ISSN 1028-334X, Doklady Earth Sciences, 2006, Vol. 406, No. 1, pp. 79–81. © Pleiades Publishing, Inc., 2006.
Original Russian Text © V.V. Adushkin, V.P. Kudryavtsev, V.M. Khazins, 2006, published in Doklady Akademii Nauk, 2006, Vol. 406, No. 2, pp. 241–243.

GEOPHYSICS

Hydrogen Degassing of the Earth and Ozone Anomalies

Academician of the RAS V. V. Adushkin, V. P. Kudryavtsev, and V. M. Khazins

Received June 7, 2005

DOI: 10.1134/S1028334X06010193

The objective of this work is to estimate the reaction of the ozone layer to the increase in molecular hydrogen concentration in the stratosphere. The performed investigations into characteristics of the ozone anomaly, caused by the increase in hydrogen concentration and investigations of hydrogen emergence in the atmosphere in the process of the Earth's degassing, have shown that the power of the known hydrogen sources is insufficient for affecting the ozone layer.

The annual supply of hydrogen into the Earth's atmosphere amounts to 40–130 Tg, and its average volumetric mixing ratio in the atmospheric is $\sim 0.5 \cdot 10^{-6}$ [1]. The oxidation of methane and other hydrocarbons, anthropogenic activity, and burning of biomass are the main sources of molecular hydrogen. The cold degassing of the Earth (release in rift zones, large faults, areas of kimberlitic diamondiferous magmatism, and so on) provides only a small contribution (~6 Tg/yr) to the total hydrogen flow [2]. The sink of hydrogen is nearly equivalent to the inflow. Thereby, the main mass of hydrogen is absorbed by soil or removed from the atmosphere by reacting with hydroxyl in the troposphere. However, anomalously high hydrogen fluxes can be created in some areas. For example, as much as 10^9 m^3/yr (0.1 Tg/yr) of hydrogen is supplied into oceanic water from rifts of the World Ocean bottom [3]. Intense hydrogen streams have been detected in shields and mountainous foldbelts. For instance, a discharge of gas stream in the Udachnaya kimberlite pipe attained 10^5 m^3/day [4], including about 50 vol % of hydrogen and the remainder represented by methane.

Hydrogen is much lighter than air and, in principle, a hydrogen cloud can rise rather high and can even partly penetrate into the stratosphere, in particular, affecting equilibrium $[O_3]$ concentration in ozone layer [1]. Moreover, one highly disputable hypothesis [5] suggests the formation of ozone anomalies as a result of generation of the vertical hydrogen flow in the atmosphere above tectonic faults.

The calculation of equilibrium ozone concentrations $[O_3]_e$ and numerical modeling of the ozone layer destruction owing to an increase in hydrogen concentration has been carried out on the basis of a one-dimensional photochemical model of the atmosphere [6]. When varying hydrogen concentration, it has been discovered that a rather appreciable destruction of ozone begins if the concentration is two orders of magnitude higher than the background value. The deepest ozone anomalies occur at high latitudes. We present here the results for the case in which hydrogen concentration at 70° N was two orders of magnitude higher than the background content. The elevated hydrogen concentration was maintained for the entire duration of computation. Under these conditions, the maximum decrease in ozone concentration at a height of 20 km reached 25%, with a decrease in the total ozone content by approximately 10%.

Figure 1 shows the relative deviations of ozone concentration $\frac{\Delta[O_3]}{[O_3]_e}$ versus the starting moment of disturbance. As follows from this figure, the ozone concentration decreases only from the early autumn to the early spring. If the disturbance is introduced within this time interval, then the maximum deviation (~25%) of ozone concentration is achieved by the introduction of a disturbance in the early autumn; however, the ozone concentration in this case drops slowly and the disturbance duration is maximal (6 months). When the disturbance is introduced later, the duration of ozone anomaly development decreases, and the deviation also becomes smaller.

Note that the ozone concentration is largely reduced at heights below the maximum of the ozone layer. According to the calculations, the deviation of ozone concentration from the background value at a height of 30 km is three times smaller than the deviation at a height of 20 km and five times smaller than at a height of 15 km.

Thus, the 100-fold increase in molecular hydrogen concentration in the stratosphere makes it possible to create an ozone anomaly under certain conditions. The characteristic duration of anomaly development is about 100 days.

---

*Institute of Geosphere Dynamics, Russian Academy of Sciences, Leninskii pr. 38/1, Moscow, 119334 Russia;
e-mail: Khazins@idg.chph.ras.ru*

