How Well do we Understand the Causes of Drought?

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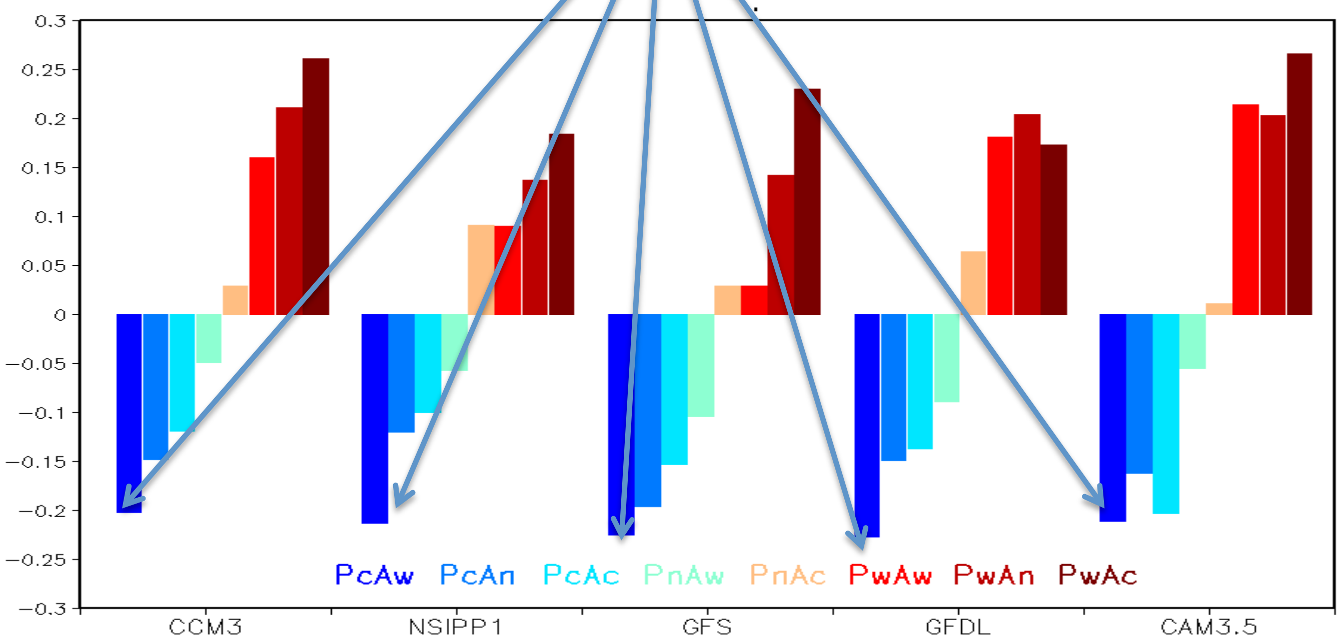
[1]NASA/GMAO; [2]UMBC/GEST

Some Indication of Our Understanding

- A cold tropical Pacific combined with a warm tropical Atlantic should lead to drought in the Great Plains

Great Plains Precip Anomaly: AGCM results with Idealized SST Anomalies*



CCM3 NSIPP1 GFS GFDL CAM3.5

- **This summer: cold Pacific, warm Atlantic and wet in Great Plains!**

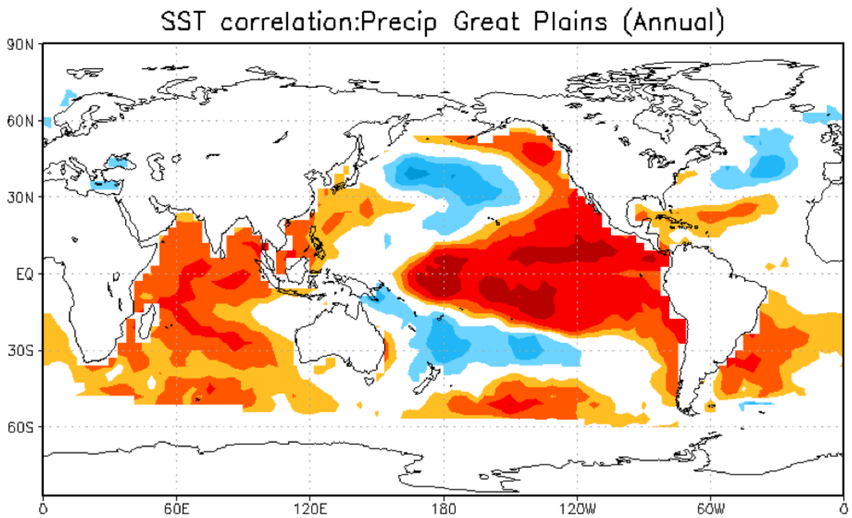
°Schubert et al. 2009

Outline

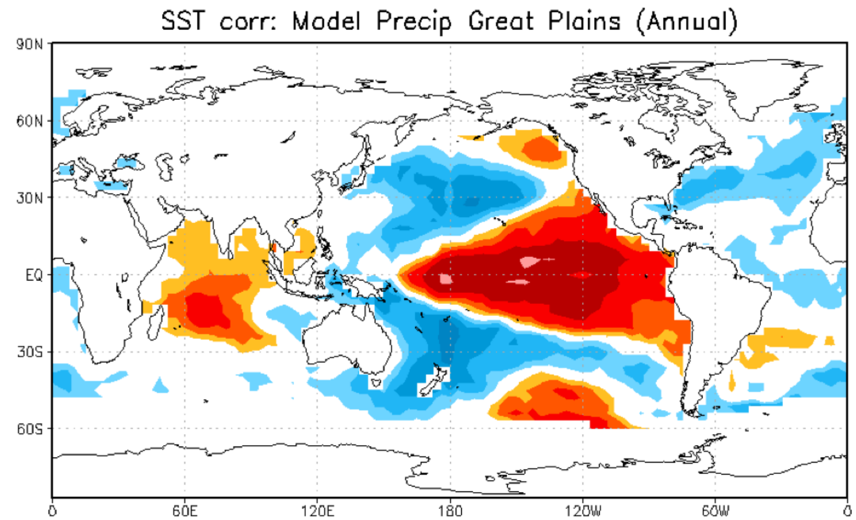
- Decadal drought
  - Importance of transition seasons
- Separating decadal drought from trends
  - Separating decadal SST variability from SST trends
- Sub-seasonal drought/heat waves
  - Important role of stationary Rossby waves

Correlations Between Great Plains precipitation and annual mean SST

Observations



NSIPP-1 AGCM



Correlations between annual mean observed (left panel, 1901-2004) and simulated (right panel, 1902-2004) Great Plains precipitation and annual mean SST. For the AGCM simulations, the values are the average of 14 correlations produced for each ensemble member.

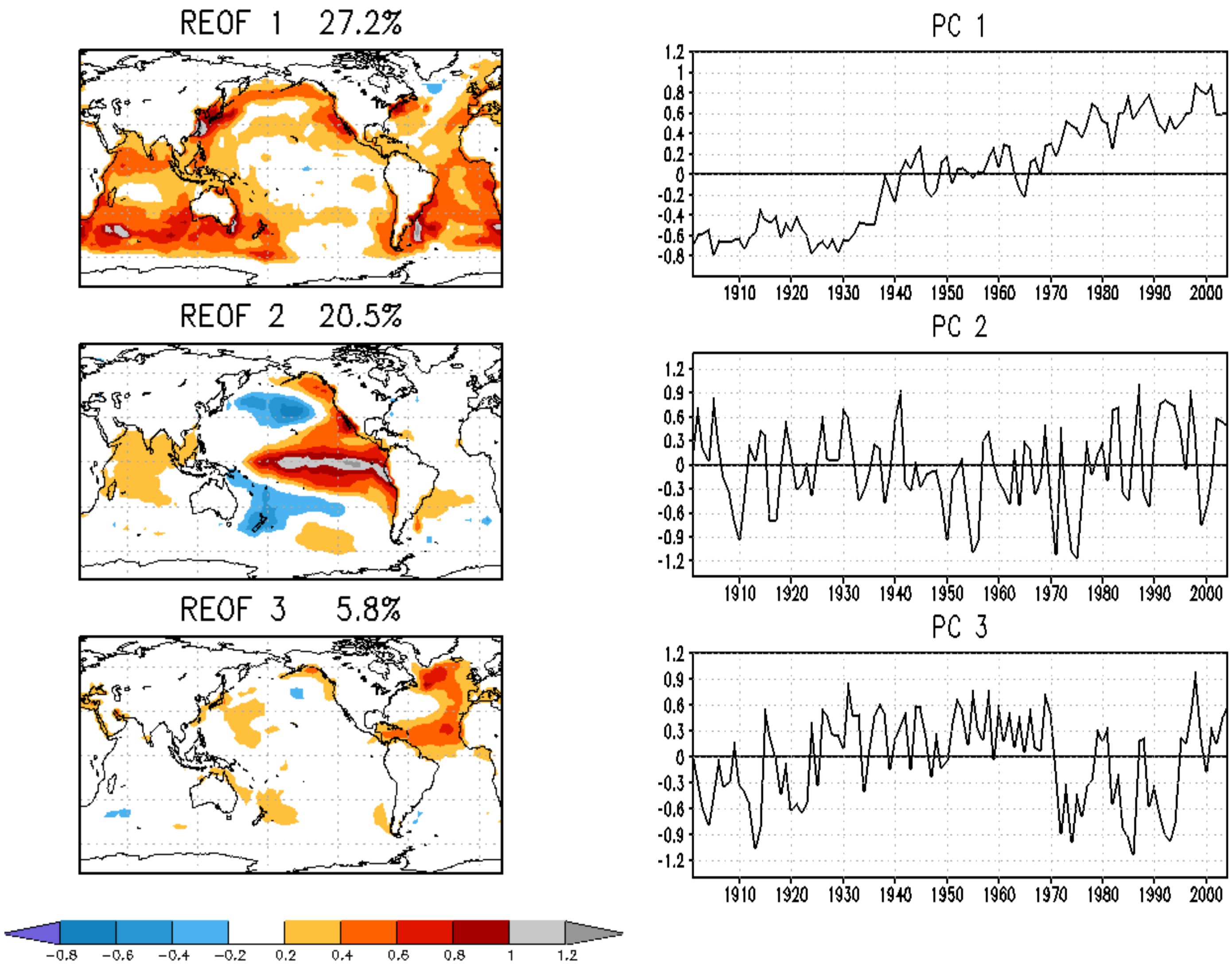
Decadal drought

Leading EOFs and Time series (annual mean SST - 1901-2004)

Linear Trend Pattern (LT)

Pacific Pattern (Pac)

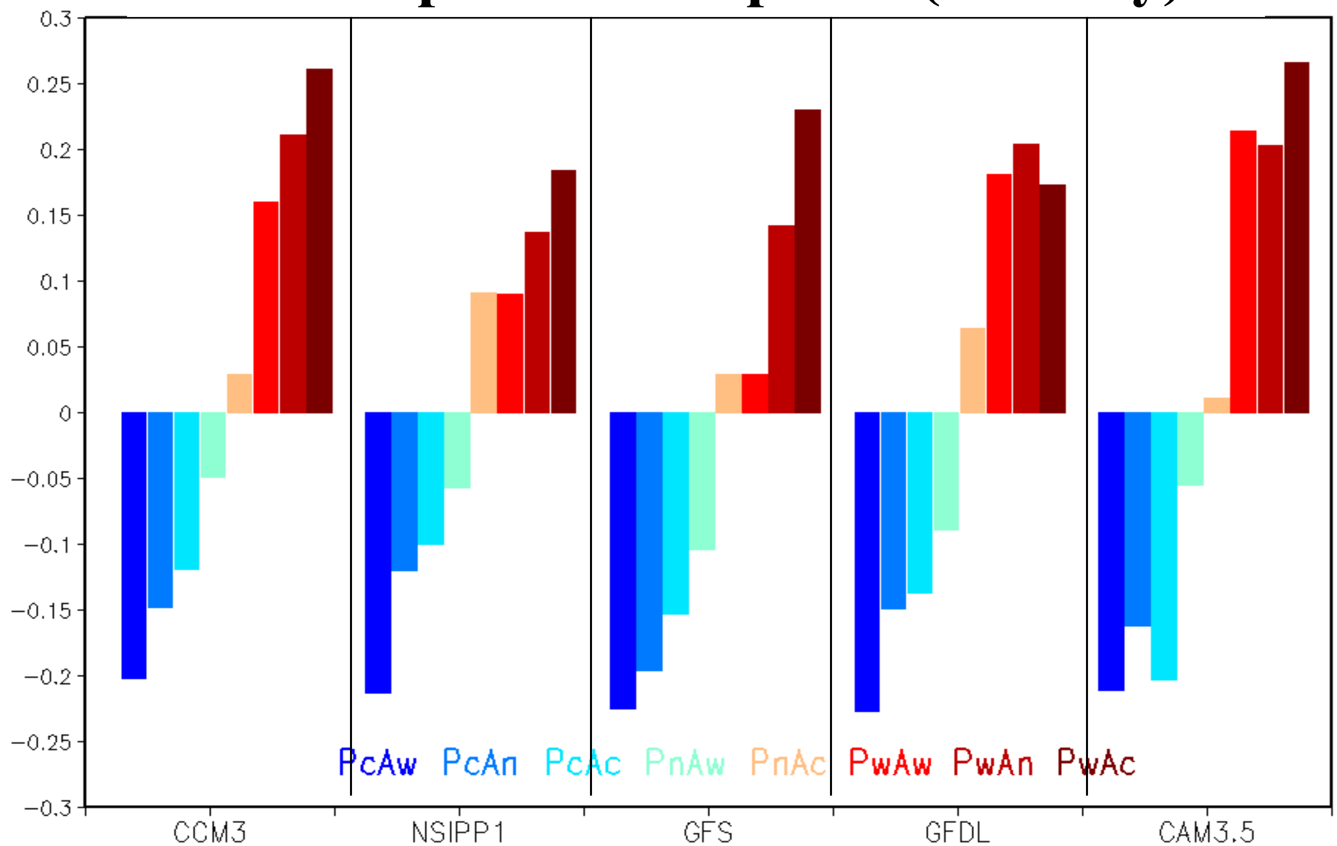
Atlantic Pattern (Atl)



