Comparison of age of air in the stratosphere in four modern reanalyses using a single transport model

S. Chabrillat, Y. Christophe, E. Botek, Q. Errera , C. Vigouroux (BIRA-IASB)

E. Mahieu (U.Lg)

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Simon.chabrillat@aeronomie.be

Outline

Intro: - S-RIP (SPARC Reanalyses Intercomparison Project)

- mean Age of Air (mAoA) in obs and models
- mAoA "trends": a hot topic

Method: - Pre-processing of reanalyses

- Set-up of transport simulations

Results: - mAoA in year 2000

- mAoA time evolution and trends (preliminary!)

(Wrap-up: Next steps, Project ACROSS, Summary)

1. The SPARC Reanalysis Intercomparison Project (S-RIP)

Intro: the reanalyses

Reanalysis (e.g. ERA-I) = best possible reconstruction of past atmospheric state.
Assimilate *consolidated* meteo obs (in strato since 1980: satellite radiances) into an NWP model (e.g. C-IFS)
Besides ERA-I there are several other reanalyses by different models, on different grids and assimilating (slightly) different datasets (de-bias procedures vary)
→ intercomparison project: S-RIP.
Here we choose 4 modern reanalyses: **ERA-I**, **JRA-55**, **MERRA**, **MERRA-2** (+CFSR)

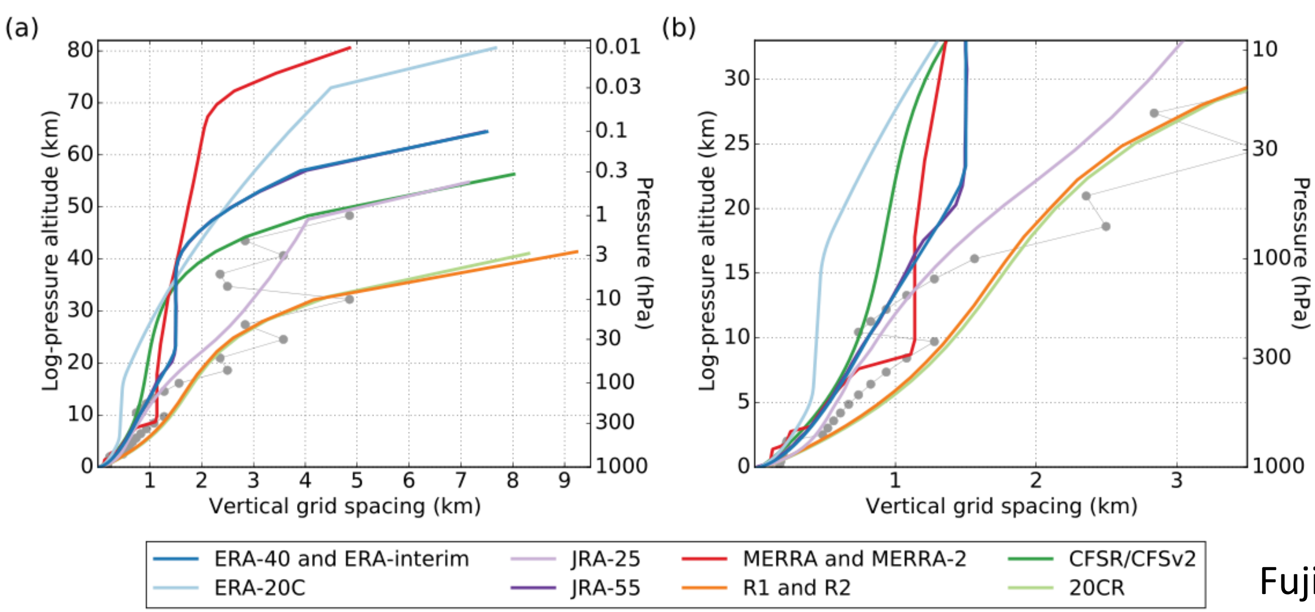
Table 3. Major physical parametrizations in the reanalysis forecast models. Radiation parametrizations are divided into shortwave (SW) and longwave (LW), cloud parametrizations are divided into convective (CU) and non-convective (LS), and gravity wave drag parametrizations are divided into orographic (ORO) and non-orographic (NON) components.

Reanalysis	Radiation	Clouds	Gravity wave drag	Ozone model
ERA-Interim	SW: Fouquart and Bonnel (1980) LW: Mlawer et al. (1997)	CU: Tiedtke (1989) LS: Tiedtke (1993)	ORO: Lott and Miller (1997) NON: none	Cariolle and Déqué (1986); Dethof and Hólm (2004); Cariolle and Teyssèdre (2007)
JRA-55	SW: Briegleb (1992); Freidenreich and Ramaswamy (1999) LW: Chou et al. (2001)	CU: Arakawa and Schubert (1974); Xie and Zhang (2000) LS: Kawai and Inoue (2006)	ORO: Iwasaki et al. (1989a, b) NON: none	Shibata et al. (2005)
MERRA	SW: Chou and Suarez (1999) LW: Chou et al. (2001)	CU: Moorthi and Suarez (1992) LS: Bacmeister et al. (2006)	ORO: McFarlane (1987) NON: Garcia and Boville (1994)	Rienecker et al. (2008)
MERRA-2	SW: Chou and Suarez (1999) LW: Chou et al. (2001)	CU: Moorthi and Suarez (1992) LS: Bacmeister et al. (2006)	ORO: McFarlane (1987) NON: Garcia and Boville (1994); Molod et al. (2015)	Rienecker et al. (2008)

Fujiwara, Wright *et al.* (ACP, 2017)

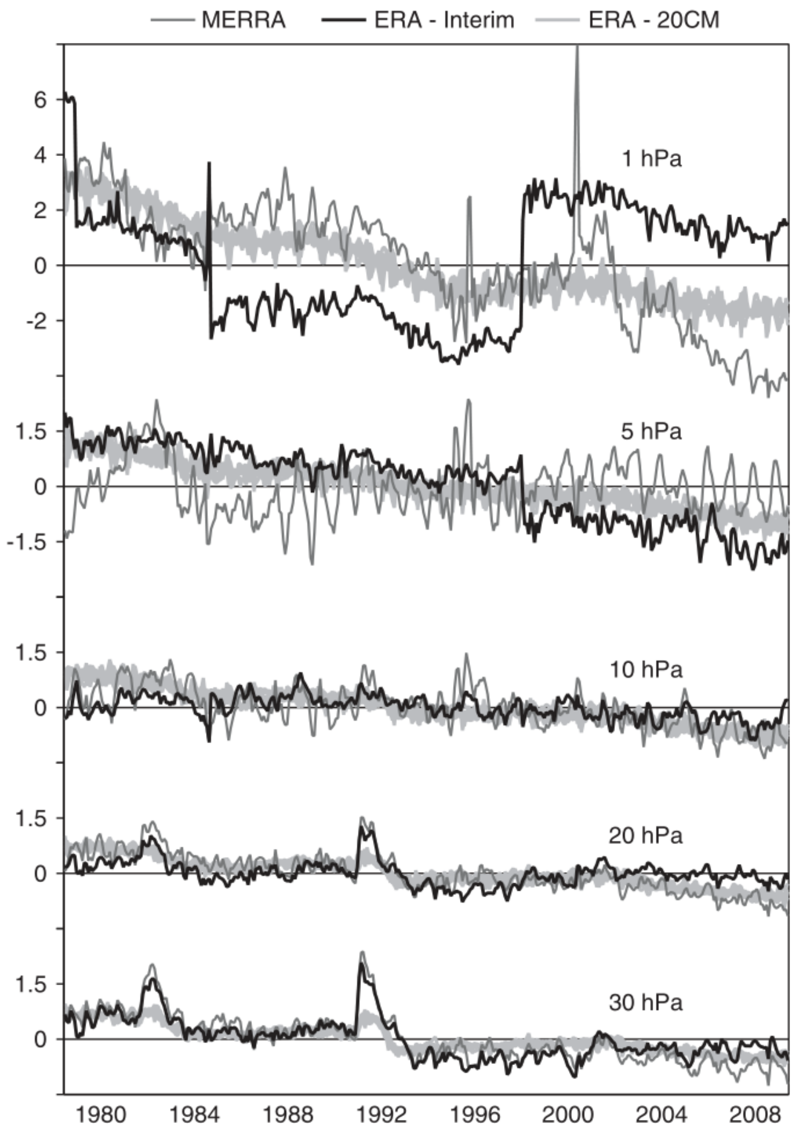
Intro: the reanalyses

Reanalysis system	Model*	Horizontal grid spacing	Vertical levels	Top level
ERA-Interim	IFS Cycle 31r2 (2007)	N128 (T_L255): ~79 km	60 (hybrid $\sigma - p$)	0.1 hPa
JRA-55	JMA GSM (2009)	N160 (T_L319): ~55 km	60 (hybrid $\sigma - p$)	0.1 hPa
MERRA	GEOS 5.0.2 (2008)	1/2° latitude × 2/3° longitude	72 (hybrid $\sigma - p$)	0.01 hPa
MERRA-2	GEOS 5.12.4 (2015)	0.5° latitude × 0.625° longitude	72 (hybrid $\sigma - p$)	0.01 hPa



Fujiwara, Wright *et al.* (ACP, 2017)

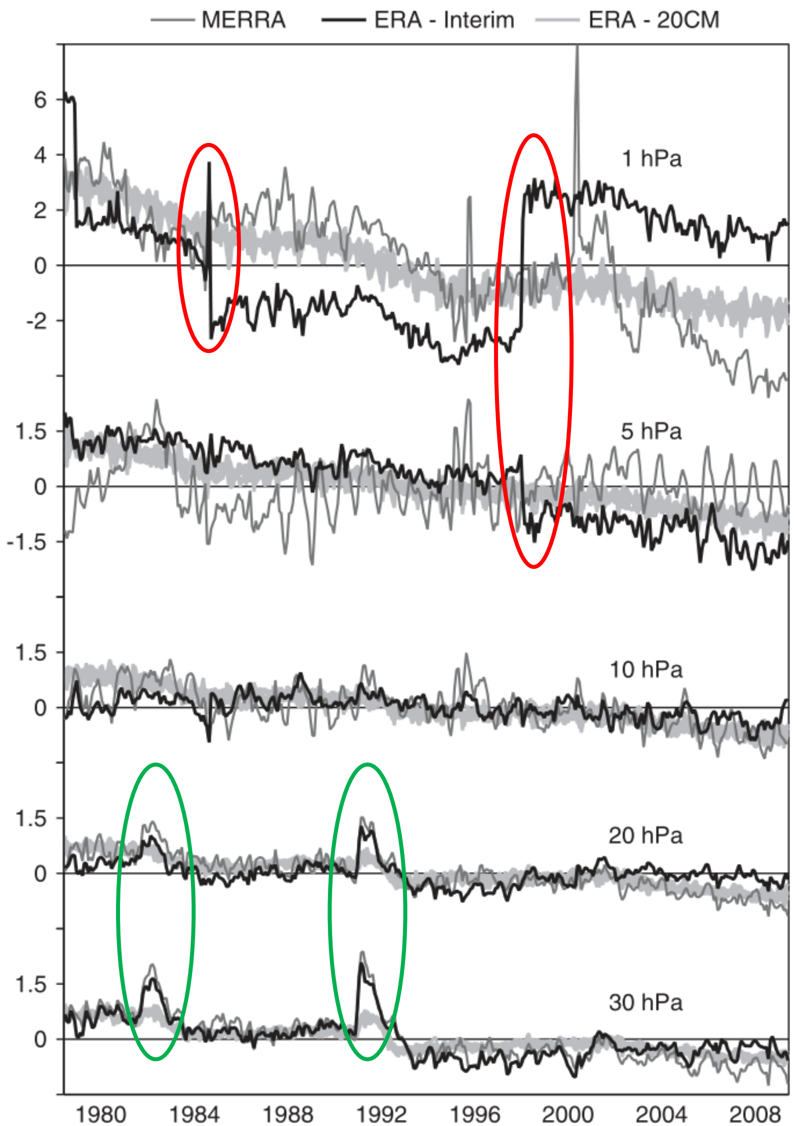
Intro: the reanalyses



Timeseries of reanalyses very useful but trend derivation is full of traps especially due to obs artefacts

Temperature anomalies at cst-p levels
Simmons *et al.* (QJRMS, 2014, fig.22)

Intro: the reanalyses

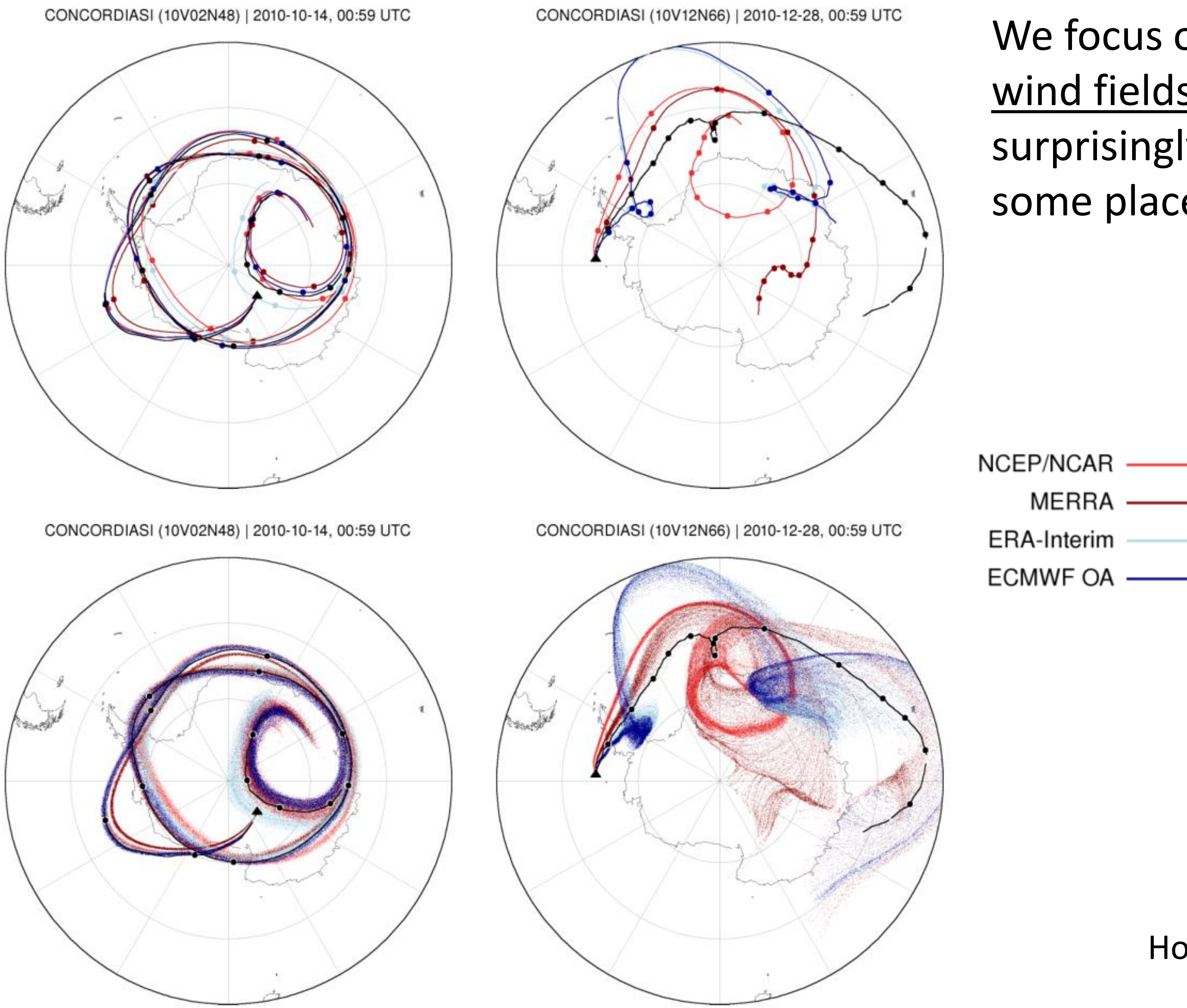


Timeseries of reanalyses very useful but trend derivation is full of traps especially due to obs artefacts

Temperature anomalies at cst-p levels
Simmons *et al.* (QJRMS, 2014, fig.22)

Intro: the reanalyses

We focus on the <u>wind fields</u> which can be surprisingly different as some places and dates

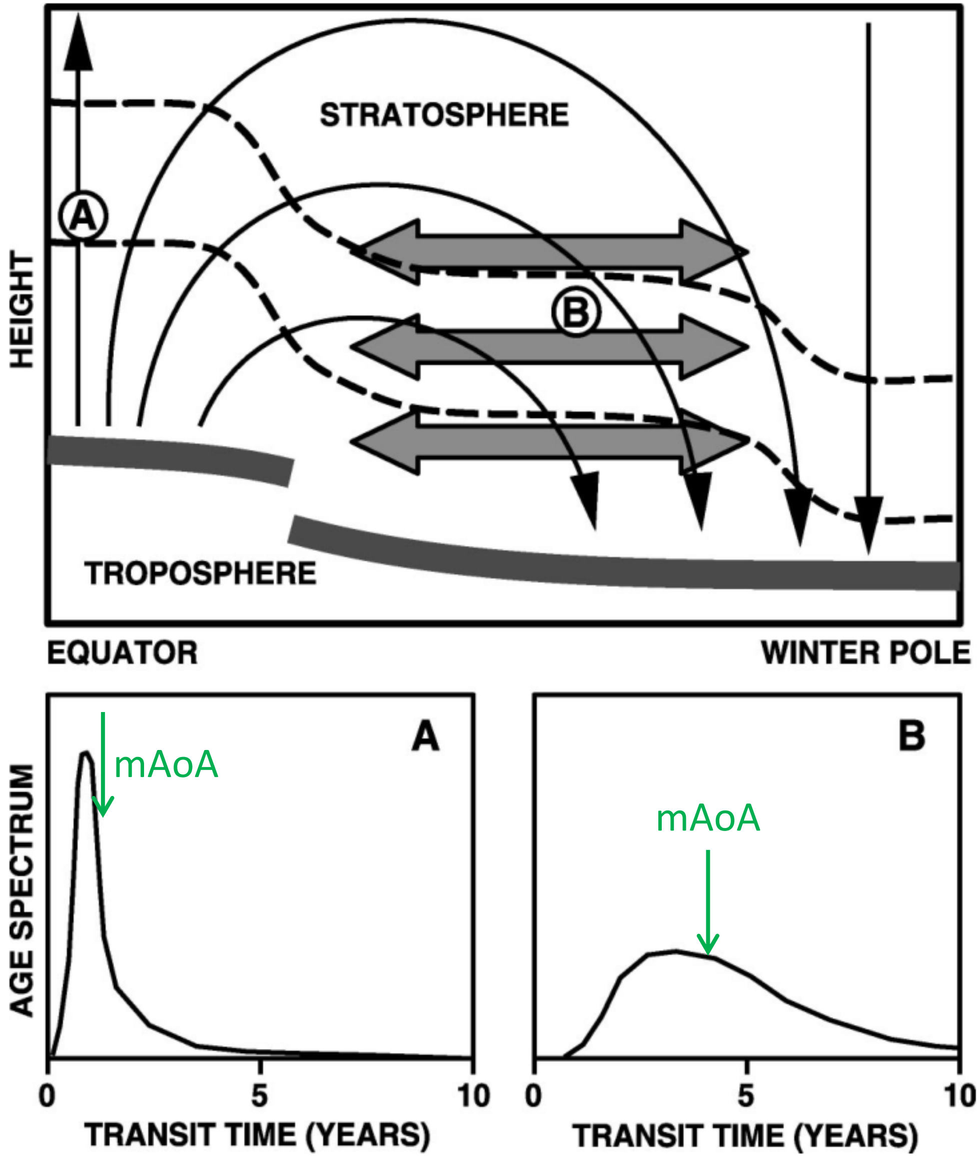


Hoffmann *et al.* (ACPD, 2017)

Introduction

2. mean Age of Air (mAoA): obs, models and the debate on "trends"

Intro: mean Age of Air (mAoA) - concept



Age of Air is <u>spectrum of transit times</u> from tropo (troposphere/tropopause) to various regions in the stratosphere.

