# Impact of Stratospheric Intrusion on High Ozone in the Lower Troposphere over the Hong Kong Region

## A case study

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# Outline

- Motivation
- Objective
- Model and Data
- Result
- Summary
- Future work

# Motivation

01 Tropospheric ozone is a key constitute in the atmosphere. High concentration of $O_3$ is an air pollutant. $O_3$ is a greenhouse gas and the source of OH radicals.

About 90 percentage ozone concentrated in the stratosphere and it makes a important contribution to tropospheric ozone budget. 02

03 Stratosphere and troposphere have different dynamic and chemical characteristics. The occurrence of high ozone and potential vorticity followed by dry air is associated with stratospheric intrusion.

It was observed that the high ozone concentrations appeared at the 2~4 km height in Hong Kong during March-May. 04

05 Stratospheric intrusion could be a significant contributor the while biomass burning from Southeast Asia plays an important role. The study of the former is much less than the latter.

# Motivation

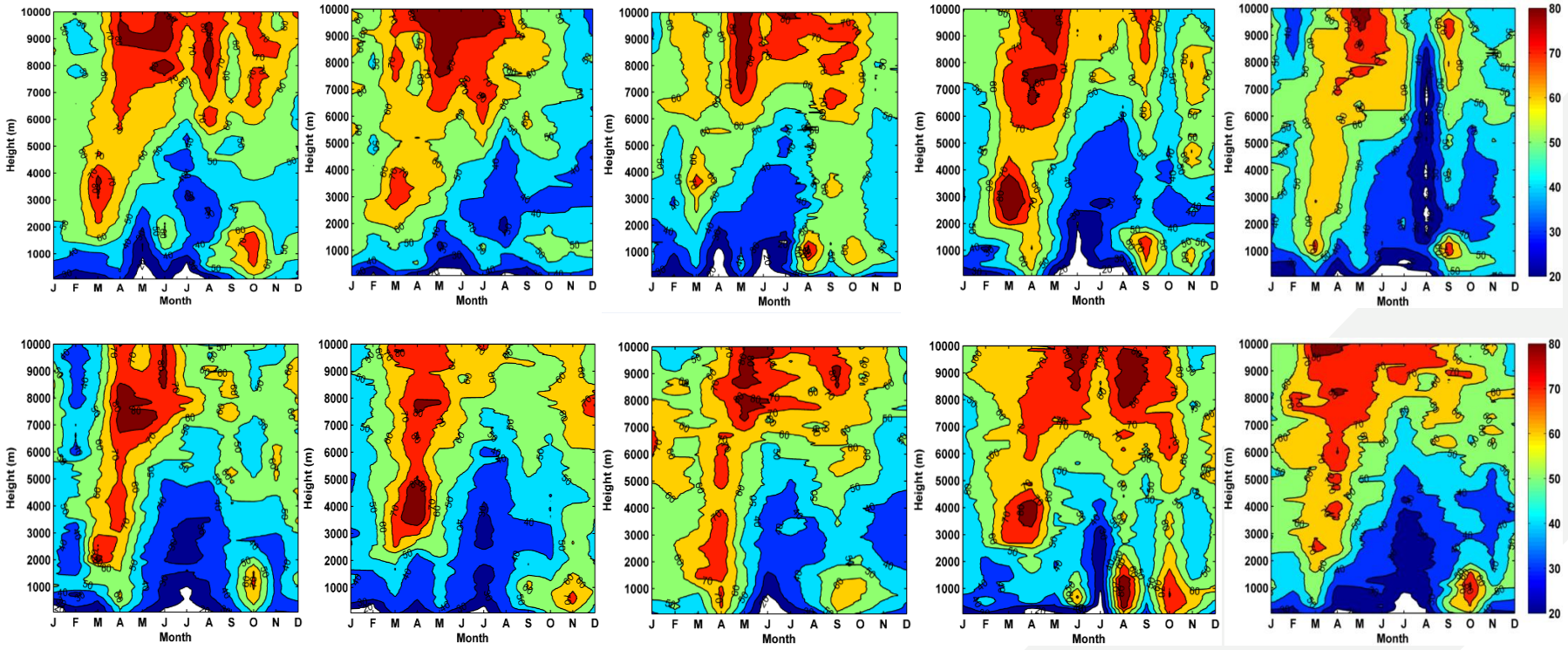



Fig 1. Spatial and temporal distribution of $O_3$ in Hong Kong from 2004 to 2013 year by year

# Objectives

## Scientific Questions and Objective

### Scientific Questions

? What is the relative contribution of STE to the high ozone concentration above the PBL (2~4 km AGL) ?

? How is the STE contribution changed with the time?

### Objectives

We combine WRF/Chem simulations with ozone sounding and other observational data to quantify the relative contribution of STE to the high concentration ozone above the PBL (i.e., 2~4 km AGL).

