Drivers of Seasonal Variability of Atmospheric Stagnation Under Anthropogenic Forcing Using a Climate Model Ensemble

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Abstract

Air pollution increases mortality risk up to 18 percent due to cardiovascular causes. Poor air quality occurs more when meteorological components prevent the dispersal of pollutants in the lower atmosphere. Atmospheric and hydrological patterns are projected to change as global warming alters the seasonal circulation and precipitation. The study uses an air stagnation index (ASI) to quantify the meteorological conditions that allow poor air quality. We examined ASI by season given that each season is dominated by the distinct synoptic meteorological characteristics. By looking at individual seasons, we aimed to better explain the change of stagnation events. Here, we applied the ASI to the bias-corrected Coupled Model Intercomparison Project (CMIP5) ensemble prediction data. An exploratory analysis of CMIP5 model biases suggested that the occurrence of stagnation days and duration of stagnation events have different seasonal patterns, and fluctuated spatially. Our result suggests that stagnation is very likely to increase among various regions of the world, including those areas with historical pollution issues. To complete this study, we will apply statistical analyses in conjunction with multi-model agreement criteria to quantify the robustness of air stagnation change. Future work will include tuning the ASI Metric for specific regions of interest.

Data and Method

Air Stagnation Index (ASI)

Following the approach of Horton et al. (2014), A given day is considered stagnant when daily-mean near surface (10-m) wind speeds are < 3.2 m s^{-1}, daily-mean mid-tropospheric (500mb) wind speeds are <13m s^{-1}, and daily-mean precipitation accumulation is <1mm (i.e., a dry day).

Reanalysis Data

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Daily Wind

- NCEP/DOE R2 (Kalnay et al.,1996)
- ECMWF ERA-Interim reanalysis (Dee et al., 2011)

Monthly Precipitation

- Willmott and Matssura (Udel) v3.02 (Willmott & Matssura, 2001)
- Monthly GPCP v2.2 (Global Precipitation Climatology Project) (Adler etal., 2003)
- Monthly CMAP (CPC Merged Analysis of Precipitation) (Xie & Arkin, 1997)

CMIP5 (Coupled Model Intercomparison Project)

WCRP CMIP5
World Climate Research Programme

Global-warming-driven stagnation changes are analyzed using an ensemble of realizations from 15 modeling groups that provide daily three-dimensional atmospheric fields from both historical and RCP8.5 experiments of the CMIP5.

- Historical 20 years (1986-2005)
- Future RCP8.5 periods (2016-2035, 2046-2065, and 2080-2099)

Bias-Correct the Uncertainties

Because the ASI is reliant on absolute thresholds, systematic errors in CMIP5-simulated stagnation-relevant variables are bias corrected using an empirical quantile mapping technique from Ashfaq et al (2010a; 2010b) was used.

Advantage:

1. Preserved the model-simulated daily variance and time-series autocorrelation of each atmospheric variable.
2. Retained the model-simulated change in the monthly-mean and daily distribution between the historic and future periods.

Bias Correction is calculated as :

Historical: $P_c(m,d_m) = [\ P_o(m,d_m) \,/\, P_o(m,\text{ave})\ ] \times P_c(m,\text{ave})$

RCP8.5 : $P_{fc}(m,\text{ave}) = [\ P_f(m,\text{ave}) \,/\, P_h(m,\text{ave})\ ] \times P_{hc}(m,\text{ave})$

Why Seasonal?

Evaluating potential for changes in all seasons in accurate long-term projections of air quality is necessary. Previous studies have been limited as they only used annual analyses. To fill this gap in literature, this study focuses on the seasonal perspective.

Goal

Research questions: What is the seasonal response of stagnation to climate change? How does it change with increasing forcing?

Goal: Understand the links among climate change, synoptic phenomena, and local stagnation in regions exposed to poor air quality.

