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	……………2024……………………….……
Project Title:	Improvement on NWP prediction at the short-range for high impact meteorological events
Computer Project Account:	………SPITFEDE…………………….……
Principal Investigator(s):	……Stefano Federico (cm4)
	……………………………………………………….……
Affiliation:	…… CNR-ISAC (National Research Council – Institute of Atmospheric Sciences and Climate)...
	…….……
Name of ECMWF scientist(s) collaborating to the project (if applicable)	……………………………………………………….……
	……………………………………………………….……
Start date of the project:	……01/01/2024…….……
Expected end date:	……31/12/2026………………………………….……

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)	20000000	16500000	20000000	13400000
Data storage capacity	(Gbytes)	100000	84000	100000	77774

Summary of project objectives (10 lines max)

The main focus is to show the potential of data assimilation at improving the forecast of intense and severe meteorological events at the short-range (0-6h) and at the regional/local scale (meso $\alpha-\beta$). Four main sources of data are considered: lightning, radar reflectivity, WInd VElocity Radar Nephoscope (WIVERN) pseudo-doppler, and GNSS (both ZTD and slant path). We investigate two different time ranges 0-3h and 3-6h after the last data assimilation time and we use 3DVAR or nudging for data assimilation. For WIVERN DA longer time ranges are considered. The model performance is evaluated against a dense network of raingauges homogeneously spread over Italy or with other observations available.

Summary of problems encountered (10 lines max)

No specific problems were encountered in the period. This year, however, a larger number of simulations were required compared to those budgeted at the start of the study. Specifically, to study in more detail the impact of WIVERN data assimilation (DA) on the prediction of the Medicane Ianos, we compared WIVERN DA with other data sources (AMV, ASCAT and RAOB). Comparison is still in progress and the SBU units available for the year, will end before fall. A request of additional SBU amount will be placed by the end of June.

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

During the following of the project, we will investigate the impact of the assimilation of GNSS-STD (slant total delay) and lightning data assimilation from MTG-LI. Possibly, more simulations of WIVERN DA will be required, if WIVERN is accepted for the final launch.

List of publications/reports from the project with complete references

There is one publication prepared using the resources of this project which is submitted to WCD (https://wcd.copernicus.org) but it is in the first stages of submission. A second paper, considering the assimilation of GNSS-ZTD for convective events over Italy is in preparation.

Summary of results

-Wind Velocity Radar Nephoscope (WIVERN) data assimilation

WIVERN is a candidate for ESA Earth Explorer 11. If accepted for launch it will be the first satellite observing 3D in cloud winds at the global scale. With its 800 km swath it will provide a large number of observations for data assimilation in NWP models. In this work we quantified the potential of WIVERN winds data assimilation for the outstanding case of the Medicane Ianos, occurred in mid-September 2020.

In this work we use the WRF model 4.1 with 400 grid points in both WE and SN directions and 55 vertical levels from the surface up to 50 hPa.

The model horizontal resolution is 4 km in both WE and SN directions. The physical parameterizations of the model include the Thompson microphysics scheme (Thompson et al. (2008)), the Mellor-Yamada-Janjic turbulent kinetic energy boundary layer scheme (Janjic (1994)). Dudhia scheme (Dudhia (1989)) and the rapid radiative transfer model (RRTM, Mlawer et al. (1997)) are used as shortwave and longwave radiation schemes respectively. Initial and boundary conditions are taken from by the European Centre for Medium-range Weather Forecast - Ensemble Prediction System (ECMWF-EPS) of the Integrated Forecasting System (IFS) run issued at 12:00 UTC on 16 September 2020. The ECMWF-EPS has an unperturbed member and 50 perturbed members, and we have a total of 51 run of WRF model nested in the ECMWF-IFS-EPS initial and boundary conditions. We use the EDA (Ensemble Data Assimilation) approach, in which 51 members of the WRF ensemble are generated starting from different initial condition provided by ECMWF-IFS-EPS. The ensemble forecast starts at 12 UTC on 16 September 2020 and ends at 06 UTC on 18 September 2020, when Ianos made its landfall over the western Greek coasts.

