Impact of lightning data assimilation on the short-term rainfall forecast over Italy

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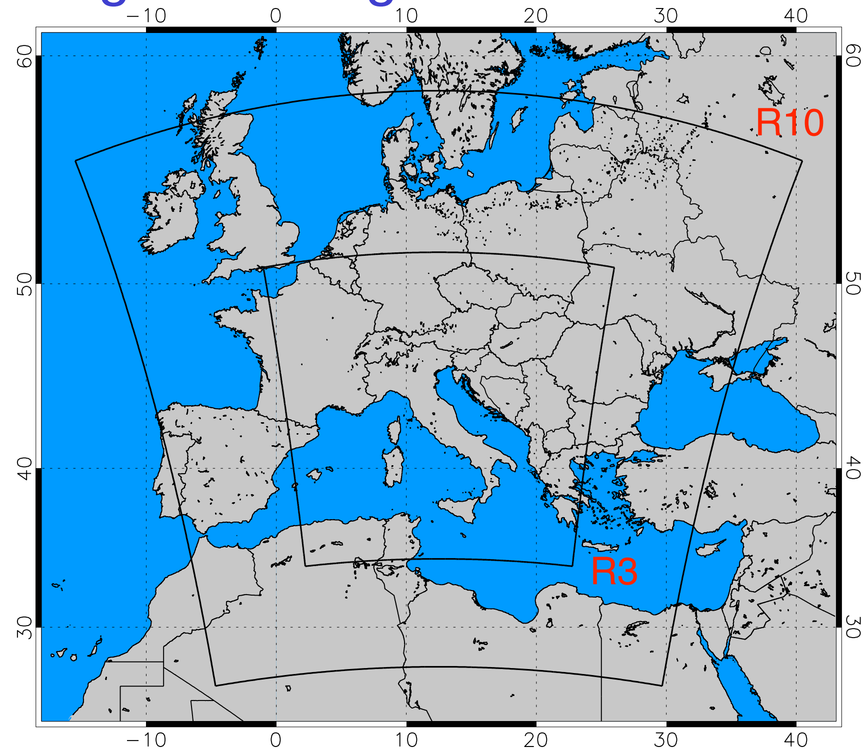
OUTLOOK

- Meteorological drivers: RAMS@ISAC and WRF;
- Lightning data assimilation (LDA);
- Radar reflectivity data assimilation (RDA);
- A challenging case study (15 July 2020, Palermo);
- An extended verification (one year period);
- Impact of LDA over the Central Mediterranean Sea.

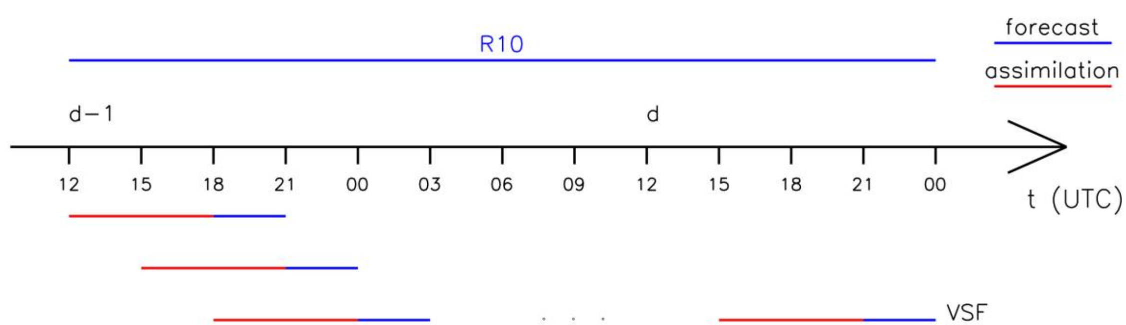
RAMS@ISAC grids configuration

	R10	R3
NNXP	351	635
NNYP	351	635
NNZP	42	42
Lx (km)	3510	1905
Ly (km)	3510	1905
Lz (km)	23.1	23.1
DX (km)	10	3
DY (km)	10	3
CENTLAT	43N	43N
CENTLON	12.5E	12.5E



Very Short-term Forecast (VSF) configuration

8 forecast for every day, lasting 9 hours each. Each forecast consists of an assimilation period of 6 hours followed by a VSF period 3 hours long.



Lightning assimilation – Nudging

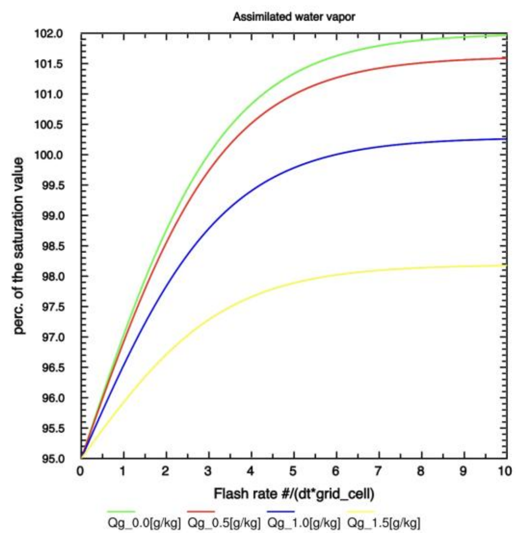
$$q_v = Aq_s + Bq_s tanh(CX)(1 - tanh(Dq_g^\alpha)) \qquad [1]$$

where q_s is the saturation mixing ratio at the model atmospheric temperature , q_v water vapour mixing ratio to be computed, q_g is the graupel mixing ratio, X is the number of total flashes falling in a grid box in a 5 minutes interval; the constants are set to: A=0.95, B=0.07 e C=0.3, D=0.25,α =2.2.

