Performance of COSMO-based ensemble systems for cases of High-Impact Weather over Italy

G. Pincini (1), **A. Montani** (2), **T. Paccagnella** (1), **M.S. Tesini** (1), **C. Marsigli** (3)
(1) Arpae-SIMC, (2) ECMWF, (3) DWD

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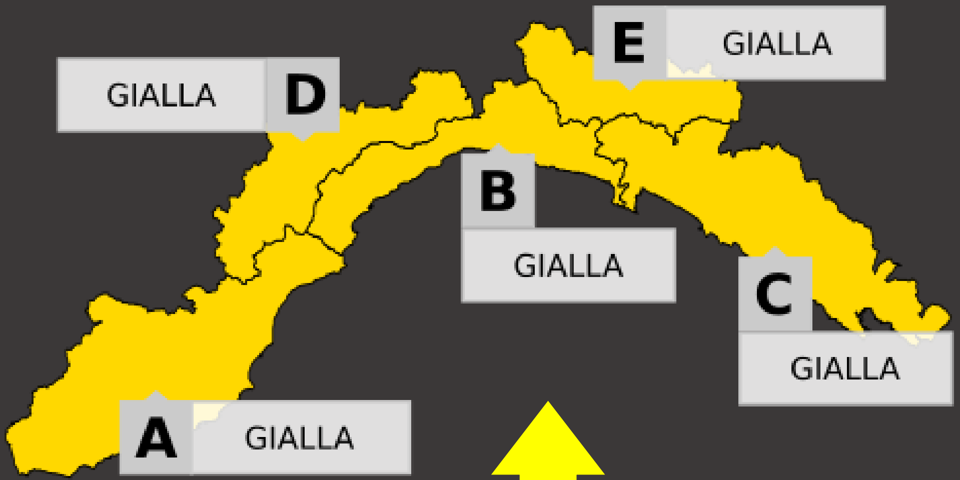
emilia-romagna

MOTIVATION OF THE WORK

➢ <u>**Motivation:**</u> the forecast of ''High-Impact Weather'' (HIW) events with high spatio-temporal detail still suffers from severe limitation because of HIW horizontal dimension too small to expliced resolved by state-of-art of Numerical Weather Prediction (NWP) systems.

Centro Funzionale di Protezione Civile della Regione Liguria
AVVISO METEOROLOGICO
per la REGIONE LIGURIA



ZONA	Intensità PIOGGE	Quantità PIOGGE	TEMPORALI Forti
A			Alta prob.
B	Forte	Elevata	Alta prob.
C	Forte	Significativa	Alta prob.
D	Forte	Significativa	Alta prob.
E	Forte	Significativa	Alta prob.

➢ **Example: 9 November 2018**

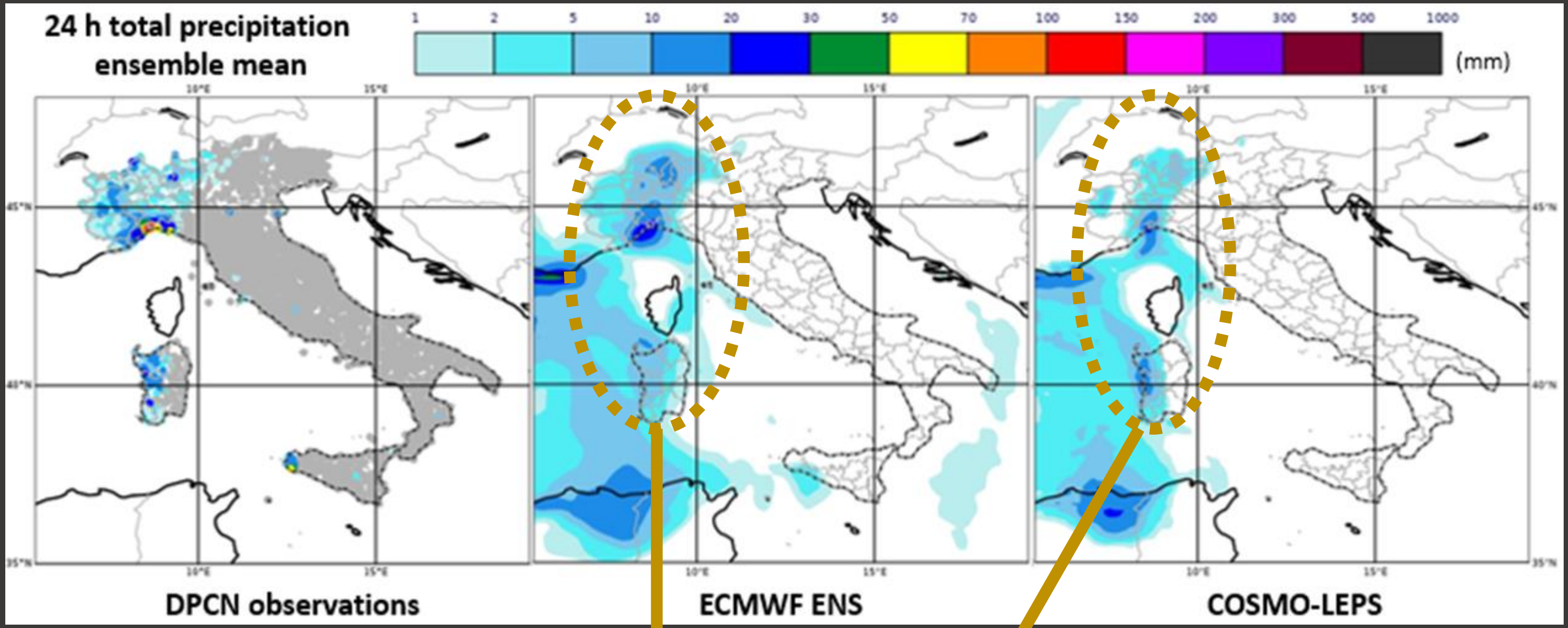
Yellow alert for thunderstorm risk

- Liguria
- Part of the southern Piedmont

(Bulletin of the National Civil Protection Department issued on 8 November 2018)

MOTIVATION OF THE WORK

➢ **Motivation:** the forecast of ''High-Impact Weather'' (HIW) events with high spatio-temporal detail still suffers from severe limitation because of HIW horizontal dimension too small to expliced resolved by state-of-art of Numerical Weather Prediction (NWP) systems.



➢ **Example**

Maps of the ensemble mean of total precipitation cumulated over 24 hours for the **9 November 2018**:

- on the left observations from rain gauges of the national network;
- in the middle as was predicted by the run of 9 November 2018 00 UTC by the ensemble mean of the global ensemble system;
- on the right the same but for the COSMO-based limited-area ensemble prediction systems.

Inaccuracies:

- In the intensity
- In the spatial localization

There is room for improvement

PURPOSE OF THE WORK

- The **main pourpose** of this study is to assess the performance of a newly developed high-resolution ensemble prediction system for a number of HIW events. It is planned to compare its performance against two state-of-art ensemble prediction systems, both running on an operational basis.

- The **main issues** to be addressed in this work are:

1. How do the different ensemble systems behave in terms of prediction skill for **precipitation**?
2. What is the added value of **high resolution**? In which type of **verification** does it emerge more clearly?

OUTLINE

- The ensemble forecast systems → ECMWF ENS / COSMO-LEPS / COSMO-2I-EPS

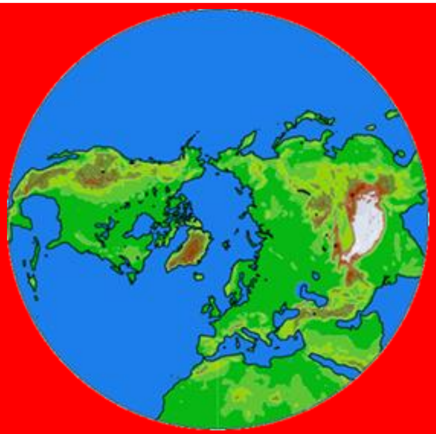
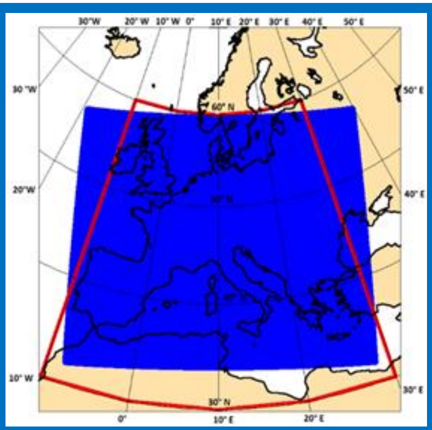
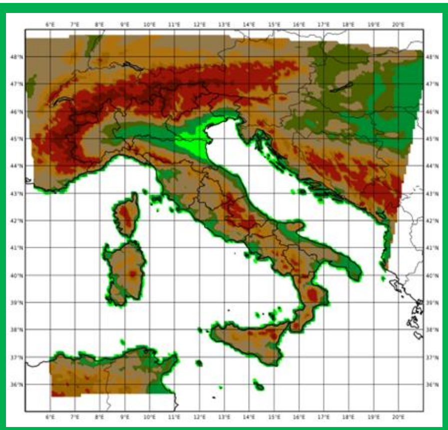
- Description of the experiment

Performance of the ensemble systems	
20 June – 27 June 2016	15 October – 15 November 2018

- Conclusions


The ensemble forecast systems
Portonovo

OVERVIEW ON ECMWF ENS , COSMO-LEPS, COSMO-2I-EPS

ENSEMBLE SYSTEM / MAIN TECHNICAL FEATURE	ECMWF ENS	COSMO-LEPS	COSMO-2I-EPS
Integration domain			
Horizontal resolution (km)	18	7	2,2
Vertical resolution (Model level)	91	40	65
Forecast range (hours)	240	132	48
Type of model	Hydrostatic model	Non-hydrostatic model	Non-hydrostatic model
Type of convection	Parameterized convection	Parameterized convection	Explicit convection
Ensemble size	51	16	10 -> 20
Starting times (UTC)	00, 06, 12, 18	00, 12	00 -> 21

DESCRIPTION OF THE EXPERIMENT

Due to the limited availability of COSMO-2I-EPS, the intercomparison is performed over two periods:

- from 20 to 27 June 2016
- from 15 October to 15 November 2018,

starting at **00 UTC** and with a forecast range of **48 hours** (post-processing frequency every 6 hours).

The systems are compared over the **Italian region**.

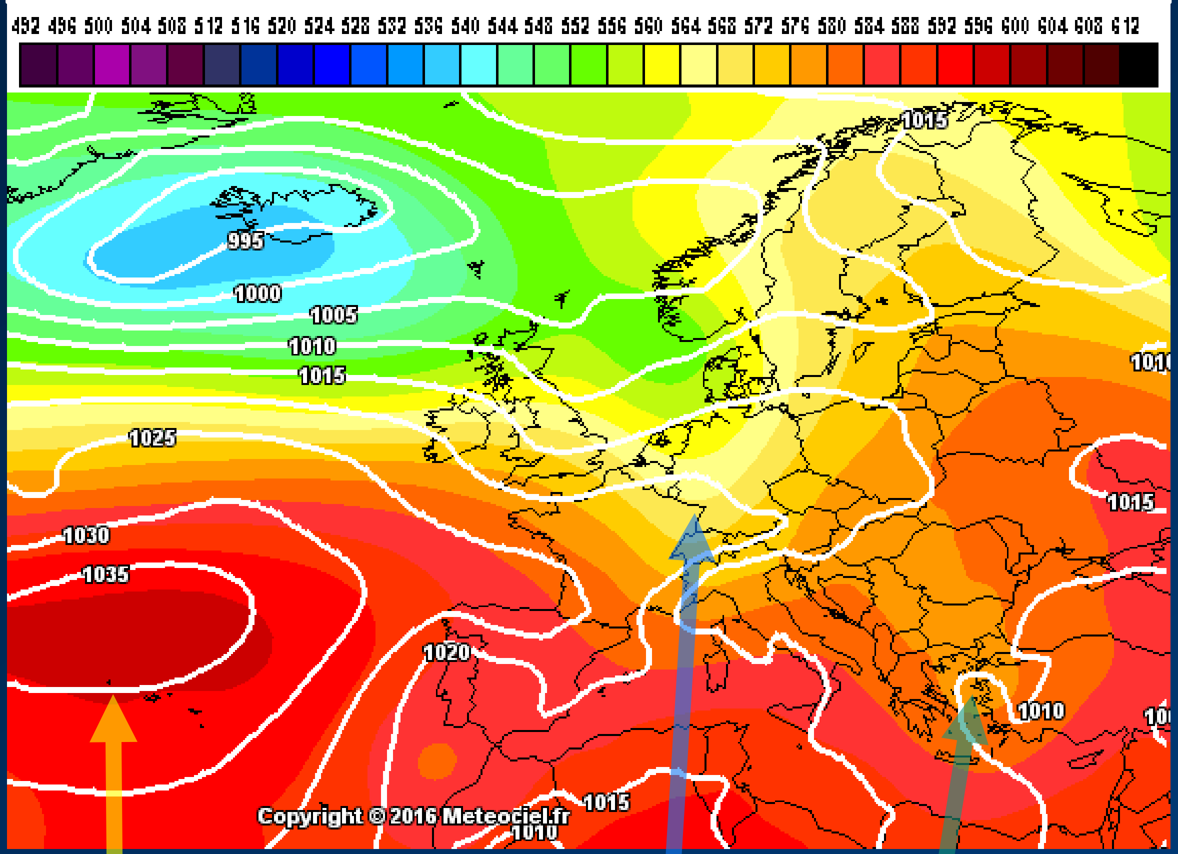
Italian domain
Latitude: 35N – 48N
Longitude: 6E - 19E


1st VERIFICATION PERIOD:
20 JUNE – 27 JUNE 2016

SYNOPTIC DESCRIPTION

27 JUNE 2016

500 hPa geopotential height (dam) shading and mslp (hPa) white lines from Reanalysis ERA-Interim



