A link between the hiatus in global warming and North American drought

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1. Observed hiatus and review of proposed contributing factors

2. Role of Pacific decadal-scale wind stress changes for:

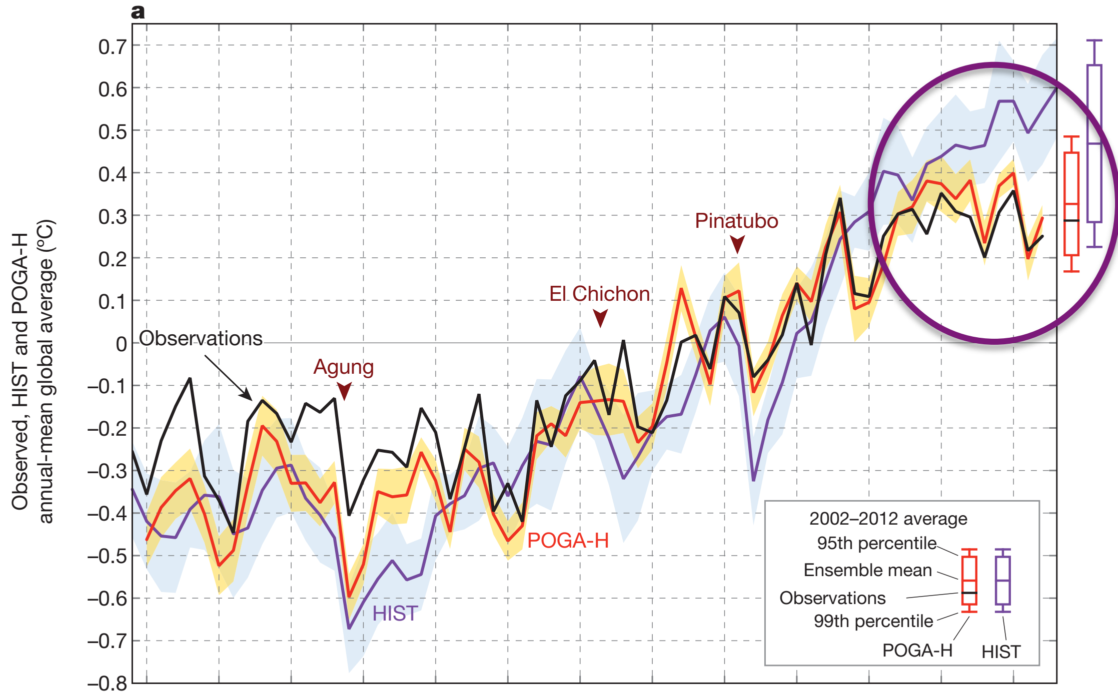
- **a. Pacific ocean changes**
- **b. Hiatus in warming**
- **c. Upper tropospheric changes**
- **d. North American decadal-scale drought and temperature**

3. Summary, discussion, unresolved issues

Kosaka and Xie, 2013: Major role of tropical Pacific SSTs for the hiatus

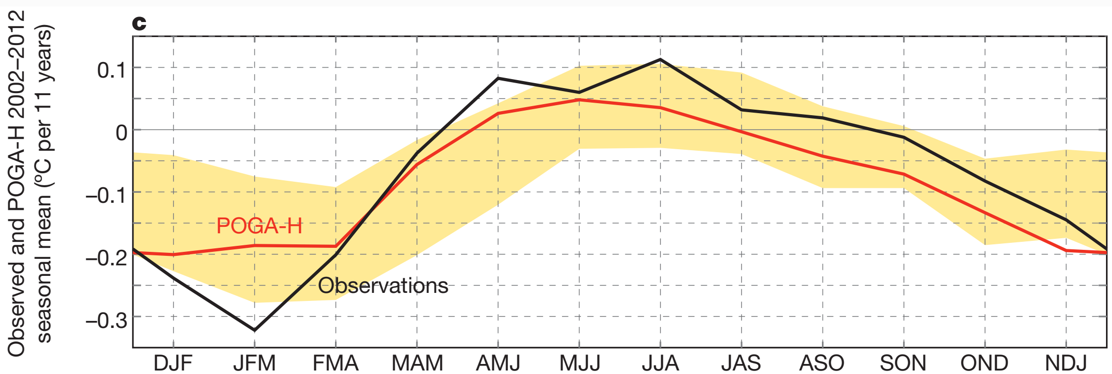
Suite of experiments using GFDL CM2.1 model, with SSTs over the tropical eastern Pacific strongly damped to observations

HIST: CM2.1 with all radiative forcings
POGA-H: same as HIST, but prescribe SST in trop east Pac



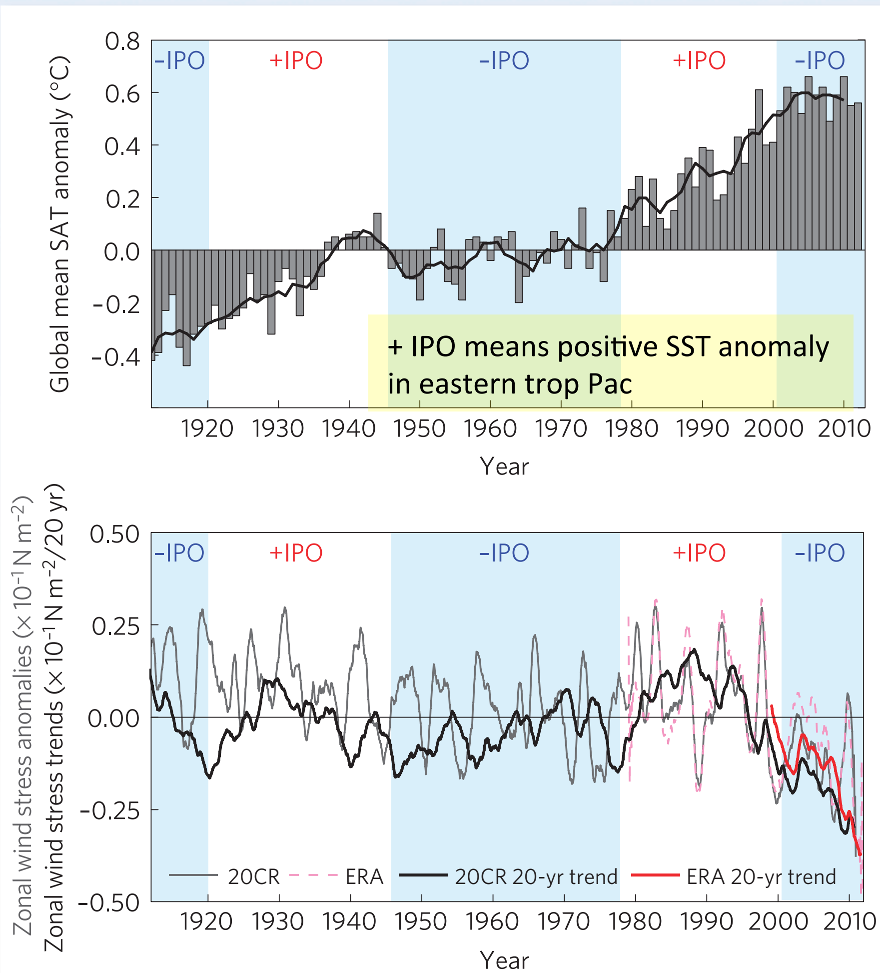
Key points:

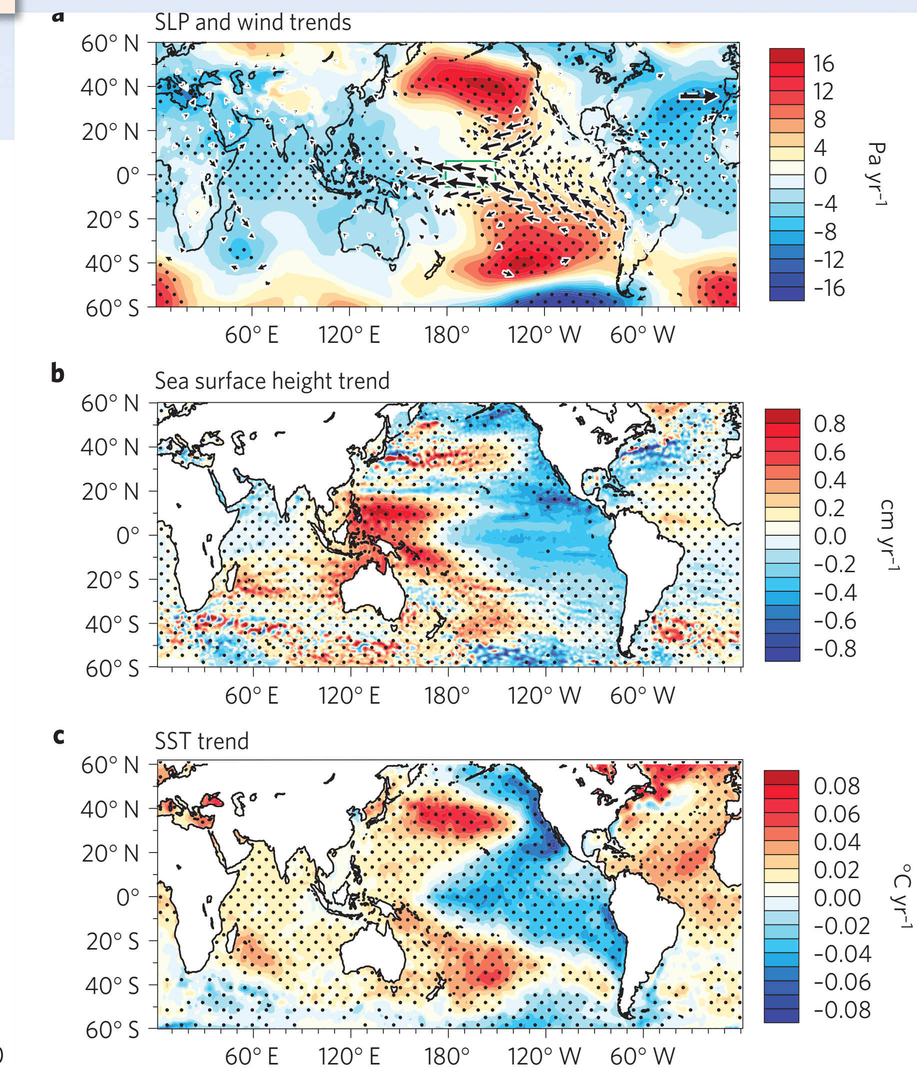
- *eastern tropical Pacific is critical*
- *seasonality of SST impact*

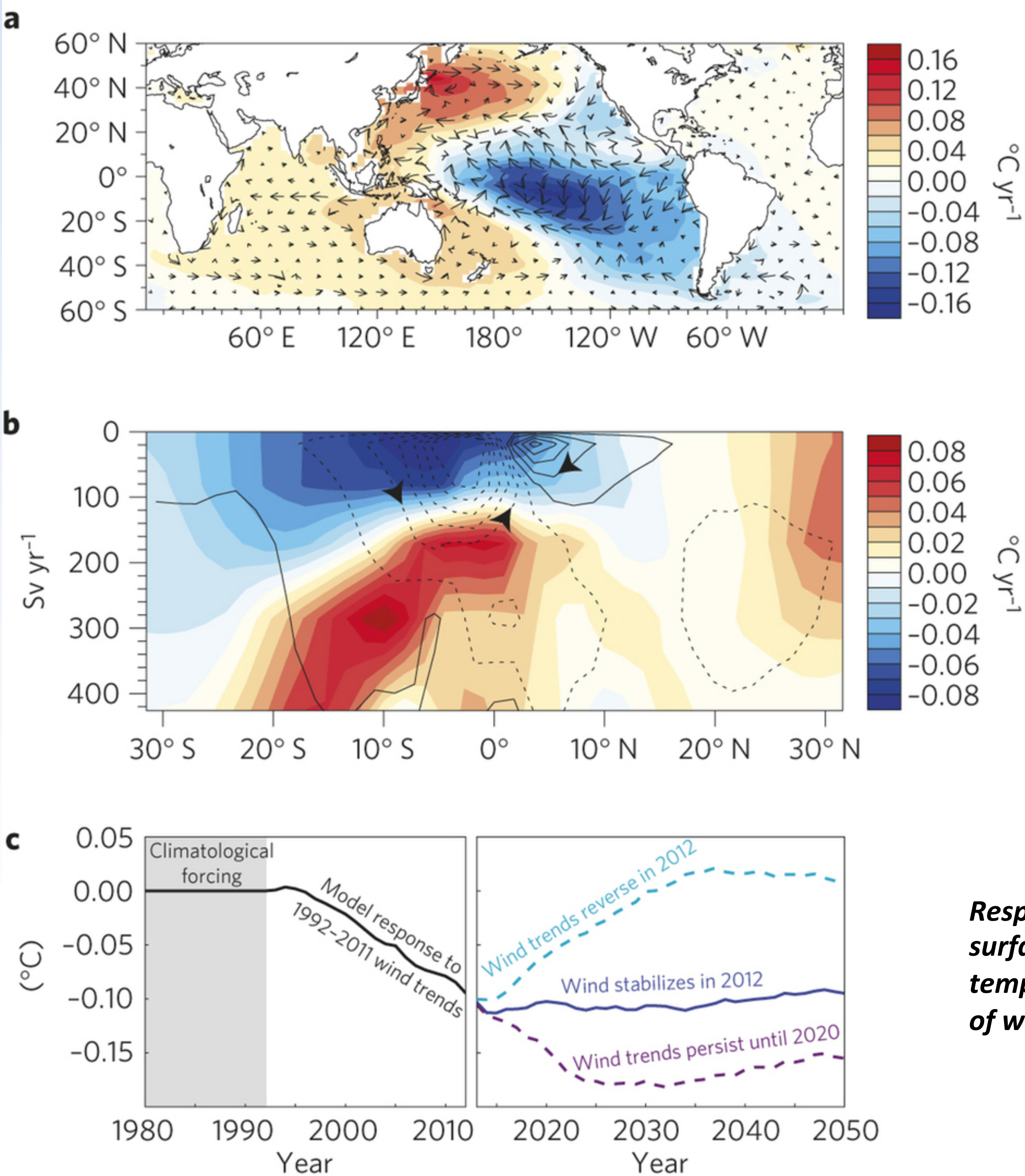


England et al (2014) advanced the idea of the role of the Pacific in the hiatus – role of decadal scale wind stress changes

Linear trends, 1992-2011





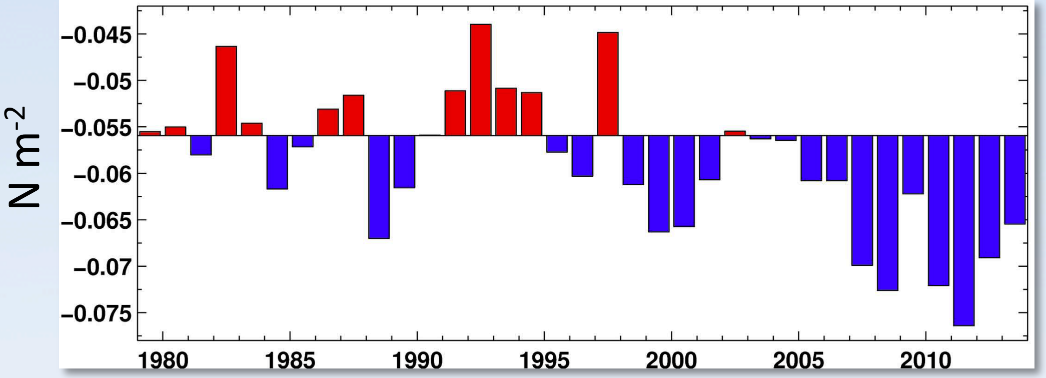


SST (color shading) and surface current response to imposed trend of wind stress

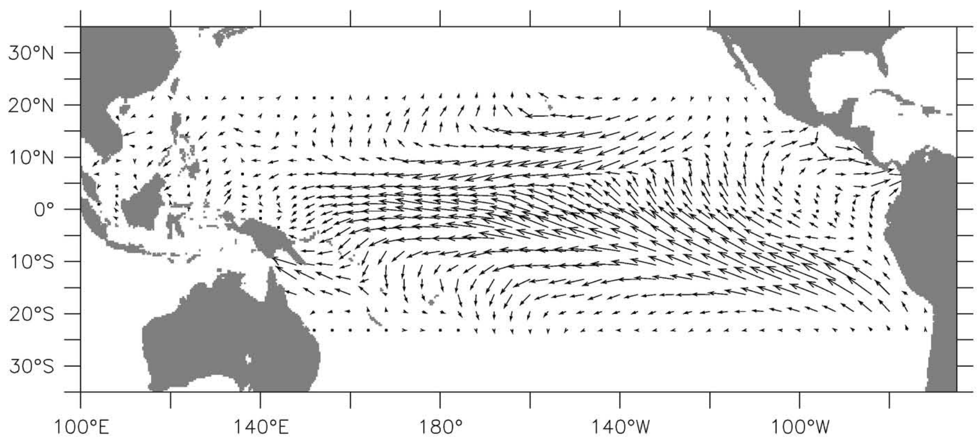
Ocean temperature (color shading) and circulation response in Pacific to imposed trend of wind stress

