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Review of 'Contributions to understanding climate interactions: stratospheric ozone' by Gennadi Milinevsky, Asen Grytsai, Oleksandr Evtushevsky, and Andrew Klekociuk. (2022).

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Огляд монографії «Внесок у розуміння кліматичних взаємодій: стратосферний озон», Г. П. Міліневський, А. В. Грицай, О. М. Євтушевський, Е. Р. Клекосюк. (2022).

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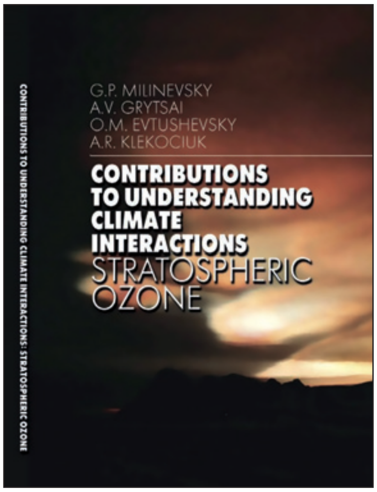


Investigations of atmospheric ozone have been fast developing in the last two centuries. Their importance became more evident after the ozone hole discovery in the mid-1980s. Today, it is clear that stratospheric ozone is essential for the Earth's biosphere, and its content (which conditionally may be named 'ozone layer thickness') varies and is determined by different chemical and dynamical processes. In this book, a team of authors considers mainly the physical, particularly dynamic processes influencing ozone in the Earth's atmosphere. The monograph has seven chapters. It studies the ozone layer, primarily focusing on the middle and high latitudes. Ukrainian researchers wrote the book in co-authorship and long-term cooperation with their Australian colleague, famous atmospheric researcher, Dr. Andrew Klekociuk. The authors are experts in atmospheric physics and present their own results and a review of the current state of the ozone-climate interaction problems. The book includes many refer-

Gennadi Milinevsky (right) learned in 1995 at Faraday Base how to work with the Dobson spectrophotometer from "Mister Ozone" – Jonathan Shanklin (left) from the British Antarctic Survey. Shanklin discovered the Ozone Hole together with Joe Farman and Brian Gardiner in 1985. Photo from the archive of the National Antarctic Scientific Center of Ukraine

ences to the recent scientific publications that direct readers to more detailed information to understand the topic better.

In the preface, the authors briefly describe the history of ozone observations in Ukraine, including their own experiences. In particular, Prof. Gennadi Milinevsky was the Base Commander and geophysicist in the First Ukrainian Antarctic Expedition in 1996–1997 after the British Antarctic Survey transferred Faraday Station to Ukraine with an obligation to continue various observations started by the British in the 1950s. He learned ozone observations with a Dobson spectrophotometer from Jonathan Shanklin, one of the discoverers of the Antarctic ozone hole announced in the first ozone depletion paper in Nature in 1985.

This station (named Akademik Vernadsky after 1996) currently operates successfully, and ozone observations with the Dobson spectrophotometer are still among the critical and mandatory tasks for Ukrainian polar researchers.

You may believe that ozone measurements are essential only in the southern polar latitudes for monitoring the Antarctic ozone hole's state. That is not entirely true: total ozone trends in both hemispheres' middle and low latitudes are also critical. Studying them helps us understand the global climate system and has many scientific and practical applications. Of course, satellite measurements show global ozone distribution from the late 1970s almost without gaps, but they also require ground-based measurements for verification and calibration. Moreover, every scientifically developed country supports and encourages researchers to provide atmospheric data. And yet, no high-quality Dobson spectrophotometer ozone measurements were available in Ukraine until 2010.

Consequently, Ukrainian atmospheric science took a significant step forward when Prof. Milinevsky organized the transfer of the Dobson spectrophotometer from Belgium, where it had been used for more than fifty years. This instrument has been actively operated since 2010 in Ukraine, and the measurements were provided almost daily, which is possible only at the limited number of ground-based stations. The spectrophotometer was installed on the roof of the Main Astronomical Observatory of the National Academy of Sciences of Ukraine, and its successful work over the years was possible due to a well-supported cooperation with the Taras Shevchenko National University of Kyiv. This introduction helps explain the goals of ozone observations and their importance. However, most of the book is dedicated to the authors' own results, discussed alongside the studies of other researchers worldwide.

