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Parameterization of the middle and upper tropospheric water vapor from ATOVS observations over a tropical climate region

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ABSTRACT

Precipitable water vapor (PWV) is a highly variable, but important greenhouse gas that regulates the radiation budget of the earth. Its variability in time and space makes it difficult to quantify. Knowledge of its vertical distribution, in particular, is crucial for many reasons. In this study, empirical relationships between isobaric layers of PWV over Peninsular Malaysia are examined. Analysis of variance (ANOVA) technique on Advanced Television and Infrared Observation Satellite Operational Vertical Sounder (ATOVS) observations, from 2005 to 2011, has been used to propose a relationship of the form, $W=\alpha(WL)^{\beta}$ for the middle (*MW*) and upper (*UW*) layers PWV. W is either *MW* or *UW* with α and β as regression coefficients, which are functions of latitude. Coefficients of determination (R^2) and root mean square error (RMSE) of respective values between 0.75–0.86 and 1.65–2.38 mm, across the zones, were obtained for both the *MW* and *UW* predictions, with a mean bias (MB) below ±1 mm.The predicted and observed PWV presented a better agreement northerly. Initial predictability test for each model was done on two independent data sets: ATOVS (2012–2015), and radiosonde (2010–2011) at Penang, Kuantan and Sepang stations, with very good outcomes. The results of the tests revealed remarkable performances, when compared with two previously reported models. The inclusion of variable regression coefficients, and the utilization of satellite-derived data, which provide soundings of data-void regions between radiosonde networks, proved to have optimized the results.

1. Introduction

Water vapor, which accounts for between 0 and 4% of the atmospheric gas constituents, is arguably the most abundant, and most influential, of the major greenhouse gases in the atmosphere. It constitutes a very high proportion of the greenhouse effect compared to other key natural greenhouse gases (Bokoye et al., 2003; Forster and Collins, 2004; Marsden and Valero, 2004; Ernest Raj et al., 2008), mainly due to its transparency and opacity to shortwave and longwave radiations from the sun and the surface of the earth.

Atmospheric water vapor is also well known for its high temporal and spatial variability, with an average residence time of about 8 days, whereby the tropical convergent zone condones it for ~12 days, while the residency at sub-tropical high regions is much shorter (Trenberth, 1998). The spatial variation of atmospheric water vapor is more pronounced in the vertical direction, in which 50% or more is found below the 850 hPa pressure level, while over 90% is confined to the layer below 500 hPa (Peixóto and Oort, 1983). This concentration slides gradually with altitude at higher latitude, but at the lower latitudes, the value experiences a steep vertical decrease (Parameswaran and Murthy, 1990).

Beside the crucial role of atmospheric water vapour in Earth's radiation budget, where it modulates the propagation of solar and terrestrial radiation, its condensation and subsequent precipitation in the lower troposphere, makes it the source of latent energy that dominates the structure of tropospheric diabatic heating (Courcoux, and Schroder, 2015). The attenuation of microwave propagation within the atmospheric window, by water vapor, exerts great influence, not only on radio and satellite communications, but also on atmospheric remote sensing and radio astronomy in general.

Knowledge of the spatial and temporal distribution of atmospheric water vapor, at all the atmospheric layers, is crucial for many purposes. For instance, meteorological and electromagnetic wave propagation (Reber and Swope, 1972), hydrological studies, prediction of clouds and precipitation (Lowry, 1972) and global climate system (Xie et al., 2011), require a good assessment, particularly, of the vertical component of this humidity quantity, also known as precipitable water vapour (PWV).

