ADM-Aeolus Workshop, ESTEC, 26-28 September 2006

Transport in the lower stratosphere: Science issues and research needs

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- Schematic of transport in the lower stratosphere
  - Brewer-Dobson circulation, tropical pipe, tropical transition region, LMS

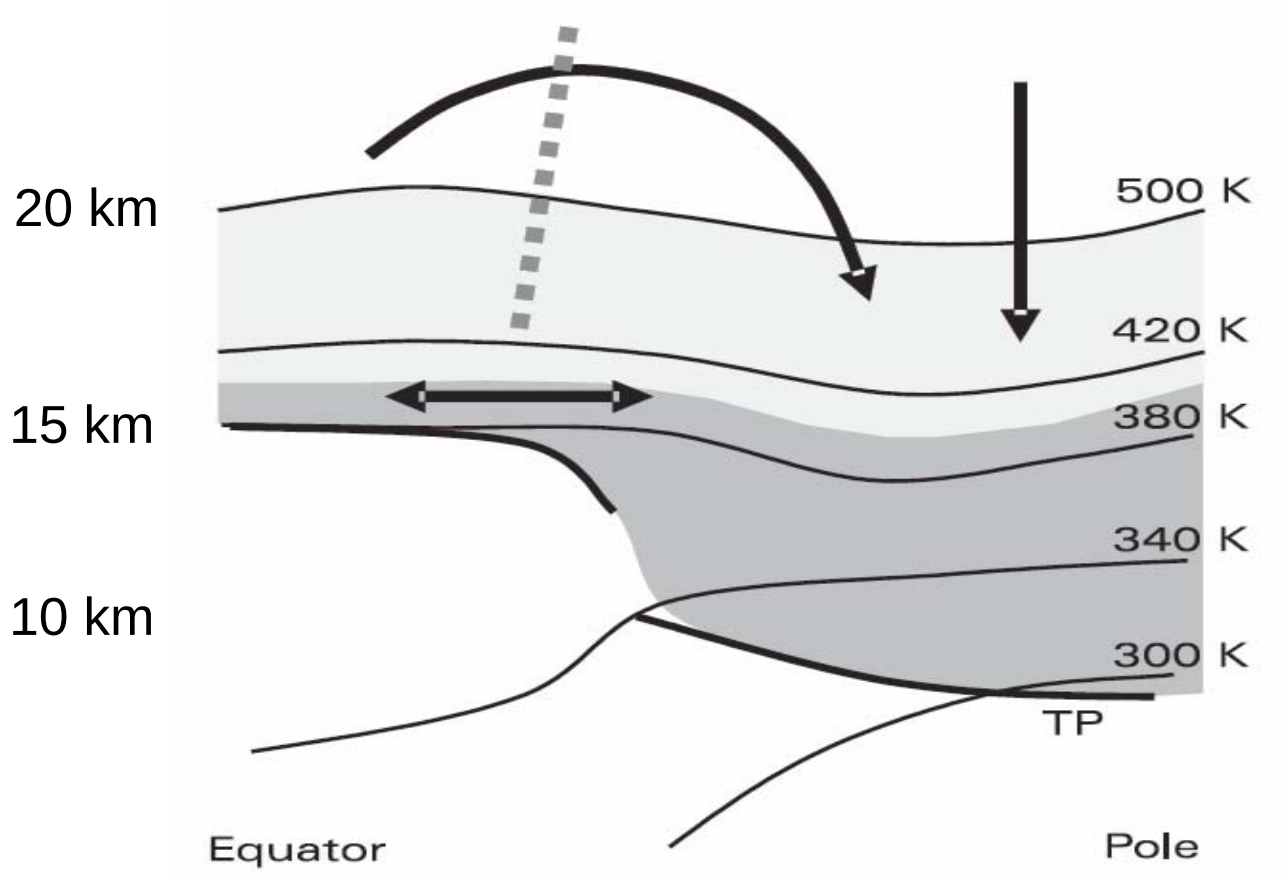
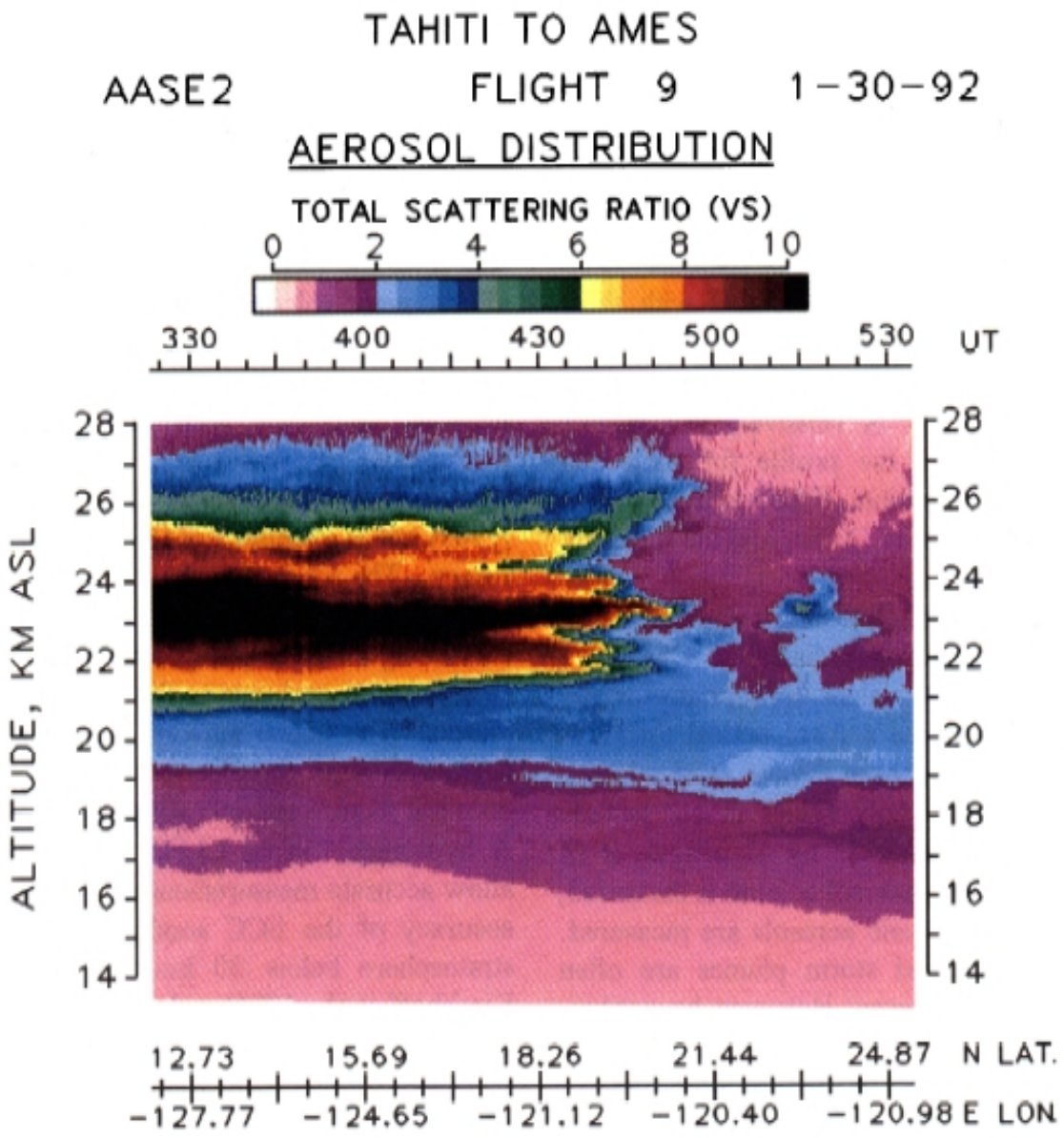


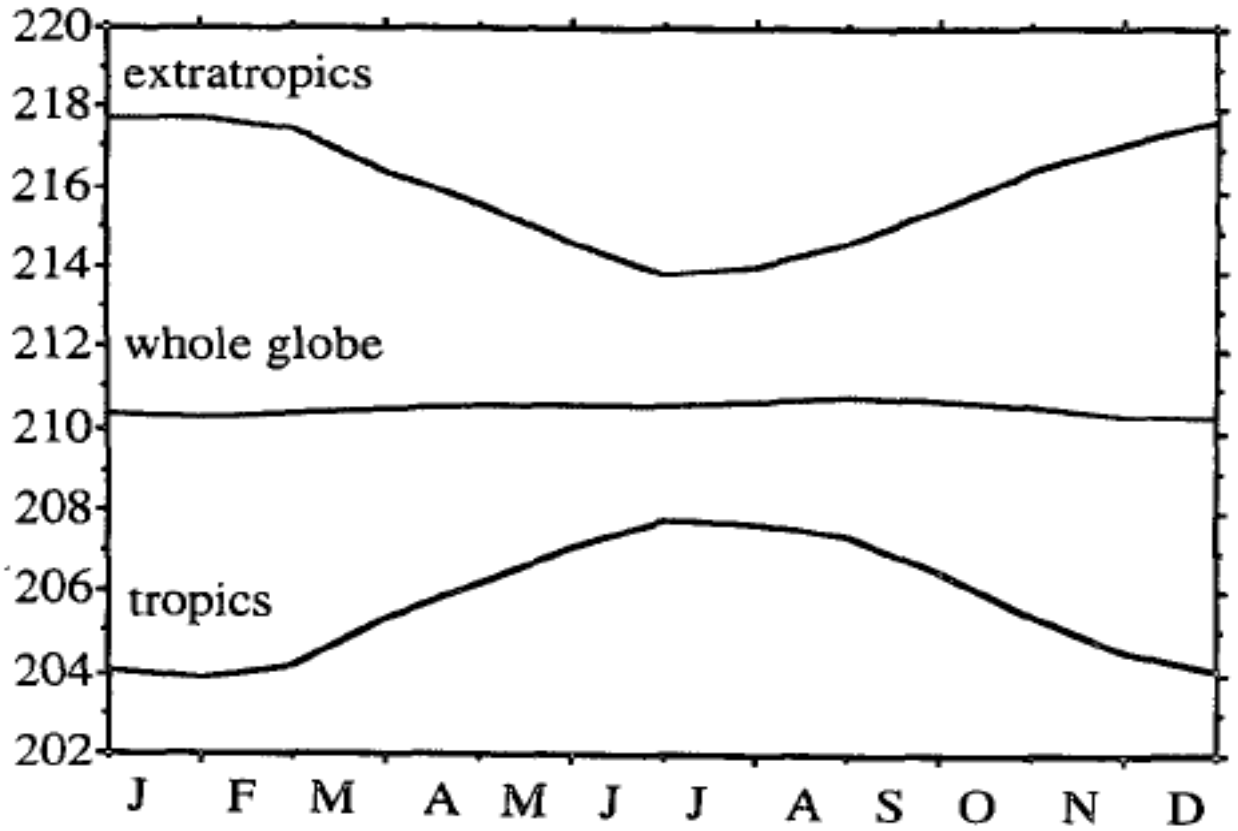
Figure courtesy of Michaela Hegglin, University of Toronto



- We know from measurements of stratospheric constituents (here aerosol four months after the Mt Pinatubo volcanic eruption, measured by airborne lidar) that the tropical lower stratosphere is well isolated from the extratropics

