

Circulation Regimes: Bridging Weather and Climate Predictability

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COLA = Center for Ocean-Land-Atmosphere Studies

Planetary-Scale Wave Amplitude Index:

An old problem re-examined*:

Is its pdf bimodal?

WAI = measure of integrated PW strength across mid-latitudes

pdf is bi-modal if only time periods in which WAI varies slowly are kept!

Daily Data →

Slow variation in WAI →

* Christiansen, 2005: Bimodality of the Planetary-Scale Atmospheric Wave Amplitude Index. *J. Atmos. Sci.*, 62, 2528-2541.

3. Low-frequency variability and robustness

The probability density of the WAI calculated with

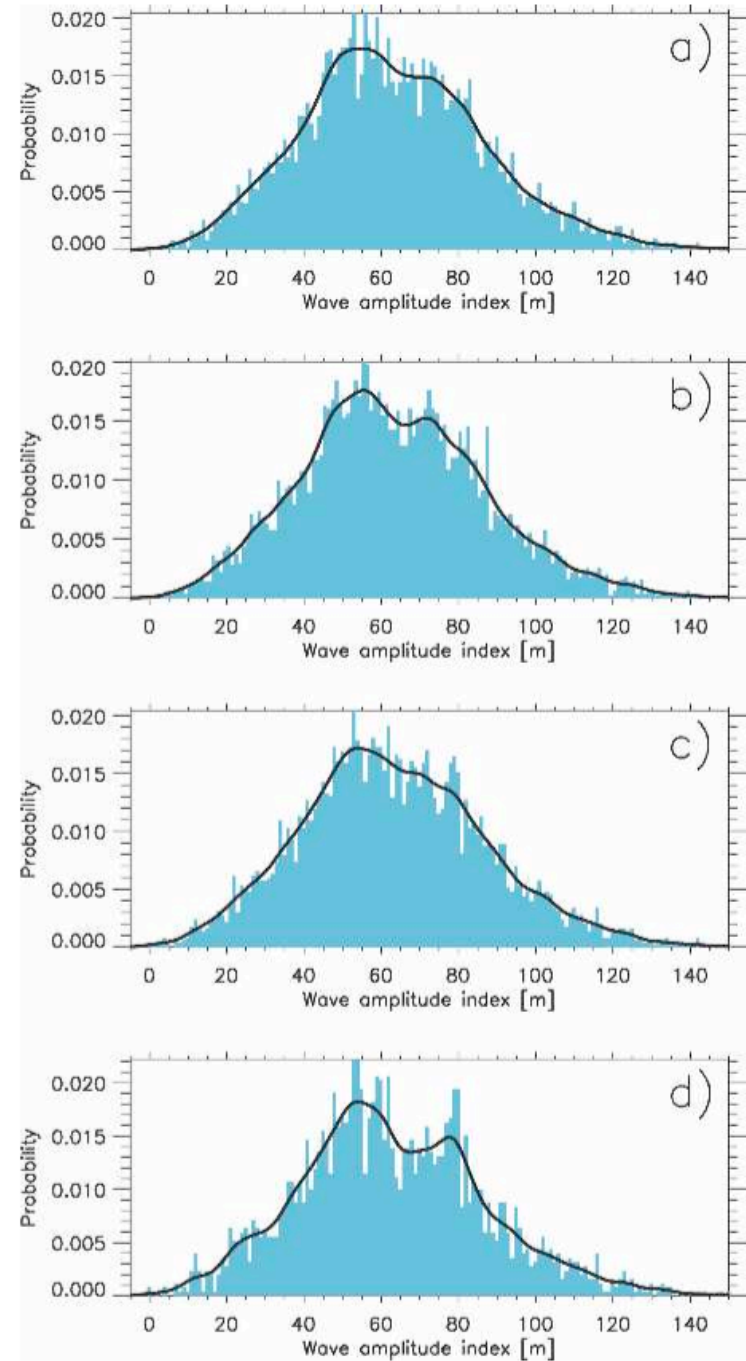


FIG. 1. Probability density of the WAI for the winter days in the period 1948–2003 calculated as a kernel density estimator with a smoothing parameter of $h = 3$ m. Also shown are the histogram estimates calculated with a bin width of 1 m: (a) variability faster than 5 days has been filtered out, (b) variability faster than 4 days

Physical Motivation for Regime, or Preferred Modes of Behavior

Existence of extended periods of one type of (possible extreme) weather has been recognized for many years (papers going back to the 1950s at least) - Examples: droughts, stormy periods, cold periods

These periods occur intermittently, and ought to be related to persistence in the “large-scale” flow

Classification of regional weather patterns into a discrete number of types - e.g. the *grosswetterlagen*

These are (collectively) called “weather regimes” and provided the original (and still the best) motivation for finding preferred patterns in the large-scale circulation in which the weather regimes are embedded. These preferred patterns are called *circulation regimes*.

Grosswetterlagen = Weather Regimes

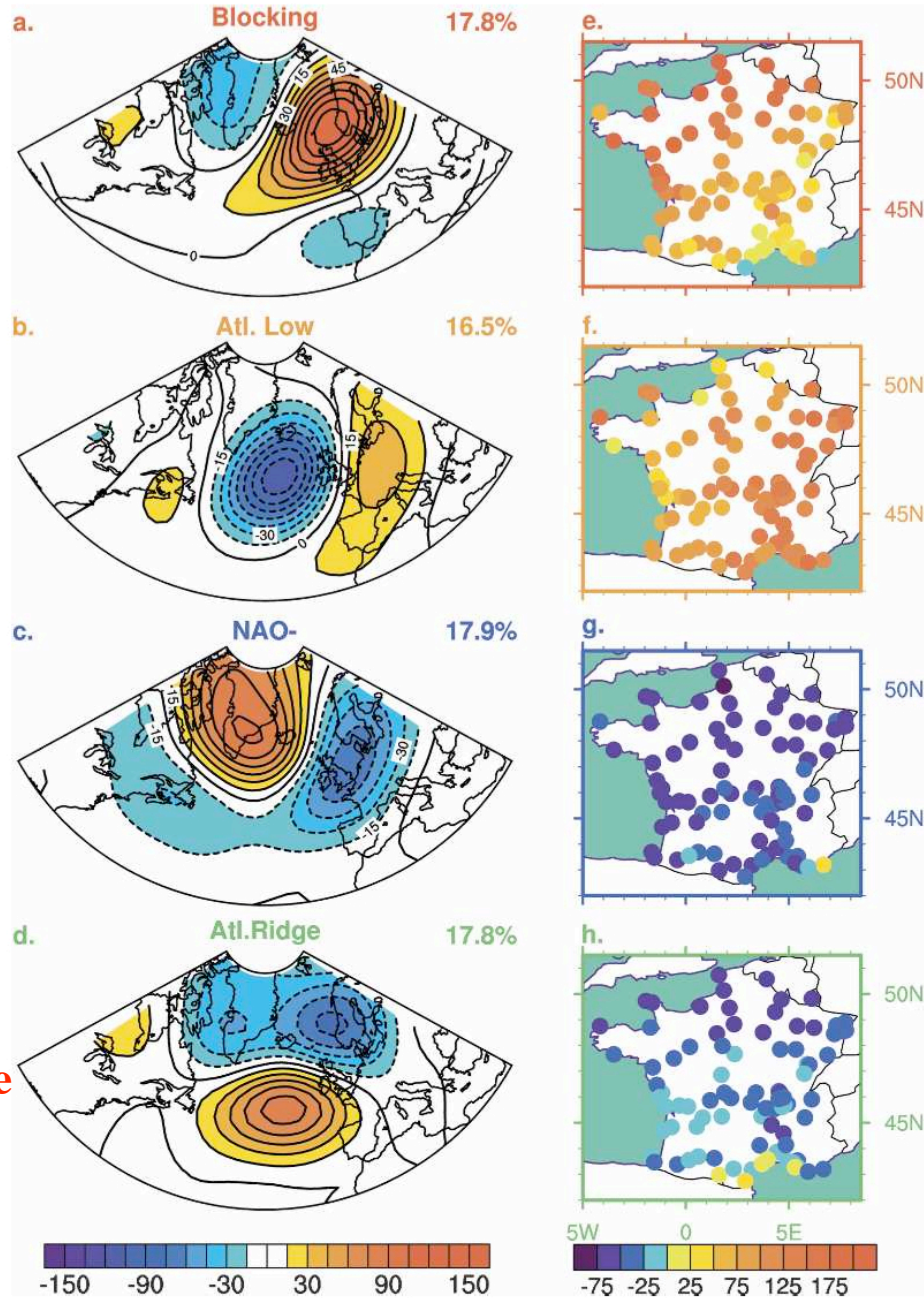
- “It has been noticed that weather patterns over certain areas and over the entire Northern Hemisphere tend to repeat themselves from time to time. Using this property of the atmosphere, classification of the *macroweather* situations over Europe was made by....” (Radinovic, 1975)
- “The *grosswetterlagen* defined by Baur ...provide a valuable classification of the extended (duration longer than three days) weather types observed in Central Europe...*28 large-scale weather types* derived from about 70 years of observations.” (Egger, 1980).

