

# 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** 2019 (first semester)

**Project Title:** Study of different configurations of the RAMS model for precipitation and lightning forecast over Italy at high horizontal resolution.

**Computer Project Account:** SPITFEDE

**Principal Investigator(s):** Stefano Federico  
.....

**Affiliation:** ISAC-CNR (Institute for Atmospheric Sciences and Climate - National Research Council).....

**Name of ECMWF scientist(s) collaborating to the project (if applicable)** .....

**Start date of the project:** ...1 January 2018.....

**Expected end date:** ...31 December 2020.....

**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
<b>High Performance Computing Facility</b>	(units)	7,000,000	7,000,000	6,000,000	600,000
<b>Data storage capacity</b>	(Gbytes)	4TB	2.9 TB	7 TB	2.9 TB

### **Summary of project objectives** (10 lines max)

The aim of this project is to test several configurations of the RAMS model for one-day precipitation forecast and for the lightning forecast. The verification of the lightning forecast will be performed during the third year of the project, after finding the best configuration of the RAMS model. The precipitation forecast will be verified using a dense raingauge network available over Italy for twenty moderate-intense precipitation events occurred over Italy during HyMeX-SOP1 (5 September-5 November 2012). The sensitivity of the forecast to the microphysical scheme (WSM6 and Thompson, the second being a two-moment microphysical scheme) and to the radiation scheme (Harrington, and Chen Cotton). Also, the performance of the CSU-RAMS model will be assessed in comparison with the RAMS model developed at ISAC-CNR (hereafter RAMS@ISAC).

### **Summary of problems encountered** (10 lines max)

In this part of the project no particular problems were found. Do to specific and particular reasons we didn't use much the ECMWF supercomputing. However, the supercomputing of ECMWF will be used in the second part of the year.

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

Elenio Avolio, Stefano Federico, WRF simulations for a heavy rainfall event in southern Italy: Verification and sensitivity tests, Atmospheric Research, Volume 209, 2018, Pages 14-35, ISSN 0169-8095, <https://doi.org/10.1016/j.atmosres.2018.03.009>.

Mascitelli, Alessandra; Federico, Stefano; Fortunato, Marco; Avolio, Elenio; Torcasio, Rosa Claudia; Realini, Eugenio; Mazzoni, Augusto; Transerici, Claudio; Crespi, Mattia; Dietrich, Stefano: Data assimilation of GPS-ZTD into the RAMS model through 3D-Var: preliminary results at the regional scale. Meas. Sci. Technol. 30 (2019) 055801 (14pp). <https://doi.org/10.1088/1361-6501/ab0b87>

Papers in review:

Federico, S., Torcasio, R. C., Avolio, E., Caumont, O., Montopoli, M., Baldini, L., Vulpiani, G., and Dietrich, S.: The impact of lightning and radar data assimilation on the performance of very short term rainfall forecast for two case studies in Italy, Nat. Hazards Earth Syst. Sci. Discuss., <https://doi.org/10.5194/nhess-2018-319>, in review, 2018.

Anna Cinzia Marra, Stefano Federico, Elenio Avolio, Luca Baldini, Daniele Casella, Leo Pio D'Adderio, Stefano Dietrich, Mario Montopoli, Paolo Sanò, R. Claudia Torcasio, Giulia Panegrossi: The precipitation structure of the Mediterranean tropical-like cyclone Numa: analysis of GPM observations and NWP simulations, Remote Sensing, In review.

### **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.

### **Implementation and test of the Thompson microphysics scheme**

During 2018-2019 the two-moments Thompson microphysics scheme (Thompson et al., 2004; 2008) was implemented in RAMS@ISAC and tested for 20 case studies of HyMeX-SOP1 (HYdrological cycle in the Mediterranean Experiment - Special Observing Period one; Ducroq et al., 2014 ). The case studies are shown in Table 1 and refer to days of moderate-intense precipitation in Italy. Initial and boundary conditions for RAMS@ISAC are given by ECMWF analysis/forecast cycle issued at July 2019

This template is available at:

<http://www.ecmwf.int/en/computing/access-computing-facilities/forms>

12 UTC for the day before the day of interest of Table 1. Forecasts are made for 36 hours and the first 12 hours of each simulation are spin-up time and are discarded. The daily rainfall forecast is considered and compared with raingauge observations of the Italian network (about 3000 raingauges over the country).

