Probabilistic fog forecasting with COSMO model

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CONSORTIUM FOR SMALL SCALE MODELING COSMO

Outline

- Introduction to SRNWP-EPS II
- Fog forecasting: methodology
- Implementation in COSMO model:
  - *deterministic mode*,
  - ensemble mode (COSMO-LEPS).
- Results for 2 case studies
- Conclusions and plans

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The project: SRNWP-EPS II

- Project founded by EUMETNET, co-coordinated by Italy (COMET, Arpae) and Spain (AEMET).
- Purpose: improve the usability of ensemble products for the prediction of high-impact weather phenomena:
  - *calibration of ensemble outputs, also for extreme events,*
  - **generation of probabilistic products for the prediction of fog** *and thunderstorms, to be extended to other high-impact weather phenomena,*
  - *associated study on the impact of land surface and PBL perturbation of the prediction of the selected phenomena.*

WMO definitions:

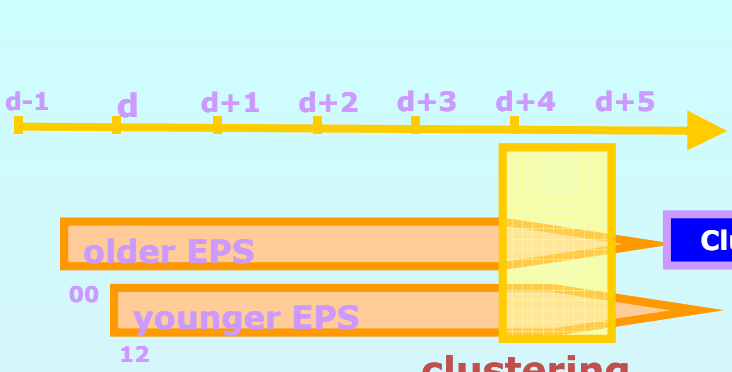
Fog:	**visibility < 1000 m**
Mist :	visibility between 1000 and 2000 m
Haze:	visibility between 2000 and 5000 m

The method: 3 approaches

Visibility is computed from model variables using 3 different methods:

1. **Boudala method** → visibility is calculated starting from the ratio between 2m dew-point temperature and 2m temperature valid at the same time.
2. **LWC method** → visibility is determined directly from the state equation for the liquid water content (LWC) at the lowest model level, using q,qc,qi,qr,qs (specific rain content, snow content, cloud water content, ice content, graupel content).
3. **Zhou method** (LWC with asymptotic approach) → visibility is again determined via LWC, which is computed keeping into account also other model fields:
   - relative humidity (> 90%),
   - cloud coverage (> 0.50),
   - cloud-base height,
   - extinction coefficient due to the number of droplets in the atmosphere,
   - advection of 2m humidity.

The ensemble system: COSMO-LEPS
(the mesoscale ensemble system of COSMO consortium)



4 variables
Z U V Q

3 levels
500 700 850 hPa

Cluster Analysis and RM identification

2 time steps

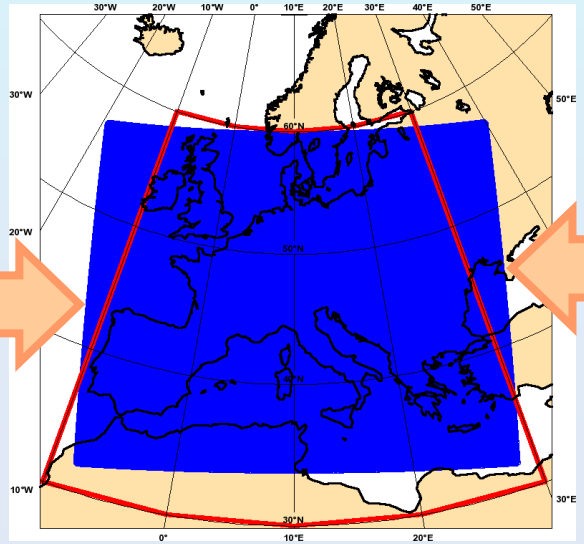
European area

Complete Linkage

20 Representative Members driving the 20 COSMO integrations (weighted according to the cluster populations)

using Tiedtke convection scheme
+
perturbations in turbulence scheme and in physical parameterisations
+
soil initial conditions from ICON-Regional

COSMO-LEPS clustering area



COSMO-LEPS integration domain

- suite runs as a "time-critical application" managed by Arpae-SIMC; runs at both 00 and 12TC;
- Δx ~ 7 km; 40 ML; fc+132h, single precision;
- COSMO v5.03 since 1 February 2016,
- computer time (57 million BUs for 2017) provided by the COSMO partners which are ECMWF member states.

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The case studies: fog events in the Po Valley

- *December 2016* → *radiation fog*
- **February 2017** → **radiation fog**
- **March 2017** → **advection fog**

Three methods are used:

1. **Boudala method**
2. **Liquid Water Content (LWC) method**
3. **Zhou method**

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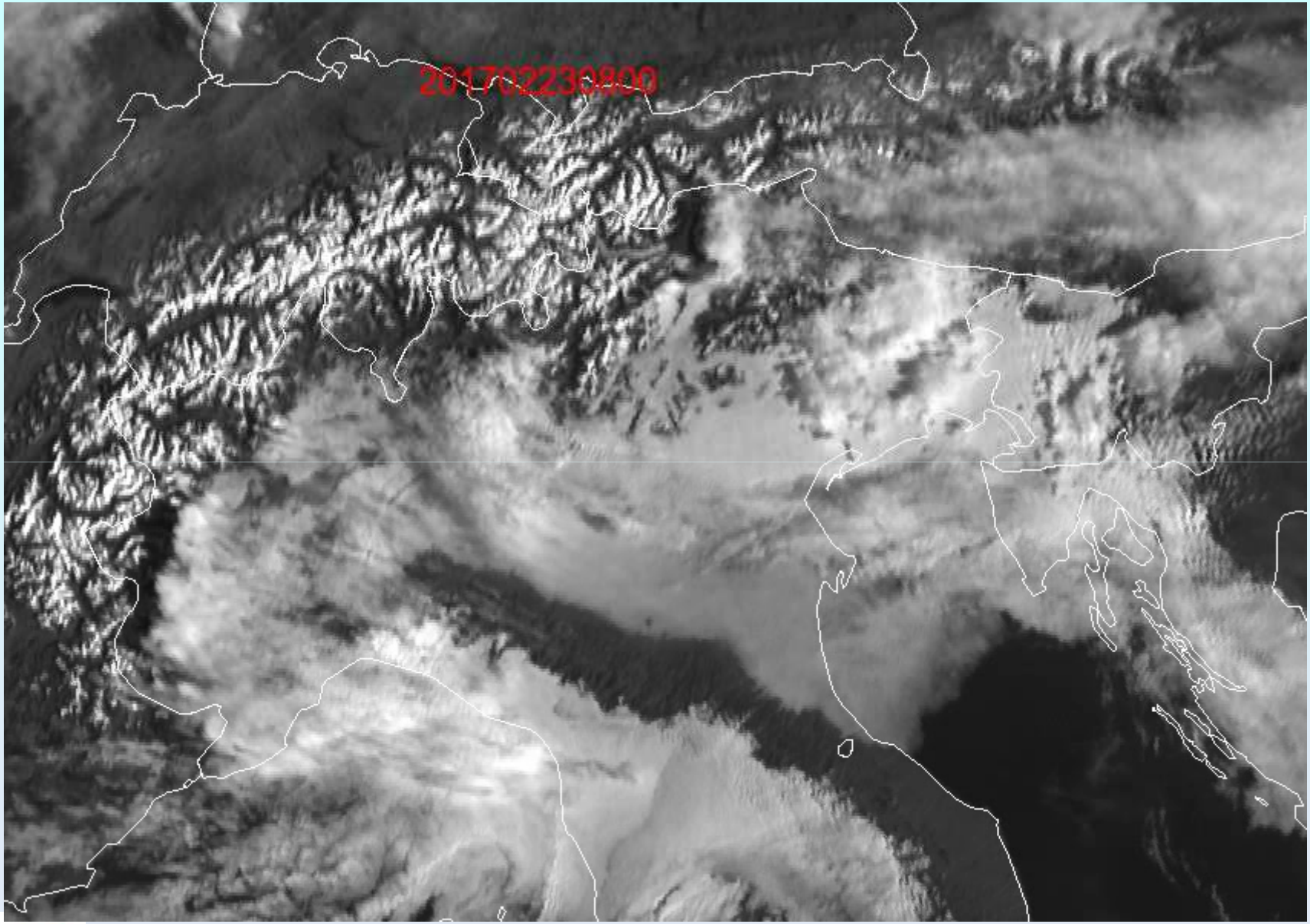
Case of 23/2/2017 - radiation fog (satellite)



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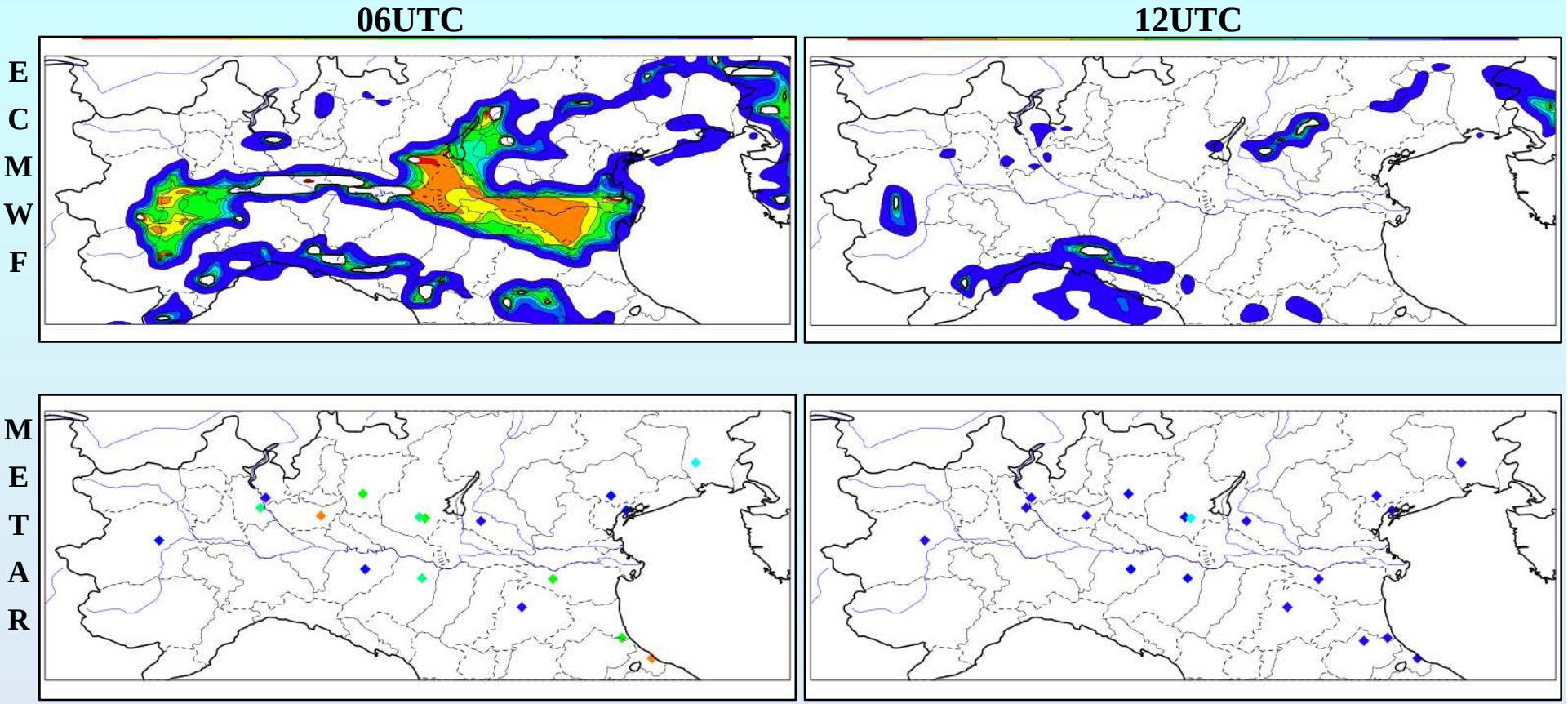
Case of 23/2/2017 - ECMWF ana vs Metar obs

(visibility in m)



Locally, there are noticeable differences in visibility between METAR observations (only available during day time) and model analyses.