Two 3DVar assimilation cycles are considered: 3h (WIV_3h) and 24h (WIV_24h). The first case, with very frequent data assimilation cycles, is used to verify the proper setting of the 3DVar and WRF model; it could represent a realistic condition if a constellation of four WIVERN satellites were operated. The second case corresponds to the realistic situation in which WIVERN samples the Ianos storm once.

To generate WIVERN pseudo-observations we adopt the following steps: a) we first generated an ensemble of the WRF model nested in the ECMWF-EPS of the IFS and starting at 12 UTC on the 16 September 2020 (CTRL ensemble); b) From the CTRL ensemble we select a representative member, which is the member whose trajectory is in best agreement with the best estimate of the Ianos trajectory provided by Flaounas et al. (2023); c) We generate pseudo-observations of WIVERN by the simulator of Battaglia et al. (2022) applied to the output of the representative member. One WIVERN pseudo-observation is generated every 3h from 15 UTC on 16 September to 09 UTC on 18 September. Pseudo-observations are the winds along the Line of Sight (LOS).

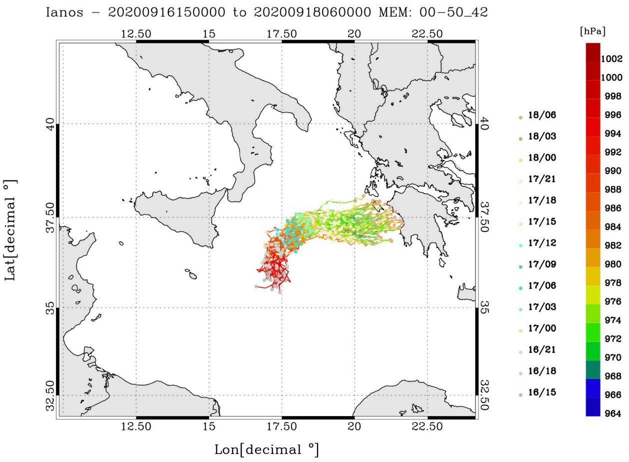

Figure 1: Trajectories followed by the ensemble members of the WRF control ensemble.

Figure 1 shows the 51 trajectories of the Medicane Ianos simulated by the WRF runs nested in the 51 members of the ECMWF-EPS. The trajectory is defined considering the positions of the minimum sea-level pressure around the area of the Medicane. The color bar corresponds to the color of the segments joining two dots and indicates the pressure at the initial point of the segment (there are three segments between two dots). The dots are plotted every 3h and correspond to different times. As expected, the trajectories of the Medicane start close to each other and tend to separate in the following hours, as the small differences among the members at the initial time are amplified by the evolution of the atmospheric flow.

The observed trajectory of Ianos is shown in Figure 2 (right panel, red curve). Among the members of the WRF ensemble, the member 42 minimizes the distance with the observed trajectory and is the representative member. The landfall of Ianos is predicted between the islands of Kephalonia and Zakhyntos. Starting from member 42, pseudo-observations of WIVERN were generated every 3h hours applying the WIVERN simulator (Battaglia et al., 2022) to the WRF output, and pseudo-observations were assimilated into the other ensemble members. Two experiments were considered WIV_3h and WIV_24h. . In WIV_3h we assimilated WIVERN pseudo-observations every 3h from 15 UTC on 16 September to 03 UTC on 18 September, while in WIV_24h we assimilated WIVERN pseudo-observations at 12 UTC on 17 September. In both cases, it is assumed that Ianos is well sampled by WIVERN and that the center of the storm is (nearly) at the center of the scene.

