# Impact of El Niño–Southern Oscillation (ENSO) on the Precipitable Water Vapor in Thailand from Long Term GPS Observation

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**Abstract**

*This paper presents the impact of the ENSO incident in Thailand based on precipitation water vapor (PWV) data obtained from GPS measurements using GPS PWV data from 2007-2016 from 11 stations of the Public Works Department and town planning to determine the relationship between PWV and Sea Surface Temperature Anomalies (SSTa). It was found that between the La Niña and El Niño events, there was a moderate to severe correlation between PWV and SSTa at all stations, respectively, but was noted for SRTN and SOKA stations located near the southern coast of Thailand. The relationship turned out to be the opposite, that is, during the La Niña events there was a high correlation, but during the El Niño event, there was no correlation. Moreover, the correlation of all stations had the exact same negative. The study results concluded that the La Niña event directly affected PWV, especially in 2011. PWV declines would result in severe flooding and storms. El Niño also affected PWV, causing the rainy season to come later with less rain.*

## 1. Introduction

The ENSO (El Niño–Southern Oscillation) phenomenon causes variations in weather systems, including El Niño and La Niña phenomena. El Niño refers to an abnormally warm sea surface temperature in the central and eastern equatorial Pacific that scientists often use ENSO warm events to describe (Glantz et al., 1987). On the other hand, ENSO's cold event is used in the same sense as La Niña. In this phenomenon, sea surface temperatures are cooler than normal in the central and eastern equatorial Pacific. La Niña events tend to follow El Niño events, usually over 2-9 years and may occur seasonally (Bjerknes, 1969 and Webster and Yang, 1992). The sea surface temperature (SST) can monitor the ENSO phenomenon. Moreover, the Oceanic Nino Index (ONI) describes sea surface temperature changes in the central Pacific Ocean. Although ENSO originates in the tropical Pacific, it affects human life and the environment through global climate and weather events such as drought, flooding, landslides, and tropical storms. However, some aspects of the ENSO mechanism affecting the South China Sea region are still challenging to understand.

Thailand is located adjacent to the Pacific Ocean; therefore, ocean changes are likely to be influenced. Furthermore, the ENSO phenomenon tends to influence cumulative rainfall significantly (Limsakul, 2011). In the year of the La Niña phenomenon, average annual rainfall increases. On the other hand, rain decreases while the El Niño phenomenon occurs. For the climate and seasons in Thailand, most of them are influenced by monsoons such as the southwest monsoon and the northeast monsoon. As a result, Thailand has different seasons, namely the rainy and dry seasons. In addition, the ENSO phenomenon is another variable that affects the variability of weather conditions that cause drought or heavy rainfall.Global Positioning System (GPS) meteorology has become an important approach for remote sensing atmospheric water vapor. It was first proposed in the early 1990s (Bevis et al., 1992). However, only significant advances have been made in the last 10-15 years (Baldysz et al., 2018 and Guerova et al., 2016). GPS meteorology has great potential to detect water vapor. This is because it has a unique advantage: accessibility in any weather conditions.

GPS has high precision, long-term stability, and high temporal resolution compared to the atmospheric sounding method. PWV from GNSS observation data is often used to fill radiosondes observation gaps. For example, high spatial and temporal resolutions from ground-based GNSS data have been used to provide rapidly vertically integrated atmospheric water vapor data in recent years. It can help overcome radiosonde observations' spatial and temporal limits (Guerova et al., 2016). Moreover, previous research looks at the relationship between ENSO events and PWV, and has suggested that ENSO events affect PWV and that GPS-derived PWV is a suitable technique for the study activities of ENSO (Suparta, 2018, Suparta et al., 2012 and 2013). Furthermore, the La Niña event affects Southeast Asia, primarily from an increase in PWV, leading to an increase in rainfall and a risk of flooding and landslides (Suparta et al., 2012).