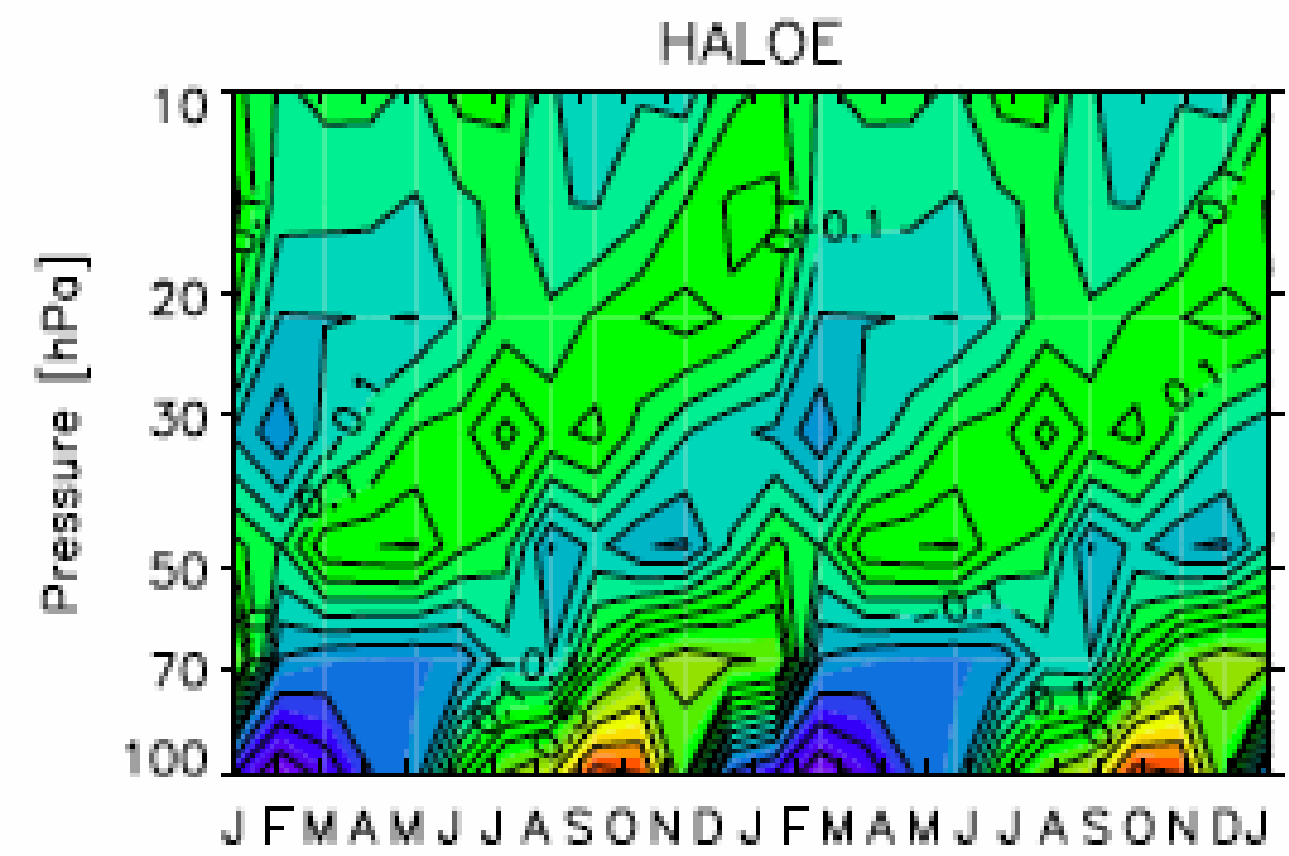
From Grant et al. (1994 JGR)

- There is a pronounced seasonal cycle in tropical tropopause temperature, associated with the diabatic circulation (seen here in MSU Channel 4 temperatures)
  - Note near exact cancellation between tropics and extratropics



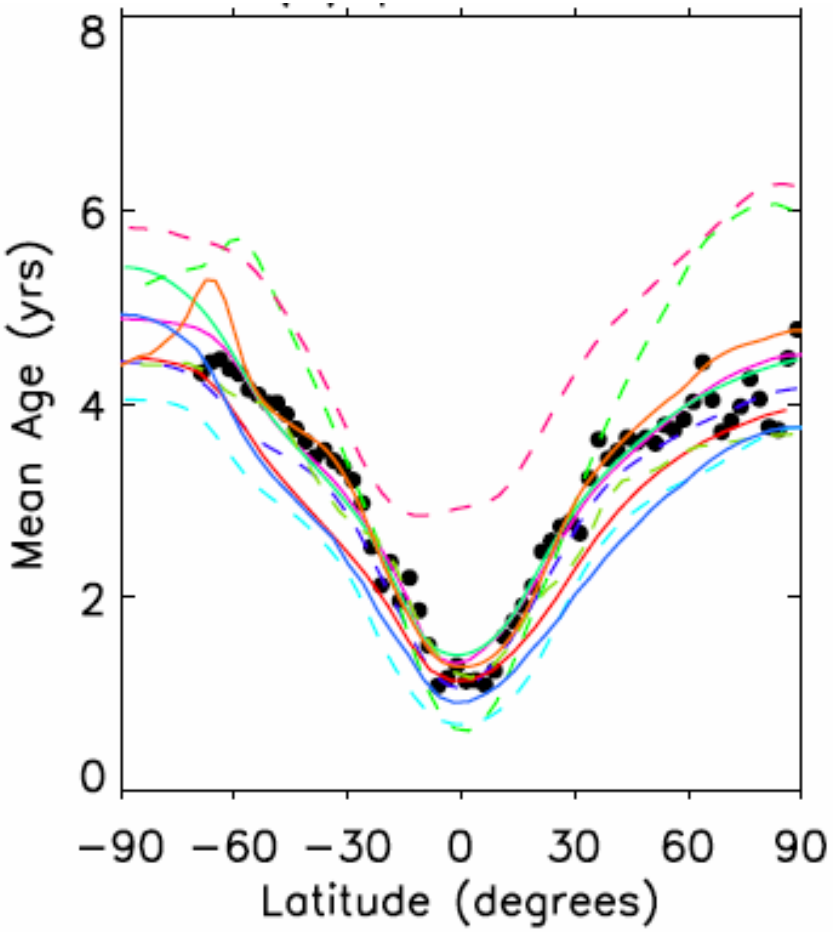
From Yulaeva et al. (1994 JAS)

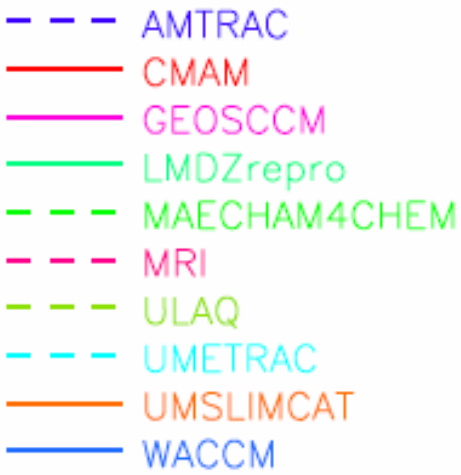
- The seasonal cycle in temperature imprints itself on stratospheric water vapour, leading to the “tape recorder” (Mote et al. 1996 JGR)
  - An indicator of tropical isolation



From Eyring et al. (2006 JGR)

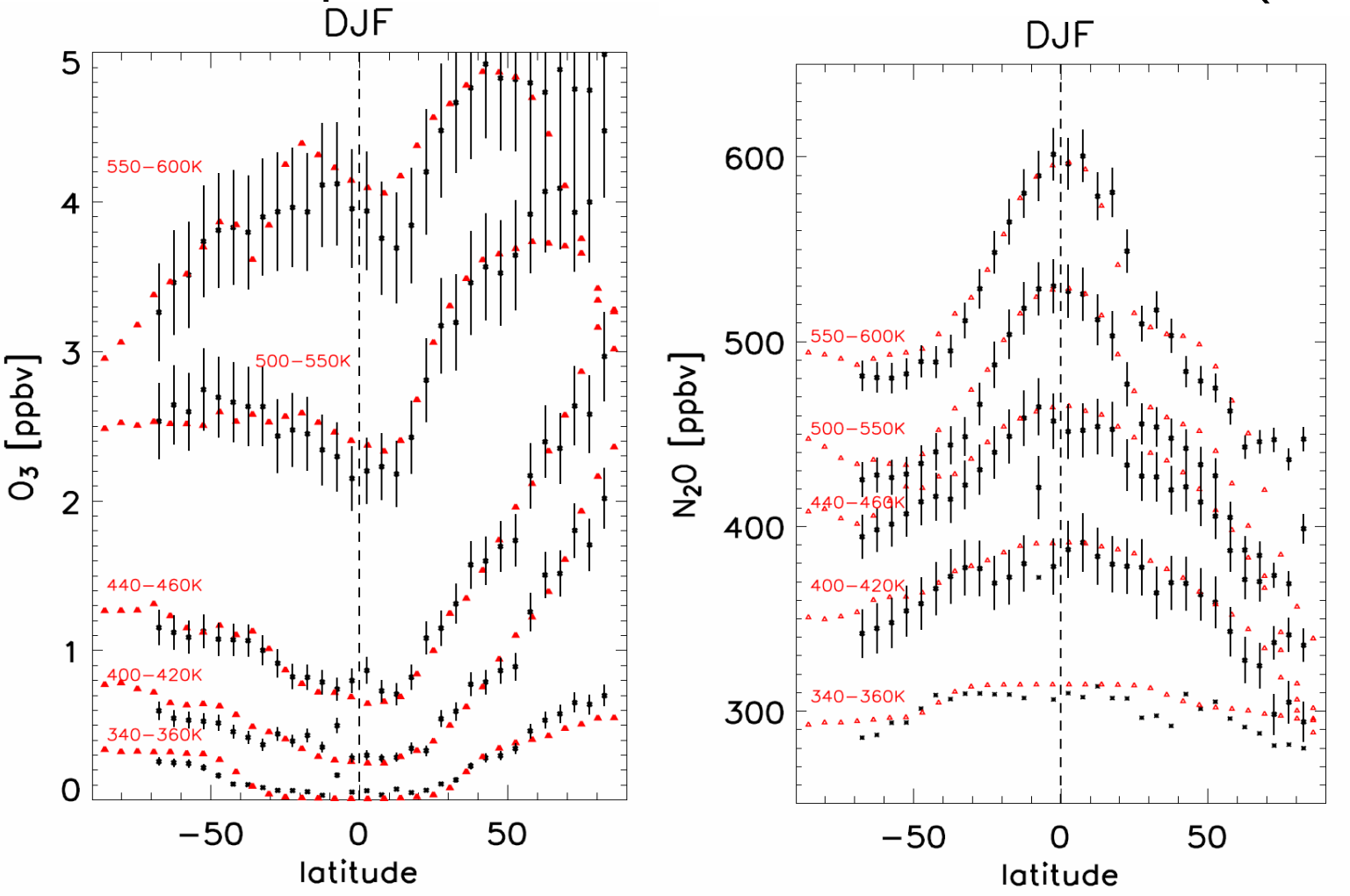
- The latest generation of Chemistry-Climate Models (CCMs) generally do a pretty good job of transport, seen here in “age of air” at 50 hPa
  - Observations (dots) are from ER-2 CO_2 obs





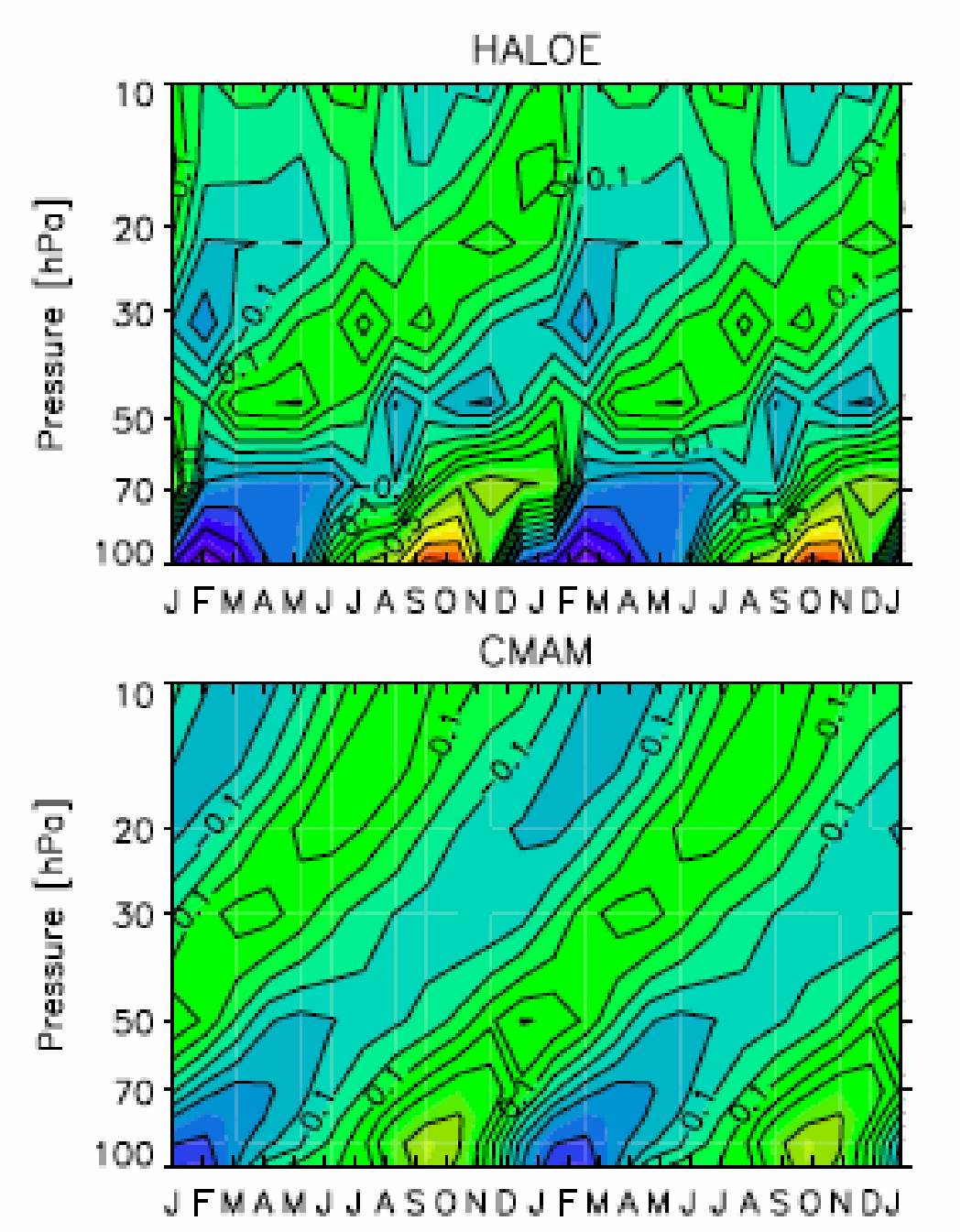
From Eyring et al. (2006 JGR)

