SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2021
Project Title:	Investigating the impact of 3-hourly cycling 3D-VAR with GNSS measurements in Weather Research and Forecasting (WRF) model
Computer Project Account:	spitmazz
Principal Investigator(s):	Vincenzo Mazzarella
Affiliation:	CIMA Research Foundation – Savona, Italy
Name of ECMWF scientist(s) collaborating to the project (if applicable)	……………………………………………………….…… ……………………………………………………….……
Start date of the project:	March 3, 2021
Expected end date:	December 31, 2022

Computer resources allocated/used for the current year and the previous one

(if applicable)
Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	950000	950000	950000	384.584
Data storage capacity	(Gbytes)	1000	500	1000	350

Summary of project objectives (10 lines max)

This special project aims to investigate the impact of the different types of GNSS data in the simulation of several convective events within the framework of the SINOPTICA project. To this purpose the GNSS Radio Occultation (RO), GNSS Zenith Total Delay (ZTD) and GNSS Precipitable Water Vapor (PWV) in combination with the weather radar reflectivity are assimilated in Weather Research and Forecasting (WRF) model using a 3-hourly cycling 3D-Var.

The performance of the different experiments will be evaluated in terms of Vertically Integrated Liquid (VIL) adopting a spatial verification technique. This method identifies the spatial patterns (or objects) in observed/predicted precipitation fields and compare them through a few attributes, e.g., distance between centroid, area of intersection, orientation, that are calculated based on fuzzy logic.

Summary of problems encountered (10 lines max)

Nothing to report. Due to the small amount of SBU, it was not possible to perform further simulations

Summary of plans for the continuation of the project (10 lines max)

The next experiments will be devoted to the assimilation of PWV data in combination with radar reflectivity. The impact of PWV will be evaluated in terms of VIL and VIL density by using the Method for Object-Based Diagnostic Evaluation (MODE) tool developed by NCAR.

List of publications/reports from the project with complete references

Presentations

Mazzarella, V., Milelli, M., Lagasio, M., Poletti, L., Biondi, R., Realini, E., Federico, S., Torcasio, R. C., Kerschbaum, M., Llasat, M. C., Rigo, T., Esbrí, L., Temme, M.-M., Gluchshenko, O., Temme, A., Nöhren, L., and Parodi, A.: Data assimilation and nowcasting of severe weather for air traffic management purposes, EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022, EGU22-2823, https://doi.org/10.5194/egusphere-egu22-2823, 2022.

Mazzarella, V., Milelli, M., Lagasio, M., Poletti, L., Biondi, R., Realini, E., Federico, S., Torcasio, R. C., Kerschbaum, M., Llasat, M. C., Rigo, T., Esbrí, L., Temme, M.-M., Gluchshenko, O., Temme, A., Nöhren, L., and Parodi, A.: How can numerical weather prediction support the ATM activity during severe weather events?, Living Planet Symposium 2022, Bonn, Germany, 23–27 May 2022, 2022.

Conference paper

Parodi, A., Mazzarella, V., Milelli, M., Lagasio, M., Realini, E., Federico S., Torcasio R. C., Kerschbaum, M., Llasat M. C., Rigo, T., Esbrì, L., Temme, M. M., Gluchshenko, O., Temme, A., Noehren, L., Biondi R., A NOWCASTING ALGORITHM OF SEVERE WEATHER EVENTS AT LOCAL SPATIAL SCALE: THE VENEZIA CASE STUDY, International Geoscience and Remote Sensing Symposium (IGARSS) Proceedings, 2022.

Summary of results

If submitted **during the first project year**, please summarise the results achieved during the period from the project start to June of the current year. A few paragraphs might be sufficient. If submitted **during the second project year**, this summary should be more detailed and cover the period from the project start. The length, at most 8 pages, should reflect the complexity of the project. Alternatively, it could be replaced by a short summary plus an existing scientific report on the project attached to this document. If submitted **during the third project year**, please summarise the results achieved during the period from July of the previous year to June of the current year. A few paragraphs might be sufficient.

