Yale-NUIST Center on Atmospheric Environment

Large climate-induced changes in ultraviolet index and stratosphere-to-troposphere ozone flux

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Outline

- Introduction
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Introduction

1

Tropospheric O_3 budget and ultraviolet are important to tropospheric radiative forcing, air quality, and human and ecosystem health.

2

Stratospheric O_3 depletion from anthropogenic halogen is expected to become negligible by the end of current century as a result of the Montreal Protocol and its amendments.

3

Climate models predict an accelerated stratospheric circulation

4

It is important to quantify the effects of climate change on ultraviolet index and stratosphere-to-troposphere ozone flux

Method: Model

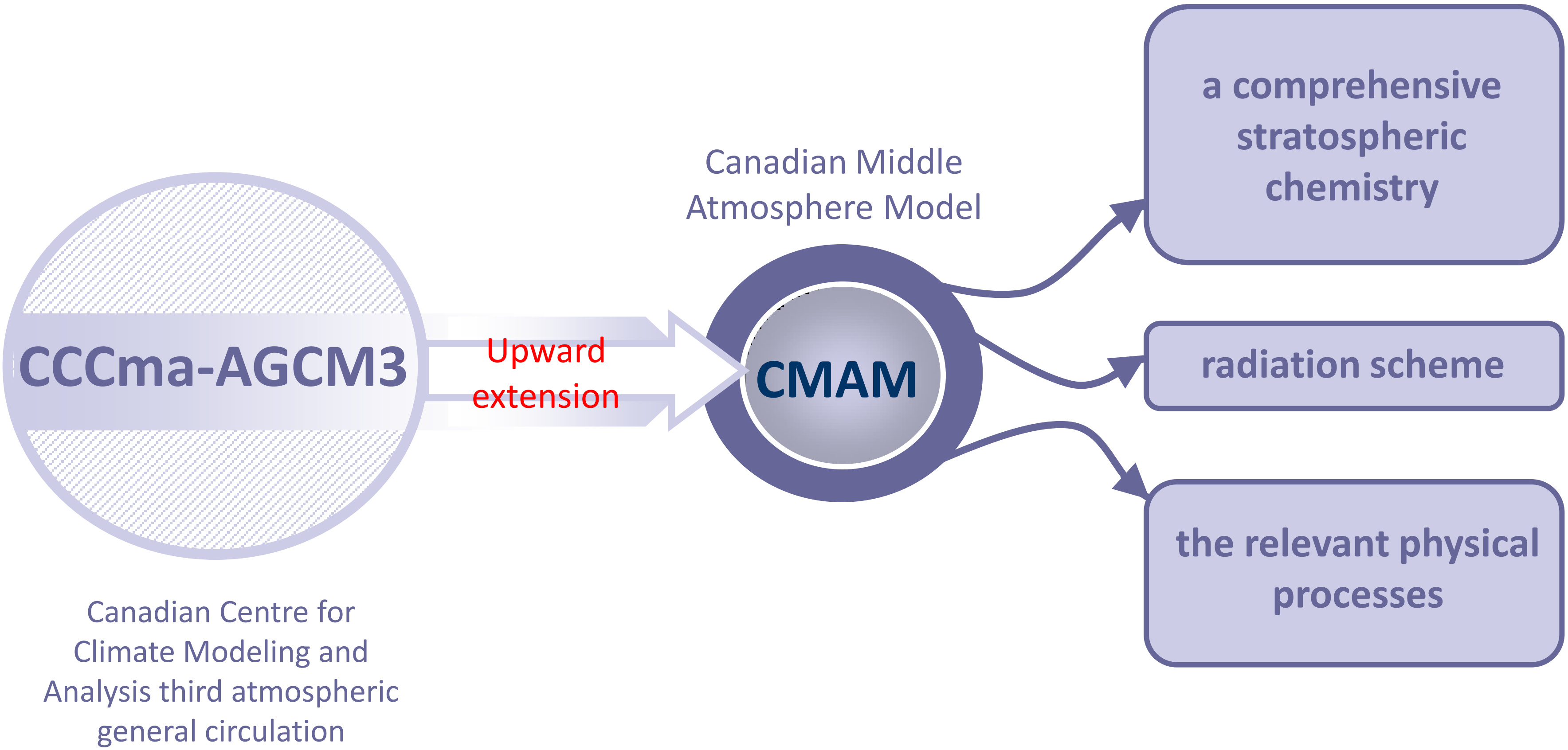
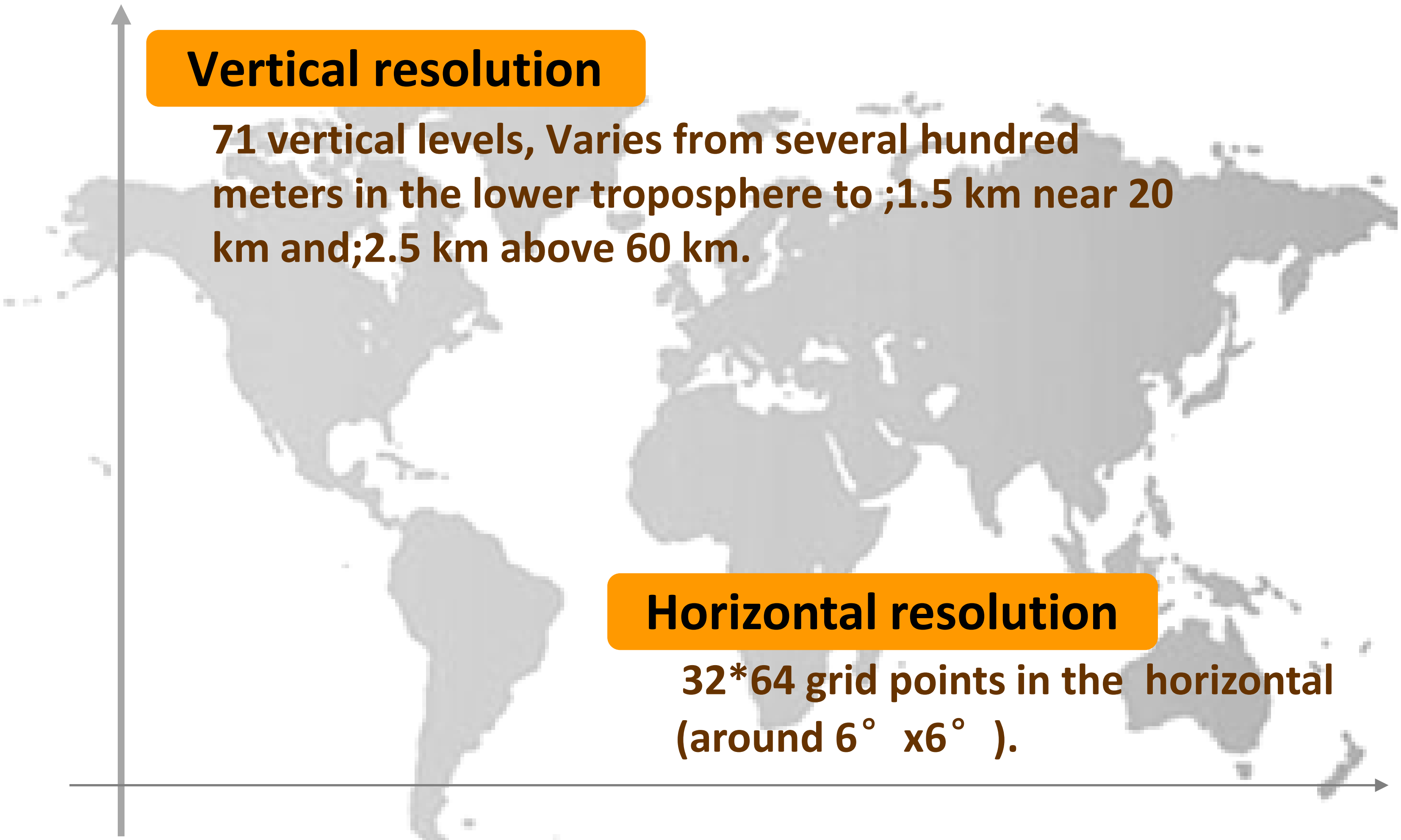