Early Aug 2003 -
Blocking

June 2003 - Atl. Low

Clusters (regimes) of
daily 500 Z from
1950-2003 JJA
(CI=15m)

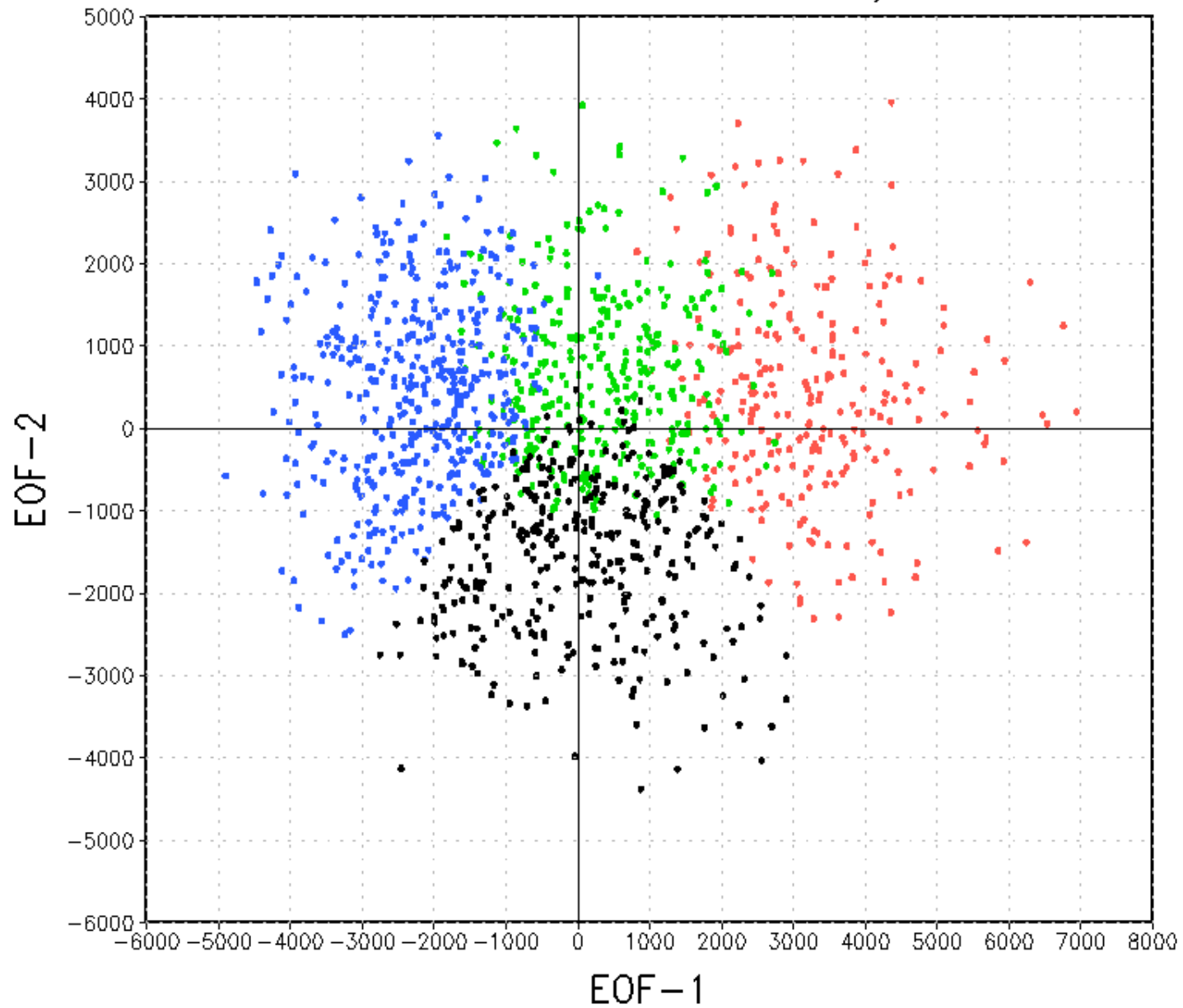
2003 European Heat Wave
June and early August
extreme T



Relative changes (in percent) in the frequency of extreme warm days (95% percentile):
100% means twice as likely to have extreme warm day

FIG. 1. (a)–(d) Summer Z500 weather regimes computed over the North Atlantic–European sector from 1950 to 2003. Contour interval is 15 m. To eliminate transient and ambiguous episodes, only sequences of 5 days or more occupied by the same cluster are retained following the regime paradigm. As a result of such a 5-day cutoff, the sum of the four regimes’ 54-yr-averaged occurrence, given on the right side of the map, is not equal to 100% but is close to 70%. For simplicity, a color code is associated with each individual regime and will be kept in the

4 Clusters Winter 1984/85



Circulation Regimes - Theory

Notion that circulation regimes involved mutual feed-back between the (quasi-stationary) large scales waves and the smaller-scale baroclinic, synoptic disturbances was developed theoretically by Reinhold and Pierrehumbert (1982) and Vautard and Legras (1988).

The feedback from the baroclinic waves to the planetary waves can be parameterized in models:

Purely dynamically (RP)

Semi-empirically (VL)

Completely statistically (multiplicative noise: Sura, Newman, Penland and Sardeshmukh, 2004: J. Atmos. Sci., 62, 1391-1409)

Circulation Regimes – Diagnostic Analysis

“Baroclinic Eddy Mediated Cluster Analysis”

[Straus, D., 2010: Synoptic-Eddy Feedbacks and Circulation Regime Analysis, *Mon. Wea. Rev.* (in press)]

- Explicit (statistical) linking of low frequency fluctuations and the low frequency *modulation* of baroclinic eddies (“storm tracks”)
- Low frequency fluctuations ($\tau > 10$ days): **filtered 200 Z fields**
- Baroclinic eddy measure is 200 hPa filtered ($\tau < 10$ days) meridional velocity **v** (emphasizes– higher wavenumbers)
- Low frequency modulation of baroclinic eddies obtained by “**envelope function**” of $v_{\text{rms}} = (v^2)^{(1/2)}$
- Linkage between **baroclinic eddy envelope function** and **low frequency** takes the form of maximum covariance (singular vector) analysis
- Coefficients subject to cluster analysis to obtain the regimes

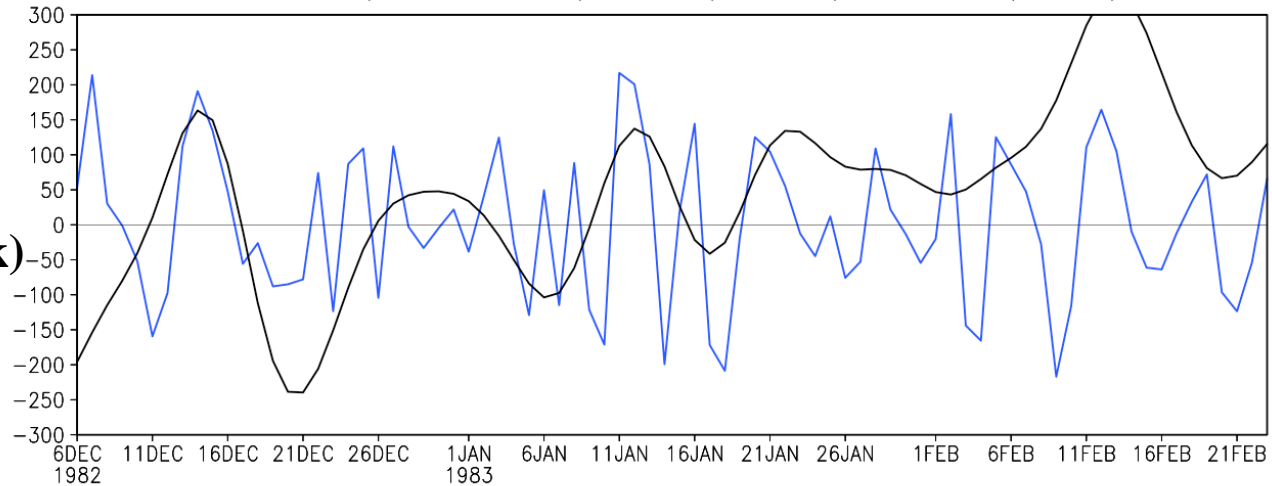
Computation of **envelope** at 20W 50N for DJFM 1982/83

Z200 (20W 60N) ZLF(black), ZHF(blue)

Filtered Z200

Z_{LF}: $\tau = 10-90$ day (black)

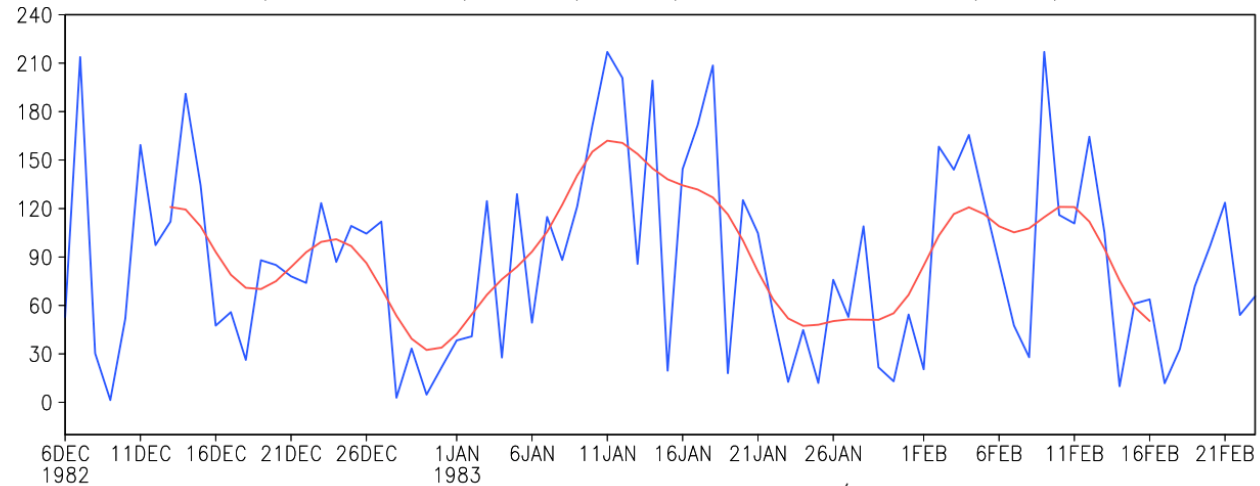
Z_{HF}: $\tau = 2-10$ day (blue)



