Improving Prediction of Large-scale Regime Transitions

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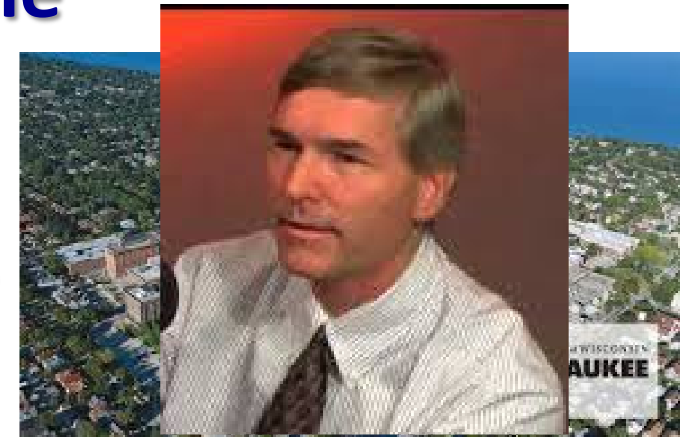
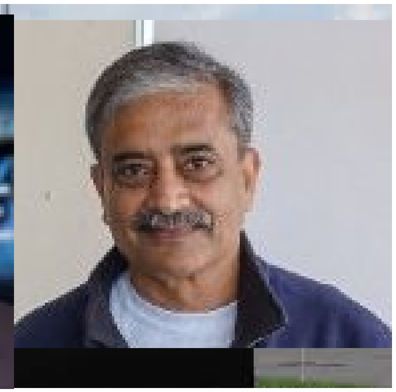


Paul Roebber

Dave Dewitt



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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;

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- 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.

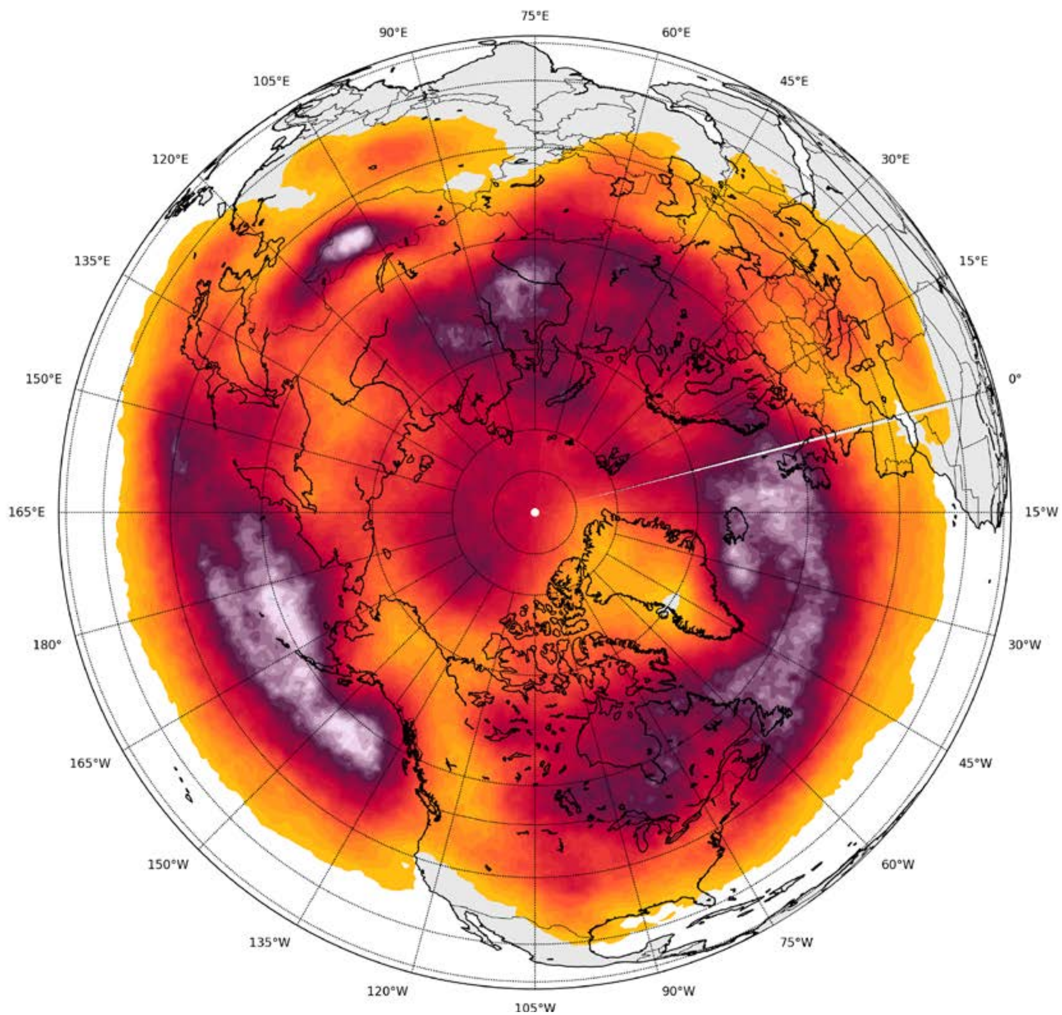
- The susceptibility of the NPJ to external perturbations is a function of the phase and amplitude of ENSO on interannual time scales, the phase and amplitude of the MJO on subseasonal time scales, and the frequency of transient tropical, midlatitude, and polar disturbances that interact with the NPJ on synoptic time scales.

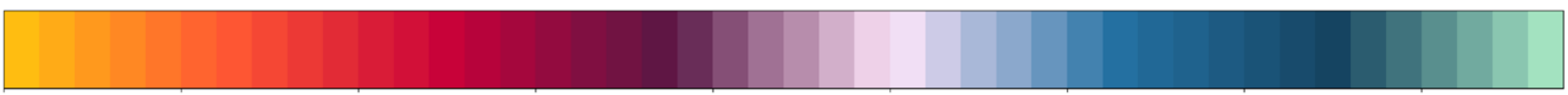
- NPJ waveguide perturbations can result in the formation of downstream propagating Rossby wave trains including clustered cyclone events that may lead to extreme weather event (EWE) occurrences.

- Selected persistent large-scale circulation regimes may be especially conducive to the occurrence of clustered cyclone events and EWEs.

Cyclone clustering (ERA-Interim; Hodges)

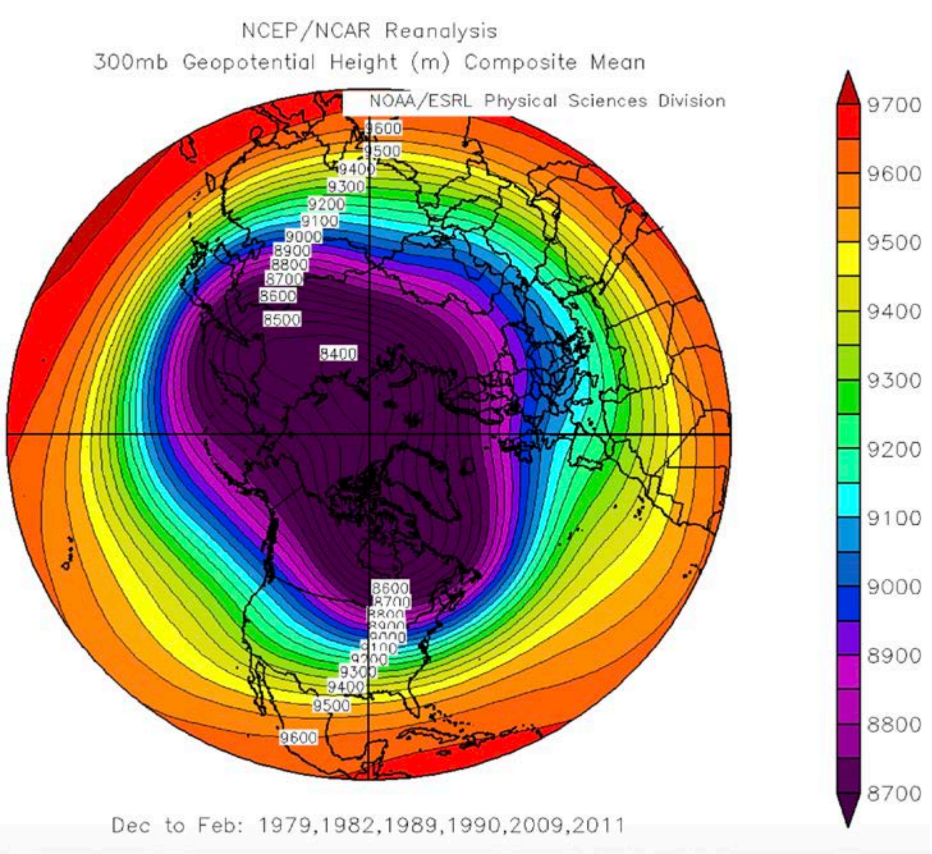
Frequency and distribution of cyclone cluster events associated with large-scale flow patterns is contingent upon the orientation and position of the midlatitude jets over the ATL and PAC.



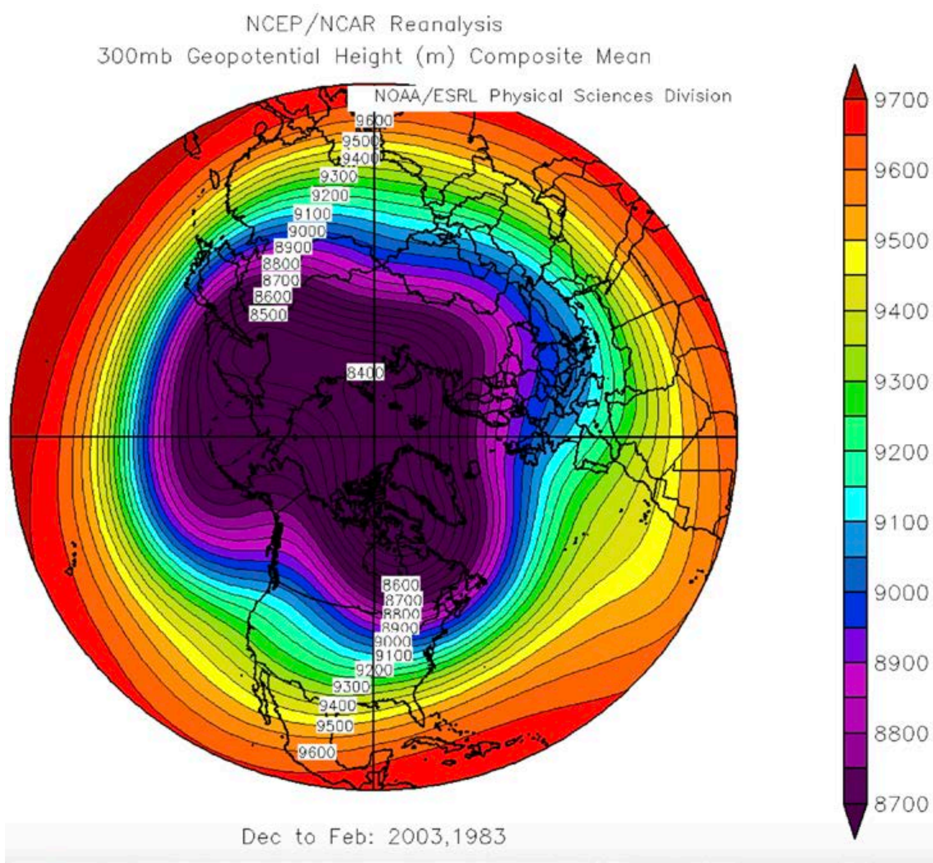


Average cyclone clusters for 1979–2014

Cyclone Clusters Vs. PNA



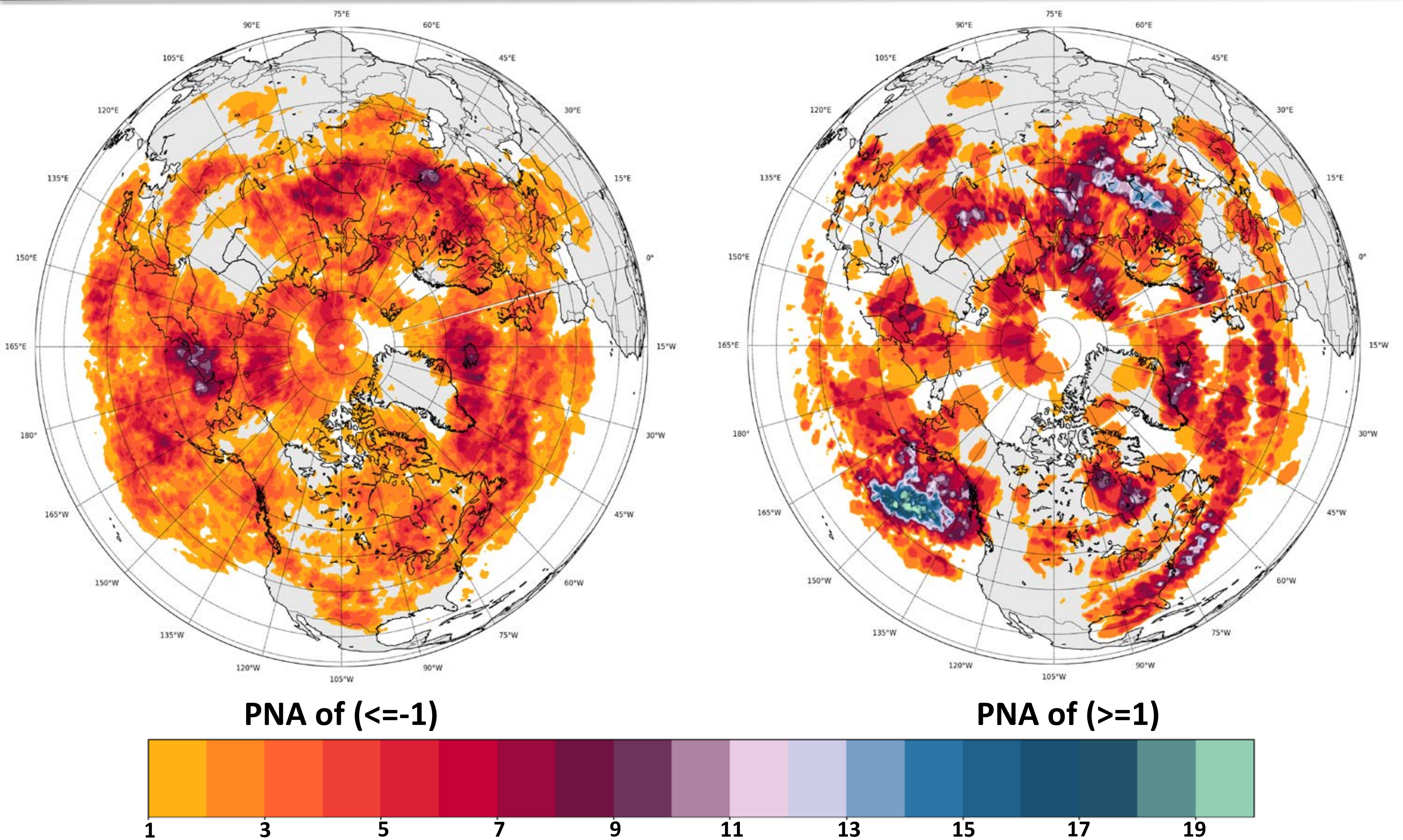
PNA of (<=-1)



PNA of (>=1)

