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Impact of stratosphere-troposphere exchange on tropospheric ozone

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9/28/12

Outline

- Motivation and objectives
- Data and methodology
- Preliminary results
- Next steps

Motivation

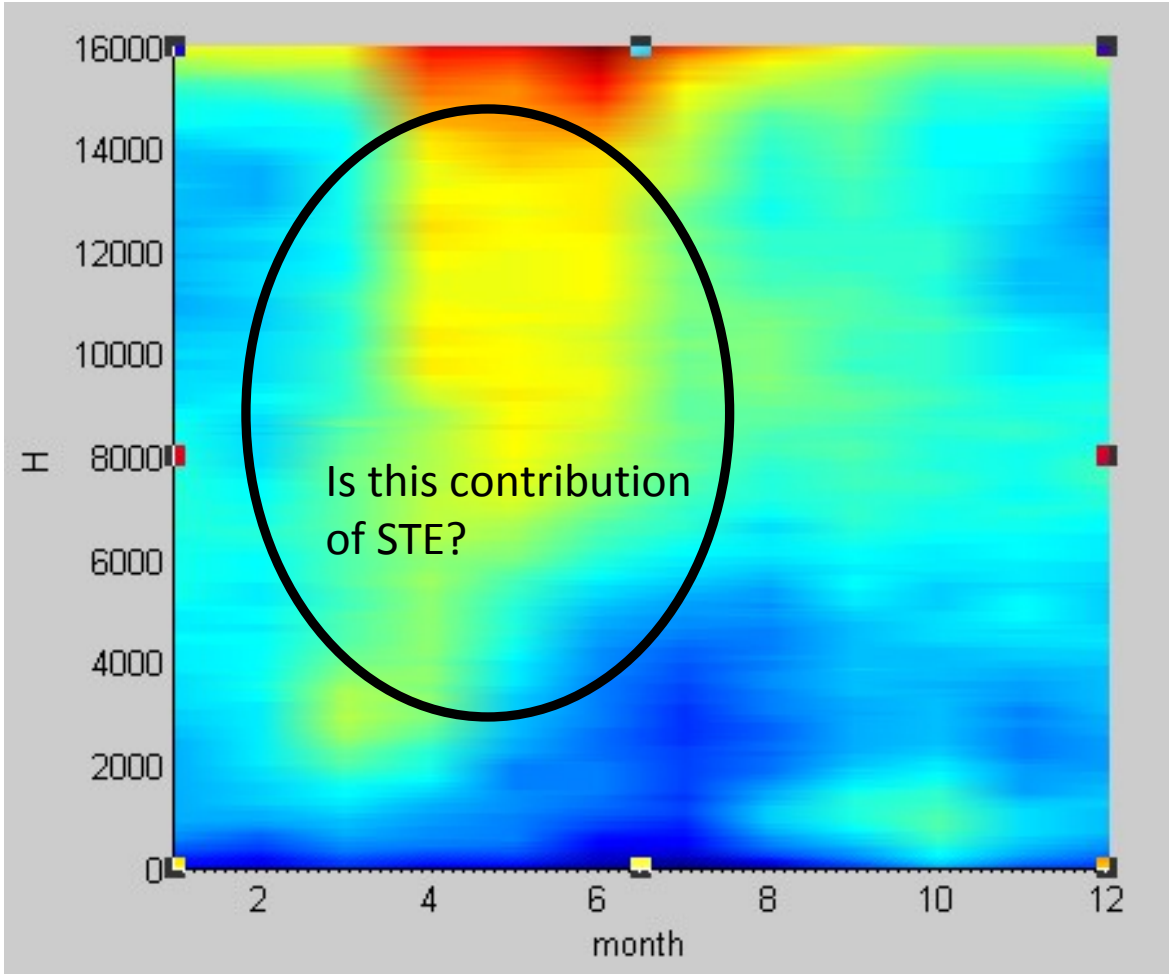

Figure .1 Month-height cross section plot of tropospheric ozone (ppb) observed by ozonesonde over Hong Kong in 2010

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Objectives: scientific questions

- What is the relative contribution of STE to tropospheric O_3 as compared to photochemical reaction?

- How does STE flux contribution change with seasons and latitude? We want to quantify this change.

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What is the STE?

STE: stratosphere-troposphere exchange

- The troposphere and stratosphere are characterized by different dynamical and chemical properties, with strong gradients of potential vorticity (PV) and ozone at the tropopause.

- STE events play a key role in controlling the ozone budget in the Upper Troposphere/Lower Stratosphere.

