Expansion of the Subtropical Dry Zones

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Expansion of the Subtropical Dry Zones

OBS: Tropical widening has been observed (since 1979). 30-yr trends in DJF $\psi_{500} = 0$ crossing latitude suggest total Hadley cell expansion of ~1°/decade. Trends in DJF P-E = 0 crossing latitude are ~ 0.5°/decade. Reliability of trends is low, there being large differences among re-analyses (Davis and Rosenlof 2012).

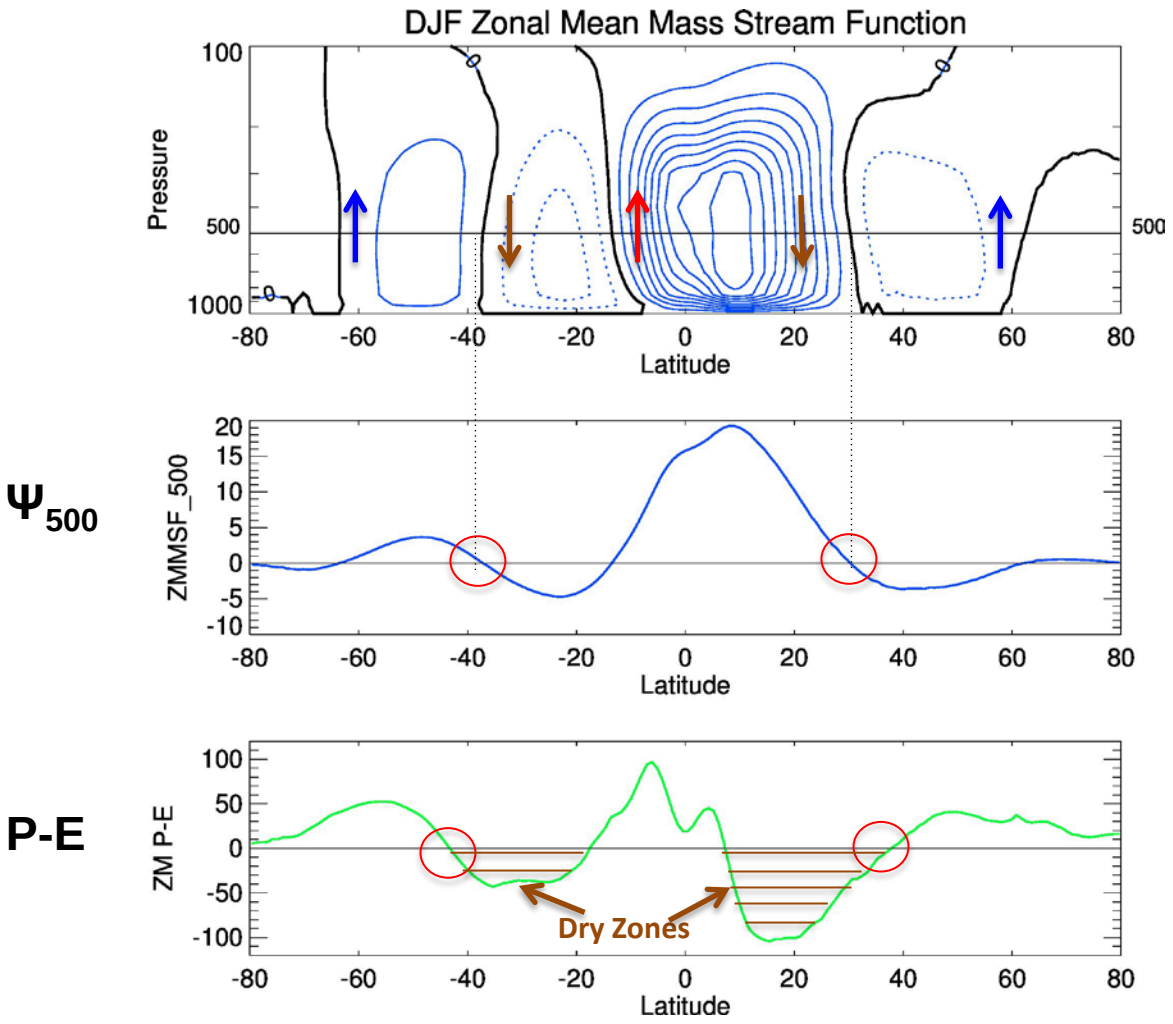
What is the interpretation of re-analysis estimates of Hadley cell expansion since 1979 vis-à-vis inherent *30-yr natural variability* of tropical width?

GCMs: Tropical widening occurs in most 20C simulations of CMIP3, though appreciably less than observed since 1979 (Johanson and Fu 2009).

What is the interpretation of re-analysis estimates of Hadley cell expansion since 1979 vis-à-vis the *forced signal of 30-yr tropical width change*?

(see also Lu et al. 2009; Staten et al. 2011; Polvani et al. 2011; Allen et al. 2012).

Indicators for Tropical Width



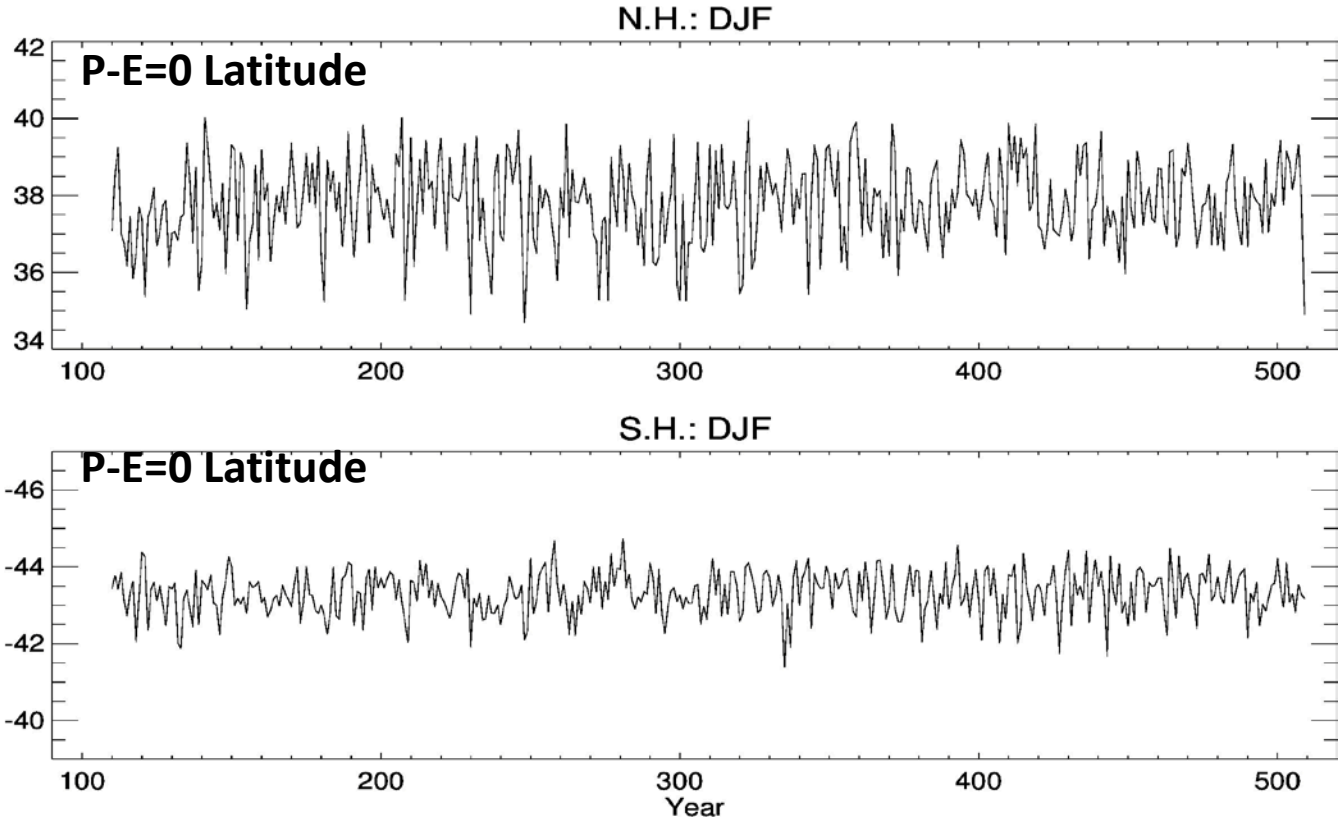
Ψ_{500}

P-E

Q: What is the natural variability of tropical width?

