Zonal Asymmetries in Age-of-air and their Relevance for Transport into the Subtropical Lowermost Stratosphere

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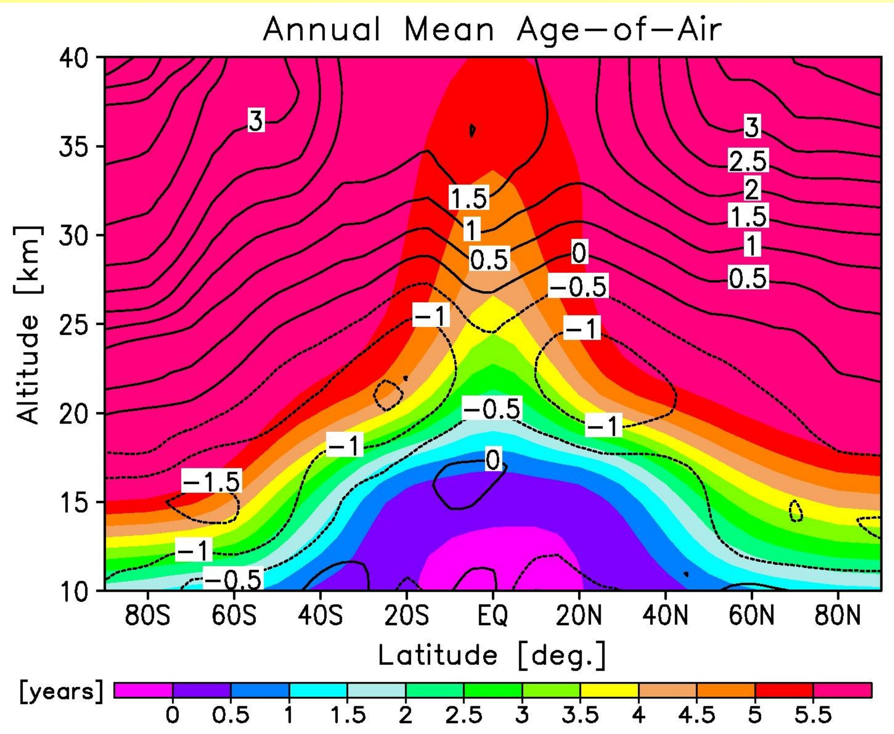
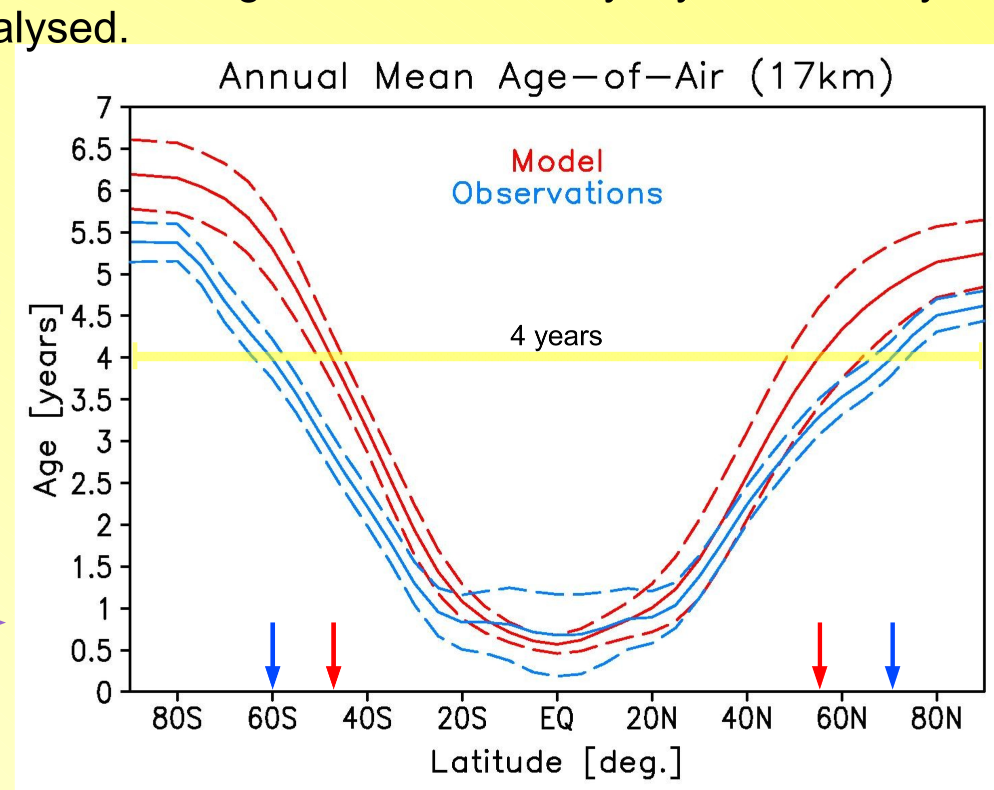
Abstract:
Age-of-air diagnostics help our understanding of large-scale transport processes. In models, age-of-air can easily be calculated using a timed tracer. Observational evidence for age-of-air can be derived using inert tracers with a distinct temporal trend. One such tracer is SF6 as measured by the MIPAS instrument on board ENVISAT. We simulate age-of-air using the Met Office's Unified Model (UM) and validate the model performance with MIPAS derived estimates. Age-of-air zonal means show good agreement in the lower stratosphere. Some deviations are apparent at high altitudes over the Polar Regions. In the northern sub-tropical lowermost stratosphere modelled age-of-air displays pronounced zonal asymmetries overlaid with a seasonal cycle. Using individual SF6 profiles we construct longitudinally resolved age-of-air maps and discuss zonal asymmetries. Consequences for representing transport into the subtropical lowermost stratosphere are explored.