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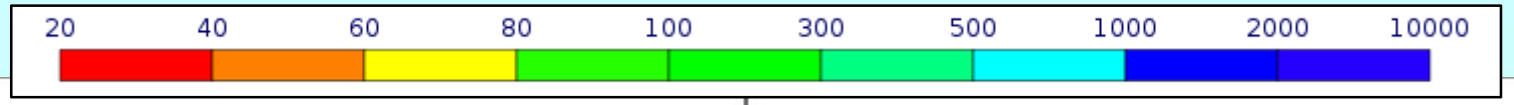
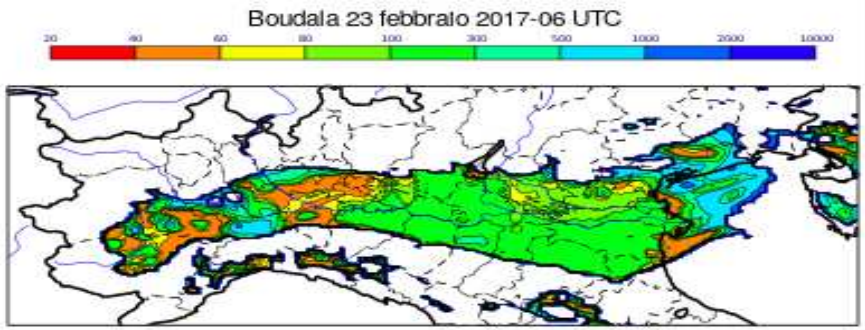
Case of 23/2/2017, 6UTC – deterministic runs

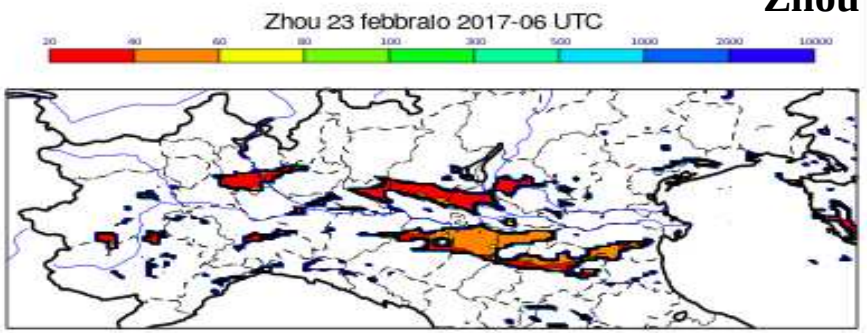
member 1 of the ensemble; fc +6h (visibility in m)



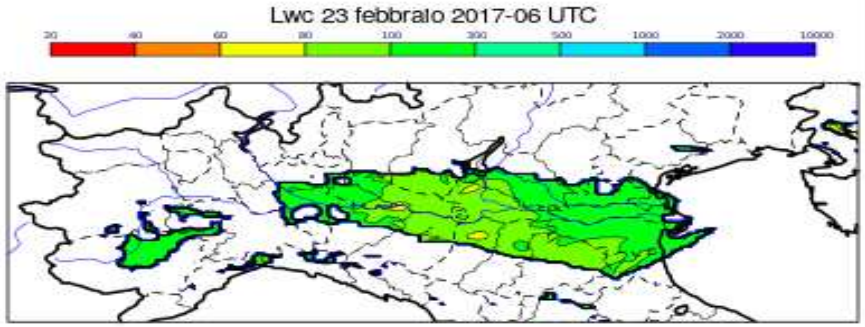
Boudala



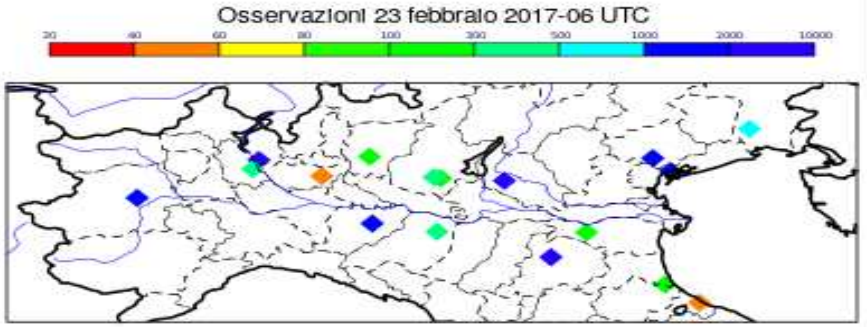
Zhou



LWC



METAR



Boudala: overestimation of the area affected by fog; too low visibility in mountainous regions.

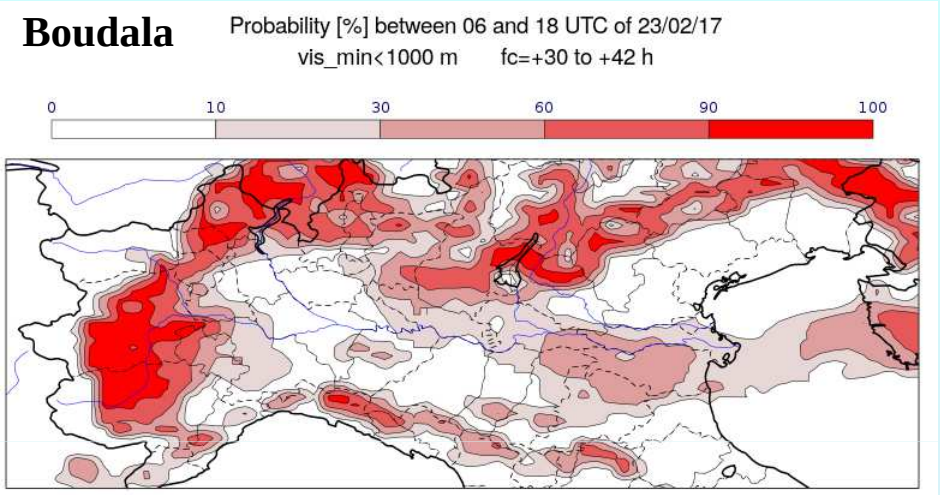
LWC: slight underestimation of visibility.

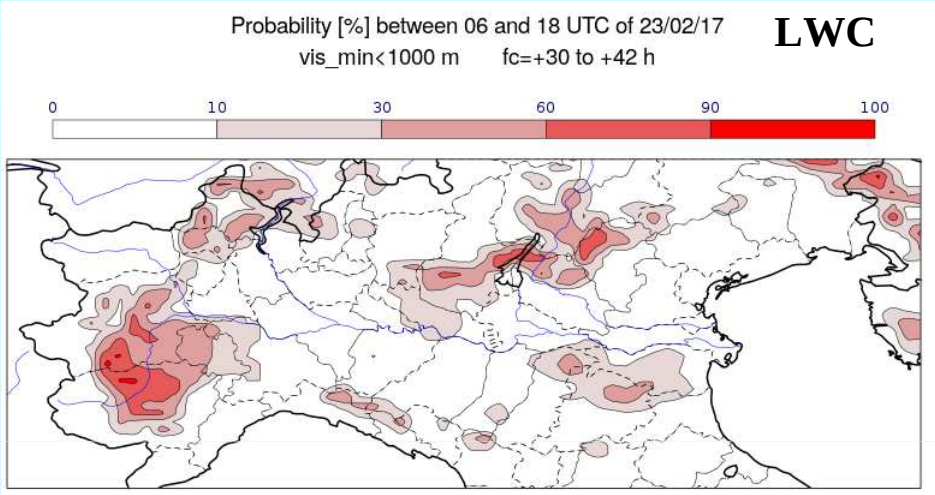
Zhou: underestimation of the extent of the regions affected by fog + very low visibility values.

Radiation fog: run of 22/2/2017, 00UTC +30-42h

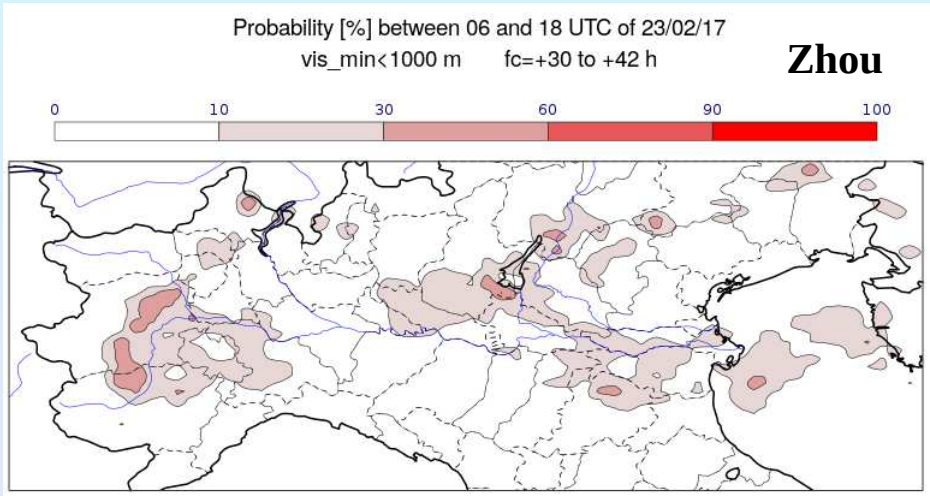
Probability of min. visibility over 12h < **1000** m

Boudala





LWC



Zhou

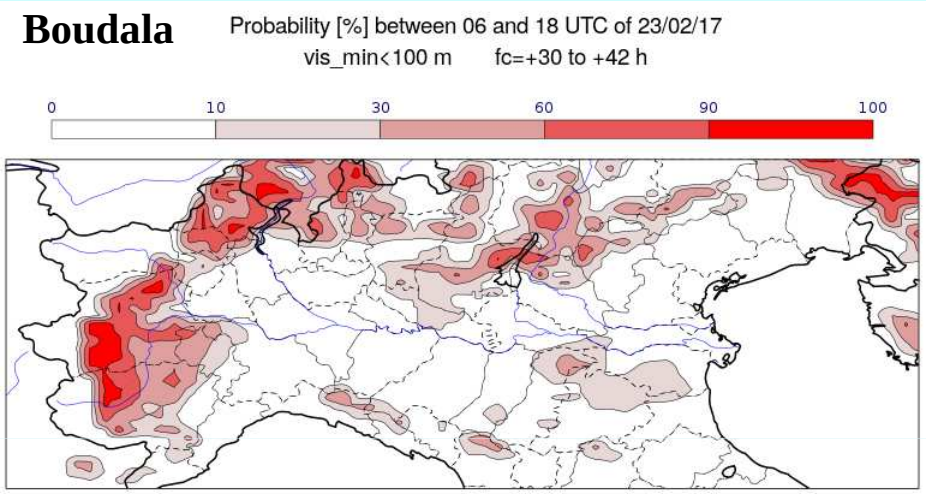
Boudala: overestimation of the area affected by fog; too low visibility in mountainous regions.

