THE IMPORTANCE OF THE GOES-10 ALGORITHM REGIONALIZATION FOR SOUTH AMERICA

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Abstract

Meteorological satellites provide a unique opportunity to obtain thermodynamic profiles in regions of the globe that do not have a dense meteorological upper air stations network, as in South America. The geostationary satellite GOES-10 made the inference of temperature and mixing ratio profiles every hour with a special resolution of 10 km over South America from July 2007 to February 2009. The GOES-10 retrieval algorithm for thermodynamic profiles was developed by the CIMMS in the United States, so some adjustments for its application in South America could be done. Among these adjustments is the construction of a new covariance matrix. In this context, the scientific focus of this research was to construct a new covariance matrix adapted to meteorological conditions of South America. In addition, a validation of the algorithm results by the use of the original and the new covariance matrices was performed. The variables validated were the air temperature and mixing ratio vertical profiles and the values of total precipitable water. The dataset used was a total of 1095 radiosonde observations located in South America tropical region at 00:00 and 12:00 UTC, as well as thermodynamic profiles from 12h forecasts of the CPTEC Global Model, used as first guess, and upwelling radiances of 18 infrared channels from GOES-10 satellite for the period from July to November 2007. In general, the results indicated that with the regionalization of the covariance matrix the algorithm performed better retrievals than when it used the original matrix. The greatest improvements were found in the mixing ratio profiles and in the values of total precipitable water. These results could be associated to the presence of the Amazon Rainforest that incorporated a greater amount of moisture in the new covariance matrix than the previous matrix had.

1 – Introduction

The Geostationary Operational Environmental Satellites (GOES), operated by the National Oceanographic and Atmospheric Administration (NOAA), aims to support weather forecasting, severe storm tracking, and meteorological research. In December 2006, GOES-10 was drifted east to 60°W longitude in order to provide coverage over South America and the west coast of Africa.

In July 2007, Center for Weather Forecast and Climate Studies of Brazilian National Institute for Space and Research (CPTEC/INPE) began producing operationally temperature and humidity sounding over South America using GOES-10. By the use of this satellite, soundings over the South American continent began being made continuously in time, which was not possible previously with polar-orbiting satellites. Another important aspect is the possibility of obtaining atmospheric soundings in remote places, where conventional observations by radiosondes could not be made (WARK and FLEEMING, 1966; LI and HUANG, 1999; CINTRA et al., 2005). This aspect contributes to a better understanding of the atmosphere, its hydrodynamics and the transformations of energy (KAPLAN, 1959).

The GOES-10 sounder is composed of nineteen channels, which eighteen operate in the infrared and one in the visible with a nadir resolution of 8.7 km (Kidder e Haar, 1995; NASA, 1996). The GOES-10 retrieval process is performed by a physical-statistical iterative algorithm based on the classic Gauss-Newton method. This algorithm was developed by the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin in the United States (MA et al., 1999). According to Li at al. (2008), the covariance matrix is a key parameter for a good performance of the GOES sounding algorithm. The covariance matrix aims to correct errors in the first guess thermodynamic profiles that are generally from a numerical forecast model. After the correction, the new profiles could be used for subsequent iterations of the algorithm. In this context, this study adapted the covariance matrix to South America.

The matrix construction is based on the calculation of errors between profiles generated by a numerical forecast model and radiosondes. Originally the GOES retrieval covariance matrix was constructed using radiosondes over the United States and data from the forecast model Global Forecast System (GFS). In this study, the first guess comes from a Global Numerical Forecast Model from CPTEC. This fact gives a great importance to the regionalization of the covariance matrix, using radiosonde data for South America and also data from the CPTEC Global Model.

Knowing the importance of a new covariance matrix adapted to South America, the scientific focus of this article is on the construction of this matrix. Additionally, this research presents analysis of the performance of the GOES-10 retrieval algorithm over South America. In this context, the thermodynamic profiles obtained by the GOES-10 retrieval, using the original and the new covariance matrix, are compared with radiosondes. In section 2, the data and methodologies performed for this research are described. A detailed discussion of the differences observed between the two covariances matrices can be seen in section 3. Section 4 is devoted to the validation of thermodynamic profiles generated by the GOES-10 retrieval algorithm. Finally, in section 5, conclusions are presented.

2 – Data and Methodologies

The total of 1100 radiosonde observations from July to November 2007 was used for describing the tropical atmosphere of South America. From the whole radiosonde observations, 1016 referring to July and August 2007 were used as basis for the construction of the new covariance matrix and 84 from September to November 2007 for validation purposes. In order to keep data consistency, it was selected radiosonde data in which temperature and mixing ratio values were until at least 200 and 300 hPa, respectively. This choice helped us to have the highest possible number of radiosondes with good coverage from the low to upper tropospheric levels.

It was used GOES-10 data for the period from September to November 2007 at 00:30 and 12:30 UTC. This database consists of brightness temperatures for the 18 infrared channels responsible for the retrieval process. According to Li et al. (2008), the GOES-10 retrieval algorithm is similar to the one presented by Ma et al. (1999). The main similarities are due to the use of a first guess provided by a forecast numerical model and the Gauss-Newton method to generate new profiles in the iterative process, as shown at Figure 1a. However, the main difference between the algorithms is that GOES-10 algorithm does not use the smoothing parameter γ to stabilize the solution of the radiative transfer equation. The algorithm used by Ma et al. (1999) used a correlation matrix, what forced the use of parameter γ. On the other hand, the GOES-10 algorithm uses a first guess covariance matrix, making unnecessary the smoothing parameter for the iterative process convergence (LI et al., 2008).

The Global Model, which runs operationally at CPTEC/INPE, was adopted as the first guess into the GOES-10 retrieval method. Twelve hour forecasts generated by the runs of 00:00 and 12:00 UTC for September, October and November 2007 were used. Data for July and August 2007 were basis for the construction of the new covariance matrix. It was used vertical profiles of air temperature and mixing ratio in addition to fields of skin temperature.

