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Ground-based Microwave Observations and Model Calculations of Ozone Depletion in the Arctic Atmosphere due to the Solar Proton Events in October/November 2003

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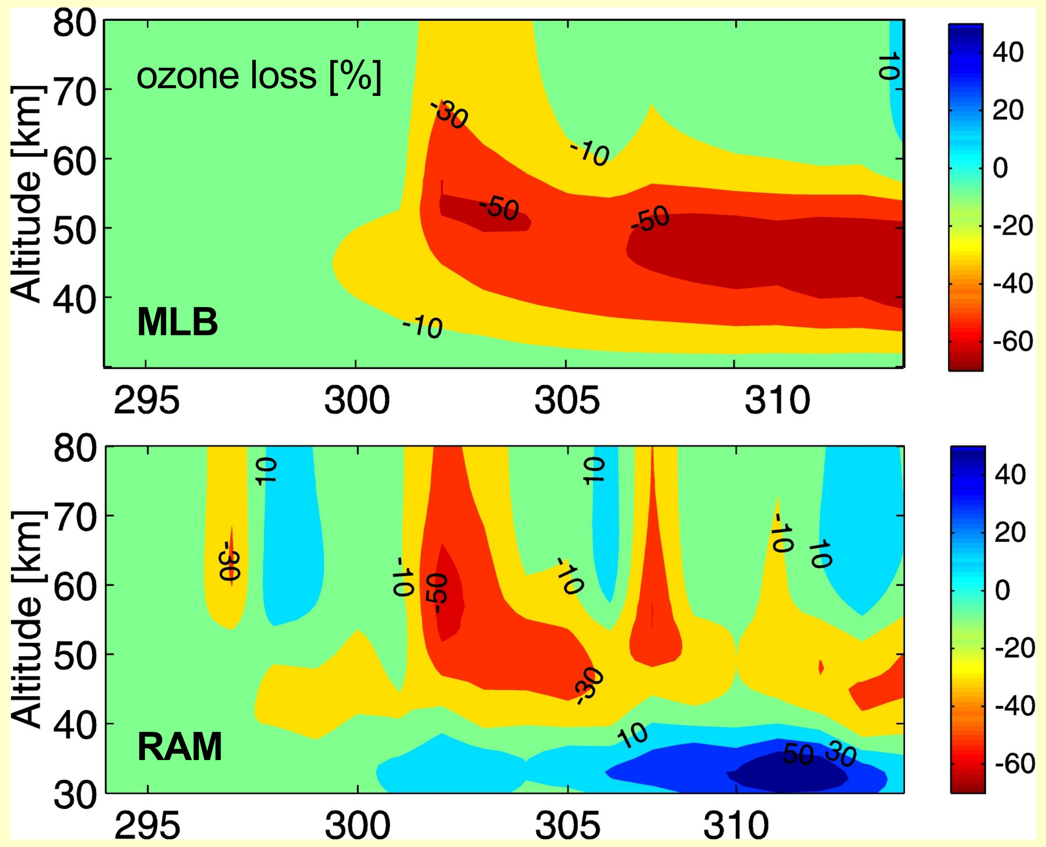

Fig. 1: Comparison of MLB model data for ozone (upper panel) and measurements of RAM (lower panel) at Ny-Ålesund from mid-October to mid-November 2003. The model data was smoothed by the averaging kernels of RAM to consider the limited vertical resolution of the instrument.

