A multi-diagnostic intercomparison of tropical width time series using models, reanalyses, and satellite observations

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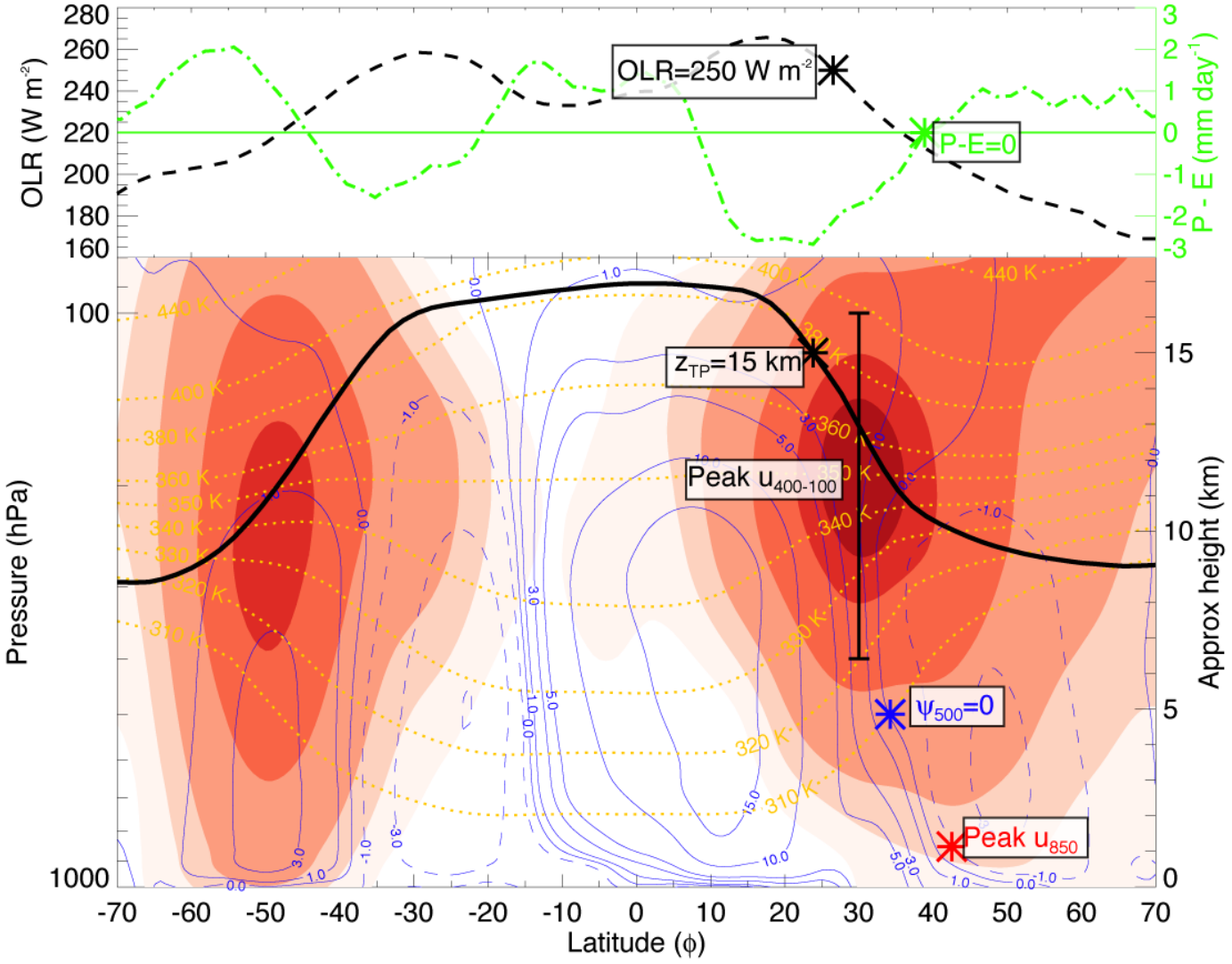
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

Motivation

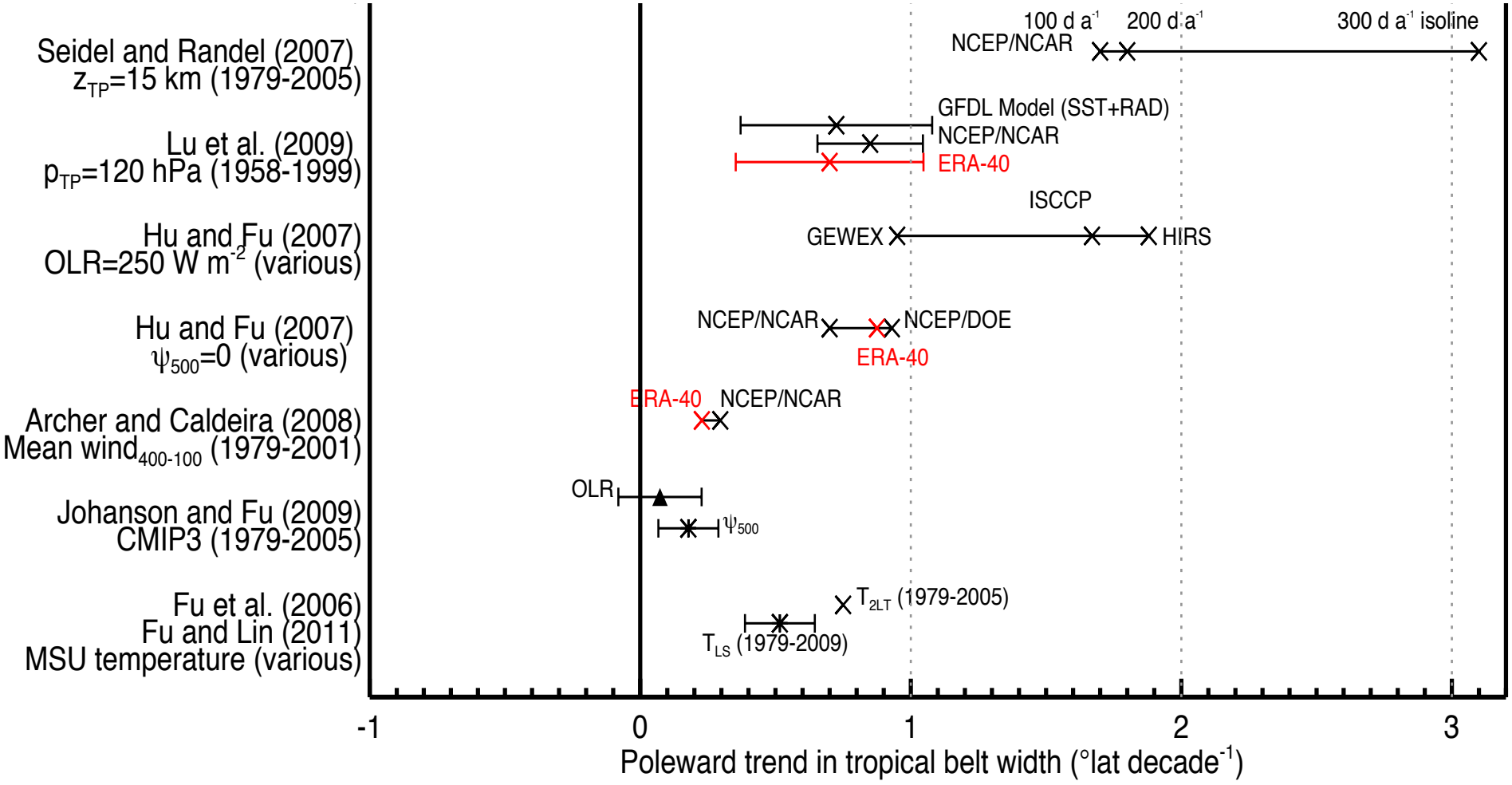
- Evidence of atmospheric circulation changes, and their poleward migration (tropical widening)
  - Potential impacts on surface climate, atmospheric composition
  - Possible drivers: GHGs, O_3, aerosols
- Numerous diagnostics of "tropical width"
  - 0.2° - 3° decade^{-1}
  - Models show less widening than reanalyses
- Do reanalysis trends agree?

