GEMS/MACC Assimilation of IASI

Richard Engelen

Many thanks to the GEMS team.

Outline

- The GEMS and MACC projects
- Assimilation of IASI CO retrievals
- Why do we prefer radiance assimilation?
- IASI CH_4: bias correction and first results
- AIRS and IASI CO_2 results

The GEMS and MACC Projects

GMES

Global Monitoring for Environment and Security

- a European initiative for the provision of information services on environment and security, led by the EC and ESA

- fostering the development of five core services: Atmosphere, Land, Ocean, Emergency Response and Security

GEMS

Global and regional Earth-system Monitoring using Satellite and in-situ data

- a 32-partner EC project developing systems for the core GMES atmospheric service

GMES atmospheric services: Services related to the chemical and particulate content of the atmosphere

National Meteorological Services and EMI

Global distributions and net sources/sinks of greenhouse gases and aerosols

European air quality

Long-range transport

Sand and dust storms

Solar energy resources

Exposure to UV radiation

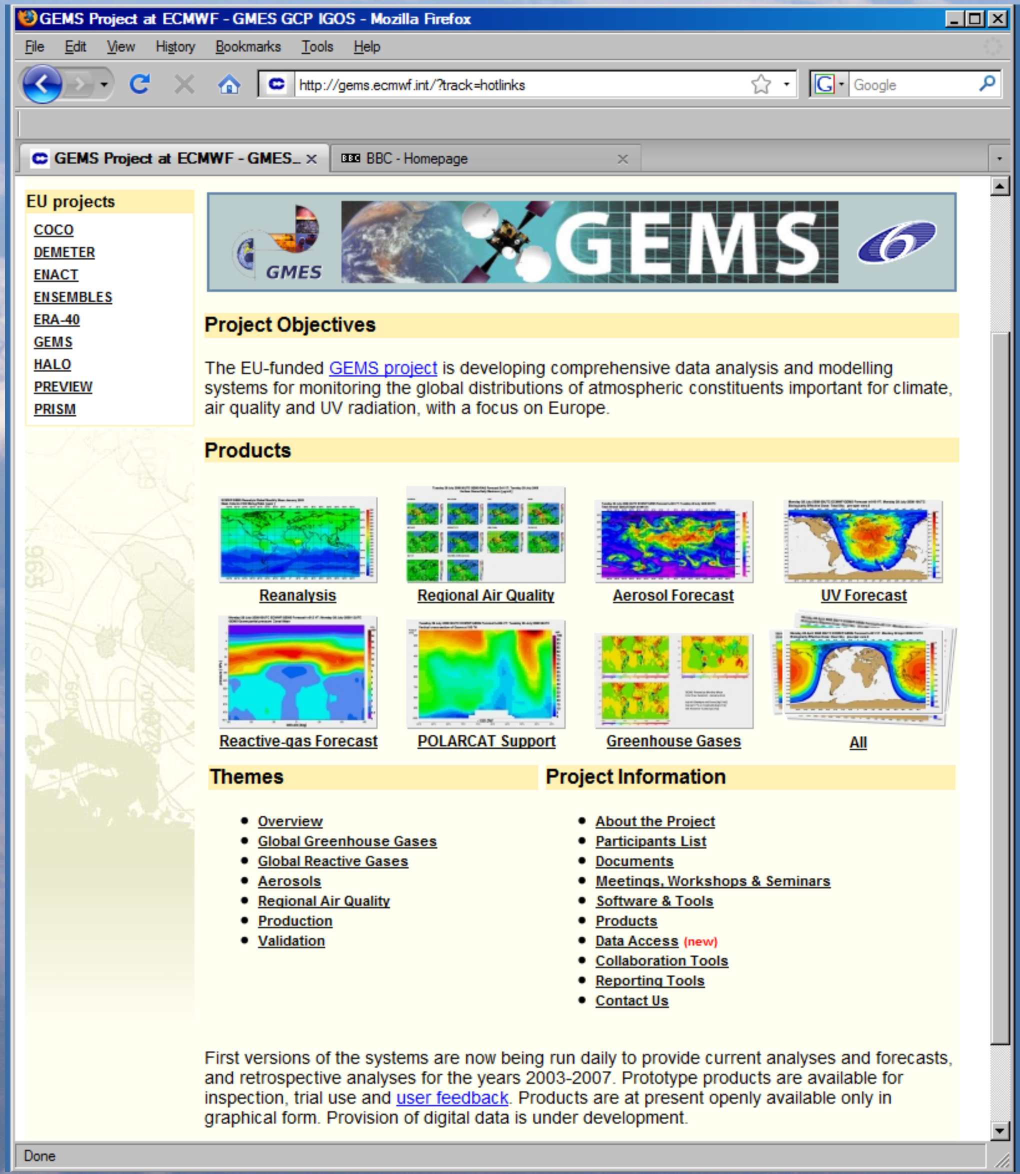
National and European environmental agencies

GEMS tasks at ECMWF

- **Coordinate project** *(Adrian Simmons)*
- **Extend IFS model to includes aerosols, carbon dioxide and methane** *(Johannes Kaiser, Jean-Jacques Morcrette, Soumia Serrar)*
- **Add faster reactive species to IFS and couple with external models for chemical tendencies** *(Johannes Flemming)*
- **Develop data assimilation for new species** *(Angela Benedetti, Antje Dethof, Richard Engelen)*
- **Acquire global data, develop validation and support regional air-quality forecasting** *(Luke Jones, Miha Razinger, Martin Suttie)*
- **Provide prototype production systems** *(Everyone)*

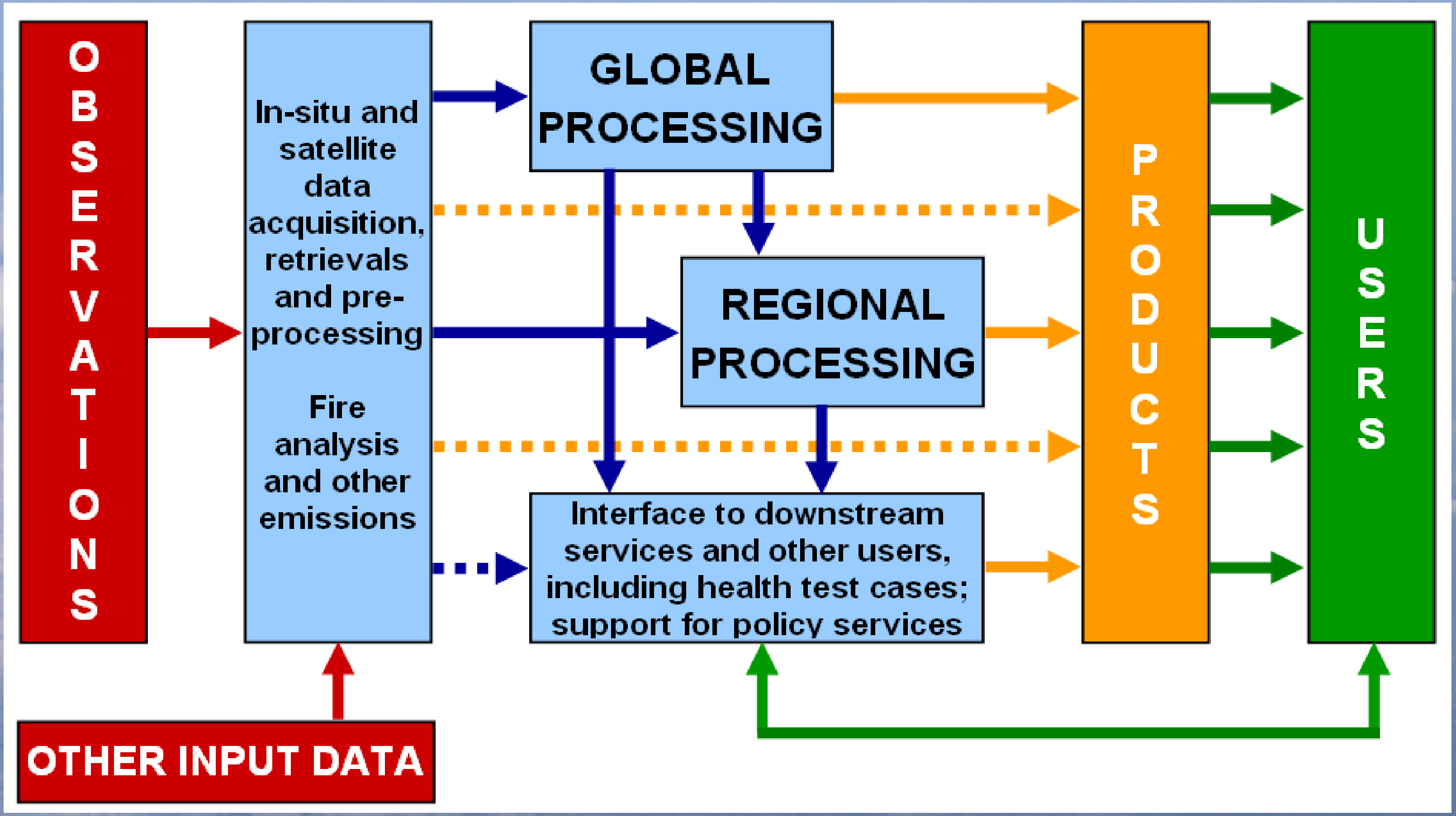
Daily GEMS production at ECMWF

- Near-real-time global systems for reactive gases, aerosols and UV radiation
- A global reanalysis for 2003-2007 for all species
- Web-hosting, archiving and verification of coordinated regional air-quality forecasts from ten systems



http://gems.ecmwf.int

MACC – Monitoring Atmospheric Composition and Climate

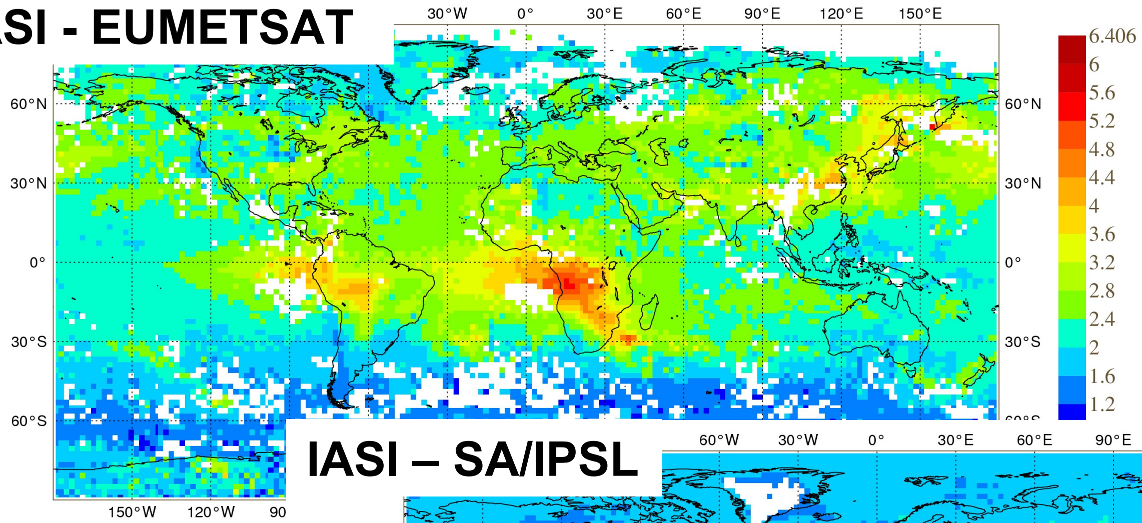


A 48-partner successor to GEMS and the ESA-funded GMES Service Element project PROMOTE.