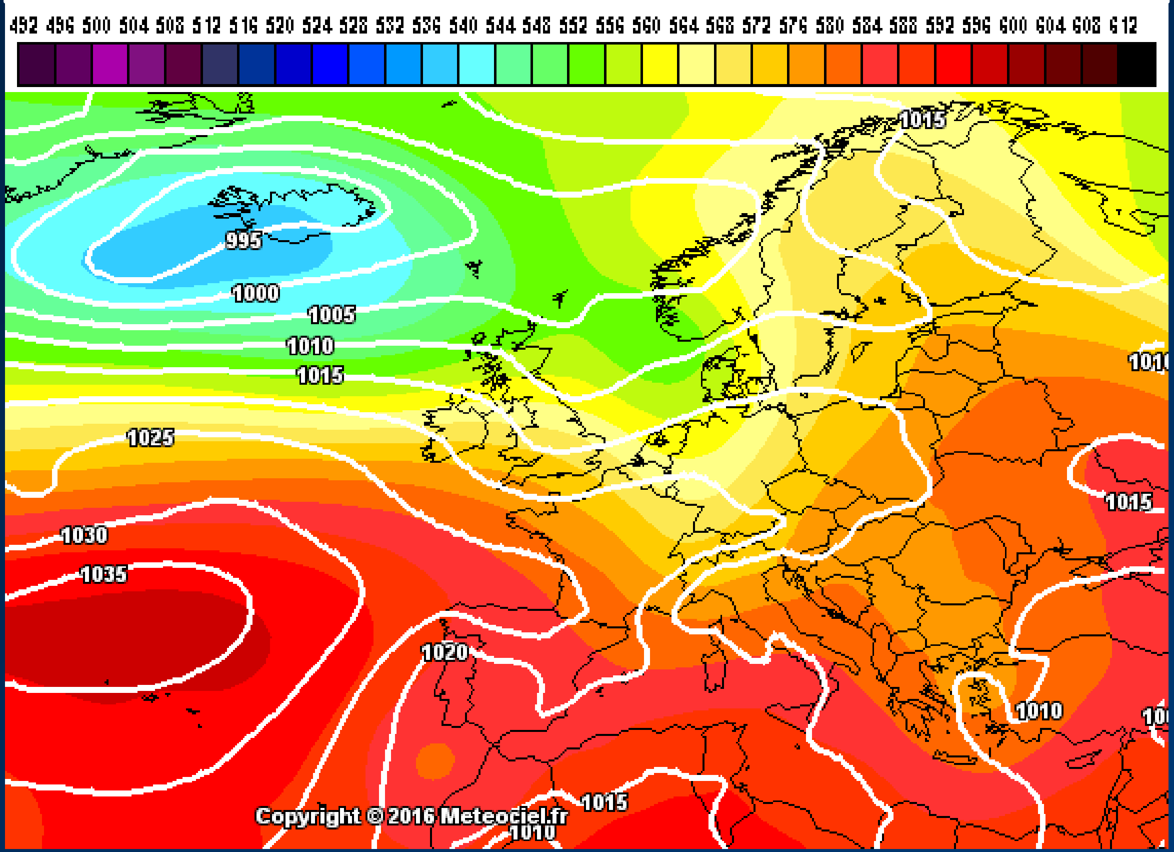
The **Azores Anticyclone** is expanding on the Iberian Peninsula and France.

An **Atlantic trough** is approaching Italy.

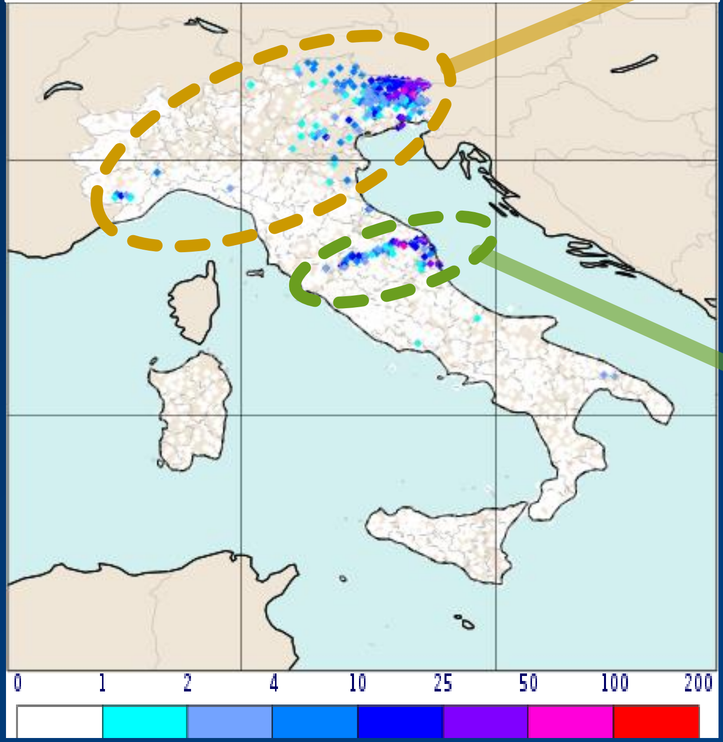
A **cut-off low** is dissolving over the Aegean Sea.

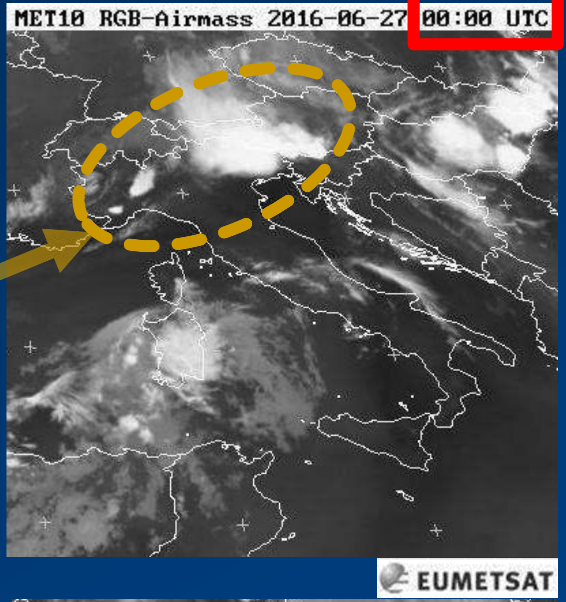
SYNOPTIC DESCRIPTION
27 JUNE 2016

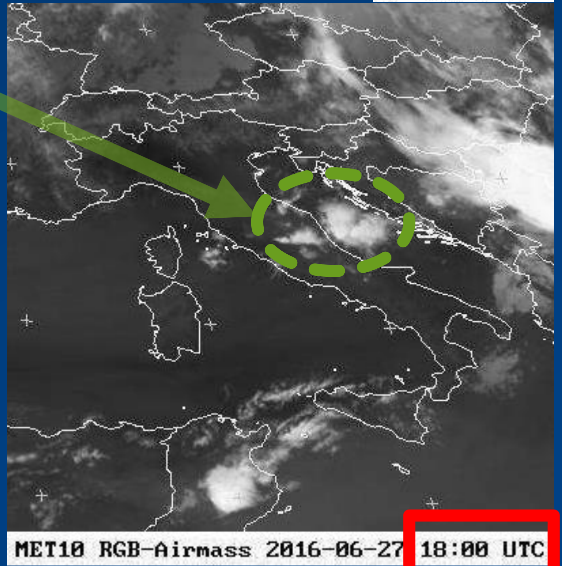
500 hPa geopotential height (dam) shading and mslp (hPa) white lines from Reanalysis ERA-Interim



24h total precipitation (mm) from national network stations







Rainfall occurred at two distinct times of the day: **during the night in the North**, **in the late afternoon in the Centre**.
In some location (**Friuli Venezia Giulia** and **Marches**) there were peaks exceeding 50 mm.

In the satellite images storm cells responsible for precipitation can be noticed.

METHODOLOGY OF VERIFICATION

ROOT MEAN SQUARE ERROR (RMSE):

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{Y}_i)^2}$$

RMSE provides the square root of the average square error of the forecast. The forecast corresponds to the ensemble mean value and an 'error' represents the difference between the ensemble mean $\bar{Y}$ and the observations x. RMSE of ensemble mean measure the distance between the forecast mean and observations.

ENSEMBLE SPREAD (SPRD):

$$SPRD = \sqrt{\frac{1}{M-1}\sum_{m=1}^{M}(f_m - \bar{f})^2}$$

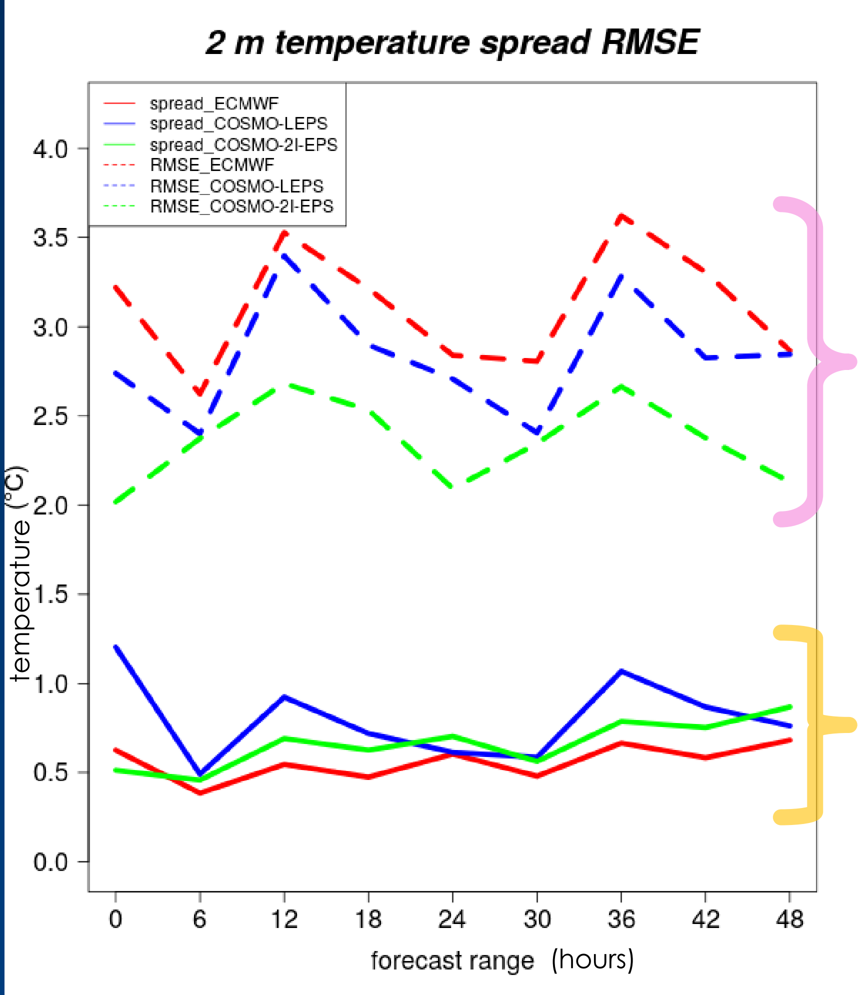
SPRD is calculated by measuring the deviation of ensemble forecasts from their mean (Zhu, 2005),

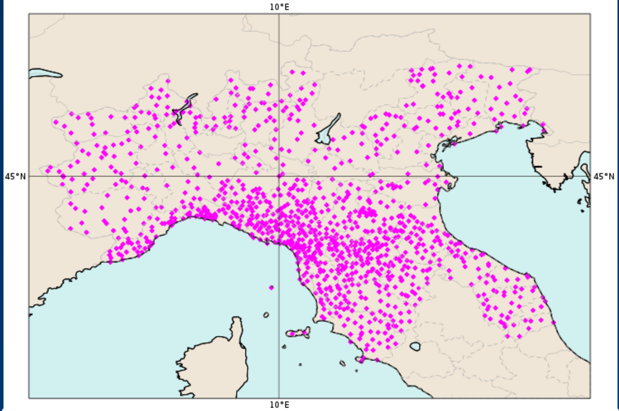
where M is the ensemble size, f_m is the m^{th} ensemble member and $\bar{f} = \frac{1}{M}\sum_{m=1}^{M} f_m$ is the ensemble mean.

In a perfect ensemble forecast the ensemble spread should match the root mean square error of the ensemble mean over the same period.

SURFACE VERIFICATION

Variable	2-M TEMPERATURE
Verification features	
Period	From 20/06/2016 00 UTC to 27/06/2016 00 UTC
Region	Central-Northern Italy
Method	Nearest grid point
Observations	Quality-controlled regional station network (≈1000), no obs error
Forecast range	0-48 h (verification every 6 h)
Systems	ECMWF ENS, COSMO-LEPS, COSMO-2I-EPS
Scores	SPRD, RMSE





Observations network

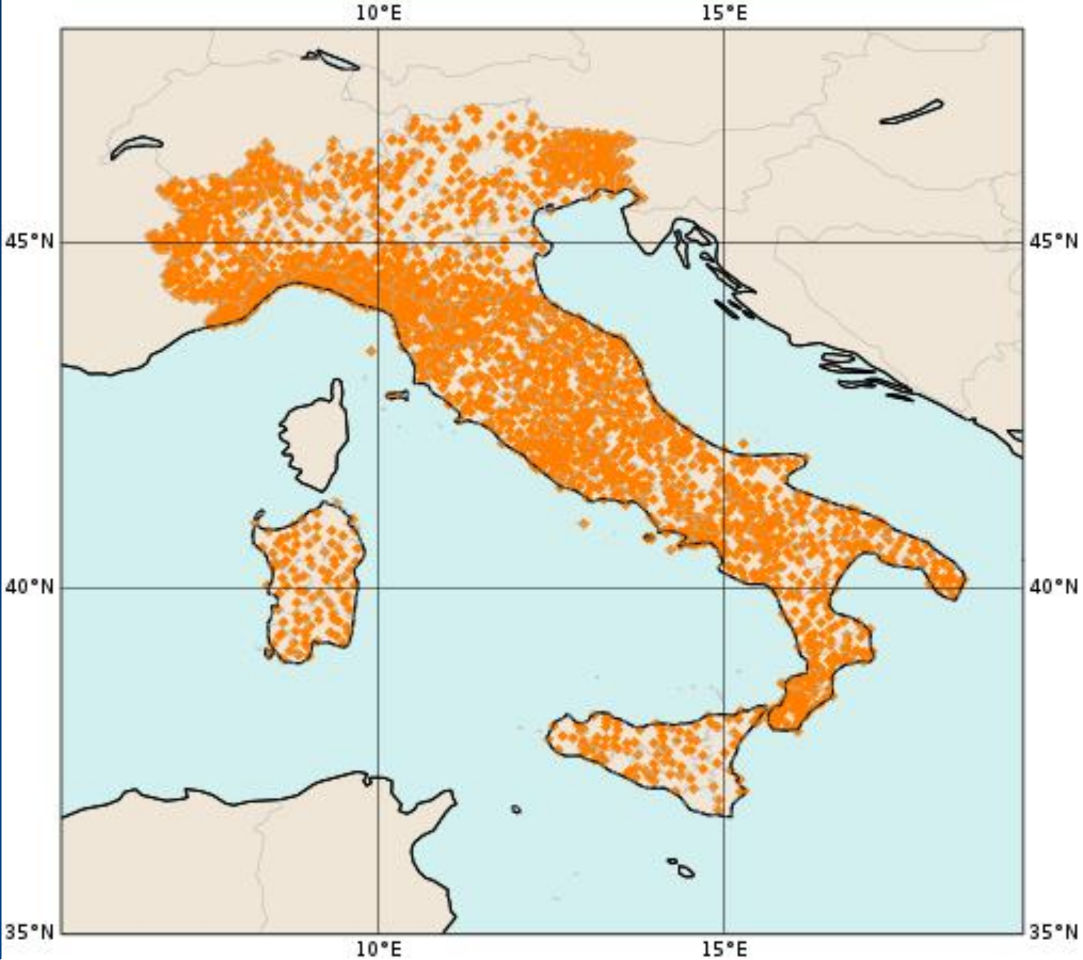
RMSE: COSMO-2I-EPS has the lowest errors among the three ensemble systems. Larger errors during day time.