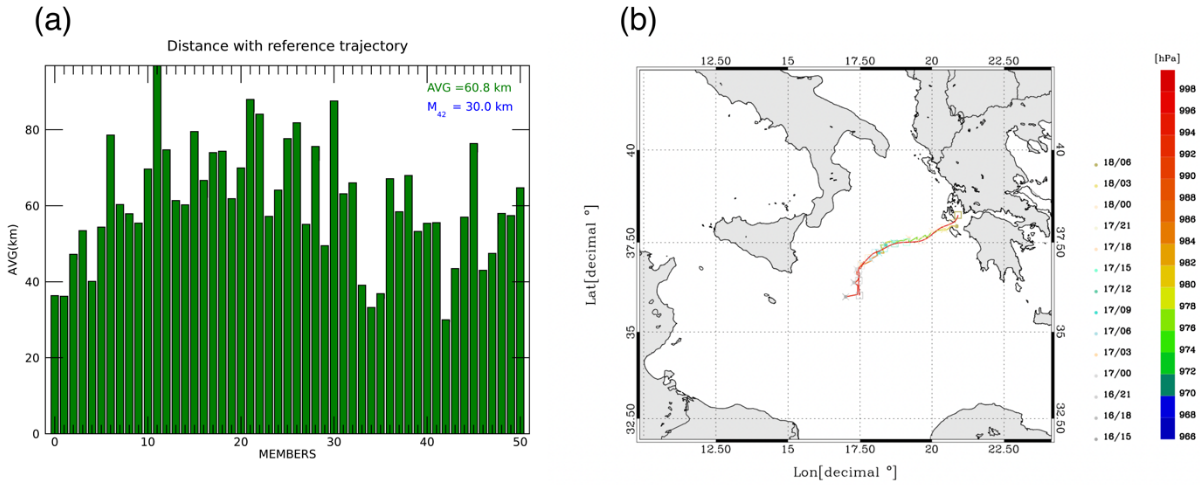

Figure 2: Histogram of the distances between the WRF ensemble members at the Ianos best estimated trajectory. The average distance is 60.8 km, while the minimum distance is achieved by the member 42 (30.0 km).

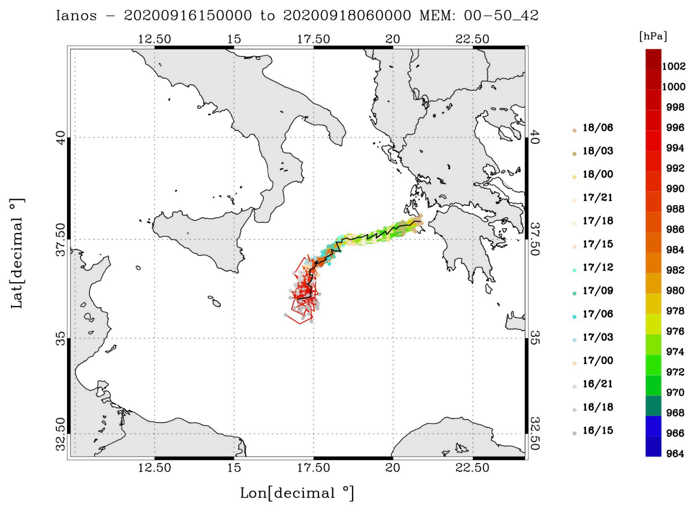

Figure 3: Trajectory followed by the WRF ensemble when WIVERN DA is applied every 3 h. The member in black is the reference member 42.

The assimilation of WIVERN winds every 3 h, shown in Figure 3, has a very important impact on the Ianos trajectory. First, all the trajectories are now focused along the trajectory of the reference member 42, which is shown in black and without dots for clarity. Second, the landfall occurs in the northern part of the Peloponnese with many members crossing the Zakynthos Island or passing in the gap between the Kefalonia and Zakynthos islands. The distance of the ensemble from the member 42 is 14.9 km, to be compared with 62.5 km of the CTRL ensemble.

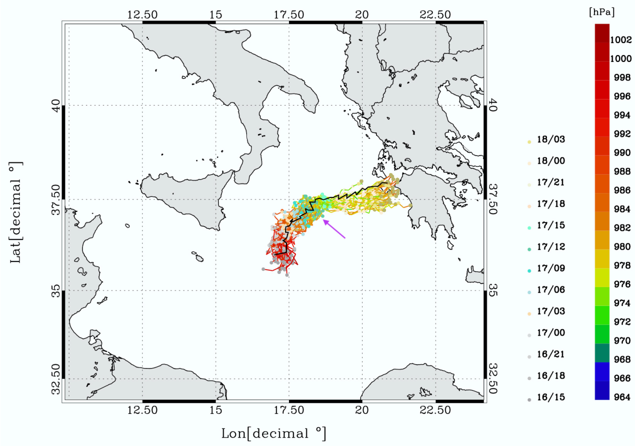

Figure 4: Trajectory followed by the WRF ensemble when WIVERN DA is applied one time at 12 UTC on 17 September 2020. The member in black is the reference member 42.

