The age of air among three reanalysis

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Motivation

- Representing Brewer-Dobson Circulation and its trend under global change is important for the composition and chemistry of the stratosphere, and ist effect upon climate.
- We investigate her the BDC in recent modern reanalysis.
- Mean age of air is a metric of the Brewer-Dobson circulation which can be directly compared to observations of long-lived species like CO2 and SF6.
- However, mean age is elusive, and can be tuned to fit the observations. It is useful to use more detailed diagnostics of the Brewer-Dobson circulation and to combine age with other metrics (effective diffusivity, mean mass flux)
- Variability of the age, correlation with the QBO
- Age spectra
- Comparisons (MERRA / ERA-Interim / JRA55)
- Trends

Most GCMs exhihit an increase of the
Brewer-Dobson circulation
Past and future trend of the tropical upwelling
Garny et al., JGR 2011

Outline

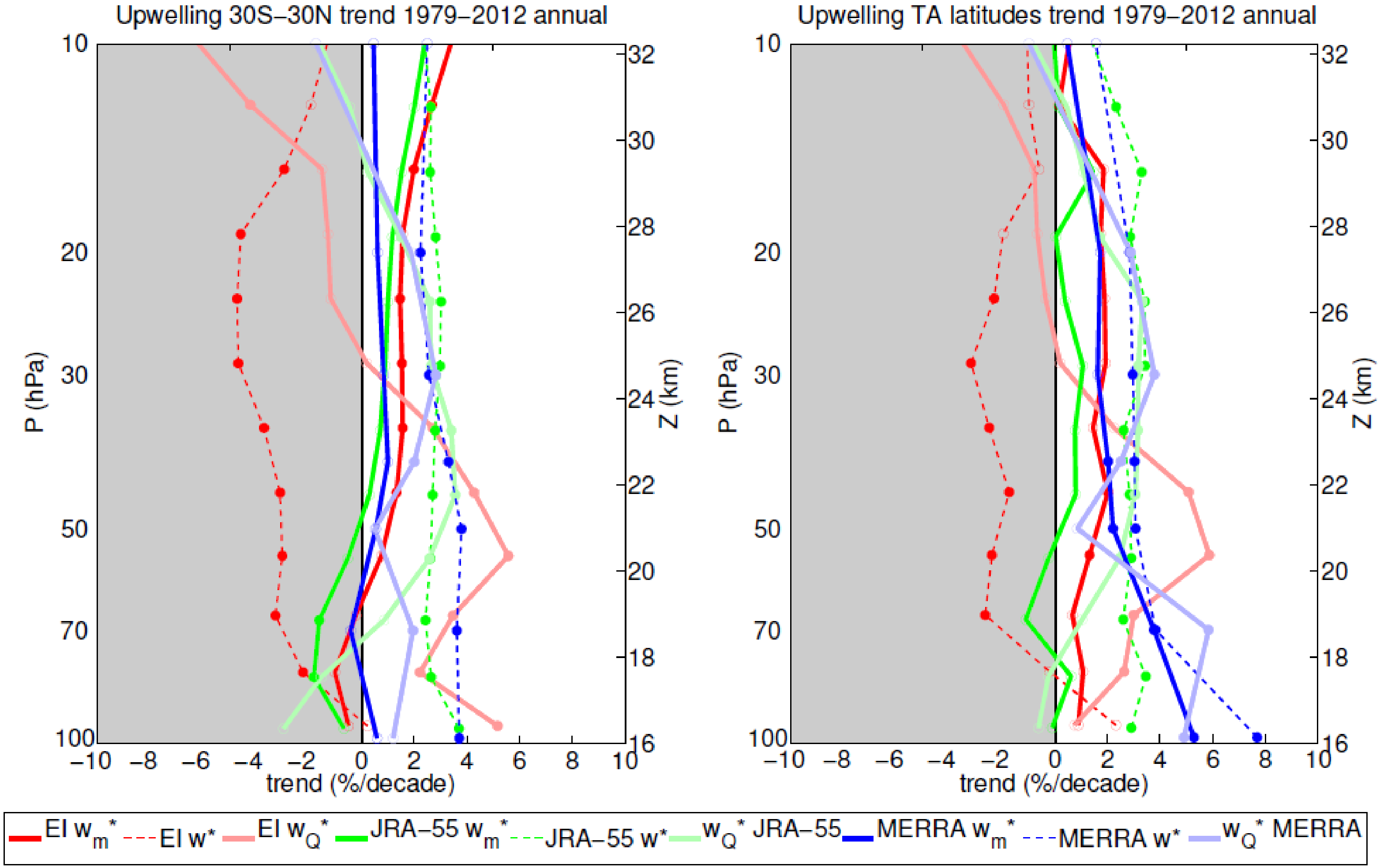
- Mean meridional circulation
- Effective diffusivity (see poster by Abalos et al.)
- Mean age
- Trends
- Annual cycle
- Age and QBO
- Age spectra
- Trajectories

Trends in tropical upwelling (1979-2012)

EI JRA-55 MERRA

30S-30N

Turnaround lats (TA)



Significant at 95%

Positive trends over the layer 100-10 hPa in most estimates

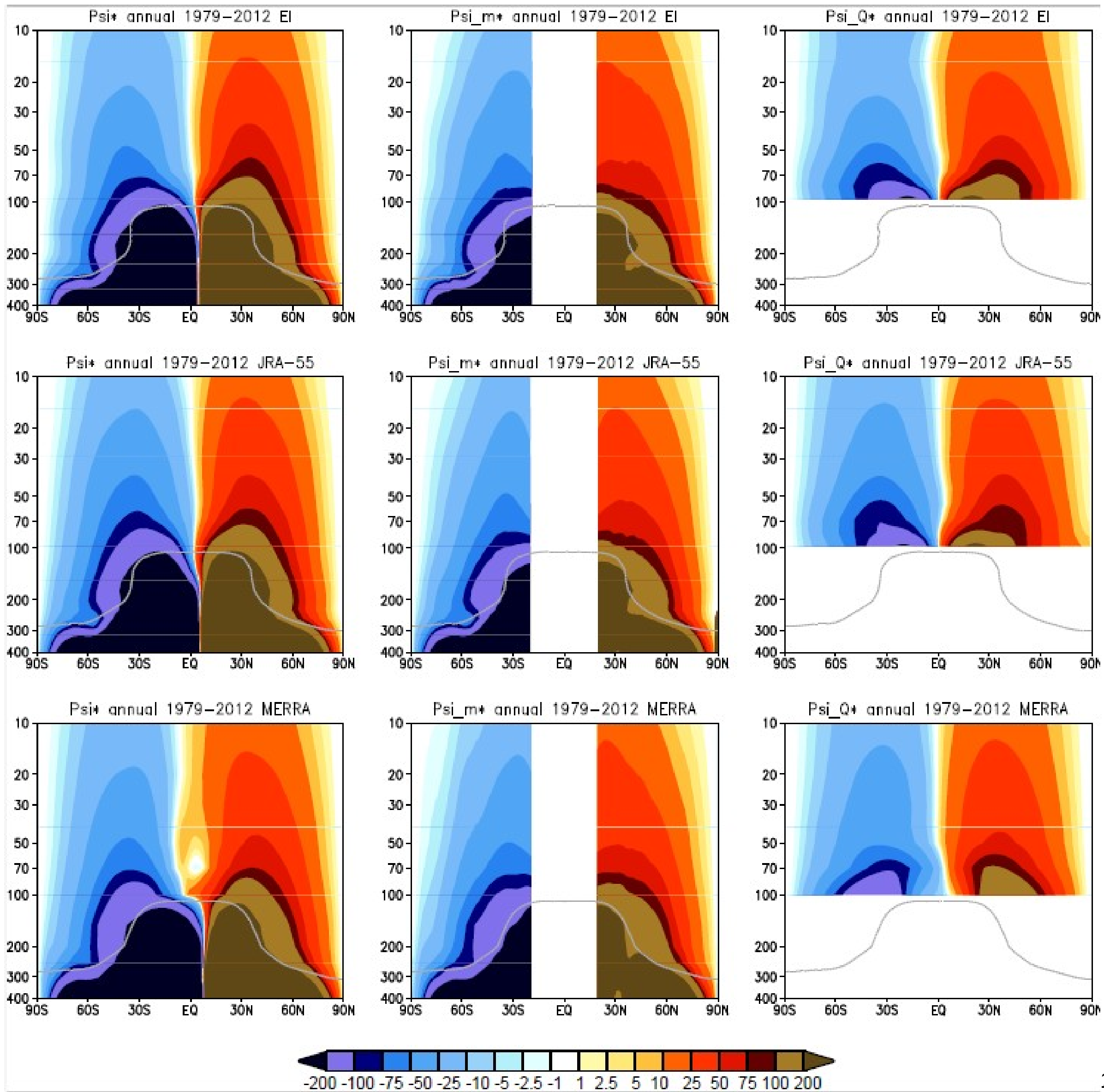
Climatology of BDC streamfunction

	Ψ^*	Ψ_m^*	Ψ_Q^*

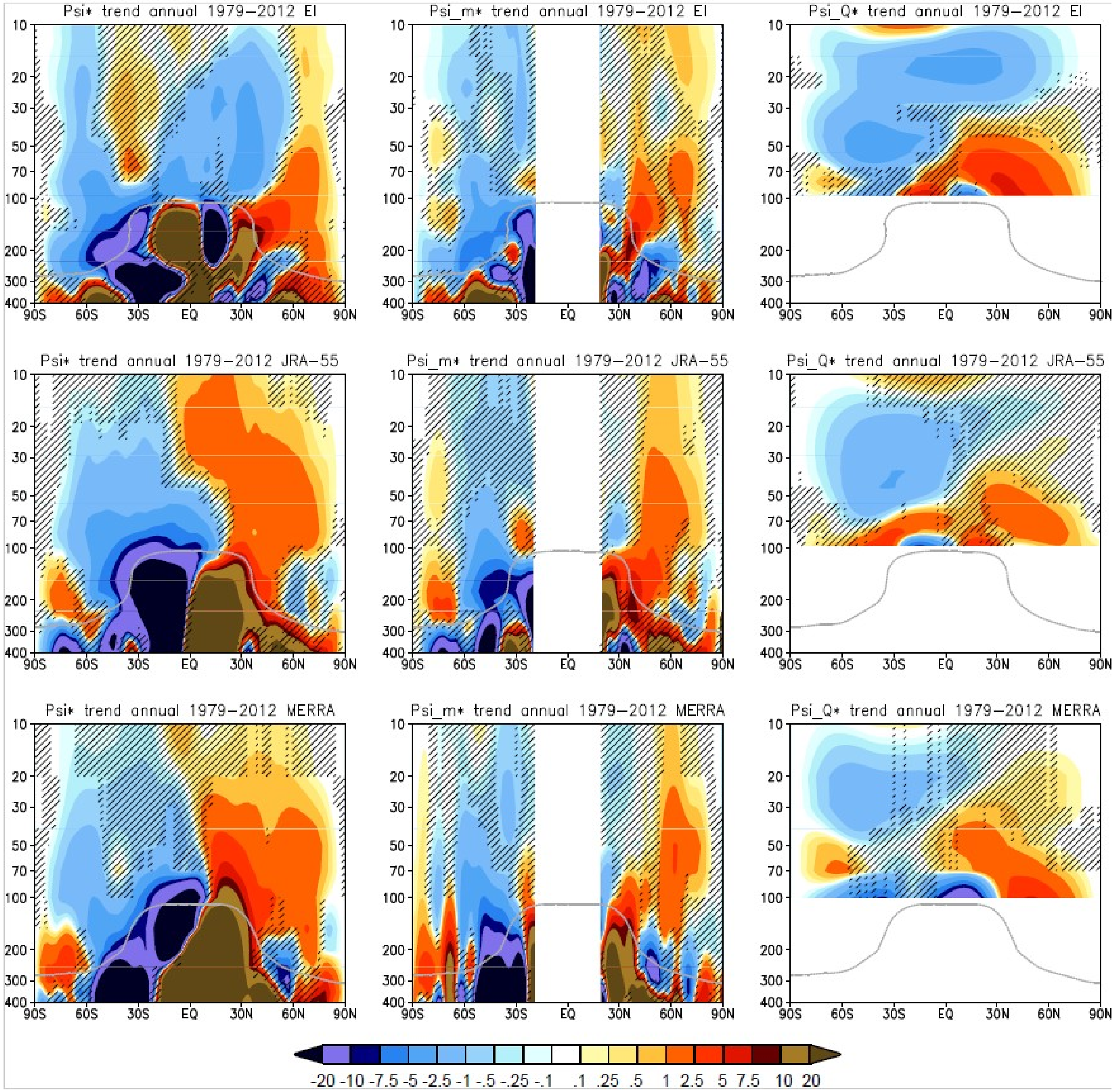
EI

JRA-55

MERRA

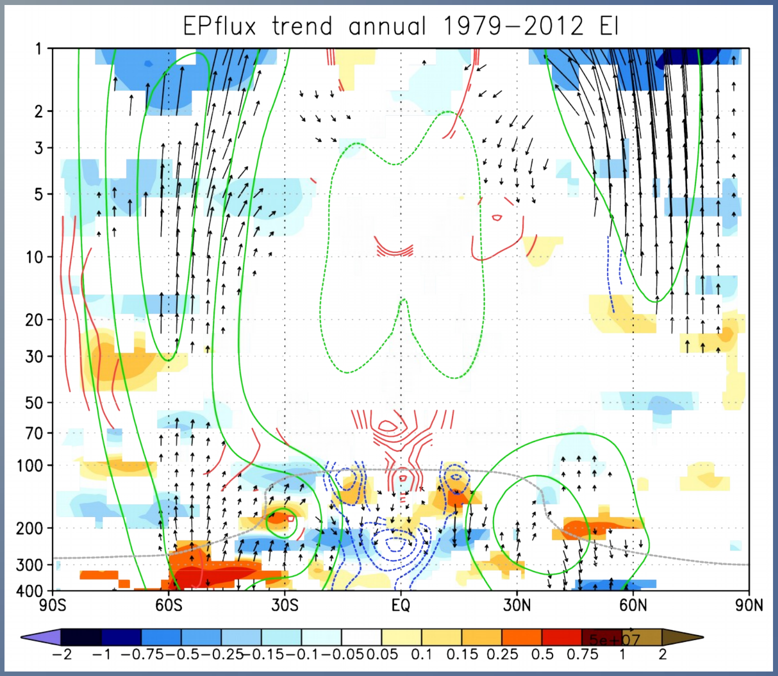


Trends in BDC streamfunction (1979-2012)

