Does external forcing alter the structure of atmospheric circulation regimes?

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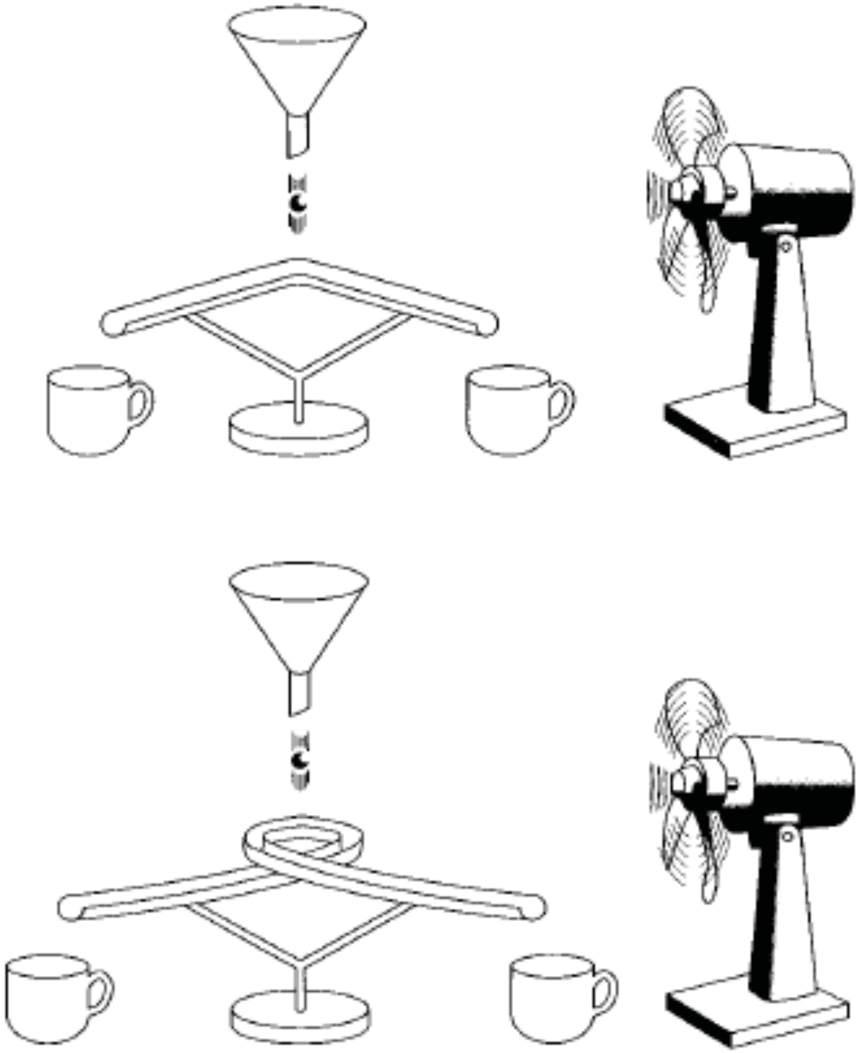
Preferred States (Regimes): Relationship to Forcing

- **By analogy with low-order chaotic systems, it has been argued that moderate changes in forcing (boundary conditions) would not lead to changes in circulation regimes, but only in their frequency of occurrence**

- **Case Studies using mid-latitude response to interannual changes in the ENSO-related forcing in tropical Pacific SST: Do regimes themselves change, or only their frequency of occurrence?**

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

- Straus, David M., Susanna Corti, Franco Molteni, 2007: Circulation Regimes: Chaotic Variability versus SST-Forced Predictability. *J. Climate*, **20**, 2251–2272.



From Tim Palmer, 1997 (J. Climate)

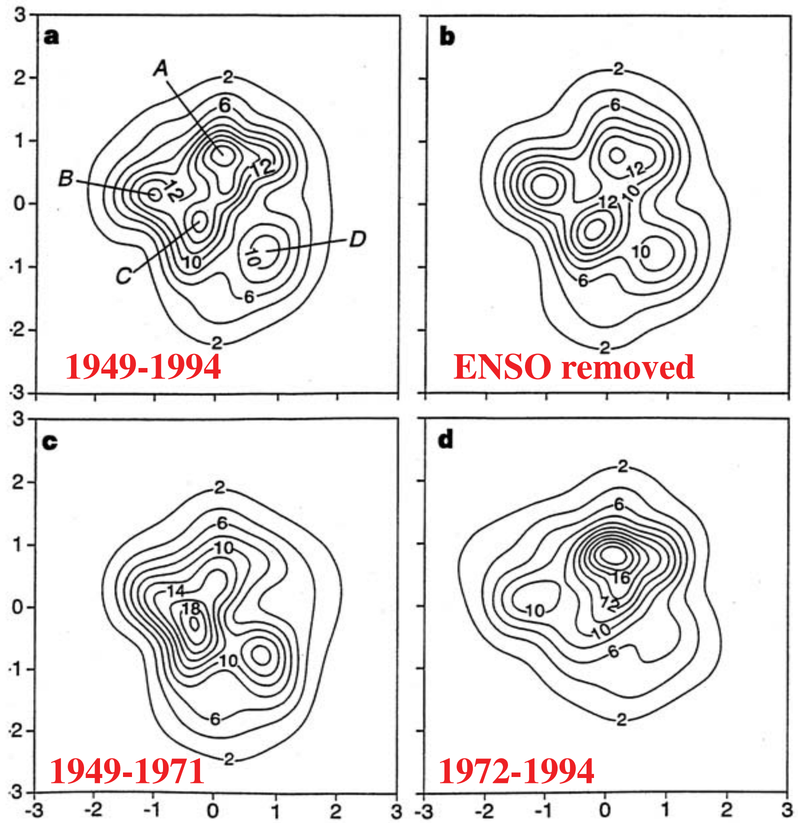
Circulation Regimes

Corti, Palmer and Molteni, 1999: Signature of Recent Climate Change in Frequencies of Natural Atmospheric Circulations, *Nature*, **398**, 799-802

Data:

Nov - Apr monthly mean 500 hPa Z from NCEP reanalysis for 46 years (49-94)

(detrended)



Plots:

2-d pdf of leading PCs

Illustration of Palmer (1997) hypothesis: Climate change seen only as difference in population of fixed regimes.

The Need for GCMs

- **The (possible) change in extra-tropical regime properties with tropical SST seriously compounds the already difficult problem of rigorous identification of regimes in observations.**

- **We only have very few (observed) realizations of winter seasons for a given tropical Pacific SST configuration.**

- **We really do need very large ensembles of realistic global GCMs to estimate the sampling properties of circulation regimes – that is, to estimate the effects of internal vs. external variability on regime properties.**

AGCM Experiments - Design

- **Simulations used COLA Atmospheric GCM V2.2**
- **T63 L18 AGCM – forced by weekly OISST**
- **For each of 18 winters (1981-82 / 1998/99) an ensemble of simulations is created:**
  - **55 simulations initialized from NCEP reanalysis in late November (+ perturbation) (yields 990 winter seasons)**
  - **Each simulation run through end of March**
  - **96 days available**
  - **In this study, only the climatological annual cycle and fluctuations with periods shorter than 10 days removed**

AGCM Experiments - Interpretation

- **Each ensemble of 55 simulations is a possible realization of the atmospheric circulation forced by the observed SST for a given winter**
- **The anomaly of the ensemble mean can be interpreted as the response forced by the SST**
- **Any deviation about the seasonal ensemble mean is due to internal variability**

