Linkages between synoptic circulation and poor air quality in Beijing

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1. ABSTRACT

Episodes of extremely poor air quality (AQ), like January 2013's "airpocalypse" in Beijing, China, can impact public health and economic vitality. Anthropogenic emissions of pollutants are key to these poor AQ episodes, but so too are the meteorological conditions that trap pollutants near the surface. Projections of future AQ in Beijing have shown conflicting results[1,2], dependent on how such conditions are characterized. Motivated by an effort to reconcile this model projection uncertainty, here we ask:

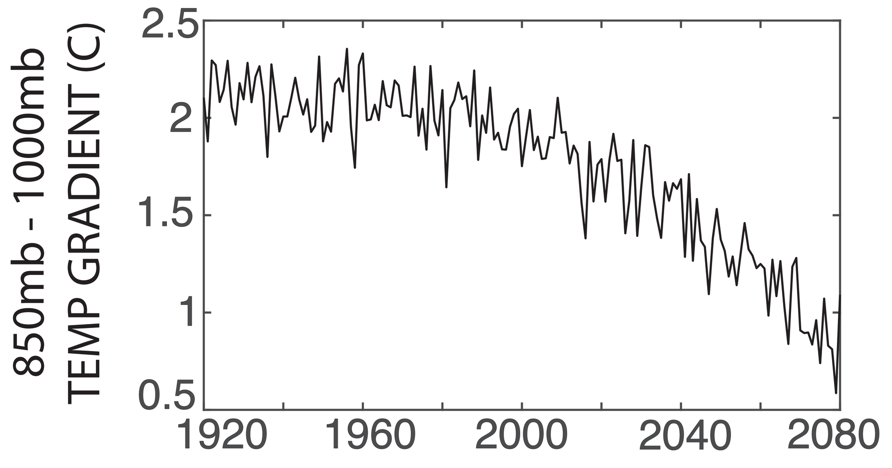
1. **What is the relative importance of different meteorological drivers of poor air quality in Beijing?**
2. **What explains the occurrence of the meteorological conditions conducive to poor air quality in Beijing?**

Using principal components regression on observations of local meteorology and air quality, we find a strong association between the occurrence of positive lapse rates[3], strong southerly winds[4], high relative humidity[5], and weak surface winds[5], with poor air quality. Each of these is strongly associated with anticyclonic synoptic-scale circulation[6]. Our findings emphasize the need to accurately assess the relative importance of present-day meteorological drivers of poor air quality to better constrain their projected changes in climate models.

2. MOTIVATION

- Studies have projected multiple futures for Beijing AQ
- The CESM Large Ensemble projects a decrease in atmospheric stability, which would improve air quality (Fig. 1)
- Different variables have different effects on AQ and responses to anthropogenic forcing
- Goal: Establish relative importances of ingredients and examine underlying drivers, to better constrain projections

Figure 1 | CESM-LE ensemble mean monthly temperature gradient (T850 - T1000) in HIST and RCP8.5, 38-60N, 115-135E



3. DATA

- NCEP/DOE R2 Reanalysis
- Integrated Global Radiosonde Archive, Beijing station soundings
- United States Embassy, Beijing, daily PM2.5 readings
- All analysis uses winter (DJF), 2010-2016

4. METEOROLOGICAL INGREDIENTS

Figure 2 | Strong relationships between individual ingredients and Beijing AQ, but they covary (see Table 1)

- ELR: Lapse rate deviates from moist adiabat; stable atmosphere restricts lifting
- V850: Strong southerly winds transport pollutants and moisture into Beijing
- RH: Moist air promotes particulate matter condensation
- WS: Weak surface winds limit dispersion, which allows pollutant accumulation