- The Canadian Middle Atmosphere Model (CMAM, red) is here compared with the ACE-FTS on SciSat-1 (black)



N.B. N_2O is offset by 80 ppbv for each level

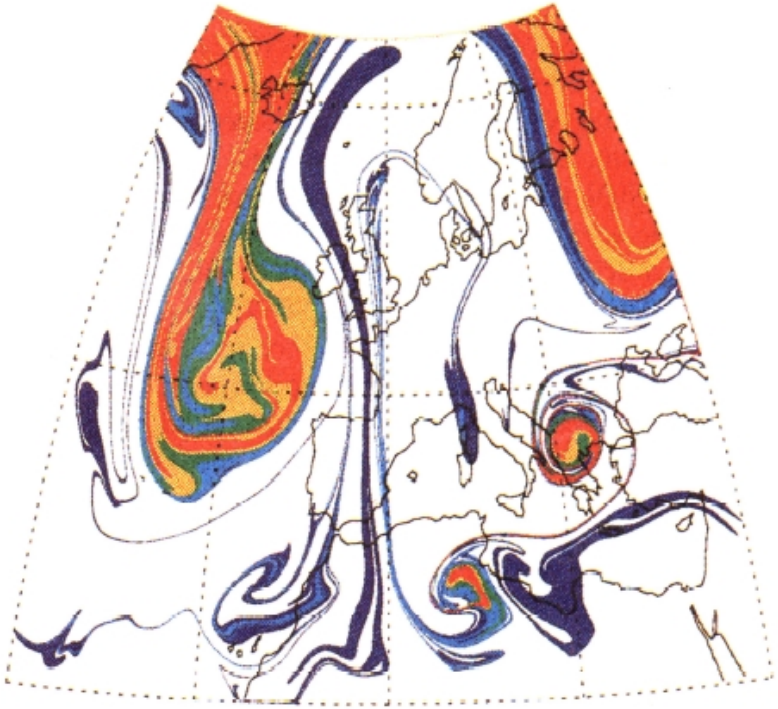
Figure courtesy of Michaela Hegglin, University of Toronto

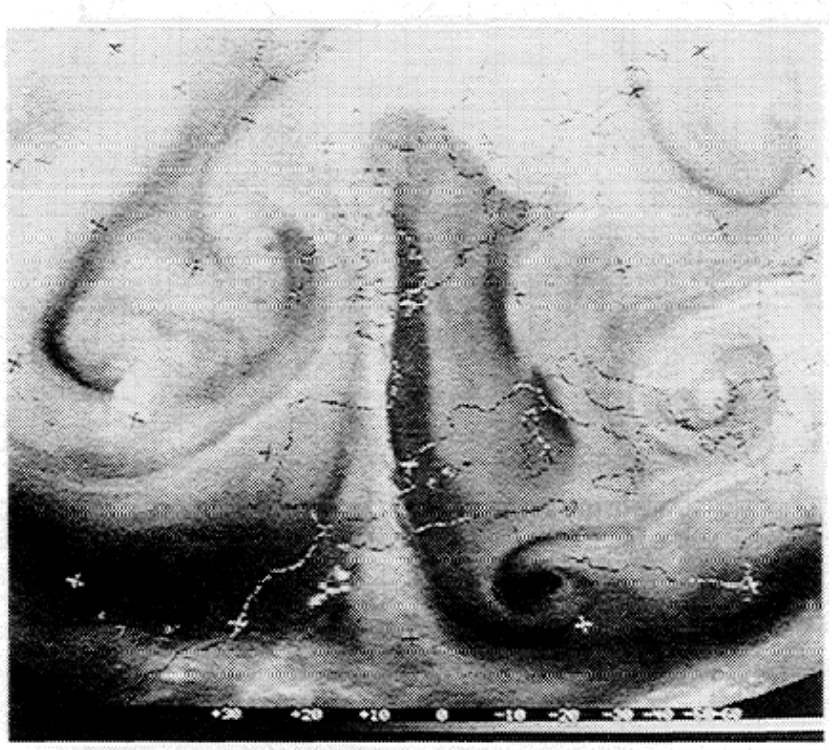


- The CMAM tape recorder is a little fast, but holds the signal pretty well

From Eyring et al. (2006 JGR)

- Transport studies of the extratropical lower stratosphere confirm the accuracy of analysed winds, on *short* timescales
  - Comparison of contour advection (from PV) on 320 K isentropic surface, with Meteosat water vapour

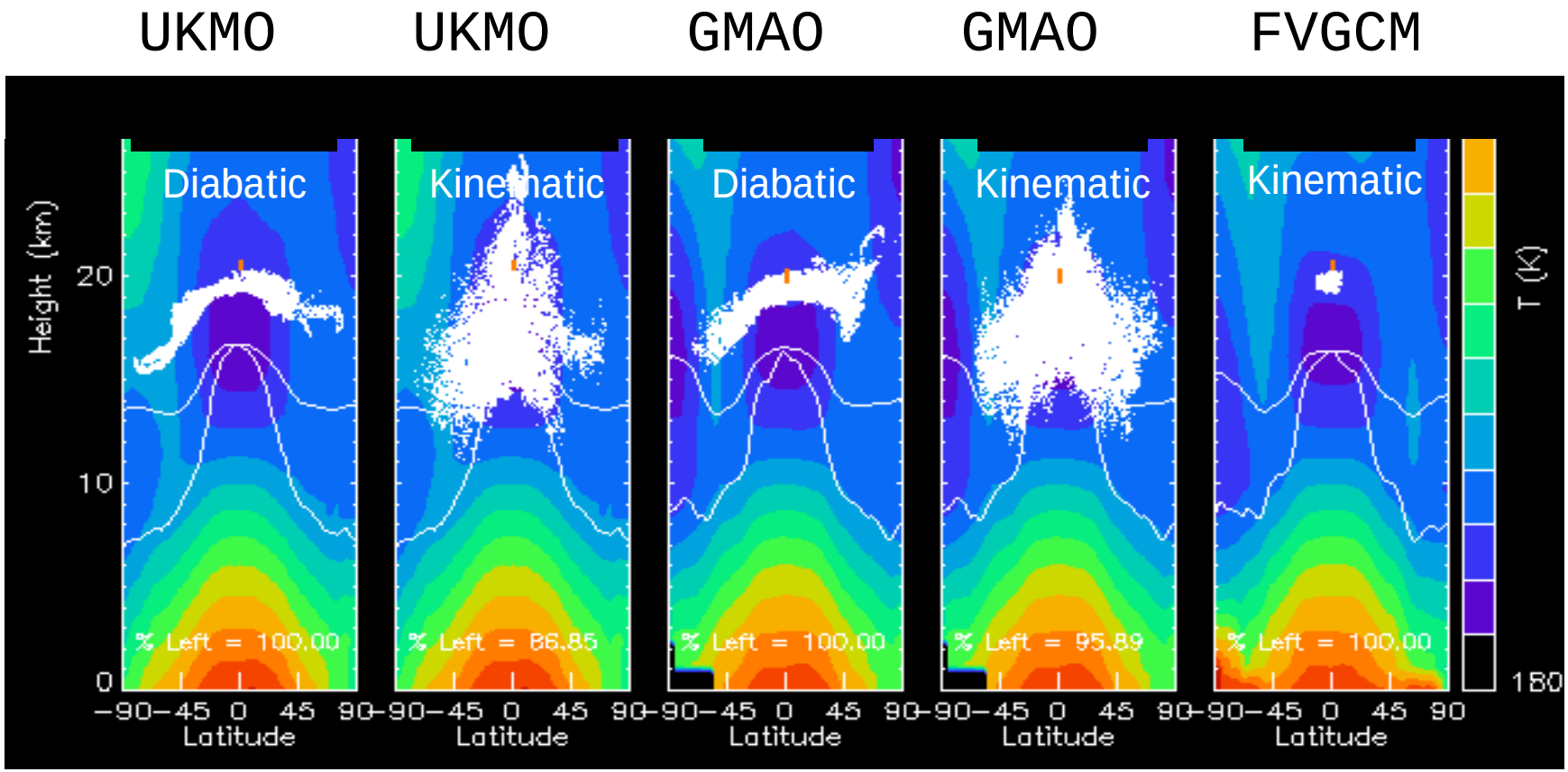




From Appenzeller et al. (1996 JGR)

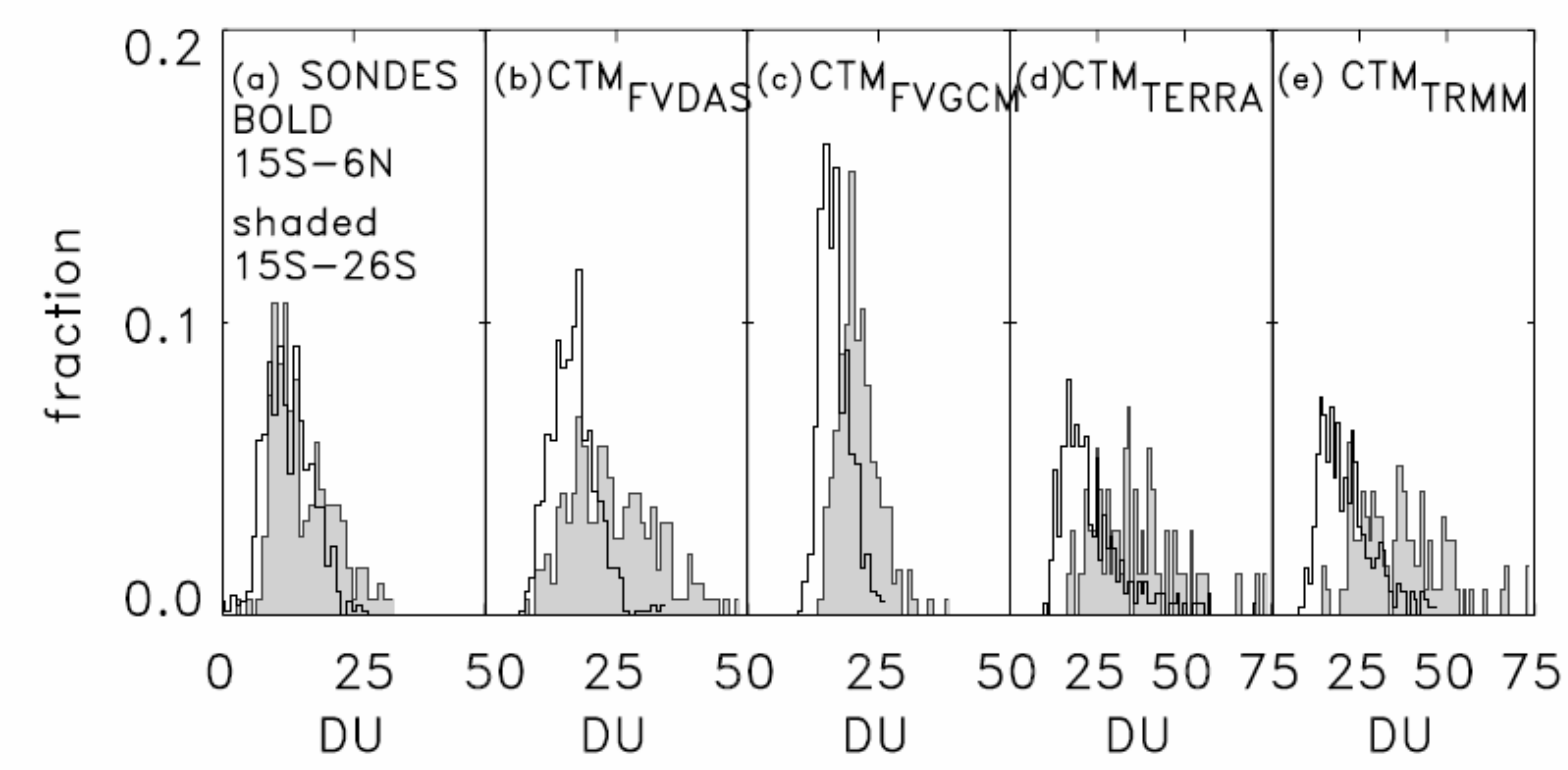
- However on longer timescales, winds from assimilation tend to produce much more dispersion, both horizontally and vertically, than GCM winds

