Nowcast and short-term forecast in the middle atmosphere based on the observed UV irradiance.

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Introduction

The nowcast and short-term forecast of the space weather based on the different observational data gained recently a lot of attention, because the perturbation of the Solar activity is able to induce substantial changes in the Earth environment, which turn out to be important for the space operations, radio-wave propagation, GPS functioning and many other aspects of the mankind activity. Among other elements of the space weather it is of interest to understand and predict the state of the neutral compounds in the middle atmosphere, which determines in part the reaction of the ionosphere to the variability of the Sun activity. An important aspect of this issue is an evaluation and prediction of the response of the middle atmosphere to the solar ultraviolet irradiance variability.

For the solar UV irradiance high quality observation data are available from a variety of satellite instruments for the past and there will be more data available in real time in the future. For example, the LYRA instrument onboard PROBA-2 satellite will provide the solar irradiance for several wavelengths important for the middle atmosphere in real time (Hochedez et al., 2004). It has not been clearly shown yet what part of the species and temperature changes in the middle atmosphere is defined by the solar irradiance variability and what is the contribution of the non-linear transport. There are some evidences that the ozone and temperature depends on the solar irradiance variability during known 27-day solar rotation cycle, but it was also pointed out by Rozanov et al. (2005) that the correlation between solar irradiance and ozone in the middle atmosphere strongly depends on the atmospheric meteorological state implying that the atmospheric dynamics and transport play an important role in the response of the middle atmosphere to solar irradiance variability. Therefore, for a successful nowcast and short-term forecast we need to show that: (i) the quantity under consideration is sensitive to the solar irradiance variability and (ii) the contribution of the dynamical noise is reasonably small.

To answer these questions we applied chemistry-climate model (CCM) SOCOL (Egorova et al., 2005) to simulate the distribution of the temperature and gas species in the upper stratosphere and mesosphere. As an input for the simulation we exploit daily spectral solar irradiance measured by SUSIM instrument onboard UARS satellite in January 1992. We have carried out an ensemble of nine 1-month long simulations using slightly different initial state of the atmosphere. We have compared the obtained time evolution of the simulated species and temperature with available satellite measurements. The obtained results allowed us to define the areas where the nowcast and short-term forecast of the atmospheric species with CCM SOCOL could be successful.

SOCOL description

(modeling tool to evaluate SOlar-Climate-Ozone Links)

General Circulation component : MA-ECHAM4 (*Manzini & McFarlane, 1998*)
Chemistry/transport component : MEZON (*Rozanov et al.,1999, Egorova et al.,2003*)

Grid: spectral model with T30 (Gaussian grid 3.75°x3.75°); L39 hybrid sigma-pressure coordinate system; in the LS ~ 2 km; model top is at 0.01hPa (~80 km);

GCM part:

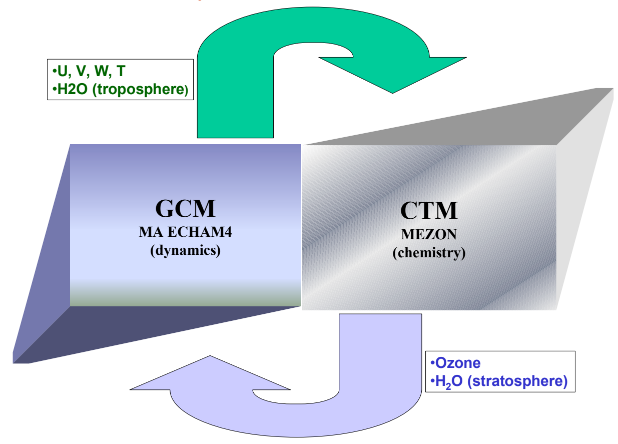
Dynamics: semi-implicit time stepping scheme with a weak time filter: Δt = 15'
Radiation: Δt = 2 h, adopted from ECMWF (Fouquart&Bonnel,1980; Morcrette, 1991) ;
Gravity wave: based on the formulation of (McFarlan, 1987), vertical propagation follows Hines(1997)
Transport: Semi-Lagrangian for water vapor, liquid water, and tracers (Williamson and Rash, 1994)
Horizontal diffusion : in the form of a hyper-Laplasian with high-diffusion sponge zone at the upper boundary(~5 km)
cloud formation, convective processes, planetary boundary layer, land-surface processes

ACTM part:

Species: 41 from O-, N-, H-, C-, Cl- and Br- families, 118 gas-phase, 33 photolysis reactions, 16 heterogeneous reactions on/in sulfate aerosol (binary and ternary solutions) and PSC particles *(Carslaw et al., 1995)*
Chemical solver : implicit iterative Newton-Raphson scheme *(Ozolin, 1992; Stott&Harwood, 1993)*, Δt=2 h
Kinetics : JPL-1997, 2000
Photolysis rates: Δt = 2 h, look-up-table approach
Transport: Hybrid numerical advection scheme *(Zubov et al., 1999)* :
Prather scheme is in vertical direction and Semi-Lagrange scheme is in horizontal

Modeling tool

Chemistry-Climate Model SOCOL



Experimental design:

Nine one-month long model runs have been carried out for 1992 conditions. The difference between ensemble members consists of slightly different initial state of the atmosphere. The boundary conditions and external forcing are identical for all ensemble members. The sea surface temperature and the sea ice distributions have been taken from Gleckler (1996), which represents climatology over the last 20 years. The stratospheric aerosol, greenhouse gas and ozone destroying substances concentrations, and the sources of NO_x, CO are the same as in (Rozanov *et al.*, 1999, 2001). The coefficients for photolysis and heating rates calculations in the model have been updated daily using the solar energy spectrum obtained by the SUSIM instrument onboard of the UARS satellite for the year 1992. The radiation in visible and near-infrared parts of the spectrum was kept unchanged. From the described simulation daily and zonal mean temperature, ozone, hydroxyl and water vapor mixing ratio have been stored, which allows analyzing the response of these quantities to the solar irradiance variability during sun rotation cycle.

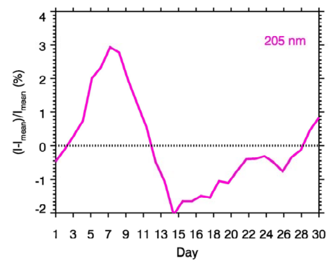


Figure 1. Deviation of the solar irradiance at 205 nm from its monthly mean for January 1992. The data are from SUSIM instrument onboard UARS satellite.

The solar irradiance variability at 205 nm during January 1992 applied for the calculation is illustrated in Figure 1. During the considered year the solar activity was rather high and due to non-homogeneity in the Sun spots distribution the solar irradiance increased from January 1 reaching its maximum on January 7. Then the solar irradiance reached its minimum on January 14 and after that it has been steadily increasing until the end of January.

Results

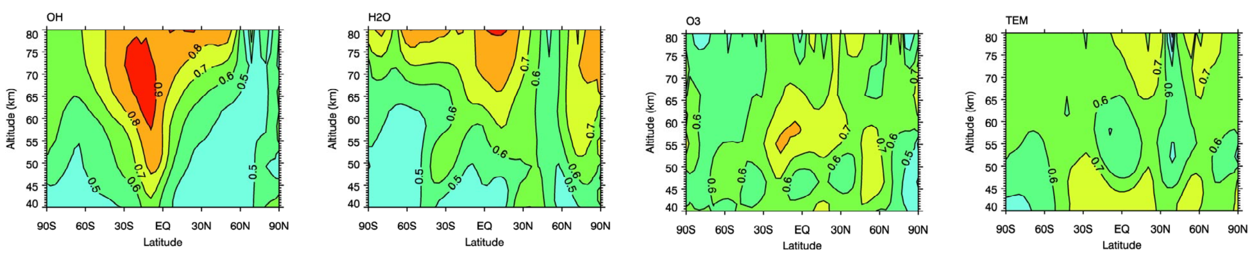


Figure 2. Maximum of the cross-correlations between simulated ensemble mean quantities and solar irradiance at 205 nm.

To estimate the dependency of the simulated quantities on the solar irradiance variability we calculated cross-correlation functions between ensemble mean hydroxyl, ozone, water vapor, temperature and solar irradiance at 205 nm with time lag ±15 days. The absolute maximum of the cross-correlation function is presented in Figure 2 for every latitude and altitude. The correlation coefficients are the highest (~0.8) in the tropical area and in the upper mesosphere. Over the northern high latitudes we cannot expect any correlations, because the solar irradiance cannot reach polar night areas, however some correlations can be induced by the dynamical changes resulting from the ozone and temperature perturbations. The ozone production due to photolysis of oxygen in Schumann-Runge bands and Herzberg continuum intensifies with increase of the solar irradiance in the lower mesosphere and most of the stratosphere, however in the rest of the mesosphere the ozone and solar irradiance anti-correlates due to enhanced ozone destruction by hydroxyl. These two processes are responsible for rather high correlation between ozone and solar irradiance. The maximum correlations occur in the tropical lower mesosphere and over the northern middle latitudes. The latter presumably reflects the changes in the atmospheric dynamics and transport. The correlation between temperature and solar irradiance is explained by the additional direct (due to increased energy flux) and indirect (due to ozone increase) heating. The highest correlation between temperature and solar irradiance take place in the upper mesosphere and upper stratosphere. The presented results confirms that the atmospheric state is sensitive to the perturbations in the solar irradiance.

