Evolution and growth of perturbations in a convection-resolving model

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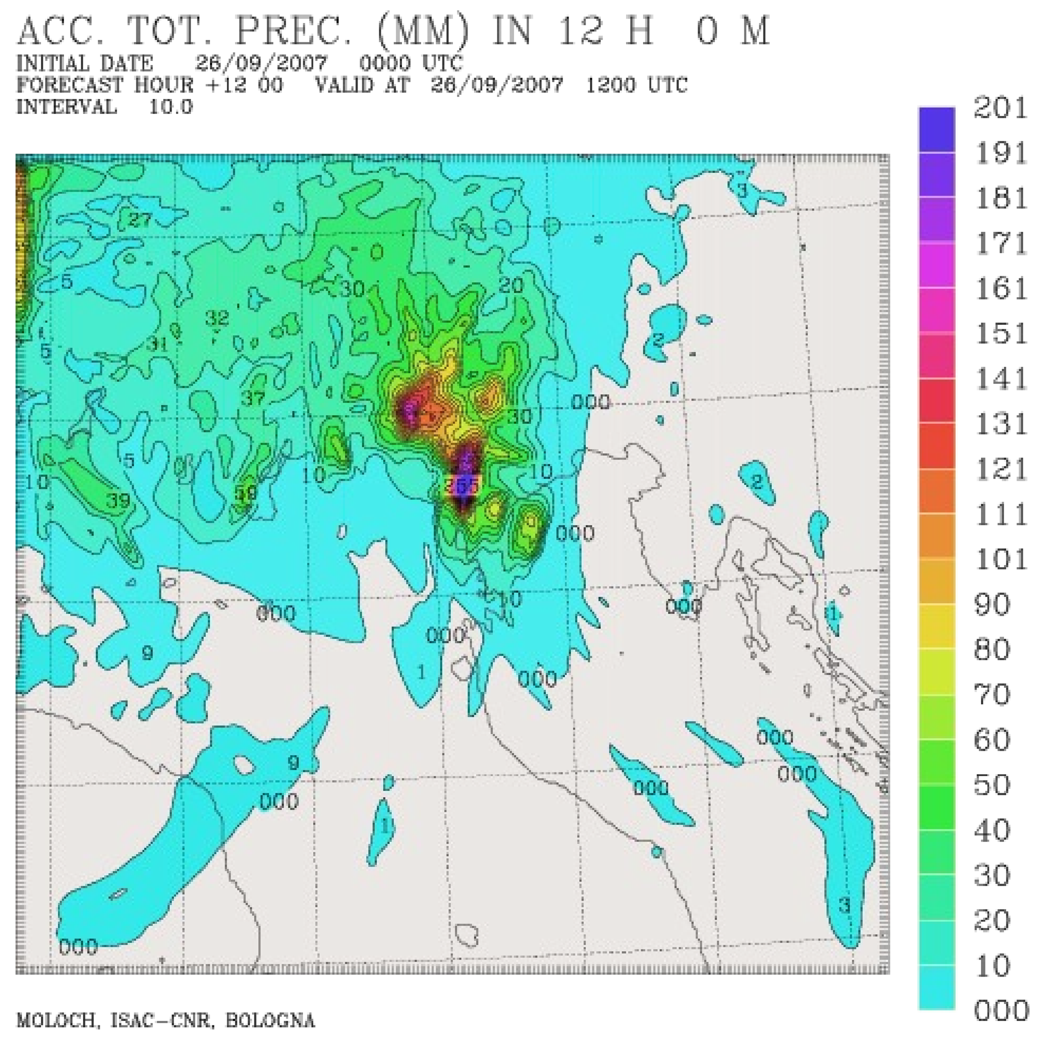
The predictability of convective systems is limited by their highly non-linear and unstable character, worsened by non-linear thresholds proper of moist thermodynamics. A breeding technique is used to estimate the evolution of small perturbations in the convection-resolving, non-hydrostatic atmospheric model MOLOCH. Perturbation growth is characterized by estimating the doubling time. Linearity indicators are used to estimate the time period of validity of the tangent linear approximation. Planned development of the work concerns the possibility of controlling error growth by assimilating appropriate observations.

