Multi-level Vector Auto-Regressive Model Prediction of Northern Summer Extra-tropical Low-Frequency Circulation

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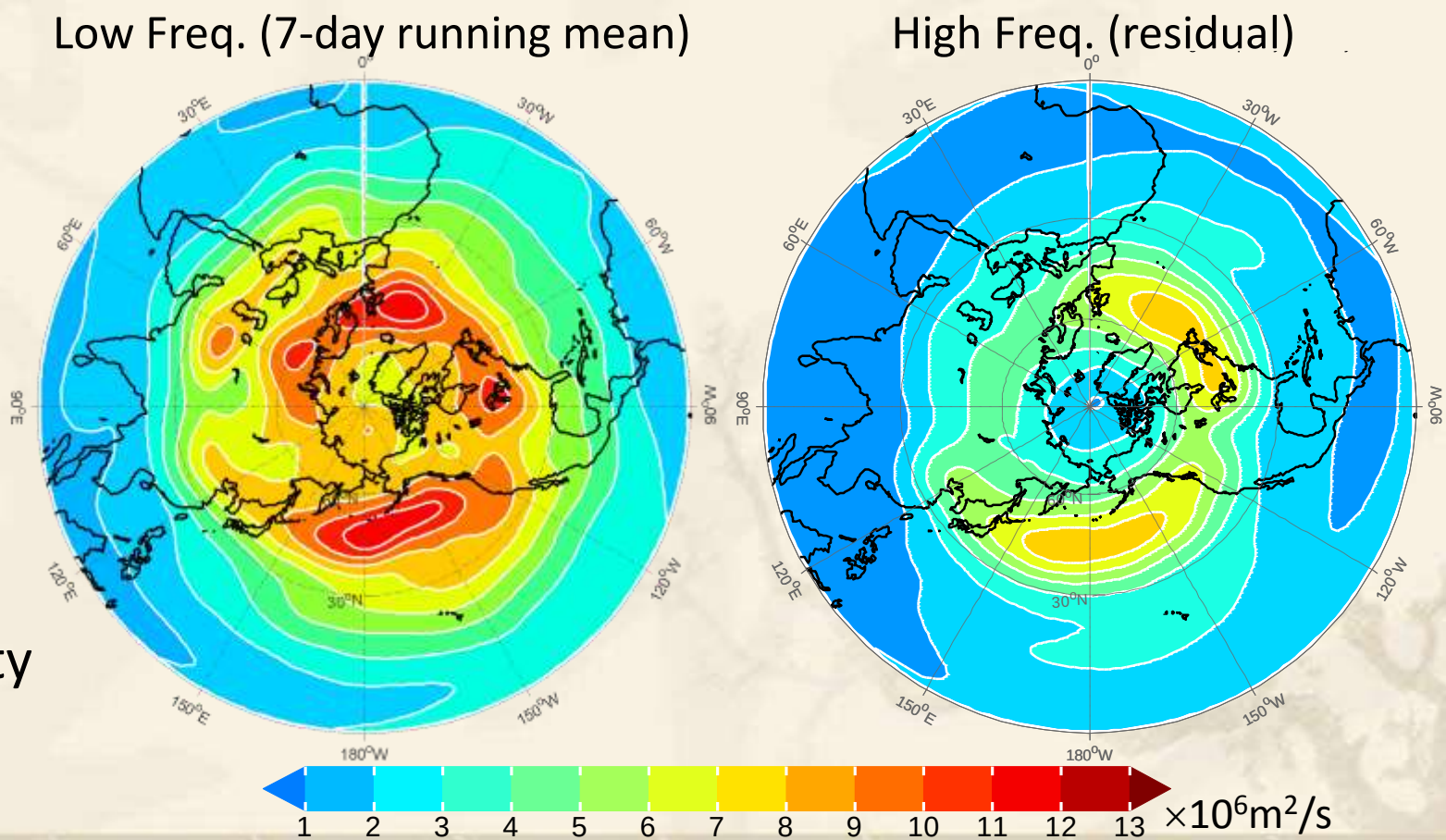
Outline

- Motivation
- Methods and Data
- NH Streamfunction Forecast Skill
- Role of Tropical Heating
- Summary

Motivation

- Extended-range forecast: gap between weather (initial condition) and climate (boundary condition);
- Summer Low frequency variability;

MERRA 250hPa Stream-function 1979-2013 MJJAS Variability (in STD)



Motivation

- Extended-range forecast: gap between weather (initial condition) and climate (boundary condition);
- Summer Low frequency variability;
- Linear Inverse Model (LIM): statistical (data-driven) approach (Penland and Ghil, 1993; Winkler et al., 2001; Newman et al., 2003);
    - Better forecast skill than simple dynamical model,
    - Skill comparable to GCMs,
    - Significant improvement over persistence for short and extended range,
    - Tropical heating can help extra-tropical extended range forecast.

Motivation

- Extended-range forecast: gap between weather (initial condition) and climate (boundary condition);
- Summer Low frequency variability;
- Linear Inverse Model (LIM): statistical (data-driven) approach (Penland and Ghil, 1993; Winkler et al., 2001; Newman et al., 2003);
- Possible role of tropical intra-seasonal variability (MJO) to the low-frequency extra-tropical predictability (Matthews et al. 2004; Cassou 2008; Lin et al. 2009; Seo and Son 2012; Hoell et al. 2013);

Methods

- Multi-level Vector Autoregressive (VAR): the current state of a vector $\vec{x}$ linearly depends on the states of L time steps in the past:

$$\vec{x}_i = \sum_{j=N}^{N+L} A_j \vec{x}_{i-j} + \vec{e}_i$$

- LIM is equivalent to a level-1 AR model:

$$\frac{d\vec{x}}{dt} = L\vec{x} + \zeta \Rightarrow \frac{\vec{x}_i - \vec{x}_{i-1}}{\delta t} = L\vec{x}_{i-1} + \vec{\zeta}_i$$

$$\Rightarrow \vec{x}_i = \left(1 + L\delta t\right)\vec{x}_{i-1} + \vec{\zeta}_i \delta t$$

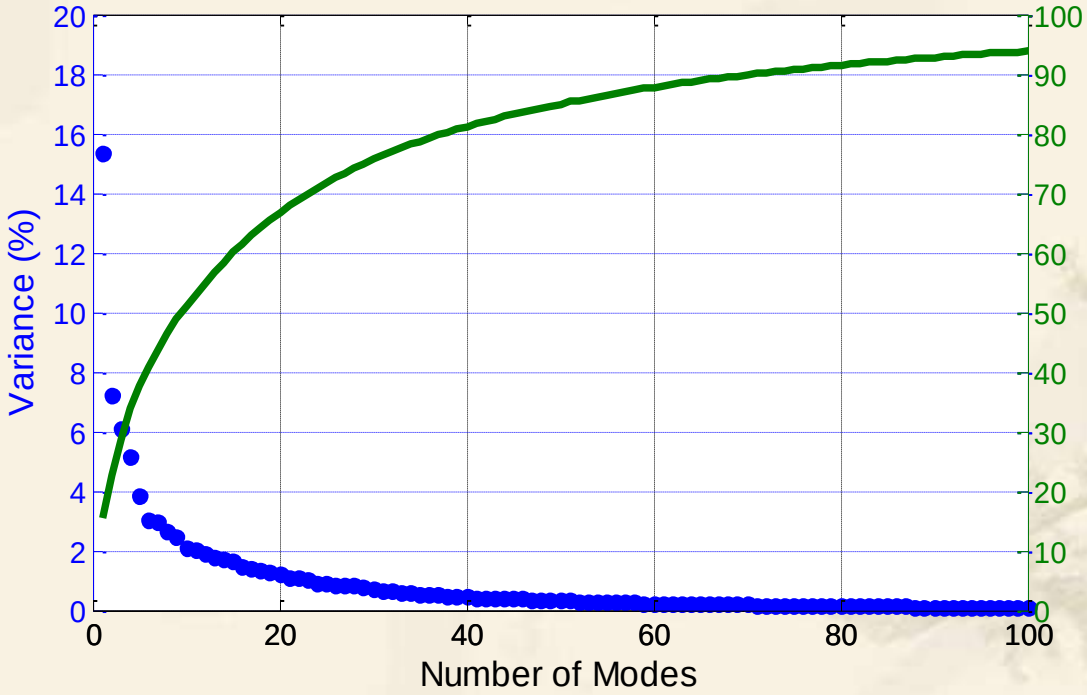
Methods

- Dimensional Reduction by EOF Analysis:

$$x_{space,time} = U_{space} \times \Sigma \times V_{time}^{T}$$

U: *EOFs* [space], Σ: eigenvalues, V^T: *PCs* [time]