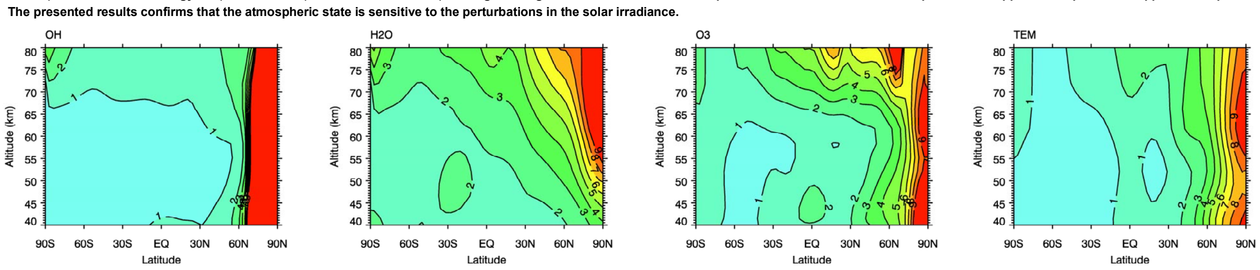


Figure 3. Mean absolute deviation among the ensemble members averaged over 30-day interval . Mean absolute deviation for species are shown in percent relative to the mean mixing ratio. Mean absolute deviation for the temperature is given in (K).

To estimate the sensitivity of the atmospheric response to the atmospheric state we calculated mean absolute deviation among our nine ensemble members for any particular day and location. The averaged mean absolute deviation over 30 days of the model run reflects the sensitivity of the model results to the atmospheric states. A small mean absolute deviation means that all ensemble members demonstrates similar behavior in reproducing the time evolution of the atmospheric state. While, a large mean absolute deviation indicates that the dynamical noise dominates and the simulated time evolution of the atmospheric state is not robust. The mean absolute deviations for hydroxyl, ozone, water vapor and temperature are presented in Figure 3. The obtained results show that the non-linear behavior is mostly confined to the northern middle and high latitudes, where the atmospheric dynamics is the most active during boreal winter. Over the tropics and southern hemisphere the time evolution of the atmospheric state is more robust.

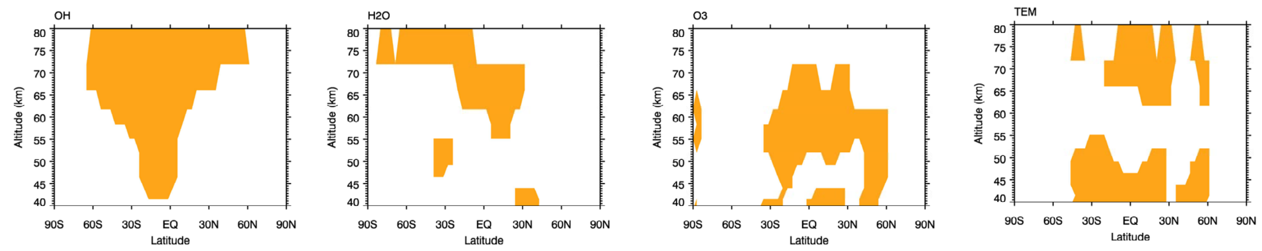


Figure 4. Areas where the nowcast and short-term forecasts of the considered quantities can be carried out with higher probability of the success.

Using the combination of two above-analyzed criteria we can define the areas where the probability of successful nowcast and short-term forecast of the considered quantities based on the solar irradiance data is higher. For these areas we request the correlation coefficient to be higher than 0.7 and mean absolute deviation to be lower then 4% for considered species and lower then 4K for the temperature. The obtained latitude-altitude cross sections of these areas are depicted in Figure 4 for all considered species. From the obtained results we can conclude that the temperature can be successfully predicted in the upper tropical stratosphere and mesosphere. For the water vapor and hydroxyl this area confines mostly to the tropical mesosphere and upper mesosphere over the southern middle and high latitudes. The ozone can be successfully predicted in the tropical lower mesosphere and upper stratosphere over the northern middle latitudes.