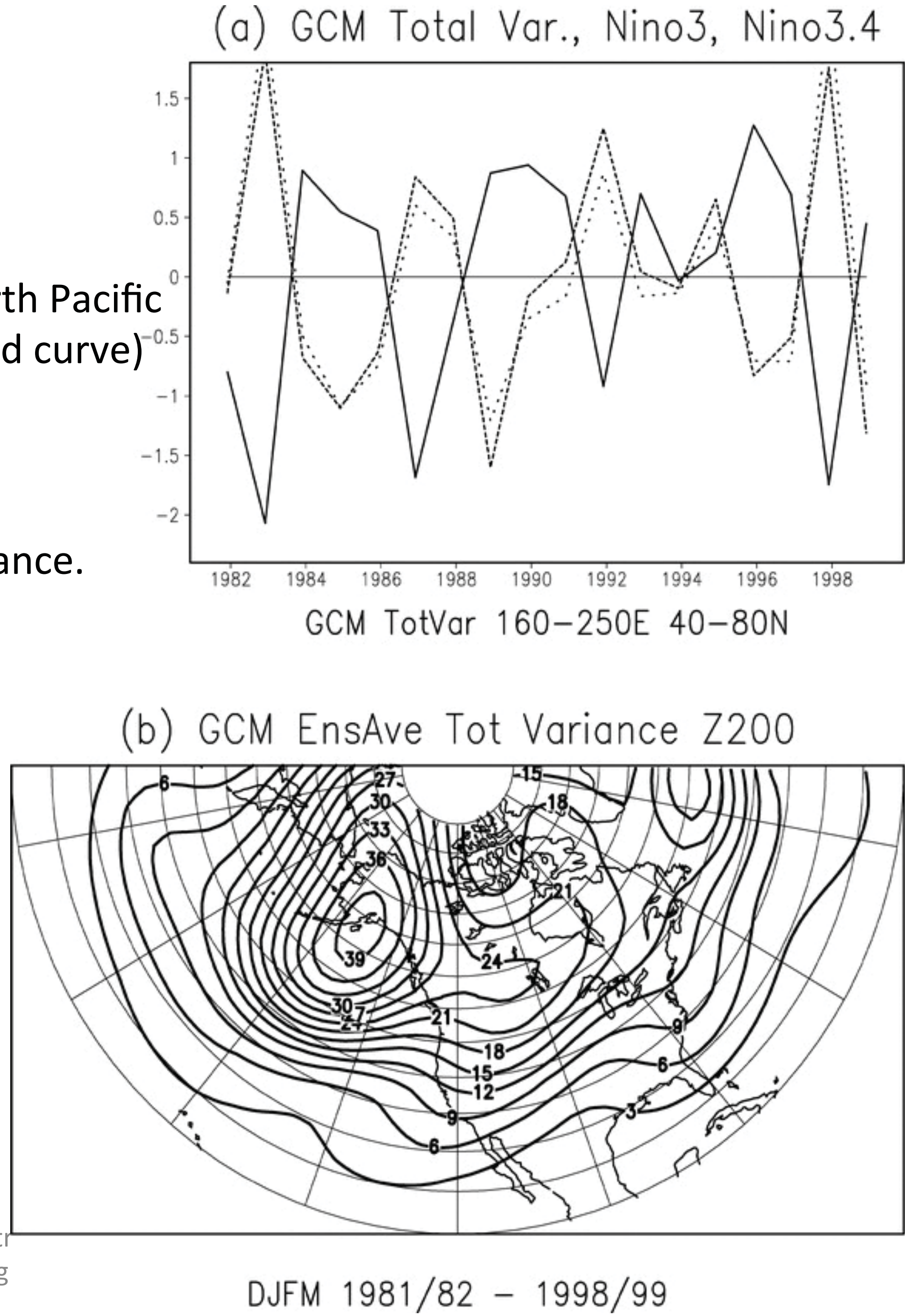
AGCM Experiments – Cluster Analysis

- **Each ensemble of 55 simulations is treated as a completely separate planet !**
  - **(Exception: We plot results as an anomaly from overall climate)**
- **Partitioning Method of Michelangeli et al. (1995) used to obtains regimes (clusters)**
  - **Method operates in state space defined by EOFs (keep 6 – 10)**
- **Regimes sought only on quasi-stationary flow patterns**

Low-frequency variance Z200
For DJF 1981/82 -1998/99.

(a) Variance integrated over the North Pacific region 40°–80°N, 160°E–110°W (solid curve)
Niño-3 index (dotted curve)
Niño-3.4 index (dashed curve).

(b) Map of mean low-frequency variance.
Contour interval is 3000 m^2



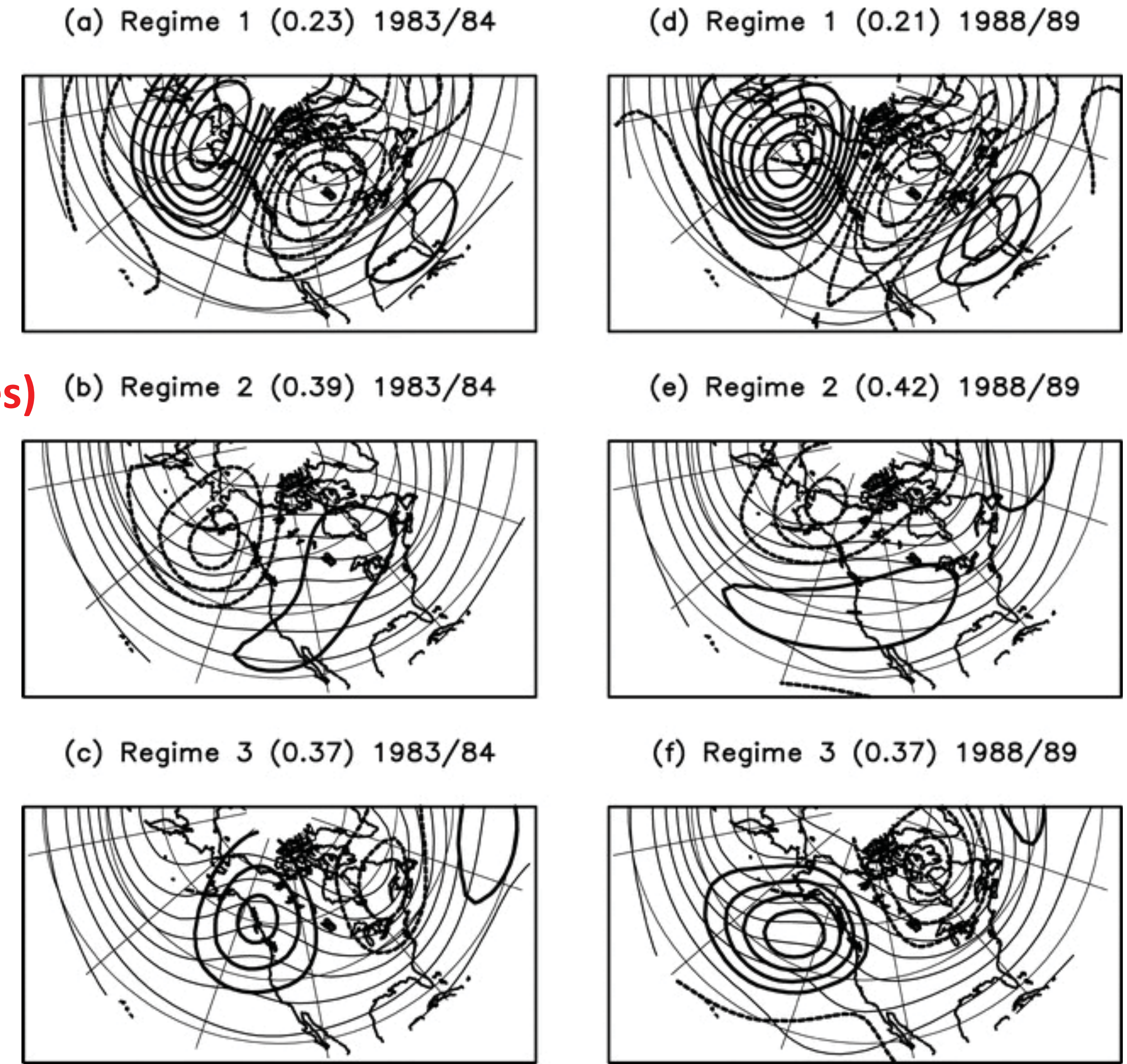
Winter	$k = 2$	$k = 3$	$k = 4$	$k = 5$	$k = 6$	Niño-3	Niño-3.4	PC
1981/82	81	89	83	**91**	**91**	−0.50	−0.13	0.52
1982/83	68	45	57	42	54	2.21	1.89	2.10
1983/84	88	**100**	**98**	**98**	**99**	−0.50	−0.68	−0.51
1984/85	86	**95**	**93**	**98**	**100**	−1.09	−1.10	−0.84
1985/86	**91**	**100**	**99**	**100**	**100**	−0.75	−0.64	0.29
1986/87	61	67	52	70	74	0.60	0.84	1.49
1987/88	60	**97**	87	87	87	0.34	0.50	0.58
1988/89	**97**	**98**	**98**	**99**	**99**	−1.21	−1.60	−1.85
1989/90	89	**98**	**98**	**99**	**100**	−0.35	−0.16	−1.00
1990/91	**94**	**100**	**97**	**99**	**100**	−0.16	0.12	−0.70
1991/92	67	**93**	**91**	**92**	**92**	0.87	1.25	0.55
1992/93	85	**99**	**100**	**100**	**100**	−0.16	0.04	−0.13
1993/94	**100**	**99**	**99**	**100**	**100**	−0.14	−0.10	0.54
1994/95	83	**99**	**94**	**99**	**100**	0.43	0.65	−0.07
1995/96	86	**99**	**96**	**99**	**99**	−0.71	−0.83	−0.74
1996/97	**95**	**98**	**97**	**100**	**100**	−0.71	−0.51	−0.37
1997/98	35	25	36	70	74	2.29	1.76	1.40
1998/99	87	**92**	**97**	**94**	**97**	−0.90	−1.31	−1.25