The water vapor mixing ratio substitution in the vertical layer (LCL; -25 °C) takes place if the model mixing ratio is lower than that calculated by [1]. This method can only add water vapour to the forecast.

From [1] follows that with 10 flashes in 5 minutes saturation is reached in absence of graupel.

Lightning data are provided by LINET (Betz, 2009; Atmos. Res.) and downloaded in real time by ISAC-CNR in Rome

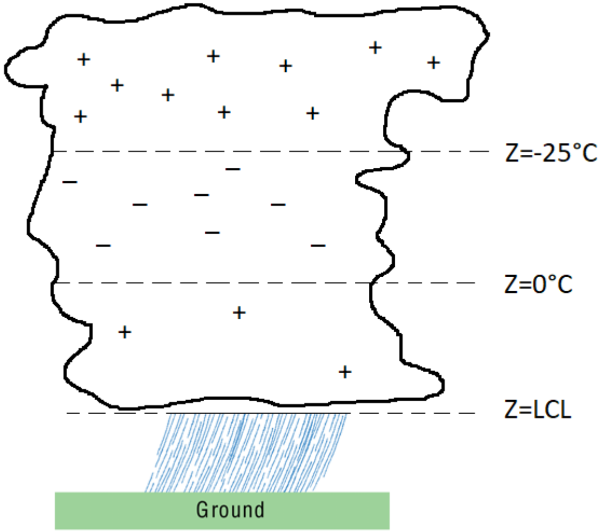


Fierro et al., 2013, MWR.

Lightning assimilation – 3DVar

A relative humidity pseudo-profile is generated when/where lightning is observed:

$$RH: \begin{cases} NO\ DATA & z < z_{LCL} \\ 100\% & z_{LCL} \leq z \leq z_{-25°C} \\ NO\ DATA & z > z_{-25°C} \end{cases}$$



Time window: 30 minutes

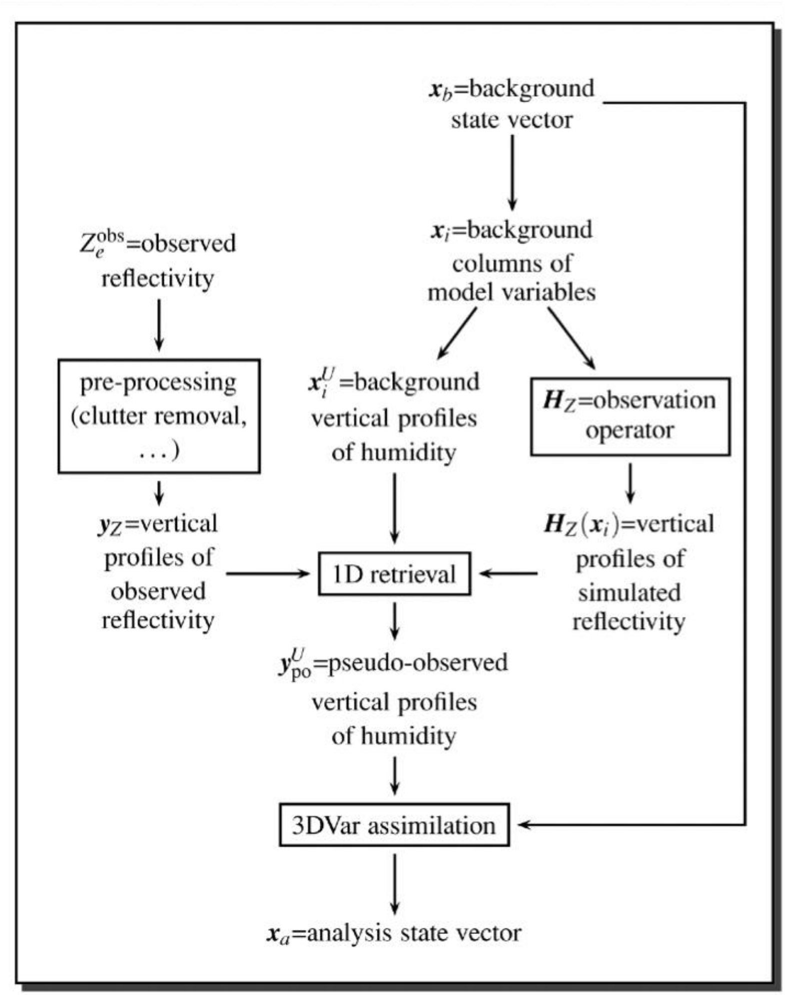
This relative humidity pseudo-profile is assimilated by RAMS-3DVar once the relative humidity has been converted in water vapor mixing ratio:

$$J(x) = \frac{1}{2}(x - x_b)^T B^{-1}(x - x_b) + \frac{1}{2}[H(x) - y_o]^T R^{-1}[H(x) - y_o]$$

The background error matrix is computed by the NMC method which considers 15 days of simulations before the event.

