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 radar data assimilation using 3D-Var, 4D-Var and ensemble Kalman Filter into the high-resolution weather forecast
Computer Project Account:	Spitferr
Principal Investigator(s):	Prof. Rossella Ferretti
Affiliation:	CETEMPS – Department of Physical and Chemical Sciences, University of L'Aquila. Italy
Name of ECMWF scientist(s) collaborating to the project (if applicable)	……………………………………………………………… ………………………………………………………………
Start date of the project:	March 19, 2019
Expected end date:	December 31, 2021

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)	10000000	9184704.89	10000000	1261402.15
Data storage capacity	(Gbytes)	20000	8330	20000	10000

Summary of project objectives (10 lines max)

The impact of 3D-Var, 4D-Var, ENKF assimilation methods are evaluated in terms of Short term Quantitative Precipitation Forecasts (SQPF). In this context, three different approaches are used: traditional, grid to grid and spatial. The traditional approach compares the observed and forecasted rain at the exact location through several statistical indexes, derived from a contingency table. The second approach compares the rainfall fields using a neighbourhood technique. And lastly, the spatial approach, identifies the spatial patterns (or objects) in observed/predicted precipitation fields and compare them through a number of attributes, e.g., distance between centroid, area of intersection, orientation, that are calculated using a fuzzy logic-based approach. The aforementioned statistical analyses are performed with the Model Evaluation Tools (MET) verification package (Brown et al. 2009), developed by the National Center for Atmospheric Research (NCAR) Developmental Testbed Center (DTC).

Summary of problems encountered (10 lines max)

WRF and WRFDA works properly.

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

Data Assimilation Research Testbed (DART) will be compiled on CRAY HPC to run the new simulations with ENKF. This method will be applied to a previous ensemble forecast, assimilating radar data and conventional observations for several hours ahead of the event with the aim of updating the ensemble members. Finally, the comparison between the three assimilation techniques, namely 3D-Var, 4D-Var and ENKF will be completed.

List of publications/reports from the project with complete references

Mazzarella, V., Ferretti, R., Picciotti, E., and Marzano, F. S.: Investigating 3D and 4D Variational Rapid-Update-Cycling Assimilation of Weather Radar Reflectivity for a Flash Flood Event in Central Italy, Nat. Hazards Earth Syst. Sci. Discuss. [preprint], https://doi.org/10.5194/nhess-2020-406, in review, 2021.

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.

This year has been devoted to the comparison between a cycling 3D-VAR and 4D-Var data assimilation methods using WRFDA. This activity aims to investigate the impact of these techniques in rainfall forecast over a complex orography region. Nowadays, the use of 4D-VAR assimilation technique has been investigated in several scientific papers showing positive results in the estimation of precipitation but the need to resolve the tangent linear and adjoint model makes this method computationally too expensive. Hence, it is used operationally only in large forecast centres. To the aim of exploring a more affordable method, a cycling approach is also adopted in 4D-Var method, to reduce the computational resources. A preliminary comparison is performed for a severe weather event occurred on 3 May 2018 in Central Italy. A cut-off low (992 hPa) located in western side of Sicily region (Southern Italy) produced a strong south easterly flow over central Italy that carried moist and warm air mass toward Adriatic regions. The interaction between this flow and the Apennines Mountain chain produced moderate and heavy rainfall along the Adriatic coast with rainfall maxima that reached 60mm/12h in Abruzzo region (Fig. 1).

