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On the intra-annual variation of cloudiness over the Mediterranean region

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ABSTRACT

The seasonal variability of cloudiness in the Mediterranean region is studied, through the examination of the mean day-to-day intra-annual variation of gridded NCEP/NCAR total cloud cover for the period 1948–2014. A dimensionality reduction process is followed by using a multivariate statistical methodology and three main modes of seasonal variation are found. The first mode is characterized by a winter maximum and a summer minimum and prevails mainly over the Mediterranean and Black Sea areas; a weak see-saw teleconnection over the Alps represents the opposite intra-annual variation. The second mode presents maxima in early autumn and late spring and minima in late summer and winter and prevails over the SW Europe and NW Africa inland regions. The third mode shows a maximum in June and a minimum in October and prevails over the eastern part of central Europe. The main characteristics of these modes are attributed to the seasonal variation of: i) the temperature and humidity of the lower and the middle troposphere affecting static stability and ii) the intensity and the position of the main circulation systems affecting the region, as for example the Azores subtropical anticyclone and the Mediterranean depressions. The examination of inter-decadal changes in the seasonal variation of cloud cover in the above core regions reveals a long-term decrease of cloudiness during the 66-year period 1948–2014. A comparison with contemporary satellite MODerate resolution Imaging Spectroradiometer (MODIS) and surface based European Climate Assessment & Dataset (ECA & D) station cloud cover data is carried out for the above core regions, evidencing a similarity among the data sets as to their seasonal variability, which supports the validity of the NCEP/NCAR reanalysis cloud cover results.

1. Introduction

The Mediterranean is a climatologically sensitive area (IPCC, 2013) located between the European and the African continents, generally characterized by warm and dry summers and cold and wet winters. Although the above seasonal temperature and precipitation characteristics are predominant and can be considered as the most important features of the so-called Mediterranean climate, the detailed seasonal variability of various other climatic parameters over the area exhibits other significant maxima and minima, especially when the intra-annual variation is examined in time scales shorter than one month. Moreover, there are many differences in the seasonal variation of specific climatic parameters among the various Mediterranean sub-regions, which can be attributed to the seasonal variation of: (i) the position and the intensity of the dominant large-scale circulation systems affecting the Mediterranean, such as the Atlantic subtropical (Azores) anticyclone, the polar front and the SW Asia summer thermal low, (ii) temperature and humidity near the earth's surface, which are strongly dependent on the local physicogeographical and relief characteristics and affect static stability of the lowest tropospheric layers and (iii) the trajectories of depressions, especially those formed over areas with complex relief under conditions of high baroclinicity (Prezerakos et al., 1990; Bartzokas et al., 2003; Kostopoulou and Jones, 2007; Lolis et al., 2008; Lolis et al., 2012; Şahin et al., 2015; Lionello et al., 2016; Kutiel and Türkeş, 2017).

Cloudiness is one of the most important climatic parameters, strongly affecting the solar shortwave and terrestrial longwave radiation fluxes. Therefore it largely determines the radiation and energy budgets and thus it significantly influences climate conditions, especially at the Earth's surface. Furthermore, apart from the radiation, clouds also affect the hydrological budget, by driving its precipitation component, and thus strongly influence the water balance at the surface and contribute to the water abundance, very significant for biological, agricultural, economical and social purposes. On the other hand, cumulonimbus clouds are responsible for thunderstorms and other extreme weather events which are dangerous even for human life. In general, clouds are closely related to weather and climate from global down to regional and local scales. Taken into account all these, the variability of cloudiness is a research subject of great importance, especially for areas located near the transitional climatic zones, being

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vulnerable to the ongoing climatic change (Barkhordarian et al., 2012). The Mediterranean region belongs to these areas and the study of the seasonal variation of cloudiness along with the possible long-term changes of its main characteristics over the various Mediterranean sub-regions would lead to interesting conclusions, useful for climate assessments. Cloud cover itself determines to a large extent the various effects of clouds on weather and climate, for example those on daily maximum, minimum and daily range of temperatures (Betts et al., 2013) or on radiation fluxes from local to regional and global scales (Matuszko, 2012; Raschke et al., 2005; Pyrina et al., 2015). Therefore, spatial and especially temporal patterns of cloud cover are of special importance. For instance, any ascertained temporal variability and trends of cloud cover should be carefully assessed as cause or result of ongoing climate change (Norris et al., 2016). However, despite their great importance, the accuracy of cloud cover data is a great challenge, subject of debate and a significant research issue, taking into account that it is difficult to achieve independently of where from they originate (from stations, satellite observations, or numerical models). The station data are influenced by the skill and the experience of the observers, while they do not ensure complete spatial coverage. On the other hand, the accuracy of satellite data is dependent on the retrieval algorithms applied to the remotely sensed radiation measurements, while the cloud cover numerical model outputs are subjected to the known unavoidable uncertainties associated with the chaotic behavior of the atmosphere, the accuracy of the initial conditions and the utilized parameterization schemes (IPCC, 2013). Hence, it might not look strange that comparisons among cloud cover data sets of different origin reveal consistencies and considerable differences (Norris, 2005; Free et al., 2016).