HadISST

$$(\bar{x} - \bar{y})$$

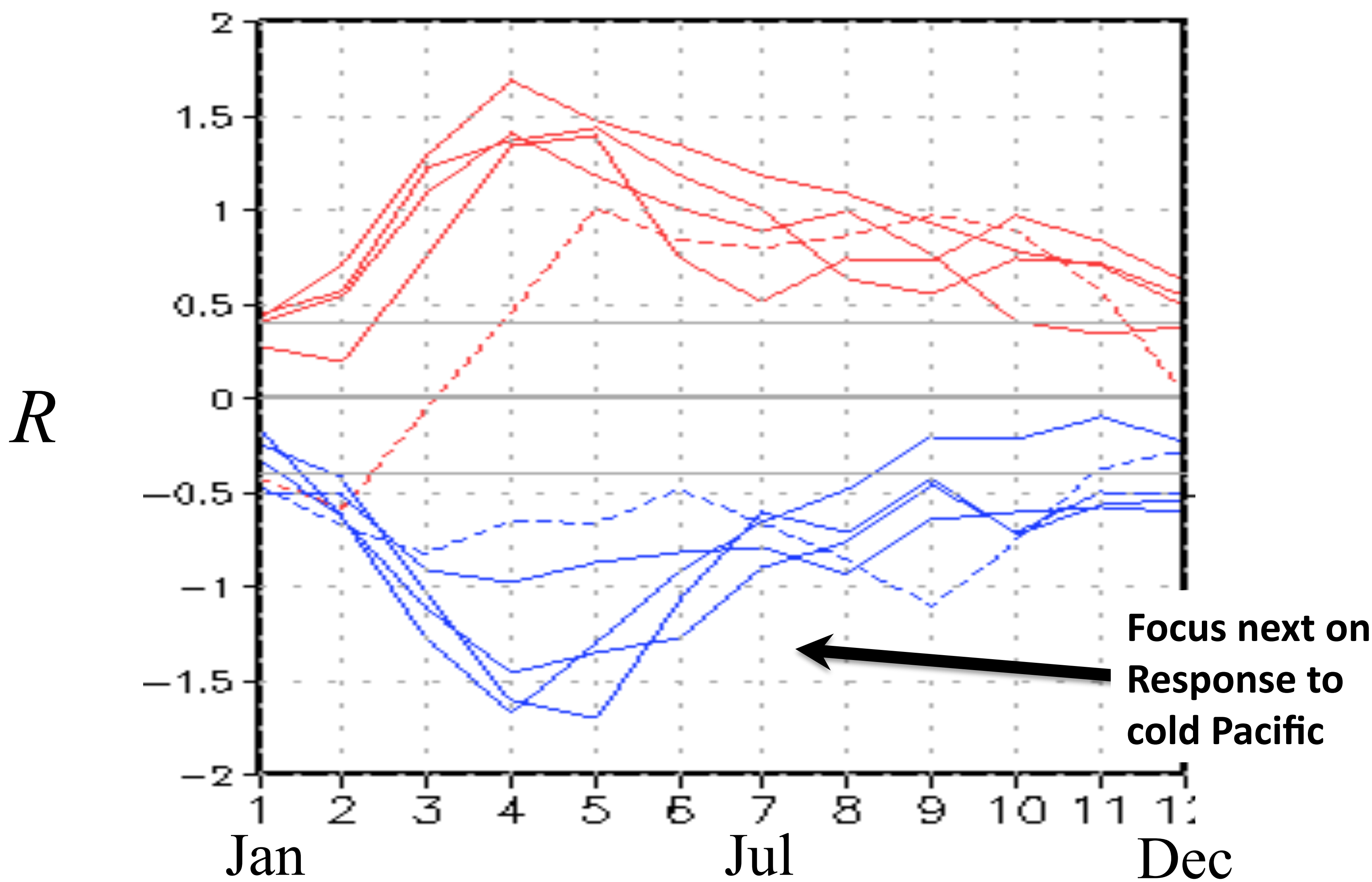
U.S. Precipitation Response (mm/day)



CCM3 NSIPP1 GFS GFDL CAM3.5

The annual and continental United States mean responses for precipitation for all 8 combinations of the Pacific and Atlantic SST patterns for the 5 AGCMs. PcAw

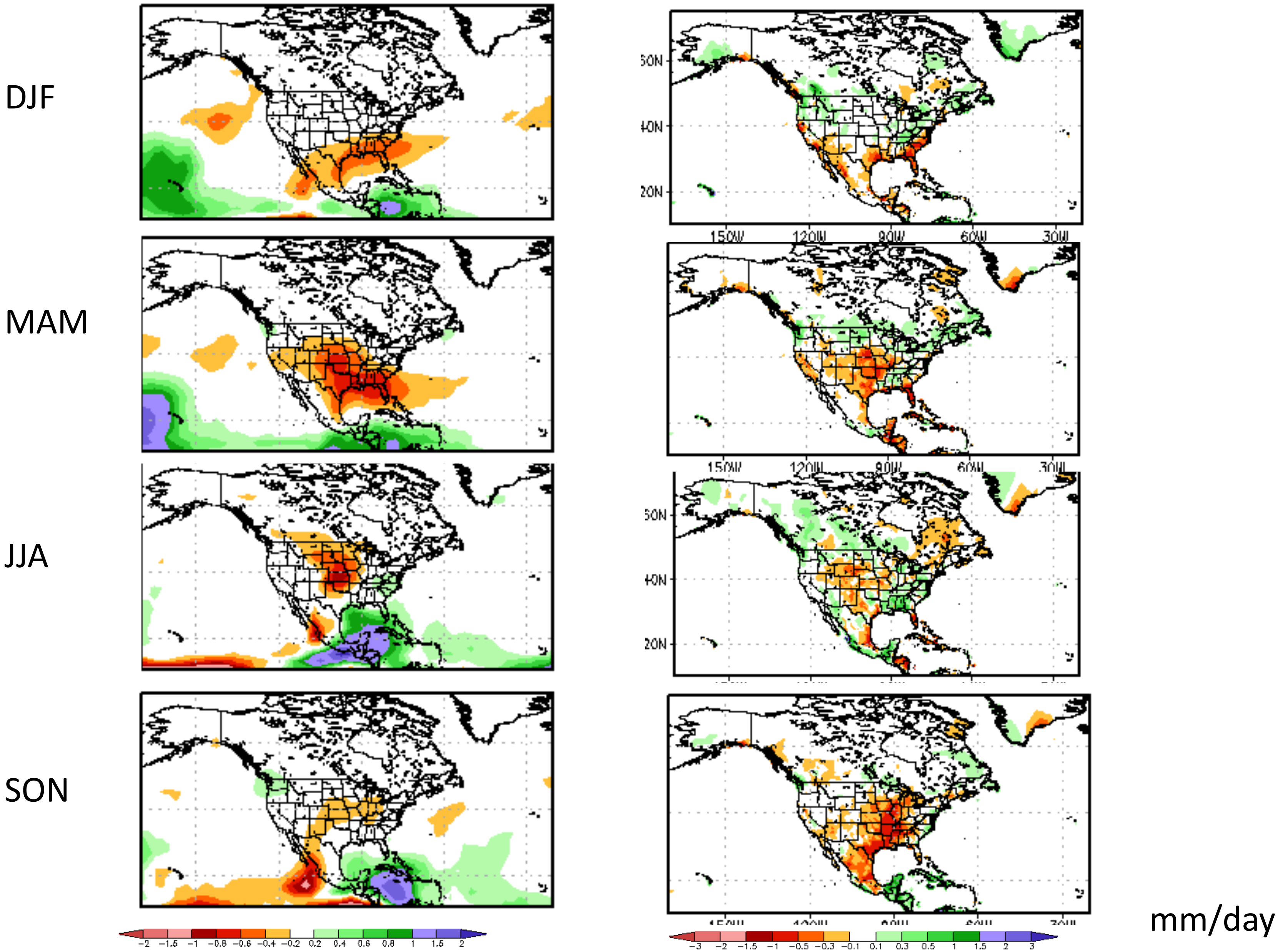
Seasonality of Sig-to-Noise Ratios of US Precipitation for each of the 5 AGCMs in Response to to the Warm and Cold Pacific SST Patterns



Response to Cold Pacific: Precipitation

Model Response (Signal)

Cold Pacific Composites (< -1 STD):
HadCRU Precipitation Data (1901-2004)

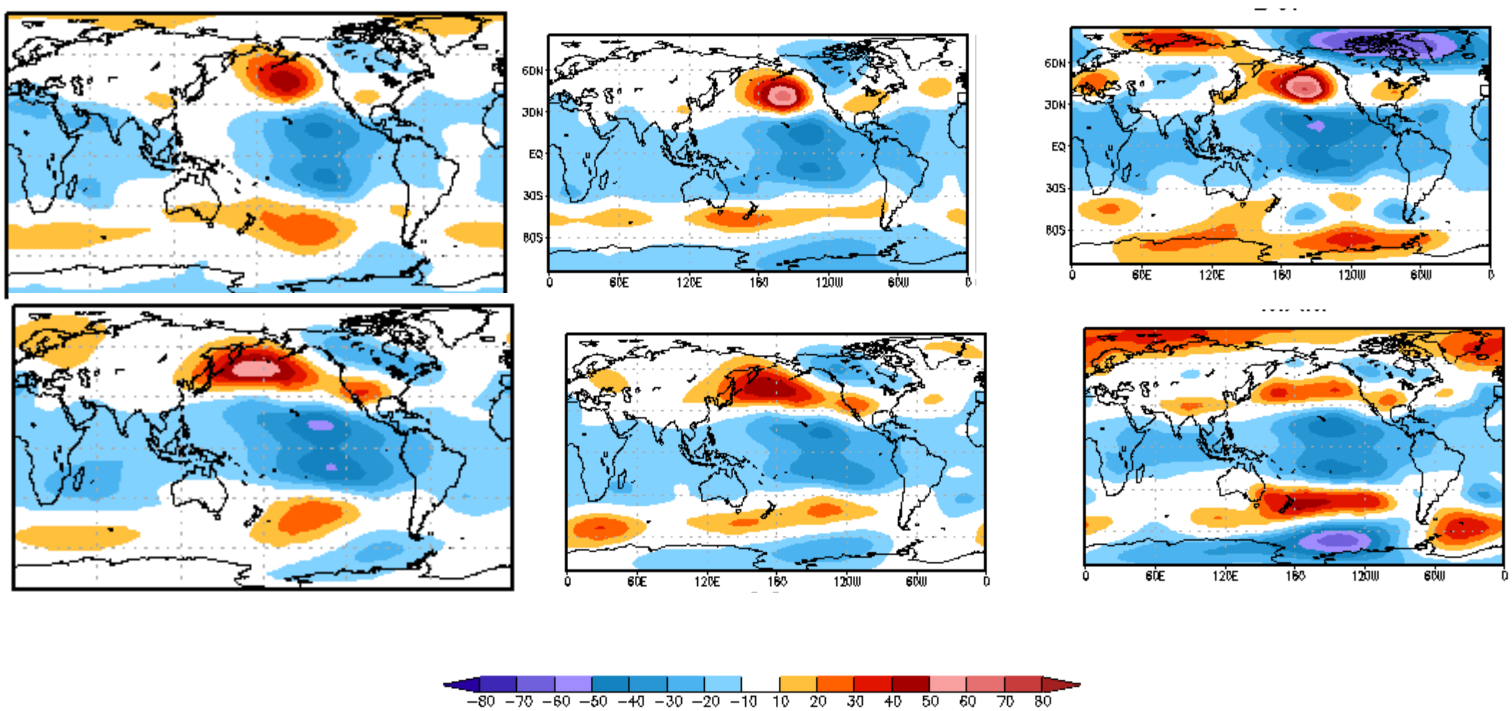


DJF to MAM Transition:
Response to Cold Pacific: 200mb Height

Robust Multi-Model Response To Idealized SST | AMIP-NSIPP: Cold Composite (1901-2004) | Reanalysis-GMAO: Cold Composite (1948-2004)

DJF

MAM



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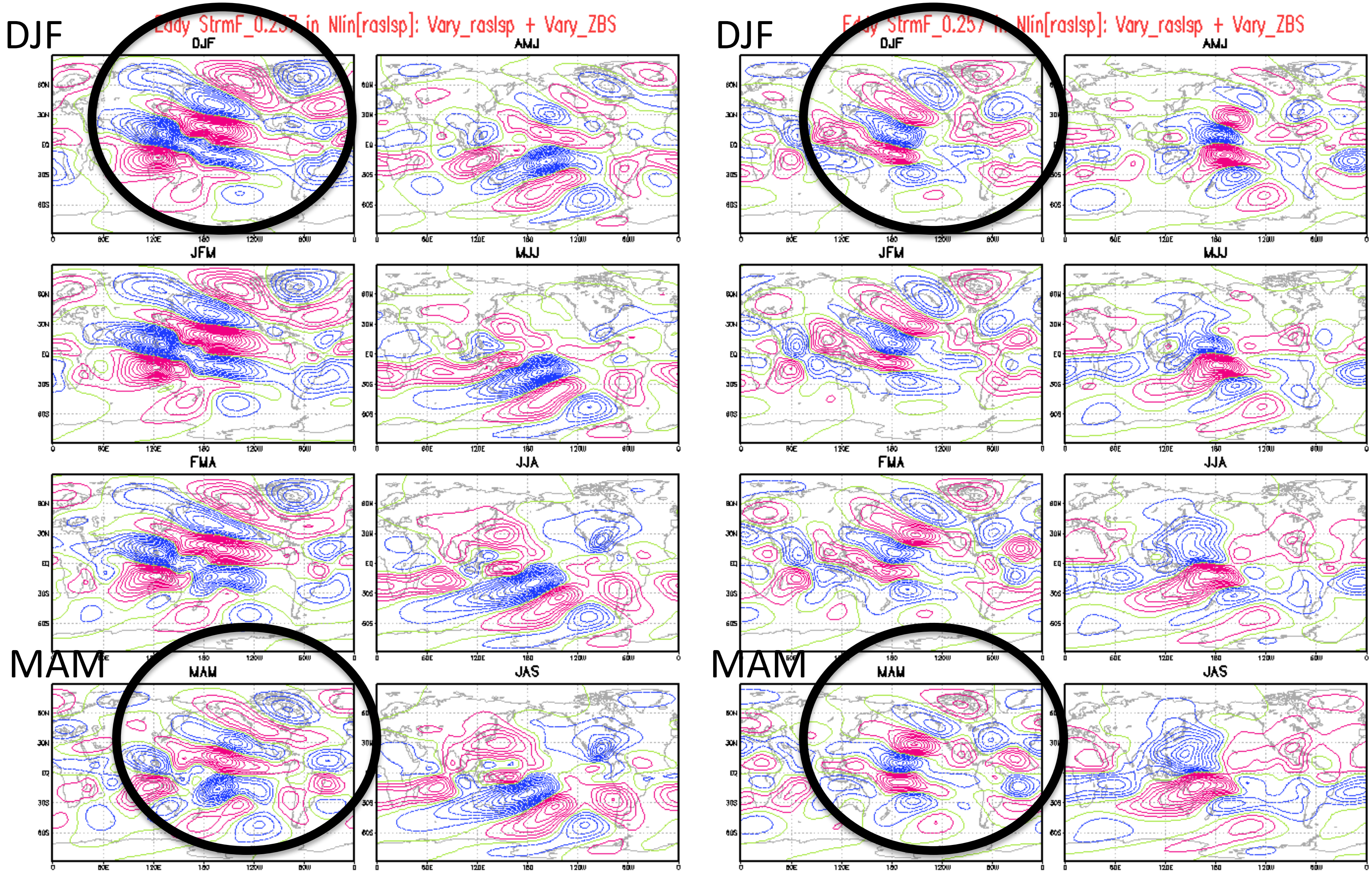
Stationary Wave Model Response in Upper Level Stream Function (Zonally-Symmetric Basic State)



