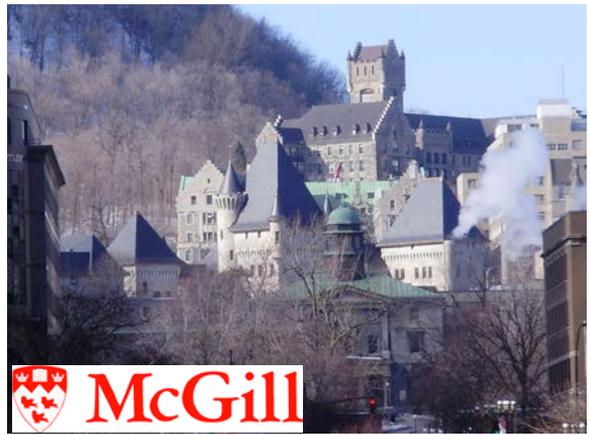
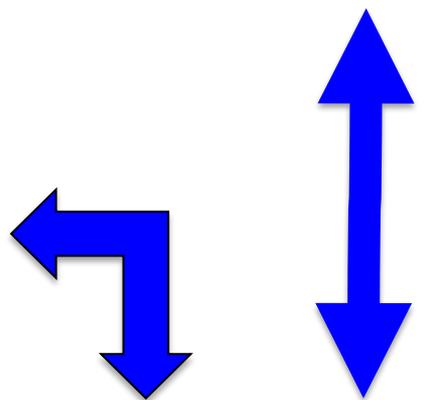
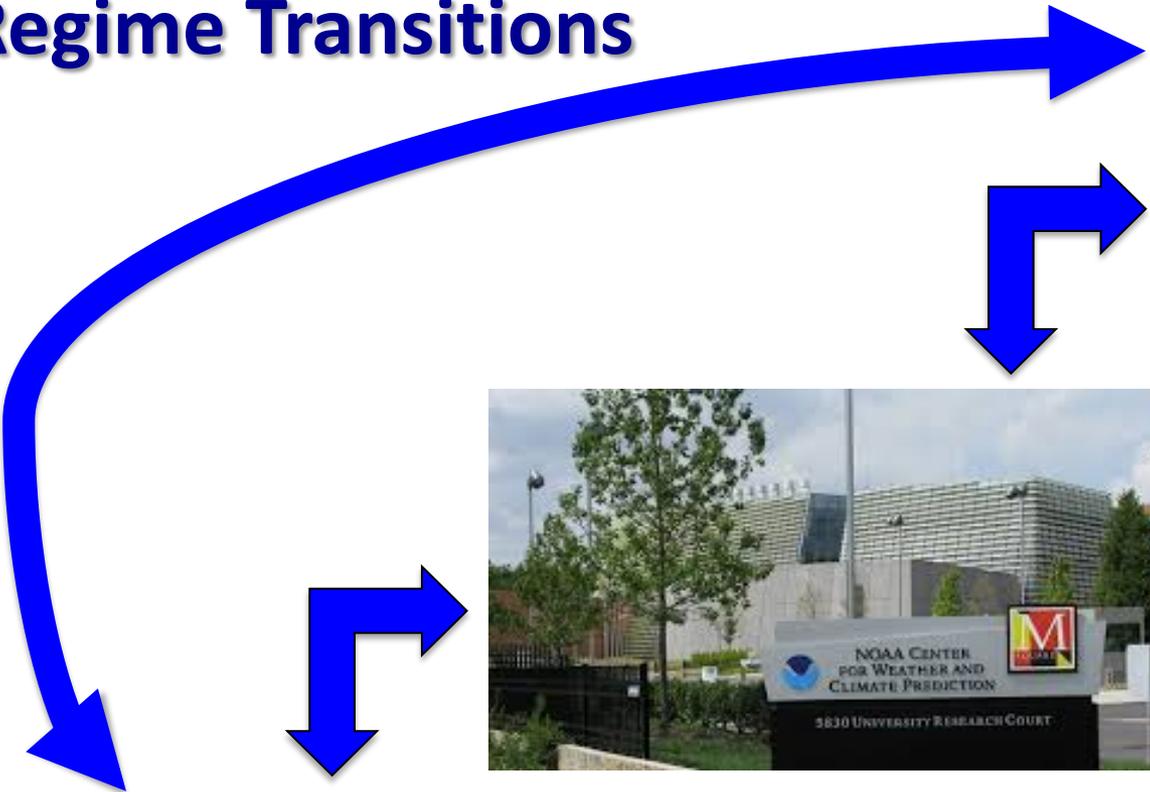
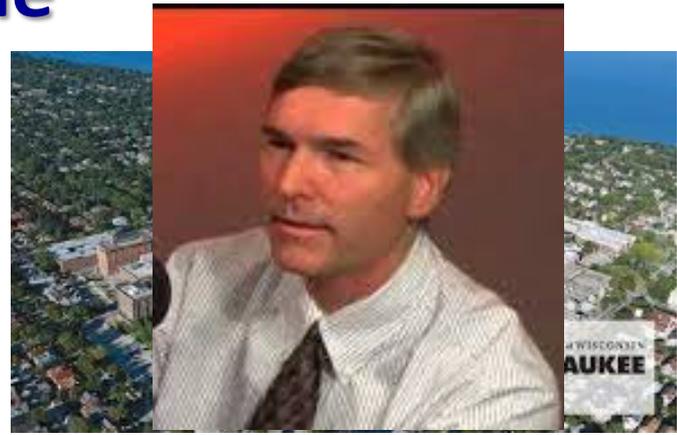
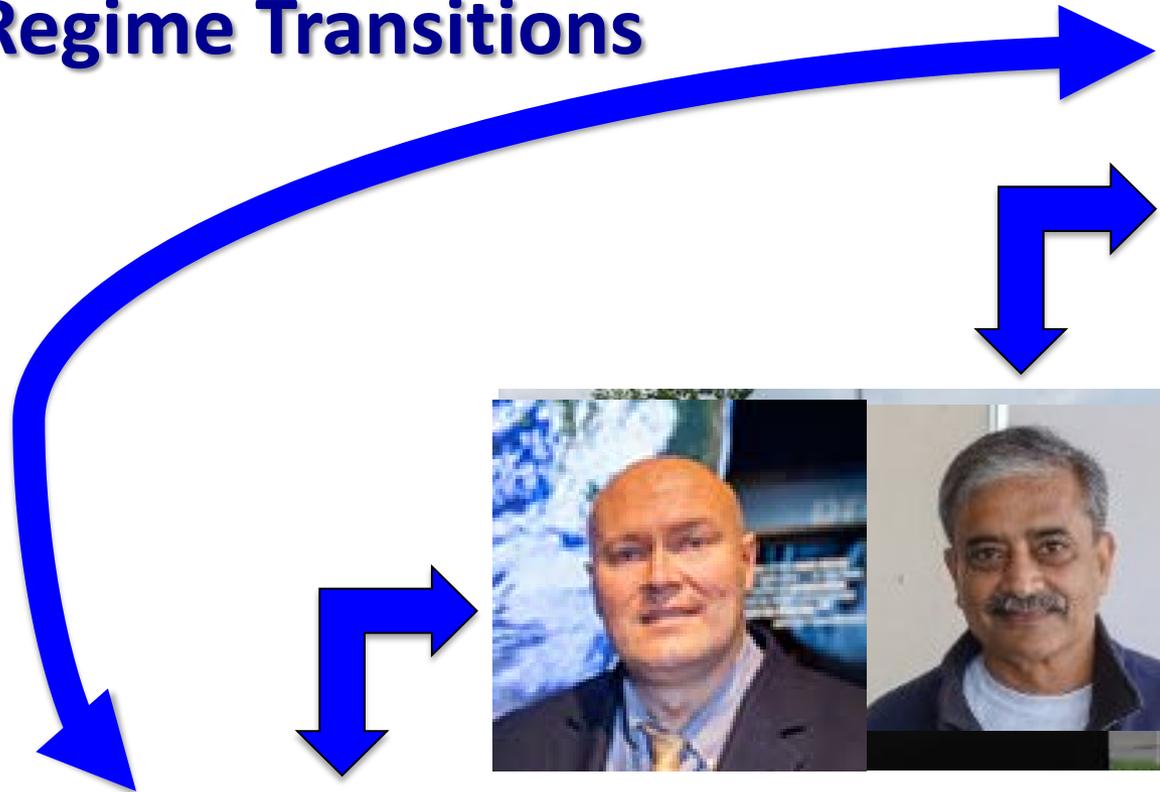


Improving Prediction of Large-scale Regime Transitions



Improving Prediction of Large-scale Regime Transitions

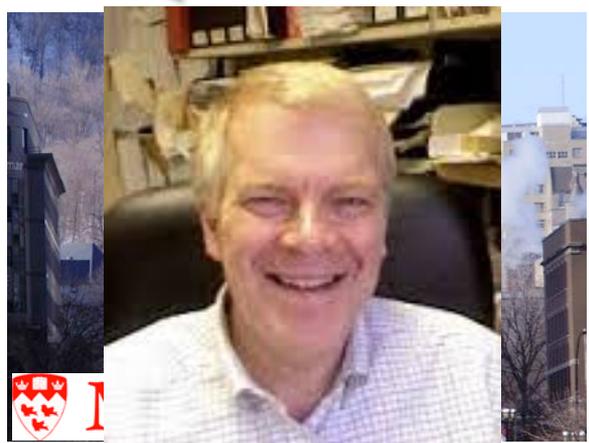
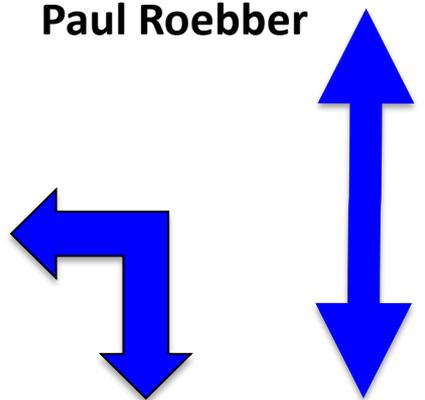


Paul Roebber



Dave Dewitt

Arun Kumar



John Gyakum



Lance Bosart

UWM

MS student Andrea Honor (completed June 2018)

University at Albany

MS student Eric M. Bunker (defending August 2018)

McGill University

Investigators: Yi Huang, Eyad Atallah

Jamie Hart (incoming senior undergraduate)

Yeechian Low (incoming senior undergraduate)

Note: 7 refereed publications/theses and two current graduate student theses in progress



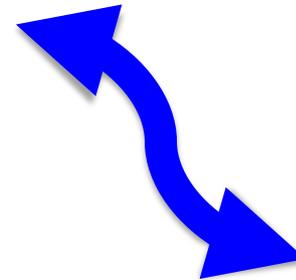
- Spatiotemporal distribution of cyclone clustering
- Influences of atmospheric blocking and phases/amplitudes of the major teleconnection indices, ENSO and the MJO
- Composite/case study analyses of cyclone clustering events
- regime change predictability horizons associated with cyclone clustering events;



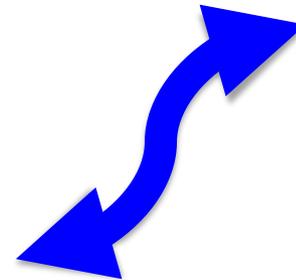
- Weather regime classification & transition probabilities
- CFSv2 model climate, integration



- Weather regime classification
- Arctic air mass generation and modification
- life cycles of the MJO
- Poleward heat and moisture transports of subtropical air masses



• Multiscale & multi-institutional process integration -> weeks 1-4 prediction tool



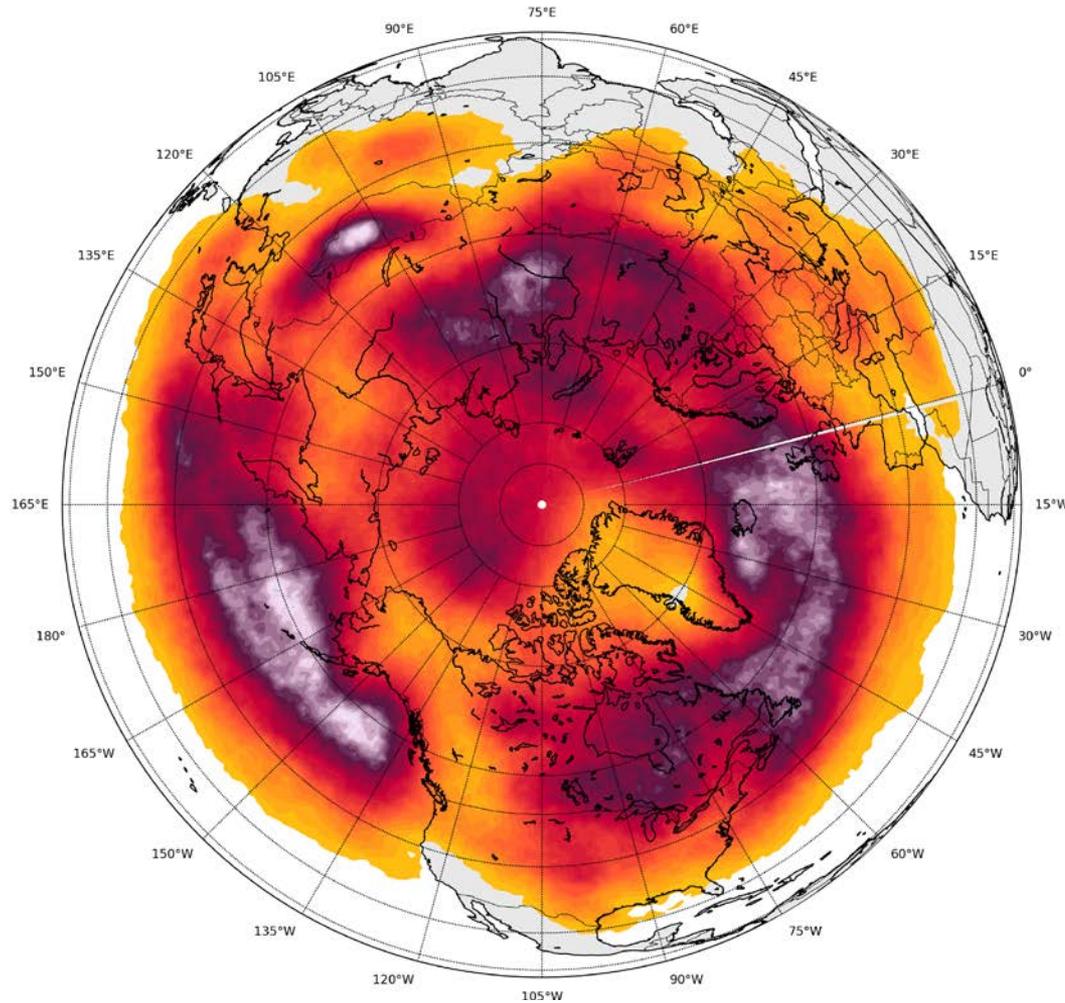


Cyclone Clustering - SUNYA

- Northern Hemisphere atmosphere predictability on sub-seasonal time scales (1–4 weeks) depends significantly on the structure, position, and evolution of the North Pacific Jet Stream (NPJ) waveguide.
- The susceptibility of the NPJ to external perturbations is a function of the phase and amplitude of ENSO on interannual time scales, the phase and amplitude of the MJO on subseasonal time scales, and the frequency of transient tropical, midlatitude, and polar disturbances that interact with the NPJ on synoptic time scales.
- NPJ waveguide perturbations can result in the formation of downstream propagating Rossby wave trains including clustered cyclone events that may lead to extreme weather event (EWE) occurrences.
- Selected persistent large-scale circulation regimes may be especially conducive to the occurrence of clustered cyclone events and EWEs.

Cyclone clustering (ERA-Interim; Hodges)

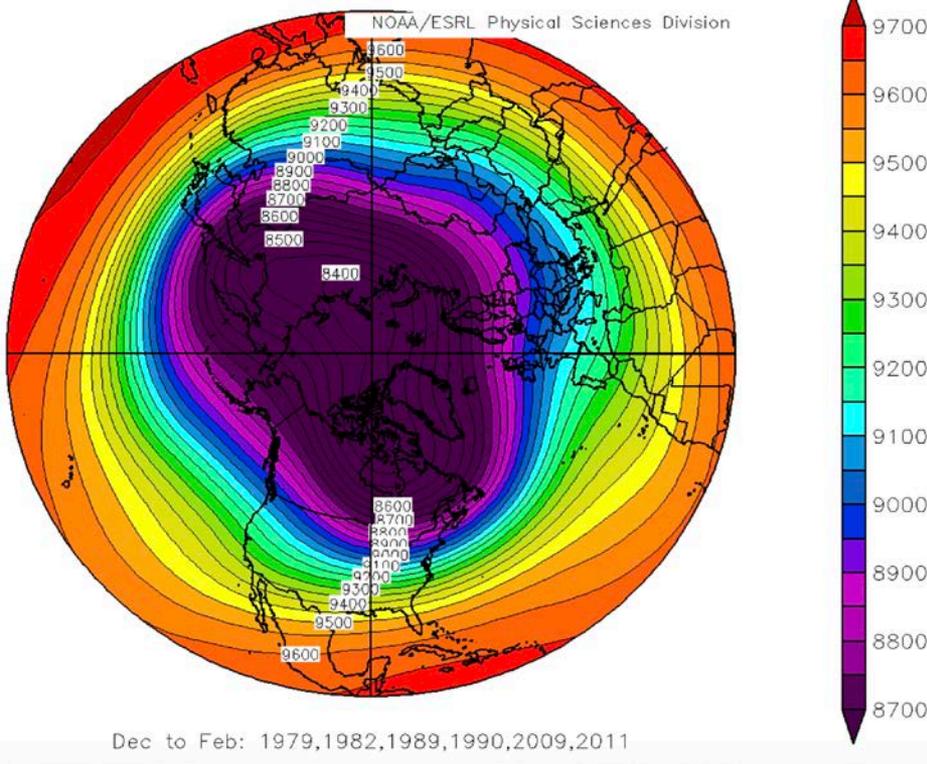
Frequency and distribution of cyclone cluster events associated with large-scale flow patterns is contingent upon the orientation and position of the midlatitude jets over the ATL and PAC.



