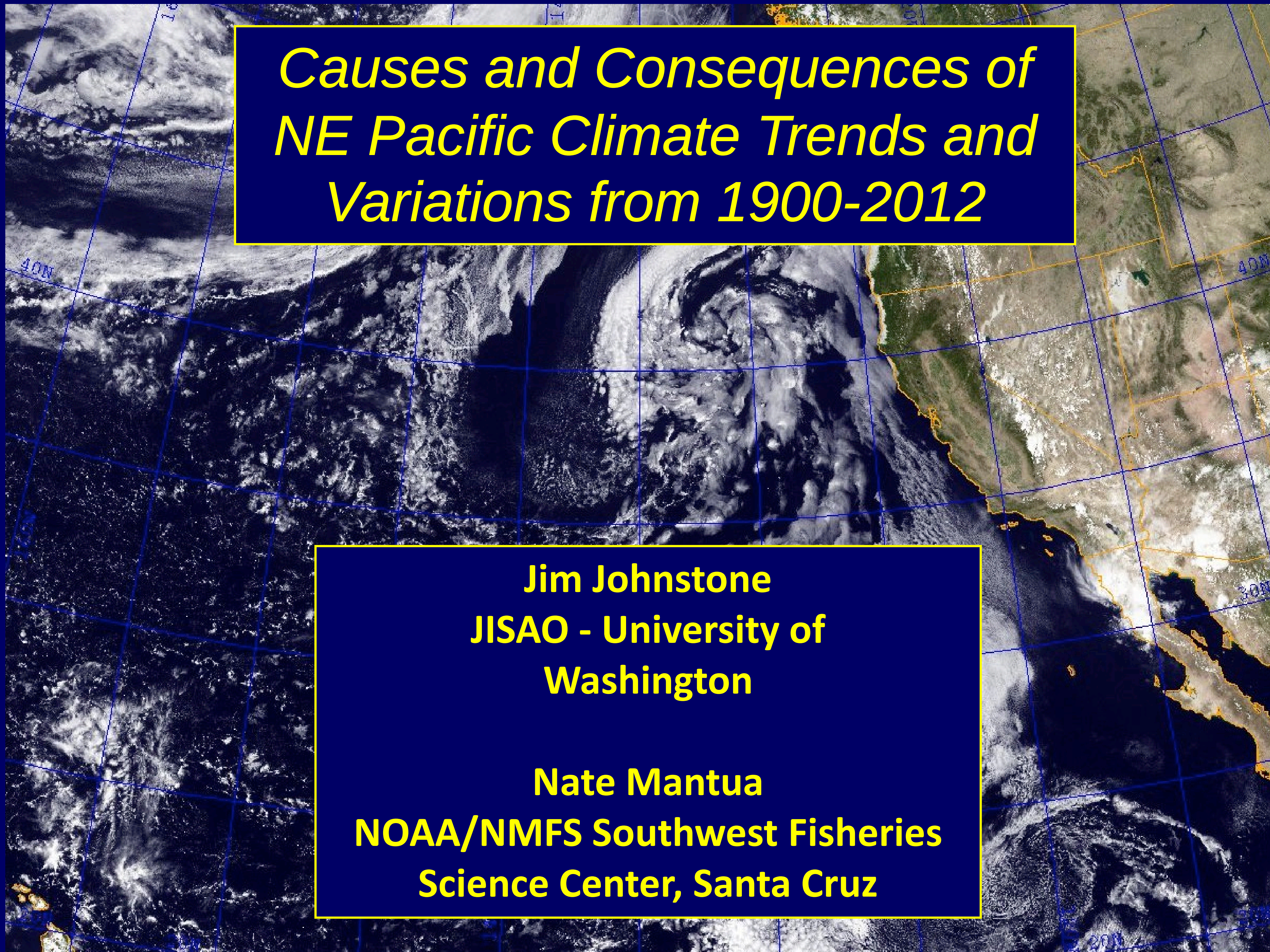
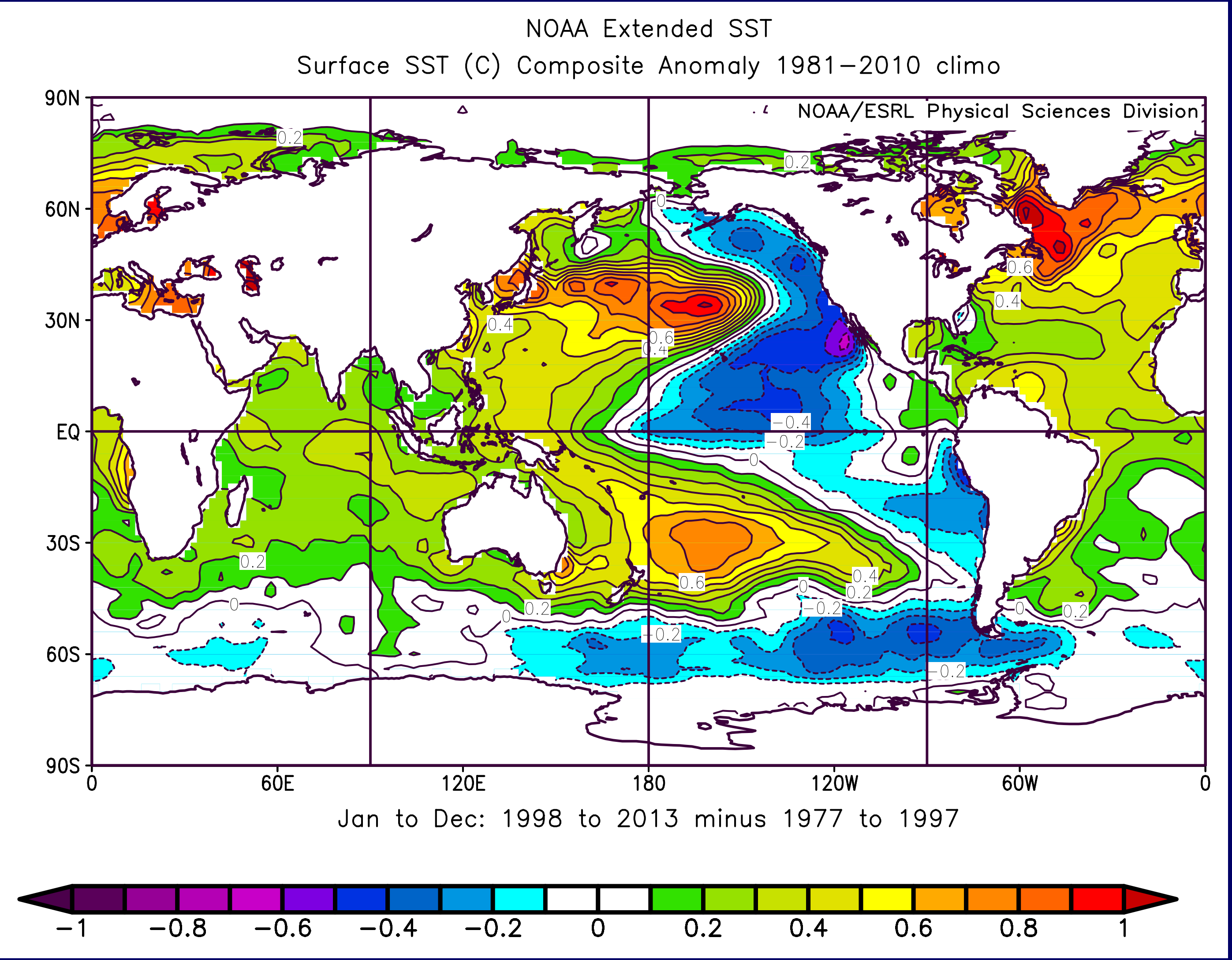


Causes and Consequences of NE Pacific Climate Trends and Variations from 1900-2012

Jim Johnstone
JISAO - University of Washington

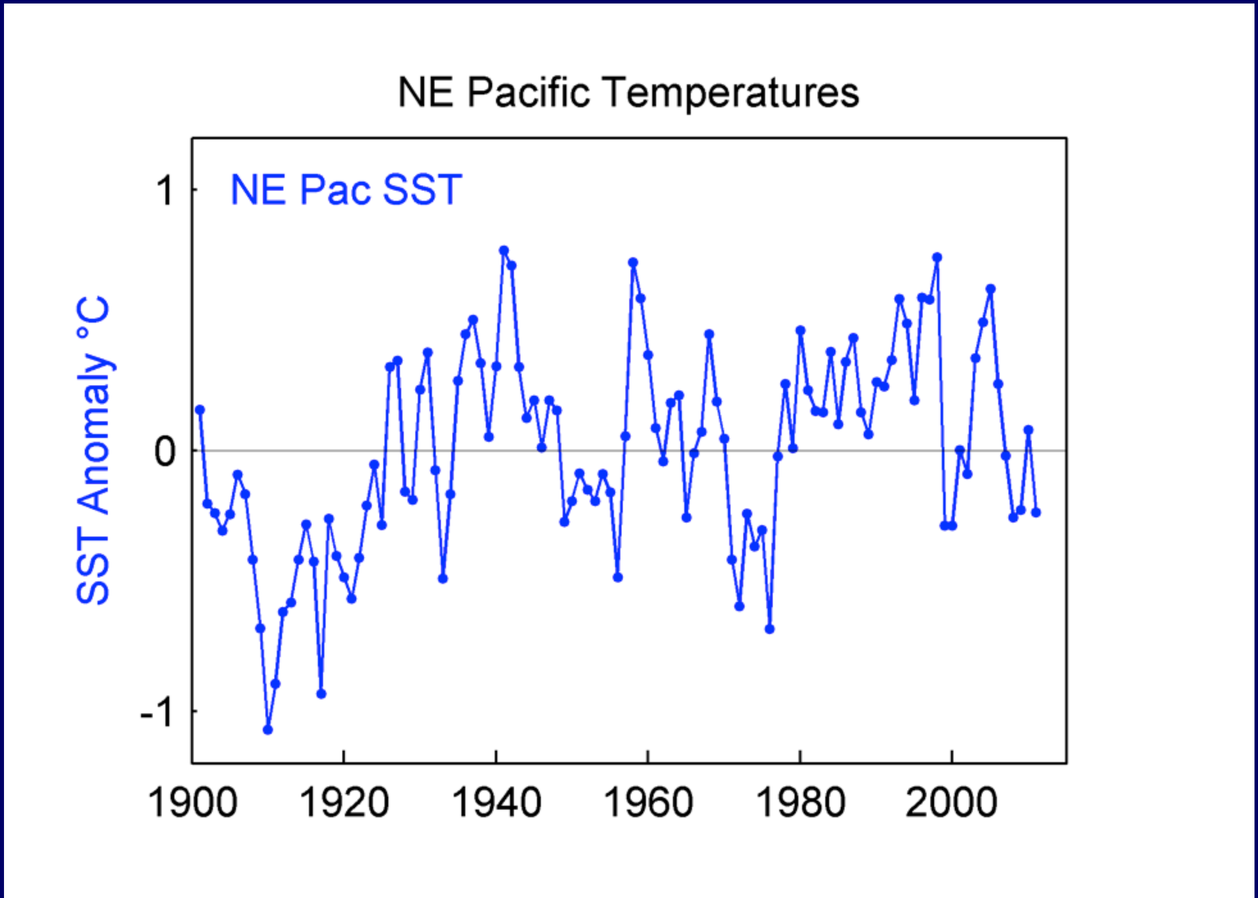
Nate Mantua
NOAA/NMFS Southwest Fisheries Science Center, Santa Cruz