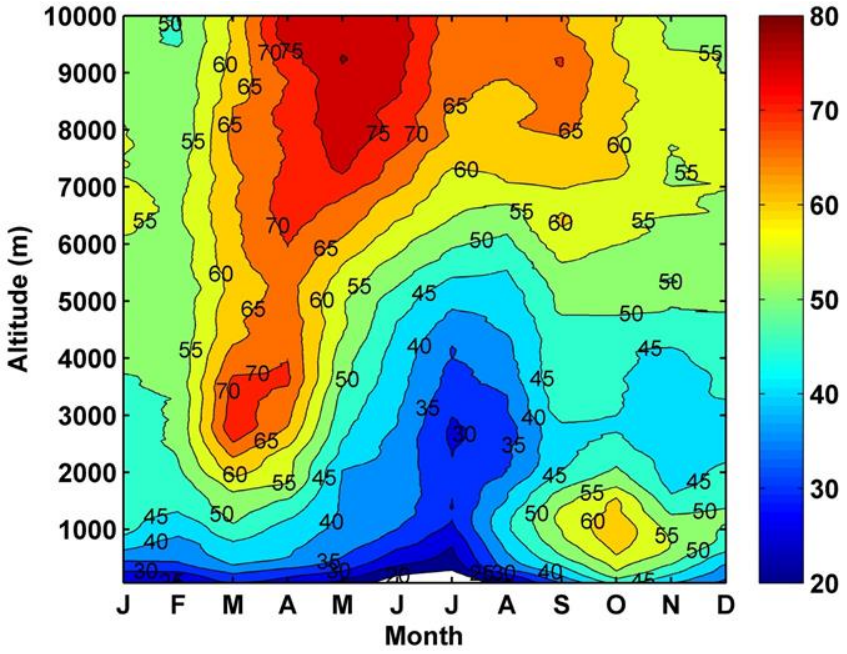
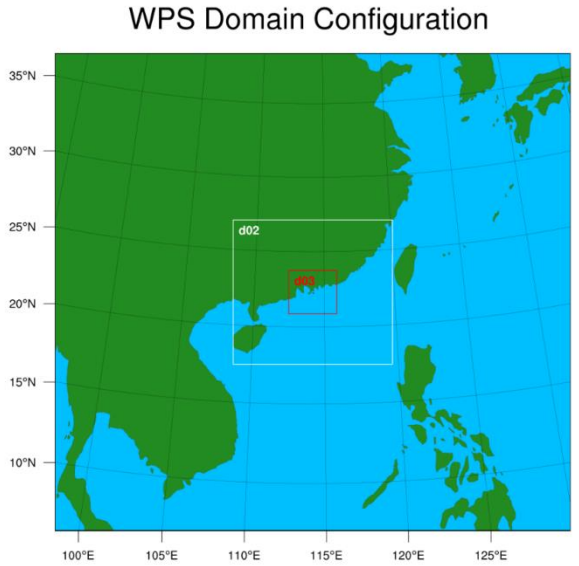



Fig 2. Spatial and temporal distribution of monthly mean $O_3$ in Hong Kong during 2004-2013

# Model and Data

## WRF-Chem




Tab. 1 Parameter settings in WRF-Chem model

| Domain | 1,2,3 |
|---|---|
| Version | 3.7.1 |
| Time | 04 March 2013 to 06 March 2013 |
| Initial Meteorological Field | Fnl (1°×1°) time: 6h<br>26 levels in vertical (1000hPa to 10hPa) |
| Horizontal Resolution | 27km 9km 3km |
| P-Top | 50 hPa |
| Horizontal Grid Point | 140×130 130×118 118×106 |
| Vertical Layers | 46 |

# Model and Data

## WRF-Chem

Tab 2. Parameter schemes used in model

| Schemes | Configuration |
|---|---|
| mp_physics | Lin Microphysics |
| Ra_sw_physics | Goddard |
| sf_surface_physics | Noah Land surfaceModel |
| Ra_lw_physics | Rapid Radiative Transfer Model |
| bl_pbl_physics | the Yonsei University planetary |
| Chem_opt | RADM2 |
| Phot_opt | Fast-J photolysis |

# Model and Data

## MOZART/GEOS-5 Data

- Model for Ozone and Related Chemical Tracers  version-4
- Initial and boundary conditions for chemical fields in WRF-Chem are used from the MOZART-4/GEOS-5 simulations (http://www.acd.ucar.edu/wrf-chem/mozart.shtml)
- Driven by meteorological fields from the NASA GMAO GEOS-5 model

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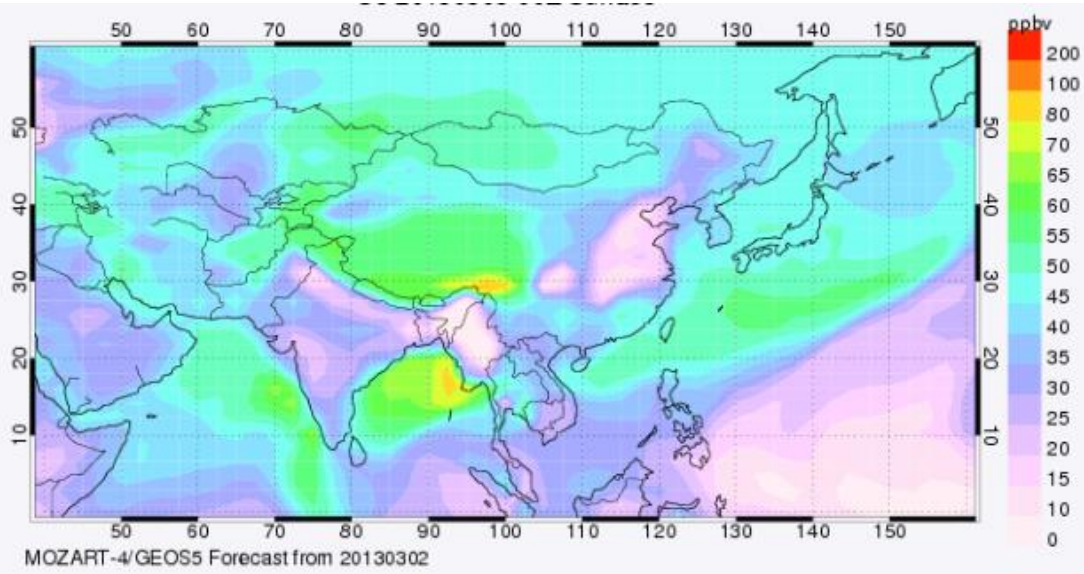
- Horizontal resolution : 1.9°×2.5°
- Vertical : 56 layers
- Spatially and temporally varying : 6h
- Uses anthropogenic emissions based on David Streets' inventory for ARCTAS and fire emissions from FINN-v1 (Wiedinmyer et al., Geosci. Model Devel, 2011).

