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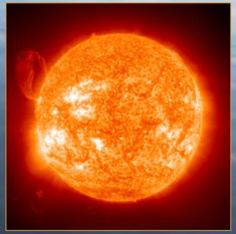
BRAM: Reanalysis of stratospheric chemical composition based on Aura MLS



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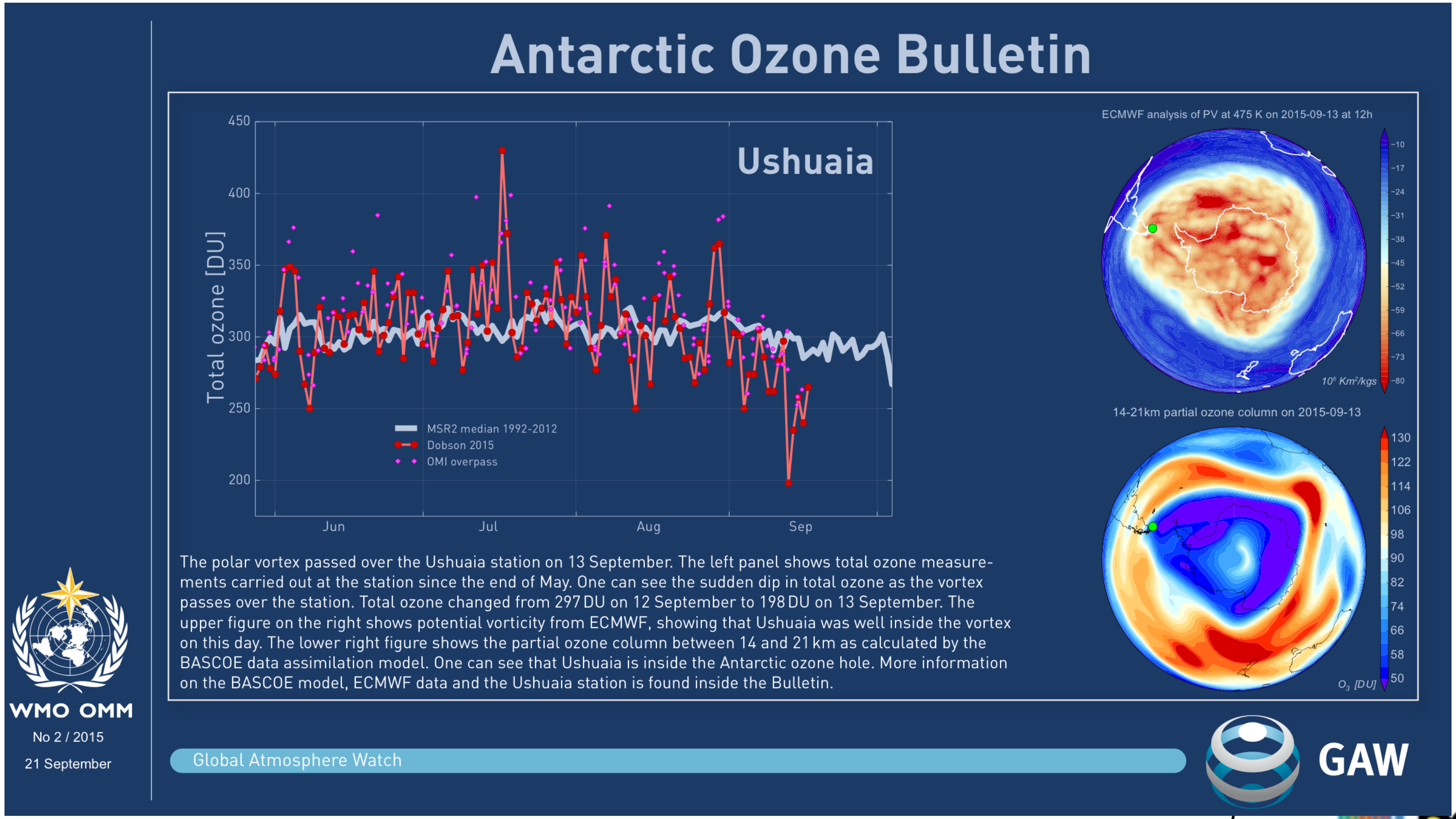
Motivations

- BASCOE produces operational analyses of MLS since 2009 for the validation of MACC O_3 (Lefever et al., 2015)
- For this service, BASCOE assimilates O_3, H_2O, HNO_3, N_2O, HCl and ClO
- These analyses are used by WMO Global Atmospheric Watch (GAW) to monitor Ozone and related trace gases and to interpret ground-based observations
- A reanalysis of MLS was requested by WMO GAW
- BRAM: **BASCOE Reanalysis of Aura MLS 2004-2016** (will be continued)



Outline

- BASCOE setup
- Observational setup
- Evaluation of BRAM
- Where to find BRAM dataset?
- Conclusions

Setup of BASCOE (Belgian Assimilation System of Chemical ObsErvations)

- CTM with 58 stratospheric species (Errera et al., ACP, 2008)
  - Advection: FFSL (Lin & Rood, MWR, 1996)
  - Chemistry: ≈200 chemical reactions (gas phase, heterogeneous, photolysis)
  - Parameterization of PSC microphysics
  - Dehydration of H_2O in the stratosphere
- Dynamics (winds and T°) from ERA-Interim with resolution:
  - 2.5° lat x 3.75° lon x 37 levels (surf to 0.1 hPa, 25 levels above 100 hPa)
- Time step: 30'
- DA method: **EnKF** (Skachko et al., GMD, 2014, 2016) chosen due to its better scalability on HPC than 4D-Var

Observations

- Assimilated observations
  - Aura MLS Version 4.2x
  - O_3, H_2O, HCl, ClO, HNO_3, N_2O (190-GHz), CO, CH_3Cl
    - These are the species that do not need to be averaged
  - Prepare according to MLS Data Quality Document
    - Pressure ranges of validity, cloud screening, …
- Monitored independent observations (for validation)
  - **ACEFTS v3.6**, **MIPAS IMK**, MIPAS ESA v6, **WOUDC ozonesondes**, O3_CCI L2 profiles, SMILES
  - To be done: MIPAS ESA v7

BRAM vs other reanalysis

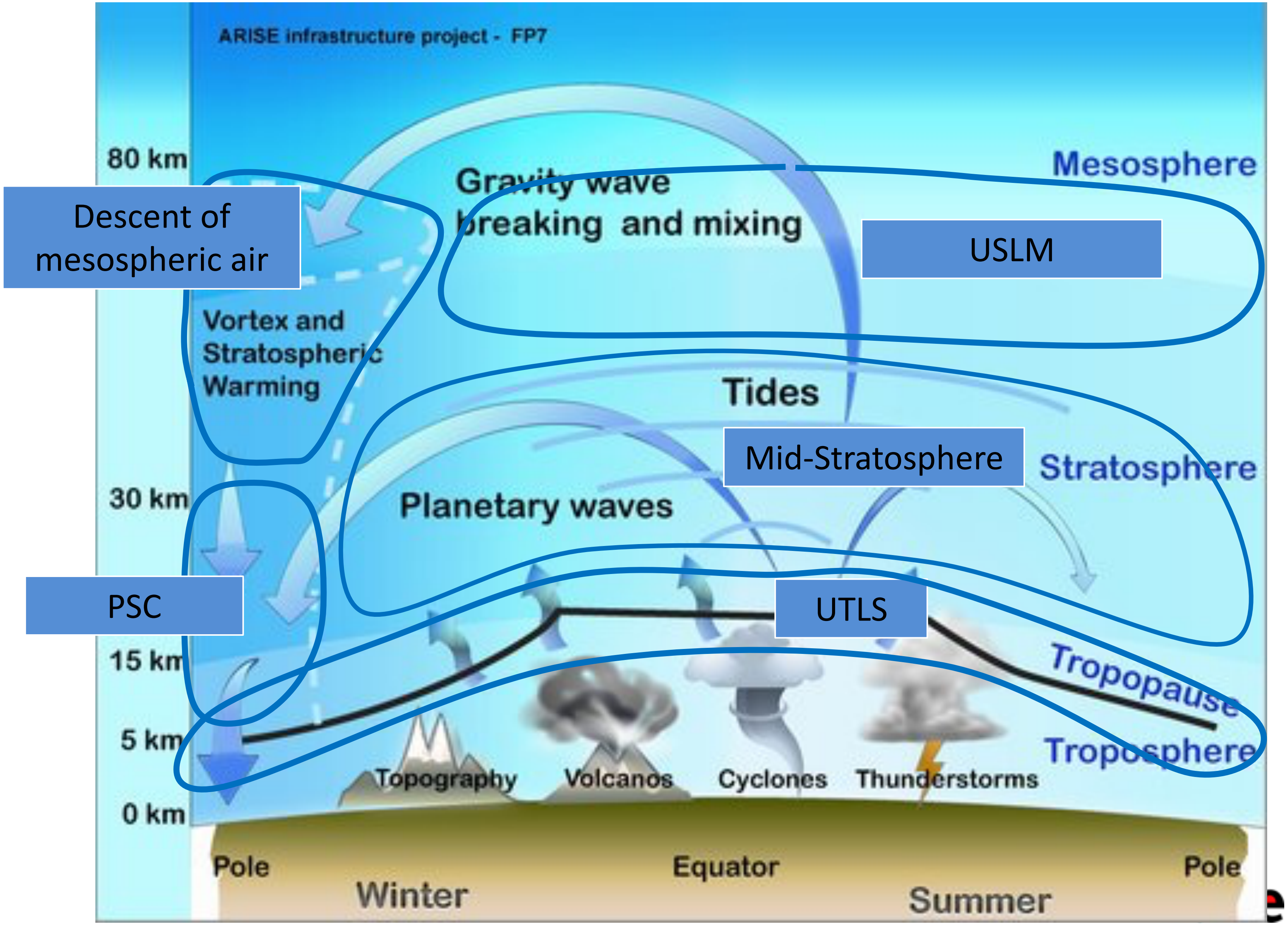
Status of existing constituents reanalysis

