On the added value of an ensemble approach at small scales: introduction to the COSMO-LEPS system

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• Motivations for EPS also at small scales;

• Operational implementation of COSMO-LEPS:
  ➢ main features and products.

• Statistical evaluation:
  ➢ time-series verification of COSMO-LEPS using SYNOP;
  ➢ COSMO-LEPS vs ECMWF EPS using a high-res network;
  ➢ raw vs calibrated COSMO-LEPS forecasts.

• COSMO-LEPS on the web.
Why Limited-Area Ensemble Prediction?

• Global Ensemble Prediction Systems:
  – have become extremely important tools to tackle the problem of predictions beyond day 2;
  – are usually run at a coarser resolution with respect to deterministic global predictions → skill in forecasting intense and localized events is currently still limited;
  – these local limitations are due, among other reasons, to the inherently low degree of predictability typical of severe and localized events.

Probabilistic approach is also required for the short range at higher resolution.
COSMO-LEPS (developed at ARPA-SIMC)

• What is it?
It is a Limited-area Ensemble Prediction System (LEPS), based on COSMO-model and implemented within COSMO (COnsortium for Small-scale Modelling, including Germany, Greece, Italy, Poland, Romania, Russia, Switzerland).

• Why?
It was developed to combine the advantages of global-model ensembles with the high-resolution details gained by the LAMs, so as to identify the possible occurrence of high-impact and localised weather events (heavy rainfall, strong winds, temperature anomalies, snowfall, …)

⇒ generation of COSMO-LEPS to improve the forecast of high-impact weather in the short and early-medium range (up to fc+132h)
Dynamical downscaling

Global Ensemble → LAM Nesting → LAM members

GCM members → Ensemble Size Reduction → Representative members

Total Downscaling (Brute-Force Approach)

LAM Nesting → COSMO-LEPS Approach

COSMO-LEPS Approach
COSMO-LEPS methodology

Possible evolution scenarios

Cluster members chosen as representative members (RMs)

LAM integrations driven by RMs
Outline

• Operational implementation of COSMO-LEPS:
  - main features and products.
COSMO-LEPS suite @ ECMWF: present status

16 Representative Members driving the 16 COSMO integrations (weighted according to the cluster populations)

Using either Tiedtke or IFS-Bechtold convection scheme (members 1-8 T, members 9-16 IFS)

+ perturbations in turbulence scheme and in physical parameterisations

+ soil initial conditions from COSMO-EU

- suite runs as a “time-critical application” managed by ARPA-SIMC; runs at both 00 and 12TC;
- Δx ~ 7 km; 40 ML; fc+132h;
- COSM0 v5.0 since Feb 2014;
- computer time (50 million BUs for 2015) provided by the COSMO partners which are ECMWF member states.
As for types and values, the results from previous experimentation were followed (* denotes default values for COSMO v5.0):

• convection_scheme: Tiedtke* (members 1-8), IFS-Bechtold (members 9-16),
• tur_len (either 150, or 500*, or 1000),
• pat_len (either 500*, or 2000),
• crsmin (either 50, or 150*, or 200),
• rat_sea (either 1, or 20*, or 40),
• rlam_heat (either 0.1, or 1*, or 5),
• mu_rain : either 0.5* (with rain_n0_factor =0.1) or 0 (with rain_n0_factor =1.0),
• cloud_num (either 5x10^8* or 5x10^7).
• convection scheme: T=Tiedtke IFS-B=Bechtold;
• tur_len: maximal turbulent length scale (default 500m); this parameter is used mainly in the calculation of the characteristic length scale for vertical mixing and thus into the calculation of the vertical transport momentum coefficient;
• pat_len: length scale of thermal surface patterns (default 500m); this parameter is mainly used in the calculation of the large-scale part of the equation addressing the heat flux parameterisation; horizontal length;
• rlam_heat: scaling factor of the laminar layer depth (default 1); it defines the layer with non-turbulent characteristics (molecular diffusion effects only);
• rat_sea: ratio of laminar scaling factors for heat over sea (default 20);
• crsmin: minimal stomata resistance (default 150);
• Cloud_num: Cloud droplet number concentration;
• Mu_rain: Exponent of the raindrop size distribution;
• ( gscp: Switch on/off of the graupel scheme).
Operational set-up

Core products:
- 16 perturbed COSMO-model runs (ICs and 3-hourly BCs from 16 ENS members) to generate, “via weights”, probabilistic output: start at 00 and 12UTC; $\Delta t = 132$ h;

