Progress Report on Stratosphere-Troposphere Exchange of O_3 in Southeast China

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Outline

- Background and objectives
- Data and method
- Preliminary results
- Discussion and summary

Background

- ❖ Ozone is a key constitute in the atmosphere.
  - High concentration of O_3 is an air pollutant
  - Greenhouse gas
  - Source of OH radicals
- ❖ There are two major sources of tropospheric O_3
  - Intrusion of stratosphere or Stratosphere to Troposphere Exchange (STE)
  - Photochemical reaction in the troposphere
- ❖ Main mechanisms of STE include
  - Polar front jet stream
  - high-altitude frontogenesis
  - cut-off low power process
  - Tropopause fold

Background: reference review1

- Guo et al.(2007) used Wei Formula and found out that
  - The compensating mass out flow from the stratosphere appears mainly over mid-latitudes near large-scale troughs;
  - Mass flux into troposphere is stronger in autumn and winter than in spring and summer;
  - Mass and flux exchange per areas are larger at high latitudes than that in low latitudes.
- Gao et al (2007) used the coupling system RAMS-CAMQ to simulate tropospheric ozone and sulfur dioxide in East Asia and found that
  - The concentration is higher in spring and summer than those in the winter agrees well with seasonal variation of solar intensity.
  - Monsoons over East Asia play an important role in ozone distribution in this area.

Background: reference review2

- KIM (2007) et al
  - quantified the relative contribution of tropospheric photochemical production versus stratospheric influx to the springtime tropospheric ozone maximum over northern mid-latitudes.
  - There is no evidence showing photochemical effects and stratospheric intrusion are the key reasons causing the springtime ozone maximum;
- Cui et al. (2001) did a case study on ozone abnormal process observed on March 29 and 30 at Lin-An. They presented detailed analyses on surface, upper air meteorological observations, and high-altitude potential vorticity, and pointed out the downward transport of O_3-rich air from stratosphere is the dominant process causing this event.

