Projecting the Impacts of Climate Change on Air Quality Using Statistical Downscaling of Atmospheric Stability Indices: A Case Study in Pearl River Delta

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Abstract - **Atmospheric stability has strong effects on air quality, driving vertical mixing of air pollutants. Literature has investigated the impact of climate changes on stability. However, the influence of associated impacts on air quality has yet to be understood.**

This study aims at projecting the impact of changes in stability on air quality under climate change. We took the Pearl River Delta region as an example to demonstrate the predictability of air quality using stability indices based on regional climate data simulated by the Weather Research and Forecasting Model, which dynamically downscaled the past and future climate under the A1B scenario simulated by ECHAM5/MPIOM. Stability indices were calculated and used to classify atmospheric conditions into two stability groups: stable and neutral & unstable. Using Generalized Linear Model, the stability indices were used to estimate the changes in Sulfur Dioxide, Ozone and PM10 due to changes in stability in the future periods of 2015-2039 and 2075-2099.

I. Motivation

Air pollution is strongly influenced by weather condition [1], for example, it was reported that heat waves and drought have significant contribution on the deaths attributable to ozone and Particulate Matter [2, 3]. The Intergovernmental Panel on Climate Change (IPCC) projected that air quality in cities will be declining in the future as a result of climate change [4]. The U.S. Environmental Protection Agency [5] has concluded climate change can affect the ground level ozone and particle pollution in many regions in U.S., such as increasing intensity and increasing length of pollution episode. Furthermore, the changes in temperature may affect gas-particle partitioning and therefore emission will increase potentially.

However, the weather events associated with air quality are not limited to heat wave and droughts. Atmospheric stability has a major effect on air quality in cities. For example, stable condition is often associated with air pollution episode [6] because the pollutants concentration in the atmospheric is highly depended on their dilution rate in the planetary boundary layer [7]. Several studies have applied the concept of atmospheric stability to predict the impact of climate change on air quality, for example, using stagnation as a reference to predict air quality in the future [8], downscale regional meteorological conditions to study the impact of air quality [9, 10]. However, these studies often required large amount of computer resource to run climate models such as Global Climate Model (GCM) and Weather Research and Forecasting (WRF) model. The aim of this study is to develop a methodology to use existing data from climate models and observation to find relationships between atmospheric stability and air quality, then we can apply this relationship to the future to predict future air quality.

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II. Method

1. The climate data used in this study is the output of WRF, which dynamical downscaled from large scale climate (NCEP/NCAR reanalysis and ECHAM5/ MPIOM) to fine resolution (5 km). The domain center of the WRF model is located in Taiwan but it covered Pearl River Delta (PRD). There were four sets of experiments: 1. NCEP/NCAR reanalysis (NNR) from 1979 to 2003, 2. 20C3M (simulated by ECHAM5) from 1979 to 2003, 3. Scenario A1B from 2015 to 2039 and 4. Scenario A1B from 2075 to2099. The temporal scale of the WRF output was 3-hourly but they were converted into daily. To ensure the WRF model was capable to simulate climate in PRD, it was first using observation data (surface temperature, humidity and pressure) in five observation sites in Hong Kong to validate the NNR-WRF output (set 1).
2. Air pollution data for O3, RSP and SO2 were collected from three observation sites in Hong Kong: Tap Mun, Yuen Long and Tung Chung. The data was available from 1998 to 2003 in daily average. Instead of using the actual pollutants concentration, this study used standardization to minimize the location effect, which is

calculated by subtracting the mean and divided by the standard deviation, i.e.

Std conc. = (conc. – mean(conc.)) / stdev(conc.)

3. Seven atmospheric stability indices were calculated from the WRF output, they are: K-index (2 levels), Total total index (2 levels), Precipitable Water, Buoyancy force and Wetbulb Zero. Based on the stability indices, the data was separated into two stability groups: 1) stable, 2) neutral & unstable.
4. For each stability group, using Generalize Linear Model (GLM) to create a statistical downscale model between standardized air pollutants (predictand) and stability indices calculated from set 1 (predictors) as showed in Figure 1. The performance of the statistical downscaling models was validated by two methods: first, used 80% of the data for model calibration and validated by the remaining 20%. Second, we applied the statistical downscaling models across PRD and validated using air pollution data from Macao and Foshan (monthly data) as shown in Figure 2.
5. It was then apply the statistical downscaling model to future climate model data (the 2nd, 3rd and 4th sets of data in step 1) to predict the future air pollutants level. (Figure 3)

III. EVALUATION

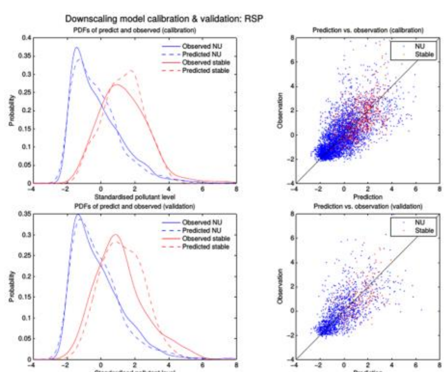

Figure 1 – Evaluation of statistical downscaling model (GLM) for pollutant (RSP). Top: Calibration; bottom: validation.

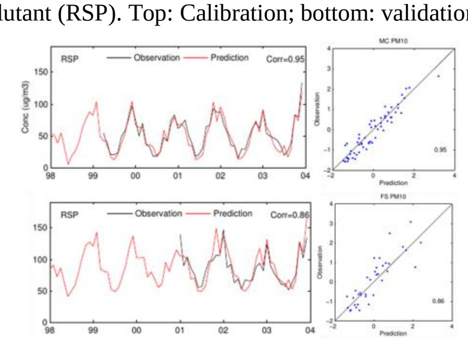

Figure 2 – Evaluation of statistical downscaling model (GLM) for pollutant (RSP) using pollutants data from Macau (Top) and Foshan (Bottom): Time series plot (left), scatter plot (right)

There was a significant correlation between the predictions and observations (Figure 1). The validation results in Figure 2 indicated that the statistical downscaling model can be applied to Macau and Foshan.

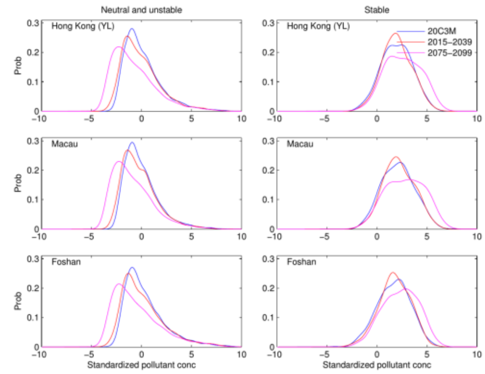

Figure 3 - Projections of standardized RSP level: RSP

From the future climate scenario A1B generated by ECHAM5, the future air pollutants level (Figure 3) in the PRD region will have a slight reduction due to the more occurrence of unstable conditions. Nevertheless, when stable condition occurs, air stagnation is likely to be more extreme in the future, causing more severe air pollution episodes.

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