

# 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<sub>4</sub>: bias correction and first results**
- **AIRS and IASI CO<sub>2</sub> results**



# The GEMS and MACC Projects

## 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**

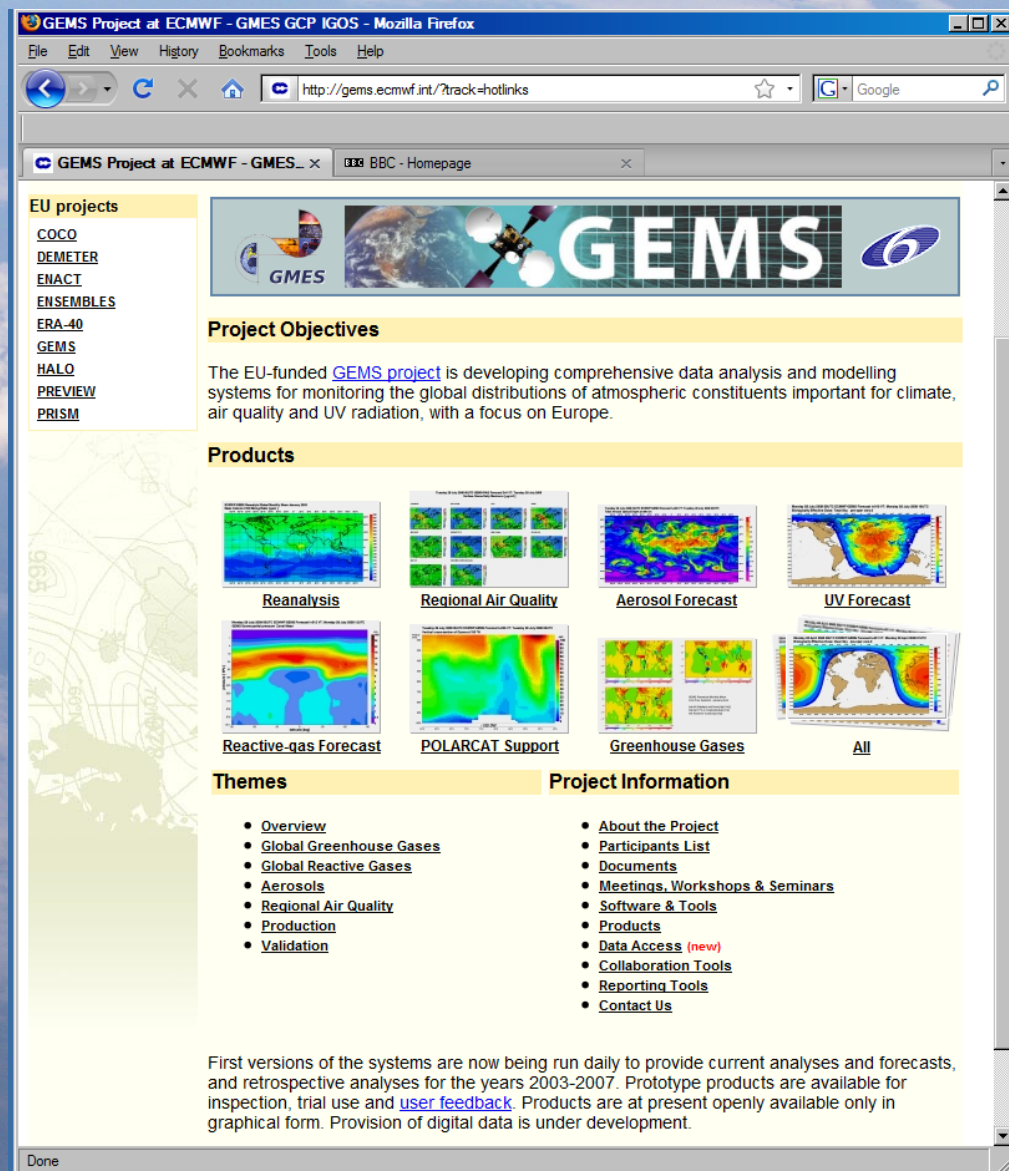
***National and European environmental agencies***

# 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

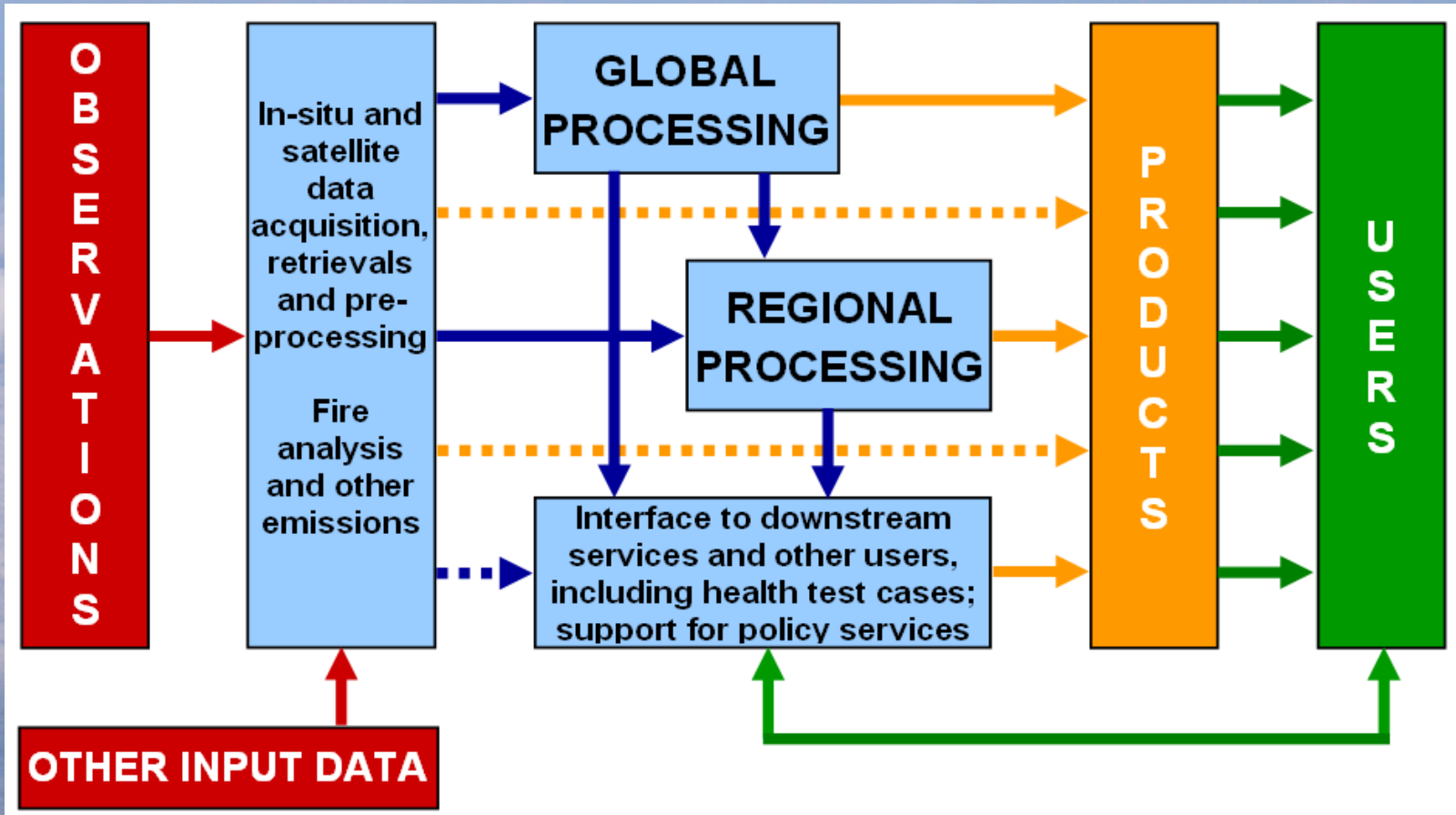
- Near-real-time global systems for reactive gases, aerosols and UV radiation
- A global reanalysis for 2003-2007 for all species
- Web-hosting, archiving and verification of coordinated regional air-quality forecasts from ten systems



The screenshot shows the GEMS Project website in a Mozilla Firefox browser window. The address bar displays <http://gems.ecmwf.int/?track=hotlinks>. The page features a header with the GEMS logo and a navigation menu on the left listing EU projects: COCO, DEMETER, ENACT, ENSEMBLES, ERA-40, GEMS, HALO, PREVIEW, and PRISM. The main content area is divided into sections: Project Objectives, Products, Themes, and Project Information. The Products section displays eight thumbnail images representing different data products: Reanalysis, Regional Air Quality, Aerosol Forecast, UV Forecast, Reactive-gas Forecast, POLARCAT Support, Greenhouse Gases, and All. The Project Information section includes links for Overview, Global Greenhouse Gases, Global Reactive Gases, Aerosols, Regional Air Quality, Production, Validation, About the Project, Participants List, Documents, Meetings, Workshops & Seminars, Software & Tools, Products, Data Access (new), Collaboration Tools, Reporting Tools, and Contact Us. A footer note states: "First versions of the systems are now being run daily to provide current analyses and forecasts, and retrospective analyses for the years 2003-2007. Prototype products are available for inspection, trial use and [user feedback](#). Products are at present openly available only in graphical form. Provision of digital data is under development."

<http://gems.ecmwf.int>

# MACC – Monitoring Atmospheric Composition and Climate



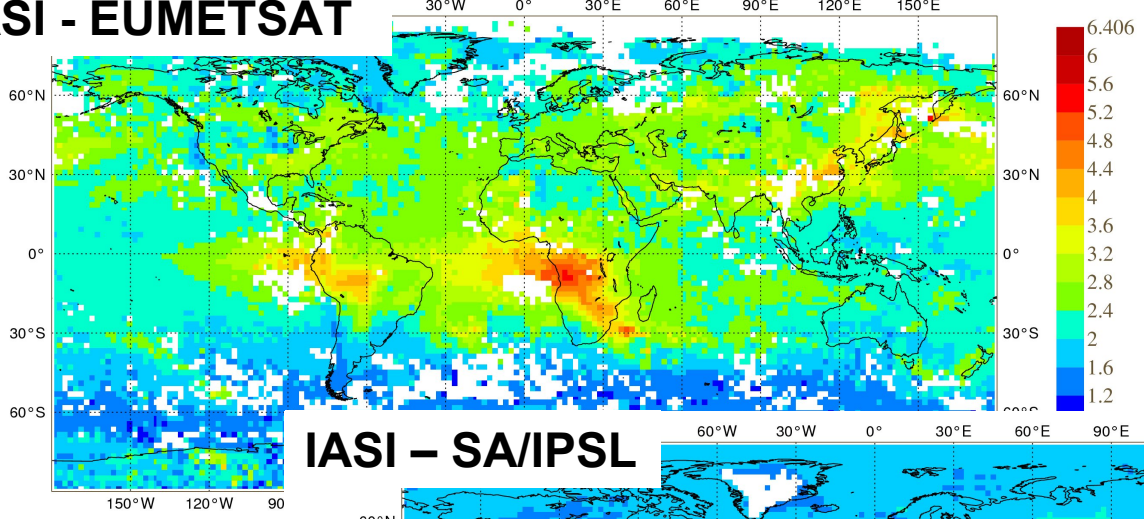
A 48-partner successor to GEMS and the ESA-funded GMES Service Element project PROMOTE.