Average cyclone clusters for 1979–2014

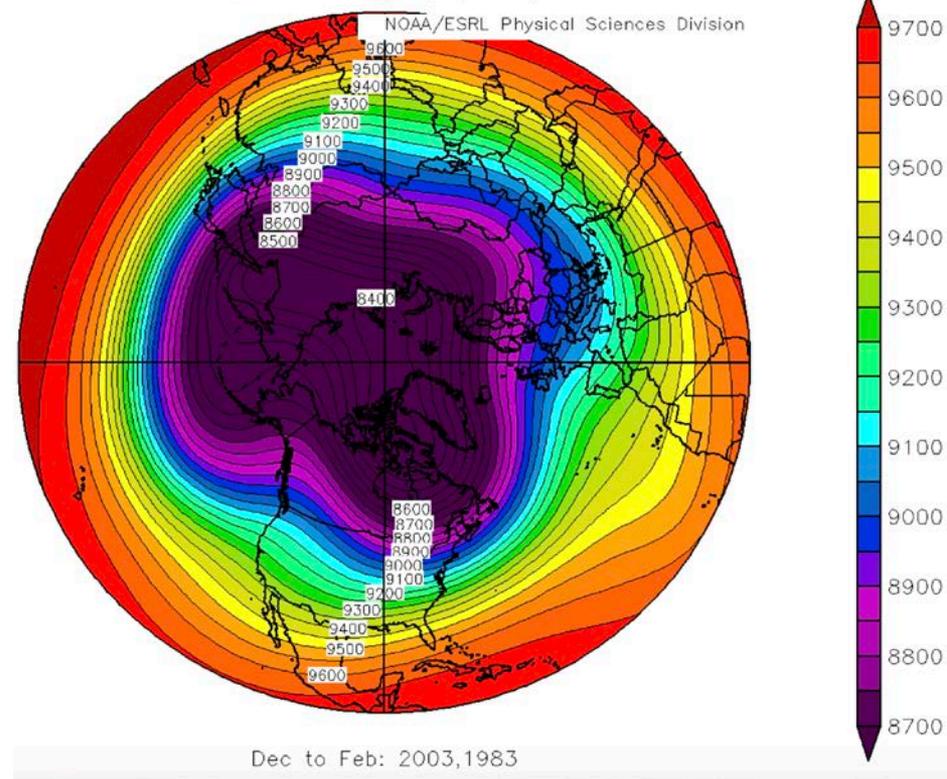
Cyclone Clusters Vs. PNA

NCEP/NCAR Reanalysis
300mb Geopotential Height (m) Composite Mean



PNA of (≤ -1)

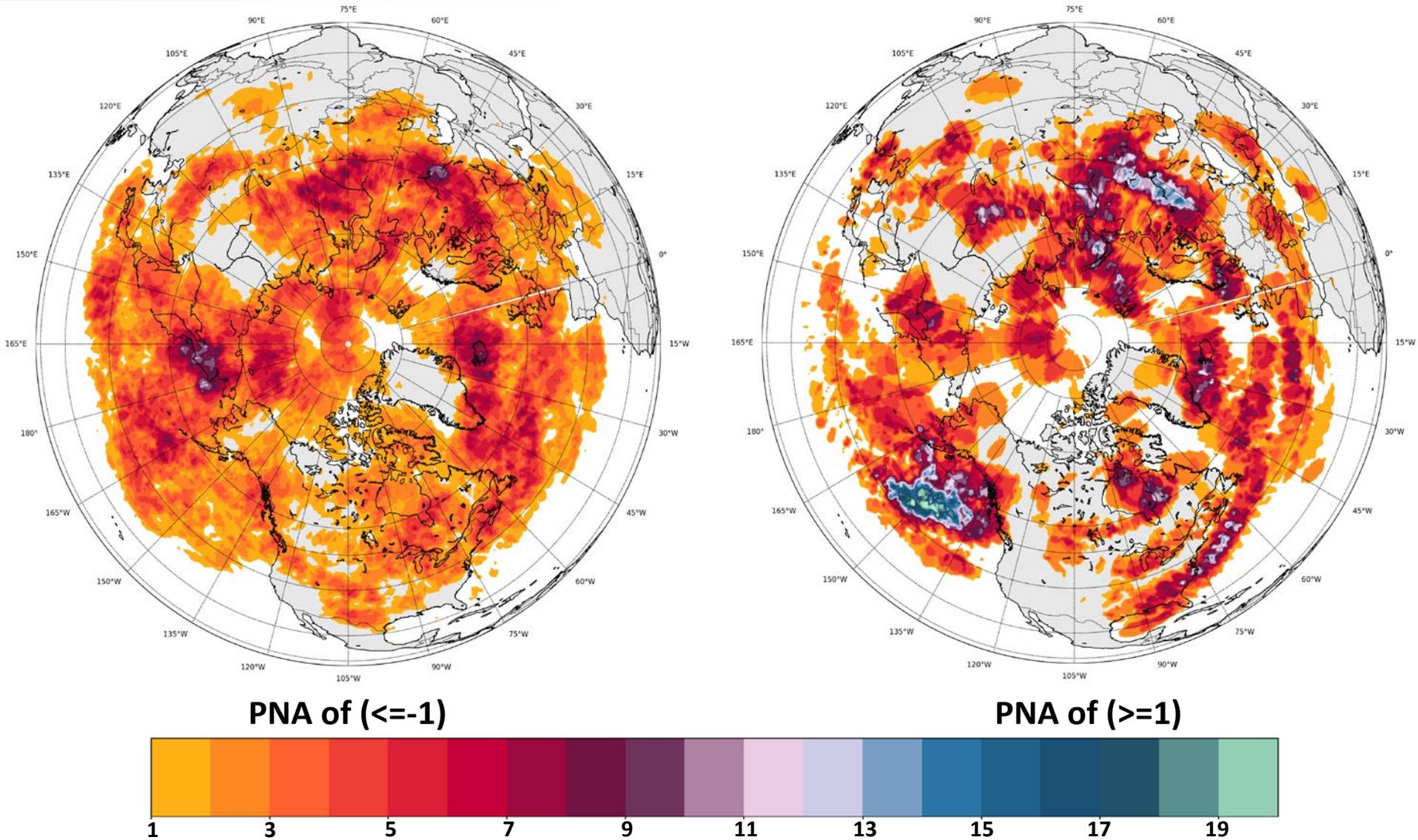
NCEP/NCAR Reanalysis
300mb Geopotential Height (m) Composite Mean



PNA of (≥ 1)

Composite mean 300-hPa heights (m) for negative PNA (left) and positive PNA (Right)

Cyclone Clusters Vs. PNA

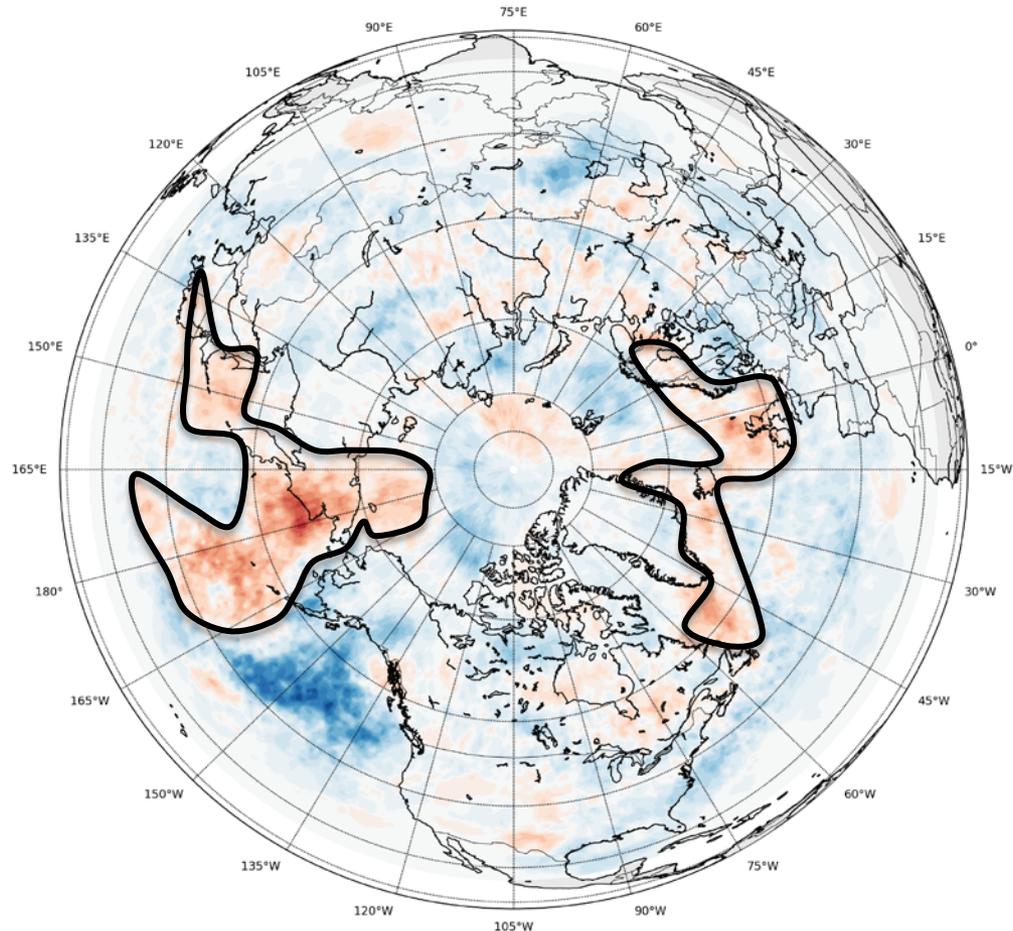


Average DJF PNA value of (≤ -1) (left) and (≥ 1) (right) of two or more clustered cyclones

Cyclone Clusters Vs. PNA

clusters form in favored northerly track across the ATL and in the central N PAC during neg PNA phase.

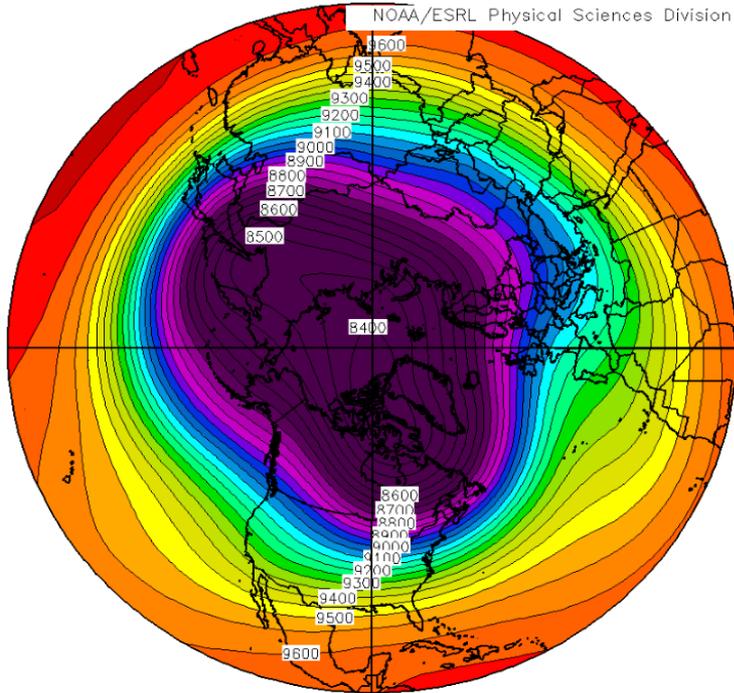
clusters form in favored southerly track across the ATL and in the Gulf of Alaska during pos PNA phase.



Difference between positive PNA and negative PNA

Cyclone Clusters Vs. Oceanic Nino Index

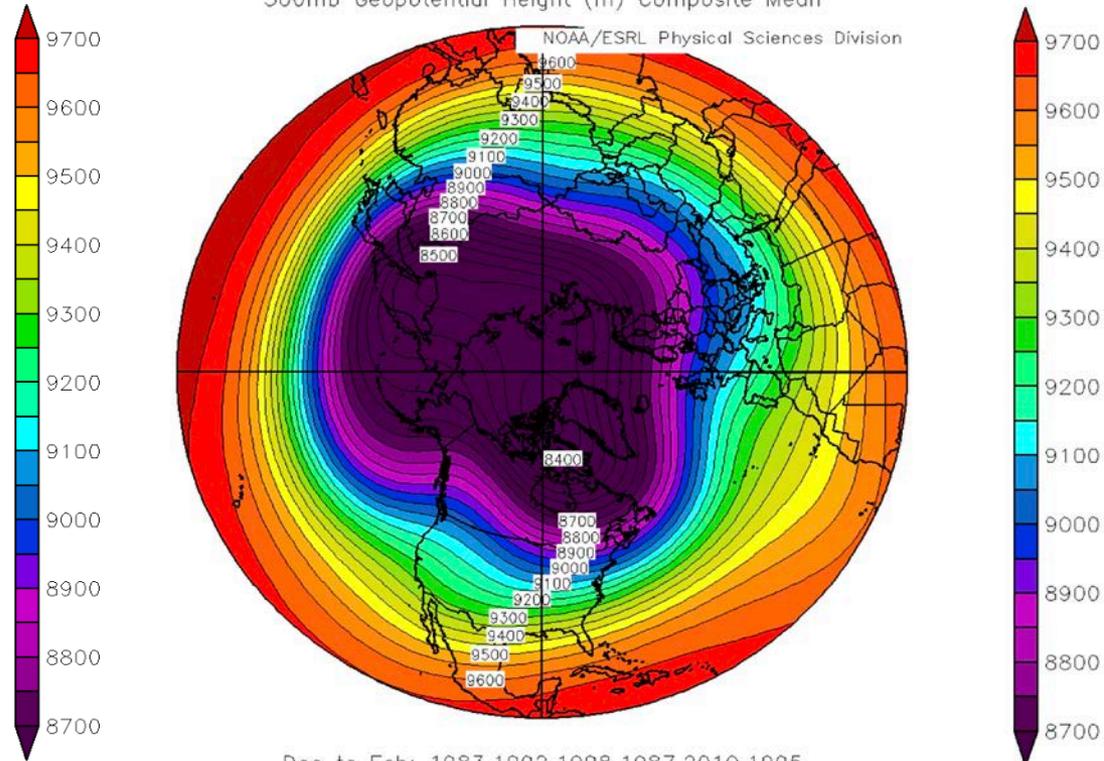
NCEP/NCAR Reanalysis
300mb Geopotential Height (m) Composite Mean



Dec to Feb: 1985,1989,1999,2000,2008,2011

ONI of (≤ -1)

NCEP/NCAR Reanalysis
300mb Geopotential Height (m) Composite Mean

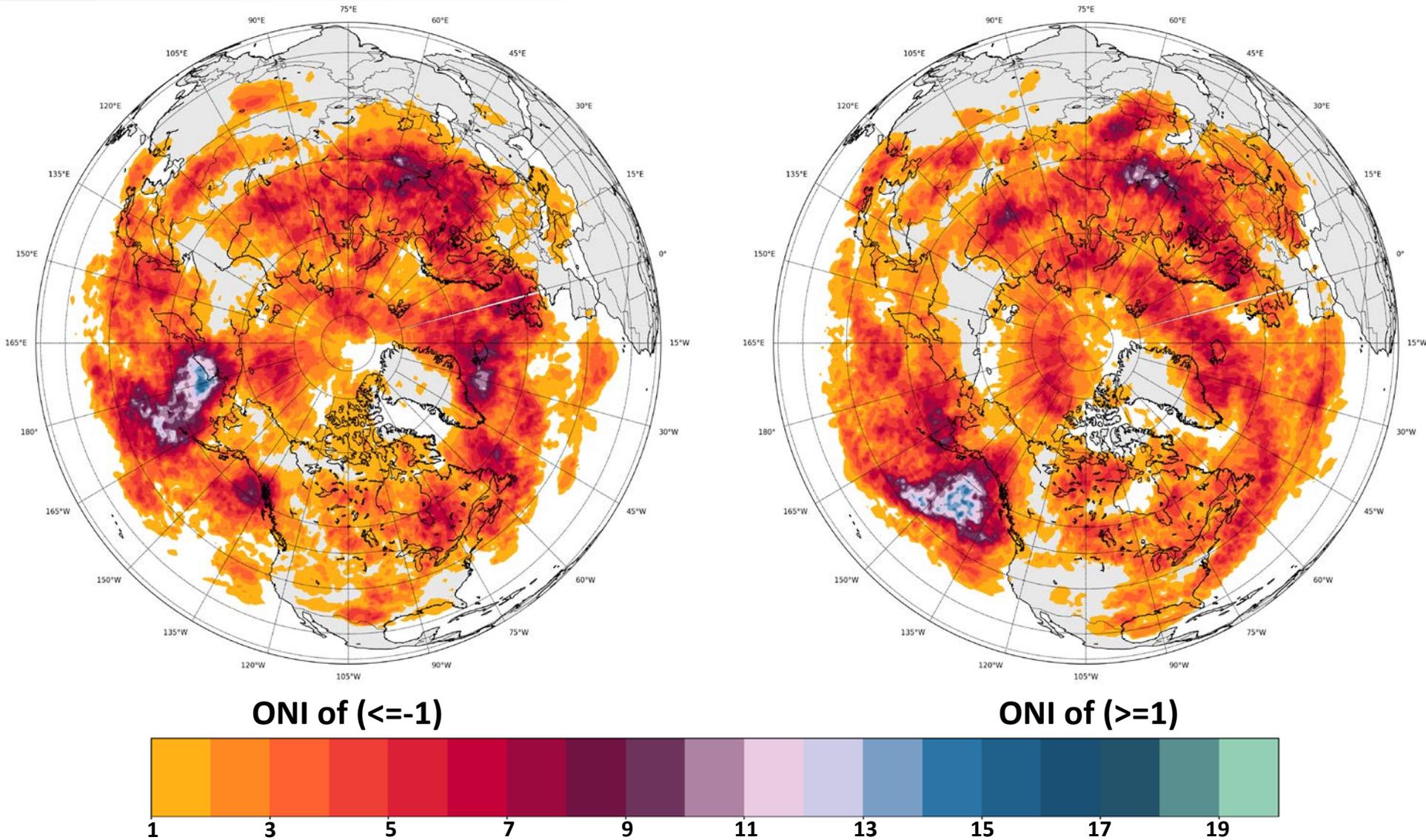


Dec to Feb: 1983,1992,1998,1987,2010,1995

ONI of (≥ 1)