Warm Pacific Forcing (from NSIPP Model)

Cold Pacific Forcing (from NSIPP Model)

Key Points- Decadal versus ENSO SST

To the extent that decadal SST persist throughout the annual cycle the transition seasons play a more important role

-Wide spread drought in MAM: a result of the annual cycle of the base state – not a seasonal change in the SST forcing

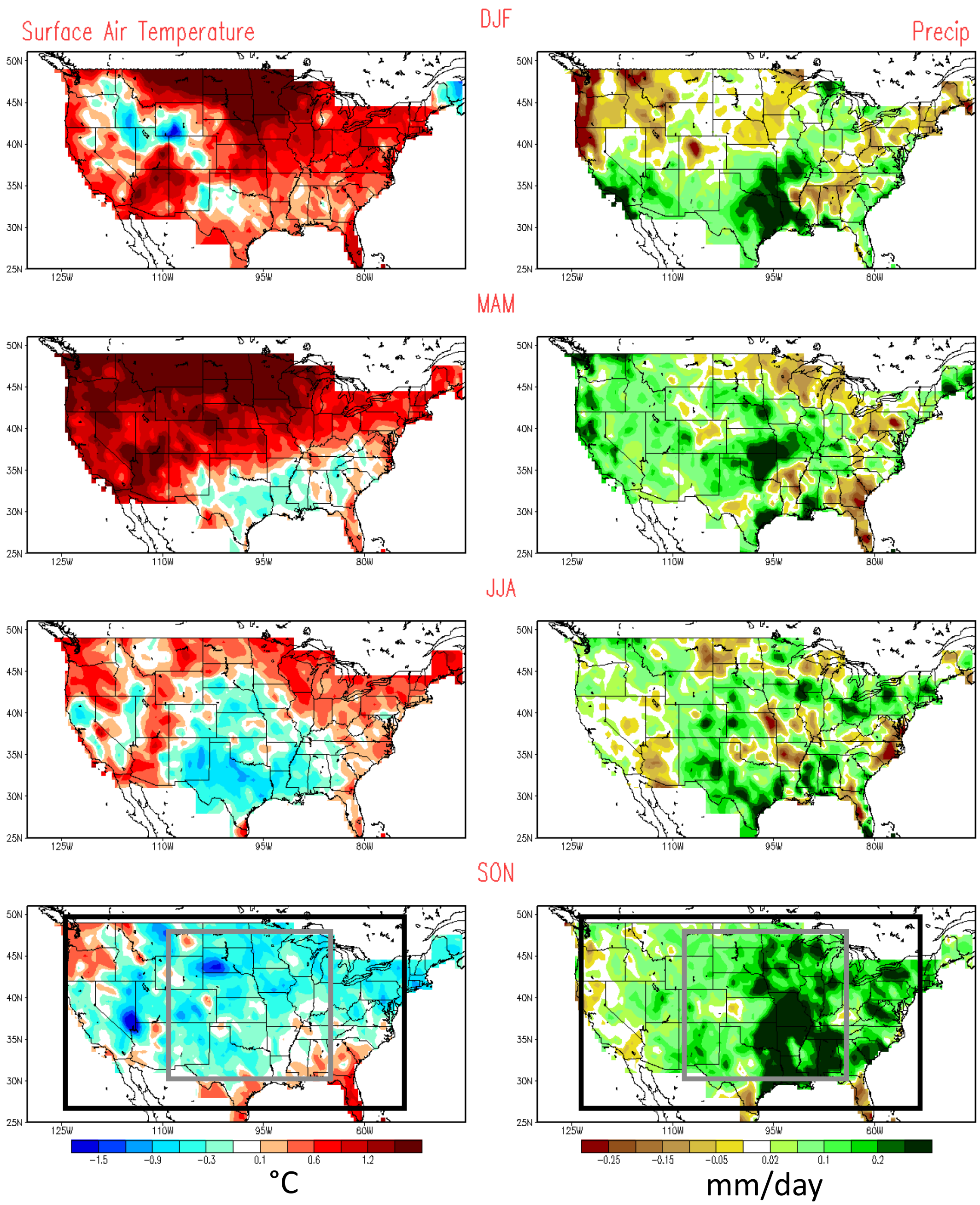
-Fall also plays an important role: note clear from models why, but likely tied to Walker Circulation response

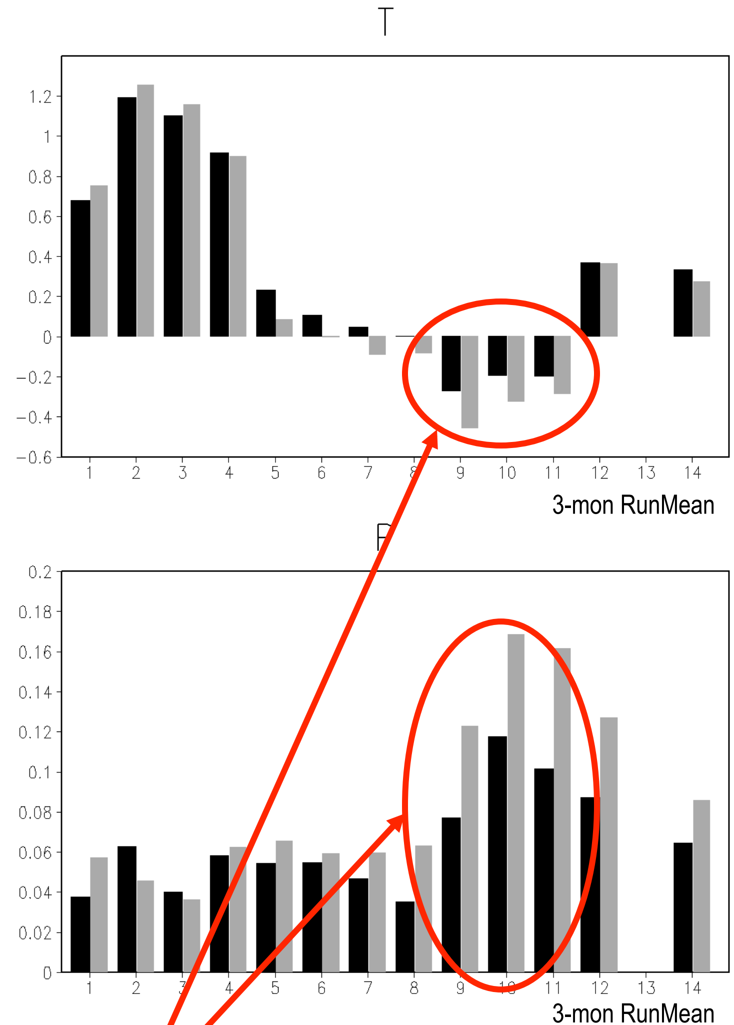
Separating decadal drought from trends

*Attribution of the seasonality and regionality in climate trends over the United States during 1950-2000". Wang, H., S.D. Schubert, M. J. Suarez, J. Chen, M. Hoerling, A. Kumar and P. Pegion, J. Climate, 2571-2590, 2009.

Observed Seasonality and Regionality in Climate Trends over U.S.

HadCRU; 1950-2000





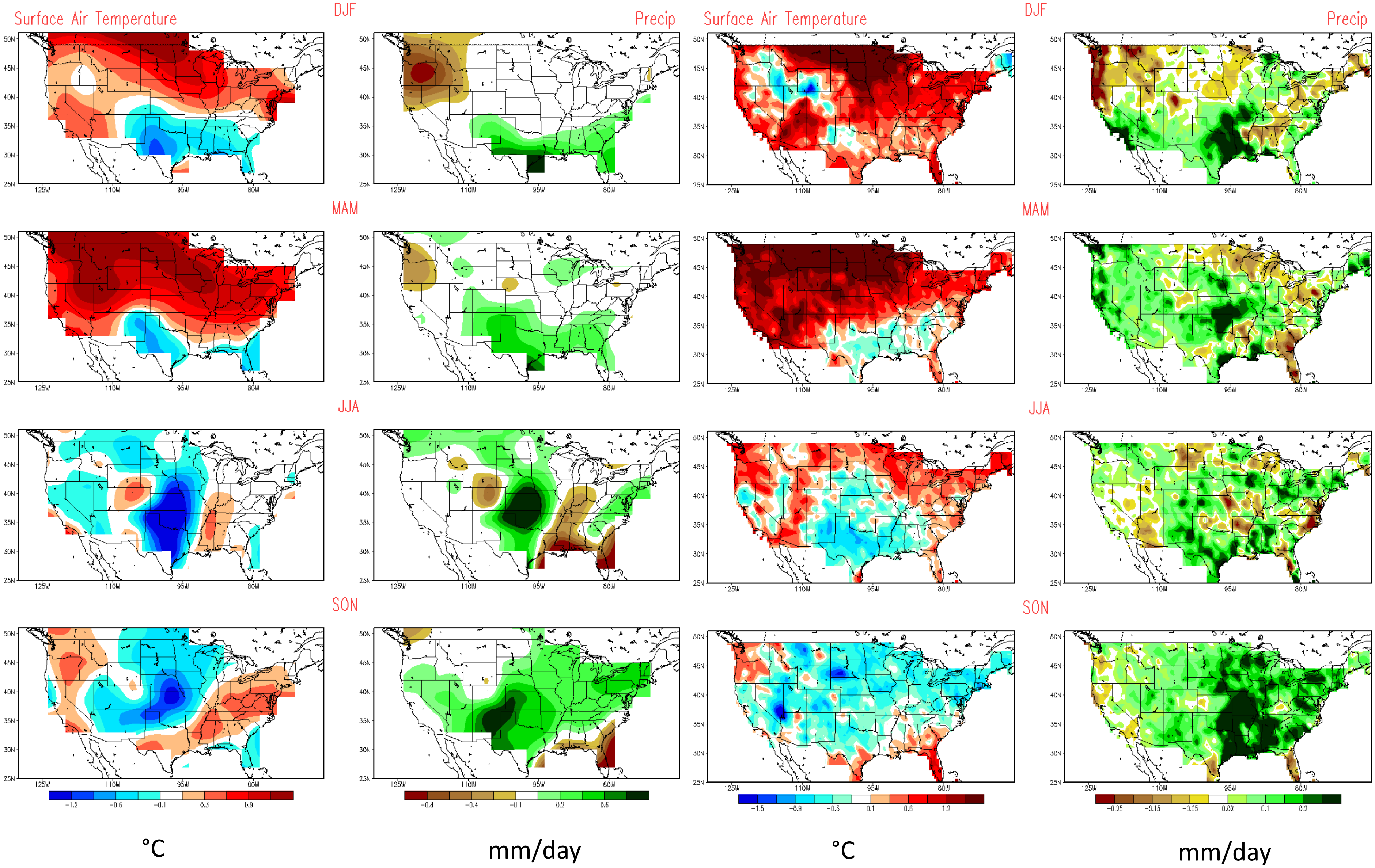
Black: US mean (235°E-285°E; 26°N-50°N)

Gray: central US mean (250°E-275°E; 30°N-48°N)