Global warming, but Eastern Pacific cooling: (1998-2013) – (1977-1997)



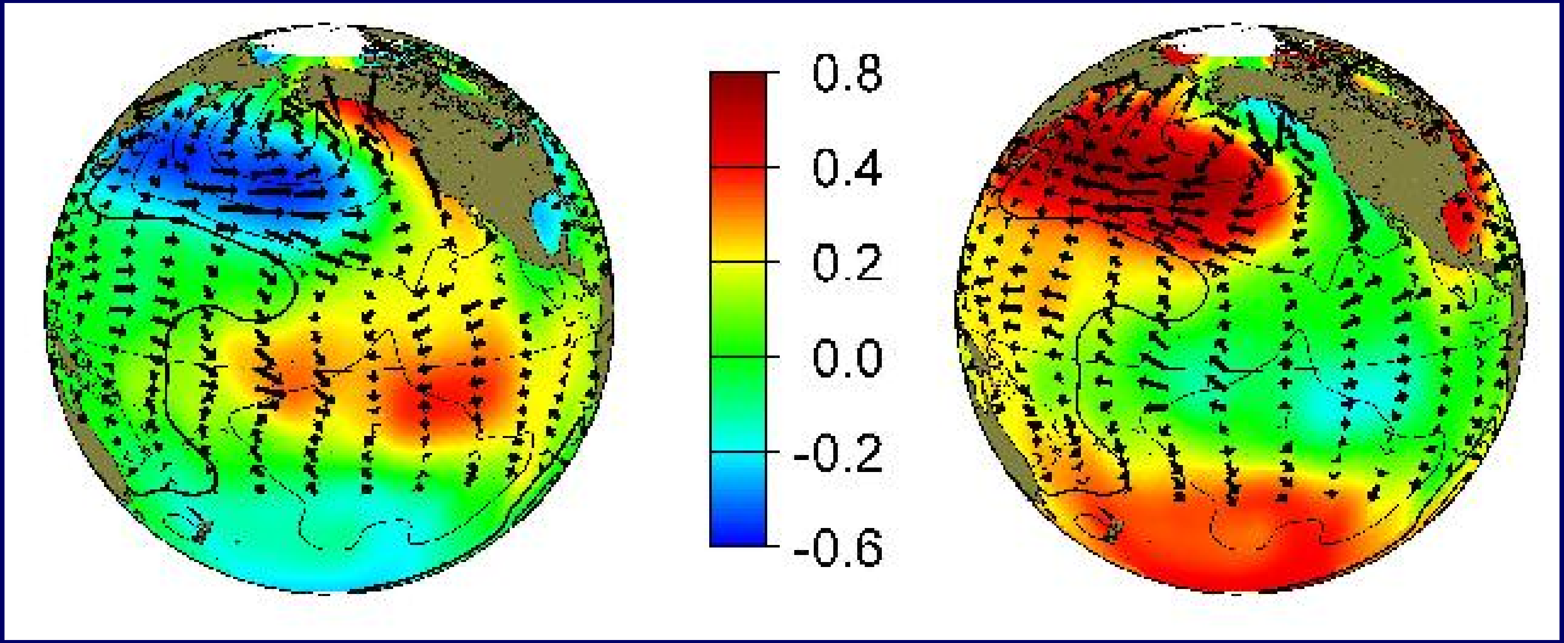
A rising baseline, with substantial variability

what's behind the trends and variations?



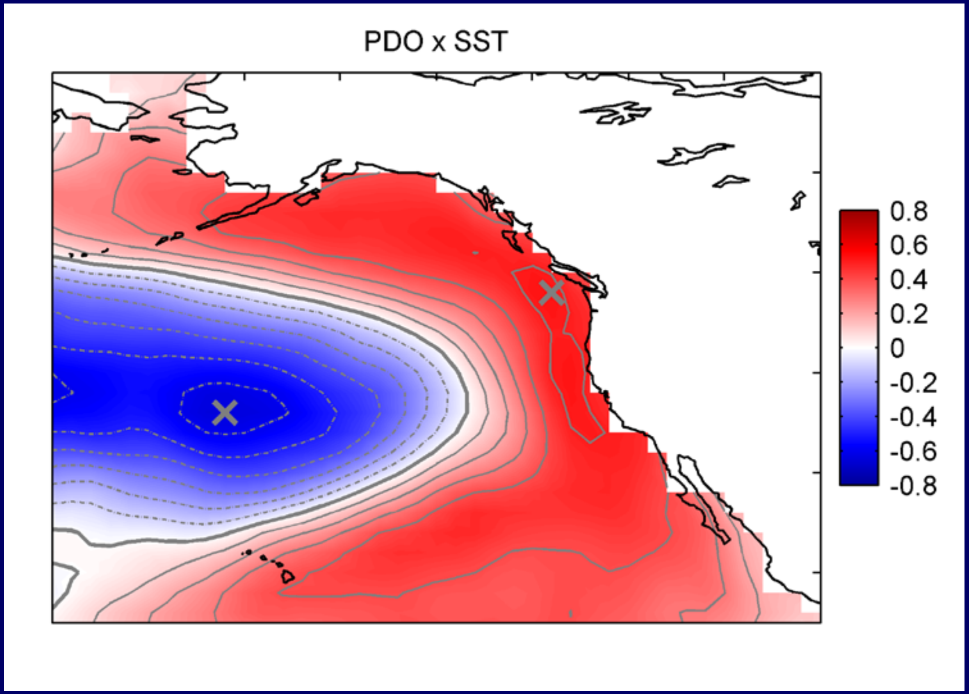
The Pacific Decadal Oscillation: defined as the leading empirical mode of North Pacific SST variability

- EOF analysis was performed on monthly SST anomalies after subtraction of the global mean (effectively de-trends the PDO index)



- Largely regulated by the Aleutian Low, variations in the Kuroshio/Oyashio currents and persistence of upper ocean temperature anomalies
- the Aleutian Low varies intrinsically and in response to atmospheric teleconnections with the tropical Pacific (e.g. related to ENSO and other tropical climate variations)

With respect to understanding the NE Pacific,
The PDO has some limitations:



- Max Correlation 0.53
- Detrended index masks lowest-frequency variability
- PDO more strongly represents the central Pacific
- Multiple regional mechanisms contribute to the basin-wide pattern

<u>Motivation</u>:
What do century-long records have to say about the climate history of the NE Pacific? Can a coherent story be obtained?

Primary Data:

Sea-level pressure and 10-m winds:

- NCAR 5° monthly gridded SLP data from Naval Maps, modern reanalysis (1899 – 2012)
- CMIP5 simulated SLP from “historical ensembles” (1900-2005)
- 20th Century reanalysis, version 2, 10-m winds (1920-2012)

Sea surface temperature (SST):

- NOAA 2° monthly Extended Reconstruction version 3B (1900-2012)

Coastal land air temperatures:

- USHCNv2, GHCNv3 (1900-2012)

Air/sea heat fluxes, upper ocean properties

- monthly SODA reanalysis, v2.2.4 (1900-2008)

Leading empirical mode of NE Pacific SST variability

(NEP SST EOF 1):

