Variability and trends in effective diffusivity in the stratosphere, and their implications for stratospheric circulation changes

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CIRES
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Overview

- Effective diffusivity as a diagnostic for mixing in reanalyses:
  - Variability (QBO, ENSO, etc.)
  - Discontinuities
  - Trends
- Understanding stratospheric circulation changes
  - Changes in mixing and impact on age-of-air

Effective diffusivity (κ_{eff})

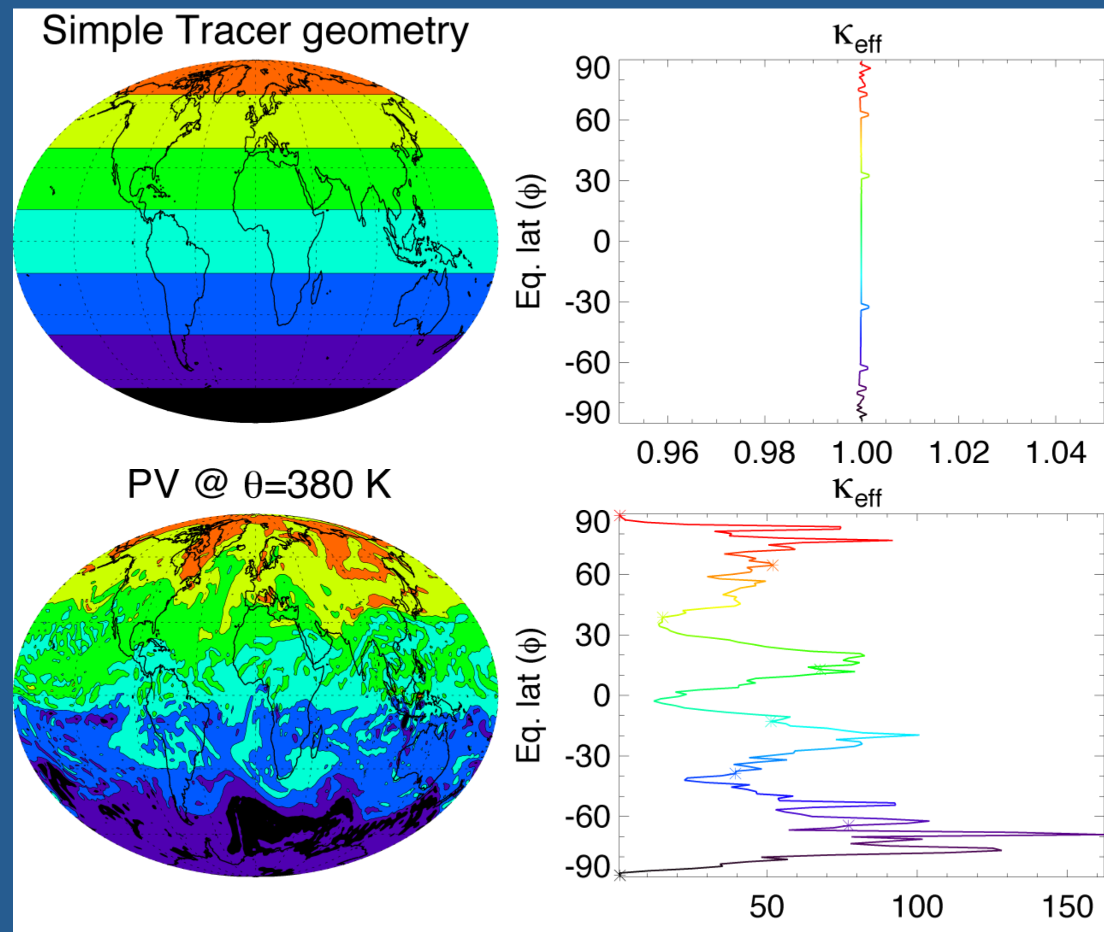
- Effective diffusivity is a mixing diagnostic in equivalent latitude coordinates
- 2D Advection-diffusion equation -> Diffusion-only eq. in equivalent latitude coords
- κ_{eff} related to length of tracer contours
  - Simple geometry → small mixing → small κ_{eff}
  - Complex geometry → large mixing → large κ_{eff}

- κ_{eff} is “normalized”

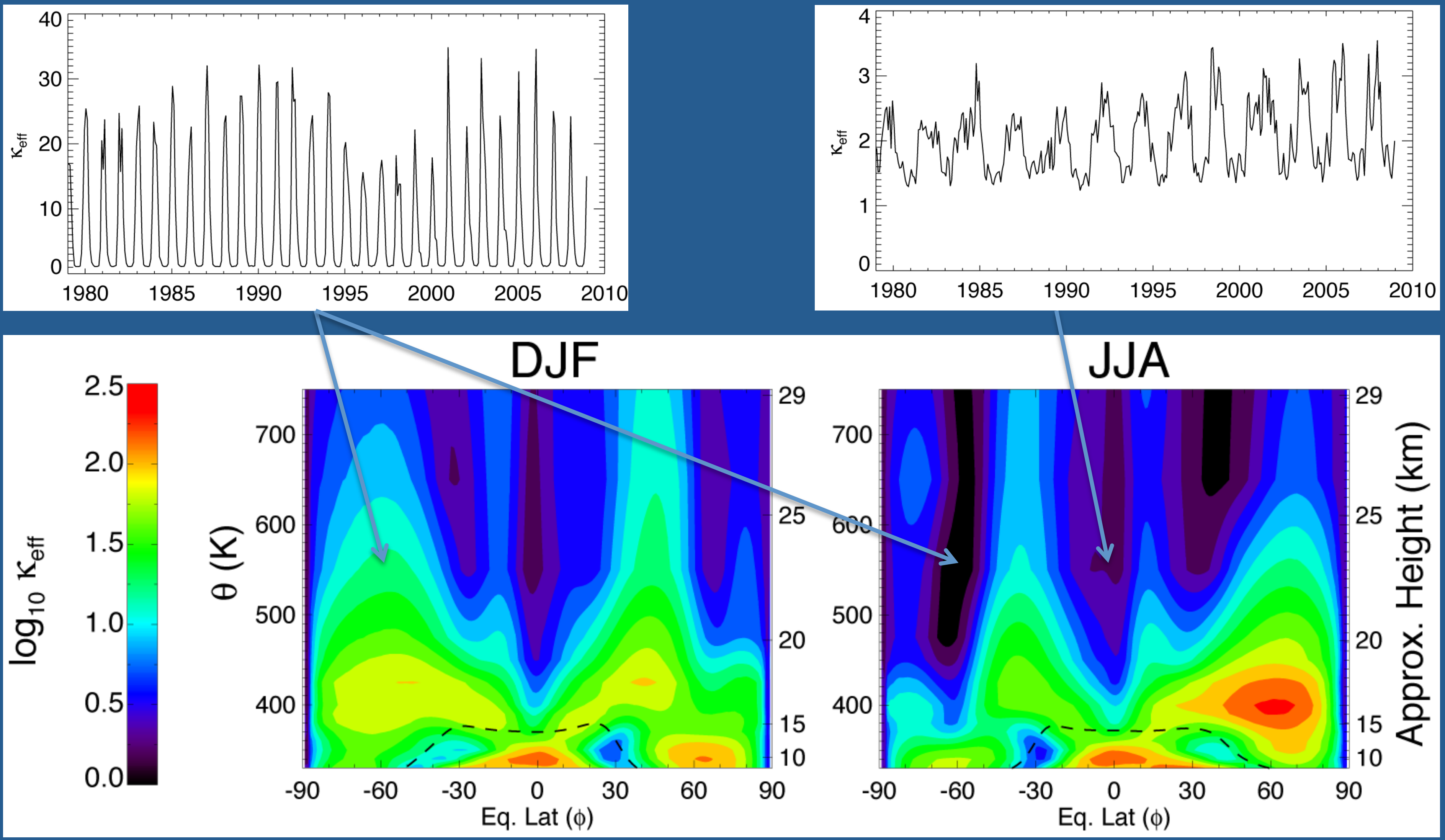
$$\frac{\kappa_{eff}}{\kappa} = \left(\frac{L_{eq}}{2\pi r \cos\phi_{eq}}\right)^2$$

•κ_{eff} calculated on isentropes using PV (Haynes and Shuckburgh 2000 a,b, JGR)

