Recent Widening of the Tropical Belt

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Recent Widening of the Tropical Belt

- How do we define tropical belt width?
- What is the observational evidence for expansion?
- Can models reproduce observations?
- What is expected in the future?
- What are unresolved questions?

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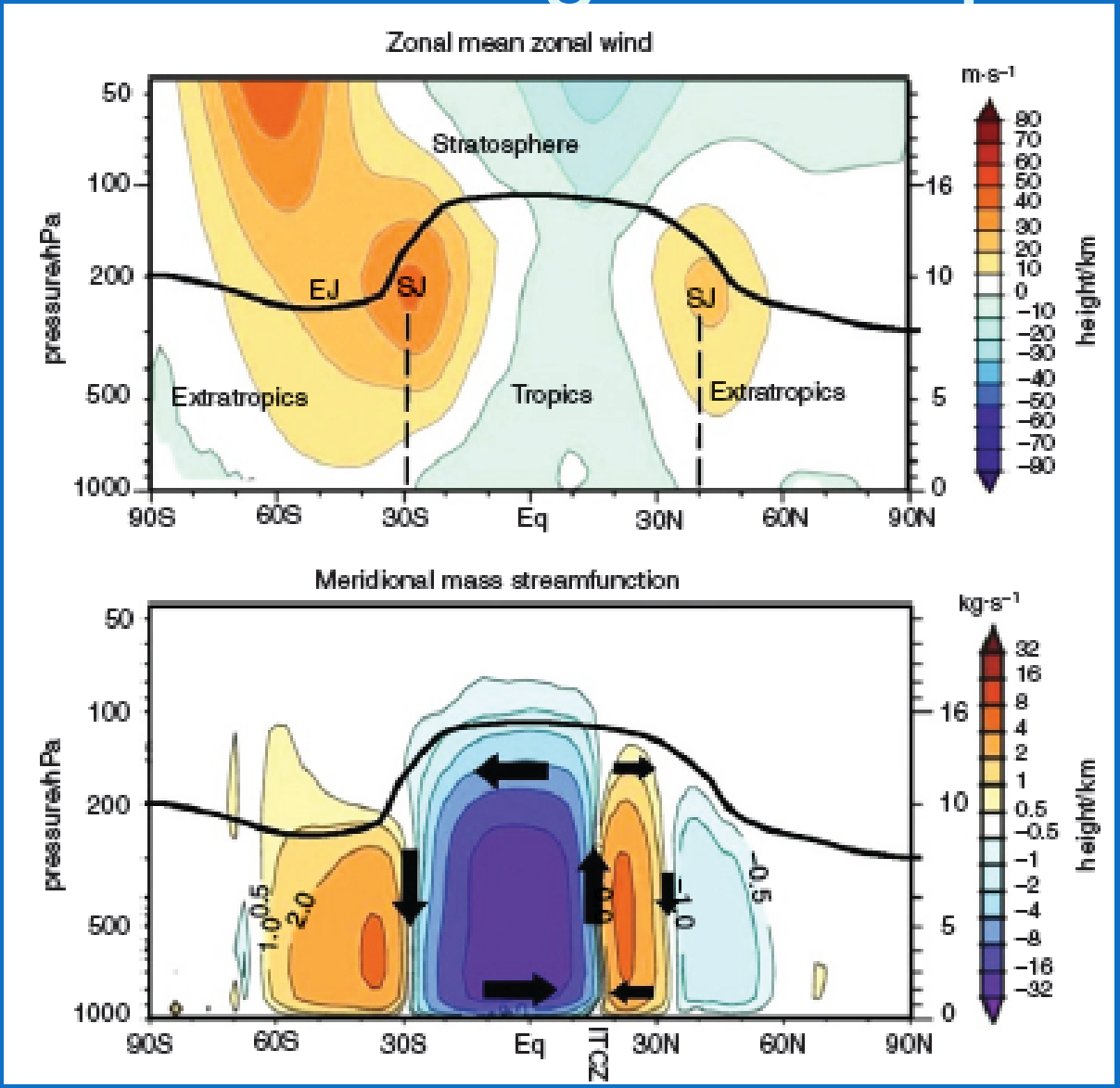
Popular Concepts of Tropics

Sources: NOAA, National Geographic

Cartographic / Astronomic Tropical Belt

Source: WorldAtlas.com

Meteorological Tropical Belt(s)



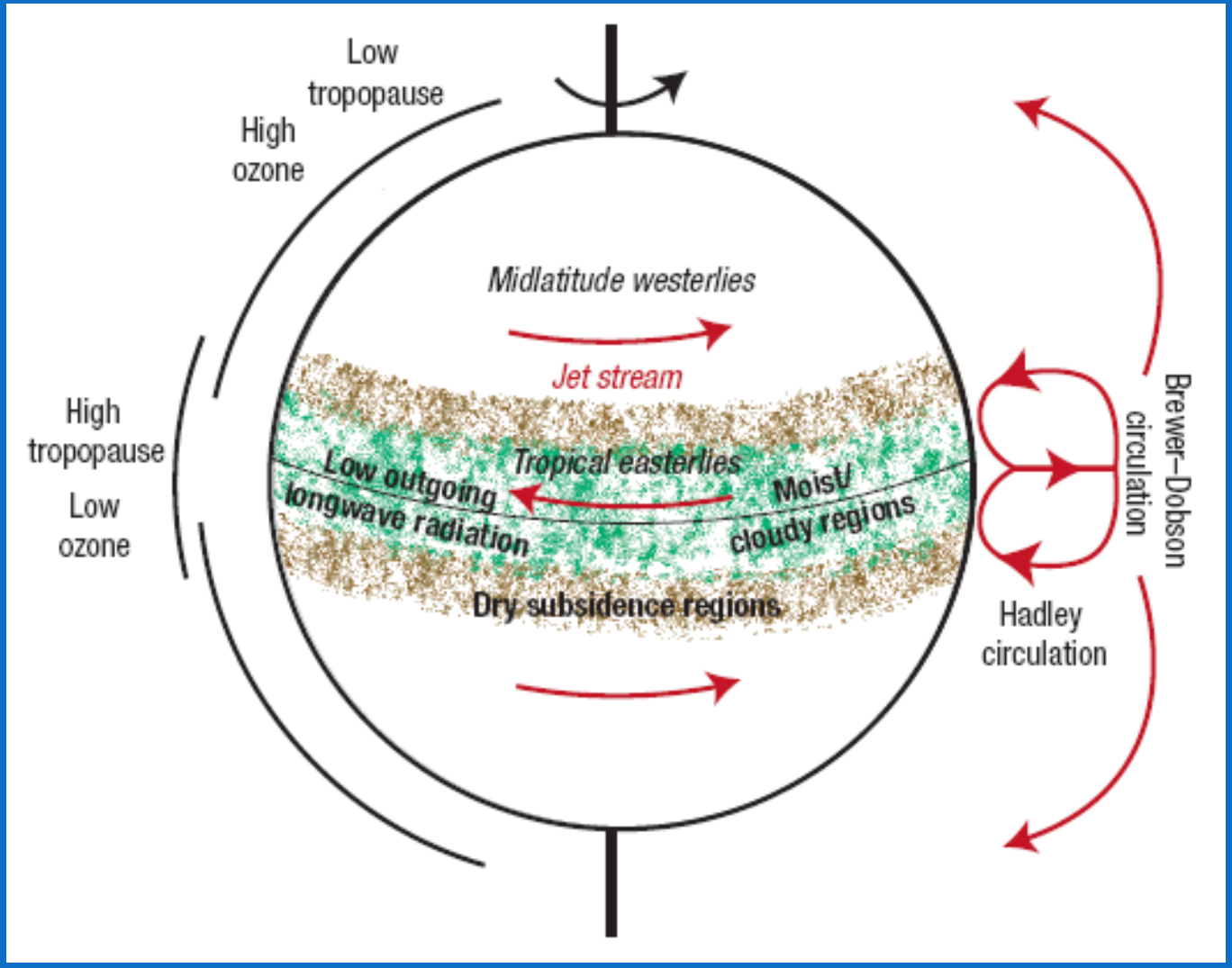
JJA zonal winds

DJF streamfunction

Hadley cell

Reichler (2009)

Meteorological Tropical Belt(s)



Seidel et al. (2008)

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Zonal Mean Meridional Mass Streamfunction in Reanalyses

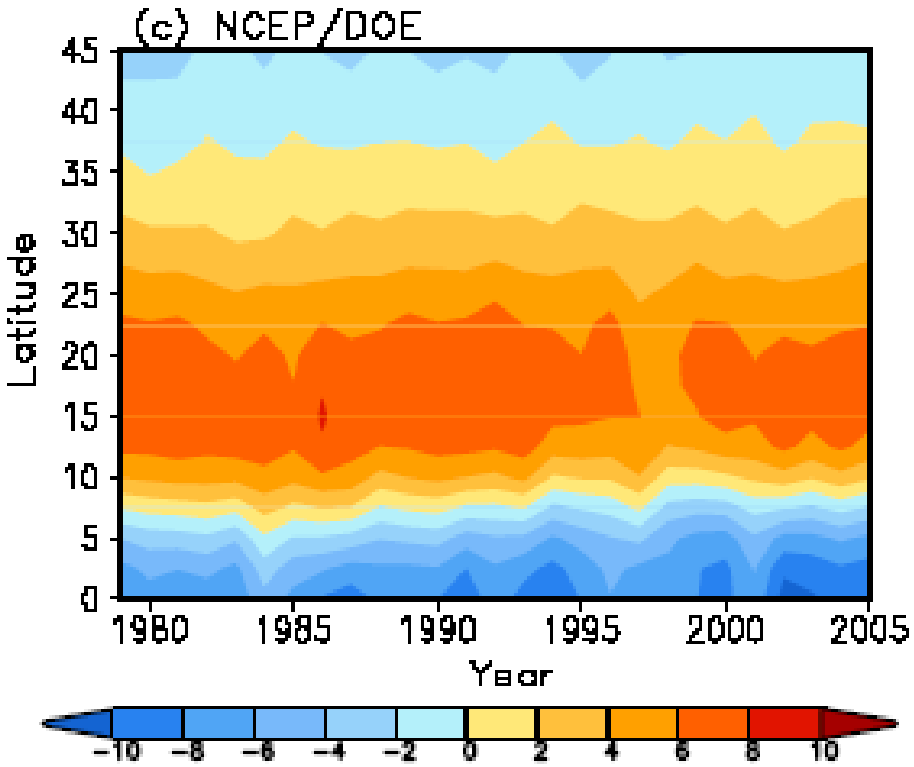
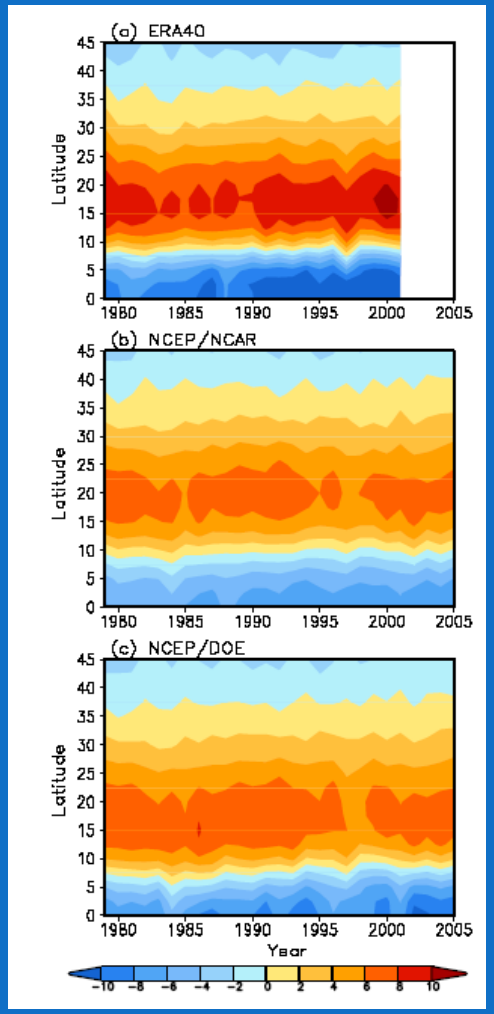


Fig. 1. Time evolution of zonal mean meridional mass streamfun
tion (MMS) at 500 hPa in NH for September-November (SO
from three reanalyses. The unit of MMS is $1.0\times10^{10}\,\mathrm{kg\,s^{-1}}$ a
the color interval is $2.0\times10^{10}\,\mathrm{kg\,s^{-1}}$.