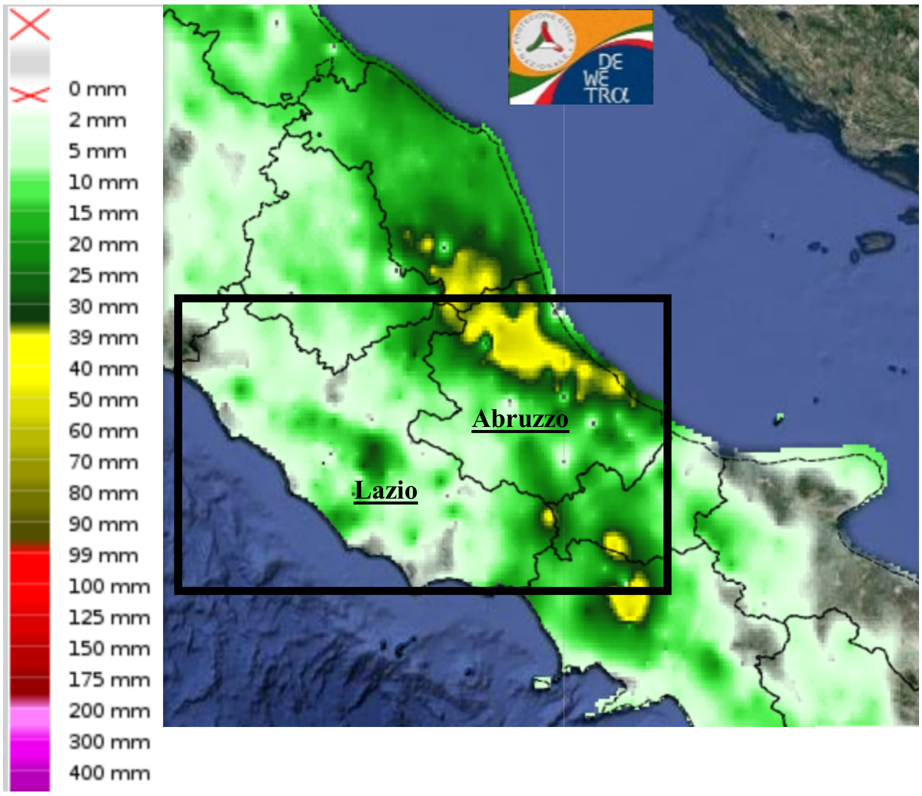

Figure 1: Precipitation amount (mm) from 0900 to 2100 UTC on May 3, 2018. Courtesy of Italian Civil Protection Department, DEWETRA platform.

A two-way nesting configuration with two domains is used for this study: the mother domain with 379x431 grid points, covers the Italian peninsula with a horizontal resolution of 3 km, while the inner domain (340x319 grid points) is centred over the Abruzzo region (central Italy) with a grid spacing of 1 km. Both domains adopt 40 vertical levels from the ground up 100 hPa. Because of the high spatial resolution, the convection is explicitly resolved. The same physical parameterizations used by the Center of Excellence in Telesensing of Environment and Model Prediction of Severe Events (CETEMPS) meteorological–hydrological forecast system, are set for this work (Ferretti et al., 2014). A total of five experiments are carried out to evaluate the impact of 3D/4D-Var in cycling mode. All simulations are initialized using ECMWF analysis and forecast and started at 0000 UTC on 3 May 2018 and last for 24 hours. Both 3D-Var and 4D-Var are applied every hour in cycling mode from 0000 UTC to 0300 UTC assimilating the CAPPI reflectivity data at 2000, 3000 and 5000 m MSL. The same number of observations has been assimilated for both 3D-Var and 4D-Var simulations, considering a 10-minute assimilation window. More specifically the CAPPI are assimilated at 0000 UTC, 0100 UTC, 0200 UTC, 0300 UTC and at 0010 UTC, 0110 UTC, 0210 UTC and 0310 UTC.

The simulations are evaluated in Lazio and Abruzzo subregion (Fig. 1, black rectangle) because these are the regions where relevant accumulated precipitations was recorded. To compare the 4D/3D-Var experiments in warm/cold start and their ability to reproduce the precipitation pattern, the Fractions Skill Score (FSS) has been calculated considering the precipitation accumulated over three specified time periods: 1, 3 and 6 hours, respectively.

The FSS time series for the hourly precipitation highlights the positive impact of radar data for both 3D-Var and 4D-Var assimilation methods compared to CTL. The benefit of using a cycling assimilation is clearly shown in the results for both light (Fig. 2a) and moderate precipitation (Fig. 2b). However, the impact reduces in the last hours of the simulation when all experiments converge to the CTL. Conversely, the poor amount of precipitation at the start time, reduce the impact of both assimilation methods at the start time for 1mm h^{-1} threshold.
The results for 3 hours precipitation for all thresholds confirm the benefits of assimilating reflectivity data (Figs. 3a and 3b). In this regard, the cycling 4D-Var has a greater impact than 3D-Var experiments and consequently higher FSS value. More specifically, the cold start initializations for cycling both 4D-Var and 3D-Var show an improvement in terms of SQPF compared to CTL at beginning of analysis, while the experiments in warm start perform better after few hours. This behaviour is probably caused by a slightly unbalanced initial field for the warm start simulations.
For what concerns the 6-hourly precipitation, the FSS for 7 mm $6h^{-1}$ threshold confirms the improvement of warm start simulations compared to CTL and cold initialization (Fig. 4a). The CYC4DVAR_warm clearly displays the greatest FSS values at 10mm thresholds, pointing out the positive impact of radar reflectivity (Fig. 4b). Also, the 4D-Var in cold start and the 3D-Var with a warm initialization produce an improvement in QPF although it is smaller than CYC4DVAR_warm. On the other hand, the CYC3DVAR_cold shows a worsening in FSS.
For further details about the 3D/4DVar comparison see the reference in the previous section.

In the second part of this year, we will perform the experiments with ENKF to finalize the statistical analysis.

