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A tropical site's integrated water vapour during active and break monsoon events, as well as its relationship to temperature, precipitation, and precipitation effectiveness

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Abstract:

The study establishes relationships between IWV and other atmospheric variables such as surface temperature, rain, and precipitation efficiency through cross-correlation studies. The results show a positive correlation coefficient between IWV and surface temperature over the two years. However, during summer monsoon months (June, July, August, and September), the correlation coefficient becomes negative. This change in correlation may be attributed to the cooling effect of rainfall during these months. Correlation studies between IWV and precipitation, IWV and precipitation efficiency (P.E), and precipitation and P.E indicate correlation coefficients of 0.05, 0.10, and 0.983, respectively, at a 95% confidence level. This suggests that the efficacy of rain does not solely depend on the level of water vapor. A proper dynamic mechanism is required to convert water vapor into rain. The diurnal variations of IWV during active and break spells have also been analyzed. The amplitudes of diurnal oscillation and its harmonics do not show clear trends, but the mean amplitudes of break spells are approximately double those of active spells. Specifically, during break spells, the amplitudes of diurnal, semi-diurnal, and ter-diurnal components are 1.08 kg/m2, 0.52 kg/m2, and 0.34 kg/m2, respectively. For active spells, the corresponding amplitudes are 0.68 kg/m2, 0.41 kg/m2, and 0.23 kg/m2.

1. Introduction

Water vapor in the atmosphere plays a crucial role in various atmospheric processes, including the greenhouse effect, cloud formation, and precipitation. Its measurement is essential for understanding climate change and improving weather forecasting. Global Positioning System

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(GPS) has been utilized as a remote sensing tool to measure water vapor by analyzing the delay in microwave signals due to its presence in the lower atmosphere [1]. The relationship between water vapor and surface temperature is complex, with certain geographical locations not following the expected trend. Low latitude regions, receiving strong solar radiation and having higher temperatures, can hold more water vapor, potentially leading to more precipitation [2]. However, the quantity of precipitation also depends on other factors such as degree of saturation and dynamic mechanisms providing cooling for precipitation. Precipitation efficiency (P.E) is a variable that measures the effectiveness of these mechanisms in converting water vapor into rain [3]. Studies have shown that atmospheric water vapor and precipitation are not strongly correlated due to the influence of various factors. Precipitation efficiency is highly variable in both space and time and deserves investigation at a global scale. Continuous monitoring of water vapor in low latitude regions is crucial for improving our understanding of tropical atmospheric processes and short-term weather forecasting [4]. This paper aims to study the variation of precipitable water vapor (PWV) during active and break spells of the Indian summer monsoon (ISM) and its relationship with different atmospheric variables, particularly precipitation efficiency. This research will contribute to a better understanding of the behavior of water vapor in low latitude regions and its impact on precipitation [5-7].

Data and method

The study utilizes GPS data collected between December 2013 and December 2015 at Vignana Bharathi Institute of Technology (VBIT) in Hyderabad. A dual-frequency receiver installed at VBIT receives microwave signals sent from GPS satellites. These signals experience delays in reaching the receiver due to the presence of water vapor in the troposphere [8]. To obtain precipitable water vapor (PWV) measurements, the delays along with meteorological variables such as pressure, temperature, and relative humidity are processed using GAMIT software version 10.61 developed by the Massachusetts Institute of Technology (MIT). The meteorological data from December 2013 to November 2014 were obtained from a Mini Boundary Layer Mast (MBLM) located on the same campus as VBIT [9-11]. However, the MBLM was not operational after November 2014, so meteorological data from December 2014 to December 2015 were obtained from the Indian Meteorological Department (IMD) in Hyderabad, which is located approximately 27 km away from VBIT. To convert the IMD meteorological data to match the conditions at VBIT, the relationships given by Musa et al.