Additional products:
- 1 deterministic run (ICs and 3-hourly BCs from the HRES ECMWF forecast) to “join” deterministic and probabilistic approaches: start at 12UTC; $\Delta t = 132$ h;
- 1 hindcast (or proxy) run (ICs and 3-hourly BCs from ECMWF analyses) to “downscale” ECMWF information: start at 00UTC; $\Delta t = 36$ h.
COSMO-LEPS
real-time products

Products disseminated to the COSMO-countries:

- 24h rainfall exceeding 20, 50, 100, 150 mm;
- 72h rainfall exceeding 50, 100, 150, 250 mm;
- 24h snowfall exceeding 1, 5, 10, 20 "cm";
- UVmax_{10m} in 24h above 10, 15, 20, 25 m/s;
- Tmax_{2m} in 24h above 20, 30, 35, 40 °C;
- Tmin_{2m} in 24h below -10, -5, 0, +5 °C;
- min height of 0 °C isotherm in 24h below 1500, 2000, 3000, 3500 m;
- max-CAPE in 24h above 2000, 2500, 3000, 3500 J/kg;
- min Showalter Index in 24h below 0, -2, -4, -6;

Deterministic products (for each LM run):

- 24-hour cumulated rainfall; mean-sea-level pressure, Z700, T850;
- meteograms (over a number of station points);
- T_{2m}, rainfall, 10m wind speed;
Dissemination

- National and regional weather Services of COSMO countries (Germany, Switzerland, Greece, Romania, CNMCA, ARPA-ER, ARPA-PIE, ARPA-Veneto, Provincia BZ, Meteotrentino, “Centro Funzionale Regione Marche”, ARPA-FVG, ARPA-Lombardia, …).
- International organizations (JRC).
- Private companies.
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+ perturbations in turbulence scheme and in physical parameterisations

+ soil initial conditions from COSMO-EU

- suite runs as a “time-critical application” managed by ARPA-SIMC; runs at both 00 and 12TC;
- $\Delta x \sim 7 \text{ km}; 40 \text{ ML}; \text{fc}+132\text{h};$
- COSMO v5.0 since Feb 2014;
- computer time (50.0 million BU for 2015) provided by the COSMO partners which are ECMWF member states.
Problems with snow cover from ECMWF

valleys “filled” by snow due to interpolation

old suite 10.4.2011
COSMO-LEPS with soil-moisture fields from COSMO-EU

Oper system (interp)

Δx = 7 km
fcst range = 132h
initial conditions: interpolated from EPS members;

perturbations: type of convection scheme; tur_len; pat_len; crsmin; rat_sea; rlam_heat.

Test system (merge)

Δx = 7 km
fcst range = 48h
initial conditions: interpolated from EPS members merged with surface and soil-layer fields from COSMO-EU (T_SO, W_SO, W_ICE, W_I, FRESHSNW, RHO_SNOW, W_SNOW, T_SNOW).

perturbations: type of convection scheme; tur_len; pat_len; crsmin; rat_sea; rlam_heat; mu_rain; cloud_num.

“Oper” and “Test” were run in parallel from 1/12/2010 to 15/3/2011 (> 100 cases).
Bias closer to zero for “test” ensemble, which uses the soil moisture fields from COSMO-EU.

Smaller amplitude in bias oscillations for “test”.

fulldom and mapdom: the improvement is systematic for all forecast ranges; the cold bias of “oper” is reduced.

mapdom < 100m: large reduction of bias for day-time verification; increase of the bias for night-time verification.

A. Montani; The COSMO-LEPS system.
MAE of T2M Ensemble Mean

- mae computed over 3 different domains for the period 1/12/2010 → 15/3/2011 (> 100 cases).

- Lower mae for “test” ensemble, which uses the soil moisture fields from COSMO-EU.
- **fulldom** and **mapdom**: the improvement is systematic for all forecast ranges, especially for day-time verification.
- **mapdom < 100m**: reduction of mae for day-time verification.

### Diagrams:

- **fulldom (~1400 synop)**: T2m forecasts are corrected with height.
- **mapdom (~410 synop)**: T2m forecasts are corrected with height.

