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The natural variability of stratospheric and mesospheric ozone as observed over Switzerland by a ground-based microwave remote sensor

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Abstract. Continuous ground-based microwave observations of the vertical middle atmospheric ozone profile are performed at the Institute of Applied Physics of the University of Berne, Switzerland, since November 1994. The high temporal resolution, associated to the continuity of the achieved datasets, allows a detailed characterization of the natural cycles affecting stratospheric and mesospheric ozone above this midlatitude observation site on a daily to decadal time scale.

Key words. Earth: ozone - Earth: atmospheric chemistry - Earth: remote sensing

1. Introduction

Ground-based remote sensing observations of the middle atmospheric ozone profile are performed at several european stations of the Network for the Detection of Stratospheric Change (NDSC, http://www.ndsc.ncep.noaa.gov/) since more than a decade (Godin et al. 1989; Claude & Wege 1991; Kämpfer 1995). The stability and continuity of the achieved datasets allows the assessment of long-term changes affecting stratospheric and mesospheric ozone at the midlatitudes. Simultaneously, the high temporal resolution of the ground-based measurements allows the characterization of short-term variations, such as the daily cycle in mesospheric ozone. Characterization of these cycles is of relevance to climate studies, for the investigation of the ozone contribution to radiative forcing. In the present study, we use ground-based microwave (MW) remote sensing measurements to determine the amplitude and phase of the natural cycles affecting middle atmospheric ozone as a function of altitude.

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2. Data Set

Since November 1994, continuous observations of the middle atmospheric ozone profile are performed at the University of Bern (46.95°N/7.45°E) using the Ground-based Millimeter-wave Ozone Spectrometer (GROMOS). GROMOS is a triple-switched, total power microwave radiometer. The instrument measures the thermal emission of ozone at 142.175 GHz. As the observed emission line is broadened by pressure, informa-

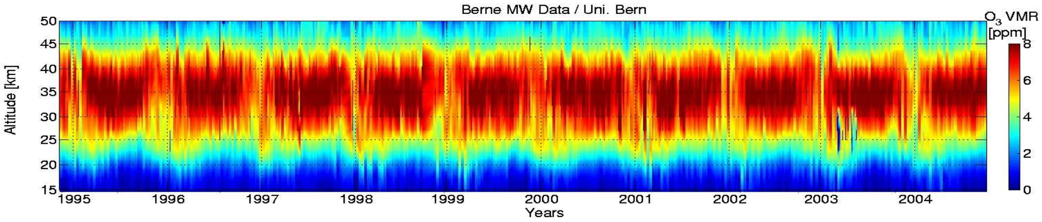

Fig. 1. Times series of the ozone profile measured above Bern between 1994 and 2004.

tion about the vertical distribution of ozone in the atmosphere can be retrieved from the measured spectra by means of an inversion algorithm (Rodgers 1976). After 2 hours, sufficient signal-to-noise ratio is achieved in the GROMOS measurements to retrieve ozone volume mixing ratio profiles in the altitude range 15 - 70 km. Ground-based microwave radiometers allow unattended, continuous observations of the atmosphere which are nearly independent of weather conditions. A review of the methodology and instrumentation used for ozone observations in the microwave frequency range is given for example in Clancy & Muhleman (1993). The time series of the GROMOS measurements is represented in Figure 1.

3. Data Analysis

We used a simple iterative spectral analysis of the GROMOS times series in order to determine the amplitude and phase of periodic cycles influencing middle atmospheric ozone above Bern. In a first step, a fast fourier-transform analysis was performed in order to identify the periodic signals contained in the times series at each altitude. A least-squares fit of the strongest signal was then performed in the analyzed data, allowing to determine the signal amplitude and phase. The last two steps were then repeated iteratively, until all significant periodic contributions were removed from the data set. Finally, the achieved periodic signals were compared to the original bandpass filtered data, in order to assess the reliability of the achieved results.

4. Results

4.1. Semi-Annual & Annual Cycles

Figure 2 shows the results of a .5 and 1-yr signals fit into the GROMOS measurements (bottom), and the original data filtered using a 5 to 15 months bandpass window (top). A consistent picture of the semi-annual and seasonal cycles contained in the Bern data is obtained in both figures. Lower stratospheric ozone, and consequently total ozone, peaks at the midlatitudes in the winter as a result of the enhanced Brewer-Dobson circulation. In the middle stratosphere, increased oxygen photolysis leads to increased midlatitude ozone concentrations during summer. In addition, large semi-annual variations are observed in the upper stratosphere and the mesosphere. Comparable results were obtained when analyzing independent lidar measurements performed at the Observatoire de Haute Provence and at the Hohenpeissenberg observatory (not shown).

4.2. Quasi Biennial Oscillation (QBO)

Figure 3 (bottom) shows the results of a QBO equivalent (2.5-2.7-yrs) signal fit into the Bern MW measurements, and the original data filtered using a 25 to 32 months bandpass window (top). Clear features appear in the bandpass-filtered data, revealing the existence of a QBO-like signal in midlatitude ozone up to the mesosphere. The seemingly random character of these features is contradicted by the results of the periodic signal fit. Those indicate a downards signal propagation with a phase-shift of several months from the mesosphere to the lower stratosphere. Similar results were

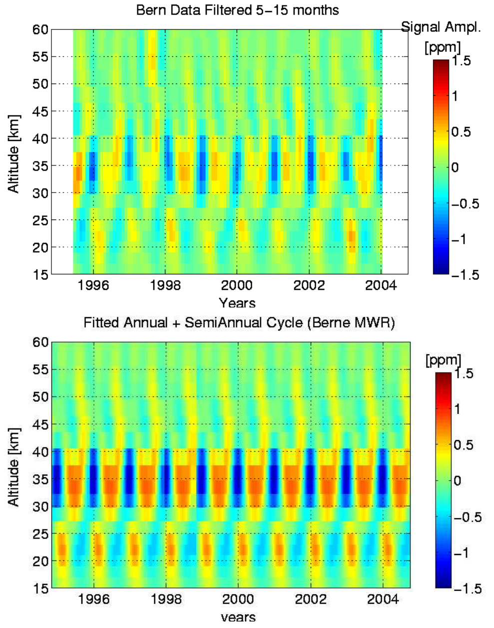

Fig. 2. Bandpass-filtered MW ozone data (top) and corresponding semi-annual and annual signal fit (bottom).

