

TOVS and the MM5 analysis over Portugal

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ABSTRACT

TOVS data retrieved from NOAA-16 satellite, by the World Data Center for Remote Sensing of the Atmosphere (WDC-RSAT), have been analyzed and compared with the one-way 3 nested domain integration of the Fifth-Generation NCAR/Penn State Mesoscale (PSU/NCAR) Modeling System (MM5). The analysis has been conducted throughout comparison with data collected by the automatic meteorological station (EMA) of the Institute of Meteorology (IM) and Lisbon radiosounding station (Portugal). The basic form of multi-scale data assimilation procedures (FDDA), based on Newtonian relaxation of analysis and observations nudging, have been used on mesoscale model MM5 for a precipitation event occurred over Portugal during summer season simulations. In order to figure-out the effectiveness of TOVS data in reducing the sounding data retrieval errors, particularly near surface levels, and to improve the precipitation forecast, the rainfall occurrence days, during October 2004 over Portugal, a particular event simulated using a weak constrained 4DVAR satellite retrieved data assimilation procedures have been selected. Several simulations mode have been conducted including observation data available, especially the asynoptic satellite data in the analysis and also without any assimilation at al. The mesoscale model forecasting has been processed employing both TOVS data from NOAA-16, as well as the EMA and upper air radio-sounding data in the analysis. The results show that vertical temperature profiles have small departures, compared with its humidity counterpart, with respect to both observations and model simulations. The results revealed that, although humidity data have suspicious quite large retrieval errors, they contribute to improve the precipitation events forecast over Portugal.

Introduction

The numerical weather forecasting models are very sensitive to small perturbations in the initial conditions. It is, therefore, a premise to have an accurate initial state of the atmosphere in order to succeed with results. In fact, Best (1956) showed that analysis errors could have serious effect on numerical prognoses, even including very small differences in the 500 hPa analyses fields, using a single barotropic model, produces different prognoses that diverge as the forecast length increases. The slight variations in the initial wind field sensitivity study conducted by Huo et al. (1995) also show the importance of using accurate initial conditions to simulate important mesoscale features associated with Super-storms. In a more recent studies, according with Spencer and Stensrud (1998), the improvement of initial conditions leads to a "significant improvement" in the precipitation field. Stensrud and Fritsch (1994) also showed that simulations of the accuracy and evolution of events, associated with mesoscale convective systems (MCS's), are highly sensitive to differences in the techniques used to create the initial conditions.

There are several factors which are responsible for the impossibility of obtaining the perfect desirable initial state and conditions of the atmosphere. The data voids and insufficient data density coverage, observational errors, and analysis errors are, among others, the crucial factors since the model itself has direct influence only on the latter one. That explains why there are a variety of techniques available for mapping observations onto a grid. Even so, differences in model analysis, or a single and small change within a particular analysis procedure, can lead to a significant changes in the forecasts for a given set of observations.

Several procedures have been currently used by modelers for mapping observations onto a grid (Bratseth, 1986; Dimet et al., 1986; McPherson, 1986; Parrish and Derber, 1992; Sashegyi et al., 1993; Stensrud and Fritsch, 1994), among which the four-dimensional data assimilation (FDDA) seems to be a suitable one to incorporate the asynoptic data into a forecast model. The Newtonian relaxation ("nudging"), which is one type of FDDA technique, adds an extra term to the prediction equation(s) in order to keep the model solution close to the observations. The second type of FDDA employs variational techniques which iteratively adjust the model forecast to the observations, by changing the initial and boundary conditions (Parsons and Dudhia, 1997). The variational technique was developed by Sasaki (1958) and is a method for adjusting an objective analysis, by a minimum amount, necessary to satisfy certain dynamical constraints (Schlatter, 1988).

The basic form of multi-scale data assimilation procedures (FDDA), based on Newtonian relaxation, of analysis and observations nudging have been applied for a precipitation event occurred over Portugal during summer season. The procedures have been configured to include all observation data available, especially the asynoptic satellite data in the analysis. The precipitation event occurred during 2004, October 24–28 period over Portugal mainland have been selected for discussion. The mesoscale model forecasting has been processed employing both TOVS data from NOAA-16, as well as the Portugal automatic meteorological observation network (EMA) and upper air radio-sounding data in the analysis. Several simulations have been conducted, with and without FDDA and using surface data and TOVS retrieved data.