30% of variance explained

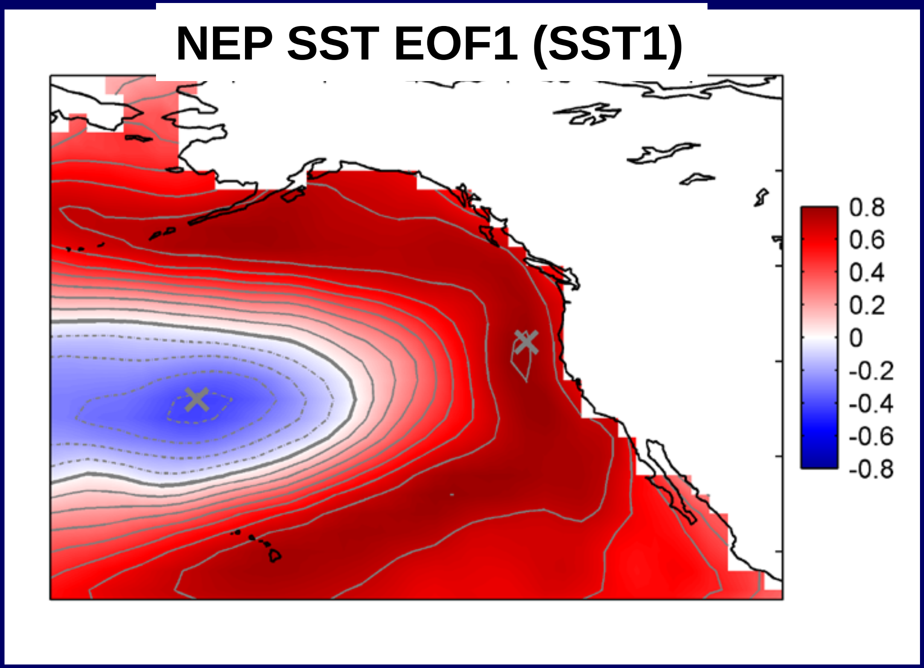
Monthly anomalies

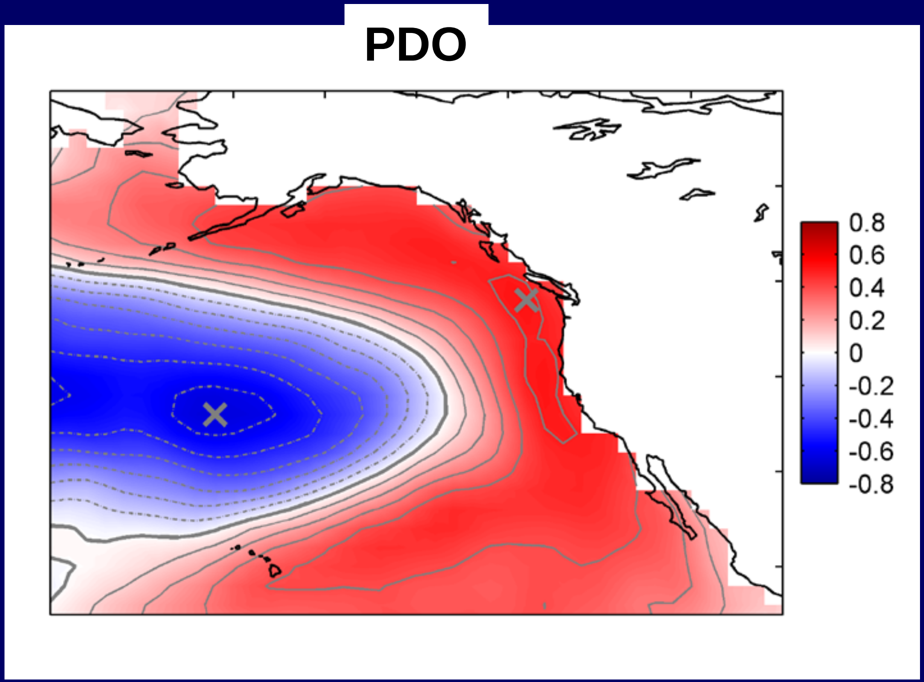
No detrending

NE Pacific domain

Max correlation 0.82

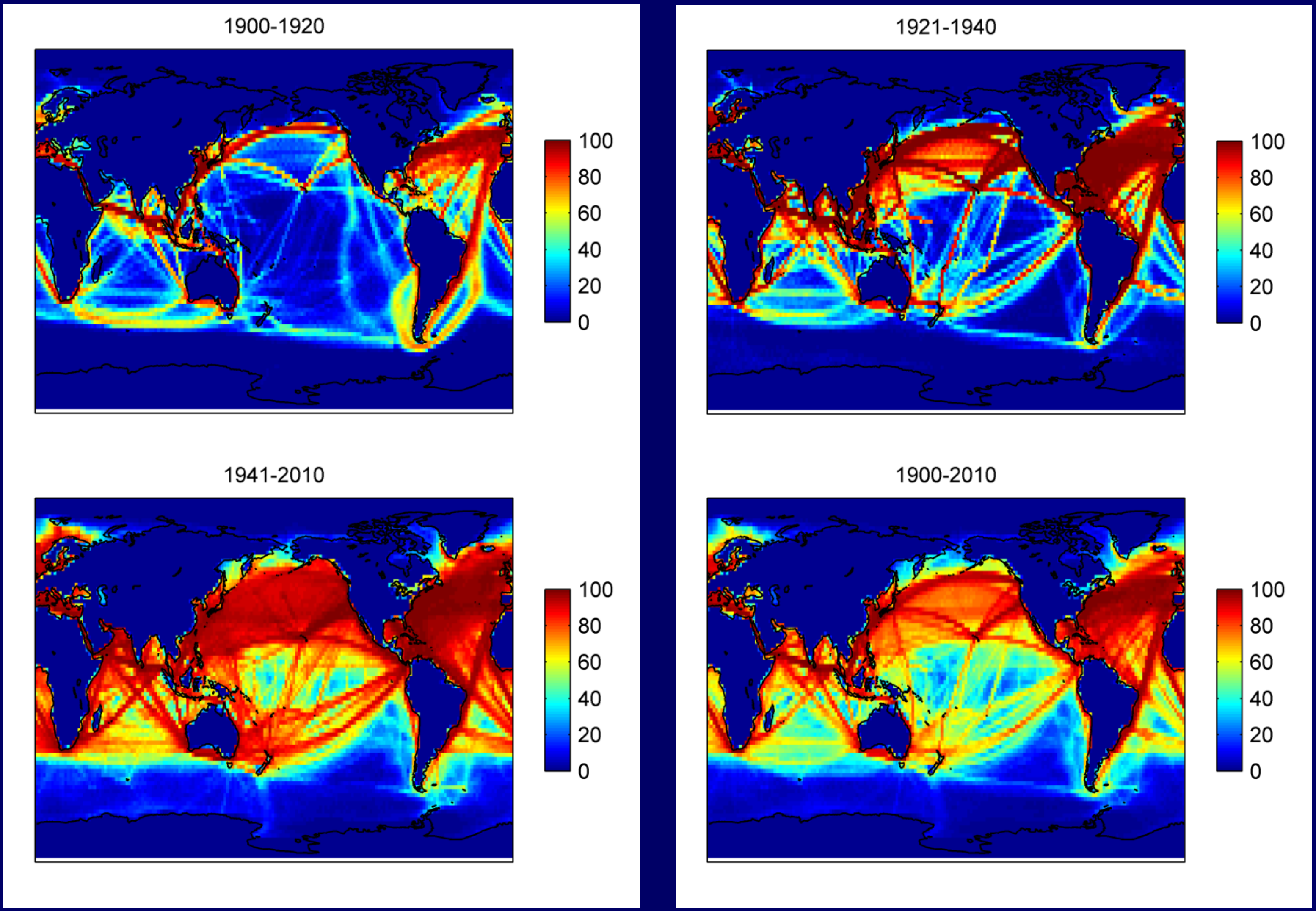
PDO max correlation is 0.53



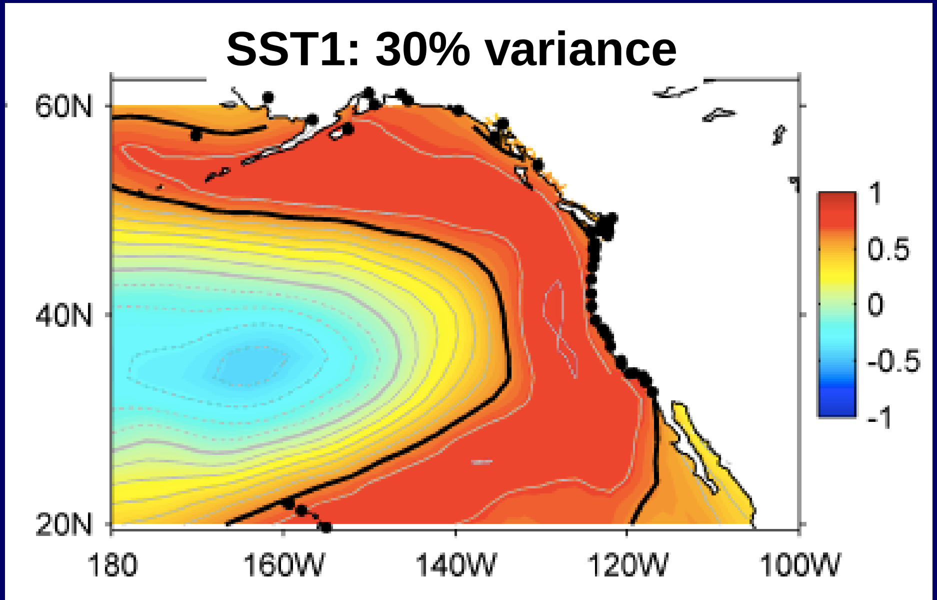


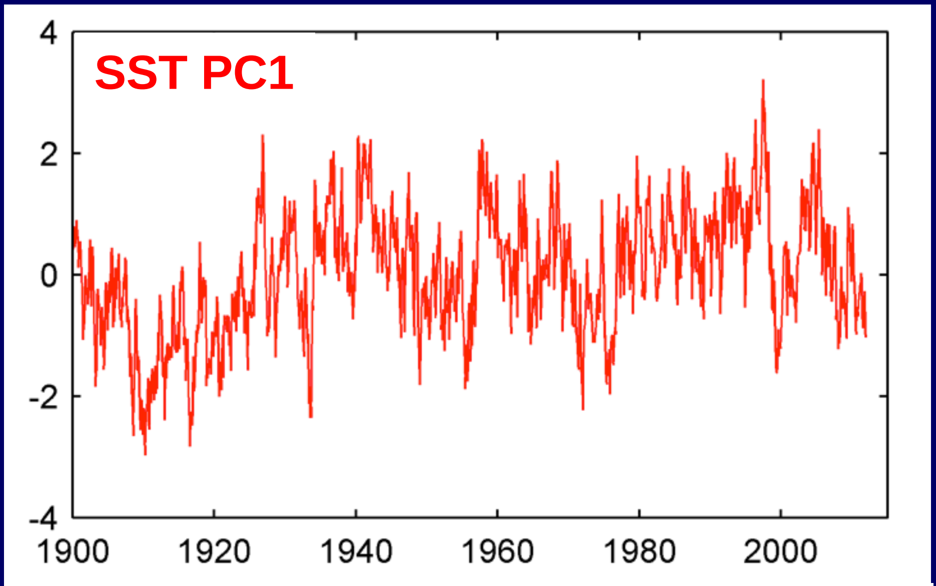
% available ICOADS ship-borne monthly 2° observations

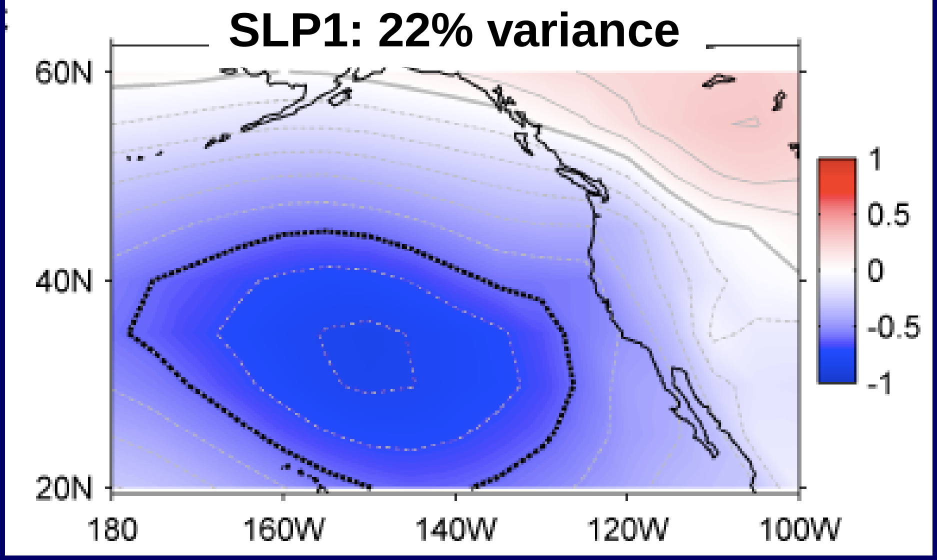
- ship tracks did a relatively good job sampling the NE Pacific Arc throughout this period

