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Geoscientific Instrumentation Methods and Data Systems Discussions
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Interactive comment on "Time Series Analysis of Ground-Based Microwave Measurements at K- and V-Bands to Detect Temporal Changes in Water Vapor and Temperature Profiles" *by* Sibananda Panda et al.

Sibananda Panda et al.

swaroop.sahoo769@gmail.com

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The authors would like to thank Dr. J. Vivekanandan for the comments. These comments have been very helpful to the authors in increasing the clarity of the paper to the reader.

Below are the comments and the response to the comments

Comment: Expand all of the acronyms e.g. SAPHIR-MADRAS, NN, AMSU,FLORA,MP-3000A... Response: This has been fixed in the paper.

Comment: Page 2, line 2: add to the reference list the following: Spuler, S. M., Repasky, K. S., Morley, B., Moen, D., Hayman, M., and Nehrir, A. R.: Field-deployable diode-laserbased differential absorption lidar (DIAL) for proïňĄling water vapor, Atmos. Meas. Tech., 8, 1073-1087, doi:10.5194/amt-8-1073-2015, 2015. Page 2, line 10: Brogniez, et al.2013 does not show any retrieved humidity or temperature proïňĄle. Add an appropriate reference.

Response: The reference (Spuler et. al., 2015) suggested by the reviewer has been added to Section 1 page 2 line 5 of the paper. In addition to that (Brogniez, et al.2013) has been replaced by Rao, T. N., Sunilkumar, K., and Jayaraman, A.: Validation of humidity profiles obtained from SAPHIR, on-board Megha-Tropiques, Special Section: Megha-Tropiques, Current Sci. 104(12), 1635-1642, June 2013 on page 2 line 14.

Comment: Page 2, line 13: What is meant by 'window frequency?'

Response: The window frequency here means the frequency range between the absorption lines (or the peaks) where the atmosphere is transparent to microwave radiation and allows the microwave radiation to pass through without significant attenuation. For example frequency ranges of 30-45 GHz, 70-110 GHz and 125-150 GHz are usually referred to as the window frequency ranges. The window frequencies are still affected by water vapor content and oxygen absorption but are not as sensitive to as the absorption line peaks.

Comment: Page 3, line 18: DeïňĄne 'oxygen complex.'

Response: The details of the oxygen complex have been added to Section 3.1 line 29 of page 4. "Similarly, microwave radiation from oxygen at the 60 GHz absorption complex can be used for retrieving temperature profile information because atmospheric absorption in the 50-75 GHz range is primarily due to oxygen molecules. The absorption due to oxygen molecule is due to magnetic moment 33 spin-rotational lines between 51.5-67.9 GHz. These spin-rotational lines blend together at lower altitude due to the pressure broadening of the lines. This blended absorption lines has a shape similar to an absorption band centered at 60 GHz. However, the absorption line intensity is not the simple addition of isolated line intensities but the "overlap interference" which gives rise to a very complex absorption band called the oxygen complex. As a result the opacity at the 60 GHz is significantly higher than that at 50 GHz, so the radiometer just observes the radiation emitted close to the ground surface. To sample the whole troposphere measurements need to be performed at a number of frequencies away from the center frequency."

Comment: Figure 2: Explain why 22 GHz weighting function is lower than the 25 GHz weighting function but TB of 22 > 25 GHz as shown in Figure 1?

Response: This has been rectified and the water vapor weighting function figure has been replaced with an appropriate one as shown in Figure 2(a). The details of the discussion have been added to Section 2 line 27 of page 3. "Figure 2(a) shows that weighting function values for 22.234 GHz are higher than those at 25.00 GHz at altitudes above 2 km while weighting function values at 25 GHz have higher values than those at 22.234 GHz below 2 km. This is because the measurements at 22.234 GHz are comparatively more sensitive to changes in water vapor at altitudes above 2.5 km while those at 25.00 GHz are more sensitive to changes in water vapor below that altitude. However, the weighting function values at 22.234 GHz for altitude range 2.5-8 km are significantly higher than those at 25.00 GHz so that brightness temperatures at 22.234 GHz are still higher than those at 25.00 GHz."

Comment: Explain why 53GHz weighting function is lower than the 51GHz weighting function but TB of 53 > 51 GHz as shown in Figure 1?

Response: The authors would like to clarify and bring to the notice of reviewers that 53.36 GHz weighting function (represented in green in Figure 2 b) is higher than 51.243 GHz weighting function (represented in blue in Figure 2 b) at all altitudes. Therefore, the brightness temperature corresponding to 53.36 GHz is significantly higher than 51.243 GHz.

Comment: Page 4, line 9: DeïňĄne apriori.

Response: This has been added to Section 3.2.1 line 18 of page 5. "A-priori in this paper represents the measurement of water vapor and temperature profiles prior to the radiometer brightness temperature measurements. This is also known as the initialization profile in this paper. The a-priori information is taken from radiosonde launched a few hours before the radiometer performs the measurement."