Observational Data

The retrieved TOVS data from NOAA 16 by German Aerospace Center (DLR)/ German Remote Sensing Data Center, have been used in the analysis. The retrieved data particularly considered have been those which have area coverage of, at least, over 50% of the Portugal mainland. Since data retrievals have been made using the IAPP with climatic average as background profile, and not any forecasting profiles, they do not include any model background influences. A particular vertical integrated water vapor content in the atmosphere, in mm, over the points on which temperature and humidity vertical profiles data have been available on 03:34 UTC of October 25th, retrieved from NOAA 16 is presented in Figure 1.

The 86 automatic meteorological surface stations (EMA) data of surface pressure, humidity, temperature and wind, for the period under analysis, of the Institute of Meteorology stations, are located about 50 km apart each other as indicated by circles in the Figure 2. These data have been used in the multi-scale data assimilation procedures (FDDA) of the MM5 system. The radio-soundings data of 12:00 UTC, from Lisbon station, have also been included in the analysis and in the mesoscale model simulations.

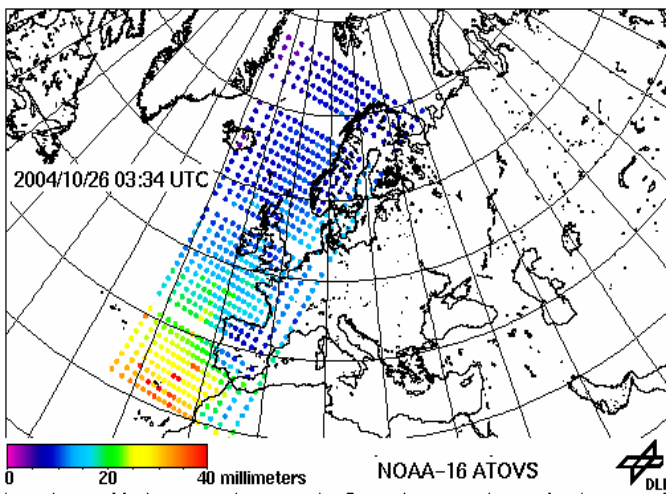


Fig. 1: NOAA-16 total water vapor

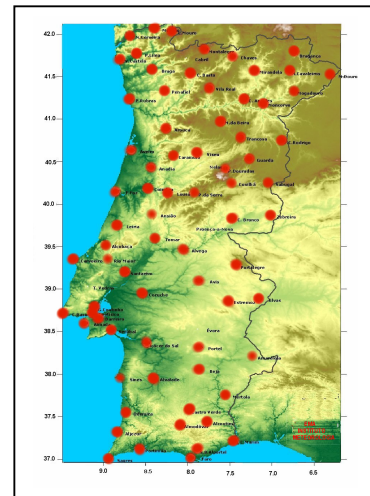


Fig. 2: EMA station

Mesoscale Model Description and Simulations

The Fifth Generation Mesoscale Model (MM5) developed and maintained by the Pennsylvania State University and National Center for Atmospheric Research (PSU/NCAR) is one of the most widely used public-domain prognostic mesoscale model. It has been developed at Penn State and NCAR, as a community mesoscale model with contributions from users worldwide, and detailed description of it is covered by Dudhia and Bresh (2002); Grell et al. (1994) and also available at <http://www.mmm.ucar.edu/mm5>. The model is also supported by pre- and post-processing programs, collectively referred as MM5 modeling system, which facilitate the development of various model inputs, and the model output analysis.

The MM5 is a limited-area, terrain-following (sigma-coordinate), prognostic meteorological model, which solves the full suite of non-hydrostatic prognostic primitive equations for the three-dimensional wind, temperature, water (in all phases), and pressure fields. The model, which can run with multiple one-way or two-way nested grids, to resolve a range of atmospheric processes and circulations on spatial scales ranging from one to several thousands of kilometers, have been configured for three nested grid domains (hereafter designated as D1, D2 and D3) covering the regions presented in Figure 3. The model equations are solved horizontally on an Arakawa-B grid structure defined, in the present simulation, on Lambert conformal conic projection centered on 40° N Latitude and 12° W Longitude. The vertical coordinate, which is a terrain-following normalized pressure coordinate, referred to as a “sigma”, have been configured with 35 vertical levels to resolve the troposphere and lower stratosphere up to 100 hPa. Other settings of the model are presented in the Table 1. The Figure 4 shows the terrain height of D3 and an East-West and North-South crossing lines over which the vertical cross sections of some variables have been analyzed.