Month	day
September 2012	12,13,14,24,26,30
October 2012	12,13,15,26,27,28,29,31
November 2012	4,5,11,20,21,28

Table 1: The twenty case studies.

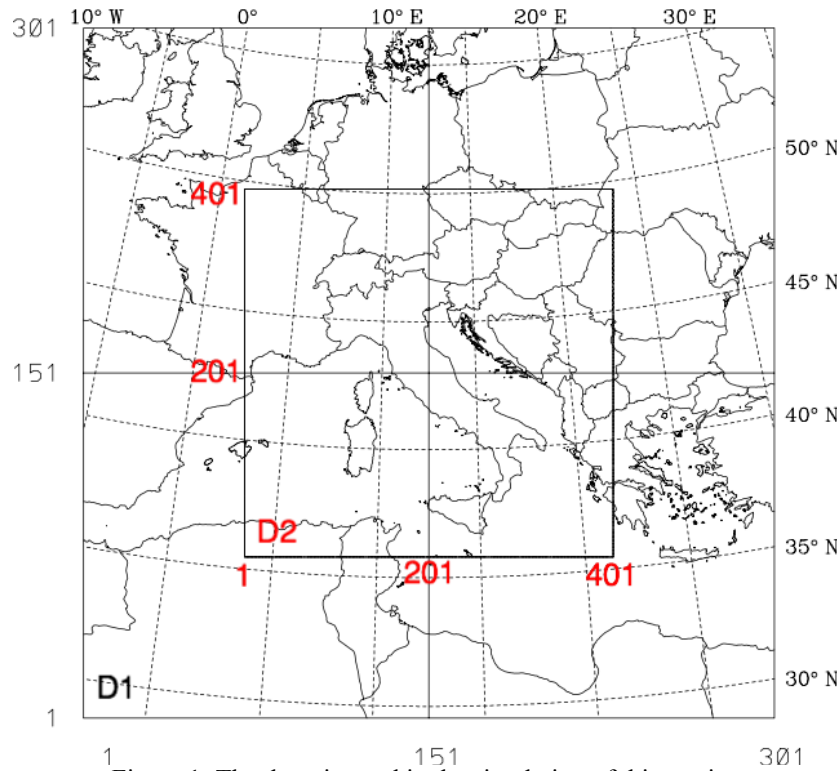


Figure 1: The domain used in the simulation of this section

The domain used for the simulations is the inner domain of Figure 1. It has 401\*401 grid points in the horizontal plane and 36 levels in the vertical. The horizontal grid-spacing is 4 km, while the vertical resolution is higher close to the ground. In particular, the first vertical level is at 50 m above the surface in the terrain following coordinates used by RAMS@ISAC, and 10 levels are below 1000 m and 17 below 3 km; the level 21 is at 5122 m. Above 6 km the model levels are about 1000 m apart, while the maximum allowed distance between two levels is 1200 m.