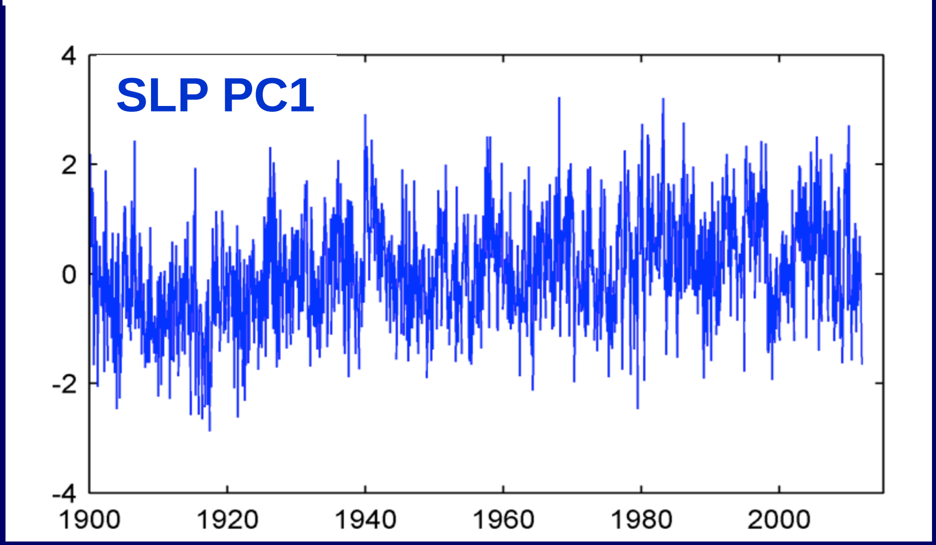


Leading EOFs/PCs of NEP SST and SLP









Relate variations in SLP and SST patterns with a Stochastic Climate Model

$$SST_t = \alpha\, SST_{t-1} + ßSLP_t + \varepsilon_t$$

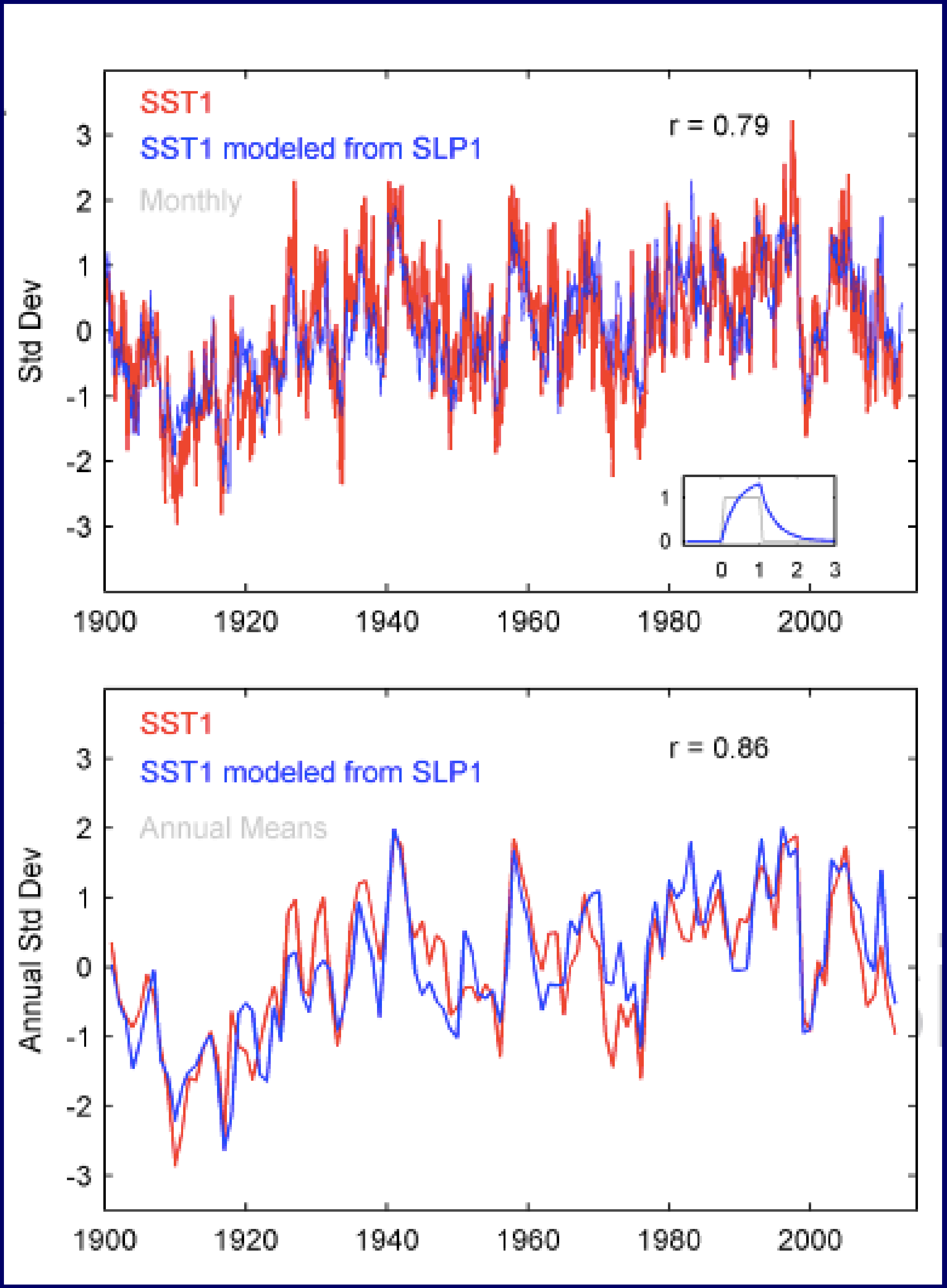
Coefficients first from lag-1 autoregression of SST
Slight adjustments guided by sensitivity experiments

$\alpha = 0.81$ *(persistence term)* ß $= 0.27$ *(SLP perturbation)*

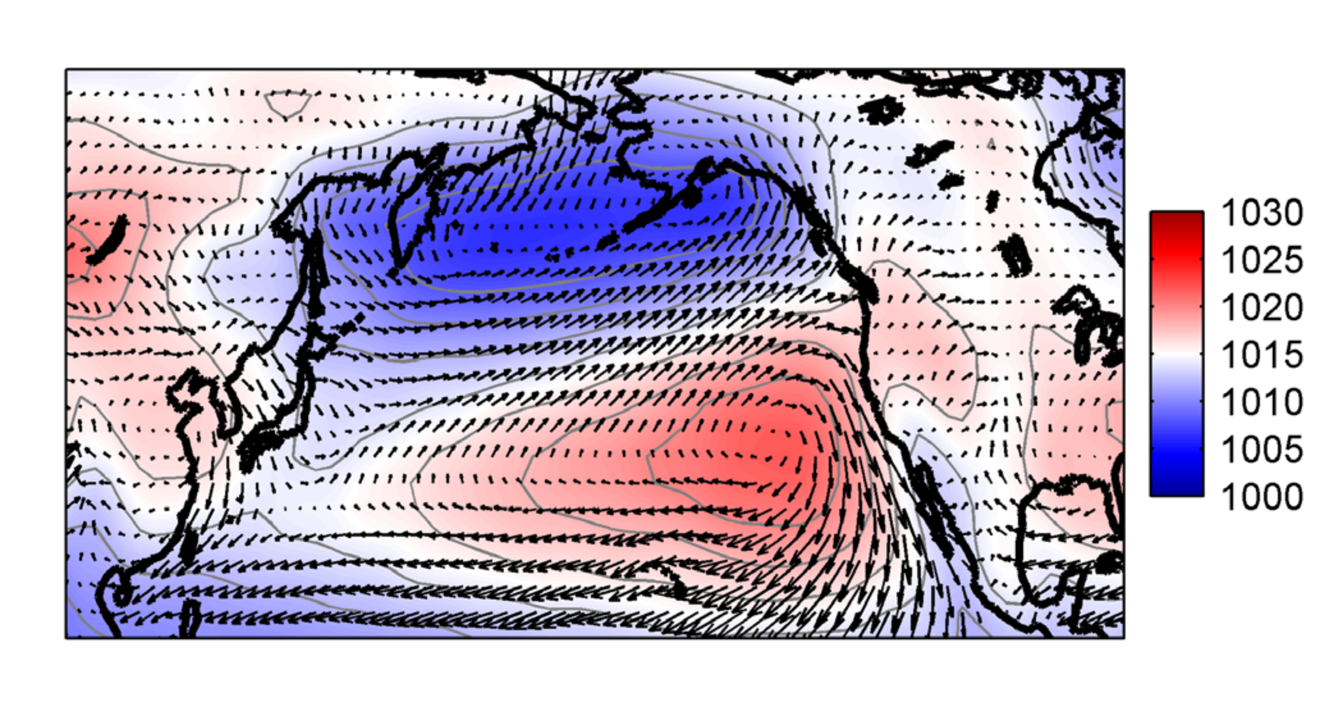
$$SST_t = 0.81\, SST_{t-1} + 0.27\, SLP_t + \varepsilon_t$$

SST1 modeled from SLP1 forcing + persistence

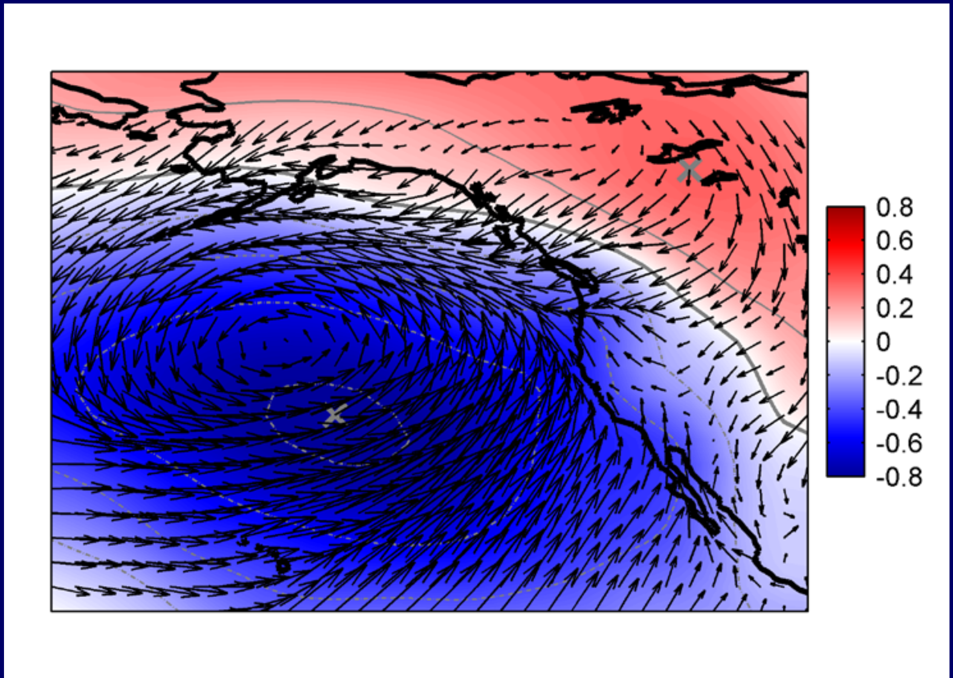
The simple stochastic climate model does about equally well reproducing observed monthly and annual mean variations in SST1



