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Patterns of carbon monoxide in the middle atmosphere and effects of solar variability

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Abstract

We determine the spatial-time patterns of zonally averaged carbon monoxide (CO) in the middle atmosphere by applying Principle Component Analysis to the CO data obtained from the Microwave Limb Sounder (MLS) measurements on the Aura satellite in 2004–2012. The first two principal components characterize more than 90% of the CO variability. Both principal components are localized in the low thermosphere near the mesopause. The first principal component is asymmetric relative to the poles. It has opposite signs in the Northern and Southern Hemisphere at mid to high latitudes and strongly oscillates with an annual periodicity. The second principal component has the same sign in both hemispheres and oscillates mainly with a semi-annual frequency. Both principal components are modulated by the 11-year solar cycle and display short-term variations. To test possible correlations of these variations with the short term solar ultraviolet (UV) variability we use the simultaneous measurements of the UV solar radiance from the Solar-Stellar Irradiance Comparison Experiment (SOLSTICE) on the Solar Radiation and Climate Experiment (SORCE) satellite to investigate the correlation between CO in the middle atmosphere and solar UV in 2004–2012. Using a wavelet coherence technique a weak, intermittent 27-day signal is detected in high-frequency parts of the CO principal components.
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Keywords: Middle atmosphere; Solar variability

1. Introduction

The primary source of carbon monoxide (CO) in the middle atmosphere is photolysis of carbon dioxide ($CO_2 + h\nu \rightarrow CO + O$). Most of the CO is produced in the upper mesosphere and thermosphere and transported down to the lower mesosphere and stratosphere near the polar regions (Solomon et al., 1985). The solar UV radiation absorbed in this reaction belongs mostly to the Schumann–Runge continuum 176–192.6 Å (Solomon et al., 1985; Allen et al., 1991/1992). Thus CO is expected to be sensitive to solar variability effects.

New accurate measurements of CO from the Microwave Limb Sounder (MLS) on the Aura satellite (Minschwaner et al., 2010; Lee et al., 2011) along with simultaneous measurements of the solar irradiance from the Solar Radiation and Climate Experiment (SORCE) satellite (McClintock et al., 2000) open an opportunity to further investigate the global distribution of carbon monoxide in the middle atmosphere and trace the influence of solar variability on it. The Aura MLS and SORCE 2004–2012 data cover the recent solar minimum period between the cycles 23 and 24 and the beginning of the 24th solar cycle allowing useful insights on the solar-driven chemistry and dynamics of the middle atmosphere. Using MLS CO data for 2002–2012 Lee et al. (2013) showed that the solar-cycle variation dominates the long-term variability of the polar mesospheric CO concentration at high latitudes. The MLS CO time series was compared with the SORCE data and a significant, positive correlation up to 0.5 was found in the winter upper polar atmosphere suggesting that the interannual variabil-

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ity in mesospheric CO was induced by solar radiance changes.

Here we identify major patterns of spatial-time variability of CO in the middle atmosphere and investigate their relationship to solar variability. In addition to the solar cycle time scale we look at possible forcing of the middle atmospheric CO by the solar radiance on shorter time scales associated with the 27-day variability, which is caused by the solar rotation modulation of the UV radiation from the bright spots (faculae) on the solar surface. The 27-day variations in MLS stratospheric ozone and temperature have been investigated and compared with SORCE ultraviolet radiation (Ruzmaikin et al., 2007). Signatures of the 27-day solar rotation in mesospheric OH and H_2O were found in MLS data by Shapiro et al. (2012). To circumvent the problem of the time scale difference between solar variability and dynamical changes in CO we will investigate the correlation between the time variability of the global CO patterns and the solar UV.