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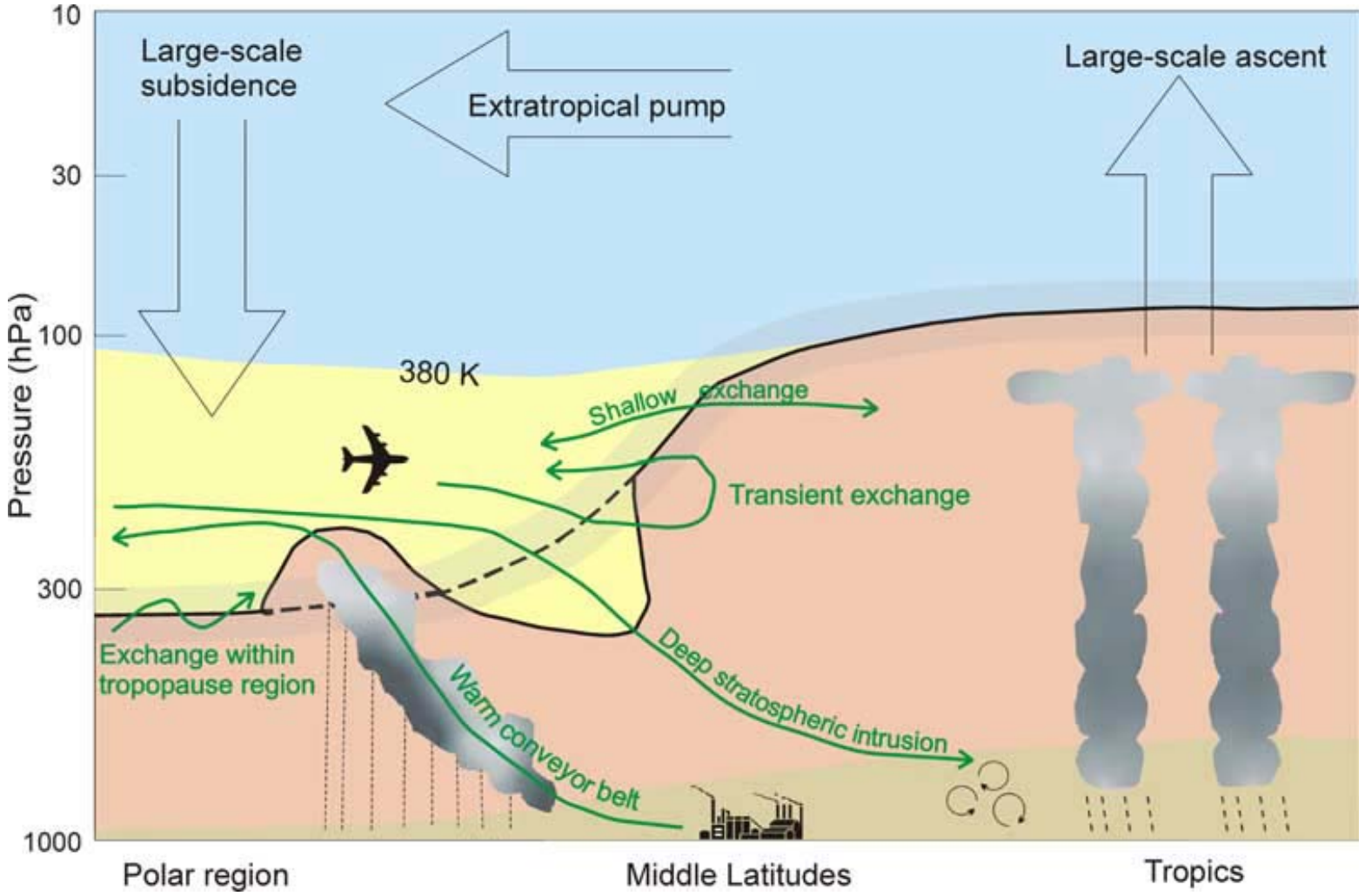
STE

- The exchange across the tropopause is bidirectional (STT and TST) and occurs via a variety of processes on different scales.

- The mechanisms of transport may be classified by diabatic and adiabatic, by shallow and deep.