Results: Global Stagnation

- Projected changes were **spatially heterogeneous**.
- Increase of approximately **6-16 days per season in all time periods**, mostly in industrialized regions, including eastern China, west U.S., northern India, Mediterranean Europe.
- Increase of 8-14 days during **winter and spring** in northern South Africa (Figure 1.a and d).
- Higher latitude in northern hemisphere (Siberia) demonstrated an increase of 2-8 stagnation days **throughout all seasons except spring**.
- **Stagnation days have increased mostly in spring and autumn.** More populated areas between the subtropics had an average projected increase of **8-16 days** for spring and autumn.

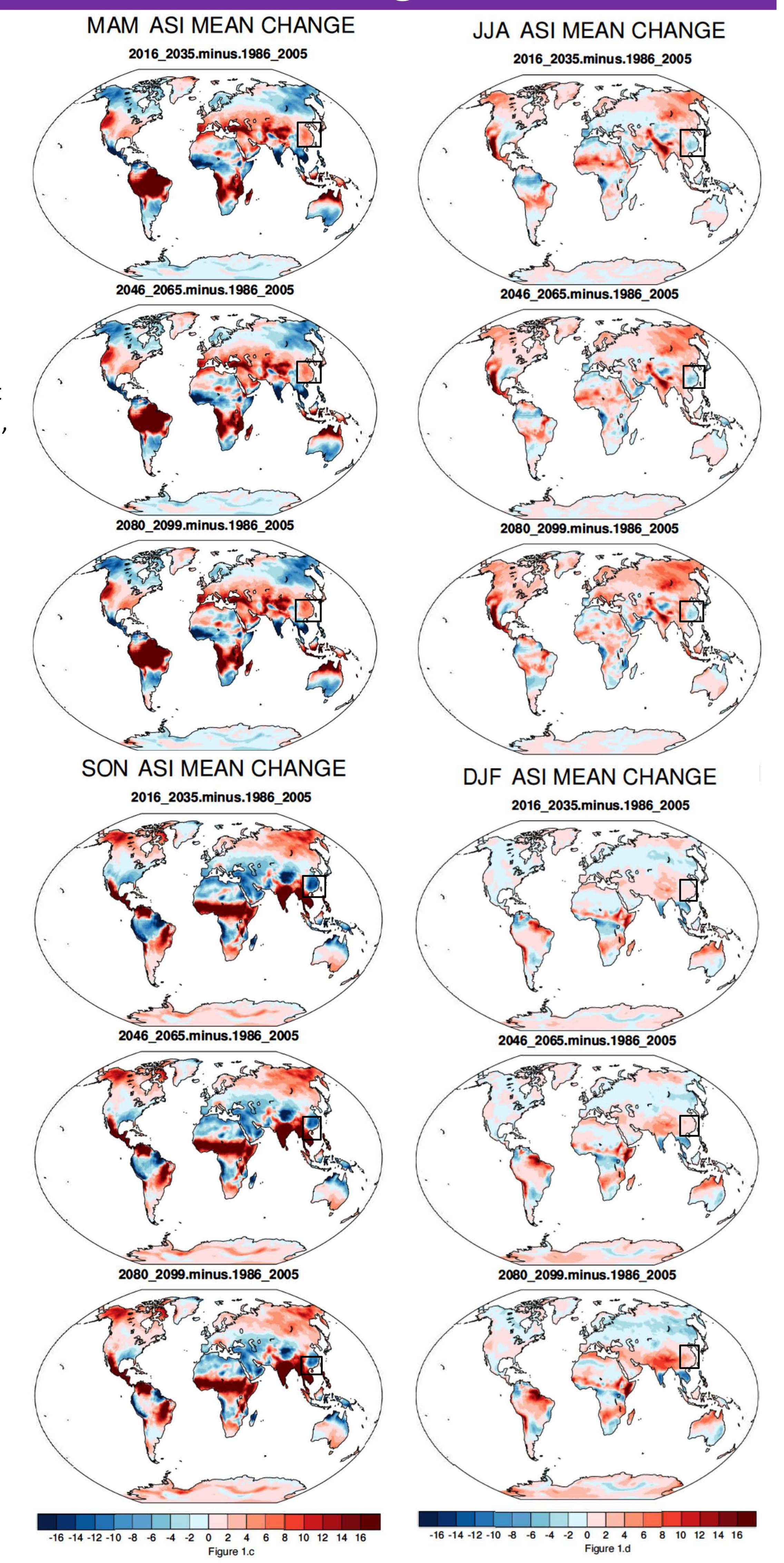

Figure 1. Average air stagnation days change in four seasons. The upper plot is the average of early 21st century 20 years data (2016-2035) minus the late 20th century baseline (1986-2005). The middle plot is generated using the mid 21st century (2046-2065) minus the baseline. The lower plot is generated using the late 21st century (2080-2099) minus the baseline. Color bar is the change of stagnation days of that season, red means increase of stagnation days, and blue indicates decrease of stagnation days.

