2011 NDACC Symposium
Network for the Detection of Atmospheric Composition Change

SESSION 8

SHORT TERM OZONE VARIABILITY

Oral Session

8-1 Diurnal Variation of Ozone- What we know? What we don't? Why we need to know?

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It is well known that diurnal variation of atomic oxygen causes diurnal variation of ozone in the mesosphere. These variations occur mostly around sunrise and sunset producing a square wave pattern with higher nighttime values. Based on the analysis of NDAAC microwave radiometer data from Payerne, Switzerland, it was recently suggested (Haefele et al., J. Geophys. Res., 113, D17303, doi:10.1029/2008JD009892, 2008) that there are smaller variations that occur throughout the day, even down to ~30 hPa. Since satellite and ground-based instruments measure ozone profiles at a wide variety of local times, such variations, if they are real, make it difficult to compare and validate different ozone measuring instruments. For example, solar occultation instruments measure at sunrise/sunset, lidar instruments typically measure at nighttime, Umkehr data are acquired between 70˚-90˚ solar zenith angles, instruments on the Aura satellite measure at ~1:30 pm, and those on ENVISAT satellite measure at ~10 am. In addition, some satellites in drifting orbits (UARS, SABER, NOAA, and International Space Station) have measured ozone profiles over a range of local times. Diurnal variations can make it difficult to extract seasonal, inter-annual, and trend information from these datasets.

Since NDAAC microwave radiometers can measure ozone profiles over the entire day, these data must play a crucial role in comparing and validating different satellite and ground-based instruments that measure at different local times. In this talk we will show that though there is agreement between various sensors regarding the sign of the ozone change between day and night, there are significant quantitative differences among the sensors regarding the magnitude of the change, including between NDAAC microwave radiometers. In addition, there is a lack of consensus as to whether there is diurnal variation during nighttime at any altitude. Since the nighttime variations, if any, are probably caused by solar tides, understanding nighttime variations can help elucidate the effect of solar tides on ozone. By contrast, daytime variations can also be caused by photochemical effects as well as changes in chemical loss rates due to temperature changes.

Oral Session

8-2 Diurnal cycle of stratospheric and mesospheric ozone above Bern and Payerne, Switzerland

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At the University of Bern, Switzerland, the ground-based millimeter- wave ozone spectrometer GROMOS measures the thermal radiation emitted by the ozone resonance at 142.17504 GHz. Ozone profiles in the altitude range of 20 to 65 km are retrieved. SOMORA, a second, similar but independent instrument, is operated by MeteoSwiss at the aerological station in Payerne, which is 43 km away from Bern. Both instruments, GROMOS at Bern and SOMORA at Payerne, provide ozone profiles to the Network for the Detection of Atmospheric Composition Change (NDACC). Continuous night- and daytime measurements of the ground-based microwave radiometers allow us to derive the mean diurnal cycle of ozone, which depends on dynamics, energetics, and photochemistry. An important application is the correction for systematic errors in long-term series of stratospheric ozone merged from satellites in different sun-synchronous orbits. Observations of the NDACC radiometers, data analysis, and modeling is needed if we want to derive a reliable climatology of the diurnal ozone cycle. Insolation of stratospheric ozone is the main cause of atmospheric solar tides. About 60% of the migrating solar tide is due to insolation of stratospheric ozone and about 30% of the solar tide is due to insolation of water vapour in the upper troposphere. Thus, the NDACC ozone microwave radiometers are monitoring the source region of solar tides, and their data contain information on the sub- sequent propagation of tides from the stratosphere into the mesosphere where tides dominate atmospheric dynamics. An interesting problem is the complex interaction between stratospheric ozone and dynamics during the tidal generation process. We analyze the diurnal variability of ozone as observed by the two radiometers and present the derived results of the relative diurnal variation of O3 VMR with respect to the monthly mean profile. While diurnal variations in the mesosphere are qualitatively understood (the ozone cycle is governed by photochemistry), diurnal variations in the stratosphere are less clear and observational reports are rare. Generally, the two instruments GROMOS and SOMORA agree well and a similar behaviour can be found for the diurnal ozone cycle. For the month of January and June, above 1 hPa, we find a clear signature for diurnal variation in O3 amplitudes exceeding 8%, as expected. Below 2 hPa, a phase reversal occurs in the measurements of both radiometers, showing more ozone during daytime than during night-time. We often find signatures of short-term variability in the diurnal ozone cycle of our observations. Periods of 2 to 6 hours could be associated with the solar terminator wave (or high-frequency tides). In addition, seasonal and interannual variability of the diurnal ozone cycle is present in the data of GROMOS and SOMORA. Notably, planetary waves are modulating the amplitude of the diurnal ozone cycle. The diurnal ozone cycle is also enhanced during winter-time when the polar vortex edge wobbles over Switzerland. In such situations of a strong horizontal ozone gradient over Switzerland, GROMOS and SOMORA are very sensitive to ozone advection by tidal waves.

