The role of CORS GNSS data for climate monitoring: case study using NIGNET network

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Key words: GNSS, CORS, Climate, Water Vapor

SUMMARY

Our planet's fragile ecosystem is being disturbed in the last decades by the emerging climate change and the lack of adequate knowledge in its causes and consequences. In Nigeria, desertification, coastal flood, urban flood, river flood, whirlwind, heat burnt from flared gas/sun and all types of erosion are common features.

In particular, many towns/cities and farmlands have been flooded causing that many people have been displaced in recent times. The flooding was associated with heavy downpour of rain and also the opening of Lagdo Dam in Cameroun. The full impacts are yet to be completely evaluated but they have environmental, economic, and social-psychology effects.

This paper focuses on investigating what can be the contribution of NIGNET – the national GNSS network managed by OSGoF (Office of the Surveyor General of the Federation) - to help identify the patterns of rainfall all over the country. We are able to estimate directly the ZTD (Zenith Tropospheric Delay) using the GNSS observations. ZTD can be converted into PWV (Precipitable Water Vapour) if Temperature and Pressure are also known for the same epochs at the location. At the moment, the NIGNET stations still do not have weather stations collocated with the GNSS receiver. Therefore, we will be limited to use global models to convert from ZTD to PWV. But, these estimations are already sufficient to analysis the short- and long- patterns and their correlation with the recent flooding events affecting Nigeria.

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1. INTRODUCTION

The 2012 rainy season in Nigeria was one of the worse ones in the last decades: heavy rains at the end of August and the beginning of September led to serious floods in most parts of the country. During the last week of September water reservoirs have overflown and the dams had to be open both in Nigeria and neighboring Cameroon and Niger, causing the destruction of river banks and infrastructures, loss of livestock and flash floods in many areas.
By 29 Sep, the floods had affected about 135000 people, displaced about 65000, injured 202 and killed 148. By the end of October, more than 7.7 million people had been affected by the floods, and more than 2.1 million had registered as Internal Displaced Person (IDP). 363 people were reported dead, almost 600000 houses had been damaged or destroyed (cf. Figure 1). Out of 36 States of the country, 32 States were affected by the floods. Only by January 2013, the rivers were back at their usual water levels and further flooding was not expected in the short term.

Figure 1 – Detail of the floods that affected millions of Nigerians in 2012 (Anambra State)

These numbers just show us the importance in better understanding the climate and monitor its major parameters. This poses significant issues in regions lacking climate monitoring instruments. The establishment of NIGNET (NIGerian GNSS Reference NETwork) formed by state-of-the-art CORS (Continuously Operating Reference Station) GNSS (Global Navigation Satellite Systems) equipments is permitting to have an additional tool to monitor one of the most important meteorological and climate parameters: the quantity of Precipitable Water Vapor (PWV) in the atmosphere which is direct correlated with the precipitation, which potential use is discussed in this paper. Precipitable Water Vapor plays a major role in many atmospheric processes concerning physics, thermodynamics and dynamics. The knowledge of the spatial and temporal distribution of Water Vapor in the lower troposphere is essential for both accurate quantitative prediction of precipitation and better understanding of convective processes. The atmospheric water vapor is particular important in clouds formation and composition, convective initiation and feeding and also precipitation processes [Baelen et al., 2005].

Figure 2 shows the current distribution of the NIGNET network. It started to be installed in 2009. Currently, there are 11 stations directly installed by OSGoF. OSGoF also manages more three stations installed in the framework of Land Reform project and also collaborates with RECTAS (Regional Centre for Training in Aerospace Surveys) on the data maintenance of RECT station at Ife. The data from the permanent stations are collected at the headquarters in Abuja [Jatau et al., 2010].

