CHEMICAL RESPONSE OF THE MIDDLE ATMOSPHERE TO SOLAR VARIATIONS*

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Abstract. The possible variation of the trace species concentration in the middle atmosphere related to long term solar irradiance variability is estimated by means of a one-dimensional numerical model.

The effect of a variation in the UV solar irradiance has been studied in the recent years by various authors. Frederick (1977) and Rycroft and Theobald (1978) have determined the possible variation in the concentration of mesospheric ozone in relation with the 27-day solar rotation period. Callis and Nealy (1978a, b), Penner and Chang (1978), and Callis *et al.* (1979) have estimated the relations between stratospheric trace species variability and the 11-year cycle of the solar emission. More recently, Penner and Chang (1980) and Brasseur and Simon (1981) have performed similar calculations taking into account the temperature feedback. The latter work has been performed with a two-dimensional model in order to estimate the latitudinal effect of the solar variability.

The spectral variation of the solar irradiance related to the 11-year cycle is not well known because of the lack of data and is thus subject to discussion. Heath and Thekaekara (1977) have suggested a variability of a factor of at 200 nm and 15% at 300 nm on the basis of their own observations performed by satellites and rockets between 1966 and 1975. Brasseur and Simon (1981) have questioned the analysis of Heath and Thekaekara and have suggested as an upper limit a variation of 20% at 200 nm. Very recently Hinteregger (1981) has provided a spectral distribution of the solar variability at wavelengths shorter than 185 nm. The ratio of irradiance at high and low solar activity condition is of the order of 2.8 at Lα (121.6 nm) and decreases with wavelength to reach about 1.20 at 185 nm. Figure 1 shows the relative variations $(F_{max} - F_{min})/F_{mean}$ adopted for the calculations discussed in this paper. The curve provided by Hinteregger has been extrapolated to reach a null variability at 205 nm (curve 2) and 340 nm (curve 1) respectively. The effect of an anticorrelation between solar irradiance and solar activity recently suggested by Heath (1980) for wavelengths between 210 and 250 nm has been considered by adding to the curve number 2 a relative variation of -15% labelled number 3 in Figure 1.

The chemical response of the stratosphere and the mesosphere is estimated by means of a 1-D model which extends from the ground to the altitude of 100 km. A standard chemical scheme including the odd oxygen, hydrogen, nitrogen, and chlorine species is used but no temperature feedback is considered here. In order to

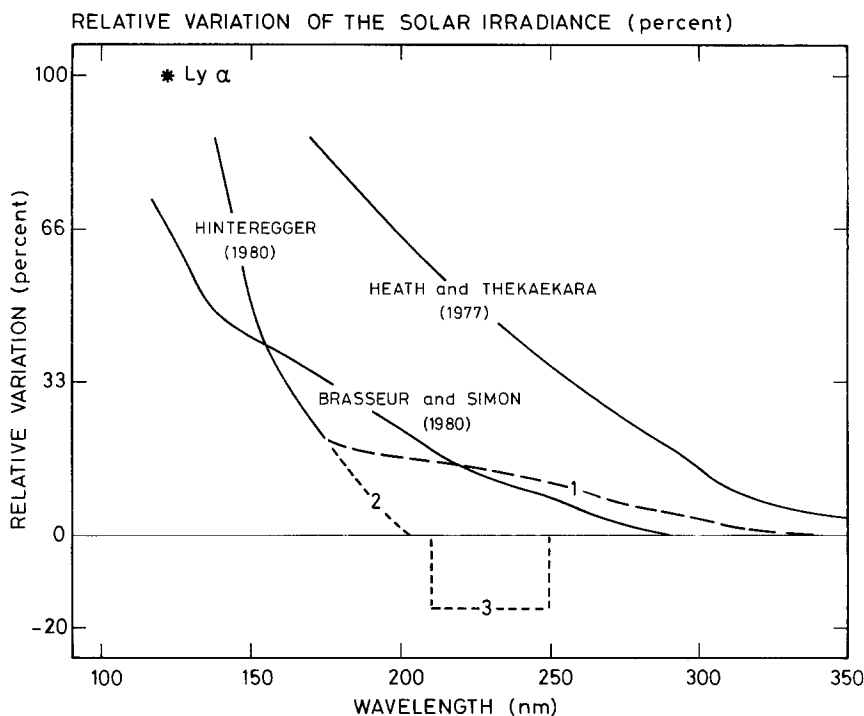RELATIVE VARIATION OF THE SOLAR IRRADIANCE (percent)

Fig. 1. Relative variation of the solar irradiance during a cycle of solar activity (11 years). Spectral distribution suggested by various authors. The curve adopted by Brasseur and Simon (1980) has been extrapolated to reach 66% at 125 nm. For the extrapolation of the Hinteregger's curve, see text.

avoid prohibitive computer time, the model is run for steady state conditions but this simpilfication should not considerably alter the conclusions (Penner and Chang, 1978).