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and Bai and Feng were used. The height of the IMD station from mean sea level (MSL) is denoted as Hi (531 m), and the height of VBIT from MSL is denoted as HV (480 m). These relationships allow for the adjustment of meteorological data to account for the altitude difference between the IMD station and VBIT [12].

2. Data validation

During the study, precipitable water vapor (PWV) or integrated water vapor (IWV) was computed for two different time periods: December 2013 to November 2014 and December 2014 to December 2015. For the first period, meteorological data from both the Mini Boundary Layer Mast (MBLM) and the Indian Meteorological Department (IMD) were used. For the second period, only IMD's MET data were used after interpolation using specific equations described in Section 2 of the study.To validate the computed data, the researchers compared it with the recent ECMWF Re-Analysis (ERA) 91 level data of IWV and 850 hPa winds. ERA-Interim is a model data that utilizes the Integrated Forecasting System (IFS) with 4-dimensional variational analysis (4D-Var) algorithms. The comparison showed good matching for all months, except for the summer months, where the ERA-Interim data deviated more from the observations for the latitude of interest.Additionally, the study also used data from the Clouds and the Earth's Radiant Energy System (CERES) for satellite-based observations of Earth's Radiation Budget and Clouds. The IWVs calculated using different MET datasets (MBLM, IMD, ERA-Interim, and CERES) were compared, and all four sets of IWVs showed good agreement within the standard deviation limits.Similarly, the wind data for the period between December 2013 and October 2014 was validated by comparing measurements from MBLM, automatic weather station (IMD), and downloaded from ERA-91 level data. The wind data for November 2014 was not available, but the comparison for the available period showed reasonable agreements, except for the summer months where some discrepancies were observed.

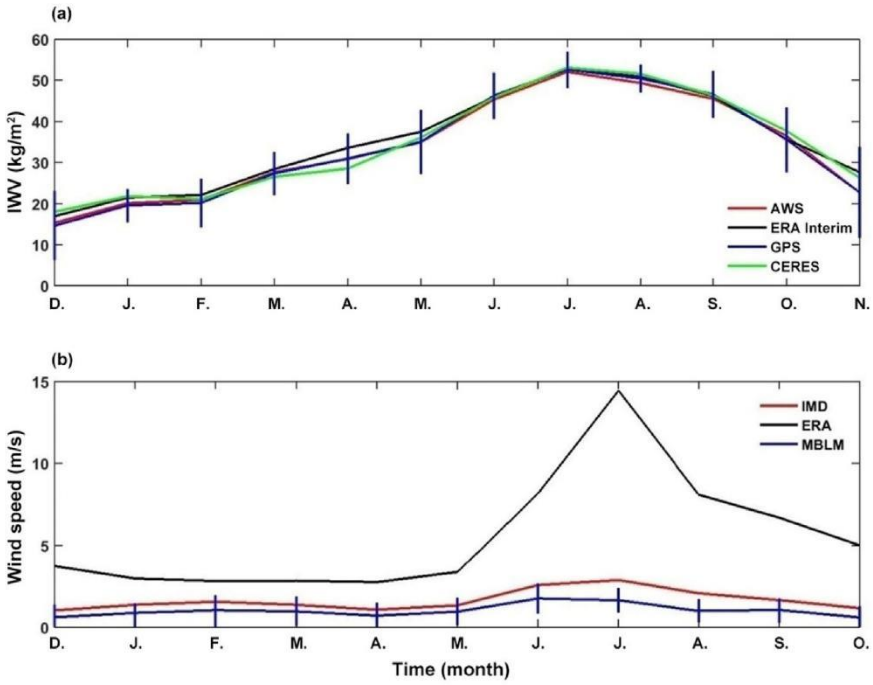

Figure 1: a) Mean IWV values for each month for several MET data sets, with standard deviations on the MBLM mean; b) Mean wind speeds for various data sets.