Distinct cooling and wetting trends during late summer and fall

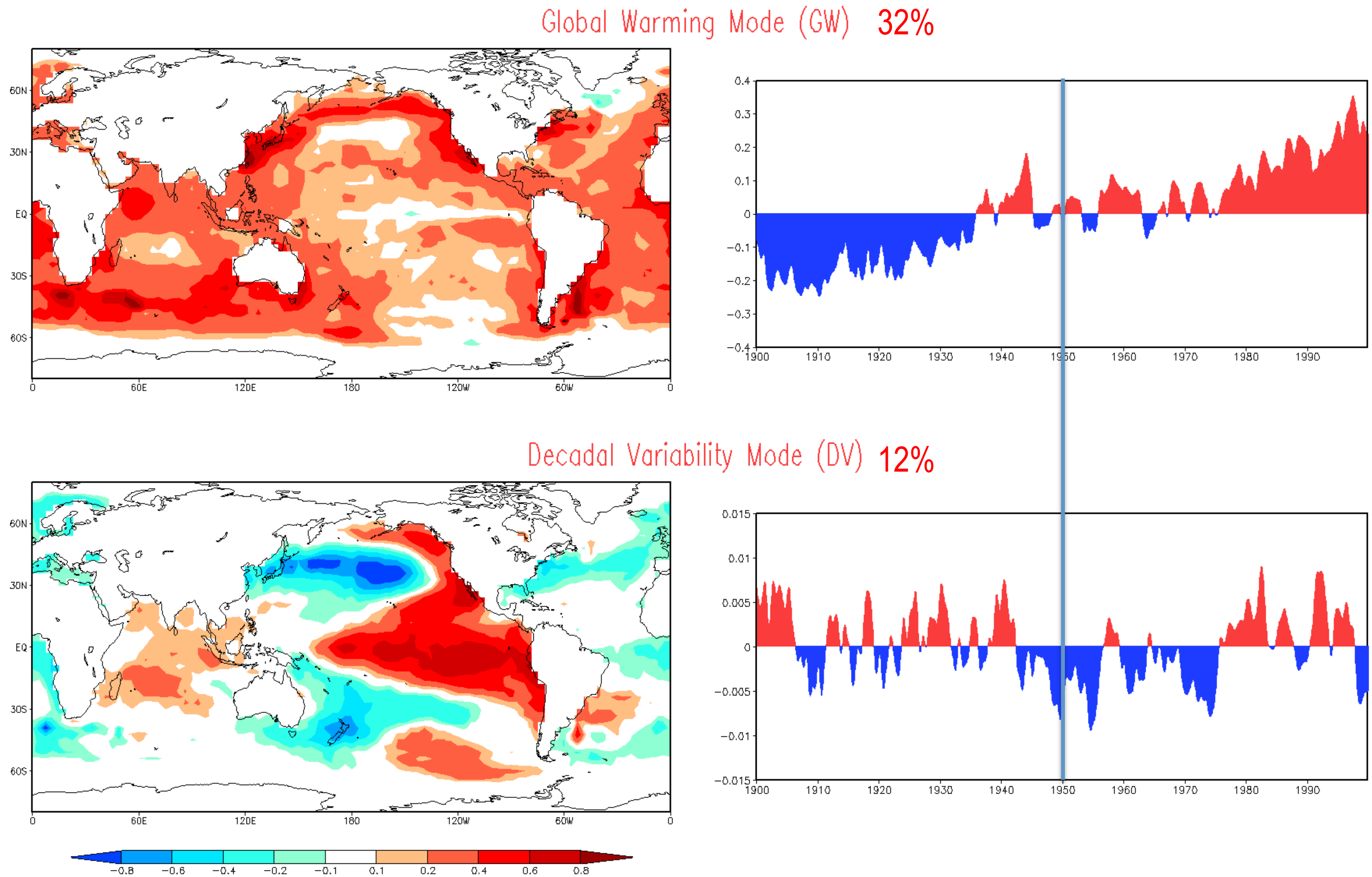
Model (AMIP) vs Obs

NASA NSIPP AMIP EnsMean(14)　　　　HadCRU



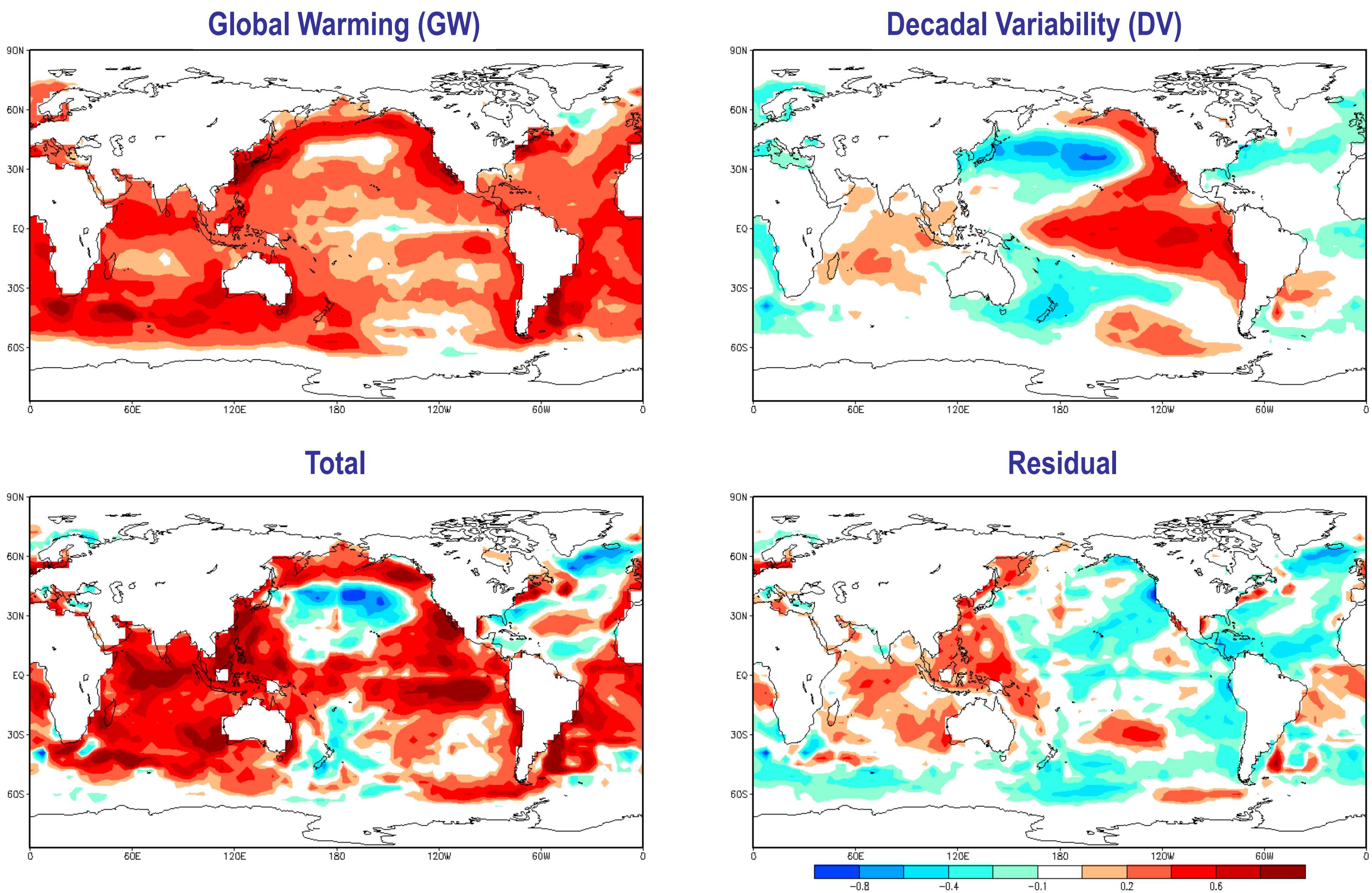
Leading SST EOFs: Global Warming (GW) and Pacific Decadal Variability (PDV)

Hadley SST; 1901-2000



Chen *et al.* (2007)

Linear trend of SST: Total=GW+DV+Residual
Hadley SST; 1950-2000



Input for a set of idealized AGCM experiments

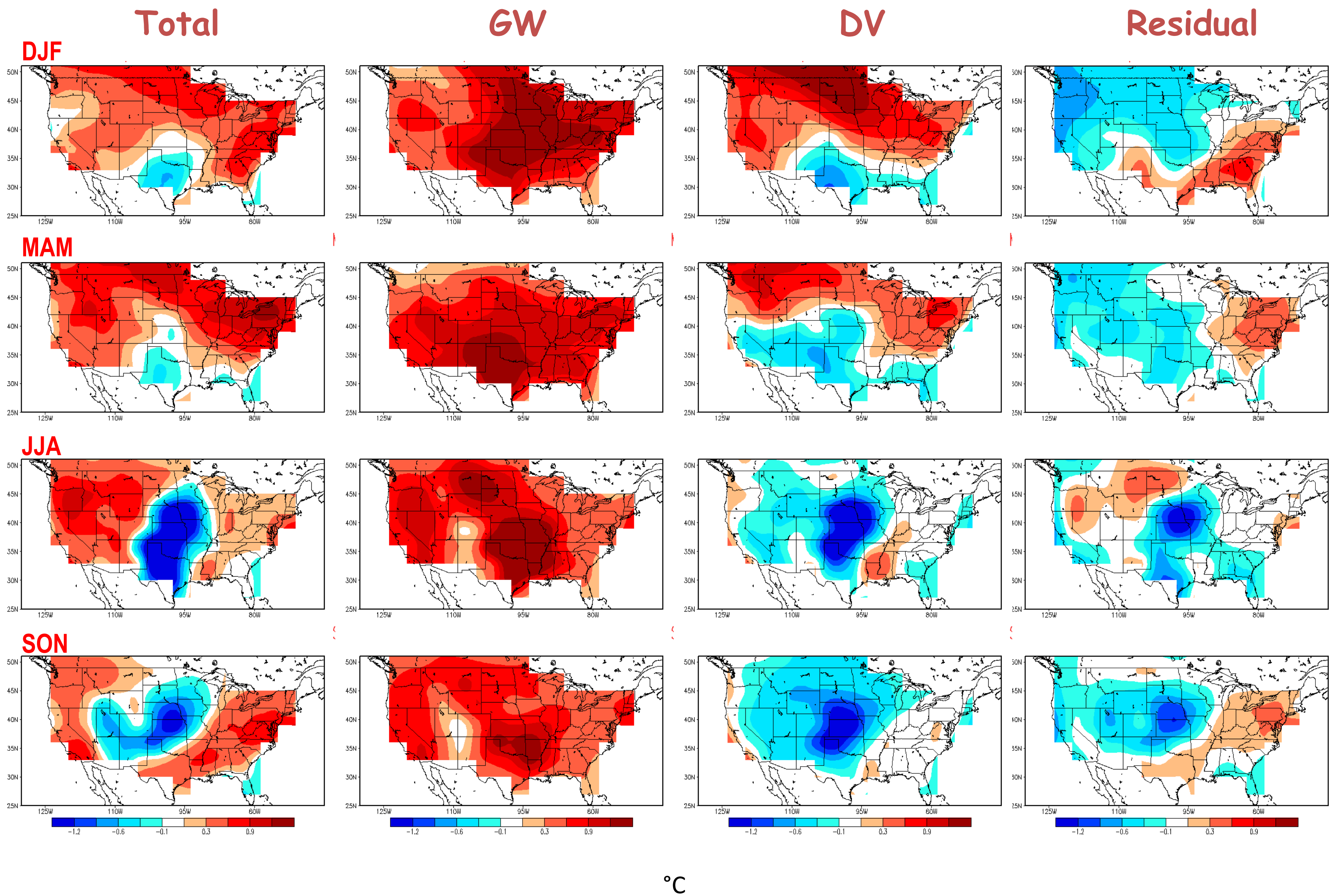
Idealized AGCM Experiments

NASA NSIPP-1 AGCM; 3deg

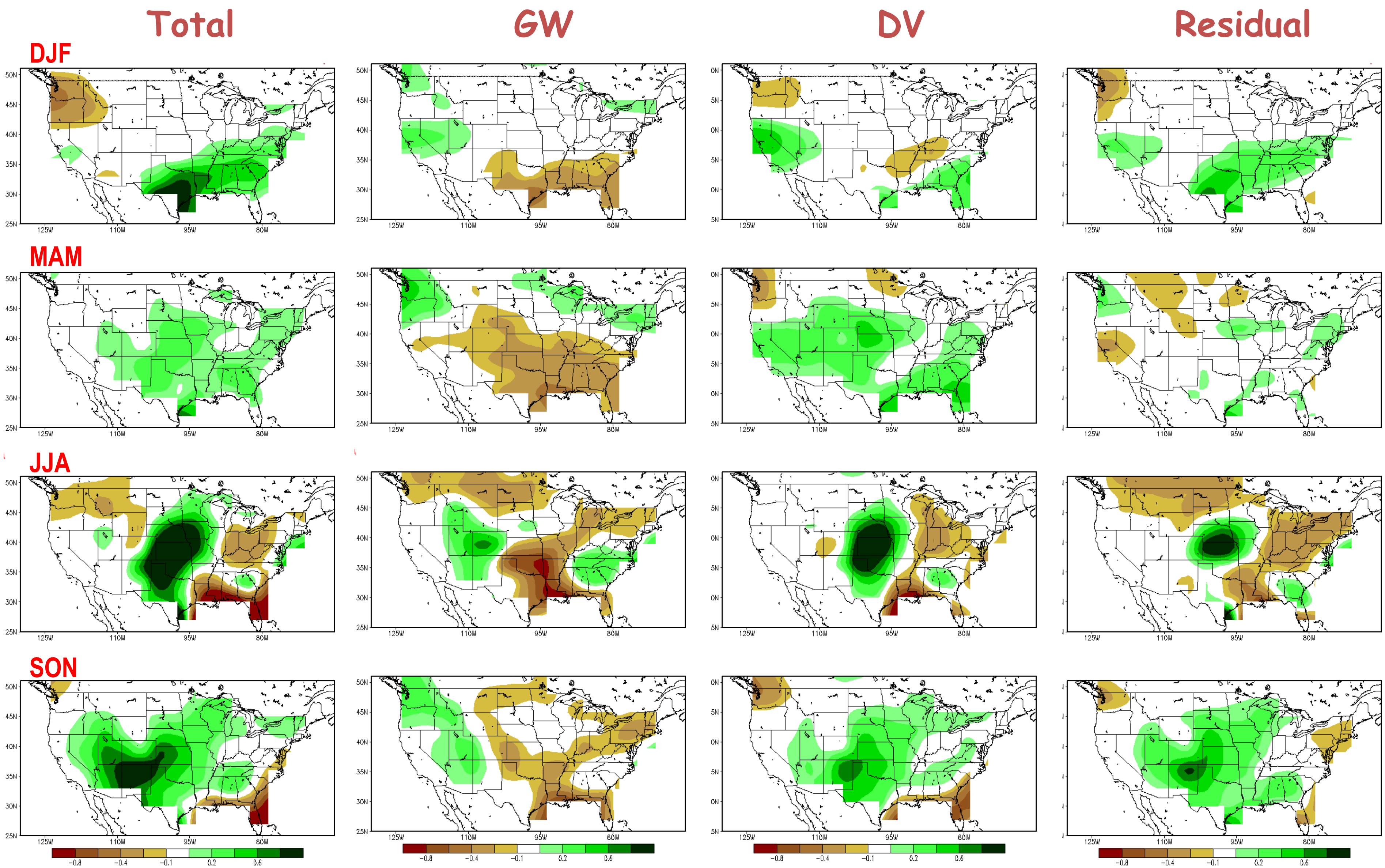
Experiments	SST
Control	SSTClim(monthly SST climatology over 1944-1976)
Total	SSTClim+SSTA_Total(linear change of SST over Jan1950-Dec2000)
Global Warming (GW)	SSTClim+SSTA_GW(linear change of SST associated with GW EOF)
Uniform Warming	SSTClim+0.32K
Decadal Variability (DV)	SSTClim+SSTA_DV(linear change of SST associated with DV EOF)
DV in Pacific	SSTClim+SSTA_DV_Pac(linear change of SST associated with DV in Pacific)
Residual	SSTClim+SSTA_Residual(SSTA_Total - SSTA_GW - SSTA_DV)

- All runs are integrated for 100 years
- Data averaged over the last 60 years taken as climatology
- Climatological difference between control run and an anomaly run represents effect of corresponding SST trend

Surface Air Temperature (T) Response in Idealized AGCM Experiments



Precip (P) Response in Idealized AGCM Experiments



mm/day

Conclusions

- The observed climate trends over the US during 1950-2000 can be mostly explained by changes in SST.
- Among the leading SST patterns:
  - Global Warming (GW):
    - mainly leads to a general uniform warming trend
  - Pacific Decadal Variability (PDV):
    - Main contributor to central US cooling and wetting trends in summer/fall
  - Residual (cool Atlantic):
    - mainly contributes in late summer and fall (warming and wetting)