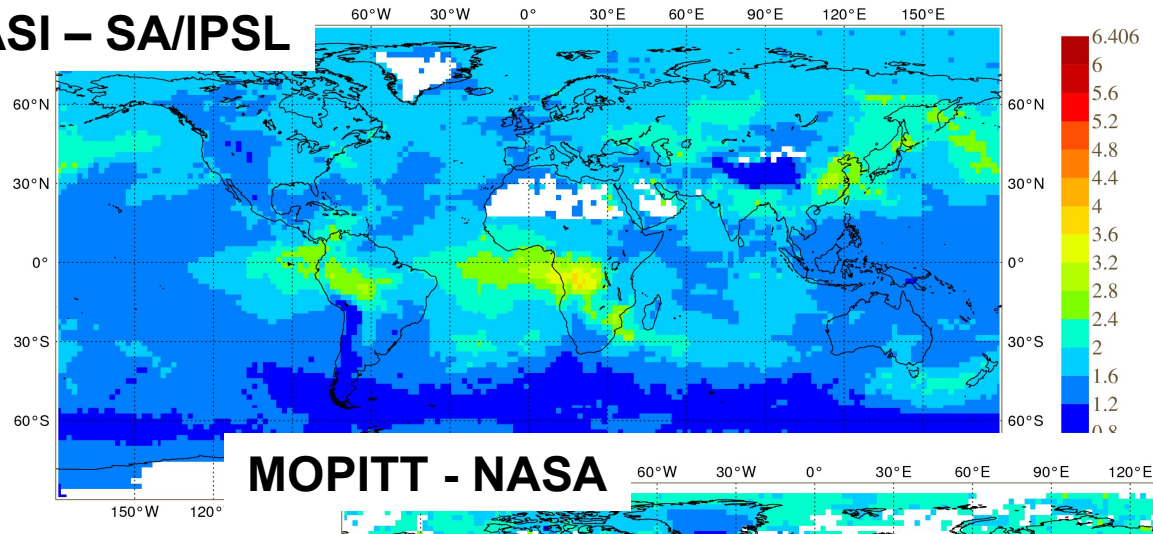
# Assimilation of IASI CO Retrievals

# IASI - EUMETSAT

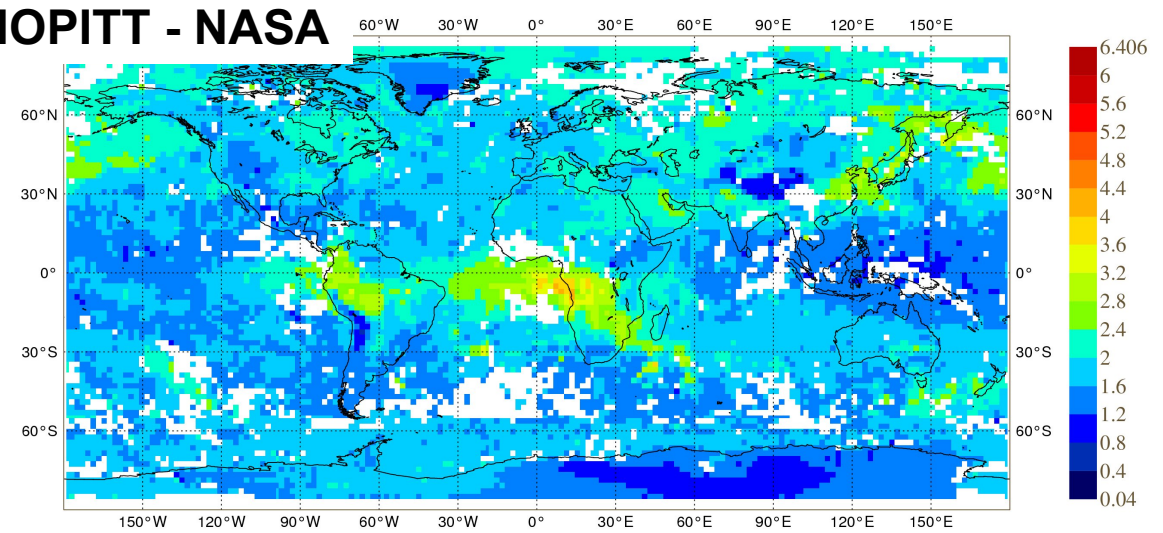


**4-day average  
of observed  
total column  
CO.**

# IASI - SA/IPSL



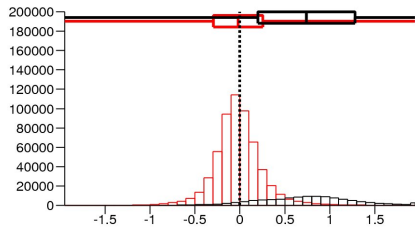
# MOPITT - NASA



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

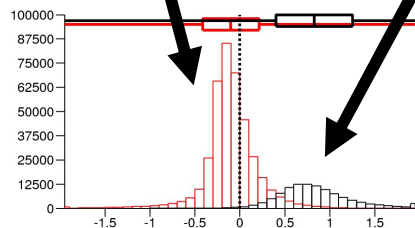
f3ie /DA (black) v. f2to/DA 2008082700-2008082700  
 Metop IASI (Carbon Monoxide) N.Hemis  
 good data CO IASI CO

background departure o-b  
 nb= 114469 (ref= 576508) rms= 0.917 ( 0.277 )  
 mean= 0.741 ( -0.206E-01) std= 0.540 ( 0.276 )  
 min= -2.11 ( -3.12 ) max= 3.70 ( 4.47 )



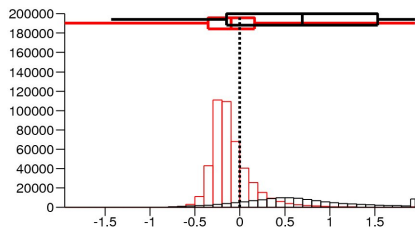
f3ie /DA (black) v. f2to/DA 2008082700-2008082700  
 Metop IASI (Carbon Monoxide) Tropics  
 good data CO IASI CO

background departure o-b  
 nb= 132 (ref= 576508) rms= 1.9 ( 0.277 )  
 mean= 0.42 ( -0.206E-01) std= 1.4 ( 0.276 )  
 min= -1.4 ( -3.12 ) max= 3.70 ( 4.47 )



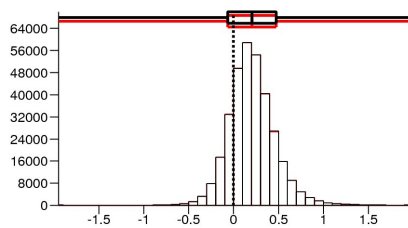
f3ie /DA (black) v. f2to/DA 2008082700-2008082700  
 Metop IASI (Carbon Monoxide) S.Hemis  
 good data CO IASI CO

background departure o-b  
 nb= 131427 (ref= 458768) rms= 1.09 ( 0.276 )  
 mean= 0.693 ( -0.969E-01) std= 0.841 ( 0.258 )  
 min= -1.43 ( -2.21 ) max= 13.2 ( 4.48 )



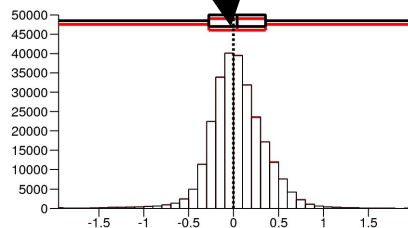
f3ie /DA (black) v. f2to/DA 2008082700-2008082700  
 TERRA MOPITT NASA (Carbon Monoxide) N.  
 all CO TERRA MOPITT

background departure o-b  
 nb= 331710 (ref= 331714) rms= 0.339 ( 0.338 )  
 mean= 0.204 ( 0.204 ) std= 0.271 ( 0.269 )  
 min= -2.69 ( -2.67 ) max= 2.82 ( 2.82 )



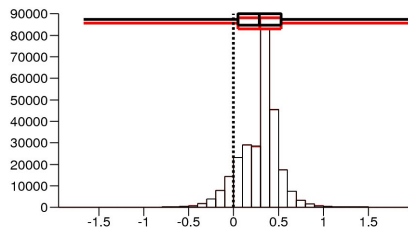
f3ie /DA (black) v. f2to/DA 2008082700-2008082700  
 TERRA MOPITT NASA (Carbon Monoxide) Tr  
 all CO TERRA MOPITT

background departure o-b  
 nb= 132 (ref= 331714) rms= 1.9 ( 0.338 )  
 mean= 0.42 ( 0.204 ) std= 1.4 ( 0.269 )  
 min= -1.4 ( -2.67 ) max= 3.70 ( 2.82 )



f3ie /DA (black) v. f2to/DA 2008082700-2008082700  
 TERRA MOPITT NASA (Carbon Monoxide) S.  
 all CO TERRA MOPITT

