A study of El Niño-Southern oscillation impacts to the South China Sea region using ground-based GPS receiver

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Abstract. We observe an ENSO activity by using ground-based GPS receiver as an effort to study the effects of global warming and climate change in the tropical region. The precipitable water vapor (PWV) derived from Global Positioning System (GPS) meteorology in line with the sea surface temperature anomaly (SSTa) is used to indicate their response on ENSO activities. The PWV data used in this study was taken from the station at Universiti Malaysia Sabah, Kota Kinabalu (UMSK) over 2011, together with NTUS station (in the Singapore), PIMO (in Philippines) and BAKO (in Indonesia) are also compared. The relationship between PWV and SSTa at all stations on weekly basis exhibited modest with correlation coefficients between -0.30 and -0.78 significantly at the 99% confidence level. The negative correlation indicates that during a La Niña phase, the PWV is increased when the sea surface temperatures getting cold causes warm air mass in the central Pacific moved to west Pacific. The increased of PWV causes the GPS signals will be getting slower.

1. Introduction

One of the most significant advances in the natural climate variability in recent years that raised concern around the world is the cycle of El Niño-Southern Oscillation (ENSO). ENSO is a complex phenomenon that results from interaction between ocean and atmosphere in the tropical Pacific Ocean, which consisted of warm (El Niño) and cool (La Niña) phases. Based on the Oceanic Niño Index (ONI), the warm phase is defined with sea surface temperature anomaly (SSTa) greater than 0.5°C, and cool phase is less than -0.5°C. An ENSO cycle is occur with aperiodic scale from 2 to 9 years (Bjerknes, 1969) depending on its location of occurrence. An ENSO phenomenon can be monitored based on the differences between sea level pressure anomalies (SLPa) at Tahiti and Darwin (Ropelewski and Jones, 1987). Other indices to monitor ENSO are the sea surface temperature (SST) in the Pacific Ocean region from central to eastern (Rasmusson and Carpenter, 1982; Reynolds and
Smith 1995), and the zonal gradient of precipitation in the equatorial Pacific (Curtis and Adler, 2000). Although ENSO originates in the tropical Pacific, it affects human life and environment through global climate and weather events such as drought/flooding, landslides and tropical storms. Some aspects of the ENSO mechanisms that affect the South China Sea region are still not well understood.

In this paper, we propose a ground-based Global Positioning System (GPS) technique to monitor ENSO activities. As the GPS signals can be used for geophysical and atmospheric studies; so they have been employed to estimate the atmosphere parameters, such as precipitable water vapor (PWV) (e.g., Bevis et al., 1994; Suparta et al., 2008). For the observation, the PWV data derived from GPS measurements at four selected GPS stations were used. In addition, the sea surface temperature anomaly (SSTa) data associated with the PWV response was used to characterize the ENSO activity. A correlation analysis was employed to indicate PWV responded to ENSO events.

2. Methodology

2.1. Data and Location
The main base of observation in this study is use GPS data located at Universiti Malaysia Sabah, Kota Kinabalu Sabah (UMSK), Malaysia. The other GPS data were taken from the Nanyang Technological University (NTUS) in Singapore, the Manila Observatory (PIMO) in Philippines and Bakosurtanal (BAKO) in Indonesia for comparison. GPS data other than UMSK were downloaded from the Scripps Orbit and Permanent Array Center (SOPAC) site. At the same time, PWV data taken from Radiosonde (RS PWV) were used to compare the GPS PWV. The location of all GPS stations used in this study is depicted in Figure 1. UMSK station is located at the geographical coordinate 6.03°N latitude, 116.12°E longitude and ellipsoidal height of 63.49 m. The geographical coordinates for other stations is summarized in Table 1.