Composite mean 300-hPa heights (m) for negative ONI (left) and positive ONI (Right)

Cyclone Clusters Vs. Oceanic Nino Index



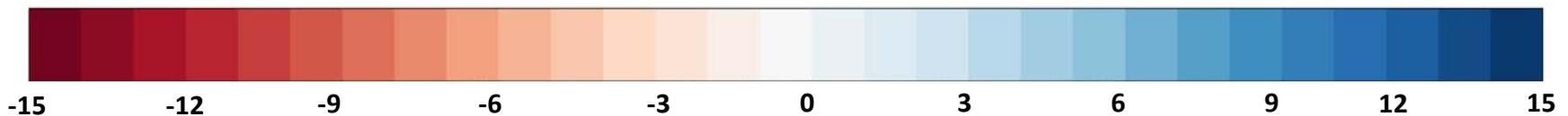
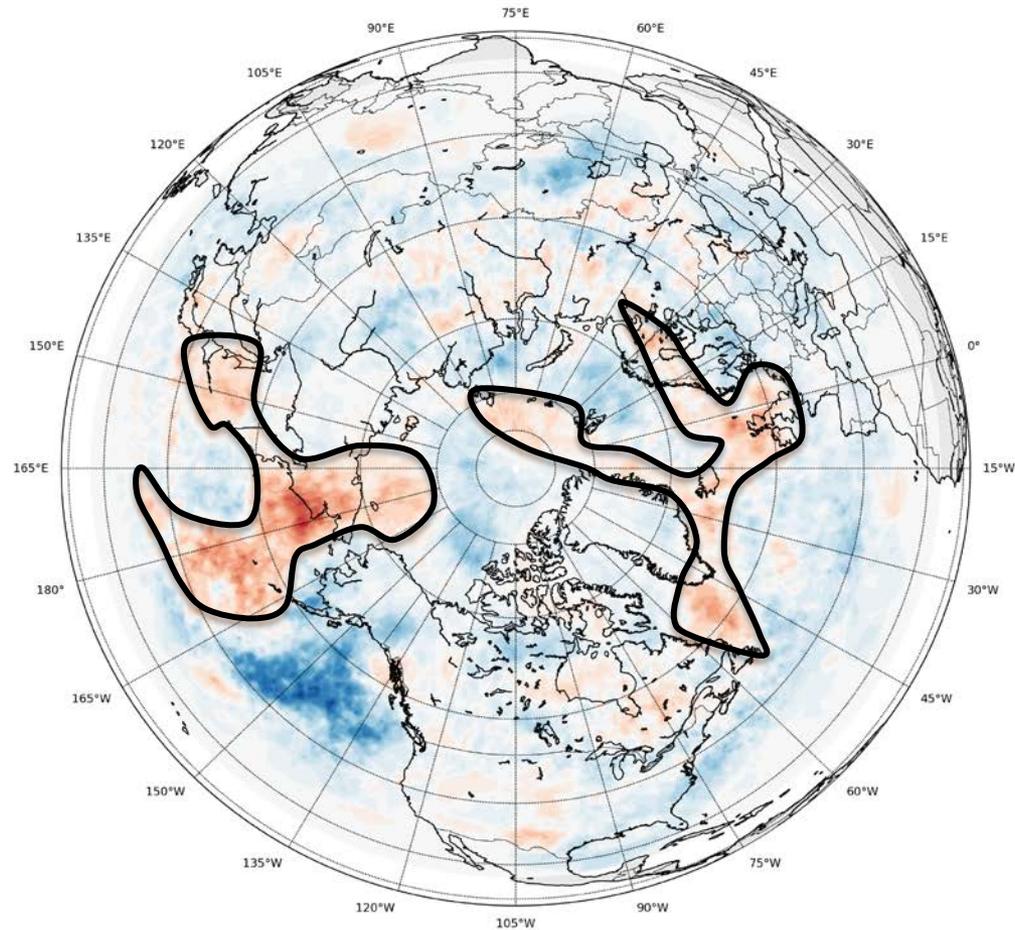
Average DJF ONI value of (≤ -1) (left) and (≥ 1) (right) of two or more clustered cyclones

Cyclone Clusters Vs. Oceanic Nino Index

clusters favor NE
PAC and NE ATL
during El-Nino years.

clusters occur
preferentially along
a southern storm
track over North
America during El-
Nino years.

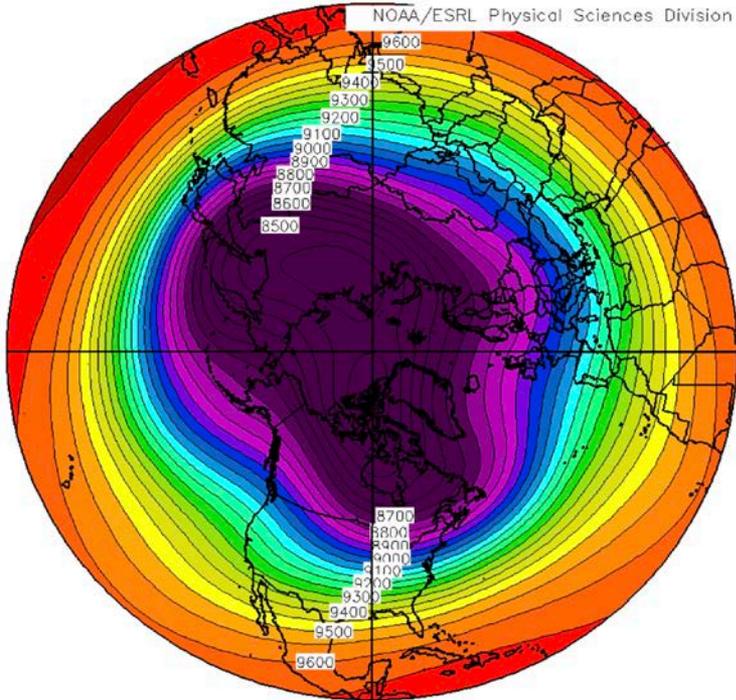
clusters favor north-
central PAC and
north-central ATL
during La-Nina
years.



Difference between positive ONI and negative ONI

Cyclone Clusters Vs. NAO

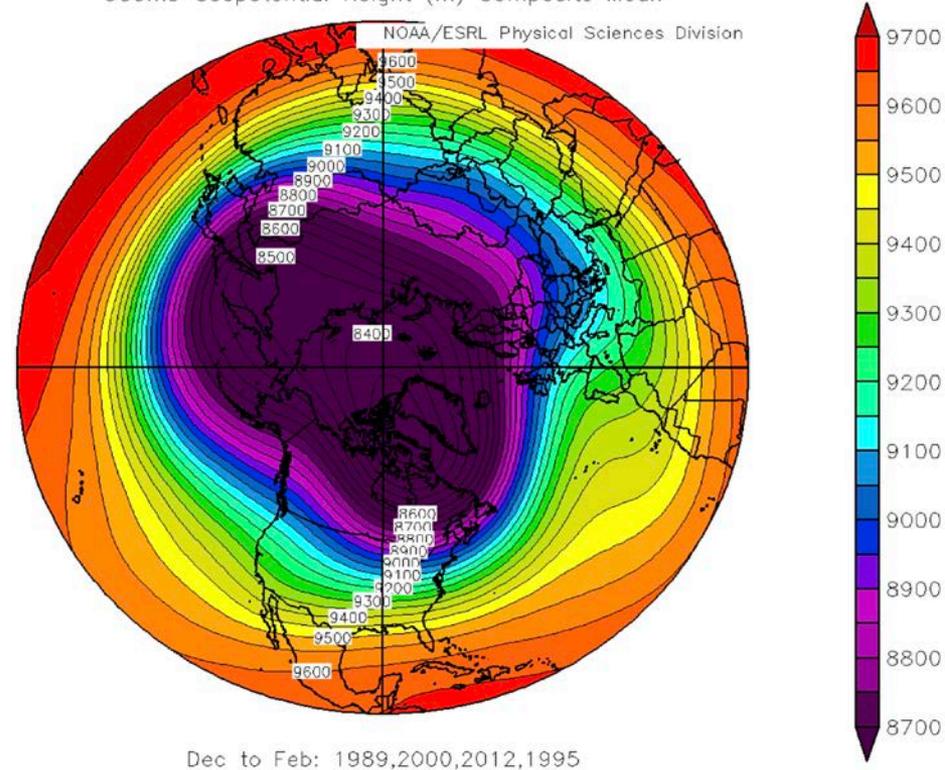
NCEP/NCAR Reanalysis
300mb Geopotential Height (m) Composite Mean



Dec to Feb: 1979,1985,2010,2011

NAO of (≤ -1)

NCEP/NCAR Reanalysis
300mb Geopotential Height (m) Composite Mean

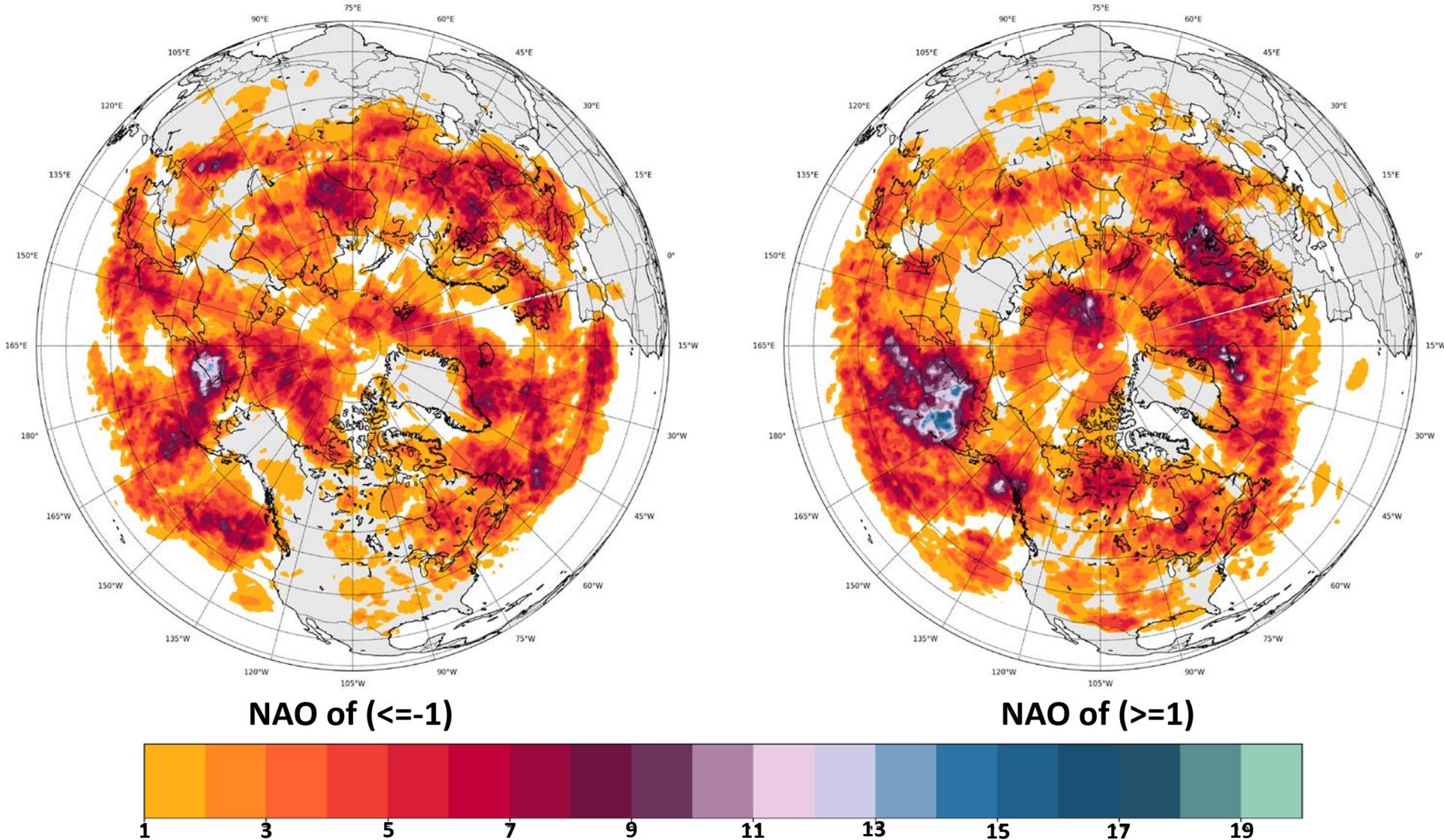


Dec to Feb: 1989,2000,2012,1995

NAO of (≥ 1)

Composite mean 300-hPa heights (m) for negative NAO (left) and positive NAO (Right)

Cyclone Clusters Vs. NAO

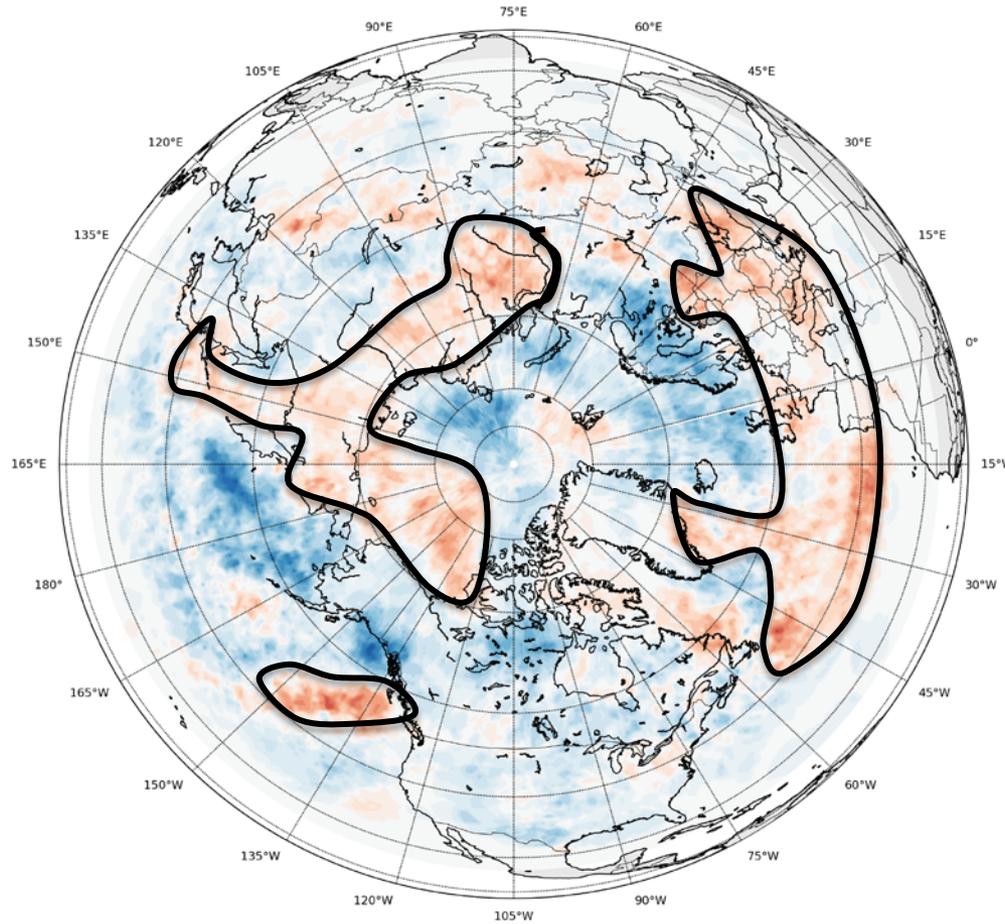


Average DJF NAO value of (≤ -1) (left) and (≥ 1) (right) of two or more clustered cyclones

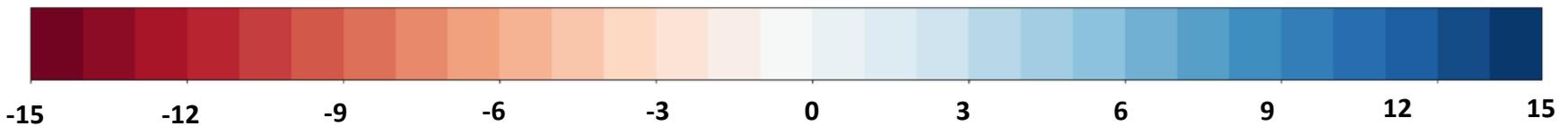
Cyclone Clusters Vs. NAO

clusters during both pos and neg NAO phases favor the north-central PAC.

clusters form in favored southerly track across the ATL and northerly track across the PAC during negative NAO phase.



clusters form in favored northerly track across the ATL and southerly track across the PAC during positive NAO phase.