Fig.1 Schematic diagram of the CMAM model

Method: Model (cont.)



Vertical resolution

71 vertical levels, Varies from several hundred meters in the lower troposphere to ;1.5 km near 20 km and;2.5 km above 60 km.

Horizontal resolution

32*64 grid points in the horizontal (around 6° x6°).

Method: STE flux calculation

$$\boldsymbol{F_{out} = F_{in} - \frac{dM}{dt}}$$

- F_{in} **: the downward flux ozone across 100hPa surface**

  $$\boldsymbol{F_{in} = C \times \overline{w}^{*}}$$

  C : each hemisphere of the zonal monthly mean ozone concentration

  $\overline{w}^{*}$: the negative of the monthly mean residual vertical velocity

- M **: total mass of ozone contained in the lowermost stratosphere (LMS)**

  LMS :the region bounded by the 2 PVU (potential vorticity unit,with 1PVU= $10^{-6} K m^2 kg^{-1} s^{-1}$) potential vorticity and 100hPa surfaces.

Method: STE flux calculation (cont.)

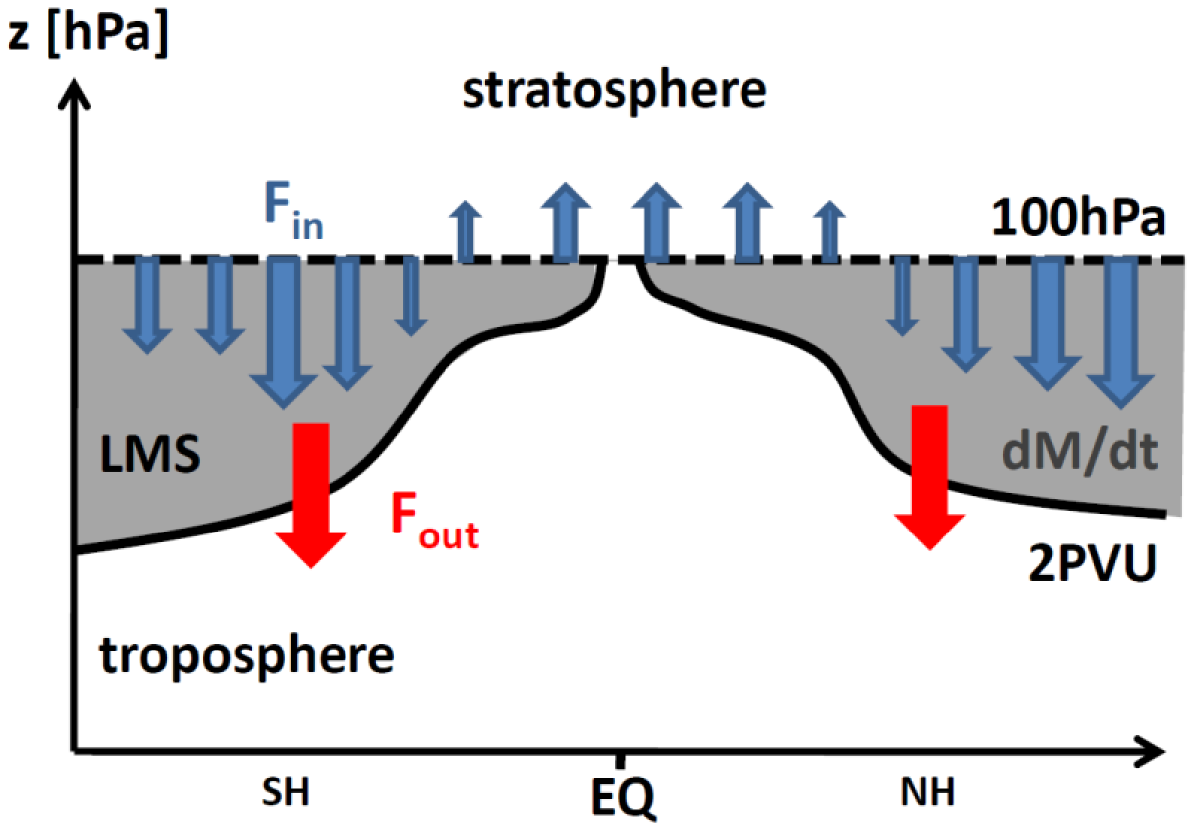


Fig.2 Box-model for STE flux

Method: residual vertical velocity