Zhou: underestimation of fog.

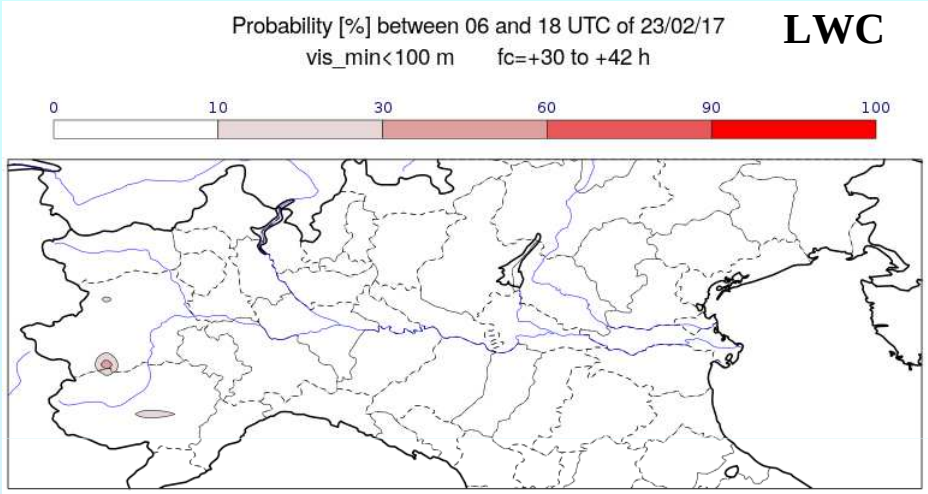
Radiation fog: run of 22/2/2017, 00UTC +30-42h

Probability of min. visibility over 12h < **100** m

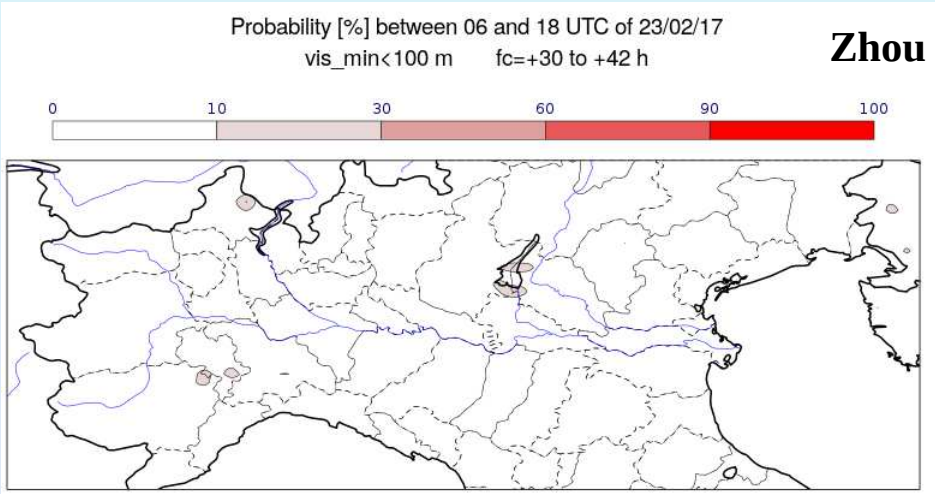
Boudala



LWC



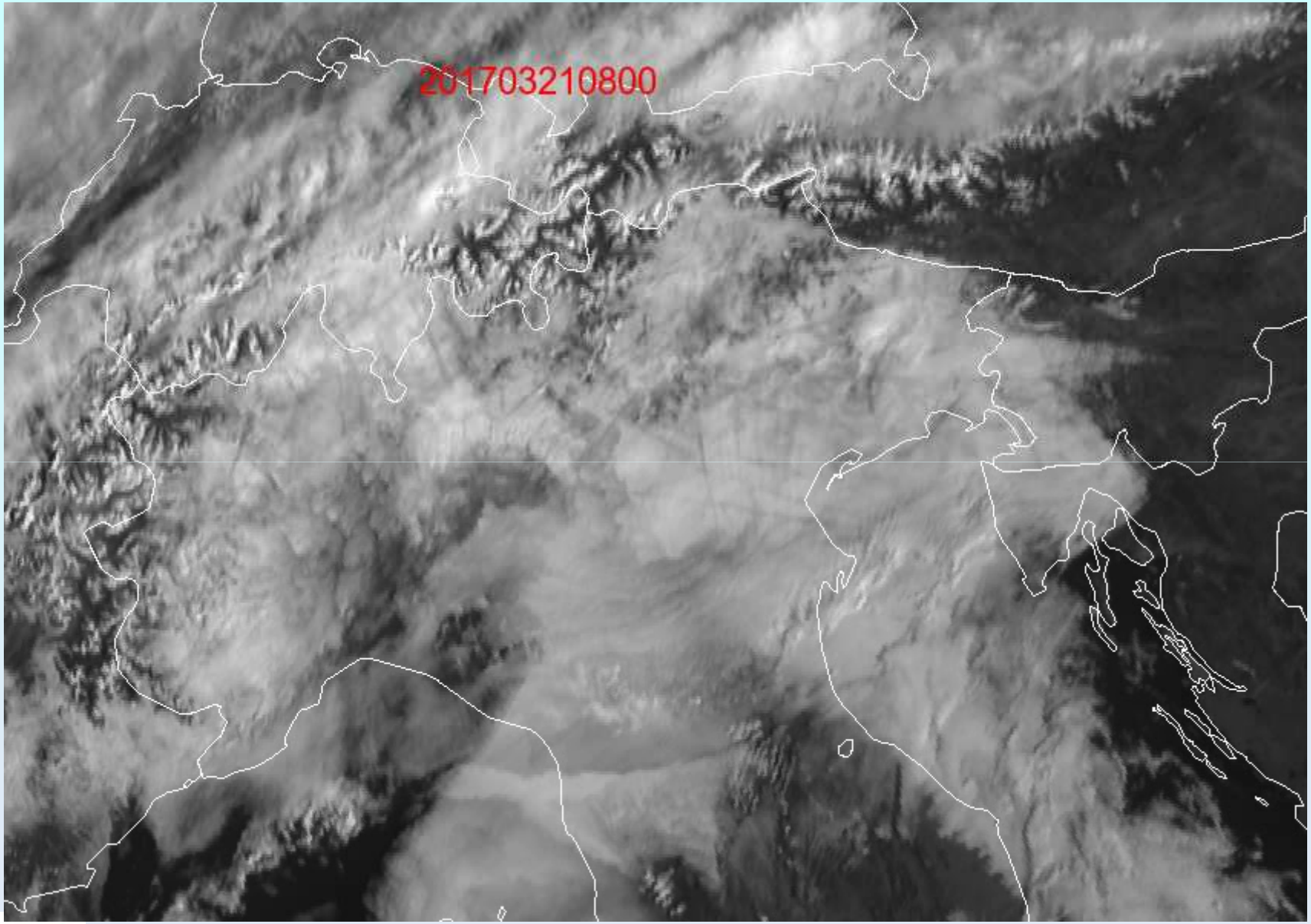
Zhou



Boudala: overestimation of the area affected by fog; too much fog in mountainous regions

LWC, Zhou: underestimation of fog intensity

Case of 21/3/2017 - advection fog (satellite)



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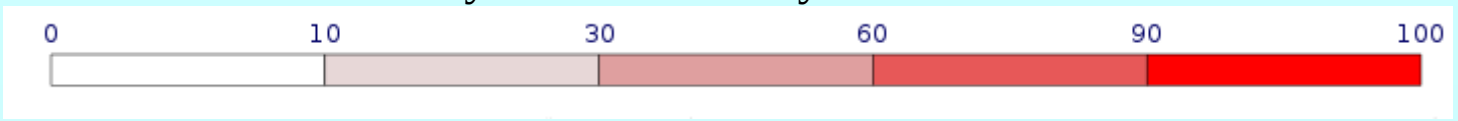
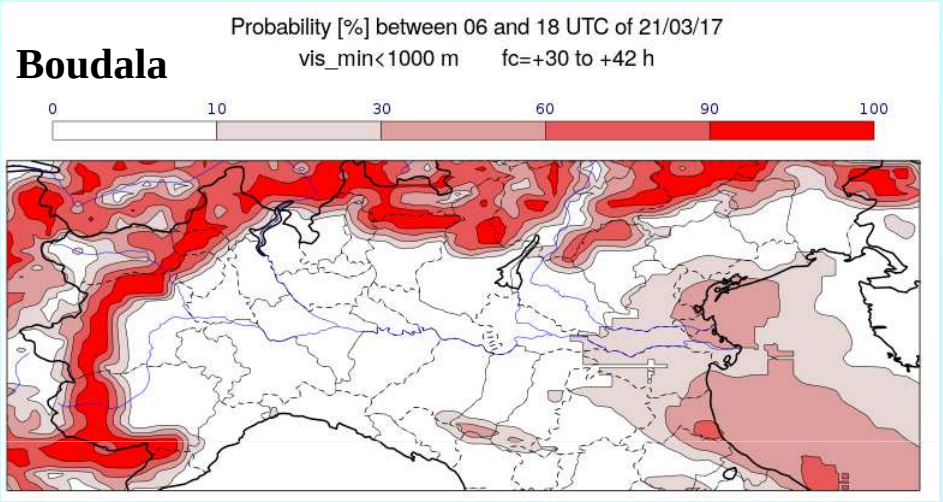
Advection fog: run of 20/3/2017, 00UTC +30-42h

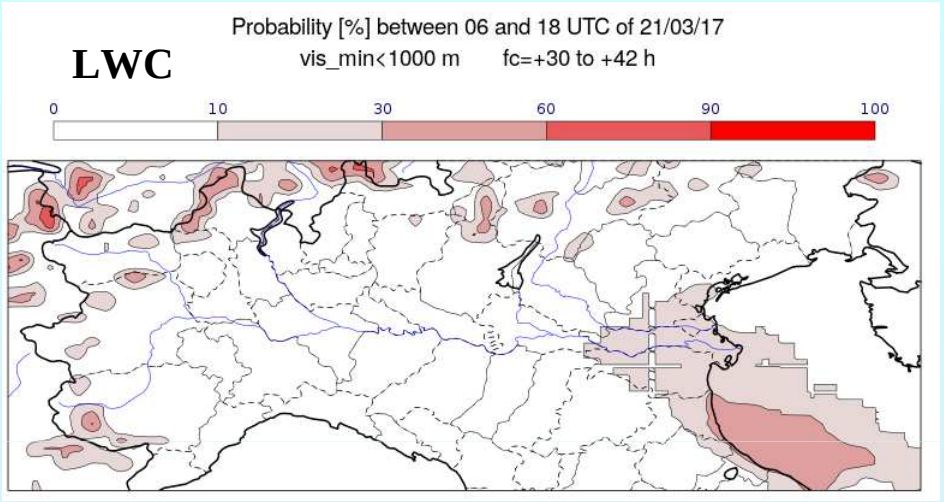
Probability of min. visibility over 12h < **1000** m



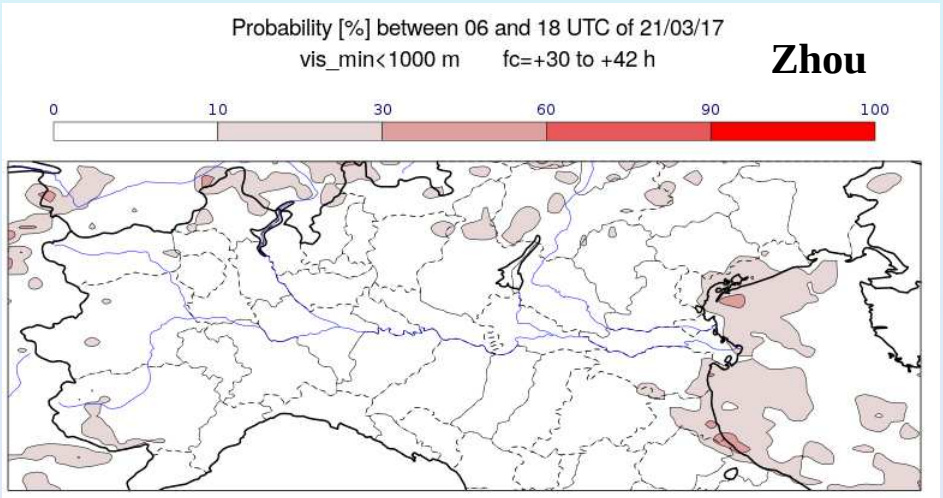
Boudala



LWC



Zhou



Boudala: still too much fog in mountainous regions; more “agreement” between LWC and Zhou methods as for the identification of the regions probably affected by low visibility.

