Characterization of MIPAS CH_4 and N_2O and MLS N_2O using data assimilation

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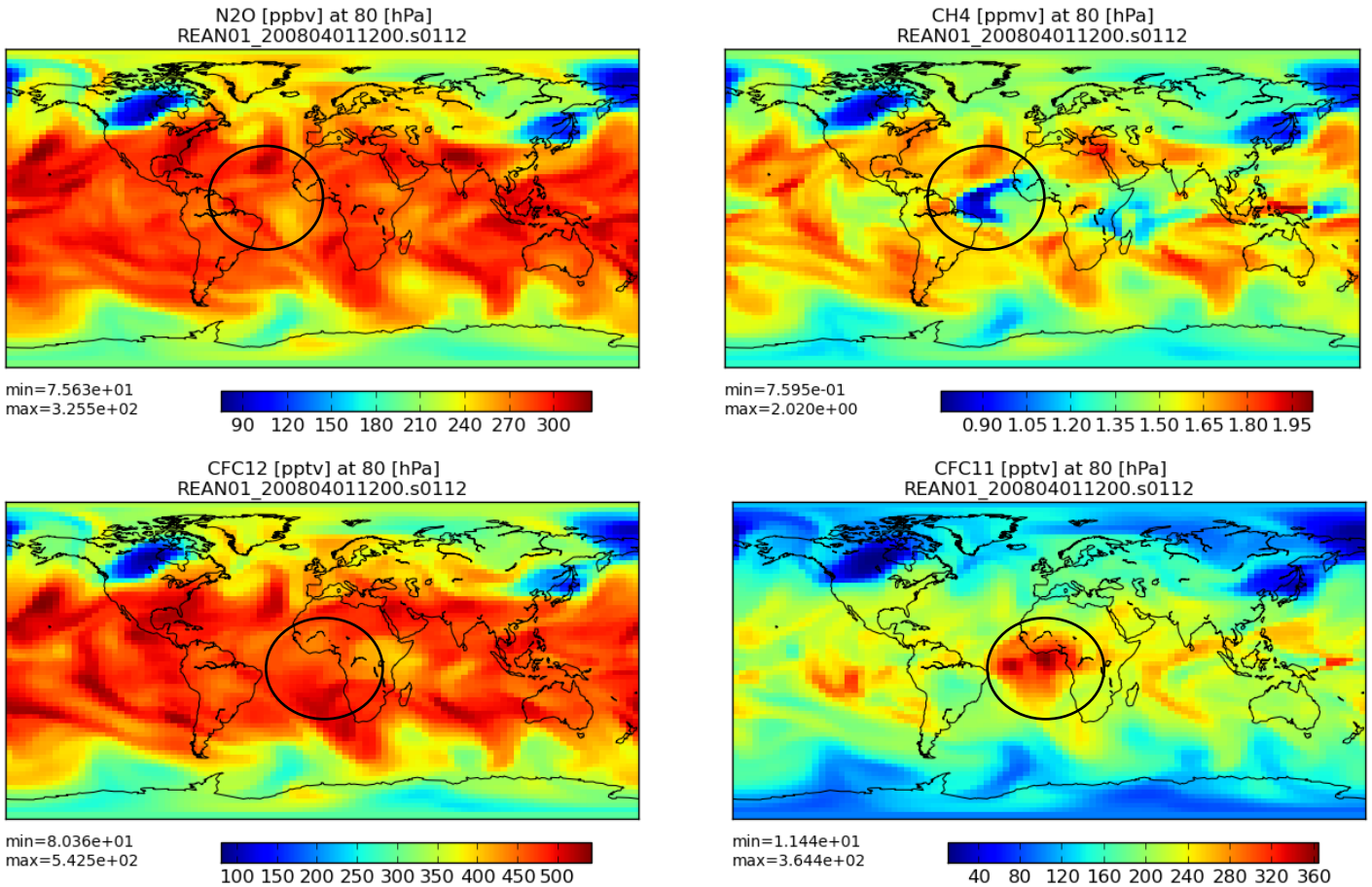
Last year presentation: Reanalysis of MLS and MIPAS between 2007 and 2012

- Several issues, in particular, many blobs in CH_4 (and CFC11) in UTLS



Outline

- Part 1: Reanalysis of MIPAS N_2O and CH_4
- Part 2: Diagnosing error statistics with DA

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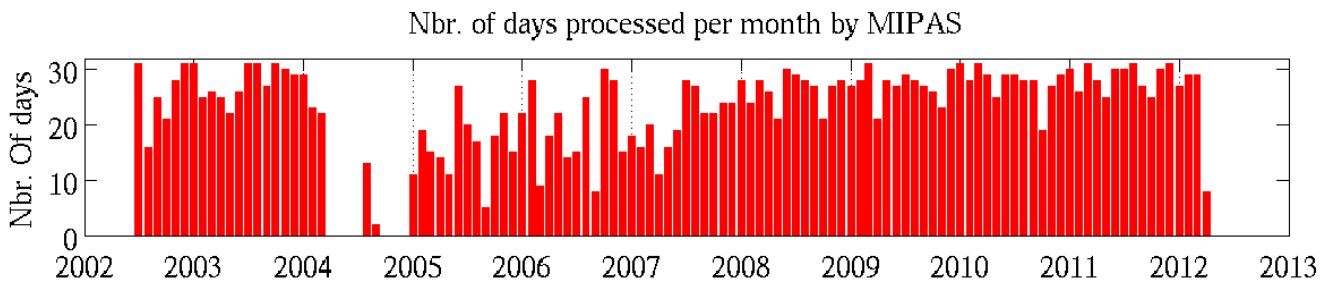
The Belgian Assimilation System for Chemical ObsErvations (BASCOE)

Errera et al., ACP, 2008, 2012

- 4D-Var system based on CTM (**chemistry is off**)
- Winds from ERA-Interim
- Resolution: 2.5° lat x 3.75° lon x 37 levels (surf to 0.1 hPa)
- Time step: 30'
- **B** matrix is given on a spherical harmonic basis assuming homogeneous and isotropic spatial correlations

Assimilated Data: MIPAS ESA v6.0 Nominal mode

- Focus on opt. resolution period: Jan 2005 – April 2012



- Error minimal threshold set to 5%
- Background quality check (BgQC) to reject outliers (Anderson and Jarvïnen, 2000, QJRMS):
  - Obs is rejected if: $(\mathbf{y}^{\mathrm{o}} - \mathbf{H}\mathbf{x}^{\mathrm{b}})^2 > \alpha(\sigma_{\mathrm{o}}^2 + \sigma_{\mathrm{b}}^2)$
  - α=5

Use of Averaging Kernels (AK) with MIPAS ESA

- Usuall use of AK: $x_m = y_0 + \tilde{A}(\tilde{x}_m - \tilde{y}_0)$

where: x_m is the modelled profile

y_0 is the obs a priori profile

A is the AK matrix

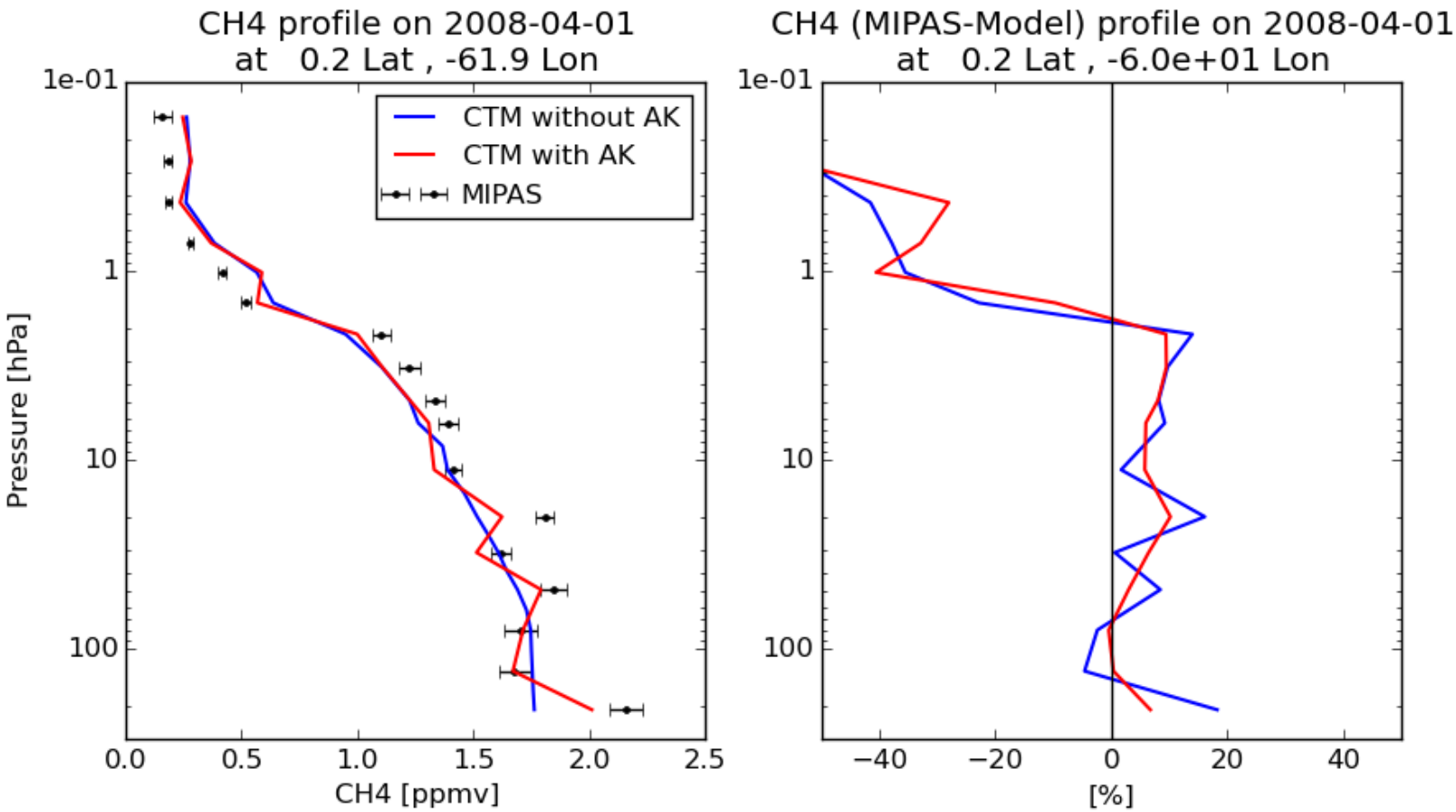
"~" denote interpolation on model levels