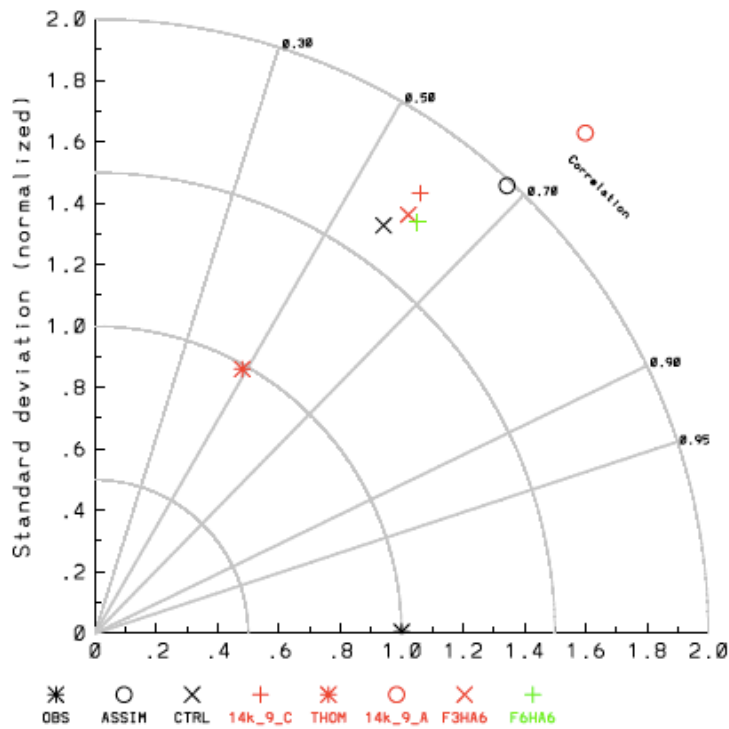


Figure 2: Taylor diagram for 20 case studies of HyMeX-SOP1.

Figure 2 shows the Taylor diagram for several configurations of the RAMS@ISAC model for the 20 case studies of HyMeX-SOP1 considered in this project. The performance refers to the 24h precipitation forecast and the neighbourhood method was selected to extract the rainfall at a specific raingauge. With this method we select, among the four grid points surrounding a specific station, the rainfall of the gridpoint which is closest to the observed value. In this way, we tolerate a spatial error of  $d * (2)^{1/2}$ , where  $d$  is the model horizontal grid-spacing (4 km), in the rainfall field simulated by RAMS@ISAC. The simulation of interest for this report are those in red. In particular, the simulation 14k\_9\_C is the reference model, using the WSM6 scheme (Hong and Lim, 2006); THOM is the simulation using the Thompson two-moment microphysical scheme implemented in RAMS@ISAC. The comparison between the simulation with WSM6 microphysical scheme and that with the Thompson scheme shows a notable difference. The WSM6 has a better correlation than THOM and it is more able to determine the correct pattern of the rainfall field. The Thompson scheme has a lower RMSE error because it is closer to the point of the observations (OBS) along the  $x$ -axis.

While Figure 2 shows some positive aspects of WSM6 and THOM schemes, the inspection of the model output clearly reveals that this behaviour is caused the greater rainfall simulated by WSM6 compared to THOM. In particular WSM6 overestimates the rainfall forecast while the THOM underestimates the precipitation field.