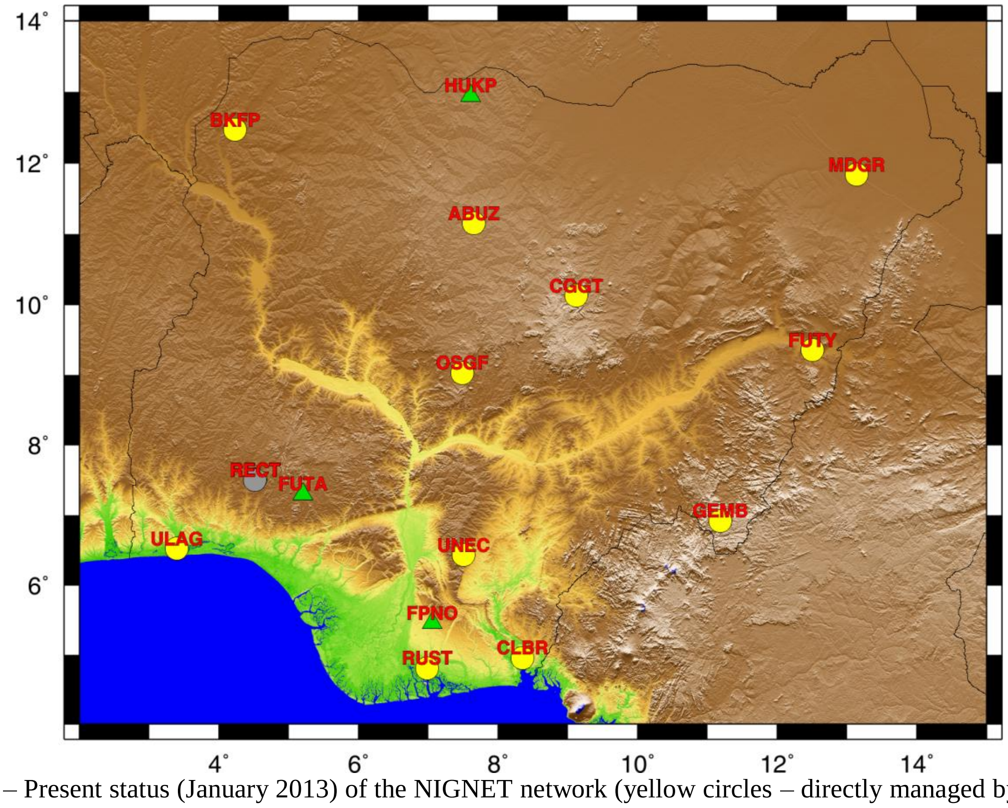

Figure 2 – Present status (January 2013) of the NIGNET network (yellow circles – directly managed by OSGoF; green triangles – installed by Land Reform; gray circle – RECTAS)

1.1 GNSS and Water Vapor

In recent years, the use of GNSS observations to sense the Precipitable Water Vapor (PWV) in the troposphere has increased significantly. GNSS has large advantages since it is a system that works in all weather conditions, with continuous unattended operation, good time resolution and an ever increment in the number of stations at many regions.
While travelling through the Earth’s atmosphere the GNSS signal is going to experience delays caused by the atmosphere, mainly the ionosphere and troposphere. Considering the dispersive character of the ionosphere for the GNSS frequencies, ionospheric effects are minimized using a fitted linear combination of the GNSS frequencies [Brunner and Gu, 1991]. Conversely, the tropospheric effects are not frequency dependent below 15 GHz. The main effect of the troposphere on GNSS positioning is an extra delay of the radio signal emitted by GNSS satellites [Davis et al., 1985]. This delay is time varying due to the variable pressure, temperature and water vapor content of the atmosphere and cannot be modeled or predicted with sufficient precision for high precision positioning, especially in real-time. To model out the perturbation, a set of tropospheric parameters is estimated during the GNSS data analysis: Zenith delays, and more recently, horizontal gradients. The correlation between these delays and the state of the atmosphere makes the GNSS an efficient tool for meteorological observation.
Most of the scientific software packages (e.g., GIPSY-OASIS, BERNESE, GAMIT) permit to estimate the Zenith Tropospheric Delay (ZTD), from which the PWV can be derived knowing temperature and pressure at the site location. ZTD (cf. Figure 3) is equal to ZHD+ZWD, where the hydrostatic delay (ZHD) is the major component (90-97%) and can be accurately inferred from measurements of surface pressure. However, the other, the wet delay (ZWD), although is much smaller, can have significant temporal and spatial variations. It is this component that is estimated in the GNSS processing. The PWV can be derived from the estimated ZWD using the following formulas, where K_2' and K_3 are empirical physical constants, ρ is the density of liquid water, R_v is the specific gas constant for water vapour, and T_m is the surface temperature:

$$PWV = \pi * ZWD$$

$$\pi = 10^6/(\rho R_v \left(K_2' + \frac{K_3}{T_m}\right))$$

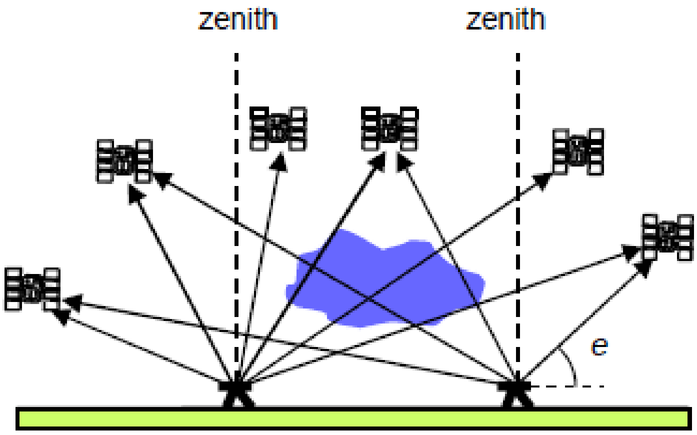

Figure 3 – Zenith Total Delay has a function of the delays for all observed satellites.

2. RESULTS

In this work we are analyzing several periods related with the flood events in 2012 using data from three stations of the network (cf. Figure 4) distributed all over Nigeria. For the different periods we computed the ZTD and we correlated them with the precipitation. Unfortunately, there are no meteorological stations collocated with the NIGNET stations that allow us to have precise values for surface temperature and pressure. Therefore, we were limited to analyze the ZTD instead of PWV. Since we are in Nigeria and particularly the temperature does not vary significantly along the day, the use of ZTD instead of PWV can still be considered to be valid. Nevertheless, it is being studied by OSGoF the installation of meteorological stations at each GNSS site in order to be able to compute the PWV directly
The precipitation was obtained at ftp://ftp.cpc.ncep.noaa.gov/fews/ for each day. This site also only provides an interpolated value in a grid of 0.1°x0.1°.

