Attribution of the Extreme U.S. East Coast Snowstorm Activity of 2010

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Introduction

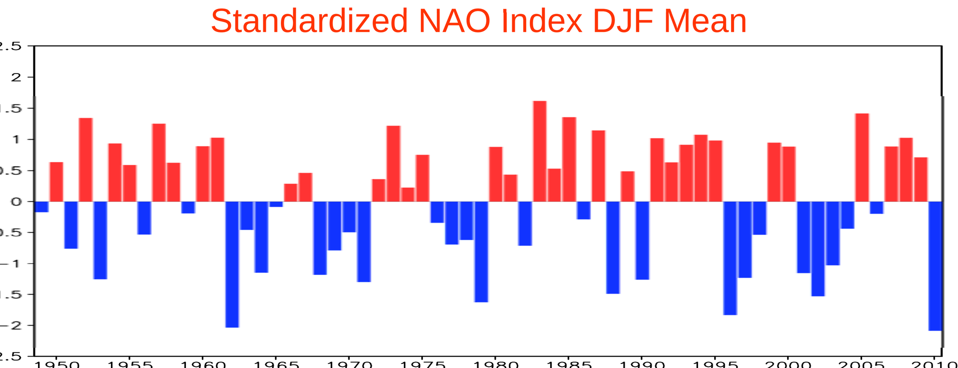
This study examines the cause of the extreme snowstorm activity along the US east coast during the winter of 2009/10 with a focus on the role of SST anomalies. The study employs the GEOS-5 AGCM run at high resolution and forced with specified observed or idealized SST. Comparisons are made with the winter of 1999/2000 – a period that is characterized by SST anomalies that are largely of opposite sign. When forced with observed SST, the AGCM response consists of a band of enhanced storminess extending from the central subtropical North Pacific, across the southern US, the North Atlantic, and across southern Eurasia, with reduced storminess to the north of these regions. Positive precipitation and cold temperature anomalies occur over the eastern US reflecting a propensity for enhanced snowstorm activity. Additional idealized SST experiments show that the anomalies over the US are to a large extent driven by the ENSO-related Pacific SST. The North Atlantic SST contribute to the cooler temperatures along the east coast, while the Indian Ocean SST act primarily to warm the central part of the country.

History of US East Coast Snow Storms

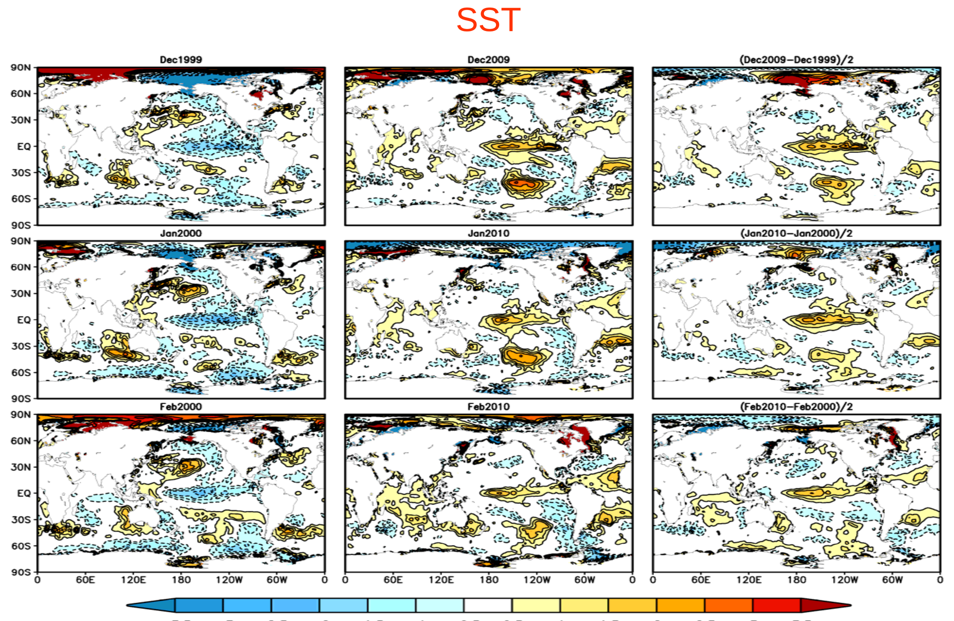
- ***Seasonality of Number of Storms:***
  - *Nov - 2*
  - *Dec - 7*
  - *Jan - 12*
  - *Feb - 22*
  - *Mar - 10*
  - *Apr - 2*