Poster Session

8P-1 Millimeter-wave measurements of mesospheric O3 diurnal variation from Thule (76.5°N, 68.7°W) and comparison with the RO SE model

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Winter measurements of stratospheric and mesospheric constituents have been regularly carried out since January 2009 from the NDACC station at Thule Air Base (76.5°N, 68.8°W), Greenland, by means of a ground-based millimeter-wave spectrometer (GBMS). The GBMS observes rotational emission lines of O3, HNO3, CO, and N2O by tuning a spectral pass band of 600 MHz in the 230-280 GHz frequency range. The maximum spectral resolution of the GBMS is 65 kHz, which combined with its pass band results in the retrieval of vertical profiles of species concentrations between ~15 and 80 km altitude. The vertical resolution of the GBMS is limited by the inversion algorithm (recently changed to a standard Optimal Estimation Method) and averages one pressure scale height: the nominal vertical resolution (FWHM of averaging kernels) is ~8 km, although relative peaks in concentration profiles can be determined within ±1 km altitude. Retrieved mixing ratio profiles have an estimated 1σ uncertainty of ~15%. This work focuses on retrievals of mesospheric O3 obtained by deconvolving the pressure-broadened emission lines at 264.925 and 276.923 GHz. In particular, we discuss the morphology and time variations of O3 vertical profiles from 50 to 80 km altitude near sunrise and sunset, when a large O3 change takes place in this altitude range. In late winter of 2011, GBMS O3 measurements were carried out during at least one of the two transition periods each day. Occasionally, when the atmospheric opacity is particularly low, O3 spectra integrated for only 15 minutes allow us to retrieve high-precision vertical profiles. Observations of the diurnal variation of mesospheric O3 at high latitudes with such a time resolution are unprecedented. They provide insights on the photochemical processes that occur in polar regions at high solar zenith angles and represent a useful benchmark for chemical dynamical models. We compare GBMS O3 observations on selected dates (chosen to have the best signal-to-noise ratio) with results from ROSE, a global 3-dimensional mechanistic chemical dynamical model. ROSE runs on a grid spaced 11.25° in longitude and 5° in latitude, with a vertical resol ution of ~2 km in the mesosphere and a time step of 7.5 minutes. It incorporates chemistry for 27 species, including all the major reactions involving odd-oxygen and odd-hydrogen. The ROSE gridpoint that is the closest to Thule is at 77.5°N and 67.5°W. The comparison shows that agreement between observations and model results is remarkable in terms of mixing ratio values displayed both at night and in daylight, but most importantly in terms of the time evolution (at steps of 15 minutes) of mesospheric O3 as the sun slowly rises/sets during a ~1.5 hour period in the range 50-80 km altitude.

Poster Session

8P-2 Ground-based network measurements of stratospheric and mesospheric ozone in southern hemisphere with millimeter-wave radiometers

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Ozone distribution in the upper stratosphere and mesosphere is strongly affected by changes of solar-terrestrial environments; for example, penetration of high energy particles from the space, such as solar protons and relativistic accelerated electrons, into the earth atmosphere induces the change of chemical composition in the upper stratosphere and mesosphere in short and long timescale. In addition, global warming caused by increasing green house gases induces temperature decrease in the middle atmosphere, leading to long-term change of their chemical composition. To investigate horizontal and vertical structures of composition change related to environment changes in the upper stratosphere and mesosphere and to understand their mechanisms, ozone is one of the most powerful molecules as a tracer of the environment change because it is abundant and its temperature dependence is relatively large. For this reason, we started a project of network measurements of the stratospheric and mesospheric ozone distribution by using ground-based millimeter-wave radiometers with a high-sensitivity receiver. Since 2008, we installed three millimeter-wave radiometers in the southern hemisphere; Atacama highland in Chile (23°S, 68°W), Rio Gallegos in Arg entina (52°S, 69°W) where the NDACC Ozone DIAL is operated by CEILAP, and Syowa station in Antarctica (69°S, 39°E). And continuous measurements of the vertical distribution of ozone in the stratosphere and mesosphere have been carried out. Each radiometer equips a superconducting (SIS) mixer receiver which provides extremely high sensitivity in millimeter-wave region and a digital FFT-type spectrometer which has a bandwidth of 1 GHz and a resolution of 68 kHz. Using these radiometers, an ozone emission in 250 GHz band at Atacama and Syowa and in 250 GHz band at Rio Gallegos has been measured every 10 minutes, and its vertical profile in stratosphere and mesosphere has been retrieved from the spectrum. In addition, NO and NO2 emissions in 250 GHz band have been measured simultaneously at Atacama and Syowa stations because they are the dominant molecules related to ozone depletion in the middle atmosphere, and are expected to be enhanced due to penetration of high energy particles. The ozone distribution measured with the radiometers was compared with independent dataset such as satellite and ozone sonde measurements, and we confirmed that they showed a good agreement within 15%. Up to present, we have clearly detected various variations of ozone in altitude. In this presentation, details of measurement strategies, instrumentation and data validation will be reported, and correlations between observed ozone variations and index of environment change in altitude will be discussed.