  Figures show 50-day trajectory calculations



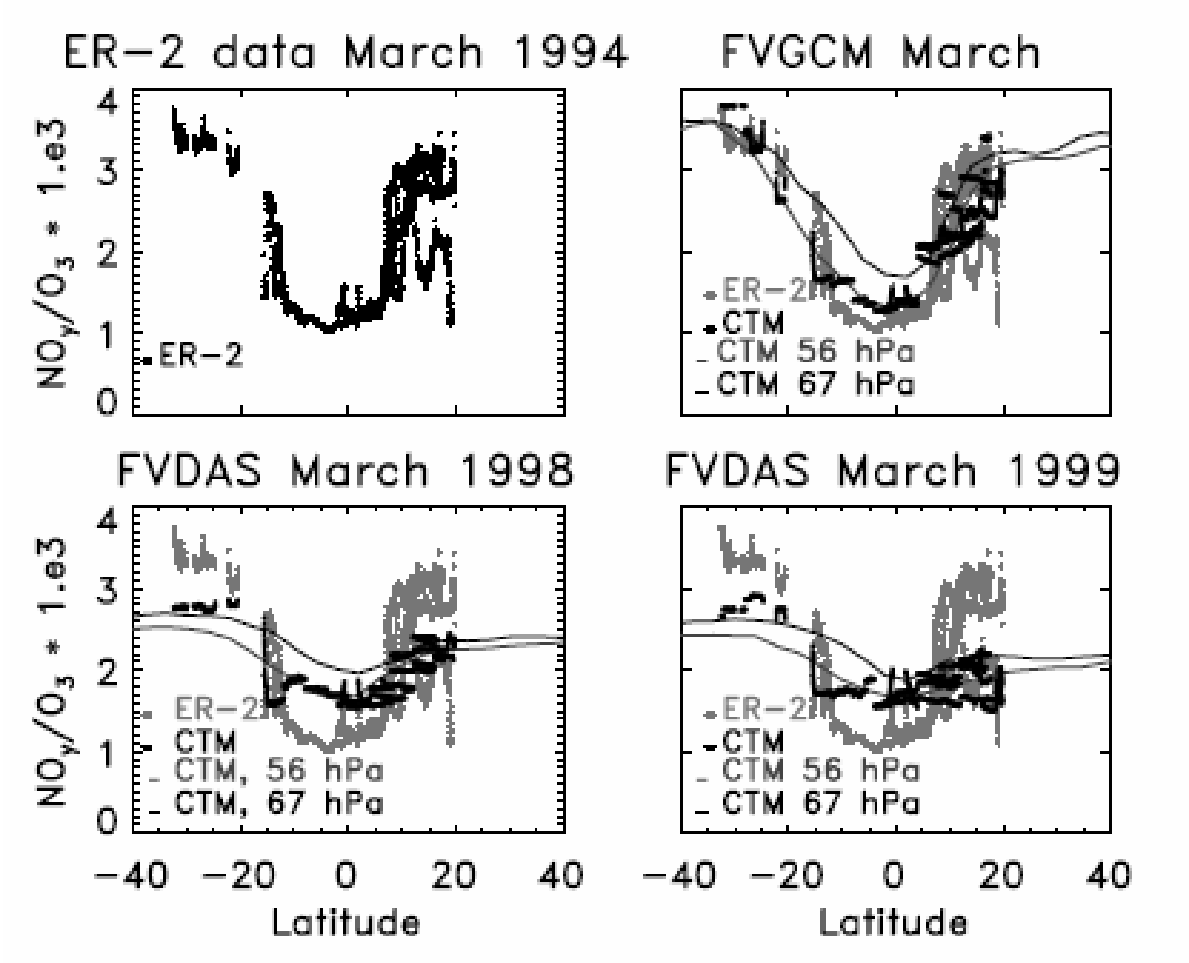
From Schoeberl et al. (2003 JGR)

- The same thing is seen in PDFs of ozone partial columns (56-140 hPa)
  - Solid line is tropical, shaded is SH subtropical
  - Note the increased horizontal range for panels (d) and (e)



From Douglass et al. (2003 JGR)

- Another example: NO_y/O_3 ratios at ER-2 altitudes (~20 km)
  - The DAS-driven CTM destroys the strong horizontal gradients



From Douglass et al. (2003 JGR)

- Comparison of NCEP/NCAR reanalysis winds with ER-2 aircraft measurements at ~20 km shows that the reanalysis is much more accurate in the extratropics than in the tropics
  - The problem with excessive dispersion from the tropics using analyzed winds to drive transport lies with the winds

Rean. Wind vs. ER-2 MMS obs. Rean. Vs. Obs. In the Tropics

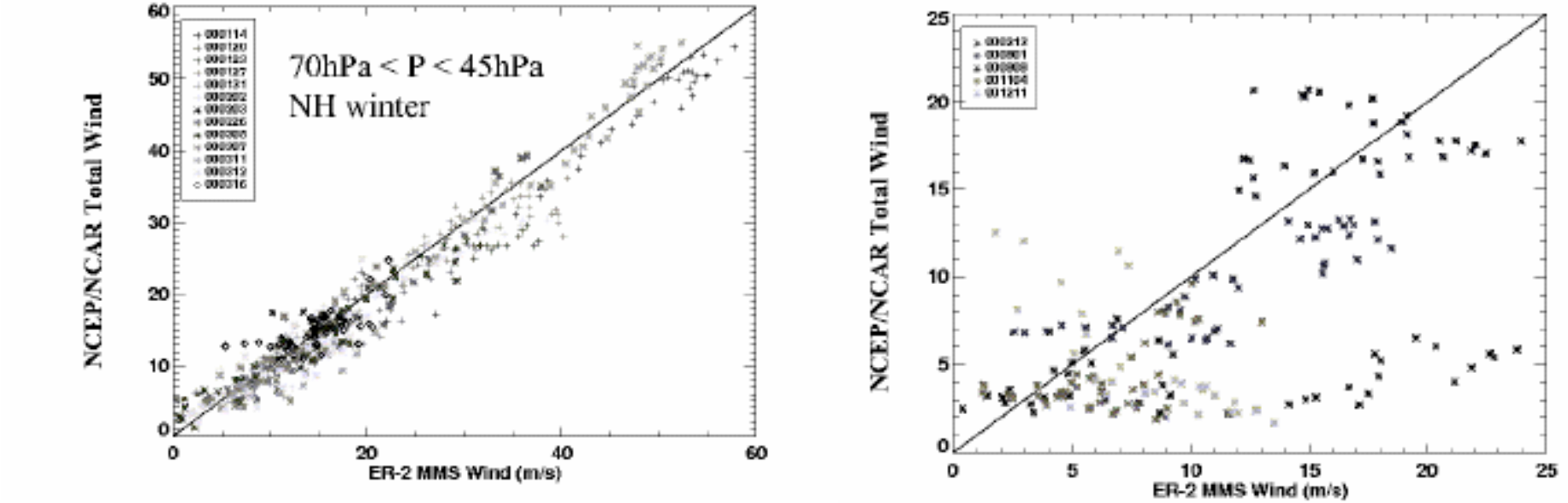
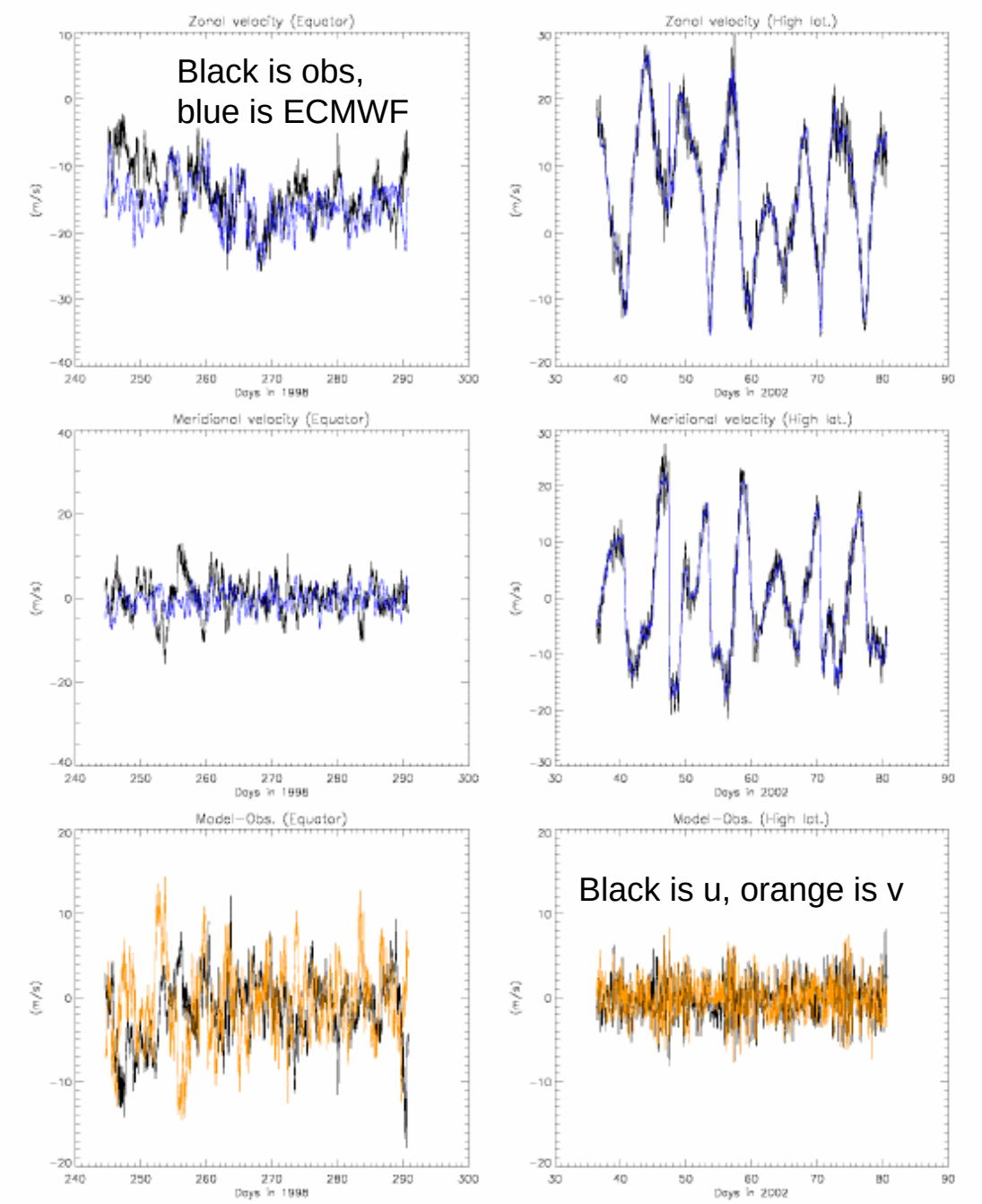


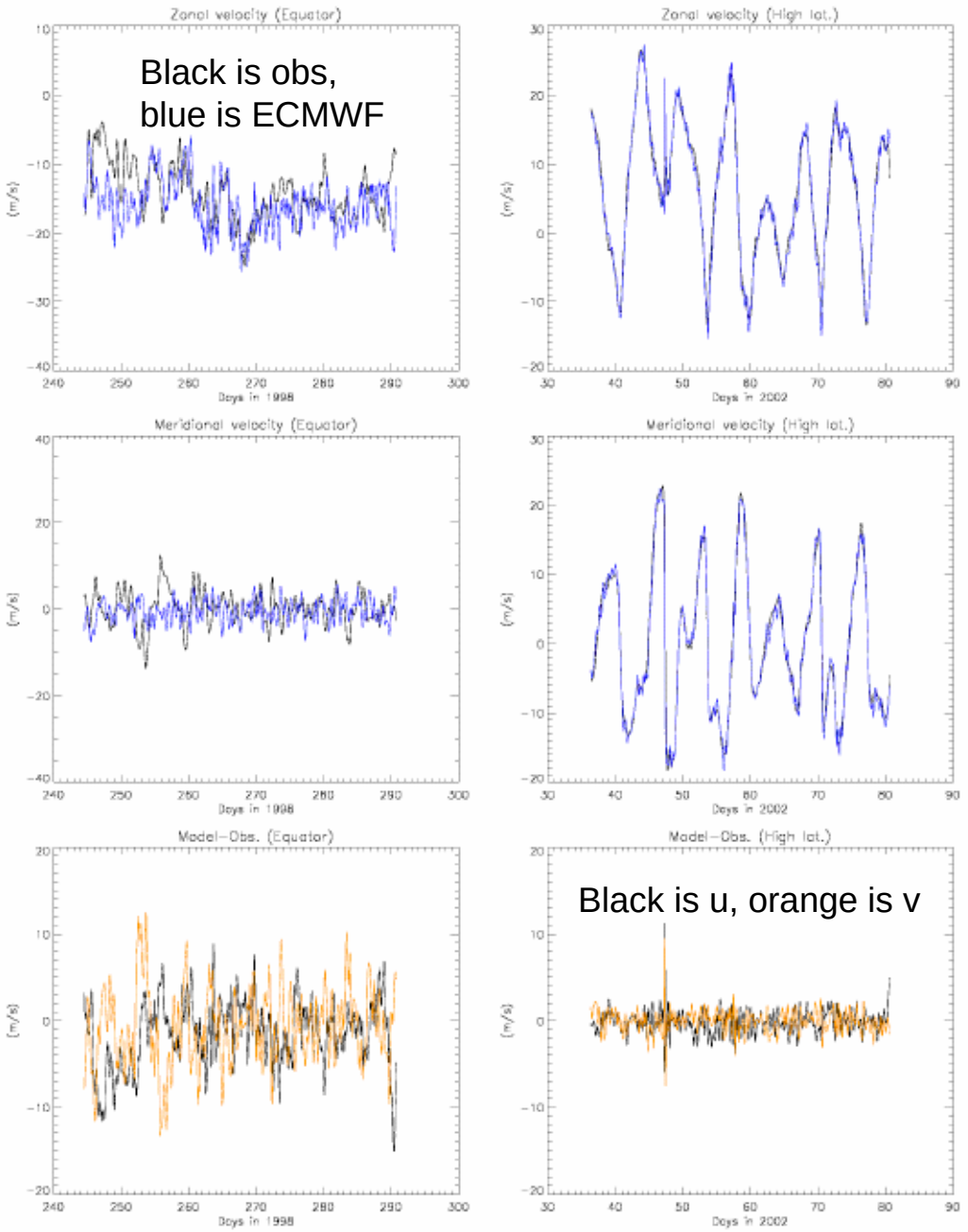
Figure courtesy of Paul Newman, NASA GSFC
Published in SPARC Newsletter No. 26 (2006)