$(Z_{HF} * Z_{HF})^{(1/2)}$ (blue) ENVELOPE (red)

$(Z_{HF} Z_{HF})^{(1/2)} = \text{blue}$

envelope function = $\{(Z_{HF} Z_{HF})^{(1/2)}\}_{LF}$



ERA40 Winter of 1982/83

Baroclinic Eddy Mediated Cluster Analysis – recipe part 1

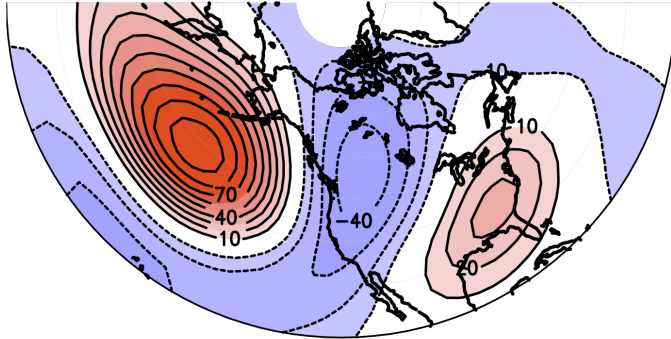
- Low frequency ($\tau > 10\text{d}$) filter on Z 200 \Rightarrow LP
- Envelope function of band-pass v ($2 < \tau < 10\text{d}$) filtered data \Rightarrow ENV
- Compute EOFs and PCs of LP
- Compute EOFs and PCs of ENV
- Maximum Covariance Analysis of LP and ENV in PC-space (3 modes explains most of the covariance)
- Obtain new time series of LP and ENV modes
- Apply partitioning algorithm to obtain clusters

Baroclinic Eddy Mediated Cluster Analysis – recipe part 2

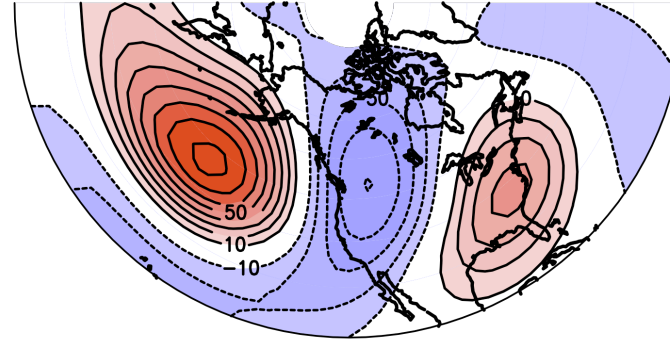
- Statistical Significance via Monte Carlo method:
 - (1) Generate many synthetic data samples of PCs of LP and ENV
random-phase approach assures that synthetic series have the same lagged auto-correrlation function as original series
 - (2) Repeat SVD and cluster analyses for each synthetic data sample
 - (3) Check what percentage of these synthetic data sets have a larger measure of clustering than the original dataset

Results from NCEP reanalysis, 54 winter seasons: 1948-49 through 2001-2002

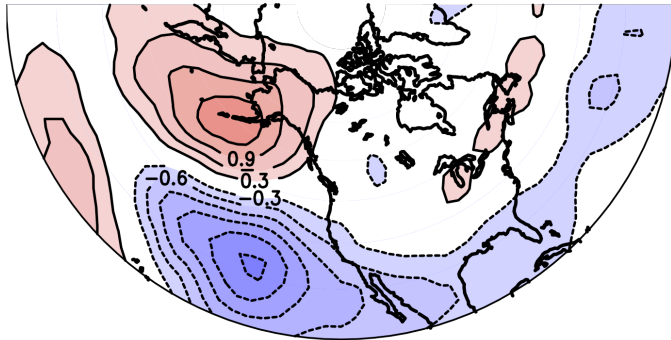
(a) Z200 SVD1 (10pcs)



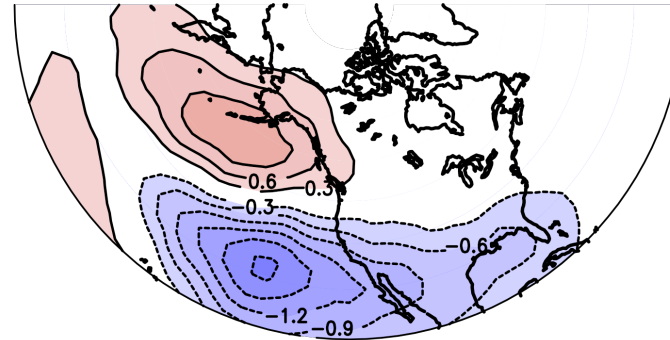
(c) Z200 SVD1 (5pcs)



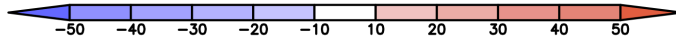
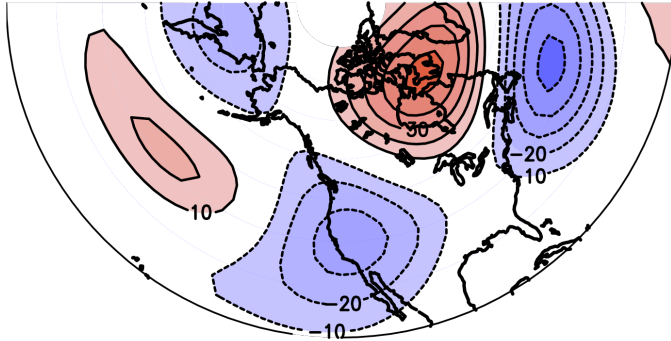
(b) Vstd SVD1 (10pcs)



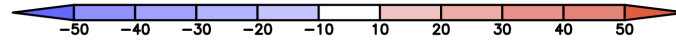
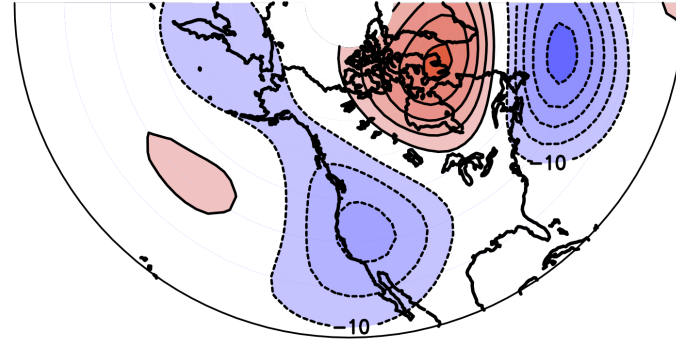
(d) Vstd SVD1 (5pcs)



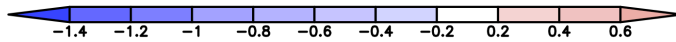
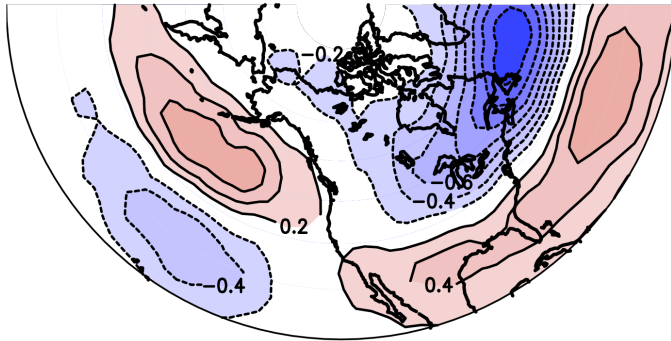
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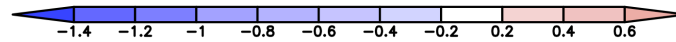
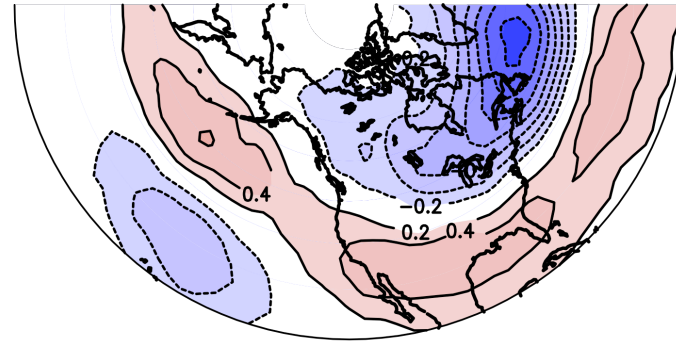
(c) Z200 SVD2 (5pcs)



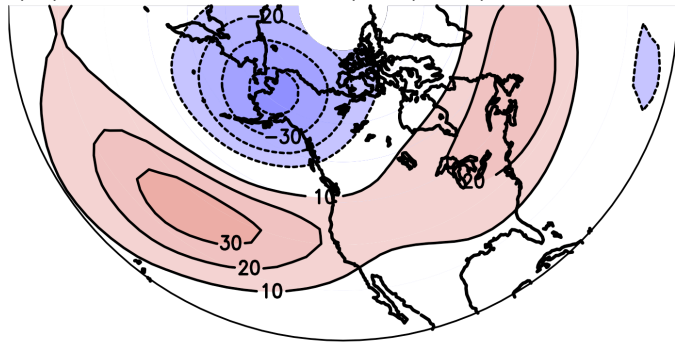
(b) Vstd SVD2 (10pcs)



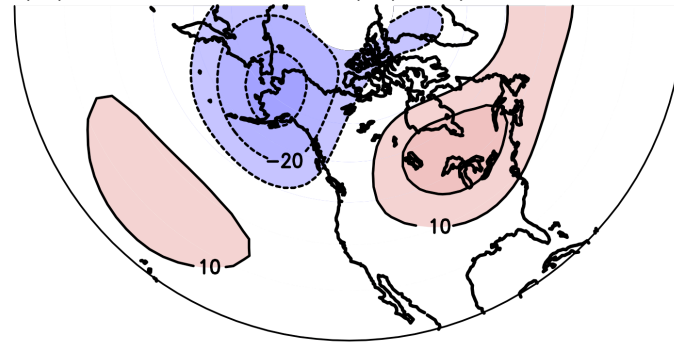
(d) Vstd SVD2 (5pcs)