$$\overline{w}^* = \frac{gH}{p\alpha \cos\phi}\frac{\partial \psi}{\partial \phi}$$

where $\psi = -\dfrac{\cos\phi}{g}\int_p^0 \overline{v^*}(\phi, p')dp'$

$\overline{v}^*$: The residual meridional velocity

p : Pressure

ϕ: Latitude

g : Gravity

α : The earth's radius

H : Pressure scale height(7km)

ψ : The mass stream function and the boundary condition $\psi = 0$

Method: UVI and relative change

- Under cloud-free, unpolluted, low-surface-albedo conditions

$$\text{UVI} \sim 12.5\mu_0^{2.42}\ (\Omega/300)^{-1.23}$$

μ_0: the cosine of the solar zenith angle
Ω : Dobson units.

- Relative change in UVI

$$\frac{\delta \text{UVI}}{\text{UVI}} \sim -1.23\,\frac{\delta\Omega}{\Omega}$$

It shows that both relative changes in UVI and stratospheric column ozone are linearly related.

Monthly evolution of different components

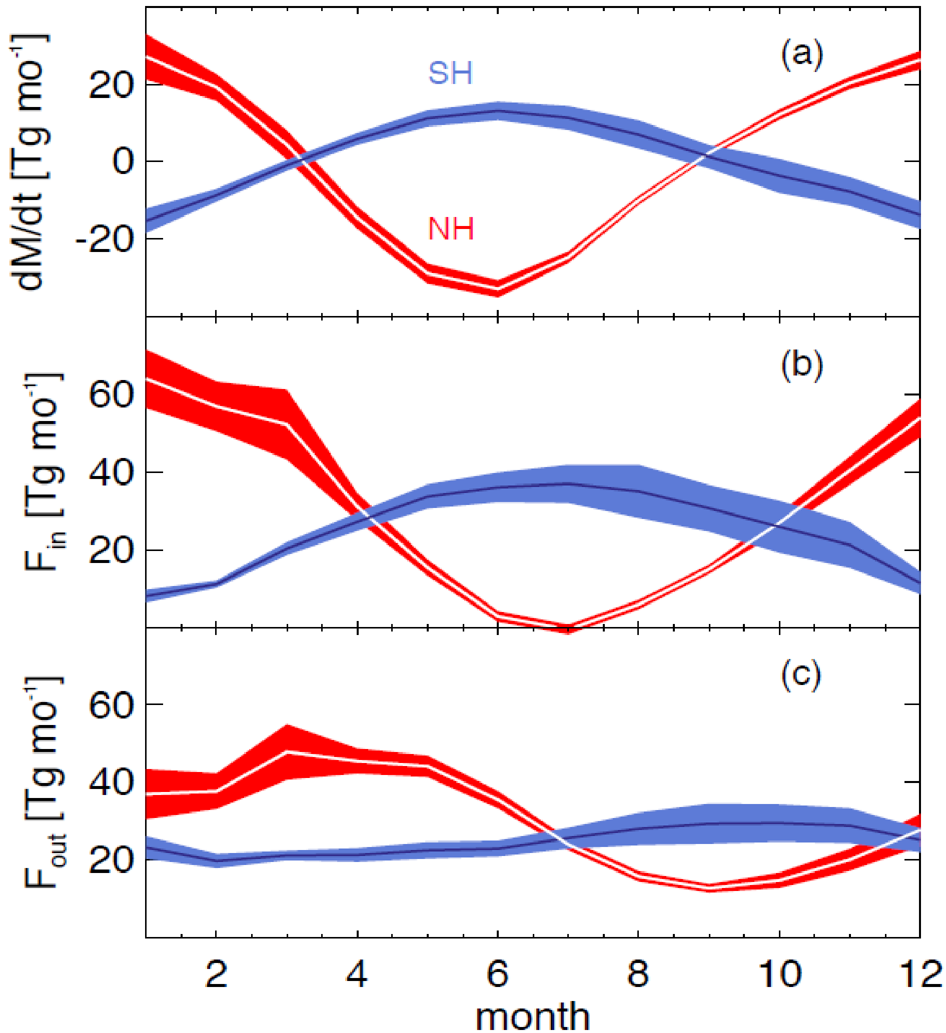


Fig.3 (a) change in ozone mass (dM/dt) in the LMS
(b) flux of ozone into the LMS across the 100 hPa surface
(c) flux of stratosphereric ozone into hetroposphere, averaged over 1995-2005