It is not symmetrical, espcially in mid-latitudes due to ireversible mixing (by breaking of PW)

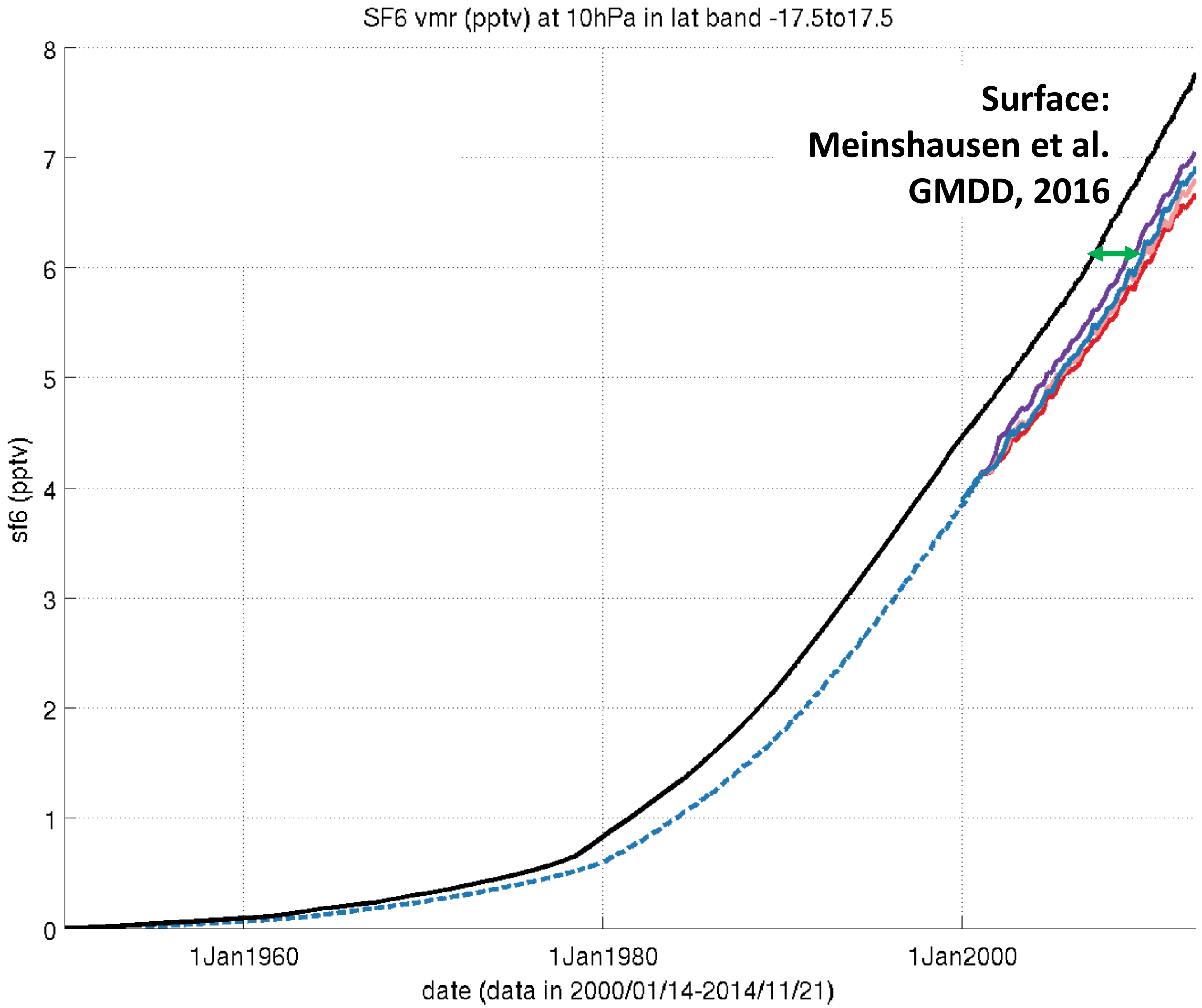
Mean AoA is the average of this spectrum

Waugh and Hall (RG, 2002)

Intro: mean Age of Air (mAoA) – from obs

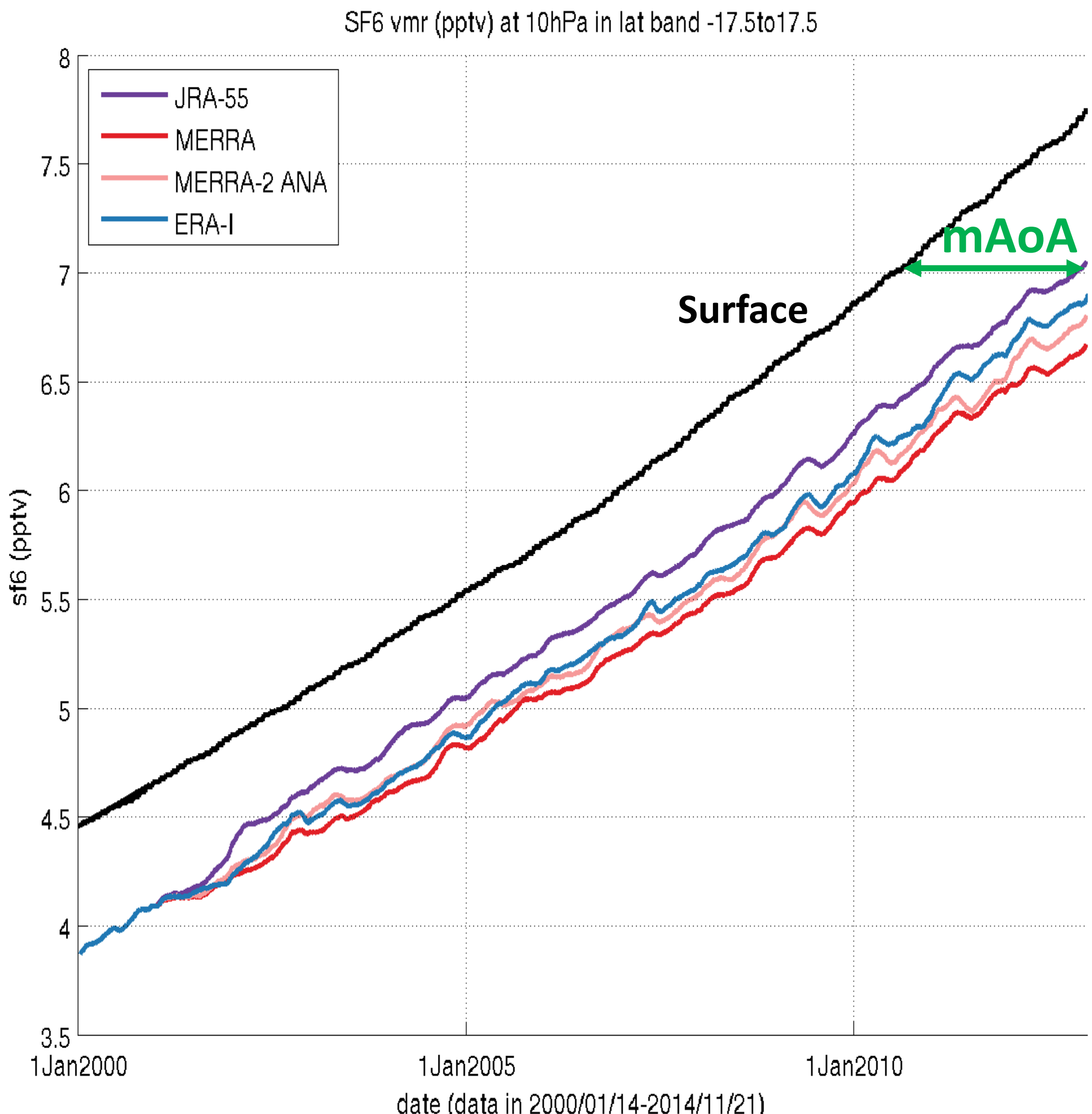
mAoA can be *derived* from time-lag of vmr obs w.r.t. surface, for very long-lived tracers which increase monotonously at surface

→ mainly SF_6 , CO_2



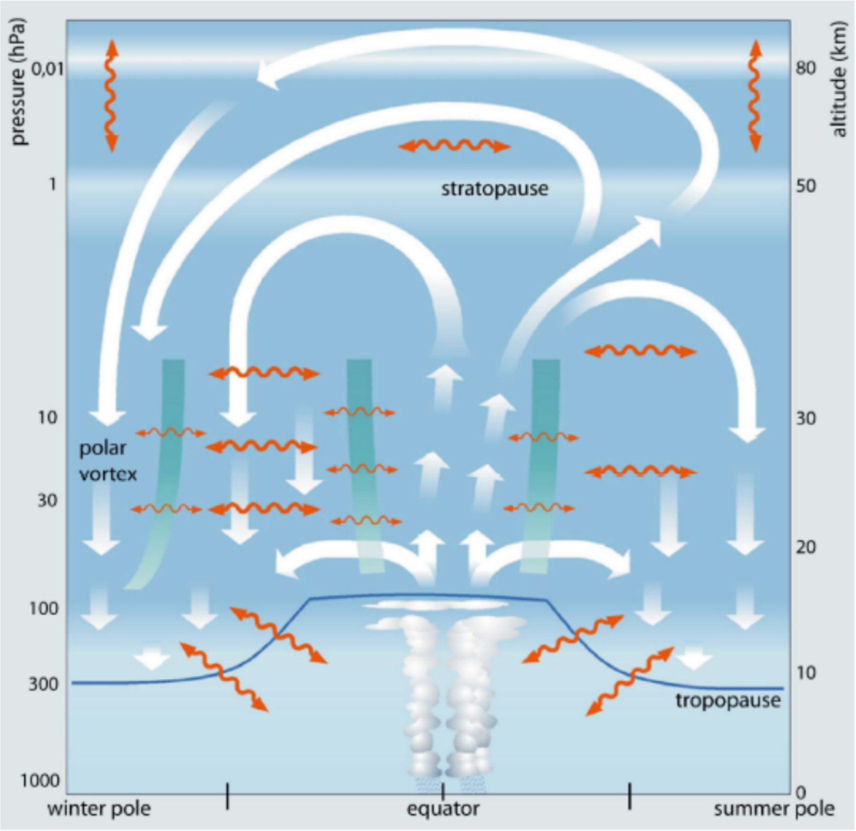
Intro: mean Age of Air (mAoA) – by models

For theoretical tracer with linear increase at surface, time-lag at each gridpoint is mAoA → easy to model

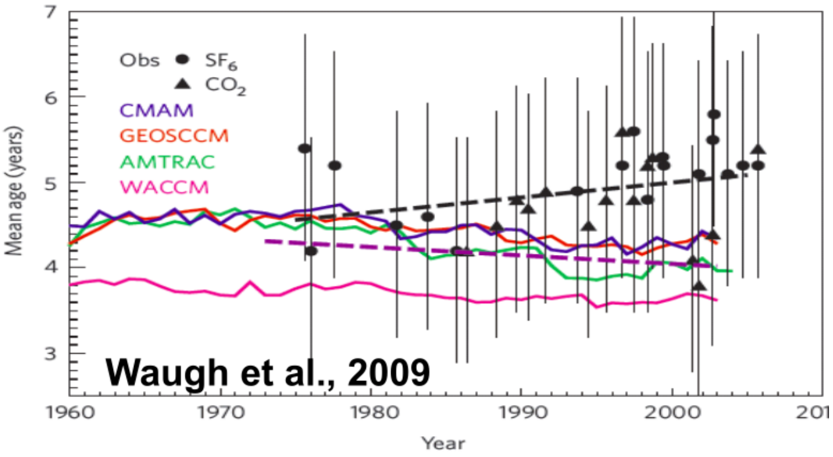


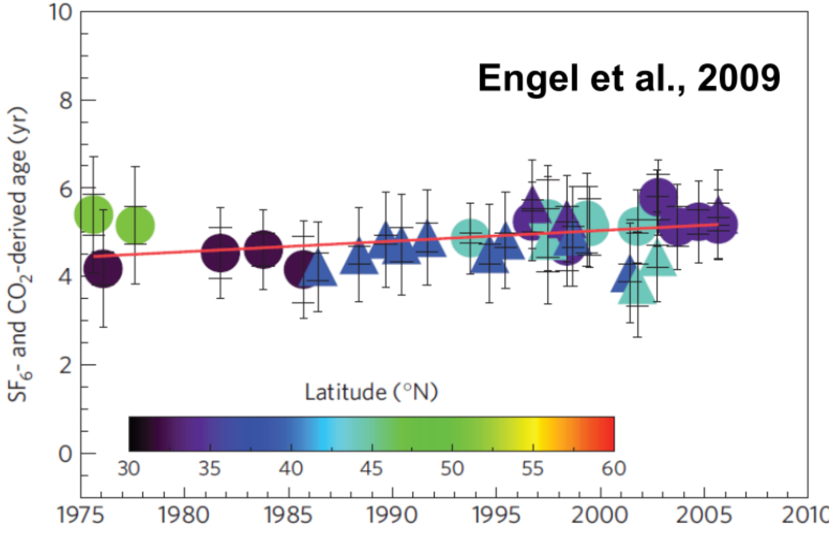
Intro: mAoA “trends” – a hot topic

Background - motivation



Boenisch et al., 2011

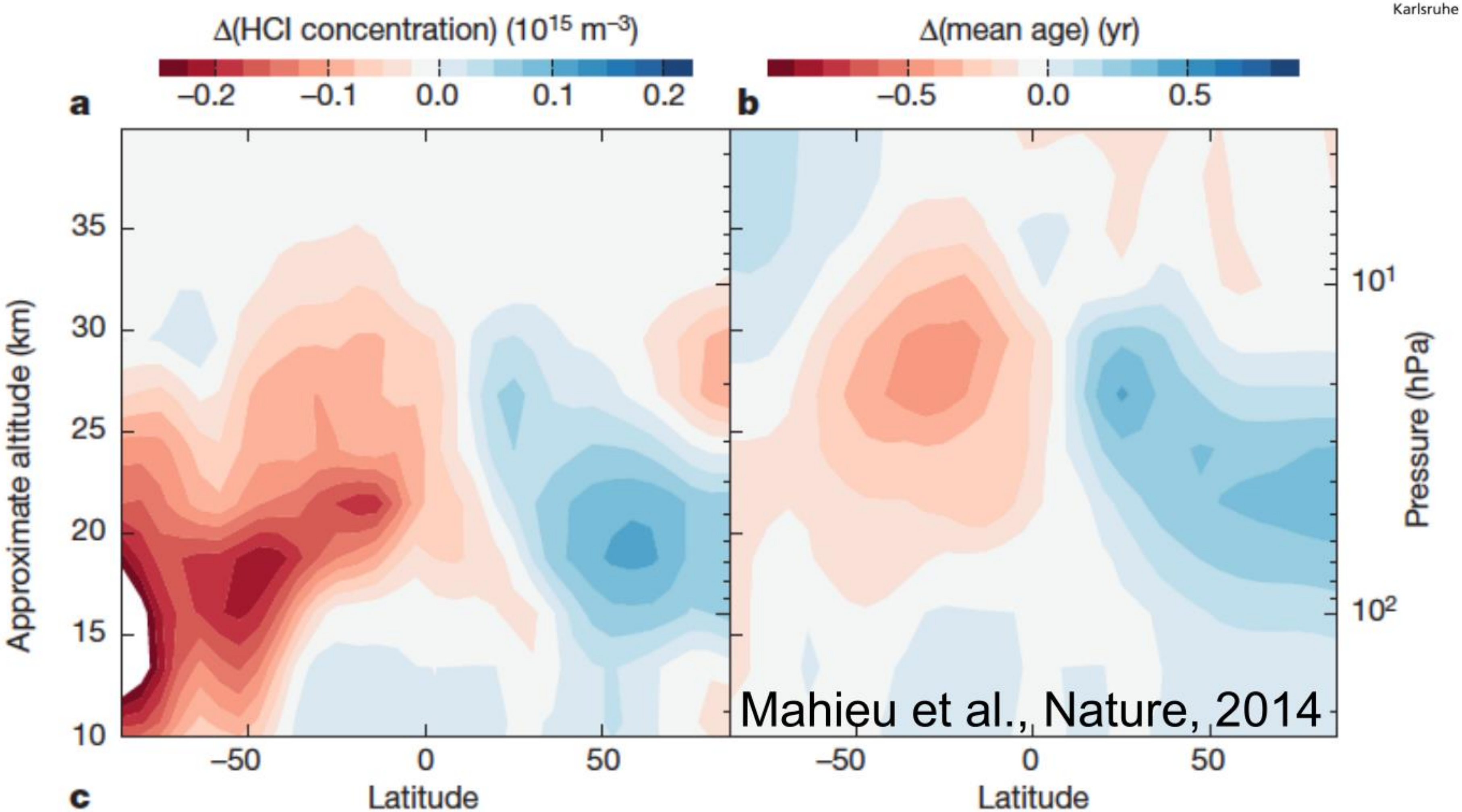




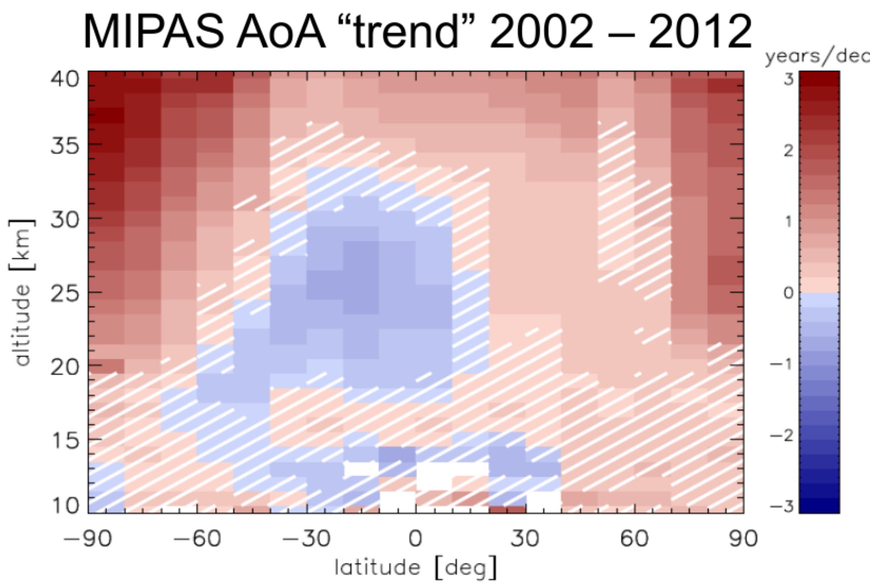
Slide courtesy G. Stiller (S-RIP workshop, Victoria, 2016/10)