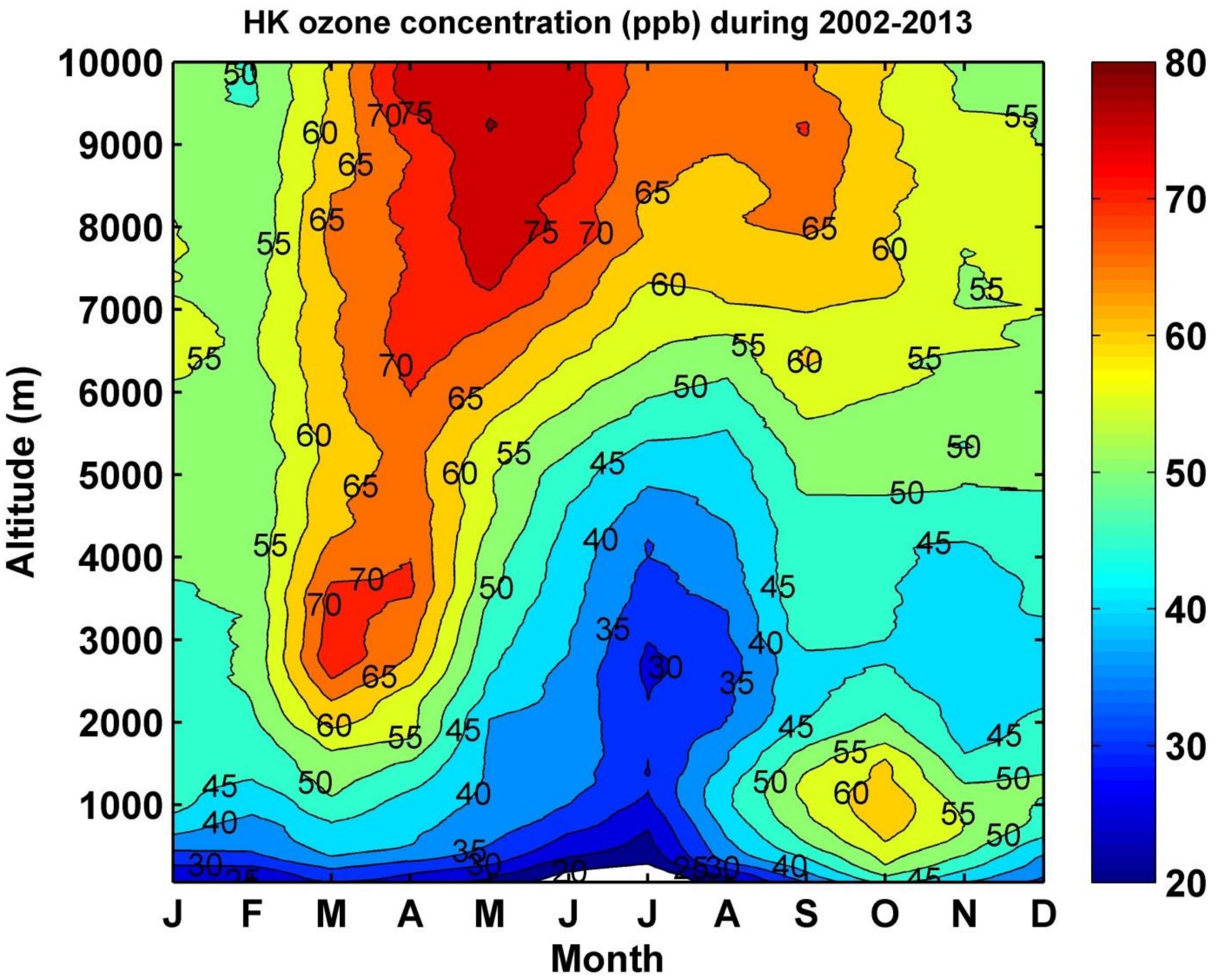
Background: reference review3

- Michaela I. Hegglin and Theodore G. Shepherd (2009) use a box model to calculate the STE flux on global scale. They conclude:
  - climate change will alter the tropospheric ozone budget and the ultraviolet index
  - STE ozone flux increases with the largest absolute increases in spring and the largest relative increases in summer.
- Yang (2003) using Wei Formula to calculate the STE flux, they found:
  - The air mass exchange flux is -0.27$\times 10^{-3}$kg· $m^{-2} \cdot s^{-1}$,and the ozone flux is about -3.2 $\times 10^{11}$~-47.3$\times 10^{11} cm^{-2} \cdot s^{-1}$ in $2.25 \times 10^{6} km^{2}$ *simulating* region in 85 hours.
  - It appears tropopause fold and cause the STE, at the entrance to the rapids and upper frontal region.

Background: reference review4

- Danielsen et al. (1968); Logan et al. (1985); Levy et al. (1985); Moody et al. (1995); Oltmans et al., 2004) agreed that stratospheric injection is important source of tropospheric O_3.
- Due to a lack of observed ozone data and its precursors over this region as compared to North America and Europe, STE-related studies is limited.
- In summary, there is still an uncertainty on the impact of STE on tropospheric O_3. It is a challenge to calculate the STE flux.

Spatial and temporal distribution of O_3 in Hong Kong during 2002-2013



Question: How can we quantify the impact of stratospheric intrusion on tropospheric O_3 ?

