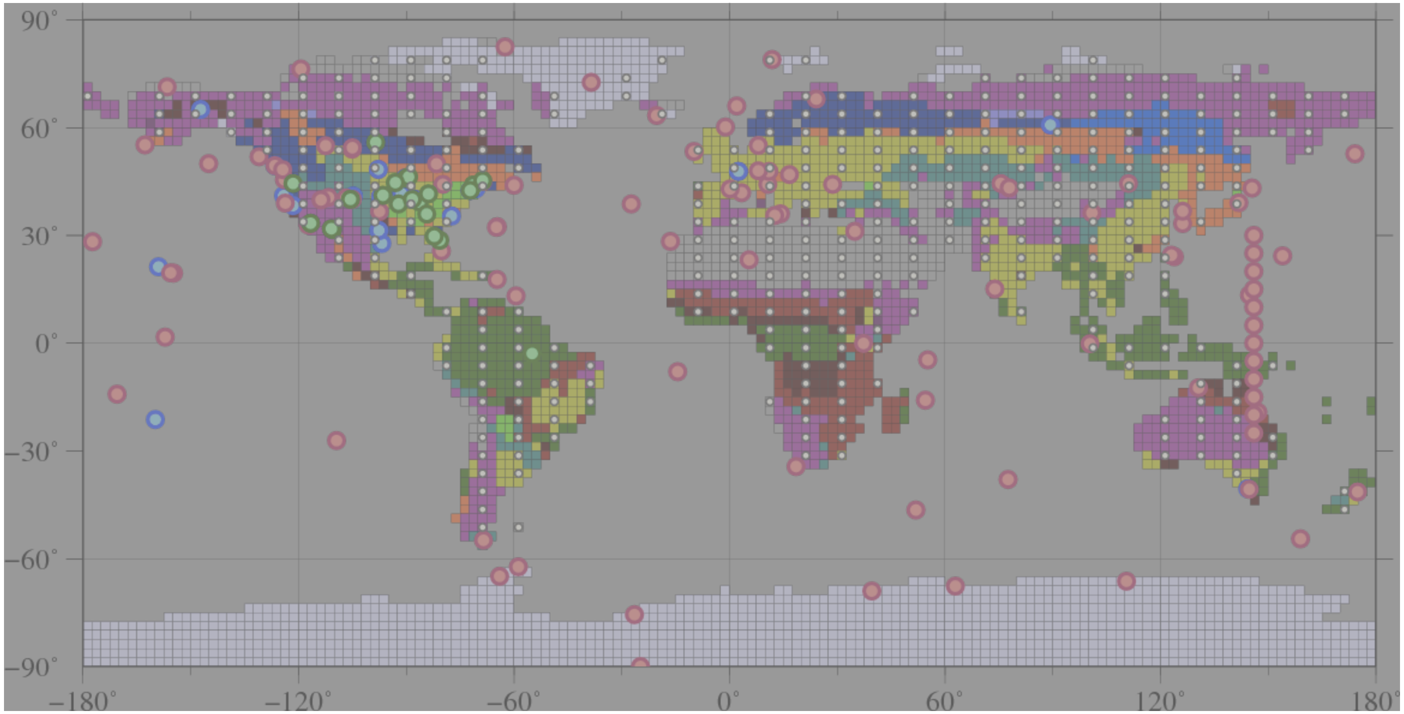
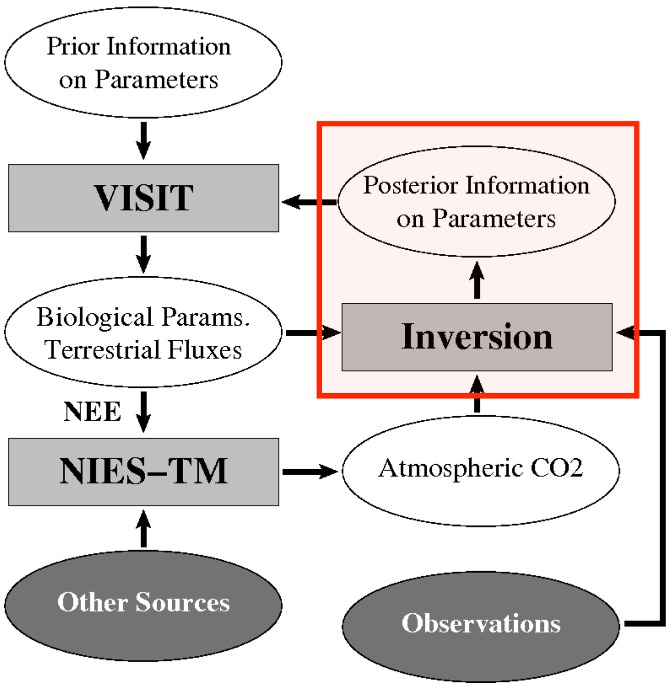


Fig. Locations of observational sites used in the VISIT optimization system.