Changes in residual vertical velocity

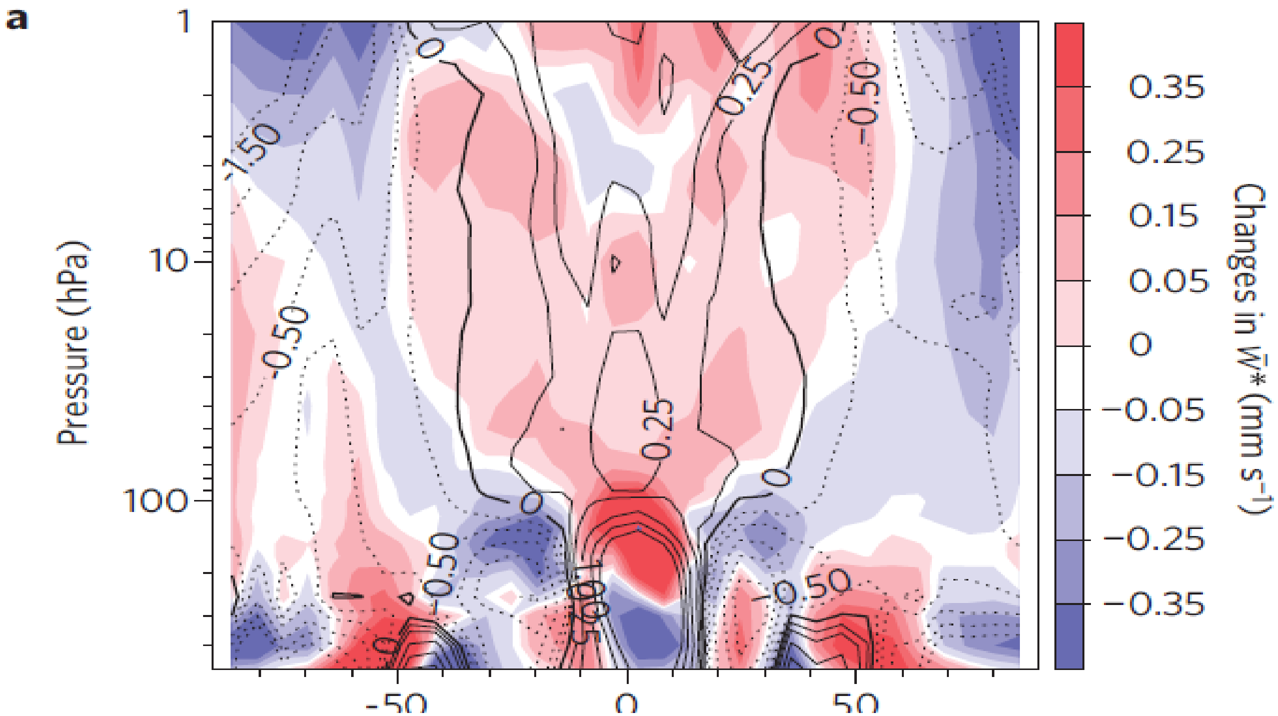


Fig.4 Vertical-latitudinal cross-sections of annual mean residual vertical velocity during 1960–1970 (black contours) and long-term changes (differences between 1960–1970 and 2090–2100, color shading)

Changes in ozone

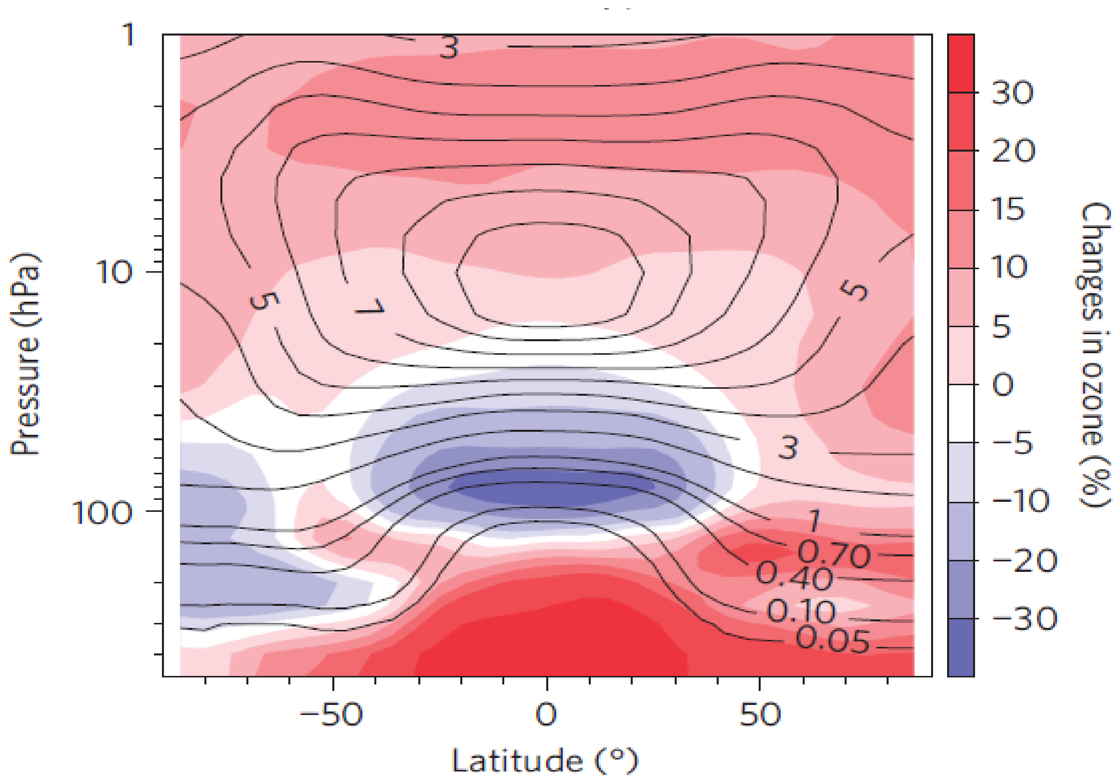


Fig.5 Vertical-latitudinal cross-sections of annual mean ozone during 1960–1970 (black contours) and long-term changes (differences between 1960–1970 and 2090–2100, color shading)