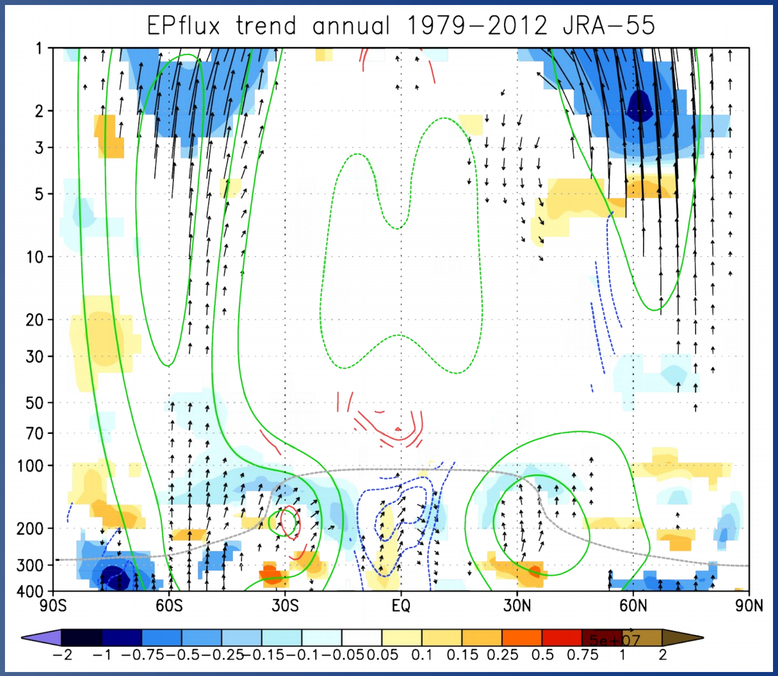


Significant
at 95%

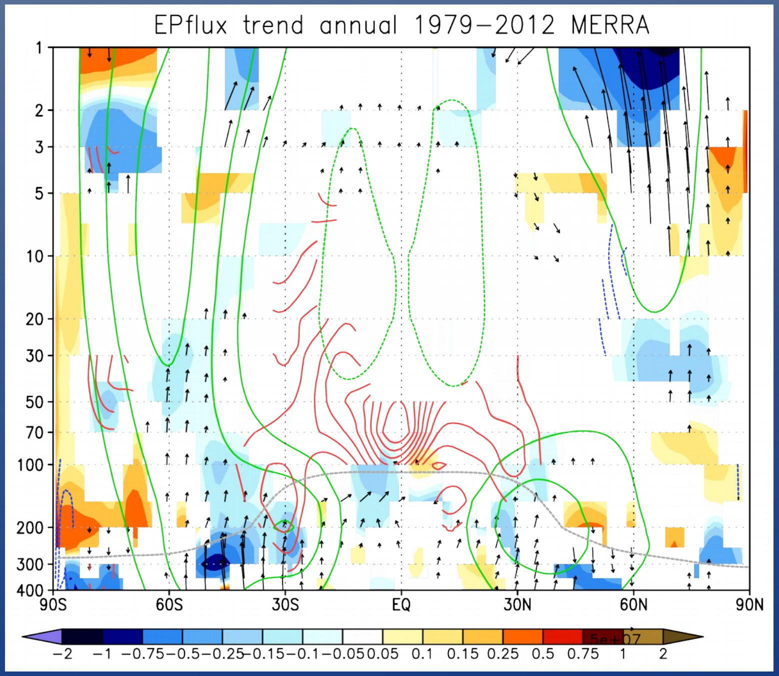
ERA-Interim



JRA-55



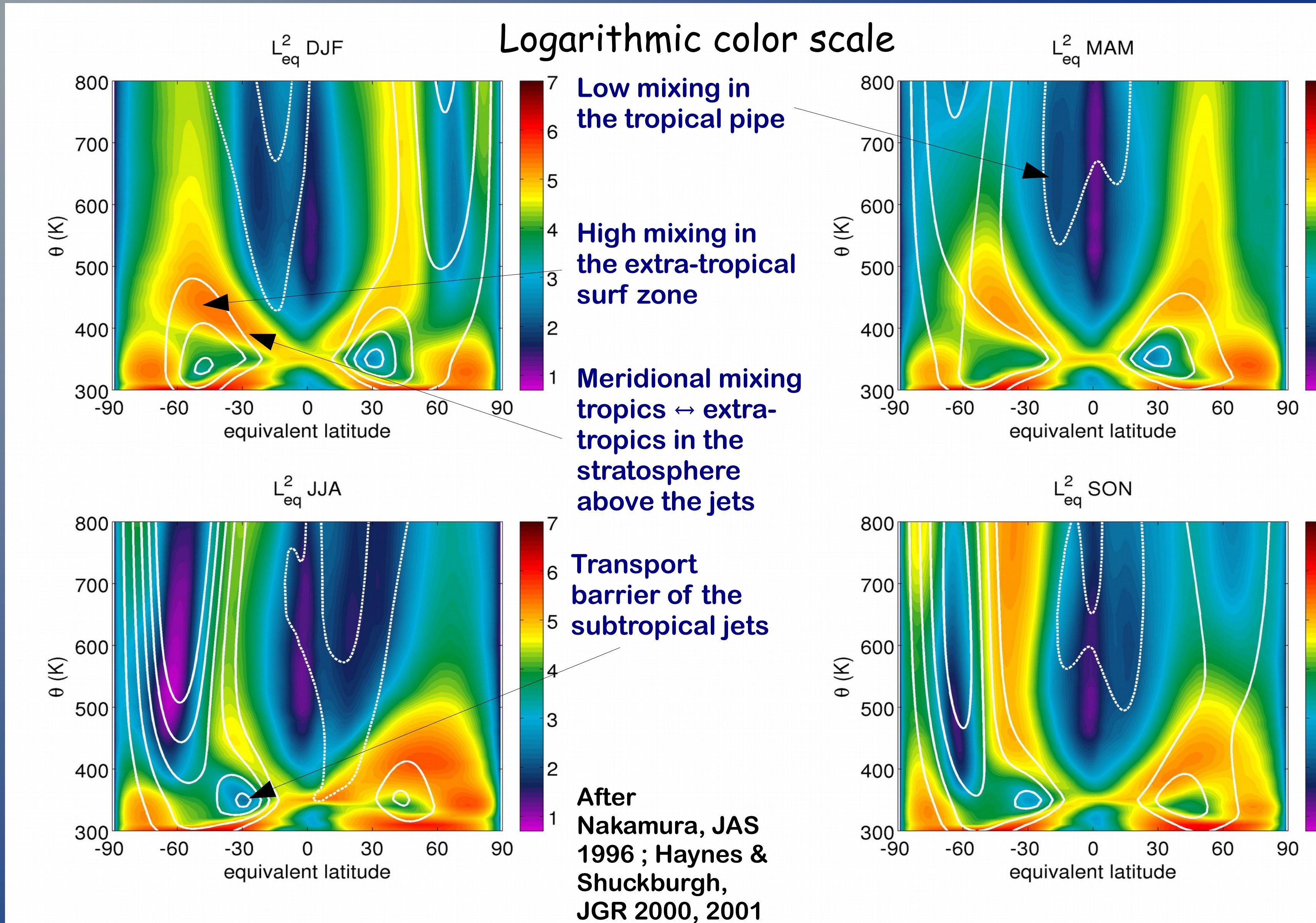
MERRA



Trends in EP flux 1979-2012
90 % confidence level

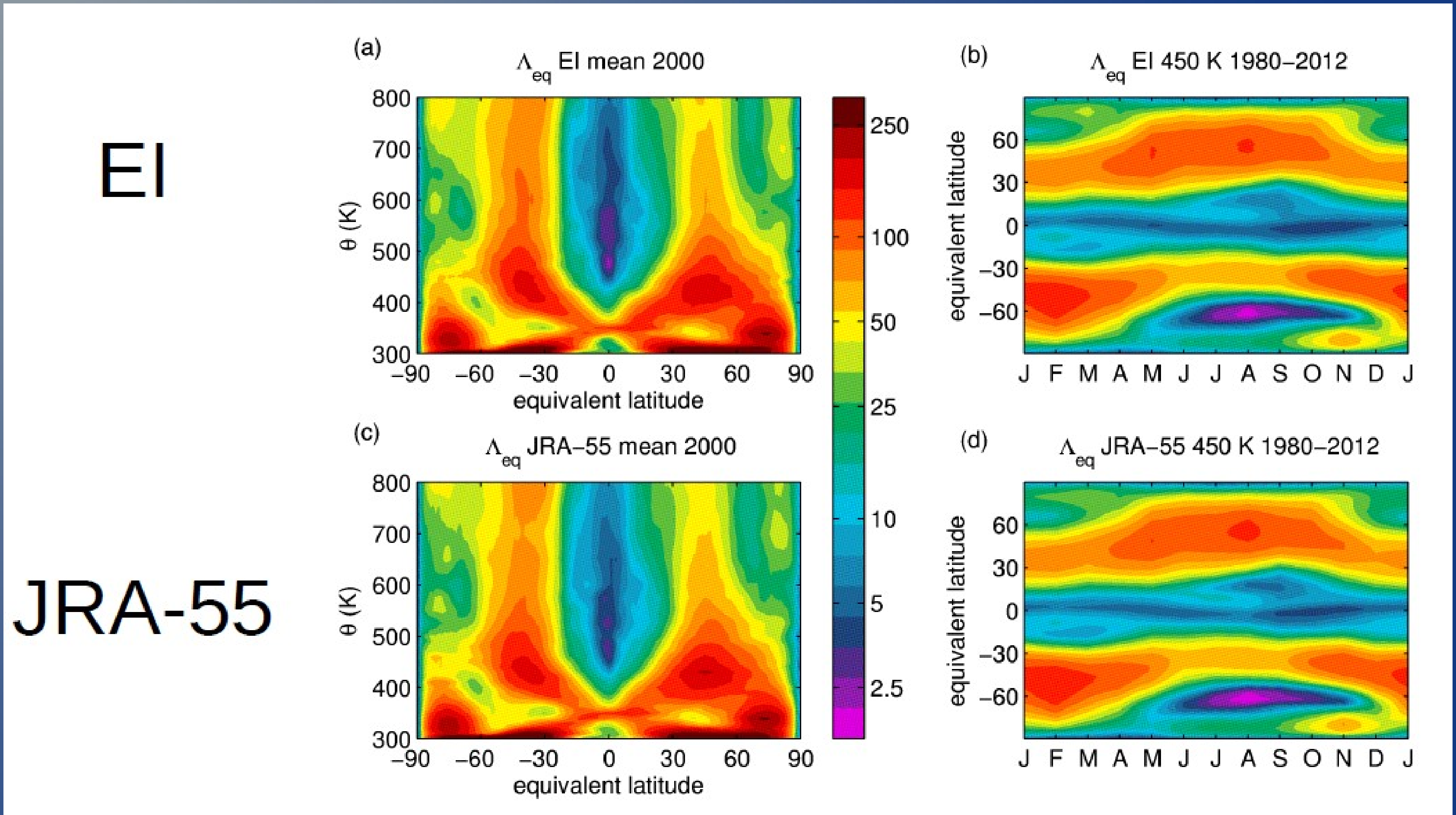
Arrows: EP flux trend
Shading: EP flux divergence trend
Contours:
- U time mean (green)
- U trend (>0 red, <0 blue)

Mixing properties in the ERA-Interim as seen from the effective diffusivity



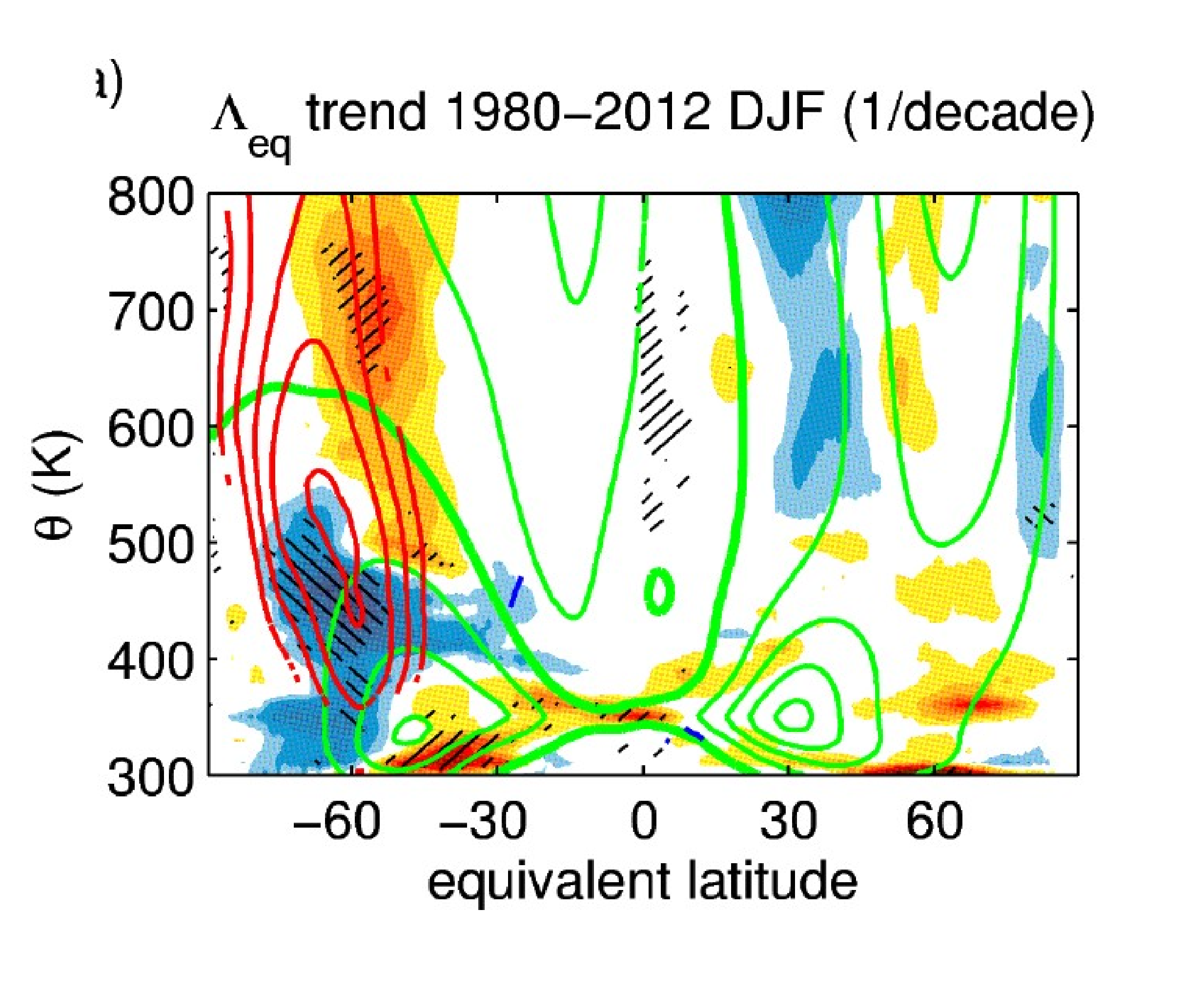
$$L_q(\varphi) \approx \frac{\text{length of a distorted contour}}{\text{length of the latitude circle with same area}}$$ is a measure of irreversible stirring (leading to mixing) by the horizontal flow. The effective diffusivity is $\kappa_{eff} = \kappa_0 L_q$

Comparison of the effective diffusivity between ERA-Interim and JRA-55



The two reanalysis exhbit very close properties of layerwise isentropic mixing.

Trend in effective diffusivity ERA-Interim



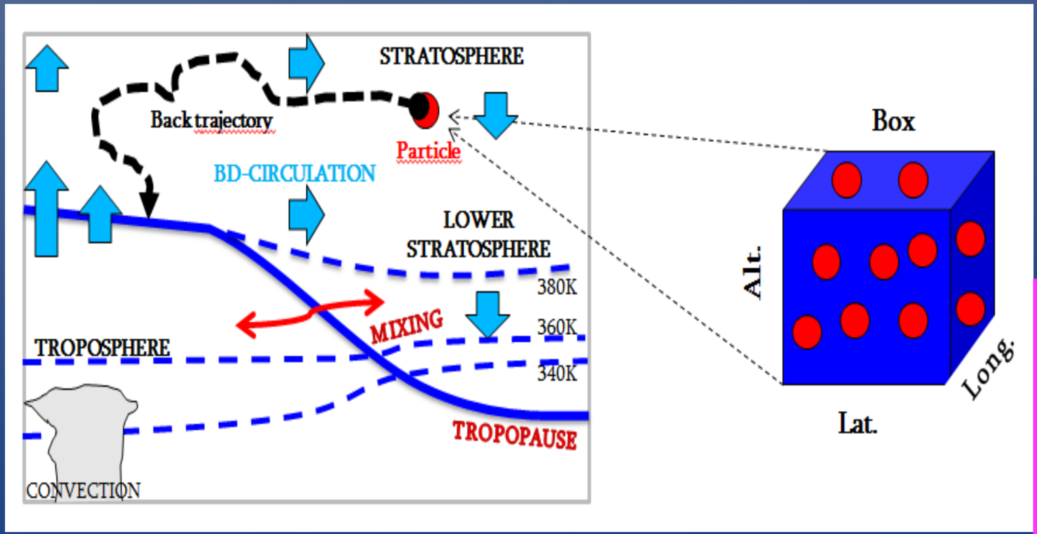
THE AGE OF AIR

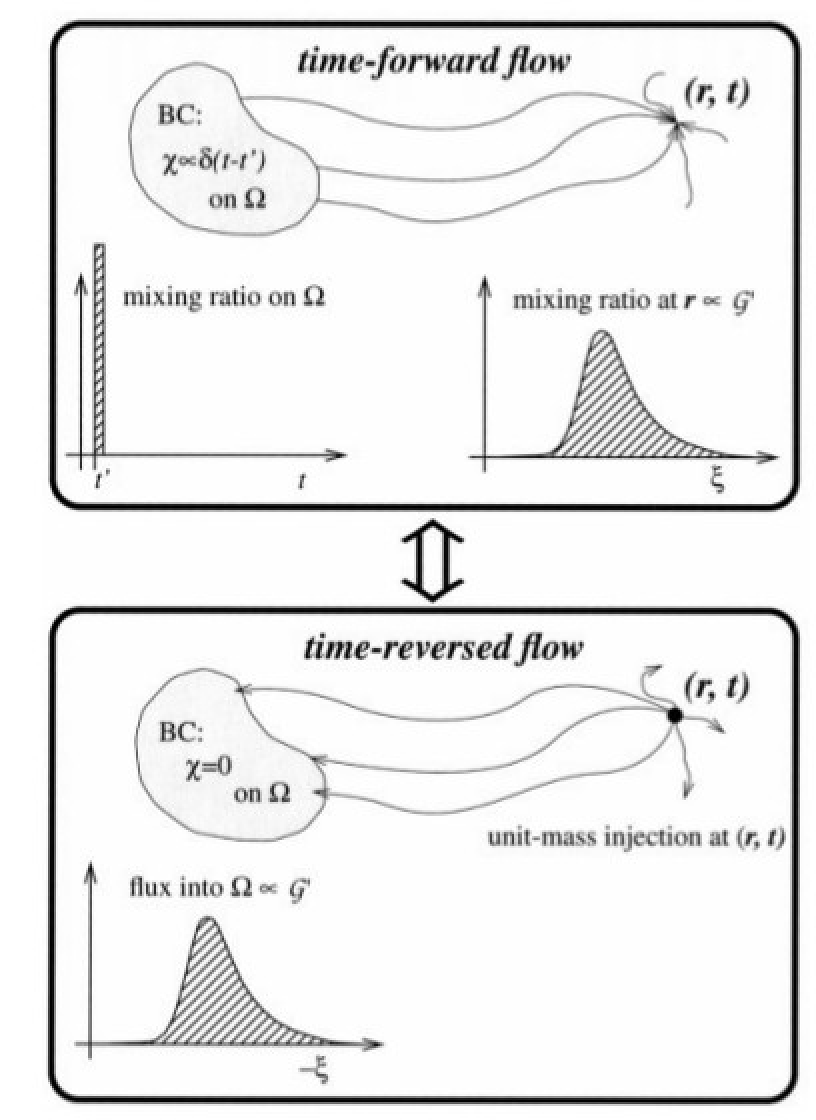
THE METHODS :

The age of air with respect to the last passage at a surface Ω (e.g. the tropopause) can be calculated either in forward time as a response in (r,t) to an impulse at time s on Ω or in backward time with parcels launched in (r,t) reaching Ω.

Here we use backward diabatic trajectories with or without mass corrections.

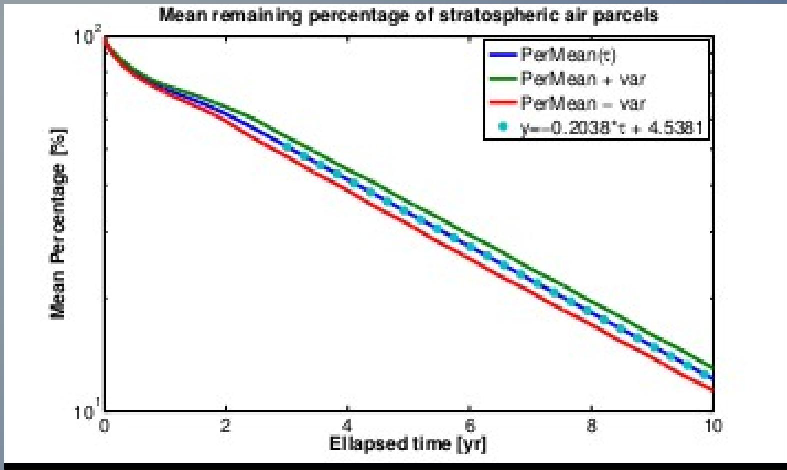
200,000,000 trajectories up to 10y have been calculated.





Holzer & Hall, JAS, 2000

Reanalysis : ERA-Interim, JRA55 and MERRA



Mean age calculated from finite duration integrations needs to be corrected for the contribution of the tail of the age spectrum.

corrected age = uncorrected age

$$+M\left(t_f+\frac{1}{b}\right)$$

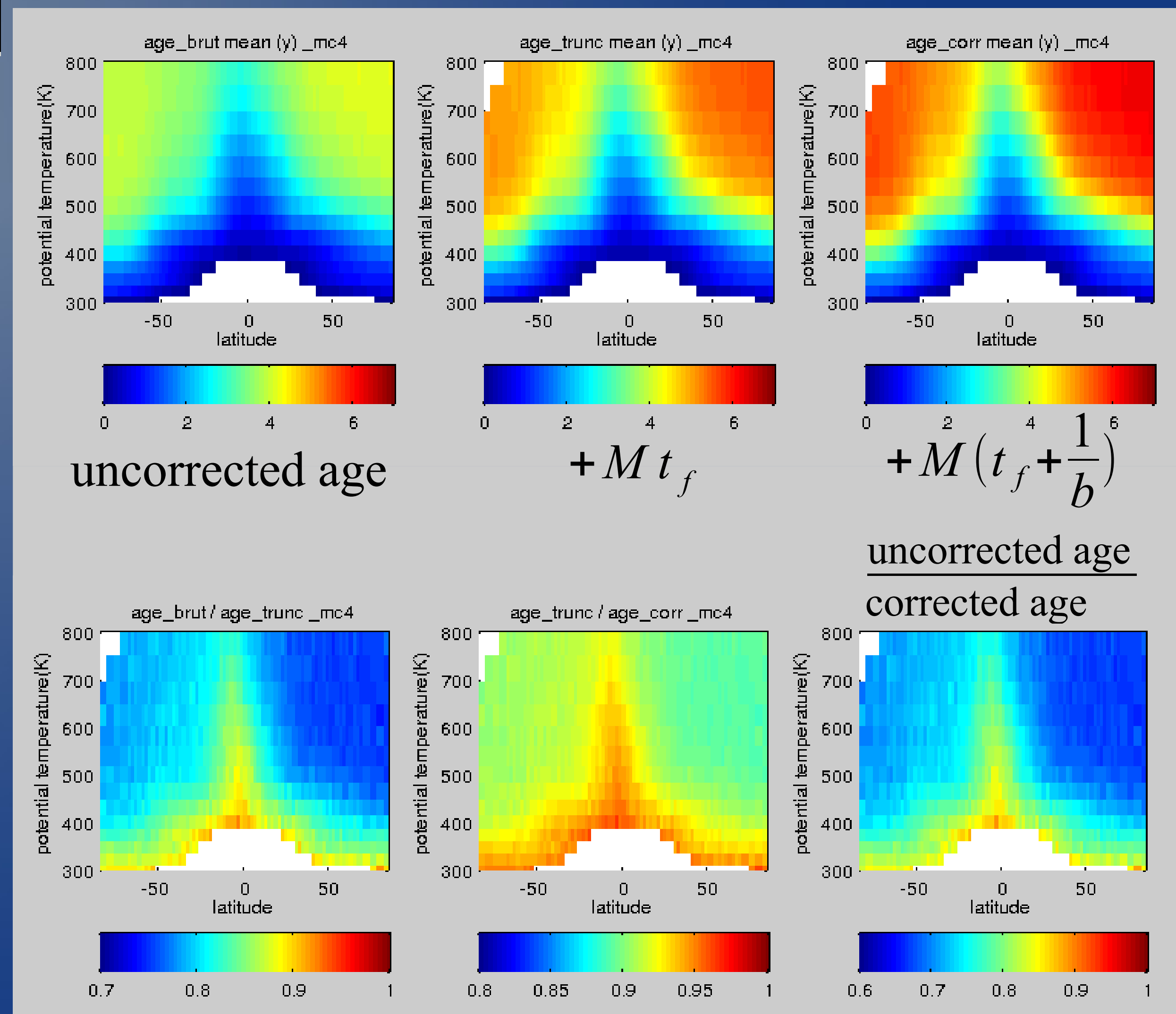
with

M fraction of remaining parcels

t_f age truncation

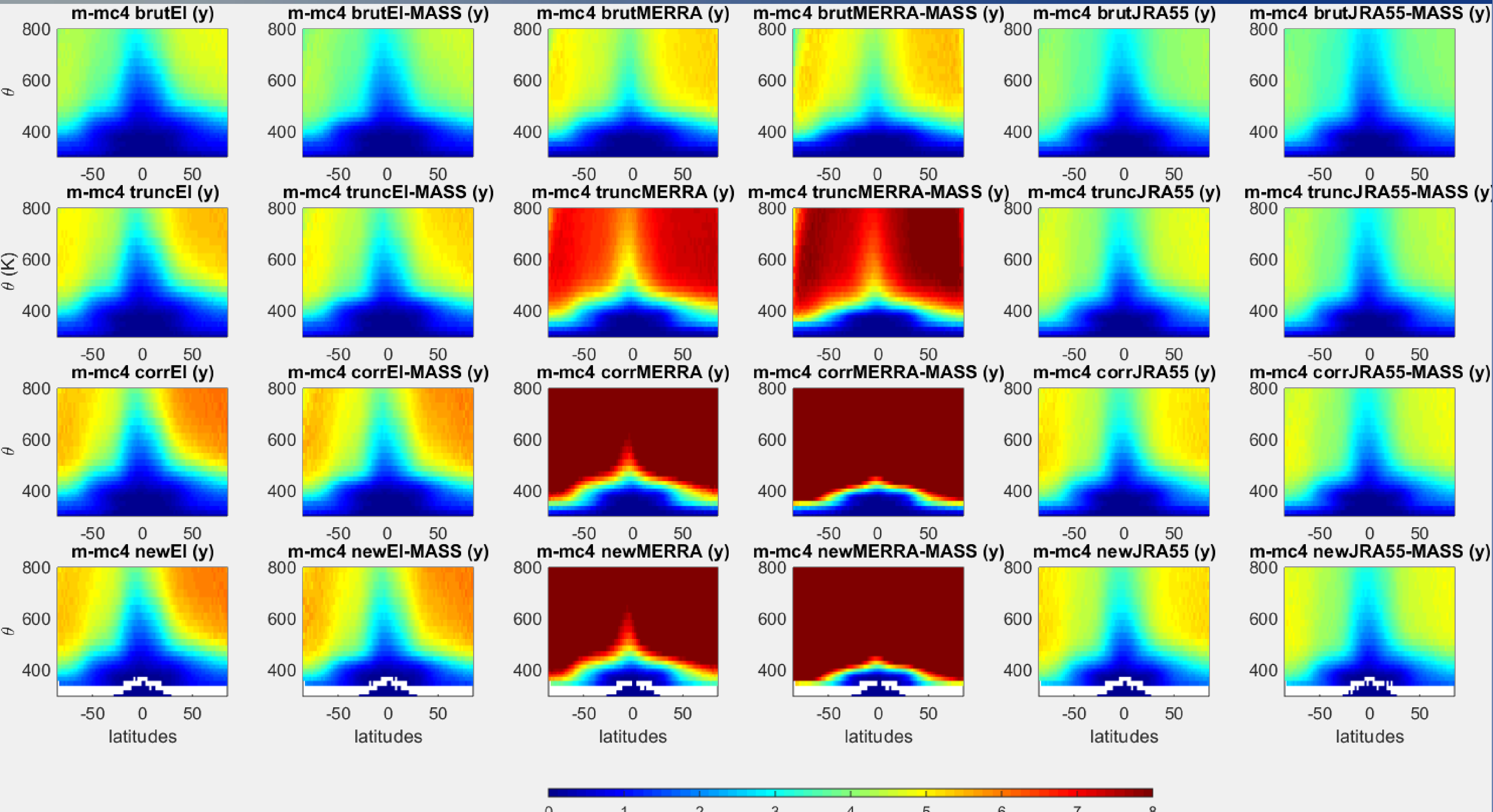
b decrement of the distribution of remaining parcels