Radar reflectivity data assimilation – 3DVar

Caumont et al., 2010, Tellus 62A

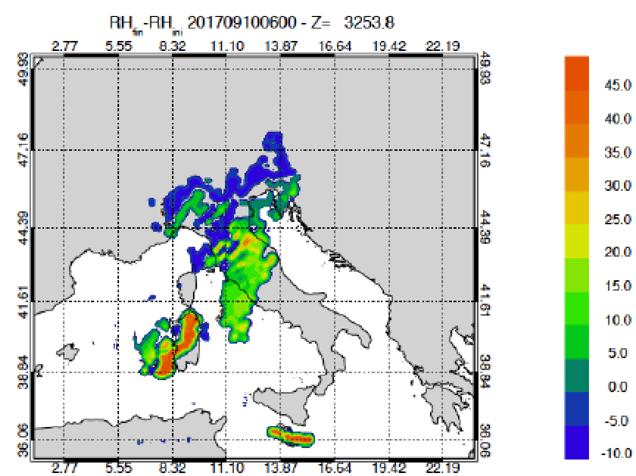


$$y_{po}^U = \sum_i x_i^U \frac{W_i}{\sum_j W_j}$$

$$W_i \equiv \exp\left\{-\frac{1}{2}[y_0 - h(x_i)]^T R^{-1} [y_0 - h(x_i)]\right\}$$

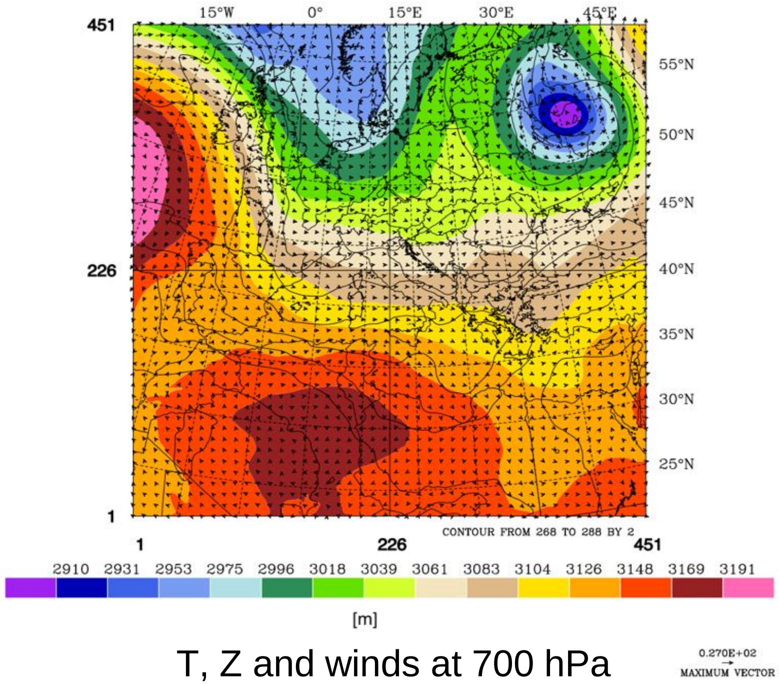
$$J(X) = \frac{1}{2}(X - X_b)^T B^{-1} (X - X_b) + \frac{1}{2}[Y - H(X)]^T R^{-1} [Y - H(X)].$$

An example:
06 UTC 10/09/2017

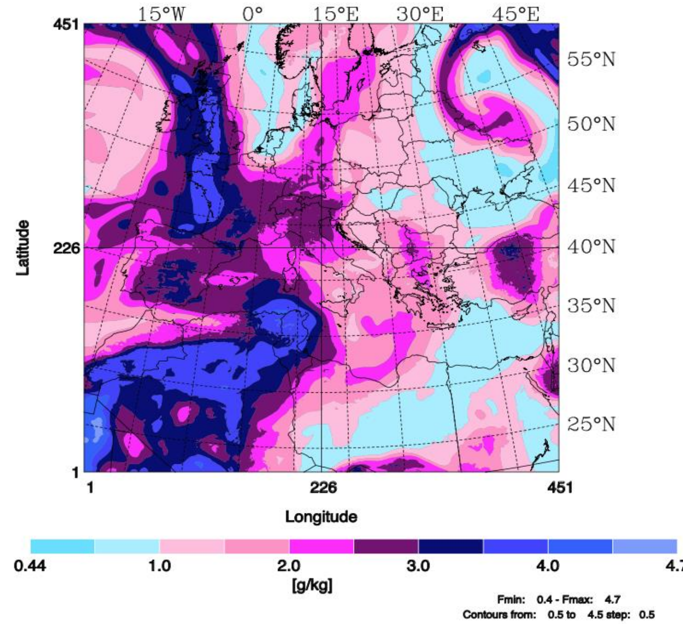


RADAR CAPPI of the national radar composite at 2000m, 3000m, 4000m and 5000m, 6000m, 7000m and 8000 mare assimilated.