Table 2. Significance *p* (in %) of clusters against the red noise Markov model constructed using the same variance and lag-one correlation of the leading four PCs of GCM data. The *k* value gives the cluster number. Here $p = 100 - e$, where *e* is the number of synthetic Markov datasets for which the ratio variance exceeds that of the GCM. Values of *p* over 90 are set in boldface. Also shown are the standardized Niño-3 and Niño-3.4 indices, as well as the standardized leading PC of the seasonal ensemble means.

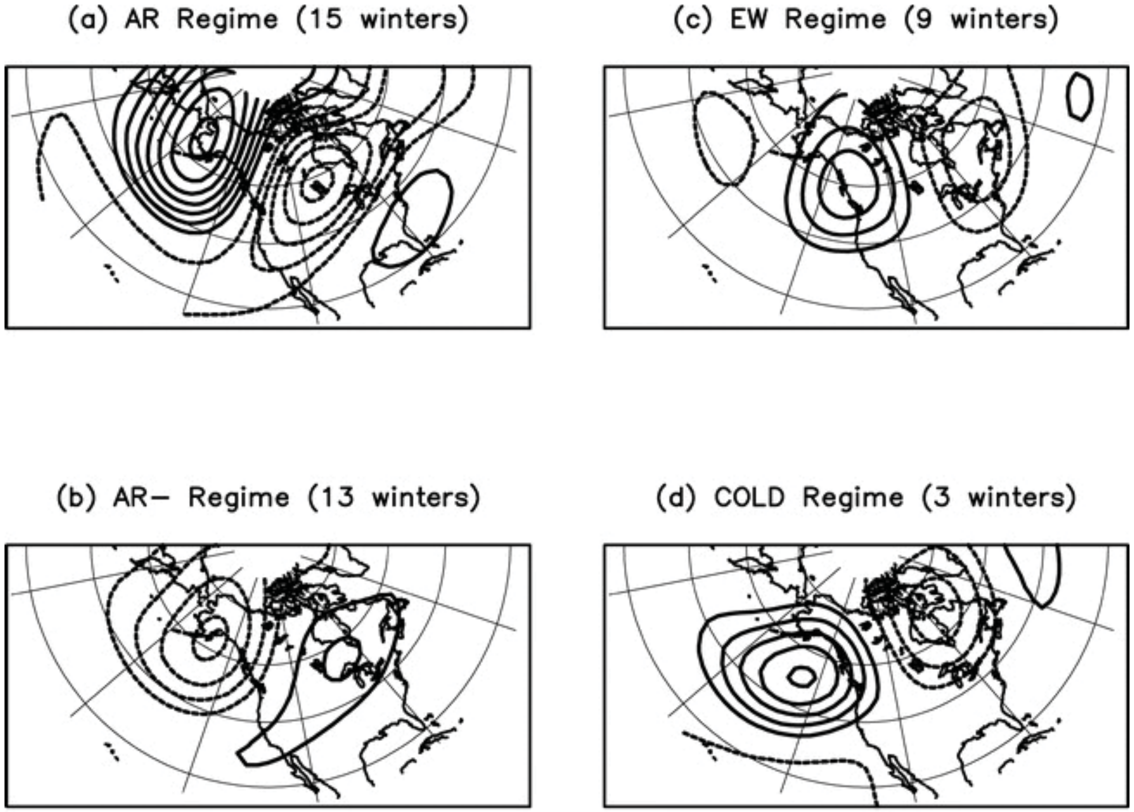
Composite Z200
k = 3 clusters.

Total Z200 (light lines)
(CI = 200)

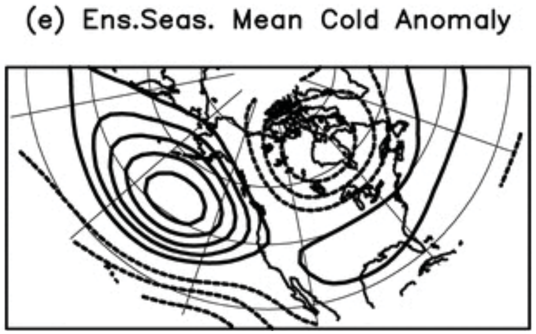
Anomaly Z200 (dark lines)
(CI = 50)



Relative fraction of the regime residence given by figure by in parentheses



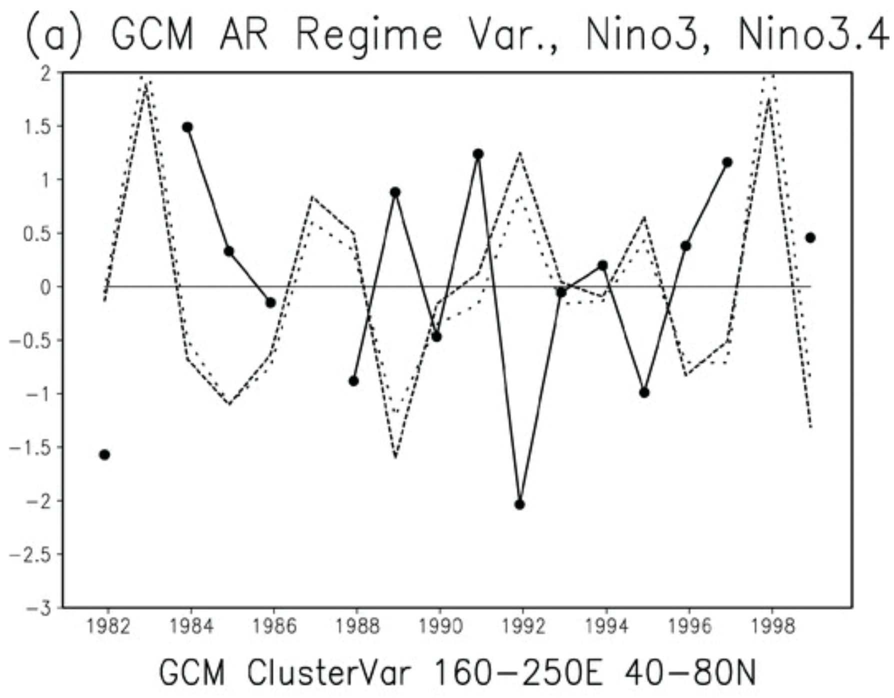
Composites of the regime centroid maps over all winters in which the individual regimes appear:
(a) AR, (b) AR−, (c) EW, (d) COLD.
(e) The ensemble seasonal mean composite of 200-hPa height averaged over the La Niña winters of 1984/85, 1988/89, and 1998/99.
All maps are anomalies from climatology of 200-hPa height. CI is 40 m in (a)–(d), 20 m in (e)