For the construction of the new covariance matrix for South America, some considerations were made for adjusting the radiosonde and Global Model data to the conditions imposed by the GOES-10 algorithm. One of the first stages of the algorithm is an interpolation of the first guess profiles to 101 predetermined levels. Thus, temperature and mixing ratio profiles from radiosondes and the Global Model were interpolated linearly to 101 pressure levels, ranging from 1100 to 0.004 hPa. It is important to emphasize that radiosonde and Global Model data for the levels greater than 1000 hPa were not available, so these levels were supplemented with values from 1000 hPa. For the upper troposphere a similar procedure was carried out for radiosonde data due to limitation of temperature and mixing ratio values above 200 and 300 hPa, respectively. According to Jun (1994) the weighting functions related to moisture are better represented when using values of natural logarithm of mixing ratio instead of the pure mixing ratio values. So, mixing ratio profiles were all modified to natural logarithm of mixing ratio.

After the interpolation, differences between Global Model and radiosondes for air temperature profiles and natural logarithm of mixing ratio were calculated at each pressure level. An error matrix was then determined, where the rows represented the collocated points of radiosonde and Global Model and the columns the differences in each level. This matrix had a configuration of 2032 rows and 101 columns. The first half of the matrix represented the air temperature differences, while the second half the differences of natural logarithm of mixing ratio.

Based on the error matrix it was obtained two covariance matrices, one for air temperature and the other one for the natural logarithm of mixing ratio. For the air temperature covariance matrix it was used the first 1016 rows of the error matrix and performed a covariance calculation between the 101 pressure levels. This calculation was done by the product of the first half of the error matrix and its transpose, giving a matrix with 101 rows and 101 columns. The same procedure was made to obtain the covariance matrix of natural logarithm of mixing ratio using the second half of the error matrix. These two matrices together represented the new covariance matrix adapted to South America.

Using the new and the original covariance matrix, the GOES-10 retrieval algorithm was ran for the period from August to November 2007. The collocated points of radiosonde and GOES-10 retrievals were determined using a maximum distance of 50 km, following the methodology proposed by Fuelberg and Olson (1991) and Rao and Fuelberg (1998). It is important to clarify that the validations were performed at the second sweep sector of GOES-10, as shown in Figure 1b. The choice of this sector is associated to data availability. GOES-10 performs soundings in the others sweep sectors at times that no radiosonde data available, which makes validation difficult. Across the second sector the algorithm performs soundings at about 00 and 12 UTC, which coincident with radiosonde launching time.

Based on the collocated pairs of radiosonde/GOES-10 data, 83 for the use of the original covariance matrix and 84 for the new covariance matrix, validations were performed using some statistical indices such as Bias, RMSE (Root Mean Square Error) and Correlation Coefficient. It was also calculated the Improvement Over the First Guess (IFG) (Fuelberg and Olson, 1991; Rao and Fuelberg, 1998), which determines if there is improvement in the GOES-10 profile compared to the first guess provided by the Global Model. The IFG can be written as,

$$\mathrm{IFG} = | FG - RD | - | SAT - RD |, \tag{1}$$

Where, *FG* is the air temperature or mixing ratio value provided by the First Guess;
RD is the air temperature or mixing ratio value provided by the Radiosondes;
SAT is the air temperature or mixing ratio value provided by the GOES-10 algorithm.

According to Equation 1, positive IFG indicates that values retrieved by the satellite are closer to radiosonde values than the first guess, and negative IFG indicates the opposite.

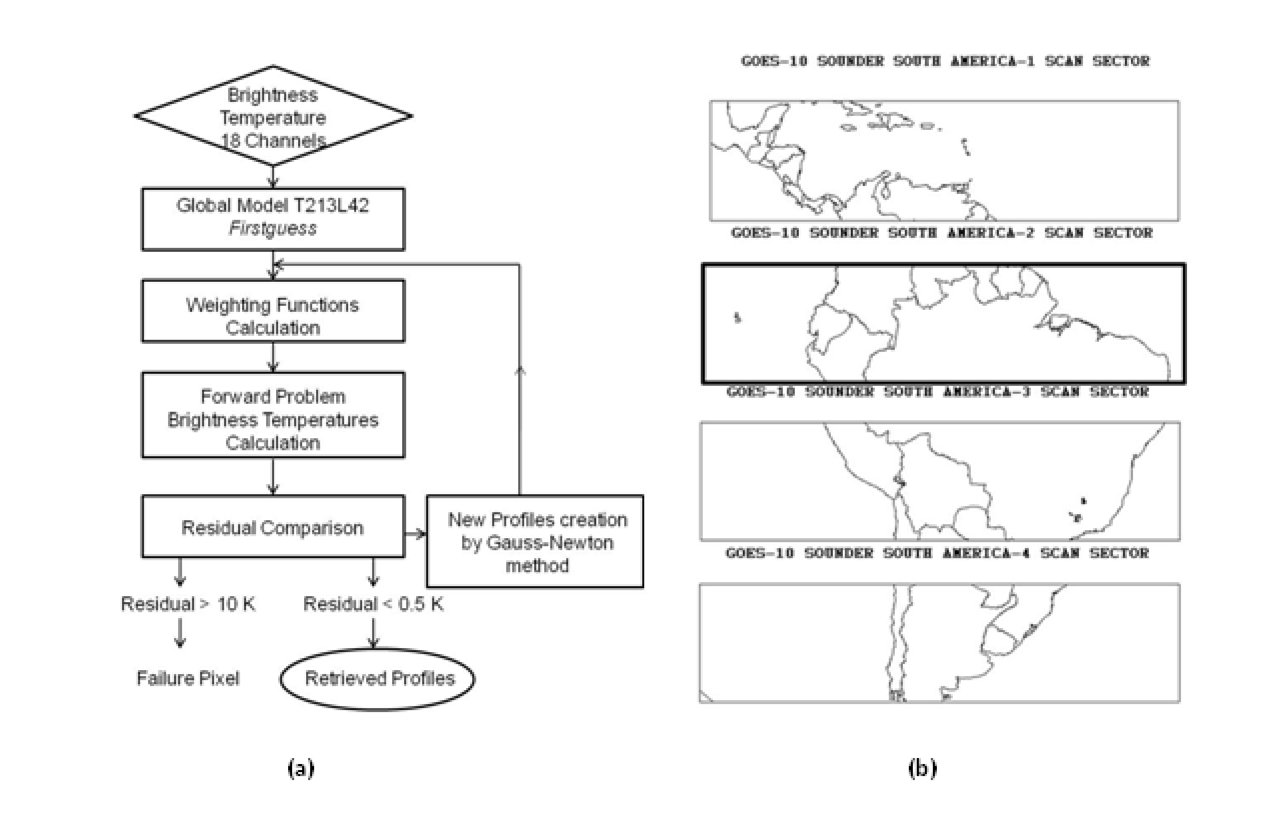

Figure 1 – (a) A flow chart summary of the GOES-10 sounder retrieval process in order to infer temperature and humidity; (b) Goes-10 scan sectors over South America with emphasis on the study area.