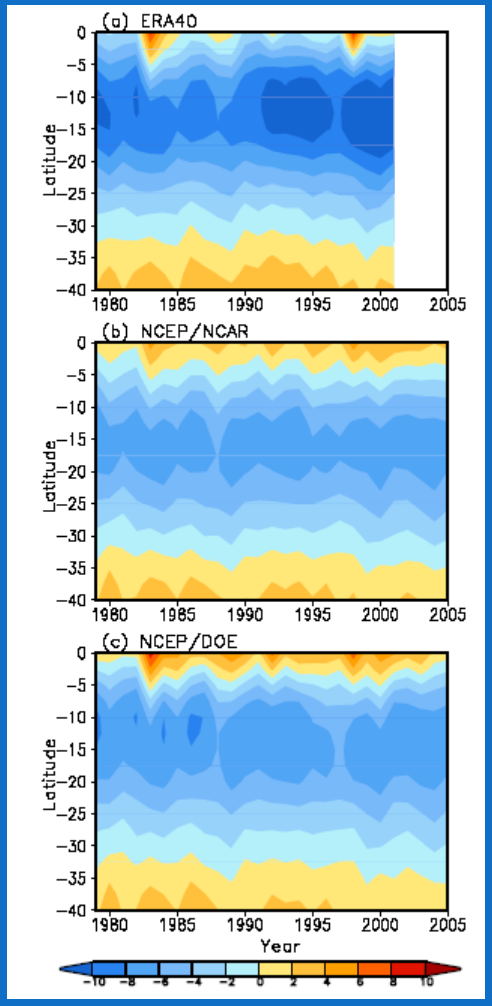
Latitude of zero net N-S flow

Hu and Fu (2007)

Zonal-Mean Meridional Mass Streamfunction in Reanalyses



SON



MAM

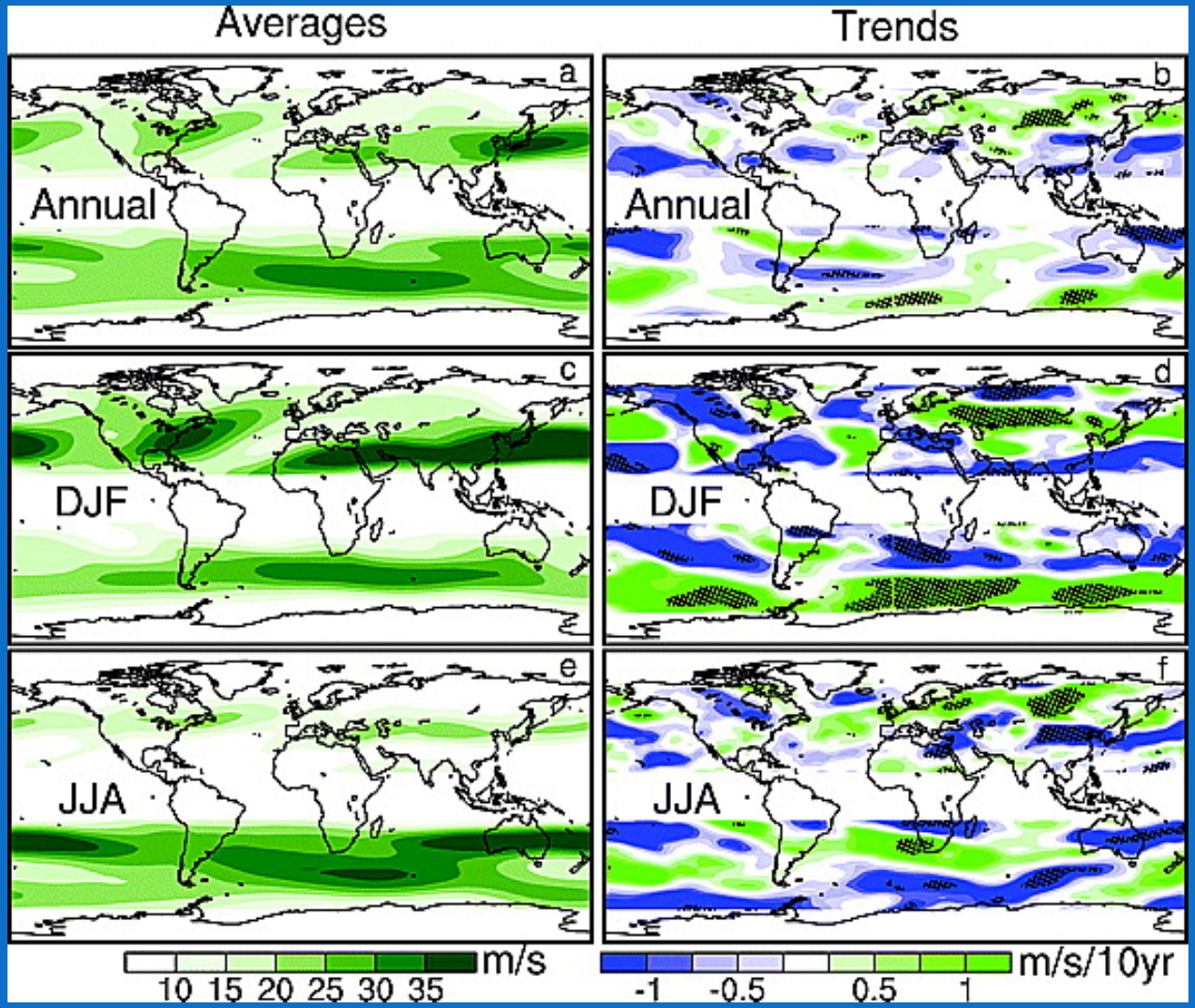
Total widening 1979-2005

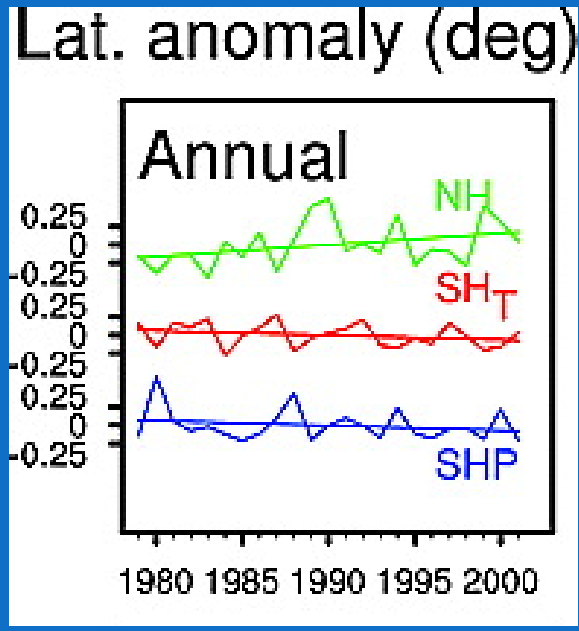
ERA40	2.6
NCEP/NCAR	2.7
NCEP/DOE	3.1

Summer and fall dominate

Hu and Fu (2007)

