Seasonal Prediction with CCSM3.0: Assessment of Dynamics - Circulation Regimes

David M. Straus and Dan Paolino*

Department of Atmospheric, Oceanic and Earth Sciences
George Mason University

****Center for Ocean-Land-Atmosphere Studies***

Community Climate System Model as a Forecast Model

Seasonal (Re)-Forecasts with CCSM3.0

Atmosphere: CAM with horizontal Resolution of T85, 26 levels

Ocean: POP (Parallel Ocean Program)

CCSM3.0 Forecasts:

Initial states in late December for 20 years: 1980 - 1999

For each year, a 10-member ensemble was integrated for 12 months

(We will examine only the initial Jan-March)

Ocean Initial States:

GFDL ocean data assimilation system based on the MOM3 global ocean model
(variational optimal interpolation scheme of Derber and Rosati, 1989).
The GFDL ocean initial states were interpolated to the POP grid
(For more details –see poster)

Atmospheric Initial States:

Created for each of the 10 days (22 Dec through 30 Dec) 1980-1999
The atmospheric initial conditions were interpolated from the daily NCEP/NCAR Reanalysis data.

The land surface initial conditions (temperature and soil wetness):

- Daily Global Soil Wetness Project data for 1986-1995,
- ERA40 for 1980-1985 and 1996-19989.

Anomalies of observed soil data from their respective long-term means were superimposed on a long-term CLM climatology to create the initial states for the CLM

The sea-ice initial conditions:

Based on climatology from a long simulation of CCSM3.0

Assessment of winter low-frequency variability
Circulation regimes and their coupling to synoptic-scale variability

Low-Frequency Variability:
Based on filtered time-series of 200 hPa geopotential height:
Low Pass filter: retains fluctuations with periods longer than about 10 days

Synoptic Scale ("Storm Track") Variability:
Based on filtered time series of 200 hPa meridional wind:
Band Pass filter: retains fluctuations with periods of about 2 to 10 days
Use of meridional wind emphasizes shorter wavelengths

Low Frequency Variability of Storm Tracks
Use of **envelope functions**

Motivation for Circulation Regimes

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 must be related to persistence in the "large-scale" flow

Example: European Heat Waves of summer 2003 - were they related to regimes in the summertime Euro-Atlantic region?

Circulation Regimes and Synoptic Feedback

Notion that weather regimes involve 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:

- **Purely dynamically (RP)**
- **Semi-empirically (VL)**
- **Completely statistically (multiplicative noise: Sura, Newman, Penland and Sardeshmukh, 2004: J. Atmos. Sci., 62, 1391-1409)**

Some Methodologies for identifying "regimes"

1) Cluster Analysis: Partitioning of PC-based state space to minimize within-cluster variance

2) Mixture model method (in PC-space): modeling entire *pdf* with a sum of Gaussian *pdfs*

3) Neural-Network related methods

-**Each method has advantages and disadvantages**

-**Synoptic scale feedback usually not accounted for**

Significance Testing

a) Significance vis-à-vis a single Gaussian pdf

b) robustness to sampling errors (reproducibility)

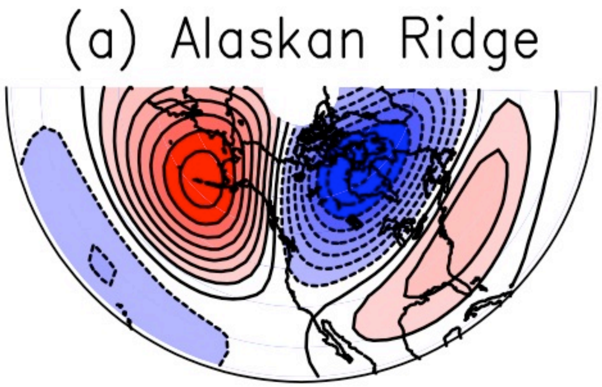
c) Significance easier to establish in large simulated datasets than in short observational record

