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Special Edition

Data assimilation for nowcasting in the terminal area of Janeiro

Assimilação de dados para previsão na área terminal do Rio de Janeiro

Vinícius Albuquerque de Almeida [I]
Gutemberg Borges França [II]
Haroldo Fraga de Campos Velho [III]

[I] Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil. E-mail: vinicius@lma.ufrj.br.

[II] Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil. E-mail: gutemberg@lma.ufrj.br.

[III] Instituto Nacional de Pesquisas Espaciais, São Paulo, Brazil. E-mail: haroldo.camposvelho@inpe.br.

ABSTRACT

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

Keywords: Data assimilation; WRF; 3D-Var; Surface data; Profile data.

RESUMO

O processo de assimilação de dados, onde observações meteorológicas e previsões do combinadas para fornecer um campo de análise, tem sido muito estudado pela c

científica e por centros operacionais. A utilização do método variacional 3D (3D-Var) imp no modelo Weather Research and Forecast (WRF) é avaliada para assimilação de dad Terminal do Rio de Janeiro (TCA-RJ). O objetivo principal de qualquer método vari assimilação de dados é produzir uma estimativa ótima do estado atmosférico no m análise. O campo de análise é estimado por um campo de estimativa inicial (campo d anterior) e um campo de observações, ponderados pelas matrizes de erro. O WRF é c para nowcasting (previsão de até 6h) para a TCA-RJ através de ciclos de assimilaçã dados de superfície, sondagem e perfilhadores de vento. Os resultados preliminares sensibilidade de cada tipo de observação e encorajam a utilização desta técnica operac para fornecer suporte ao controle de tráfego aéreo controlado pela Força Aérea Brasilei
Palavras-chave: Assimilação de dados; WRF; 3D-Var; Dados de superfície; Dados de p

1 INTRODUCTION

Numerical weather prediction (NWP) is considered an initial-value problem, current state of the atmosphere is used as input to a numerical model for simulating or evolution over space and time. The problem of determination of the initial conditions for model is very important and complex, and has become a science in itself (DALEY, 199 methods have been developed since the 1950s to tackle this problem. Daley (1991) a (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 estimate the state of the atmosphere, including conventional and non-conventi Conventional data include surface observations, balloon soundings, aircraft and ship ob On the other hand, data retrieved from satellites (e.g. radiance), wind profilers (e.g LiDAR), and radar are usually known as non-conventional. Conventional data are assimilated in global models, but such data very often represent local conditions an smoothed due to interpolation methods and quality control routines. Also, some obser out from the observation network, and they are not processed by data assimilation proce the global models. Therefore, the best determination for the atmosphere state for resolution limited area model is obtained by assimilating local retrieved data.

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

2 MATERIAL AND METHODS

2.1 Data and study area

The experiments performed in this work used (i) data from Global Forecast Sys forecasts for model initialization and boundary conditions; (ii) METAR/SPECI data retr the surface meteorological stations at several airports in Rio de Janeiro (Figure 1

sounding data retrieved daily at the International Airport of Rio de Janeiro, known as Gal
(SBGL). Table 1 show details of the used data and its source for reproducibility. Figure 2
study domain and also the model grid used on the simulation runs.