- Meteorological reanalyses usually only consider O_3 in the stratosphere
- Same for MACC/CAMS reanalysis (Inness et al. 2013, Flemming et al. 2017)
- van der A et al. (2010) has produced a 30-year O_3 TC reanalysis (no profiles) based on multi-sensor assimilation
- Miyazaki et al. (2015) has produced a 7-year multi-species reanalysis for the tropospheric composition

BRAM is the first reanalysis that focus on the stratospheric composition with other species than O_3

Evaluation of BRAM reanalysis: strategy

- Evaluation of BRAM in different stratospheric region of interest
  - Mid-stratosphere
  - Winter pole in the lower stratosphere
  - Winter pole in the upper stratosphere
  - UTLS
  - USLM



Evaluation of BRAM reanalysis: strategy

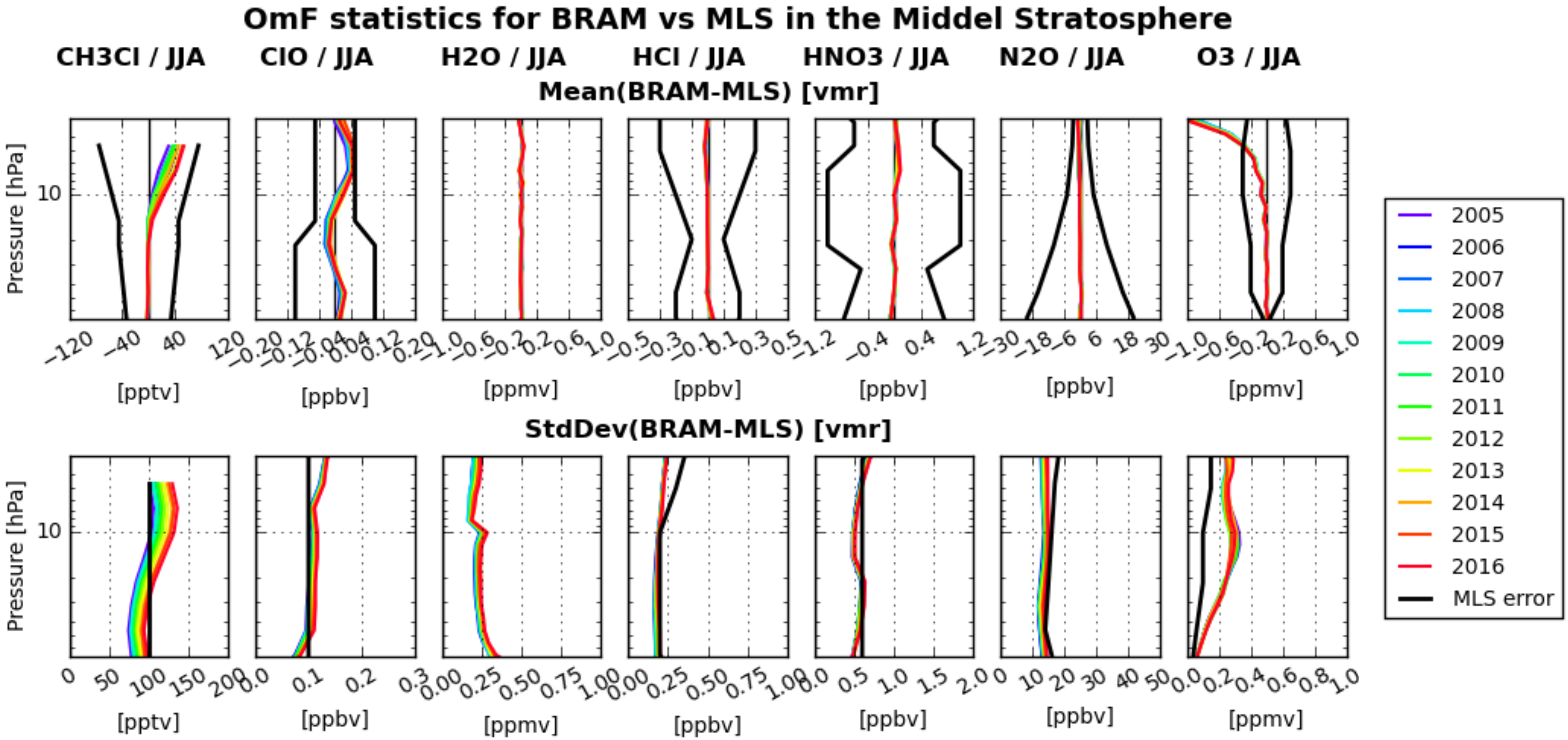
Atm. Conditions	Vertical Ranges	Latitude ranges	Season	Species
Middel Stratosphere	3-70 hPa	60°S-60°N	-*	O_3, H_2O, HCl, ClO, HNO_3, N_2O, CH_3Cl
PSC	10-100 hPa	South pole region	JJA or SON	O_3, H_2O, HCl, ClO, HNO_3, N_2O
Descent of meso. air	0.1-6.8 hPa	South pole region	JJA	H_2O, HNO_3, CO
USLM	0.1-3 hPa	Tropics	-*	H_2O, HCl
Tropical UTLS	68-200 hPa	Tropics	JJA	O_3, H_2O, CO, CH_3Cl, (HCl?, HNO_3?)
Mid-lat. UTLS	68-200 hPa	Tropics	-*	O_3, H_2O, CO, CH_3Cl, (HCl?, HNO_3?)