- Surface CO_2 concentration (103 points) from *GLOBALVIEW*
- Column CO_2 concentration (20) from *GLOBALVIEW*
- Eddy Covariance CO_2 Fluxes (21) from *AmeriFlux*
- Aboveground Biomass (351) from *IIASA*

◉ Control Variables (2. Optimization Study)



12 Parameters X 15 biomes

= **180 Tracers**

=== Photosynthesis Parameters ===

ek0 : Light Attenuation Coefficient

$\mathbf{P_{max}}$: Potential Maximum Rate

gsb : Stomatal Conductance

$\mathbf{T_{min}}$: Minimum Temperature

kmn : Soli Moisture Limitation Factor

=== Respiration Parameter ===

rgf : Leaf Specific Growth Resp. Rate

rmf : Leaf Specific Maintenance Resp. Rate

rgr : Fine Root Growth Resp. Rate

rmr : Fine Root Maintenance Resp. Rate

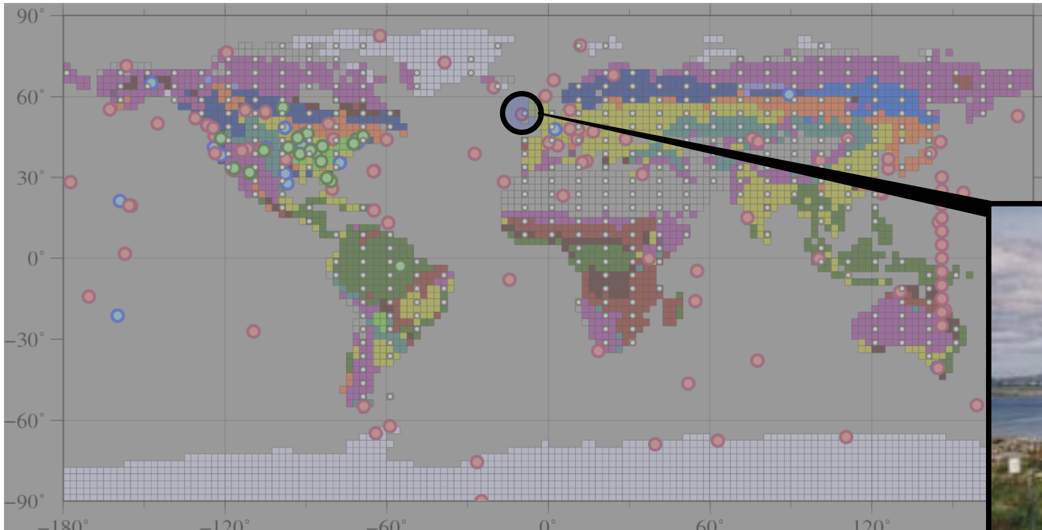
q10 : Temperature Dependence

=== Litterfall ===

lf0 : Leaf Specific Litterfall

lc0 : Stem Specific Litterfall

◉ Mace Head Research Station (3. Results and Discussion)



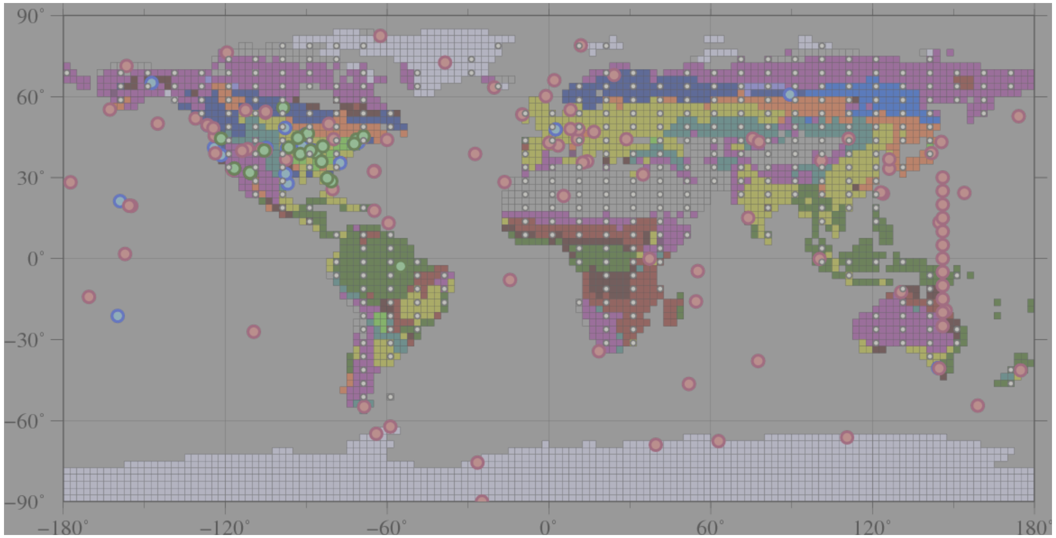
http://macehead.nuigalway.ie/

Mace Head:

- Ireland (53.3°N, 9.9°W)
- Flask Sampling
- representing atmospheric total conditions (local, regional and background effects)

