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Atmospheric water vapor measurement in order to estimate continental precipitation over Algeria region based on the INCT-GNSS network

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Abstract : Northern Algeria region is characterized by a Mediterranean climate, cold, humid, dry winters and warm summers, same as other countries in the world, and is exposed to desertification problems. Along its coast, the average annual precipitation is 384 mm, so more than 75% of its territory has an annual precipitation lower than 384 mm. This is a global problem that affects a large number of people and land, and is now one of the most important environmental problems in Algeria. The work presented in this paper describe a preliminary study of GNSS meteorology technique based on GNSS positioning and estimation of the tropospheric water vapor quantity based exclusively on the INCT-GNSS network. According to our results, we noted that the integrated content of water vapor is a highly variable parameter that depends on the study region, in our study it is between the South and the North of Algeria, this variation is related to the geographical position in relation to the Mediterranean Sea, as well as the season, noticing that during the winter the quantities of water vapor are low compared to the summer. No relationship could be found between GNSS IWV and precipitation values, except for a significant increase in GNSS IWV that frequently precedes the arrival of precipitation. Improving atmospheric observation techniques and understanding of the key processes of precipitation formation is thus a major challenge for our society. In fact, a better prediction of precipitation would allow bettering anticipating the occurrence of floods and consequently to minimize the damages related to these events.

Keywords : GNSS data post-processing, Water vapor, Algeria region, IWV, ZTD, INCT GNSS network.

1. Introduction

Water vapor plays a fundamental role in the atmosphere, both in climatology and meteorology. Its observation remains very partial because of its strong spatiotemporal variability. Several measurement systems already exist such as radiosondes, radiometers, but their spatial or temporal resolutions are not sufficient to quantify this quantity. Weather forecasts have constantly improved in recent years, particularly through the development of models that take into account more and more parameters and assimilate new data, with increasingly fine resolutions. The positioning by GNSS satellites in addition to its important role for geodetic positioning and navigation, can be used for the study of meteorological phenomena as well as climate change [1], it allows indeed to measure the water vapor in the atmosphere with a high temporal resolution and a moderate spatial resolution, depending on the number of GNSS stations available on the ground, [2], [3] ; [4] and [6], this water vapor measurement technique has many advantages, due to its very moderate cost and its ability to provide good quality data continuously, regardless of weather conditions and with good temporal resolution. The propagation of GNSS signals through the troposphere generates a tropospheric elongation that adds to the geometric distance between the satellite and the receiver. However, recent modeling of tropospheric elongation, supported by continuous improvement of processing tools, allows us to significantly reduce this limitation. [6]. Studies show the importance of the contribution of estimated tropospheric delays in GNSS data processing for meteorological applications. The total atmospheric delay is the sum of two terms, a first term which is the hydrostatic zenith delay ZHD (corresponding to about 90% of the total delay) that can be calculated by knowing the atmospheric pressure at the GNSS antenna, and a second term wet zenith delay ZWD due to water vapour (about 10% of the total delay), with this last term we can estimate the amount of water vapour in the atmosphere CIVE integrated content in water vapor or IWV Integrated Water Vapor. To do this we processed and analyzed data of the first ten days of each season (January and July) for the year 2020, provided by the four GNSS stations located in Algiers, Bechar, Tindouf

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and Tamanrasset. We present in the first part a detailed description of the Algerian GNSS network and the method of estimation of the IWV (Integrated Water Vapor). The second part is devoted to a description of the various stages of processing. At the end, we find an illustration of the results and an interpretation of the IWV estimation in the different Algerian regions.

II. Methodology and data

II.1. GNSS Network and processing

In this study a treatment in post processing has been made of GNSS data from four active permanent stations which are located over Algeria, for the first ten days of each season (January and July) for the year 2020 of observations. One approach has been experienced by the use of the BERNEE GNSS Software 5.2 developed by the Institute of Astronomy of the University of Bern (AIUB) [9], it is the Precise Point Positioning (PPP), using code and phase measurements with precise clocks, orbit information and Earth orientation parameters provided from IGS (International GNSS Service) [7], and using zero-difference observations from stand-alone stations. The coordinates are constrained to the ITRF2014 reference system values using IGS Continuously Operating Reference Stations (CORS) during the treatment. The raw data are in the RINEX (Receiver Independent Exchange) format of the local and IGS dual-frequency stations are processed using the precise ephemeris and satellite clock corrections published by the IGS. The a priori model corresponds to the dry component of the VMF (Vienna Mapping Function).