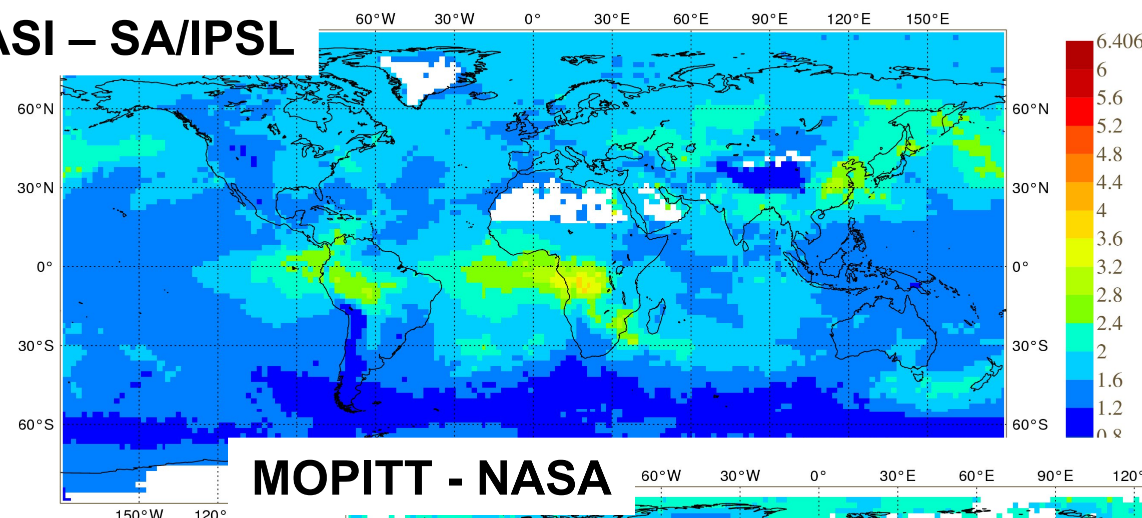
Assimilation of IASI CO Retrievals

4-day average of observed total column CO.

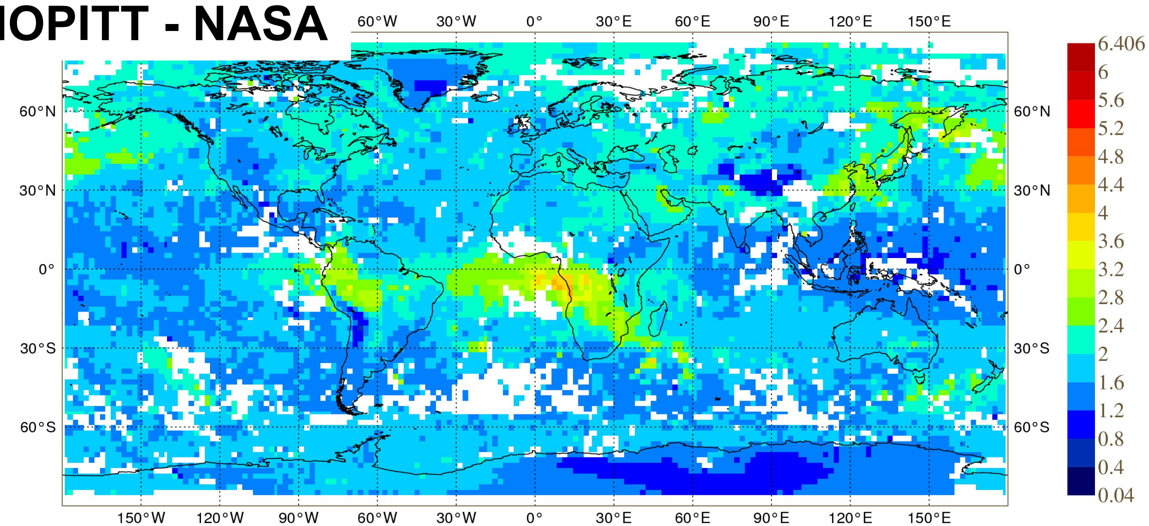
IASI - EUMETSAT



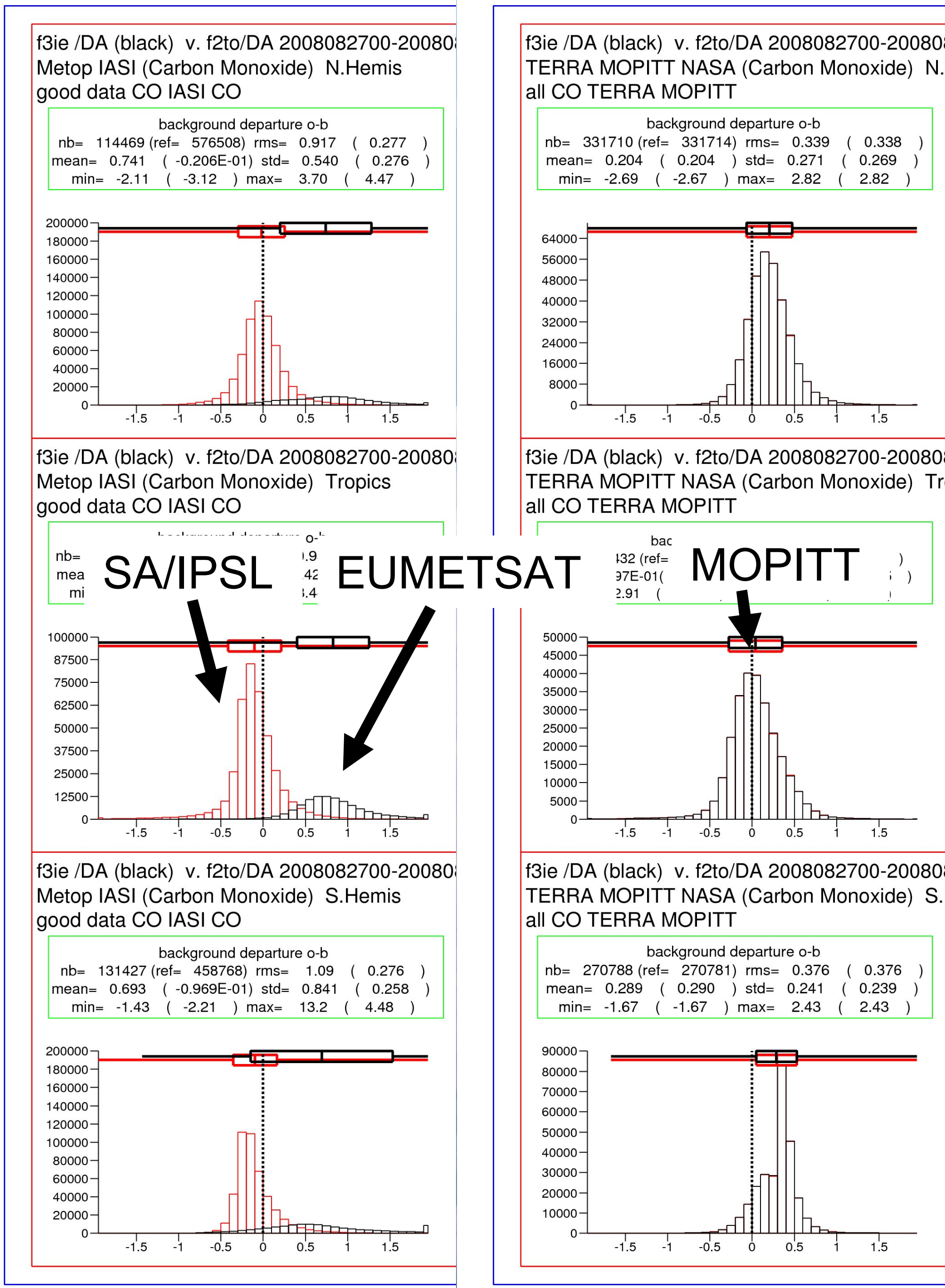
IASI – SA/IPSL



MOPITT - NASA



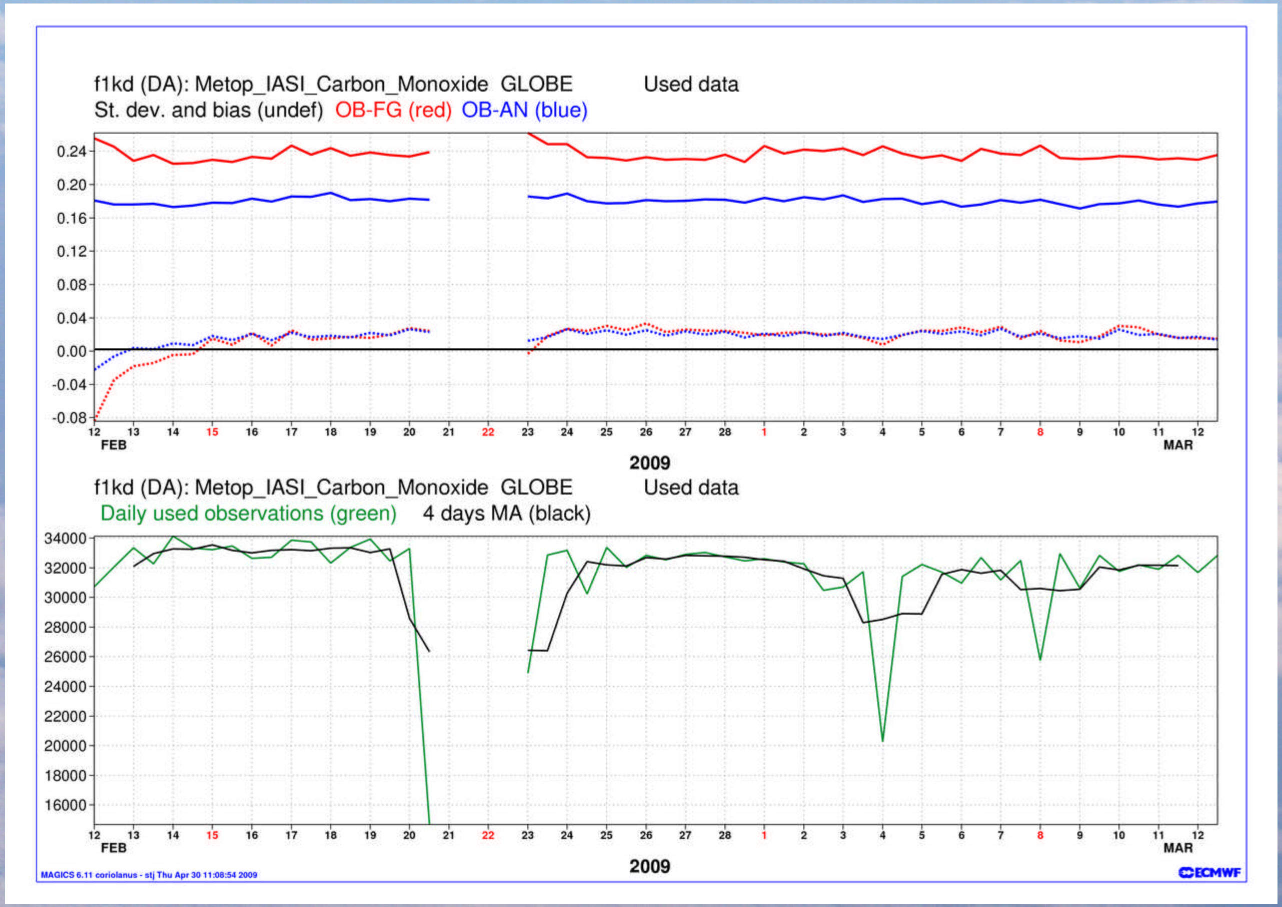
2 IASI products, available in NRT, and 1 MOPITT product, that is not yet available in NRT.



