Yale-NUIST Center on Atmospheric Environment

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Source analyses of high ozone events in the lower troposphere of Hong Kong: tropospheric intrusion vs. biomass burning

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Outline

- Motivation
- Objectives
- 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.

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

03 There are three major sources of ozone in the lower troposphere: the intrusion of stratosphere (or stratosphere-troposphere exchange, STE), the local photochemical production, and the long-range transport (e.g., biomass burning).

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

05 Both STE and biomass burning pollutants from Southeast Asia are two major contributors to the events with high value of ozone in Hong Kong. Very few studies are able to quantify the relative contributions to such events.

Objectives

Scientific Questions and Objective

Scientific Questions

? What are the relative contributions of STE and biomass burning to the high ozone concentration above the PBL (2~4 km AGL) ?

? What are the governing weather systems that are favorable for STE and long-range transport of biomass burning

Objectives

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

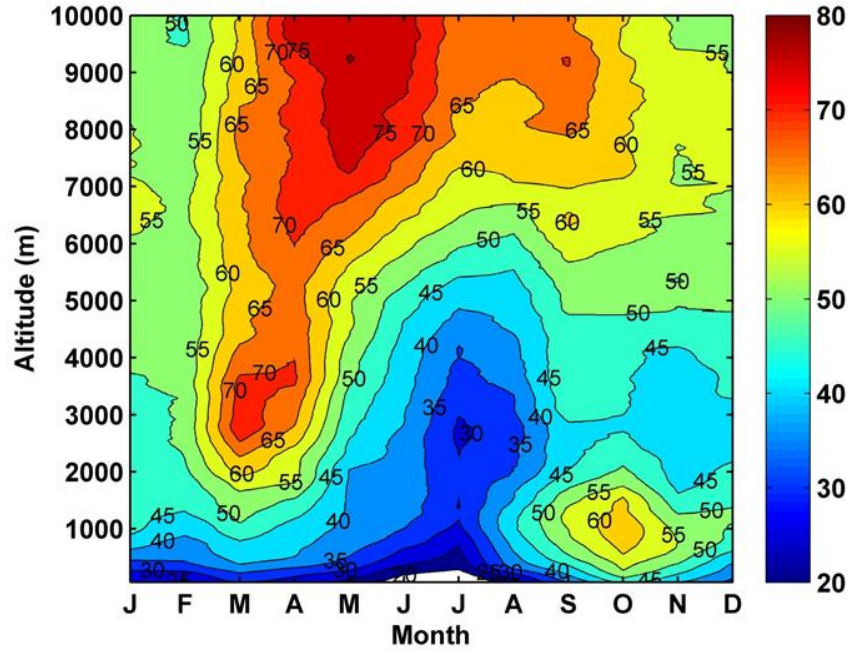


Fig.1 Spatial and temporal distribution of monthly mean O_3 in Hong Kong during 2004-2013

High ozone events in the lower troposphere over Hong Kong

Tab.1 A summary of the cases with ozone concentration greater than 70 ppb at 2-4 km during (2004-2014)

type	case
STE(11)	20040324 20040312 20040412 20040510 20050309 20090408 20090506 20100324 20130306 20140402 20050525
Biomass burning(24)	20040317 20040402 20040405 20040303 20050331 20070314 20080409 20060315 20060322 20070321 20070328 20070418 20070502 20080312 20100407 20100413 20110406 20110427 20120321 20120328 20120403 20130410 20130523 20140415
Unknown(8)	20040426 20050523 20080514 20090415 20100310 20110420 20120418 20120502

High ozone events in the lower troposphere over Hong Kong (cont.)

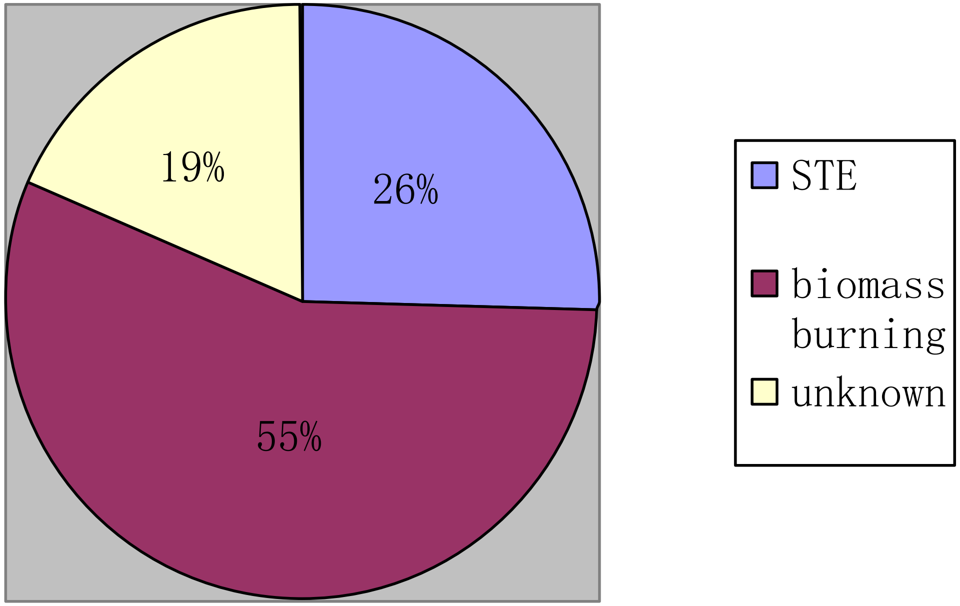
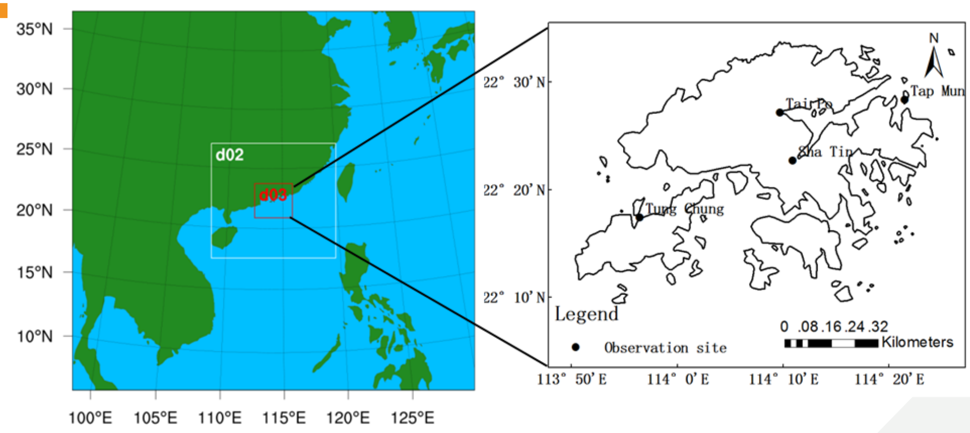