Method:

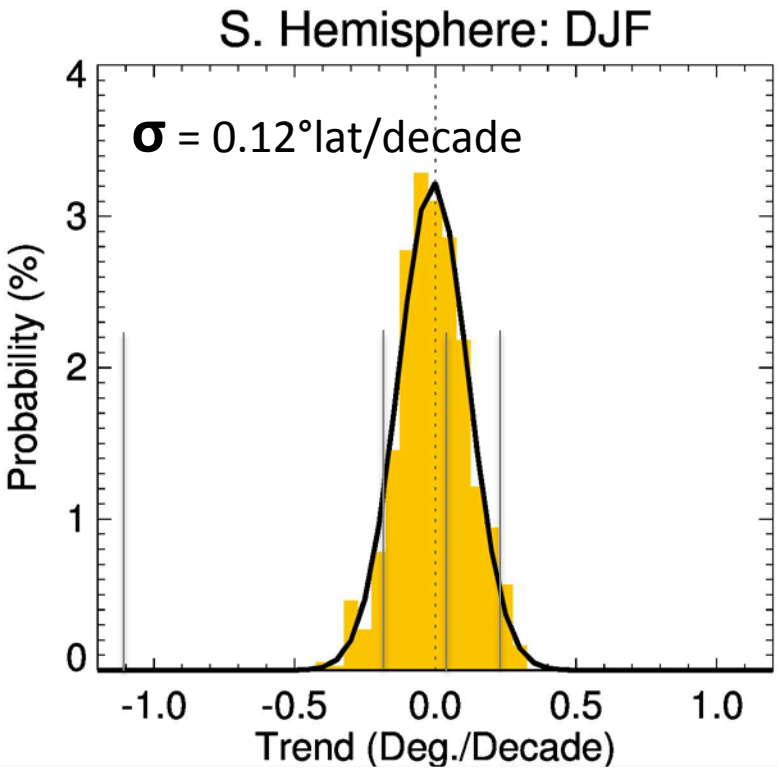
1) Analyze long time series of coupled model simulations
2) Two 500-yr CCSM4 runs----1850 and 2000 radiative forcing
3) Calculate 30-yr trends in (P-E = 0) crossing latitude
4) Results for DJF, for NH and SH separately.

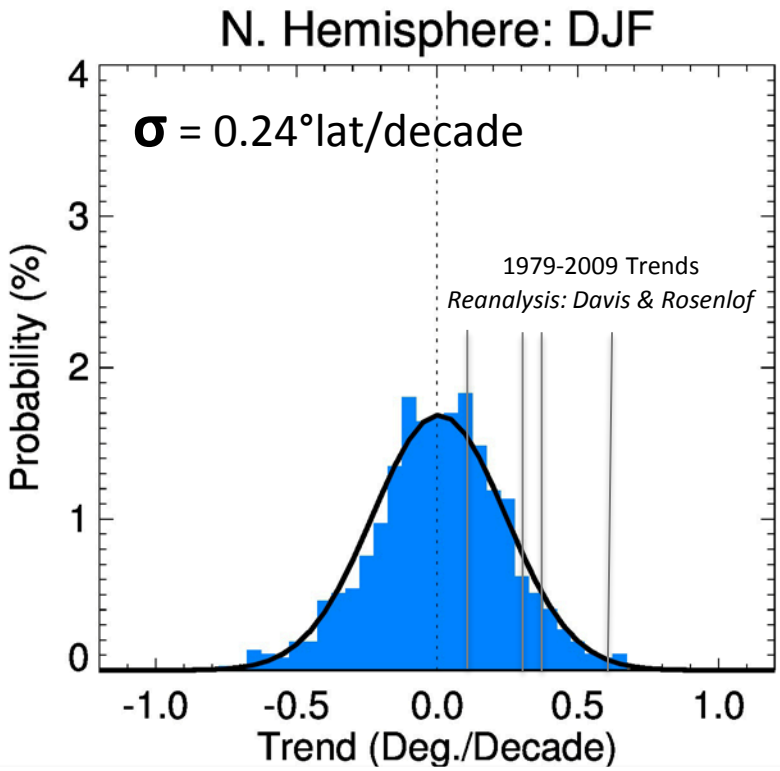


See *Gent et al. (2011)* for a detailed assessment of CCSM4
Simulations Run on NASA-Ames NAS System in Collaboration w/Rama Nemani

Natural Variability in Extent of Subtropical Dry Zones:

30-Yr Trends in (P-E=0) Crossing Latitude





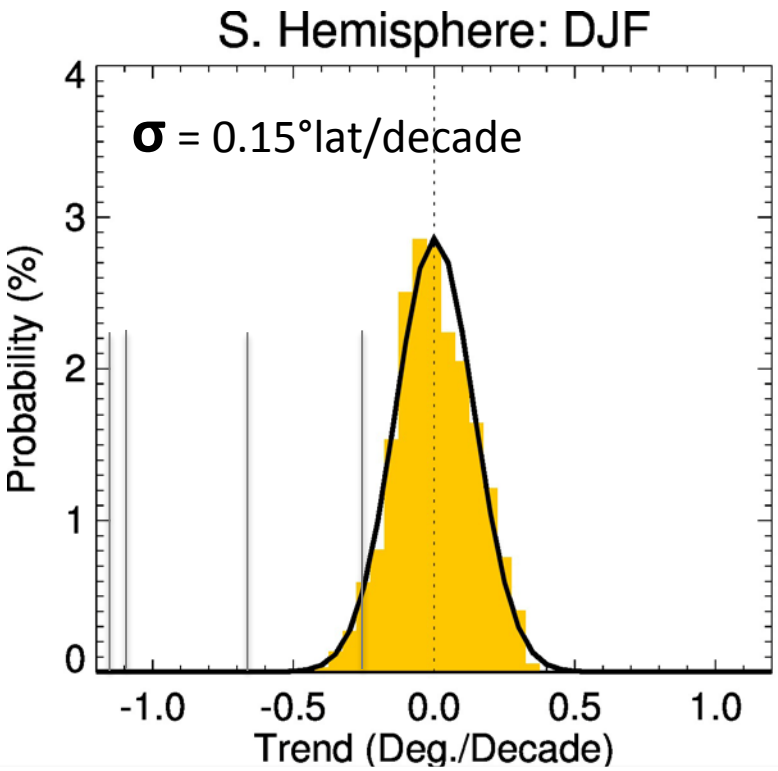
° Reanalysis estimates of 1979-2009 change in extent of subtropical dry zones are mostly within the range of model estimated natural variability

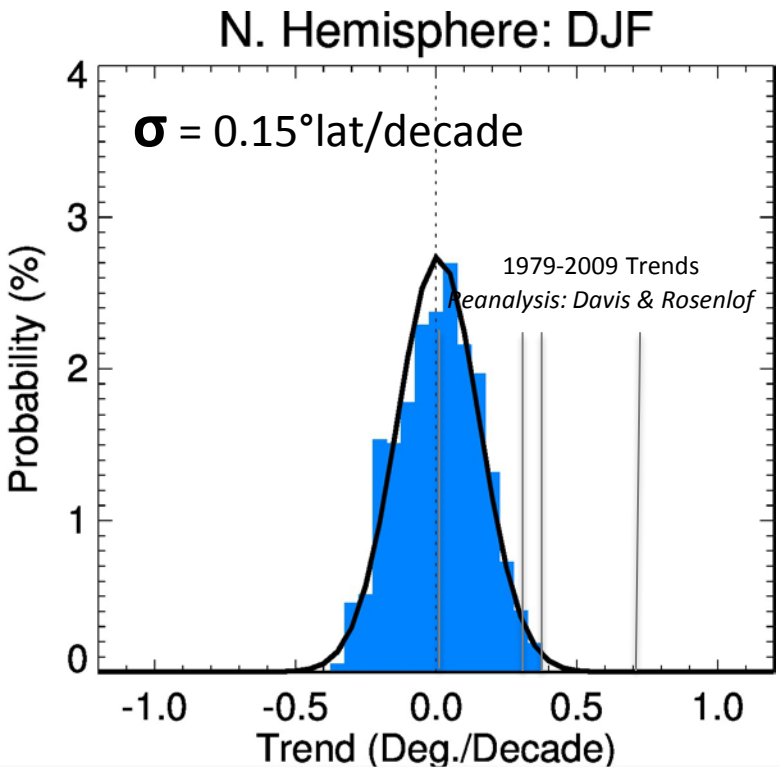
° Cannot reject the hypothesis that the observed DJF expansion of the subtropical dry zones since 1979 may be due mostly to natural variability