Histograms of first-guess departure statistics show reasonable agreement between MOPITT and IASI-SA/IPSL.

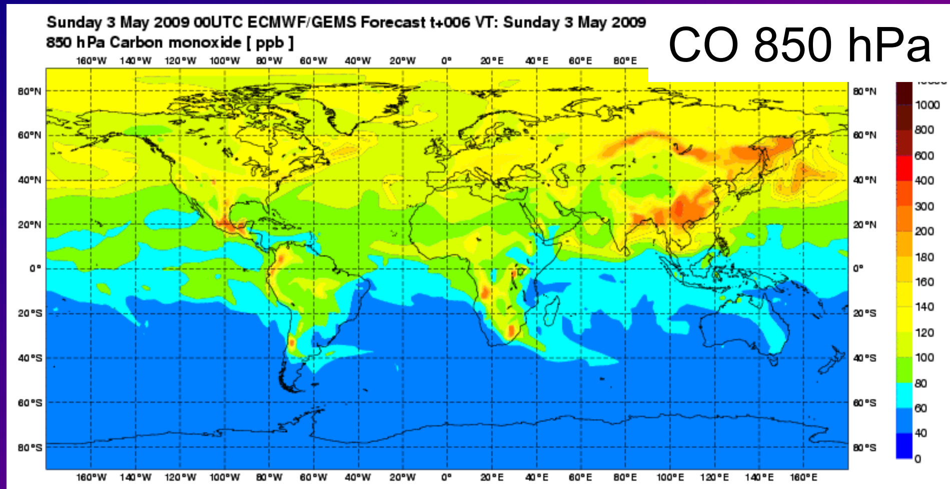
The IASI-EUMETSAT data agree much less with the other two products.

The IASI-SA/IPSL data are now assimilated in NRT.

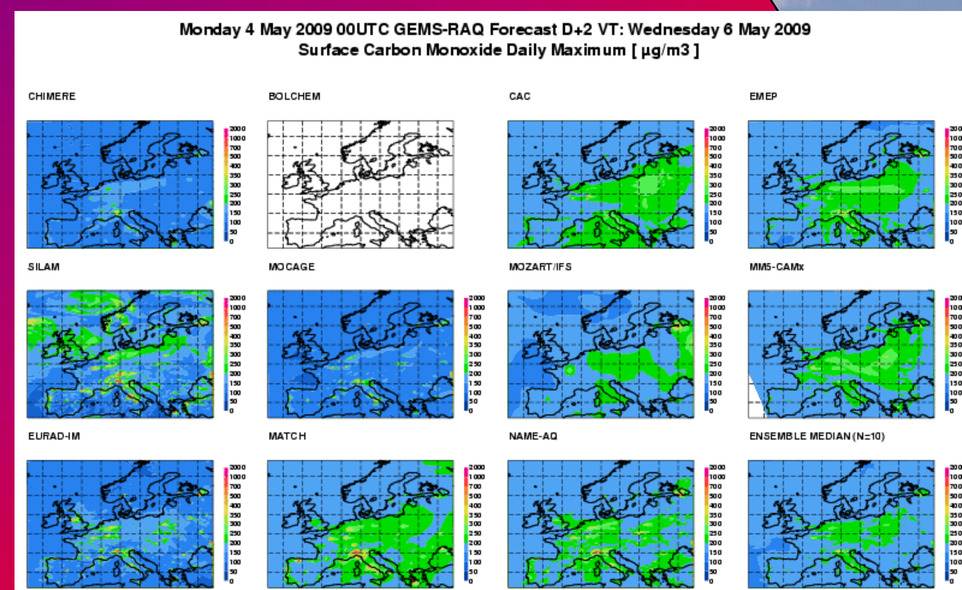


The IASI-SA/IPSL data are now assimilated in NRT. The results look all right, but there is currently no in-situ data available in NRT for validation.

MOPITT data will also be assimilated in NRT in the near future.

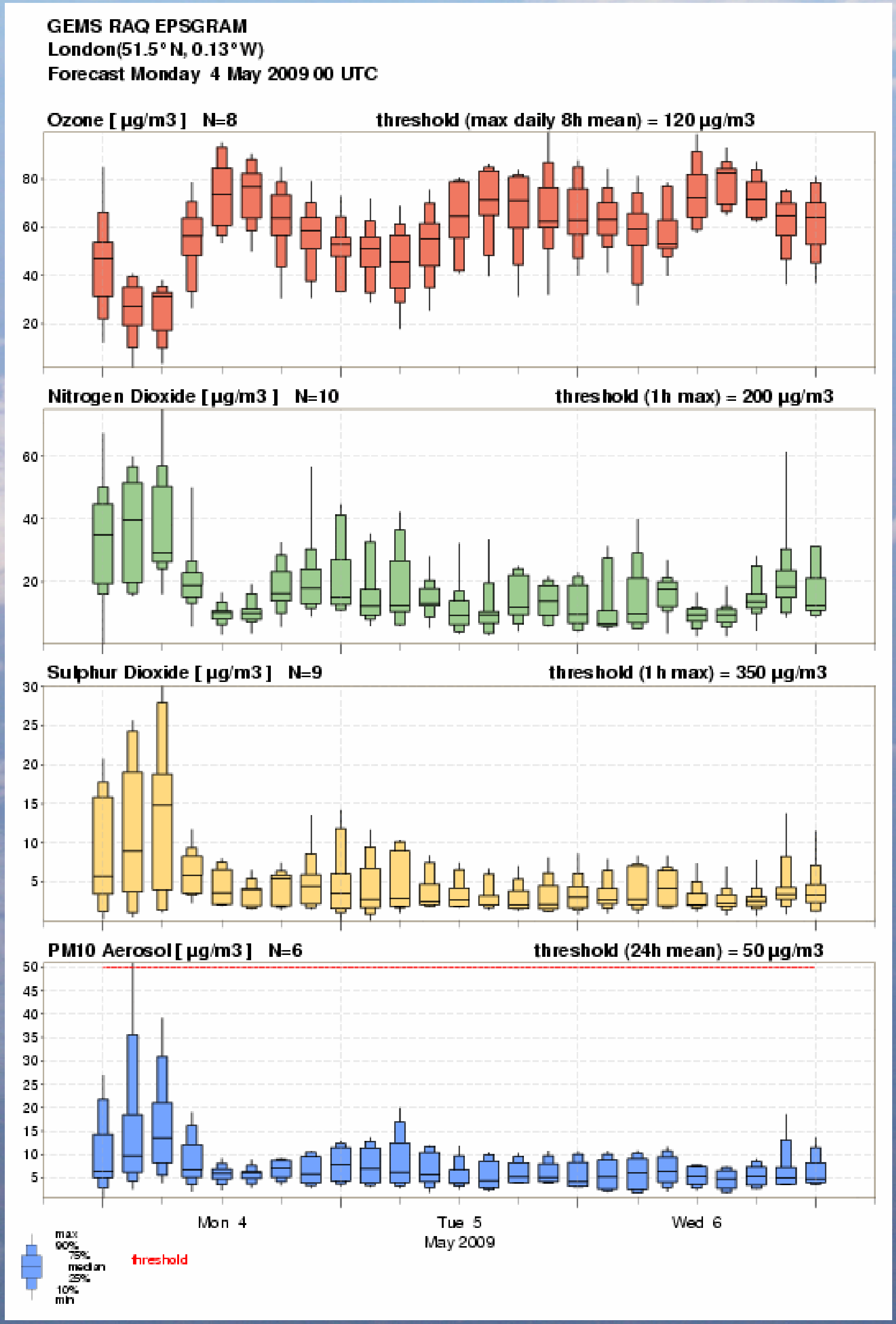


Boundary conditions from the global data assimilation system are used to drive the regional air quality models within GEMS to provide detailed forecasts.



The spread of the ensemble of regional air quality models provides an indication of the uncertainty of the forecasts.

At the same time we can also show how the forecasted concentrations of the various constituents relate to their warning thresholds.



Why do we prefer Radiance Assimilation?

$$\mathbf{y} = \hat{\mathbf{x}}$$

$$H(\mathbf{x}) = \mathbf{x}_a + \mathbf{A}(\mathbf{x} - \mathbf{x}_a)$$

$$\hat{\mathbf{S}} = \left(\mathbf{K}^T \mathbf{S}_y^{-1} \mathbf{K} + \mathbf{S}_a^{-1}\right)^{-1}$$

$$\mathbf{A} = \hat{\mathbf{S}} \mathbf{K}^T \mathbf{S}_y^{-1} \mathbf{K}$$

Although the assimilation of retrieval products is relatively simple, it is much more difficult to stay consistent and to not discard information.

Ideally, retrieved profiles at sufficient high vertical resolution should be assimilated with their full retrieval error covariance. This means that a specific covariance matrix should be provided for each single observations.

Of course, various approximations to this ideal case can be made, but this always means loss of information.

$$\hat{z} = \mathbf{g}^T \hat{\mathbf{x}}$$

$\mathbf{g}^T$ is a simple integration operator

$$\sigma_{\hat{z}}^2 = \mathbf{g}^T \hat{\mathbf{S}} \mathbf{g}$$

$$\mathbf{a}^T = \mathbf{g}^T \mathbf{A}$$

If we, for instance, use a column retrieval product, we lose information, even when we take the reduced averaging kernel a^T into account.