Case study Palermo 15/07/2020 – Synoptic analysis 00 UTC



T, Z and winds at 700 hPa
Diffluent flow over Sicily



A key ingredient of this event is the water vapour plume from tropical latitudes towards Sicily.

Raingauge	Longitude (°)	Latitude (°)	Height (m)	Observed precipitation (mm)			Total observed precipitation (mm) 14-17 UTC
				14-15 UTC	15-16 UTC	16-17 UTC	
Palermo SIAS	13.3276	38.1298	0	37.80	84.99	11.19	133.98
Palermo UIR	13.3350	38.1167	55	47.20	66.80	1.60	115.6
Palermo Zootecnico	13.3006	38.1164	120	33.60	68.70	1.20	103.5
Average Precipitation	/	/	/	39.5	73.5	4.6	117.8

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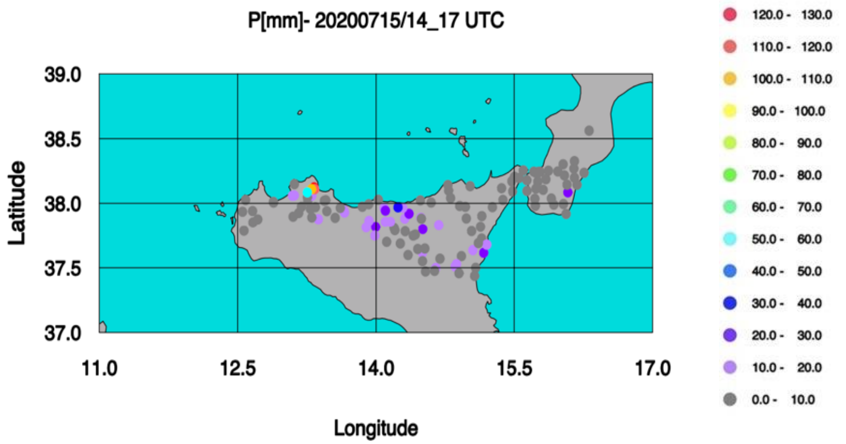
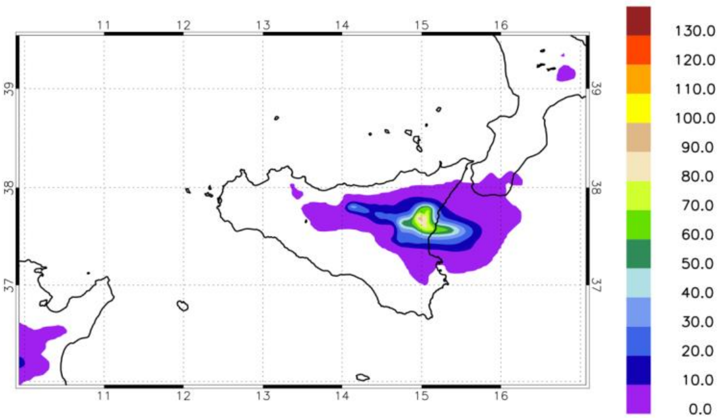
Case study Palermo 15/07/2020 – Precipitation 14-17 UTC