In this paper, we present monitoring of ENSO activity using Precipitable Water Vapor (PWV) obtained from ground-based GPS stations (Bevis et al., 1994), which is now a key variable in regional and local climate studies (Liang et al., 2015). PWV can also be used for Numerical Weather Prediction (NWP) models (Bevis et al., 1992) and for geophysical and atmospheric studies, where PWV is a practical, comprehensive alternative. In addition, the area can be used continuously and at a low cost (Coster et al., 1996, Jade and Vijayan, 2008, Suparta and Iskandar, 2012 and Takiguchi et al., 2000). For meteorological work in Thailand, there has been a continuous study and development on the application of PWV in various fields, such as the determination of PWV variability in time-series (PWV Time-series) (Trakolkul and Satirapod, 2021). It was also used to study the onset of the monsoon season in Thailand using PWV values combined with other meteorological data (Takiguchi et al., 2000, Trakolkul and Satirapod, 2020 and Uang-aree et al., 2015). For observation data, PWV was used from 11 GNSS ground-based stations (Continuously Operating Reference Station: CORS) of the Department of Public Works and Town & Country Planning. Moreover, Sea Surface Temperature Anomalies (SSTa), an indicator for detecting ENSO activity, was used in the correlation analysis to identify PWV responses to ENSO events in Thailand. That was the primary objective of this research. However, in previous research, the time series PWV has never been used in the ENSO analysis, which will be helpful for future climate studies.

## 2. Methodology

### *2.1 Data and Locations*

The PWV used in the analysis was obtained from 11 ground-based GPS stations of the Department of Public Works and Town & Country Planning. which is characterized by the distribution of the station covering all regions of Thailand. During the period 2007-2016, the distribution consisted of Chiang Mai Station (CHMA) and Uttaradit Station (UTTD) in the Northern region, Udon Thani Station (UDON), Nakhon Ratchasima Station (NKRM), and Sisaket Station (SISK) in the Northeastern region, and Bangkok Station (DPT9) and Nakhon Sawan Station (NKSW) in the Central region. In addition, Chanthaburi (CHAN) and Prachuap Khiri Khan (PJRK) stations is in the Eastern region and Surat Thani Station (SRTN) and Songkhla (SOKA) in the Southern region. For examining the correlation of PWV in response to ENSO activity, the Oceanic Niño Index (ONI) of the Niño 3.4 region derived from the National Oceanic and Atmospheric Administration (NOAA) was used to determine compliance with El Niño-Southern Oscillation in the tropical Pacific Ocean. The positive episode of ENSO is called El Niño only when the threshold of SST in the Pacific is above 0.5°C. On the other hand, when the SST is below 0.5°C, it is called El Niña. Figure 1 shows the locations of the 11 ground-based GPS stations used.

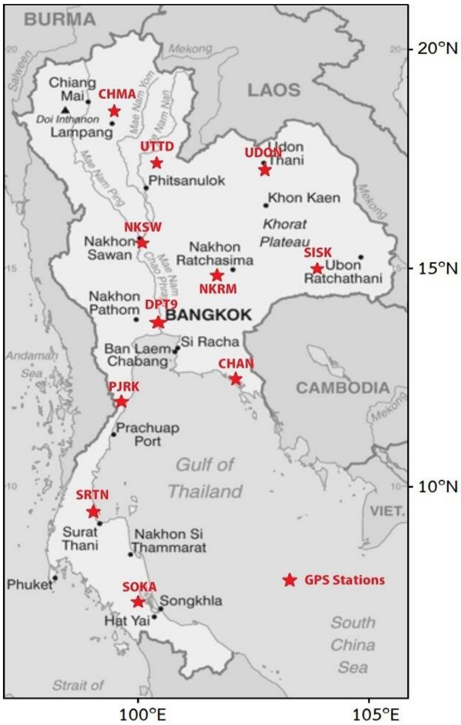


Figure 1: Location of ground-based GPS Stations for this study (modified from CIA World Factbook, 2007)

*2.2 Data Processing and Analysis Step*

In this paper, Precise Point Positioning (PPP) techniques are used to process PWV data by PANDA (Positioning and Navigation Analysts) software package developed at Wuhan University of China (Li et al., 2015). Satellite orbit errors and satellite clock offset from IGS (Kouba, 2015) are used to help obtain more accurate PWV values. Furthermore, it is processed using the Global Mapping function (GMF) to obtain Zenith Total Delay (ZTD). The ZTD obtained by the PPP technique can be represented in the relationship form of the three components ZTD, ZWD, and ZHD as an equation.