Annual Mean wind, SLP

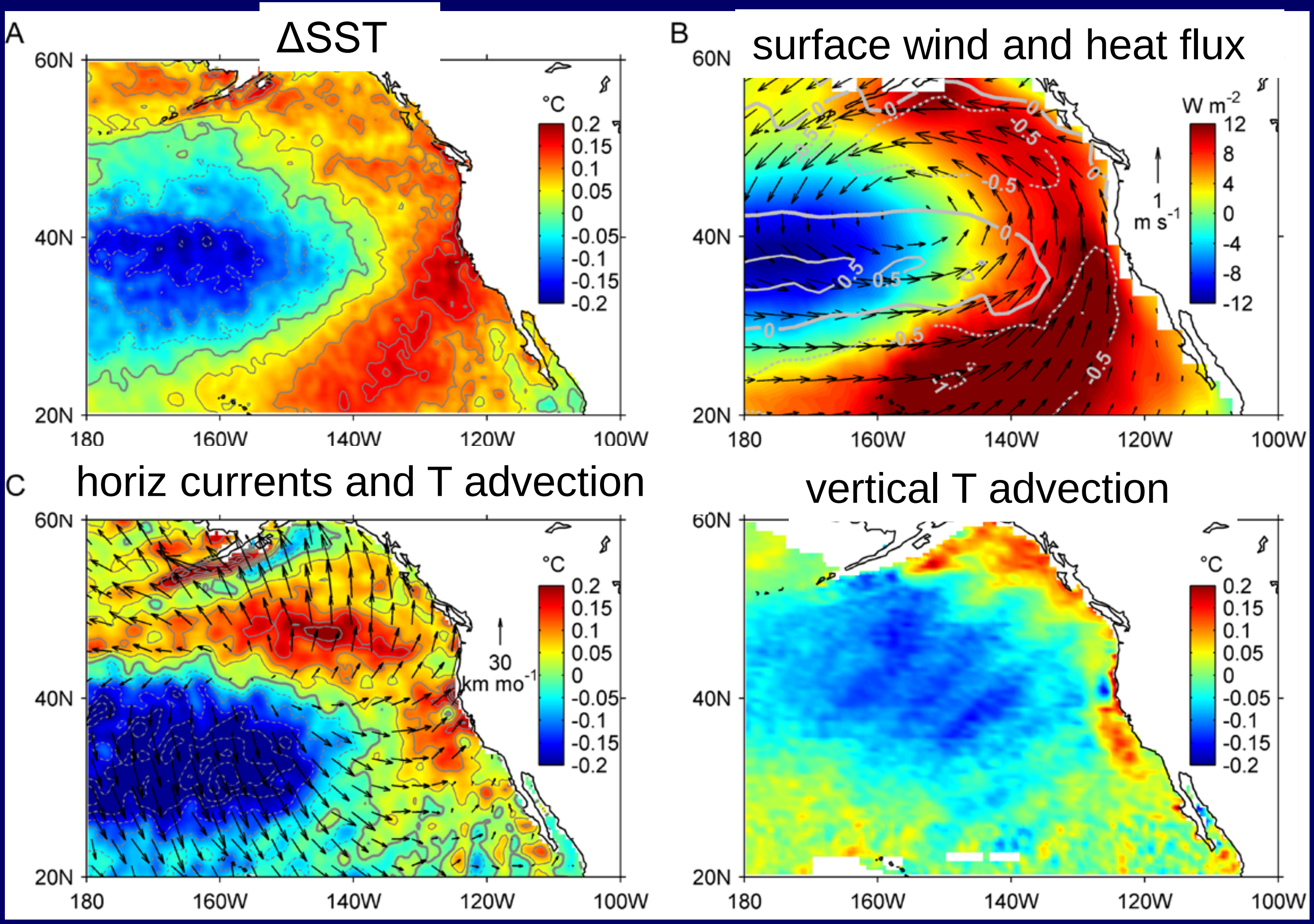


SLP1 anomalies

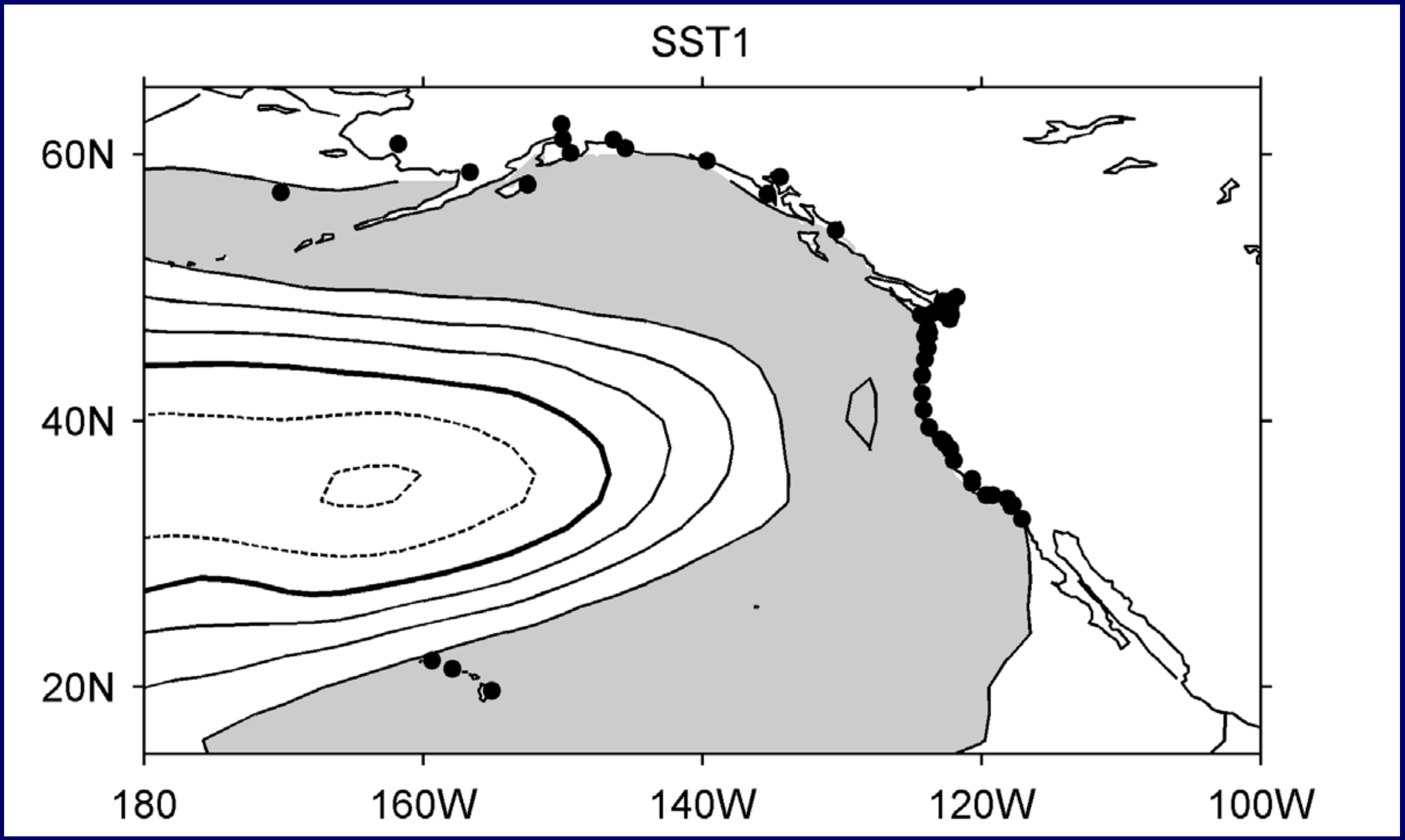


When this pattern amplifies, the Aleutian Low intensifies and/or the North Pacific High weakens; winds are more counterclockwise in the NE Pacific

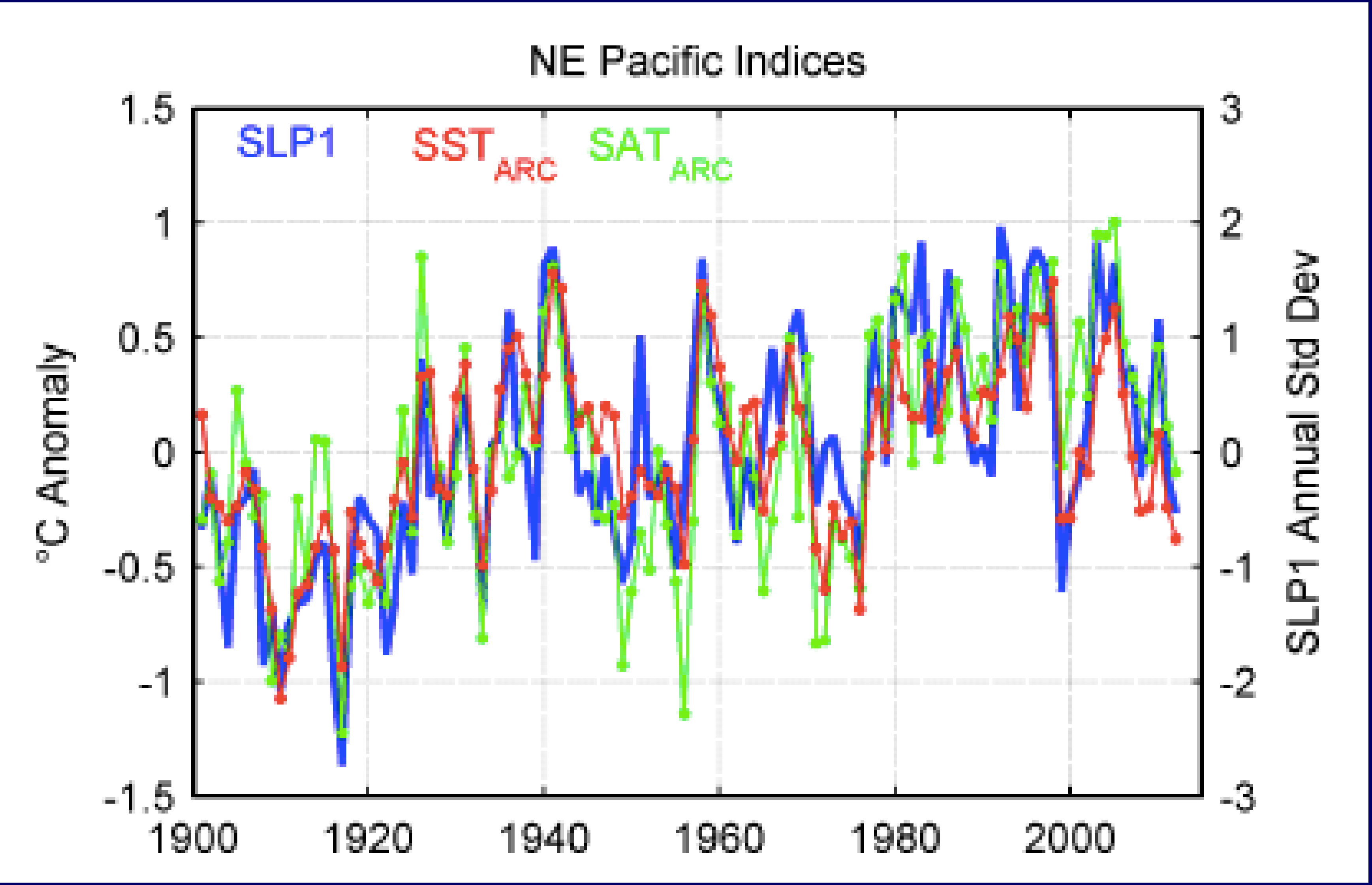
SST tendency and heating terms associated with SLP1 of +1σ



Next, we compare area-averaged SST in (shaded) NE Pacific Arc with coastal land surface air temperatures from 51 long-term stations indicated by black dots