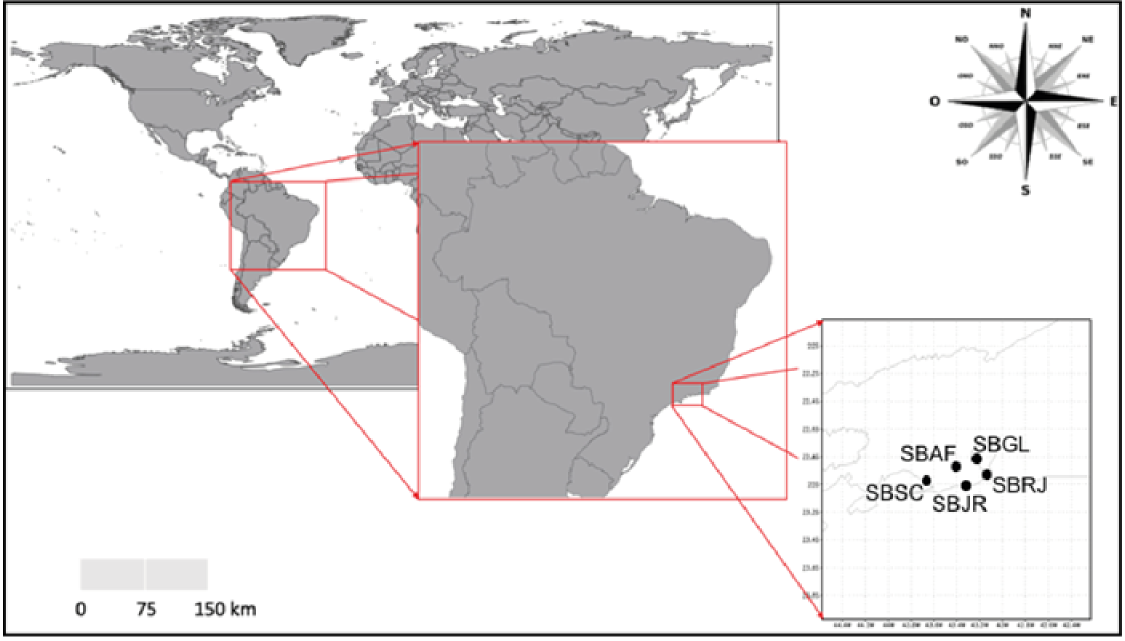
Table 1 – Source, description, and frequency of the data used for assimilation sensibility

Source	**Description**	**Frequency**	**Da**
GFS https://rda.ucar.edu/datasets/ds084.1	Initial and boundary atmospheric conditions at 0.25-degree resolution	3 h	2
METAR/SPECI data https://www.redemet.aer.mil.br	Surface data at airports	1 h	1
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 (0 and 12Z)	1

2.2 WRF model

The Weather Research and Forecasting (WRF) Model is a next-generation numerical weather prediction system designed for both atmospheric research and forecasting applications. The code embraces two dynamical cores, a data assimilation s a software architecture supporting parallel computation and system extensibility. Th develop WRF began in the latter 1990's, and was a collaborative partnership of the Natic for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Adr (represented by the National Centers for Environmental Prediction (NCEP) and the Ea Research Laboratory), the U.S. Air Force, the Naval Research Laboratory, the Ur Oklahoma, and the Federal Aviation Administration (FAA). Please refer to the WRF U and the Technical Note document available at http://www2.mmm.ucar.edu/wrf/ 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 i conservation of momentum; (ii) thermodynamic energy conservation; (iii) mass conser geopotential relation; and (v) the equation of state. Also, several physical proc parameterized, because they may be too small, too brief, too complex, too poorly und too computational costly to be explicitly represented, e.g. short and longwave radiatic planetary boundary layer, turbulence, cumulus convection, cloud microphysics, and preci

The WRF model was integrated in a 5-km grid with 35 levels in vertical, genera outputs from surface and pressure-level variables. Regarding the parametrizations, th options were chosen: Microphysics - WRF Single–moment 3 (HONG *et al.*, 2004), Grell–Freitas Ensemble Scheme (GRELL AND FREITAS, 2014), Radiation – Dudhia Scheme (DUDHIA, 1989) / RRTM Longwave Scheme (MLAWER *et al.*,1997), Planetary Layer - Yonsei University Scheme (YSU) (HONG, 2006), and Land-Surface model: Ur Land Surface Model (TEWARI et al., 2004).

2.3 3D-Var

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

Among various data assimilation methods, the variational approaches have b used in meteorology, specifically the method 3D-Var. In the 3D-Var approach, a co (equation 1) is defined as the difference between observation ($\vec{y}^o$) and the analysis val observational grid [$H(\vec{x})$] under norm-R, regularized by the difference between the analy the background ($\vec{x}^b$) under norm-B (SASAKI, 1970; KALNAY, 2012). The analysis field is by the direct minimization of such function. Matrices for both, the background (R) and c

(B), are considered in the minimization process. The operator H transforms the gridded the observation space for comparison against the observation vector $\vec{y}^{O}$.