SPRD: generally too small and very similar to each other.

VERIFICATION

6-H TOTAL PRECIPITATION

Verification features	
Period	From 20/06/2016 00 UTC to 27/06/2016 00 UTC
Region	Italy
Method	Nearest grid point
Observations	Network of Dipartimento Protezione Civile Nazionale (5524 stations), no obs error
Forecast range	0-48 h (verification every 6 h)
Systems	ECMWF ENS, COSMO-LEPS, COSMO-2I-EPS
Scores	**RPS** **percentage of outliers**
Thresholds	(1, 5, 10, 15, 25, 50) mm/6h



Observations network

VERIFICATION
6-H TOTAL PRECIPITATION

- **Ranked Probability Scores (RPS)** is an extension of the RMSE to the probabilistic world and to the multi-category events. RPS ϵ (0,1)

$$RPS = \frac{1}{J-1}\sum_{m=1}^{J}\left(\sum_{j=1}^{m} f_j - \sum_{j=1}^{m} o_j\right)^2$$

J is the number of forecast categories (one per threshold)

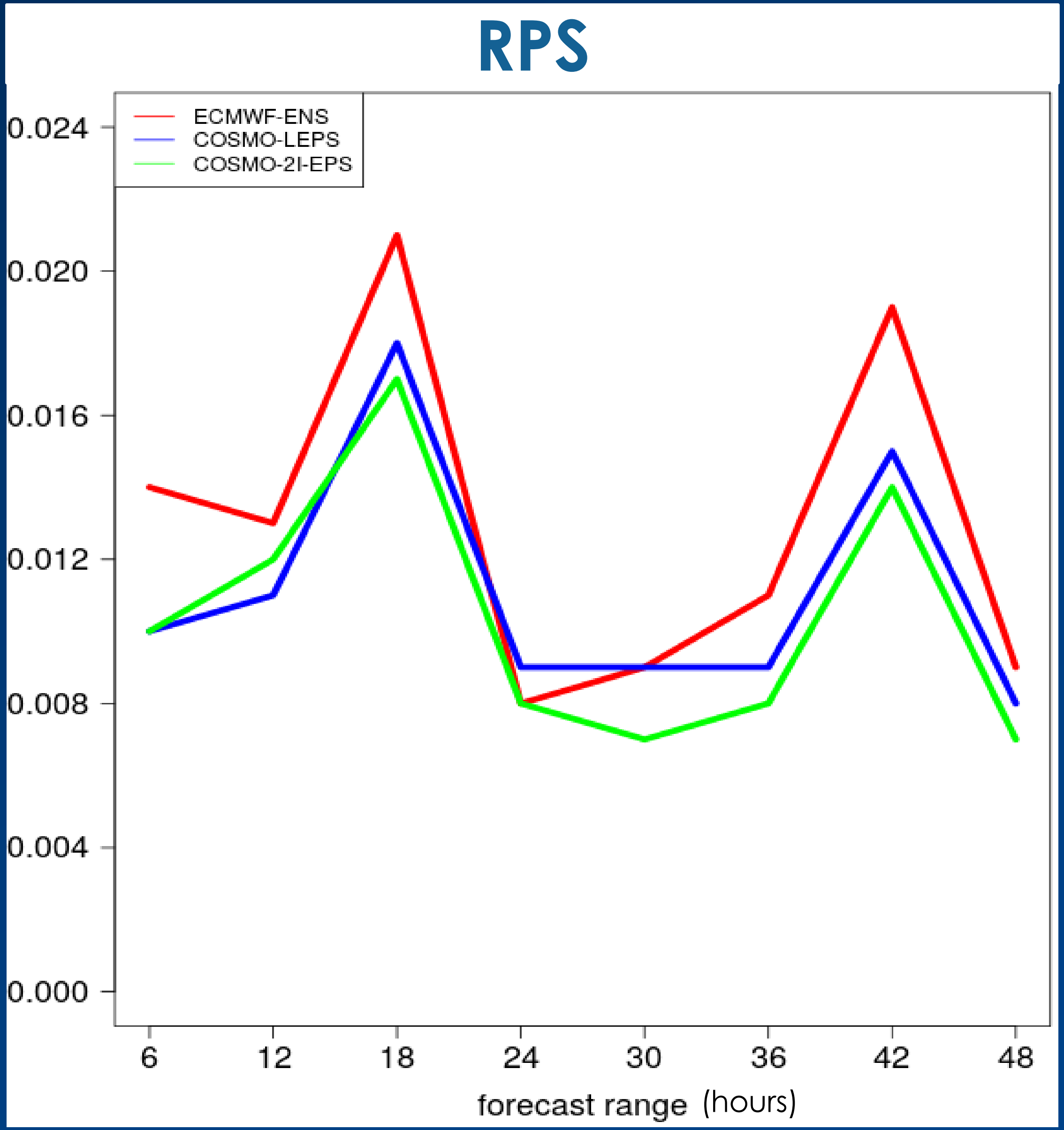
$O_j = 1$ if the event occurs in category j

$O_j = 0$ if the event does not occur in category j

f_j is the probability of occurence in category j

The lower the RPS, the better the ensemble system

- The diurnal cycle of precipitation is very marked. Precipitation occurred mainly in the afternoon, when the RPS are the highest (12-18 h, 36-42 h);
- The RPS of COSMO-2I-EPS, and generally the RPS of COSMO-systems, is lower than ECMWF ENS one for all forecast ranges.



VERIFICATION

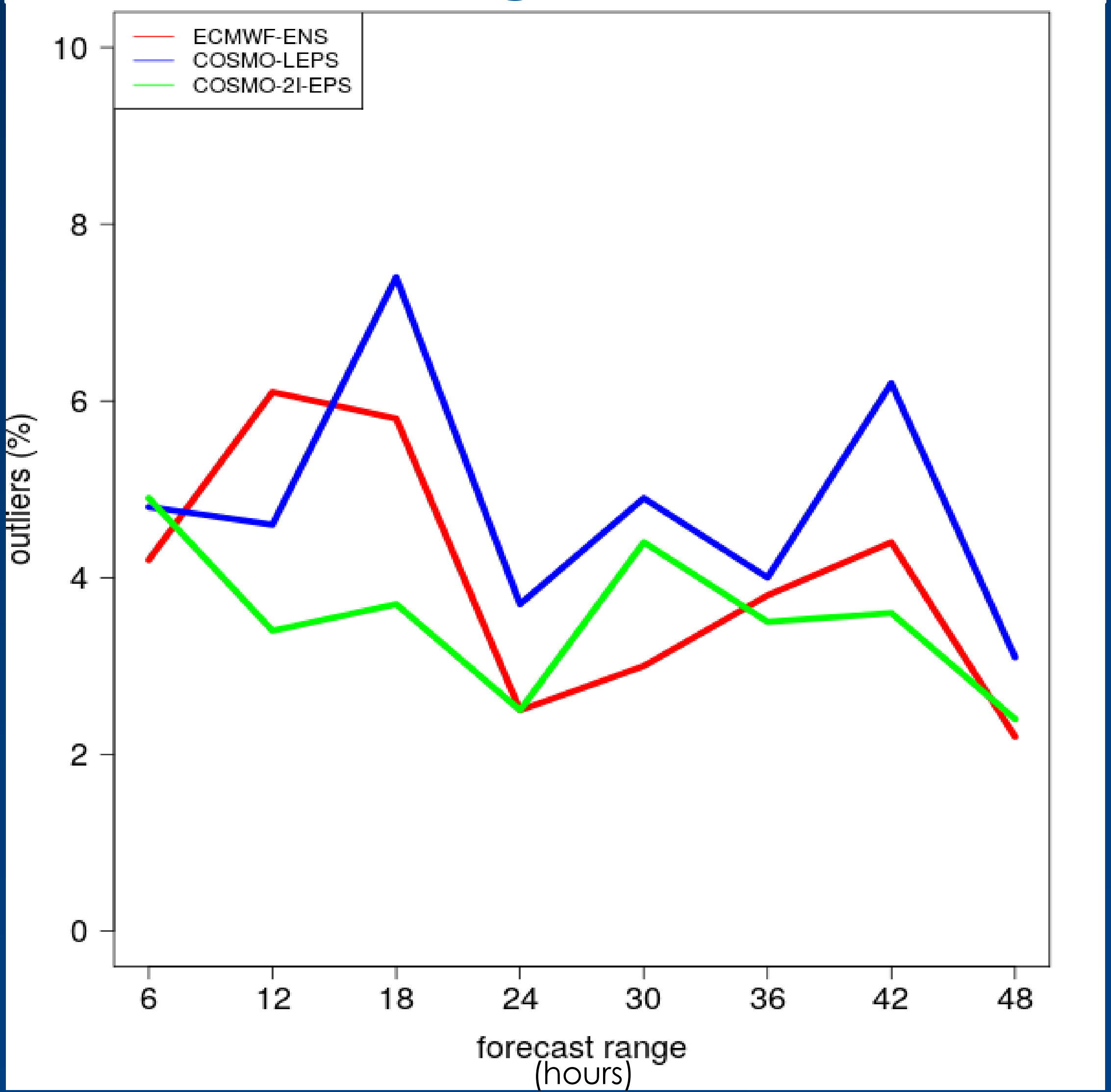
6-H TOTAL PRECIPITATION

- **The percentage of outliers** of a probabilistic forecast system is defined as the probability of the observations lying outside the range spanned by the forecast values (Buizza, 1997).

Here it is computed as the fraction of points of the domain where the observed value lies outside the minimum or maximum forecast value.

COSMO-2I-EPS has almost always the lowest percentage of outliers, so this ensemble system is the one whose members calculate the ‘truth’ (observed values) better.

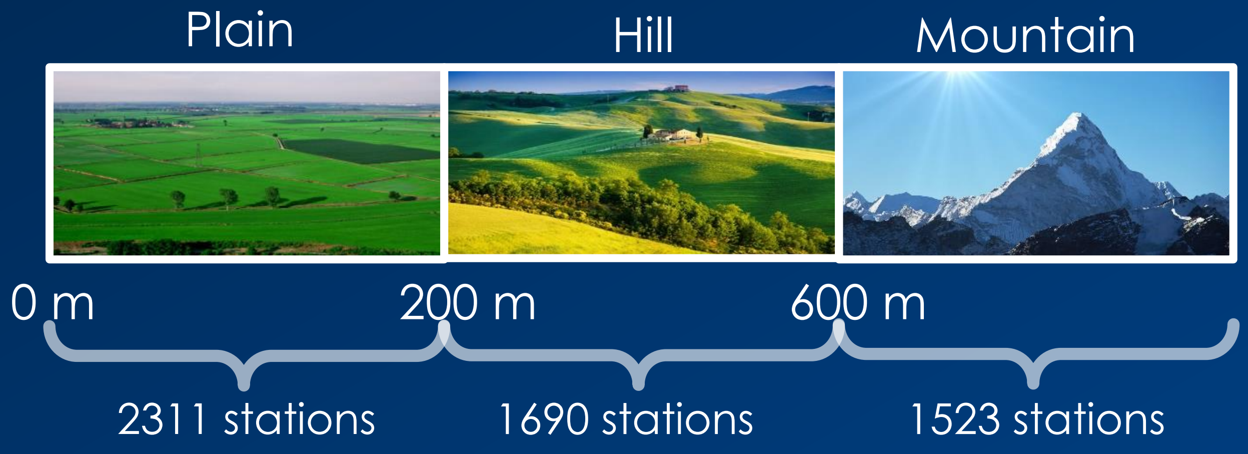
percentage of outliers



VERIFICATION

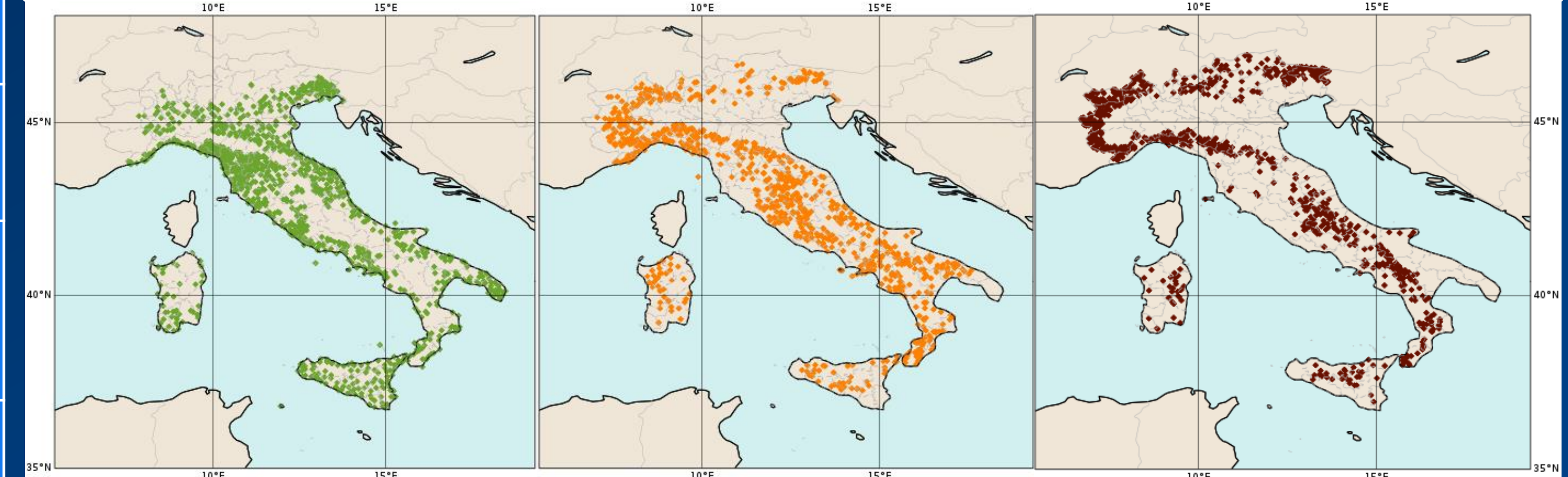
6-H TOTAL PRECIPITATION: A 'NON-STANDARD' EVALUATION