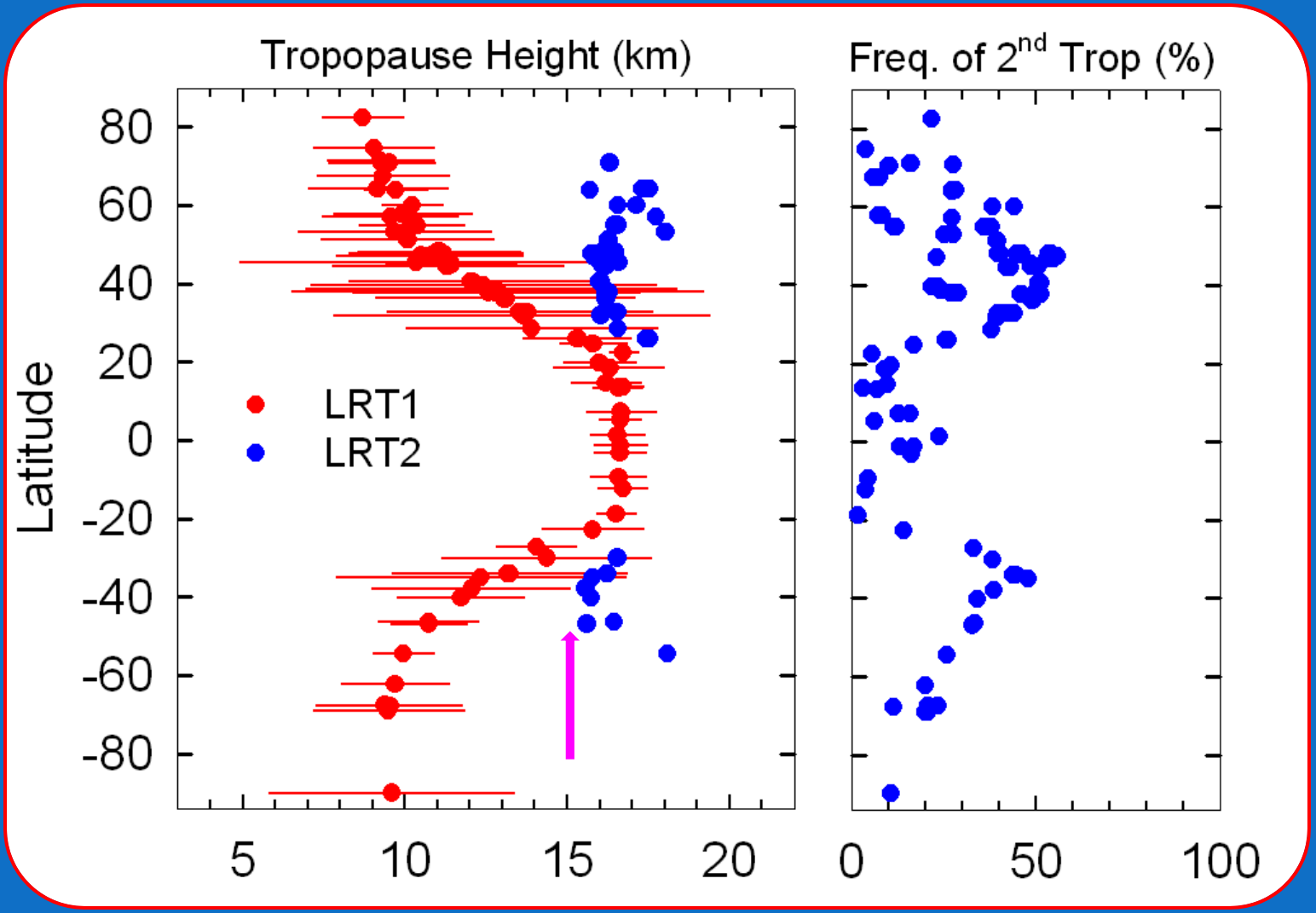
Jet Stream in ERA40





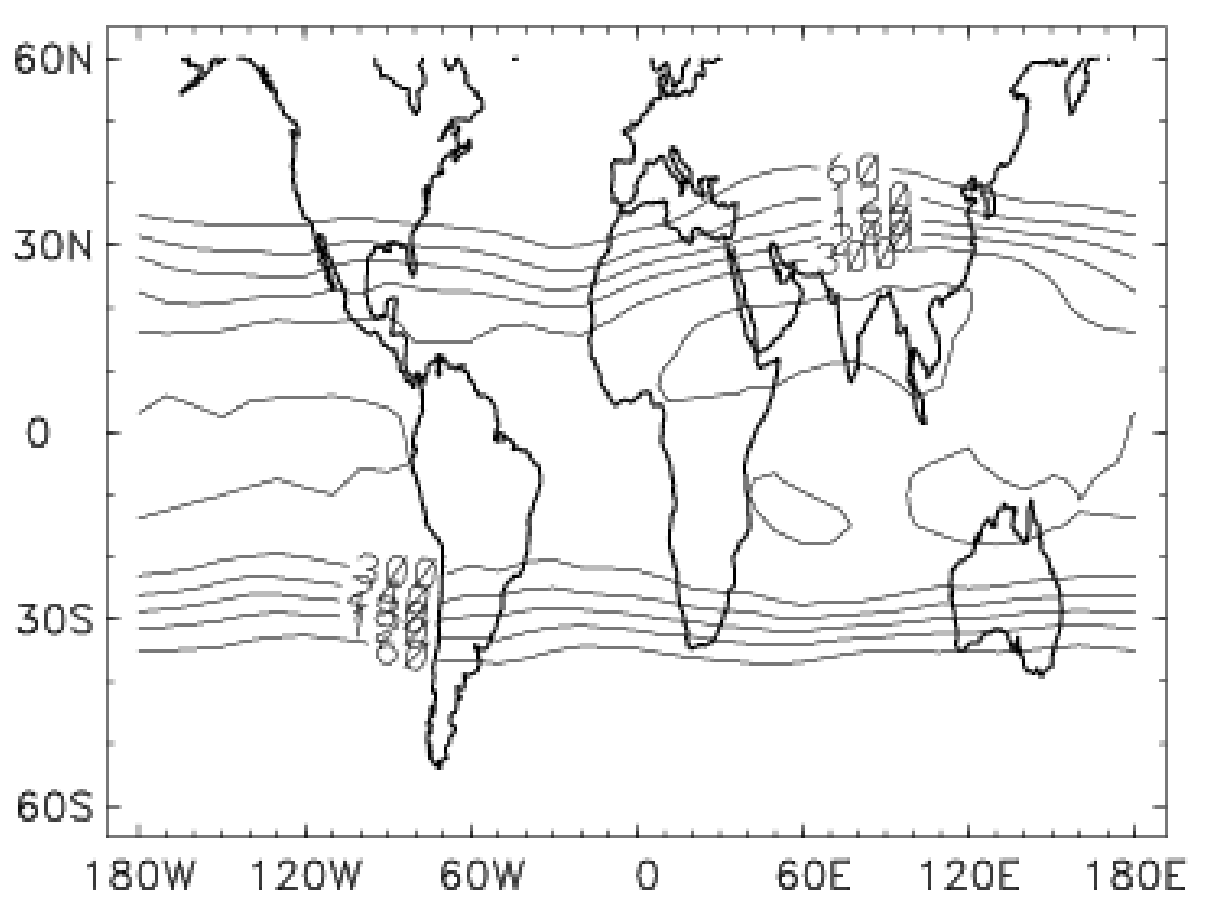
Archer and Caldeira (2008)

Tropopauses Height in Radiosonde Observations



Seidel and Randel (2006)

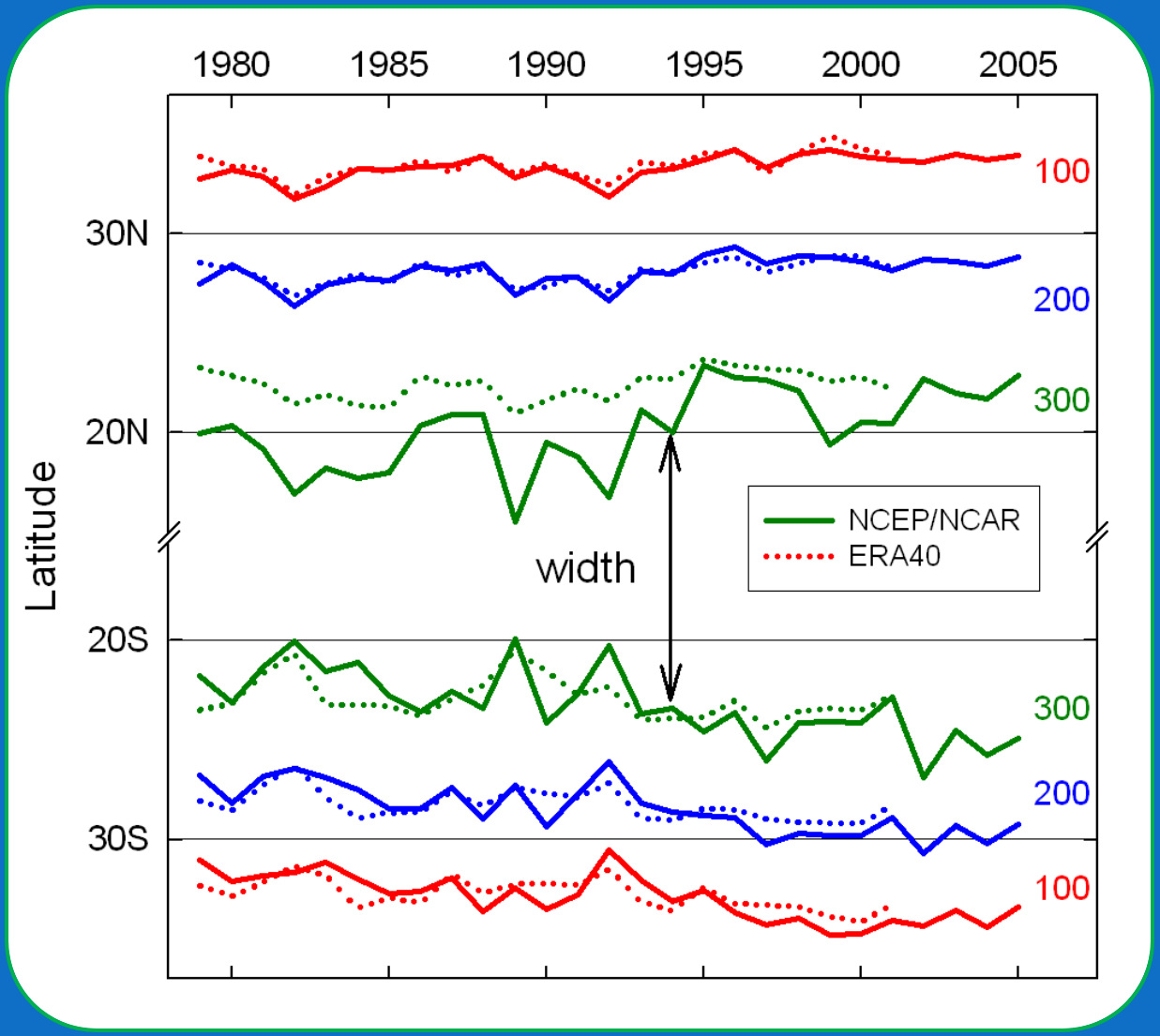
Tropopause Heights in NCEP/NCAR Reanalysis



Days/Yr with Height > 15 km

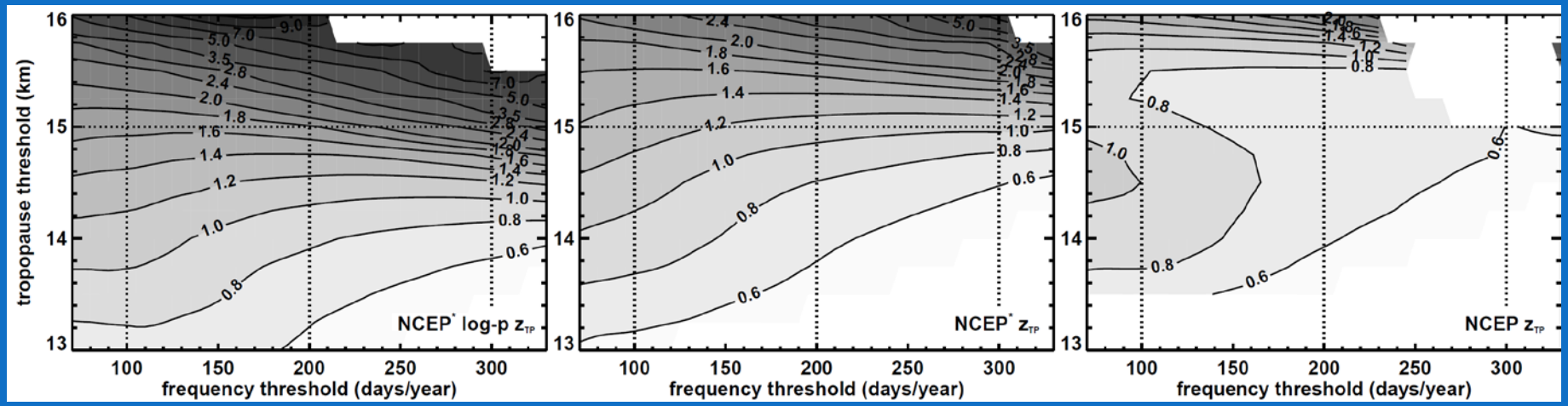
Seidel and Randel (2007)

