The inclusion of integrated water vapor estimates from AIRS/AMSU and SSM/I sensors into the CPTEC's data assimilation system

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ABSTRACT

The atmospheric water vapor plays a crucial role in the atmospheric processes and its distribution is associated with cloud concentration and rainfall. The inclusion of Integrated Water Vapor (IWV) estimates into Numeric Weather Prediction (NWP) improves the vertical structure of the humidity and consequently contributes to obtain a more realistic atmospheric state. Nowadays, remote sensing data is the most important source of humidity measurements, which provides information with good horizontal resolution and global coverage. However, the assimilation of the IWV values from humidity sounding satellites has not been properly explored in the CPTEC NWP model. This study investigates the impacts of IWV retrieved from Atmospheric InfraRed Sounder/Advanced Microwave Sounding Unit (AIRS/AMSU) and Special Sensor Microwave/Imager (SSM/I) as additional information in the CPTEC data assimilation system (PSAS: Physical-space Statistical Analysis System). In order to assess the impact of IWV into the CPTEC data assimilation cycle, two experiments were performed using the CPTEC/COLA (T126L28, with horizontal resolution of 100 km and 28 levels in the vertical sigma coordinate) with and without the IWV inclusion in the period of March of 2004. In the results analysis the improvement in the forecast of the specific humidity, geopotencial height and wind field in different global areas was considered, with special attention in the South America region. The impact of the IWV assimilation was assessed by applying O-F analysis (considering only observations from operational radiosondes) and A-F analysis. The results shown that the impacts of IWV including from AIRS/AMSU and SSM/I are significant over the regions where the density of conventional information is lower, such as South America region. In this area, the inclusion of the IWV values improved the prediction of specific humidity in 850 and 700 hPa, the geopotencial height and of the wind components in 250 hPa. These results indicates that IWV assimilation minimizes the humidity vertical profile errors, consequently produce a better adjust in the mass budget in the troposphere, generating an indirect impact in the prediction of prognostic variable, particularly the geopotencial height in 250 hPa.

Introduction

Integrated Water Vapor (IWV) plays a fundamental role in atmospheric processes and its distribution is associated with cloud concentration and rainfall. Such characteristics are intensified in tropical regions, where the release of latent heat associated with cumulus convection is the primary factor in forcing the tropical circulation (Ledvina et al., 1995). As a result, accurate information of the temporal and spatial distribution of the humidity is especially important to characterize adequately the global atmospheric circulation.

The efficiency of Numerical Weather Prediction (NWP) in generating reliable forecasts depends on the performance of the Assimilation System in representing the state of the atmosphere (Kalnay, 2003). However, reproducing atmospheric humidity distribution appropriately is still a great challenge, particularly in the regions where atmospheric observations are sparse. In these regions, the low data density allows the model to create its own climatology, which can represent a very different atmospheric state from that found in the physical reality. The deficiencies in the physical parameterizations of cumulus convection and in other processes that involve atmospheric water vapor are possible causes of this problem (Starr and Melfi, 1991). The combination of low data density and such model deficiencies can generate serious effects in the Tropics, because in those areas small-scale structures of the humidity distribution can modify the location and intensity of precipitation prescribed by convective parameterizations.

The radiosondes are the most reliable source of atmospheric humidity information, which measure the dew point temperature reasonably well. However, the launching of radiosondes presents a deficiency in the temporary and spatial resolution. Operational radiosonde launching is done twice a day and most of the launching stations is concentrated in continental areas of the Northern Hemisphere. This distribution does not benefit the vast global oceanic area, or the Southern Hemisphere. This fact made it evident that radiosondes are not enough to describe global distribution of humidity appropriately, and that other information sources, such as humidity sounding satellites, should be explored.

This paper investigates the benefits of assimilating IWV values (Kuo et al, 1993) from AIRS/AMSU (Atmospheric InfraRed Sounder/Advanced Microwave Sounding Unit) and SSM/I (Sensor Special Microwave/Imager) sensors. These sensors are used as additional sources of humidity information in the CPTEC/INPE's data assimilation system (PSAS: Physical-space Statistical Analysis System) since, in the current CPTEC operational configuration radiosondes have been used as principal humidity direct source. Processing in parallel with and without the inclusion of IWV values from AIRS/AMSU and SSM/I sensors were done in different experiments.