3 - The new vs. the original covariance matrix

Figures 2 and 3 shows the covariance matrices (original and new) for air temperature and natural logarithm of mixing ratio respectively. In order to reduce the computational time, the GOES-10 retrieval algorithm uses only the main diagonal of the covariance matrices that represents the variance. It can be noticed that the original air temperature covariance matrix has lower error variance than the new covariance matrix for most pressure levels (Figure 2). The temperature error variance based on radiosonde and GFS for the United States is lower than error variance based on radiosonde and T213L42 model for South America. Greatest difference between the temperature covariance matrixes is found between 800 and 600 hPa. It will be shown in the next section that

GOES-10 algorithm shows significant improvement at these levels by using the new covariance matrix. The new covariance matrix has smaller values of error variance close to surface (between 1100 and 1000 hPa) in comparison to the original matrix. However, this difference in the lower troposphere did not cause influences on the final retrieval results since all the validations were made with ground stations that presented a surface pressure always less than 1000 hPa.

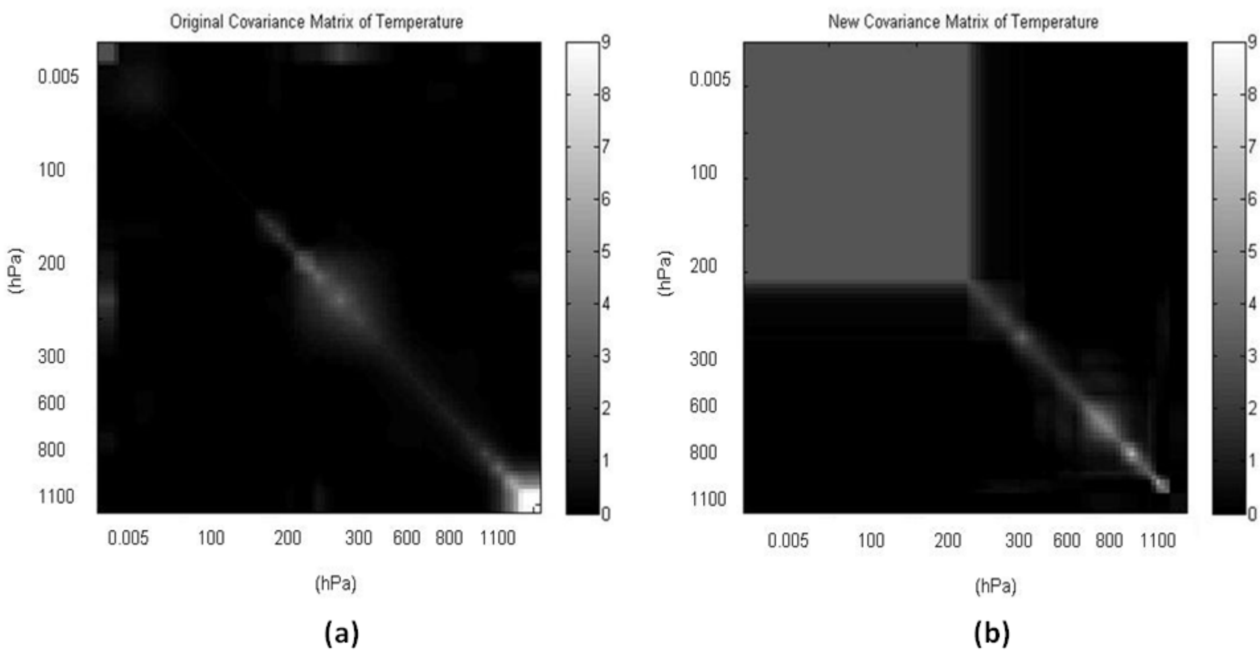

Figure 2 – Covariance Matrices for air temperature: (a) Original Matrix; (b) New Matrix.

The differences between the two covariance matrices of the natural logarithm of mixing ratio were higher (Figure 3) than the air temperature matrices. The new covariance matrix presented higher error variance values than the original matrix. These differences can be associate mainly due to Amazon Rainforest presence in the study area, which is wetter than the United States atmosphere, in which original covariance matrix were based.