- With MIPAS ESA v6.0 (Ridolfi et al., 2011):

$$x_m = y_k + \tilde{A}(\tilde{x}_m - \tilde{y}_k)$$

where: y_k denote retrieved obs profile

Impact of Averaging Kernels (AK)



Calibration of the **B** matrix

- Previous setup: std(**B**)=20%, corr(**B**) Gaussian with L_h=800km and L_v=1 level
- New setup: **B** is calibrated using an ensemble method (Fisher et al., 2003, ECWMF seminar)
  - Each member starts with perturbed initial conditions
  - Each member assimilates his set of perturbed observations

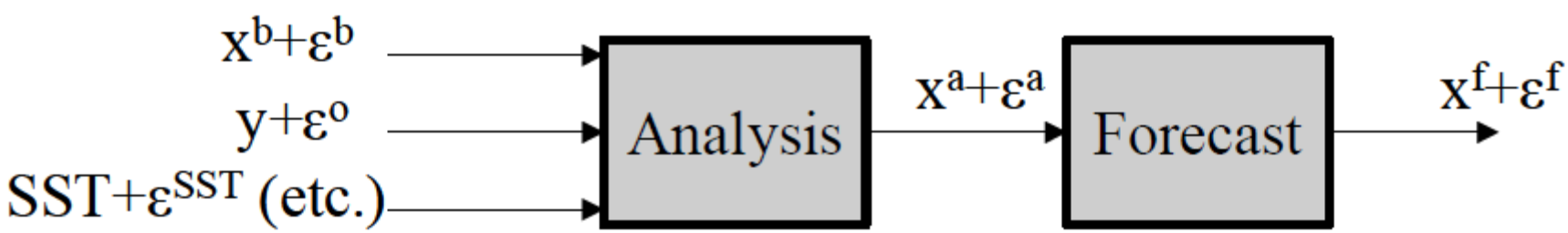


Figure 2: Schematic illustration showing how a perturbed analysis and forecast may be generated by perturbing the inputs to the analysis system.

Calibration of the **B** matrix

- In our case, ensemble of size 2 that run for 1 year
- Initial **B** used in ens. runs: 20 % std dev, Gaussian spatial correlations, L_h=400 km, L_v=0.5 lev

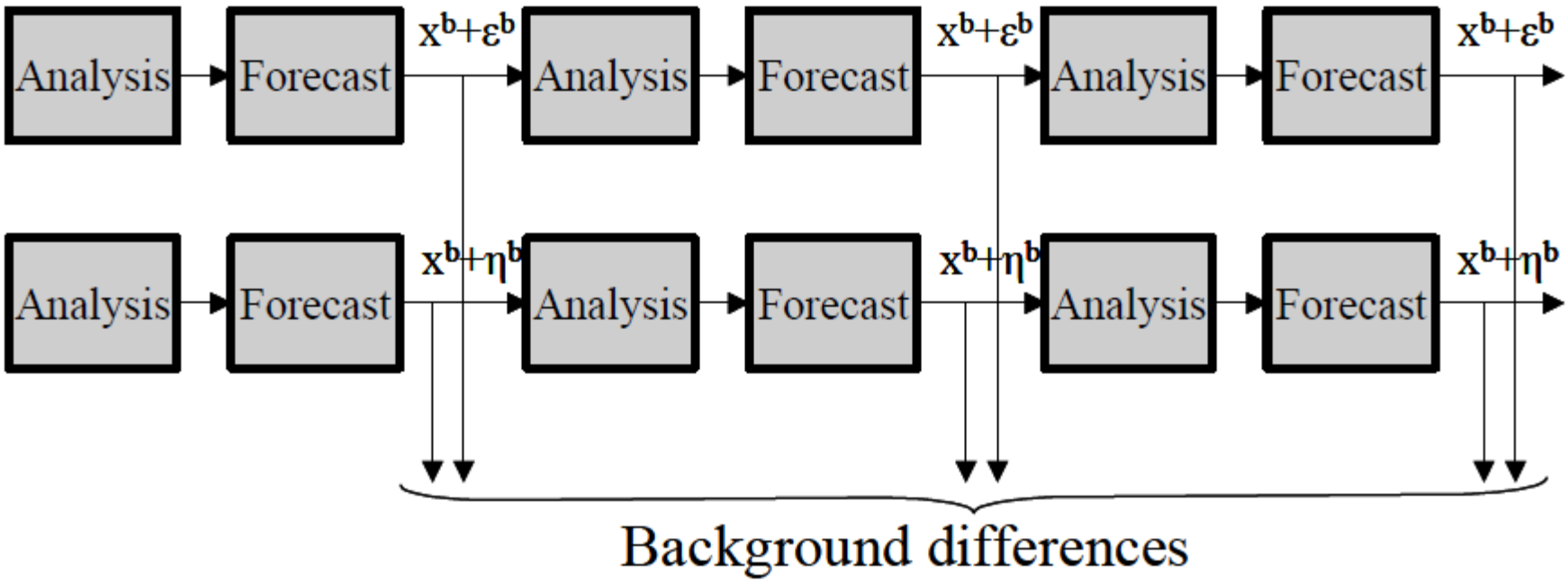
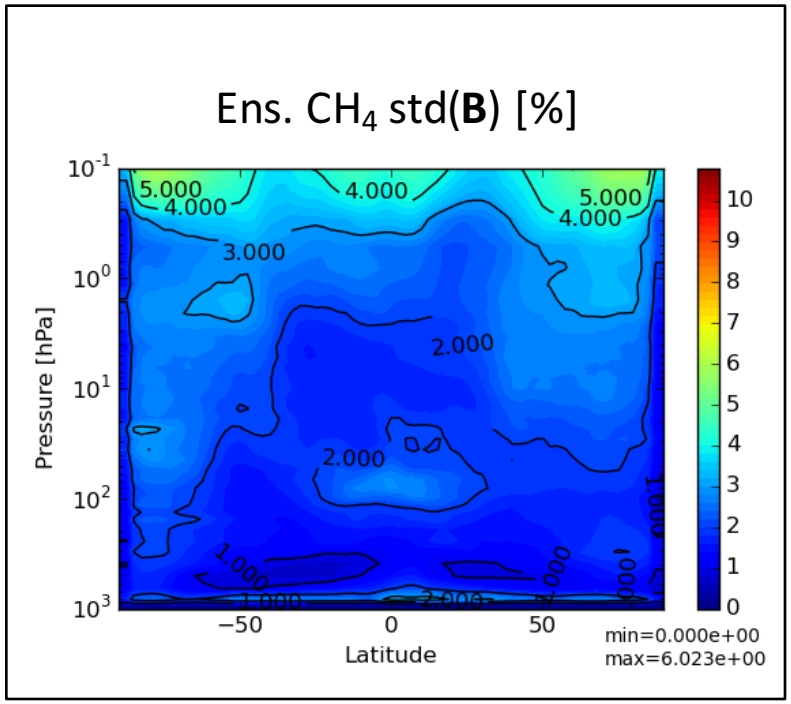
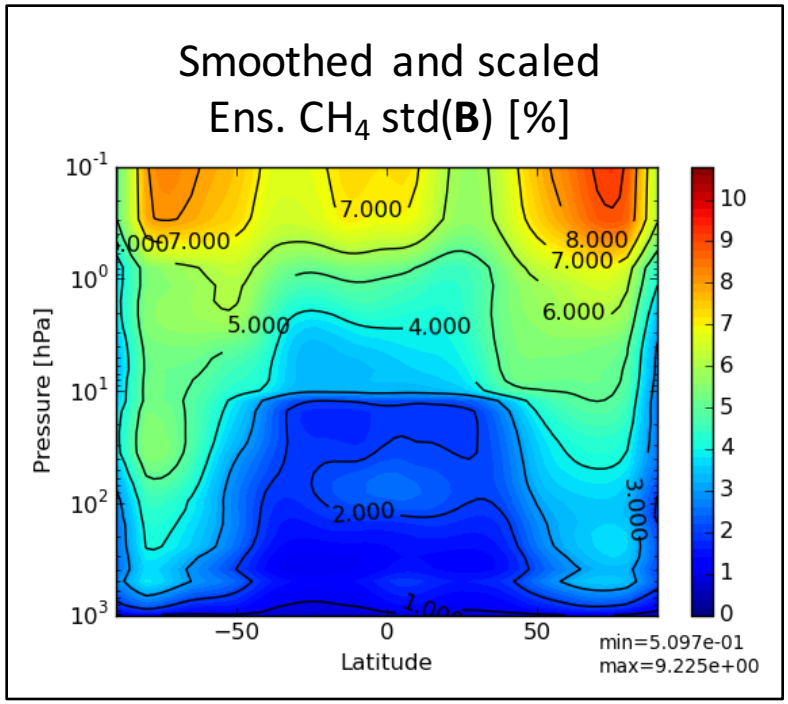