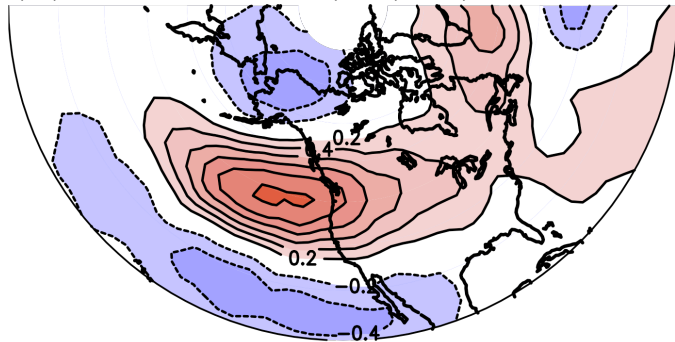
(a) Z200 SVD3 (10pcs)



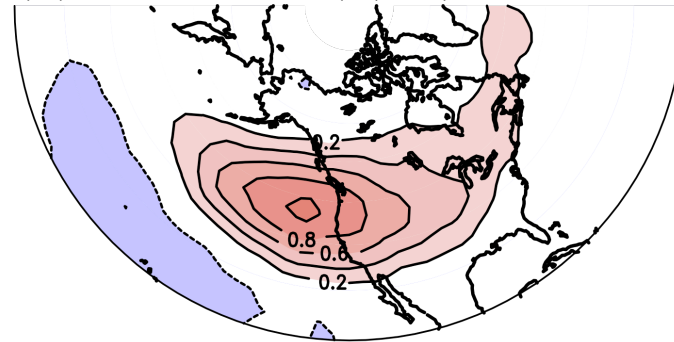
(c) Z200 SVD3 (5pcs)



(b) Vstd SVD3 (10pcs)

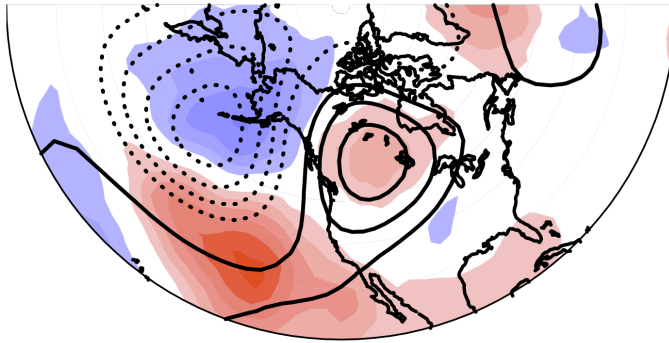


(d) Vstd SVD3 (5pcs)

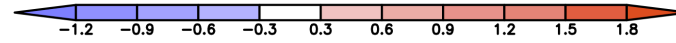
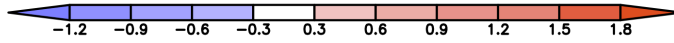
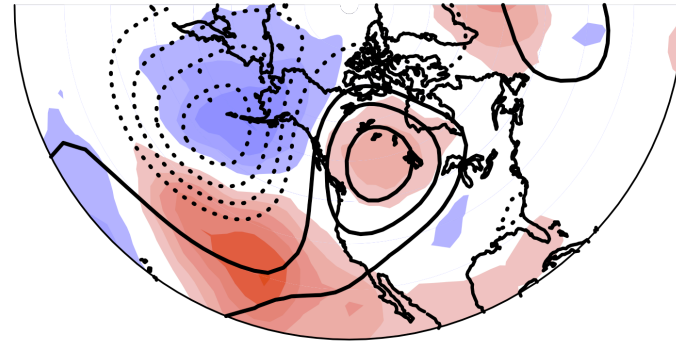


First of four cluster patterns “Pacific Trough” obtained by compositing fields in one cluster
Contours = Z 200 (CI = 30 m) ; shading = envelope v field = $(v^2)^{(1/2)}$

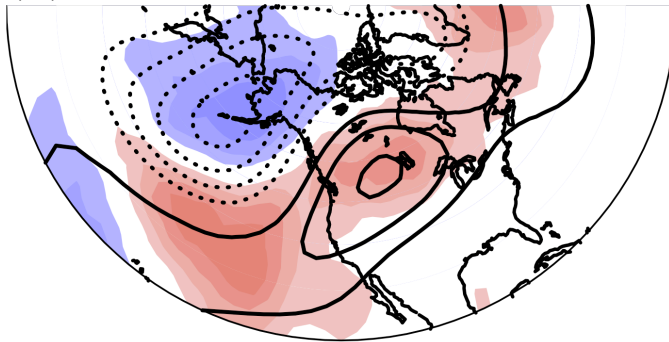
(a) trun=10 dim=10 PacT



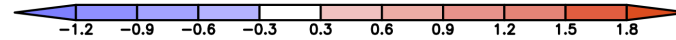
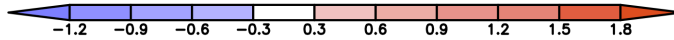
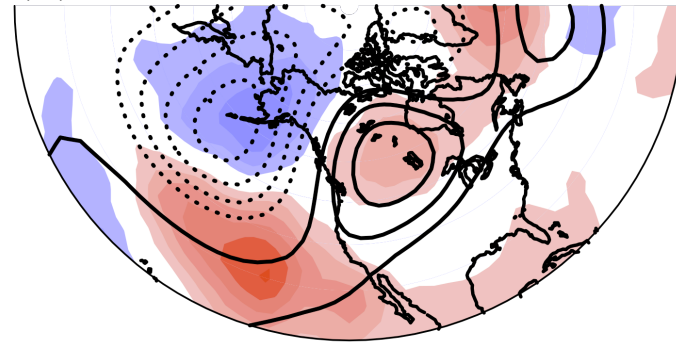
(c) trun=5 dim=5 PacT



(b) trun=10 dim=5 PacT



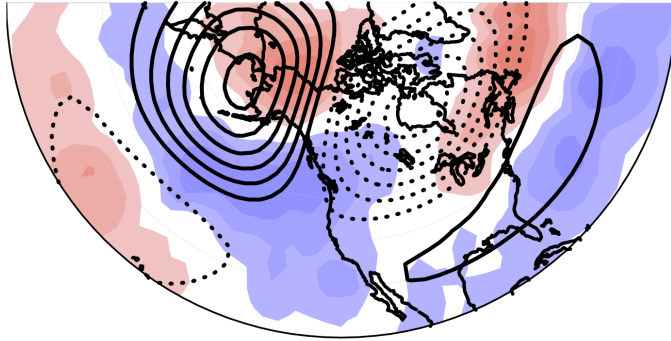
(d) trun=5 dim=3 PacT



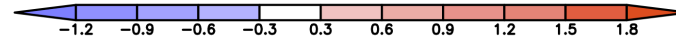
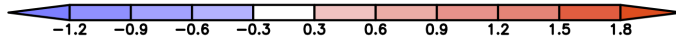
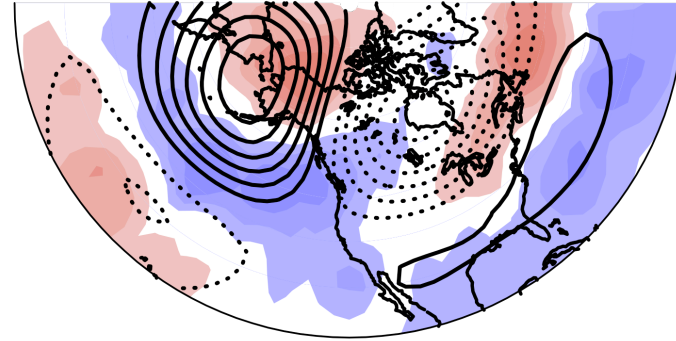
“trun” = number of PCs in SVD; “dim” = number of SVDs in clustering

Second of four cluster patterns “Alaska Ridge” obtained by compositing fields in one cluster
Contours = Z 200 (CI = 30 m) ; shading = envelope v field = $(v^2)^{(1/2)}$

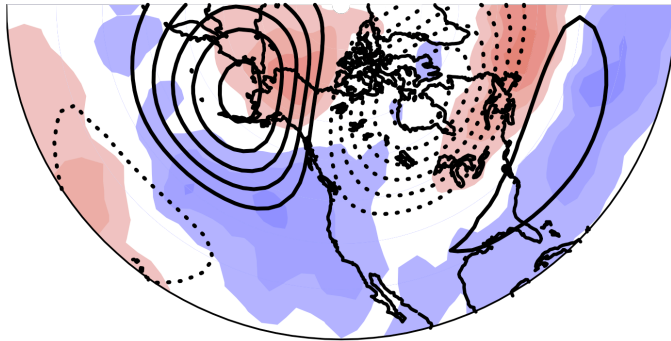
(a) trun=10 dim=10 ALRid



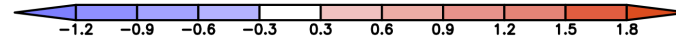
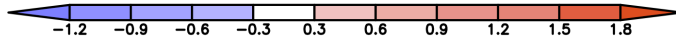
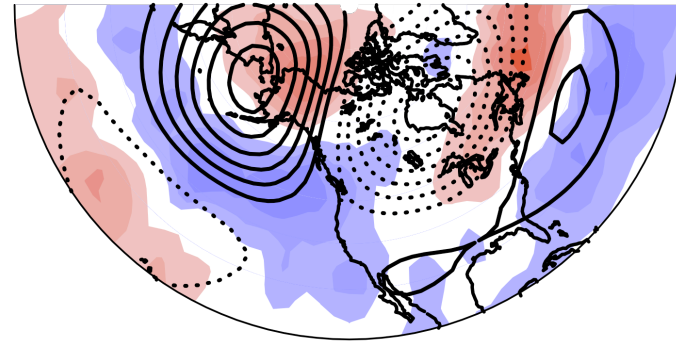
(c) trun=5 dim=5 ALRid