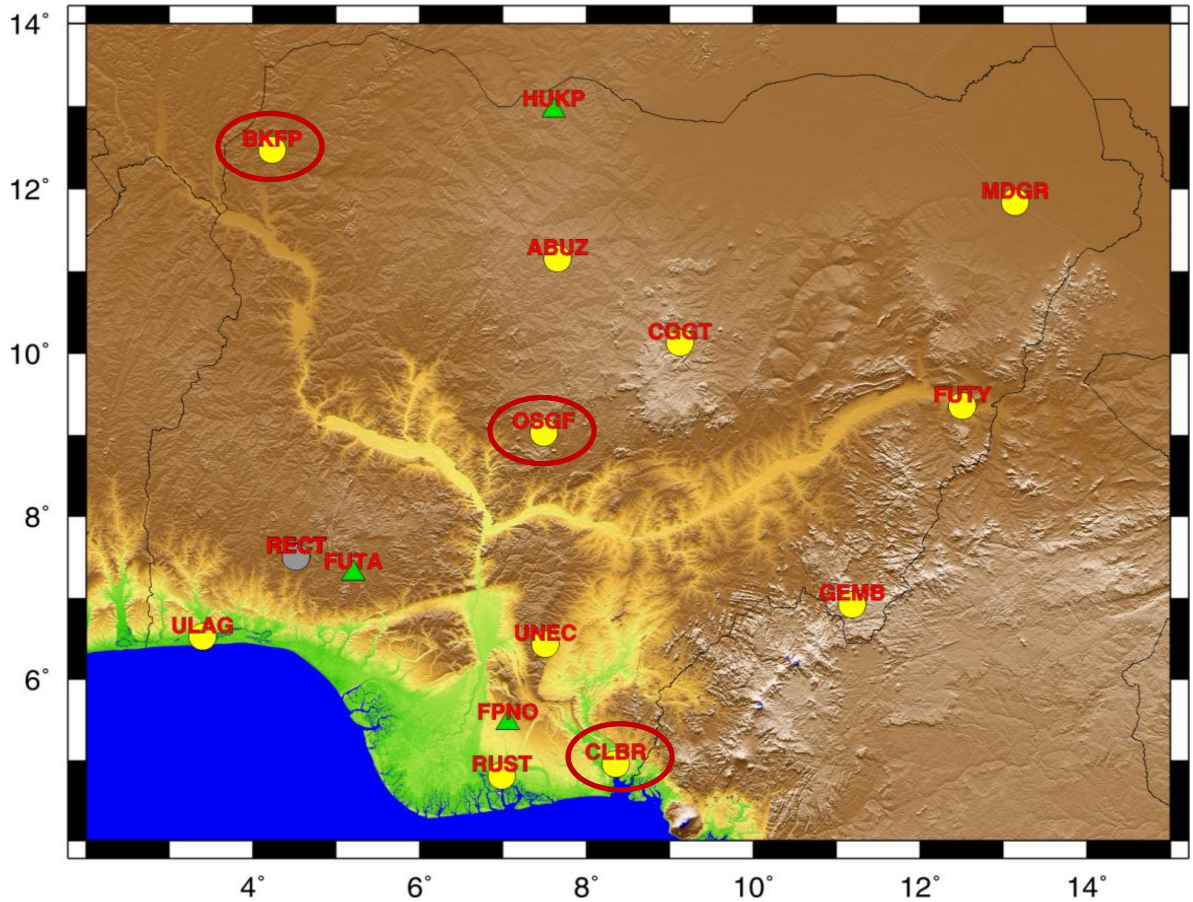

Figure 4 – Analyzed NIGNET stations in this work.

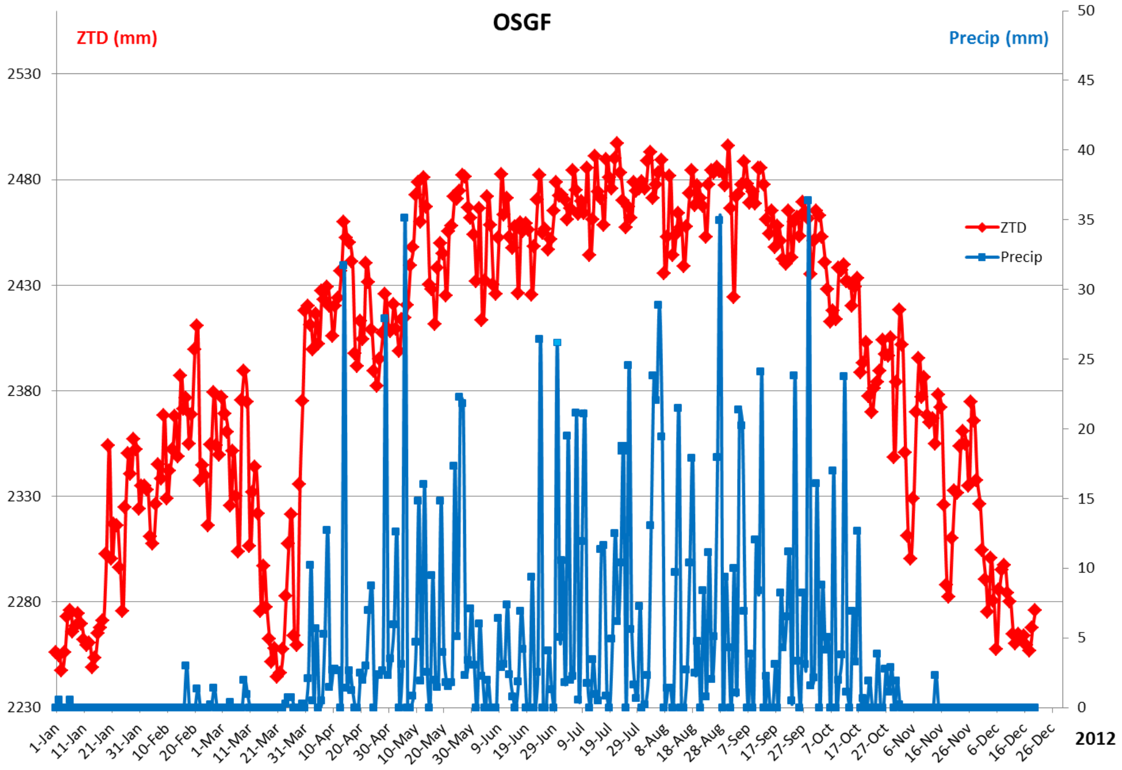

Figure 5 – ZTD and Precipitation for OSGF (Abuja) for 2012

Figure 5 shows the ZTD and Precipitation at Abuja for the entire year of 2012. It is clear the correlation between the values of ZTD and Precipitation. The high values of the daily averaged ZTD correspond to the rainy months. However, at a short scale, such correlation is not so obvious, as it can observed in Figures 6-8 for one of the most rainy periods of 2012 (15^{th} August – 15^{th} September) which corresponds to the period when the floods started. Nevertheless, it is observed that relative high values of ZTD correspond to high values of precipitation. However, sometimes there is a delay of 1-2 days between peaks in both parameters. Two possible reasons for this effect: first, we are averaging daily values of ZTD and comparing with precipitation. Second, not all water vapour on the atmosphere is converted into rain.