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

Cyclone Clusters Vs. PNA

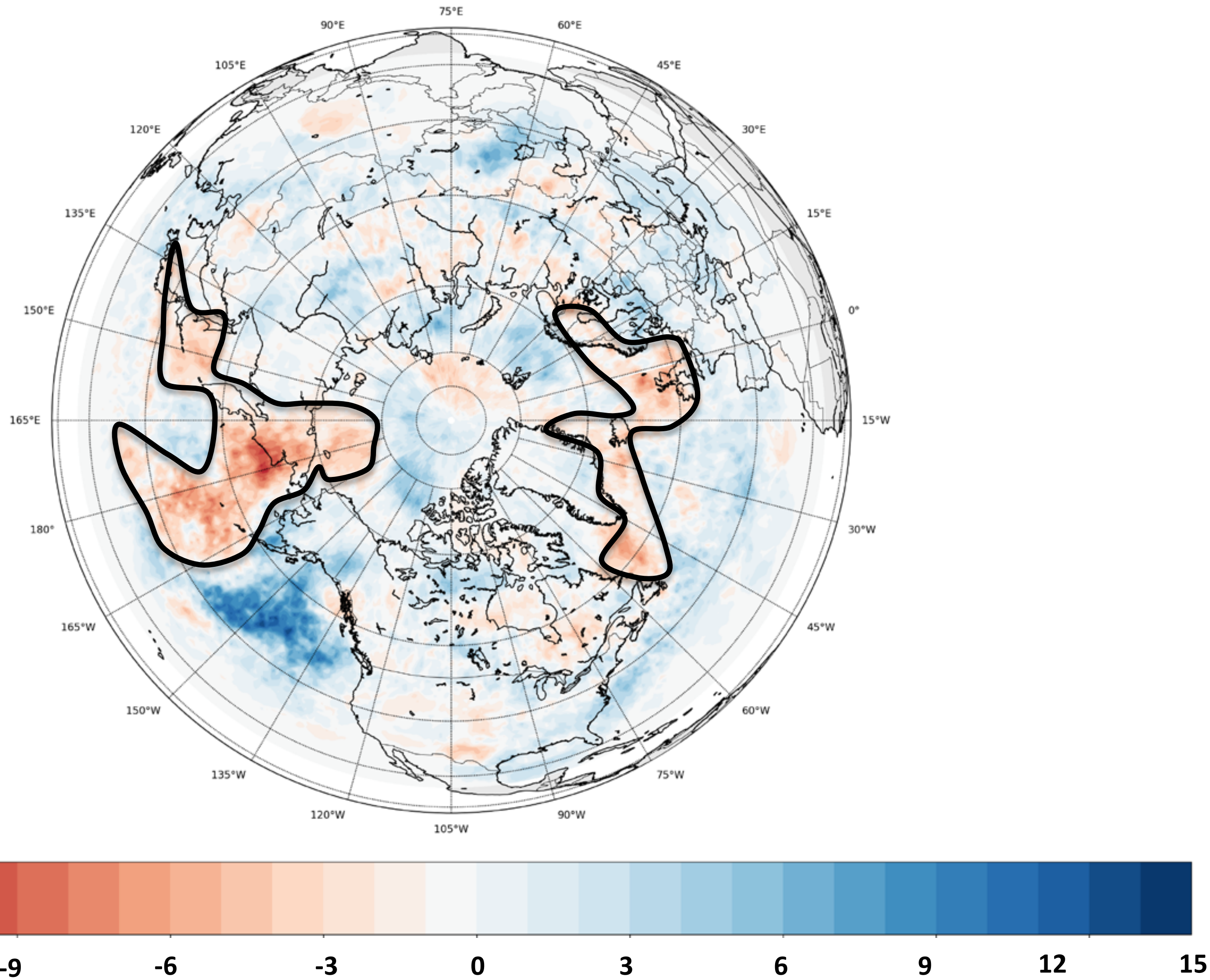


Average DJF PNA value of (<=-1) (left) and (>=1) (right) of two or more clustered cyclones

Cyclone Clusters Vs. PNA

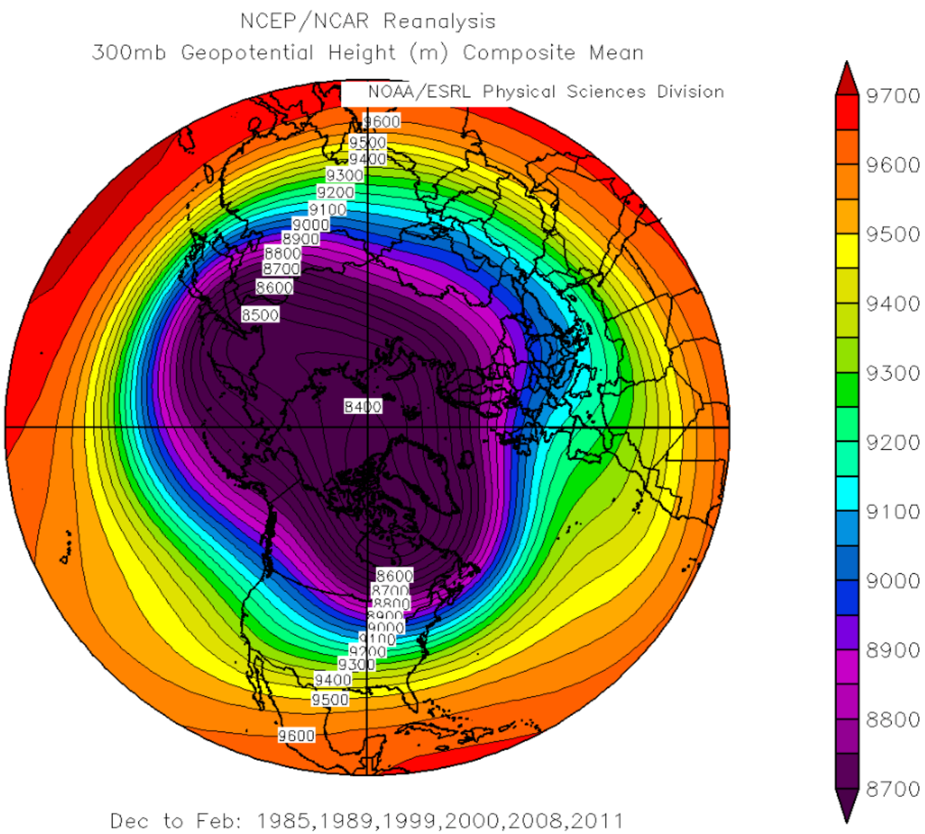
clusters form in favored northerly track across the ATL and in the central N PAC during neg PNA phase.

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

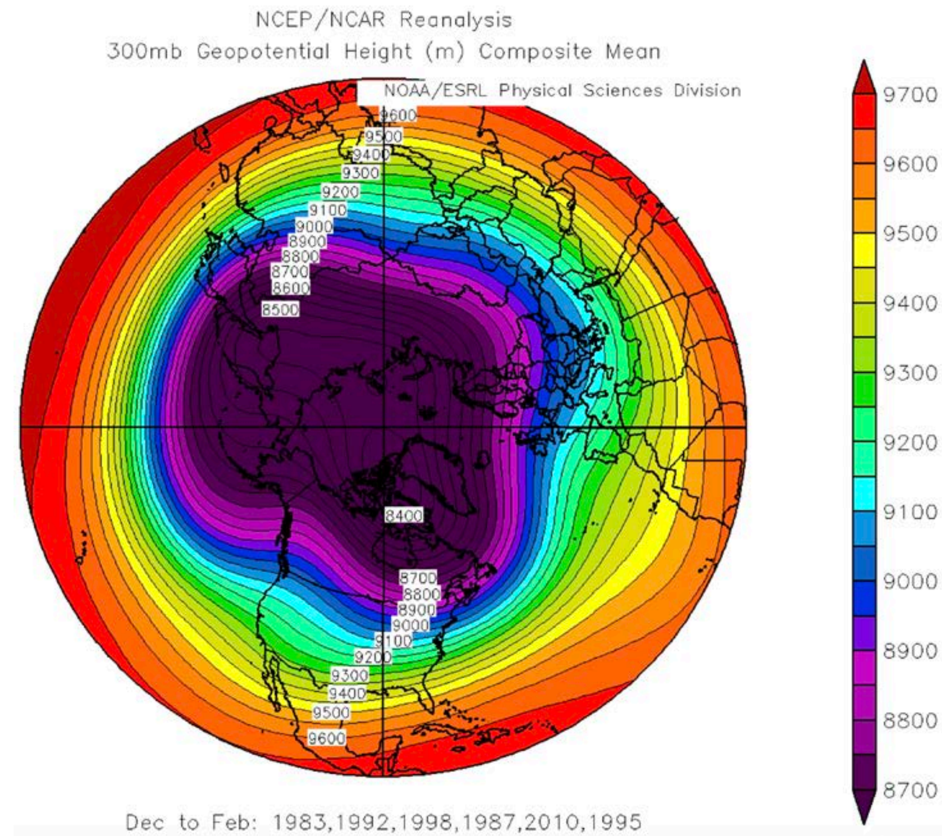


Difference between positive PNA and negative PNA

Cyclone Clusters Vs. Oceanic Nino Index



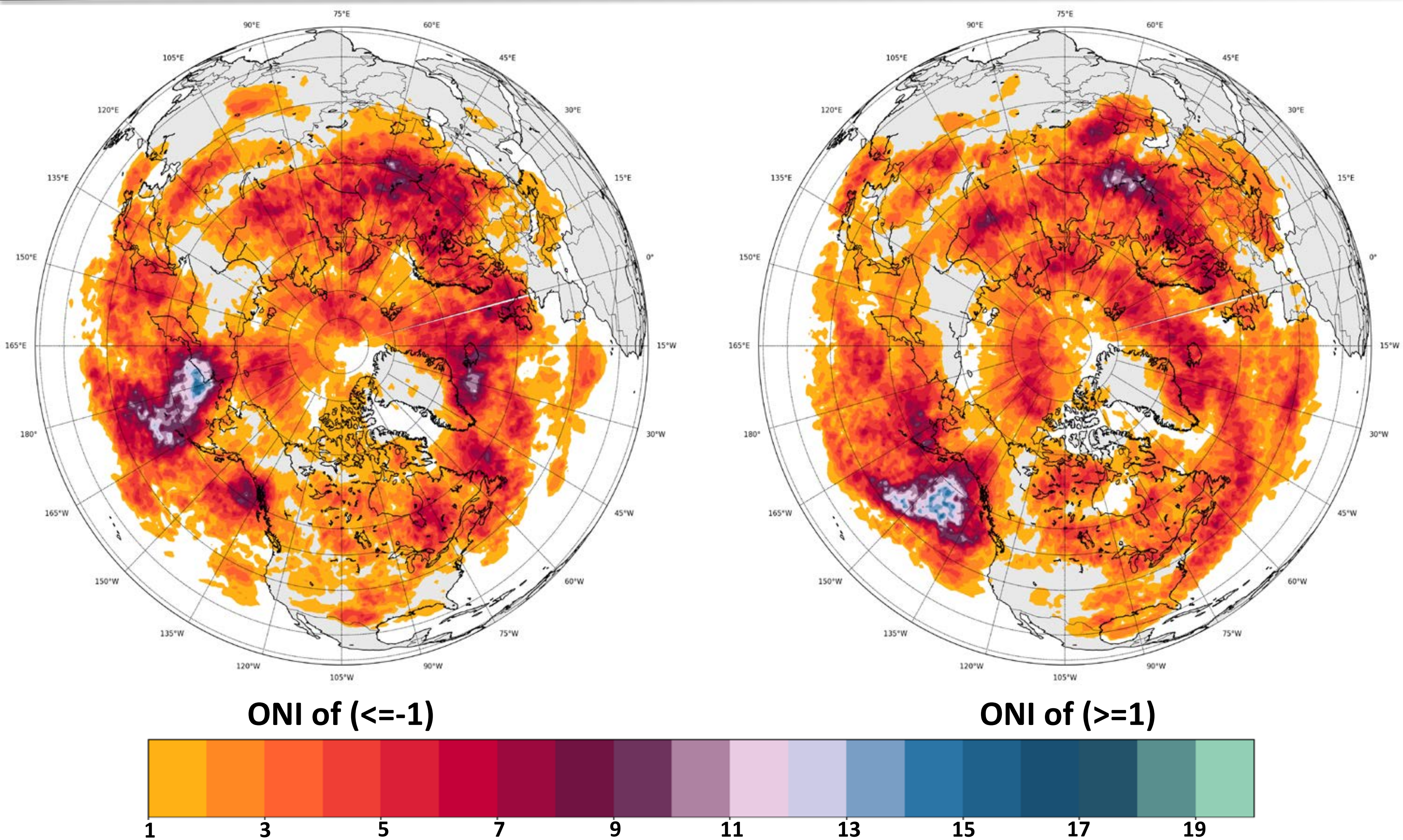
ONI of (<=-1)



ONI of (>=1)

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

Cyclone Clusters Vs. Oceanic Nino Index



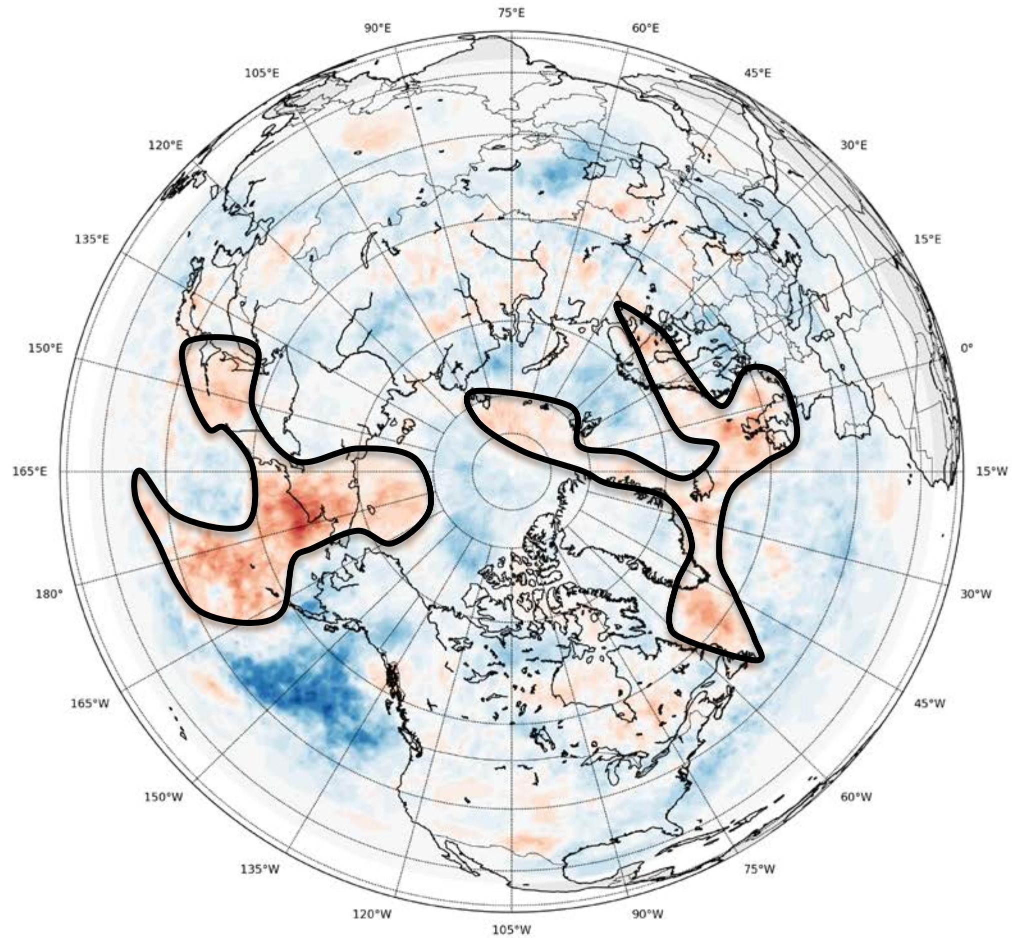
Average DJF ONI value of (<=-1) (left) and (>=1) (right) of two or more clustered cyclones

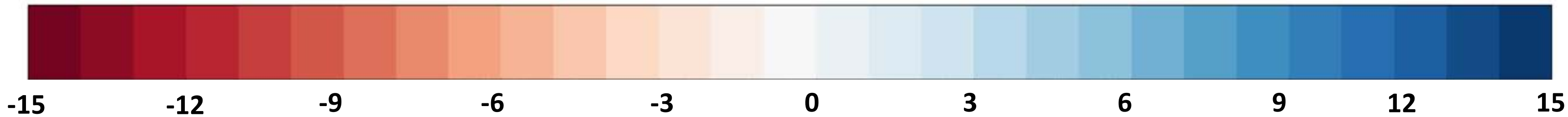
Cyclone Clusters Vs. Oceanic Nino Index

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.

