Setting up COSMO EPS perturbing lower boundary conditions

Riccardo Bonanno, Nicola Loglisci

COSMO General Meeting - Eretria – 8-11 September 2014

Introduction

- In the previous study we performed a sensitivity test to assess the impact of different soil moisture initializations on short range ensemble variability in COSMO model using different soil moisture analysis from global, regional and land surface models.

Model	COSMO EU analysis	ECMWF analysis	GFS analysis	GLDAS – NOAH LSM reanalysis	UTOPIA LSM reanalysis
Resolution (°)	0.063	0.125	0.500	0.250	0.250

- Spread stronger in the spring/summer case studies with convective conditions, weaker in autumn season and nearly absent in stable winter conditions.

- Not only the surface, but also the upper levels in the troposphere are affected by soil moisture variability.

R. Bonanno, N. Loglisci, 2014: A sensitivity test to assess the impact of different soil moisture initializations on short range ensemble variability in COSMO model. **COSMO Newsletter no. 14**, 95-105 , Available at http://www.cosmo-model.org/content/model/documentation/newsLetters/newsLetter14/cnl14_11.pdf

Perturbation technique

Spherical Harmonics

(Lavaysse et al. 2013)

$$f(\lambda,\phi) = \mu + \sum_{l=1}^{L} \sum_{m=-l}^{l} a_{lm} Y_{lm}(\lambda,\phi) \qquad \lambda_L \approx \frac{2\pi R}{L}$$

L is horizontal truncations of the random function. The inverse of *L* can be interpreted in terms of spatial decorrelation length scales (or horizontal wavelength)

Streatching Function

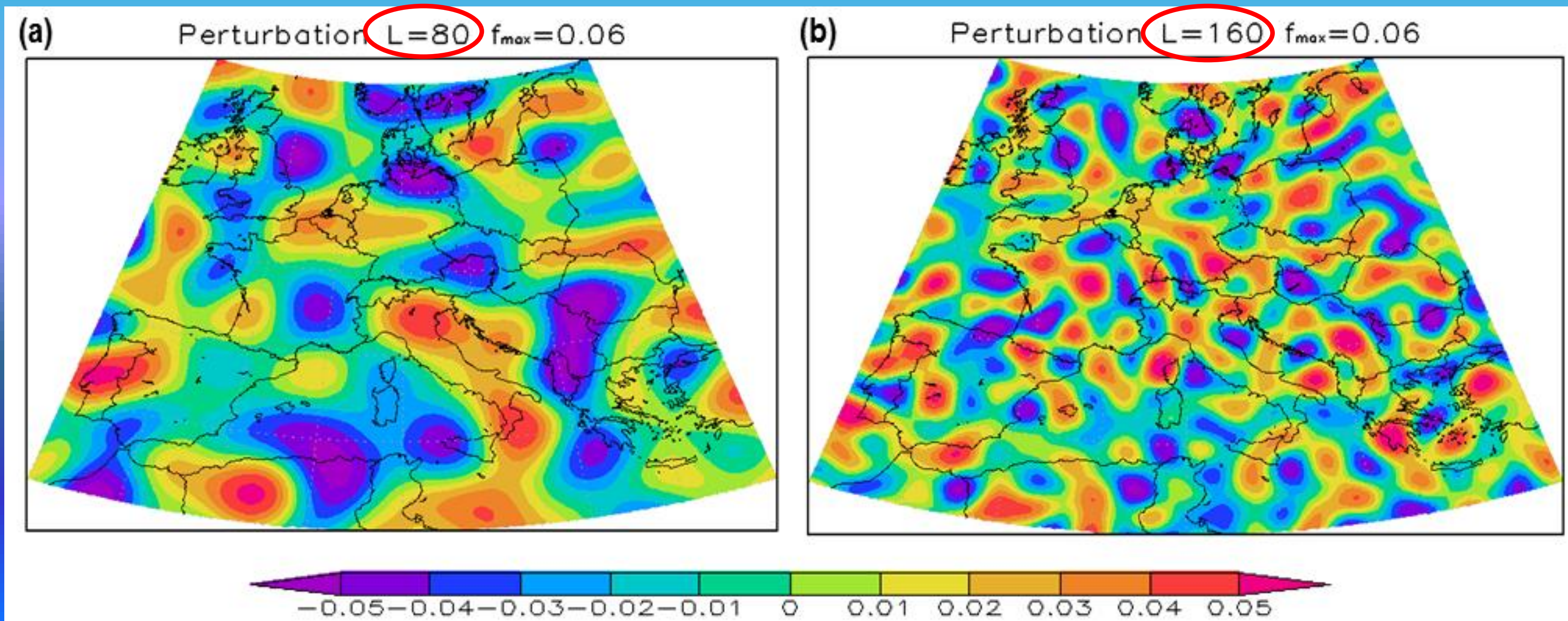
Gaussian random noise

(Lavaysse et al, 2013, Charron et al, 2010)

$$F = \mu + S(f,\mu)(f-\mu) \qquad S(f,\mu) = 2 - \frac{1-\exp\left[\beta\left(\frac{f-\mu}{f_{\max}-\mu}\right)^2\right]}{1-\exp(\beta)}$$

$$\beta \approx -1.27$$

Horizontal Wavelength
Examples with different settings



$\lambda_L/2 \approx 500$ km

$\lambda_L/2 \approx 250$ km

Stochastic Pattern Generator

M Tsyrulnikov, I Mamay, D.Gayfulin - *HydroMetCenter of Russia*

***KENDA** Priority Project*

- The Generator is based on solution of a partial stochastic differential equation in spectral space on a 3-dimensional torus. Variance, spatial and temporal scales are tunable.

$$\left(\frac{\partial f}{\partial t} + \mu (1 - \lambda^2 \Delta)^q \right)^p f = \sigma \alpha$$

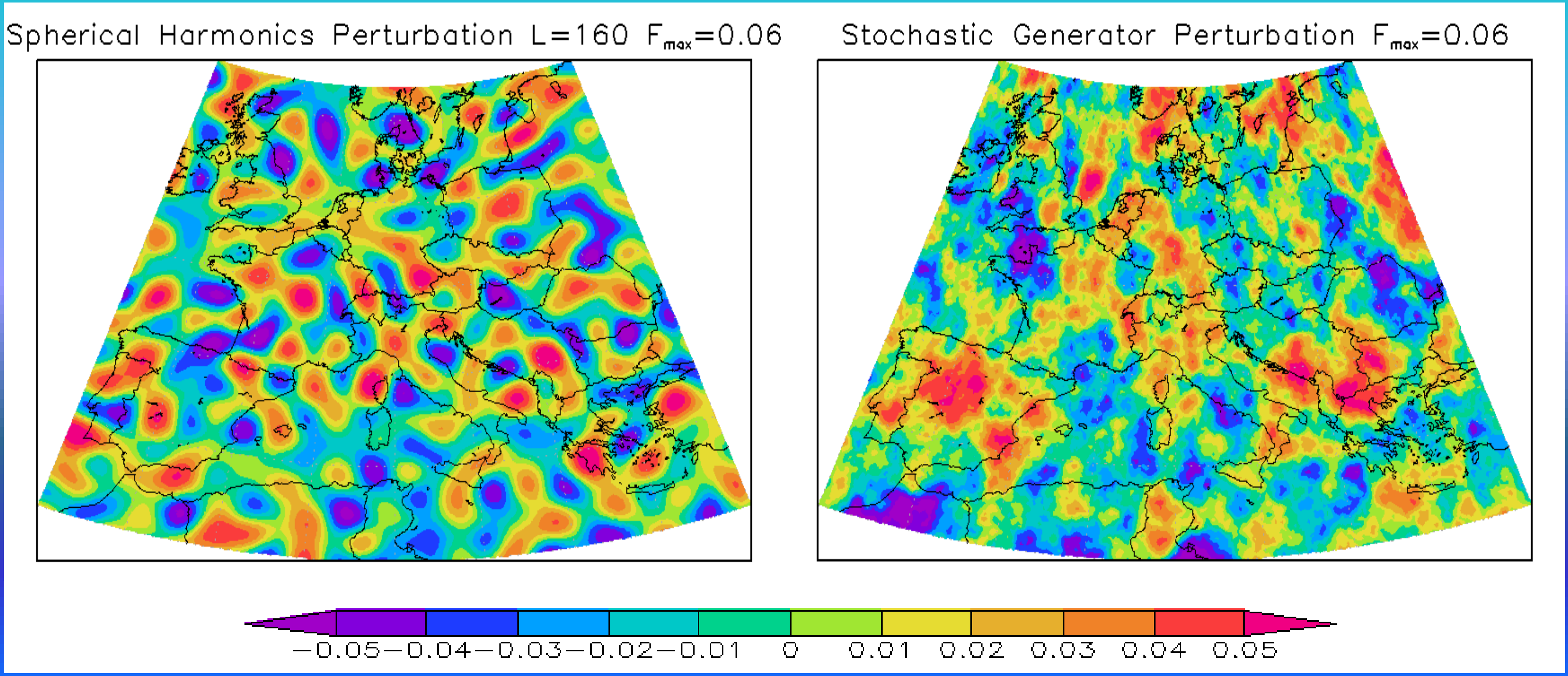
- *p* and *q* are external parameters, σ, λ and μ are parameters related to the desired variance, spatial and temporal correlation scale. α is the spatio-temporal white noise.
- The value of λ is computed from ***L(0.5)***, defined as the distance at which the correlation function falls to 0.5. This value is set in the configuration file of the generator.

<u>Advantages:</u>

- Already implemented in Fortran
- Much cheeper from the computational point of view

Examples:

Spherical Harmonics vs. Stochastic Generator



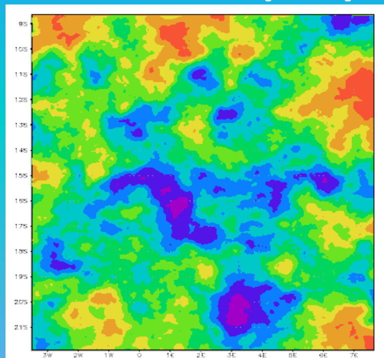
$\lambda_L/2 \approx 125$ km

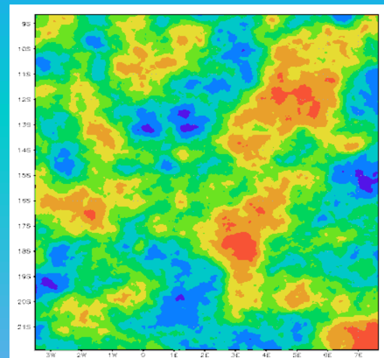
$L(0.5) \approx 125$ km

Stochastic Generator (or Sph. Harm.)
L(0.5)=125 km

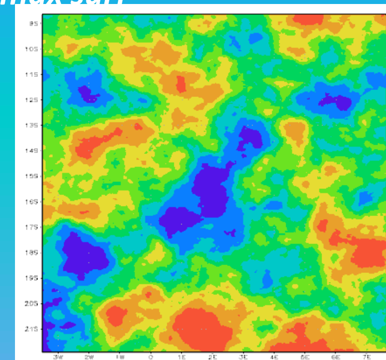
&

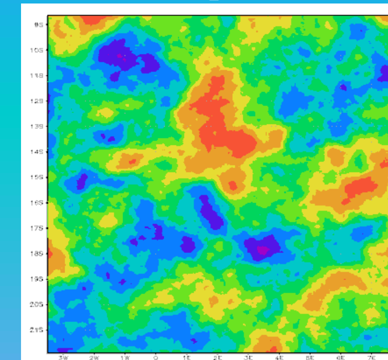
Stretching Function
$F_{max\ surf} = 0.06\ m^3m^{-3}$ Bounds [-0.06, 0.06]


Perturbation ***F1***


Perturbation ***F2***

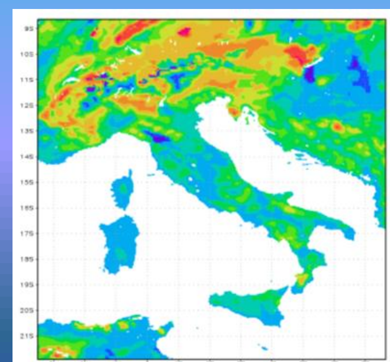
……


Perturbation ***F9***

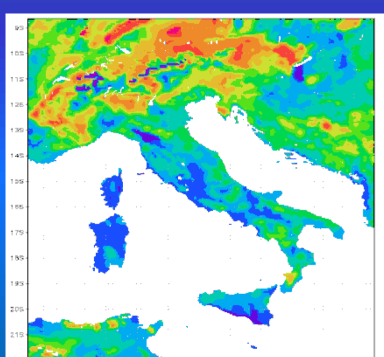

Perturbation ***F10***

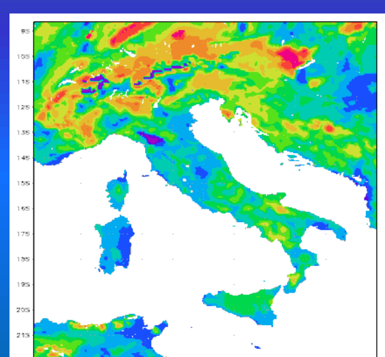
+

IFS soil moisture
INT2LM

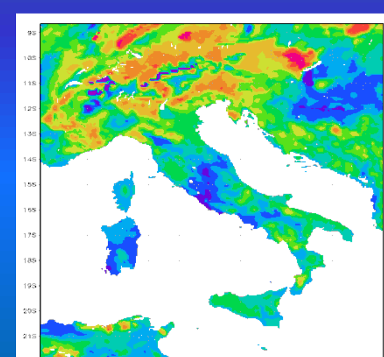


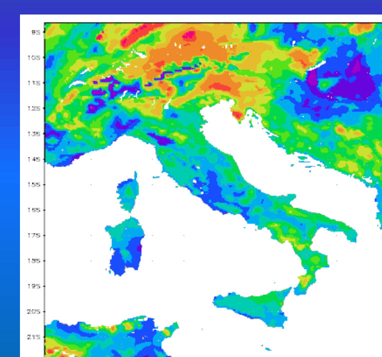
Check with soil porosity $0 \leq W\_SO \leq \eta_s$


W_SO 1


W_SO 2

……


W_SO 9


W_SO 10

Preliminary test: perturbation settings

1. *Horizontal wavelength λ_l :*
   - Lavaysse et al. 2013 used λ_l /2 between 500 and 1000 km.