Sub-seasonal drought/heat waves

Siegfried Schubert[1], Hailan Wang[12] and Max Suarez[1]
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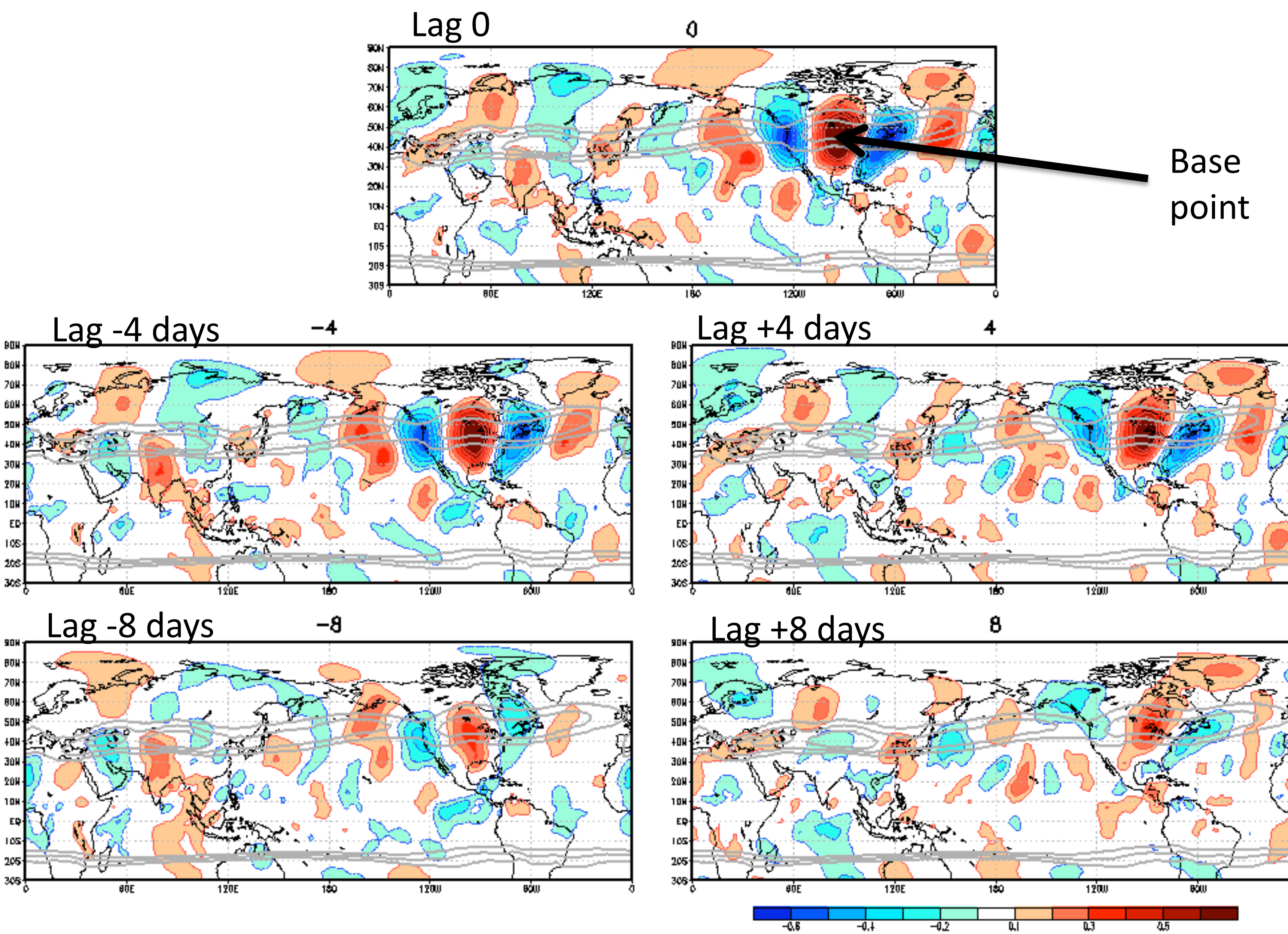
One- point lead/lag Correlation (V250mb)

(30-90 day filter, MERRA - JJA 1979-2008)



One- point lead/lag Correlation (V250mb)

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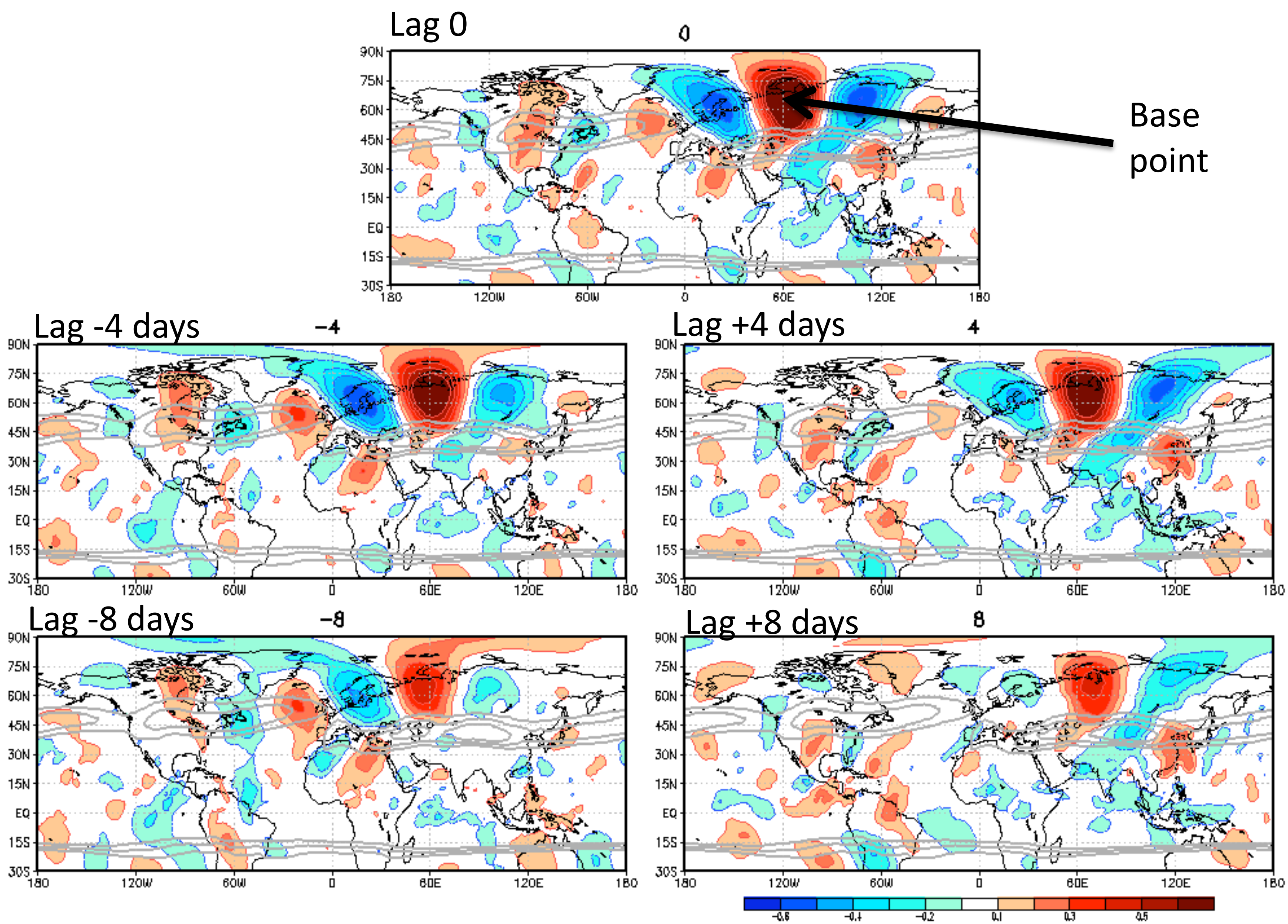
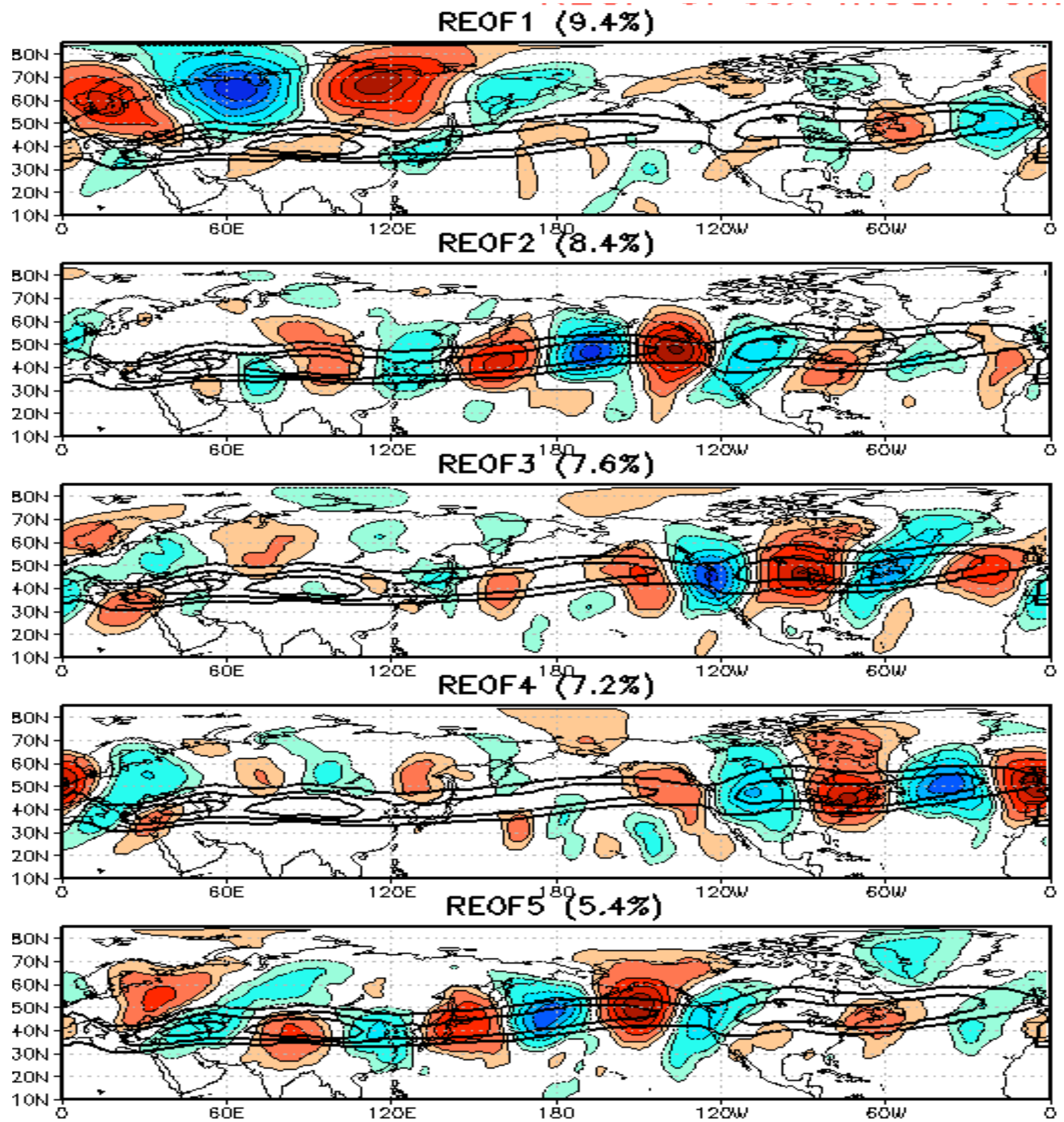


Leading Rotated EOFs of Intraseasonal (Monthly JJA) V250mb



MERRA: 1979-2008

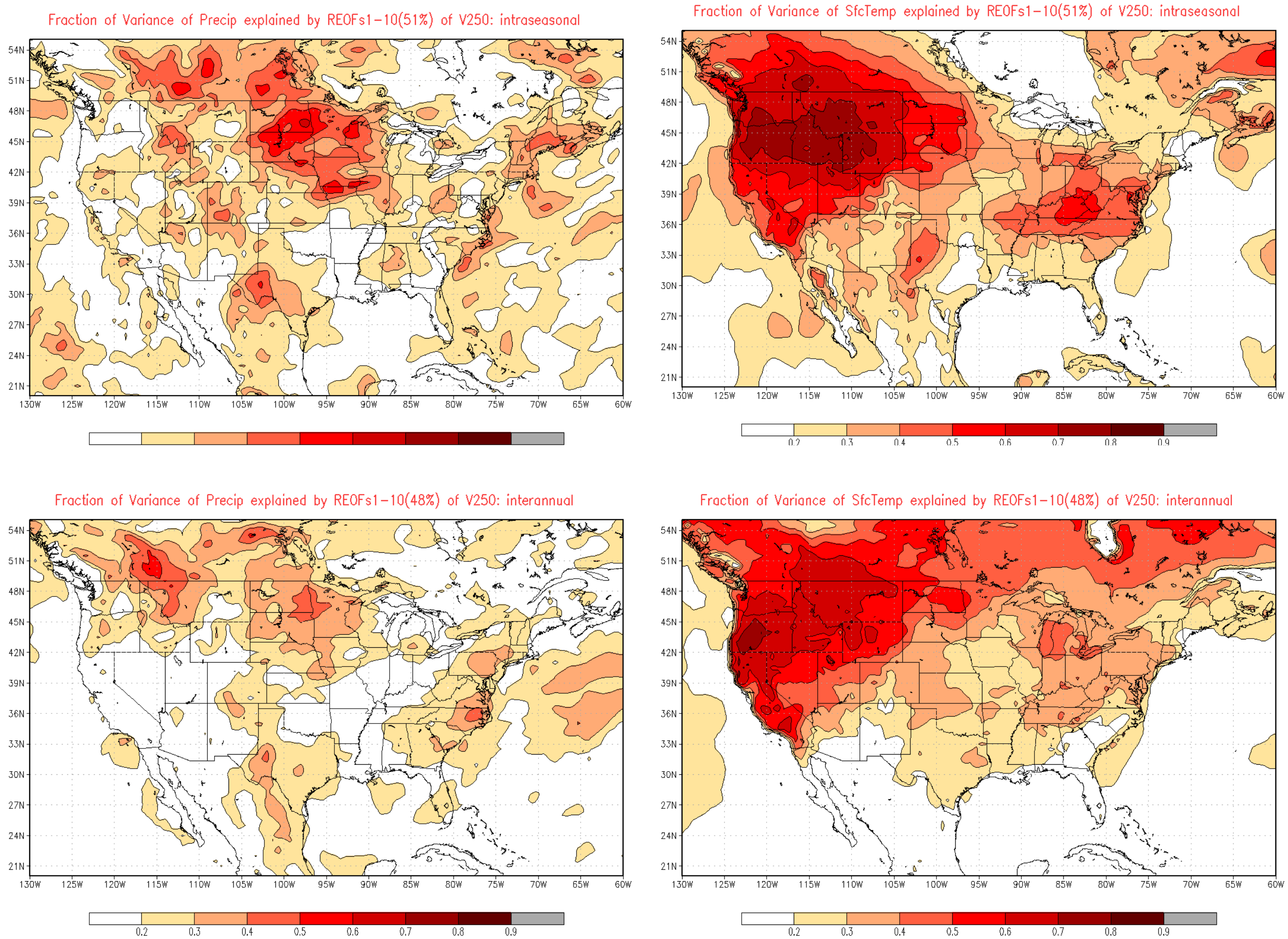
Fraction of Variance Explained by first 10 REOFs of 250 v-wind