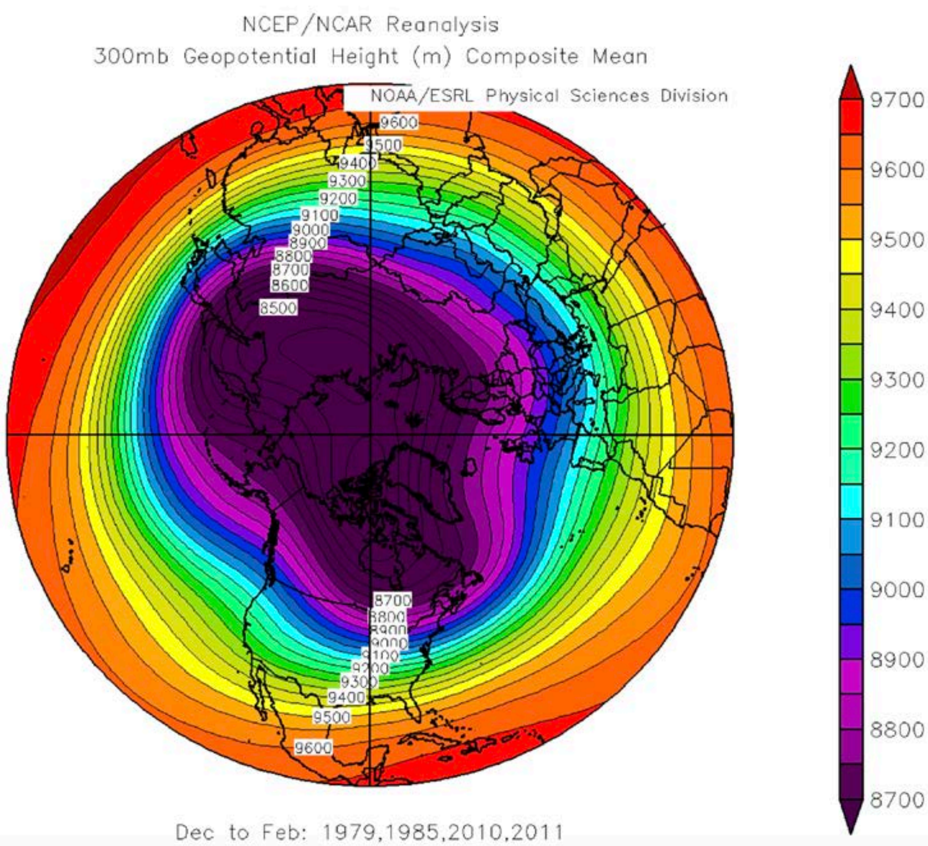
clusters favor north-central PAC and north-central ATL during La-Nina years.



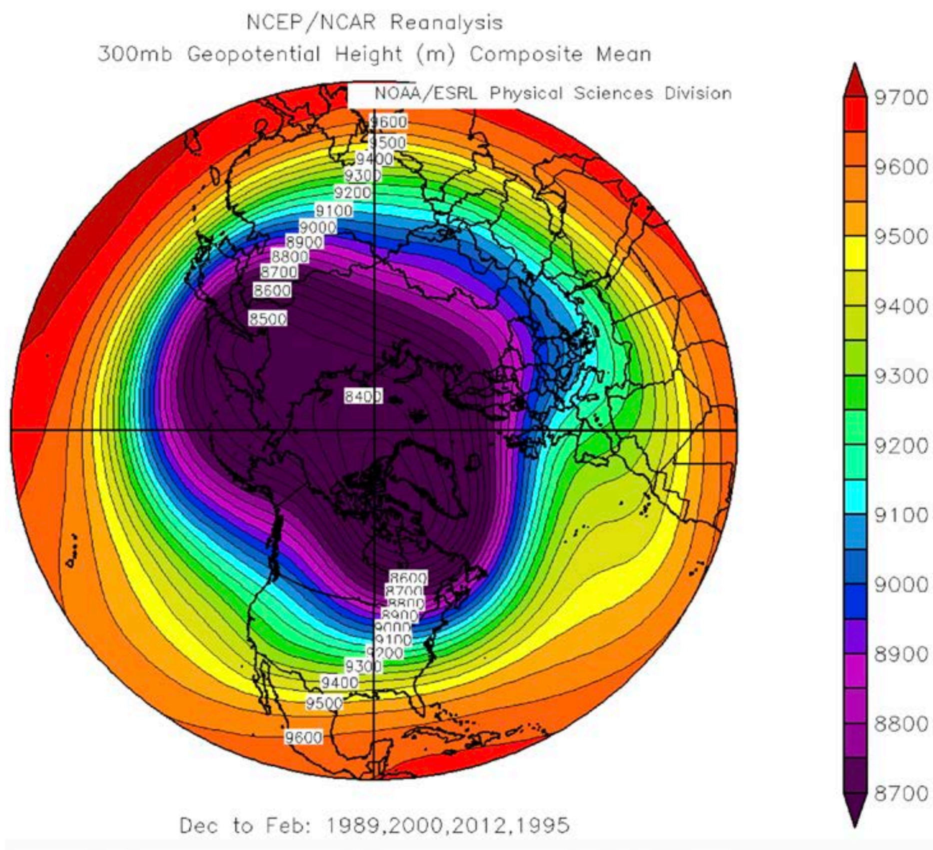


Difference between positive ONI and negative ONI

Cyclone Clusters Vs. NAO



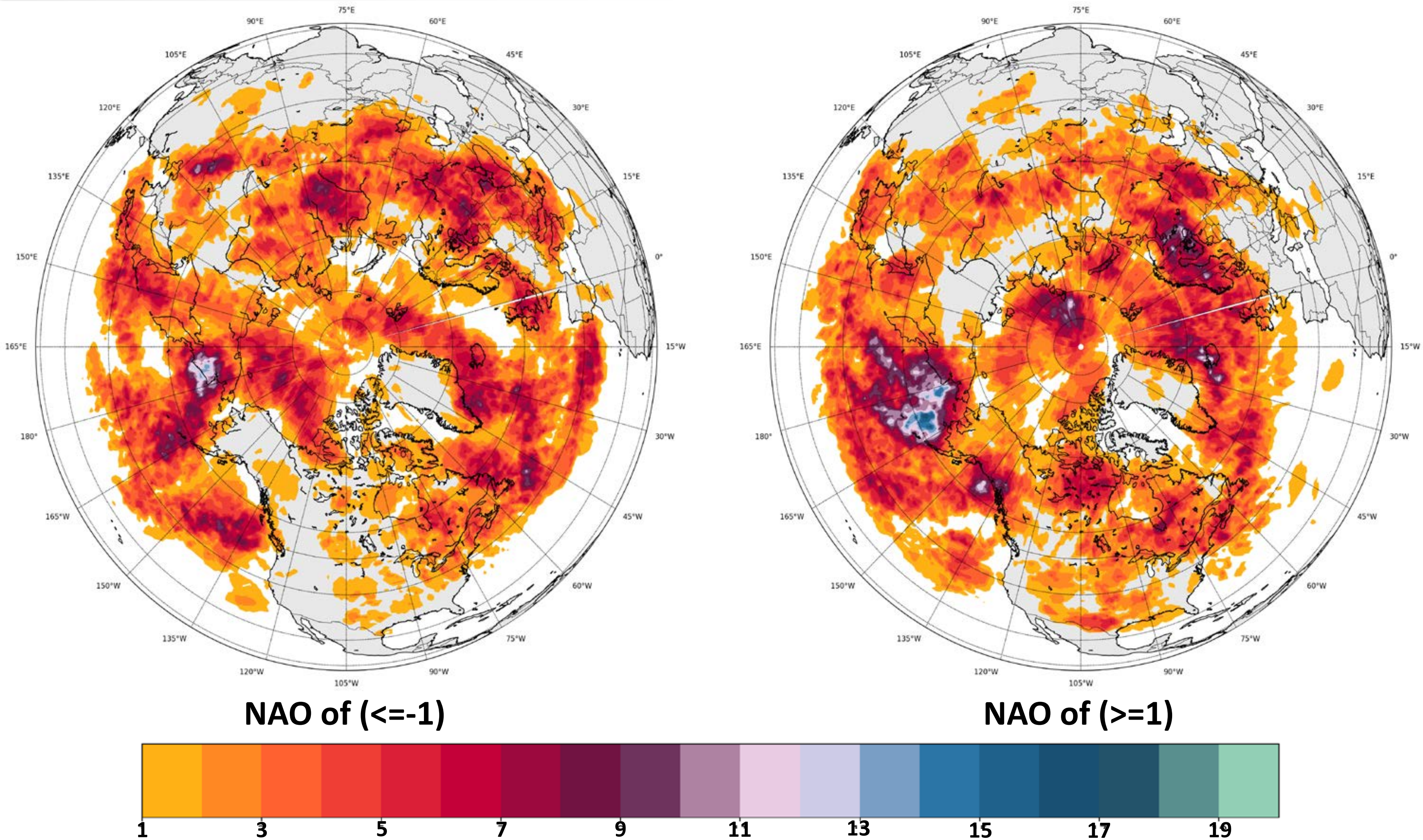
NAO of (<=-1)



NAO of (>=1)

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

Cyclone Clusters Vs. NAO

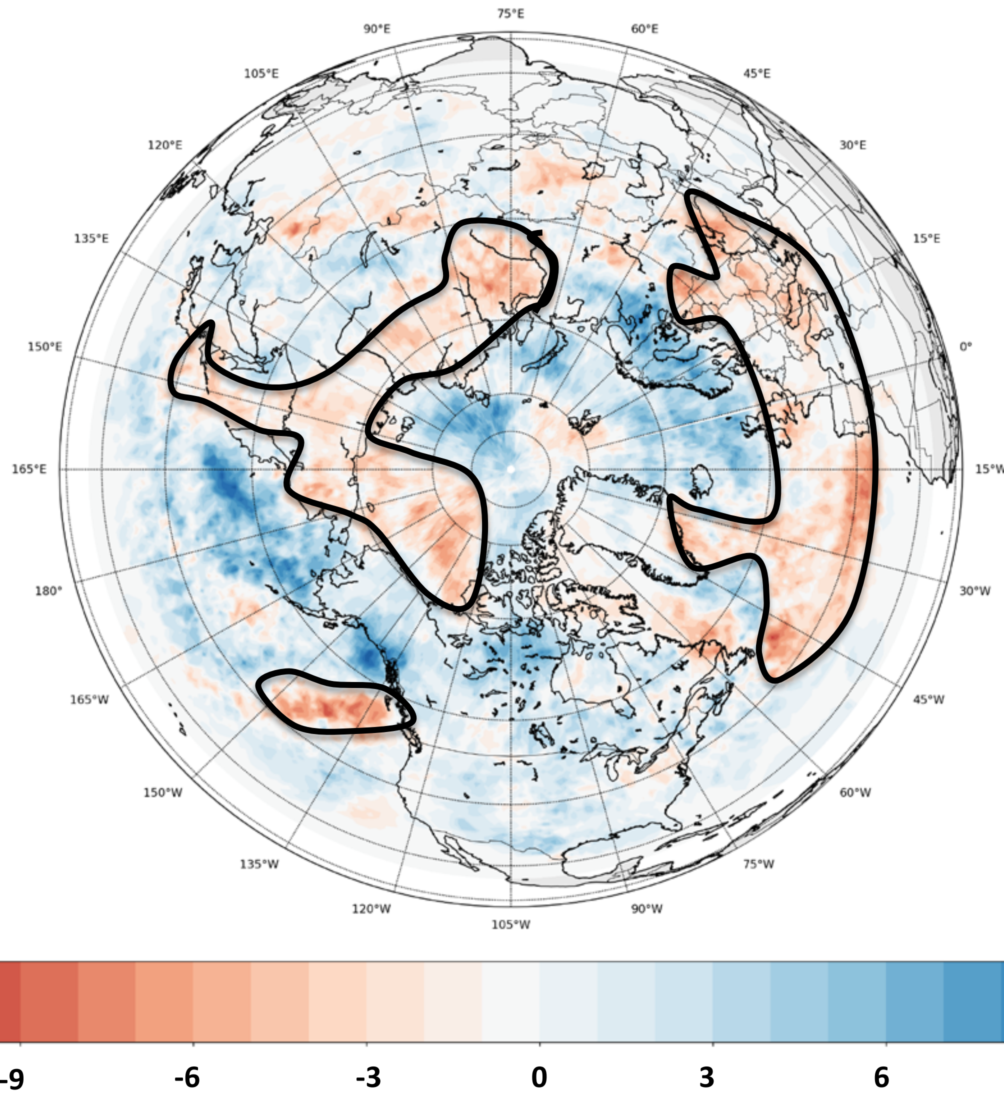


Average DJF NAO value of (<=-1) (left) and (>=1) (right) of two or more clustered cyclones

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.