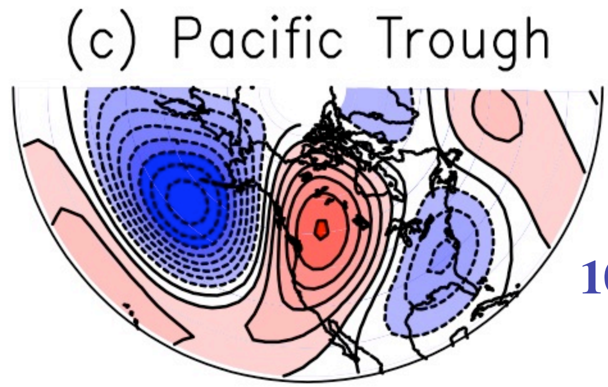
Basic Cluster Analysis

- **Traditional low-pass (10-90 day) filter on Z 200 $\Rightarrow$ ZLP**
- **Compute EOFs and PCs of ZLP**
- **Apply quasi-stationary filtering (following pioneering studies by Toth)**
- **Apply partitioning algorithm - measure of success is given by the ratio of in-cluster variance to total variance (want it as small as possible)**

- **Assess Significance by comparison to cluster analysis carried out on many synthetic data sets (e.g. each PC modeled by Markov process)**
- **Assess reproducibility in subsets of data**
- **A unique number of clusters not usually found - just a range**

Straus, Corti and Molteni, 2007 J. Climate





$10d < \tau < 90d$

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

(a) Only quasi-stationary time periods used (clusters of 200Z low-pass filtered)

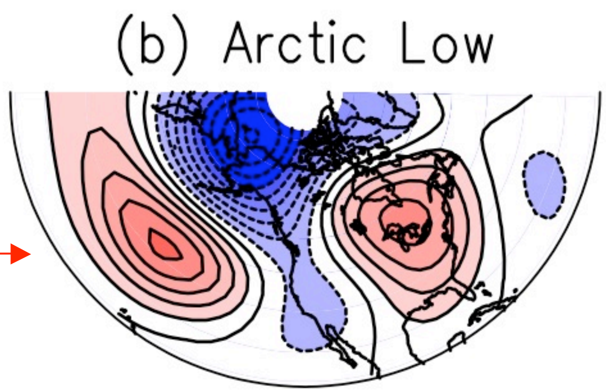
(b) H0 can be rejected at the 90% level using partitioning method

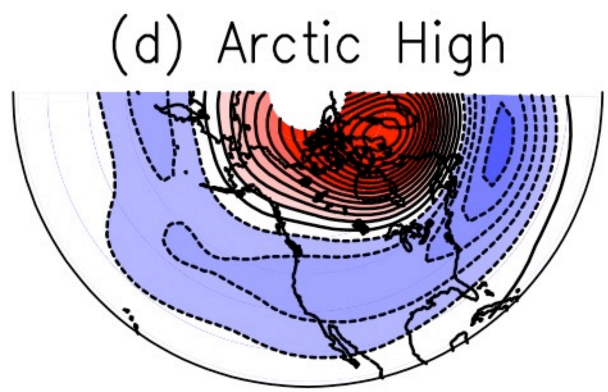
(c) Can not say whether 3 or 4 clusters is optimal

(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

least well-defined





Pacific - North American Winter Regimes in CCSM3.0 Seasonal Forecasts

Explicit coupling between planetary and synoptic scale “envelope” is incorporated

Data:

- **Model - T85 CAM coupled to POP Ocean**
- **Historical Forecasts: Late Dec starts for 10 years: 1980-1999**
- ***Daily* 200 hPa height and v-wind analyzed: January-March**
- **10 ensemble members for each forecast start date**
- **Observational comparison: NCEP reanalysis**