Difference between positive NAO and negative NAO



Regime classifications and prediction

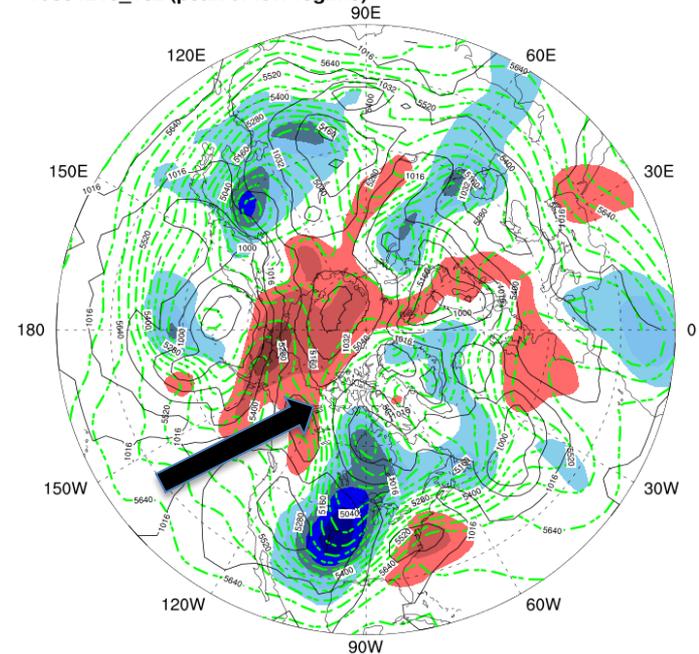
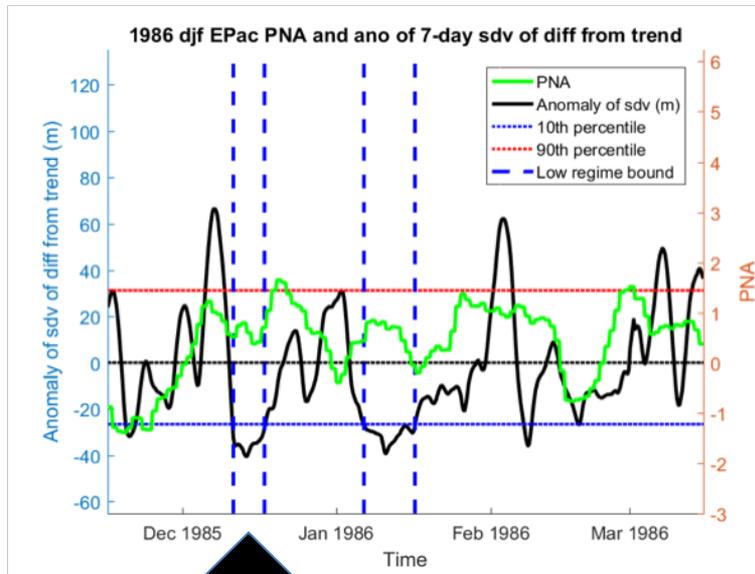
- Define a regime-based metric
- Assess this regime-based metric's relevance to extreme sensible weather over North America
- Identify state-of-the-art prediction capability at short- and medium ranges

Low-variance regime example

The cold-season of 1985-86

1800 UTC, 13 December 1985

1000-500 hPa thickness and anomaly (m) and sea-level pressure (hPa)
19851213_18z (peak of low regime)

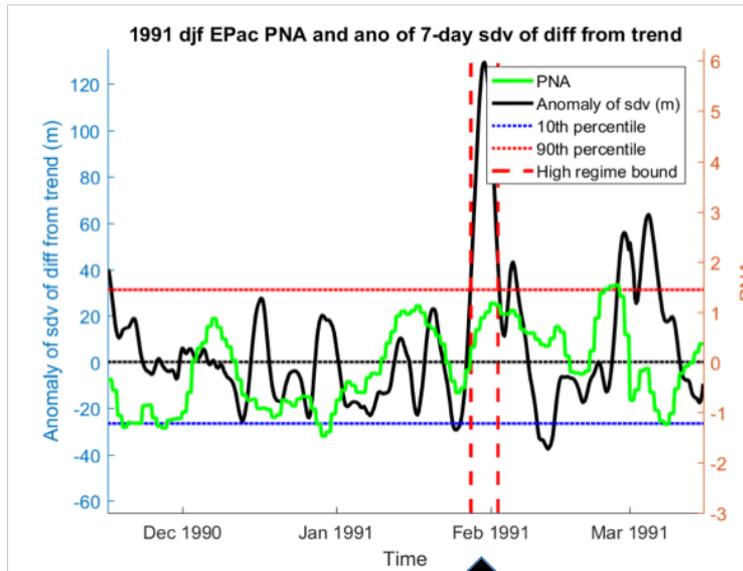


**Low-variance regime of December 1985 (a pineapple express case);
Roberge et al. 2009**

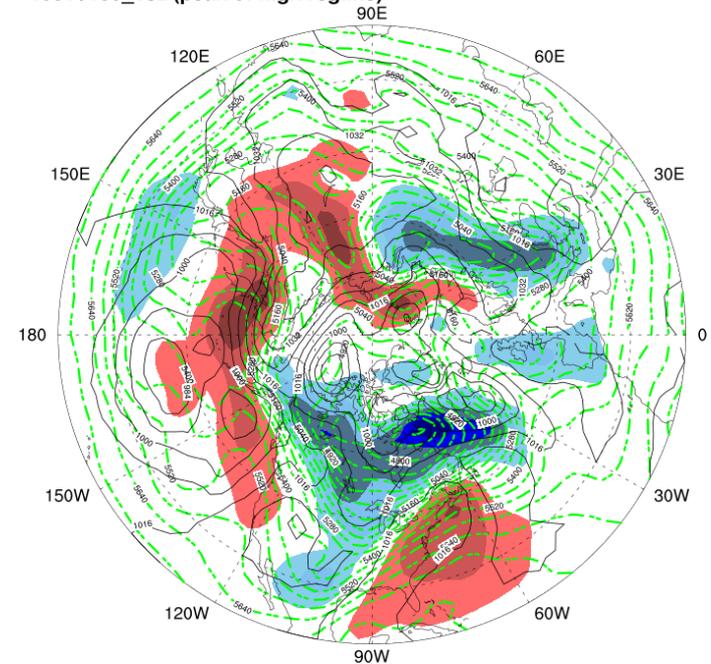
High-variance regime example

The cold season of 1990-91

1800 UTC, 30 January 1991



1000-500 hPa thickness and anomaly (m) and sea-level pressure (hPa)
19910130_18z (peak of high regime)



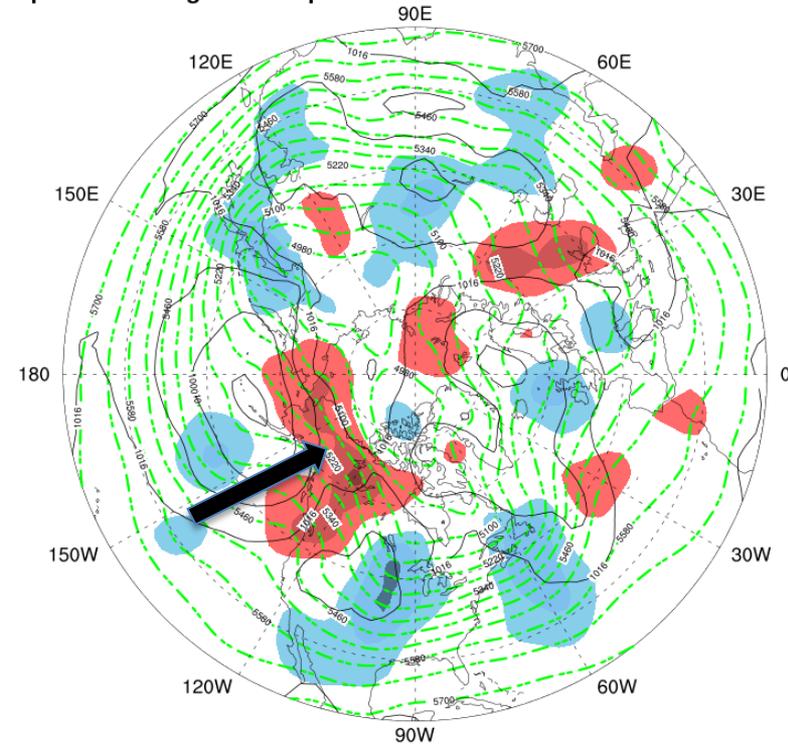
High-variance regime case of Jan-Feb 1991

Extreme Precipitation

Pineapple express/atmospheric rivers (*low variance*)

1. Roberge et al. (2009): four cases
2. Lackmann et al. (1998): one case
3. Lackmann et al. (1999): one case (17-18 Jan. 1986)
4. Turner and Gyakum (2011): one case of Arctic air mass generation

1000-500 hPa thickness and anomaly (m) and sea-level pressure (hPa)
peak of low regimes composite



-140 -120 -100 -80 -60 -40 -20 20 40 60 80 100 120 140

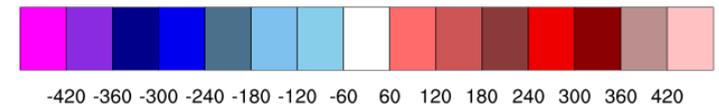
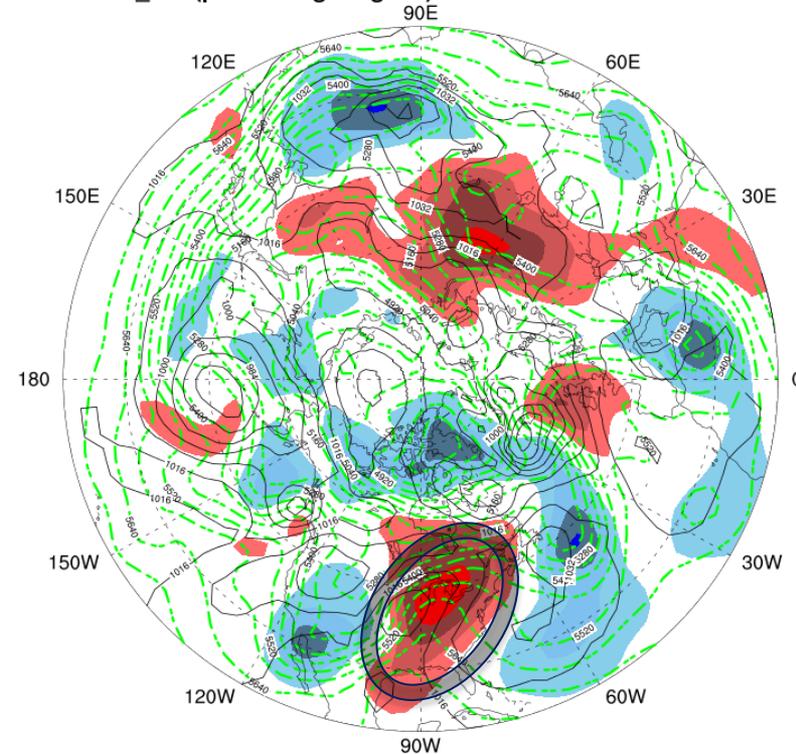
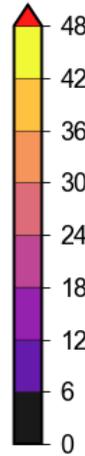
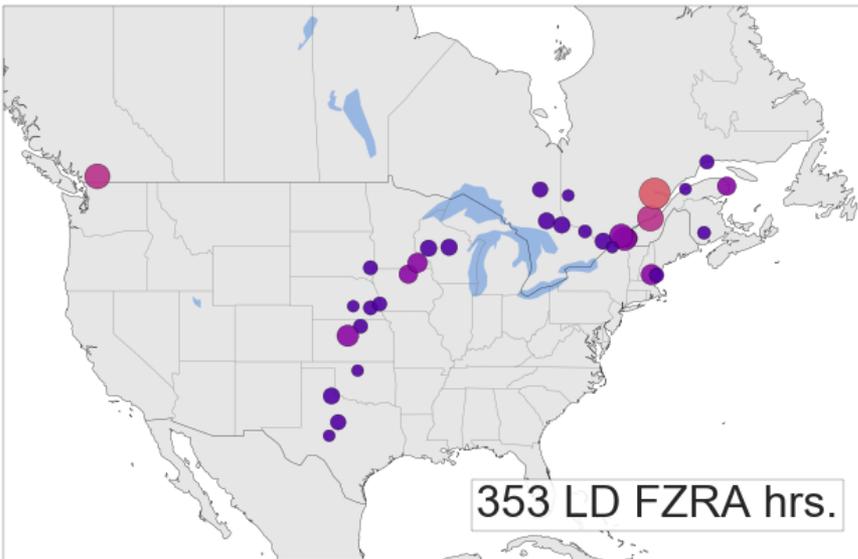
Low-variance regimes (composite;
18 cases; SLP and 1000-500 hPa
thickness anomaly)

Extreme Precipitation

Long-duration freezing rain events (*high variance*)

1000-500 hPa thickness and anomaly (m) and sea-level pressure (hPa)
19821225_06z (peak of high regime)

19821223/22z-19821229/10z



McCray (2018) case of long-duration freezing rain events (Dec. 82)

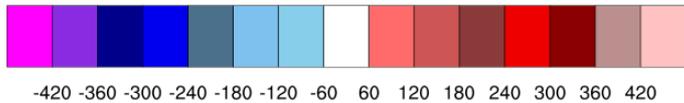
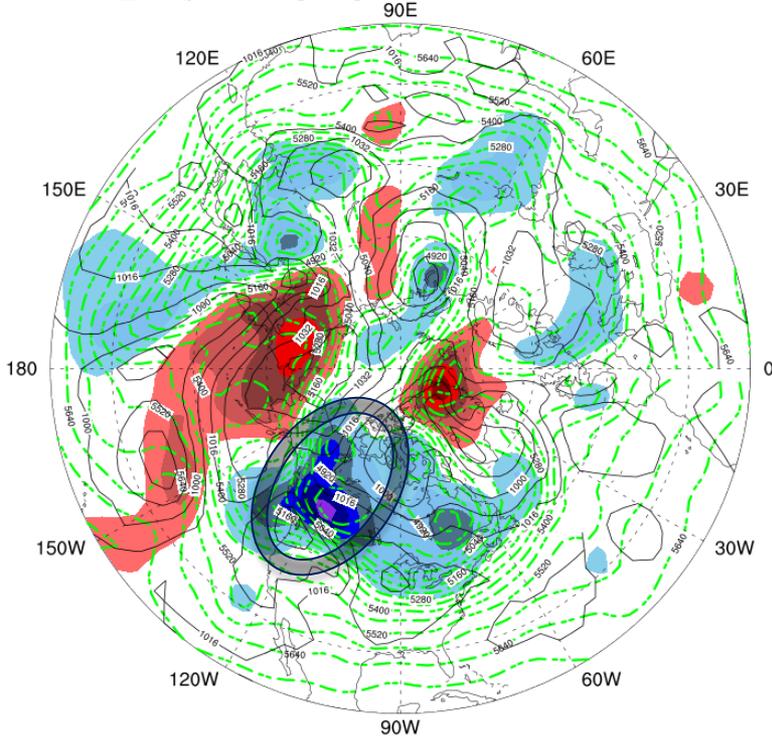
Wood (2015) case of extreme 850-hPa equivalent potential temperature

0600 UTC, 25 December 1982; peak of high-variance regime

Extreme temperatures

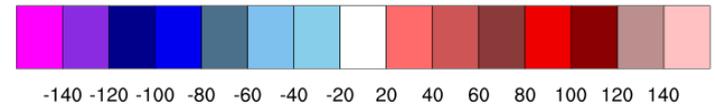
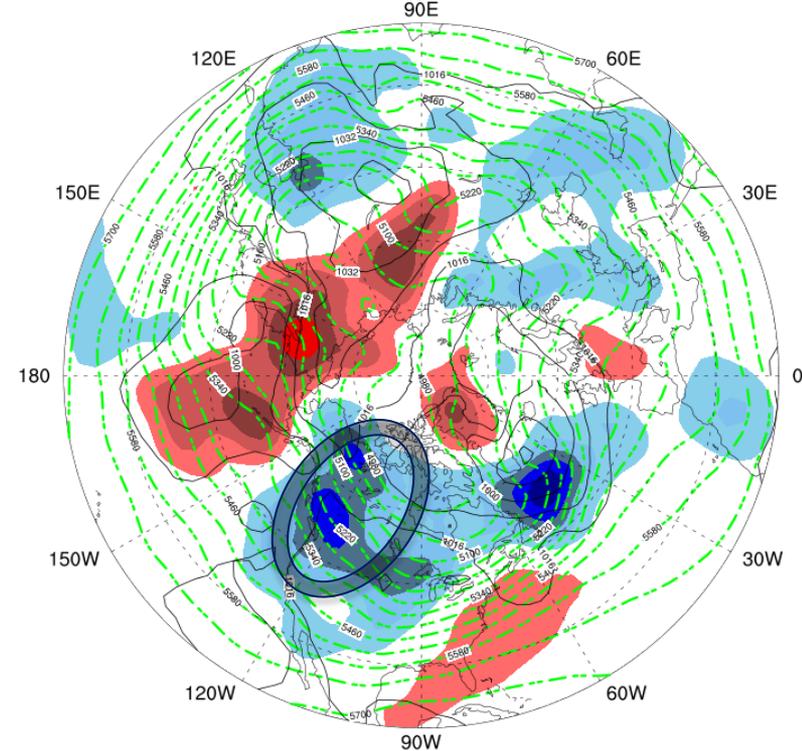
Arctic air mass generation (*high variance*)