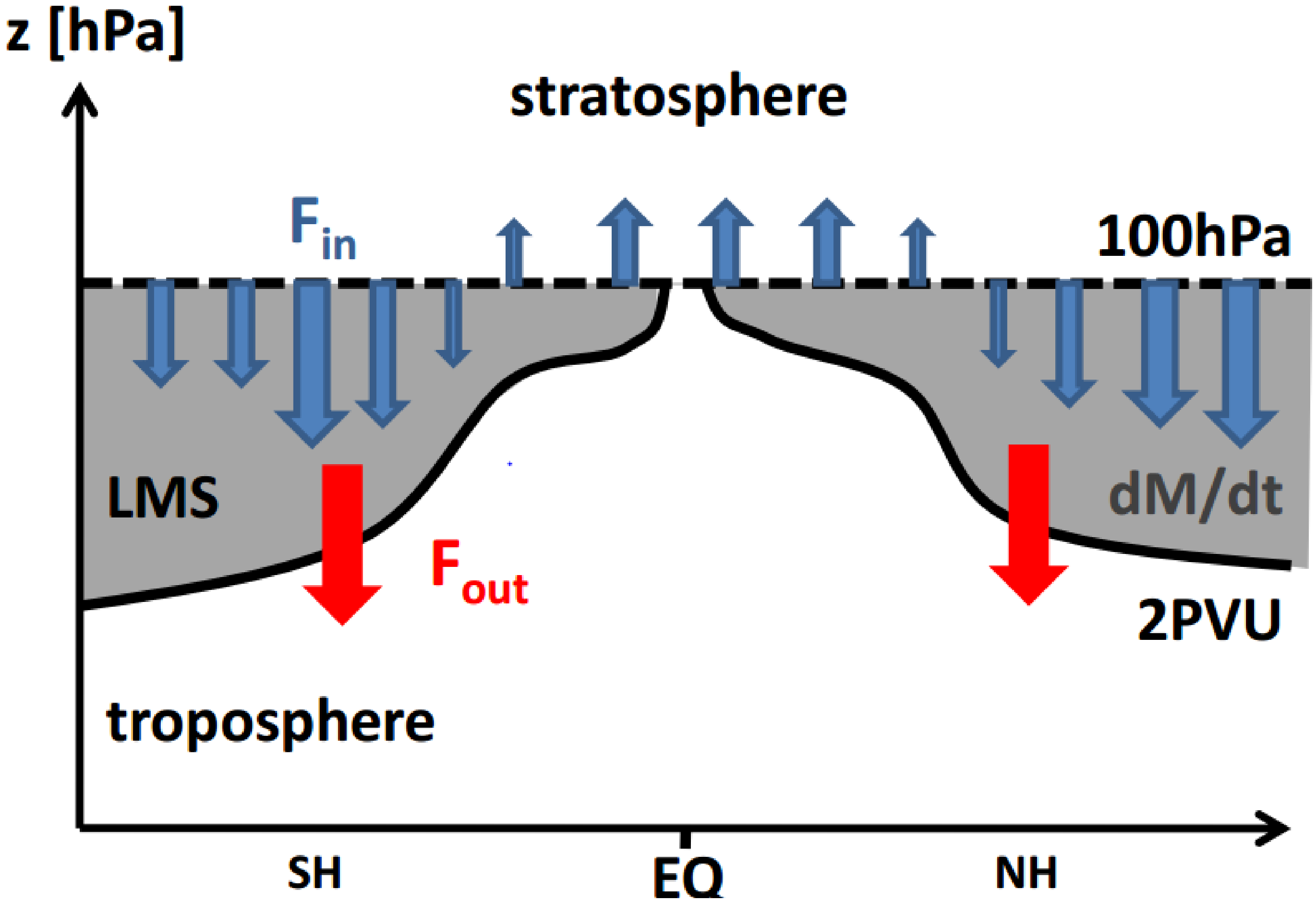
Objectives

- To calculate the STE flux
- To quantify the impact of STE flux on O_3 concentrations and their changes in lower troposphere

Data and Method

- HKO provided ozone sounding data
- 2002 to 2013
- On a weekly base
- O_3 was changed from Partial pressure to ppb, and interpolated to constant heights at vertical resolution of 10 m.
- NCEP reanalysis data (1° × 1°)
- 2002 to 2013

A box model for STE calculation



Source: Michaela I. Hegglin and Theodore G. , Nature geoscience (2009)

Question: Can this box model be used for STE calculation on a regional scale with some assumptions ?

