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Data assimilation for an operational nowcasting tool

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Abstract

In the Basque Meteorology Agency (EUSKALMET), numerical weather prediction (NWP) models, adapted to the characteristics of the territory, are executed daily for many different purposes. In order to improve nowcasting and forecasting tasks, a WRFDA based data assimilation tool, was implemented. Assimilation of meteorological data combines the information provided by measured data with the information coming from numerical models, supplying the numerical representation more consistent with observations.

1. Introduction

Working with continuous assimilation-forecast cycles of the assimilation system allows constant updating of limited area forecasts, improving nowcasting tasks, especially severe weather events. Nowadays, the tool is being executed routinely in operational basis. The assimilation system includes several datasets from different sources (surface and upper air data), available in the forecast domains: RAOB soundings, SYNOP, Buoy, METAR, Automatic weather stations and Radar. The Basque Country Weather Mesonet, managed by EUSKALMET, is a high-density network with more than 100 Automatic Weather Stations (AWS) (see Figure 2), representative of a territory of complex orography such as the Basque Country (see Figure 1). Some observations registered in this network (ten-minute data) are included on the Data assimilation system. Euskalmet Radar is a METEOR 1500 Doppler Weather Radar with Dual polarization capabilities located on Kapildui mountain top (1174 m). Two volumetric scan are available each 10 minutes (range 300 km in reflectivity mode, range 150km in Doppler/Reflectivity mode). Reflectivity data is included in assimilation cycles.

The objective of this paper is to present the assimilation system included in the tool and to explain the results of some sensitivity experiments during high-impact weather events, to test the system's skill nowcasting extreme weather events. We present different validation analysis based on punctual and areal approaches. With a special focus on the use of datasets from the Basque Country Automatic Weather Station (AWS) Mesonetwork and the available radar data.

2. Data Assimilation. WRFDA

Data assimilation techniques allows combining observations with a field product of numerical NWP ("first guess" or background prediction) and with the associated error statistics, to provide an estimate of the state of the atmosphere or analysis.

In NWP it essential to know, as accurately as possible, the state of the atmosphere at the starting time of the forecast (initial conditions). A plausible way to improve the quality of initial conditions at the local level is by incorporating information from sufficiently dense observation networks of tested quality. This is achieved by applying different assimilation techniques, in this implementation is used the variational method known as 3DVAR incorporated in the WRFDA application module in WRF. The WRFDA module allows adjust the initial conditions by incorporating real observations within the initial field derived from the output of the synoptic or global model or previous WRF executions. In this way, is obtained initial quality data field that considers, in addition to the larger-scale information, the local information obtained from different observations. Assimilation is made through an iterative process that minimizes the values of a predefined cost function, allowing to quantify the variation of the first-guess field that generates the greatest possible improvement without generating an imbalance with the other variables of the model and with it the estimation of an initial field closer to reality.

Optimization of initial data allows to improve the numerical prediction in the very short term (nowcasting) in the hours close to the instant in which the data assimilation has been made. Assimilation is not just a punctual process that takes place at an initial instant of numerical prediction. Data assimilation allows, working with an assimilation cycle, to gradually introduce the observations of different hours in order to improve the results of the mesoscale prediction system in the instants of time closest to the recording of the observations, and therefore the whole prediction steps due to forecasts were initialized with higher quality initial and boundary conditions.

The WRFDA module includes tools to perform quality control on data with the possibility of being assimilated, such as the Observation Preprocessor (OBSPROC), by comparing the observed data with those present in the numerical data of the model (temperature, humidity, wind, etc.).

The data from the satellite (radiance) and meteorological radars (reflectivity and radial velocity) are not tested by this tool, since it does not have direct comparison with data included in the model.

Weather radar data requires a data transformation that complements the OBSPROC capabilities and enables the provision of as many observations as possible to the WRFDA. For this reason, the necessary tools for the pre-processing of radar data have been developed.

Fig. 1: Basque country location.