Comment: Page 4, line 10: Describe 'background information statistics' and how it is used to constrain the inversion.

Response: This has been added to Section 3.2.1 line 22 of page 5.

"In addition to the a-priori information, water vapor density and temperature background information statistics is also introduced as the inversion constraint. These statistics provide variability information associated with the atmospheric humidity and temperature profiles as well as the inter layer correlation during a particular time period. The number of elements in the background data set and the relationships among them determines the values of the background information covariance matrix elements. Since, in this study the dataset used for calculating the background statistics has been taken close to measurement time it will be more representative of weather conditions during that time period and location. Background information statistics here means the background information covariance information represented by the matrix S Ì£_a."

Comment: Figure 3: Add X and Y-axis labels. Why is Y-axis inverted? Response: Figure 3 has become Figure 5. The axes have been fixed in the manuscript.

Comment: Page 4, line 24: Spurious character '5'; something is missing. Response: This has been fixed in the manuscript.

Comment: Page 4, last line: What is the difference between apriori and background information covariance matrix? Response: Apriori here is the observation of the state vector (water vapor and temperature profile) prior to the radiometric measurement. It is also known as the initialization profile in this paper. Background information statistics here means the background information covariance information represented by the matrix S Ì£_a and determines the range of variability information associated with water vapor or temperature profiles during a time period represented by the background data set. It is calculated using a background data set, which is typically a collection of water vapor or temperature proïňĄles measured over a specific time period and location. Since this matrix provides the variability information it is used to constrain the range of variation in the water vapor or temperature profile.

Comment: Page5 line15: Why values of diagonal elements are ïňĄxed as 0.25K? How is this value determined?

Response: The details of observation error covariance matrix have been added to Section 3.2.1 line 8 of page 6.

"S Ì£_Ïţ is the observation error covariance matrix and contains the uncertainty information associated with the measurement. The observation error covariance matrix takes into consideration the radiometric measurement noise, representativeness error and radiative transfer model errors. The diagonal elements of the observation error covariance matrix are approximately in the range of 0.23 to 0.29 K2 and some of the off-diagonal elements are close to zero. The observation error covariance, R, determines the uncertainty associated with the observations. This uncertainty has contributions from radiometric noise (E), forward model (F) and representativeness (M) errors. Radiometric noise is determined based on radiometric resolution which is the minimum difference in scene brightness temperature that can be sensed by the receiver. This value for MP3000-A varies from 0.1 to 1 K depending on integration time (Radiometrics Corporation, 2008). The typical value is 0.25 K for each measurement frequency while considering an integration time of 250 msec. In addition to the radiometric noise, forward model errors introduced due to inadequate absorption models. These are determined using the difference between brightness temperatures simulated by two absorption models i.e., the Rosekranz model as well as MPM93 (Liebe et al., 1993)

which are then used to determine the forward model error covariance matrix. Another source of uncertainty is the representativeness error which takes into consideration the radiometer's sensitivity to fluctuations in the atmosphere on a time scale shorter than that can be represented by any numerical weather prediction model or radiosondes profiles. The representative covariance is calculated in Eq. 2. M=E(T ÌĚ_Bˆ' (t+∆t)-T ÌĚ_Bˆ' (t)) (T ÌĚ_Bˆ' (t+∆t)-T ÌĚ_Bˆ' (t))ˆT (2) where t is time and ∆t is the time scale of difference. The observation error covariance matrix is shown in Figure 3 and given by R=E+F+M."

Comment: How sensitive is this value to RMS errors shown in Figures 7 and 8?

Response: The authors assume that the reviewer wants to know the sensitivity of the retrieval errors to measurement error covariance matrix. Figure 7 has become Figure 9 and Figure 8 has become Figure 11. The explanation has been added to Section 4.3 Page 11 line 10. In addition, another analysis was performed to determine the sensitivity of retrieved profile to changes in observation error covariance matrix in the Bayesian optimal estimation. Water vapor and temperature profiles have been already retrieved for various days as shown in Figure 6 and Figure 7. The profile retrieved for 7-August-2011 has been reanalyze where the profile is retrieved using the observation covariance matrix shown in Figure 3. Again the profile is retrieved after increasing the diagonal element of the observation error covariance matrix by 0.25 K2. The retrieved profiles for water vapor and temperature profile for both the observation error covariance matrices are shown in Figure 10. It can be observed that the retrieved water vapor profile for the new covariance matrix has higher error than the profile for the covariance matrix shown in Figure 3. The increase in error for the retrieved water vapor profile is in the range of 0.3 to 1.9 g/m3 (0 to 8 km altitude) as the diagonal elements are increased by 0.25 K2. Similarly, the increase of 0.25 K2 in the diagonal elements of the temperature observation covariance matrix shown in Figure 3 increases the temperature error by 0.2 to 0.5 K (0 to 8 km altitude). Thus, the observation error covariance matrix has a significant impact on the retrieved profile quality and accuracy.