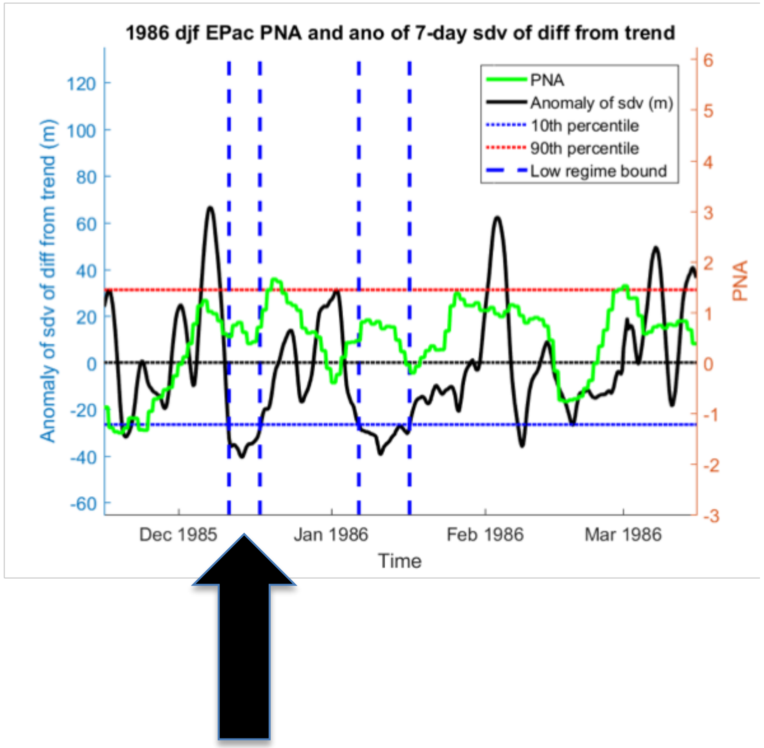
Difference between positive NAO and negative NAO

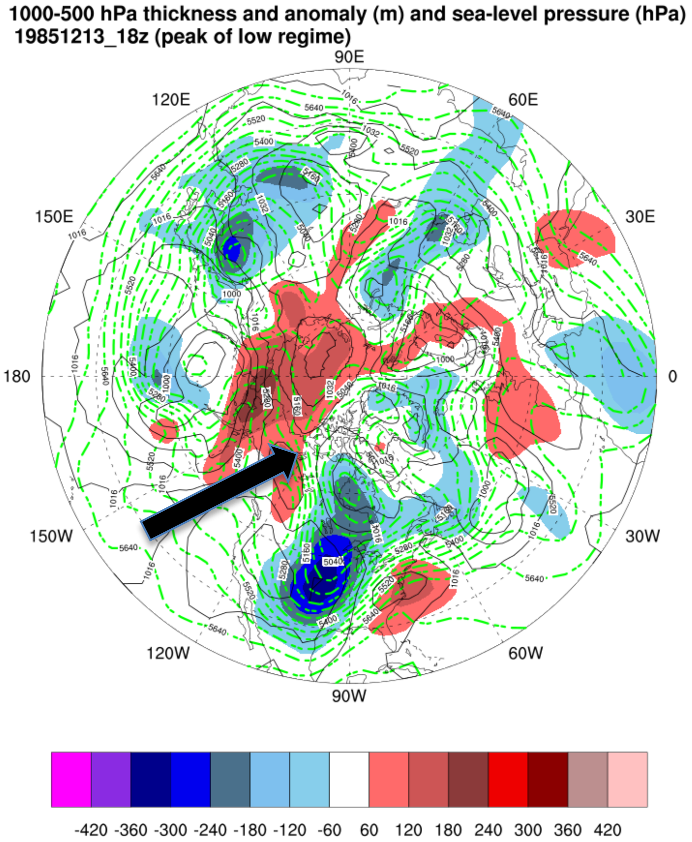
Regime classifications and prediction

- 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

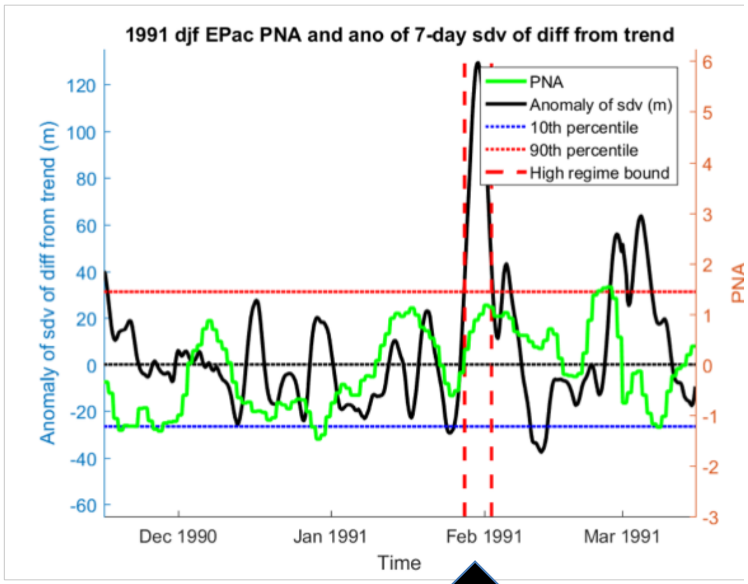


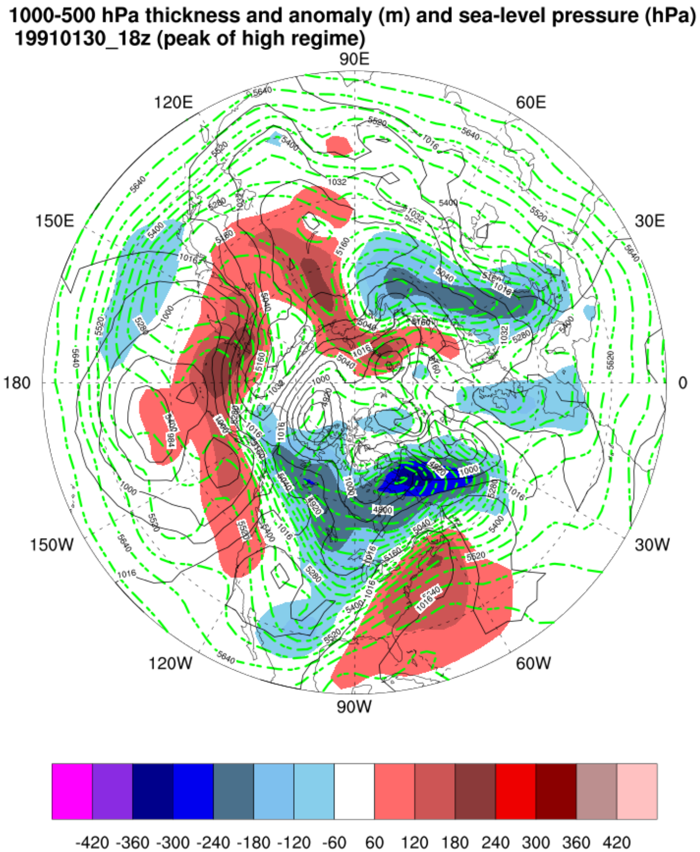


Low-variance regime of December 1985 (a pineapple express case); Roberge et al. 2009

High-variance regime example
The cold season of 1990-91

1800 UTC, 30 January 1991



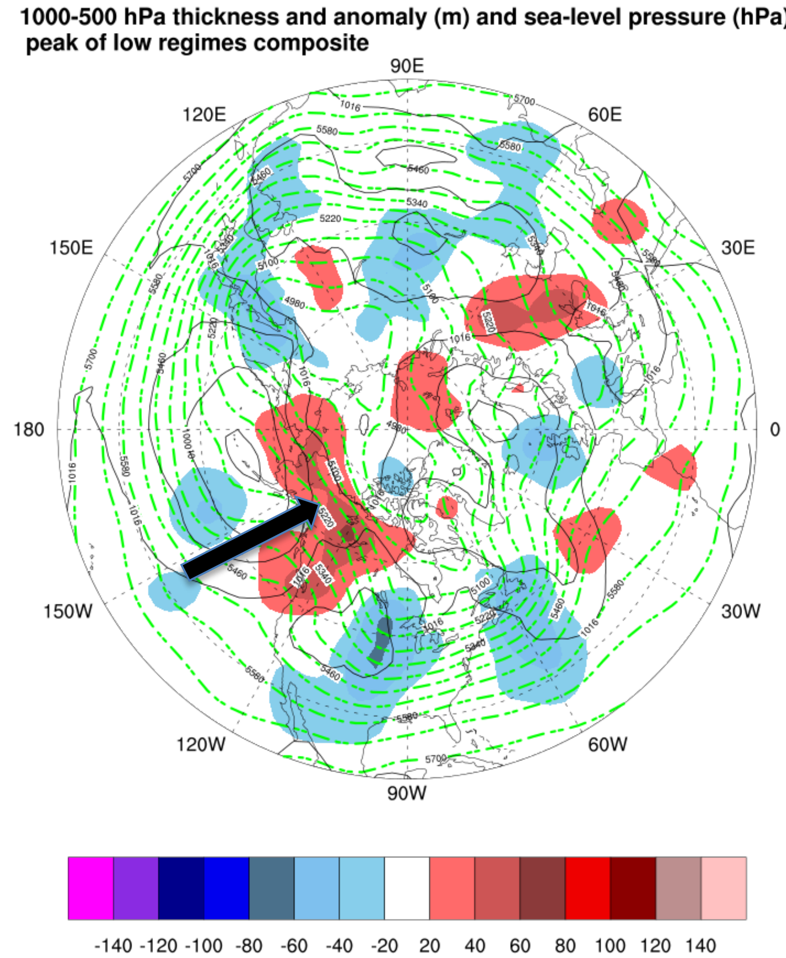


High-variance regime case of Jan-Feb 1991

Extreme Precipitation

Pineapple express/atmospheric rivers (*low variance*)

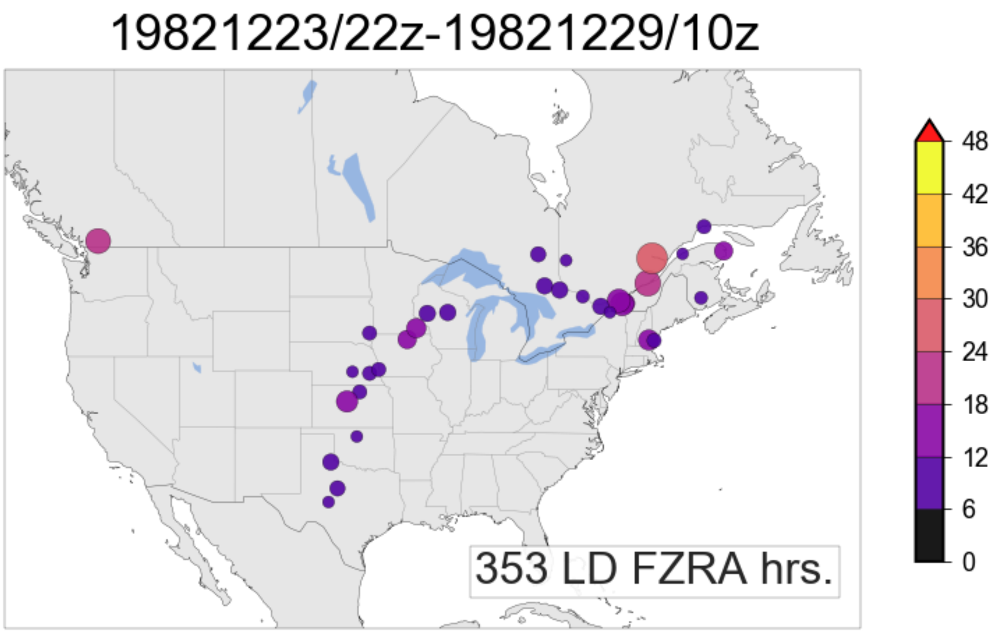
1. Roberge et al. (2009): four cases
2. Lackmann et al. (1998): one case
3. Lackmann et al. (1999): one case (17-18 Jan. 1986)
4. Turner and Gyakum (2011): one case of Arctic air mass generation

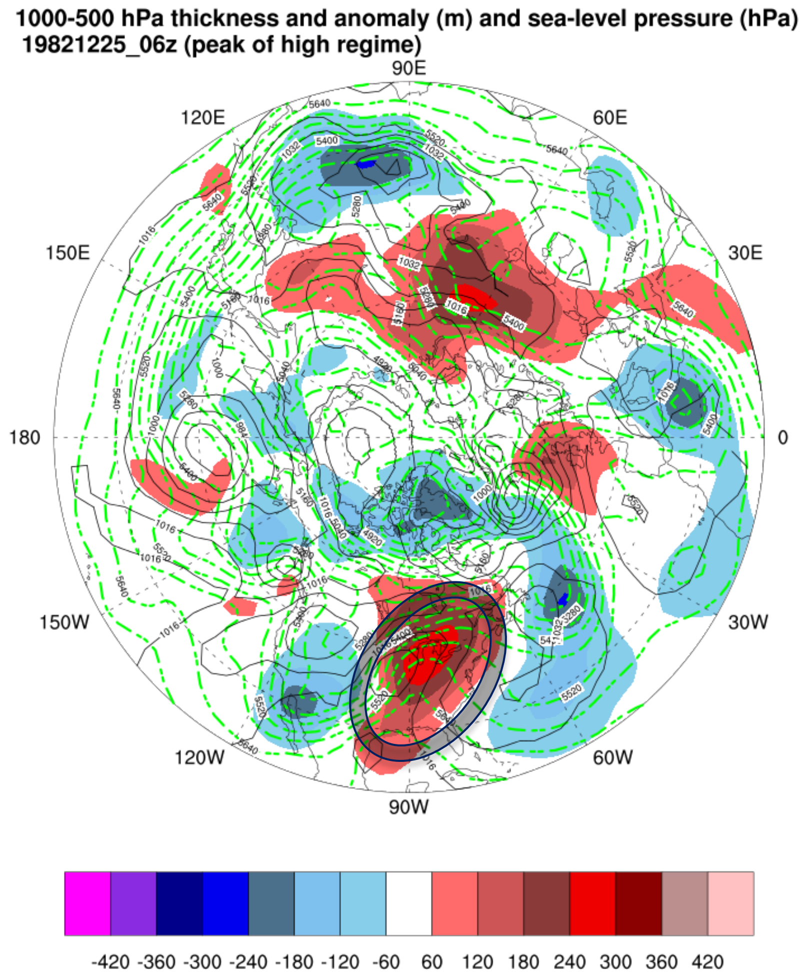


Low-variance regimes (composite; 18 cases; SLP and 1000-500 hPa thickness anomaly)

Extreme Precipitation

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





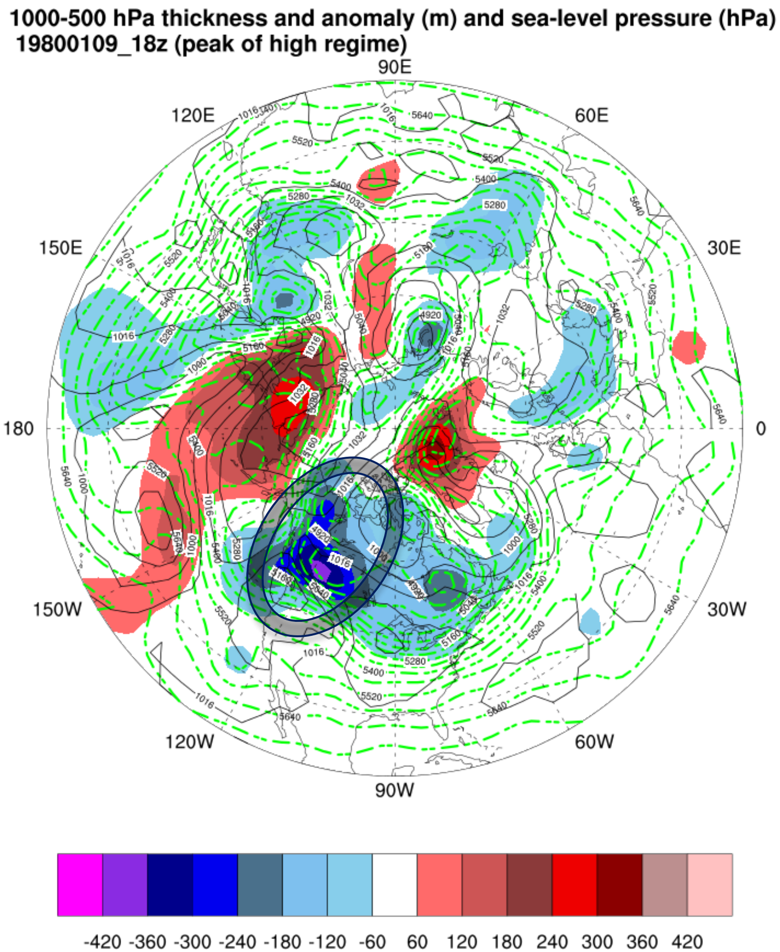
McCray (2018) case of long-duration freezing rain events (Dec. 82)