1000-500 hPa thickness and anomaly (m) and sea-level pressure (hPa)
19800109_18z (peak of high regime)



Bliankinshtein (2018) case of extreme Arctic air mass generation (3-9 Jan. 1980)

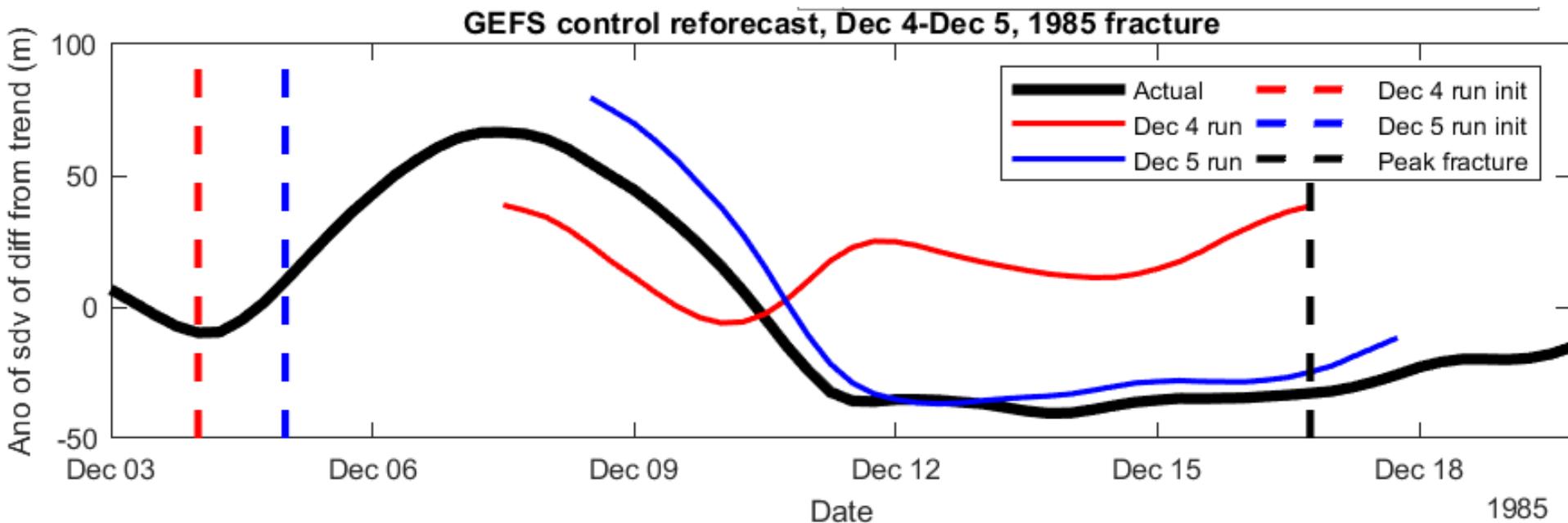
1000-500 hPa thickness and anomaly (m) and sea-level pressure (hPa)
peak of high regimes composite



High variance regimes (composite; 10 cases; SLP and 1000-500 hPa thickness anomaly)

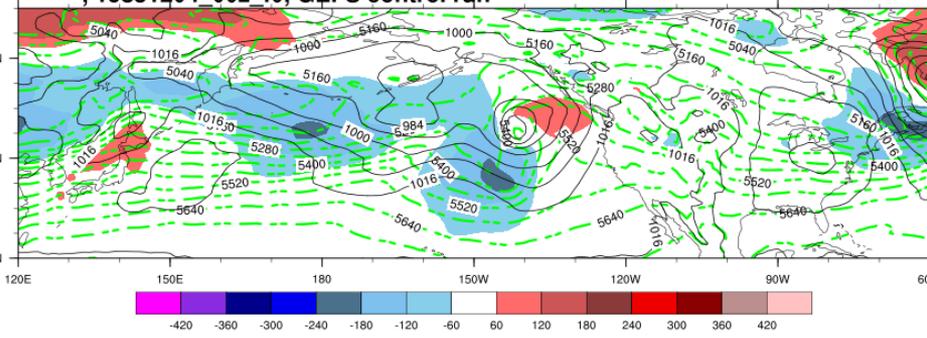
Regime Prediction (Forecast “fractures”)

Using the Global Ensemble Forecasting System (GEFS; Hamill et al. 2013) archive, we identify successive forecast cycles, separated by 24 h, in which the difference in forecasted anomalous standard deviation of the height at verification time during a regime exceeds the 90th percentile.

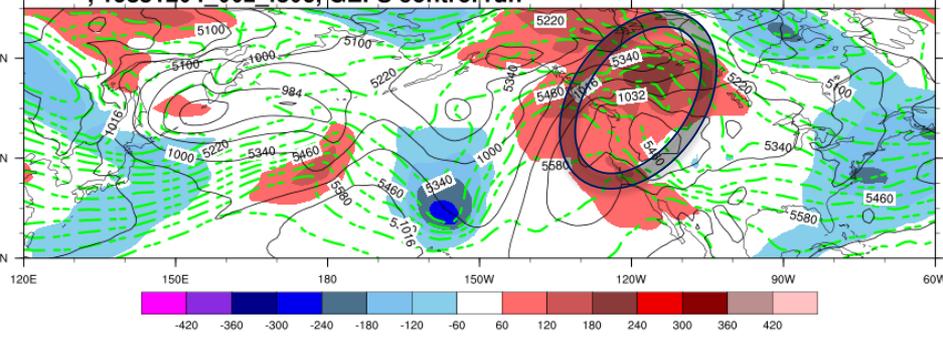


Forecast fracture (282/306 h) in *low-variance* regime of Dec 1985 (12/13 days)

1000-500 hPa thickness and anomaly (m) and sea-level pressure (hPa)
, 19851204 00z f0, GEFS control run

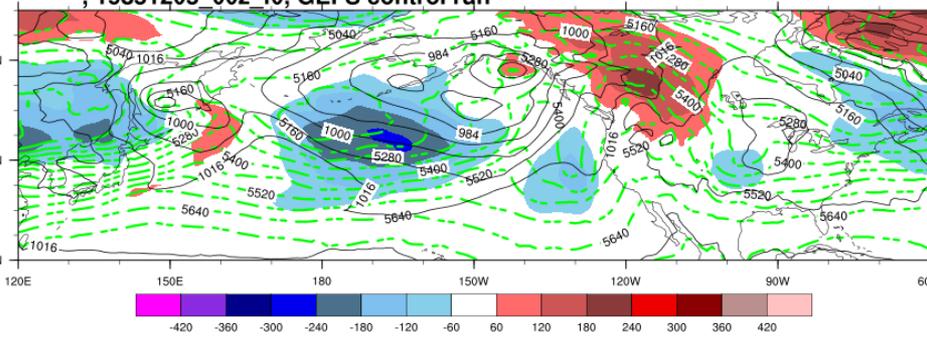


1000-500 hPa thickness and anomaly (m) and sea-level pressure (hPa)
, 19851204 00z f306, GEFS control run



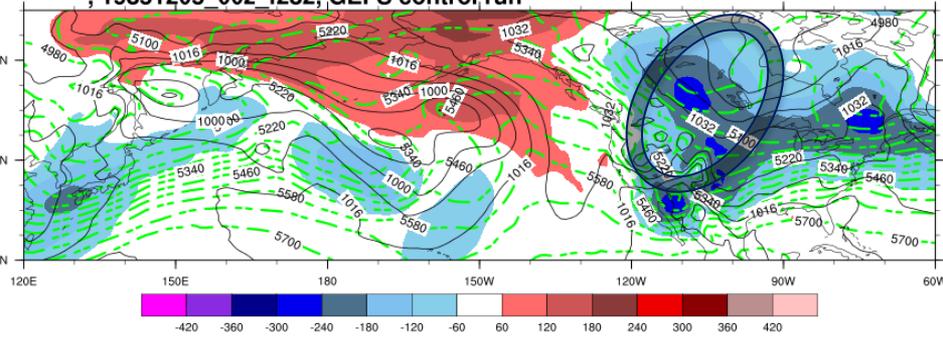
C(CONTOUR FROM 952 TO 1048 BY 8

1000-500 hPa thickness and anomaly (m) and sea-level pressure (hPa)
, 19851205 00z f0, GEFS control run



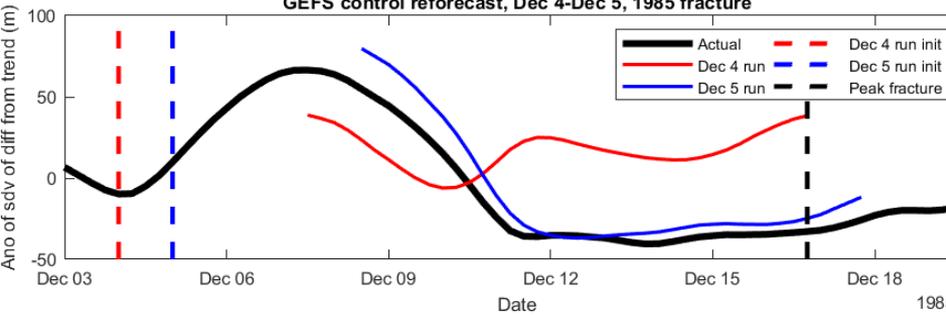
C(CONTOUR FROM 944 TO 1040 BY 8

1000-500 hPa thickness and anomaly (m) and sea-level pressure (hPa)
, 19851205 00z f282, GEFS control run



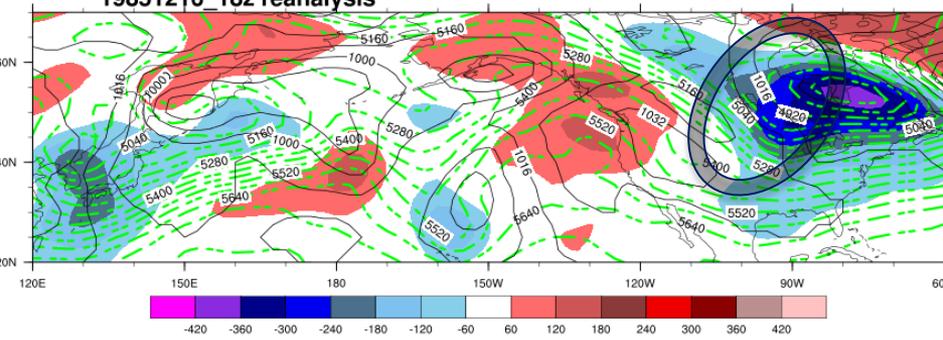
C(CONTOUR FROM 944 TO 1048 BY 8

GEFS control reforecast, Dec 4-Dec 5, 1985 fracture



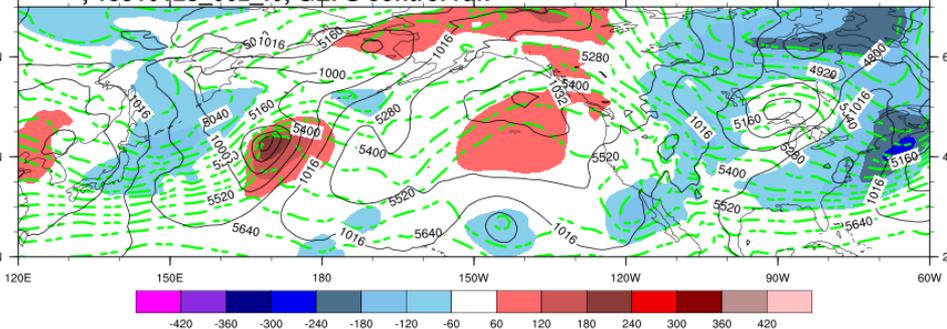
C(CONTOUR FROM 968 TO 1040 BY 8

1000-500 hPa thickness and anomaly (m) and sea-level pressure (hPa),
19851216 18z reanalysis

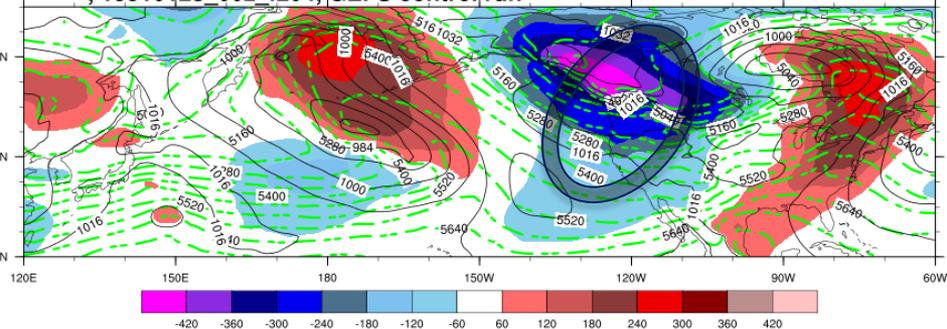


Forecast fracture (180/204 h) in *high-variance* regime of Jan-Feb 1991 (7.5/8.5 days)

1000-500 hPa thickness and anomaly (m) and sea-level pressure (hPa)
, 19910123 00z f₀, GEFS control run

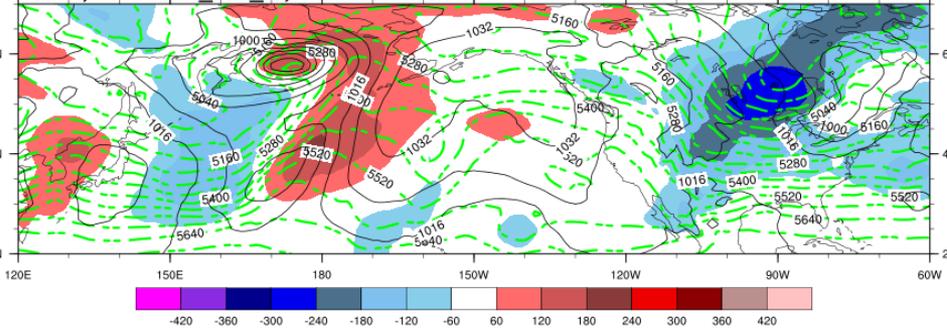


1000-500 hPa thickness and anomaly (m) and sea-level pressure (hPa)
, 19910123 00z f₂₀₄, GEFS control run



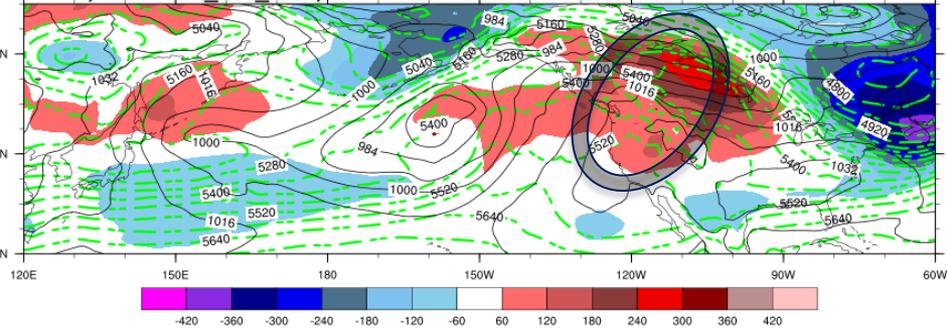
C(CONTOUR FROM 960 TO 1040 BY 8

1000-500 hPa thickness and anomaly (m) and sea-level pressure (hPa)
, 19910124 00z f₀, GEFS control run



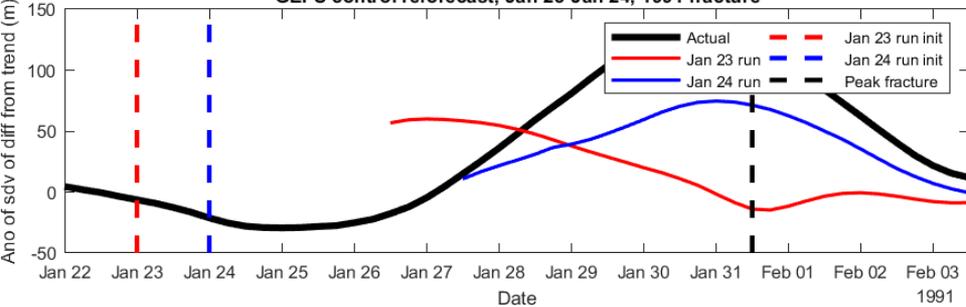
C(CONTOUR FROM 960 TO 1040 BY 8

1000-500 hPa thickness and anomaly (m) and sea-level pressure (hPa)
, 19910124 00z f₁₈₀, GEFS control run