Verification features	
Period	From 20/06/2016 00 UTC to 27/06/2016 00 UTC
Region	Italy
Method	Nearest grid point
Observations	Network of Dipartimento Protezione Civile Nazionale, no obs error
Forecast range	0-48 h (verification every 6 h)
Systems	ECMWF ENS, COSMO-LEPS, COSMO-2I-EPS
Scores	**RPS** **percentage of outliers**



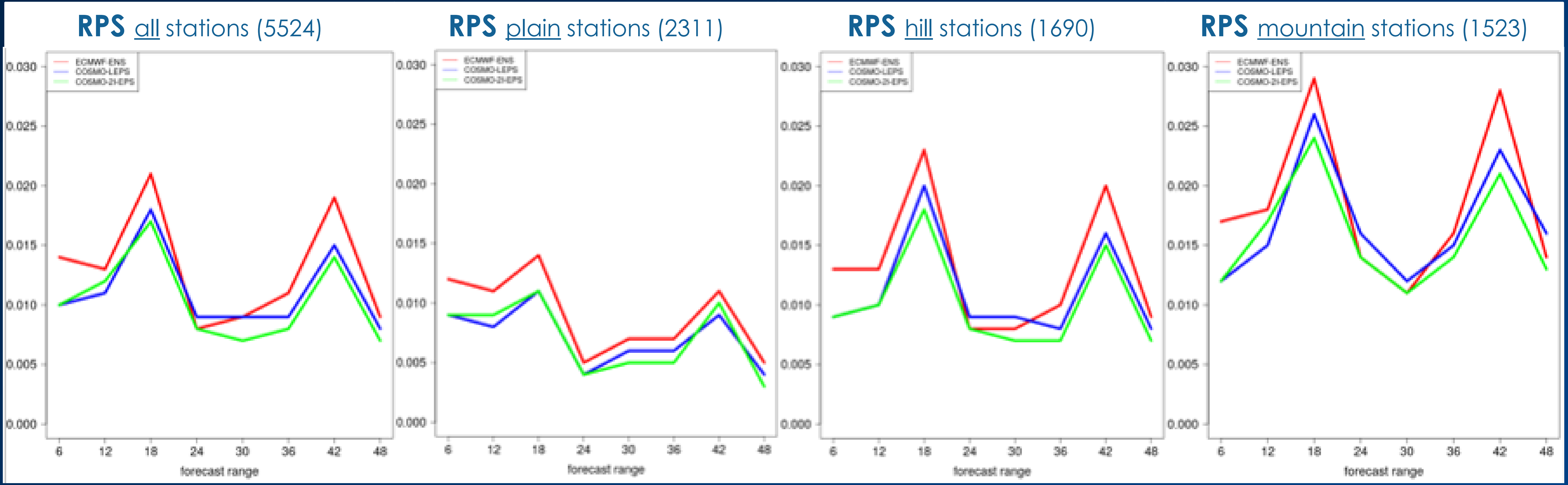
(according to WMO standards)

Network of Dipartimento Protezione Civile Nazionale (DPCN)



Plain stations Hill stations Mountain stations

6-H TOTAL PRECIPITATION: A ‘NON-STANDARD’ EVALUATION

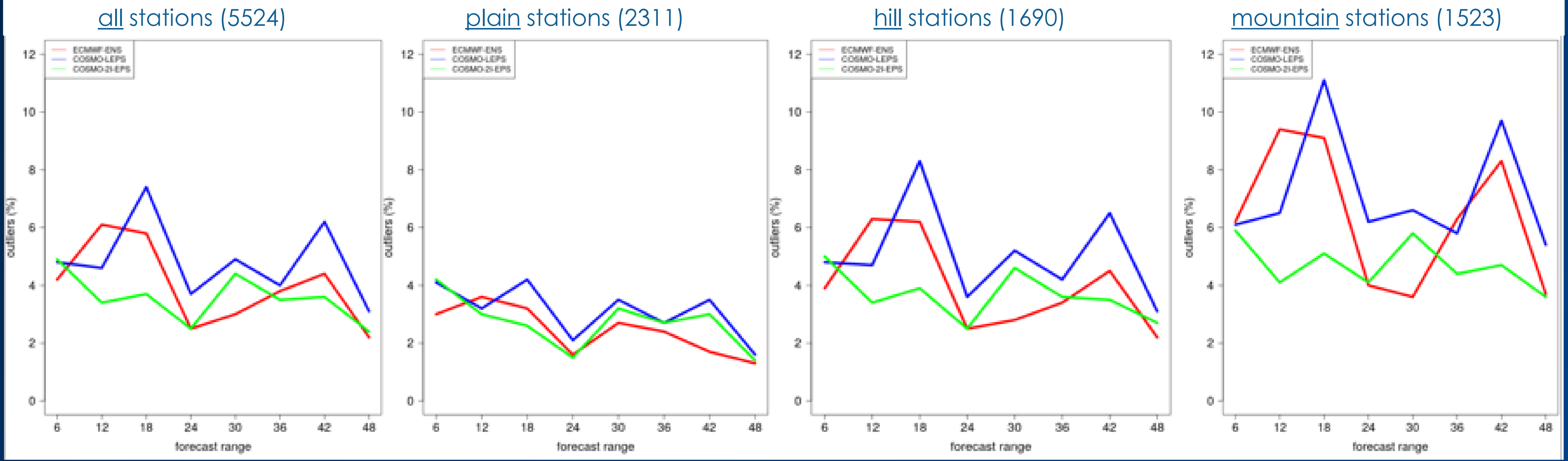


- In most cases, regardless of the altitude, the RPS obtained for COSMO-2I-EPS is the lowest;
- The RPS values for the plain stations are lower than for hill and mountain ones;
- The strong daytime cycle for hill and mountain stations is due to the pluviometric regime of those days.

VERIFICATION

6-H TOTAL PRECIPITATION: A 'NON-STANDARD' EVALUATION

Percentage of outliers

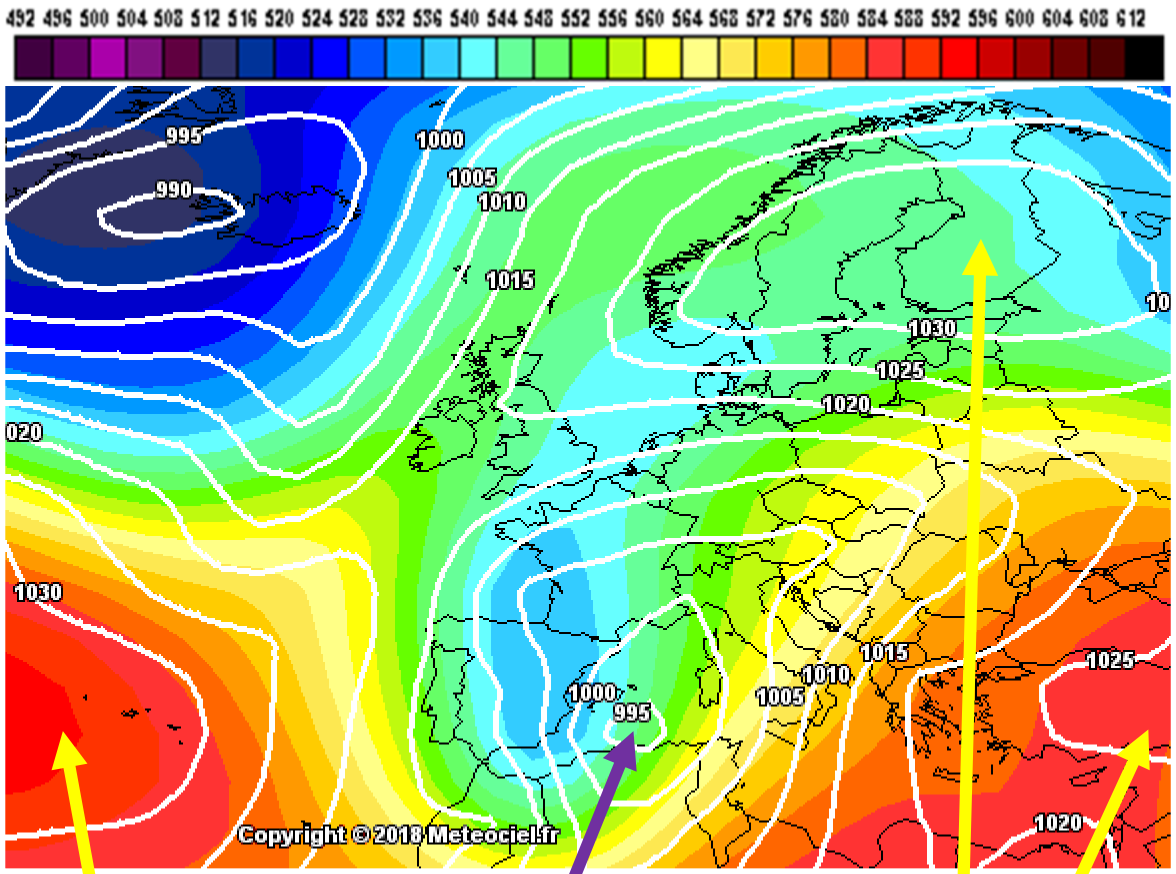


- The percentage of outliers increases according to the station altitude;
- A diurnal cycle is visible only in systems with parameterized convection (ECMWF ENS, COSMO-LEPS) for hill and mountain datasets;
- Regardless of the altitude, COSMO-2I-EPS has the lowest percentage of outliers for most forecast ranges.

2nd VERIFICATION PERIOD:
15 OCTOBER - 15 NOVEMBER 2018

SYNOPTIC DESCRIPTION 29 OCTOBER 2018

500 hPa geopotential height (dam) shading and mslp (hPa) white lines from Reanalysis ERA-Interim

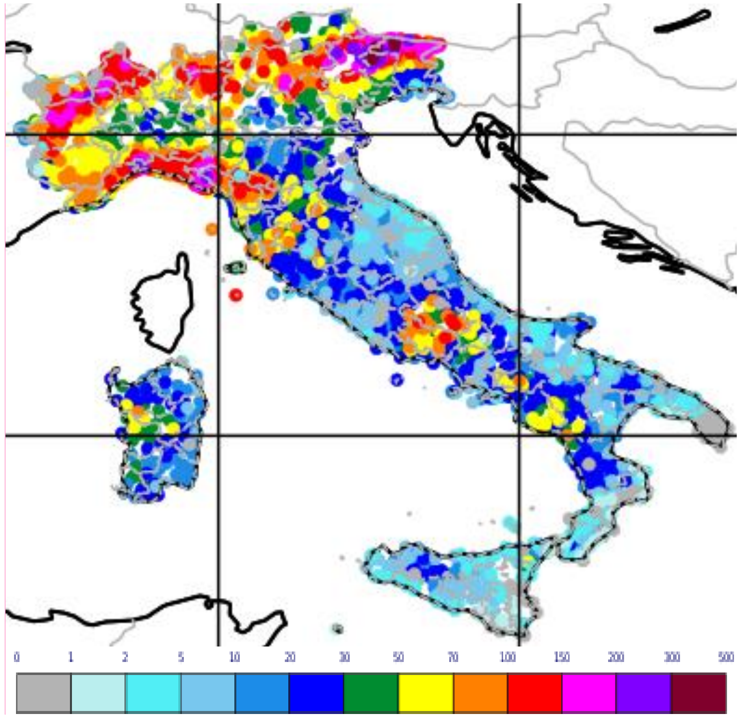


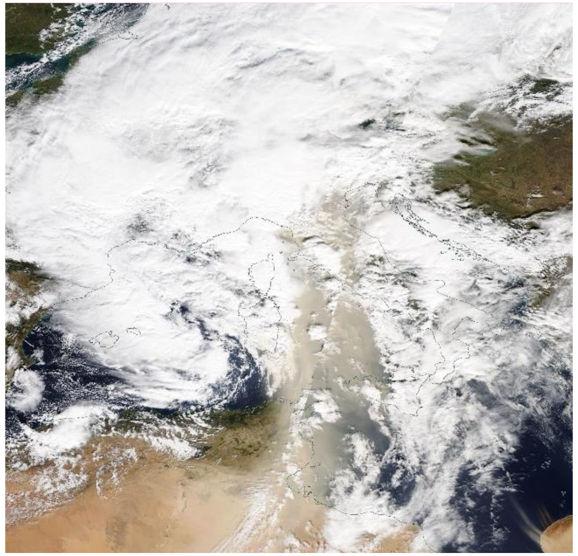
Deep closed cyclonic circulation on the Western Mediterranean