STE calculation

- $F_{out}=F_{in}-\frac{dm}{dt}$

- F_{in}=c×w

  C： ozone concentration， w: vertical speed

- M calculation:

  n=r*NA*P/(R*T)   NA=6.02*10^23

  R: the universal gas constant 8.31 J/(mol*k)

  r: mixing ratio

  P: pressure (pa)

  T: temperature (K)

When the volume mixing ratio r units is ppb ，

Ozone number density :n=7.244*10^7*r*P/T

density=Mi/NA*n =5.3156*10^(-23)*n   (Mi=32)

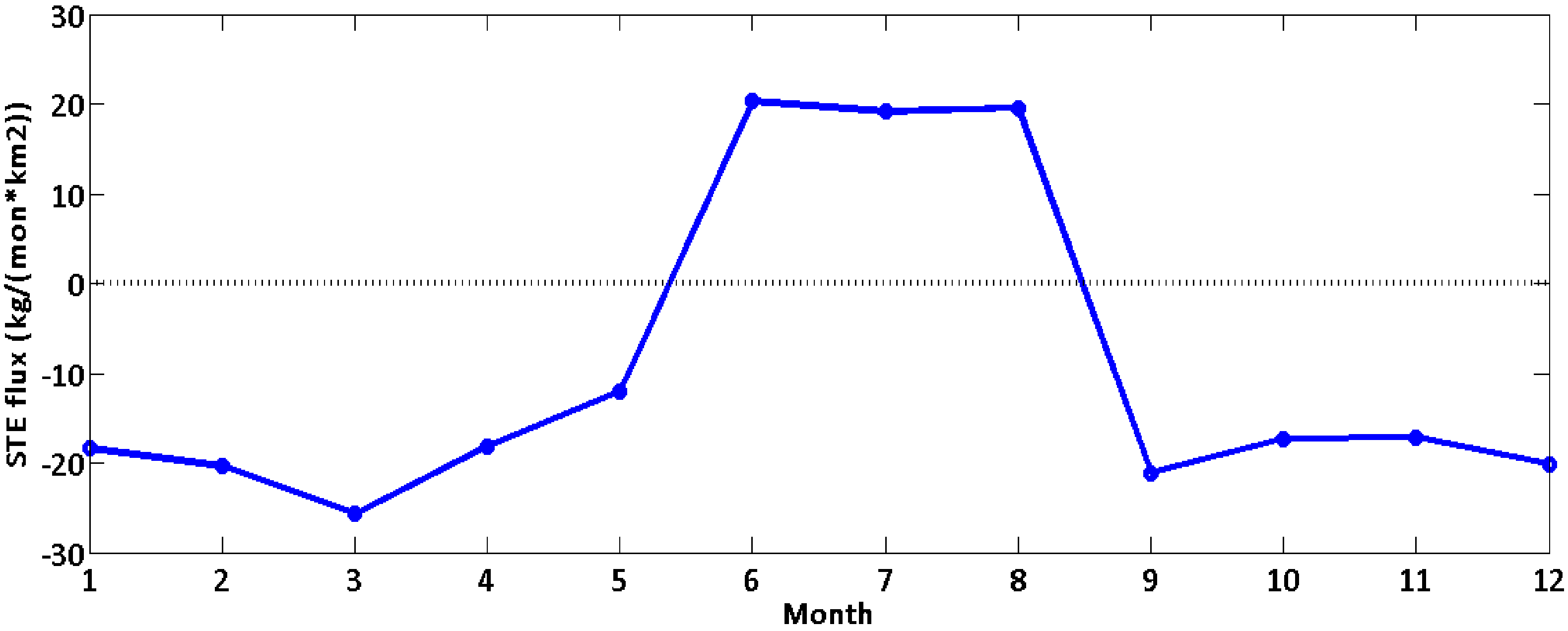
v:using 1° *1° NCEP reanalysis data, So bottom area considered 103km * 103km.

The height of the upper boundary select 80hpa, choose the lower boundary of Hong Kong tropopause height