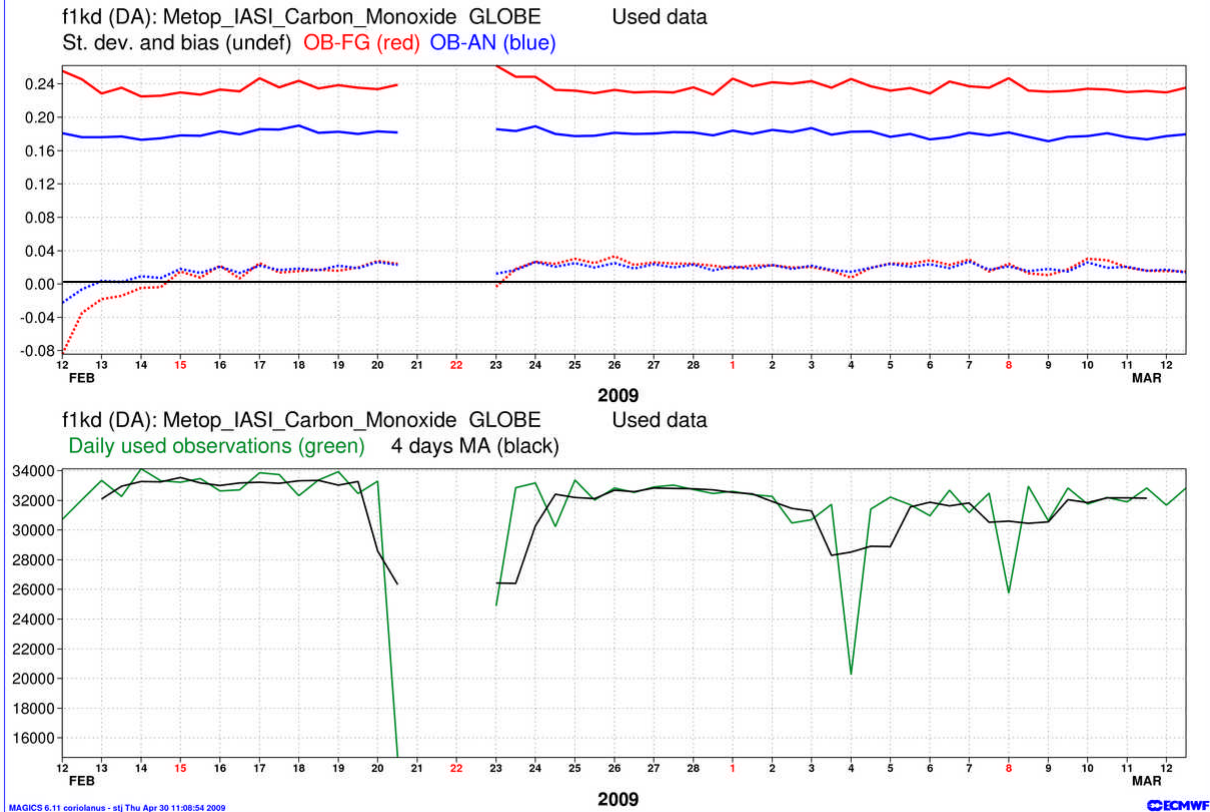
background departure o-b  
 nb= 270788 (ref= 270781) rms= 0.376 ( 0.376 )  
 mean= 0.289 ( 0.290 ) std= 0.241 ( 0.239 )  
 min= -1.67 ( -1.67 ) max= 2.43 ( 2.43 )



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

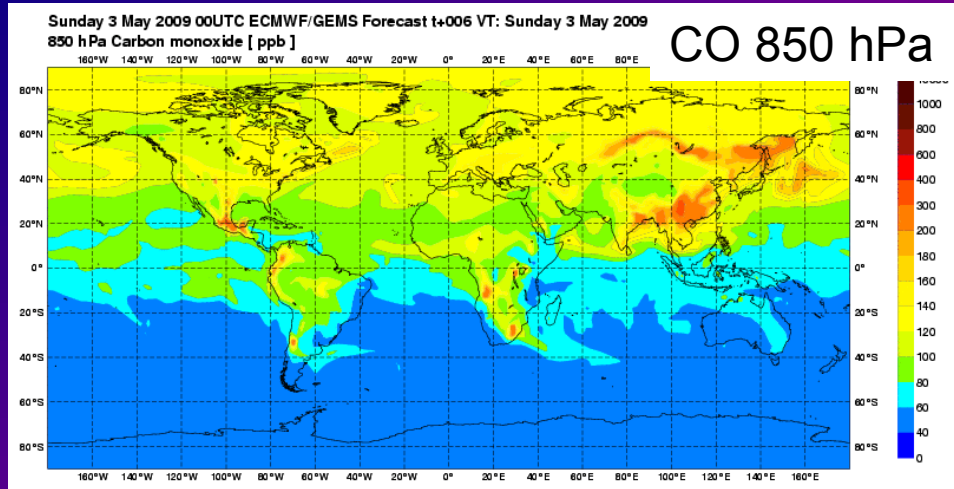
**The IASI-EUMETSAT data agree much less with the other two products.**

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

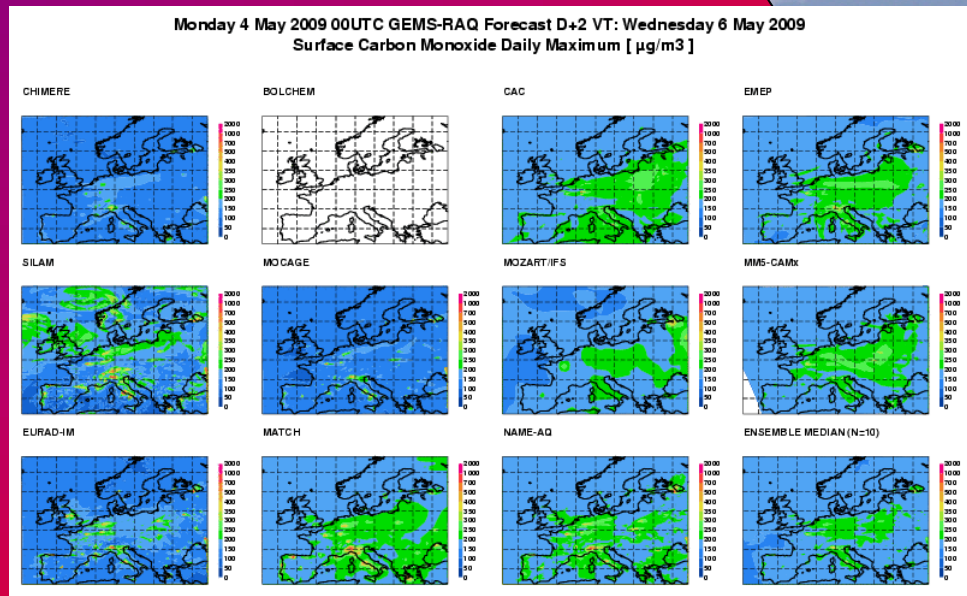


The IASI-SA/IPSL data are now assimilated in NRT. The results look all right, but there is currently no in-situ data available in NRT for validation.

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



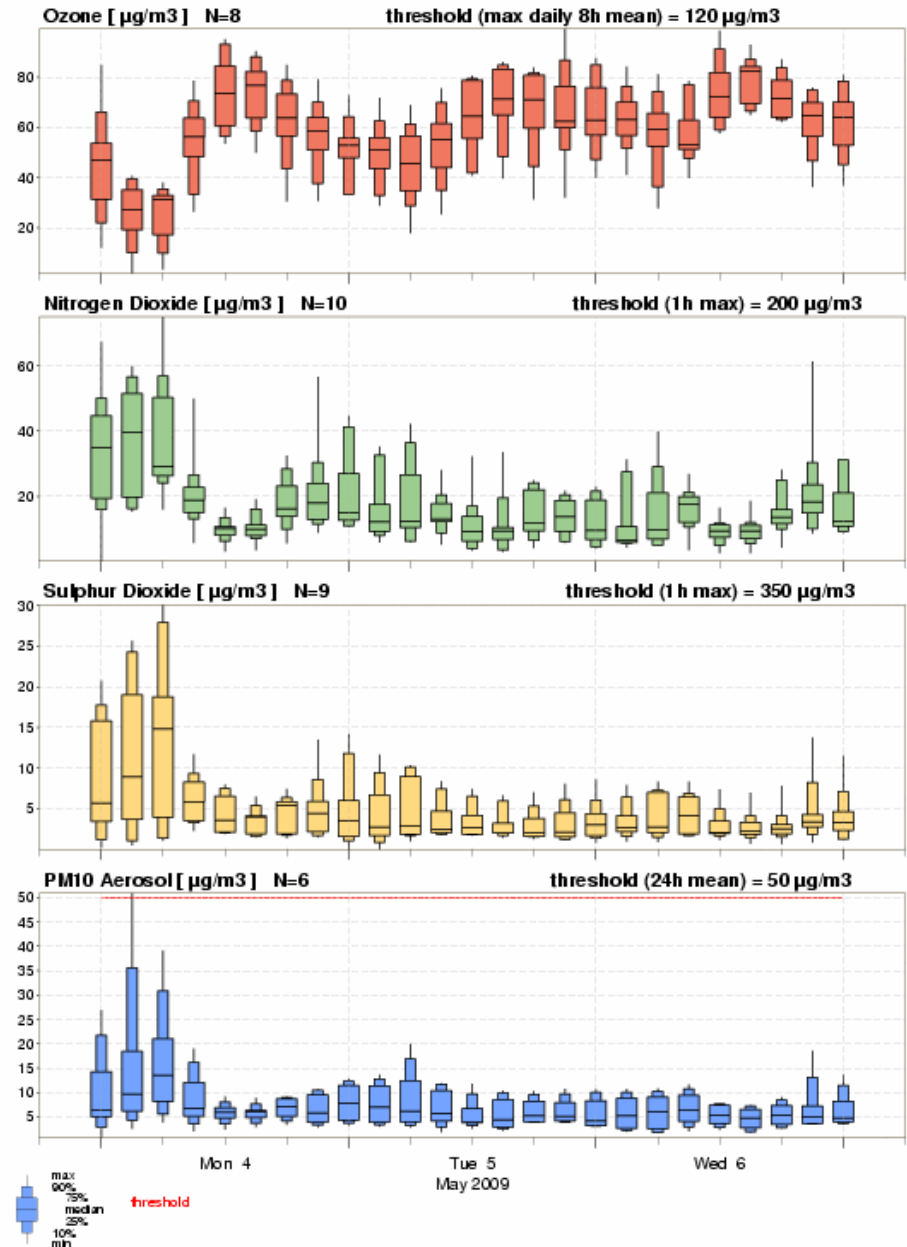
Boundary conditions from the global data assimilation system are used to drive the regional air quality models within GEMS to provide detailed forecasts.




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.