There is a strong covariation among annual mean temperature anomalies and SLP1

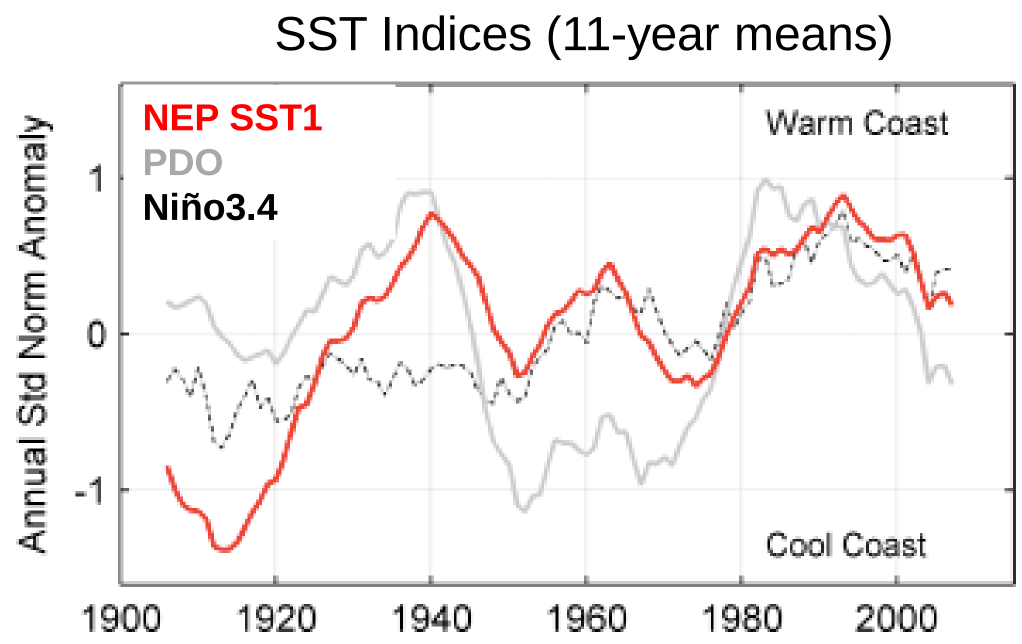


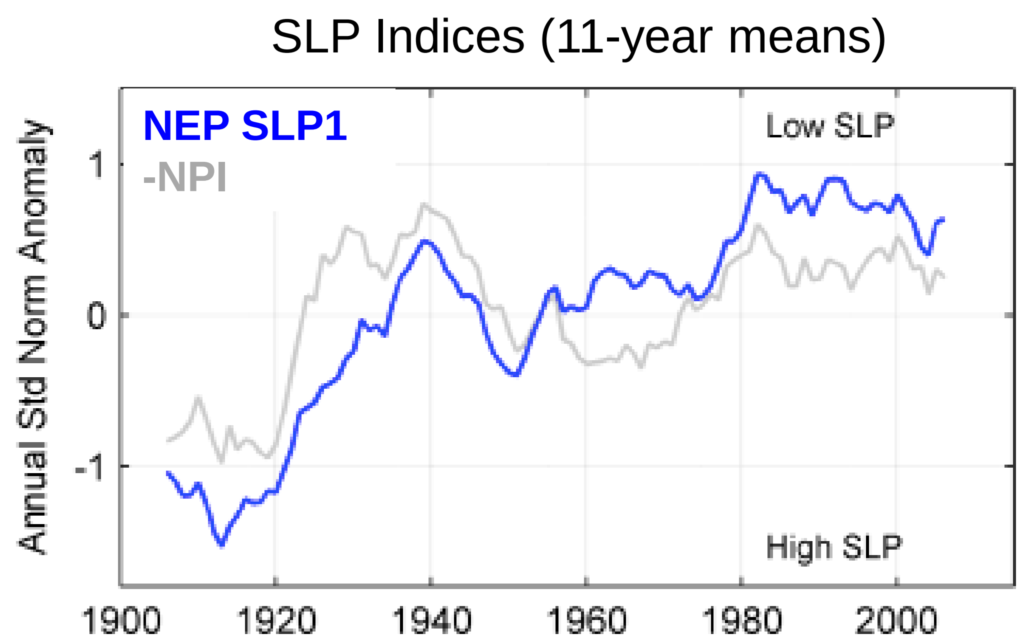
SST and SLP indices

NE Pacific SST was especially cool between 1900 and 1920; this is not a feature of the PDO index or Niño3.4 index

Compared with SLP trends over the North Pacific captured by the NPI, trends to lower pressure are stronger in the NE Pacific

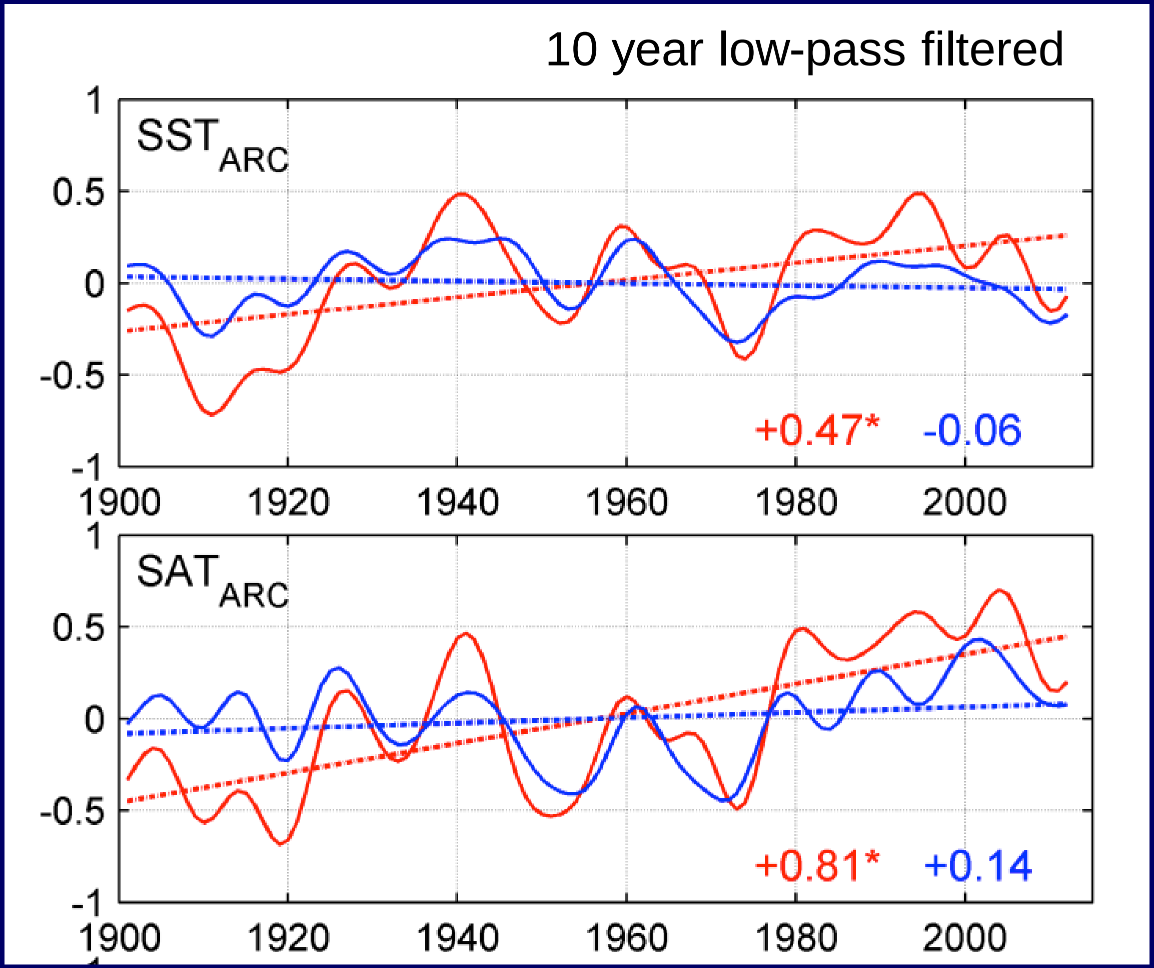
<u>SLP1 correlations (July-June annual means)</u>:
PDO 0.43
NPGO -0.43
Niño3.4 0.61



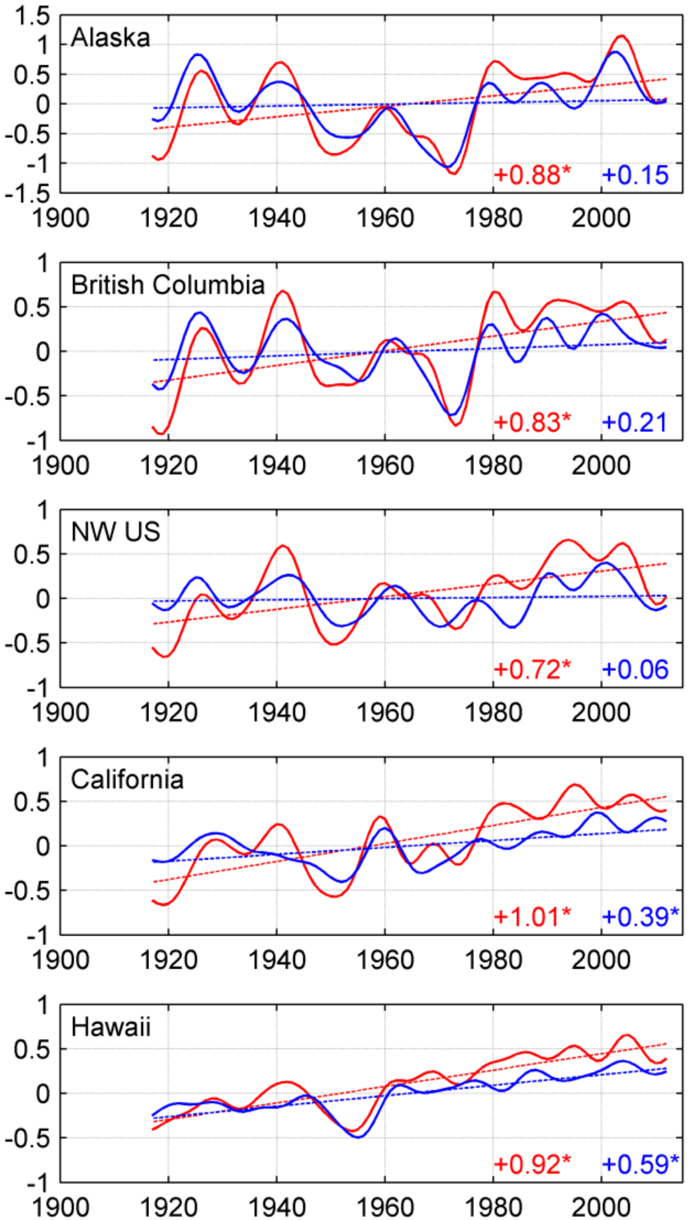


How much of the trend in NE Pacific temperature records can be attributed to trends in SLP1?

- red curves and trends reflect observed temperatures
- blue curves depict residuals after removal of the annual SLP1 index by simple linear regression
- SLP forcing accounts for all of the SST trend, and most of the SAT trend!