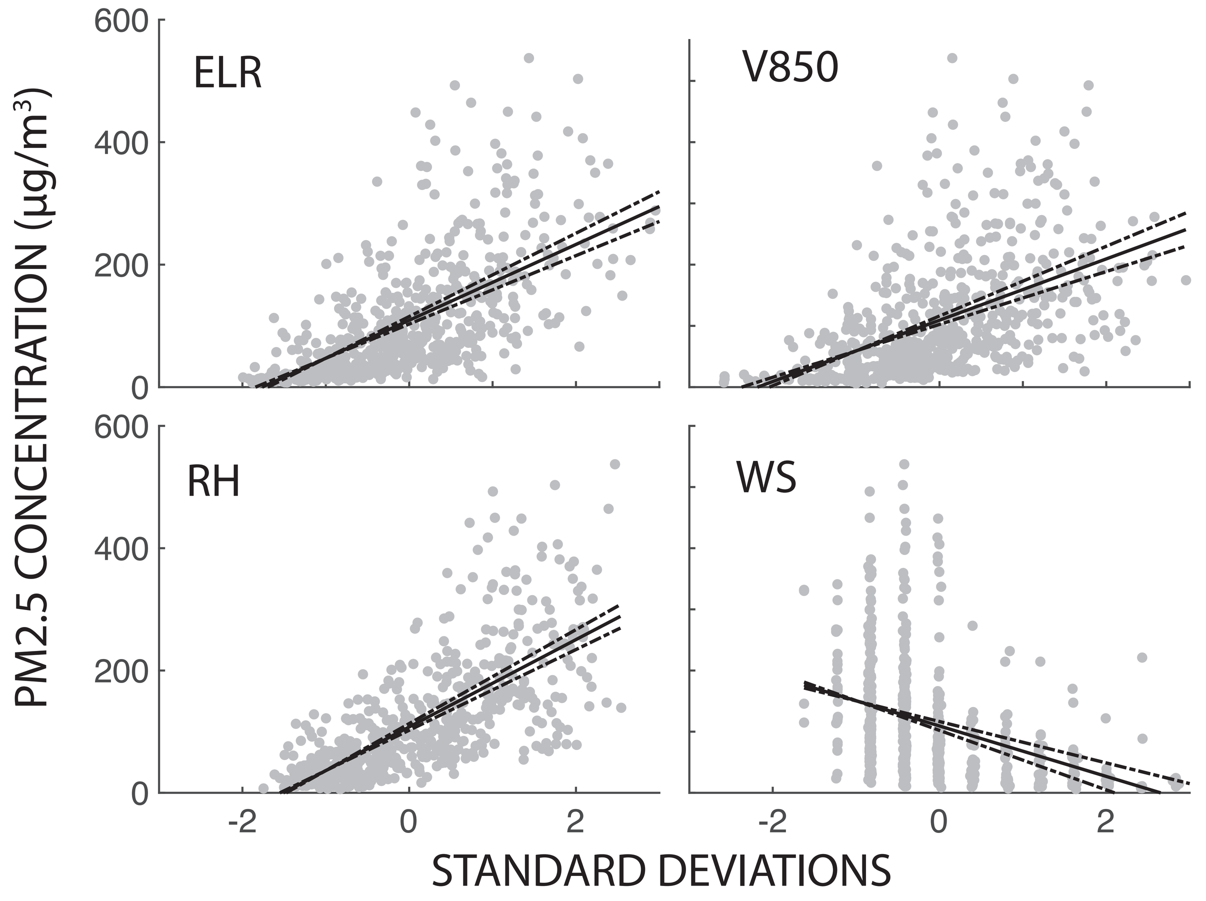


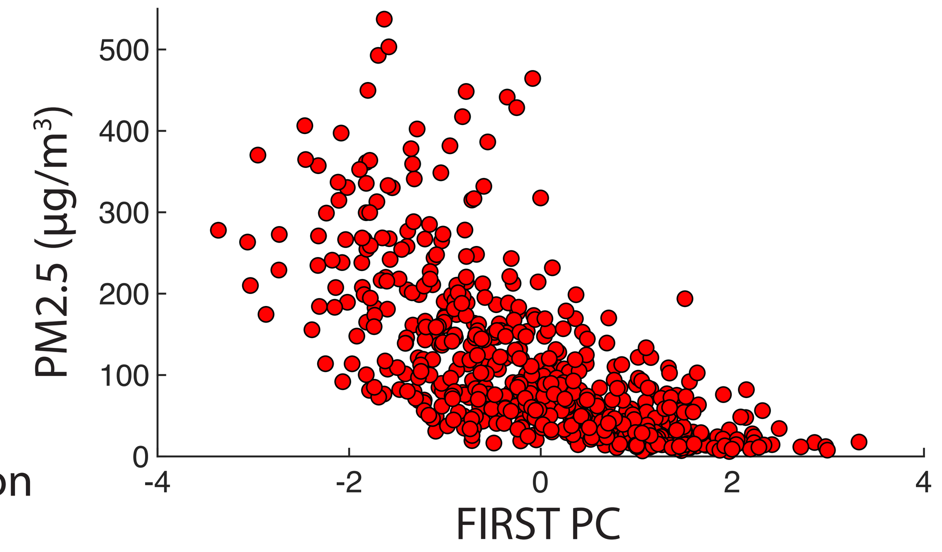
Table 1 | Correlation matrix for ingredients; covariance complicates regression

r	ELR	V850	WS
RH	0.61	0.6	-0.5
ELR		0.54	-0.61
V850			-0.59

Principal components regression addresses such covariance; PC1 explains 68.9% of variation

Coefficients for ingredients in first PC:
RH: 30 μg/m³/SD | ELR: 24.9 μg/m³/SD
V850: 23.1 μg/m³/SD | WS: -20.9 μg/m³/SD

Figure 3 | 1st principal component vs. Beijing AQ



Key takeaway: Controlling for covariance, RH is most strongly associated with PM2.5 concentrations

5. SYNOPTIC CIRCULATION

Given strong covariance among ingredients and first principles, we suspect a common synoptic-scale driver[2,6].

Figure 4 | Composite of 500mb GPH on extreme ingredient days (left) and correlation of 500mb GPH with ingredients at the Beijing station (right)