IWV Inclusion Experiments

In order to assess the impact of IWV on the CPTEC data assimilation cycle, two cyclical experiments were performed using the CPTEC/INPE PNT model for the same period, where in the first experiment the IWV values were assimilated and in the second they were not. The assimilation system used was PSAS (da Silva and Guo, 1996; Cohn et al., 1998) (2003 version) and the NWP model was CPTEC-COLA (Kinter et al., 1997). The period focused on in these experiments was March 2004, which was chosen to facilitate investigations into the possible benefits that IWV assimilation can be generated in the extreme events forecastability in a case study (Catarina hurricane).

Other available data was also assimilated in both experiments, such as: geopotential height from temperature profiles measured by NOAA satellites-ATOVS [Advanced TIROS (Television Infrared Observation Satellite) Vertical Operational Sounder] (Reale, 2002); wind components measurements over the oceans from Titan II satellite, QuikScat (NASA's Quik Scatterometer) mission; geopotential height, pressure, specific humidity, and wind component measurements from GTS (Global Telecommunication System), containing measurements taken by surface meteorological stations and operational radiosondes.

The IWV values used here are from the RSS (Remote Sensing Systems) Program SSM/I sensor obtained by the DMSP (Defense Meteorological Satellite Program) satellite measurements (Ledvina and Pfaendtner, 1995) applying the Wentz algorithm (Wentz et al, 1986). The IWV values (level L2) from the AIRS sensor aboard the AQUA satellite were obtained using version 4 of the NASA algorithm (Susskind et al. 2003), which incorporates the most recent inversion procedure progresses. These sensors were chosen because these satellites' passages are temporally well distributed over the South America. Whilst the DMSP passages (SSM/I) are concentrated at 0:00 UTC and 12:00 UTC, the AQUA (AIRS) passages are concentrated at 6:00 UTC and 18:00 UTC.

Results

Prognostic variable field analysis was used in the results analysis, taken from five days of forecasts generated in the processing without the IWV assimilation (Control), and another with IWV included. Two different analyses were done. In the first, the forecast field was compared with observation (O-F analysis), and root mean square (rms) measurements were calculated. In this analysis, only measurements from radiosondes available in the GTS were used as a reference. In the second analysis, the forecast was compared with initial condition fields (A-F analysis), and rms, bias and Anomaly Correlation (AC) were calculated. The direct impact of IWV assimilation on prediction fields was evaluated in the specific humidity values, and the indirect impact was evaluated in the geopotential height and wind components. Different global areas were considered in these analyses: Northern Hemisphere; Southern Hemisphere, Tropical Areas (latitude between 20°N - 20°S) and South America (60°S - 15°N latitude and of 90°W - 30°W longitude).

Figure 1 shows the rms value of specific humidity at 850, 700 and 400 hPa regarding the radiosondes launched in the South America region. This figure shows that the rms of the forecast field obtained with IWV inclusion is lower than the control process. Such differences are more significant at 850 hPa (Fig. 1a) than in 400 hPa (Fig. 1c) and show that the IWV assimilation impact is correlated with the humidity concentration in the atmospheric profile. The small improvement of the IWV assimilation in the initial condition field is due the fact that the radiosondes used in the evaluation were assimilated in both processes. The impact of radiosondes data assimilation succumb the IWV assimilation impact, because the weight of the data radiosondes is larger than satellite data.

