Reanalysis of the Stratospheric Chemical Composition Based on Assimilation of MIPAS: methane (CH$_4$) and nitrous oxide (N$_2$O)

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Motivations

- Climate models deal stratospheric chemistry of GHG via **linear scheme**
- Linear scheme relies on **climatology** of GHG
- Complexity of **climatology** matters
- Waugh et al. (GRL, 2009) showed that 3D or 2D O₃ in CCM radiative scheme provide different projections for T°, U and surface pressure
- Motivation: **build 3D climatology of CH₄ and N₂O** using data assimilation (DA) method

From Waugh et al. (GRL, 2009)
Choice of Assimilated Data: CH$_4$

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

- **MIPAS IMK CH$_4$ (and N$_2$O) 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$_2$O**

**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
Assimilated Data: MIPAS ESA v6.0 Nominal mode

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

- Background quality check (BgQC) to reject outliers (Anderson and Jarvinen, 2000, QJRMS):
  - Obs is rejected if: $(obs - mod)^2 > 5(\sigma_{obs}^2 + \sigma_{mod}^2)$
Use of Averaging Kernels (AK) with MIPAS ESA

• Usual 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  

=> *Net effect: oscillations in MIPAS profiles is introduced in model profiles*
Impact of Averaging Kernels (AK)
Setup of BASCOE (Belgian Assimilation System for Chemical Observations)  

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’

\[ J(x) = \frac{1}{2} [x - x^b]^T B^{-1} [x - x^b] + \frac{1}{2} [y - H(x)]^T R^{-1} [y - H(x)] \]

- \( B \) matrix is given on a spherical harmonic basis assuming homogeneous and isotropic spatial correlations
- \( B \) is calibrated with an ensemble method (Fisher, 2003, ECMWF sem.)
Calibration of $B$

- $B$ is calibrated instead of using a priori values (5% std dev, Gaussian spatial correlations, $L_h$ 800 km, $L_v$ 1 lev)
- $B$ error std dev matrix is much lower than observational error
  $\Rightarrow$ DAS provides more weight to background than to observations
- At Poles and above 10hPa, $B$ error std dev is multiplied by 2 $\Rightarrow$ to increase the weight of the obs. where there are known to be good
Impact of AK and calibration of B

$\text{N}_2\text{O-CH}_4$ correlations in 2010 between 30°S-30°N

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

- N$_2$O analysis at 100 hPa for different config of BASCOE

=> AK and calibrated B are important
Validation against ACEFTS V3.5 in 2010

- Excellent agreement between reanalysis and ACEFTS
Time stability of reanalysis: N$_2$O

- Time series of reanalysis is “noisy” at some dates
- This noise is due to noisy MIPAS data
- Some filtering/averaging will be necessary
- 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$_2$O
- Again, some filtering/averaging will be necessary
Conclusions

- A reanalysis of MIPAS ESA CH₄ and N₂O has been produced for 2005-2012
- General good agreement vs. ACEFTS in all regions/seasons ...
- ... but reanalysis is still noisy (time series):
  - filtering/averaging is necessary
  - what could we expect from MIPAS v7?
- DA add value to MIPAS: the use of AK and B largely reduce the oscillations in CH₄ and N₂O Eq. lower stratospheric profiles
- Additional work is necessary to assess quantitatively the quality of the reanalysis and its period of validity
- Perspective: reanalysis of stratospheric CFC-11 and CFC-12
Calibration of $B$

Zonal Mean $\text{CH}_4$ $B$ error std dev matrix [%]

Zonal Mean $\text{N}_2\text{O}$ $B$ error std dev matrix [%]