(b) trun=10 dim=5 ALRid

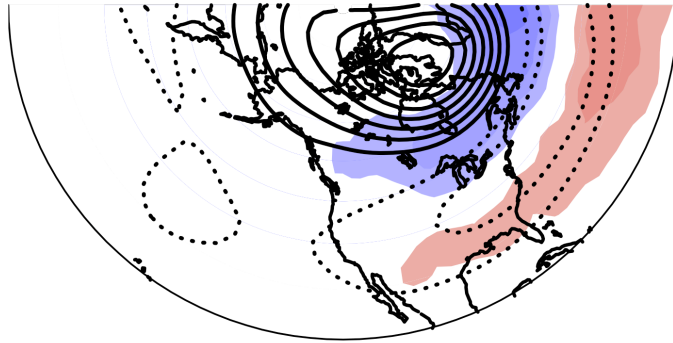


(d) trun=5 dim=3 ALRid

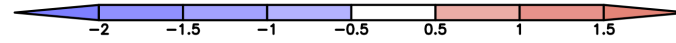
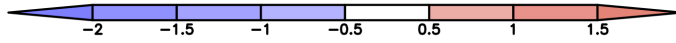
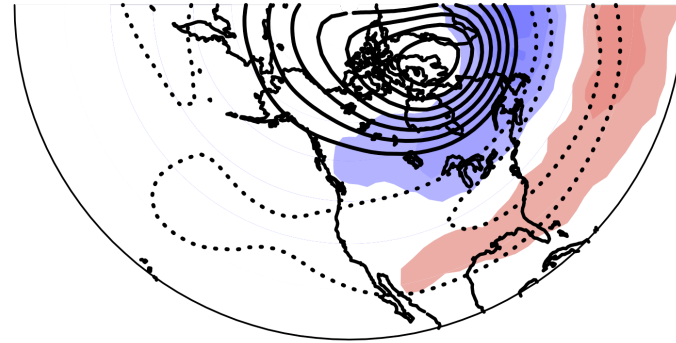


Third of four cluster patterns “Arctic High” obtained by compositing fields in one cluster
Contours = Z 200 (CI = 30 m) ; shading = envelope v field = $(v^2)^{(1/2)}$

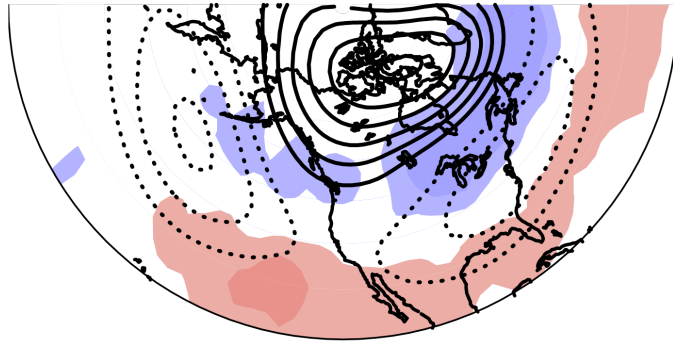
(a) trun=10 dim=10 ArcHi



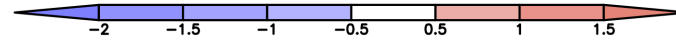
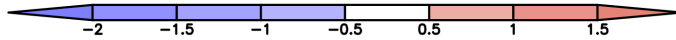
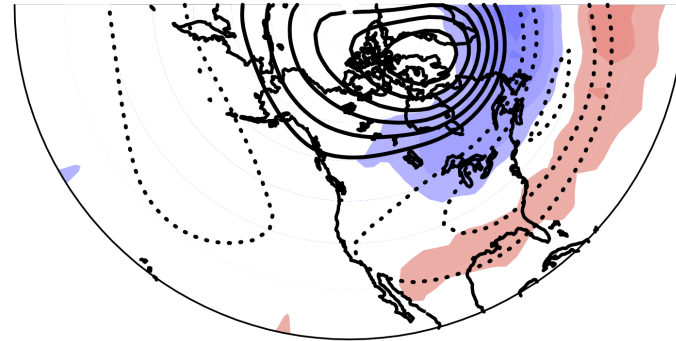
(c) trun=5 dim=5 ArcHi



(b) trun=10 dim=5 ArcHi



(d) trun=5 dim=3 ArcHi

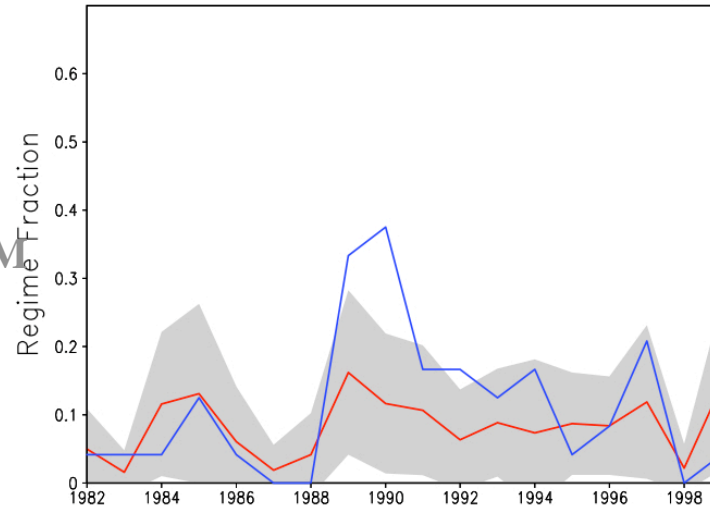


Red line: GCM

Blue line: NCEP

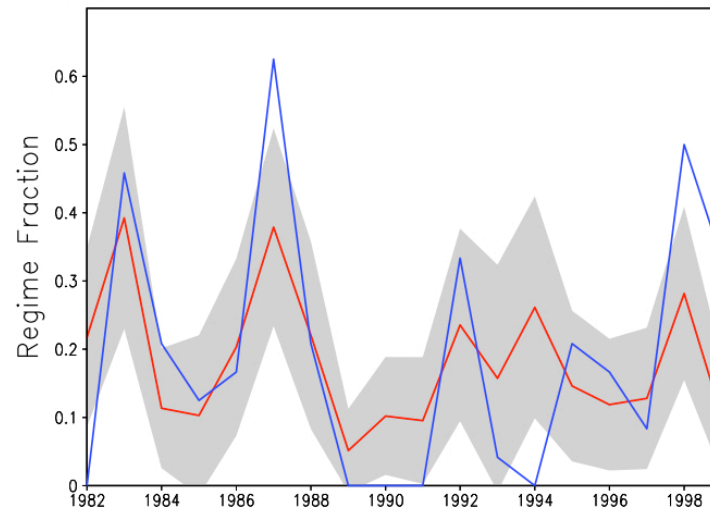
Gray: intra-ensemble σ in GCM

(a) Alaskan Ridge NCEP(blue),GCM(red)



Is the frequency of occurrence of Alaskan Ridge and Pacific Trough even partly predictable on the basis of SST? - Look at frequency of occurrence year by year for the recent 18-winter period - results are encouraging!

(c) Pacific Trough NCEP(blue),GCM(red)



Conclusions

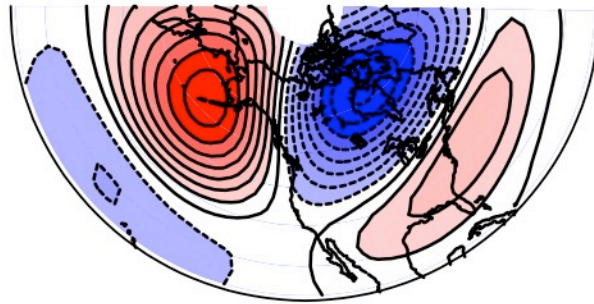
- There is enough evidence for significant circulation regimes in quasi-stationary, data records of sufficient length for the concept to be taken seriously.
- However, statistical significance, reproducibility, are still real issues to be dealt with for each region, variable, period.
- Large ensembles of model simulations can provide some estimates of significance, pdfs, when observed data record is too short
- Simulation of Frequency of occurrence as a function of SST gives some hope of predictability
- Link to true weather regimes has proven to be useful

Future Directions

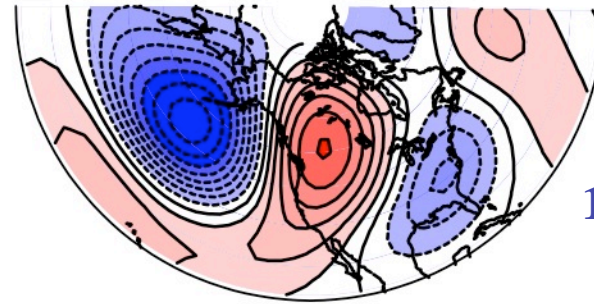
- More explicit connections between regional circulation regimes and weather regimes need to be made
- The transitions between circulation regimes within a season need to be more intensively studied - are they totally unpredictable?