# Model and Data

## MOZART Data



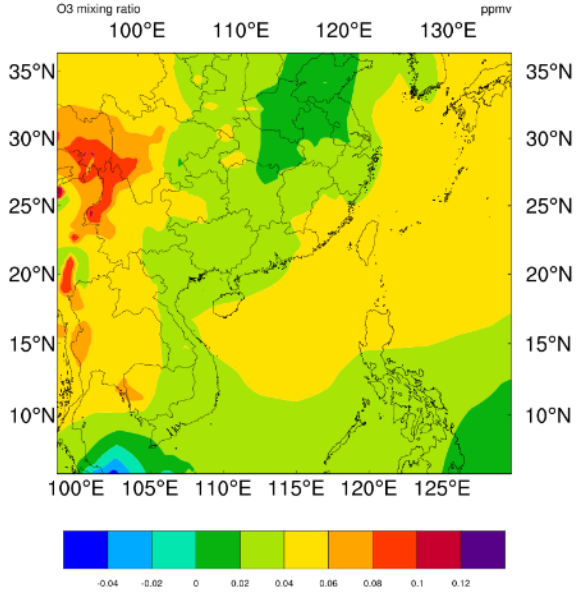




Fig 3. MOZART data (left) and chemical boundary conditions for the model

# Model and Data

## Upper Boundary Condition

WRF-Chem does not have a stratosphere- possible issues when looking at UTLS, STE influence or comparing to satellite products

UBC-Motivation Stratosphere

⬇

affects the troposphere

have_bcs_upper

defaults to .false.

Wherein no species concentrations are specified near the upper boundary

set to .true.

Then the following species will have concentrations from the model top down to the tropopause overwritten: $O_3$, NO, $NO_2$, $HNO_3$,$CH_4$,CO,$N_2O$ and $N_2O_5$

Impose an upper boundary condition to keep key species at values representative of the stratosphere

# Model and Data

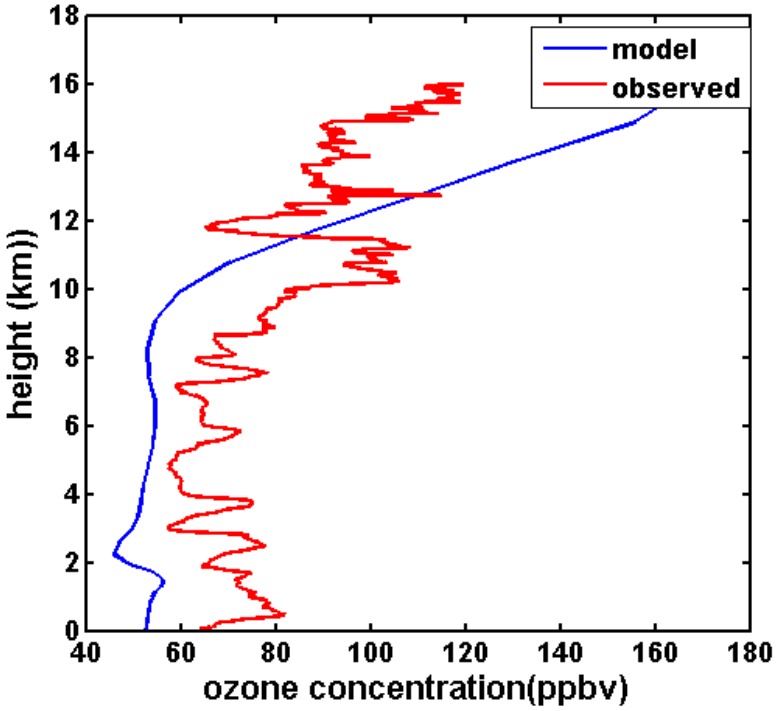
## Data

Tab 3. The data used in following research

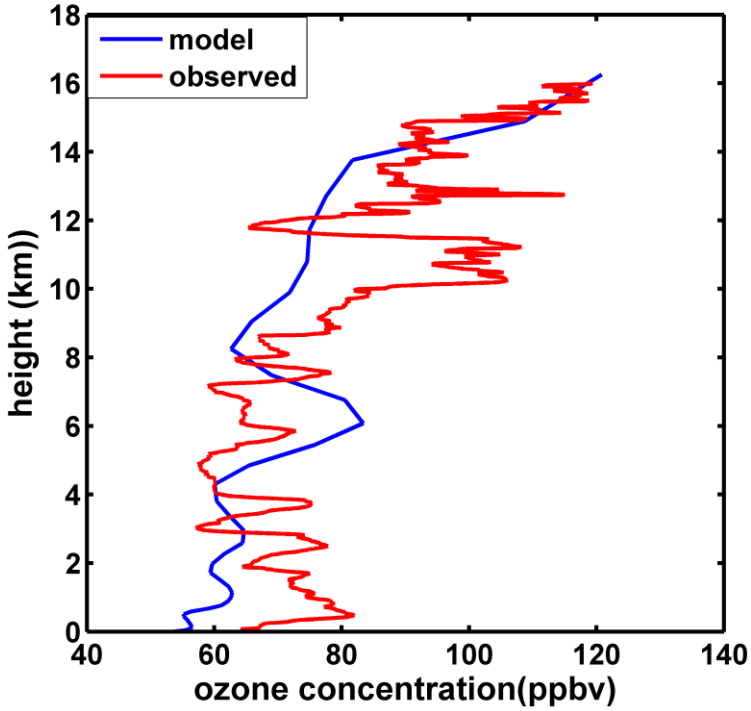
| Ozonesonde Data | Surface Site | ECMWF Reanalysis Data |
|---|---|---|
| Hong Kong observatory(22.18°N，114.1°E) | Hourly ozone concentration | Horizontal resolution:0.125°×0.125° |
| Observed once a week | Sha Tin<br>Tap Mun<br>Tai po | Time resolution:6h |
| Linear Interpolated in 10m distance | | 37 vertical pressure levels: from 1000 to 1 hPa |