MERRA NH Summer (MJJAS) daily Streamfunction 250,750hPa 1979-2013



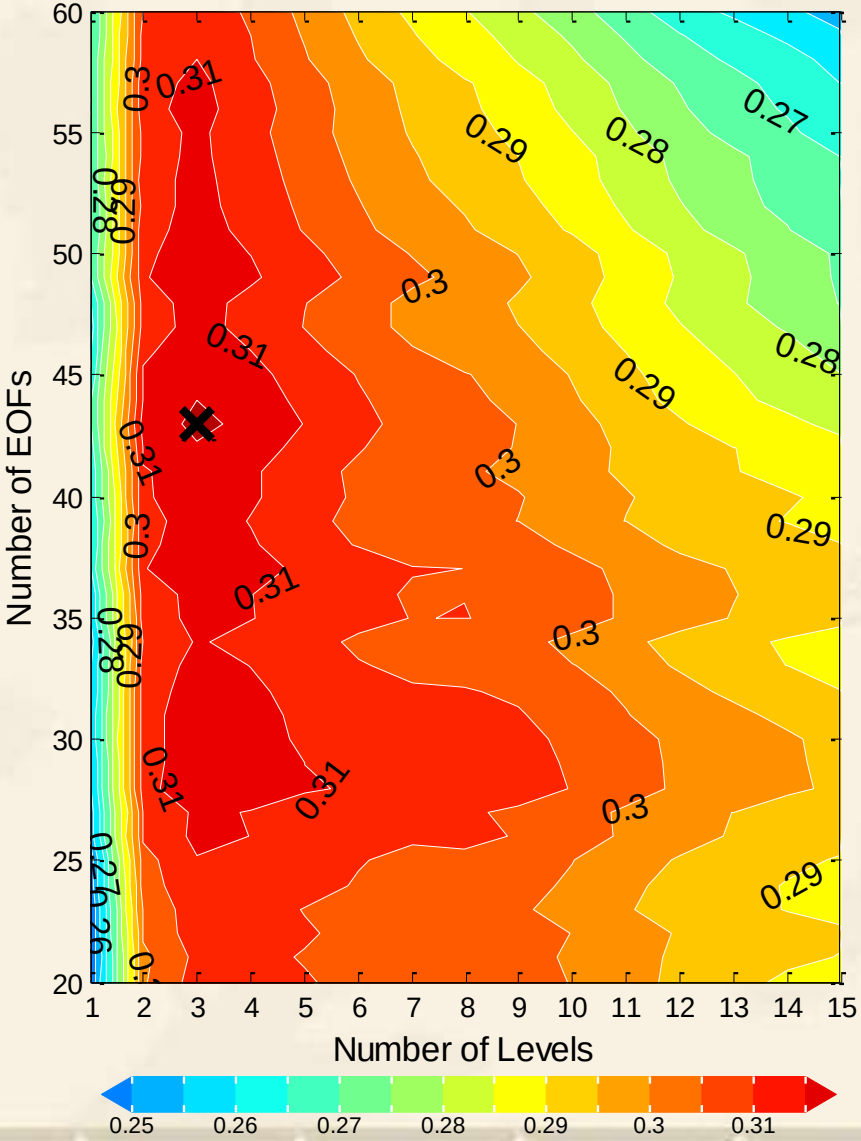
Data

- MERRA NH Streamfunction 250,750hPa (T80→T21) 1979-2013 MJJAS daily;
- MERRA tropical (25S-25N) heating (100-1000hPa vertical integrated);
- Data process:
  - Linear trend and first three harmonics of annual cycle (1yr/6mon/3mon) are removed,
  - 7-day running mean is applied,
  - All fields are area-weighted and domain-standardized;
- Evaluation: anomaly correlation, linear regression; t-test (degree of freedom based on 5 months / 153 days).