II.2. ZTD and ZHD derived from GNSS data

For a decade, GPS observations have shown their ability to estimate the zenith tropospheric delay (ZTD). This total delay can be divided into the hydrostatic part defined as zenithal hydrostatic delay (ZHD) and wet part named zenithal wet delay (ZWD). Following [6], ZWD is closely linked to the water vapor in the atmosphere and can be transformed into IWV using a simple scale factor II. This factor is usually estimated as a function of the surface temperature by empirical equation derived from regional radiosonde observations. Thus, GPS dense networks may provide vertically integrated tropospheric water vapor observations. The aim in this part is to describe humidity field locally in Algeria during rainfall episode. The common analysis procedure is described in several publications [5], [6] ; [7]. Thus, we give only a brief overview here. The tropospheric delay estimate is expressed as ZTD, which is decomposed into the zenith hydrostatic delay (ZHD) and the ZWD as is shown in the following relation :

$$\mathrm{ZTD} = \mathrm{ZHD} + \mathrm{ZWD} \qquad \textbf{(1)}$$

The ZTD yields the water vapor information. To hydrostatic equilibrium, ZHD can be expressed as a function of surface pressure Ps, measured at GPS antenna. The ZHD is expressed as :

$$\mathrm{ZHD} = (2.2768 \pm 0.0005)\ \rho_s / f(\varphi, \mathrm{H}) \qquad \textbf{(2)}$$

Where ZHD is in mm and Ps is the surface pressure (in millibars).

$$f(\varphi, \mathrm{H}) = 1 - 0.00266\ \cos 2\varphi - 0.00028\ \mathrm{H} \qquad \textbf{(3)}$$

The Relation 3 describes the dependence of gravity acceleration from latitude φ and surface height H (in Km) over the ellipsoid. The ZWD estimates were then obtained by subtracting the ZHD from the ZTD data (Formula 1) [8]. The relation between IWV and ZWD is given by the following formula :

$$\mathrm{IWV} = \mathrm{ZWD}.\ \mathrm{II} \qquad \textbf{(4)}$$

The factor II depends on the water vapor-weighted atmospheric mean temperature Tm as following :

$$\Pi^{-1} = 10^{-6} \rho H_2 O R_v (\frac{C_2}{T_m} + C_2) \qquad \textbf{(5)}$$

Where : R_v is the explicit gas for water vapor (461.45 J/kg/K), $\rho H_2 O$ is the water density (1000 kg/m^3). The two constants are determined by [5] :

$$\begin{aligned} C_1 &= (3.739 \pm 0.012) 10^5 K^2 h{P_a}^{-1} \\ &= (2.21 \pm 2.2) K h{P_a}^{-1} \end{aligned} \qquad \textbf{(6)}$$

The weighted mean temperature Tm of the atmosphere can be expressed as :

$$T_m = \frac{\int \frac{P_v}{T} dz}{\frac{p_v}{T^2} dz} \approx \frac{\sum_{i=1}^{N} \frac{P_i}{T_i}}{\sum_{i=1}^{N} \frac{P_i}{T_i^2}} \qquad \textbf{(7)}$$

Where P_vv is the partial pressure of water vapor, T the absolute temperature, and z the vertical coordinate. T_m can be estimated from ECMWF weather forecasting models using the linear relation to air temperature at the ground surface Ts [6] :

$$T_m \approx 70.2 + 0.72\ T_s \qquad \textbf{(8)}$$

An order of magnitude linking ZWD and IWV is given by : 1 kg.m^{-2} in IWV is equivalent to about 6.5 mm in ZWD. In the same way it is necessary to retain that 1 kg.m^{-2} is equal to 1 mm of IWV [5].

II.3. GNSS and Meteorological data

The stations that are the subject of our work are distributed between these two networks. During our study period during the year 2020, and we selected the four stations (HUSS, BECH, TIND, TAMA), these stations are distributed across the Algerian national territory and presented in (figure 1). This choice was made because of the availability of GNSS and Radiosonde data, and the climatic variation between these regions. After the initiation of the project, the name of the GNSS station of Algiers (DZAL) was changed to HUSS.

Meteorological data sampled hourly, corresponds to the three selected Algerian stations and were provided from the American University of Wyoming Atmospheric Science Department [10].

