空氣品質模式 $PM_{2.5}$ 預報效能評估、預報誤差修正以及光達資料同化系統對 $PM_{2.5}$ 預報的改善效益

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摘 要

本論文評估 Weather Research and Forecasting (WRF)氣象模式耦合 Community Multiscale Air Quality (CMAQ)空氣品質模式對於細懸浮微粒($PM_{2.5}$)的預報效能。此外，建構預報誤差統計後處理方法來提升 $PM_{2.5}$ 預報成效。空品模式預報校正方法，使用了綜觀尺度天氣型態分類定義預報誤差，再行建立線性迴歸方程。其中天氣型態分類，使用 K-means 群集分析方法，分類綜觀尺度天氣型態。

CMAQ 空品預報模式 $PM_{2.5}$ 預報誤差，與天氣型態有相當高的相關性。整體而言，CMAQ 低估 $PM_{2.5}$ 濃度，且在弱綜觀的大氣條件，低估更為嚴重。而弱綜觀的大氣條件，因為靜風加上大氣較為穩定，通常也容易造成高污染事件的發生。預報誤差統計後處理方法，能反應出 CMAQ-WRF 預報模式在氣象場、排放量以及大氣化學模式本身的系統性誤差特性，也因此能有效降低預報誤差，提升各地 $PM_{2.5}$ 濃度的預報準確度。

透過 WRF-LETKF 同化系統，同化環保署光達觀測資料，進而能改善 WRF 中尺度氣象模式及 CMAQ 大氣化學模式的預報性能。特別是 WRF 預報風場原本白天風速高估問題，透過同化光達資料，有效降低白天預報風場，使得污染物能夠累積於臺灣西半部污染源區，也因此改善白天 $PM_{2.5}$ 預報低估問題。此外，WRF-CMAQ 邊界層垂直結構發展以及 $PM_{2.5}$ 濃度垂直剖面的預報結果也獲得更佳的改善。

關鍵字：空氣品質模式預報系統、$PM_{2.5}$ 預報、預報誤差修正、天氣型態、WRF-CMAQ、光達資料同化

Performance assessment of $PM_{2.5}$ forecasts with CMAQ air quality model, bias-adjusted $PM_{2.5}$ forecasts, and ensemble $PM_{2.5}$ forecasts in Taiwan

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Abstract

An operational air quality forecasting (AQF) system was developed in Taiwan using the Weather Research and Forecasting (WRF) meteorological model and Community Multiscale Air Quality (CMAQ) model framework. This study assessed the performance of $PM_{2.5}$ forecasts. In addition, to enhance the $PM_{2.5}$ forecasting capability, a bias-correction method was developed. The bias-correction method incorporates a synoptic weather pattern classification, that are determined using K-means cluster analysis and the historical AQF $PM_{2.5}$ bias. A linear-regression relationship between the AQF $PM_{2.5}$ bias and $PM_{2.5}$ forecasts for each WP is developed to correct the $PM_{2.5}$ forecasts. The CMAQ $PM_{2.5}$ bias is found to have a strong dependency on the synoptic weather pattern. There is a systematic $PM_{2.5}$ underprediction, and the most pronounced underprediction occurs on the days associated with weak synoptic weather conditions. The bias-correction method is able to reduce the $PM_{2.5}$ forecast error.

Moreover, a Lidar data assimilation system based on the WRF-Local Ensemble Transform Kalman Filter (WRF-LETKF) framework coupled with the CMAQ model was developed. The error of the $PM_{2.5}$ forecast from the WRF-LETKF and CMAQ coupled system were further reduced. The lidar data assimilation is able to improve the PBL vertical structures and reduce the predicted wind flow, which allows the $PM_{2.5}$ to be accumulated in the emission source region. Assimilation of the lidar data also improves the prediction of the leeside vortex structures formed in the northwestern Taiwan. The enhanced performance of the wind flow, PBL vertical structures and leeside vortex, furthermore improved the CMAQ predicted $PM_{2.5}$ concentrations.

Keywords: Air quality forecasting system; $PM_{2.5}$ forecast; bias correction; synoptic weather pattern; WRF-CMAQ, Lidar data assimilation