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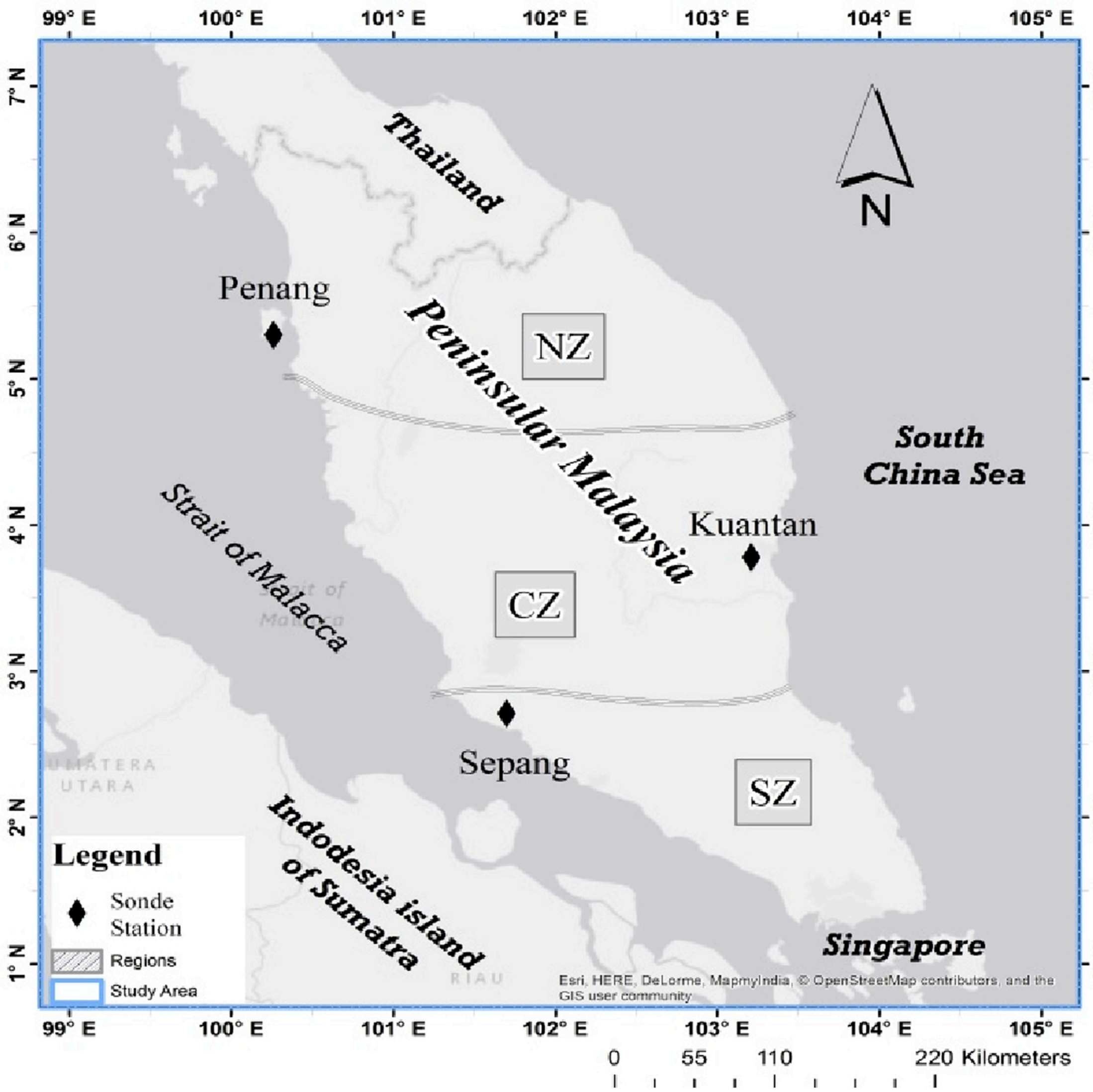

Fig. 1. Study area showing radiosonde stations at Penang, Kota Bharu and Sepang, as representatives of the 3 geographical zones – northern (NZ), central (CZ), and southern (SZ).

Satellite communications, remote sensing of the atmosphere and radio astronomy are also influenced by the ability of the vertical component of water vapour to attenuate microwave signals (Reber and Swope, 1972). Mixing ratio, which gives the state of convection in the atmosphere, could be inferred through the relationships between the boundary layer PWV and other layers aloft. Moreover, for the effective prediction of columnar (total) PWV, using surface humidity (Tuller, 1977), knowledge on inter-layer relationship is also a requirement.

To discern the physical and chemical processes of PWV distribution, variation and trends, different techniques are used to observe the parameter from different platforms, such as in-situ (ground-based or traditional radiosonde) devices (Rose and Elliot, 1996; Wang et al., 2001). Satellite observations such as microwave radiometers (Buehler et al., 2008) and infrared sounders (Brown et al., 2007) have also been utilized in various quantifications of PWV variability and changes, (Choy et al., 2015). Although the in-situ instruments have higher precision and better vertical resolution, compared to their satellite counterparts, they are only good for the studies of small-scale water vapor variations. Satellite observations, on the other hand, have better spatial coverage and, therefore, thrive in the study of humidity over large areas. A detailed review of the studies on PWV is documented in Gaffen et al. (1992).

Despite the foregoing importance of the vertical component of this highly variable greenhouse gas, there are, surprisingly, very few studies in its respect, particularly in the tropics. Few earlier investigators on layered precipitable water used radiosonde data to obtain inter-layer correlations (e.g. Adedokun, 1983; Adeyemi, 2009), or to create climatology of precipitable water and other humidity variables in the lower troposphere (Gaffen et al., 1992). All these studies utilized data from point observations to generalize the result for a given area, leading to the masking of local variations in humidity due to considerable spatial extrapolation. However, the vertical profiling of moisture, using satellites, provides soundings for data-void regions between radiosonde networks, both continentally and over the oceans (Trenberth et al., 2005).

While earlier studies relied on radiosonde (or upper air) observations to explore the relationship between layers of PWV, over individual stations, as earlier mentioned, we used satellite data to propose a relationship between the lower and middle/upper isobaric layers of PWV over a region in order to minimise the over-masking of local variability in humidity. This study, therefore, focuses on the variation of PWV at the various isobaric layers using data retrieved from Advanced Television and Infrared Observation Satellite Operational Vertical Sounder (ATOVS) on board National Oceanic and Atmospheric Administration (NOAA) satellite. The objective is to establish the space-time distribution of layered PWV over a tropical climate, with the view of determining the existence and nature of the relationship between the isobaric layers of this humidity variable. A general and reliable model to predict, in each