3. Results and discussion

3.1. Active and break spells of monsoon

Various methodologies have been used in previous studies to identify active and break spells of the monsoon season based on different atmospheric variables such as wind circulation patterns and temperature. However, rainfall is considered the most important parameter for defining active and break spells. In this study, a method developed by Rajeevan et al. [29] and further refined by Rao et al. [23] was adopted to identify active and break spells.According to this method, active/break spells of the monsoon were identified based on the average standardized rainfall anomaly. If the rainfall anomaly exceeded ±0.5 for three or more consecutive days, it was designated as an active spell, and if it was less than -0.5, it was considered a break spell. The threshold of ±0.5 was chosen following Rao et al. [23].

The time series of active and break spells for the years 2014 and 2015 were illustrated in Fig. 2a and b. In 2014, there were 2 active spells and 9 break spells, while in 2015, there were 2 wet spells and 6 dry spells. The duration of dry spells was longer, ranging from 3 to 18 days, while the wet spells were shorter, varying from 3 to 9 days. These findings were consistent with other

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reports in the literature [23, 29]. The study also looked at the spatial variation of active and break spells across different regions in India.

3.2. Correlation study

A cross-correlation study was conducted to investigate the relationships and dependencies between various atmospheric variables. Higher temperatures are expected to lead to greater evaporation, which would result in a positive correlation between surface temperature and integrated water vapor (IWV). In this study, a correlation coefficient (r) of 0.446 with a 95% confidence level was found between surface temperature and IWV for the entire two-year dataset.Interestingly, Wang et al. [32] reported a stronger correlation between surface temperature and precipitable water vapor (PWV) during the nighttime compared to the daytime, indicating a diurnal asymmetry trend.When the data was split into two individual years (2014 and 2015), the correlation coefficients were found to be 0.449 and 0.368, respectively. When the summer months (June, July, August, and September) were removed from the dataset, the correlation coefficients increased to 0.454 and 0.534 for the respective years. The correlation coefficients for only the summer months of 2014 and 2015 were 0.235 and 0.462, respectively. However, when the summer months of both years were combined, the correlation coefficient decreased to -0.08.