Cloud cover variability in the Mediterranean region has been a subject of research during the last decade with the use of various approaches including multivariate statistics, climate modeling etc. Lolis (2009) examined the inter-annual variability of NCEP/NCAR winter total cloud cover over the Mediterranean region and its connection to the atmospheric circulation for the period 1948–2005, identifying the main atmospheric circulation centers of action affecting cloudiness over the various Mediterranean sub-regions and revealing negative long-term cloudiness trends over most of them associated with positive geopotential height trends over specific areas of Europe and North Africa. Enriquez-Alonso et al. (2016) compared satellite and reanalysis cloud cover data sets with surface observations for the period 1984–2005. They found a good agreement between the mean values of cloud cover estimated from satellite products and from surface meteorological station observations and much lower cloud cover values from reanalysis. They also found a common annual cycle of cloud cover among all data sets. Sanchez-Lorenzo et al. (2017) used station, satellite and reanalysis data and climate model simulations and found a widespread cloud cover decrease over the Mediterranean region during the period 1971–2005 and specifically in the 1970s and 1980s, especially for spring in the Central and the Eastern Mediterranean.

In the present study, the seasonal variability of total cloud cover over the Mediterranean region is examined for the 66-year period 1948–2014, by applying the multivariate statistical method Factor Analysis (FA) on the NCEP/NCAR Reanalysis data. The 66-year study here offers a longer climatological temporal coverage than in the previous studies and its main objectives are: (i) the identification of the principal modes of intra-annual variation of cloudiness over the various Mediterranean sub-regions, (ii) the examination of possible long-term changes in the characteristics of these seasonal cycle modes and also total cloud cover values during the study 66-year and (iii) the intercomparison among the Reanalysis (NCEP/NCAR), satellite (MODIS) and surface observation (ECA & D) cloud cover data sets, as it concerns the seasonal variability.

2. Data and methodology

2.1. Data

The data basis used in the present work consists of:

(i) Daily (12:00 UTC) grid point (1.875° × 1.905°) values of total cloud cover (%) at 324 grid points covering the broader Mediterranean region (10°W to 40°E and 30°N to 50°N) for the 66-year period 1948–2014, obtained from the NCEP/NCAR Reanalysis data set (Kalnay et al., 1996; Kistler et al., 2001). Clouds in this as in other reanalyses (e.g. ERA, ECMWF) are derived by the NCEP/NCAR reanalysis system which is consisted of three major modules (Kalnay et al., 1996) one of them being the NCEP global operational model that generates clouds through parameterizations for the large-scale ascent, convection, boundary layer turbulence and radiative cooling processes. Clouds, as other reanalyzed variables, are influenced by the changes in data assimilation input, especially for the period of the satellite epoch after the late 1980s. The NCEP cloud cover data have been evaluated against visual surface observations assimilated in the International Comprehensive Ocean-Atmosphere Data Set (ICOADS) for the period 1948–2002 and they were found to underestimate fractional total cloud cover by 10–25% everywhere in the mid and high latitudes and to systematically overestimate in the tropics by 3–5% (Bedacht et al., 2007). On a global and hemispherical scale, NCEP/NCAR total cloud cover was found typically smaller than ICOADS by 20%, while reproducing major climate variability patterns such as North Atlantic Oscillation (NAO) and El Nino Southern Oscillation (ENSO). Over the Mediterranean Sea, on an annual basis, NCEP/NCAR cloud cover data were found to be mainly smaller than ICOADS by up to 5%, while slight overestimations up to 5% were found over the coasts of Italian peninsula. These difference patterns were found to be stronger and more spatially extended during local winter (January) than summer (July) (Bedacht et al., 2007).

(ii) Daily grid point (1° × 1°) values of total cloud cover at 1000 grid points covering the broader Mediterranean region (10°W to 40°E and 30°N to 50°N) for the period 2003–2014, obtained from the Moderate resolution Imaging Spectroradiometer (MODIS) Aqua satellite data set. The MODIS radiometer placed on the polar orbiting satellite Aqua of NASA (National Aeronautics and Space Administration), 705 km from the Earth, with equatorial crossing time 13:30, has a swath width of the order of 2330 km, enabling almost full planetary coverage on a daily basis. More specifically, these data are level-3 (L3) MYD08 data set derived from MYD06 level-2 (L2) products. The MODIS Cloud Product combines infrared and visible techniques to determine both physical and radiative cloud properties. The MOD06_L2 cloud fraction product is produced by the infrared retrieval methods both day and night at 5 × 5 1-km-pixel resolution. These MODIS L2 cloud parameter products are subsequently re-gridded to 1° × 1° cartesian grids and constitute the MODIS L3 cloud products used here. Details about the MODIS cloud retrieval methods can be found in the MODIS Algorithm Theoretical Basis Document (ATBD) (Menzel et al., 2015) as well as in the MODIS Collection 6 Cloud optical properties User Guide, v1.0, Oct. 2015 (Platnick et al., 2015), or in King et al. (2003). An overview of MODIS global clouds can be found in the study by King et al. (2013) whereas a validation against CloudSat-CALIPSO cloud profiles is given by Wang et al. (2016).

(iii) Mean daily cloud cover observations at 35 meteorological stations (Table 1) covering a part of the Mediterranean region, obtained from ECA & D (European Climate Assessment and Dataset), for the period 2003–2014. The stations belong to Spain (31), Italy (2) and Croatia (2). The ECA & D started in 2003, with the initial objective of analyzing temperature and precipitation climate of WMO climate region VI, with special focus on trends in climatic extremes

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