Annual Mean Age-of-Air:
Shaded: A five year average of annual and zonal mean age-of-air from the UM. The age is calculated using a "timed" tracer release throughout the boundary layer and is adjusted to the age in the upper tropical troposphere (see Stiller et al., 2008).
Isolines: Difference between measured (estimated using MIPAS measured SF6) and modelled age-of-air. Positive numbers indicate older age in observations. Above the tropopause the UM has slightly older air than observed.

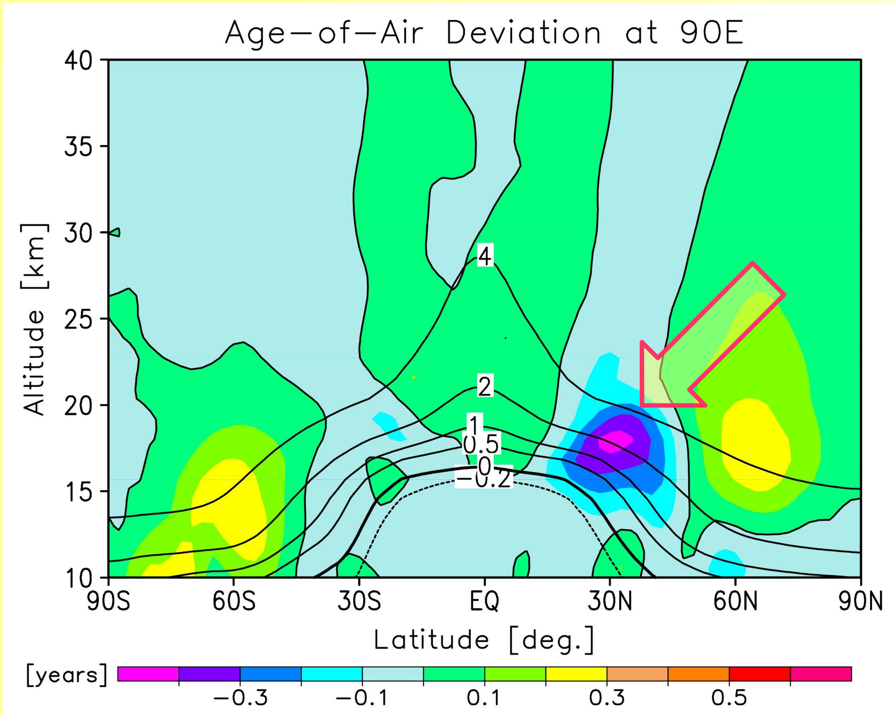
Model:
The Met Office Unified Model (UM) with 60 levels (L60) extending from the surface to around 83km and N48 horizontal resolution (3.75˚x2.5˚ degrees in longitude and latitude) is used. A timed tracer is released throughout the boundary layer in a ten year integration. The last five years are analysed.

