The Impact of Tropical Recirculation on Age of Air

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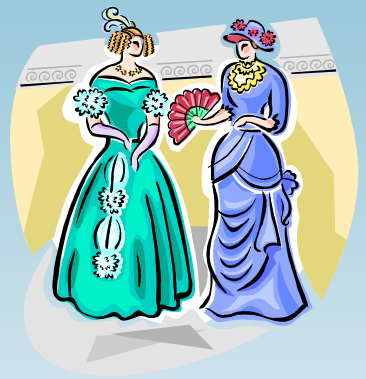
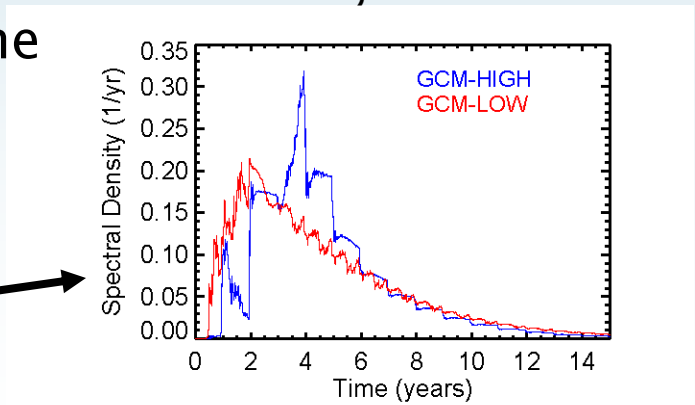
Mean age used to be a great model diagnostic



- Back in the days of M&M II (Hall et al., 1999), most models had mean age too young and they differed from each other.
- Some models have improved transport schemes and many get good age of air at 20 km.
- Unfortunately, it's possible to get the right mean age for the wrong reasons.

These spectra have the same mean age.

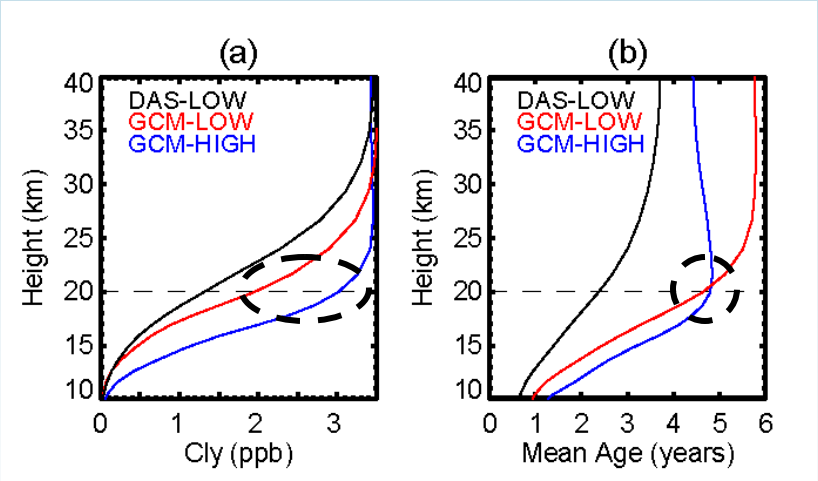
82°S, 57 hPa



You need more than mean age to validate transport

GCM-HIGH: a 2x2.5 CTM simulation with high lid (0.01 mb) – ***GMI Hindcast***
GCM-LOW: a 4x5 CTM simulation with low lid (0.4 mb) ***– older GMI 'WMO'run***

These simulations have very different circulations. Compared to **GCM-HIGH (blue),** the **4x5 (red)** is too young below 20 km and too old above. At 20 km the differences are zero but this is *not* because their transport is the same.

