Observed and Simulated Atmospheric Circulation Patterns Associated with Extreme Temperature Days over North America

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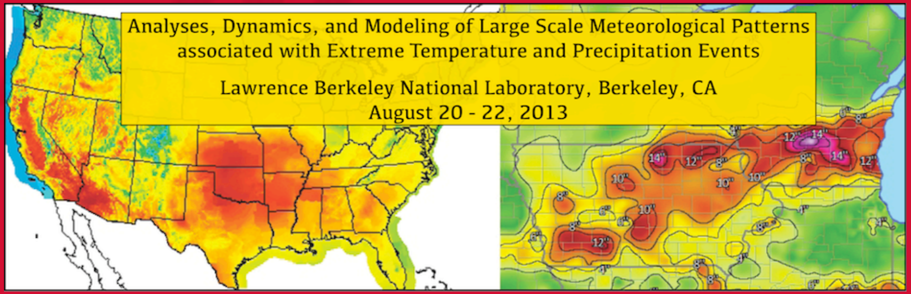

Project Overview

- Phase 1: What are the large scale meteorological patterns (LSMPs) and physical processes associated with daily temperature extremes?
- Phase 2: How well do climate models simulate these LSMPs and processes?
- Phase 3: Will these patterns and processes be altered as a consequence of future changes in climate?

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Papers on LSMPs and extremes

- Loikith, P. C., and A. J. Broccoli, 2012: Characteristics of observed atmospheric circulation patterns associated with temperature extremes over North America. *J. Climate,* **25,** *7266–7281*, doi:10.1175/JCLI-D-11-00709.1.
- Loikith, P. C., and A. J. Broccoli, 2013: Comparison between observed and simulated atmospheric circulation patterns associated with extreme temperature days over North America using CMIP5 historical simulations. To be submitted to *J. Climate*.
- Loikith, P. C., and A. J. Broccoli, 2013: The influence of recurrent modes of climate variability in the occurrence of winter and summer extreme temperatures over North America. *J. Climate,* under review.
- DeAngelis, A. M., A. J. Broccoli, and S. G. Decker, 2013: A comparison of CMIP3 simulations of precipitation over North America with observations: Daily statistics and circulation features accompanying extreme events. *J. Climate,* ***26,*** *3209-3230,* doi:10.1175/JCLI-D-12-00374.1.

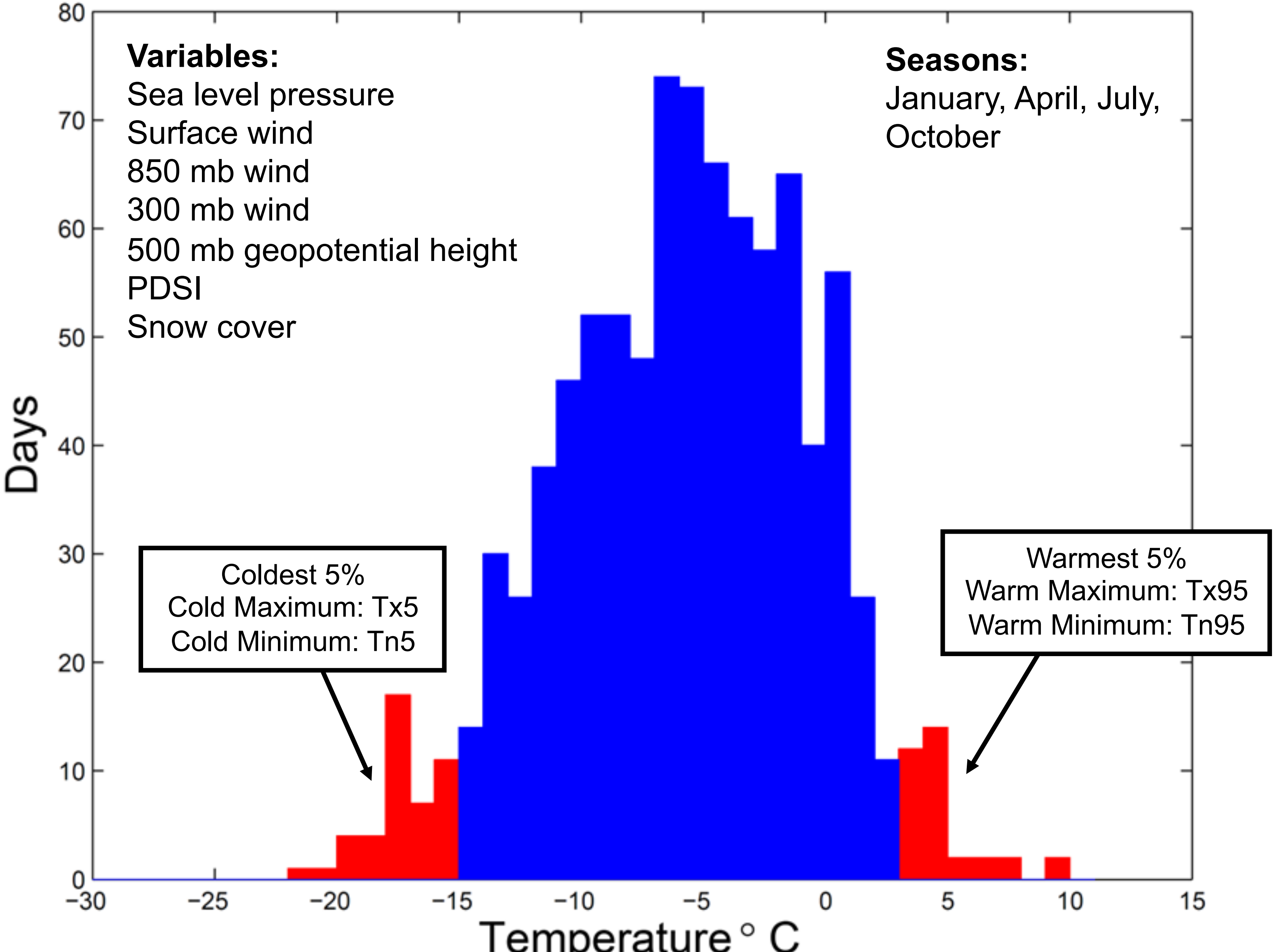
Data and Methods

- HadGHCND (Caesar et al. 2006)
  - Collaboration between Hadley Centre and National Climatic Data Center
  - Daily maximum and minimum temperatures and anomalies
  - 2.5 ° latitude by 3.75 ° longitude, global domain
  - Period: 1946-2000
- NCEP/NCAR Reanalysis 1 (Kalnay et al. 1996)
  - 2.5 ° latitude by 2.5 ° longitude, global domain
- CMIP5 historical simulations
  - Selection criteria based on availability of daily output