Comparison of direct wind measurements with ECMWF analysed winds in long-duration stratospheric balloon flights (at 60 hPa) leads to the same conclusion

Figure courtesy of Albert Hertzog, LMD

Published in SPARC Newsletter No. 26 (2006)



Filtering the directly measured winds to exclude periods shorter than 12 hr leads to excellent agreement at high latitudes, but has little impact in the tropics

Figure courtesy of Albert Hertzog, LMD

Published in SPARC Newsletter No. 26 (2006)

- Transport errors from assimilated winds severely limit the quantification of transport changes due to dynamical variations
  - An example is the contribution of changes in ozone transport to changes in ozone abundance
- They also compromise chemical assimilation, by introducing biases
- Better assimilation methods may improve the situation, but there remain many fundamental limitations

- There is some hope of constraining winds from tracer measurements, using 4D methods. However:
  - Such measurements are only sensitive to one component of the wind, that parallel to the tracer gradient
  - Unfortunately, tracer gradients tend to align perpendicular to the wind (the “stirring” effect)
  - Tracer gradients tend to be weak in the tropics
  - In any case, will require validation

- Why does transport between the tropics and the lowermost stratosphere matter?
  - Distribution of the greenhouse gases ozone and water vapour in the LMS, close to the tropopause, is important for climate
  - Ozone recovery depends on Cl_y abundance in the lower stratosphere, which depends on age of air
  - Transport of very short-lived species (VSLS) into the LMS also affects stratospheric ozone depletion

- Also, exchange between the LMS and the tropical tropopause layer (TTL) affects the ozone distribution in the TTL
  - Here seen as a deficit in a simple 1-D tropical convective model

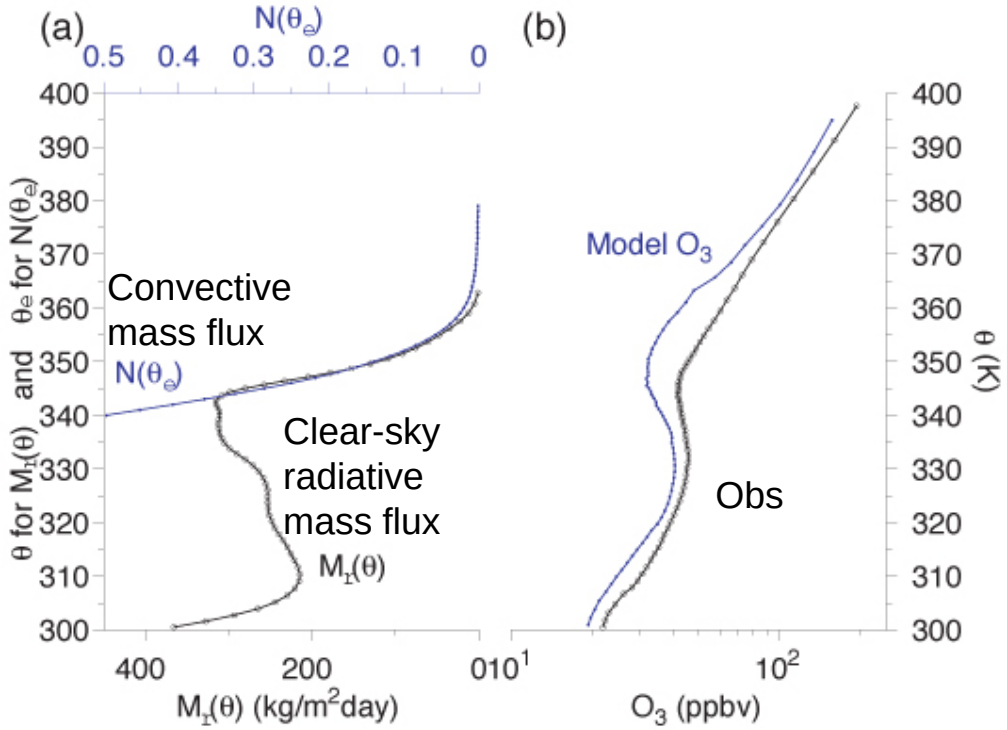
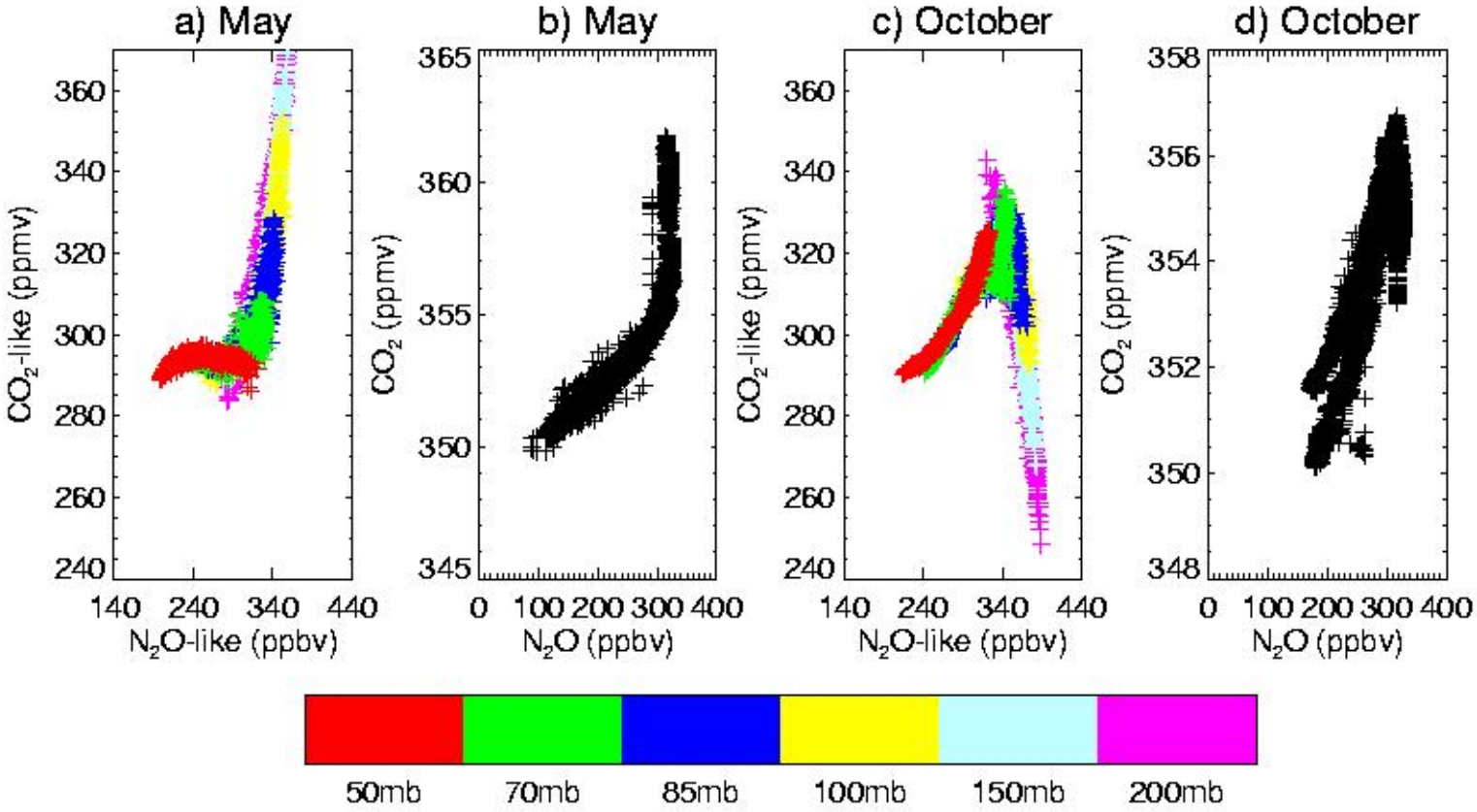


Figure courtesy of Ian Folkins, Dalhousie University
Published in SPARC Newsletter No. 17 (2001)

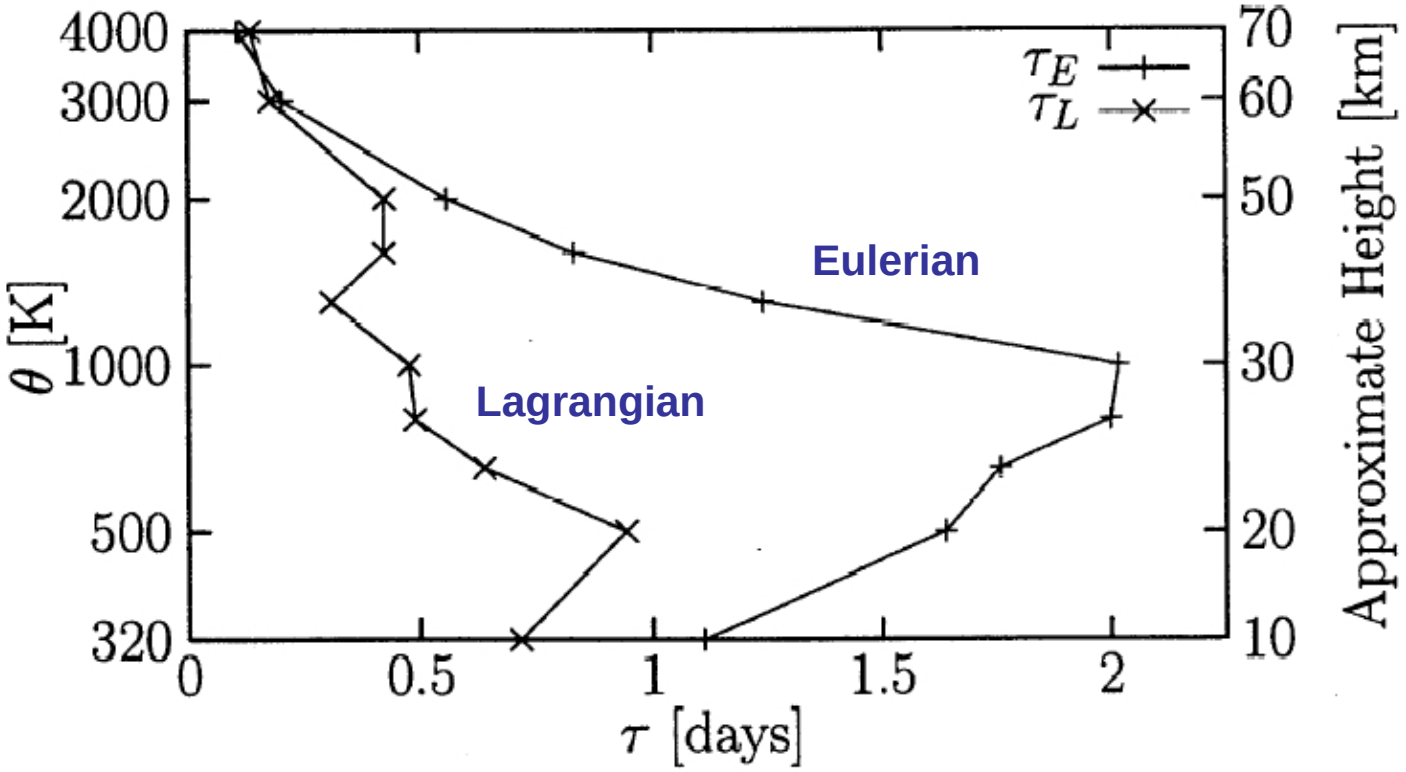
An indicator of transport into the LMS is the seasonal cycle of CO_2, which gives a "CO_2 tape recorder" in the LMS

