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Solar signal in atmospheric ozone, temperature and dynamics simulated with CCM SOCOL in transient mode

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Abstract. We have carried out a set of transient runs of the Chemistry-Climate Model SOCOL covering 1975-2000 driven by time evolving sea surface temperature and sea ice distributions, sulfate aerosol loading, spectral solar irradiance, greenhouse gases and ozone destroying substances. We present the solar signal in the atmosphere extracted from these transient runs. For the estimation of the atmospheric response to the solar irradiance variability we use multiple regression analysis to define the contribution of the imposed solar radiance changes to the time evolution of the simulated quantities and to estimate their sensitivity to the solar irradiance changes from the solar maximum to minimum cases. The solar signal extracted from the transient runs has been compared to the solar signal obtained from the steady-state simulations with the same model. In general, the ozone response obtained from the transient simulation is closer to the observation data analysis than the results obtained from the steady-state experiment. The ozone response in the lower mesosphere and upper stratosphere to the solar irradiance changes is mostly positive ($\approx 1-2\%$). Above 30 km the ozone response is well pronounced ($< 5\%$) and occurs at 40 km over the middle latitudes. The ozone response is smaller ($< 2\%$) in the tropical middle stratosphere, while two additional maximums appear in the UTLS over the northern high and southern middle latitudes. The solar signal in the temperature extracted from the transient runs resembles the results of the steady-state run by the location and magnitude of the warming spots. The differences appear to be substantial only in the UTLS region over the middle latitudes. They comprise in the additional warming with magnitude exceeding 0.6 K. These elevated temperatures presumably reflect an intensification of the polar vortices. The solar signal obtained for several other simulated quantities is also analyzed.

1. Introduction

The interest to the different aspects of sun-climate relationship issues is driven by the necessity to understand the role of solar activity in observed climate change. According to IPCC the last few decades have seen a rapid rise in globally averaged surface temperature (IPCC 2001). Observations and statistical models suggest that solar variability might be a significant contributor to the observed climate change. One of the proposed mechanisms how solar variability might influence the Earth's atmosphere is based on the idea that changes in solar UV flux affect ozone production and radiative heating in the stratosphere and involve a modulation of dynamical processes. To study this mechanism Climate-Chemistry model (CCM) SOCOL has been developed (Egorova et al. 2005). Results of the steady-state experiments for solar maximum and solar minimum conditions have been described by (Egorova et al. 2004) where it has been shown that the simulated solar signal is not in a reasonable agreement with the solar signal observed from the analysis of the observations. Because the solar signal in the real atmosphere is transient by nature the question arises whether the agreement between simulated and observed solar signals can be improved if we analyze the solar signal simulated with the same model in transient mode? To answer this question we performed transient experiments with SOCOL covering 1975-2000 period of time and driven by realistic set of time evolving forcing: sea surface temperature and sea ice (SST/SI), greenhouse gases (GHG), ozone depleting substances (ODS), volcanic aerosol, and solar irradiance changes (varying spectral solar irradiance affecting solar fluxes, photolysis and heating rates). The set up of the experiment and the applied forcing have been described by Rozanov et al. (2005). To extract the solar signal from the simulated time series we applied linear multiple-regression analysis. This approach is based on the representation of the simulated time series of the considered quantities as a linear combination of the considered forcing mechanisms. For GHG and ODS forcing mechanisms we have used time series of the applied CO_2 mixing ratio and total chlorine loading. As a proxy for volcanic forcing we used time series of the vertically integrated aerosol extinction at 550 nm in the tropical area. The solar irradiance variability is represented by the time series of the solar irradiance at 205 nm.

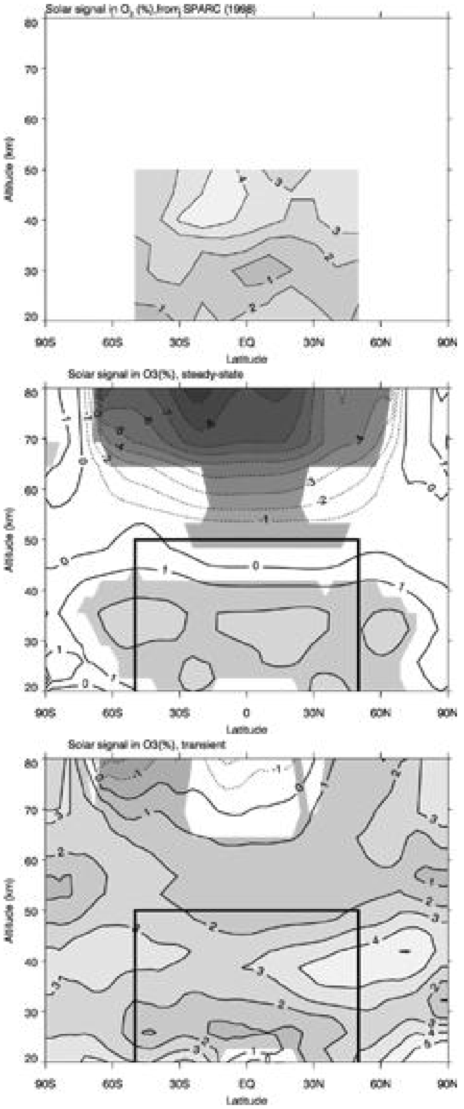

Fig. 1. The changes of the zonal and annual mean ozone(in percent) from the solar maximum to solar minimum estimated from (a) the SPARC, 1998, (b) steady-state runs(solar max minus solar min), (c) transient run (multiple regression analysis). Shaded areas on (b) and (c) show where the simulated signal is statistically significant.