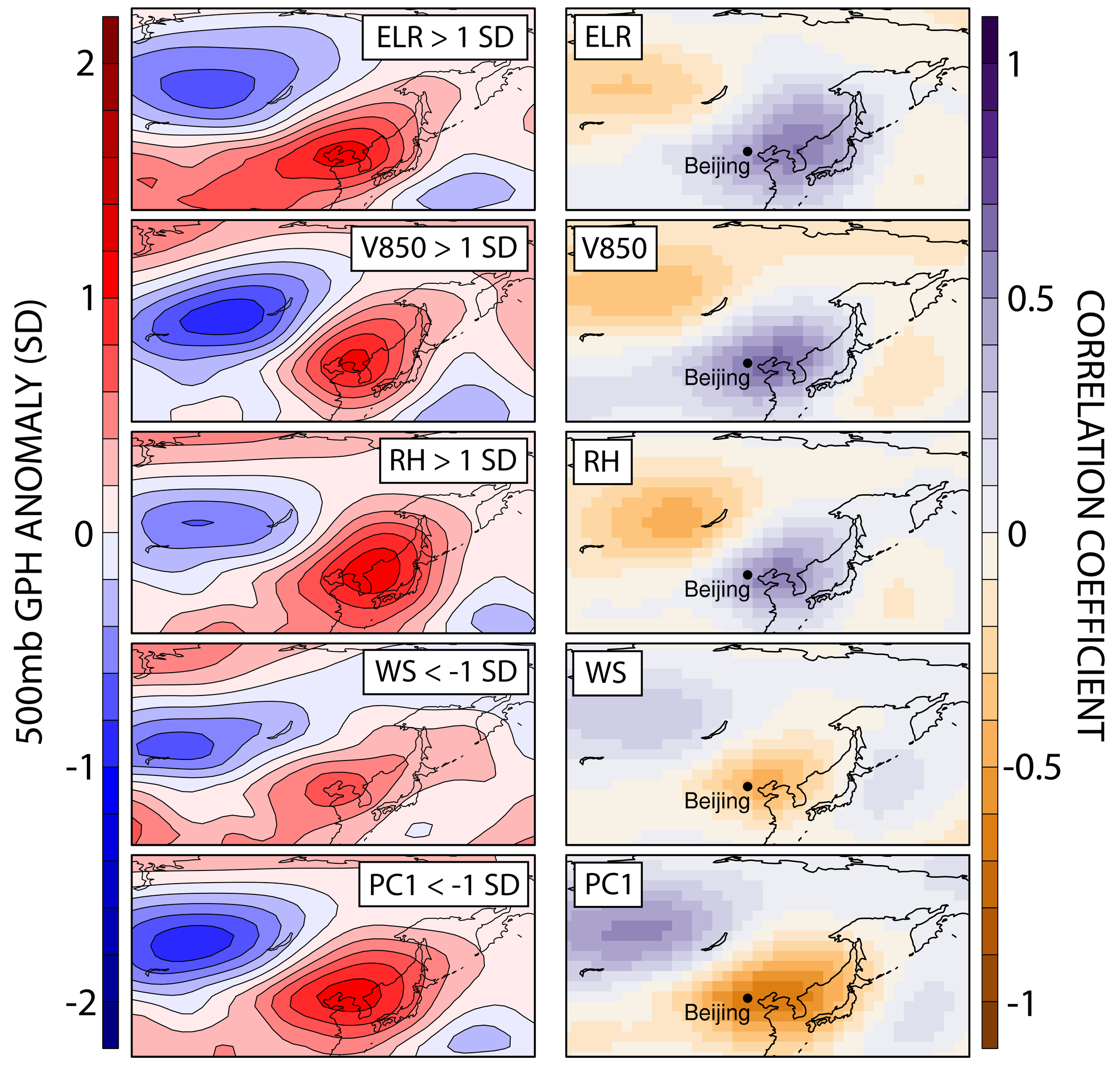