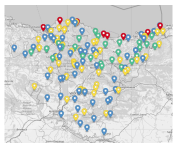

Fig. 2: Basque Country AWS network

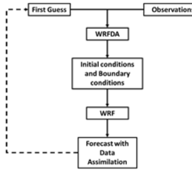

Fig. 3: Data assimilation-prediction rapid update cycles diagram

WRF	2019-2021	DJF	MAM	JJA	SON
C003	1.99	2.11	1.92	2	1.91
C016	2.03	2.37	1.76	2.05	1.86
C017	1.88	1.84	1.97	1.93	1.75
C023	2.21	2.36	2.11	2.23	2.12
C039	2.32	2.35	2.4	2.41	2.07
C043	2.23	2.4	2.16	2.24	2.09
C064	1.78	1.89	1.73	1.7	1.84
C079	2.25	2.58	2.1	2.07	2.28

WRFDA	2019-2021	DJF	MAM	JJA	SON
C003	1.74	1.88	1.66	1.65	1.78
C016	1.79	1.98	1.61	1.81	1.72
C017	1.57	1.47	1.61	1.61	1.55
C023	1.78	1.74	1.74	1.87	1.74
C039	1.53	1.57	1.57	1.58	1.39
C043	2.03	2.11	2	2.02	2
C064	1.7	1.75	1.77	1.62	1.66
C079	1.78	1.95	1.73	1.73	1.7

Table 1: RMSE for 2m-air temperature. WRF forecast (top).WRFDA system forecast (bottom)

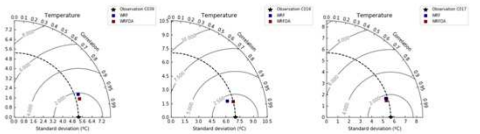

Fig. 4: Taylor Diagrams for 2m-air temperature WRF (blue) WRFDA (red). For Bilbao (left), Vitoria-Gasteiz(middle) and Donostia-San Sebastian (right) stations.

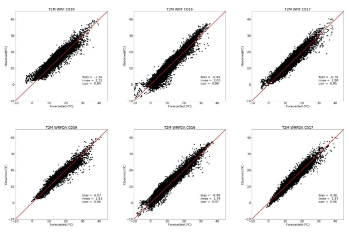

Fig. 4: 2m-air temperature Scatterplots. WRF (top) WRFDA (bottom). For Bilbao (left), Vitoria-Gasteiz(middle) and Donostia-San Sebastian (right) stations.

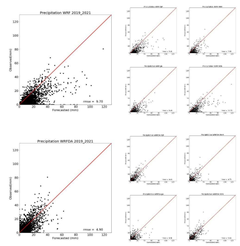

Fig. 5: Daily precipitation scatterplots. WRF (top) WRFDA (bottom). In the left for the entire period. In the right by season of the year (DJF,MAM,JJA and SON)

3. Data and Methodology

Several datasets from different sources (surface and upper air data), available in the execution time are used in the assimilation system. The Basque Country Weather Mesonet, is a high-density network with more than 100 Automatic Weather Stations (AWS), representative of a territory of complex orography such as the Basque Country (see figure 2 and more details in Gaztelumendi et al 2018). Another surface data, METAR (hourly or 30-minute data) and SYNOP (3-6 hour data) in Basque country and surrounding areas, up to 7-9 locations, Basque country Buoys and Santander RAOB operational sounding (00 and 12 Z). Basque meteorology agency weather radar data is pre-processed for inclusion in the system. The preprocessing system works with raw radar data, in the first steps of development, an application for using use PPI imagery was developed.

The Basque country is located in the north of Iberian Peninsula, and it is a region of complex topography. The Kapildui weather radar is located inland, on the top of a mountain (Kapildui), 1000 meters height a.s.l. and 100 km far from the coast. The system is a Dual Doppler Weather Radar, Meteor 1500C of SelexGematronik (Aranda et al 2006, Selex-Gematronik, 2005). The system gives information of the reflectivity, differential reflectivity and wind field every 10 minutes. For that purpose, the system operates with two volumetric scans (Gaztelumendi et al 2006).

Raw volumetric data, generated by Rainbow software, of the radar. Metadata files that contain reflectivity and radial velocity data of different elevation angles.

Pre-processing tools have been developed to extract 3D radar reflectivity and radial velocity data. Python scripts have been developed to process data in binary format. In the case of volumetric data, we have worked with the open source wradlib library in Python.

