Comparing the mean age of air since 1989 in five modern reanalyses: large disagreements using a kinematic transport model

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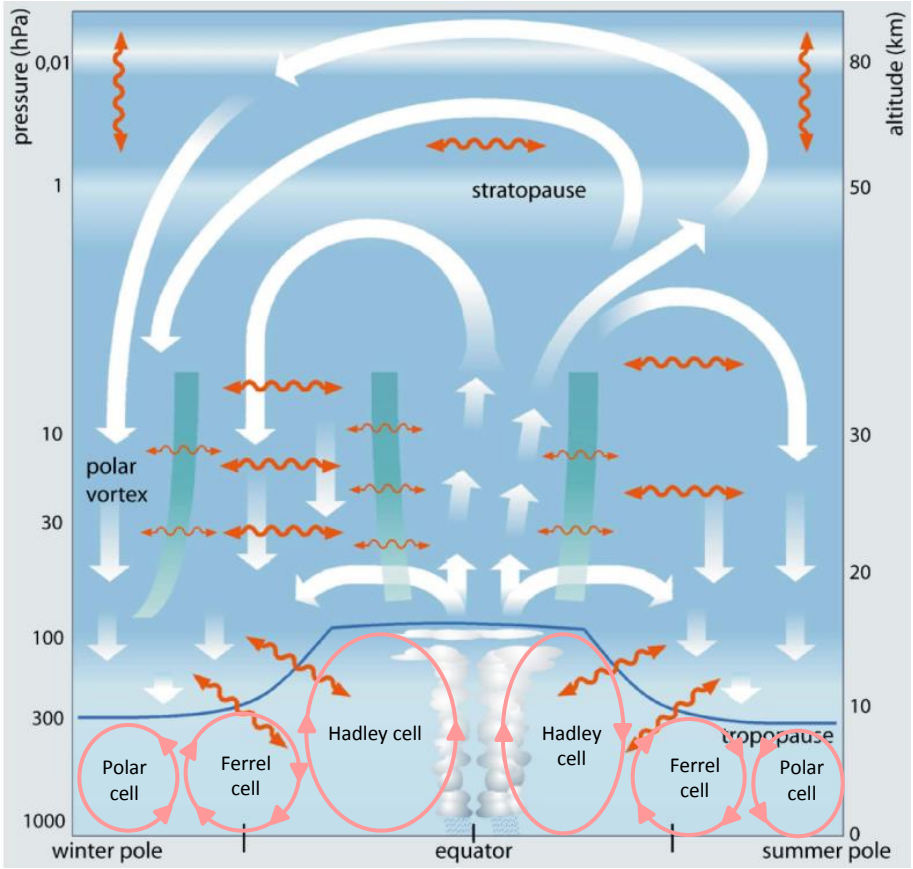
Intro: Brewer-Dobsdon Circulation (BDC)



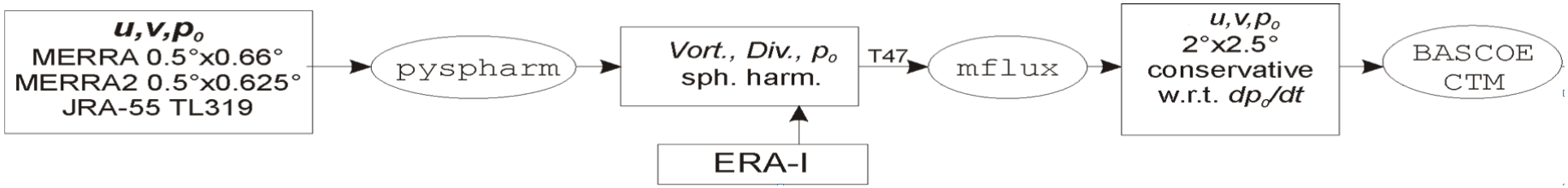
- BDC induced by planetary+gravity wave activity
- residual circulation (white arrows) + two-way mixing (orange double arrows)
- Mixing also accross transport barriers (green bands) and tropopause

After Bönisch et al., ACP, 2011

Intro: mean Age of Air (AoA)

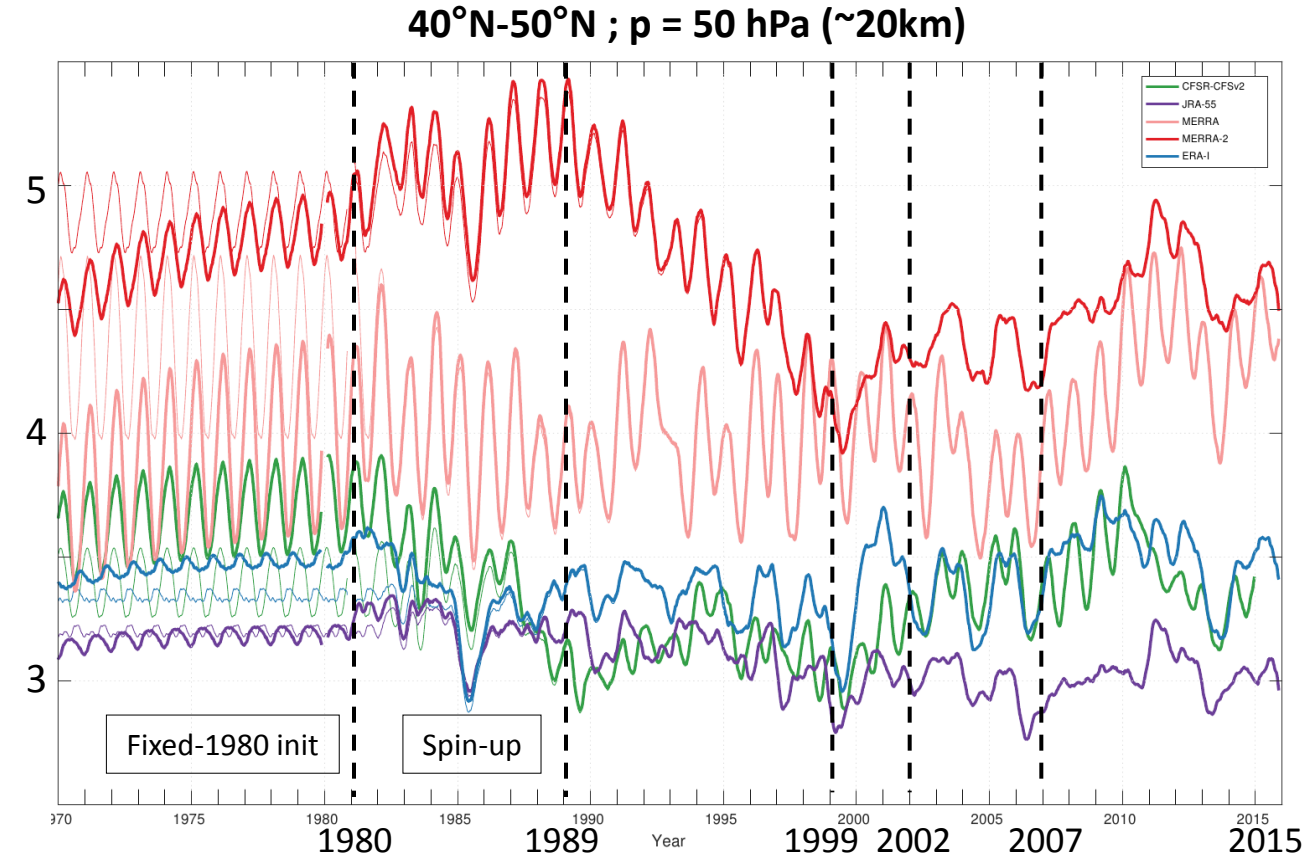
- Transit time [years] from surface (or tropopause) to various regions in stratosphere
- Obs estimates (in-situ or satellite) from tracers CO_2 or SF_6 (LBC: ~ exponential growth)
- Easy to model offline with synthetic tracer
- Classical diagnostic of BDC strength used to eval GCCM or reanalyses (e.g. ERA-I versus ERA-40)
- Note: offline transport models may be
  diabatic (*theta* vert. grid: vert. motion from heating rates) or
  kinematic (*hyb-p* vert. grid: vert. motion from mass conservation)