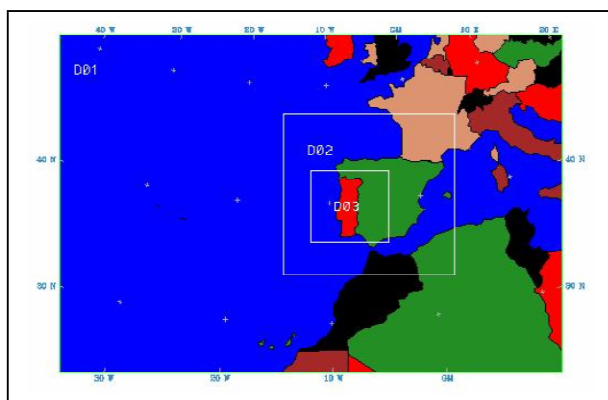


Table 1 – MM5 Settings

MM5 - Model domains	D1	D2	D3
Horizontal Resolution (~ km)	81	27	9
#Grid points East-West	57	58	79
#Grid points North-South	39	55	73
Topography resolution (~ km)	56	19	9
Time step (seconds)	240	80	26,6

Fig. 3: MM5 Domains

The MM5 system Version 3.6 is highly modular and facilitates the interchange of physics and data assimilation options. Among the several physical selection setting options, the one related to the humidity microphysics and cumulus parameterization are the ones mostly explored, at least when the main objective is related to precipitation forecasting (Chien et al., 2003). In this respect, the cumulus parameterization selected has been the one which presented the best results on study already conducted for Portugal region (Yamazaki and Orgaz, 2003): Kain-Fritsch 2 for D1 and D2 and Grell for D3. The explicit schemes of single ice of Dudhia, for D1 and D2; and Reisner mixed phase for D3 have been also pre-established. Details of these parameterizations are well documented by Grell et al., (1994) and other parameters, as well as detailed descriptions are presented by Dudhia and Bresch (2002).

The multi-scale data assimilation procedures (FDDA) have been applied for a precipitation event occurred over Portugal during the 2004, October 24–28 period. They have been processed employing TOVS and automatic meteorological observation network (EMA) data sources. The TOVS data available for the FDDA model assimilation procedures, aside from the one presented in Figure 1, have been from 13:24 UTC October 24; 13:35 UTC October 25; 00:14, 03:34, 13:24 and 15:08 UTC of October 26; 03:23, 14:56 UTC of October 27 and 03:11, 14:44 UTC of October 28.

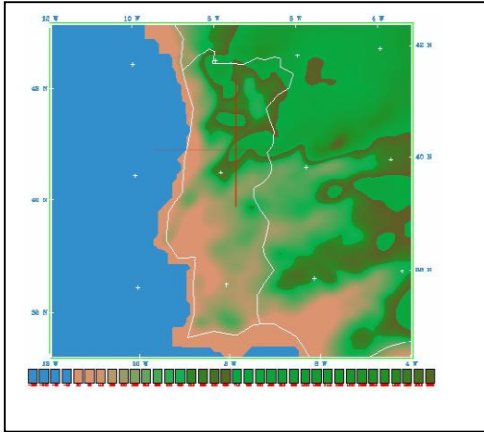


Figure 4: D3 Terrain height

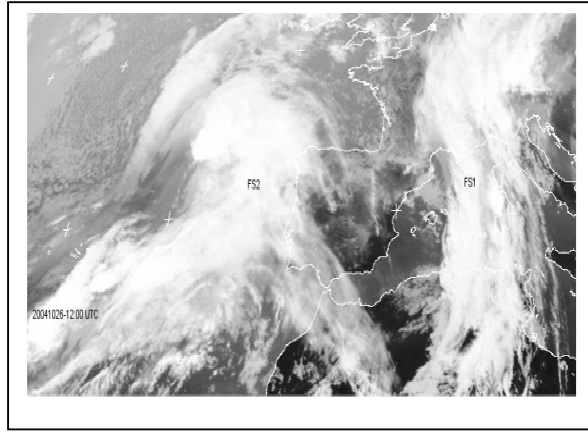


Figure 5: Meteosat IR-26/10/04-12:00UTC

The forecasts have been simulated for the three one-way nesting MM5 integration domains using the 6 hourly NCEP-NWS/GFS global atmospheric forecast model data as boundary and first guess fields for the October 24–28 period. A total of 15 simulations have been conducted, each day starting at 00 UTC and integrated during 48 hours, from 24th of October. Five simulations have been made with no FDDA, five with surface data FDDA and five with surface and TOVS data. The FDDA have been applied only in the first day of each simulation.