Intro: mAoA "trends" – a hot topic

HCl and mAoA (SLIMCAT + ERA-I) changes between 2010/2011 and 2005/2006



Intro: mAoA “trends” – a hot topic



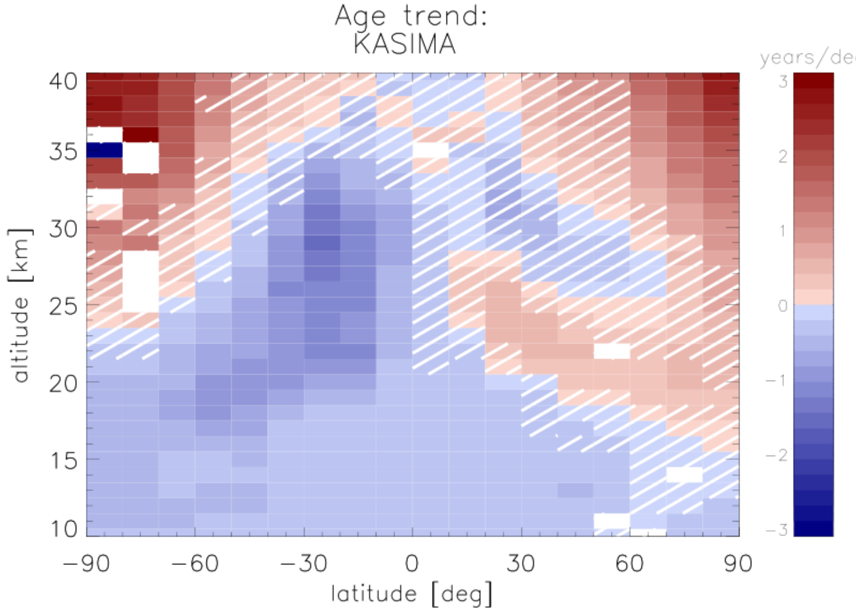
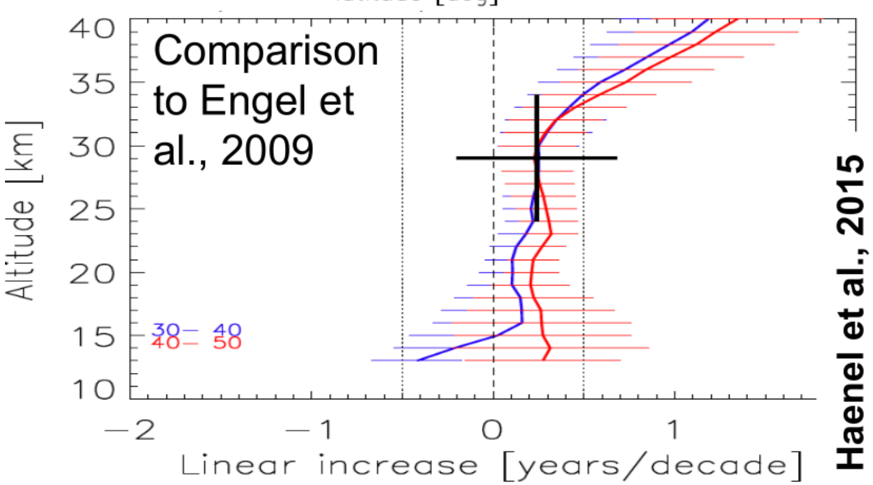


Figure 10. Calculated AoA trends for 2002–2012 from the KASIMA model with consideration of empirical errors and autocorrelation. Hatched areas indicate where the trend is not significant.



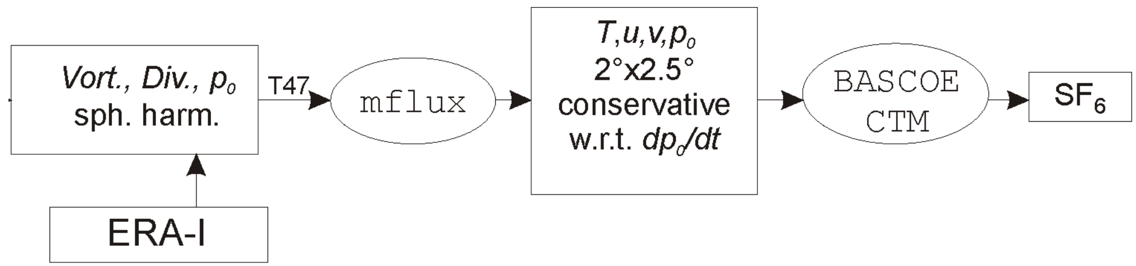
Method

3. Modelling method:
pre-processing of reanalyses,
set-up of transport simulations,
sensitivity tests

Brief description of BASCOE Transport Model

- FFSL advection (Lin and Rood, MWR, 1996) i.e. kinematic winds: no use of *T* ; input p_0, *u*, *v* ; *w* from mass conservation
- We use instantaneous (not time-averaged) analyses (not short-term forecasts), here updated every 6 hours
- FFSL advection must fit CFL condition in *v* direction → dt=1800s with auto sub-tsteps
- No explicit horizontal diffusion
- Eddy vertical diffusion to help propagation of LBC from surface to 2 km altitude (K_{zz} = 0 above)

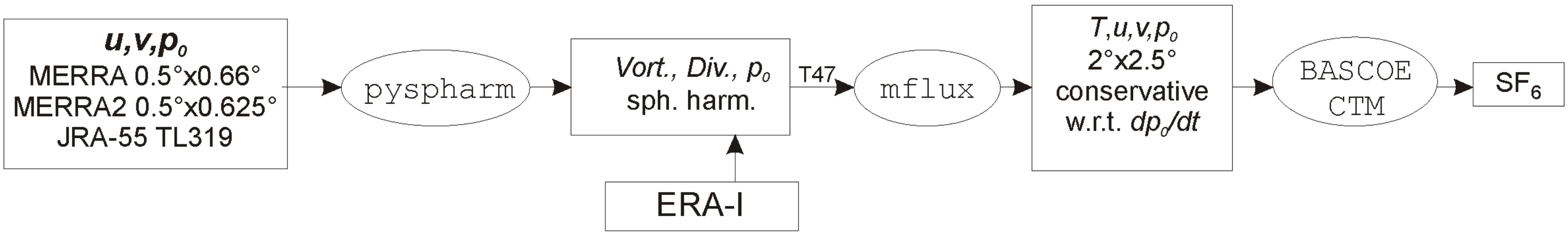
Pre-processing of ERA-I (i.e. spectral models)



BASCOE usually driven by ECMWF analyses:

- Start from *VO, D,* p_0 in spherical harmonics
- Keep native vertical grid (ERA-I: 60 levels)
- Choose coarse horiz grid: 2°x2.5° (Rotman et al., JGR, 2001)
- Truncate for FFSL on 2°x2.5° grid: T47
- Correct horiz winds for dp_0/dt and eval *u, v, p0* on 2°x2.5° grid (Segers et al., 2002)

Pre-processing of other (gridded) reanalyses



Other reanalyses provide *p0, u,v* on hi-res horiz grid

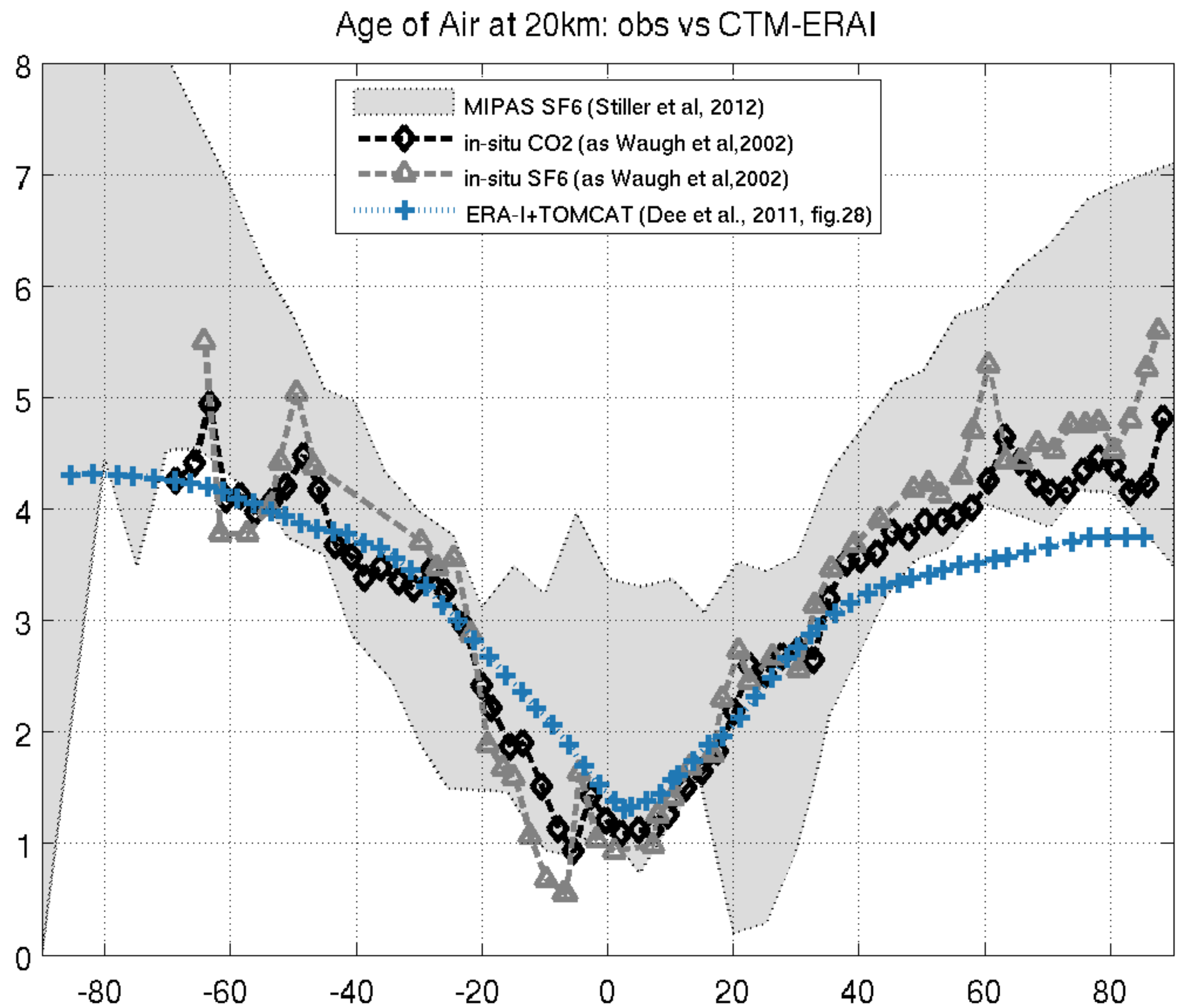
→evaluate *VO, D,* p_0 in spherical harmonics and keep same pre-processing as for ERA-I

→All reanalyses are truncated to T47

→each reanalysis is run on its original vertical grid (model levels → CFSR currently out)

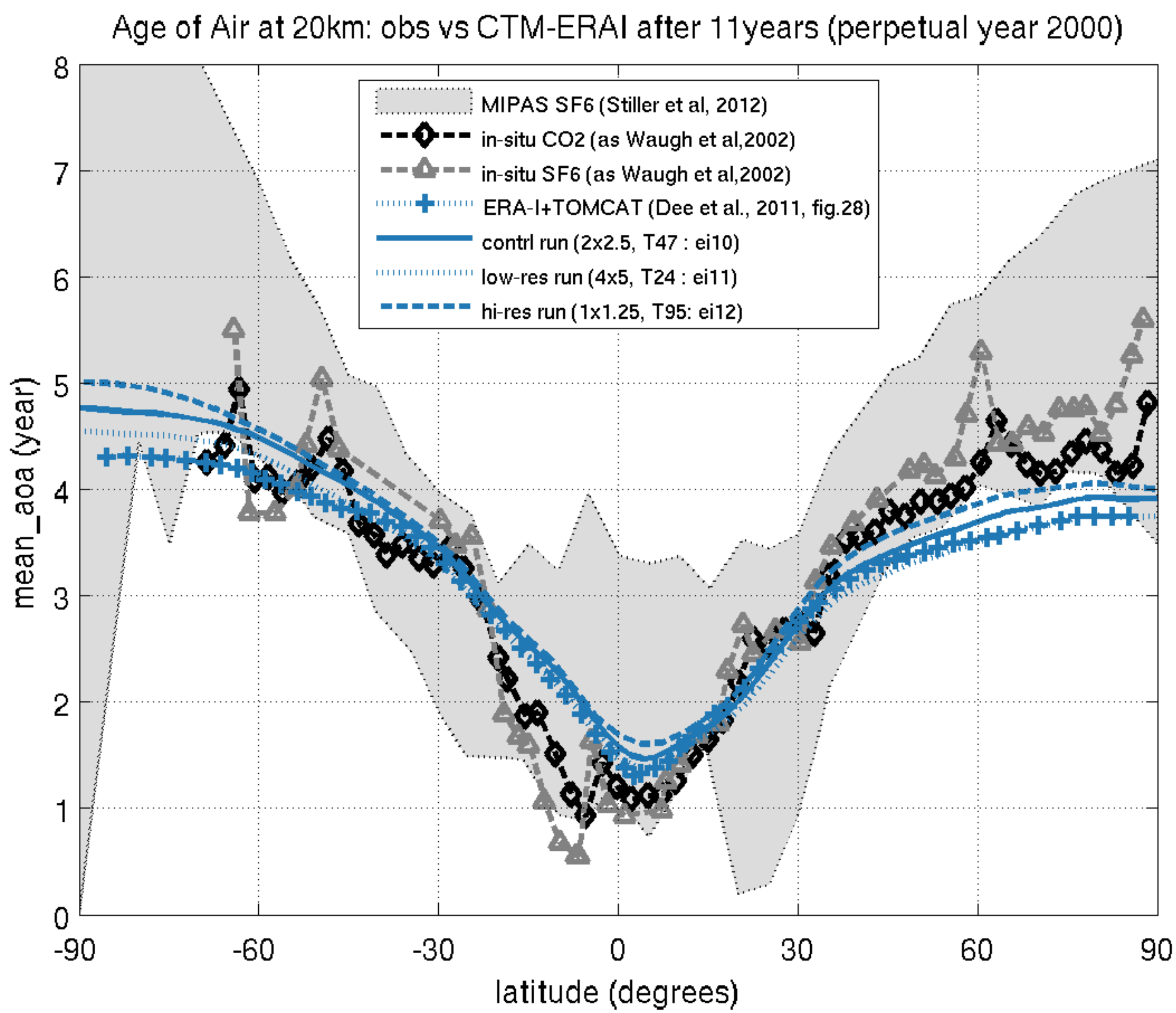
Set-up of transport simulations and method to eval sensitivity tests

- Spin-up time: 20 years of "perpetual year" winds
- 3-D output of mAoA every 5 days
- Vregrid to height + zonal averaging
- Classical model eval: compare wit obs at 20 km



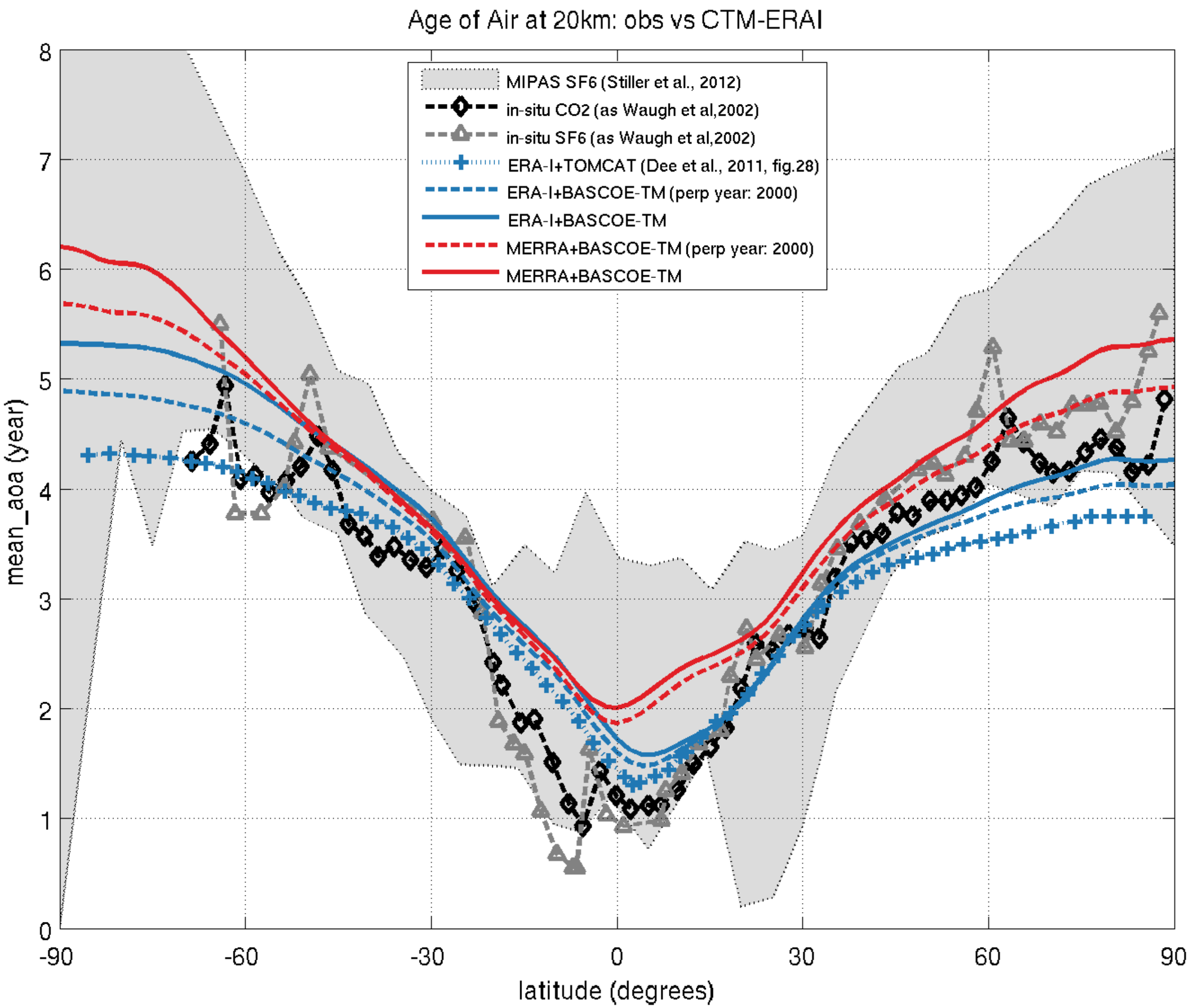
Impact of horizontal resolution

- High-resolution runs deliver "older" runs which may be more realistic at middle and high latitudes (but not in Tropics)
- Such runs are too expensive for 40-yr simulations (pure transport, 1 species → 1 CPU)



