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Common summertime total cloud cover and aerosol optical depth weekly variabilities over Europe: Sign of the aerosol indirect effects?

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ABSTRACT

In this study, the summer total cloud cover (TCC) weekly cycle over Europe is investigated using MODIS and ISCCP satellite data in conjunction with aerosol optical depth (AOD) MODIS data. Spatial weekly patterns are examined at a 1° × 1° (MODIS) and 250 × 250 km^2 (ISCCP) resolution. Despite the noise in the TCC weekly cycle patterns, their large-scale features show similarities with the AOD_{550} patterns. Regions with a positive (higher values during midweek) weekly cycle appear over Central Europe, while a strong negative (higher values during weekend) weekly plume appears over the Iberian Peninsula and the North-Eastern Europe. The TCC weekly variability exhibits a very good agreement with the AOD_{550} weekly variability over Central, South-Western Europe and North-Eastern Europe and a moderate agreement for Central Mediterranean. The MODIS derived TCC weekly variability shows reasonable agreement with the independent ISCCP observations, thus supporting the credibility of the results. TCC and AOD_{550} correlations exhibit a strong slope for the total of the 6 regions investigated in this work with the slopes being higher for regions with common TCC–AOD_{550} weekly variabilities. The slope is much stronger for AOD_{550} values less than 0.2 for Central and South-Western Europe, in line with previous studies around the world. Possible scenarios that could explain the common weekly variability of aerosols and cloud cover through the aerosol indirect effects are discussed here also taking into account the weekly variability appearing in ECA&D E-OBS rainfall data.

1. Introduction

The interest in the detection and interpretation of weekly cycles in air pollution meteorological and climatic parameters has been recently refreshed. The existence of 7-day periodicities could potentially be used as an index of anthropogenically induced modification of weather due to the human working cycle. In fact, the idea of studying the weekly variability of pollution and meteorology is not new (e.g. Ashworth, 1929; Haagen-Smit and Brunelle, 1958). An updated list of studies considering weekly cycles of photochemical parameters, ozone and primary pollutants (NOx, CO, aerosols, etc.) at ground level in several urban centers in Central and North America, Europe and Asia from the mid 70s to the present can be found in Georgoulias and Kourtidis (2011). As far as aerosol ground levels are concerned, some the most recent results are presented in Barmpadimos et al. (2011) for Central Europe, and Choi and Kim

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(2012) and Wang et al. (2012) for Eastern Asia. The weekly variability of tropospheric aerosols has been investigated mainly using ground-based CIMEL sunphotometric measurements from the AERONET (e.g. Jin et al., 2005; Bäumer et al., 2008; Xia et al., 2008). Following the satellite-based study of Beirle et al. (2003), where the weekly variability of tropospheric NO_2 was investigated for several regions around the planet, the large scale weekly variability of aerosols in the U.S., Europe and Asia has also been studied recently with the use of satellite observations (Xia et al., 2008; Quaas et al., 2009; Georgoulias and Kourtidis, 2011, 2012).

In addition to atmospheric pollutants, numerous studies have investigated aspects of the large-scale weekly variability of precipitation with different and sometimes debatable results for different regions and time periods (for a review, see Sanchez-Lorenzo et al., 2012 and references therein). A rather detailed historical review of the early studies on the weekly cycle of rainfall can be also found in Schultz et al. (2007). While a number of studies suggest the existence of precipitation weekly cycles in the U.S., Europe and Asia (e.g. Cerveny and Balling, 1998; Bäumer and Vogel, 2007; Gong et al., 2007; Bell et al., 2008, 2009a, 2009b; Sanchez-Lorenzo et al., 2008; Tuttle and Carbone, 2011), other studies argue against the existence of a statistically significant weekly cycle (DeLisi et al., 2001; Schultz et al., 2007; Hendricks Franssen, 2008; Barmet et al., 2009; Hendricks Franssen et al., 2009; Stjern, 2011). Significant weekly cycles in a number of other meteorological parameters (surface temperature, diurnal temperature range, cloud cover, surface radiation, wind speed, etc.) have also been shown around the globe (Gordon, 1994; Forster and Solomon, 2003; Bäumer and Vogel, 2007; Gong et al., 2006, 2007; Choi et al., 2008a, 2008b; Sanchez-Lorenzo et al., 2008; Laux and Kunstmann, 2008; Kim et al., 2009, 2010) but also challenged (e.g. Beck, 2012). In fact, there is a great concern about the validity of the methods used for the assessment of the statistical significance of the weekly cycle (Daniel et al., 2012; Sanchez-Lorenzo et al., 2012). However, despite the discussion about the statistical significance of the results, the study of the large-scale weekly cycles of various meteorological parameters and aerosols has led to a general consensus that weekly cycles in meteorological variables might be partly explained through the aerosol direct radiative effect and the aerosol–cloud–precipitation interactions (e.g. Sanchez-Lorenzo et al., 2012), which in turn may trigger changes in atmospheric dynamics and further affect the meteorological parameters. Up to now, observations of cloud condensation nuclei (CCN)-sized aerosol concentrations from background stations in Europe (Asmi et al., 2011; Asmi, 2012) have not revealed a significant weekly cycle. However, as discussed in Georgoulias and Kourtidis (2012), the weekly cycle of aerosol total column does not necessarily have to agree with the ground level aerosol concentrations. Aerosols are transported from region to region within the troposphere, which is critical for the phase and the significance of the weekly cycle exhibited by various aerosol datasets.