The zonal mean atmosphere



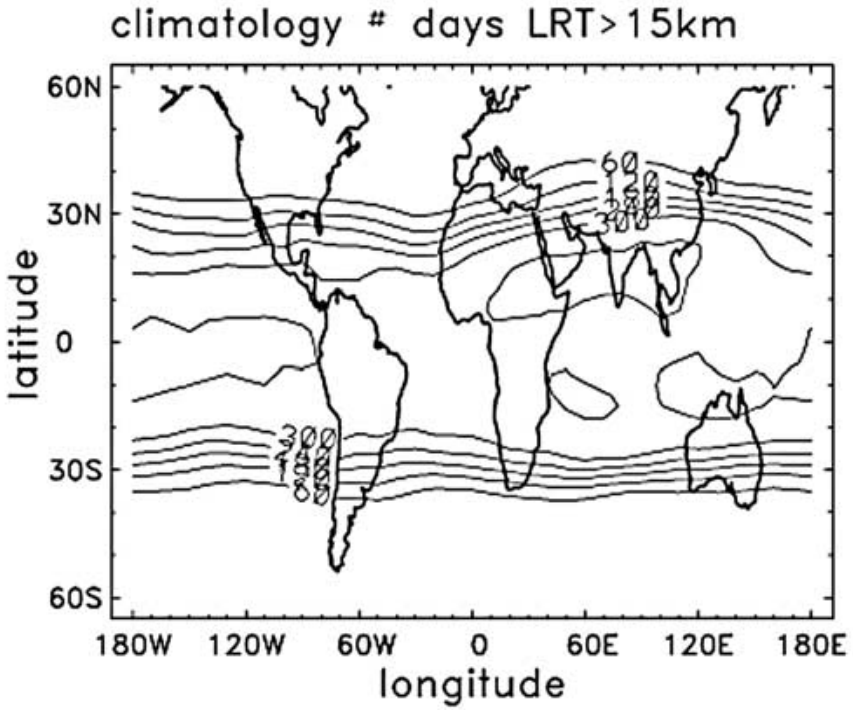
Davis and Rosenlof, J. Clim, 2012

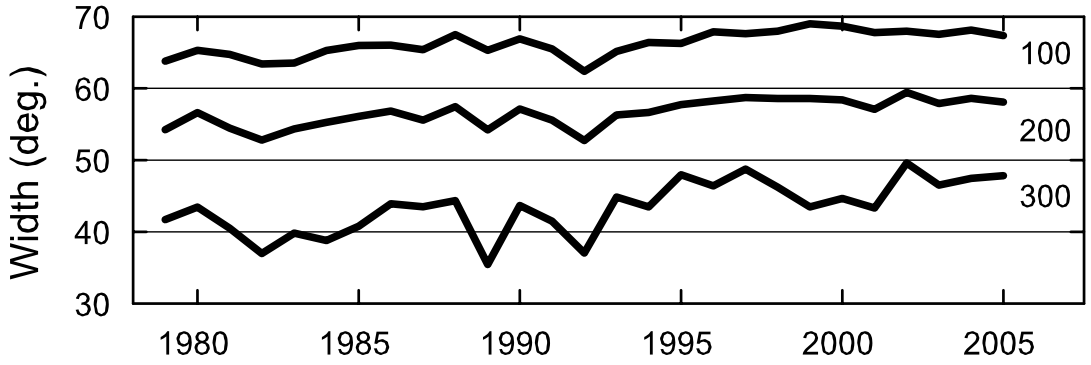
Previous widening estimates



Davis and Rosenlof, J. Clim, 2012

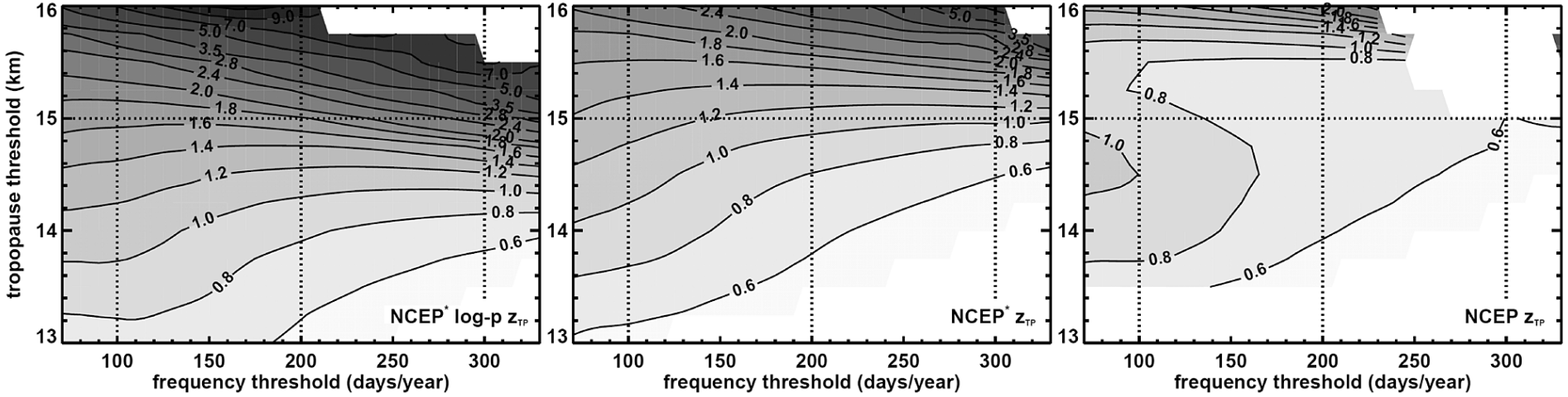
Previous work - tropopause





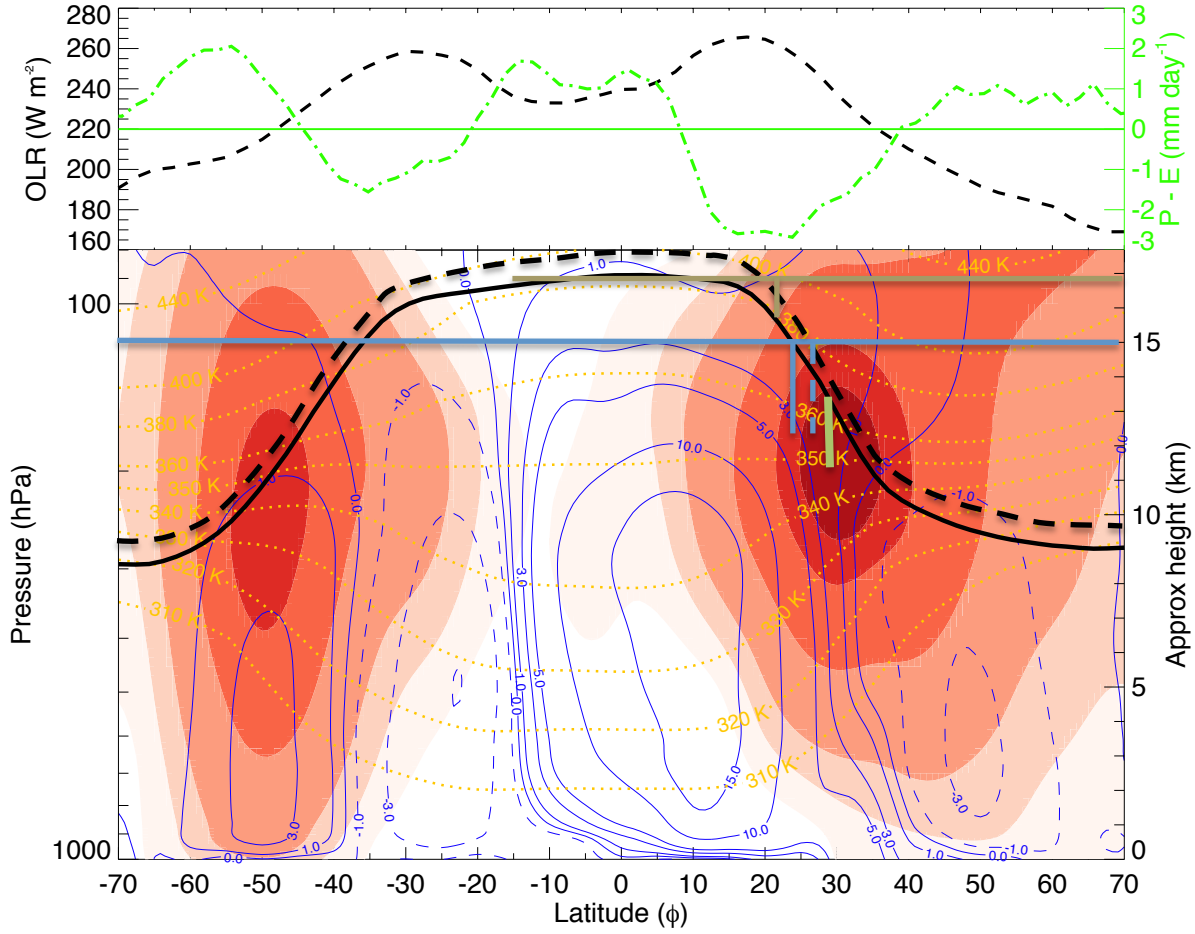
From Seidel and Randel, JGR, 2007

Tropopause metrics – sensitivity



Birner, JGR, 2010

Alternative tropopause metrics



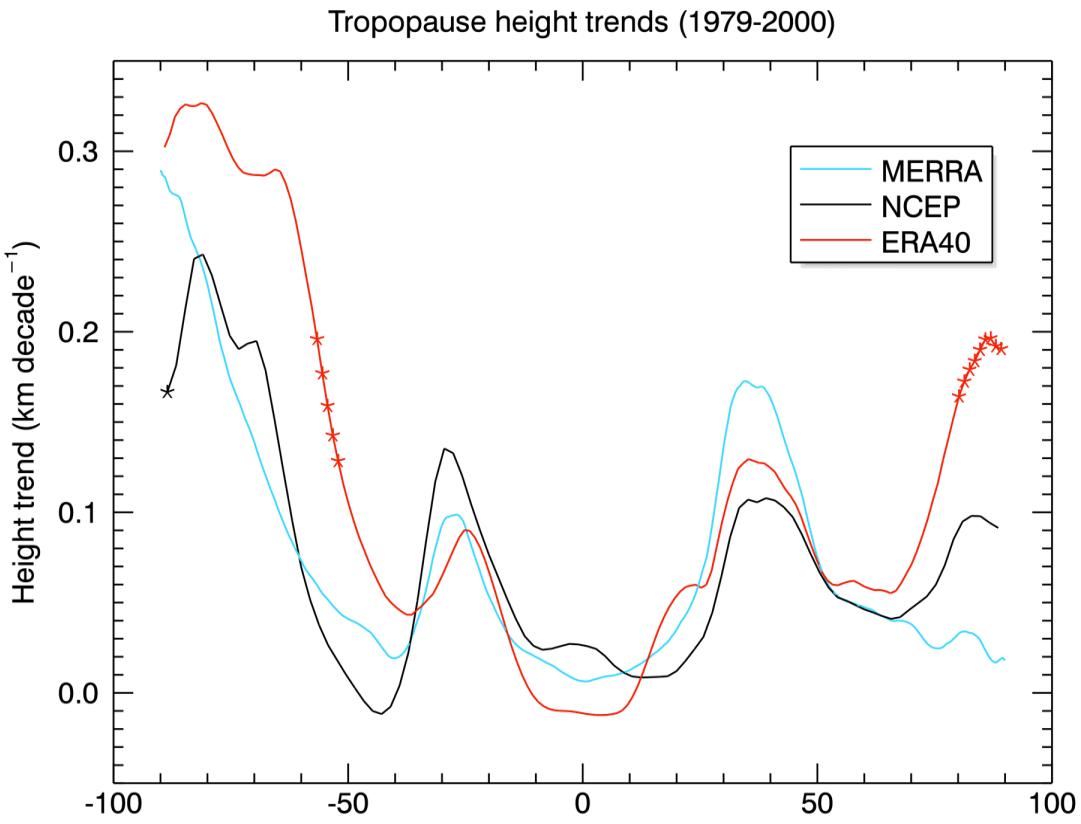
Δz_{TP}=1.5 km

z_{TP}=15 km

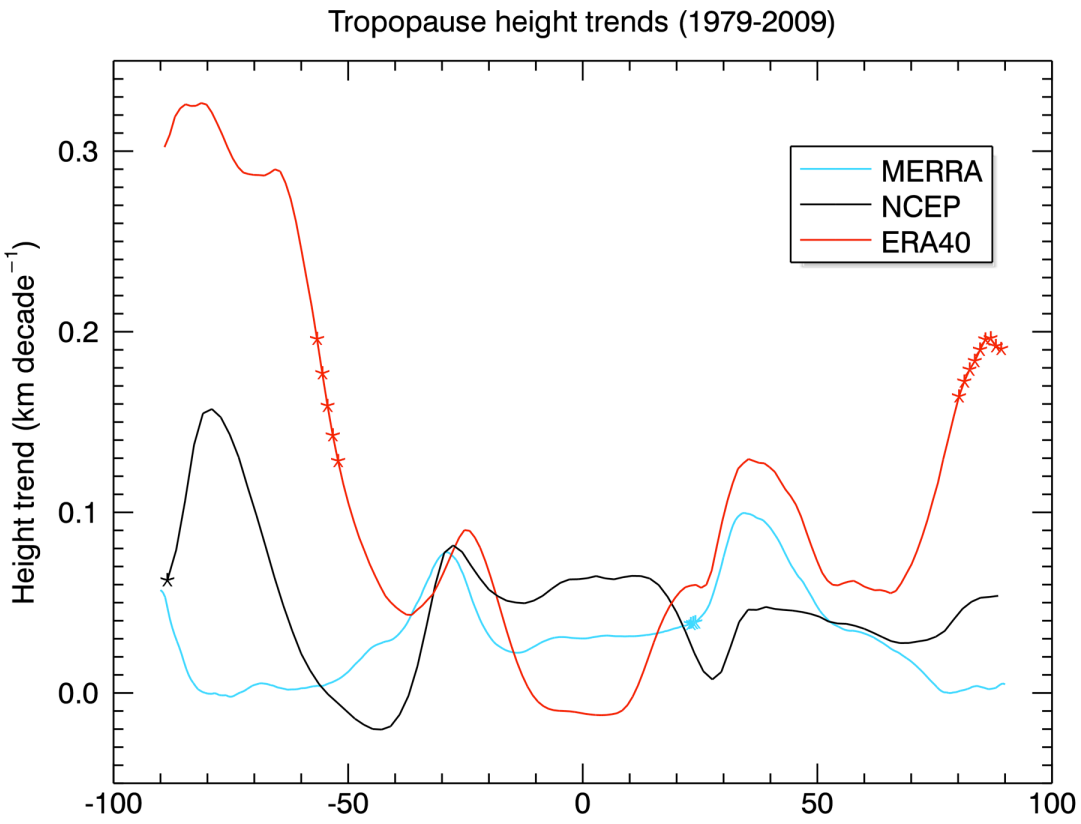
Peak $\frac{\partial z_{TP}}{\partial \phi}$