Conclusions

- Three different methods to diagnose visibility were developed at COMET and implemented by Arpae-SIMC for the prediction of fog probability.
- There are issues with the quantitative estimate of fog: limited availability and representativeness of obs; so far, only qualitative comparison was performed.
- The differences between the three methods turn out to be more marked for cases of radiation fog (February case); more similarities for advection fog (March):
    - Boudala: overestimation of fog areas; too many “false alarms”,
    - LWC: partly removes “wrong areas” of fog forecasts,
    - Zhou: the most sophisticated method still needs to be tuned and refined; so far, too little fog is predicted.
- At the moment, LWC method seems the best compromise.
- Ensemble products seem useful and will be operationally tested next winter in COSMO-LEPS.

Thanks for your attention!

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Boudala

1. **Boudala method** → visibility is calculated by the ratio between 2m *dew point* temperature and 2m air temperature valid at the same time
2. **LWC method** → visibility is determined directly from the state equation for the liquid water content (LWC) at the lowest model level;
3. **Zhou method** → visibility is again determined by LWC, which is computed using a multivariable approach, keeping into account several parameters such as:
   - liquid water content at the lowest model level,
   - relative humidity greater than 90%,
   - cloud coverage, cloud-base height,
   - extinction coefficient due to the number of droplets in the atmosphere (Nd is constant in COSMO model),
   - advection of 2m humidity .

Boudala

visibility is calculated starting from the ratio between TD2M and T2M

Ratio > 0.9998

Diagnostic methods:

Asymptotic liquid water content approach

In a steady **radiation or advection** fog, LWC can be expressed by:

$$\begin{cases} K\dfrac{\mathrm{d}^2(LWC)}{\mathrm{dz}^2} + 2\,\alpha\,\mathrm{LWC}\dfrac{\mathrm{d}(LWC)}{\mathrm{dz}} + \beta(\mathrm{T,p})\mathrm{C_0(z)} + \mathrm{Adv} = 0 \\ \mathrm{LWC(0)} = 0\,, \qquad \mathrm{LWC(H_{sat})} = 0 \end{cases}$$

LWC: liquid water content $\left[{}^{g}/_{kg}\right]$; K: turbulent exchange coefficient $\left[{}^{m^2}/_{s}\right]$

α: gravitational settling parameter ; T: temperature $[k]$; P : pressure $[Pa]$

$C_0(z) = -\frac{\partial T}{\partial t}$: total local cooling rate $[Pa]$

$\beta(T,p)C_0(z)$: fog water generation rate $\left[{}^{g}/_{kg\ s}\right]$

$Adv = -V\cdot\nabla LWC$: is LWC generation/reduction rate by horizontal moisture advection $\left[{}^{g}/_{kg\ s}\right]$

V: horizontal wind vector $\left[{}^{m}/_{s}\right]$; H_{sat}: saturated layer depht $[m]$

$\delta = \dfrac{K}{2\left[\alpha\,\beta(\mathrm{T,p})\,\mathrm{C_0(z)H_{sat}}\right]^{1/2}}$: fog boundary layer $[m]$; z: vertical coordinate $[m]$

Solution

$$\mathbf{LWC(z)} = \left\{\frac{[\mathbf{Adv} + \beta(\mathbf{T,p})\mathbf{C_0(z)}]\mathbf{H_{sat}}}{\alpha}\right\}^{1/2} + \left[\left(1 - \frac{\mathbf{z}}{\mathbf{H_{sat}}}\right)^{1/2} - \frac{\mathbf{2}}{\mathbf{1} + \mathbf{e}^{\mathbf{z}/\delta}}\right]$$

Visibility parametrizations

The liquid water content (LWC) can be related to visibility (Vis) in several way:

- $Vis = \frac{-\log(0.002)}{144.7\ LWC^{0.88}}\ [km]$ (Stoelinga and Warner (1999)[4])
- $Vis = \frac{1.002}{(LWC\ N_d)^{0.6473}}\ [km]$ (Gultepe et al. (2006)[5])
  - N_d is the droplet number concentration
- $Vis = \frac{1.13}{(LWC\ N_d)^{0.51}}\ [km]$ (Gultepe and Milbrandt (2007)[6])

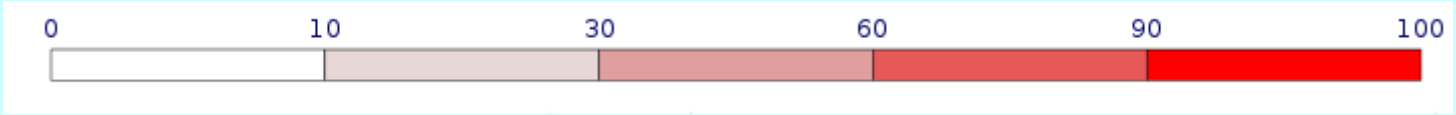
Used in the test case

SRNWP-EPS II

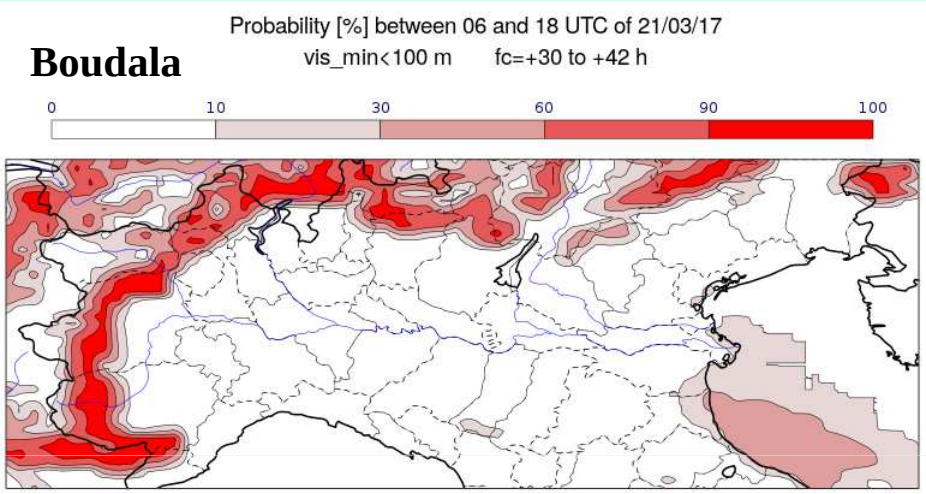
- Project founded by EUMETNET, co-coordinated by Italy (COMET, Arpae) and Spain (AEMET)
- EUMETNET (http://eumetnet.eu/) is a grouping of 31 European National Meteorological Services that provides a framework to organise co-operative programmes between its Members in the various fields of basic meteorological activities.
- Puropose: improve the usability of high-resolution ensemble products for the prediction of high-impact weather phenomena
  - Calibration of ensemble outputs, also for extreme events
  - Generation of probabilistic products for the prediction of thunderstorms and fog, to be extended to other high-impact weather phenomena
  - Associated study on the impact of land surface and PBL perturbation of the prediction of the selected phenomena

Advection fog: run of 20/3/2017, 00UTC +30-42h

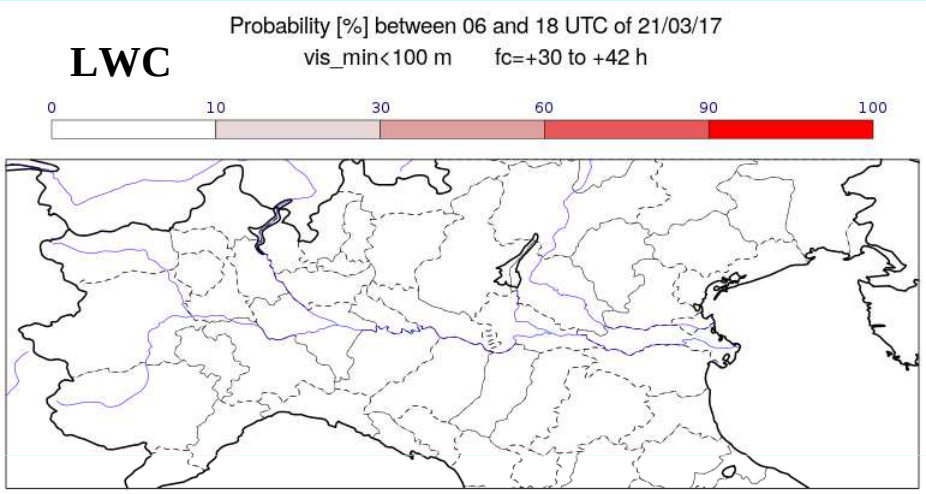
Probability of min. visibility over 12h < **1000** m



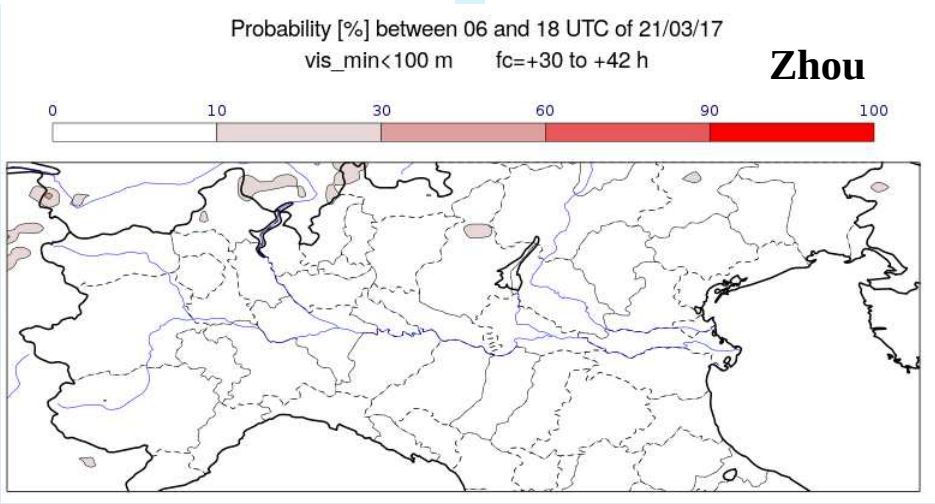
Boudala



LWC



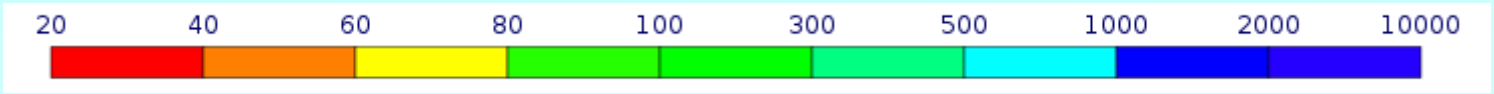
Zhou



Boudala: still too much fog in mountainous regions.