# Result

## Ozone Concentration




(a) no MOZART data and upper boundary condition

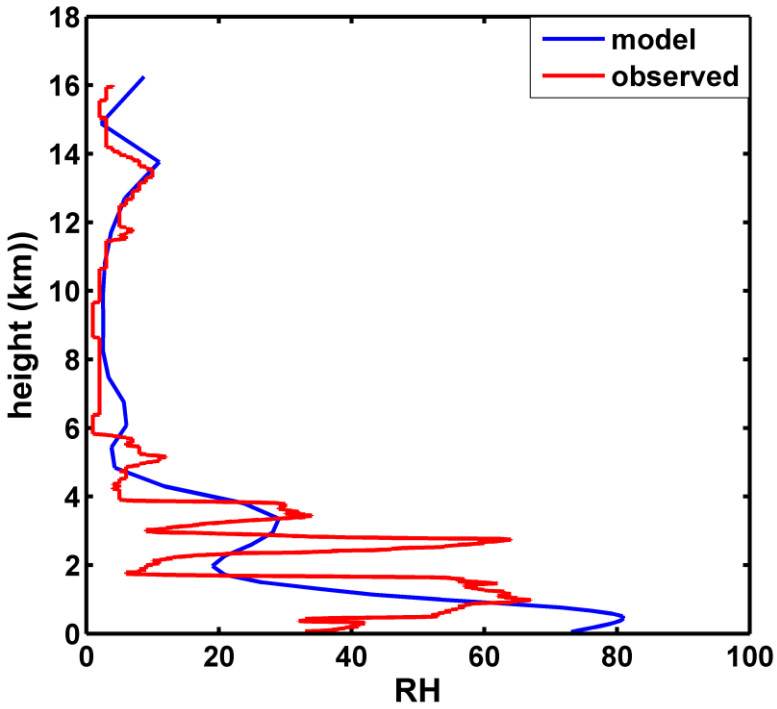



(b) with MOZART data and upper boundary condition

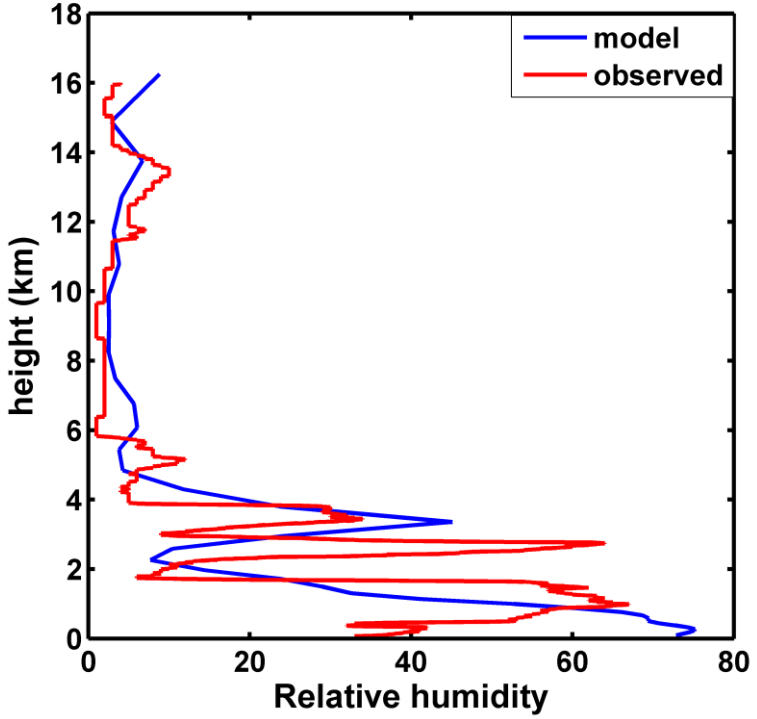
Fig 4. Simulated vertical profiles(blue) of ozone concentration in comparison with measured profiles(red) at Hong Kong observation(22.31°N，114.17°E) at 0600 UTC 06 March 2013

# Result

## Relative Humidity




(a) no MOZART data and upper boundary condition




(b) with MOZART data and upper boundary condition

Fig 5. Simulated vertical profiles(blue) of relative humidity in comparison with measured profiles(red) at Hong Kong observation(22.31°N · 114.17°E) at 0600 UTC 06 March 2013