Fig.2 Pie-chart of the three sources during 2004-2014

Model and Data

WRF-Chem



Tab.2 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 26 levels in vertical (1000hPa to 10hPa)
Horizontal Resolution	27km 9km 3km
P-Top	50 hPa
Horizontal Grid Point	140×130 130×118 118×116
Vertical Layers	46

Model and Data

WRF-Chem

Tab.3 Parameter schemes used in model

Schemes	Configuration
mp_physics	Lin Microphysics
Ra_sw_physics	Goddard
sf_surface_physics	Noah Land surface Model
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 generated from the MOZART-4/GEOS-5 simulations (http://www.acd.ucar.edu/wrf-chem/mozart.shtml)
- Meteorological Ics and BCs are from the NASA GMAO GEOS-5 simulations

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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

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: O3, 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

Emissions Data

- MIX emissions inventory
- 2008 and 2010 Asian anthropogenic emissions inventories developed for the East Asia Model Comparison Program Phase 3 (MICS-Asia III) and the United Nations Hemispheric Air Pollution Transmission Program (HTAP)

➢ Include: Power, industrial, residential, transportation, agriculture

➢ Monthly grid emissions data

➢ Spatial resolution: $0.25^{\circ} \times 0.25^{\circ}$

Model and Data

Data

Tab.4 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	HK environmental protection department	Time resolution:6h
Linear Interpolated in 10m distance		37 vertical pressure levels: from 1000 to 1 hPa

Results

A STE case

Vertical profiles

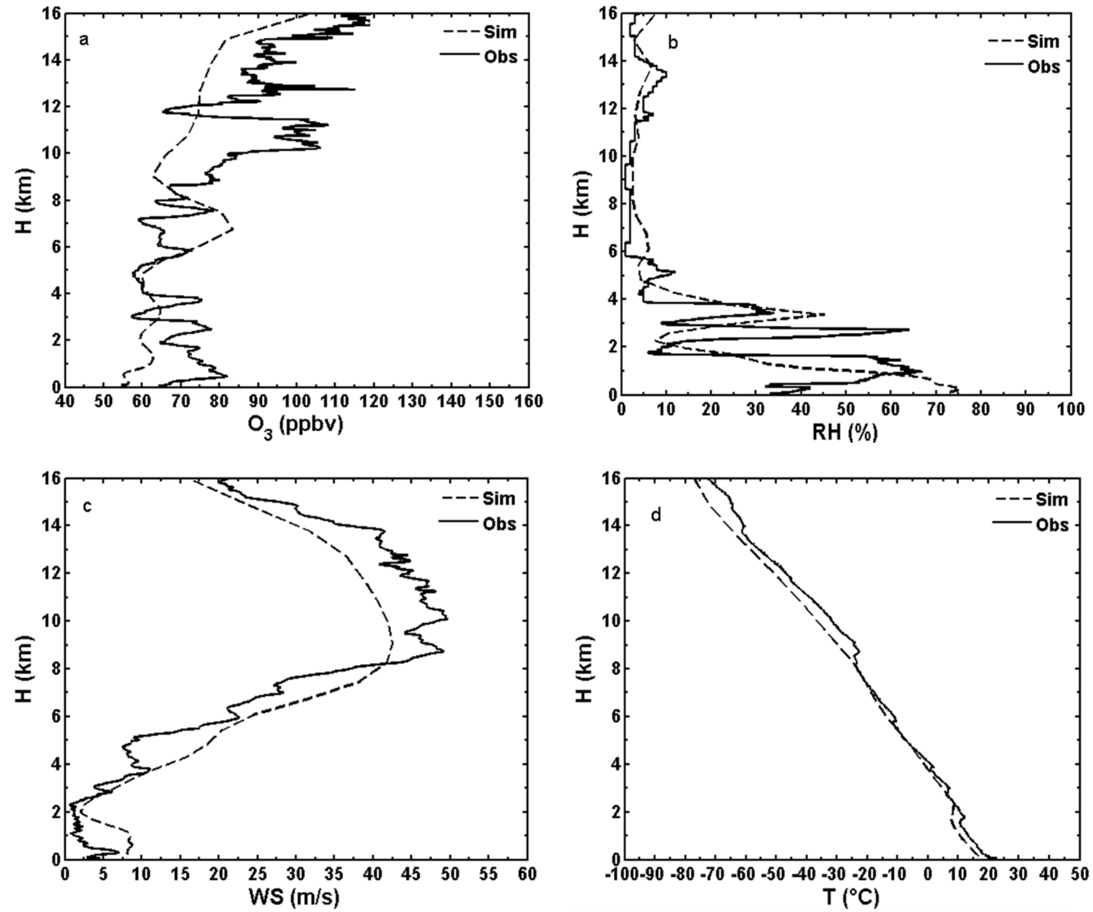


Fig.3 A comparison of simulated vertical profiles(dashed) with measured profiles (solid) for (a) ozone concentration, (b) relative humidity, (c)wind speed, and (d) temperature at Hong Kong at 0600 UTC 06 March 2013

