ATMOSPHERIC SCIENCE

Putting the wind up ozone

As the Earth warms, the overturning circulation of the upper atmosphere is projected to speed up. Model simulations suggest that this will increase the flux of ozone from the stratosphere to the troposphere, and alter surface levels of ultraviolet radiation.

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Ozone in the stratosphere — between about 10 and 50 km altitude — regulates the amount of ultraviolet radiation reaching the Earth's surface[1]. Consequently, stratospheric ozone depletion is a major source of concern owing to its impacts on human and ecosystem health. Below ~10 km, in the troposphere, ozone is a key greenhouse gas[2] and air pollutant[3]; here, ozone increases are the problem. Although the Montreal Protocol and its amendments have largely controlled the disastrous impacts of man-made halogenated compounds on the stratospheric ozone layer, there are other anthropogenic influences on ozone that need our urgent attention. In a modelling study reported online in *Nature Geoscience*, Hegglin and Shepherd show that human-induced climate change will increase the flux of ozone from the stratosphere to the troposphere, and alter the distribution of stratospheric ozone[4]. This change in stratospheric ozone will result in an increase of up to 20% (over 1960 levels) in the amount of ultraviolet radiation reaching the Earth's surface in the high latitudes of the Southern Hemisphere during spring and summer.

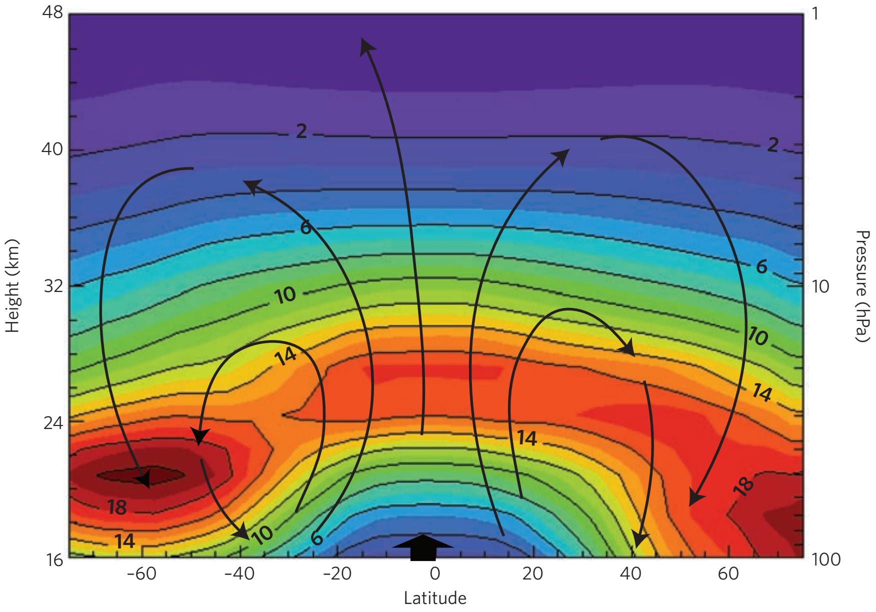

Figure 1 | Schematic of the Brewer–Dobson Circulation and the annual mean distribution of ozone (DU km^{-1}). Hegglin and Shepherd[4] use a chemistry–climate model to show that climate change — which speeds up the Brewer–Dobson circulation (arrows) — will increase the flux of ozone from the stratosphere to the troposphere, and alter the amount of ultraviolet radiation reaching the Earth's surface. Figure reproduced from ref. 12.

The distribution of ozone in the stratosphere is controlled by transport and photochemistry. The Brewer–Dobson circulation moves air from the tropics — where most ozone is produced — upwards and then polewards; the air then descends into the lower stratosphere, where the lifetime of ozone is longer (Fig. 1). The net result is an accumulation of ozone in the high-latitude lower stratosphere. The flux of air from the troposphere to the stratosphere in the tropics is balanced by an equal but opposite downward flow of ozone-rich air at high latitudes — this is a significant source of tropospheric ozone.