Coloured points are from CMAM, black symbols are in-situ data from the ER–2 aircraft (Boering et al. 1994 GRL)

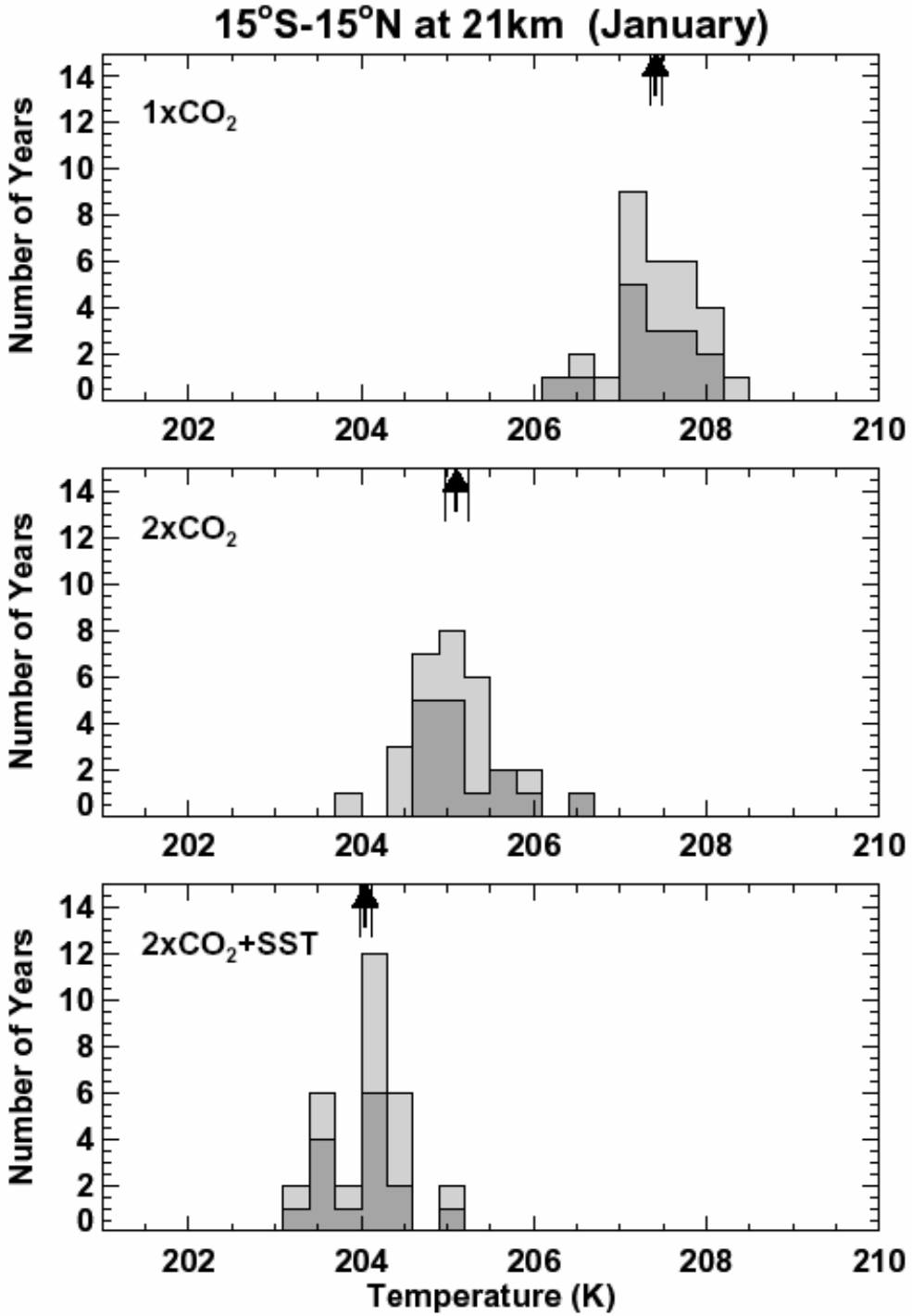


From Sankey & Shepherd (2003 JGR)

- Calculating transport becomes more challenging at lower stratospheric altitudes
- Figure shows Eulerian and Lagrangian autocorrelation times of horizontal wind shears from CMAM
  - They decrease and become more similar at lower altitudes



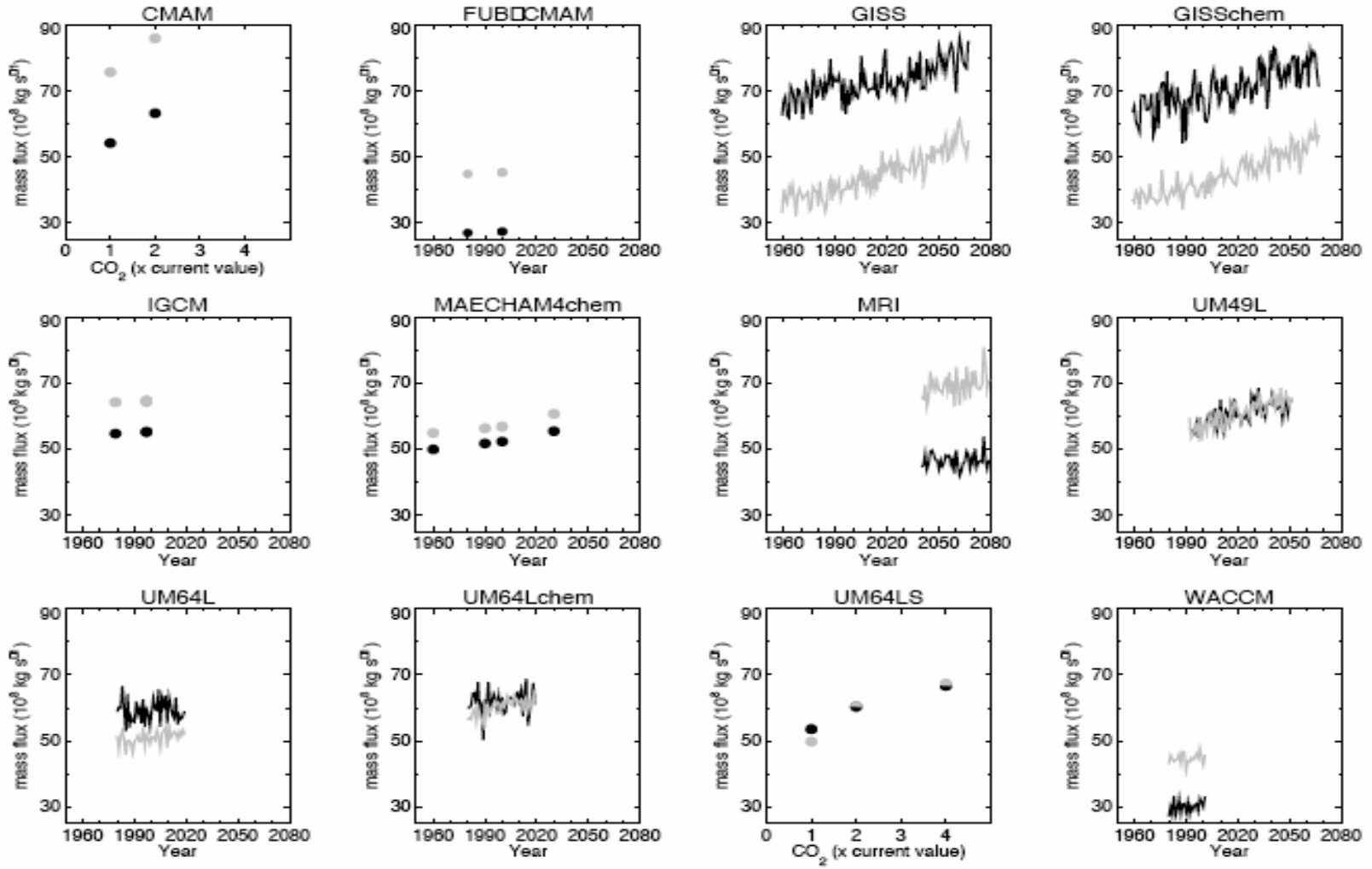
From Shepherd et al. (2000 JGR)



- Winds are also important for wave drag, which drives the diabatic circulation
- There is a robust dynamical response to doubled CO_2 in the lower tropical stratosphere
  - Here seen in timeslice experiments with CMAM
- Tropospherically induced changes augment the CO_2-induced cooling
- Increased upwelling from stratospheric wave drag (in both NH and SH)

From Fomichev et al. (JC, in press)

- Changes to tropical upwelling at 70 hPa
  - Black from resolved EPFD, gray total
  - Half these models use Rayleigh drag



From Butchart et al. (2006 CD)

- As with many CCMs, CMAM's age of air decreases over time, by ~0.75 yr at 10 hPa from 1960 to 2050