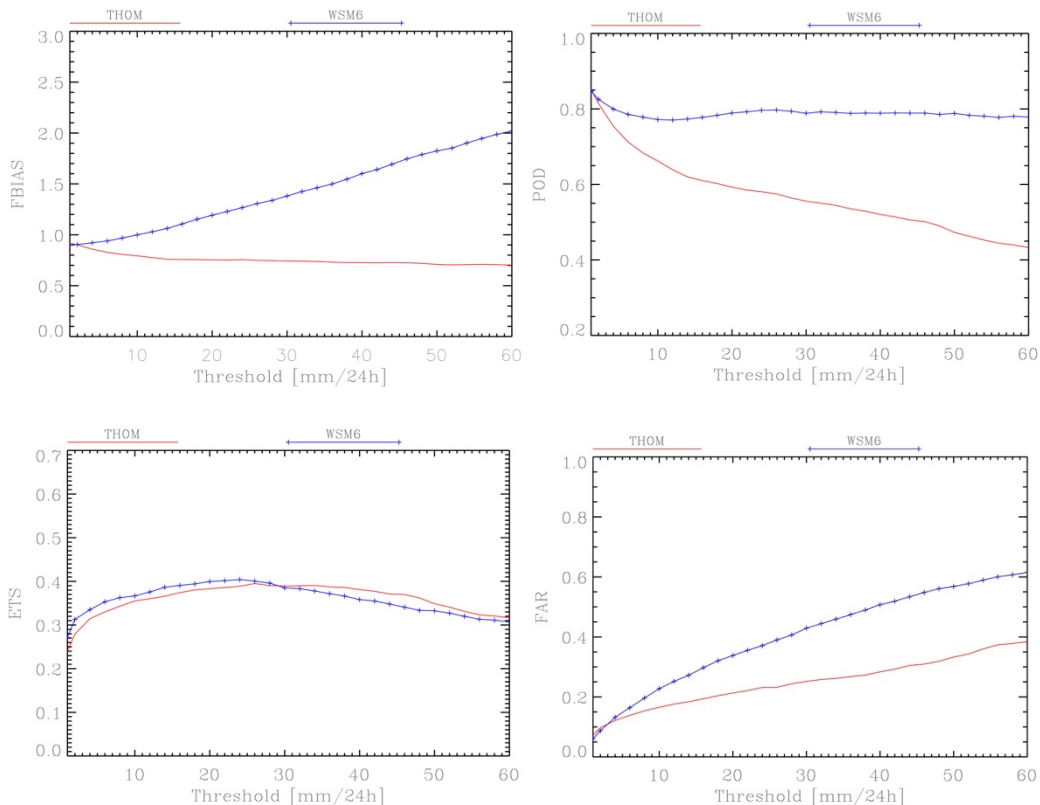


Figure 3: Scores computed from contingency tables for the HyMeX-SOP1 for WSM6 and THOM. A) Bias; b) Probability of detection (POD); c) Equitable Threat Score (ETS); d) False Alarm Rate (FAR).

This is confirmed by the analysis of the scores computed from dichotomous contingency tables (Figure 3). Figure 3a shows the Bias for WSM6 and THOM for the twenty case studies of HyMeX-SOP1. Scores are computed for the thresholds: 0.2 mm/24h; 1 mm/24h and from 2 mm/24 h to 60 mm/24h every 2 mm/24h. The Bias of WSM6 increases for increasing thresholds, while that of THOM decreases. In particular the Bias is around 2.0 for the 60 mm/24h threshold for WSM6, while it is 0.7 for THOM. Bias shows that WSM6 configuration, which is currently used in RAMS@ISAC operational setting, overestimates the precipitation field as the rainfall threshold increases. On the contrary, THOM underestimates the rainfall for higher precipitation thresholds.

POD score shows better performance for WSM6 compared to THOM, especially for higher rainfall. At 60 mm/24h, RAMS@ISAC with WSM6 microphysical scheme has a POD of 0.8, which reduces to 0.45 for THOM. So, THOM is able to correctly forecast about half of the correct forecast of WSM6. The FAR, however, clearly shows that 60% of the forecast predicted by WSM6 for 60 mm/24h threshold are false alarms, while this number reduced to 40% for THOM. Because WSM6 gives more correct forecast and more false alarms compared to THOM for different precipitation thresholds, the ETS is comparable for both configurations. The ETS of WSM6 is slightly higher for WSM6 up to 30 mm/24h, while the ETS of THOM is better than WSM6 for higher rainfall thresholds.

### **RAMS-3DVar and very short-term (3h) precipitation forecast**

In this section, we introduce the assimilation scheme of RAMS (hereafter RAMS-3Dvar), which is developed at ISAC-CNR and will be used in the future development of this project. We limit the attention to the lightning observations. In the current stage of development also the GPS-ZTD and radar reflectivity factor can be assimilated (Mascitelli et al., 2019 and Federico et al., 2018, respectively).

The general framework of RAMS-3DVar is presented in Federico (2013). The analysis system uses the incremental formulation of the cost function (Courtier et al., 1994), which reduces the computational cost, and a control variable transform to make the minimization of the cost function practicable. Details about RAMS-3DVar can be found in Federico (2013). Here we consider how the lightning are assimilated via 3D-Var.