- ***Impact of ENSO phase (# of storms):***
  - *Cold: 5*
  - *ENSO Warm: 22*
  - *Neutral: 26*
- ***Impact of NAO:***
  - *2009/2010: El Nino, negative NAO*
  - *1999/2000: La Nina, positive NAO*

Standardized NAO Index DJF Mean



SST



SST anomalies with respect to the long term mean (Dec 1979 – Feb 2010). Left panels: December, January, February of 1999/2000. Middle panels: December, January, February of 2009/2010. Right panels: The difference fields (2009/2010 - 1999/2000) divided by 2. Units: °C.

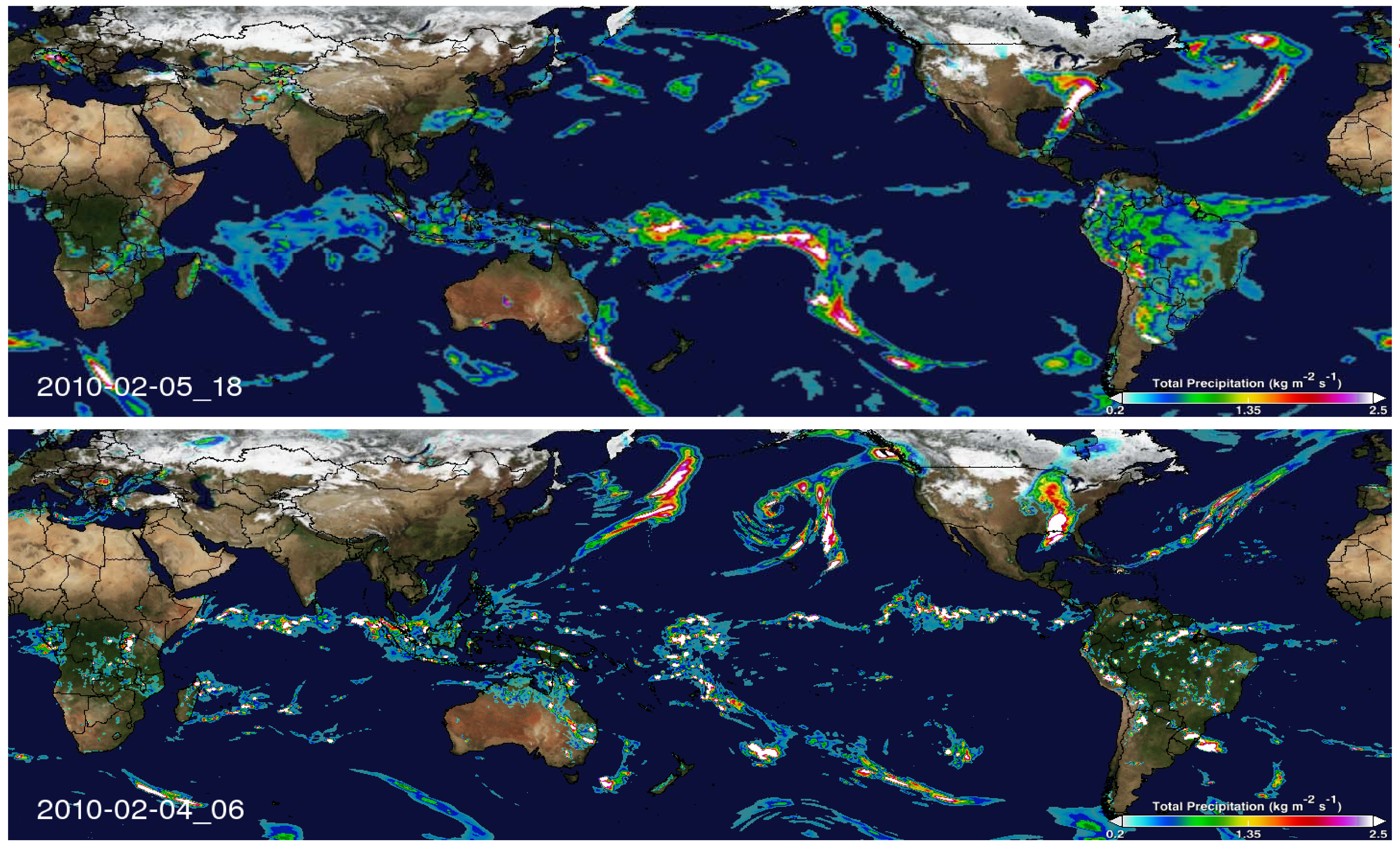
GEOS-5 Hindcasts

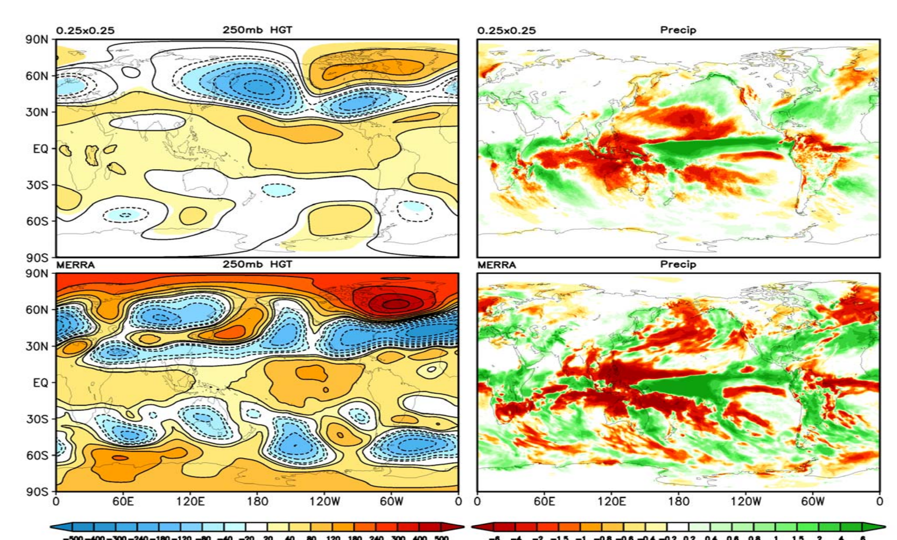
Table The GEOS-5 AGCM hindcast experiments. The "Switched NA" runs have the SST fields in the Atlantic (between 10°S to 75°N) switched between the two winters. The "Switched Ind" runs have the SST fields in the Indian Ocean switched between the two winters. Each run has 50 ensemble members. The primes indicate a model horizontal latitude/longitude resolution of ¼°. All other runs were done at ½°.

