# 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** | ……………2025-2026…………………………..…… |
| **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)<br>………………………………………………………..…… |
| **Affiliation:** | …… CNR-ISAC (National Research Council – Institute of Atmospheric Sciences and Climate)... |
| **Name of ECMWF scientist(s) collaborating to the project** (if applicable) | …………Claudio Transerici (cmn)<br>…………Rosa Claudia Torcasio (it85)…….…… |
| **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+ 9000000 (extension requests) | 29000000 | 20000000 | 11000000 |
| **Data storage capacity** | (Gbytes) | 100000 | 84000 | 100000 | 100000 |

## Summary of project objectives (10 lines max)

The 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 3-6hafter 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.

## 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. In addition, a possible study of the 2022

## List of publications/reports from the project with complete references

Two papers were published in the last year using the computational resources of this Special Project. The papers are:


- Stefano Federico, Rosa Claudia Torcasio, Claudio Transerici, Mario Montopoli, Cinzia Cambiotti, Francesco Manconi, Alessandro Battaglia, and Maryam Pourshamsi, Assimilating WIVERN wind pseudo-observations in WRF model: an application to the outstanding case of the Medicane Ianos, Weather Clim. Dynam., 7, 165–183, 2026 https://doi.org/10.5194/wcd-7-165-2026
- Stefano Federico, Rosa Claudia Torcasio, Claudio Transerici, Eugenio Realini, Xiangyang Song, Giovanna Venuti, Forecasting convective precipitation over northern Italy: A comparison of lightning and GNSS-ZTD data assimilation, Atmospheric Research, Volume 331, 2026, 108687, ISSN 0169-8095, https://doi.org/10.1016/j.atmosres.2025.108687.


## Summary of results

*-Wind Velocity Radar Nephoscope (WIVERN) data assimilation*

WIVERN has been selected as ESA Earth Explorer 11 mission. 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 the previous report we showed an application of WIVERN winds pseudo-observations data assimilation for the outstanding case of the Medicane Ianos, occurred in mid-September 2020. Here we will show some sensitivity tests performed for the same experiment: a test considers the sensitivity to the initialization time and another test considers the sensitivity to the observation error and to the background error matrix.
All results can be found in the paper:
Stefano Federico, Rosa Claudia Torcasio, Claudio Transerici, Mario Montopoli, Cinzia Cambiotti, Francesco Manconi, Alessandro Battaglia, and Maryam Pourshamsi, Assimilating WIVERN wind pseudo-observations in WRF model: an application to the outstanding case of the Medicane Ianos, Weather Clim. Dynam., 7, 165–183, 2026 https://doi.org/10.5194/wcd-7-165-2026

WRF model has been run 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 the European Centre for Medium-Range Weather Forecast - Ensemble Prediction System (ECMWF-EPS) of the Integrated Forecasting System (IFS) run. 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.

In the previous report we showed the results of an experiment initialized at 12:00 UTC on 16 September 2020. Here we show a sensitivity test which considers an ensemble initialization on the day before, i.e. on 15 September 2020, considering two analysis/forecast: (a) assimilation at 12:00 UTC on 16 September and forecast from 12:00 UTC on 16 September to 00:00 UTC on 18 October (experiment $WIV_{24h16}$) and (b) assimilation at 00:00 UTC on 16 September and forecast from 00:00 UTC on 16 September to 00:00 UTC on 18 October (experiment $WIV_{12h}$). Results of these two assimilation experiments are compared with the CTRL ensemble starting at 12:00 UTC on 15 September 2020.
A representative member has been selected from the CTRL ensemble, choosing the member whose trajectory is in best agreement with the best estimate a-posteriori trajectory of Ianos provided by Flaounas et al. (2023). WIVERN pseudo-observations, i.e. winds along the Line of Sight (LOS) are generated every 3h by the simulator of Battaglia et al. (2022) applied to the output of the representative member. These pseudo-observations are then assimilated in experiments with data assimilation.
Results are reported in Figure 1. For CTRL ensemble (Figure 1a) the spread of the trajectories is larger compared to the experiment initialized at 12:00 UTC on 16 September, not giving a clear indication that the storm would have deepened. Many trajectories go south of Greece and towards the Aegean Sea and, for these trajectories, the surface pressure remains greater than 1000 hPa. For the experiment $WIV_{24h16}$ forecast (Figure 1b) trajectories are all going towards the western Peloponnese and the storm is deepening. For the experiment $WIV_{12h}$ (Figure 1c) all trajectories, with just one exception, approach the western and southern Peloponnese and most of these trajectories show a clear deepening of the cyclone improving the forecast of the CTRL ensemble.
All in all, we can conclude that WIVERN assimilation would have been able to constrain the forecast of the Medicane Ianos also for the ensemble issued on 15 September 2020, giving a clear suggestion, with more than a day of advance, that the Medicane would have made its landfall in western/southern Peloponnese and that the storm would have deepened.