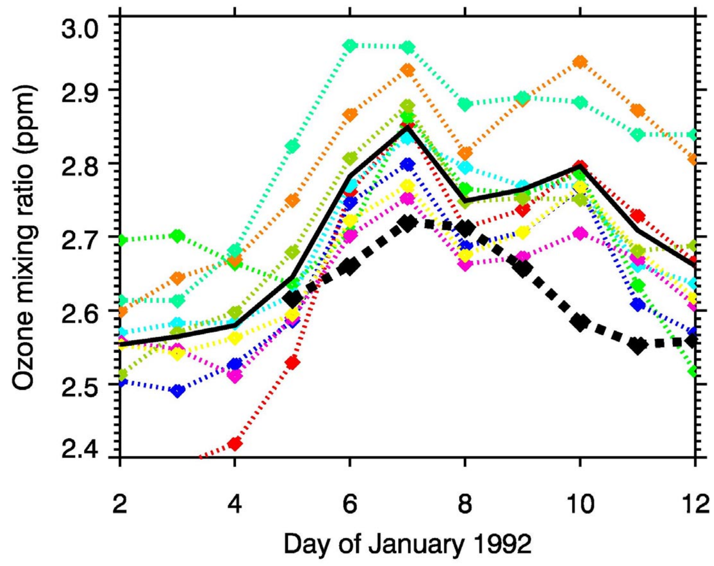


Figure 5. Zonal mean ozone volume mixing ratio (ppmv) at 48 km averaged over 40°N-50°N from HALOE data (dotted black line) and from the model results. The ensemble mean is shown by solid black line, color lines represent different ensemble members.

It is of great interest to examine our conclusions using satellite data obtained during January 1992. For this purpose we made use of the ozone daily data measured by HALOE instrument onboard UARS satellite. Unfortunately, the quality of the ozone data in the mesosphere is rather poor, therefore we compare our model results with HALOE ozone only near the stratopause. For the comparison we used satellite data collected during sunrise events, which cover northern middle latitudes (~40°N-50°N) from January 5 up to January 12. The zonal mean and daily mean simulated ozone mixing ratio is presented in Figure 5 together with smoothed HALOE data. Despite of some differences all ensemble members reveal an increase of ozone mixing ratio from January 2 to January 7 and a subsequent decrease, which correlate reasonably well with the time evolution of the solar irradiance shown in Figure 1. The simulated and observed ozone behavior do not coincide completely, but it can be hardly expected because the satellite data have been collected during sunrise and the latitudes of data sampling are slightly different from day to day, while the simulated data represent daily and zonal mean values. However, the similar features are clearly visible in HALOE and simulated ozone, which confirms our conclusions about potentially successful nowcast and short-term forecast of the ozone in this area.

Conclusions and outlook

With the chemistry-climate model SOCOL we simulated the time evolution of the temperature and several atmospheric constituents during January 1992 using solar UV irradiance observed by SUSIM instrument onboard UARS satellite. We have estimated the correlation between time series of the simulated quantities and solar irradiance at 205 nm and defined the area in the middle atmosphere where the UV solar variability is one of the main driving forces. Performed ensemble simulation of the atmospheric state allowed to define the level of noise due to non-linear atmospheric dynamics and transport. Using the combination of these two limiting factors we define the area in the middle atmosphere where the nowcast and short-term forecast can be performed using our model with the highest level of success. Comparison of the simulated ozone behavior with observation data confirmed that successful nowcasting and short-term forecasting is possible inside the defined areas. It should be noted that our results are valid only for January 1992, when the variability of the solar irradiance was rather well pronounced and the meteorological conditions were typical for boreal winter season. Further studies are necessary to define these areas for different seasons and years. In the future we intend to address this issue using CCM SOCOL driven by the highly accurate irradiance obtained from LYRA (Hochedez et al., 2004) measurements. The simulated results will be compared with time evolution of the species obtained from the different data available from a variety of ongoing satellite missions. Another aspect which should be taken into account for the further studies is the influence of the particles entering the Earth's atmosphere during geophysical events.

Main References:

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2. Hochedez, J.-F. et al., LYRA: the Solar UV radiometer aboard the ESA Proba-2, Advances in Space Research, submitted, 2004.
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