Radiative Heating Rates in Tropical Stratosphere: Implications to Brewer-Dobson Circulation Upward Mass Flux & Top of Tropical Tropopause Layer

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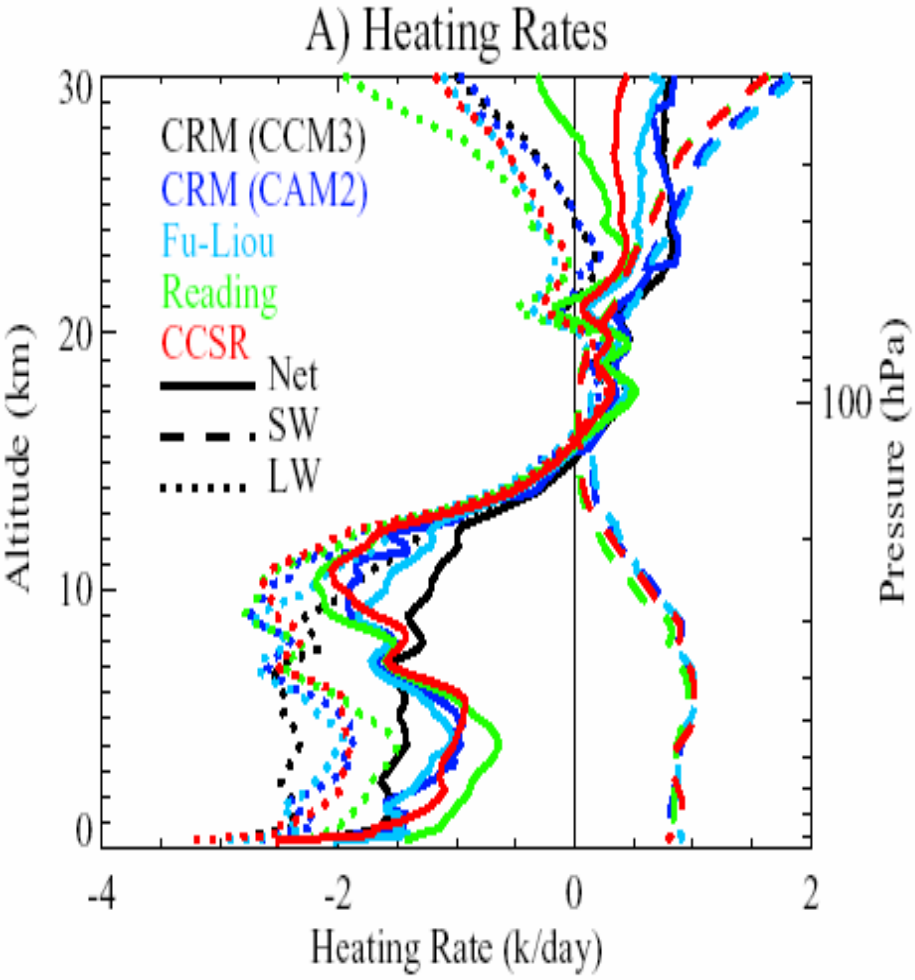
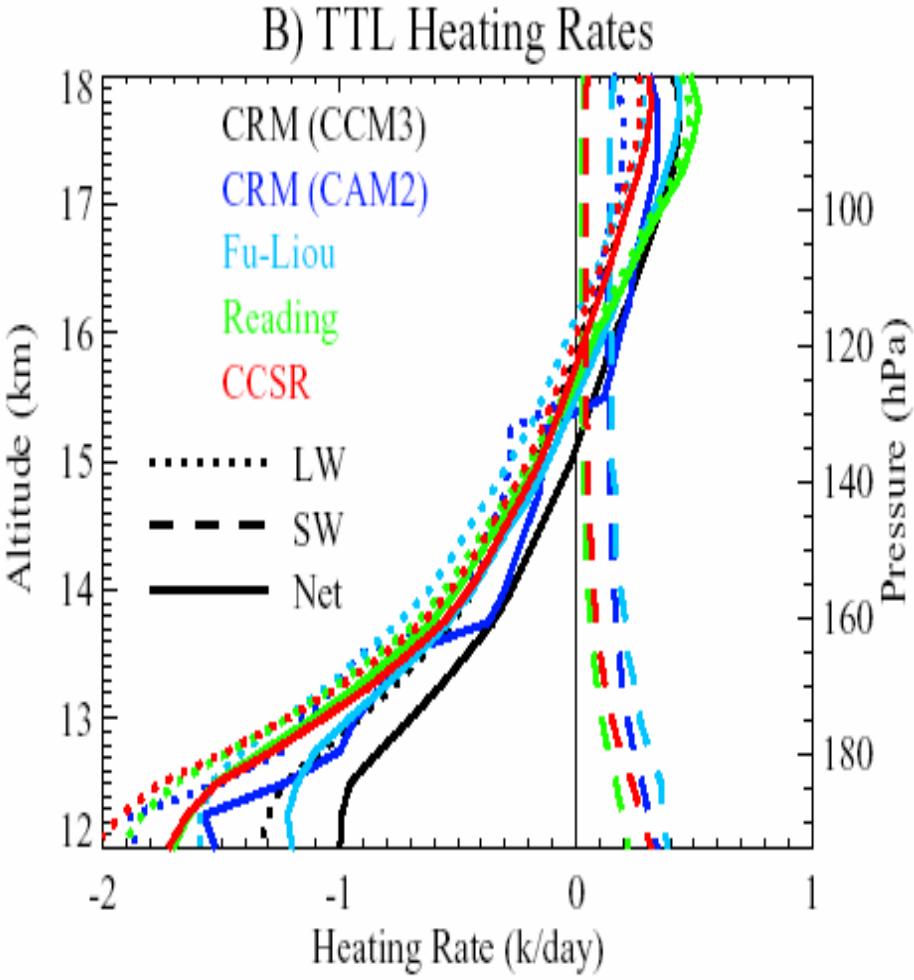
- Radiative Heating rate in the tropical stratosphere
- Quantifying the vertical velocity and upward mass flux of Brewer-Dobson circulation in the tropics
- Defining the top of tropical tropopause layer (TTL)

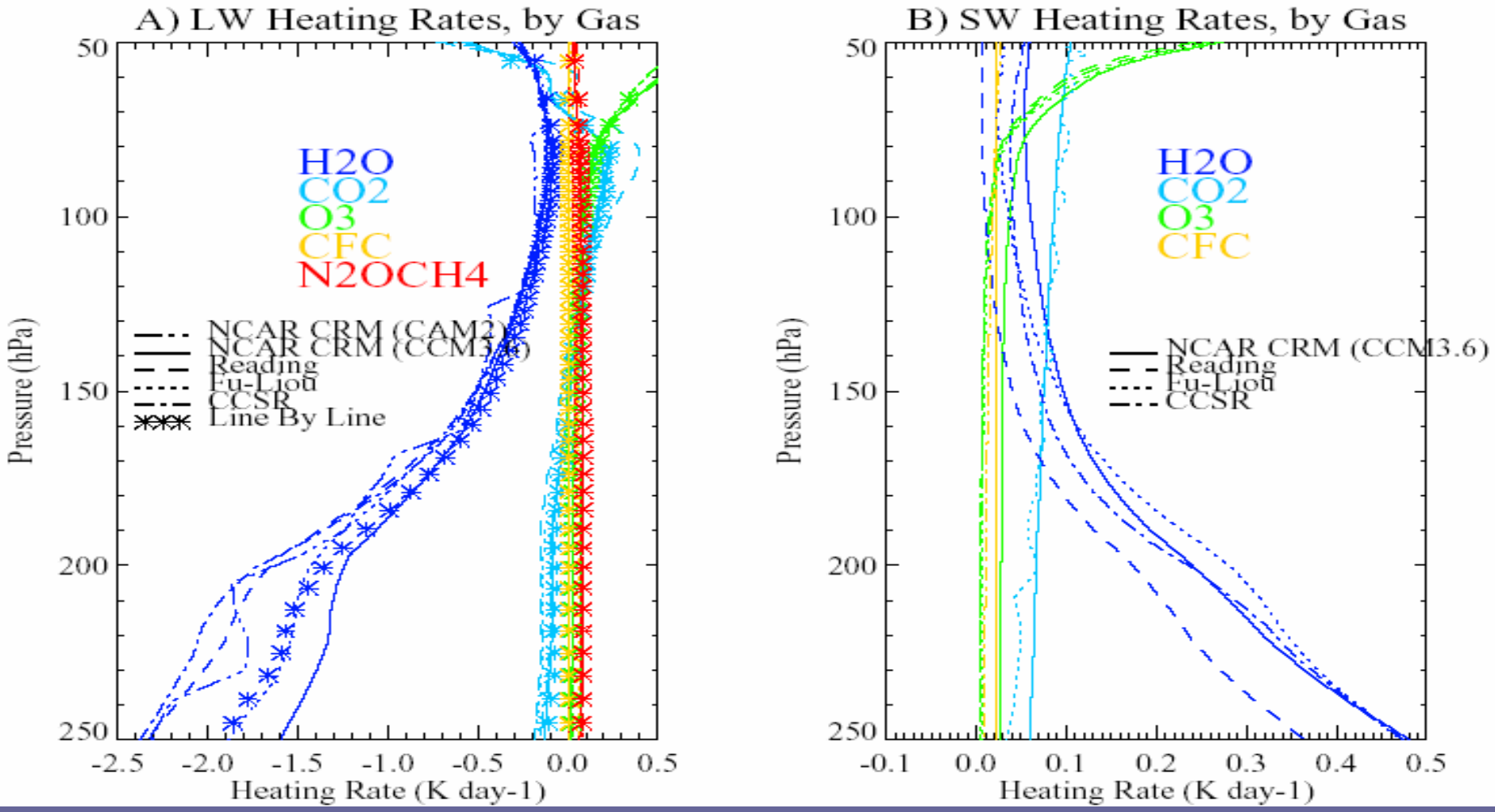
Radiative Heating rate in tropical atmosphere