Today, it is widely accepted that high aerosol concentrations lead to an increase of cloud droplet number concentration which, under constant cloud liquid water paths, leads to smaller cloud droplet effective radii and consequently enhanced cloud albedo (first aerosol indirect effect) (Twomey, 1974). The smaller droplets are expected to delay precipitation formation, increasing cloud lifetime and cloud cover (second aerosol indirect effect or cloud lifetime effect) (Albrecht, 1989). In addition, when polluted convective clouds develop to greater heights than unpolluted, which is usual during summertime over land, cloud droplets may reach greater heights where their freezing can release additional latent heat and further invigorate the cloud updrafts. This is expected to further suppress the precipitation and the development of downdrafts and so prolong the growth of convective clouds, allowing more water vapor ingestion and leading to more intense storms (Rosenfeld et al., 2008 and references therein). The cloud lifetime effect and the storm invigoration effect have been used for the interpretation of the observed cloudiness, precipitation and by extension lightning, hailstorm and tornado weekly variability in previous works (e.g. Gong et al., 2007; Bell et al., 2008, 2009a, 2009b; Rosenfeld and Bell, 2011). In addition, Farias et al. (2012) found a significant weekly cycle variability of lightning activity over the metropolitan region of São Paulo in Brazil suggesting that there is a saturation trend of aerosol concentrations on lightning activity intensification.

In this study, we focus on the spatiotemporal variability of the summer (June–July–August) total cloud cover (TCC) weekly cycle over Europe. TCC measurements retrieved from TERRA and AQUA MODIS were used to map the weekly cycle. We focus on summer for two main reasons: 1) the weekly variability of the aerosol optical depth at 550 nm (AOD_{550}) over Europe is driven by the summer AOD_{550} weekly patterns (Georgoulias and Kourtidis, 2011) and 2) convection is intense during summertime, which favors the aerosol–cloud interactions described in the previous paragraph (e.g. see Bell et al., 2008). So, it is expected that if aerosol–cloud interactions partly drive the TCC patterns, this would be more evident in summer. The general TCC weekly variability is investigated with a spatial averaging method focusing on six European regions (see Georgoulias and Kourtidis, 2011). The results are compared with results from the analysis of corresponding AOD_{550} MODIS data. The TCC weekly patterns and the weekly variability over the six regions mentioned above are also studied using independent observations from the International Satellite Cloud Climatology Project (ISCCP) in order to verify the results from MODIS observations. By examining the TCC–AOD_{550} relations over these regions, we discuss how a possible cloud cover and aerosol weekly covariance could be explained through aerosol indirect effects. The weekly variability appearing in the ECA&D (European Climate Assessment & Dataset) E-OBS (ENSEMBLES Observations gridded dataset) rainfall dataset is also taken into account.

2. Data and methods

In the present study, TCC and AOD_{550} data from the level-3 MODIS TERRA (MOD08_D3) and MODIS AQUA (MYD08_D3) 1 × 1 degree daily gridded Collection 005 dataset (Platnick et al., 2003; Remer et al., 2005) are used. The data have been acquired through LAADS (Level 1 and Atmosphere Archive and Distribution System) (http://ladsweb.nascom.nasa.gov). Using data from MODIS TERRA (daytime equator crossing at 10:30 LT) and MODIS AQUA (daytime equator crossing at 13:30 LT) we get some insight into the diurnal variability of the phenomena we study. The analyzed datasets span from 2/2000 to 2/2009 for TERRA and from 7/2002 to 12/2008 for AQUA MODIS. The region under investigation is the greater European area (30°N–70°N, 15°W–60°E), which contains 3000 1 × 1