2. Comparison observation analysis

The applied multiple regression analysis enables to estimate the sensitivity of the model quantities to the solar irradiance variability during 11-year cycle of the solar activity. This sensitivity has been compared with the results of the steady-state run to elucidate how the solar signal depends on the experimental set-up and retrieval procedure.

2.1. Ozone

Figure 1 represents the solar signal in the zonal and annual mean ozone obtained from the (a) data analysis (SPARC 1998), and simulated in (b) steady-state (Egorova et al. 2004) and (c) transient modes. The solar signal extracted from the transient simulation using multiple regression analysis substantially deviates from the steady-state results. In the mesosphere and upper stratosphere the ozone response is mostly positive (≈1-2%) and the negative response in the upper mesosphere is reduced. However, the ozone increase near mesopause over the high latitudes resembles the steady-state results very well. Above 30 km the maximum ozone response is more pronounced (up to 5%), occurs at higher altitudes (≈40 km) and shifted toward the poles. The ozone response is smaller (<2%) in the tropical middle stratosphere, while two additional maximums appear in the upper troposphere/lower stratosphere (UT/LS) over the northern high latitudes and southern middle latitudes. In general, the response obtained from the transient simulation is closer to the observation data analysis than the results of steady-state simulations.

2.2. Temperature

Figure 2 represents the solar signal in the zonal and annual mean temperature obtained from the (a) data analysis (WMO 1999), and simulated in (b) steady-state (Egorova et al. 2004) and (c) transient modes. Simulated transient solar signal in the temperature reasonably resembles the results of the steady-state run by the location and magnitude of the warming spots. The differences appear to be substantial only in the UT/LS region over the middle latitudes. They comprise in additional warming with magnitude exceeding 0.6 K. These elevated temperatures presumably reflect an intensification of the polar vortices. Presented here preliminary analysis confirms that our model is sensitive to the solar irradiance variability and the obtained results are rather promising.

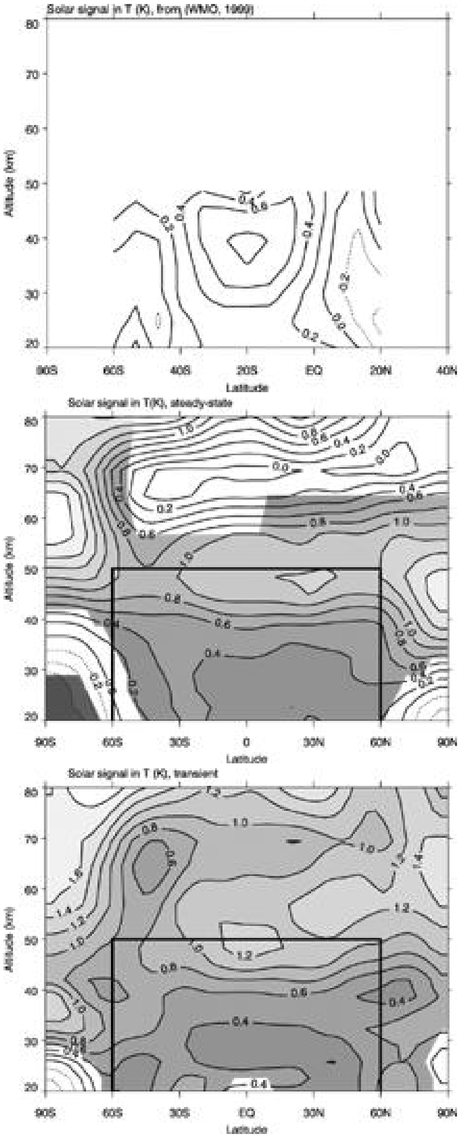

Fig. 2. The changes of the zonal and annual mean temperature (in K) from the solar maximum to solar minimum estimated from (a) the WMO, 1999, (b) steady-state runs(solar max minus solar min), (c) transient run (multiple regression analysis). Shaded areas on (b) and (c) show where the simulated signal is statistically significant.

2.3. Conclusions

We compare the solar signal obtained from the results of transient and steady- state runs carried out with CCM SOCOL and compare with the results of observation data analysis. The pattern of the solar signal extracted from the transient run is similar to the steady-state one. Transient solar signal in the temperature and zonal wind is less pronounced than steady-state, while the transient solar signal in ozone is more pronounced. The solar signal in ozone and temperature extracted from the transient run using multiple regression analysis is closer to the observations than the results of the steady-state run. Further analysis of the obtained simulation results is required to elucidate the causes of disagreement between the results of steady-state and transient simulations.

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