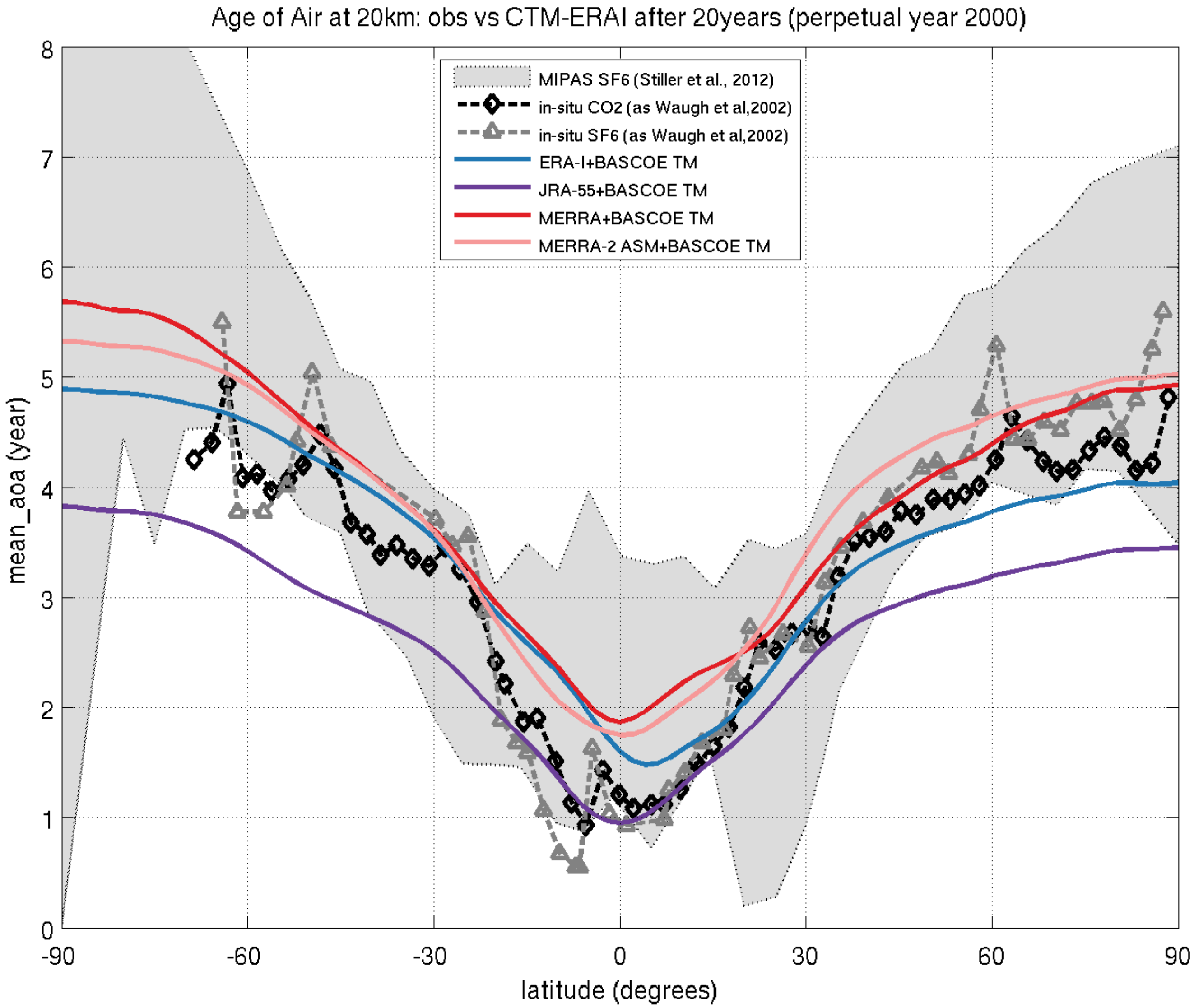
Difference between perpetual and actual year

- Age is older using ear-dependent winds than using perpetual years!
- Especially at high latitudes
- 40-year run in each case



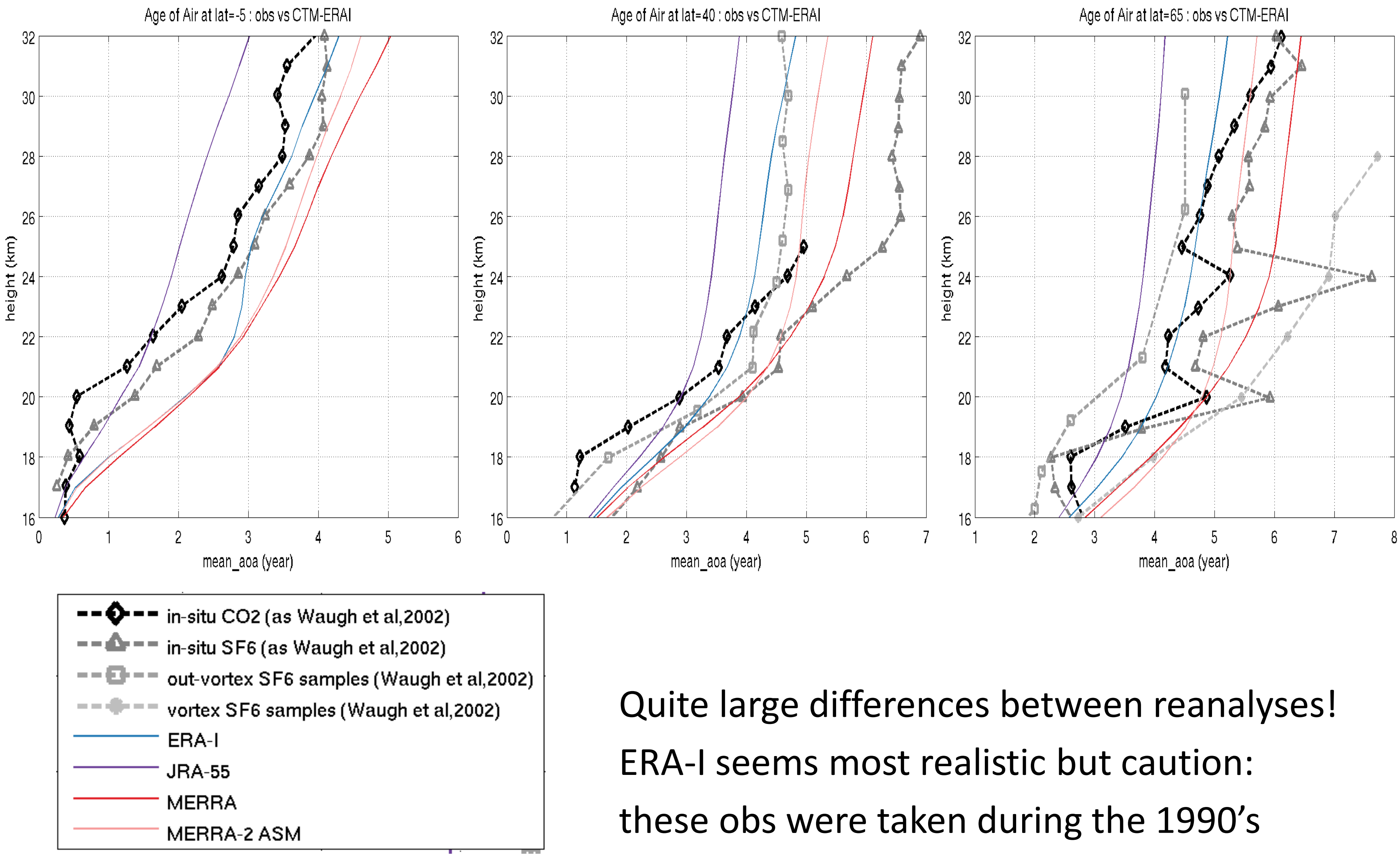
4. Intercomparison of 4 reanalyses for year 2000, time evolution and trends (preliminary!)

mAoA at 20km in 2000



- **MERRA** and **MERRA-2** oldest
- **JRA-55** youngest
- **ERA-I** in between (but older than using SLIMCAT)

mAoA in 2000 at 5°S, 40°N and 65°N



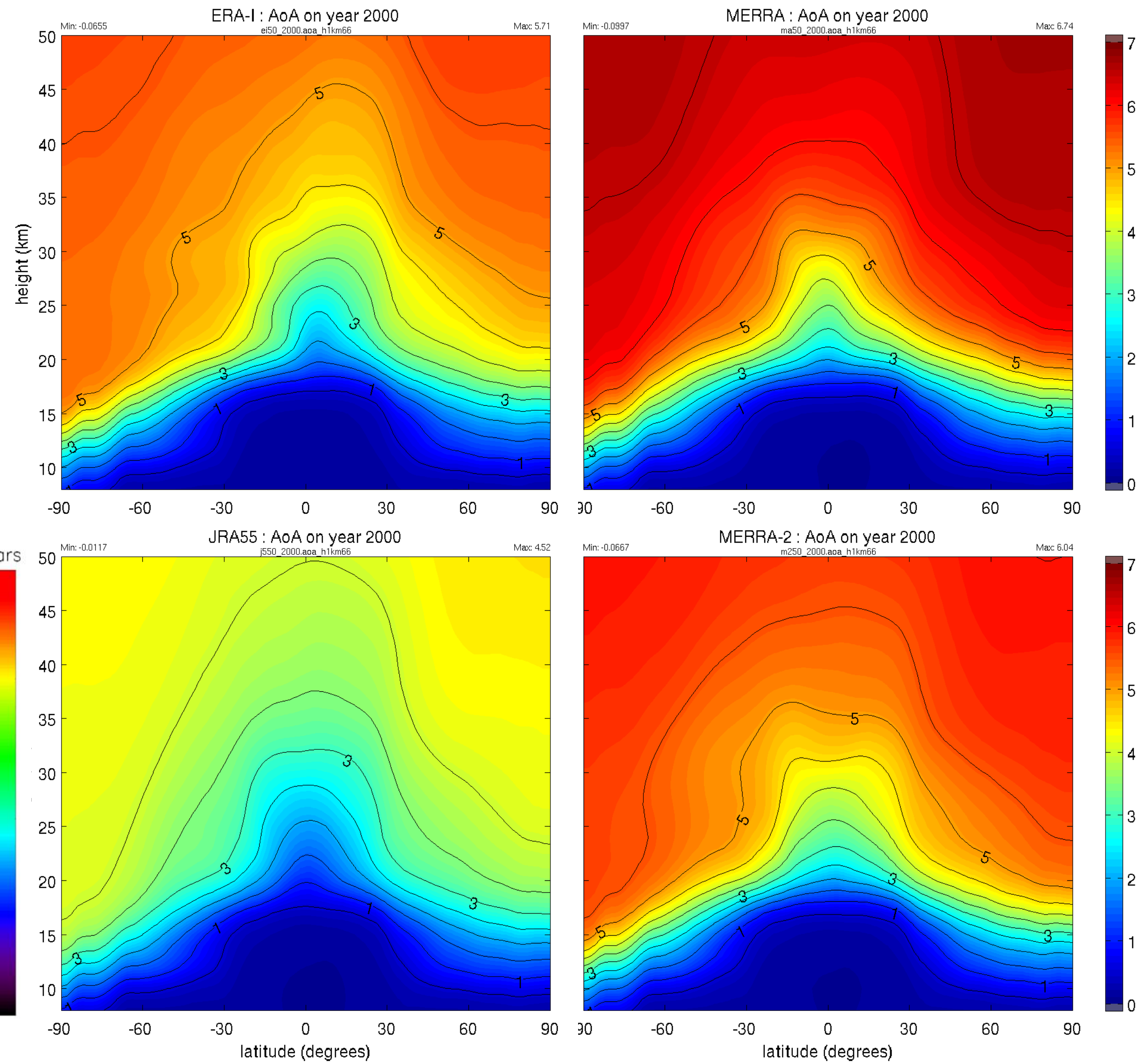
Quite large differences between reanalyses!

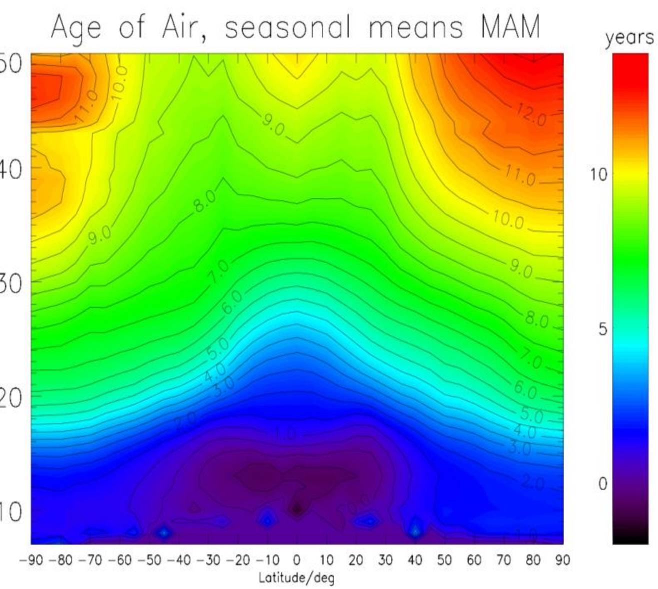
ERA-I seems most realistic but caution:

these obs were taken during the 1990's

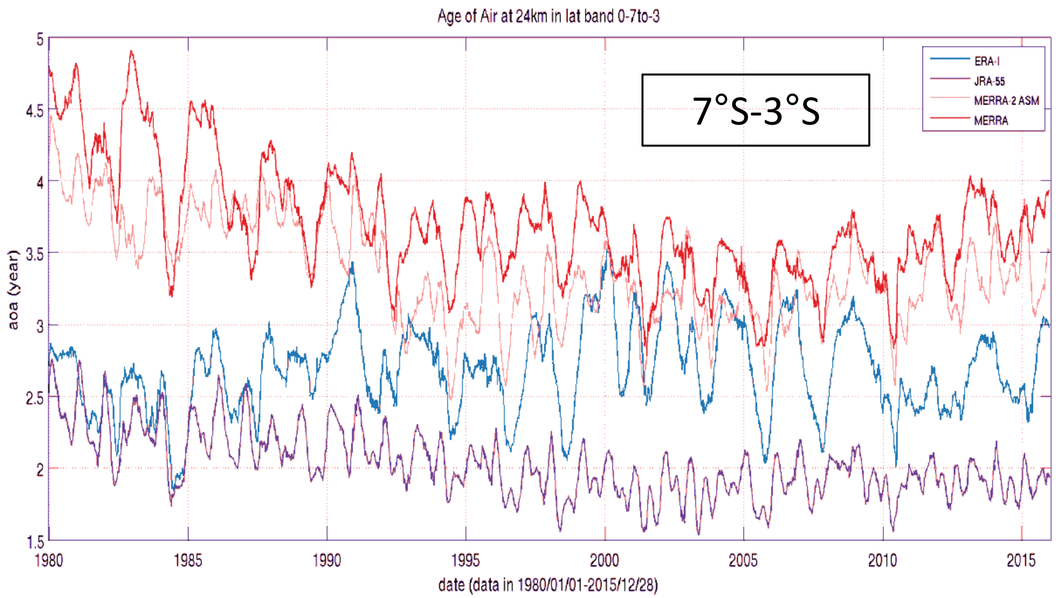
mAoA in 2000: MIPAS obs versus models

Note scale 0-14yr for MIPAS versus 0-7yr for model:
MIPAS obs of SF6 deliver <u>apparent</u> mAoA, not taking its mesospheric losses into account