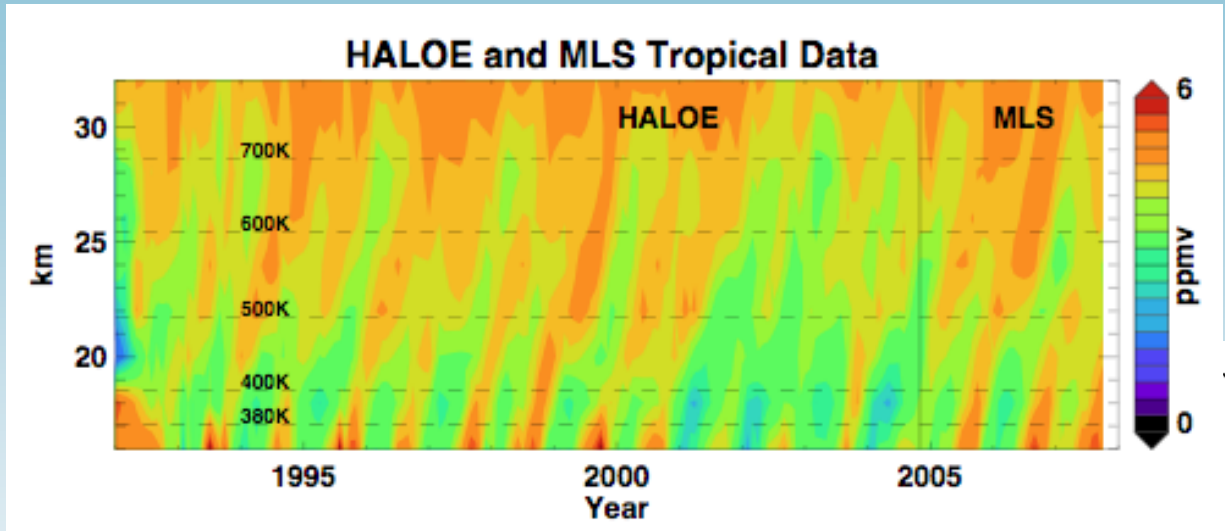


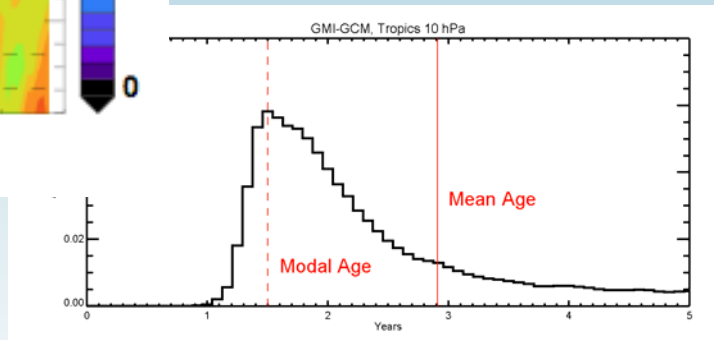
Cl_y and Mean Age at 80°S.

From Waugh, Strahan, and Newman, Atmos. Chem. Phys., 2007.

The differences in these circulations will give very different Cl_y in the Antarctic lower stratosphere. **Transport pathways matter for chemistry!**

Schoeberl et al. (submitted, 2008) have derived vertical velocities from 15-years of HALOE and MLS H_2O data