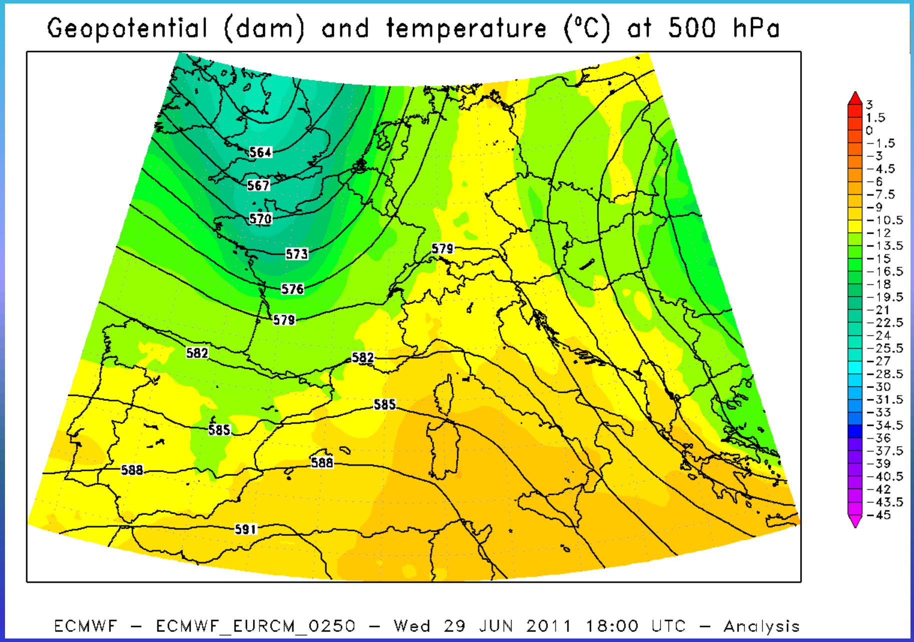
2. *Intensities of perturbation F_{max}:*
   - 0.06 m^3m^{-3} for the surface layer and 0.04 m^3m^{-3} for root layers (Lavaysse et al., 2013, Mc Laughlin et al., 2006).
   - These values are comparable or smaller than errors of the operational soil moisture analysis at ECMWF (bias = −0.081 m^3 m^{-3}, RMSE = 0.113 m^3 m^{-3} over the period 2008-2010, Albergel et al. (2012) or ECMWF Newsletter No. 133, Autumn 2012)

3. *Sensitivity to the F_{max} and λ_l.*
   - Test with 10 different spatial correlated *additive* gaussian patterns

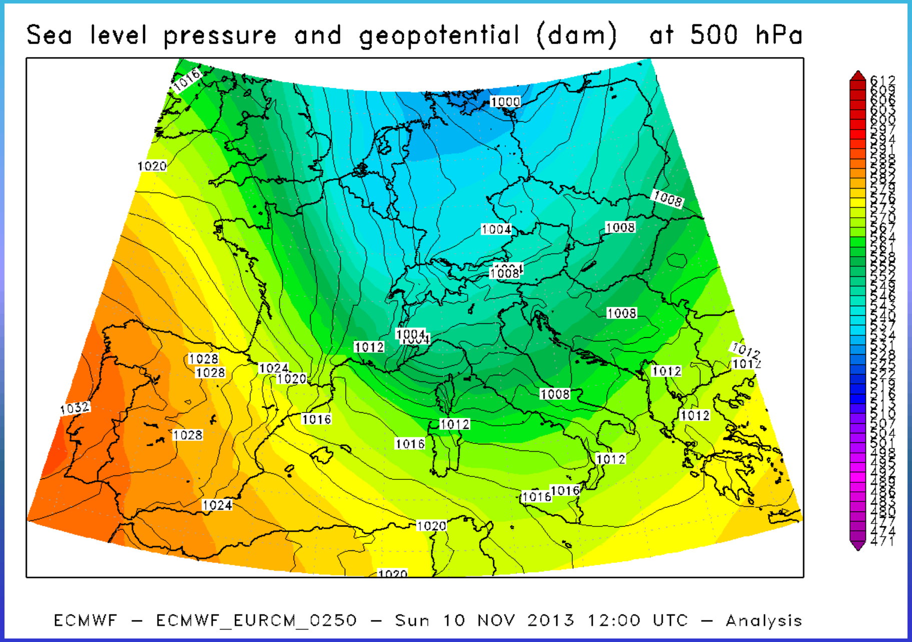
Test	$F_{max\ surf}$ (m^3 m^{-3})	$F_{max\ root}$ (m^3 m^{-3})	L	λ_l/2 (km)
1	0.06	0.04	400	50
2	0.06	0.04	160	125
3	0.06	0.04	80	250
4	0.06	0.04	50	400
5	0.08	0.06	80	250

Case studies

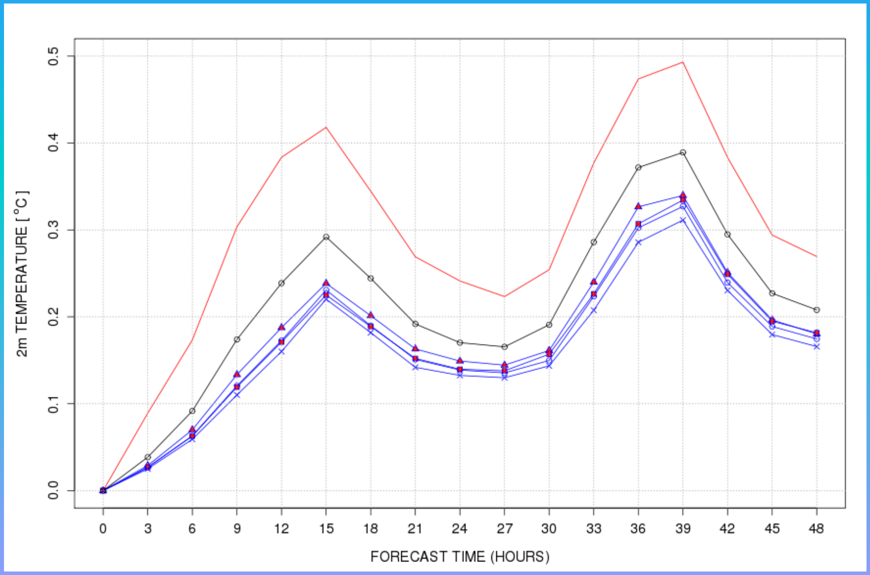
(1) 29-06-2011 00UTC - STRONG SYNOPTIC FORCING



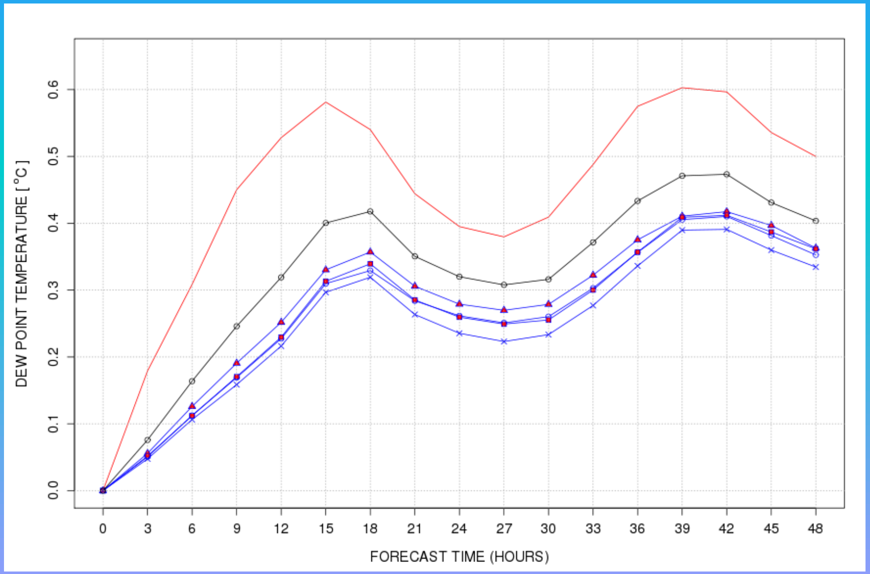
(2) 10-11-2013 00UTC - STRONG WINDS (FOEHN + MISTRAL) AND LOW LEVEL PRESSURE OVER TYRRHENIAN SEA



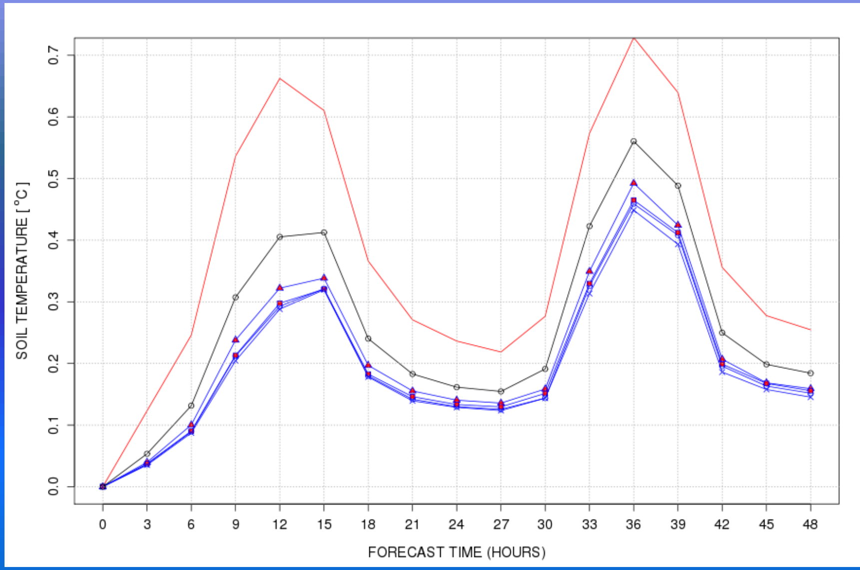
2 m TEMPERATURE [°C]



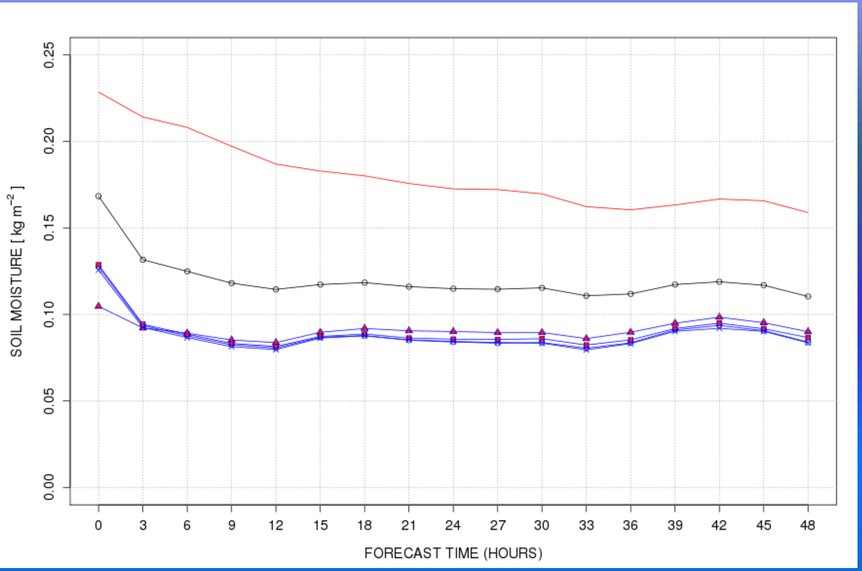
DEW POINT TEMPERATURE [°C]



SOIL TEMPERATURE [°C]

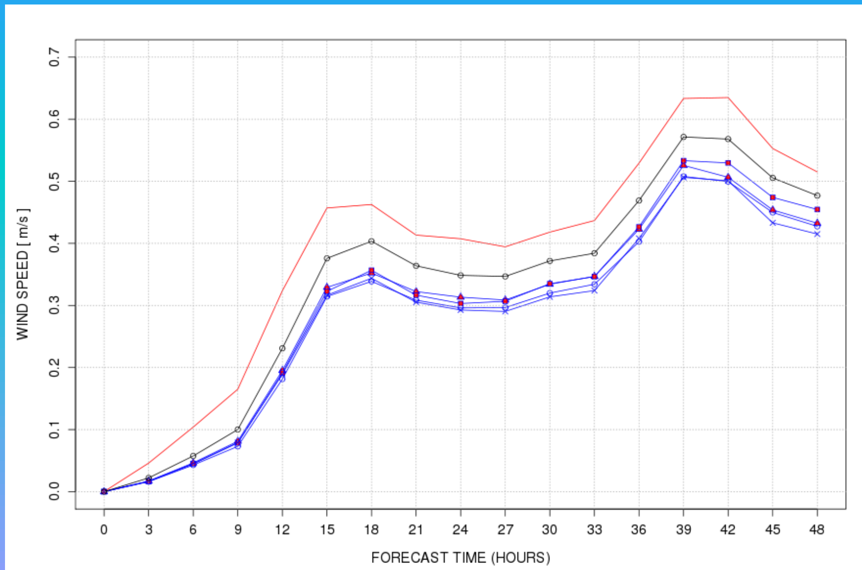


SOIL MOISTURE [kg/m²]

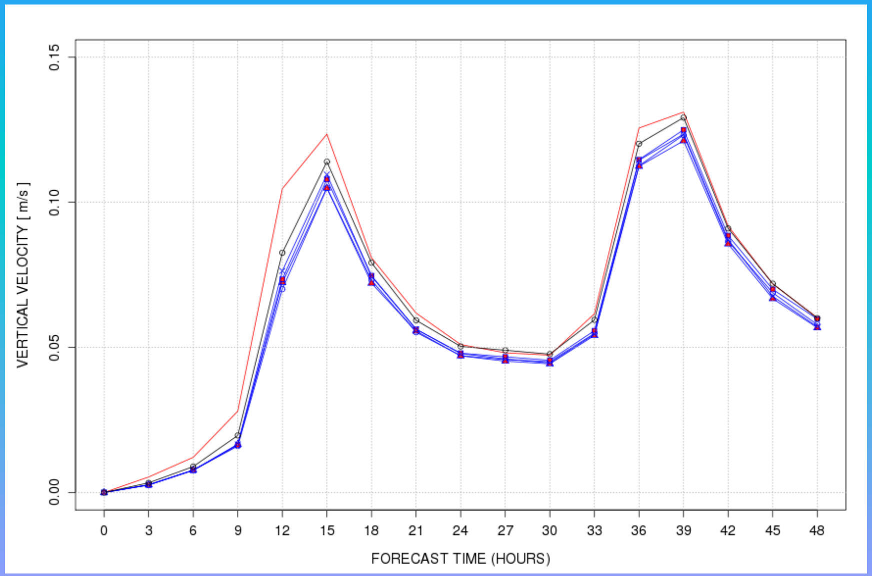


sensitivity test
F_{max} = 0.06, L = 400, λ/2 ~ 50 km
F_{max} = 0.06, L = 160, λ/2 ~ 125 km
F_{max} = 0.06, L = 80, λ/2 ~ 250 km
F_{max} = 0.06, L = 50, λ/2 ~ 400 km
F_{max} = 0.08, L = 80, λ/2 ~ 250 km

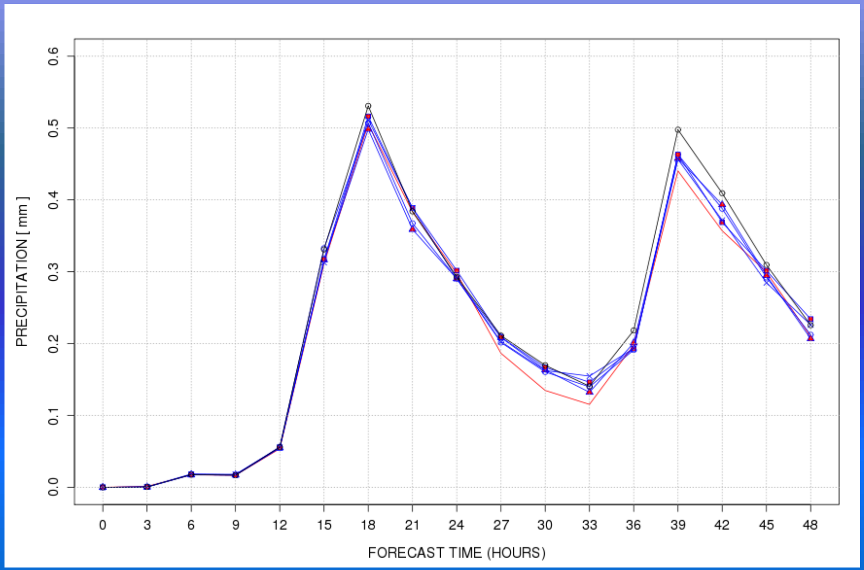
WIND SPEED [m/s]