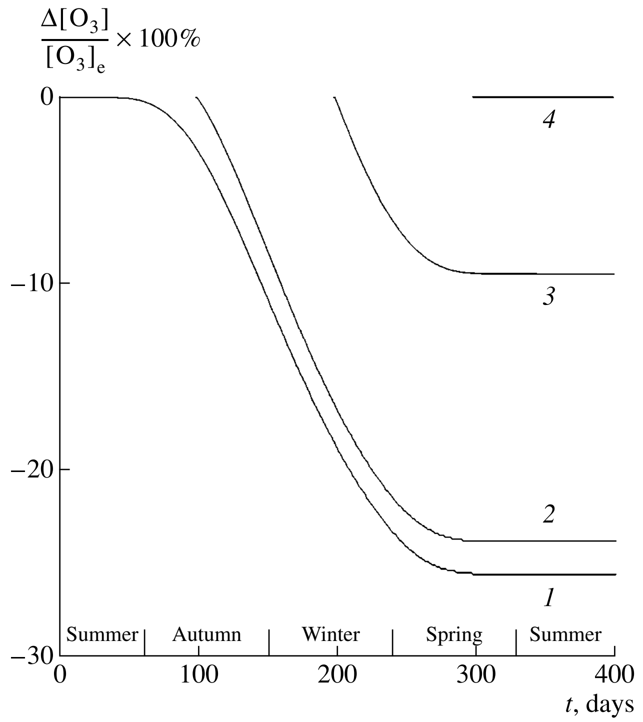

Fig. 1. Variation of ozone concentration at a height of 20 km vs. time (curves *1, 2, 3*, and *4* correspond to the disturbances beginning from the 1st, 100th, 200th, and 300th days from July 1, respectively).

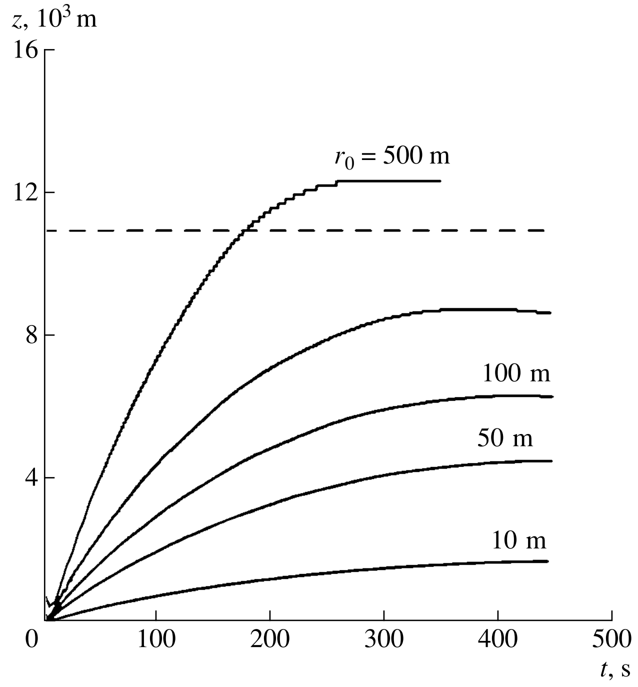

Fig. 2. Dynamics of hydrogen bubble emergence at various initial radii r_0 (dashed line designates the tropopause).

Let the characteristic area *S* of the ozone anomaly be 10^4 km^2. Using [7], it is not difficult to show that the 100-fold increase in hydrogen concentration within a cylindrical body with a base area *S* and with a height *h* of the ozone layer requires a supply of ~0.05 Tg of hydrogen. The supply to the ozone layer may be either as a gradual process, provided by the multifold penetration of relatively small portions of hydrogen released from the lithosphere, or as a spontaneous powerful emission of hydrogen from the lithosphere. To constrain the possibility of hydrogen emergence into the stratosphere, the numerical modeling has been carried out.

Let us consider a case of spontaneous hydrogen outflow from the Earth, i.e., suggest that the time of hydrogen emission is much less than the characteristic time of emergence. Under such conditions, one may assume that at the initial moment hydrogen occupies a spherical volume of radius r_0 near the Earth's surface. This regime of outflow appears to be the most efficient in terms of reaching the maximal height of ascent at the given mass of hydrogen, because the surrounding air does not mix during outflow. Thus, one can estimate the minimal volume of hydrogen outflow that provides for a break of the tropopause. If this volume turns out to be comparable with hydrogen supply from known sources, this may serve as a ground for setting new, more comprehensive studies that take into account the development of outflow.

We conducted calculations of the emergence of the spherical hydrogen body at variable r_0. The modeling of convective flows was carried out in terms of two-dimensional axisymmetric Navier–Stokes equations in hyposound approximation [8]. The technique [8] satisfactorily describes slow gas dynamic processes in a heterogeneous compressible atmosphere. The turbulent mixing of hydrogen with the surrounding air was taken into account using a constant effective Reynolds number. The standard stratification of the atmosphere was accepted.

Figure 2 demonstrates the dynamics of hydrogen cloud emergence as a function of the initial radius of the parental spherical hydrogen bodies. The cloud height is determined by the location of the concentration maximum. As follows from calculations, the hydrogen emission with a bubble radius as large as 350 m (mass of emission is less than 0.01 Tg) remains within the troposphere. Hence, the relatively small portions of hydrogen will not penetrate into the stratosphere.