Figure 3: Schematic illustration of the analysis-ensemble method of generating fields of background difference.

Calibration of **B**: std(**B**)

- Estimated std(**B**) much smaller that in past setup
- At Poles and above 10hPa, std(**B**) is multiplied by 2 => to increase the weight of the obs. where there are known to be good

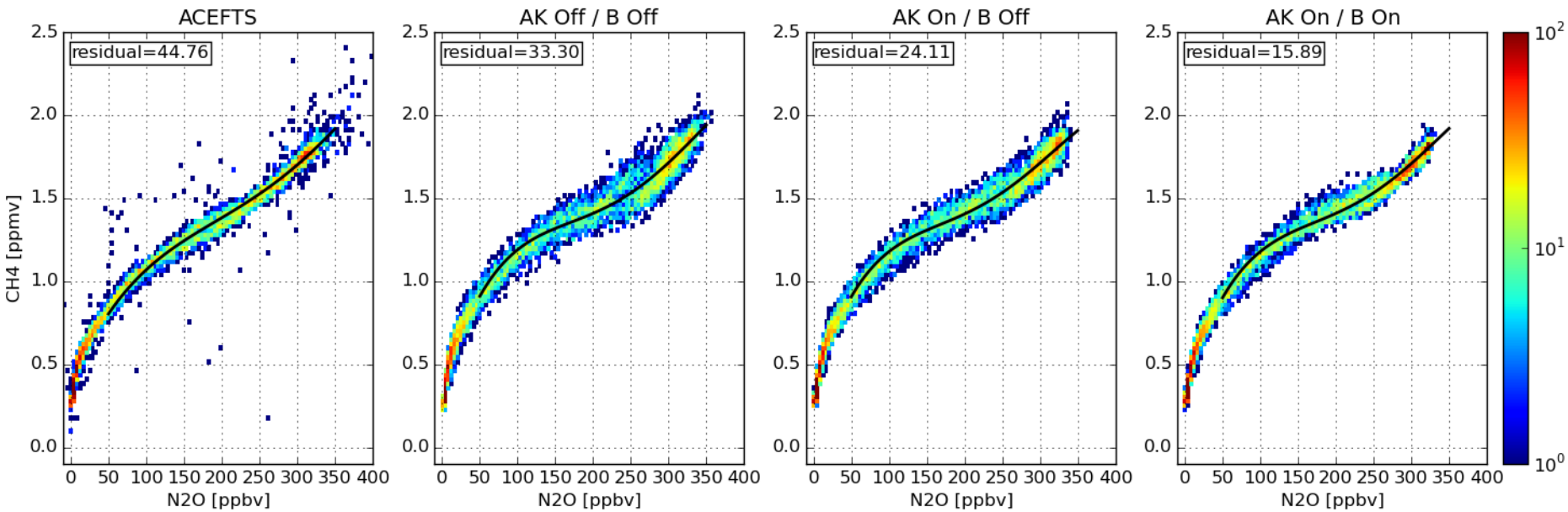




Impact of AK and calibration of **B**

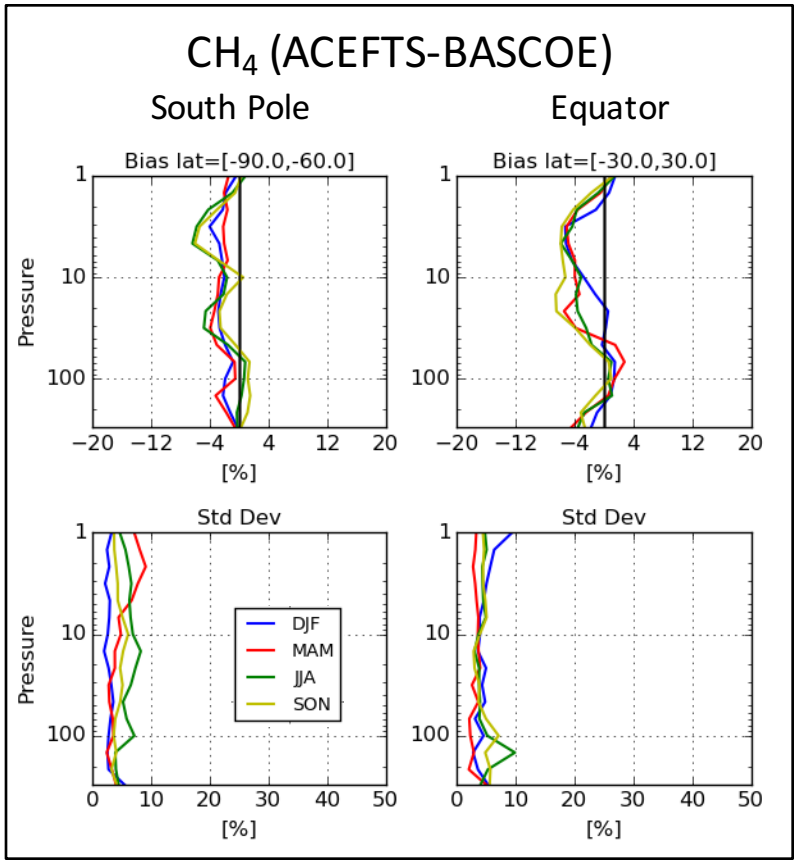
N_2O-CH_4 correlations in 2008 between 30°S-30°N in ACEFTS observation space

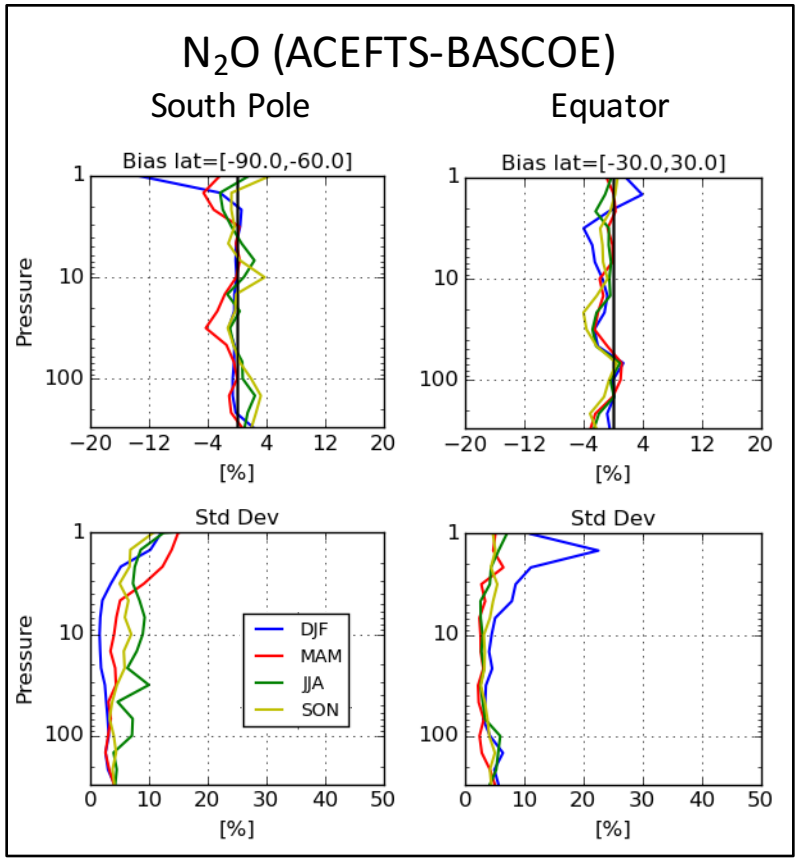
- Using AK and calibrated **B**, correlations are much compact, in particular in the lower stratosphere
- Better agreement with ACEFTS