• Calculated from 6-hourly data, then monthly averaged

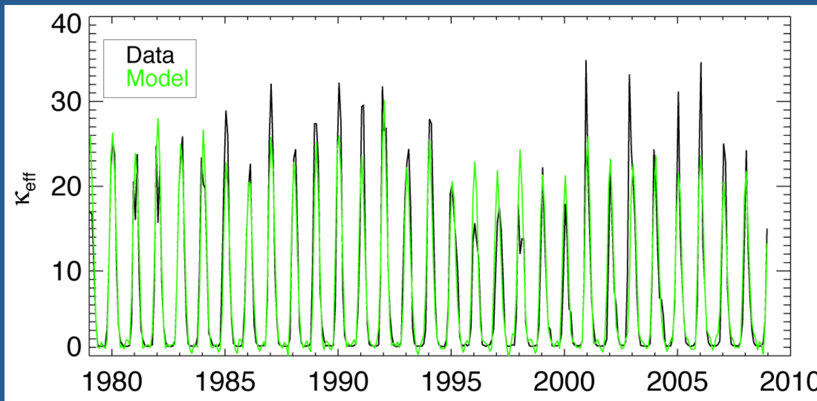


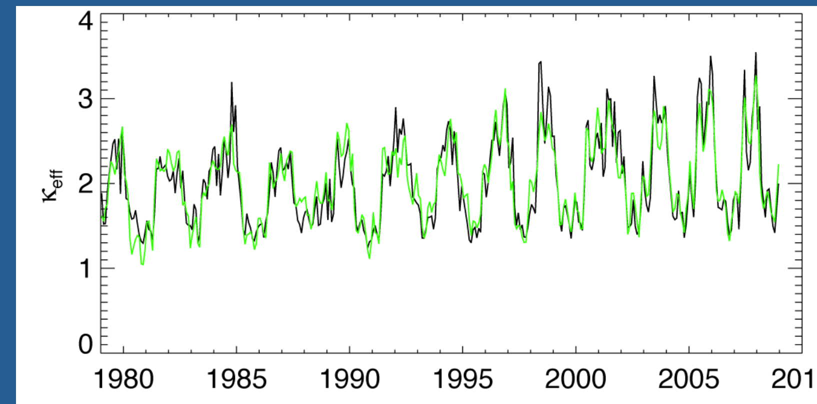
κ_{eff} variability



Calculated from JRA

κ_{eff} variability



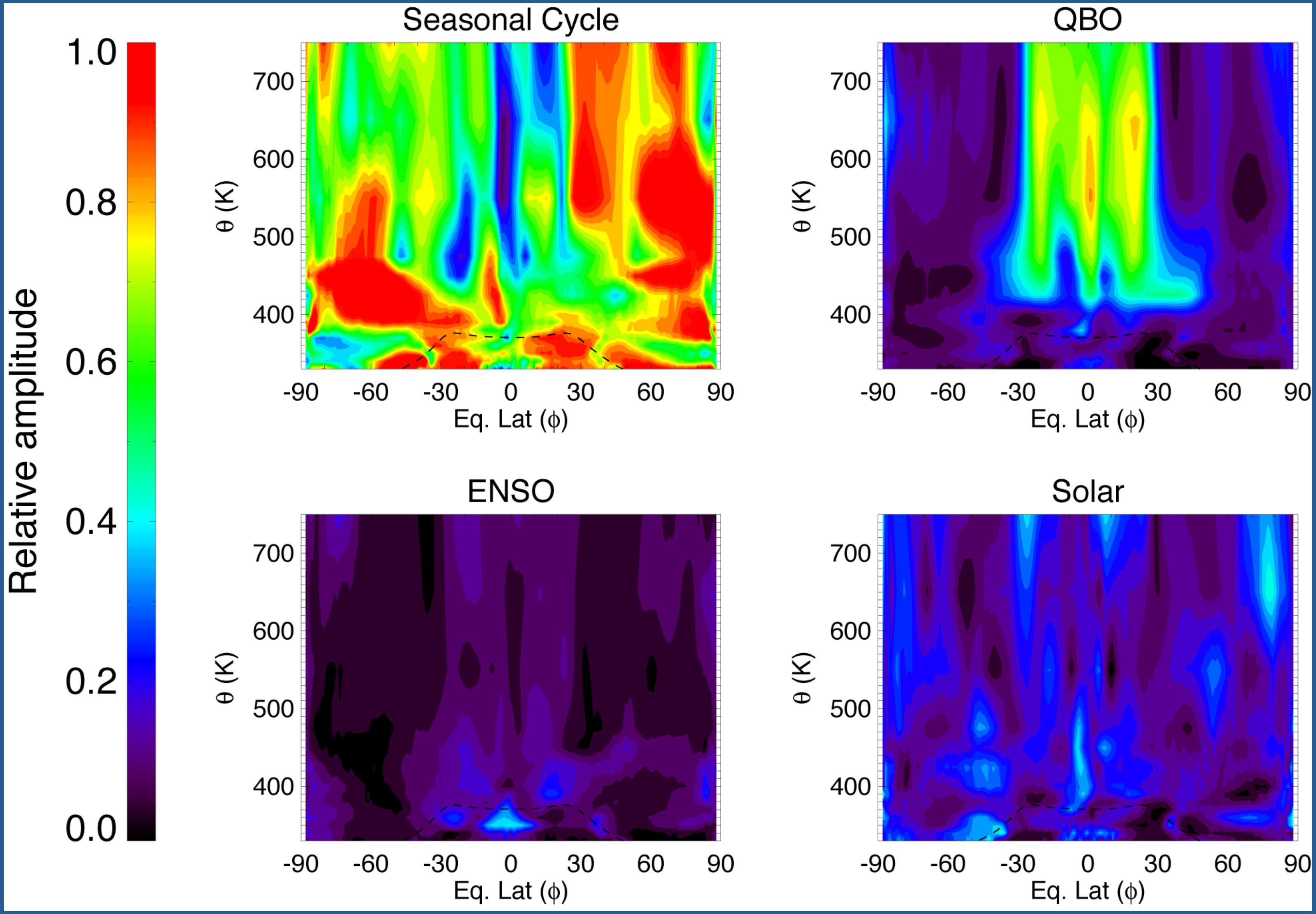


- Fit of monthly-mean κ_{eff} at each ϕ,θ, with 2-4 seasonal harmonics

$$\kappa_{eff}(\phi,\theta,t) = \underbrace{a_1(\phi,\theta,t)}_{\text{Seasonal Cycle}} + \underbrace{a_2(\phi,\theta,t)}_{\text{Lagged-QBO response}} \cdot QBO_{70\ \mathrm{hPa}}(t) + \underbrace{a_3(\phi,\theta,t)}_{\text{Lagged-QBO response}} \cdot QBO_{30\ \mathrm{hPa}}(t) + \underbrace{a_4(\phi,\theta,t)}_{\text{Solar}} \cdot F10.7(t) + \underbrace{a_5(\phi,\theta,t)}_{\text{ENSO}} \cdot SOI(t)$$

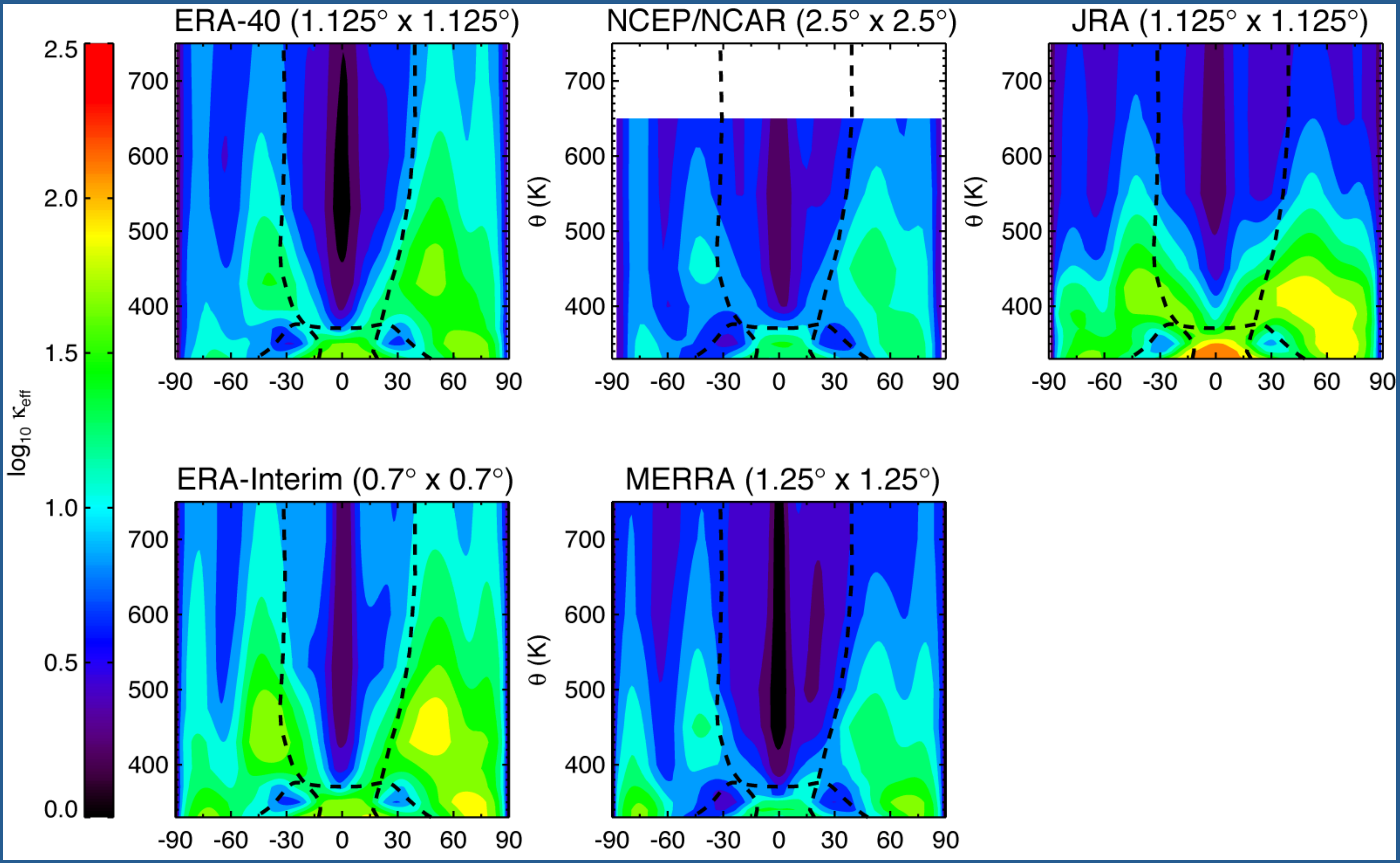
$$a_i(\phi,\theta,t) = a_{i0}(\phi,\theta) + \sum_{k=1}^{N}\left[a_{ikc}(\phi,\theta)\cos\left(\frac{2\pi k(t-0.5)}{12}\right) + a_{iks}(\phi,\theta)\sin\left(\frac{2\pi k(t-0.5)}{12}\right)\right]$$