Changes in O_3 fluxes in northern and southern hemisphere

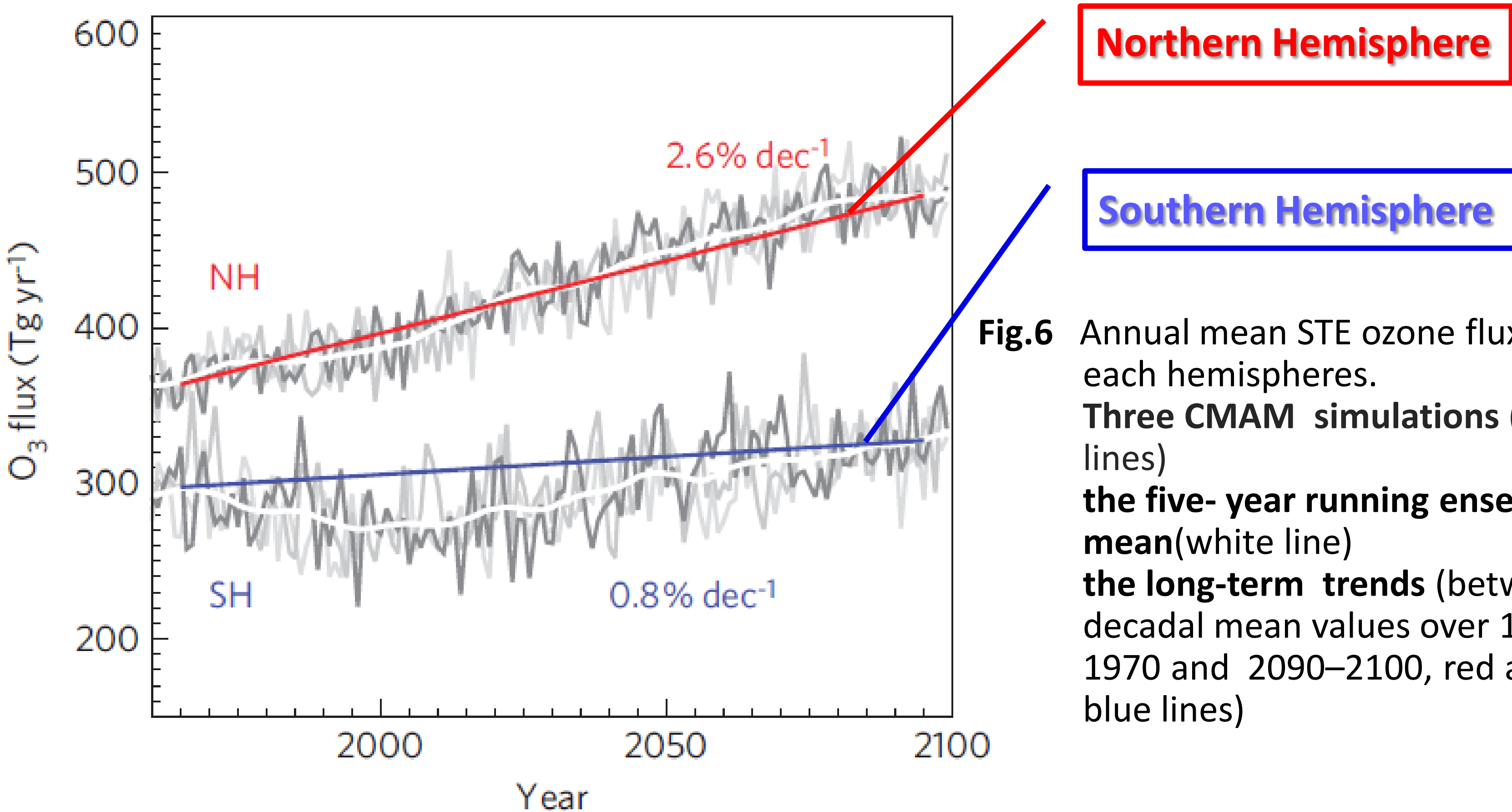


Fig.6 Annual mean STE ozone flux for each hemispheres.
Three CMAM simulations (grey lines)
the five- year running ensemble mean(white line)
the long-term trends (between decadal mean values over 1960–1970 and 2090–2100, red and blue lines)