Resolution °lat X °lon	Initial Date		SST
	Dec 1, 1999	Dec 1, 2009	
¼ X ¼	A'	B'	Observed
½ X ½	A	B	Observed
½ X ½	C	D	Switched NA
½ X ½	E	F	Switched Ind

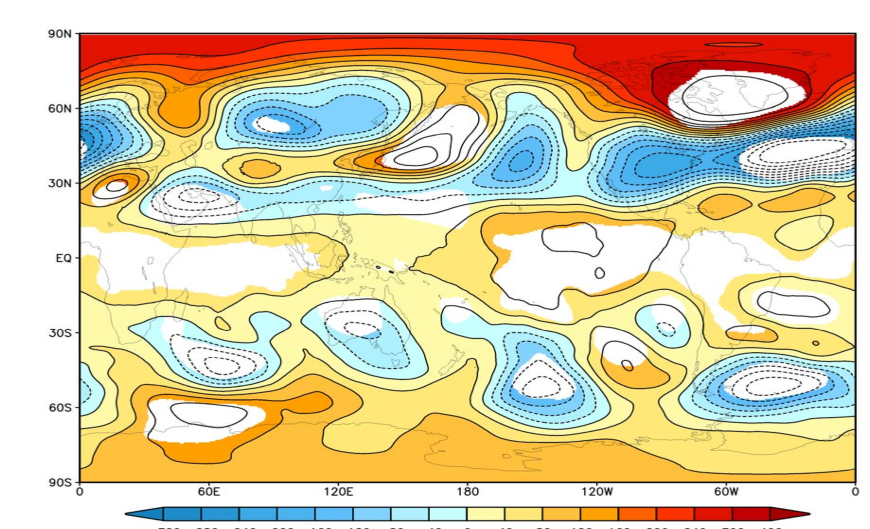
The impacts of the different ocean basins