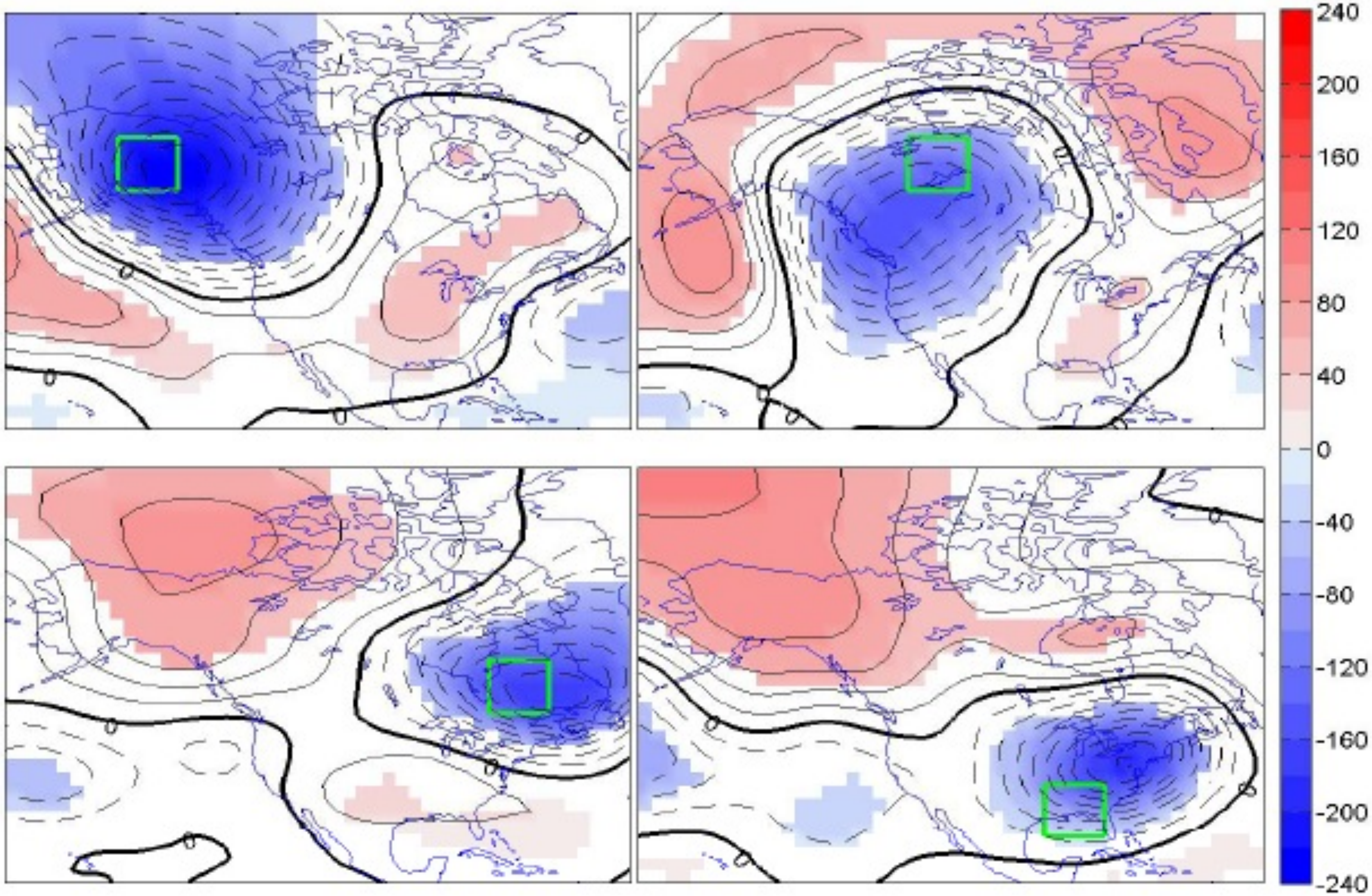
CMIP5 models used in this study

Model Name	Horizontal Resolution (lat x lon)	Modeling Group
BNU-ESM	2.81x2.81	GCESS, China
CanESM2	2.81x2.81	CCCma, Canada
CMCC-CM	0.75x0.75	CMCC, Italy
CNRM-CM5	1.41x1.41	CNRM-CERFACS, France
FGOALS-g2	3.00x2.81	LASG-CESS, China
FGOALS-s2	1.67x2.81	LASG-IAP, China
GFDL-ESM2G	2.00x2.50	GFDL, United States
GFDL-ESM2M	2.00x2.50	GFDL, United States
HadGEM2-CC	1.25x1.88	MOHC, United Kingdom
INM-CM4	1.50x2.00	INM, Russia
IPSL-CM5A-LR	1.88x3.75	IPSL, France
IPSL-CM5A-MR	1.26x2.50	IPSL, France
MIROC5	1.41x1.41	MIROC, Japan
MIROC-ESM-CHEM	2.81x2.81	MIROC, Japan
MPI-ESM-LR	1.88x1.88	MPI-M, Germany
MPI-ESM-MR	1.88x1.88	MPI-M, Germany
MRI-CGCM	1.13x1.13	MRI, Japan

For grid points over North America, construct composite LSMPs based on events in the tails of the daily temperature distribution.



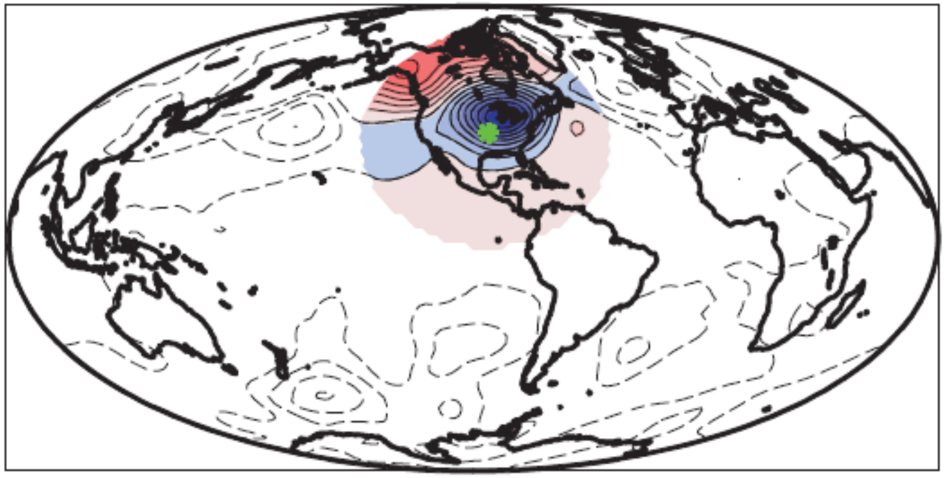
Composite Z_{500} anomalies for January Tx5



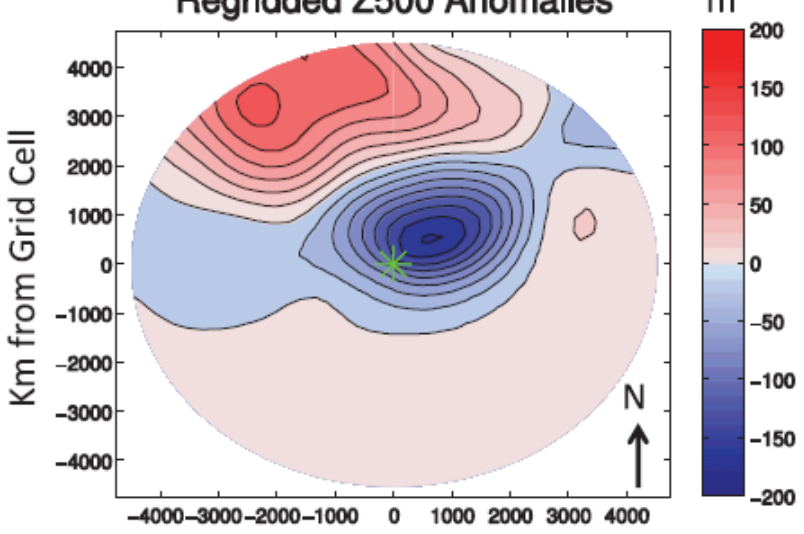
Composites based on temperature distribution at the locations of the green boxes.
Shading indicates anomalies are statistically significant at 5% level based on t-test.