Methodology: offline transport using FFSLT



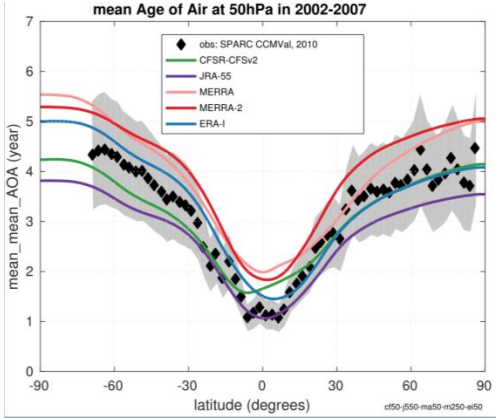
- Kinematic model: Uses only *u, v* (through *Vo, D*) and p_0 – not *T* !
- Coarse horiz grid: 2°x2.5° → All reanalyses are truncated to T47
- each reanalysis is run on its original (hybrid-pressure) vertical grid
- Applied on **ERA-I**, **MERRA-2**, **MERRA**, **JRA-55**, **CFSR/CFSv2**
- Simulated 1980-2015

Setting up the intercomparison

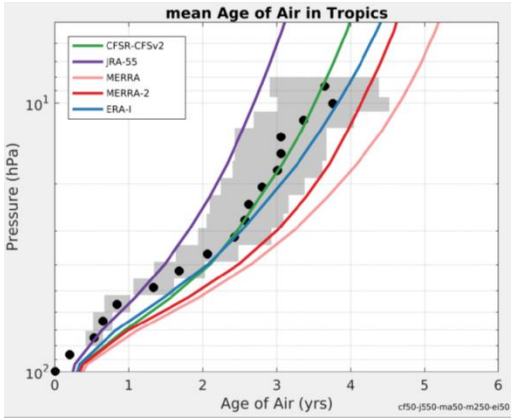


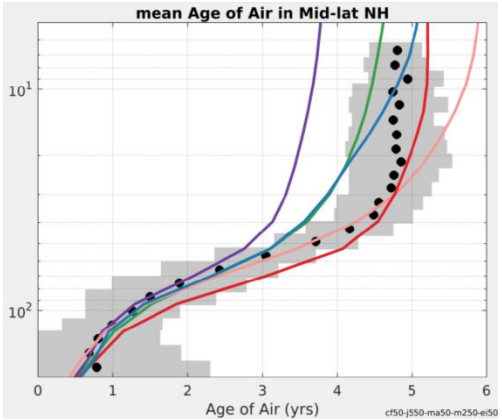
- Applied on **ERA-I**, **MERRA-2**, **MERRA**, **JRA-55**, **CFSR/CFSv2**
- Simulated 1980-2015 (I.C.: 20 years of fixed-year 1980)
- Init details unimportant only after spin-up = 9 years
- **Large differences between reanalyses:** abs. vals; ampl. season. and QBO cycles; trends
- ATOVS hiatus around 1999: clearly seen in MERRA-2 (seasonal ampl; trend)
- First compare 2002-2007 mean

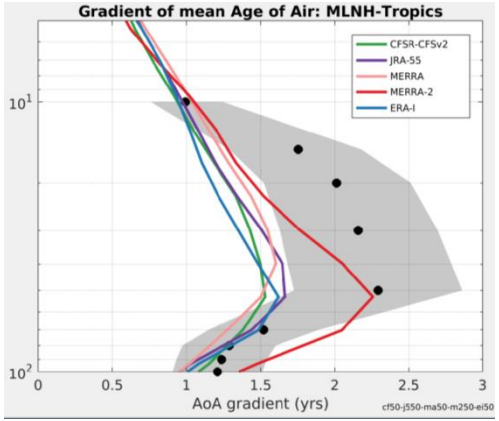
2002-2007 mean: lat and p profiles, Tropical ascent rate



- Large spread at 50 hPa (~20km): up to 1.5 yr at poles.
- **MERRA-2** and MERRA have older AoA, **JRA-55** youngest, **CFSR/CFSv2** young/intermediate (SH/NH), **ERA-I** intermediate
- Same hierarchy at higher levels, both in Tropics and mid-lat
- Lat gradient (MLNH-Tropics) evaluates tropical ascent rate: **all reanalyses ascend too fast above 50 hPa**…
- …. except for **MERRA-2** which ascends **too slow below 50 hPa**



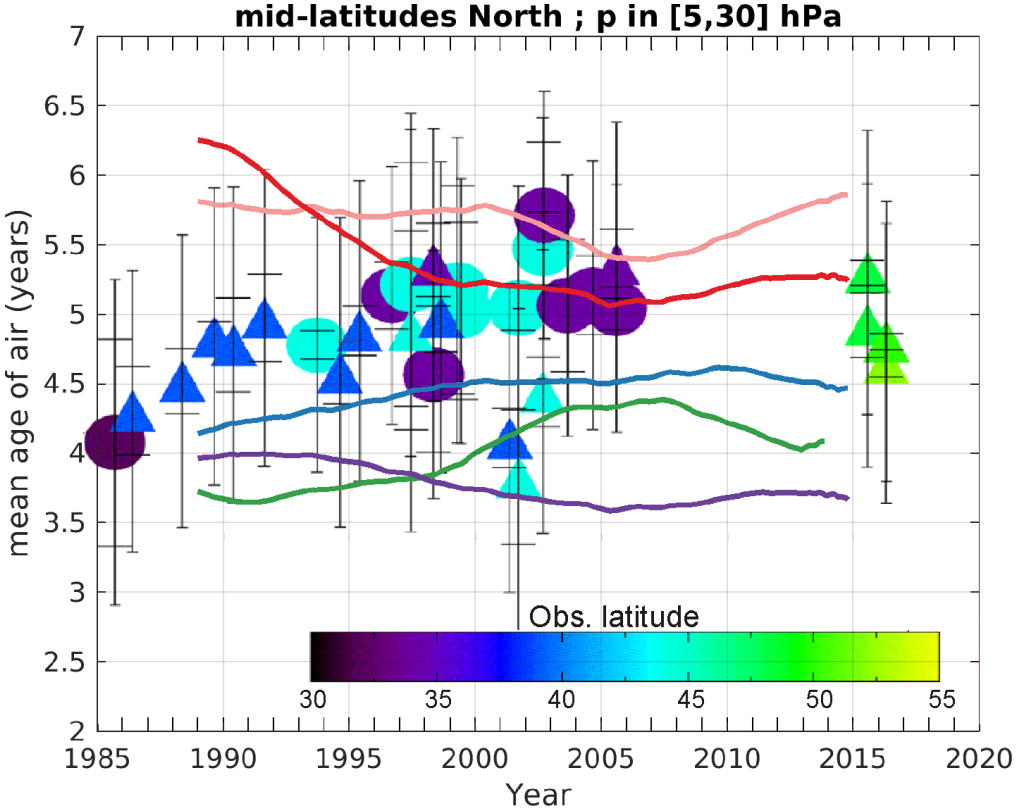




In-situ obs as in Chipperfield et al. (JGR, 2014)

Time evolution in mid-strato N. mid-lat. versus ballon obs

(Engel et al., 2017)