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A. Montani; The COSMO-LEPS system.
BIAS of TD2M Ensemble Mean

- Bias slightly closer to zero for “test” ensemble, which uses the soil moisture fields from COSMO-EU.
- fulldom and mapdom: the impact is small, but positive.
- mapdom < 100m: the “dry” bias in low-level stations is reduced for all forecast ranges.
- MAE of TD2M Ensemble Mean

- mae computed over 3 different domains for the period 1/12/2010 → 15/3/2011 (> 100 cases).

- **Lower mae for “test” ensemble**, which uses the soil moisture fields from COSMO-EU.

- **fulldom** and **mapdom**: the mae reduction is small, but **systematic** and lasts for about 2 forecast days.

- **mapdom < 100m**: the mae reduction is more evident.
Summary of results for soil-merge experiments

- **T2M and TD2M:**
  - reduction of bias and mean-absolute error if the COSMO-LEPS members take the initial conditions from the soil moisture fields provided by COSMO-EU;
  - the improvement is confirmed over larger and smaller domains;
  - the reduction of errors lasts for more than 2 forecast days;

- **TOT_PREC:**
  - the impact is neutral (not shown).

the transfer of SMA files from DWD to ECMWF is solid and timely.

Soil-merge was implemented in the operational COSMO-LEPS suite on 11 April 2011.
Soil merge: Impact on snow cover

**New suite 11.4.2011**

Snow height merged from COSMO-EU

**old suite 10.4.2011**

Snow height interpolated from IFS

→ Large improvement due to higher resolution of snow analysis
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SYNOP verif T_2M CH JJ A2010

SUMMER 2010

lead-time +(25-48)h

Observations
COSMO-LEPS ensemble mean
Deterministic COSMO-7

~2K

T_2M: MNDO COSMO-LEPS@ch COSMO-7_12@ch, MOBS

00 UTC 00 UTC

2010-06-01 0:00 to 2010-08-31 23:00 25-48
SYNOP verif T_2M CH JJ A2011

COSMO-LEPS ensemble mean outperforms COSMO-7 for all lead-times
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- \( \Delta x \sim 7 \text{ km}; 40 \text{ ML}; \text{fc+132h}; \)
- COSM0 v5.0 since Feb 2014;
- computer time (50.0 million BU for 2015) provided by the COSMO partners which are ECMWF member states.
Sensitivity to the convection schemes (courtesy of Andre Walser)

COSMO-LEPS ENSEMBLE_FORECAST
24h Sum of Total Precipitation

Thu 24 Jul 2014 12UTC
23.07.2014 12UTC +24h

mm/24h

300
250
200
150
120
100
80
60
50
40
30
20
15
10
5
2
1
Types of convection schemes

With the introduction of COSMO V5.0, Kain-Fritsch convection scheme is no more supported:
members 1-8 use Tiedtke convection scheme (8TD),
members 9-16 use IFS-Bechtold scheme (8BE).

MAM 2014 (very rainy):
compare cleps16, 8TD, 8BE over the full domain
in terms of total precipitation
• As expected, best performance by the full ensemble (cleps16).

• Tiedtke-members better than IFS-Bechtold members (very clearly for some scores).
COSMO-LEPS suite @ ECMWF: present status

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COSMO-LEPS clustering area

COSMO-LEPS Integration Domain

Cluster Analysis and RM identification

2 time steps

European area

Complete Linkage

4 variables Z U V Q

3 levels 500 700 850 hPa
Combined use of EDA- and SV-based perturbations in the EPS

Reliability of COSMO-LEPS and ECMWF upgrades

The simulation of initial aspects in ensemble prediction of the first version (EPS) in 1992, these related with singular vectors (SV) by the fastest growth, mean over a finite time interval. With the forthcoming implementation in Cycle 39R of an Ensemble of Data Assimilations (EDA, see the companion article in this edition of the ECMWF Newsletter, pages 17 to 21), the methodology used to generate the EPS initial perturbations will be changed. EDA-based perturbations will replace evolved singular vectors in the generation of the EPS initial conditions. Following this change, the EPS initial perturbations will have a better geographical and vertical coverage than in the earlier system. This results in a better spread-skill relationship in the early forecast range over the extra-tropics, and for the whole forecast range over the tropics. Limited-area ensemble prediction systems (e.g. COSMO-LEPS) that use EPS initial and boundary conditions will benefit from this improvement. Over the tropics the substantial increase of the EPS spread leads to much smaller spread under-dispersion. In terms of skill, the EDA-SVNI configuration of the EPS has a higher skill than the earlier SV based system everywhere.