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

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

2.4 Experiment

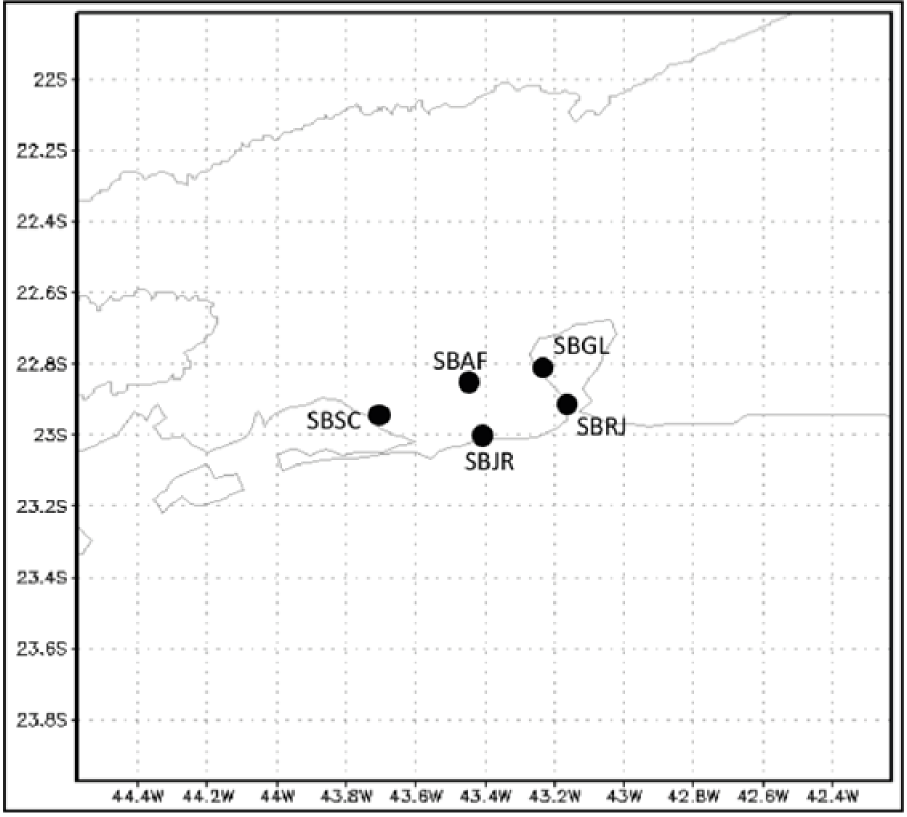
The WRF model was configured on the spatial domain shown in figure 2, in a resolution. The domain in centered in the metropolitan area of Rio de Janeiro and encon the airports described in figure 1, where the observations are retrieved.

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

The initial and boundary conditions for the control run were obtained from the 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 Jan 1st 0Z to Jan 4th 0Z, 2017; (ii) a synthetic observation run, where Gaussian white added to the GFS analysis field at SBGL location, and then the model was integrate without data assimilation; and (iii) an assimilation run where a synthetic profile of tempe dew-point temperature, extracted from the observation run at SBGL location, was ass the initial timestep.