Results

Surface temperature

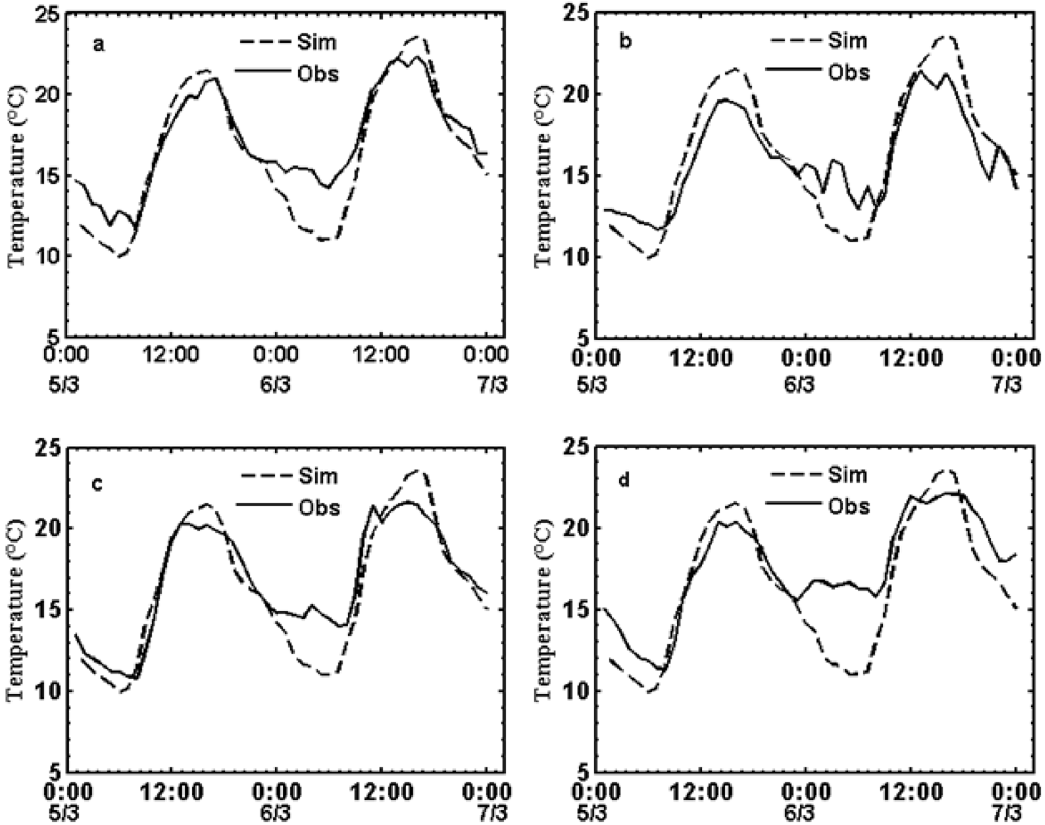


Fig.4 A comparison of simulated (dashed) surface temperature (° C) with observed (solid) at (a) Sha Tin, (b)Tap Mun, (c)Tai Po, and (d)Tung Chung on 05-06 March 2013