Response to global mean surface air temperature temperature to imposed trend of wind stress

Model used: CSIRO Mk3L
Atmosphere: 5.6° X 3.2°, 18 levels
Ocean: 2.8° X 1.6°, 21 levels

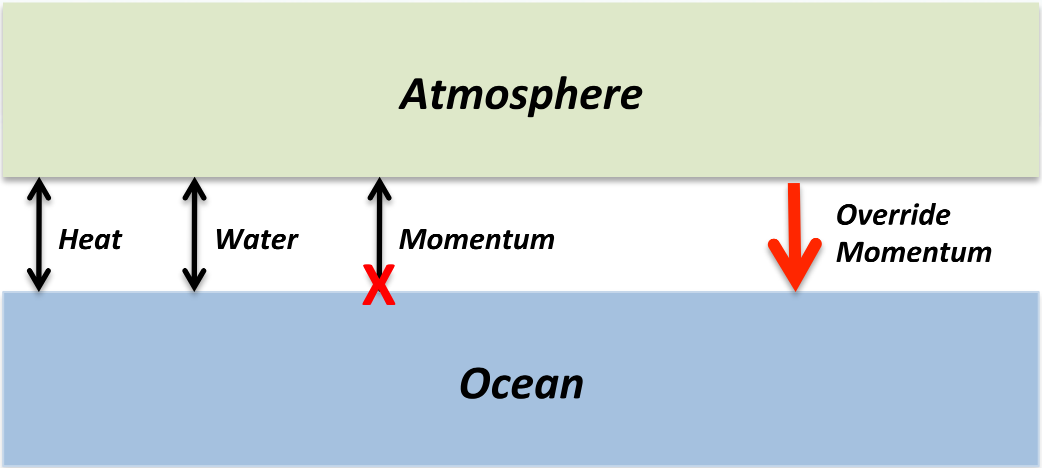


Time series of annual mean wind stress in central Pacific [ECMWF-Interim]



Spatial pattern of wind stress differences: 2002-2012 minus 1979-1996 [ECMWF]

Goal: Evaluate the climatic impact of observed interannual to decadal variations in tropical Pacific wind stress



The ocean model in the tropical Pacific "feels" wind stresses computed as follows:

Override wind stress = High frequency + Seasonal cycle + Interannual variations

Use arbitrary sequence of daily wind stress values after high-pass 30-day filter

Use mean seasonal cycle from model

Use interannual variations of wind stress from ECMWF-Interim reanalysis

In addition to a 1000 year control simulation, we use three 10-member ensembles of experiments with the GFDL CM2.1 model:

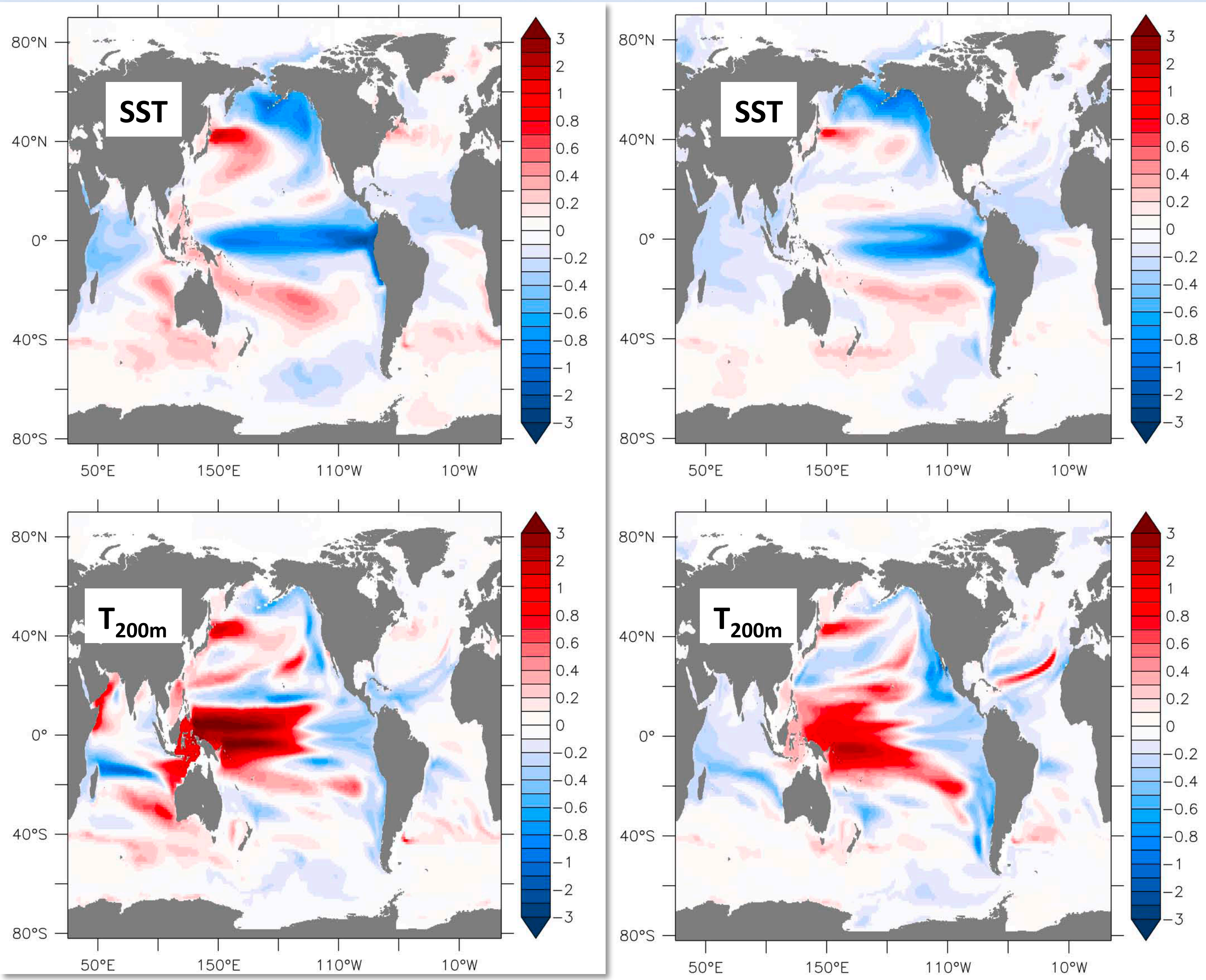
1. **HIST** – uses all available estimates of radiative forcing change, including greenhouse gases, anthropogenic aerosols, ozone, solar irradiance, volcanic aerosols, and land use change
1861-2013