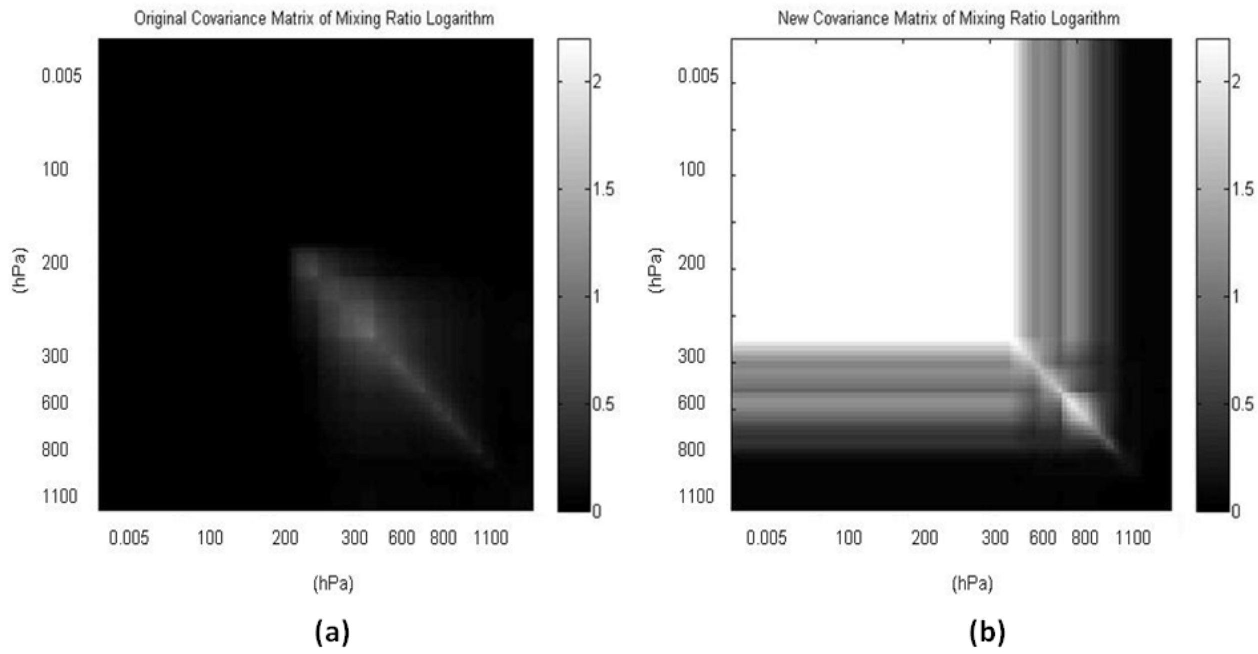

Figure 3 – Covariance Matrices for natural logarithm of mixing ratio. (a) Original Matrix; (b) New Matrix.

4 - GOES-10 Product comparison with RAOB and firstguess data

4.1 – Temperature

Figure 4 shows statistical parameters calculated for the temperature profiles based on GOES-10 retrieval and radiosondes measurements data. Statistical parameters change insignificantly when using original (dashed lines) and the new covariance matrix (solid lines). In a general, biases are between -0.5 and 0.5K, agreeing with the results obtained by Rao and Fuelberg (1998) using GOES-8 for the United States. The biggest bias is found at 780 hPa that seems to be associated to the firstguess from global model used in the retrieval scheme. For instance, the T213L42 model showed the poorest statistical correlation with the radiosonde (not shown) at 780 hPa. It can be also highlighted the increase in bias above 300 hPa due to the lack of weighting functions in GOES-10 sounder at higher levels.

RMSE and Correlation curves (Figures 4 b and c) show also a small difference between results using the two matrices. In spite of this, RMSE values were predominantly smaller than the ones showed by Ma et al. (1999), for an older version of GOES-10 algorithm. The unique level that did not present this behavior was 780 hPa. For this research, the RMSE was 1.79 K for the original matrix and 1.75 K for the new matrix, which is close to values of around 1.5 K found by Ma et al. (1999).

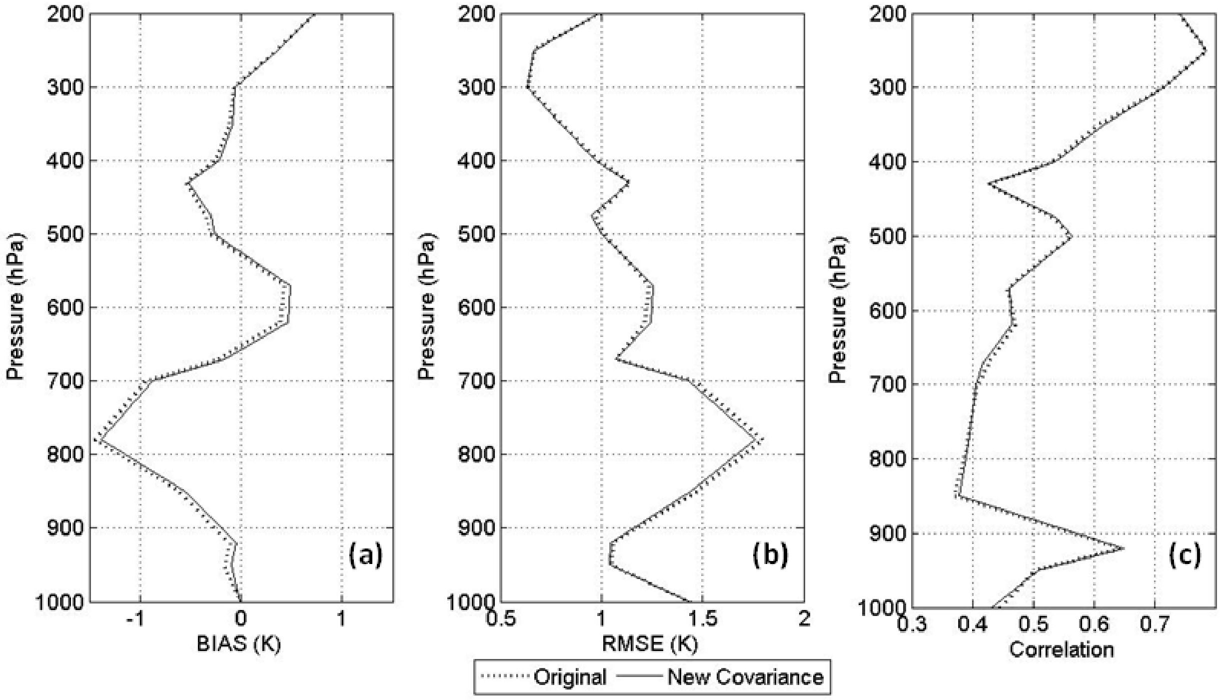

Figure 4 – (a) BIAS, (b) RMSE and (c) Correlation between air temperature profiles retrieved by GOES-10 and radiosondes. Solid lines indicate a comparison in which the GOES-10 algorithm used the original covariance matrix and dashed lines the use of the new covariance matrix.

Figure 5 presents scatter plots of radiosonde versus GOES-10 retrieval temperatures for the two covariance matrices at 500 and 780 hPa. These levels were chosen because they presented respectively a good and poor agreement between GOES-10 retrieval and radiosondes. Even with few statistical changes when using the new covariance matrix, it can notice that improvements were made. For both levels, statistical indices show a better agreement between GOES-10 retrieved and radiosondes temperature when the new covariance matrix was used. This result indicates that the retrieval algorithm accuracy is directly influenced by the use of a covariance matrix adapted to the weather conditions of the study area.