Latitudinal-seasonal pattern of relative changes in UVI

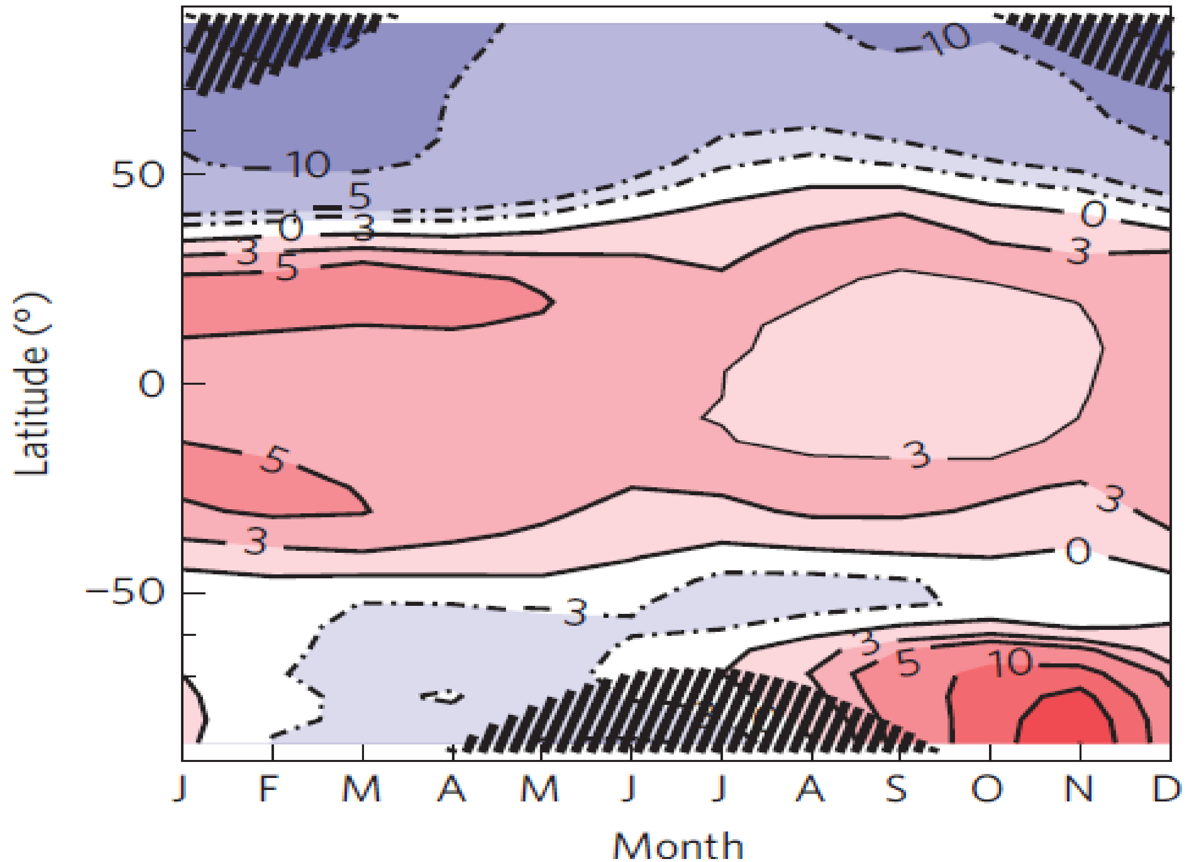


Fig.7 Latitudinal-seasonal dependence of relative change in ultraviolet index between 1960-1970 and 2090-2100.

Time evolution of relative changes in UVI

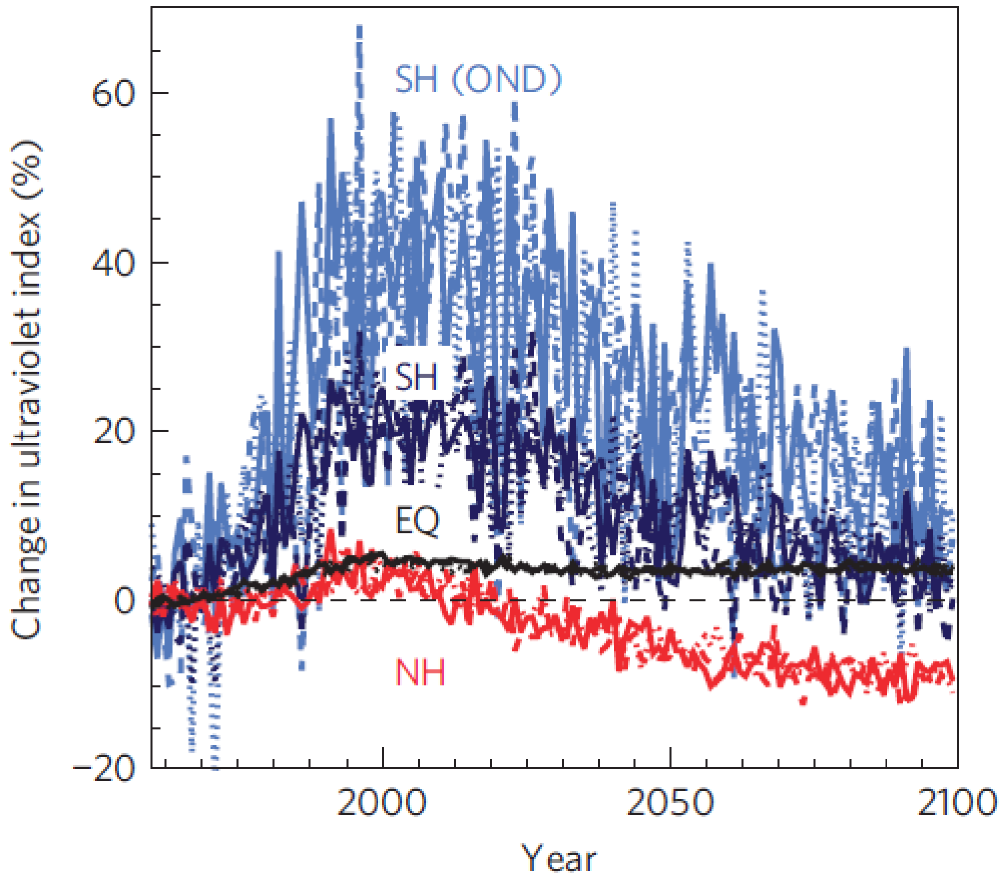


Fig.8 Time evolution of the ultraviolet index changes for 30 S–30 N (EQ, black) 60 N–90 N(NH, red), 60 S–90 S (SH, dark blue) and 60 S–90 S ,October–December (SH (OND), light blue)