# Result

## Temperature

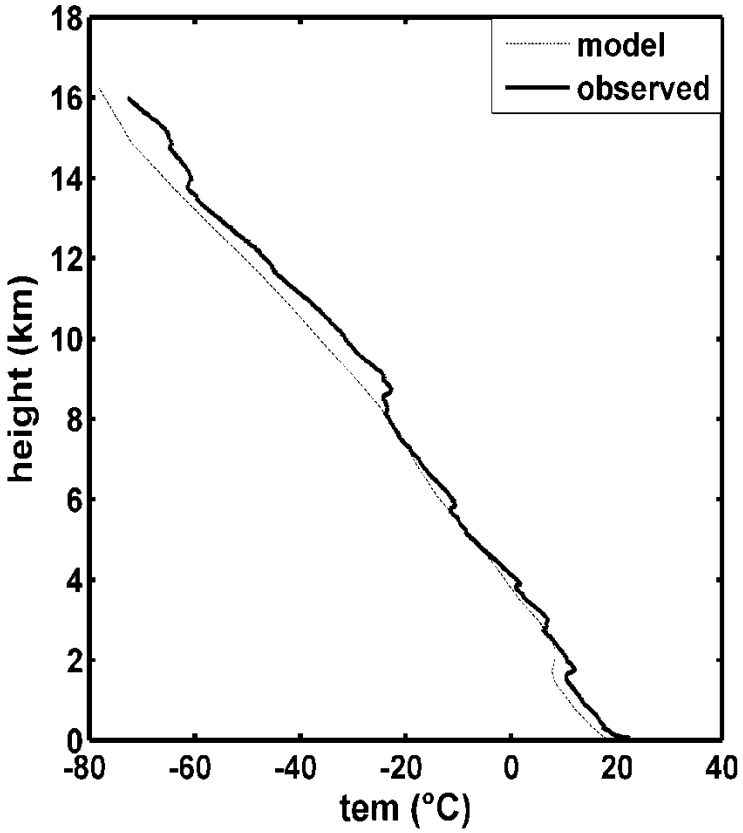



Fig 6. Simulated vertical profiles(dashed) of temperature(°C) in comparison with measured profiles(solid) at Hong Kong at 0600 UTC 06 March 2013

# Result

## Surface temperature

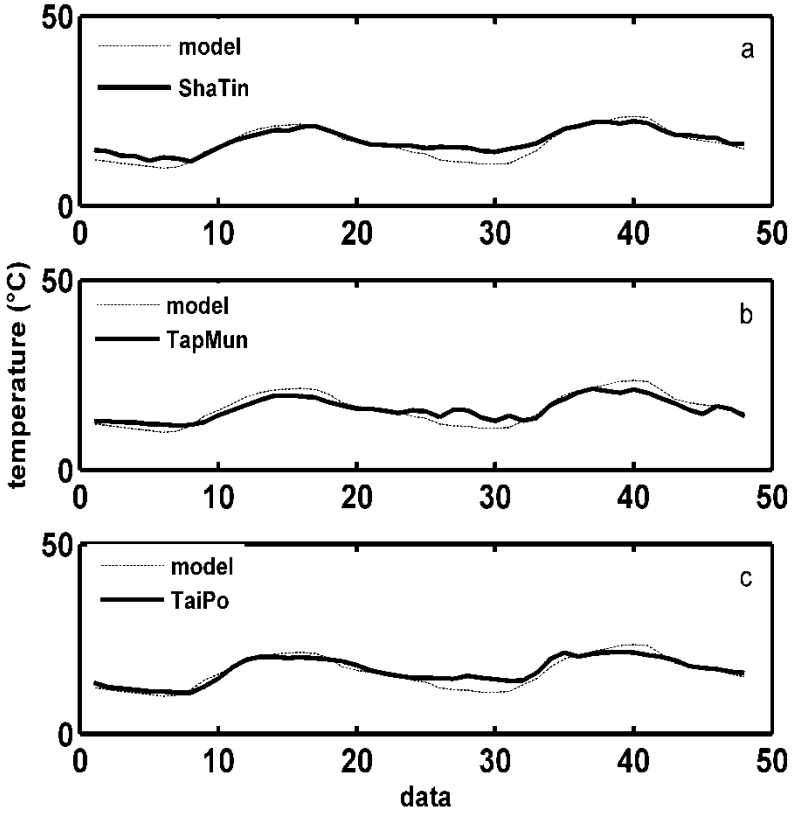



Fig 7. Simulated (dashed) surface temperature(°C) in comparison with measured profiles(solid) (a)Sha Tin (b)Tap Mun (c)Tai Po site at 05-06 March 2013

# Result

## Ozone Concentration

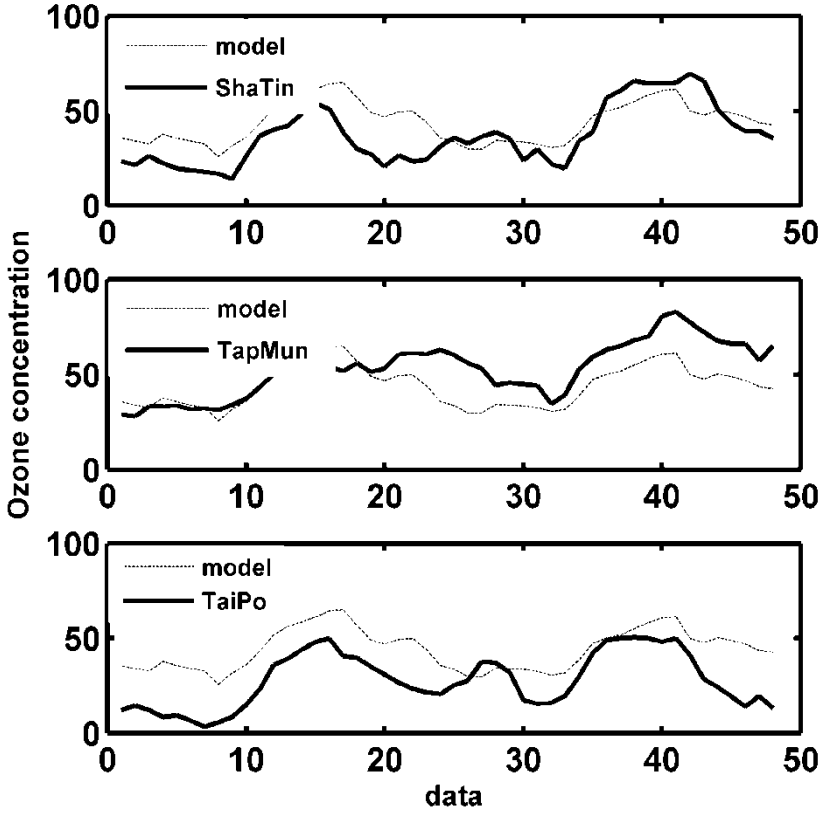



Fig 8. Time series of surface ozone concentration at Hong Kong (a)Sha Tin (b)Tap Mun (c)Tai Po site at 05-06 March 2013