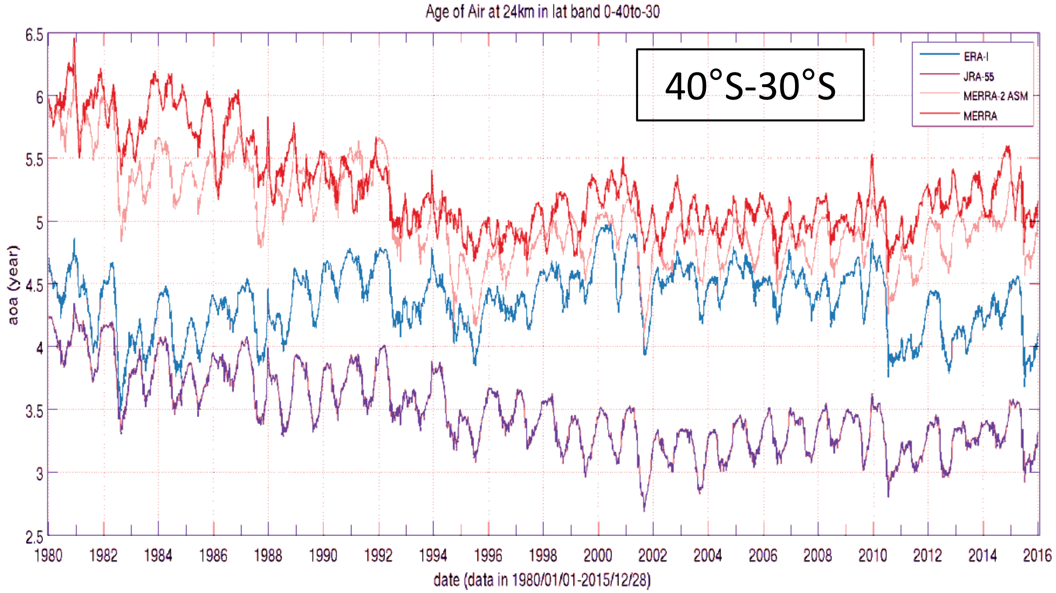




Time evolution of mAoA at 24 km: Tr and SHML

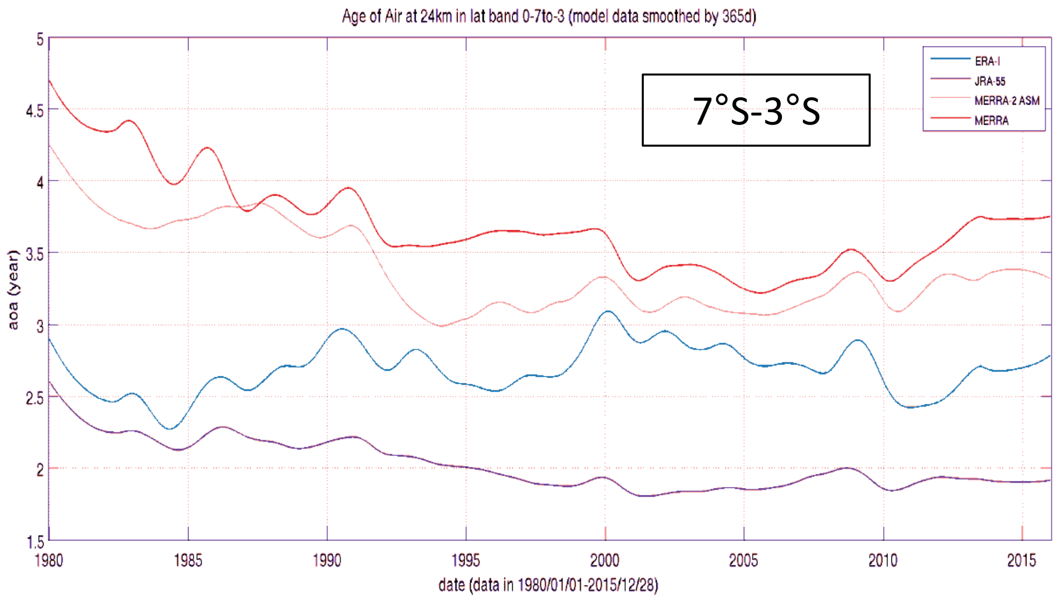


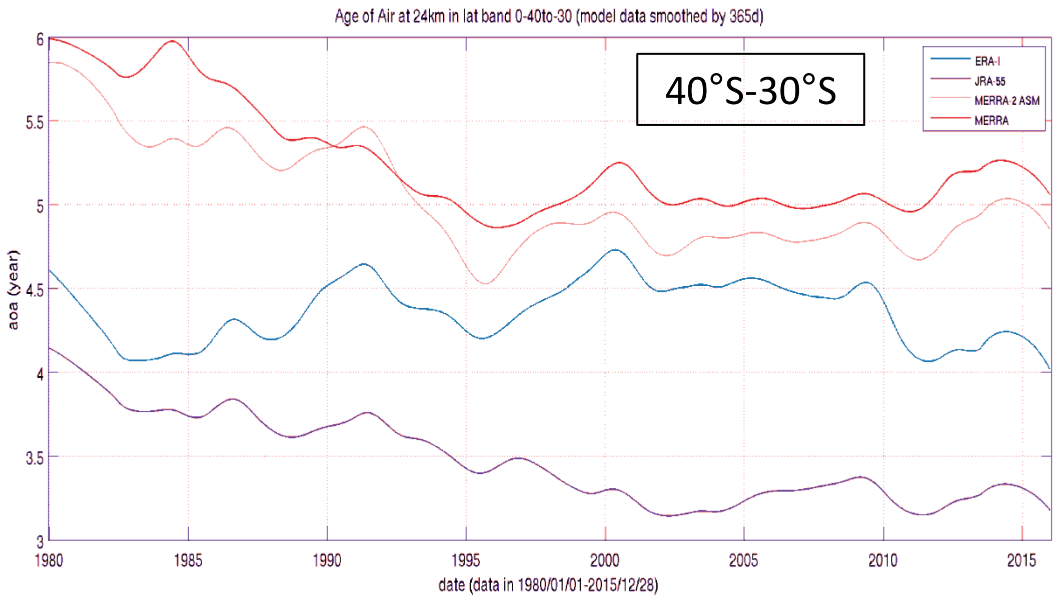
7°S-3°S: QBO very important in **ERA-I** , less in **MERRA** or **MERRA-2** and not in **JRA-55**



40°S-30°S: QBO much less important; seasonal vars dominate

"Trends" of mAoA at 24 km: Tr and SHML





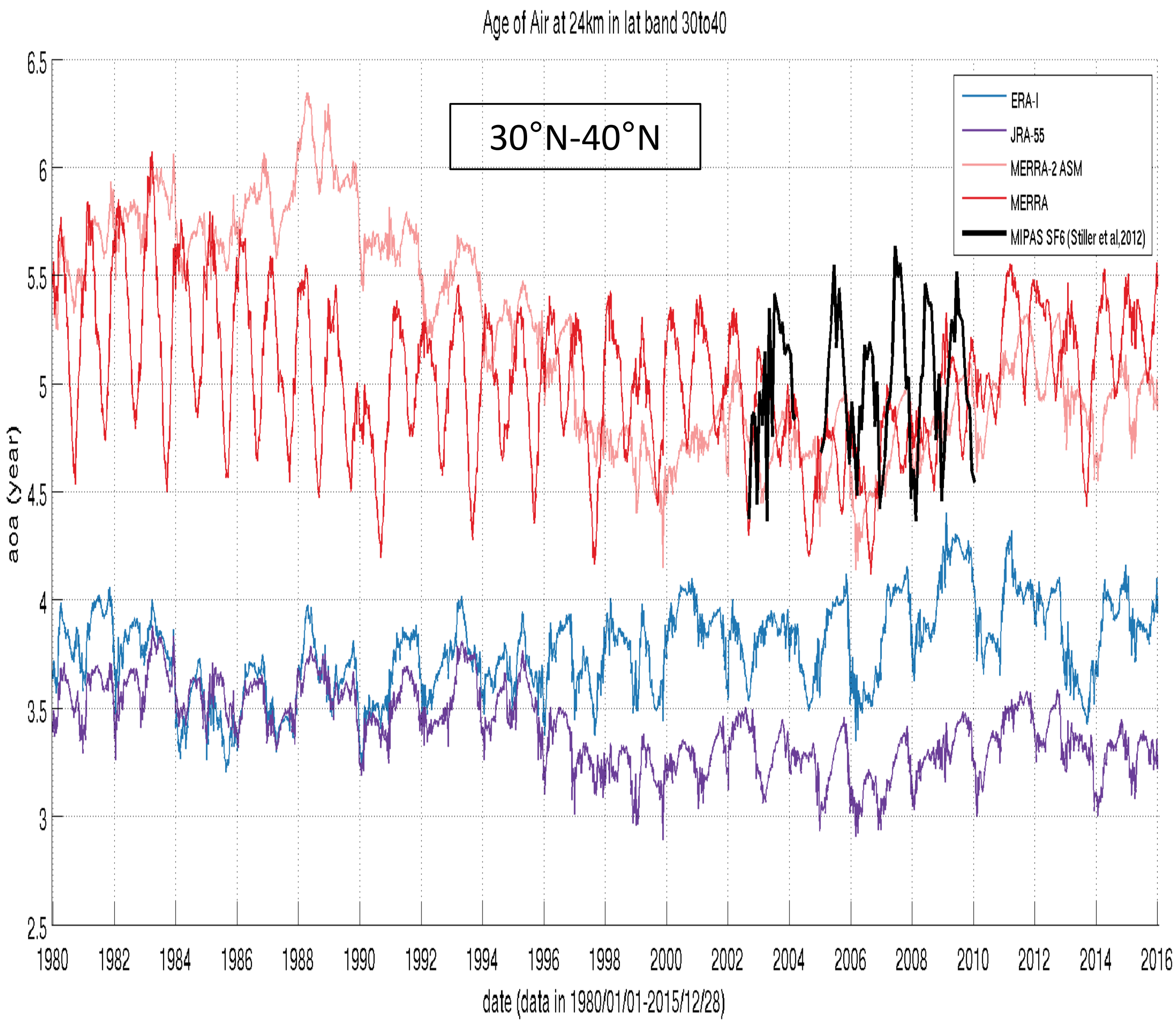
<u>Very</u> preliminary way to de-seasonalize: smoothed with 365-d moving rectangle.

Long-term evolution <u>changed around 2000</u>:

- until ~2000 mAoA gets younger with JRA-55 and MERRA,MERRA-2 but older with ERA-I (→slower BDC!?)
- Since ~2000 the trends are much smaller

NOTE: all 4 reanalyses may be wrong due to some common obs artifact…

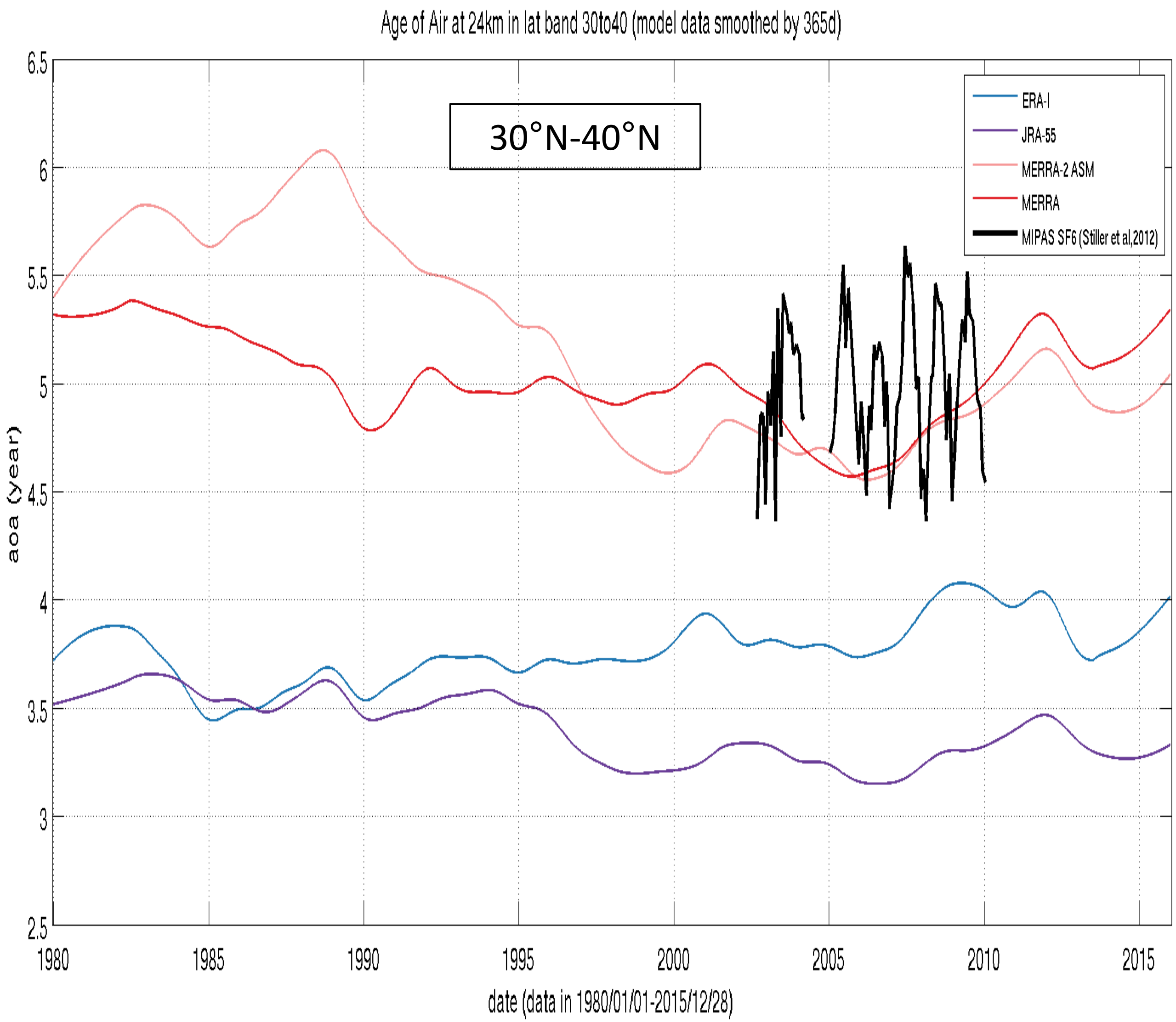
Time evolution of mAoA at 24 km, 30°N-40°N



QBO plays large role.
MERRA seems to agree best with MIPAS obs but QBO has much smaller role in MIPAS than in models !

(but here we are using older retrieval of MIPAS obs: Stiller et al., 2012)

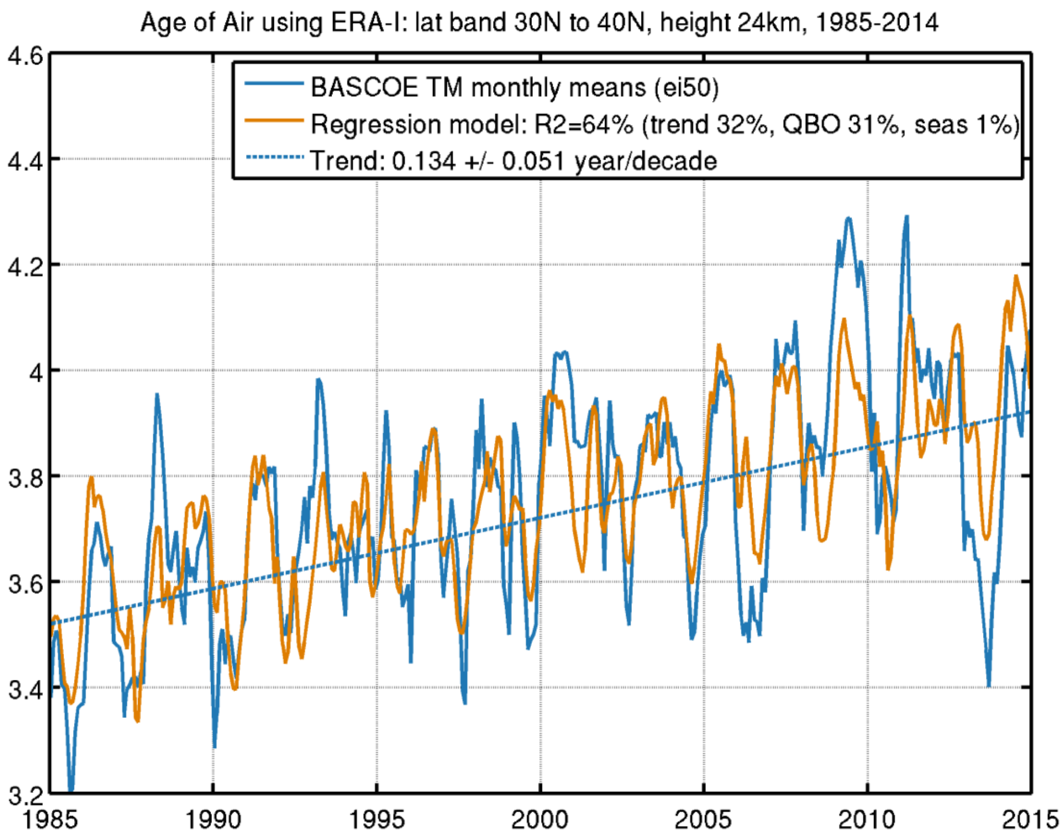
“Trends” of mAoA at 24 km, 30°N-40°N



At Northern mid-lat, change of behaviour can be seen only in JRA-55 and MERRA-2 with air getting younger until ~2000.

With ERA-I, air seems to get older during whole period (at 24km!)

mAoA at 24 km, 30°N-40°N: regression model, 1985-2015

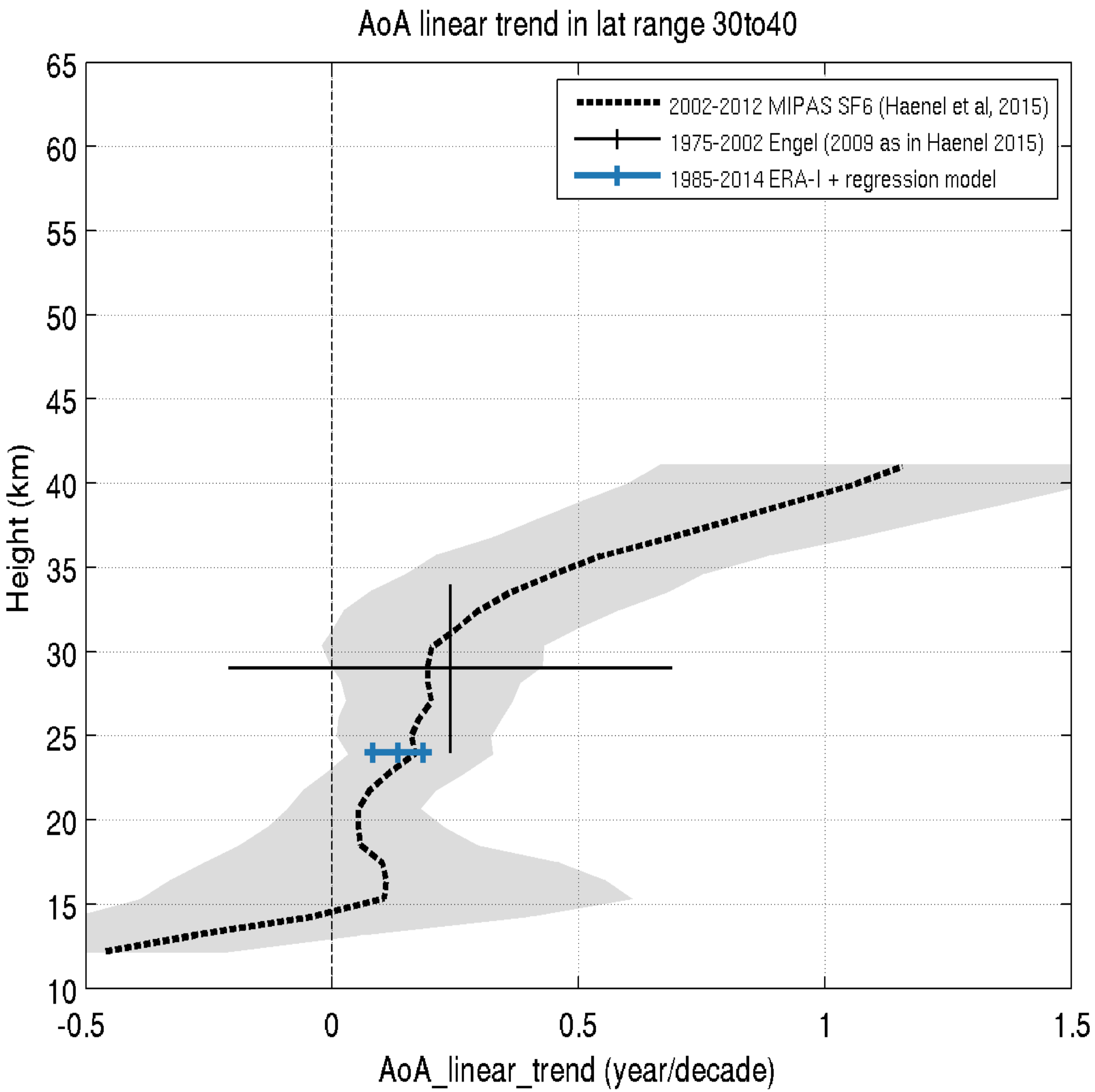


With ERA-I, air seems to get older during whole period (at 24km!)