Expressing patterns in "gridcell-relative" space

Z500 Anomalies

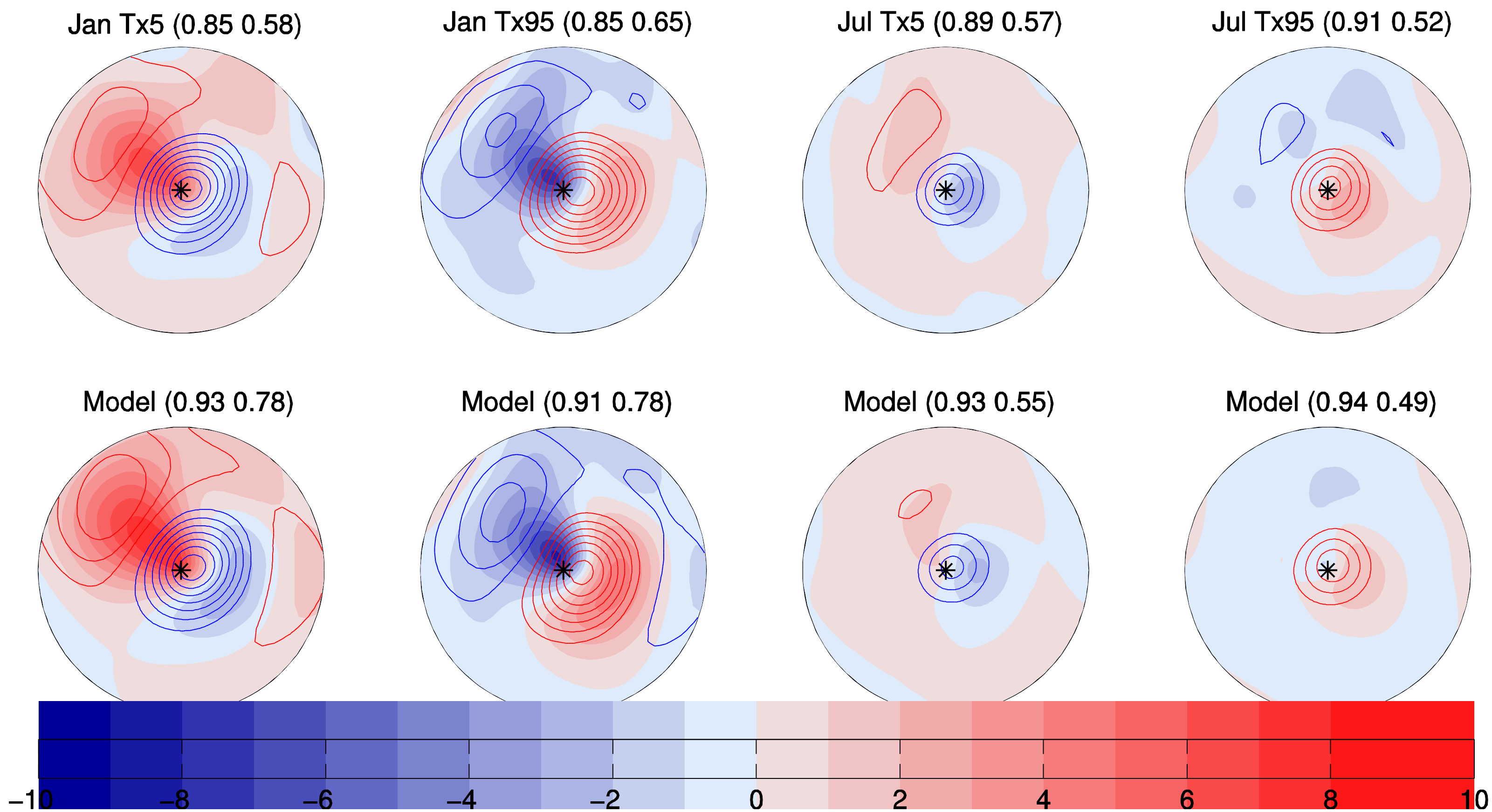


Regridded Z500 Anomalies



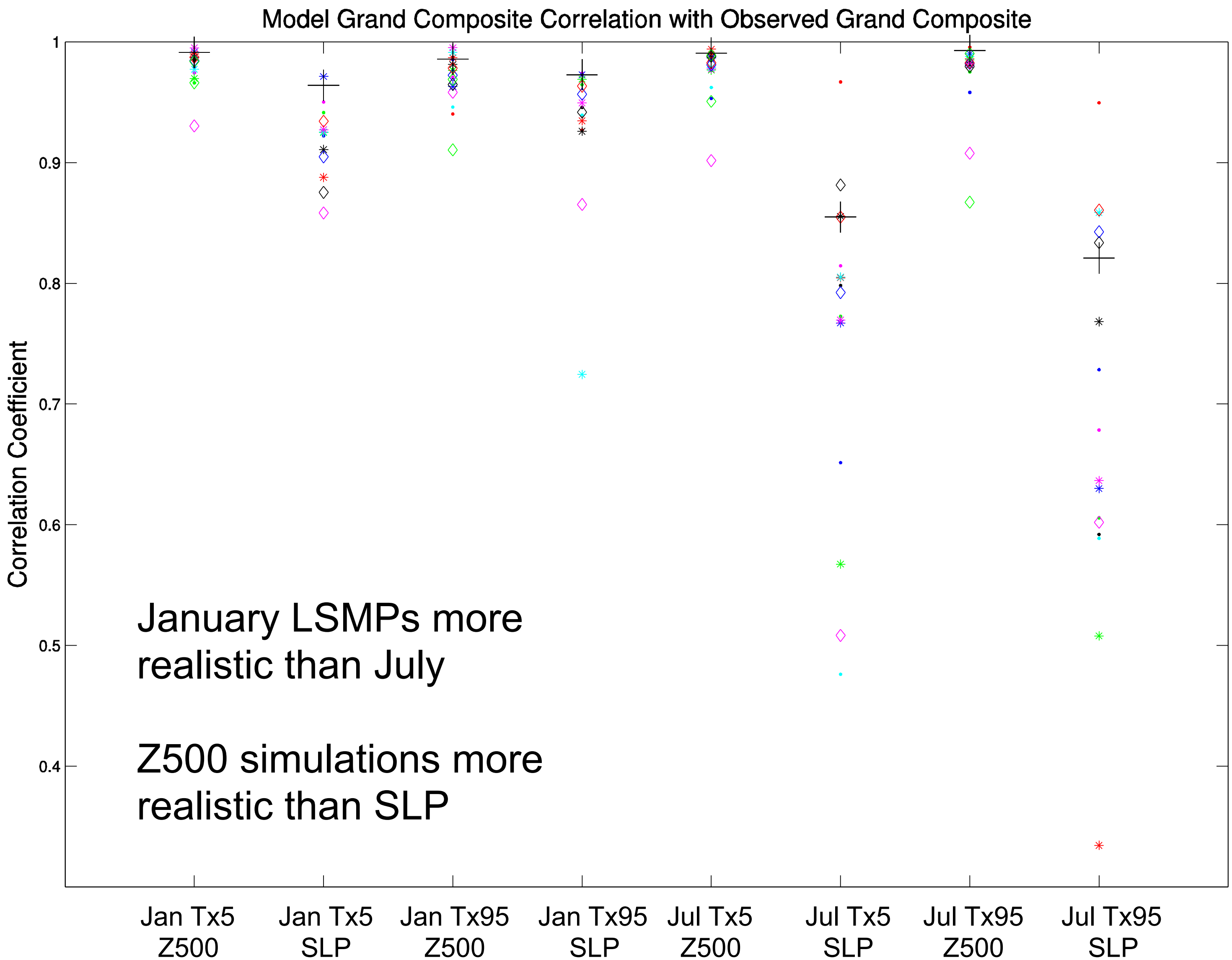
Referencing circulation anomaly patterns to the location experiencing a daily temperature extreme facilitates comparisons among locations, including the construction of a "grand composite" by averaging across all locations.