Results

Ozone Concentrations

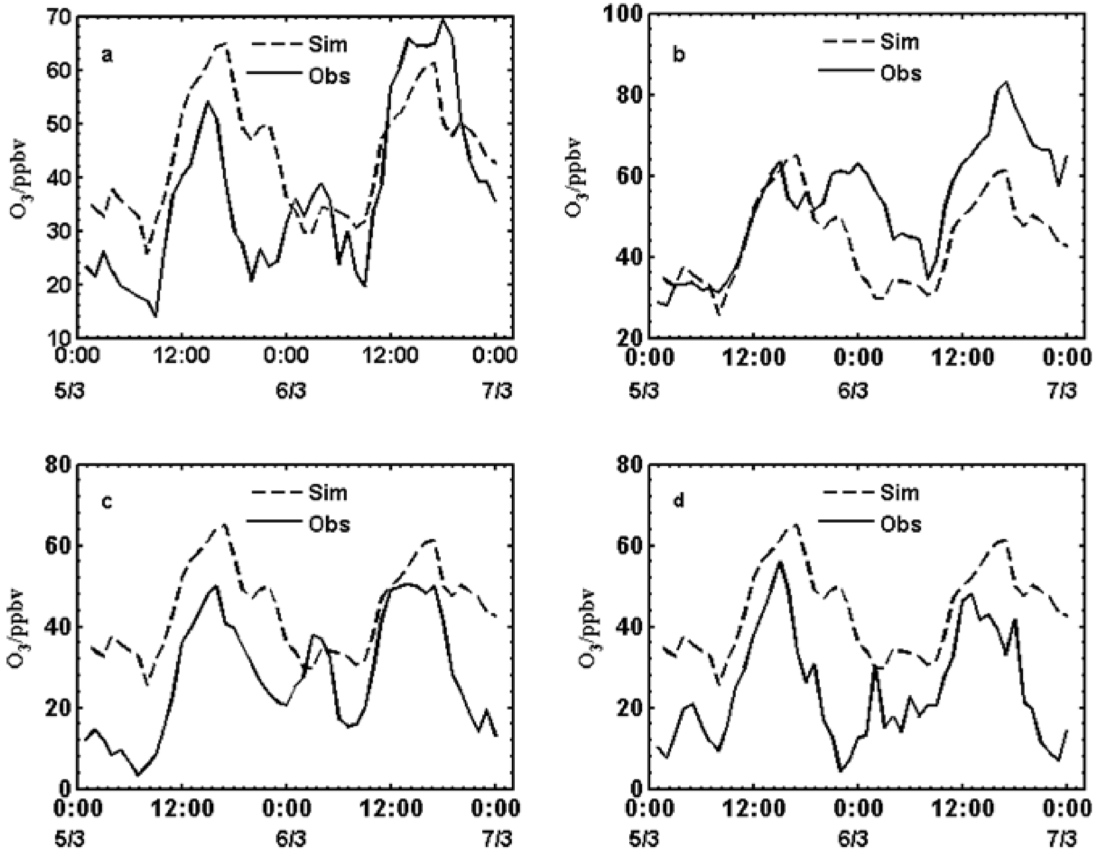


Fig.5 Time series of surface ozone concentrations (ppbv) at (a)Sha Tin, (b)Tap Mun, (c)Tai Po, and (d)Tung Chung at 0600 UTC on 05-06 March 2013

Results

Other related parameters

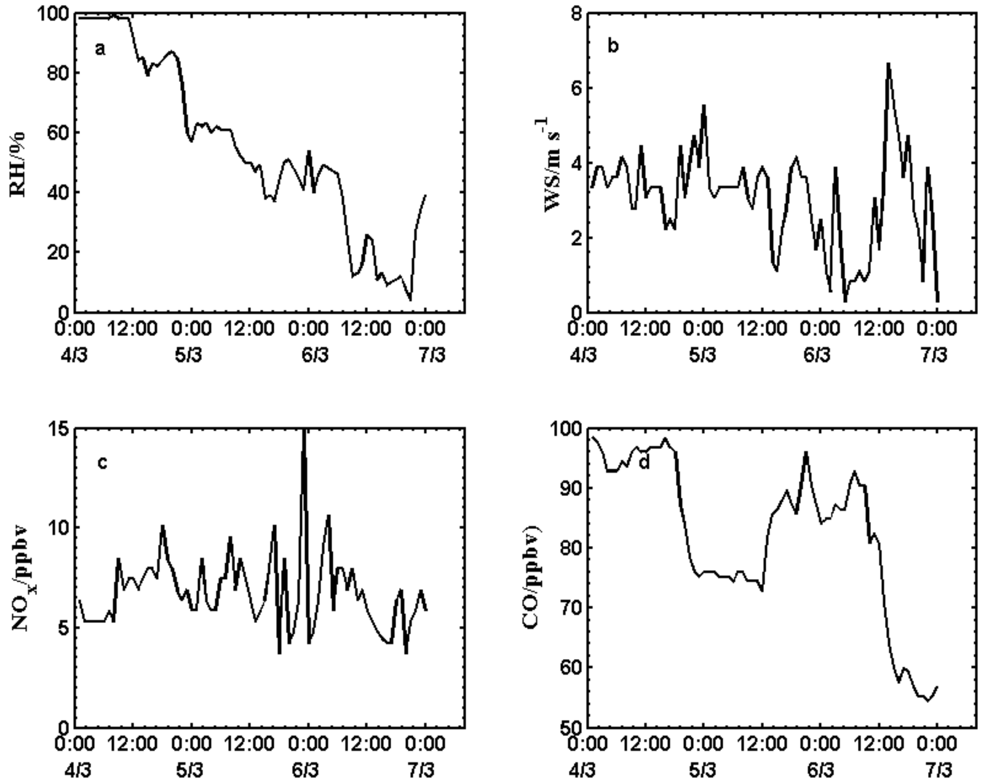


Fig.6 Observation-simulation comparison of (a)RH, (b)Wind speed, (c)Nox, and (d) CO on 04-06 March 2013

Results

Statistical evaluations

Tab.5 A summary of statistical evaluations of O_3 and meteorological variables simulations at Hong Kong in March, 2013

	R	P	RMSE	MB
O_3 vertical profile	0.73	<0.0001	22.472	10.33
RH vertical profile	0.76	<0.0001	21.0465	-8.2322
WS vertical profile	0.9638	<0.0001	4.9214	-1.69
T vertical profile	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
Tung Chung (O_3)	0.66	<0.0001	22.147	-19.61
Kwun Tong(O_3)	0.42	<0.001	15.78	-7.9
Sha Chau(O_3)	0.64	<0.0001	13.44	-3.3
Yuen Long(O_3)	0.45	<0.001	23.74	-13.2
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
Tung Chung (T)	0.8863	<0.0001	2.3809	1.2647