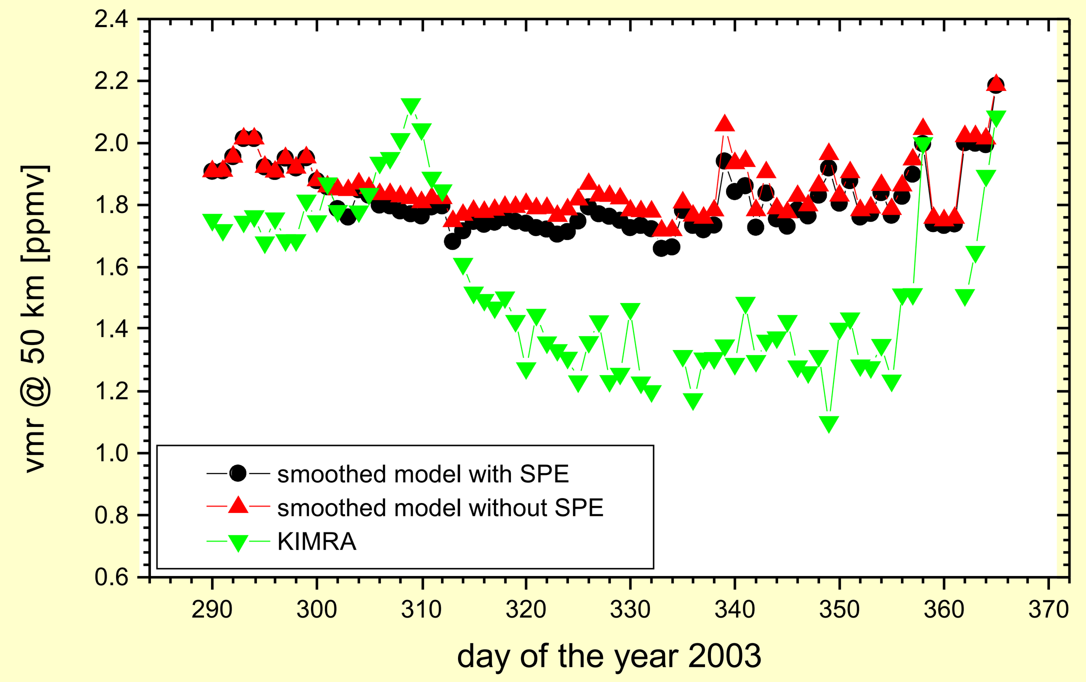

Fig. 2: Comparison of MLB model data for ozone and measurements of KIMRA at KIRUNA at 50 km altitude from mid-October to end of December 2003. The model data was smoothed by the averaging kernels of KIMRA to consider the limited vertical resolution of the instrument.

CAWSES

PEP

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Introduction

Between 26 October and 6 November 2003 large solar storms caused a series of strong solar proton events (SPEs) in the earth's atmosphere. The high energetic particles led to the formation of odd hydrogen (HO_x) and odd nitrogen (NO_y) and had an impact on ozone chemistry in the atmosphere.

Two ground-based microwave radiometers, the KIMRA instrument at IRF Kiruna (67.8°N, 20.4°E) and the RAM instrument at Ny-Ålesund (78.9°N, 11.9°E), measured ozone during the solar proton events and in the following months. The effect of the SPEs on ozone chemistry in the atmosphere is investigated by comparison of the measurements to model calculations using the Modified Leeds-Bremen Model (MLB, IUP Bremen) and the Karlsruhe Simulation Model of the Middle Atmosphere (KASIMA, Forschungszentrum Karlsruhe).

The Measurements

KIMRA and RAM are heterodyne radiometers using schottky mixer diods. Spectral analysis is performed by acousto optical spectrometers with about 1 GHz bandwidth and a spectral resolution of about 1 MHz. RAM measures the strong ozone line at 142.2 GHz and KIMRA the ozone twin-peak at 195.5 GHz. For the retrieval a modified Optimal Estimation Method is used resulting in vertical ozone vmr profiles of at best 7 km vertical resolution in the altitude range 17-60 km.

The MLB Model

The MLB model is a 2-dimensional chemistry and transport model of the middle atmosphere. The chemistry is based on the SLIMCAT code (Chipperfield, 1999), which was adapted to the mesosphere and runs from the surface up to about 93 km. The model includes a parameterization of NO_x and HO_x production due to ionization (Jackman et al, 2005). It calculates its own temperature, pressure and horizontal transport on isentropic surfaces with a vertical spacing of about 3 km, from the surface up to about 100 km (Kinnersley, 1996). Vertical transport is derived from heating rates calculated with the models trace gas composition. Ionization rates are calculated from GOES-11 proton flux measurements using a Bethe-Bloch algorithm. Isentropic ionization is assumed within the polar caps (> 70° geomagnetic latitude). Both, Kiruna and Ny-Ålesund are considered to be within the polar cap.