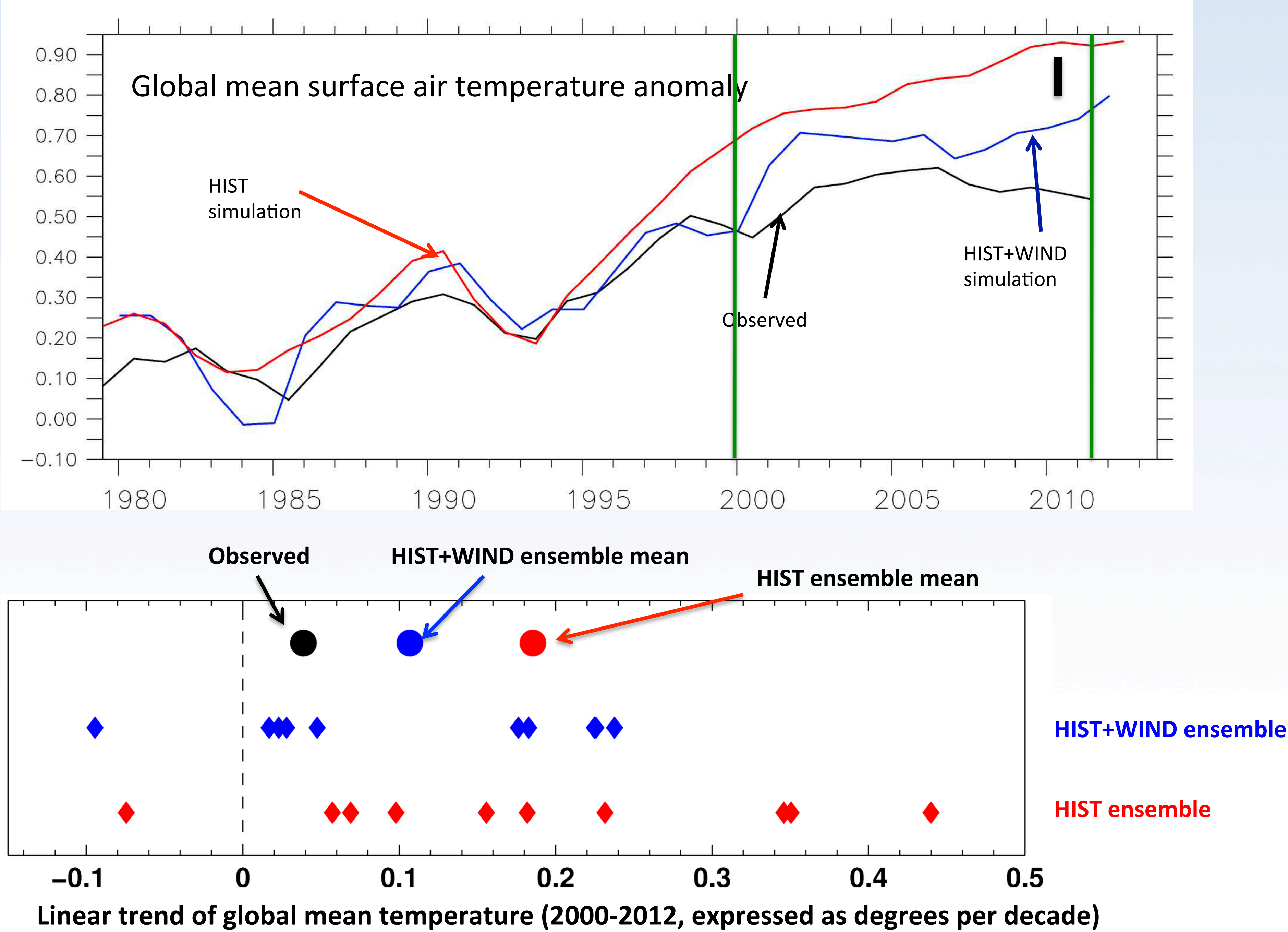
2. **HIST+WIND** – same as HIST, but replaces wind stress flux that the ocean feels over the tropical Pacific.
1979-2013

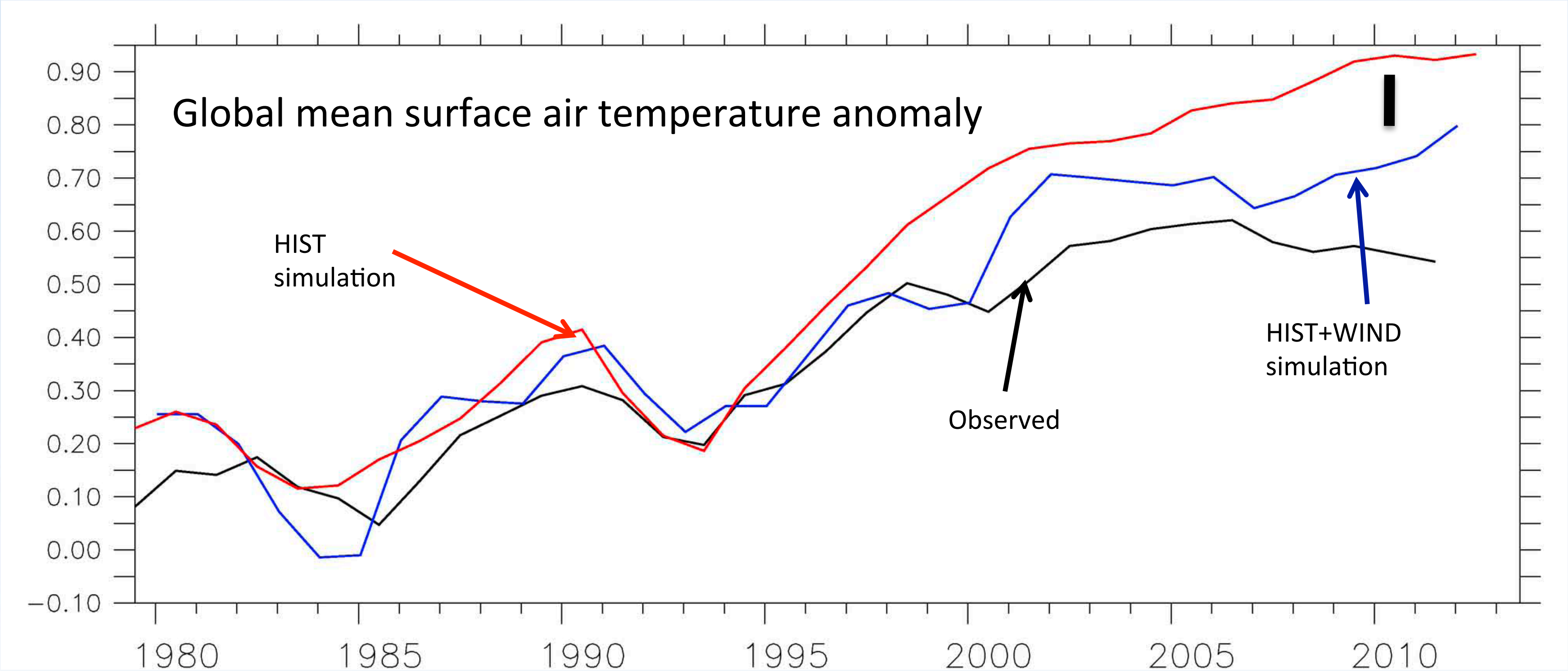
3. **IDEALIZED** – as departure from Control simulation, apply constant, uniform anomalous easterly wind stress (-0.08 N m^{-2}) over the same domain as **HIST+WIND**

➔ **HIST+WIND** minus **HIST** is the effect of the anomalous wind stress variations

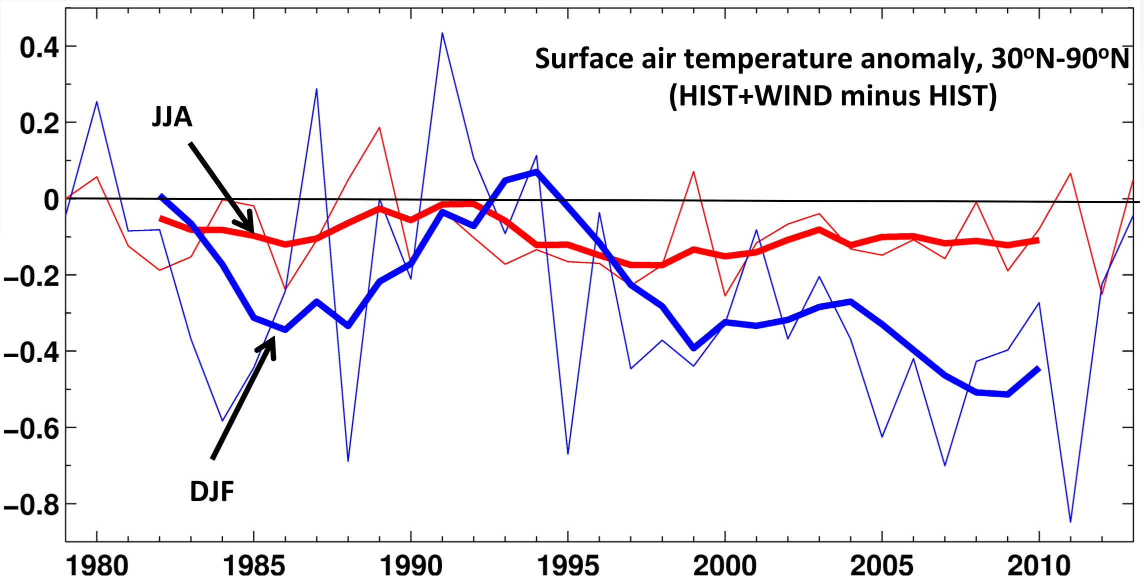
➔ **IDEALIZED** minus **CONTROL** is the effect of the uniform, constant extra wind stress