NAtl = ½ {(B-A)+(C-D)}
Ind = ½ {(B-A)+(E-F)}
Pac = ½ {(D-C)+(F-E)}

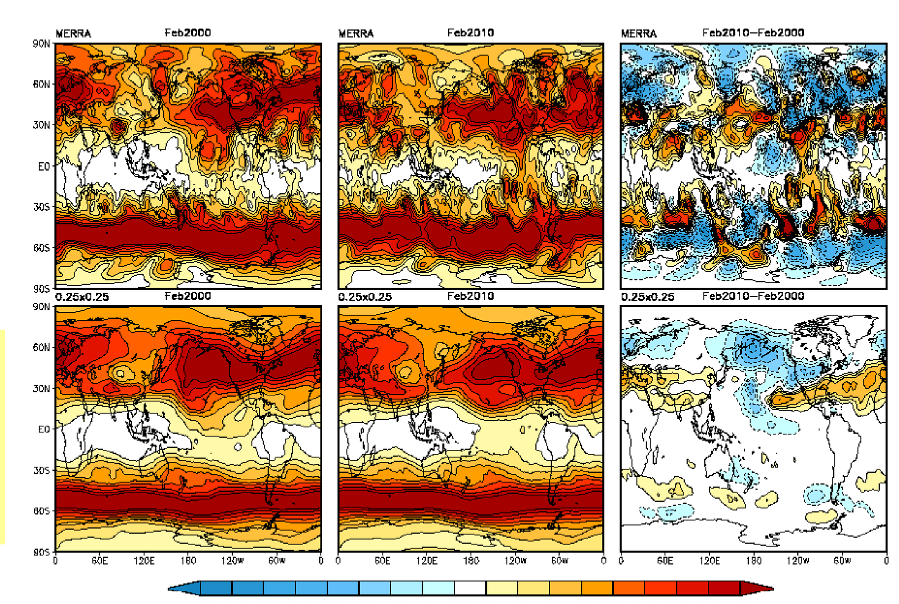




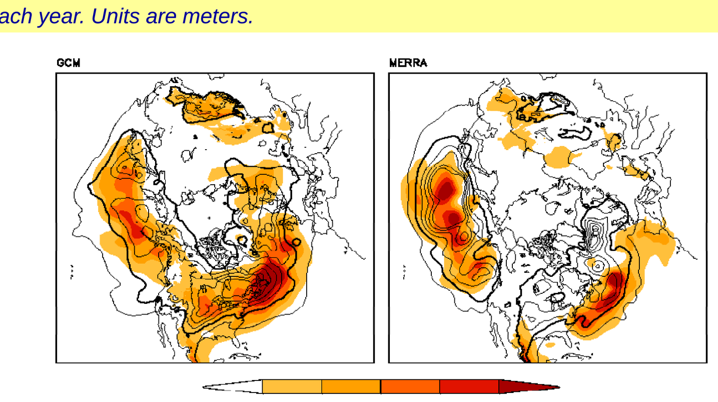
Top: Fifty- member ensemble mean of GEOS-5 hindcasts run at ¼° resolution. The results are the differences between Feb 2010 and Feb 2000. Left – 250mb height differences (meters), and right – precipitation differences (mm/day). Bottom: Same as above but from MERRA reanalysis



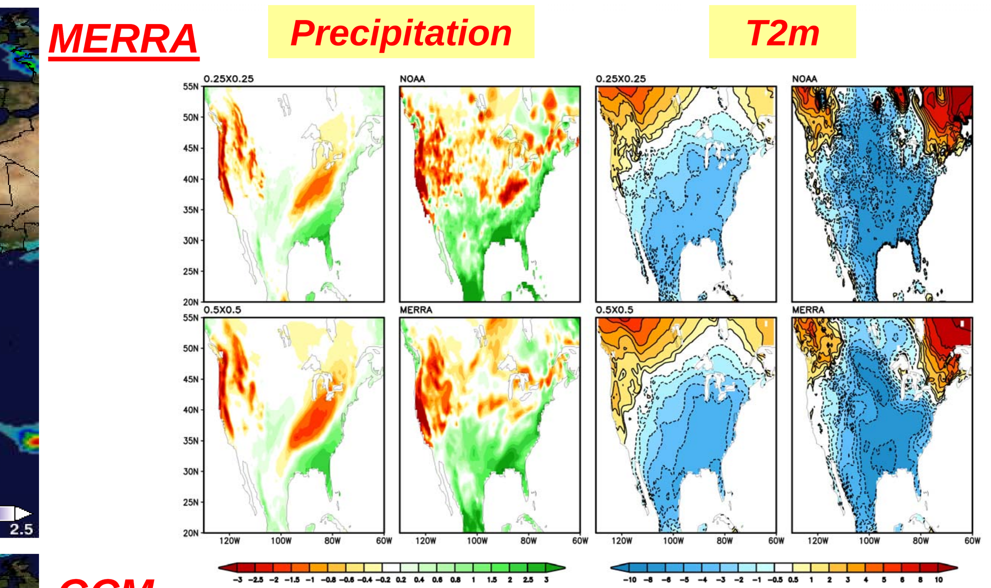
The 250mb height difference (Feb 2010-Feb 2000) from MERRA. The un-shaded regions are where the MERRA difference value falls outside the 90% confidence interval (less than 5% or greater than 95%) of the model difference values. The model confidence intervals are estimated from the 50 ensemble members from each year. Units are meters.