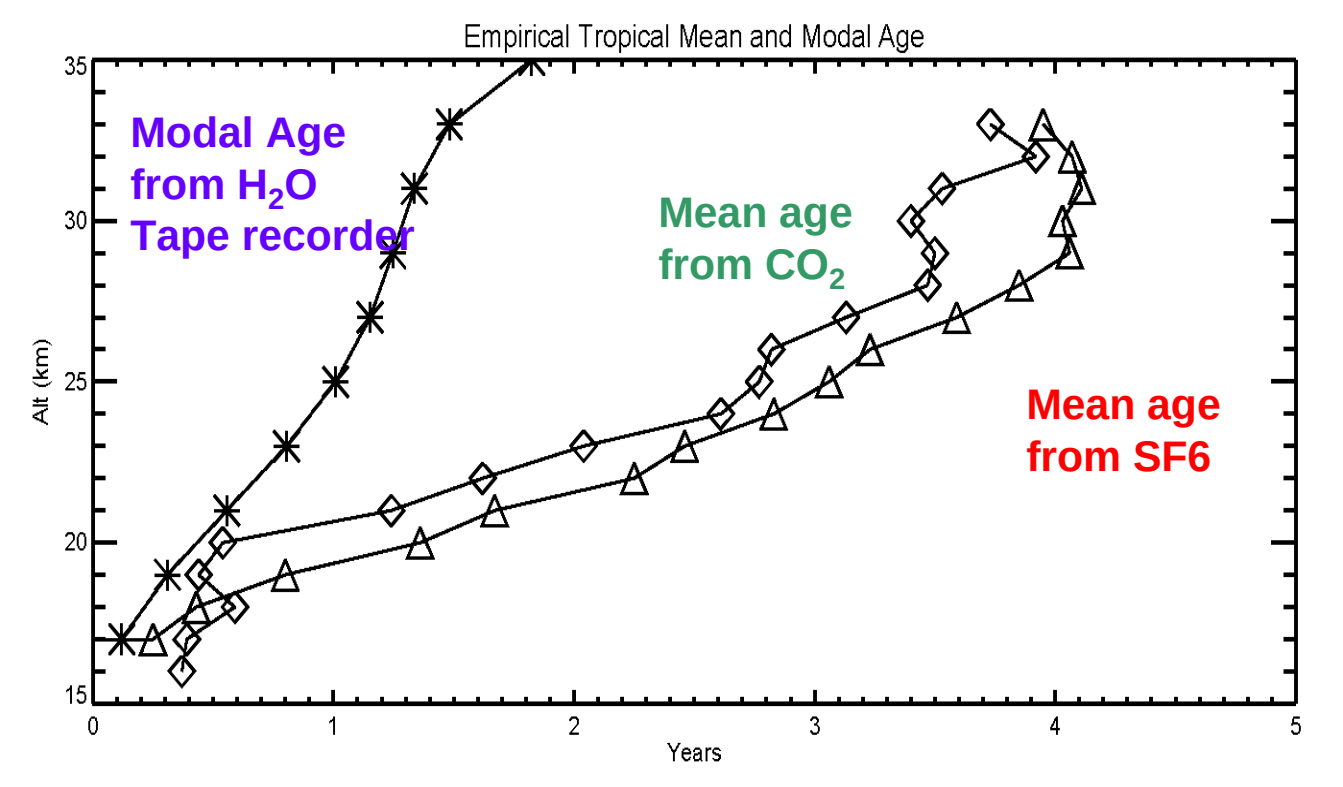


As noted in Waugh and Hall (2002), the **modal age in the tropics is roughly the same as the vertical advection time**. The Schoeberl et al. analysis of the water tape recorder determined the vertical velocities between 15-35 km.

Now we have empirically derived modal age in the tropics!

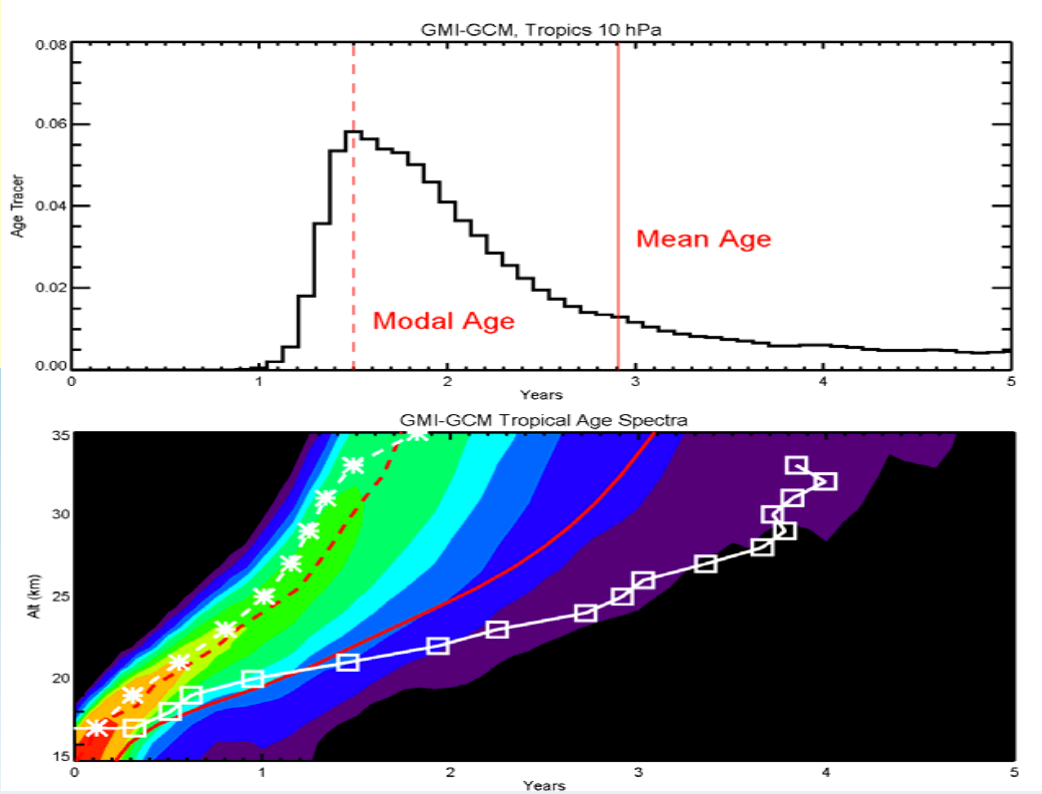
Balloon measurements of CO_2 and SF_6 in the tropics provide us with tropical mean age [Ray et al., 1999].