GEMS RAQ EPSGRAM  
London(51.5°N, 0.13°W)  
Forecast Monday 4 May 2009 00 UTC





**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.**



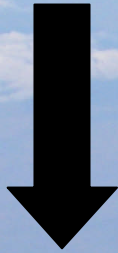
$\hat{\mathbf{z}} = \mathbf{g}^T \hat{\mathbf{x}}$      $\mathbf{g}^T$  is a simple integration operator

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

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

If we, for instance, use a column retrieval product, we lose information, even when we take the reduced averaging kernel  $\mathbf{a}^T$  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**

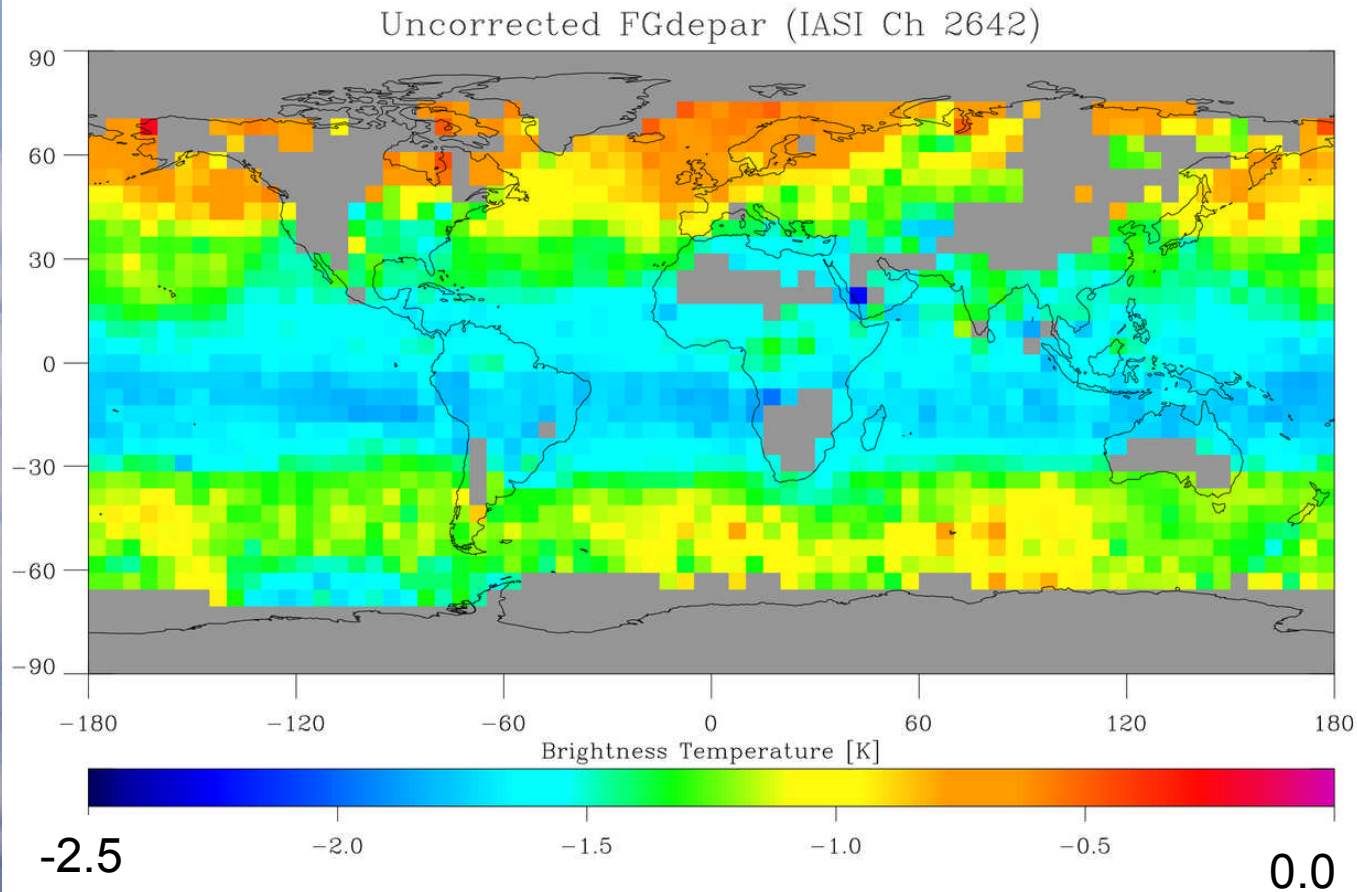
**Radiance  
assimilation  
with fast  
approximate  
RT model**

**Radiance  
assimilation  
with very  
accurate RT  
model**



# **IASI CH<sub>4</sub>: bias correction and first results**

The IASI methane channels show large biases relative to the CH<sub>4</sub> model. These biases also have strong geographical patterns. The data assimilation of these IASI channels would not provide good CH<sub>4</sub> 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.**

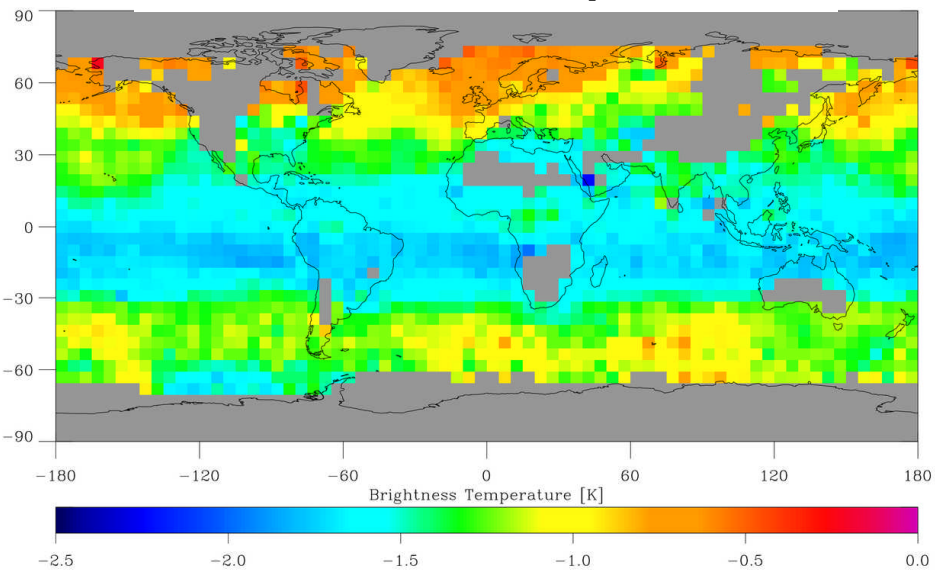
$$T(p) = \exp\left[-\gamma \int_p^0 \kappa(p) \rho(p) dp\right]$$

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

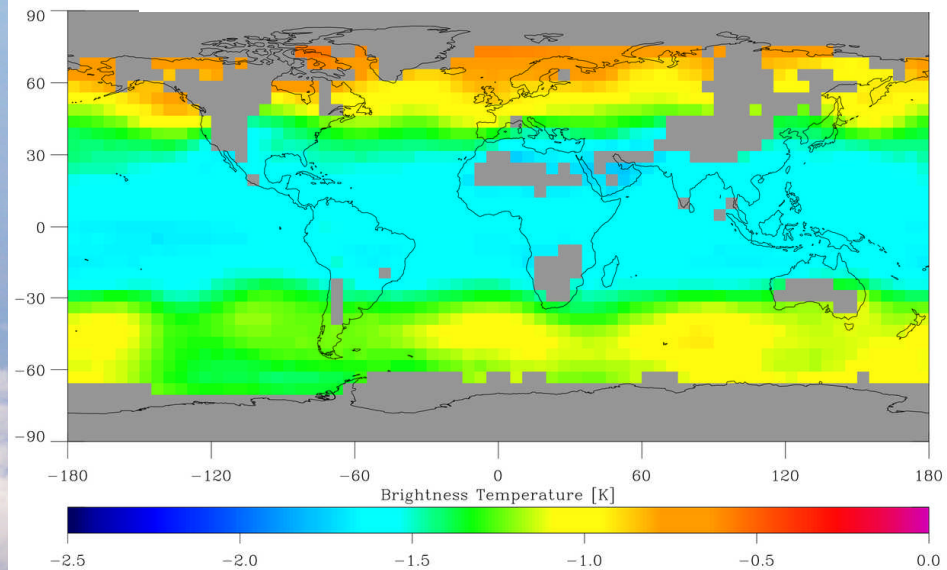
**However, it can also correct a relative error in the trace gas concentration.**

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

### Uncorrected FG departures



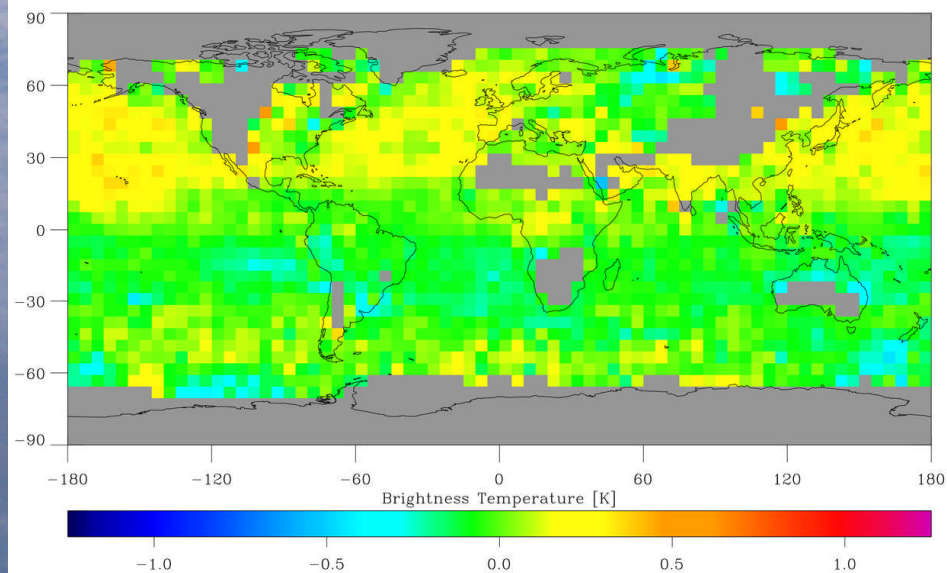
### Gamma-based bias correction



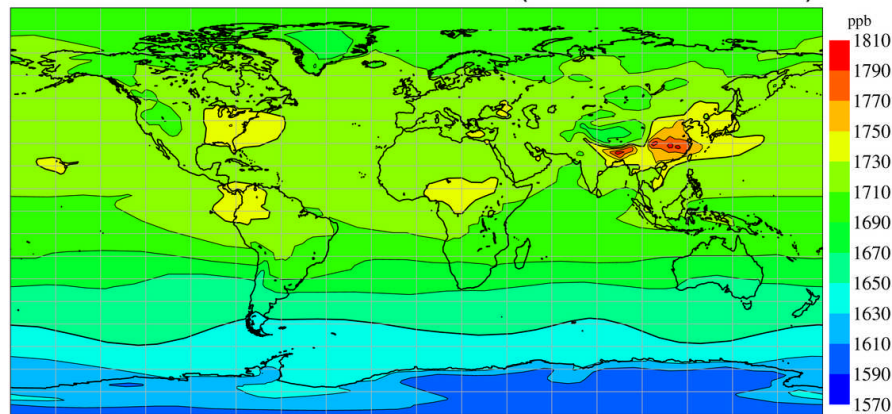
The gamma model fits the mean uncorrected FG departures for the CH<sub>4</sub> channels very well.

The remaining FG departures represent ideally the real differences between the observations and the CH<sub>4</sub> model.