Gettelman et al. (2004)

Radiative Heating rate in tropical atmosphere



Gettelman et al. (2004)

Radiative Heating rate in tropical stratosphere

- Radiative Heating rate in the tropical TTL and stratosphere from Fu-Liou radiation scheme is validated with the line-by-line calculations as well as inter-comparison with other radiation schemes

- O_3, CO_2 and H_2O along with temperature profiles play critically important roles in the radiative energy budget there

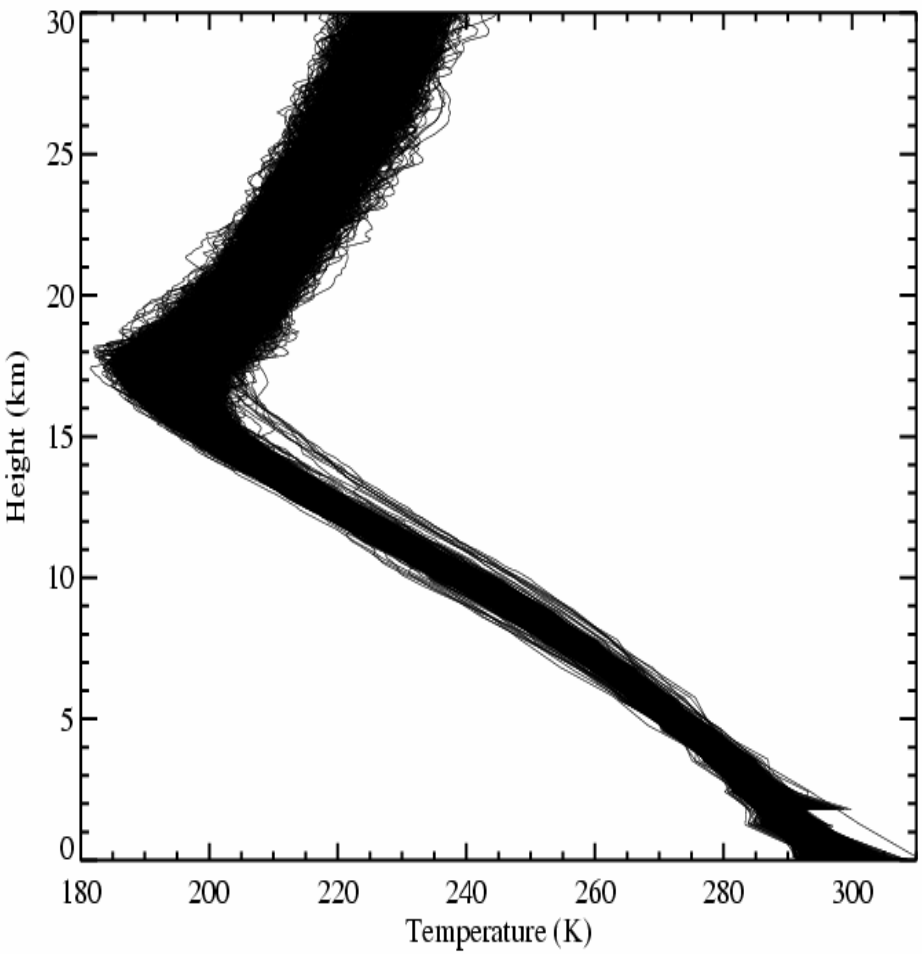
SHADOZ data (temperature, O_3)

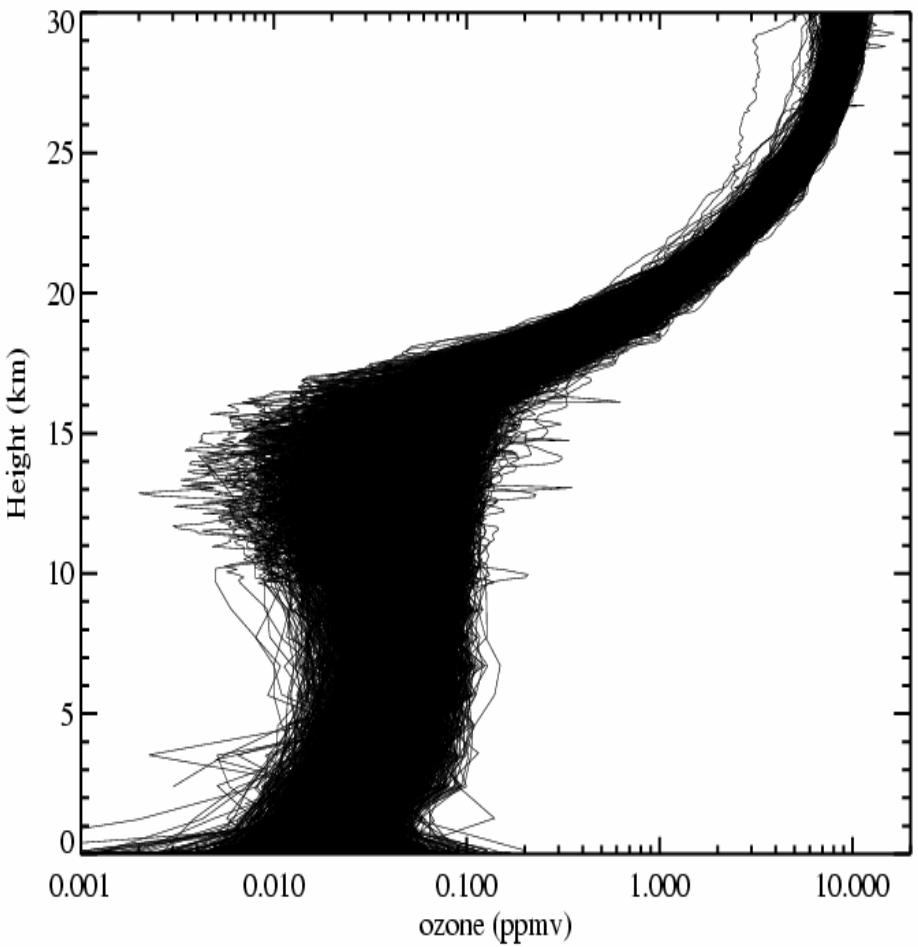
http://croc.gsfc.nasa.gov/shadoz

12 stations within -20S—20N from 1998 to 2005): 2244 profiles

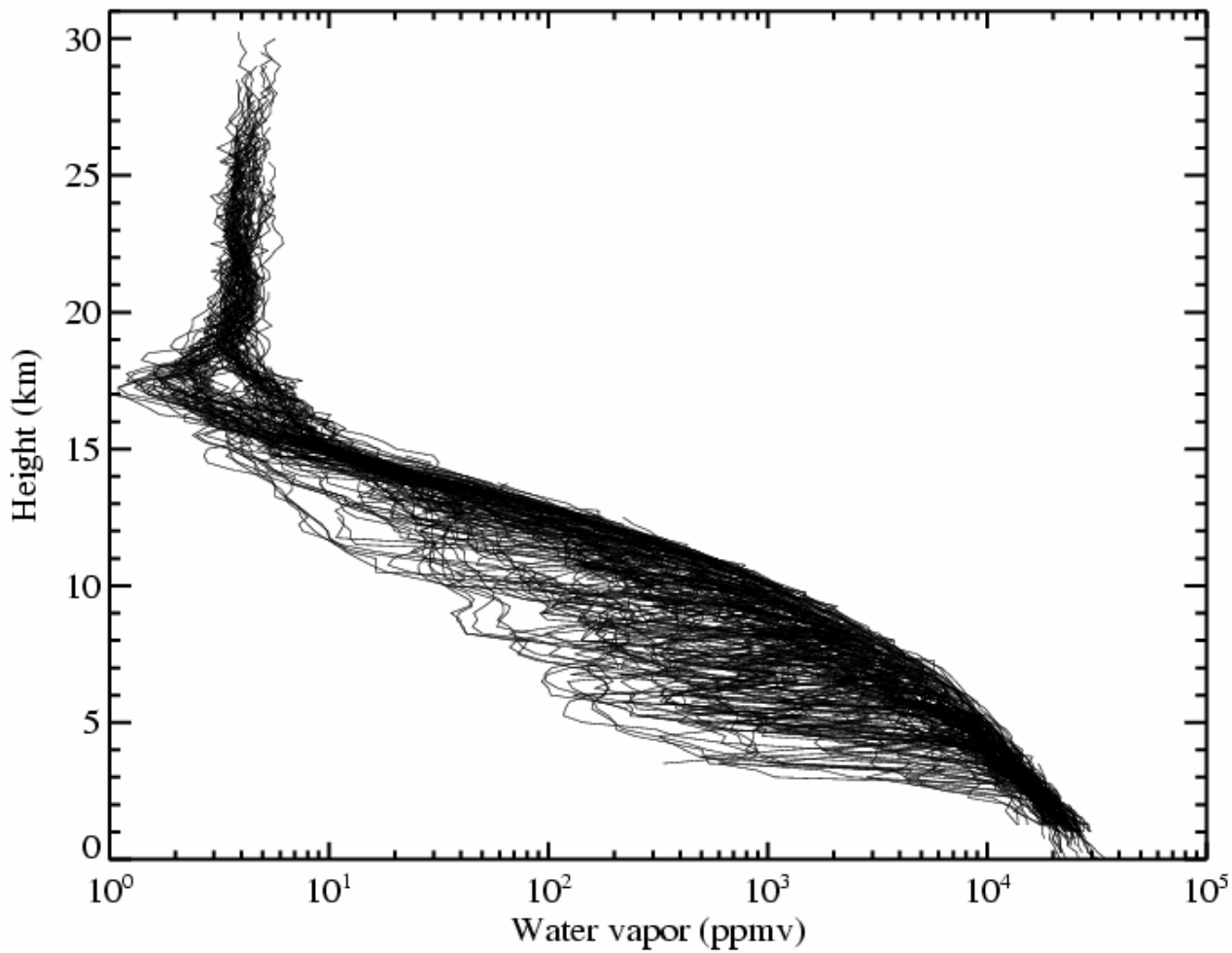
Thompson et al. (2003)