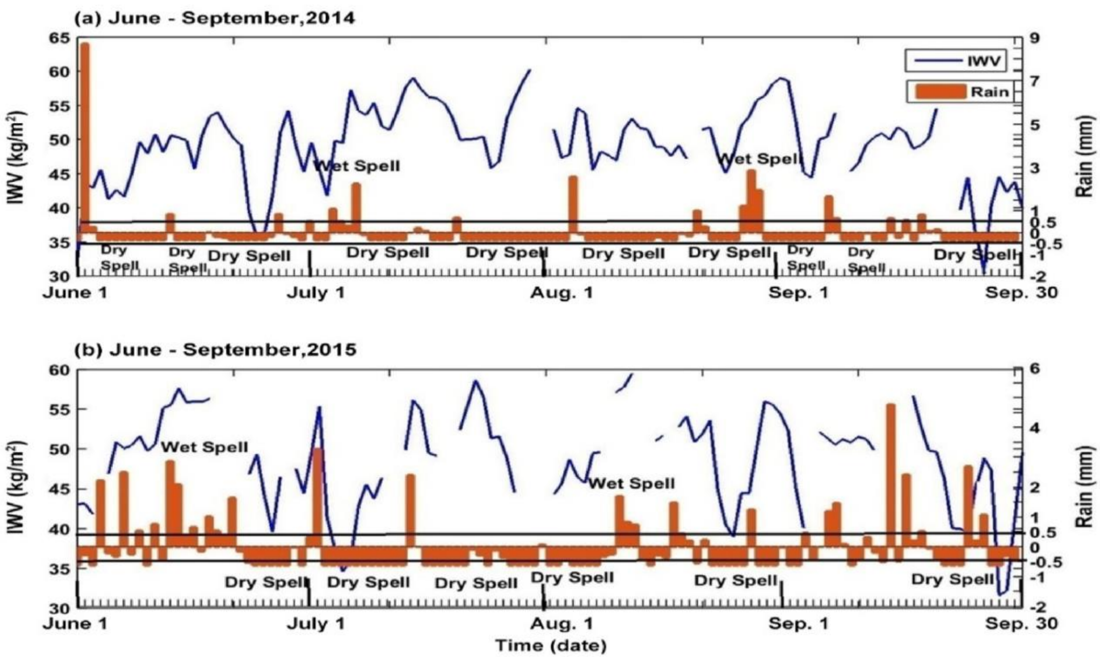

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Fig. 2. a) During the 2014 monsoon, IWV (blue, left-hand ordinate) and time series of standardised rainfall anomaly (red, right-hand ordinate) were used to detect dry and wet spells. The horizontal lines represent 0.5 standardised rainfall anomalies; b) IWV (blue, left-hand ordinate) and standardised rainfall anomaly time series (red, right-hand ordinate) during the 2015 monsoon to distinguish dry and wet spells. The horizontal lines represent 0.5 standard deviations in rainfall.

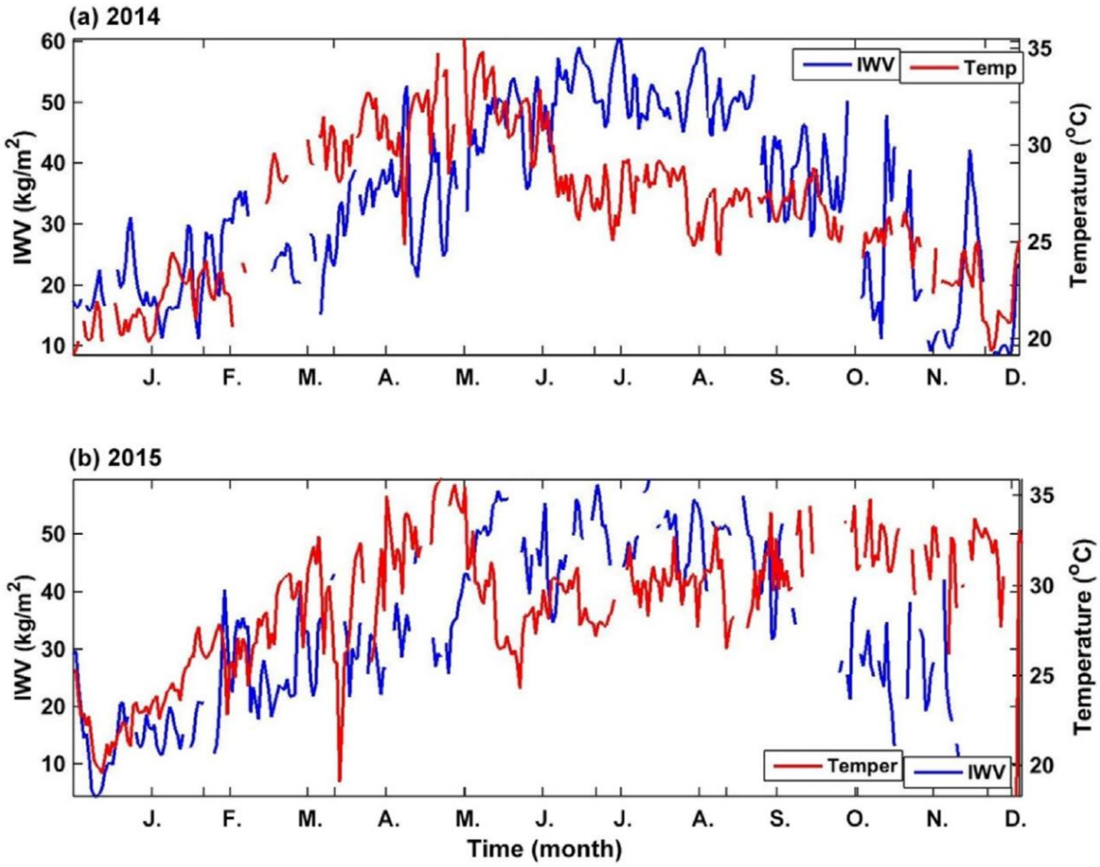

Figure 3: a) 2014 daily mean IWV (blue, left-hand ordinate) and surface temperatures (red, right-hand ordinate); b) 2015 daily mean IWV (blue, left-hand ordinate) and surface temperatures (red, right-hand ordinate).