Based on Scheele et a., ACP, 2005



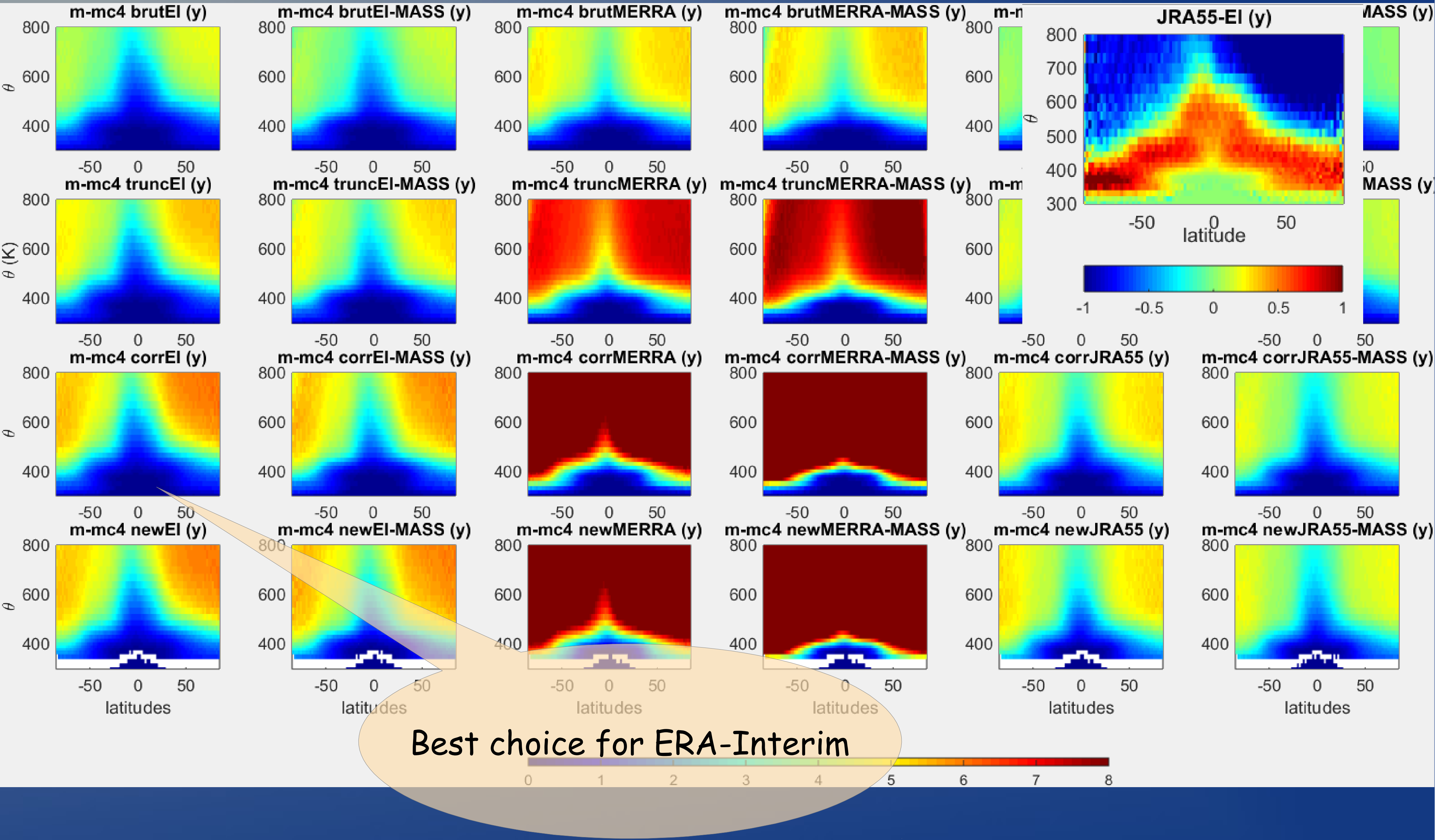
The age is further truncated by discarding all parcels going above 0.5 hPa.

Comparison of the age of air among reanalysis with and without ass correction



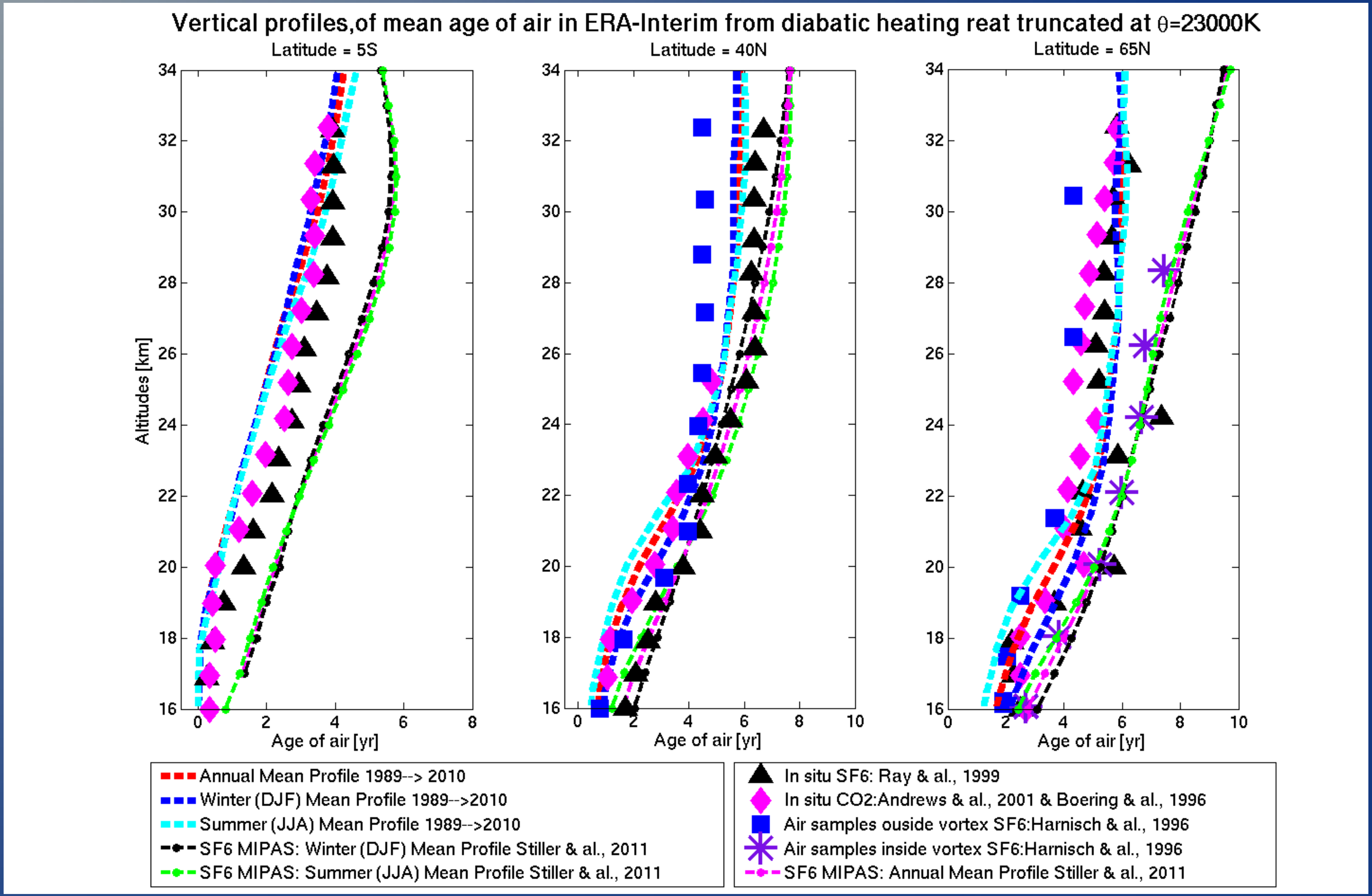
Clipping at 2300K has been applied. Brut : no correction. Trunc : remaining trajectories set at 10yr. Corr and new : tail correction applied.

Comparison of the age of air among reanalysis with and without ass correction



Clipping at 2300K has been applied. Brut : no correction. Trunc : remaining trajectories set at 10yr. Corr and new : tail correction applied.

Comparison of ERA-Interim ages with ballon profiles and ages derived from SF6 MIPAS retrieval



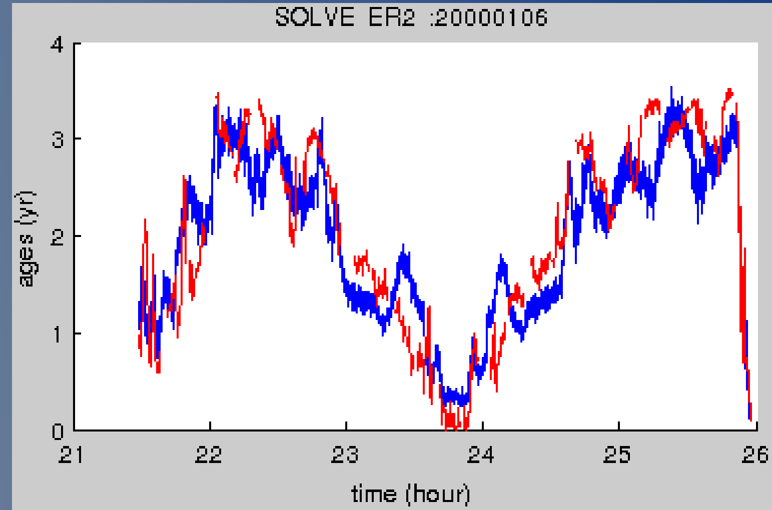
Backward space filling Lagrangian diabatic trajectories

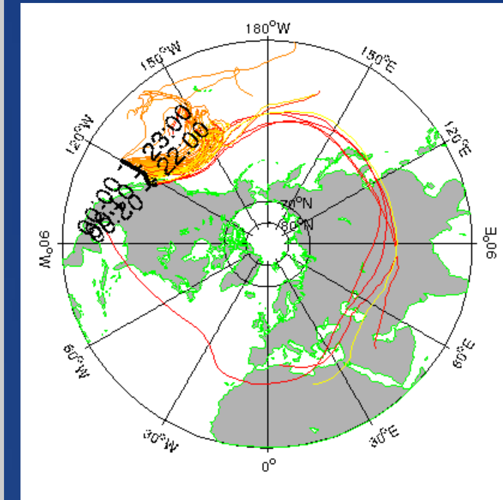
Ages from the SOLVE campaign of the ER2 combining CO_2, N_2O and CH_4 measurements. (Andrews, Daube, Gerbig, Wofsy, 2000).

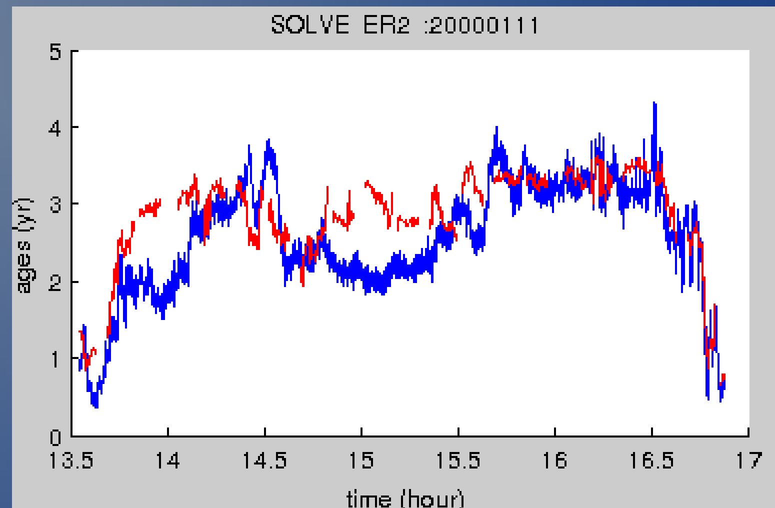
versus

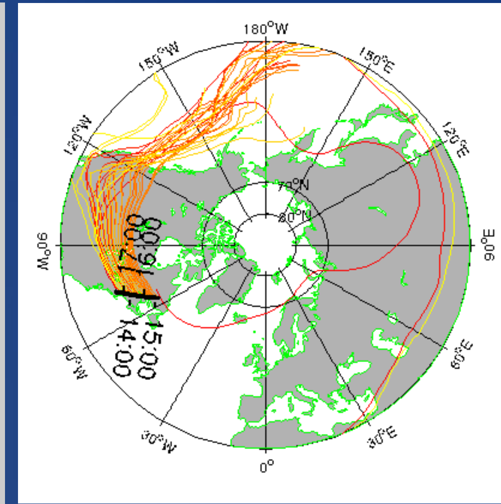
ages from the ERA-Interim using diffusive reconstruction (Legras et al., 2005ACP)

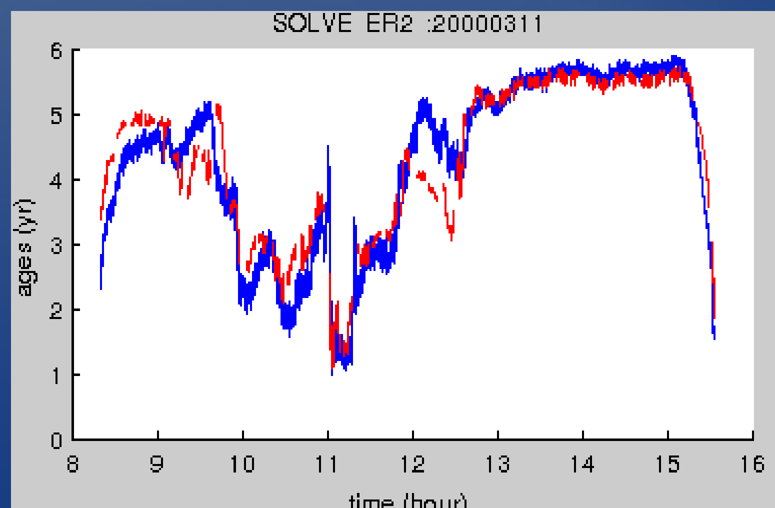
Backward space filling Lagrangian diabatic trajectories

