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SHORT CONTRIBUTION

Possible climatic implications of depletion of Antarctic ozone

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ABSTRACT

The total amount of ozone overhead in late winter and early spring has decreased considerably during the past decade. Recent satellite data confirm that the column abundances of ozone at Antarctica are among the lowest recorded anywhere on the globe. Our radiative-convective model calculations demonstrate that this depletion of Antarctic ozone could lead to a surface cooling of about 0.47°K which is in contrast to that observed from climatological temperature records. This calls for a detailed investigation of the air chemistry in relation to dynamic-radiative balance for the Antarctica atmosphere.

Recent observations by Farman et al. (1985) have revealed a remarkable depletion in the total atmospheric ozone content in Antarctica. The observed ozone column amount has decreased by about 30% during the past decade, the magnitude far exceeding the climatological variability. These ozone changes, largely confined to the region at and below the altitudes where maximum number densities of ozone occur from about 10 to 20 km during the spring season and generally associated with air within the polar vortex, have been attributed to the heterogeneous chemical reactions and high frequency of polar atmospheric clouds (Solomon et al., 1986; McElroy et al., 1986). While this surprising "ozone hole" in the remote icy continent of Antarctica emphasizes the potential importance and complexity of processes in the high-latitude stratosphere, it also motivates a study of the nature of the greenhouse effect on polar climate due to perturbations in ozone amounts in Antarctica.

The polar regions respond more dramatically than mid-latitudes or tropics to changes in atmospheric trace constituents and are potential early warning system indicators of climatic changes. They maintain their climatic equilibrium temperatures by energy transport from lower latitudes. The heat balance of these regions is primarily determined by the transport of sensible heat by the atmospheric and oceanic circulation, by the infrared emission to space from the atmosphere and surface and by solar radiation absorbed. The extent of snow and ice with their high albedo has a positive feedback in this region which greatly enhances the climate sensitivity to cooling and more than doubles the response of mean surface temperature at the poles, to an increase in heat available to the system. Further, a general global warming of the surface due to a small increment of heat could be amplified in polar regions due to positive feedback, as a result of atmospheric stability and moisture content. These probable feedback mechanisms complicate the nature of greenhouse effect due to perturbations in trace gases.

In this paper, we have examined the potential climatic effects of ozone depletion in Antarctica using a one-dimensional radiative-convective model, described in Lal and Ramanathan (1984), of the earth-atmosphere system. The model used here provides the requisite details in the radiation computations to account for the effects of perturbations in radiatively active trace constituents of the atmosphere in addition to several climatic feedback mechanisms.

In general, the model represents the globally-averaged thermal structure of the atmosphere at equilibrium. The model has a surface boundary layer which explicitly allows for the exchange of latent and sensible heat between atmosphere and lithosphere/hydrosphere/cryosphere and also solves for the boundary layer moisture. The solar and thermal flux divergences averaged over clear and cloudy fractions are computed in the model at 16 unequally spaced altitudes covering the lowest 54 km of the atmosphere. The present model also has additional sources/sinks of energy from horizontal convergence (prescribed as seasonal meridional heat fluxes) due to climatological dynamics. This facilitates the applicability of this model to represent not merely the globally averaged atmosphere but also the polar atmospheres. The model includes radiative transfer processes such as pressure and doppler broadening, H_2O continuum, hot and minor isotopic bands of CO_2 and overlap of the H_2O continuum and rotation bands with CO_2 and O_3 bands. The effect of clouds is incorporated by adopting a three-layer cloud scheme with prescribed cloud locations and fractional amounts. The atmospheric distributions of CO_2, O_3 and other radiatively active gases (methane and nitrous oxide) are compiled from a variety of sources and are prescribed in the model. We have conducted a series of numerical experiments with the model for globally averaged conditions and with Antarctica climatology. In the first case, the model solves directly for averaged annual global conditions as a steady state and without meridional heat transport. For Antarctica (60°S–90°S), the model uses average cloud, gaseous absorber concentrations, solar inputs, meridional heat transport and albedo for the spring season (Berlyand et al., 1980; Ellis, 1978; Kidwell, 1984; Oort, 1983; Stowe, 1984; Schwerdtfeger, 1984; WMO, 1986) and solves for average vertical temperature profile representative of the spring season (September to November) under radiative-convective equilibrium. Next, we perturb the concentration of ozone in both cases, and obtain the model computed changes in the atmospheric thermal structure. We shall restrict our findings here to radiative-convective model calculations of changes in the mean surface temperatures caused by perturbations to the concentration of stratospheric ozone for the globally-averaged atmosphere and the Antarctic atmosphere. It may be mentioned here that the observed surface temperature response to a decrease in ozone is primarily the result of two competing factors: the increased absorption of solar radiation by the troposphere and the decreased downward emission of long-wave radiation by the stratosphere.