Comment: Page 5: How equations 1 and 2 are related?

Response: Eq. (2) has become Eq. (3). Eq. (1) is the first step to start the iterative process to determine the water vapor and temperature profiles which are then provided as input to the cost function Eq. (3) as well as the convergence criterion as input for checking the validity.

Comment: Page 7, line 9: Do the authors mean inversion instead of the gradient?

Response: The authors mean the significant changes in the water vapor profiles with respect to altitude in the lowest 4 km as shown in the figures. The word inversion is not used because it is not clear whether it is inversion or just change in water vapor.

Comment: Page 7, line 29: Change Section 4C to Section 4.3 Response: This has been fixed in the paper.

Comment: Figure 6b: Explain why a few of the water vapor proïňĄles have errors > -2 g/ mËĘ2?

Response: Figure 6 has become Figure 8. This response has been added to Section 4.3 page 10 line 27. “In addition to that, it can be observed that some of the retrieved profiles in Figure 8 (b) showed higher than usual errors i.e., 2 g/m2 and above. This is because the water vapor profile retrieval accuracy is significantly affected by the a-priori profile as shown by Sahoo et al., 2015. If the atmospheric conditions during the a-priori profile measurement (radiosonde launch) are very different from the conditions during the radiometer measurements then the actual profile will be different from the a-priori. This will result in errors which are higher than when the a-priori and estimated profiles are similar or the weather conditions for the two times are not very different. This difference in weather conditions is due to a weather phenomenon or a rain event.

Comment: Page 9, line 21-22: Describe what aspects of background information are correlated with measurements and why they are correlated? Response: This has been

added to Section 3.2.2 line 24 of page 7.

“Background information statistics here means the background information covariance information represented by the matrix S Ì£_a and determines the range of variability information associated with water vapor or temperature profiles during a time period. Background data set is very important for the performance of the retrieval algorithm in terms of accuracy and ability to sense temporal changes. This is because background data set taken closer in time to the radiometer measurement will describe the atmospheric conditions i.e., the temperature and humidity profiles as well as the wind vector etc. during the measurements. So, the inversion of the measurements results in retrieval of the most persistent water vapor and temperature profile while being constrained by the background data set and a-priori. As a result, the retrieved profiles will detect similar features as the actual profile and hence will represent the gradients and dynamic changes in the actual profile. The atmospheric conditions during a particular season or month are correlated because the atmospheric conditions are similar throughout the time period accept a few outliers which cannot be correlated to the time of interest. Therefore, measurements along with the background data set and the a-priori will retrieve the most probable water vapor and temperature profile while an outlier might or might not be detected depending on whether that event is properly described by the background covariance matrix.”

Please also note the supplement to this comment:
http://www.geosci-instrum-method-data-syst-discuss.net/gi-2016-16/gi-2016-16-AC5-supplement.pdf

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Interactive comment on Geosci. Instrum. Method. Data Syst. Discuss., doi:10.5194/gi-2016-16, 2016.

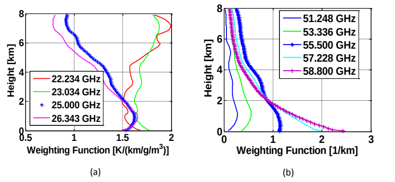

Figure 2. (a) Weighting functions for measurement frequencies used for water vapor profile retrieval. (b) Weighting functions for measurement frequencies used for temperature profile retrieval.

Fig. 1. Figure 2

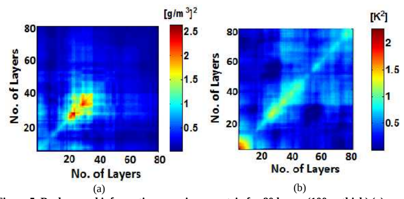

Figure 5. Background information covariance matrix for 80 layers (100 m thick) (a) water density (b) temperature profiles. The x and y axes are in kilometers for both the figures.

Fig. 2. Figure 5

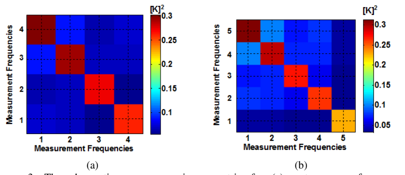

Figure 3. The observation error covariance matrix for (a) water vapor frequency measurements (b) temperature measurements.

Fig. 3. Figure 3

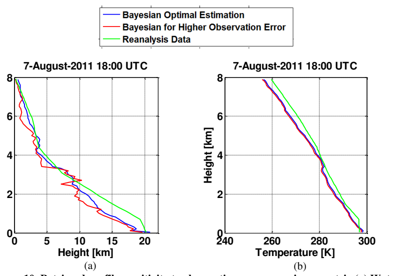

Figure 10. Retrieved profile sensitivity to observation error covariance matrix (a) Water vapor profile (b) Temperature profile

Fig. 4. Figure 10