OBS

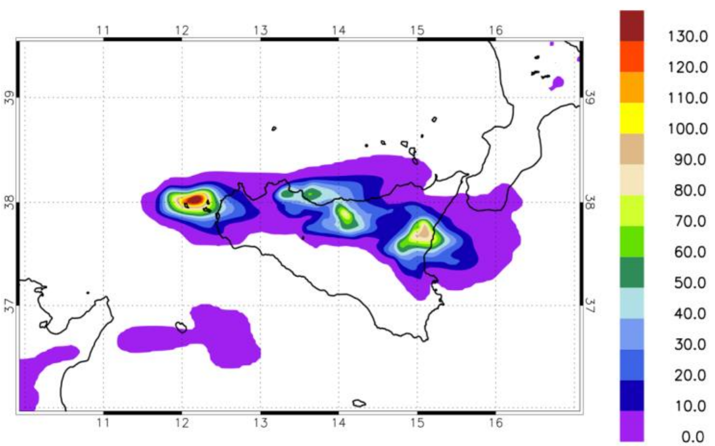


BCKG

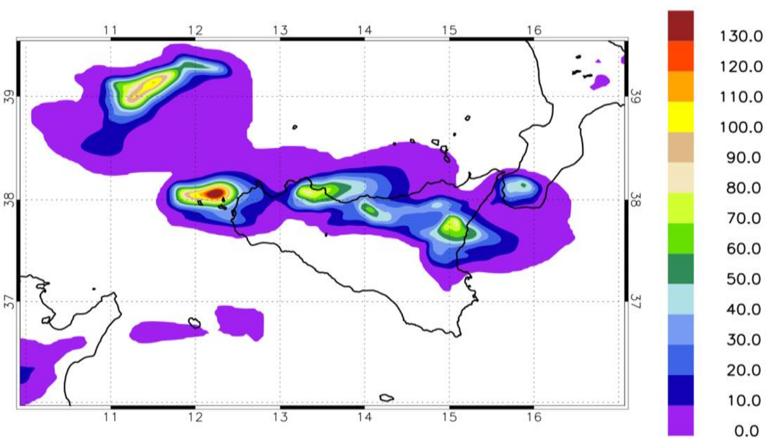


RAMS@ISAC

LDA



RDA+LDA



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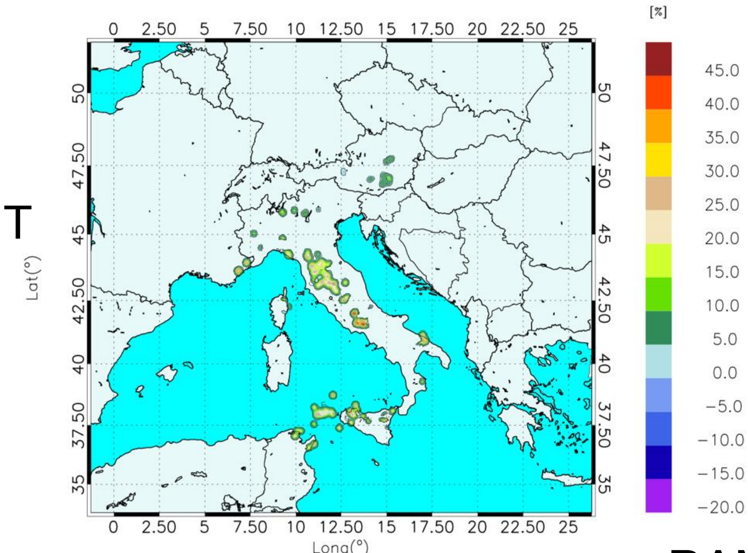
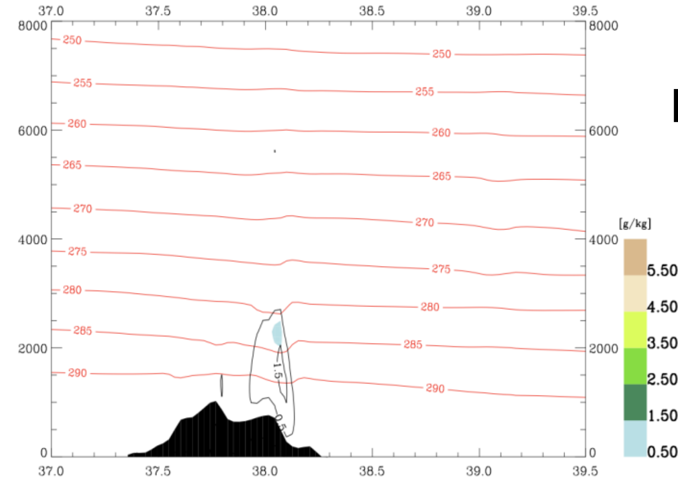
Case study Palermo 15/07/2020 – Analyses and FCST