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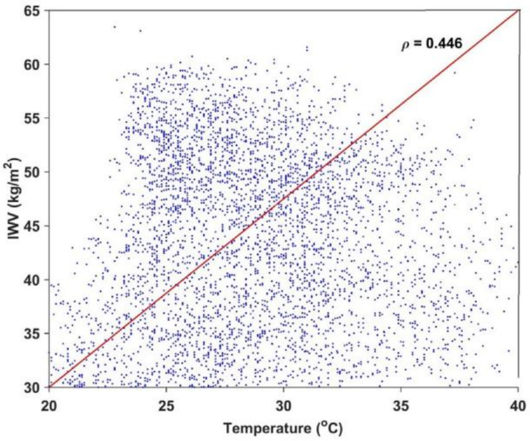

Figure 4 shows a scatter plot of IWVs and surface temperatures for the years 2014 and 2015.

The cross-correlation coefficients are as follows: e 0.054 (IWV-Rain), 0.104 (IWVeP.E), and 0.983 (Rain eP.E). All of these correlation coefficients are 95% certain. The scatter plots are shown in Figures 6a, b, and c. Many investigations [3,35e37] have found a poor/negative connection between water vapour and rain. However, Majumder et al. [34] discovered a positive connection (0.5) between daily IWV and rainfall during a three-year period (2012e2014). Ortiz de Galisteo et al. [13] found no association between IWV and precipitation.Ye et al. [11] investigated the association between precipitation, relative humidity (RH), P.E, and PWV using data from 505 sites in Northern Eurasia from 2003 to 2010. They discovered that greater temperatures result in higher PWV in the winter.

3.3. IWV diurnal fluctuation during active and break spells

The diurnal variation of integrated water vapor (IWV) is influenced by various atmospheric processes such as convection, rain, evaporation, winds, temperature, incoming solar radiation, and local topography. Numerical weather prediction models have improved short-range forecasting by incorporating GPS IWV data. Understanding the diurnal variation of atmospheric IWV at different scales is essential for weather forecasting and climate studies.In this study, the diurnal variation of IWV during active and break spells of the monsoon is investigated. For the 2014 summer monsoon, there were nine dry spells and two wet spells, while for 2015, there were three dry spells and one wet spell. The data consists of 48 half-hourly averaged IWV values for each spell, allowing for detailed analysis of the diurnal cycle. The data are detrended by removing mean values to obtain half-hourly fluctuations.The diurnal variation of IWV shows large day-to-day variabilities. Two prominent maxima (peaks) are observed at 15:30 and 23:30 (IST), and these peaks are more pronounced during dry spells compared to wet spells. To quantify the diurnal variation, harmonic analysis technique is used to compute the amplitudes of the diurnal (24 h), semi-diurnal (12 h), and ter-diurnal (8 h) components of IWV variation.

