Flood prediction with the ECMWF EPS

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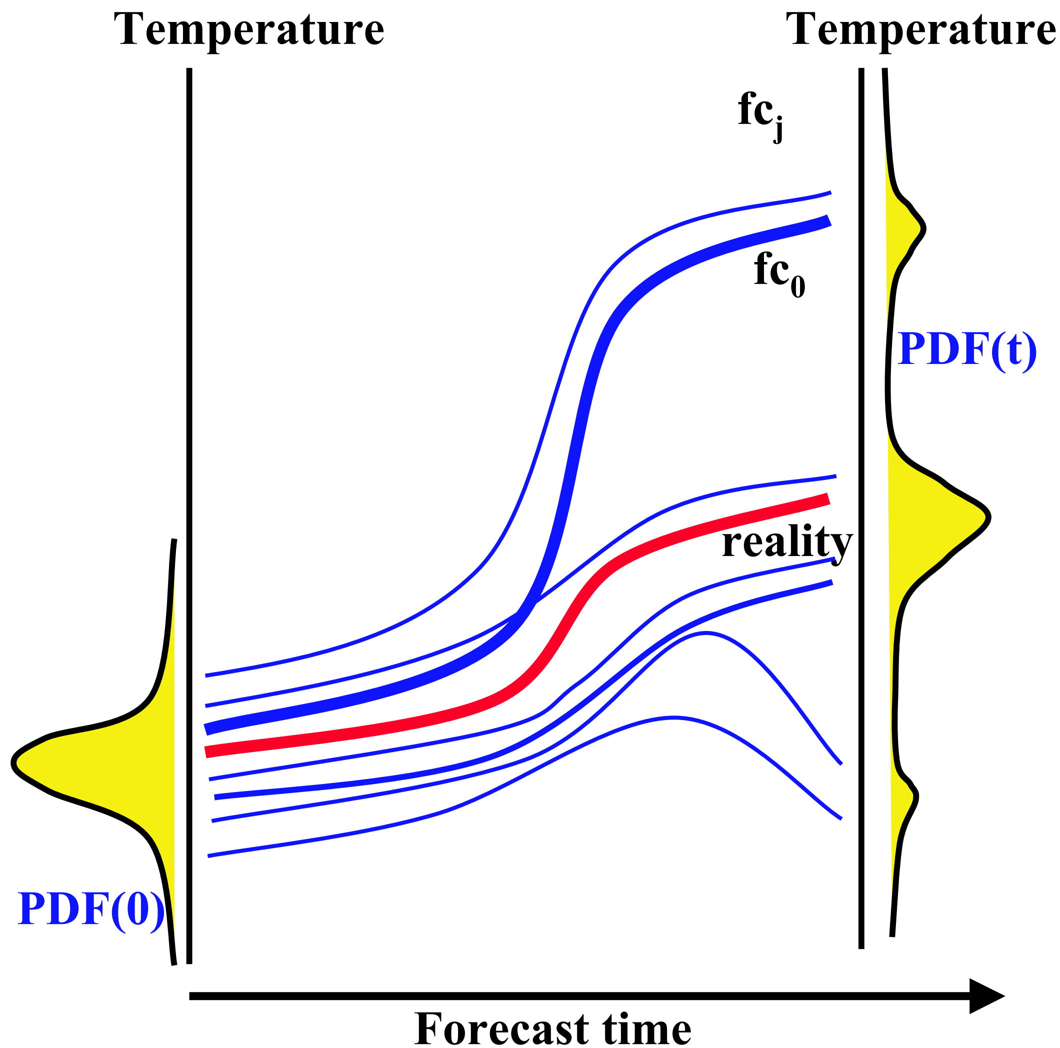
Outline

- ❖ **The ECMWF Ensemble Prediction system**
  - Sources of forecast errors: initial and model uncertainties.
- ❖ **Flood prediction using a cascade of M~al and H~al models**
  - Firenze 1966: analysis of the flood that hit Tuscany and NE Italy in 1966.
- ❖ **The three key messages from this talk.**

The probabilistic approach to NWP: ensemble prediction

A complete description of the weather prediction problem can be stated in terms of the time evolution of an appropriate probability density function (PDF).

Ensemble prediction based on a finite number of deterministic integration appears to be the only feasible method to predict the PDF beyond the range of linear growth.



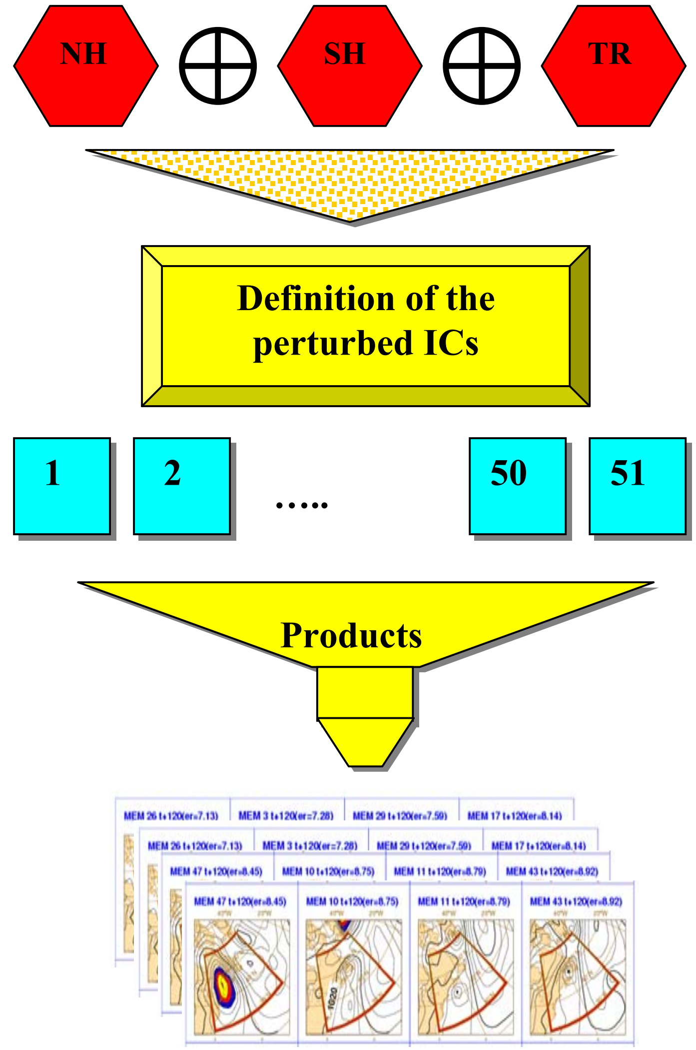
The operational EPS configuration

The Ensemble Prediction System (EPS) consists of 51 10-day forecasts run at resolution T_L255L40 (~80km, 40 levels).

The EPS is run twice a-day, with initial time 00 and 12 UTC.

Initial uncertainties are simulated by adding perturbations generated using singular vectors.

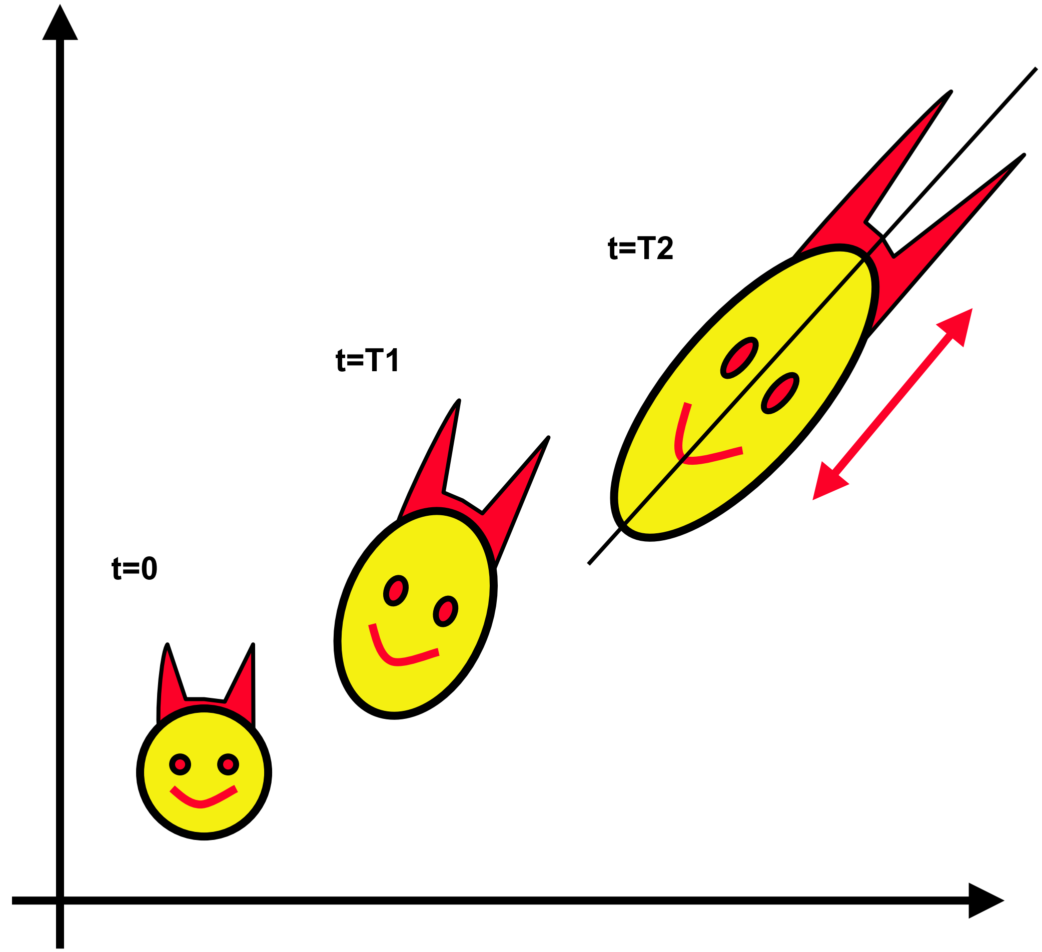
Model uncertainties are simulated by stochastic perturbations added to tendencies due to parameterized physical processes.



