Major sudden warming and strange twist of the ozone hole over Antarctica in 2002

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The disaster of ozone depletion

The development of civilization has given rise to new problems: on the one hand, the sensitivity of humans and their economic activity to various external impacts has increased; on the other, the phenomena have appeared of human-induced disasters, whose consequences were sometimes catastrophic. In accordance with its very definition, a disaster is perceived as a sudden phenomenon (e.g. an earthquake, a volcanic eruption, etc.). However, it is everybody's knowledge that disasters are actually the results of long-time development of relevant processes [1]. The 20th century is characteristic of the appearance of human-induced potential disasters of "slow" (or "delayed") action, such as, for instance, the so-called "global warming" (a surface air temperature rise as a result of increased concentrations of greenhouse gases and total ozone depletion due to the emission to the atmosphere of some ozone-destroying gases (above all, freons) [2].

History and background of the ozone hole over Antarctica

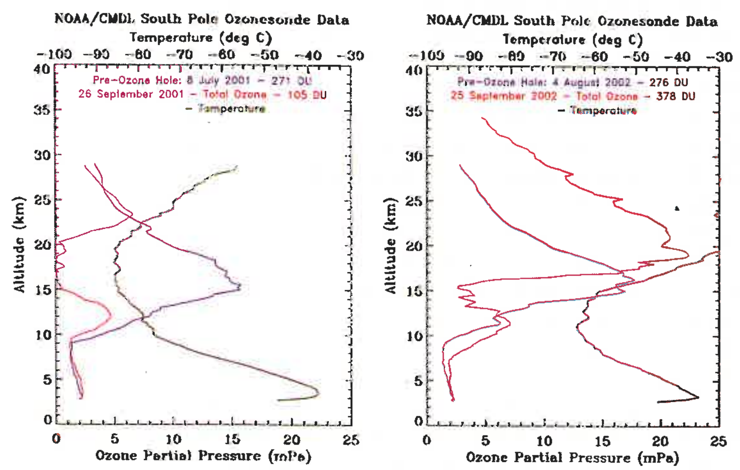
It is general knowledge that the ozone layer in the stratosphere (about 90% of ozone is located in the stratospheric layer between approximately 10 and 50 km above the earth's surface, which is called *the ozone layer*) protects life on the Earth from the Sun's destructive ultraviolet (UV) radiation [2, 3]. The measurements and observations of the changes in ozone come from ground-based instruments at research stations, from free-balloons, from aircrafts, and from satellites [3].

Due to the continuing human-induced destruction of the ozone layer, the UV radiation on the earth's surface is increasing, and this in the long run may be ruinous for humans and the biosphere as a whole. In 1970, P.J. Crutzen [4] was among the first to reveal that nitrogen oxides emitted into the atmosphere as a result of using agricultural fertilizers, together with nitrogen oxides emitted by sub- and supersonic aircraft, can be ruinous for the ozone layer. In 1974 M. Molina and S. Rowland [5] revealed the ozone-destructive role of chlorofluorocarbons (CFCs) that are industrial products, used in refrigeration systems, air conditioners, aerosols, and solvents; their conclusions were later confirmed by subsequent studies. These studies won public recognition, and the authors were awarded the Nobel Prize in 1995. In September 1984, S. Chubachi [6] announced that the Antarctic station at Syowa (69°S, 40°E) had recorded a drop in ozone values during many days of the 1982 Antarctic spring and in May 1985, J. Farman *et al.*, [7] reported the severe ozone depletion over Antarctica. It is worth noting that the USA satellite data did not record the unprecedented loss of ozone because the software processing the raw ozone data was programmed to treat very low values of ozone as bad readings [2].

In general, the "ozone hole" is defined as the area with a substantial reduction below the naturally occurring concentration of ozone in the overhead column. As a factor involved in the formation of the "ozone hole" at the high latitudes of the Southern Hemisphere, of great importance is the specific dynamics of the Antarctic atmosphere, which is characteristic of the presence of a circumpolar vortex in winter and spring seasons, which "captures" the circumpolar air; the air temperature then drops to -90°C, and this provokes the formation of polar stratospheric clouds (PSC). Heterogeneous chemical reactions on the surfaces of the ice particles of these clouds transform comparatively inert $ClONO_2$ and HCl into active forms of chlorine compounds, catalyzing ozone depletion, and also combining (binding) nitrogen compounds [2].

Two types of PSC have been discovered, which consist of either particles of nitric acid trihydrate, concentrated on the nuclei of sulphate aerosols (the prevailing type), or of large particles of water ice. Both types of PSC fulfill the function of stratosphere denitrification (removal of gaseous nitrogen compounds), which is a condition necessary for the total ozone decrease. Laboratory investigations confirm that the particles of nitric acid trihydrate play the key role in the formation of active chlorine compounds in the Antarctic stratosphere [2].