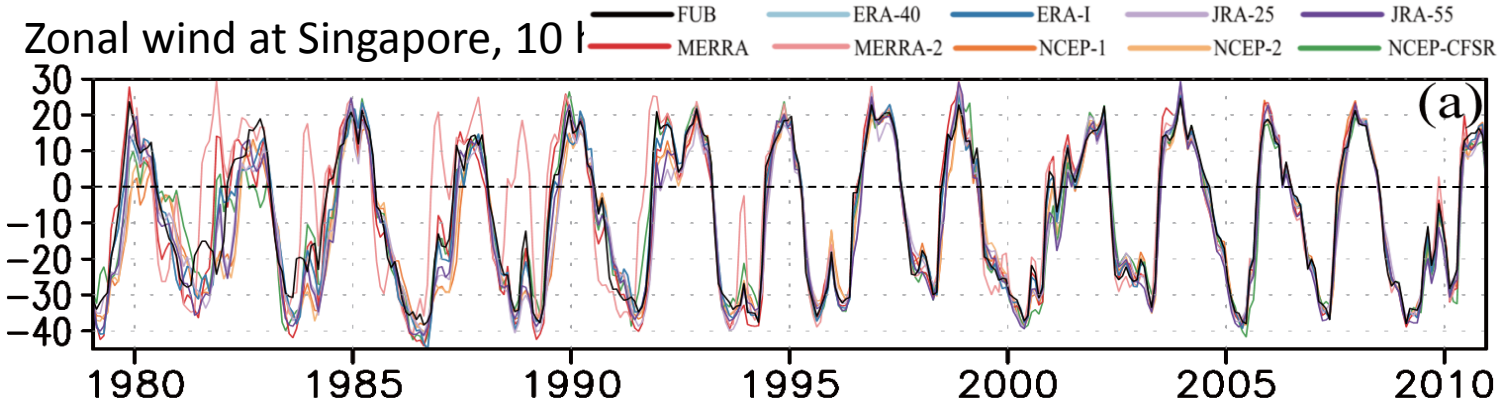
- Balloon obs are sparse
  → outer error bars include representativeness uncertainties
- MERRA, **MERRA-2** higher during 1980's
- **CFSR/CFSv2** lower during 1990's
  JRA-55 lower during early 2000's
- **ERA-I** : weakly positive trend over 1985-2015 seems to agree with obs but obs trend is not significant
- **ERA-I** : no overall trend after 2000 (unless one arbitrarily ends in 2010)
- **Clear disagreements between trends by 5 reanalyses** but no change > 0.5 yr over 1989-2015 (except for MERRA-2…)
- Reminder: results obtained with one specific CTM !

Why does MERRA-2 stand out?

Did I do anything wrong ("slave")?

- Initial confusion between ANA and ASM (incl. IAU) products. Here we use recommended ASM
- Proposal to use 6h time-averages (Pawson et al., JGR, 2007): rejected to be consistent w/other reanalyses
- AoA studies with SD-WACCM but they all use MERRA, not MERRA-2

→ Go back to litterature and check input ("master"):



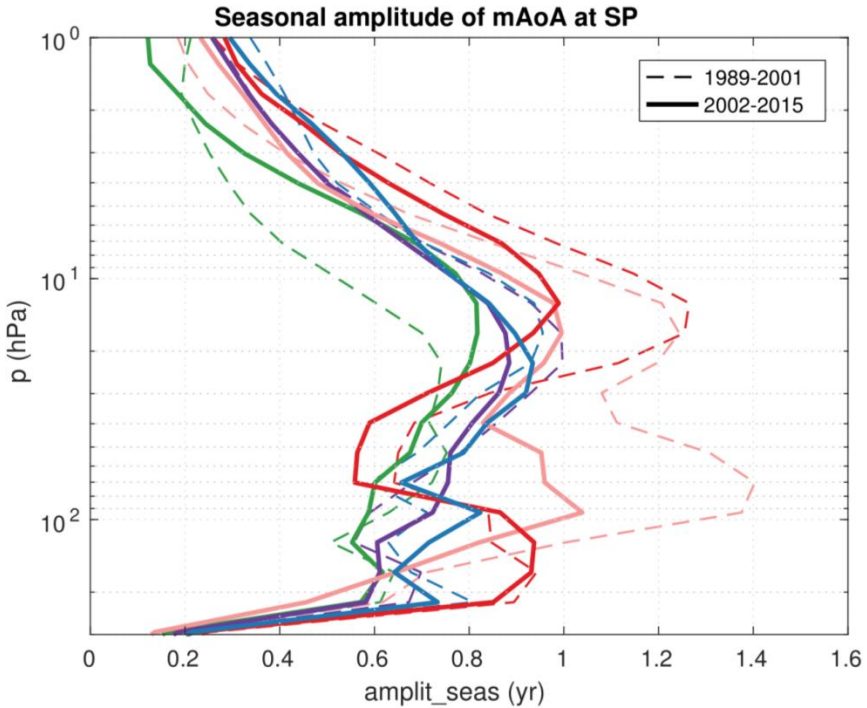
'*Before 1995, **MERRA-2** presents spurious semiannual variations in the 1980s and in late 1993, particularly during easterly phase of the QBO* " - Kawatani et al. (ACP, 2016).

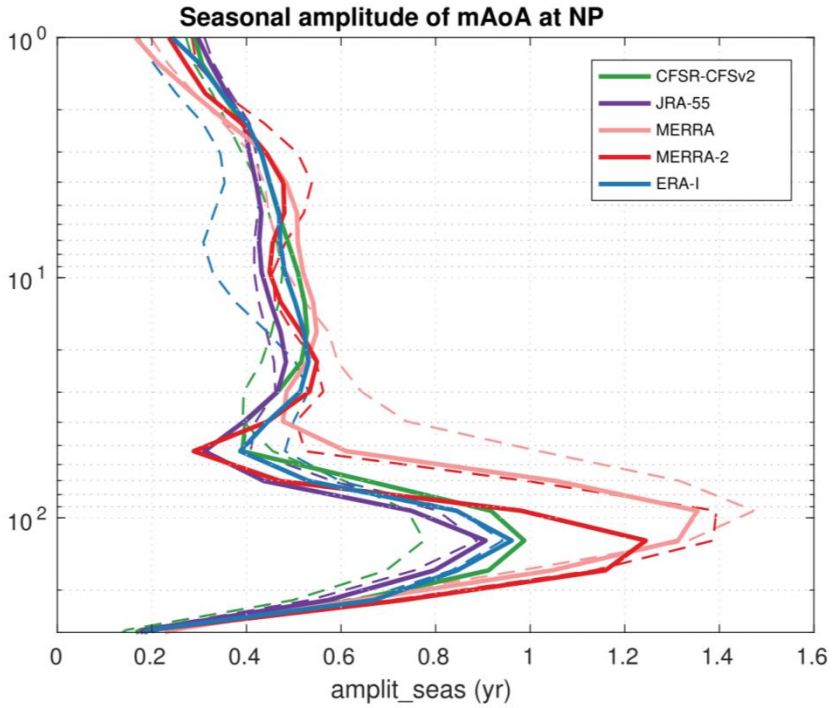
See also Coy et al. (J.Clim.,2016); Long et al. (ACPD, 2017)

Amplitude of seasonal variations at poles

- Vertical structure ~same for 5 reanalyses
- MERRA amplitudes twice larger than others
- **MERRA-2** larger at N.P., double max. at S.P.

- Amplitudes in MERRA, **MERRA-2** larger during early period (1989-2001)
- Opposite for **CFSR/CFSv2** above S.P.
- Amplitudes in **JRA-55** and **ERA-I** do not depend on considered period

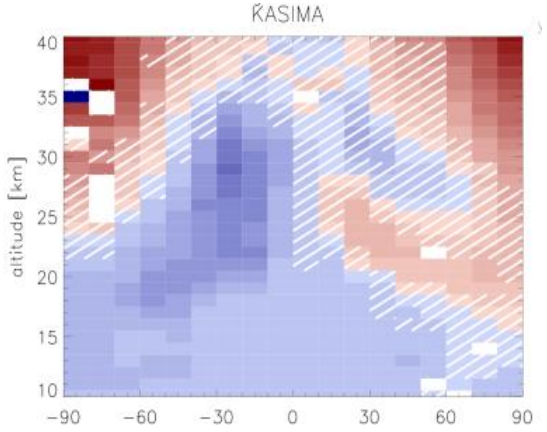




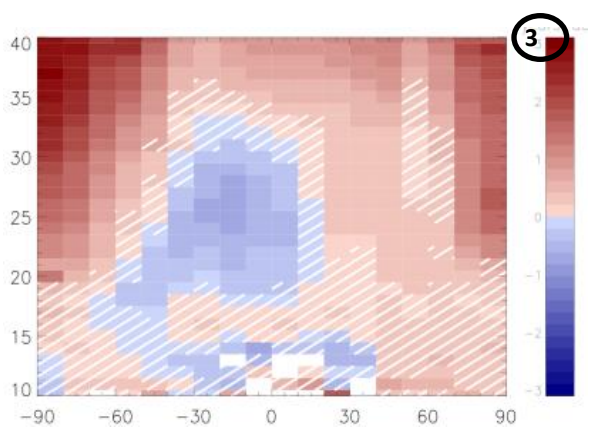
Trends of mean Age of Air (yr/dec): 2002-2012

- GCCMs systematically predict faster BDC → decreasing AoA during 21st century
- Mahieu et al. (Nature Geosci., 2014) showed HCl obs increase after 2007 in northern lower strato. Used transport model driven by ERA-I: for 2005-2010 AoA in NH gets older, not younger (dipole structure of AoA trends) → interpreted as slowdown of BDC in NH
- Haenel, Stiller et al. (ACP, 2015) confirmed this with satellite obs (MIPAS SF6) and GCCM nudged to ERA-I
- Here confirmed as well (for period 2002-2012!)