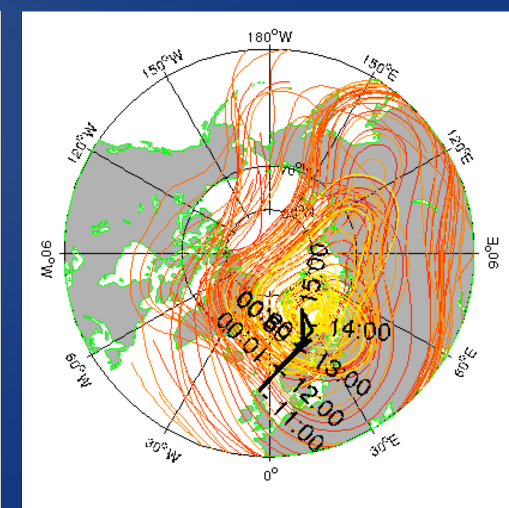




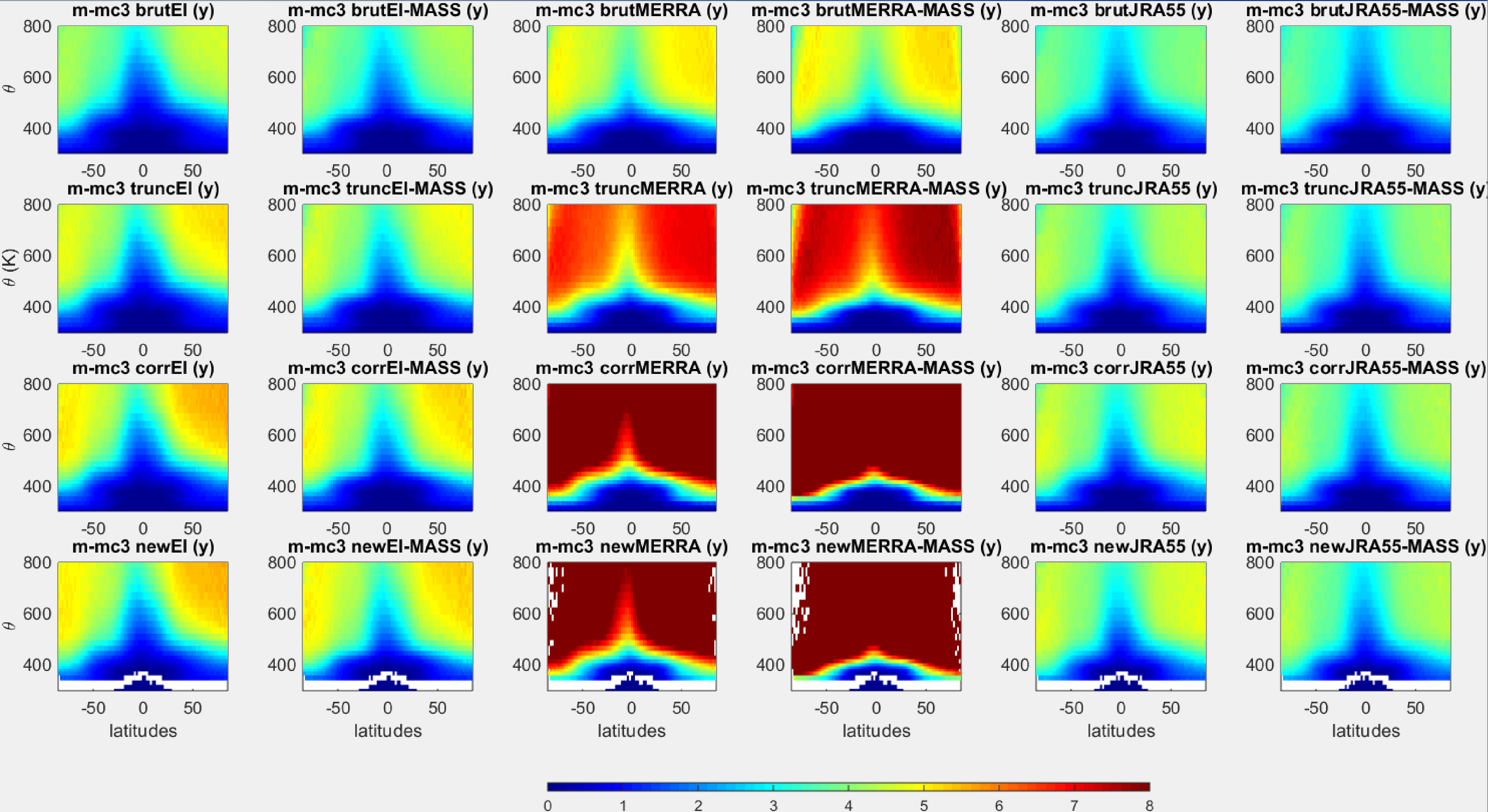






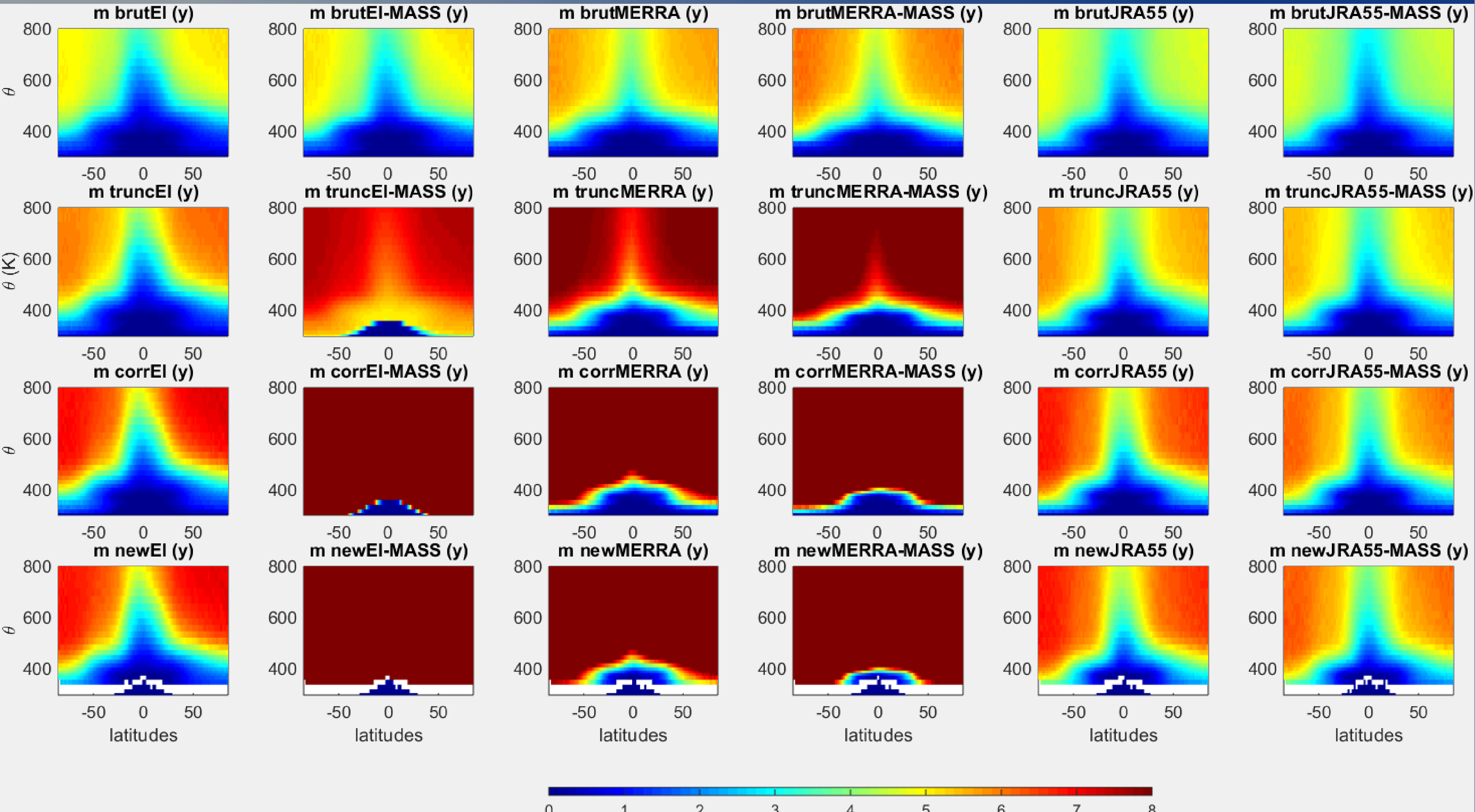


Comparison of the age of air among reanalysis with and without ass correction



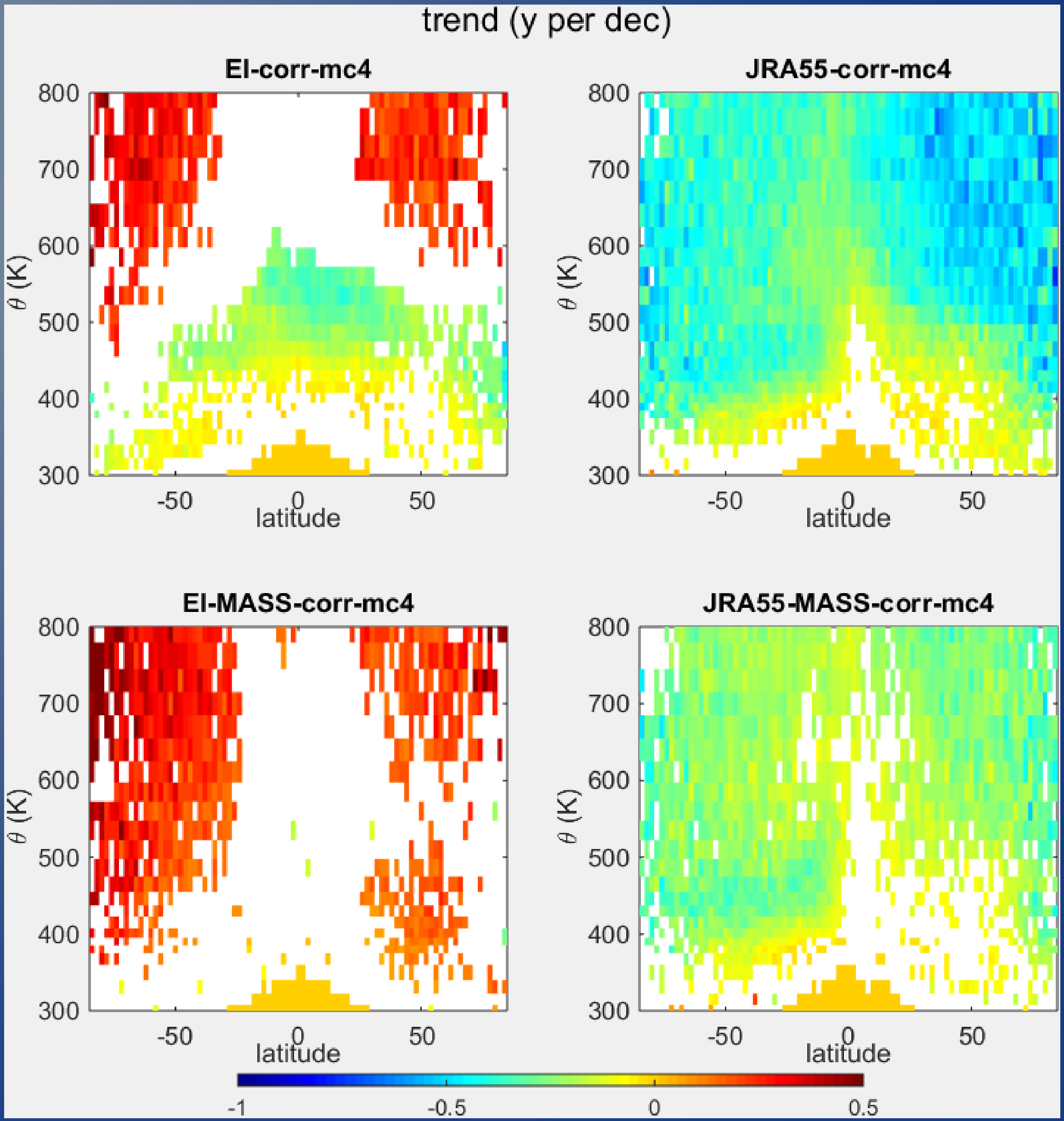
Here, clipping is made at 1800K, as in Schoberl & Dessler, 2011, using forward diabatic trajectories with MERRA. This clipping reduces the mean age.

Comparison of the age of air among reanalysis with and without ass correction



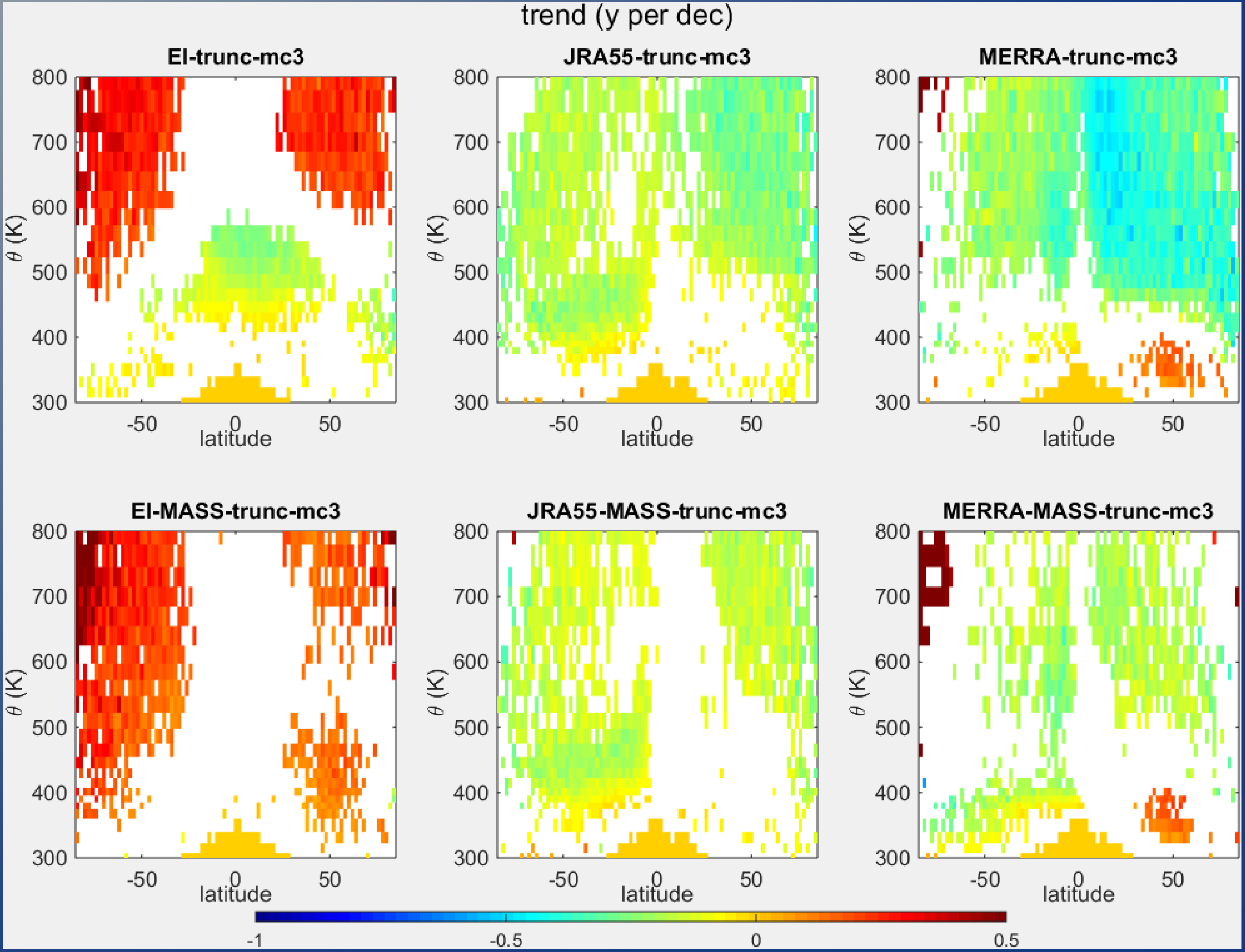
Applying no clipping increases the age and the ERA-Interim ages are now too old. The mass-corrected JRA-55 ages are now providing the best match.

Trend (non significant regions are masked)

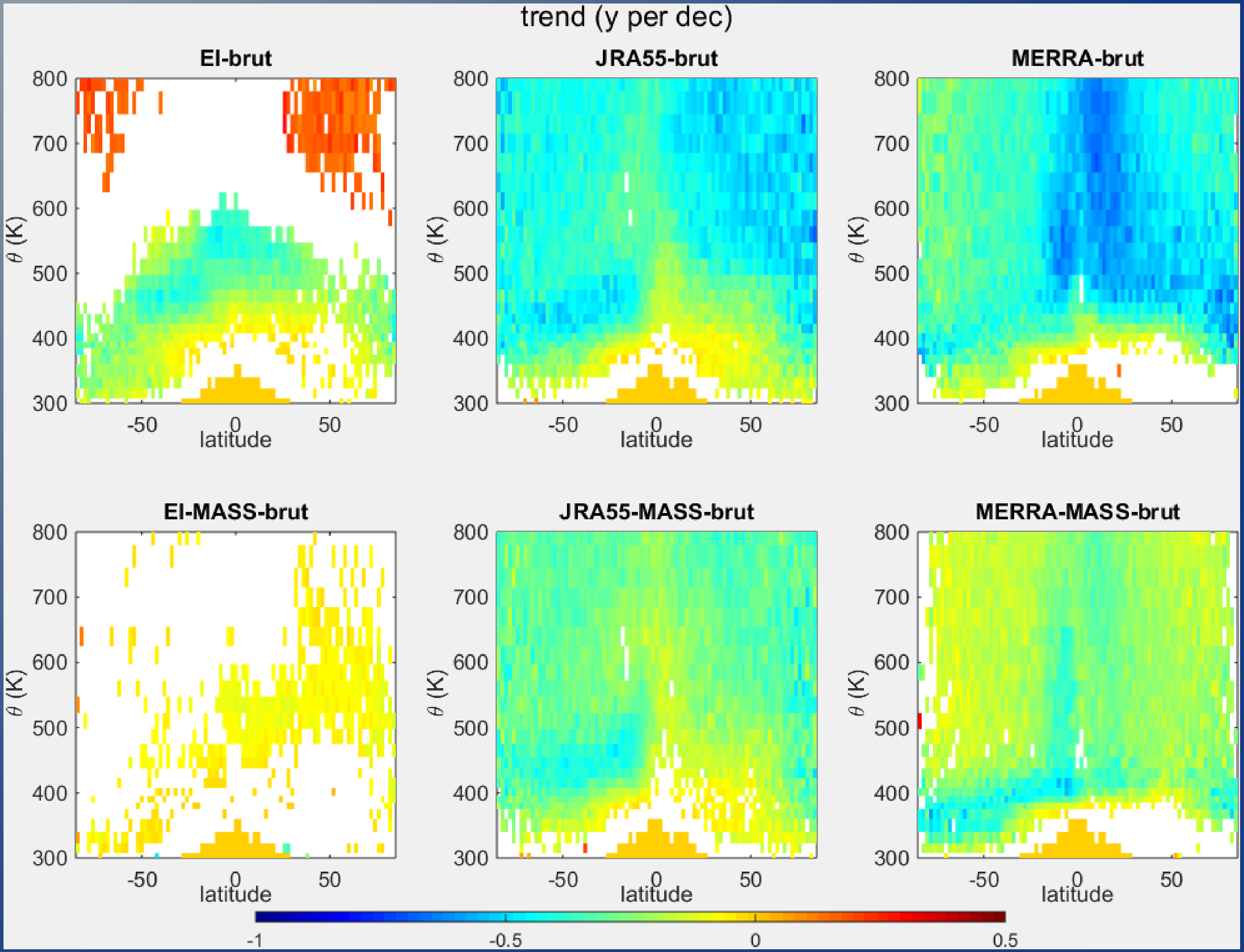


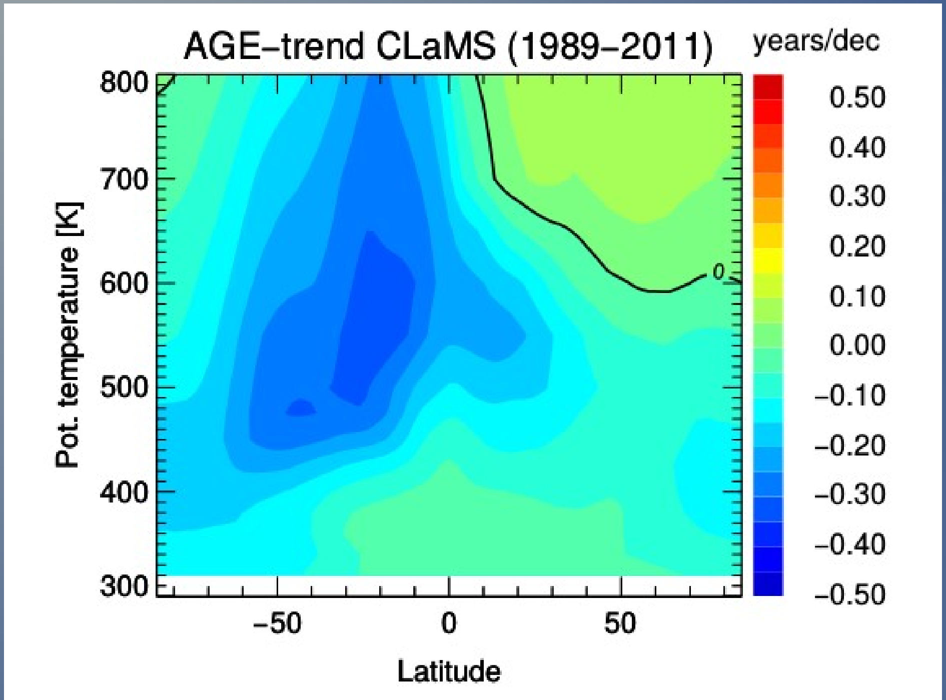
Disagreement between ERA-Interim and JRA55. No aging in JRA55.
Mass correction induces aging trend for both reanalysis

Trends including MERRA in the partially corrected ages , including MERRA. MERRA is quite in agreement with JRA55 with larger amplitude. Effect of mass correction varies.



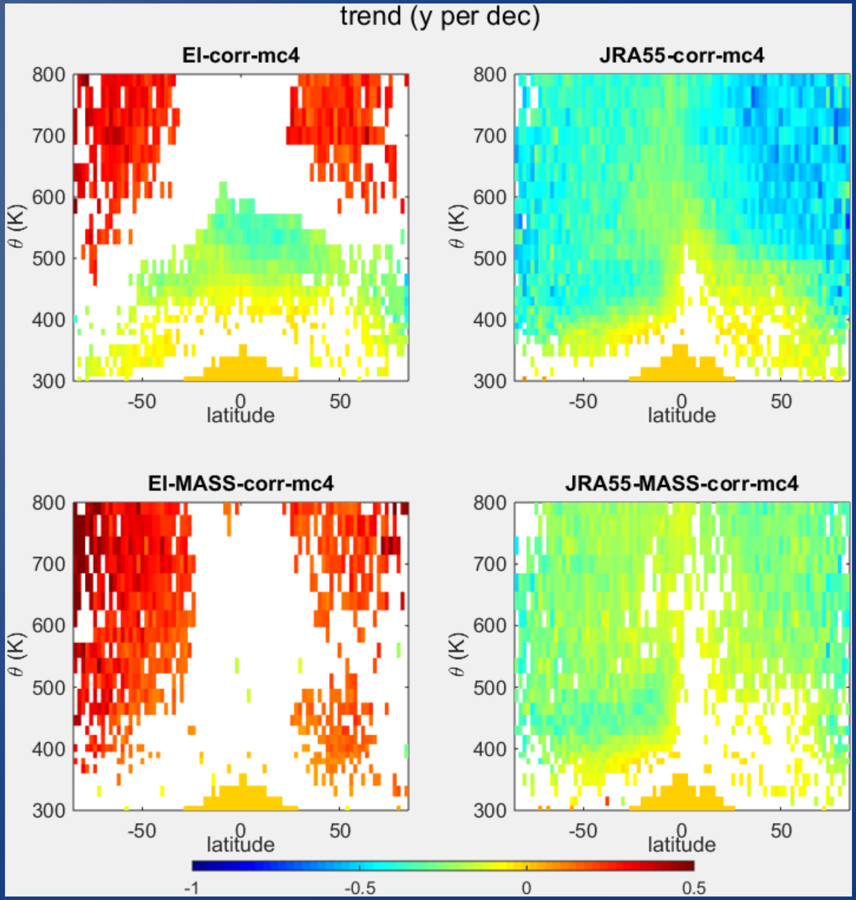
Non corrected ERA-Interim ages show less postive trend. Negative trend reinforced in the other reanalysis.



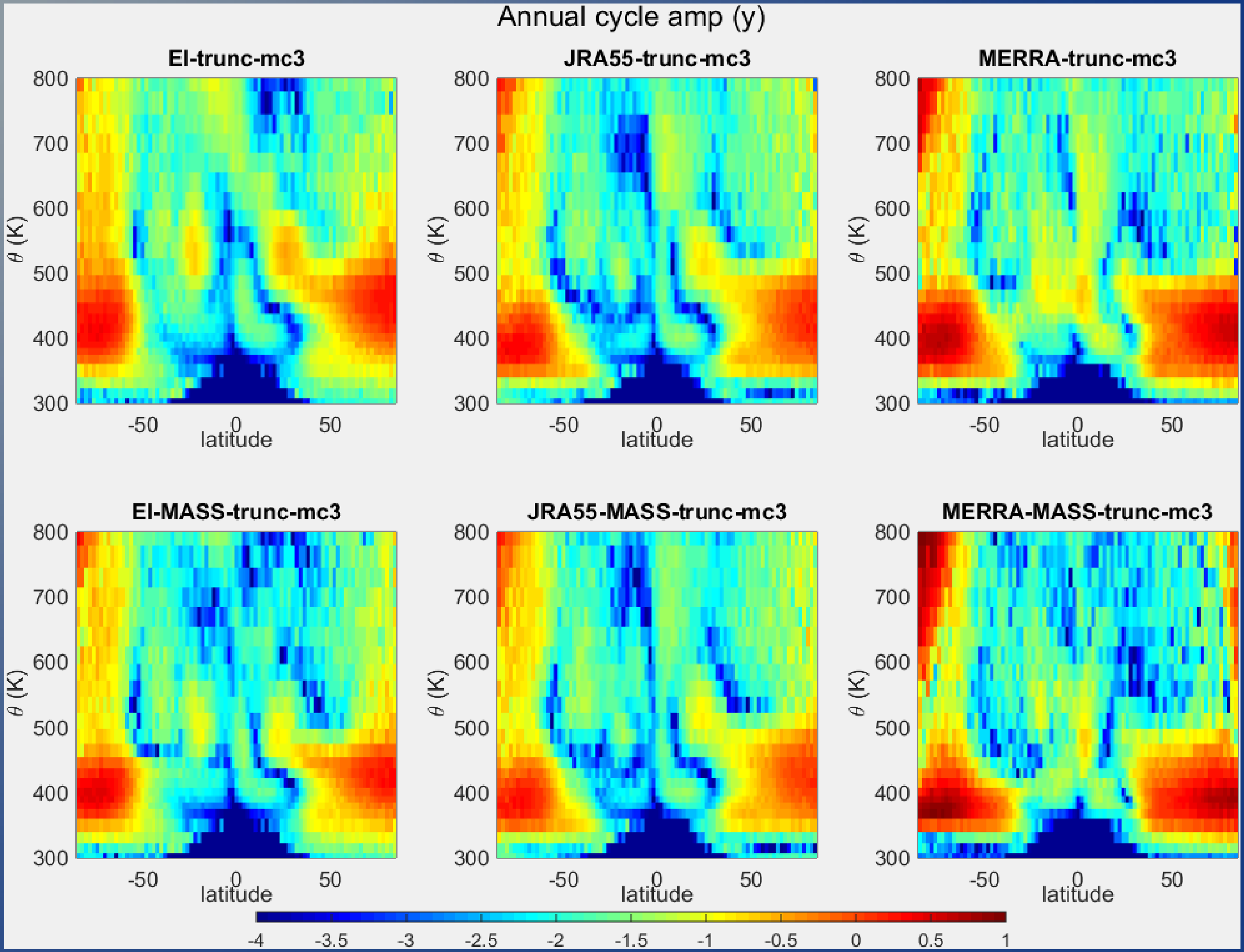


ClaMS trend of the mean age of iar is very different from the Lagrangian calculations