Validation against ACEFTS V3.5 in 2010

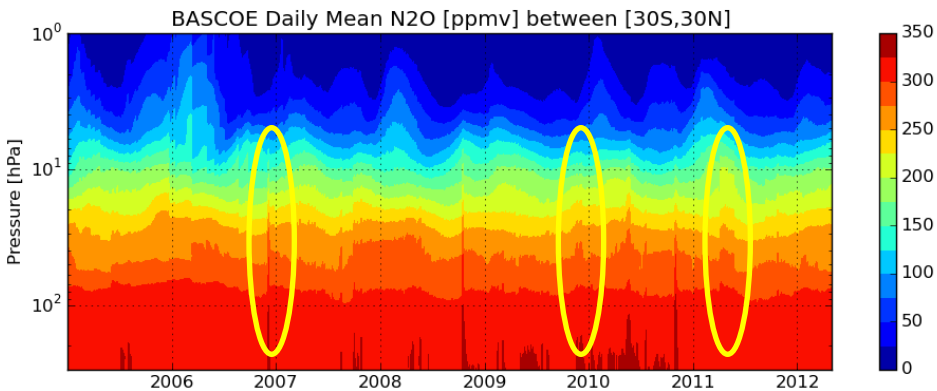
- Excellent agreement between reanalysis and ACEFTS

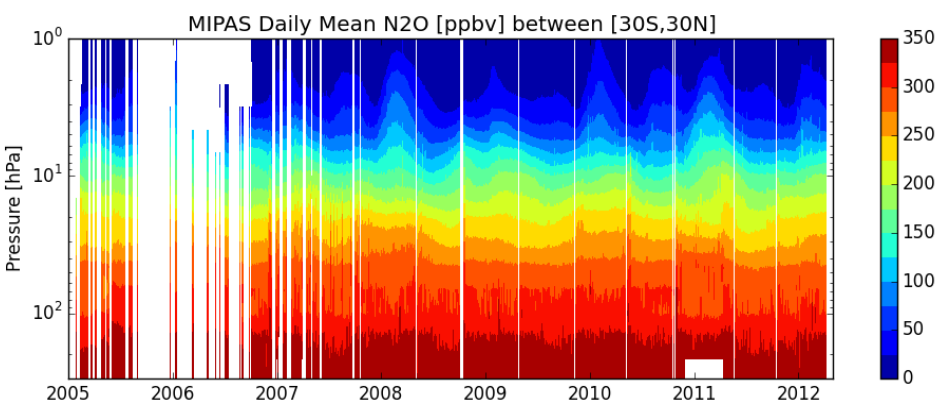


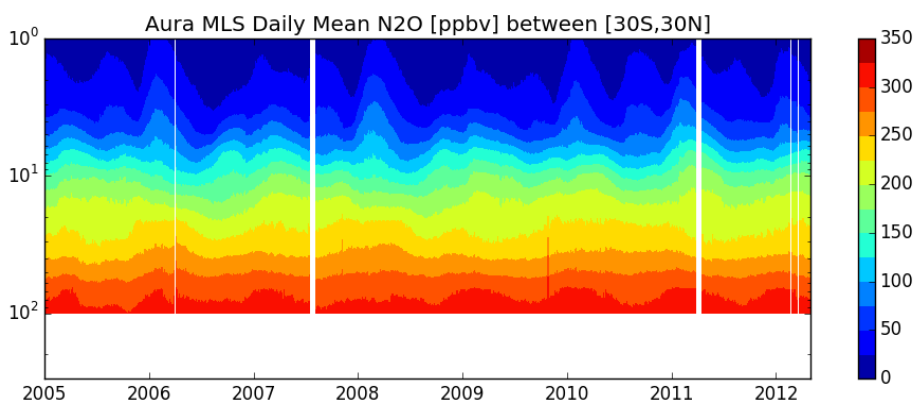


Time stability of reanalysis: N_2O

- Time series of reanalysis is "noisy" at some dates
- This noise is due to noisy MIPAS data
- Is MIPAS v7 will improve BASCOE analyses?

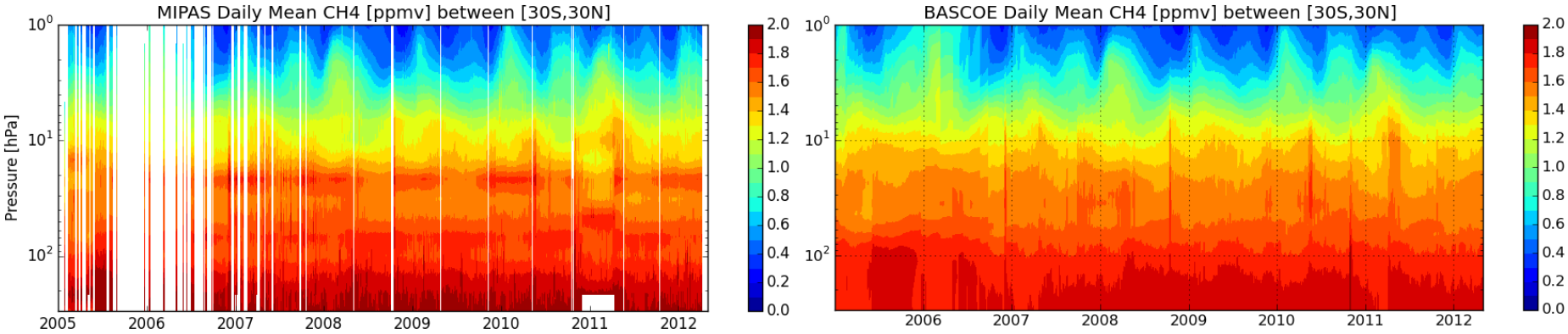






Time stability of reanalysis: CH_4

- Peaks in MIPAS CH_4 around 20 hPa are removed in reanalysis
- Time series of reanalysis is even more noisy than for N_2O



Conclusions of Part 1

- A reanalysis of MIPAS ESA CH_4 and N_2O has been produced
- General good agrement vs. ACEFTS in all regions/seasons …
- … but reanalysis is still noisy (time series):
  - MIPAS discontinuities are problematic
  - what could we expect from MIPAS v7?
- **DA add value to MIPAS**: the use of AK and **B** largely reduce the oscillations in CH_4 and N_2O Eq. lower stratospheric profiles

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- Part 1: Reanalysis of MIPAS N_2O and CH_4
- Part 2: Diagnosing error statistics with DA

Diagnosing error statistics of **B** and **R**

$$J(\mathbf{x}) = \underbrace{\frac{1}{2}[\mathbf{x}-\mathbf{x}^{\mathrm{b}}]^T\mathbf{B}^{-1}[\mathbf{x}-\mathbf{x}^{\mathrm{b}}]}_{J^{\mathrm{b}}\equiv\text{background term}} + \underbrace{\frac{1}{2}[\mathbf{y}-H(\mathbf{x})]^T\mathbf{R}^{-1}[\mathbf{y}-H(\mathbf{x})]}_{J^{\mathrm{o}}\equiv\text{observation term}}$$

- If **B** and **R** correctly defined: $J(\mathbf{x}^{\mathrm{a}}) = p/2$
- Desrosiers et al. (2005, QJRMS): iterative method to estimate observational and background errors in the **observation space**

$$\begin{aligned}\sigma_o^2 &= <(\mathbf{y}^{\mathrm{o}}-\mathbf{H}\mathbf{x}^{\mathrm{a}})(\mathbf{y}^{\mathrm{o}}-\mathbf{H}\mathbf{x}^{\mathrm{b}})^T> \\ \sigma_b^2 &= <(\mathbf{H}\mathbf{x}^{\mathrm{a}}-\mathbf{H}\mathbf{x}^{\mathrm{b}})(\mathbf{y}^{\mathrm{o}}-\mathbf{H}\mathbf{x}^{\mathrm{b}})^T>\end{aligned}$$