Simulation of initial uncertainties: the singular vector approach

Perturbations pointing along different axes in the phase-space of the system are characterized by different amplification rates. As a consequence, the initial PDF is stretched principally along directions of maximum growth.

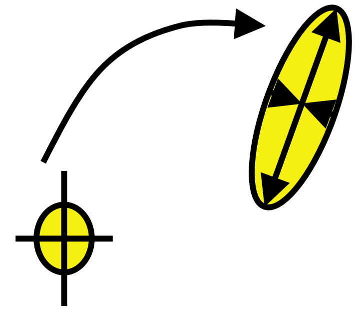
The component of an initial perturbation pointing along a direction of maximum growth amplifies more than a component along another direction (*Buizza et al* 1997).



Simulation of initial uncertainties: the singular vector approach

The problem of the computation of the directions of maximum growth of a time evolving trajectory is solved by computing the **singular vectors** of **$K=E^{1/2}LE^{-1/2}$**, i.e. to solving the following eigenvalue problem:

$$E^{-1/2}L^{*}ELE^{-1/2}\nu = \sigma^{2}\upsilon$$



where *L* and *L** denotes the forward and adjoint model versions, and *E* the energy metric. By definition, the singular vectors depend:

- on the **initial and final time metrics E_0 and E;**
- on the **linear propagator *L(t,0)***;
- on the **time-evolving trajectory** along which they are computed**;**
- on the **optimization time interval.**

Simulation of random model errors: stochastic physics

In 1998 ECMWF implemented a simple scheme to simulate the effect of model uncertainties based on the following principles:

- The parameterization scheme ('stochastic physics') should be simple.

- It should simulate the sort of random errors in parameterized forcing which are coherent among the different parameterization models (moist-processes, radiation, turbulence, ..). A way to take this into account is to apply the stochastic forcing on the total tendency.

- Model tendencies due to parameterized physical processes have a certain coherence on the space and time scales associated, for example, with organized convection. A way to simulate this is to impose space-time correlation on the random numbers.

The EPS with perturbed physics

Each ensemble member evolution is given by the time integration

$$e_j(T) = \int_{t=0}^{T} [A(e_j,t) + P(e_j,t) + \delta P_j(e_j,t)]dt$$

of the perturbed model equations starting from the perturbed initial conditions

$$e_j(0) = e_0(0) + \delta e_j(0)$$

The model tendency perturbation is defined at each grid point by

$$\delta P_j(\lambda,\phi,p) = r_j(\lambda,\phi) P_j(\lambda,\phi,p)$$

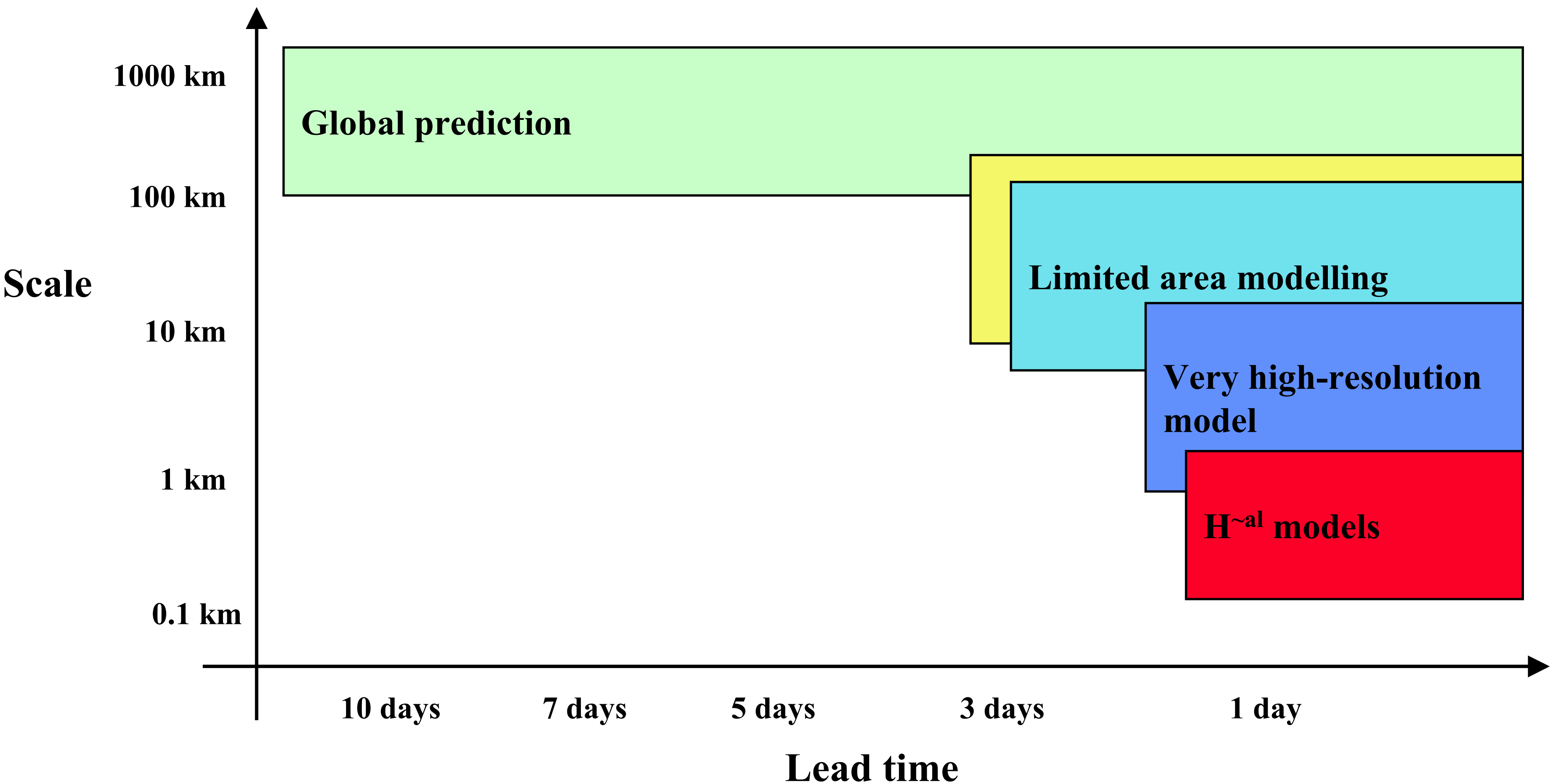
where $r_j(x)$ is a set of random numbers.

Flood prediction using a cascade of M~al and H~al models

A collaborative project of ISAC/CNR Bologna (*A Buzzi*, *P Malguzzi*), University of Brescia (*G Grossi*, *R Ranzi*) and ECMWF (*E Klinker, S Uppala, R Buizza*) with three main objectives:

- Assess the value of the ERA-40 database for a-posteriori studies of the ECMWF forecasting system value for weather risk assessment.
- Examine the accuracy of single deterministic and probabilistic forecasts during the period of the Florence 1966 flood.
- Investigate the possibility to use single and probabilistic predictions to drive river-basin discharge models.