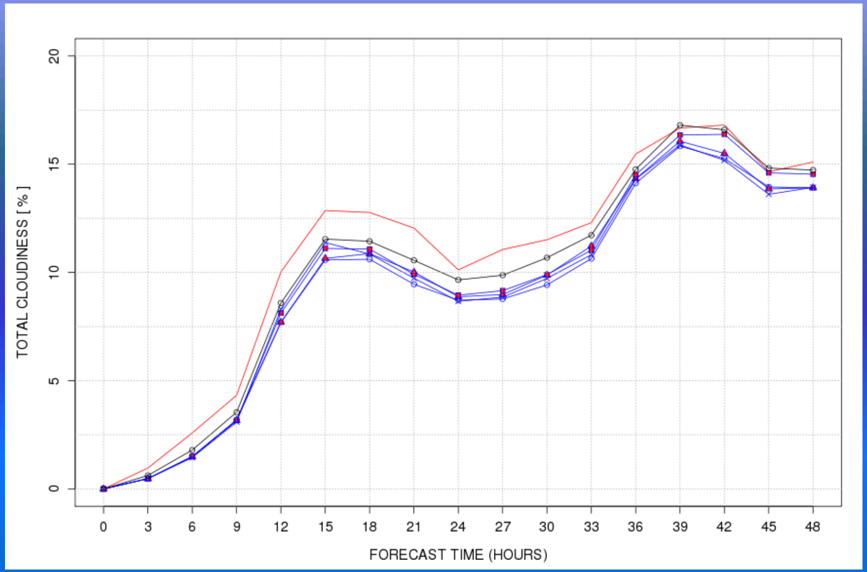
VERTICAL VELOCITY [m/s]



3h PRECIPITATION [mm]



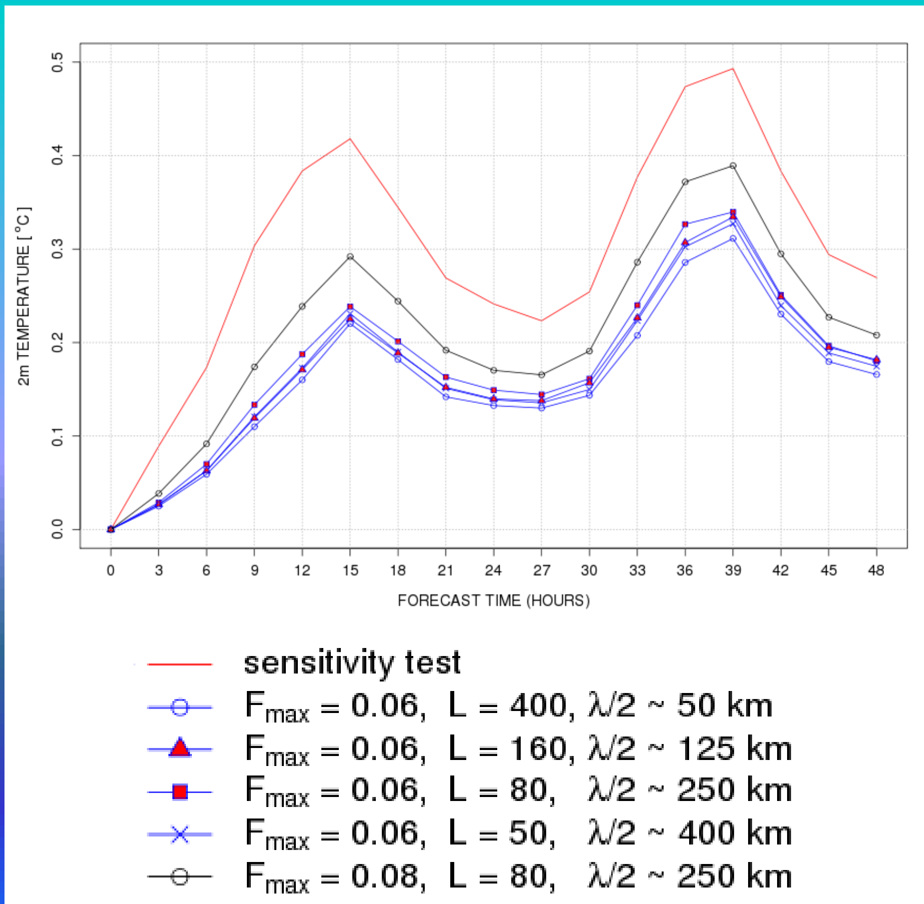
CLOUDINESS [%]

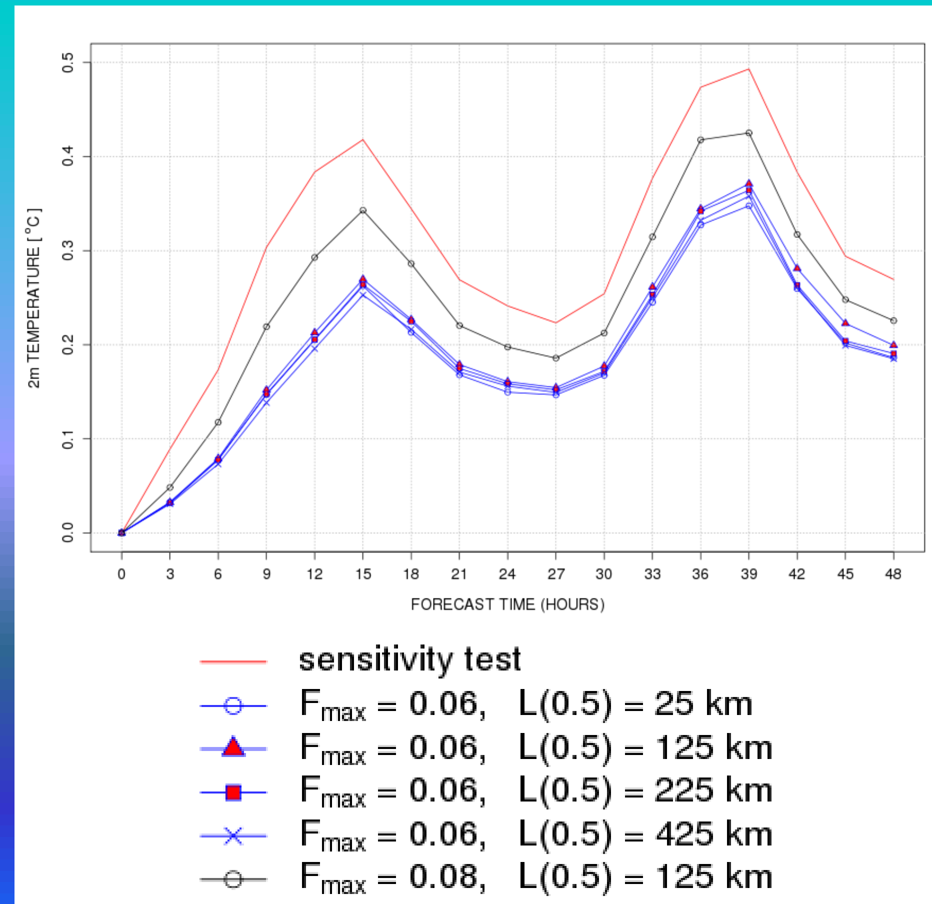


- sensitivity test
- F_{max} = 0.06, L = 400, λ/2 ~ 50 km
- F_{max} = 0.06, L = 160, λ/2 ~ 125 km
- F_{max} = 0.06, L = 80, λ/2 ~ 250 km
- F_{max} = 0.06, L = 50, λ/2 ~ 400 km
- F_{max} = 0.08, L = 80, λ/2 ~ 250 km

Spherical Harmonics vs. Stochastic Generator

2m temperature





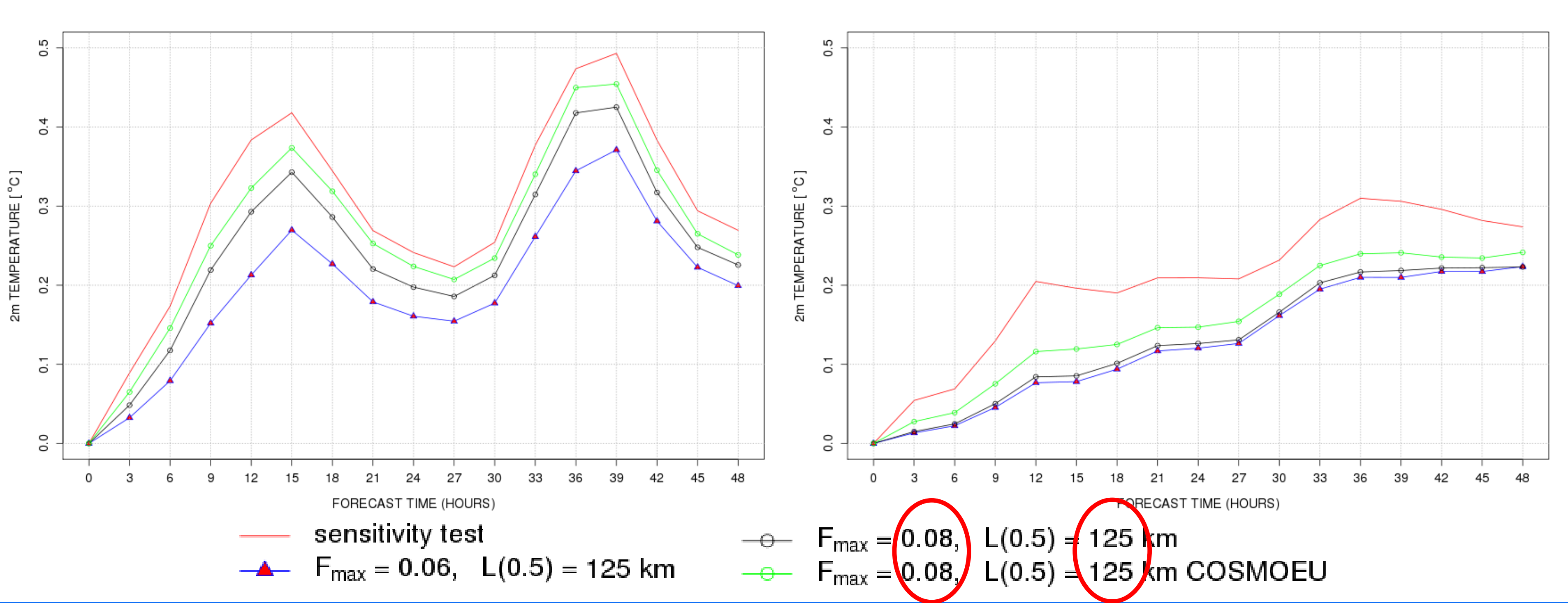
The variation of the horizontal wavelength from small to big scales doesn't lead to an evident change in spread. An higher sensitivity can be noticed increasing the perturbation intensity (from 0.06 to 0.08 $m^3\ m^{-3}$)

The same results can be obtained using the Stochastic Generator (with higher values of spread).

Change in the original soil moisture analysis
COSMO EU vs. IFS

(1) 29-06-2011 00UTC - STRONG SYNOPTIC FORCING

(2) 10-11-2013 00UTC - STRONG WINDS (FOEHN + MISTRAL) AND LOW LEVEL PRESSURE OVER TYRRHENIAN SEA



2m TEMPERATURE [°C]

External parameters perturbation:

Leaf Area Index, Roughness Length and Plant Cover

- Multiplicative perturbation (Lavaysse et al. 2013)
- Choice based on the assumption that the errors are proportional to the values of the considered variable.
- For Plant Cover perturbation is assumed to be lower when the values of plant cover are close to the limits (0 or 1)
  - Simmetric perturbation centered at 0.5 is used
- Same spatial length scale for all the variables considered (L(0.5)=125 km)

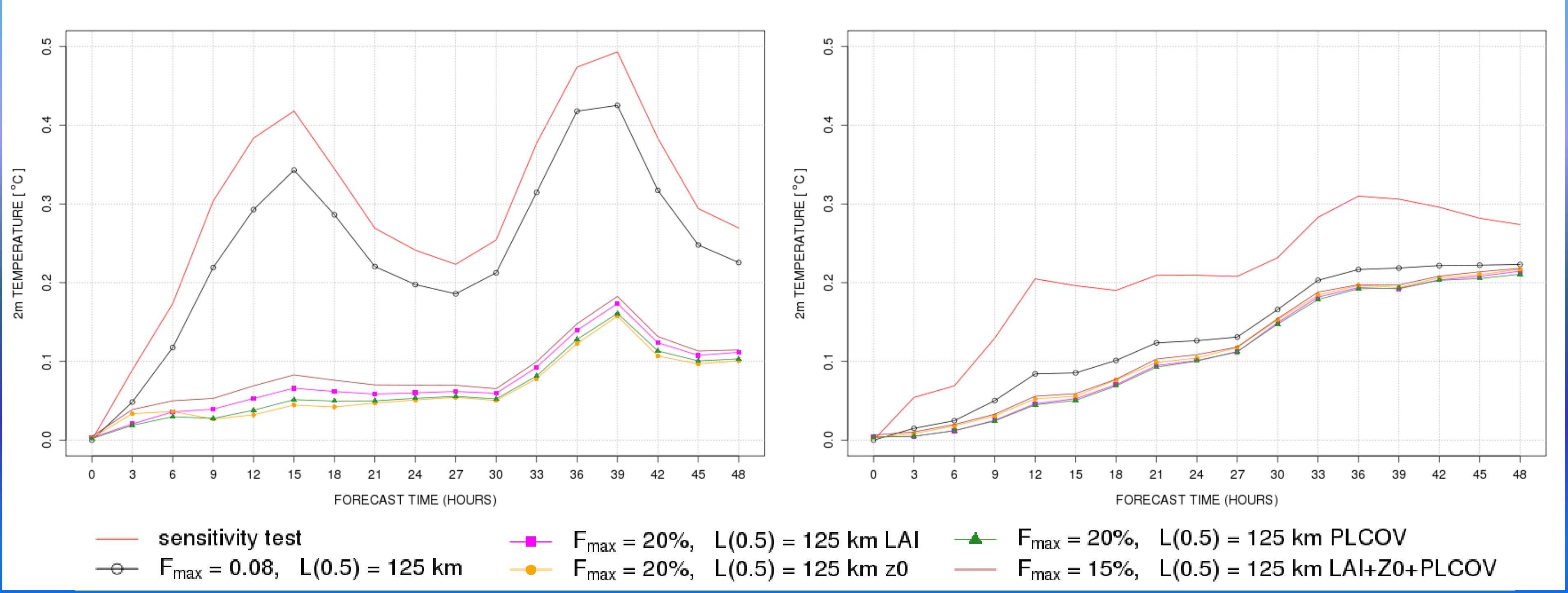
	Variables	**Layer**	**Type of perturbation**	**Intensity F_{max}**	**Boundaries**
1	*Leaf Area Index – **LAI***		x	0.2; 1.8 – 20%	[0; [
2	*Roughness Length - **z0***		x	0.2; 1.8 – 20%	[0; [
3	*Plant Cover - **PLCOV***		x	0.2; 1.8 – 20% (centered at 0.5)	[0; 1]
4	*Ext. Param. - **LAI + z0 + PLCOV***		x	0.2; 1.8 – 20%	[0; [and [0; 1]
5	*Soil moisture - **W_SO***	***W_SO*** Surface	+	± 0.08 $m^3\ m^{-3}$	[0; 1], porosity
		W_SO Root zone	+	± 0.06 $m^3\ m^{-3}$	[0; 1], porosity
	*Ext. Param. - **LAI + z0 + PLCOV***		x	0.2; 1.8 – 20%	[0; [and [0; 1]

External parameters perturbation:

Leaf Area Index, Roughness Length and Plant Cover

(1) 29-06-2011 00UTC - STRONG SYNOPTIC FORCING

(2) 10-11-2013 00UTC - STRONG WINDS (FOEHN + MISTRAL) AND LOW LEVEL PRESSURE OVER TYRRHENIAN SEA



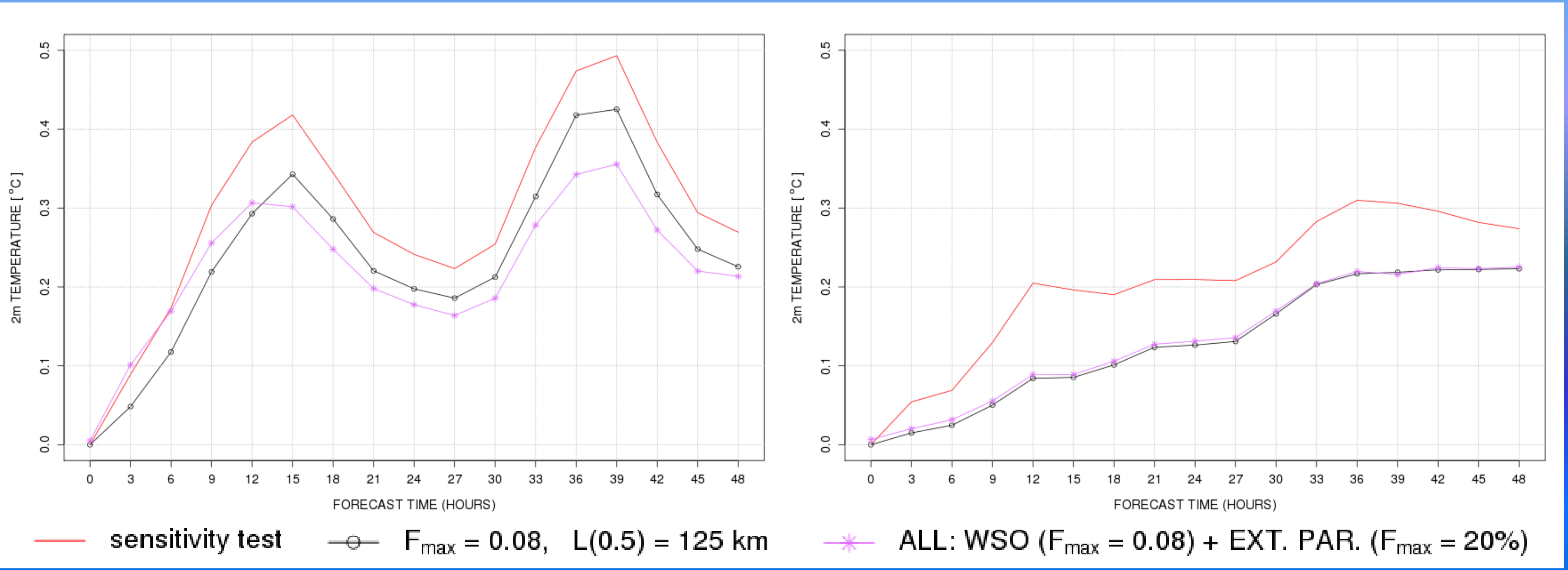
2m TEMPERATURE [°C]

Complete Perturbation

- external parameters: F_{max} = 20%, *L(0.5)* = 125 km
- soil moisture: $F_{max\ surf}$ = 0.08 $m^3\ m^{-3}$, *L(0.5)* = 125 km

(1) 29-06-2011 00UTC - STRONG SYNOPTIC FORCING

(2) 10-11-2013 00UTC - STRONG WINDS (FOEHN + MISTRAL) AND LOW LEVEL PRESSURE OVER TYRRHENIAN SEA



2m TEMPERATURE [°C]

Comparison with the spread of an ensemble system with IC e BC perturbations: COSMO LEPS

Variables considered: *2m Temperature* T_{2m} *, Dew Point Temperture* T_d*, Precipitation P, Wind Speed* $\sqrt{U^2 + V^2}$

Case study:

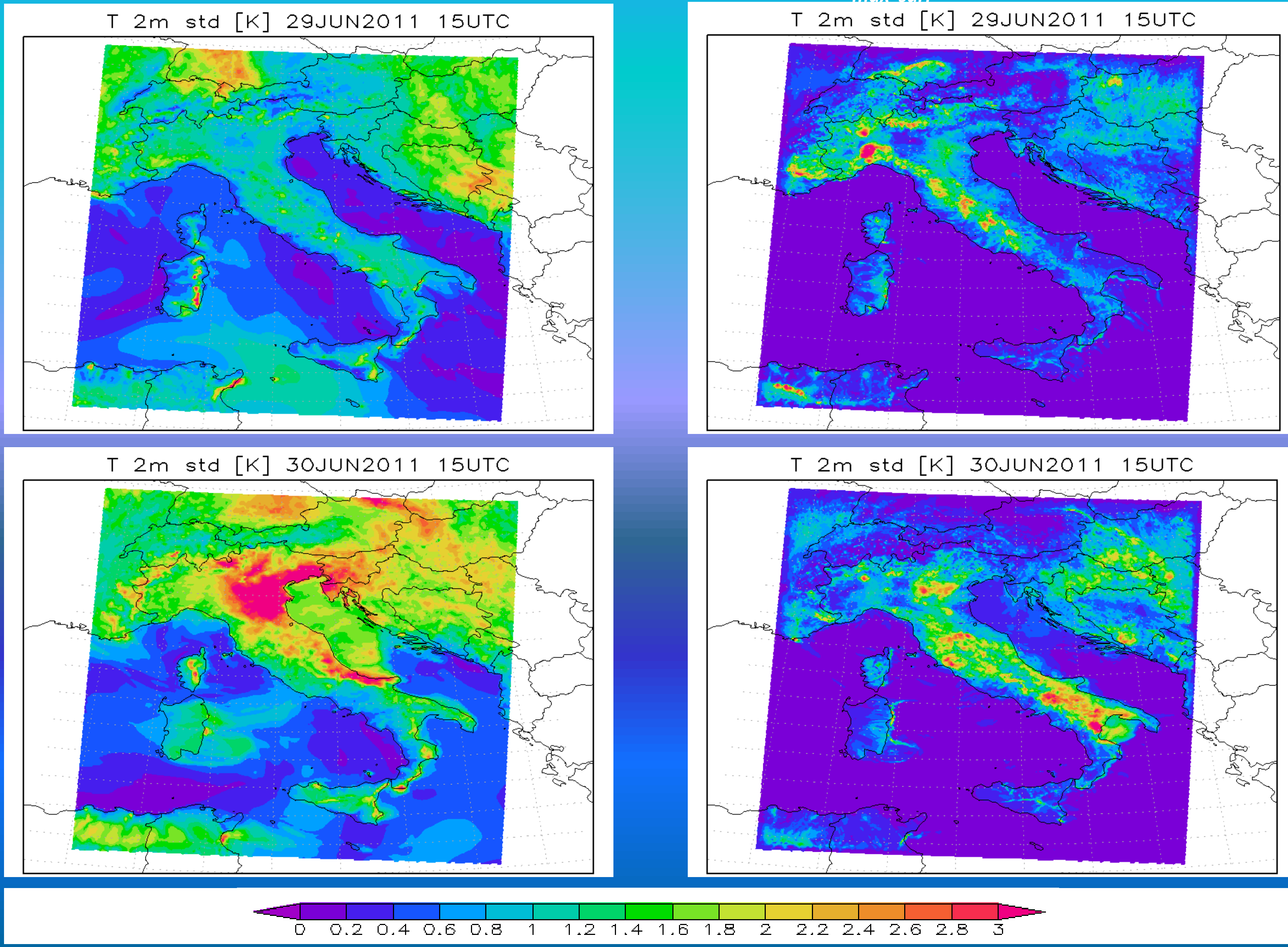
- *29-06-2011 00UTC – Strong synoptic forcing (cold front)*
- *10-11-2013 00 UTC – Strong winds (Foehn + Mistral) and low pressure system over Tyrrhenian sea*

Settings: $L(0.5) = 125$ km, $F_{max\ surf} = 0.08$, $F_{max\ root} = 0.06\ m^3\ m^{-3}$

2m Temperature – case study 29062011 00 UTC

COSMO LEPS – run 28062011 12 UTC

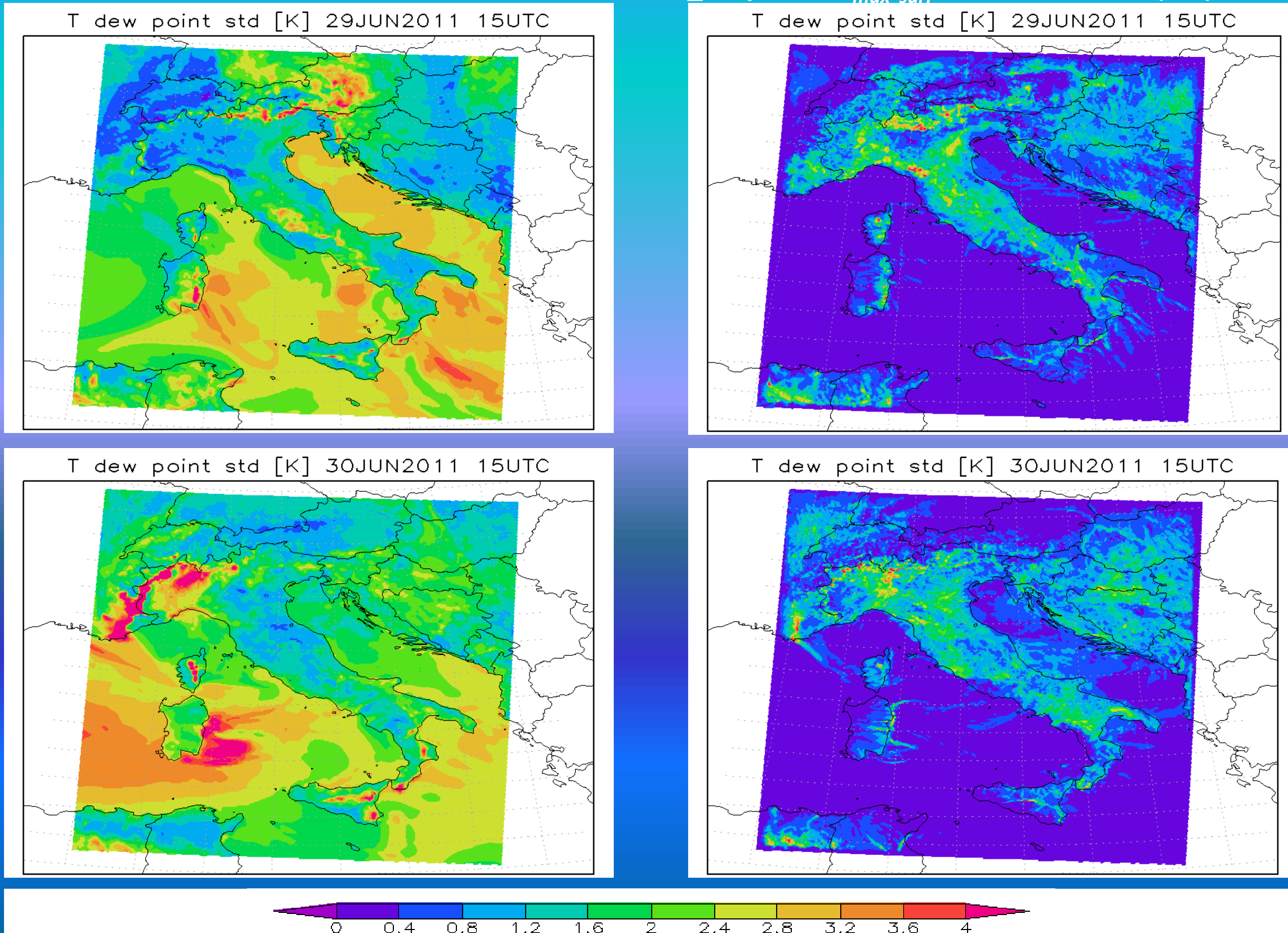
W_SO pert. – F_{max_surf} = 0.08 $m^3\ m^{-3}$, L(0.5) = 125 km



Dew Point Temperature – case study 29062011 00 UTC

COSMO LEPS – run 28062011 12 UTC

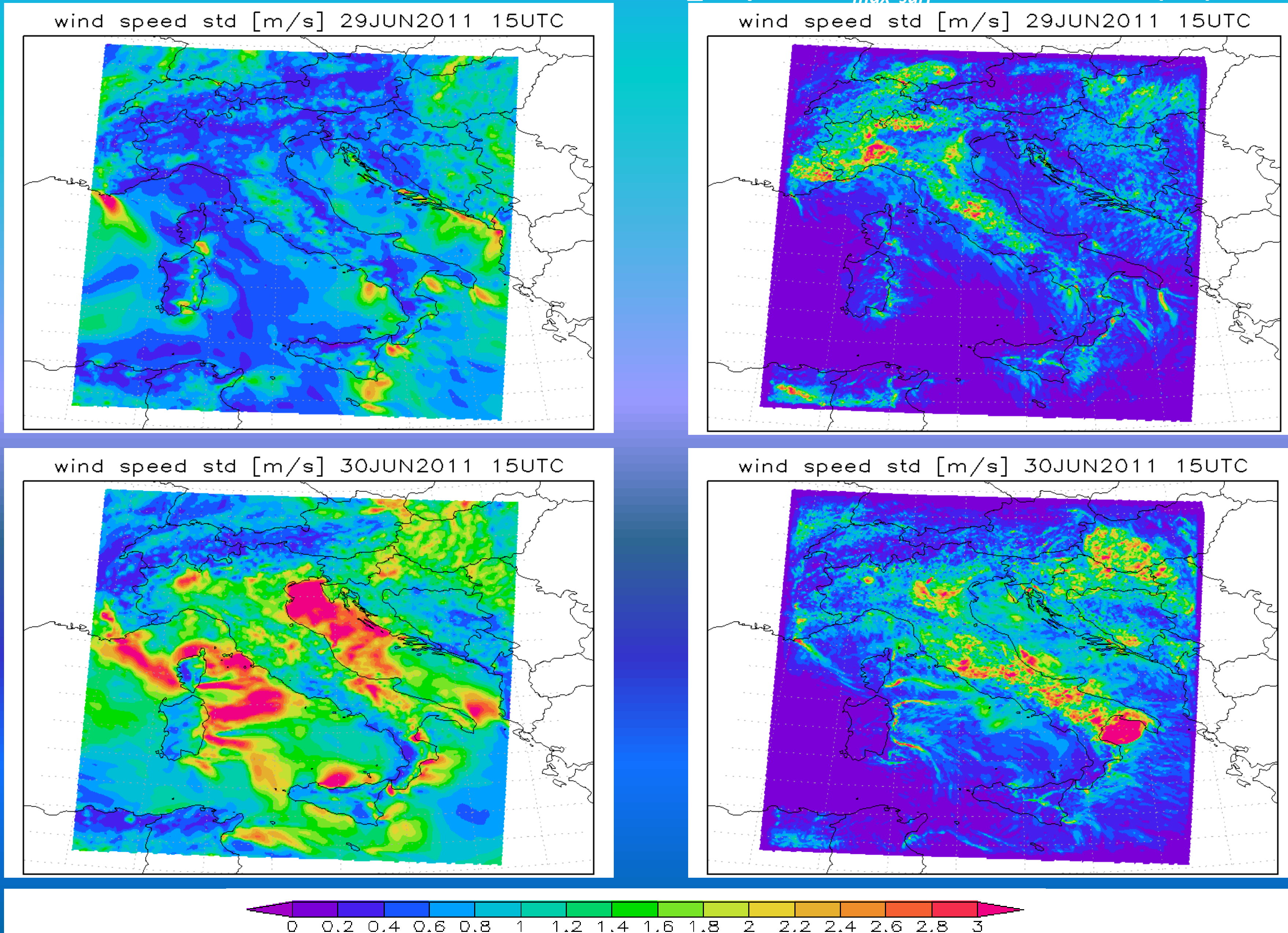
W_SO pert. – $F_{max\ surf}$ = 0.08 $m^3\ m^{-3}$, L(0.5) = 125 km