Tropopause Heights in Reanalyses



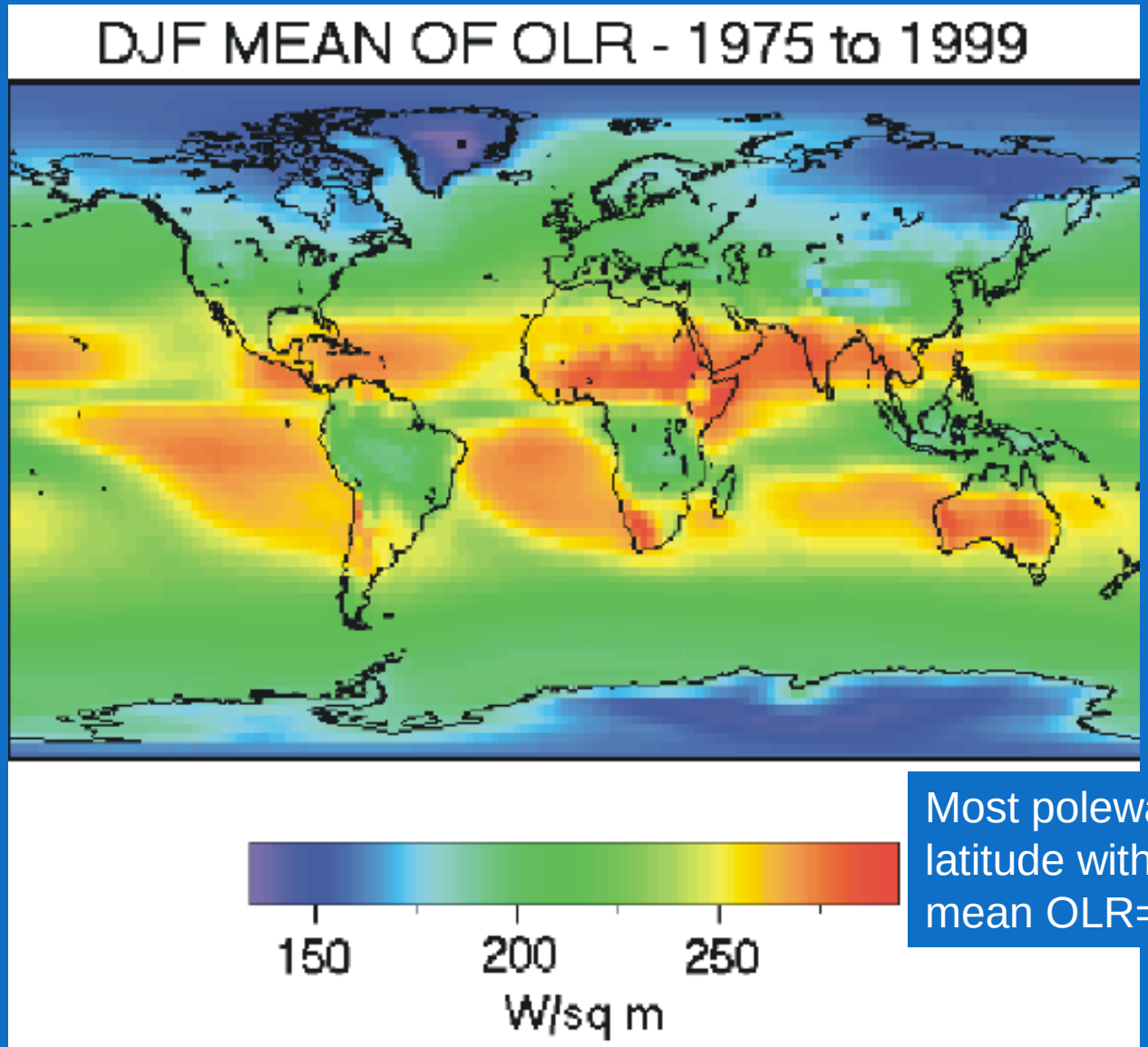
Seidel and Randel (2007)

Dependence of trends (lat/10 yr) on tropopause thresholds and reanalysis dataset



T. Birner (submitted)

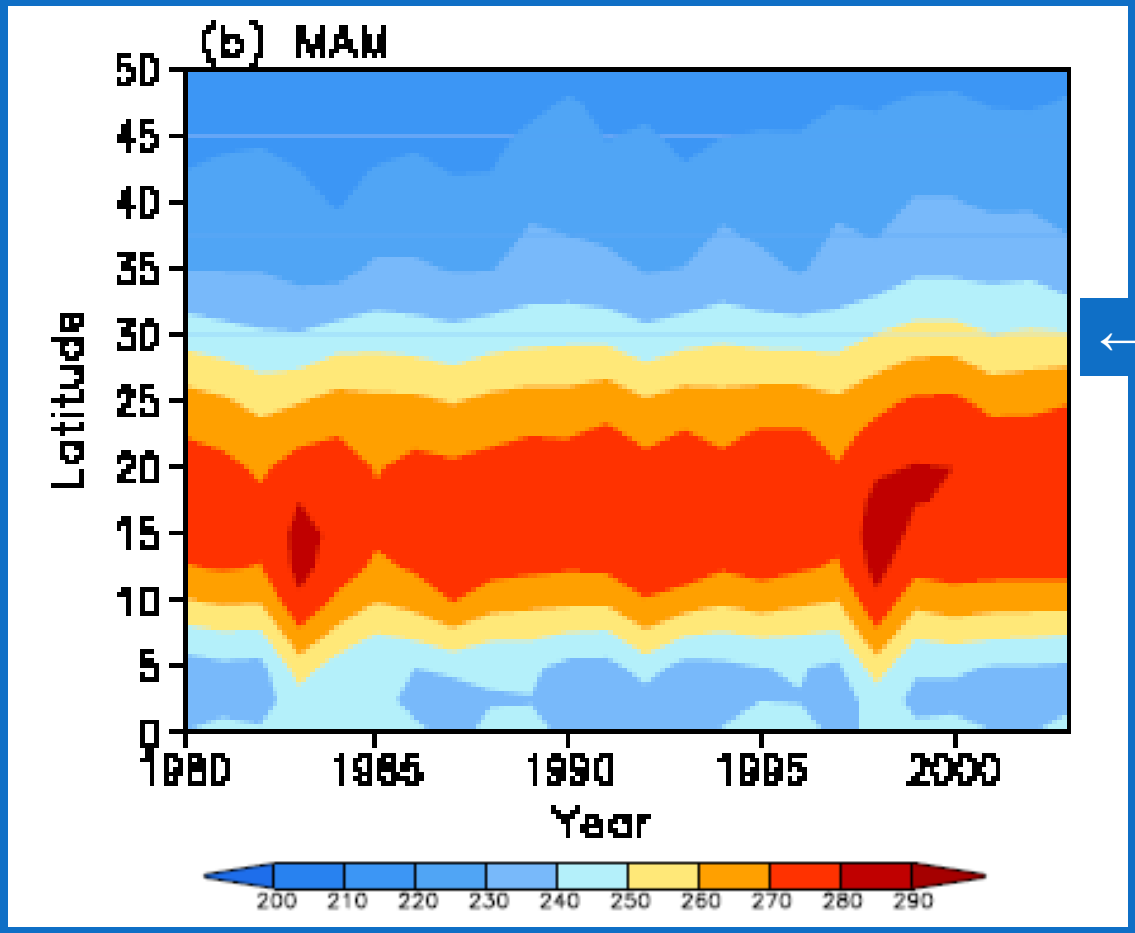
Outgoing Longwave Radiation



Hu and Fu (2007)

Most poleward latitude with zonal mean OLR=250Wm^{-2}

Seasonal and Zonal Mean Time Series Outgoing Longwave Radiation

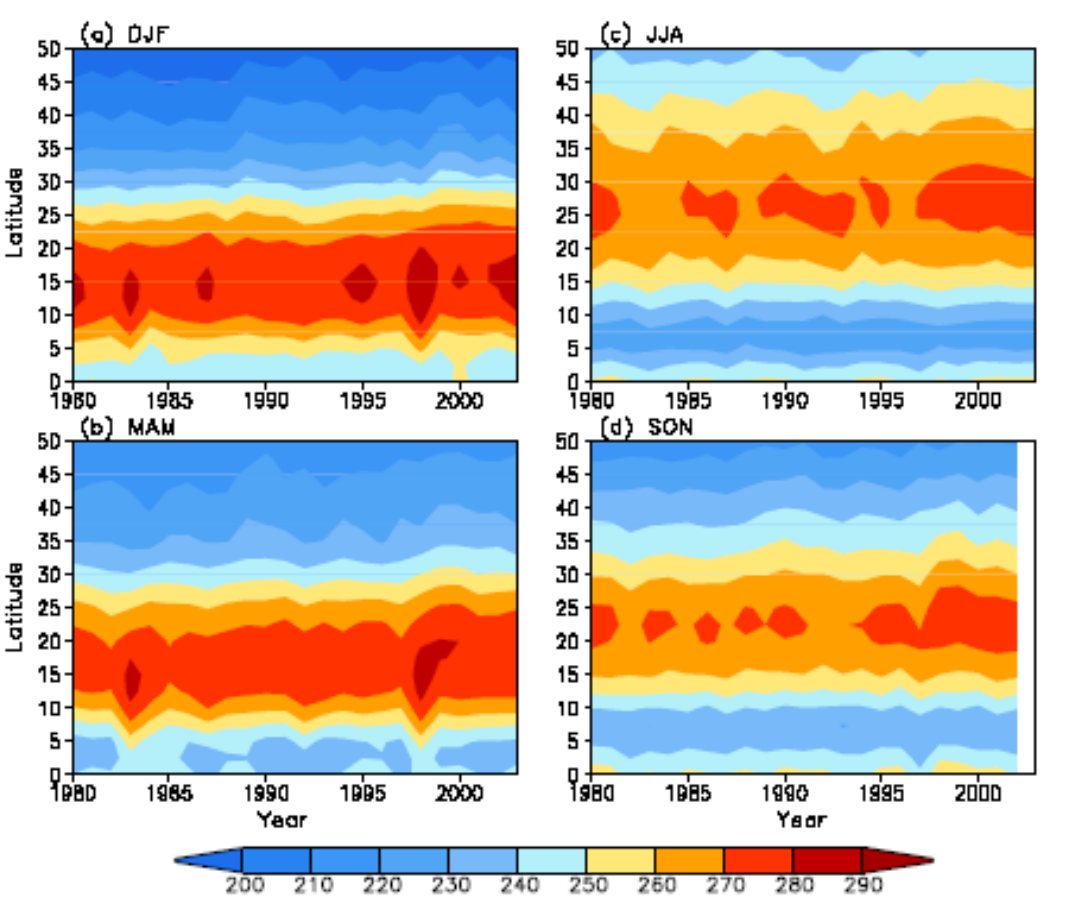


HIRS Pathfinder

←

Hu and Fu (2007)

Seasonal and Zonal Mean OLR Time Series



Total widening 1980-2003

← HIRS Pathfinder 4.5

GEWEX RFA 2.3

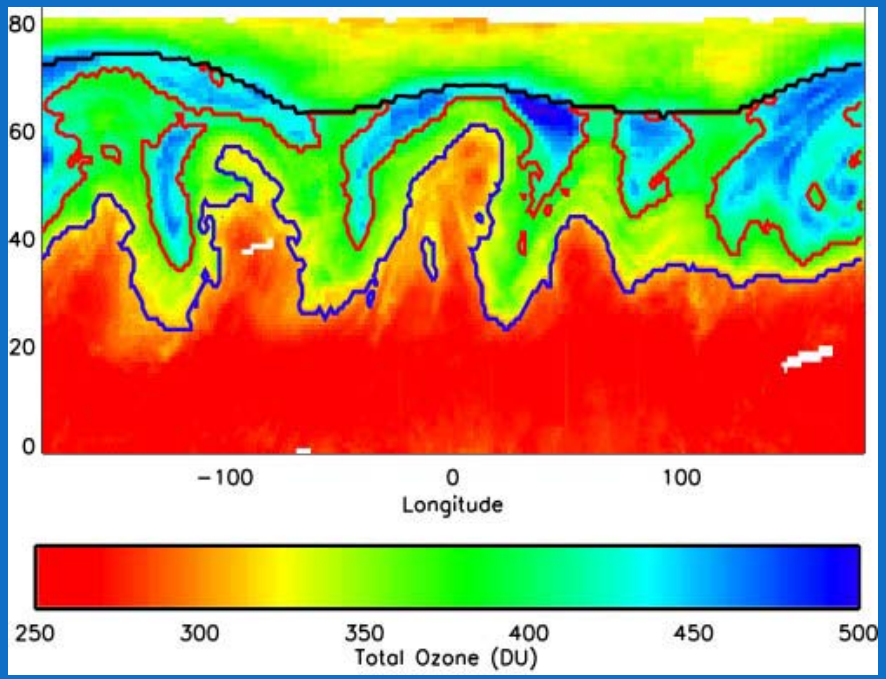
ISCCP 4.0

Little seasonal variation

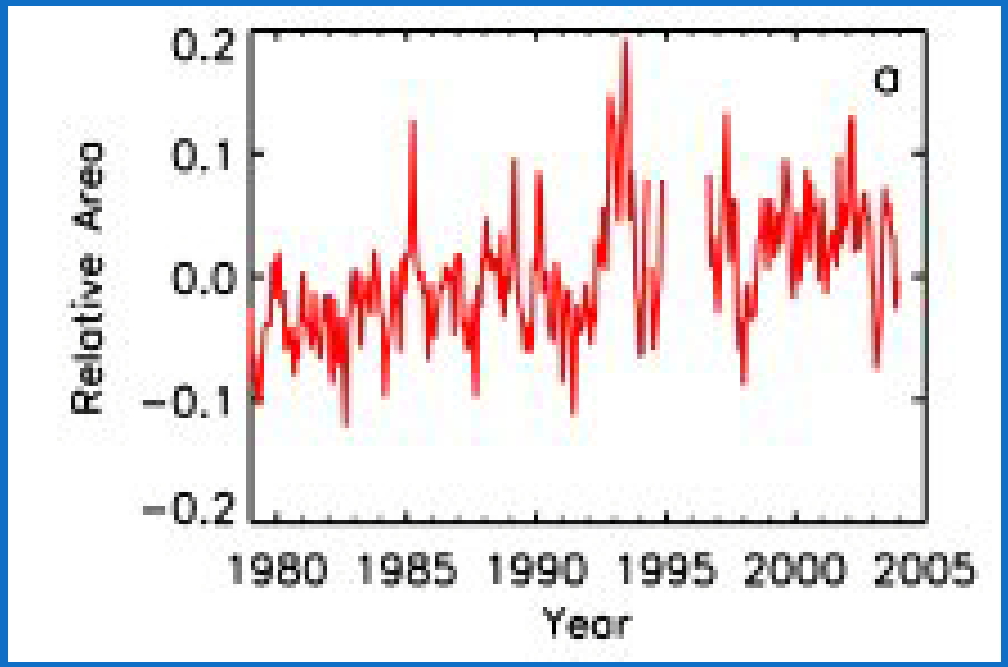
Hu and Fu (2007)