ERA Interim diabatic transport



Amplitude of the annual signal (in log scale)

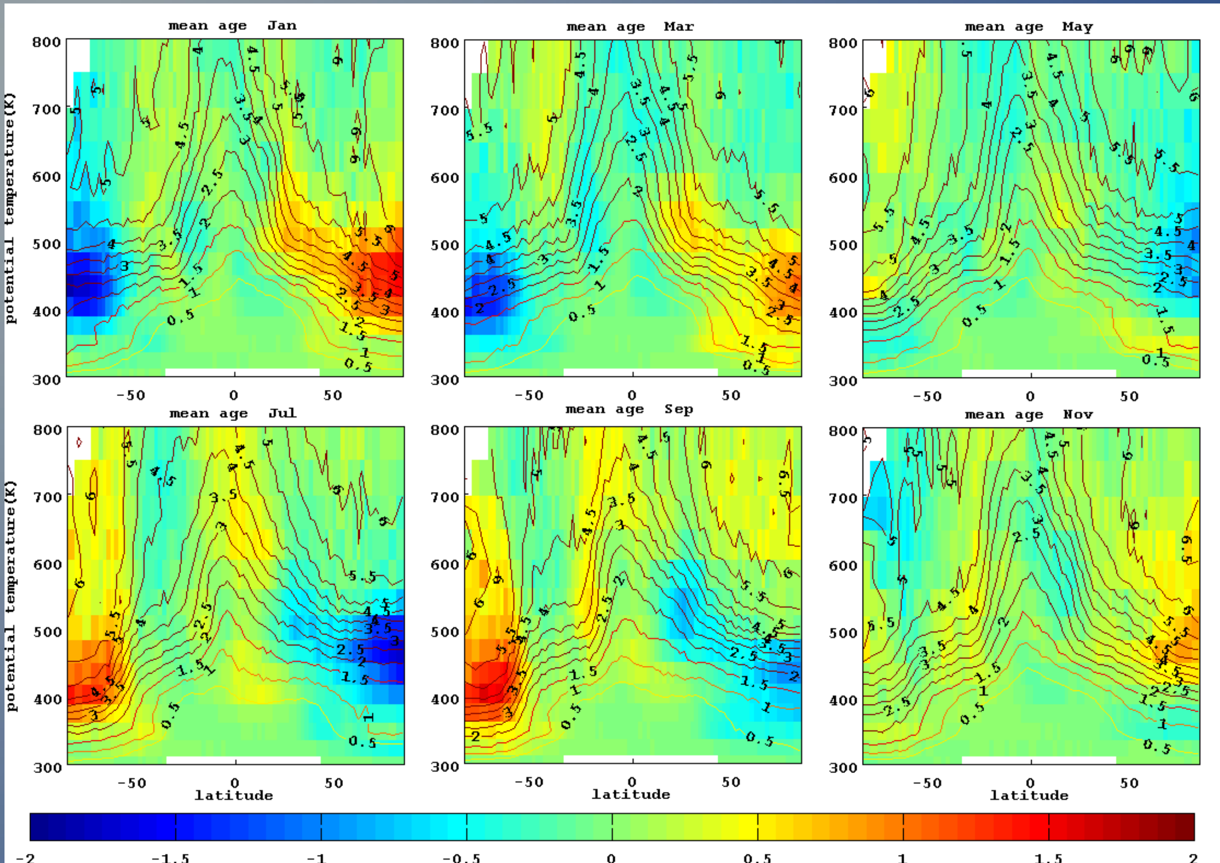


Depends weakly of the age correction

Mostly localized in the high latitude. Intensity MERRA>ERA-Interim>JRA55

Very good agreement between ERA-Interim and JRA55 for patterns in the tropics.

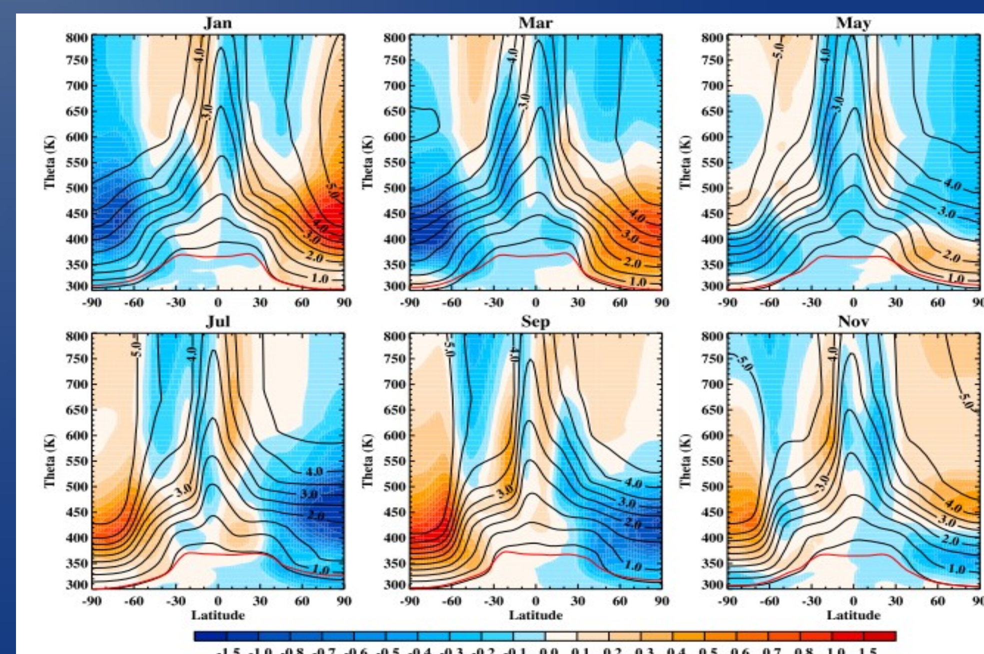
Annual cycle of the age of air



Contour : monthly mean
Color : monthly anomaly

GEOSCCM, Li et al., JGR 2012

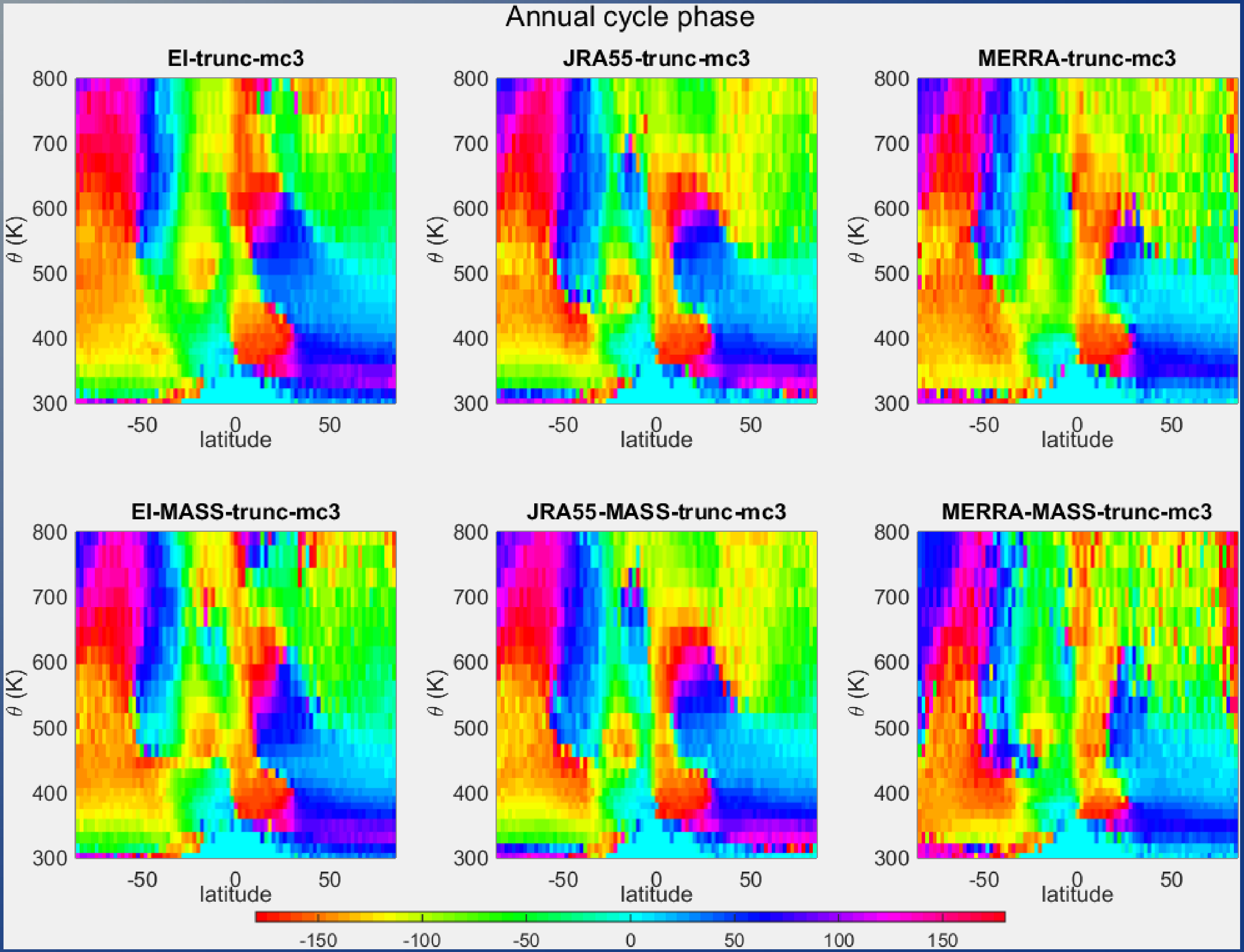
ERA-Interim



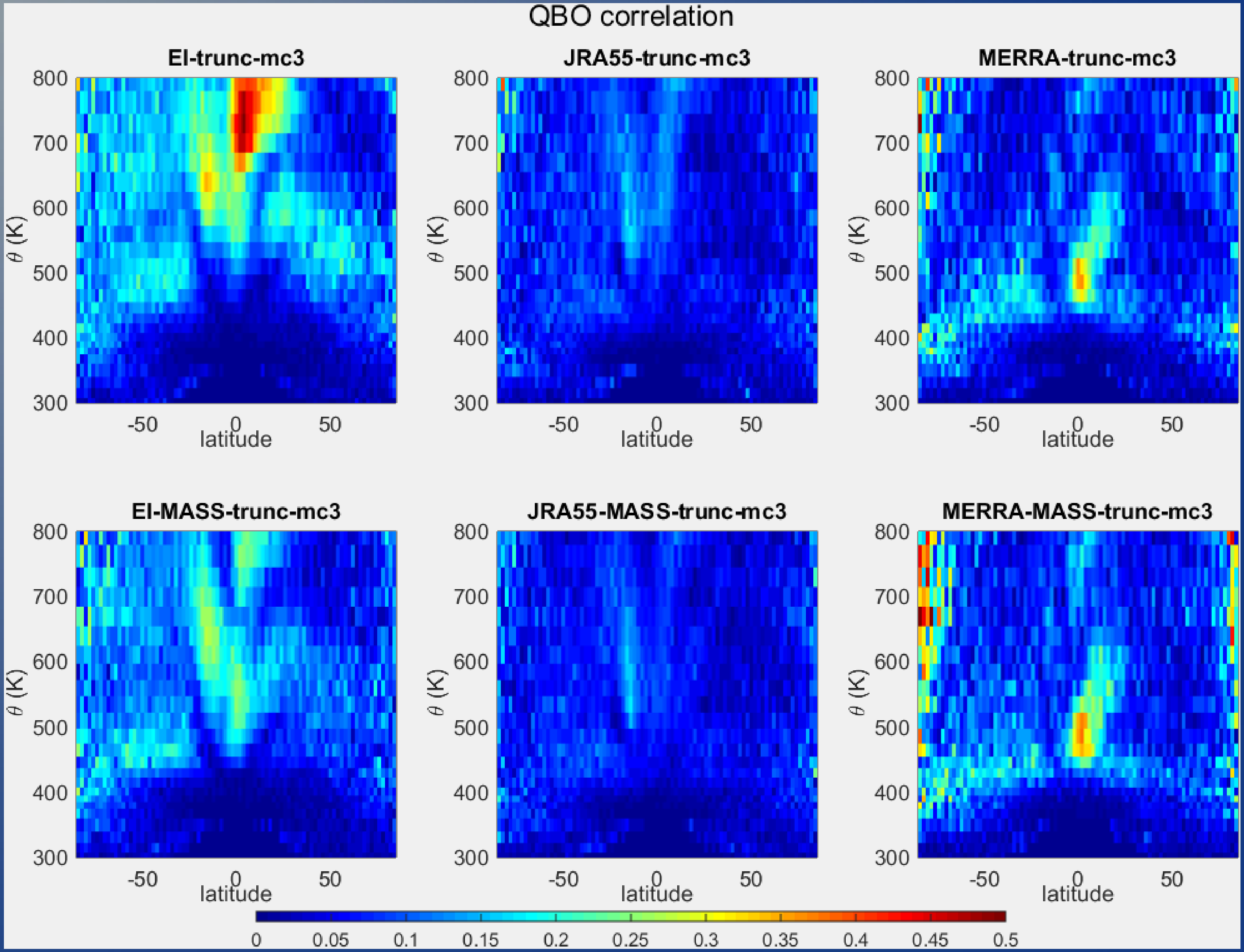
Maximum modulation in the lower polar stratosphere : old during winter and young during summer

Also good agreement with GEOSCCM.
Models are good at representing the annual cycle.

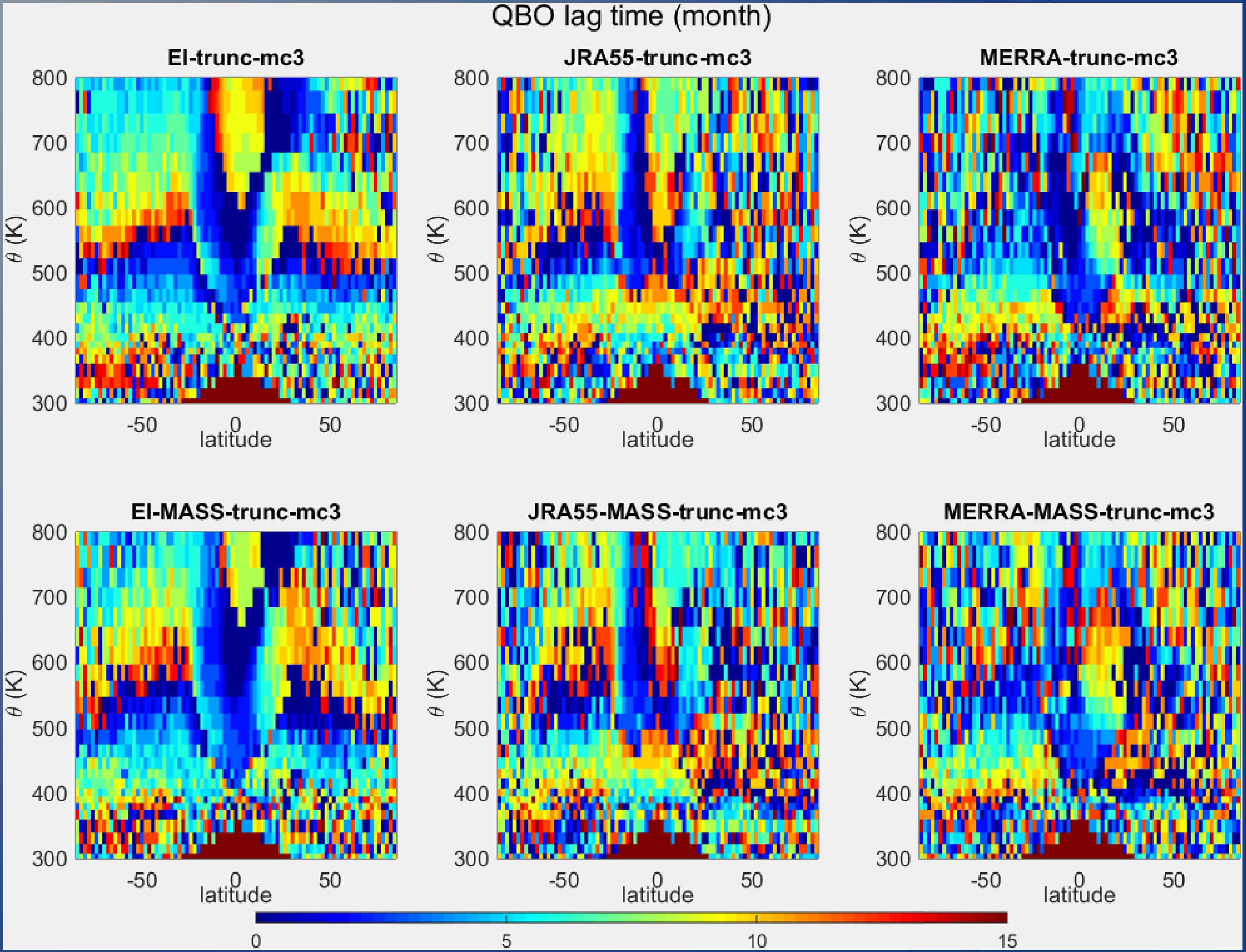
Phase of the annual cycle



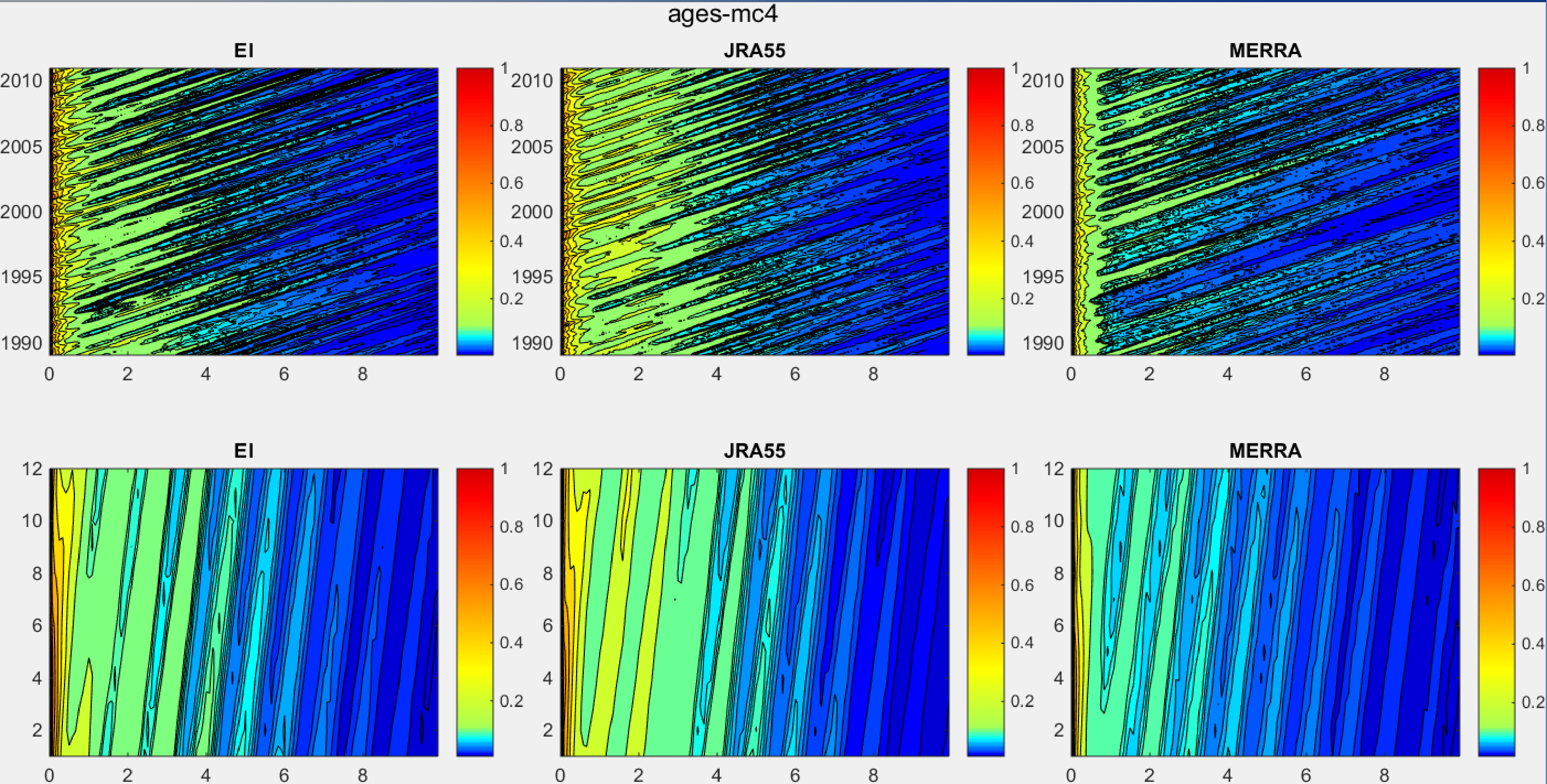
Something where the reanalysis are not good (or disagree) is the amplitude of the correlation with QBO.



Lag of the age with respect to the QBO (30 hPa zonal wind).