The authors review the ground-based ozone satellite instruments with a particular focus on Dobson spectrophotometer's principles and characteristics. Several different types of observations with the Dobson spectrophotometer are described, and their possibilities are analyzed using, in particular, the authors' experimental results. The capabilities of the M-124 filter ozonometer, which has been used for total ozone measurements in Ukraine since the 1970s, are also discussed.

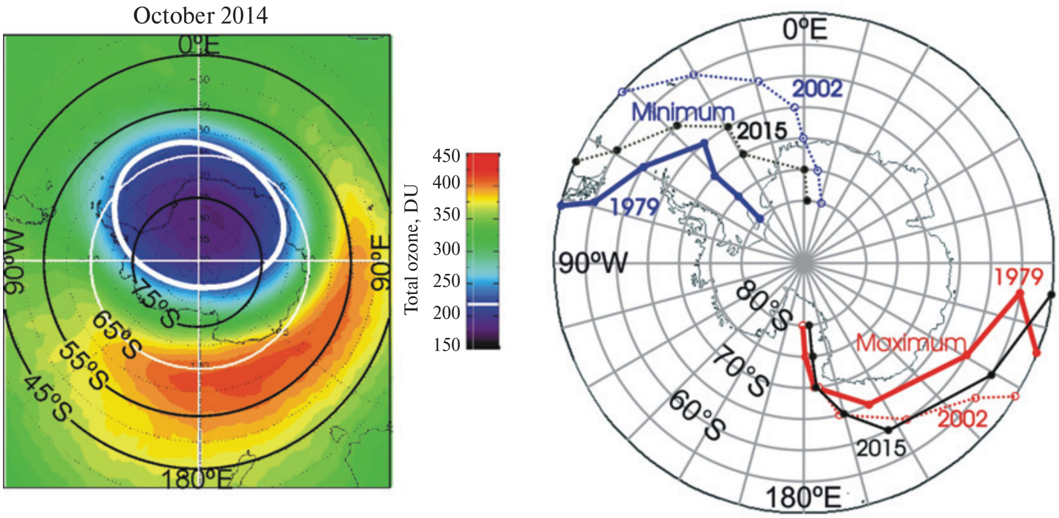
Comparison of the ground-based and satellite total ozone data is a technical task mostly. However, it is necessary to understand the advantages and disadvantages of both data series. Readers can see the ozone observation results at mid-latitude (Kyiv-Goloseyev) and polar (including Akademik Vernadsky) stations. Seasonal variations were also studied, and they are very different. Total ozone variations over Ukraine display a spring maximum and an autumn minimum. At the Akademik Vernadsky station, very low total ozone values (to only a third of the typical value) are possible in the Antarctic spring (September—November) when the ozone hole develops. This substantial ozone depletion must be taken into account by the winterers. Studies help them choose the optimal work regime in the open air during the ozone hole season. From the first chapter, readers also learn about other research methods, including an analysis of long-term tendencies and a study of vertical ozone profiles by the Umkehr method that can be provided using Dobson spectrophotometer unique measurements without launching ozone sondes available at an extremely limited number of sites.

The second chapter of the book considers the annual ozone cycle in the northern mid-latitudes, presenting the complicated character of many atmospheric processes based on the data from satellite measurements and reanalyzes in particular. Formation of ozone molecules requires solar ultraviolet, which could lead to a conclusion that total ozone would be high in summer and low in winter. However, the reality is different because the Earth's atmosphere is in motion, and dynamic processes are essential. As a result, mid-latitude ozone predominantly forms in tropical latitudes, and it is carried by the so-called Brewer-Dobson circulation poleward during the cold season. Therefore, European (including Ukrainian) ozone levels are lower than the average for the northern middle latitudes, with a later maximum and minimum appearance. These distinctions in the annual ozone cycle are probably caused by tropospheric centers of action primarily by steady regions of low and high pressure known as Aleutian low and Azorean high, respectively.