The use of GNSS as a sensor for the precipitation is also shown in Figure 10 where we compare the ZTD and precipitation in Abuja for the same period of the year in 2011 and 2012. It is clearly observed that, on average, the ZTD in 2012 is higher than in 2011, and that is reflected on the observed values of the precipitation in this region of Nigeria.

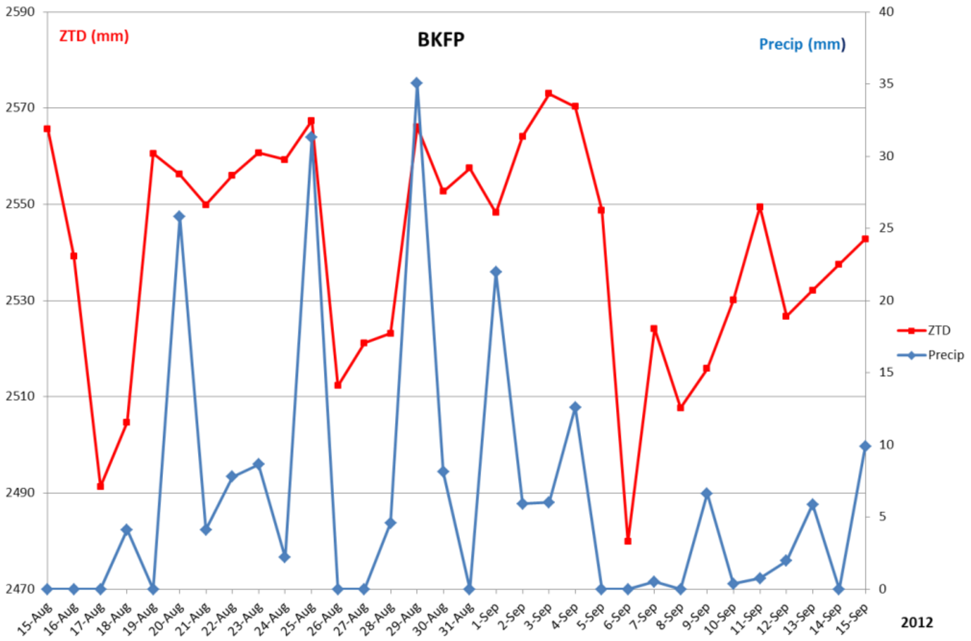

Figure 6 – ZTD and Precipitation for BKFP (Birnin Kebbi) for August-September 2012