Source: GJR Holton et al 1995

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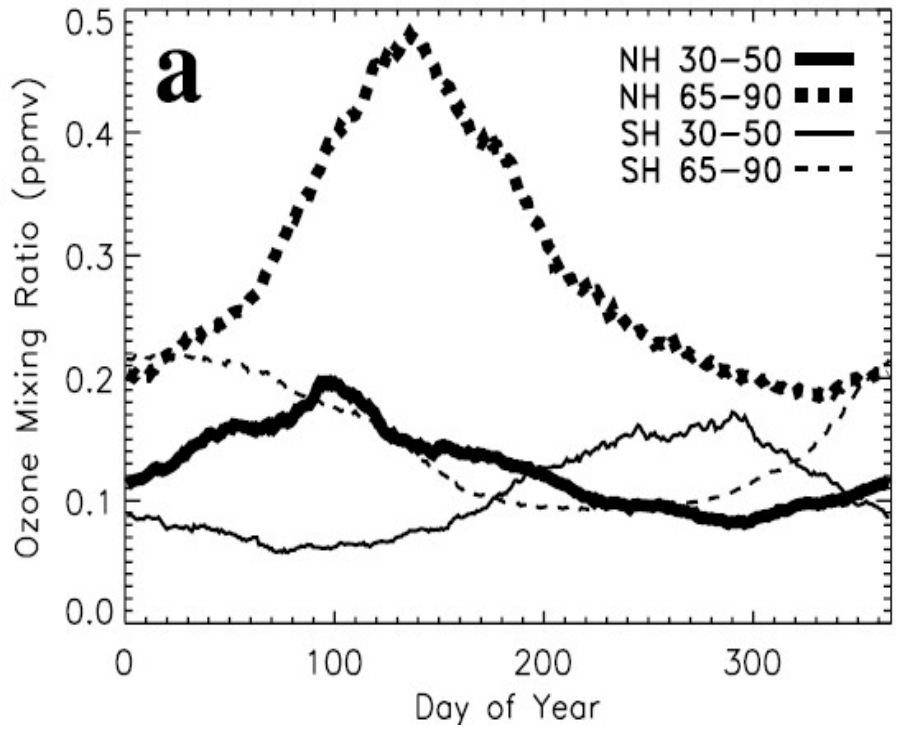
STE

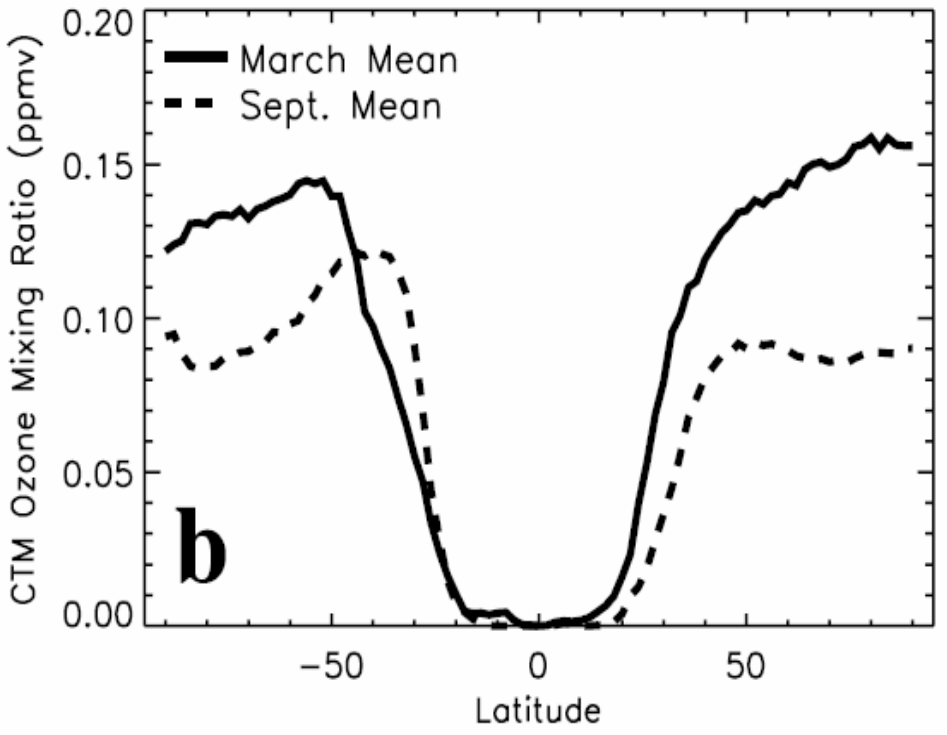
- The strong seasonal cycle of global STE as first noted by Staley [1962] is primarily caused by the vertical movement of the tropopause which is indirectly connected to overworld wave driving.

- The maximum downward flux of ozone from the stratosphere occurs in the spring of each hemisphere as the tropopause rises relative to the background. Likewise, a fall minimum in the flux exists as the tropopause moves back downward.

STE

- Ozone mixing ratio at the tropopause is anomalously high where STT occurs and/or anomalously low where TST occurs.





Source: GJR Mark A et al 31/12/2004

STE Flux

- Over the past 20 yr, three-dimensional (3-D) models , assimilation systems and empirical diagnostic methods , using varying domains, time periods and horizontal resolution, have estimated STE fluxes.

- The 25 models in Stevenson et al. (2006) gave values for the ozone flux as 550 $\pm$ 150 Tg yr^{-1} .

- Collins et al. [2000] give estimates from a range of models of 340–930 Tg yr^{-1}compared to a photochemical production of 2820–4190Tg yr^{-1}.

- Roelofs and Lelieveld [1997] assessed the contribution of the stratosphere to tropospheric ozone using a global chemistry transport model. They concluded that on average 40% of the tropospheric ozone originated in the stratosphere. At the surface the stratospheric contribution was between 10 and 60%.

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STE Flux

- The temporal and spatial scales of STE related processes is important for investigating stratospheric ozone influx.