Poster Session

8P-3 Intraseasonal oscillations of stratospheric ozone above Switzerland

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GROMOS, the ground-based millimeter-wave ozone spectrometer, continuously measures the stratospheric ozone profile between the altitudes of 20 and 65 km above Bern (46°57'N, 7°27'E) since November 1994 in the frame of NDACC (Network for the Detection of Atmospheric Composition Change). Characteristics of intraseasonal oscillations of stratospheric ozone are derived from the long-term data set. Spectral analysis gives evidence for a dominant oscillation period of about 20 days in the lower and middle stratosphere during winter time. A strong 20-day wave is also found in collocated geopotential height measurements of the microwave limb sounder onboard the Aura satellite (Aura/MLS) confirming the ground-based observations of GROMOS and underlining the link between ozone and dynamics. Remarkably, the ozone series of GROMOS show an interannual variability of the strength of intraseasonal oscillations of stratospheric ozone. The interannual variability of ozone fluctuations is possibly due to influences of planetary wave forcing and the quasi-biennial oscillation (QBO) on the meridional Brewer-Dobson circulation of the middle atmosphere. The summer spectra of intraseasonal oscillations clearly have smaller amplitudes than the winter spectra. This finding is in agreement with the explanation that tropospheric planetary waves can propagate into the winter stratosphere but not into the summer stratosphere because of a zonal wind reversal at the summer tropopause. The strongest ozone variations above Bern are probably caused by displacements of the stratospheric polar vortex towards the European longitude sector. These vortex displacements are caused by planetary waves, planetary wave breaking, shear flow instabilites, or sudden stratospheric warmings. In detail, time series of the mean amplitude of ozone fluctuations with periods ranging from 10 to 60 days are derived at fixed pressure levels from GROMOS. The mean amplitude series are regarded as a measure of the strength of intraseasonal oscillations of stratospheric ozone above Bern. After deseasonalizing the mean amplitude series, we find QBO-like amplitude modulations of the intraseasonal oscillations of ozone. The amplitudes of the intraseasonal oscillations are enhanced by a factor of 2 in 1997, 2001, 2003, and 2005. QBO-like variations of intraseasonal oscillations are also present in wind, temperature and other parameters above Bern as indicated by meteorological reanalyses of the European Centre for Medium-range Weather Forecasts (ECMWF). In several years, the observed enhancements of the 20-day wave are coincident with the occurence of sudden stratospheric warmings. Further, intercomparisons of interannual variability of intraseasonal tropospheric and stratospheric oscillations are performed where the NAO index (North-Atlantic oscillation) and the MJO index (Madden-Julian oscillation) are taken as proxies for tropospheric oscillations. As a result, interannual variability of intraseasonal oscillations of the stratosphere seems not to be well correlated with respect to that of the troposphere.

Poster Session

8P-4 A new millimeter wave radiometer installed in the NDACC site of Río Gallegos, Argentina

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With the aim of contribution to the study of atmospheric ozone layer, a new sensitive radiometer for atmospheric minor constituents has been installed in the Observatorio Atmosférico de la Patagonia Austral, División LIDAR, CEILAP (CITEDEF-CONICET), in October 2010. This observatory is established in the city of Río Gallegos (51º 36’ S, 69º 19’ W) Argentina, close to the spring ozone hole. The millimeter wave radiometer was developed in STEL (Solar Terrestrial Environment Laboratory), Nagoya University, Japan. This passive remote sensing instrument is able to measure the ozone (O3) amount in the high stratosphere and mesosphere continuously and automatically with a high time resolution each thirty minutes. The millimeter wave radiometer ozone profiles will be supplemented with the ozone profiles obtained from the DIAL system existent in the observatory as part NDACC. The aims of this work are to show the potential of the millimeter wave radiometer installed in the subpolar latitudes close to the polar ozone hole and to present the preliminary result of the first measurements.