But is that true?

Consider COSMO-LEPS spread-skill for a few seasons:

**SON 2009** - MAM 2010 before 24/6/2010

**SON 2010** - MAM 2011 after 24/6/2010

Verification against ECMWF analysis (0.5x0.5); **T850**
A cold bias persists in COSMO-LEPS forecasts (more outliers “to the right”), but the short-range spread is increased from 2009 (before EDA) to 2010 (after EDA).
For both events and forecast ranges, COSMO-LEPS is under-confident (“above” the diagonal), but the reliability is increased from 2009 (before EDA) to 2010 (after EDA).

Need to study more seasons and more variables to confirm these results.
Outline

• **Statistical evaluation:**
  - time-series verification of COSMO-LEPS using SYNOP;
  - COSMO-LEPS vs ECMWF EPS using a high-res network;
  - raw vs calibrated COSMO-LEPS forecasts.
Time-series verification of COSMO-LEPS

SYNOP on the GTS

Main features:

- variable: 12h cumulated precip (18-06, 06-18 UTC);
- period: from Dec 2002 to May 2014;
- region: 43-50N, 2-18E (MAP D-PHASE area);
- method: nearest grid point; no-weighted fcst;
- obs: synop reports (about 470 stations/day);
- fcst ranges: 6-18h, 18-30h, ..., 102-114h, 114-126h;
- thresholds: 1, 5, 10, 15, 25, 50 mm/12h;
- system: COSMO-LEPS;
- scores: ROC area, BSS, RPSS, Outliers, ...

both monthly and seasonal scores were computed
A.Montani; The COSMO-LEPS system.

- Area under the curve in the HIT rate vs FAR diagram; the higher, the better ...
- Valuable forecast systems have ROC area values > 0.6.

- Highest scores in the 2nd part of 2011 and, for the highest threshold, in 2013.
- Drier seasons during 2011 and 2012 with few heavy-precipitation events: limited significance of the results for the 15mm threshold.
- **fc 30-42h**: ROC area is high for last winter and spring. Positive trend can be noticed.
- **fc 78-90h**: the best scores date back to the end of 2011.
- Limited loss of predictability with increasing forecast range.
Outliers: time series + seasonal scores (DJF)

- How many times the analysis is out of the forecast interval spanned by the ensemble members.
- …the lower the better…
- Performance of the system assessed as time series and for the last 4 winters.

- Evident seasonal cycle (more outliers in winter).
- Overall reduction of outliers in the years up to 2007; then, again in the last 1.5 year.
- Need to take into account the different statistics for each season.
- For all forecast ranges, best results for last winter.
- For longer ranges, the performance of the system is “stable”: outliers before 10% from day 3 onwards.
BSS is written as $1 - \frac{BS}{BS_{ref}}$. Sample climate is the reference system. Useful forecast systems if BSS > 0.

BS measures the mean squared difference between forecast and observation in probability space.

BS equivalent to MSE for deterministic forecast.

- **fc 30-42h**: very good scores in 2010 and 2011; BSS positive for all thresholds since April 2009; fewer and fewer problems with high thresholds.

- **fc 78-90h**: good trend in 2010 and 2011 for all thresholds.

In the last 2 years, limited “dispersion” in BSS values for the different threshold values.

Month-to-month variability is higher than for the ROC area.
A sort of BSS “cumulated” over all thresholds. RPSS is written as $1 - \frac{RPS}{RPS_{\text{ref}}}$. Sample climate is the reference system. RPS is the extension of the Brier Score to the multi-event situation.

- Useful forecast systems for RPSS > 0.
- Performance of the system assessed as time series and for the last 4 springs (MAM).

- The increase of the COSMO-LEPS skill is detectable for all forecast ranges along the years, **BUT**
- Low skill in the first months of 2012 (the problem comes from MAM), then recovery.
- Best results for MAM 2011; quick decrease of RPSS with forecast range for MAM 2012; “normal” scores in 2014.
Seasonal scores of ROC and BSS: last 4 springs

- **Fixed event** ("12h precip > 10mm"): consider the performance of the system for increasing forecast ranges.
- Valuable forecast systems have ROC area values > 0.6 and BSS > 0.

- Need to take into account the different statistics for each season (MAM 2014 was the wettest spring).
- BSS: positive for all forecast ranges in MAM 2013 and 2014.
- Similar results for the other thresholds (not shown).
- Diurnal cycle of the score less marked in the last 2 years.