° The range in re-analysis estimates of subtropical dry zone change almost spans model PDF

Natural Variability in Extent of Subtropical Dry Zones:

30-Yr Trends $\psi_{500} = 0$ Crossing Latitude





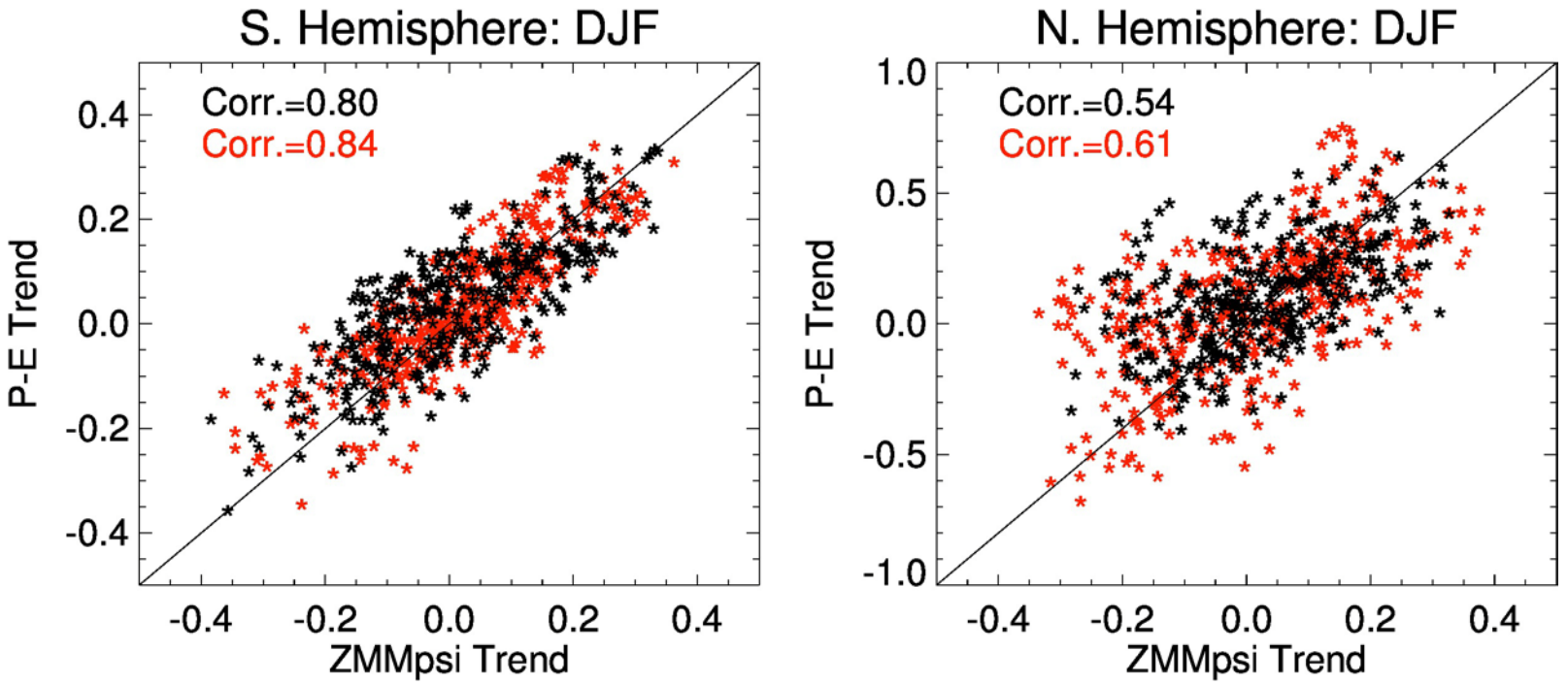
° *Reanalysis estimates of 1979-2009 change in Hadley cell width based on $\psi_{500} = 0$ are mostly <u>beyond the range</u> of model estimated natural variability*

° *Implication is that the observed DJF expansion of Hadley cell width since 1979 is unlikely consistent with natural variability, alone.*

° *The range in re-analysis estimates of Hadley cell width change almost spans the model PDF*

Comparing 30-Yr Trends in (P-E = 0) vs $\psi_{500} = 0$ Crossing Latitudes

(X and Y-axes display °/decade)



Based on analysis of consecutive 30-yr trends in CCSM4 Yr1850 and Y2000 equilibrium simulations

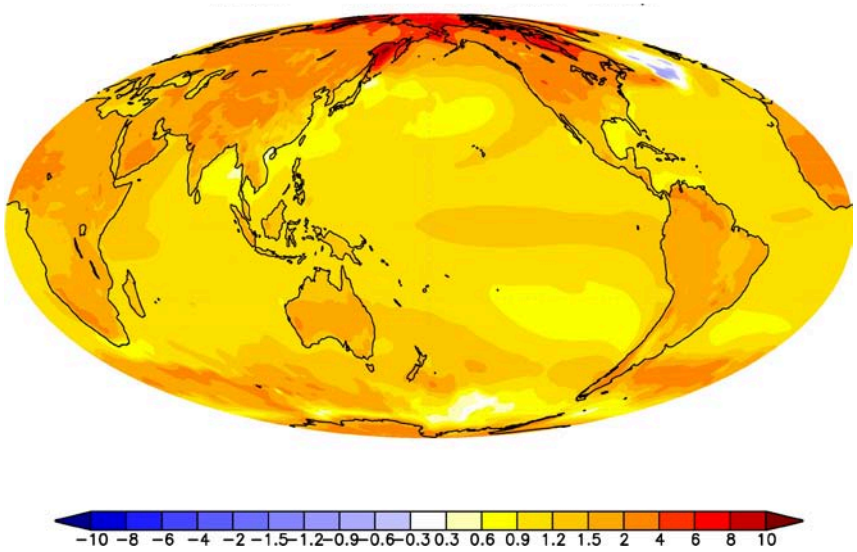
° Coherence among (P-E = 0) vs $\psi_{500} = 0$ trends on 30-yr time scales, especially strong in the SH.

° The appreciable difference in Reanalysis (P-E = 0) vs $\psi_{500} = 0$ SH trends during 1979-2009 is a further symptom of unreliability of the reanalysis products.