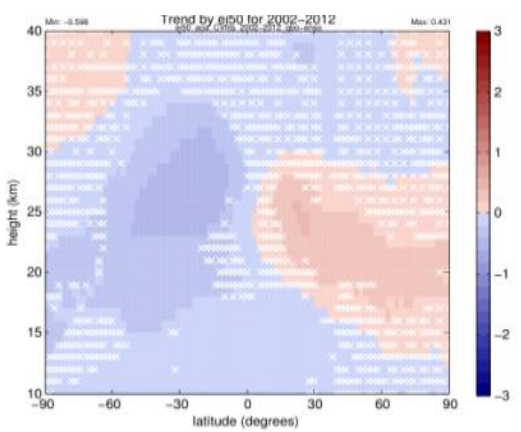
ERA-I + GCCM KASIMA



MIPAS SF_6



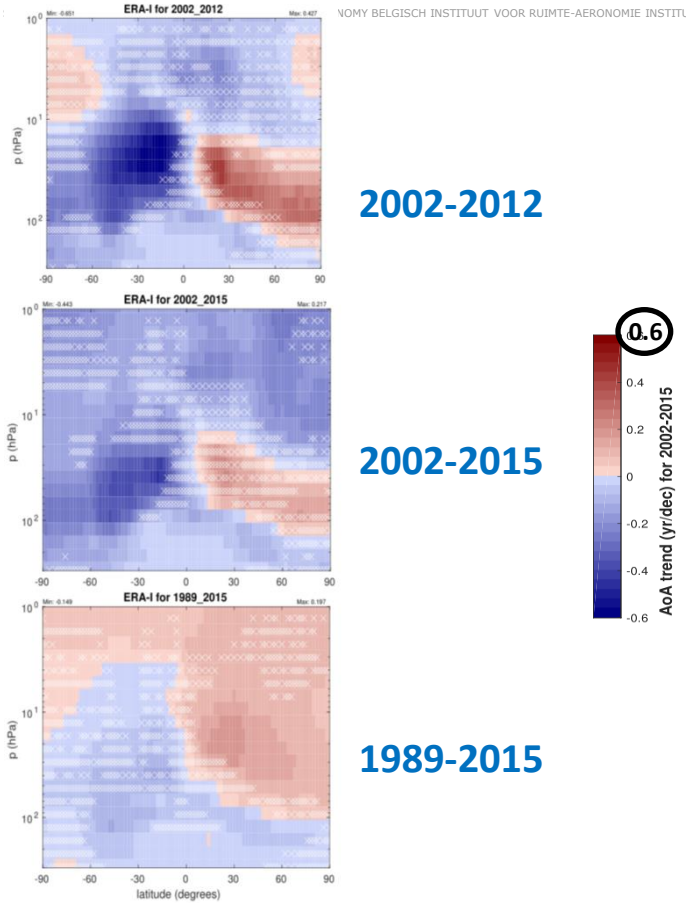
ERA-I + BASCOE CTM



Haenel, Stiller, et al., ACP, 2015

(SF6 has photochem losses in mesosphere→ larger apparent AoA in polar regions)