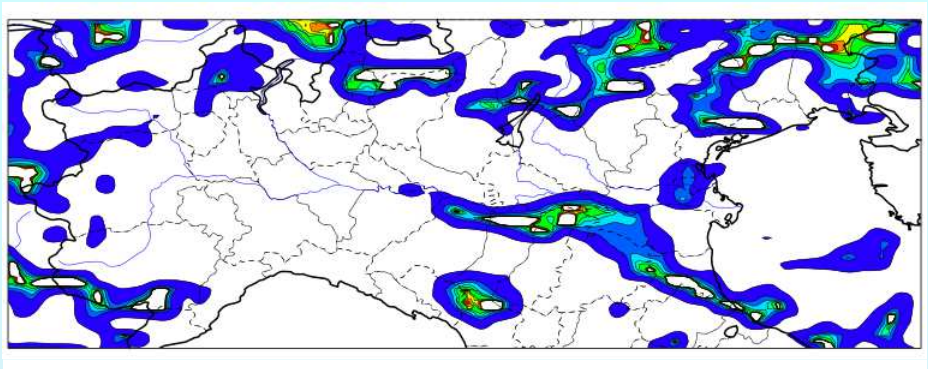
Case of 21/3/2017 - ECMWF ana vs Metar obs

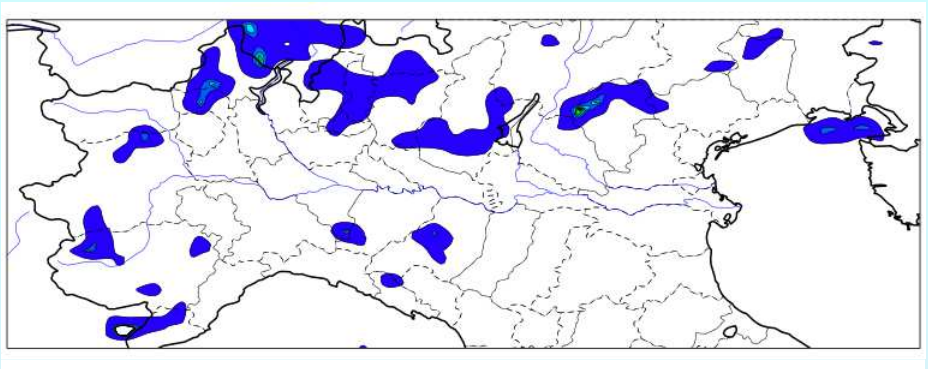
(visibility in m)



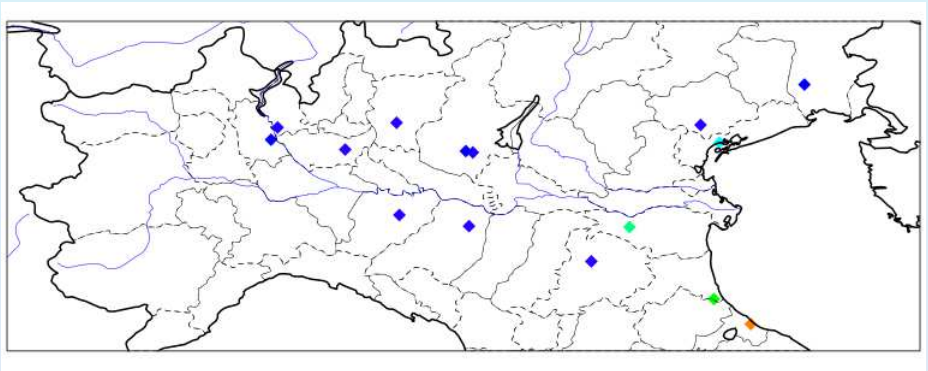
06UTC **12UTC**

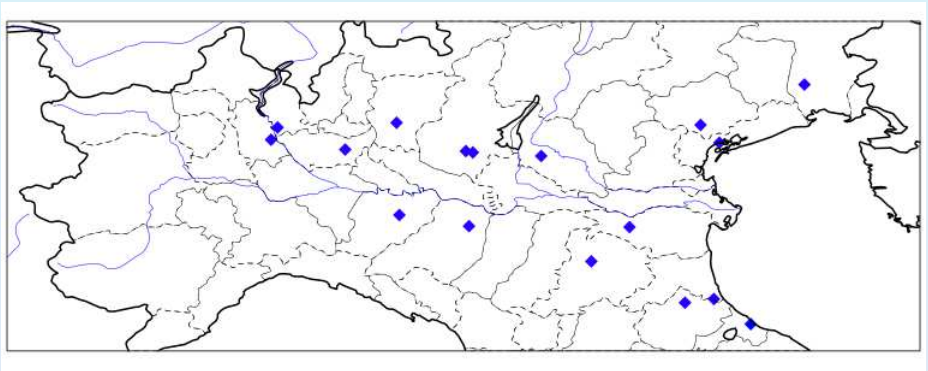
ECMWF





METAR





More agreement between METAR observations and model analyses.

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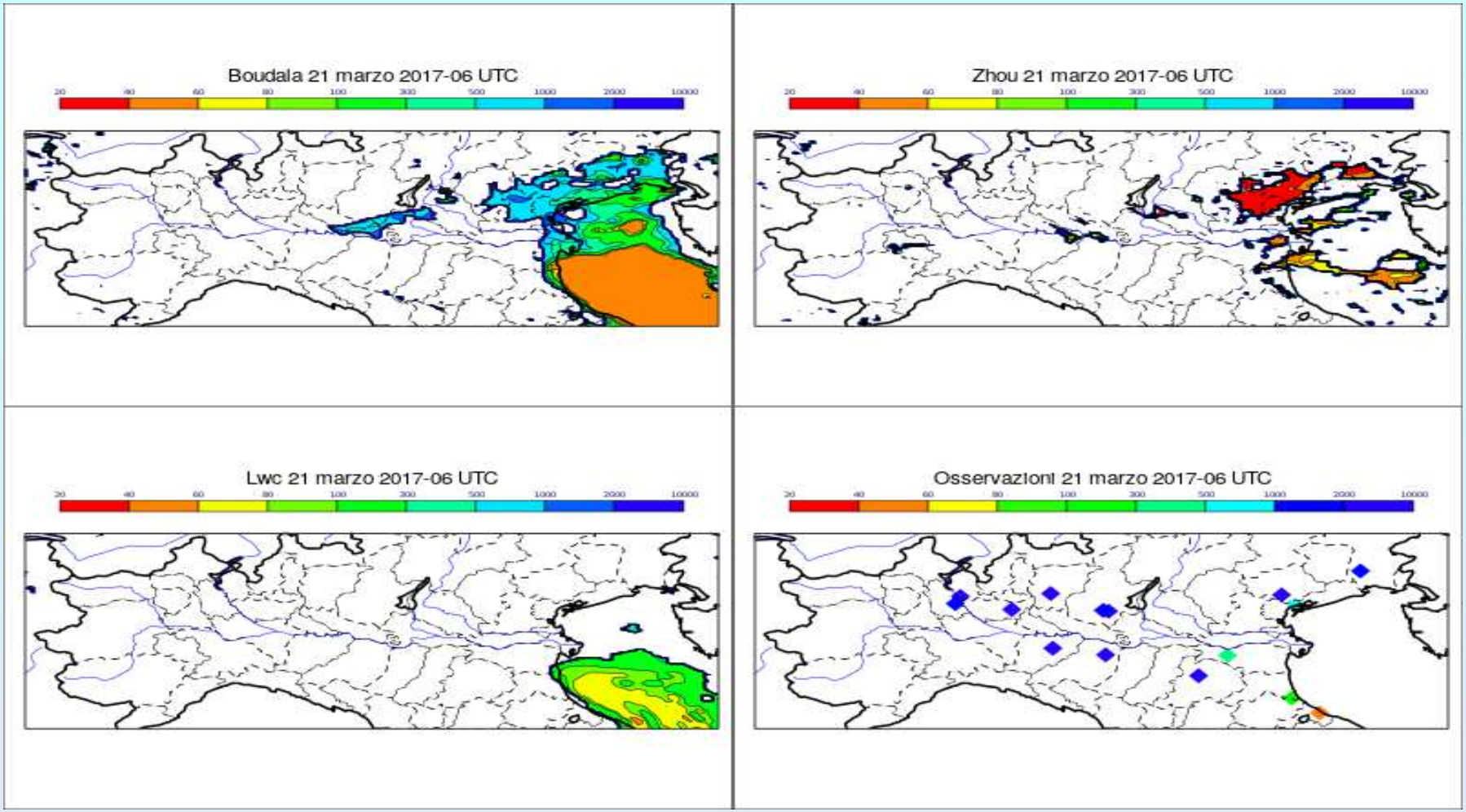
Case of 21/3/2017, 6UTC – deterministic runs

(member 1 of the ensemble)