Radiatively Forced Change in Extent of Subtropical Dry Zones

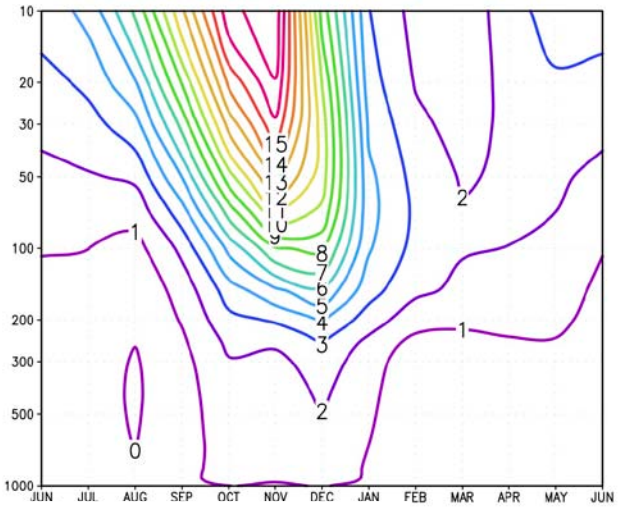
CCSM4 Equilibrium Response

DJF SfcT Response



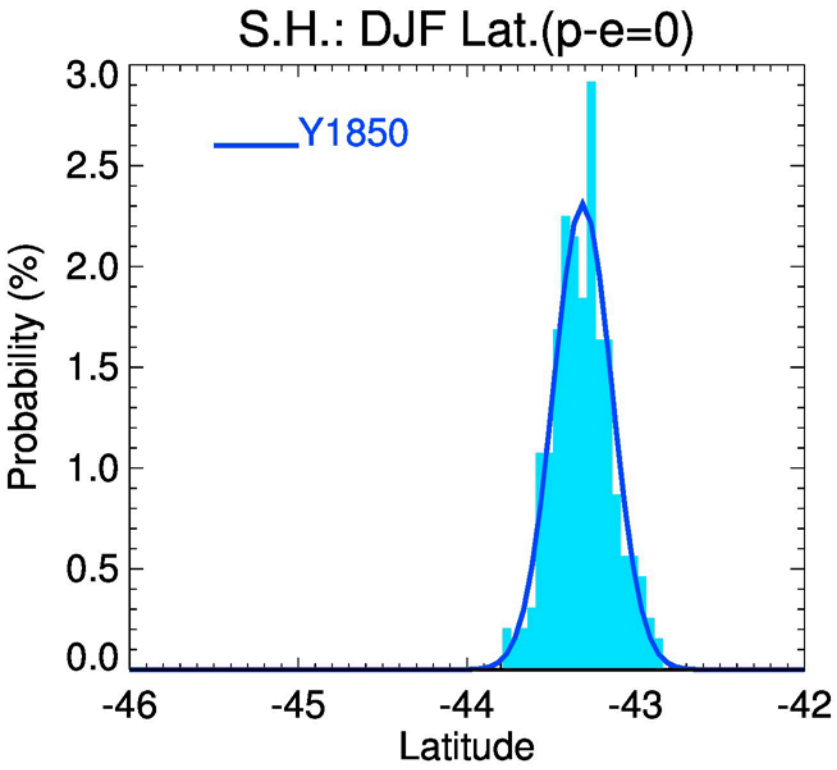
~ 1.6°C Global Avg Sfct Warming

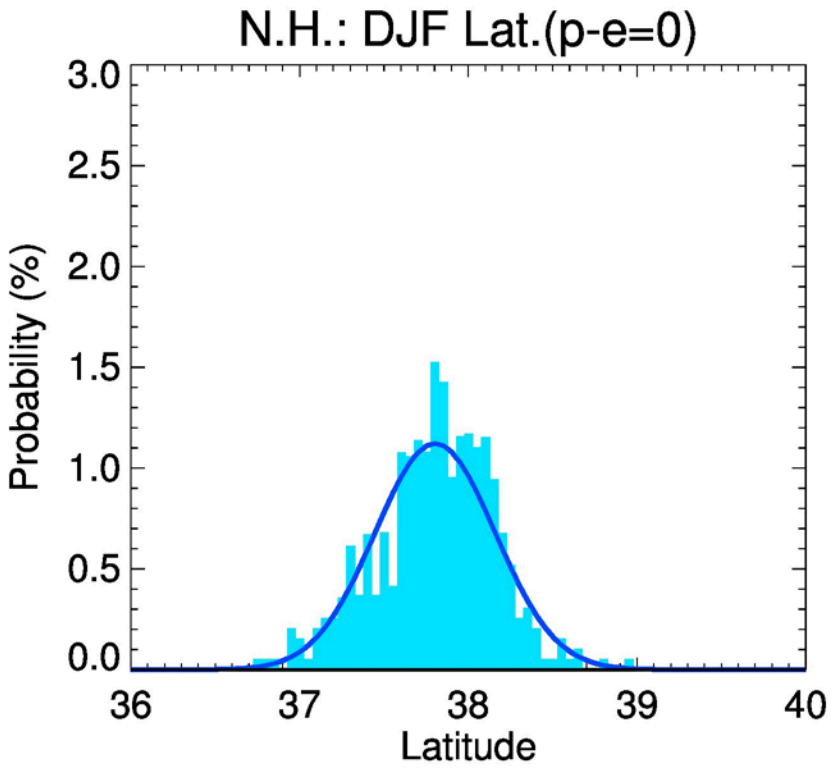
SH Zonal Wind Response: 60°S



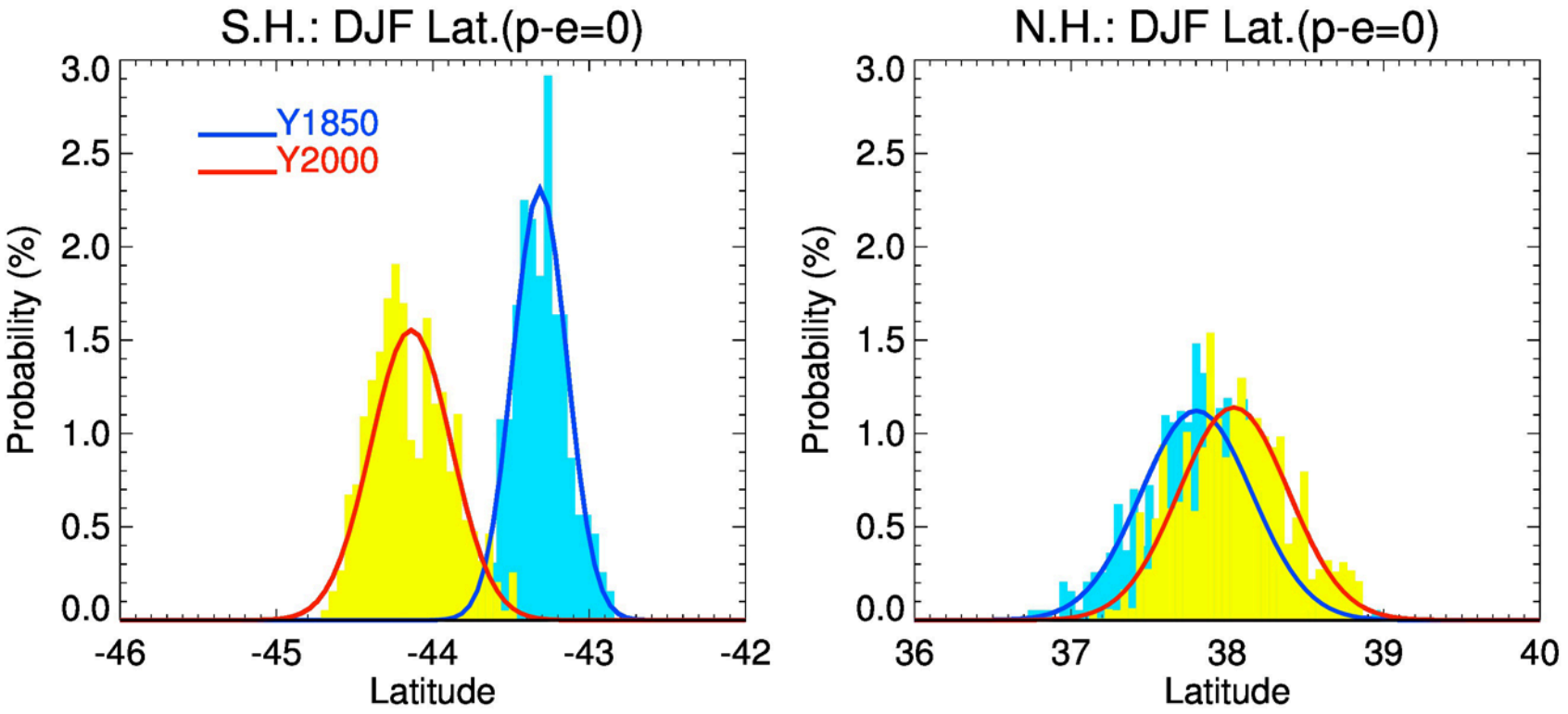
Stengthened SH Stratospheric Westerlies

Q2 : What is the Sensitivity of Tropical Width to Radiative Forcing?





