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Ozone, water vapor, and temperature anomalies associated with atmospheric blocking events over Eastern Europe in spring - summer 2010

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HIGHLIGHTS

- Atmospheric blocking influences regional atmospheric composition.
- Water vapor increases in the troposphere and stratosphere over the blocks.
- Negative total column ozone anomalies dominate within the blocking domains.
- The ozone and water vapor anomalies is due mainly to atmospheric dynamics.
- Interconnection of blocking anticyclone with stationary Rossby wave.

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ABSTRACT

Using data from the AIRS satellite instrument (V6, L3), ozone, water vapor (WV), and temperature anomalies associated with the relatively short spring atmospheric blocking event and anomalously prolonged summer block over European Russia (ER) in 2010 are analyzed. Within the domain of the blocking anticyclones, negative total column ozone (TCO) anomalies and positive total column water vapor (TCWV) anomalies reaching the values of −25 and −32 Dobson Units (DU) and 10 and 11 kg m^{-2} during the spring and summer blocks are observed, respectively. Conversely, within the regions adjacent to the anticyclones to the west and east, positive TCO anomalies (77 and 45 DU) and negative TCWV anomalies (−3 and −4 kg m^{-2}) are found. These TCO and TCWV anomalies are conditioned by the regional atmospheric circulation associated with the strong omega-type blocking. The TCO deficit and TCWV surplus within the atmospheric blocking domain are explained primarily by the poleward advection of subtropical air with low TCO and high TCWV content and tropopause uplift. The TCO and TCWV anomalies are also associated with quasi-stationary Rossby wave trains that accompanied these blocking events. An analysis of the anomaly vertical structure shows that the marked TCO decrease is primarily due to the lower stratospheric ozone decrease, while the strong TCWV increase is mainly the result of an increase of lower tropospheric WV content. The possible role of photochemical ozone destruction in the lower stratosphere due to WV advection within the blocked regions is also discussed. Vertical profiles of the thermal anomalies during both atmospheric blocking events reveal dipole-like structures characterized by positive temperature anomalies in the troposphere and negative anomalies in the lower stratosphere.

1. Introduction

Atmospheric blocking is associated with the formation of a strong stationary anticyclone, which impedes the westerly transfer of air masses in the mid-latitude troposphere (Rex, 1950). It is believed that block formation is closely related to nonlinear

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instability and overturning of Rossby waves (Pelly and Hoskins, 2003; Lupo et al., 2012).

Summer blocking episodes are accompanied by heat waves, lack of rainfall, drought, and often with the wildfires (Mokhov, 2011). Anomalously hot and dry weather associated with the unusually persistent atmospheric block over European Russia (ER) during the summer of 2010 contributed to the development of severe wildfires and pyrogenic emission into the atmosphere of various combustion products (including toxic ones) that in aggregate with a heat wave adversely affected human health (Witte et al., 2011; van Donkelaar et al., 2011; Sitnov, 2011a; Huijnen et al., 2012). In the pre-fire period for the summer of 2010, a rise in regional surface temperature in ER resulted in an increase of the regional atmospheric abundance of formaldehyde formed in the atmosphere due to the oxidation of isoprene emitted by plants (Sitnov and Mokhov, 2017).

Changes in regional atmospheric composition during atmospheric blocking events can be conditioned also by the peculiarities of the regional atmospheric circulation associated with blocks (Peters et al., 1995). It was shown that during the omega-type atmospheric blocks over ER during the summer 1972 and 2010, the total column water vapor (TCWV) field was characterized by anomalous spatial distribution, with a water vapor (WV) excess over the northern part of ER and a deficiency over the southern part of ER (Sitnov and Mokhov, 2013). The anomalous TCWV spatial distributions were associated mainly with the advection of humid maritime air from Mediterranean and Atlantic into the poleward flank of the blocking anticyclone (Sitnov et al., 2014).

A deficit of total column ozone (TCO) was found repeatedly within the domain of anticyclone (including the block) (e.g. Petzold, 1999; Barriopedro et al., 2010). The TCO deficit within the domain of atmospheric block is explained generally by the advection of ozone-depleted tropical air poleward, and the uplift of the tropopause and ascending air motions (Koch et al., 2005; Orsolini and Nikulin, 2006). The photochemical mechanisms of ozone destruction are also discussed (Petzold, 1999; Barriopedro et al., 2010). Sitnov and Mokhov (2015) argued that the TCO decrease within the domain of the prolonged atmospheric block over ER during the summer of 2010 was conditioned by the strong decrease of ozone in the lower stratosphere caused by the poleward quasi-horizontal advection of ozone-depleted tropical air and tropopause uplift. They also hypothesized that the negative TCO anomalies during this blocking event could be in part the result of the photochemical ozone destruction in the lower stratosphere due WV advection into this region (Sitnov and Mokhov, 2016).