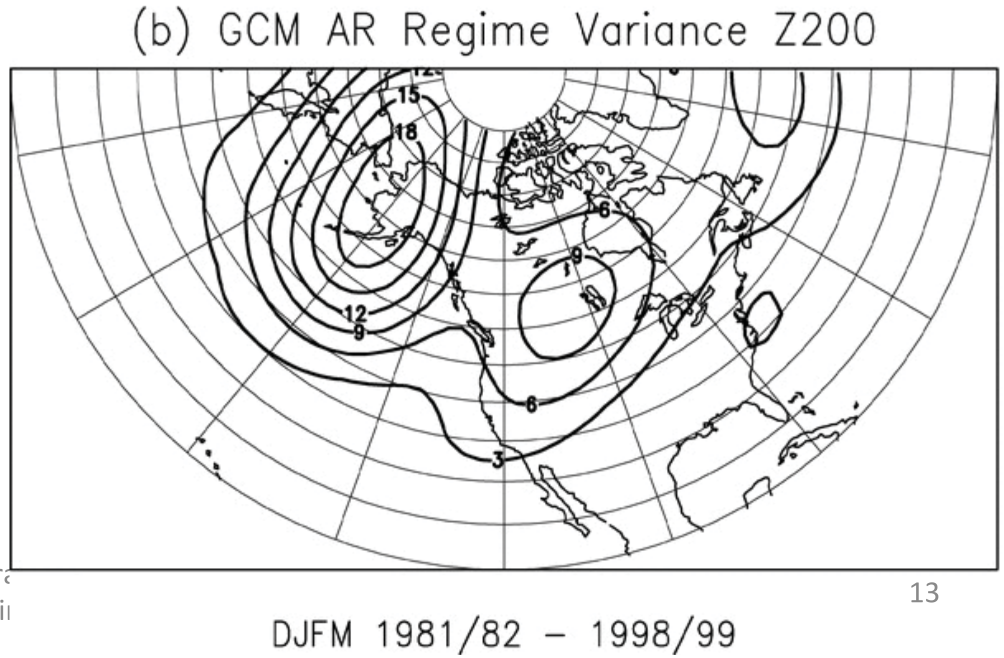


Variance of 200-hPa height associated
 with the AR regime, obtained by summing the
square of the time series at each grid point
 over all occurrences of the AR regime,
and dividing by 96.

(a) Variance integrated over N Pac region
40°–80°N, 160°E–110°W (solid curve),
Niño-3 index (dotted curve),
Niño-3.4 index (dashed curve).

(b) Map of AR variance.
Contour interval is 3000 m^2





Interpretation

The result that multiple circulation regimes cannot be identified during the major warm ENSO winters of 1982/83, 1986/87, and 1997/98 can be understood in terms of the behavior of the AR (or Alaskan Ridge) state.

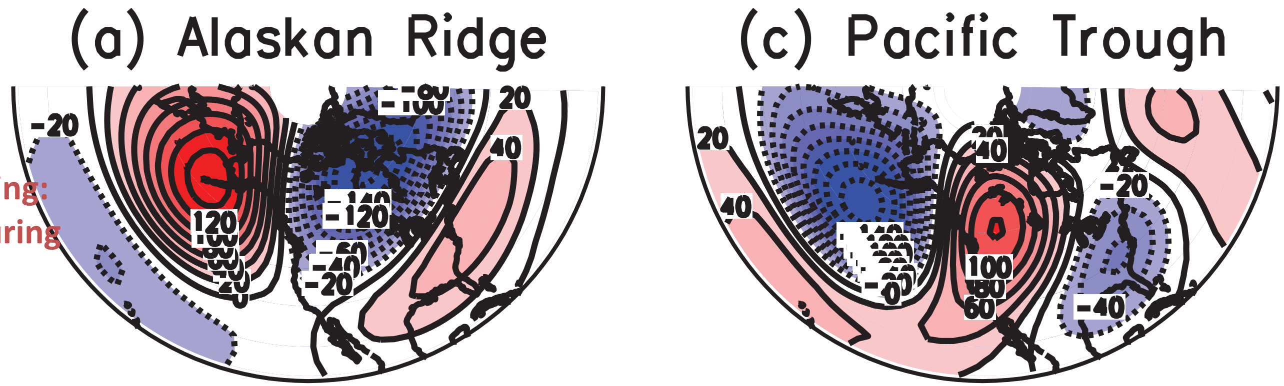
This apparently unpredictable state is related to Pacific blocking, the formation of which is known to be dependent on the synoptic transient feedback.

During warm events, the synoptic eddy activity in the Pacific Ocean shifts equatorward and eastward, along with the jet. The steering of the synoptic eddies away from high latitudes suppresses the tendency to form strong ridges in the Alaskan region; consequently the AR pattern is no longer seen as a distinct circulation pattern.

Estimating Circulation Regime Properties: Uncertainty and Predictability

Straus, David M., Susanna Corti, Franco Molteni, 2007: Circulation Regimes: Chaotic Variability versus SST-Forced Predictability. *J. Climate*, **20**, 2251–2272.

Related to Pacific blocking: enhanced during La-Nina

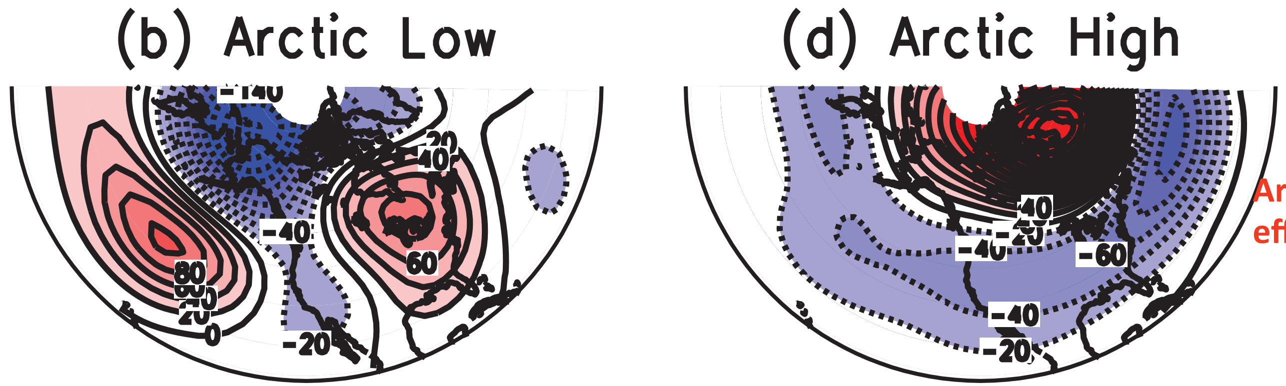


"PNA"-like

200 hPa Height Regime Maps from NCEP reanalysis 54 winters (1948/49 – 2001/2002)

6 EOFs retained - ~90% significant vis-à-vis multi-normal distribution (significance is about the same for 10 EOFs)

Choice of 4 regimes reasonable but not unique



Are boundary effects important?