Mean Age-of-Air at 17km:
Modelled (red) and observed (blue) age-of-air at 17km (for details see left and below). The latitudinal width of the observed age-of-air is wider compared to the model and at this height the model is older in high latitudes, reaching an age of slightly above 6 years in the SH and slightly below 5.5 years in the NH.



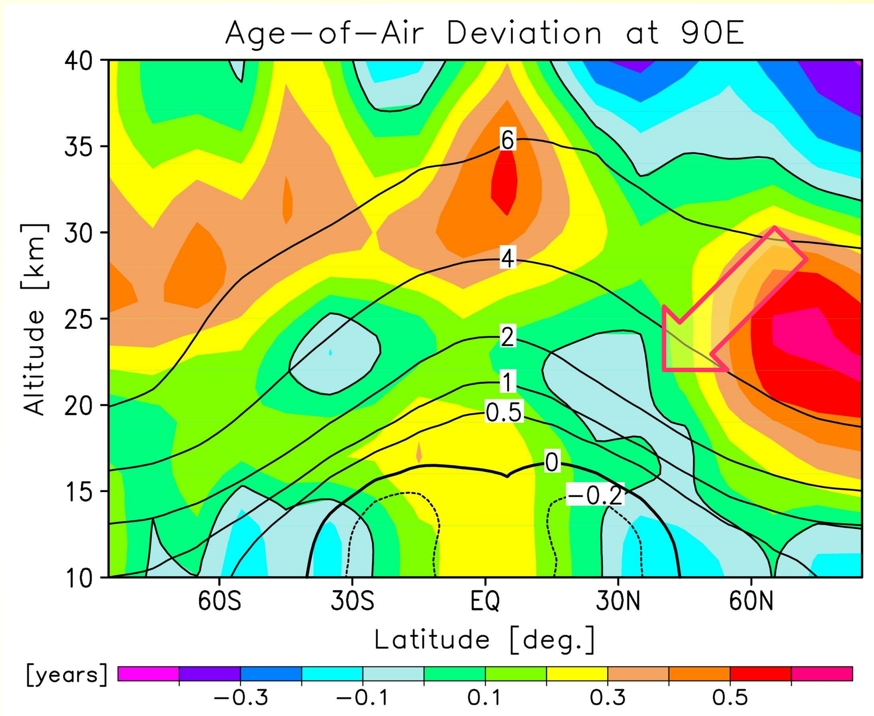
Observations:
SF6 is a suitable tracer to derive age-of-air. It was observed by MIPAS with high precision between late 2002 and early 2004. The zonal mean age is calculated relative to the mean and trend in SF6 for the region 17.5˚S to 17.5˚N and 9 to 15km as shown in Stiller et al. (2008), Figure 7. For the annual and zonal mean comparison between observed and modelled age-of-air, the model is re-gridded like observations and uses the same "reference" region. For the comparison of zonal asymmetries the individual observed age profiles are processed (details below left).

Unified Model:



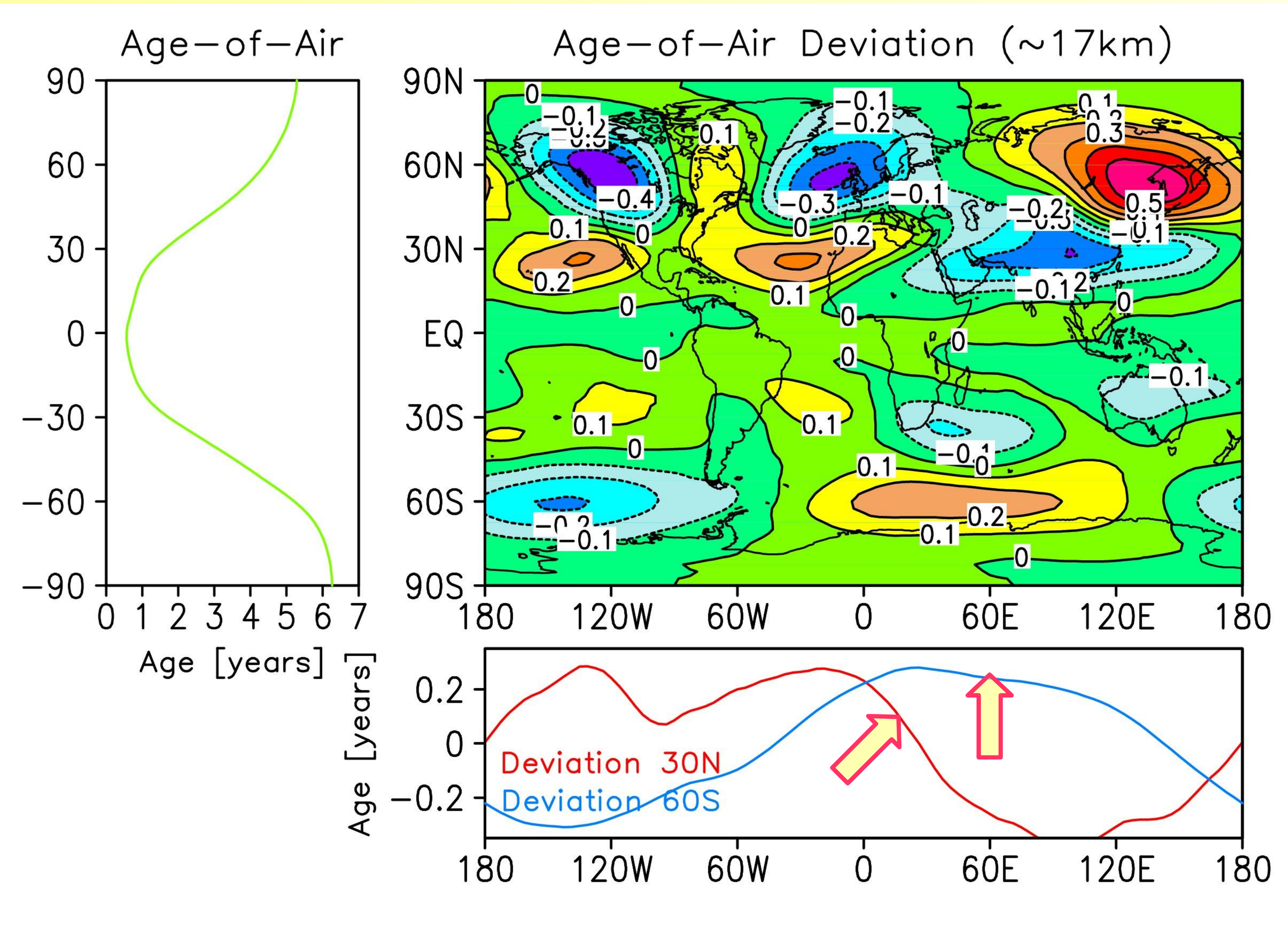
Processing of Observations:

- All age profiles for 2003 are considered.
- 3166 profiles are rejected due to poor visibility.
- 48483 profiles are used in the binning.
- The binning uses 10°x10° boxes globally.
- The annual mean age is calculated in each box.
- The data is spatially smoothed with a 3x3 grid-point running average.
- Deviations from the zonal mean are calculated.