◉ Column CO_2 Stations (3. Results and Discussion)

GOSAT Greenhouse gases Observing SATellite



: Column Stations (20 sites)

1. AIA : Bass Strait/Cape Grim, Australia (-40.5, 144.3)
2. BME : St. Davids Head, UK (32.4, -64.7)
3. CAR : Briggsdale, Colorado (40.4, -104.3)
4. DND : Dahlen, North Dakota (48.4, -99.0)
5. ESP : Estevan Point, Canada (49.6, -126.4)
6. HAA : Molokai Island, Hawaii (21.2, -159.0)
7. HFM : Harvard Forest, Massachusetts (42.5, -72.2)
8. HIL : Homer, Illinois (40.1, -87.9)
9. ITN : Grifton, North Carolina (35.6, -77.4)
10. LEF : Park Falls, Wisconsin (46.0, -90.3)
11. NHA : Worcester, Massachusetts (43.0, -70.6)
12. ORL : Orleans, France (47.8, 2.5)
13. PFA : Poker Flat, Alaska (65.1, -147.3)
14. RTA : Rarotonga, Cook Islands (-21.3, -159.8)
15. TGC : Sinton, Texas (27.7, -96.9)
16. THD : Trinidad Head, California (41.1, -124.2)
17. WBI : West Branch, Iowa (41.7, -91.4)
18. WGC : Walnut Grove, California (38.3, -121.5)
19. WKT : Moody, Texas (31.3, -97.3)
20. ZOT : Zotino, Siberia (60.8, 89.4)

◉ Partial Column CO_2 (defined as in Nakatsuka BG 2009)