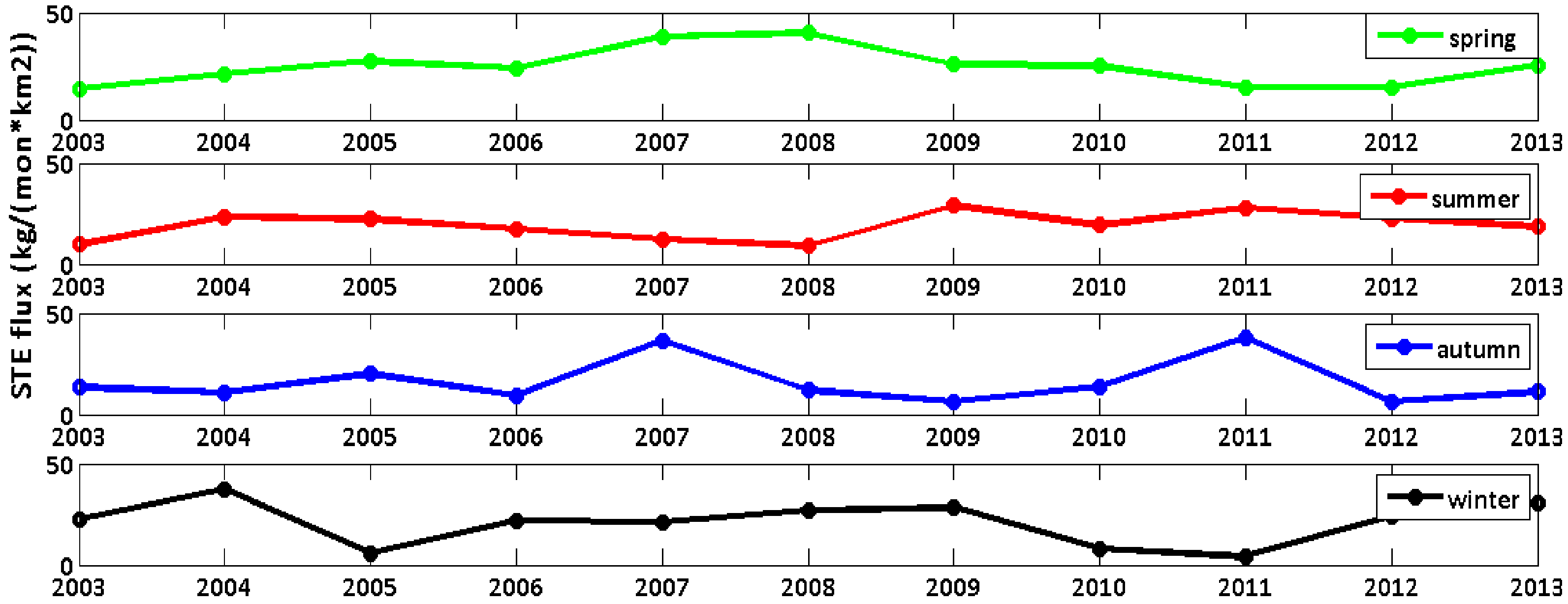
The frequency of air (O_3>80 ppb and RH<20%) in Hong Kong

Air Frequency (%)												
Height(km	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0-1 km	0	0	0	0	0	0	0	0	0	0	0	0
1-2km	0	0	0	0	0.4	0.6	0	0	0	0	0	0
2-3km	0	0	0.5	0.7	0	2.5	0	0	0.9	0	0	0
3-4km	1.1	0	2.0	0.6	1.5	0.5	0	0.4	0.4	1.7	0	0.4
4-5km	0	0	2.6	0.4	3.0	0	0.1	3.4	1.2	2.8	0.8	0
5-6km	2.9	0	7.4	4.4	5.7	2.7	3.3	3.8	4.1	4.3	1.3	0
6-7km	4.4	2.3	6.4	6.8	12.8	4.5	9.1	7.3	5.6	7.7	1.4	2.1
7-8km	1.5	2.0	11.9	11.5	23.3	12.1	11.4	7.9	6.3	10.5	1.7	4.0
8-9km	3.6	4.7	11.6	19.1	28.6	16.2	13.2	9.5	13.0	11	3.4	4.2
9-10km	0.3	0.6	9.9	18.7	32.7	20.5	10.7	13.8	13.6	10.2	7.8	3.4
10-11km	0	1.7	10.5	21.2	34.2	16.6	16.0	13.5	10.5	12.2	5.6	5.1
11-12km	0	2.8	10.6	24.8	30.2	16.3	18.1	13.7	5.6	11.5	3.3	4.6
12-13km	0	6.0	9.6	32.8	36.0	26.0	19.0	11.6	6.6	16.4	3.5	0.9
13-14km	0	7.9	9.7	31.4	39.3	24.5	17.5	15.9	13.5	14.3	4.6	5.5
14-15km	7.7	14.5	21.1	52.4	47.7	27.2	21.7	22.1	16.4	9.8	6.1	8.7
15-16km	27.7	35.6	33.6	68.0	59.6	36.2	41.0	32.1	24.4	10.2	19.5	19.8
对流层顶	16850	16895	16909	16942	17025	16914	16652	16450	16619	16685	16663	16713