*: in these cases, JJA has been chosen arbitrarily

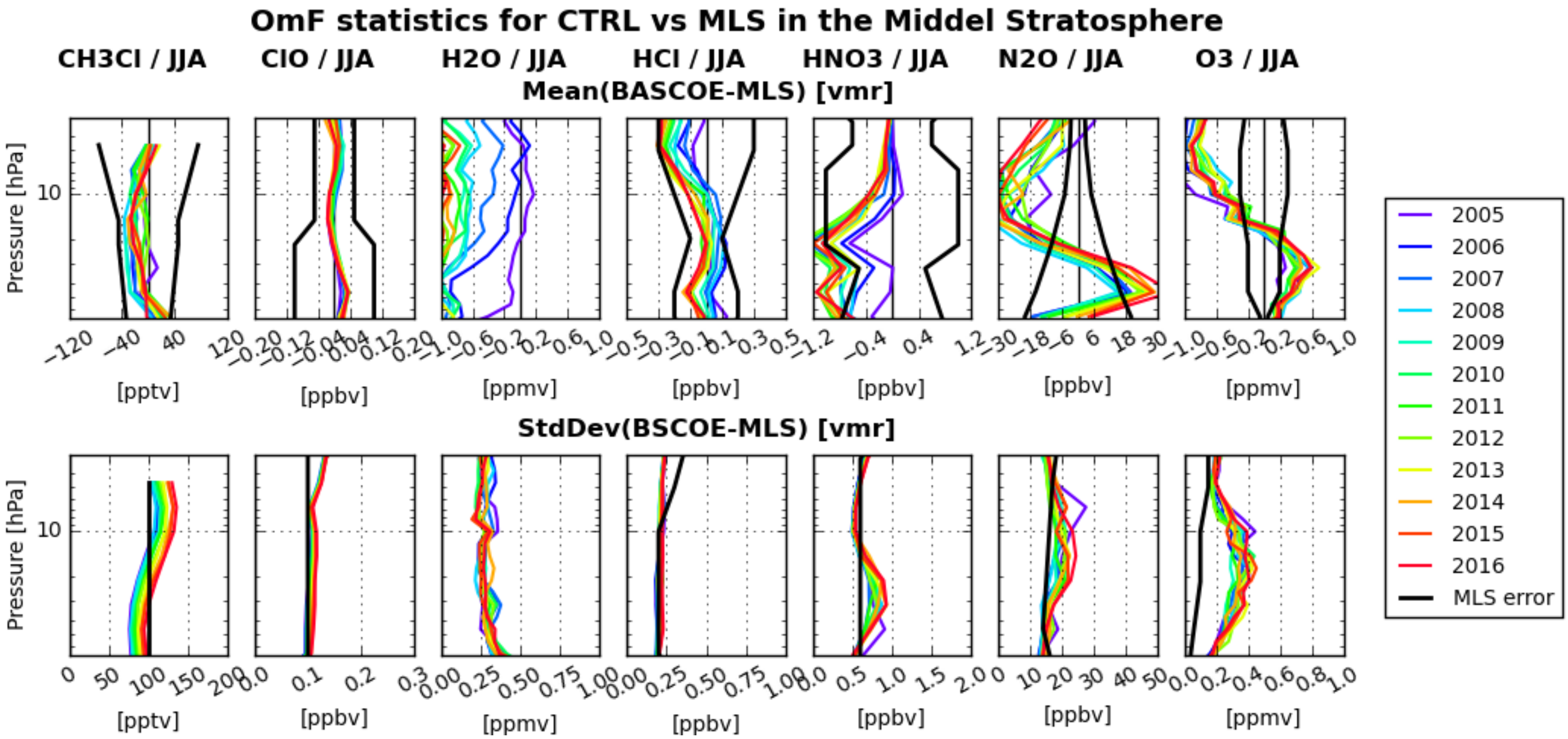
O_3 not assimilated in the USLM, see Jonas Debosscher's poster

Middle stratosphere

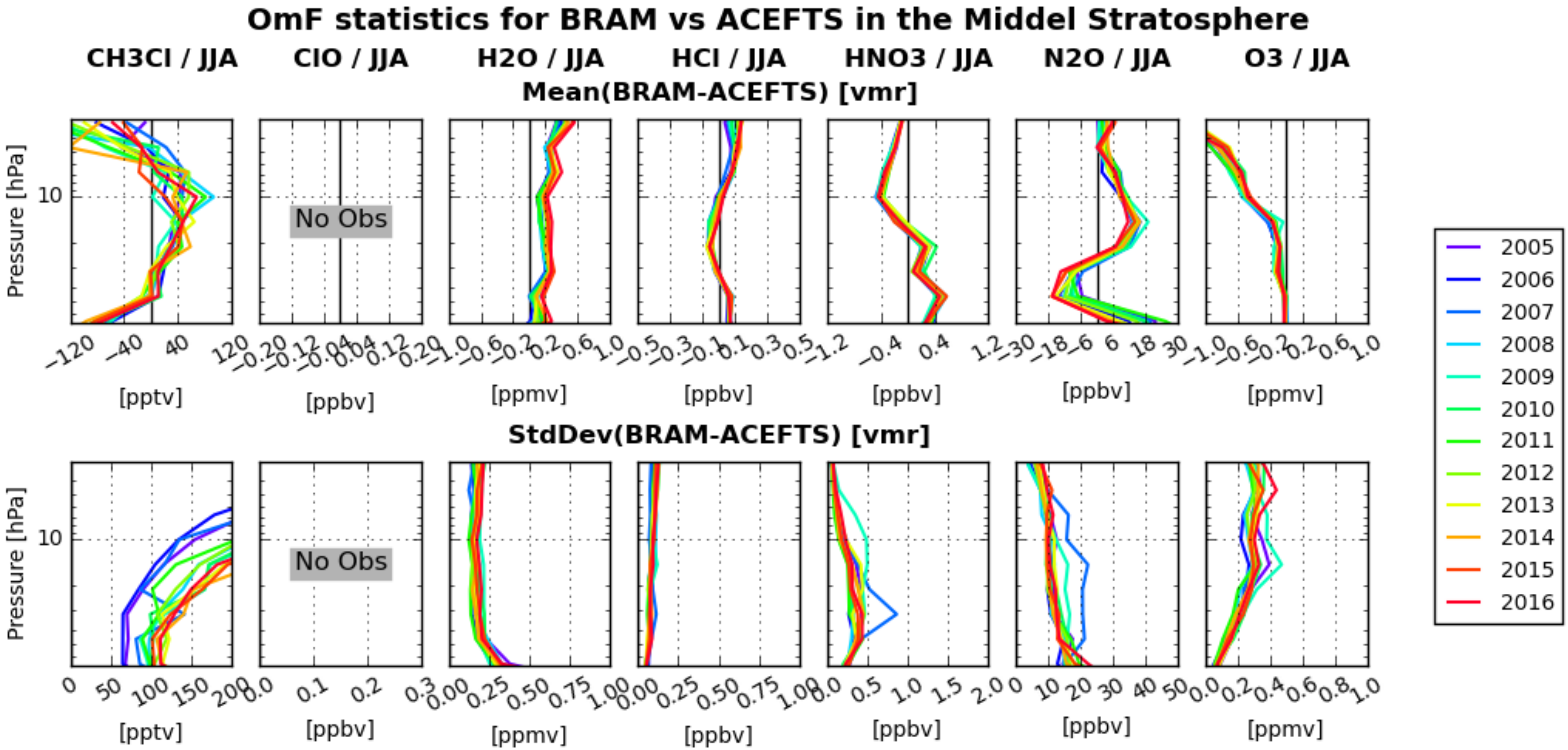
Middle Stratosphere: BRAM vs MLS



Middle Stratosphere: CTRL vs MLS



Middle Stratosphere: BRAM vs ACEFTS



Error covariances in BRAM

- Forecast covariances estimated from ensemble covariances (20 members)
- For each species, observational variances scaled using Desroziers's method (Desroziers et al., 2005) which states:

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

scaling factor

Altitude

Observational (MLS) variances

- Knowing that:

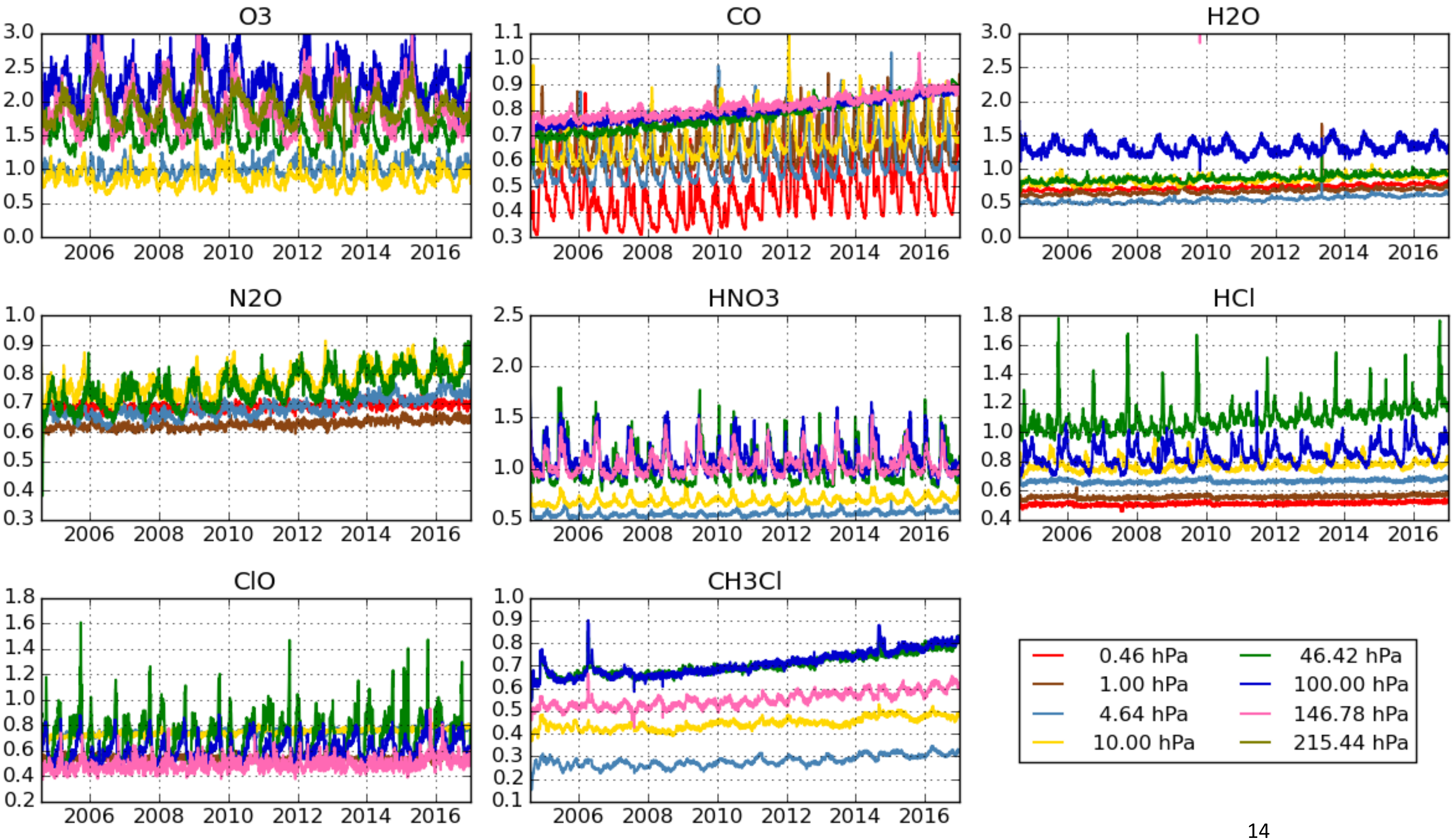
$$\sigma_o^2 = < (\mathbf{y}^o - \mathbf{H}\mathbf{x}^a)(\mathbf{y}^o - \mathbf{H}\mathbf{x}^b)^T >$$

