Numerical simulation of the low visibility event at the Hong Kong International Airport on 25 December 2009

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1. INTRODUCTION

Close to the largest economic development zone – the Pearl River Delta (PRD) region (see Fig.1 for PRD location), there is an issue with visibility deterioration in Hong Kong (HK) due to trans-boundary particulate transport (Fung et. al, 2005). Analysis of the concentration of particulate matters species suggests a link between the amount of particulate matters from regional transport and synoptic weather system. With continental airflow, concentrations of particulate matters may be elevated (Wai et. al, 2005). The winter monsoon may affect HK's air quality with particulates transported by continental flow.

An extremely low visibility event occurred over HK on 25 December 2009, and the daily average visibility was 3.1km (the instantaneous value was as low as 150 m). To study details of the transport, diffusion, and trapping of particulates during this low visibility episode, the WRF-SMOKE-CMAQ system was utilized to simulate the influence of the northeast monsoon. Simulation result shows that: from 23 December to 24 December aerosol particles were generated and trapped in the lower troposphere from surface to 1000m to the north of Guangzhou, where concentration of PM2.5 in the air column was over 100μg/m^3, and huge amount of aerosol particles was stored. As the monsoon spreaded southwards, PM2.5 was transported to HK. And on 25 December, the low PBL height in HK suppressed the dispersion of the transported as well as the locally generated aerosol particles (Yuan et al 2006) so that they were concentrated in a very thin layer near the ground. As a result, aerosol concentration was very high, making the visibility rather low. The simulated particle matter concentration was consistent with the observed PM2.5, which was as high as 145μg/m^3.

2. METHODLOGY

2.1 Model Setting

Four nested domains, zooming down from the outermost one for Southern China (D1) to Guangdong Province (D2), PRD region (D3) and HK (D4) with grid resolutions of 27 km, 9km, 3km and 1km respectively, are set up in CMAQ (V4.6) for the case study. Initial conditions of the aerosol concentration are reconstructed by running the model 7 days before the event. 23 vertical layers are used with the first layer 17 m above the ground. Yamartino mass-conserving scheme, the CBIV mechanism for gas-phase chemistry and the AE3 for aerosol module are selected for the model run. Meteorological fields are provided by WRF simulation (V3.2) with observation nudging. The base emission inventory is built up by Trace-P (Streets et al., 2003) result, and PRD inventory data provided by a local authority and MODIS data, and both of them are processed with SMOKE (V2.4).

3 RESULTS

Figure 2 summarizes the overall model performance for hourly PM2.5 data. Five air quality monitoring stations, namely Central (CL), Tap Mum (MB), Tsuen Wan (TW), Tung Chung (TC), and Yuen Long (YL), are used to perform model evaluation. The model performance is acceptable, namely, mean normalized bias of 39.8%, and correlation coefficient of 0.71.

Figure 3(a) shows the simulated spatial distribution of PM2.5 over PRD region on Dec 24 05:00pm. Because of weak surface wind, PM2.5 got accumulated in Guangzhou, and its concentration was over 200μg/m^3. When the replenishment of the monsoon came near HK, the prevailing wind became northerly and regional transport became more important. On Dec 25 12:00am, Hong Kong PM2.5 concentration was around 150μg/m^3.

The height of the planetary boundary layer plays an important role in building up the particulate concentration. Typically, the top of the boundary layer is marked by a temperature inversion that is a layer above which environmental temperature increases with height. Such a "capping" inversion usually traps particulates released from the earth's surface within the boundary layer since vertical motion is suppressed. When the PBL height decreases, it can cause elevation in atmospheric particulate concentrations because there is less depth available for dilution of the particulates. Figure 4 gives the relation between PBL height and PM2.5 concentration in HK. At station TC, PBL height dropped during the arrival of the monsoon replenishment. On Dec 23 and 24, daytime PBL heights were 770 m and 700 m respectively, and on Dec 25 PBL height decreased to 410 m due to descending motion. As a result of the strong suppression, the aerosol concentration increased in the PBL.