Temperature & O_3 profiles: Raw data





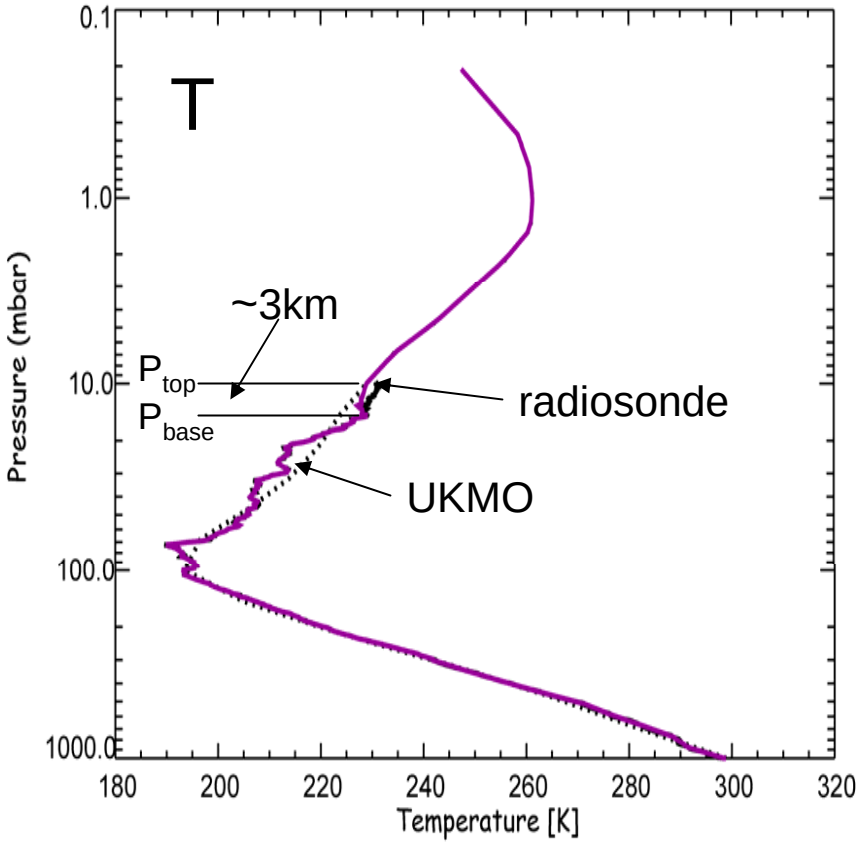
H_2O profiles

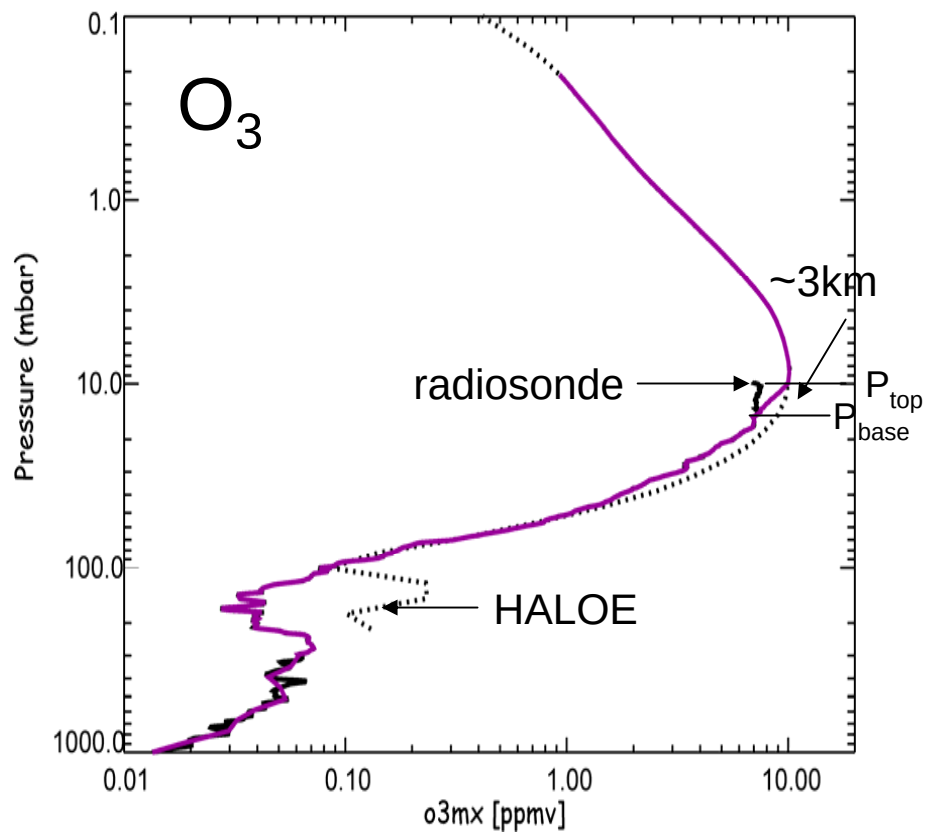


Balloon-borne frost point hygrometer observations
(H. Vomel, personal communications, 2006)