Atmospheric blocking events are accompanied often by deep non-stationary mid-latitude local minima of TCO, called ozone mini-holes (OMHs) (Barriopedro et al., 2010). The maximum frequency of OMHs in the NH is observed within the Euro-Atlantic sector (James, 1998; Orsolini and Nikulin, 2006), where atmospheric blocking events also occur frequently (Lupo and Smith, 1995; Wiedenmann et al., 2002). The average duration of OMH is about three days, but under blocking conditions the duration may be up to two weeks (James, 1998). Since TCO modulates the intensity of solar ultraviolet (UV) radiation reaching the Earth's surface, living things within the domain of atmospheric block can be exposed to hazardous doses of biologically active UV radiation (Stick et al., 2006).

The purpose of this paper is to analyze the similarities and differences in the spatial and temporal variations in ozone, WV and temperature associated with a relatively short spring atmospheric block and anomalously persistent summer event over ER in 2010. Since numerical models project a warmer climate, an increase in anomalously prolonged summer atmospheric blocking events over ER may be expected (Mokhov et al., 2014). Another motivation for this study is to obtain a more complete knowledge of possible changes in the atmospheric composition under unusual weather regimes occurring over the most densely populated region of Russia.

2. Data

Profiles of ozone, WV, and temperature as well as the tropopause characteristics obtained by the Atmospheric InfraRed Sounder (AIRS) instrument during the period from 30 August 2002 to 31 December 2015 were utilized for this study. AIRS is a space-borne high-resolution spectrometer, which measures infrared (IR) radiation in 2378 channels within the wavelength range of 3.7–15.4 μm (Chahine et al., 2006). The scanning system provides 95% daily data coverage for the Earth's surface. The AIRS algorithm for profile retrieval also utilizes the measurements from a collocated microwave radiometer AMSU (Advanced Microwave Sounding Unit), having the spatial resolution of 45 km in nadir (Mo, 1996). It is believed that joint analysis of radiation measurements in the infrared and microwave bands allows AIRS/AMSU to retrieve physically reasonable profiles in cases with up to 80% cloud cover (Susskind et al., 2006). The AIRS instrument was designed to retrieve temperature profiles with an accuracy of 1 K in a 1 km layer, the WV profile below 100 hPa with the accuracy of 15% in a 2 km layer, the ozone profile with the accuracy of 20%, as well as retrieving TCWV and TCO with the accuracy of 5% (Pagano et al., 2010). The validation of the AIRS TCO version 5 (V5) data for May–September 2010 using high-precision ground-based TCO measurements by Brewer spectrophotometers, operated at world ozone observation network stations Kislovodsk (43.7° N, 42.7° E) and Obninsk (55.1° N, 36.6° E) revealed a good agreement between satellite and ground-based TCO measurements (Sitnov and Mokhov, 2016; see also supplementary materials). AIRS and AMSU are installed on board the Aqua satellite, launched 4 May 2002 in a near-polar sun-synchronous orbit at a height of 705 km and a rotational period of 98.8 min (Aumann et al., 2003).

The AIRS V6 level 3 standard products (L3) comprising daily averaged measurements on the ascending and descending branches of an orbit with the quality indicators 'best' and 'good' and binned into 1° × 1° (latitude × longitude) grid cells [Tian et al., 2013] were used here. Ozone and temperature profiles are represented by data on 24 pressure levels between 1000 hPa and 1 hPa. WV profiles are represented at 12 levels between 1000 and 100 hPa, however the 150 hPa and 100 hPa level data are considered unreliable. TCO and TCWV data are calculated by integrating ozone and WV profiles, respectively. Tropopause pressure (P_{trop}) is derived from the air temperature profile using thermal tropopause definition (WMO, 1957). AIRS data (V6, L3) were obtained using the Giovanni system through http://giovanni.gsfc.nasa.gov (Acker and Leptoukh, 2007).

The daily zonal and meridional wind components as well as geopotential heights from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis were used to represent atmospheric dynamics (Kistler et al., 2001). The data are provided on 2.5° by 2.5° latitude-longitude grids and available on 17 mandatory levels from 1000 hPa to 10 hPa available at http://www.esrl.noaa.gov/psd/data/reanalysis. These data are of sufficient resolution for determining the important dynamics related to a large-scale phenomenon such as blocking as shown in many published studies (e.g. Lupo et al., 2012).