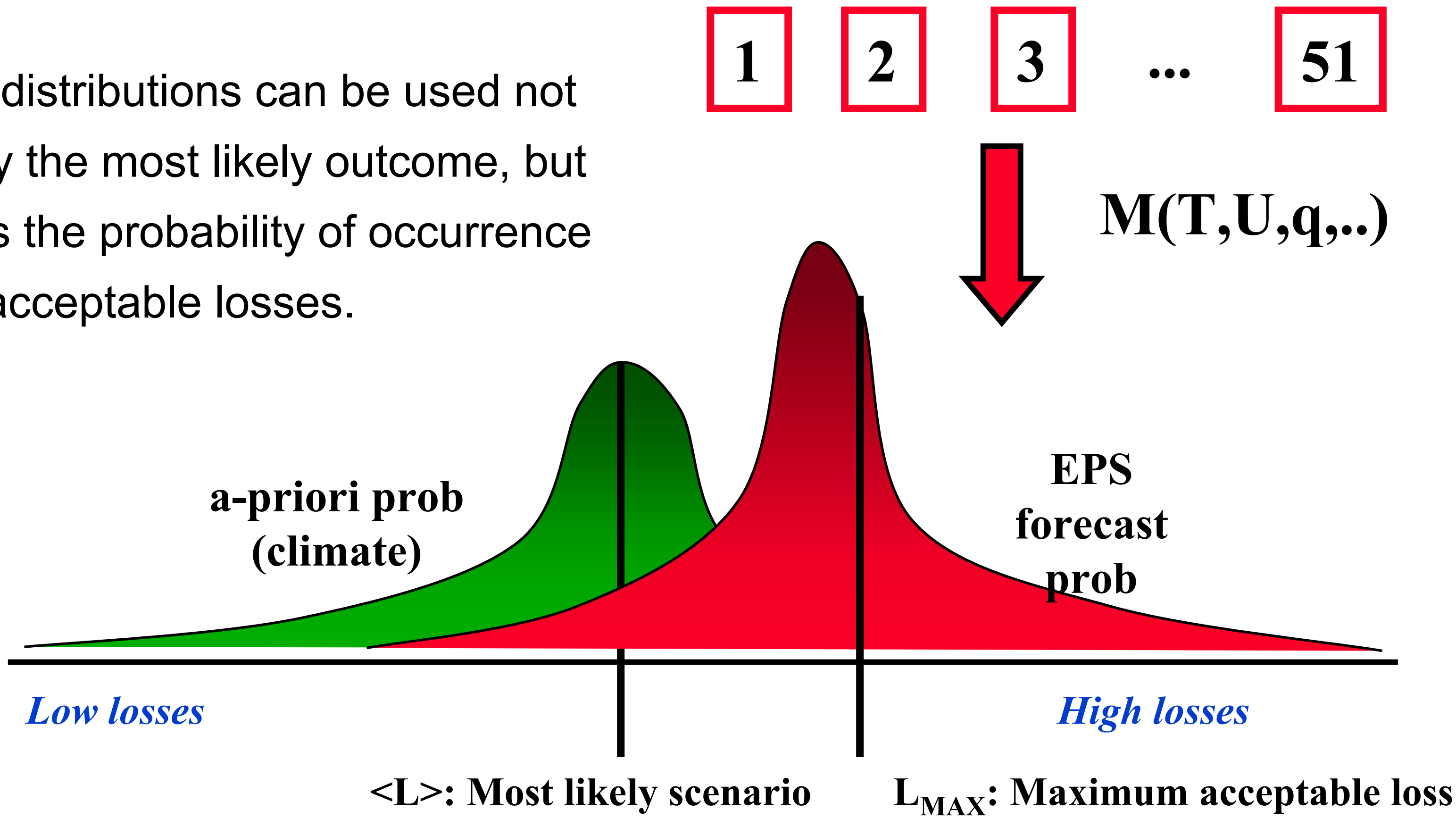
Flood prediction using a cascade of M~al and H~al models



Scenario prediction using ensemble forecasts

❖ Ensemble forecasts can be translated into forecast probability distribution of gains/losses.

❖ Probability distributions can be used not only to identify the most likely outcome, but also to assess the probability of occurrence of maximum acceptable losses.



Flood prediction using a cascade of M$^{\sim al}$ and H$^{\sim al}$ models

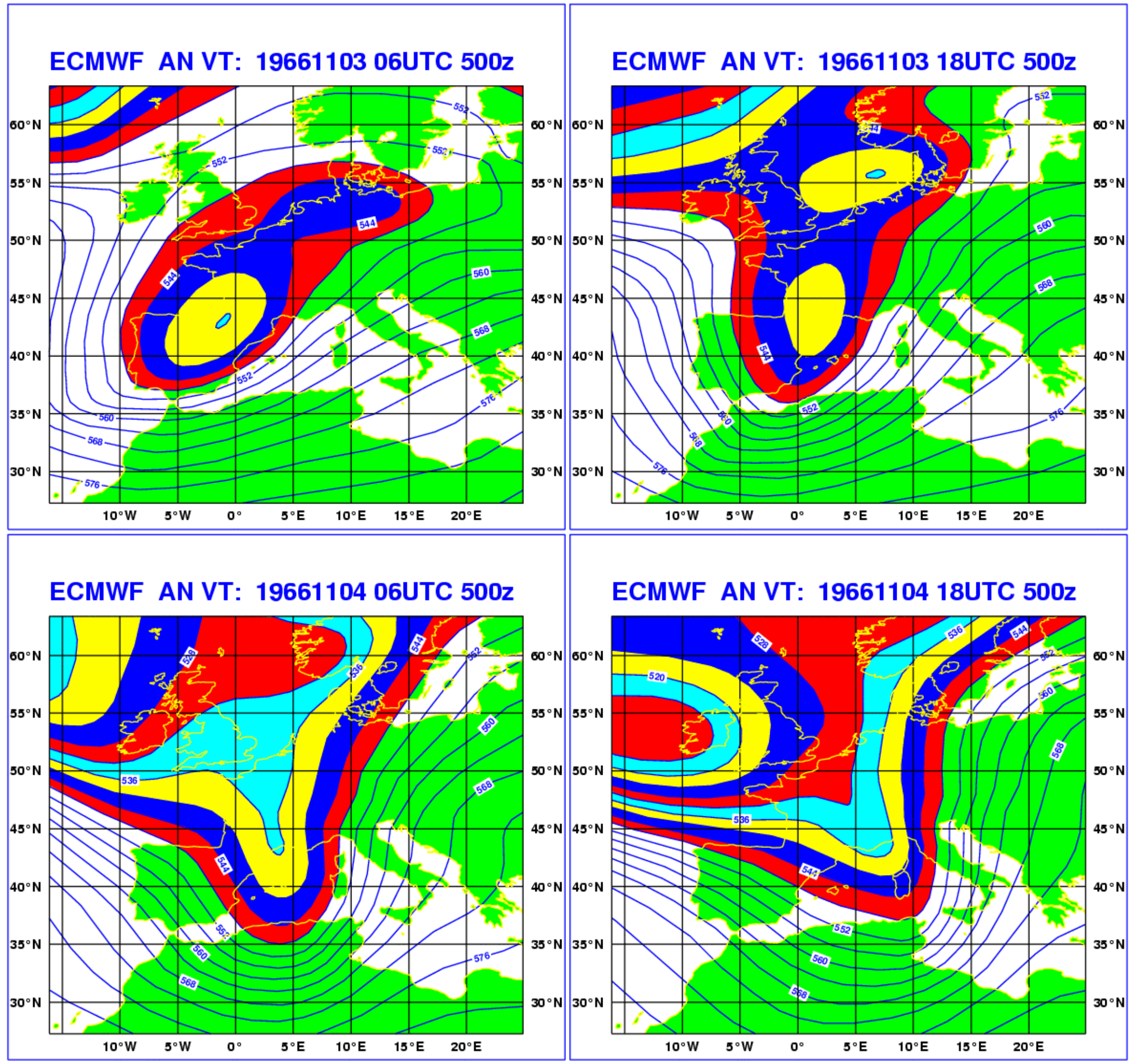
Observations	Data assimilation	Global M$^{\sim al}$ modelling	Local M$^{\sim al}$ modelling	Basin H$^{\sim al}$ modelling	Quality control
• Weather data • Hydro data	• ECMWF ERA40 (T_L159L31) • ECMWF High-res T_L511L60 DA experiments	• ECMWF +240h 40km (T_L511L60) deterministic predictions • ECMWF +240h 80km EPS (51*T_L255L40) probabilistic predictions	• ISAC/CNR BOLAM +72h 18km (*pater*) • ISAC/CNR BOLAM+72h 6km (*filius*) • ISAC/CNR MOLOCH +48h 2km (non-hydr.)	• University of Brescia (IT) simple rainfall/runoff model	• Verification of precipitation and runoff predictions

The November 1966 situation (Z500 from ERA40)

The meteorological situation was characterized by the rapid movement and amplification of a baroclinic wave, associated with a strong northward transport of heath and moisture.