See also Birner, JGR, 2010

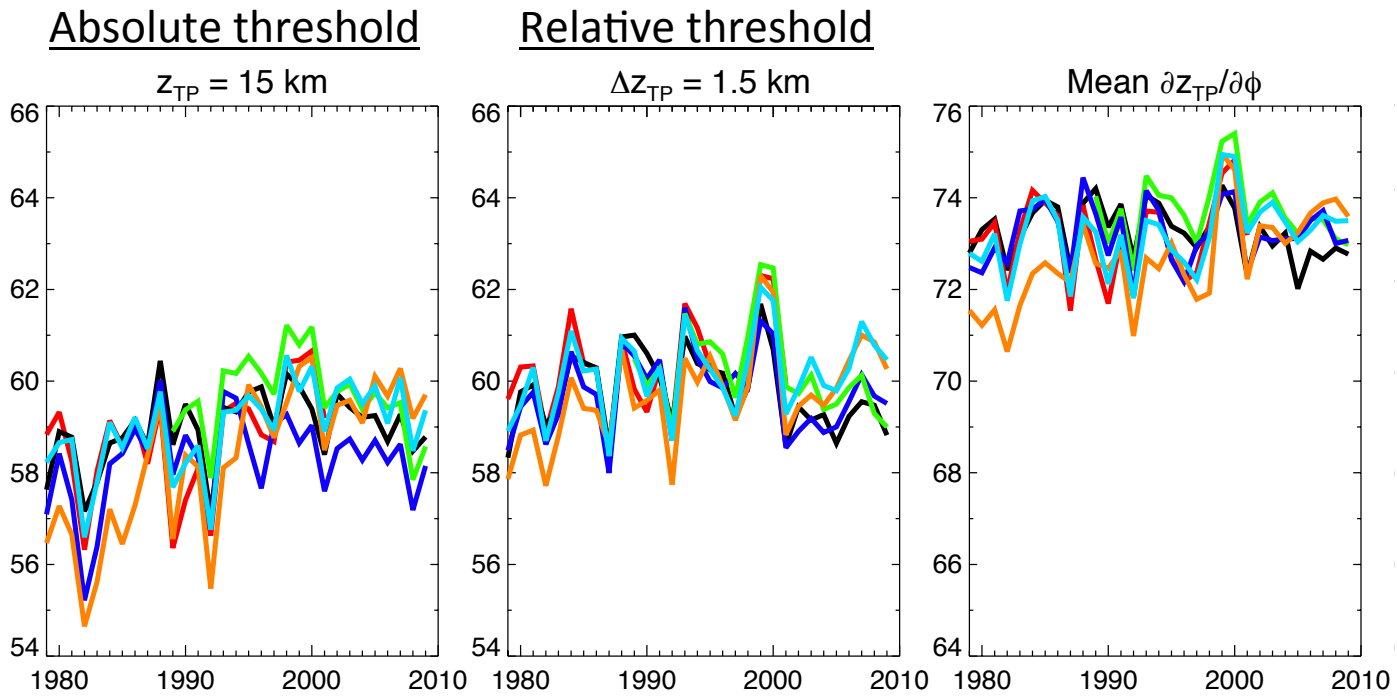
Tropopause height trends



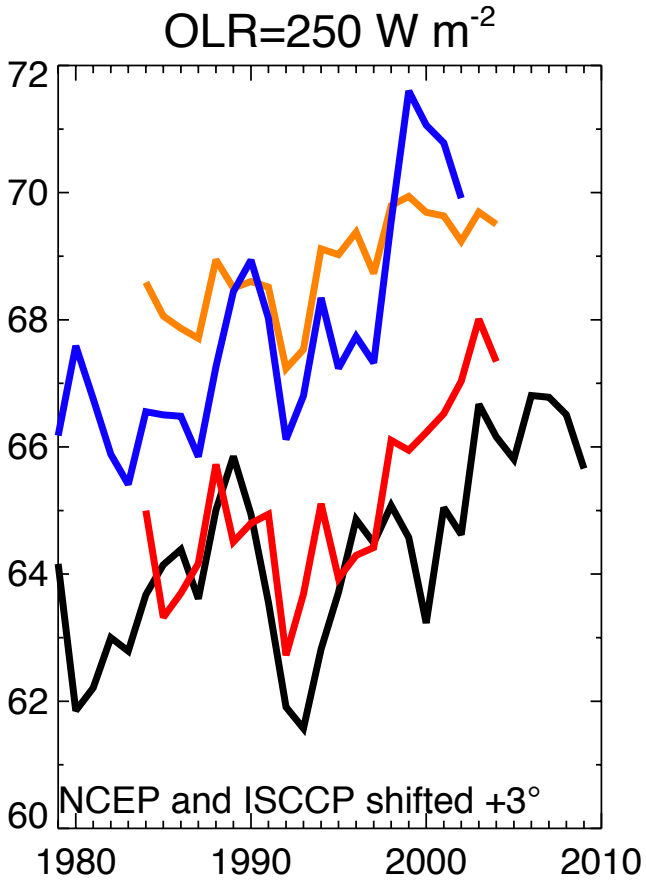
Tropopause height trends



Alternative tropopause metrics

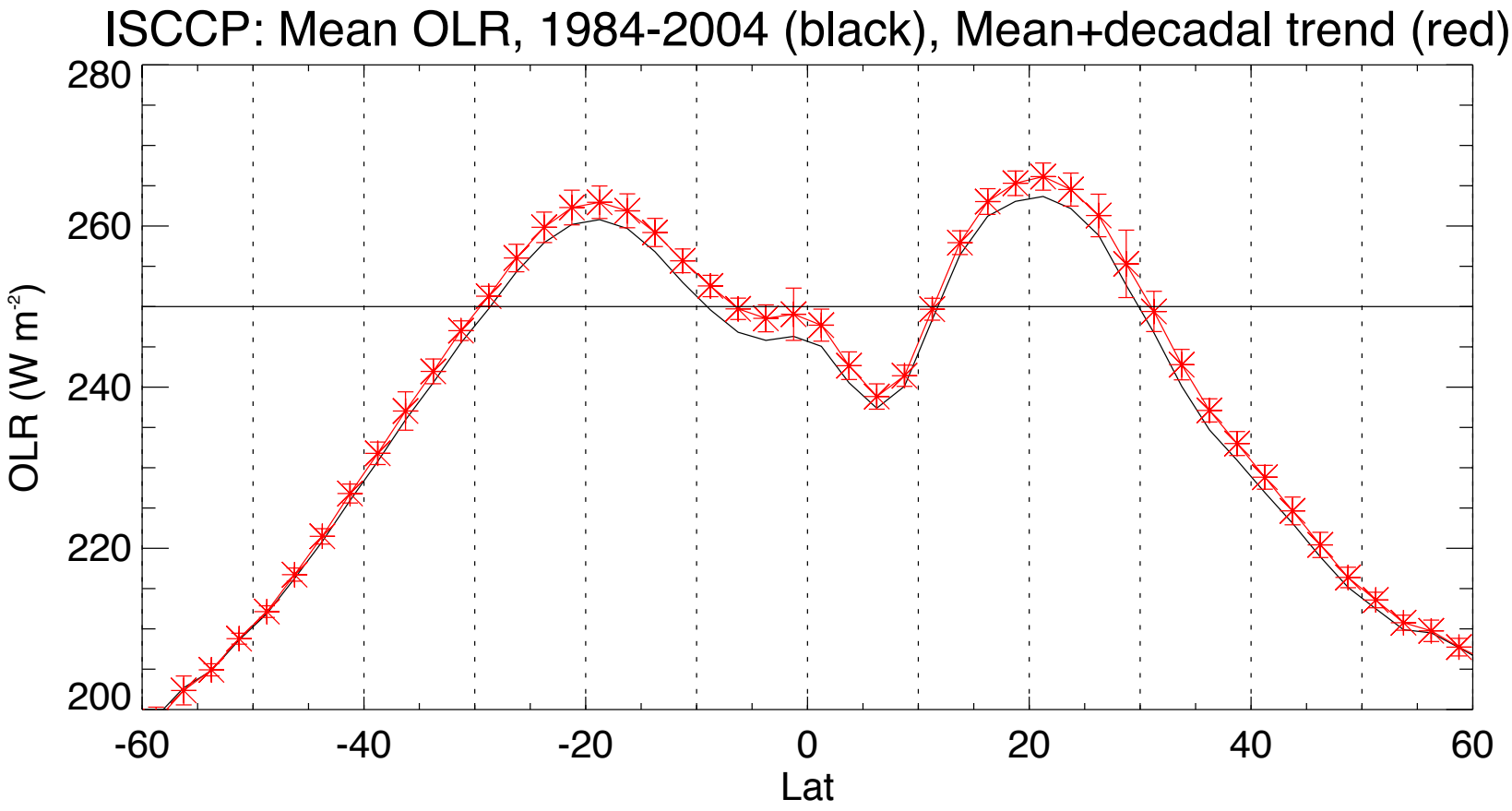


OLR-based widening

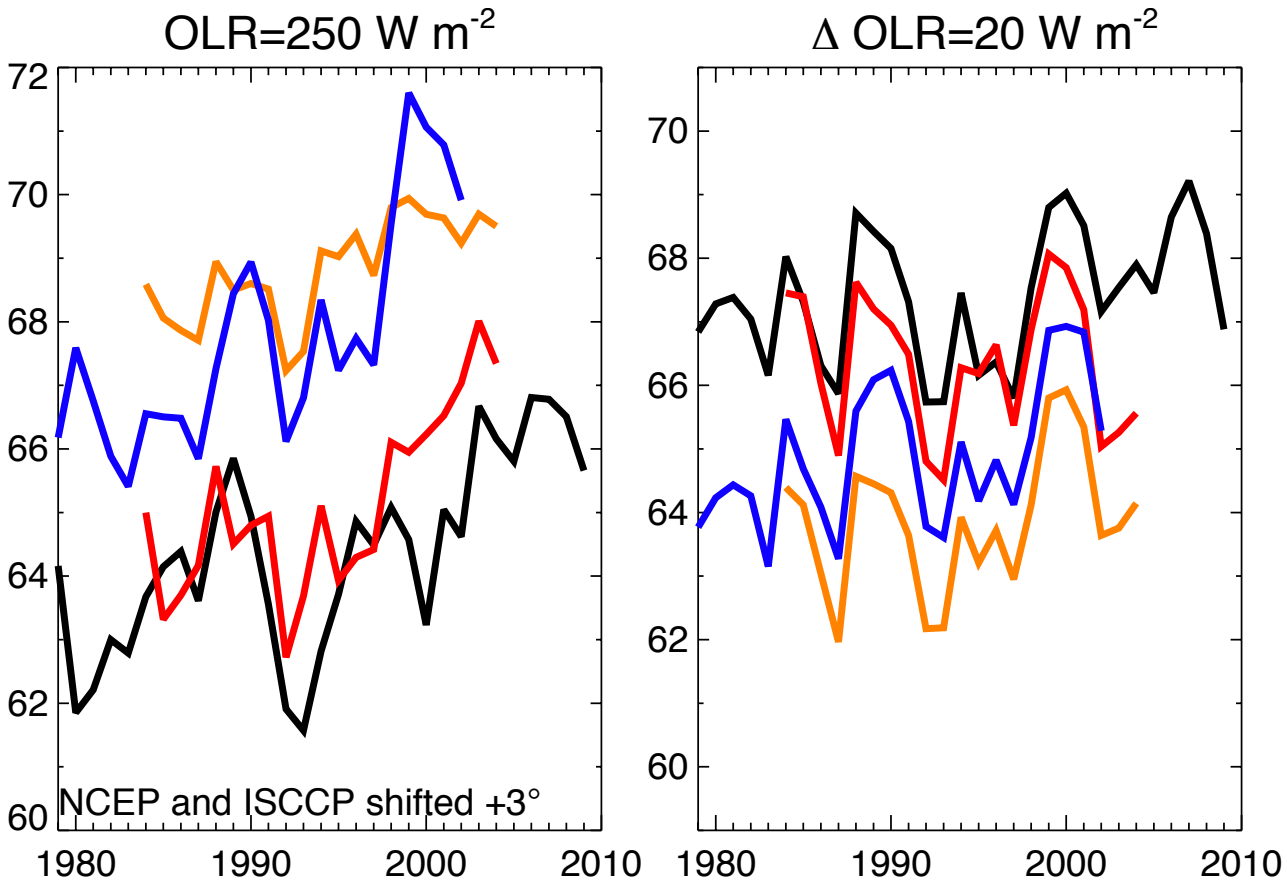