Monthly mean O_3 fluxes and their changes in northern and southern hemisphere

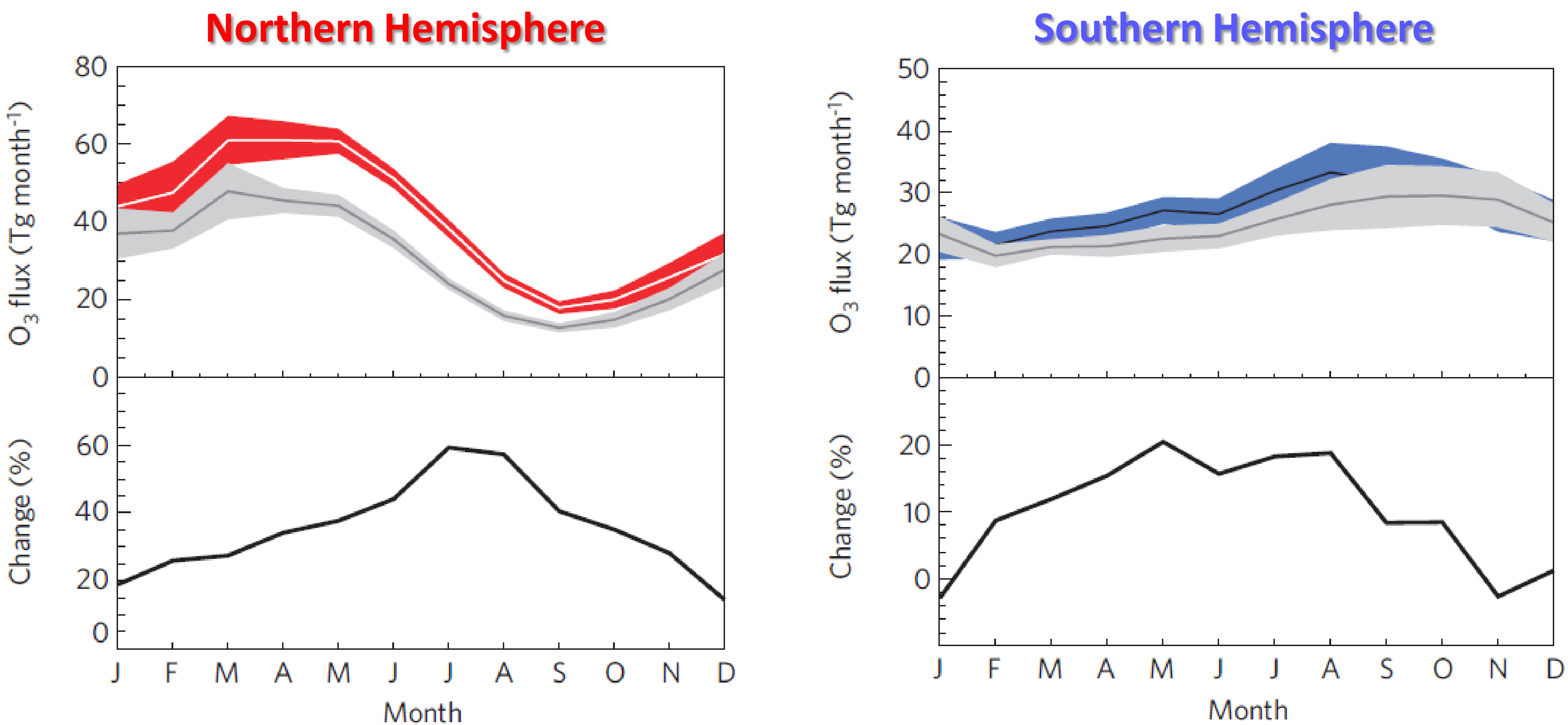


Fig.9 monthly mean ozone fluxes $\pm 1\ s.d.$ in the northern hemisphere and southern hemisphere over the past (1960-1970, grey) and in the future(2090-2100, red and blue)

Changes in UVI versus strat. column O_3

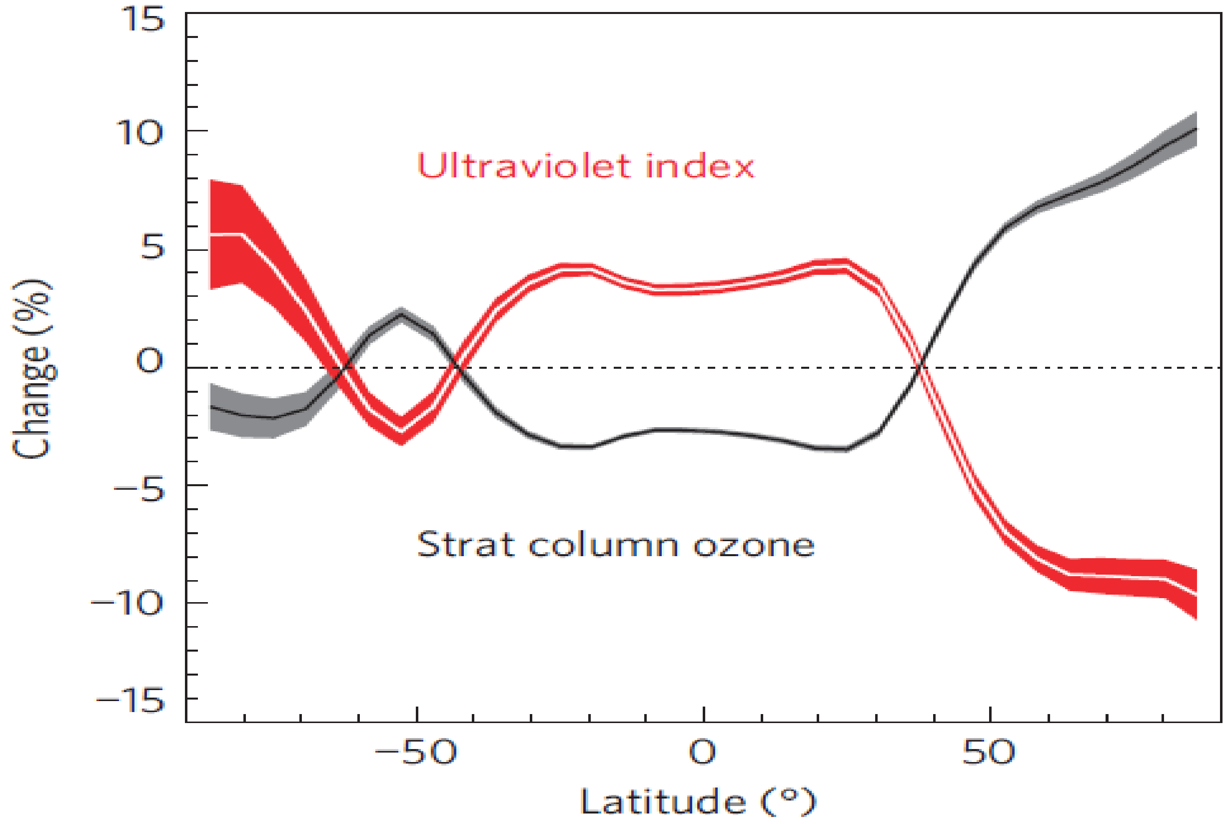


Fig.10 Relative change in annual mean UVI and stratospheric column ozone between 1960–1970 and 2090–2100

Changes in STE O_3 flux and UVI

Table 1 (a) NH,SH and/or Tropics absolute/relative change in STE ozone flux
(b) ultraviolet index for different time periods.