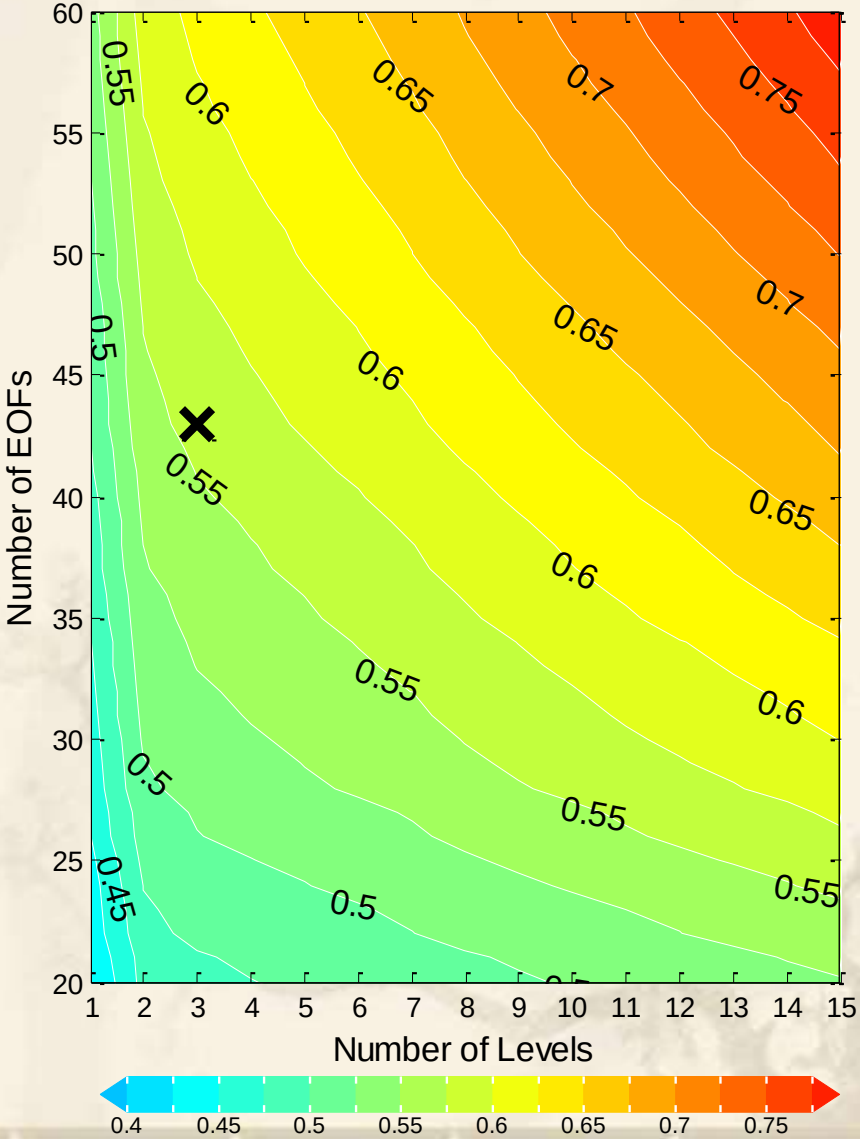
MERRA NH 250hPa Streamfunction MJJAS

Leave-one-year-out Cross Validation: 10~14 Day Lead

Anomaly Correlation

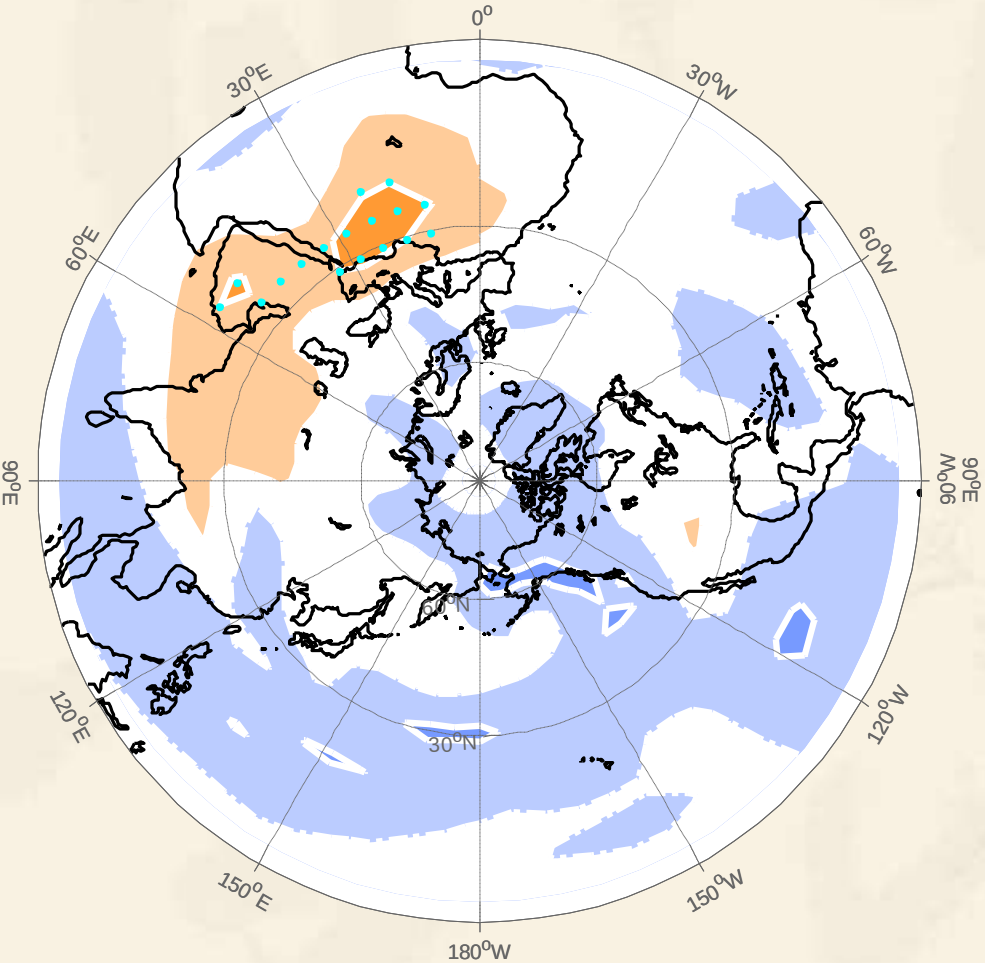


Relative Amplitude

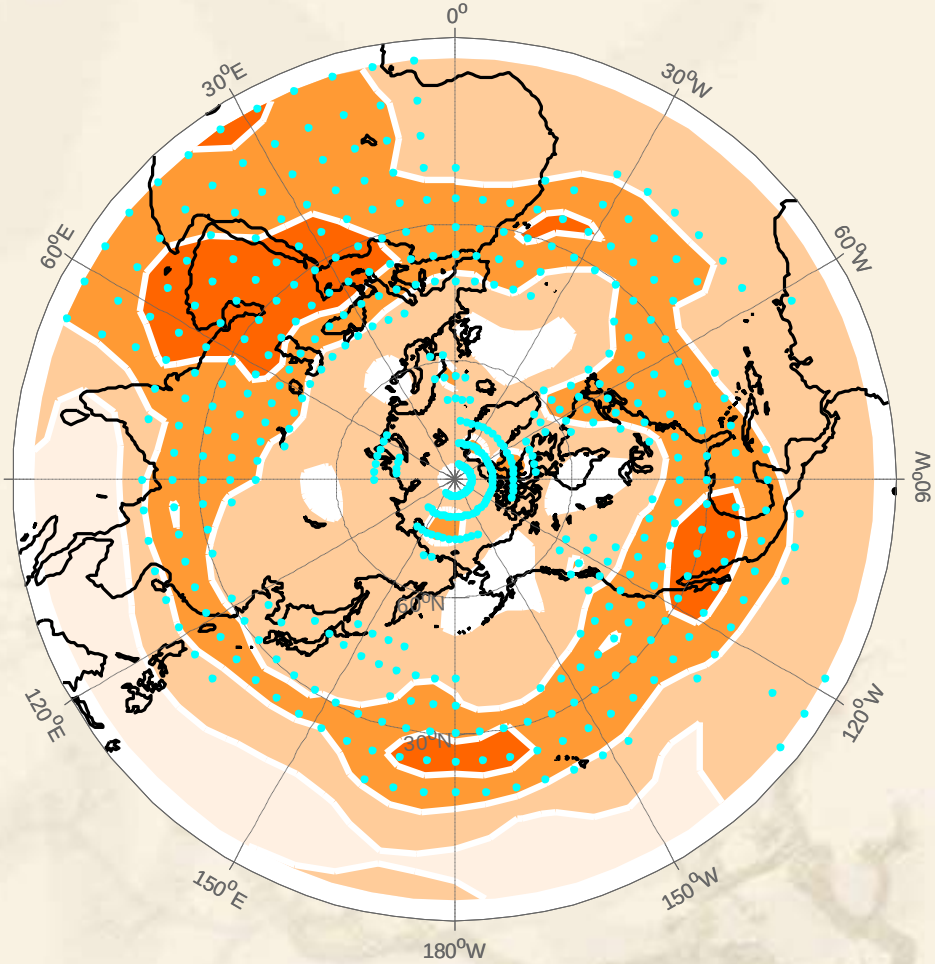


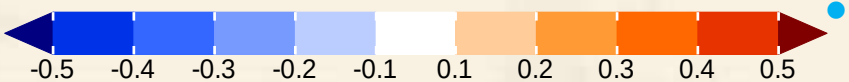
14-Day Lead