Precipitation

T2m

Intraseasonal

Includes Inter-annual and Intraseasonal



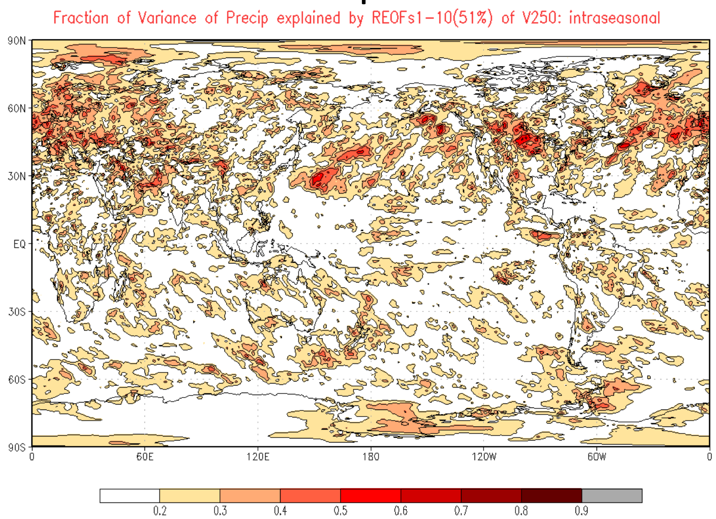
Based on Monthly MERRA data JJA (1979-2008)

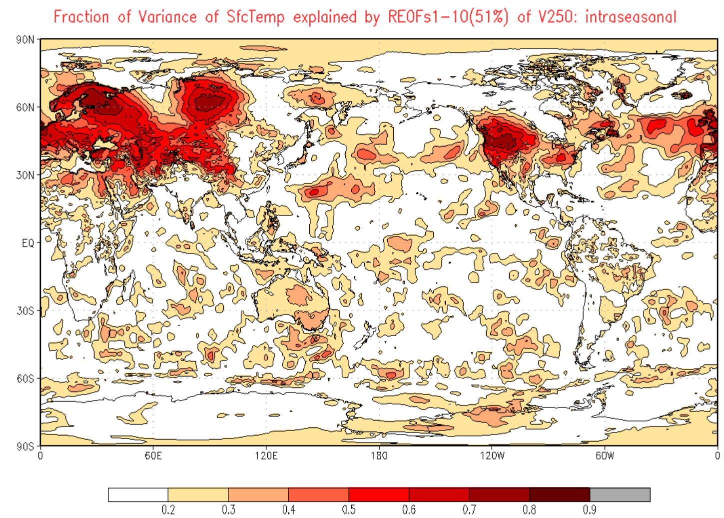
Fraction of Variance Explained by first 10 REOFs of 250 v-wind

Precipitation

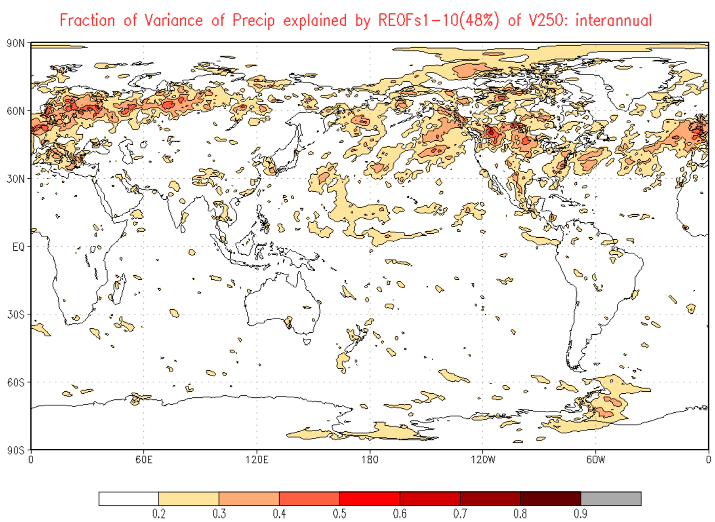
T2m

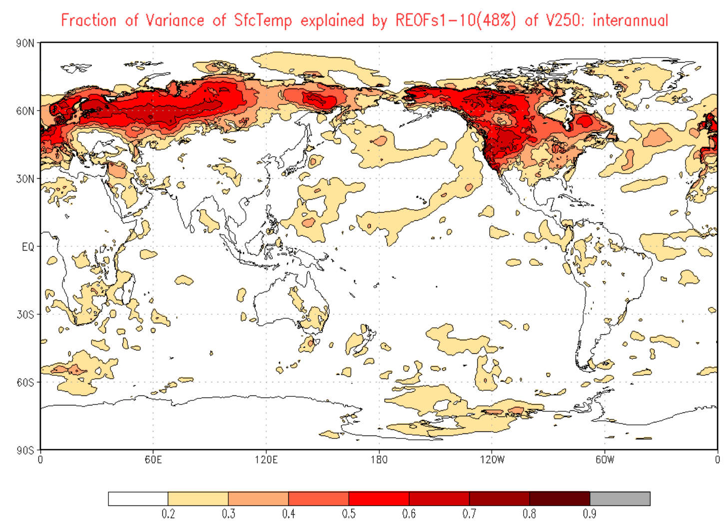
Intraseasonal





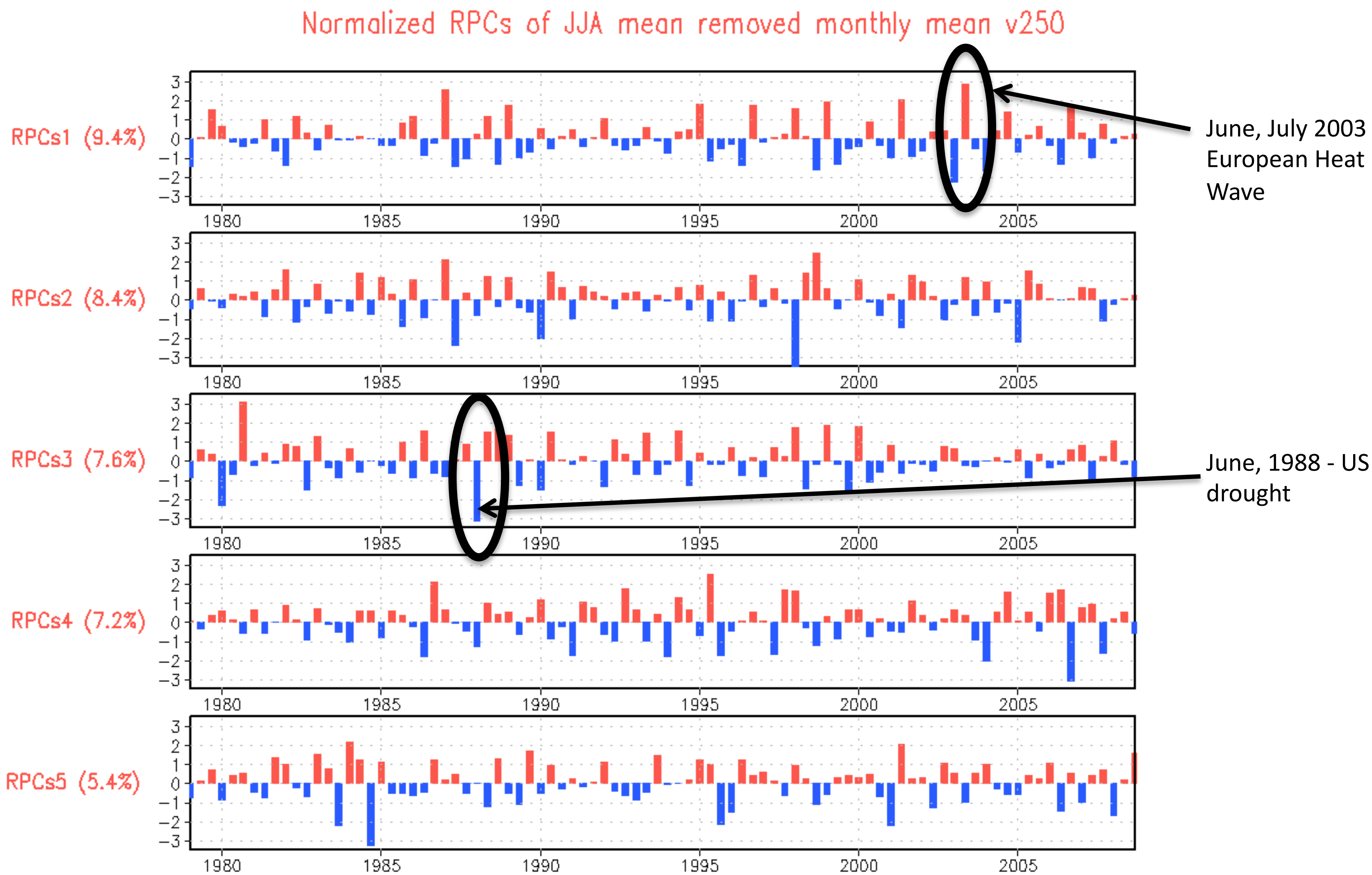
Includes Inter-annual and Intraseasonal





Based on Monthly MERRA data JJA (1979-2008)

Leading Normalized Rotated PCs (Intraseasonal Monthly JJA)