Temperature & O_3 & H_2O profiles above ~10 mb

Vertical resolution ~100m



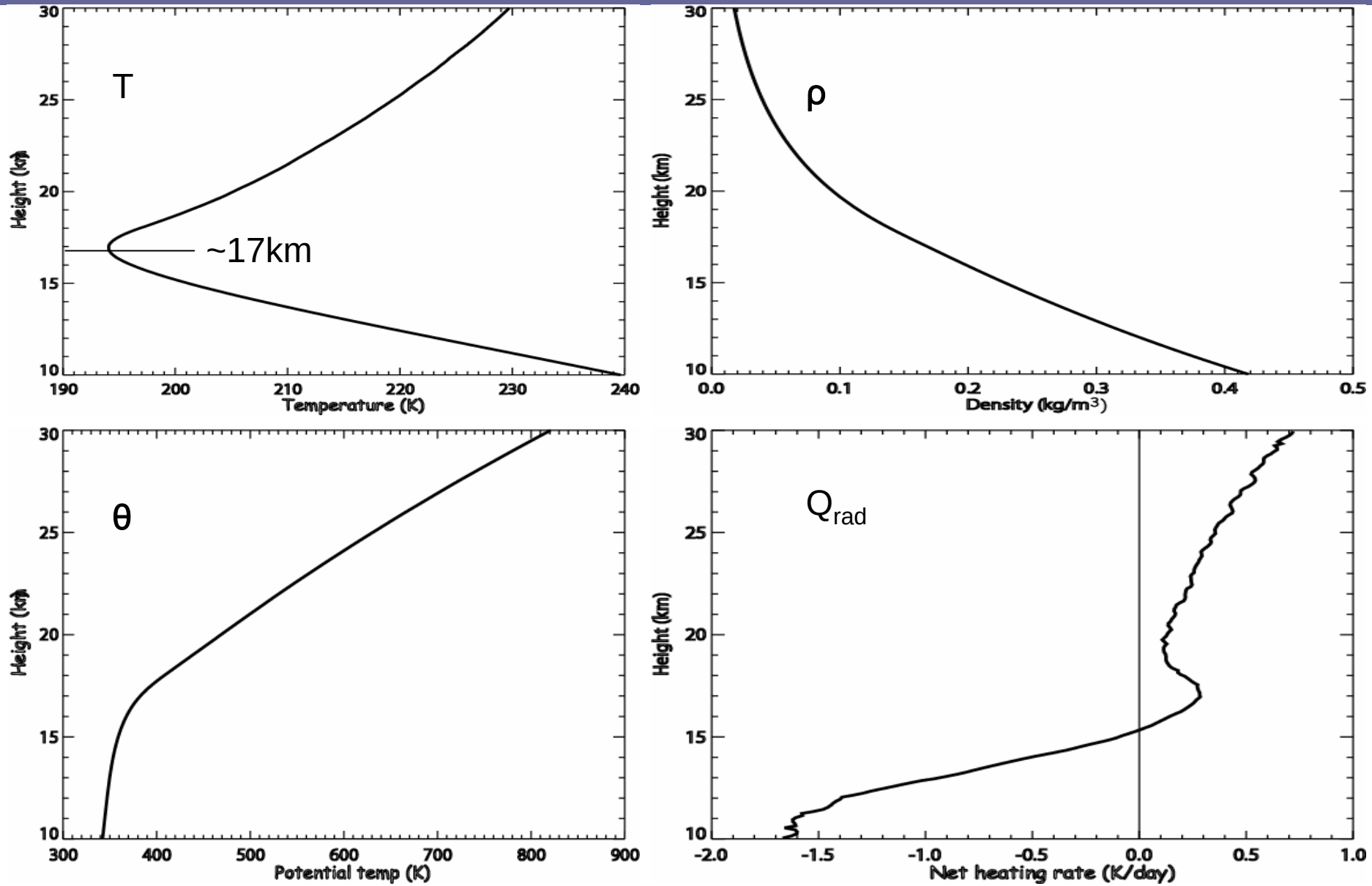


Weight function: $W=1-(\ln P_{base}-\ln P)/(\ln P_{base}-\ln P_{top})$

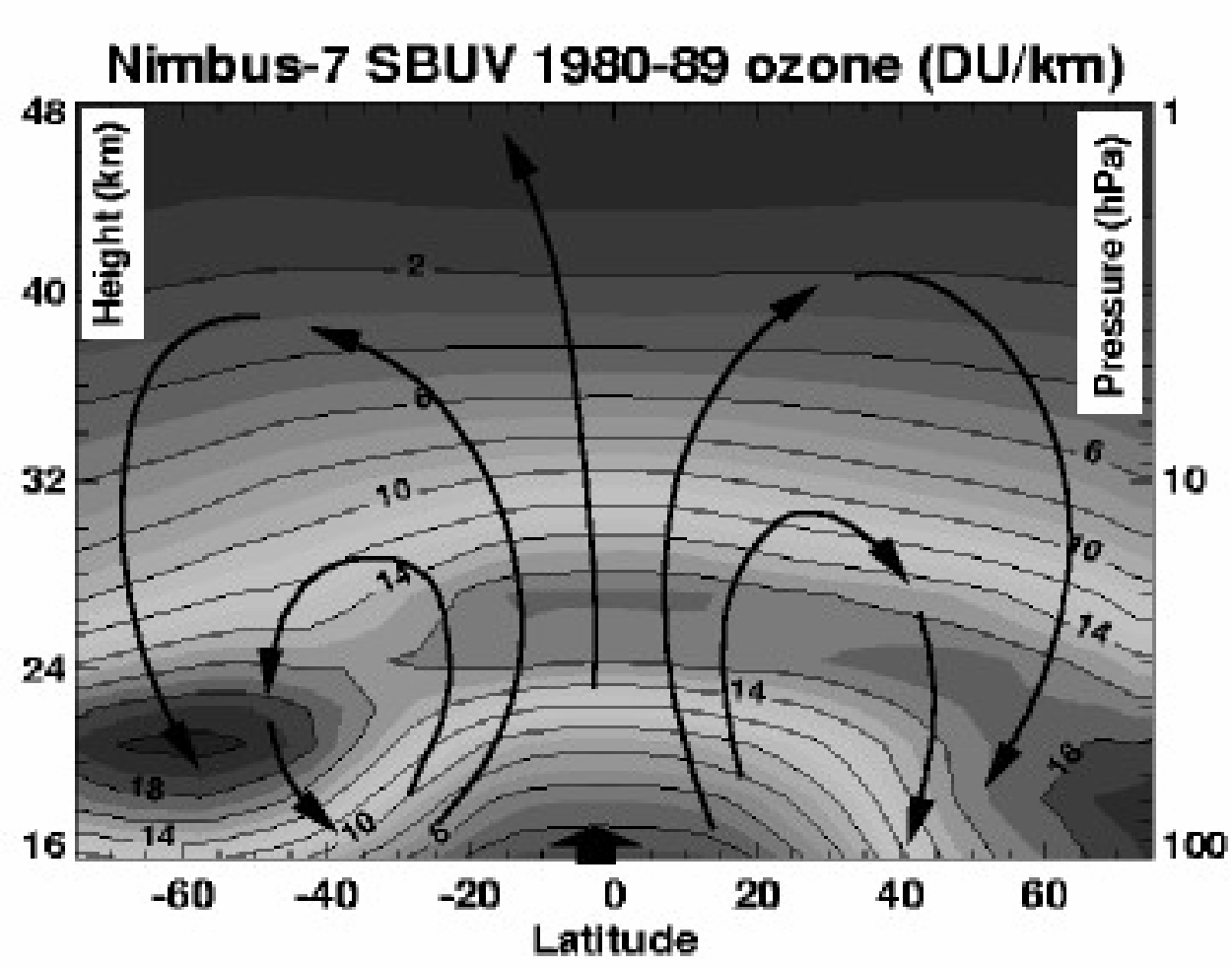
$Var_{transition}(P) = (1-W)*climate(P)+W*Var_{radiosonde}(P)$

climate: UKMO/HALOE

Radiative heating rate profile (total mean)



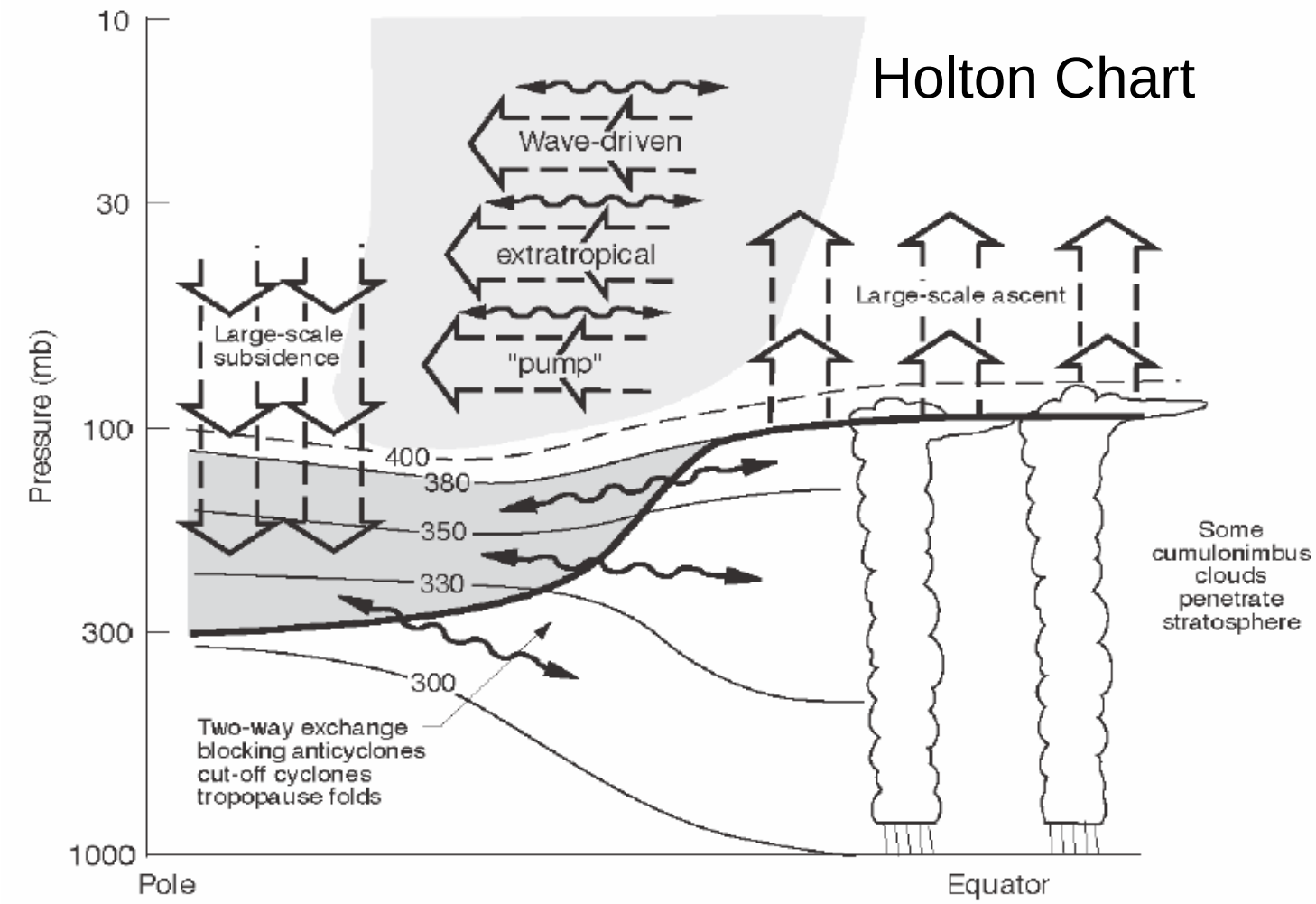
Brewer-Dobson Circulation



The idea was not started to be accepted until the late of 1970s

Brewer (1949) and Dobson (1956)

What forces the Brewer-Dobson Circulation



Haynes et al. (1991); Holton et al. (1995)

Motivation

- Brewer-Dobson circulation is crucial for the stratosphere-troposphere exchange and interactions between the stratosphere and troposphere and between low and high latitudes in the context of current climate and climate changes (Holton et al. 1995).
- Quantitative estimates of the strength of B-D circulation are difficult to make (Rosenlof 1995).
- Previous work to estimate the vertical velocity and upward/downward mass flux of B-D circulations based on observations:

(1) By examining the temporal and spatial dependences of trace gaseous concentrations in the stratosphere from satellite observations (e.g. Mote et al 1998).