Observed and simulated grand composites: Z_{500} and SLP

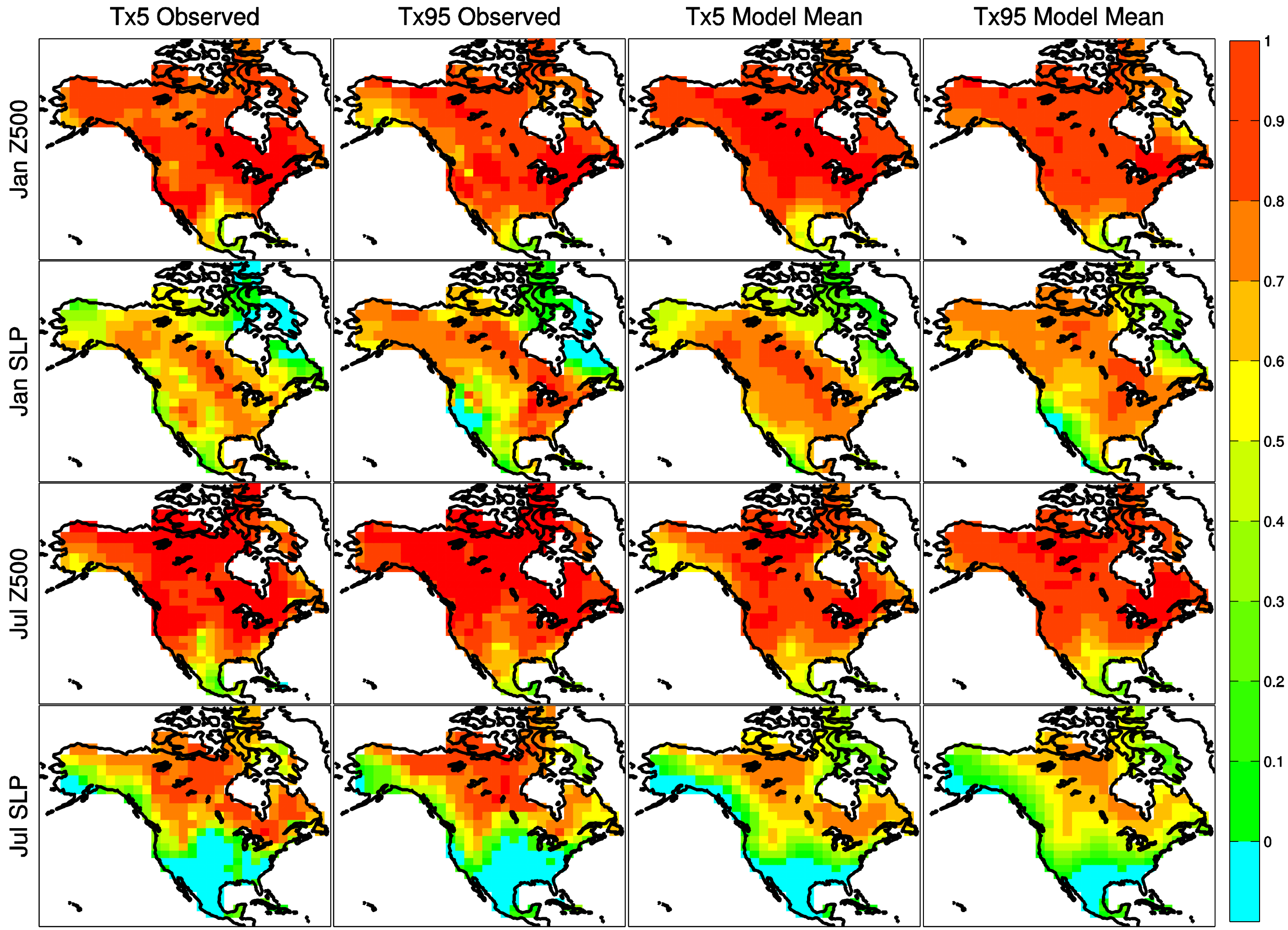


Contours: Z_{500} anomalies (positive in red, negative in blue, interval: 18 m)
Shading: SLP anomalies (color scale above)
Patterns correlations within composites indicated above each map (Z500, SLP)
Model results from multi-model ensemble mean
Radius of plotted area: 4500 km

Fidelity of individual model grand composites



Pattern correlation: Local pattern vs. grand composite



Observed

Multi-model Mean

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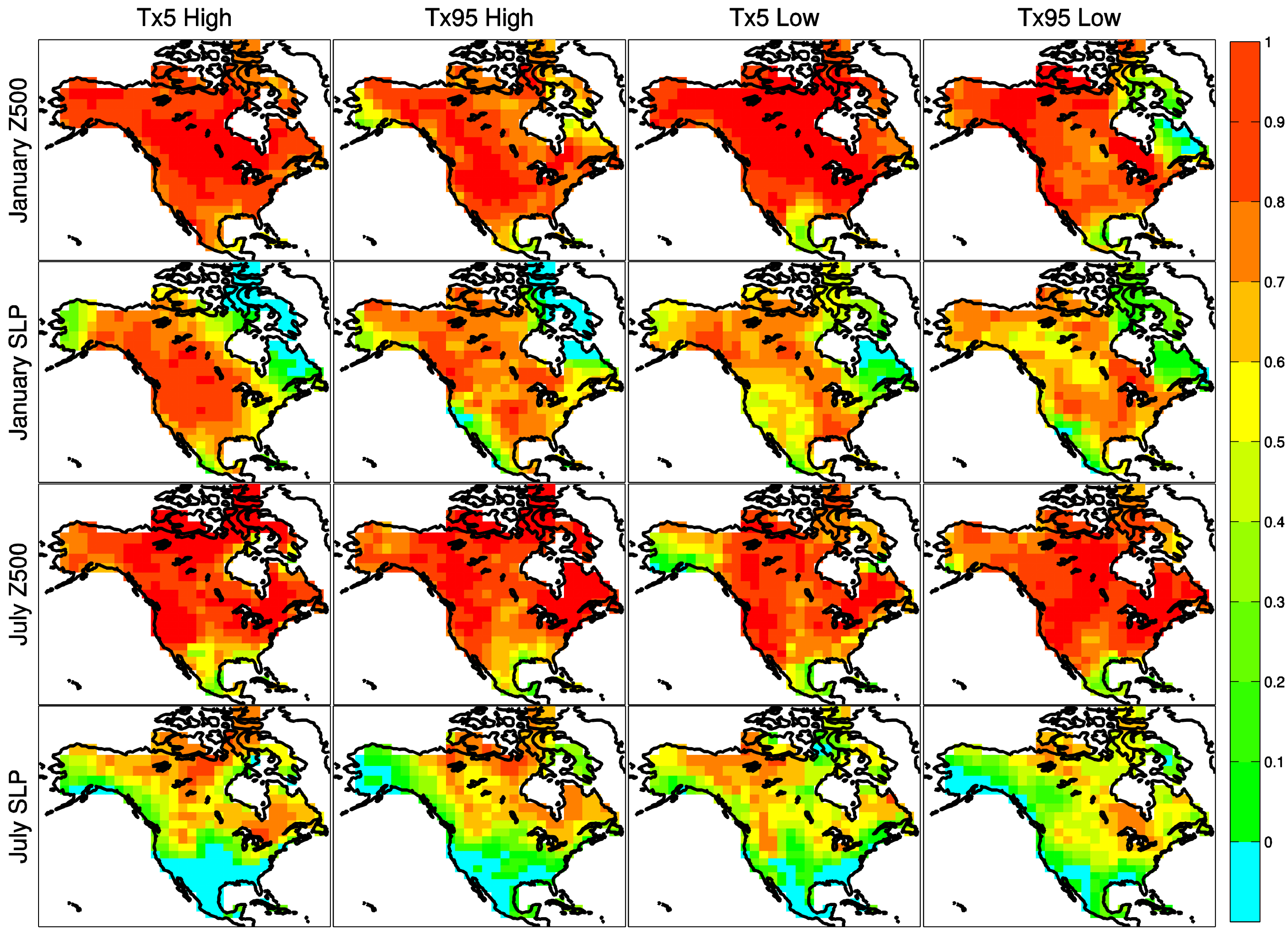
Pattern correlation: Local pattern vs. grand composite