Monthly mean daily meridional wind variance at 250mb. Top panels: MERRA. Bottom panels: Model simulations (50 ensemble members run at ¼°). Left panels: Feb 2000. Middle panels: Feb 2010. Right panels: Feb 2010 - Feb 2000.

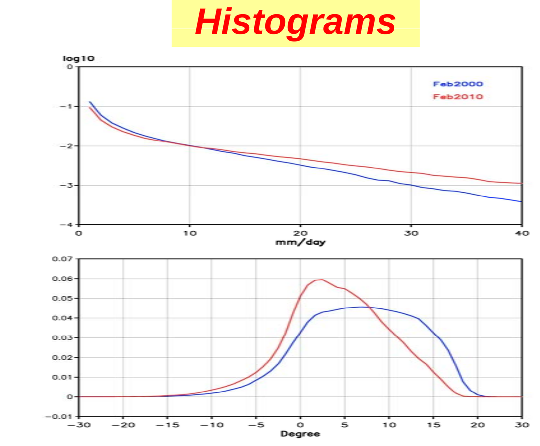


The storm activity during Feb 2000 (contours) and Feb 2010 (shading). The fields consist of the variance of the daily surface pressure tendencies normalized by the Coriolis parameter. The left is based on the two sets of ¼ degree 50-member ensemble runs forced with observed SST. The right panels are from MERRA. The bold contours for 2000 correspond to the first shading level for 2010.