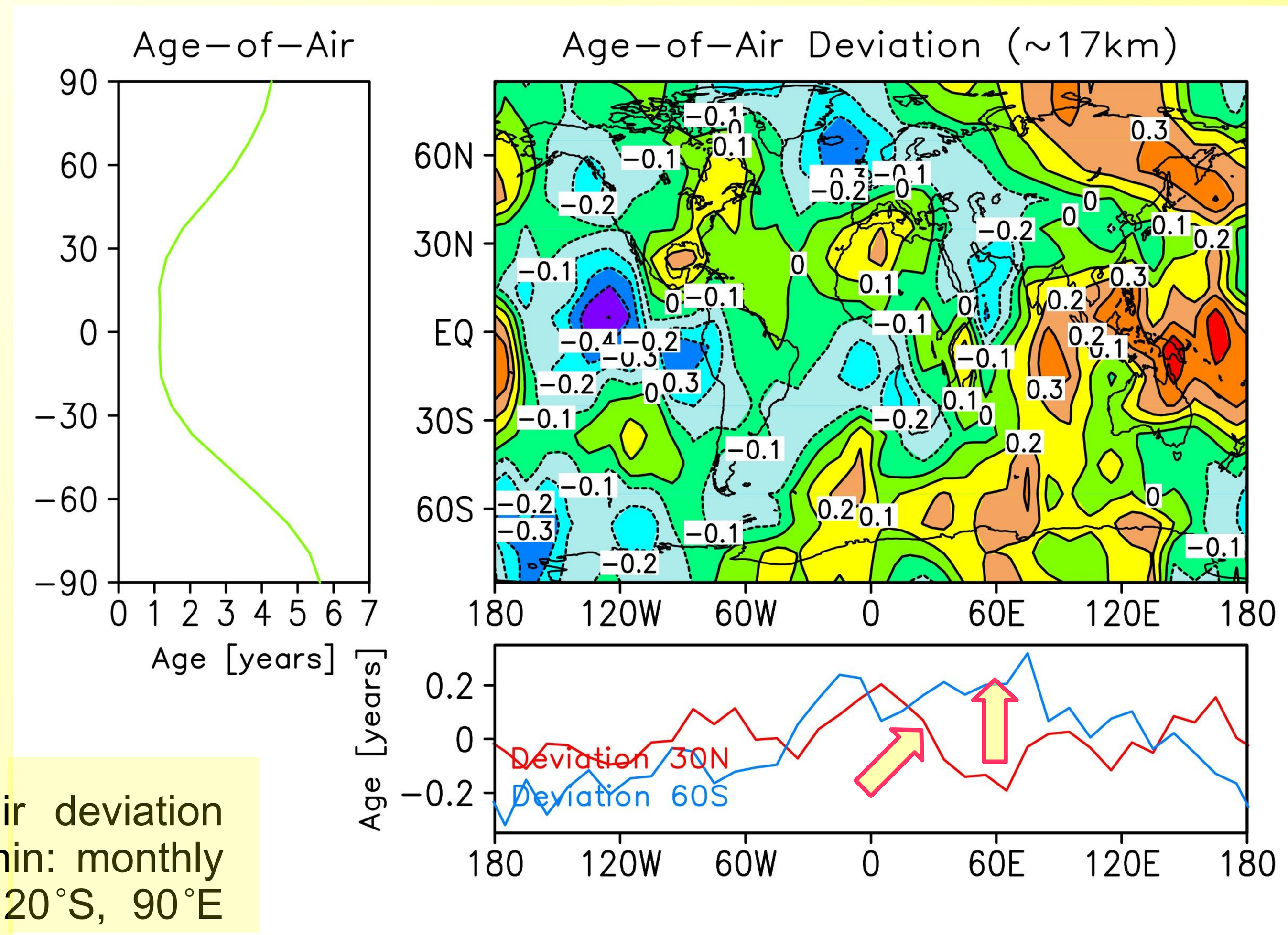


MIPAS Observations:

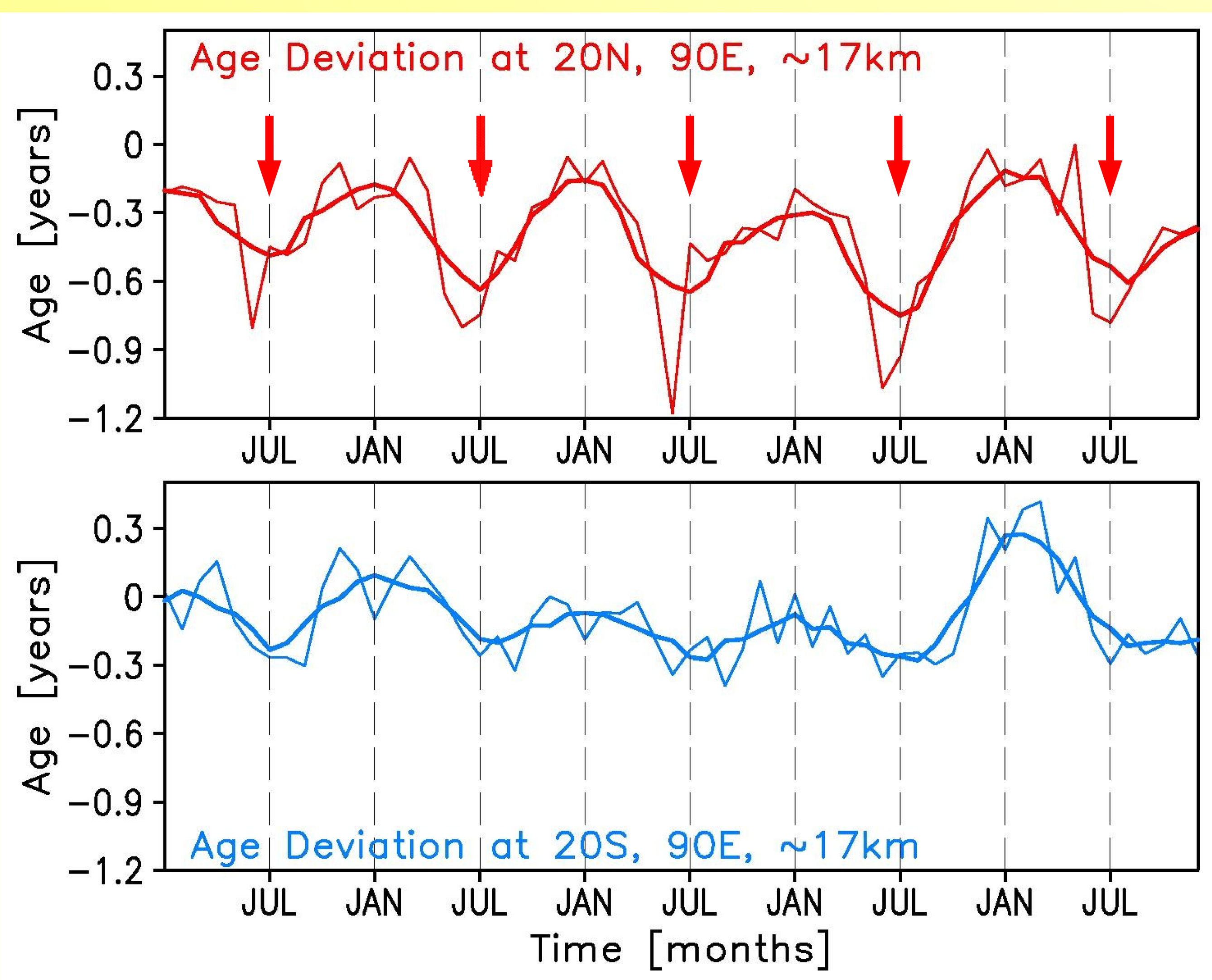
Age-of-Air Deviation at 90E:
Age-of-air deviation from the zonal mean at 90˚E (shaded). Note the coherence and depth of the negative anomaly (younger than the zonal mean) sideways of the sub-tropical tropopause in both model and observations. The lower amplitude in observations might be in part due to averaging over larger areas (10˚x10˚ compared to 3.75˚x2.5˚), which is required to keep the "errors" down.



Mean Age-of-Air Deviations at 17km:
Modelled (left) and observed (right) deviations from the zonal mean of the annual mean age-of-air. The green graph indicates the zonal mean age-of-air. Blue areas correspond to regions were the age-of-air is younger than the zonal mean. There are stronger negative and positive anomalies on the NH in the model. Note the negative anomaly in low subtropical latitudes on the NH.
The bottom red and blue graphs show the age-of-air deviations at 30˚N or 60˚S respectively. Model and observations agree surprisingly well (see arrows).