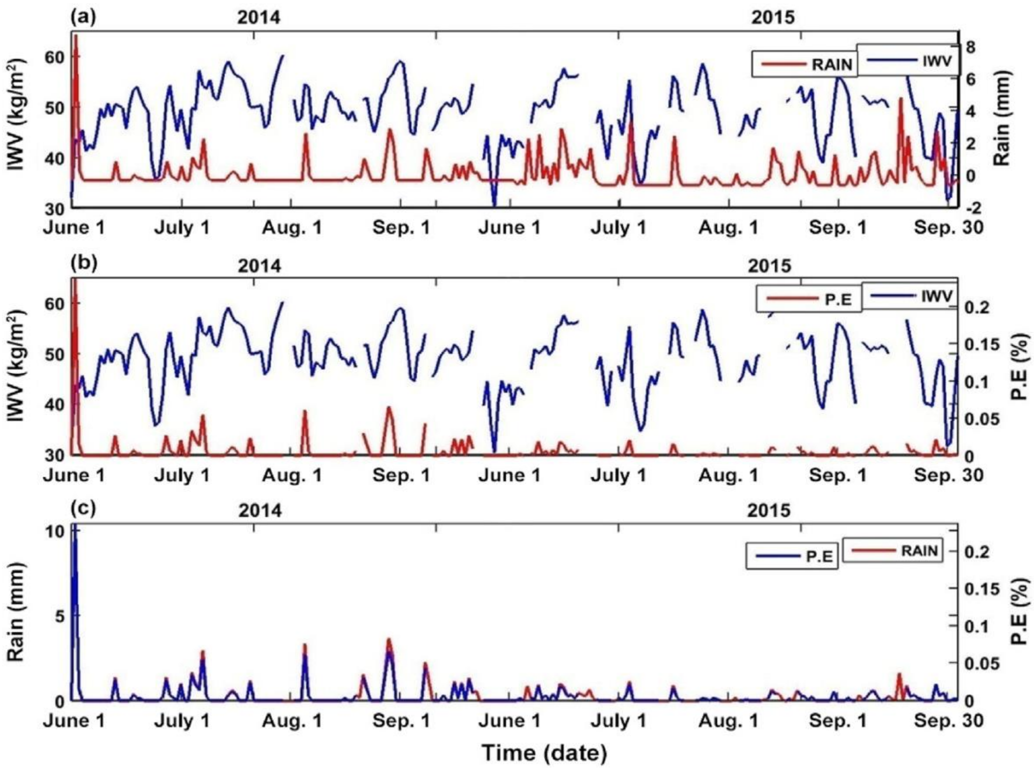

Fig. 5. a) IWV (blue, left-hand ordinate) and rain (red, right-hand ordinate) for the years 2014 and 2015; b) IWV (blue, left-hand ordinate) and P.E (red, right-hand ordinate) for the years 2014 and 2015; c) rain (red, left-hand ordinate) and P.E (blue, right-hand ordinate) for the years 2014 and 2015

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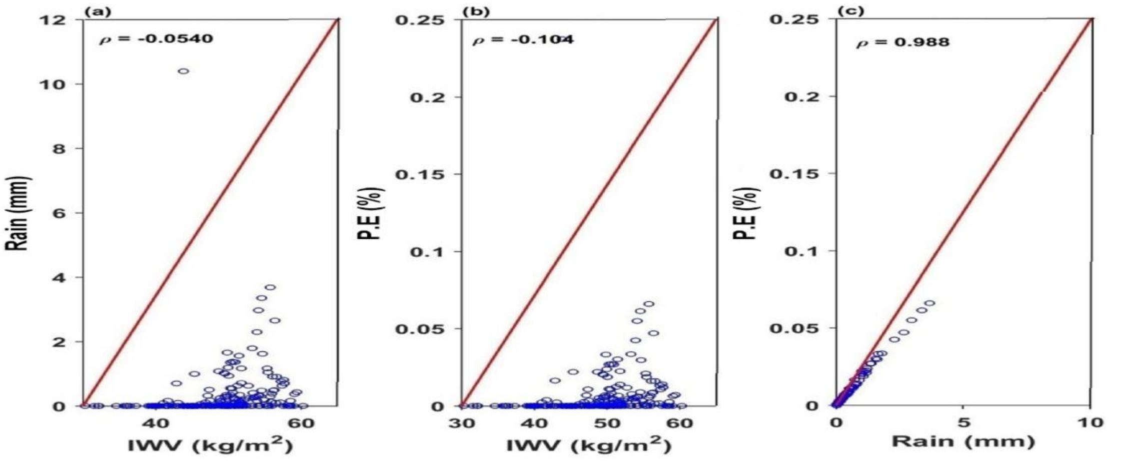

Fig. 6: a) Scatter plot of rain and IWV for 2014 and 2015; b) Scatter plot of P.E and IWV for 2014 and 2015; c) Scatter plot of P.E and rain for 2014 and 2015.