Anomalous data is filtered as a ground clutter (reflectivities generated by the terrain) and the resolution of the radar data is adapted and formatted to the resolution and the data format of the data assimilation system (Maruri et al 2008).

The temporal resolution is 10 minutes, the spatial resolution of the radar data is 250 m for the 100 km radius scan and 15 elevation angles are available.

The nowcasting tool consists of, among others, a weather forecasting system working with data assimilation-prediction rapid update cycles (RUC) based on WRFDA (WRF assimilation module) and high resolution WRF simulations (see Figure 3).

The meteorological forcing to generate first initial and boundary conditions come from the GFS 0.25º (approx. 25 km) with forecast data up to 24 hours and hourly granularity. The horizontal resolution for WRFDA and WRF runs is 5 km.

The system is based on assimilation cycles of at least 60 minutes. Every 60 minutes, data is assimilated into the system and forecasts up to 6 hours and hourly granularity forecast are generated. Daily, the cycles begin with the execution corresponding to 18Z. From GFS data, the boundary conditions (BC) for the next 24 hours and the initial conditions (IC) for 18Z are generated. Once each cycle is finished BC are updated and new IC are created. This is made by assimilating observations in fields predicted by a previous run, field that are used as the first guess data. The assimilation system runs generating numerical forecast data required for nowcasting and short-term weather forecasting tasks. For radar data, the intra-hour assimilation viability is being analysed, to be applied in summer convective situations.

The execution of each cycle begins when the data is available, both from the METAR locations and the Basque Country agency AWS network. If they are available for that cycle RAOB and SYNOP are also incorporated.

4. Results and Discussion

To estimate the ability of the data assimilation-based system, we proceeded to the validation of two operational forecasting systems. Working with similar configurations and parameterizations, using both GFS as meteorological forcing. One of them working with 3-hour data assimilation-prediction cycles. Hourly 2m temperature and daily accumulated precipitation are analyzed. The study period runs from June 2019 to July 2021. Time series of predicted data were extracted for representative meteorological stations of the study area. Error statistics are calculated and various graphics such as Taylor diagrams and scatterplots have been made.

In the case of temperature forecast a rmse error decrease is observed when system with data assimilation is used. The calculated rmse shows values lower than 2. The reduction of the error round the 15% for the analyzed stations (see Table 1).

The application of the system with data assimilation corrects the underestimation of the maximum and minimum values of the study period (see Figure 4). This correction is more evident in the case of the minimums at different locations, in Bilbao and San Sebastián located in coastal areas and in Vitoria-Gasteiz, which is located far from the coast and with a significant number of temperatures below zero. The dispersion of the data decreases throughout the observed temperature range.

In the case of the daily precipitation forecast, the results that have been analyzed in this section correspond to the operational forecast system with data assimilation, which currently does not include radar data.

In the case of accumulated daily precipitation, a notable improvement is observed, comparing the two forecasting systems, when data assimilation is used in the forecast (see Figure 5). Most evident in the range from 20 to 60 mm observed data.

The rmse reduction of the amount of precipitation is in the range of 40-60%

To perform a better analysis and detect trends, the data has been categorized according to the season of the year.

The overestimation of the WRF is evident for Winter (DJF) and Autumn (SON) periods. The system with data assimilation significantly reduces that overestimation in all seasons. Although, in the maximums values registered in Spring (MAM) and Summer (JJA) seasons, there is an increase of underestimation more evident in the summer season.

There is an underestimation for the cases with higher accumulated precipitation that we intend to correct with the assimilation of radar data without rejecting the use of other tools.

5. Remarks and conclusions

Optimization of initial data allows to improve the numerical prediction in the very short term (nowcasting) in the hours close to the instant in which the data assimilation has been made.

In the application of operational systems with data assimilation, an improvement is observed in the forecast of rain accumulations even without radar data assimilation.

Work with assimilation cycles improve not just the single forecast closest to the assimilation times but also the rest of the forecasts steps because the forecasts were initialized with higher quality initial and boundary conditions.

Techniques based on data assimilation rapid update cycles should be combined with others based on Lagrangian advection to improve the nowcasting of convective adverse precipitation events.

For radar data, the intra-hour assimilation viability will be analyzed, to be applied in adverse summer convective situations.

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