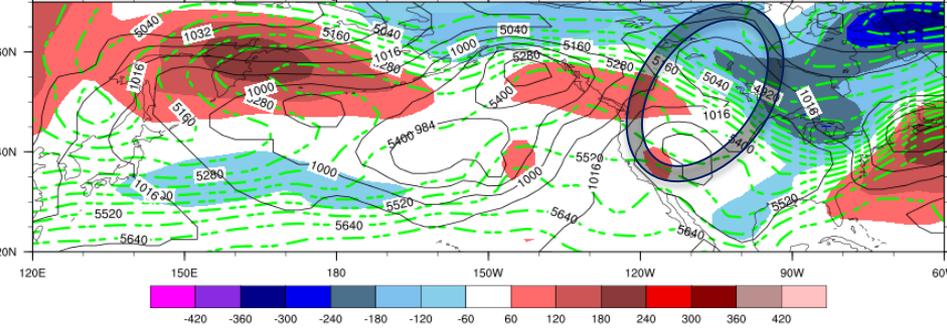
C(CONTOUR FROM 960 TO 1048 BY 8

GEFS control reforecast, Jan 23-Jan 24, 1991 fracture



C(CONTOUR FROM 952 TO 1040 BY 8

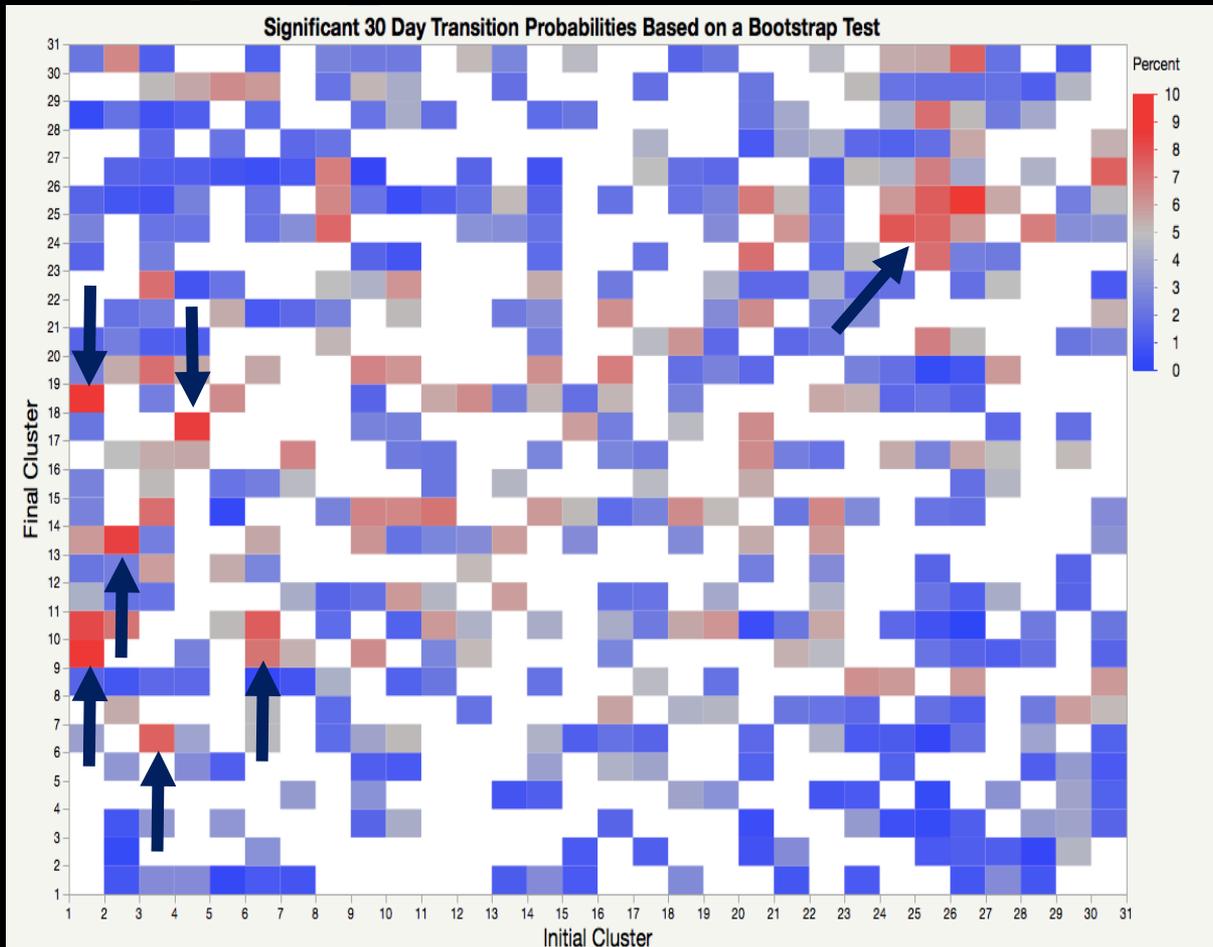
1000-500 hPa thickness and anomaly (m) and sea-level pressure (hPa),
19910131 12z reanalysis



Regime Classification - SOM

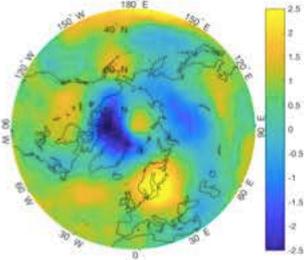
- **Compare weather regime classifications defined via several methods (SOM using theta on the DT; SUNYA results via clustering; McGill results via GC metric) and evaluate predictability**
- **Evaluate predictive utility of regime transition probabilities**
- **Evaluate robustness of CFSv2 model climate**

Statistical Significance of 30 Day Transitions

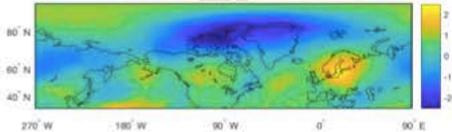


- Bootstrap test of the statistical significance:
 - high transitions are significant at the 95% level.
 - low transitions are also statistically significant.

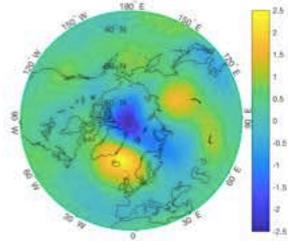
What do these regimes look like?



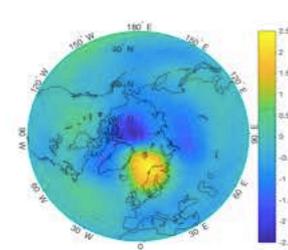
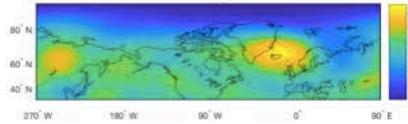
Mean Regime 25



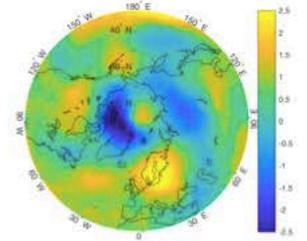
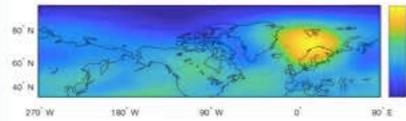
Transitions into...



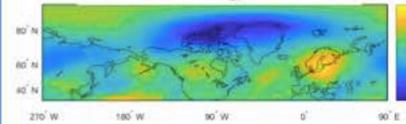
Mean Regime 23



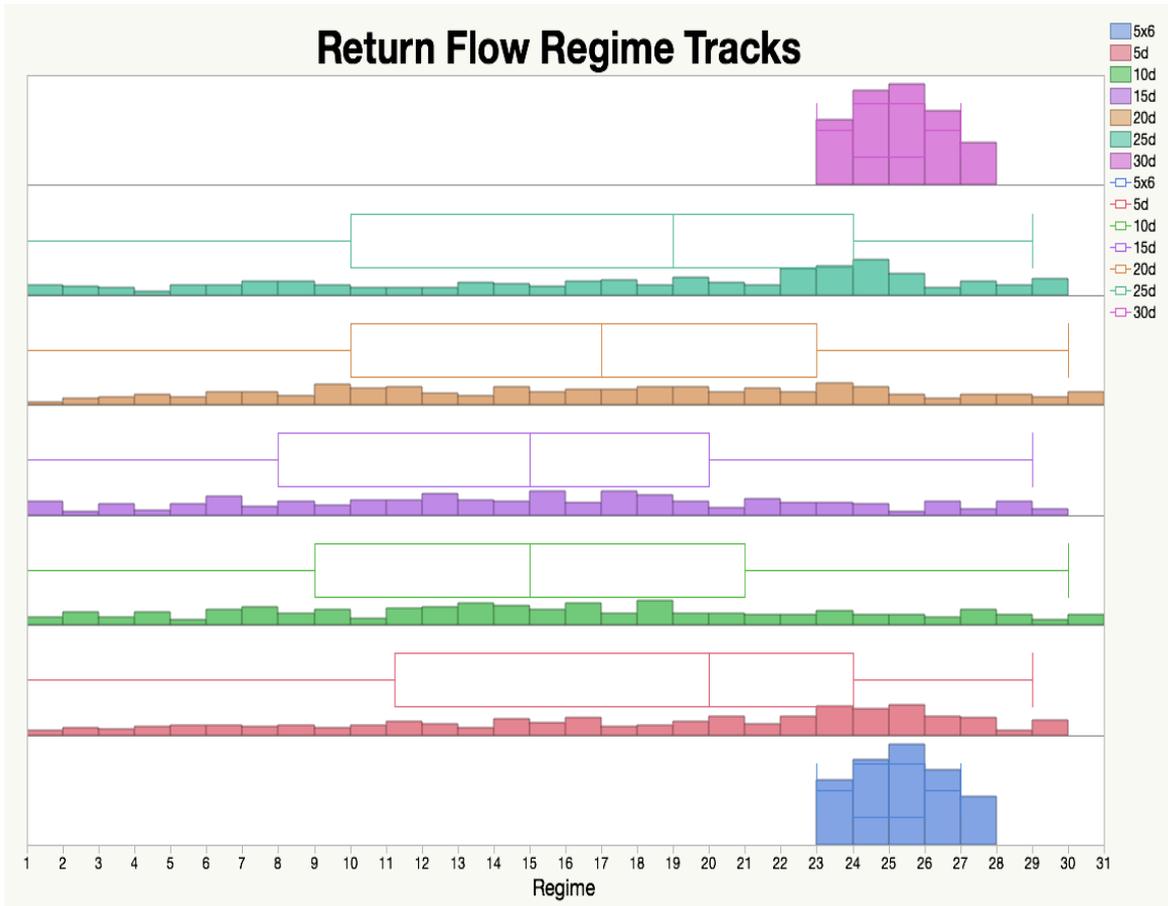
Mean Regime 24



Mean Regime 25



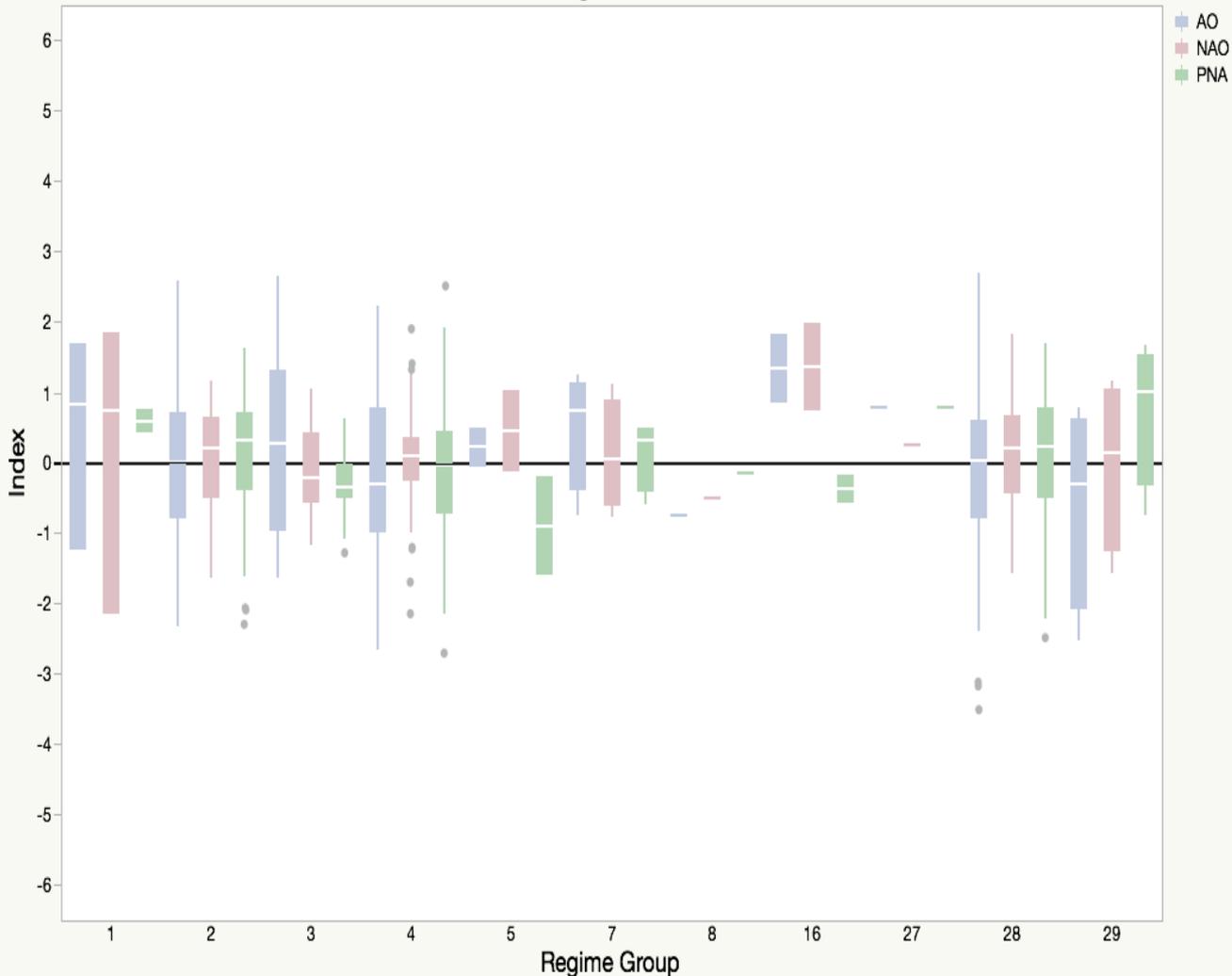
Recurrent Regime Pathways



- No “preferred” pathway enroute to recurrence.
- What is connection to Plaut and Vautrad (1993)?

Links to AO, PNA, and NAO

Spread of AO (Blue), NAO (Red), and PNA (Green) on Days with Correlation to Leading 5 PCs



- **Cluster 1**
 - PNA is positive
 - NAO, AO variable
- **Cluster 5, 16**
 - PNA negative
 - NAO, AO positive
- **Cluster 8**
 - PNA negative?
 - NAO, AO negative
 - 16 - all positive?
- **Cluster 16**
 - PNA positive?
 - NAO, AO positive
- **Others variable**

Ongoing and future work – Predictive tools

- **Integration of individual pieces of predictive information from U at Albany, McGill, UWM**
- **Variety of effective spatio-temporal approaches exist**

Evolutionary Programming

Using the principles of evolution to produce skillful NWP postprocessors

1. Impose interpretable algo structure
2. Initialize random structure
3. Measure "success" or "fitness"
4. Produce next generation (w/ mutations) based on "fitness"
5. Repeat #3-4*

* Searching some small subset of the library of all possible solutions!