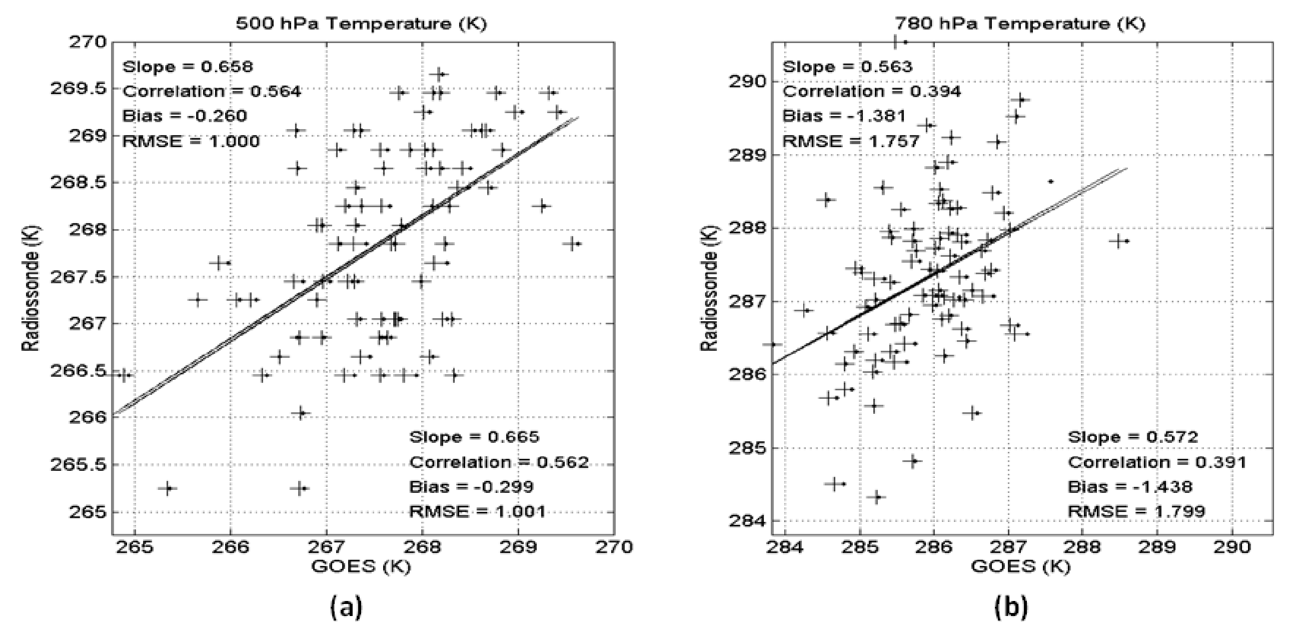

Figure 5- Scatter plots between air temperature obtained by GOES-10 and radiosondes for (a) 500 and (b) 780 hPa. The upper left statistical parameters are related to the new covariance matrix and the lower right to the original matrix.

Table 1 shows the percentages of positive, negative and null IFG values for the validations with the two matrices. This statistical index has a great importance, because it analyzes if GOES-10 retrieved profile improved or not compared to the first guess. It can be shown at Table 1 that from 17 used levels, 9 have a predominance of positive IFG when the new matrix was used, against 8 with the use of the original one. The levels of 950 and 780 hPa presented negative values of IFG with the original matrix, but when was used the new covariance matrix the values became positive. A great importance can be given to the level of 780 hPa, because it had IFG>0 of 43.37% with the original matrix and became higher than 80% with the new one. It is important to highlight that this level was one which had a poor statistical agreement with radiosondes. However, a high value of positive IFG is linked to the differences observed at Figure 2, where the variance between the errors of the first guess and radiosondes were lower in the original matrix. It could be affirmed, in a general way that with the use of a covariance matrix adapted to the study area the algorithm worked in a satisfactory manner. Between the 17 levels, 13 showed an increase of IFG>0, and for the levels which presented a decrease, it was mostly less than 1%.

Table 1- IFG for air temperature profiles obtained by GOES-10. The left values are related to the algorithm running with the original covariance matrix, and the right values to the new covariance matrix.

Pressure Levels (hPa)	IFG > 0 (%)	IFG = 0 (%)	IFG < 0 (%)
1000	*22.95* / **22.58**	*0.0* / **0.0**	*77.05* / **77.42**
950	*44.57* / **53.57**	*0.0* / **0.0**	*55.43* / **46.43**
920	*57.83* / **55.95**	*0.0* / **0.0**	*42.17* / **44.05**
850	*33.73* / **46.42**	*0.0* / **0.0**	*66.27* / **53.58**
780	*43.37* / **84.52**	*0.0* / **0.0**	*56.63* / **15.48**
700	*75.90* / **80.95**	*0.0* / **0.0**	*24.1* / **19.05**
670	*43.38* / **44.04**	*0.0* / **0.0**	*55.62* / **55.96**
620	*67.46* / **67.85**	*0.0* / **0.0**	*32.54* / **32.15**
570	*66.27* / **66.66**	*0.0* / **0.0**	*33.74* / **33.34**
500	*55.42* / **60.71**	*1.20* / **0.0**	*43.38* / **39.29**
475	*37.34* / **42.86**	*0.0* / **0.0**	*62.66* / **57.14**
430	*69.88* / **70.24**	*0.0* / **0.0**	*30.12* / **29.76**
400	*50.60* / **52.38**	*0.0* / **0.0**	*49.40* / **47.62**
350	46.99 / **46.42**	*0.0* / **1.18**	*53.01* / **52.40**
300	*50.60* / **46.43**	*0.0* / **1.19**	*49.40* / **52.38**
250	*42.17* / **42.86**	***0.0*** / **0.0**	*57.83* / **57.14**
200	*19.27* / **22.62**	*0.0* / **0.0**	*80.73* / **77.38**

4.2 - Mixing Ratio

The retrieved moisture evaluation is done in terms of mixing ratio using similar statistical analyses to that of temperature profile in previous section. Overall, the new covariance matrix introduced to the GOES10 retrieval scheme improved reasonable well the mixing ratio in relation to the air temperature. Figure 6 shows bias (retrieval minus RAOB), RMSE and correlation coefficients of temperature for retrieval – RAOB pairs. This improvement is clearly notice in lower atmospheric level between 1000 and 780 hPa. Mean bias of mixing ratio is smaller than 0.5 g/kg at first level, above this the bias are between -1 and 1 g/kg. Although bias and RMSE change only slightly in this layer when the new covariance matrix is used, the correlation is significantly higher. For instance, the correlation is around 0.5 for original matrix and increases significantly to 0.7 for the new covariance matrix around 950 hPa. Additionally, correlation coefficients are higher than 0.8 above 600 hPa.