Q : What is the Sensitivity of Tropical Width to Radiative Forcing?



- *Poleward migration of the subtropical dry zone occurs in both hemispheres*
- *CCSM4 Simulated equilibrium response is ~0.3° in NH and ~1.0° in SH*
- *Higher (lower) detectability of SH (NH) forced signal of tropical widening*

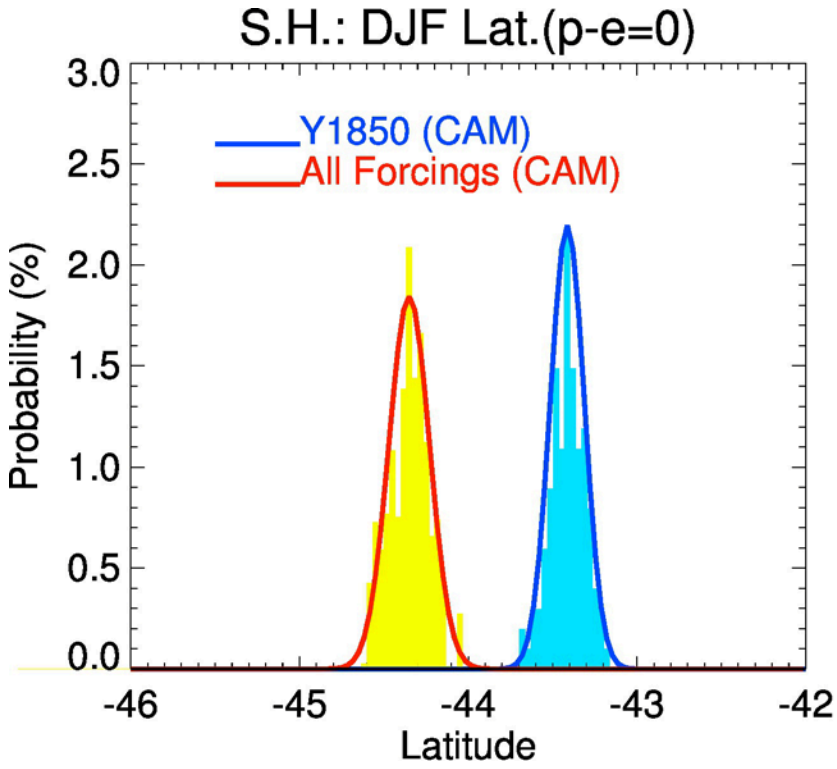
Q: What physical processes drive tropical widening in response to radiative forcing?

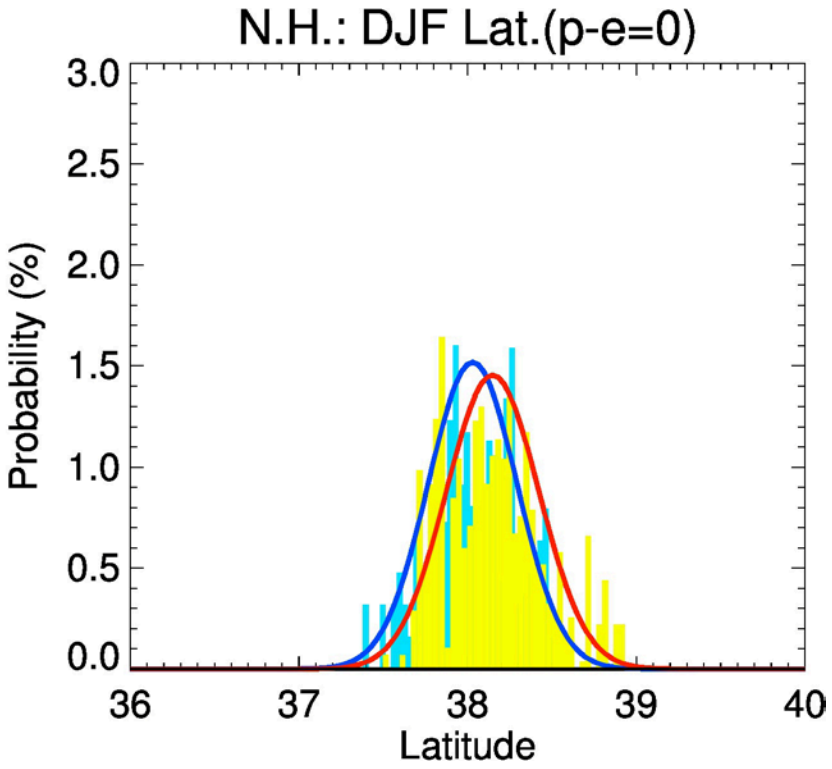
Method:

1) Specify the 1850 to 2000 boundary forcing changes in AGCM
2) Suites of 100 yr CAM4 simulations:

° *Assess Impacts of Direct Radiative Forcing vs SST/sea ice change*

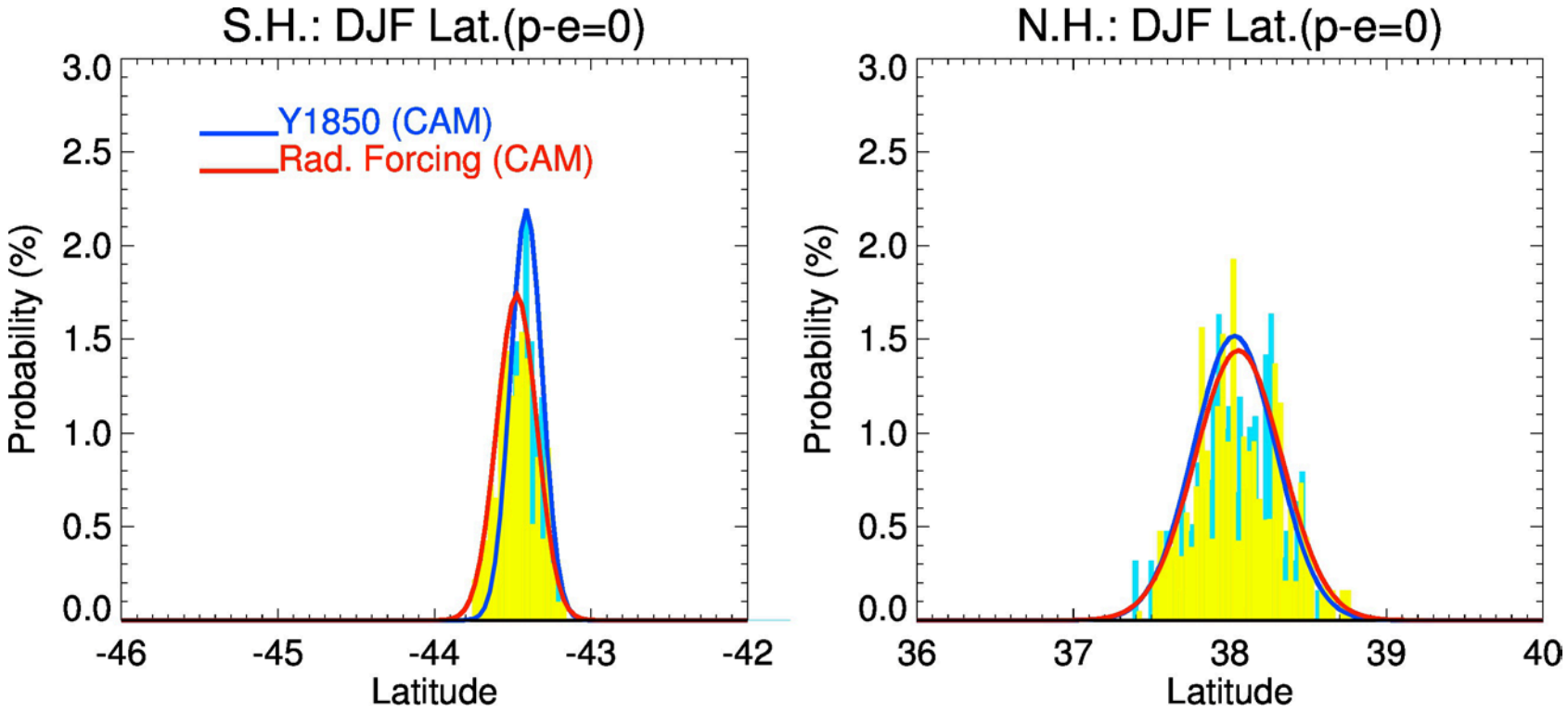
Assessing Suitability of AGCM Method





° CAM4 simulations, using specified SST, sea ice, and radiative forcing changes, reproduce key features of the CCSM4 response to the same radiative forcing in coupled mode