SST
SST
T200m
T200m
80°N
40°N
0°
40°S
80°S
50°E
150°E
110°W
10°W
3
2
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
−2
−3


Global mean surface air temperature anomaly
HIST simulation
HIST+WIND simulation
Observed
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
−0.10
1980
1985
1990
1995
2000
2005
2010
Observed
HIST+WIND ensemble mean
HIST ensemble mean
HIST+WIND ensemble
HIST ensemble
–0.1
0
0.1
0.2
0.3
0.4
0.5
Linear trend of global mean temperature (2000-2012, expressed as degrees per decade)

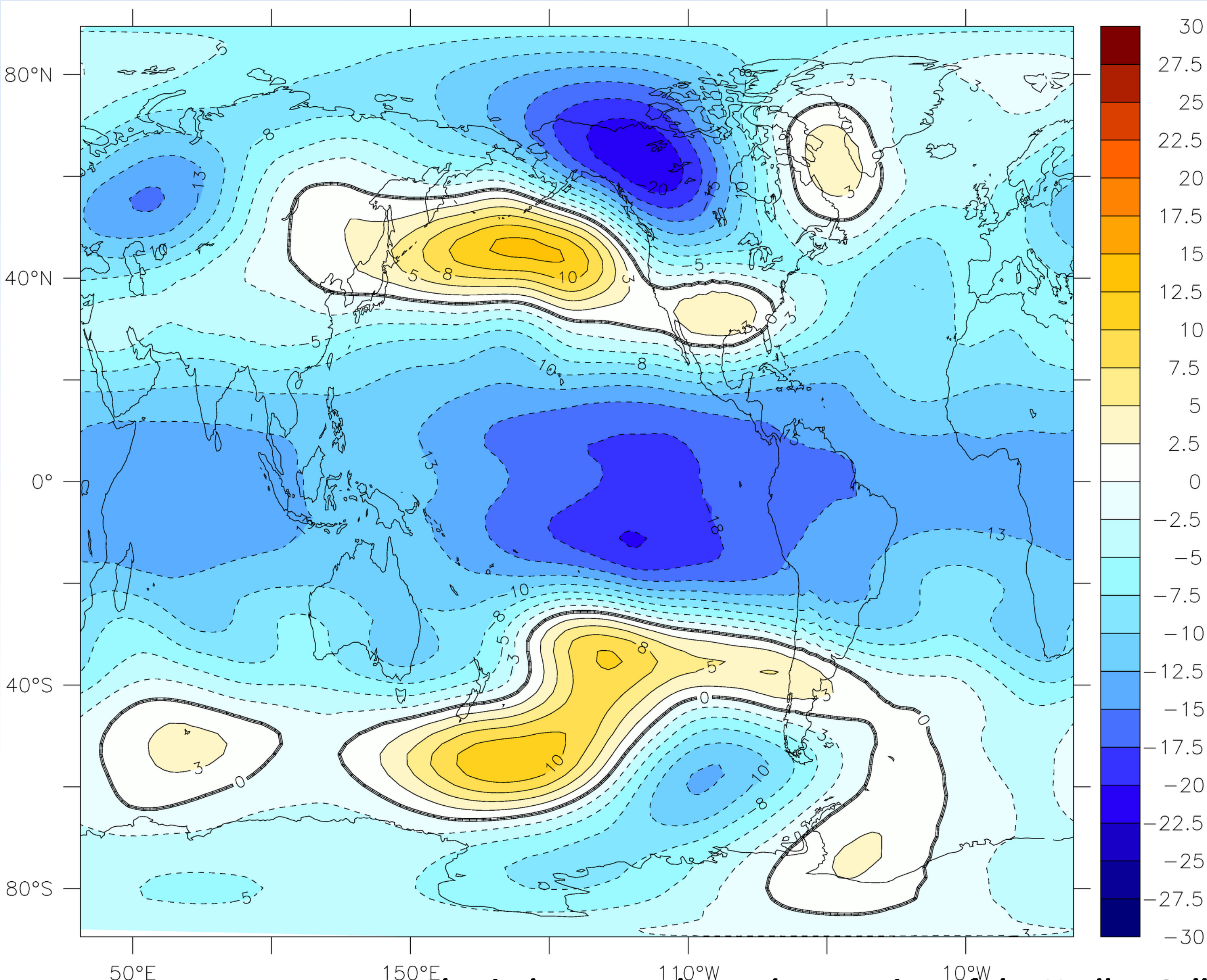


Extratropical NH impact of tropical wind stress is stronger in NH winter than summer



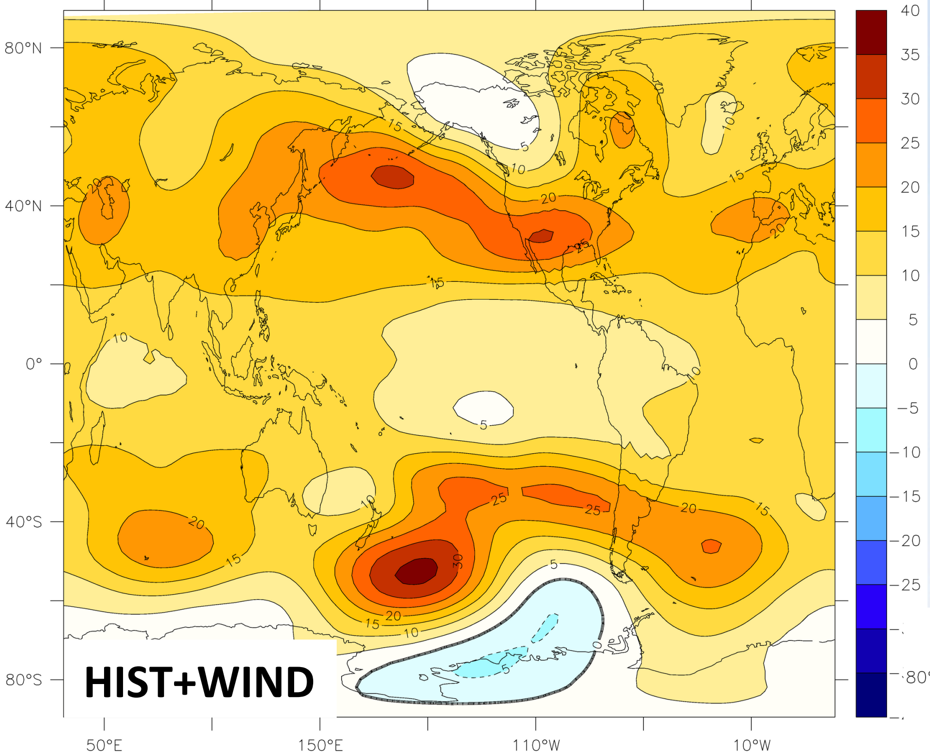
Impact of tropical wind override on annual mean 300 hPa height, 2002-2012