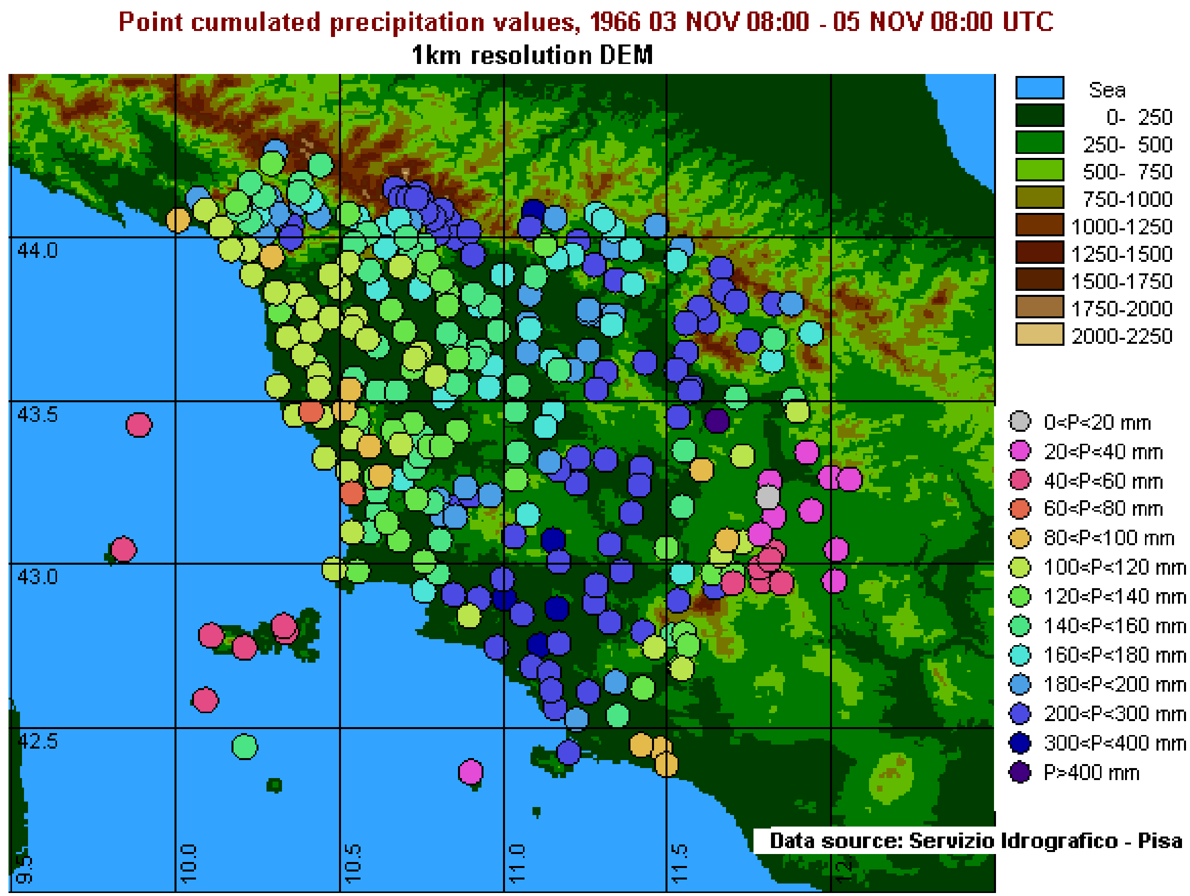
The Scirocco wind along the Adriatic caused the highest surge on record in Venice.

The orography apparently hampered the near-surface cyclogenesis but enhanced mesoscale features like jet-like winds and precipitation.



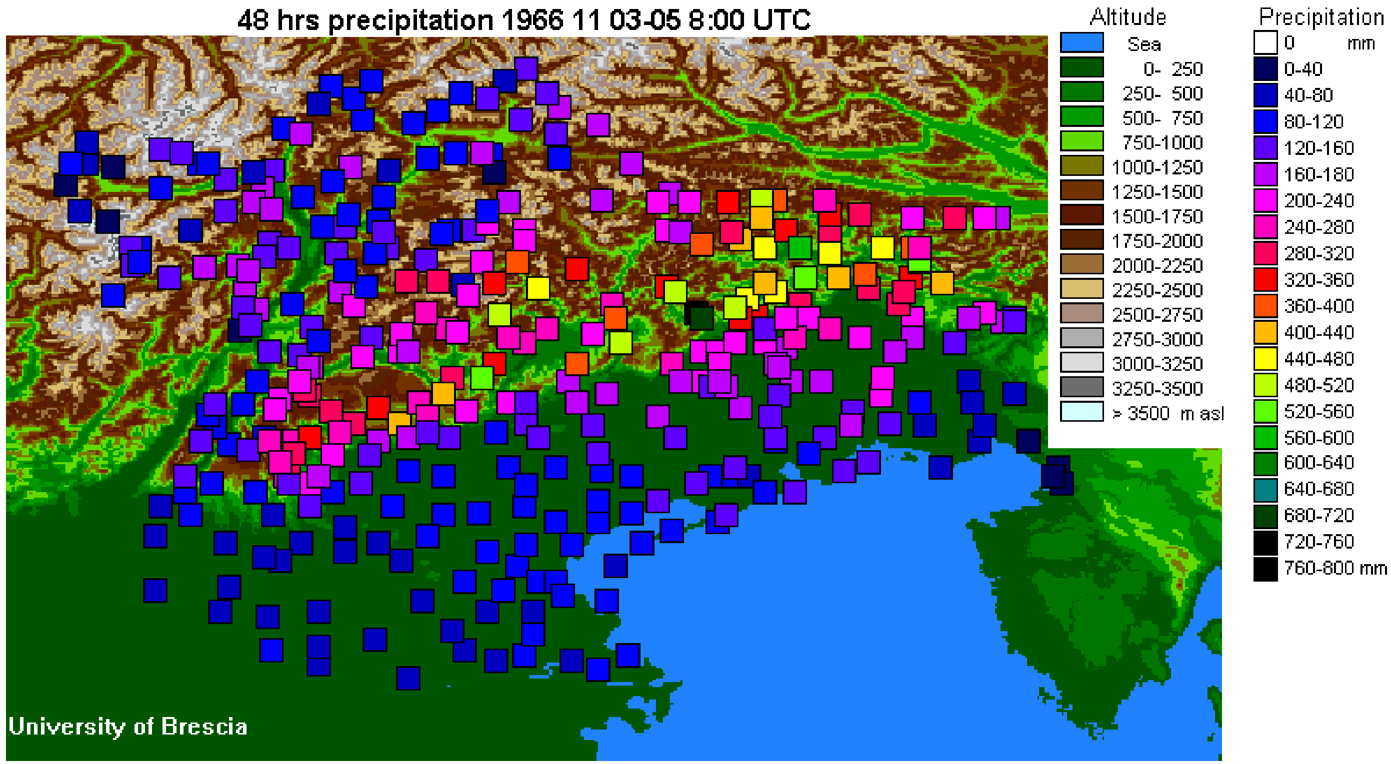
Observed 48h precipitation (3-5 Nov 1966) over Tuscany

The event was exceptional in terms of amplification of a baroclinic wave, southerly flow intensity and precipitation intensity and volume.
In Tuscany, precipitation in excess of 200mm/48h was observed over a large region.



Observed 48h precipitation (3-5 Nov 1966) over NE Italy

In Friuli-Venezia-Giulia (NE Italy), total precipitation in excess of 400mm/48h (peak of 700) was observed over a large region.