The discovery of the essential role of CFCs in the formation of the "ozone hole" in the Antarctic provoked interest towards studying CFCs concentrations in the Antarctic atmosphere. At first (over 20 years ago) at the Amundsen-Scott station at the South Pole, and later at the Palmer station (66.46°S; 64.04°W), regular observations of concentrations of chlorine-containing compounds in the atmosphere were performed. The data of these observations are important for the assessment of the effects of measures intended for CFCs emission reduction, in accordance



▲ Fig. 1: The difference in the ozone and temperature vertical profiles from 2001 (cold stratosphere, low ozone) to 2002 (warm stratosphere, high ozone) (source: http://www.cmdl.noaa.gov/ozwv/ozsondes/spo/ozppp2002.html)

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with the Montreal Protocol (the CFCs production was reduced by 10-20% with respect to the maximum level of the 1980s).

The exceptional event over Antarctica in September 2002

According to the September 30 Press Release from NASA and NOAA (NASA/NOAA 2002), the size of the Antarctic ozone hole was around 15 million km^2 during the last two weeks of September 2002, which is well below the more than 24 million km^2 seen in this season during the last six years [8].

Very recently, the analysis of the ozone and temperature observations showed that the most important factor for the smaller size of the Antarctic ozone hole in September 2002 was the prevalence of much higher (than normal) temperatures at the Antarctic stratosphere that resulted in limited action there of the ozone destruction processes (Fig. 1) [9, 10]. The reason for the high temperatures in Antarctica is mainly the presence of strong planetary waves (long waves that circle the globe, or planetary scale weather systems).

In addition, the basic polar vortex in the stratosphere of the southern hemisphere during 21-26/9/2002 was step-by-step elongated and distorted up to the occurrence of the polar vortex split into two cyclonic centres, leading thus to a corresponding split of the ozone hole (Fig. 2) [9,10]. This event may probably be attributed to the unprecedented occurrence of the major sudden stratospheric warming over Antarctica (induced from the strong planetary waves) [8,9].

Conventionally, sudden stratospheric warmings (increases in stratospheric temperature as much as 70°C for periods of a few weeks during midwinter) do occur in Antarctica although they are not as intense as in the Arctic [2]. However, according to the available record of observations the major warming events in the stratosphere only occur in one of two northern winters, and they do not occur in the southern hemisphere. Therefore, the most interesting thing is that the major warming of 2002 had not been seen up to now. It is worthwhile to mention here that some scientists argue that the destruction of ozone by chlorofluorocarbons is the direct and primary cause of delayed stratospheric warmings in Antarctica. If this was the major effect, the early major stratospheric warming of 2002 would not have occurred since chlorofluorocarbon loading of the stratosphere has remained relatively stable in recent years (due to the Montreal Protocol and its Amendments).

It should be emphasized however that the diminutive Antarctica ozone hole in 2002 does not support a recovery of the ozone layer, since the smaller ozone loss was mainly induced from the unexpected major stratospheric warming that occurred there.

Conclusion

The unprecedented occurrence of a major sudden stratospheric warming over Antarctica (induced from the strong planetary waves) has led to the split of the ozone hole in September 2002. These unusual events denote that there still exists a long way to go in understanding strange phenomenological twists of the Antarctic ozone hole on the long-term.

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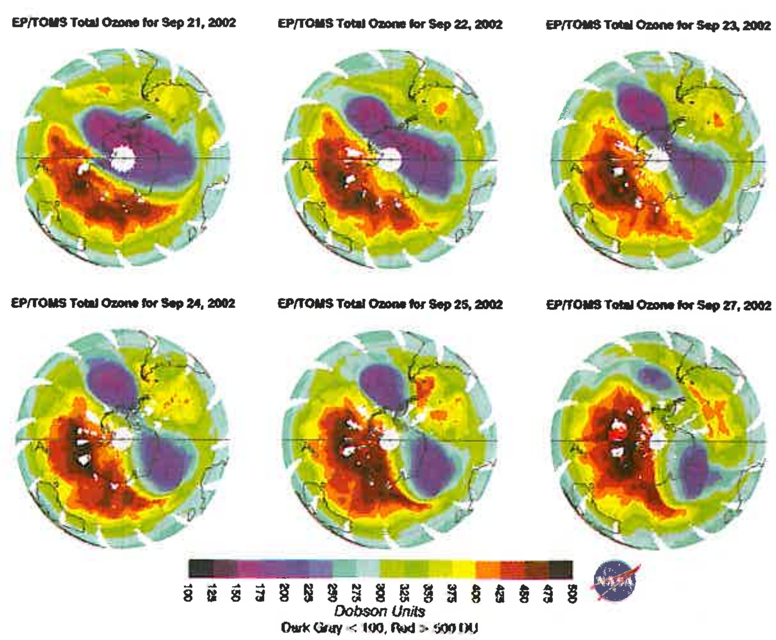

◄ **Fig. 2:** Southern hemisphere total ozone content during Sep 21-27, 2002 obtained from Earth Probe (EP) / Total Ozone Mapping Spectrometer (TOMS) observations. (source: NASA)