Results

Relative Humidity

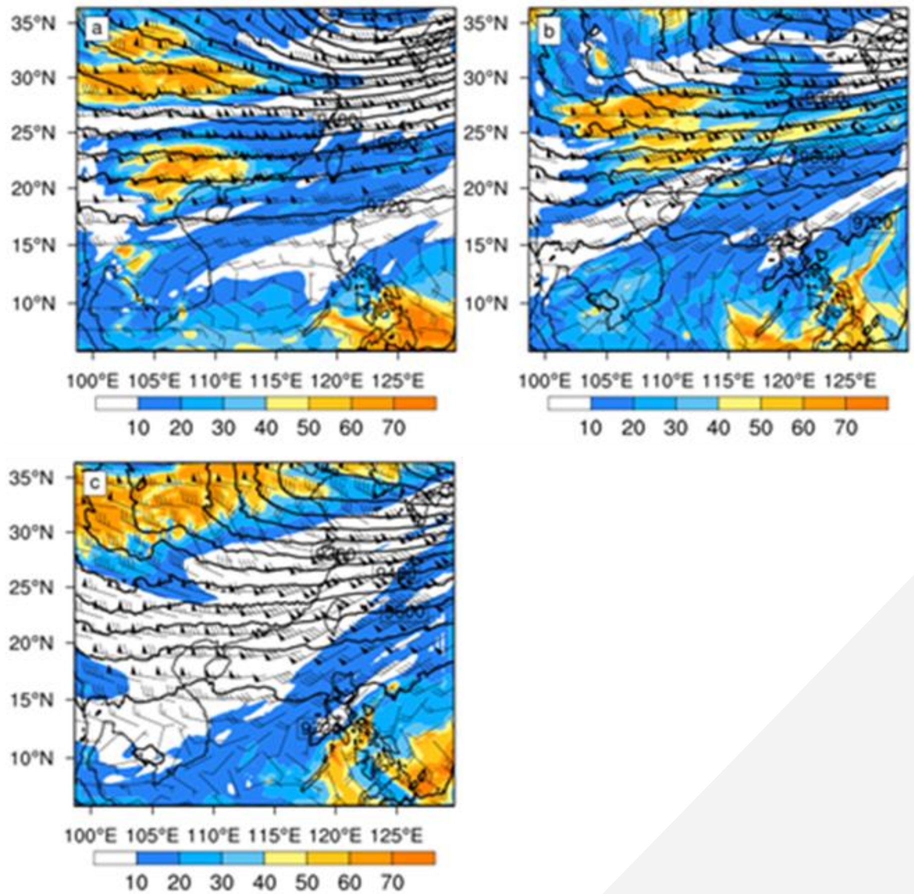


Fig 7. Simulated relative humidity at the 300hPa level at 0600 UTC 04-06 March 2013

Results

Upper-level Ozone /Potential Vorticity

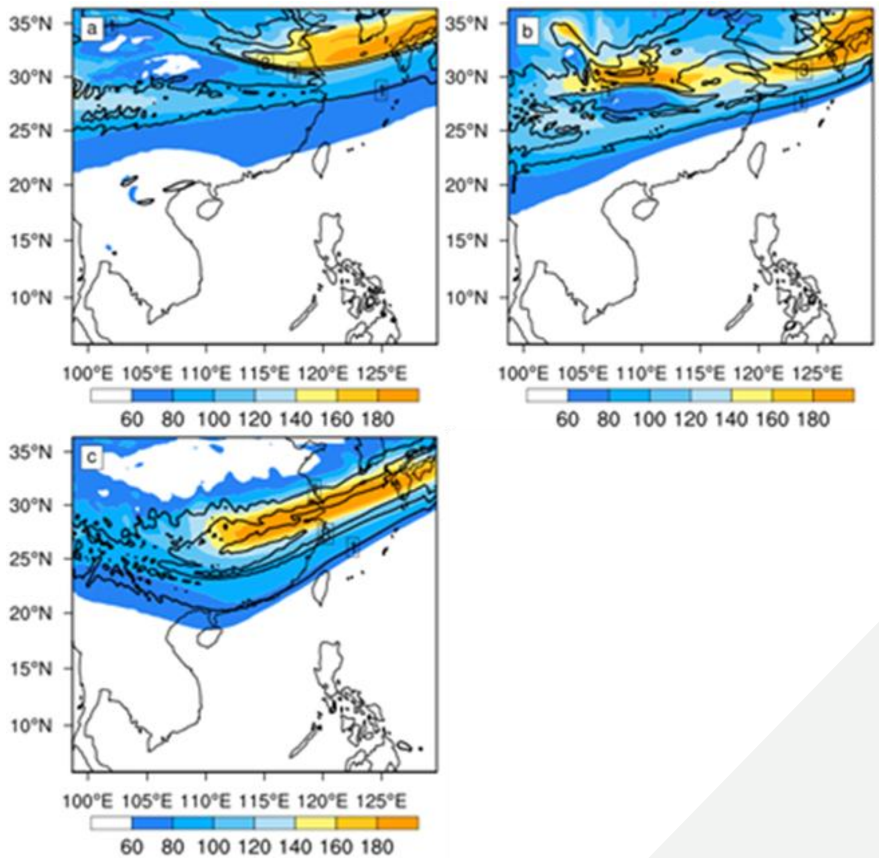


Fig 8. Simulated ozone concentrations (color-map) and PV (contour) at the 300hPa level at 0600 UTC 04-06 March 2013