(a)	Time period (yr)	O_3-flux change ($Tg\ yr^{-1}$)	O_3-flux change (%)
Global	1965-2000	−1.9 (±5.6)	−0.3 (±0.8)
	2000-2035	60.8 (±7.1)	9.2 (±1.1)
	1965-2095	151.6 (±5.7)	22.9 (±0.9)
NH (0° N-90° N)	1965-2000	22.5 (±3.7)	6.2 (±1.0)
	2000-2035	41.4 (±4.2)	10.7 (±1.1)
	1965-2095	121.6 (±3.7)	33.4 (±1.0)
SH (0° S-90° S)	1965-2000	−24.4 (±5.0)	−8.2 (±1.7)
	2000-2035	19.4 (±5.2)	7.1 (±1.9)
	1965-2095	30.0 (±5.6)	10.1 (±1.9)

1965-2000 : Ozone depletion;
2000-2035 : Initial ozone recovery;
1965-2095 : Climate change

(b)	Time period (yr)		UVI change (%)
Tropics (30° S-30° N)	1965-2000	–	4.7 (±0.1)
	2000-2035	–	−1.1 (±0.1)
	1965-2095	–	3.8 (±0.1)
NH (30° N-60° N)	1965-2000	–	3.6 (±0.2)
	2000-2035	–	−3.9 (±0.3)
	1965-2095	–	−3.6 (±0.2)
NH (>60° N)	1965-2000	–	3.2 (±0.5)
	2000-2035	–	−6.3 (±0.5)
	1965-2095	–	−9.1 (±0.4)
SH (30° S-60° S)	1965-2000	–	7.4 (±0.4)
	2000-2035	–	−3.6 (±0.4)
	1965-2095	–	0.0 (±0.4)
SH (>60° S)	1965-2000	–	21.0 (±1.0)
	2000-2035	–	−8.7 (±1.4)
	1965-2095	–	3.2 (±1.0)
SH (>60° S, OND)	1965-2000	–	37.2 (±2.9)
	2000-2035	–	−13.2 (±3.4)
	1965-2095	–	10.2 (±2.0)

Discussion: strength and novelty

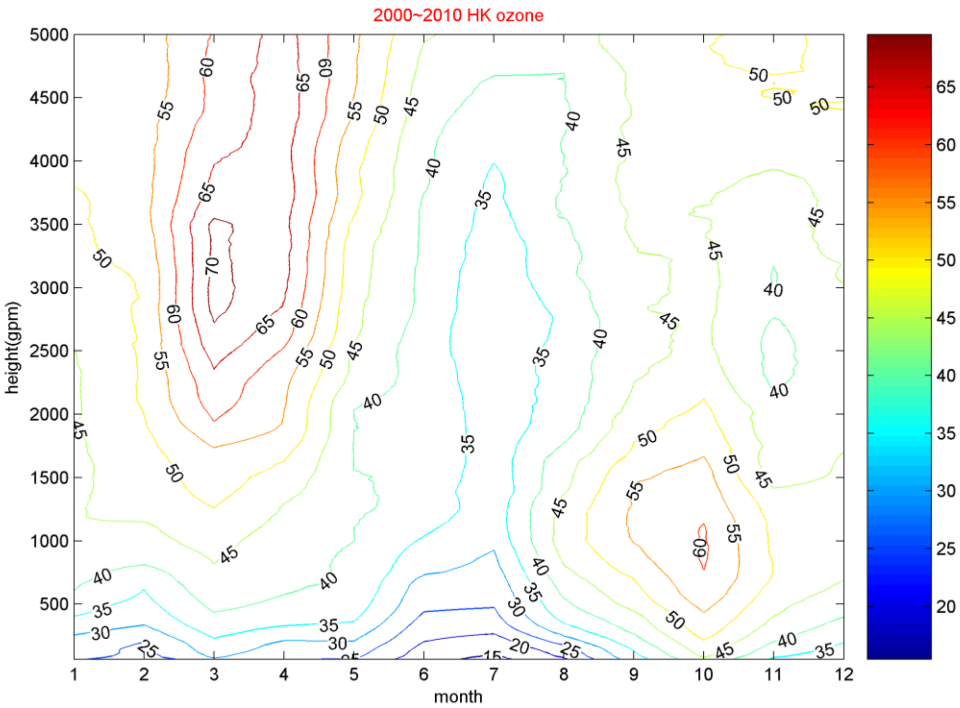
The stratospheric CCM is used for run over long timescales which allows the identification of the effects of climate change and their separation from the effects of ozone depletion and recovery.

It is justifiable that using CCM to quantify the changes in STE ozone flux and ultraviolet index. These quantities are controlled by stratospheric circulation and the distribution of stratospheric ozone

Conclusion

- Under the IPCC moderate emission change, the model results show that climate change may induce
  - 23% increase in stratosphere-to-troposphere O_3 flux between 1965 and 2095 on global scale;
  - 9% decrease in clear-sky ultraviolet radiation index in northern high latitude, 4% increase in the tropics, and 20% increase in southern high latitude in late spring and early summer.
- The impact of climate change is much stronger in the northern hemisphere than in the southern hemisphere.
- Climate change will alter the tropospheric ozone budget and the ultraviolet index.

Some thoughts



Observed monthly mean ozone concentration in Hong Kong from 2000 to 2010 (unit: ppbv).

In my thesis research, I will use the latest version GEOS-Chem model (with stratosphere chemistry) to investigate the STE flux changes and their impact on tropospheric O_3 over East Asia during the period of 1990-2014.

Thank you