Answers to Referee n°2

The referee's comments are repeated below in black italics and our answers are given in blue.Reviewer 1 - Specific Comments XX are abbreviated as RW1-SC-XX.

Reviewer 2 General comments

This paper assesses the variation of GPS tropospheric estimates (ZWD, ZTD gradients and IWV) in connection with passages of mesoscale convective systems (MCS) above and past a set of GPS sites in West Africa. It does so for two types of GPS data processing, network versus PPP.
It is demonstrated convincingly that indeed the GPS derived tropospheric estimates are sensitive to MCSs.
It is a concise, nicely written paper that I enjoyed reading. It can be published with only minor changes.

We thank the referee for his positive appreciation and all comments which helpedus to improve the manuscript. Please find below detailed clarifications and responses:

RW2-SC-01: "why ECMWF pressure?"

p 3: ECMWF pressures are used to determine ZHD. Why that when every site is equipped with meteorological sensors including a barometer?

Reply to RW2-SC-01

You are right, the surface pressure observations could actually be used to compute the a priori ZHD values but this is not done for two reasons. First, it is a standard and convenient procedure to use ECMWF ZHD estimates as a priori and estimate ZWD during the processing because all GNSS software can download and handle automatically the ECMWF data provided by Tech. Univ. Vienna, (simultaneously with the VMF1 mapping function parameters). Second, for the six stations analysed in this study, the ECMWF surface pressure field is very accurate, the comparison to our observations is at the level -0.9 ± 1.1 hPa, and the ECMWF data have no gaps contrary to the observations.

RW2-SC-02: "cm -> mm"

p 5 top in connection with table 1: Consider using mm throughout. At first I got fooled not noticing cm being used for the constraint on the ZWD rate of variation in table 1.

Reply to RW2-SC-02: done

RW2-SC-03: "relative surface humidity"

p 7 bottom: .. the relative humidity -> ... the relative surface humidity .. humidity increases again to reach a maximum of 76 % before the first rainfall. -> .. humidity starts rising again before the first rainfall, passing 76 % before it occurs.

Reply to RW2-SC-03: done

RW2-SC-04: why no wind data?

p 8 around line 20: I was surprised not to see wind included in "best way to identify CPCT", but much later in the manuscript realised that possibly you don't have wind observations from all the sites. If so it would be good to give that as a reason wind is not included in you id CPCT scheme.

Reply to RW2-SC-04

- ➔ **To meet recommendations of the two reviewers**, The last paragraph of section 3.1 page 8 line 17-25 becomes:

There is really added value of having the high sampling data from ARM-MF to capture details of the internal dynamics of the MCS. However, such data are only available at Niamey (Niger) for 2006 only. The data retrieved from the PTU200 sensor are in good agreement with data from ARM-MF but the 15-min sampling is not sufficient to detect that the surface temperature drops in two consecutive stages or the sudden and brief drop in relative humidity (not shown). Moreover, because of GPS stations were aimed at providing IWV data, the wind has not been recorded. The best way to identify the CPCT with only PTU200 data at the other AMMA GPS stations is thus to detect significant drops in surface temperature over a period between 30 minutes to 1 hour followed by strong rainfall (see section 4).

RW2-SC-05: talk about convergence of air, not separate convergence of moisture

*p 8 around line 35: It is preferable to talk about convergence of air, not separate convergence of moisture. Low level convergence brings air to the column including additional humidity, and initiate a lift, which leads to cooling, saturation, latent heat release, etc***.**

Reply to RW2-SC-05

The sentence was changed to: "The dynamics of the active convective cell involves a low-level convergence of moist air from its immediate environment, which initiate a lift and leads to the significant rainfall amount of 37 mm."

RW2-SC-06: more data to detect MCS

p 11: Possibly observations of precipitation and lightning from ground, as well as of clouds and lightning from geostationary satellites can be added to the MCS detection arsenal?!