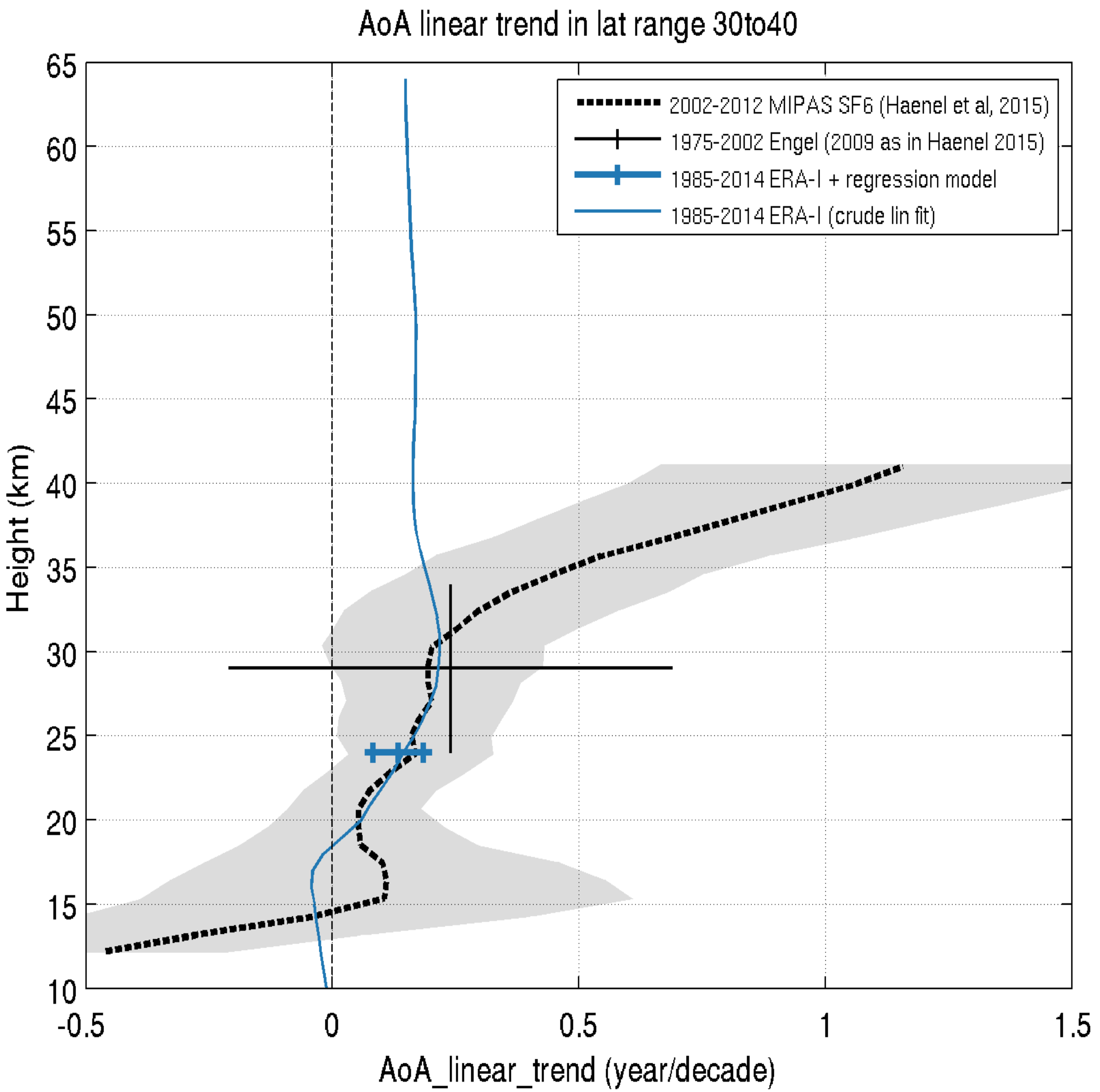
For this point: applied same regression model as for trend study of O3 FTIR (Vigouroux et al., ACP, 2015)

→ QBO quite important, positive trend is confirmed by confidence interval

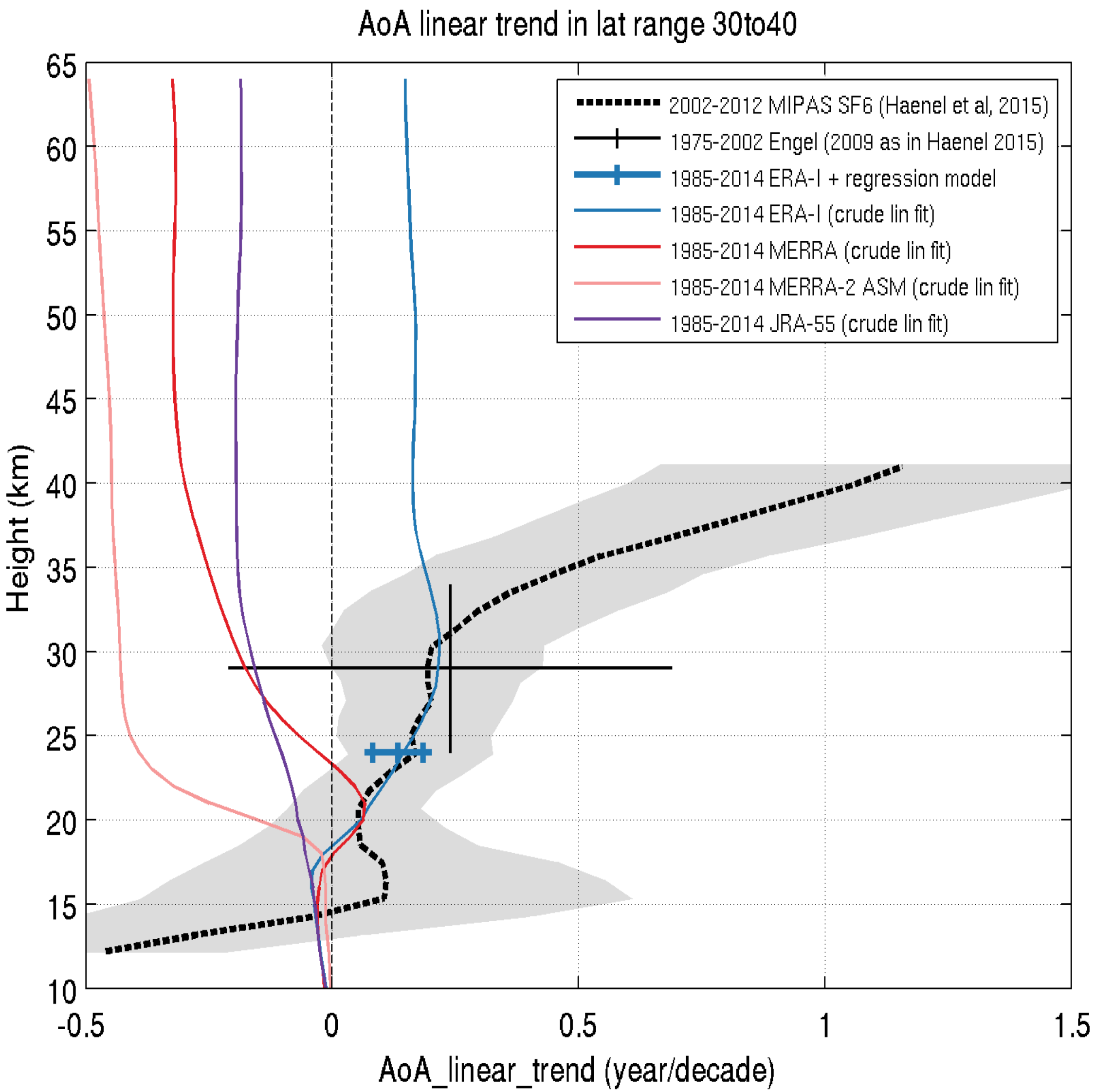
mAoA at 24 km, 30°N-40°N: regression model, 1985-2015



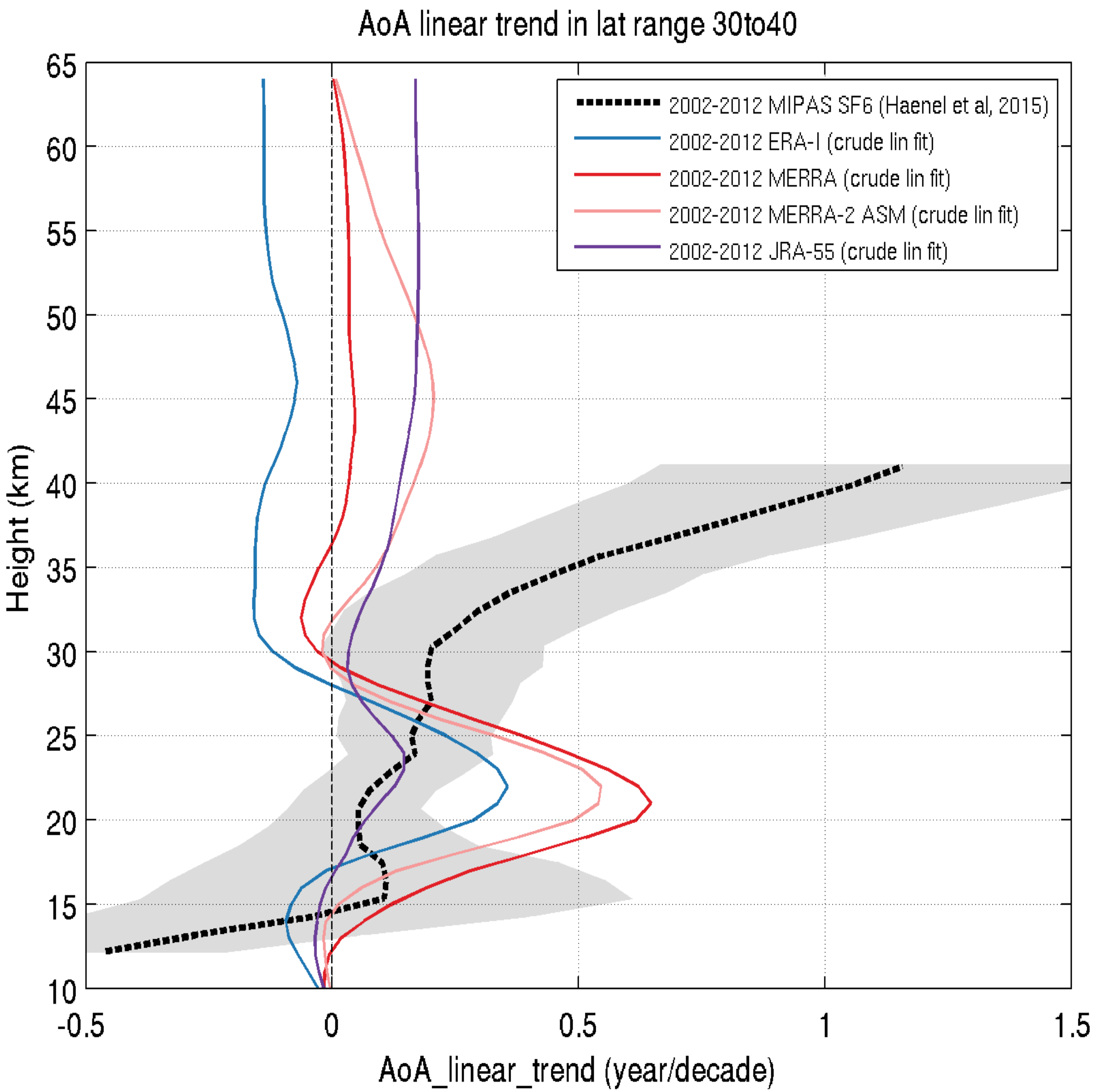
mAoA at 24 km, 30°N-40°N: regression model, 1985-2015



mAoA at 24 km, 30°N-40°N: regression model, 1985-2015



mAoA at 24 km, 30°N-40°N: crude linear fit, 2002-2012



Merci !

Slides not shown

Next steps

- Re-do AoA experiments over 1980-2014:
  fixes caveat 1; allows future derivation of trends
- Drop attempt to simulate SF_6 – use linear source:
  fixes caveats 2; clears caveat 3 (SF_6 mesospheric loss)
- Perform quantitative comparison with MIPAS SF_6 AoA
- Extract amplitudes and phases of seasonal and semi-annual signals; compare with MIPAS

Summary and conclusions

- Significantly different AoA depending on reanalysis!
- All reanalyses deliver AoA younger than SF_6 obs at all latitudes and all altitudes above 20km
- JRA-55 much "too young ", MERRA nearly "old enough"
- ERA-I and MERRA-2 ANA in between, quite similar
- MERRA-2 ANA and MERRA-2 ASM quite different!
  → Which one should be used in S-RIP?
- ERA-I is the only analysis to present SAO at 40km Tropics
- Eulerian kinematic approach (*u,v, w*) provides useful results: complimentary to Lagrangian and Eulerian thermodynamic approaches (*u,v, dθ/dt*)

Follow-up slides
(made after talk)

Difference between MERRA-2 ANA and MERRA-2 ASM

Rienecker et al. (J. Clim., 2011) :

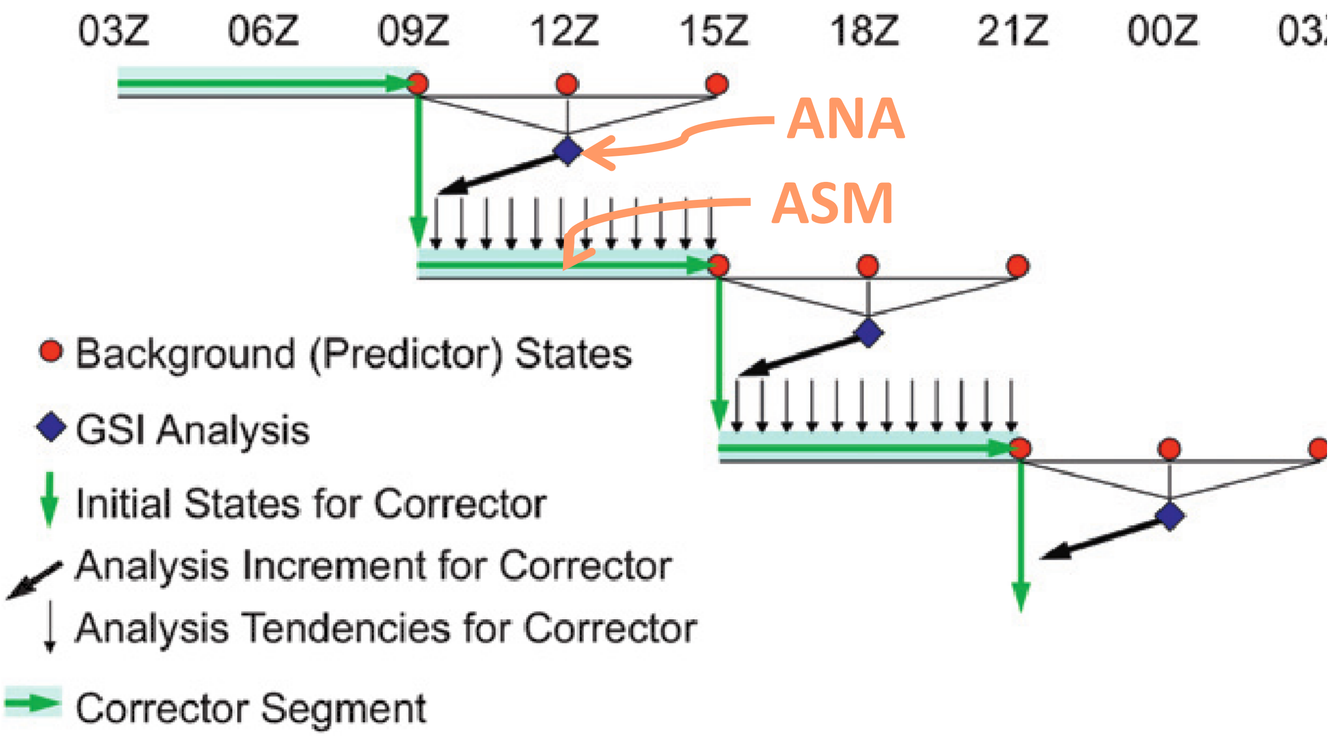
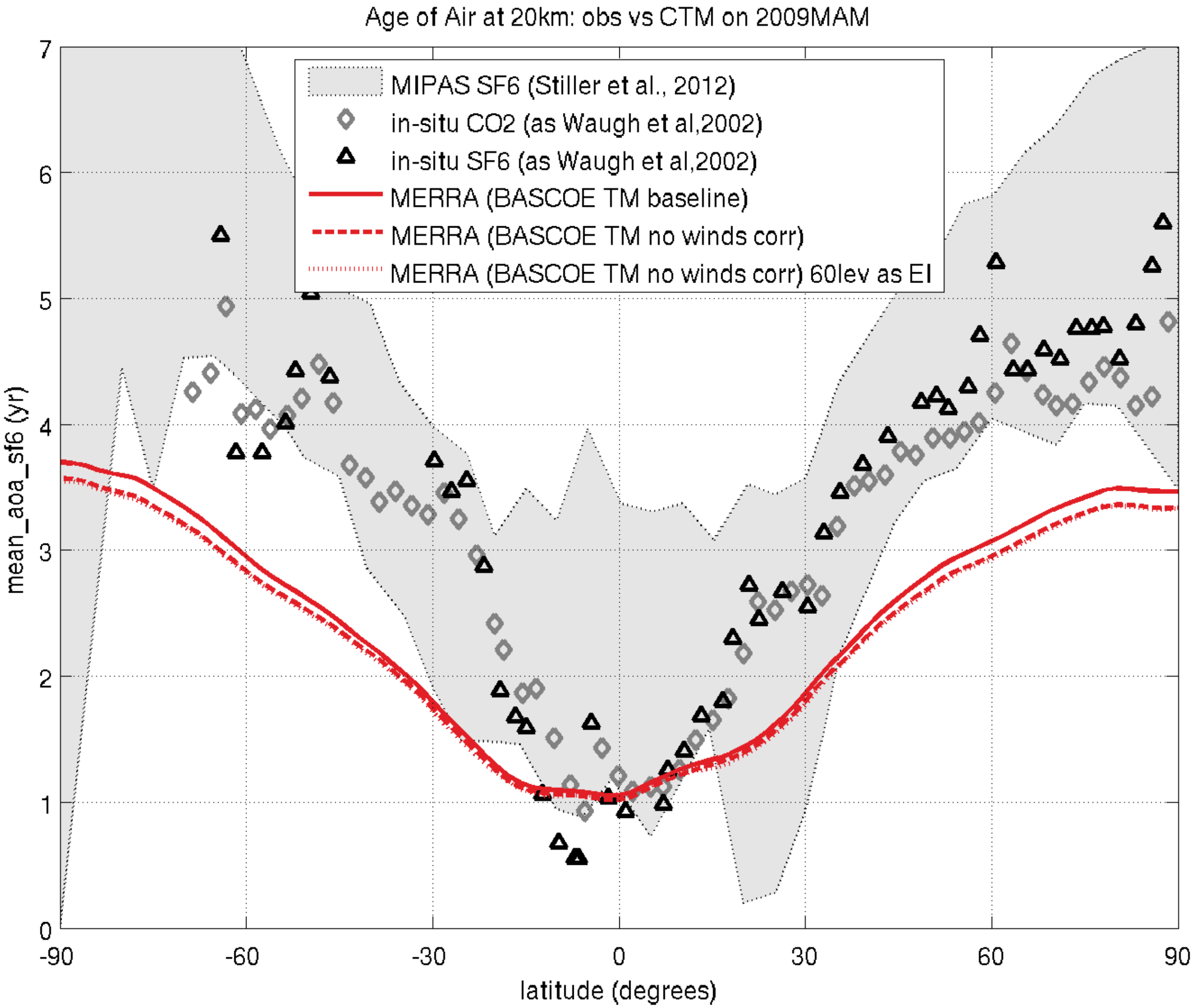


FIG. 1. A schematic of the IAU implementation in GEOS-5.