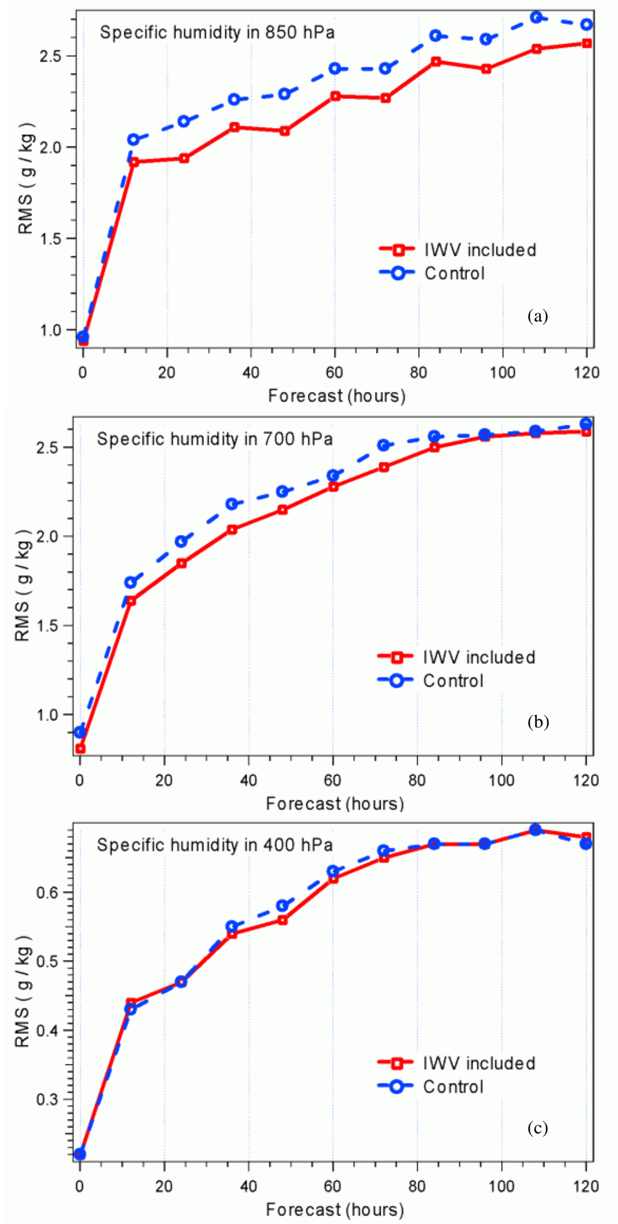

Fig. 1- Rms values for specific humidity at 850 hPa (a), 700 hPa (b) and 400 hPa (c) from processing with and without the inclusion of IWV values for the radiosondes launched in the South America region.

Similar analysis was done for the geopotential height and wind components to assess the indirect impact of IWV assimilation on these prognostic variables. Figure 2 shows rms values at 250 hPa for such variables considering the radiosondes launched in Tropical regions. Although humidity concentration in the highest layers of the atmosphere (250 hPa) is lower, the impact of IWV assimilation on other variables was positive in such conditions. Regarding the geopotential height (Fig. 2a), the IWV assimilation impact was very significantly positive, presenting a large difference of 5 m in 120 hours of forecast. It is noted that in the wind components the IWV inclusion benefit was more significant in the meridional component (Fig. 2b) than in the zonal one (Fig. 2c).

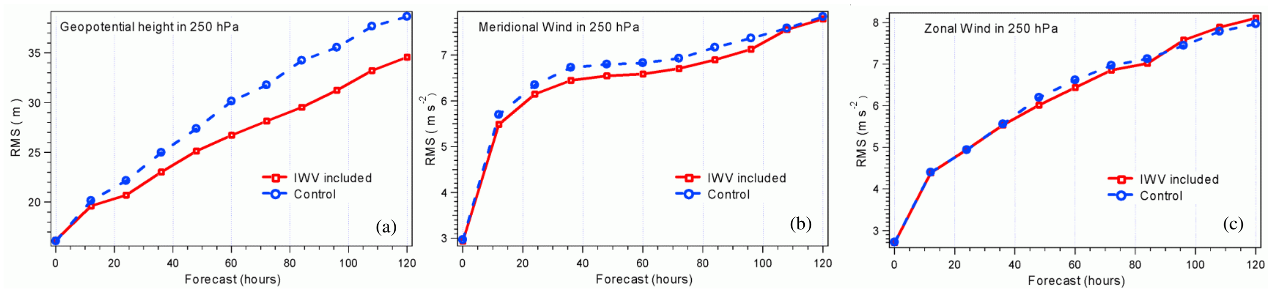

Fig. 2- Rms values for geopotential height (a), meridional wind (b) and zonal wind at 250 hPa from processing with and without the inclusion of IWV values for the radiosondes launched in the Tropical region.

In this analysis the initial condition is used as a reference and Anomaly Correlation, rms and bias values are calculated. Figure 3 shows Anomaly Correlation (Fig. 3a), rms (Fig. 3b) and bias (Fig.3c) for Integrated Water Vapor with and without IWV assimilation over the South America regions during March 2004. The AC values show that there is a significant positive impact obtained with IWV assimilation. When the IWV values are assimilated, the useful life of IWV predictions is extended from 59 to 72 hours. Besides, the rms values in short-range predictions are 2 kg m^{-2} lower than the control process. The rms difference between IWV assimilated and the control process decreases slightly and approaches zero at 120 hours, while the bias values show a lower difference.