![Figure 1. Location of GPS stations used in this study.](image)

**Table 1.** Geographical coordinates and instruments set up of GPS receivers.
| Station (Country) | Latitude (Deg) | Longitude (Deg) | Height (m) | Type of GPS receiver (year) | Cut off elevation-angle (Deg) |
|------------------|---------------|----------------|-----------|-----------------------------|-----------------------------|
| UMSK (Malaysia)  | 6.03 N        | 116.12 E       | 63.49     | Trimble NetR8 (2011)        | 13                          |
| NTUS (Singapore) | 1.35 N        | 103.68 E       | 75.38     | LEICA GRX1200GGPRO (2007)    | 0                           |
| PIMO (Philippines)| 14.64 N      | 121.08 E       | 95.53     | ASHTECH UZ-12 (2009) LEICA  | 4                           |
| BAKO (Indonesia) | 6.49 S        | 106.85 E       | 158.2     | GRX1200+GNSS (2010)         | 0                           |

2.2. Data Processing

To calculate the PWV, GPS data must be combined with meteorological data like pressure \( P \) in hPa, temperature \( T \) in °C and relative humidity \( H \) in percent to remove the errors during GPS transmission to the ground. The meteorological data were obtained from the meteorology station which same location with GPS station, or downloaded from another source like weather underground site. Figure 1 shows the GPS signal propagation to a receiver on the ground that has been interacting with sea surface. As seen in the figure, when the GPS signal propagates through the Earth’s atmosphere, it is affected by the variability of the refractive index of the ionosphere and troposphere. The excess delay of the signal causes bending of the signal and the total delay along the slant path can be determined (Suparta, 2012). In contrast, the total tropospheric delay (ZTD) in the neutral atmosphere, which comprised of zenith hydrostatic delay (ZHD) and zenith wet delay (ZWD) can be calculated based on the improved Modified Hopfield model. The ZHD was calculated using the Saastamoinen model. A Vienna mapping function (VMF1) was employed to reduce the atmospheric bias in the ZTD estimation (Suparta et al., 2011). The ZWD was computed by subtracting the ZHD from the ZTD. The ZWD was then transformed into an estimate PWV by employing the surface temperature measured at a particular site. The total PWV (in mm) from a receiver position to the top of the atmosphere was calculated based on the formula proposed by Bevis et al. (1994). Details of PWV determination by means GPS observations for this study can be found in the paper of Suparta et al. (2008).
Figure 2. Propagation of GPS signals to a receiver on the ground that covers the sea surface influences.

To process and analyze the above parameters, we used the tropospheric water vapor program (TroWav, a set of Matlab codes) developed by Suparta et al. (2008), Suparta (2010) and Suparta et al. (2011). A schematic representation of the TroWav algorithm for processing the PWV is depicted in Figure 3. After cleaning and equalize the size matrix of both GPS and the surface meteorological data, they were processed to obtain PWV. Then to relate the ENSO activity with response to the PWV changes uses the SSTa Oceanic Niño Index (ONI) in pathways of Niño 3.4 and Niño 4 regions. The SSTa data were taken from the National Oceanic and Atmospheric Administration (NOAA). All the data were analyzed on a weekly basis based on GPS week because the SSTa data only provided by NOAA in a weekly.
3. Result and Discussion

3.1. PWV and SSTa variability

The weekly PWV variability from the GPS and RS measurements is presented in Figure 4. Although the pattern of PWV at each station exhibited changeable, their variation showed a similar trend. For UMSK and NTUS stations, the PWV value is recorded between 45 mm and 55 mm. For PIMO station, the PWV was ranged between 35 mm and 50 mm, while BAKO station was between 35 mm and 45 mm. Table 2 gives the summary of PWV value between GPS and RS. From the table, the PWV value for GPS was ranged between 40 mm and 50 mm (45.76 mm on average) with a STD of 2.66 mm, while for RS was ranged between 37 mm and approximately 60 mm (50.61 mm on average) with a STD of 4.96 mm. The different variability in PWV at each station is due to many factors, including latitude coordinate, topography and the distance between GPS station with the sea. For example, the nearest distance between the stations with the sea will obtained higher variability of water vapor, and conversely, the more distant will lower the PWV variability. This influence gives the indication that the sea is the greatest evaporation, and PWV will move later to mainland by the wind. The further moves ashore, PWV will be reduced because some of the water vapor falls as rains.
Figure 4. A weekly PWV variability from GPS and RS over the 2011 at eight selected stations.