MERRA Persistence



LIM 43 EOFs, 1 level

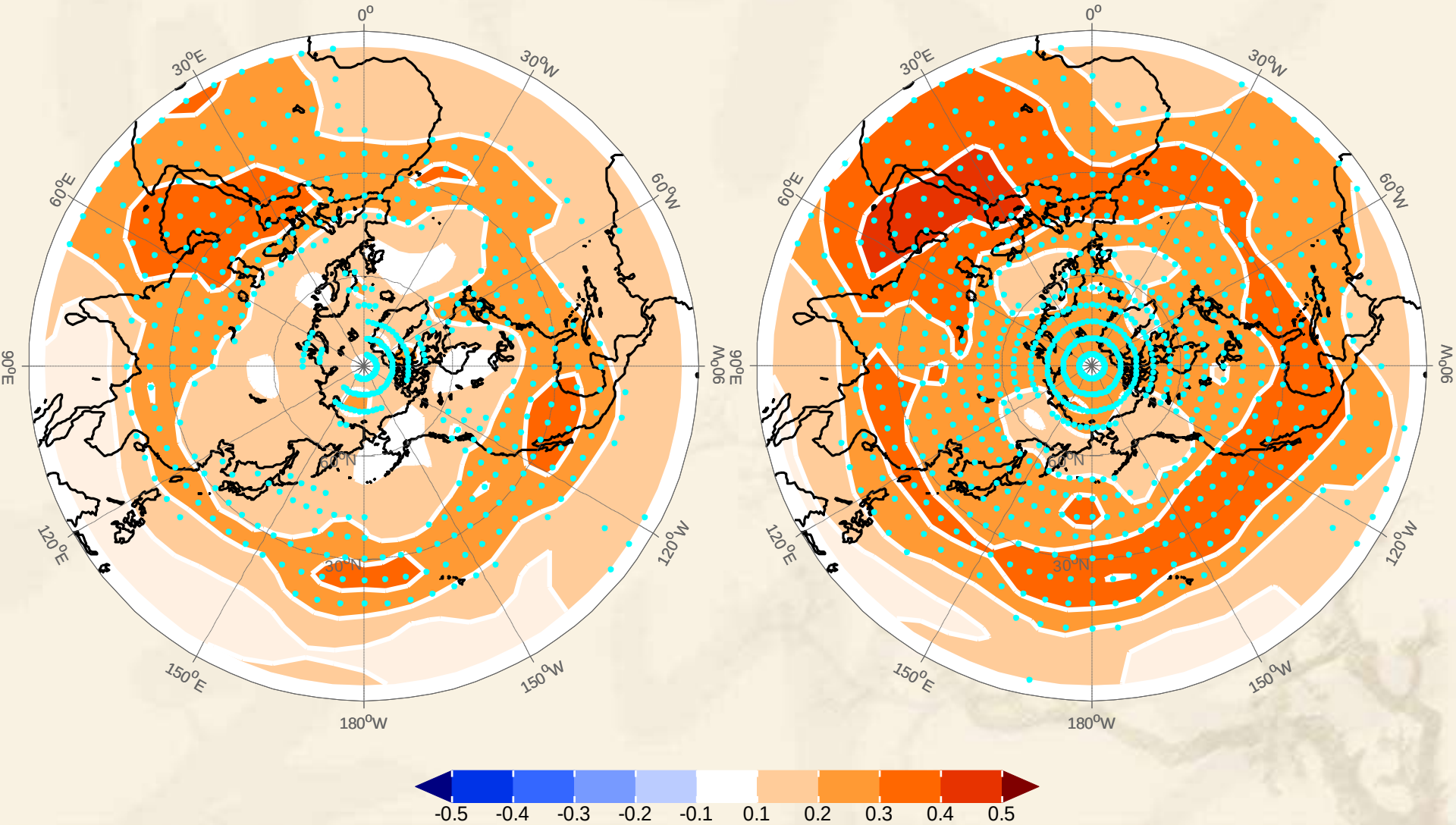




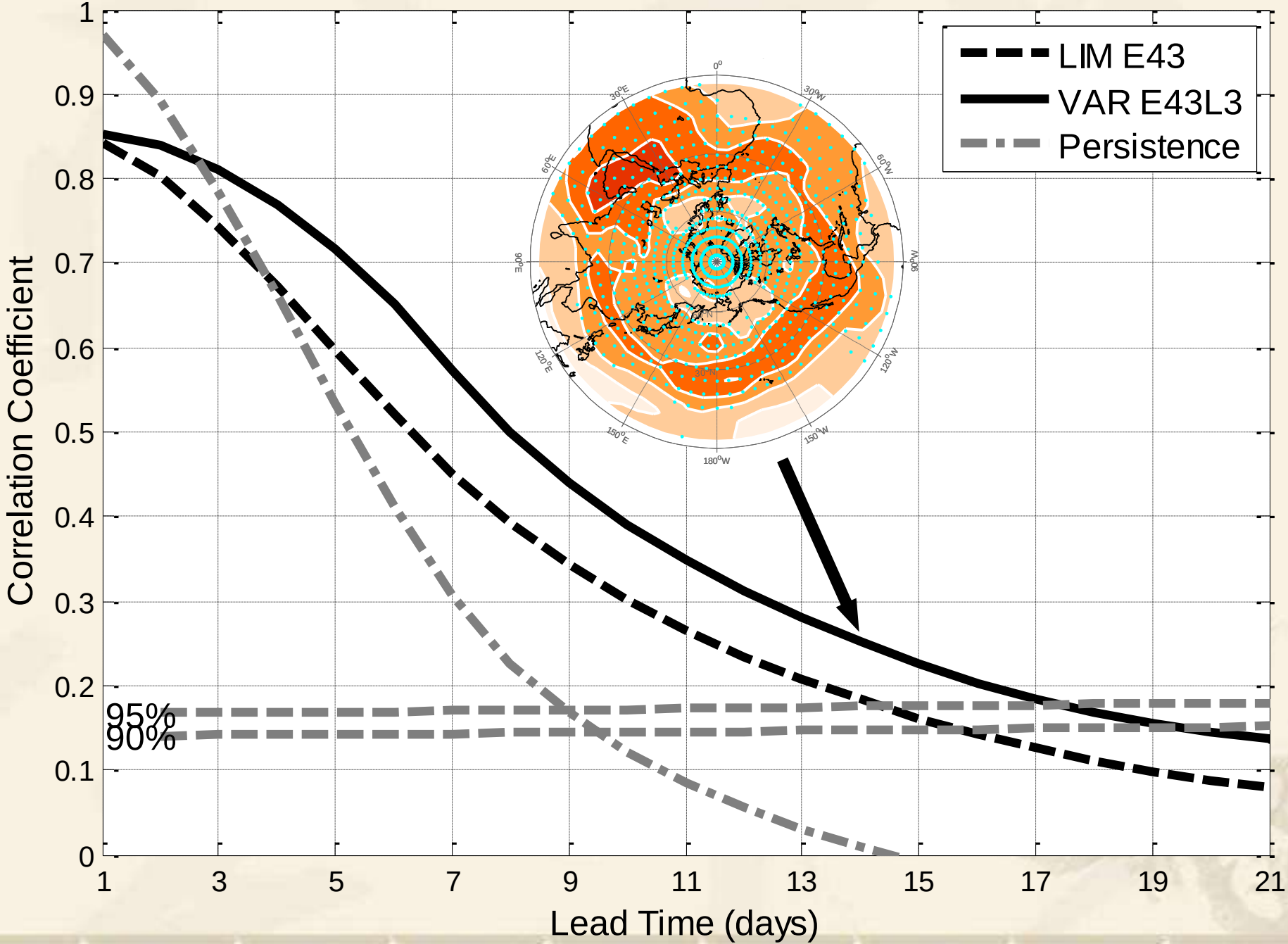
• 95% significance by *t*-test

14-Day Lead

LIM (1 Level) vs. VAR (3 Levels)



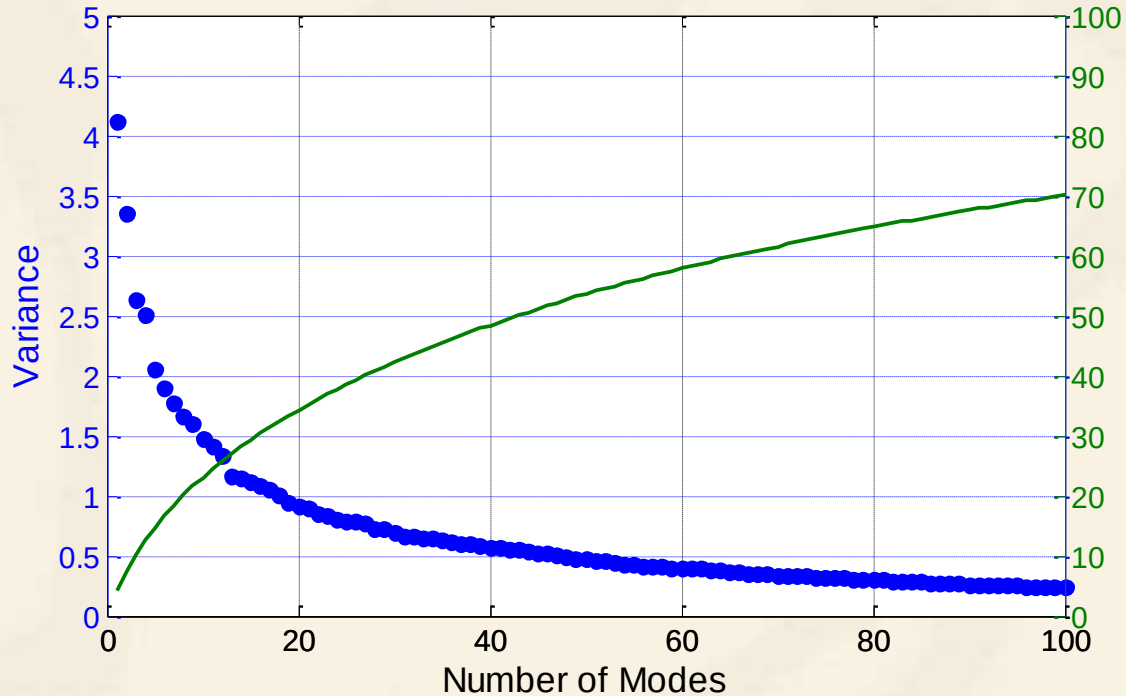
Anomaly Correlation for MERRA NH 250hPa Streamfunction