From discussion with Kris Wargan: recommended dataset is ASM which is smoother in time than ANA!

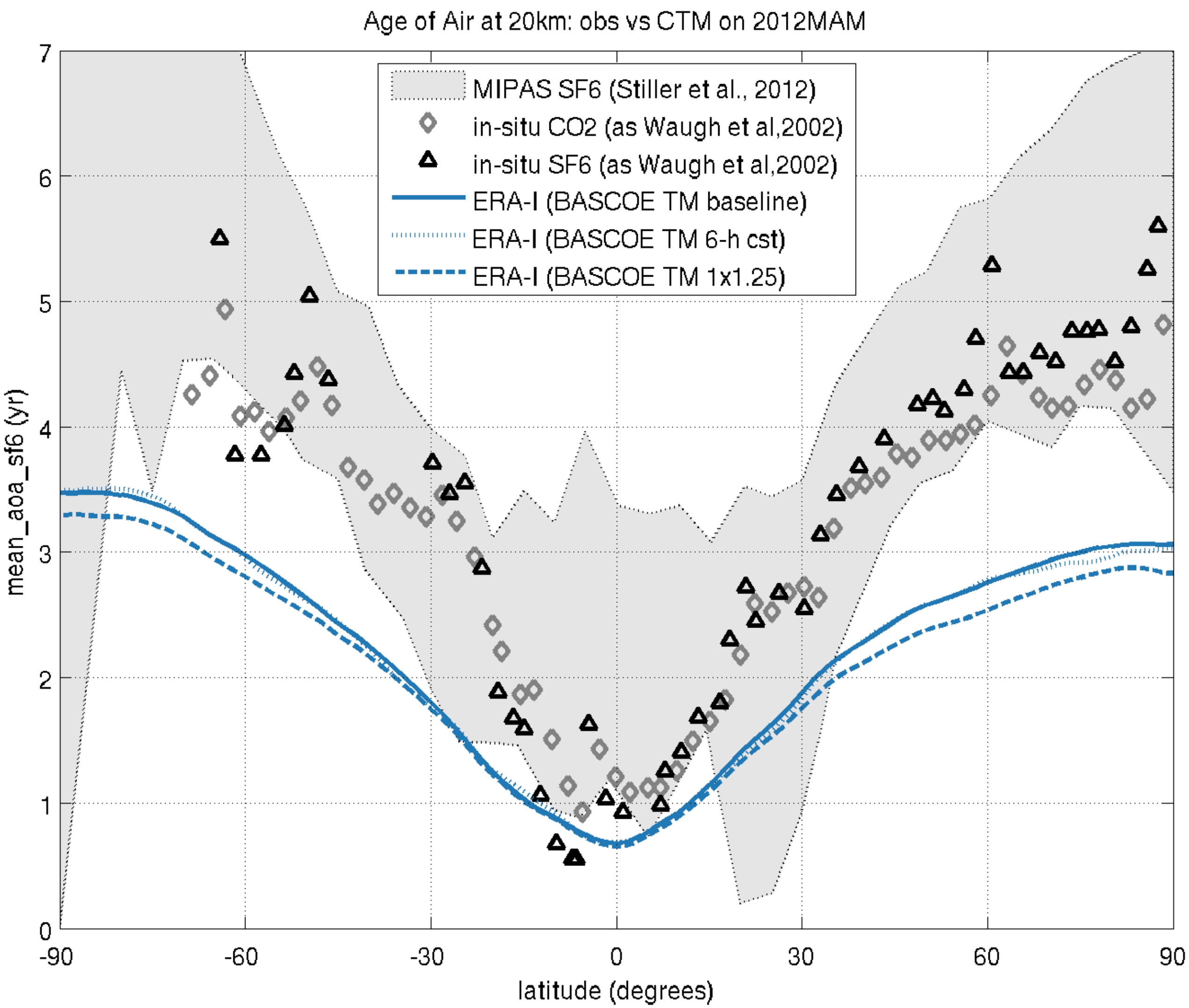
Every MERRA dataset has its own DOI - our papers should cite it !!

Sensitivity to vgrid: MERRA using 60lev from ERA-I



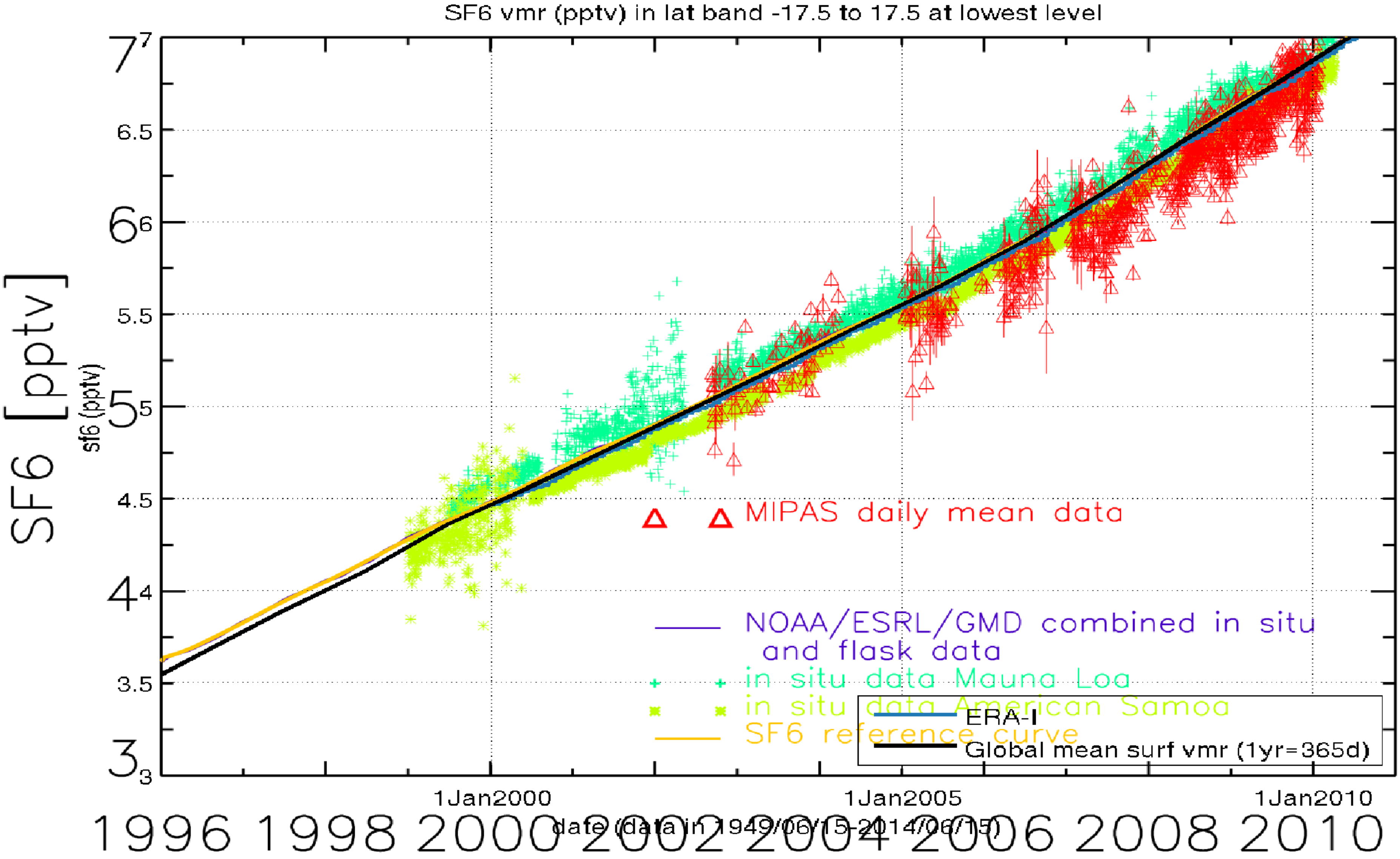
- Impact of winds correction similar with ERA-I and MERRA, relatively small
- Running MERRA winds on ERA-I vgrid has almost no impact

Sensitivity to horiz. resol. : 2°x2.5° *vs* 1°x1.125° ERA-I, 2012MAM



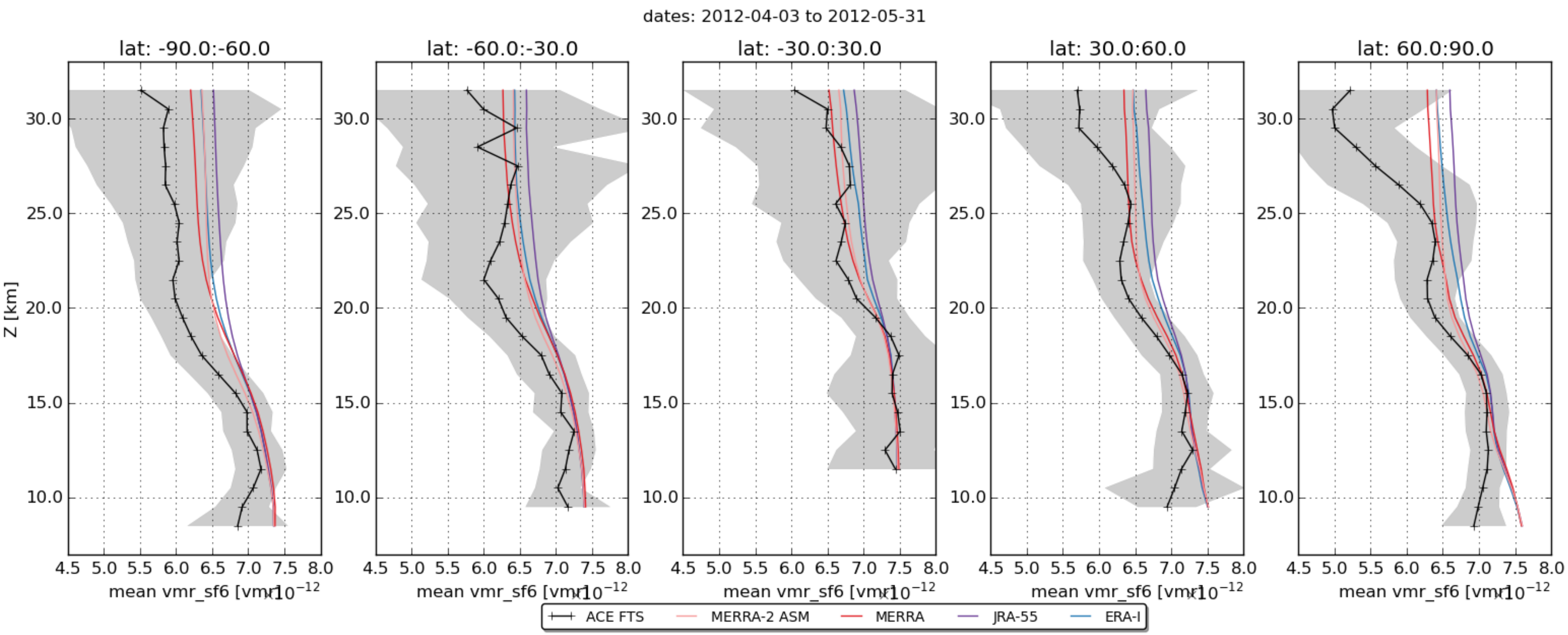
- Unexpectedly, AoA younger with higher resol !
- Lin and Rood (1996) was mainly used at lower resolutions and does not include horiz diffusion explicitly. Maybe it is tuned to work best at 2x2.5° ?
- Test with winds constant during 6h: no impact!? (contradicts MERRA-2 ANA vs ASM?)

Extra slides



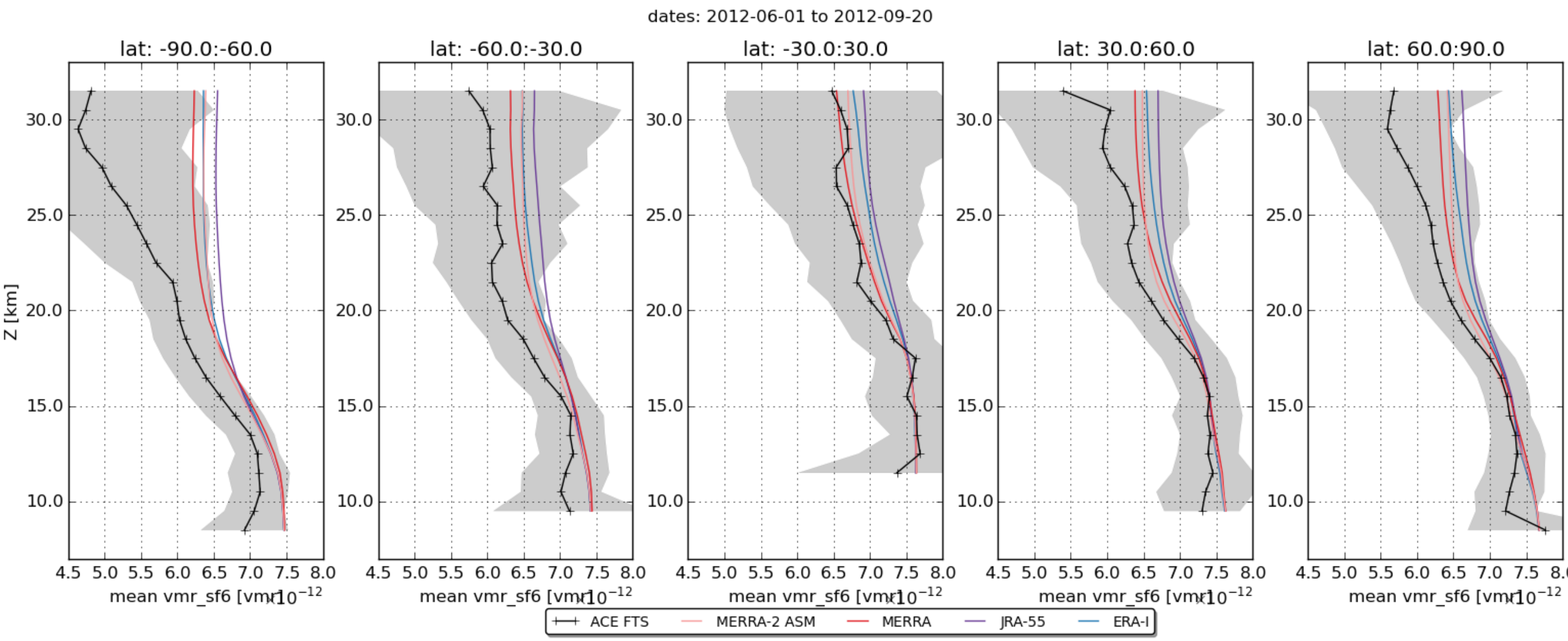
2. Direct comparison with ACE-FTS obs

Direct comparison of SF_6 with ACE-FTS obs 2012 MAM



- All comparisons in obs space (no sampling error)
- Significant differences depending on reanalysis used
- Tropics: good agreeement, especially using MERRA
- Poles: model overestimation

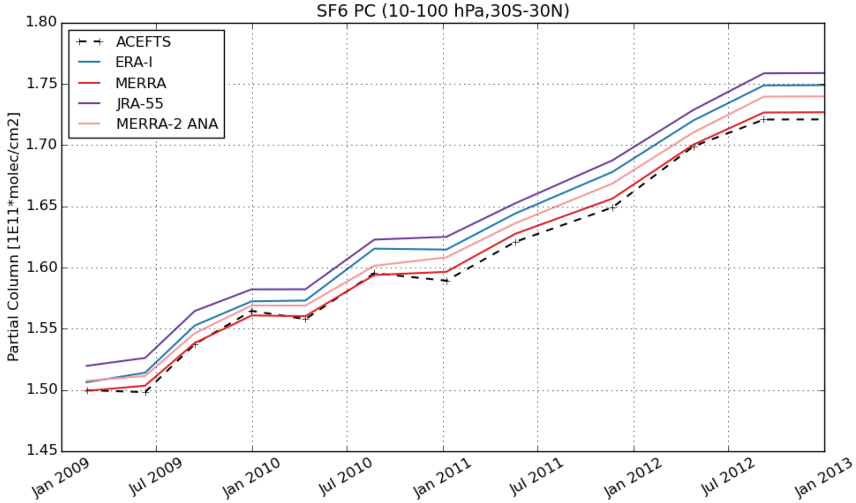
Direct comparison of SF_6 with ACE-FTS obs 2012 JJA



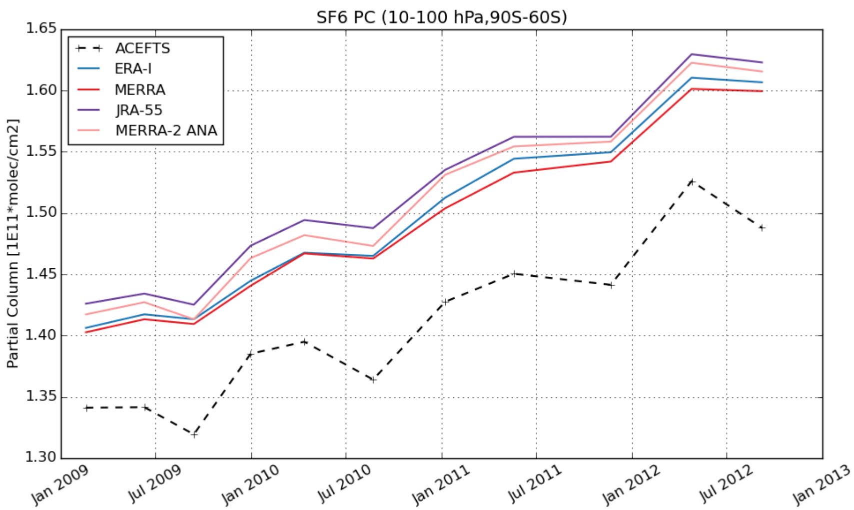
- Winter Vortex: obs decrease, not model
  → descent of air masses photochemically depleted in SF6 (not modelled)
- Process contaminates mid-latitude obs at 20km (?)