Trends of mean Age of Air in ERA-I: depends on considered period



2002-2012

2002-2015

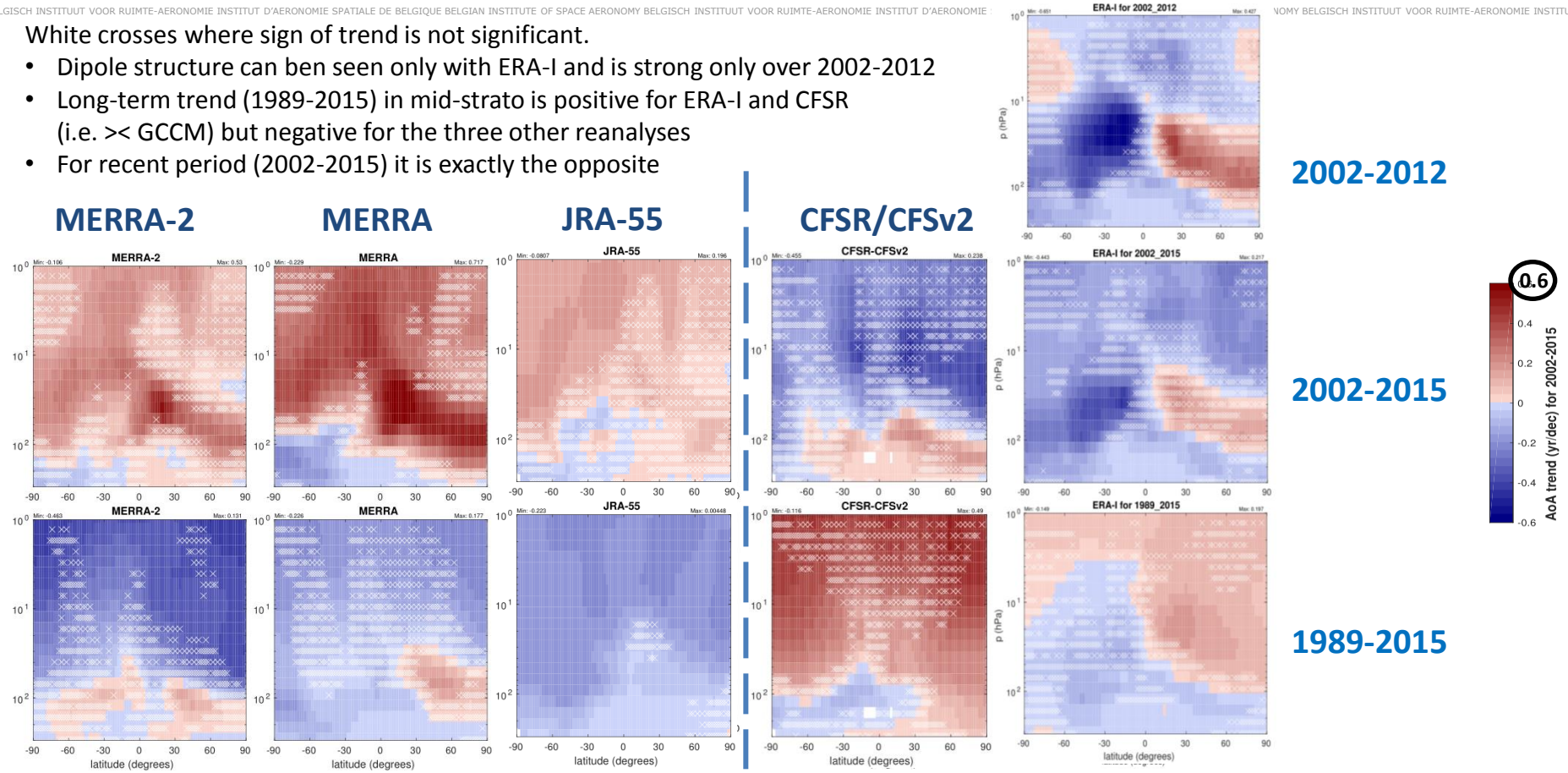
1989-2015

See also poster by B. Monge-Sanz

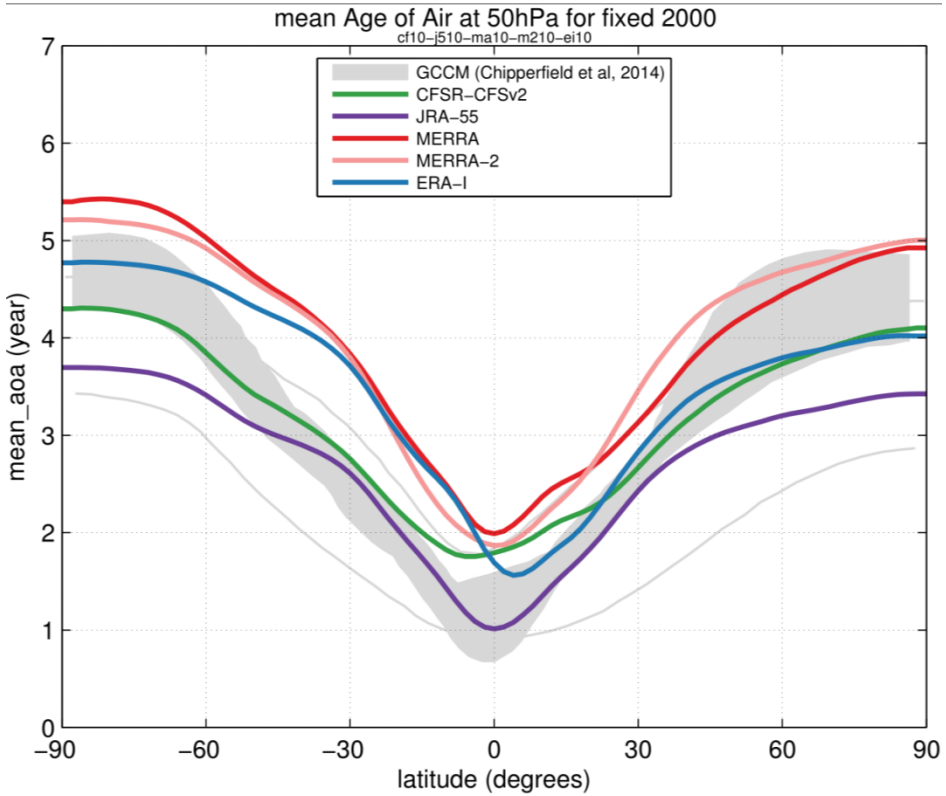
S-RIP Trends of mean Age of Air (yr/dec)

White crosses where sign of trend is not significant.

- Dipole structure can ben seen only with ERA-I and is strong only over 2002-2012
- Long-term trend (1989-2015) in mid-strato is positive for ERA-I and CFSR (i.e. >< GCCM) but negative for the three other reanalyses
- For recent period (2002-2015) it is exactly the opposite



Outlook: compare with GCCMs



Grey: GCCM intercomparison (Chipperfield et al., 2014)

- Envelope: 5 GCCM
- 2 lines: outlying GCCM with coarse vert. resol. (L39)

Spread of reanalyses (using winds only) >= spread of GCCMs

(see also poster by B. Monge-Sanz)

Summary and conclusions

I. AoA in 5 modern reanalyses are compared with a kinematic transport model using native vertical grids and common (coarse) horizontal grid.

II. Large differences are found, with **spread at least as large as between GCCMs: Residual Circulation from wind fields alone does not seem well constrained by assimilation**

III. JRA-55, CFRS/CFSv2 quite young; MERRA, MERRA-2 quite old; ERA-I in between and seems to agree best with (sparse!) dataset of balloon obs

IV. MERRA-2 problematic before 1995

V. tropical ascent rate seems **too fast in all reanalyses** except for MERRA-2 which is **too slow below 50 hPa**

VI. In MERRA and MERRA-2 , the amplitudes of seasonal variations depend on considered period (assim artifact?)

VII. Linear trends of ERA-I AoA for 2002-2012 has same dipole structure as found in MIPAS SF_6 (as in earlier modelling studies) but for 2002-2015 this dipole in ERA-I is weaker and not found with any other reanalysis

VIII. Large disagreements also in trends: for 2002-2015, ERA-I and CFSR yield *decreasing* AoA trends in middle strato but MERRA, MERRA-2, JRA-55 yield *increasing* trends; for 1989-2015 it is exactly the opposite…

IX. Results should be confirmed with other types of transport models (diabatic; nudged GCCMs).

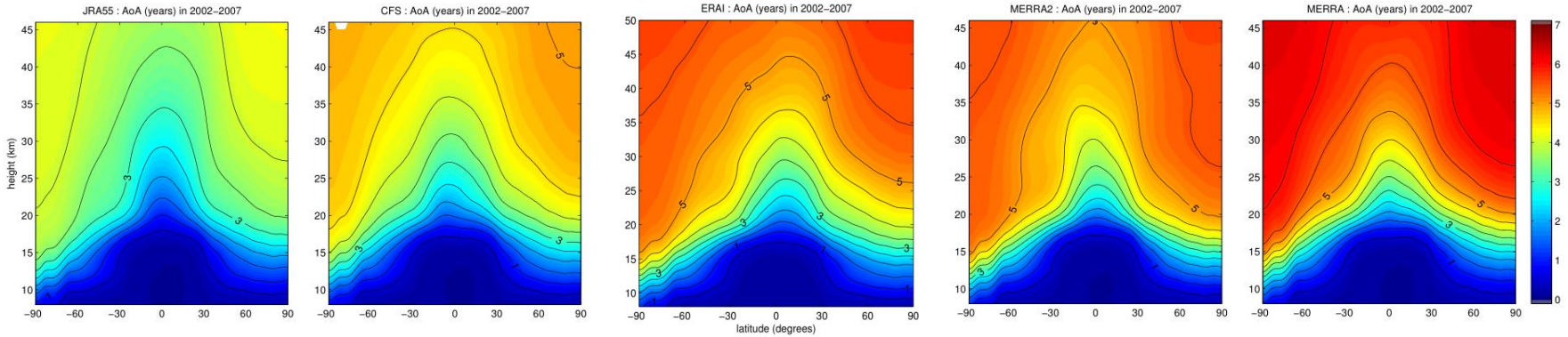
X. Next steps: quantitative comparisons with obs ; comparisons with GCCMs

Paper will be submitted shortly to ACP (S-RIP special issue)

Merci !

