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DATA ASSIMILATION FOR NOWCASTING IN THE TERMINAL CONTROL AREA OF RIO DE JANEIRO

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Resumo

O processo de assimilação de dados, onde observações meteorológicas e previsões do tempo são combinadas para fornecer um campo de análise, tem sido muito estudado pela comunidade científica e por centros operacionais. A utilização do método variacional 3D (3D-Var) implementada no modelo Weather Research and Forecast (WRF) é avaliada para assimilação de dados na Área Terminal do Rio de Janeiro (TCA-RJ). O objetivo principal de qualquer método variacional de assimilação de dados é produzir uma estimativa ótima do estado atmosférico no momento da análise. O campo de análise é estimado por um campo de estimativa inicial (campo de previsão anterior) e um campo de observações, ponderados pelas matrizes de erro. O WRF é configurado para nowcasting (previsão de até 6h) para a TCA-RJ através de ciclos de assimilação utilizando dados de superfície, sondagem e perfilhadores de vento. Os resultados preliminares mostram a sensibilidade de cada tipo de observação e encorajam a utilização desta técnica operacionalmente para fornecer suporte ao controle de tráfego aéreo controlado pela Força Aérea Brasileira.

Palavras-chave: assimilação de dados; WRF; 3D-Var; dados de superfície; dados de perfil.

Abstract

The process of data assimilation, in which meteorological observations and weather forecasts are merged to provide an analysis field, has been largely studied by the scientific community and operational centers. The 3D-Variational (3D-Var) approach available in the Weather Research and Forecast (WRF) computer model is evaluated for data assimilation for the Terminal Control Area of Rio de Janeiro (TCA-RJ). The basic goal of any variational data assimilation system is to produce an optimal estimate of the atmospheric state at analysis time. The analysis field is estimated from a first guess (previous forecast) and an observation field, weighted by the error matrices. The WRF is designed for nowcasting (forecasts up to 6h) for the TCA-RJ through assimilation cycles using surface, sounding, and wind profile data. The preliminary results show the model sensibility for each observation type and encourage the use of this technique operationally for the support of the air traffic management controlled by the Brazilian Air Force.

Keywords: data assimilation; WRF; 3D-Var; surface data; profile data.

1 Introduction

Numerical weather prediction (NWP) is considered an initial-value problem, where the current state of the atmosphere is used as input to a numerical model for simulating or forecast its evolution over space and time. The problem of determination of the initial conditions for a forecast model is very important and complex, and has become a science in itself (Daley, 1991). Several methods have been developed since the 1950s to tackle this problem. Daley (1991) and Kalnay (2012) can be used to a broader review on data analysis and assimilation techniques.

In meteorology, there is a wide variety of data sources able to be assimilated to accurately estimate the state of the atmosphere, including conventional and non-conventional data. Conventional data include surface observations, balloon soundings, aircraft and ship observations. On the other hand, data retrieved from satellites (e.g. radiance), wind profilers (e.g. SODAR, LiDAR), and radar are usually known as non-conventional. Conventional data are commonly assimilated in global models, but such data very often represent local conditions and they are smoothed due to interpolation methods and quality control routines. Also, some observations are out from the observation network, and they are not processed by data assimilation procedures from the global models. Therefore, the best determination for the atmosphere state for the high resolution limited area model is obtained by assimilating local retrieved data.

Preliminary tests on the sensibility of a regional model are evaluated for the assimilation of profile data (sounding) in the terminal control area of Rio de Janeiro (Brazil).

2 Data and study area

The experiments performed in this work used (i) data from Global Forecast System (GFS) forecasts for model initialization and boundary conditions; (ii) METAR/SPECI data retrieved from the surface meteorological stations at several airports in Rio de Janeiro (Figure 1); and (iii) sounding data retrieved daily at the International Airport of Rio de Janeiro, known as Galeão airport (SBGL). Table 1 show details of the used data and its source for reproducibility. Figure 2 shows the study domain and also the model grid used on the simulation runs.