NCEP
ISCCP
GEWEX
HIRS

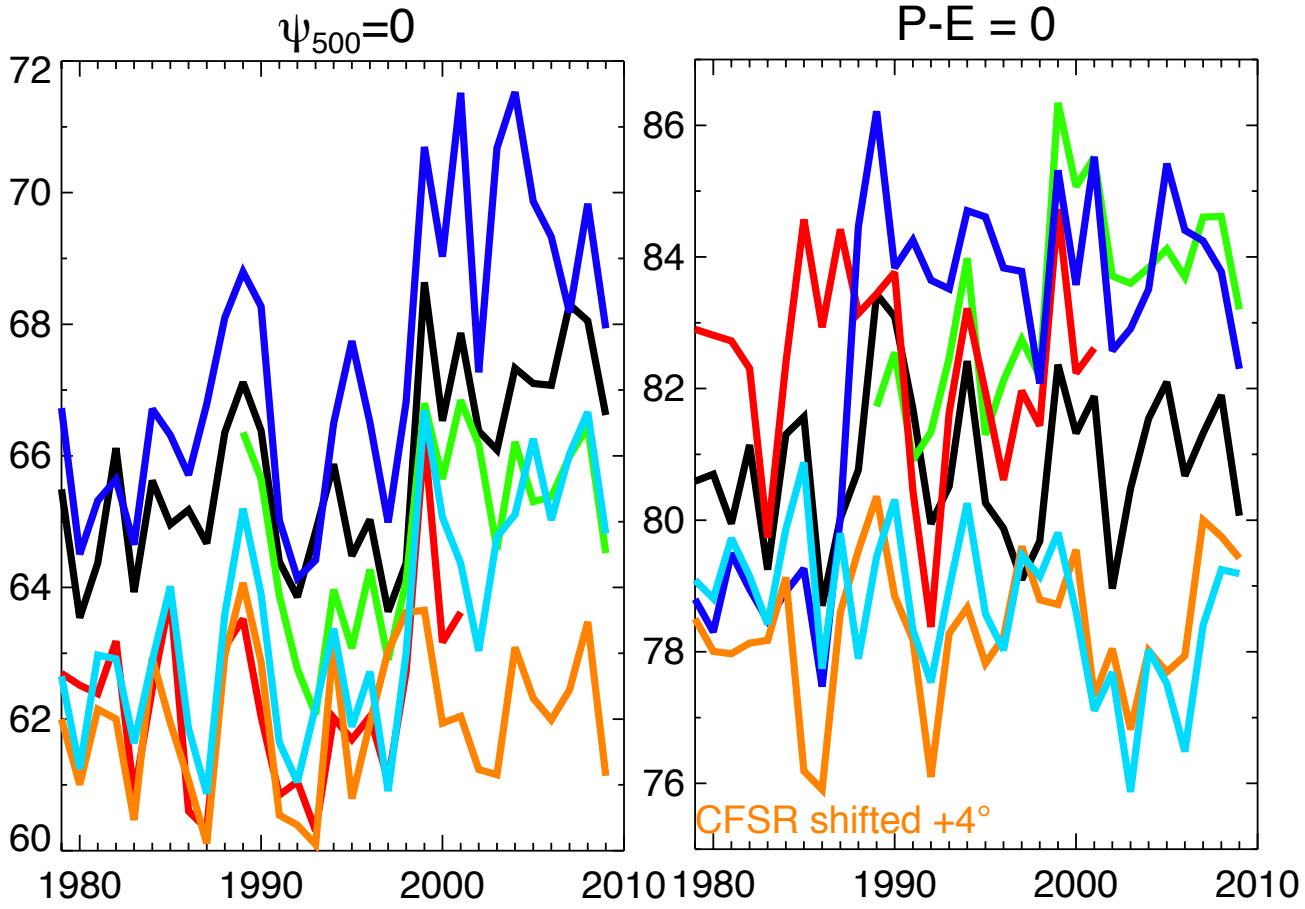
OLR trend example



OLR-based widening

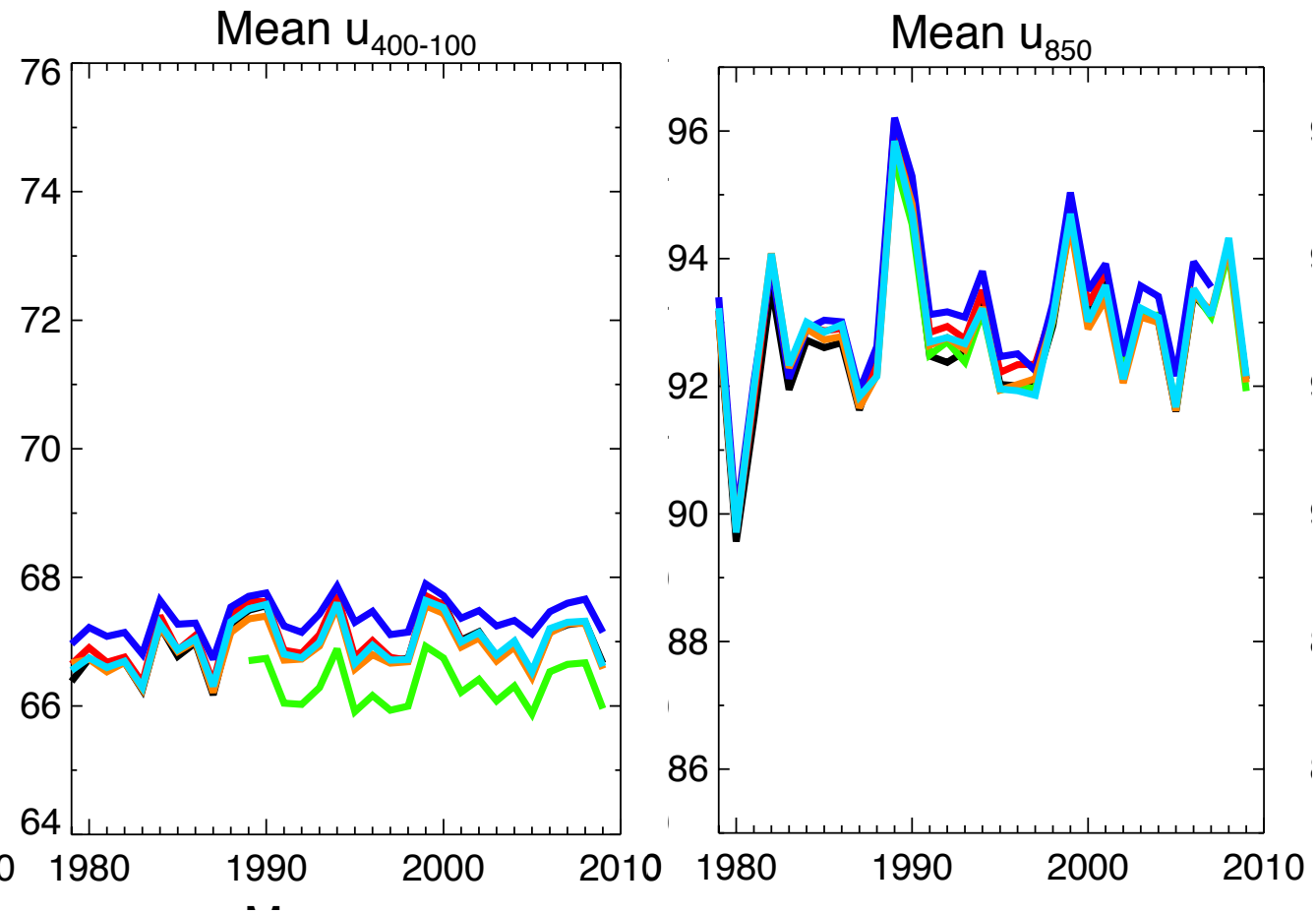


Hadley-cell metrics



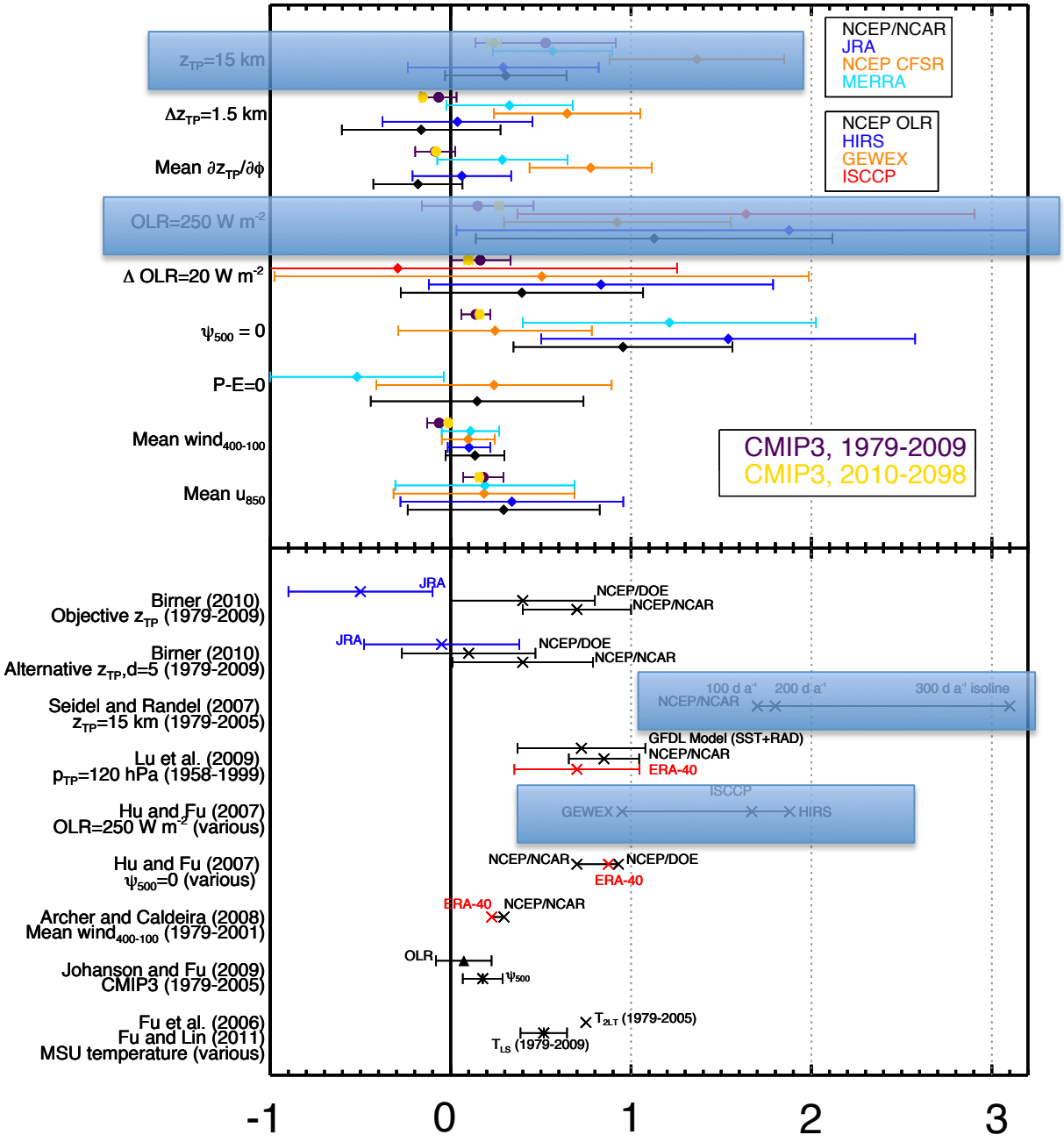
NCEP/NCAR
NCEP CFSR
ERA-40
ERA-Interim
JRA
MERRA