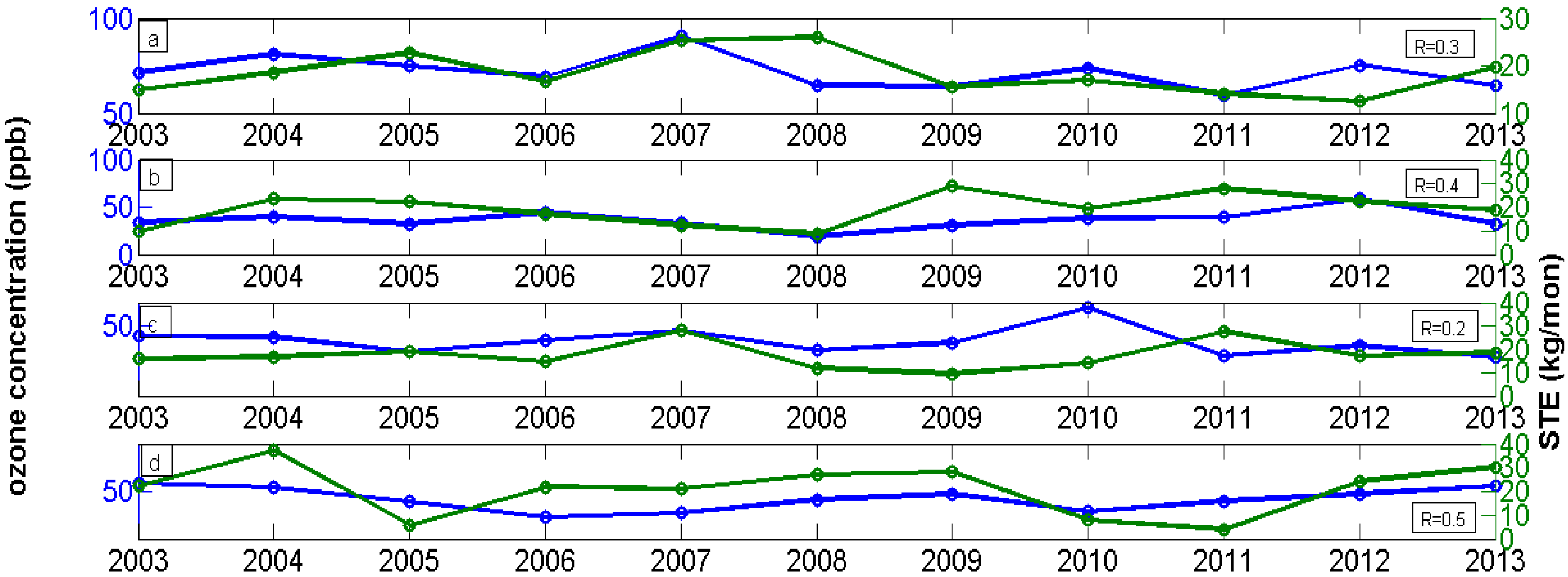
Monthly mean STE flux in Hong Kong during 2003- 2013