Azores Anticyclone

Blocking pattern on the Eastern Europe

24h total precipitation (mm) from national network stations





In the satellite image are visible:

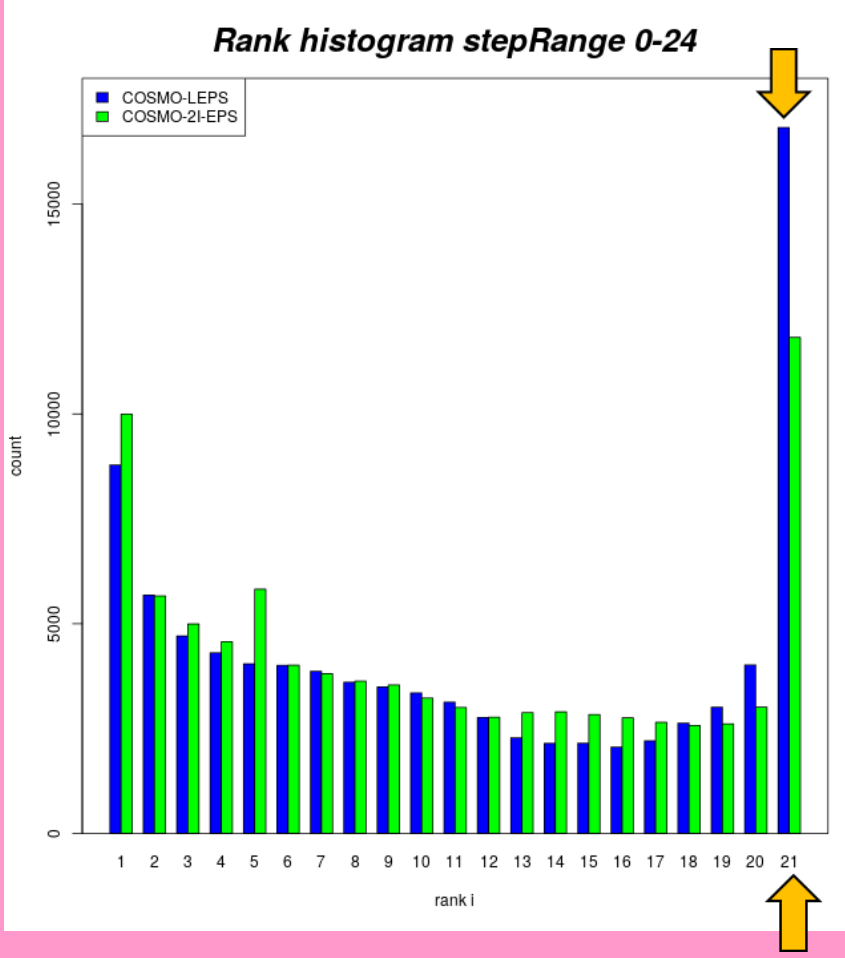
- The saharian dust transported on Italy by the currents coming from the Algerian desert;
- The warm front rising from the Central Mediterranean Sea.

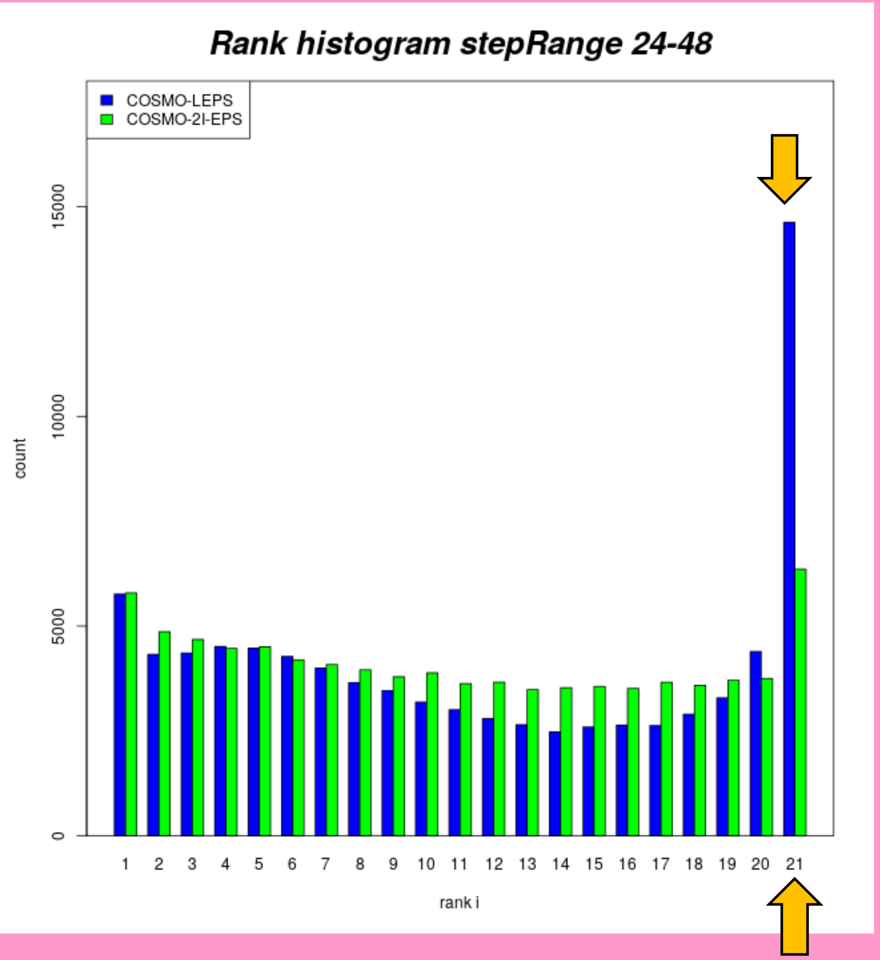
- Precipitation throughout Italy;
- Heavy rainfall (even over 300mm) on areas exposed to southern wet winds: Alps, Prealps, Liguria, northern Tuscany, Lazio, Campania.

VERIFICATION

24-H TOTAL PRECIPITATION

The rank histogram is a diagnostic tool to evaluate the **spread of an ensemble**.
The ensemble member forecasts are distributed so as to delineate ranges or **''bins''** of the predicted variable such that the probability of occurence of the observation within each bin is equal.
The bins are determined by ranking the ensemble member forecasts from lowest to highest.
The assumption underlying the rank is that the **probability** that the observation will fall in each bin is **equal**.





- Verification with the method of **nearest grid point**.
- Verification between COSMO-LEPS and COSMO-2I-EPS: the number of members is the same.

- ✓ The **U-shape** of the rank histograms indicates the **subdispersion** of both ensemble systems, in particular COSMO-LEPS.
- ✓ This subdispersion is stronger in the last bin of the most intense precipitation and in particular for COSMO-LEPS.

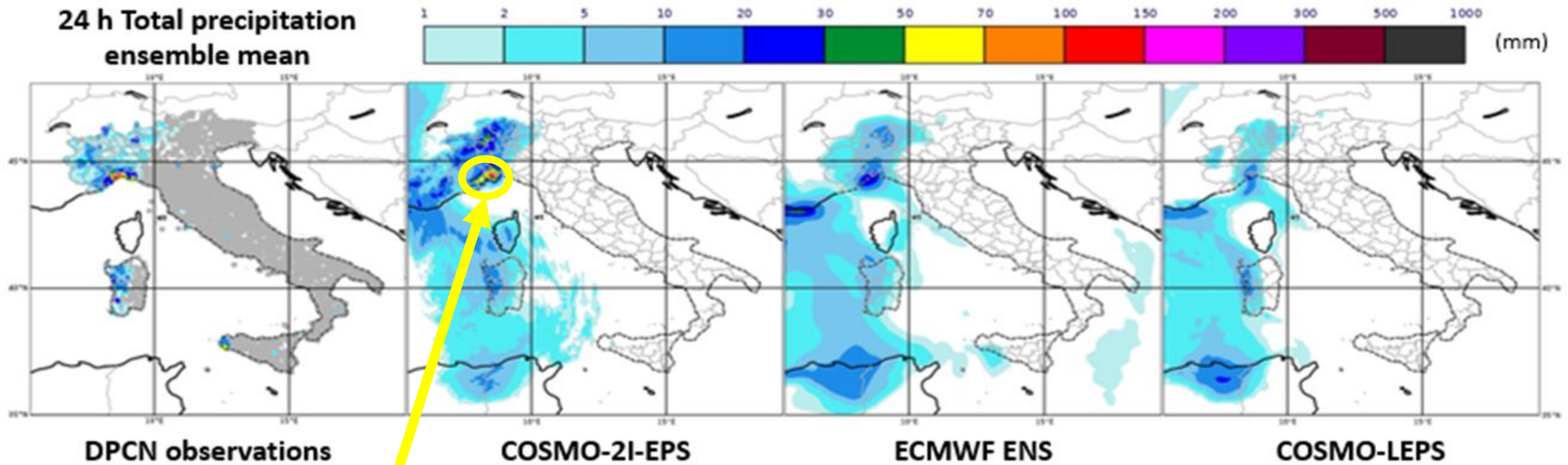

CONCLUSIONS

Period from 20 to 27 June 2016

- The results for 2-m temperature indicate the under-dispersion issue for the different ensemble systems, although the performance obtained by COSMO-2I-EPS (and in general by the COSMO-based ensembles) is quite satisfactory;
- The probabilistic scores indicate COSMO-2I-EPS having the best performance, regardless of the altitude of the station;
- The performances of the systems tend to worsen with the altitude, also enhancing the diurnal cycle.

Period from 15 October to 15 November 2018

- Rank histogram: COSMO-based systems show a subdispersion of the ensembles, in particular COSMO-LEPS in cases of heavy precipitations.



Thunderstorm in Liguria: COSMO-2I-EPS is the only ensemble system that correctly forecasts the heavy precipitation peak over 100 mm/24h.

The national civil protection department issued the **yellow alert** for thunderstorms thanks to the correct precipitation estimation of high resolution models such as COSMO-2I-EPS.

Maps of the ensemble mean of total precipitation cumulated for the 9 November 2018 as predicted by the run of 9 November 2018 00 UTC from the ensemble mean of the three ensemble system.

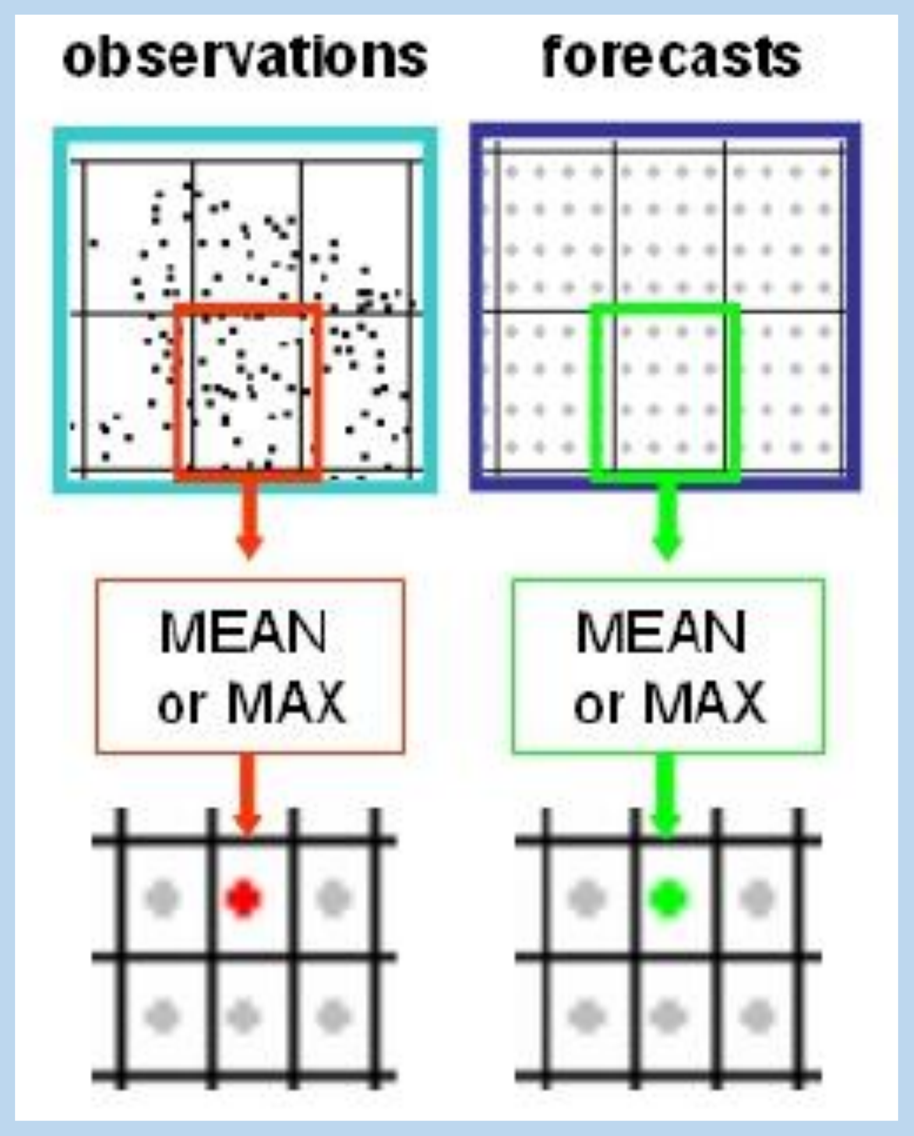
Despite this is only a pilot study, the added value of high resolution in mesoscale ensemble seems to play a crucial role in the probabilistic prediction of precipitations.