Table 1 - Source, description, and frequency of the data used for assimilation sensibility evaluation.

Source	**Description**	**Frequency**	**Data availability**
GFS https://rda.ucar.edu/datasets/ds084.1	Initial and boundary atmospheric conditions at 0.25 degree resolution	3 h	2015-present
METAR/SPECI data https://www.redemet.aer.mil.br	Surface data at airports	1 h	1977-present
Atmospheric Sounding https://www.redemet.aer.mil.br	Atmospheric profiles of SBGL of temperature, relative humidity, atmospheric pressure, winds and sounding-derived atmospheric instability indices.	daily (12Z)	1977-present

3 Methods

The experiment was performed using the WRF model for: (i) 72-h control run; (ii) 72-h synthetic observation run generated by an initial perturbation (white noise) on the forecast run; (iii) data assimilation of surface and profile synthetic observations retrieved at the SBGL location every 12 h.

3.1 WRF model

The Weather Research and Forecasting (WRF) Model is a next-generation mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting applications. The code embraces two dynamical cores, a data assimilation system, and a software architecture supporting parallel computation and system extensibility. The effort to develop WRF began in the latter 1990's, and was a collaborative partnership of the National

Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (represented by the National Centers for Environmental Prediction (NCEP) and the Earth System Research Laboratory), the U.S. Air Force, the Naval Research Laboratory, the University of Oklahoma, and the Federal Aviation Administration (FAA). Please refer to the WRF Users Guide and the Technical Note document available at http://www2.mmm.ucar.edu/wrf/users/ for completeness of the 3D-Var implementation present at WRF (Skamarock et al., 2019).

Figure 1 – Terrain map and airport locations.

The WRF model solves a set of equations for atmospheric state evolution, which includes: (i) conservation of momentum; (ii) thermodynamic energy conservation; (iii) mass conservation; (iv) geopotential relation; and (v) the equation of state. Also, several physical processes are parameterized, because they may be too small, too brief, too complex, too poorly understood, or too computational costly to be explicitly represented, e.g. short and longwave radiation transfer, planetary boundary layer, turbulence, cumulus convection, cloud microphysics, and precipitation.

The WRF model was integrated in a 5-km grid with 35 levels in vertical, generating hourly outputs from surface and pressure-level variables. Regarding the parametrizations, the following options were chosen: Microphysics - WRF Single–moment 3 (Hong et al., 2004), Cumulus - Grell–Freitas Ensemble Scheme (Grell and Freitas, 2014), Radiation – Dudhia Shortwave Scheme (Dudhia, 1989) / RRTM Longwave Scheme (Mlawer et al.,1997), Planetary Boundary Layer - Yonsei University Scheme (YSU) (Hong, 2006), and Land-Surface model: Unified Noah Land Surface Model (Tewari et al., 2004).

3.2 3D-Var

The 3D-Var approach was selected, as implemented in the Data Assimilation component of the WRF framework. An introduction to the basic ideas of variational data assimilation and specifically the WRF Data Assimilation (WRFDA) system is deeply discussed in Barker et al. (2004) and Barker et al. (2012).

Among various data assimilation methods, the variational approaches have been widely used in meteorology, specifically the method 3D-Var. In the 3D-Var approach, a cost function (equation 1) is defined as the difference between observation ($\vec{y}^O$) and the analysis values on the observational grid [$H(\vec{x})$] under norm-*R*, regularized by the difference between the analysis ($\vec{x}$) and the background ($\vec{x}^b$) under norm-*B* (Sasaki, 1970; Kalnay, 2012). The analysis field is computed by the direct minimization of such function. Matrices for both, the background (R) and observation (B), are considered in the minimization process. The operator H transforms the gridded analysis to the observation space for comparison against the observation vector $\vec{y}^O$.

$$J = \frac{1}{2}\{[\vec{y}^O - H(\vec{x})]^T R^{-1} [\vec{y}^O - H(\vec{x})] + \left(\vec{x} - \vec{x}^b\right)^T B^{-1} \left(\vec{x} - \vec{x}^b\right)\} \qquad (1)$$

In essence, the 3D-Var approach consists in processing observed information in a temporal window (typically from 1 h before the analysis time to 1 h after) over a spatial domain. After this process, a subset of the observed data is retrieved to be assimilated in a previous forecast grid by minimizing the cost function.