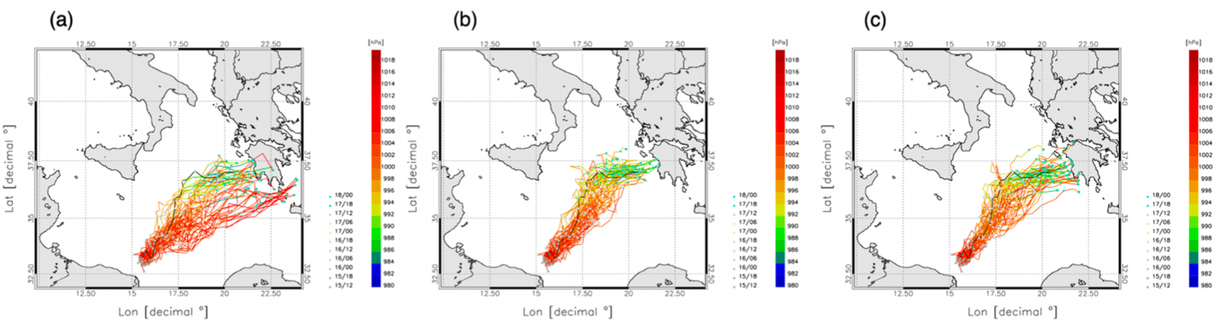


**Figure 1.** Trajectories of the Medicane Ianos for the experiment starting at 12:00 UTC on 15 September; (a) CTRL ensemble; (b) $WIV_{24h16}$; (c) $WIV_{12h}$. In panel (b) the assimilation is done at 12:00UTC on 16 September; in panel (c) the assimilation is done at 00:00UTC on 16 September. The trajectory in black is that of the reference member.

Another sensitivity test considers two experiments: one in which the observation error is inflated and the other one in which the background error matrix is changed. In the first experiment (named E2) we assume an observation error equal to the model wind speed error and dependent only on height, which roughly corresponds to inflating the WIVERN estimated observations error by a factor of 1.5–2. In the second sensitivity experiment (named NMC), the background error covariance matrix is was computed applying the NMC (National Meteorological Center; Parrish and Derber, 1992) method to the period 1–30 September 2020, considering the differences of two WRF forecasts, with lead times of 12 and 24h, verifying at the same time, both 12:00 and 00:00 UTC, for the whole period. WRF initial and boundary condition come from the operational analysis/forecast cycle issued by the ECMWF at 00:00 and 12:00 UTC on each day of September as initial and boundary conditions. In the experiment considered in the $WIV_{24h}$ simulations, the background error covariance matrix is computer from the ensemble, and therefore it is representative of the error of the day. The NMC method gives a background error matrix which is representative of the meteorological conditions of the month of September 2020.

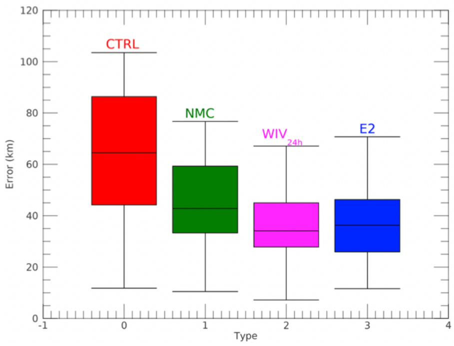


**Figure 2.** Trajectories error distribution, respect to the representative member of the ensembles CTRL, NMC, $WIV_{24h}$ and E2. The boxes show the 25th and the 75th percentile, the black line inside the box is the median and the maximum and minimum values are the extremes of the error bar.

Results of both sensitivity experiments (Figure 2) of the CTRL experiment (without WIVERN pseudo-observations data assimilation) and of the $WIV_{24h}$ experiment are represented by the distribution of the trajectory errors of the ensemble members, i.e. the distance averaged over time between the members and the best a-posteriori estimated trajectory.