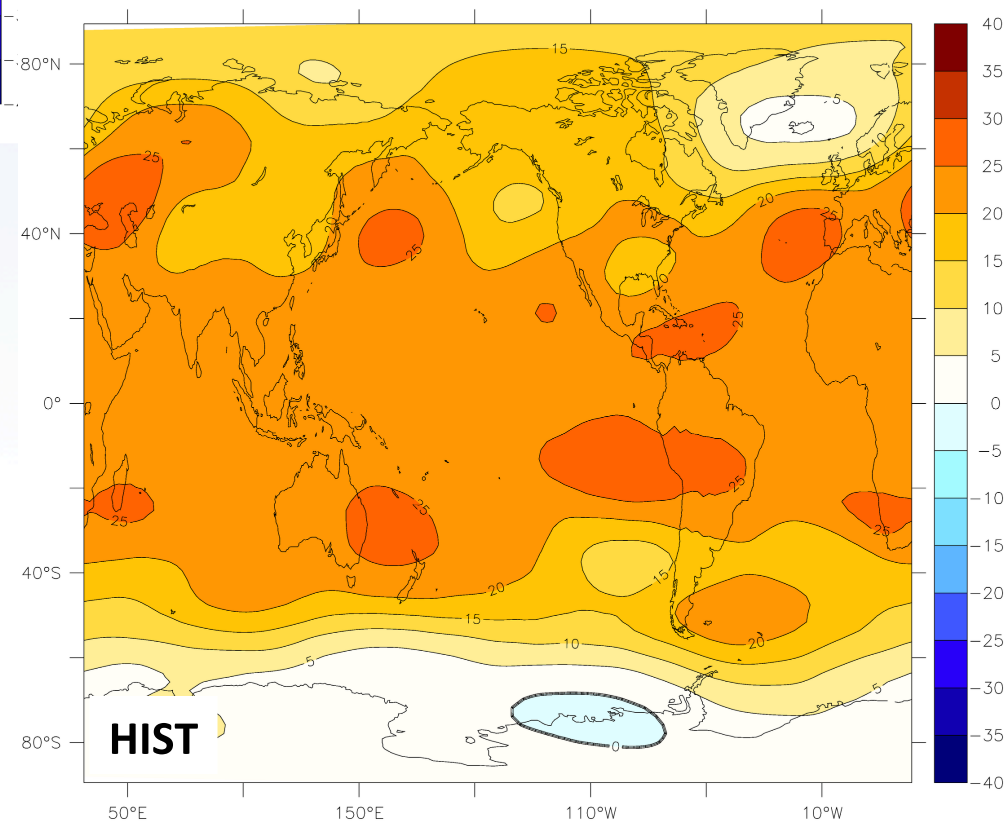
[HIST+WIND] *minus* [HIST]



Also induces a poleward expansion of the Hadley Cell in each hemisphere (of order 0.5°) and a change in vertical wind shear

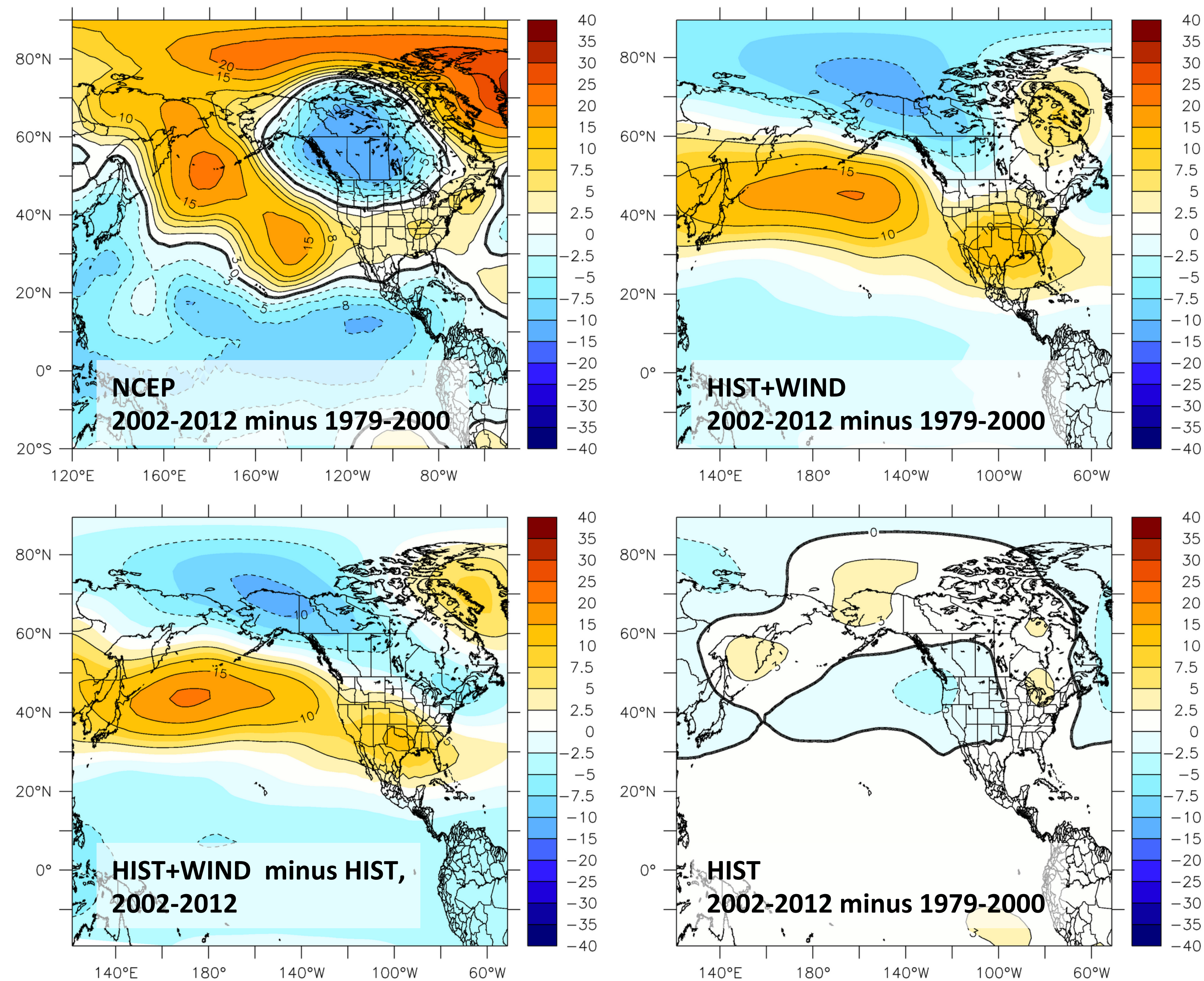
300 hPa geopotential height
2002-2012 minus 1991-2001