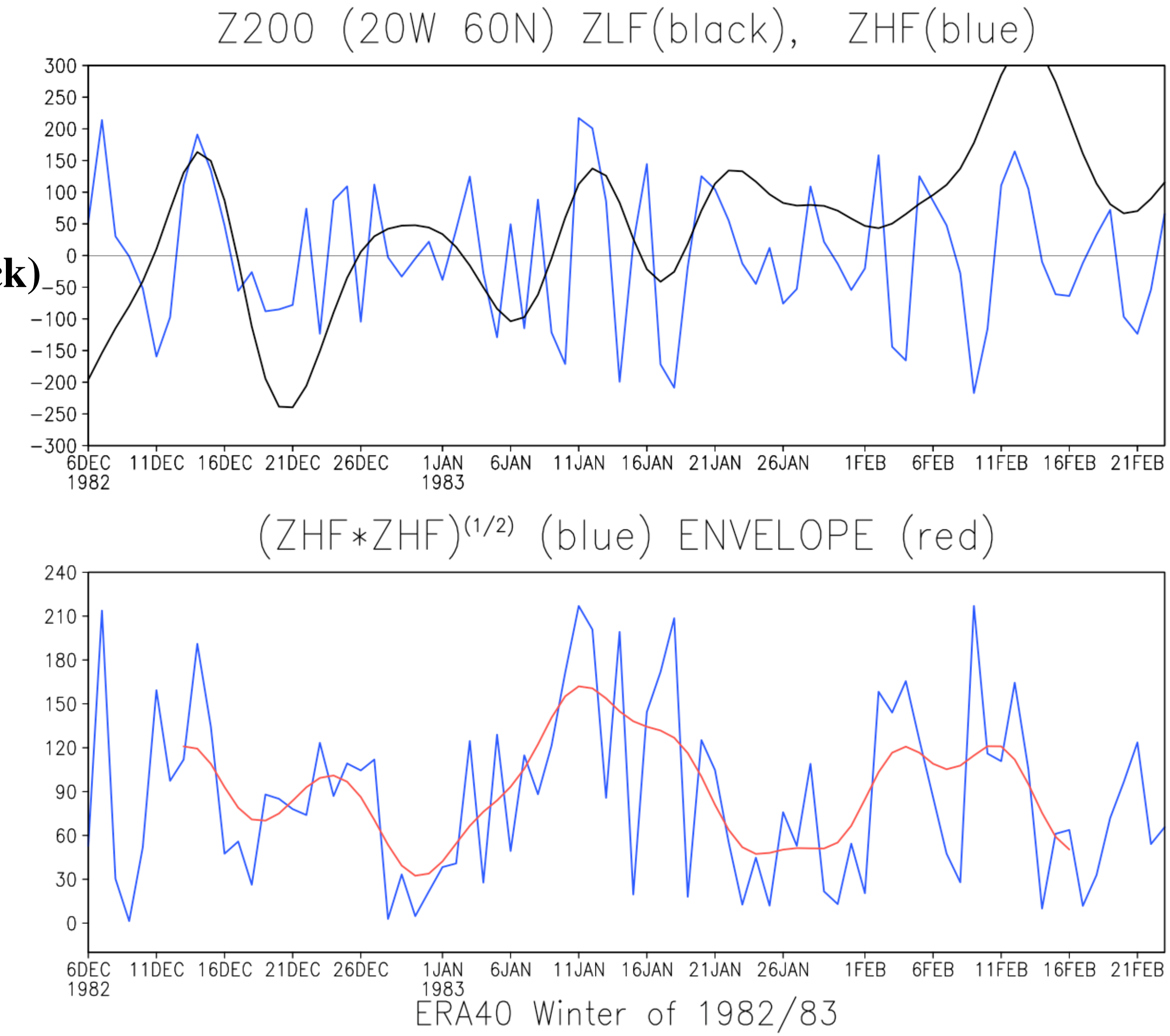
Envelope Function: Tracks low-frequency variations of synoptic scale activity

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

Filtered Z200

Z_{LF}: τ = 10-90 day (black)

Z_{HF}: τ = 2-10 day (blue)



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

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

Regime Analysis:

CCSM3.0 forecasts and parallel NCEP reanalysis

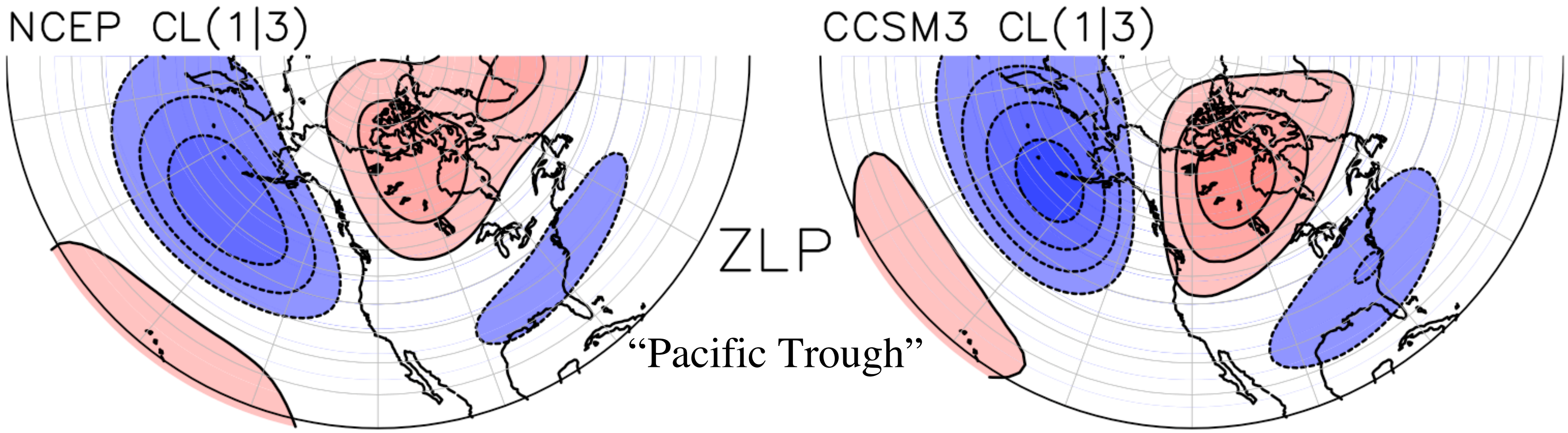
•Traditional low-pass (10-90 day) filter on Z 200 $\Rightarrow$ ZLP
• Envelope function of band-pass (2-10 day) v-winds $\Rightarrow$ VENV
• Compute EOFs and PCs of ZLP
• Compute EOFs and PCs of VENV
• Compute Singular Value Decomposition using leading N PCS of VENV and ZLP

• Leading 3 SVD modes capture ~ 90% of squared covariance N
• Use SVD-defined coordinates - keep only 3 modes:
•Apply quasi-stationary filtering (following pioneering studies by Toth)
•Apply partitioning algorithm

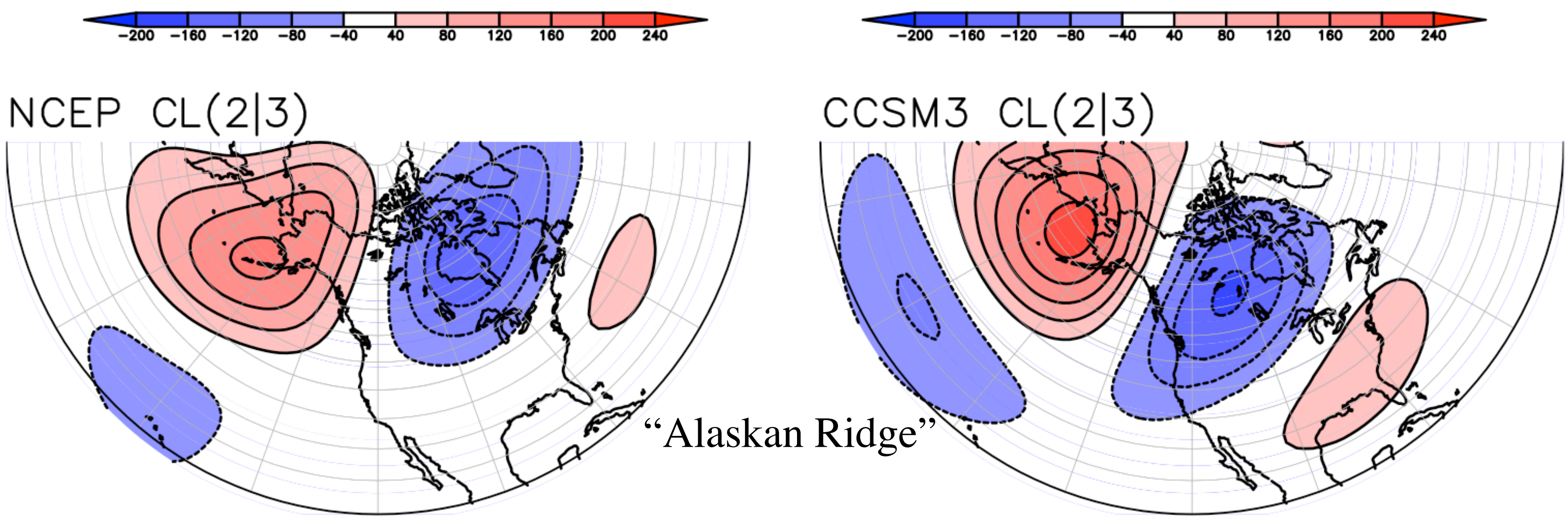
• Technical note: Algorithm is insensitive to orthogonal rotation defined by SVD,
• but the SVD analysis leads to a unique truncation (N) in state space