κ_{eff} variability – RMS amplitude

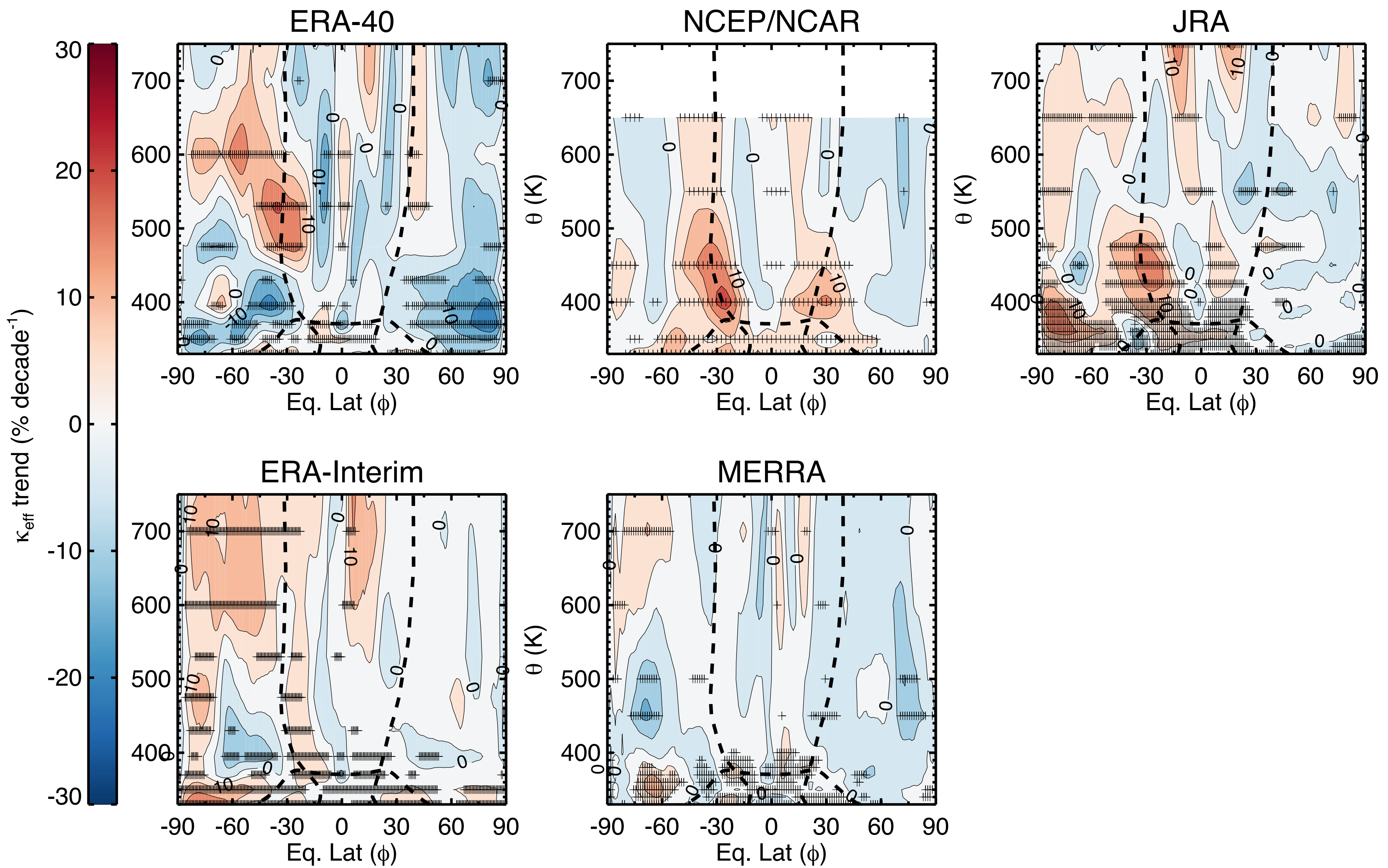


JRA data

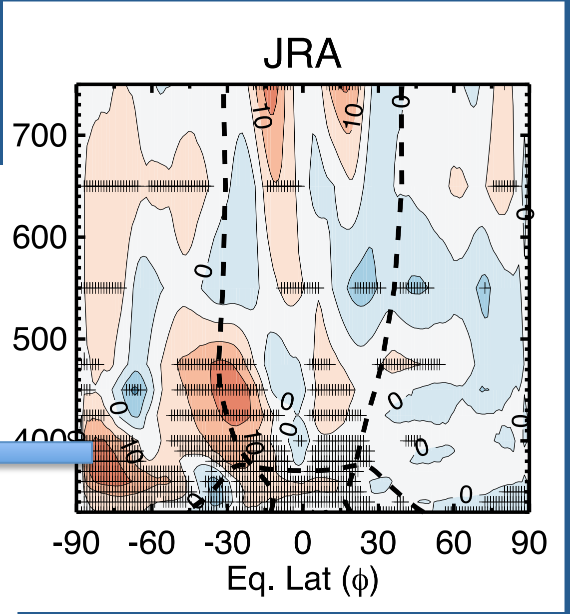
κ_{eff} intercomparison (mean)