Physical Process : Direct Radiative Forcing

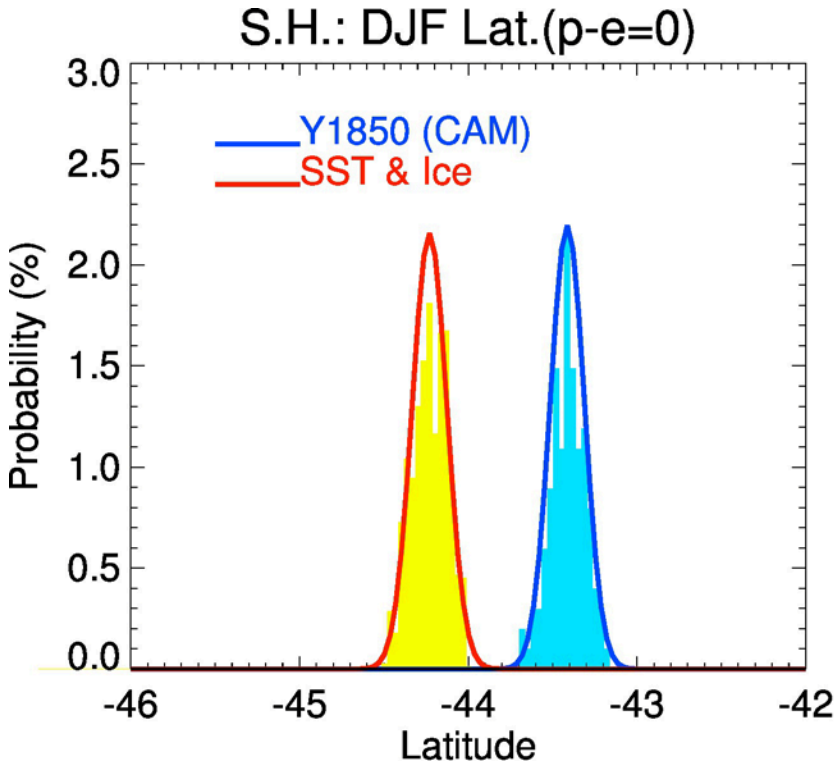


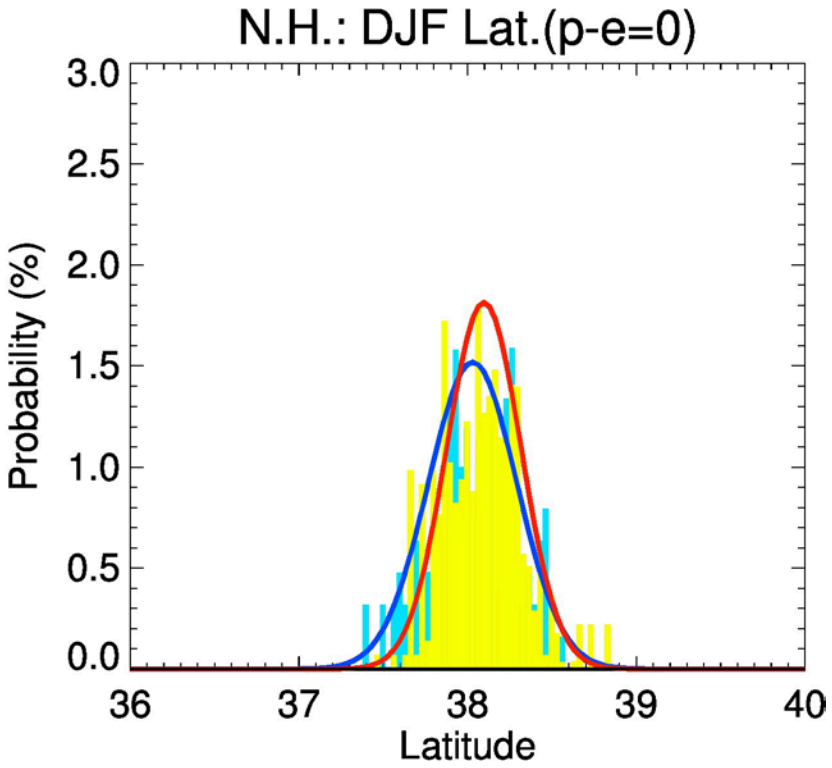
° Direct radiative forcing induces little appreciable tropical widening.

° Result differs from Lu et al. (2009) who use a tropopause metric of the tropical belt.

° Result consistent with Staten et al. (2011) who use a P-E metric

Physical Process : SST/Sea Ice Change





° SST/sea ice changes are the principal causes for tropical widening in CCSM4

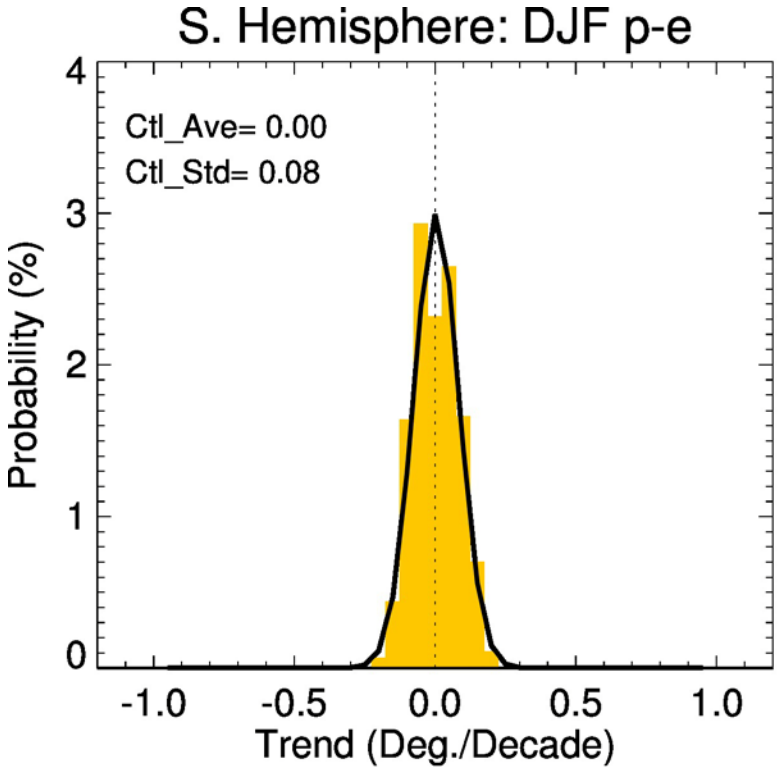
° Consistent with Staten et al. (2011)

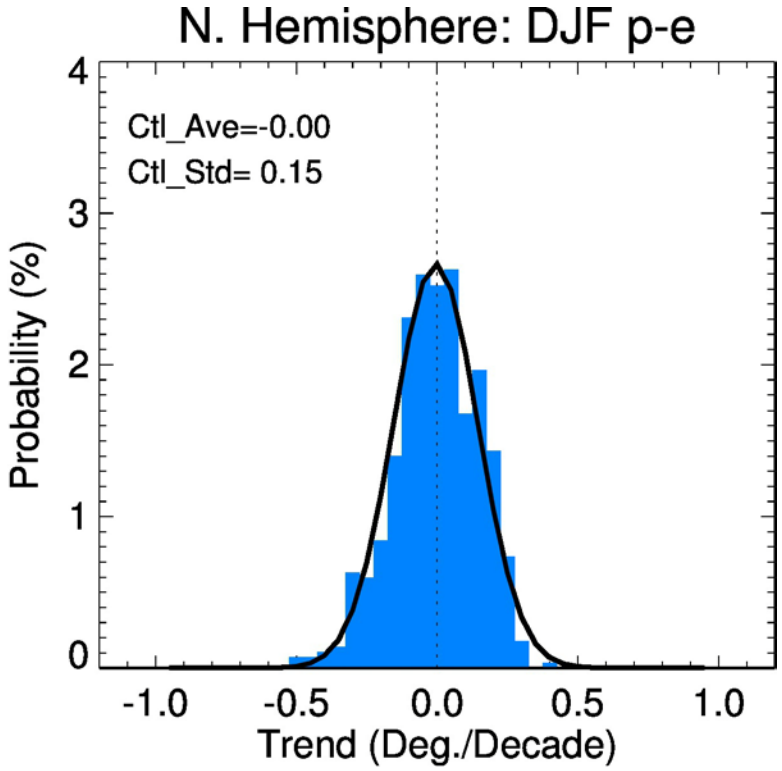
Q: What are the most likely causes for the "observed" tropical widening since 1979?