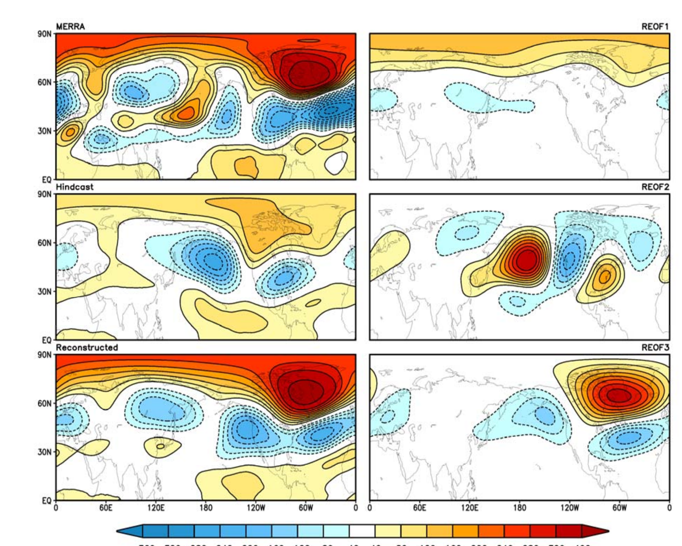


Mean precipitation and 2m temperature difference (Feb 2010 – Feb 2000) based on an ensemble of 50 AGCM hindcasts. The hindcasts were initialized (Dec 1, 1999 and Dec 1, 2009) and are verified by the NOAA station observations and MERRA reanalysis for the same periods. The units are (mm/day) for the precipitation and (°C).for the temperature.