Wind-based metrics



NCEP/NCAR
NCEP CFSR
ERA-40
ERA-Interim
JRA
MERRA

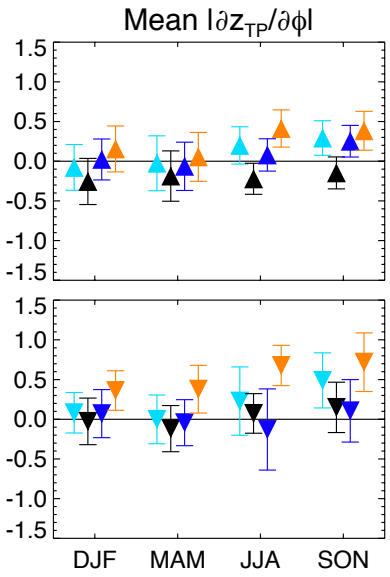
Global tropical width trends, ° latitude decade^{-1}

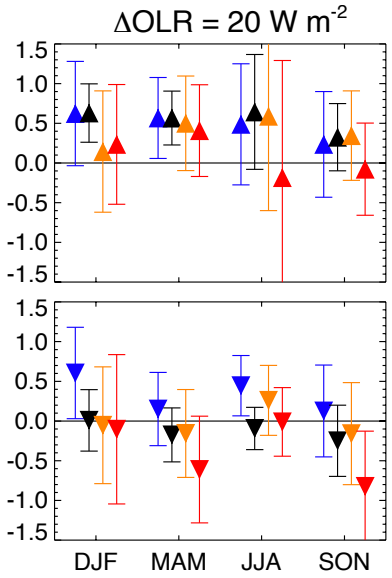


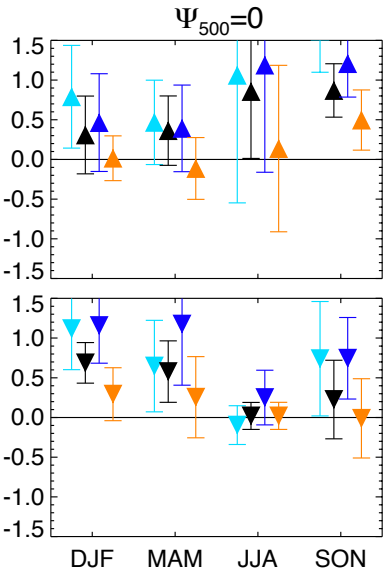
Conclusions

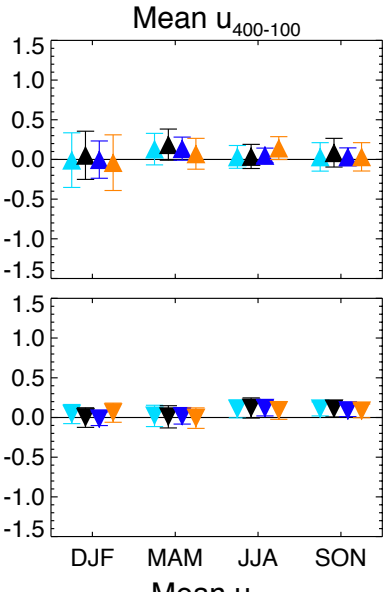
- Tropical widening trends based on absolute thresholds are biased high
  - OLR, tropopause
- Reanalyses in good agreement in zonal-wind metrics, not others
- Trend range 0 – 1.5° dec^{-1}
  - Most trends are positive, but insignificant
  - Largest reanalysis trends in ψ_{500} (1-1.5° dec^{-1})
  - Largest disagreement in ψ_{500}

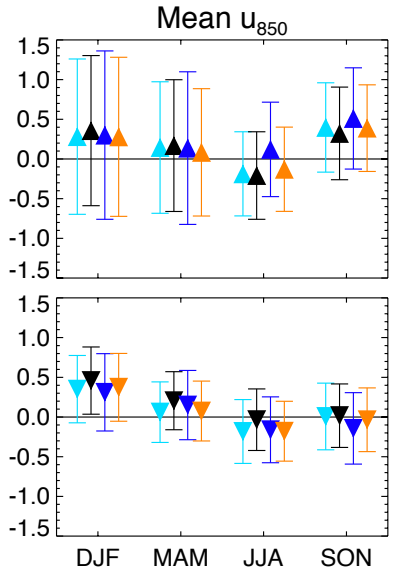
Seasonal trends



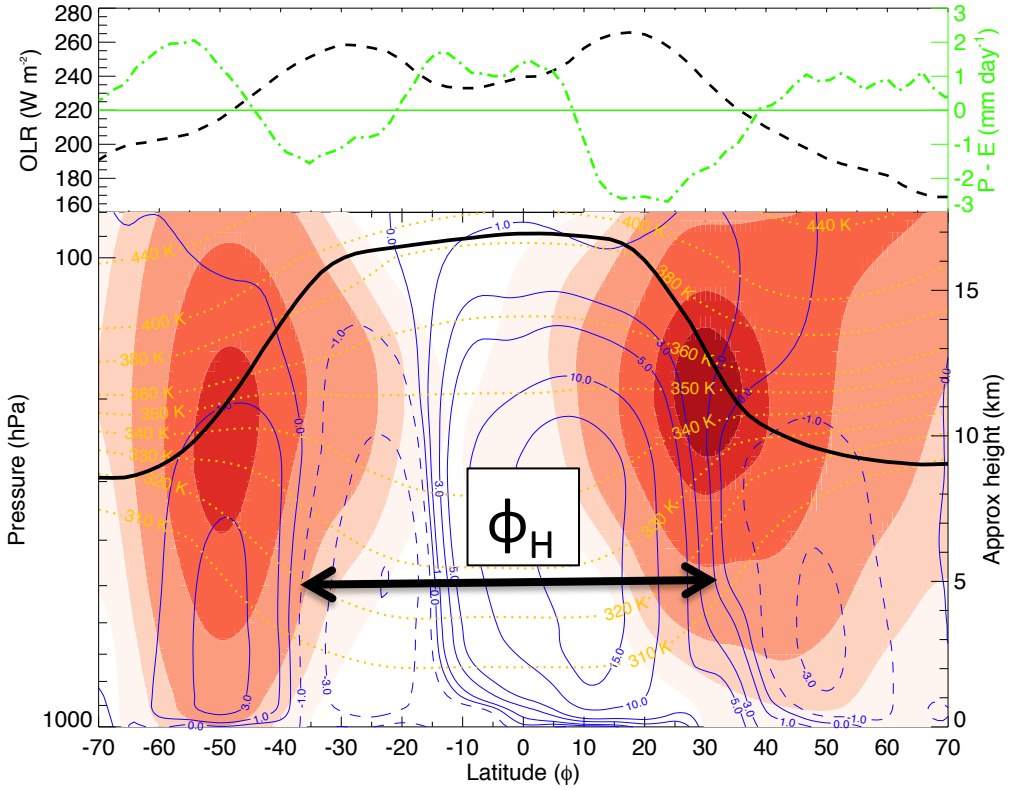








Tropical width drivers



$$\phi_H \sim \left(\frac{g}{\Omega^2 a^2} \frac{H_t \Delta_h}{\theta_0} \right)^{\frac{1}{2}}$$