Straus, Corti
and Molteni,
2006 J. Climate
(under revision)

(a) Alaskan Ridge



(c) Pacific Trough

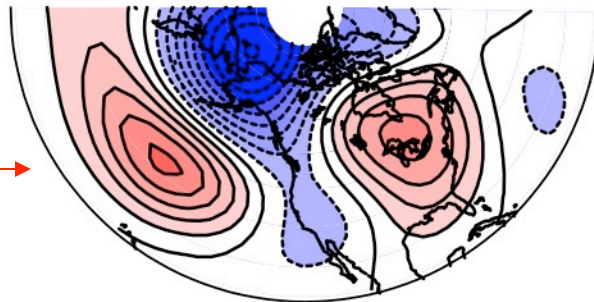


$10d < \tau < 90d$

Regimes in 200 hPa Z from 54 NCEP winters (contour interval = 20 m)

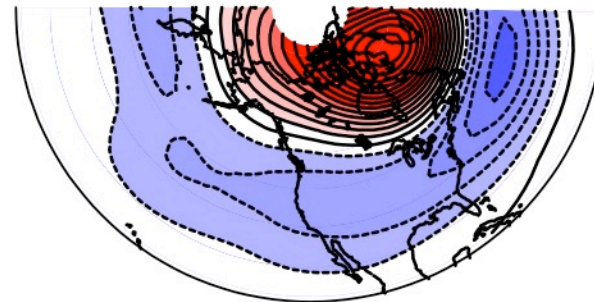
- (a) Only quasi-stationary time periods used
- (b) H_0 can be rejected at the 90% level using partitioning method
- (c) Can not say whether 3 or 4 clusters is optimal
- (d) Patterns reproducible using randomly drawn half length samples (always from same winter !!!!)
- (e) Clusters are due to true “clumping” of states in PC-space, and not just skewness

(b) Arctic Low



least well-
defined →

(d) Arctic High



Are regimes a useful concept? - Yes!

- In characterizing North Atlantic Ultra-High Frequency (storm-related) variability in preparation for FASTEX*, Aryrault et al (2005) found that “The concept of weather regime is central to any statistical approach of European weather systems.” Here weather regimes were identified by a cluster analysis of 700 hPa height in the Atlantic reigon (similar to that of Vautard, 1990).
- Joly et al (1999) found that regimes were useful in discussing the organization of the large scale flow during FASTEX*
- In assessing basic measures of skill for ECMWF ensemble winter forecasts, Chessa and Lalaurette (2001) found the same clusters to be useful in categorizing forecast skill
- Two other examples presented below in detail

FASTEX* = Fronts and Atlantic Storm-Track EXperiment

References:

- Ayrault, F., F. Lalaurette, A. Joly and C. Loo, 1995: North Atlantic ultra high frequency variability. *Tellus*, **47A**, 671-696.
- Chessa, P. A. and F. Lalaurette, 2001: Verification of the ECMWF Ensemble Prediction System Forecasts: A Study of Large-Scale Patterns. *Weather and Forecasting*, **16**, 611-619.
- Joly, A., and co-authors. Overview of the field phase of the Fronts and Atlantic Storm-Track EXperiment (FASTEX) project. *Quart. J. Royal Meteor. Soc.*, **125**, 3131-3164

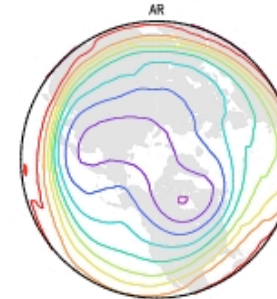
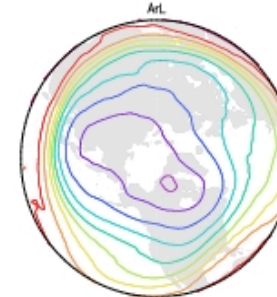
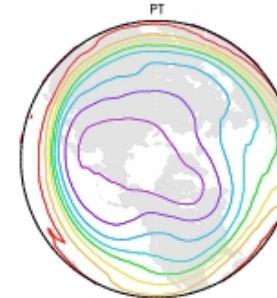
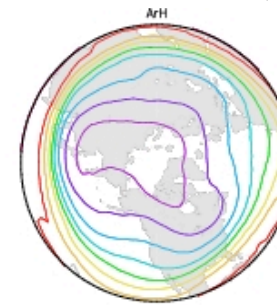
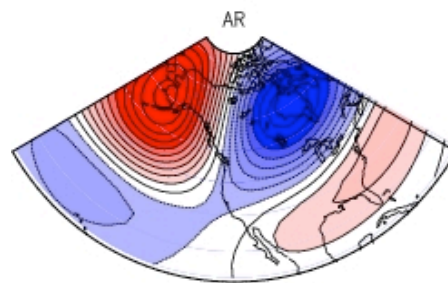
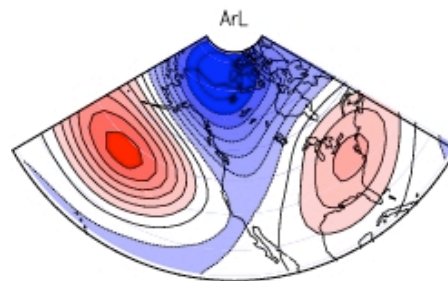
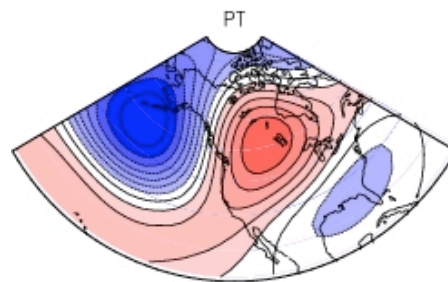
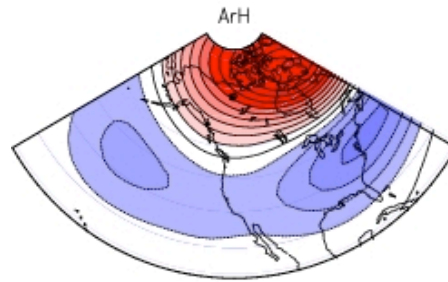
Regimes and Blocking (work with Cristiana Stan)

Arctic High

Clusters (regimes) almost as in Straus et al 2006 but for a narrower region

Pacific Trough

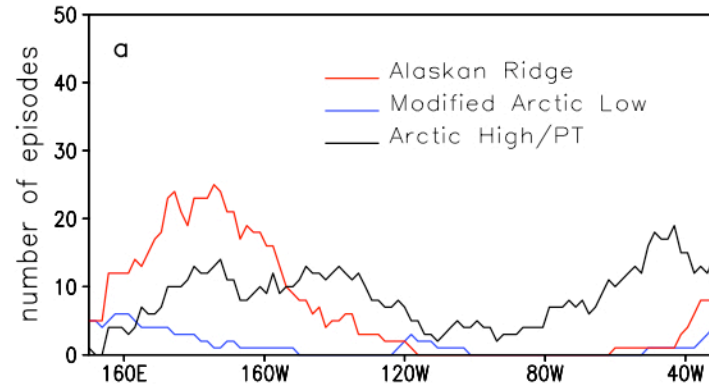
Alaskan Ridge



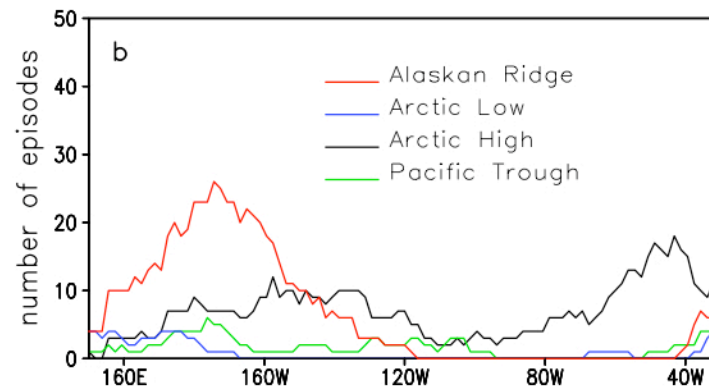
Corresponding potential temperature θ on PV = 2 surface (tropopause)

Frequency of “Large-Scale” Blocking Episodes* as a function of longitude

3 clusters



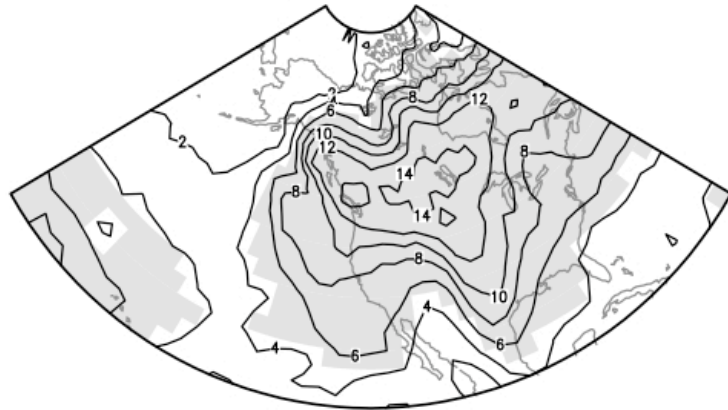
4 clusters



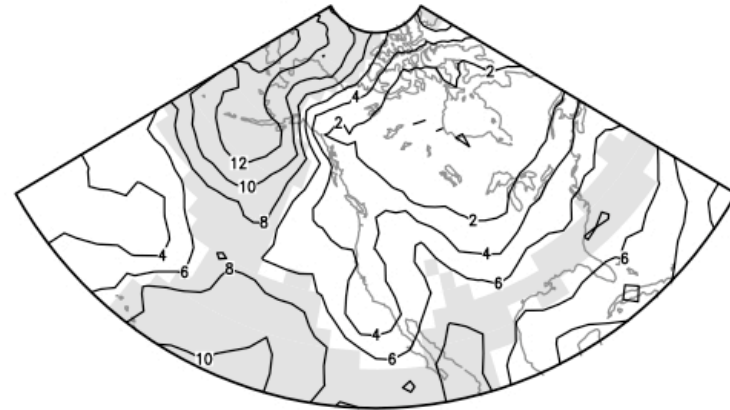
*Blocking Episodes based on θ on PV=2 surface (tropopause): (Pelly and Hoskins 2003)
“Large Scale” means covering at least 15° of longitude