With the Schoeberl et al. analysis **we now have a 2nd key parameter of the tropical age spectrum – the mode**!



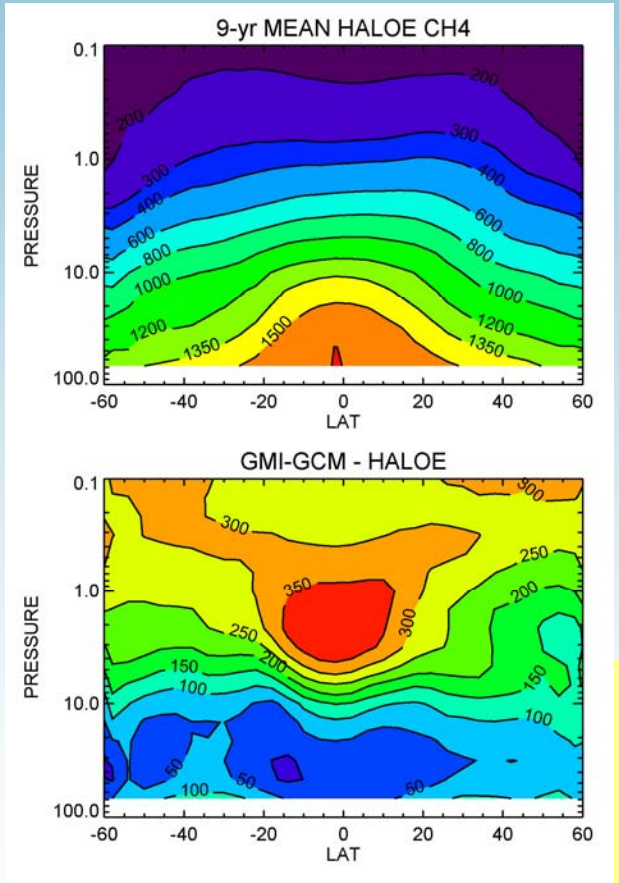
Together, mean and modal age allow independent diagnosis of tropical ascent (advection) of mixing (recirculation)

- In the tropics, the most probable transit time for arrival of the age tracer is the mode.
- The mean age is given by the solid red line.
- By contouring the age spectra, we can see the mean and modal ages as a function of height in the tropics (red lines).
- Empirically determined modal and mean ages are overlaid in white.



<u>Results</u>: GMI CTM with GEOS4-GCM met fields has realistic vertical advection in the tropics (to 35 km). The low mean age shows there is too little recirculation of older, extratropical air into the tropics above 22 km. **<u>The GEOS4-GCM tropics are TOO ISOLATED.</u>**

How does tropical age affect the rest of the stratosphere? Use CH_4 as a proxy for age…



CH_4 is a tropospheric source gas, long-lived in the stratosphere. It requires transport pathways through the upper stratosphere and above to experience significant loss.

