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Spatial observation of the ozone layer

Observation spatiale de la couche d'ozone

Sophie Godin-Beekmann

Laboratoire atmosphères, milieux, observations spatiales, institut Pierre-Simon-Laplace, CNRS-UPMC, 4, place Jussieu, case 102, 75231 Paris cedex 05, France

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ABSTRACT

This article provides an overview of the various satellite instruments, which have been used to observe stratospheric ozone and other chemical compounds playing a key role in stratospheric chemistry. It describes the various instruments that have been launched since the late 1970s for the measurement of total ozone column and ozone vertical profile, as well as the major satellite missions designed for the study of stratospheric chemistry. Since the discovery of the ozone hole in the early 1980s, spatial ozone measurements have been widely used to evaluate and quantify the spatial extension of polar ozone depletion and global ozone decreasing trends as a function of latitude and height. Validation and evaluation of satellite ozone data have been the subject of intense scientific activity, which was reported in the various ozone assessments of the state of the ozone layer published after the signature of the Montreal protocol. Major results, based on satellite observations for the study of ozone depletion at the global scale and chemical polar ozone loss, are provided. The use of satellite observations for the validation of chemistry climate models that simulate the recovery of the ozone layer and in data assimilation is also described.

RÉSUMÉ

Cet article fait le point sur les différents instruments satellitaires mis en œuvre pour l'observation de l'ozone stratosphérique et des constituants qui jouent un rôle clé dans la chimie de l'ozone. Les instruments satellitaires fournissent des champs globaux d'ozone en termes de colonne intégrée (ozone total) et de distribution verticale. Nous disposons de séries globales d'ozone total de façon quasi-continue depuis la fin des années 1970. Après la découverte du trou d'ozone printanier au-dessus de l'Antarctique au début des années 1980, un effort important a été consenti dans l'amélioration de la précision des différents systèmes d'observation de la couche d'ozone, afin de pouvoir détecter des changements de quelques pour cents par décennie. Ces efforts ont impliqué la mise en place d'une stratégie de validation par les réseaux de mesures au sol, du fait de la dégradation progressive des performances des instruments spatiaux au cours du temps. Les mesures satellitaires ont joué un rôle important dans la caractérisation du trou d'ozone et l'étude des mécanismes chimiques impliqués dans la perte d'ozone polaire. Plusieurs plates-formes satellitaires multi-instrumentées d'envergure ont été lancées, afin de mesurer les espèces stratosphériques clés, jouant un rôle dans l'équilibre photochimique de l'ozone. Les observations satellitaires d'ozone et des espèces associées contribuent de façon essentielle aux différents rapports d'évaluation de la couche d'ozone, élaborés depuis la signature du protocole de Montréal. Les résultats les plus récents de ces mesures, quant à l'étude du trou d'ozone antarctique et de l'évolution de la couche d'ozone à l'échelle globale sont passés en

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E-mail address: sophie.godin-beekmann@latmos.ipsl.fr.

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revue dans cet article, qui présente également l'utilisation des mesures satellitaires pour la validation des modèles de chimie du climat, mis en œuvre pour simuler le rétablissement de la couche d'ozone et l'assimilation de ces mesures dans les modèles de prévision numérique.

1. The need for global observation of the ozone layer

The depletion of the stratospheric ozone layer was the first environmental issue that aroused international concerns on the possible impact of human activities on the Earth's atmosphere at a global scale. While ozone abundance is very small in the atmosphere, not exceeding 8 to 10 molecules per million air molecules, its role on the equilibrium of the atmosphere and life on Earth makes it one of the key species in the atmosphere. Ozone absorbs ultraviolet (UV) radiation from the incident solar light. Much of the absorbed energy is input into the atmosphere and is responsible for the temperature inversion in the stratosphere, an atmospheric region that extends from about 12 to 50 km altitude. The other remarkable property of ozone is that it shields the Earth's surface from damaging UV-B radiation (280–320 nm spectral range) due to its spectroscopic properties. Before there was ozone, life was restricted to marine environments and it was only after the ozone layer was formed, about two billion years ago, that life could expand at the surface. While ozone is beneficial when it exists at high altitude, its oxidizing properties makes it harmful to human health when it is produced as a pollutant close to the surface, where it can also affect animals and plants.

Since the 1970s, as their understanding of the ozone equilibrium in the atmosphere grew, scientists raised concerns about the potential threat to the ozone layer caused by increased emission of human-manufactured chlorofluorocarbons (CFC) and halons. However, the major event was the discovery of the ozone hole over Antarctica (e.g. Chubachi, 1984; Farman et al., 1985). Although satellite measurements were not at the origin of this discovery, made from ground-based Dobson spectrometer and balloon-borne ozone sonde measurements, they played an important role on the quantification of the spatial extent of the chemical ozone destruction over Antarctic. Indeed, after the Farman et al. publication, satellite measurements showed that in each late winter/early spring season starting in the early 1980s, the ozone depletion extended over a large region centered near the South Pole. The term "ozone hole" came about from satellite images.

Since then, spatial ozone measurements have been widely used to evaluate and quantify the spatial extension of the ozone hole and global ozone decreasing trends as a function of latitude and height. Validation and evaluation of satellite ozone data have been the subject of intense scientific activity, which has been reported in the various ozone assessments of the state of the ozone layer published after the signature of the Montreal protocol. This article provides an overview of the various satellite instruments, which were developed for the observation of ozone and chemical compounds playing a key role in stratospheric chemistry. It describes the instruments that have been launched since the late 1970s for the measurement of the total ozone column and vertical distribution, as well as the major satellite missions designed for the study of stratospheric chemistry. Major satellite instruments are listed in Table 1. The main results, based on satellite observations for the study of ozone depletion at global scale and chemical polar ozone loss, are provided. The use of satellite observations for the validation of atmospheric models and data assimilation is also described.

2. Total ozone column observation from space

2.1. Satellite instruments for the measurement of total ozone column

A convenient way to measure ozone abundance is to measure its total column, which corresponds to the total number of ozone molecules in a column from the Earth's surface to the top of the atmosphere. It is generally expressed in Dobson units[1]. From the various satellite instruments that measure the total ozone column, probably the most famous is the Total Ozone Mapping Spectrometer (TOMS) that has been operated by the National Aeronautic and Space Administration (NASA) from 1978 until 2006. TOMS measures solar ultraviolet radiation scattered back into space by air molecules. Total ozone is retrieved from the different absorption of solar radiation by ozone at various wavelengths in the UV range. The first TOMS instrument began operation on board the Nimbus 7 meteorological satellite, which included also the Solar Backscatter Ultraviolet (SBUV) instrument, another ozone-measuring sensor. TOMS looked downward at several angles across the nadir track of the satellite to measure backscattered radiation at six wavelengths ranging from 312 to 380 nm. SBUV was designed to measure the ozone vertical distribution and total ozone. It looked in the nadir direction and measured the backscattered radiation at 12 wavelengths ranging from 250 to 400 nm. The concept of these instruments was based on the original Backscatter Ultraviolet (BUV) launched in 1970. The SBUV and TOMS instruments on board Nimbus 7 continued to make measurements until 1990 and 1994, respectively. The SBUV was followed by the series of SBUV/2 instruments launched on the NOAA polar orbiting series.

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[1] The Dobson Unit (DU) corresponds to the thickness of an atmospheric layer of pure ozone compressed to standard temperature and pressure (STP, 1 atmosphere surface pressure and 0 °C). Over the Earth's surface, the average thickness of the ozone layer is about 3 mm or 300 Dobson Units.