Characterizing diurnal variations of ozone for improving ozone trend estimates

Abstract

Stratospheric ozone profiles from satellite and ground-based instruments are collected at different local times. To create a homogeneous long-term record of O_3 from these sensors one needs to remove possible biases between instruments caused by diurnal effects. Several ground-based microwave radiometer instruments that are part of the Network for the Detection of Atmospheric Composition Change (NDACC), including instruments at two Swiss stations located at Payerne and Bern, have been measuring diurnal variations of O_3 for more than 20-30 years. Recent analyses of these data indicate that there is significant local time variation of ozone in the upper stratosphere, perhaps down to the mid stratosphere (20 hPa). The variations are particularly large (10-15%) around 1 hPa, and appear to have significant seasonal and latitudinal dependence. Satellite data and model results show similar variations. However, the differences between models and measurements, and between measurements themselves can sometimes be quite large. It is necessary to resolve these differences in order to develop a scientific consensus on the diurnal variations of O_3 at different altitudes. The aim of this proposed effort is to bring together a representative group of scientists from the measurement and modelling community to develop such a consensus.

History, Scientific Rationale, and Goal

The diurnal variation of ozone in the stratosphere and mesosphere was already a research topic in the late 1970s and early 1980s (Herman, 1979; Lean, 1982; Pallister and Tuck, 1983). The motivation was to investigate the time response of atmospheric constituents participating in large photochemical reaction chains. The diurnal ozone variation depends on the altitude, solar zenith angle, advection processes, temperature, and the concentrations of halogens such as NOx, HOx, ClOx (also having diurnal variations). At that time, observational evidence of the small diurnal variation of stratospheric ozone was based on a few rocket measurements (Lean, 1982) while the large diurnal variation of mesospheric ozone was clearly observed by in situ rocket measurements and ground-based microwave radiometers (Hilsenrath, 1971; Lobsiger and Künzi, 1986). It seems that the research theme „diurnal ozone variation" disappeared in the following years from 1986 to 2007 because of the appearance of the ozone hole.

A comprehensive picture of diurnal ozone variations in the middle atmosphere does not exist yet. However, based on the past research work, recent advances in chemistry-climate modelling and atmospheric remote sensing, it should be feasible to derive a global climatology of the diurnal ozone variation. Such a climatology and understanding of the diurnal ozone variation are needed for accurate merging of ozone data sets from satellites in different sun-synchronous orbits. Figure 1 illustrates the problem of ozone trend estimation from a series of BUV instruments (Backscatter UV radiation) of Nimbus and NOAA satellites with drifting equator-crossing LT (local time). The derivation of a harmonized global data set of stratospheric ozone profiles for the past 40 years clearly requires the removal of local time effects due to the drifting satellite orbits. Otherwise, the trend estimates of stratospheric ozone are biased by systematic errors of a few percent per decade. Merging of measurements from different satellite types is even trickier and correspondingly larger errors are possible if no accurate correction methods are applied. Monitoring of the expected, slow increase of stratospheric ozone in the next 40 years until 2050 requires a higher accuracy than the past measurement of the large depletion of stratospheric ozone from 1975 to 1995. Long-term monitoring of stratospheric ozone certainly remains an important task for mankind because of the complex interactions between man-made climate change, ozone depletion, and natural variability of the Sun-Earth system.