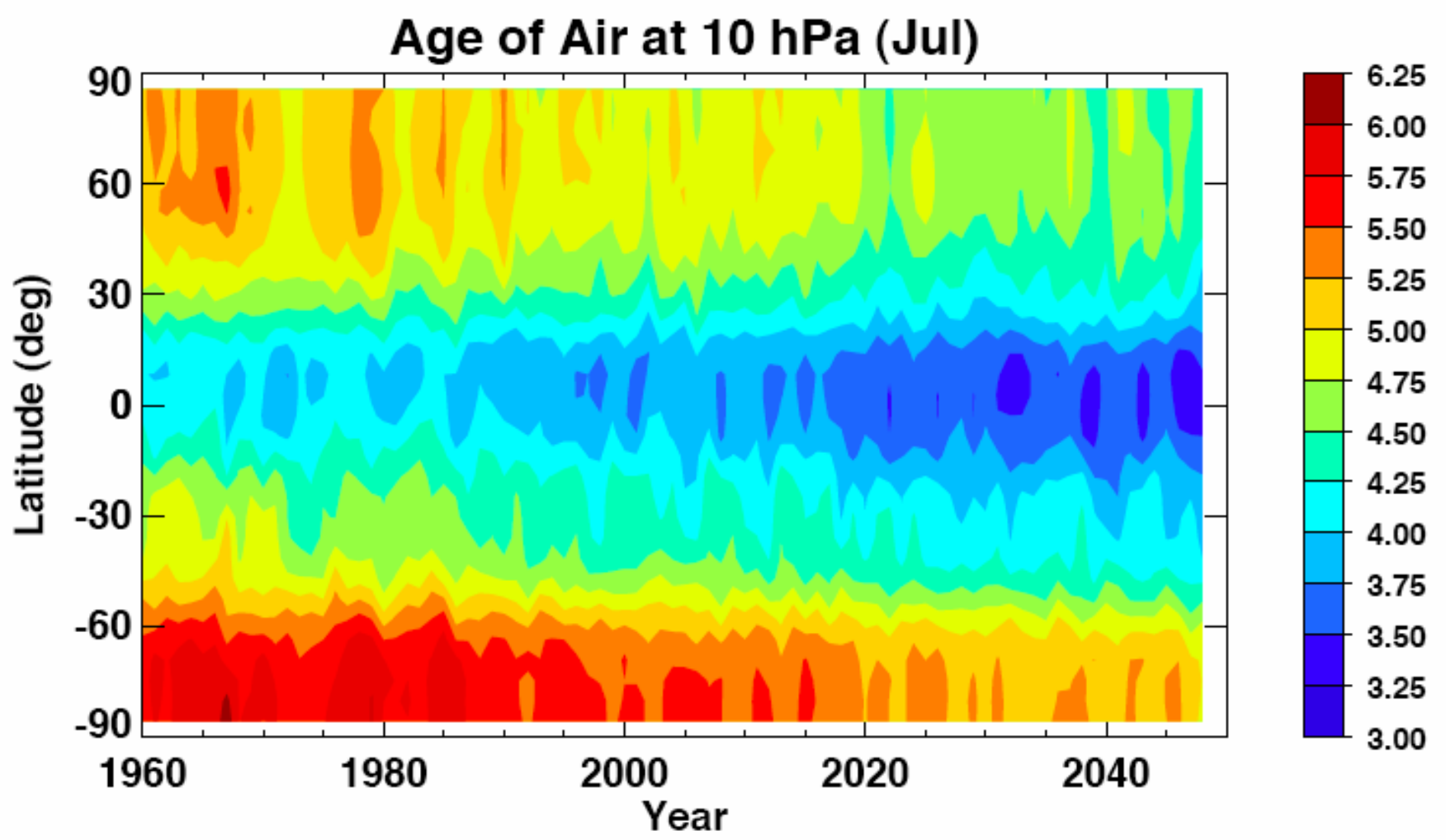
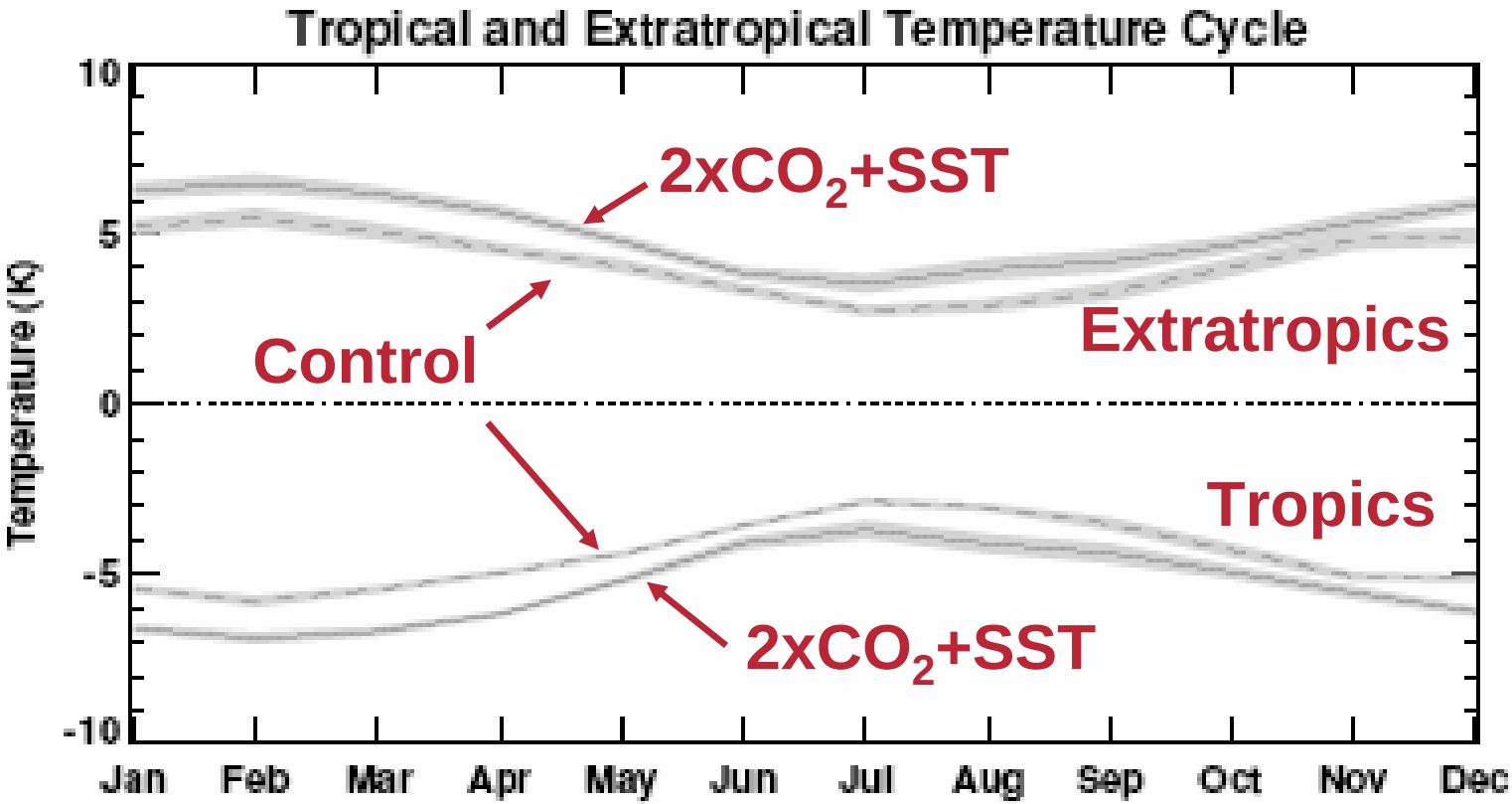


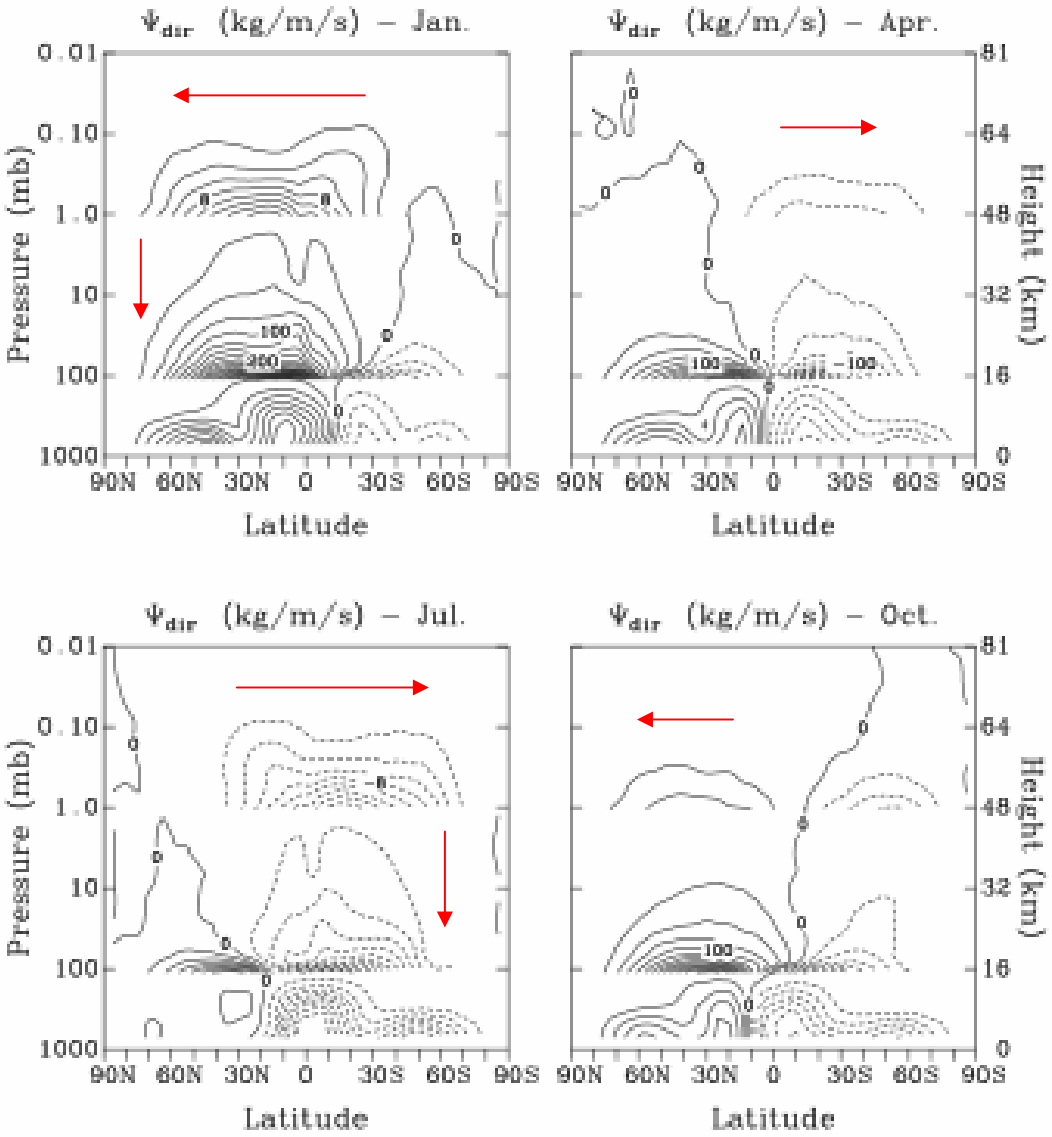
Figure courtesy of Kirill Semeniuk, York University

- The annual cycle of tropical and extratropical 50 hPa temperature (global mean is subtracted) points to a strengthened diabatic circulation in CMAM



From Fomichev et al. (JC, in press)

Seasonal cycle of meridional (TEM) circulation in CMAM

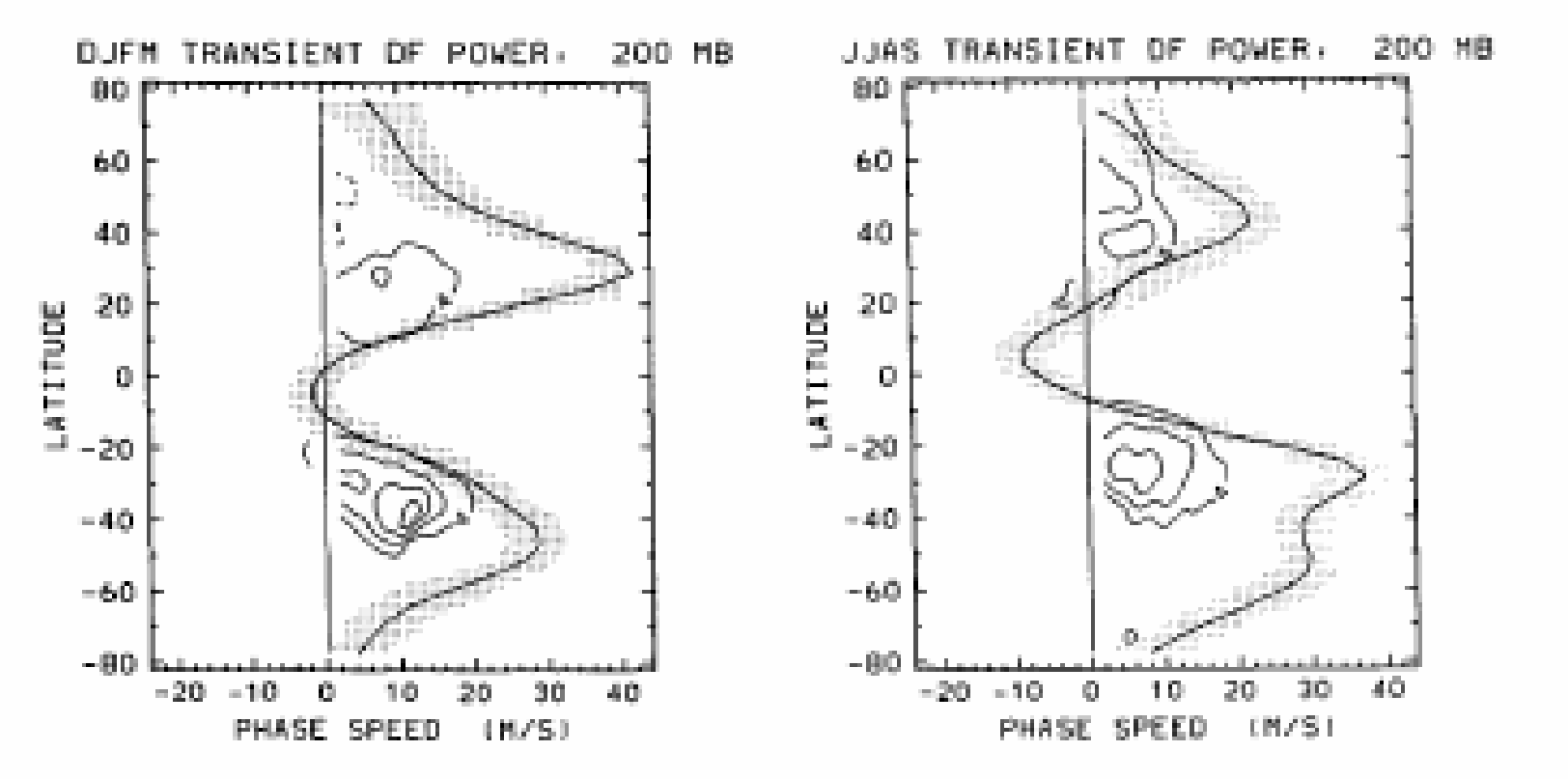


- Most of the upwelling through the tropical lower stratosphere is confined to the very lowest part of the stratosphere

- Suggests it is largely driven by synoptic-scale wave drag in the subtropics

From Beagley et al. (1997 Atmos.-Ocean)

- Observations clearly indicate significant wave drag, with non-zero phase speeds, in the subtropical lower stratosphere (figure shows EPFD)



From Randel & Held (1991 JAS)

Synoptic scale wave breaking (cat's eyes) in the lower stratosphere is also evident from tracer distributions