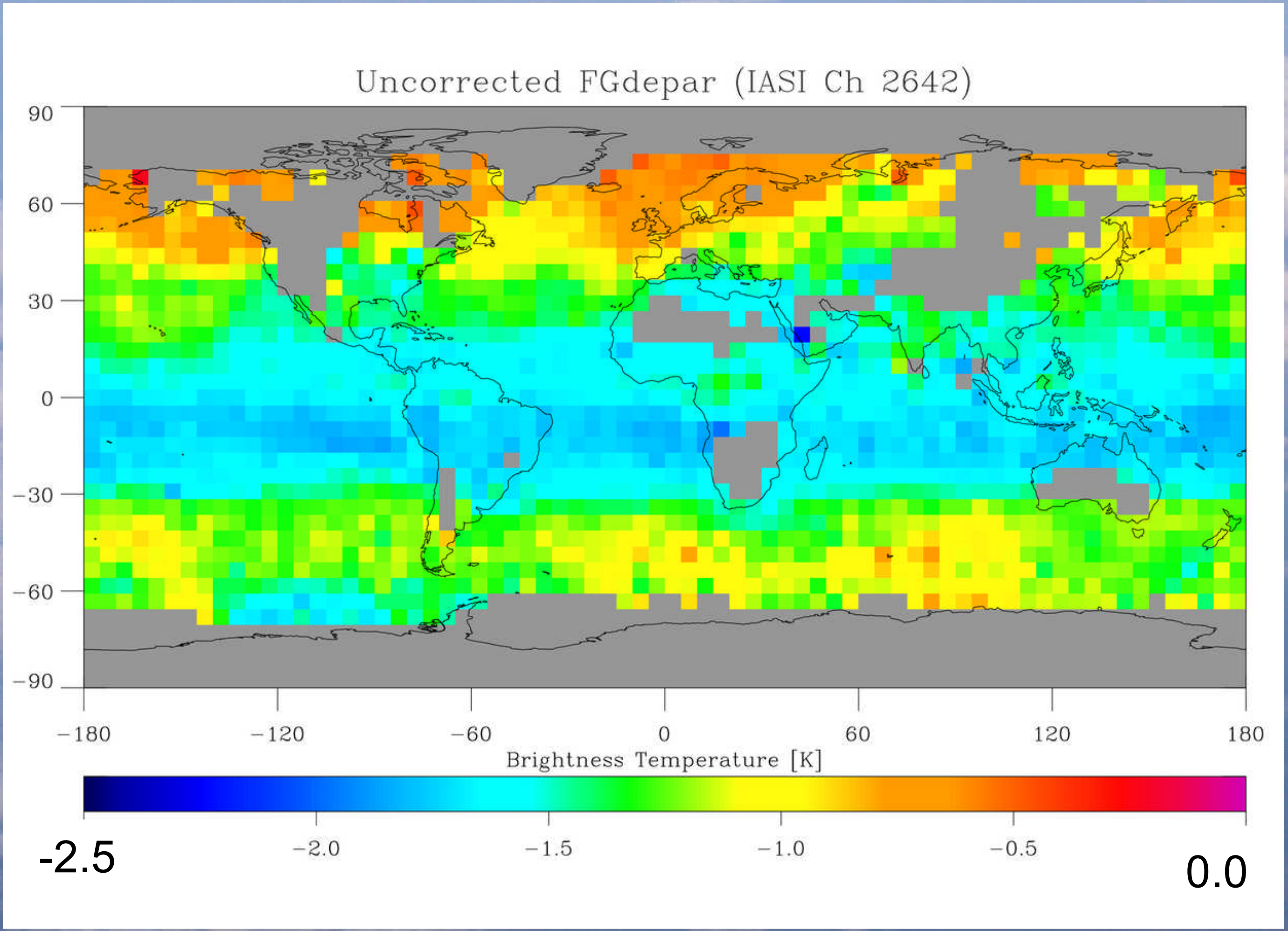
If this reduces the quality of the assimilation, will probably vary on a case-by-case basis, but it should be kept in mind.

What is pragmatic and accurate?

- **Fully specified profile retrieval with all needed information**
- **Column retrieval with averaging kernel**
- **Radiance assimilation with fast approximate RT model**
- **Radiance assimilation with very accurate RT model**

IASI CH_4: bias correction and first results

The IASI methane channels show large biases relative to the CH4 model. These biases also have strong geographical patterns. The data assimilation of these IASI channels would not provide good CH4 results if the bias would be left uncorrected.



What is the likely cause of these biases??
Our first assumption is that the spectroscopy of the RT-model is responsible.

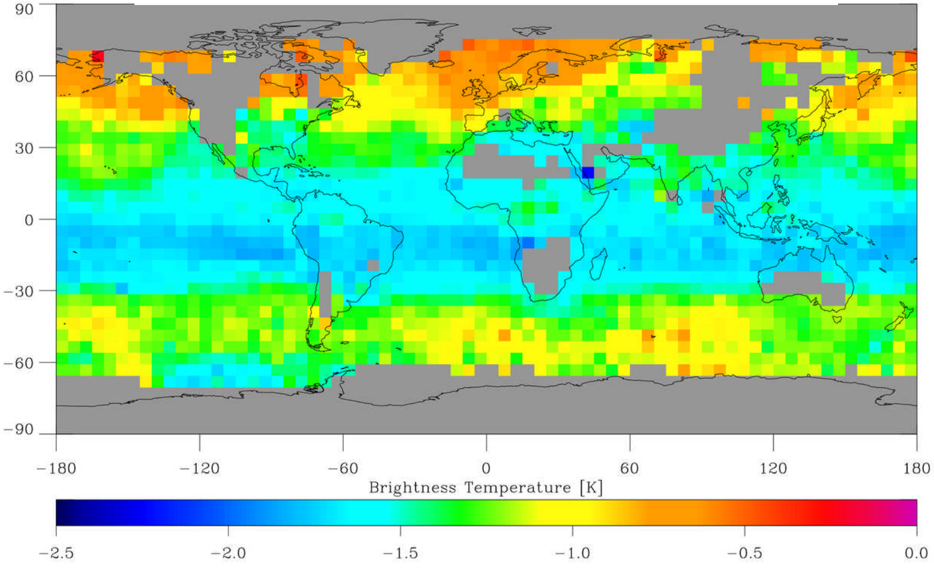
$$\mathrm{T}(p) = \exp[-\gamma \int_{p}^{0} \kappa(p)\rho(p)\mathrm{d}p]$$

The gamma bias correction model is chosen because it can roughly correct an error in the absorption coefficient.

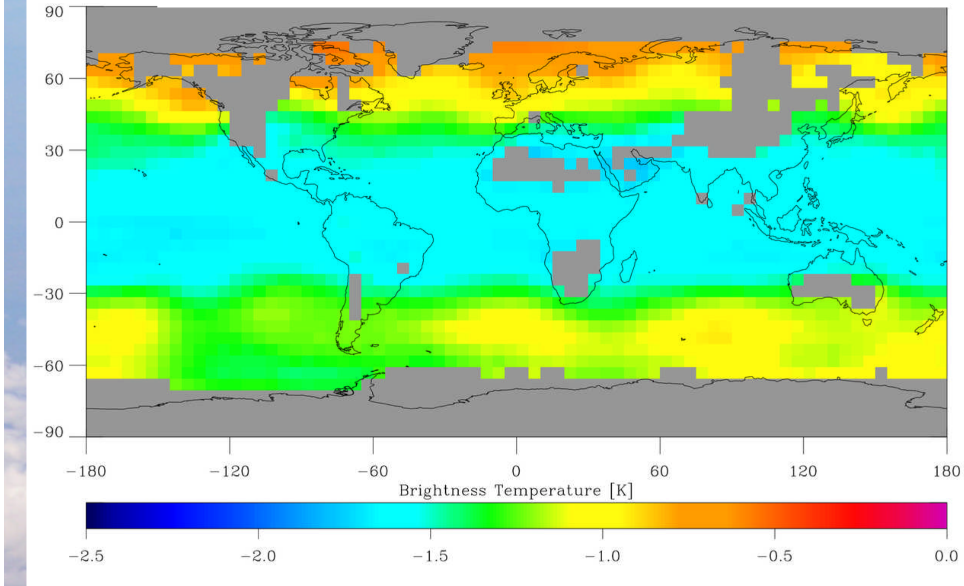
However, it can also correct a relative error in the trace gas concentration.

The assumption is that the chance of significantly fitting a relative error in the trace gas distribution is small.

Uncorrected FG departures



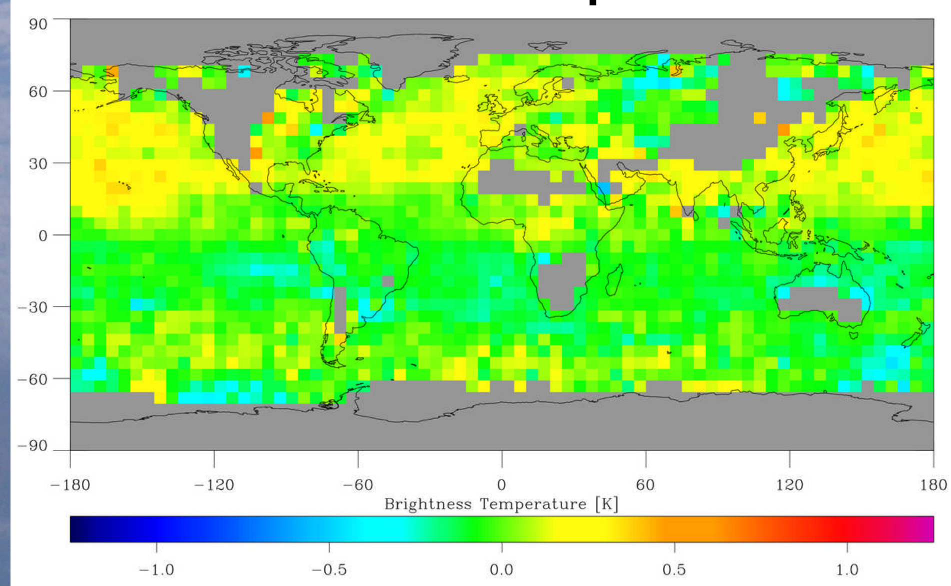
Gamma-based bias correction

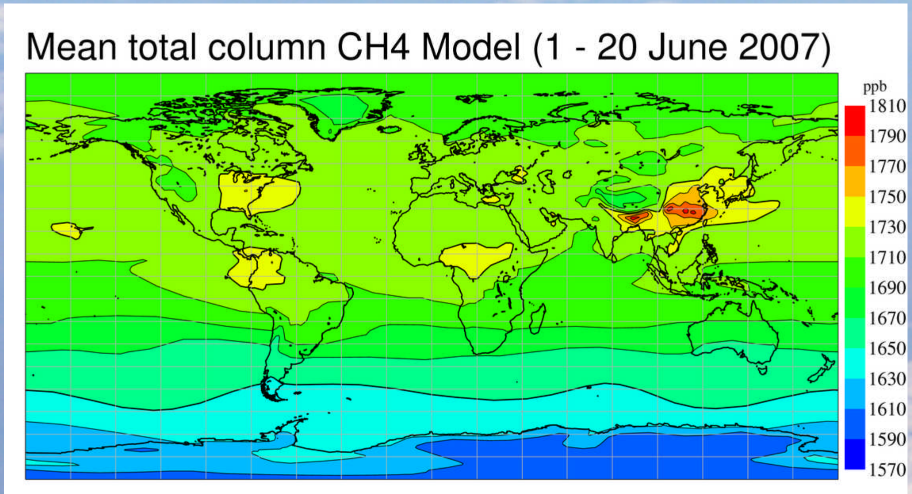


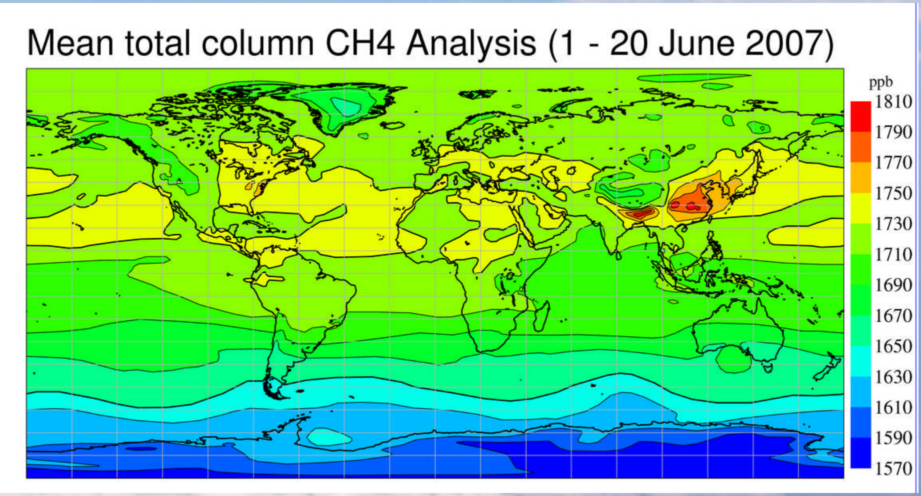
The gamma model fits the mean uncorrected FG departures for the CH4 channels very well.