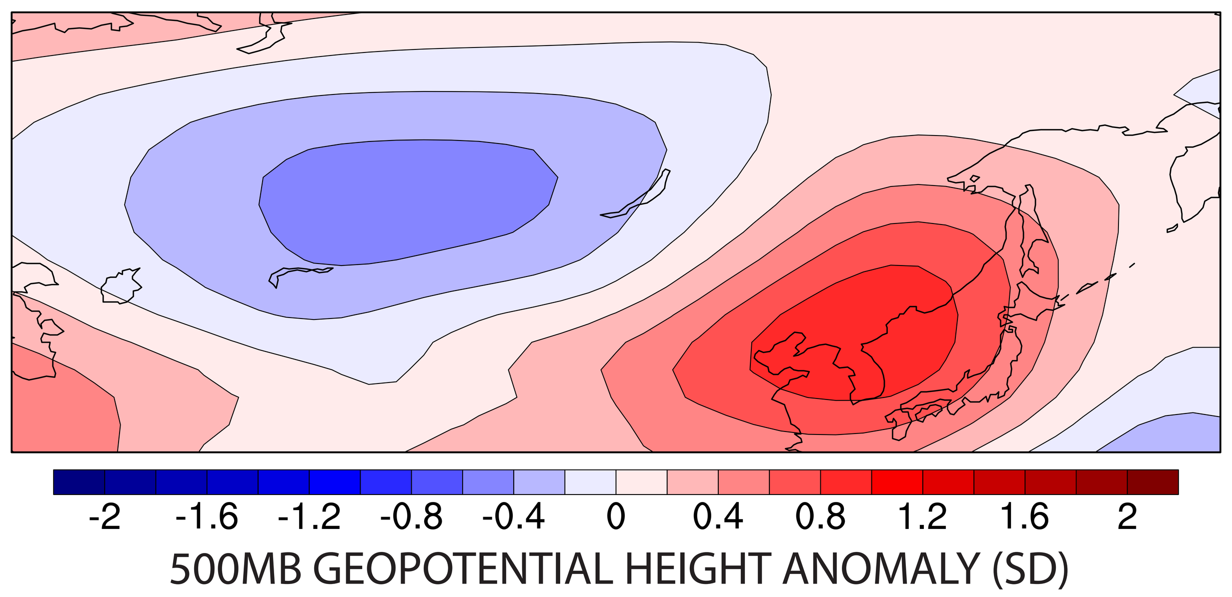