CTRL has the largest error, followed by NMC, E2, and $WIV_{24h}$. The E2 experiment performance is closer to $WIV_{24h}$ than to CTRL, showing the positive impact of WIVERN assimilation on the prediction of the Medicane Ianos. E2 has an average error similar to $WIV_{24h}$ but a larger median error. The spread of the ensemble is also larger for E2 compared to $WIV_{24h}$.
The NMC experiment shows a notable impact of the choice of the background error matrix on the trajectory forecast. Both the averaged and the median trajectory errors of NMC are larger compared to $WIV_{24h}$ and also the spread of the ensemble is larger.

*-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.

The results of these experiment show that: a) lightning and GNSS-ZTD data assimilation are both useful to improve the short-range precipitation forecast; b) the lightning impact is most effective in the first three-hours of forecast; c) the synergy between lightning and GNSS-ZTD data assimilation is positive for both 1-4h and 3-6h forecasts, even if the impact of data assimilation is much reduced after 4h of forecast. Finally, requiring a minimum threshold of flashes observations to assimilate lightning gave controversial results.
The results of this experiment have been detailed in the paper:
Stefano Federico, Rosa Claudia Torcasio, Claudio Transerici, Eugenio Realini, Xiangyang Song, Giovanna Venuti, Forecasting convective precipitation over northern Italy: A comparison of lightning and GNSS-ZTD data assimilation, Atmospheric Research, Volume 331, 2026, 108687, ISSN 0169-8095,https://doi.org/10.1016/j.atmosres.2025.108687.
and the reader is referred to this paper for details.

*-GNSS slant data assimilation*

Besides the assimilation of GNSS data in the zenith direction, the GNSS information along slant paths can be considered for data assimilation into the WRF model. A way to assimilate the Slant Total Delay (STD) is by means of tropospheric gradients in the East and North directions. Assimilation of gradients has been recently added in a version of the WRFA Data Assimilation (WRFDA) and presented in the paper of Thundathil et al. (2024). We applied this method over Italy to estimate the impact of gradients assimilation compared to ZTD assimilation alone. The method gave positive results for some case studies. An example is reported hereafter.

We considered three kinds of simulations: one without GNSS data assimilation (named CTRL), one with ZTD data assimilation (named ZTD) and one with ZTD and gradients data assimilation (named ZTDGRAD). We assimilated GNSS data over a 6h period and we produced the forecast for the following 6 hours. Figure 3 shows an example for the forecast hours from 1 to 4 after the assimilation phase. The case study occurred on 30 May 2023 and we focus on the hours between 19 and 22 UTC. The case study is centered over Lombardy region. Figure 1a shows the observed precipitation over the area, with many rain gauges reporting more than 20 mm/3h and local maxima over 40 mm/3h.