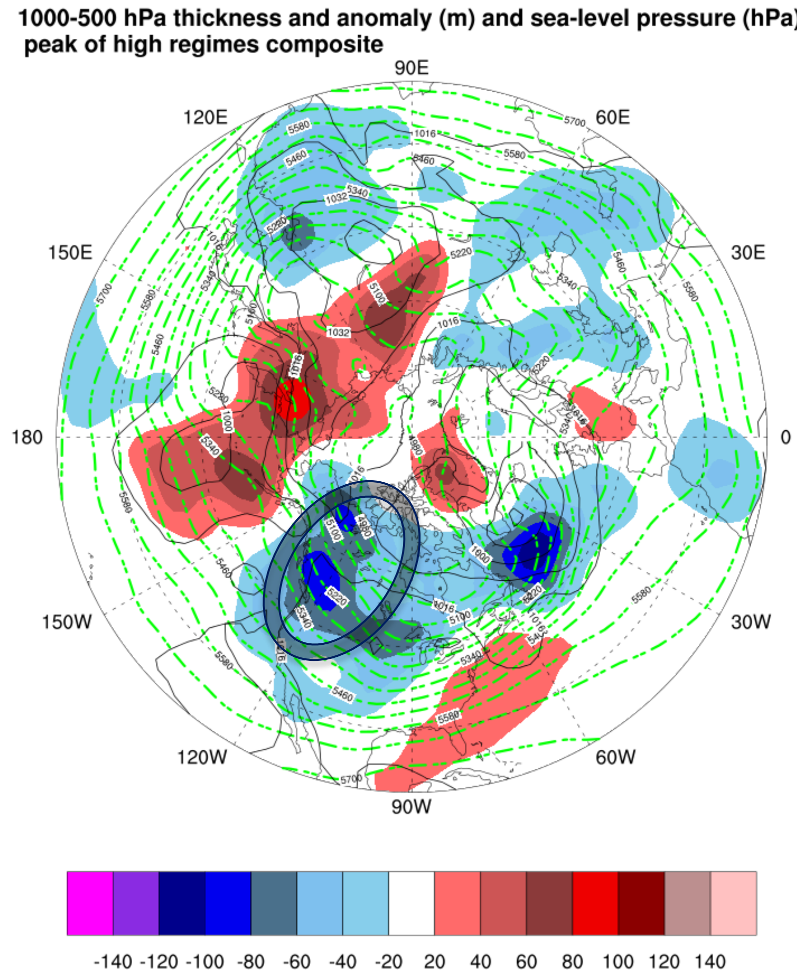
Wood (2015) case of extreme 850-hPa equivalent potential temperature

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

Extreme temperatures

Arctic air mass generation (*high variance*)



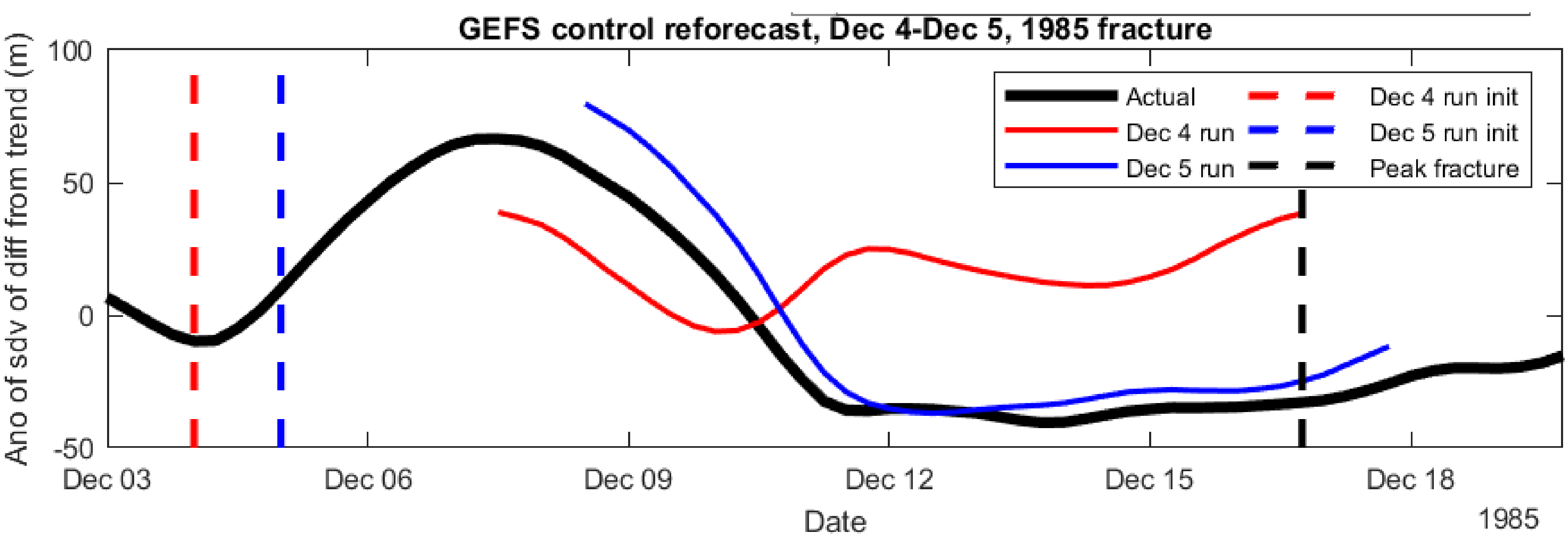


Bliankinshtein (2018) case of extreme Arctic air mass generation (3-9 Jan. 1980)

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

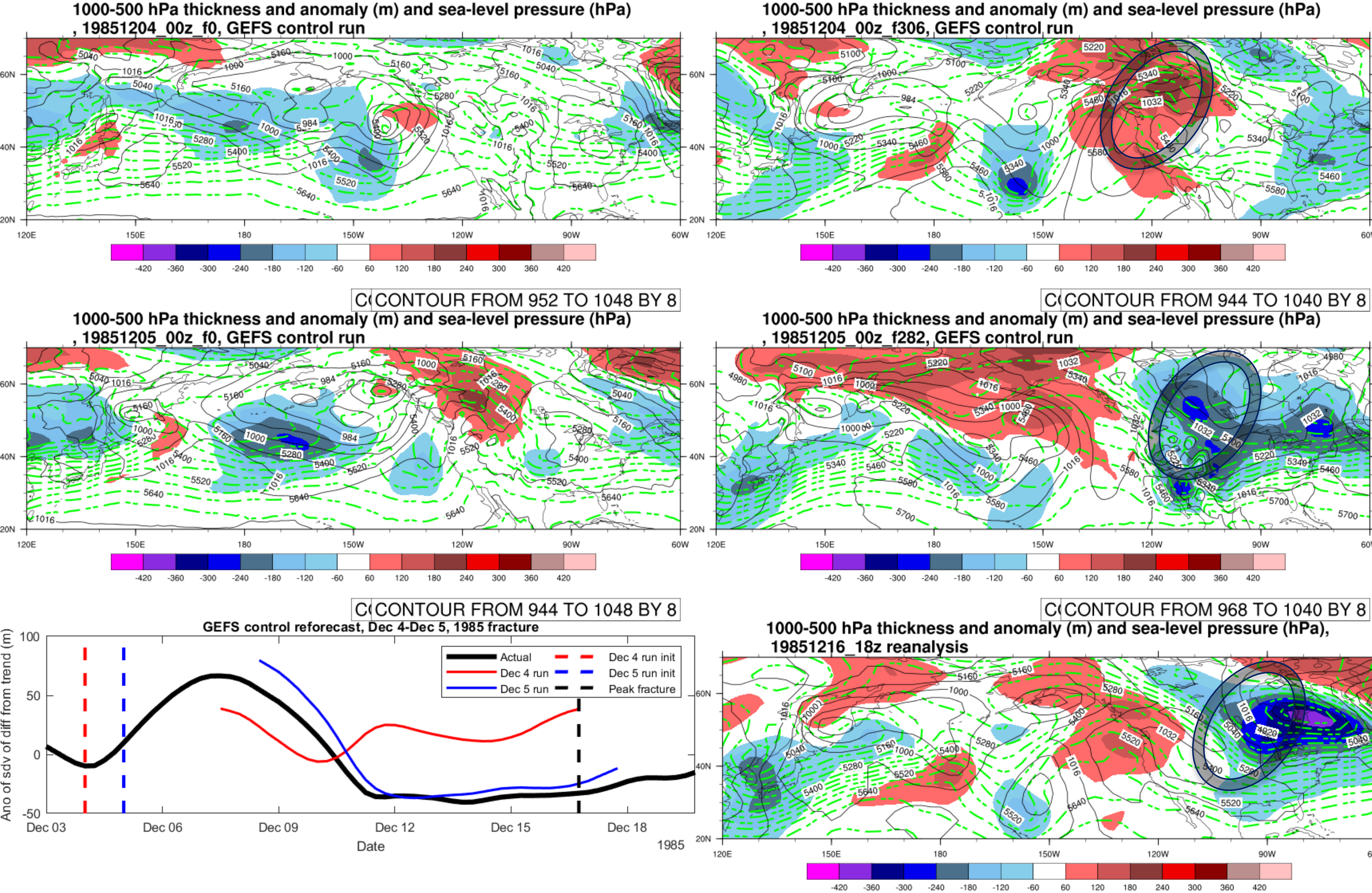
Regime Prediction (Forecast "fractures")

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

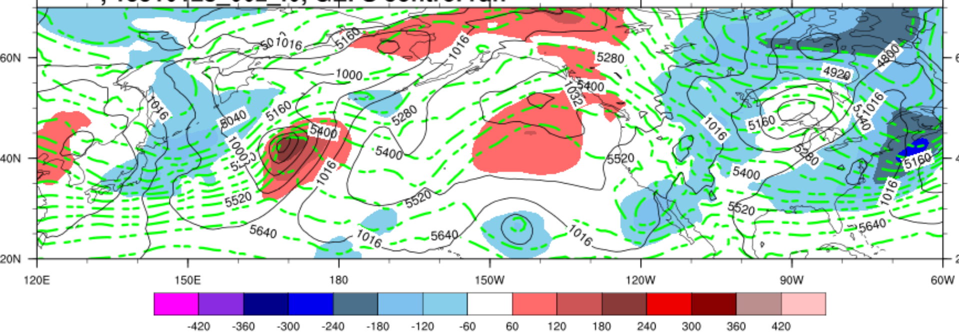
(12/13 days)



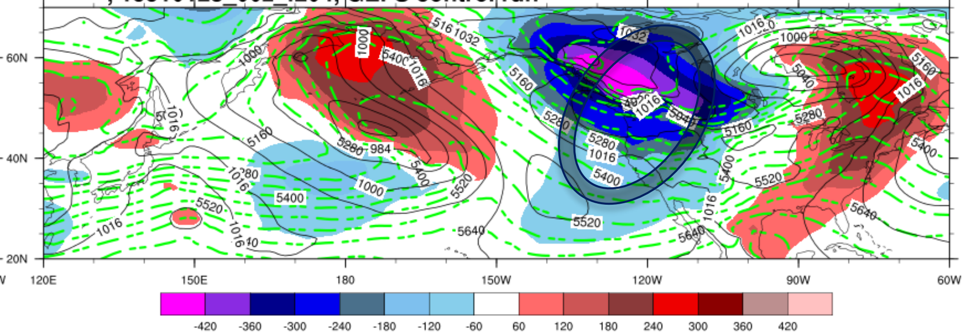
Forecast fracture (180/204 h) in *high-variance* regime of Jan-Feb 1991

(7.5/8.5 days)

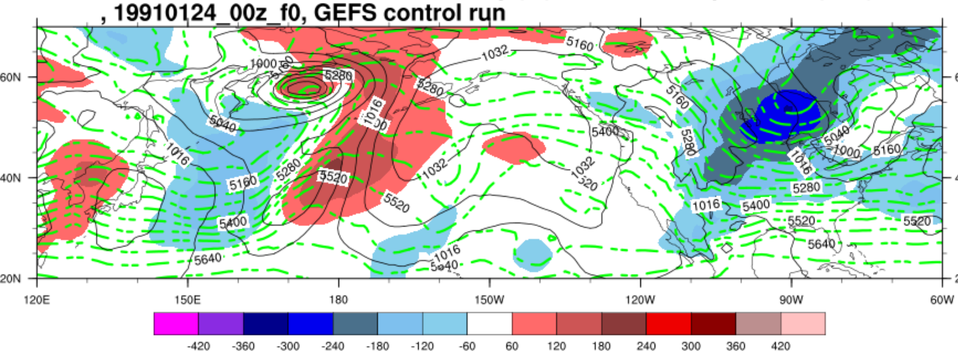
1000-500 hPa thickness and anomaly (m) and sea-level pressure (hPa)
, 19910123_00z_f0, GEFS control run



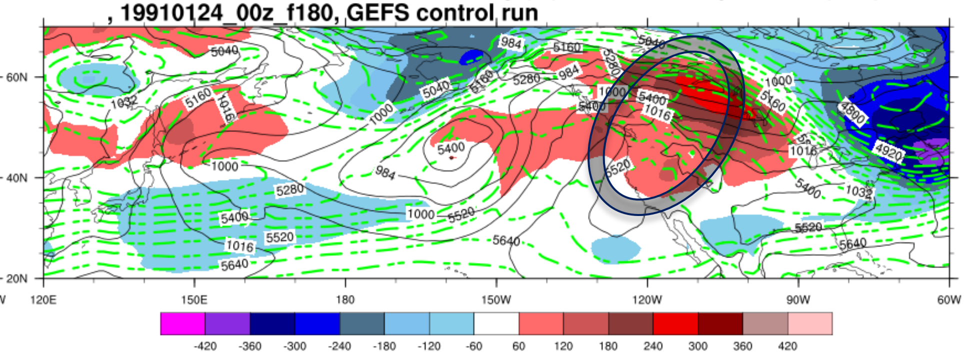
1000-500 hPa thickness and anomaly (m) and sea-level pressure (hPa)
, 19910123_00z_f204, GEFS control run

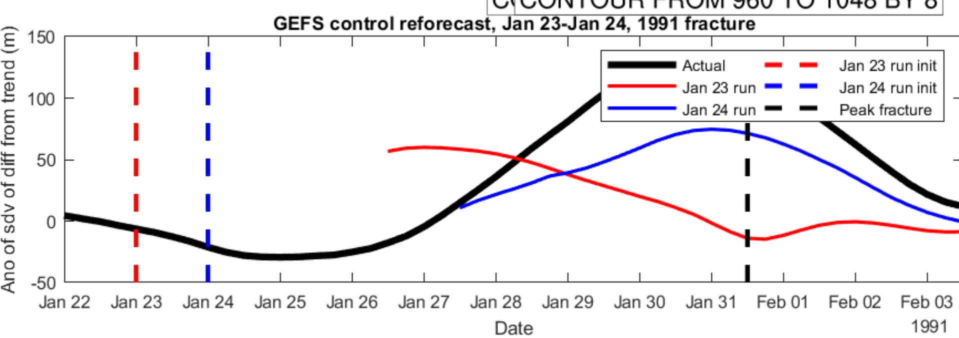


1000-500 hPa thickness and anomaly (m) and sea-level pressure (hPa)
, 19910124_00z_f0, GEFS control run