Analysis innovations

Forecast innovations

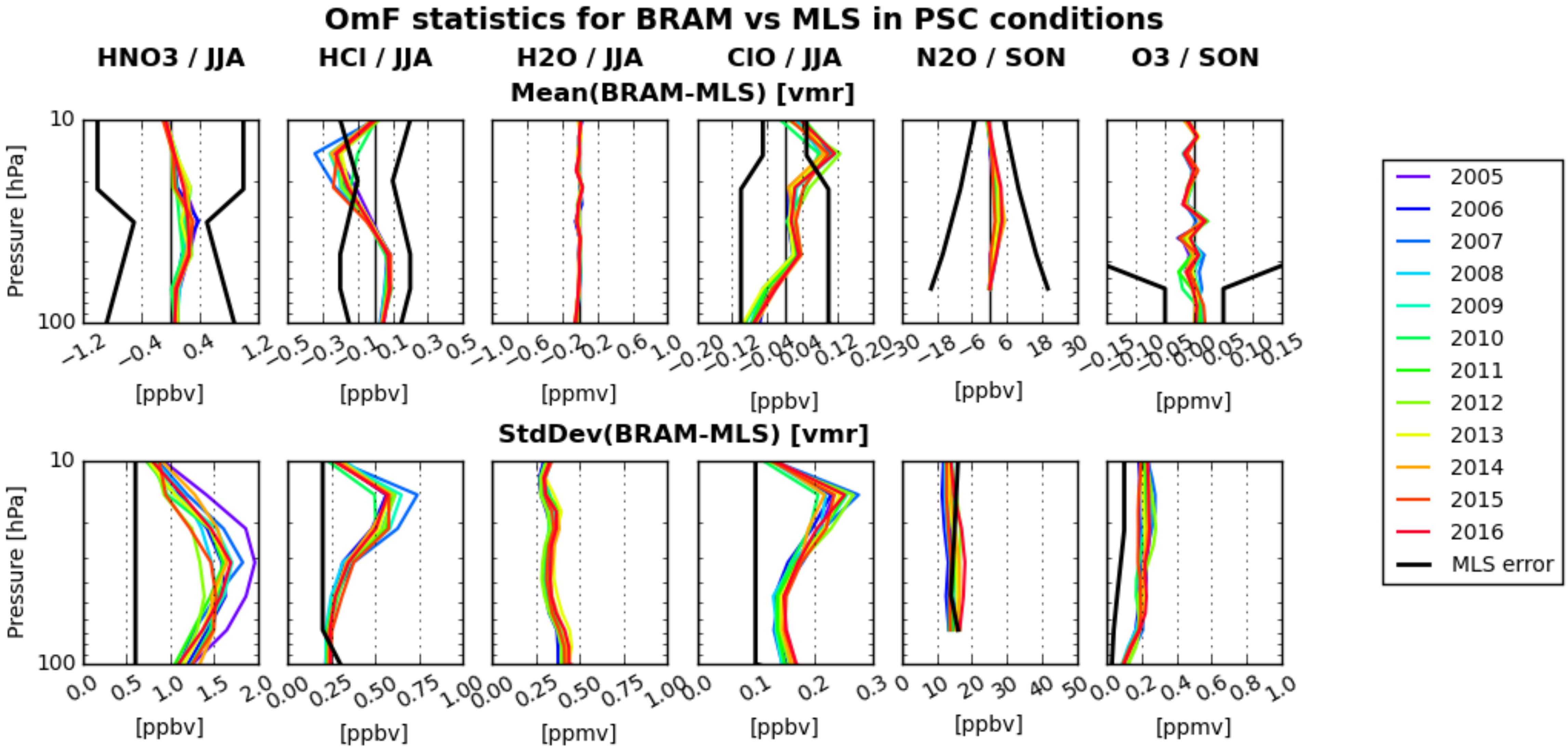
Error covariances in BRAM

Time series of s_o for assimilated species at several MLS levels

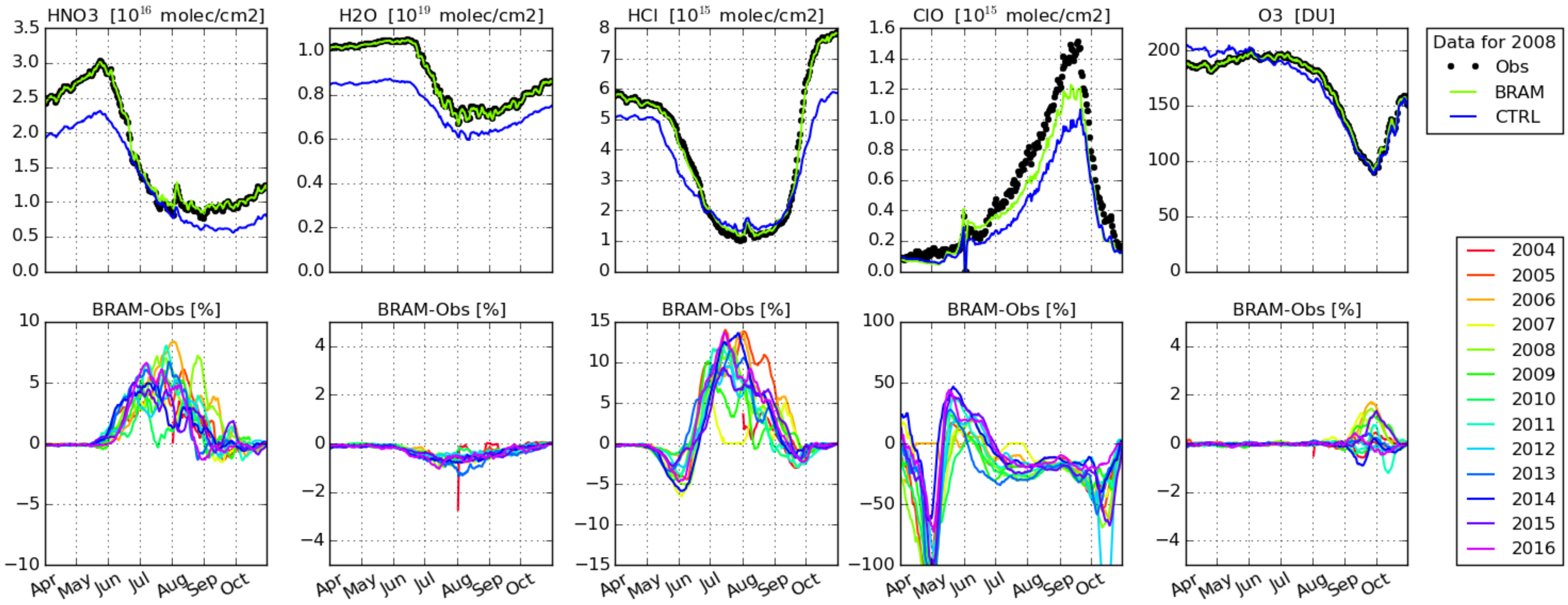


PSC conditions

PSC conditions: BRAM vs MLS



Winter Pole in the lower stratosphere (South Pole)



Top: 2008 timeseries of MLS partial column [10-100] hPa averaged between 90°S-60°S for 5 key constituents involved in O3 hole development and corresponding values of BRAM and CTRL
Bottom: Timeseries of the differences BRAM-MLS for 2004-2016

- BRAM corrects most of the deficiencies of the model (I.C. and physics)
- … and highlights systematic errors in the PSC scheme of the model

Tropical UTLS

BRAM O_3 in the tropical UTLS

- BRAM vs MLS in UTLS exhibits vertical oscillations for O_3 (Fig. 1a)
- Not seen in BRAM vs ACEFTS (Fig. 1b)
- Probably due to oscillation in MLS O_3 v4.2 (see MLS DQD), although improvements since v2.2 (Fig. 2)

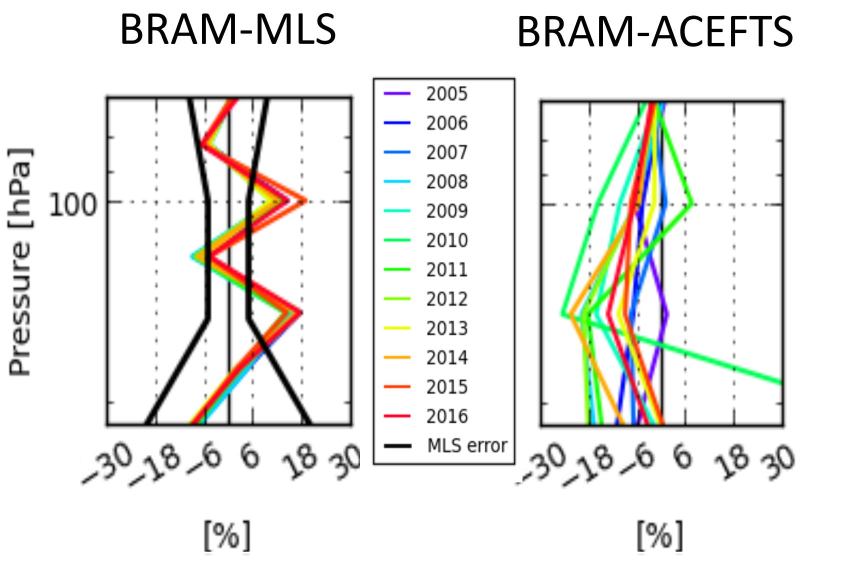
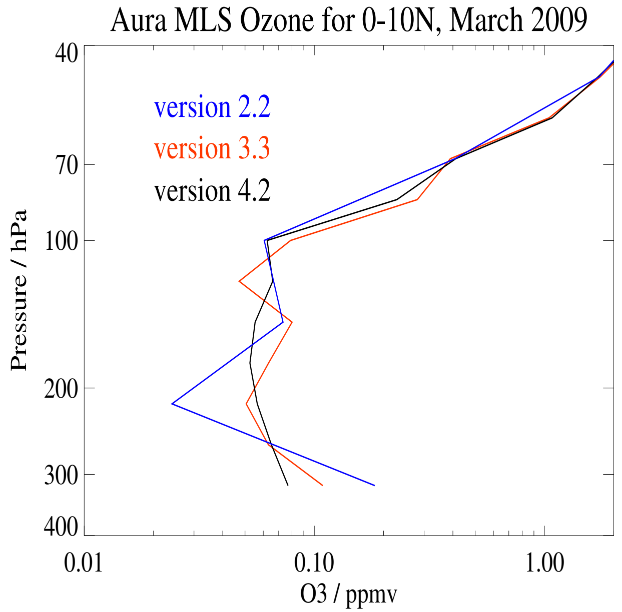
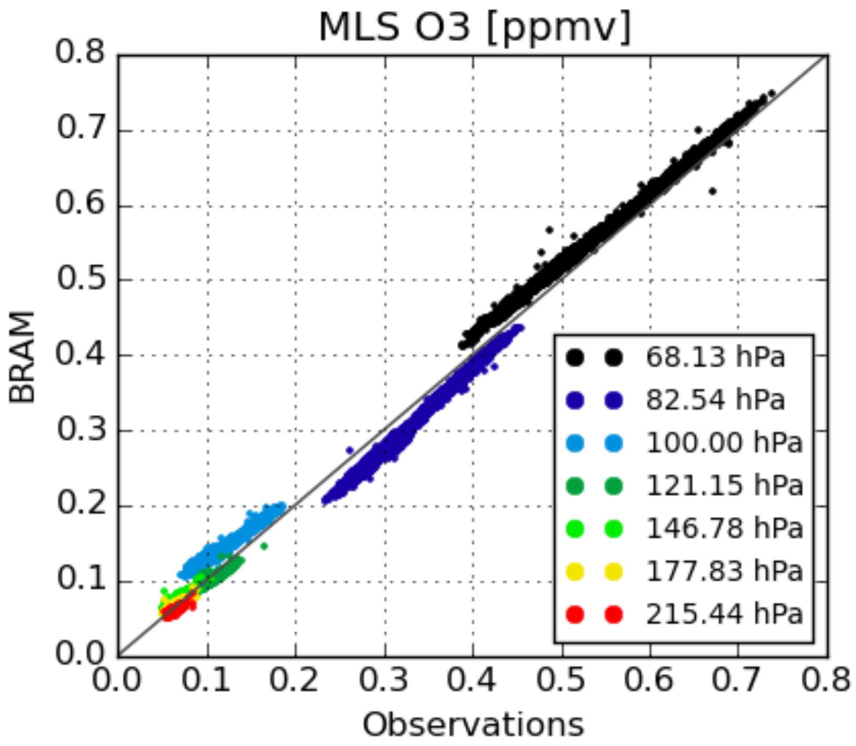
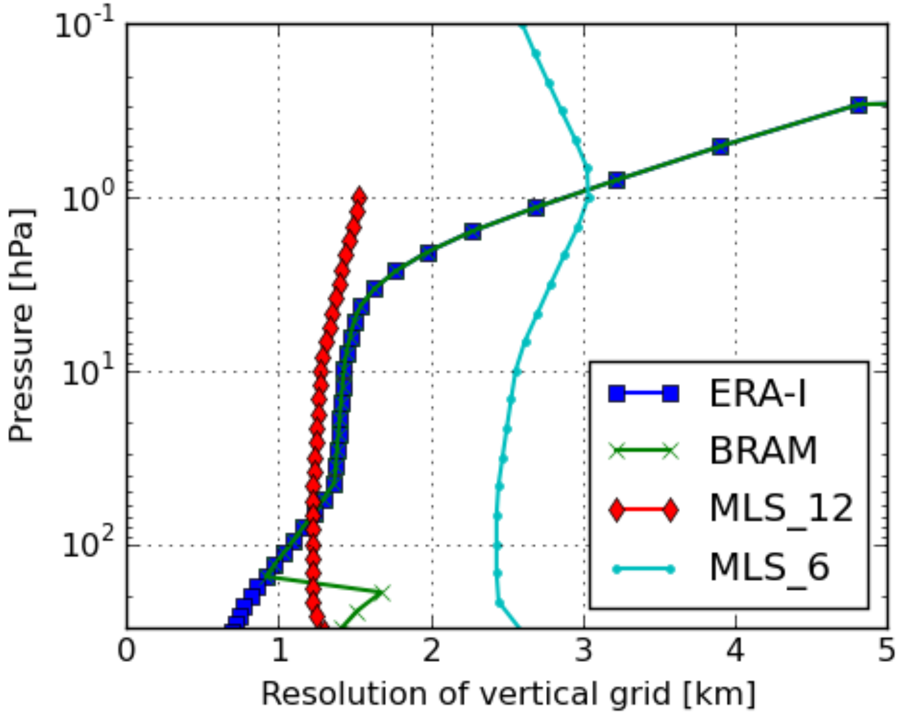