- Deep STT has the most important affect for O_3.

- The net stratospheric ozone flux is nearly an order of magnitude greater than the net tropospheric ozone flux. Therefore, the impact of the TST to ozone flux is very small.

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Wei's (1987) Formula

- This method is from *Diagnosing extratropical synoptic-scale stratosphere-troposphere exchange: A case study.*

- Wei's formula has been applied to model data from global numerical models in order to learn how the hemispheric mass exchange is distributed in space and time.

Wei's (1987) Formula

- Wei's original equation:

$$F(\rho) = \rho\, J_\eta \left(\frac{\mathrm{D}\eta}{\mathrm{D}t} - \frac{\partial \eta^{\mathrm{tp}}}{\partial t} - \mathbf{v} \cdot \nabla \eta^{\mathrm{tp}} \right)$$

- Geometric height z as vertical coordinate Wei-z:

$$F(\rho) = \rho \left(w - \frac{\partial z^{\mathrm{tp}}}{\partial t} - \mathbf{v} \cdot \nabla z^{\mathrm{tp}} \right)$$

Wei's (1987) Formula

- Pressure p as vertical coordinate

  Wei-p:

$$F(\rho) = -g^{-1}\left(\omega - \frac{\partial p^{tp}}{\partial t} - \mathbf{v}\cdot\nabla p^{tp}\right)$$

- Potential temperature θ as vertical coordinate Wei-θ:

$$F(\rho) = \rho\frac{\partial z}{\partial \theta}\left(\frac{D\theta}{Dt} - \frac{\partial \theta^{tp}}{\partial t} - \mathbf{v}\cdot\nabla\theta^{tp}\right)$$

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Wei's (1987) Formula

- PV as vertical coordinate

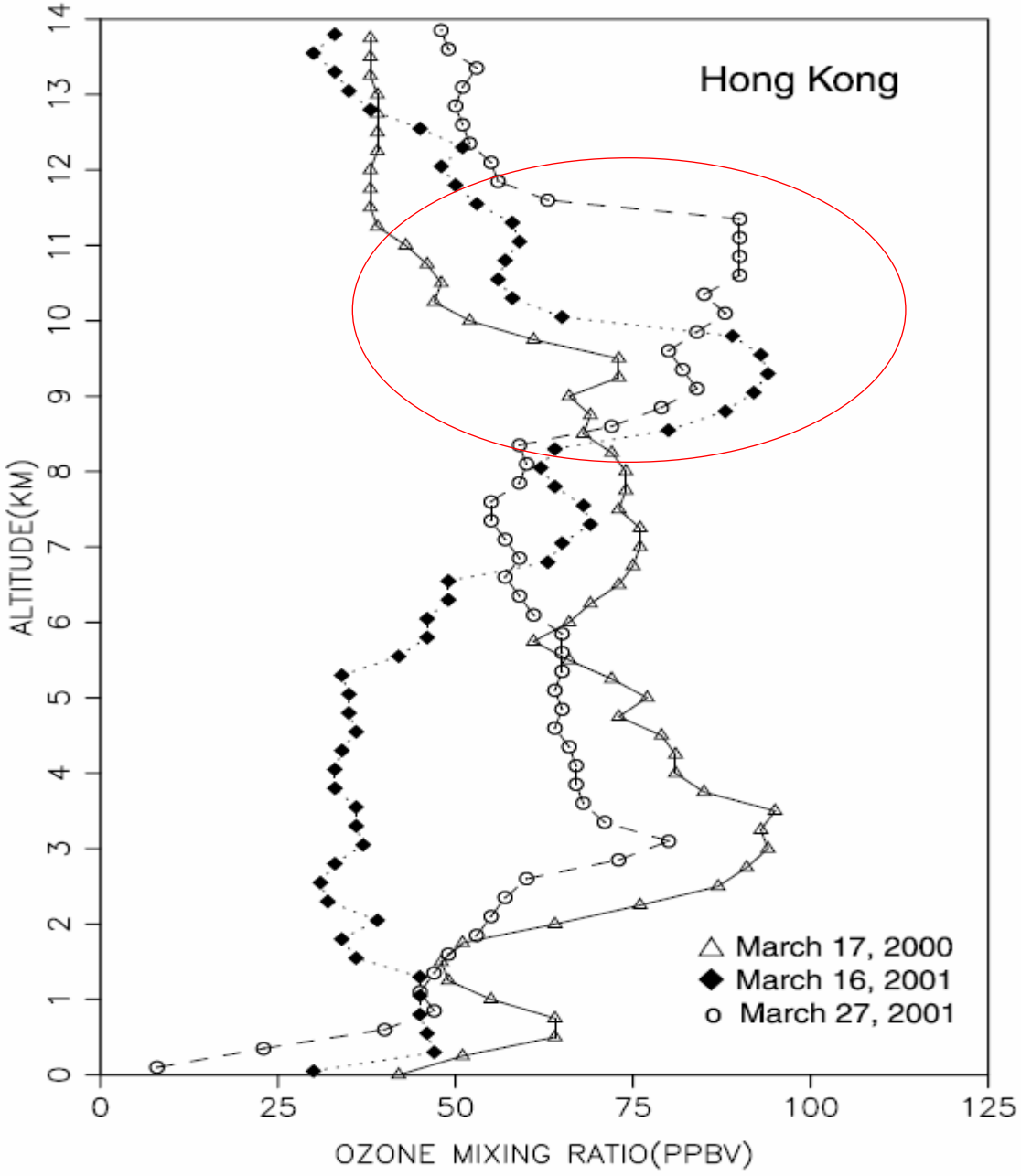
  Wei-pv:

$$F(\rho) = \rho \frac{\partial z}{\partial P} \frac{\mathrm{D}P}{\mathrm{D}t}$$

Wei's (1987) Formula

- Wei-PV is able to diagnose the cross-tropopause mass exchange for the event investigated in a way that is qualitatively realistic and quantitatively broadly correct.

- The others of Wei's formula turn out to be unreliable as they suffer from strong cancellation of large terms such as wind, temperature and pressure .



Source: *GJR* S. J. Oltmans et al 20/5/2004

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The Formula of Calculating The STE Flux

- As the first step, we try to use ozone-sounding data and NCEP reanalysis data to estimate the STE flux for O_3 in tropopause and at different heights.

Simplified equation:

$$F_{ozone} = -W \cdot \Delta C$$

w: vertical velocity in tropopause

ΔC: concentration difference of ozone in the tropopause

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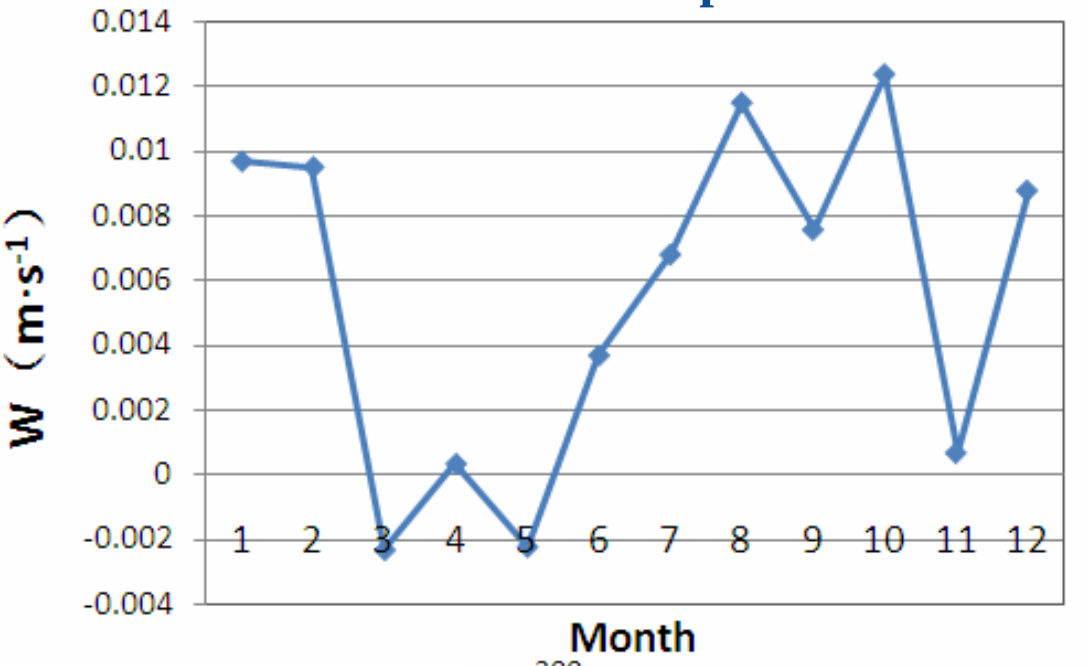
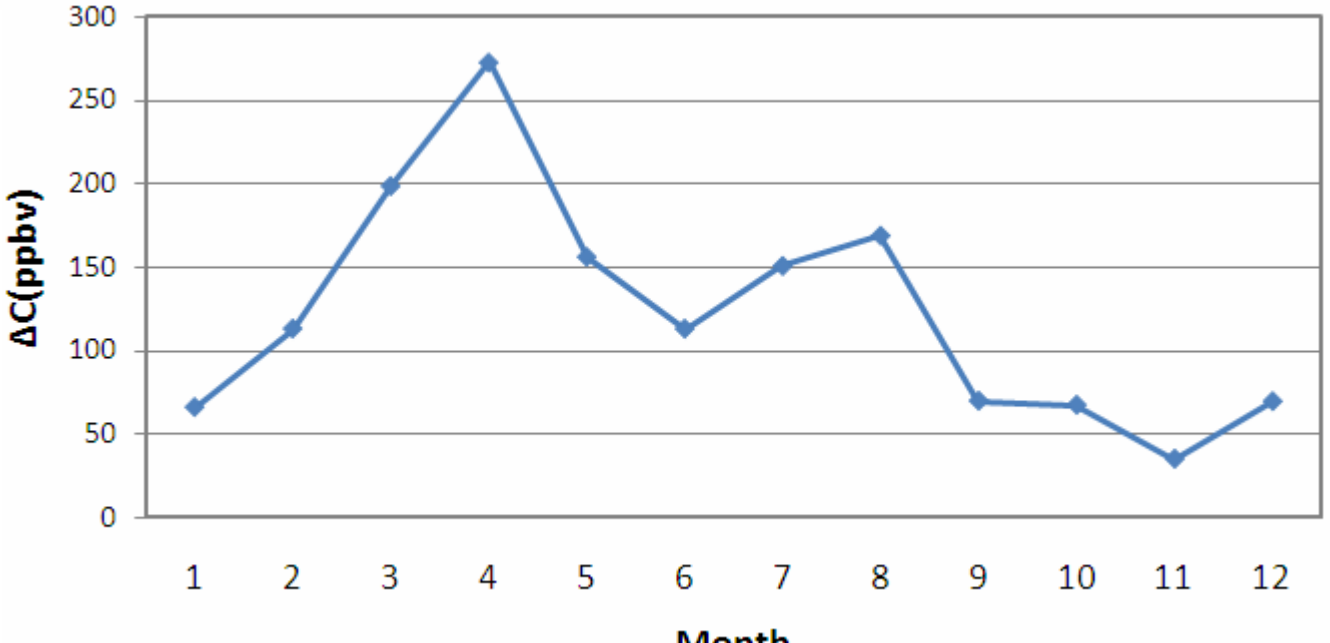