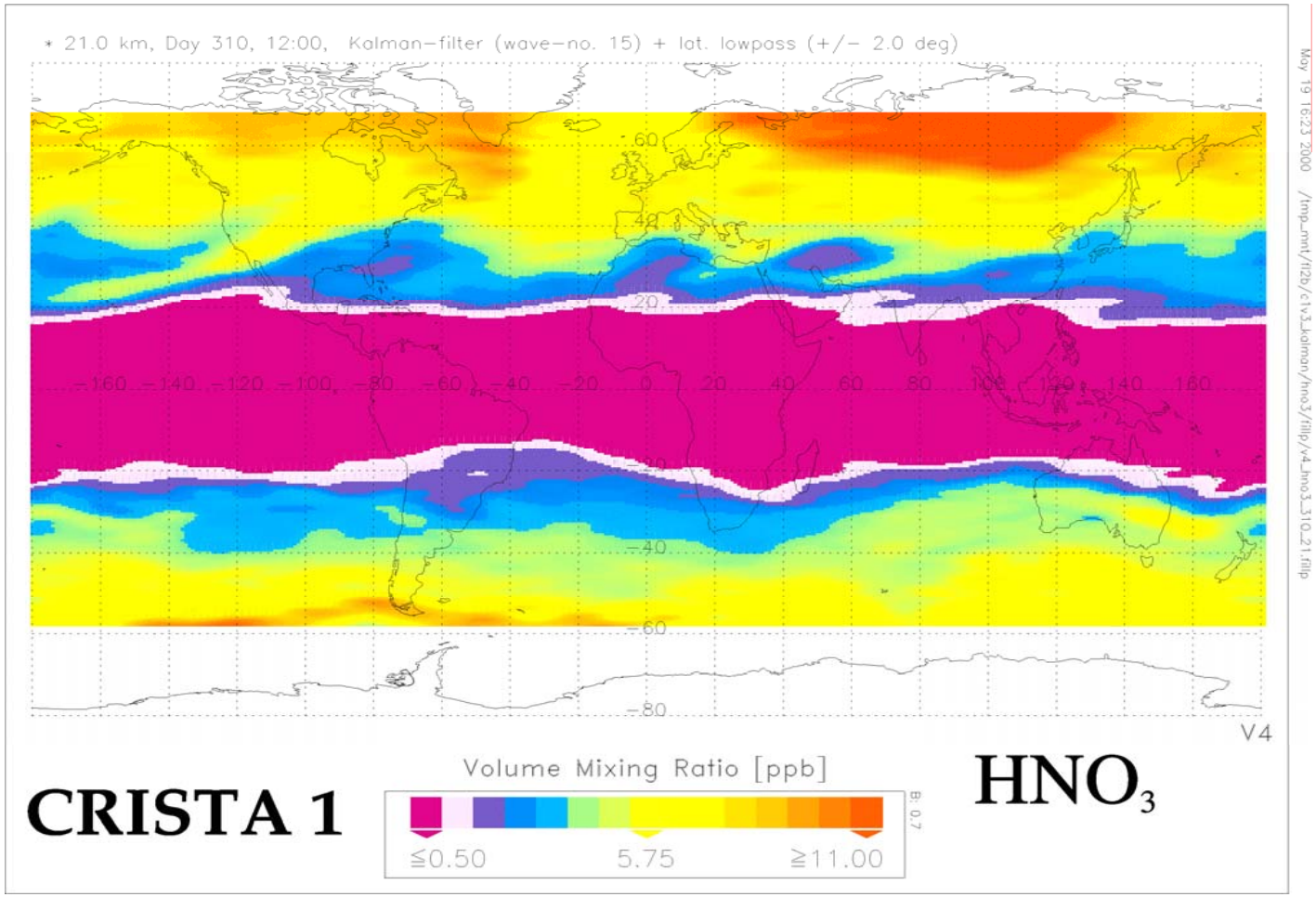
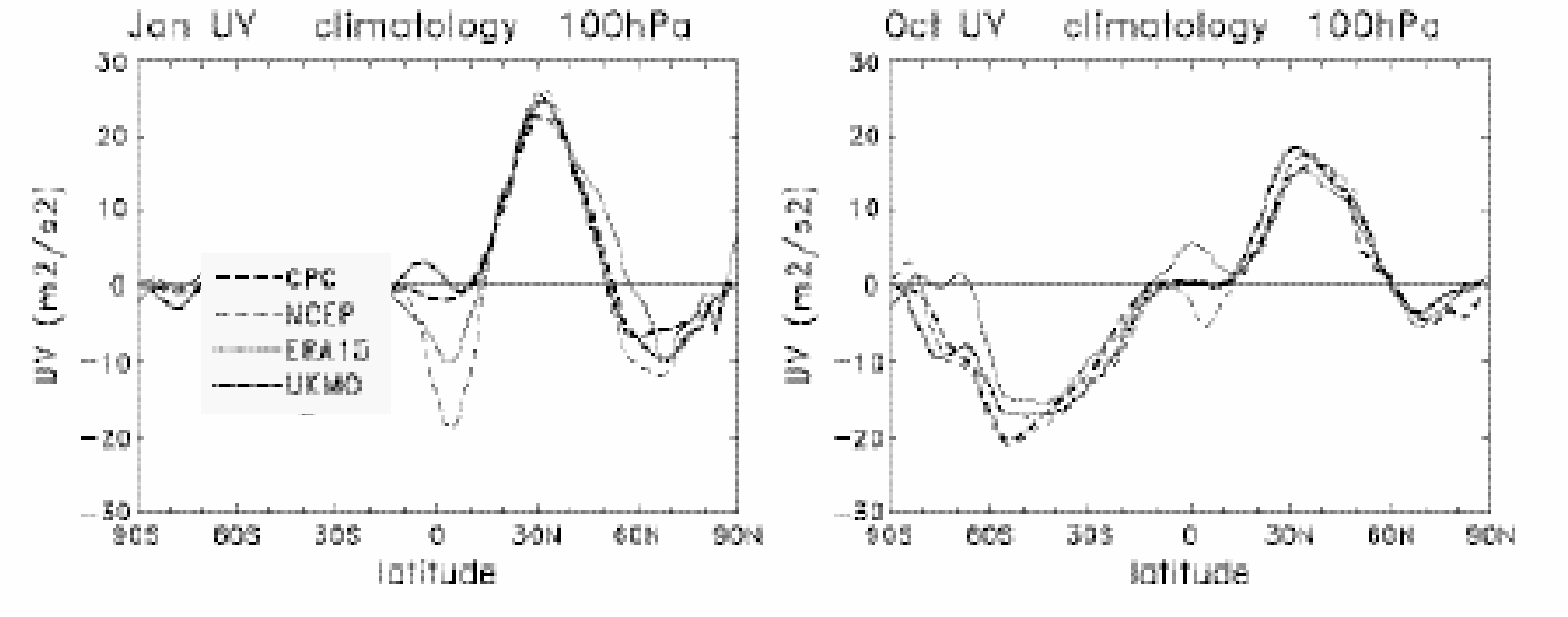


Figure courtesy of Dirk Offermann, Wuppertal University

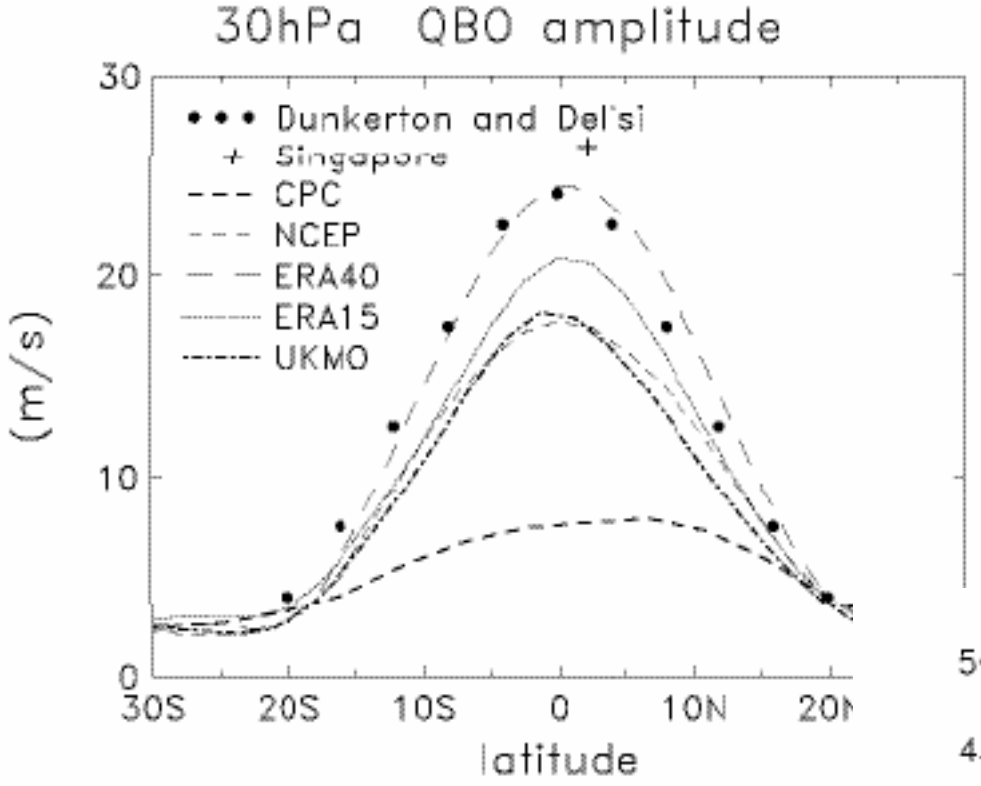
From Shepherd (2000 JASTP)

Yet the wave forcing in this region is not well quantified

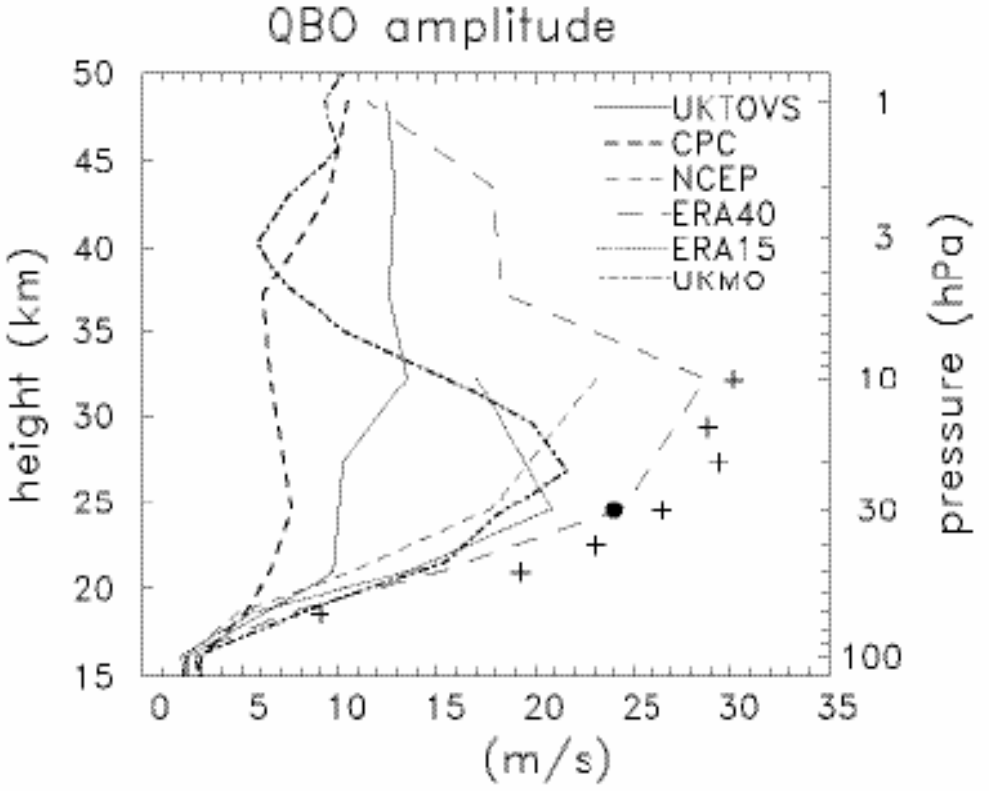
Figure shows meridional structure of horizontal momentum flux *u'v'* at 100 hPa



From SPARC Report No. 3 (2002)



Another area where we need better wind information is in determining the QBO amplitude



From SPARC Report No. 3 (2002)

Summary

- Transport in the lower stratosphere is highly structured
  - Tropical pipe above about 22 km altitude
  - Leaky “tropical transition layer” below that
  - In the TTL, exchange with midlatitudes
- Current winds from analyses are not adequate for transport calculations in the tropics and subtropics
- CCM winds show much better properties

- There are also uncertainties in the wave drag which drives tropical upwelling
  - Important for tropical tropopause temperatures, and the Brewer-Dobson circulation
  - There seems to be a large contribution from subtropical drag
  - There is substantial interannual variability
  - There are indications this drag could change as a result of climate change
- For all these reasons, we need better observational estimates of winds in the tropical and subtropical lower stratosphere