Figure 5(a) presents the vertical cross sections of PM2.5 over Guangzhou on Dec 24 06:00pm. PM2.5 was stored from surface to 1500 meters high above urban area. At a height of 1000 meters, PM2.5 concentration was around 80μg/m3, and at 800 meters high, PM2.5 concentration was 100μg/m3. Figure 5(b) shows on Dec 25 10:00pm, there was strong subsidence over HK. From early morning of Dec 25, concentration of transported and local PM2.5 started to increase within a thin PBL (see Fig. 4 for PBL trend and PM2.5 trend). Convergence resulting from urbanization (Lo et. al., 2007) may also slow down the transportation of PM2.5, and surface PM2.5 concentration reached 140μg/m3. Figure 6 gives the comparison between simulated and observed visibility values.

4 Conclusions

A WRF-SMOKE-CMAQ modeling system was set up to evaluate the influence of northeast monsoon on the local visibility over HK. On Dec 25, 2009, the daily averaged visibility was less than 3.1 km (the instantaneous value was less than 200m).The analysis shows that this event is related to the arrival of a replenishment of the northeast monsoon. The replenishment first passed the urban cities like Guangzhou and Foshan to the north of HK. Strong subsidence, low PBL and weak surface wind helped the accumulation of particulate matters over Guangzhou. When northerly wind transported the particulate matter into a very shallow boundary layer over HK, PM2.5 concentration increased. The high concentration of PM2.5, together with a very moist atmosphere (over 90% relative humidity), led to rather low visibility over HK.