In previous studies (Federico et al., 2017; Federico et al., 2018) lightning were assimilated by the method of Fierro et al. (2012), i.e. with the nudging. The method starts by computing the water vapour mixing ratio  $q_v$ :

$$q_v = Aq_s + Bq_s \tanh(CX)(1 - \tanh(Dq_g^\alpha)) \quad (1)$$

Where coefficients are set to  $A=0.86$ ,  $B=0.15$ ,  $C=0.30$ ,  $D=0.25$ ,  $\alpha=2.2$ ,  $q_s$  is the saturation mixing ratio at the model atmospheric temperature, and  $q_g$  is the graupel mixing ratio ( $\text{kg kg}^{-1}$ ).  $X$  is the number of total flashes (IC+CG) falling in a grid box of domain D2 (R4) in the past five minutes. The mixing ratio  $q_v$  of Eq. (1) is computed only for grid points where flashes are recorded. More specifically, for each grid point we consider the number of flashes falling in a grid box centered at the grid point in the last five minutes. The mixing ratio of Eqn. (1) is compared with that predicted by the model. If the mixing ratio of Eqn. (1) is larger than the simulated one, the latter is nudged towards the value of Eqn. (1) (strong nudging with 300 s e-folding time), otherwise the modelled mixing ratio is left unchanged.

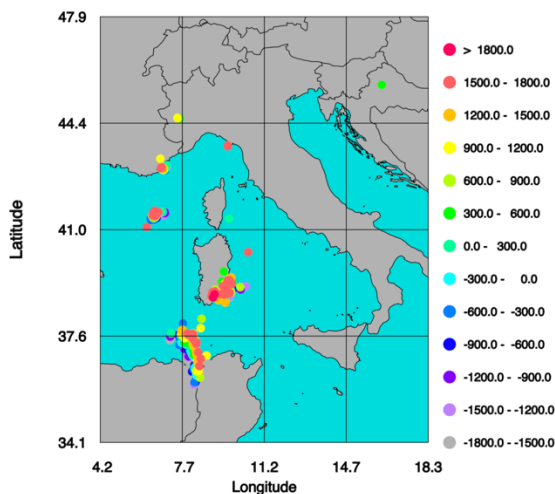
The check and eventual substitution of the water vapour is performed every five minutes and it is made within the mixed phase layer zone ( $0^\circ\text{C}$ ,  $-25^\circ\text{C}$ ), wherein electrification processes caused by the collision of ice and graupel are the most active.

In RAMS-3DVar, the assimilation of lightning is made by pseudo-profiles of relative humidity (similarly to Fierro et al., 2016). In particular, we consider all lightning recorded in a time interval of 1 h centred at the analysis time and, for each lightning, we assume a saturated atmospheric profile between the Lifting Condensation Level (LCL) and the  $-25^\circ\text{C}$  isotherm. The choice to saturate the column from LCL instead of the freezing level follows from the study of Dixon et al. (2016).

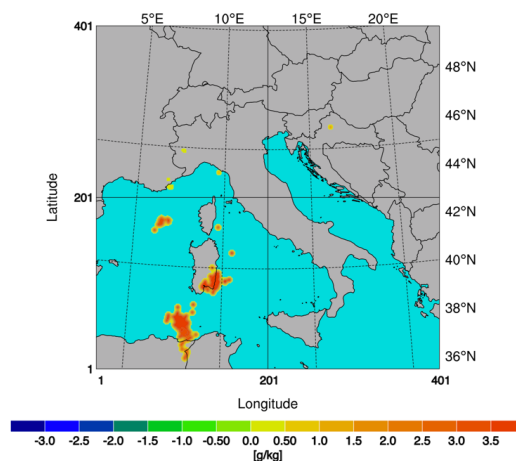
The assimilation of lightning within RAMS-3DVar was tested for a case study of deep convection occurred over the Sardinia island on 9 October 2018.

This event was quite well predicted using 3km horizontal grid spacing, 42 vertical levels and ECMWF operational analysis/forecast cycle issued at 12 UTC on 09 October 2012. However, the event was missed by the 4km horizontal grid resolution 36 levels, which is the current operational version of the model. Also, the operational model uses GFS  $0.25^\circ$  fields as initial and boundary conditions. The microphysical scheme used in the following simulations is WSM6 (operational setting).