While the second chapter describes the phenomena induced by the atmosphere dynamics, the third chapter ('Quasi-stationary planetary waves in the spring Antarctic ozone distribution') considers those more directly and presents results on interannual variations in the total ozone asymmetry. The critical consequence obtained and published by the authors in several papers concerns the eastward shift in the minimum of the Antarctic ozone distribution during the 1980s—2000s. This change in the quasi-stationary structure influenced total ozone values in the Atlantic longitudinal sector, particularly at the Akademik Vernadsky station. It is well known that the ozone hole phenomenon is mainly caused by chemical factors, particularly halogen catalytic cycles in the polar stratosphere. Still, a thorough explanation should take into account the atmospheric dynamics.

In winter and spring, the stratospheric polar vortex governs the polar stratosphere. This large-scale cyclonic structure prevents air mixing between the middle and high latitudes. The stronger the stratospheric polar vortex, the lower the high-latitude stratosphere temperature and the faster ozone destruction at polar stratospheric cloud nuclei. The state of the stratospheric polar vortex depends on the activity of the large-scale atmospheric waves propagating from the troposphere to the stratosphere. They have been named planetary, or Rossby, waves, and their intensity is partly determined by orography and land-ocean temperature contrasts. As a result, the polar vortex is stronger and colder over Antarctica — the highest continent with an average elevation of 2500 m and more uniform surface conditions, than in the Arctic, with the low ocean surface disrupted by continental orography. This phenomenon results in a stable ozone hole development in Antarctica while, on the contrary, higher ozone levels appear near the North Pole. Thus, not only studies of chemical processes in the stratosphere are necessary to understand the ozone hole formation, but the pattern will be significantly incomplete without studies of planetary waves which in the Southern Hemisphere are mainly presented by Quasi-Stationary Waves (QSW) with a zonal wave number of $m = 1$ (QSW1).

The **fourth chapter** continues the analysis of quasi-stationary features in total ozone distribution. Long-term tendencies are studied with attention to total ozone values, zonal asymmetry amplitude, and spatial location of ozone maximum and minimum. Satellite data showed a complicated character of processes in the Antarctic stratosphere. Ozone recovery is an important phenomenon observed in the Southern polar region. Results of the measurements demon-



(a) (b)

The Southern Hemisphere total ozone in October 2014 (a) from the OMI observations (http://www.temis.nl/protocols/O3global.html), the white thick contour indicates the ozone hole boundary at 220 DU; (b) map of longitudinal locations of zonal QSW1 maximum (red) and zonal QSW1 minimum (blue) at seven latitudes between 50°S and 80°S; westernmost (easternmost) longitudes in 1979 (2002) determined from the polynomial fit. Black dotted line marks longitudes of ozone minimum for 2015. Modified from the book

strate ozone variations in time, with a sharp decrease in the 1980s and 1990s following its stabilization. Due to significant interannual variations, monitoring is needed to understand the following perspectives of ozone layer recovery. These studies will help evaluate the reliability of many models forecasting the complete or partial ozone recovery in the twenty-first century. The strongest long-term changes are typical for ozone content in the spring months. Its values in other seasons are more uniform. The longitude tendencies are also complex, with the slowing (hiatus) of the eastward trend in the minimum’s position in the 2010s. A separate question relates to the origin of the interannual variability in the Antarctic stratosphere. The connection between different atmospheric parameters and total ozone is considered, but another source of the changes is far from Antarctica, in the central part of the Pacific Ocean. This relationship is analyzed in the next chapter.

The Central Pacific is essential for meteorological processes on our planet. The phenomena known as El Niño / La Niña have a crucial influence on the weather of the western coast of South America, but not only there. The **fifth chapter** demonstrates the relationship between the sea surface temperature in the Central Pacific and the Antarctic stratosphere. The provided studies indicate the tropical region’s maximal impact on high-latitude conditions. The proposed CTP index is an excellent tool to describe this phenomenon. The correlation between sea surface temperature and ozone hole state shows interdecadal changes described in the leading atmosphere physics journals. Interestingly, the region of the maximal correlation covers the Antarctic Peninsula, demonstrating the importance of atmospheric investigations at the Akademik Vernadsky station. The time and spatial characteristics of the interconnection are analyzed in detail.