$$ZWD = ZTD - ZHD$$

Equation 1

The ZHD varies with temperature and air pressure. Therefore, for the area of Thailand, the Saastamoinen model (Saastamoinen, 1972), which is the most appropriate (Satirapod and Chalermwattanachai, 2005), was used to calculate the ZHD value, as shown in the equation.

$$ZHD = \frac{2.2768 \text{ x } Ps}{1\text{-}0.00266\cos(2\phi)\text{-}0.00000028H}$$

Equation 2

where Ps is surface air pressure (hPa), $\phi$ is station latitude (rad), and H is the mean height above sea level (m). Once the ZWD value is obtained from the relationship of ZTD and ZHD, we can find PWV. It is obtained by the following equation (Bevis et al., 1992):

$$PWV = \Pi * ZWD$$

Equation 3

$$\Pi = \frac{10^6}{\rho_w R_\upsilon\left(\frac{k3}{T_m} + k'2\right)}$$

Eqaution 4

where $\Pi$ is a function of the weighted average temperature ($T_m$), where $\rho_w$ is the density of liquid water, $R_\upsilon$ is the specific gas constant of water vapor (461.525 $JK^{-1}kg^{-1}$), k'2 is 22.1 K/hPa. k3 is 3,739 $K^2$/hPa, and $T_m$ is the weighted average temperature of the atmosphere. Here, $T_m = 113.2914 + 0.6066T_s$ is used. ($T_s$ is the temperature in ºK), which is a value suitable for the area of Thailand (Suwantong et al., 2017). The GPS PWV obtained in this study has a momentary resolution of 2 hours for the processing step and is described in Figure 2.

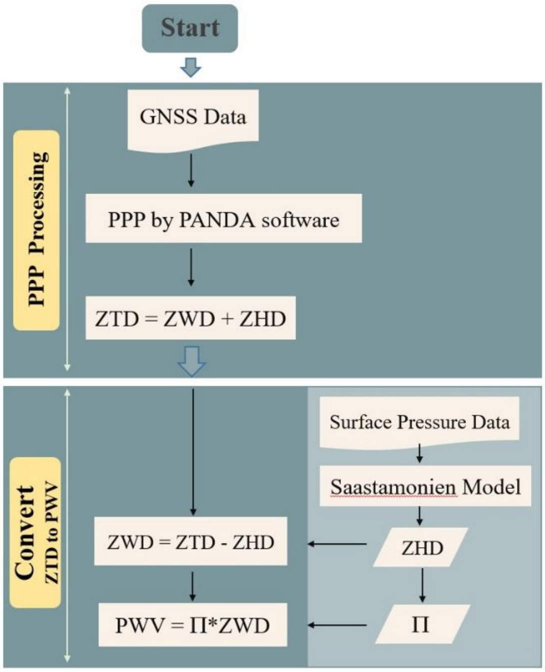


Figure 2: Data Processing from Tropospheric Delay to PWV (modified from Trakolkul and Satirapod, 2020)

In addition, the PWV obtained from this ground-based GPS station provides an accurate replacement for more expensive meteorological instruments (Li et al., 2015) such as the Microwave Radio Meter (MWR), Radiosonde (RS), and meteorological satellite data. For meteorological work in Thailand, there is an ongoing study and development on a feasible and easy way to use GPS-derived PWV, which has been confirmed to be accurate PWV from GPS data (Satirapod et al., 2010, Satirapod and Rizos, 2011, Suwantong et al., 2017, Charoenphon and Satirapod, 2019 and Meunram and Satirapod, 2019). In studying the relationship between PWV and ENSO activity, correlation analysis was used to look at the change response of PWV data to ENSO activity in Thailand.

## 3. Result and Discussion

*3.1 PWV and SSTa Variations*

Figure 3 shows the PWV pattern from all 11 ground-based GPS stations for 2007-2016. The figure shows that the annual variation in PWV amplitudes in the southern and coastal regions (e.g., SRTN and SOKA) is smaller than in the country's regions due to the impact of the sea on the climate or as a result of more precipitation than other regions.