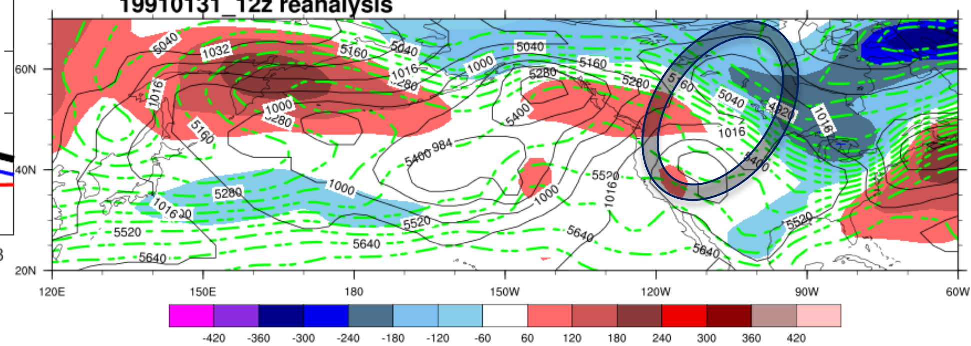


1000-500 hPa thickness and anomaly (m) and sea-level pressure (hPa)
, 19910124_00z_f180, GEFS control run





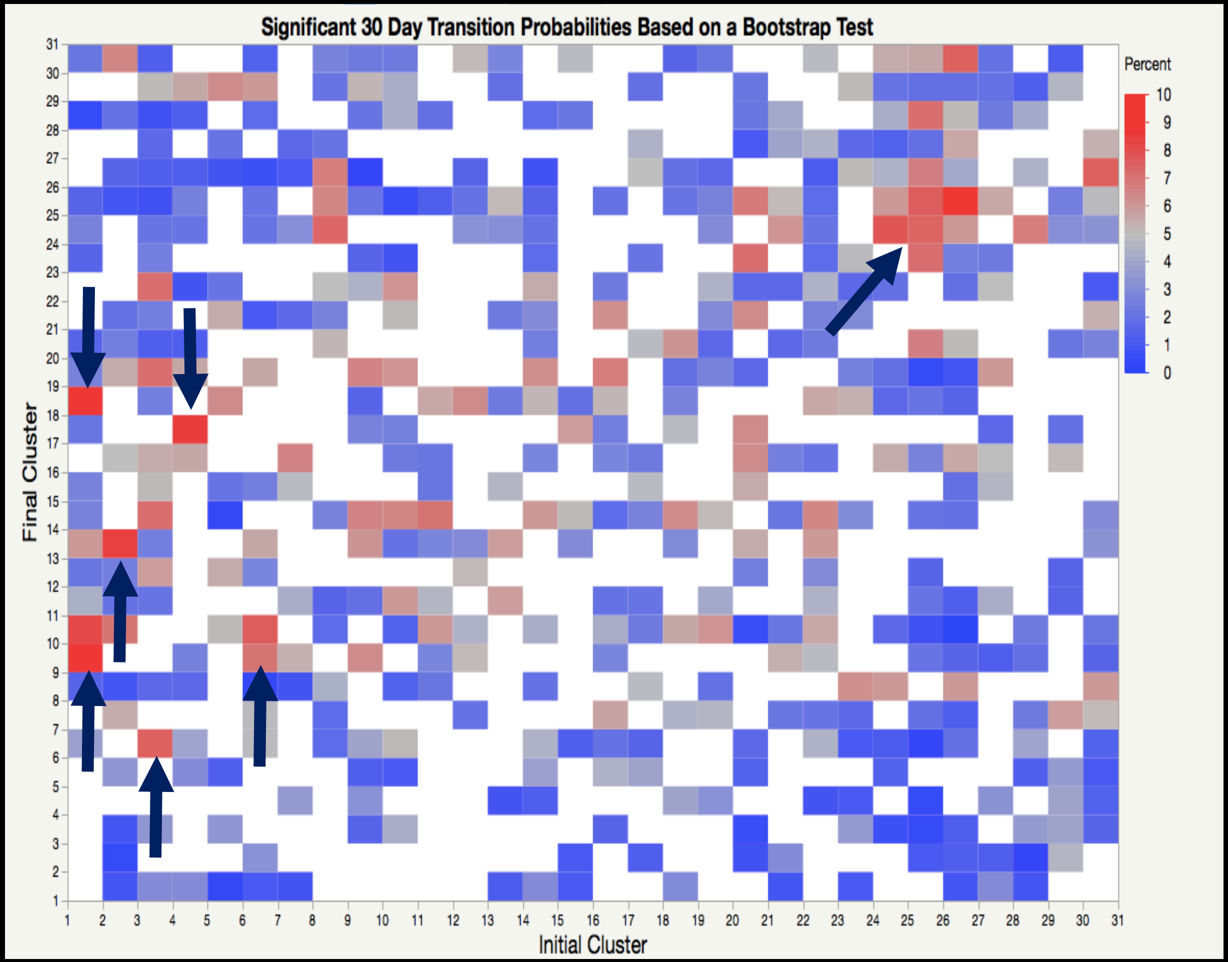
1000-500 hPa thickness and anomaly (m) and sea-level pressure (hPa),
19910131_12z reanalysis



Regime Classificiation - SOM

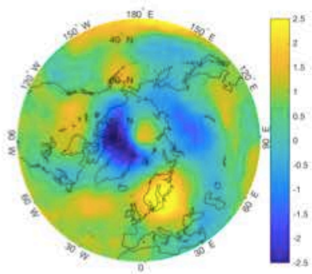
- **Compare weather regime classifications defined via several methods (SOM using theta on the DT; SUNYA results via clustering; McGill results via GC metric) and evaluate predictability**
- **Evaluate predictive utility of regime transition probabilities**
- **Evaluate robustness of CFSv2 model climate**

Statistical Significance of 30 Day Transitions

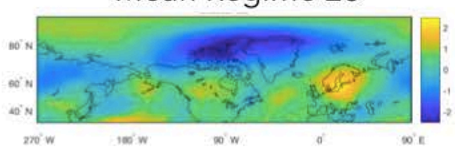


- Bootstrap test of the statistical significance:
  - high transitions are significant at the 95% level.
  - low transitions are also statistically significant.

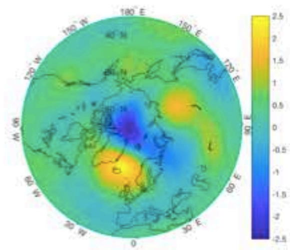
What do these regimes look like?