Poster Session

8P-5 New Millimeter-wave spectroscopic radiometer in Syowa station and a study of the influence of solar activity on the polar middle atmosphere

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The polar regions have a significant importance to understand the global Earth system, and some unique phenomena such as ozone hole, polar stratospheric clouds, noctilucent clouds reflect the anthropogenic effects on the Earth's environmental. In addition, the atmospheric composition of some minor constituents is more sensitive to solar activity because the terrestrial magnetic fields that shield the Earth against the energetic charged particles open to space from the polar regions. When a huge solar explosion occurs, energetic solar protons directly enter the middle atmosphere, and the induced magnetic storm increases the auroral electron precipitation into the upper atmosphere, leading to trigger ion-molecule reactions that influence the atmospheric composition in the polar middle atmosphere. To date, several observational examples of such energetic particle precipitation (EPP) effects have been reported, for example, as ozone depletion in the mesosphere coincident with a strong solar proton event (e.g., Jackman et al, 2001) and as descending NOx-rich and Ozone-poor air formed by auroral electrons in the vortex during the polar nights (e.g., Seppälä et al. 2007). Most of those observations were carried out by satellite instruments, and the observing position moves from hour to hour in spite of the short timescale of the EPP effect by solar proton event lasting only a few days. In contrast, ground-based observations can trace the continuous time variation from a fixed location with shorter time resolution if the observing instrument has appropriate sensitivity. Such EPP effects are expected to increase in the next few years toward the solar maximum. Thus we planed to install a millimeter-wave spectroscopic radiometer in Antarctica to study the influence of solar activity on the polar middle atmosphere. The millimeter-wave spectroscopic observation allows us to obtain vertical profiles of minor constituents from 20km to 70km.

In the end of 2010, STEL (Solar-Terrestrial Environment Laboratory) of Nagoya University and NIPR (National Institute of Polar Research) installed a millimeter-wave spectroscopic radiometer at Japanese Syowa station in Antarctica The radiometer is equipped with a very low noise SIS (superconductor–insulator -superconductor) receiver operating around 250GHz and a digital spectrometer with 1GHz band width and 60kHz resolution. The SIS receiver is cooled down to ultralow temperature by using a cryogenic refrigerator that required large electric power, but the capacity of power generator in Syowa station is limited and almost saturated. Therefore we newly developed a power-saving cryogenic receiver system, and we succeeded to reduce the power consumption by factor of 3. The receiver noise temperature is ~80K (DSB), and we can obtain ozone vertical profiles every 30 min – 1 hour from ground under the typical condition of atmospheric optical depth of ~ 0.2. In this presentation, we will describe the new feature of the radiometer system and present the initial observational results.

This research program is conducted as a part of the VIII-th term Prioritized Research Project of National Institute of Polar Research (NIPR) entitled “Global environmental change revealed by observations of the Antarctic middle and upper atmosphere” and the medium-term project of Solar-Terrestrial Environment Laboratory (STEL) of Nagoya University , “Research on magnetic storm and atmospheric change at the solar maximum”.

Poster Session

8P-6 Diurnal Variations of Stratospheric Ozone Measured by Ground-based Microwave Remote Sensing at Two NDACC sites: Results and Error Estimates

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Ground-based measurements of ozone in the stratosphere and mesosphere can be made throughout the day using ground-based microwave remote sensing techniques. For the substantial diurnal ozone variations in the upper stratosphere and mesosphere, observations have long since been reported and interpreted in terms of the relevant photochemistry (e.g. Connor, et al., 1994, and references therein). There is presently renewed interest in these measurements for the purpose of supporting homogenization of records of various ozone measurements that are made at different times of day. For example, solar occultation measurements can be made with satellite-borne instruments only at sunrise and sunset, while lidar measurements are only made at night. This problem can also affect records made with a single satellite-borne instrument if the local time at which the measurement is made changes substantially during the lifetime of the satellite. These issues are discussed in more detail by Bhartia, et. al. We have reprocessed our NDACC microwave ozone data for Mauna Loa, Hawaii and Lauder, New Zealand with hourly time resolution to allow measurement of diurnal variations over a wider altitude range than previously reported. While the well-known, photochemically driven variations are typically seen at levels above about 1 hPa, our data, as normally processed, also show statistically significant variations, of the order of a few percent, below that level. The physical interpretation of these variations is beyond the scope of this paper. Because the observed variations below 1 mb are small yet important for homogenization purposes, we here concentrate on validation of our observed variations. We have searched for diurnally varying spectral errors, and have considered potential mechanisms through which the intensity calibration of the spectra may be diurnally affected. We will discuss our technical approach to this investigation, and present climatologically representative plots of diurnal ozone variations for both sites and their estimated statistical and diurnally systematic errors as we understand them at the time of the meeting. We will also compare our measurements to collocated AURA MLS day and night and SBUV morning and

afternoon (NOAA 16, 17, and 18) measurements. References: Bhartia, P. K., Diurnal Variation of Ozone – What we know, what we don't, why we need to know, submitted for presentation at this meeting. Connor, B. J., D. E. Siskind, J. J. Tsou, A. Parrish, and E. E. Remsburg, Ground based microwave observations of ozone in the upper stratosphere and mesosphere, J. Geophys. Res., 99, 16757-16770, 1994.