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Correlation between Precipitable Water Vapor and heavy rainfall over a semi-mountainous area in Cyprus

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Abstract

Nowcasting and understanding of locally evolving severe weather events is a demanding task that requires the combined investigation of different type (both ground- and space-based) of datasets. Atmospheric water vapor (WV) which is the most abundant greenhouse gas (accounting for ~70% of global warming) comprises a significant energy source which generates severe weather and climate phenomena. The rapid spatiotemporal variations of WV in the low atmosphere poses one of the main challenges to NWP models forecasting accuracy. Abrupt increase of WV several hours before extreme rainfall has been temporally correlated with rainfall in various studies, followed by a decrease after the event. Other studies have investigated the joint effect of WV and atmospheric pressure on extreme rainfall. Though many studies have evidenced ongoing accumulation of WV before the heavy rainfall, there is still a great difficult to determine a tight relationship between rainfall and WV, that could be reproduced by a plain, physically motivated two-layer nowcasting model.
In this context, the present study attempts a first comparison of Precipitable Water Vapor with the respective rainfall measurements with the ultimate aim to investigate the possible correlation between WV and heavy rainfall, during a selected extreme precipitation event occurring during 19-31 December 2024 over a semi-mountainous area in Cyprus Island. To achieve this, we exploited ERA5 Reanalysis dataset and rainfall observations over Xyliatos meteorological station (35.0295° N, 33.0436° E), owned by the Department of Meteorology of Cyprus.

1. Introduction

Cyclones are the main weather modulators in the Mediterranean region and constitute a major environmental risk, often producing windstorms and heavy rainfall. “Medicanes”, hurricane-like cyclonic systems in the Mediterranean Sea, are becoming an increasingly severe problem for many Mediterranean countries, causing loss of lives and extensive damages [3, 4]. Water Vapour is an important component of the atmosphere and a direct indicator of severe weather events such as heavy precipitation. It is the largest greenhouse gas (accounting for ~70% of global warming) and plays an important role in both the energy budget and hydrological cycle of the earth. Precipitable Water Vapur (PWV) is the amount of water potentially available in the atmosphere for precipitation, integrated in a vertical column of air. Accurate estimation of water vapor is critical for both weather forecasting and climatology. The spatial and temporal rapid variations of water vapour in the low atmosphere poses one of the main challenges to Numerical Weather Prediction (NWP) models forecasting accuracy (Mazzarella et al., 2022). The available atmospheric measurement techniques are still insufficient to measure tropospheric PWV at a high temporal and spatial resolution necessary for NWP model precise forecasts and for near real-time forecast (nowcast) information on sudden heavy rain episodes anticipation (Grzegorz et al., 2022).
The relationship between heavy rainfall and PWV has been also examined by numerous studies showing that high-temporal resolution GNSS-PWV can be used as a reliable data source for extreme rainfall investigation (Ziarani et al., 2021). In their work Zhang et al., 2022 and Barbarosa et al., 2023 conclude that there is a significant positive correlation between PWV and precipitation measurements in the studied regions. Another study by Sapucci et al., 2018 refers that Global Positioning System precipitable water vapour (GPS-PWV) jumps before intense rain events. This sharp increase was observed for any precipitation event in their study, but it was preponderant before more intense and extensive precipitation events. Although PWV content has a significant correlation with precipitation, the physical mechanism of PWV and precipitation is complicated, associated with deep convective activities triggered by moisture convergence, and precipitation cannot be determined simply by the PWV value in the short term (Zhang et al., 2022).
To this end, this investigation is an initial attempt to investigate the potential relationship between Precipitable Water Vapor with rainfall by using ERA5 Reanalysis and , ground meteorological data from the semi-mountainous meteorological station Xyliatos in Cyprus, during an extreme precipitation event.

2. Method

In this study, 10-minute rainfall data from the permanent meteorological station of the Cyprus Department of Meteorology was used during an abrupt heavy rainfall event that took place during 19-31 December 2024 over Xyliatos. Furthermore, hourly ERA5 Reanalysis Water

Vapour data were employed for the same period and compared with the respective rainfall observations in order to detect potential relation between Precipitable Water Vapor and rainfall.

3. Results

The PWV variations were examined in relation to rainfall variations during the selected extreme event over the semi-mountainous station Xyliatos. In Figure 1, the PWV derived by using ERA5 Reanalysis dataset and precipitation are plotted on an hourly basis for the 13-day period. As seen, abrupt precipitation is noted at seven times, while the PWV sharply increases prior to the first five precipitation maxima. This is in accordance with Benevides et al., (2015) who found that the most intense precipitation events occur after steep ascents in precipitable water vapour (PWV) by investigating a number of extreme precipitation cases in the period 2010-2012 at Lisbon with the aid of GNSS derived PWV data. Similarly, a sharp increase of PWV contents before raining was identified by Yao et al., (2017) by using GNSS-derived PWV for a two year period over Zhejiang station. Various studies have been conducted to assess the possibility this relationship of PWV with rainfall to be utilized for nowcasting prediction of precipitation (Cao et al., 2016, Haase et al., 2003).

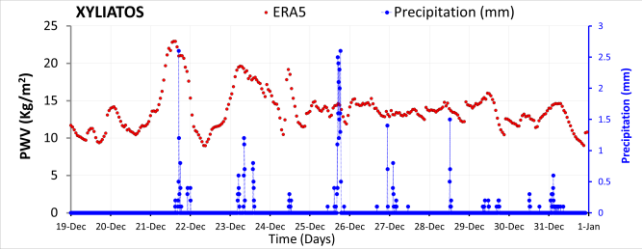

Figure 1. Variations of PWV and Precipitation over Xyliatos station during 19-31 December 2024. Red dotted line represents the ERA5-derived PWV and light blue dotted line show 10-minute rainfall by using in situ meteorological observations.

4. Conclusions

A rapid rise of PWV few hours (1-2 hours) prior to the sudden rainfall events during the period under investigation over Xyliatos station was revealed, however, additional investigation is required in order to derive statistics that will allow a possible tight relationship between PWV and Rain that can be utilized as an additional tool for nowcasting of extreme precipitation events.

6. Acknowledgements

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