N. Hemisphere Total Ozone

TOMS total ozone March 11th, 1990



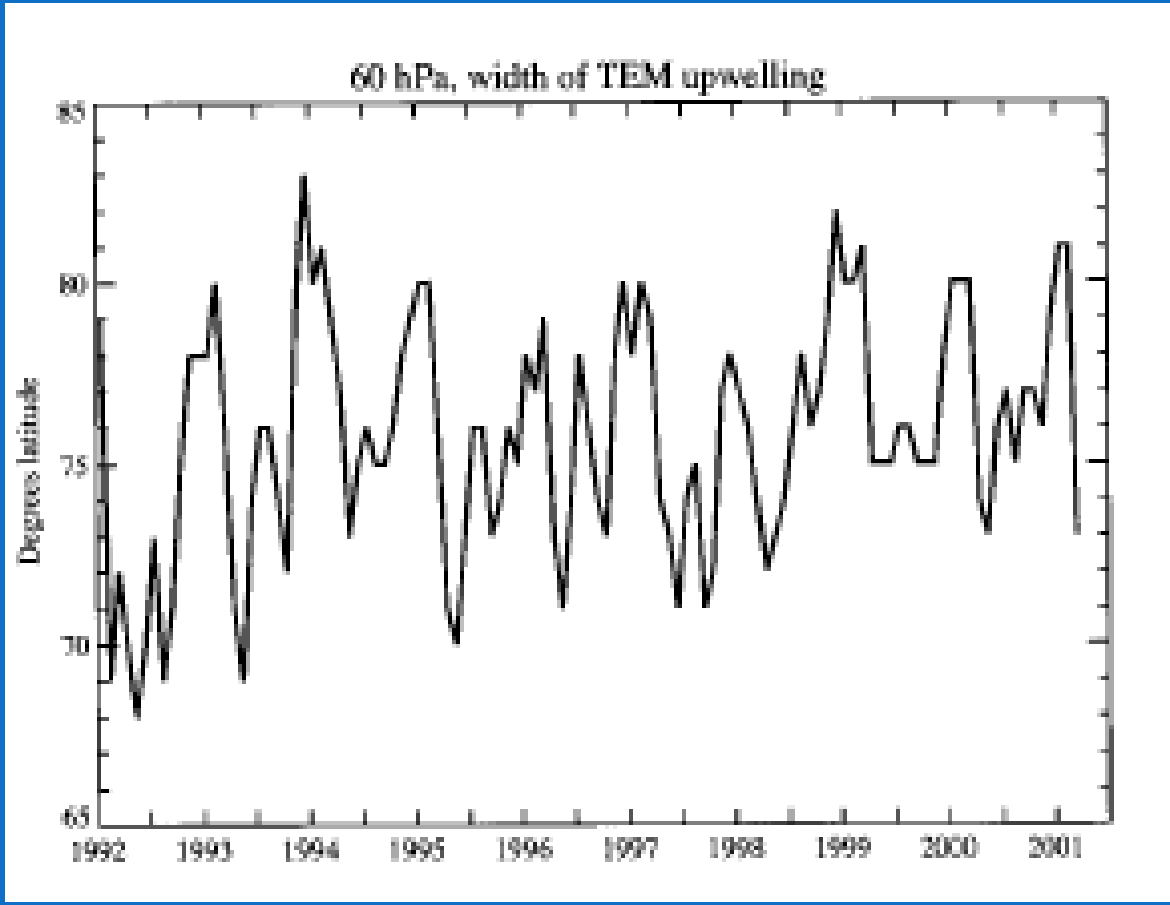
Tropical Area Anomalies



1979-2003 NH tropical expansion ~ 2.7

Hudson et al. (2006)

Stratospheric Residual Circulation



Transformed Eulerian Mean Residual Circulation invoked to explain stratospheric H_2O and CH_4 trends

Rosenlof (2002)

Summary of Observed Trends

TABLE 1 Estimates of tropical widening (in degrees latitude per decade) from observation-based studies

Study	Indicator	Data	Widening
Rosenlof [13]	Tropical upwelling (60 hPa)	Analyses	3.0
Reichler and Held [14]	Tropopause height	Radiosonde	0.4
	Tropopause height	Reanalyses	0.7
Fu et al. [15]	Tropospheric temperatures	MSU	0.7
Hudson et al. [16]	Total ozone	TOMS	1.0 (NH only)
Seidel and Randel [17]	Tropopause height	Radiosonde, reanalyses	1.8–3.1
Hu and Fu [59]	Outgoing longwave radiation	Various satellite sensors	1.5
	Mean meridional circulation	Reanalyses	1.0
Archer and Caldeira [92]	Jet stream separation	Reanalyses	0.3
Seidel et al. [23]	Jet stream separation	Reanalyses	1.0

Reichler (2009)

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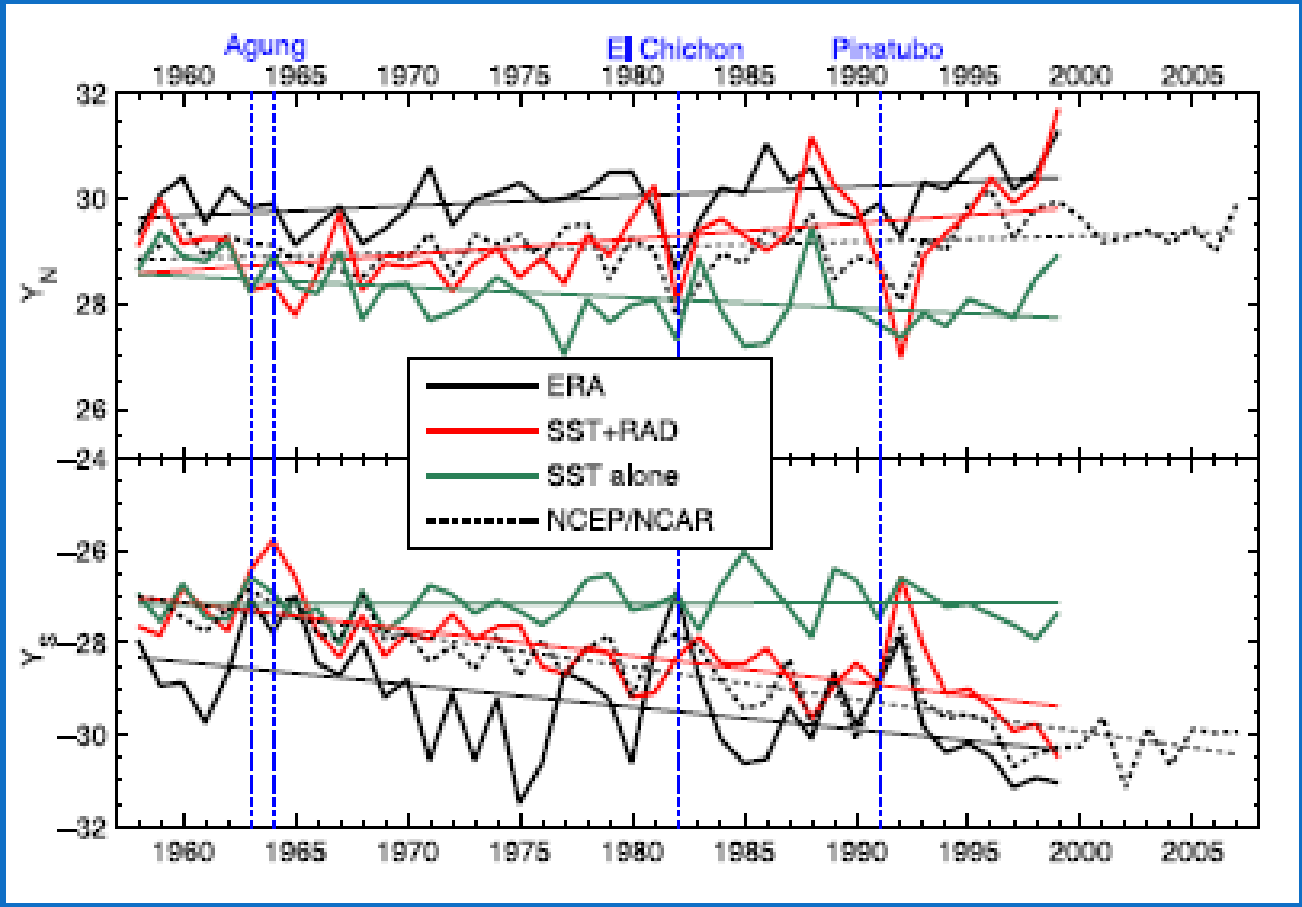
Tropical Width (Tropopause Height) in GFDL AM2.1 Simulation