As part of the SINOPTICA project, several experiments were carried out by assimilating the radar reflectivity acquired by the national radar network with the ZTD data from the GNSS network in combination with radar data using Weather Research and Forecasting (WRF) model.

WRF is a next-generation mesoscale atmospheric model, developed at National Center for Atmospheric Research (NCAR), which uses a fully compressible non-hydrostatic set of equations, Arakawa C-grid staggering, terrain-following hydrostatic-pressure vertical coordinates, and multiple-nesting capabilities. Three domains in two-way nesting with respectively 22.5 km (domain D1, 216 × 191 grid points) 7.5 km (domain D2, 523 × 448 grid points) and 2.5 km (domain D3, 430 x 469 grid points) grid spacing, are adopted for the numerical experiments (Fig. 1). For each domain, 50 unequally spaced vertical levels are used, from ground level up to 50 hPa. The simulations were carried out for a severe weather event that caused inconvenience to air traffic and the closure of the airport. The case study, occurred on 11 May 2019, was characterized by a squall line that hit the Malpensa airport (hereafter MXP). The thunderstorm produced a large amount of hail on the runways that caused the closure of the airport for 40 minutes and some flights delay. In addition, nine planes were diverted to other airports. The heavy precipitation also produced several floods in the city of Milan, where some underpasses and metro stations were closed.

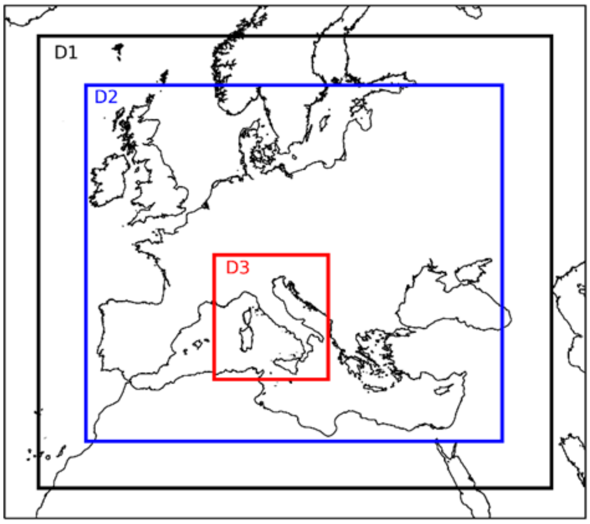

Figure 1: WRF domains D1 (black), D2 (blue) and D3(red) with a spatial resolution of 22.5 km, 7.5 km and 2.5 km, respectively.

For this case study, the reflectivity CAPPI at 2 km, 3 km, and 5 km, have been assimilated from 06UTC to 12UTC every three hours, then the simulations run for 6h in free forecast mode. The radar data play a key role in adjusting the initial conditions considering the moderate precipitation in north-eastern Sardinia and the early convective cells in Po valley and central Italy. Moreover, around 460 GNSS-ZTD observations have been assimilated to further improve the temperature and water vapor fields at the initial time. To analyse the impacts of assimilation, a qualitative comparison between the maximum of observed VIL (Fig. 2d), over the period 14:30UTC-15:30UTC, when the squall line affected MXP, and the predicted VIL has been performed. The RDR experiment (Fig. 2b) misses the correct timing and localization of convective cell, in fact the peak of VIL occurred about 30 km East of Malpensa airport. The use of ZTD and reflectivity (RDR+GNSS) improves the VIL forecast in terms of intensity compared to CTL (Fig. 2a) and moves the cell closer to the airport (Fig. 2c).

To strengthen the statistical analysis, we have also performed an object-based comparison considering the maximum of VIL over the same interval (14:30 UTC-15:30 UTC). To this purpose, the Method for Object-based Diagnosis and Evaluation (MODE) tool has been used with a VIL threshold of 10 kg/m^2, precursor of intense convective events. By applying a filter function to the raw data field, the tool is able to identify the objects (convective cells) and compare them in terms forecast area, observed area, intersection area, centroid distance and interest. The latter is a parameter that summarize all attributes into a single number. The results are reported in Table 1, while a qualitative comparison between the observed and predicted objects is shown in Figure 3.