Table 1 summarizes the equilibrium surface temperature and its changes for a uniform reduction by 30% of ozone amount only between its levels of maximum concentration for the case of globally-averaged atmosphere (between 12 and 40 km) as well as for the Antarctic atmosphere (between 10 and 30 km) and also for a shift in the altitude of the maximum ozone concentration, keeping the total column amount of ozone constant. The surface temperature obtained in model computations for the globally-averaged atmosphere and Antarctic atmosphere are in good agreement with climatology. For the globally-averaged atmosphere, the reduction of ozone between the levels of maximum concentration (12

Table 1. *Model-computed surface temperature and its change due to perturbation in stratospheric ozone*

Case	Globally averaged atmosphere (annual)	Antarctic atmosphere (spring)
Equilibrium surface temperature (unperturbed case)	288.85°K	232.19°K
(a) Change in surface temperature $\Delta O_3/O_3 = -30\%$ $12 \leqslant z \leqslant 40$ km	−0.24°K	−0.31°K
(b) Change in surface temperature $\Delta O_3/O_3 = -30\%$ $10 \leqslant z \leqslant 30$ km	−0.36°K	−0.47°K
(c) Change in surface temperature (altitude of maximum O_3 concentration reduced by 5 km)	−0.13°K	−0.18°K

to 40 km) leads to a surface cooling of the order of 0.24°K. Further, the surface temperature change is apparently sensitive to the altitude at which the decrease in ozone begins.

Moving the ozone decrease into the troposphere reduces the radiative heating of the troposphere and thereby contributes to a cooling at the surface. Further, the model atmosphere is sensitive to changes in the vertical distribution of ozone without affecting the total column concentration of ozone. As the peak of the ozone profile is shifted to lower altitudes, more ozone enters the upper troposphere thereby contributing to the radiative heating of the troposphere and surface. The surface cooling in Antarctica during the spring season due to a reduction of 30% ozone between the 10 to 30 km level (level of maximum ozone concentration) is of the order 0.47°K. This is contrary to that inferred from observed annual as well as seasonal mean Antarctic temperature series (Raper et al., 1984), which shows a warming trend from about 1960 until the mid-1970's (a positive linear trend in temperature anomaly for the period 1957/58 to 1982 has been reported as 0.74°K for annually averaged conditions and 0.36°K for the spring season). Possibly, the polar stratospheric clouds consisting mainly of ice crystals with temperatures below 192°K so frequently observed in Antarctic winter and early spring (contribute substantially to a larger stratospheric aerosol area) together with increasing trends in atmospheric CO_2 and other trace gas concentrations in Antarctica, might be responsible for counter-balancing the radiative effects of ozone depletion. This necessitates an extensive campaign for monitoring stratospheric ozone and aerosols with other chemical species at several stations in Antarctica such as that planned by US, UK, New Zealand and India for 1986–87, a better understanding of the stratospheric polar chemistry as well as a closer look into calculations of the dynamical radiative balance to account with greater reliability for the stratospheric polar night vortex and its low temperatures.

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