Fig. 1: (left, a) Mean(BRAM-MLS) between 30°S-30°N for JJA. (right, b) same as left but for ACEFTS



BRAM O_3 in the tropical UTLS





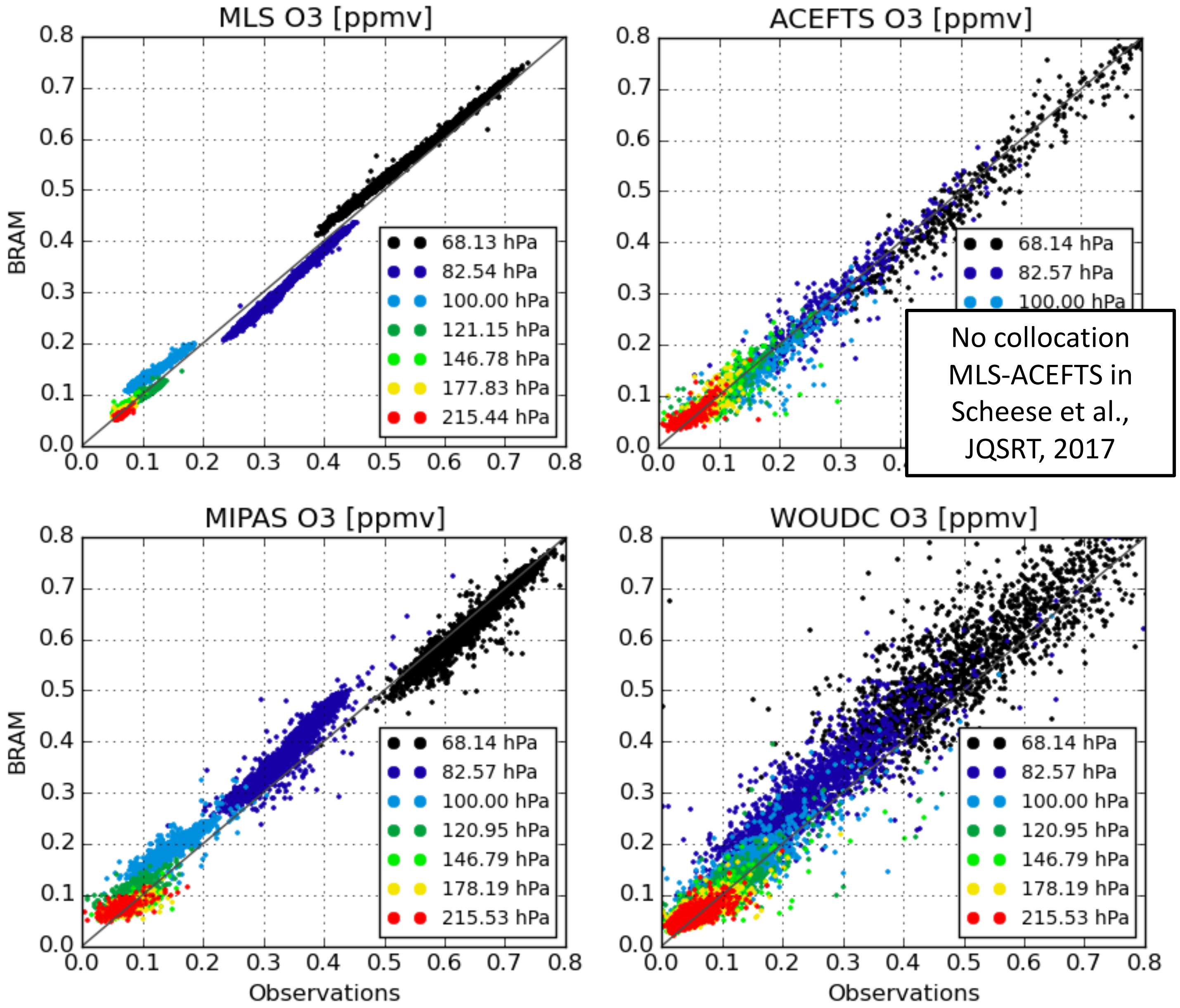
Left: Daily mean MLS O3 in the tropical UTLS (30°S-30°N) and the BRAM corresponding values.
right: Resolution of vertical grid of ERA-I, BRAM, MLS 6 and 12 levels per decade of pressure

BRAM cannot reproduce MLS in tropical UTLS because:

- Vertical oscillation in MLS
- MLS and BRAM vertical grid have similar resolution

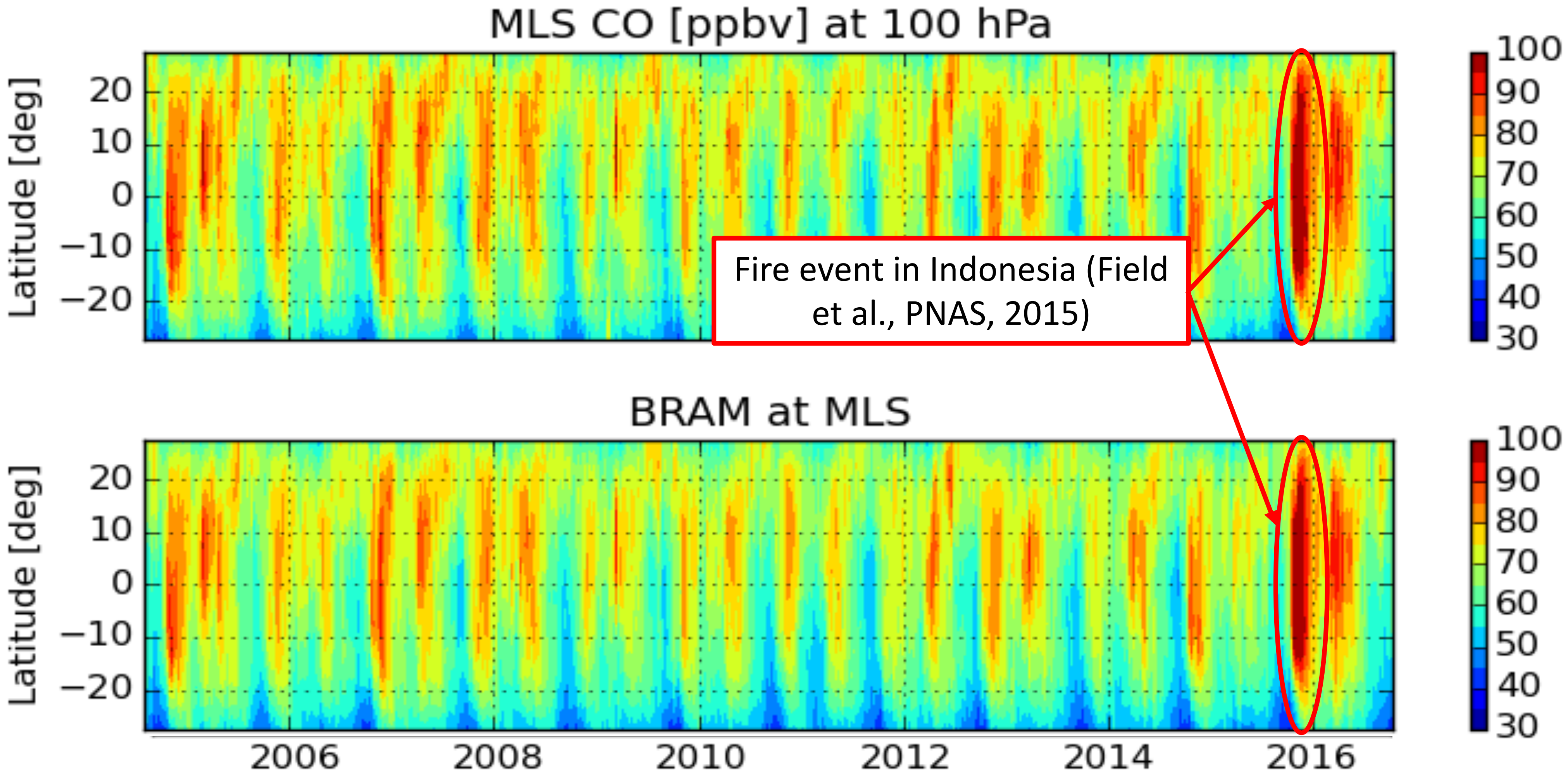
BRAM O_3 in the tropical UTLS

- BRAM highlight systematic differences between different instruments
- Good agreement with ACEFTS
- Could BRAM be used as transfer function between different observational datasets to estimate (and correct) their systematic differences?