Results

Cross-section of ozone

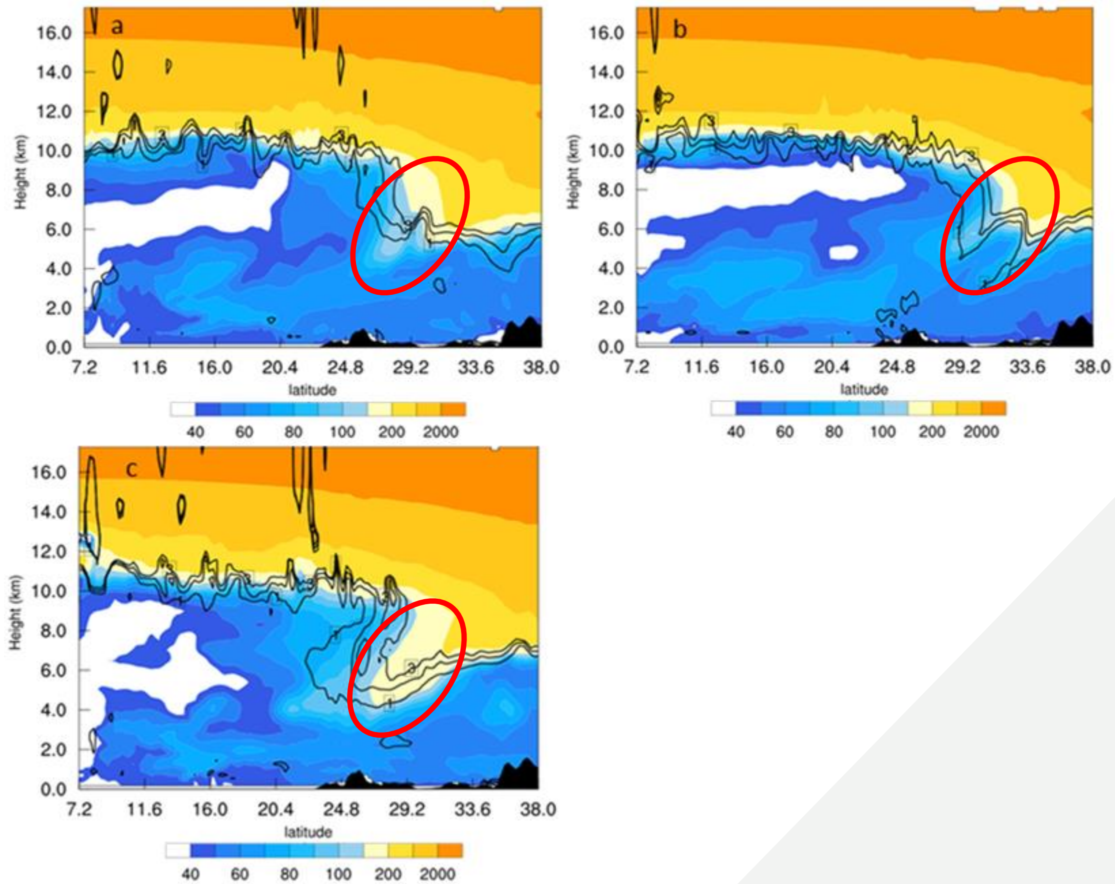


Fig 9. Zonal-vertical cross sections (pressure–latitude) of ozone centered at Hong Kong(114.17° E) at 0600 UTC 04-06 March 2013 (terrain: black shaded)

Quantify the STE Flux (Wei Formula and box-model)

Stratosphere - Troposphere air Mass flux exchange(Wei Formula):

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

$$V_h \cdot \nabla P_{tp} = u_i \times \frac{p_{1i} - p_{2i}}{\Delta x} + v_i \times \frac{p_{3i} - p_{4i}}{\Delta y}$$

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

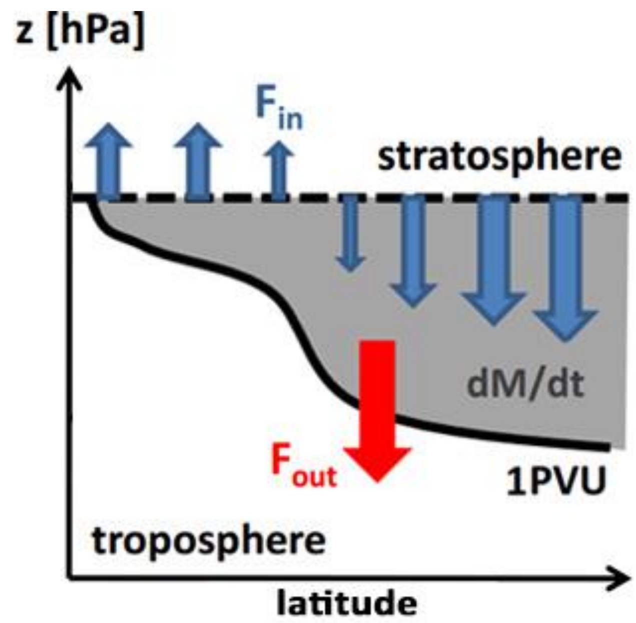
- First term: caused by vertical movement of air
- Second term: caused by horizontal movement of air
- Third term: caused by movement of tropopause

Tab.6 cross tropopause flux compared to previous study

	Lmarque	Spaete	Vaugham	Wirth	Ebel	YangJian	Our result
Tropopause pv	2	3	1.5	2	3	3.5	1
Time	4d	1d	2d	3d	1.96	85h	1d
Acreage/km^2	$3.2*10^6$	10^6	$2.5*10^5$	$8*10^5$	$2.25*10^5$	$2.5*10^6$	$4.16*10^4$
Flux (10^{-3} kg*$m^{-2}s^{-1}$	-0.4	-3.5	-2.4	-3.5	-1.4	-0.73	-1.5889
Mass kg	$-4.9*10^{14}$	$-3*10^{14}$	$-1.1*10^{14}$	$-7.2*10^{14}$	$-5.4*10^{14}$	$-5*10^{14}$	$-5.68*10^{12}$

Box model

- $F(out) = F_{in} - \frac{dm}{dt}$
- F_{in}=c × w
- F_{in}=0.2695*10^{13}mol/cm^2 s
- $\frac{dm}{dt}$=0.01161 × 10^{13}mol/cm^2 s
- F_{out}=0.2579 × 10^{13}mol/cm^2 s
- Compared to Wei Formula
  F=0.23 × 10^{13}mol/cm^2 s