LIGHT



13:30 UTC

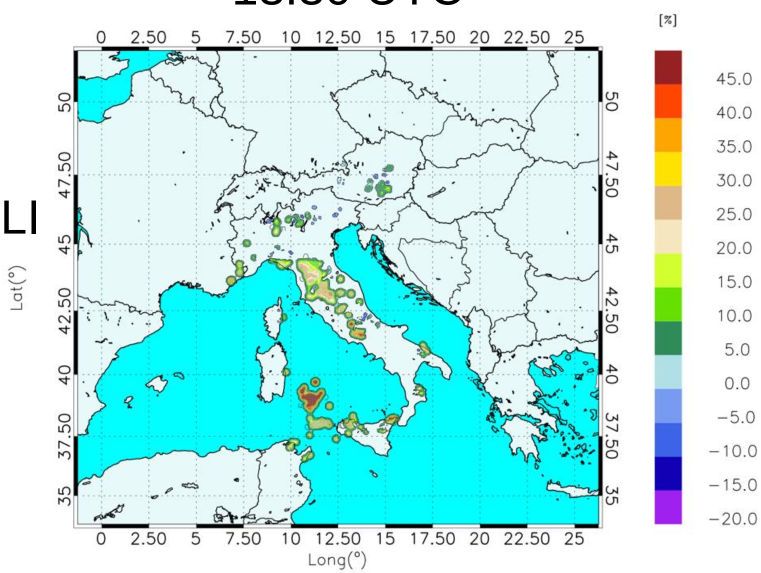
BCKG



14:00 UTC

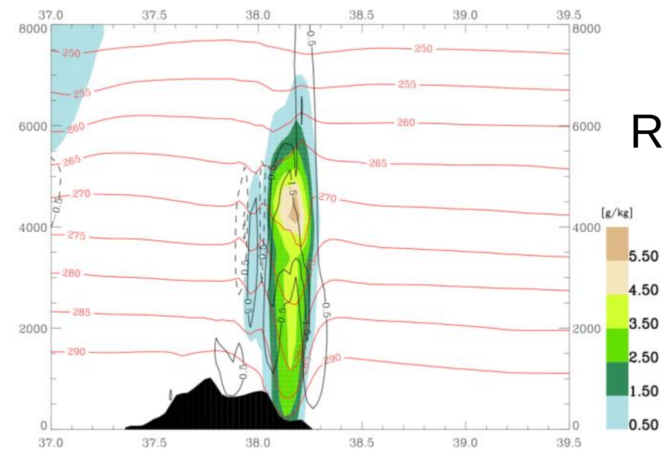
RAMS@ISAC

RADLI



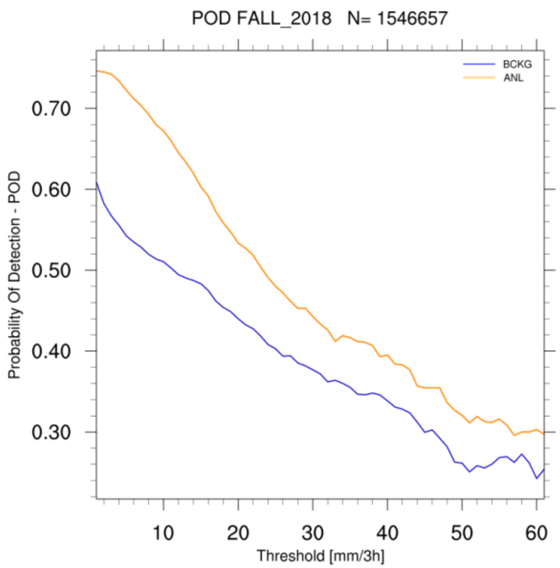
Relative humidity adjustment (%)

RDA+LDA

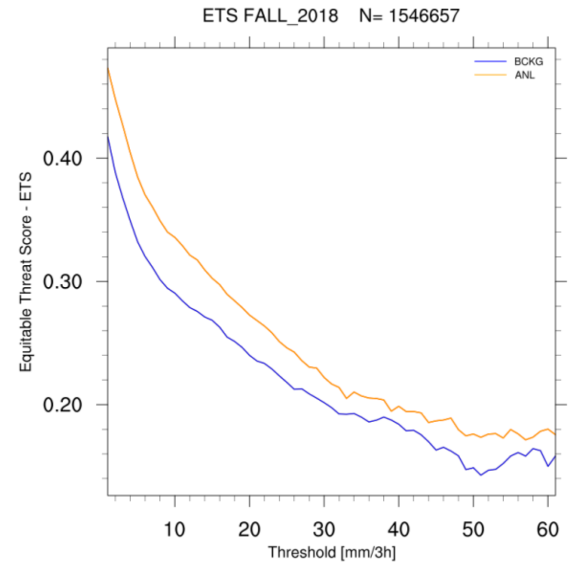


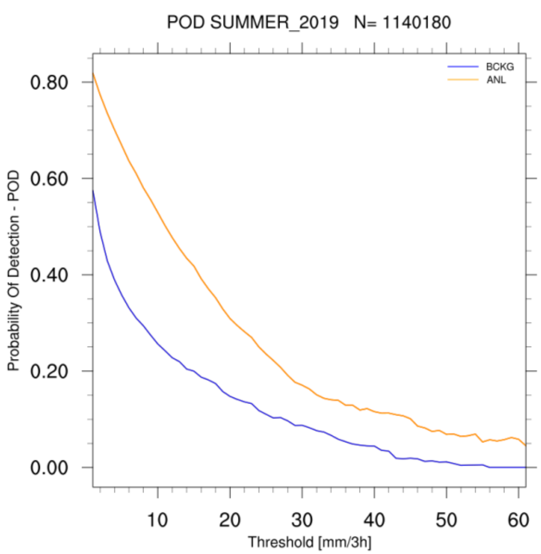
Total condensate (filled),
w (black contours), T (red contours)

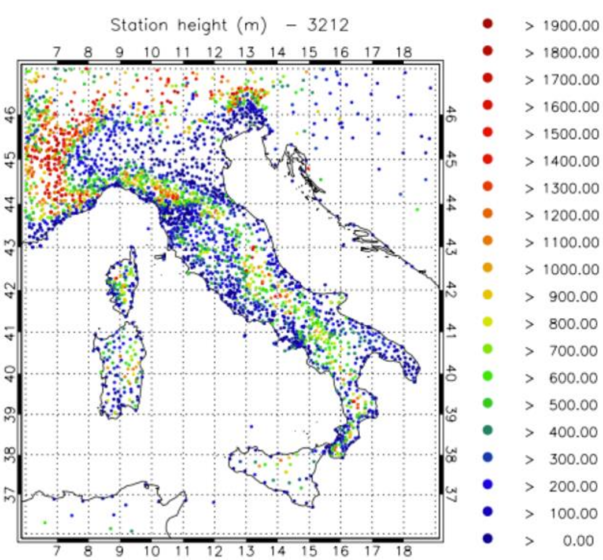
Lightning assimilation: Verification on a one-year period (1 September 2018– 31 August 2019). Results for fall 2018 and summer 2019