Diagnosing error statistics of **B** and **R**

- Estimating variance scaling factors $s_o(z_o)$ and $s_b(z_b)$ as function of altitude such that:

$$J(\mathbf{x}) = \frac{1}{2}[\mathbf{x} - \mathbf{x}^b]^T \boxed{s_b^2} \mathbf{B}^{-1}[\mathbf{x} - \mathbf{x}^b] + \frac{1}{2}[\mathbf{y}^o - \mathbf{H}\mathbf{x}]^T \boxed{s_o^2} \mathbf{R}^{-1}[\mathbf{y}^o - \mathbf{H}\mathbf{x}]$$

$$s_o^2(z_o) = \frac{\sigma_o^2(z_o)}{\mathrm{tr}(\mathbf{R}(z_o))}$$

$$s_b^2(z_b) = \frac{\tilde{\sigma}_b^2(z_b)}{\mathrm{tr}(\mathbf{B}(z_b))}$$

- Where:
  - z_o is the observation vertical grid
  - z_b is the model vertical grid
  - $\tilde{\sigma}_b^2$ is σ_b^2 interpolated to the model vertical grid

Experiments

Four types of experiments have been done

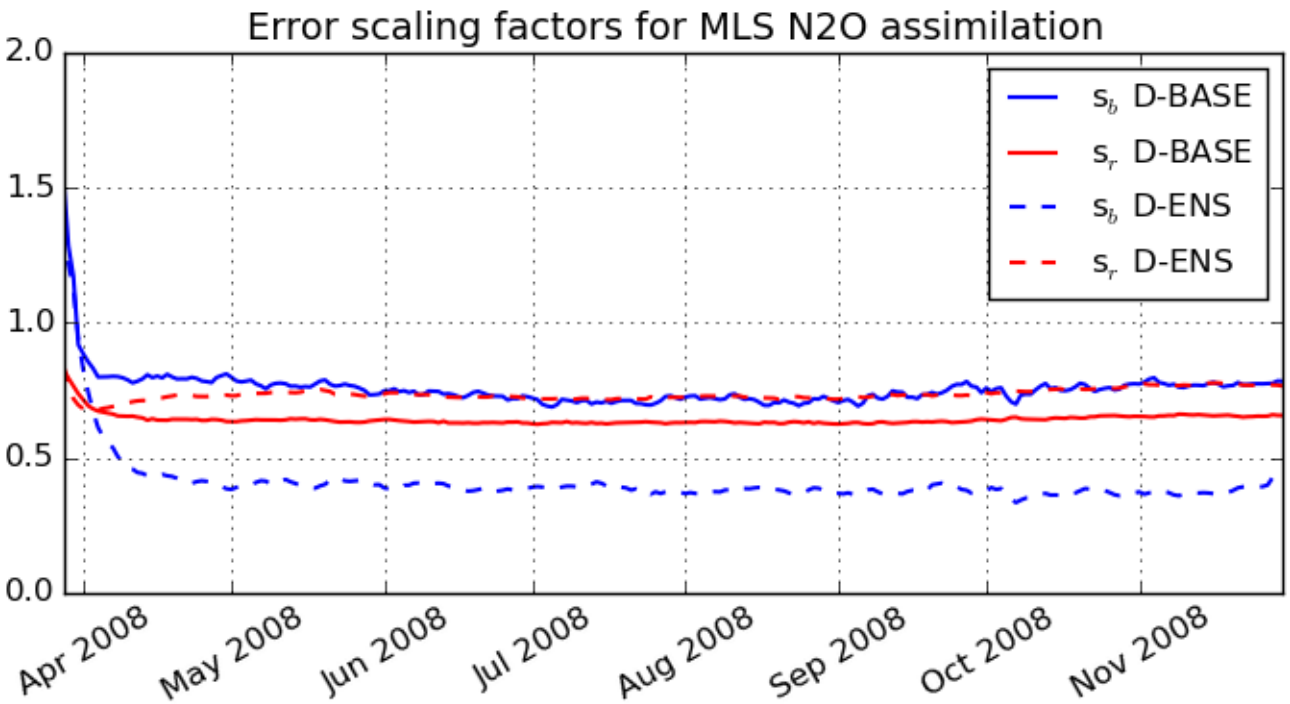
- **BASELINE:** corr(**B**) Gaussian correlations (L_h=800 km, L_v=1 level), std(**B**) = 5%
- **ENS**: corr(**B**) are provided by ensemble method, std(**B**)=5%

In these two cases, **R** is instrumental error with **min. threshold of 1%**, assuming no correlations

- **D-BASE**: s_o and s_b estimated by Desrosiers method, corr(**B**) as in BASELINE
- **D-ENS**: s_o and s_b estimated by Desrosiers method, corr(**B**) as in ENS

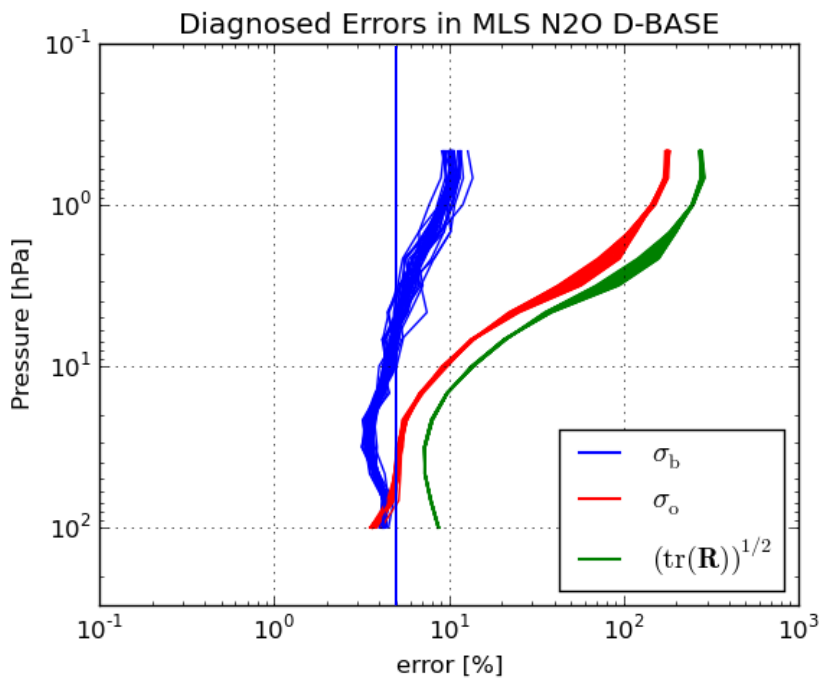
Case 1: Assimilation of MLS N_2O

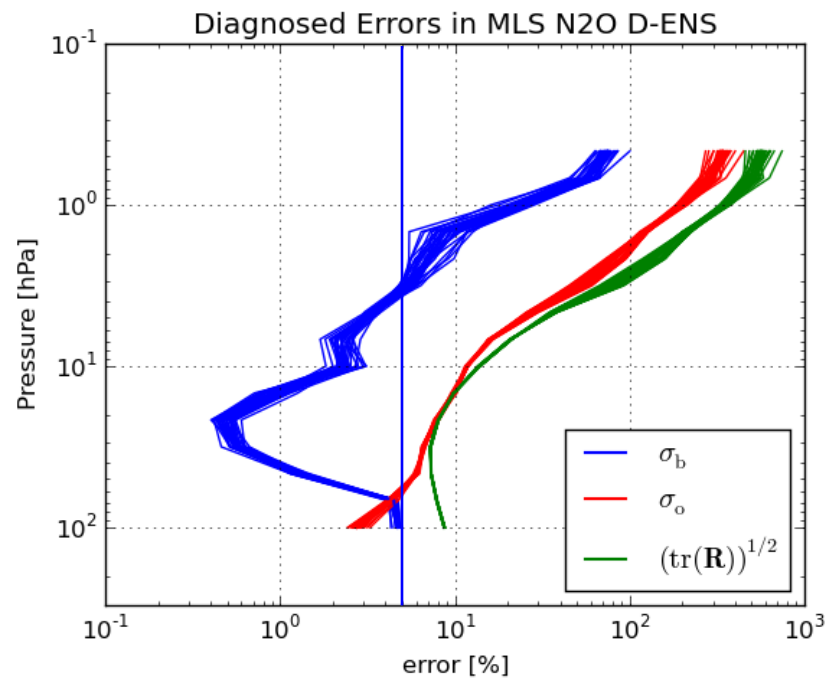
- Evolution of mean $<s_b>$ and $<s_o>$ between 4-100 hPa
- Both scaling factors are reaching a stable value after few days of spin-up