The trajectories of WIV_24h ensemble are shown in Figure 4. From the comparison of Figure 4 and Figure 1 it is apparent the positive impact of WIVERN DA on the forecast of the Ianos trajectory. In particular, the CTRL forecast shows several trajectories going towards the southern part of the Peloponnese; these trajectories are shifted northward in the experiments with WIVERN DA, even if the WIV_24h trajectories still tend to go to the south of the member 42 trajectory. Another interesting point is that the pressure along the final part of the trajectories increases compared to the ensemble CTRL, as shown by the yellow-green colors of the segments in the last part of the trajectories of Figure 4 compared to the green colors of the same traits in Figure 1. This is attributed to the change in the storm dynamics after DA and by the WRF physics that propagates the wind changes to the mass fields by physical laws.

Results show an important impact of WIVERN wind DA on the WRF forecast. Considering the trajectory forecast with just one data assimilation (WIV_24h experiment), the average error is improved by more than 40% and the error decreases from 62.5 km to 35.4 km. It is shown that the trajectory forecast is improved for 46 out of 50 members and that this improvement lasts at least 18 h. The forecast improvement is not confined to the trajectories, but it is transferred from the dynamic to the mass field through the model physics, as shown by the improvement of the sea level pressure forecast and surface wind speed.

-GNSS data assimilation

In this experiment we compared the relative role of GNSS-ZTD and lightning data assimilation for 116 convective case studies occurred over northern Italy in 2019.

The WRF model with advanced WRF dynamic (WRF-ARW) version 4.1.3 (Skamarock et al., 2019) has been used in this study with two domains (Figure 5a). The first domain (D1) covers the Central Europe and the Central Mediterranean and has a spatial horizontal resolution of 6 km, while the second domain (D2) covers Northern Italy and has a spatial horizontal resolution of 2km. The domains D1 and D2 account for 400x400 grid points and 301x301 grid points in both NS and WE directions, respectively. The model top is at 50 hPa.