3.3 Experiment

The WRF model was configured on the spatial domain shown in Figure 2, in a 5-km grid resolution. The domain in centered in the metropolitan area of Rio de Janeiro and encompasses all the airports described in Figure 1, where the observations are retrieved.

The period of 72 hours was considered for the sensibility test, from Jan 1st 0Z and Jan 4rd 0Z, 2017. This period was randomly chosen for the preliminary results, but a larger period (e.g. several years) will be consider in the future.

The initial and boundary conditions for the control run were obtained from the GFS 0.25-degree resolution, and consists of gridded meteorological data for the study period.

The experiment was performed in three steps: (i) a **control run** was performed for 72 h from Jan 1st 0Z to Jan 4th 0Z, 2017; (ii) a **synthetic observation run**, where Gaussian white-noise was added to the GFS analysis field at SBGL location, and then the model was integrated for 72 h without data assimilation; and (iii) an **assimilation run** where a synthetic profile of temperature and dew-point temperature, extracted from the observation run at SBGL location, was assimilated at the initial timestep.

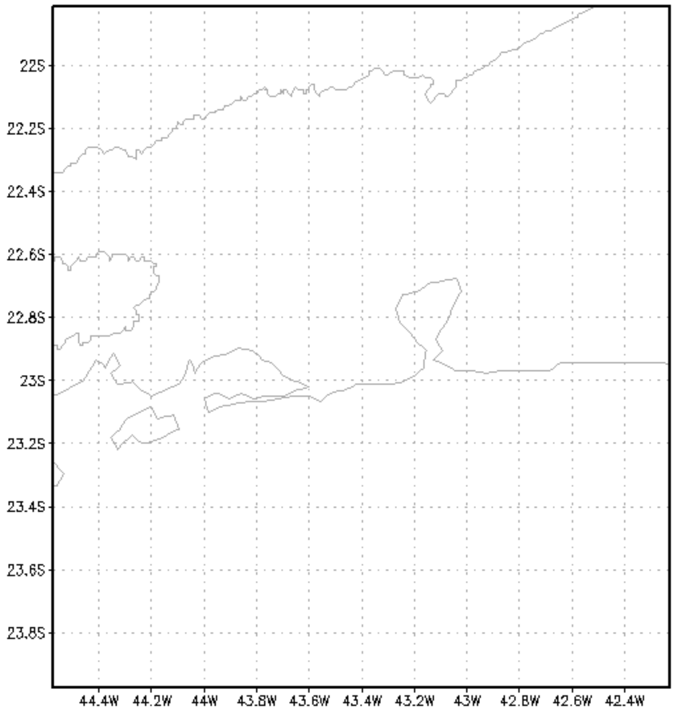


Figure 2 – Horizontal computational domain used for model executions.

4 Results

This section presents the results of the experiments performed in this work showing the spatial-temporal characteristics of data assimilation on study area.

Data assimilation result for air temperature difference at 850 hPa is shown in Figure 3. The difference for the initial condition (Jan 1st, 2017 0Z) between experiment-(ii) and experiment-(i) is displayed in Figure 3a, and the difference experiment-(ii) and experiment-(iii) is in Figure 3b. The same differences are displayed in Figures 3c and 3d on Jan 1st, 2017 12Z, respectively.