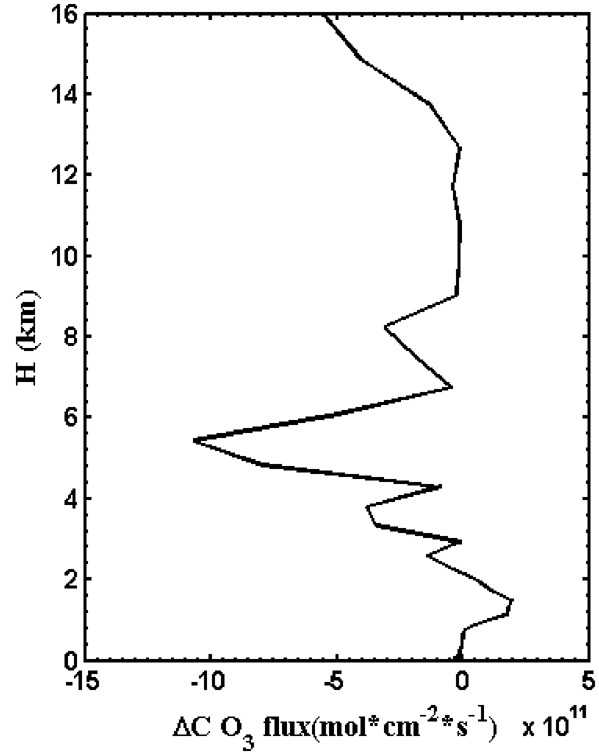


Fig.10 Vertical profile of ozone flux at 0600 UTC 06 March 2013 （negative value: downward transport， positive value： upward transport）

A biomass burning case

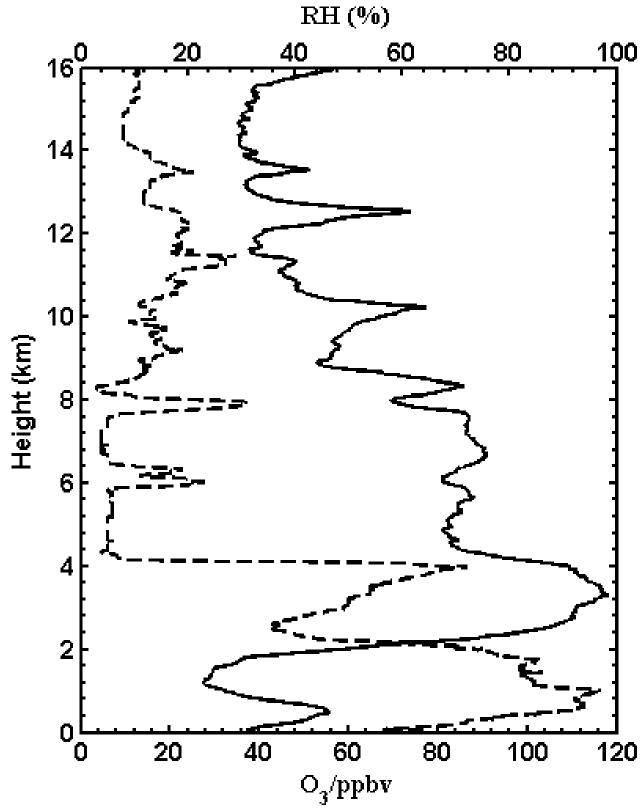


Fig.11 Observed vertical profiles of ozone concentration (solid) and relative humidity (dashed) at 0600 UTC 28 March 2007

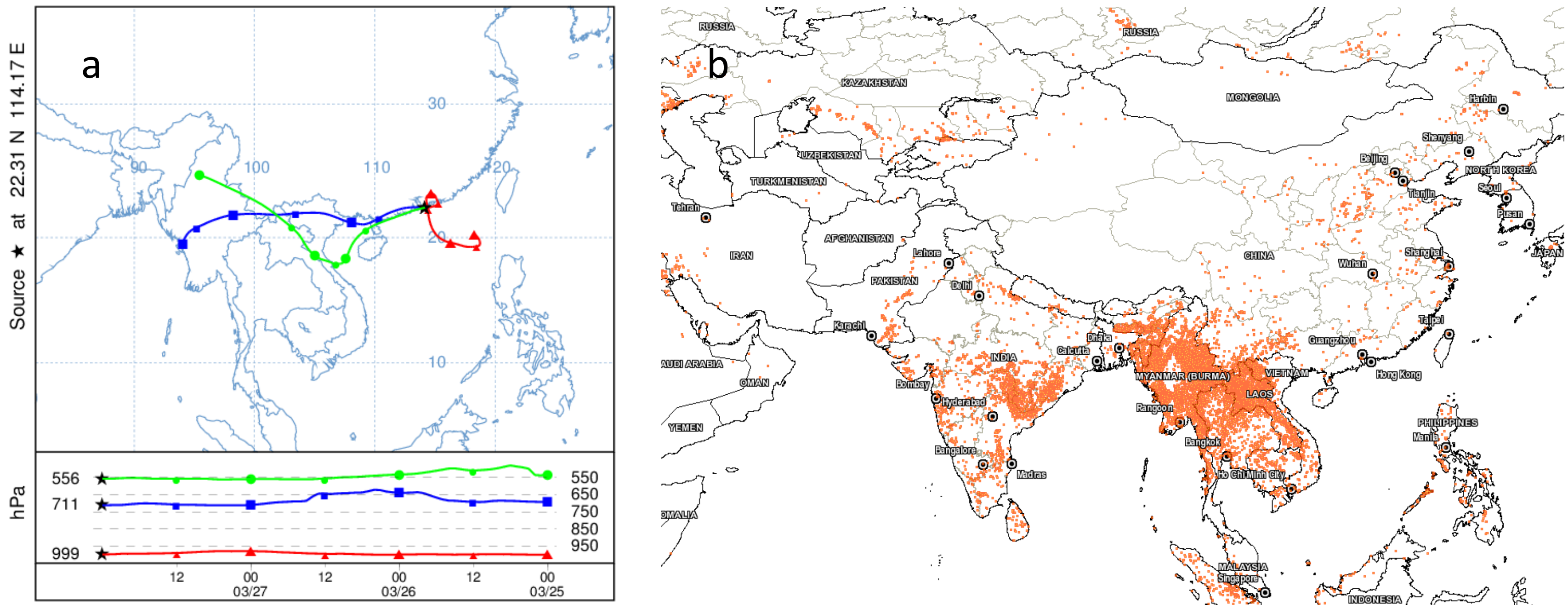


Fig.12 (a) Analysis of back trajectories calculated with HYSPLIT model at Hong Kong during 26-28 March 2007 (b)fire maps (https://firms.modaps.eosdis.nasa.gov/firemap/)