The KASIMA Model

Two KASIMA simulations have been perfomed to investiagte the influence of SPEs: a standard run without SPEs and a perturbed run with SPEs. Both have been initialized on March 30, 2002, with a horizontal resolution of 5.6 x 5.6 degrees. To account for the SPEs MIPAS-ENVISAT nighttime measurements of enhanced NO_2 during the SPE's has been used to reinitialize the calculated NO_x in the perturbed KASIMA model run. For more details see: Reddmann et al., 2006.

Short-Term Effects lasting several days

To investigate the short-term effects of the 2003 SPEs lasting for about one month the microwave measurements were compared to the MLB model results. One model run was done including the SPEs and one without the SPEs. To consider the limited vertical resolution of the radiometers the model results were smoothed by the averaging kernels of the measurements.

The contour plots of Fig. 1 show the loss of O_3 compared to a mean vmr calculated from 21 to 24 October for Ny-Ålesund. The model run captures the SPE well although the dynamic of the O_3 loss and recovery is underestimated. It has to be mentioned, however, that the model run is on a latitude of 75°N whereas the RAM-measurements are at 79°N. This might explain the discrepancy. The model does also miss the dynamical effects which may interfere with the effects due to the SPE's.

The comparison of the smoothed MLB model data and the measurements of KIMRA at an altitude of 50 km is shown in Fig 2. Neither the model nor the measurements show a significant effect of the event. However, the comparison is complicated by the strong dynamical variability at 50 km altitude, which is not reproduced well by the model. This explains for example the discrepancies during the increasing vmr values in the measurements before day 310. The effect of the SPEs in the model data itself is smaller than that which was found for Ny-Ålesund due to the lower solar zenith angle over Kiruna and the resulting higher background HO_x concentration during that time at this lower latitude.

Long-Term Effects lasting several Months

The long-term effects of the SPEs lasting several months are investigated by the comparison of the KIMRA measurements and model data of KASIMA. The limited vertical resolution of the measurements was also regarded by smoothing the model data using the averaging kernels of the measurements.

Fig. 3 shows the comparison of the Kiruna data to KASIMA model results. An ozone decrease at 35 km altitude in the KASIMA data lasting for about six months is clearly visible and a good agreement between measurement and model is found. Fig. 4 shows the plot of KASIMA model results versus KIMRA measurements between end of October 2003 and end of August 2004. Values closer to the line through origin and gradient one can be seen in the model data including the SPEs.