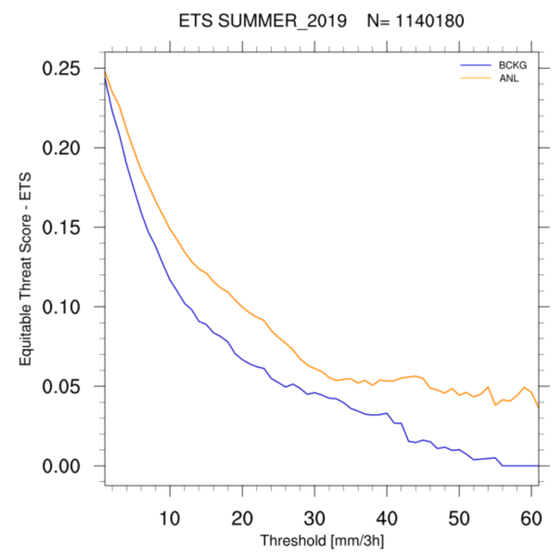


Season	N. data
Fall	1546657
Winter	1313174
Spring	1576461
Summer	1140180





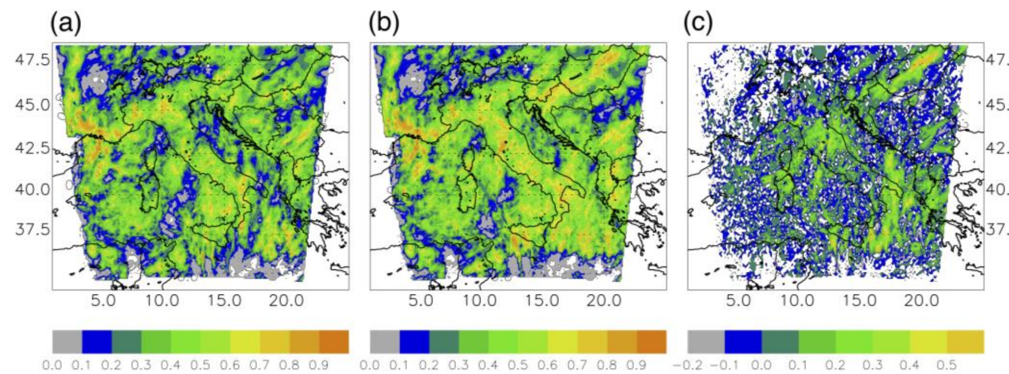




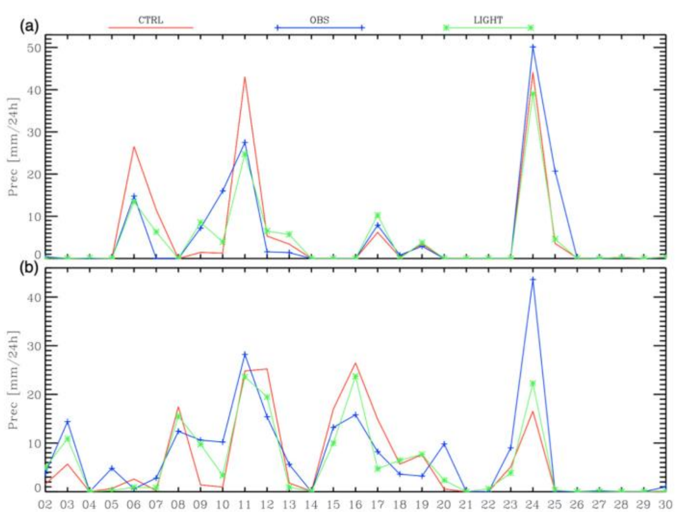
RAMS@ISAC

Impact of the LDA on the VSF over the Central Mediterranean Sea

WRF model domain. The horizontal grid spacing is 3km. The yellow dots represent the islands'positions.



Comparison between WRF precipitation forecast and IMERG Final Run dataset for the whole month of November 2019: Pearson correlation coefficient calculated for CTRL forecast (a), LIGHT forecast (b), and correlation coefficient differences between LIGHT and CTRL (c).



	Elba		Giglio		Lipari		Montecristo		Pantelleria		Ponza	
	C	L	C	L	C	L	C	L	C	L	C	L
RMSE [mm]	1.76	1.36	4.36	4.22	2.34	1.50	2.26	2.15	1.39	1.32	2.46	2.60
r	0.70	0.83	0.45	0.49	0.58	0.78	0.40	0.47	0.49	0.54	0.66	0.60

RMSE and Pearson correlation coefficient for six Italian small islands in the Central Mediterranean Sea, with available rain gauge data. Statistics are computed considering all the 3 h rainfall forecasts for November 2019 (C is for CTRL; L is for LIGHT).

Torcasio et al., 2021 – Remote Sensing

Conclusions

Lightning has been assimilated into the RAMS@ISAC model since 2016 and in WRF since 2019 (at CNR-ISAC).

Two different methods are available: nudging and 3DVar.

Flashes can be assimilated with radar reflectivity data, GPS-ZTD and others data.

Lightning can locate convection precisely and its assimilation in NWP improves the very short-term forecast (RAMS@ISAC).

Quantitative precipitation statistics and qualitative score are substantially improved by lightning assimilation for a one-year long simulations (RAMS@ISAC).

We get a robust and positive impact of the very short-term (3h) precipitation forecast over the central Mediterranean Sea when lightning are assimilated (WRF).