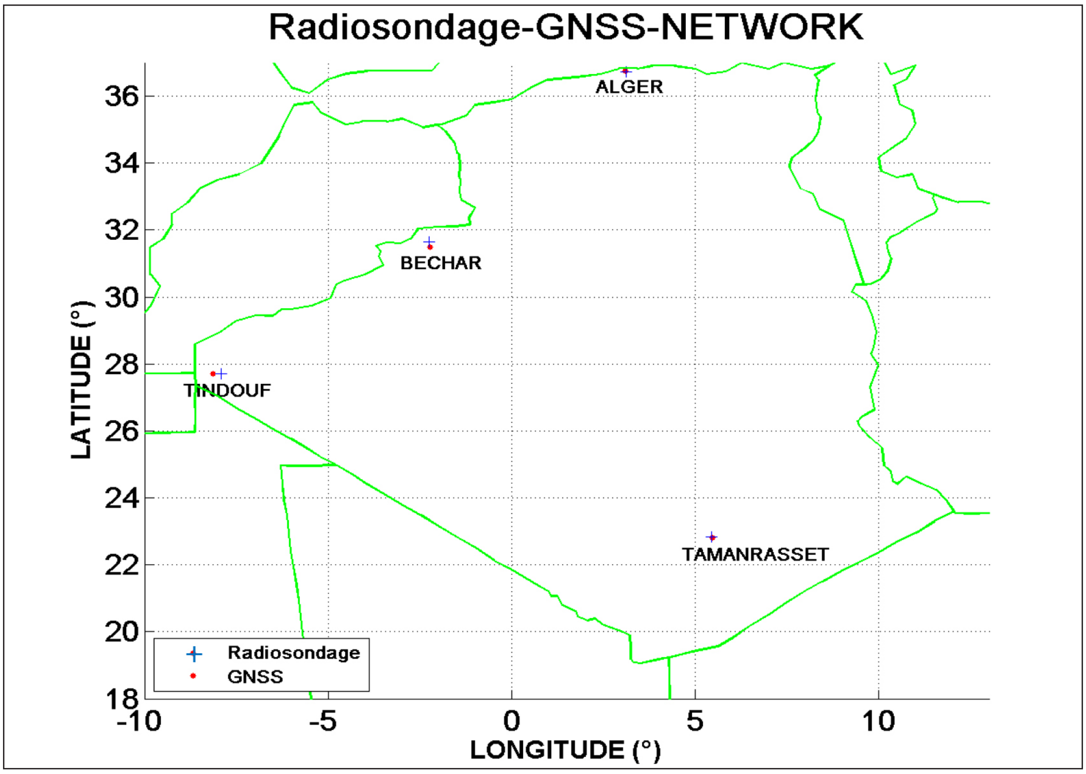

Fig. 1 Distribution of the GNSS stations operated by the Algerian INCT network

Tab 1. Coordinates of Algerian radiosonde stations

Stations Coordinates	DAR-EL-BEIDA	BECHAR	TINDOUF	TAMANRASSET
ϕ(°)	366833	31.5000	27.7000	22.8000
λ(°)	3.2167	-2.2500	-8.1997	5.433
H(m)	25.0	811.0	443.0	1377.0
Code WMO	60390	60571	60656	606080

With :

WMO code : station code assigned by the World Meteorological Organization.

ϕ(°) : Latitude of the station.

λ(°) : Longitude of the station.

H(m) : Height of the station's antenna.

III. Results and interpretation

III.1. IWV Variation during 2020

From year 2020, the station DZAL has been renamed and becomes HUSS, when the new project is realized. The variations of the total tropospheric zenith delay ZTD and the zenith wet delay ZWD are shown in the figures (figure 2 to figure 4) for the year 2020 for the stations HUSS, BECH, TIND, TAMA. For the month of January, the values of tropospheric delay ZTD and wet ZWD as well as IWV are much lower than in the month of July when the humidity is very high. These observations are well highlighted in (figure 2 and figure 3) which represent the variations of ZTD, ZWD and IWV for the months of January and July respectively.

Note that only station HUSS, has the availability of data for the month of July unlike the other three stations that were not visible during this period. According to the figures of the year 2020, there is a lack of GNSS data recording for some days of the study period for example the 3rd and 4th day of January 2020.