Thanks for the attention
Ph Daniele D’Alessandro

VERIFICATION METHODS

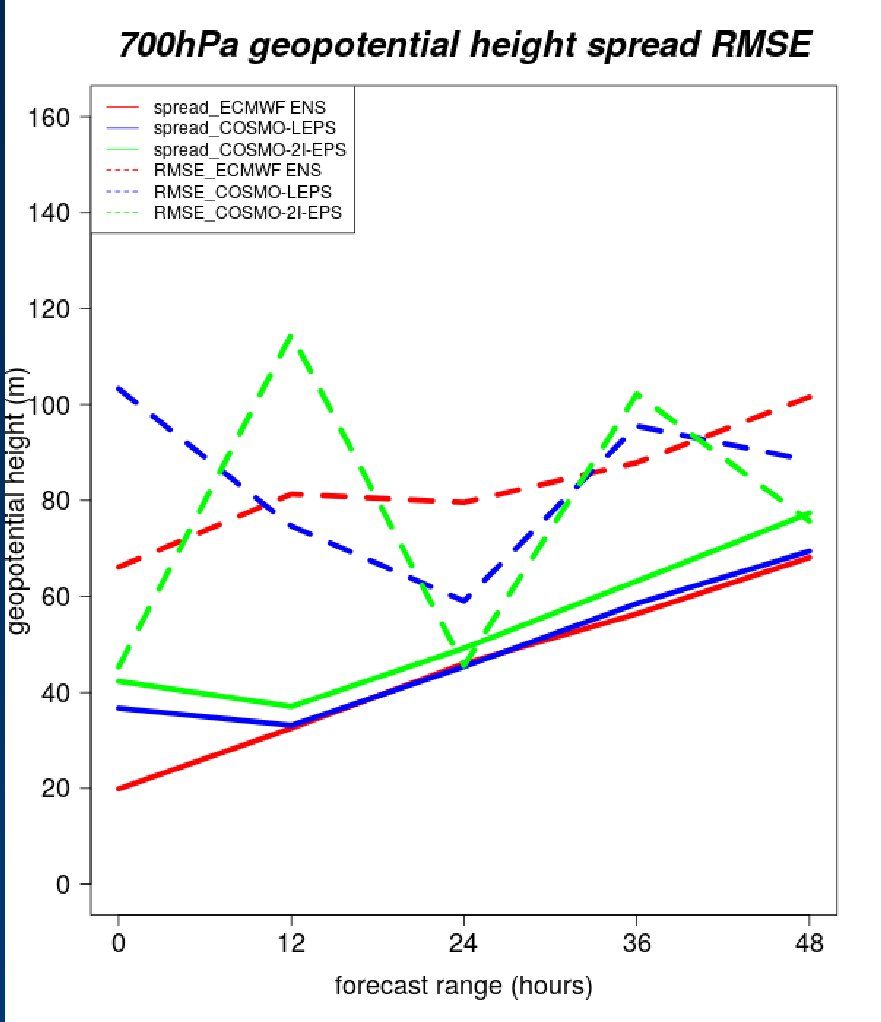
- **Nearest grid point**: the model grid point closest to the observation station was selected

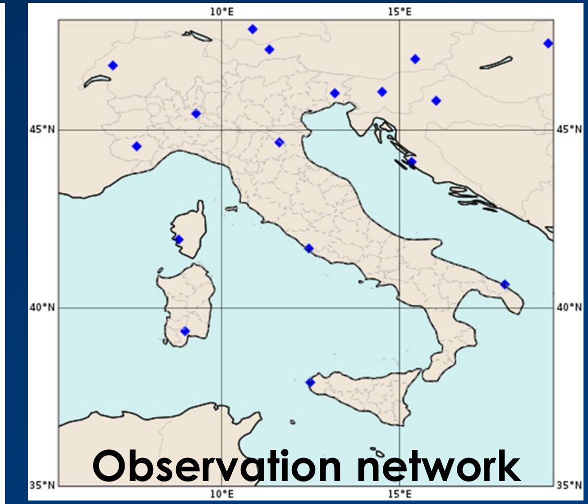
- **Boxes**: The domain is divided in squared area (in this work ***0.5° x 0.5°***, about 50 x 50 km); the precipitation values of all stations and all model grid points falling in the same box are aggregated and processed. The evaluation of a summarizing value for the precipitation field in each box, such as the ***average*** or the ***maximum***, has been performed.



UPPER LEVEL VERIFICATION

Variable	GEOPOTENTIAL HEIGHT, temperature
Verification features	
Pressure levels (hPa)	500, **700**, 850
Period	From 20/06/2016 00 UTC to 27/06/2016 00 UTC
Region	Italy and neighbouring Countries
Method	Nearest grid point
Observations	17 radiosoundings, no obs error
Forecast range	0-48 h (verification every 12 h)
Systems	ECMWF ENS, COSMO-LEPS, COSMO-2I-EPS
Scores	SPRD, RMSE





SPRD

- spread values are similar for all forecast systems;
- COSMO-2I-EPS spread is always higher than in the other systems.

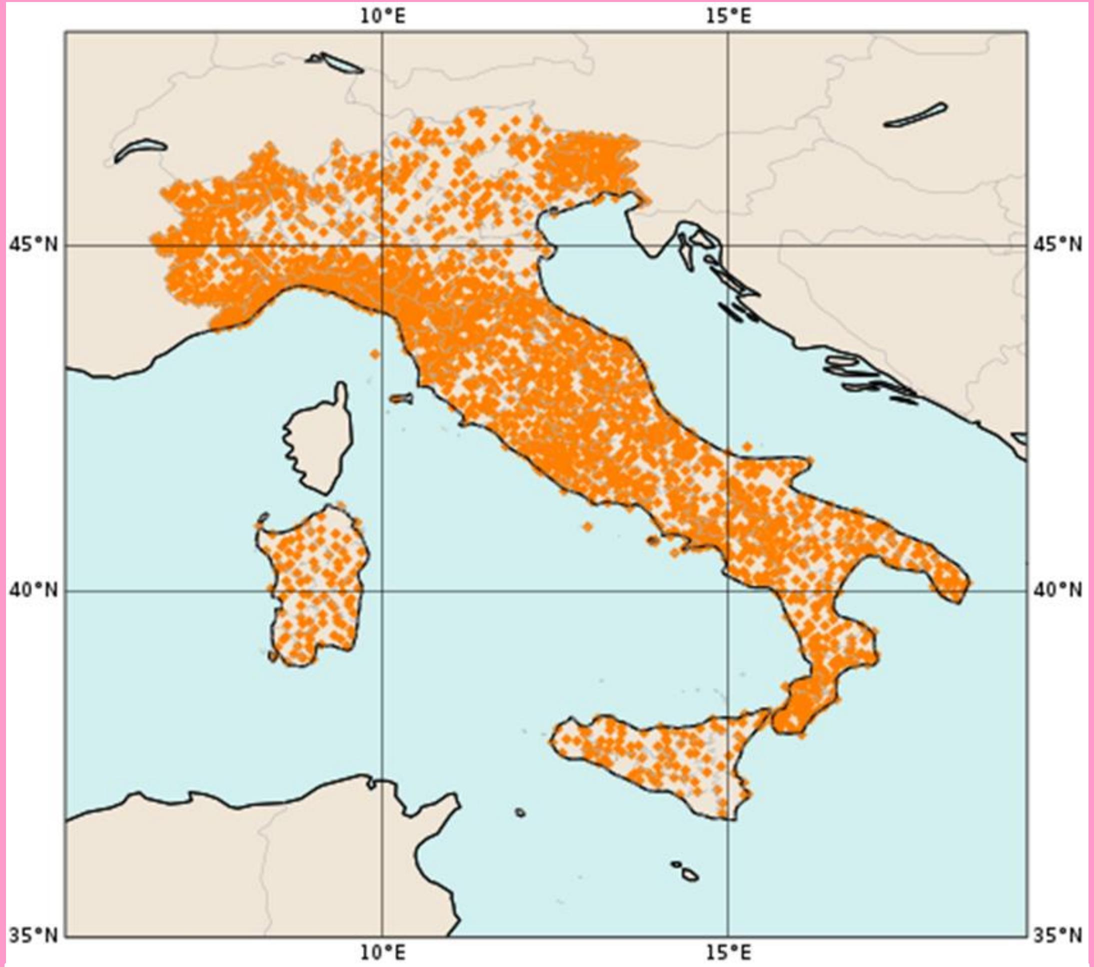
RMSE

- COSMO-based models have a marked diurnal cycle;
- COSMO-2I-EPS RMSE is very close to the corresponding spread during the night;
- COSMO-2I-EPS RMSE is the lowest during the night.

VERIFICATION

24-H TOTAL PRECIPITATION

Verification features	
Period	**From 15/10/2018 00 UTC to 15/11/2018 00 UTC**
Region	Italy
Method	**Boxes 0.5° (max, average)**
Observations	Network of Dipartimento Protezione Civile Nazionale (5524 stations), no obs error
Forecast range	0-48 h (verification every 6 h)
Systems	**ECMWF ENS, COSMO-LEPS, COSMO-2I-EPS**
Scores	**RPS percentage of outliers**
Thresholds	(1, 5, 10, 15, 25, 50) mm/6h



Observations network

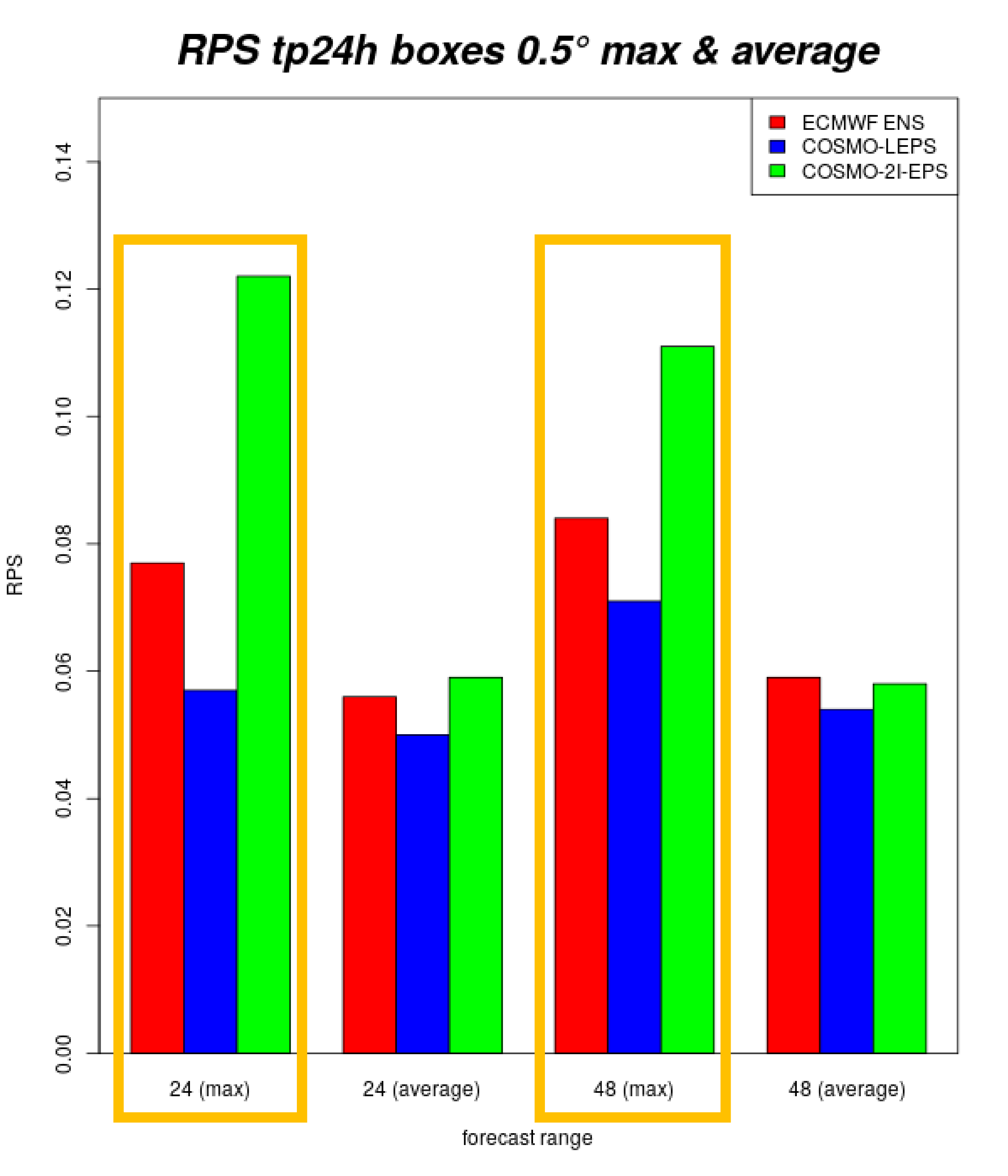
VERIFICATION

24-H TOTAL PRECIPITATION

- Ranked Probability Scores (RPS) is an extension of the RMSE to the probabilistic world and to the multi-category events. RPS ϵ (0,1)
- The lower the RPS, the better the ensemble system

Max: the **RPS** of COSMO-LEPS is the lowest, the COSMO-2I-EPS one is the highest.

Average: the **RPS** of the three ensemble systems does not show substantial differences.