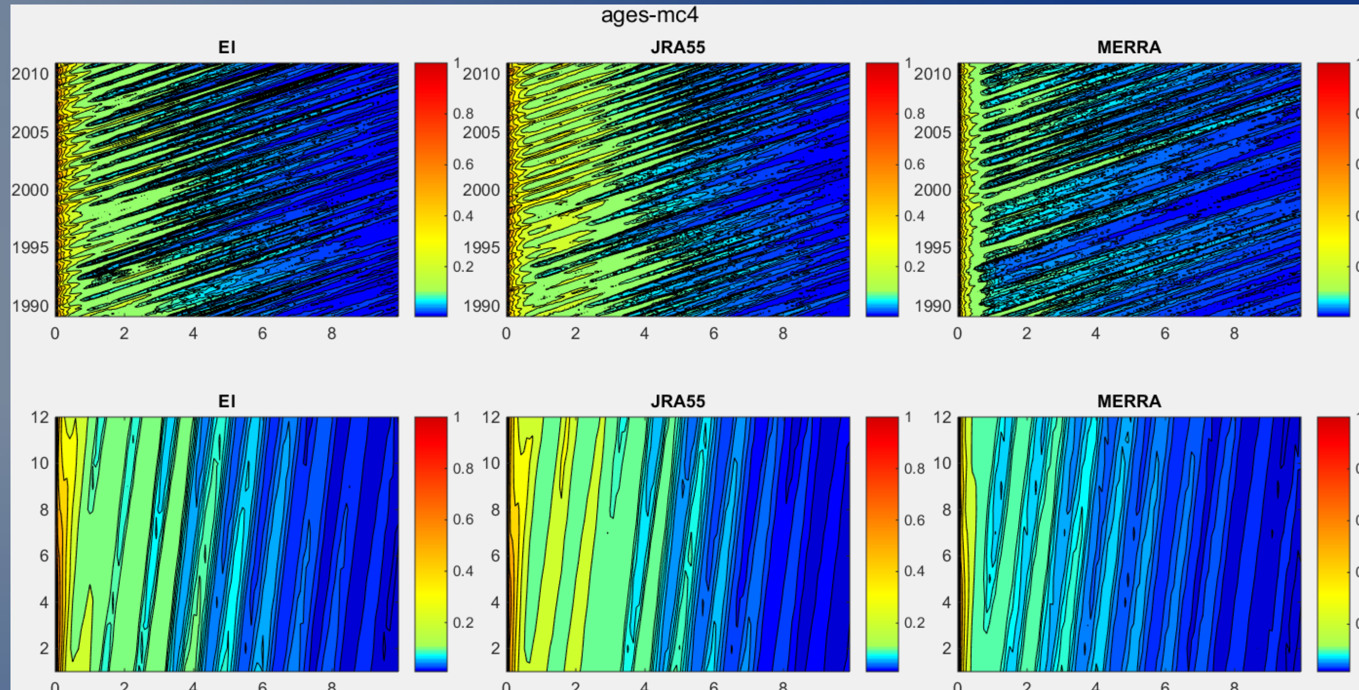


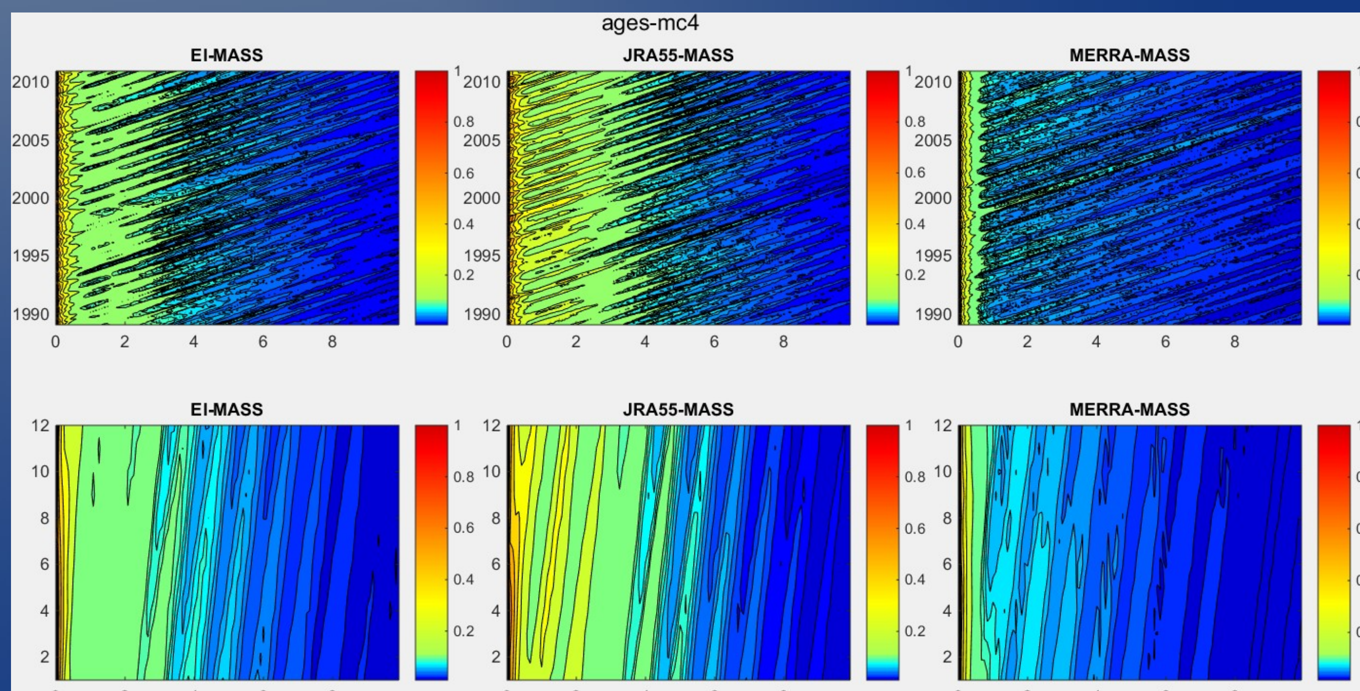
Age spectrum (whole stratosphere)
Age on the horizontal axis (in y)
Annual cycle in the lower row



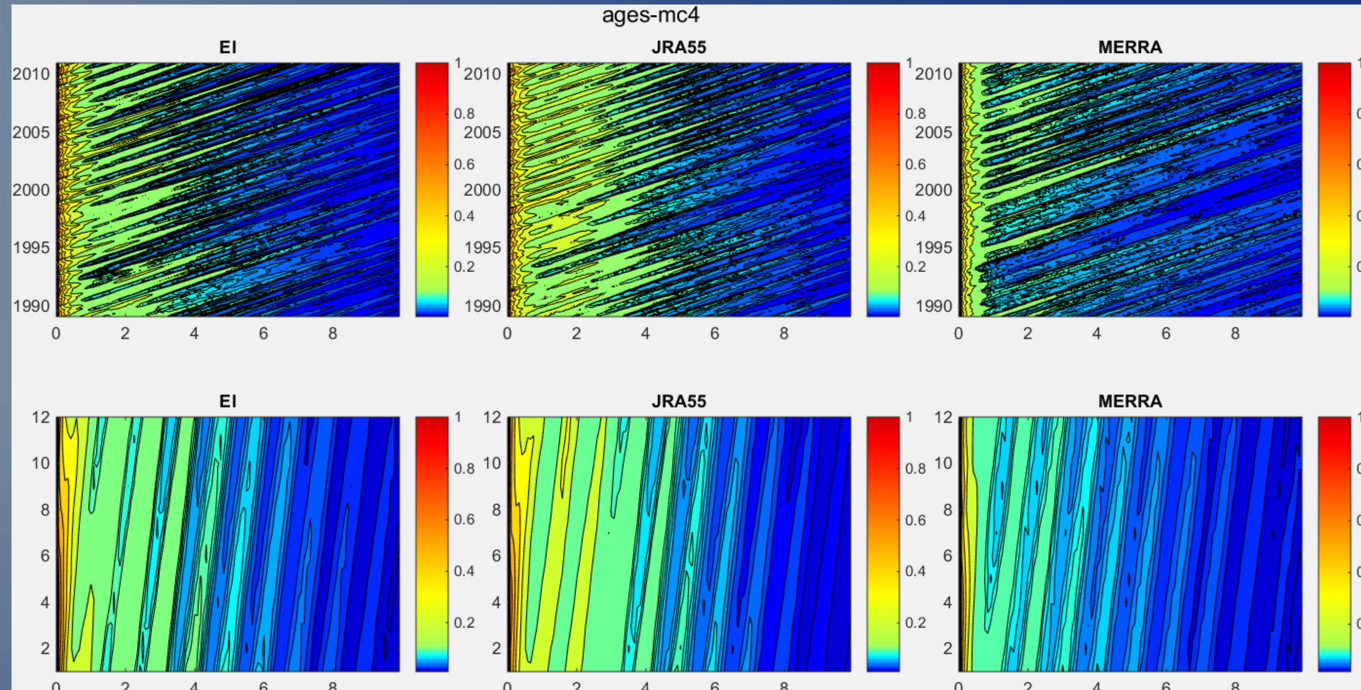
With respect to the two other reanalysique MERRA differs by fast decay followed by a flat tail. Effect of the Pinatubo propagates across the 90's.

The age spectrum is sensitive to the mass correction with damping of the annual modulation in ERA-Interim and MERRA and increase of the modulation in JRA55.



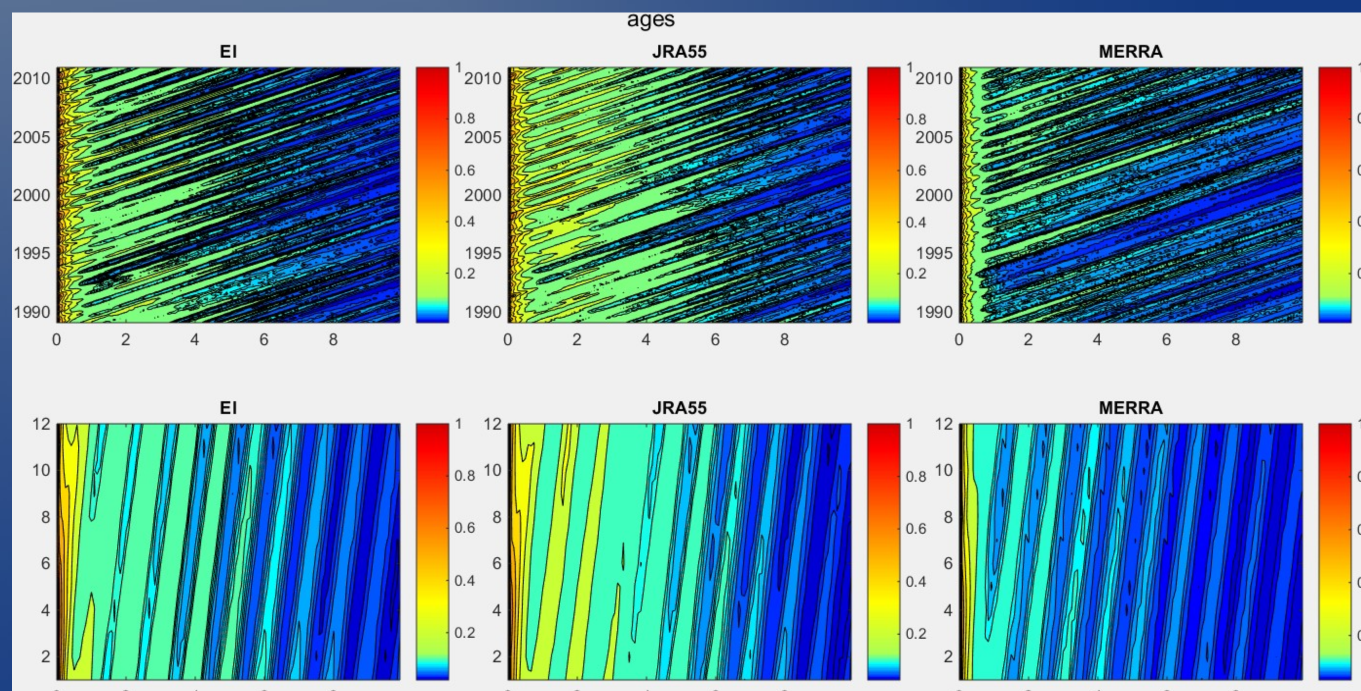


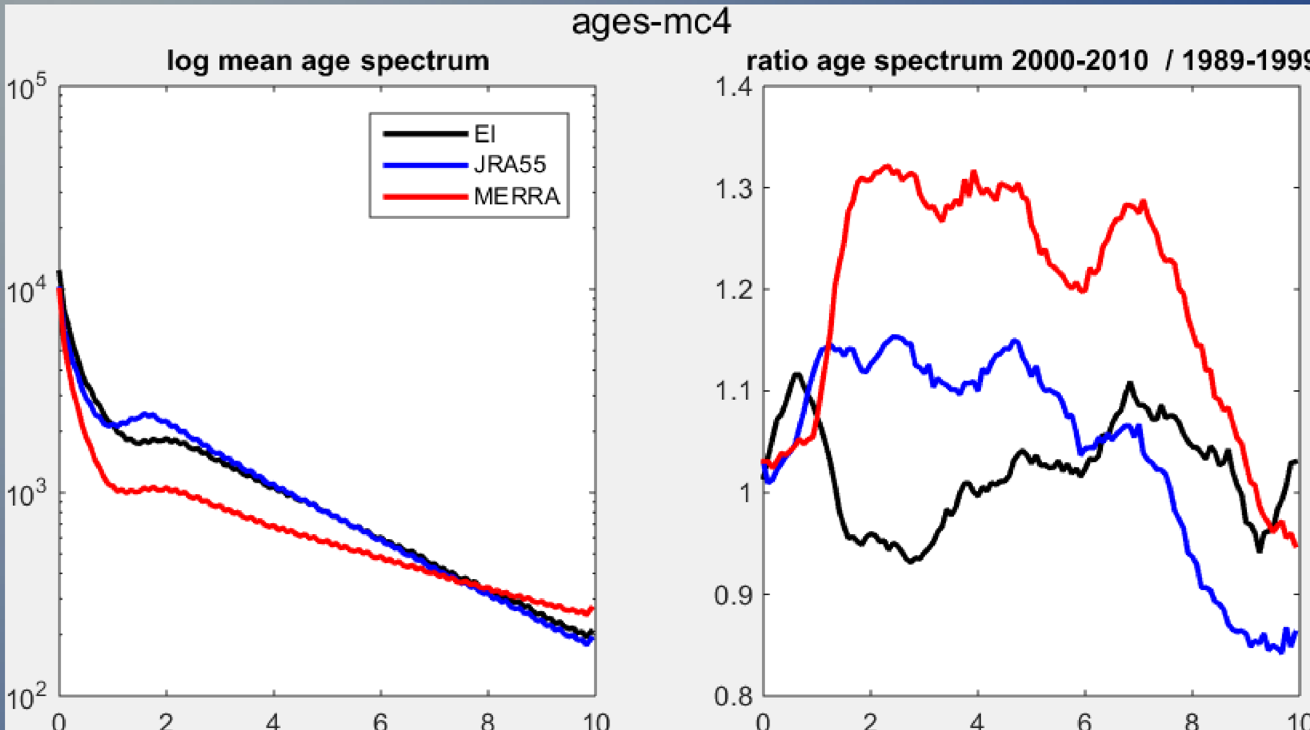
Clipping at 2300K



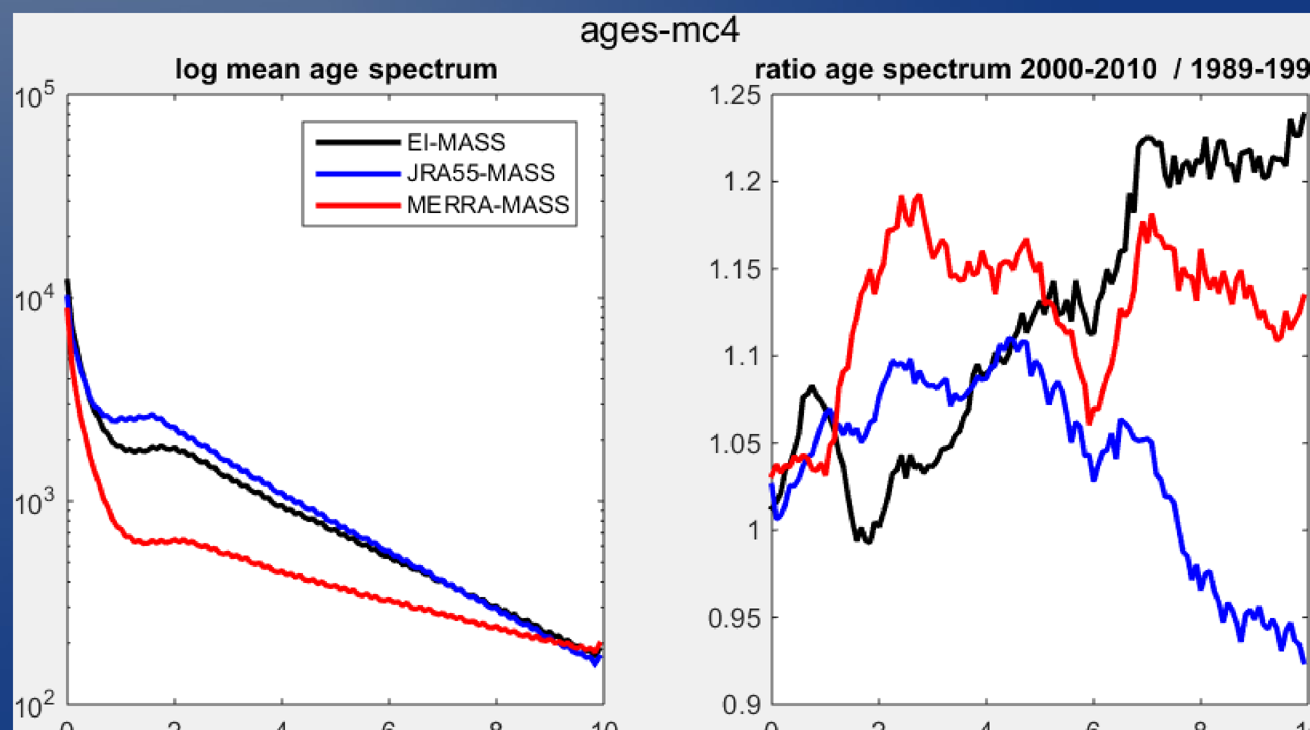
The age spectrum is weakly sensitive to the clipping.

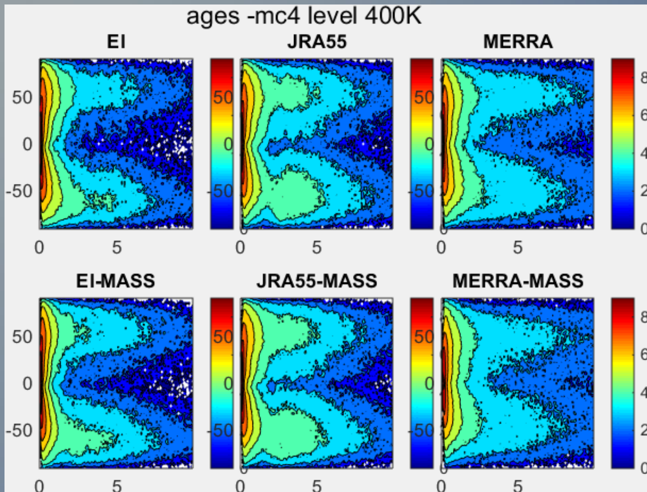
No clipping

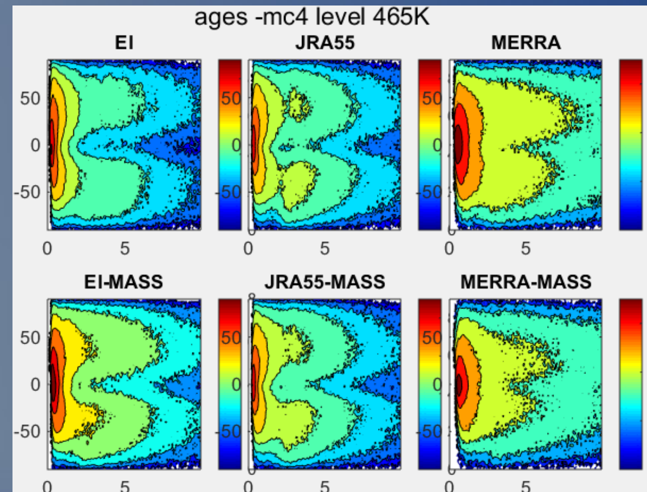


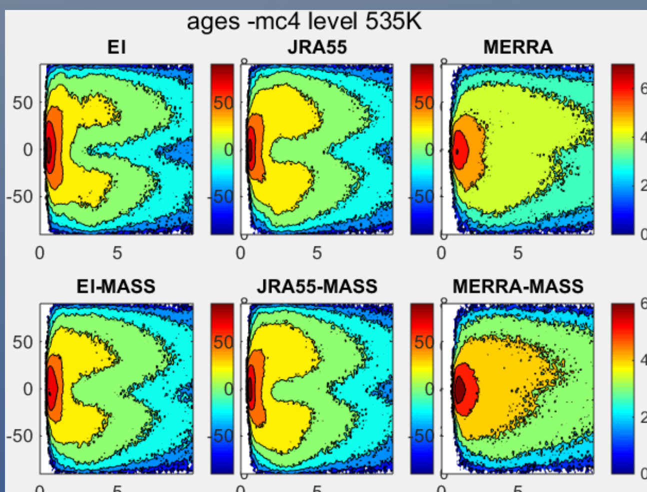


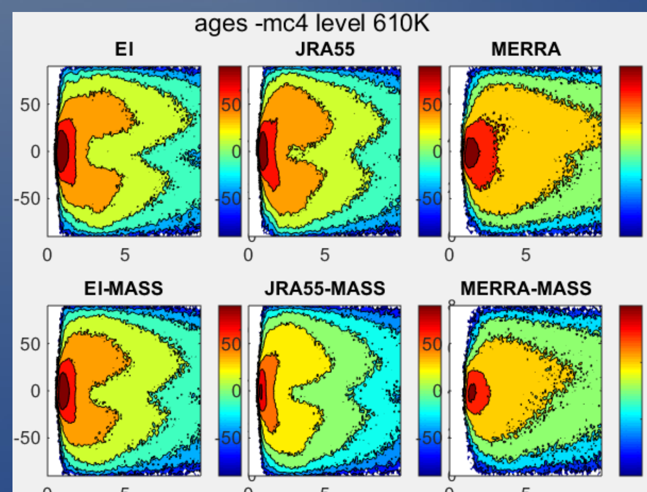
Sensitivity of the age spectrum to the mass correction.