“Episode” means lasting at least 4 days

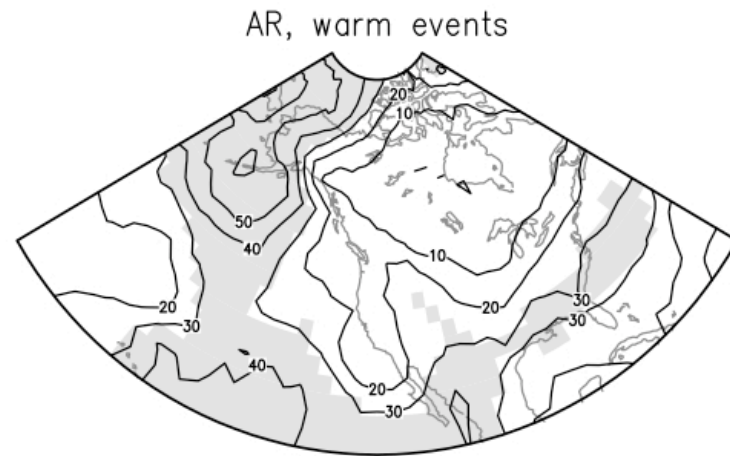
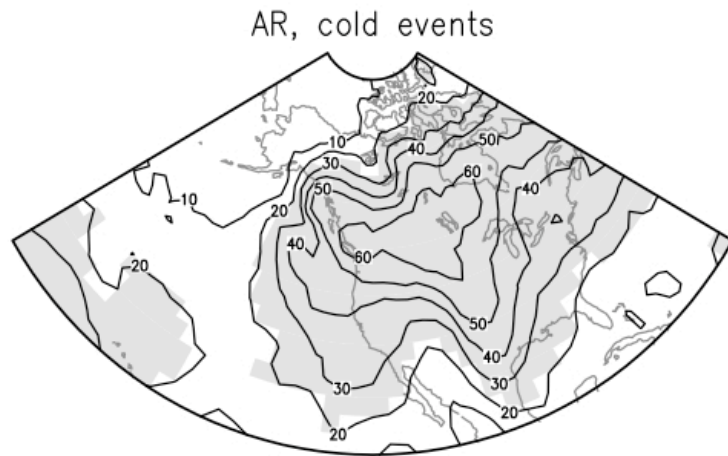
AR, cold events



AR, warm events



How often are extremely **warm** and **cold** days associated with the AR cluster?



Cold Events: Days for which
1000 hPa T is below 95% percentile

Warm Events: Days for which
1000 hPa T is above 95% percentile

Plots show percentage of extreme cold (warm) days for which the circulation is in the Alaskan Ridge regime

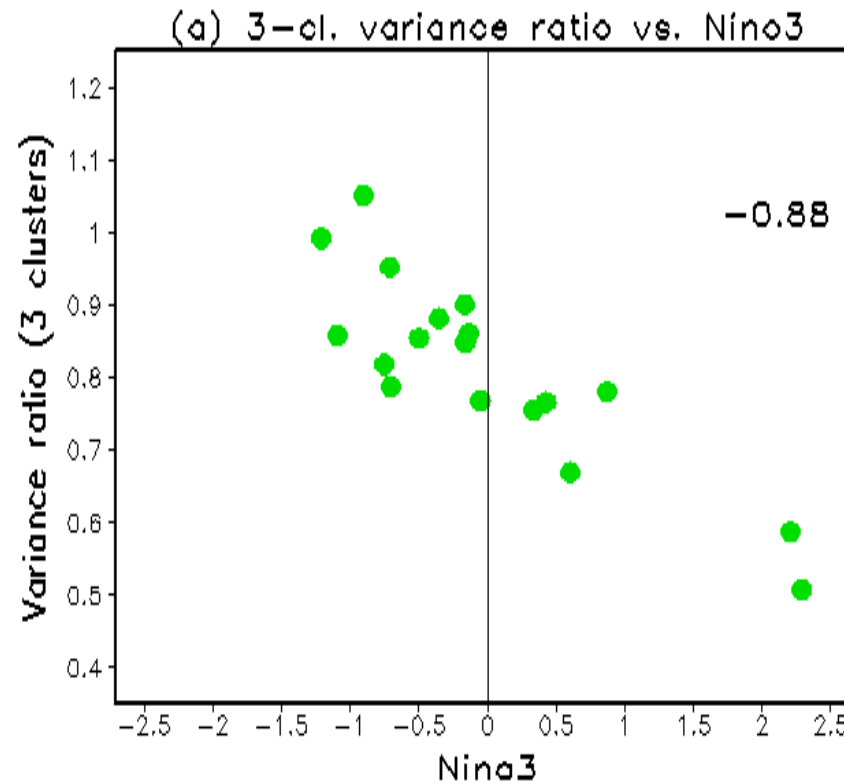
Palmer's hypothesis and inter-annual variability

Relationship to Boundary Forcing - Tropical SST

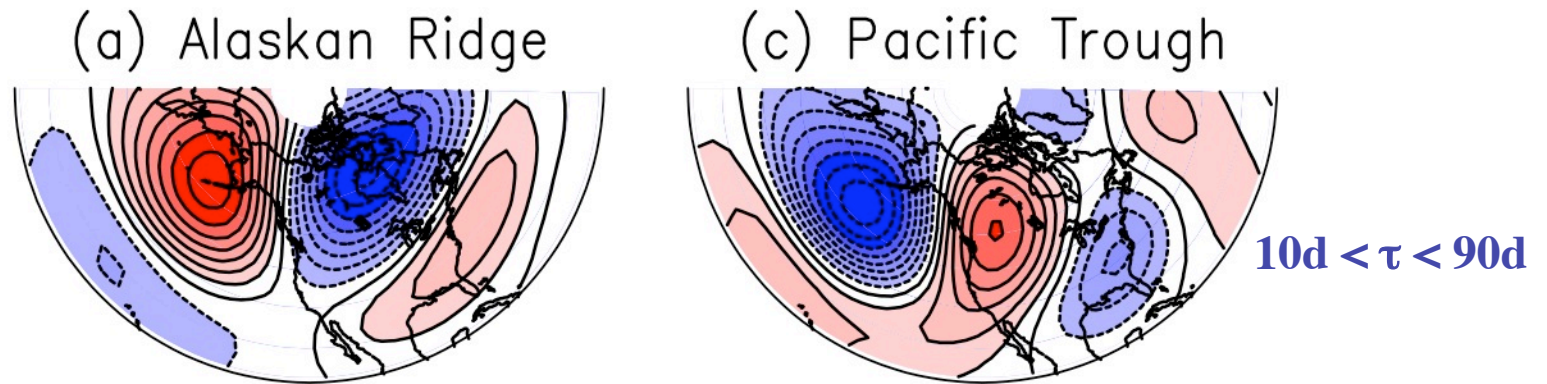
Examine “super-ensembles” of seasonal AGCM simulations made **with observed SST** for each of 18 recent winters. (Ensemble size = 55).

Cluster analysis on each winter (55 realizations) **separately** --> set of 18 independent analyses.

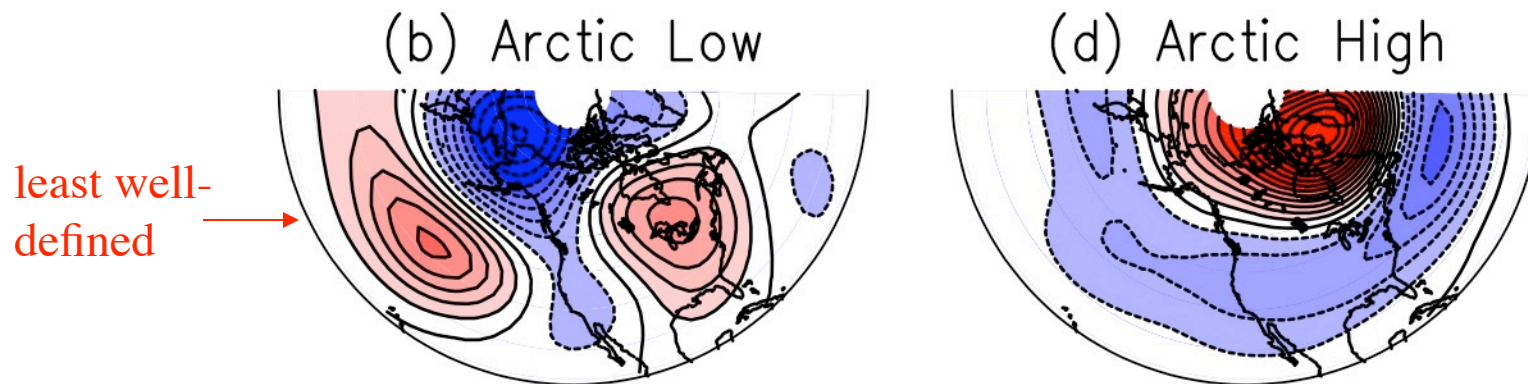
Results show significant clustering for each winter **except the warm ENSO winters** (El-Ninos): 1982/83, 1986/87 and 1997/98.



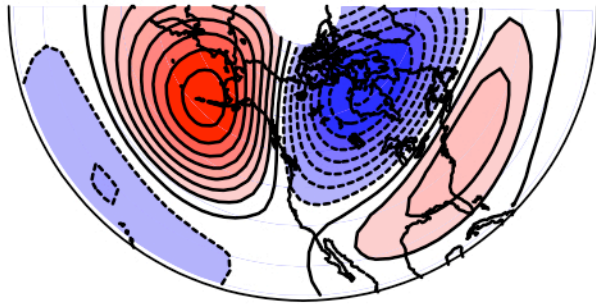
Straus and Molteni, 2004: Circulation Regimes and SST Forcing: Results from Large GCM Ensembles. *J. Climate*, **17**, 1641-1656.