The analysis field (Figures 3a and 3b) shows smoother fields from the assimilation process. The difference from the observation field mainly at the airport location and its surroundings illustrates the smoothing. After 12 h of integration (Figures 3c and 3d), the differences increase in both fields, but still the assimilation field presents less difference in comparison to the control run. The results from Figure 3 indicate that even a single temperature profile assimilation at the initial timestep can positively impact the analysis field.

A time evolution of the vertical cross-section at SBGL is displayed in Figure 4. Analogously to Figure 3, Figures 4a shows the difference between experiment-(ii), the observation field, and the experiment-(i); while Figure 4b also shows the difference of the observation field to experiment-(iii). The red rectangle in Figure 4 highlights the most important forecast time for aviation operational purposes, up to 24 h; while the blue rectangles show the errors in a medium-range forecast, up to 72 h.

The differences are quite similar for the first 12 h of forecast but they start to diverge thereafter. The red rectangle in Figure 4, after 24 h of integration experiment-(i), shows errors in different levels, from surface to upper atmosphere, while experiment-(iii) shows errors only close to surface. These results imply that experiment-(iii) is able to retain the observation field characteristics in the short-range forecast period, the most critical for aviation purposes. As the integration approximates to 72 h of integration, the errors increase significantly both in experiment-(i) and experiment-(iii), as shown by the blue rectangle in Figure 4. However, it is possible to notice the effect of the temperature profile assimilation at the initial timestep, since the errors in experiment-(iii) are smaller than the errors in experiment-(i).

5 Conclusions

The 3D-Var approach of the WRF framework was evaluated for the assimilation of a temperature profile assimilation at the Galeão International Airport, Rio de Janeiro (SBGL) for a 72-h period in January 2017.

Preliminary results showed that the assimilation routine was able to adjust the initial field to the airport temperature profile, and also keep these atmospheric characteristics present up to 72 h in the study domain.

The experiments performed have shown the positive impact of the assimilation on the model's overall performance. As shows by the red rectangle in Figure 4, the assimilation method can be effective for the nowcasting time-window, under 24-h. Also, even after 72 h the forecast, the assimilation still have smaller errors than no-assimilation forecasts, encouraging the operational use of such methods to increase reliability in those forecast.

In the future the assimilation of different data types will be evaluated (e.g. profiles from SODAR and LiDAR) and the assimiliation will be expanded for a greater period, evaluating the performance for reproducibility of different meteorological events.