CONDITIONAL							RESULT										
1	IF	V _{1.1}	O _{1,r}	V _{1.2}	1	THEN	C _{1.1}	*	V _{1.3}	O _{1.1}	C _{1.2}	*	V _{1.4}	O _{1.2}	C _{1.3}	*	V _{1.5}
2	IF	V _{2.1}	O _{2,r}	V _{2.2}	1	THEN	C _{2.1}	*	V _{2.3}	O _{2.1}	C _{2.2}	*	V _{2.4}	O _{2.2}	C _{2.3}	*	V _{2.5}
3	IF	V _{3.1}	O _{3,r}	V _{3.2}	1	THEN	C _{3.1}	*	V _{3.3}	O _{3.1}	C _{3.2}	*	V _{3.4}	O _{3.2}	C _{3.3}	*	V _{3.5}
4	IF	V _{4.1}	O _{4,r}	V _{4.2}	1	THEN	C _{4.1}	*	V _{4.3}	O _{4.1}	C _{4.2}	*	V _{4.4}	O _{4.2}	C _{4.3}	*	V _{4.5}
5	IF	V _{5.1}	O _{5,r}	V _{5.2}	1	THEN	C _{5.1}	*	V _{5.3}	O _{5.1}	C _{5.2}	*	V _{5.4}	O _{5.2}	C _{5.3}	*	V _{5.5}
6	IF	V _{6.1}	O _{6,r}	V _{6.2}	1	THEN	C _{6.1}	*	V _{6.3}	O _{6.1}	C _{6.2}	*	V _{6.4}	O _{6.2}	C _{6.3}	*	V _{6.5}
7	IF	V _{7.1}	O _{7,r}	V _{7.2}	1	THEN	C _{7.1}	*	V _{7.3}	O _{7.1}	C _{7.2}	*	V _{7.4}	O _{7.2}	C _{7.3}	*	V _{7.5}
8	IF	V _{8.1}	O _{8,r}	V _{8.2}	1	THEN	C _{8.1}	*	V _{8.3}	O _{8.1}	C _{8.2}	*	V _{8.4}	O _{8.2}	C _{8.3}	*	V _{8.5}
9	IF	V _{9.1}	O _{9,r}	V _{9.2}	1	THEN	C _{9.1}	*	V _{9.3}	O _{9.1}	C _{9.2}	*	V _{9.4}	O _{9.2}	C _{9.3}	*	V _{9.5}
10	IF	V _{10.1}	O _{10,r}	V _{10.2}	1	THEN	C _{10.1}	*	V _{10.3}	O _{10.1}	C _{10.2}	*	V _{10.4}	O _{10.2}	C _{10.3}	*	V _{10.5}

Becomes

CONDITIONAL							RESULT										
1	IF	V _{1.1}	O _{1,r}	V _{1.2}	1	THEN	C _{1.1}	*	V _{1.3}	O _{1.1}	C _{1.2}	*	V _{1.4}	O _{1.2}	C _{1.3}	*	V _{1.5}
2	IF	V _{2.1}	O _{2,r}	V _{2.2}	1	THEN	C _{2.1}	*	V _{2.3}	O _{2.1}	C _{2.2}	*	V _{2.4}	O _{2.2}	C _{2.3}	*	V _{2.5}
3	IF	V _{3.1}	O _{3,r}	V _{3.2}	1	THEN	C _{3.1}	*	V _{3.3}	O _{3.1}	C _{3.2}	*	V _{3.4}	O _{3.2}	C _{3.3}	*	V _{3.5}
4	IF	V _{4.1}	O _{4,r}	V _{4.2}	1	THEN	C _{4.1}	*	V _{4.3}	O _{4.1}	C _{4.2}	*	V _{4.4}	O _{4.2}	C _{4.3}	*	V _{4.5}
5	IF	V _{5.1}	O _{5,r}	V _{5.2}	1	THEN	C _{5.1}	*	V _{5.3}	O _{5.1}	C _{5.2}	*	V _{5.4}	O _{5.2}	C _{5.3}	*	V _{5.5}
6	IF	V _{6.1}	O _{6,r}	V _{6.2}	1	THEN	C _{6.1}	*	V _{6.3}	O _{6.1}	C _{6.2}	*	V _{6.4}	O _{6.2}	C _{6.3}	*	V _{6.5}
7	IF	V _{7.1}	O _{7,r}	V _{7.2}	1	THEN	C _{7.1}	*	V _{7.3}	O _{7.1}	C _{7.2}	*	V _{7.4}	O _{7.2}	C _{7.3}	*	V _{7.5}
8	IF	V _{8.1}	O _{8,r}	V _{8.2}	1	THEN	C _{8.1}	*	V _{8.3}	O _{8.1}	C _{8.2}	*	V _{8.4}	O _{8.2}	C _{8.3}	*	V _{8.5}
9	IF	V _{9.1}	O _{9,r}	V _{9.2}	1	THEN	C _{9.1}	*	V _{9.3}	O _{9.1}	C _{9.2}	*	V _{9.4}	O _{9.2}	C _{9.3}	*	V _{9.5}
10	IF	V _{10.1}	O _{10,r}	V _{10.2}	1	THEN	C _{10.1}	*	V _{10.3}	O _{10.1}	C _{10.2}	*	V _{10.4}	O _{10.2}	C _{10.3}	*	V _{10.5}

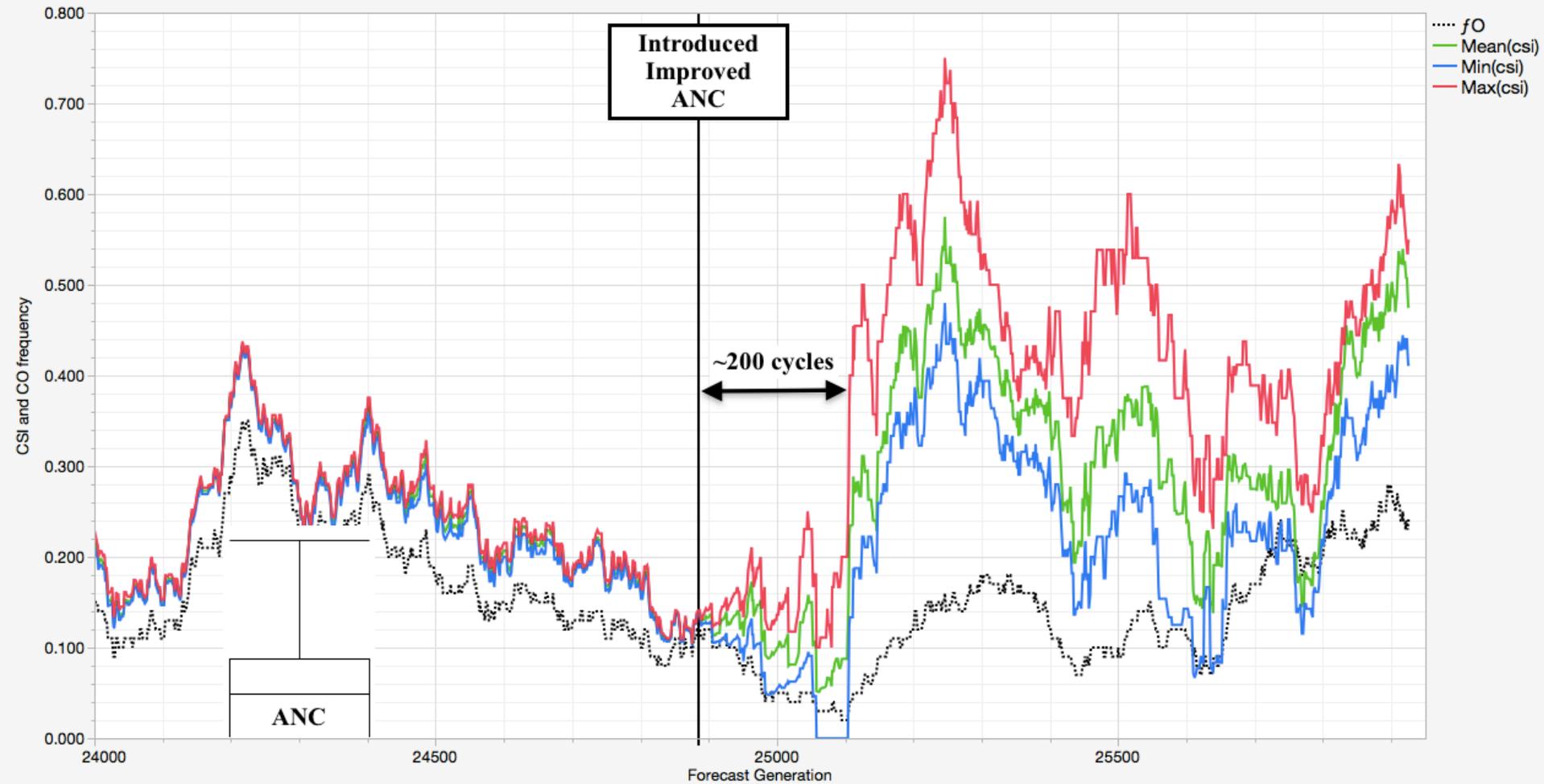
Or

CONDITIONAL							RESULT										
1	IF	V _{1.1}	O _{1,r}	V _{1.2}	1	THEN	C _{1.1}	*	V _{1.3}	O _{1.1}	C _{1.2}	*	V _{1.4}	O _{1.2}	C _{1.3}	*	V _{1.5}
2	IF	V _{2.1}	O _{2,r}	V _{2.2}	1	THEN	C _{2.1}	*	V _{2.3}	O _{2.1}	C _{2.2}	*	V _{2.4}	O _{2.2}	C _{2.3}	*	V _{2.5}
3	IF	V _{3.1}	O _{3,r}	V _{3.2}	1	THEN	C _{3.1}	*	V _{3.3}	O _{3.1}	C _{3.2}	*	V _{3.4}	O _{3.2}	C _{3.3}	*	V _{3.5}
4	IF	V _{4.1}	O _{4,r}	V _{4.2}	1	THEN	C _{4.1}	*	V _{4.3}	O _{4.1}	C _{4.2}	*	V _{4.4}	O _{4.2}	C _{4.3}	*	V _{4.5}
5	IF	V _{5.1}	O _{5,r}	V _{5.2}	1	THEN	C _{5.1}	*	V _{5.3}	O _{5.1}	C _{5.2}	*	V _{5.4}	O _{5.2}	C _{5.3}	*	V _{5.5}
6	IF	V _{6.1}	O _{6,r}	V _{6.2}	1	THEN	C _{6.1}	*	V _{6.3}	O _{6.1}	C _{6.2}	*	V _{6.4}	O _{6.2}	C _{6.3}	*	V _{6.5}
7	IF	V _{7.1}	O _{7,r}	V _{7.2}	1	THEN	C _{7.1}	*	V _{7.3}	O _{7.1}	C _{7.2}	*	V _{7.4}	O _{7.2}	C _{7.3}	*	V _{7.5}
8	IF	V _{8.1}	O _{8,r}	V _{8.2}	1	THEN	C _{8.1}	*	V _{8.3}	O _{8.1}	C _{8.2}	*	V _{8.4}	O _{8.2}	C _{8.3}	*	V _{8.5}
9	IF	V _{9.1}	O _{9,r}	V _{9.2}	1	THEN	C _{9.1}	*	V _{9.3}	O _{9.1}	C _{9.2}	*	V _{9.4}	O _{9.2}	C _{9.3}	*	V _{9.5}
10	IF	V _{10.1}	O _{10,r}	V _{10.2}	1	THEN	C _{10.1}	*	V _{10.3}	O _{10.1}	C _{10.2}	*	V _{10.4}	O _{10.2}	C _{10.3}	*	V _{10.5}

MUTATIONS

... and we can make this adaptive!

Note: CSI is computed from prior 100 forecast cycles



2. **Evolutionary arms race**- coevolution can occur in competitive relationships



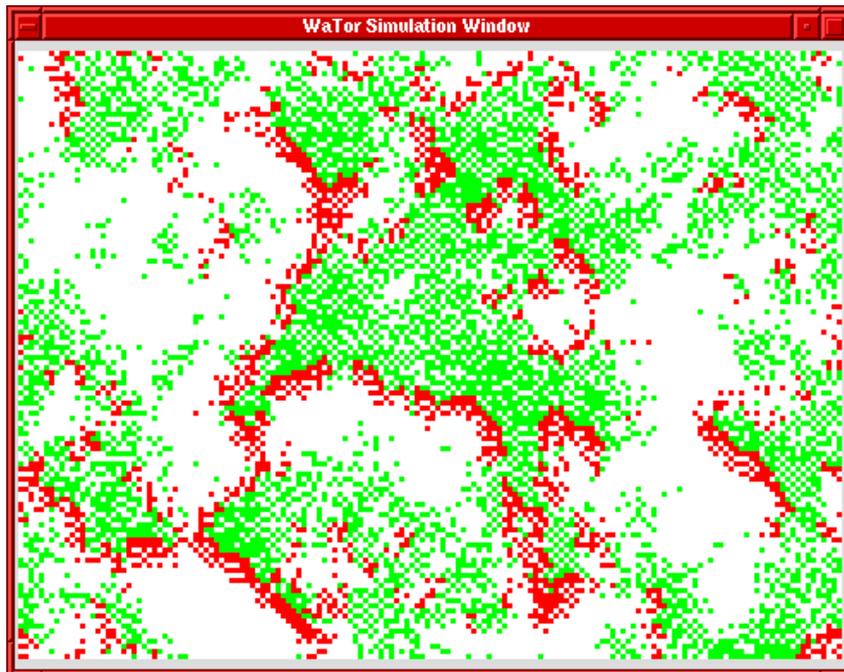
The crab is the natural predator of the snail.

Natural selection favors snails with thicker shells and spines.

Through natural selection, crabs evolve more powerful claws that can pierce the snails' thick, spiny shells.

In response, natural selection favors snails with even thicker shells and spines.





Predator-prey leads to clustering and thus might produce more genetic diversity over the domain (Dewdney 1984).

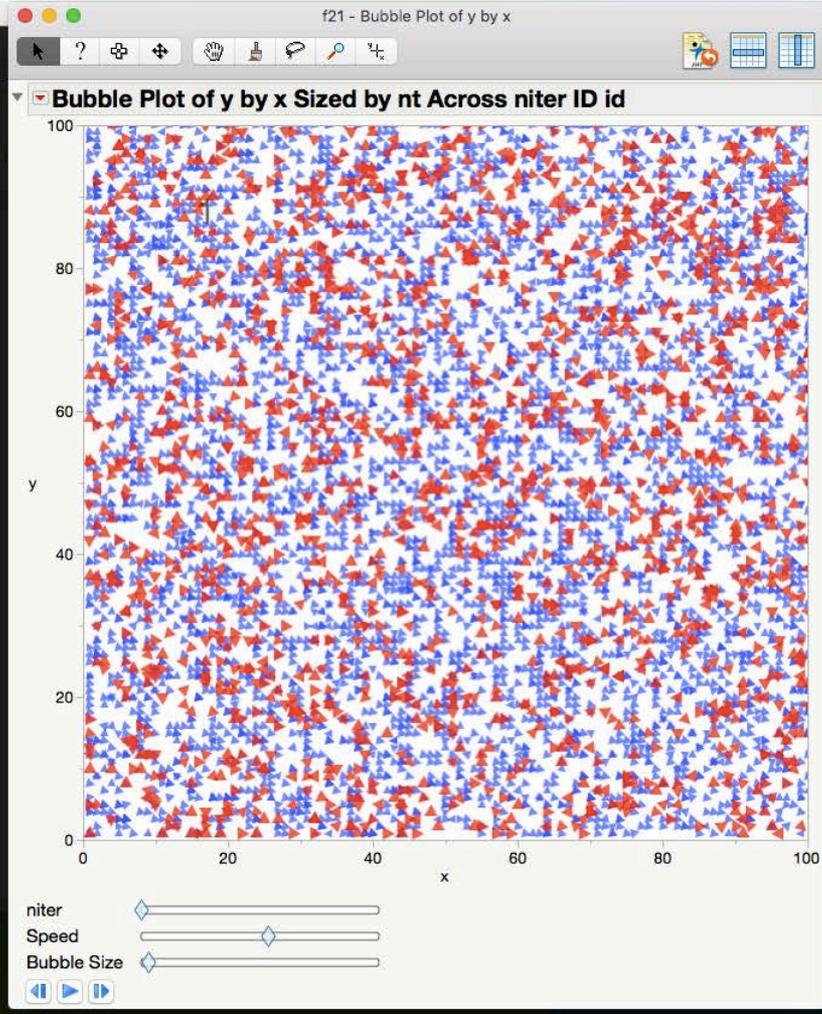
Ecosystem Dynamics

Attribute	Prey Algorithms	Predator Algorithms
Location	Initially randomly dispersed on 100x100 grid	Initially randomly dispersed on 100x100 grid
Structure	f (IF-THEN, VARS) L1+L2+L3+L4+L5	f (IF-THEN, VARS) L1+L2+L3+L4+L5
Food	Variables distributed on 100x100 grid as food for prey. If consumed on one iteration, takes another iteration to "regrow." (overgrazing). Can build over time to max of 5.	Predator accumulates food reserves with each prey consumed and depletes this only through spawning.
Feeding strategy	Seek food or avoid predator within 3x3 neighborhood with probability $\alpha_1 = f(RMSE \text{ for } T, CSI \text{ for } CO)$	Seek prey at location where maximum prey exist within the 3x3 neighborhood with probability $\alpha_2 = f(RMSE \text{ for } T, CSI \text{ for } CO)$
Hunger	If food at grid location does not contain variables used by prey algorithm, then prey does not feed. If prey is hungry (has no accumulated food reserves) it may die with probability $\beta = f(1 - \alpha_1)$	If predator is hungry (has no accumulated food reserves) it may die with probability $\beta = f(1 - \alpha_2)$
Aging	If prey has existed for at least N iterations (8 for T, 4 for CO) then it may die with probability $\gamma = f(1 - \alpha_1)$. Additionally for CO, prey always dies after 8 iterations.	If predator has existed for at least 7 iterations then it may die with probability $\gamma = f(1 - \alpha_2)$. Always dies after 14 iterations.
Breeding	If prey has at least 2 accumulated food reserves, then prey produces one clone of itself within 3x3 neighborhood, depleting food reserves by 2. The clone may have a mutation with probability $1 - \alpha_1$. There is a 10% chance of producing an atavism. (carrying capacity is dictated by predator-prey-food dynamics).	If predator has at least 3 accumulated food reserves, then predator produces one clone of itself within the 3x3 neighborhood, depleting food reserves by 2. The clone may have a mutation with probability $1 - \alpha_2$. There is a 10% chance of producing an atavism. (carrying capacity is dictated by predator-prey-food dynamics).
Learning	If there is another algorithm of either type within the 3x3 neighborhood which has a higher performance level, then the worse-performing algorithm "learns" by copying at random one of the 5 lines from the better algorithm.	If there is another algorithm of either type within the 3x3 neighborhood which has a higher performance level, then the worse-performing algorithm "learns" by copying at random one of the 5 lines from the better algorithm.

Table 1: Overview of the rules governing prey and predator behaviors on the 100x100 ecological grid. See text for details.