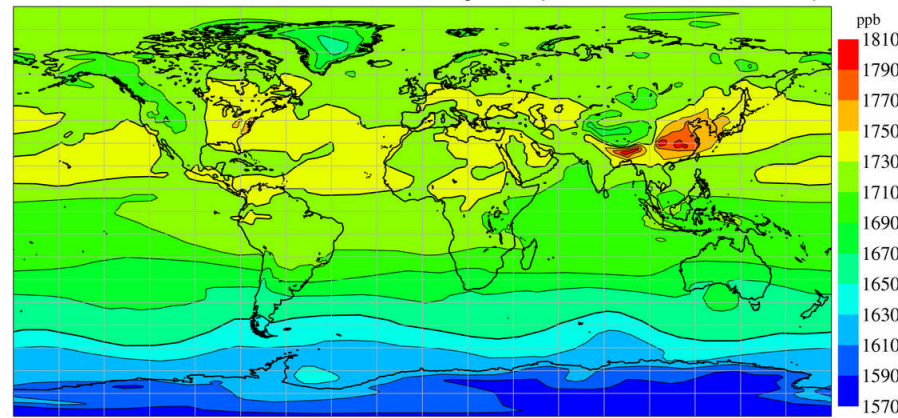
### Corrected FG departures



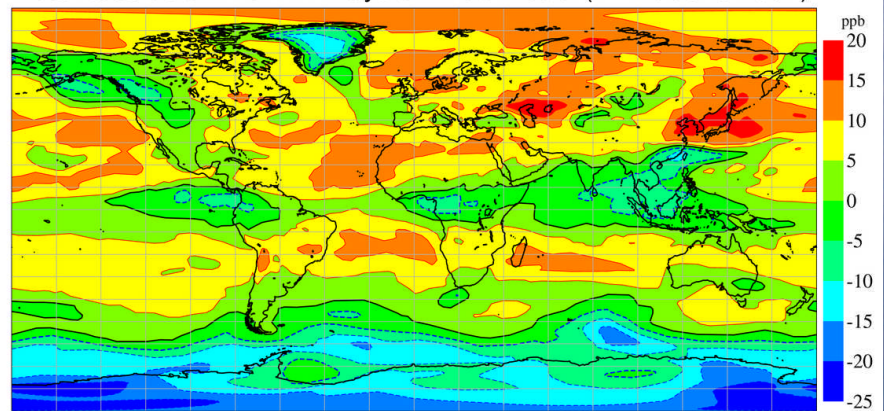
Mean total column CH<sub>4</sub> Model (1 - 20 June 2007)



Mean total column CH<sub>4</sub> Analysis (1 - 20 June 2007)



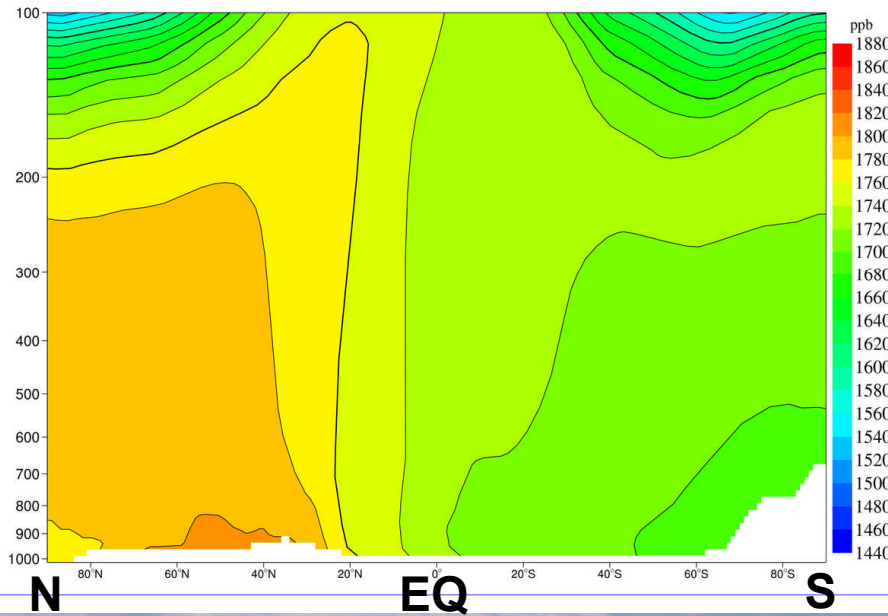
Mean total column CH<sub>4</sub> Analysis minus Model (1 - 20 June 2007)



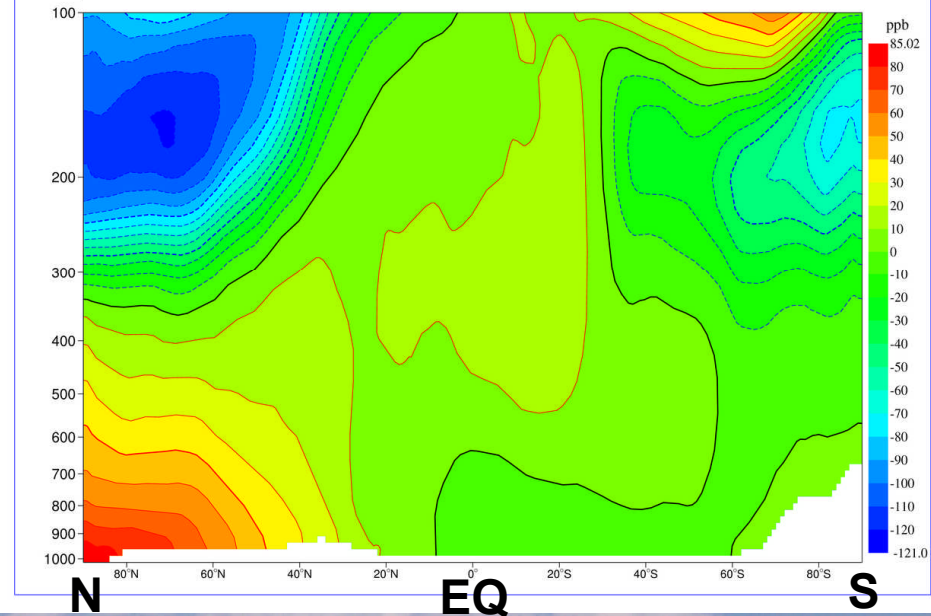
**Using the estimated gammas, the IASI assimilation makes small but significant changes to the mean column mixing ratios.**

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

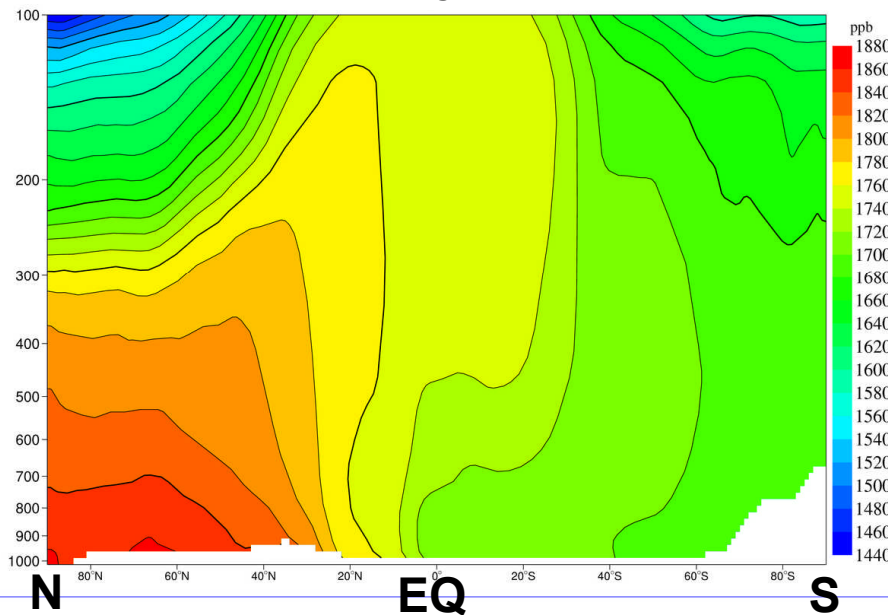
model



analysis - model



analysis

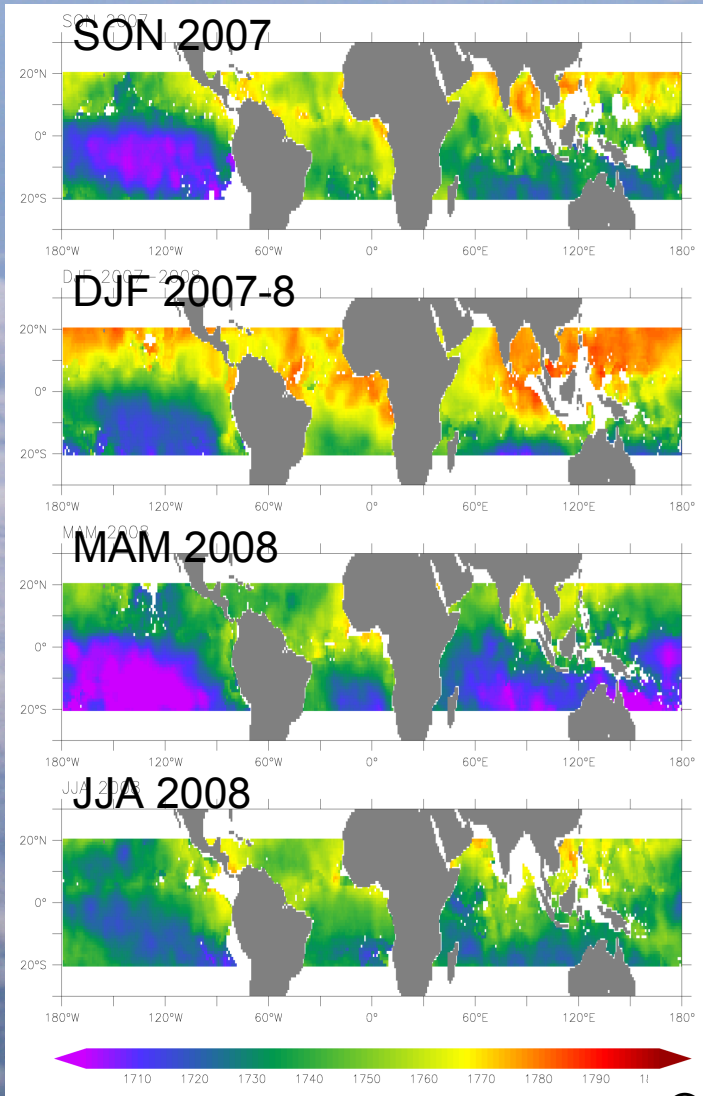


The zonal mean vertical distribution shows some larger changes, even at low altitudes.