![ROC area values in spring (MAM); TP_12h > 10mm](image)
A. Montani; The COSMO-LEPS system.

Outline

- about operational verification using SYNOP (time-series scores show positive trend; good performance for winter 2013-14, “normal scores” for MAM2014),
- about the inter-comparison vs ECMWF ENS;
Comparison of COSMO-LEPS and ECMWF EPS

Main features:

variable: 24h cumulated precip (06-06 UTC);
period: from December 2009 to May 2014;
region: Northern Italy;
method: BOXES (1.0 x 1.0);
obs: non-GTS network (~1000 stations x day);
fcst ranges: 18-42h, 42-66h, 66-90h, 90-114h;
thresholds: 1, 5, 10, 15, 25, 50 mm/24h;
systems:
- COSMO-LEPS (16m, 7 km, 40ML) – cleps16
- full EPS (51m, 30 km, 62ML) – eps51
Verification of the distributions

The verification has been made in terms of:

- Average value
- **Maximum value**
- 50th percentile (Median)
- 75th, 90th, 95th percentiles

in a box

two measures of precipitation:
➢ the cumulative volume of water deployed over a specific region;
➢ the rainfall peaks occurring within the same region.
The COSMO-LEPS system.

BSS “cumulated” over all thresholds. RPSS is written as $1 - \frac{\text{RPS}}{\text{RPS}_{\text{ref}}}$. Sample climate is the reference system. RPS is the extension of the Brier Score to the multi-event situation; useful forecast systems for RPSS > 0.

RPSS depends on the ensemble size $N$ and penalises small ensemble sizes.

Consider debiased RPSS: $\text{RPSS}_d = 1 - \left(\frac{\text{RPS}}{\text{RPS}_{\text{ref}}} + \frac{\text{RPS}_{\text{ref}}}{N}\right)$; a 3-month running mean is applied.

Seasonal cycles of the scores; worse performance in winters, possibly related to the presence of snow (some stations are not heated).

Either way (RPSS or RPSS$_d$), ECMWF-EPS had initially higher scores; then, COSMO-LEPS has had higher scores than ECMWF-EPS since 2013 in the short range, despite the lower ensemble size.

The same applies (COSMO-LEPS has higher scores than ECMWF-EPS) for all forecast ranges.
BSS “cumulated” over all thresholds. RPSS is written as 1-RPS/RPS_ref. Sample climate is the reference system. RPS is the extension of the Brier Score to the multi-event situation; useful forecast systems for +ve RPSS.

RPSS depends on the ensemble size N and penalises small ensemble sizes.

Debiased RPSS: \( \text{RPSS}_D = 1 - \left( \frac{\text{RPS}}{\text{RPS}_{\text{ref}} + \frac{\text{RPS}_{\text{ref}}}{N}} \right) \)

The same applies (COSMO-LEPS has higher scores than ECMWF-EPS) for all forecast ranges.
Area under the curve in the HIT rate vs FAR diagram; the higher, the better …

Valuable forecast systems have ROC area values > 0.6.

The performances of the systems are assessed for the event: 10mm of tp in 24h at two forecast ranges.

In the short range, similar performance of the 2 systems throughout the years.

For longer ranges, higher skill of ECMWF-EPS.
How many times the analysis is out of the forecast interval spanned by the ensemble members.

...the lower the better ...

The performances of the systems are assessed for two different forecast ranges (18-42h and 90-114h)

More outliers in winters, possibly related to the presence of snow (some stations are not heated).

Better performance (fewer outliers) for COSMO-LEPS both in the short and early-medium range
A. Montani; The COSMO-LEPS system.

- about operational verification using SYNOP (time-series scores show positive trend; good performance for winter 2013-14, “normal scores” for MAM2014),
- about the inter-comparison vs ECMWF ENS (higher skill of COSMO-LEPS since 2013 for verification over boxes),
- about calibration.
For each COSMO-LEPS member, calibrated precipitation is operationally generated over Germany, Switzerland and Emilia-Romagna; the calibration technique is based on CDF-based corrections, making use of COSMO-LEPS reforecast.

For MAM2013, inter-comparison between raw and calibrated 24h TP forecast.