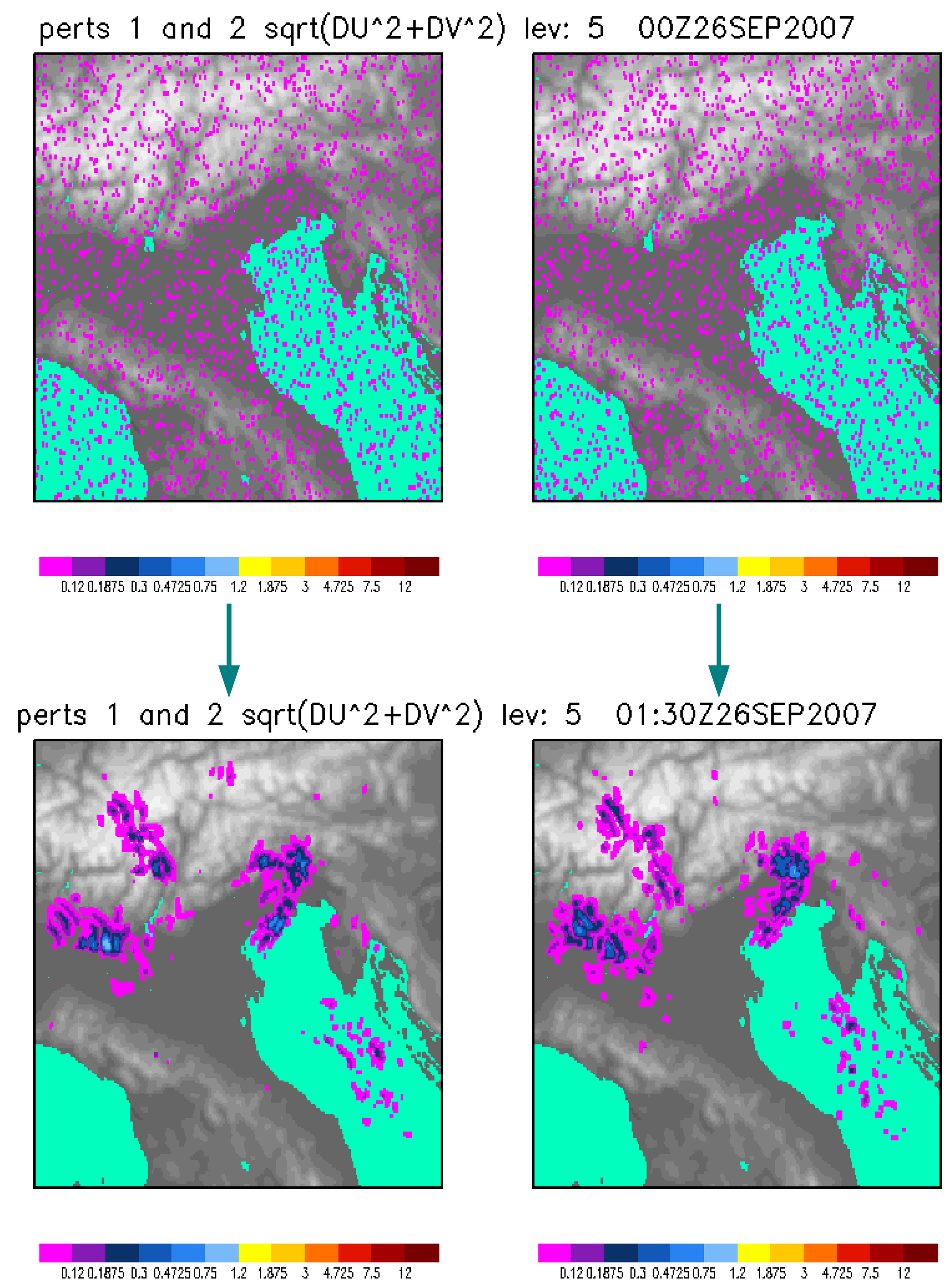
MOLOCH is a convection-resolving, non-hydrostatic model developed by the atmospheric dynamics group of ISAC-CNR (Bologna).
The control trajectory is a MOLOCH simulation of the heavy precipitation event occurred on 26 September 2007.
The simulation is performed at about 2.3 km resolution over a domain including an Alpine area and portions of both the Ligurian Sea and the Adriatic Sea, and using GFS analysis/forecasts as initial and boundary conditions.
The circulation at 500 hPa is characterized by a deep trough approaching the western Alpine region which favours the development of a shallow orographic cyclone centred over the Gulf of Genoa. A low level south-easterly jet flows over the Adriatic Sea. The Venice area is affected by intense convective precipitation, mostly during the morning: different scattered convective cells at the beginning, a well organized Mesoscale Convective System later.



Integration domain and total precipitation, cumulated from 00 to 12 UTC in the control run.