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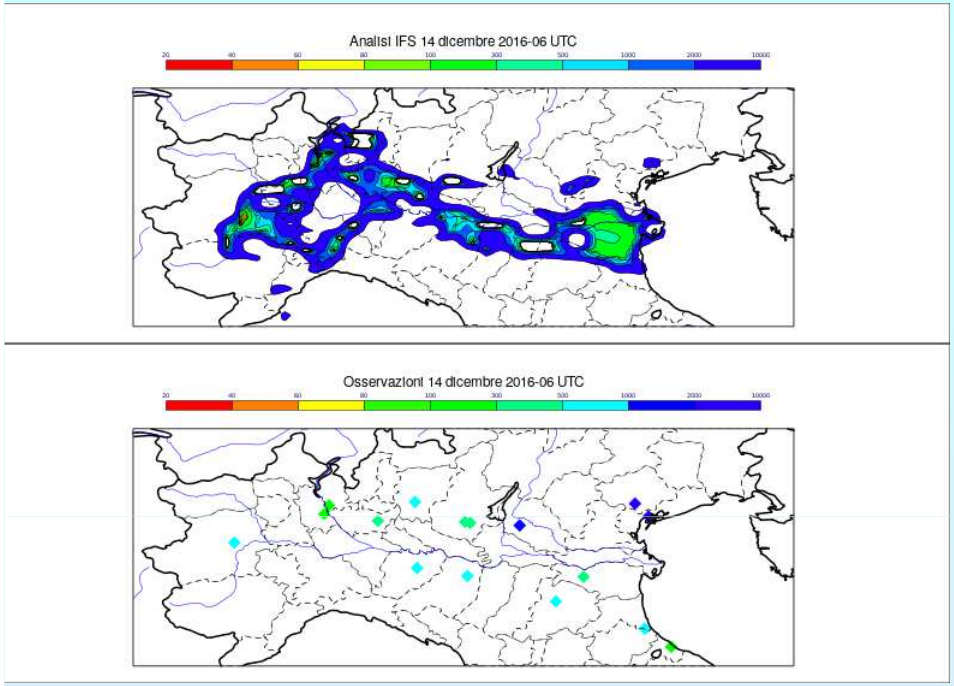
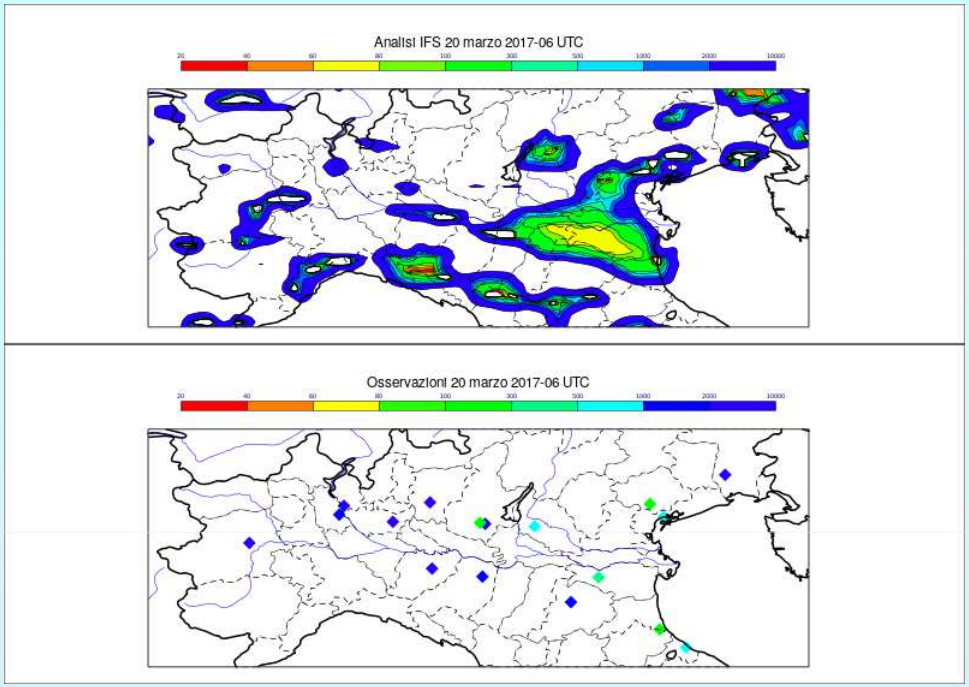
Case of February: ECMWF analysis vs Metar obs





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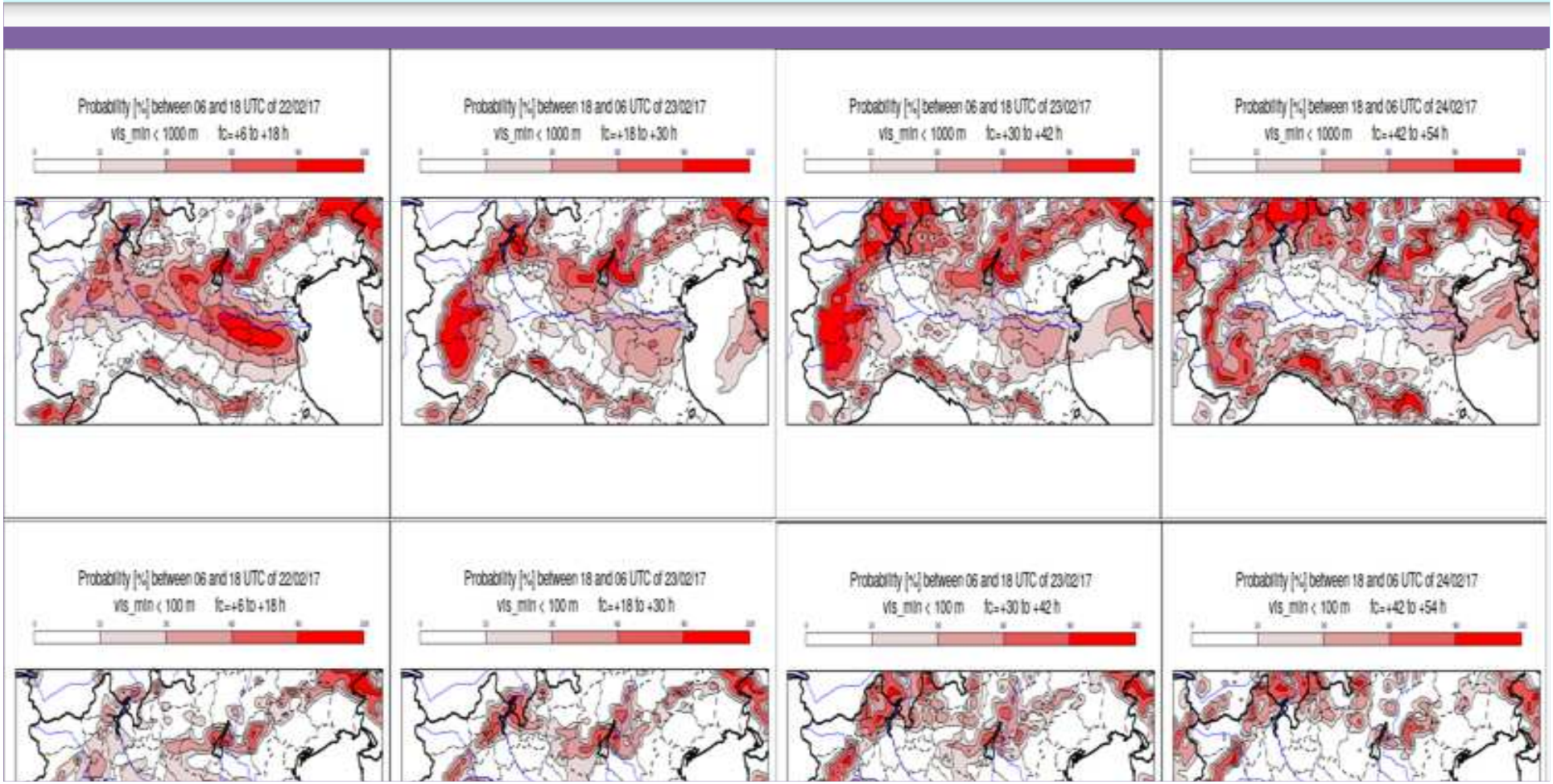
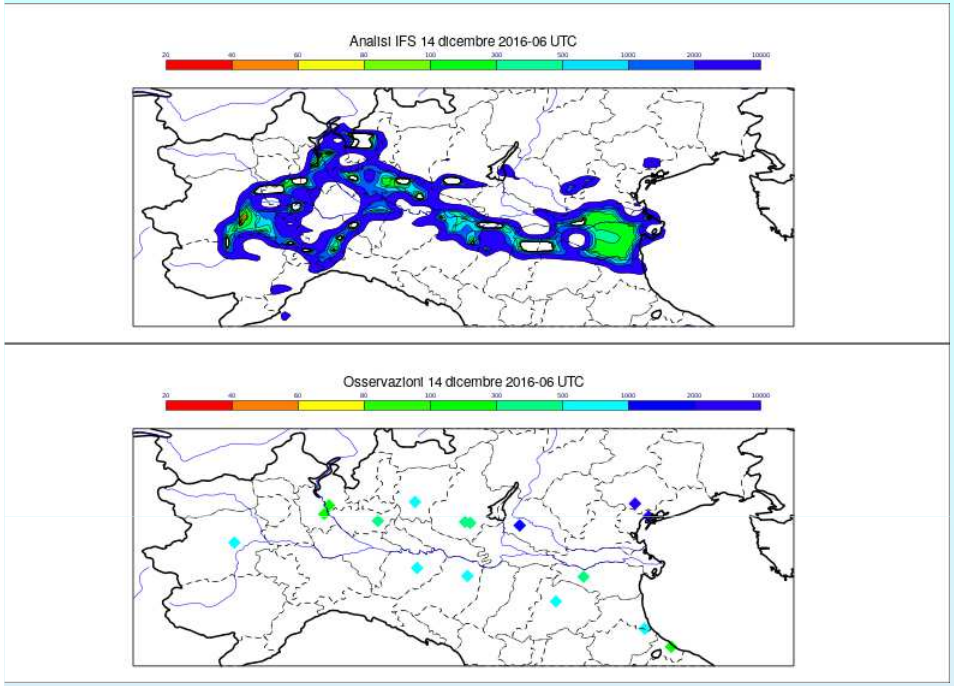
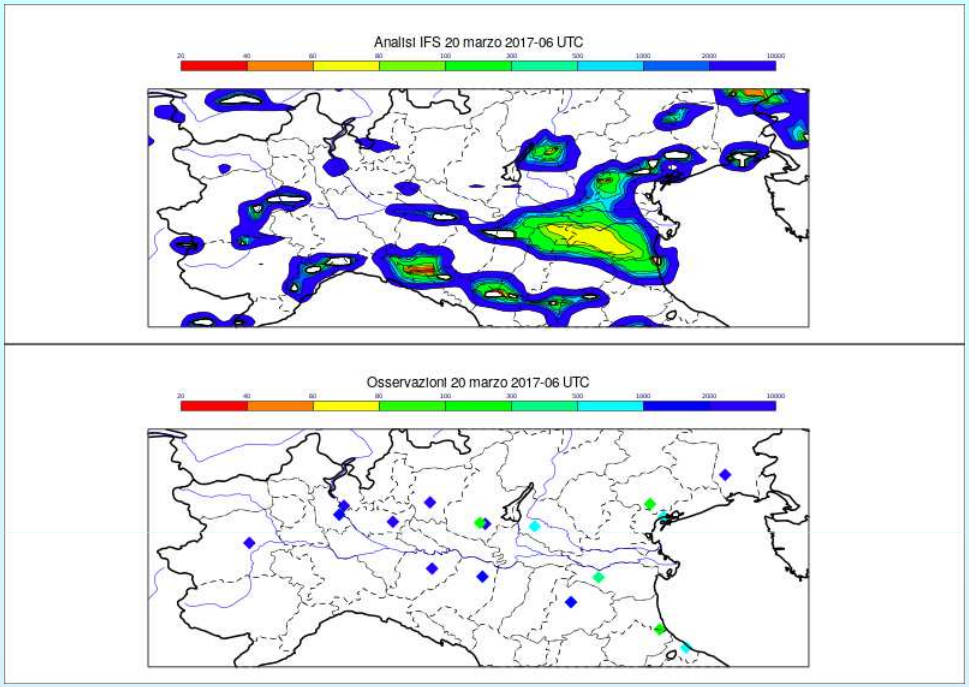
Prob. of min vis<1000m over 12 h Run init.: 2017022200 + 30-42h (Boudala, LWC, Zhou)