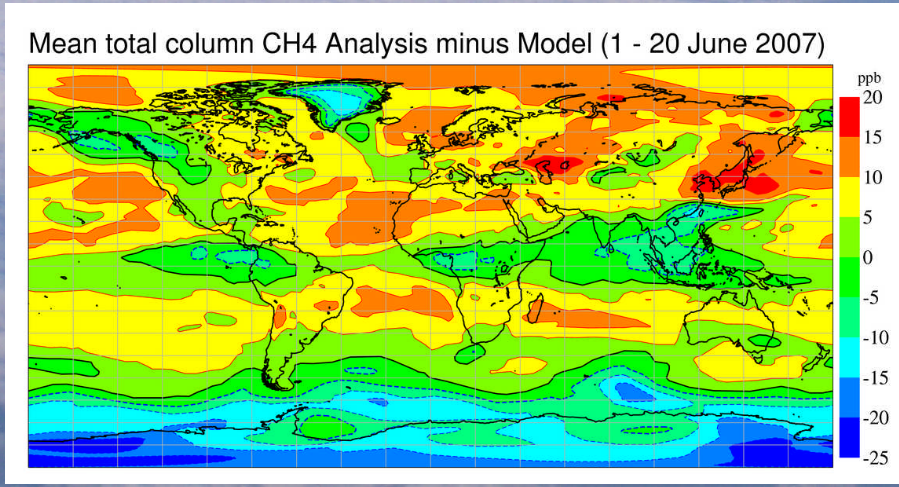
The remaining FG departures represent ideally the real differences between the observations and the CH4 model.

Corrected FG departures



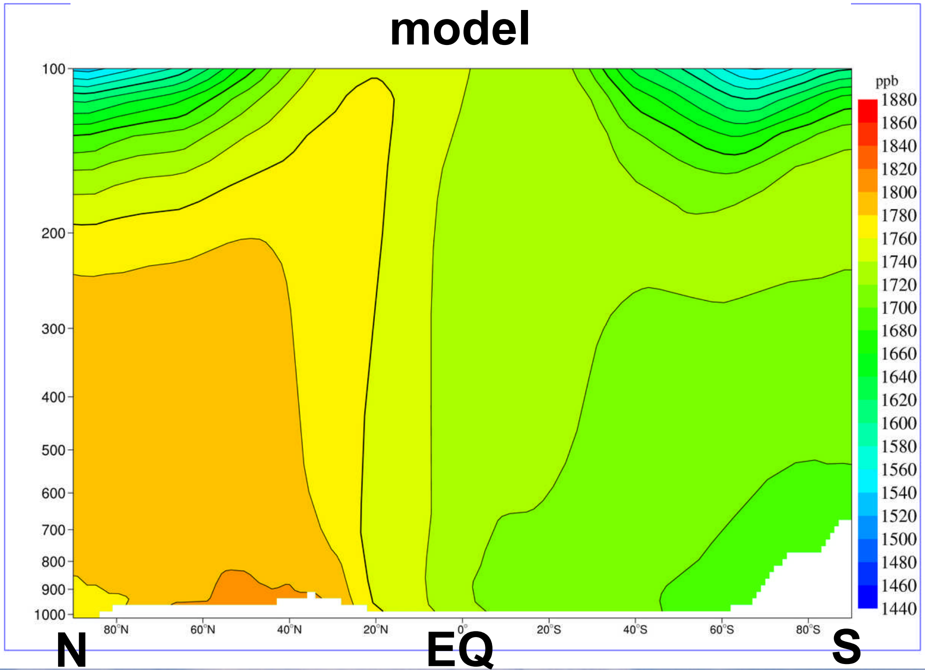


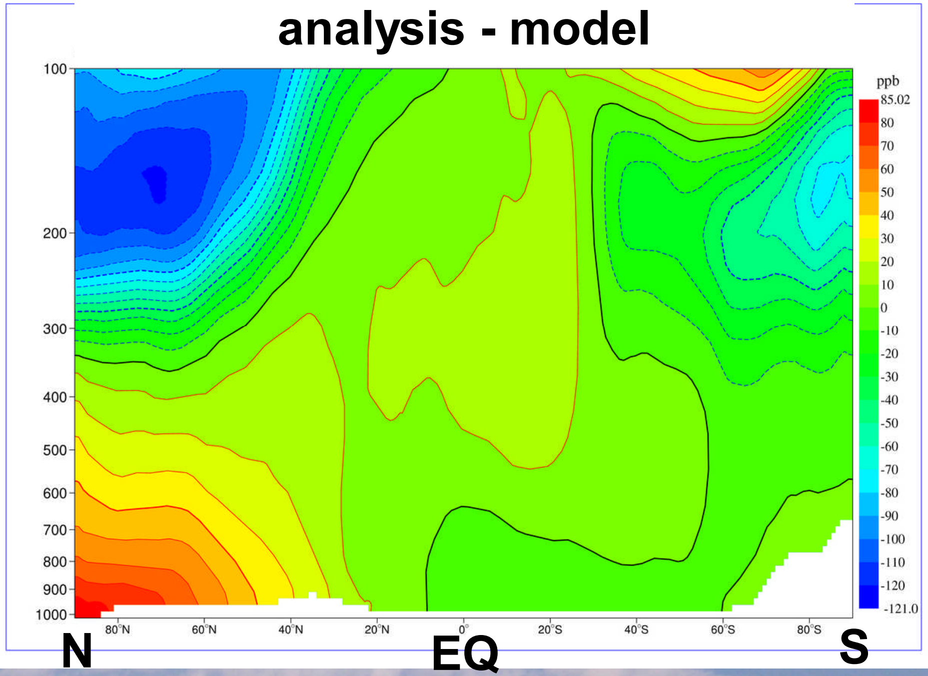


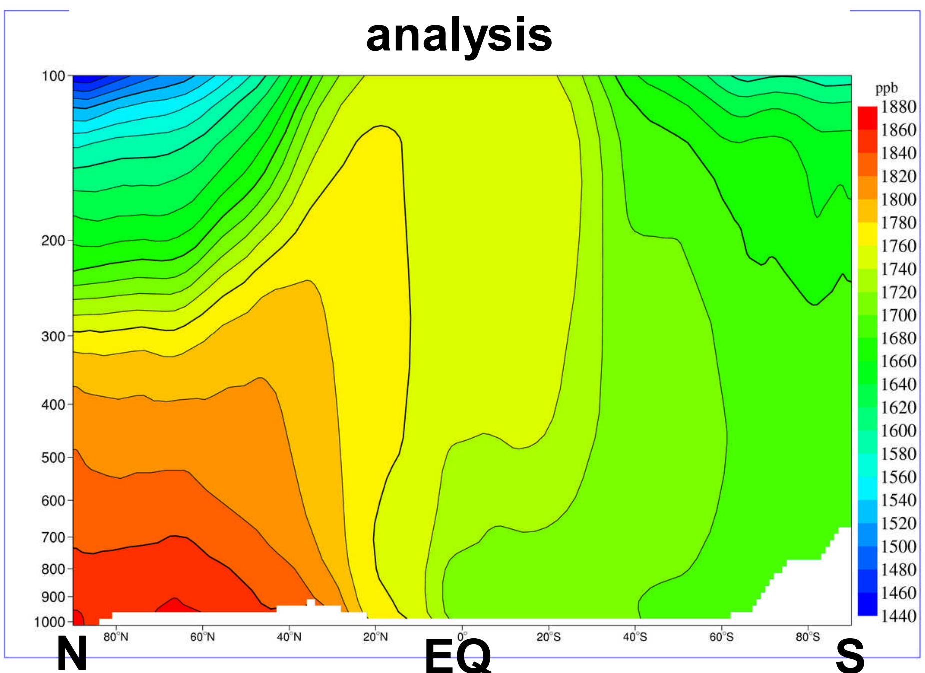


Using the estimated gammas, the IASI assimilation makes small but significant changes to the mean column mixing ratios.

Validation of the changes to the model fields are the next step.