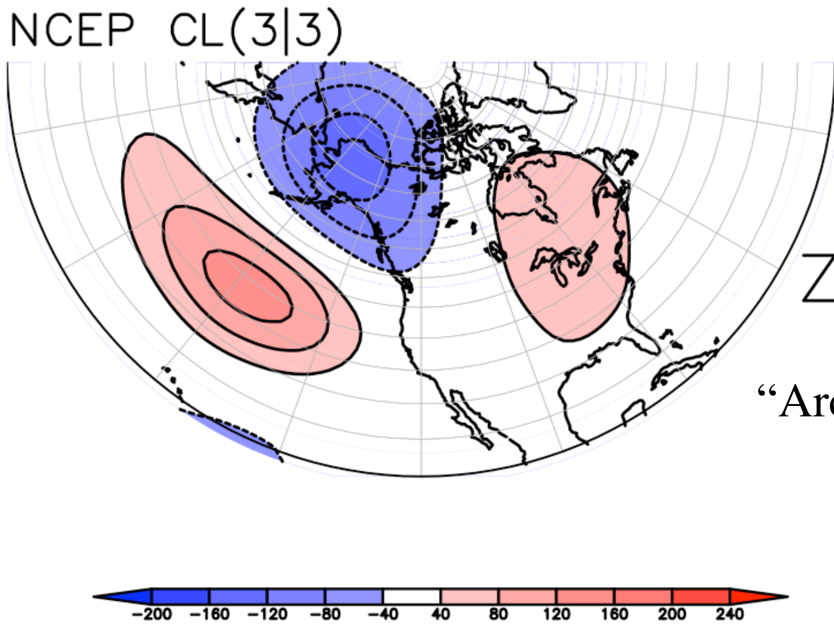
Presentation of cluster patterns

- Classify all quasi-stationary states into one of 3 clusters,
- Full-field composite anomalies of ZLP based on cluster assignment
- Full-field composite anomalies of the envelope function
  based on cluster assignment
- Examination of envelope function anomalies shows storm track shifts
  in association with low-pass height shifts



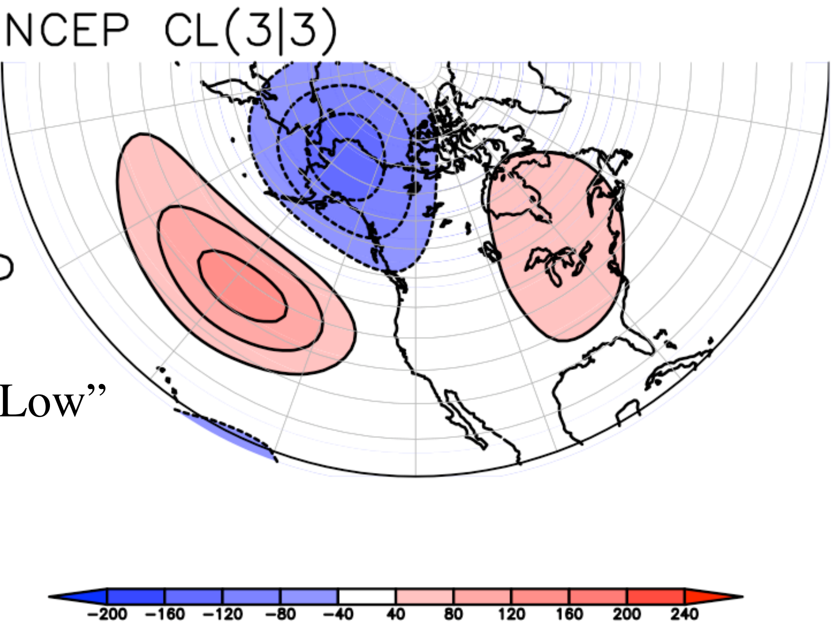
Results for 3 regimes: Maps of geopotential height composite anomalies