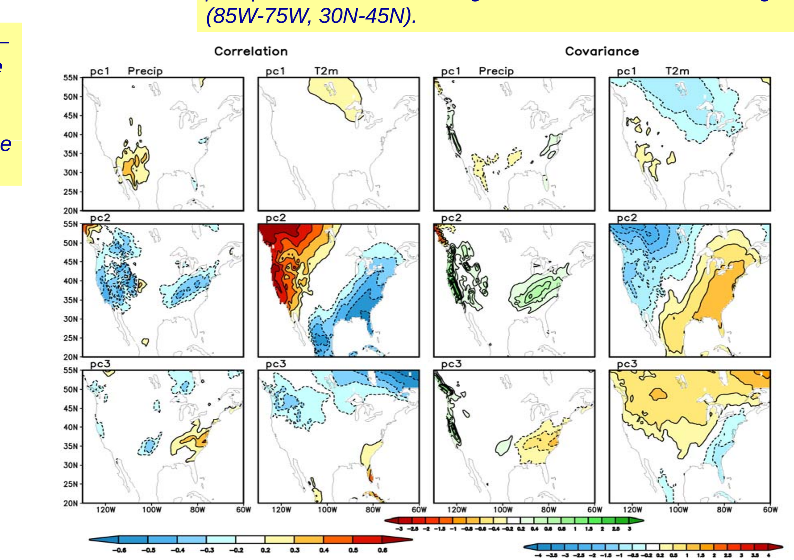
Histograms



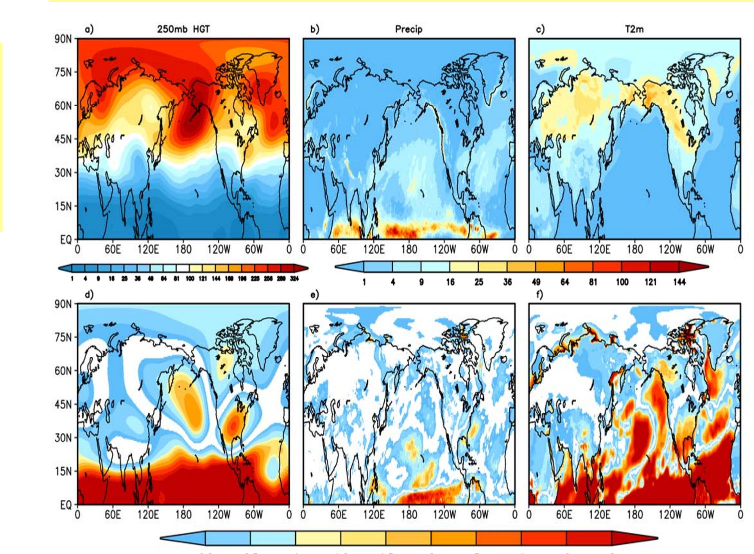
The normalized histograms of precipitation (top panel) and T2m (bottom panel) for Feb 2000 and Feb 2010. The results are based on the two sets of ¼ degree 50-member ensemble runs forced by the observed SST, using daily values of the precipitation and T2m averaged over the wet area in the region (85W-75W, 30N-45N).



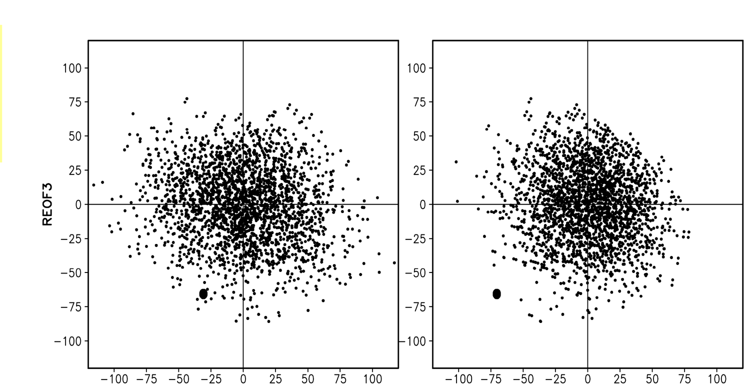
Right: the three leading REOFs of the 250mb height intra-ensemble variance, computed from monthly (Feb) model data. The weightings amplitude of the three leading REOFs are determined from a linear regression that fits the MERRA difference field as a linear combination of the three REOFs plus the model ensemble mean difference. The results of the fit to the observed difference field are shown in the lower left panel. Units are meters.