2. Data and methods of data analysis

We use version 2.2 of the MLS CO data gridded separately for day and night. The data are assembled over pressure levels from the upper troposphere (316 hPa) to the top of the thermosphere (10^{-5} hPa). The typical single-profile precision of MLS V2.2 CO varies from 0.02 ppmv at 100 hPa, 0.2 ppmv at 1 hPa, to 11 ppmv at 0.002 hPa, with vertical resolution of 4, 3, and 9 km, respectively (Pumphrey et al., 2007). Here we focus on the range of levels from 0.5 hPa (bottom of the mesosphere) to 0.001 hPa (low thermosphere). The MLS CO product at these heights has a systematic error of about 20% (see Table 2 in Pumphrey et al. (2007)). Because the errors increase with heights we do not use the data above 0.001 hPa. The daily CO fields are mapped onto a $4^\circ \times 8^\circ$ latitude-longitude grid. The Aura MLS data are provided for latitude bins between 84°S and 84°N. The data are processed for ascending (day) and descending (night) part of the satellite orbit. Here we show the results for the day-time data. The time period used in our study is from day 221, 2004 to day 265, 2012. There are 81 missing days in the MLS CO measurements. A large data gap occurred in between day 85–109 in 2011 with 23 missing days. To cover the gaps we interpolate the data between the missing days. For the interpolation we use the “inpaintn” algorithm (Garcia, 2010). The algorithm, based on the discrete cosine transform and a penalized least squares method, allows fast smoothing of data including data with large gaps that occurred in the MLS record. An iteratively weighted robust version of the algorithm takes care of missing and outlying values.

For solar UV we use the SORCE/SOLSTICE) data (McClintock et al., 2000) available at http://lasp.colorado.edu/sorce/ from February 25, 2003 to May 2013. Here we use the measurements made by SOLSTICE B in the mid ultraviolet range 170–320 nm. The spectral radiance in the Schumann–Runge continuum is provided by the UV channels that measure the solar spectral irradiance in ultraviolet (UV) from 115 to 320 nm with a resolution of

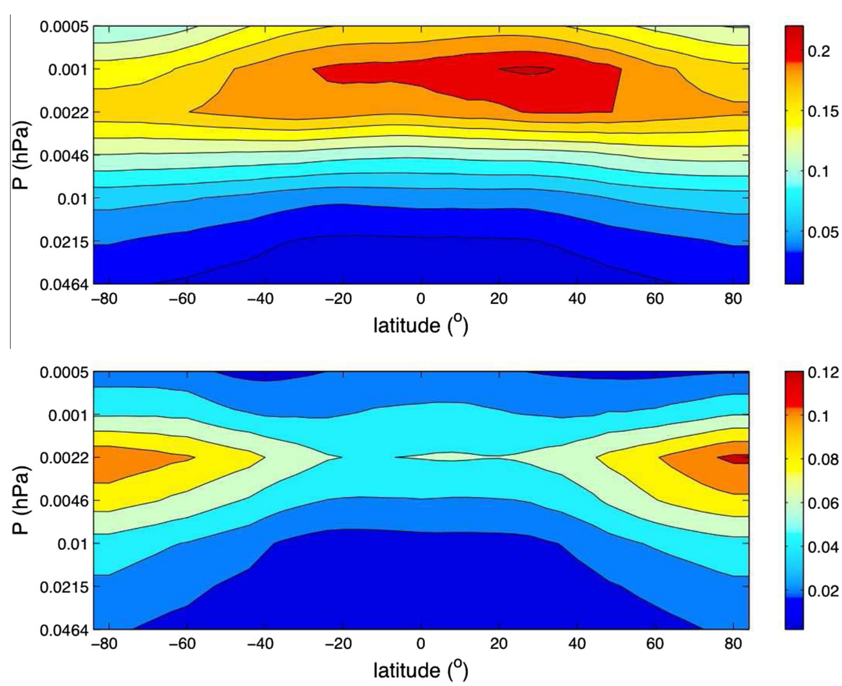

Fig. 1. The time mean of the zonally averaged CO (upper panel) and the standard deviation from this mean (lower panel). The colorbars show the values in filled contours in ppb. The standard deviation peaks near 0.002 hPa (in lower thermosphere at approximately 90 km). It is almost North–South symmetric and strongest in the mid and polar latitudes. The mean peaks above the 0.002 hPa height and is more concentrated around the equatorial region but not symmetrically with a slight bias toward the Northern latitudes.