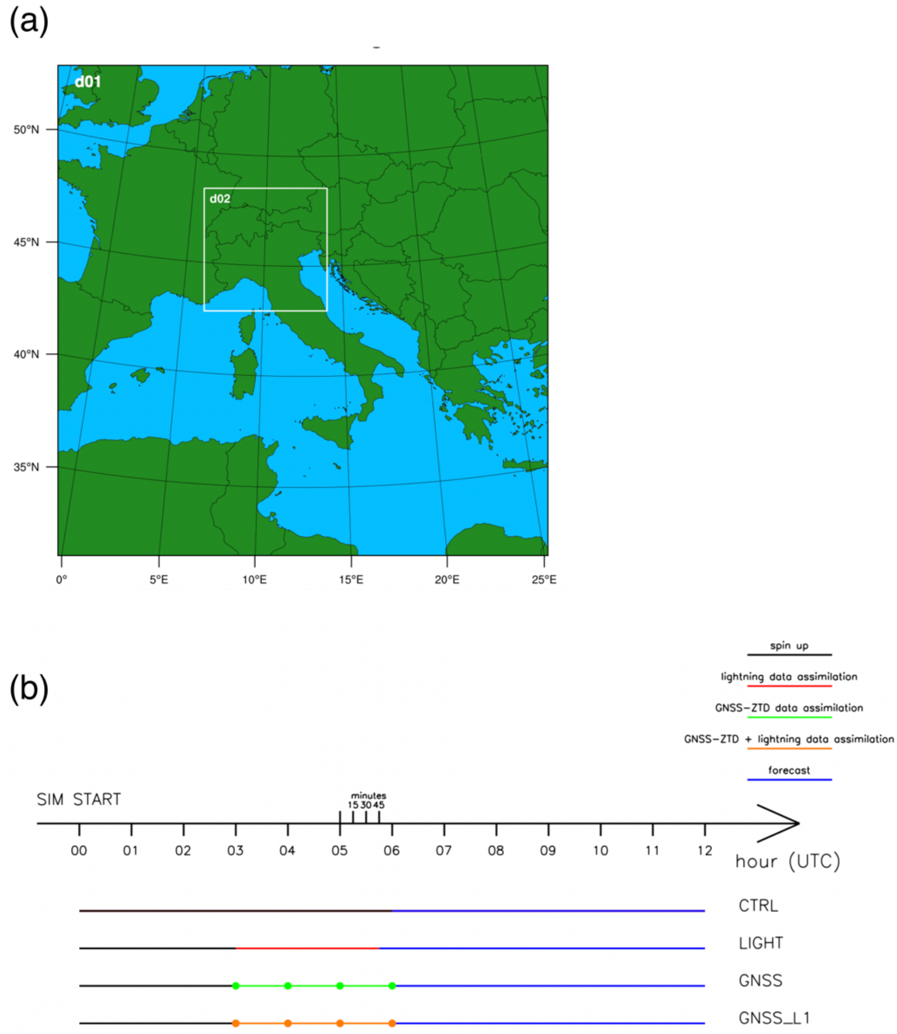

Figure 5. (a)WRF model domains; (b) VSF scheme. Dots denote analyses' times.

The WRF physical parameterizations are the same of the Ianos case study. For each case study we considered four types of simulations:

- CTRL, without lightning and GNSS-ZTD data assimilation
- LIGHT, with lightning data assimilation by nudging
- GNSS, with GNSS-ZTD data assimilation by 3DVar
- GNSS_L1, with lightning data assimilation by nudging and GNSS-ZTD data assimilation by 3DVar.

Simulations follow a Very Short-term Forecast (VSF) approach (Figure 1b). Each simulation lasts 12 hours, in which the first 3 hours are used as spin-up time, the second 3h are used for data assimilation, while the last 6 hours represent the forecast period. More specifically, data assimilation takes place in LIGHT, GNSS and GNSS_L1. For LIGHT, assimilation is done on a 2 hour and 45 minutes period, starting from the third hour of run and lasting until 15 minutes before the end of the sixth hour of run, leaving the last 15 minutes of the hour for the forecast. In this way, in LIGHT simulations the forecast for the period between the sixth and the seventh hour of run would have been available in an operational context at the end of the sixth hour of run. For GNSS and GNSS_L1, assimilation is performed once per hour between the third and the sixth hour of run (four analyses). Therefore, for GNSS and GNSS_L1 the forecast between the sixth and the seventh hour of run, would not have been available at the end of the sixth hour of run in an operational context. In this case, the first hour of forecast available in time before its real occurrence would have been the hour between the seventh and the eighth hour of the run.

Depending on the case study, simulations can start at 00, 06, 12 or 18 UTC of the day to forecast.

Simulations were initialized using the European Centre for Medium-Range Weather Forecasts (ECMWF) Integrated Forecasting System (IFS) operational analysis-forecast cycle at 0.125° starting at 12:00 UTC on the day to forecast for simulations starting at 18:00 UTC and on the day before the day to forecast for simulations starting at 00:00 UTC, 06:00 UTC and 12:00 UTC. Boundary conditions are updated every 3h. Importantly, the setting above is representative of a possible operational weather forecast setting.
Performance diagrams for all model types and for all case studies are shown in Figure 6. Three forecast phases 0-3h, 1-4h and 3-6h and three precipitation thresholds, i.e. 1 mm/3h, 10 mm/3h and 30 mm/3h are considered.
All configurations with assimilation are better than CTRL for all forecast phases and for all thresholds. Looking more in detail to the 0-3h phase, we note that all configurations with assimilation have a higher POD than CTRL for all three thresholds. We also note that the forecast performance decreases with the rainfall threshold; this is expected as the forecast of convective events becomes more difficult when they are more intense.