The cycle jumps correspond to a loss of signal reception from a satellite for a certain time. Often, this jump is due either to hardware problems, or to jumps related to ionospheric delays, or related to too low signal-to-noise ratios, correlated to multipath [11]. We also note the presence of some outliers in some GNSS data records. As an example, let us quote the spikes like the value assigned to the first hour of the 185th day recorded by the HUSS station. All these results are confirmed by the histogram of (figure 6) which shows that the highest values of IWV are reached during the month of July, the highest values are displayed by the GNSS stations of North Algeria.

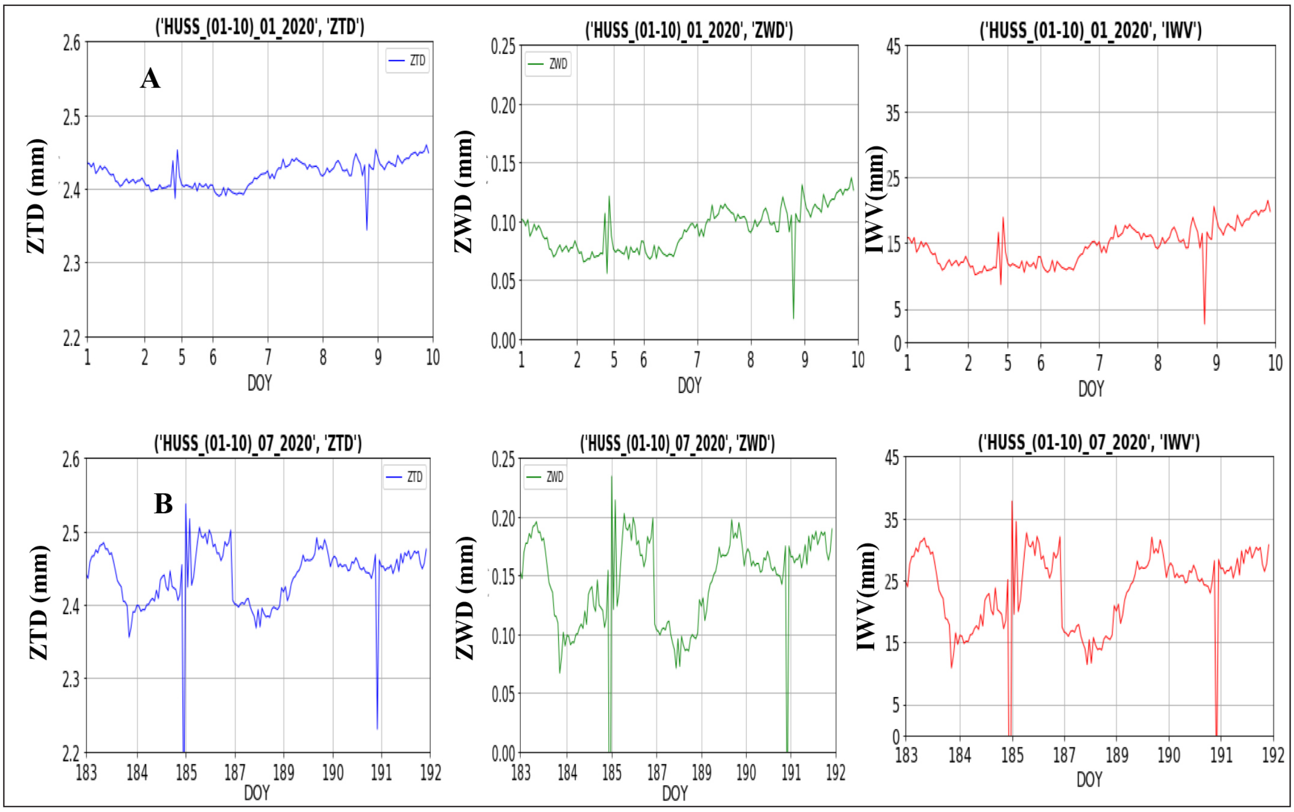

Fig. 2 Variation of IWV for station HUSS (A_ 01/2020 B_07/2020)