MERRA Streamfunction + tropical heating

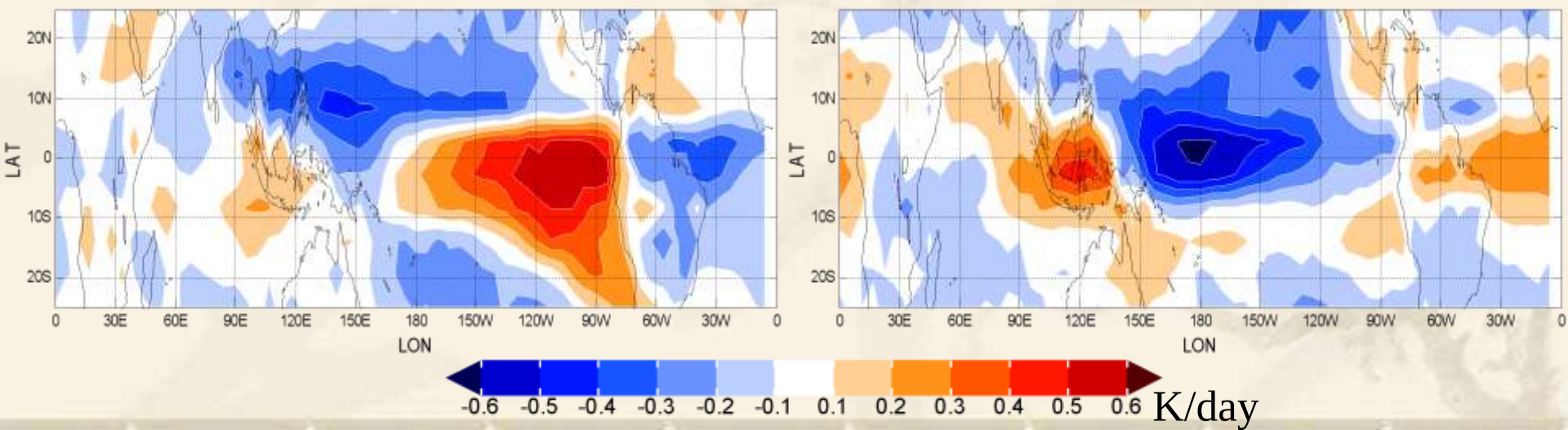
25S-25N

Vertically integrated 100-1000hPa

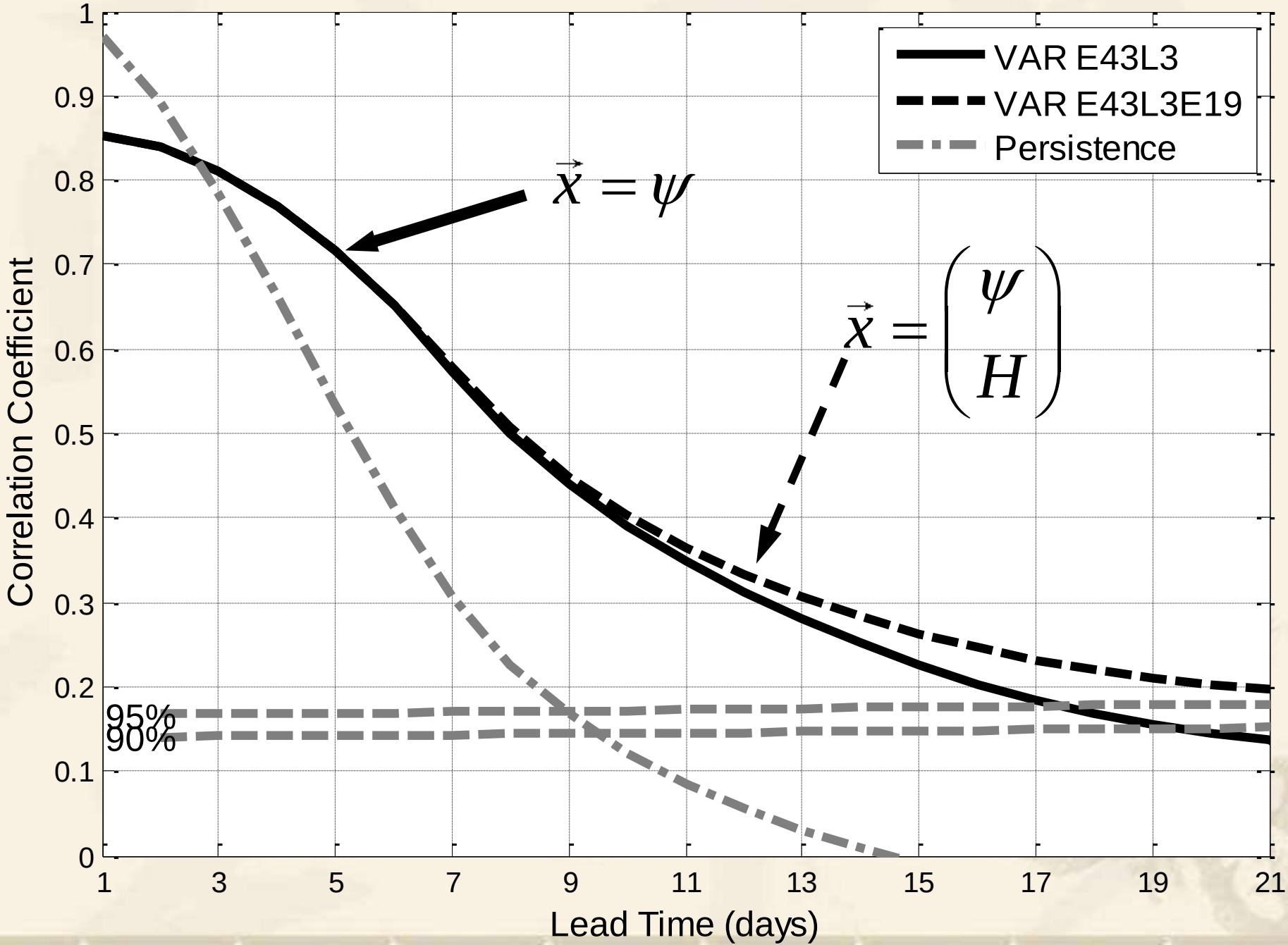


EOF1 pattern (4.1%)

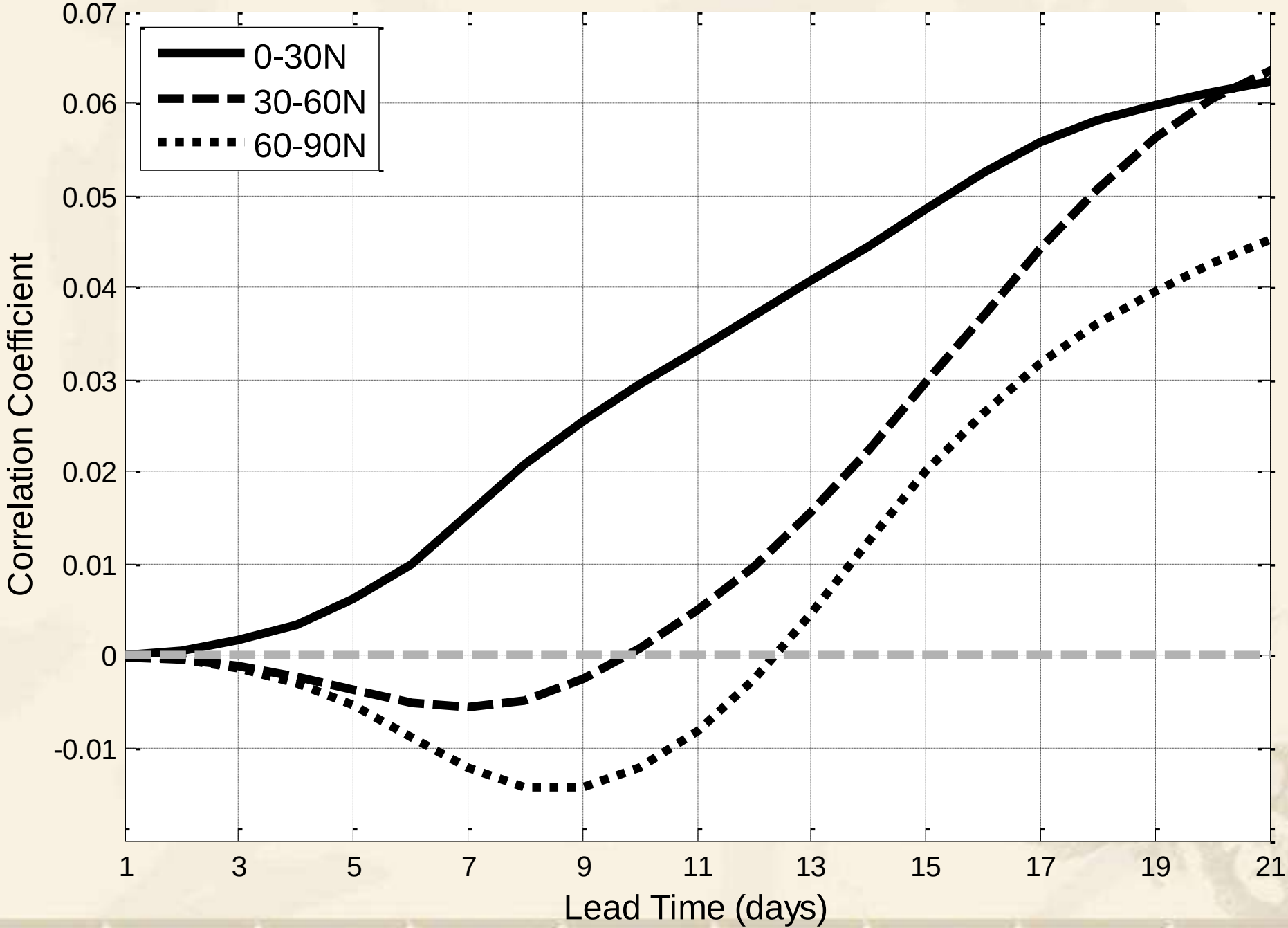
EOF2 pattern (3.4%)