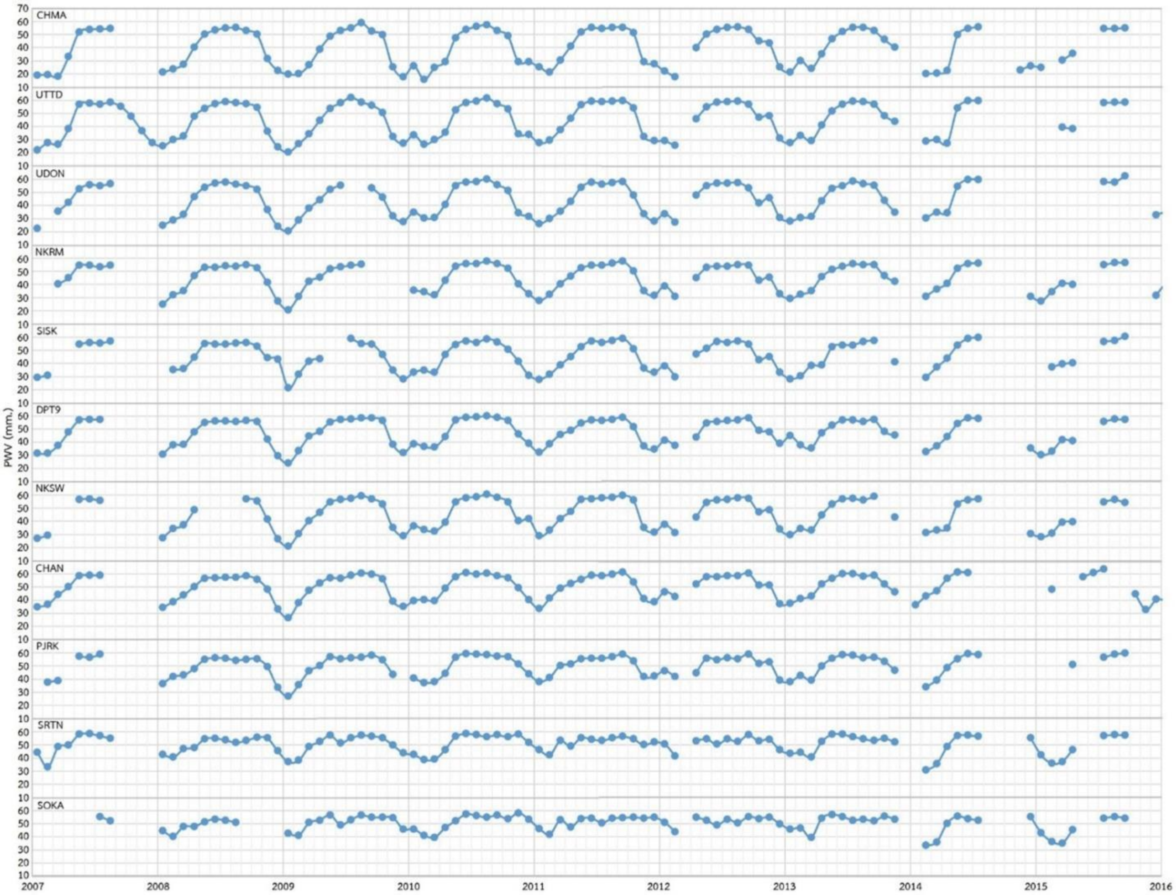


Figure 3: PWV Monthly Average Variations from all 11 ground-based GNSS stations 2007-2016

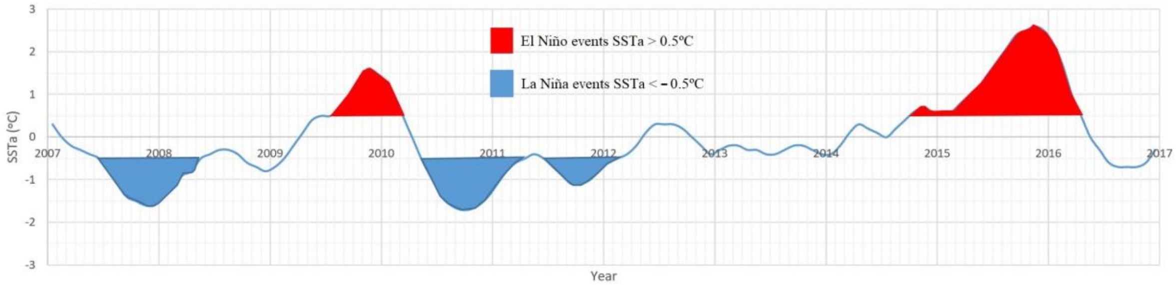


Figure 4: SSTa from ONI index for the Niño 3.4 region (Golden Gate Weather Services, 2020)