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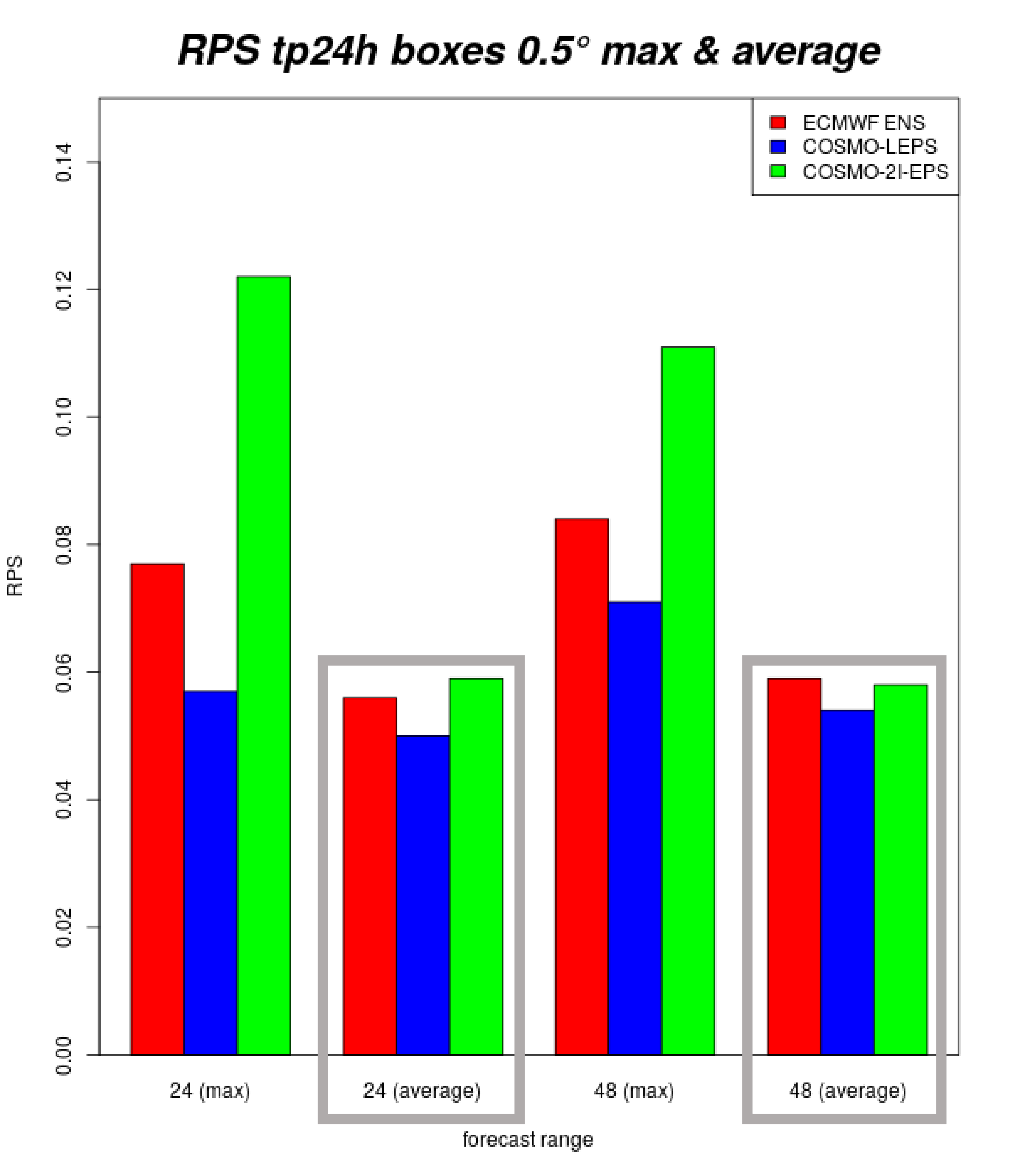


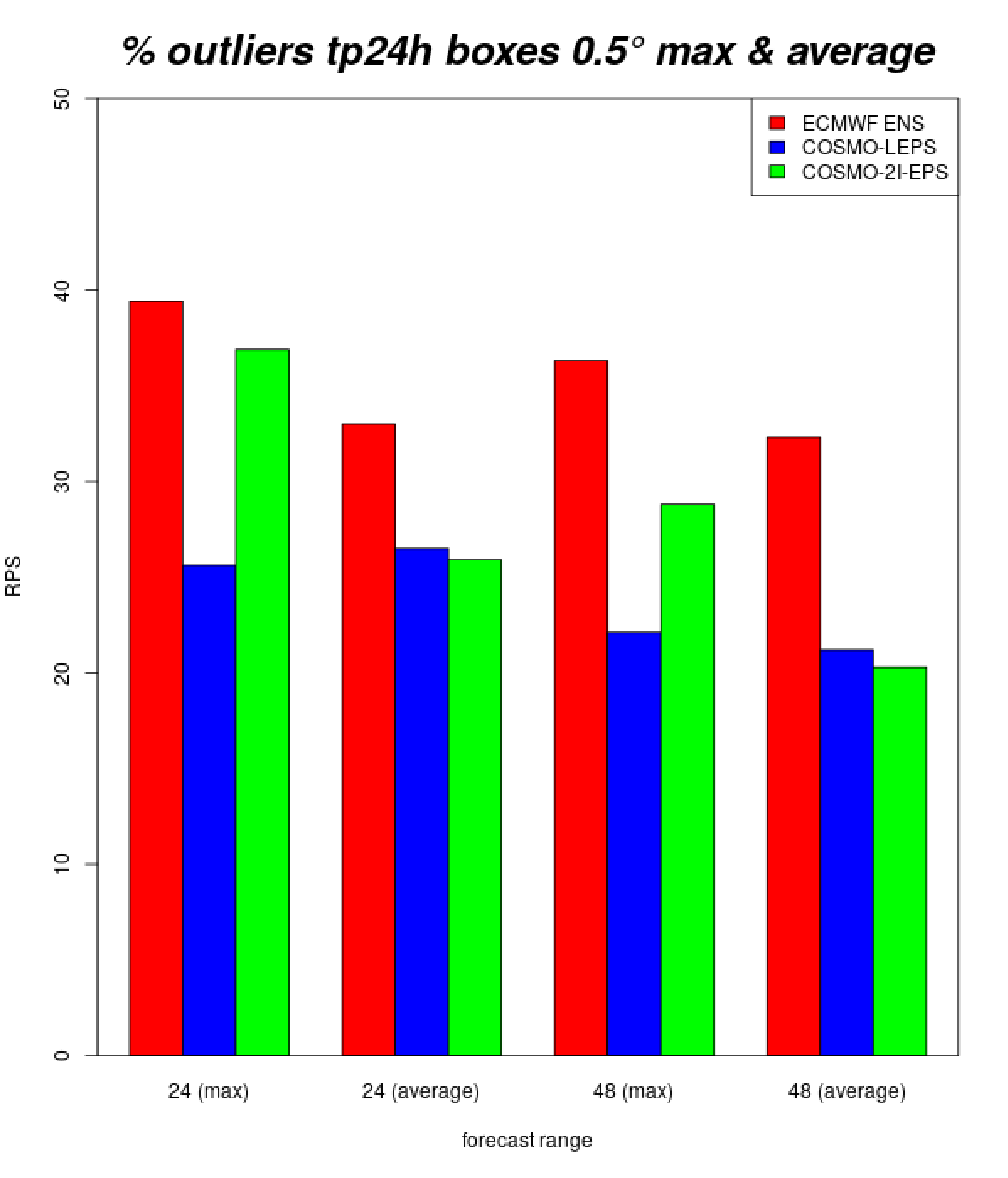
VERIFICATION

24-H TOTAL PRECIPITATION

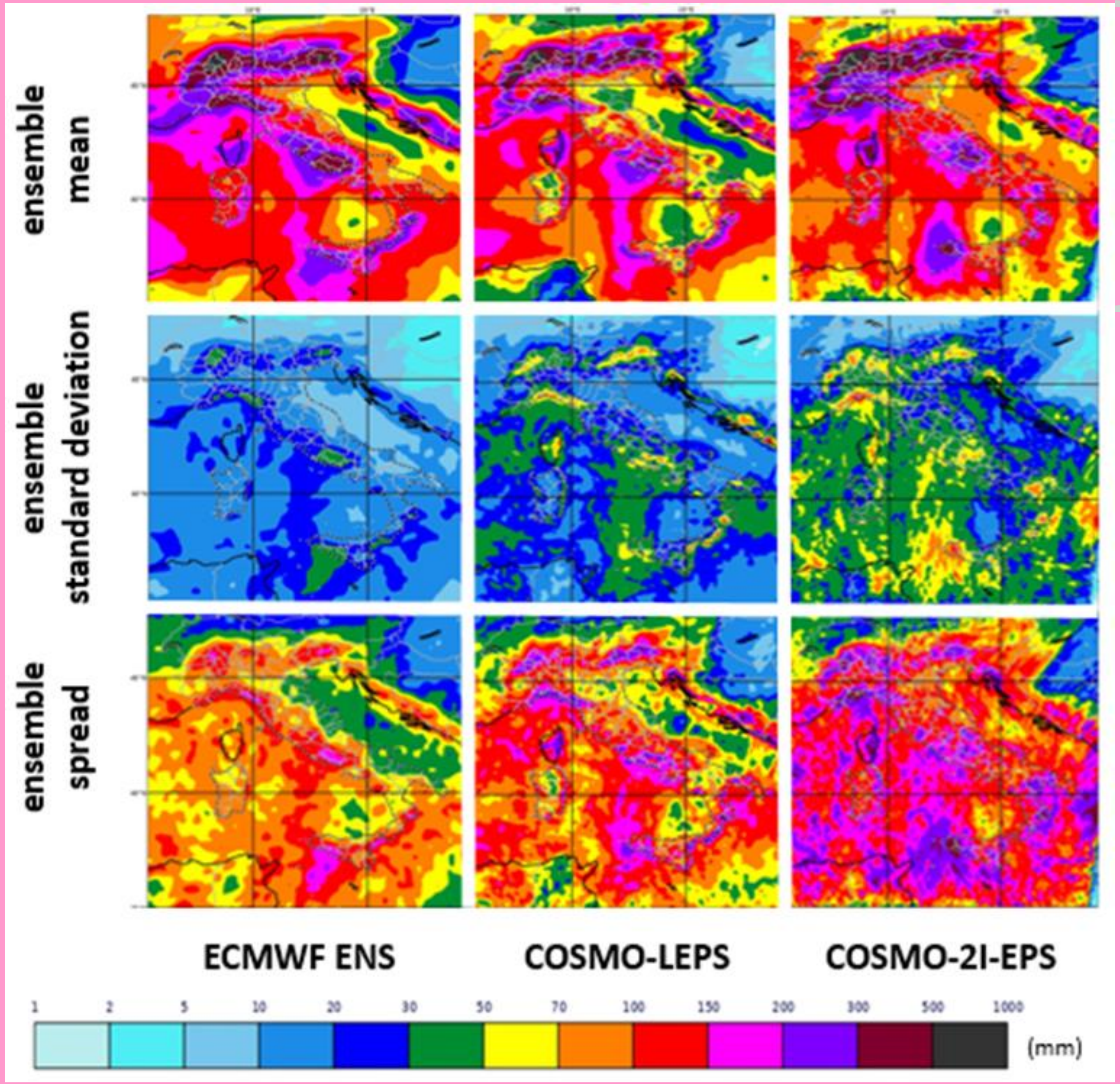
- **The percentage of outliers** of a probabilistic forecast system is defined as the probability of the observations lying outside the range spanned by the forecast values (Buizza, 1997).
- Here it is computed as the fraction of points of the domain where the observed value lies outside the minimum or maximum forecast value.

Max and average:

The COSMO-based ensemble systems have the lowest **percentage of outliers**, despite the lower ensemble size with respect to ECMWF ENS. So these ensemble systems are the ones whose members calculate the 'truth' (observed value) better.