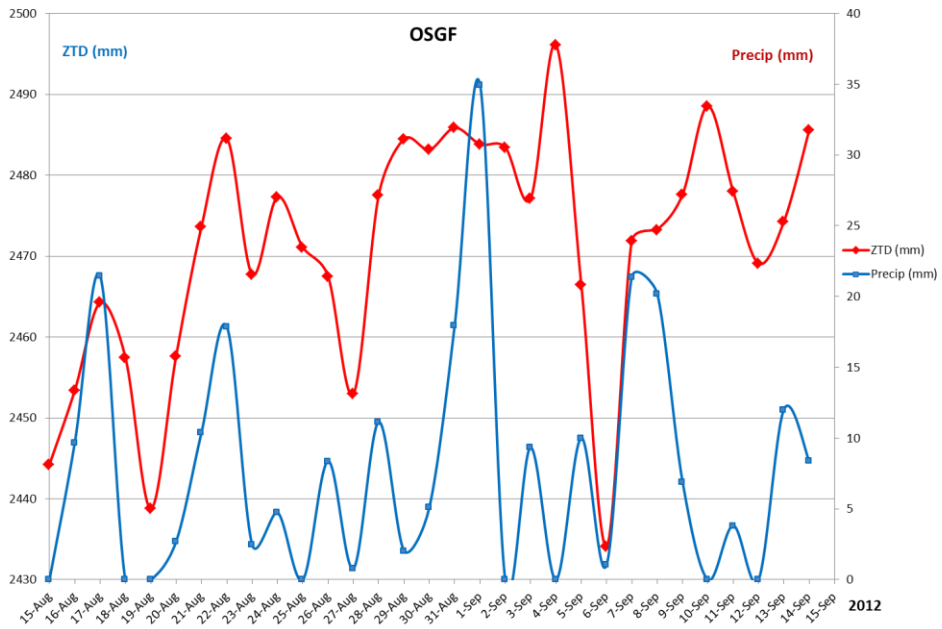

Figure 7 – ZTD and Precipitation for OSGF (Abuja) for August-September 2012

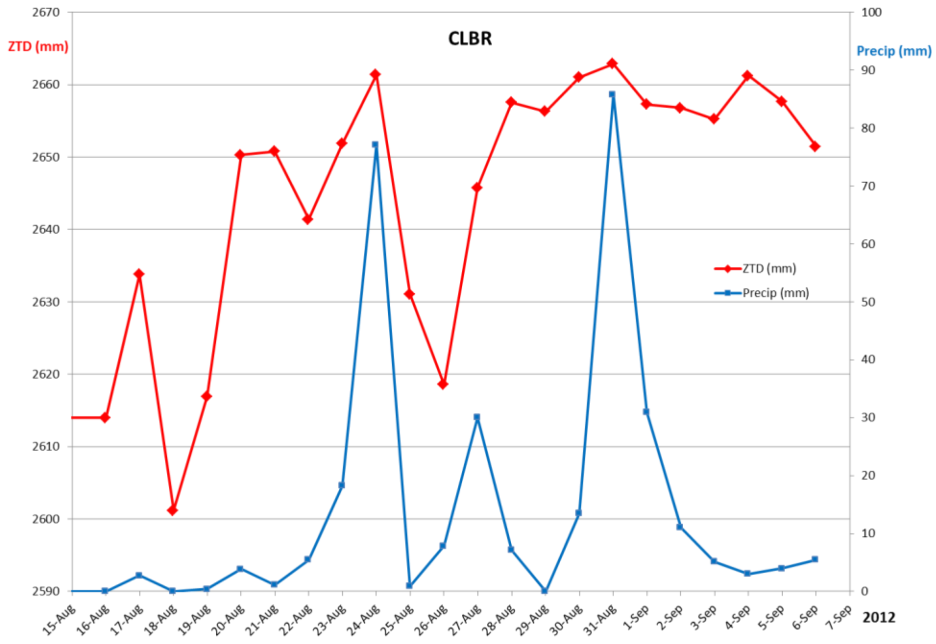

Figure 8 – ZTD and Precipitation for CLBR (Calabar) for August-September 2012

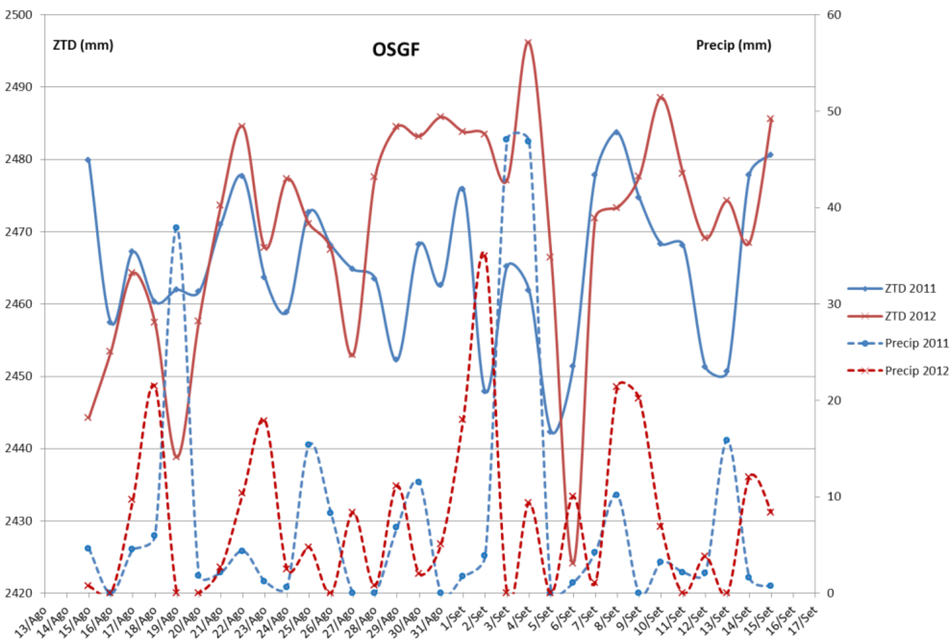

Figure 9 – Comparison between 2011 and 2012 for the ZTD and Precipitation at OSGF (Abuja) for August-September 2012

3. CONCLUSIONS

Although we are unable to do a very detailed study since we lack a dense spatial coverage and also we miss important meteorological data in order to compute the PWV directly, this study shows that the NIGNET network can be used to detect variations of precipitation through the

different periods of the year. With more data, we will also be able to compare more significantly the differences between different years.
The ultimate goal is that the data from NIGNET network can be integrated in forecasting numerical models as it is already being done in other parts of the world in a routinely procedure.

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