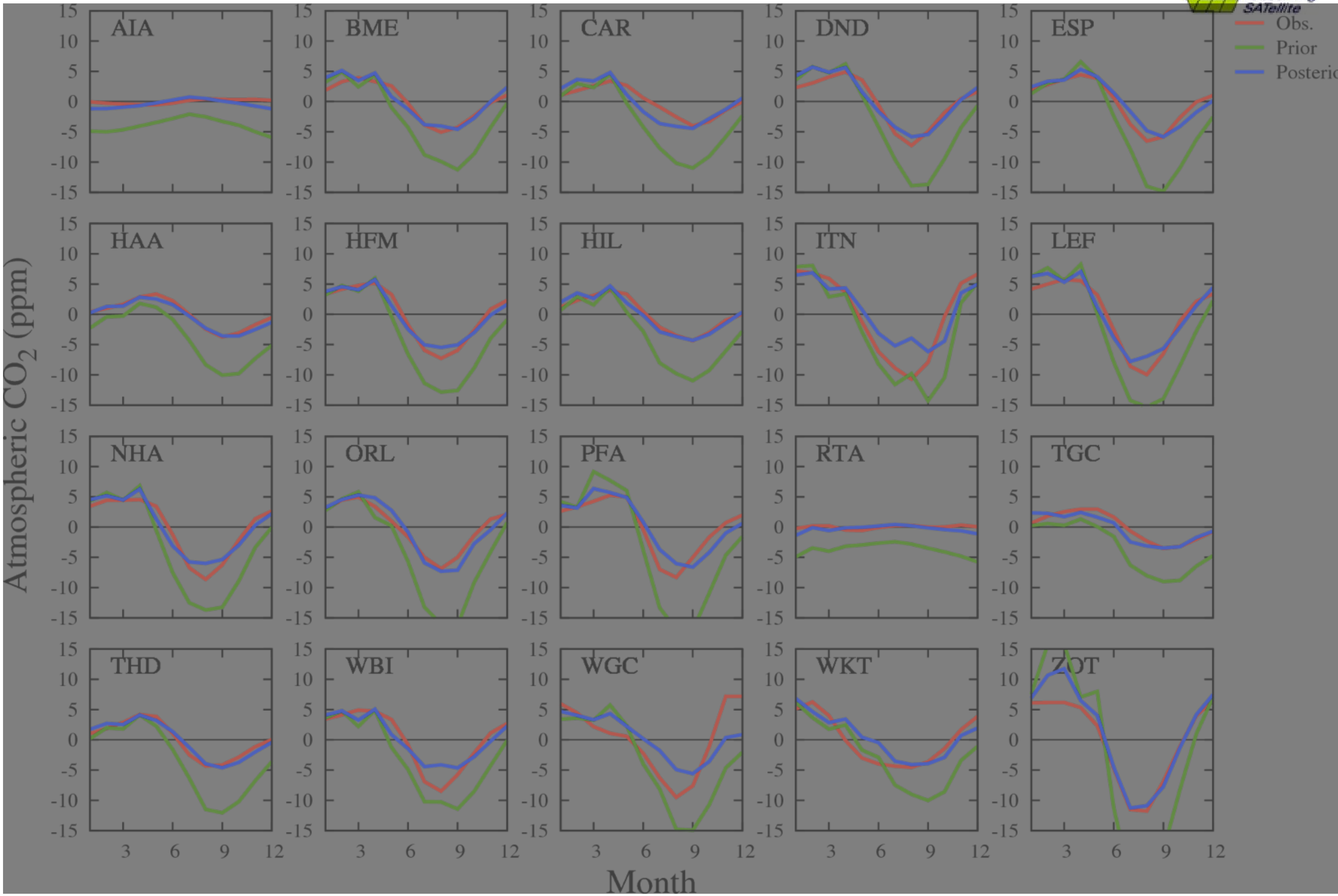
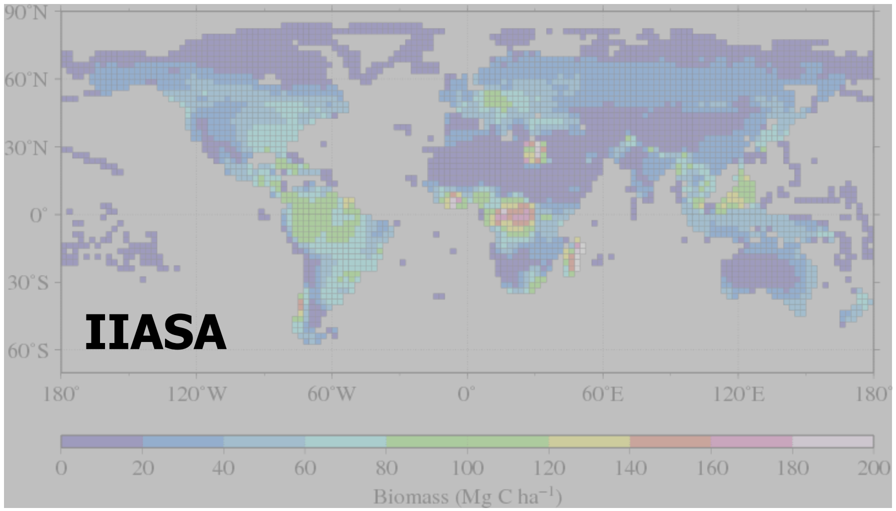
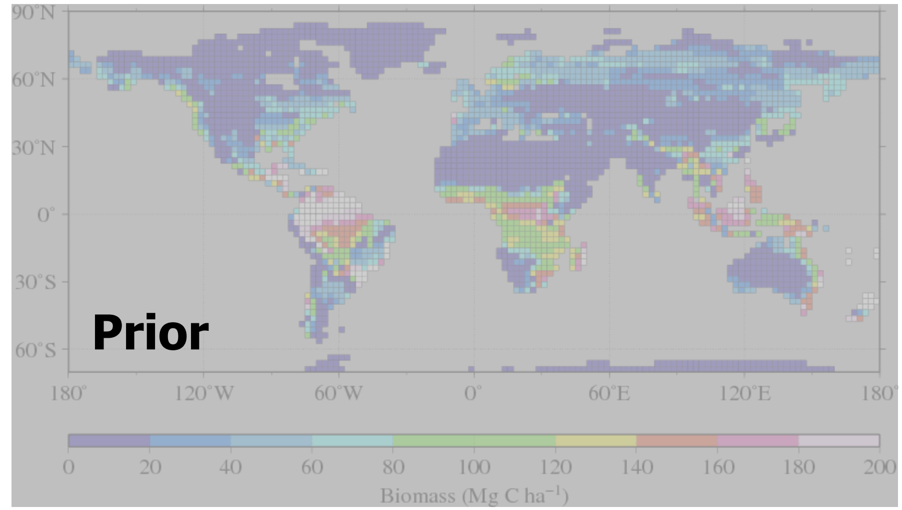
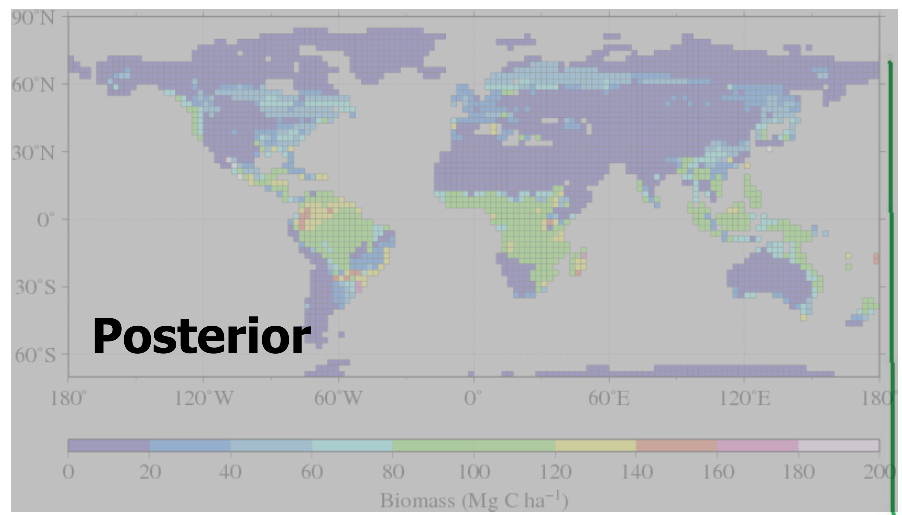


Fig. Seasonal variations of atmospheric CO_2 at the column stations in 2007.