Case 1: Assimilation of MLS N_2O

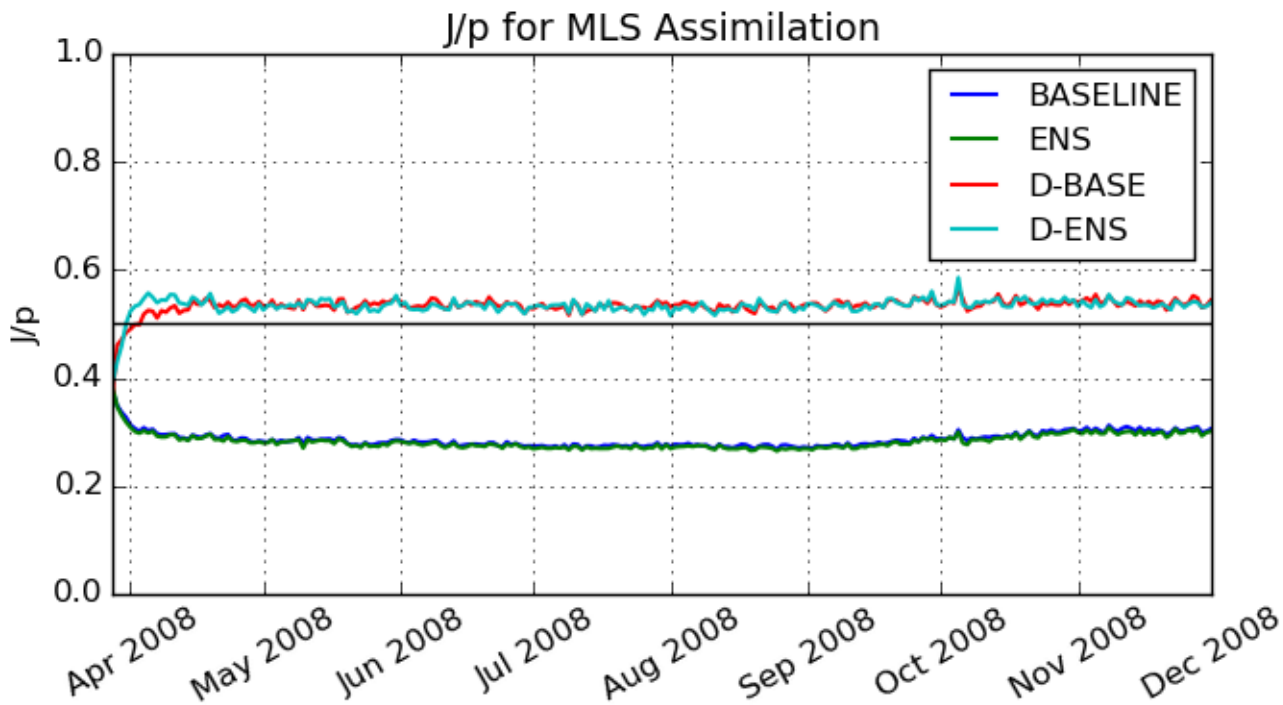
- Both experiments suggest that MLS N_2O error is overestimated w.r.t. the BASCOE
- In D-ENS, σ_b^2 is irrealistic around 30 hPa (<1%)