Reply to RW2-SC-06

You are right. Such observations could be added to strengthen the MCS detection. Thefollowing sentence wasadded at the end of section 4.1: « We note that precipitation and lightning from ground, as well as of clouds and lightning from geostationary satellites could be added to the MCS detection arsenal. These additional information will be considered in the future.»

RW2-SC-07: limitations of the CPCT detection

p 12: Are there some sunrise/sunset (which can also be associated with rapid warming/cooling) limitations to this method?

Reply to RW2-SC-07

RW2 is quite right to question out the possible limitations of the detection of MCS and CPCT, especially due to the sub-daily variations of soil surface temperature due to the sun (sunrise and sunset). For this reason, the detection method is done in two steps:

- ➔ The first step is the detection of sufficiently important precipitations which implies the presence of a significant cloud cover attenuating the variations of the soil surface temperature due to the sun.
- ➔ The second step is the search for a significant drop in soil surface temperature.

The detection method would not have been valid if it had relied solely on variations in soil temperature.

We add in the manuscript, section 4.1, p11, 2nd paragraph:

"The first detection step is fundamental because an important rainfall implies the presence of a significant cloud cover which attenuates the variations of the surface temperature due solar radiation and thus avoids the false detections and fails due to the daily solar cycle."

RW2-SC-08: convergence/advection ?

p 14 line 3: There is certainly a strong change in moisture levels associated with the passage of the MCS. But which part of that is due to convergence taking place in the neighborhood of the GPS site, and which part is just due to advection of an MCS that already contains large variations in humidity past the GPS site is less clear.

Reply to RW2-SC-08

This is a valuable question. From those time series alone, it is not possible to conclude. However, we can note from Fig. 14 that the fluctuations of ZWD occurs on sub-daily scales (typically about 6-12h), which suggest that the associated spatial scale are sub-synoptic.

- ➔ Initial version: Though there is a strong moisture convergence associated with the passage of the MCS, the tendency after it is a slightly drier air column, especially in the more arid climate (this is consistent with typical signatures found in sounding data, not shown). The ZWD peak is also narrower from the southern to the northern sites, which suggests faster MCS in the north (again consistent with existing studies, e.g. (Maranan et al., 2018)).
- ➔ Modified version:Though there is a strong moisture convergence associated with the passage of the MCS, the tendency after it is a slightly drier air column, especially in the more arid climate (this is consistent with typical signatures found in sounding data, not shown). The ZWD peak is also **relatively narrow (less than 12h), and** narrower from the southern to the northern sites, which suggests faster MCS in the north (again consistent with existing studies, e.g. (Maranan et al., 2018)). **It also implies that the moisture convergence occurs at sub-synoptic scales.**

RW2-SC-09:

p 15, end of conclusion: Your study underlines the ability of PPP to provide high frequency estimates of ZWD and ZTD gradients, which is valuable for NWP (both for verification and assimilation) and meteorologists. Consider adding a few words on this in the discussion or the conclusion.

Reply to R2-SC-10

The benefit of high frequency was already mentioned in the conclusion (P15L8-9): "Thanks to the high temporal sampling of the gradient estimates, the GIPSY-OASIS solution provides additional information on the atmospheric anisotropy."

As requested we reformulated the last paragraph:

"To conclude, this study showed that the high frequency estimates of ZWD and tropospheric delay gradients are relevant for climate monitoring and documentation of intense weather events such as

MCSs. They could also be used to study other rapid meteorological processes and for the verification and assimilation in numerical weather prediction models."

RW2-SC-10: ZWD -> IWV which Tm?

Figure 8 a: Is the variation of the Tm used when converting from ZWD to IWV really so little that the GAMIT curve for ZWD and the points for IWV can be placed precisely on top of one another?

Reply to R2-SC-10

In this figure we used a constant value for the conversion coefficient. The goal is to give an idea of the amount IWV the ZWD variations represent. This is actually the only place where we show IWV values.