10m Wind Speed – case study 29062011 00 UTC

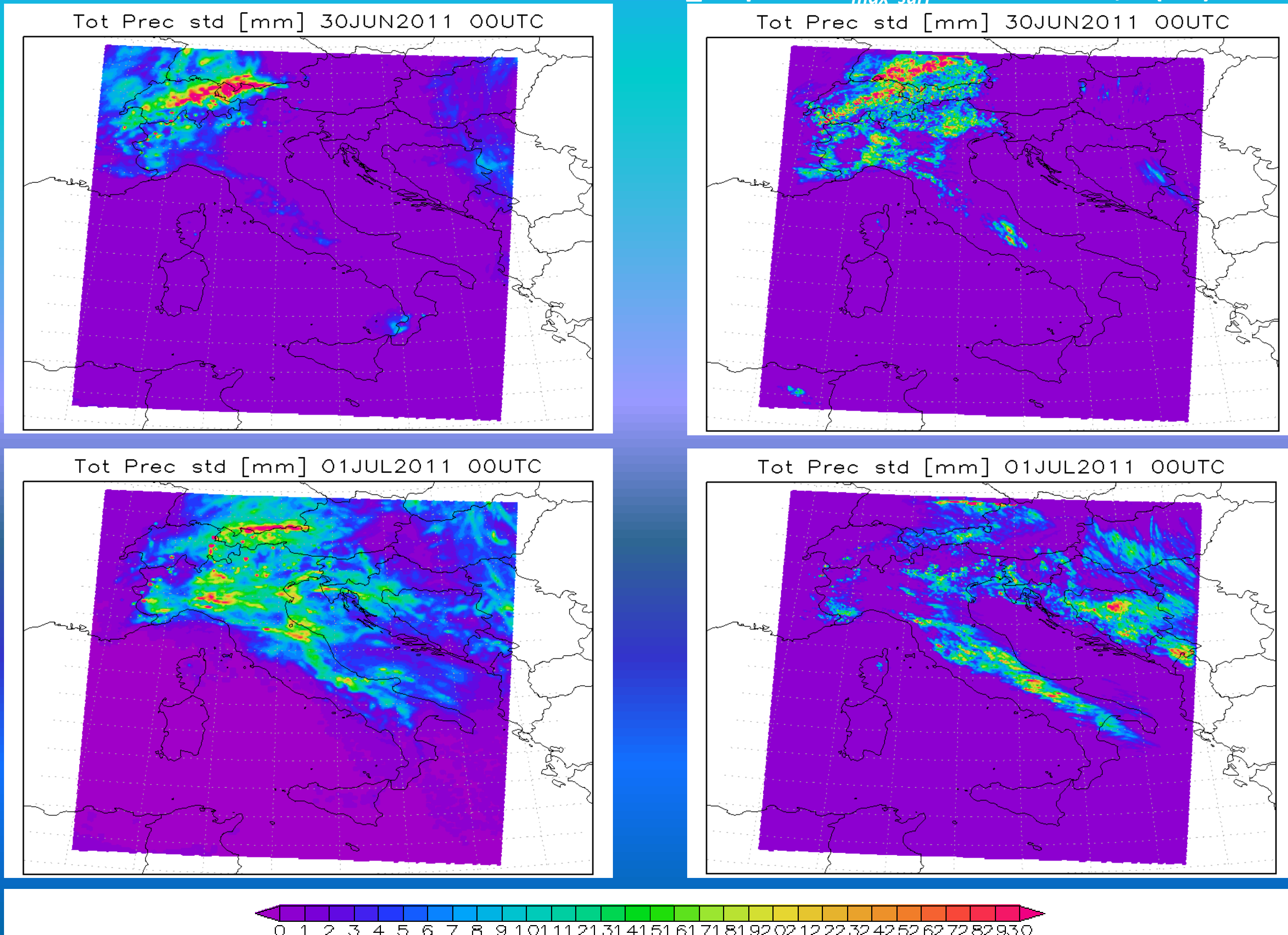
COSMO LEPS – run 28062011 12 UTC

W_SO pert. – $F_{max\_surf} = 0.08\ m^3\, m^{-3}$, L(0.5) = 125 km

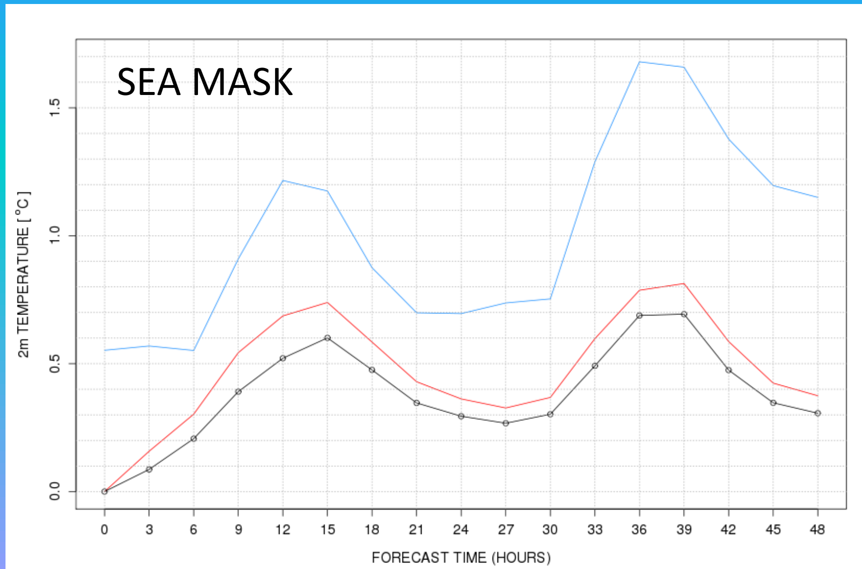


Daily Cumulated Precipitation – case study 29062011 00 UTC

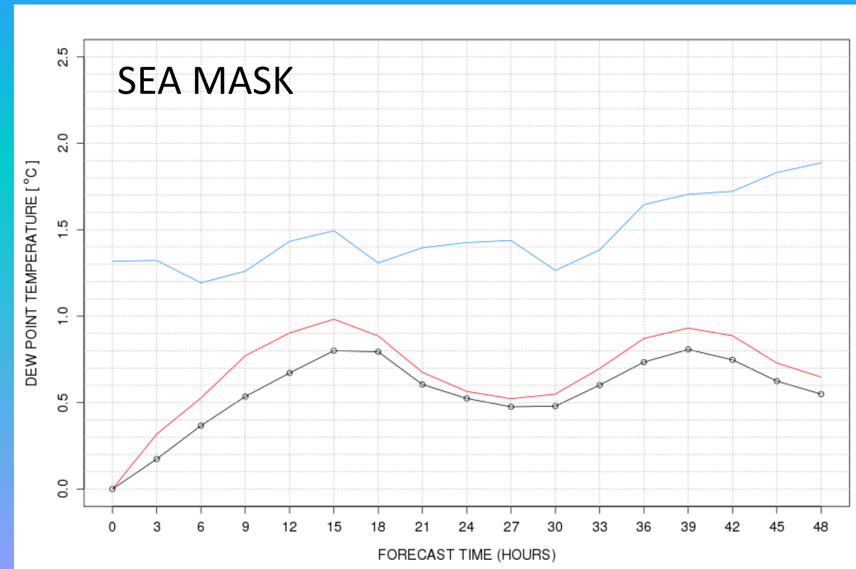
COSMO LEPS– run 28062011 12 UTC | **W_SO pert. – $F_{max\ surf}$ = 0.08 $m^3\ m^{-3}$, L(0.5) = 125 km**



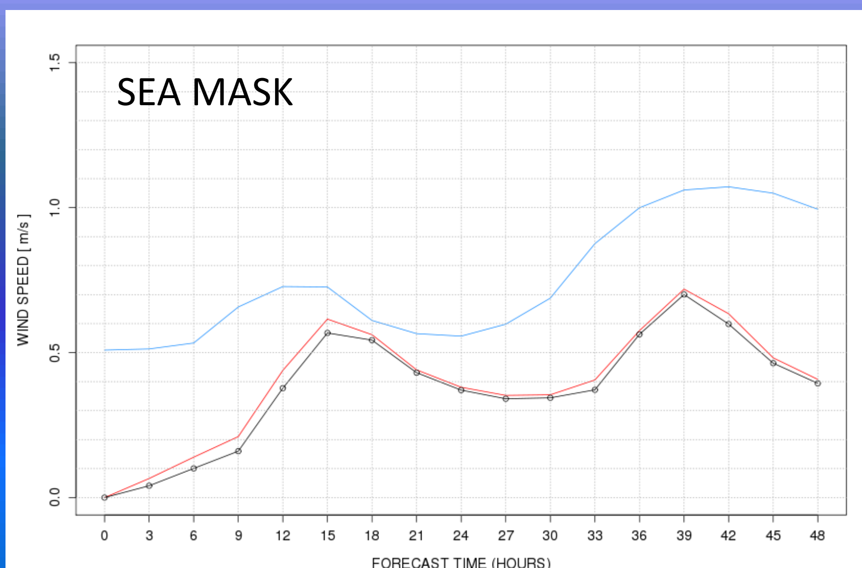
2 m TEMPERATURE [°C]



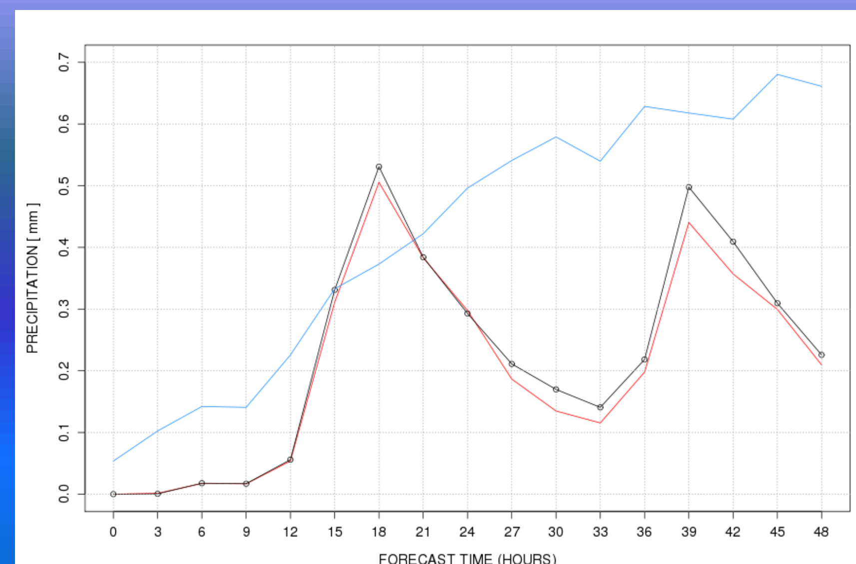
DEW POINT TEMPERATURE [°C]



WIND SPEED [m/s]



3h PRECIPITATION [mm]

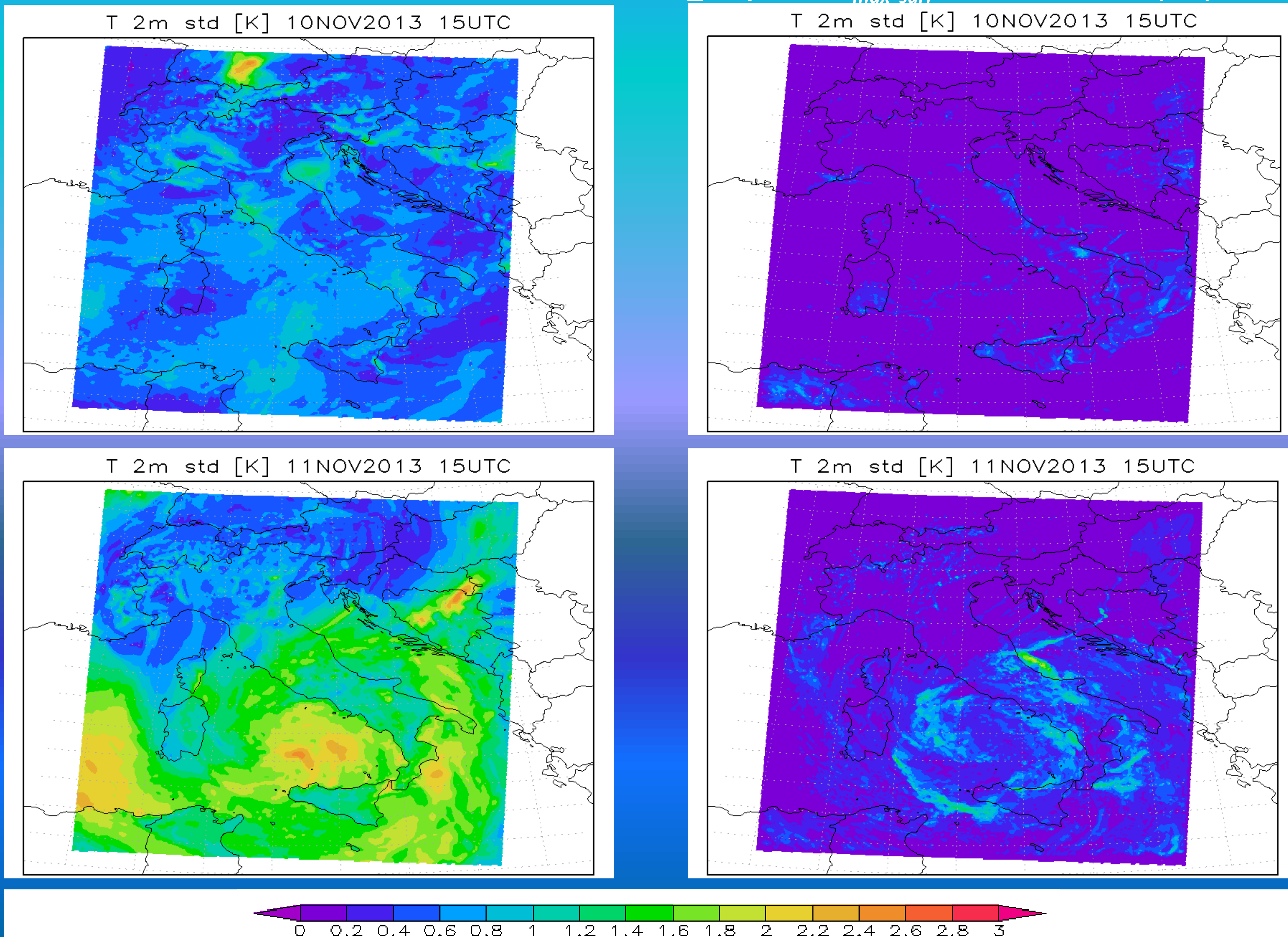


COSMO LEPS run: 28062011 12UTC — sensitivity test — F_{max} = 0.08, L(0.5) = 125 km

2m Temperature – case study 10112013 00 UTC

COSMO LEPS – run 10112013 00 UTC

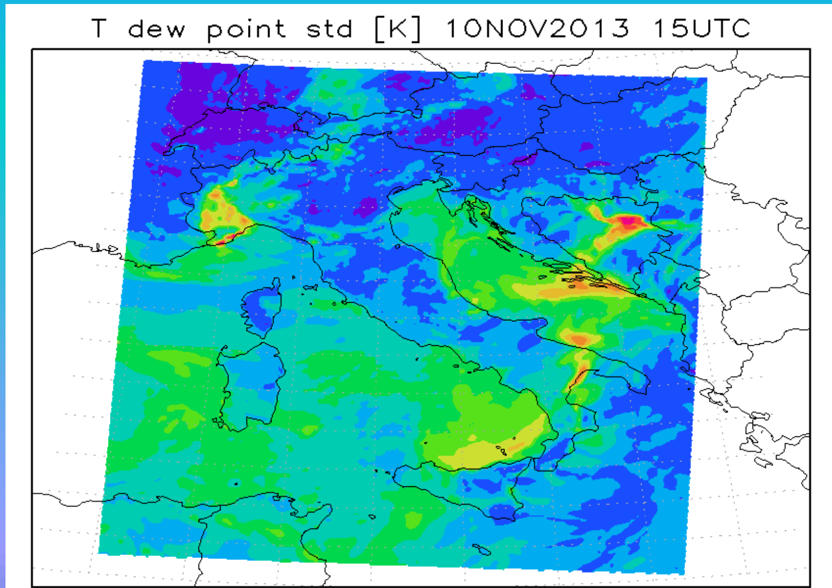
W_SO pert. – F_{max_surf} = 0.08 $m^3\ m^{-3}$, L(0.5) = 125 km