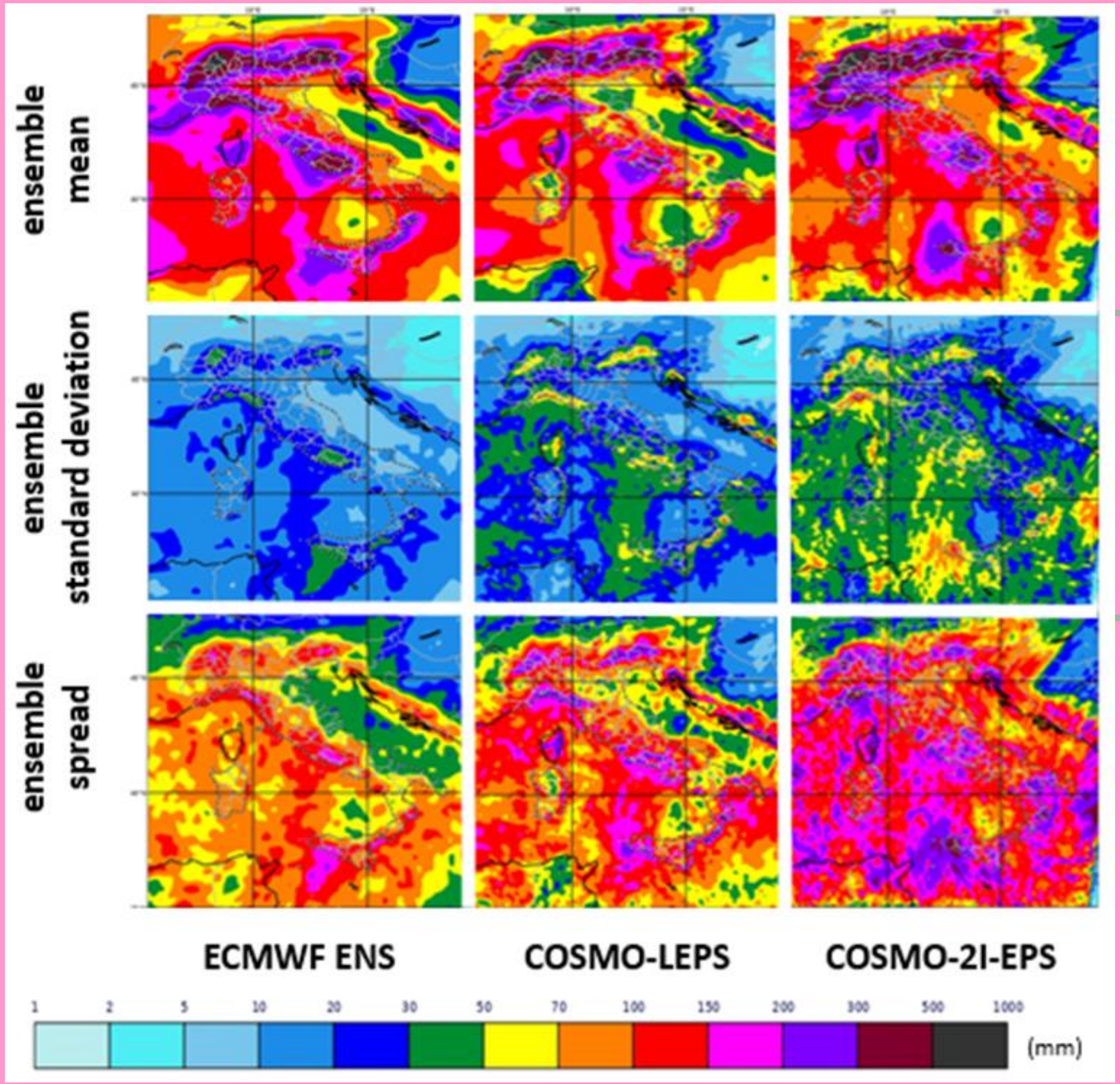


VERIFICATION 768-H TOTAL PRECIPITATION



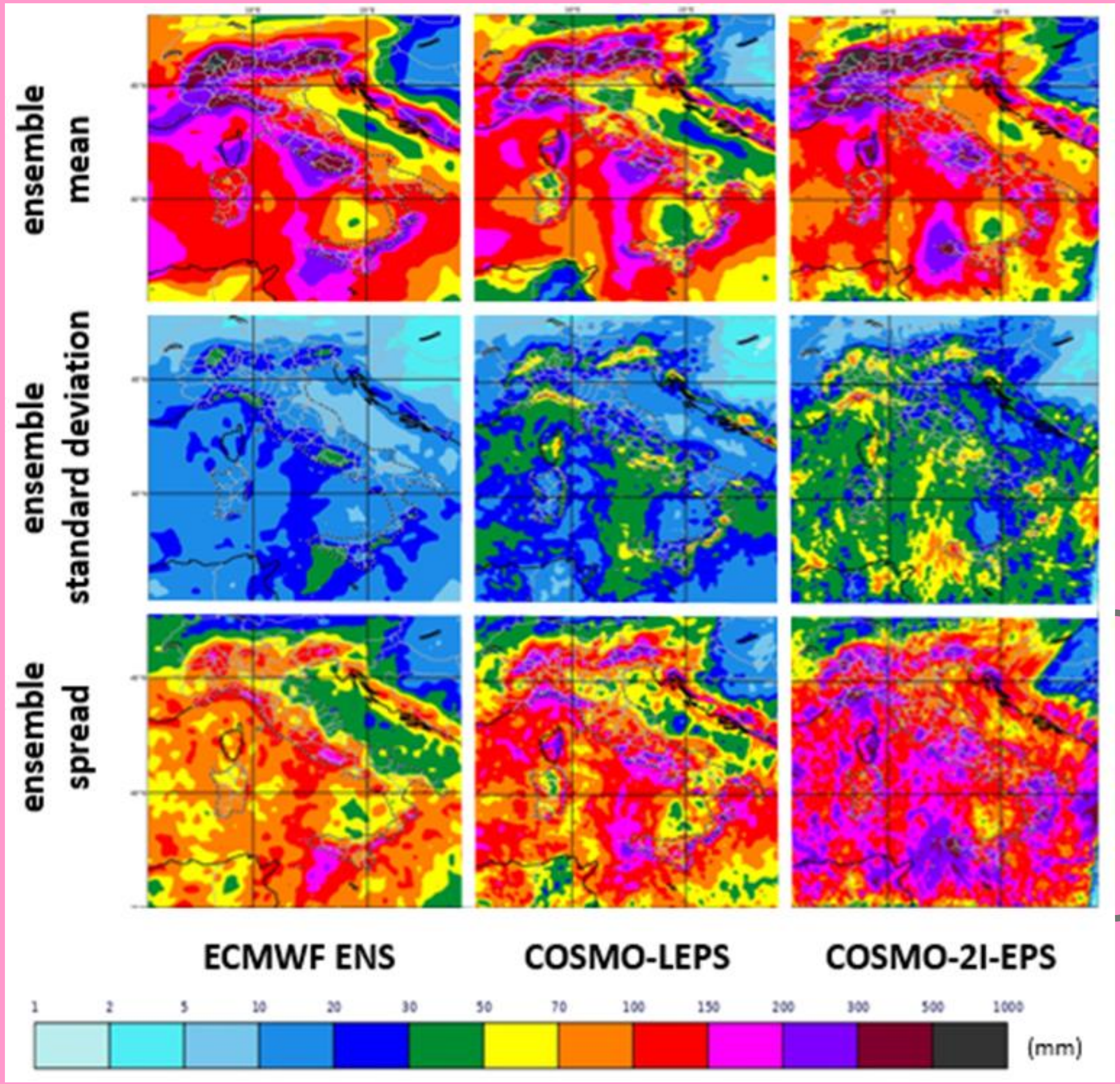
- ❖ The rainiest ensemble system is COSMO-2I-EPS followed by ECMWF and COSMO-LEPS
- ❖ The areas with the largest forecasted precipitation quantities are the same and with comparable cumulate
- ❖ The main differences concern areas where it rained less

VERIFICATION 768-H TOTAL PRECIPITATION



- Standard deviation increases with the ensemble resolution.
- Standard deviation increases in areas where the forecasted rainfall is greater.

VERIFICATION 768-H TOTAL PRECIPITATION



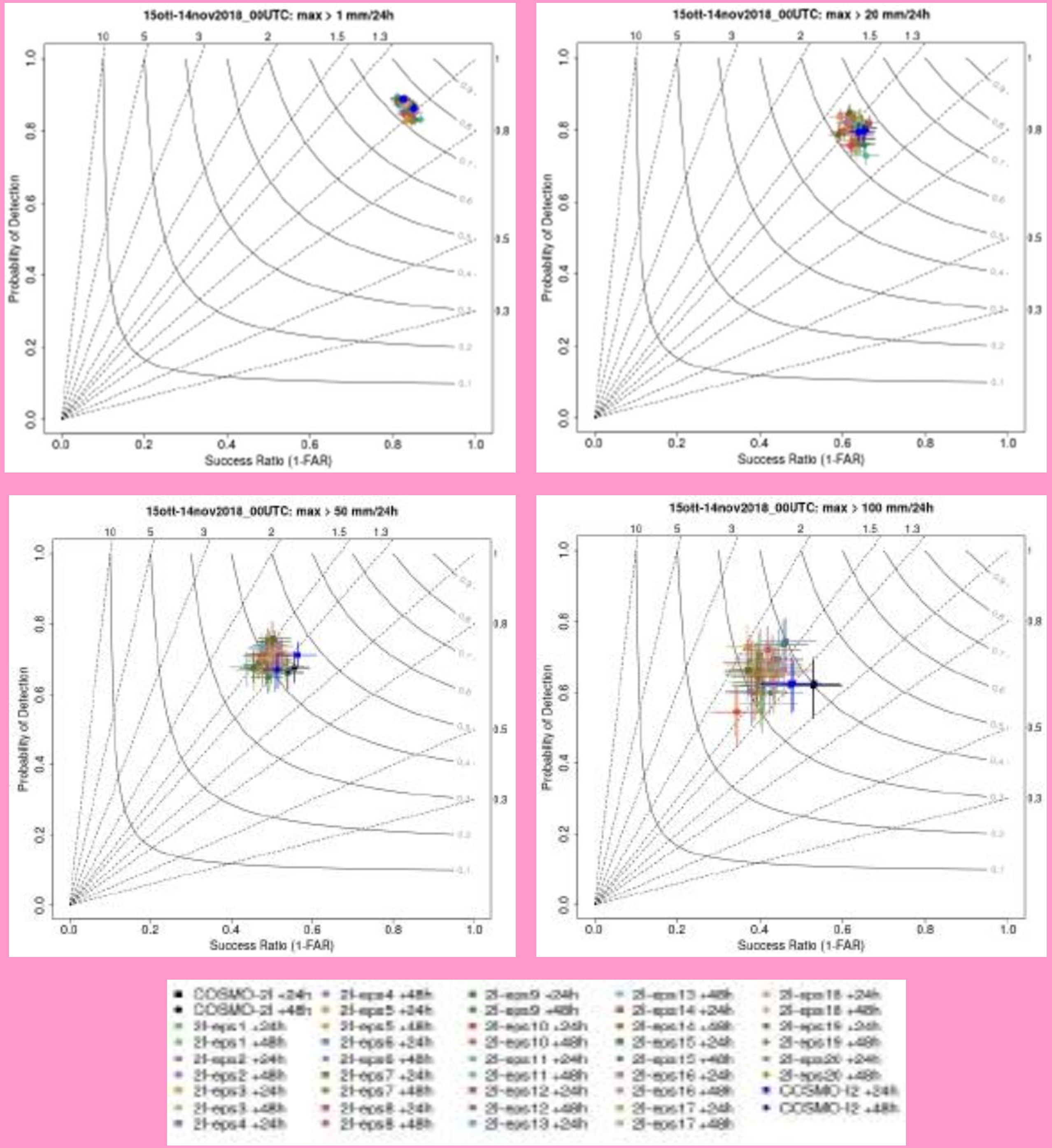
- The ensemble spread increases with the resolution of the model.
- The ensemble spread increases in areas where the forecasted amounts of precipitation are greater.

VERIFICATION
24-H TOTAL PRECIPITATION

<u>Perfomance diagram</u>

It is possible to exploit the geometric relationship between four measure of dichotomous forecast performance: *<u>Probability Of Detection</u>* (POD), the *<u>Success Ratio</u>* (SR), *<u>bias</u>* and *<u>Critical Success Index</u>* (CSI). For good forecast, POD, SR, bias and CSI approach unity, such that **a perfect forecast lies in the upper right of the diagram**.

<u>Systems</u>:
COSMO-2I-EPS ensemble 20 members
COSMO-2I deterministic
COSMO-I2 deterministic
<u>Variable</u>: 24h total precipitation
<u>Verification method</u>: max precipitation on DPCN macroareas of alerting
<u>Thresholds</u>: 1 mm/24h, 20 mm/24h 50 mm/24h, 100 mm/24h

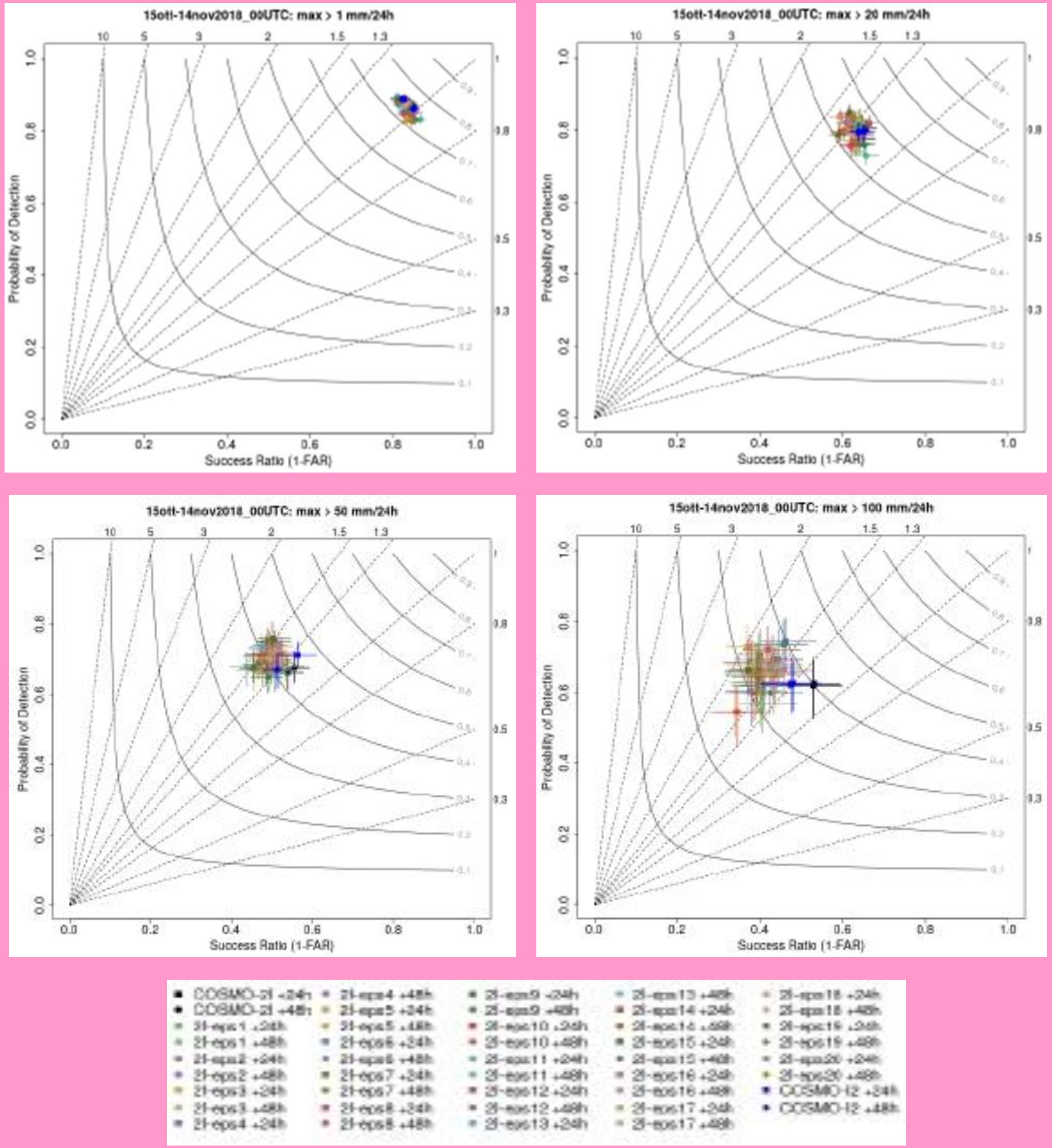


VERIFICATION

24-H TOTAL PRECIPITATION

__Systems__:
COSMO-2I-EPS ensemble 20 members
COSMO-2I deterministic
COSMO-I2 deterministic
__Variable__: 24h total precipitation
__Verification method__: max precipitation on DPCN macroareas of alerting
__Thresholds__: 1 mm/24h, 20 mm/24h 50 mm/24h, 100 mm/24h

- ✓ The results worsen and spread slightly with more intense precipitation.
- ✓ The forecasts of 20 members of COSMO-2I-EPS are similar to COSMO-2I and COSMO-I2.



DESCRIPTION OF THE OROGRAPHY

The different **horizontal resolutions** of the three ensemble systems play a crucial role in the representation of the orography.

Models with a higher horizontal resolution can capture smaller details of the territory; models with a lower resolution are able to solve only the broad features of a geographical area.