Figure 5 | Composite of 500mb GPH on days with PM2.5 > 150 μg/m³



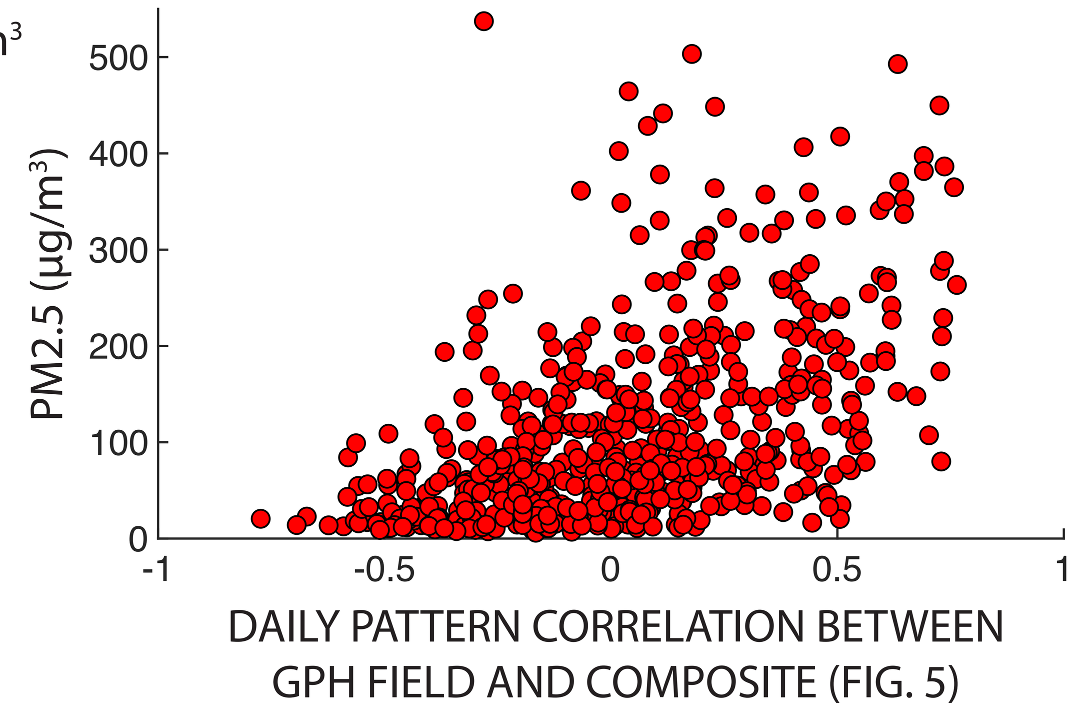


Figure 6 | Pattern correlation between daily GPH and GPH composite (Fig. 5) versus PM2.5 concentrations