Extra slides…

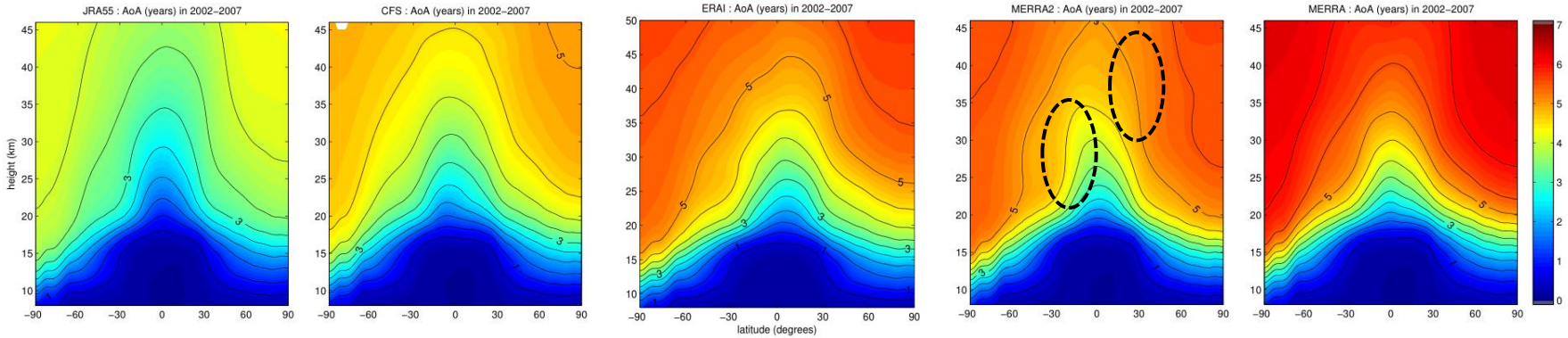
Absolute values: 2002-2007 mean



JRA-55 **CFSR/CFSv2** **ERA-I** **MERRA-2** **MERRA**

youngest: max(AoA) < 4.5 yr **oldest: max(AoA) >= 6 yr**

Absolute values: 2002-2007 mean



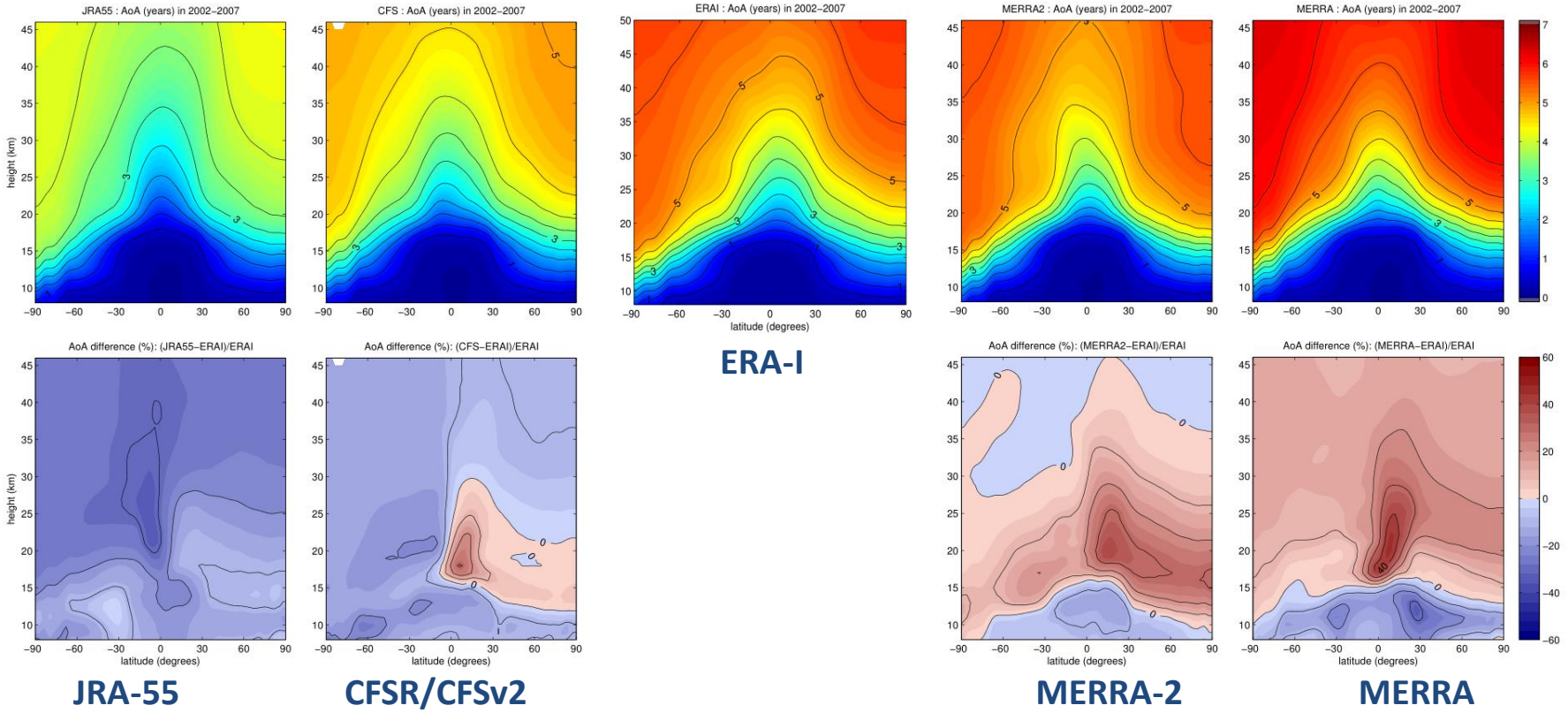
JRA-55 **CFSR/CFSv2** **ERA-I** **MERRA-2** **MERRA**

youngest: max(AoA) < 4.5 yr

oldest: max(AoA) >= 6 yr

Vertical isolines
not in MIPAS obs

2002-2007 mean: relative diff. w.r.t. ERA-I

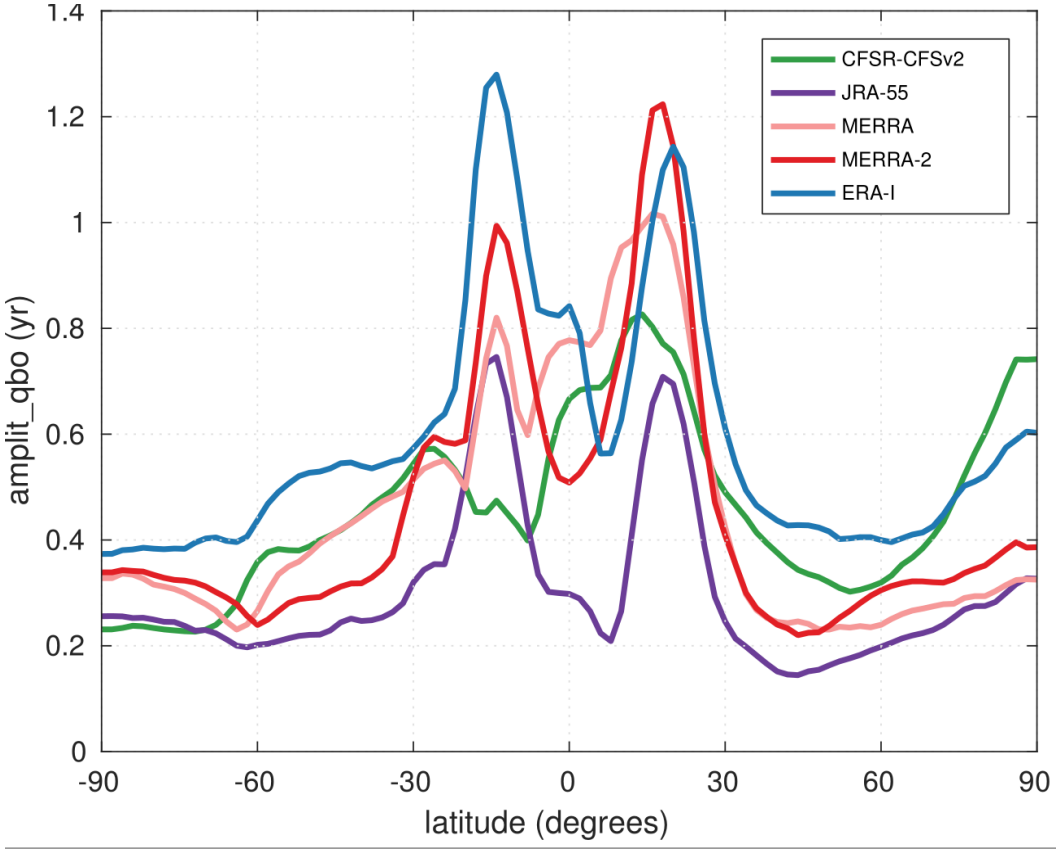


ERA-I

JRA-55 **CFSR/CFSv2** **MERRA-2** **MERRA**

Largest relative differences are in **tropical lower strato**

Amplitude of QBO at 30 hPa

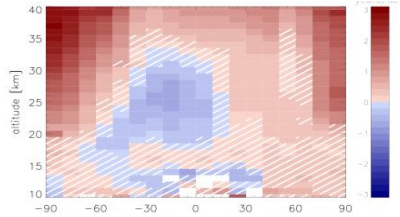


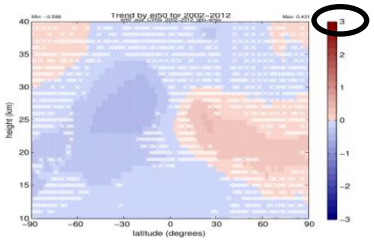
- Max at ~15°N and 15°S and min at equator - except in **CFSR/CFSv2**.
- QBO amplitudes by **ERA-I**, and **MERRA-2** twice larger than by **JRA-55**

Trends of mean Age of Air (yr/dec): a compilation

2002-2012

MIPAS (Haenel et al., 2015)