Model with
better agreement

Model with
poorer agreement

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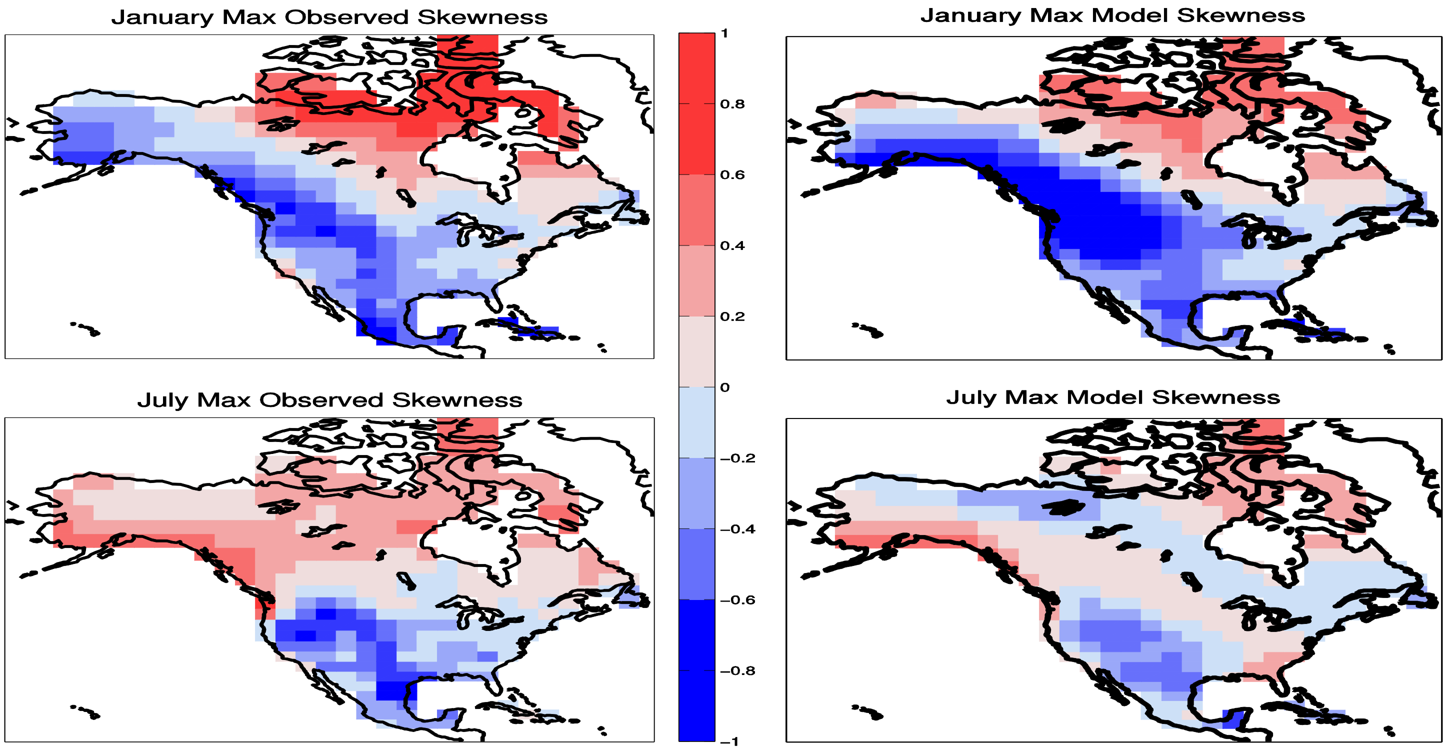
Skewness