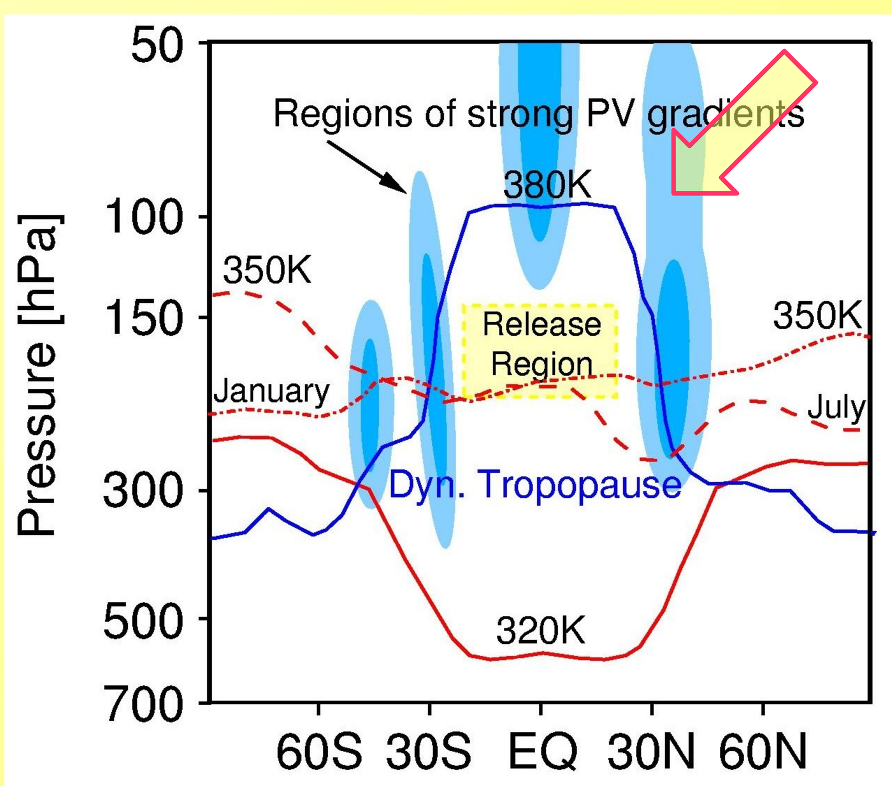


Interannual Variability in Age-of-air:
Modelled interannual variability in age-of-air deviation from the zonal mean for 20˚N, 90˚E (red; thin: monthly mean values; thick: running average) and 20˚S, 90˚E (blue) at 17km. The amplitude in the NH is larger than in the SH and the values are almost always negative (younger than the zonal mean).



Discussion:

- Modelled zonal mean age-of-air shows good agreement with observations in the lowermost stratosphere.
- Model and observations highlight hemispheric and zonal asymmetries in the age of air distribution.
- Model and observations suggest younger air (relative to the zonal mean) in the subtropical lower stratosphere between east Africa and the Indian subcontinent (and even further to the east in the model).
- A strong Monsoon component may be implied given the extent and location of the sub-tropical negative anomaly and the interannual variability shown by the model (see left).
- Levine et al. (2007) argue for the possibility of fast lateral transport from the tropical upper troposphere to the extra-tropical lowermost stratosphere which seems to be consistent with younger than average air.
- Note that 2003 was influenced by an El Niño event that peaked early in the year. This might explain some of the younger air in observations west of the Americas in tropical latitudes.



Schematic Tropopause Position:
Schematic illustration of the position of strong PV gradients relative to the subtropical tropical tropopause (Levine et al., 2007). Note the hemispheric asymmetry and the stronger gradient in the NH.

Levine, J. G., P. Braesicke, N. R. P. Harris, N. H. Savage, and J. A. Pyle, Pathways and timescales for troposphere-to-stratosphere transport via the tropical tropopause layer and their relevance for very short lived substances, *J. Geophys. Res., 112*, doi:10.1029/2005JD006940, 2007.
Levine, J. G., P. Braesicke, N. R. P. Harris, and J. A. Pyle (2007), Seasonal and Inter-annual Variations in Troposphere-to-Stratosphere Transport from the Tropical Tropopause Layer, *ACP*, 8, 3689-3703, 2008.
Stiller, G. et al., Global distribution of mean age of stratospheric air from MIPAS SF6 measurements, ACP, 8, 677-695, 2008.

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