Numerical Simulation of Regional Ozone Transboundary Pollution to the Philippines

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Abstract. A numerical simulation during the typhoon Parma in the first week of October 2009 showed a rare northwesterly wind flow pattern induced in the Philippines, providing a pathway for the transport of the photochemical pollutant ozone from the main Asian continent. This transboundary air pollutant was investigated using a new generation fully coupled weather research and forecasting – Chemistry (WRF/CHEM) regional air quality model. Simulation results showed an increase in O\textsubscript{3} concentration of approximately 40 ppbv for most of the northern islands of the Philippines and this is expected to increase from year to year under similar meteorological condition as emissions of East Asian countries increase.

Keywords: transboundary pollution, tropospheric ozone, numerical simulation, WRF-Chem

1. Introduction

Anthropogenic emissions in Asia are now larger than those in Europe and North America and is expected to continue to increase in the future [1]. One reason for this is China's rapid economic and industrial expansion over the last decades, which resulted to tremendous increase in energy consumption as well as emission of atmospheric pollutants [2]. Despite this, the Philippines, unlike China's other east Asian neighbours, is rarely affected by transboundary pollution due to some geographic and meteorological factors.

The Philippines belongs to the North Western Pacific summer monsoon region, which is part of the Asian-Pacific southwest monsoon system. The South West Monsoon (SWM) is active around the second half of May to September while the North East Monsoon (NEM) is active around October until around February. During these monsoon periods, SWM and NEM, predominant southwesterly and northeasterly wind flow patterns prevail, respectively [3,4]. Also, the Philippines is separated from the main Asian continent by the south China sea, these factors isolates the Philippines from atmospheric transboundary pollution. However, effects of the downdraft from a long-lived typhoon (typhoon Parma) during the first week of October 2009 at the northern tip of the Philippines resulted to a rare northwesterly wind flow that provided a transport path for atmospheric pollutants from the main Asian continent.

Numerical simulation is one of the most important and cost-effective ways in studying transboundary ozone pollution. Ozone is a secondary pollutant formed in the atmosphere from anthropogenic NO\textsubscript{X} and non-methane hydrocarbons (NMHC) and biogenic emissions of NMHC which subsequently undergo photochemical reactions [5]. It is difficult to assess \( O_3 \) with direct measurements since \( O_3 \) is affected by transport or through combination of imported precursor with local emissions [6]. Chemical transport models give us a glimpse on the different mechanism (i.e. production, transport) of \( O_3 \). Effects of \( O_3 \) include production of the radical Hydroxyl (OH) which plays a crucial role in the oxidizing capacity of the atmosphere [7]. \( O_3 \) is a greenhouse gas in the upper troposphere [8]. At concentrations higher than
background levels $O_3$ damages natural vegetation [9], reduces yields of agricultural crops [10], and is detrimental to human health [11].

It is the aim of this study to simulate long-range transport of tropospheric ozone from the Asian mainland to the Philippines under synoptic meteorological conditions.

2. Model description

Weather Research and Forecasting (WRF) (http://www.wrf-model.org) is a new generation mesoscale numerical weather system designed for both operational forecasting and atmospheric research applications. It is a non-hydrostatic model, with several dynamic cores including a fully mass and scalar conserving coordinate version that is widely used in air quality prediction applications. WRF also includes various choices for physical parametrizations to represent processes (i.e. microphysics, cloud, radiation, etc.).

The chemistry component of the WRF/CHEM is a regional air quality modelling system, which is being continually developed by NOAA (National Oceanic and Atmospheric Administration of USA) and several other research institutes (http://ruc.noaa.gov/wrf/WG11/). The model treats the processes of transport, wet and dry deposition, chemical transformation, emission, photolysis, aerosol chemistry and dynamics, etc. [12]. WRF/CHEM is fully consistent with the meteorological component, having the same transport scheme, same time steps, same horizontal and vertical grids and same physical schemes for subgrid scale transport.

For the simulation in this study, model domain includes China, Taiwan, parts of Korea and Japan, and parts of Southeast Asia. The model has a horizontal grid spacing resolution of 50 km. The meteorological initial and boundary conditions are from the National Center for Environmental Prediction (NCEP) Final Operational Model Global Tropospheric Analyses (FNL) data, available every 6 hours at $1^0 x 1^0$ grid spacing resolution (http://dss.ucar.edu/datasets/ds083.2/). Anthropogenic emissions for gaseous species was from the global emission inventory data for year 2000 was from the Reanalysis of tropospheric chemical composition (RETRO)(http://retro.enes.org/index.shtml).

3. Results and discussion

Figure 1 shows the wind flow pattern across the simulation domain on 1200 UTC of 4 October 2009. A tropical cyclone (typhoon Parma) was located at the northern tip of the Philippines. On the first week of October 2009, typhoon Parma had virtually zero horizontal speed in northern Philippines due to its

Wind Vector

![Wind Vector](image)

Fig. 1: Wind vector over the domain on 1200 UTC 4 October 2009.
interaction with another typhoon (Melor) via the Fujiwara effect. This meteorological condition induced a rare northwesterly wind that provided a transport path for pollutants from mainland China and to some extent, Taiwan.

Simulation of O₃ production and transport was done for a period of 7 days, from 00 UTC on 1 October 2009 to 24 UTC on 7 October 2009. Fig. 2 (a) and (b) show O₃ concentration over the simulation domain for 00 UTC and 24 UTC of 4 October 2009, respectively. This situation persisted for several days brought about by the weather condition. O₃ concentration of approximately 40 ppbv enveloped most of the northern part of the Philippines and only slight increase was seen for the rest of the archipelago. The simulation also shows relatively high O₃ concentration from Japan moving towards southwest to Taiwan then follows the spiral path of the typhoon.

![Fig. 2: Simulated Ozone concentration on (a) 00UTC and (b) 24UTC on 4 October 2009.](image)

It is important to note here that emission data used in the simulation is from the year 2000. From that year to 2003, NOₓ emissions, which is a precursor of O₃, in China had increased from 11Tg/yr to approximately 14.5Tg/year in 2003 [13] and is expected to further increase year to year. Future NOₓ emission prediction for China puts it at 39 and 128% by 2020 for the Reference Case Scenario (sustainable scenario with moderate emission rates caused by the suppression of energy consumption through energy conservation, a change to clean energy, and the moderate deployment of new energy technologies and new emission control technologies) and Policy Failure Scenario (pessimistic scenario with high emission rates caused by continuation of the current energy structure, increased energy consumption, and the slow deployment of new energy technologies and new emission control technologies), respectively [14]. The concentration values of this numerical simulation were most likely underestimated, and will only tend to increase for future instances under the same synoptic meteorological condition.

4. Conclusion

With the use of a new generation air quality modelling system, the WRF/CHEM ver. 3.2.1, an assessment of transboundary air pollution in the Philippines was investigated. Under certain weather conditions, that is a typhoon system in the north or north-west of the Philippines, air pollutants undergo long range transport from the main Asian continent to most of the Philippines’ northern islands. In the future, it is expected that increasing emissions of pollutants in China will adversely affect air quality in the Philippines.

5. References