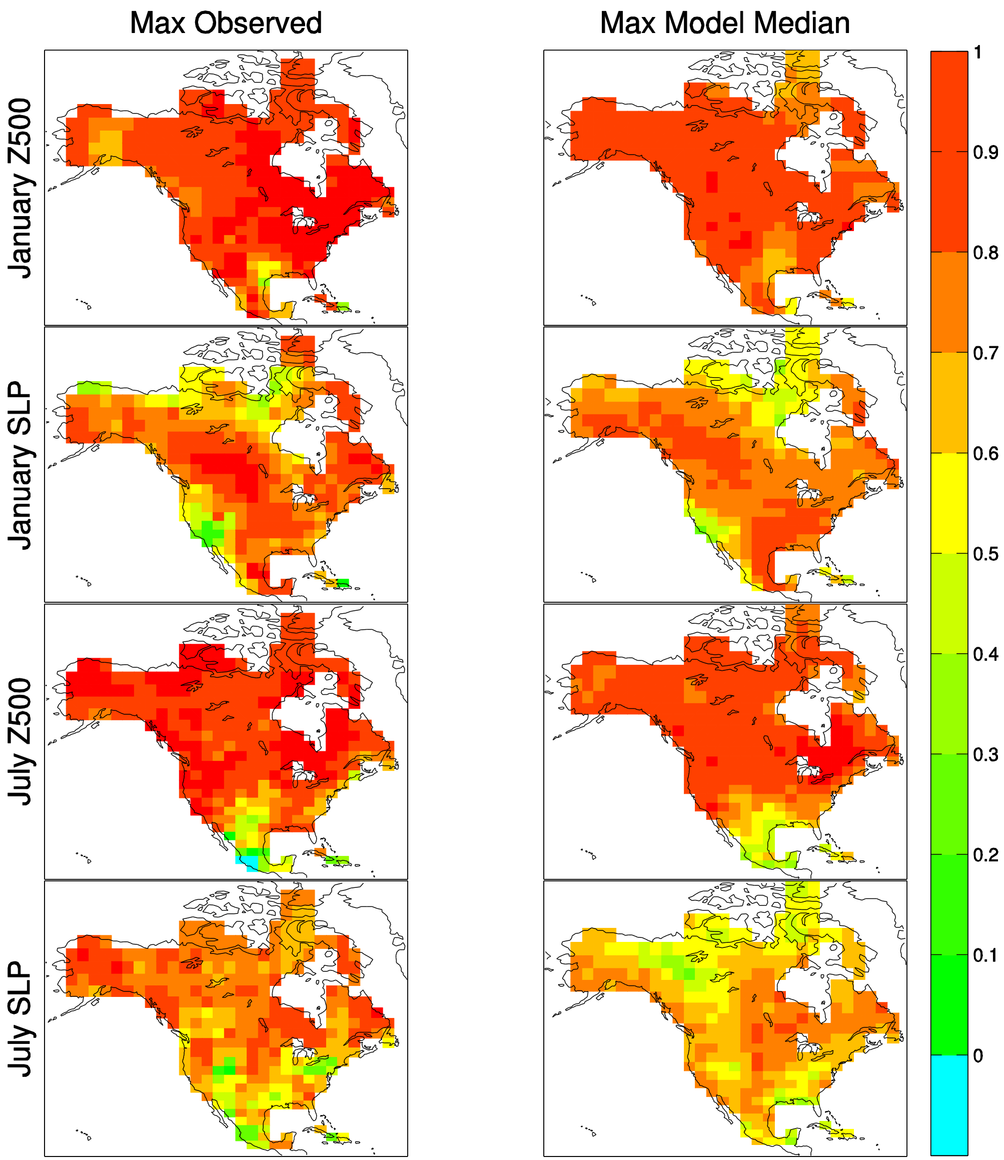


- Overall patterns captured by mutli-model ensemble
- January skewness has small negative bias in multi-model ensemble
- July skewness pattern has more disagreement

Symmetry of LSMPs: Cold vs. warm

The pattern correlation between the local composites for events outside the 5th and 95th percentiles is used as an index of symmetry between cold and warm extremes.

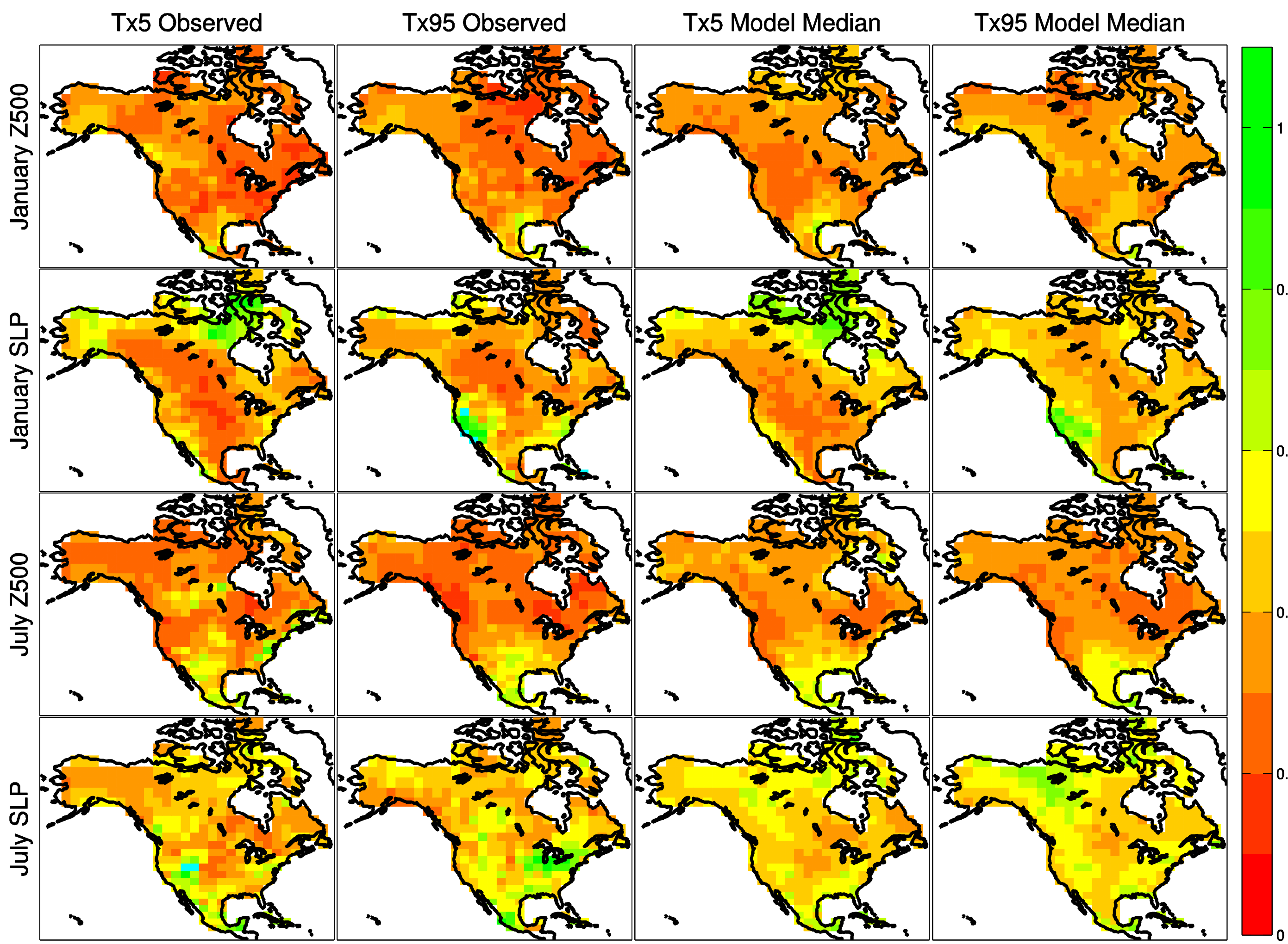
The pattern correlations is multiplied by -1 so that an index value of 1 at a particular location would indicate that the patterns there are perfectly symmetric, i.e., the LSMP for a warm extreme is a mirror image of that of a cold extreme.



Linearity

An index of pattern linearity is defined as the RMS difference between the composite pattern at each grid cell and a pattern determined by linear regression using all days.

An index value of 0 at a particular location would indicate that the patterns there are perfectly linear.