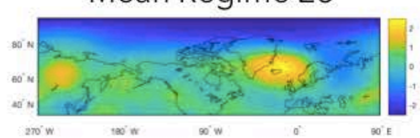
Mean Regime 25

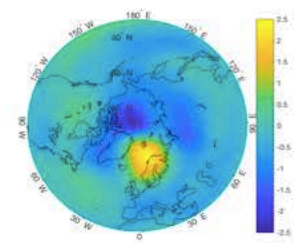


Transitions into…

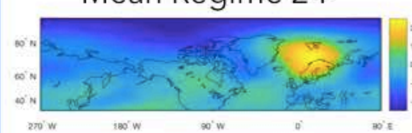


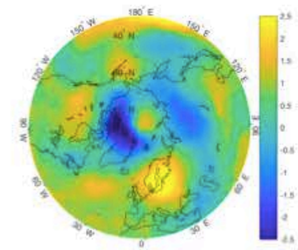
Mean Regime 23



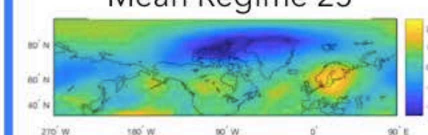


Mean Regime 24

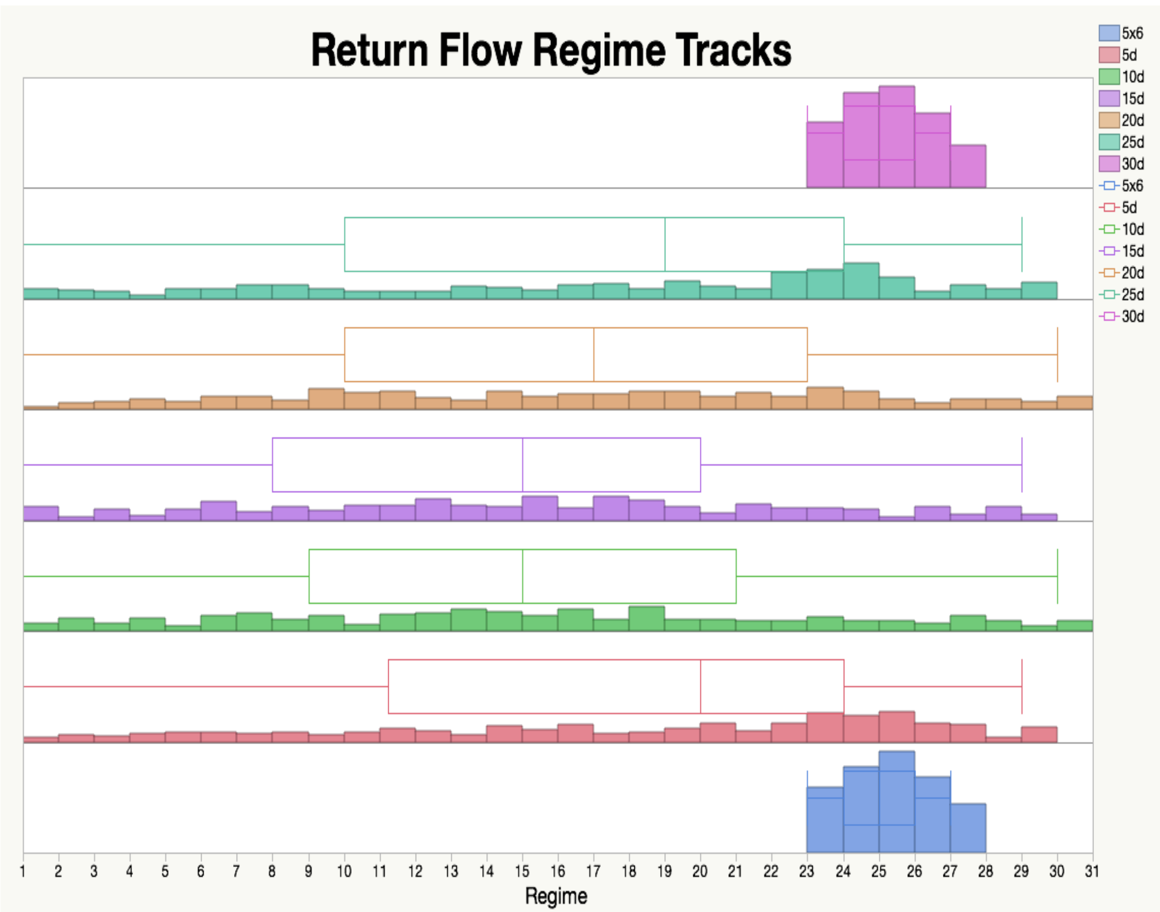




Mean Regime 25

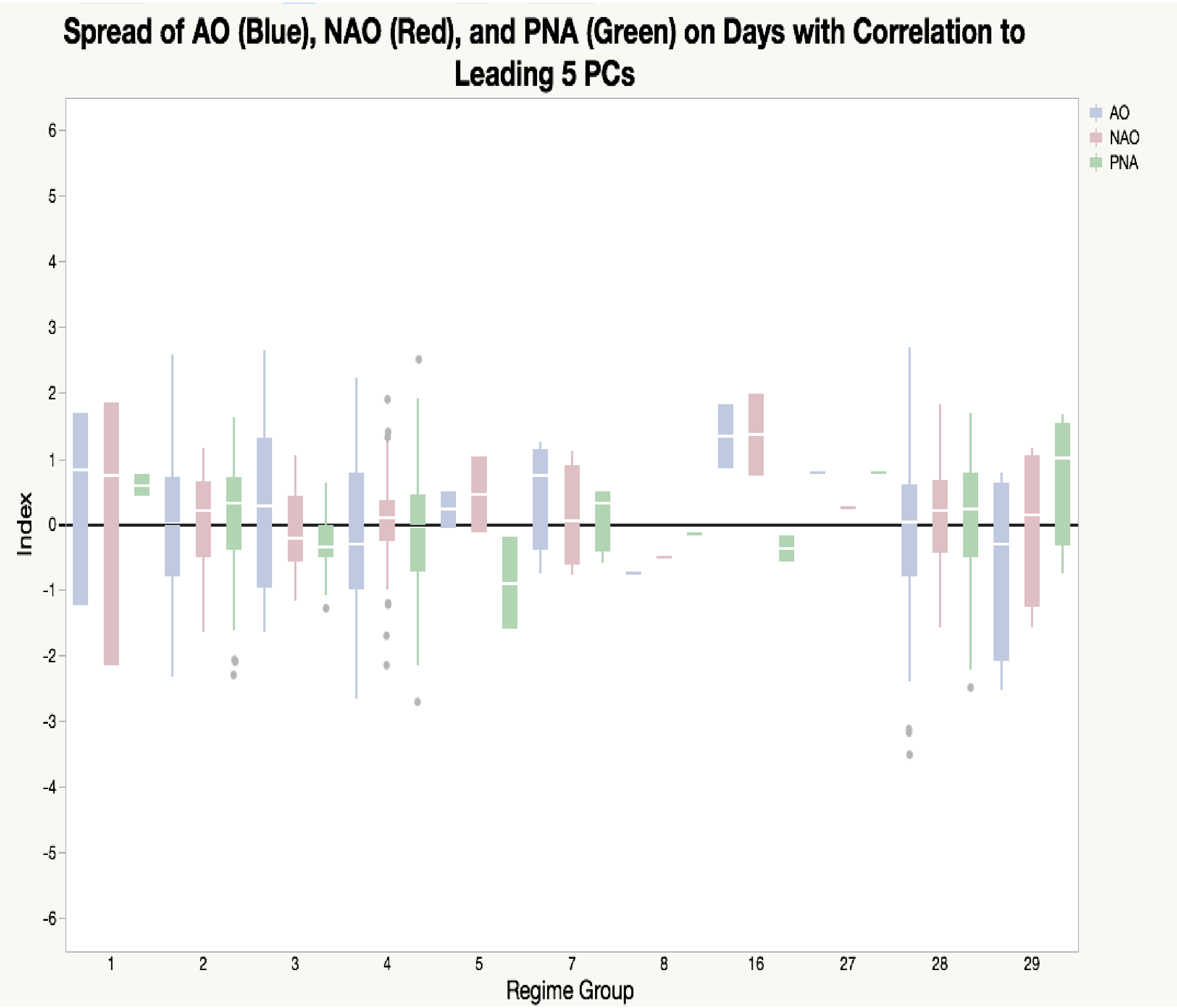


Recurrent Regime Pathways



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

Links to AO, PNA, and NAO



- **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

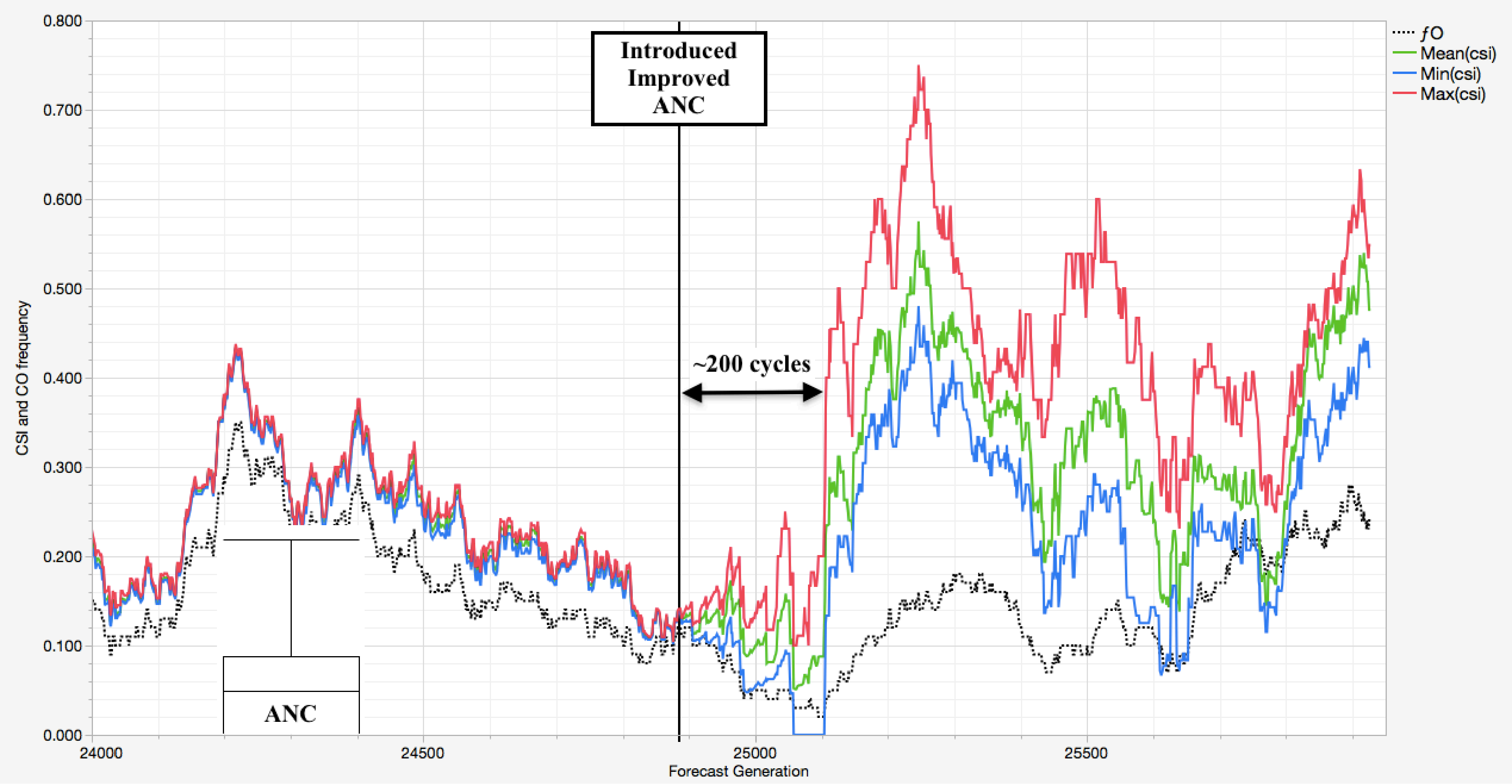
Using the principles of evolution to produce skillful NWP postprocessors

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*

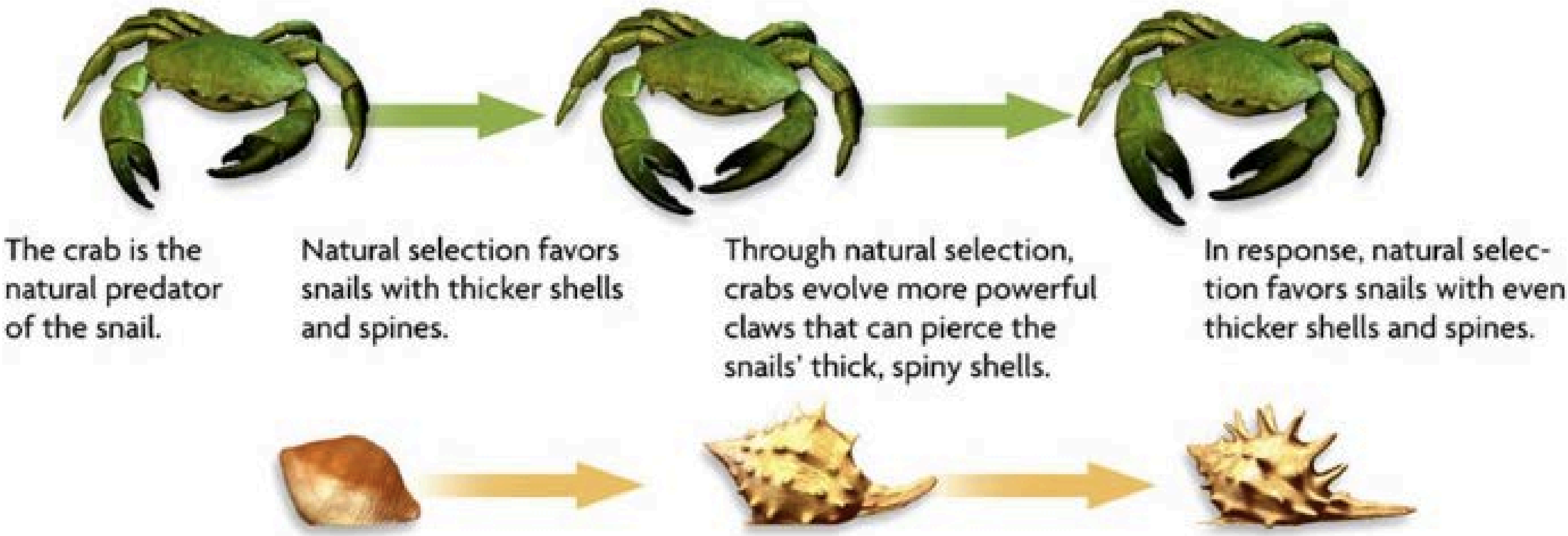
*Searching some small subset of the library of all possible solutions!

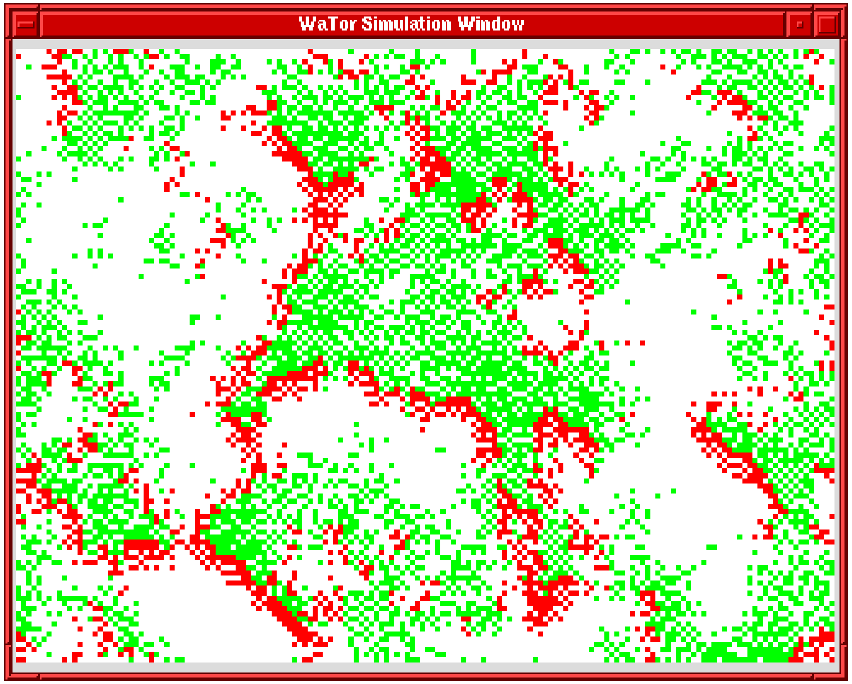
… and we can make this adaptive!

Note: CSI is computed from prior 100 forecast cycles



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



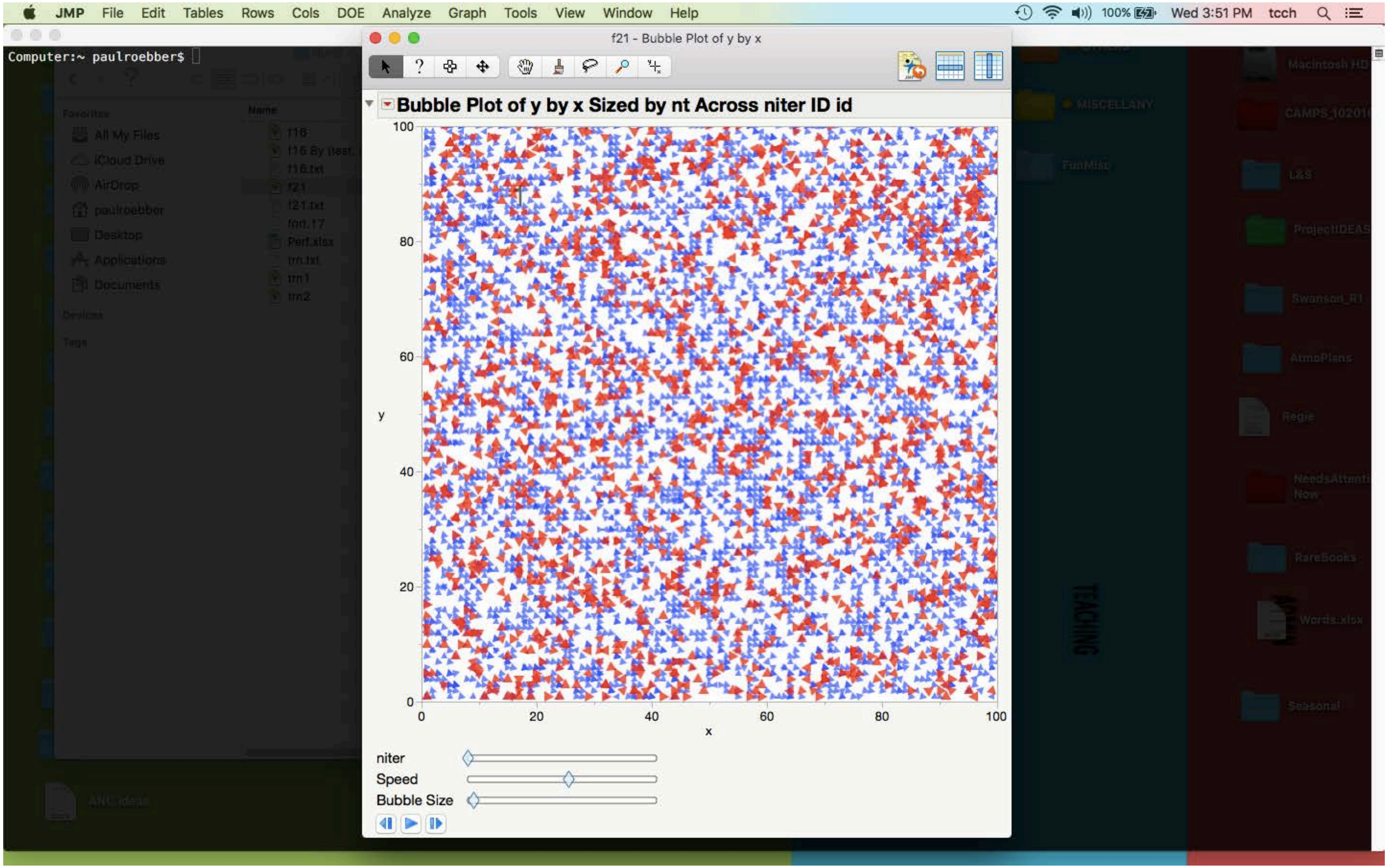


Predator-prey leads to clustering and thus might produce more genetic diversity over the domain (Dewdney 1984).

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 $\alpha_1 = f(RMSE\ for\ T, CSI\ for\ CO)$	Seek prey at location where maximum prey exist within the 3x3 neighborhood with probability $\alpha_2 = f(RMSE\ for\ T, CSI\ for\ CO)$
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.



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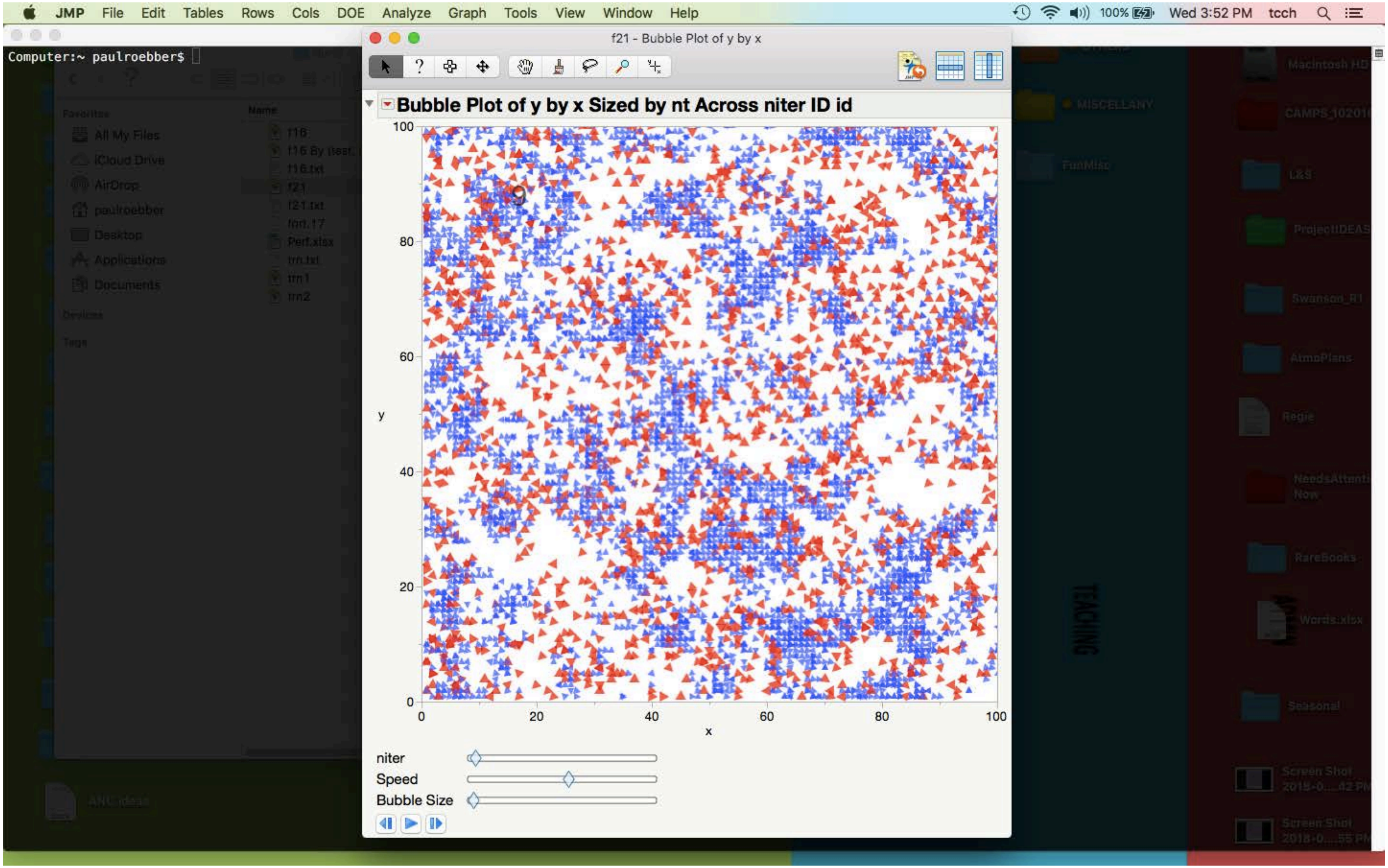