Figure 7 shows scatter plots of GOES-10 retrieval with the two covariance matrices versus the radiosonde mixing ratio for 500 and 780 hPa. Statistical analyses show that the mixing ratio retrieved using the new covariance matrix has better agreement with radiosonde than the mixing ratio retrieval using the original covariance matrix. The average RMSE of mixing ratio retrieval here is less than 1 g/kg and 2.5 g/kg for 500 and 800 hPa, respectively.

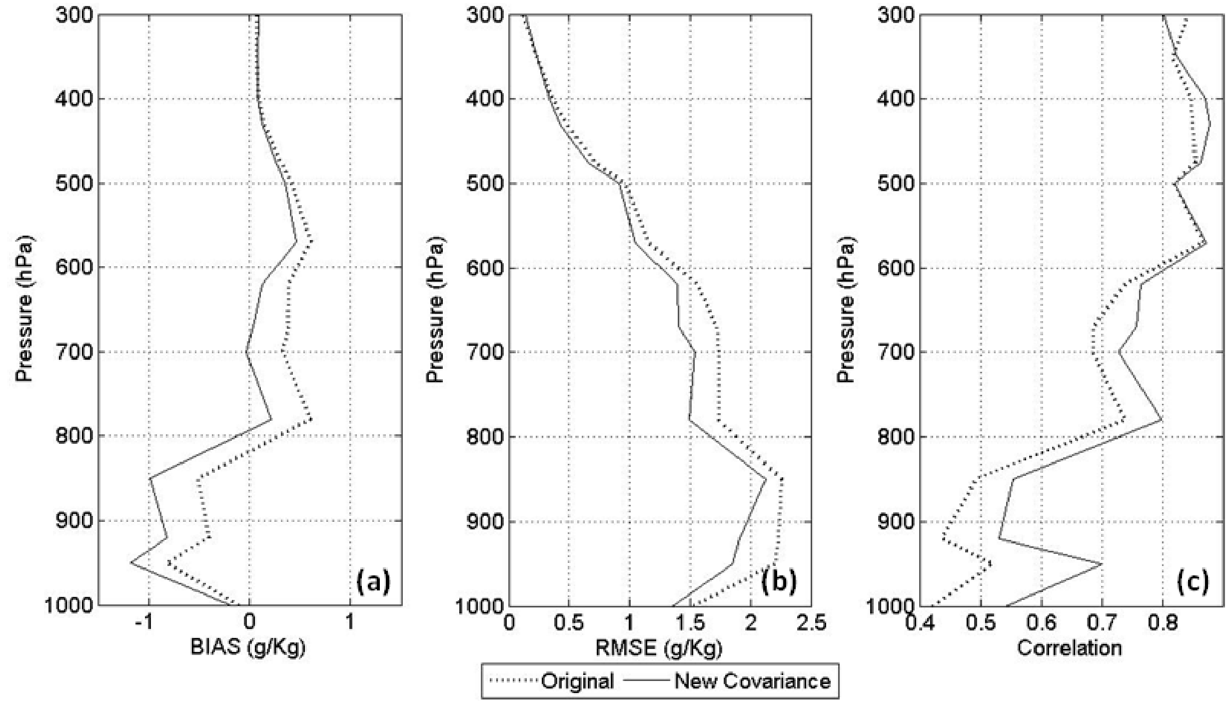

Figure 6 – (a) BIAS, (b) RMSE and (c) Correlation between mixing ratio profiles retrieved by GOES-10 and radiosondes. Solid lines indicate a comparison in which the GOES-10 algorithm used the original covariance matrix and dashed lines the use of the new covariance matrix.