Acknowledgments: LINET data were provided by Nowcast GmbH (https://www.nowcast.de/) within a scientific agreement between H.D. Betz and the Satellite Meteorological Group of CNR-ISAC in Rome. Part of the computational time used for this paper was granted by the ECMWF (European Centre for Medium range Weather Forecast) throughout the special project SPITFEDE.

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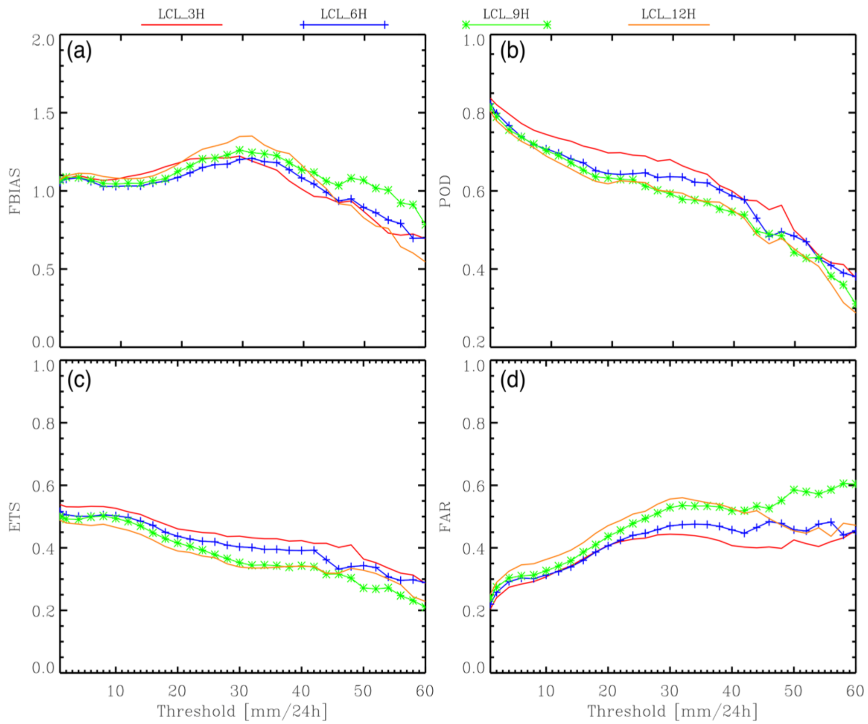
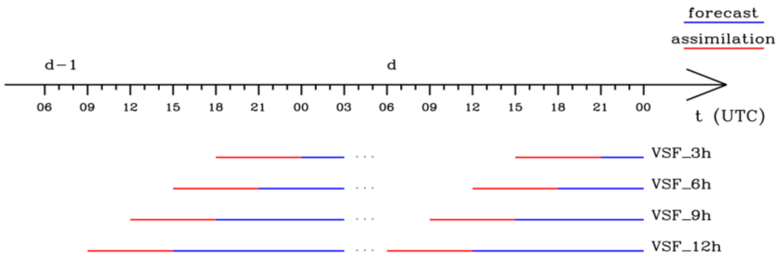
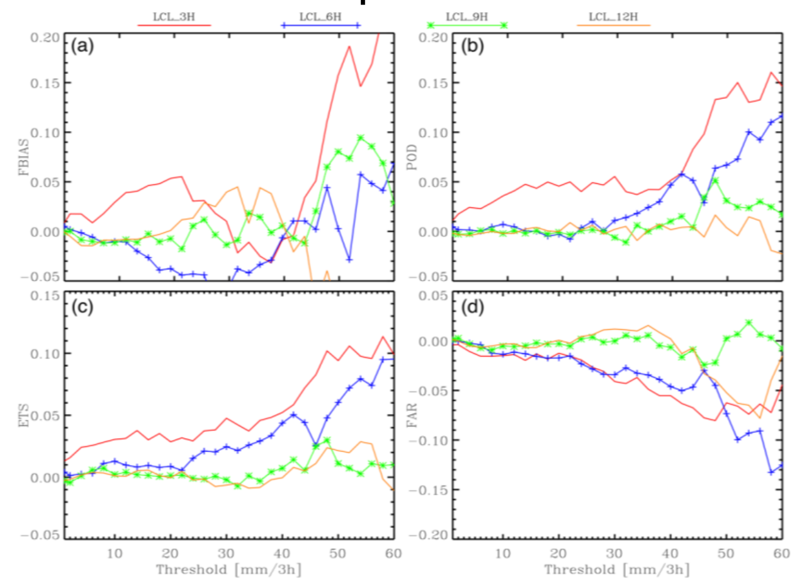
Performance decrease with forecasting time



a) FBIAS; b) POD; c) ETS; d) FAR computed from cumulative contingency tables of 10 days in November 2019. Flashes are assimilated by nudging from the lifting condensation level to the -25°C isotherm.



VSF implementations



Difference between the scores of LCL_3h and CTRL (red curve), LCL_6h and CTRL (blue curve), LCL_9h and CTRL (green curve) and LCL_12h and CTRL (orange curve); a) FBIAS, b) POD; c) ETS; d) FAR. Flashes are assimilated by nudging from the lifting condensation level to the -25°C isotherm.

Federico et al., book chapter. In press.