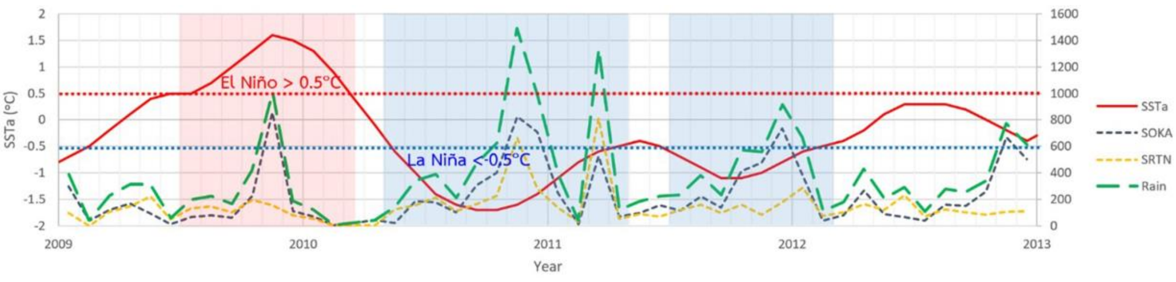


Figure 5: SSTa variation pattern for ENSO phenomenon between 2009-2012 and average monthly rainfall from SRTN and SOKA stations in coastal areas of Thailand

Table 1: The relationship between PWV and SSTa during La Niña and El niño events

| Station | La Niña | | El Niño |
|---|---|---|---|
| | 2010-2011 | 2011-2012 | 2009-2010 |
| CHMA | -0.33 | -0.63 | -0.65 |
| UTTD | -0.28 | -0.57 | -0.72 |
| UDON | -0.26 | -0.51 | -0.66 |
| SISK | -0.26 | -0.55 | -0.78 |
| NKRM | -0.25 | -0.51 | -0.84 |
| NKSW | -0.32 | -0.54 | -0.72 |
| DPT9 | -0.27 | -0.44 | -0.68 |
| CHAN | -0.20 | -0.39 | -0.71 |
| PJRK | -0.28 | -0.47 | -0.50 |
| **SRTN** | **-0.48** | **-0.72** | **-0.37** |
| **SOKA** | **-0.56** | **-0.82** | **-0.07** |

The variance depends on the station height. Stations near the sea tend to have low variance, and continental or higher territories have high variability. The highest annual PWV is in late July in the rainy season (Trakolkul and Satirapod, 2021).

Figure 4 shows the SSTa from ONI index for the Niño 3.4 region as an indicator for ENSO detection, including the La Niña phase. The La Niña incident happened three times. It was stated as Case 1 in June 2007-May 2008, Case 2 in May 2010-April 2011, and Case 3 in July 2011-February 2012. For this case, an intense La Niña period is evident in Case 1 and Case 2, with an SSTa of -1.7 ºC and up to 12 months in both cases. In the case of two El Niño incidents, case 1 occurred in June 2009-February 2010 and case 2 in October 2014-April 2016. The severity was evident in Case 2, with the SSTa reaching 2.6 ºC and lasting 19 months. However, for the La Niña and El Niño events, the severity of the incidents was rated from mild, moderate, to severe.