The differences between a 9-yr HALOE CH_4 annual average and the 5-yr GMI-GCM average show:

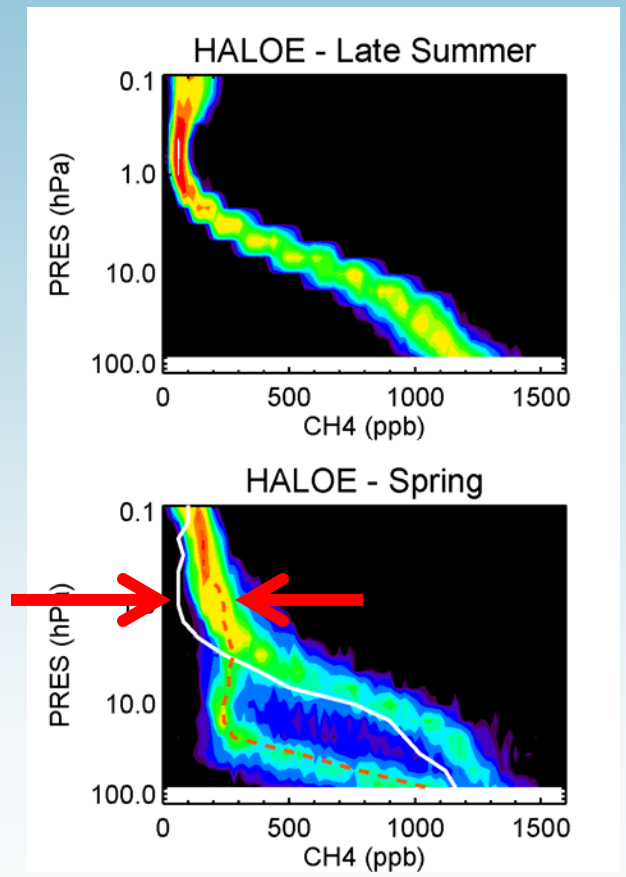
· There is excellent agreement below 10 hPa (much better than 10%).

· **Tropical upper stratosphere has worst agreement – this is where the model is too young.**

CH_4 too high = air that's too young

Polar effects of young tropical age?
Transport in the Antarctic: Summer (Feb/Mar) to Spring (Oct/Nov)