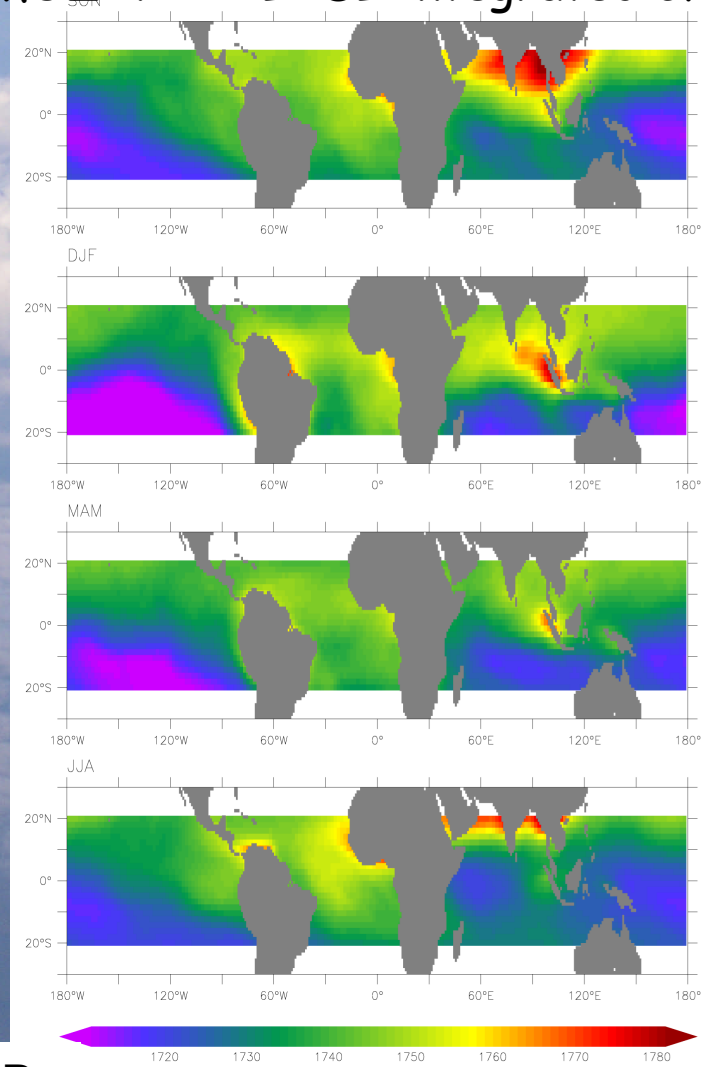
The large changes at high northern latitudes are hopefully representing real improvements.



**First Laboratoire de Meteorologie Dynamique results for CH<sub>4</sub> are also promising. More validation needs to be done.**




**MOZART-2 IASI-integrated CH<sub>4</sub>**

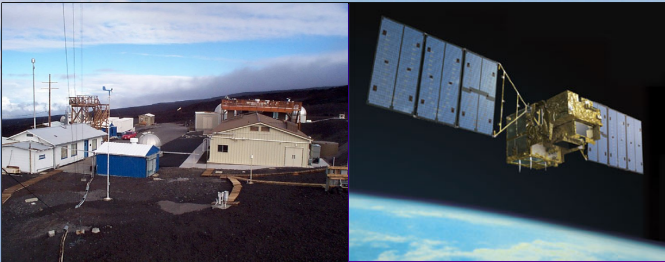


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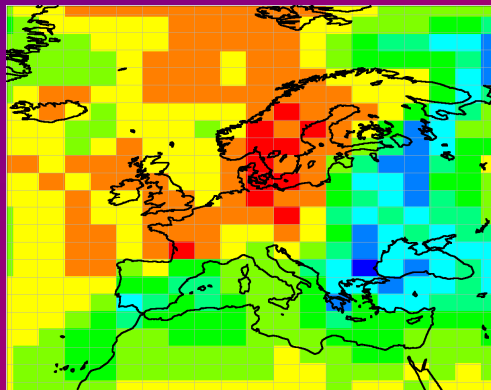


# AIRS and IASI CO<sub>2</sub> results

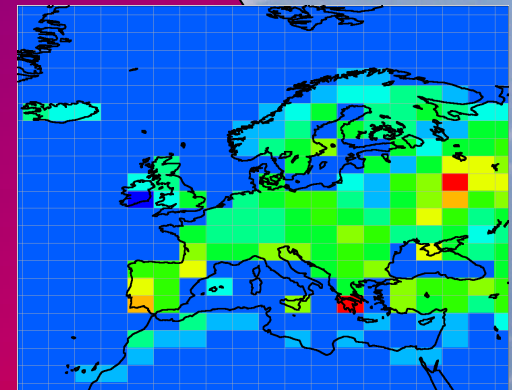


**Observations**

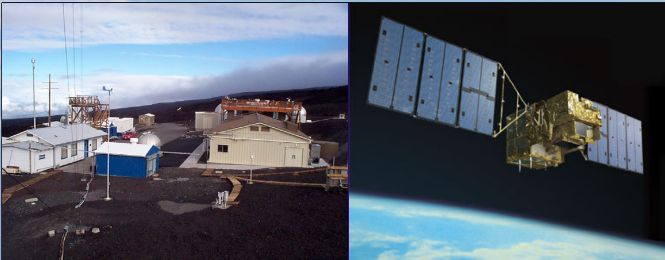
**Flux Inversion**



**Inversion model**

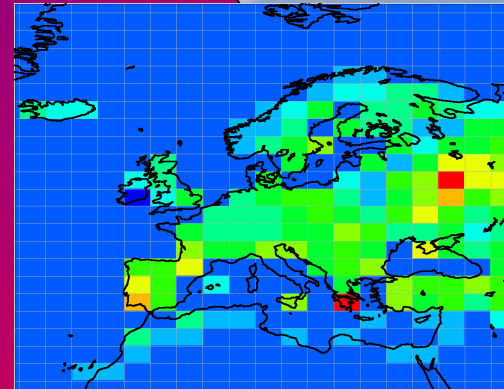
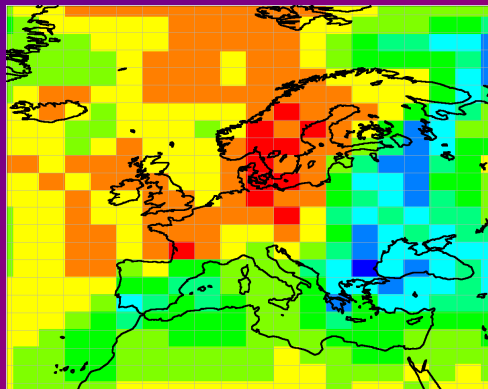


**Fluxes**

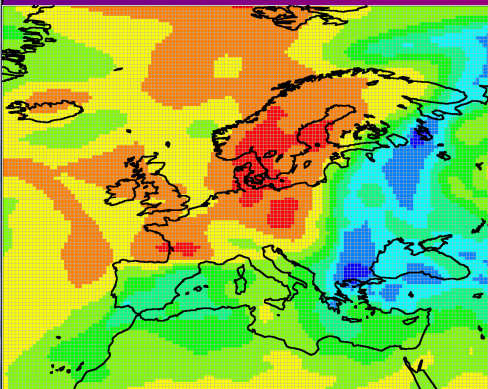


**Observations**

**Inversion model**



**Fluxes**

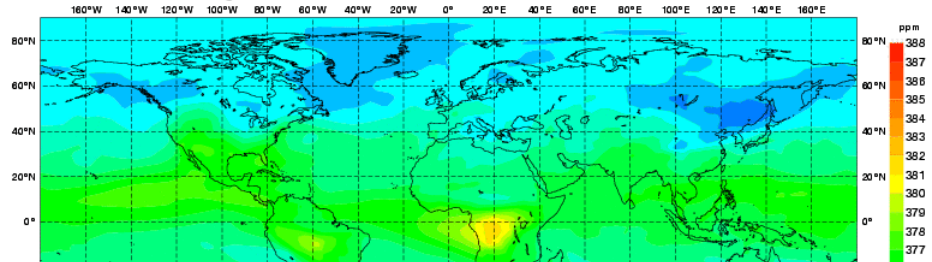


**Assimilation model**

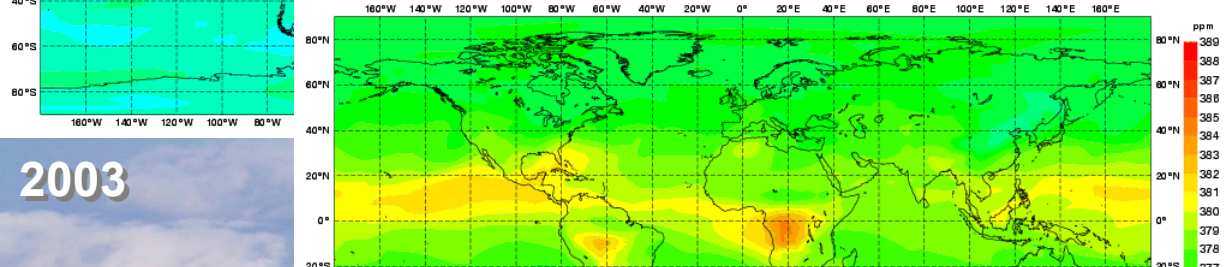
## Benefits of 2-step approach

- 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

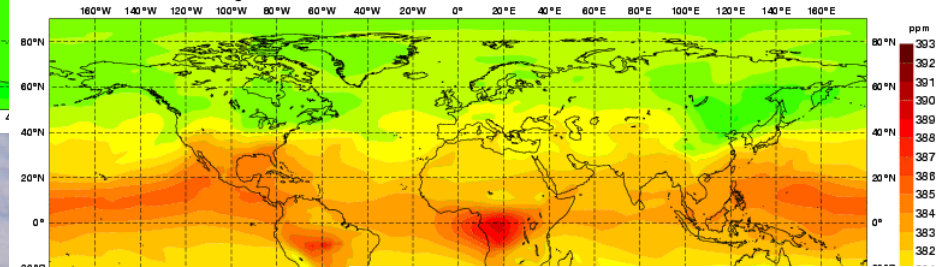
**GEMS Reanalysis Monthly Mean, August 2003**  
 Mean column CO<sub>2</sub> mixing ratio mean: 373.8 max: 381.8