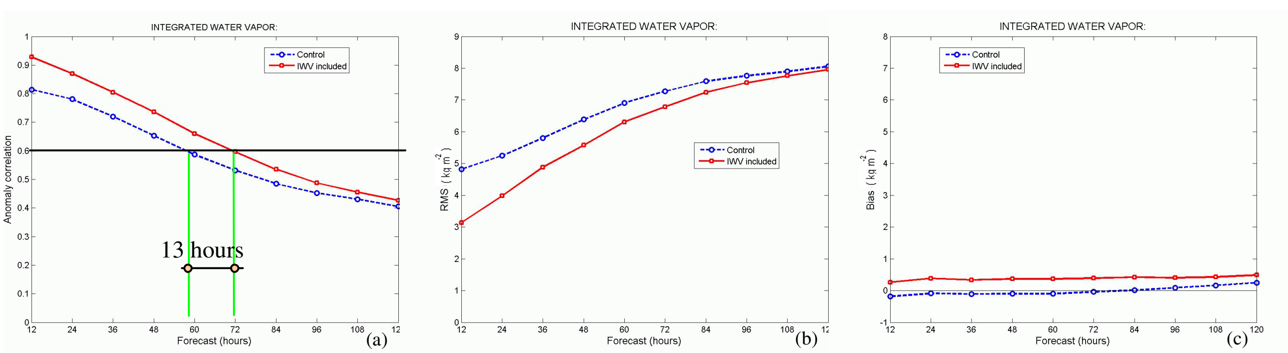

Fig. 3- Anomaly correlation (a), rms (b) and bias (c) from A-F analysis of the integrated water vapor with and without the IWV inclusion over the South America region.

Figure 4 shows rms values as a function of forecast hours for relative humidity at several atmospheric profile levels. The impact of IWV assimilation is significant only for short-range humidity predictions (up to 72 hours) at different levels (Fig. 4a-4f). However, the IWV assimilation impact in the geopotential height and wind components at 250 hPa shows contrasting behavior, because the rms is lower in the short-range predictions and grows slightly as a function of forecast hours. The figure 5 shows the rms values as a function of the forecast hours for geopotential height and wind components. The IWV assimilation impact was more significant for geopotential height (Fig. 5a). This behavior should be associated with the improvement in the virtual temperature in the analysis given by the improvement in the humidity field.