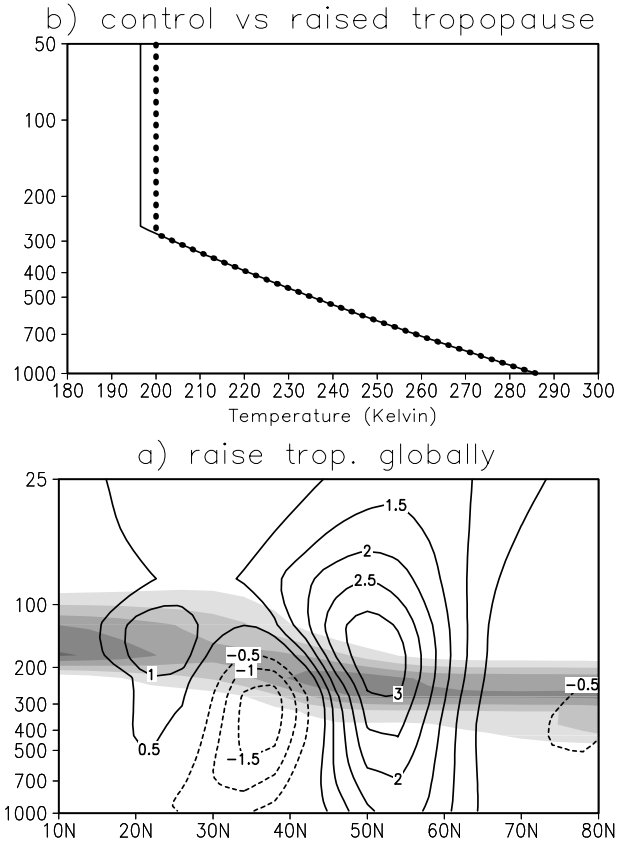
Held and Hou, 1980

$$\phi_H \sim \left(\frac{N H_e}{\Omega^2 a} \right)^{\frac{1}{3}}$$

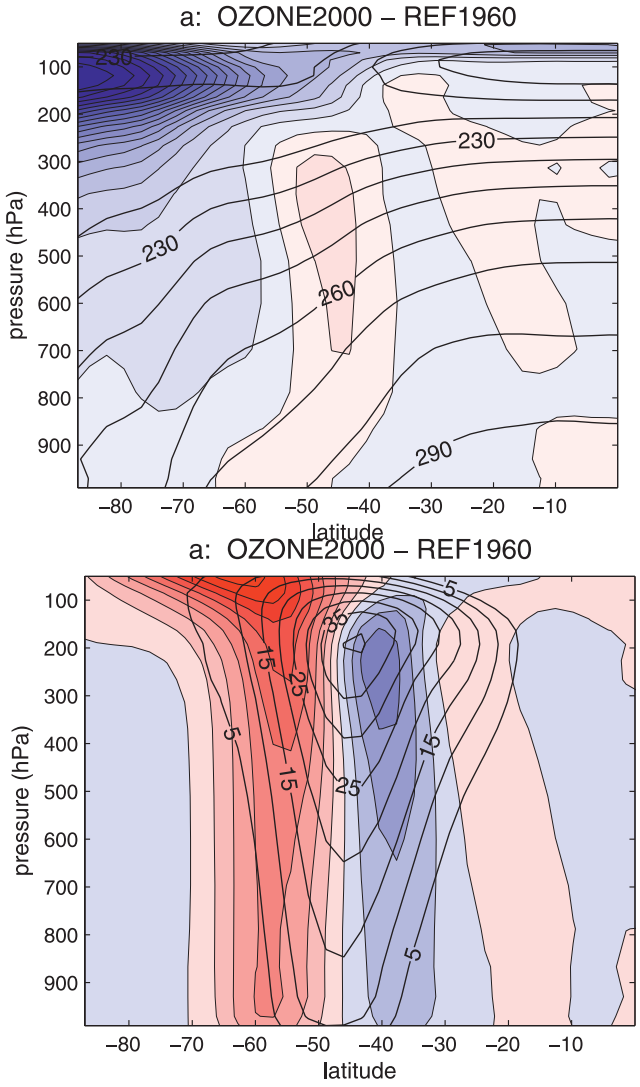
Lu et al., 2007

Tropical width drivers

- Thermal and tropopause changes induce dynamical changes

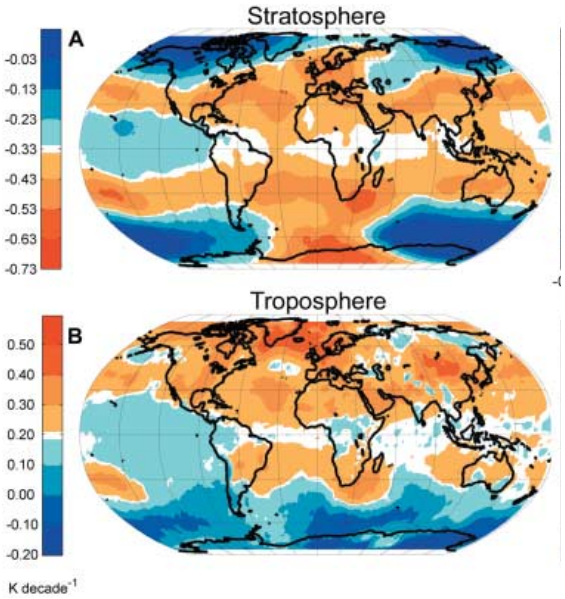


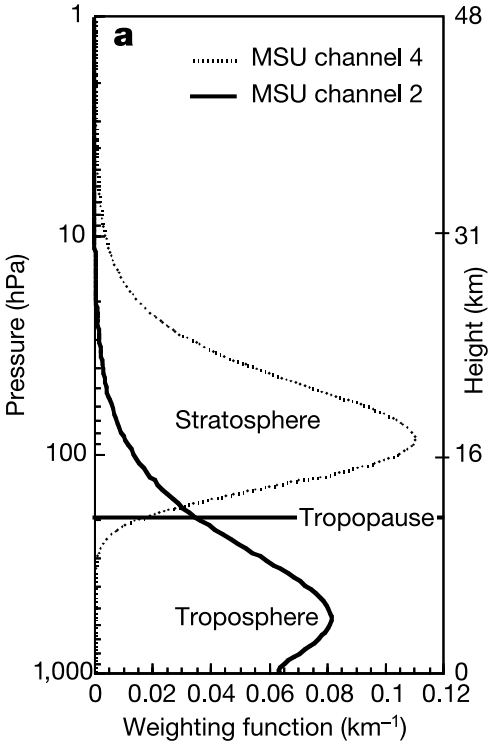
Lorenz and DeWeaver, JGR, 2007

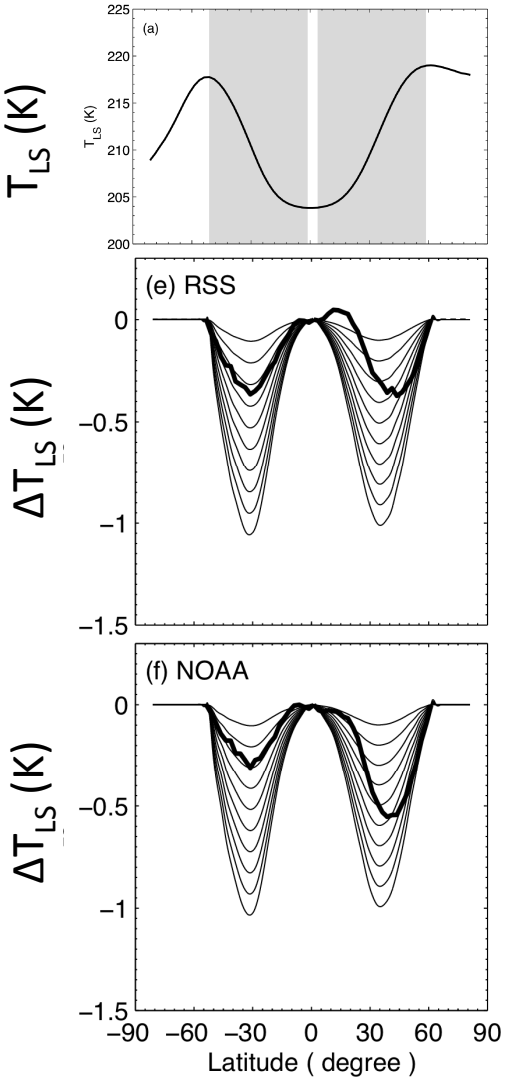


Polvani et al., J. Clim, 2011

Previous work – MSU temperature







0.8° decade^{-1}

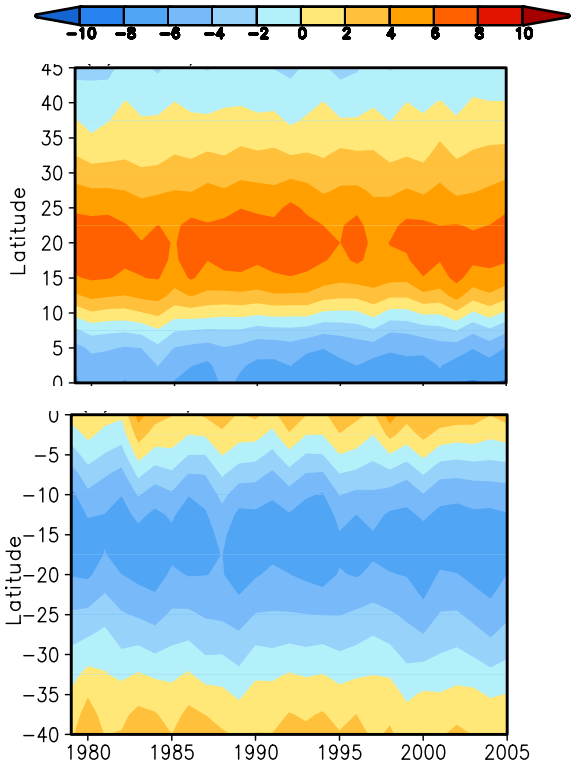
Fu et al., Science, 2006

0.5° decade^{-1}

Fu and Lin, J. Clim., 2011

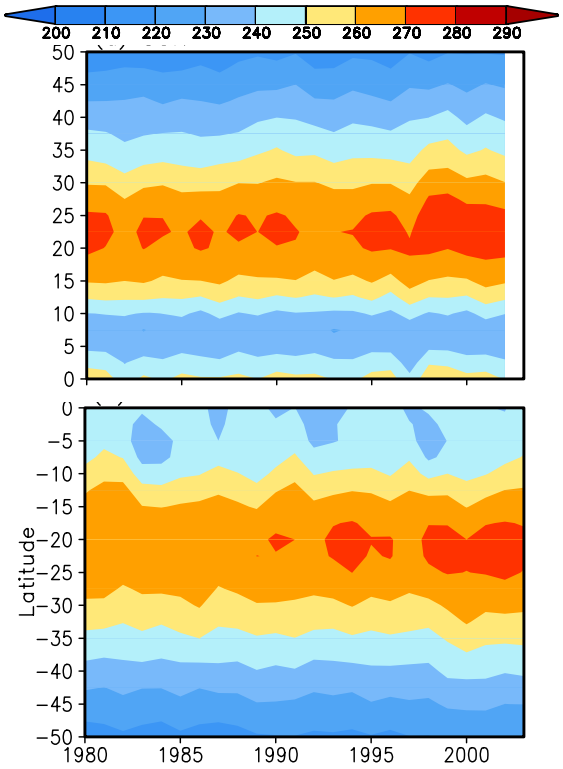
Previous work – Hadley cell

NCEP/NCAR ψ_{500} (streamfunction)



1-1.5° decade^{-1}

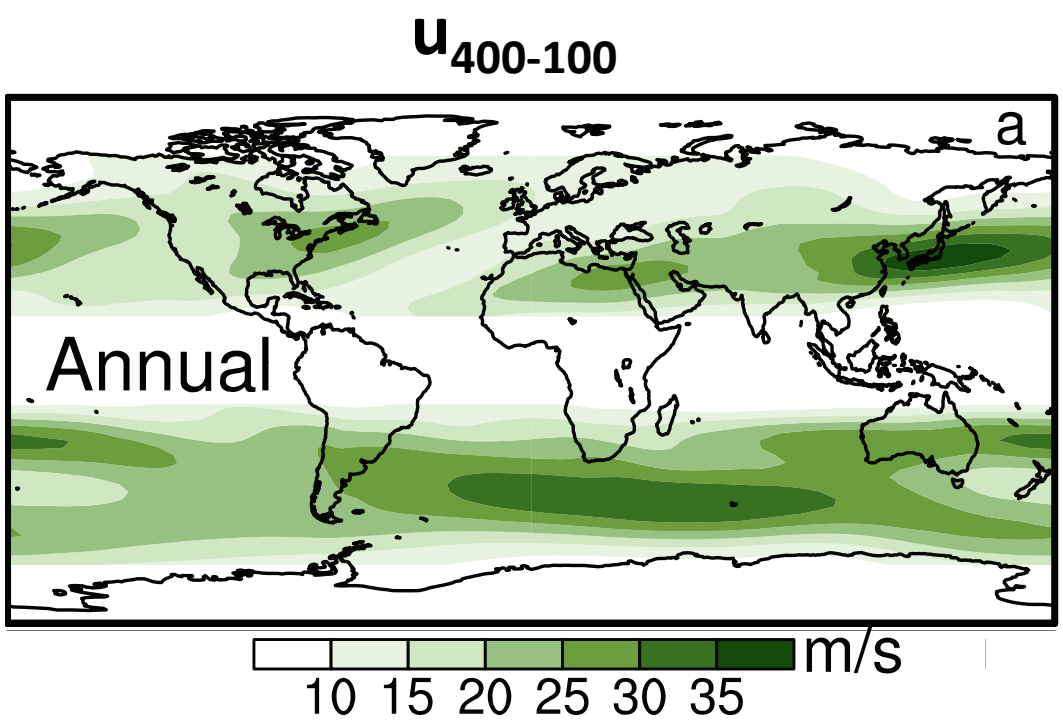
Satellite OLR (W m^{-2})