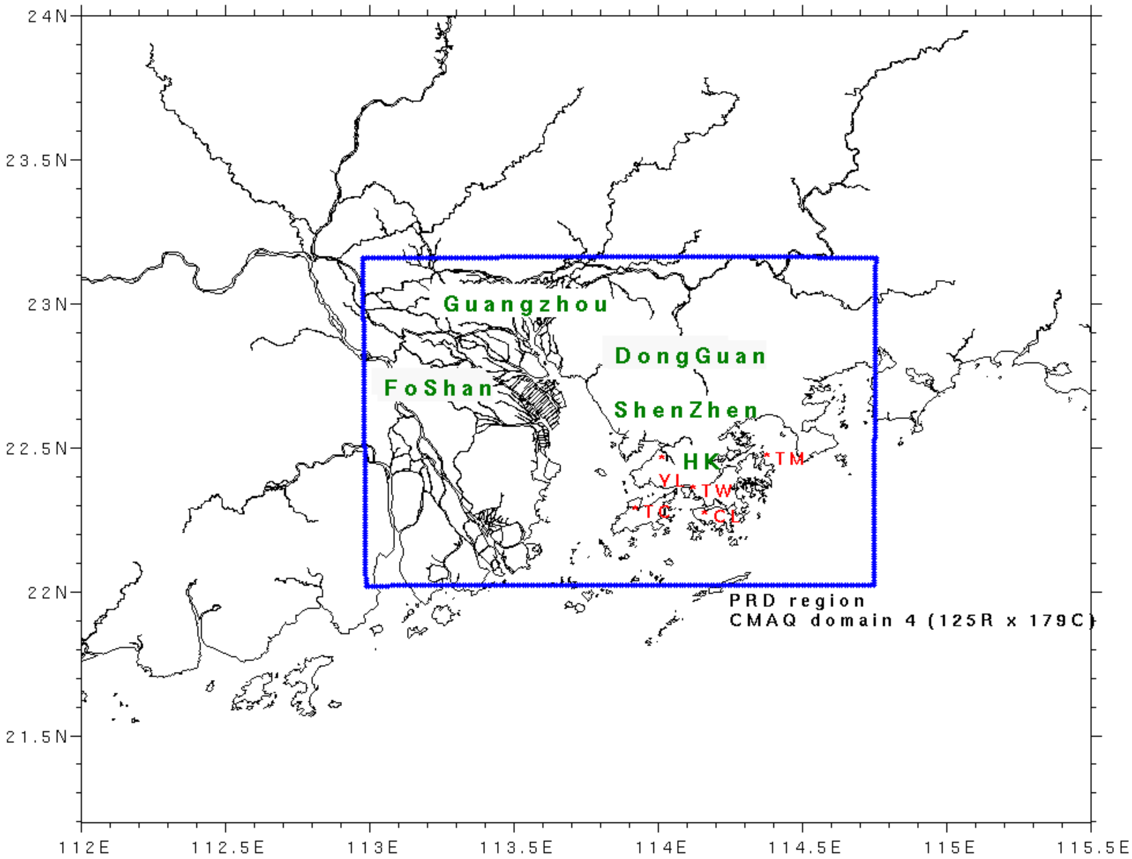


Fig 1. PRD region as CMAQ domain 4 (blue frame)；the locations of Guangzhou, FoShan, DongGuan, Shenzhen and HK (green words); the locations of five air quality monitoring stations (red stars)

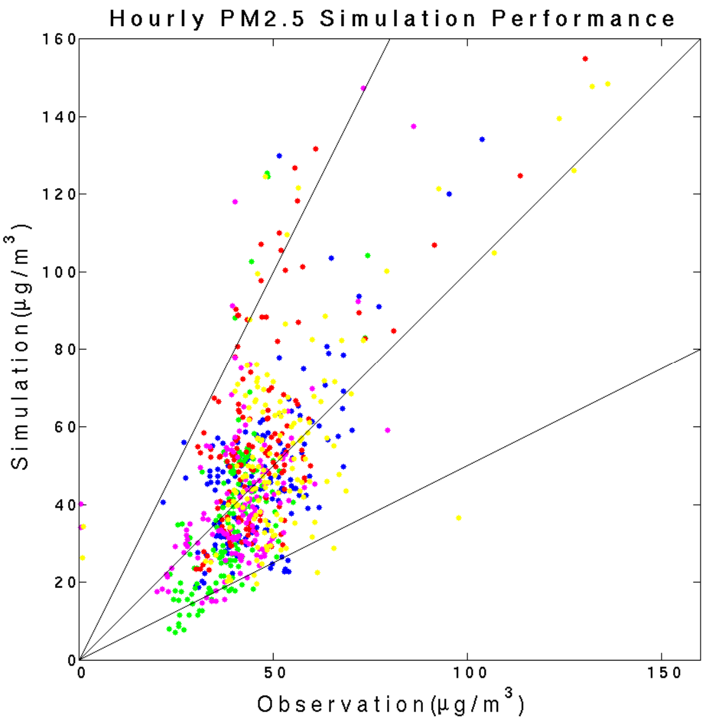


Fig 2. Comparison between simulated hourly PM2.5 from base emission source and air quality monitoring data (blue for CL, green for TM, red for TW, magenta for TC and yellow for YL)