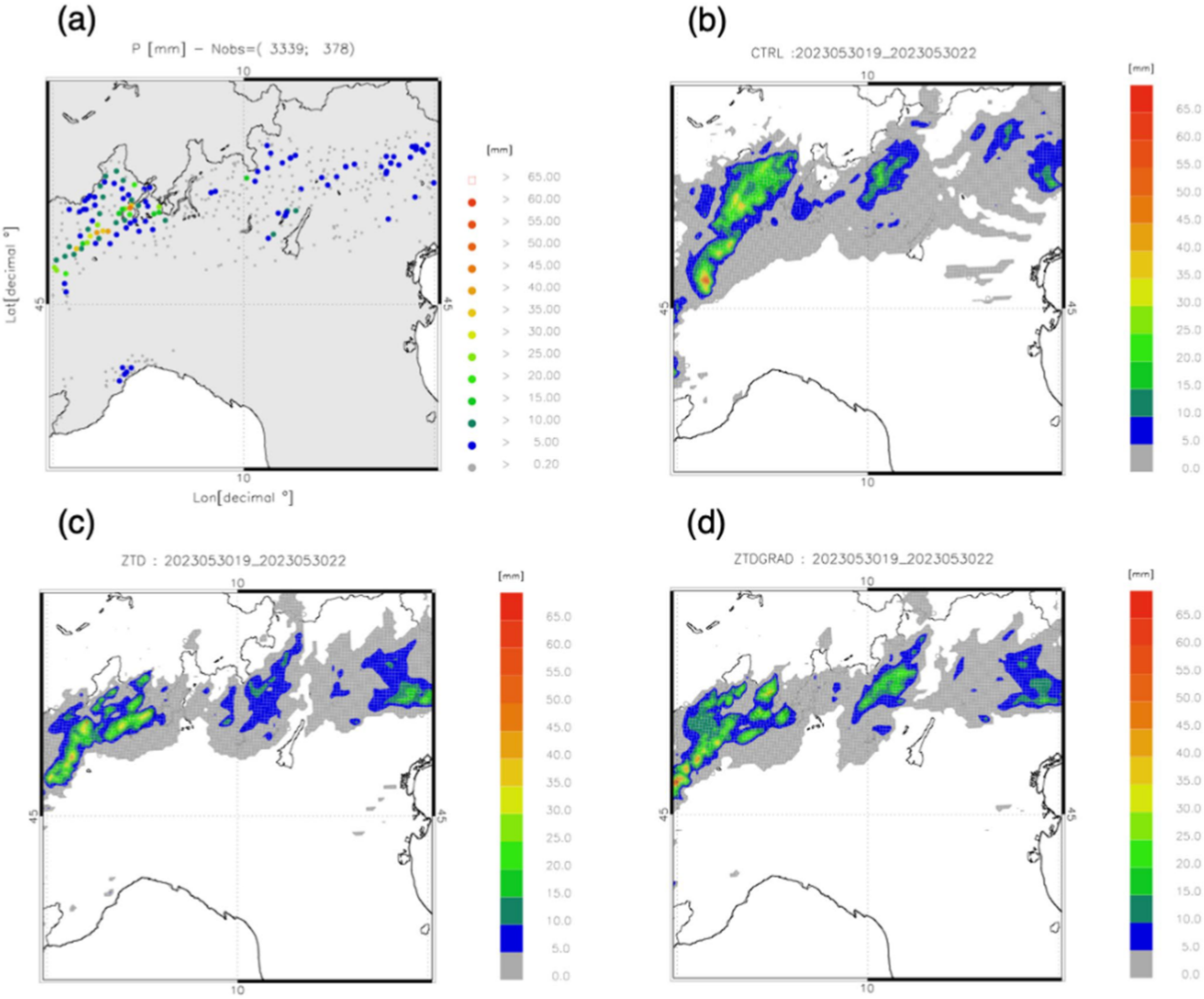


**Figure 3:** Precipitation between 19 and 22 UTC on 30 May 2023 recorded by the Italian rain gauge network (**a**) and predicted by CTRL (**b**), ZTD (**c**) and ZTDGRAD (**d**).

Thunderstorms over northern Italy are represented by the different forecasts. CTRL however predicts a larger and wider precipitation in the NW part of the domain, with precipitation patterns shifted to the east compared to observations in some measure. CTRL forecast overestimation is reduced by the assimilation of GNSS data (both ZTD and ZTDGRAD). In addition, the line of intense thunderstorms occurring in the NW part of the domain is better represented by ZTD and by ZTDGRAD simulations.

Changes in the precipitation field caused by data assimilation, are of course related to the increments in relative humidity introduced by GNSS data assimilation. Innovations, i.e. difference in relative humidity fields before and after assimilation, are shown in Figure 4 for the last analysis before the forecast phase. The assimilation of GNSS gives both positive and negative increments, but when gradients are assimilated, increments are locally larger. Gradients' assimilation gives a positive relative humidity increment along a line oriented in the SN direction at about 9°E and, in general, the assimilation of gradients increases the water vapor added to the analysis compared to the assimilation of GNSS-ZTD alone.