◉ Biomass (3. Results and Discussion)







- IIASA biomass data of 351 grids were also used to optimize a set of VISIT parameters.
- Biomass are time invariant data.

Fig. Global map of gridded mean biomass (Mg C ha^{-1}): (left) IIASA; (right top) Prior; (right bottom) posterior.

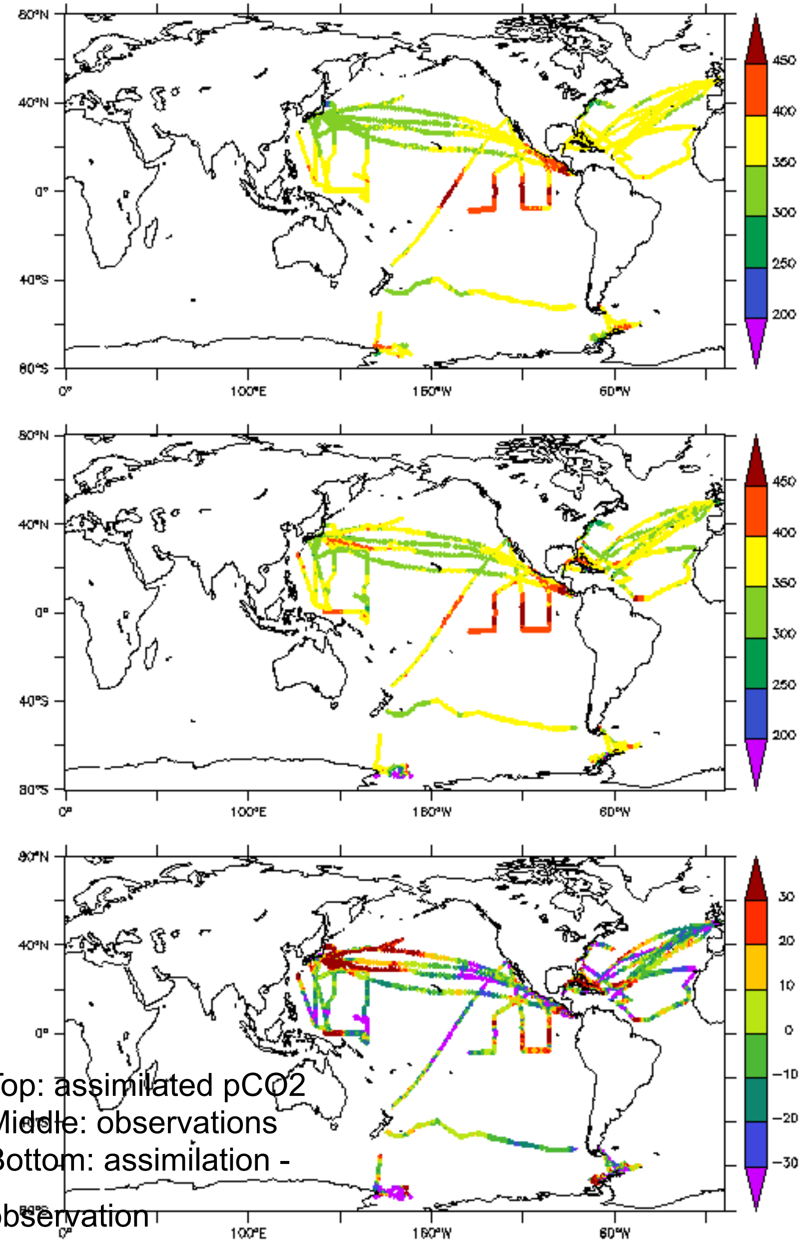
4D-var assimilation of the surface ocean pCO_2

Objective:
Provide ocean CO_2 flux for GOSAT L4A inverse model.

Physical : Oceanic TM (Valsala et al., 2008)
Chemical: OCMIP-II (Watson and Orr, 2003)
Biological: McKinley et al. 2004
4D-var: Ikeda and Sasai (2002)

