Author response to reviewers comments
on
"Observations of precipitable water vapour over complex topography of Ethiopia from ground-based GPS, FTIR, radiosonde and ERA-Interim reanalysis" by Mengistu Tsidu et al

We thank both reviewers for their thoughtful comments and suggestions on improving the manuscripts. We have used all the comments and suggestions except under circumstances where they only need clarifications.

We also thank the handling editor and the journal editorial team for allowing us to improve the manuscript.

The response to comments and suggestion are indicated in bold face following each comment.

Anonymous Referee #1

Major comments

The paper could benefit from making the presentation more concise and avoiding excessive redundancies in the discussions. It could be shortened significantly without any loss in content.

Response
We have taken this comment and that of reviewer #2 and have made some changes to shorten the manuscript. These changes are incorporated in all parts of the manuscript.

Major comments
Since several radiosonde correction algorithms have been published to account for the dry bias, it would have been good to see these applied and verified here. In fact, there are very few validations of these correction algorithms at high altitude, low latitude sites and this would be a valuable contribution the paper could easily provide.

Response
We have employed one of the radiosonde correction algorithm and incorporated the results in the revised manuscript. The solar radiation dry bias (SRDB) correction algorithm implemented by Wang et al (2013) is used in this work. The the algorithm is based on the idea that the effect of solar heating on the humidity sensor can be estimated by the effect of the temperature warm bias on the saturation vapour pressure. Vaisala RSN2010 table is used to drive temperature correction. A figure on relative humidity (RH) correction for a typical radiosonde measurement, mean of all the corrections along its estimated standard deviation is now included since this was also suggestion from reviewer's #2. The corresponding dry bias in PWV is estimated to be 1.18±0.4 mm and included in the revision under Section 2.3.

Major comments
Some biases of the different instruments are known and documented. Throughout the paper it was

difficult to follow, which instrument is biased against which and in which direction. This concern could be addressed by rigorously trying to include estimated uncertainties with the observations and to evaluate the biases with the estimated uncertainties. The conclusion section could summarize, which is the optimal method of estimating PWV given this mix of data sources.

Response
The biases in one instrument are always stated with respect to the other. Since there is no reference observations against which all others are evaluated, the comparison is always for a given pair of data set at a time. We accepted that it is important to reformulate the discussion on bias and included summary in Tables 4-5 in the revised manuscript.

Minor comments:

Page 9876, lines 18-19: GPS PWV can be determined either from a network solution or from precise point positioning. It appears that the network solution is used in this study. This could be made clearer. Can you say something about the uncertainty of a single point observation in the network solution?

Response
The uncertainty in a network solution depends on the number of GPS in the network at a given epoch. As the number of observations decreases, the uncertainty increases in contrast to precise point position. However, the precise point position requires accurate knowledge of satellite etc from other information. However, as this difference is well known, we opted not to include this statement in the revision for the sake brevity.

Minor comments:

Section 2.3: The Vaisala RS92 radiosonde and its known dry bias should be introduced in this section. The entire section 3.1.3 should be included in section 2.3.

Response
We have included the suggested changes. This applies also to all subsections of Section 3.1 as proposed also by reviewer #2.

Minor comments:

The integration of PWV in radiosondes should start at P=0, although for practical purposes the tropopause pressure can be used reliably without any significant error. Later in the paper P=500 hPa is mentioned, which would be incorrect. g0 should be given in m/s not cm/s.

Response
The p=500 hPa mentioned in the manuscript on page 9891 line 12 refers to integrated moisture flux given in Fig. 12 and has nothing with radiosonde. Moreover, it appears in a Section on GPS and ERA-Interim PWVs. Since the directions of horizontal winds may change above level of nonconvergence, integration over the whole troposphere may not be appropriate because of possible change in sign of moisture flux and cancellation in the integrated moisture flux. Therefore, the integrated moisture flux up to 500 hPa level can fairly be considered as indicator of moisture transport in the region in the lower troposphere.

Minor comments:

Section 3.2: You frequently talk about dry bias. You should clarify, whether the bias you find should be considered as offset of scaling factor.

Response
The dry/wet bias discussed in this section and others is relative since comparison is always between pair of instruments.

Minor comments:

Page 9884, line 28: What do you mean by 'dry biased at the upper end of PWV time series'. I guess you just mean 'dry biased'.

Response
We are referring to the distribution of PWV. The upper end of the PWV distribution is dry biased. This point is clarified in the revised manuscript.

Minor comments:

Page 9886, line 1: Why are there more FTIR / ERA interim comparisons than FTIR /GPS comparisons? GPS should run on a much higher temporal resolution and should produce more data that ERA interim.

Response
The reason was indicated immediately on the next lines 2-3 of the older manuscript.

Minor comments
Page 9887, lines 1-8: Can you make a statement about the sensitivity of PWV to surface pressure. It would be interesting to know which error in surface pressure causes which error in PWV. In this context it would be good to know what the difference between observed pressures at some stations is to the modeled pressure at these stations.

Response
The observed difference between modeled pressure and observations varies between 1-10 hPa and the impact of such difference was estimated for a typical 1.65 hPa along with uncertainty in zenith path delay and mean temperature to be about 1.32 mm (see lines 6-16 of the older manuscript). The choice of such uncertainty values is aimed at comparing with similar study by Wang et al. (2007) as indicated in the manuscript. This discussion is now available in last paragraph of Section 2.2 of the revised manuscript.

Minor comments
Page 9892, lines 11-12: This sentence mentions the 500 hPa integration. It is not clear where this sentence comes from and what its purpose is.

Response
The clarification to this concern is already given in connection with one of previous comments.

Technical comments:

Page 9872, line 25: Change 'due to slow balloon ascent' to 'due to the fact that radiosondes are launched only once per day'

Page 9874, line 12: Change ‘GPS sites are installed since 2007’ to ‘GPS sites have been installed since 2007’
Page 9874, line 13: Change to ‘as permanent stations’
Page 9874, line 15: Change ‘albeit some interruption at some stations’ to ‘despite some interruptions’
Page 9875, line 17: Change ‘latitude’ to ‘altitude’
Page 9881, line 16: Delete ‘considerably’, delete ‘remains’
Page 9886, line 29: Change ‘observations that provide PWV from ground’ to ‘source of PWV data.’

Response
We have taken all technical comments and updated the manuscript.