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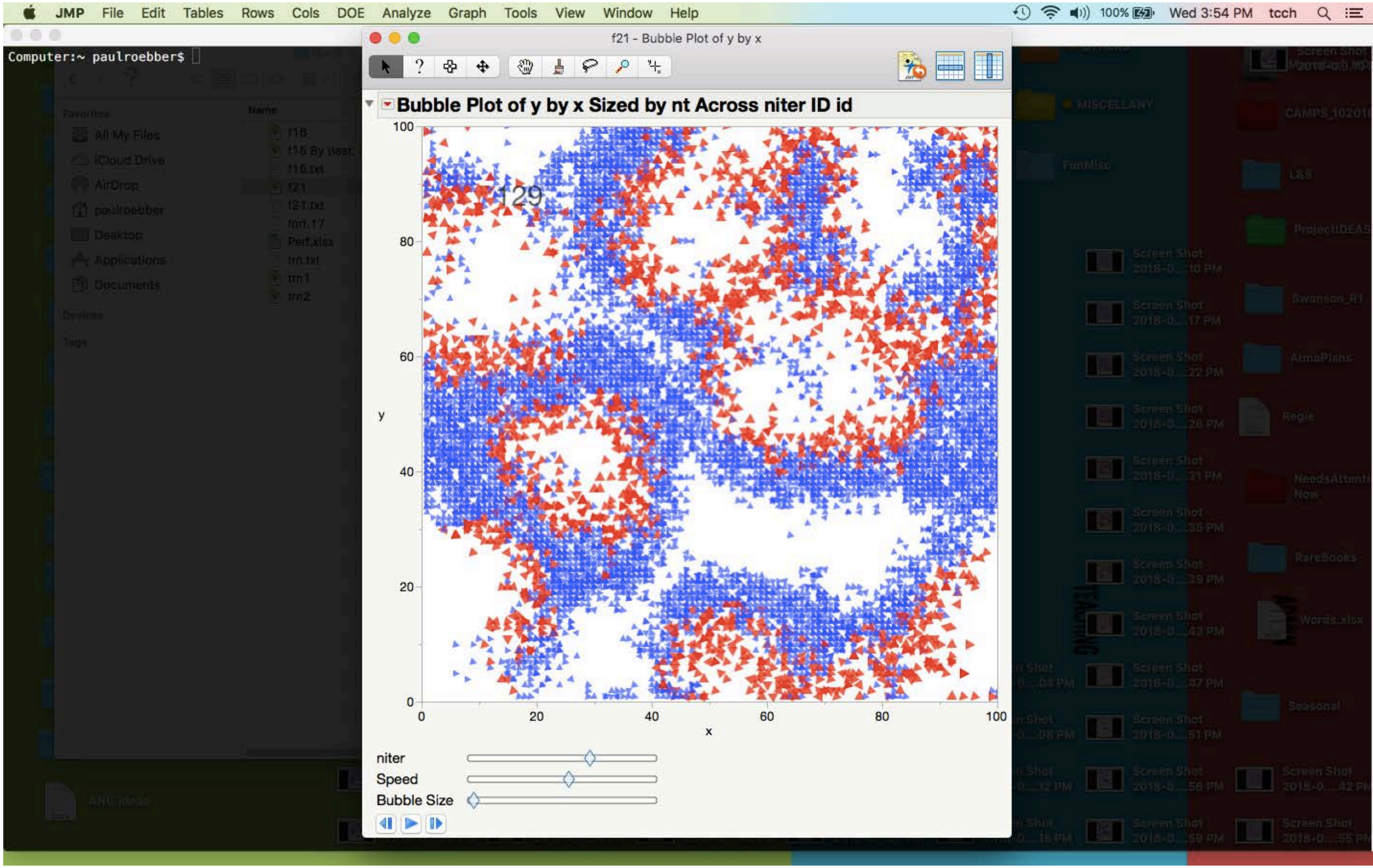
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Speed
Bubble Size

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)

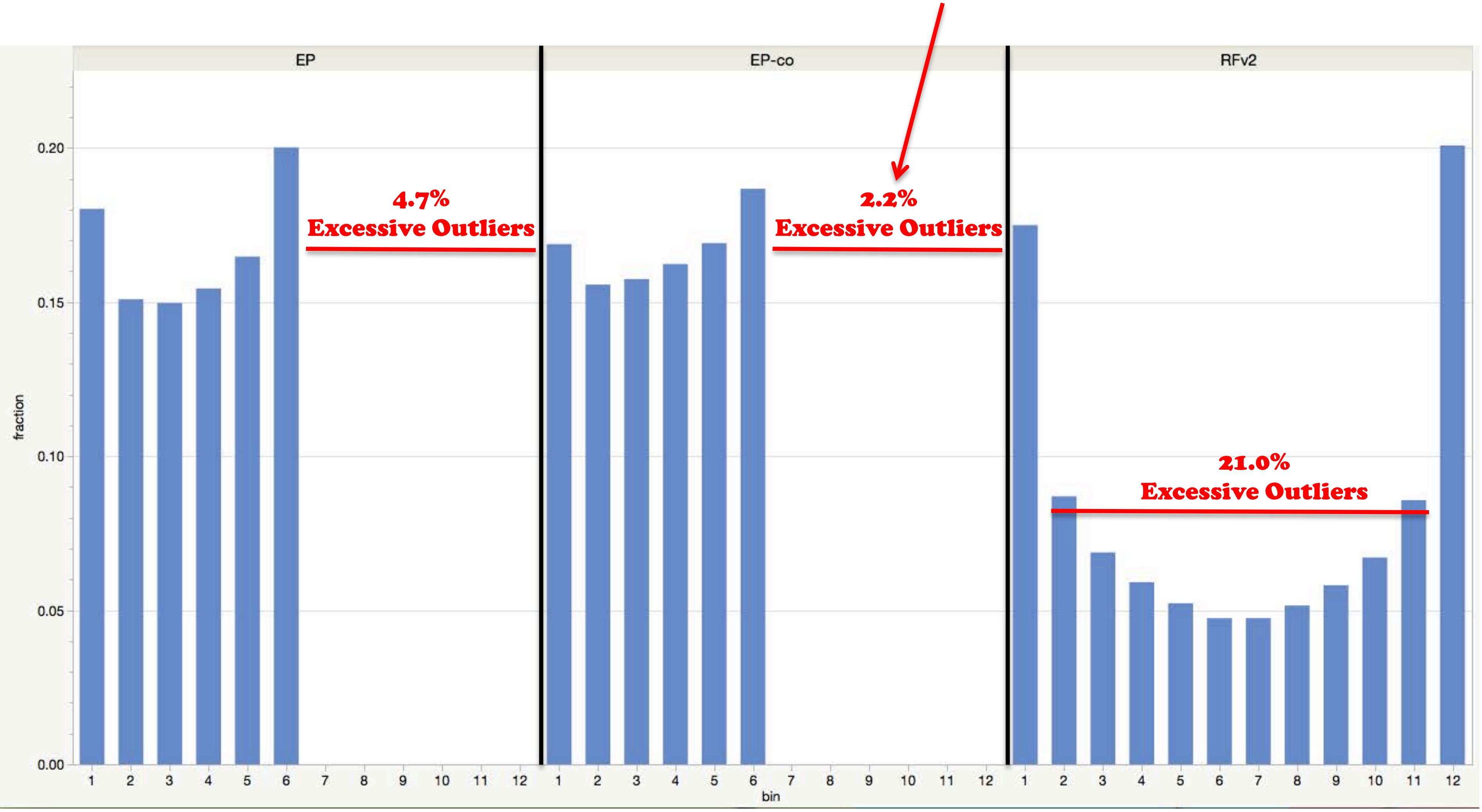
- **Probabilistic 72h T forecasts**

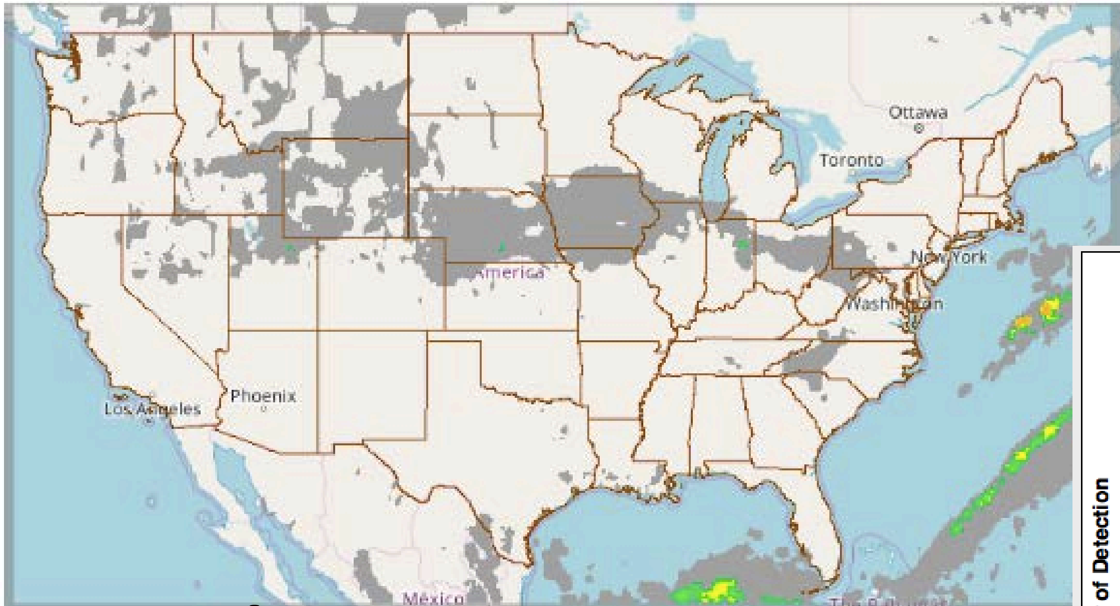
  Improves Ranked Probability Score

  - over standard EP by 3.6%

  - over RFv2 by 6.4 %

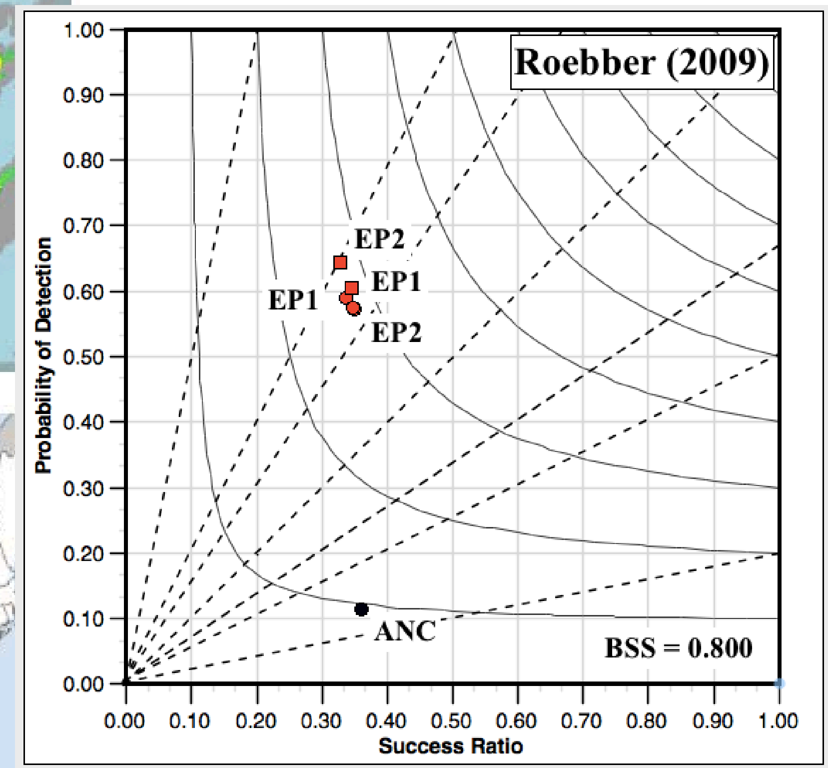
Impact of Co-evolution (reliability)

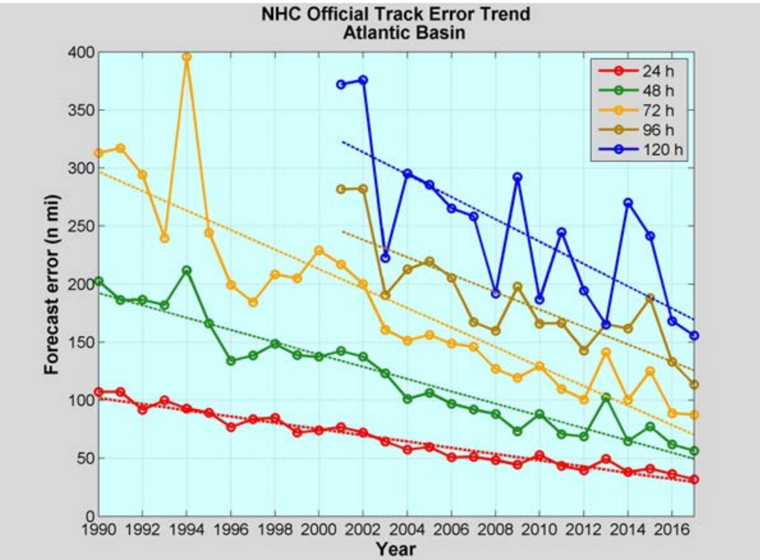


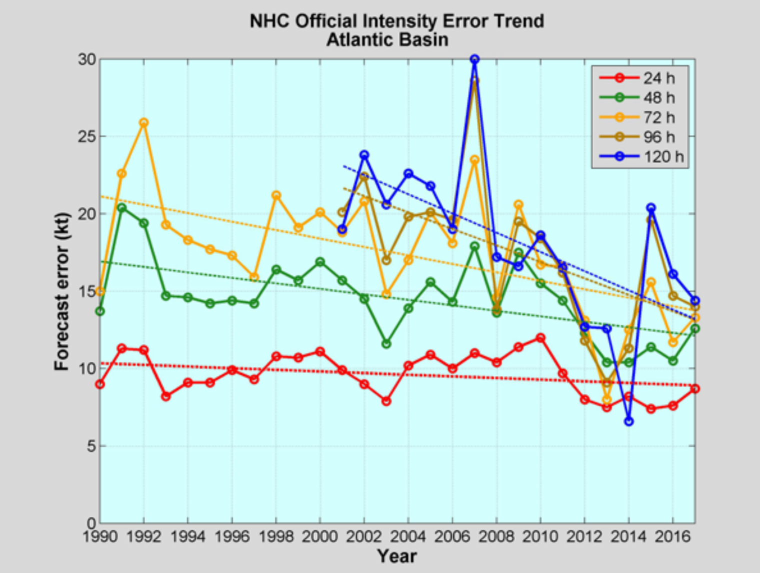


NOAA/MDL Autonowcaster

(convective occurrence)







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