Method:

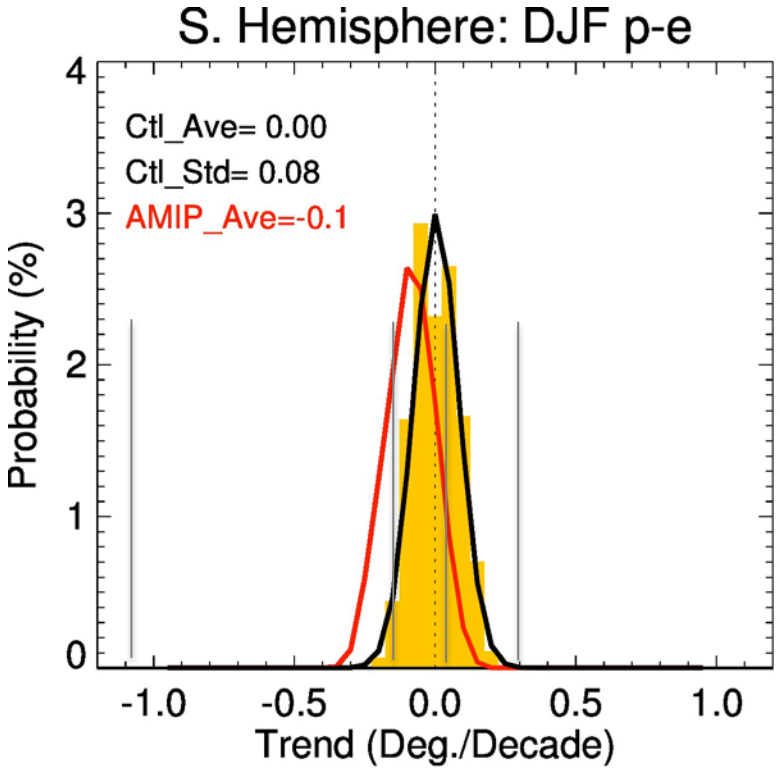
1) Specify OBS monthly varying SST, sea ice, and radiative forcing in CAM4
2) Perform 20-member ensemble, from January 1979-December 2012
3) Repeat, but w/o variability in radiative forcing
4) 600-yr CAM4 control run w/o variability in boundary or radiative forcing.

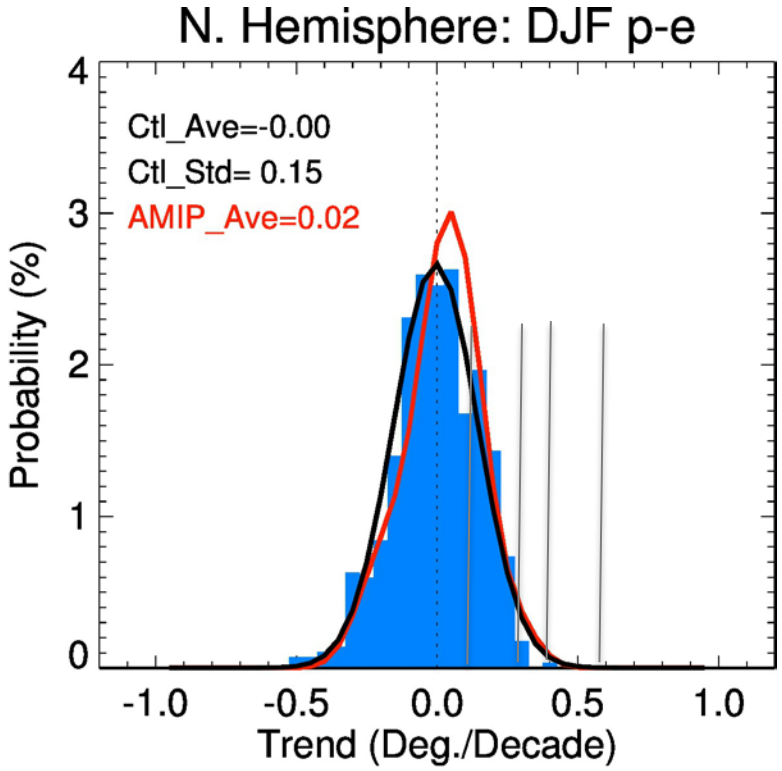
° *Assess the Simulated 1979-2009 Trends in Tropical Width*
° *Provide a Signal-to-Noise Assessment of 1979-2009 30-yr Trends*
° *Assess the Effect of SST/sea ice Variations Alone.*


S. Hemisphere: DJF p-e
Ctl_Ave= 0.00
Ctl_Std= 0.08
Probability (%)
0
1
2
3
4
-1.0
-0.5
0.0
0.5
1.0
Trend (Deg./Decade)


N. Hemisphere: DJF p-e
Ctl_Ave=-0.00
Ctl_Std= 0.15
Probability (%)
0
1
2
3
4
-1.0
-0.5
0.0
0.5
1.0
Trend (Deg./Decade)

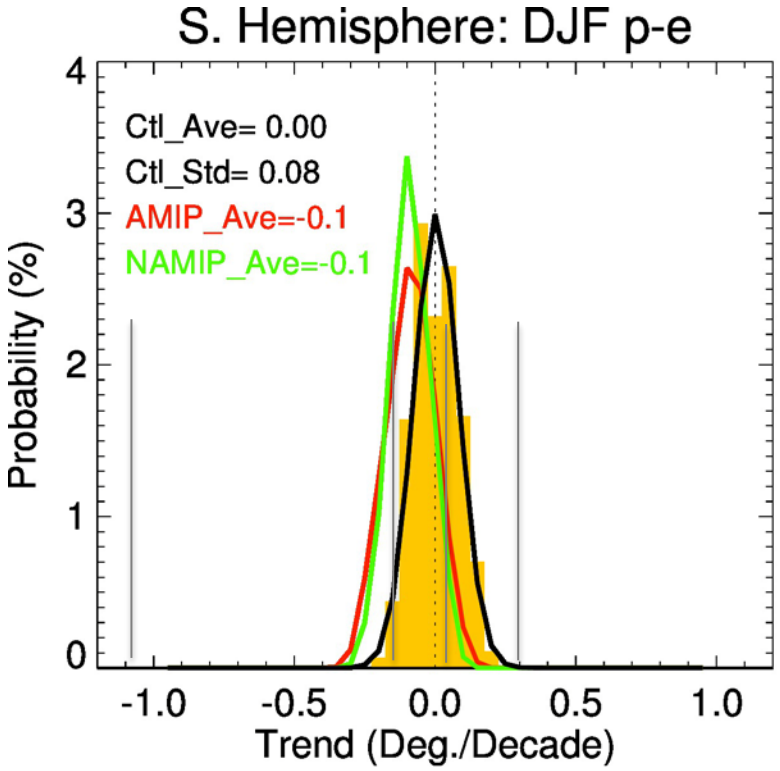
Assessment of the 1979-2009 Expansion of Subtropical Dry Zones Fully-Forced CAM4 Simulations