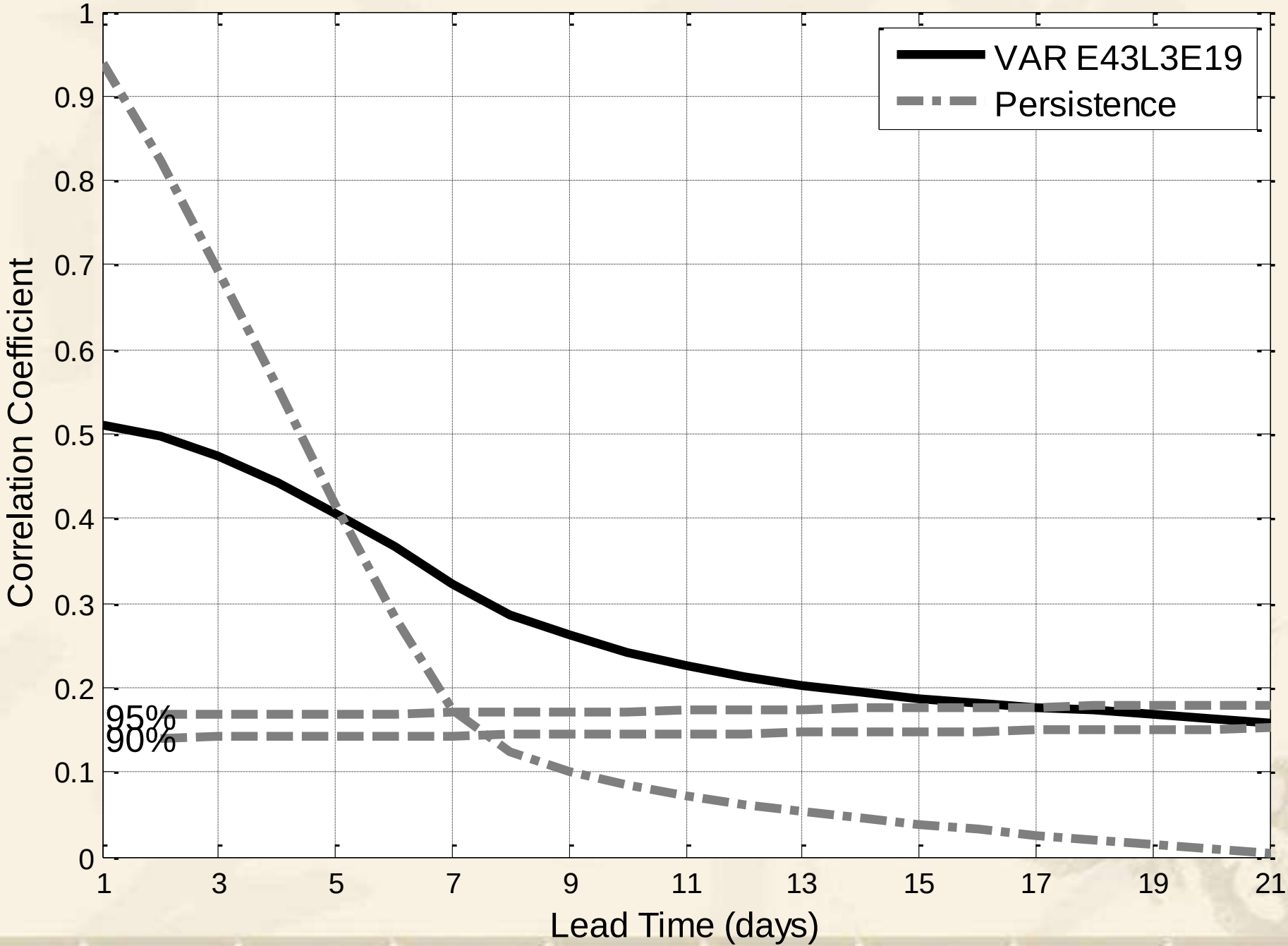
Anomaly Correlation for MERRA NH 250hPa Streamfunction



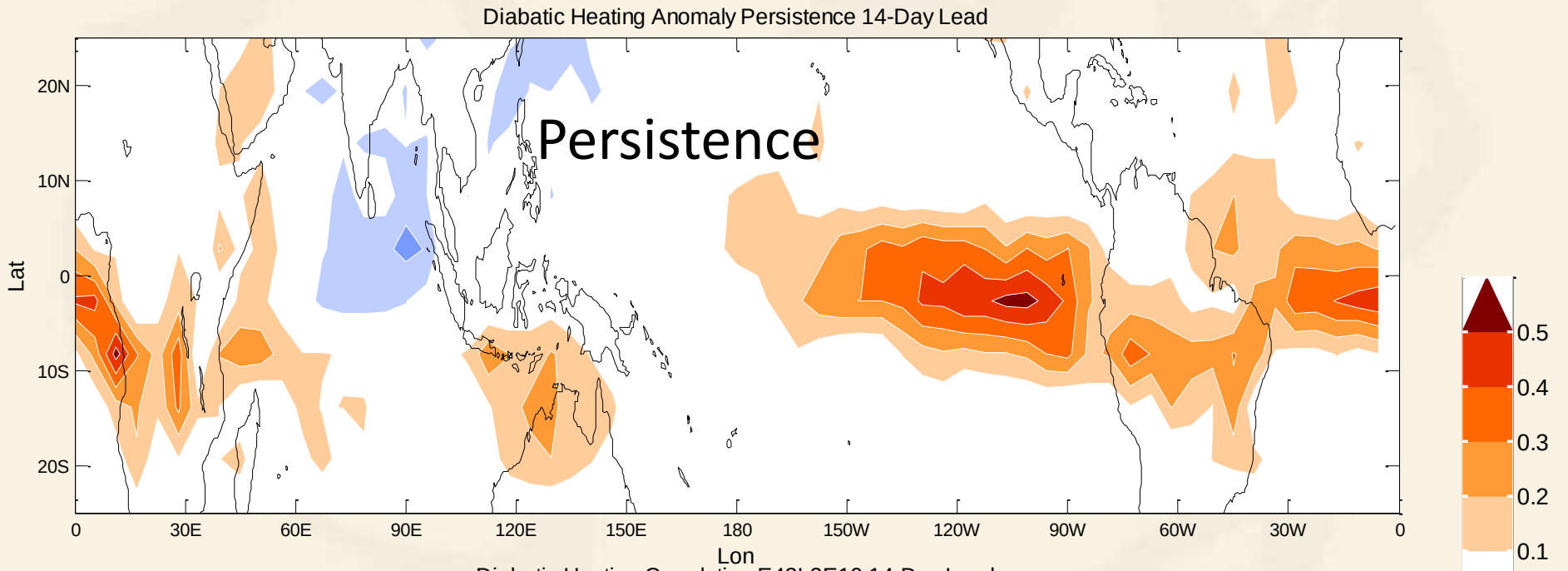
Anomaly Correlation Difference for MERRA NH 250hPa Streamfunction

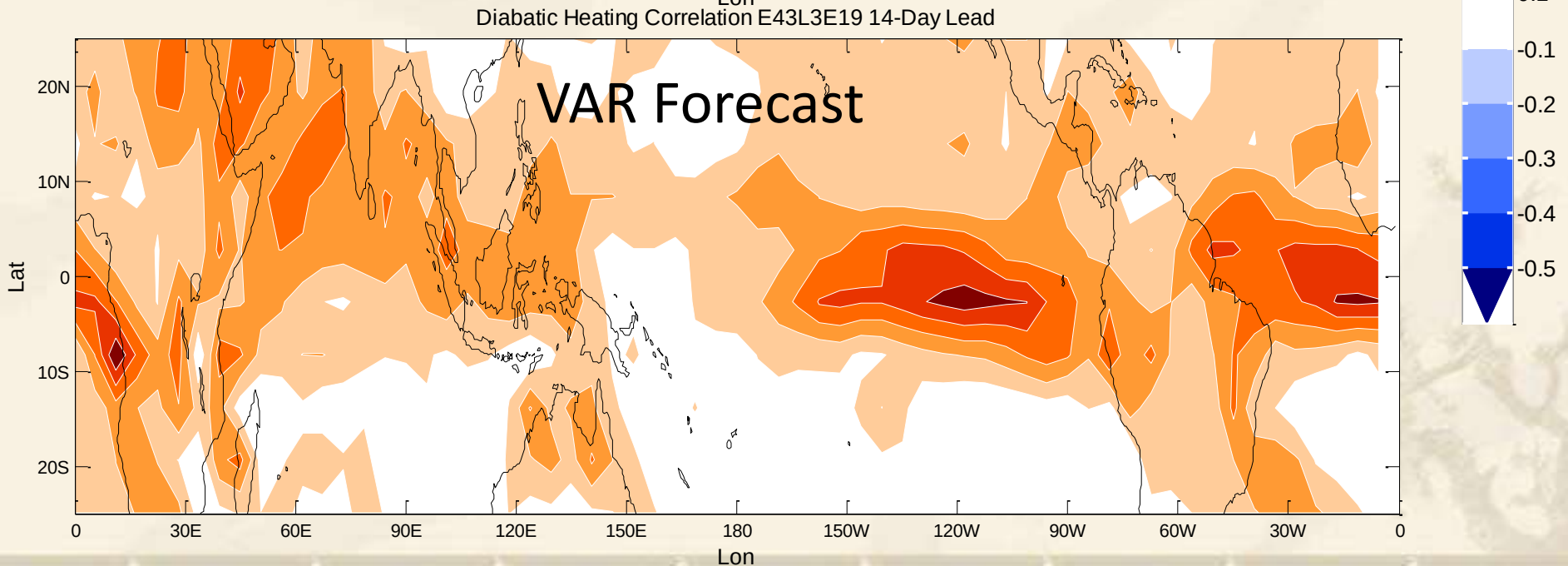


Anomaly Correlation for MERRA 25S-25N Diabatic Heating



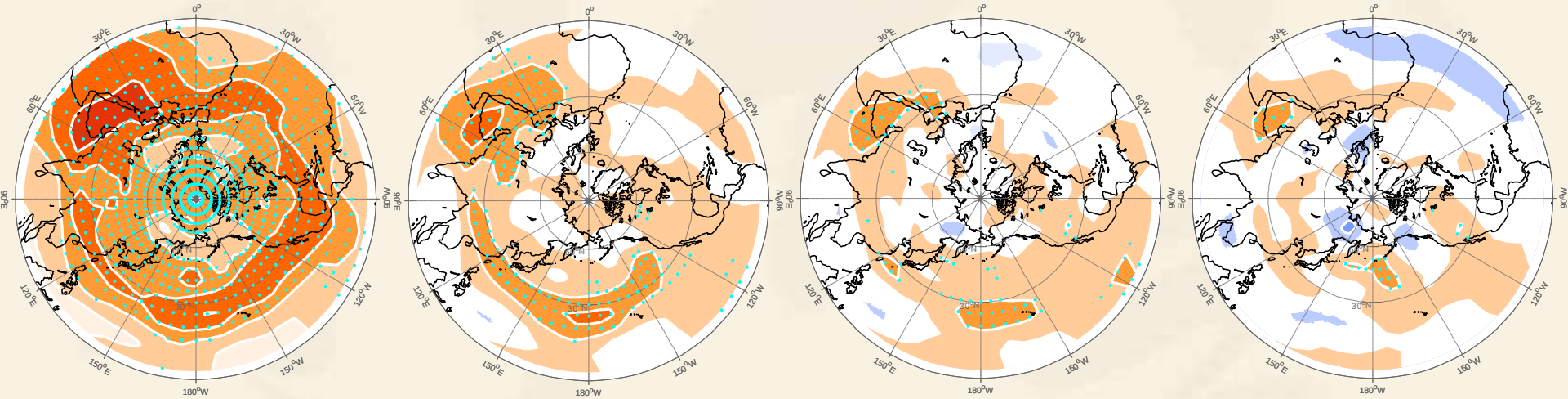
Anomaly Correlation for MERRA Tropical Heating 25S-25N: 14-Day Lead