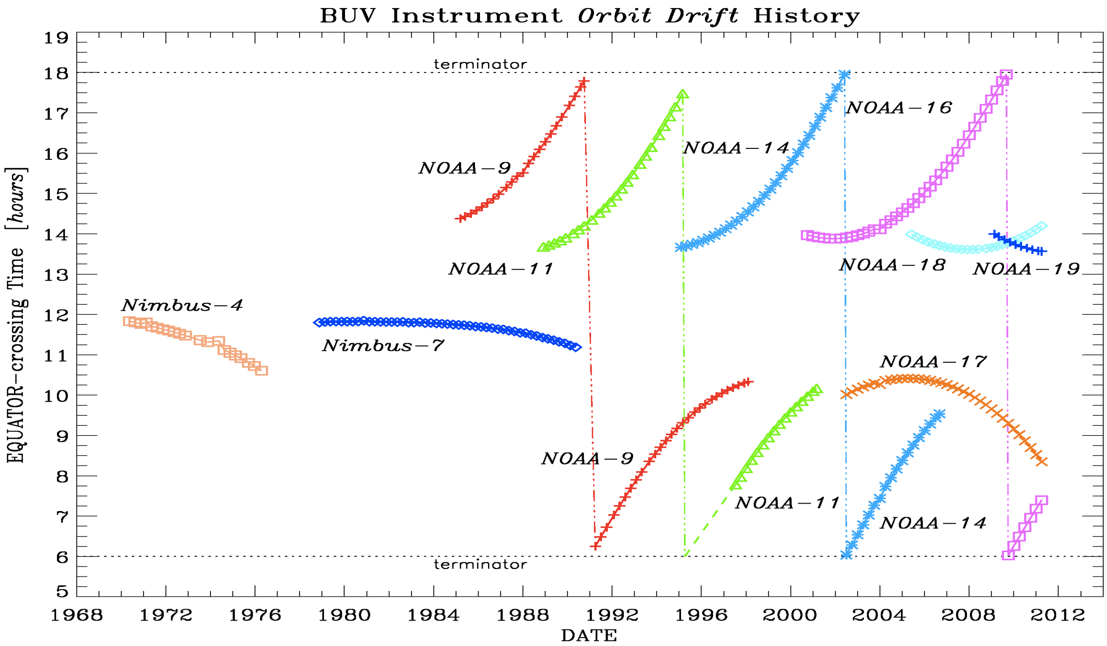

Figure 1 Orbit drift history as shown by equator-crossing local time of ozone instruments aboard of Nimbus and NOAA satellites since 1970. A reanalyzed 40 year record of ozone profiles from 8 BUV instruments is being released. Since the instruments measured at different LTs, diurnal variation of ozone may complicate the analysis of trends (Courtesy of P. K. Bhartia).

Some characteristics of the diurnal ozone variation are shown in Figure 2 where we select as an example the diurnal ozone variation above Switzerland. The observational results well agree with the model results. However we need much more cross-validations before we can derive a global climatology of the diurnal ozone variation. The goal of the ISSI team is to foster such cross-validations and to derive at least a preliminary climatology. Then we can test wether we can correct the satellite data for diurnal effects of ozone.

The modelers are not sure if their models can handle the complex interactions between solar radiation, chemistry, and dynamics. In addition, realistic estimations of the concentrations of many atmospheric constituents are required for modelling of the diurnal ozone variation. The data sets of SMILES, Odin/SMR, TIMED/SABER, ENVISAT/MIPAS, Aura/MLS and other satellite instruments may give narrow constraints to the models. However, the observers (ground and space) are uncertain about occurrence of systematic errors in measurement and retrieval which may affect the derived diurnal variation of ozone and ozone depleting substances (ODS). The proposed ISSI team brings modellers and observers together in order to combine their knowledge on the diurnal variation of ozone with the aim to improve ozone trend estimates.

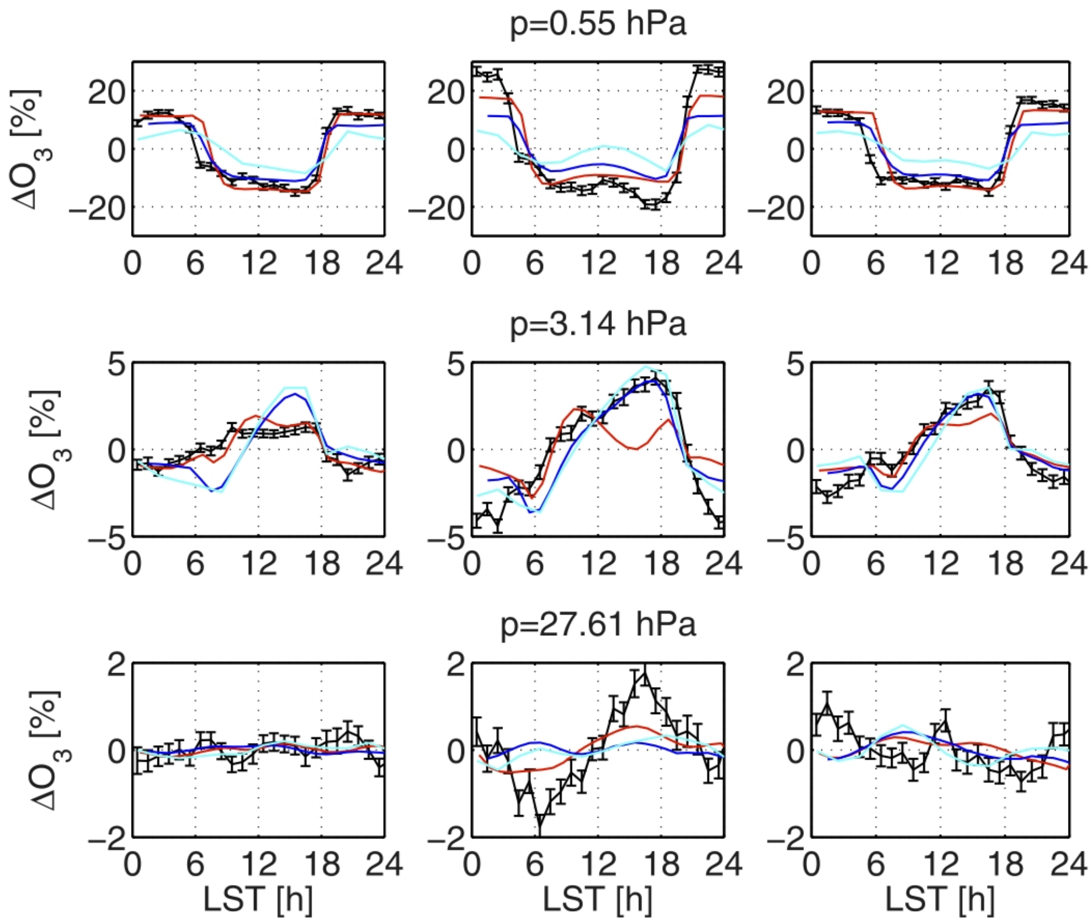

Figure 2 Dependence of the diurnal ozone variation at Payerne Switzerland on altitude and season (spring equinox, summer solstice, fall equinox - from the left to the right). The observations (black line) are obtained by a ground-based microwave radiometer. The colored lines show the diurnal ozone variation estimated by 3 chemistry-climate models (Haefele et al., 2008).