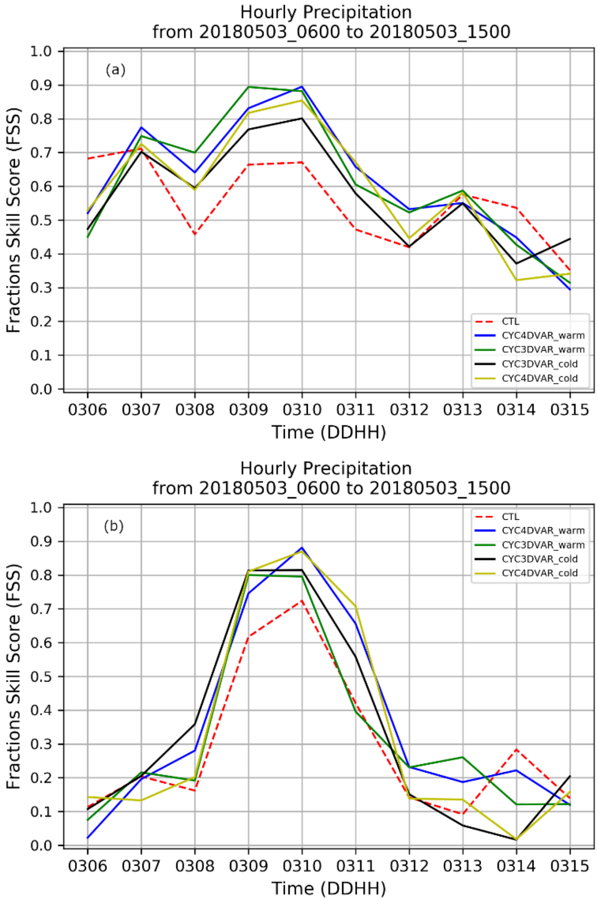

Figure 2: Evolution of FSS calculated in Lazio-Abruzzo subregion for the threshold values: 1mm/h (a) and 3mm/h (b), respectively.

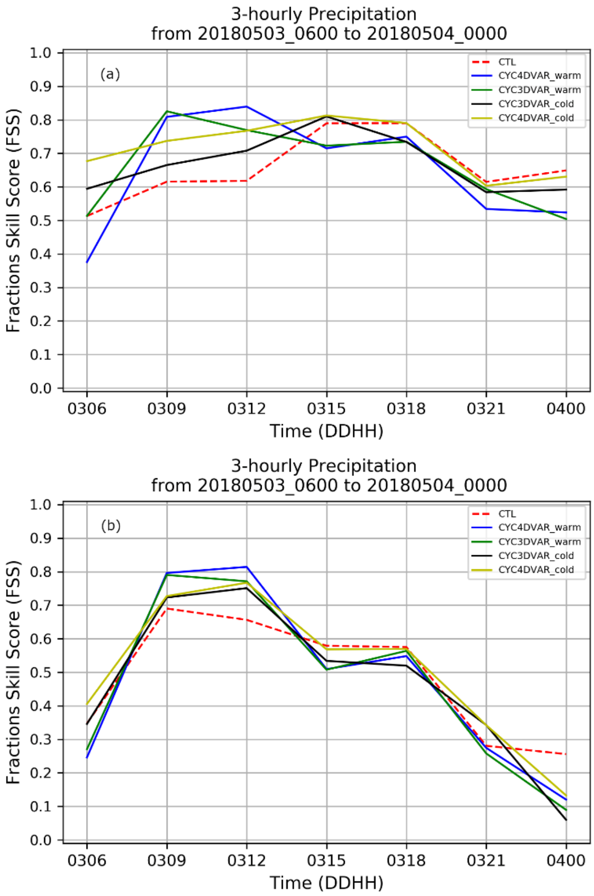

Figure 3: Figure 2: Evolution of FSS calculated in Lazio-Abruzzo subregion for the threshold values: 1mm/3h (a) and 3mm/3h (b), respectively.

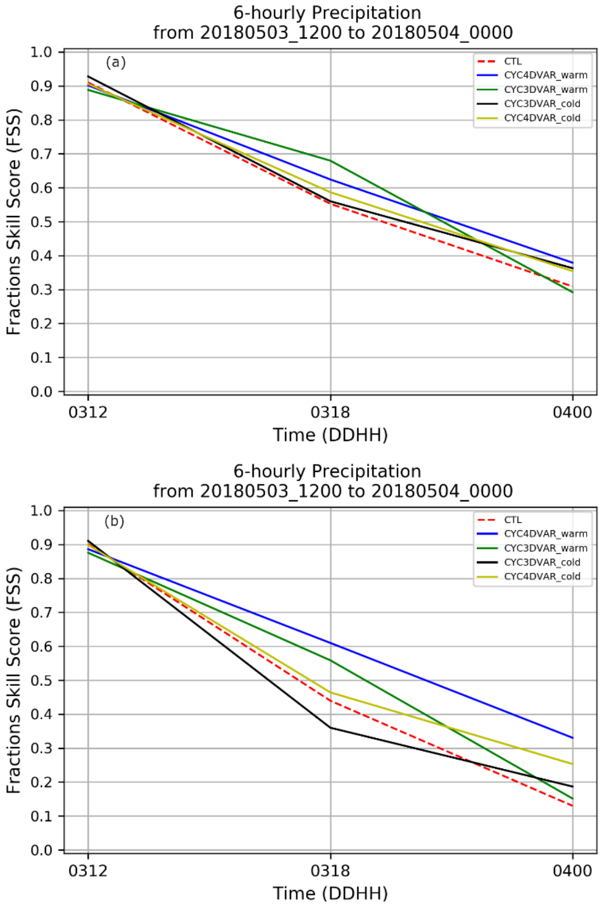

Figure 4: Evolution of FSS calculated in Lazio-Abruzzo subregion for the threshold values: 7mm/6h (a) and 10mm/6h (b), respectively.