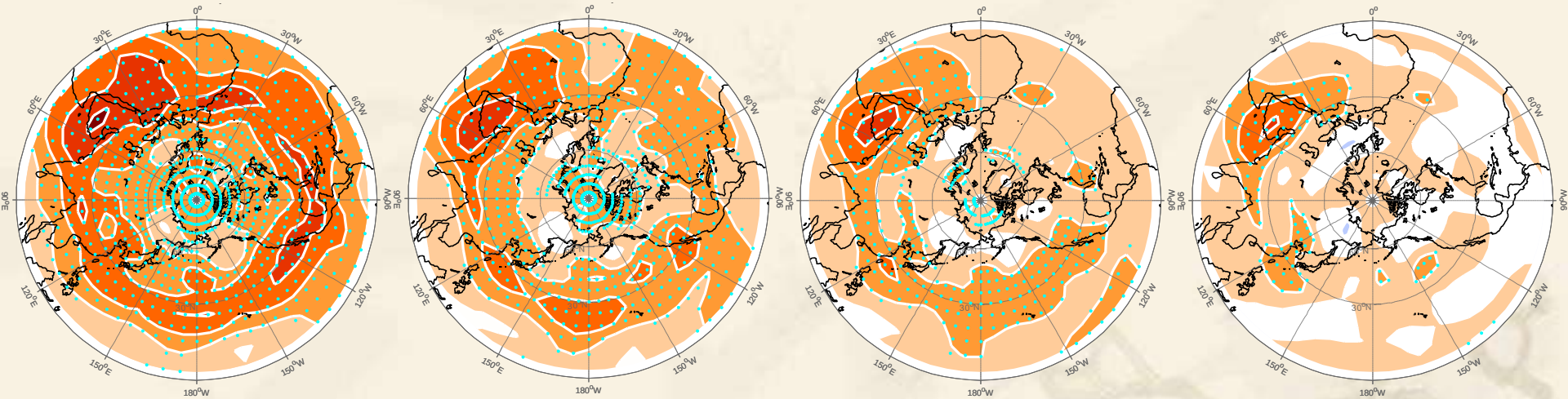


Anomaly Correlation for MERRA NH 250hPa Streamfunction

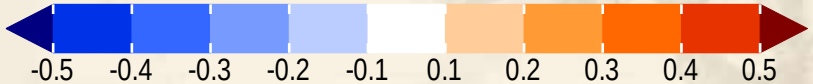
Streamfunction only: 43 EOFs, 3 levels

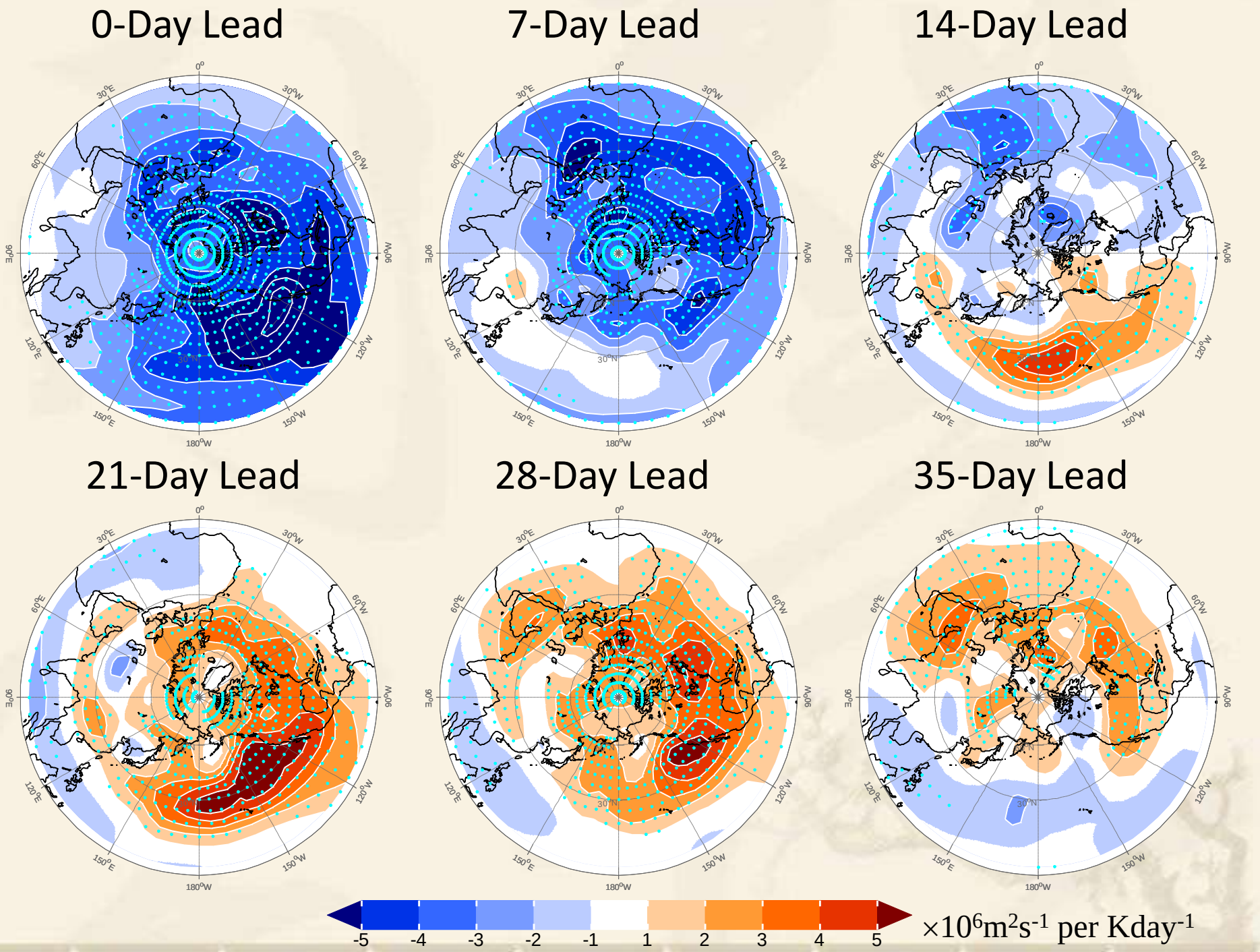


14-Day Lead | 21-Day Lead | 28-Day Lead | 35-Day Lead



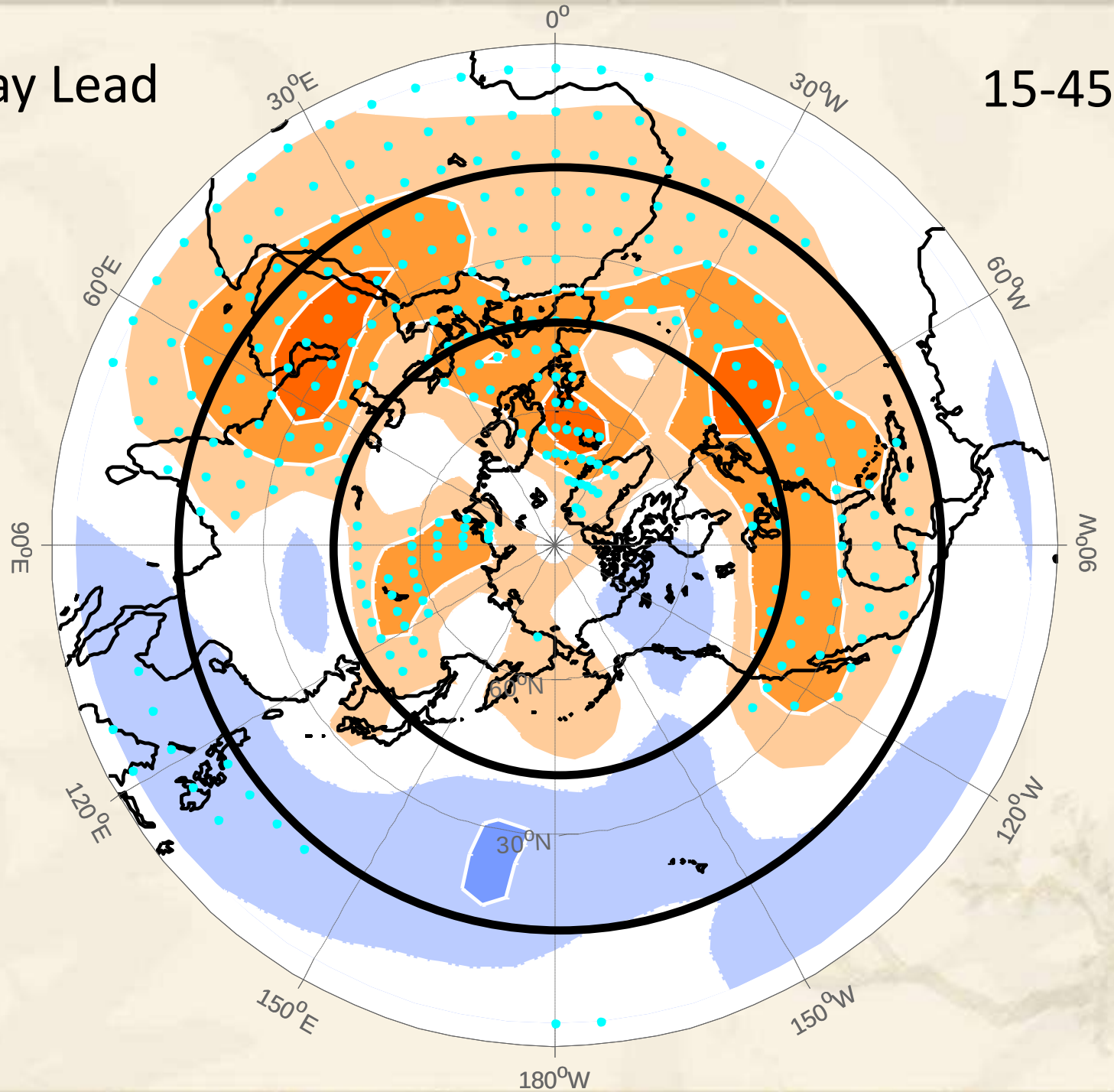
Streamfunction + Tropical Heating



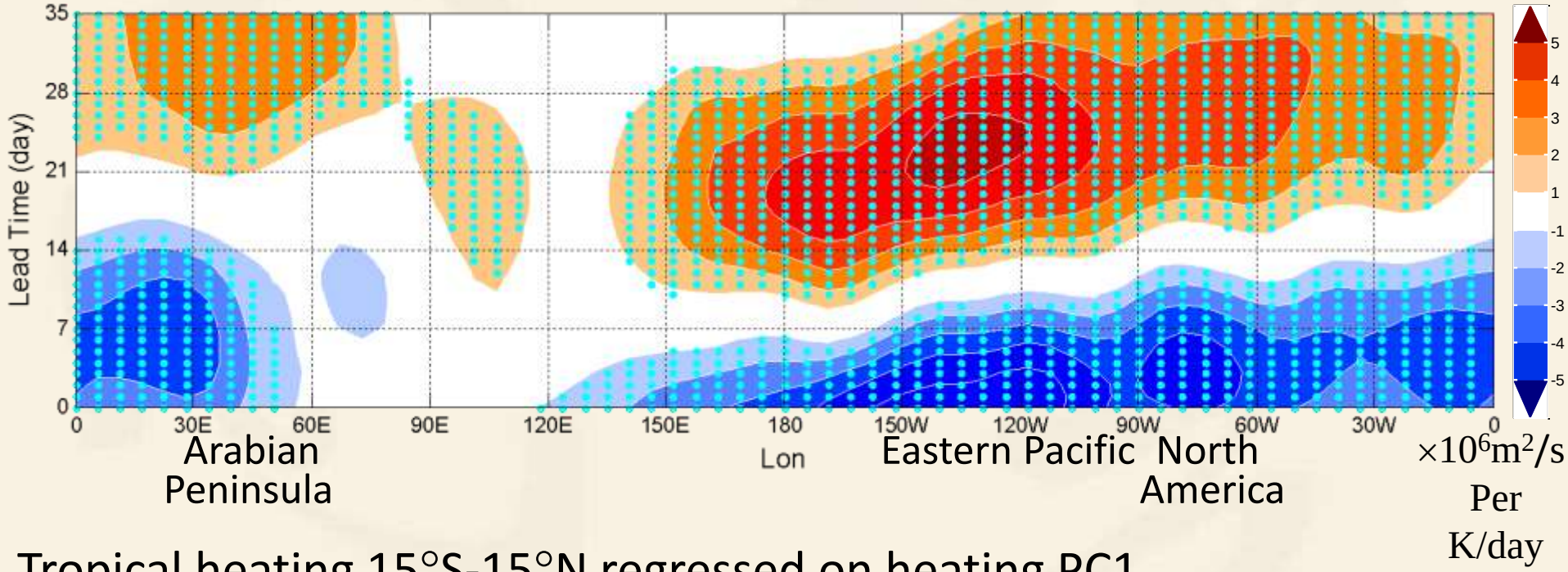

0-Day Lead
7-Day Lead
14-Day Lead
21-Day Lead
28-Day Lead
35-Day Lead
0°
30°E
30°W
60°E
60°W
90°E
90°W
120°E
120°W
150°E
150°W
180°W
30°N
-5
-4
-3
-2
-1
1
2
3
4
5
×10⁶m²s⁻¹ per Kday⁻¹

35-Day Lead

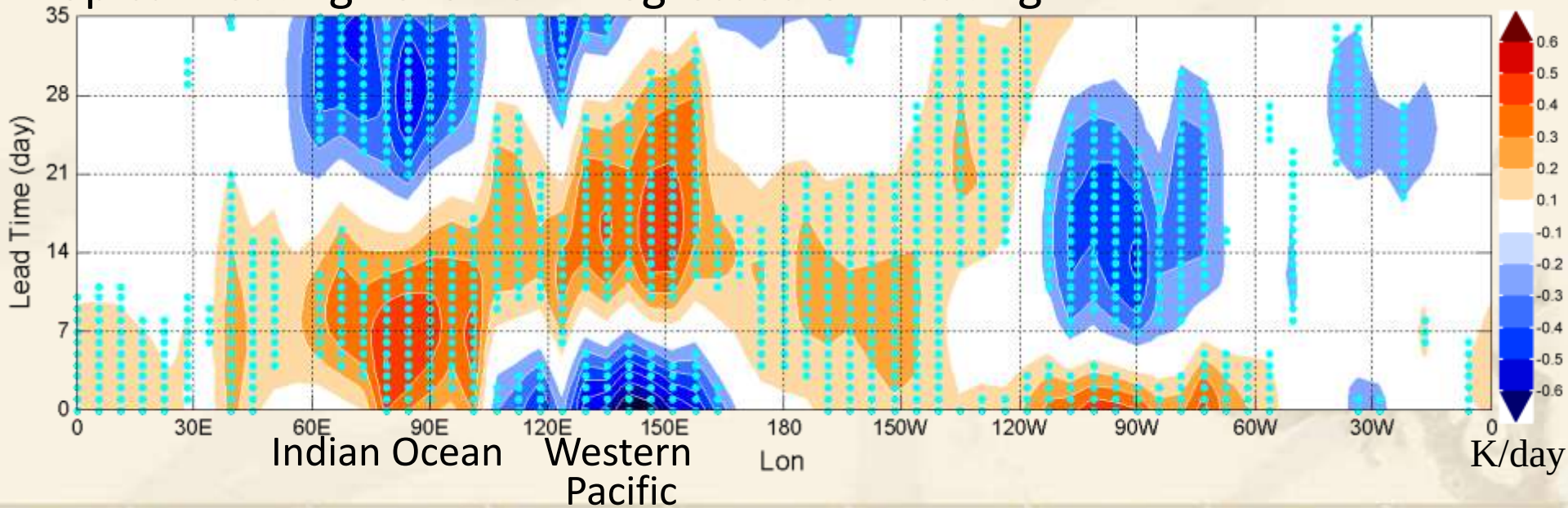
15-45°N



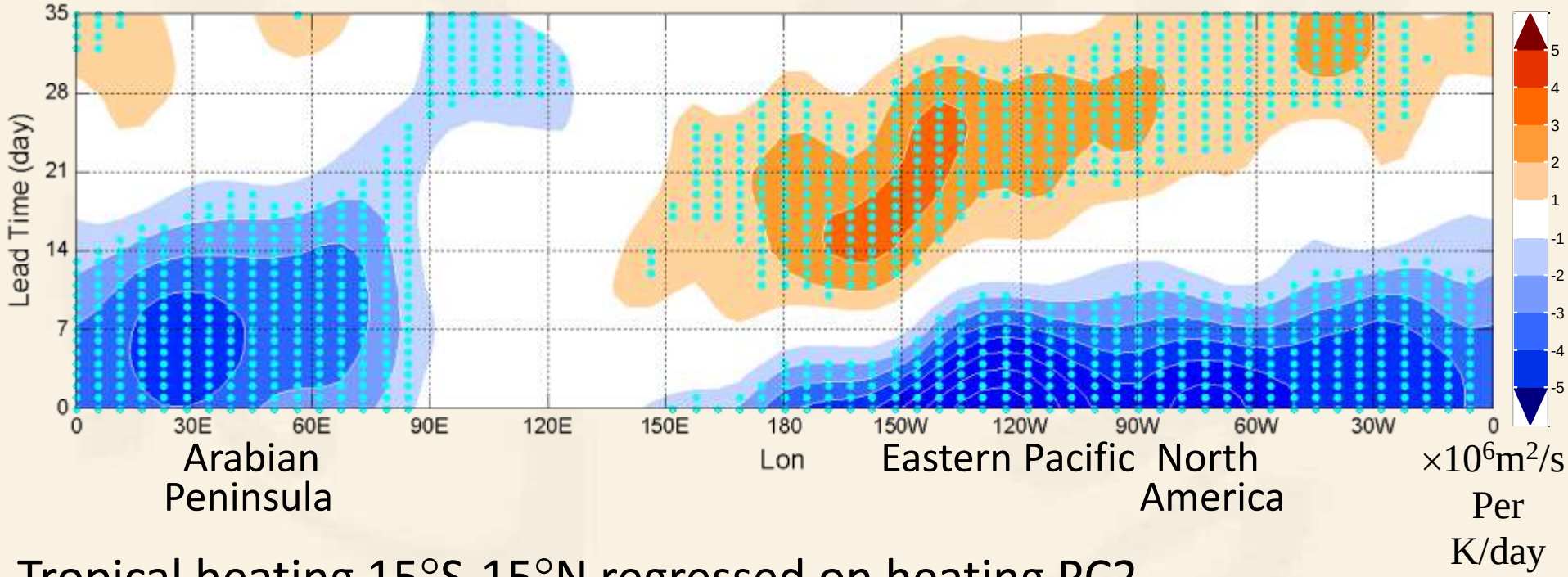
250 hPa streamfunction 15-45°N regressed on heating PC1