Figure 2 – Horizontal computational domain used for model executions



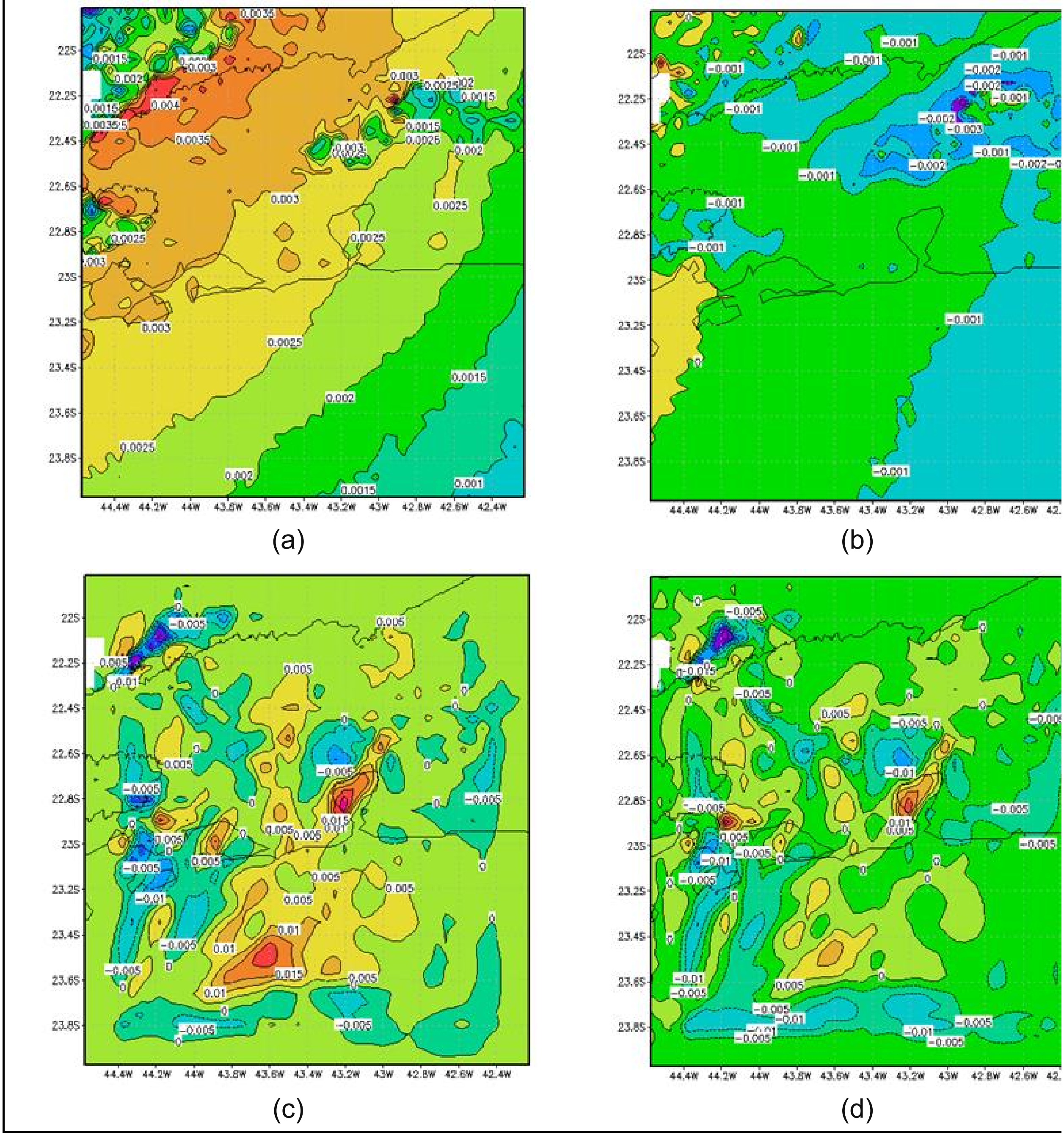
3 RESULTS AND DISCUSSION

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

Data assimilation result for air temperature difference at 850 hPa is shown in Fig difference for the initial condition (Jan 1st, 2017 0Z) between experiment-(ii) and exper displayed in Figure 3a, and the difference experiment-(ii) and experiment-(iii) is in Figu 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 assimilatic The difference from the observation field mainly at the airport location and its su illustrates the smoothing. After 12 h of integration (Figures 3c and 3d), the differences both fields, but still the assimilation field presents less difference in comparison to the c The results from Figure 3 indicate that even a single temperature profile assimilation a timestep can positively impact the analysis field.