Figure 2 depicts the change in the ozone *production* rate when the solar variability suggested by Hinteregger is adopted. In the upper mesosphere, the enhancement is of the order of 25–30% from solar minimum to solar maximum activity. The results obtained below 80 km are critically dependent on the type of extrapolation adopted above 175 nm since the dissociation of O_2 leading to ozone occurs essentially in the Schumann–Runge bands (175–200 nm) and in the Herzberg continuum (200–242 nm). Therefore new measurements of the time dependence of the solar irradiance above 175 nm are required in order to estimate the chemical response of the middle atmosphere due to natural causes.

The relative variation of the ozone *concentration* below 100 km as computed in our model is given in Figure 3 for different solar variabilities. If the Heath and Thekaekara curve (Figure 1) is adopted, the ozone concentration is increased by more than 40% in the upper stratosphere. This number is much higher than long term variations ever recorded. Even if the temperature feedback is taken into account, the large variation given by Heath and Thekaekara should be questioned (Brasseur and Simon, 1980).
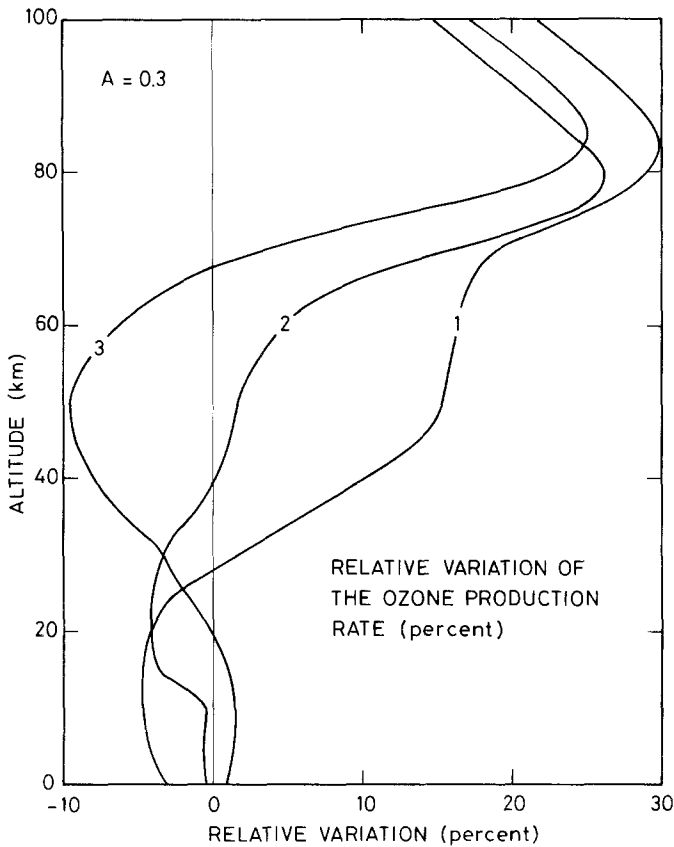
Fig. 2.   Relative variation of the ozone production rate during a solar cycle of 11 years when the solar irradiance variability suggested by Hinteregger is adopted. Curves 1, 2, and 3 refer to the different extrapolations suggested on Figure 1.

The variability suggested by Brasseur and Simon (1980) leads to a maximum ozone enhancement of the order of 15%. This value is still high but as shown by our 2-D model calculations (Brasseur and Simon, 1980) it should be reduced to about 10% when the temperature feedback is taken into account. Finally, the Hinteregger's irradiance variability (extrapolated to 205 nm – curve 2 on Figure 1) leads to an increase of the ozone concentration from minimum to maximum activity conditions which is of the order of 5%.