As was shown above, the development of an ozone anomaly 10^4 km^2 in area is provided by an increase in hydrogen mass in the ozone layer by approximately 0.05 Tg that corresponds to a spherical hydrogen body with a radius of ~500 m. The height of cloud emergence in this case is ~12.5 km (Fig. 2). Thereby, a relatively small (tens of kilometers in the lateral direction and a few kilometers in the vertical direction) inhomogeneity is formed. The maximal hydrogen mass concentration therein reaches $\sim 15 \cdot 10^{-4}$ ($t = 250$ s, see Fig. 3). Because the molecular weight of hydrogen is approximately 15 times lower than the molecular weight of air, the volumetric mixing ratio is $\sim 2 \cdot 10^{-2}$, i.e., more than

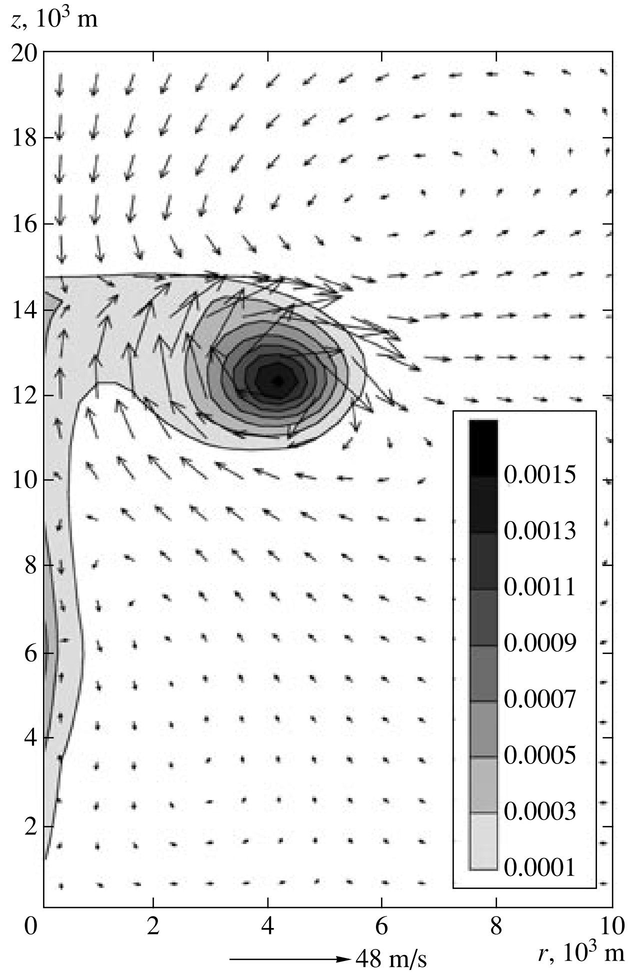

Fig. 3. Fields of velocity and mass concentration of hydrogen at $t = 250$ s.

four orders of magnitude higher than the background value ($\sim 0.5 \cdot 10^{-6}$). Thus, during ~5 min, i.e., virtually instantaneously as compared to the characteristic time of the ozone anomaly development (100 days), the concentration of hydrogen became substantially higher than the background value in a cylindrical body with a base of ~100 km^2 in area. The subsequent wind diffusion becomes the crucial process controlling the decrease in hydrogen concentration. According to our estimates, the hydrogen concentration may drop by three to four orders of magnitude over the course of 15–30 days owing solely to winds in the stratosphere and diffusion.

Thus, the ozone anomaly may develop by the release of more than $5 \cdot 10^8$ m^3 (0.05 Tg) of hydrogen over a duration of time that is much less than that necessary for the cloud formed by spontaneous emission (~5 min, see Fig. 2) to hover in the stratosphere. The release of such volumes of hydrogen in the course of a year or longer period is typical of vast territories. In this case, hydrogen is supplied slowly and is caught up by winds. Thus, it is involved in the general circulation of the troposphere. The localized sources of such volumes of hydrogen that could be rather quickly emitted in the atmosphere are unknown. Hence, the ozone anomalies cannot be formed above the slow hydrogen sources in the course of the Earth's degassing.

ACKNOWLEDGMENTS

This work was supported by the Program *Global Changes of Natural Environment* of the Presidium of the Russian Academy of Sciences.

REFERENCES

1. G.P. Brasseur and S. Solomon, *Aeronomy of the Middle Atmosphere* (Reidel, 1984; Gidrometeoizdat, Leningrad, 1987).
2. G. I. Voitov, Zh. Vses. Khim. O-va **31**, 533 (1986).
3. J. Welhan and H. Graig, Geophys. Res. Lett. **6**, 829 (1979).
4. D. G. Osika, *Fluid Regime of Seismically Active Zones* (Nauka, Moscow, 1981) [in Russian].
5. V. L. Syvorotkin, *Deep Degassing of the Earth and Global Catastrophes* (Geoservis, Moscow, 2002) [in Russian].
6. L. A. Zhuravleva and V. P. Kudryavstev, in *Dynamic Processes in the Upper Geospheres* (IDG RAN, Moscow, 1994), pp. 191–204 [in Russian].
7. *Standard Atmosphere: Parameters. State Standard 4401-81* (Izd. Standartov, Moscow, 1981) [in Russian].
8. M. A. Zatevakhin, A. E. Kuznetsov, D. A. Nikulin, and M. Kh. Strelets, TVT **32** (1), 44 (1994).