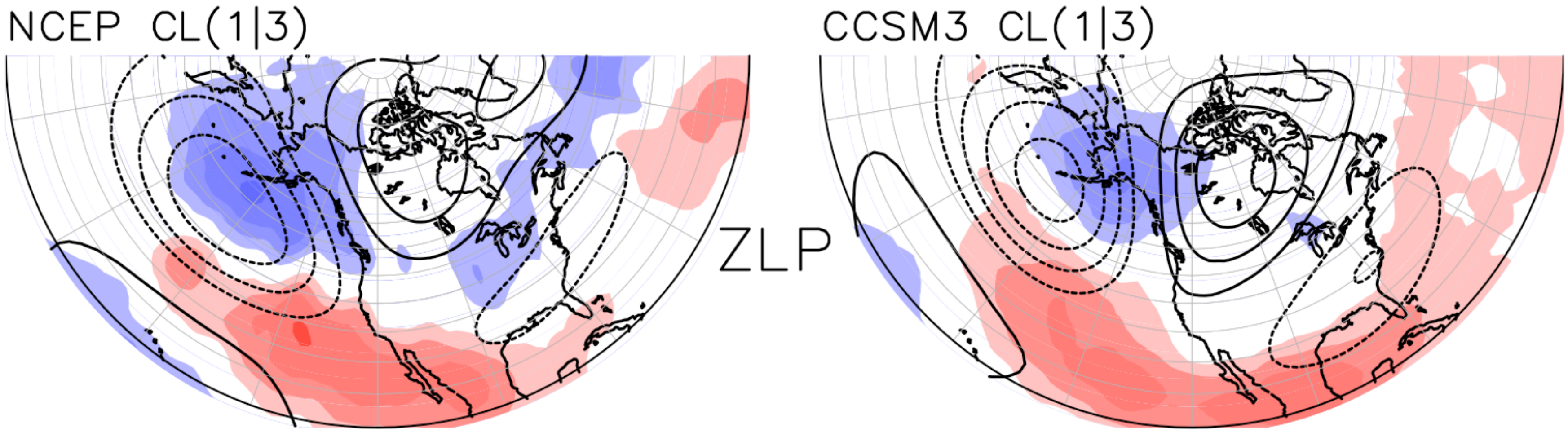
ZLP

"Arctic Low"

