Meteorological Modes of $PM_{2.5}$ Variability and Application to Evaluate GEOS-Chem Simulations of $PM_{2.5}$ Sensitivity to Future Climate Change

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Effects of Climate Change on $PM_{2.5}$ Air Quality

- $PM_{2.5}$ is sensitive to climate change through stagnation, transport, precipitation, and meteorological dependence of emissions and aerosol thermodynamics.

- GCM-CTM simulations show $PM_{2.5}$ sensitivity of ±0.1-1 μg m^{-3} to 2000-2050 climate change, but with no consistency across models even in sign of effects.

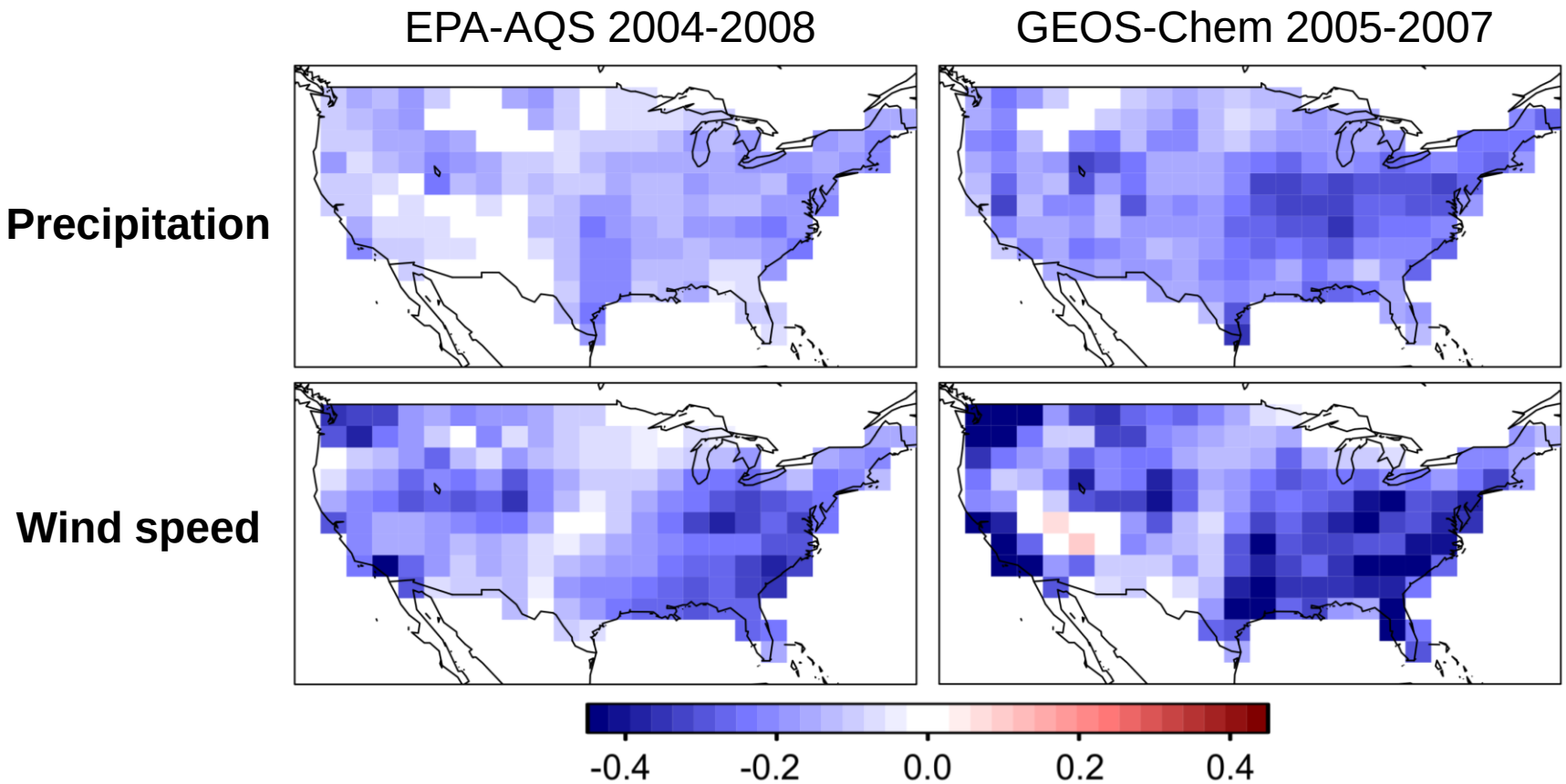
- Can we use observed correlations of $PM_{2.5}$ with meteorological variables to test ability of models (e.g. GEOS-Chem) to project $PM_{2.5}$ sensitivity to changing climate?