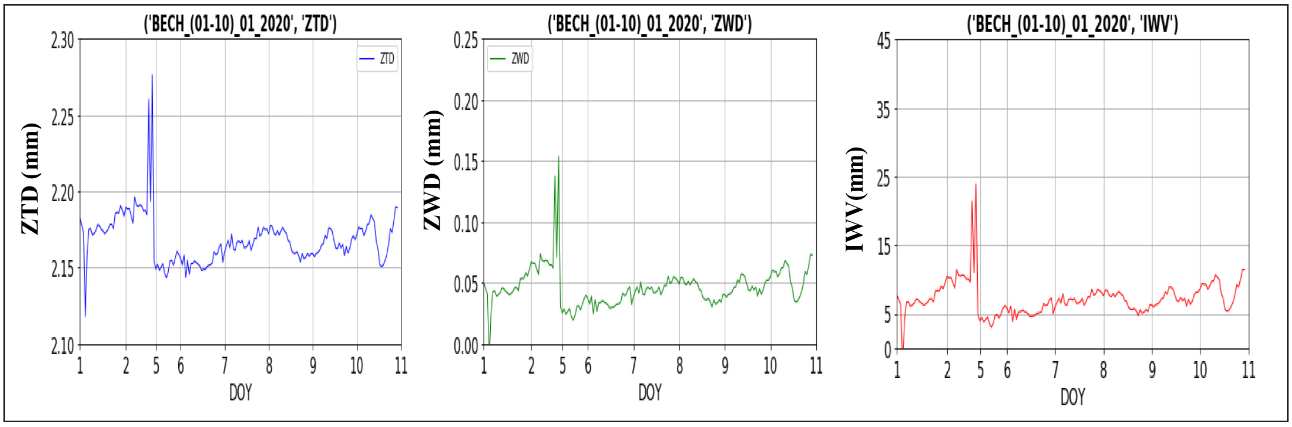

Fig. 3 Variation of IWV for station BECH (janv 2020)

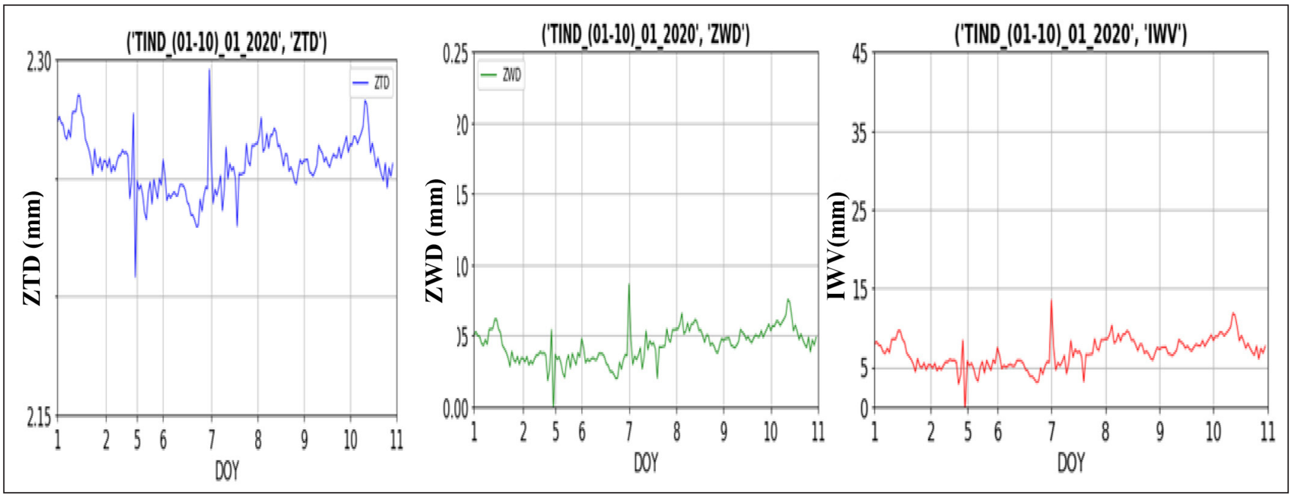

Fig. 4 Variation of IWV for station TIND (janv_2020)