Figure. 2 Time series of vertical velocity in tropopause over HongKong in 2010

Figure. 3 Concentration difference of ozone in the tropopause



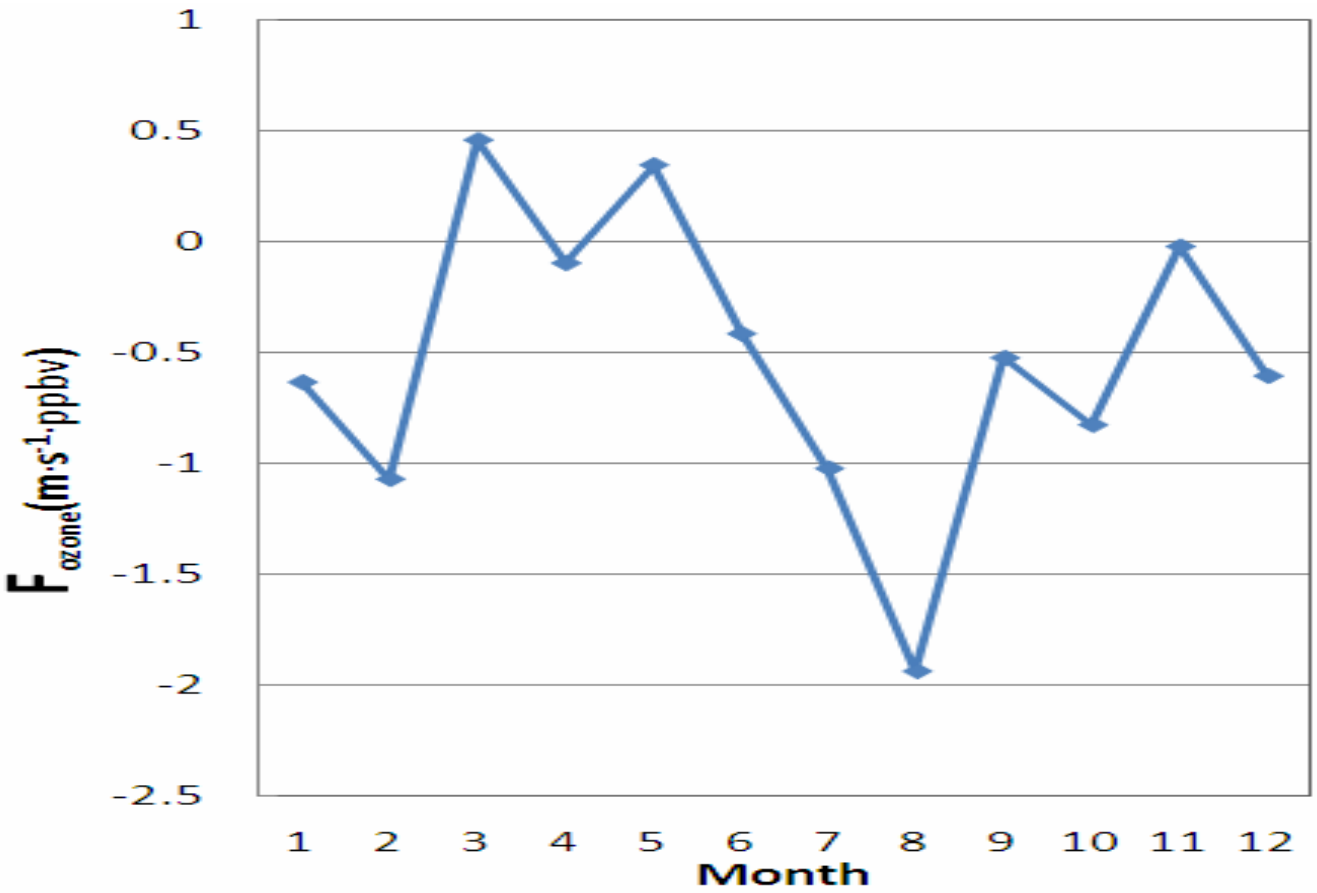


Figure. 4 The vertical fluxes of O_3 in tropopause over HongKong in 2010

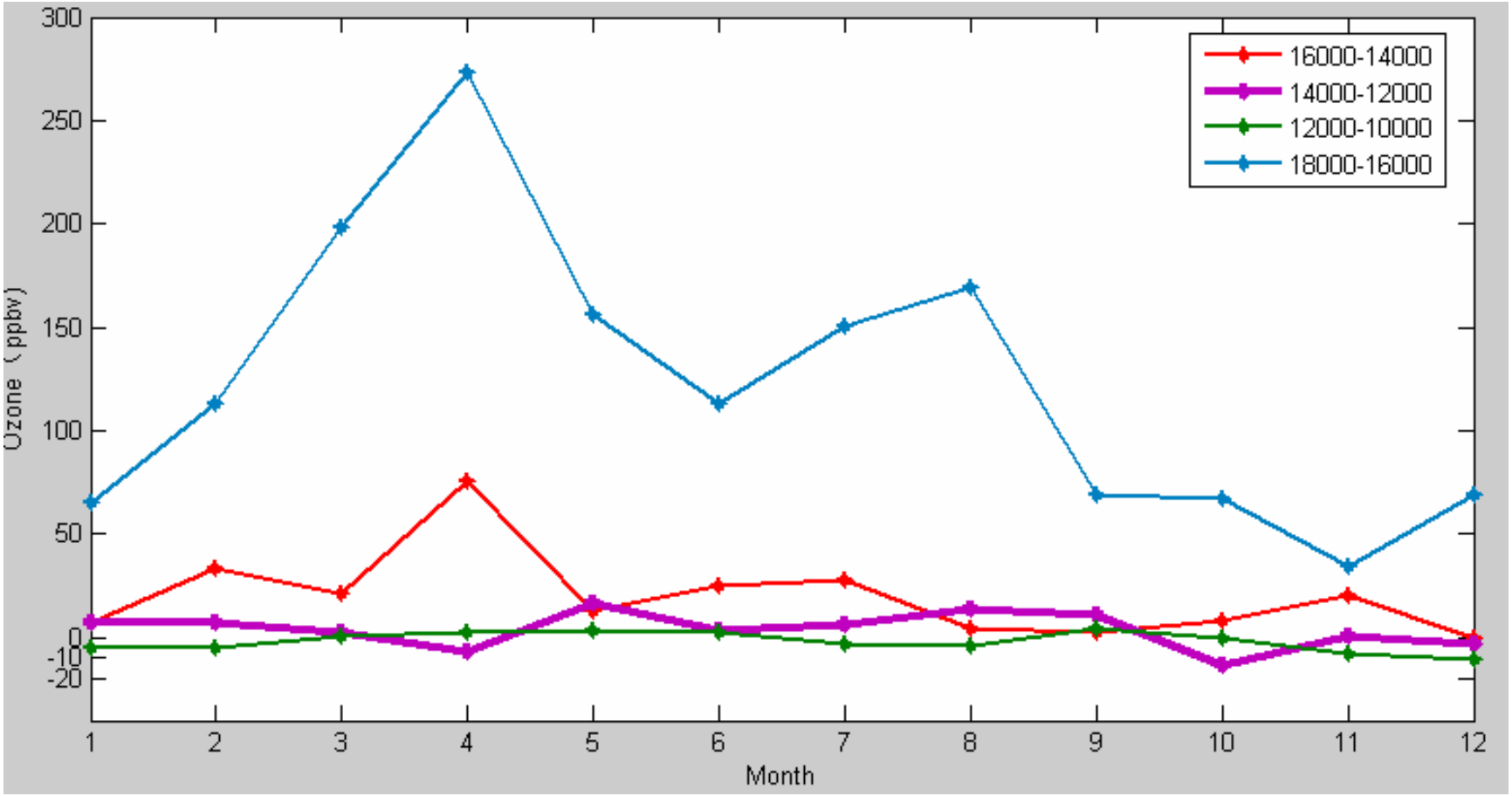


Figure. 5 Concentration difference of ozone at different heights（1）

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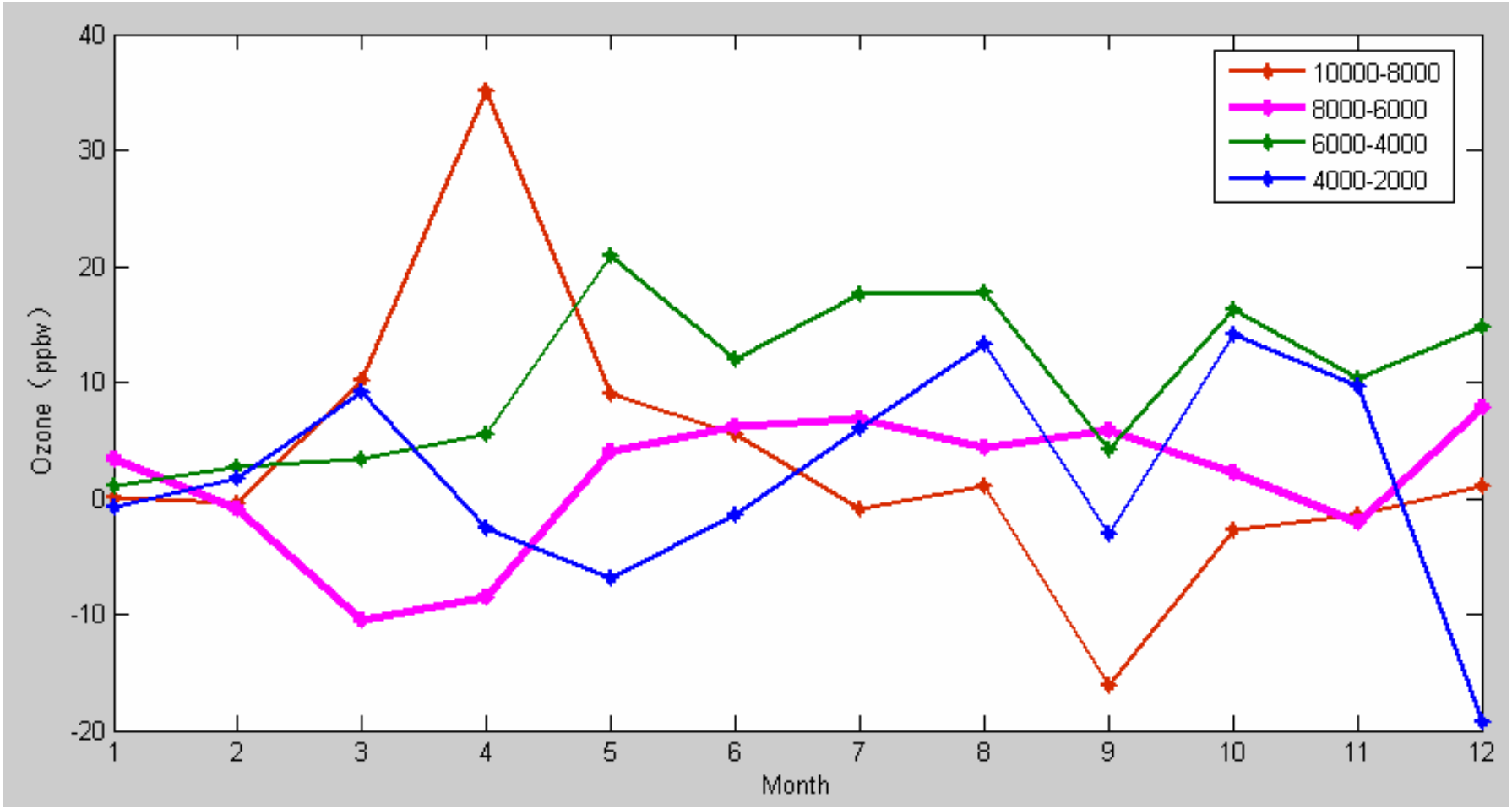

Figure. 6 Concentration difference of ozone at different heights（2）

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The Formula of Calculating The STE Flux

- However we still miss some important process like horizontal advection is not included. It is better to use more complicated formula like Wei's formula.

- We will continue to improve that simplified equation, and calculate the more accurate results.

Next steps

- To determine the change of STE at different seasons or months and at different locations (HK, Naha, Hilo, etc.)

- To compare the relative contribution of STE to tropospheric ozone with photochemical production at different seasons and different sites.

Next steps

- To calculate the vertical fluxes of O_3 at different heights.
- We do not have an accurate and effective method to determine the tropopause region.

Thank you