Results

The IR satellite image of October 26, 12:00 UTC, from METEOSAT, presented in Figure 5 shows the frontal system FS1 and FS2 which passed through the Iberian Peninsula producing thunder showers over Portugal Mainland which has been simulated. The first of it, FS1 only developed after passing over Portugal, during morning dawns of October 26, and did not produced any significant inland rain. On the other side FS2 developed, mostly during night time and particularly over the Northern sector of Portugal, and was the responsible for the rain, measured by the EMA's stations, as the 24 hours accumulated precipitation presented in Figure 6a. It is worth to mention that Barne's type of interpolation have been used to plot the rainfall field, without any data void procedure applied to suspicious observed data, which probably explains the lack or rain in some region of the Central region of Portugal, or probably the excess of precipitation registered over other regions; opposing to model simulation presentations. It is clearly shown that almost all MM5 simulations, initialized on day 25, present a quite consistent rainfall distribution, irrespective to amount of it, for the occurrence between 23:00 – 24:00 UTC of October 26. The no FDDA run, as presented in Fig. 6-b shows less precipitation compared to the other runs. The use of surface data observations from EMA, as well as a single radio-sounding station data (Lisbon) in the FDDA produces more rain (Fig. 6-c). The Figure 6-d shows the rainfall distribution surface and TOVS data have been used in the FDDA.

The vertical cross sections, along the lines presented in Figure 2, of the circulation vector, equivalent potential temperature and Potential Vorticity are presented in Figure 7 a-d. As it shows, the comparison between no FDDA (a,c) presents differing configurations on all these fields. The potential vorticity over the mountain region are too enhanced in no-FDDA run case and although not presented here, the pre-storm phase development presented much more enhanced vertical velocity field along the mountain region in the FDDA run as compared with no-FDDA case.

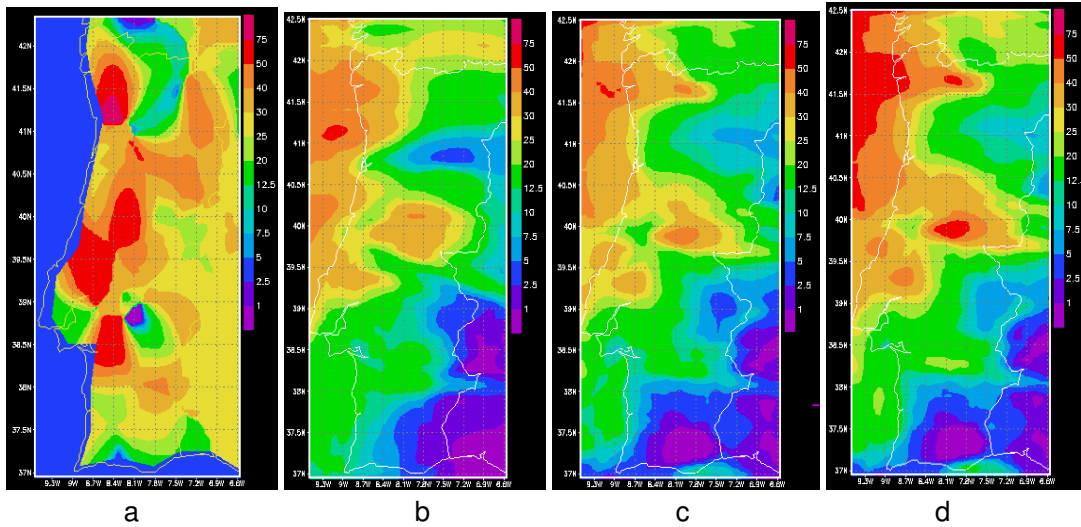


Figure 6: Rainfall distribution for October, 26. a- Observation; b-MM5 no FDDA; c- MM5 with surface FDDA; d- MM5 with full FDDA.

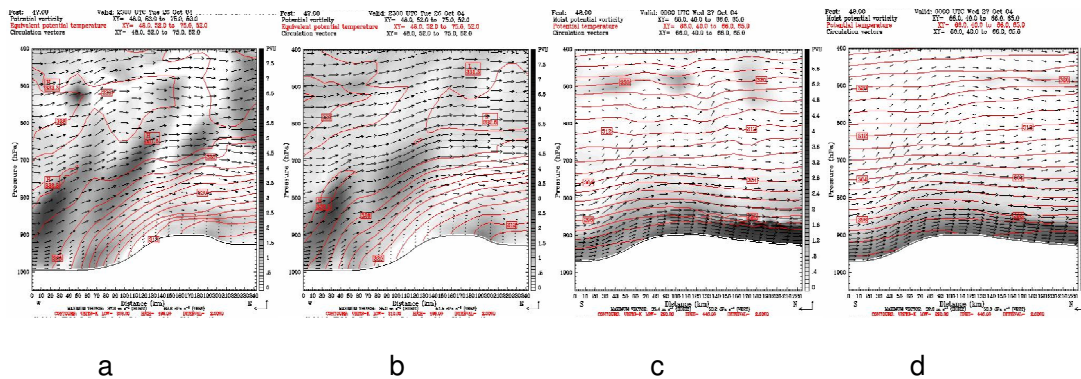


Figure 7: Potential Vorticity, Equivalent Potential Temperature and Circulation Vector Vertical cross sections for October: 23:00 UTC (a,b) over West-East direction and 24:00 UTC (c,d) over South-North direction.