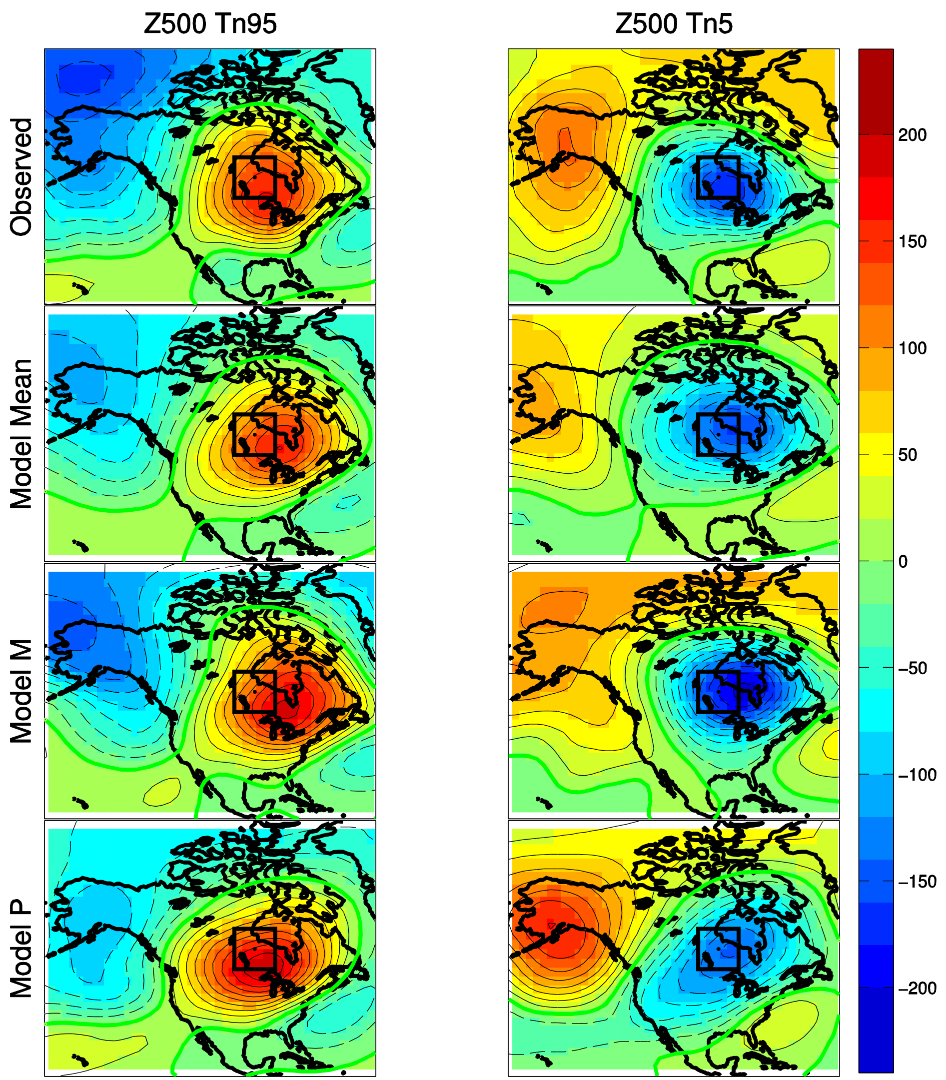
Interior North America: January Z500 Tn5 and Tn95

This location is relatively unaffected by coastal or topographic influences.

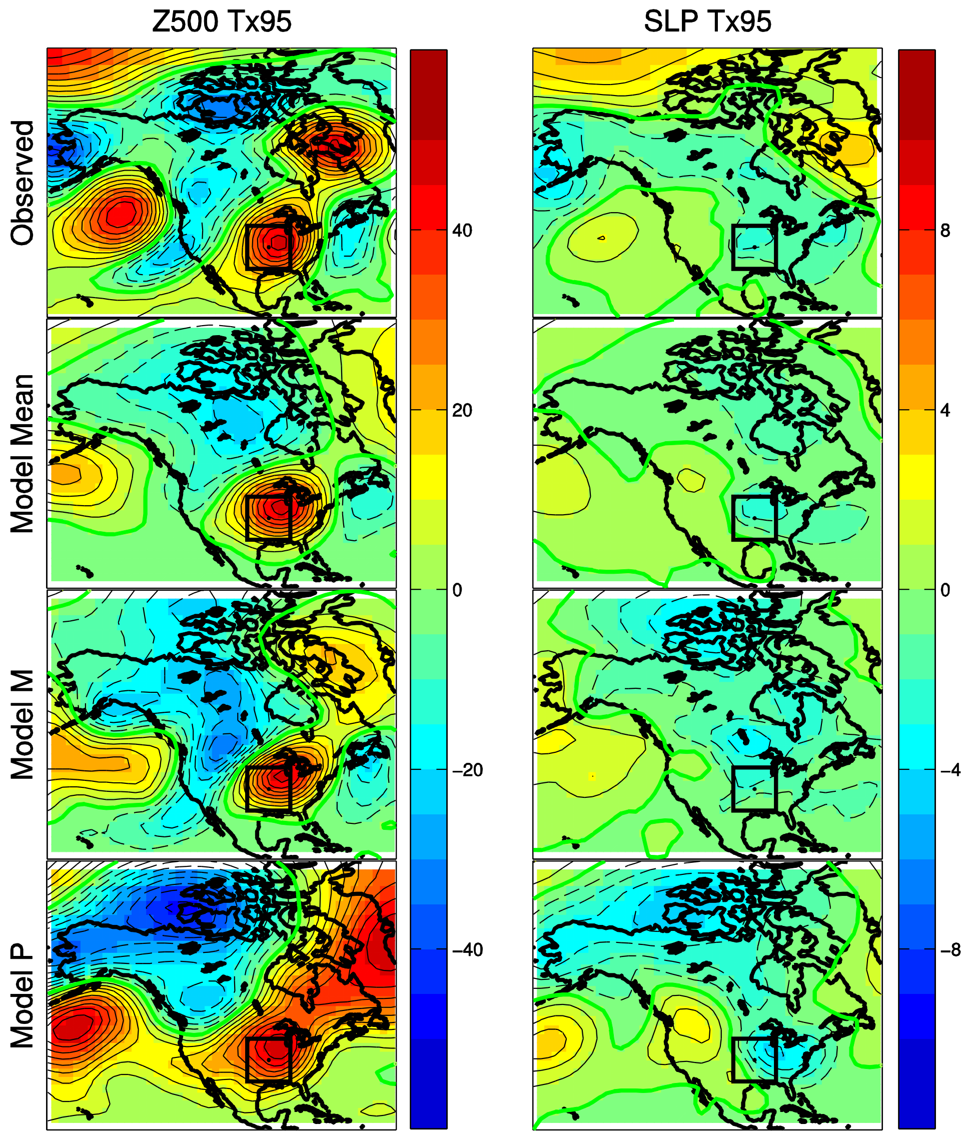
LSMPs are highly symmetrical and linear.

Better model is quite similar to MME mean and observed

Even the poorer model bears considerable resemblance to observed



Central United States: July Tx95 Z500 and SLP



Ensemble mean captures local Z500 anomaly well.

Ensemble mean also shows upstream wave train, but with spatial scale distorted.

Better model captures wave train more realistically.