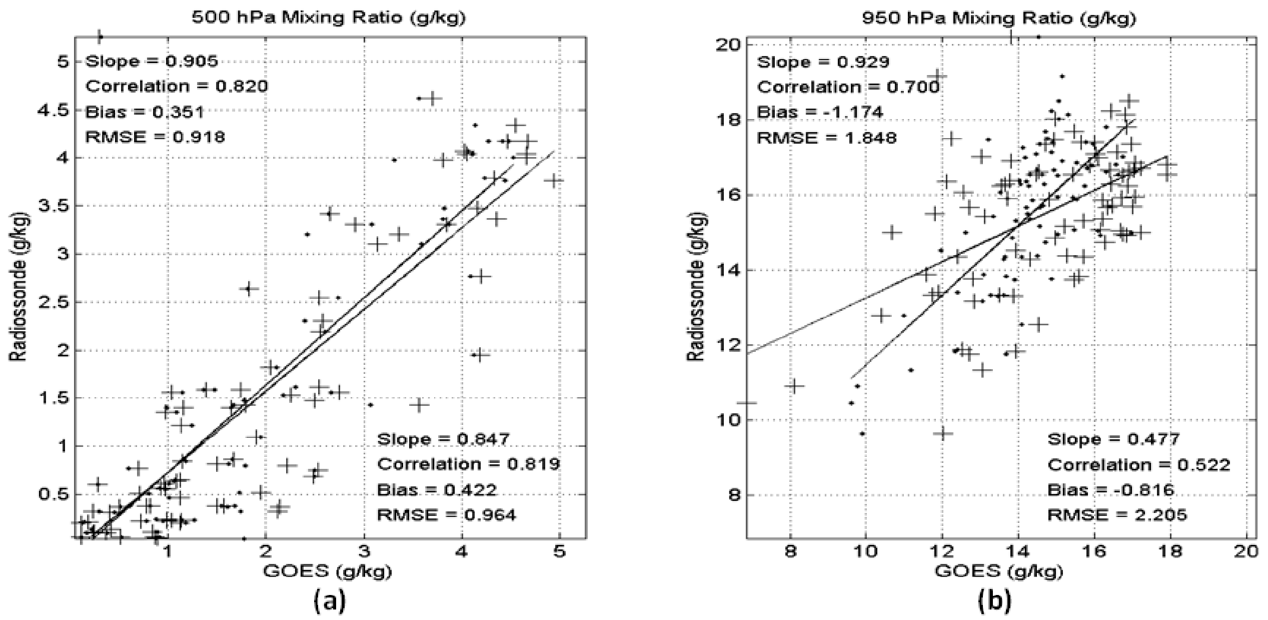

Figure 7- Scatter plots between mixing ratio obtained by GOES-10 and radiosondes for the levels of (a) 500 and (b) 950 hPa. The upper left statistical parameters are related to the new covariance matrix and the lower right to the original matrix.

GOES retrieval depends greatly on the first guess. Table XX2 shows the improvement of the first guess condition (IFG) for 15 levels from 1000 to 300 hPa. Considering those fifteen levels, five levels have IFG higher than zero (IFG>0) when considering the original covariance matrix and it increases to eleven for the new covariance matrix.

Figure 3 shows that original covariance matrix underestimates the variance error associated to first guess and radiosonde. The underestimation is related to different database used for build the covariance matrix. The original matrix was build using GFS forecast and radiosonde launched over United States (Li et al., 2008), while the present study is used the CPTEC global model and radiosonde over Amazon region. Additionally, the present study area is very different from those places where original covariance matrix where based. The study area is over Amazon Forest, where is one of the wettest place in the world.

Table 2 – IFG for mixing ratio profiles obtained by GOES-10. The left values are related to the algorithm running with the original covariance matrix, and the right values to the new covariance matrix.

Pressure Levels (hPa)	**IFG > 0 (%)**	**IFG = 0 (%)**	**IFG < 0 (%)**
1000	*42.62* / **62.90**	*0.0* / **0.0**	*57.38* / **37.10**
950	*44.57* / **55.95**	*0.0* / **0.0**	*55.43* / **44.05**
920	*45.78* / **50.00**	*0.0* / **0.0**	*54.22* / **50.00**
850	*48.19* / **45.23**	*0.0* / **0.0**	*51.81* / **54.77**
780	*46.98* / **55.95**	*0.0* / **0.0**	*53.02* / **44.05**
700	*46.97* / **50.00**	*0.0* / **0.0**	*53.03* / **50.00**
670	*45.78* / **42.85**	*0.0* / **0.0**	*54.22* / **57.15**
620	*39.76* / **50.00**	*0.0* / **0.0**	*60.24* / **50.00**
570	*48.19* / **59.52**	*0.0* / **0.0**	*51.81* / **40.48**
500	*57.83* / **60.71**	*0.0* / **0.0**	*42.17* / **39.29**
475	*53.01* / **63.09**	*0.0* / **0.0**	*46.99* / **36.91**
430	*55.42* / **65.47**	*0.0* / **0.0**	*44.58* / **34.53**
400	*54.21* / **63.09**	*0.0* / **0.0**	*45.79* / **36.91**
350	*62.65* / **61.90**	*0.0* / **0.0**	*37.35* / **38.10**
300	*73.49* / **70.23**	*0.0* / **0.0**	*26.51* / **29.77**

4.3 – Total Precipitable Water

Total Precipitable Water (TPW) is the amount of liquid water if all the atmospheric water vapour in the column were condensed. Many studies have been evaluated the humidity retrievals in term precipitable water instead of the retrieved vertical humidity profile. This is because radiosonde, which is used as reference, represents temperature and humidity in a specific atmospheric pressure levels (local value), while satellite is a volumetric observation. Therefore, it is expected that integrated values in the column, such as precipitable water, is more consistent parameter to be compared to local observation (FUELBERG e OLSON, 1991). Additionally, TPW is one of the most important parameters widely used to describe the amount of water vapor in the atmosphere. High values of TPW in clear air often become antecedent conditions prior to the development of heavy precipitation and flash floods. Therefore, the GOES retrieval scheme was validated in terms of TPW.

Figure 8 shows the statistical analyses from the evaluation of the retrieved TPW assuming the original and new covariance matrix. It is shown that the retrieved TPW has good agreement with radiosonde for both matrices, and the correlation for TPW is higher than for the temperature and humidity profiles. Results using the new covariance matrix have higher correlation than those using the original matrix showing the importance of regionalization of the error matrix.

GOES retrieval scheme using the new covariance matrix has better performance for TPW in comparison to previous studies for the same variable since better statistical relation is founded. Rao e Fulberg (1998) found correlation below 90% for the satellite GOES-8. The RMSE found here of around 4 mm were higher than founded by Schmit et al. (2002) e Li et al (2008) (around 2,5 mm) but similar bias (i.e. between -0,25 and -0,67 mm) for GOES-10. Unfortunately, the number of radiosonde and satellite dataset used in the present study was reduced by 1/3 because the time lag between radiosonde observation and satellite overpass assumed in the present study is less 1h 30 minutes.