Case of February: ECMWF analysis vs Metar obs





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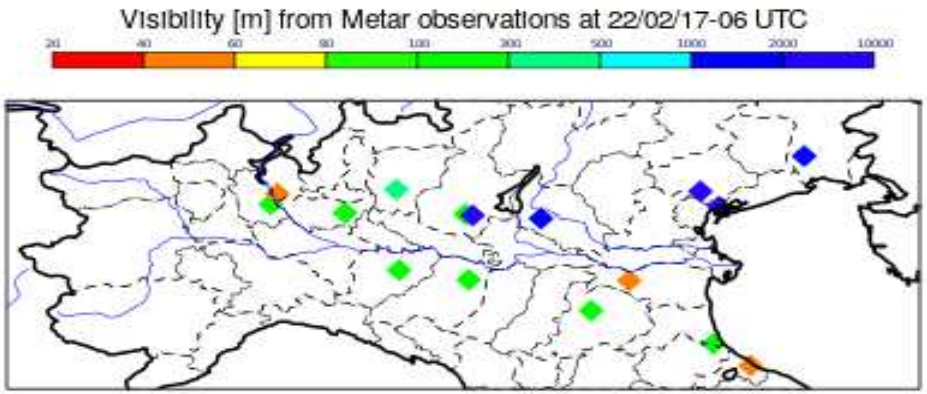
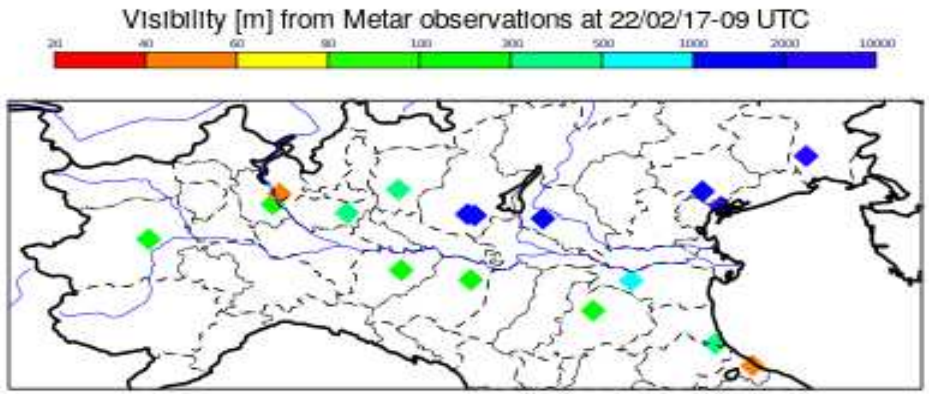
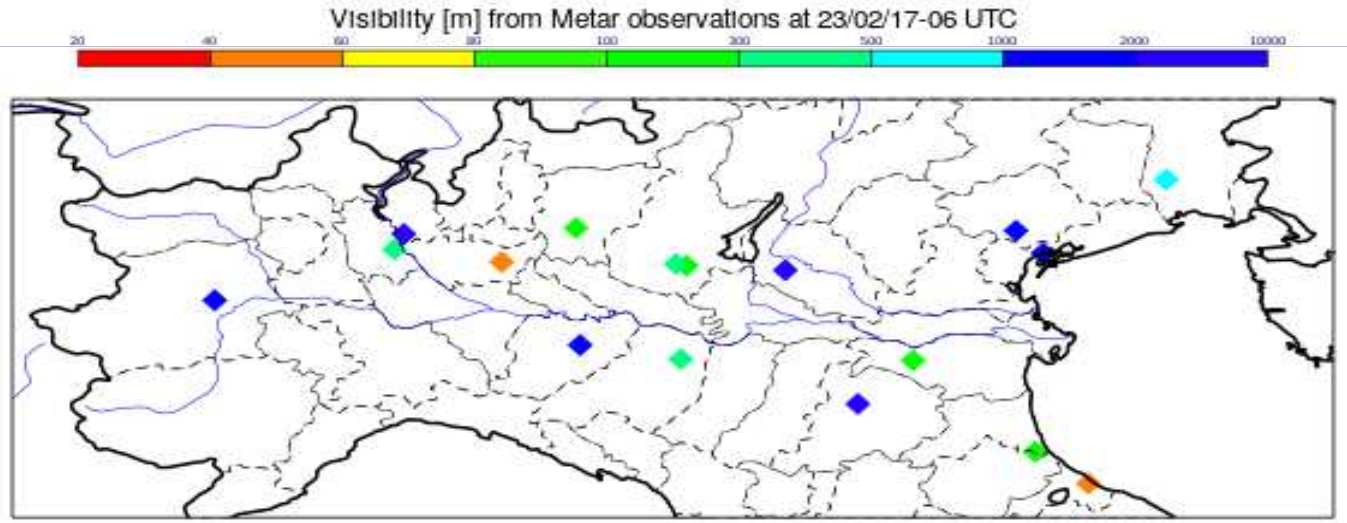
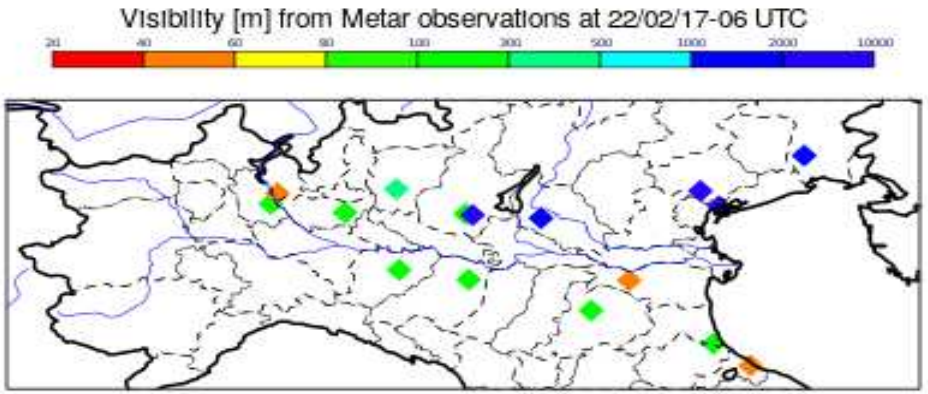
Metar observations for 22nd and 23th Feb 2017