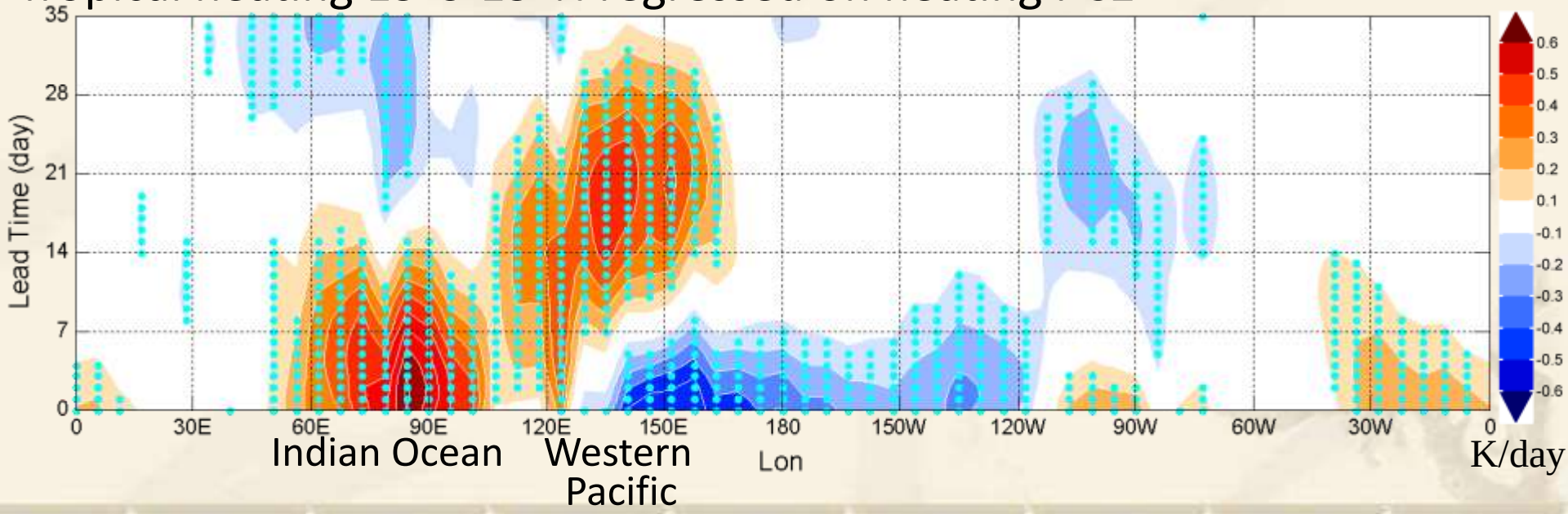
Tropical heating 15°S-15°N regressed on heating PC1

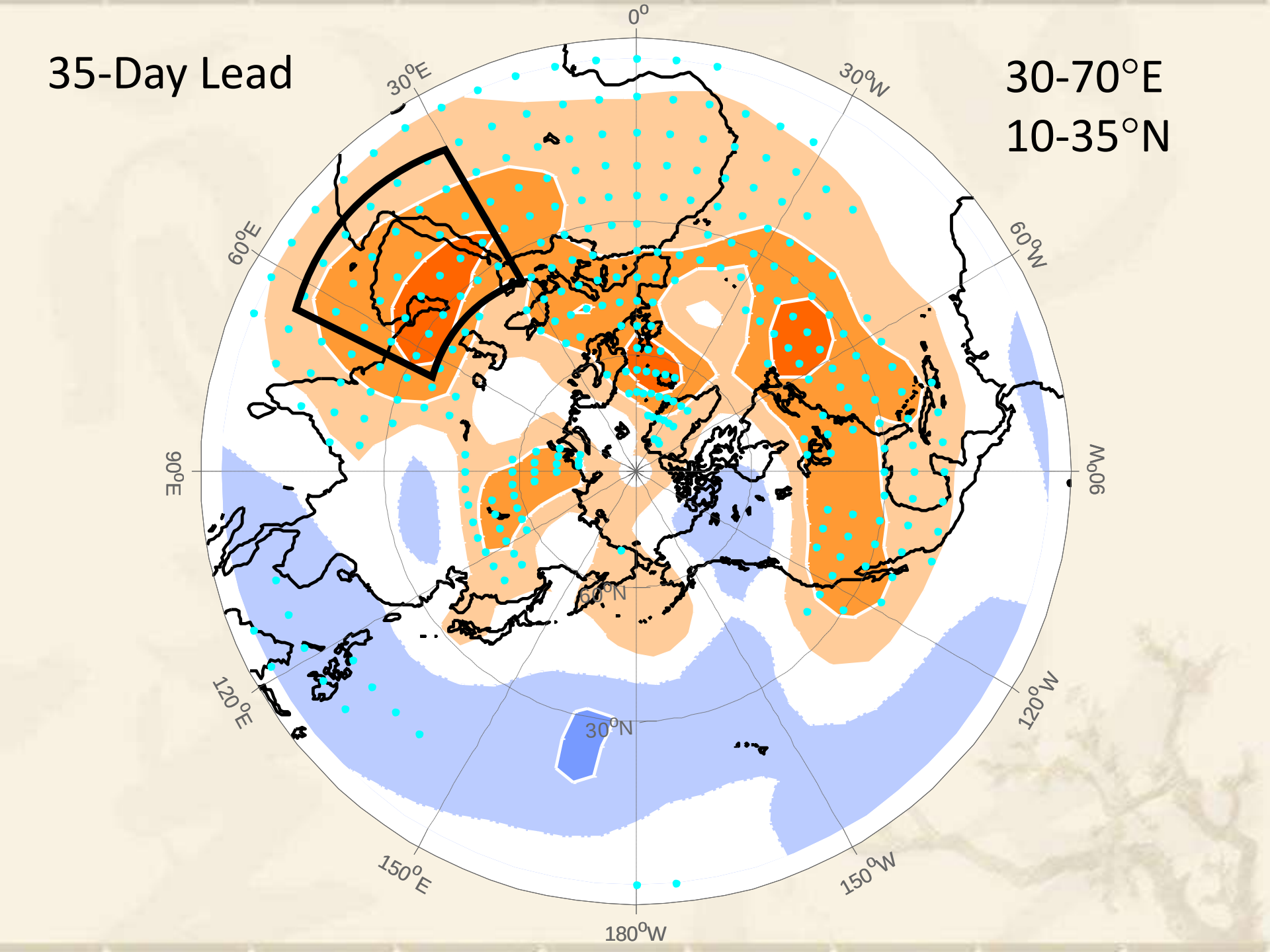


250 hPa streamfunction 15-45°N regressed on heating PC2

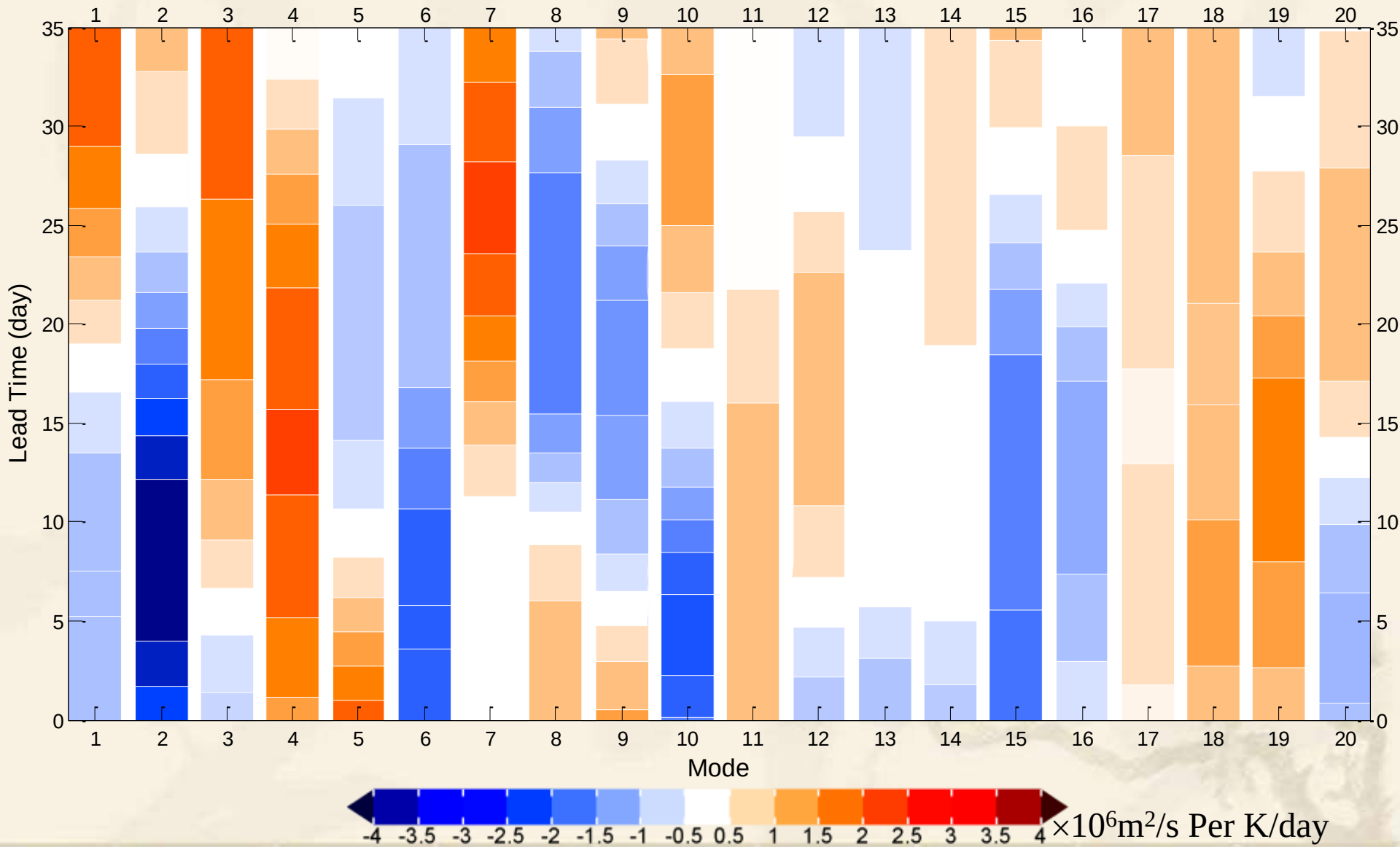


Tropical heating 15°S-15°N regressed on heating PC2




35-Day Lead
30-70°E
10-35°N
0°
30°E
30°W
60°E
60°W
90°E
90°W
120°E
120°W
150°E
150°W
180°W
60°N
30°N

250 hPa streamfunction 30-70°E 10-35°N regressed on heating PCs



Summary

- Multi-level VAR model improves extended-range forecast skill over single-level models such as LIM;
- Tropical heating significantly helps predict NH summer low frequency flow;
- NH summer low frequency flow can be modulated by tropical heating associated with the MJO through the eastward propagation of tropical heating initiated from the Indian Ocean and western equatorial Pacific;
- Regional forecast skill at Arabian Peninsula is particularly enhanced for up to 5 weeks lead-time.

(Submitted to Climate Dynamics)