CI: 20 m (blue negative, red positive)

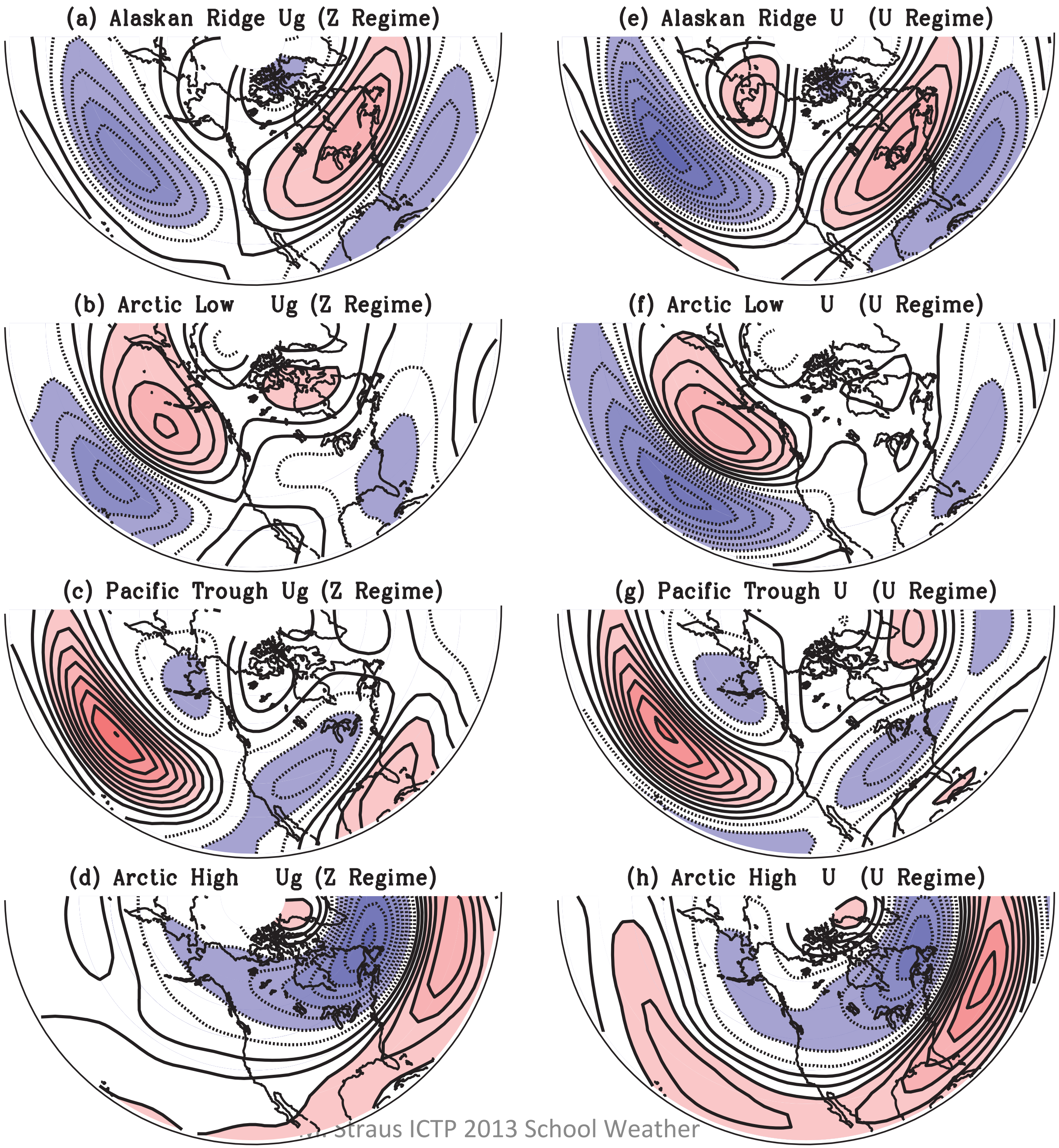
Consistency of Clusters

- **Compare geostrophic u-wind maps obtained from 200 hPa height regimes**

With

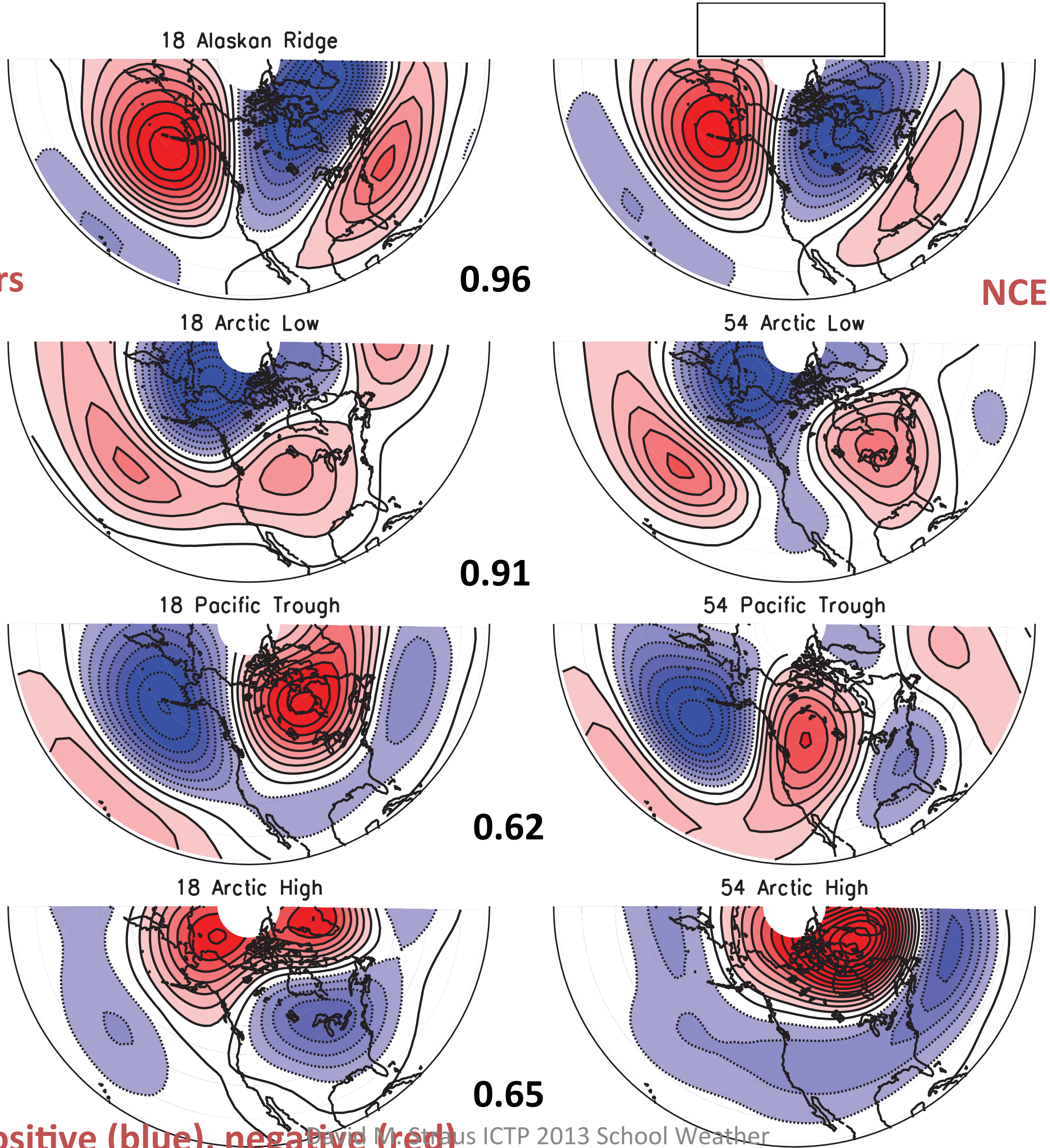
- **Regime maps obtained directly from 200 hPa u-wind fields**

- **Equivalent to using a different distance metric in phase space**


(a) Alaskan Ridge Ug (Z Regime)
(e) Alaskan Ridge U (U Regime)
(b) Arctic Low Ug (Z Regime)
(f) Arctic Low U (U Regime)
(c) Pacific Trough Ug (Z Regime)
(g) Pacific Trough U (U Regime)
(d) Arctic High Ug (Z Regime)
(h) Arctic High U (U Regime)