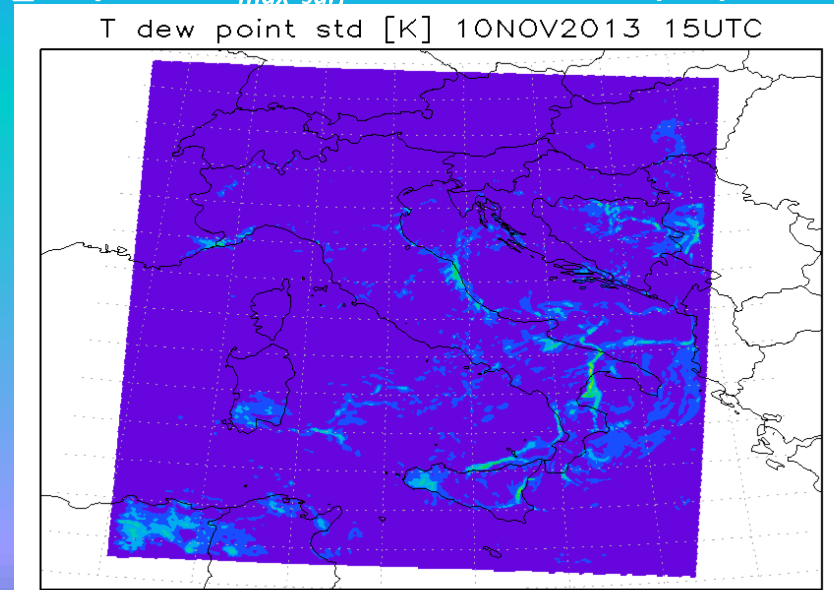


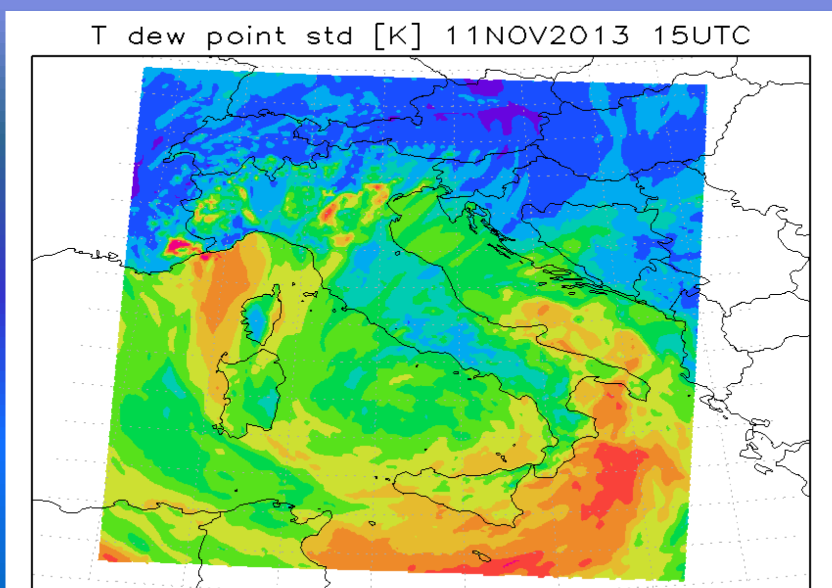
Dew Point Temperature – case study 10112013 00 UTC

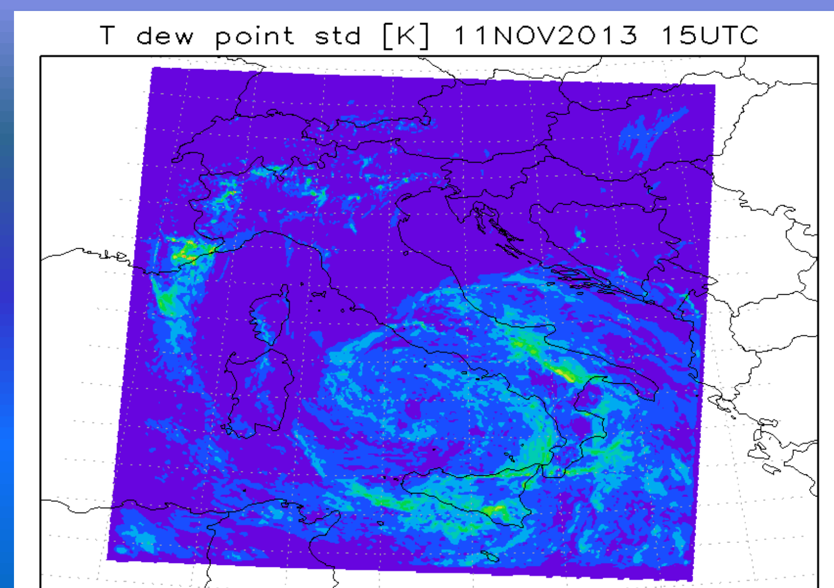
COSMO LEPS – run 10112013 00 UTC

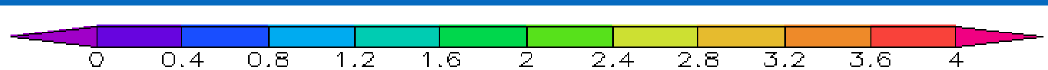
W_SO pert. – $F_{max\ surf}$ = 0.08 $m^3\ m^{-3}$, L(0.5) = 125 km







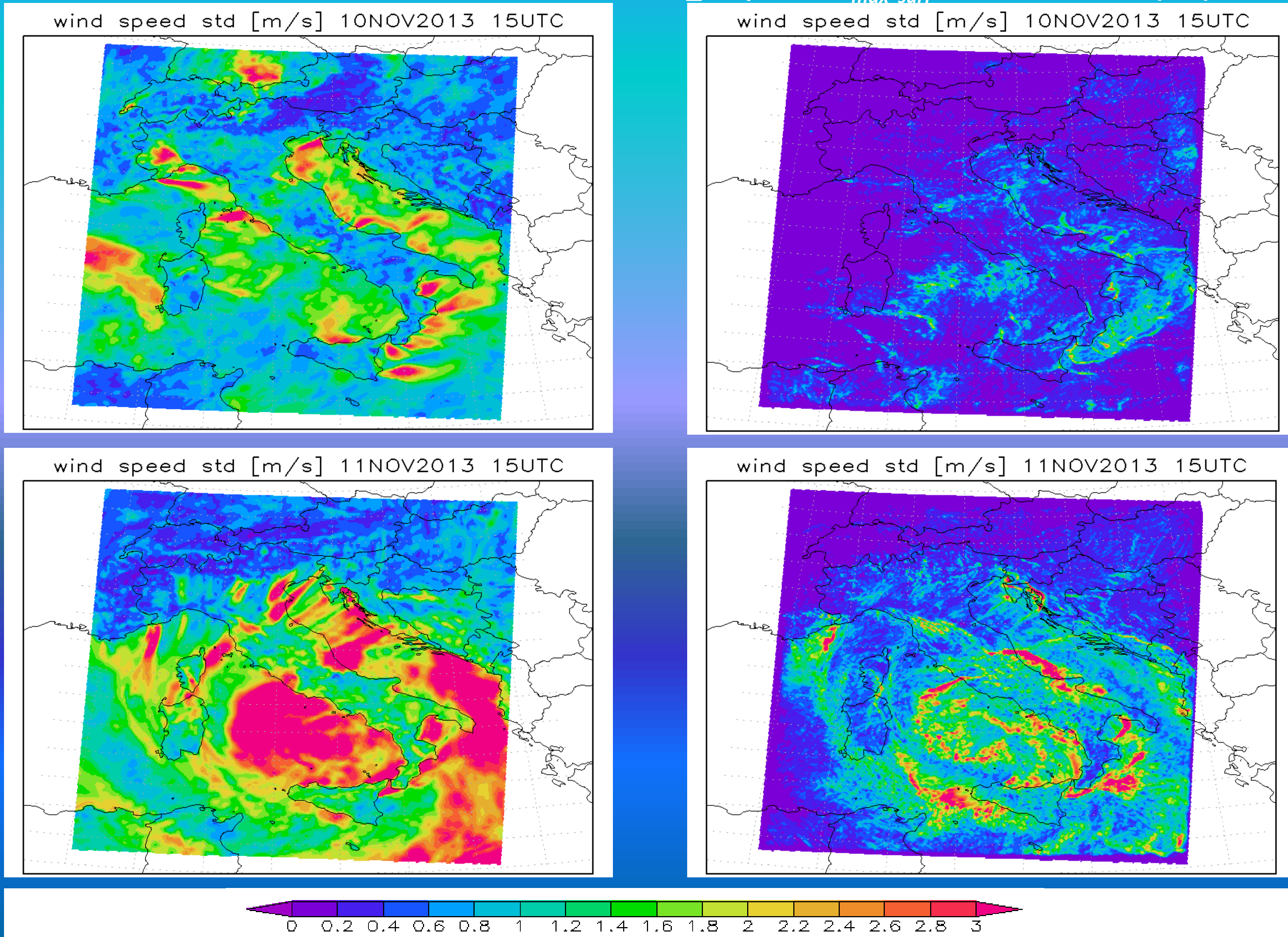




10m Wind Speed – case study 10112013 00 UTC

COSMO LEPS – run 10112013 00 UTC

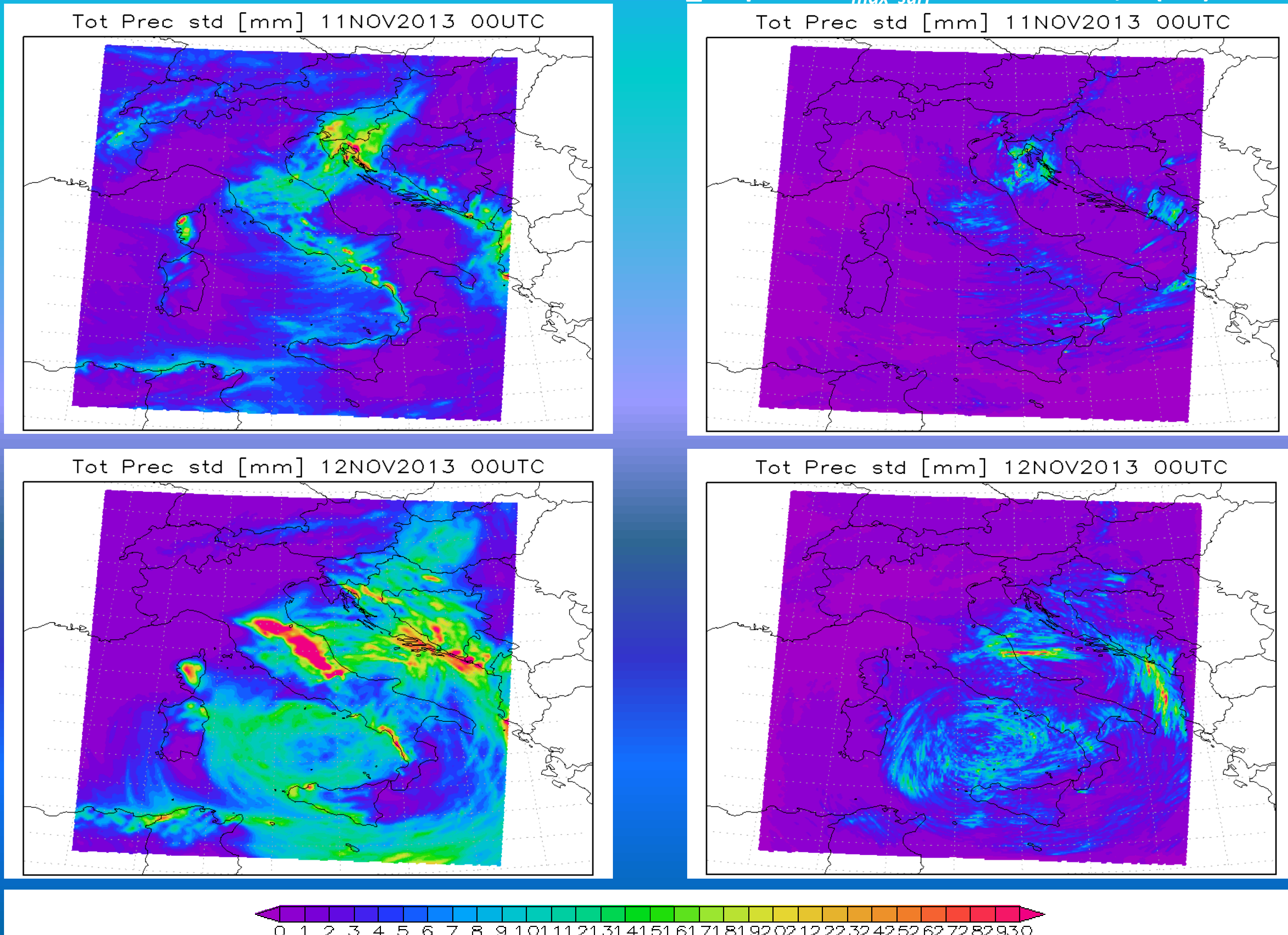
W_SO pert. – F_{max_surf} = 0.08 $m^3\ m^{-3}$, L(0.5) = 125 km



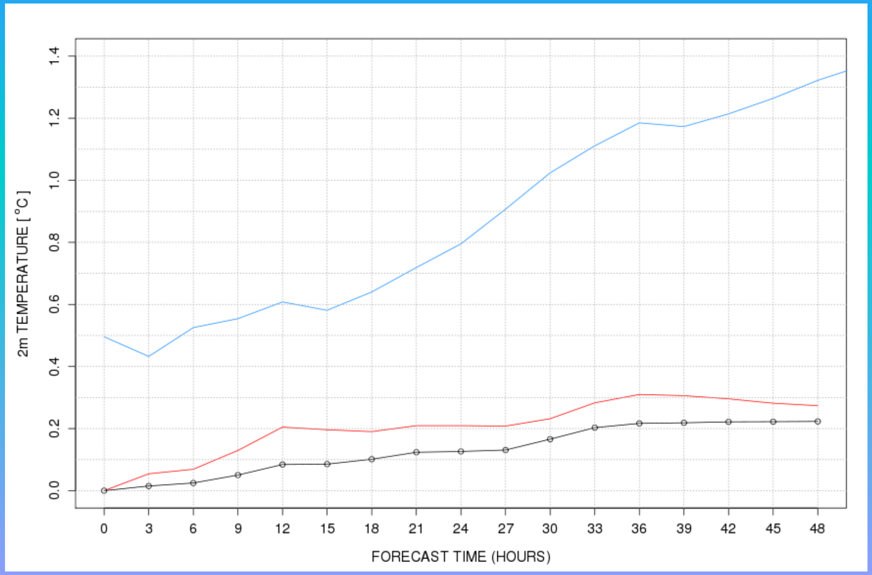
Daily Cumulated Precipitation – case study 10112013 00 UTC