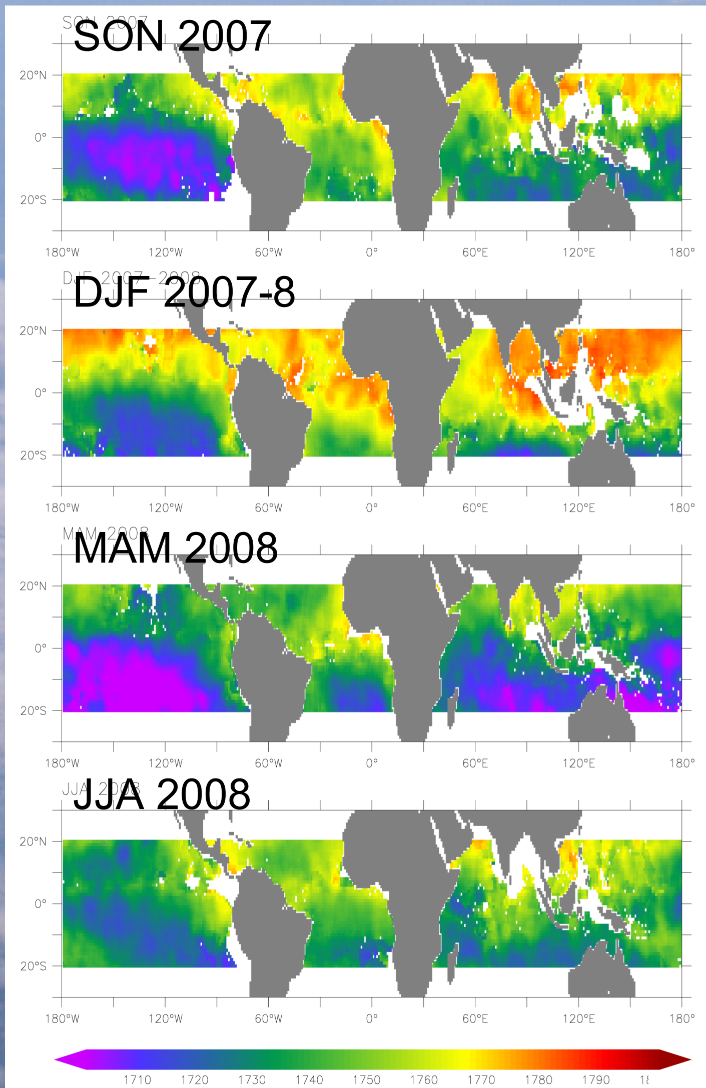




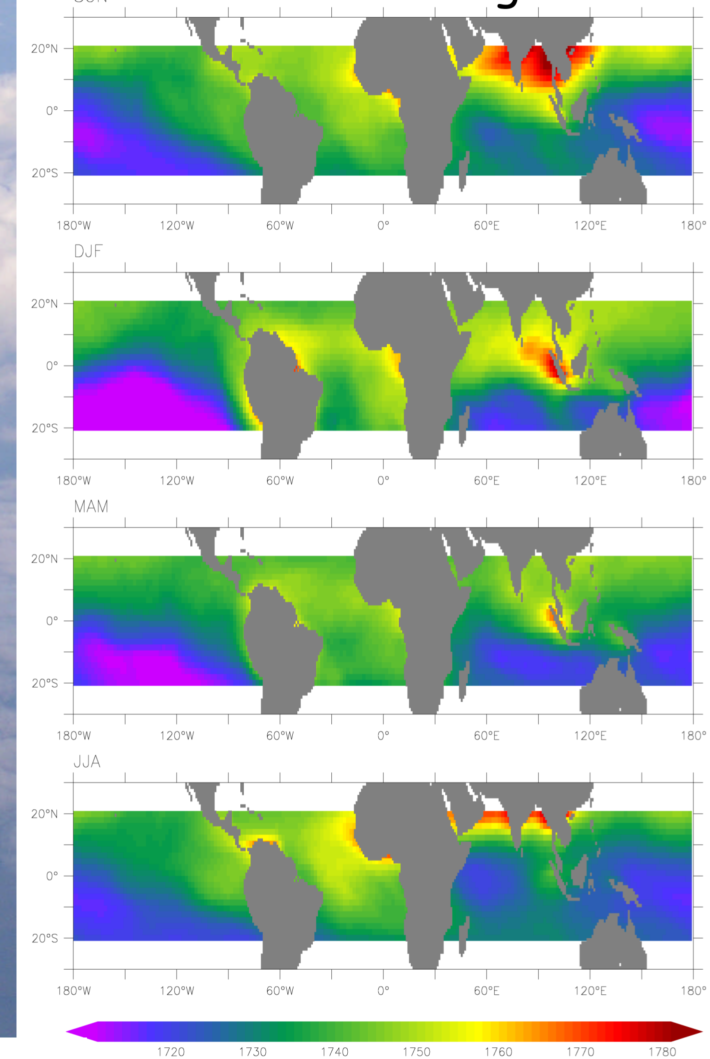
The zonal mean vertical distribution shows some larger changes, even at low altitudes.

The large changes at high northern latitudes are hopefully representing real improvements.

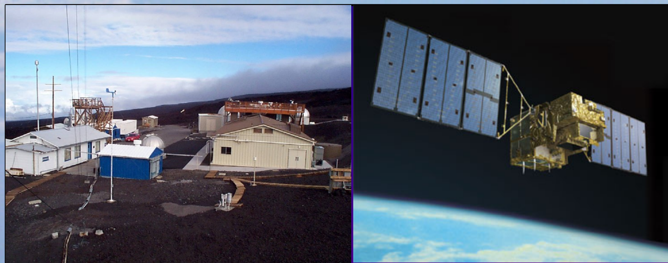
First Laboratoire de Meteorologie Dynamique results for CH_4 are also promising. More validation needs to be done.