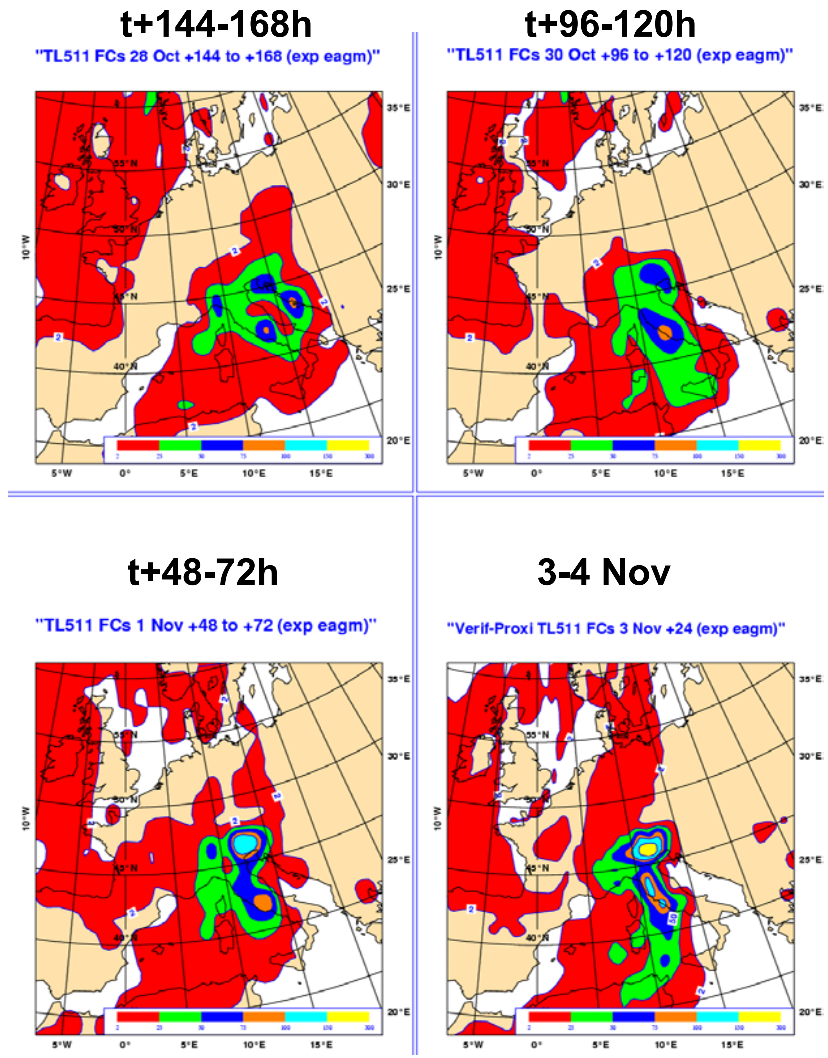


The M~al 40km global medium-range prediction

This figure shows T_L511L60 forecasts of 24h-accumulated precipitation started at 12UTC of the 28 (144-168h) and 30 (96-120h) October, and 1 November (48-72h) and valid for 3-4 November.

The right-bottom panel shows a proxi for verification defined by the T_L511L60 24h forecast started at 12UTC of 3 November.

In the shorter range, the T_L511L60 model predicts 150-300mm/24h in the region of interest (contour isolines are 2-25-50-75-100-150-300 mm for precipitation).



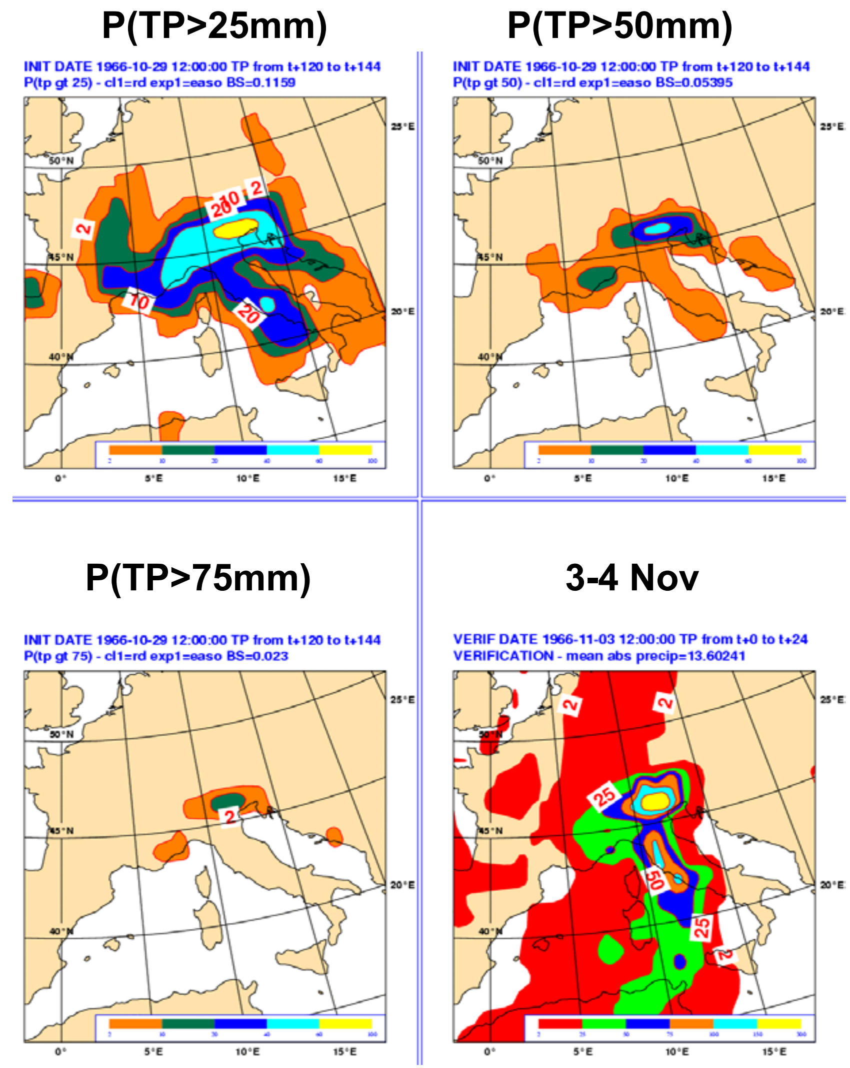
HRES
40 km

The M~al EPS 80km global t+120-144h prob prediction

This figure shows three EPS probabilistic forecasts started at 12UTC of 29 October (120-144h) and valid for 3-4 November, for 24-h accumulated precipitation in excess of 25, 50 and 75 mm.

Considering TP>50mm/24h, at this forecast range, the EPS gives a 40-60% probability of TP>50mm/24h over NE Italy and a weak signal over Tuscany (contour isolines for probabilities are 2-10-20-40-60-100%).

The right-bottom panel shows a proxi for verification.



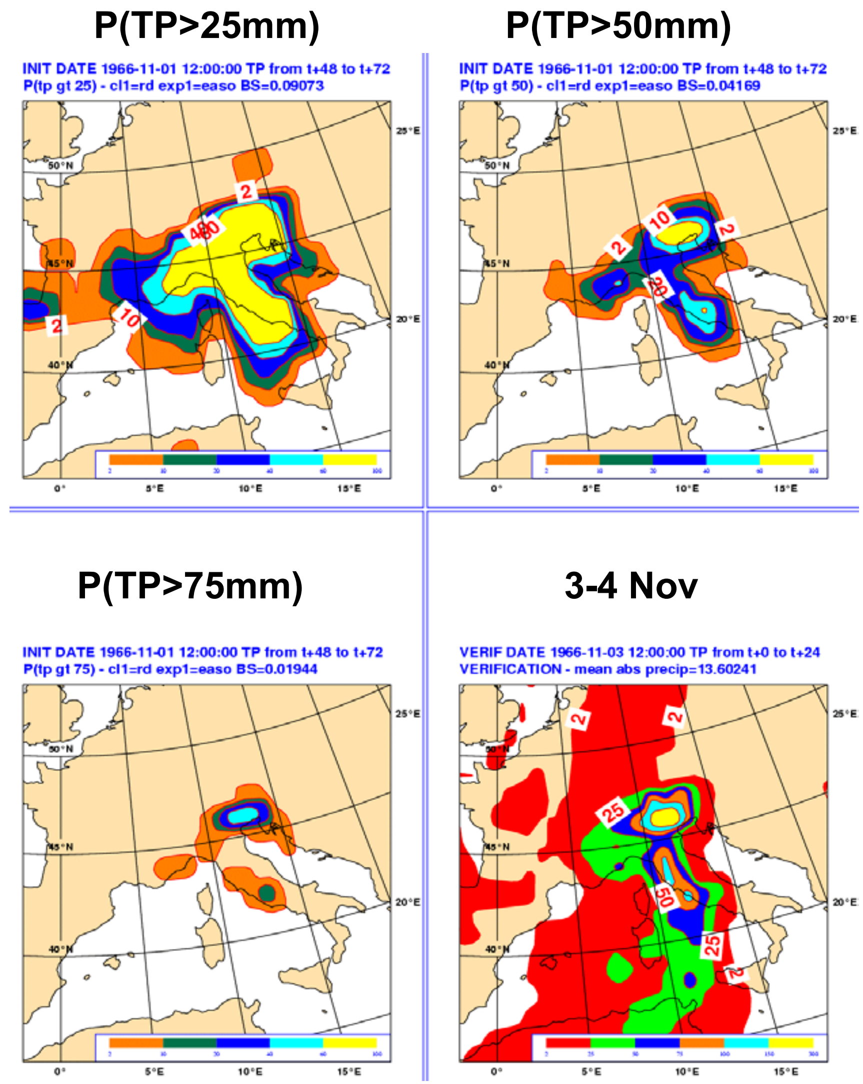
EPS
80 km

The M~al EPS 80km global t+48-72h prob prediction

This figure shows three EPS (51*T_L255L40) probabilistic forecasts started on 30 October (96-120h) and valid for 3-4 November, for 24-h accumulated precipitation in excess of 25, 50 and 75 mm.

Considering TP>50mm/24h, at this forecast range the EPS gives a >60% probability of over NE Italy and 20-40% probability over Tuscany (contour isolines for probabilities are 2-10-20-40-60-100%).