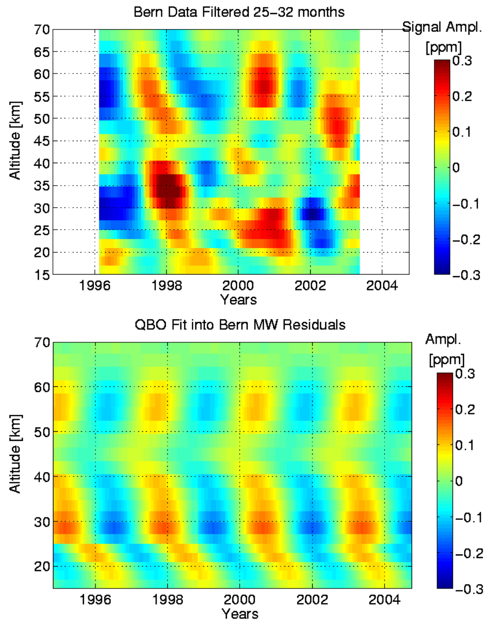

Fig. 3. Bandpass-filtered MW ozone data (top) and corresponding QBO signal fit (bottom).

obtained when analyzing the independent lidar measurements series, confirming the existence of consistent QBO features in all data sets.

4.3. Decadal Ozone Variation

Despites the rather restricted length of the considered times series compared to a solar cycle, an attempt was made to estimate the influence of decadal changes in solar irrandiance on middle atmospheric ozone. A least-squares fit of an imposed 11-yr period signal was thus performed in the GROMOS data. The corresponding results are shown in Figure 4. Increased ozone concentrations are observed in the lower stratosphere during periods of increased solar activity, while a signal with opposite phase is obtained in the mesosphere. No unambiguous relationship to solar activity can however be derived from the present results, due to the limited length of the considered data set and the possible interference of the fitted signal with long-term linear ozone trends.

4.4. Mesospheric Ozone Cycle

The amplitude of the diurnal variations in mesospheric ozone was investigated by considering season-dependent composite times-series of the Bern MW measurements as function of altitude (Figure 5). After sunset, fast recombination of atomic and molecular oxygen leads to a significant increase of ozone concentrations at the high altitudes.

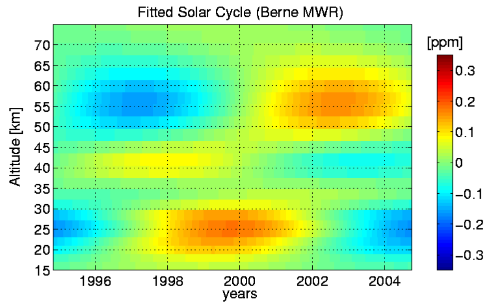

Fig. 4. 11-yr periodic signal fitted in the Bern MW data.

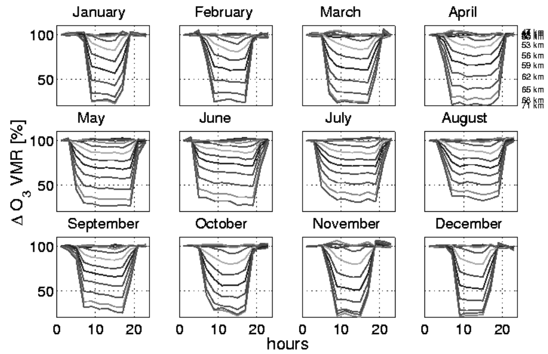

Fig. 5. Daytime decrease in mesospheric ozone relative to nighttime values.

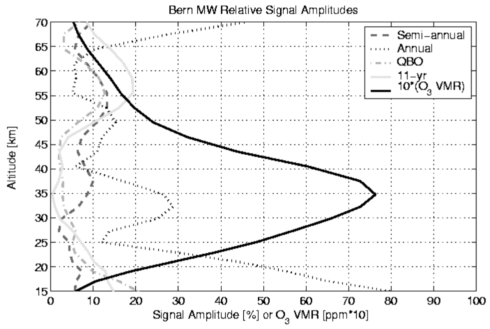

Fig. 6. Baseline profile and relative amplitude of ozone cycles fitted in Bern MW data.

4.5. Summary

Figure 6 shows the relative amplitude of the periodic signals fitted into the MW times series as a function of altitude. The results are dominated by the annual cycle in the stratosphere, and by the decadal signal in the mesosphere. The semi-annual, quasi-biennial, and decadal oscillations show comparable relative amplitudes. These results can be compared to the amplitude of day-to-day variations in mid-latitude ozone during winter, which locally can reach up to 40% as a result of enhanced planetary wave activity (Calisesi et al. 2001).

5. Conclusions

The performed analysis provides a quantitative insight into the periodic cycles influencing middle atmospheric ozone above a mid-latitude observation site. Strong seasonal variations determine the ozone contrentations in the middle and the lower stratosphere, while a QBO-analogue signal is observed throughout the stratosphere and the mesosphere. Decadal changes seem to dominate over all other cycles in the lower mesosphere, however, with an ambiguous relationship to solar variability.

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