CH_4 PDFs, 80º-68ºS

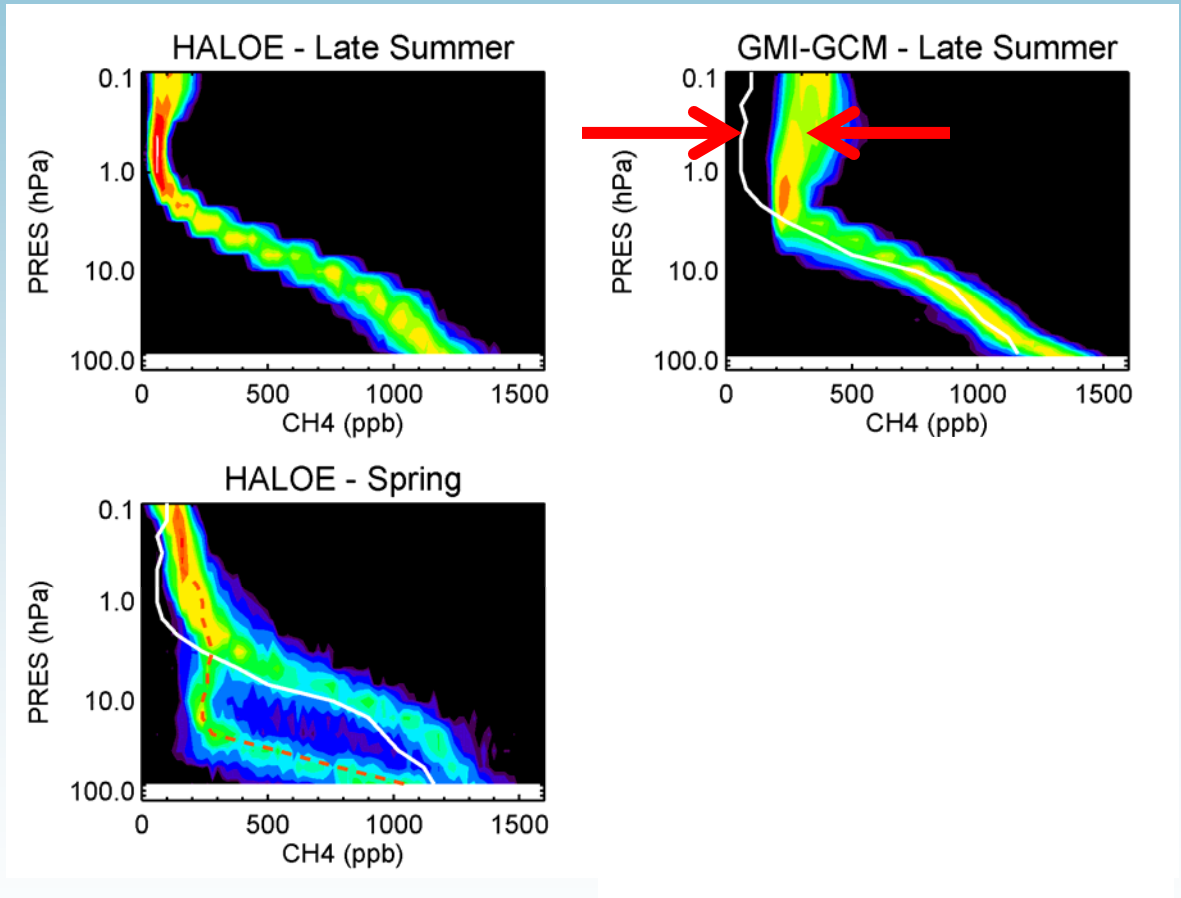


During fall and winter, the summer profile descends. At the same time, higher CH_4 air from the low latitudes is transported poleward, increasing mixing ratios by 100-200 ppb in the upper stratosphere and lower mesosphere.

The summer profile is overlaid in white.

Polar effects of young tropical age?
Transport in the Antarctic: Model Summer (Feb/Mar)