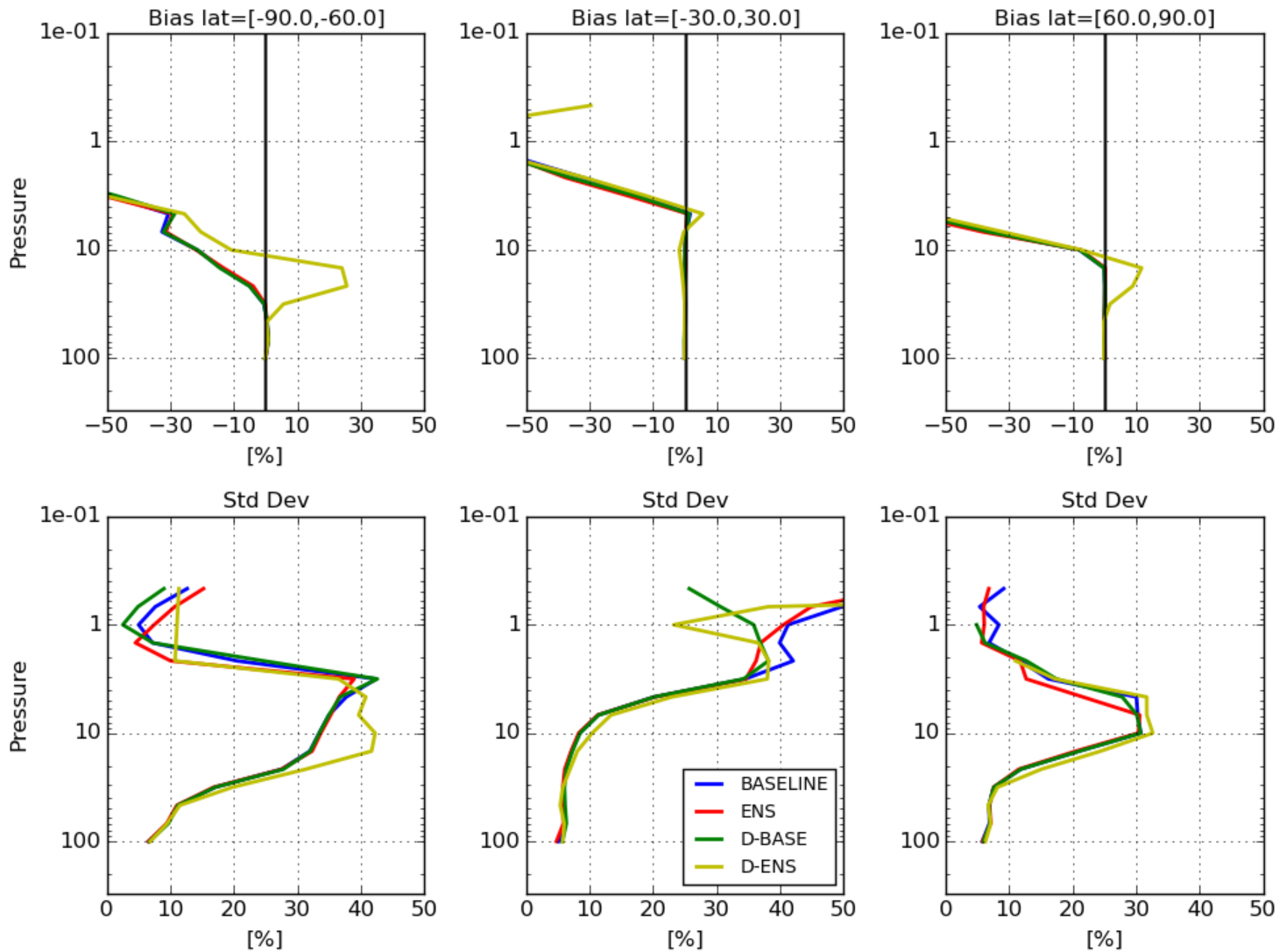


Case 1: Assimilation of MLS N_2O

- Evolution of $J(\boldsymbol{x}^a)/p$ is clearly better when errors are scaled

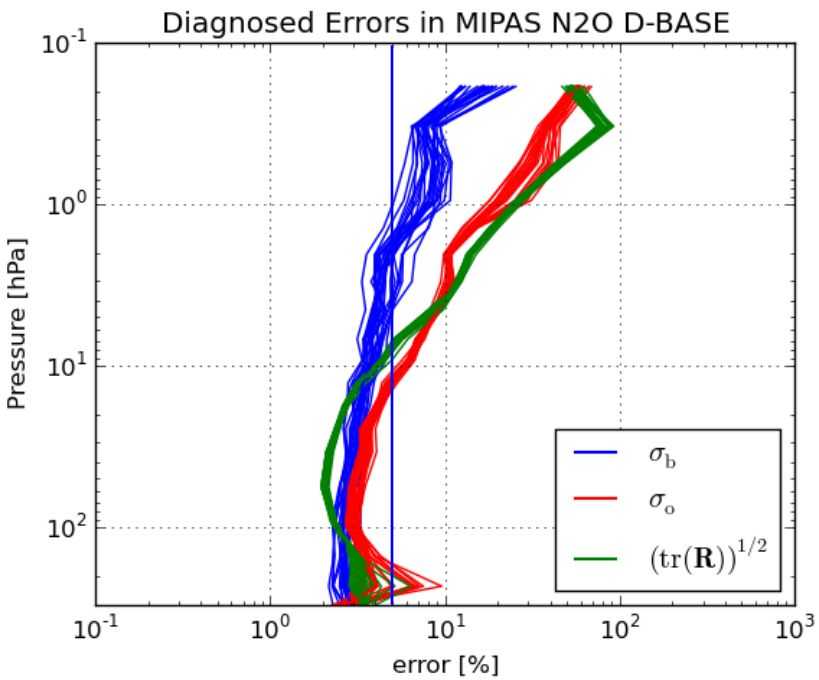


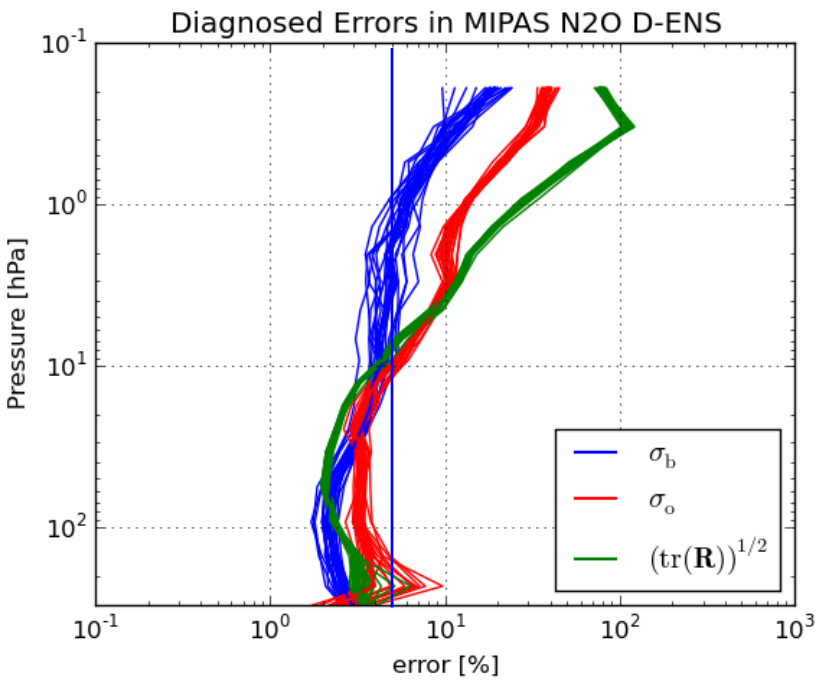
BASCOE-MLS N_2O in Sept 2008



Case 2: Assimilation of MIPAS N_2O

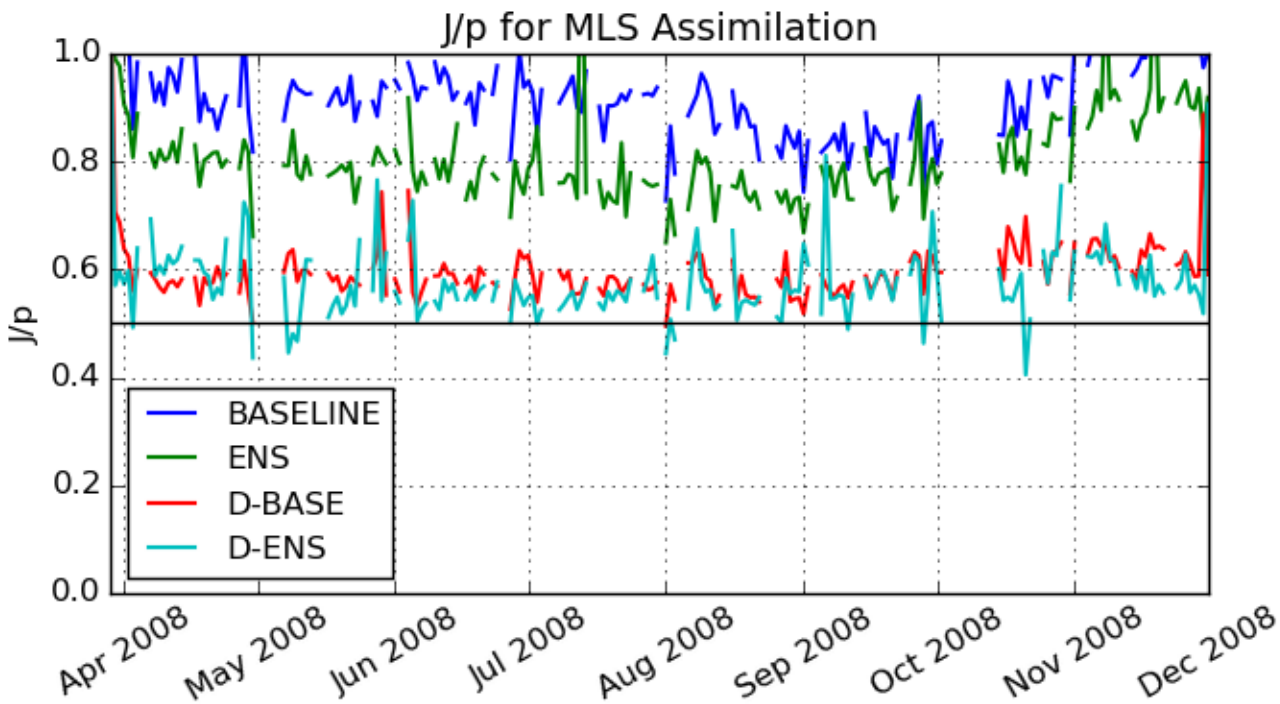
- BASCOE suggests to increase MIPAS errors >< MLS case





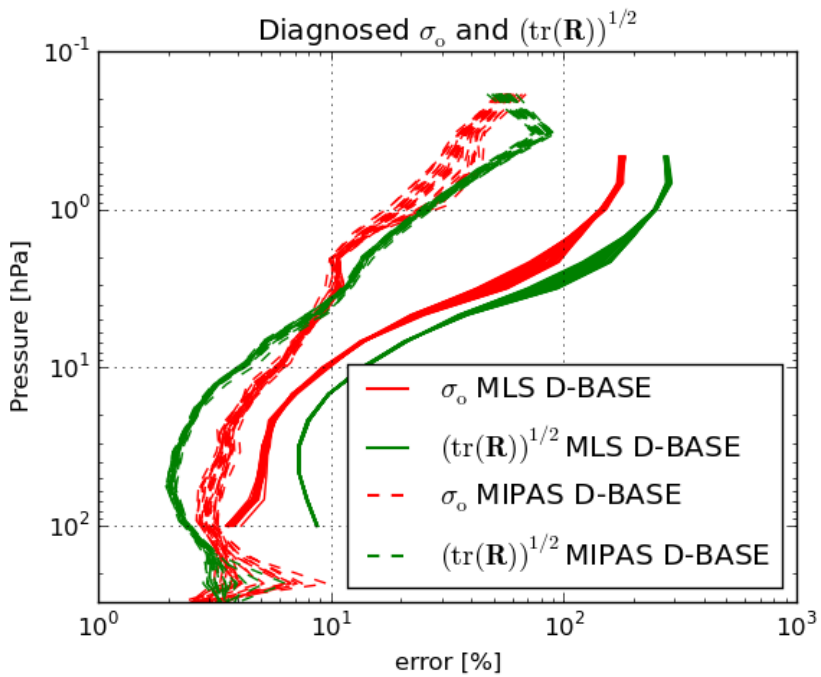
Case 2: Assimilation of MIPAS N_2O

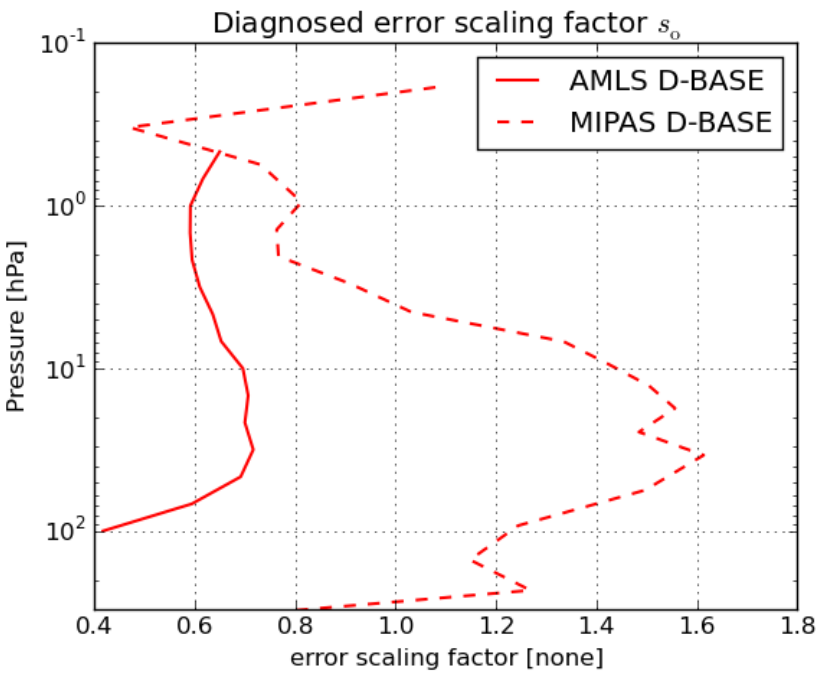
- Again, evolution of $J(\boldsymbol{x}_a)/p$ is better when errors are scaled but J/p is noisy => MIPAS discontinuities?
- Is MIPAS N_2O suited for a reanalysis?