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



(a) (b)

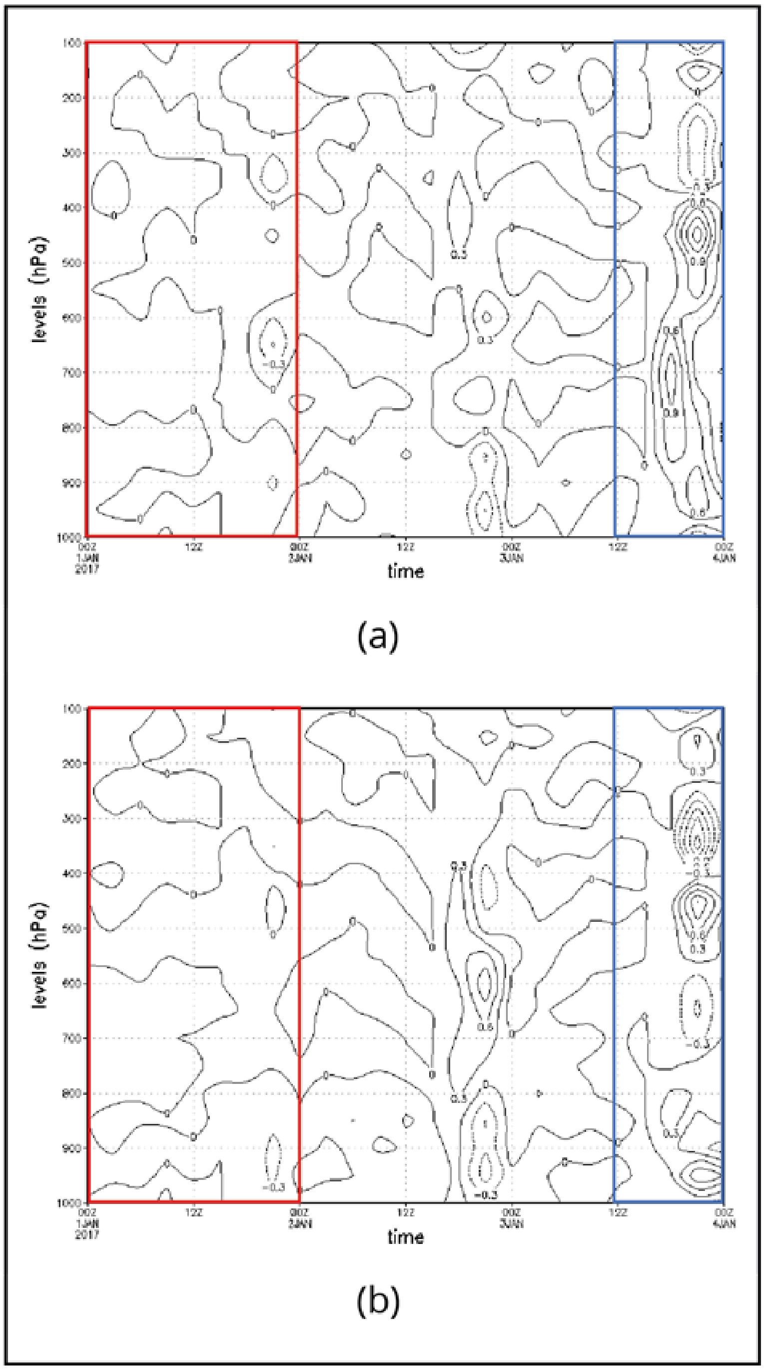
(c) (d)

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

The differences are quite similar for the first 12 h of forecast but they start thereafter. The red rectangle in Figure 4, after 24 h of integration experiment-(i), show different levels, from surface to upper atmosphere, while experiment-(iii) shows errors or surface. These results imply that experiment-(iii) is able to retain the observ characteristics in the short-range forecast period, the most critical for aviation purpos

integration approximates to 72 h of integration, the errors increase significantly both in e
(i) and experiment-(iii), as shown by the blue rectangle in Figure 4. However, it is possibl
the effect of the temperature profile assimilation at the initial timestep, since the
experiment-(iii) are smaller than the errors in experiment-(i).

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



4 CONCLUSION

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

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

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

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

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