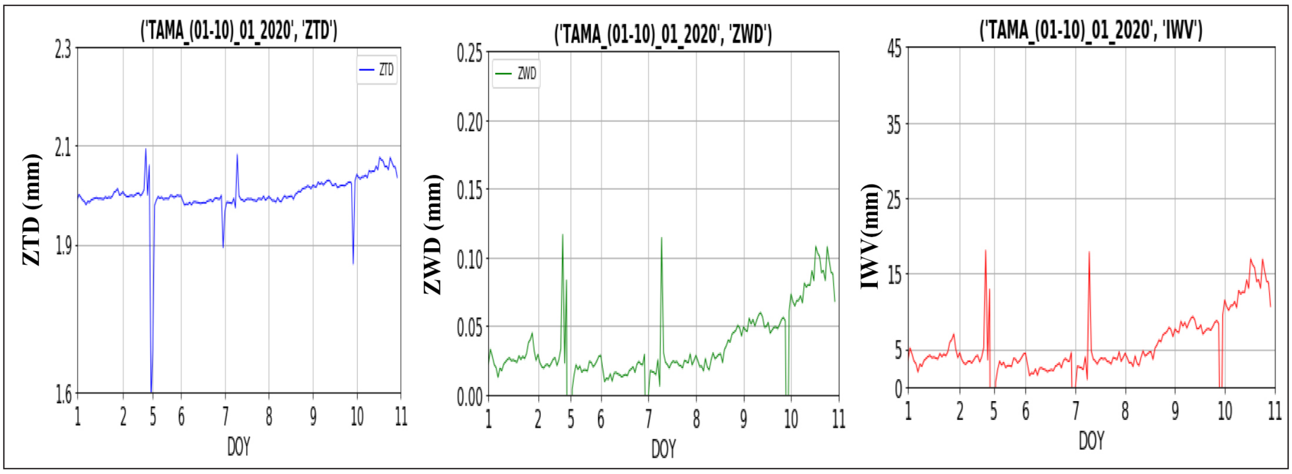

Fig. 5 Variation of IWV for station TAMA (janv_2020)

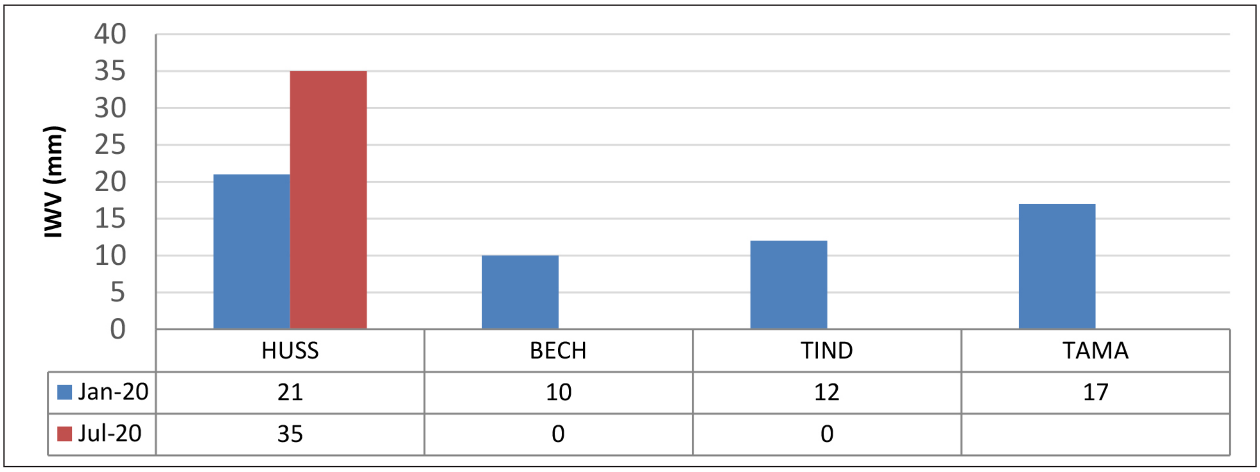

Fig. 6 Histogram of the variation of the IWV maximum during 2020

IV. Conclution

The objective of this work is to present a model on the processing and use of GNSS data and to use these data to improve the understanding of key mechanisms for the formation of rainfall based on a simple statistical study and a detailed case study. And from this work done we can conclude that the integrated content of water vapor is a highly variable parameter that varies according to the study region in our case between the South and North Algeria, and this variation is related to the geographical position in relation to the Mediterranean Sea, and also according to the season, note that during the winter the quantities of water vapor are low compared to the summer. There is no relationship could be found between GNSS IWV values and precipitation values, except for a marked increase in GNSS IWV that often proceeds the arrival of precipitation. The improvement of atmospheric observation techniques and of the understanding of key processes for precipitation formation is therefore a major societal issue. Indeed, better prediction of precipitation would allow better anticipation of floods and consequently reduce the damage associated with them.

V. References

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