Results: Regional---China

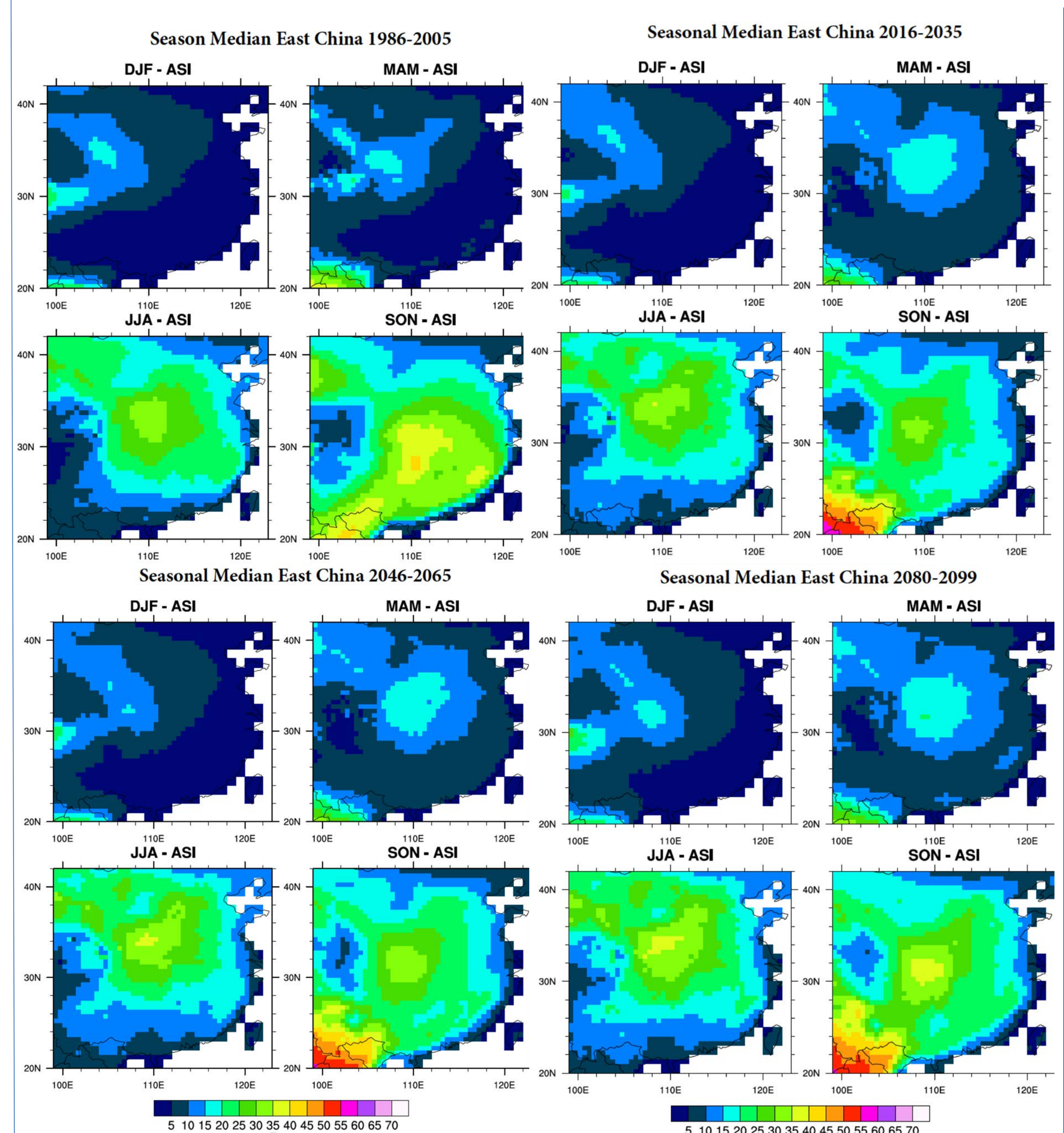

Figure 2 is the seasonal median of stagnation days over east China. Figure a is late 20th century, b) is early-21st century, c) is mid-21st century, and d is late 21st century.

Why Regional?

Analysis of different regions of the world is necessary as regional meteorology is highly dependent on local characteristics including topography, ocean-continent relationship, and dominant climate phenomenon.

Why China?

In various locations throughout China, there has long been poor air quality that leads to problems in public health. While it is well known that Beijing has a winter haze, other areas also have severe pollution events during different seasons. (*Wang and Mauzerall, 2006*).

Preliminary Results:

- Average of 40-50 stagnation days during **fall** centered in the **Sichuan basin**, and 5 stagnation days in the **Tibetan plateau.**
- An increase of stagnation days since the early 21st century during **fall** originated from the **southeast Asia**, and the stagnation days of Tibetan plateau increased from **5 days per season to 10-20 days.**
- 500mb stagnation days decreased.
- Enlarged ASI stagnation area during **spring**. However, we didn't notice an obvious component that dominated this expansion, since the increase of stagnation appeared on all three components during spring.

Results: Seasonal Bias Correction(BC) Improvement

Stagnation BC Improvement (%)	ASI(Precip)	Asi(500mb Wind)	ASI(10m Wind)
DJF	3.74324	1.02652	2.4843
JJA	2.89582	0.44364	3.44234
MAM	0.2054	-0.0325	2.63325
SON	1.58597	0.15128	2.36103
Native Data BC Improvement (%)	**Precip**	**500mb Wind**	**10m Wind**
DJF	1.07163	1.61707	10.6537
JJA	2.10547	0.31148	6.44197
MAM	-0.1343	0.11035	6.53955
SON	7.63449	-0.0868	7.62775

Table 1. a) Percent improvement of bias corrected stagnation days of individual component compared to observations.
b) Percent improvement in percentile of bias corrected raw data of individual component compares to observations.