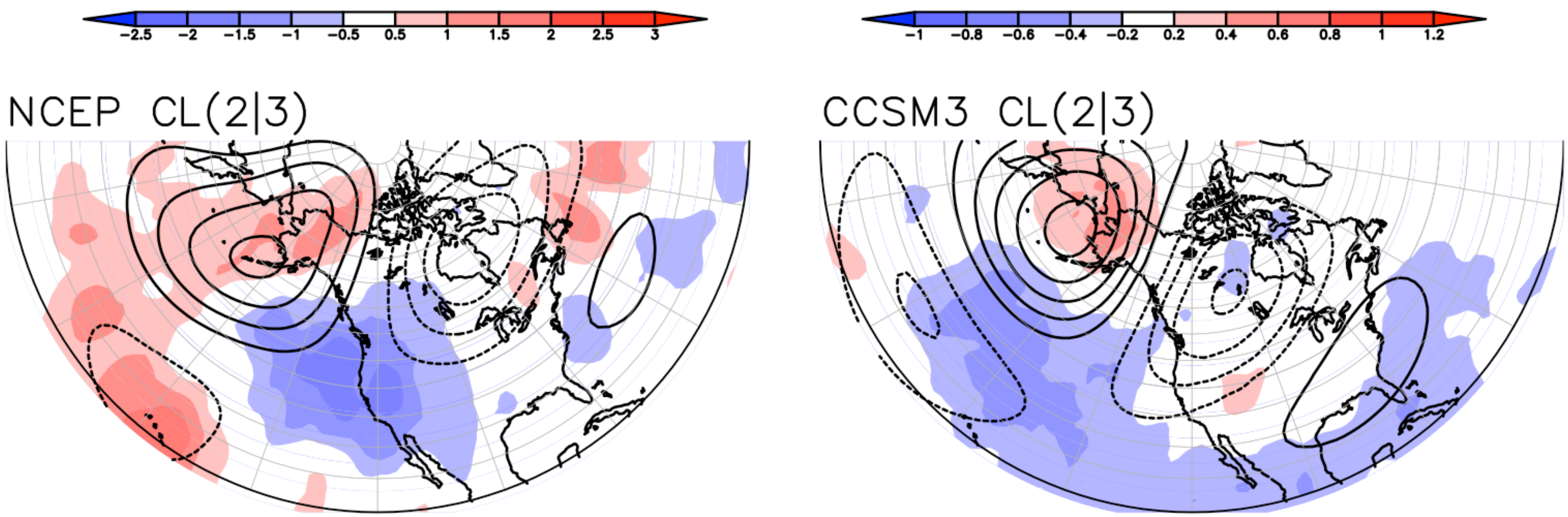


Results for 3 regimes: Maps of geopotential height composite anomalies

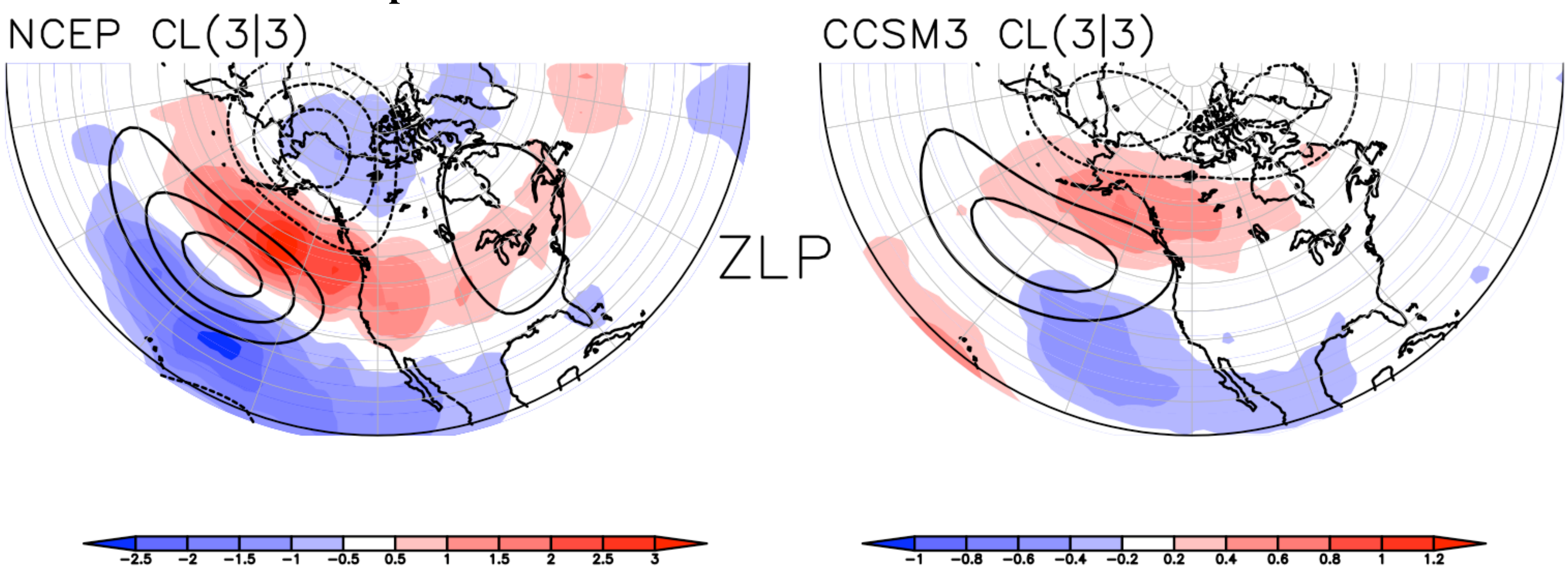
Envelope Function anomalies associated with clusters



Contours = ZLP anom. Shading = VENV anom.