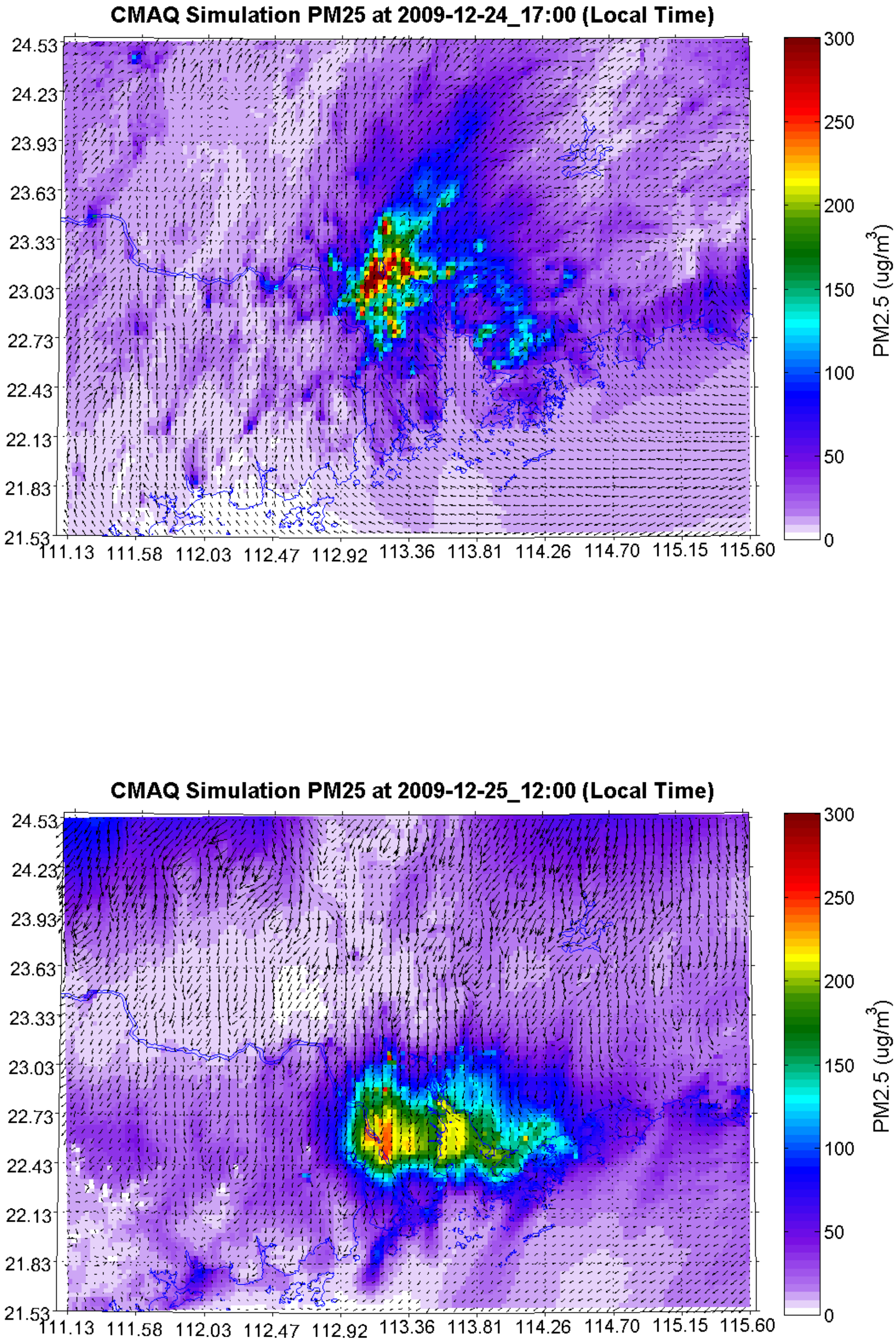
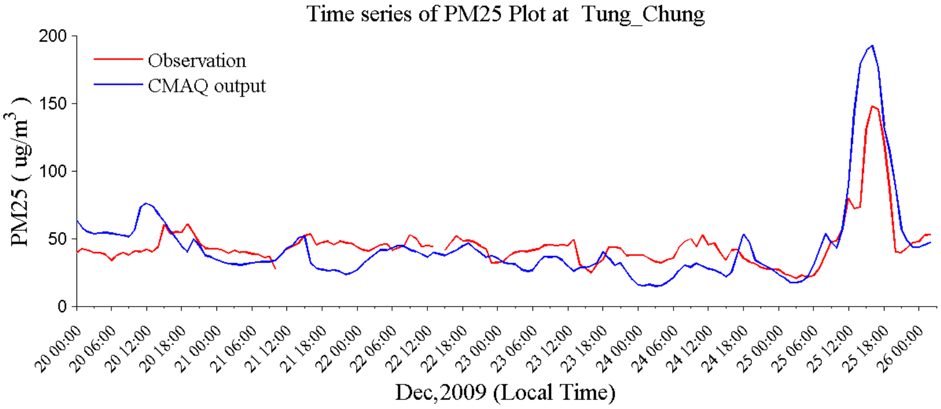