The Fig. 8a and 8b show the temperature profiles of the radiosounding and MM5 simulations for October 25th and 26th without any FDDA. The result clearly shows that MM5 forecasted profiles, after 36 hrs. of integration, have a quite good agreement with observational data, except for being smoothed due to vertical resolution. It has been found that MM5 produced no significant improvement at all, on Temperature forecasting, with any of the experiments conducted using FDDA. However, the results, using surface and TOVS FDDA, presented a very significant improvement on dew point temperature profiles on all simulations as presented in Fig. 8c, which show the case of no FDDA and 8d the one with FDDA. Although MM5 dew point temperature profiles presents significant deviations compared with observations,

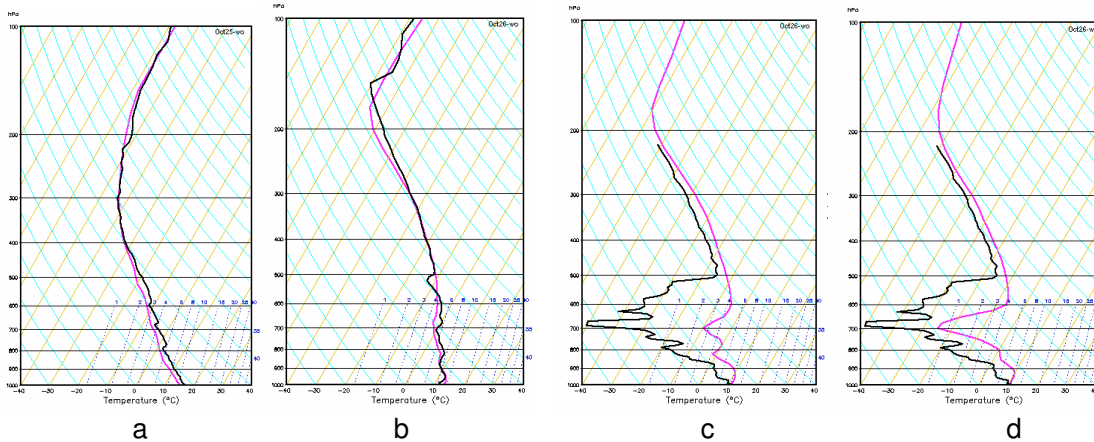


Figure 8: Radiosounding (black line) and MM5 (pink line) T and Td profiles. Oct.25 and 26 Temperature without FDDA (a,b), Oct.26 without (c) and with (d) surface and TOVS FDDA.

Conclusions

The basic form of multi-scale data assimilation procedures (FDDA), based on Newtonian relaxation, of analysis and observations nudging, adapted for precipitation events occurrence simulations, using MM5 mesoscale model over Portugal, show that wind field over mountain region, as well as the potential vorticity present an enhancement when FDDA is applied, as compared with the case without it, especially when frontal system evolution occurs.

The results of precipitation data analysis indicate that, even using weak constraint coefficient values, the FDDA makes a significant improvement in the MM5 numerical prognosis in this variable distribution field, on both space and time integration levels.

Although there are a lack of a desirable space and time surface data observational network distribution, particularly over the Atlantic Ocean side of the Inland Portugal, with reliable data to allow an exhaustive comparison with observations, the conducted experiments presents the real potential of satellite data in the improvement of mesoscale model forecast.

The results of the comparisons between radiosounding and MM5 forecasted profiles of temperature, with or without use of any observational data, present no significant improvement. However, the main breakthrough of FDDA on MM5 has been on the dew point temperature profile forecast, which is an important fact since it significantly contributes for the improvement of rainfall forecast.

Acknowledgements

The research has been supported by Science and Technology Foundation (FCT) under grant-FCT/REEQ946/2001, as well all first authors' support FCT/BD/19284.

The authors thank to National Meteorological Institute (IM) of Portugal and to the German Aerospace Center (DLR)/ German Remote Sensing Data Center for providing the data

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