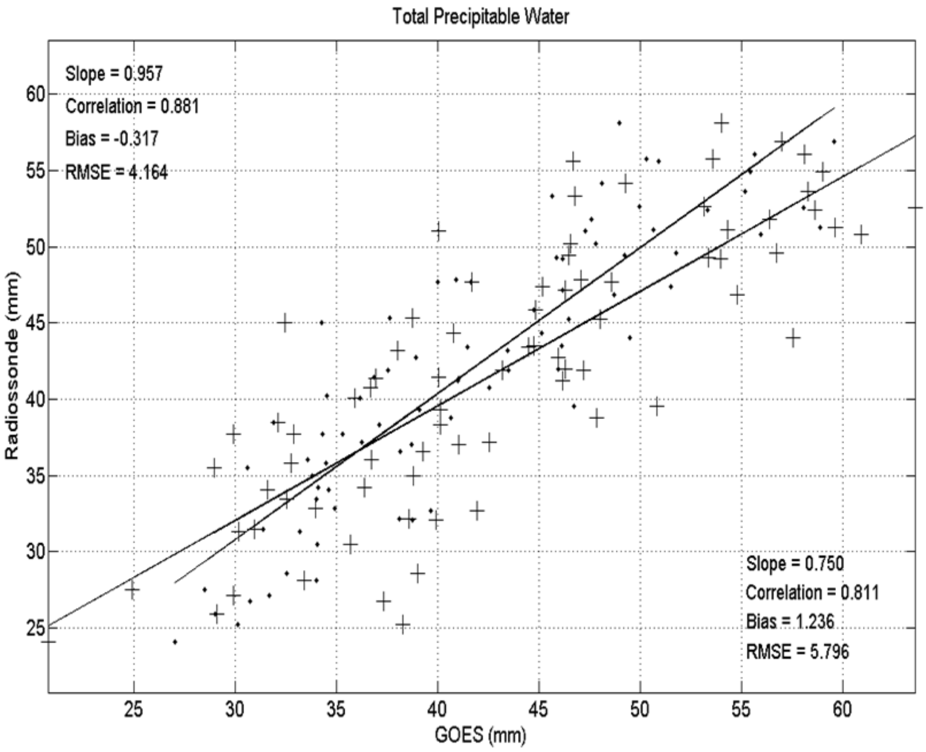

Figure 8 – Scatter plot of TPW obtained by GOES-10 and radiosondes. The upper left statistical parameters are related to the new covariance matrix and the lower right to the original matrix.

5 - Conclusions

The scientific focus of this research was to validate the thermodynamic profiles obtained from the GOES-10 retrieval algorithm for the tropical region of South America, highlighting the regionalization of the covariance matrix. In this context, comparison between profiles obtained from radiosondes and from the satellite were developed for the period from September to November 2007.

It was not found great statistical differences for air temperature profiles with the use of the new covariance matrix, however, improvements were observed. The algorithm could infer better values of air temperature between 600 and 800 hPa, where the error variance was underestimated by the original matrix.

The mixing ratio profiles showed major changes when the new covariance matrix was used. This result was expected because the original matrix underestimated the error variance for all analyzed levels. By the use of the new matrix, almost all levels presented better statistical results when compared to radiosondes, highlighting the importance of regionalization of the covariance matrix.

The total precipitable water showed higher statistical agreement with radiosondes than level by level validations. This behavior occurred because the satellite performs volumetric measurements while radiosondes perform punctual. Thus, by integrating the moisture in the vertical, in a form of precipitable water, a more consistent comparison between satellite and radiosondes data can be obtained.

Besides the covariance matrix, other parameters of the retrieval algorithm must be regionalized for it application in South America. However, with this research it was found significant improvements with the new covariance matrix utilization. This study showed that the GOES-10 retrieval algorithm is an important tool for monitoring the atmosphere in South America, where few observation are available.

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REFERENCES

CINTRA, R. S. C.; LIMA, W. F.; ESPINOZA, E. S.; CAMPOS VELHO, H. F. C. Inclusão de dados ATOVS no sistema de assimilação de dados GPSAS do CPTEC. In: Simpósio Brasileiro de Sensoriamento Remoto, 12 (SBSR), 2005, Goiânia. Anais... São José dos Campos: INPE, 2005. P. 2917-2924. CD-ROM, On-line. ISBN 85-17-00018-8. (INPE-12706-PRE/7996). Available at: <http://urlib.net/ltid.inpe.br/sbsr/2004/11.20.23.49>. Acessed: 20 mar. 2008. Goiânia, Brasil, 2005.

FUELBERG, H. E.; OLSON, S. R. An assessment of VAS-derived retrievals and parameters used in thunderstorm forecasting. Monthly Weather Review, v. 119, n.3, p. 795-814, 1991.

JUN, L. Temperature and water vapor weighting functions from radiative transfer equation with surface emissivity and solar reflectivity. Advances in Atmospheric Science, v.11, n.4, 421-426, 1994.

KAPLAN, L. D. Inferences of atmospheric structures from satellite remote radiation measurements. Journal of the Optical Society of America, v. 49, p. 1004, 1959.

KIDDER, S. Q.; HAAR, V. Satellite meteorology, an introduction. Orlando, Florida, United States. Academic Press, 1995. 466 p. ISBN (0-12-406430-2).

LI, J.; HUANG, H. L. Retrieval of atmospheric profiles from satellite sounder measurements by use of the discrepancy principle. Applied Optics, v. 38, n. 6, p. 916-923, 1999.

LI, Z.; Li, J.; MENZEL, W. P.; SCHMIT, T. J.; NELSON, J. P.; DANIELS, J.; ACKERMAN, S. GOES sounding improvement and applications to severe storm nowcasting. Geophysical Research Letters, v. 35, 2008.

MA, X. L.; SCHMIT, T. J.; SMITH, W. L. A nonlinear physical retrieval algorithm - its application to the GOES 8/9 Sounder. Journal of Applied Meteorology, v. 38, n.5, p. 501-513, 1999.

NASA. GOES I-M DataBook, 1996. Available at: <http://goes.gsfc.nasa.gov/text/goes.databook.html>. Acessed: 10 mar. 2008.

RAO, P. A.; FUELBERG, H. E. An evaluation of GOES-8 retrievals. Journal of Applied Meteorology, v. 37, n.12, p. 1577–1587, 1998.

SCHMIT, T. J; FELTZ, W. F.; MENZEL, W.P.; JUNG, J.; NOEL, A. P; HEIL, J. N.; NELSON, J. P.; WADE, G. S. NOTES AND CORRESPONDENCE. Validation and use of GOES sounder moisture information. Weather and Forecasting, v. 17, n.1, 139-154, 2002.

WARK, D.Q.; FLEMING, H.E. Indirect measurements of atmospheric temperature profiles from satellites: Introduction. Monthly Weather Review, v.94, n.1, p. 351-362, 1966.