Computer: ~ paulroeber\$

File Explorer sidebar showing Favorites (All My Files, iCloud Drive, AirDrop, Desktop, Applications, Documents) and a list of files including 116, 116 By Heat, 116.txt, Q21, Q21.txt, fnr1.17, Perf.xlsx, trn.txt, trn1, trn2.



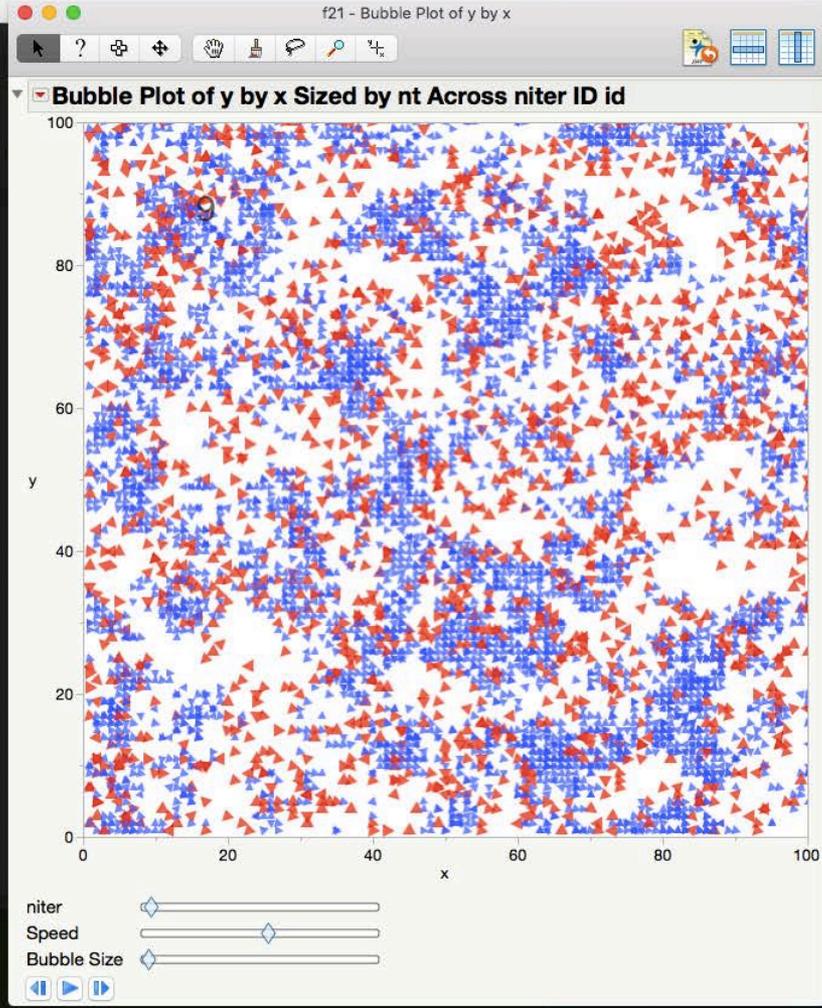
Macintosh HD

- MISCELLANY
- FunMisc
- CAMPS_10201
- L&S
- ProjectIDEAS
- Swanson_R1
- AtmoPlans
- Regie
- NeedsAttent1 Now
- RareBooks
- Words.xlsx
- Seasonal

TEACHING

Computer: ~ paulroeber\$

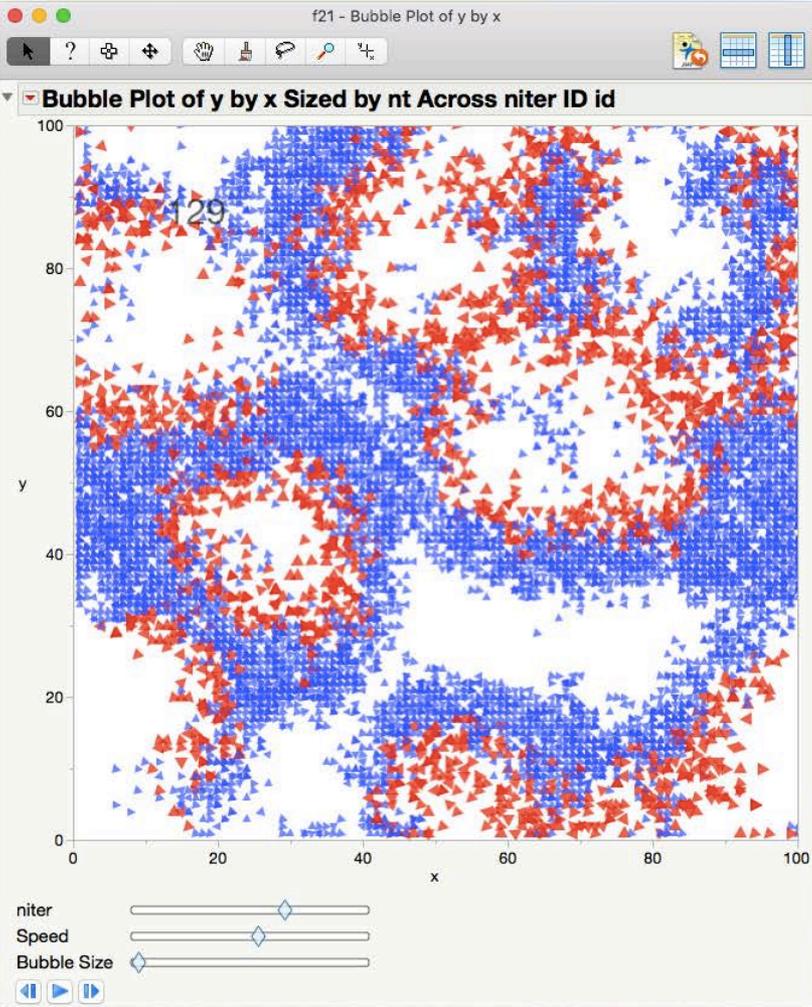
File Explorer sidebar showing folders like All My Files, iCloud Drive, Desktop, and Documents.



Macintosh HD sidebar showing folders like MISCELLANY, FunMisc, and various project files.

Computer: ~ paulroebber\$

File Explorer sidebar showing folders like All My Files, Desktop, Documents, and files like 116, 116 By Heat, 116.txt, etc.



File Explorer sidebar showing folders like MISCELLANY, FunMisc, and files like Screen Shot, 2018-0... 10 PM, etc.

Impact of Co-evolution

- **Deterministic 72h T forecasts**

Improves RMSE to 2.95°F

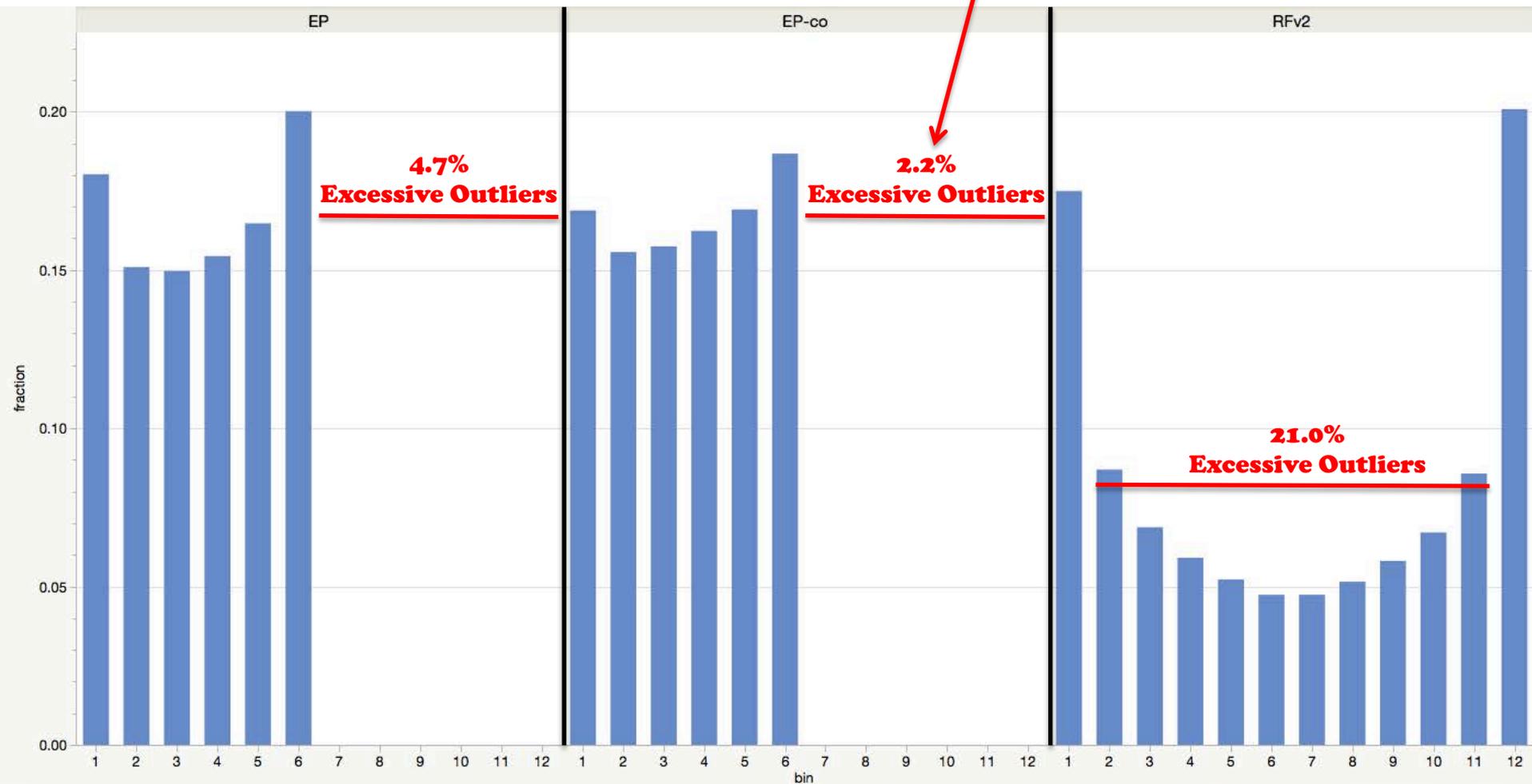
- over standard EP by 3.0% (averaged by grid)
- over RFv2 by 11.4% (averaged by grid)

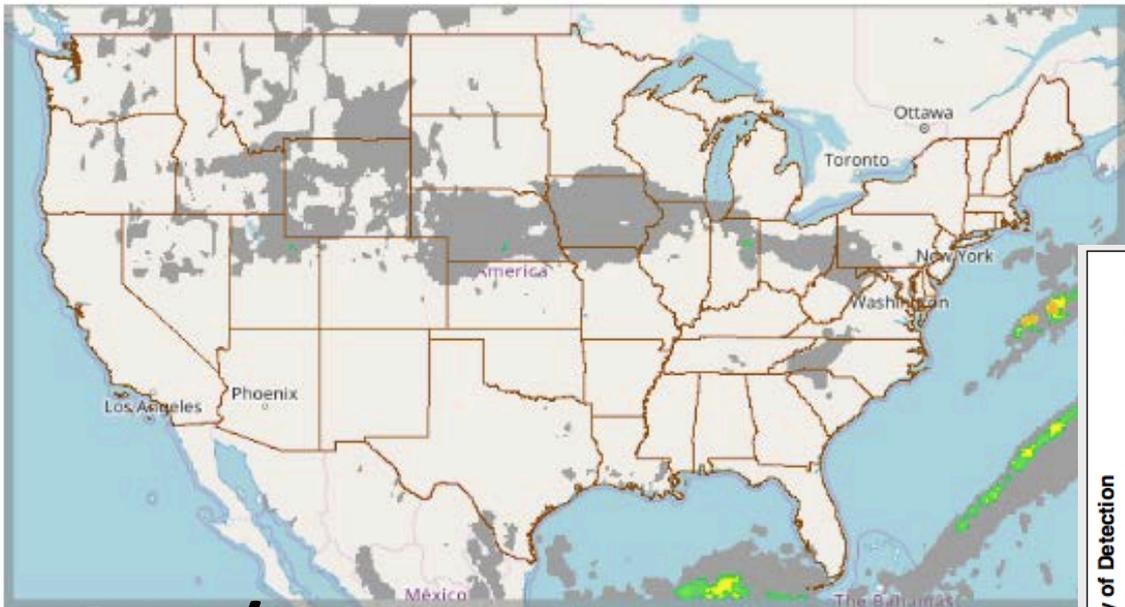
- **Probabilistic 72h T forecasts**

Improves Ranked Probability Score

- over standard EP by 3.6%
- over RFv2 by 6.4 %

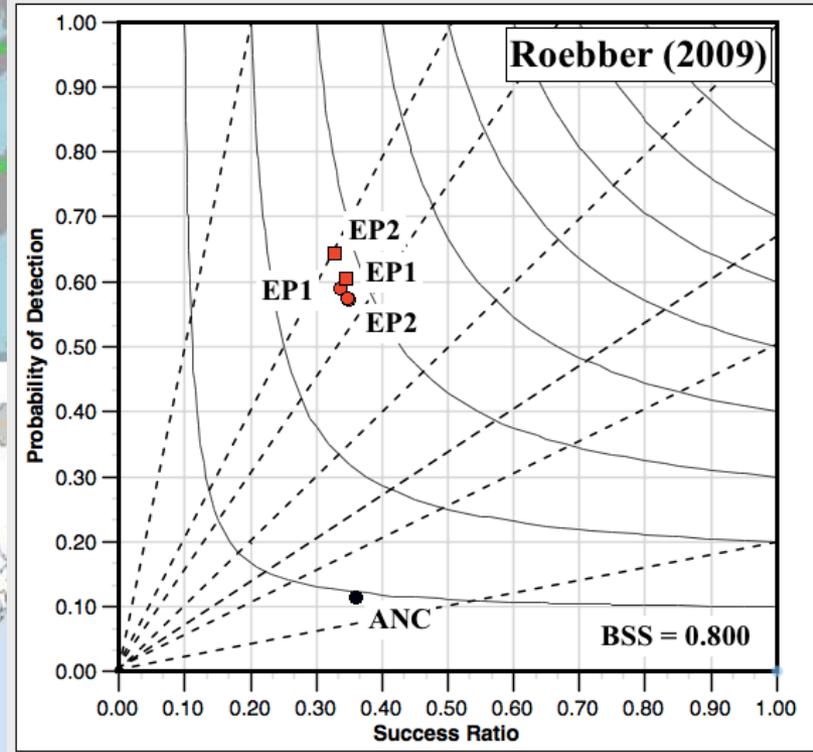
Impact of Co-evolution (reliability)





NOAA/MDL Autowcaster

(convective occurrence)



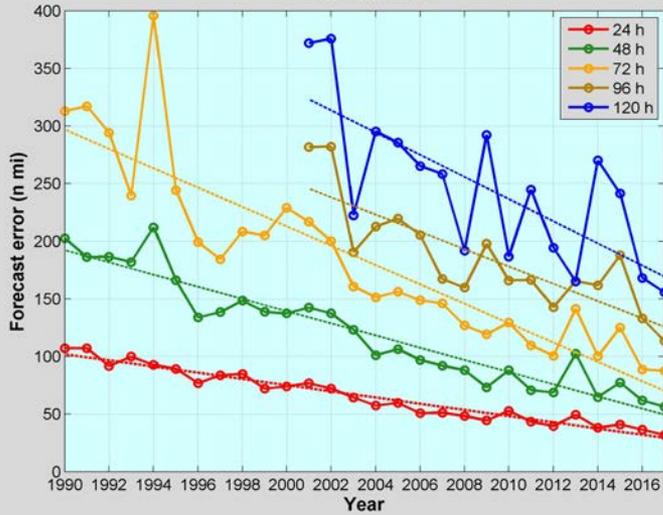
NOAA
 SPC DAY 1 CATEGORICAL OUTLOOK
 ISSUED: 1247Z 05/11/2018
 VALID: 11/1300Z-12/1200Z
 FORECASTER: Edwards/Mosier
 NOAA/NWS Storm Prediction Center, Norman, Oklahoma

Categorical Outlook Legend:

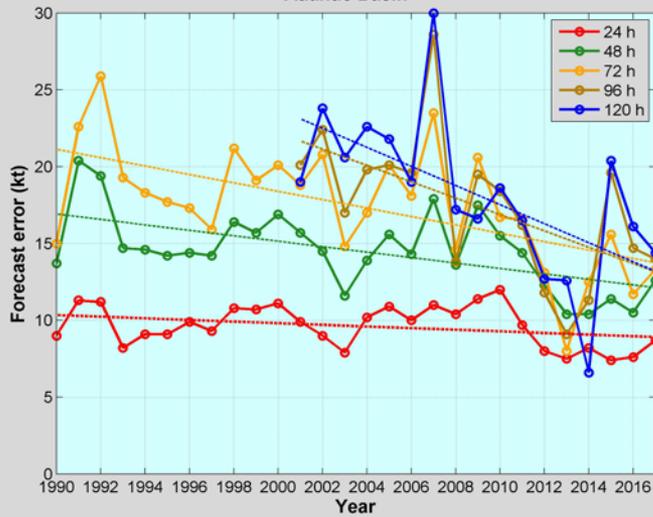
1: TSTM	2: MRGL	3: SLGT
4: ENH	5: MDT	6: HIGH



NHC Official Track Error Trend
Atlantic Basin



NHC Official Intensity Error Trend
Atlantic Basin



Tropical Cyclone Intensity Forecast Performance (independent test data – Atlantic basin)