Envelope Function anomalies associated with clusters

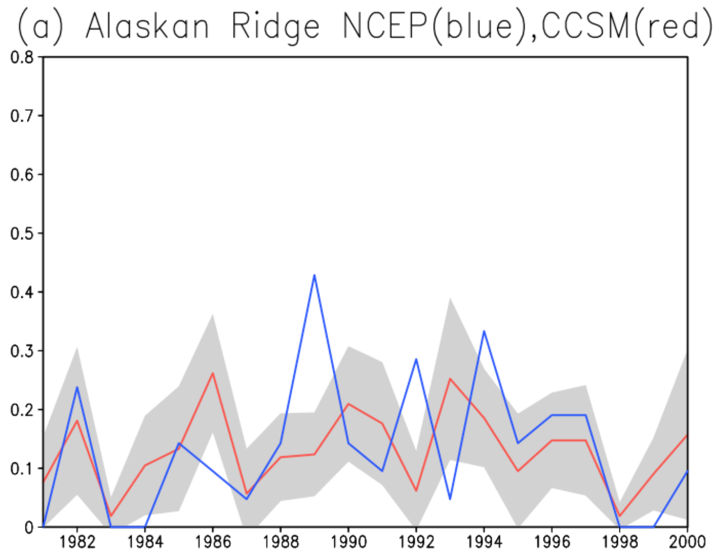


Contours = ZLP anom. Shading = VENV anom.

Blue = NCEP

Red = CCSM3

Gray band: ± σ (within ensemble)



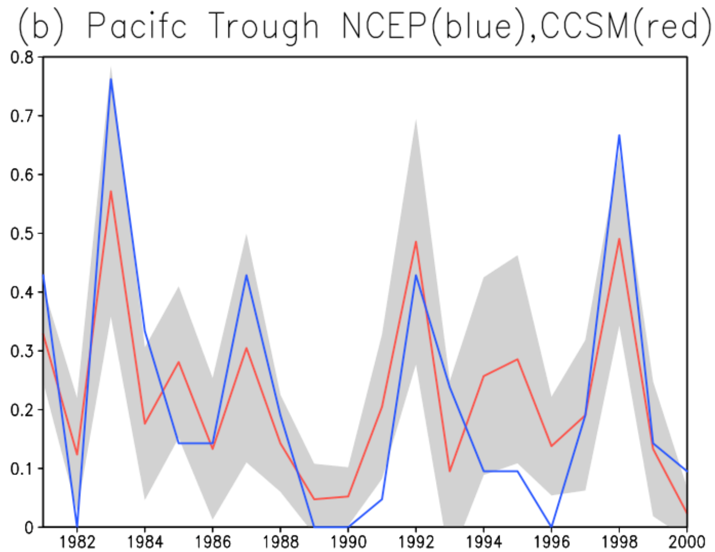
Alaskan Ridge:

-related to blocking

-little predictability: WHY?

Interannual variability of occurrence of each cluster:

Is there any sign of predictability?



Pacific Trough:

-related to ENSO

- reasonably well predicted

Summary of CCSM3.0 Forecast Behavior

- Somewhat under-predicts magnitude of higher frequency / small scale variability
- ENSO related shifts in synoptic variability fairly well captured
- Regime patterns seem qualitatively realistic, as do mean frequencies
- Interannual variability of Pacific Trough regime occurrence is quite realistic
- Interannual variability of Alaskan Ridge (blocking) occurrence is not particuarly realistic.
- Some hint of predictability of occurrence of Arctic Low (not shown)

Some Further Work

- More systematically establish significance of SVD-based regime results
- Assess “sampling properties” of the ensemble: Construct many samples of forecasts, one forecast per calendar year, and construct pdfs of regime patterns with observed
- Independent analysis of blocking to understand Alaskan Ridge results