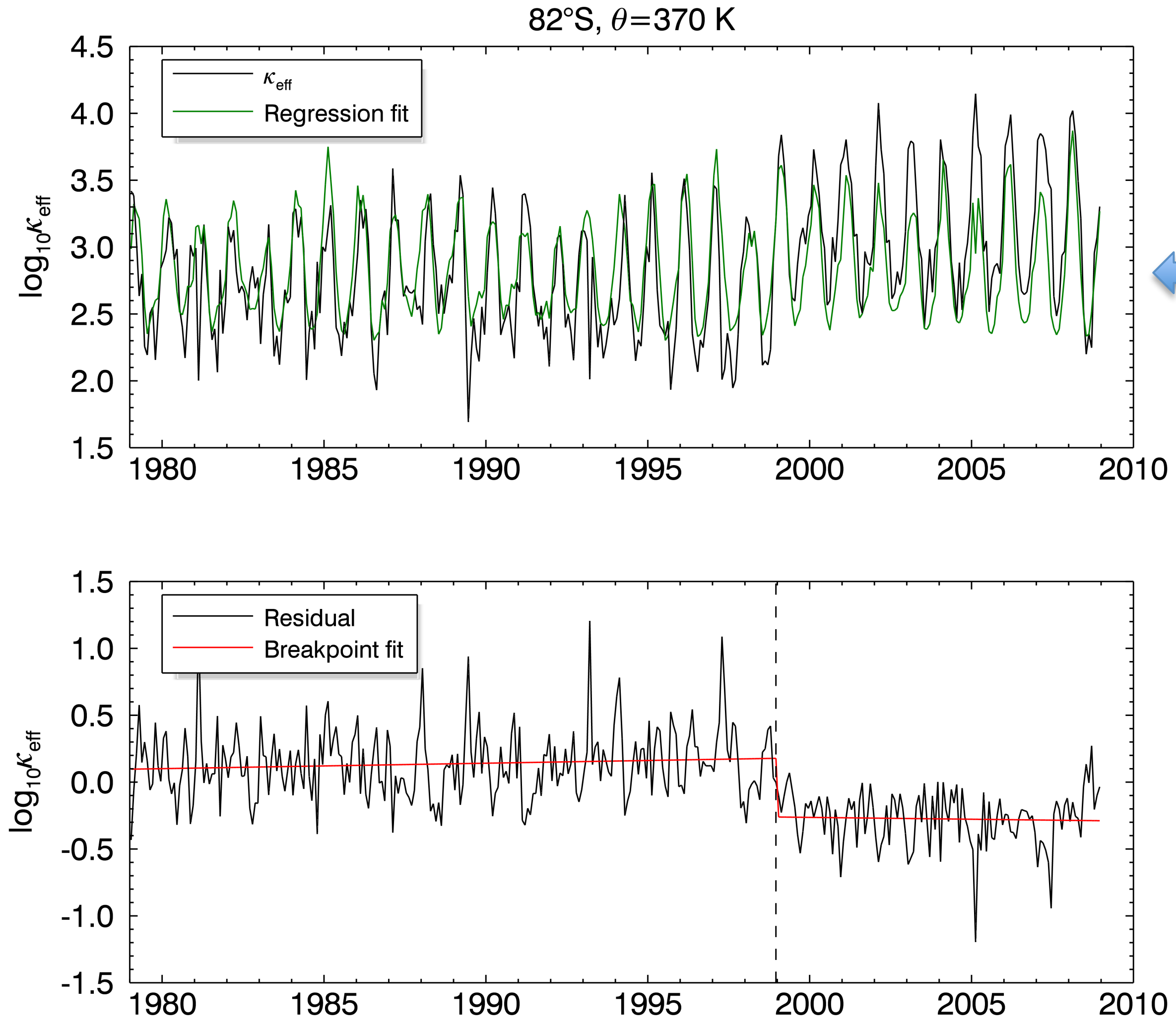


κ_{eff} trends (1979-2008)



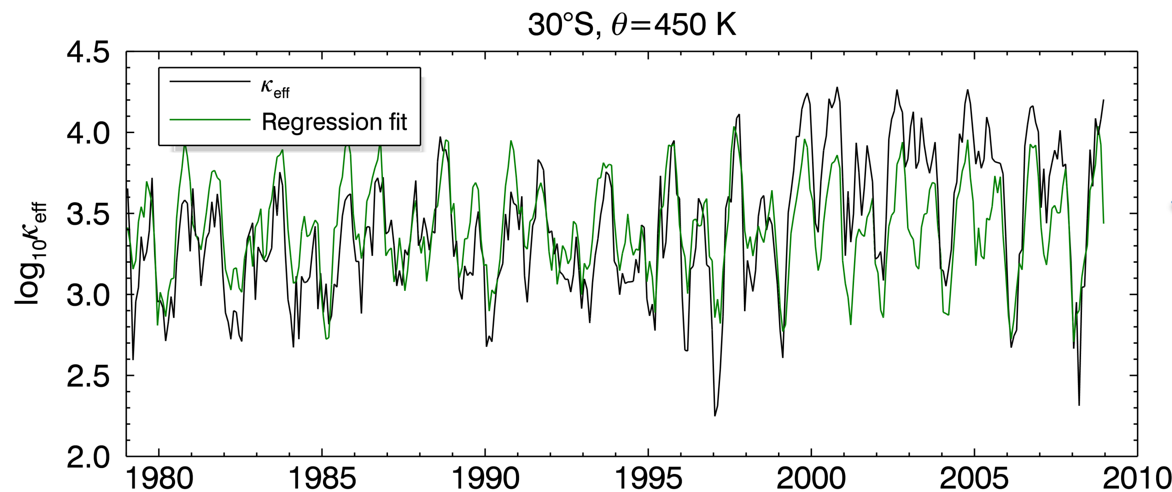
κ_{eff} discontinuities?

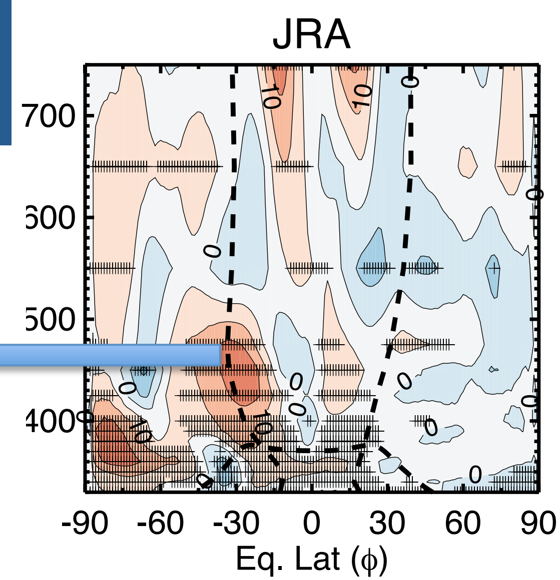


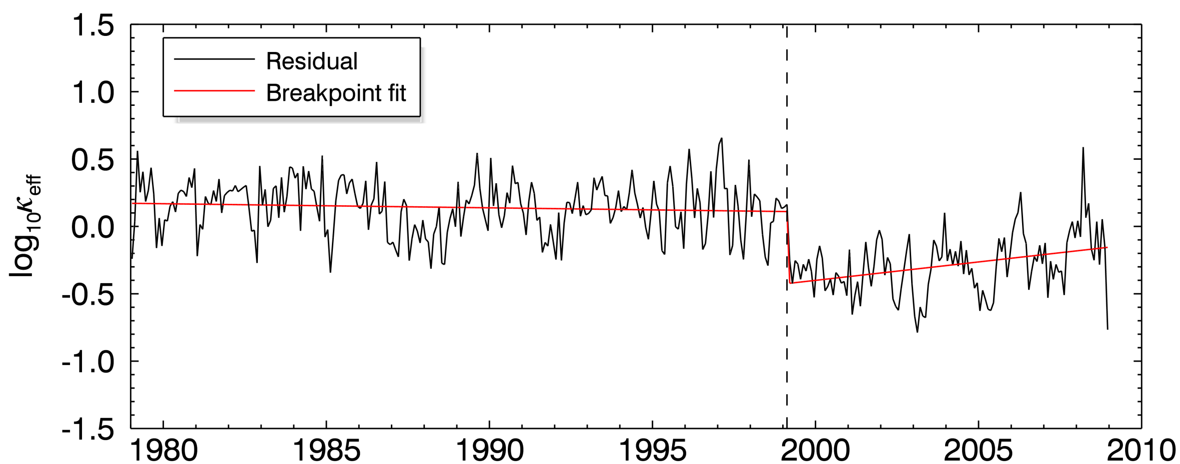


- Breakpoint: 12/1998
- ATOVS introduced 11/1998

κ_{eff} discontinuities?