Changes of seasonal mean STE flux during 2003-2013

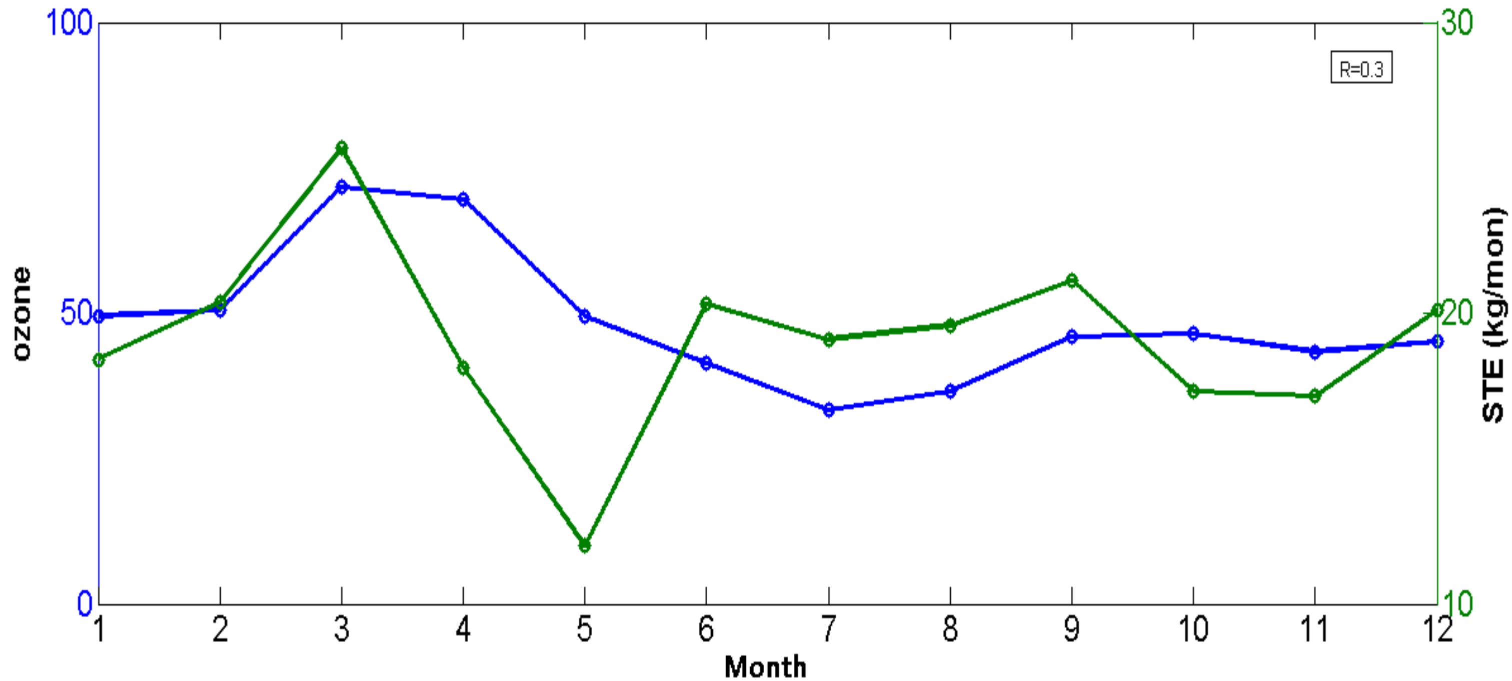


Relation of seasonal STE flux with tropospheric O_3at 3-4km



a), spring; b), summer ; c)autumn; and d)winter

Changes of monthly mean STE flux and tropospheric O_3 at 3-4km during 2003-2013



Discussion

- ➢ Data for this calculation
  - Ozone soundings for monthly mean calculations

- ➢ Uncertainty of STE calculations
  - Assumptions for the box calculation
  - The region size: representative

Summary

- A significant tropospheric intrusion with concentration greater than 70ppb was observed in spring.
- A box model was first applied to the calculation of STE fluxes. The results show that O_3 was transported from stratosphere to troposphere (negative) except summer. The STE fluxes varied from -27 to 20 kg/km^2/month in Hong Kong during 2003-2013.
- The change of O_3 in lower troposphere (3~4km) does not show a high correlation with the STE fluxes. This is not what we expected in Spring. The calculation with box model method still needs to be revisited.

Next step

- Comparing the box model calculation with other method like Wei Formula and model (e.g., MAZART) calculations.

Thank you