2003 European Heat Wave

2003 Monthly Anomalies (V250mb)

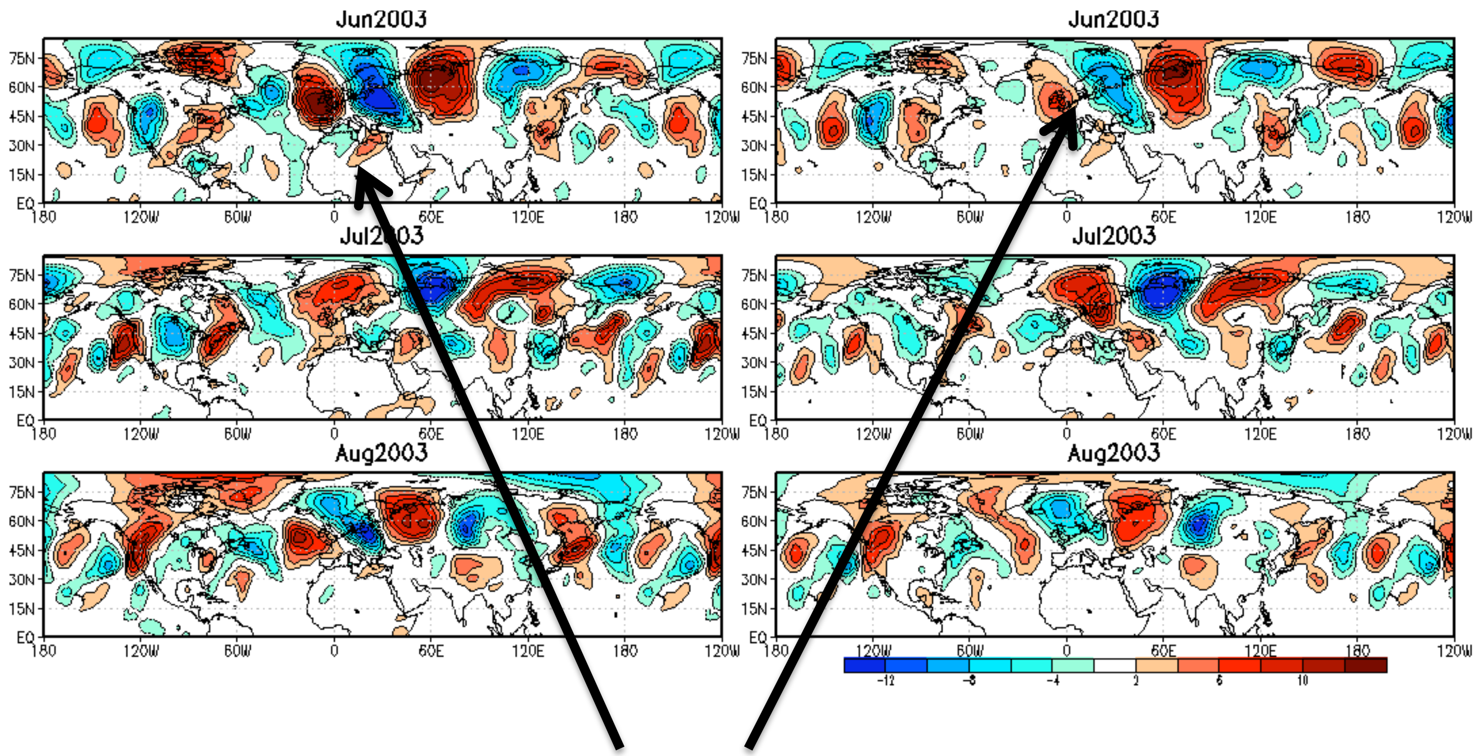
Interannual

Intraseasonal

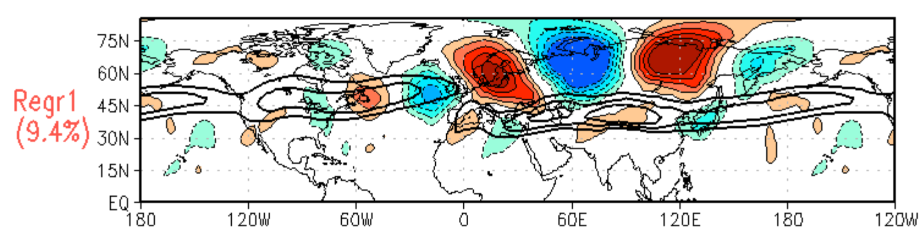
June

July

Aug

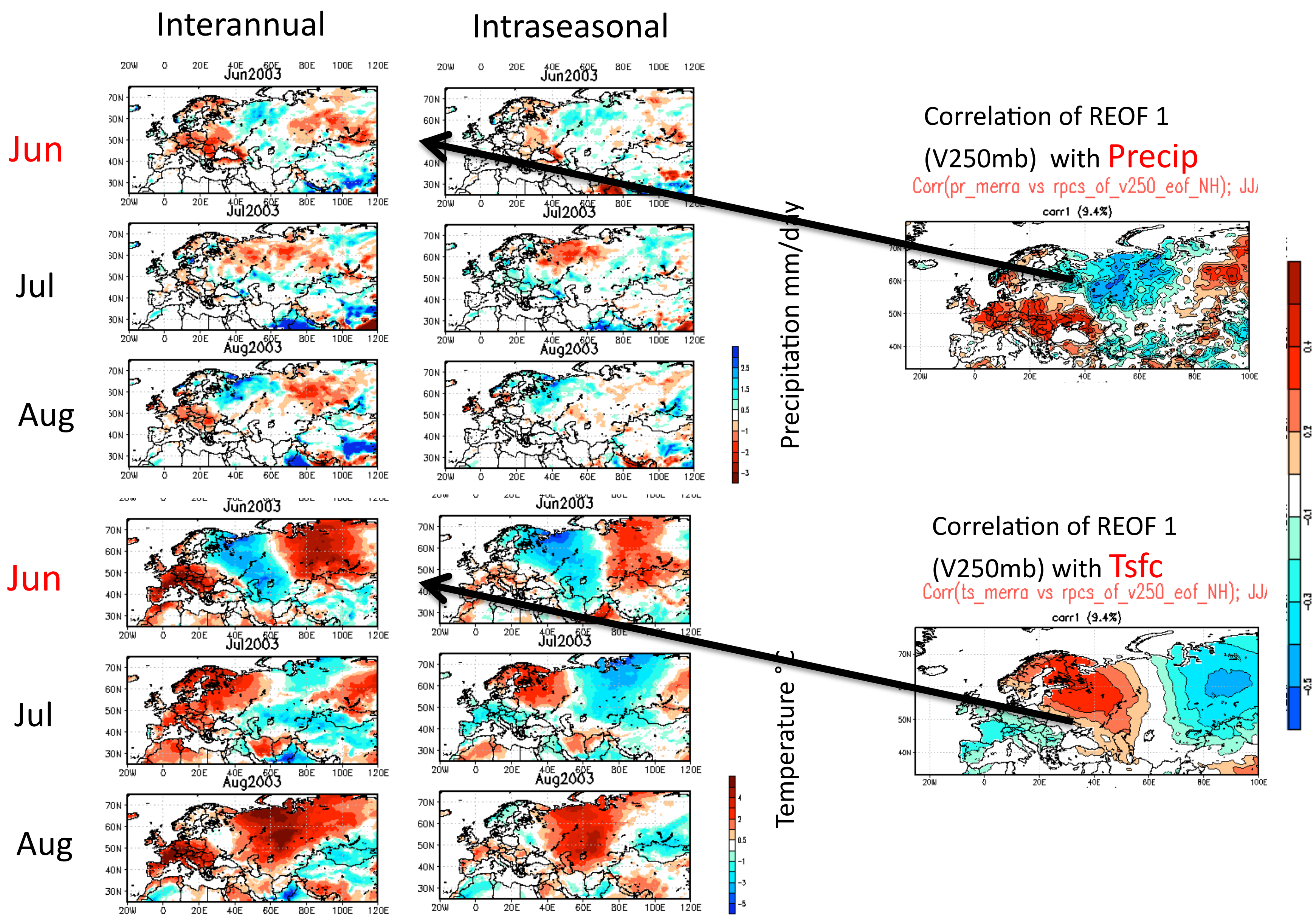


REOF 1 – Regression with V250mb



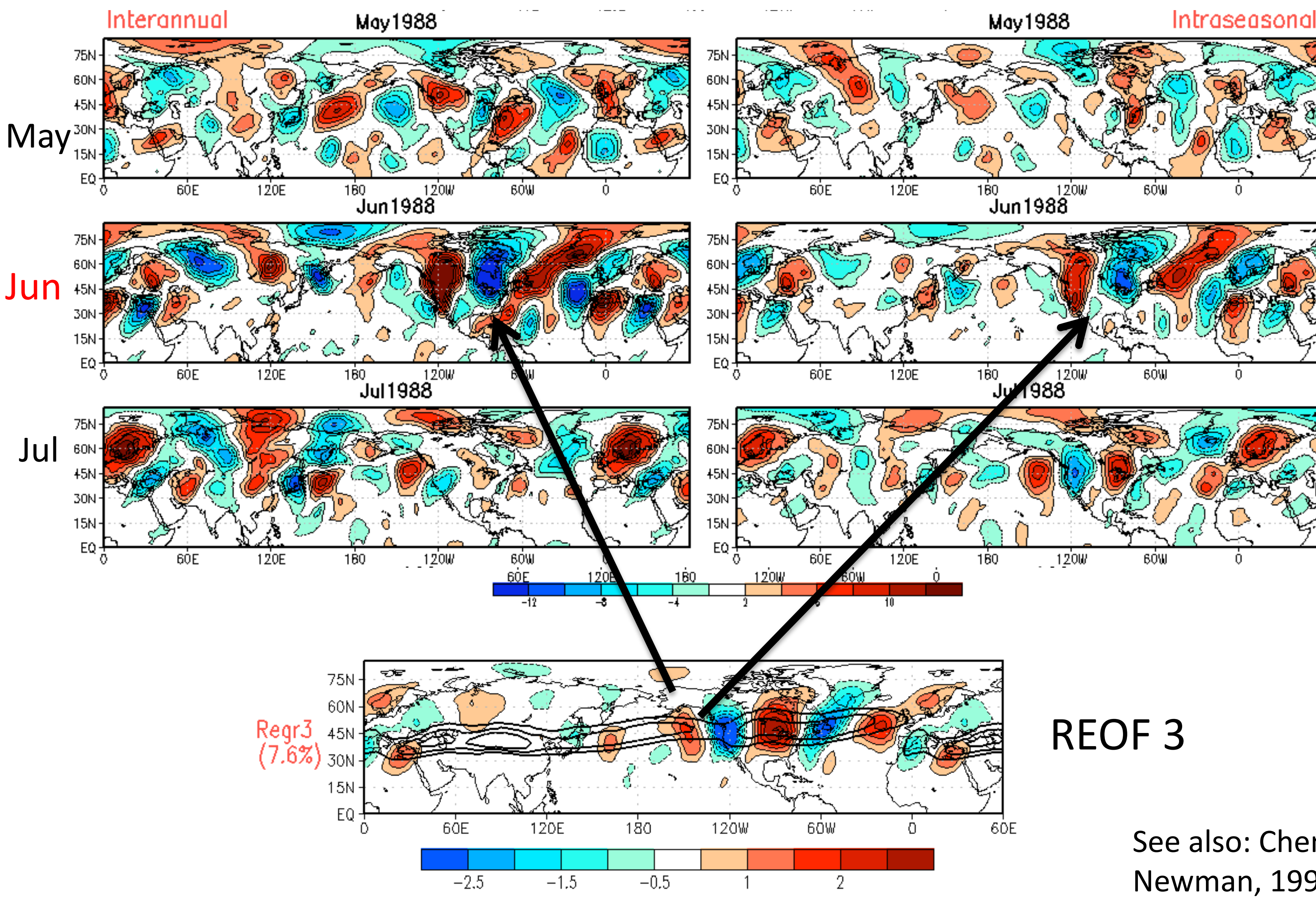
REOF 1

2003 European Heat Wave Monthly Anomalies (MERRA)



1988 US Drought/Heat Wave

1988 Monthly Anomalies (V250mb)



REOF 3

See also: Chen and Newman, 1997

1988 Monthly Anomalies (Tsfc)

Interannual

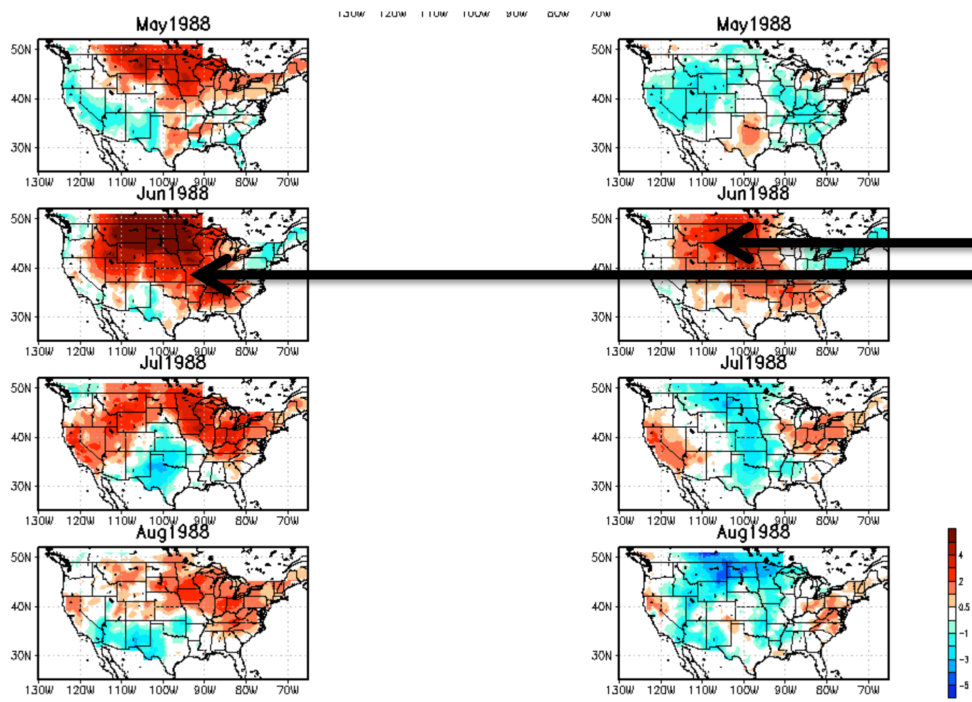
Intraseasonal

May

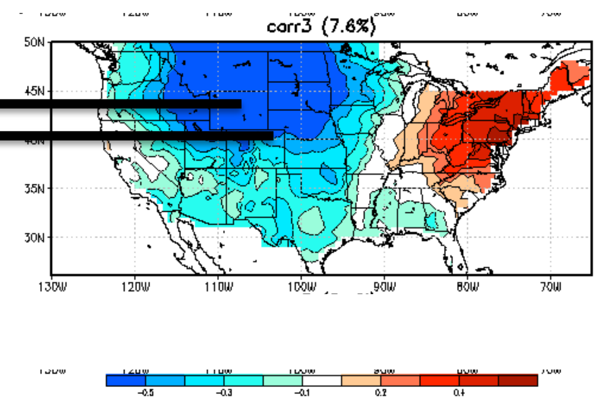
Jun

Jul

Aug



Correlation between V250 REOF 3 and Tsfc (MERRA)



1988 Monthly Anomalies (Precipitation)

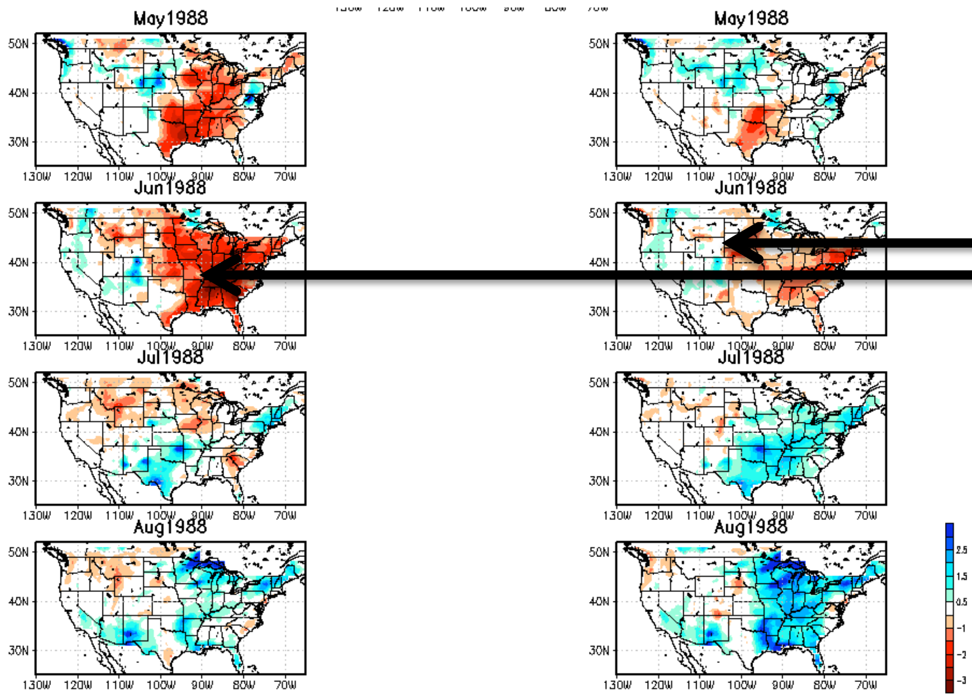
Interannual Intraseasonal

May

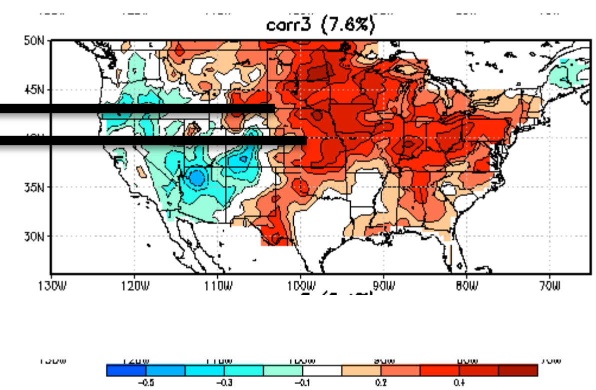
Jun

Jul

Aug



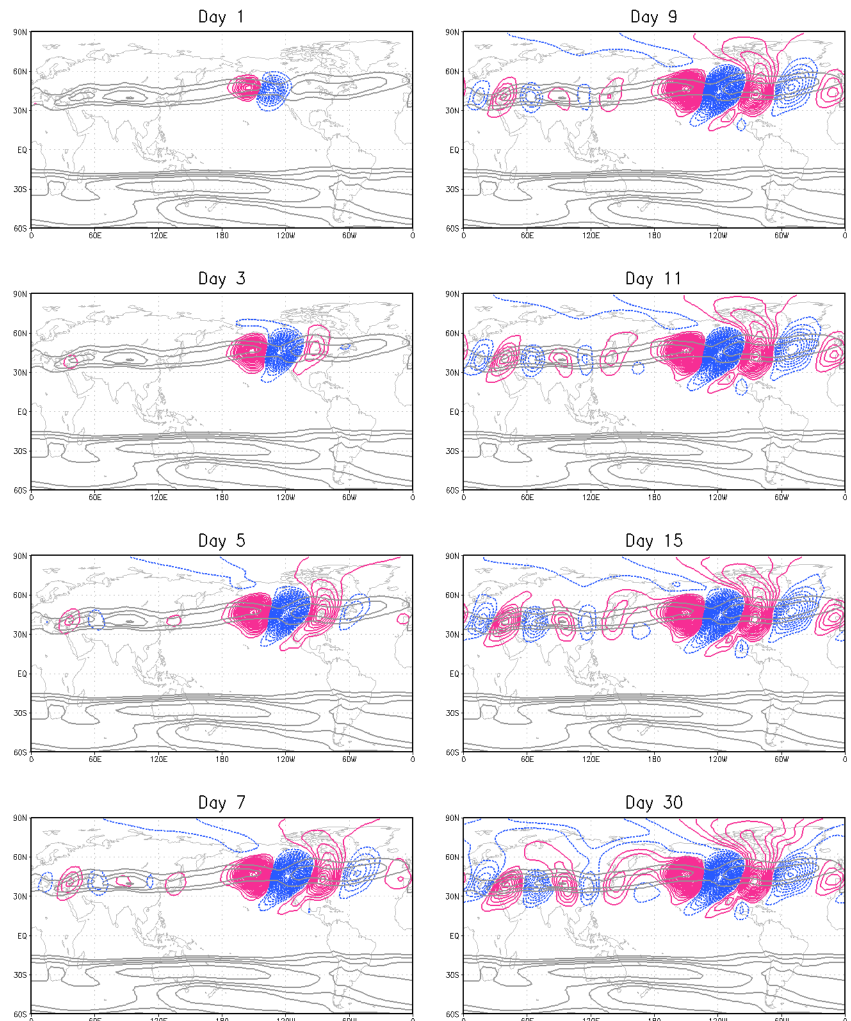
Correlation between V250 REOF 3 and Precipitation (MERRA)