Simulated and Observed Correlations with Meteorological Variables

- **Multiple linear regression** to fit **deseasonalized** daily $PM_{2.5}$ concentrations (y) (simulated and observed) to eight meteorological variables (x_k) for each model grid square:

$$y = \beta_0 + \sum_{k=1}^{8} \beta_k x_k$$

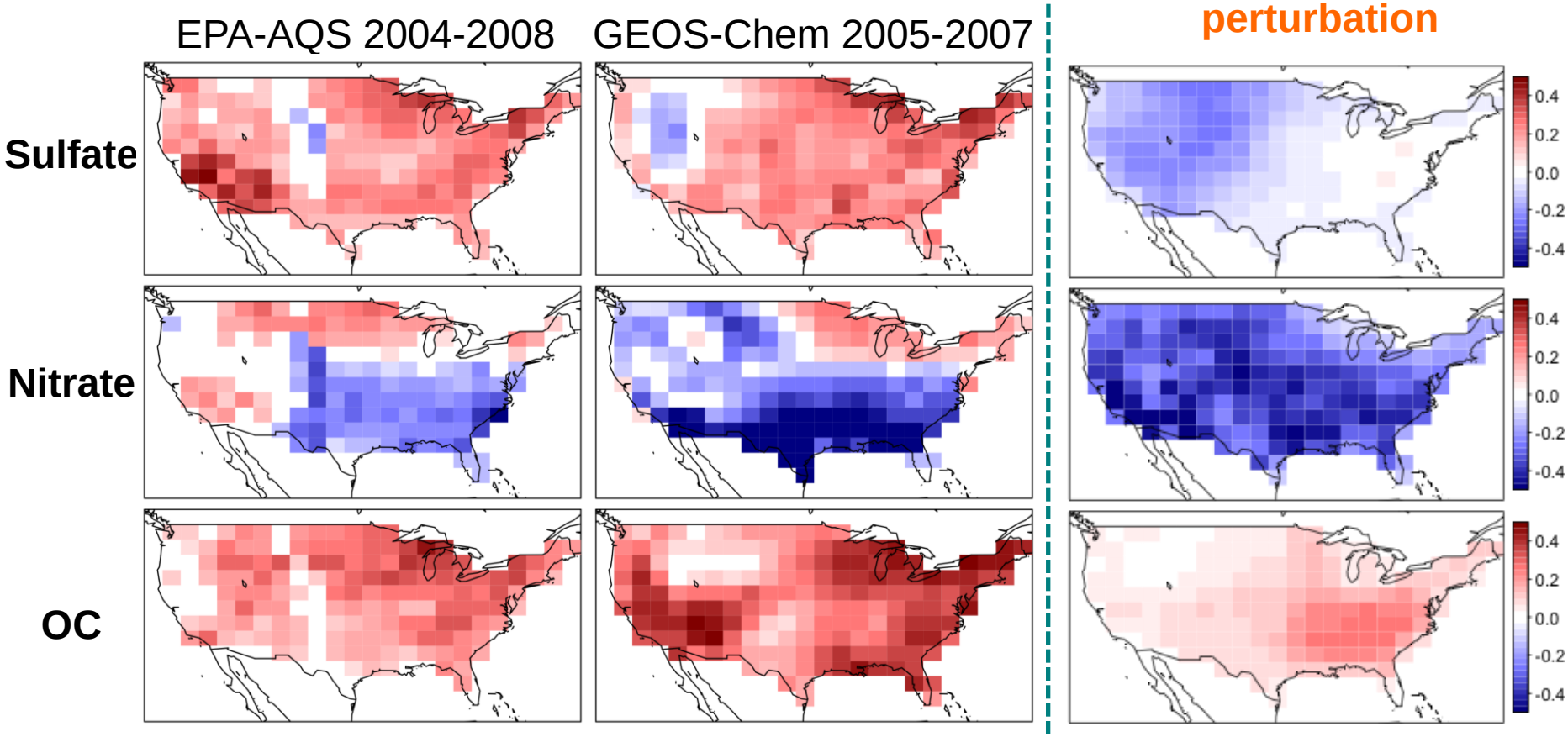
Regression coefficient for total $PM_{2.5}$ normalized to standard deviations