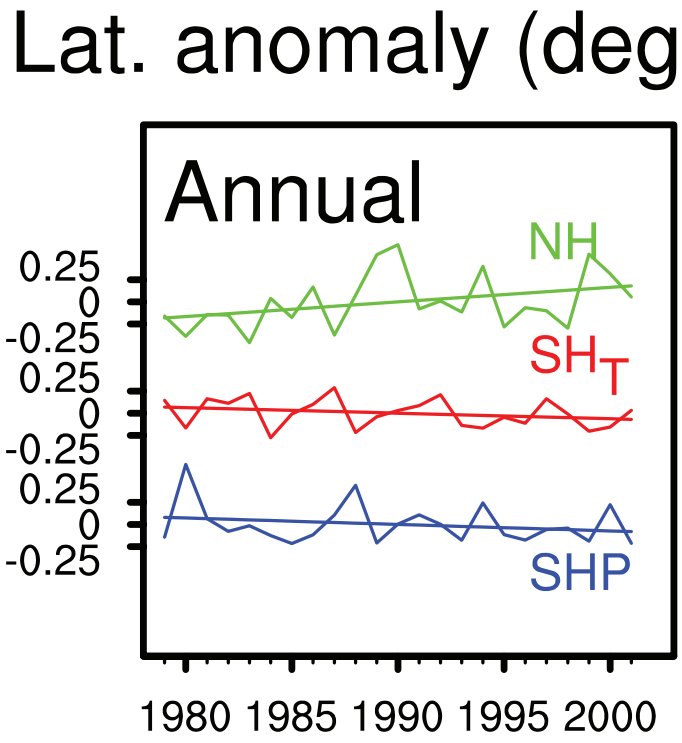


~1 decade^{-1}

Hu and Fu, ACP, 2007

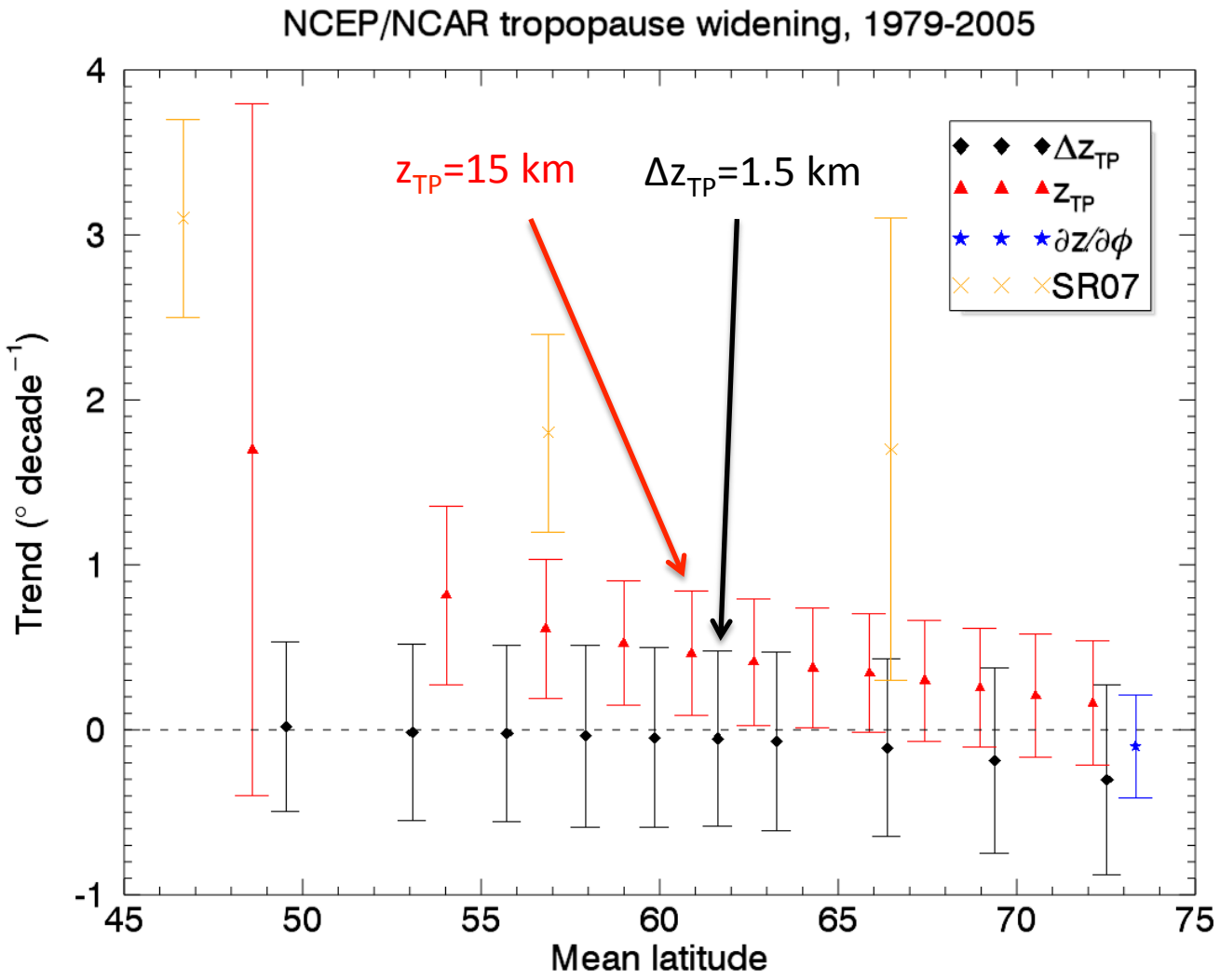
Previous work – winds





Archer and Caldeira, GRL, 2008

Tropopause sensitivity– threshold

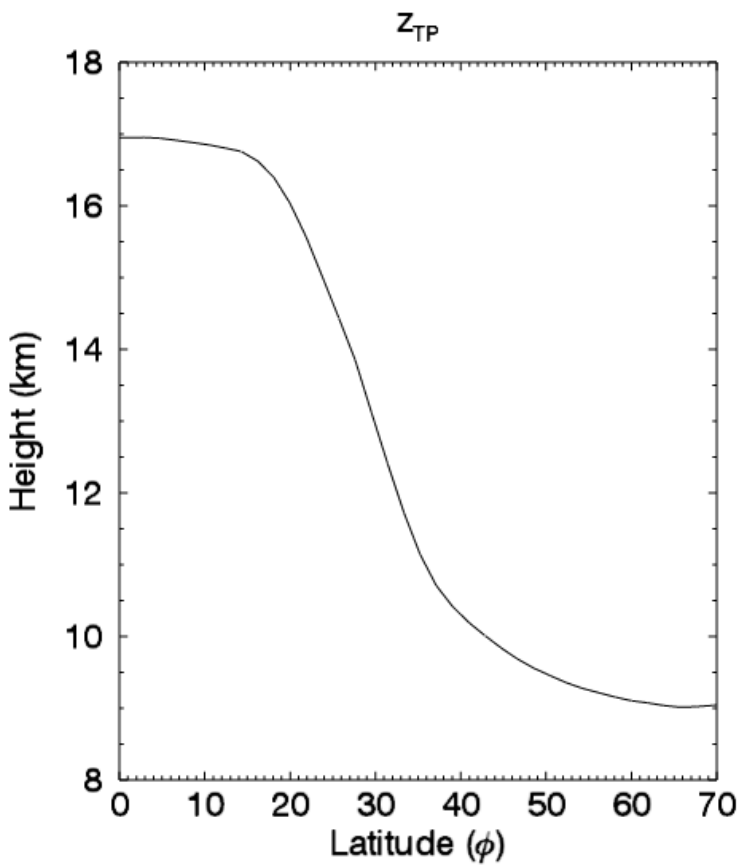


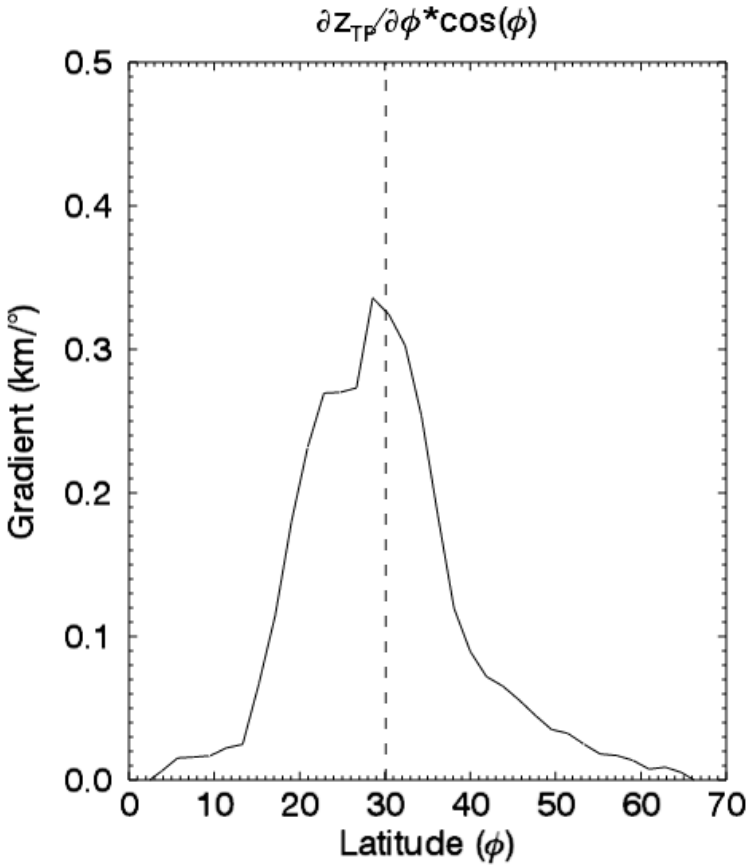
Outline

- Defining the tropics - edge latitude overview
- Summary of previous work
- Trend sensitivity to edge definitions
- Trend comparison from different reanalyses, satellite obs
  - Davis and Rosenlof, J. Climate, in press