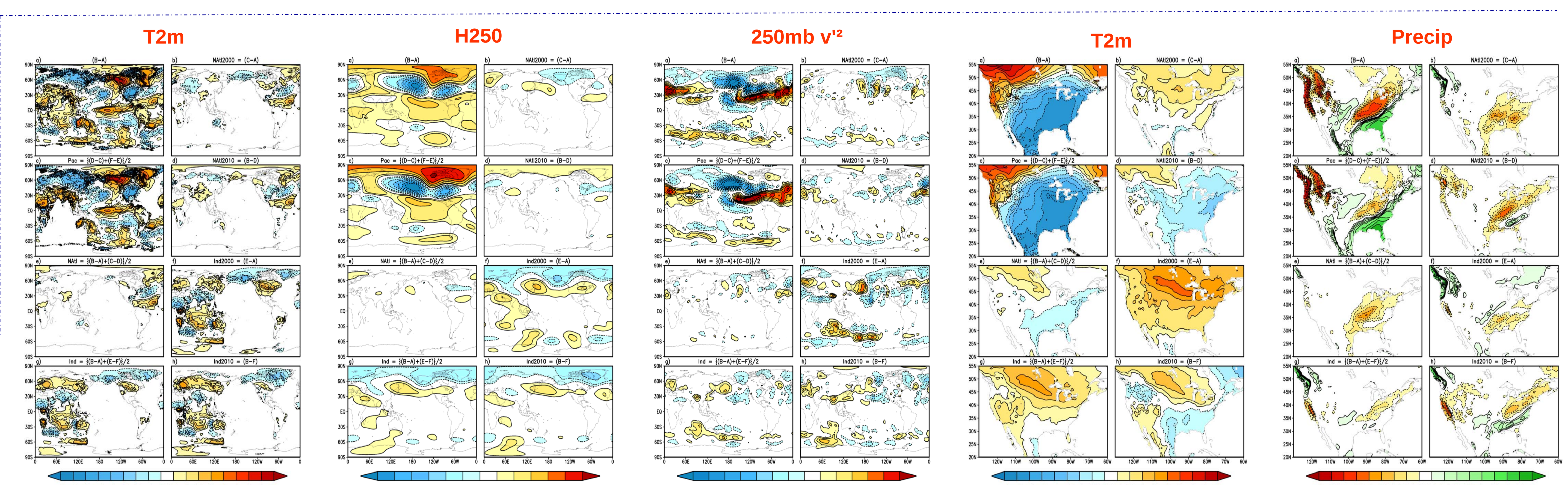
The correlation and covariance between 3 leading noise PCs and the precipitation and T2m. The PCs are normalized by the standard deviation. Results are based on the Feb monthly-mean noise (intra-ensemble variance) computed from the 50-ensemble runs with observed SST for the years 2010 and 2000. With 100 ensemble members, a correlation coefficient of 0.2 is significantly different from zero at the 5% level, based on a t-test. Units for the normalized covariances are mm/day and °C.



Top panels: Intra-ensemble variance of the (Feb 2010 –Feb 2000) differences for 250mb height, precipitation and T2m. Units are m², (mm/day)² and (°C)², respectively. Bottom panels: Same as the top except for the signal-to-noise ratio (S/N) of the differences. White areas in the S/N fields indicate where the difference fields are not significantly different from zero at the 0.5% level based on a one-sided t-test.



A scatter plot of the differences between the leading PCs of the intra-ensemble variance (based on the Feb 250mb height REOFs) for 2010 and 2000. The y-axis is for PC 3 and the x- axis is for PC 1 in the left panel and PC 2 in the right panel. The large dot in each panel indicates the values obtained from the regression that fit the noise REOFs to the observed difference fields.



Conclusions

- *The observed SST force global-scale anomalies in the model upper level height field, precipitation, and surface temperature that are largely consistent with the observed anomalies. In particular, the model produces positive precipitation and cold temperature anomalies along the southeastern and east coast of the US reflecting a propensity for enhanced snowstorm activity.*
- *The ensemble mean temperature and precipitation anomalies over the US are primarily driven by the ENSO-related Pacific Ocean SST.*
- *The impact of the North Atlantic SST is to contribute to the cooler temperatures along the US east coast, as well as to extend the Pacific-forced storminess anomalies eastward into Eurasia.*
- *The response to the Indian Ocean SST is an Arctic Oscillation-like pattern that largely acts to counteract the response to the Pacific Ocean SST at middle and high latitudes.*
- *The Pacific SST are the main forcing of the predictable part of the anomalous storm activity. The east coast of the US is less influenced by the noise, and is in fact characterized by some of the largest signal-to-noise (S/N) ratios. The S/N ratios of the precipitation are more modest, but nevertheless suggest a potential for predicting the unusual storm activity along the US east coast several months in advance.*
- *The observed NAO anomaly can be considered to be comprised of three components consisting of 1) a noise component that dominates the anomaly, 2) a smaller but significant part that is directly forced by the Pacific SST and 3) another yet smaller contribution occurring as a response to the North Atlantic SST.*