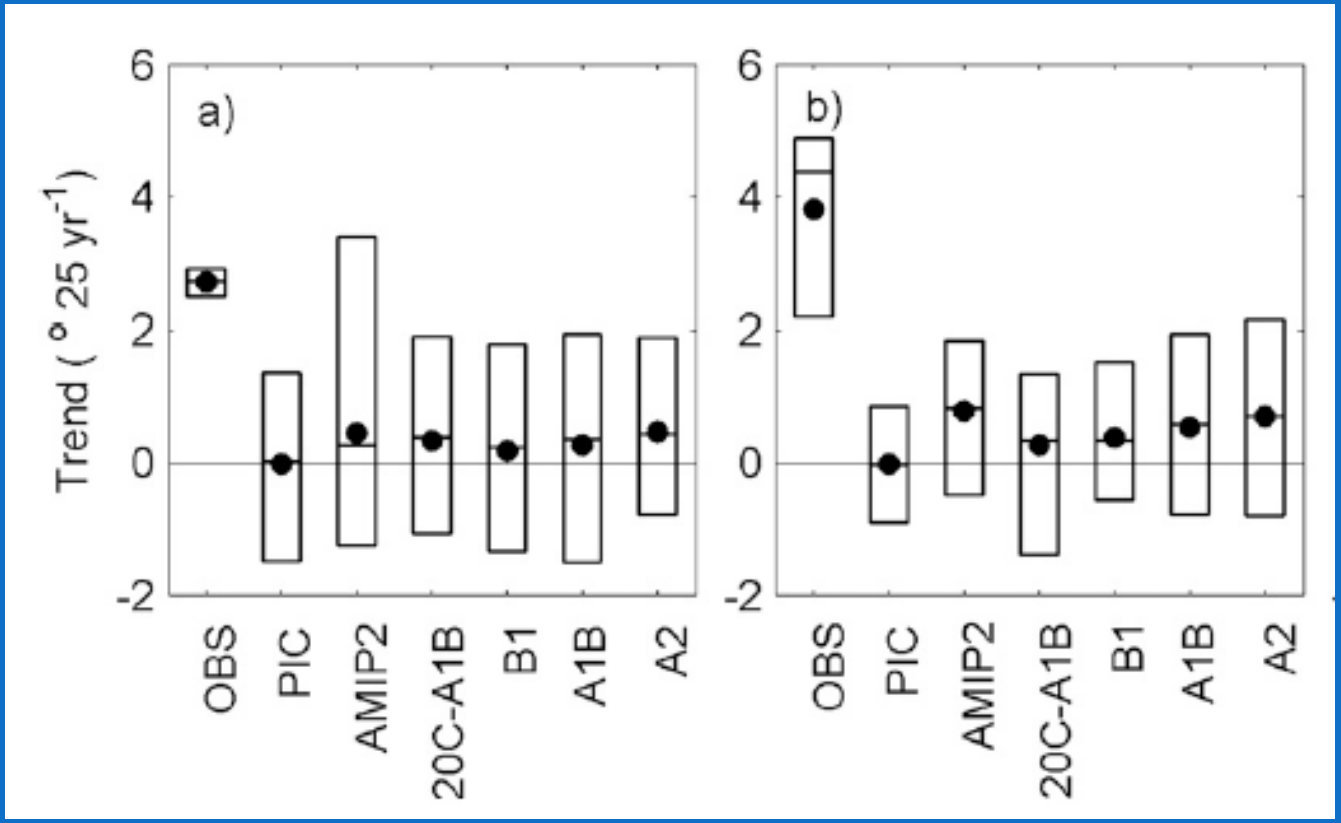


Natural forcings (SST and sea ice) alone do not explain widening.

Lu, Deser, Reichler (2009)

GCM Simulated Trends

OLR-based width streamfunction-based width



PIC = pre-industrial control ~ natural variability

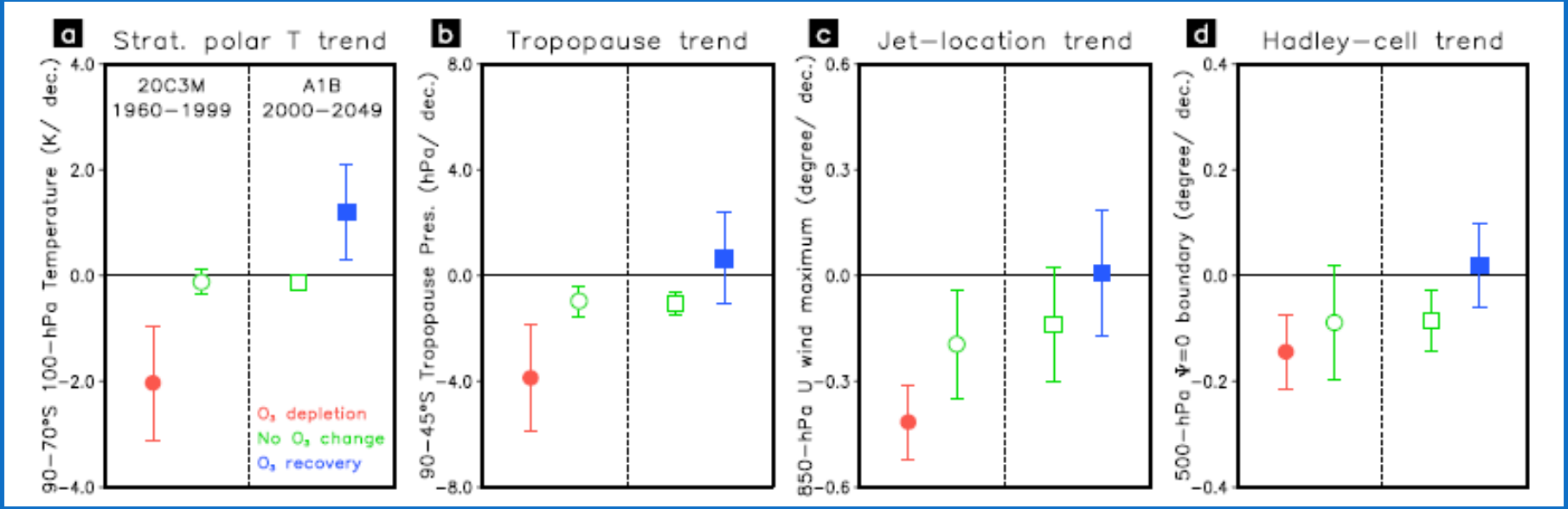
AMIP2 and 20C-A1B = forced 20th century forcings

B1, A1B, A2 = future

ALL smaller than observed 20th century trends

Johanson and Fu (2009)

Role of Antarctic Ozone Hole



Past Future

Ozone recovery reverses some trends in IPCC AR4 GCM runs

Son et al. (2009)

Multiple Forcings, Multiple Models, Multiple Measures of Tropical Width

- Lamarque and Solomon (2010)
  - Coupled chemistry climate model forced by sst, ghg, halocarbons shows
  - Different forcings cause changes in different tropical width metrics (ozone, tropopause, winds)
- Lorenz and DeWeaver (2007)
  - GCM IPCC runs w/CO_2 increase and simple runs with raised tropopause
  - Poleward shift of jets associated with increase in tropopause height

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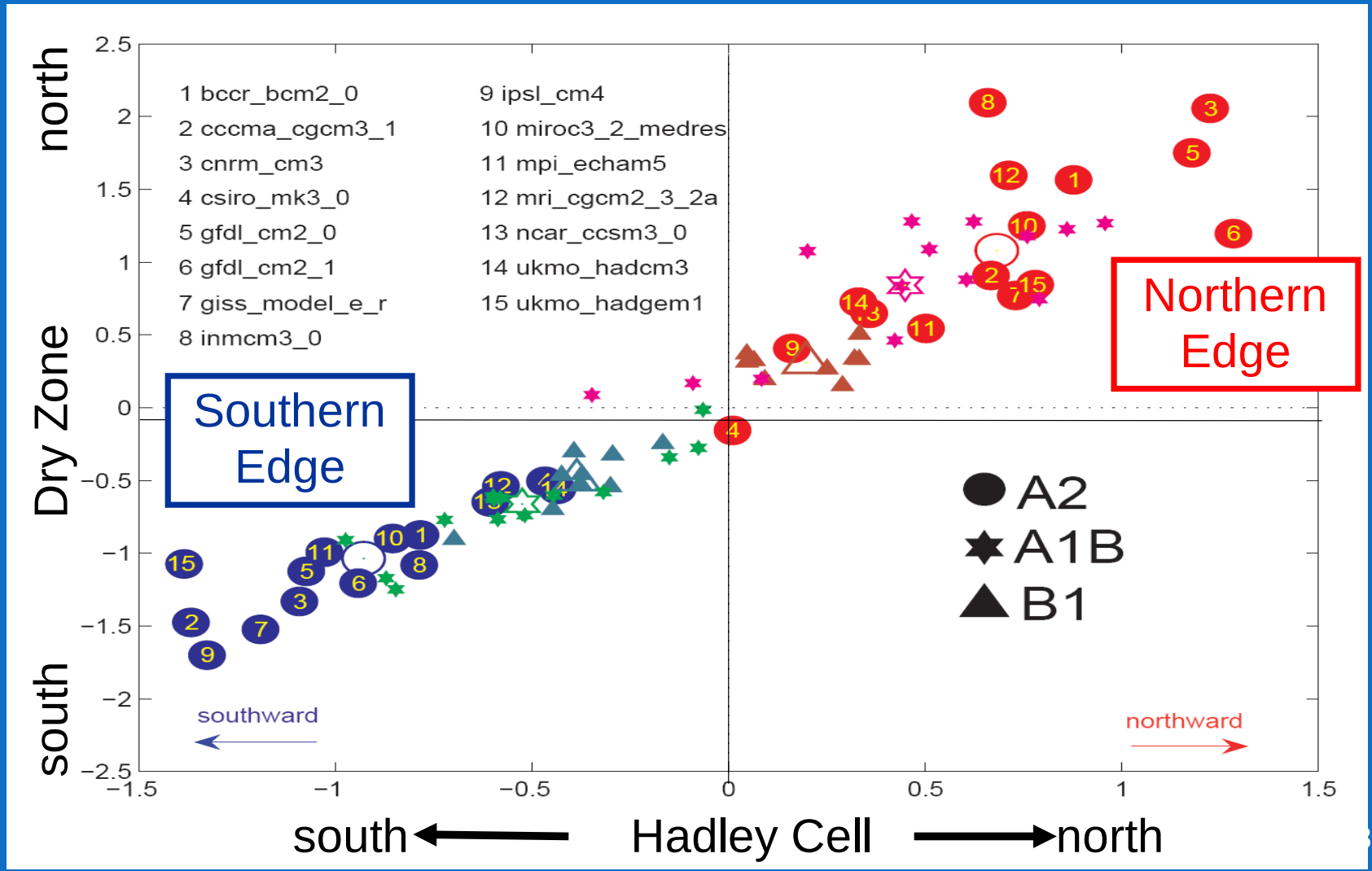
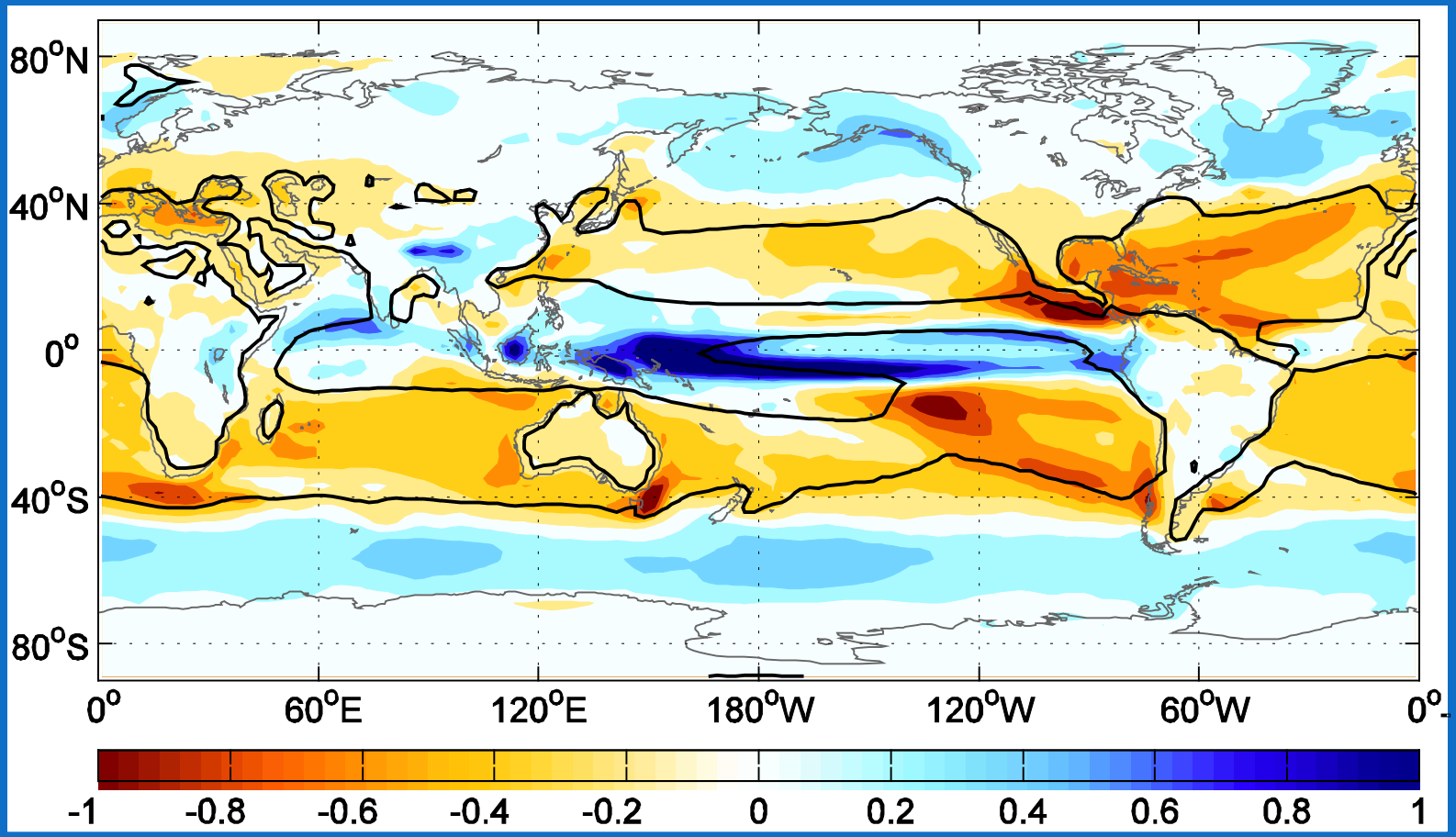
21st Century Predicted Widening