NCEP 18 winters

NCEP 54 winters

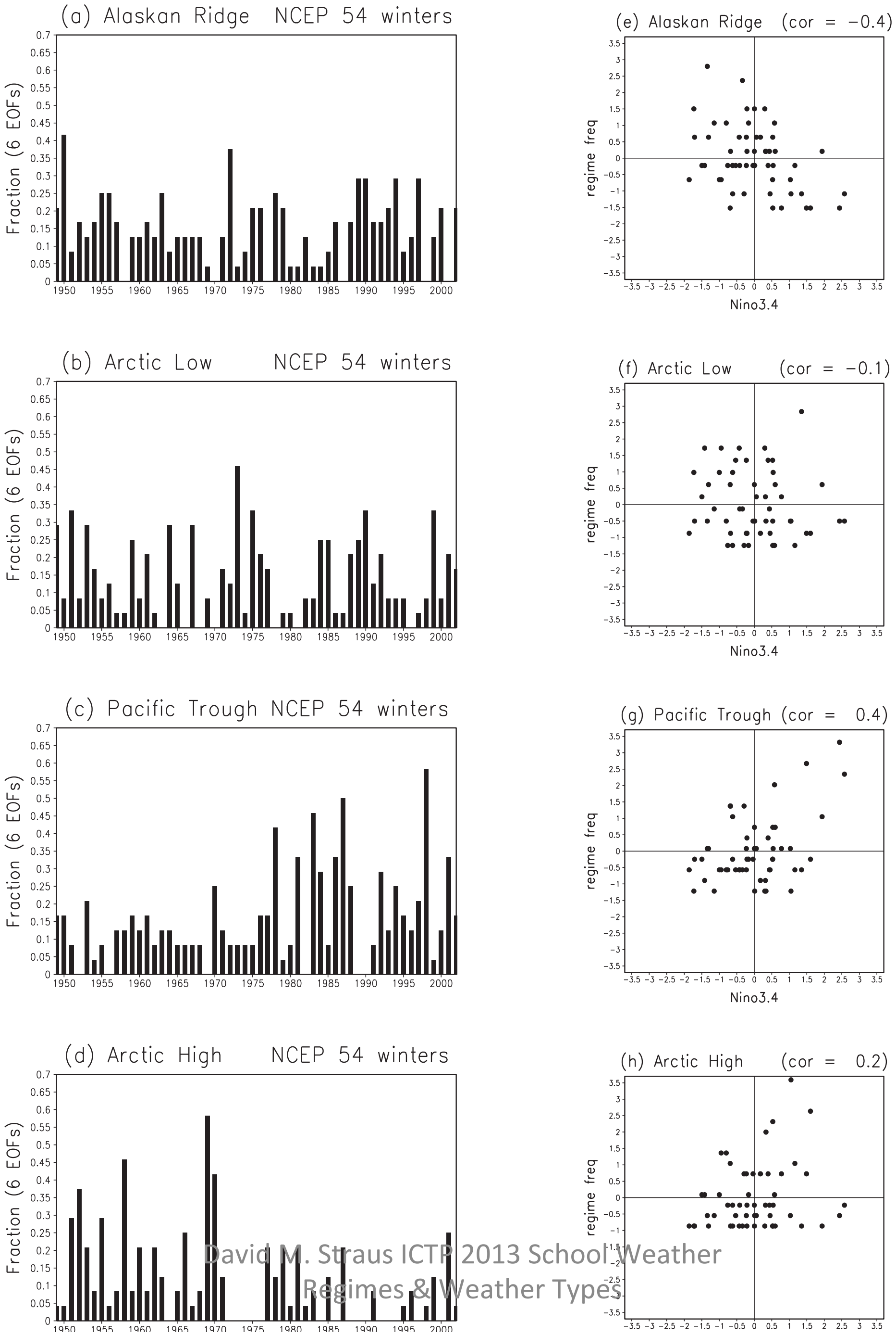


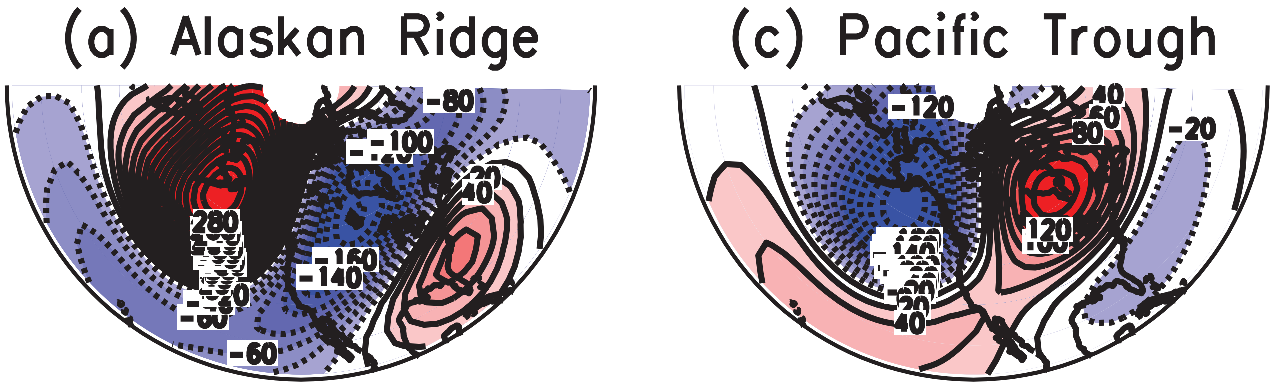
"TNH"

"PNA"

200 hPa Z

CI: 20m positive (blue), negative (red)


(a) Alaskan Ridge NCEP 54 winters
(b) Arctic Low NCEP 54 winters
(c) Pacific Trough NCEP 54 winters
(d) Arctic High NCEP 54 winters
Fraction (6 EOFs)
(e) Alaskan Ridge (cor = −0.4)
(f) Arctic Low (cor = −0.1)
(g) Pacific Trough (cor = 0.4)
(h) Arctic High (cor = 0.2)
regime freq
Nino3.4

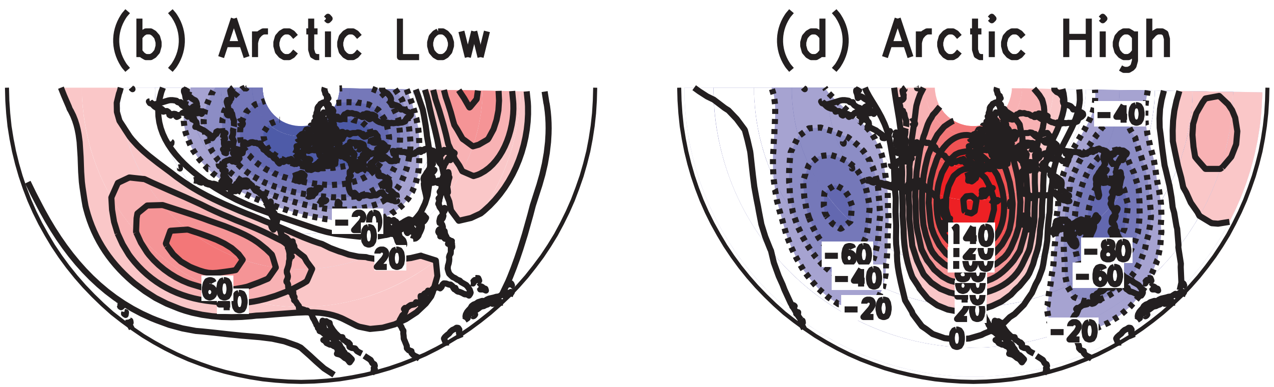


"TNH"

200 hPa Z Regime Maps from GCM Ensemble reanalysis for all simulations from 18 winters (1981/82 – 1998/99), the "Grand Ensemble"