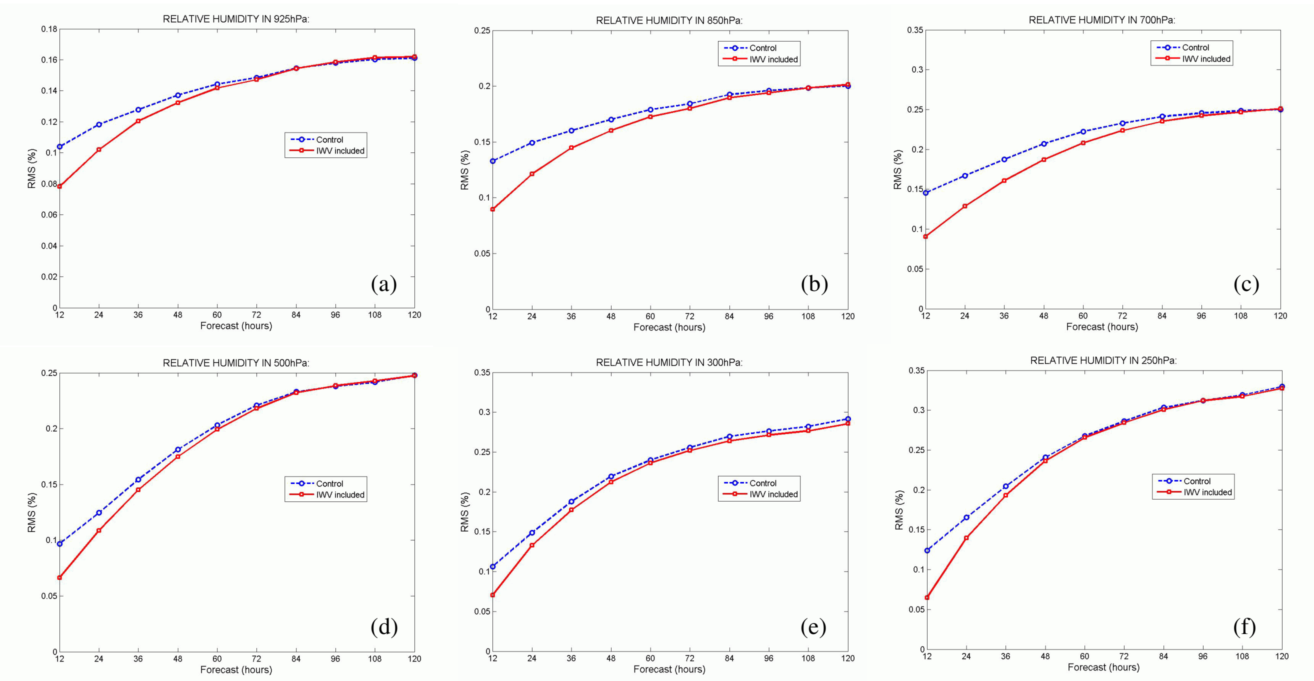

Fig. 4- Rms values from A-F analysis for relative humidity with and without the inclusion of IWV values over the South America region at different atmospheric levels.

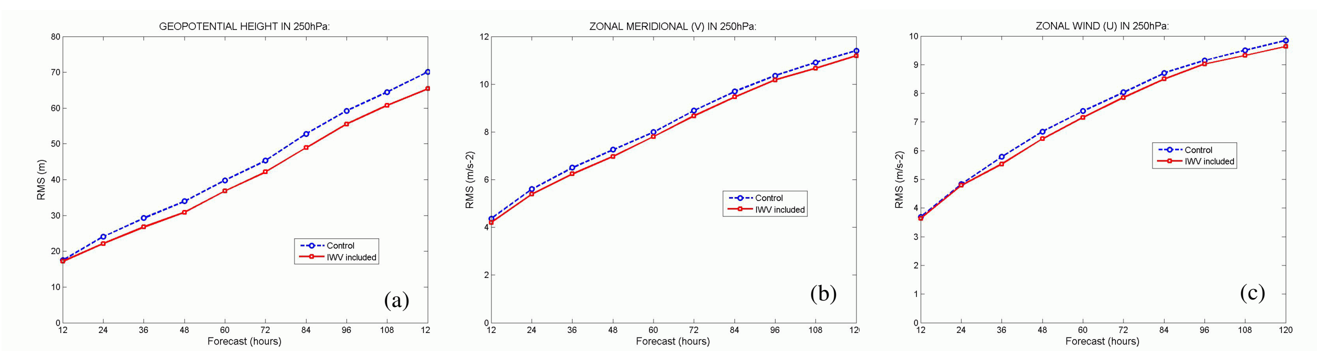

Fig. 5- Rms values from A-F analysis of the geopotential height and wind components with and without the inclusion of IWV values over the South America region at 250 hPa.

The anomaly correlation values for relative humidity (Figure 6) show that prediction of this variable has a short useful life because after 36 hours the anomaly correlation values are lower than 0.6 at 850 and 700 hPa and after 54 hours at 500 hPa. However, this figure clearly shows that IWV inclusion improved the model’s ability to predict this variable. The useful life was improved in approximately 12 hours at 36 hours at 850 (Fig. 6a) and 700 (Fig. 6b) hPa, while at the 500 hPa level (Fig. 6c) this improvement was more modest (only a few hours at 48 hours).

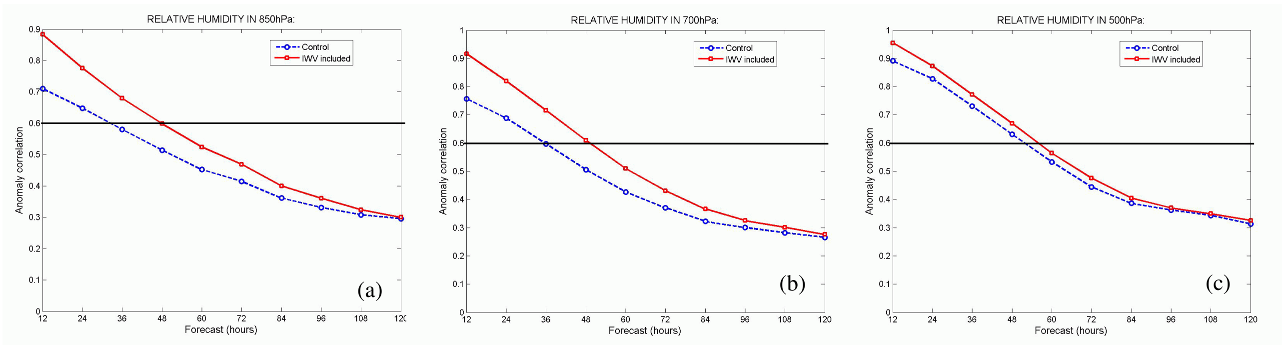

Fig. 6- Anomaly correlation values from A-F analysis of relative humidity with and without the inclusion of IWV values over the South America region at 850, 700, and 500 hPa.