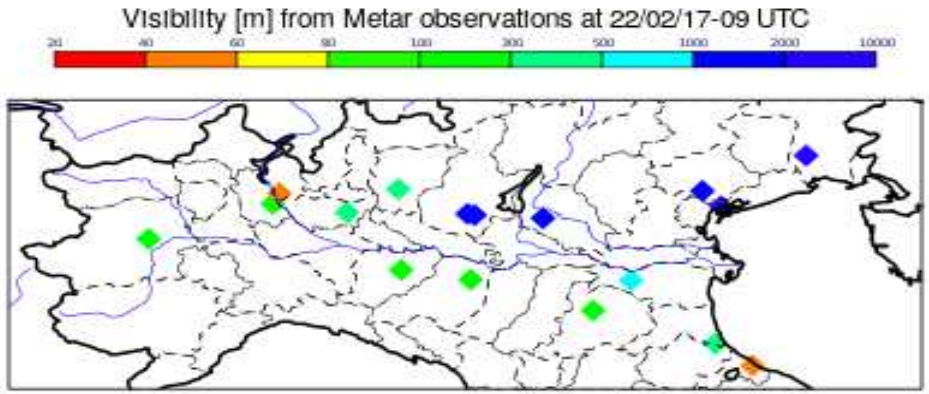


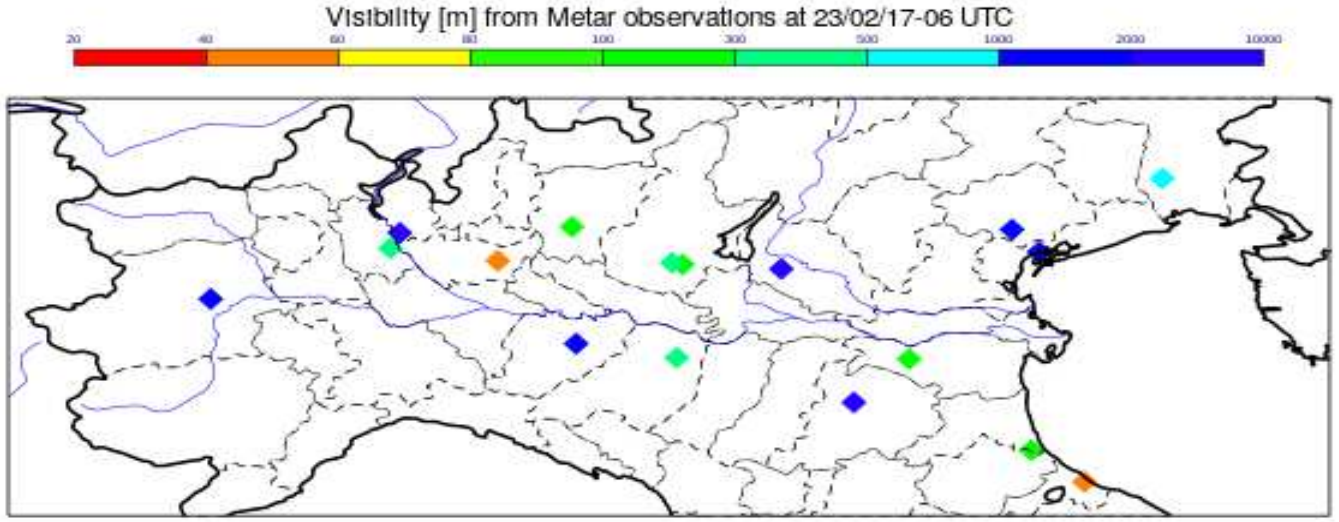




Metar observations for 22nd and 23th Febraury 2017



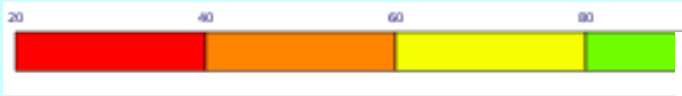


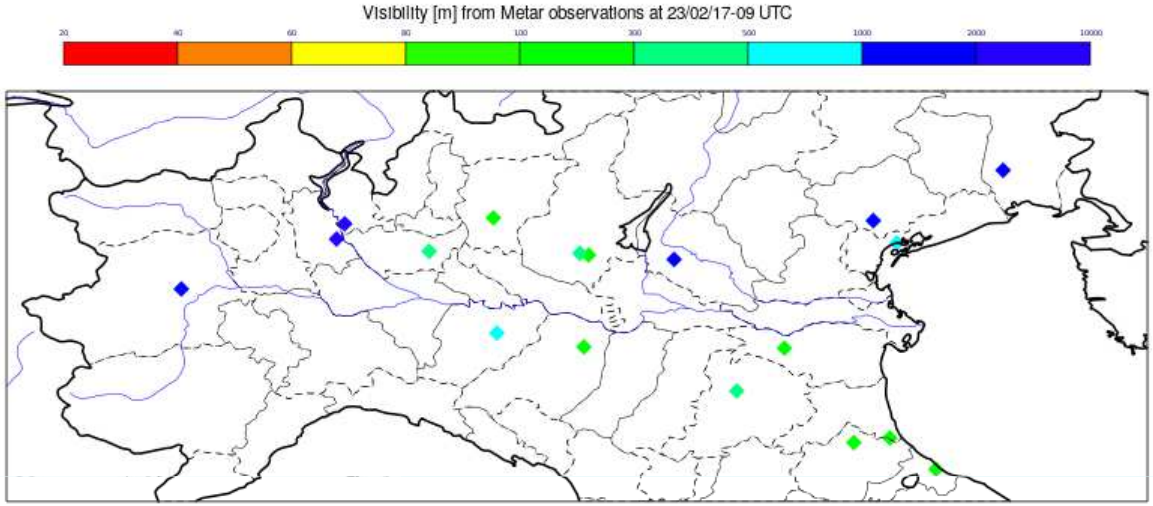


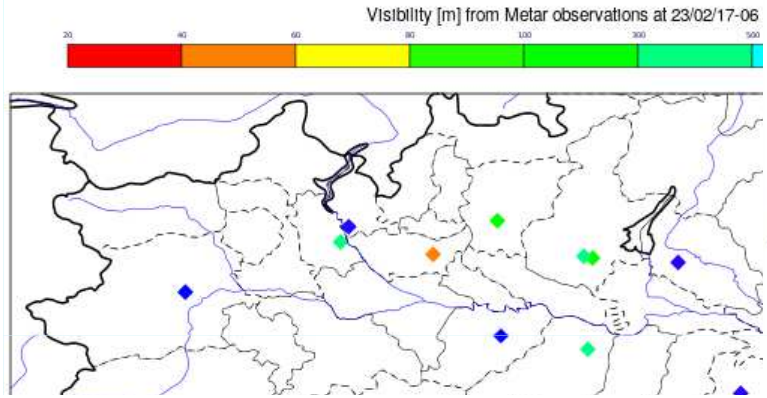
06UTC 09UTC

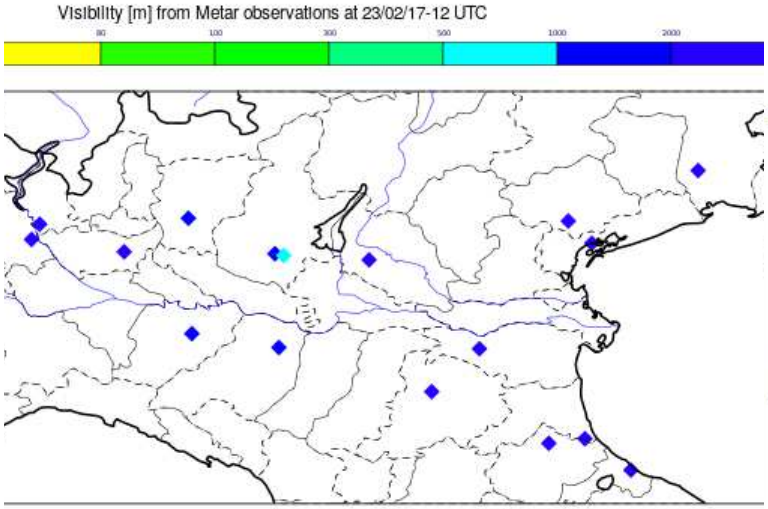
12UTC 15UTC

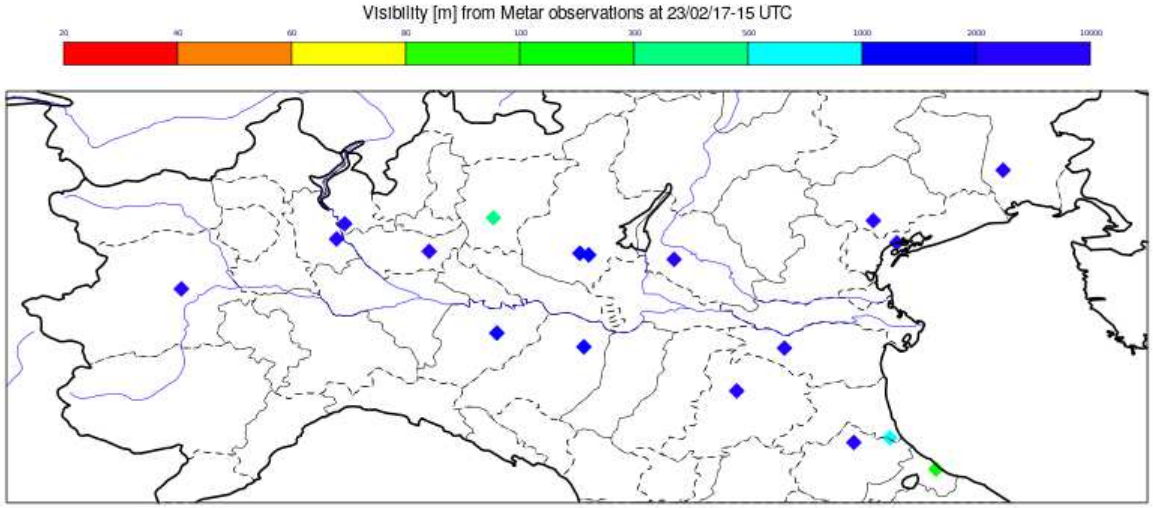
Case of 23 February 2017 (Metar obs)











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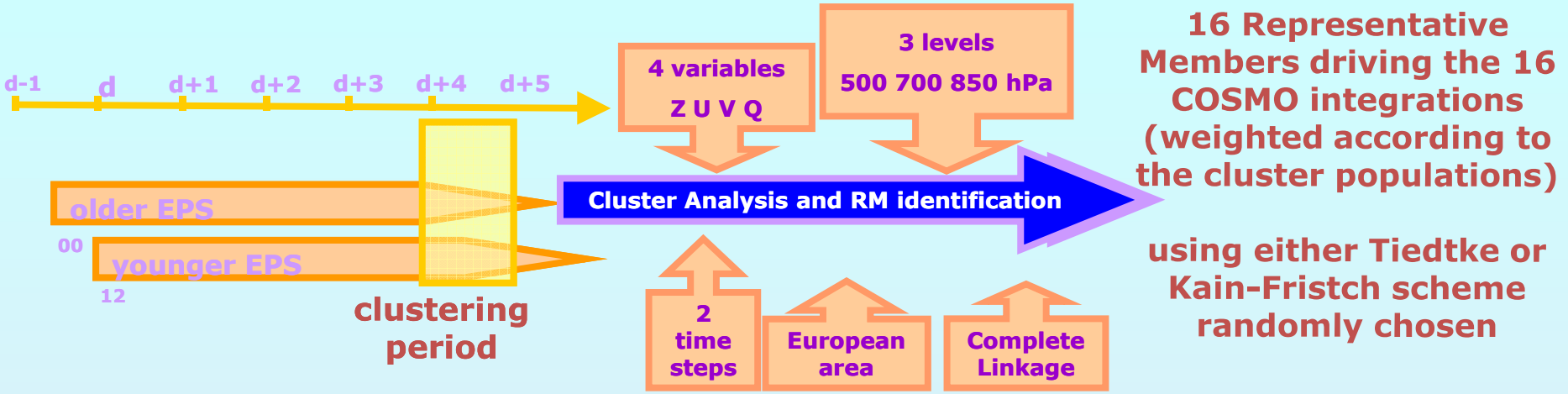
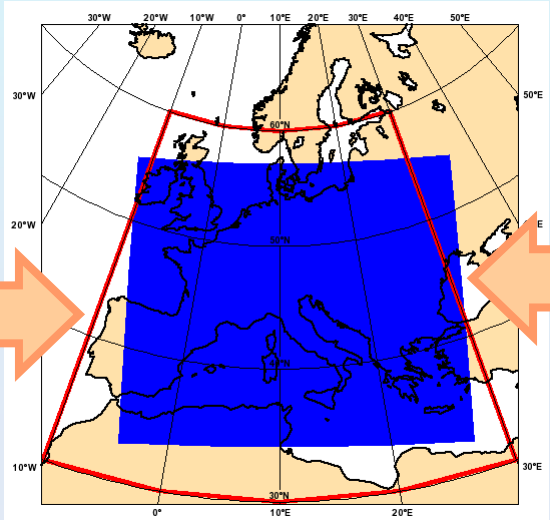
COSMO CONSORTIUM FOR SMALL SCALE MODELING

COSMO-LEPS suite @ ECMWF: status in 2007

Limited-area-model Ensemble Prediction System based on COSMO model



COSMO-LEPS clustering area



COSMO-LEPS Integration Domain

- suite runs as a "time-critical application" managed by ARPA-SIMC; runs ONLY at 12UTC; 6-hourly post-processing;
- Δx ~ 10 km; 32 ML; fc+132h;
- COSMO v3.20 in 2007,
- computer time provided by the COSMO partners which are ECMWF member states.

Montani et al., 2011, Tellus A

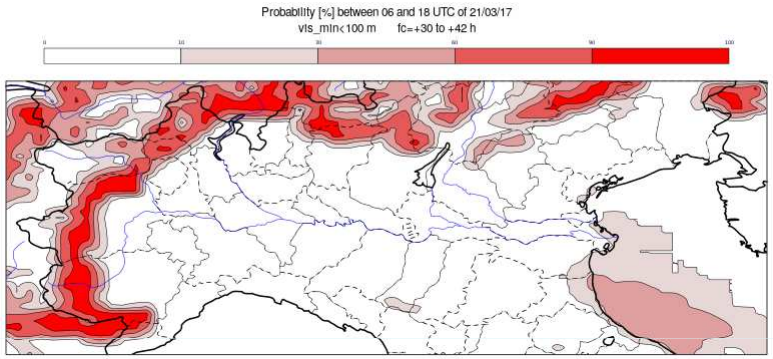
Conclusions_2

- Boudala: good forecast of fog areas, but too many “false alarms”, since it does not distinguish properly between cloud and fog (case of 20170222 with improper fog prediction over the Apennines and over Southern Switzerland)
- LWC: removes “wrong areas” of fog forecasts
- Zhou method: the most complicated methods still need to be tuned and refined (the present constant value of Nd in the software implementation and in COSMO could be a limitation); at the moment, too little fog is predicted.
- at the moment, LWC method seems the best compromise for operational implementation

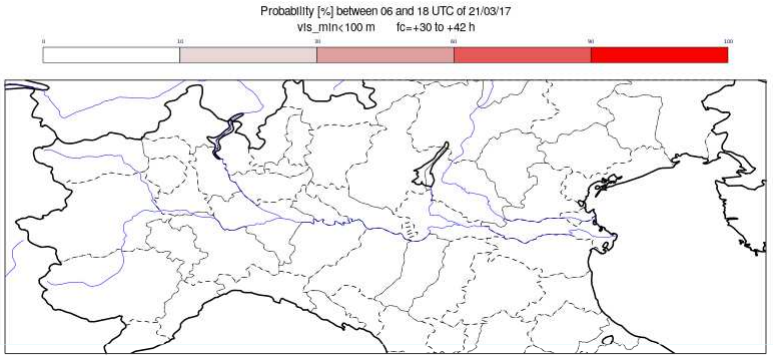
Probability maps for March (30-42h) -100m

Probability of min. visibility over 12h < 100 m (fc 30-42h)

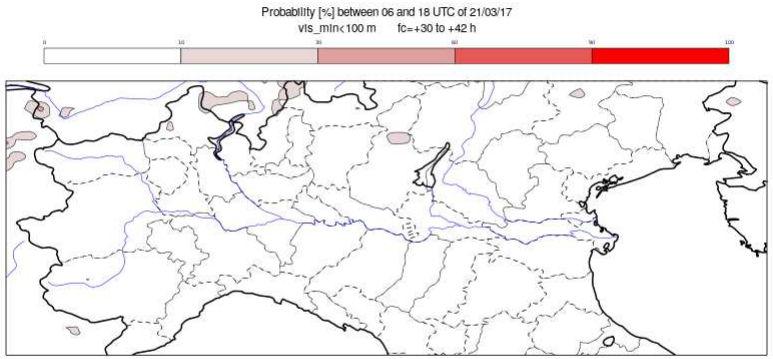
Boudala



LWC



Zhou



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CONSORTIUM FOR SMALL SCALE MODELING COSMO