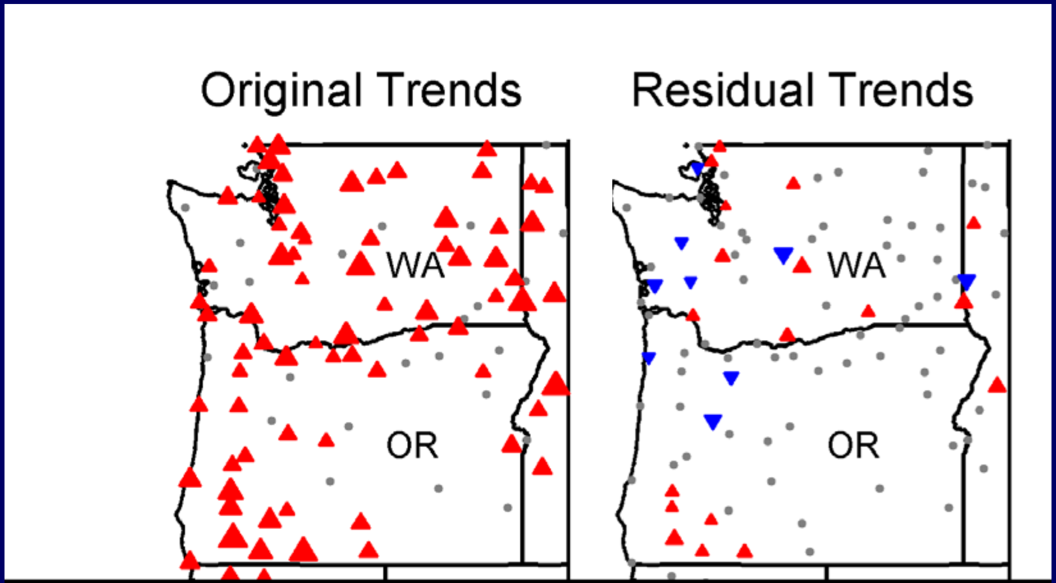


- Coastal surface air temperature trends are substantially reduced in all sub-regions by regressing out SLP1 contributions



Inland temperature trends and SLP1

Over the 1900-2012 period, trends in SLP1 explain 80 to 100% of the trends in annual mean (July-June) surface air temperature in WA, OR, NV and northern CA



Underlying Causes for regional surface temperature trends? (after Wallace et al 2014)

	Thermo-dynamically induced	Dynamically induced
Forced (natural or anthropogenic)	**changing concentrations of GGs and aerosols impact radiative forcing**	**Changing concentrations of GGs and aerosols impact circulation**
Free		**Intrinsic variations in the climate system alter circulation**

Dynamic or thermodynamic?

IPCC WG1 AR5 estimates total anthropogenic radiative forcing of **2.23 W/m²** for 2011 relative to 1750

We estimate a +1σ trend in SLP1 between 1900 and 2012, which amounts to a heat flux anomaly of ~**10W/m²** over the SST arc region

changes in NEP circulation dominate changes in anthropogenic radiative forcing over the 1900-2012 period

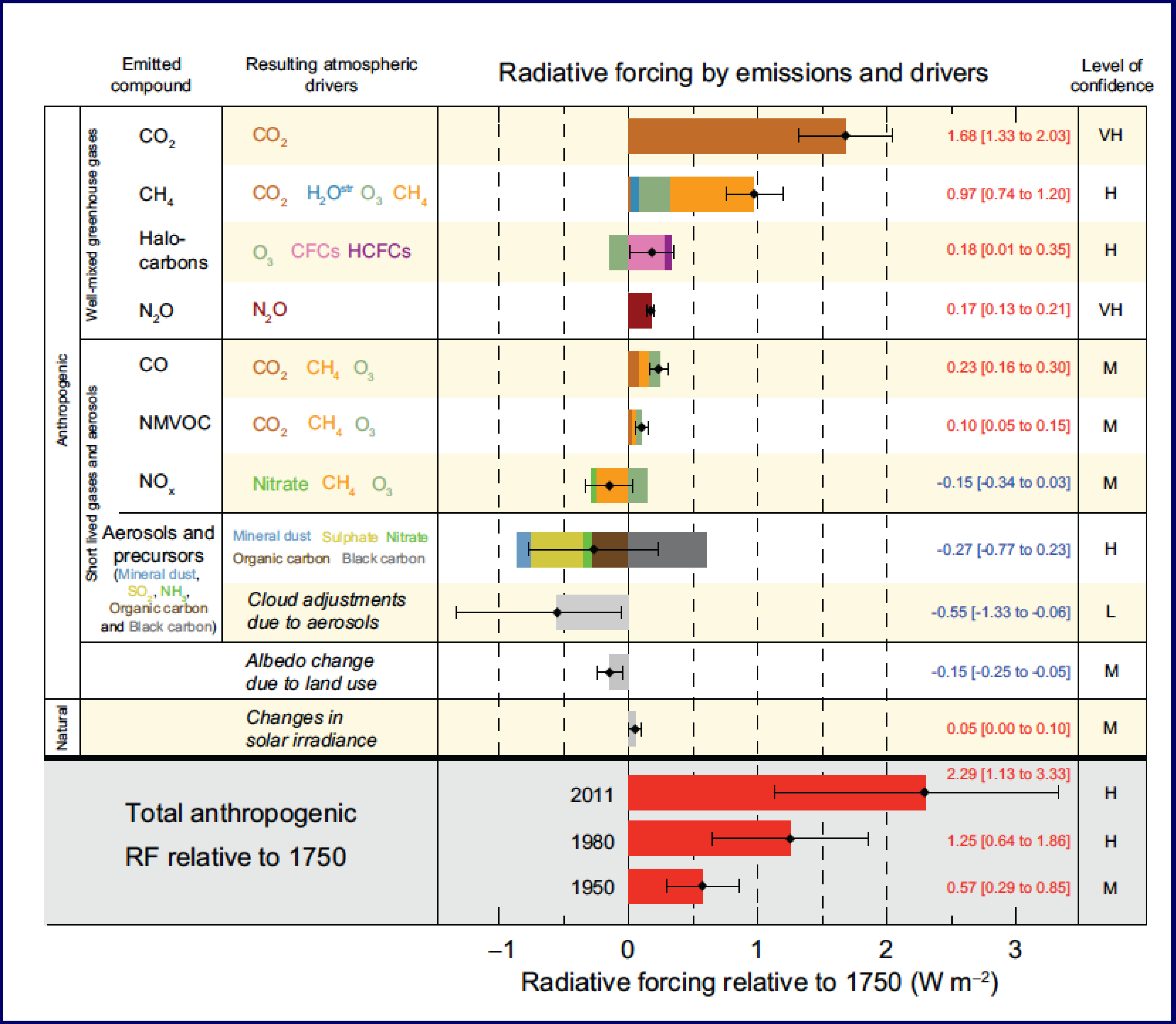
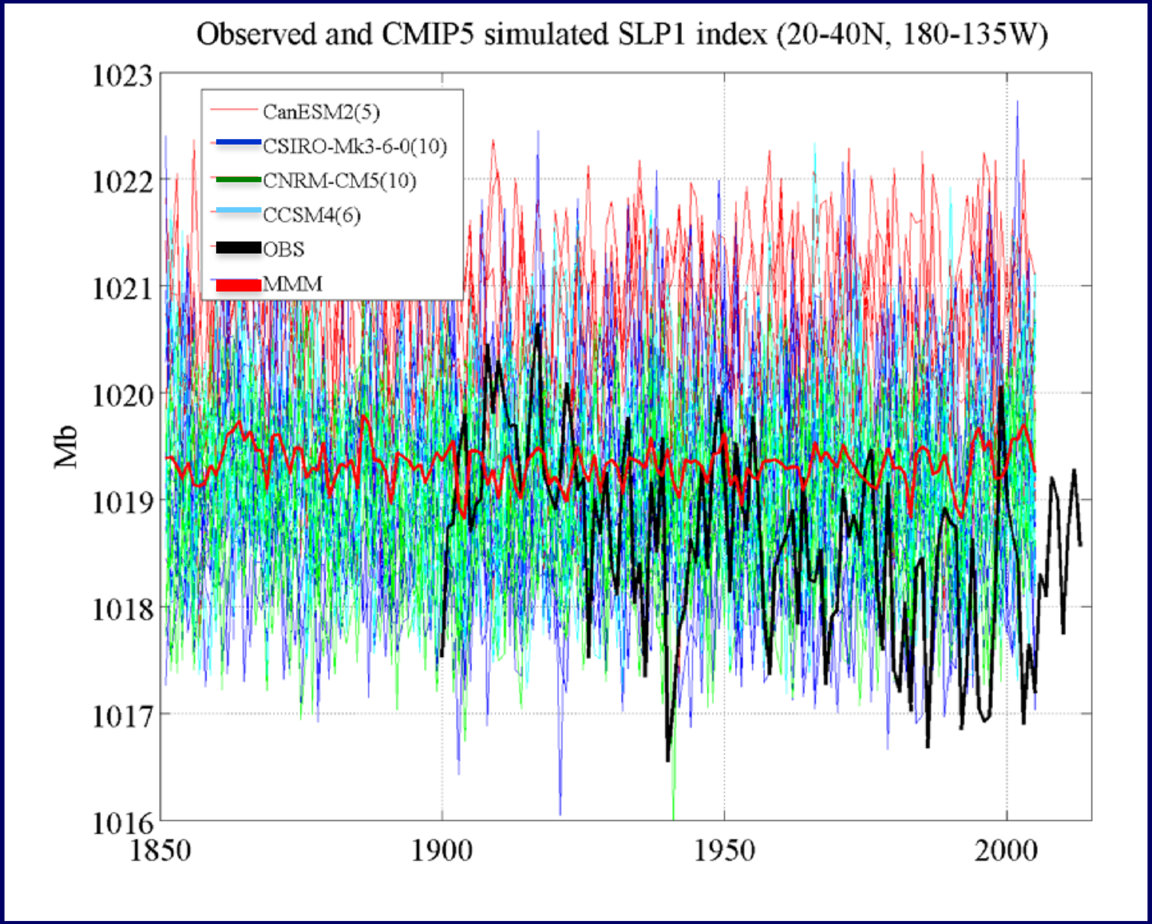