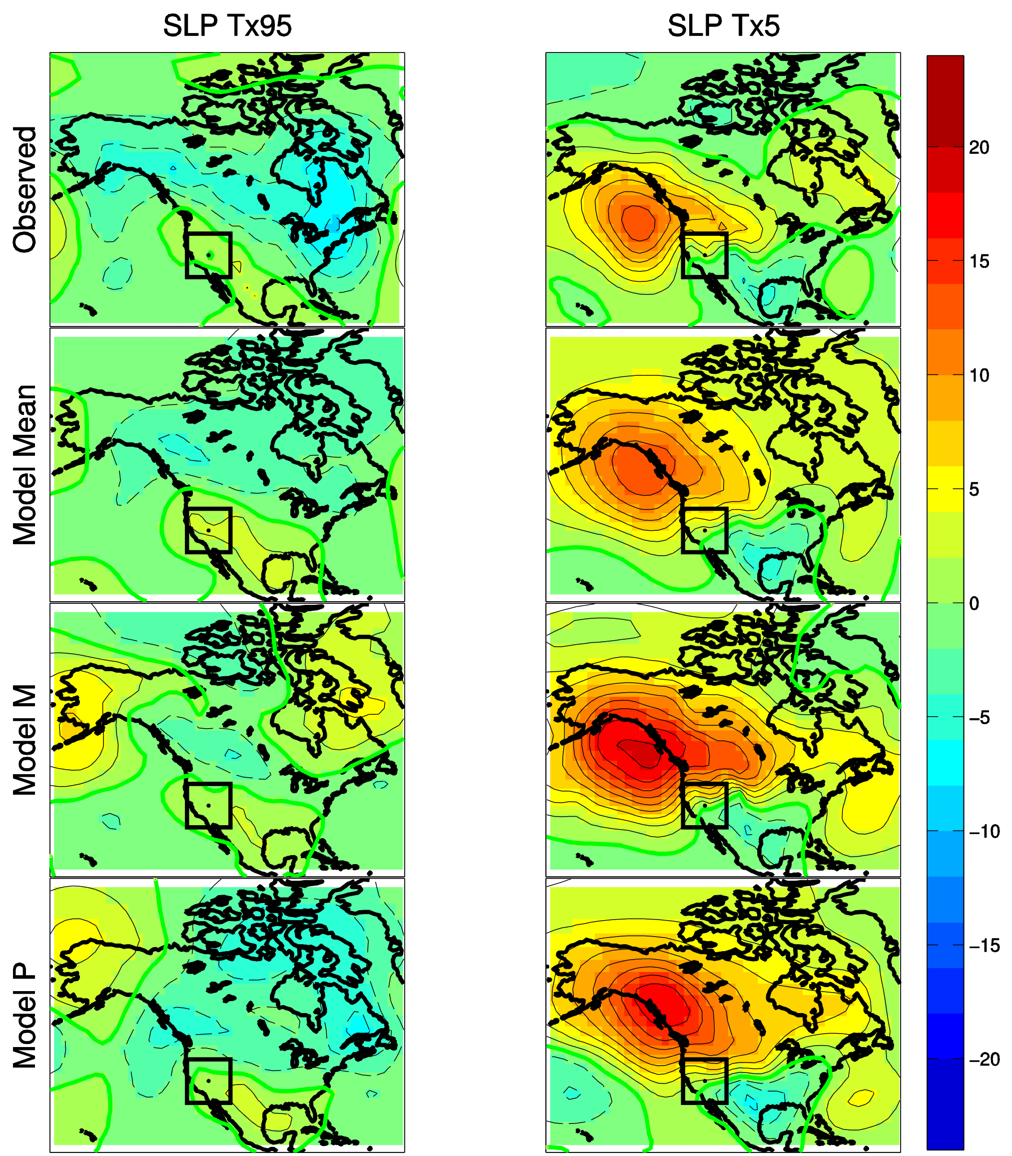
Poorer model has unrealistically large amplitude for non-local anomaly centers.

Southwest United States: January SLP Tx5 and Tx95

LSMPs are asymmetrical and nonlinear.

The asymmetry is captured well by MME mean.

Models M and P capture the asymmetry reasonably well, although both exaggerate the strength of the positive SLP anomaly center to the northwest.



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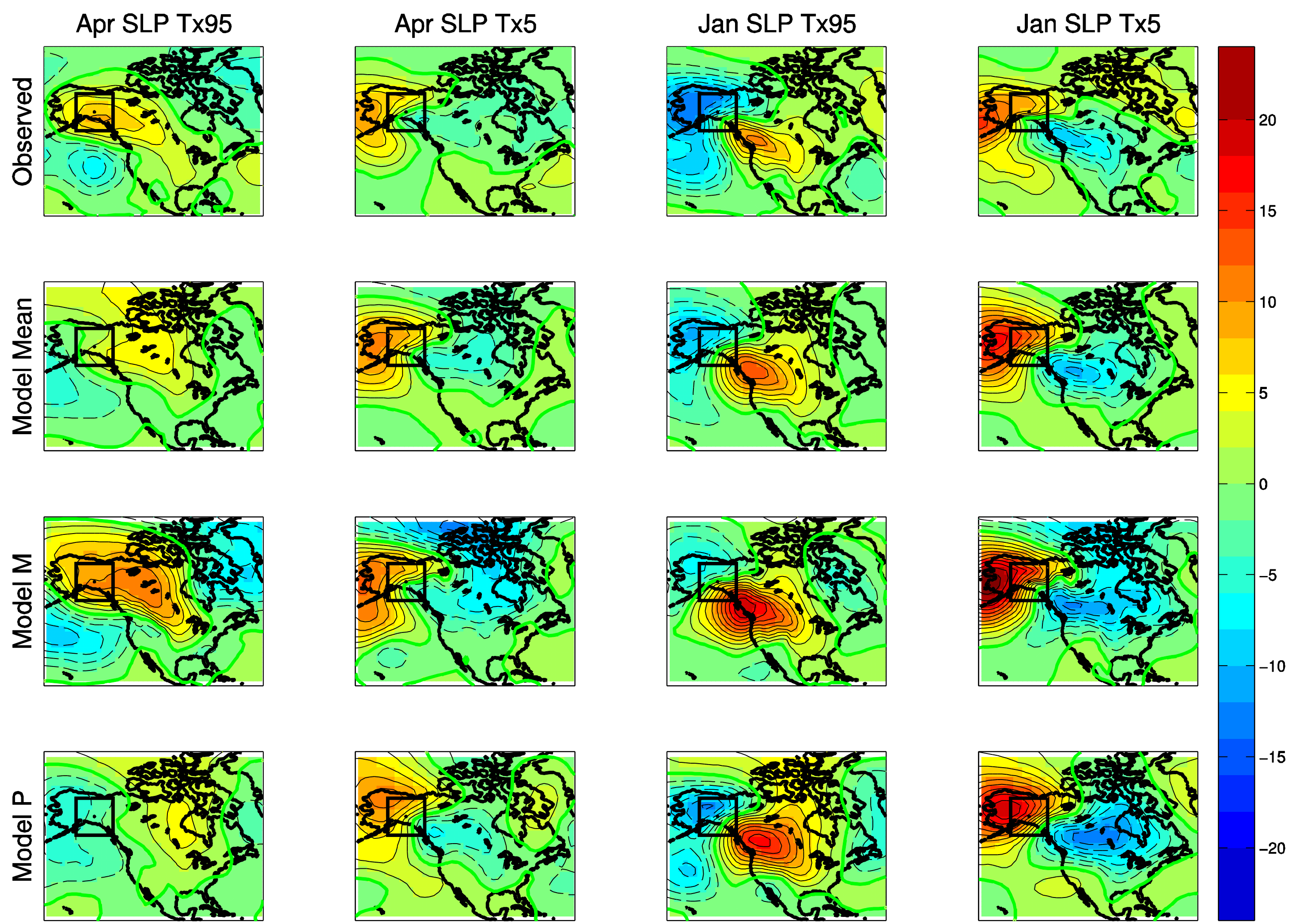
Eastern Alaska: January and April SLP Tx5 and Tx95



Conclusions: Characteristics of observed patterns

- Warm events are generally associated with positive 500 mb height and SLP anomalies just downstream with negative anomalies farther upstream.
- The anomaly patterns associated with cold events tend to be similar to, but opposite in sign of, those associated with warm events, especially within the westerlies and away from marine and topographic influences.
- The orientation and spatial scale of these circulation patterns vary based on latitude, season, and proximity to mountains and coastlines.
- Circulation patterns aloft are more consistent across the continent than those at the surface.
- Circulation anomalies at some locations resemble those associated with recurrent large-scale teleconnection patterns.
- Land surface-atmosphere coupling appears to play a role in the occurrence of some types of extremes.

Conclusions: Simulated vs. Observed

- Most models generally capture the broad features of the LSMPs associated with extreme temperature days.
- There are substantial intermodel differences in the quality of the simulation of LSMPs, with model differences greatest in areas where topography and coastal influences are important.
- LSMPs are more realistically simulated in winter than in summer.
- Midtropospheric circulation patterns are more realistically simulated than those at the surface.
- Results from the mutli-model ensemble mean generally agree better with observations than most models, suggesting that model errors are more random than systematic.