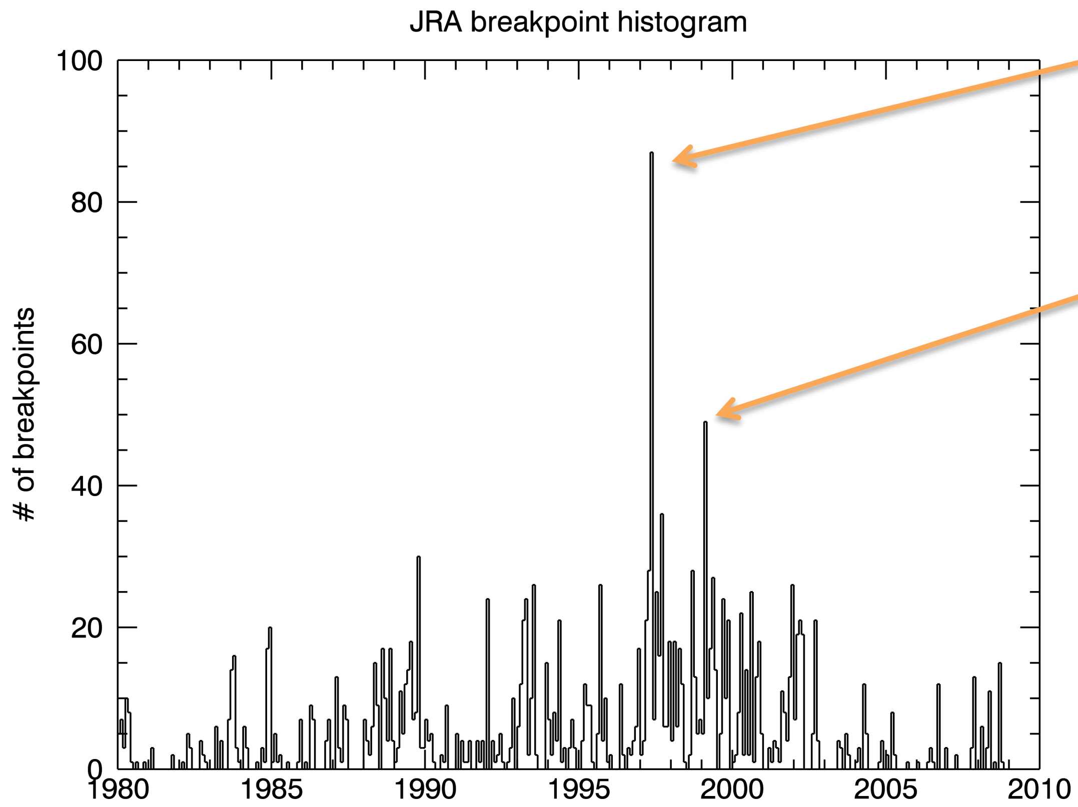






- Breakpoint: 2/1999
- ATOVS introduced 11/1998

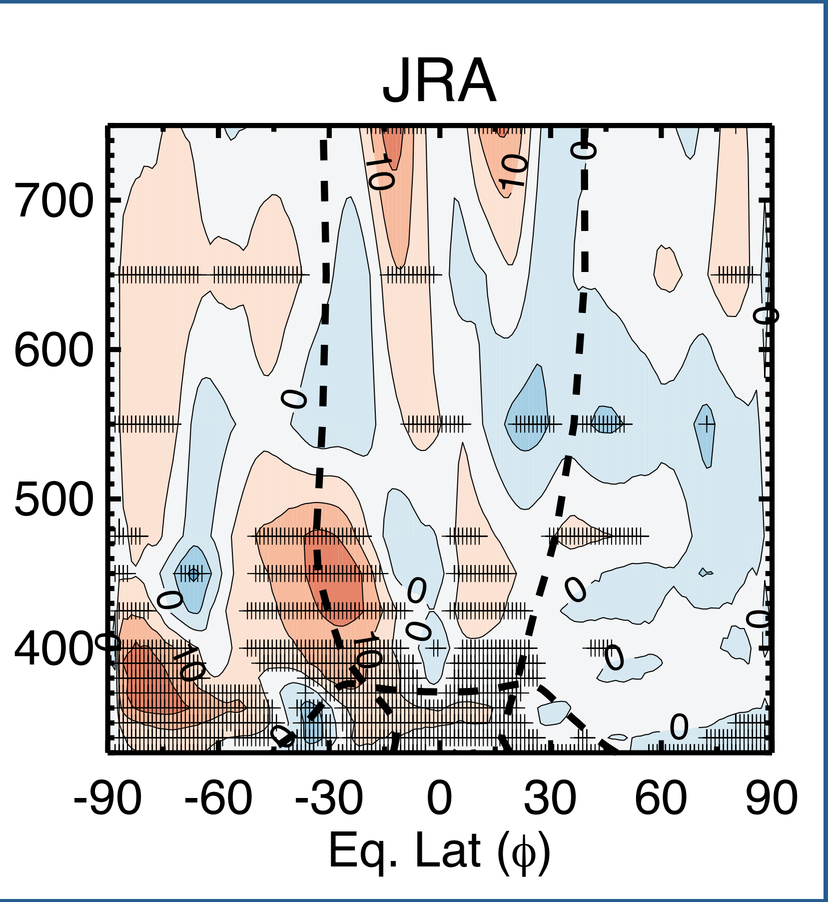
κ_{eff} discontinuities?

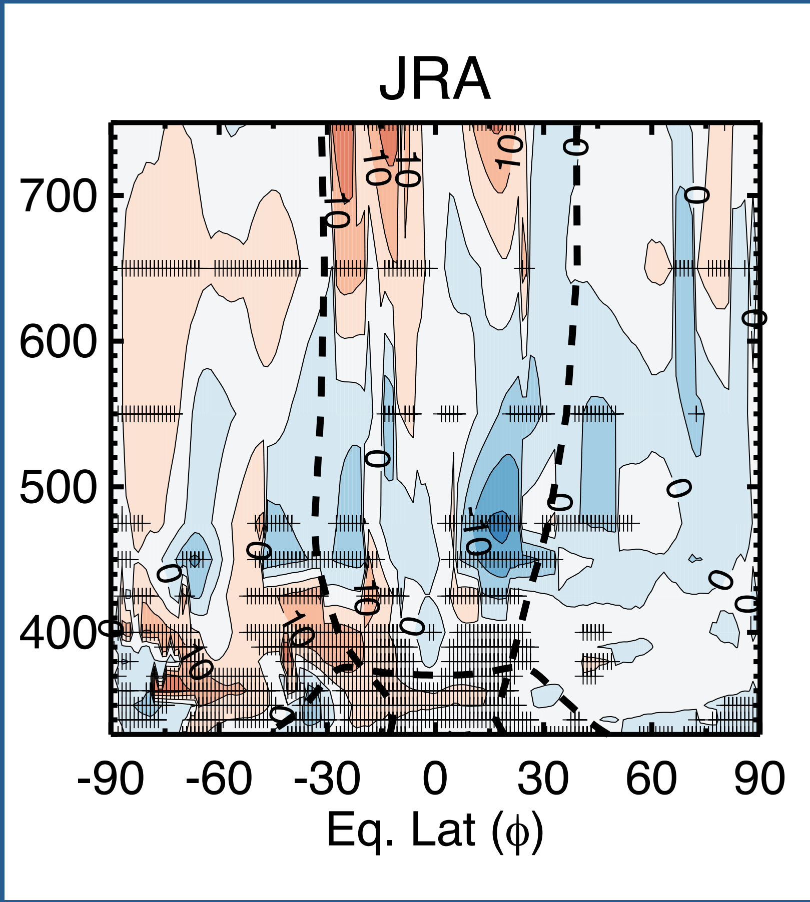


El Niño?
End of NOAA-12 MSU?
SSM/I F-14 introduction?

ATOVS introduction

κ_{eff} discontinuities?

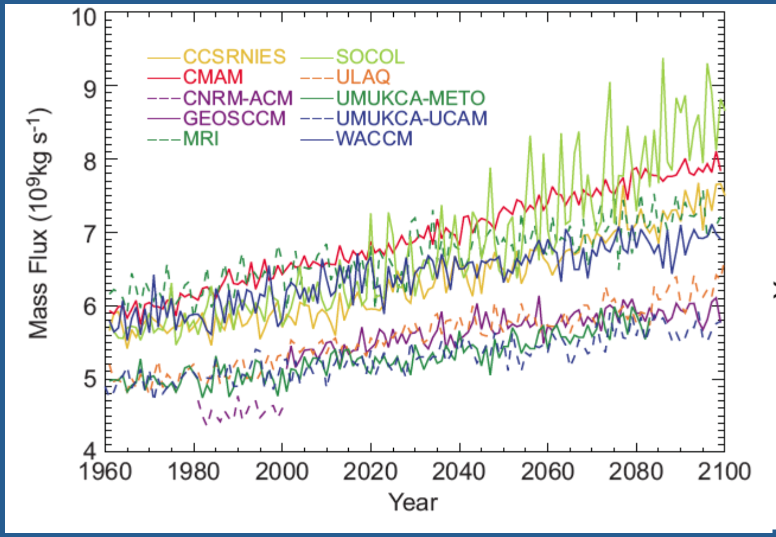




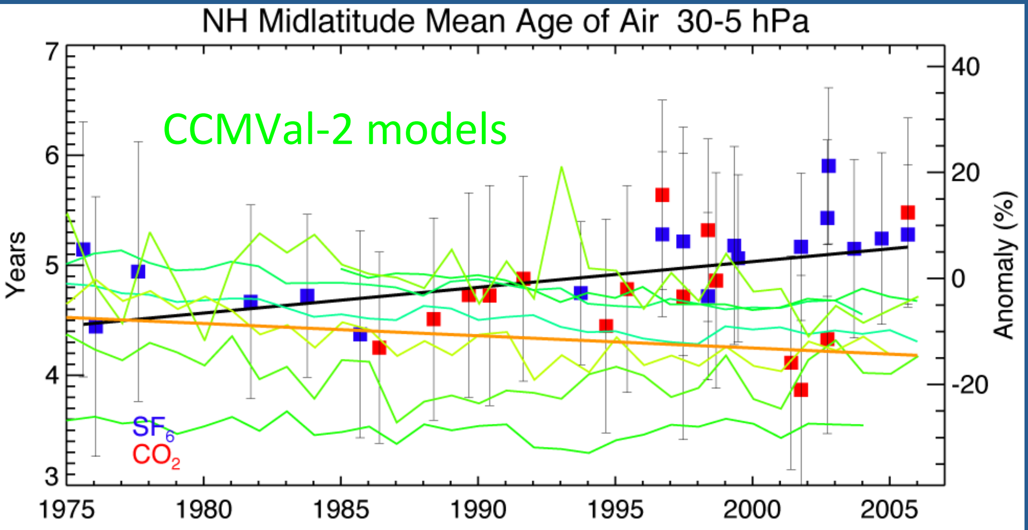
Breakpoint removal

κ_{eff} and stratospheric circulation changes

- Models and observations show B-D circulation increases
- Upwelling increases -> decreases in midlatitude age of air
- Ballon-based observations do not show a decrease in age of air
- Could changes in mixing help resolve this apparent discrepancy?