Before Bias correction:

Component perspective

- Precipitation has the greatest bias.
- Mid-tropospheric (500mb) wind has the least bias.

Seasonal perspective

- Spring precipitation has the greatest bias on both ASI(Precip) and raw data.
- Summer and winter have relatively low bias compare with other seasons.

After Bias correction:

Component perspective

- Bias Correction overall decreased the bias.
- Larges improvement in surface wind speed for all seasons.

Seasonal perspective

- Overcorrect the spring stagnation mid-tropospheric wind and raw precipitation.
- Overcorrect the fall raw 500mb wind.

Discussion and Conclusion

- Global climate change will increases the frequency of stagnation days continuously in the late 21st century
- Anthropogenic climate change is altering the level of pollutant management required to meet future air quality targets.
- In order to cope with climate change risk in different seasons, this study provides a distinct and comprehensive analysis that informs scientists and policy makers
- Our projections do not consider emitted pollution as chemistry transport models do. Instead, we separate the variables anthropogenic pollution and natural meteorology to quantify the future potential of regions to develop bad air quality.
- Although a multi-model approach leads to additive inter-model uncertainties, it is a straightforward method to capture holistic natural variability that a single model might not account for.

Future Steps

- Analyze the data after significant test, and include the episode/duration study suggested by *Dawson et al (2014).*
- Detect synoptic phenomenon related with our results in order to better understand the link between stagnation, synoptic phenomenon and climate change.
- Adjust ASI metric for specific regions at specific seasons to target severe air quality events that occurs repeated during one season.

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