Preliminary Work With Stationary Wave Model* (SWM)

Evolution of Eddy V-wind σ=.257

(Heating at 210E, 45N)



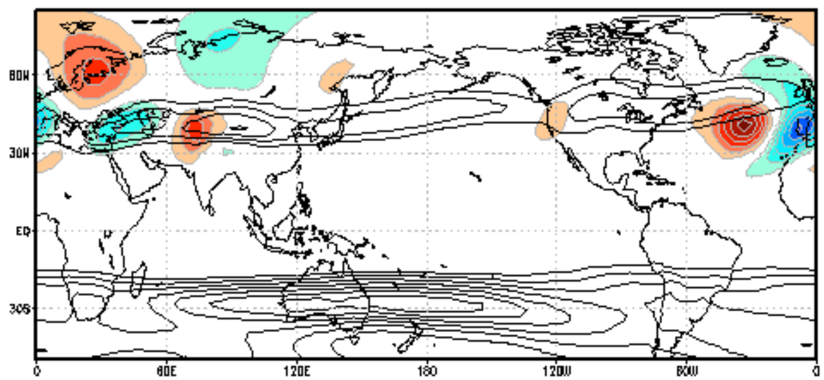
MERRA JJA Base State

*Ting and Yu 1998

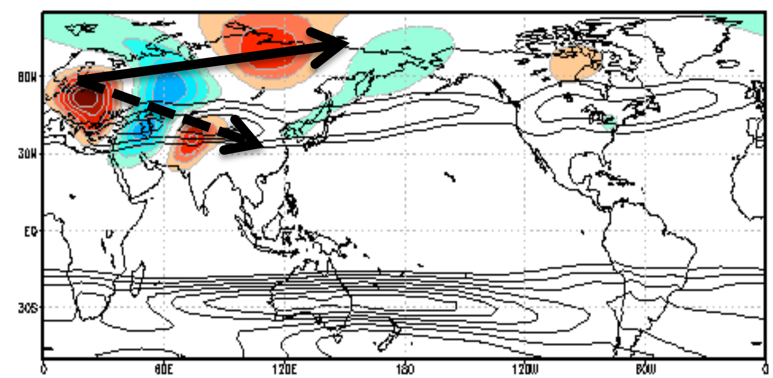
SWM - Examples of responses to idealized forcing in N. Atlantic and Europe

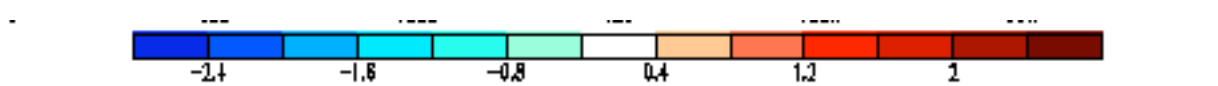
Eddy V-wind σ=.257

SWM Response to Idealized Heat Source at 330E, 40N



SWM Response to Idealized Heat Source at 20E, 50N

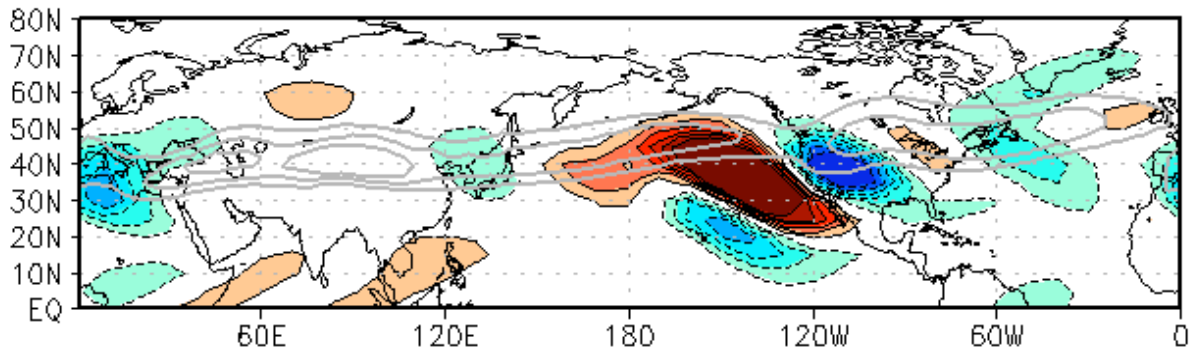




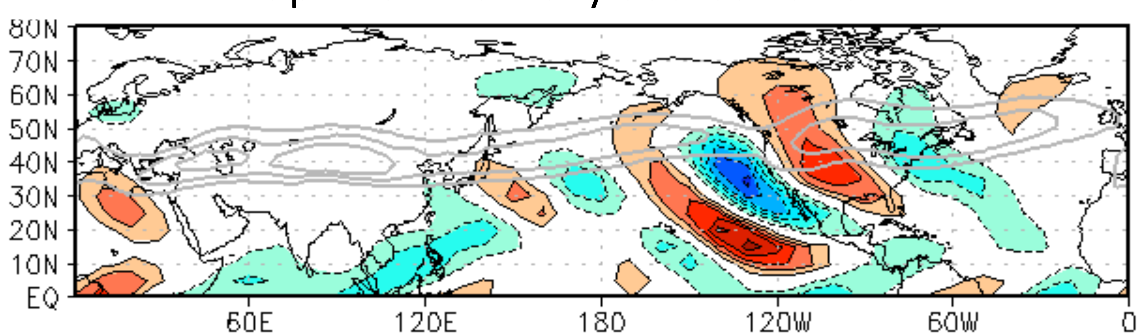
Resembles REOF 1

SWM -Example of optimal forcing patterns for REOF3

"Optimal" Heat Source Pattern

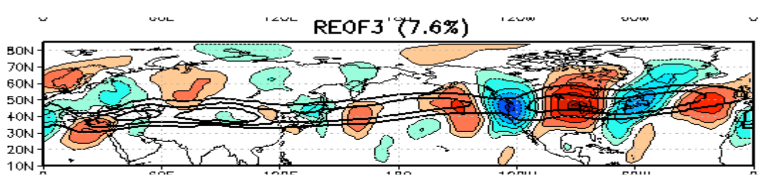


"Optimal" Vorticity Source Pattern



Optimal pattern is computed by calculating the responses to forcings located at every 5° lat and 10°lon and taking the inner product between the response and REOF3 and plotting that at each location

REOF 3

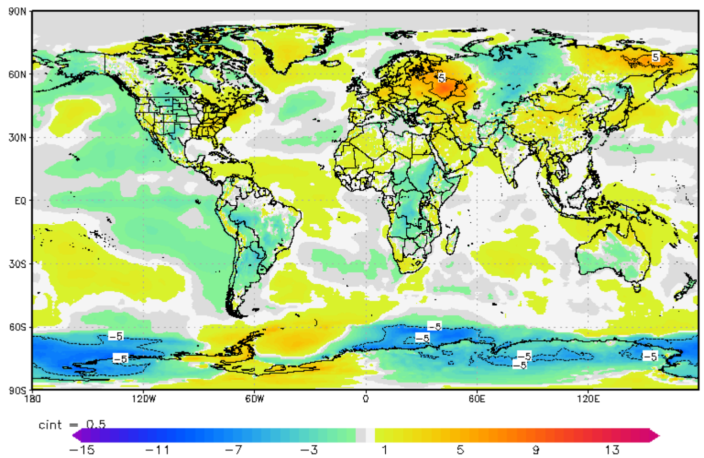


Conclusions

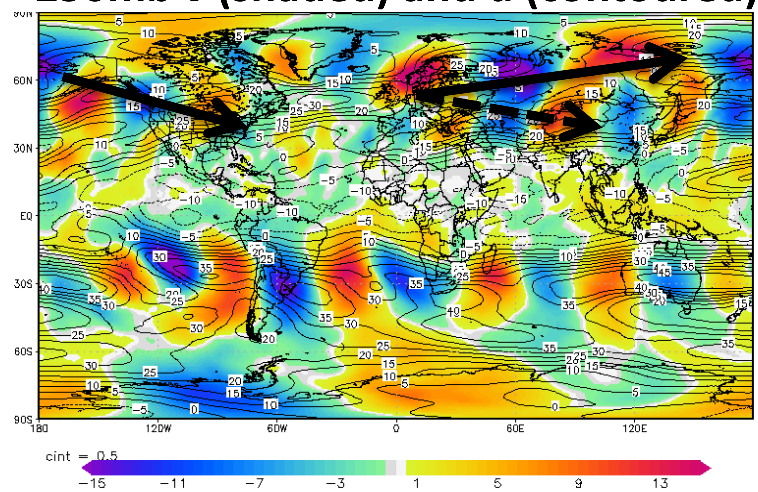
- Stationary Rossby Waves appear to play a significant role in modulating summer precipitation and Tsfc in northern middle latitudes on monthly time scales
- At times, they appear to play a dominant role in the development of regional extremes (e.g., 2003 European heat wave, 1988 US drought)
- What about 2010? During July a Rossby wave seems to play a key role in the extremes in Russia (drought), Pakistan (floods), US Great Plains (very wet) and east coast (very hot) – see next figure.

July 2010 Anomalies

T2m

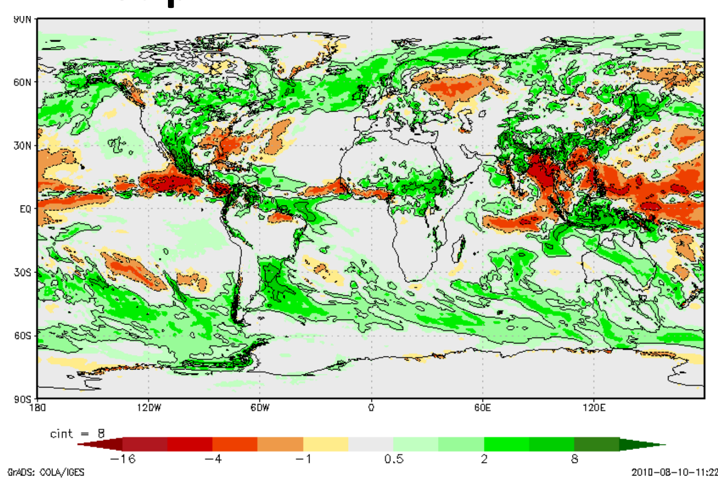


250mb v (shaded) and u (contoured)

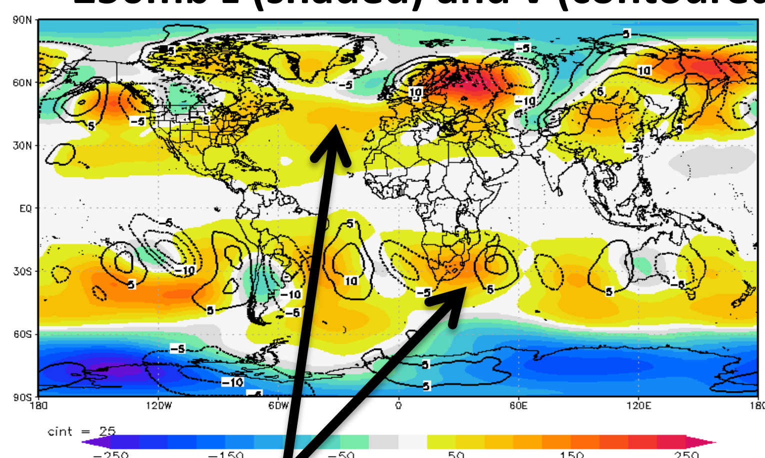


Extremes in Russia, Pakistan, US GP and east coast are all connected by Rossby Wave?

Precip



250mb z (shaded) and v (contoured)



Drought signature: zonally symmetric positive height anomalies in both hemispheres– forced by cold Pacific and warm Atlantic, but appears to have little impact on the July rainfall except regionally in concert with the Rossby Wave

Overall Conclusions

- We have made major strides in the last decade or so
  - Key role of SST (especially tropical Pacific) at interannual/ longer time scales
  - Importance of seasonality in the response to SST
    - Changes in planetary waves/storm tracks in winter and spring
    - Changes in Walker circulation in summer and fall
    - Importance of transition seasons on decadal time scales

- Key Uncertainties
  - Role of Atlantic (and Indian Ocean) SST less clear
  - Model uncertainties (land impacts, Walker circulation response, resolution issues – regional phenomena, weather, basic seasonal cycle, ocean variability in coupled models)
  - Impact of climate change versus decadal variability, aerosols, vegetation, etc

- Issues limiting our ability to predict/monitor
  - SST provide only a relatively weak "background forcing" with a substantial level of noise (stochastic component is large – but presumably depends on time scale)
  - Especially need to address the fact that there is a substantial subseasonal component associated with Rossby waves likely not directly forced by SST that is responsible for short-term modulation of drought/heat waves and other extremes