Research plan of the ISSI team

The proposed ISSI team is dedicated to following challenges:

1) Generate a comprehensive picture of diurnal ozone variations by using ground-based and space-based observations, model simulations, and reanalysis data. Cross-validation and merging of data sets possibly leads to this goal

2) Derive characteristics of the diurnal ozone variation as function of altitude, season, geographic location, and other parameters

3) Explain the physics and chemistry of diurnal ozone variations. Describe connections to diurnal variations of temperature and halogens

4) Discuss the sytematic errors in trend estimation caused by diurnal effects. Discuss the feasibilty of a correction of diurnal effects in long-term ozone series from satellites and ground stations

5) Improving ozone trend estimates by a correction method for diurnal effects

The team members have access to necessary data and within the last few years have authored/coauthored papers on different aspects of the proposed project. Many of the team members have new data sets of model simulations and observations which may contain a comprehensive picture of diurnal ozone variations. An example is the new data set of ozone chemistry obtained by the SMILES instrument on the International Space Station. The main goal of the ISSI team is foster the exchange between the researchers, to initiate cross-validations, and to combine the latest results from remote sensing and modelling of the diurnal ozone variation.

Timeliness of project

Recovery of ozone layer, O_3 assessment, impact on policy, ESA/EU Sentinel-4 and Sentinel-5 mission.

Expected output

We expect studies of different nature: a) Cross-validation studies between models and observations, b) Studies on the characteristics of the diurnal ozone variation, c) Studies on the physics and chemistry of the diurnal ozone variation. We expect to submit three or four papers to the leading peer-reviewed journals. An important spin-off of the project could be a better observation, modelling and understanding of the generation of atmospheric tides in the middle atmosphere.
In the best case, a correction method is found and tested for the diurnal effect in long-term ozone series. This enables an improved long-term trend estimation of stratospheric ozone. A possible recovery of the stratospheric ozone layer could be detected with a higher accuracy. Impacts of the ozone recovery on climate change could be faster addressed. Results of the proposed project will be presented at multiple national and international conferences, including EGU and AGU meetings. Several members of the team are actively involved as organizers, conveners, and invited speakers at these meetings. A special session on diurnal variations in temperature and ozone is prepared by Philippe Keckhut at the EGU 2013.

The added value of ISSI

The project team members are the leading experts in different aspects of the proposed topic from several European countries, as well as USA and Japan. The team members establish links between atmospheric chemistry and dynamics. They are experts for modelling, remote sensing, and analysis of stratospheric ozone. Due to the interdisciplinary nature of this research as well as limited resources within a particular sub discipline and country, these experts do not have an opportunity to jointly address the research topic in a systematic and comprehensive manner. The ISSI offers a unique opportunity to bring together many experts. The synergy of this team therefore warranties a major impulse to this research, particularly to the research programmes Integrated Global Atmospheric Chemistry Observations (IGACO) within Global Atmosphere Watch (GAW), SPARC SI2N initiative on Past Changes in the Vertical Distribution of Ozone, and the Network for the Detection of Atmospheric Composition Change (NDACC). Additional added value for ISSI is advanced diagnostics and merging of satellite ozone data. Several team members are involved in satellite missions led by JAXA, ESA, and NASA.

Schedule of the project

All team members confirm availability and willingness to attend the proposed ISSI workshop on the planned dates. Team members will also make every effort to attend at alternate times if the dates would be adjusted in consultation with ISSI. Before first meeting: Preparation of the initial material by each group member. Every team member shall inspect their data and summarize initial results. Several team members will plan and discuss in advance of the first ISSI meeting. This activity takes place at the Quadrennial Ozone Symposium in Toronto (27-31 August, 2012).

First meeting (end of 2012): Presentation of the state of research, initial results, planing of joint analysis and cross-validations
Second meeting (fall 2013): Derivation of characteristics of diurnal ozone variations. Discussing the physics and chemistry of diurnal ozone variations.
Third meeting (summer 2014): Testing a correction method for diurnal variations in ozone.

Between the team meetings at ISSI, we plan to study the diurnal ozone variations in every institution, providing results to all team members. Series of online meetings is proposed within 3-4 months after meetings at ISSI.

Facilities required

One meeting room with

a. Internet access for laptops
b. Printer connection for laptops (or access to a computer with a printer).
c. Video-conference facility: if available: Access Grid rather than Skype

Financial support requested of ISSI

- Per diem to individual team members to cover living expenses while in Bern
- Team leader travel costs is transfered to a scientist from abroad
- Support of 2 Young Scientists (per diem)

References

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