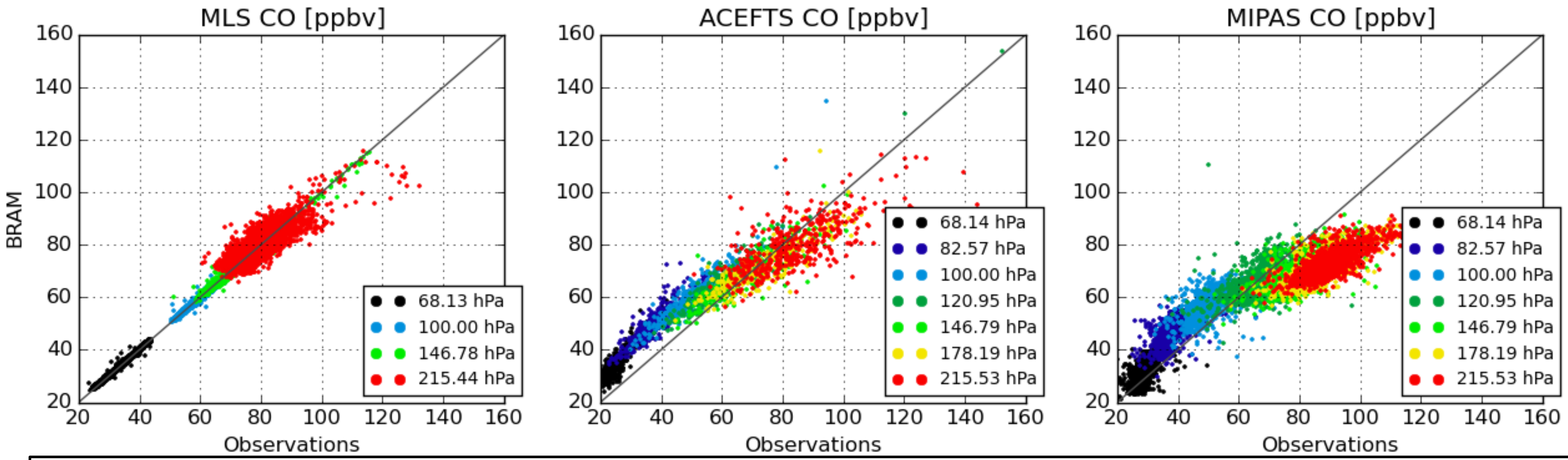


BRAM CO in the tropical UTLS

- CO at 100 hPa: very good agreement between BRAM and MLS



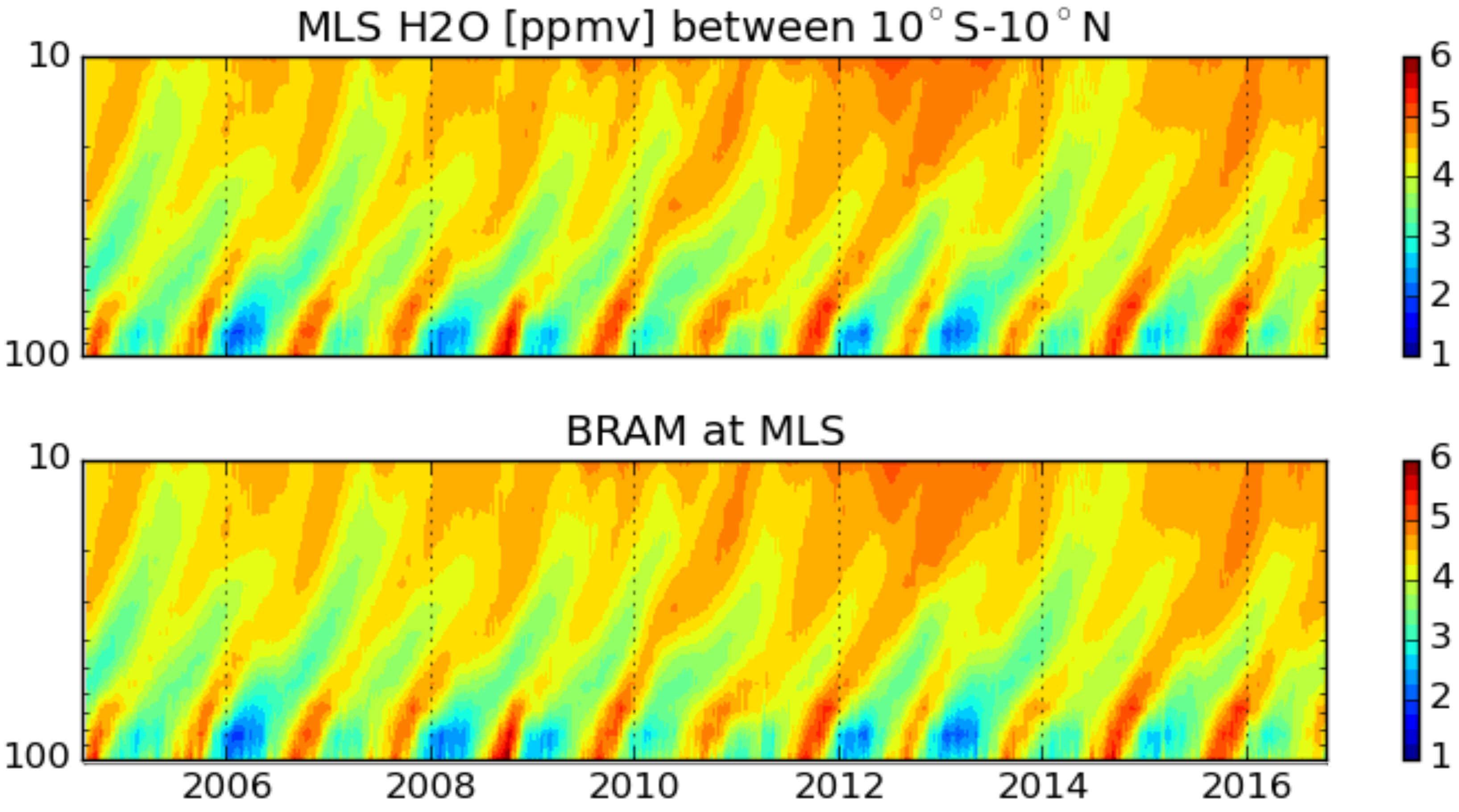
BRAM CO in the tropical UTLS



Daily mean CO in the tropical UTLS (30°S-30°N) from observations and the BRAM corresponding values.
Left to right: MLS, ACEFTS and MIPAS

- BRAM highlight systematic differences between different instruments
- Could BRAM be used as transfer function between different observational datasets to estimate (and correct) their systematic differences?