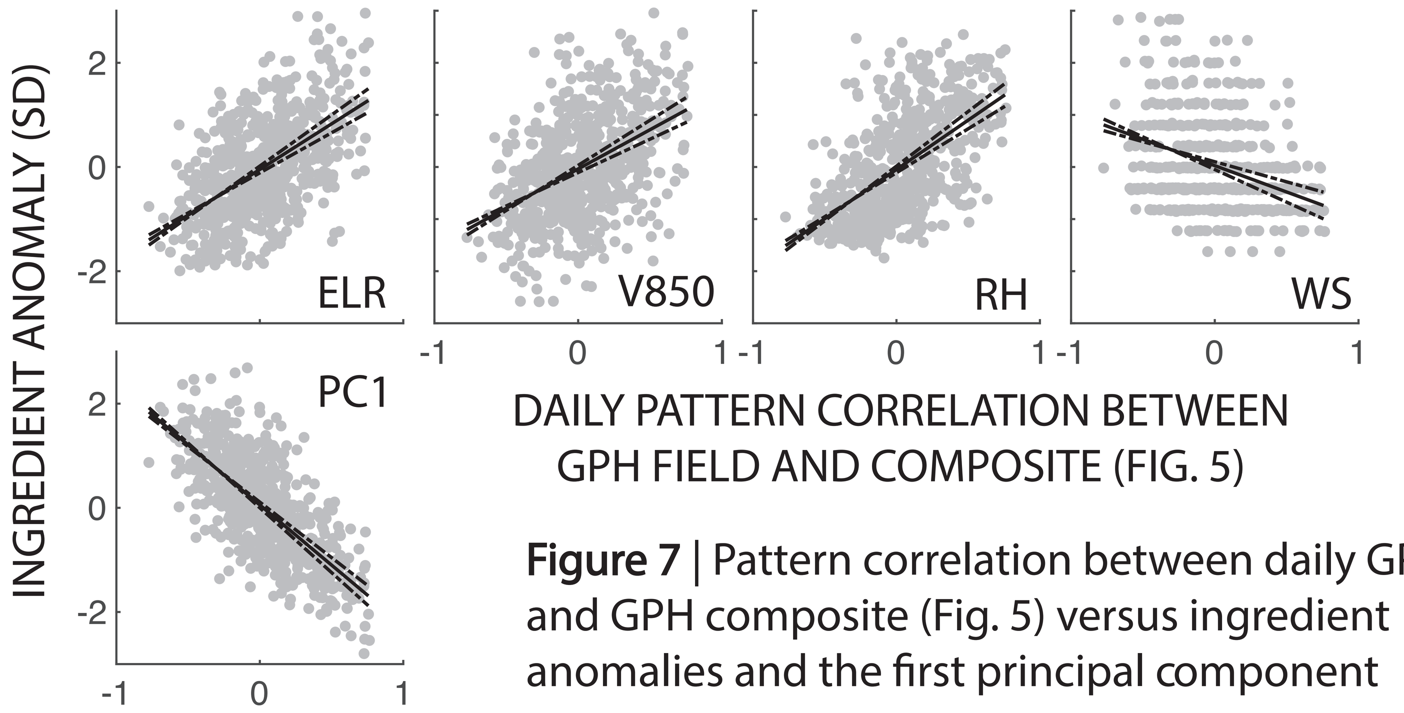


Figure 7 | Pattern correlation between daily GPH and GPH composite (Fig. 5) versus ingredient anomalies and the first principal component

Key takeaway: All ingredients are strongly associated with anticyclonic circulation, which physically explains the covariance between them

6. CONCLUSIONS

Given constant emissions, synoptic circulation ⟶ Meteorological ingredients ⟶ Poor AQ

- Relative humidity has the strongest association with air quality, but lapse rate changes, anomalous southerlies, and surface winds also have important influences; this is generally consistent with other studies, but we provide a more exact quantification of the relative importances of each variable
- Covariance of ingredients suggests a common synoptic driver
- Anti-cyclonic circulation generates subsidence inversions from descent, weakens the East Asian Winter Monsoon, which generates anomalous southerlies and advects moisture, and weakens surface wind speeds
- Future work will apply these insights to climate models to assess their bias and determine possible changes in individual ingredients and stagnant circulation more broadly

7. REFERENCES

[1] Cai et al, Nature Climate Change, 2017
[2] Leung et al, Atmospheric Chemistry and Physics, 2018
[3] Zou et al, Science Advances, 2017
[4] Pei et al, Atmospheric Chemistry and Physics, 2018
[5] Chen and Wang, Journal of Geophysical Research: Atmospheres, 2015
[6] Li et al, Geophysical Research Letters, 2018