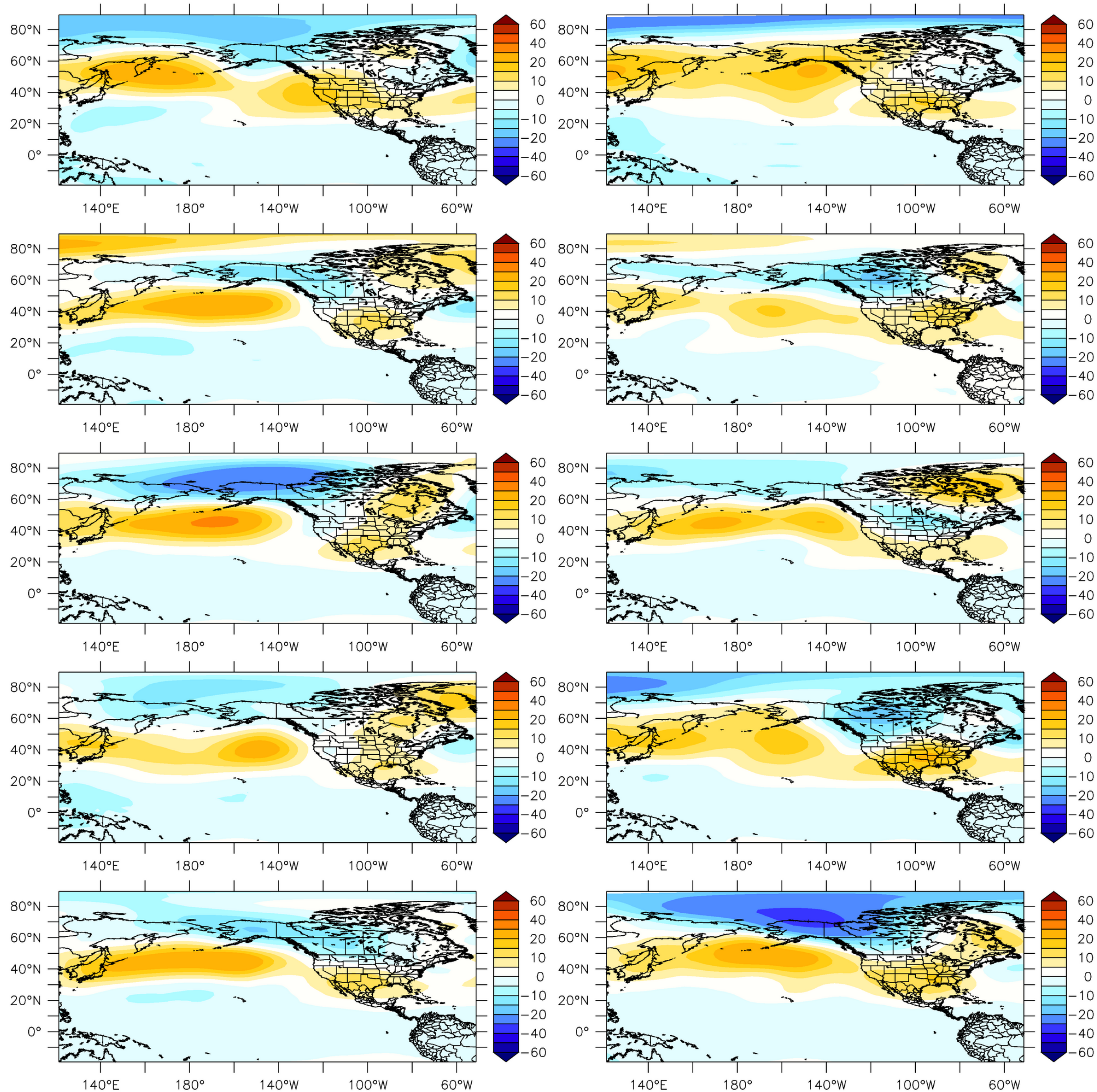




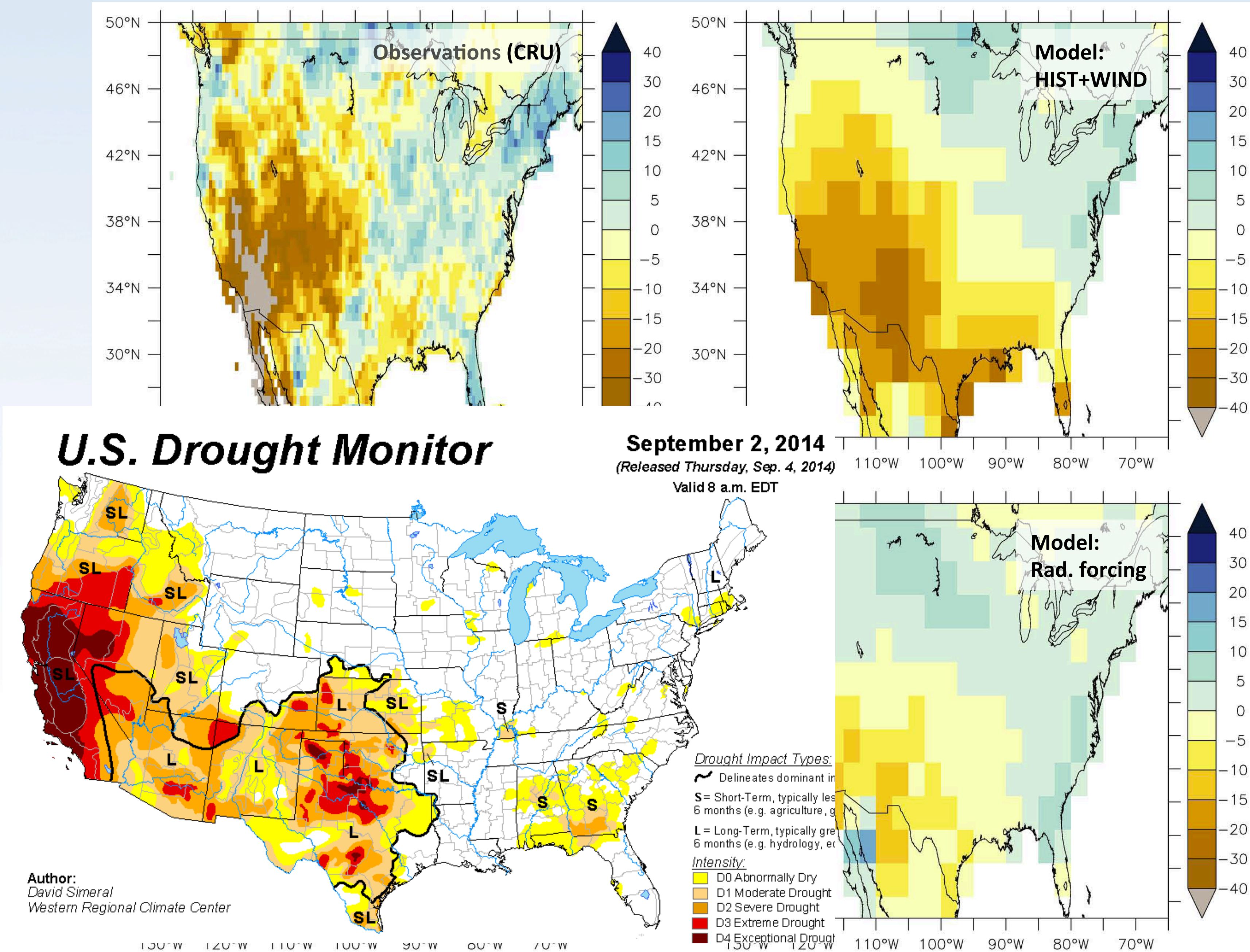
500 hPa height changes, MAMJJA

(global mean removed in each panel)




80°N
60°N
40°N
20°N
0°
140°E
180°
140°W
100°W
60°W
60
40
20
10
0
−10
−20
−40
−60

Percentage change in precipitation, MAMJJA, 2002-2012 versus 1979-2000



The wind stress anomalies in the tropical Pacific and radiative forcing changes push the system toward a drier climate over Western North America. Let's view that probabilistically using different model populations:

HIST_80s_90s: 10 member ensemble; 1979-2000 (22 years * 10 ensembles)

HIST+WIND_80s_90s: 10 member ensemble; 1979-2000 (22 years * 10 ensembles)

HIST_2000s: 10 member ensemble; 2002-2013 (12 years * 10 ensembles)

HIST+WIND_2000s: 10 member ensemble; 2002-2013 (12 years * 10 ensembles)