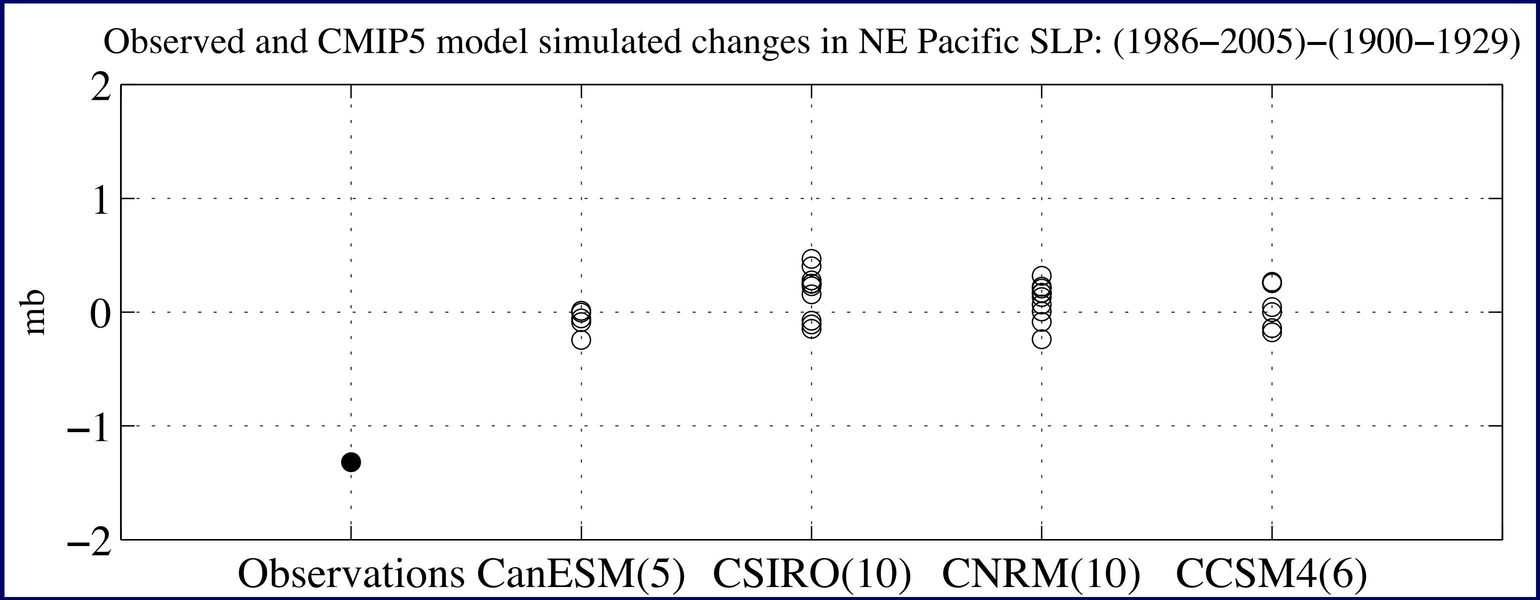
Figure from IPCC's AR5 Summary for Policymakers (2013)

Next question: are circulation changes free or forced?

- 31-member multimodel ensemble for simulated SLP1 in 4 CMIP5 models suggests no robust “forced” trends over the 1850-2005 period
- Circulation changes look to us to be FREE (natural, unforced variability internal to the climate system)



Observed and CMIP5 model simulated changes in NEP SLP: (1986-2005)-(1900-29)



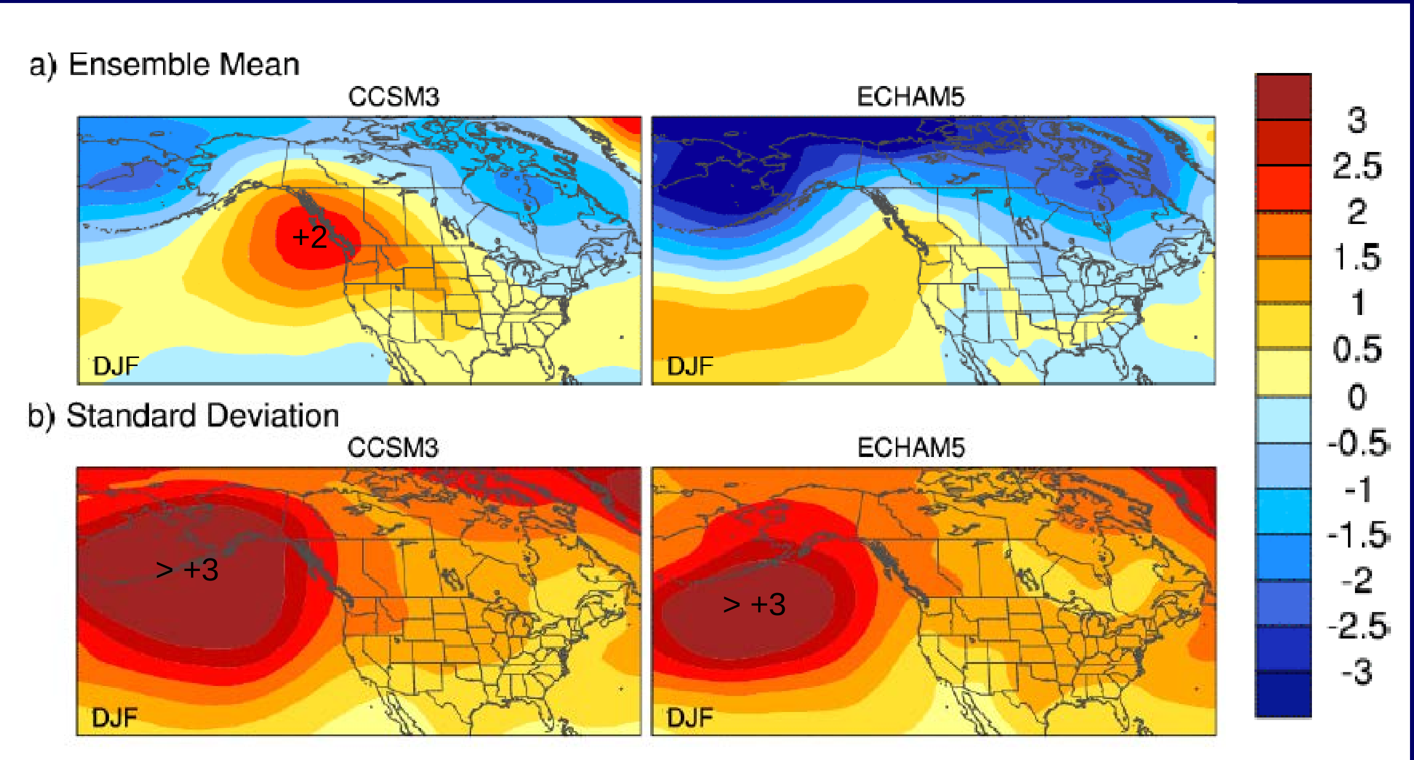
None of the 31 historical climate simulations produces trends in NEP SLP that approach the magnitude of observed changes

The ensemble average changes for each individual climate model are all very small (<0.3mb)

The multi-model ensemble averages are even smaller

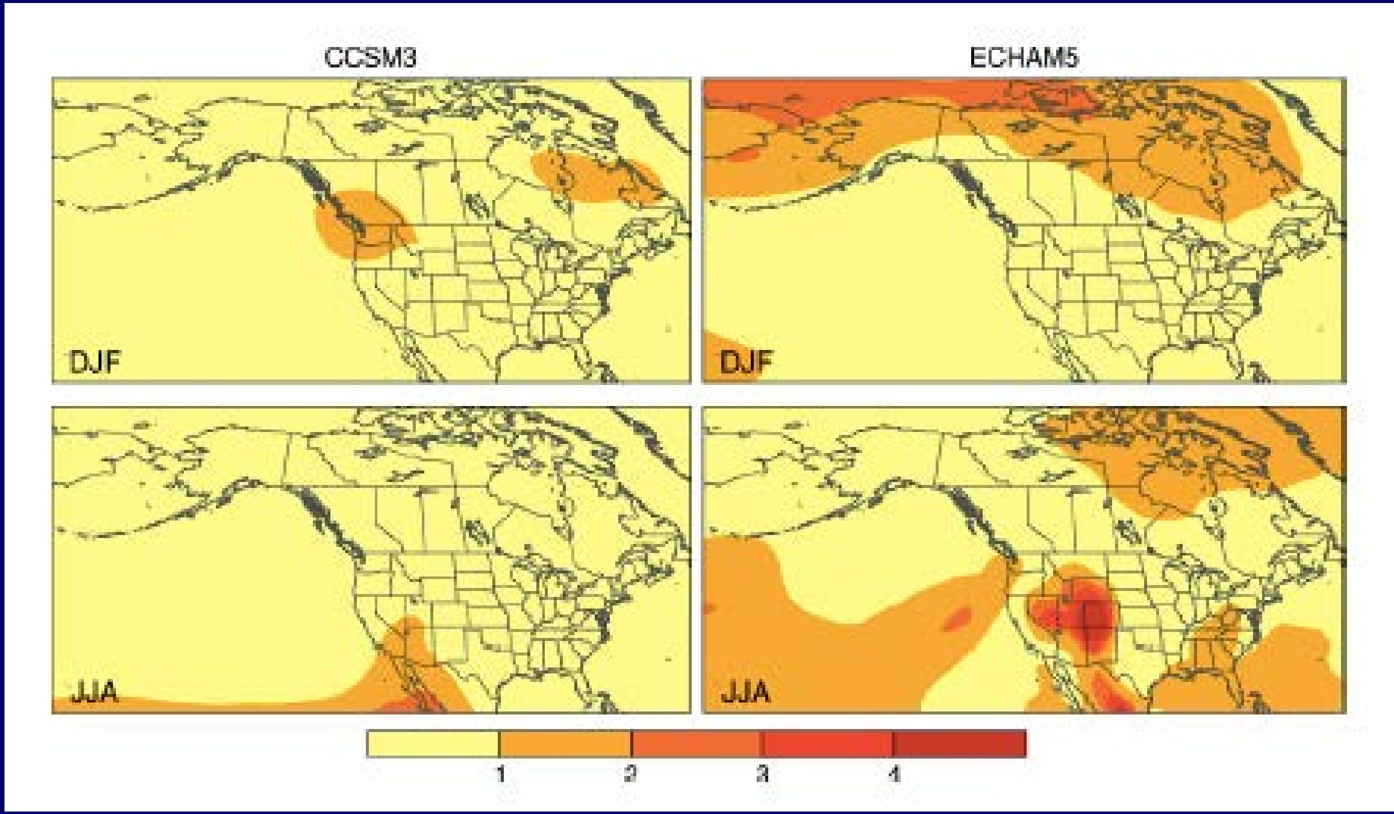
Large-ensemble climate model experiments indicate low signal to noise ratios for SLP trends over 2010-2060

Deser et al. (2012, 2014), Oshima et al (2012)



Standard deviation maps show the standard deviation across multiple ensemble member trends for the 2010-2060 simulations.

Signal-to-noise ratio maps for simulated SLP trends during 2010—2060



S/N ratio is defined as the absolute value of the forced (ensemble-mean) trend divided by the standard deviation of trends across the individual ensemble members. From Deser et al. (2014); J. Climate

Conclusions:

Strong warming 1910-40, modest warming since with peaks near 1960, late 1990s

At regional scales, not all century-long climate trends are due to CO_2 / greenhouse forcings

- For the NE Pacific, 1900-2012: changes in NEP circulation dominate changes in anthropogenic radiative forcing over the 1900-2012 period for most sub-regions (except Hawaii); surface temperature **trends and variations** can largely be explained by regional pressure/wind-driven heat-flux changes related to regional circulation changes

Some consequences

- Natural (free) variations can amplify or dampen long-term warming trends due to anthropogenic forcing, depending on the circulation changes

- If CMIP5 and CMIP3 climate models are correct, signal to noise ratios for circulation trends in the NE Pacific will be small through ~2060 … time of emergence for anthropogenic impacts on key aspects of NE Pacific climate may be decades into the future
  - SST, coastal fog, coastal upwelling …