(2) By solving transformed Eulerian-mean (TEM) zonal momentum and continuity equations based on UKMO stratospheric reanalyses data (e.g. Rosenlof and Holton 1993): O*nly works for extra-tropics.*

(3) By solving TEM thermodynamic and continuity equations based on radiative heating rates from a radiative transfer model using satellite observations (e.g. Rosenlof 1995; Eluszkiewicz et al 1996).

- We have a validated radiative transfer model (Fu and Liou 1992; 1993; Gettelman et al. 2004) and high-quality newly available sonding profiles of T, O_3, and H_2O.

Method

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

$$\overline{w}\frac{\overline{T}}{\overline{\theta}}\frac{\partial\overline{\theta}}{\partial z} = \overline{Q}_{radiation} \qquad \overline{w} = \overline{Q}_{radiation} / (\frac{\overline{T}}{\overline{\theta}}\frac{\partial\overline{\theta}}{\partial T}) \qquad \overline{M} = \overline{w}\overline{\rho}$$

Method

QuickTime™ and a
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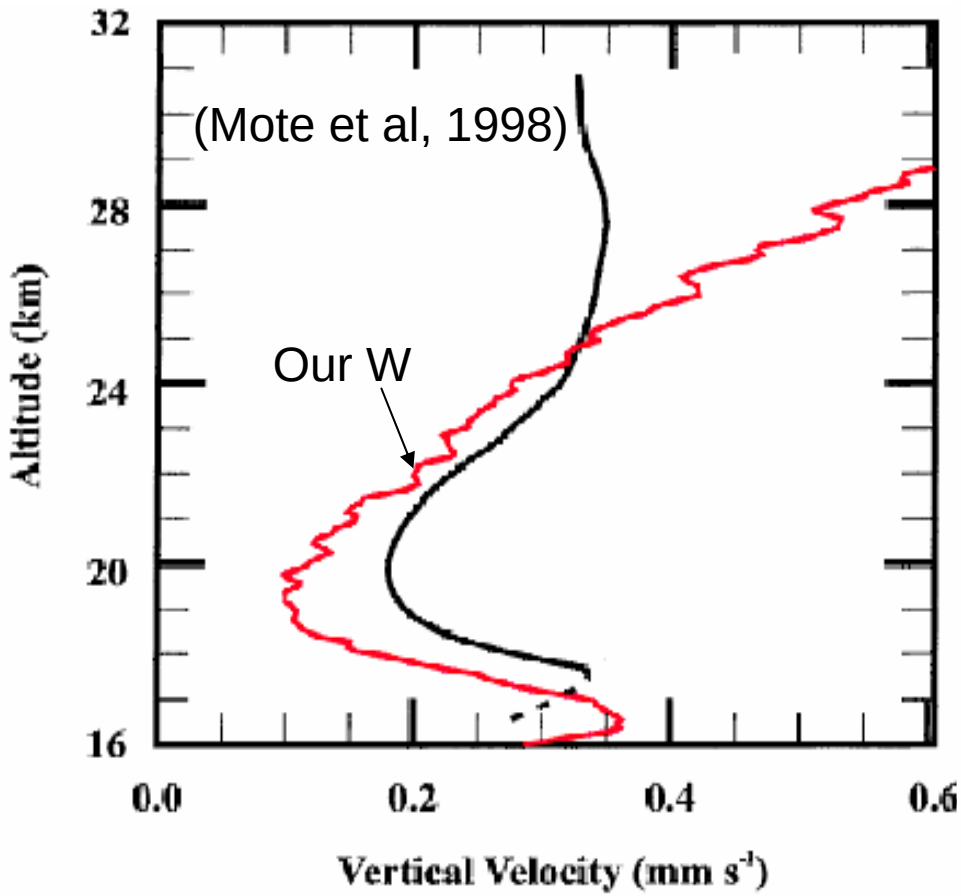
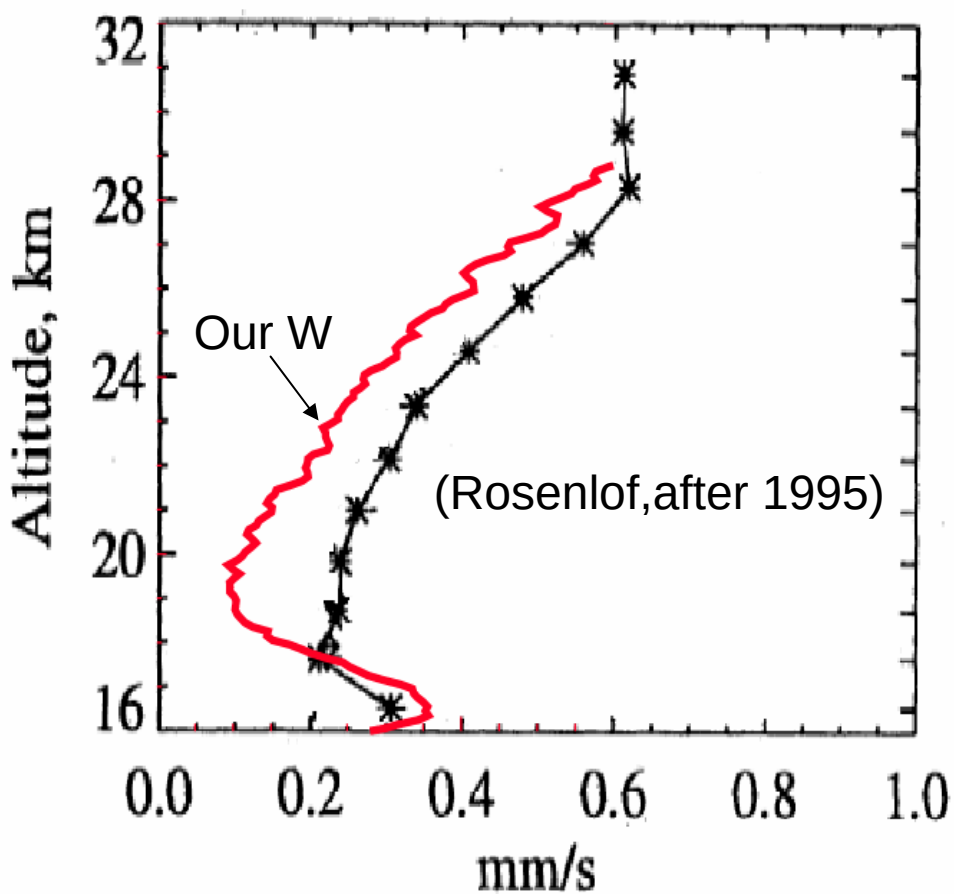
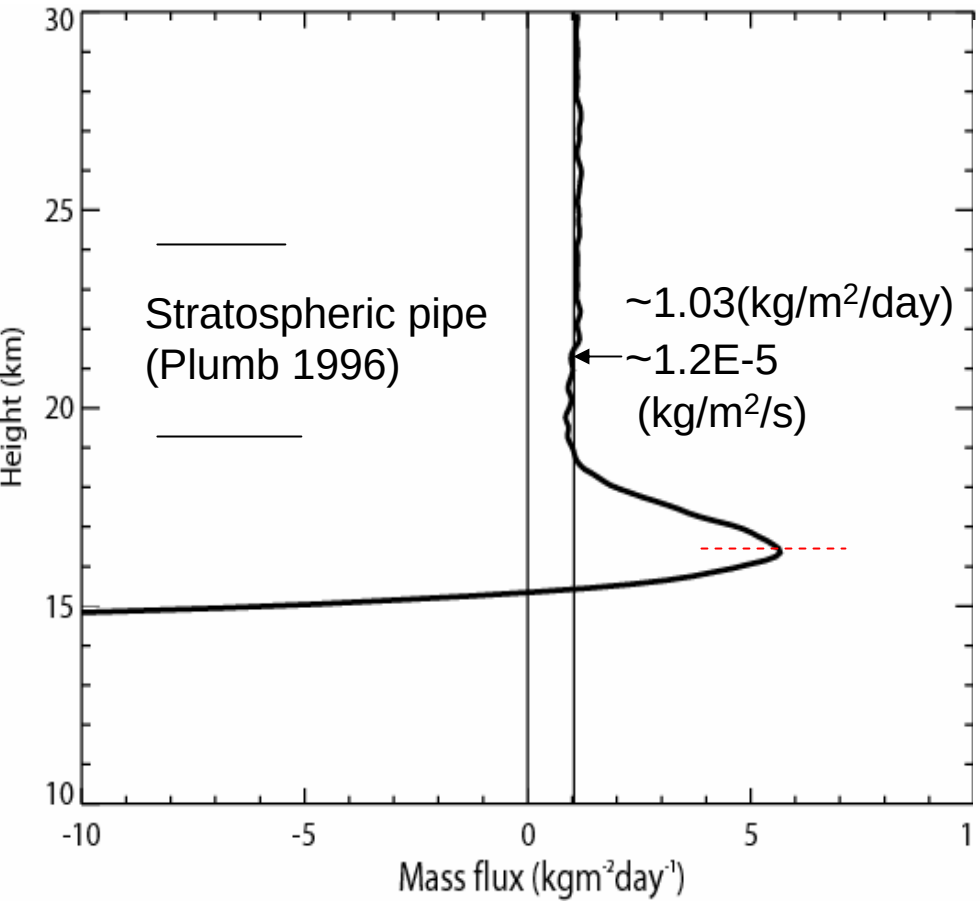
Rosenlof (1995)