# Result

## Correlations

Tab 4. The correlation coefficient, root-mean-square and mean bias errors of measured and predicted at Hong Kong in March, 2013

| | R | P | RMSE | MB |
|---|---|---|---|---|
| $O_3$ Vertical Obs | 0.73 | <0.0001 | 22.472 | 10.33 |
| RH Vertical Obs | 0.76 | <0.0001 | 21.0465 | -8.2322 |
| T Vertical Obs | 0.998 | <0.0001 | 2.8 | 2.2 |
| Sha Tin ($O_3$) | 0.69 | <0.0001 | 13.2 | -7.1 |
| Tap Mun($O_3$) | 0.69 | <0.0001 | 13.8 | 9 |
| Tai Po ($O_3$) | 0.76 | <0.0001 | 18.7 | -16.2 |
| Sha Tin (T) | 0.958 | <0.0001 | 1.7892 | 0.8524 |
| Tap Mun (T) | 0.9342 | <0.0001 | 1.8325 | -0.208 |
| Tai Po (T) | 0.947 | <0.0001 | 1.5418 | 0.4816 |

# Result

## Simulated Ozone

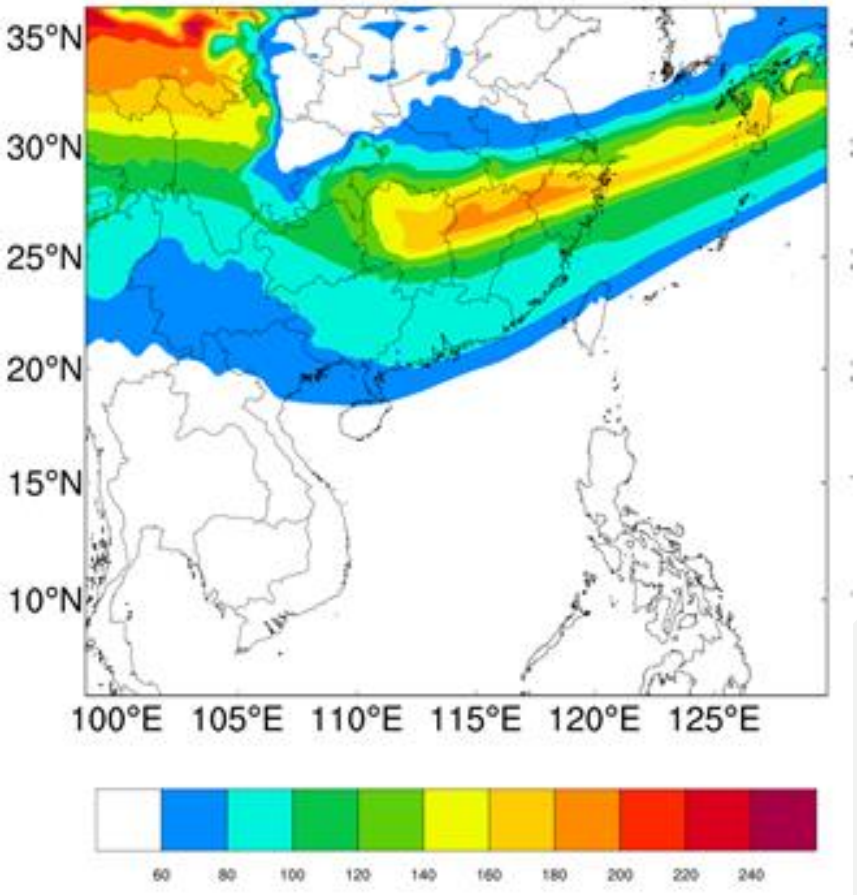



Fig 9. Ozone concentration (ppbv)at the 300hPa level from WRF-Chem model at 0600 UTC 06 March 2013