Currents: GODAS

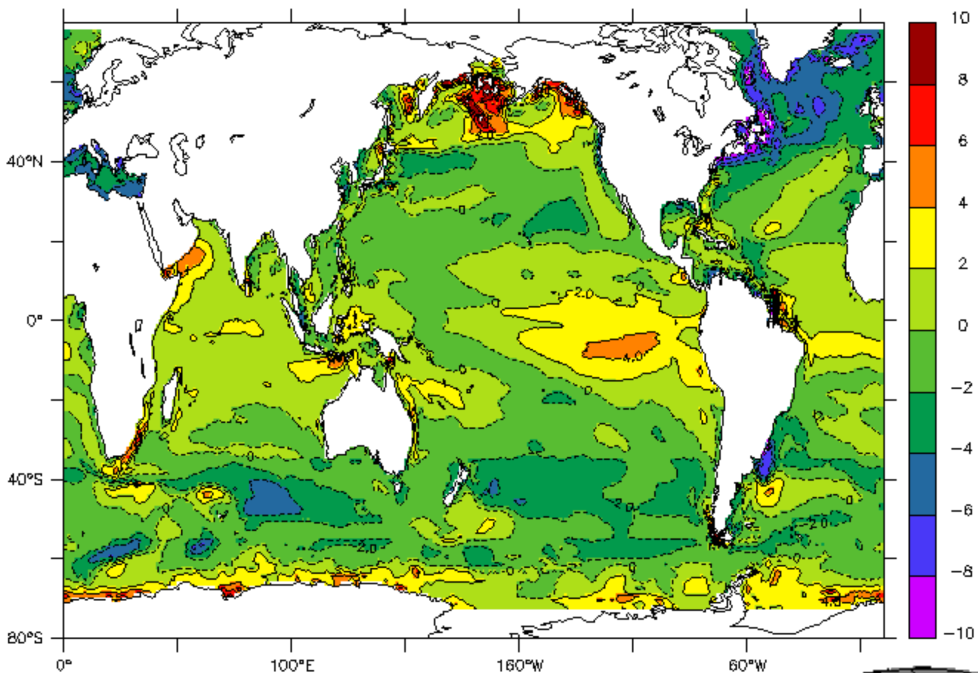
DIC/pCO2 observations:
LDEO database, Takahashi 2008,
North Pacific – Nojiri et al



Top: assimilated pCO2
Middle: observations
Bottom: assimilation - observation

Ocean fluxes: assimilation output

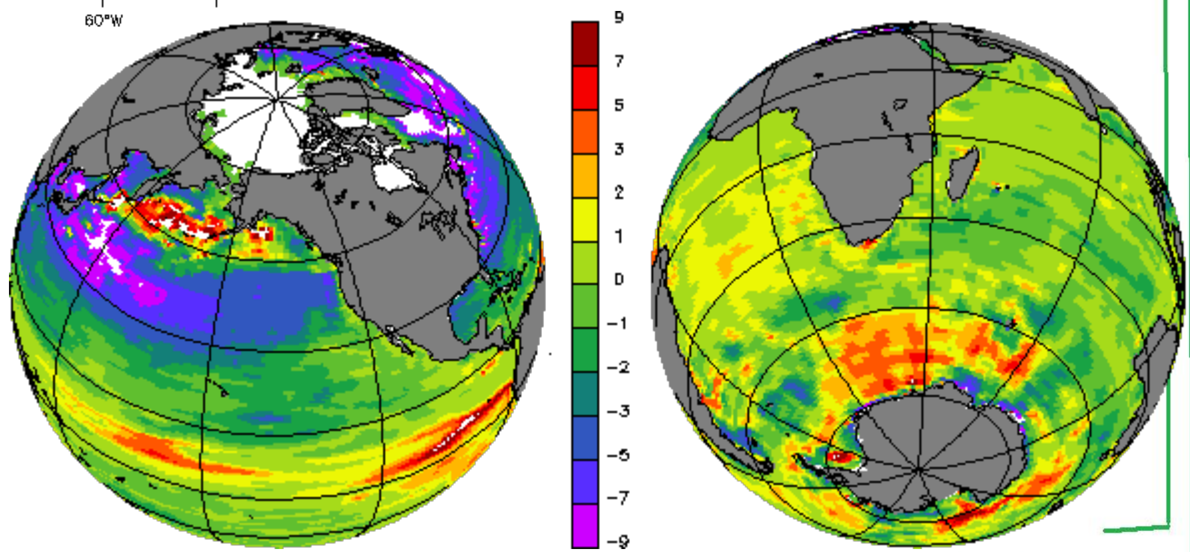
ECCO annual mean co2 flux (spin up; mole/m2/yr)



4D-Var assimilation of ocean CO_2 flux

Period:
Near-Real time
Completed: 1996-2004.
Going on: 2004-2009.
Animation Multi-year assimilated air-sea CO_2 flux .

Ocean currents by ECCO reanalysis (MIT ocean GCM) are available with approximately 1 month delay.