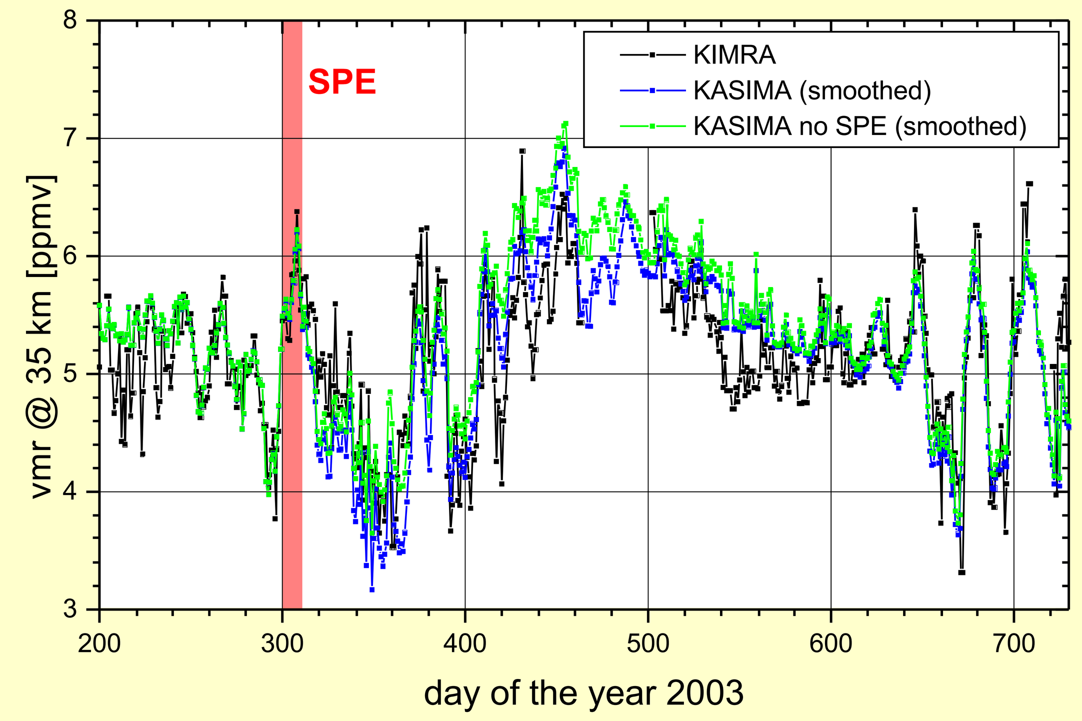

Fig. 3: Ozone at 35 km altitude over Kiruna from mid-July 2003 to end of December 2004 as measured by KIMRA and modeled by KASIMA. One model run was done with (blue series) and one without (green series) the solar proton events. The KASIMA calculations are smoothed by the KIMRA averaging kernels to account for the limited vertical resolution of KIMRA.

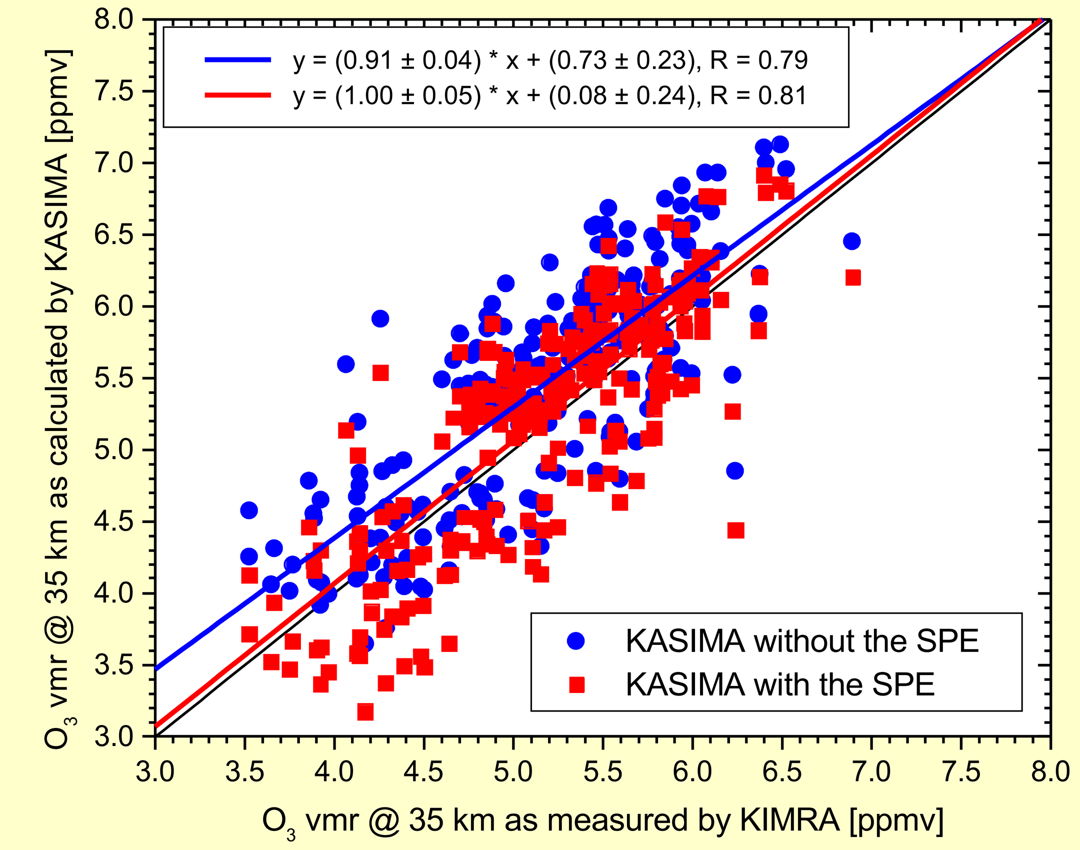

Fig. 4: Correlation of ozone vmrs at 35 km altitude as measured by KIMRA and modeled by KASIMA. The KASIMA run in blue was calculated without the effects of the solar proton events, the run in red including these effects.

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