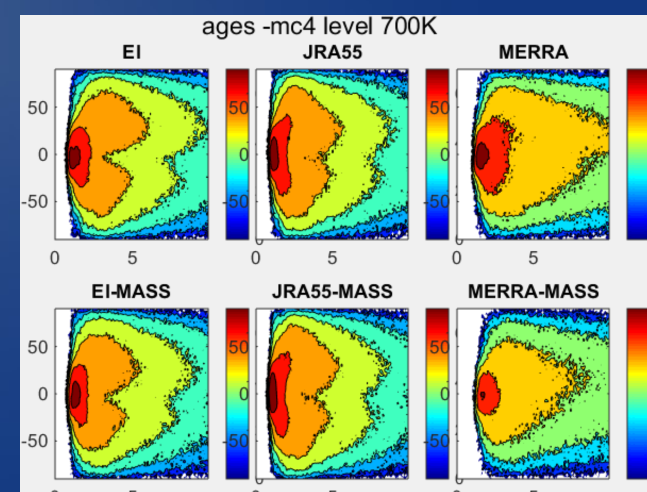




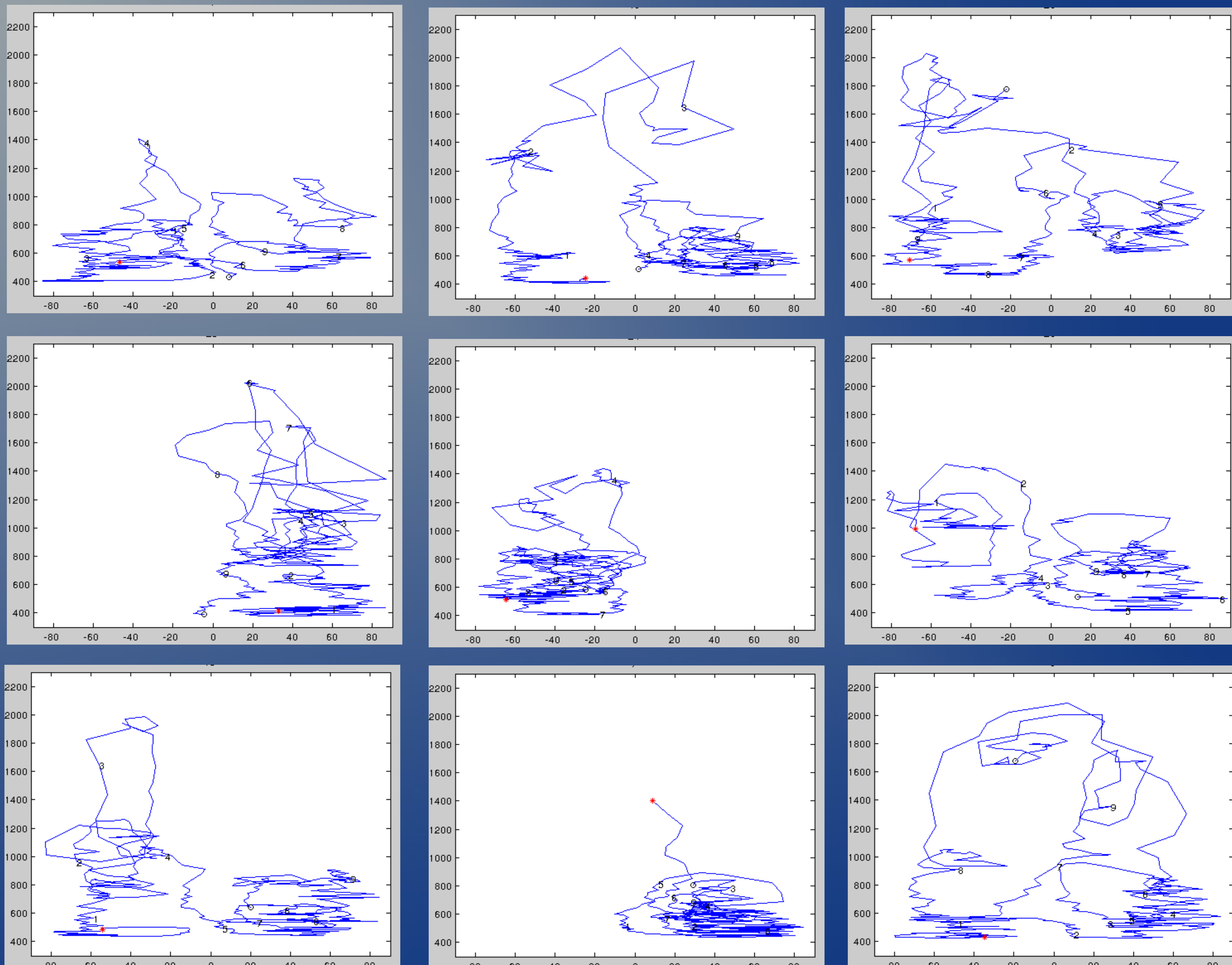




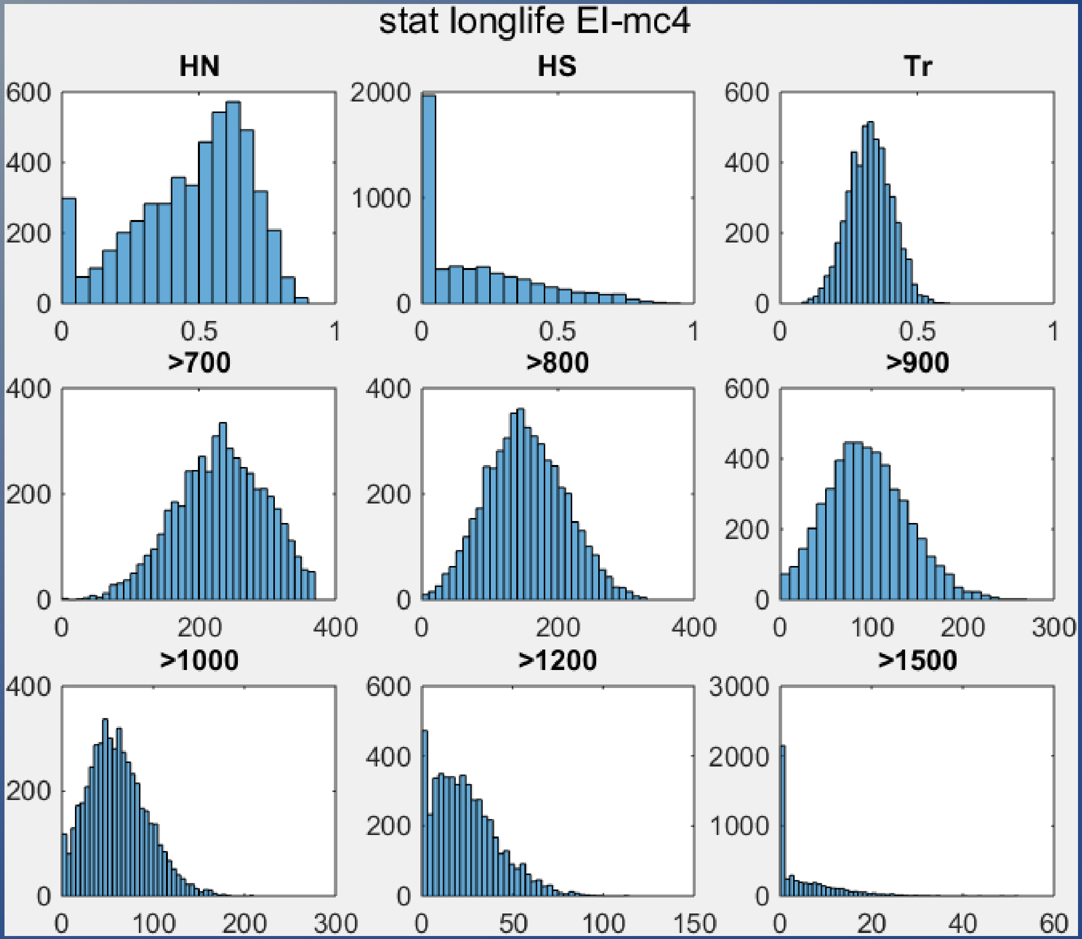
Horizontal sections of mean spectrum.
As altitude grows ;
MERRA tends to differ from the two other reanalysis.



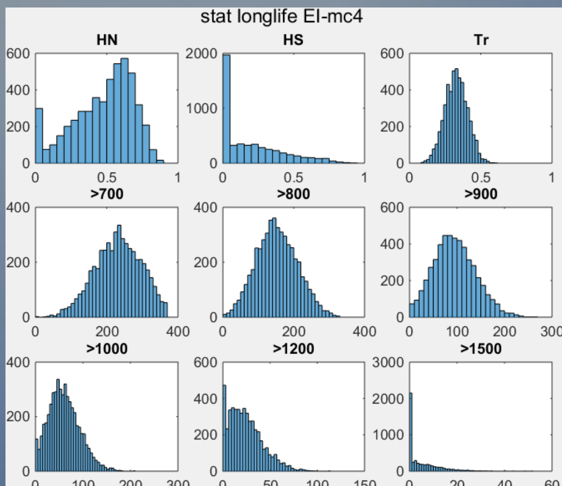
Examples of long-lived trajectories (10y) : transport and mixing at work

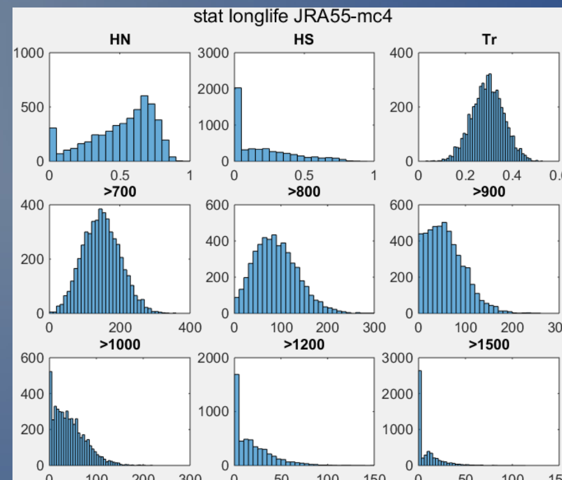


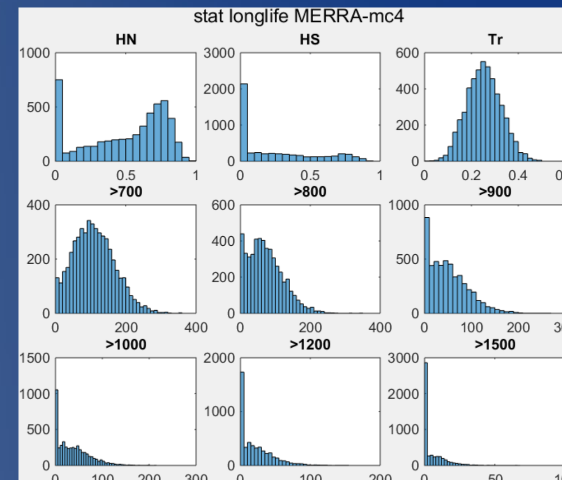
The long-lived parcels spend most of their time in the northern hemisphere . Sojourn in the tropical region follows a Gaussian law (random walk).

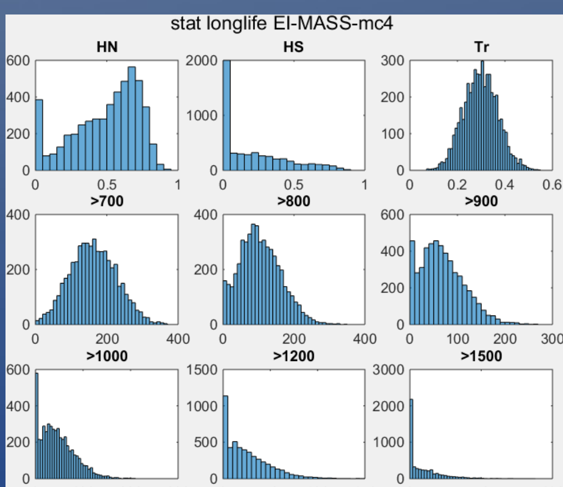


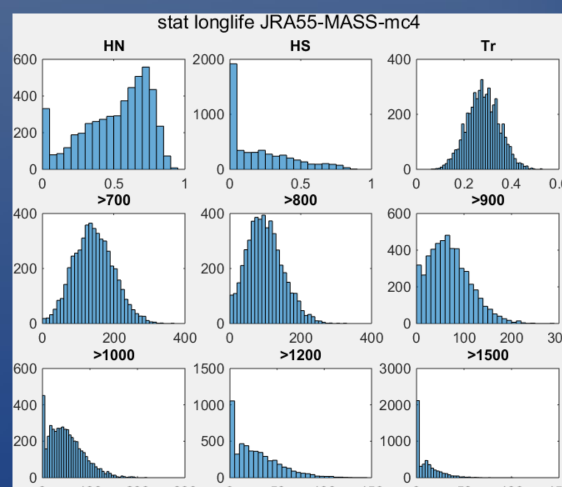
ERA-Interim | JRA55 | MERRA

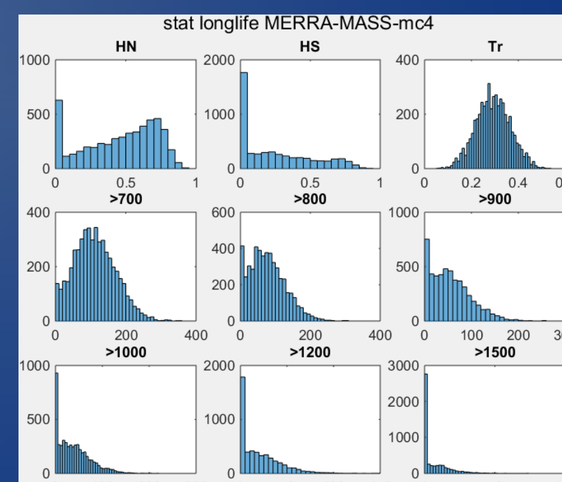








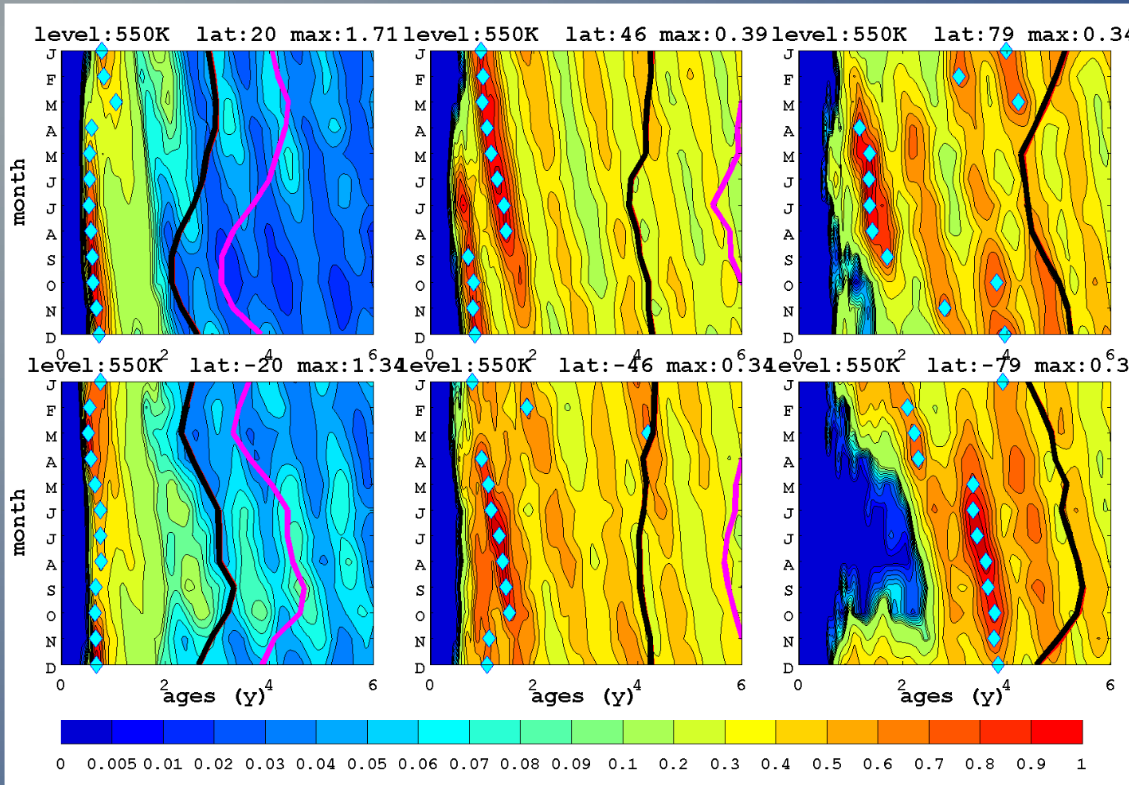




Discussion on AoA

- Modern reanalysis produce mean AoA in much better agreement with observations than the previous generation of reanalysis (e.g. ERA40)
- There are however remaining significant discrepancies among reanalysis and with data.
- The mean AoA depends on the tail of the AoA distribution. In polar region it depends on trajectories travelling in the mesosphere. Clipping such trajectories can be adjusted to fit the data [Sensivity to sponge layer & upper bndry should be considered in CTM?].
- The trends are different.
- The age spectrum and age variability patterns carry much more information than the mean AoA, are less sensitive to the tail and should be used more systematically for model intercomparison
- The spectrum slope is a key parameter.
- The long-lived parcels live preferentially in the northern hemisphere.