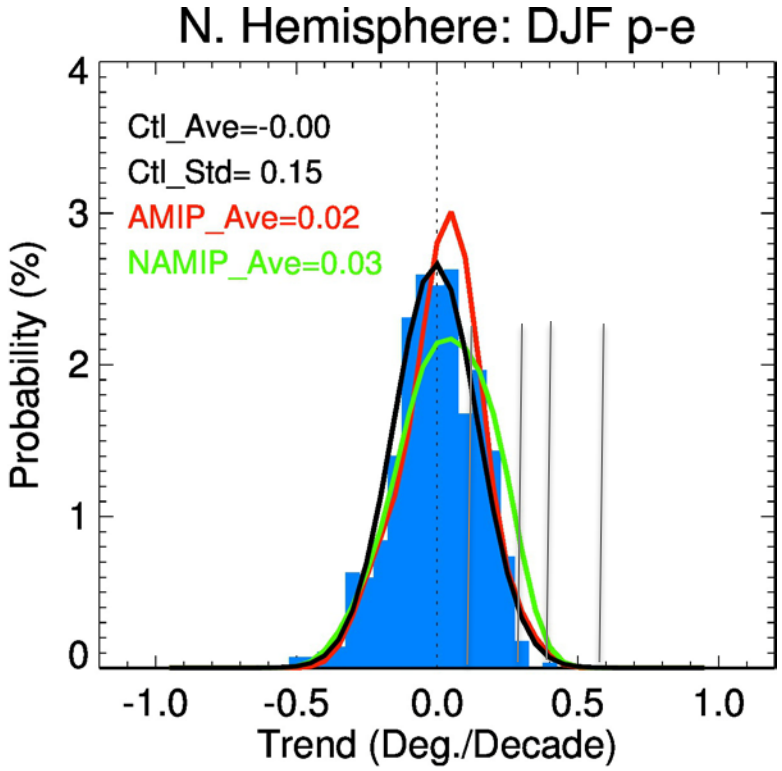




- *Forced poleward shift of the subtropical dry zone occurs in both hemispheres*
- *Mean response is ~0.02°/decade in NH and ~0.1°/decade in SH*
- *SH force signal is more detectable that the NH forced signal*

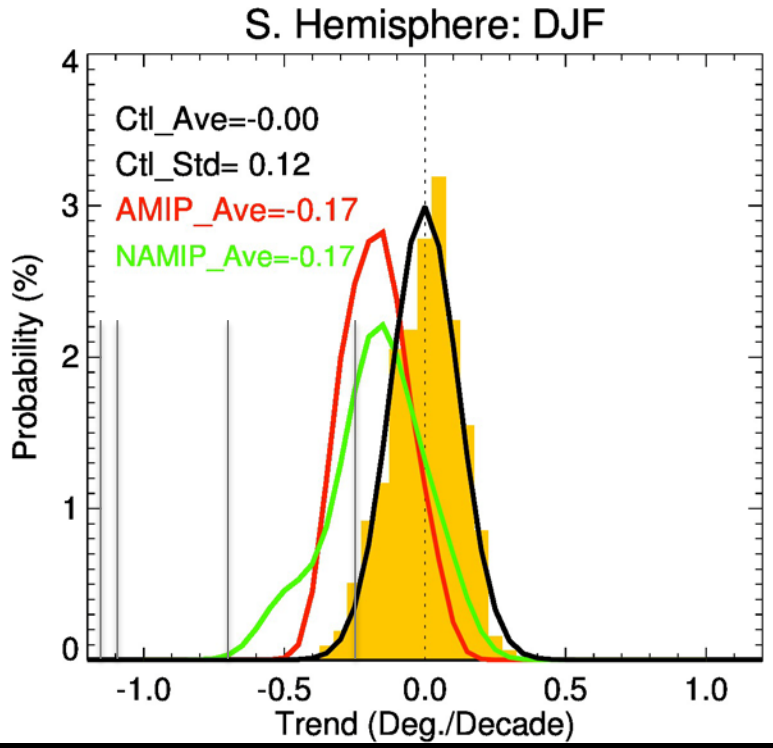
Assessment of the 1979-2009 Expansion of Subtropical Dry Zones SST/sea ice-Forced CAM4 Simulations

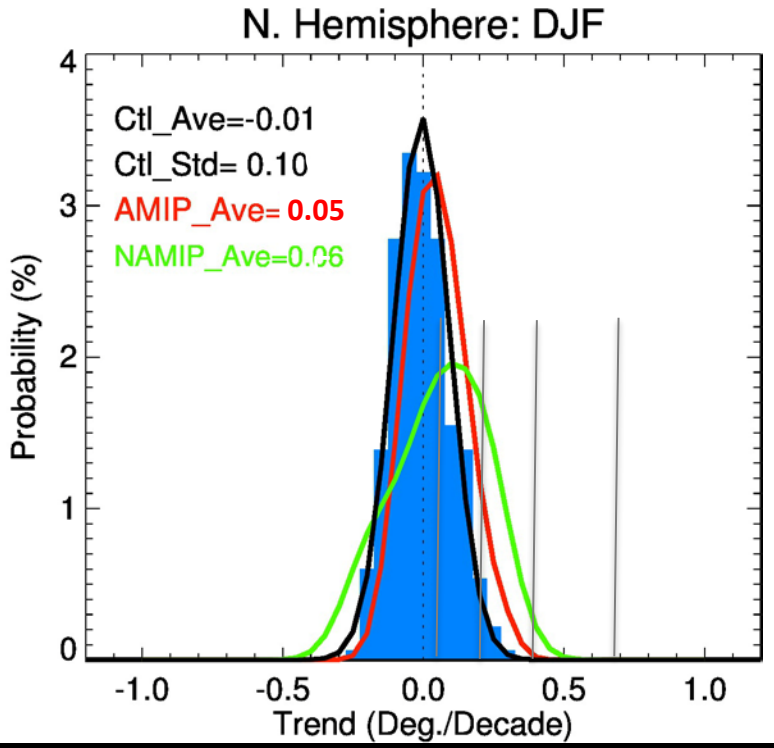




° *The forced signal of 1979-2009 expanded subtropical dry zones is almost entirely due to sensitivity to the observed SST/sea ice change*

Assessment of the 1979-2009 Hadley Cell Expansion ($\psi_{500} = 0$ Crossing Latitude)
Fully-Forced CAM4 Simulations





- *Forced poleward shift of the subtropical dry zone occurs in both hemispheres*
- *Mean response is ~0.05°/decade in NH and ~0.17°/decade in SH*
- *SH force signal is more detectable that the NH forced signal*

Interpretation of Main Findings

(i) *Concerning Re-analysis Estimates*

- Re-analysis estimates of DJF poleward expansion of subtropical dry zones (*P-E=0*), and poleward expansion of the Hadley Cell ($\psi_{500} = 0$) since 1979 are unreliable ---- we find several to be inconsistent with statistical distributions of 30-yr trends occurring in climate model simulations with and without forcing.

- The range among Re-analysis estimates of the poleward expansion of subtropical dry zones (*P-E=0*), and poleward expansion of the Hadley Cell ($\psi_{500} = 0$) since 1979 span PDFs of simulated 30-yr trends occurring due to internal variability alone– we find re-analysis uncertainty to greatly exceed the inherent noise of 30-yr trends.

Interpretation of Main Findings

(ii) Concerning the Forced Signal of Change 1979-2009

- A forced signal of ***expanded*** subtropical dry zones *(P-E=0)* in DJF is found in our simulations: Total change is ~0.12° latitude/decade during the 1979-2009 period. The SH signal is larger than the NH signal, and is likewise more detectable.

- A forced signal of ***expanded*** Hadley Cell $(\psi_{500} = 0)$ in DJF is found in our simulations: Total change ~0.22° latitude/decade during the 1979-2009 period. The SH signal is larger than the NH signal, and is likewise more detectable.

- Global SST/sea ice variability is shown to be the principle driver of the poleward expansion of subtropical dry zones, and the increasing Hadley cell width since 1979.