“Mean” (1st moment) metrics

$$\bar{\phi} = \frac{\sum \phi f(\phi)}{\sum f(\phi)}$$

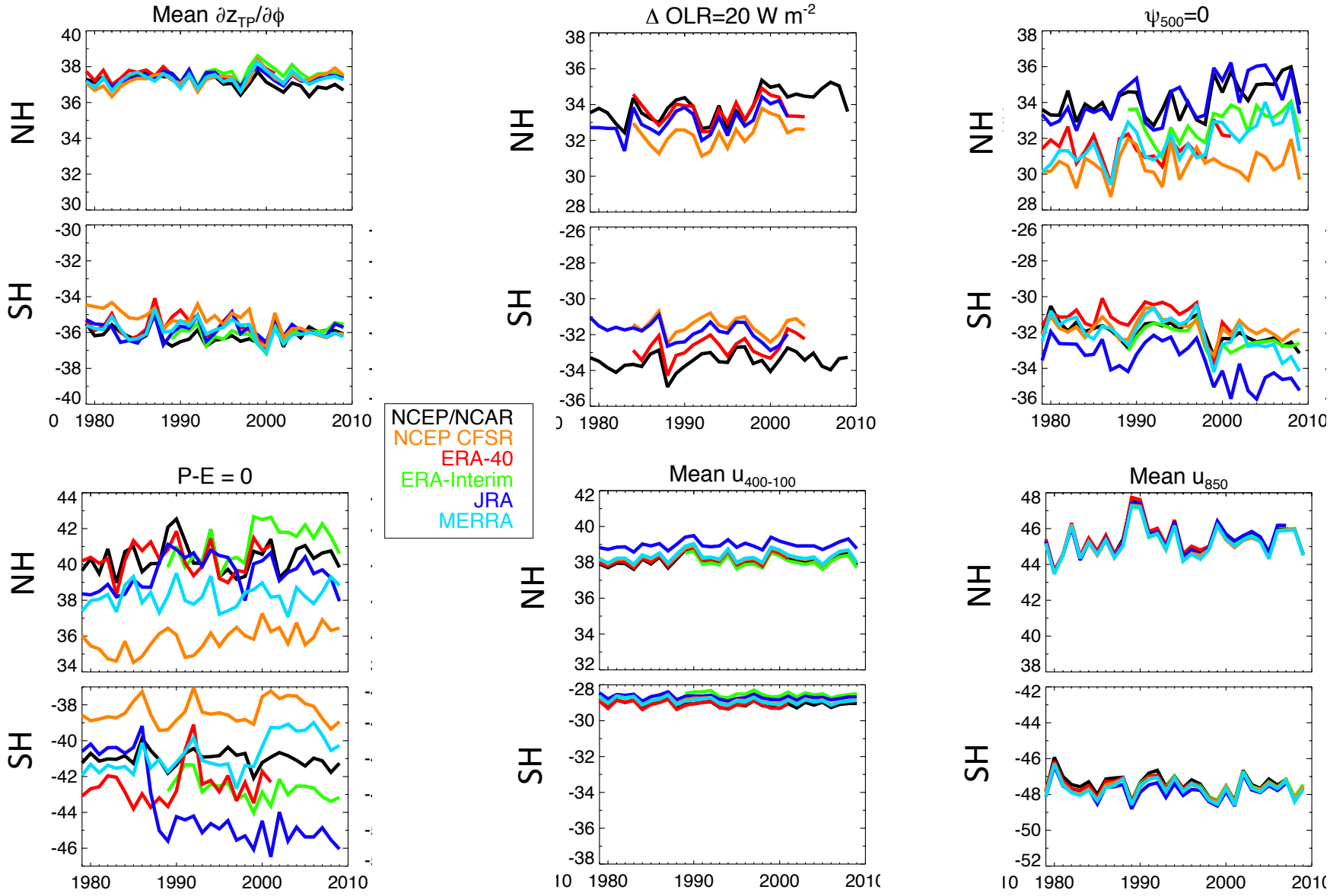




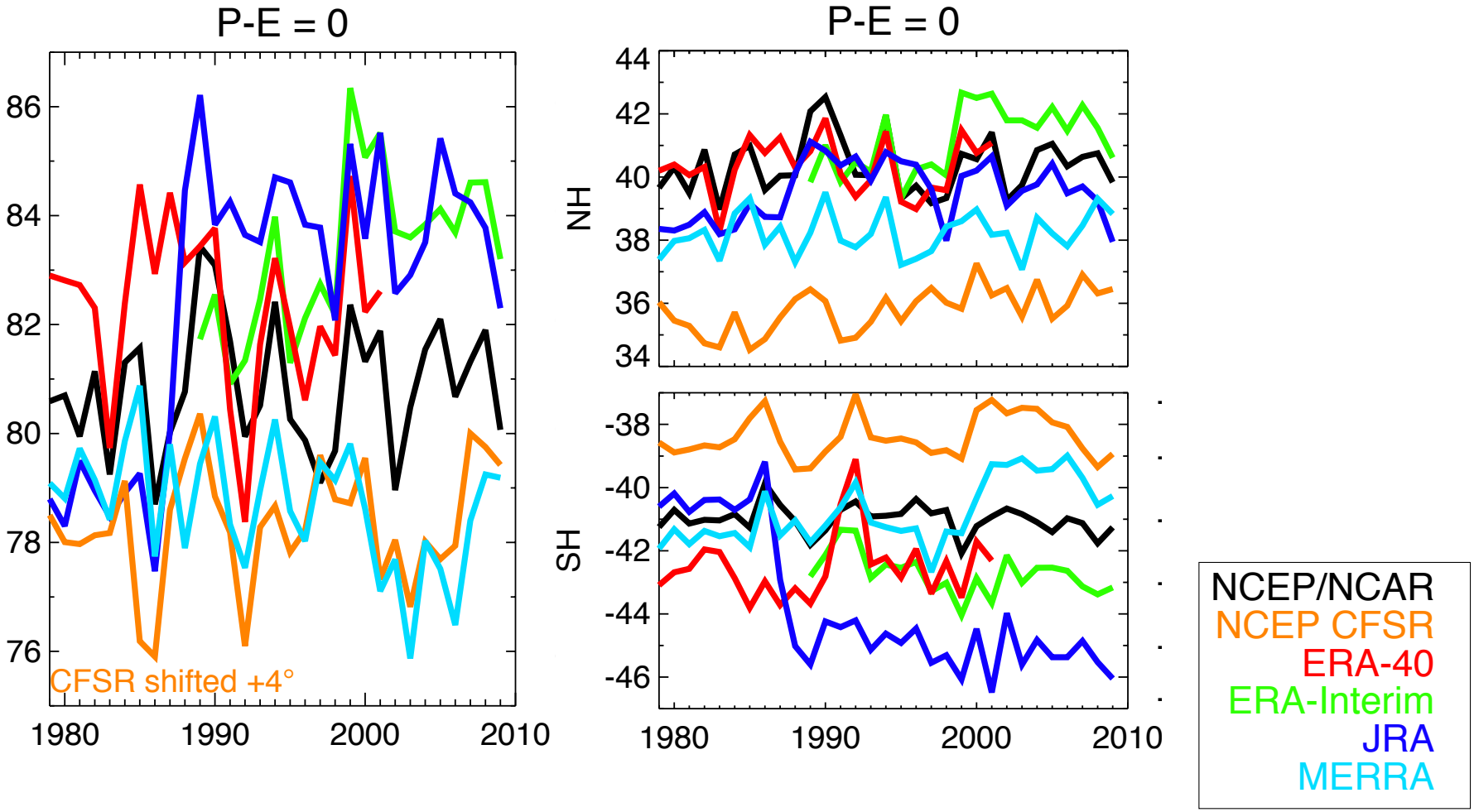
Reanalysis overview

Reanalysis	Number of tropopause levels*	Vertical resolution (# of levels)		Horizontal resolution (lon x lat)	
		Model-grid	Pressure-grid	Model-grid	Pressure-grid
NCEP/NCAR	6	28	17	1.875° x ~1.9°	2.5° x 2.5°
NCEP CFSR	11	64	37	0.5° x 0.5°	0.5° x 0.5°
ERA-40	10	60	23	1.125° x ~1.125°	1.125° x 1.125°
ERA-interim	10	60	37	0.703° x ~0.703°	1.5° x 1.5°
JRA	9	40	23	1.125° x ~1.125°	1.25° x 1.25°
MERRA	9	72	42	0.667° x 0.5°	0.667° x 0.5°

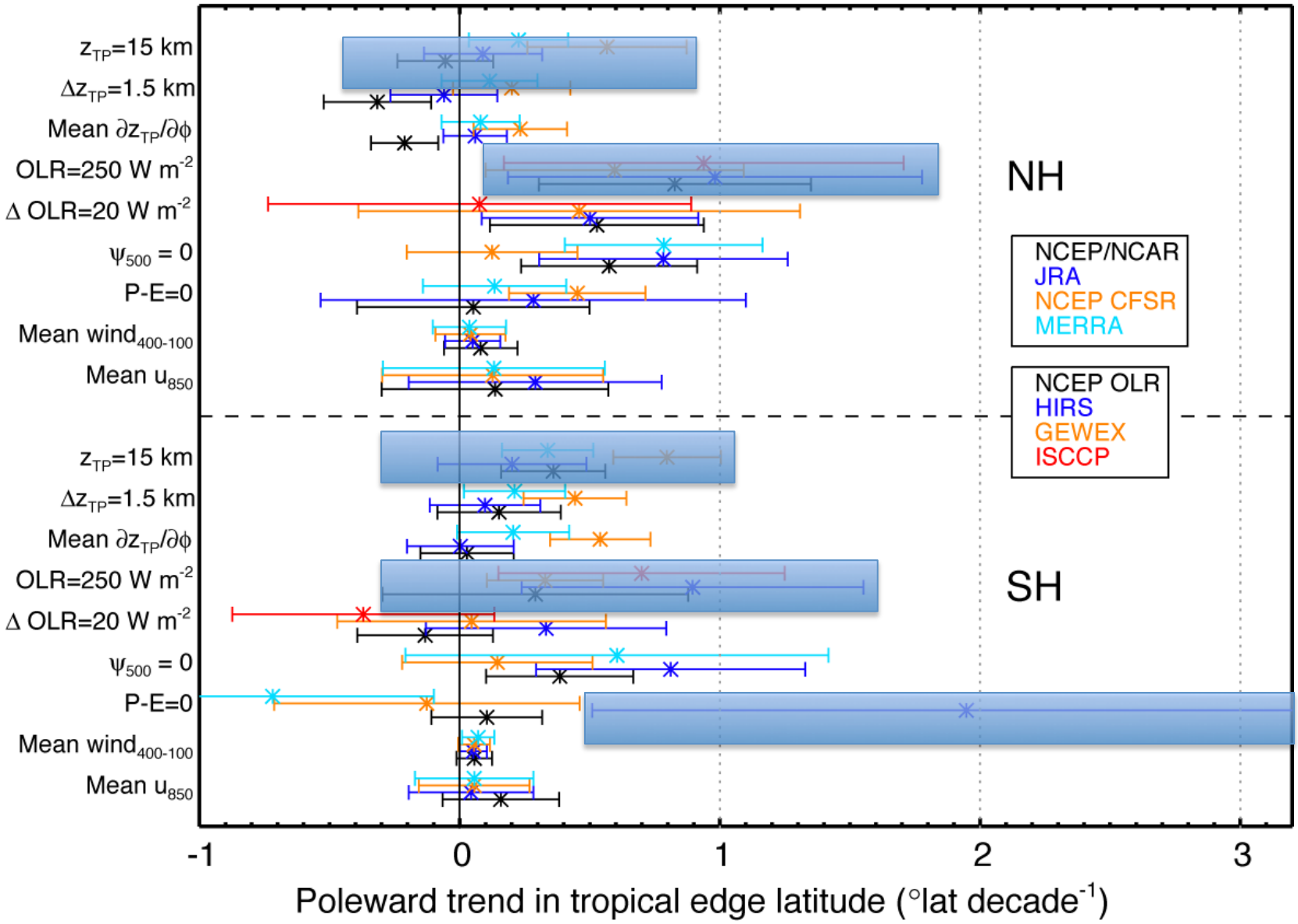
Hemispheric timeseries



Hadley-cell metrics



Hemispheric trends



Summary (part 1)

- Tropical width value and interannual variations:
  - Good agreement for wind, tropopause
  - Medium agreement for ψ_{500}, OLR
  - Poor for P-E
- Tropopause trends:
  - Absolute threshold trends biased high
  - Relative threshold/gradient trends in agreement, insignificant (except CFSR)
  - No hemispheric differences (except NCEP)
- OLR trends:
  - Absolute threshold trends biased high
  - Relative threshold trends insignificant
  - Some significant trends in NH. NH > SH

Summary (part 1)

- ψ_{500} trends:
  - 1-1.5° decade^{-1} (except CFSR)
- P-E=0 trends:
  - Poor agreement
  - Spurious SH shift in 1987 in JRA
  - SH shift in MERRA around 2000
- u trends:
  - Good agreement, but small, insignificant
- No correlation between ψ_{500} and P-E trends
- Disagreements not more widespread in SH than NH

Summary (part 2)

- Stratospheric WV changes could contribute to widening
  - IF increases are similar to those pre-2000
  - ~20 - 50% effect, relative to GHG/O_3
- Affect jet more than Hadley cell
- Extratropical cooling causes widening
  - Tropical cooling in opposite direction
  - Tropopause height change secondary