MOLOCH:
Malguzzi et al., JGR-Atmospheres, 2006
Davolio et al., MAP, 2007; 2009
http://www.isac.cnr.it/dinamica/projects/forecasts/

Selection of unstable structures by Breeding
A perturbation breeding technique is used to estimate the local unstable structures that characterize the dynamic growth of small perturbations and errors.
Two initial small, random, independent perturbations are created, each variable scaled with its variability.
The initial perturbation amplitude is 0.05 m s[-1] for horizontal velocity at model level 5 (corresponfing to about 925 hPa over sea).
After **breeding** for **1h30'** (rescaling to initial norm every 5 minutes), the organized bred vectors show similar spatial structures, localized in dynamically active areas, (intense winds and convective precipitation in the control trajectory).
The maps show the horizontal velocity module of the perturbation, $\sqrt{\delta u^2+\delta v^2}$, at model level 5.



NON-linear evolution of states perturbed by organized bred vectors
The growth of perturbations is characterized by estimating the **growth exponent** λ and the **doubling time** T_d: $e^{\lambda T_d}=2$

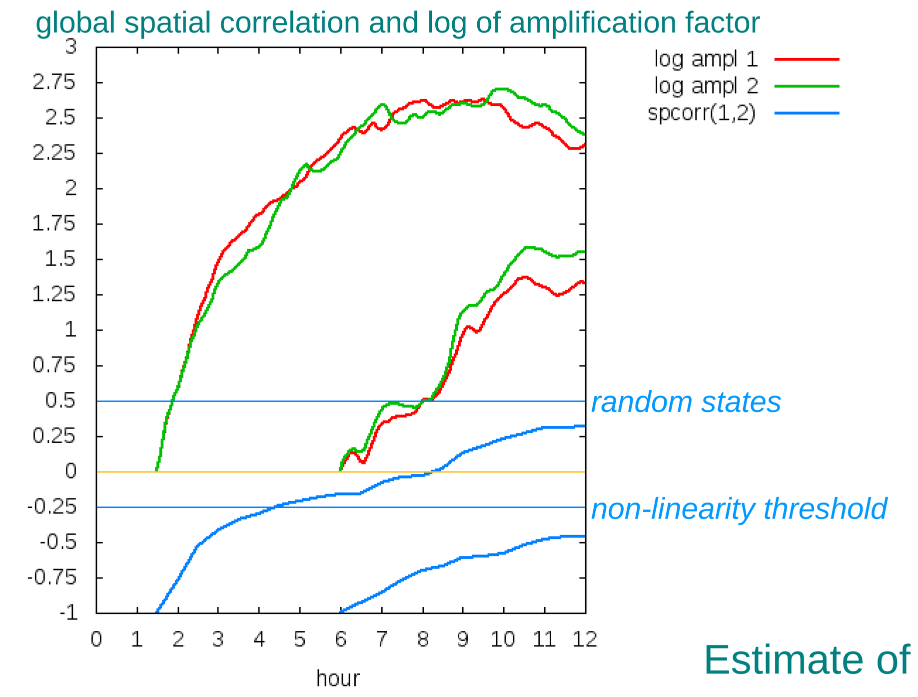
The logarithm of the amplification factor after *n* time steps is approximately linear in time during a period of linear growth regime. $\ln\frac{\|\boldsymbol{\pi}_n\|}{\|\boldsymbol{\pi}_0\|}=\overline{\lambda}_n n\Delta t$

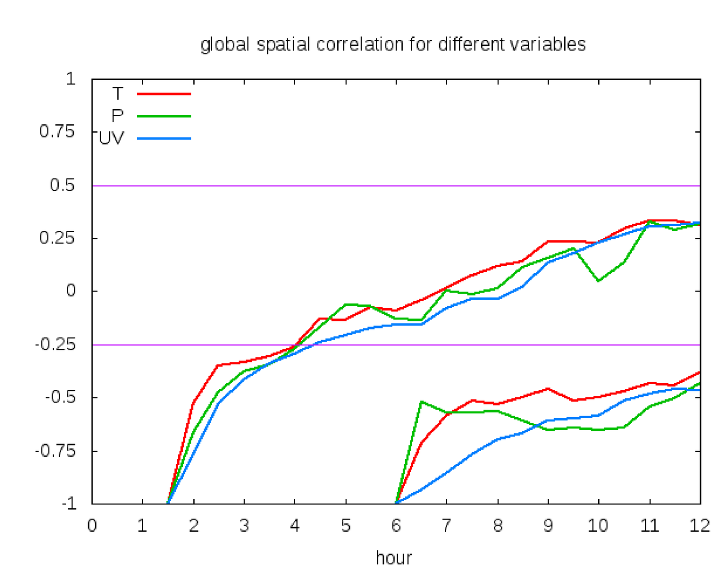
Free non-linear evolution of two "opposed" perturbations (same direction, different sign) after a breeding period (1h30'). At initial time: $\mathbf{x}^{p1,2}=\mathbf{x}^c\pm\boldsymbol{\pi}$. At later times: $\boldsymbol{\pi}^{1,2}=\mathbf{x}^{p1,2}-\mathbf{x}^c$.
Linearity indicators (Hohenegger et al., *BAMS* 2006) are used to estimate the time period Tlin of validity of the tangent linear approximation along the non-linear evolution.