BRAM H_2O Tape Recorder



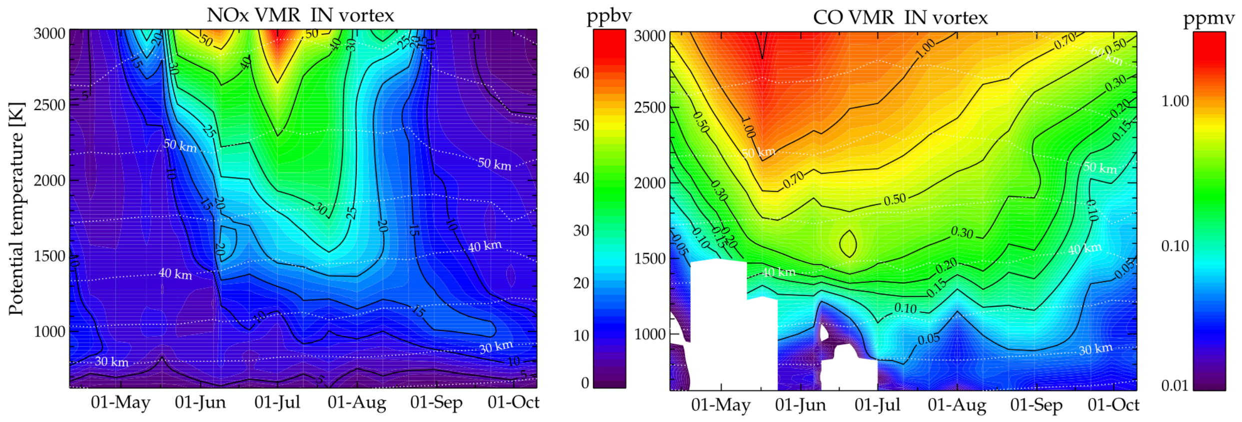
Top: time series of mean MLS H2O between 10°S-10°N
Bottom: Corresponding BRAM values

- H_2O Tape recorder (Mote et al., JGR, 1996)
  - Very good agreement between BRAM and MLS
  - Might be useful to evaluate vertical transport of CCMs/GCMs

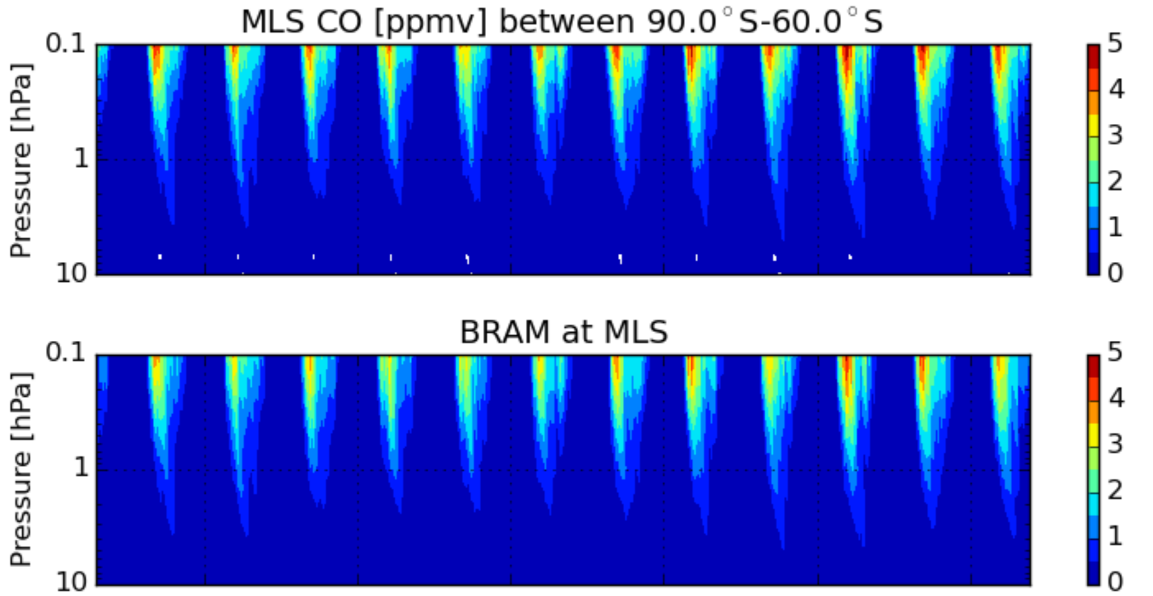
Descend of mesospheric air

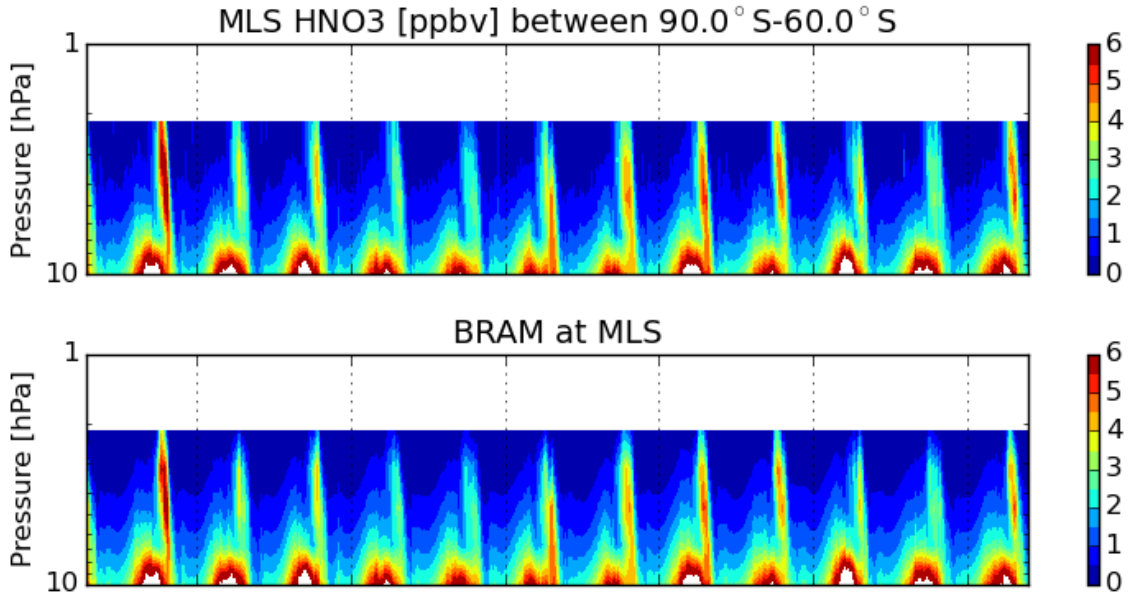
Winter Pole in the upper stratosphere (South Pole)

- USLM polar winter characterized by descend of mesospheric air in the stratosphere (CO, NO_x, H_2O)
- Good representation of CO descent by BRAM while no source of CO at model lid
- HNO_3 enhancement (due to NO_x descent) well capture by BRAM
- Nevertheless, EnKF cannot correct NO_x (not shown)



Time evolution of NO_x and CO in May-Aug 2003 measured by MIPAS IMK (Funke et al., JGR, 2005)





Getting the BRAM dataset

- BRAM Release 1 **is available**
  - Only assimilated species plus Cl_2O_2 will be delivered:
    - O_3, H_2O, HCl, ClO, Cl_2O_2, HNO_3, N_2O, CO, CH_3Cl
  - File format: NetCDF-CF, one file per year per species
  - BRAM datasets available on BIRA-IASB ftp site
  - To get login/pw, contact quentin@aeronomie.be
  - Website: strato.aeronomie.be -> Datasets -> BRAM

Conclusions and perspectives

- BASCOE EnKF successfully assimilate MLS observations of O_3, H_2O, HCl, ClO, HNO_3, N_2O, CO, CH_3Cl for 2004-2016
- … but also highlight:
  - Model deficiencies (PSC microphysics, model O_3 deficit, …)
  - Instrumental issues (O_3 vertical oscillations in MLS, MLS CO bias…)
    - Could BRAM be useful to correct systematic differences between different instruments (MLS, ACEFTS, MIPAS, O3 sondes)?
- Would the replacement of ERA-Interim by ERA5 improve BRAM?
- This work also suggests themes for DAWG 2019-2022
  - Assessing (and correct) systematic difference between instruments using DA

Thank you for your attention!

What about unobserved species?

- Little attention yet given to other species than: O_3, H_2O, HCl, ClO, HNO_3, N_2O, CO, CH_3Cl
- Here, example for NO_x ($NO+NO_2$)
  - BRAM overestimates MIPAS ESA and is closer to a CTM

BASCOE Assim of MIPAS ESA including NO_2 observations

BASCOE CTM run