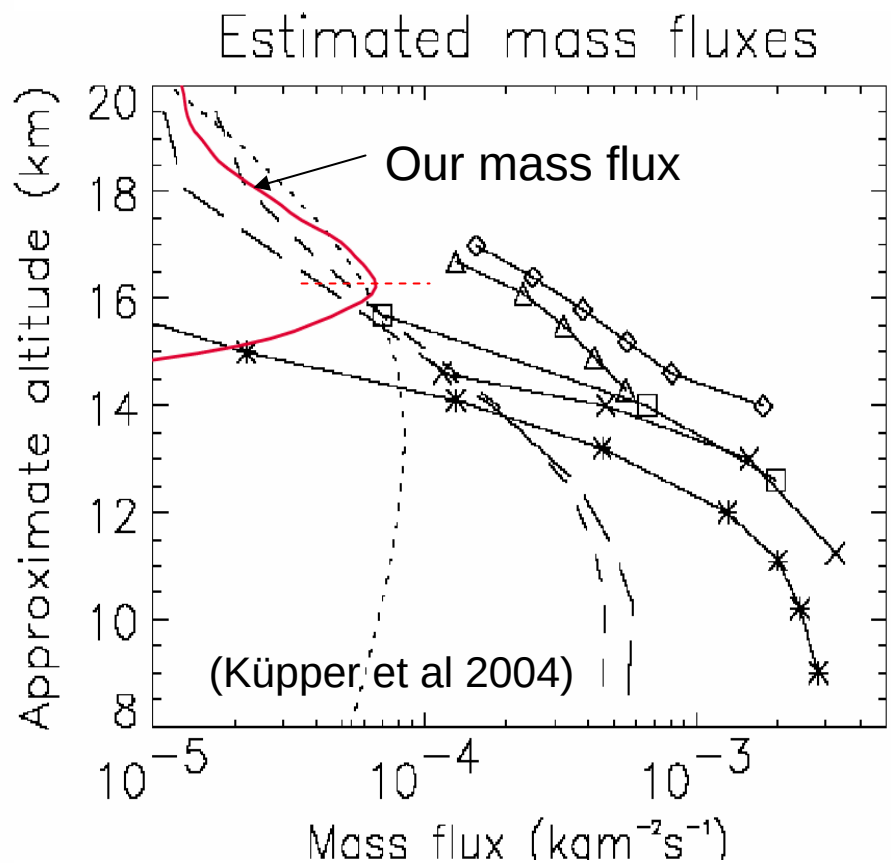
Upward vertical velocity in tropical stratosphere: Comparison with previous studies





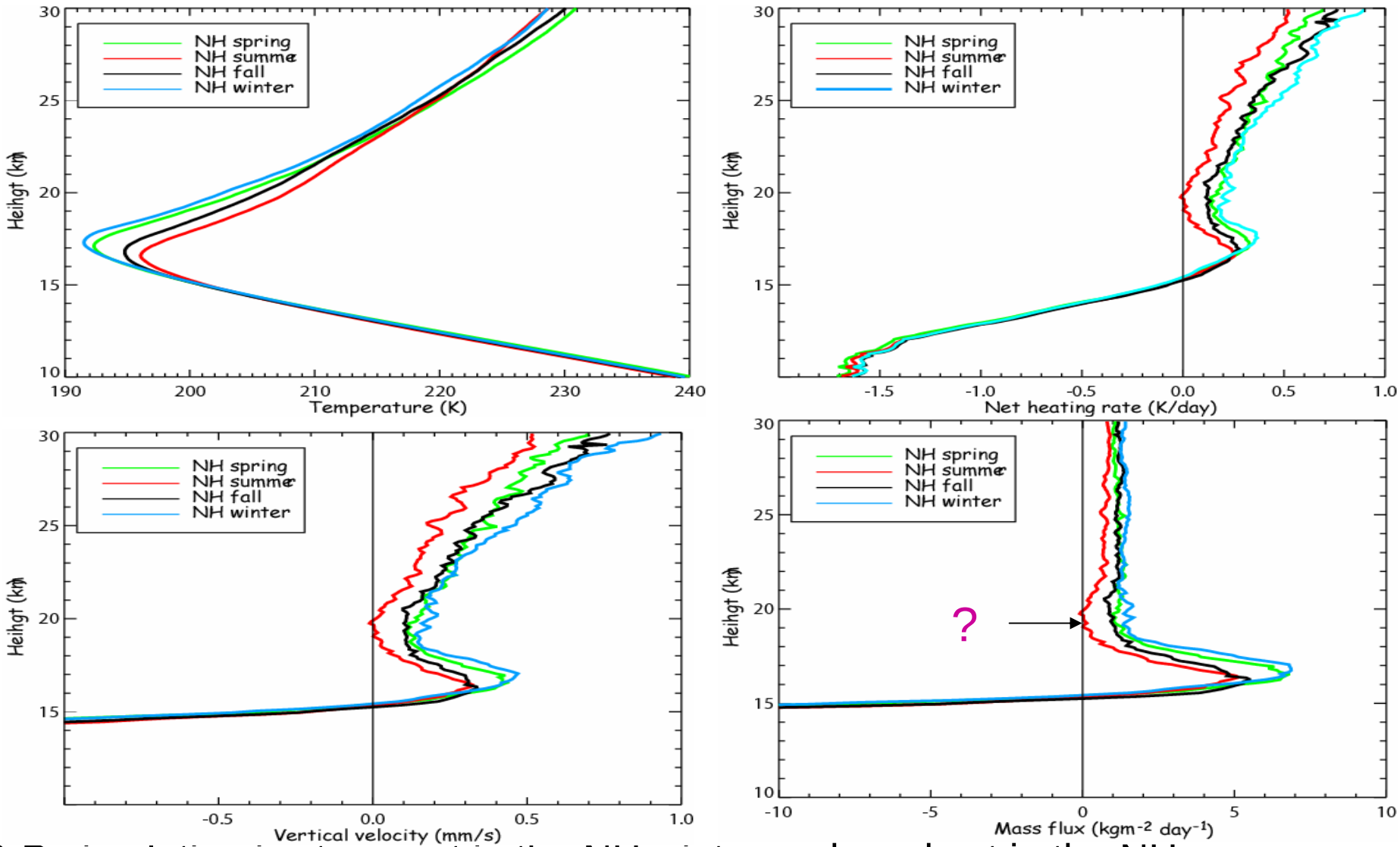
Upward mass flux in tropical stratosphere





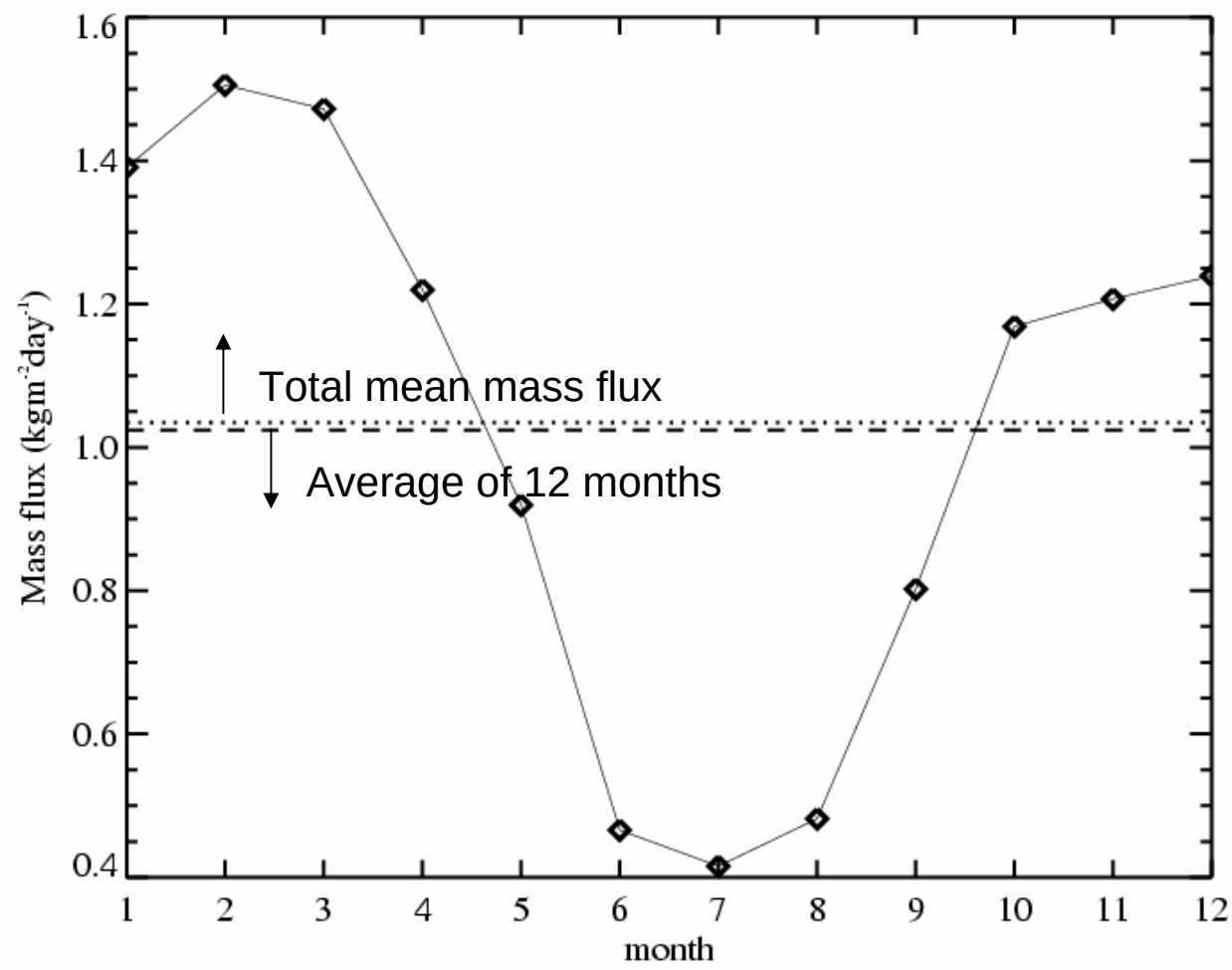
Mean mass flux = average of mass fluxes between 19 and 24 km.