(a)



(b)



(c)

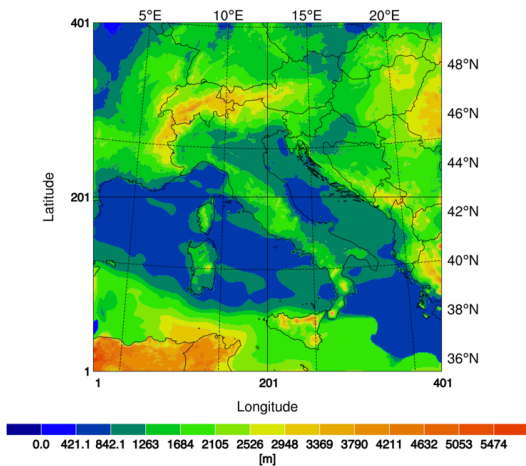


Figure 4: a) lightning recorded by LINET between 17:30 and 18:30 UTC on 10 October 2018. Difference between specific humidity after and before the lightning data assimilation by 3D-Var at 18 UTC on 10 October 2018. The height is 3122 m in the terrain following coordinate system.

Before considering the impact of lightning data data assimilation on the precipitation forecast, it is useful to consider an example of analysis. We consider the analysis made at 18 UTC on 10 October (Figure 4). Figure 4a shows the flashes recorded by LINET (Betz et al., 2009) from 17:30 UTC to 18:30 UTC on 10 October 2018. A total of 1194 lightning, both intra-cloud and cloud to ground, are observed for this hour.

The adjustment given by the analysis to the water vapour mixing ratio, which is the variable assimilated in RAMS@ISAC, is shown in Figure 4b for the 3122 m level. Differences up to 4 g/kg are found for this time/level. Figure 4c shows the height of the LCL simulated by RAMS@ISAC at this time. For comparison the freezing level is at about 2 km over Sardinia at this time.

Lightning data assimilation improved considerably the forecast over Sardinia. Figure 5a shows the precipitation observed by raingauges of the Regional Network of Italy.

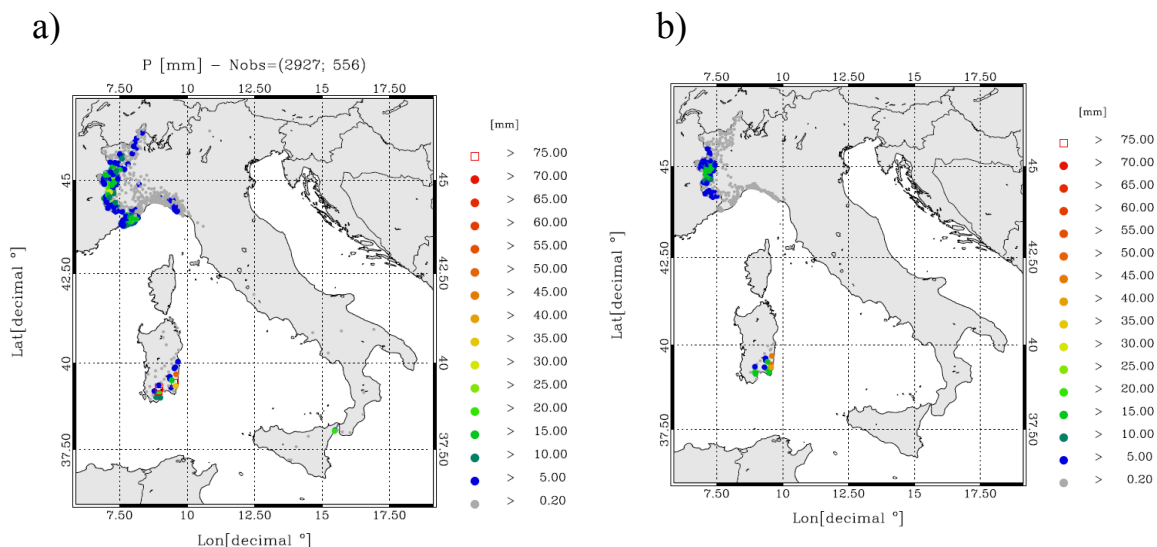


Figure 5: a) Precipitation observed between 18 and 21 UTC on 10 October 2018, only raingauges reporting at least 0.2 mm are shown; b) as in a) for the simulation assimilating the lightning.