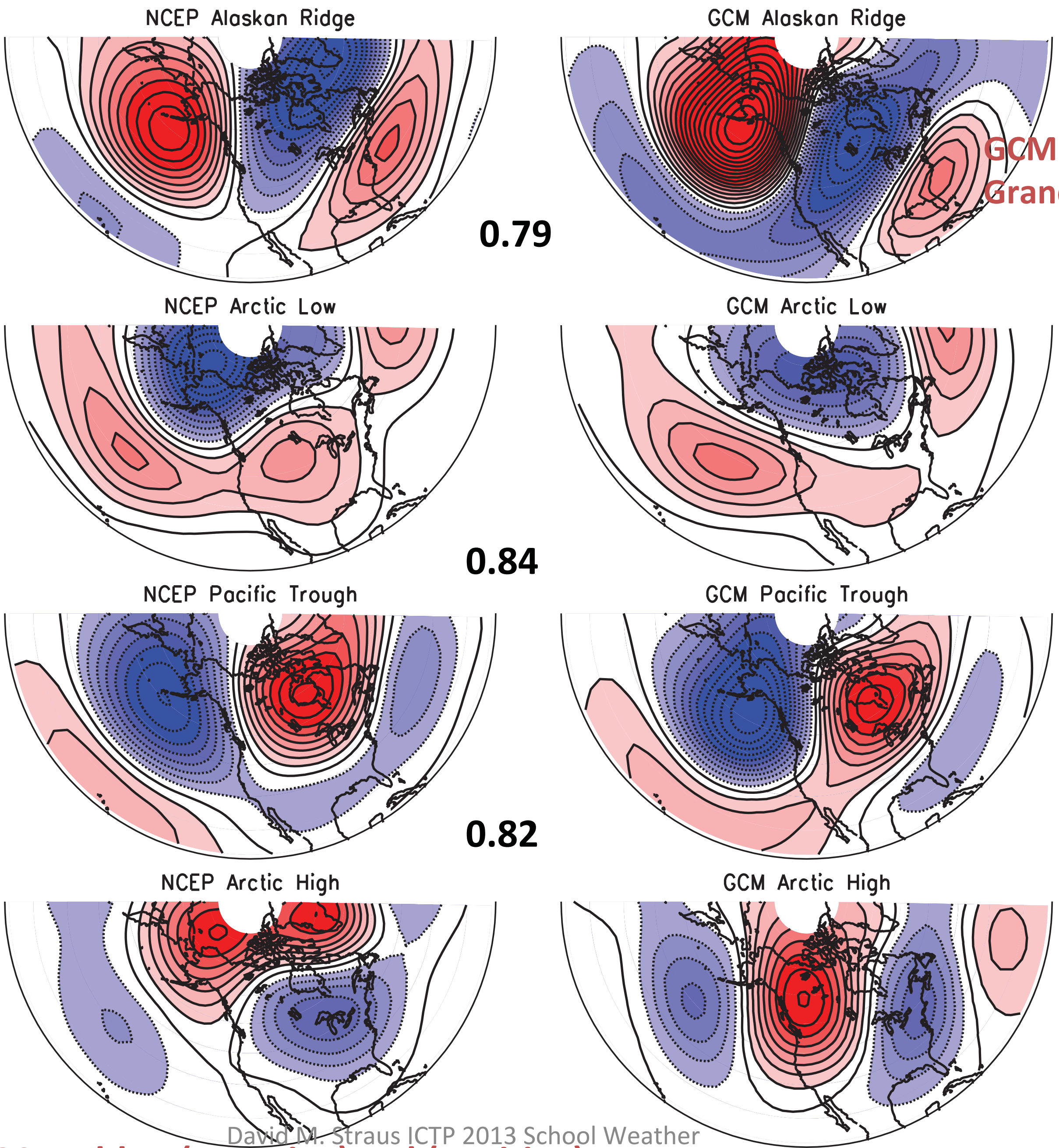
6 EOFs retained – virtually 100 % significant vis-à-vis multi-normal distribution (because of very large data sample)

Three of the Four Regimes are "quite similar" to observed



????

NCEP 18 winters



GCM:
Grand Ensemble

200 hPa Z CI:20 m blue (negative) red (positive)

NCEP-54 vs. NCEP-18 Regimes

- **Are the differences in regime patterns seen between the 54-year record of NCEP and the 18-year record of NCEP just due to internal variability ?**
- **"PNA" vs. "TNH"**
- **Or are they due to (tropical) SST forcing differences?**

Creating Synthetic Sampling Datasets from GCM Experiments

EXP18 dataset:

E(i,y) is time series of 96 GCM maps from ensemble member i, year y
y = 1, … , 18
i = 1, …, 55

Sample 1: 18 winters consisting of E(1,y) for y=1, …, 18
Sample 2: 18 winters consisting of E(2,y) for y=1, …, 18
…
Sample 55: 18 winters consisting of E(3,y) for y=1, …, 18

EXP54 dataset:

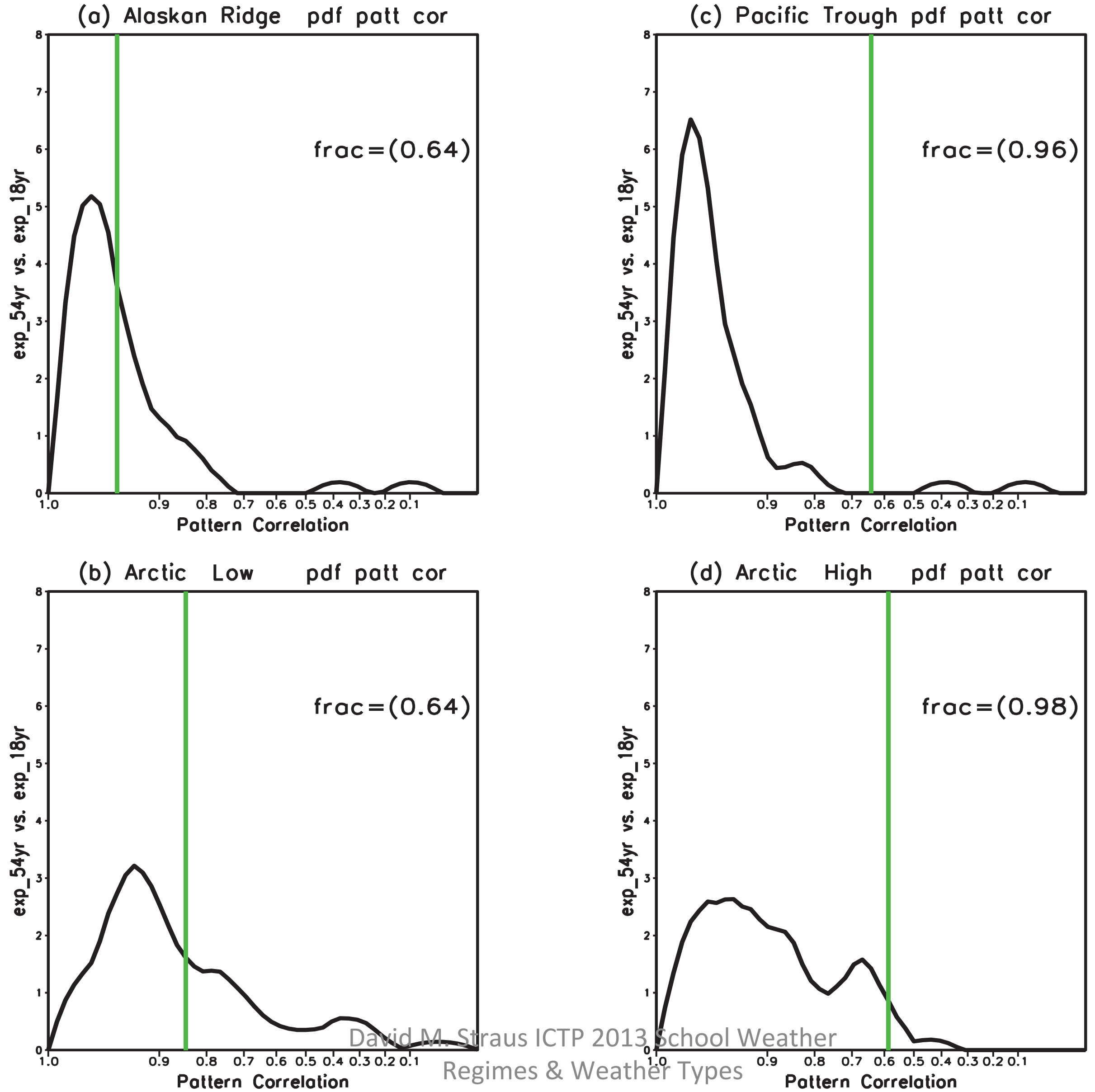
Sample 1: 54 winters: E(1,y) and E(r,y) and E(s,y) for y=1, … , 18
(r and s picked randomly)
Sample 2: 54 winters: E(1,y) and E(r,y) and E(s,y) for y=1, … , 18
(r and s picked randomly)
…
Sample 55: 54 winters: E(1,y) and E(r,y) and E(s,y) for y=1, … , 18
(r and s picked randomly)