# Result

## Relative Humidity

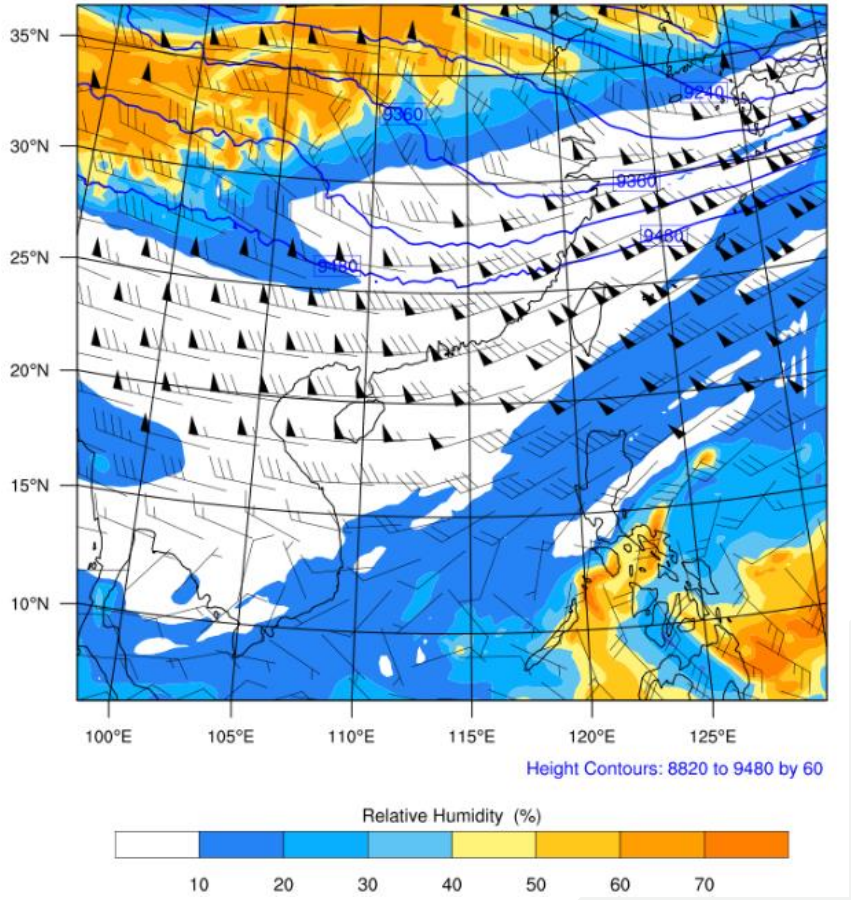
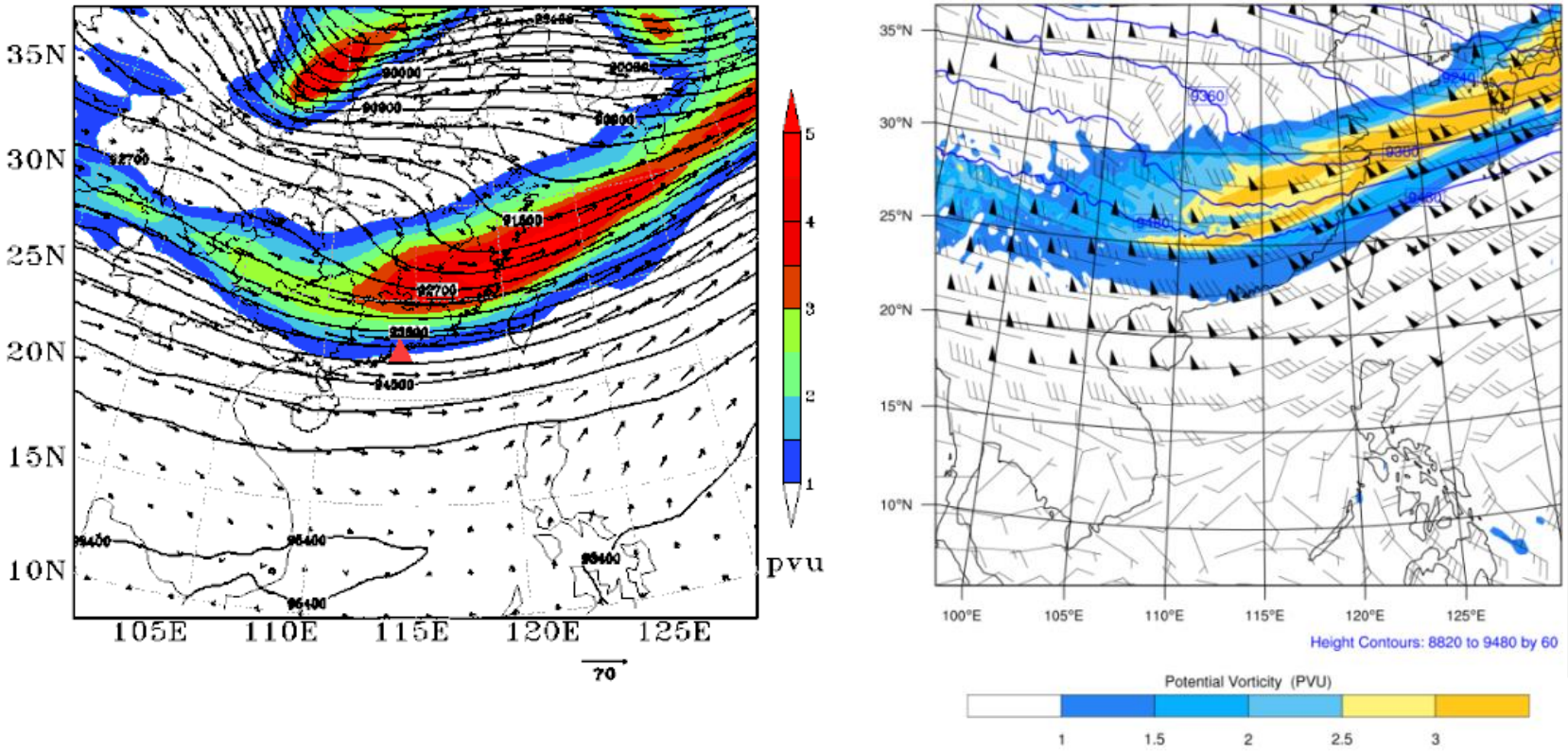



Fig 10. Relative humidity at the 300hPa level from WRF-Chem model at 0600 UTC 06 March 2013

# Result

## Wind/Geopotential Height/Potential Vorticity




a ECMWF

b WRF-Chem result

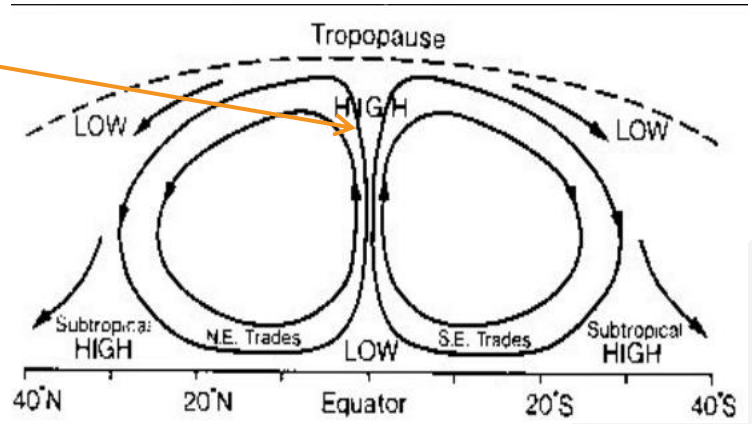
Fig 11. Wind (kts bar),geopotential height (gpm,contours) and potential vorticity (color scale)at the 300hPa level at Hong Kong at 0600 UTC 10 May 2013