Fig 3. Simulated spatial distribution of PM2.5 over PRD region



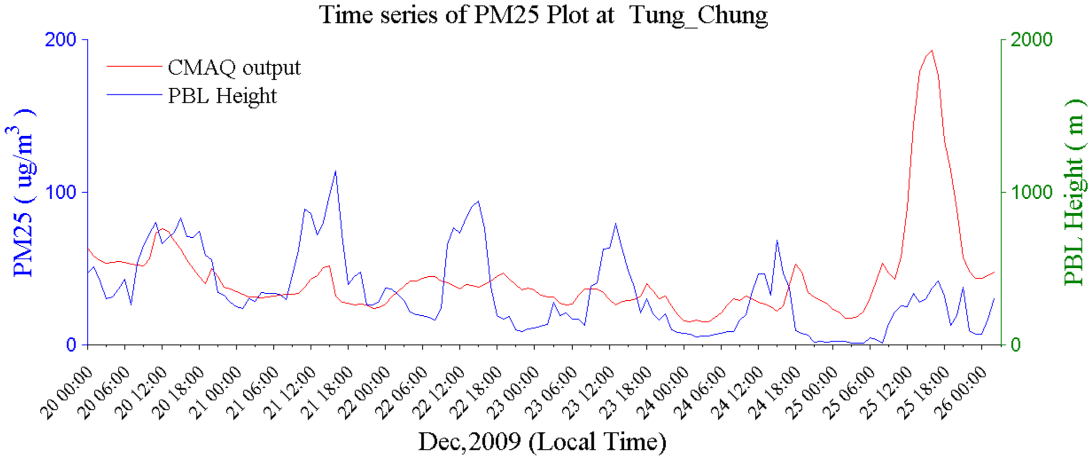


Fig 4. PM2.5 concentration and PBL height time series at Station Tung Chung

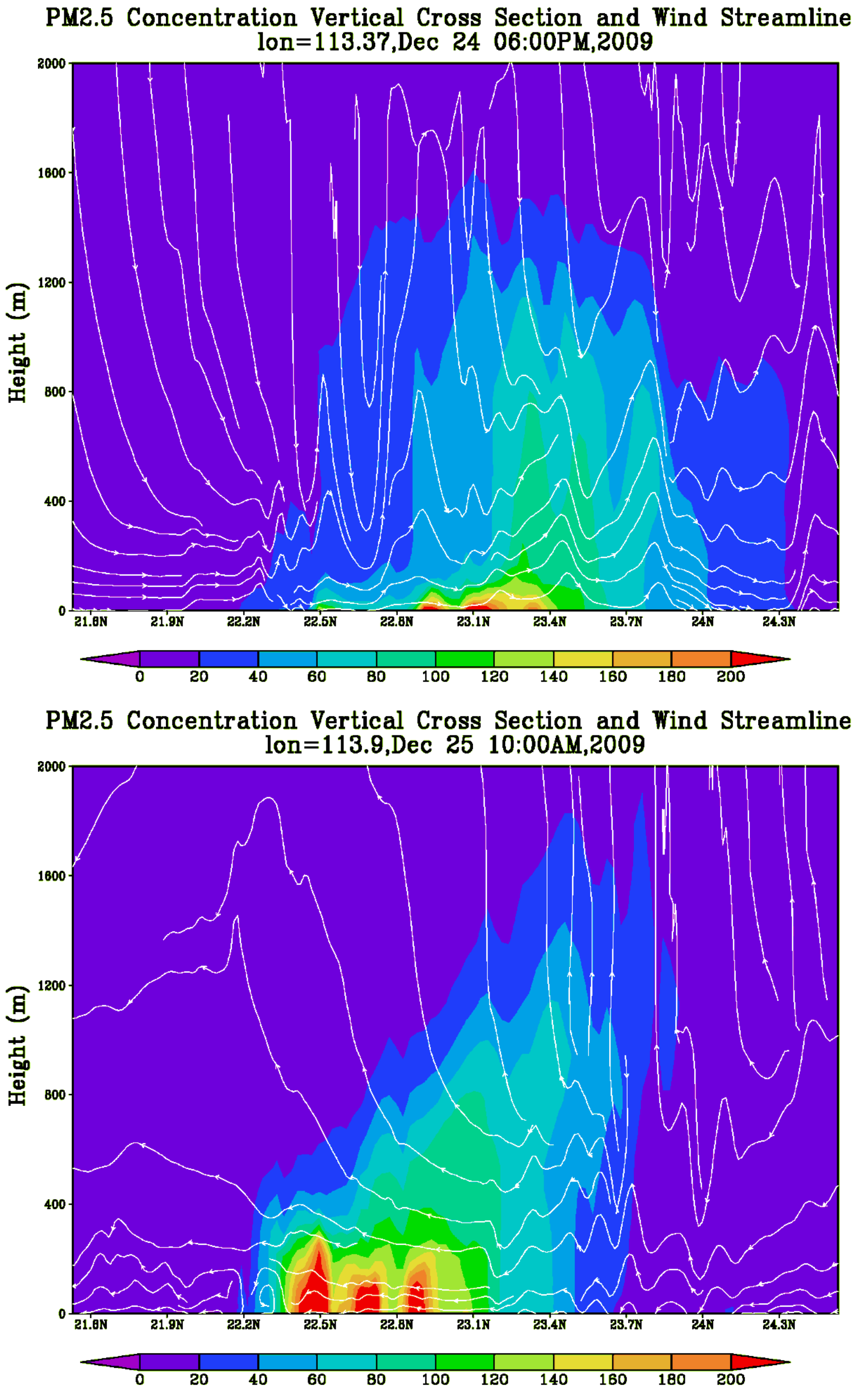