Seasonal variations



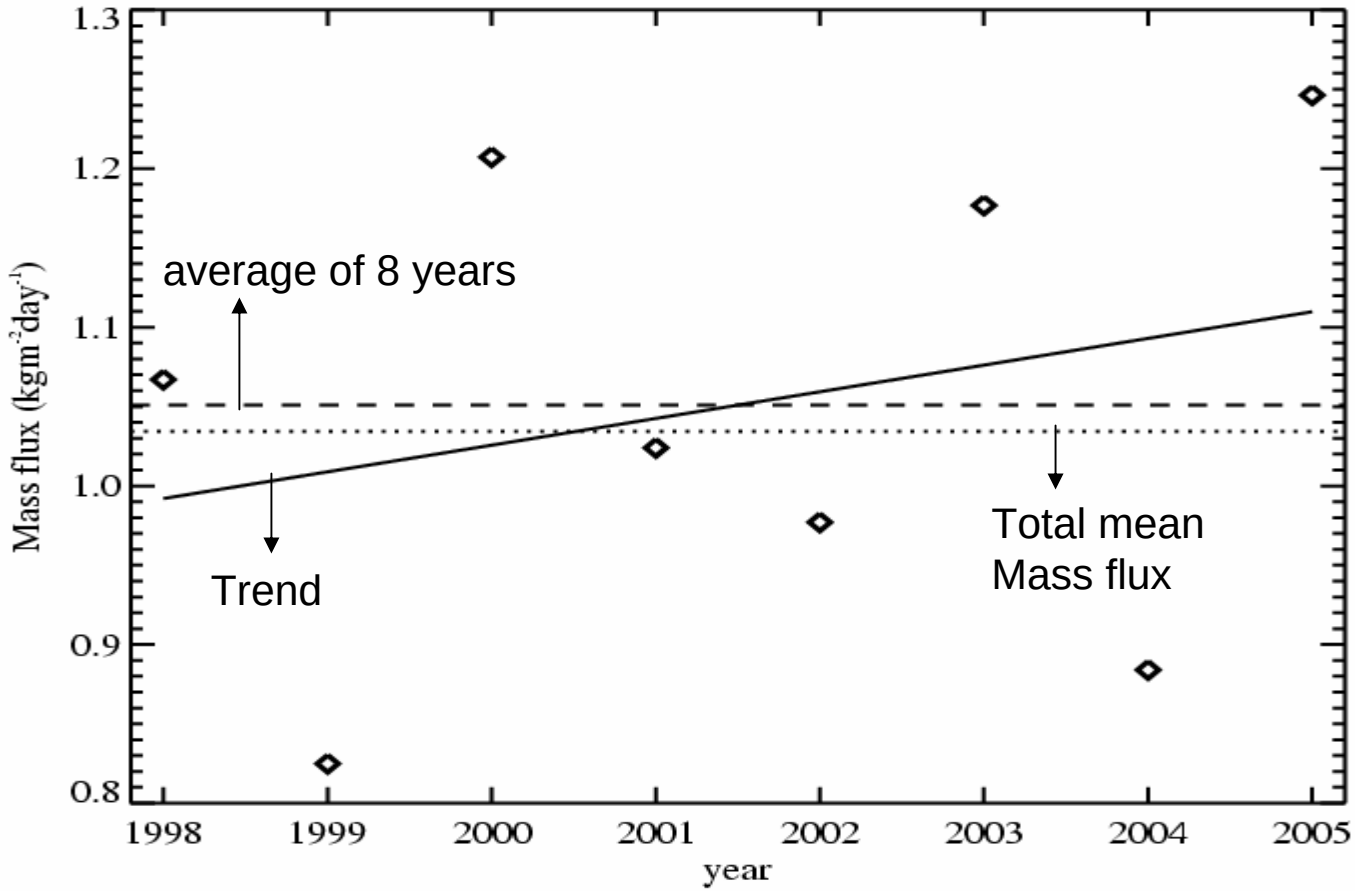
B-D circulation is strongest in the NH winter and weakest in the NH summer

Annual cycle of upward mass fluxes (averaged between 19 and 24 km)



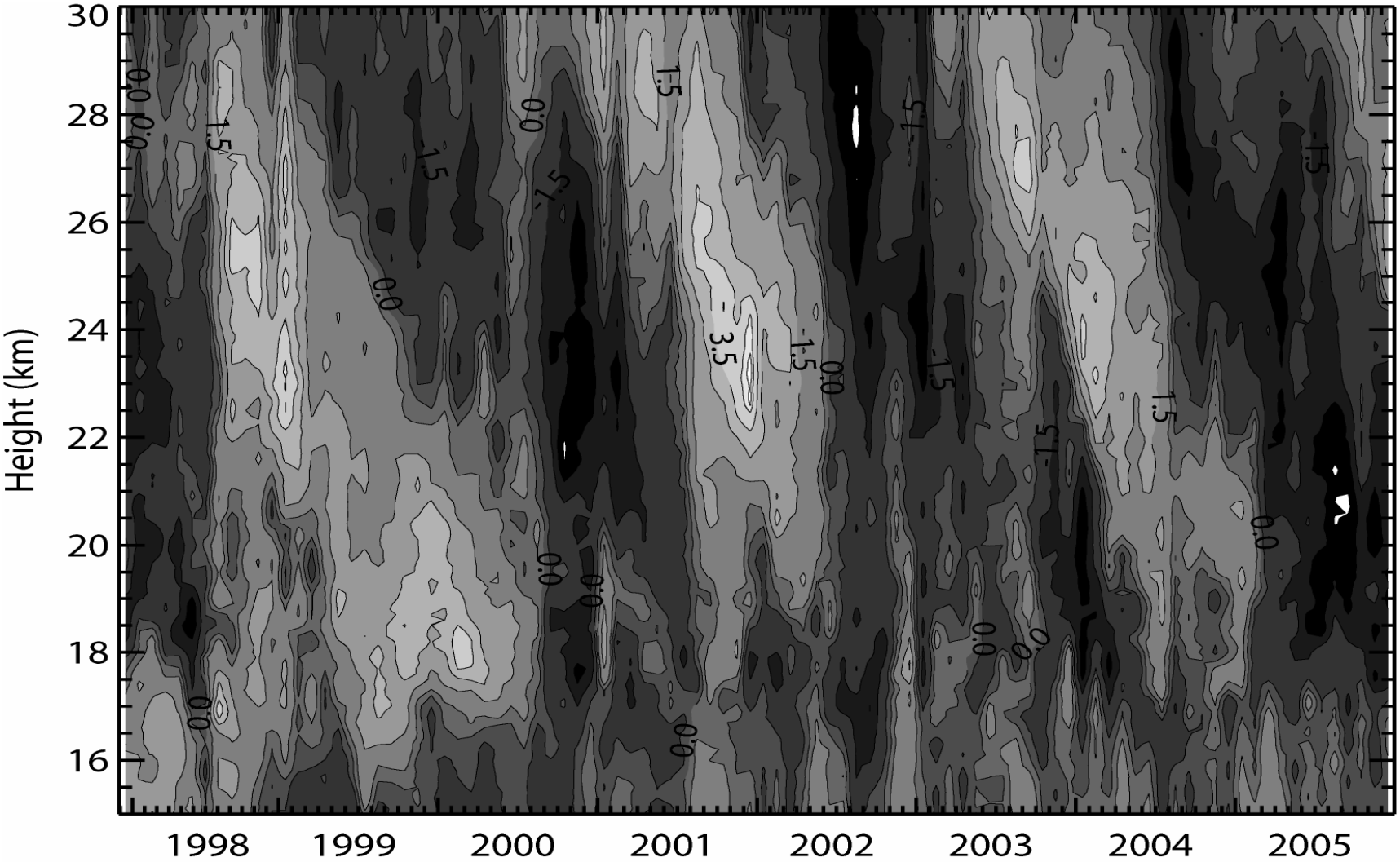
Mass flux has a minimum during NH summer.