The CTL simulation (without data assimilation) anticipates the triggering of the squall line, in fact the forecasted object appears few kilometres further east of that predicted (Fig. 3a). In addition, the experiment shows the lowest interest value and a significant distance between the centroids (156 km). On the other hand, the experiment with radar data (RDR) shows a reduction of the overestimation in the eastern area of Malpensa airport and a higher interest value compared to the CTL, pointing out the positive impact of radar data. However, also RDR simulation does not correct the timing (Fig. 3b); the convective cell hit the MXP about 1h before. Finally, the simulation with ZTD in combination with radar data (RDR+GNSS) further improves the prediction of the cell in terms of intensity (Fig. 3c) compared to the RDR. The interest value, instead, does not show any significant variations in comparison with RDR but the centroid distance reduces from 109.65 km to 106.37 km (Fig. 3c) and the intersection area, compared to CTL, increase from 262 km^2 to 206 km^2. The results suggest that the assimilation of ZTD produces a slight improvement in the prediction of VIL for this case study. In the framework of the SINOPTICA project, however, the performance of 3D-Var with ZTD and radar data has been also evaluated for two more convective events occurred in summer season, the results of which are discussed in a under review paper.

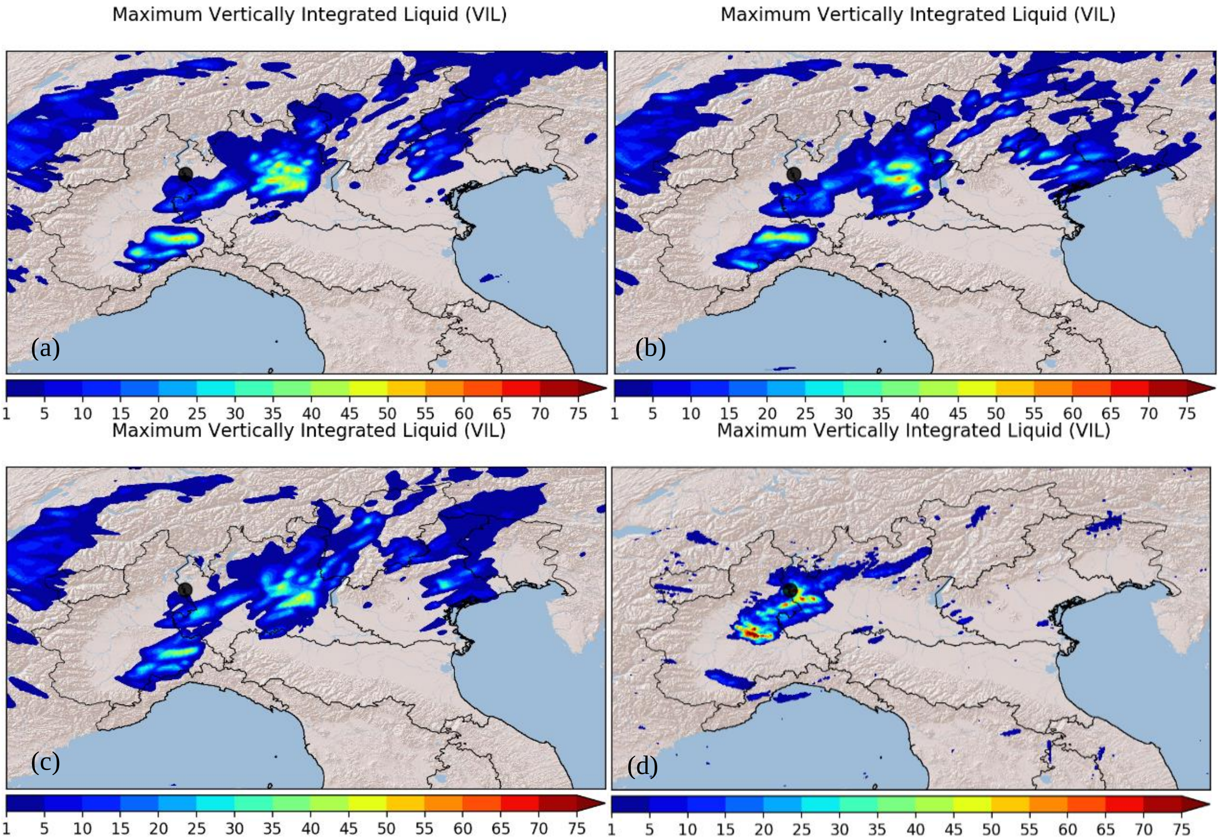

Figure 2: Maximum VIL (mm) calculated over the interval 14:30 UTC - 15:30 UTC from the simulations CTL(a), RDR (b), RDR+GNSS (c) and observed (d).

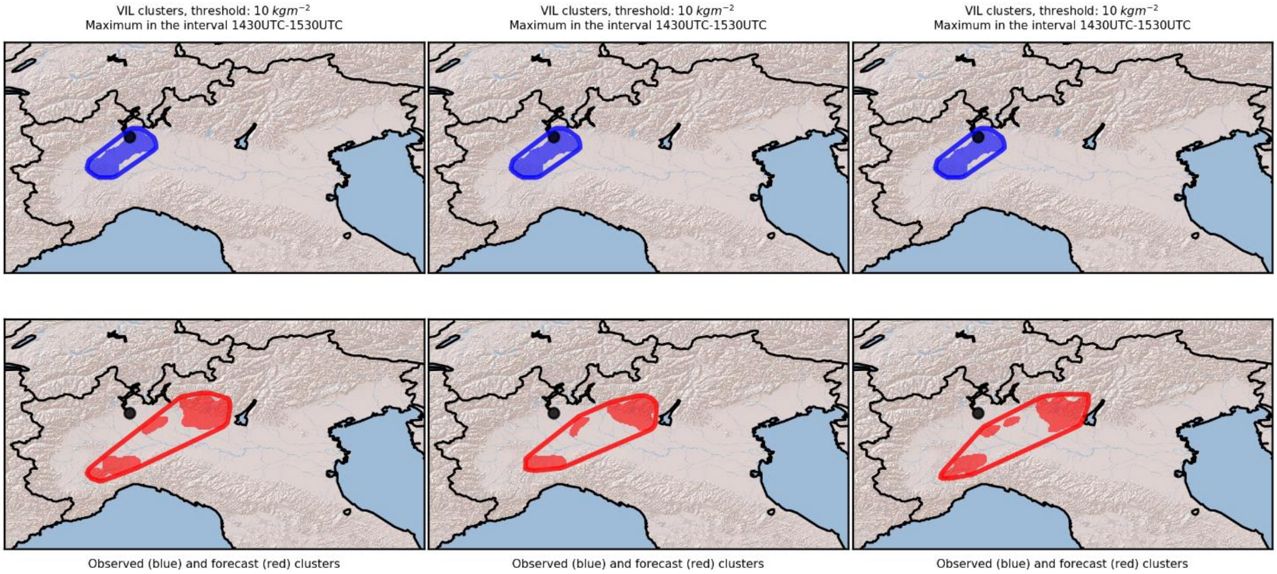

Figure 3: Comparison between the observed (blue) and predicted (red) cluster objects identified by using a VIL threshold of 10 kg/m^2 for the simulations: CTL (left), RDR (middle) and RDR+GNSS (right),

Table 1: Spatial attributes calculated using the MODE tool for a VIL threshold of 10 kg/m^2.

Experiment	**Centroid distance (km)**	**Observed area (km^2)**	**Forecast area (km^2)**	**Intersection area (km^2)**	**Interest**
CTL	93.62	5462.5	9243	206	0.78
RDR	109.65	5462.5	7075	162	0.80
RDR+GNSS	106.37	5462.5	8631	262	0.80