Ensemble mean ~2 latitude

Lu et al. (2007)



Predicted Hydrological Response



P minus E (mm/day) change from 2001-2020 to 2081-2100
in ensemble of IPCC AR4 runs; A2 emissions scenario

Lu et al. (2007)

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Outstanding Questions

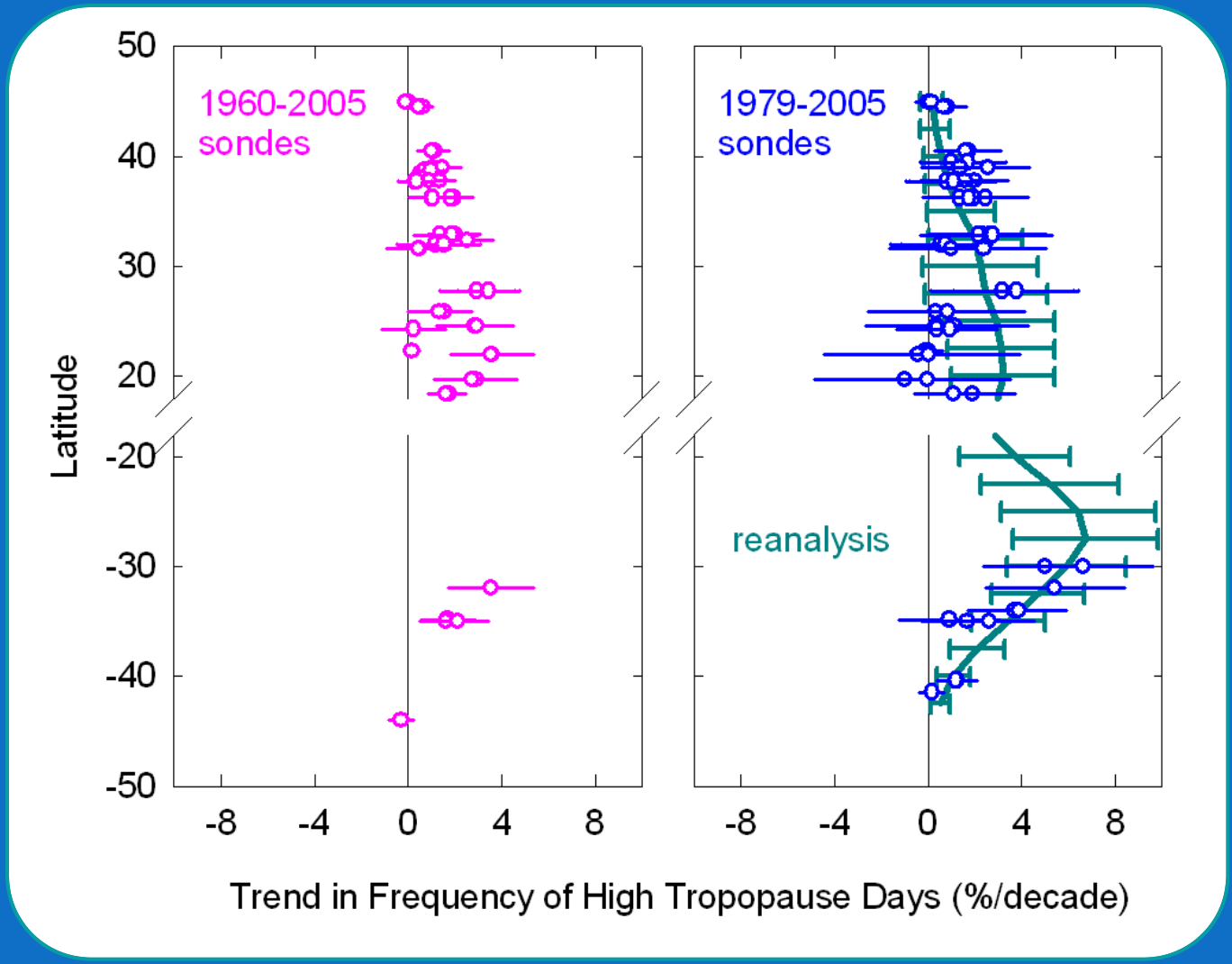
- Observed widening
  - How robust are estimated widening rates?
  - What is seasonal, regional structure of changes?
  - Have trends continued since published studies?
- Causes of widening
  - Can forcings (and natural variability) be sorted out (with formal detection and attribution)?
  - Are changes related to changes in climate modes of variability?
- Implications of widening
  - How are UTLS changes connected with surface and stratospheric climate?
  - What are likely future changes?

Take-home messages

- Many ways to measure tropical width
- Observational evidence exists for expansion since 1979, but not consistent
- Variety of models, with variety of forcings, do not fully reproduce observed changes
- Future evolution uncertain, but ozone recovery may reverse some changes
- Many unresolved questions remain

EXTRAS

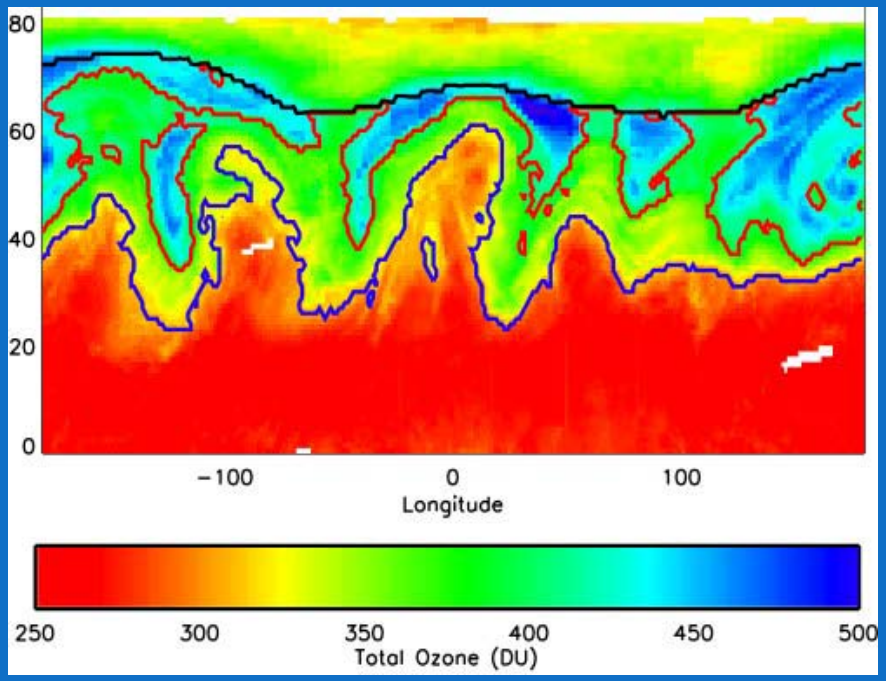
Tropopause in Subtropics More Frequently Tropical



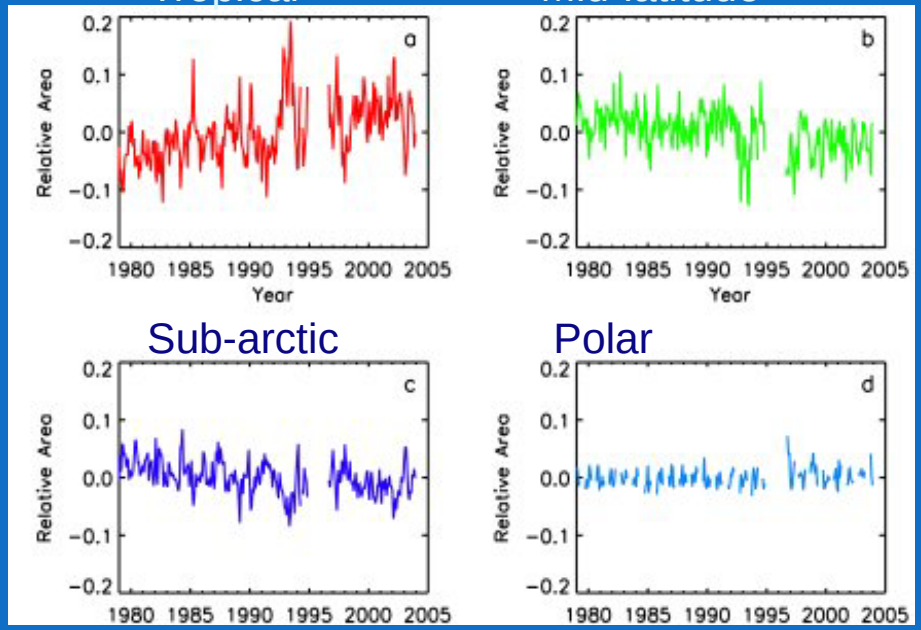
Seidel and Randel (2007)