MLS N_2O vs MIPAS N_2O

- If joint assimilation of MIPAS and MLS N_2O is considered, scaling the observational error will be important
- Taking BASCOE as reference, it is suggested that MLS errors are too high and MIPAS errors are too low





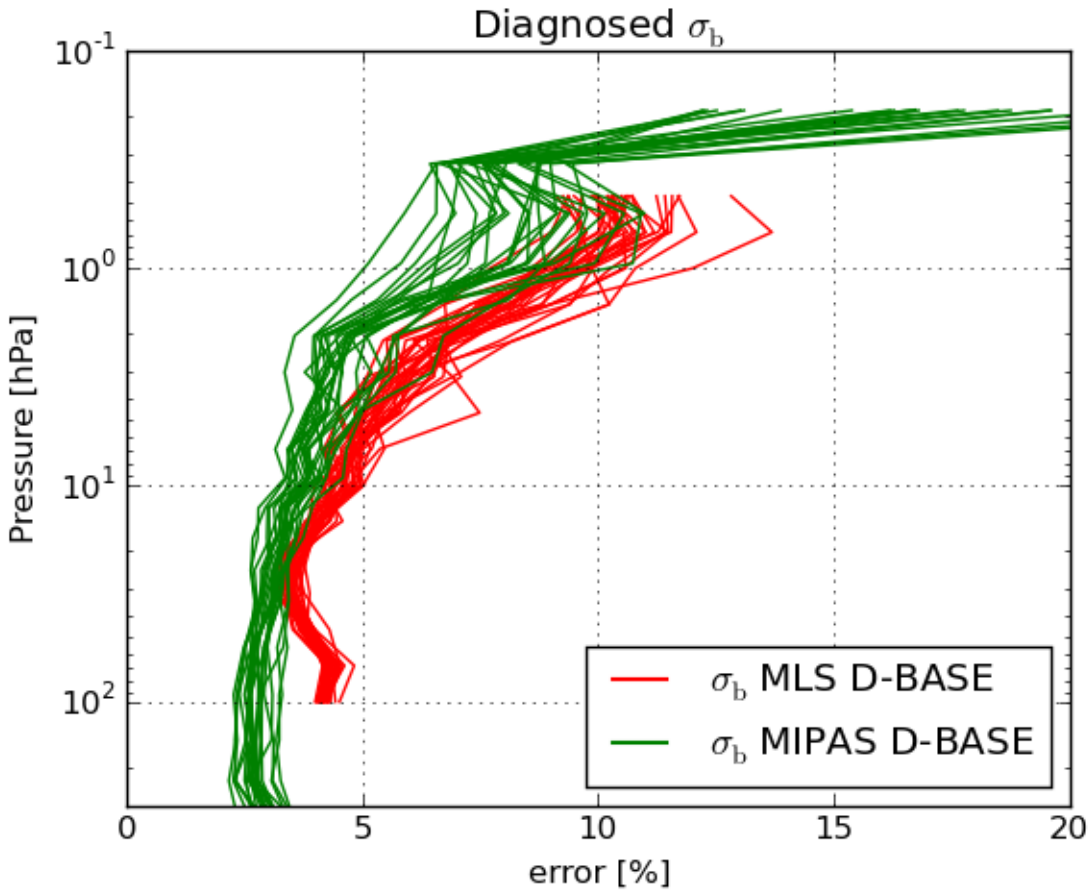
Conclusions

- Part 1: DA add value to MIPAS
  - The use of AK and **B** largely reduced the oscillations in CH_4 and N_2O Eq. lower stratospheric profiles
  - But MIPAS discontinuities degrade the analyses

    => Is MIPAS CH_4 and N_2O suited for a reanalysis?
- Part 2: Diagnosing of error statistics
  - Desroziers method improves the system configuration but no impact on O-F statistics
  - Desroziers method suggests that MLS errors and MIPAS errors are not well balanced for N_2O
    - MLS error is overestimated
    - MIPAS error is underestimated

Extra Slides

MLS N2O vs MIPAS N2O

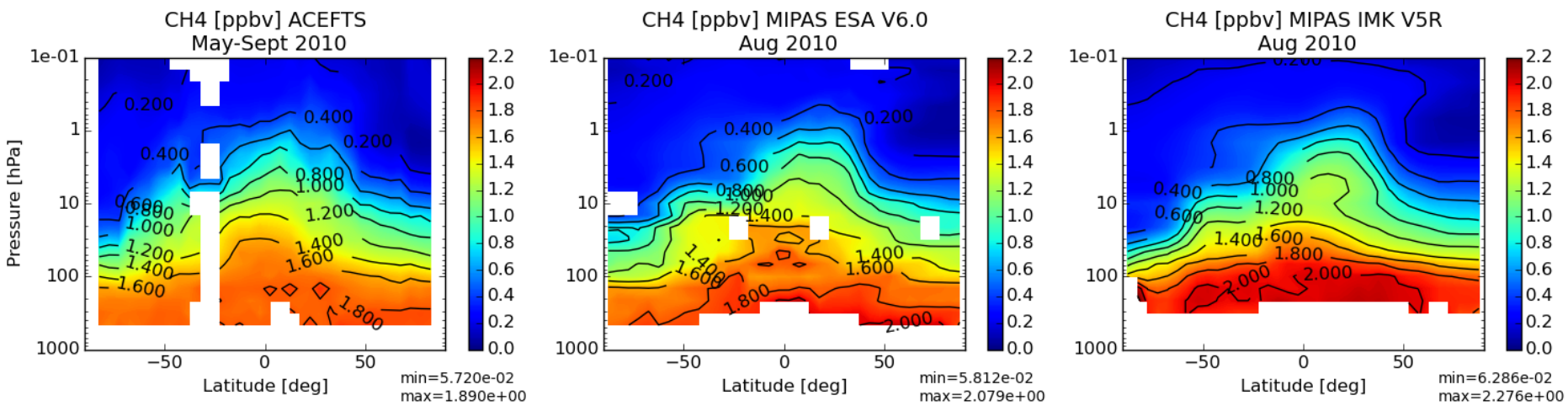


Choice of Assimilated Data: CH_4

MIPAS **ESA** v6.0 **or** MIPAS **IMK** V5R?

- MIPAS IMK CH_4 (and N_2O) is **high biased** in the Eq lower stratosphere and **low biased** in polar vortex
- MIPAS ESA v6.0 is know to have **oscillated profiles** in the Eq lower stratosphere (Payan et al., ACP, 2009)

=> MIPAS ESA is choosen although oscillation in profiles (see later)



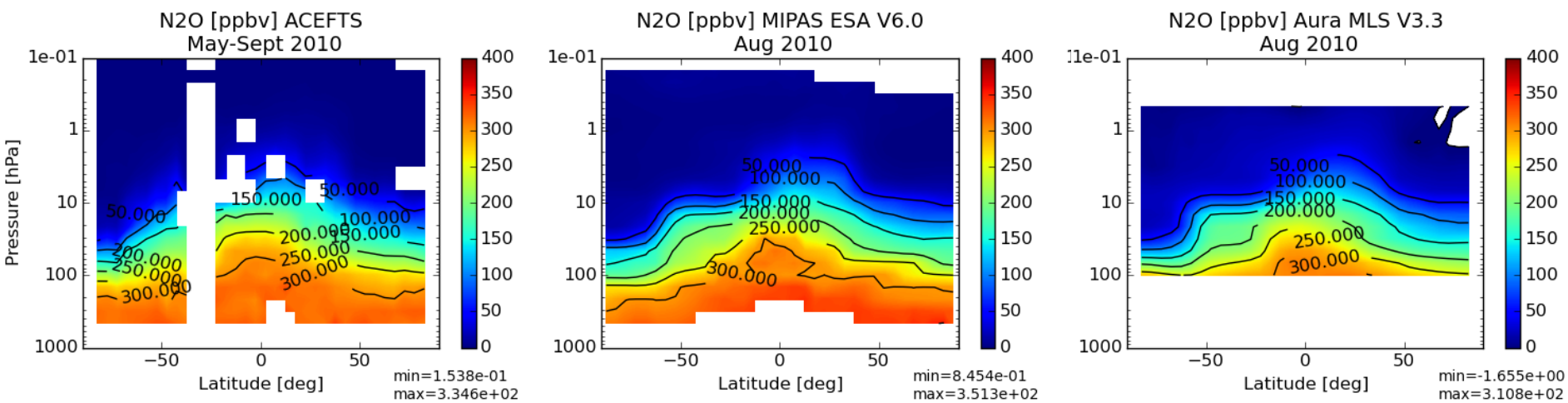
Choice of Assimilated Data: N_2O

MIPAS **ESA** V6.0 **and** Aura **MLS**?

- Assimilating both datasets would have request to remove the biases between them
- Effort to harmonize MIPAS and MLS using ACEFTS as anchor failed

MIPAS ESA V6.0 or Aura MLS?

- Aura MLS excellent between 10-100 hPa, above 10 hPa error bars too large (>50%) to constrain the DA system



Impact of AK with Aura MLS N2O