The right-bottom panel shows a proxi for verification.



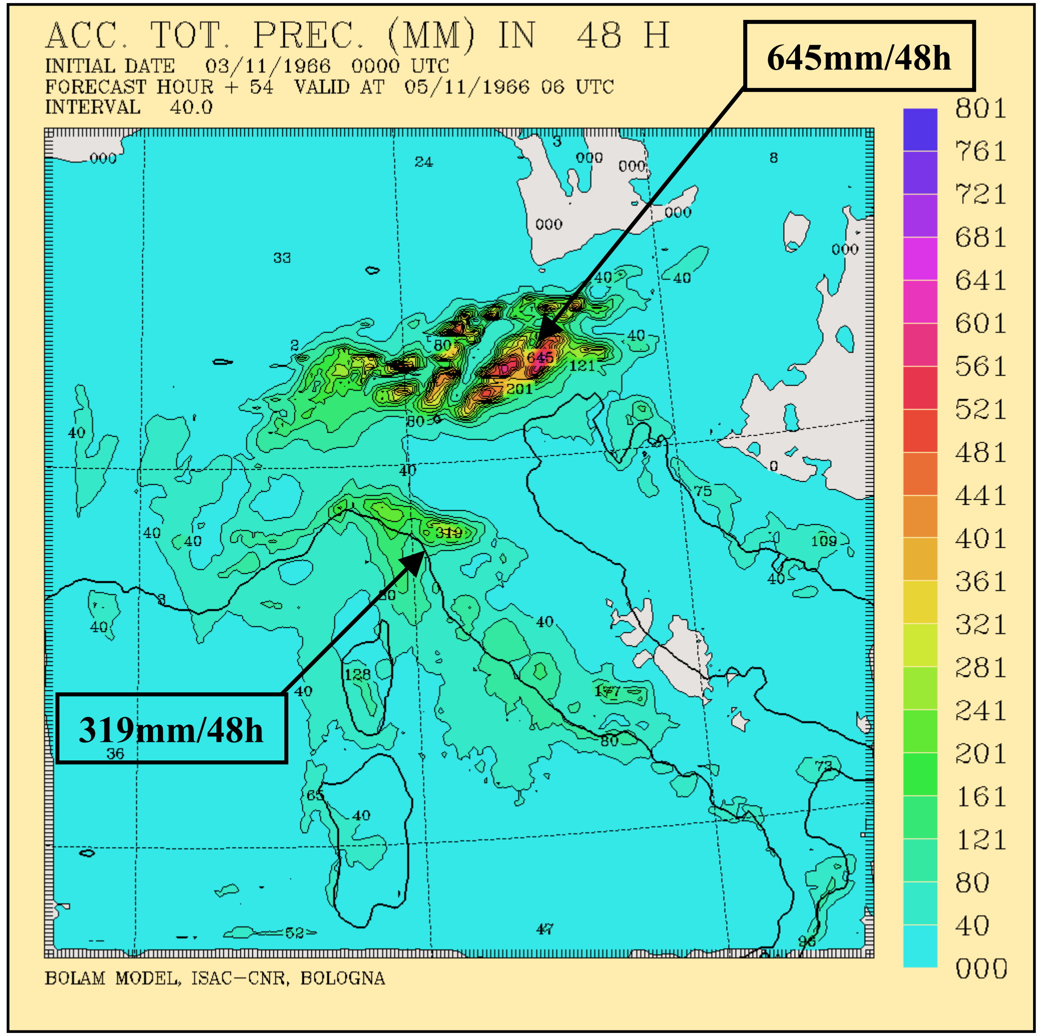
EPS
80 km

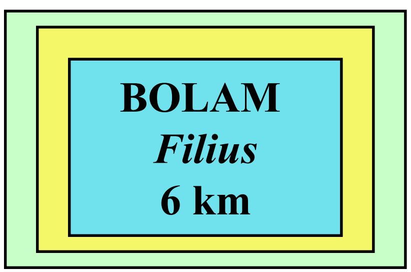
The M~al BOLAM *filius* 6km prediction (BCs from *pater*)

3 November 1966, 00UTC. Corresponding 0-48h accumulated precipitation forecast from BOLAM 6km (*filius*) driven by *pater*'s ICs/BCs.

Very good prediction over NE Italy, but less accurate prediction over Tuscany.

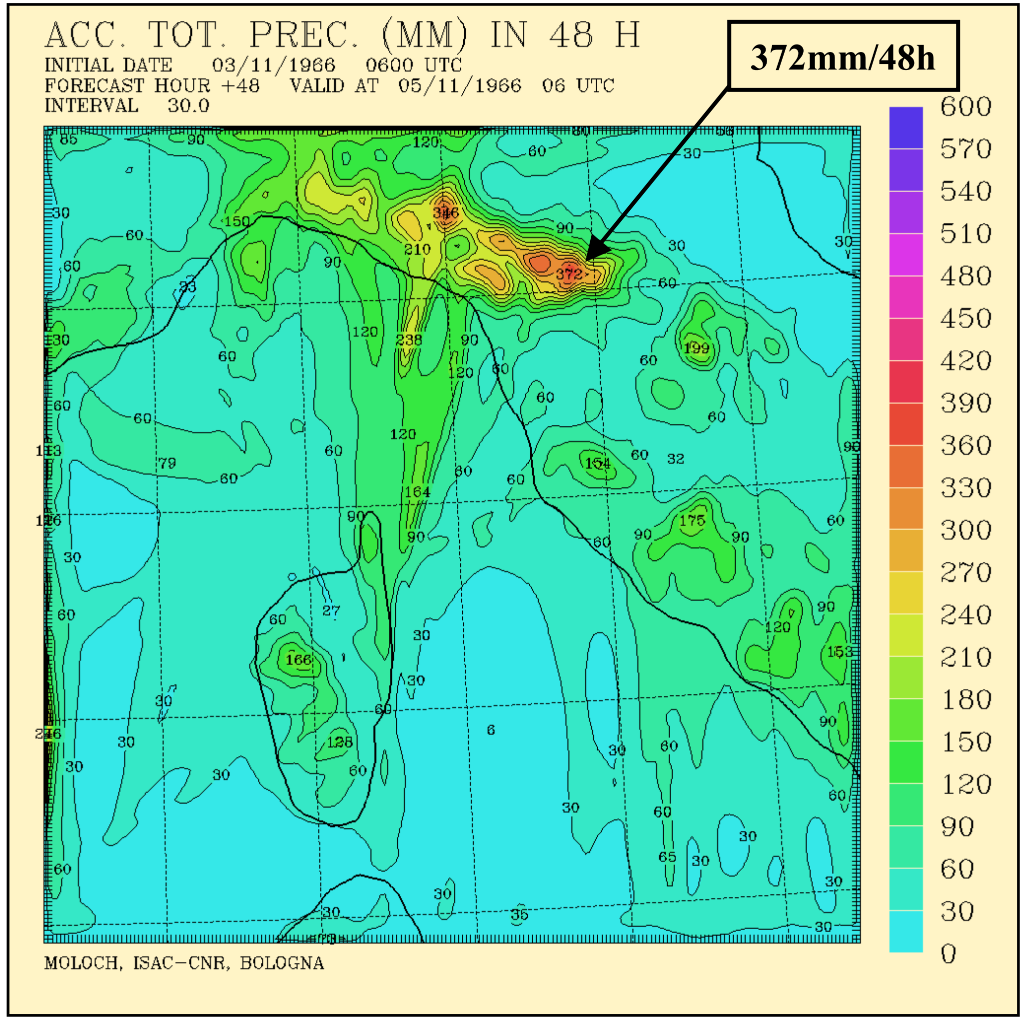
On-going sensitivity experiments are indicating a strong sensitivity to ICs/BCs.

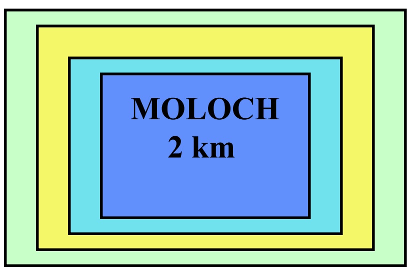




The M~al MOLOCH 2km prediction (BCs from *filius*)

3 November 1966, 00UTC. Corresponding 0-48h accumulated precipitation forecast from MOLOCH 2km (non-hydrostatic model) run over Tuscany, driven by *filius*’s ICs/BCs.