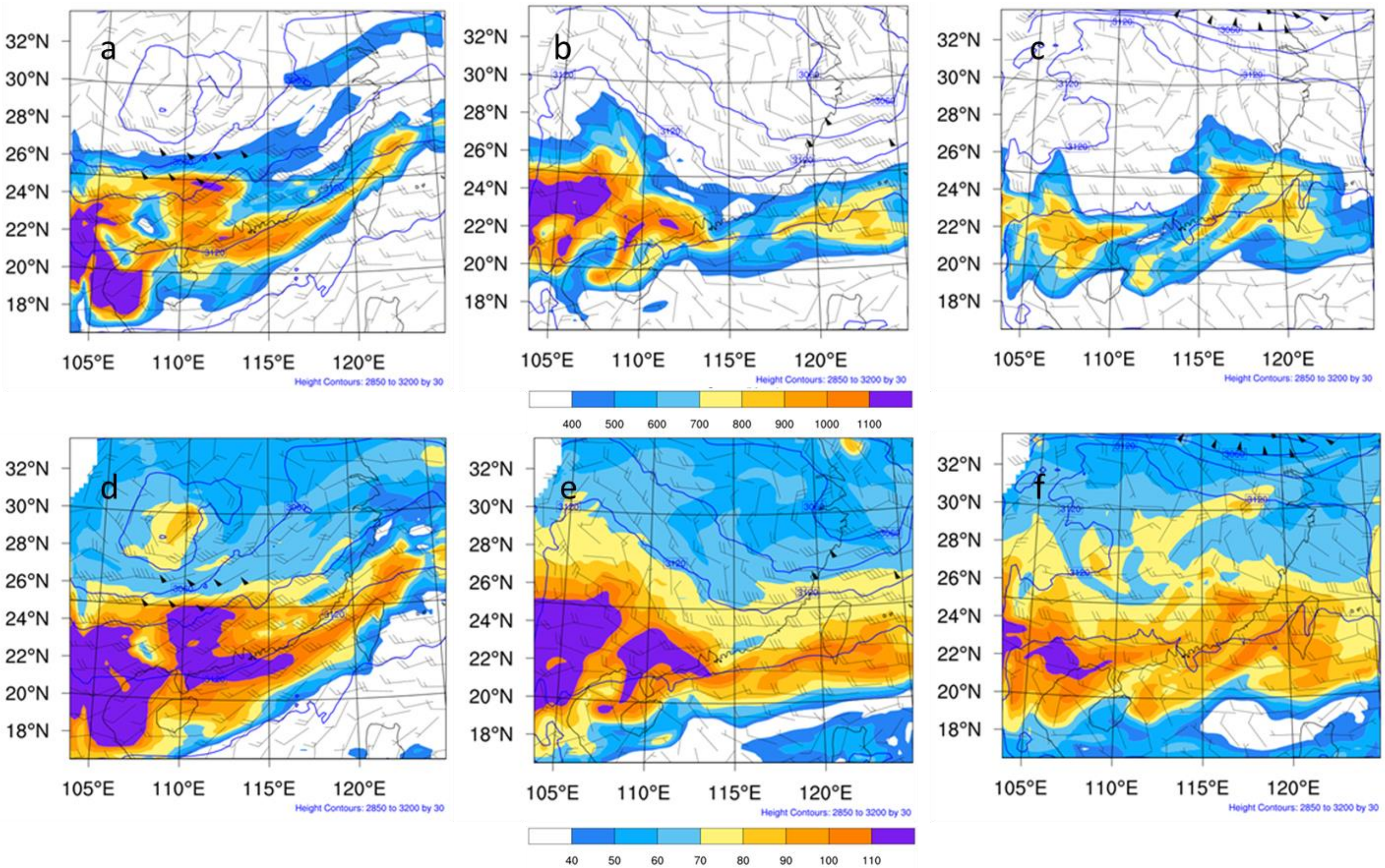


Fig.13 Simulated CO concentration(a ,b ,c) and ozone (d ,e ,f) at the 700hPa level at 0600 UTC 26-28 March 2007 (unit: ppbv）

Summary

High concentration ozone events were observed above the atmospheric boundary layer (i.e. 2-4 km above the ground level) in Hong Kong during Springtime. Both STE and long-range transport of biomass burning show significant contributions.

WRF-Chem model is able to simulate the STE process. Wei formula and Box-model show similar calculations of STE fluxes of ozone. And our results are in agreement with previous studies.

Compared to biomass burning case, the STE case shows much less fluctuations in relative humidity and higher ozone concentrations at upper troposphere.

Our study shows that biomass burning pollutants from southeastern Asia will transport high concentration of co and ozone to Hong Kong by the strong western wind.

Future work

1.Classify the governing weather systems that are favorable for STE and long-range transport of biomass burning pollutants.

2.Improve the simulations by including the fire inventory. Evaluations of the model results between with and without fire emissions.

THANK YOU!