CH_4 PDFs, 80º-68ºS



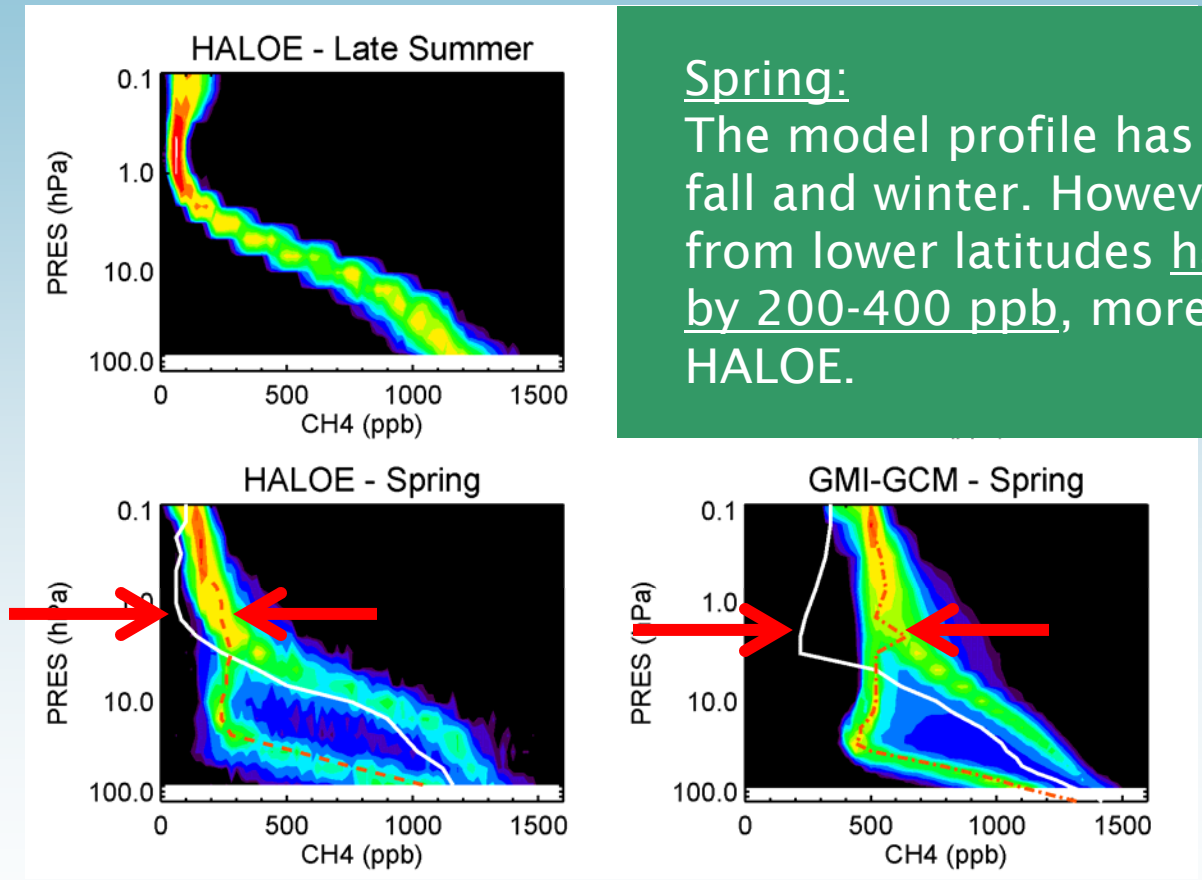
<u>Late summer:</u>

The model profile agrees very well below 3 hPa.

It is too high by 200-300 ppb in the lower mesosphere. (HALOE is overlaid in white.)

Polar effects of young tropical age?
Transport in the Antarctic: Summer (Feb/Mar) to Spring (Oct/Nov)

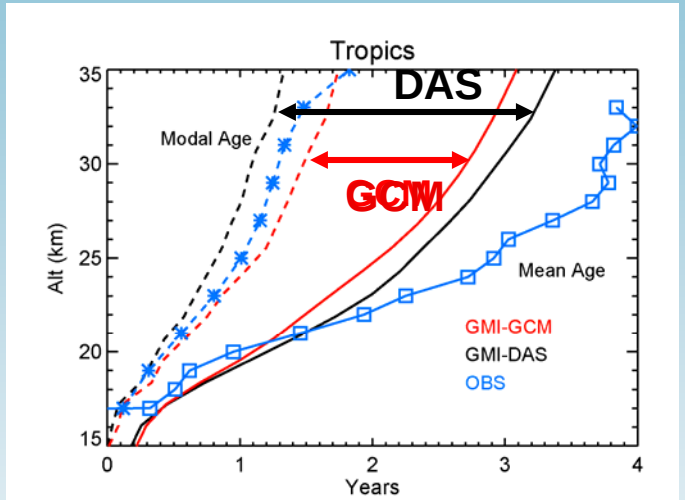
CH_4 PDFs, 80º-68ºS



Spring:
The model profile has descended during fall and winter. However, transport of air from lower latitudes has increased CH_4 by 200-400 ppb, more than observed by HALOE.

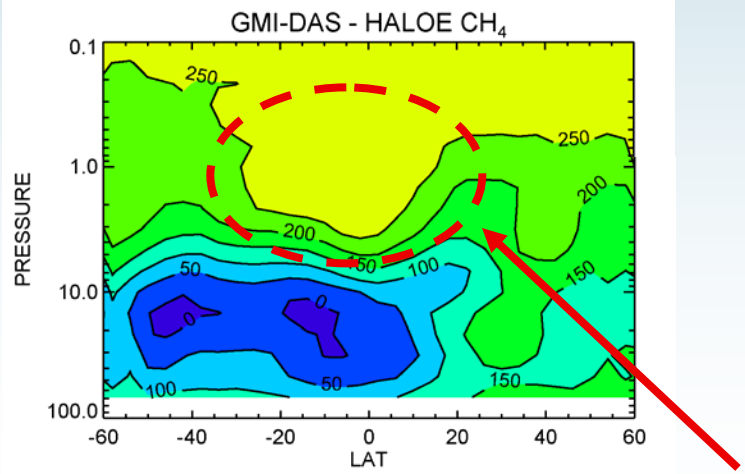
The excessive increase in Antarctic upper stratospheric CH_4 comes high CH_4 in the tropical upper stratosphere (and above). **Young air from the tropics is now affecting age in the polar region.**