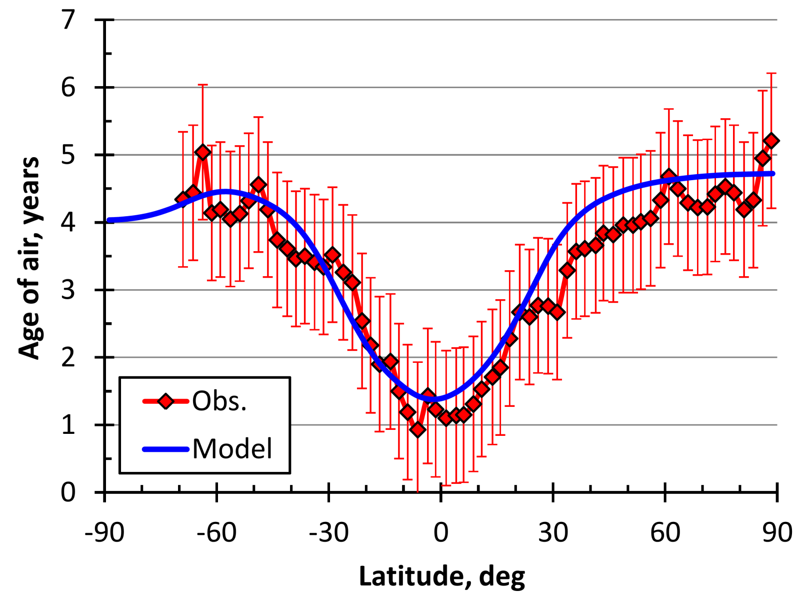
Fixing CO_2 transport in PBL, cumulus clouds and stratosphere

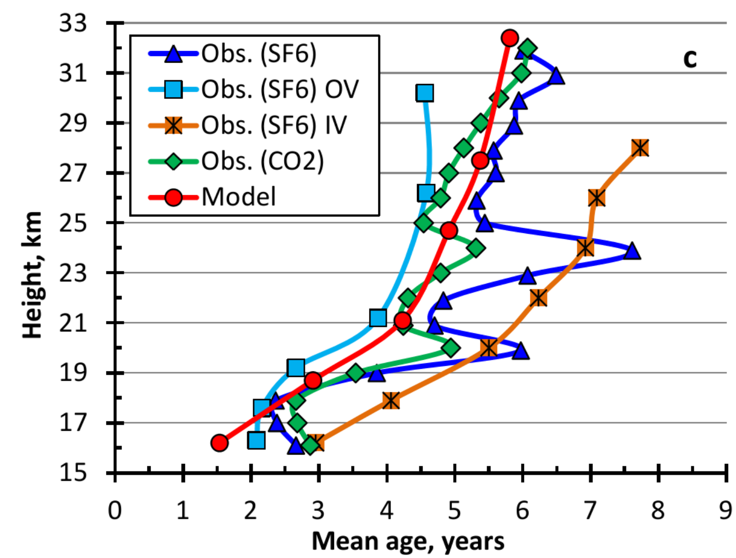
Problem:
Tracer mixing in stratosphere is very slow – CO2 growth is 5 years behind troposphere.

Solution:
Isentropic vertical grid in stratosphere above 350 K

Result:
Our model can simulate realistic profiles using only 32 vertical levels

Other features:
PBL Height from ERA-interim
Penetrative convection – Kuo parameterisation





Summary

GOSAT project team has achieved progress in the near-realtime CO_2 flux and transport modeling in global scale including:

- Fossil fuel emissions model, including seasonality and spatial distribution
- Process-based modeling of the terrestrial ecosystem fluxes
- Observation-driven data assimilation system for near real-time surface pCO2 and ocean-atmosphere flux estimation
- Realistic model of the stratospheric and total column CO_2 transport modeling

Overview published in

Maksyutov, S., Takagi, H., Valsala, V. K., Saito, M., Oda, T., Saeki, T., Belikov, D. A., Saito, R., Ito, A., and coauthors.: Regional CO2 flux estimates for 2009–2010 based on GOSAT and ground-based CO2 observations, Atmos. Chem. Phys. Discuss., 12, 29235-29288, 2012

Publications (1)

- Belikov, D. A., Maksyutov, S., Miyasaka, T., Saeki, T., Zhuravlev, R., and Kiryushov, B.: Mass-conserving tracer transport modelling on a reduced latitude-longitude grid with NIES-TM, Geosci. Model Dev., 4, 207-222, 2011.
- Belikov, D. A., Maksyutov, S., Sherlock, V., Aoki, S., Deutscher, N. M., Dohe, S., Griffith, D., Kyro, E., Morino, I., Nakazawa, T., Notholt, J., Rettinger, M., Schneider, M., Sussmann, R., Toon, G. C., Wennberg, P. O., and Wunch, D.: Simulations of column-average CO2 and CH4 using the NIES TM with a hybrid sigma-isentropic (σ−θ) vertical coordinate, Atmos. Chem. Phys., 13, 1713–1732, 2013a.
- Belikov, D. A., Maksyutov, S., Krol, M., Fraser, A., Rigby, M., Bian, H., Bergmann, D., Bousquet, P., Cameron-Smith, P., Chipperfield, M.P., Fortems-Cheiney, A., Gloor, E., Haynes, K., Hess, P., Houweling, S., Kawa, S.R., Law, R.M., Loh, Z., Meng, L., Palmer, P.I., Patra, P. K., Prinn, R.G., Saito, R., Wilson, C., and Agusti-Panareda, A.: Off-line algorithm for calculation of vertical tracer transport in the troposphere due to deep convection, Atmos. Chem. Phys. Discuss., 13, 1093–1114, 2013b.
- Maksyutov, S., Patra, P. K., Onishi, R., Saeki, T., and Nakazawa, T.: NIES/FRCGC global atmospheric tracer transport model: description, validation, and surface sources and sinks inversion, J. Earth Simulator, 9, 3-18, 2008.
- Oda, T., and Maksyutov, S.: A very high-resolution (1km×1 km) global fossil fuel CO2 emission inventory derived using a point source database and satellite observations of nighttime lights, Atmos. Chem. Phys., 11, 543-556, 2011