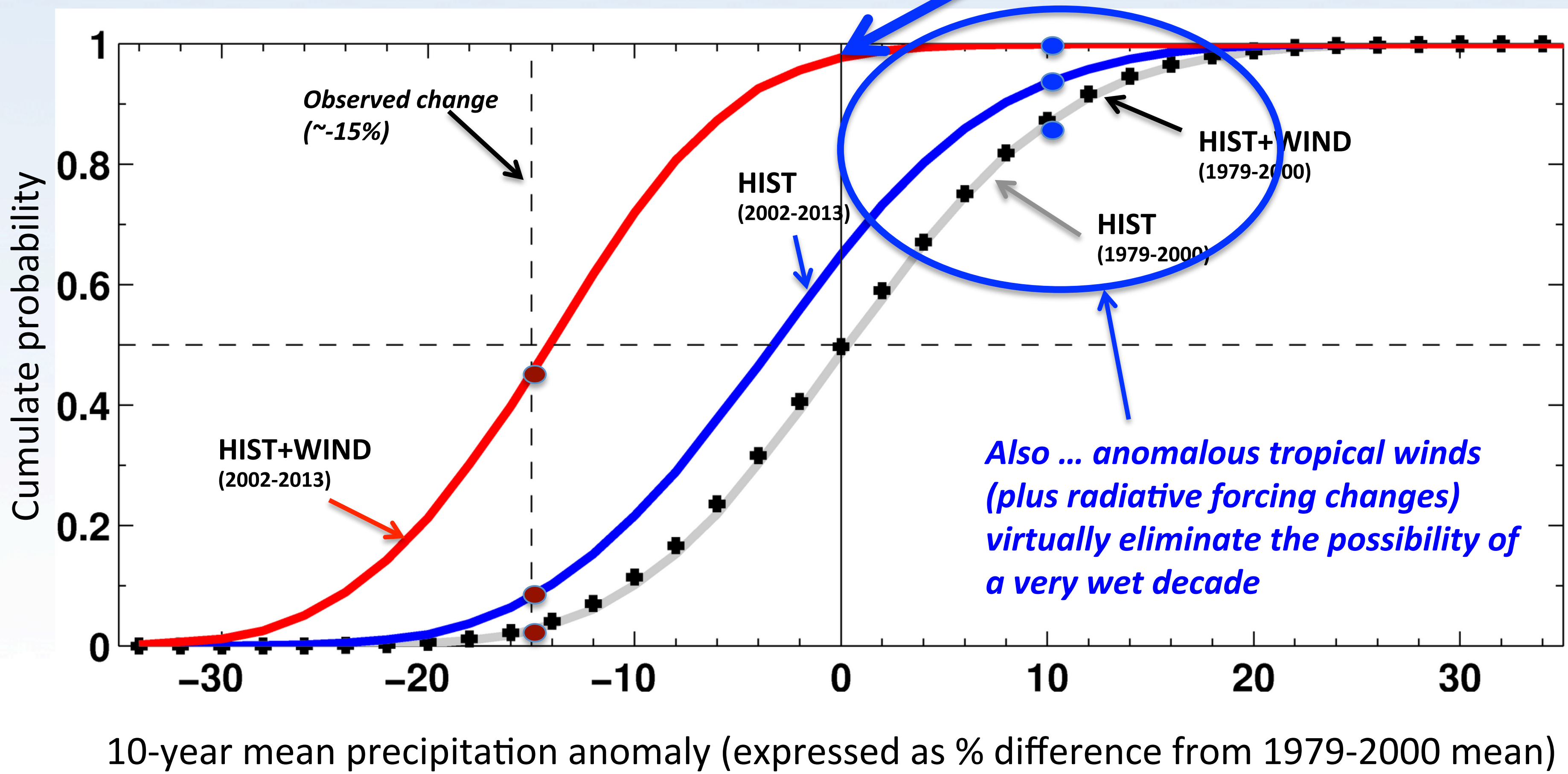
Question: How has the probability of 10-year mean anomalies been influenced by the inclusion of radiative forcing changes and wind stress forcing changes?

Technique: resample each of the above populations separately to derive separate pdfs of 10-year mean anomalies; examine how pdfs change in response to radiative forcing and wind stress changes

Probability of areal mean precipitation anomaly of -15% (or larger):

- Based on 1979-2000 period simulation: 3%
- Based on 2002-2013 period simulation using radiative forcing changes alone: 8%
- Based on 2002-2013 period simulation using radiative forcing and tropical Pacific wind stress: 46%

2% chance of wetter decade than mean of 1980s-1990s



So ... a once in 300 year decadal event is transformed to a once in 120 year decadal event (by radiative forcing changes) and then to a once every 20 year decadal event (by tropical winds)

Summary

1. Prolonged, unusually strong tropical easterly winds contribute very significantly to the hiatus in global warming [England et al., 2014]

2. This process also leads to:

a. Changes in Pacific ocean circulation and heat uptake

b. Upper tropospheric cooling in Tropics

c. Substantially increased odds of drought over western North America

Discussion Points

1. What process has generated the enhanced easterly wind stress over the last decade?

- Are there any mechanisms by which this is a response to anthropogenic forcing? Thermostat?
- Most models suggest weakening of Walker circulation, not strengthening

- Null hypothesis suggests natural variability (IPO/PDO)
  - *How unusual is this decadal wind stress anomaly? (observational issues)*
  - *Are models deficient in their simulation of internal decadal variability?*
  - *If models are deficient, what are the implications for detection/attribution studies using current models?*
  - *If wind stress trends from natural variability, then much of drought over western North America in last decade is likely due to natural variability*

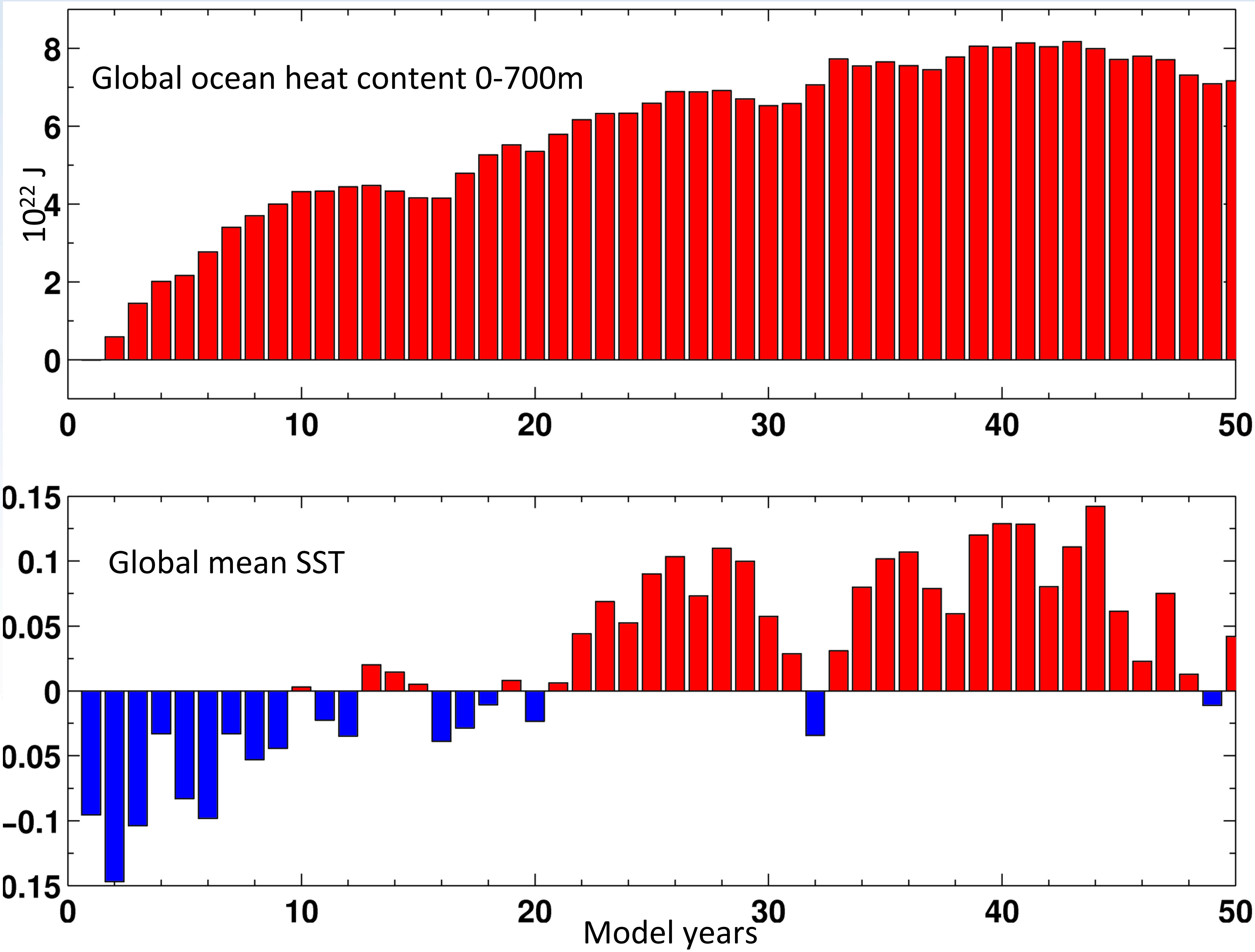
2. Drought over western North America tightly coupled to tropical Pacific winds – what will happen over next decade?

- If the unusually strong easterly winds continue, it is likely that the drought continues

- If the unusually strong easterly winds disappear, it is likely that the drought ends

→ Can we make any credible statements on the likelihood of either case?

Idealized stress run minus Control



Percentage change in precipitation, MAMJJA, 2002-2012 versus 1979-2000 CM2.5 FLOR HAD13