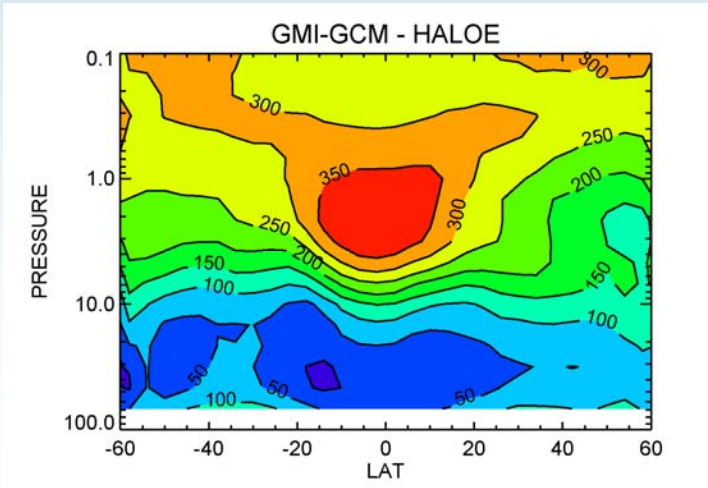
Mean and Modal Age in GEOS4-DAS and Comparison with GEOS4-GCM



DAS vertical advection is a little faster than the GCM, but still very closer to observed.

DAS mean age is greater. The ***separation*** of modal and mean is greater: **DAS has greater tropical recirculation – a good thing!**

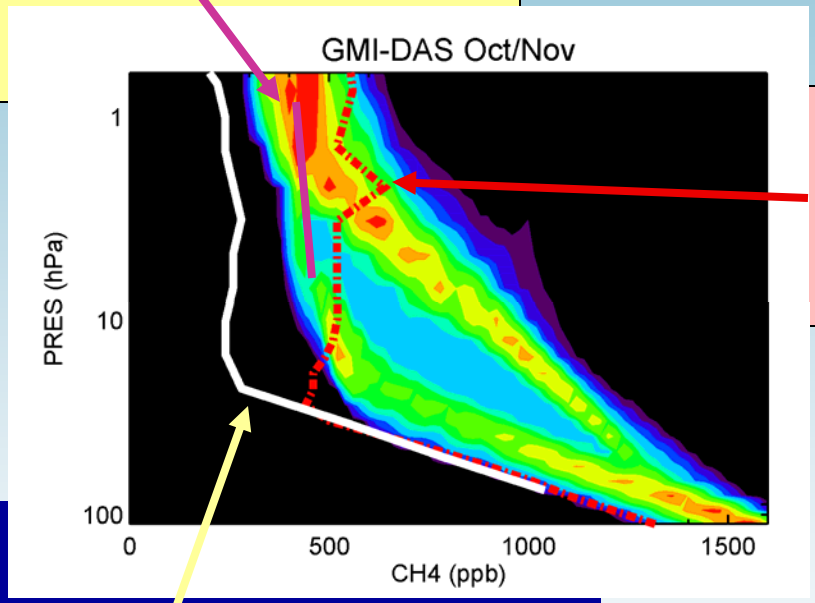




More recirculation = Better CH_4 agreement!

Better tropical CH_4 (age) translates into better polar CH_4

DAS vortex profile



GMI-GCM vortex profile

HALOE vortex profile

The GMI-DAS Antarctic upper and middle stratosphere are ~100 ppb lower than the GMI-GCM – a result of lower GMI-DAS tropical CH_4.

Mean and modal age give us NEW diagnostic information: tropical advection and mixing can be independently evaluated

- GEOS4-GCM has realistic vertical advection from 15-35 km in the tropics
- GEOS4-DAS is a little faster but not by much and not necessarily wrong
- Recirculation IS an important part of the tropical mean age
- GEOS4-GCM has too little recirculation above 22 km
- GEOS4-DAS has more recirculation but still not enough

- If we could improve model mean age in the tropical middle and upper stratosphere, we could improve mean age in the polar region. This has important implications for accurately simulating:
  - CFC lifetimes
  - Cl_y in the vortex
  - O_3 recovery in chemistry-climate models