Publications (2)

- Saeki, T., Maksyutov, S., Sasakawa, M., Machida, T., Arshinov, M., Tans, P., Conway, T. J., Saito, M., Valsala, V., Oda, T., and Andres, R. J.: Carbon flux estimation for Siberia by inverse modeling constrained by aircraft and tower CO2 measurements, J. Geophys. Res. Atmos., 118, 1100–1122, doi:10.1002/jgrd.50127, 2013.
- Saito, M., Ito, A., and Maksyutov, S.: Evaluation of biases in JRA-25/JCDAS precipitation and their impact on the global terrestrial carbon balance, J. Climate, 24, 4109-4125, 2011.
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- Takagi H., Saeki, T., Oda, T., Saito, M., Valsala, V., Belikov, D., Saito, R., Yoshida, Y., Morino, I., Uchino, O., Andres, R. J., Yokota, T., and Maksyutov, S.: On the benefit of GOSAT observations to the estimation of regional CO2 fluxes, SOLA, 7, 161-164, 2011
- Valsala, V., Maksyutov, S., and Ikeda, M.: Design and validation of an offline Oceanic Tracer Transport Model for Carbon Cycle study, J. Climate, 21, 2752-2769, 2008.
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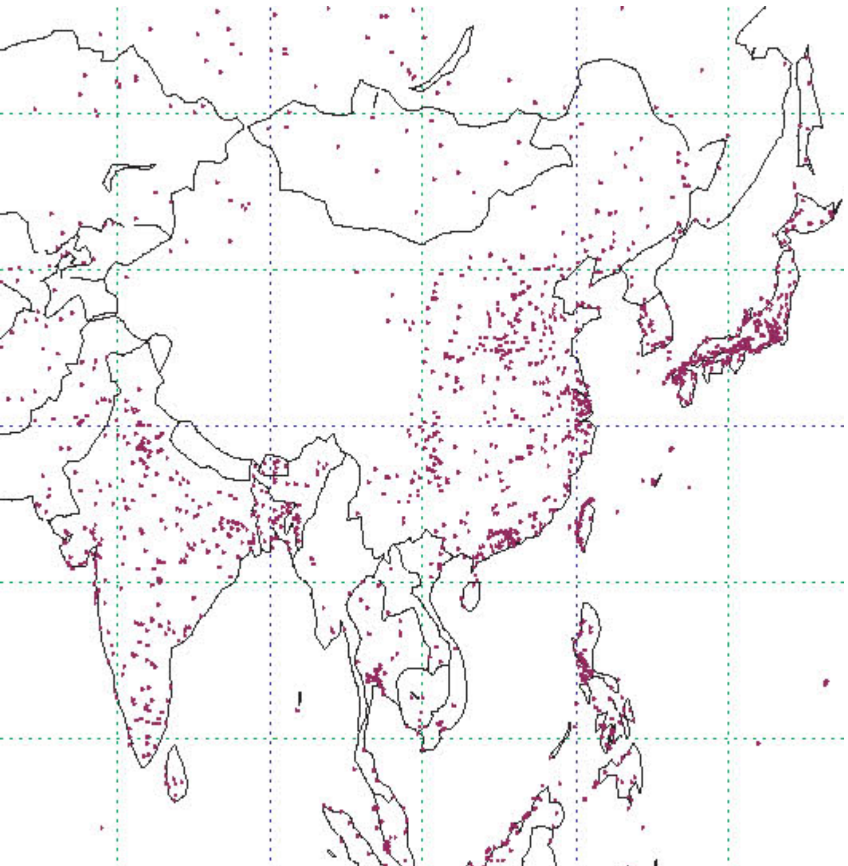
- Valsala, V., Maksyutov, S., Telszewski, M., Nakaoka, S., Nojiri, Y., Ikeda, M., and Murtugudde, R.: Climate impacts on the structures of the North Pacific air-sea CO2 flux variability, Biogeosciences, 9, 477-492, doi:10.5194/bg-9-477-2012, 2012a.

Thank you

Fossil fuel fluxes: ODIAC inventory

Problem: how to produce up-to-date fossil CO2 emissions map at transport model resolution, with seasonal variations, globally
Emissions are reported as country total per year – need to disaggregate into grid cells and seasons



Hints:
Large point source data are available from EPA, ETER, CARMA and other sources

Spatial: emission proxies population and night lights (DMSP and VIIRS satlite) are available at ~ 5km to 1 degree resolution

Temporal/seasonal: temperature dependent energy demand for heating and cooling
Target resolution: 50 and 1 km globally,
Seasonal – monthly mean