To assess the spatial distribution of IWV assimilation impact over the South America region the difference was calculated between rms values of the Integrated Water Vapor from A-F analysis with and without IWV inclusion. Figure 7 shows the spatial distribution of these values in different forecast hours. This figure clearly demonstrates this impact is more significant over the Amazonian region and ocean areas. Although this result is expected because these areas enjoy lower conventional data coverage, it has become evident that the usage of the additional humidity source in the CPTEC data assimilation system is important for Numeric Weather Prediction over the Amazonian region.

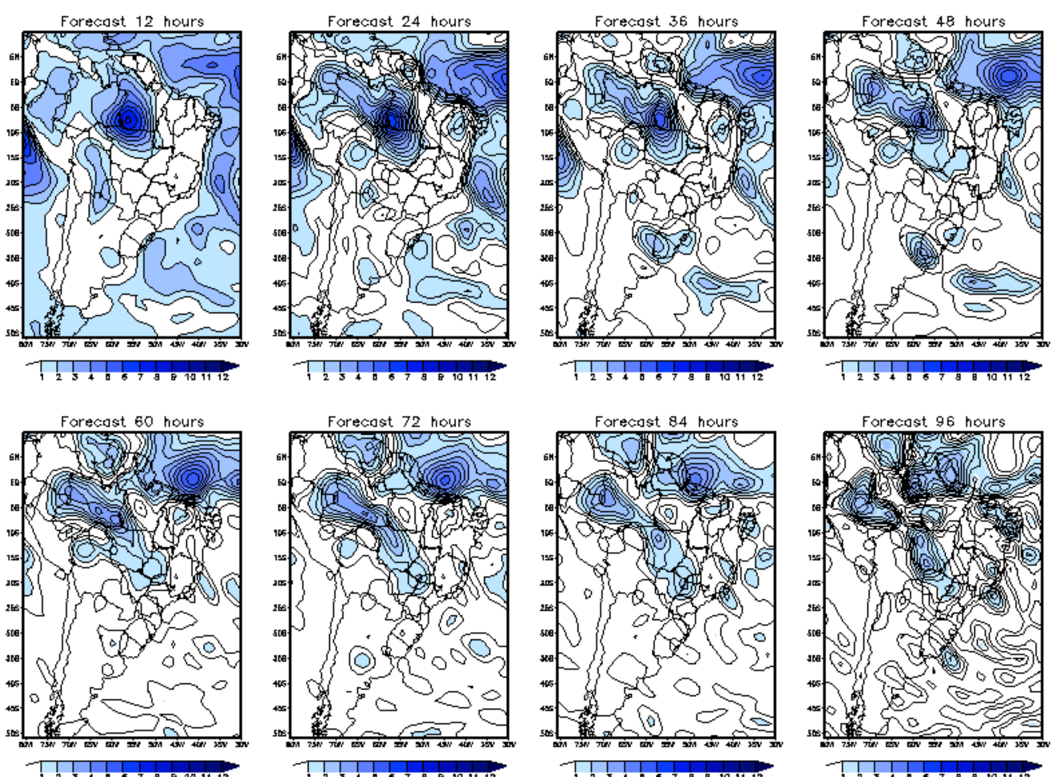

Fig. 7- Spatial distribution of the rms difference of the Integrated Water Vapor values from A-F analysis with and without IWV inclusion (values in kg m^{-2}).

Conclusions

This paper has presented the preliminary results of the assimilation of the IWV values from the AIRS/AMSU and SSM/I sensors in the CPTEC data assimilation system. The impact was assessed to compare results generated in the process with and without the inclusion of IWV. O-F (radiosondes Observation minus Forecast) and A-F (Initial condition minus Forecast) analyses were carried out. The results indicate that IWV assimilation minimizes vertical humidity profile errors, consequently producing a better adjustment in the mass budget in the troposphere, having an indirect impact on prediction of the prognostic variable, particularly the geopotencial height at 250 hPa.