MOZART-2 IASI-integrated CH_4

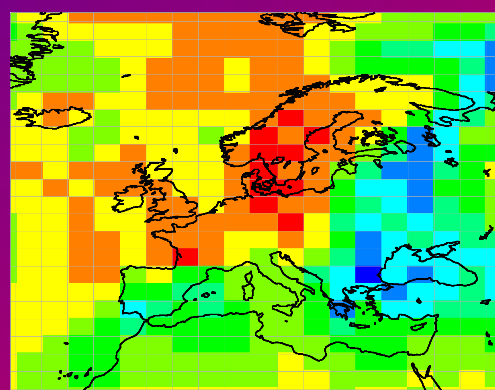


AIRS and IASI CO_2 results

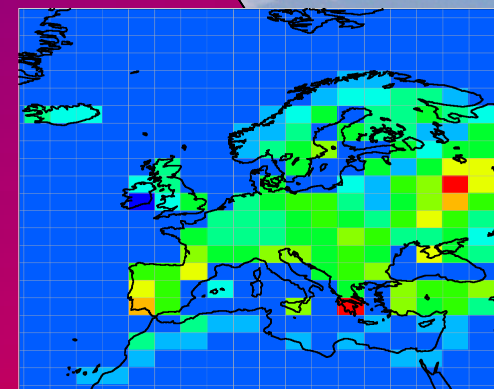


Observations

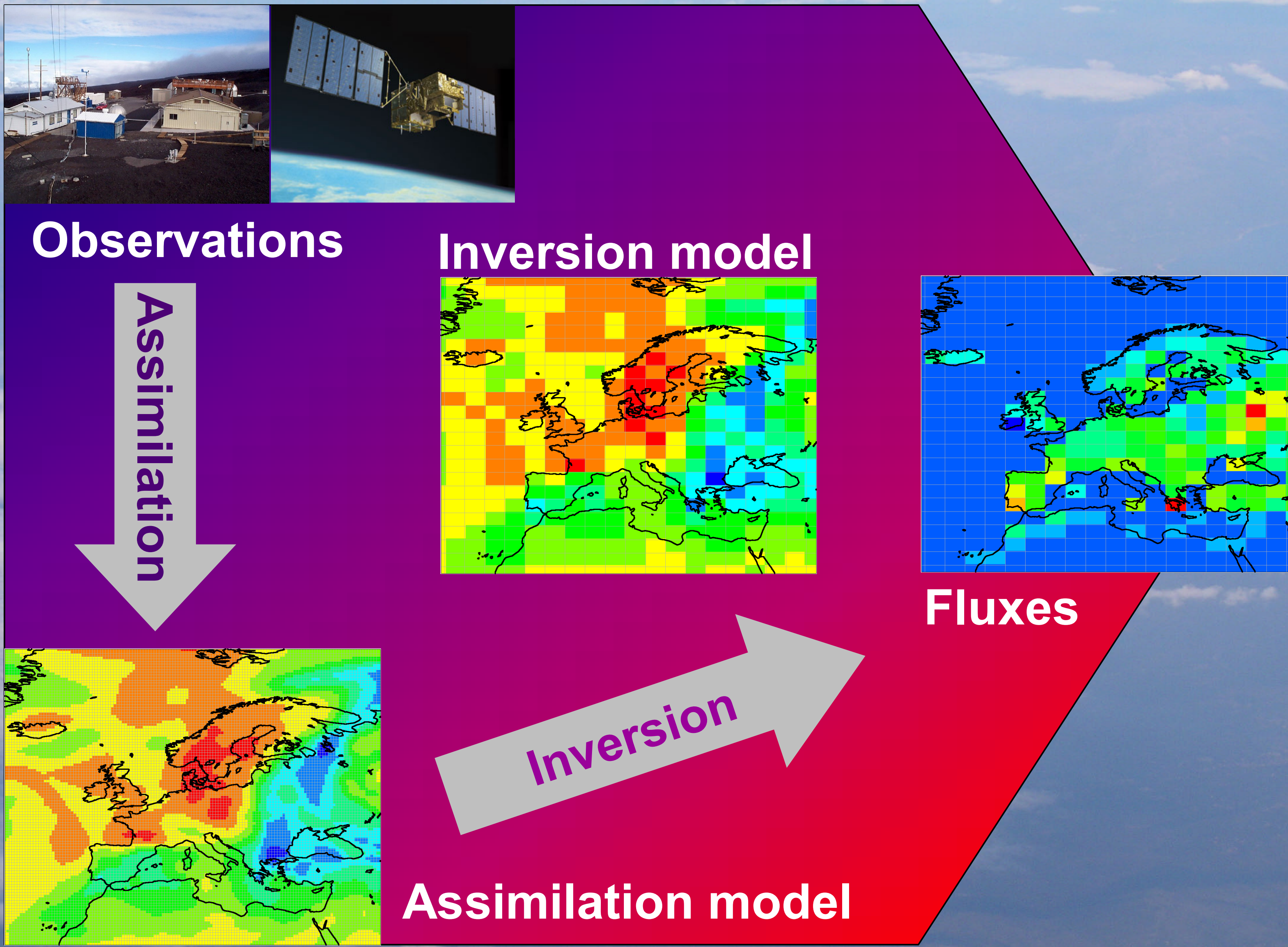
Flux Inversion



Inversion model

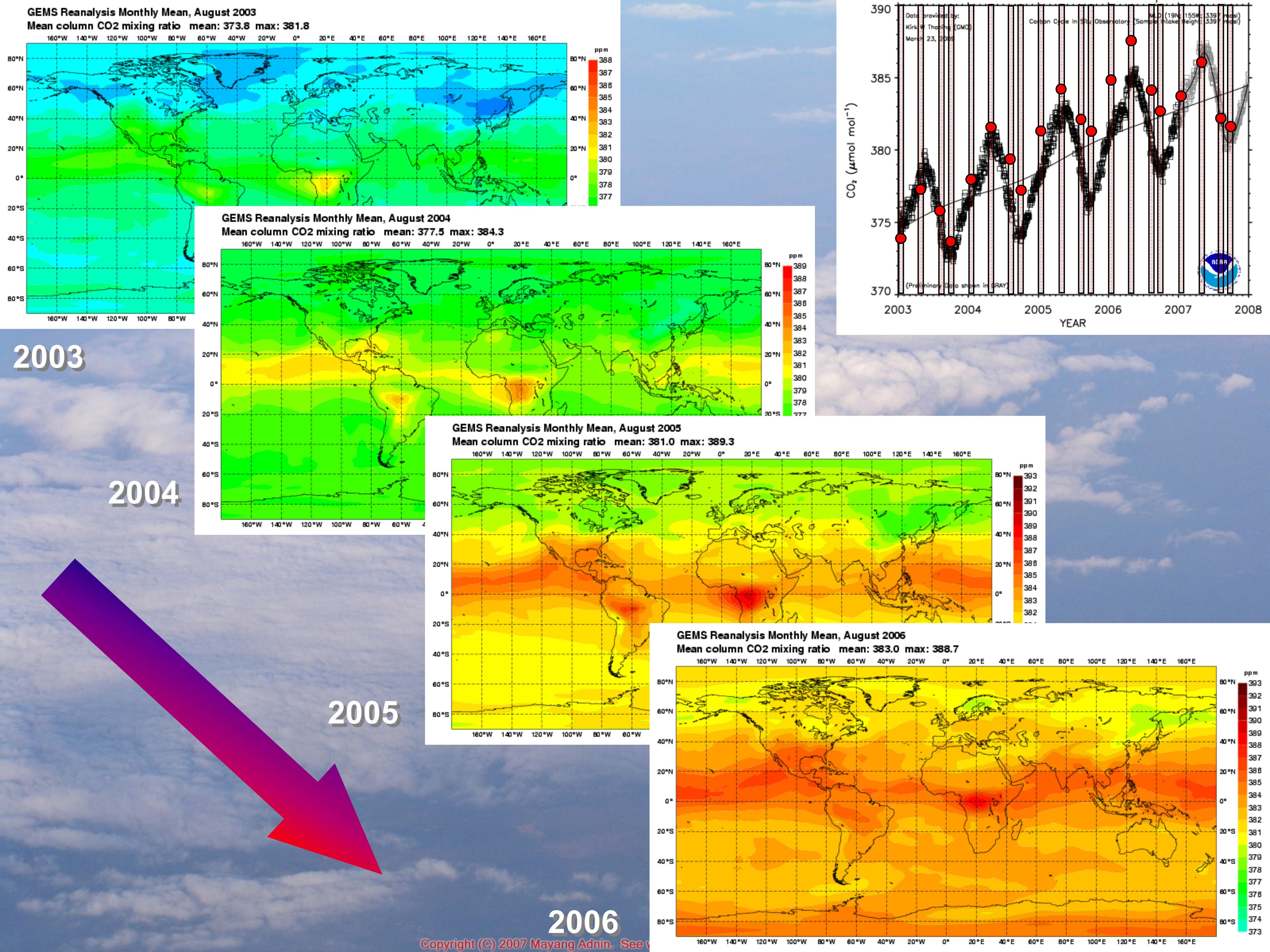


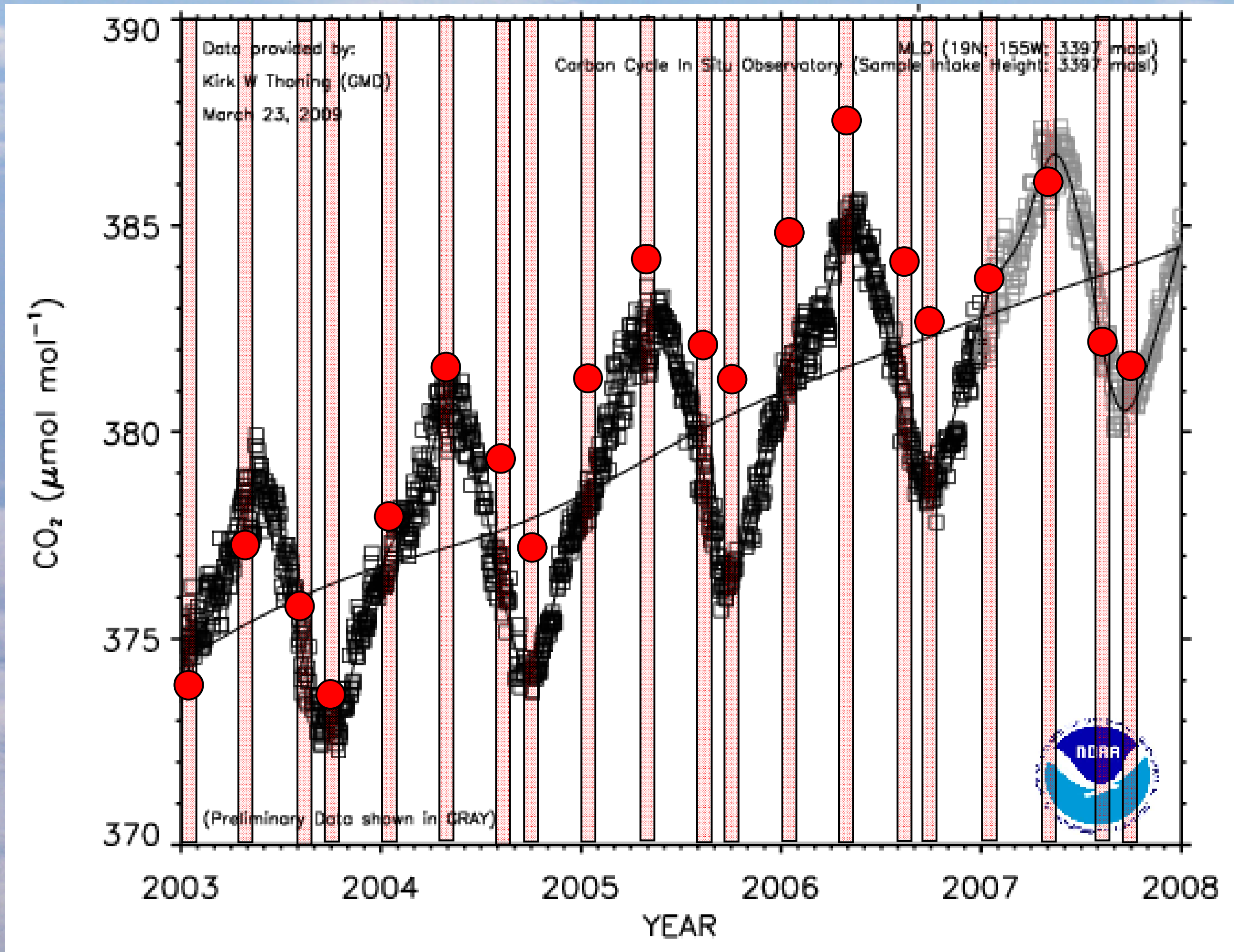
Fluxes


Observations
Assimilation
Inversion model
Fluxes
Inversion
Assimilation model

Benefits of 2-step approach

- High model resolution minimizes representation error
- All meteorological observations available at time of assimilation
- Capability of assimilating satellite radiances
- Better suited to detect systematic errors

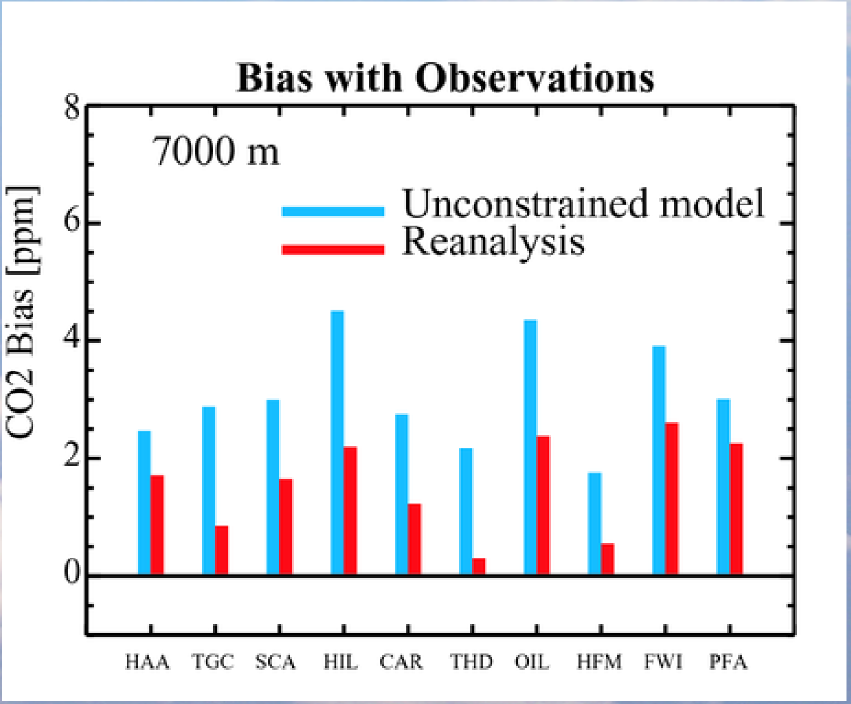

GEMS Reanalysis Monthly Mean, August 2003
Mean column CO2 mixing ratio mean: 373.8 max: 381.8
GEMS Reanalysis Monthly Mean, August 2004
Mean column CO2 mixing ratio mean: 377.5 max: 384.3
GEMS Reanalysis Monthly Mean, August 2005
Mean column CO2 mixing ratio mean: 381.0 max: 389.3
GEMS Reanalysis Monthly Mean, August 2006
Mean column CO2 mixing ratio mean: 383.0 max: 388.7
ppm
CO₂ (μmol mol⁻¹)
YEAR
2003
2004
2005
2006
2007
2008
Carbon Cycle In Situ Observatory
(Preliminary Data shown in GRAY)
2003
2004
2005
2006
Copyright (C) 2007 Mayang Adnin. See w

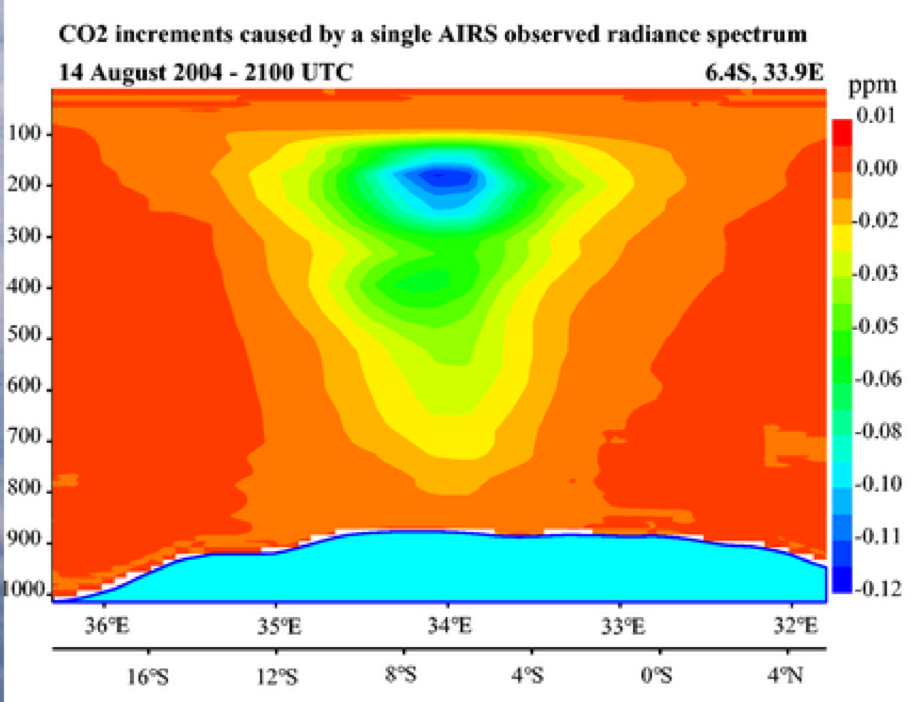


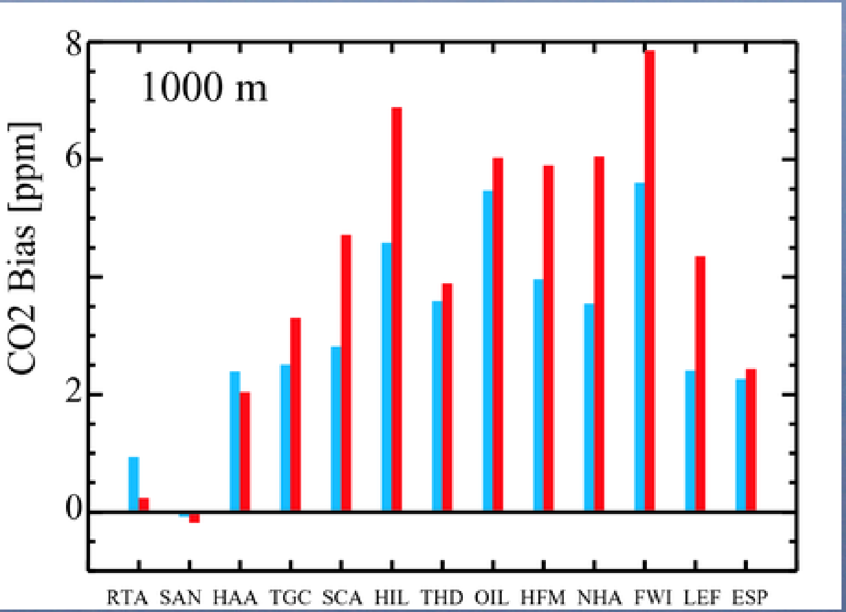
Just to illustrate the challenges we are facing, the CO_2 reanalysis started to perform better, when GPS occultation data from the CHAMP and COSMIC sensors were assimilated. Coincidence???

AIRS has a limited view of the atmosphere. The observations do not constrain the lower troposphere.