NCEP-54 vs. NCEP-18 Regimes

- Construct 55 individual 18-year records from the GCM simulations, by choosing (for each record) one simulation per winter – each record is equivalent to the NCEP18-year reanalysis record. (**EXP-18 dataset**)
- For each of these 18-year records, choose two additional simulations per winter from the GCM simulations. This leads to a set of 55 individual 18 x 3 = 54 year records. (**EXP-54 dataset**)
- **Comparing EXP-18 and EXP-54 datasets, we have 55 samples of two datasets with the same SST forcing but different lengths.**
- From the cluster analyses on each of these samples, we can compute the pdf of pattern correlation of regimes between the 18-year vs. 54-year data sets – that is the pdf of pattern correlation due to sampling error alone.

PDFs of pattern correlation of EXP-18 vs. EXP-54 (sampling error)

Vertical line – pattern correlation of NCEP-18yrs vs. NCEP 54-years



Changes in Regime Patterns

- **The Pacific Trough and Arctic High show significant pattern differences between NCEP-18 year and NCEP-54 year records. These differences are therefore due to forcing, most likely SST-related forcing**

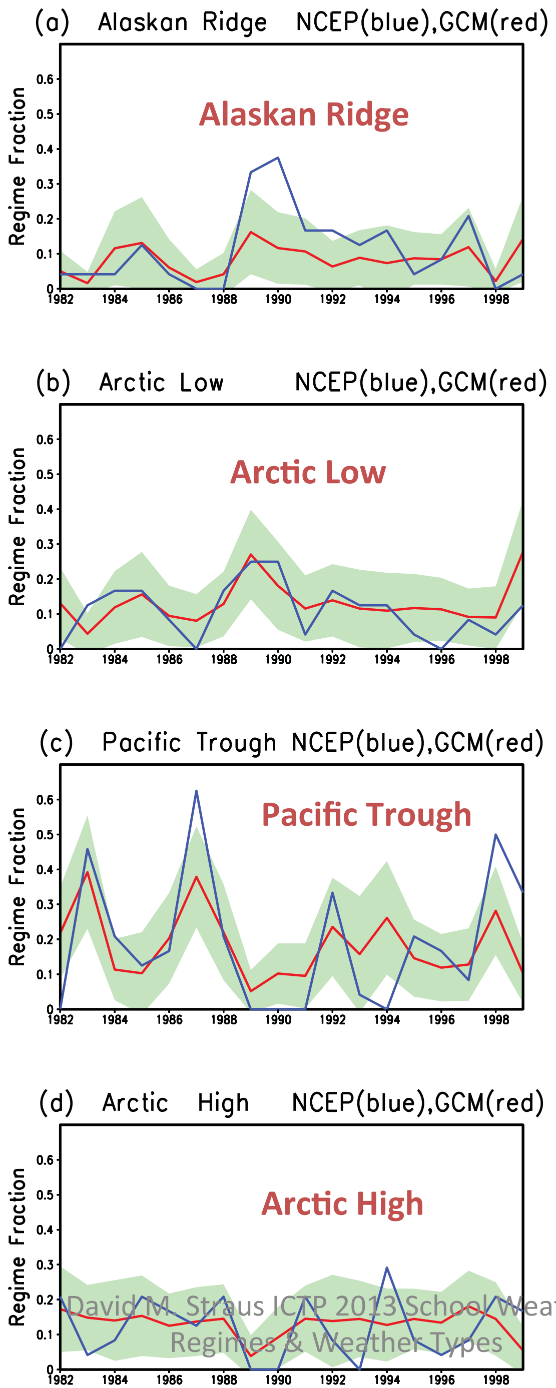
- **The Alaskan Ridge and Arctic Low are consistent (within sampling error) for the 54-year and 18-year record**

- **Difference between more recent NCEP-18 year "TNH" version of the Pacific Trough and the "PNA" NCEP-54 year version are consistent with studies of recent ENSO responses** (Straus and Shukla, 2002)

Blue lines: NCEP-18 time series of frequency of occurrence for each cluster for 18 years

Red lines: Grand Ensemble time series of frequency of occurrence for each cluster for 18 years

Green shading: +/- one standard deviation



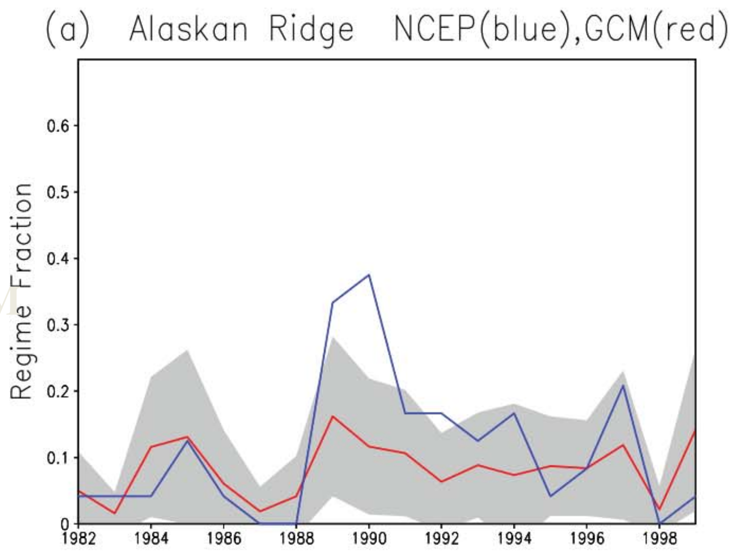
Alaskan Ridge (Pacific Blocking) underestimated by GCM, but in most years not significantly.

Pacific Trough response to El-Nino underestimate by the GCM for big events

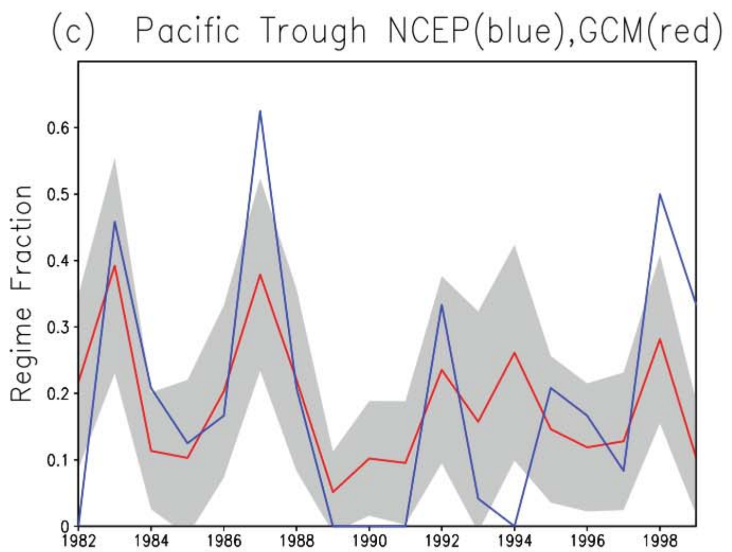
Red line: GCM

Blue line: NCEP

Gray: intra-ensemble σ in GCM



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!*



Conclusions

Difference between the Pacific Trough regime pattern in NCEP 18 and NCEP 54 (TNH vs. PNA) is outside range of internal variability – caused by SST forcing

Year-to-year variability in regime frequency is largely reproducible on the basis of SST only (with a good GCM).