Heavy precipitation is occurring over Sardinia, where two raingauges observed more than 75 mm/3h. The control simulation, without data assimilation, was unable to predict rainfall over Sardinia, while it represented, at least in part, the rainfall over NW of Italy (not shown).

Rainfall simulated by the simulation assimilating lightning is able to forecast the rainfall over South-eastern Sardinia (Figure 5b) even if the amount is underestimated, especially in the southern part of the region where 25-30 mm/3h were forecasted while one rainauge observed more than 75 mm/3h.

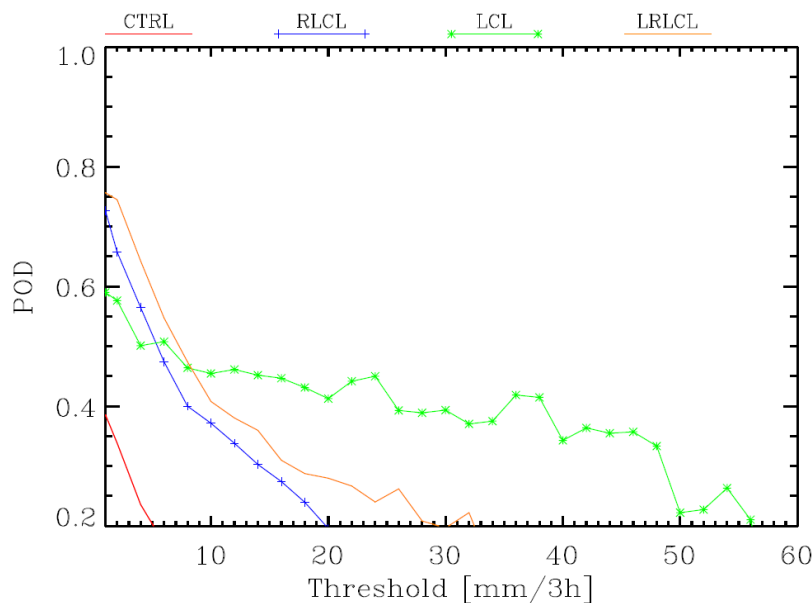


Figure 6: a) POD score computed for several configuration of RAMS@ISAC model.

Similar results were found for others three-hour precipitation forecasts over Sardinia. Figure 6 shows the composition of the POD score for height 3h precipitation forecasts on 10 October 2018. The curve of interest are the green curve (LCL), which refers to simulations assimilating lightning, and the red one (CTRL), without data assimilation. The improvement of lightning data assimilation is substantial.

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Mascitelli, Alessandra; Federico, Stefano; Fortunato, Marco; Avolio, Elenio; Torcasio, Rosa Claudia; Realini, Eugenio; Mazzoni, Augusto; Transerici, Claudio; Crespi, Mattia; Dietrich, Stefano: Data assimilation of GPS-ZTD into the RAMS model through 3D-Var: preliminary results at the regional scale. *Meas. Sci. Technol.* 30 (2019) 055801 (14pp). <https://doi.org/10.1088/1361-6501/ab0b87>

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

For the continuation of the project we will test further the performance of the Thompson scheme for specific cases, and eventually we will implement another two-moment scheme (WSD6, which is the same of WSM6 but with two moments). The aspects related to the implementation of RAMS-CSU are becoming less important because the implementation of the two-moment scheme should be explored in more detail and because the data assimilation system of RAMS is now available to evaluate the impact of different observation types on the RAMS@ISAC forecast. We believe that the latter aspect is more interesting than the evaluation of RAMS-CSU performance and we will focus on this topic in place of the evaluation of RAMS-CSU in the following of this special project.