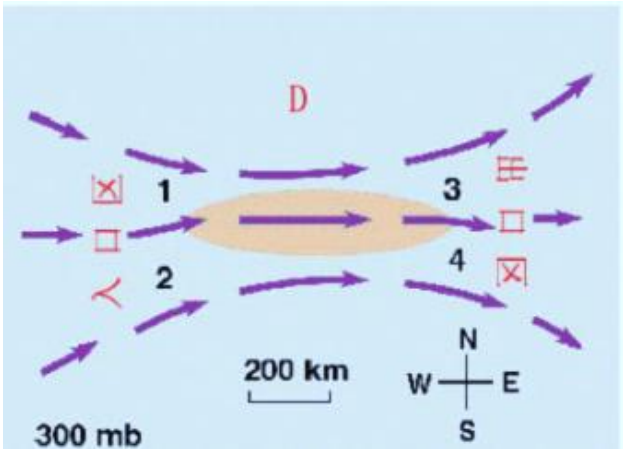
# Result

## Subtropical Jet Stream

As the air moves poleward, it cools, becomes more dense, and descends at about 30th parallel, creating a high-pressure area.

Hadley cell is a closed circulation loop, which begins at the equator where air is warmed.




On the left side of entrance, vorticity is negative.
There is a large-scale subsidence occurred in this area.

# Result

## Ozone Concentration

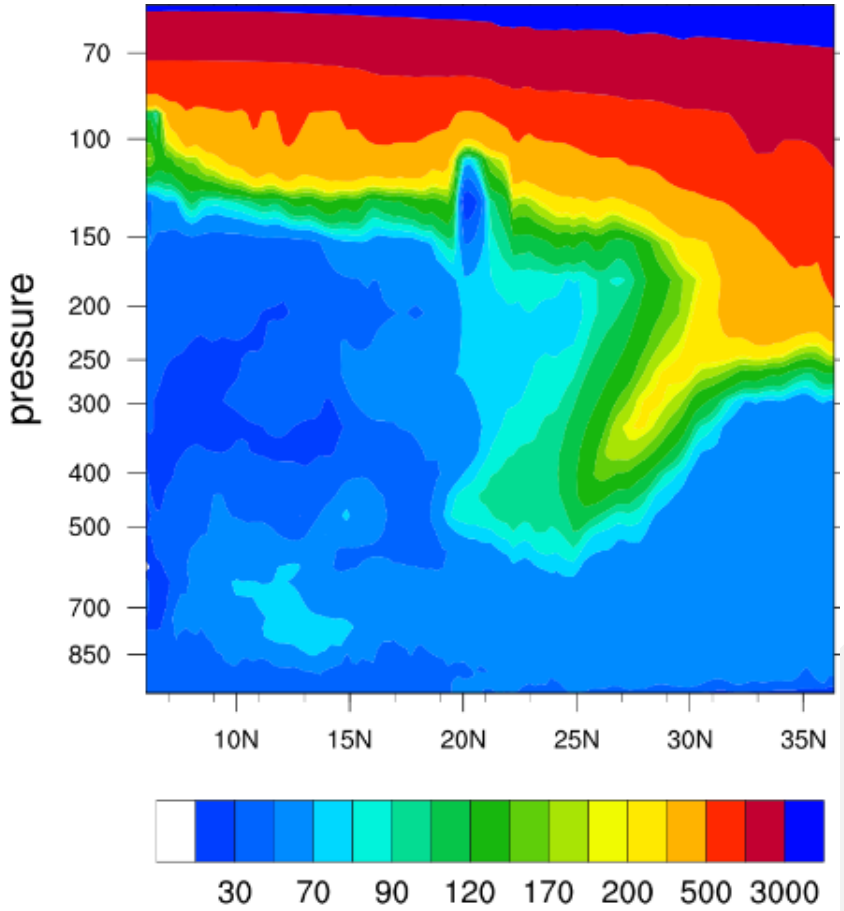



Fig 12. Zonal-vertical cross sections (pressure–latitude ) of ozone concentration(ppbv) centered at Hong Kong(114.17°E)

# Summary

High concenration ozone was observed right above the atmospheric boundary layer (i.e. 2-4 km above ground level). The month-height cross section shows a significant contribution of the stratospheric intrusion.

WRF-Chem model is capable of simulating the STE process. The model result is improved after using MOZART outputs as initial and boundary conditions for the simulation.

The case is a typical stratosphere intrusion case. It was associated with the activity of sub-tropic jet stream and Hong Kong was located at the entrance of jet with large-scale subsidence.

The WRF-Chem model shows similar results to the ECMWF reanalysis data.

# Future work

## Quantify the STE Flux by Wei Formula

Stratosphere - Troposphere air Mass flux exchange:

$$F(m) = \frac{1}{g}\left(-\omega + V_h \cdot \nabla P_{tp} + \frac{\partial P_{tp}}{\partial t}\right) = \left(-\frac{\omega}{g} + \frac{1}{g} V_h \cdot \nabla P_{tp} + \frac{1}{g}\frac{\partial P_{tp}}{\partial t}\right)$$

$\omega$: Vertical velocity
$P_{tp}$: Tropopause pressure
$V_h$ : Horizontal wind
$g$: Acceleration of gravity

- First term: caused by vertical movement of air
- Second term: caused by horizontal movement of air
- Third term: caused by movement of tropopause

# THANK YOU!