Table 2. The statistical value of PWV for GPS and RS data for 2011.

| Station | Min  | Mean | Max  | STD  |
|---------|------|------|------|------|
| UMSK (G)| 48.48| 50.81| 53.66| 1.56 |
| NTUS (G)| 48.30| 52.97| 56.39| 1.78 |
| PIMO (G)| 31.80| 42.39| 48.80| 4.78 |
| BAKO (G)| 32.21| 36.92| 42.02| 2.53 |
| WBKK (R)| 51.39| 55.66| 60.72| 2.36 |
| WSSS (R)| 47.18| 54.61| 63.03| 3.45 |
| TANAY (R)| 18.67| 41.51| 51.74| 6.92 |
| WII (R)  | 34.22| 51.68| 61.47| 7.11 |

**Average**: 39.03 48.19 54.72 3.81

G and R are for GPS and Radiosonde, respectively.

SSTa is a good indicator to represent an ENSO activity. The SSTa variability for Niño 3.4 and Niño 4 regions for the year 2011 is demonstrated in Figure 5. In general, only La Niña phase taken place in the West Pacific region during 2011 based on NOAA definition. The phase is active from January to April and the middle of July to December, while the other month is in normal phase. For
the period of January to April, the intensity of La Niña was strong to weak condition with SSTa minimum of -1.8°C for Niño 3.4 region, while the middle of July period to December was weak to strong condition with SSTa minimum of -1.6°C for Niño 4 region.

Figure 5. SSTa variability for Niño 3.4 and Niño 4 regions for the year 2011

3.2. Relationship between GPS PWV and SSTa

Figure 6 shows the relationship between GPS PWV and SSTa for a La Niña case (SSTa below -0.5°C) of Niño 4 region. Note that due to incomplete GPS data at UMSK station, the PWV from Radiosonde was used. Based on the correlation analysis, the relationship between the two variables at all stations shows modest correlation with correlation coefficients between -0.30 and -0.78 significantly at the 99% confidence level. For the Niño 3.4 region (not shown), the correlation coefficients for NTUS, PIMO, WBKK and BAKO stations are -0.58, -0.73, -0.67 and -0.66, respectively. The better relationship given by Niño 4 region than 3.4 region is due to the Niño 4 region is more western and near with the location of study (GPS station). More than that, the correlation coefficient obtained is negative, although the relation trend is positive. This indication during the cold phase can be explained as follows. Cooler air cannot hold much water vapor in the atmosphere because the density of water molecules easily depressed and falls as rain. The variation of water vapor is a function of the temperature. Moist climates tend to have a lower diurnal range in temperature. Because of latent heat, condensational cooling is at a maximum and there is a little water vapor to trap longwave radiation.
during the night. Therefore, during heavy rainfall, the temperature is cool. Generally speaking, water vapor in the atmosphere will be reduced by heavy rain.

![Figure 6](image)

Figure 6. Scatterplot for relationship between GPS PWV and SSTa below -0.5°C (La Niña case) for Niño 4 region.

4. Conclusion

The impact of ENSO events such as La Niña over the South China Sea region to the variation in the GPS PWV during the period of 2011 has successfully addressed. Analyses of association between PWV and SSTa below -0.5°C (La Niña phase) found low-to-moderate negative correlations at four selected GPS stations. The negative correlation indicates that during the La Niña phase, the PWV is increased that causes warm air mass in the central Pacific Ocean moved to west Pacific. The increased of PWV causes the GPS signals will be getting slower because of ocean-atmosphere interactions. This implies that La Niña events that associated with unusually wet conditions (higher rainfalls) have an impact to the western Pacific Ocean as well as South China Sea region, which seem directly through the changes of the water vapor amount in the atmosphere. The La Niña effects with increased PWV will bring a consequence to increase the rainfall that can generate flooding and severe storms. As a conclusion, an ENSO activity can be studied from the atmospheric path delay of GPS signals through the response of PWV variability, and we suggest that this tool be used on monitoring platforms.

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