NH Total Ozone

TOMS total ozone March 11th, 1990



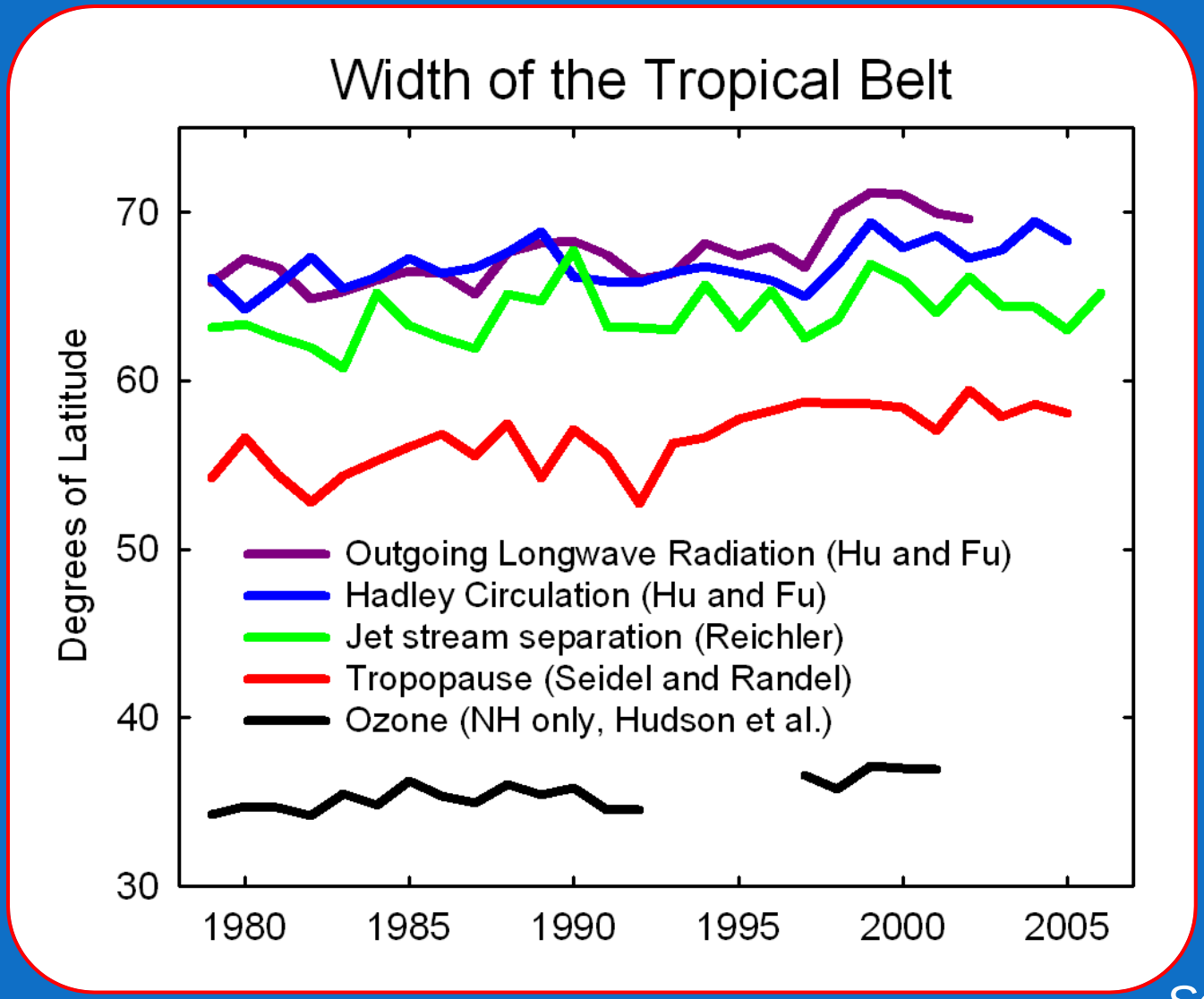
Monthly mean relative areas



1979-2003 NH tropical expansion ~ 2.7

Hudson et al. (2006)

Comparison of Observations



Seidel et al. (2008)

Seager et al 2003

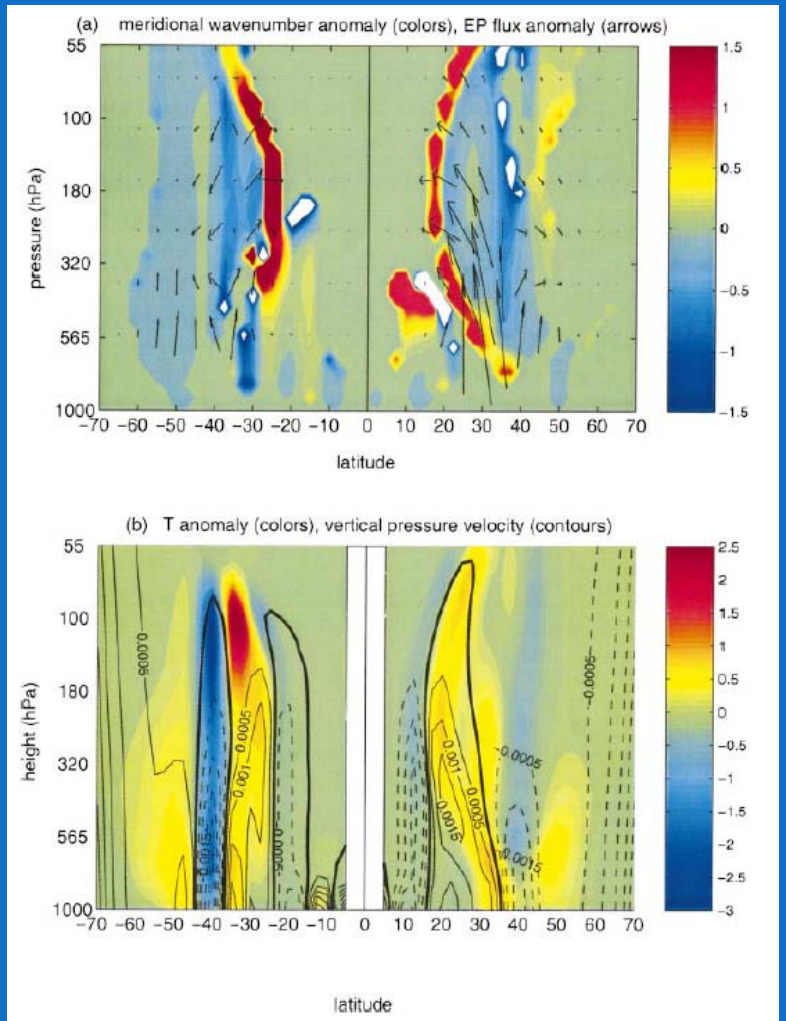


FIG. 14. (a) The anomaly in meridional wavenumber (El Niño minus the climatology, units of yr^{-1}, colors), and the anomalous EP fluxes (arrows). (b) The anomalous mean vertical pressure velocity (Pa s^{-1}, black contours, negative values dashed, zero line thick) and the corresponding temperature anomalies (°C, colors, see text for details).

Johanson and Fu (2009)

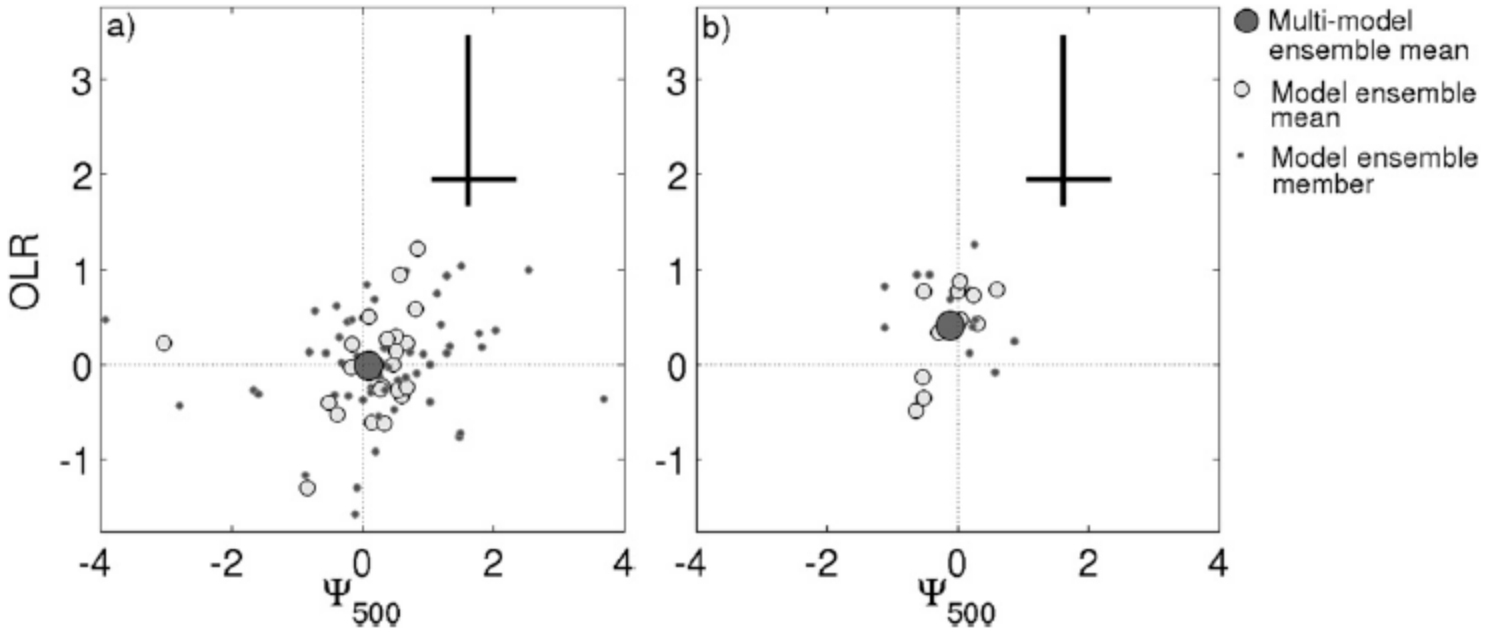


FIG. 5. Widening of the Hadley cell from 1979 to 1999 [°(lat) (21 yr)$^{-1}$] from ψ_{500} and OLR in observations and (a) GCM simulations of 20C and (b) AMIP2. The range of observed widening from individual datasets is given by the crossbars, which are centered at the multidataset mean widening. Also shown is the multimodel ensemble mean widening (large circles), ensemble mean widening from each individual model (medium circles), and widening from each model ensemble member (small circles). Only models providing output for both ψ_{500} and OLR are included here.

Son et al. (2009)

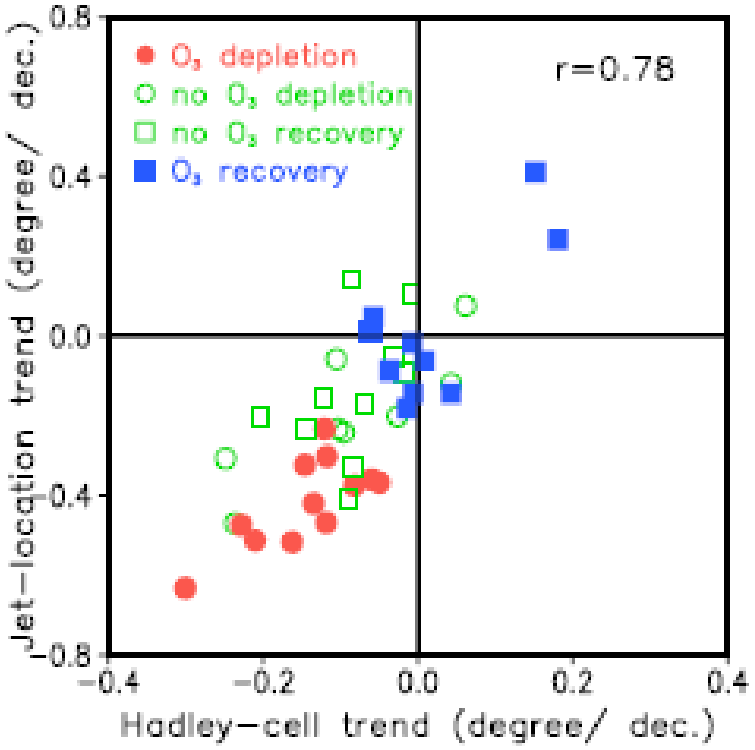


Figure 2. Trend relationship between the location of westerly jet and the poleward boundary of the Hadley cell in the SH summer. Color code is identical to one in Figure 1, and negative values denote the poleward shift of westerly jet and poleward expansion of the Hadley cell.