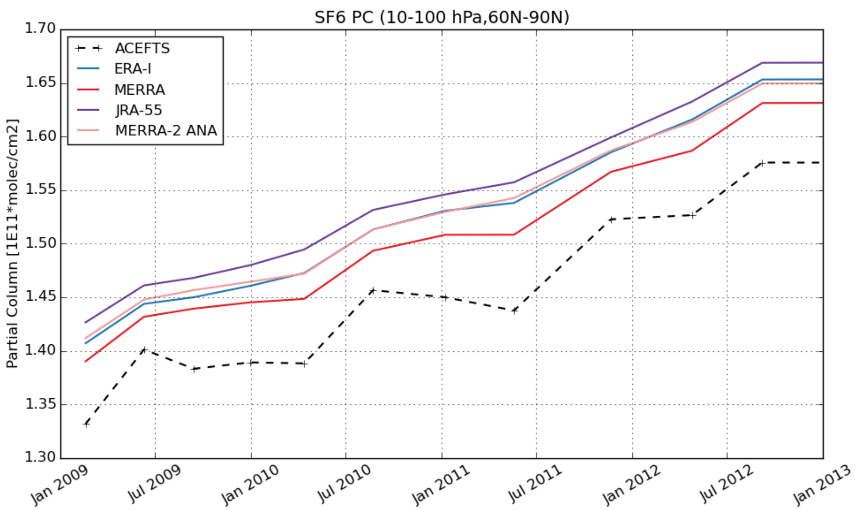
Direct comparison with ACE-FTS obs of SF6: Partial column 10-100hPa

Polar overestimation and model differences ~cst over 2009-2012

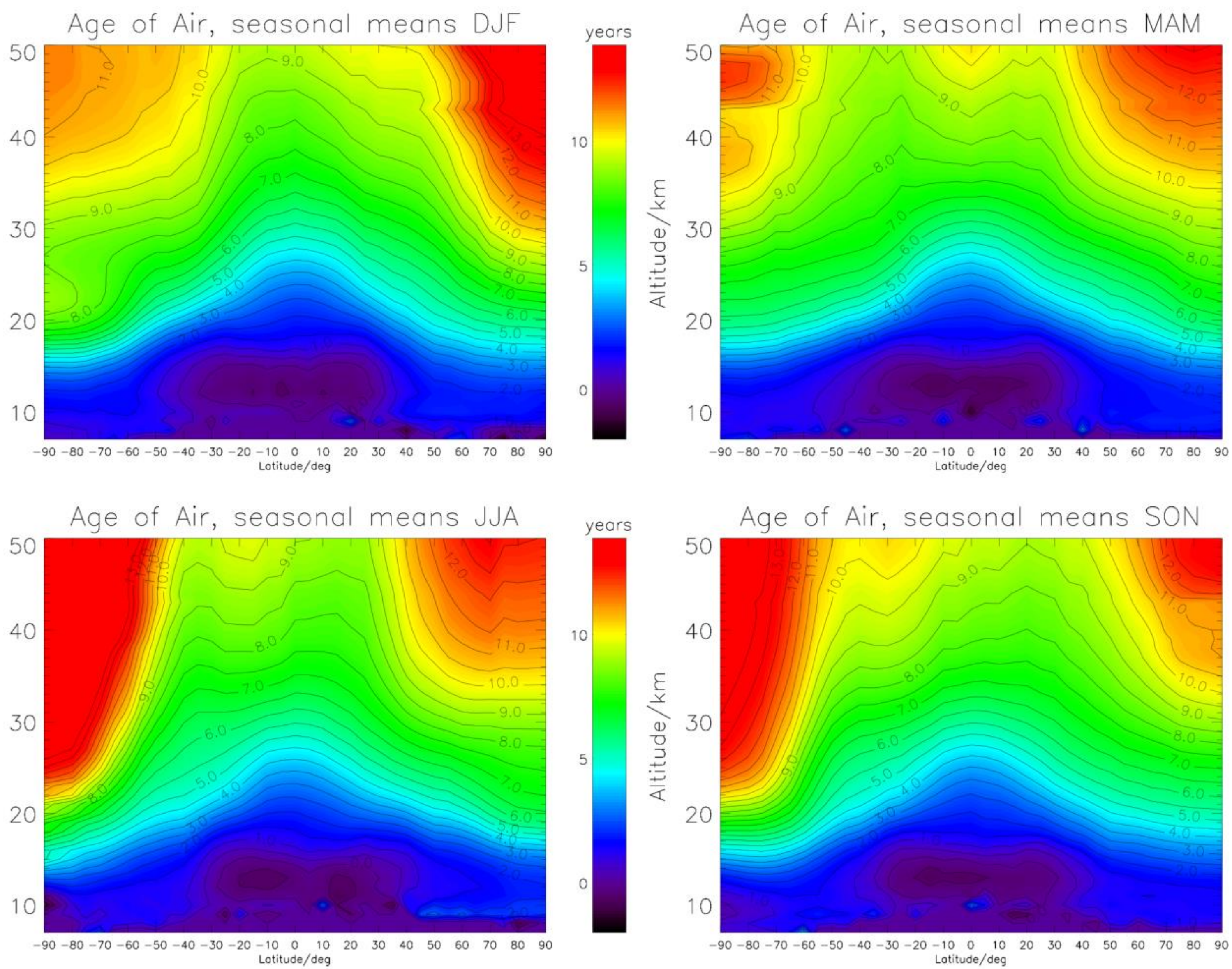


MERRA-2 and ERA-I agree very well over N.P. but not over S.P.



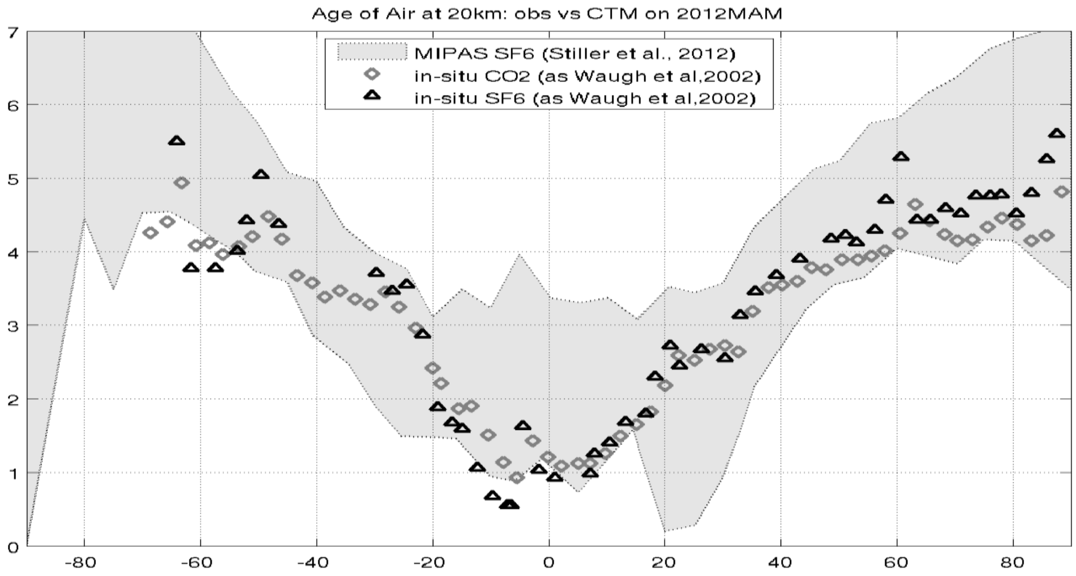


Latest obs dataset: MIPAS-IMK



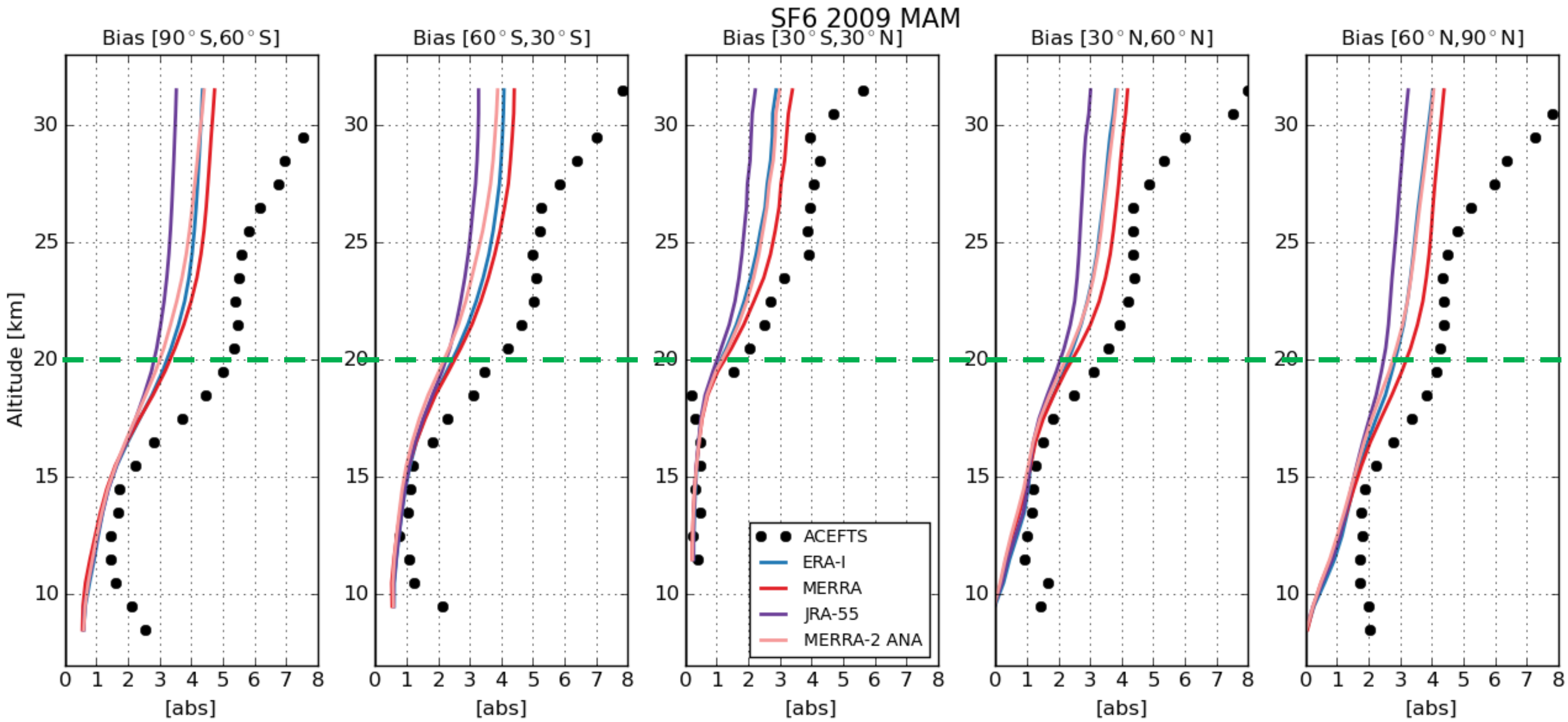
Haenel et al. (ACP, 2015)

Latest obs dataset: MIPAS-IMK

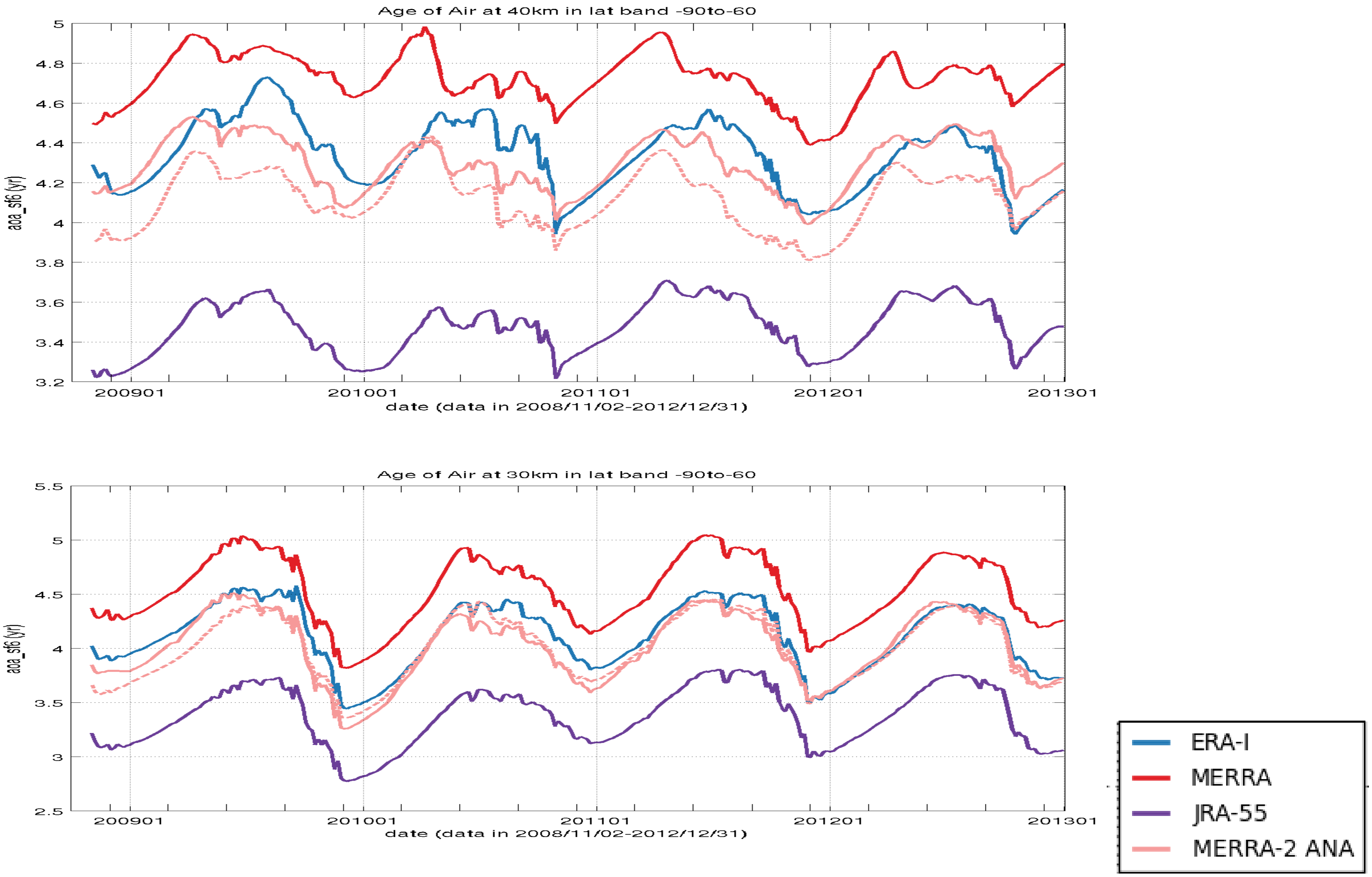


Here we simply use enveloppe of all MIPAS obs at 20km in previous retrieval (Stiller et al., ACP, 2012)

AoA comparison with ACE-FTS
2009 MAM

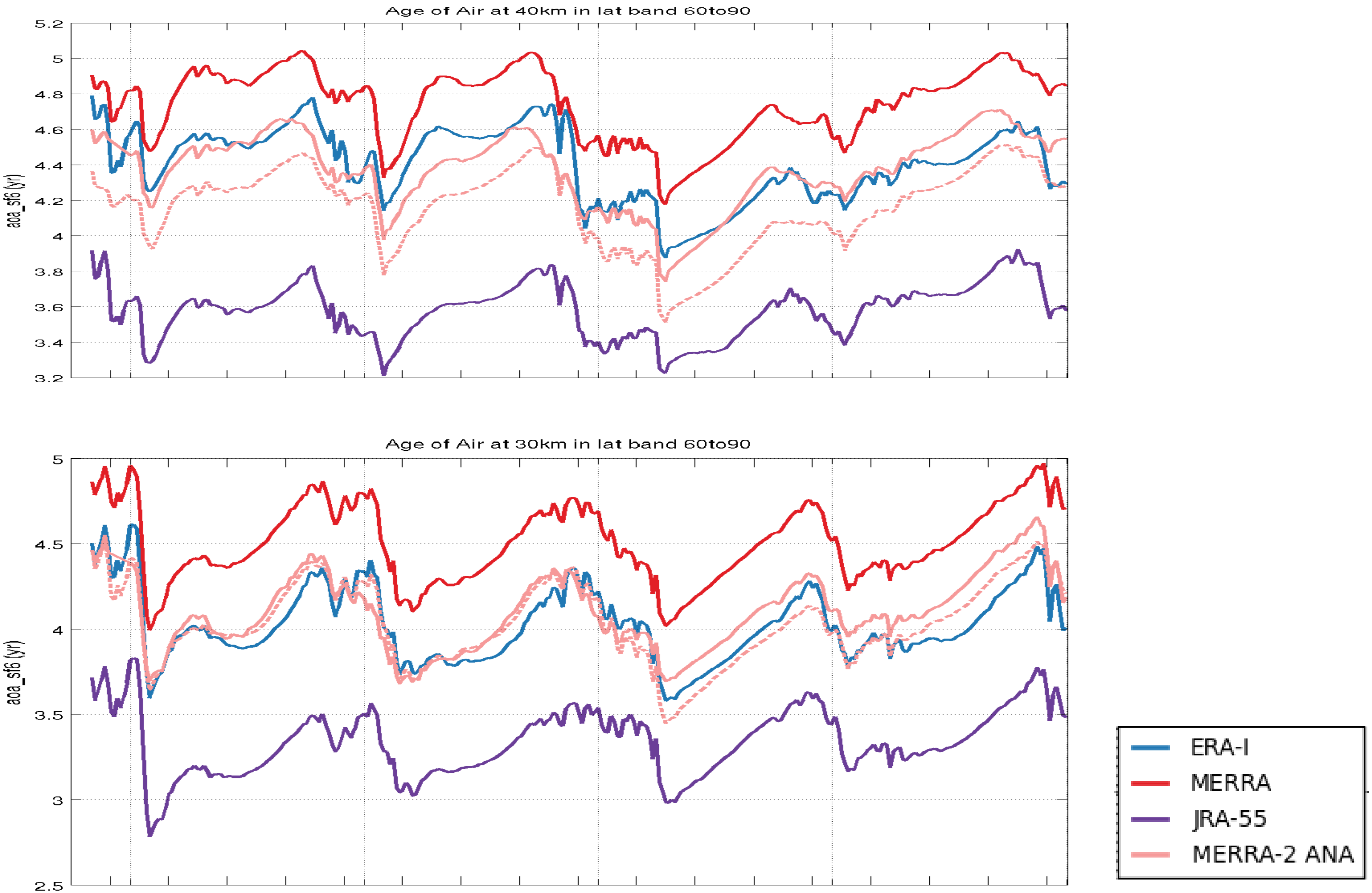


AoA at 30 and 40km using BASCOE TM: S.P. (90°S-60°S) timeseries 2009-2012



AoA at 30 and 40km using BASCOE TM: N.P. (60°N-90°N) timeseries 2009-2012

BIRA•IASB 1964•2014



Long-duration simulations: 1980-2012