Main features:

- **variable:** 24h cumulated precip (06-06 UTC);
- **period:** DJF 2012-13 and MAM 2013;
- **region:** Germany, Switzerland, Emilia-Romagna;
- **method:** nearest grid point; no-weighted fcst;
- **obs:** synop reports (about 300 stations/day);
- **fcst ranges:** 18-42h, 42-66h, 66-90h, 90-114h;
- **thresholds:** 1, 5, 10, 15, 25, 50 mm/12h;
- **system:** opecleps and Calibcleps;
- **scores:** ROC area, BSS, RPSS, Outliers, RelDiag, …
COSMO-LEPS reforecast suite (run by Meteoswiss)

- Reforecasts over a period of 20 years (1989-2008);
- Every 3rd day with 90h lead time (~1 month in advance).
- Same model version and configuration as COSMO-LEPS suite.
- ERA-interim reanalysis as initial and boundary fields.
- **New**: To account for COSMO-EU soil merge, a soil moisture bias correction is applied, based on a comparison of COSMO-EU and interpolated ERA-interim for 2008.
- Available at ECMWF mars archive.

**Intention:** statistically independent data set for a long period.

```
retrieve,
time=12:00:00,
date=2011-08-11,
stream=enfh,
step=0/to/90,
levtype=sfc,
expver=1,
type=cf,
hdate=1989-08-11/to/2008-08-11
class=co,
param=61.2
```
CALIBRATION STRATEGY - data

reforecasts

COSMO model
1971-2000 (deterministic run nested on ERA-Interim)

COSMO-LEPS
2003-2007 (ensemble run)

observations

rain gauge measurements
1971-2007 for Emilia-Romagna (158 stations) and Switzerland (450 stations)
1989-2007 for Germany (1038 stations)
Cumulative Distribution Function based corrections

For each model grid point:

- **blue line** ⇒ CDF of COSMO-LEPS reforecasts
- **red line** ⇒ CDF of historical observations
- “raw forecast” ⇒ each member of the operational COSMO-LEPS
A. Montani; The COSMO-LEPS system.

**opecleps vs Calibcleps**

MAM 2013: Ranked Probability Skill Score; 24-h cumulated precipitation; ~ 300 stations

MAM 2013: Outlier percentage; 24-h cumulated precipitation; ~ 300 stations (CH/DJ)

fc 42-66h; 10mm/24h

MAM 2013: Outlier percentage; 24-h cumulated precipitation; 10 stations (I)
➤ about operational verification using SYNOP (time-series scores show positive trend; good performance for winter 2013-14, “normal scores” for MAM2014);
➤ about the inter-comparison vs ECMWF ENS (higher skill of COSMO-LEPS since 2013 for verification over boxes);
➤ about calibration (positive impact, especially over Emilia-Romagna!).
• COSMO-LEPS on the web.
Probabilistic products at ARPA-SIMC

Previsioni

Modelli ad area limitata
Cosmo-I7
Lami e-suita
Cosmo-I2
Cosmo-I7 corsa SIMC di backup
Cosmo LEPS (probabilistico)
ultima corsa disponibile

cape
indice di instabilità di Showalter
neve cumulata in 24 ore
Altezza zero Termico
pioggia cumulata in 24 ore
pioggia cumulata in 72 ore
temperatura massima
temperatura minima
Meteogrammi EPS
pluviogrammi plumes
resea del vento
box plot
superamenti soglie macroaree
vento a 10 metri
poor_man_ensemble
Probabilities

COSMO-LEPS +Preci nev cum[al suolo] CORSA 00 : ven 30 gen '15
fc: ore 00 di ven 30 gen - ore 00 di sab 31 gen

neve cumulata in 24 ore [mm equivalenti acqua] soglia > 10

neve cumulata in 24 ore [mm equivalenti acqua] soglia > 20
15 station points in the region
Pluviogrammi plumes

15 station points in the region

Cosmo-Leps: Precipitazione Totale Cumulata - corsa del 30-01-2015 alle 00 U.T.C.
Bologna  lat: 44.53 lon: 11.30 alt-mod: 58.8

Cosmo-Leps: Precipitazione Totale Cumulata - corsa del 30-01-2015 alle 00 U.T.C.
Ferrara  lat: 44.83 lon: 11.62 alt-mod: 8.1
Box plots

15 station points in the region
Wind roses

15 station points in the region
Poor man ensemble

14 station points in the region
Emilia-Romagna region is divided into 8 macro-areas of similar size (~3000 km², 60 grid points)
Uncertainty description may depend on the user.
THANKS FOR YOUR ATTENTION!