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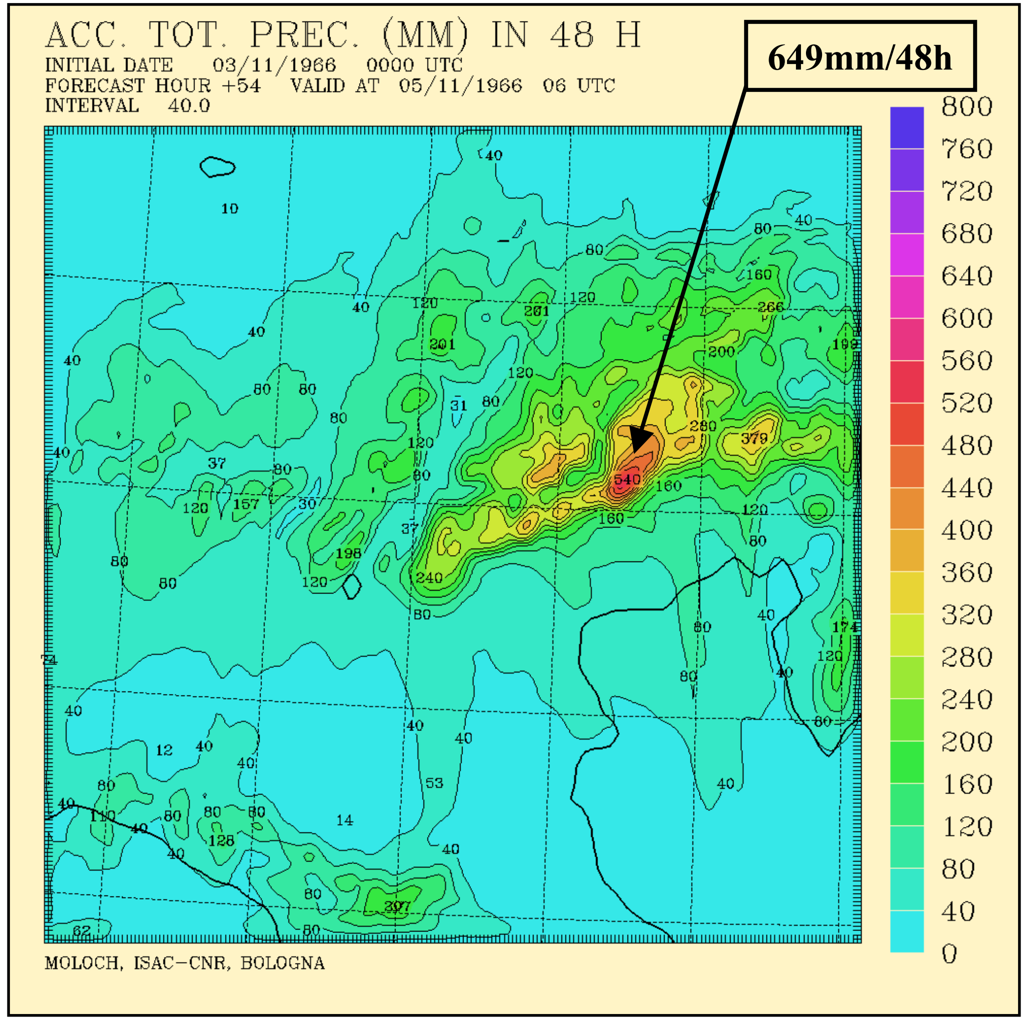
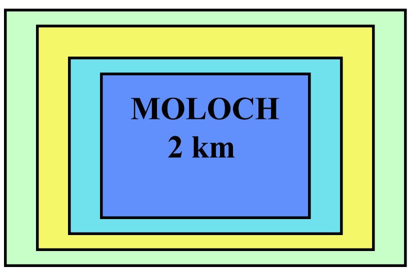
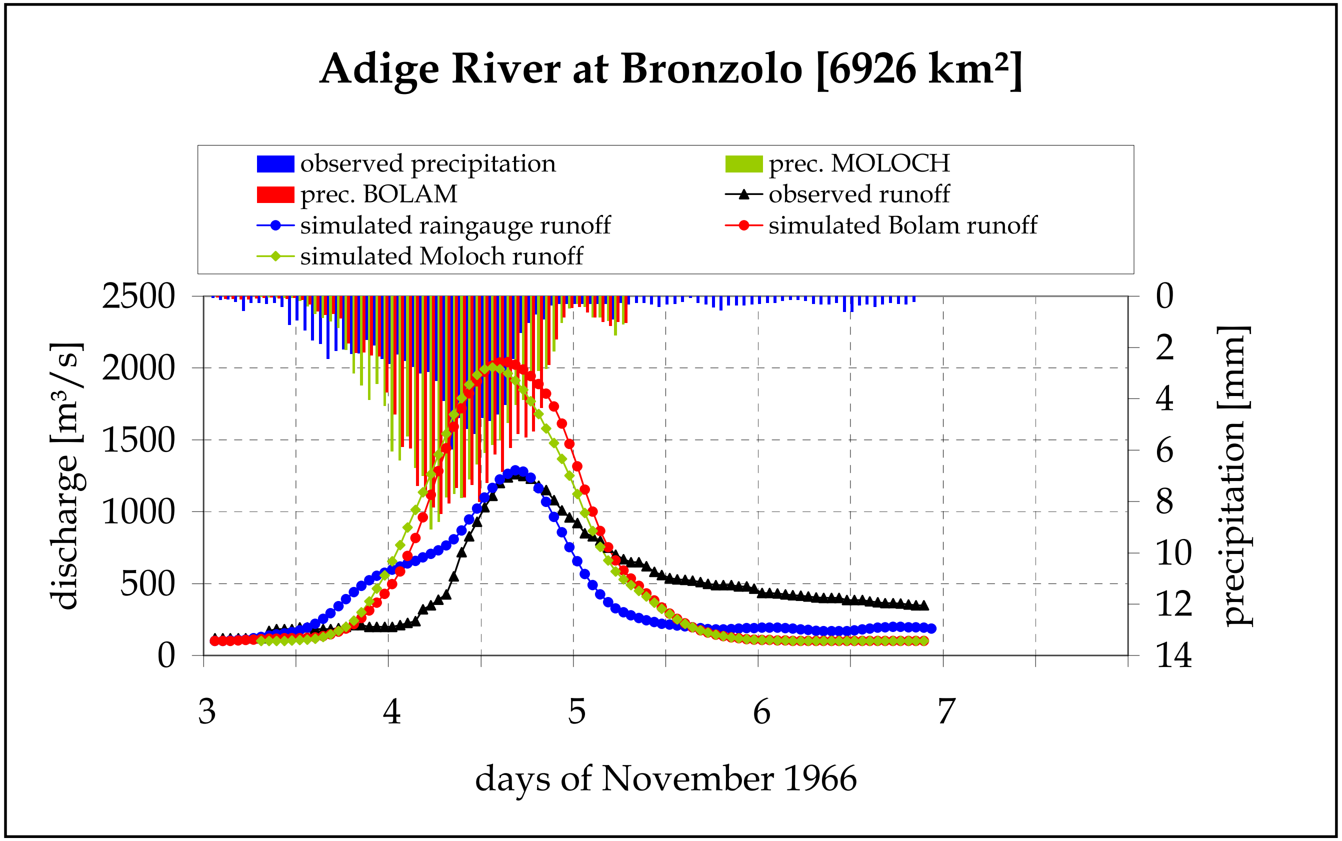


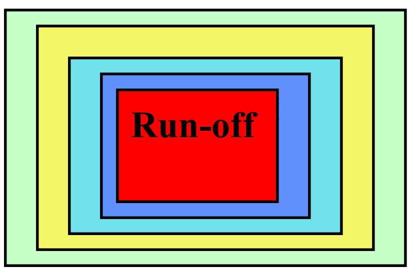


The H~al run-off prediction (precip from MOLOCH) for Adige

Agreement between BOLAM-*filius* and MOLOCH driven run-off.

Both simulation correctly predict the timing of the peak discharge, but overestimate the observed runoff (due to precipitation over prediction).