Simulated and Observed Correlations with Temperature

Regression coefficient with temperature normalized to standard deviations

Direct *T* dependence: GEOS-Chem +1K perturbation



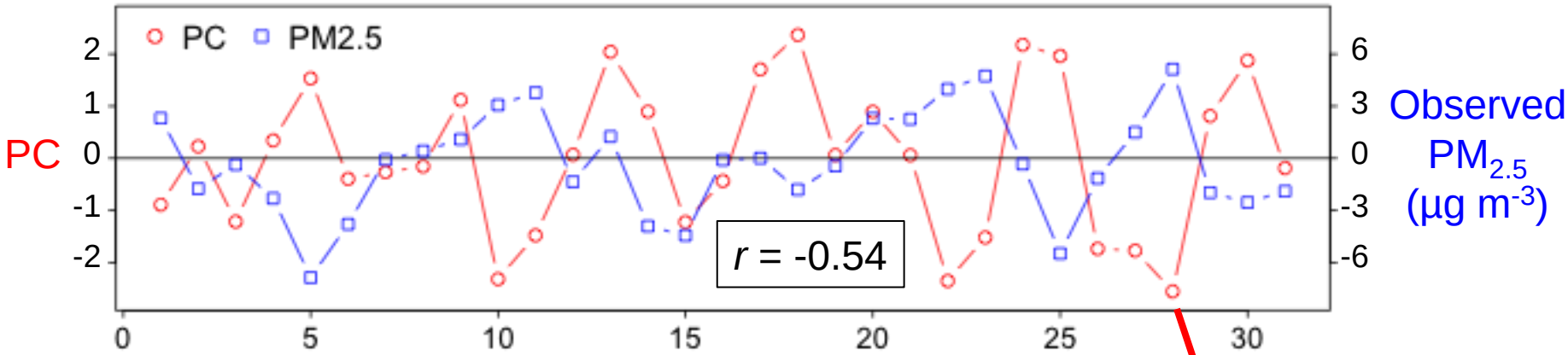
- Correlations with *T* in NE and MW mostly reflect indirect association with synoptic circulation (air mass, cyclone, cold front).
- Correlations with *T* in SE mostly reflect direct dependence for nitrate (volatilization) and for OC (biogenic VOC, SOA).

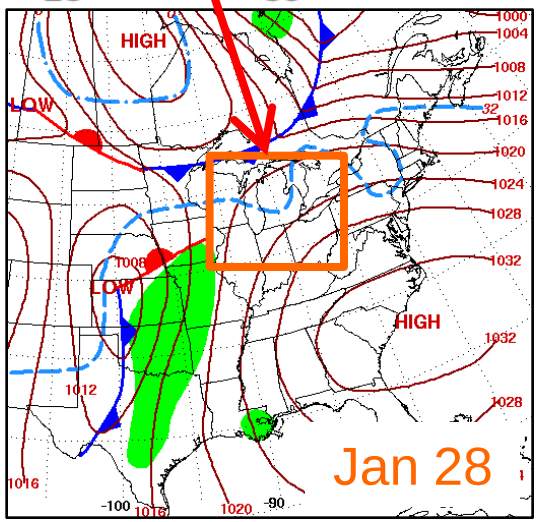
Dominant Meteorological Modes of $PM_{2.5}$ Variability

- **Principal component (PC)** decomposition of eight meteorological variables (x_k) to identify dominant meteorological regimes that drive $PM_{2.5}$ variability:

$$\mathrm{PC}_j = \sum_{k=1}^{8} \alpha_{kj} \frac{x_k - \bar{x}_k}{\sigma_{xk}}$$

Time series for dominant PC and deseasonalized $PM_{2.5}$: Midwest in Jan 2006





- We identify a dominant PC that is strongly anticorrelated with observed $PM_{2.5}$ in Midwest, consisting of low T, low and rising pressure, strong NW wind.

- This indicates passage of **mid-latitude cyclone** with **cold front** at tail end.

Dominant Meteorological Modes of $PM_{2.5}$ Variability

- **Principal component regression** to find effects of dominant meteorological modes (PC_j) on $PM_{2.5}$ (y), and how they influence apparent correlations of $PM_{2.5}$ with individual meteorological variables:

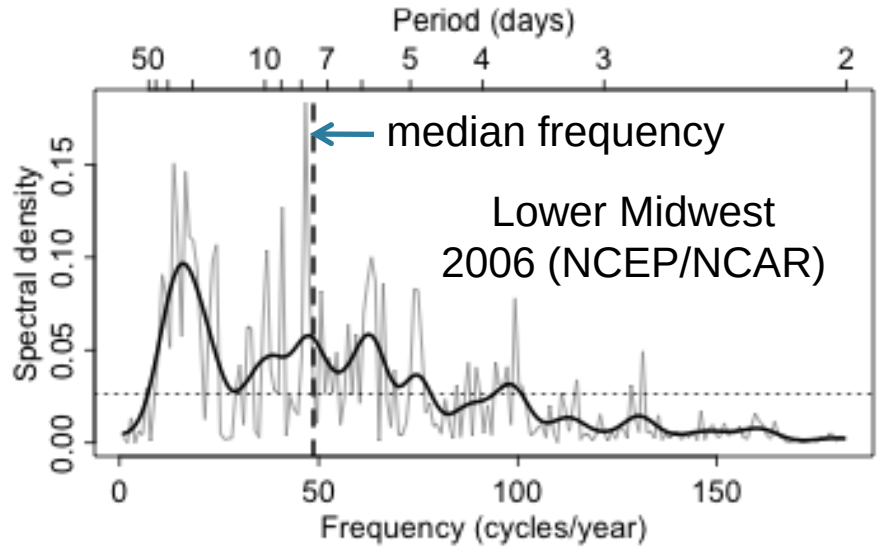
$$\frac{y-\bar{y}}{\sigma_y} = \sum_{j=1}^{8} \gamma_j \mathrm{PC}_j$$

Region	Features of dominant PC	$PM_{2.5}$ variability explained		PC regression coefficient	
		Observed	Modeled	Observed	Modeled
Northeast	Cold front with strong NW winds at tail end of mid-latitude cyclone	17%	21%	-0.31	-0.33
Midwest		29%	25%	-0.41	-0.38
Southeast		31%	15%	-0.42	-0.29
Pacific NW	Strong, cold marine westerlies south of low-pressure system	36%	45%	-0.35	-0.39
California		26%	13%	-0.28	-0.21

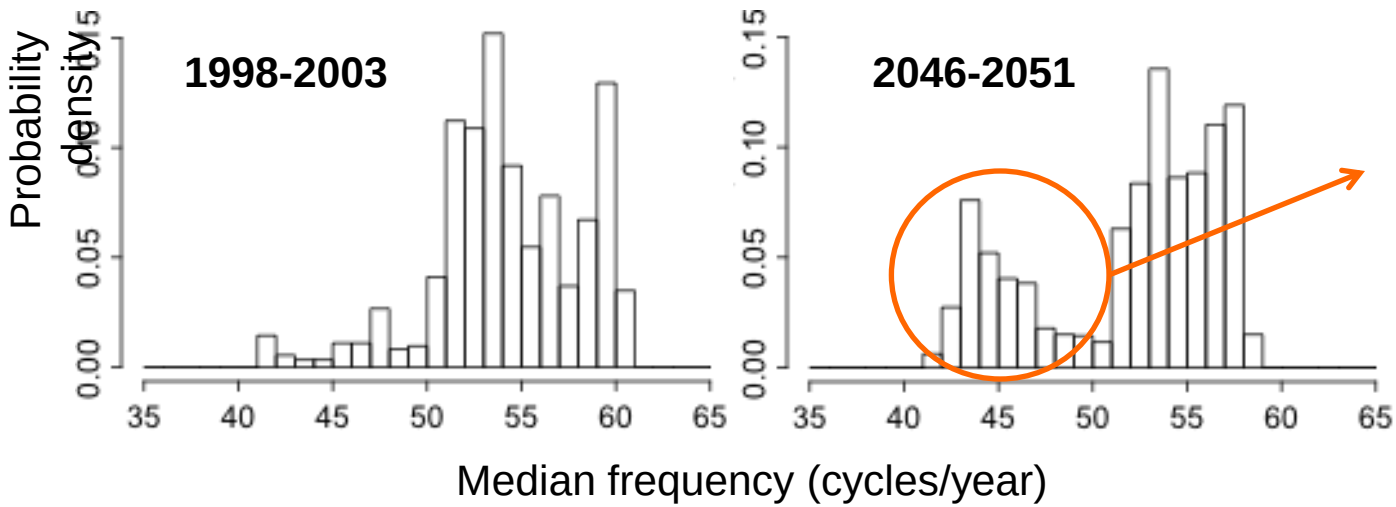
Frequency of Dominant Meteorological Modes in Future Climate

- Find spectrum for time series of dominant meteorological mode (PC), and use median frequency as metric to quantify frequency of synoptic weather systems
- Applied to diagnose future changes in synoptic frequency from GCM outputs and impacts on $PM_{2.5}$

Spectrum for cyclone/frontal passage



Interannual variability of annual median synoptic frequency for Lower Midwest from NASA GISS-GCM



Less frequent frontal ventilation leading to +0.1-0.7 $\mu g\ m^{-3}$ increase in annual mean $PM_{2.5}$