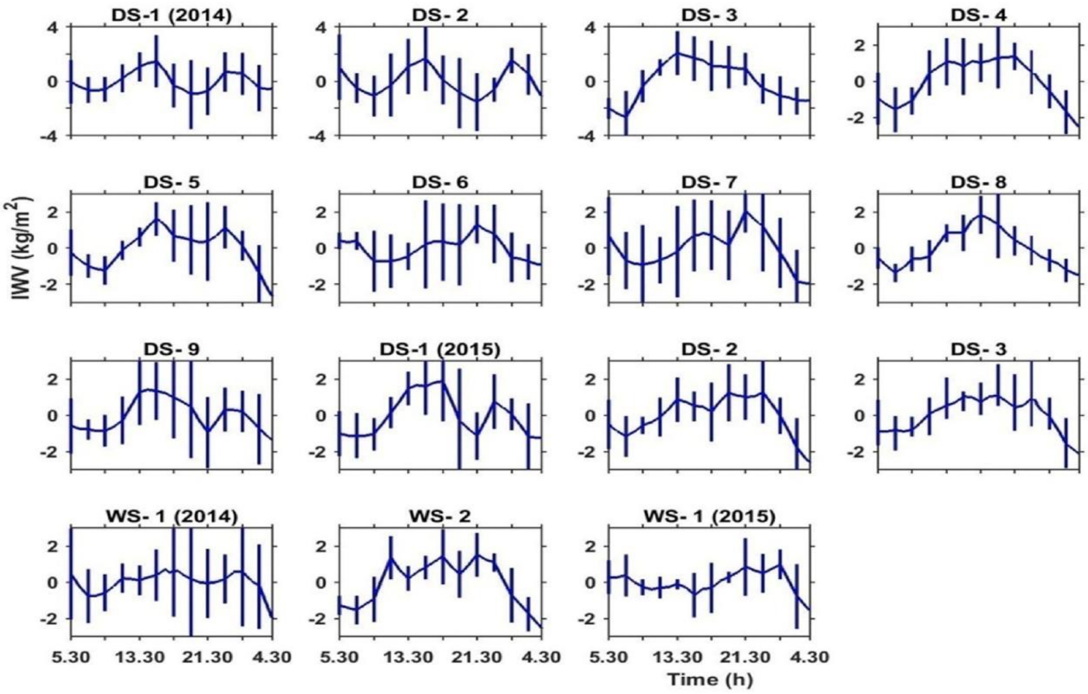

Figure 7 depicts the mean diurnal changes in IWV during dry and wet spells in 2014 and 2015. Vertical bars represent standard deviations.

Summary

The correlation analysis revealed interesting relationships between IWV and other atmospheric variables. The correlation coefficient between IWV and surface temperatures for the two years

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was positive (0.446). However, when the summer months were excluded from the data, the correlation coefficient increased slightly. This suggests that precipitation during the summer months lowers surface temperatures, leading to a negative correlation between IWV and temperatures.The correlations between IWV and precipitation, as well as between IWV and precipitation efficiency (P.E), were found to be relatively weak (0.054 and 0.104, respectively). On the other hand, a strong correlation coefficient (0.983) was observed between precipitation and P.E. This indicates that precipitation is not solely dependent on high values of IWV; it requires a combination of factors, including the degree of saturation and appropriate dynamics, to convert water vapor into measurable precipitation.Overall, the study highlights the importance of dynamic mechanisms in determining the occurrence and efficiency of precipitation, and it emphasizes the complex interactions between water vapor, temperature, and precipitation in the atmosphere.

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