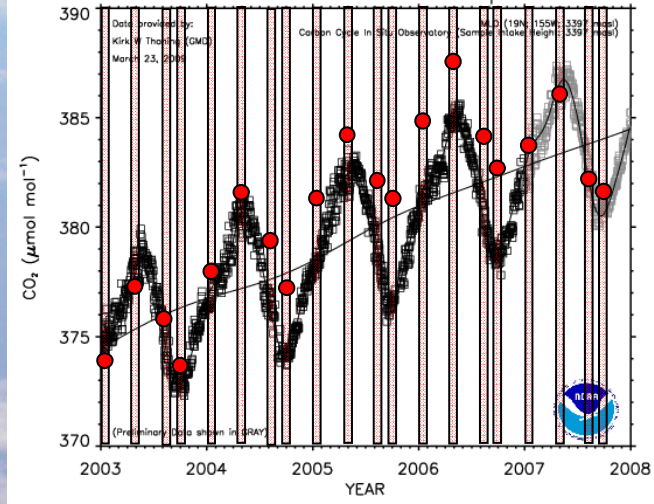
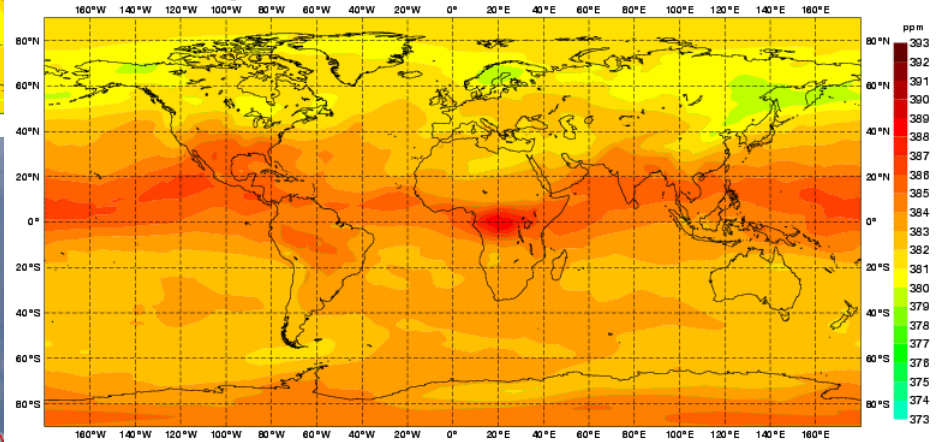
**GEMS Reanalysis Monthly Mean, August 2004**  
 Mean column CO<sub>2</sub> mixing ratio mean: 377.5 max: 384.3



**GEMS Reanalysis Monthly Mean, August 2005**  
 Mean column CO<sub>2</sub> mixing ratio mean: 381.0 max: 389.3



**GEMS Reanalysis Monthly Mean, August 2006**  
 Mean column CO<sub>2</sub> mixing ratio mean: 383.0 max: 388.7



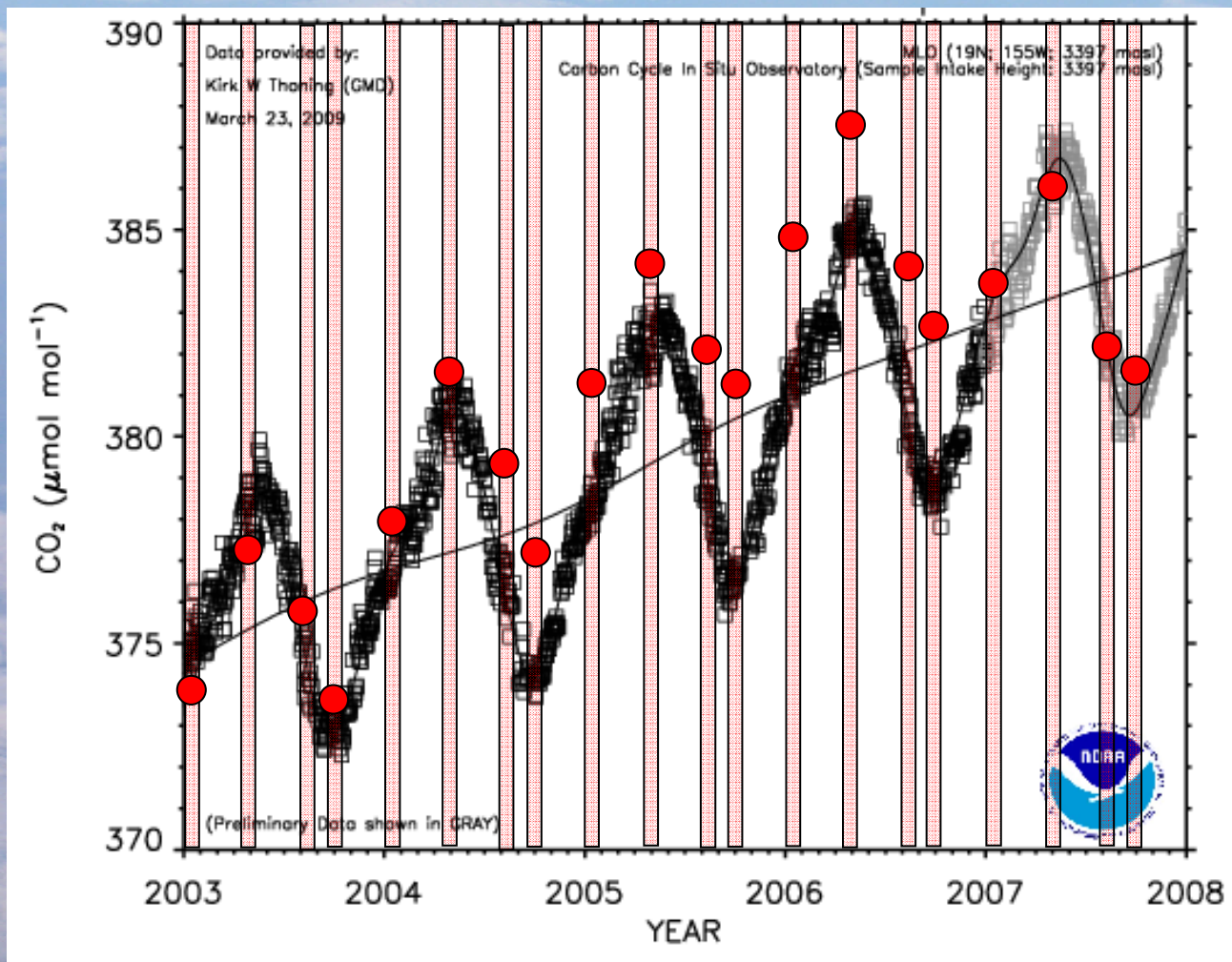
2003

2004

2005

2006

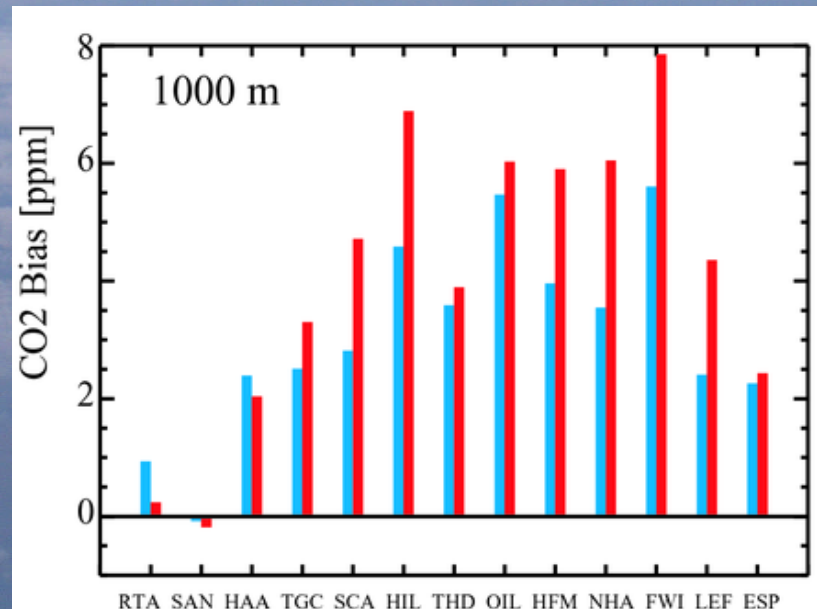
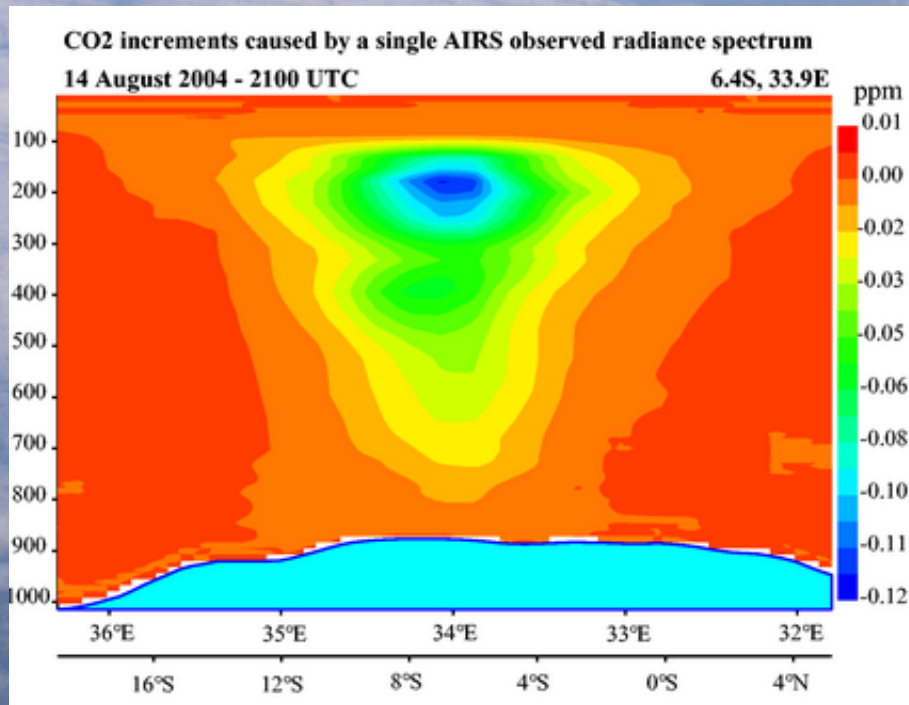
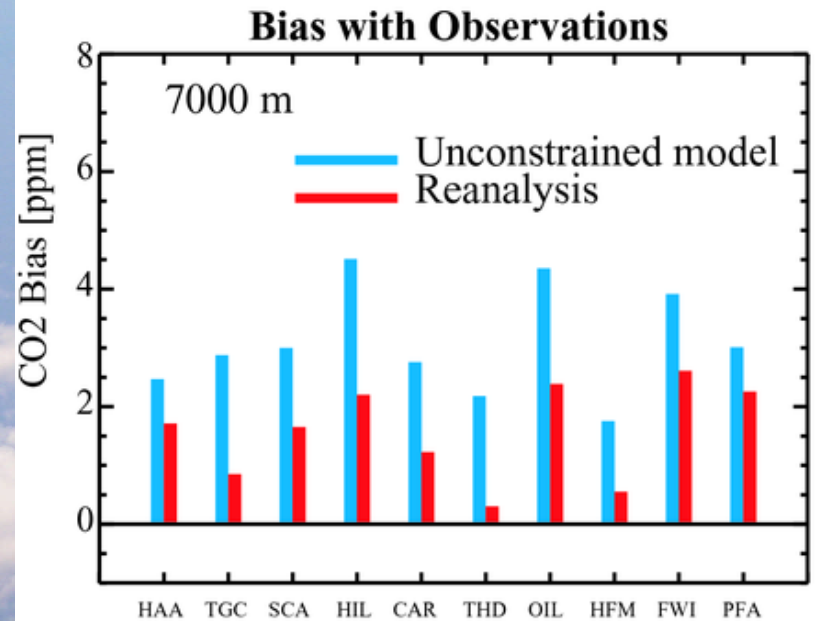