Interannual variation & trend of upward mass fluxes

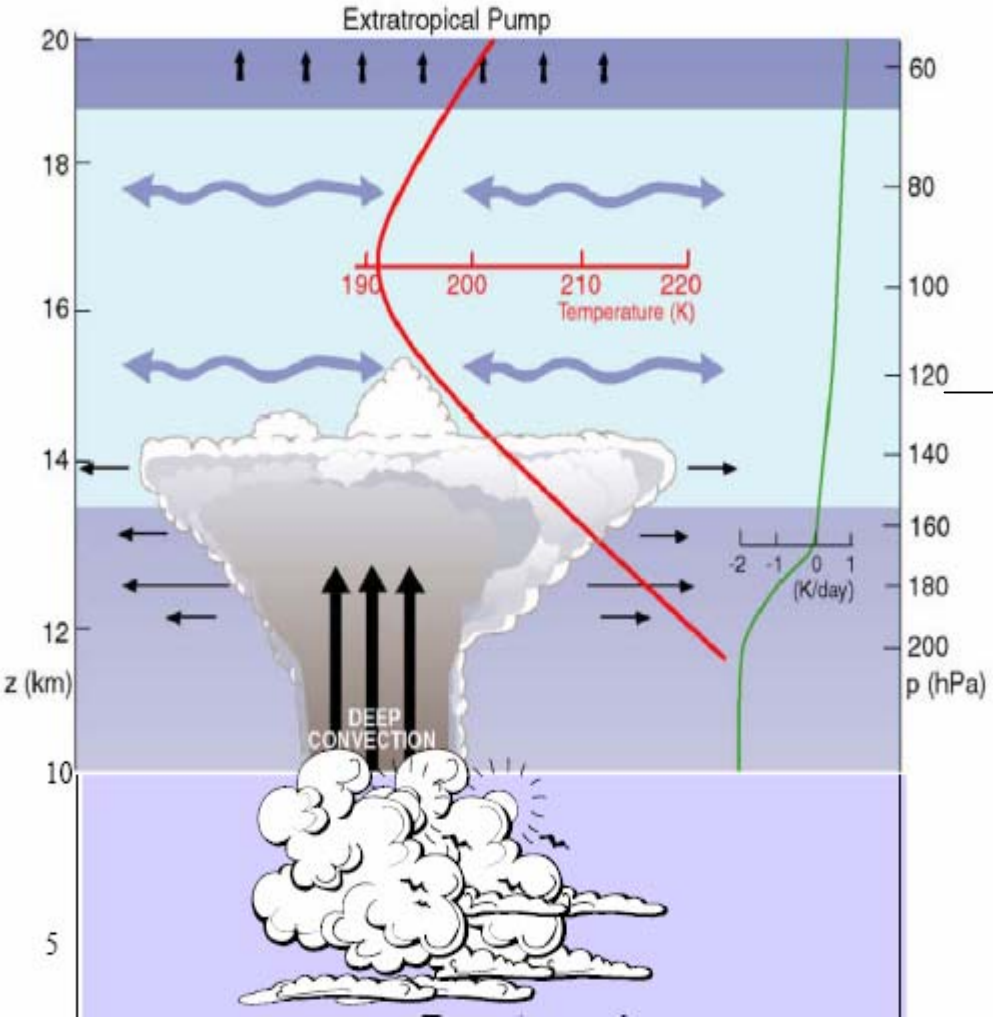


Eichelberger & Hartmann (2005): The strength of the modeled Brewer-Dobson Circulation increases in response to tropospheric warming.
Butchart et al (2006): All GCMs consistently predict an increasing trend in the Brewer-Dobson Circulation mass flux in response to global warming.

Monthly temperature anomalies



Tropical Tropopause Layer (TTL)



Fueglistaler et al. (2007)

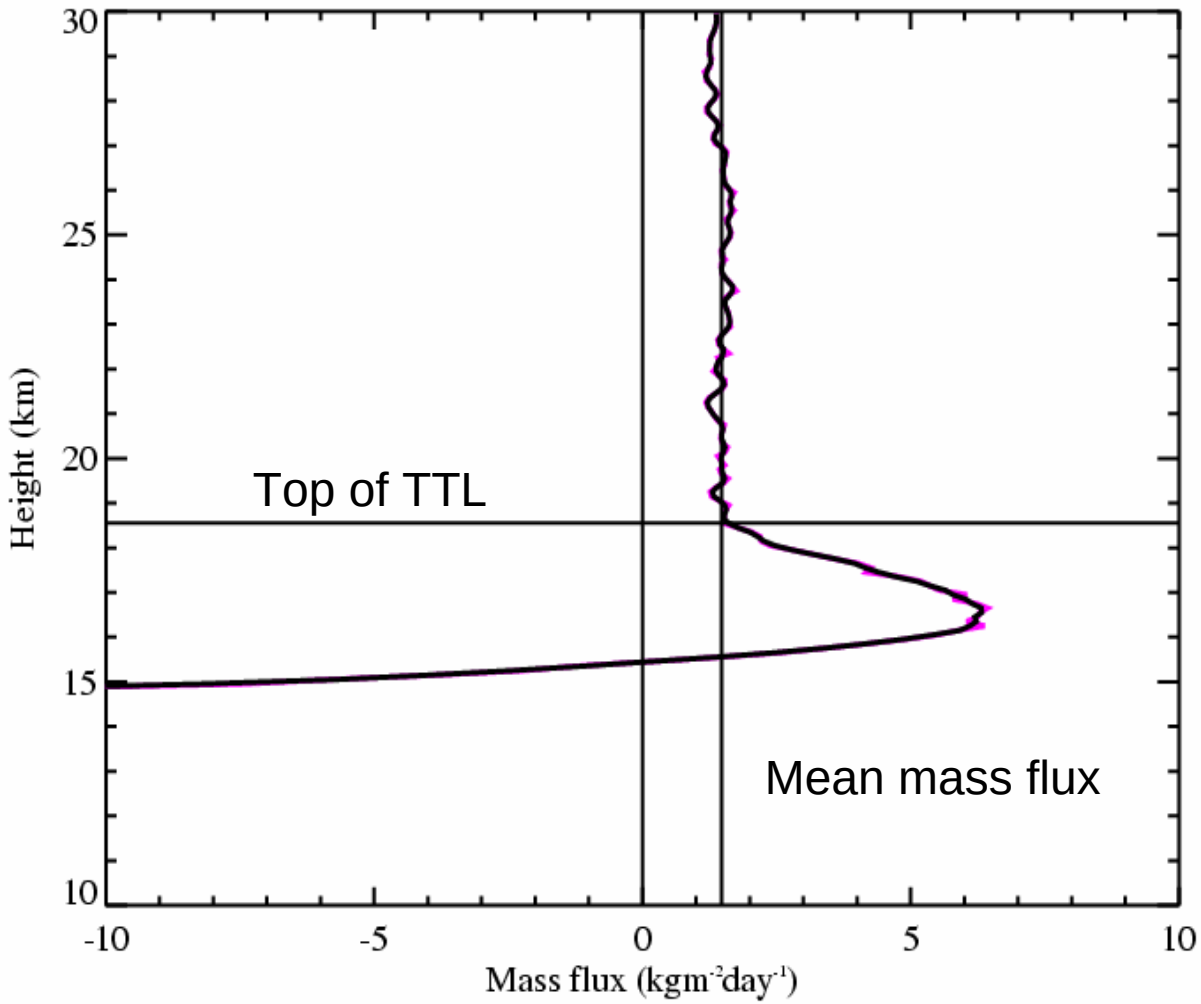
- TTL is a transition region whose properties are intermediate between the troposphere and stratosphere, rather than a material surface (Highwood and Hoskins, 1998; Folkins et al, 1999).

The base of TTL (~15 km):
The level of zero net radiative heating rate

It is more difficult to define the top of the TTL. A useful conceptual definition is that it is the height at which the upward convective mass flux becomes small in comparison to the B-D mass flux.

Unfortunately, it is intrinsically difficult to diagnose the high altitude tail of the convective detrainment profile from observations (Folkins, 2006).

Define the top of TTL



We define the top of the TTL as the level at which the vertical mass flux is less than 110% of the mean mass flux between 19 and 24 km.

Top of TTL in terms of height and pressure

	mean	range*	stddev
height at top of TTL (km)	18.71	18.15--19.65	0.37
pressure at top of TTL (mbar)	69.53	59.31--76.57	4.39

Range*: The range represents the variability of top of TTL due to inter-annual, seasonal/monthly and spatial variations.

Some remaining issues & future work

- The cloud impact on the tropical stratospheric radiative heating rates and upward mass fluxes.
- ARM tropical site MMCR cloud observations (O_3 profiling at ARM sites?).
- Examining the simulated Brewer-Dobson circulation upward mass fluxes from GFDL and NCAR GCMs (with high vertical resolution of more than 40 vertical layers) with those based on observations.

SHADOZ data (temperature, O_3)

http://croc.gsfc.nasa.gov/shadoz

12 stations within -20S—20N from 1998 to 2005): 2244 profiles

Thompson et al. (2003)

Stratospheric radiative heating rates at Manus

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Fueglistaler and Fu (2006)