*3.2 Relationship Between PWV and SSTa*

From the PWV data in Figure 3, during the three La Niña events, it was found that in Case 1, almost all stations were lost due to system failures. Therefore, data were analyzed only in cases 2 and 3 for each GPS station. Table 1 shows the relationship between PWV and SSTa during the La Niña events in 2010-2011 (Case 2). Correlation is the magnitude of the effect. Therefore, we can describe the correlation's strength using a guide of Evans (1996) to explain the meaning of the R-value as follows:

- 0.00-0.19: "very weak"
- 0.20-0.39: "weak"
- 0.40-0.59: "moderate"
- 0.60-0.79: "strong"
- 0.80-1.0: "very strong"

A low correlation was found at all stations, except for SRTN and SOKA stations with moderate correlation. A stronger correlation was observed in 2011-2012 (Case 3), with a moderate to very high correlation, especially for the SRTN and SOKA stations located in the provinces near the sea. The correlation coefficients (R) were -0.72 and -0.82, respectively, and the correlation of all stations had the exact negative correlation at all stations. For both El Niño events, the second case in 2014 and 2015 was incomplete due to a system crash. Therefore, a certain amount of data is missing at various intervals at every station. Therefore, the analysis was chosen for case 1 in the period 2009-2010 only. From Table 1, the PWV and SSTa correlations between El Niño events for Case 1 were moderate to high, except for the SRTN and SOKA stations, which were not correlated. The correlation of all stations had the exact negative correlation across all stations. The P-value was less than 0.05 across all stations. Twenty-eight observations were made for El Niño events and thirty-two for La Niña events.

From the 2010-2011 La Niña cases (Case 2), it indicates that La Niña's influence was on PWV. La Niña's influence causes rainfall without significance (Figure 5). The influence of the Intertropical Convergence Zone was across the upper South, Central and Eastern regions and the southwest monsoon. As a result, such bad weather and flooding is caused by heavy rain in many areas. During October-November, heavy damage is caused, especially from October 10, 2010, to December 14, 2010, when some provinces were severely affected by a flood, namely Nakhon Ratchasima and Hat Yai District in Songkhla Province. The apparent rainfall pattern from the monthly cumulative precipitation rate is shown in Figure 5 (green line graph). Both the precipitation amount and the monthly mean of the precipitation rate show the opposite pattern over the La Niña events.


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For Case 3 of La Niña, 2011-2012, the relationship between PWV and SSTa, La Niña's influence was moderate to very high, especially at the SRTN and SOKA stations, and Case 2 had the exact negative correlation. This was across all stations and the case is characterized by an inverse relationship with the annual variations of PWV. The SSTa of La Niña activity ranges from 0.6 ºC to 1.1 ºC. In this case, the strength of La Niña is not the same as in Case 2 but still affects it. In addition, the monsoon trough lies across the North and the upper Northeast. Moreover, the strong southwest monsoon prevails over the Andaman Sea and the Gulf of Thailand, resulting in heavy rainfall in all parts of the country and extreme rainfall in some areas.

For the 2009-2010 El Niño cases (Case 1), the correlation between PWV and SSTa was moderate to very high, except for the SRTN and SOKA stations that were not correlated. In this case, the influence of El Niño caused the rainy season to be later than usual and rainfall to be less than normal (Figure 5). Additionally, the daily and monthly precipitation rates showed the lowest values in February 2010, demonstrating the effect and the impact of residual El Niño events after the peak in December 2009. The results show that ENSO events had an impact on Southeast Asia, primarily to the change in atmospheric water vapor content, especially at the end of 2011. The decreased PWV effect will bring a consequence to increase the rainfall that will cause flooding and severe storms. The results from this research are consistent with previous research looking at the relationship between ENSO events and PWV, suggesting that ENSO events affect PWV and suggesting that GPS-derived PWV is a suitable technique for the study activities of ENSO (Suparta, 2018, Suparta et al., 2012 and 2013). In short, the La Niña event affects Southeast Asia, primarily from an increase in PWV, leading to an increase in rainfall and a risk of flooding and landslides (Suparta et al., 2012).

## 4. Conclusion

Correlation between PWV and SSTa for ENSO events at 11 ground-based GNSS stations in Thailand found a negative correlation between PWV and SSTa at all stations during La Niña and El Niño events. Respectively, for the SRTN and SOKA stations located near the coast, the relationship was reversed. That is to say, during the La Niña events, there was a high correlation. Nevertheless, for El Niño events, there was no correlation. A negative correlation indicates that during the La Niña event, PWV increases as sea surface temperatures cool. In particular, at the end of 2011, a decline in PWV had the consequence of causing flooding and severe storms.

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