COSMO LEPS– run 10112013 00 UTC

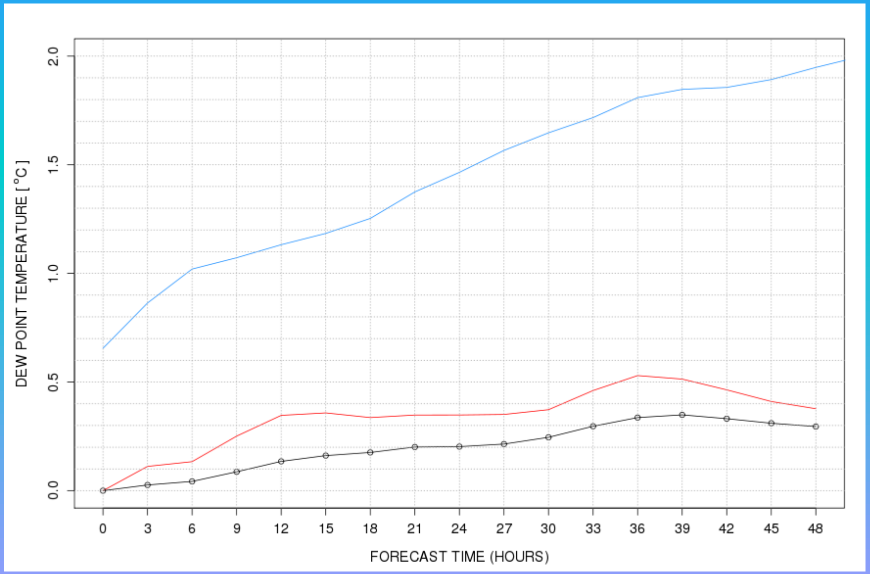
W_SO pert. – F_{max_surf} = 0.08 $m^3\ m^{-3}$, L(0.5) = 125 km



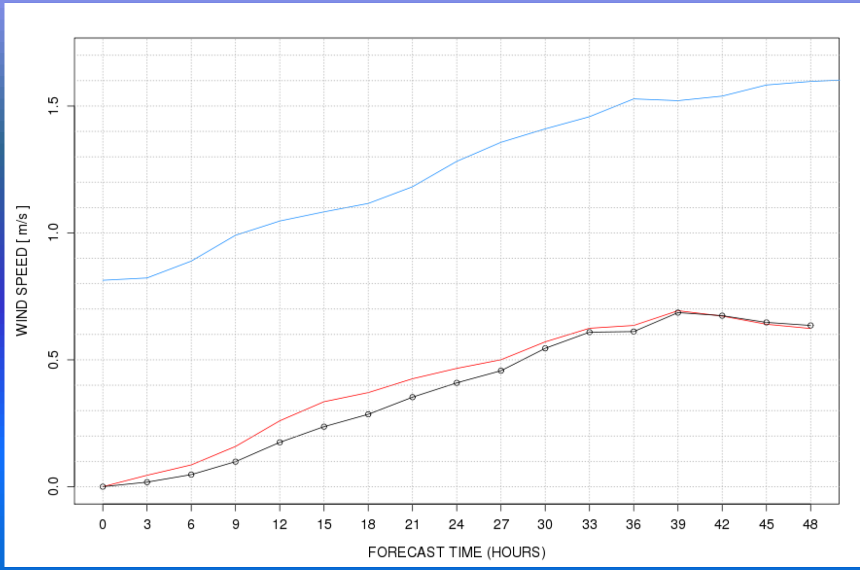
2 m TEMPERATURE [°C]



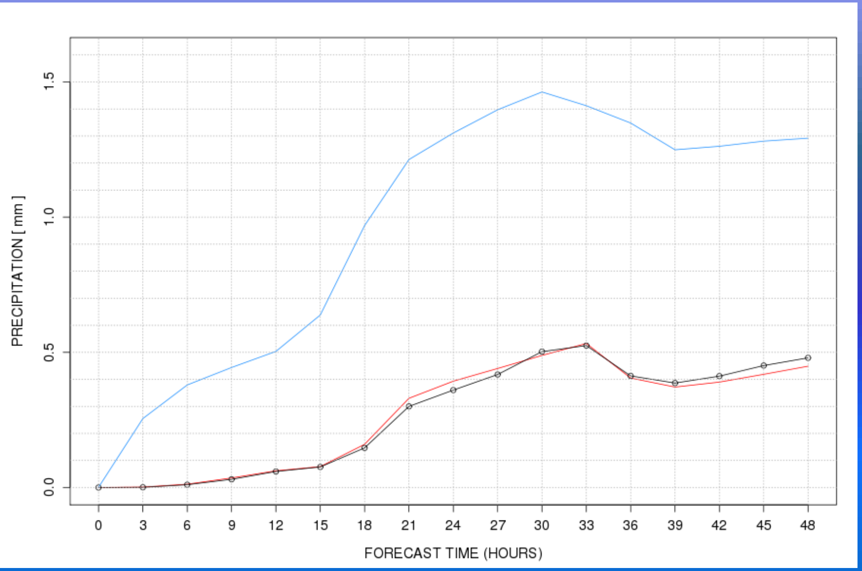
DEW POINT TEMPERATURE [°C]



WIND SPEED [m/s]



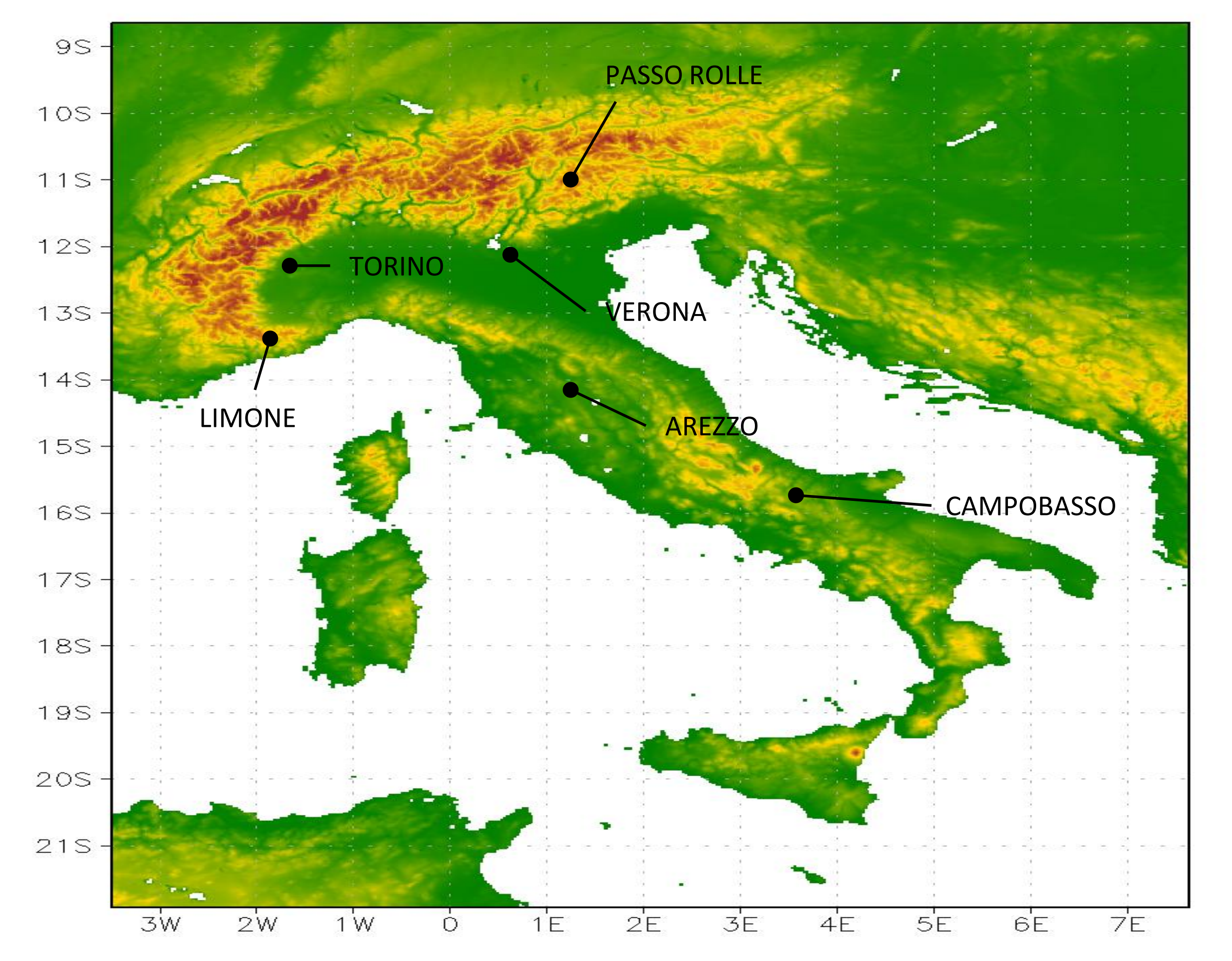
3h PRECIPITATION [mm]



COSMO LEPS run: 28062011 12UTC — sensitivity test — F_{max} = 0.08, L(0.5) = 125 km

Comparison with observations (SYNOP)
1° case study – 29/06/2011

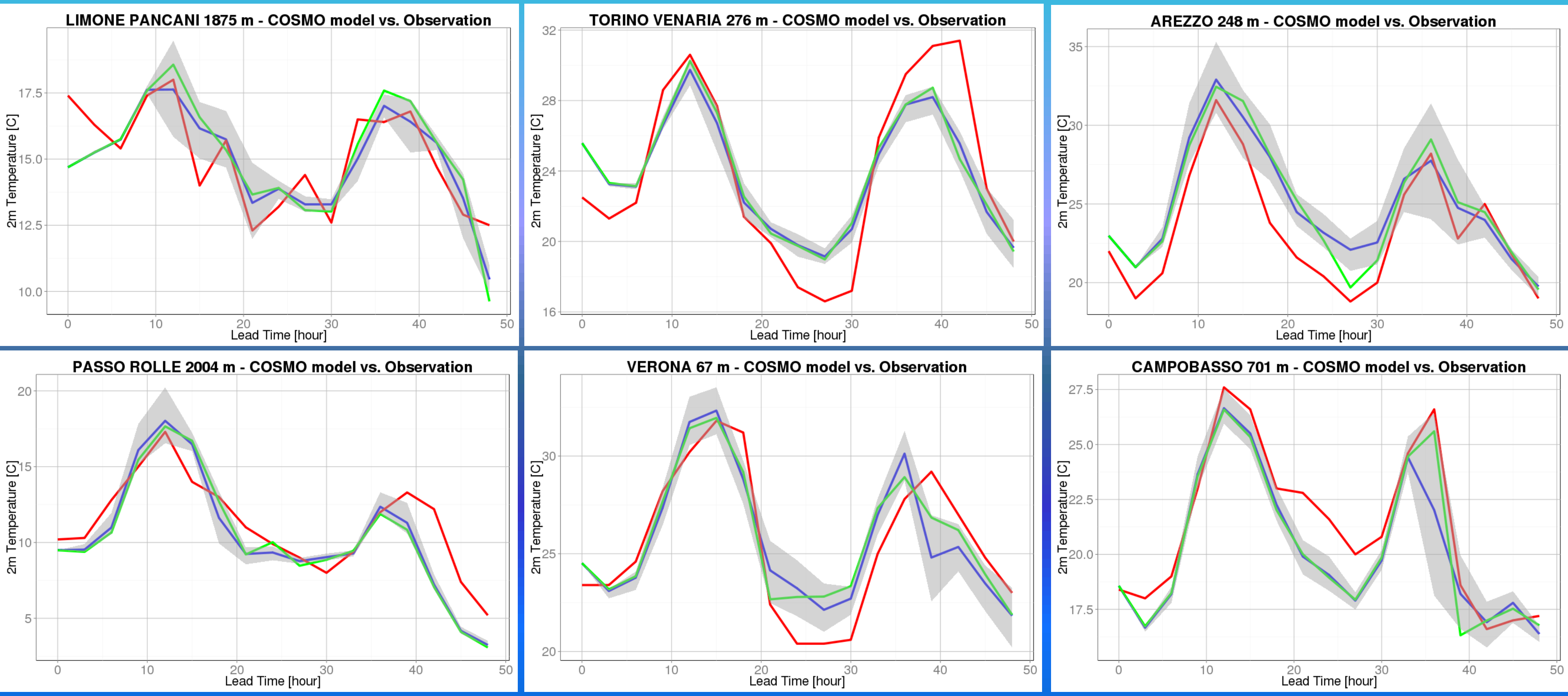
W_SO pert. – $F_{max\ surf}$ = 0.08 $m^3\ m^{-3}$, L(0.5) = 125 km



Comparison with observations (SYNOP)
1° case study – 29/06/2011

2m Temperature

ALPS | PO VALLEY | CENTRAL ITALY

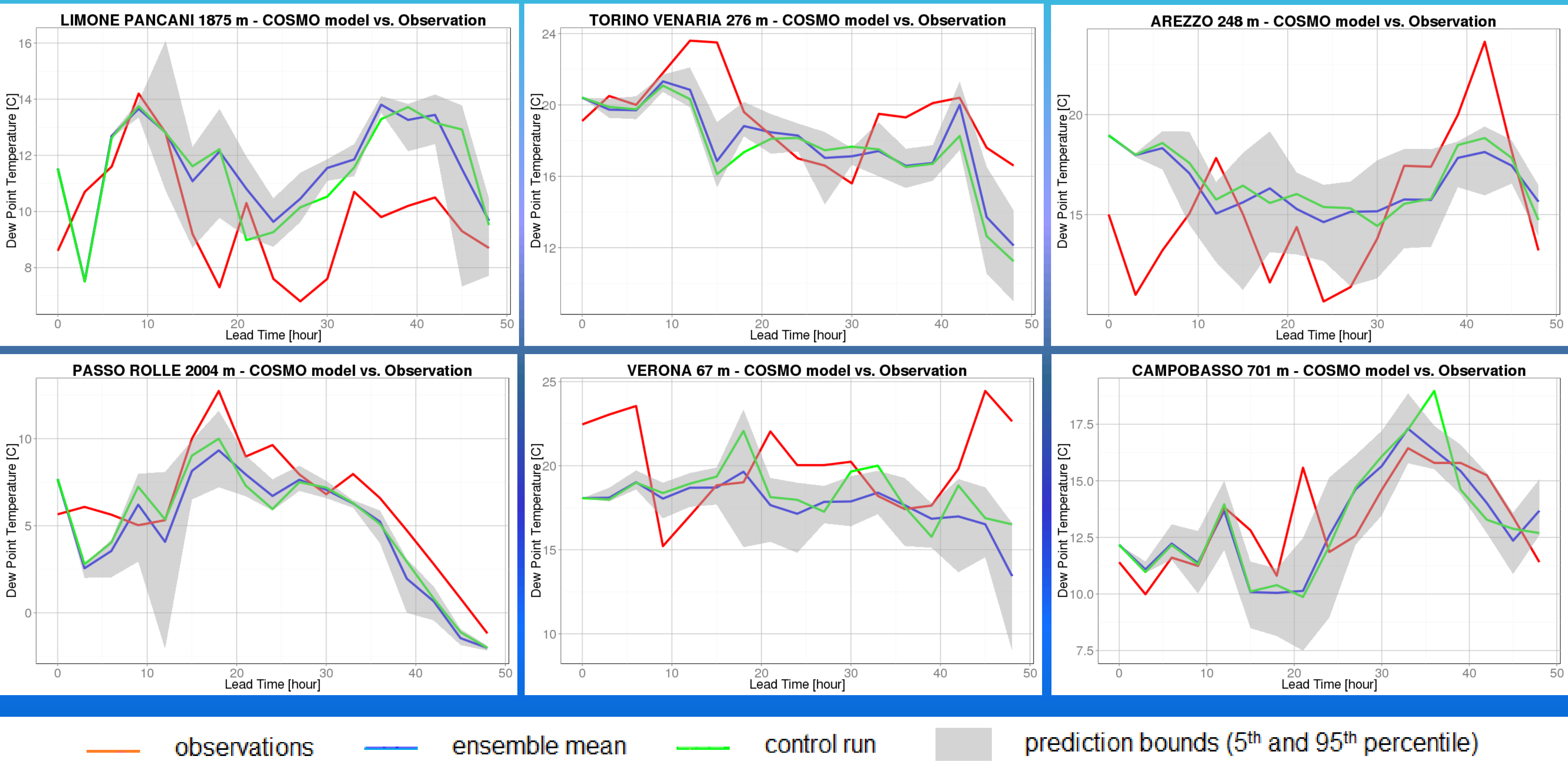


observations — ensemble mean — control run — prediction bounds (5^{th} and 95^{th} percentile)