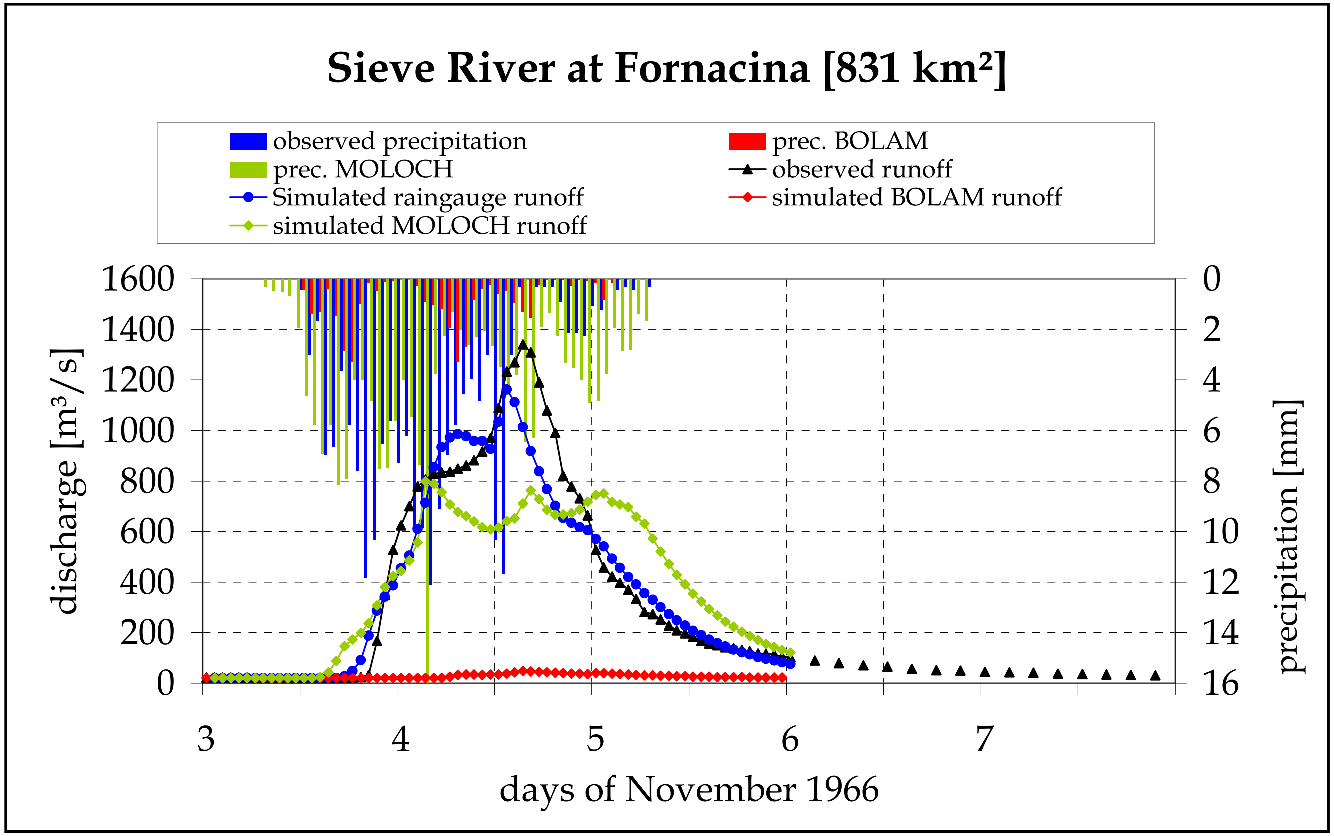


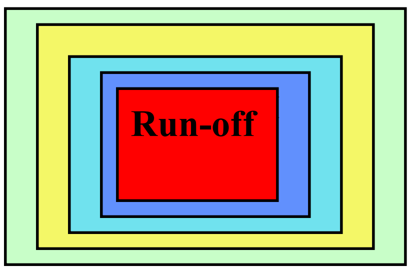


The H~al run-off prediction (precip from MOLOCH) for Sieve

Non-hydrostatic MOLOCH gives more accurate prediction, while BOLAM-*filius* fails.

The more accurate prediction is due to a more accurate forecast of the precipitation pattern.

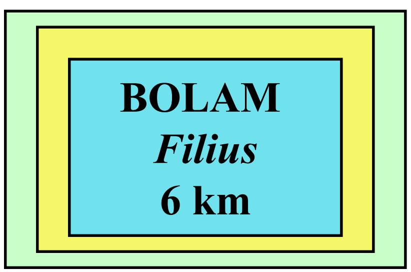


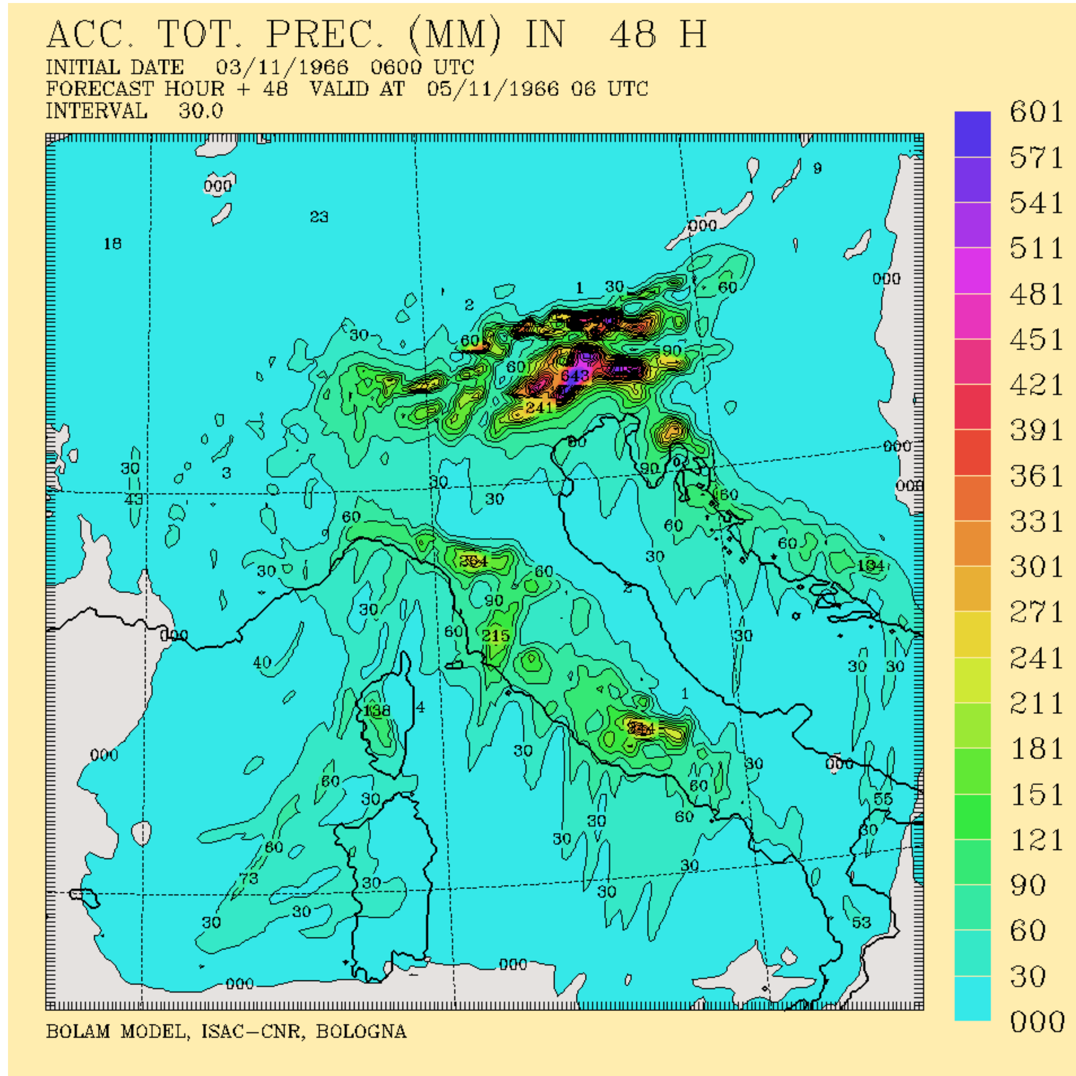


The M~al BOLAM *filius* 6km predict (BCs from FC-mode *pater*)

3 November 1966, 00UTC. Simulations using FCs as BCs has started. This figure shows the 0-48h accumulated precipitation forecast from BOLAM 6km (*filius*) driven by *pater*'s ICs/BCs.

Very good prediction over NE Italy, and improved prediction over Tuscany.





The three key messages of this presentation

❖ **A probabilistic approach to M$^{\sim al}$ and H$^{\sim al}$ prediction is more valuable** than a deterministic one: it allows users not only to estimate the most likely scenario, but also to compute the probability that events of interests may occur in the future.

❖ The analysis of the flood of Firenze 1966 shows that **flood prediction using a cascade of M$^{\sim al}$ and H$^{\sim al}$ is feasible** and can provide valuable information. The next step will be to generate probabilistic flood predictions.

❖ **HEPEX should provide a framework** to help developing a M$^{\sim al}$/H$^{\sim al}$ system capable to deliver valuable flood predictions in real time.

The three key messages of this presentation

- **A probabilistic approach to M~al and H~al prediction is more valuable** than a deterministic one: it allows users not only to estimate the most likely scenario, but also to compute the probability that events of interests may occur in the future.

- The analysis of the flood of Firenze 1966 shows that **flood prediction using a cascade of M~al and H~al is feasible** and can provide valuable information. Work is in progress to generate probabilistic flood predictions using the EPS.

- **HEPEX should provide a framework** to help developing a M~al/H~al system capable to deliver valuable flood predictions in real time.

Selected bibliography

On the ECMWF ensemble prediction system (EPS):

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