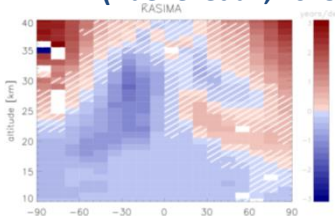




ERA-I

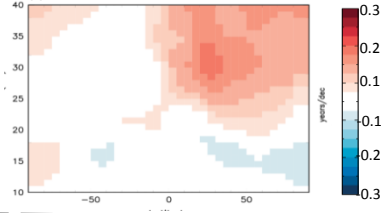
Chabrillat et al., 2017

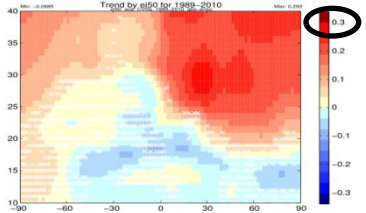
ERA-I (Haenel et al., 2015)

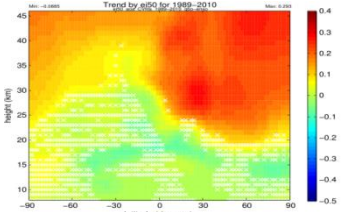


1989-2010

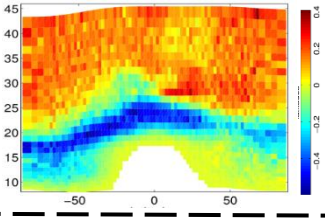
ERA-I (Monge-Sanz et al., 2012)





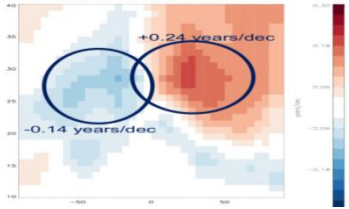


ERA-I (Diallo et al., 2012)

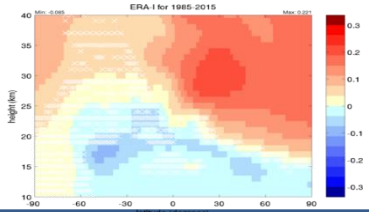


1990-2013

ERA-I (Monge-Sanz update)

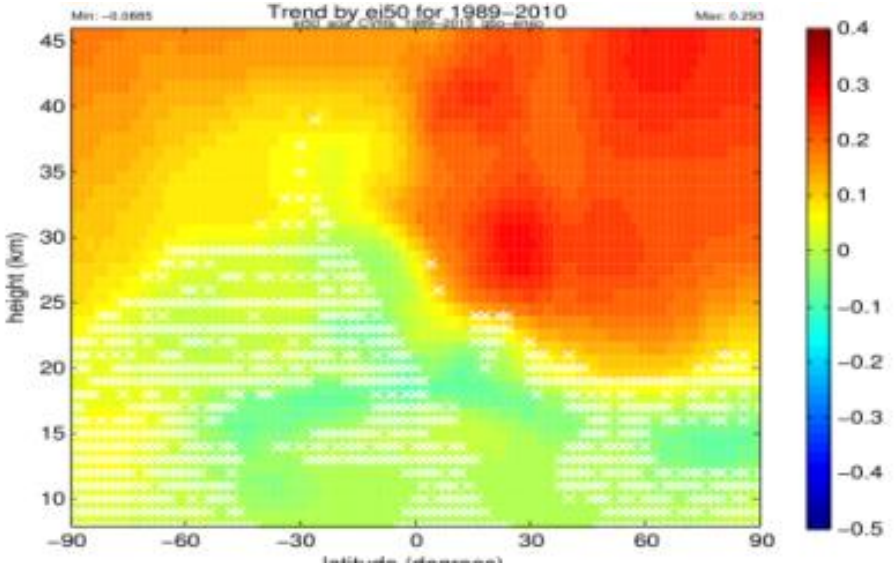


1985-2015



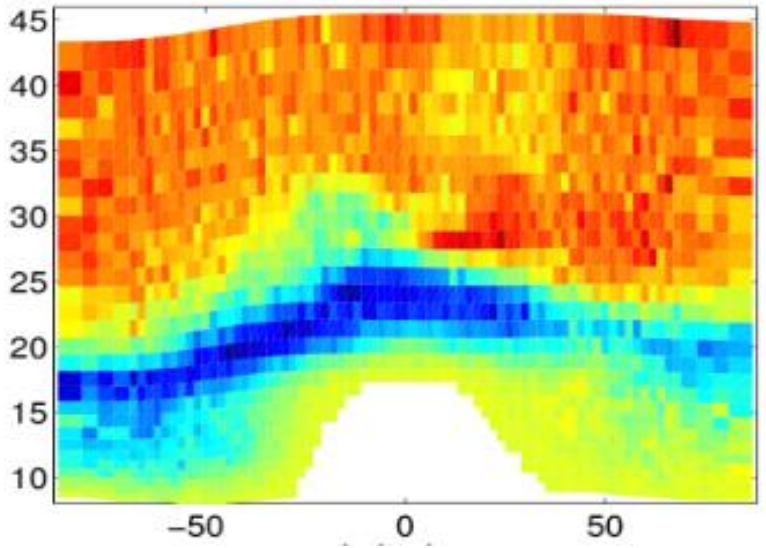
Outlook: use other types of transport models

AoA trends in ERA-I over 1989-2010



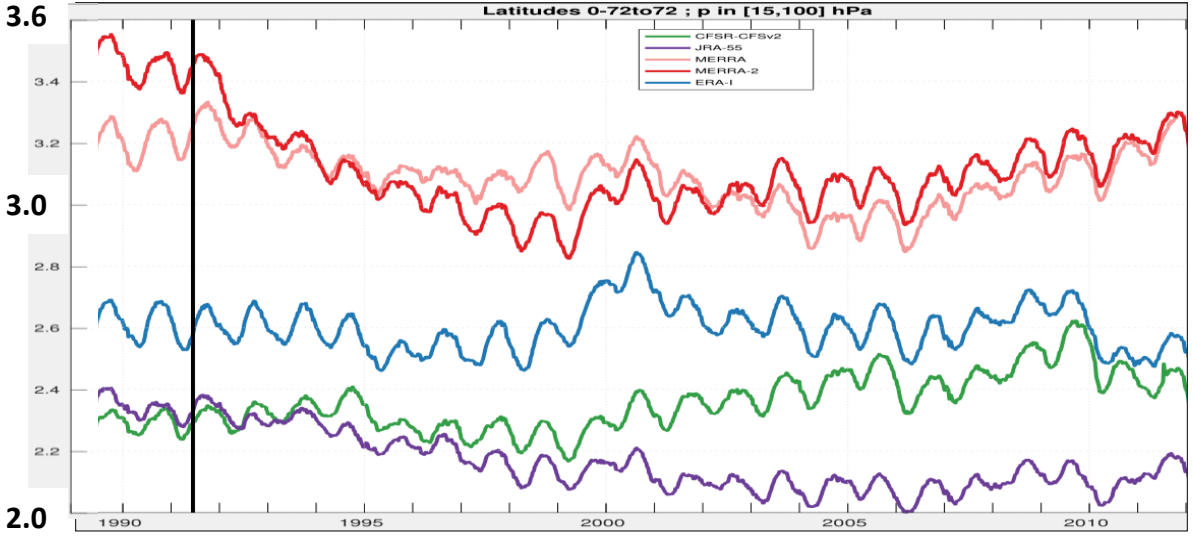
BASCOE CTM (this work)

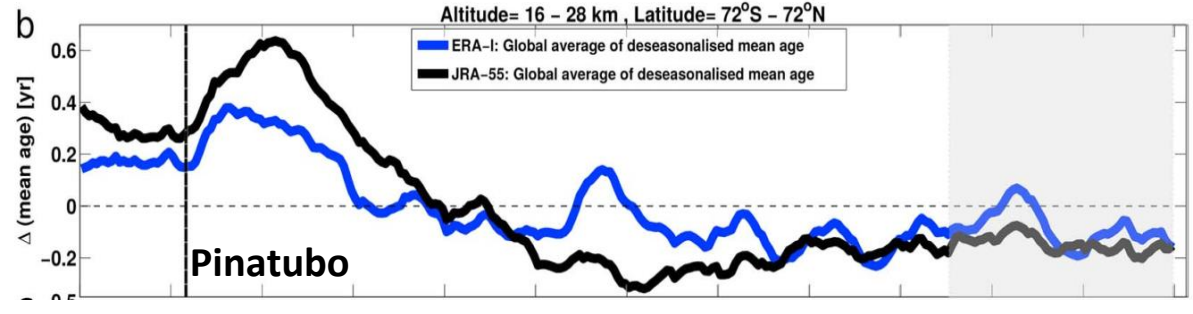
ERA-I (Diallo et al., 2012)