Comparison with observations (SYNOP)
1° case study – 29/06/2011

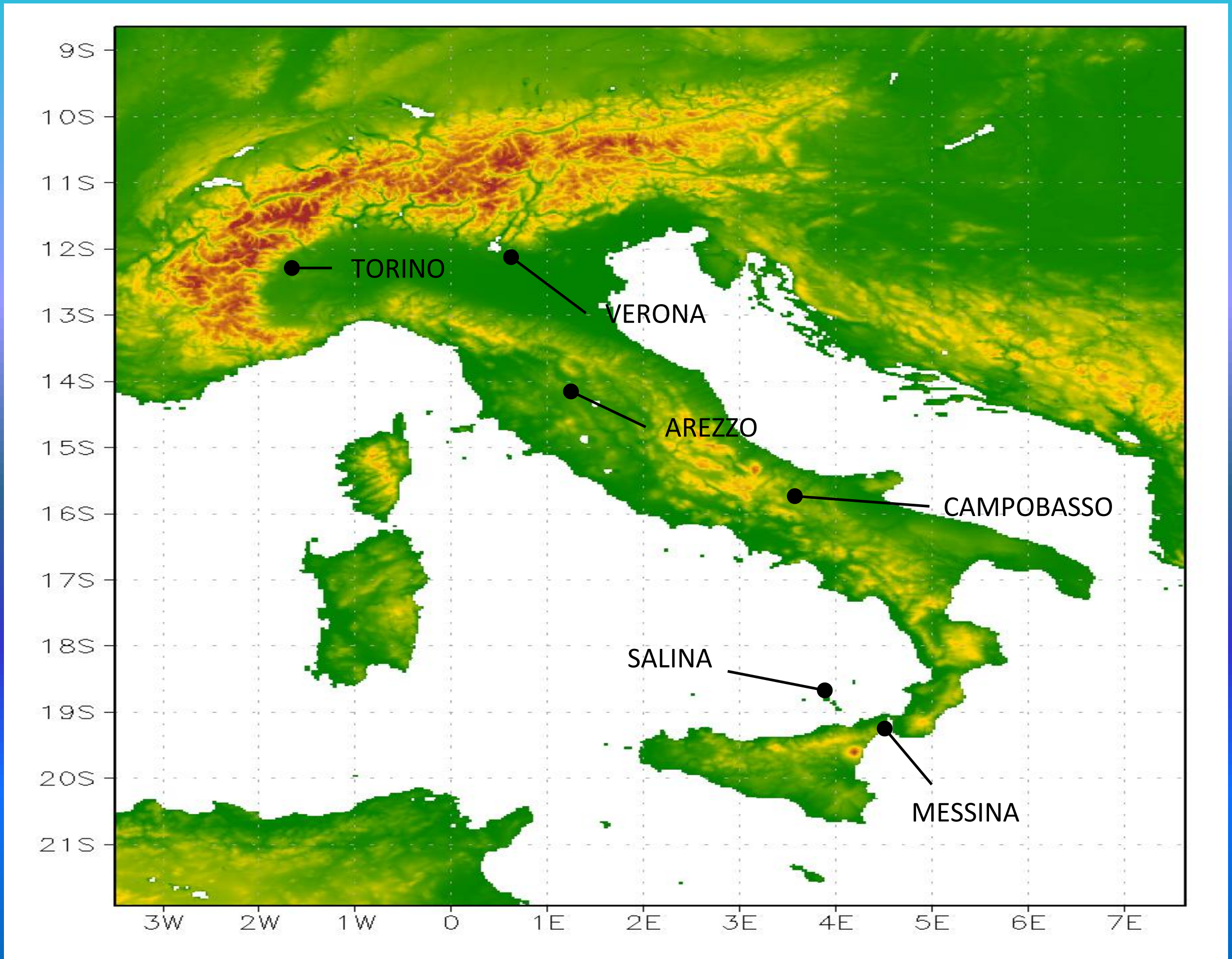
Dew Point Temperature

ALPS | PO VALLEY | CENTRAL ITALY



Comparison with observations (SYNOP) 2° case study – 10/11/2013

W_SO pert. – $F_{max\ surf}$ = 0.08 $m^3\ m^{-3}$, L(0.5) = 125 km

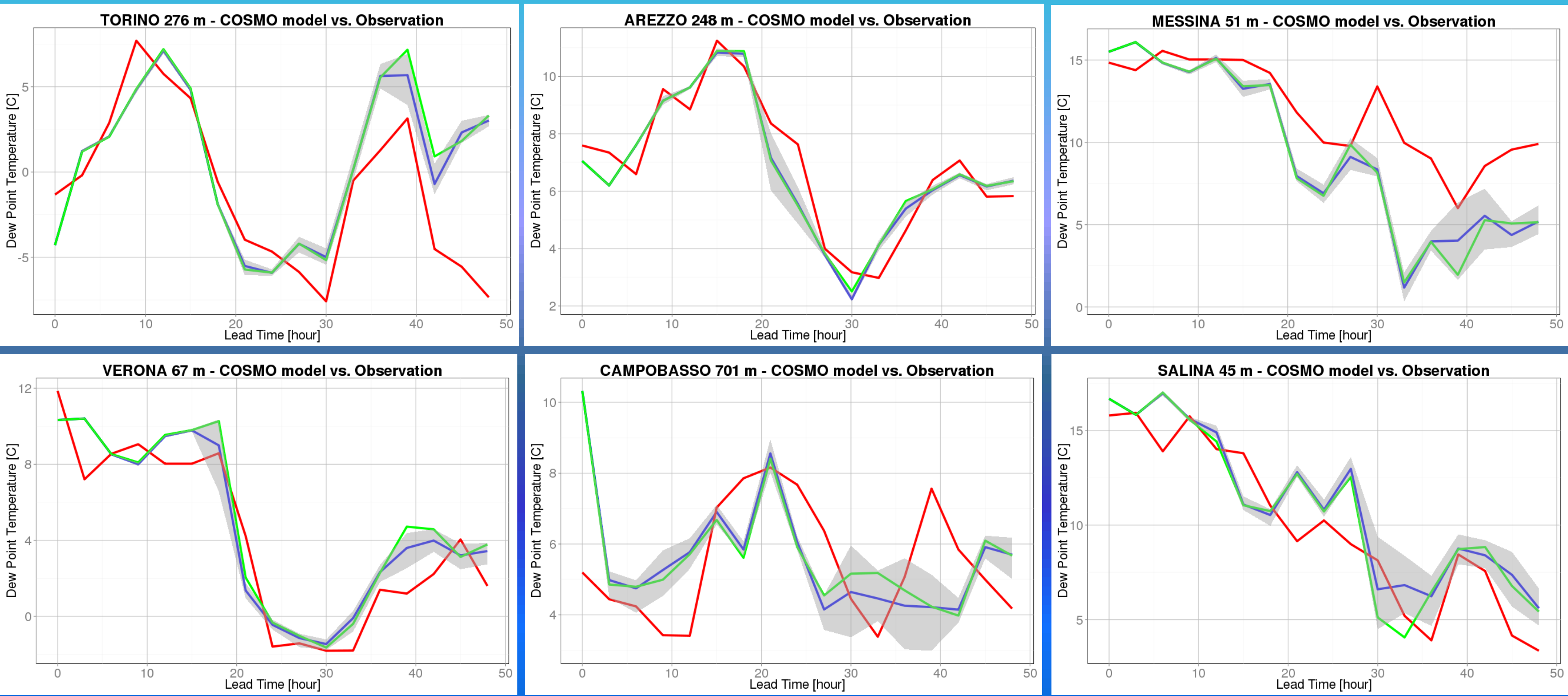


Comparison with observations (SYNOP)

2° case study – 10/11/2013

Dew Point Temperature

PO VALLEY | CENTRAL ITALY | SOUTHERN ITALY



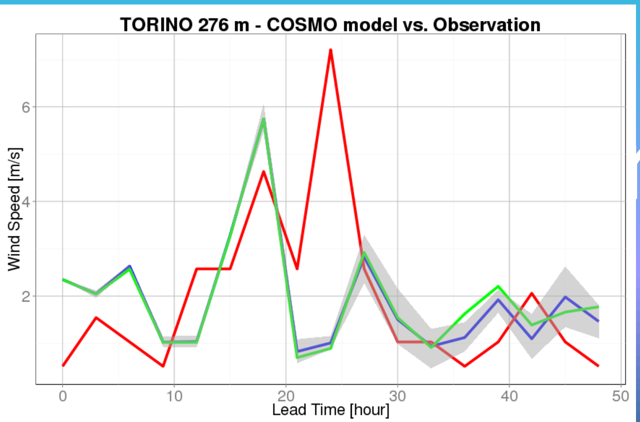
observations | ensemble mean | control run | prediction bounds (5th and 95th percentile)

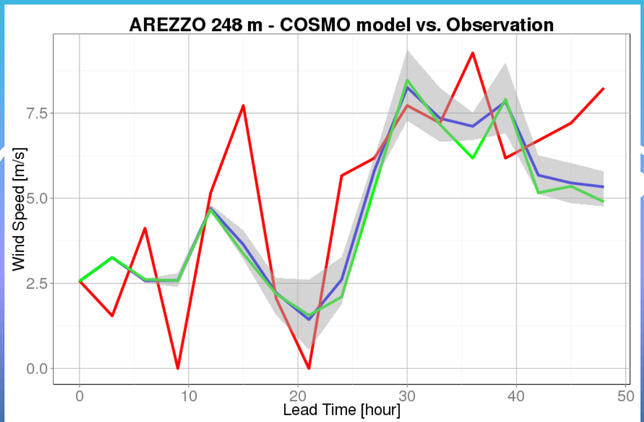
Comparison with observations (SYNOP)

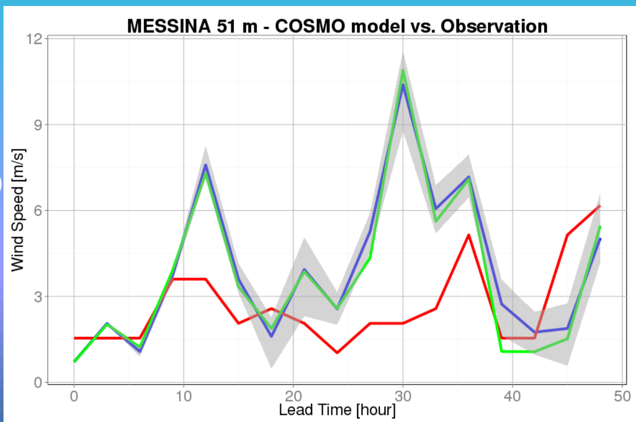
2° case study – 10/11/2013

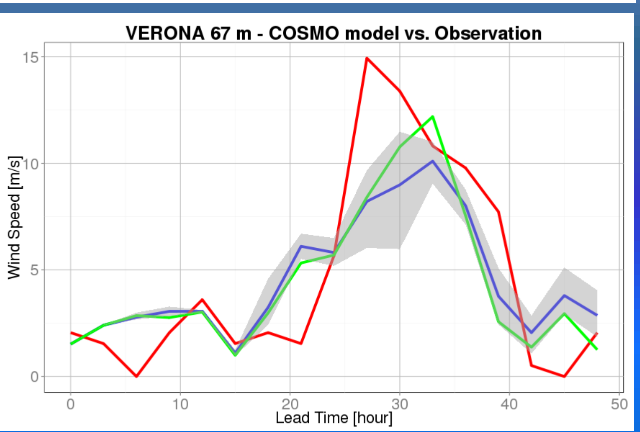
Wind Speed

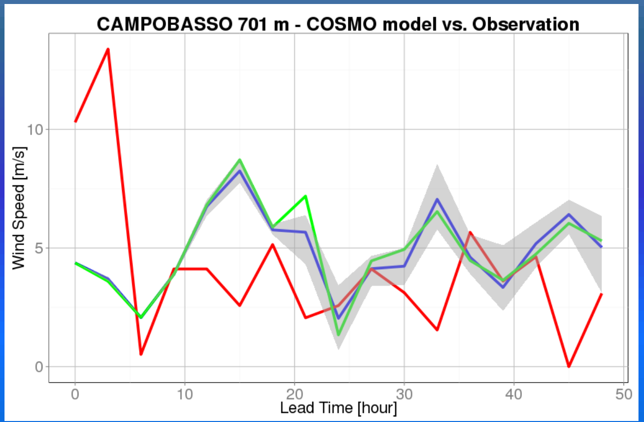
PO VALLEY | CENTRAL ITALY | SOUTHERN ITALY

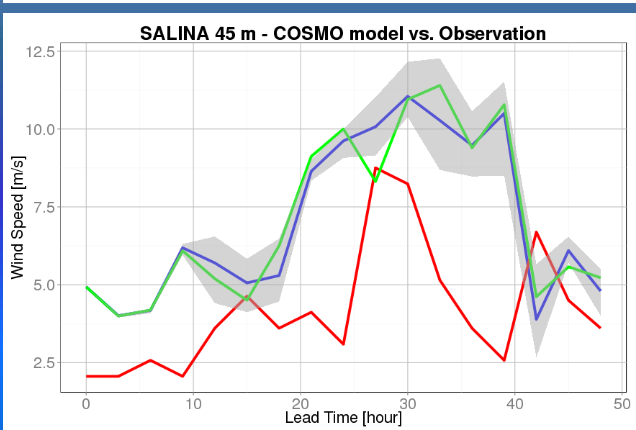












observations — ensemble mean — control run — prediction bounds (5th and 95th percentile)

Conclusions

1. Equivalence between Spherical harmonics approach and Stochastic generator
2. Low sensitivity with respect to the spatial length scale and higher sensitivity to the intensity of the perturbation.
3. COSMO EU soil moisture initialization lead to higher values of spread (considering the same value of the intensity of the perturbation F_{max}) for both the case studies.
4. Weak sensitivity of COSMO model to the perturbation of some external parameters like Leaf Area Index, Roughness Length and Plant Cover.
5. Non additive effect when perturbing all the external parameters together (in this case, the contribution to the spread is similar to the contribution obtained by perturbing a single parameter)
6. Complete perturbation (external parameters + soil moisture) doesn't have in general a positive effect in the spread production.
7. Lower values of spread (but not negligible!) compared to the case of an ensemble system with IC and BC perturbation (COSMO LEPS). Sometimes strong contribution coming from sea surface.
8. Locally, considering the comparison with SYNOP observation, reasonable values of spread can be noticed.

8. Using a Uniform stretching function (instead of a Gaussian one) can lead to a considerable increase in spread. This function might be used also for the soil moisture stretching to obtain a further increase in spread.
9. Spread diffusion from the surface to the upper levels of the atmosphere

Future developments

1. Assess the sensitivity of the COSMO model to the perturbation of the soil temperature. The perturbation technique will be inspired by the same used for the soil moisture
2. Definition of the ‘final’ perturbation technique that includes the perturbation of the soil moisture and eventually of the soil temperature
3. Implementations of the algorithm in an ensemble systems for testing (eg COSMO-IT-EPS).
4. Comparison with observations to evaluate quantitatively the skill of the complete ensemble system with IC + BC + LBC perturbation. For this purpose one or more interesting case studies of Hymex Project will be considered.

Thank you for your attention!