The **sixth chapter** (‘Preconditioning of the spring Antarctic ozone hole’) discusses possibilities for forecasting the Antarctic ozone state using the atmospheric data of previous months as predictors. It is well-known that the atmosphere is a dynamic medium with chaotic behavior. That is why we can forecast weather with high precision for 5–7 days only and not longer. But actually, the accuracy of forecasts depends not only on time but also on the spatial extent of phenomena. So, the larger a phenomenon the earlier it is possible to predict its mean parameters with enough confidence. Something similar is considered in this chapter, where preconditioning factors correlating with the ozone hole size over Antarctica are studied.

Primary attention is paid to unusual events with a small ozone hole and relatively high total ozone values. Such situations arise from sudden stratospheric warmings, which are frequent in the Arctic but rare in the Southern Hemisphere. An outstanding event (unique for the whole observational period) of major sudden stratospheric warming happened in 2002, when anomalously high ozone levels were observed, particularly at Akademik Vernadsky station. Similar but lesser stratospheric warmings with small ozone hole areas occurred in 1988, 2017, and 2019 austral springs. The ozone holes usually develop in September and continue in October. The October ozone hole areas differed more in the neighboring years than in September. The cited studies showed that the disturbances do not develop quickly, but the atmospheric processes in the previous several months before the ozone hole appeared in September had prepared them. The authors proposed the stratospheric temperature in the August months at the 60°S latitude as a good indicator of the future ozone hole size. It is important that the authors made a prediction of the high ozone values in 2019 at the early stage of the ozone hole evolution. It should also be noted that according to the same indicators, the ozone holes in the three following years after 2019 had a considerable size. On the other hand, this ozone hole variation demonstrates a significant role in interannual variability and difficulty in predicting the ozone recovery processes.

Finally, in the **last chapter, the** authors discuss one more aspect of the ozone variability in the Earth's climate system associated with the 11-year solar cycle. It is well known that the total solar irradiance changes to a low degree over the main cycle of solar activity. However, the variability is significant in the shortwave (X-ray, ultraviolet) and long wave (radio) electromagnetic radiation spectra. Therefore, we may expect a stronger influence on the high-stratosphere ozone, which is predominantly determined by photochemical causes. Besides, trigger effects induced by a small factor are not excluded. Therefore, searching for different atmospheric processes' reactions to solar activity is a prevalent (but sometimes speculative) task. In this case, the authors analyzed satellite data of ozone vertical distributions because total ozone does not exhibit a significant dependence on the solar cycle. Using the wavelet analysis, the authors revealed periodicity corresponding to the tropical stratosphere's solar cycle. In addition, the asymmetry between the hemispheres was analyzed with a more noticeable solar influence in the upper stratosphere of the Southern Hemisphere high latitudes.

In general, this book can be helpful for readers who are aware of the ozone hole, ozone depletion, and recovery. The book will also be useful for scientists studying the ozone distribution and dynamics in the Earth's atmosphere. Of course, this field is broad, and the authors described the phenomena they had previously studied. That is obvious because the monograph, however exhaustive, can only touch upon some problems associated with atmospheric ozone. Thus, for example, total ozone observations and dynamic processes in the stratosphere are considered in detail, but ozone-destroying reactions or pollution by tropospheric ozone are not specially analyzed. Nonetheless, an interested reader can obtain additional information from the peer-reviewed papers widely cited in the book.

Many scientists worldwide are working on the problem of atmospheric ozone since this issue is critical both for contributing to climate change and for the existence of biological life on the planet. Therefore, researchers working in atmospheric ozone and neighboring scientific fields can use this exceptional monograph in their study. The book will also be helpful for students, PhDs, and Post Docs studying the Earth atmosphere. In any case, the appearance of this new, well-written treatise on atmospheric physics is a remarkable event for the Ukrainian research community and a valuable contribution to the scientific understanding of our planet.

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