TracZilla (Diallo et al., 2012)

No clear sign of Pinatubo eruption…



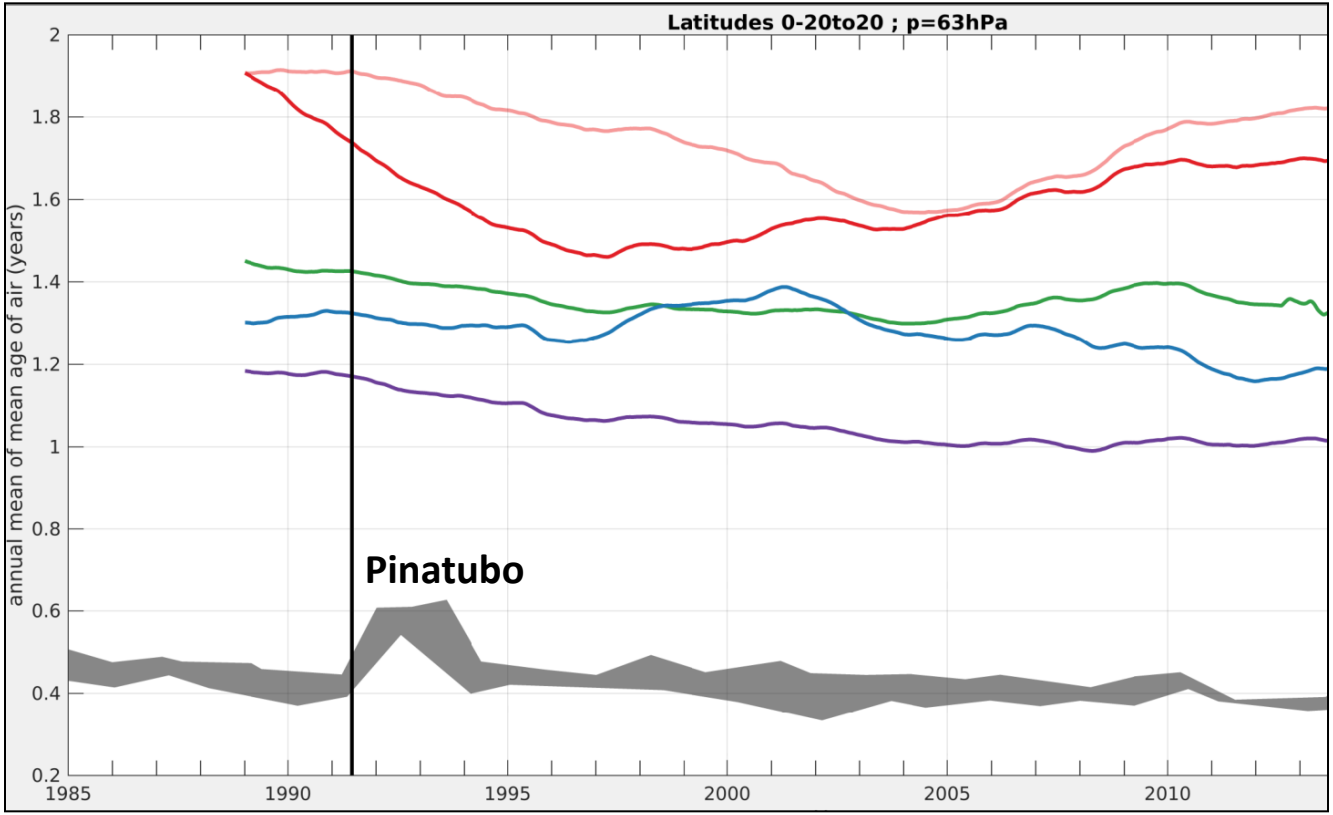


… while another offline transport model (Diallo et al., GRL, 2017) does find it with ERA-I and JRA-55.
How come?

- Strato aerosols in underlying models *do not know* about eruptions
  → reanalyses rely entirely on assim of radiances (i.e. *T*)
- Transport model in D2017 is diabatic
  → vert. grid based on (assim.) *T*
- Our transport model is kinematic
  → AoA derived from wind fields shows not Pinatubo impact

Diallo et al., GRL, 2017

Outlook: compare timeseries with GCCMs



Comparison with **GCCM SOCOL**:
Tropics, 63hPa

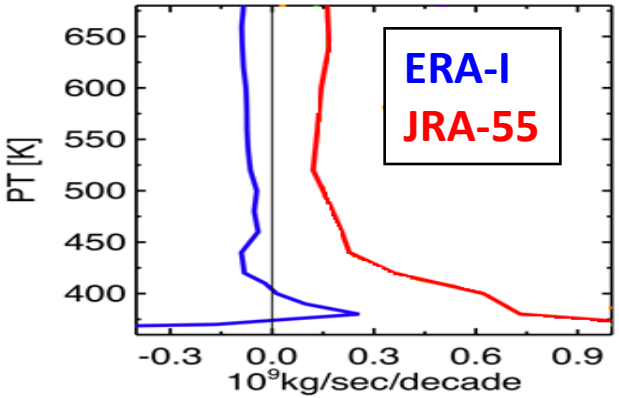
Muther et al.:
Stratospheric age of air variations between 1600 and 2100 (GRL, 2016)

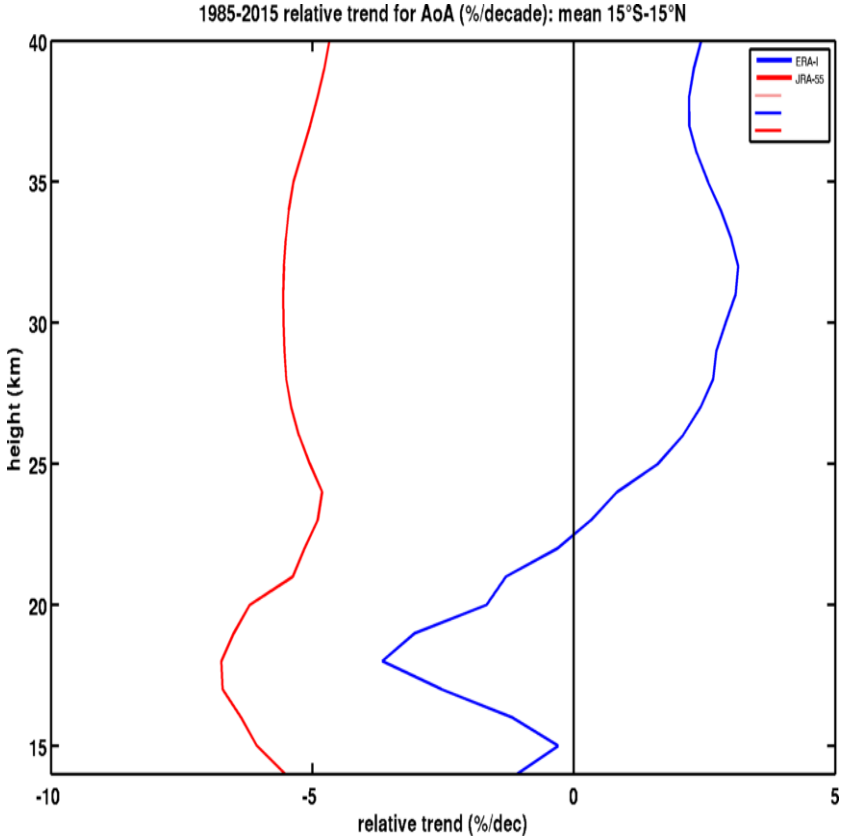
Trend of AoA in Tropics versus trend of tropical upward mass flux

Flux increases

→ AoA should decrease: OK!

Miyazaki et al. (ACP, 2016): 1979-2012 trend of Tropical upward flux (DJF)





Tropical z=[14,17,26] km at θ=[370,400,675] K