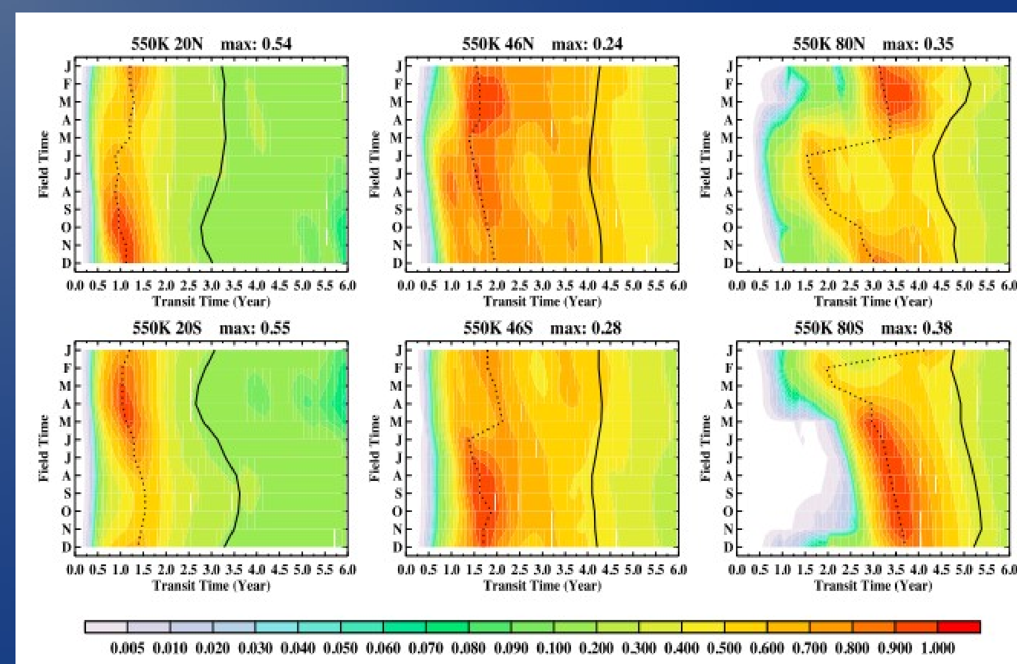
Extra slides



Age spectrum at θ=550K

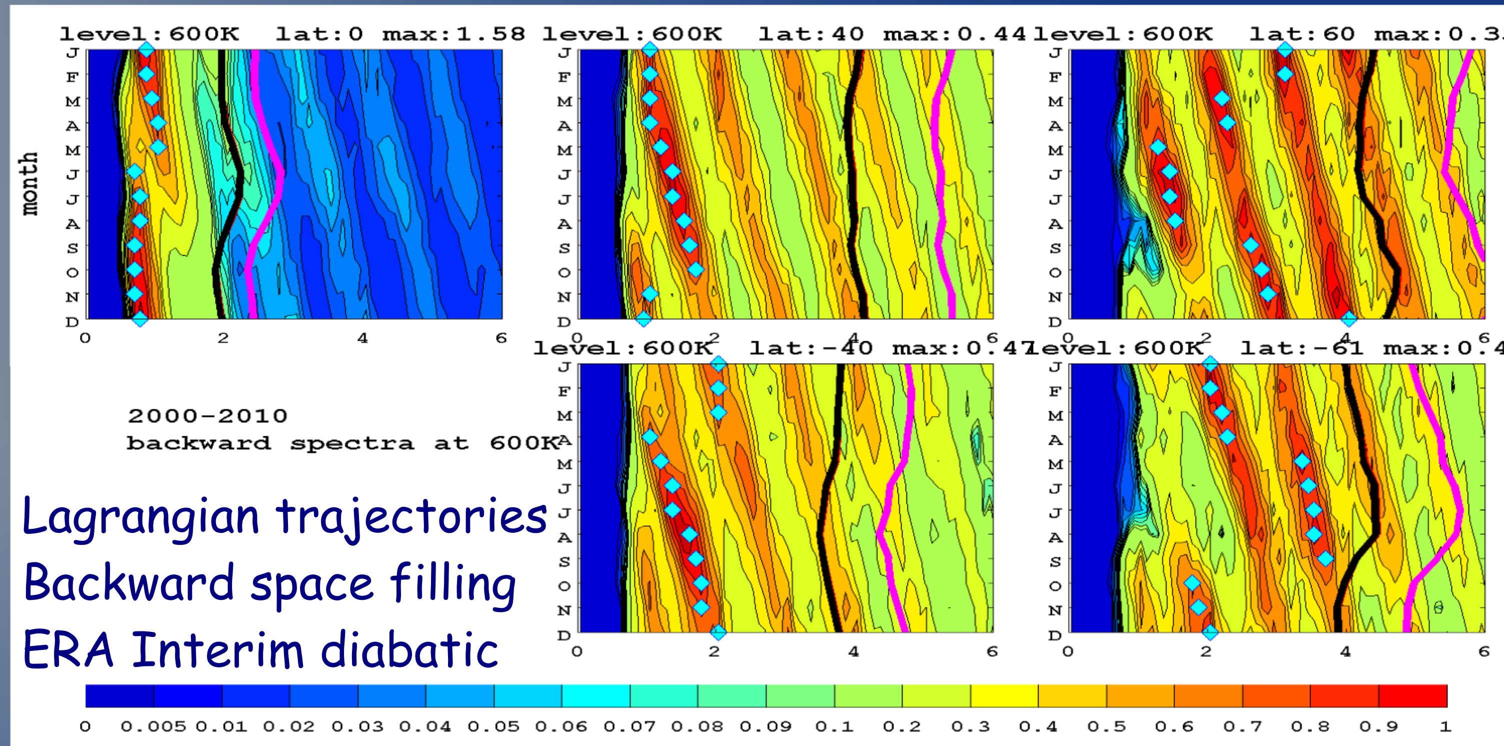
GEOSCCM, Li et al., JGR 2012

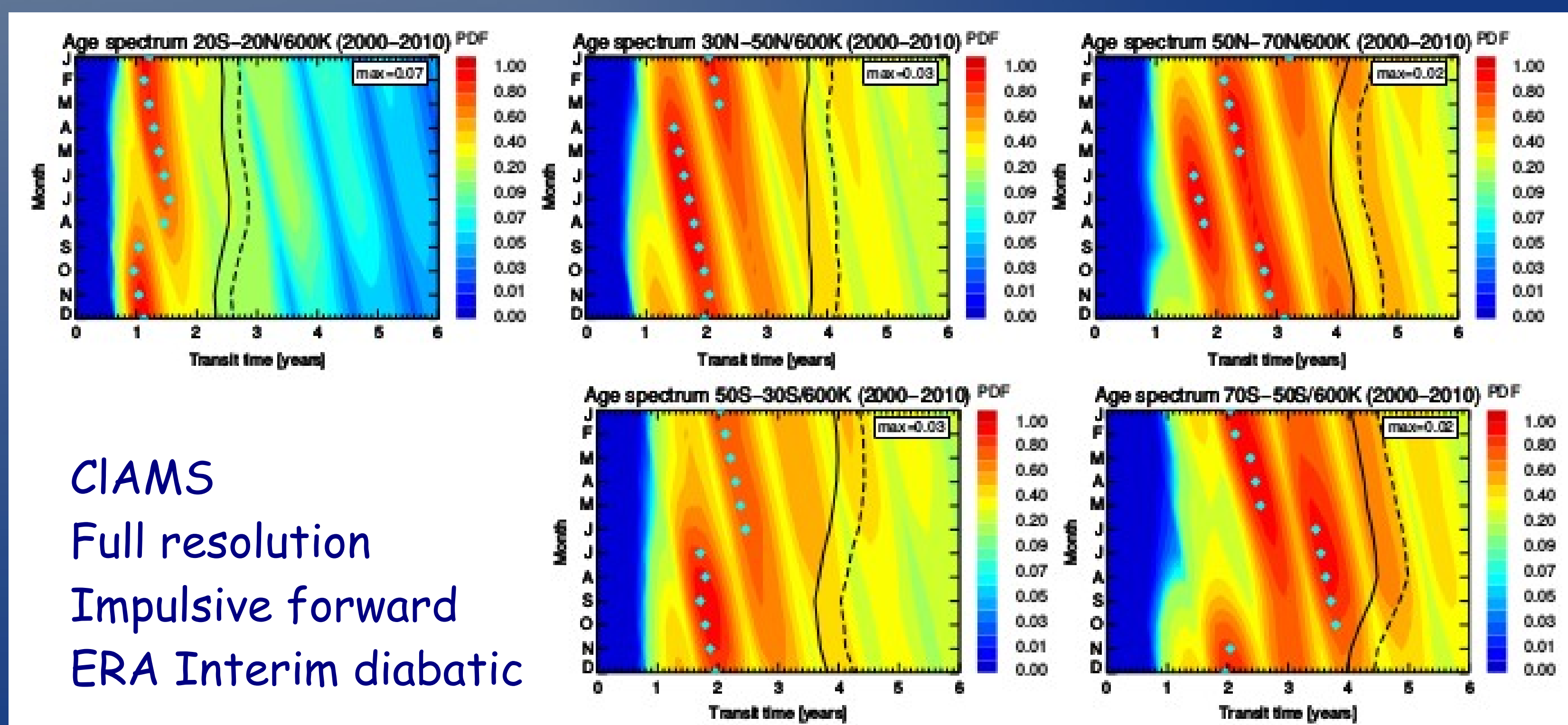
ERA-Interim



Propagation of the annual modulation of the tropical upwelling. In phase at all altitude and latitude (except in GEOSCCM at polar latitudes).

Two very different methods provide very similar age spectrum but for the tail distribution which decays faster in ClAMS in the extratropics. Very similar raw ages but differences in the corrected ages.

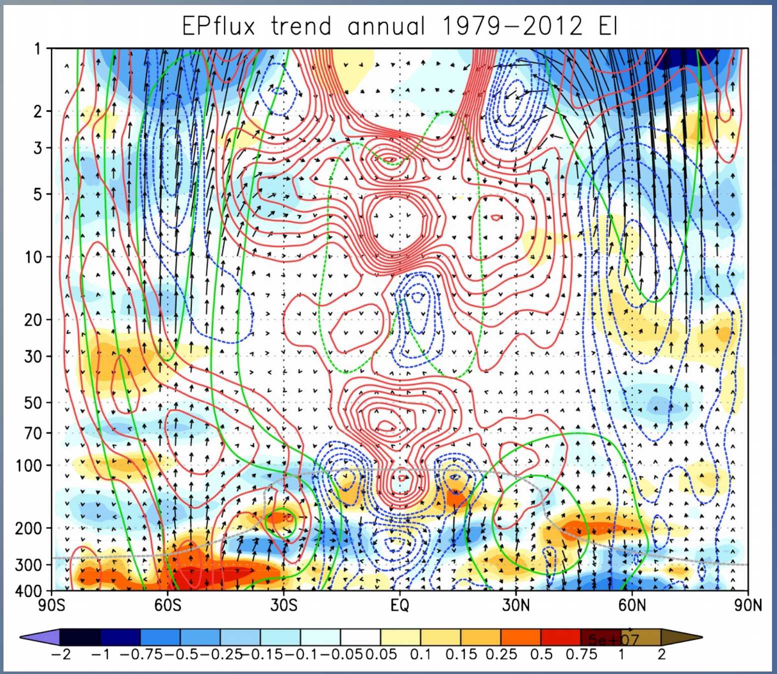




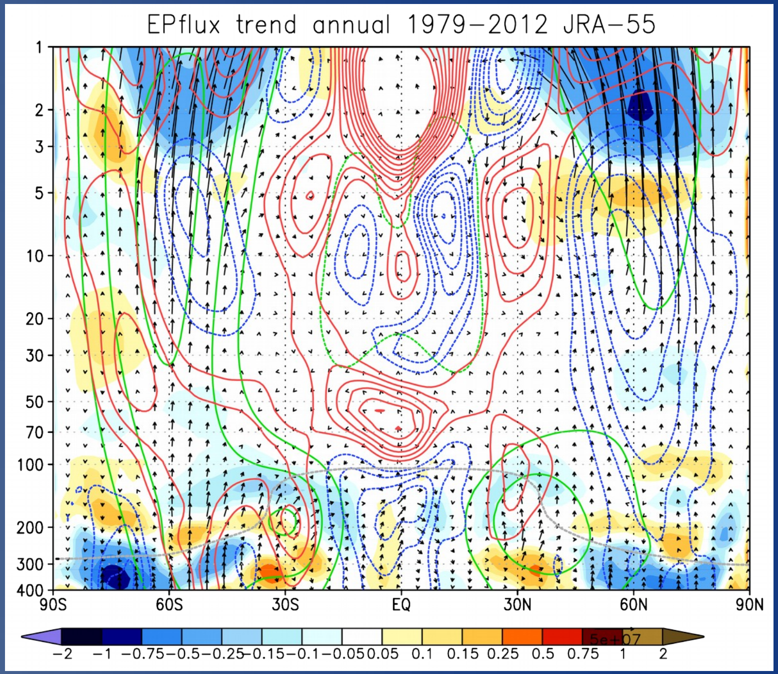
Issues about the mean age of air

- The main reason to use the mean age of air as a measure of the Brewer-Dobson circulation is that it can be measured in the atmosphere from long-lived tracers like CO2 anf SF6
- It is, however, a highly integrated quantity which is sensitive to the tail of the distribution of ages. Therefore corrections are needed for finite duration calculations over one or two decades. These correction depend on the tail distribution which is badly determined.
- Truncating velocity fields or trajectories above a cetain level (in the top of the stratosphere) is often necessary.

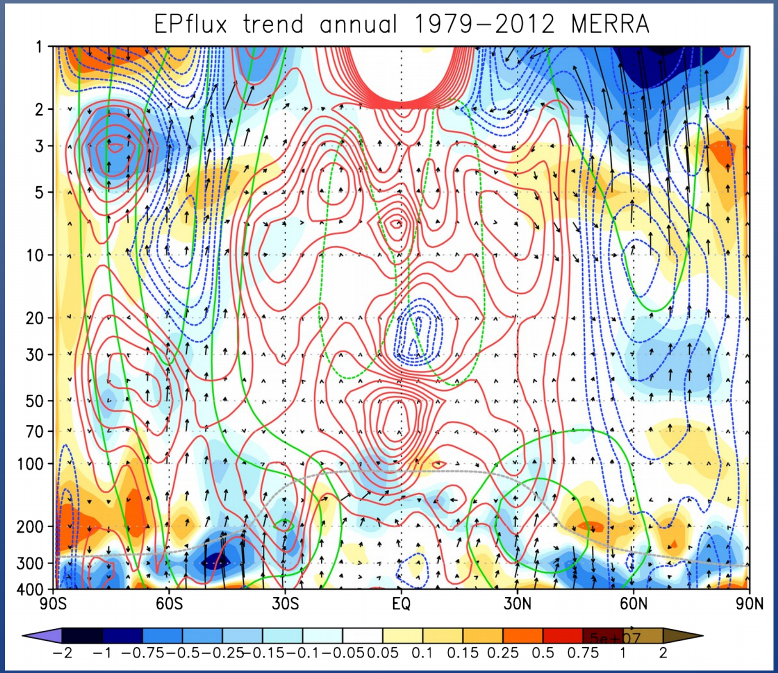
ERA-Interim



JRA-55



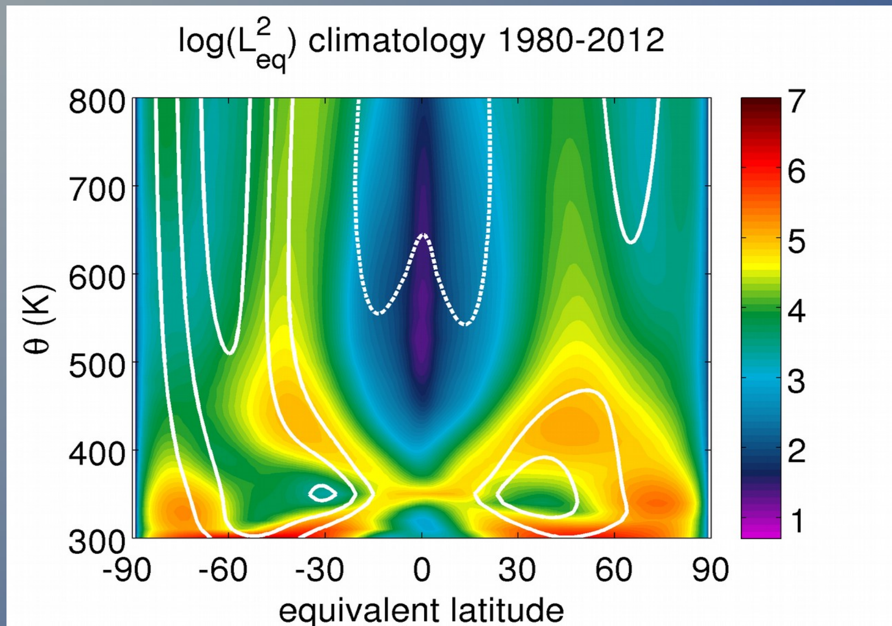
MERRA

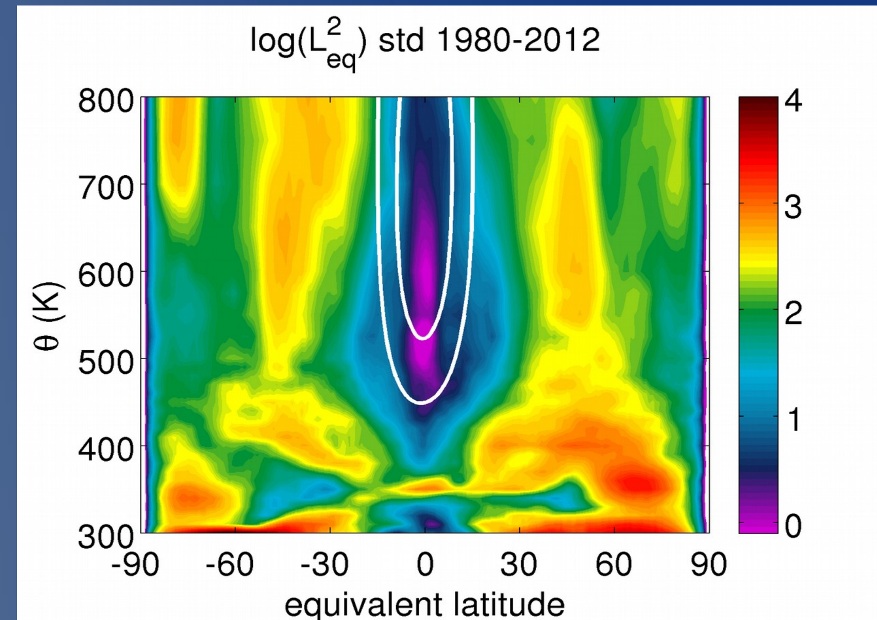


Trends in EP flux 1979-2012

Arrows: EP flux trend
Shading: EP flux divergence trend
Contours:
- U time mean (green)
- U trend (>0 red, <0 blue)

Variability and trend of the effective diffusivity





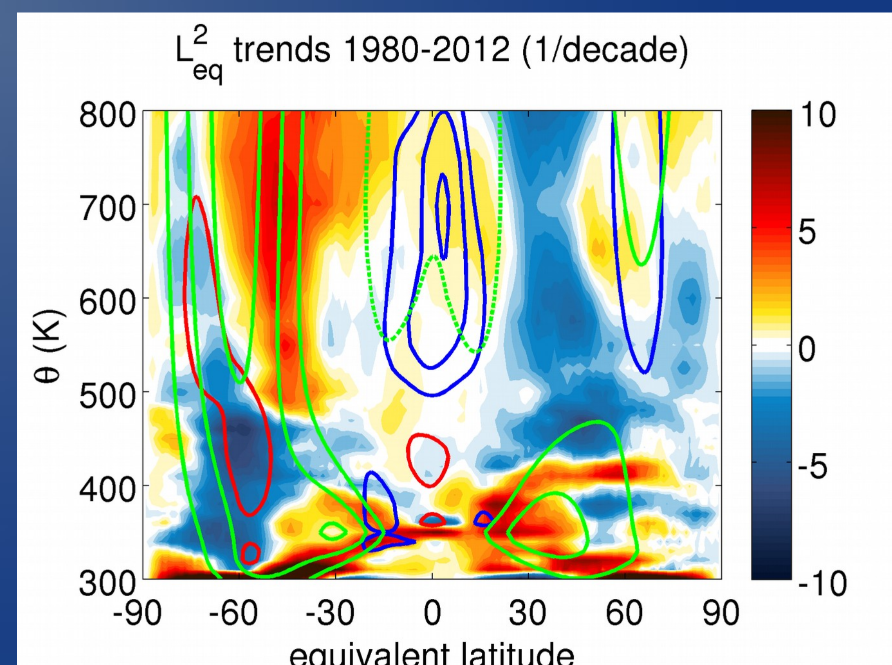
1980-2012 ERA-Interim

Shading : L_{eq}^2 trend

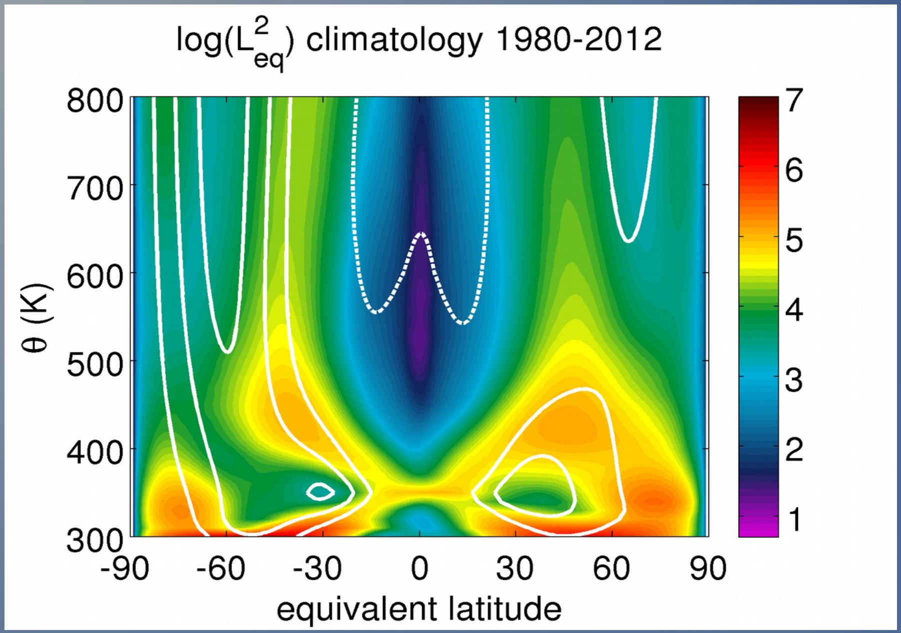
Contours :

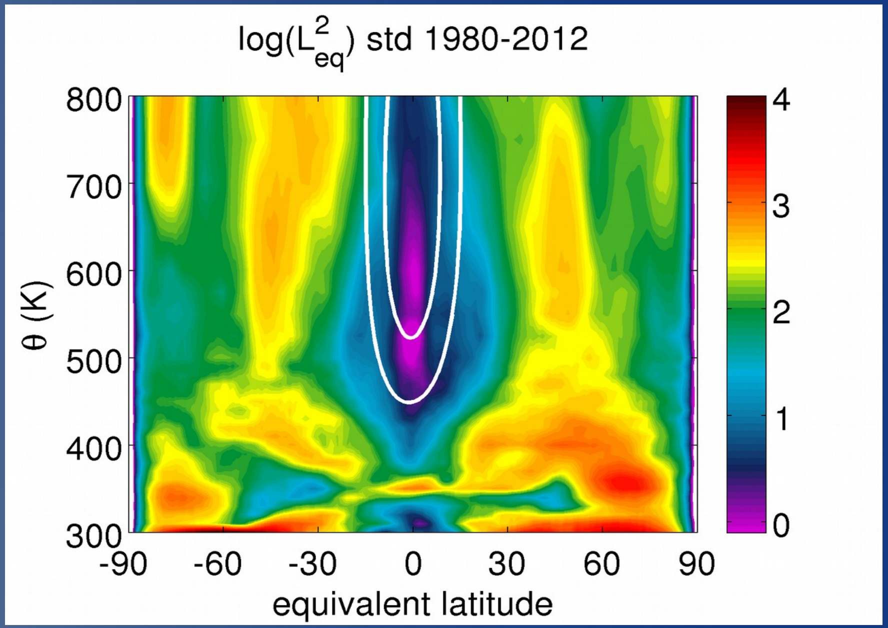
U time mean (green)

U trend (>0 red, <0 blue)



Variability and trend of the effective diffusivity





Trends in mixing 1980-2012 ERA-Interim
90 % confidence level

- Decreased mixing in SH extratropical lower stratosphere
- Increased mixing upper stratosphere SH
- Increased mixing across the subtropical jets