In the future some adjustments in the IWV assimilation process will be investigated, such as improving the stochastic model used in this process, using other humidity information sources, as well as getting the IWV assimilation including precipitation data. Hou et al (2000) showed that the assimilation of precipitation data with IWV values intensifies the benefits created by each one of those variables separately.

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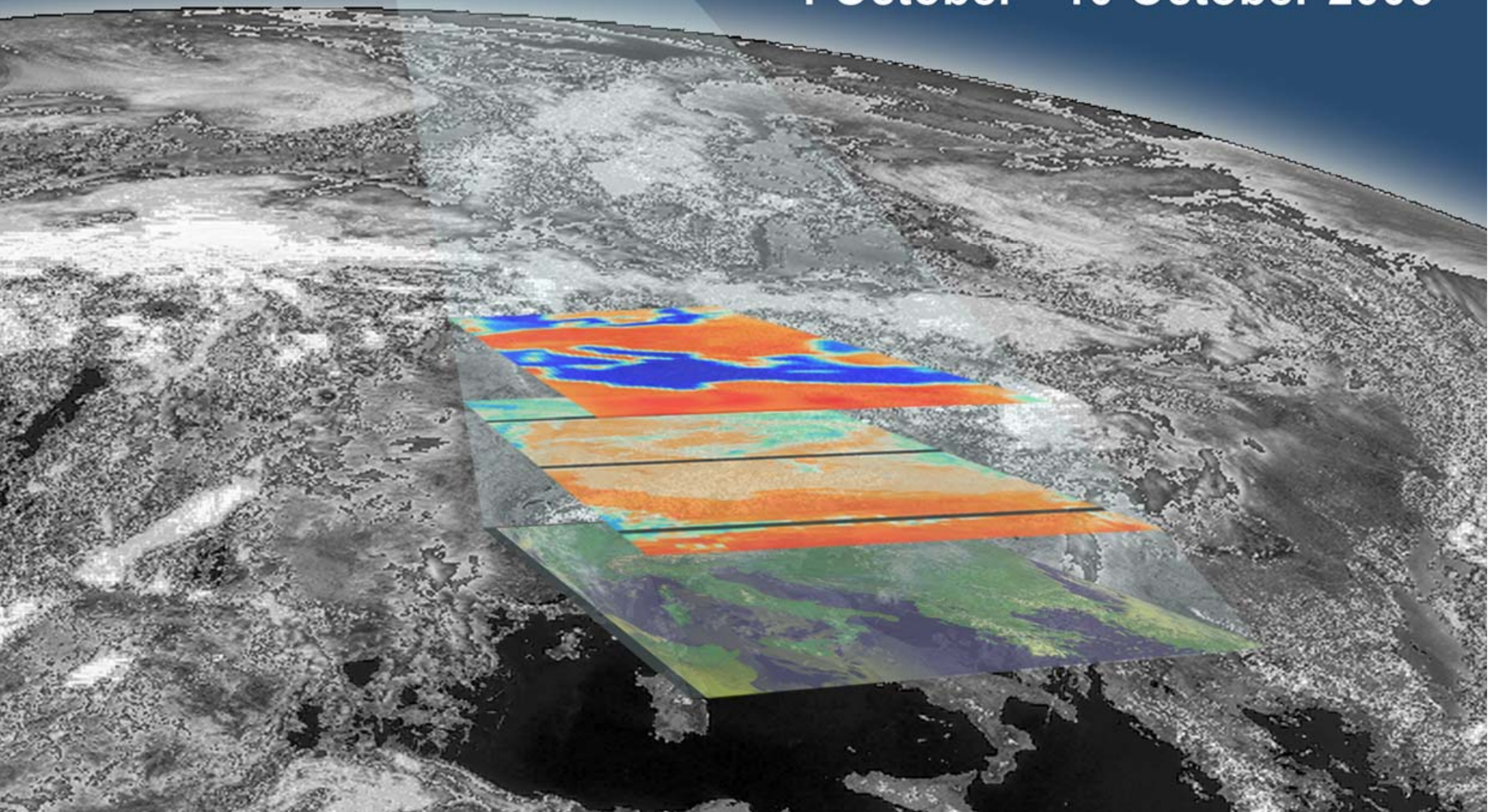

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