The Brewer–Dobson circulation results from the energy released by breaking atmospheric waves, termed wave drag, in the upper parts of the extra-tropical stratosphere. Just like ocean waves, when atmospheric waves break they deposit energy, pushing air polewards. The source of the wave drag that underpins the Brewer–Dobson circulation remains uncertain[5]. However, it is known that hemispheric asymmetry in wave drag, and in the strength of the Brewer–Dobson circulation, is partly related to the distribution of land and large mountain ranges, which influence the generation of atmospheric waves. In the Northern Hemisphere, large topographic features such as the Rocky Mountains and the Himalayas disturb the flow and excite atmospheric waves, making the northern limb of the Brewer–Dobson circulation stronger than its southern counterpart. One consequence is that the Northern Hemisphere stratosphere-to-troposphere ozone flux is roughly twice that of the less disturbed Southern Hemisphere[4].

Global climate–chemistry models consistently predict a strengthening of the Brewer–Dobson circulation as surface climate warms[6], owing to the structure of the atmosphere and its response to climate change. As tropospheric temperatures rise with increasing concentrations of greenhouse gases, the stratosphere cools. Given that the troposphere extends to about 16 km altitude in the tropics, but only stretches to ~10 km at mid-latitudes, tropospheric warming and stratospheric cooling increase the latitudinal temperature gradient at ~10–16 km altitude between the tropical upper troposphere and the extra-tropical lower stratosphere. This, in turn, intensifies winds in this region[5], stimulating wave activity and wave breaking, and strengthening the Brewer–Dobson circulation[5,6].

Hegglin and Shepherd[4] use a climate model with a stratospheric chemistry component to examine the effect of climate change on ozone distribution. According to their simulations, climate change increases the globally averaged flux of ozone from the stratosphere to the troposphere between the 1960s and the 2090s. The increase in flux is greatest in the Northern Hemisphere, where the amount of ozone injected into the troposphere increases by 2.6% per decade. Furthermore, climate change alters the vertically averaged concentration of stratospheric ozone, resulting in a decrease in surface ultraviolet radiation levels (annual mean clear-sky conditions) of 9% in the northern high latitudes, and an increase of 4% in the tropics and up to 20% in Antarctica during spring and summer. These changes in ozone distribution and ultraviolet radiation levels have nothing to do with the chemical effects of anthropogenic halogens, but are solely due to an acceleration of the Brewer–Dobson circulation associated with climate change.

The projected changes in stratospheric ozone and circulation are broadly consistent with those found by a large suite of models[1,6], suggesting that they are robust. However, the changes have yet to be confirmed by stratospheric observations[7]. If real, they may help to explain strong upward trends in ground-level ozone measured over the past two decades at European mountain-tops[8] and on the west coasts of North America and Europe[9]. Models fail to reproduce these trends when forced with estimated changes in ozone precursor emissions[3], and it seems plausible that increases in the stratospheric influx of ozone, driven by an enhanced Brewer–Dobson circulation, may be at least partly responsible for these rising concentrations of tropospheric ozone.

Downward transport of ozone from the stratosphere to the troposphere is a significant source of tropospheric ozone, and — given that ozone is a key greenhouse gas[2] — an increase in this flux represents a potentially important positive climate feedback[10]. However, warming is accompanied by other factors that act to reduce concentrations of tropospheric ozone, notably an increase in ozone destruction related to higher absolute humidity. Thus the net effect of climate change on tropospheric ozone remains uncertain[11].

Hegglin and Shepherd[4] show that climate change could have significant consequences for the distribution of ozone and Earth's ultraviolet radiation budget. Clearly, climate–chemistry feedbacks and tropospheric ozone trends must be better understood to guide the implementation of policies aimed at limiting any detrimental impacts of climate change. For example, if the influx of stratospheric ozone to the troposphere does increase with climate change, and background tropospheric ozone levels rise, then increasingly stringent ozone pollution control policies will be needed to attain the air quality standards required to protect the biosphere. A key step will be the development and application of climate models that resolve, in sufficient detail, the dynamics and chemistry of both the troposphere and stratosphere — these models are in their infancy at present. ❒

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