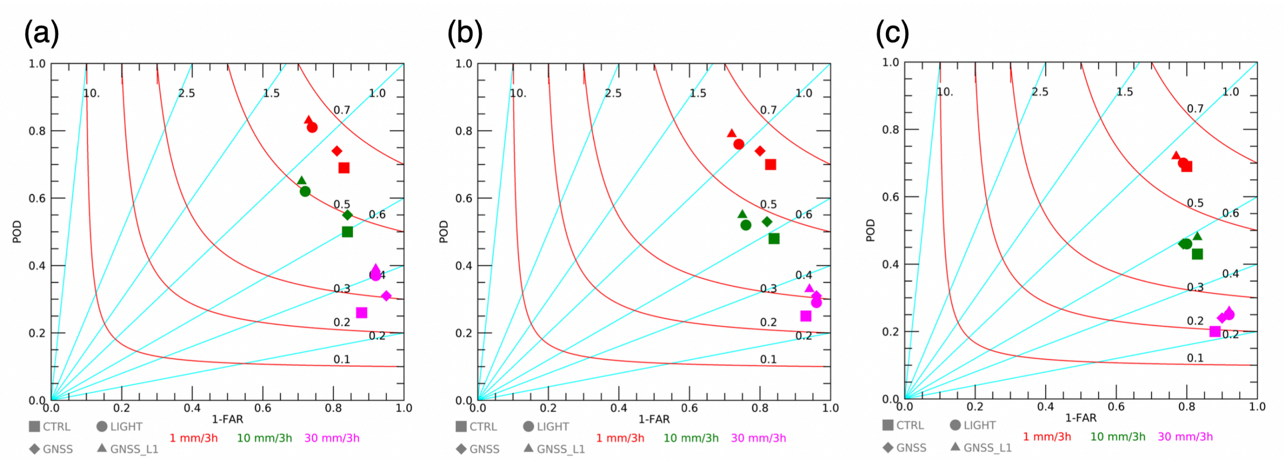

Figure 5. Performance diagrams for all case studies for the three forecast phases, 0-3h (a), 1-4h (b) and 3-6h (c) for the precipitation thresholds of 1 mm/3h, 10 mm/3h and 30 mm/3h and for the model simulation types CTRL, LIGHT, GNSS and GNSS_L1.

For the 1-4h phase, all configurations with assimilation have a higher POD than CTRL, while the FAR is increased by data assimilation except for the 30 mm/3h threshold. Similarly to the 0-3h phase, the performance decreases as the events become more intense. For the 1 mm/3h threshold, LIGHT has the best performances, with a POD of about 80% compared to 70% for CTRL, while GNSS and GNSS_L1 perform in a similar manner (75%). The 10 mm/3h threshold records again the highest POD and the lowest FAR for GNSS_L1. Finally, GNSS_L1 is the best configuration also for the 30 mm/3h threshold, with a POD of about 35%, and a difference of about 10% with CTRL.
As regards the 3-6h phase, scores are slightly worse than the previous forecast phases. GNSS_ L1 records the best performances for all thresholds.
In summary, both lightning and GNSS-ZTD data assimilation improve the precipitation forecast compared to CTRL, in all forecast phases and for all thresholds, producing a higher POD and TS score. Overall GNSS_L1 is the best configuration and is useful in an operational context for the last two forecast phases (1-4h and 3-6h). For the 0-3h, the only useful configuration for operational purposes is LIGHT, which however shows a significant improvement compared to CTRL, with POD positive differences of about 15%.

Conclusions
In the first one and half-year of this project, the impact of WIVERN DA on the forecast of the Medicane Ianos was investigated. In addition, the impact of GNSS-ZTD and lightning data assimilation was studied. In all experiment a positive impact of data assimilation was shown.

During the following of the project, we will investigate the impact of the assimilation of GNSS-STD (slant total delay) and lightning data assimilation from MTG-LI. Possibly, more simulations of WIVERN DA will be required, if WIVERN is accepted for the final launch.

References

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