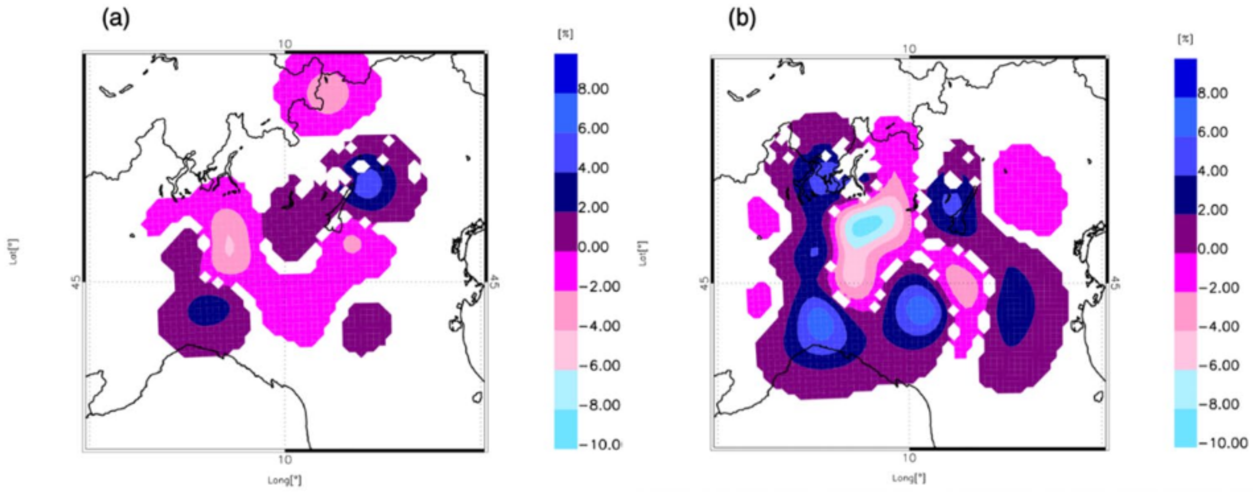


**Figure 4** Relative humidity innovations at 2757 m a.s.l. for ZTD (**a**) and ZTDGRAD (**b**).

The better performance of the forecasts assimilating GNSS data compared to CTRL is confirmed by precipitation scores (Figure 5). POD of ZTD and ZTDGRAD forecasts is increased by more than 10% for rainfall larger than 20 mm/3 h compared to the CTRL forecast. In addition, the ZTDGRAD simulation has the best performance for thresholds larger than 16–18 mm/3 h for all scores, showing the positive impact of assimilating part of the anisotropy of GNSS observation in the WRF forecast for this case study. The FAR is, in general, low for this case study for all configurations.

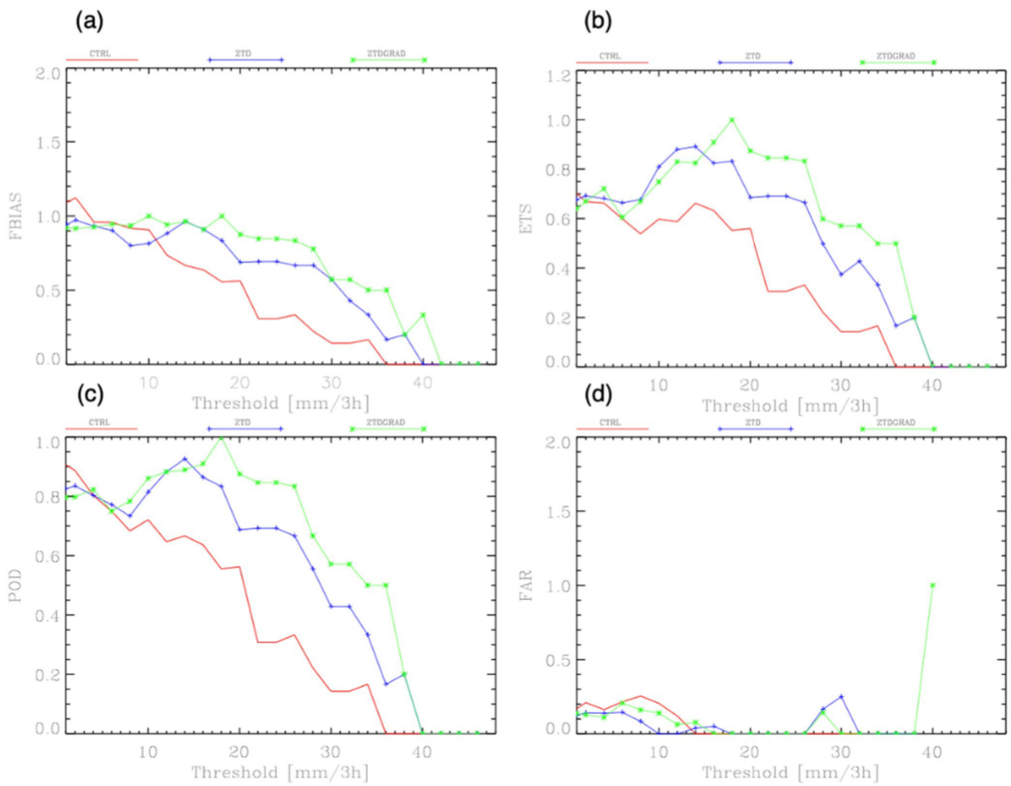


**Figure 5.** FBIAS (**a**), ETS (**b**), POD (**c**) and FAR (**d**) for the 3 h-period 19–22 UTC on 30 May 2023 for CTRL, ZTD and ZTDGRAD.

Results for some case studies show that GNSS data assimilation reduces false alarms compared to CTRL and better represents the events both for precipitation intensity and positioning. ZTDGRAD configuration better represents intense events and precipitation areas. However, general conclusions cannot be drawn since experiments over a wider period are needed. Studies in this direction are ongoing.

**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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