Fig 5. Cross section (latitude vs. pressure) of PM2.5 concentration and airflow as projected on the cross-sectional plane

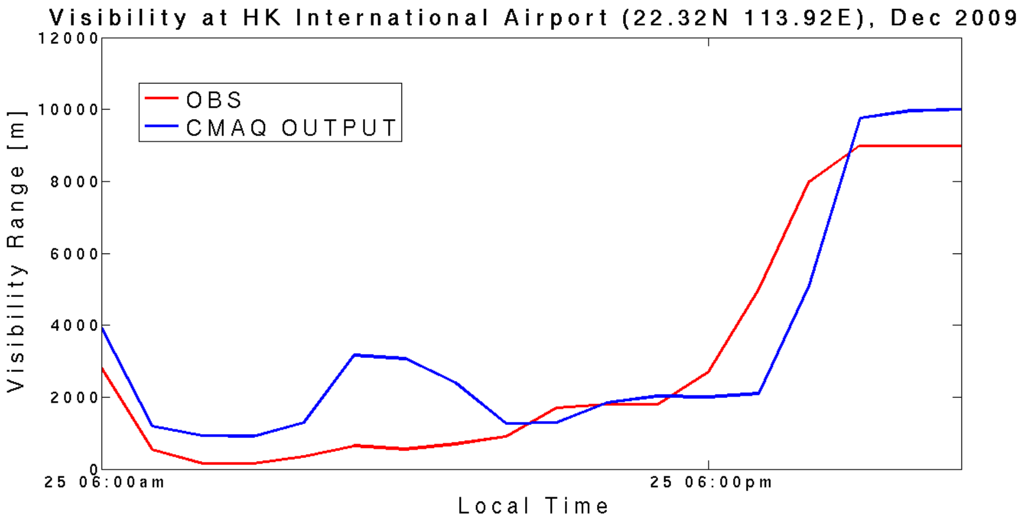


Fig 6. Observed and simulated visibility at HK international airport

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