**Just to illustrate the challenges we are facing, the CO<sub>2</sub> reanalysis started to perform better, when GPS occultation data from the CHAMP and COSMIC sensors were assimilated. Coincidence???**

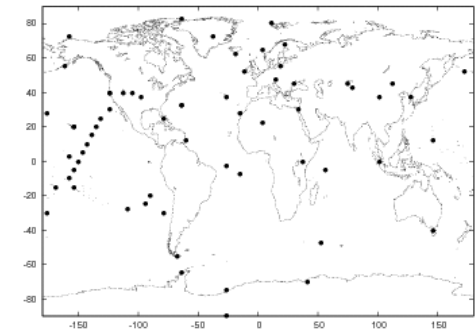
**AIRS has a limited view of the atmosphere. The observations do not constrain the lower troposphere.**

**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.



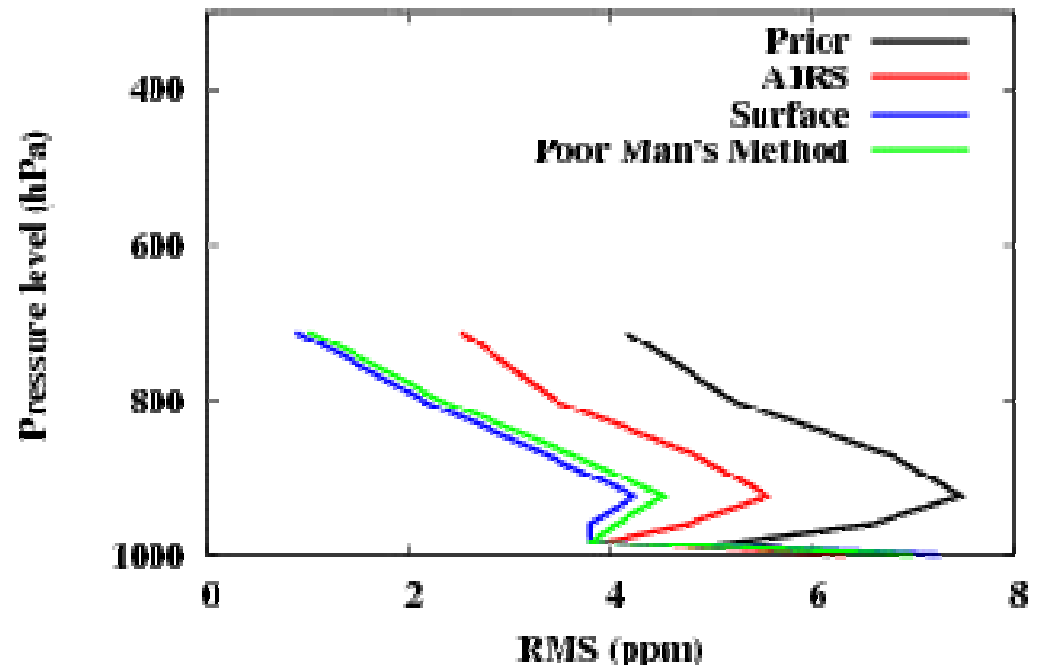
Surface flask observations provided by T. Conway (NOAA/ESRL)

Validation with CERES campaign (C. Gerbig)



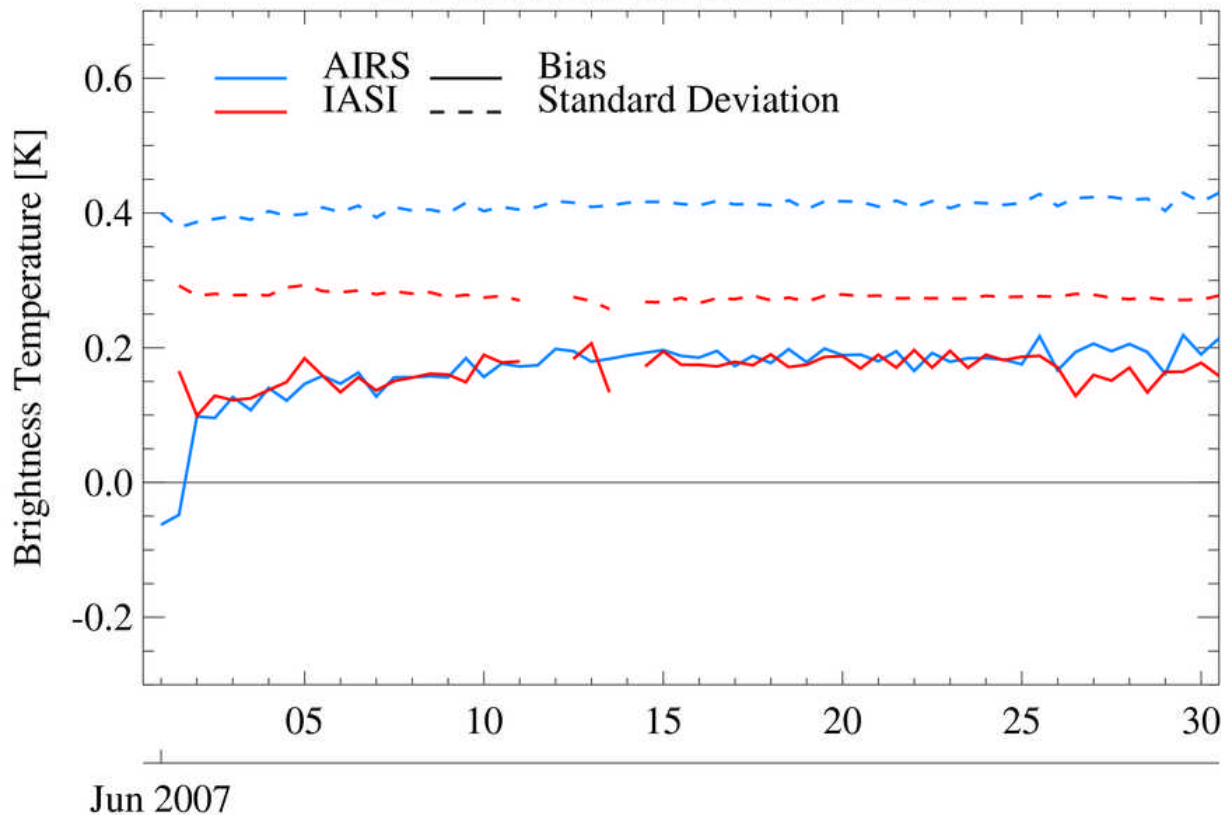
© F. Chevallier, LSCE

CERES



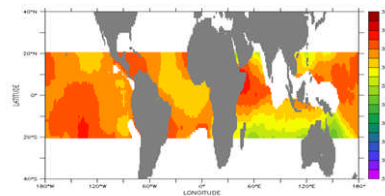
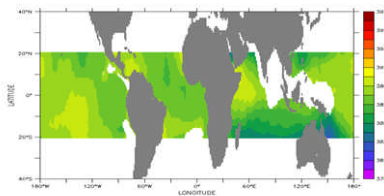
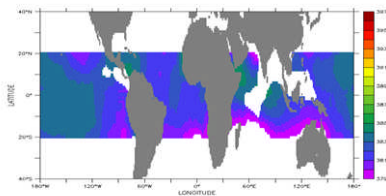
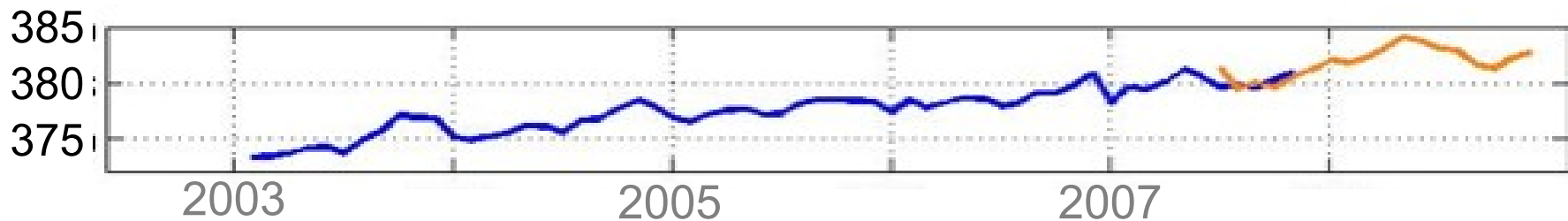
The next step is to use both AIRS and IASI radiances for the CO<sub>2</sub> data assimilation. On top of that we will use observations from the GOSAT satellite that constrains lower tropospheric CO<sub>2</sub>.

Observation-model differences



CO<sub>2</sub>-sensitive  
channel at  
14  $\mu\text{m}$

Almost 8 years of AIRS and IASI data have been processed by LMD to provide a time series of tropospheric integrated CO<sub>2</sub> content.



← AIRS →

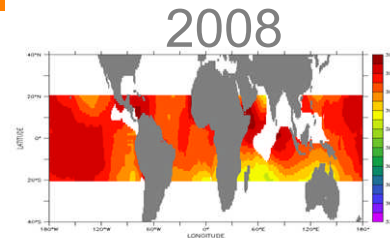
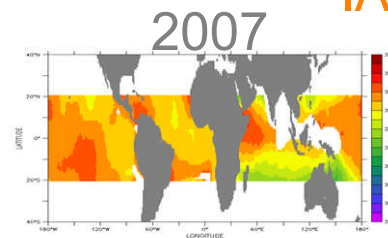
← IASI →

**Aqua/AIRS : 2003-2007**

**MetOp/IASI : 2007-...**

**IASI-2 : 2013-...**

**IASI-3 : 2016-...**



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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?**