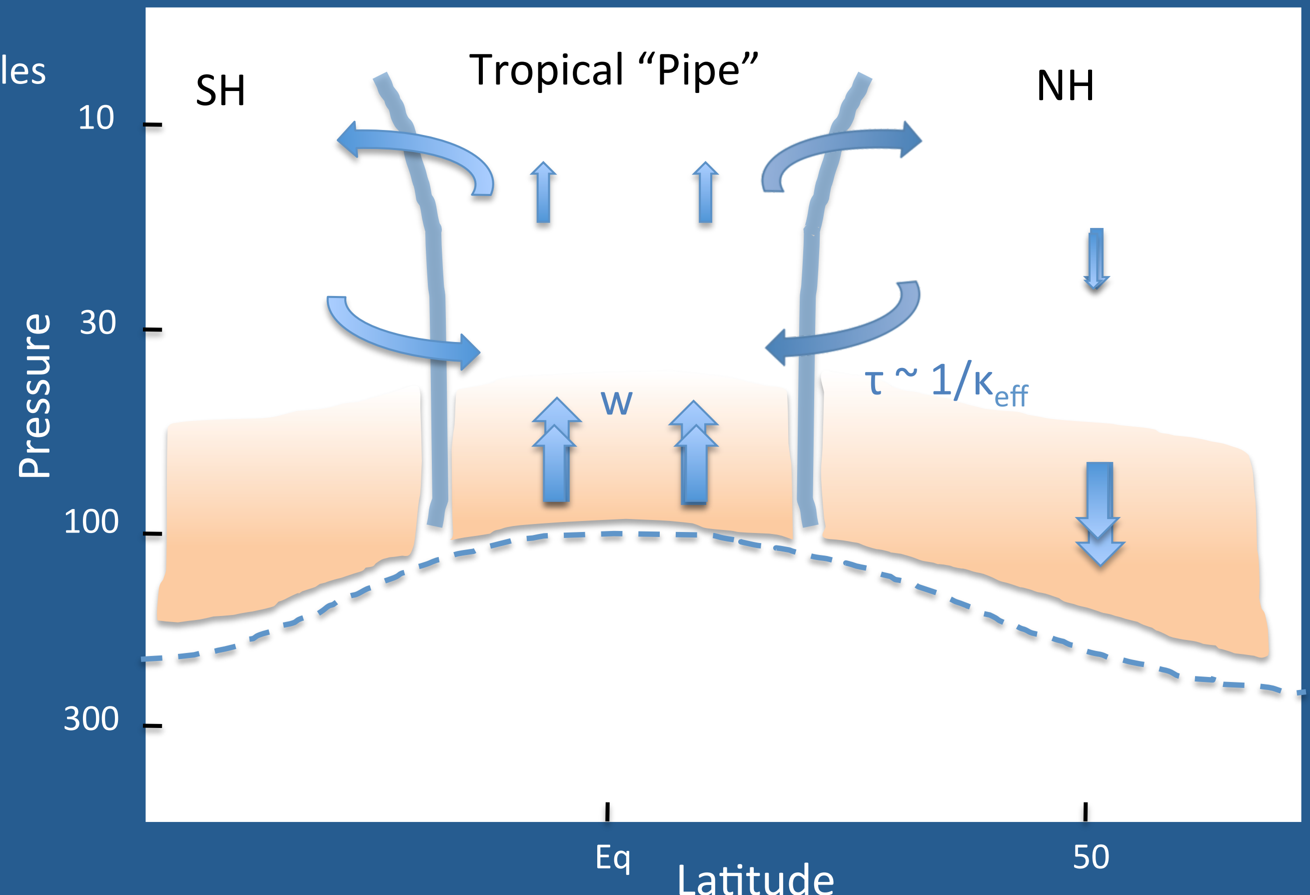
Ch 4., SPARC CCMVal report, 2010



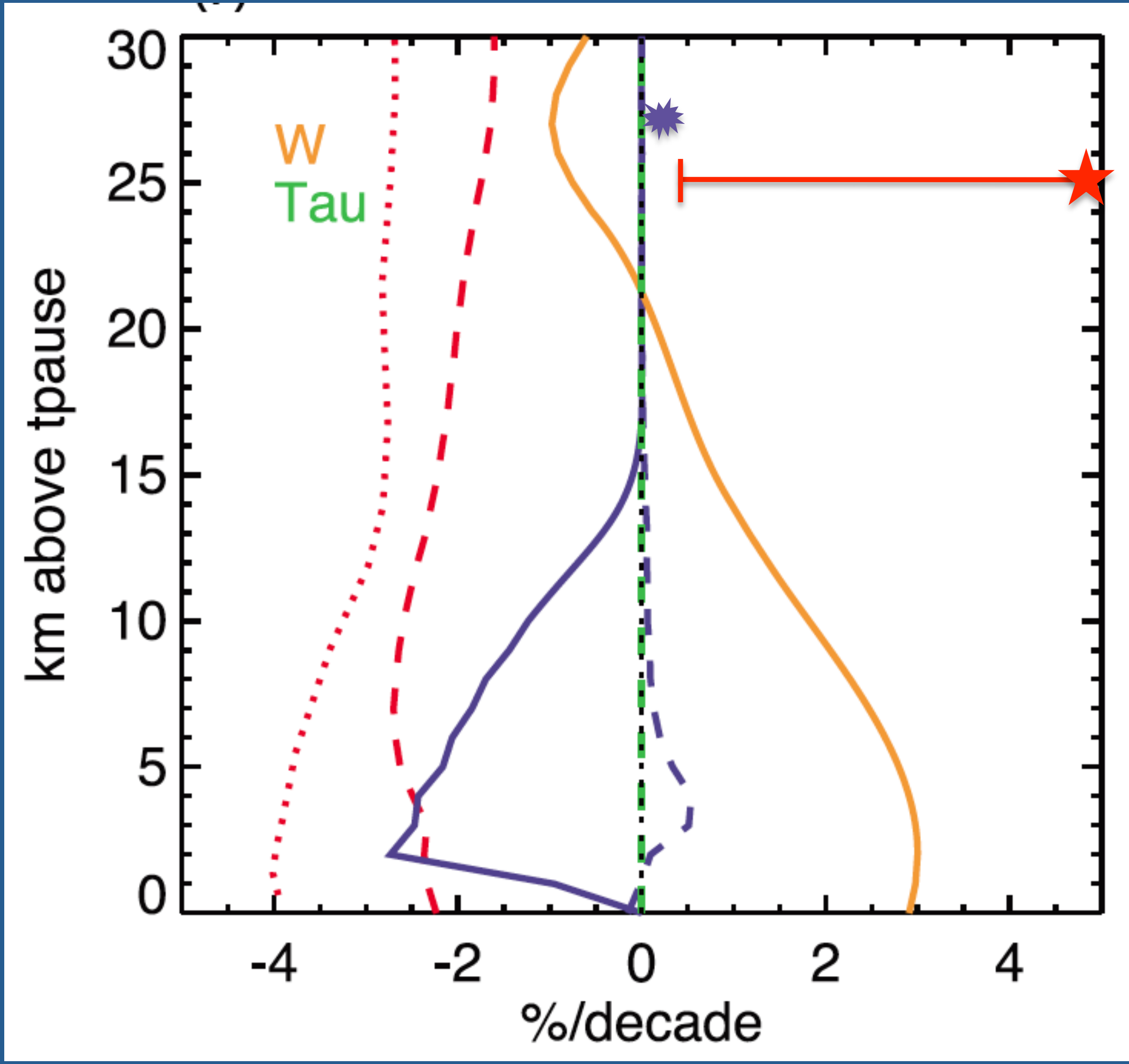
Engel et al., *Nat. Geosci.*,2009;
Ray et al., *JGR*, 2010

Tropical leaky pipe (TLP) model

- Results from Ray et al., JGR, 2010
- Sensitivity of age changes to changes in upwelling, mixing
- **Inputs:**
  – Vertical profiles of changes in upwelling and in-mixing timescale (τ)
- **Outputs:**
  – Changes mean age profiles



TLP model: CCMVal w trend



TLP input:

CCMVal w trend

τ trend

TLP output:

Midlat age trend

Midlat O_3 trend

Tropical O_3 trend

CCMVal age trend

Engel age trend

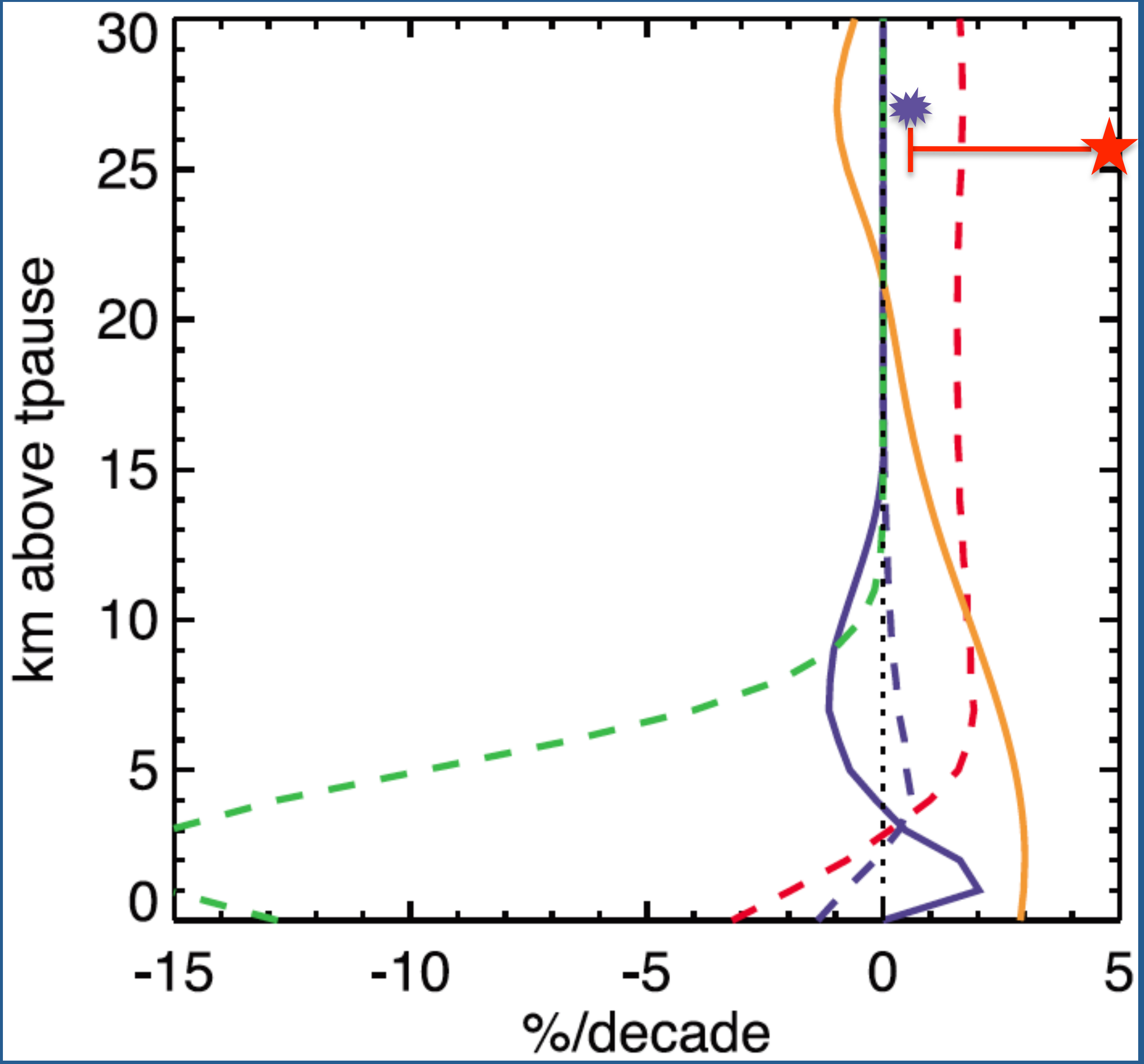
Ray residual O_3 trend (tropics & midlat)

TLP model: CCMVal w trend + NCEP τ trend

TLP input:
CCMVal w trend
τ trend

TLP output:
Midlat age trend
Midlat O_3 trend
Tropical O_3 trend

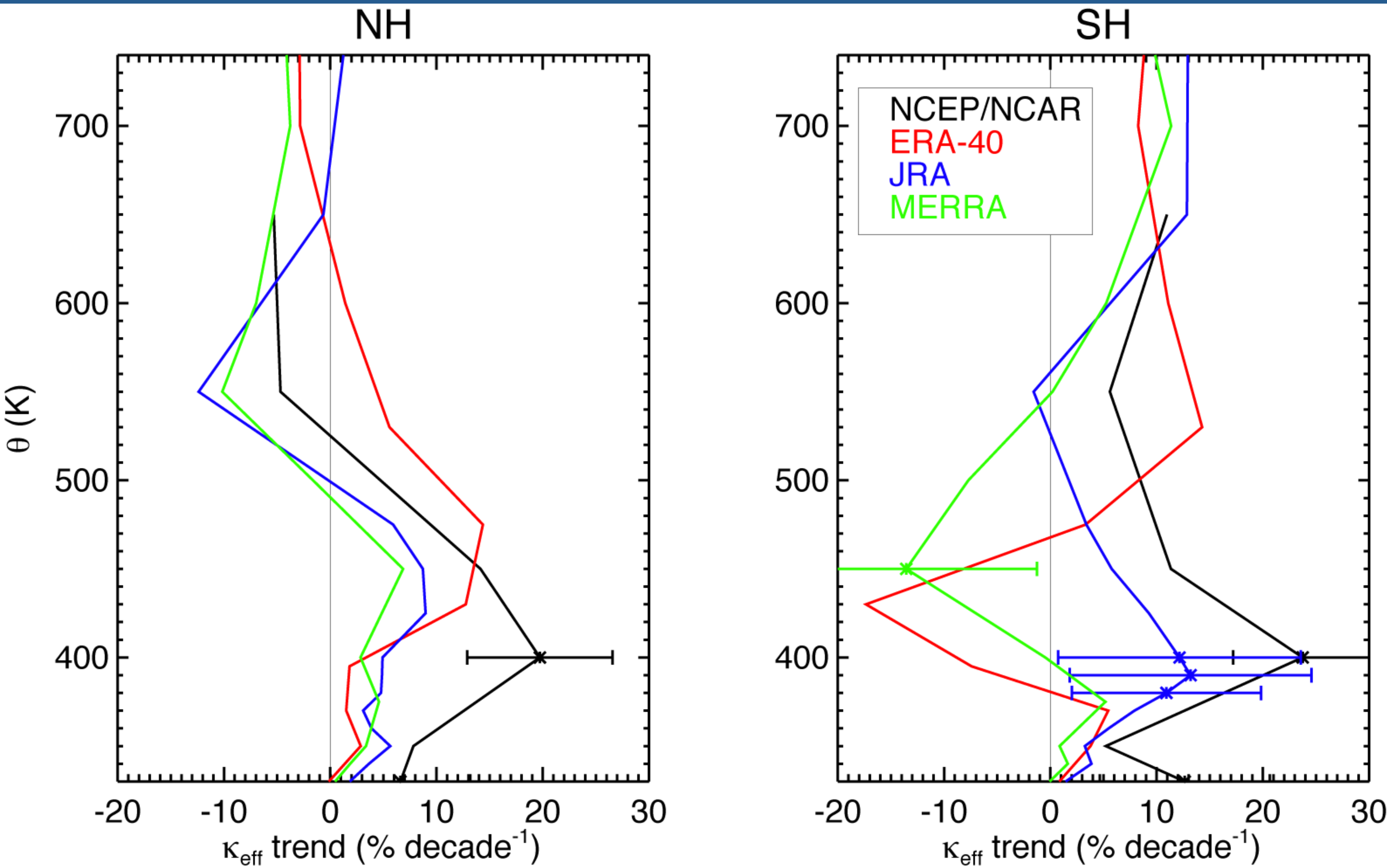
CCMVal age trend
Engel age trend
Ray residual O_3 trend (tropics & midlat)



Summary

- κ_{eff} is a mixing diagnostic that can be calculated directly from reanalysis PV
- κ_{eff} variability seems reasonable, but likely some fundamental differences in between reanaylses in mean state.
- κ_{eff} from reanalysis PV reveals the possibility that mixing has increased between the tropics-midlatitudes, with the big caveats that
  - trends from reanalyses should always be treated with caution
  - trends are not consistent across all reanalyses
  - discontinuities associated w/ observing system changes
- Midlatitude mean age trends are sensitive to mixing trends
  - Increased mixing → increased recirculation → increased age
  - Observed mean age and total O_3 trends are consistent with increases in both upwelling and mixing (Ray et al., 2010)

κ_{eff} trends, ± 10° turnaround lat



TLP model results: CCMVal w trend + inferred τ trend

TLP input:

CCMVal w trend

τ trend

TLP output:

Midlat age trend

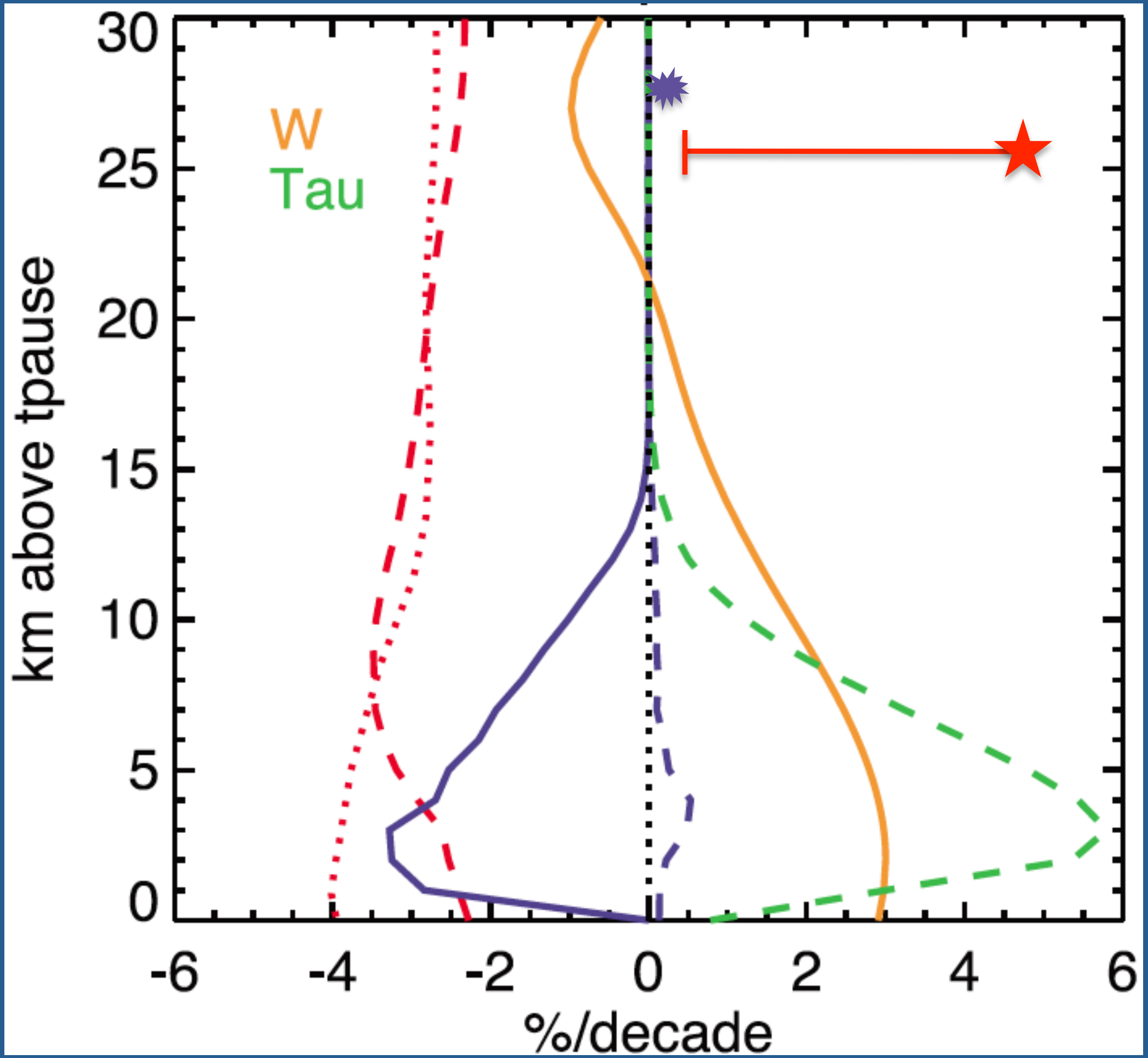
Midlat O_3 trend

Tropical O_3 trend

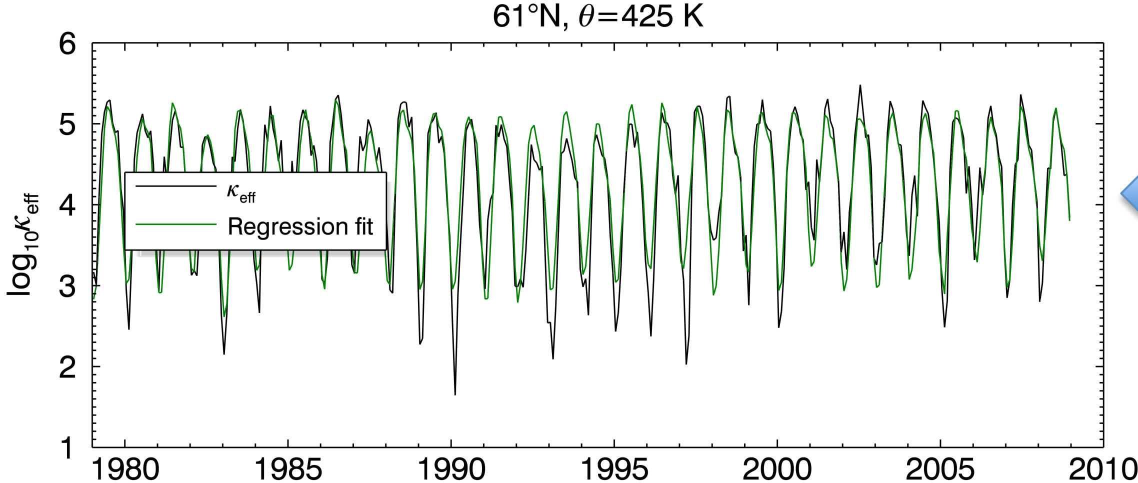
CCMVal age trend

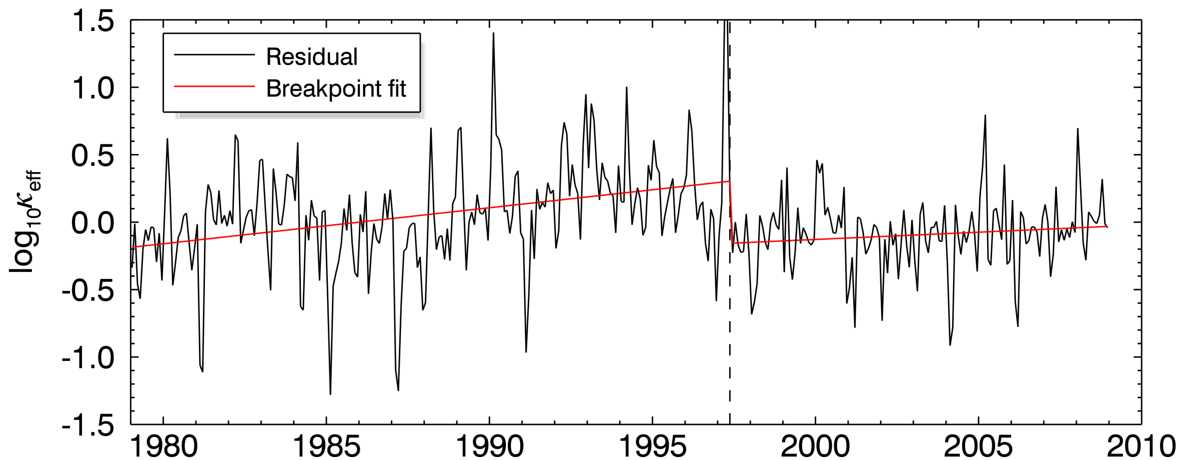
Engel age trend

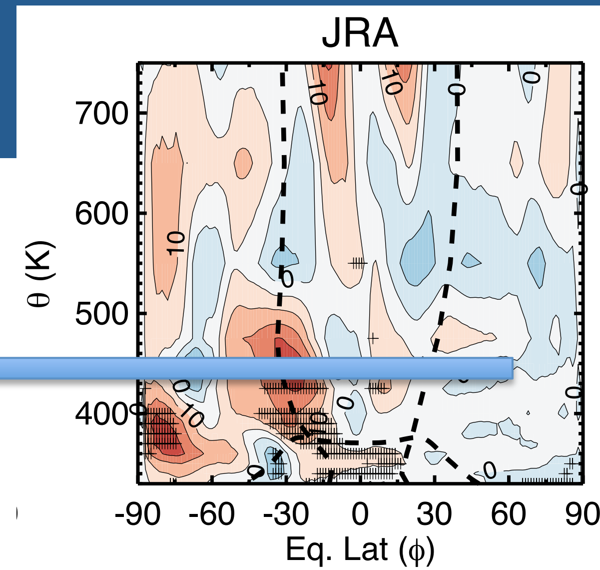
Ray residual O_3 trend (tropics & midlat)



κ_{eff} discontinuities?







- Breakpoint: 5/1997

TLP model results: Sensitivity to τ trend

- Increasing mixing leads to increased age of air, with smaller changes to total O_3