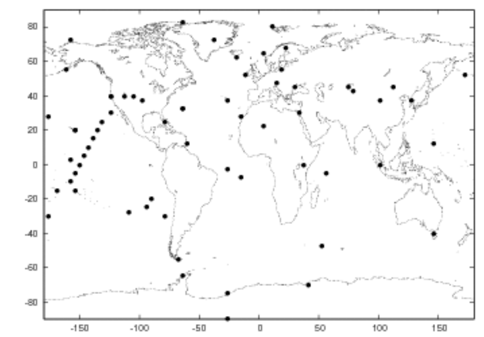
GOSAT will significantly improve this.



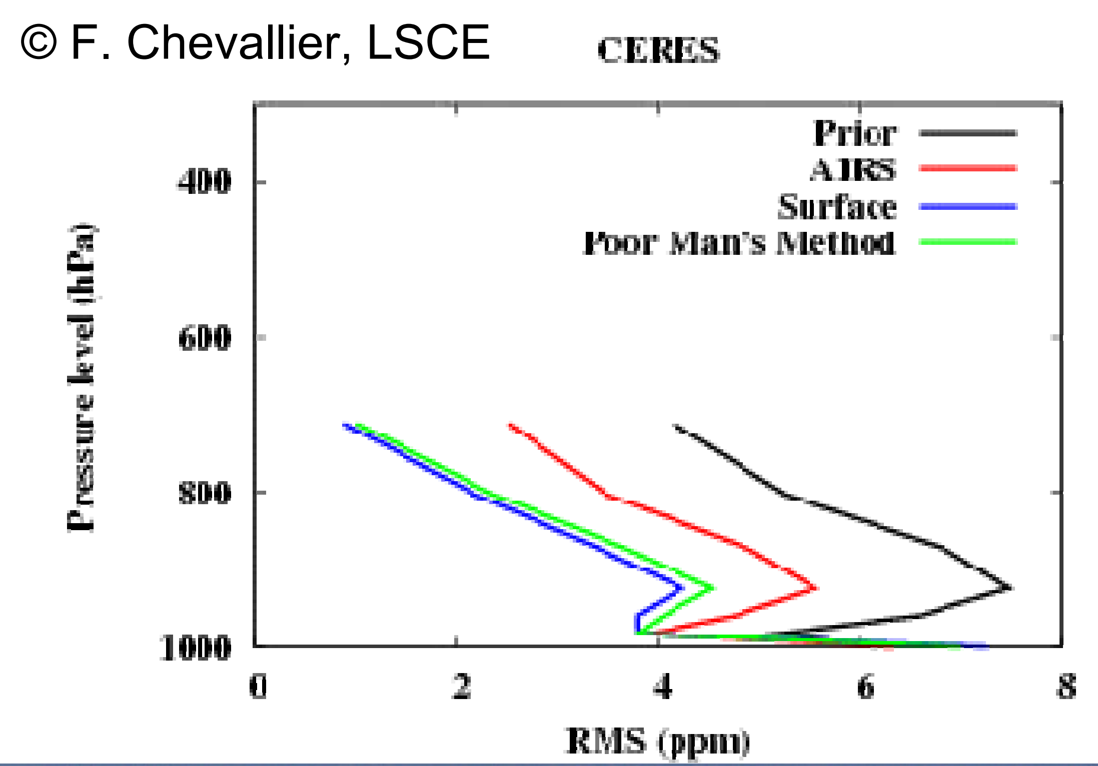




The flux inversion using the intermediate atmospheric 4D-Var reanalysis from AIRS observations performs reasonably well compared to a straight surface flask flux inversion.



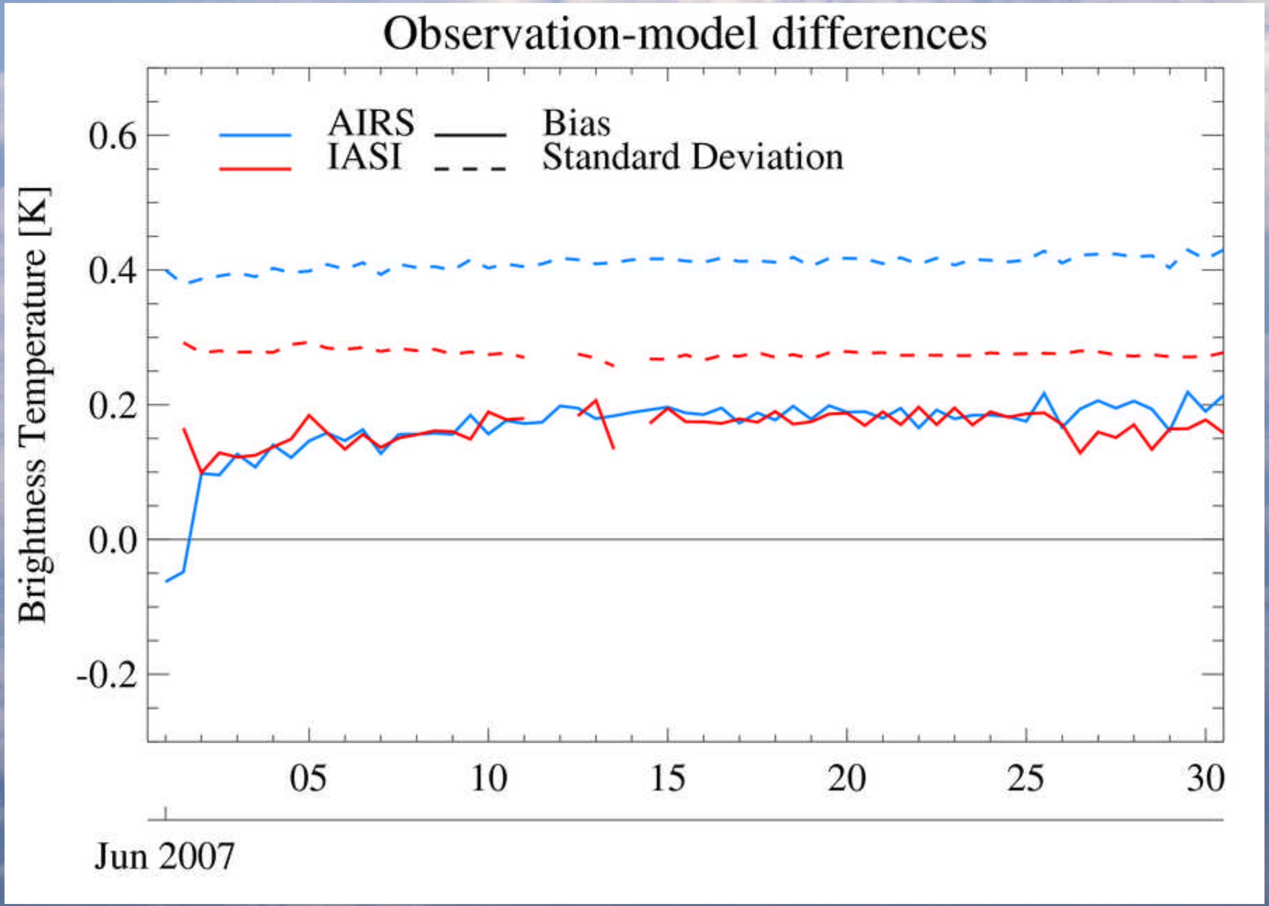
Surface flask observations provided by T. Conway (NOAA/ESRL)



Validation with CERES campaign (C. Gerbig)

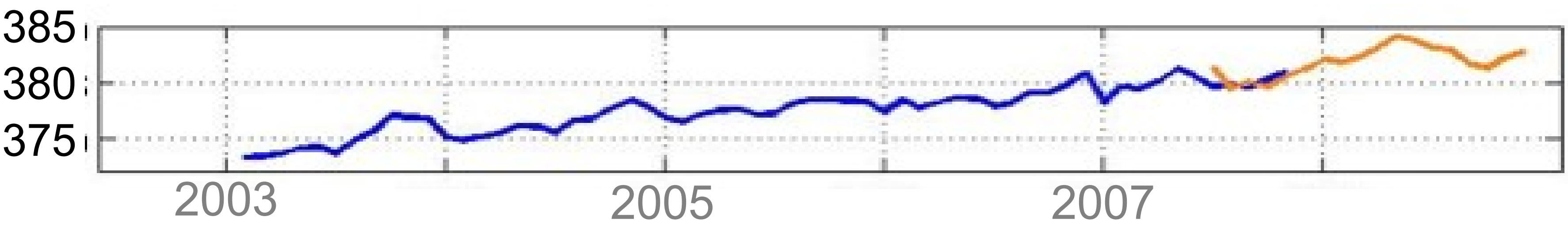
GEOmon
Global Earth Observation and Monitoring

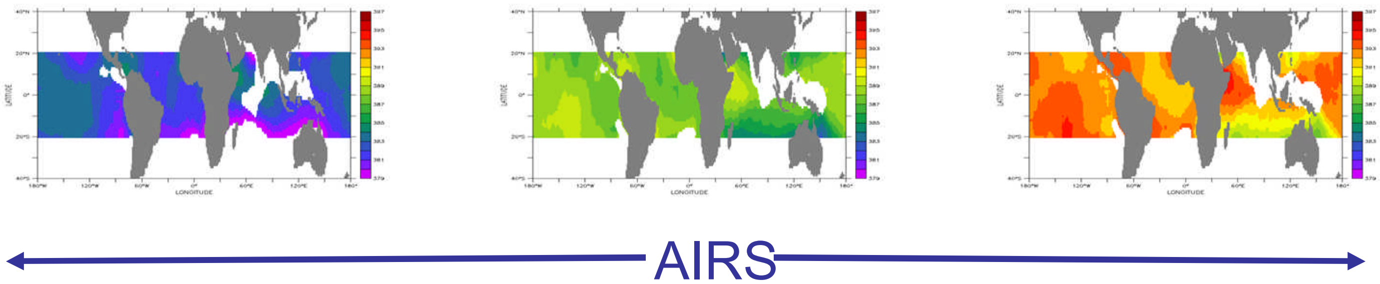
The next step is to use both AIRS and IASI radiances for the CO_2 data assimilation. On top of that we will use observations from the GOSAT satellite that constrains lower tropospheric CO_2.

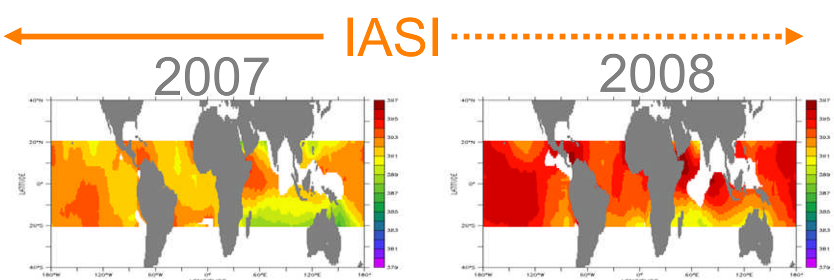


CO_2-sensitive channel at 14 μm

Almost 8 years of AIRS and IASI data have been processed by LMD to provide a time series of tropospheric integrated CO_2 content.







Aqua/AIRS : 2003-2007

MetOp/IASI : 2007-…

IASI-2 : 2013-…

IASI-3 : 2016-…

375 383 391

Precision: AIRS 2.5 ppmv / IASI 2 ppmv for 1 month/5°x5°

Items for the working group

- Bias correction
- Validation (especially in NRT)
- Background covariance statistics
- Retrieval or radiance assimilation?
- Surface emissivity?