Above 65–75 km, the ozone concentration is expected to decrease when the solar irradiance is enhanced. In fact, the ozone production increase is counterbalanced by the change in the concentration of hydroxyl, hydroperoxyl radicals, and of atomic hydrogen. At these levels, H, OH, and HO_2 are produced by the water vapor photodissociation in the spectral range of the $L\alpha$ emission line. Since, in the model the intensity of this line is assumed to vary by 100% during a solar cycle, the response of the odd hydrogen species is rather impressive. At 80 km, the concentration of OH
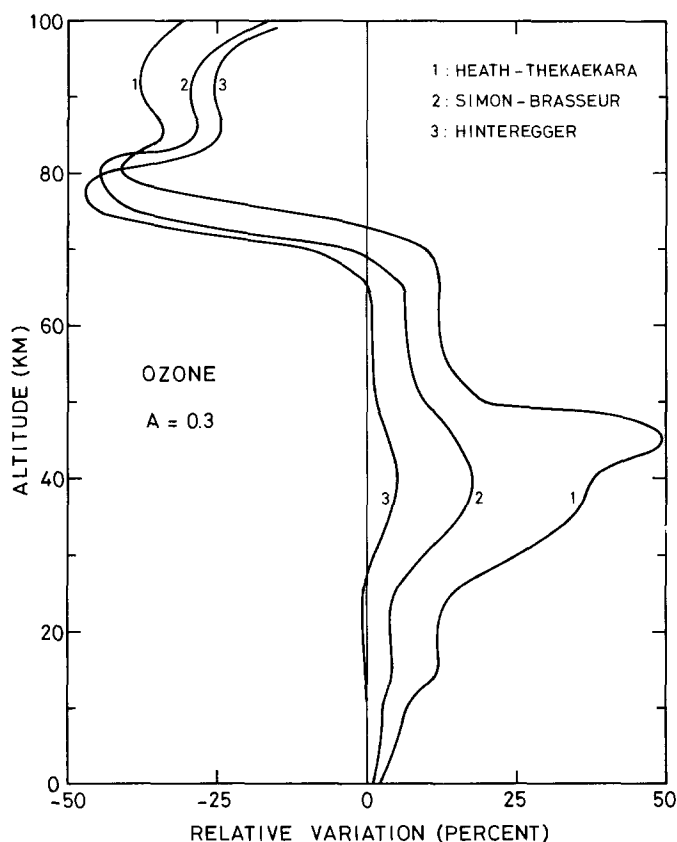
Fig. 3. Relative variation of the ozone concentration computed for the solar variability suggested by Heath and Thekaekara (1977), Brasseur and Simon (1981) and Hinteregger (1981; extrapolation number 2 on Figure 1). Ground albedo: 30%.

and HO_2 is increased from the minimum to the maximum period of solar activity by about 50% and that of H by 25% when the curve by Brasseur and Simon is adopted.

The concentration of oxygen atoms in their ^3P and ^1D states is reduced as does the ozone in the upper mesosphere (−35% at 80 km), whereas below 75 km it is enhanced (+15% between 45 and 65 km). In the stratosphere the expected increase in the atomic oxygen concentration due to the simultaneous enhancement of the ozone amount and solar irradiance at the top of the atmosphere is reduced by the presence of an increased ozone column which absorbs the UV radiation. The relative variation of the amount of $O(^1D)$ becomes even negative in our model below 35 km when the solar variability suggested by Brasseur and Simon (1980) is used for the calculation.

The concentration of carbon monoxide is enhanced especially above the strato-pause where the variability of the $L\alpha$ line which dissociates carbon dioxide becomes sensitive. At 80 km the corresponding increase could reach about 80% from solar minimum to solar maximum (Figure 4). Finally, the behavior of nitric oxide is also

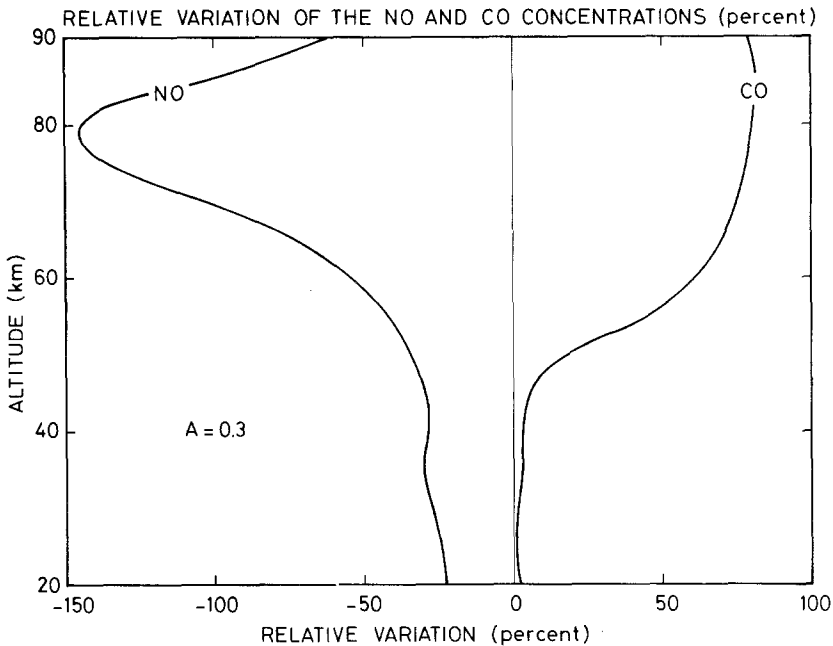RELATIVE VARIATION OF THE NO AND CO CONCENTRATIONS (percent)

Fig. 4.   Relative variation in the concentration of carbon monoxide and nitric acid during a solar cycle of
11-years. The calculations refer to the solar variability suggested by Brasseur and Simon (1981).

interesting since its distribution is sensitive to the value of its photodissociation rate. In the mesosphere the loss of NO is essentially compensated by its transport from the thermosphere and a high sensitivity to the solar activity is observed in Figure 4.

It should be noted that our results assume constant thermal and dynamical averaged conditions and that the introduction of temperature and transport feedbacks could modify considerably the values presented here. Therefore simplied 1-D models provide only crude estimates of the possible response of the trace species to the solar variations.

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