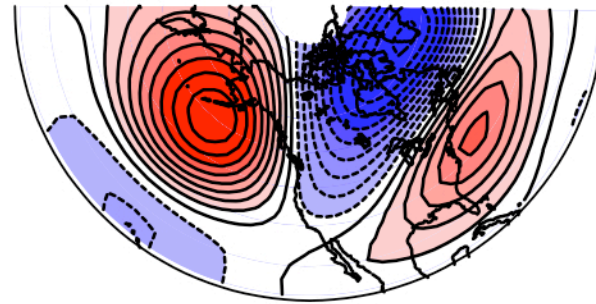
Relationship to Boundary Forcing in observations (NCEP54)



(a) Alaskan Ridge 54



(b) Alaskan Ridge 18



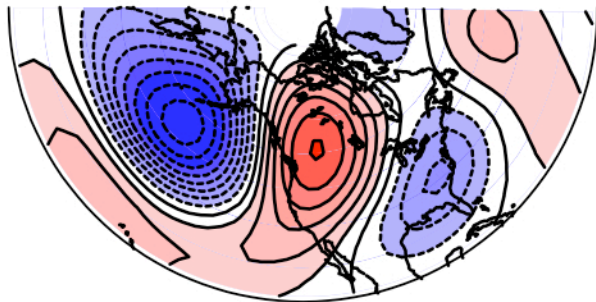
Lets compare these “NCEP54” preferred patterns “Alaskan Ridge” and “Pacific Trough” with analogous states obtained for a shorter, more recent 18 winter record (81/82-98/99)

Is the change from “PNA”-like to “ENSO”-like a real effect?

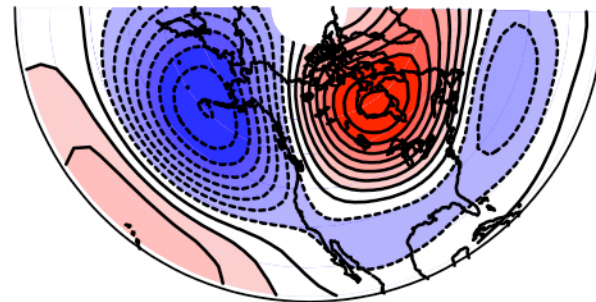
With only 18 winters there is no way that statistical significance can be established!

We use GCM “super-ensemble” simulations (55 members per winter for each of the same 18 winters **with obs SST**) to establish significance for the change in pattern!

(c) Pacific Trough 54



(d) Pacific Trough 18



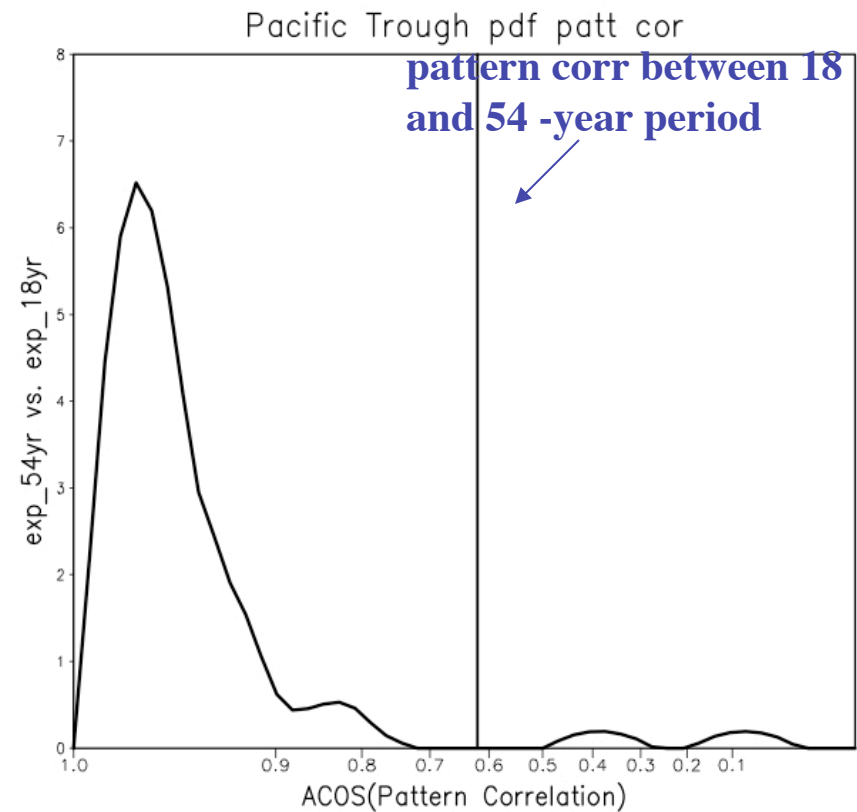
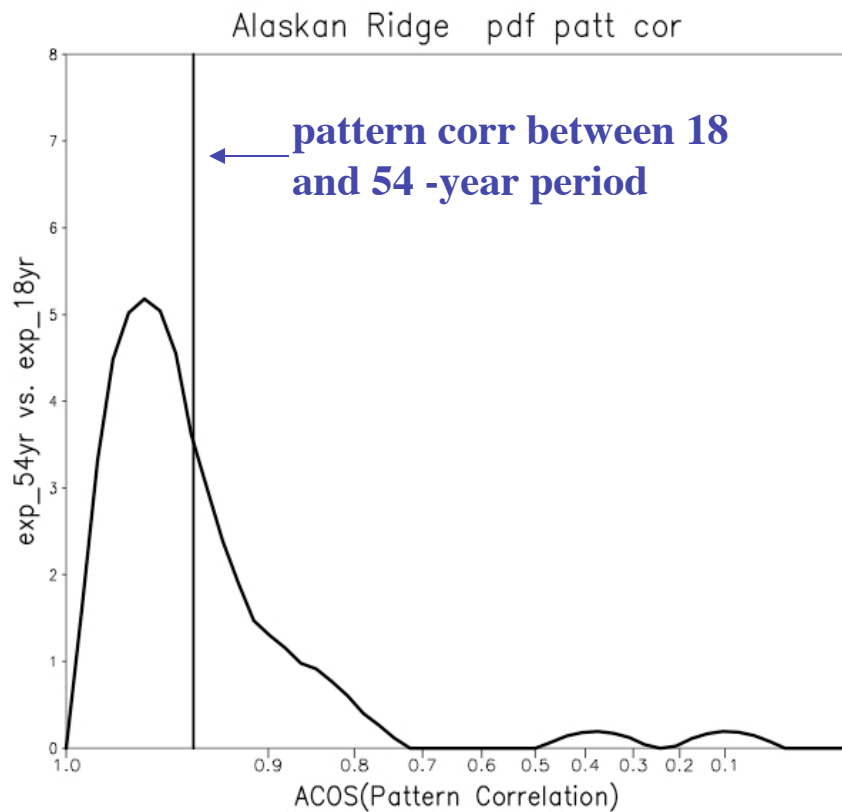
From 18 x 55 simulations, pick many “paired samples”

Sample A - 1 simulation (out of 55) per winter, for each of 18 winters - size 18

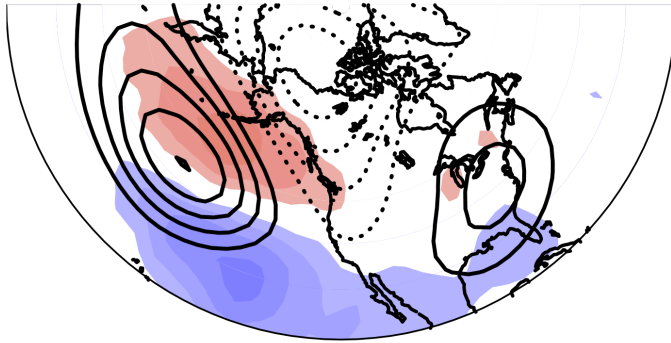
Sample B - 3 simulations (out of 55) per winter, for each of 18 winters - size 54

Each Sample A (B) equivalent to NCEP18 (NCEP54) record, but SSTs are the same!

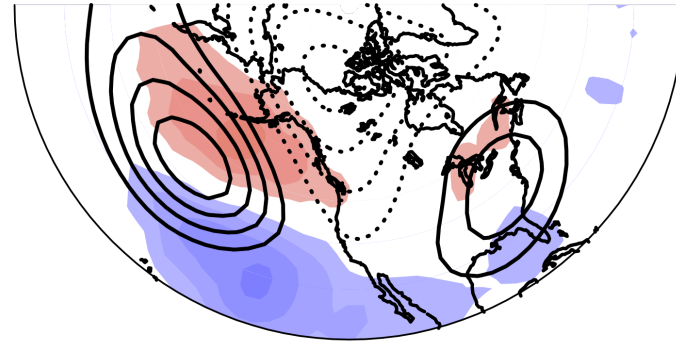
Difference between two sets of paired samples is due to internal variability only!



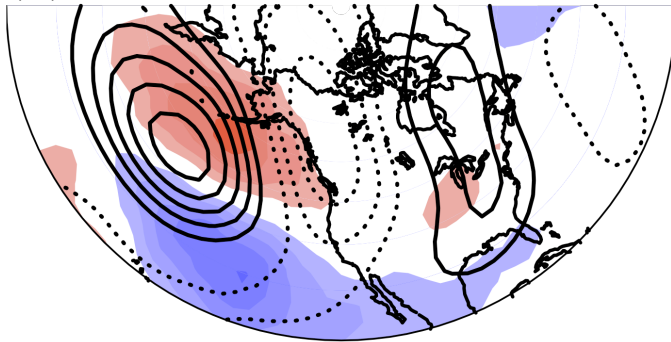
(a) trun=10 dim=10 ArcLo



(c) trun=5 dim=5 ArcLo



(b) trun=10 dim=5 ArcLo



(d) trun=5 dim=3 ArcLo

