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Time distribution of the precipitable water vapor in central Saudi Arabia and its relationship to solar activity

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Abstract

Water vapor is the most important greenhouse gas. It plays a major role in the dynamics of atmospheric circulation, radiation exchange within the atmosphere, and climate variability. Knowledge of the distribution of water vapor is important for understanding climate change and global warming.

In this study, radiosonde data from 1985 to 2012 were used to examine the monthly, interannual, and annual variations and trends of precipitable water vapor (PWV) in central Saudi Arabia in the city of Riyadh (24° 43′N; 46° 40′E, 764 m a.s.l.). The results revealed a clear seasonal cycle of PWV with a maximum during the summer months (June–August) and a minimum during the winter (December–February). This variation follows the mean monthly variation of air temperature.

The PWV displays considerable variability at the interannual scale. We could not attribute the variations to the air temperature because no relationship was found between the two variables when the interannual variations were examined. Study of the annual variations of the PWV showed cyclic variations with a period of approximately 10–11 years. The two maximums and minimums were in 1996 and 2007 and 1989 and 2000, respectively. The results showed that the annual PWV values are anticorrelated with solar activity, represented by sunspot number, during solar cycles 22 and 23. The physical mechanism underlying this relationship remains unclear. This finding is preliminary, and future investigations are recommended.

Keywords: Precipitable water vapor; Interannual distribution; Solar activity; Riyadh; Climate change; Radiosonde

1. Introduction

Water vapor is the most abundant and variable of the important atmospheric gases, and it possesses many features of interest to scientists. For instance, the water molecule creates strong absorption bands at both solar and terrestrial wavelengths. In addition, the vapor phase plays an important role in the hydrological cycle and has effects on climate and weather systems (Maghrabi and Clay, 2010).

The environmental impacts of water vapor are so important that there is increasing interest in its measurement at the surface, its distribution with altitude, and its total abundance in a vertical column through the atmosphere. The last parameter, the measurement of which is the central subject of this study, is the amount of liquid water that would be obtained if all of the vapor in the atmosphere were compressed to the point of condensation and is known as the integrated or precipitable water vapor (PWV).

In the lower troposphere, water vapor in the atmosphere acts as the main resource for precipitation, providing latent heating in the process and dominating the structure of adiabatic heating in the troposphere (Elliott et al., 1991). Its

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changes in the upper troposphere are especially important for climate change (Soden and Lanzante, 1996) but are poorly understood. Changes in water vapor amounts are therefore key determinants of climate change character (Hense et al., 1988). Recently, however, there has been heightened interest in water vapor, not only because of its radiative properties but also because trends in tropospheric water content may be an indication of global-warming-related changes in the nature of the hydrological cycle (Forster and Shine, 2002).

In contrast to other greenhouse gases, the amount of PWV in the atmosphere can vary considerably with prevailing conditions, including time of day, wind direction, and temperature. This makes PWV an extremely difficult quantity to measure. Both experimental and empirical attempts have been made over a long period of time, generally with limited accuracy. Furthermore, poor knowledge of the water vapor distribution in the atmosphere has until recently limited the accuracy of global climate models and precipitation forecasts (Bevis et al., 1992).

Despite water vapor's obvious importance for the climate and life on earth, it has received less attention in the literature compared with the other greenhouse gases. Additionally, scientists were unable to study its spatial and temporal distribution until radiosonde data became available.

The number of measurement techniques for making observations of PWV increased considerably in the 1990s (Borbás, 1998; Emery et al., 1979; Gerding et al., 2004;Kuwahara et al., 2008; Ottle et al., 1997). A summary of these techniques and a discussion of their advantages, disadvantages, and limitations are given in Maghrabi and Clay (2010) and references therein.

The characterization of the present PWV distribution and its interannual changes is thus an important undertaking. Hence, advancing the understanding of the variability and changes in water vapor is vital, but knowledge is limited by inadequate observations.

Numerous efforts have been made to study the water vapor distribution in different regions around the world, including Europe, America, Africa, and Asia (see, e.g., Angell et al., 1984; Hense et al., 1988; Okulov et al., 2002; Elliott and Angell, 1997; Long et al., 2000; Gueymard, 1994; Sajith et al., 2003; Zhai and Eskridge, 1997; Phillips and McGregor, 2001). However, in some places, knowledge of the water vapor distribution is still sparse or absent, and data from more locations are still required.

The contribution of the present study is the presentation of the mean PWV distribution and its trends on different time scales in an arid region of Saudi Arabia during the period 1985–2012. This study is the first to cover a more recent and longer time pe riod from this part of the world. The reason for choosing Riyadh is that, it is the site that has the longest available records of data in Saudi Arabia.

The details of the experimental site and the methodologies followed in treating the data and calculating the PWV will be given in Section 2. In Section 3, results will be presented. Conclusions and future work will be given in Section 4.

2. Data set and methodologies

Radiosonde observations and surface data were provided by the Saudi Presidency of Meteorology and Environment (PME). Saudi's atmospheric radiosonde observations date back to the 1970s. Because of the inhomogeneities found in radiosonde data in both temperature and dewpoint depression during the 1970s, and early years of the 1980s, only the data from 1985 to 2012 were selected. The observations were made using Vaisala RS80A sondes. Pressures, temperatures, and dewpoint depressions were extracted from each sounding at all reported levels (i.e., mandatory and significant levels) from the surface to 300 mb. Data extraction was terminated at 300 mb because of the poor performance of radiosonde hu midity sensors at cold temperatures (Elliott and Gaffen, 1991; Free et al., 2004; Kassomenos and McGregor, 2006).

Assuming water vapor to be a perfect gas, its absolute humidity ρ at sounding level z was obtained by a classic formula derived from the equation of state of an ideal gas:

$$\rho_v(z) = \frac{217 \times RH(z) \times e(z,T)}{T} \tag{1}$$

where T is the observed absolute temperature and $RH(z)$ is the relative humidity. The last term is the saturation water vapor pressure $e(z,T)$ in mb, calculated using a set of formulae proposed by Hyland and Wexler (1983a,b). Integration of Eq. (1) along the vertical profile gives the total PWV (Kassomenos and McGregor, 2006):

$$\mathrm{PWV} = \int_0^z \rho_v(z)dz \tag{2}$$

The methodologies so far assume complete data series. Unfortunately, this is never the case with real data. Some type of interpolation is necessary to complete the series. Interpolation must be kept to a reasonable level to preserve the nature of the information contained in the data (Zhai and Eskridge, 1997). In our case, we linearly interpolated up to five missing data points. Larger gaps were not considered, and months that have large amounts of missing data are excluded from the analysis. After these cuts, a total of 12,501 (mean 15.12 ± 1.1 mm) data points were available, 6394 of them from 0000 UT times (mean $= 15.24 \pm 1.4$ mm) and 6107 from 1200 UT times (mean $= 14.98 \pm 1.9$ mm). The PWV at 1200 and 0000 UTC are highly correlated ($r^2 = 0.95$, significant at the 0.01 level), and their mean values do not differ much from each other. Because diurnal variations in PWV have not been considered, the mean PWV values of 0000 UT and 1200 UT was treated as a proxy of the total PWV. This hypothesis seems to be adequate for the purposes of this study because PWV trends are the major concern, not the