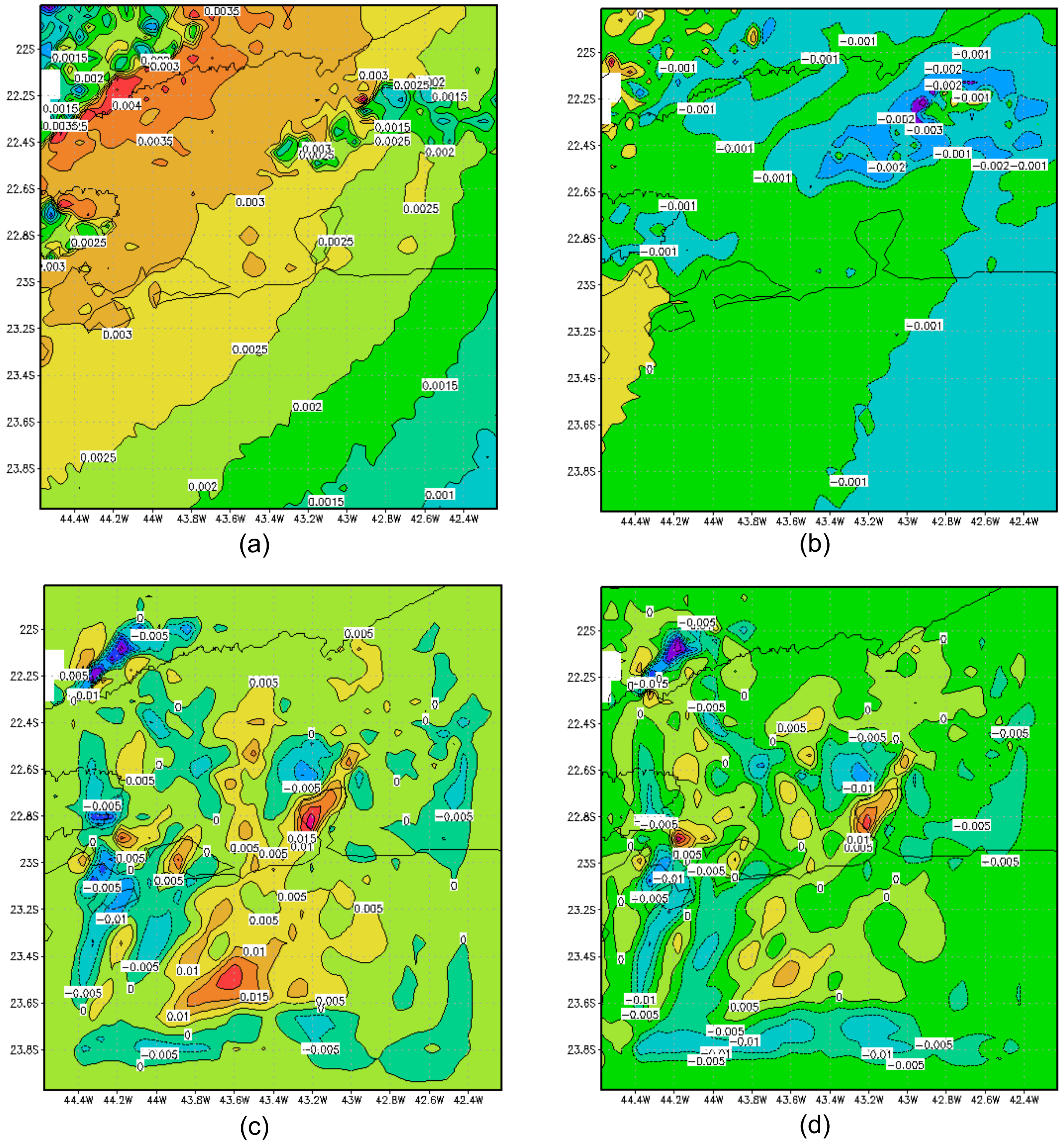
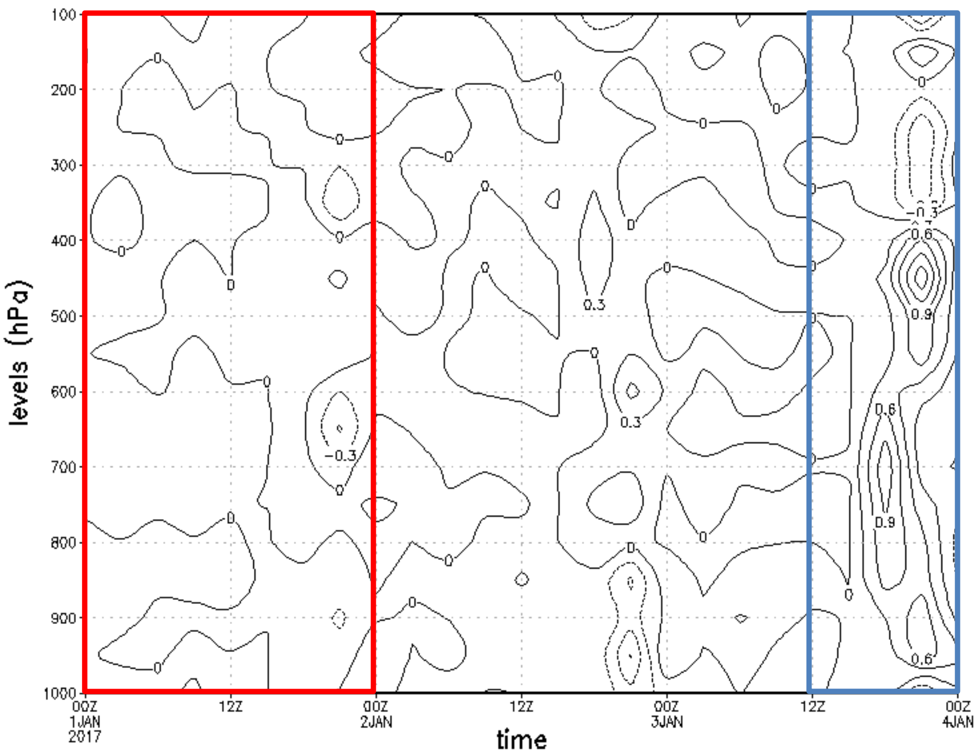
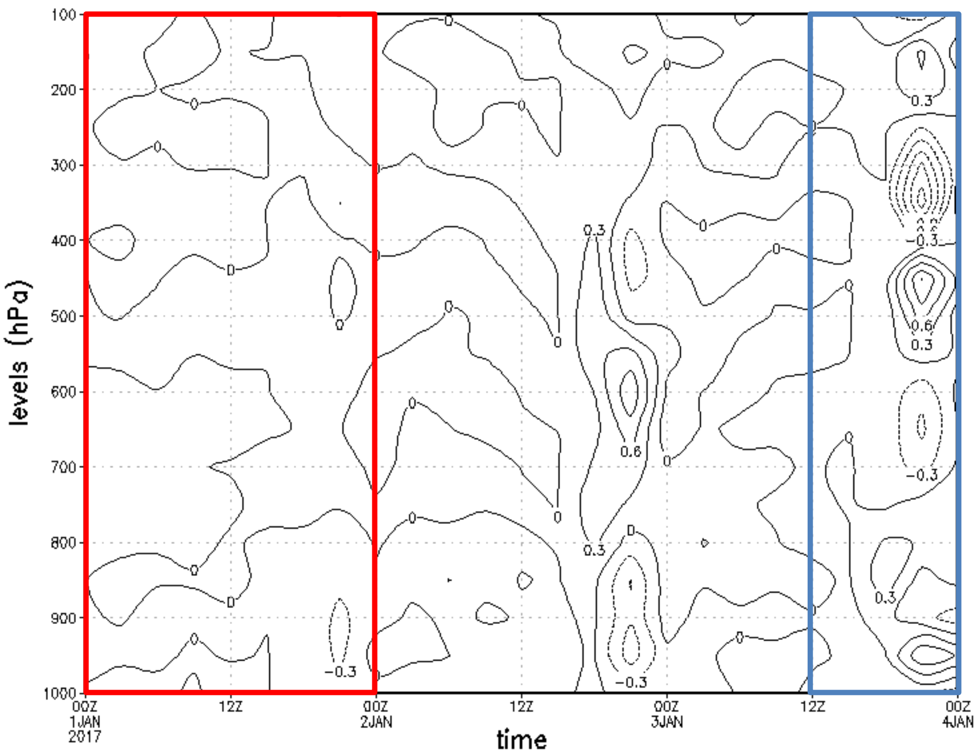


Figure 3 – The 850-hPa air temperature field at 00Z for: (a) the difference between experiment-(ii) and experiment-(i); and (b) the difference between experiment-(ii) and experiment-(iii). Analogously, Figures (c) and (d) show the same difference, respectively, after 12Z of integration.



(a)



(b)

Figure 4 – Vertical cross-section and time evolution at SBGL for: (a) the difference between observation field (experiment-(ii)) and experiment-(i); and (b) the difference between the observation field and experiment-(iii). Red square represents the short-forecast time-window (up to 24 h) and the blue square highlights the medium-range forecast, close to 72 h.

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