Spatial correlation: $corr(\boldsymbol{\pi}^1,\boldsymbol{\pi}^2)=\frac{\langle\boldsymbol{\pi}^1|\boldsymbol{\pi}^2\rangle}{\|\boldsymbol{\pi}^1\|\;\|\boldsymbol{\pi}^2\|}$ where: $\|\boldsymbol{\pi}\|=\sqrt{\langle\boldsymbol{\pi}|\boldsymbol{\pi}\rangle}$ $\langle\boldsymbol{\pi}^1|\boldsymbol{\pi}^2\rangle=\sum_i \pi_i^1\pi_i^2$

The spatial correlation is computed for each variable separately. The scalar product is extended: ***A***) to the whole domain to obtain **global** indicators; ***B***) **locally**, in the neighbourhood (10 km) of each gridpoint.
Two experiments are shown, starting at 01h30 and at 06h00, before two different episodes of convection (the second one more intense). In the first one, linearity is lost at 04h00, 2.5h after the initial time: $T_{lin}\simeq 2.5\,h$. In the second one the spatial correlation remains below the threshold until the end of the simulation. Even considering a stabilizing effect of the boundary forcing after 10h00, the estimate is still large: $T_{lin}>4.0\,h$.
The doubling time is estimated by a 2h running mean of the logarithm of the amplification factor, for the first experiment: $T_d\simeq 2.5\,h$; for the second one: $T_d\simeq 2.0\,h$.
The second convective episode, yet more intense, appears more stable and predictable, probably because large scale forcing has a more important role.

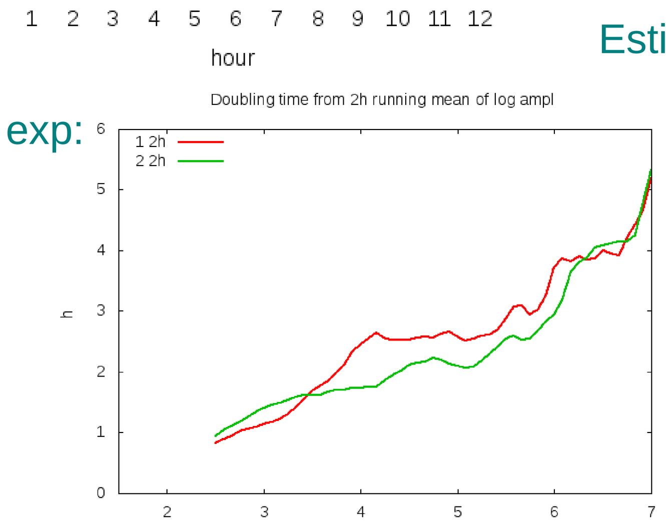
A) Non-linear evolution, **global correlation**. Initially: $corr(\boldsymbol{\pi},-\boldsymbol{\pi})=-1$.
Random states: $corr(\boldsymbol{\pi}^1,\boldsymbol{\pi}^2)=+0.5$. By convention, linearity is lost when: $corr(\boldsymbol{\pi}^1,\boldsymbol{\pi}^2)\simeq -0.25$



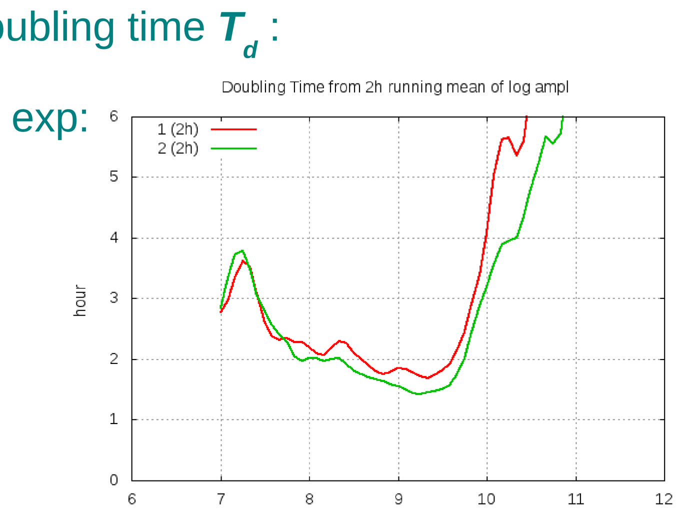


Estimate of doubling time T_d :

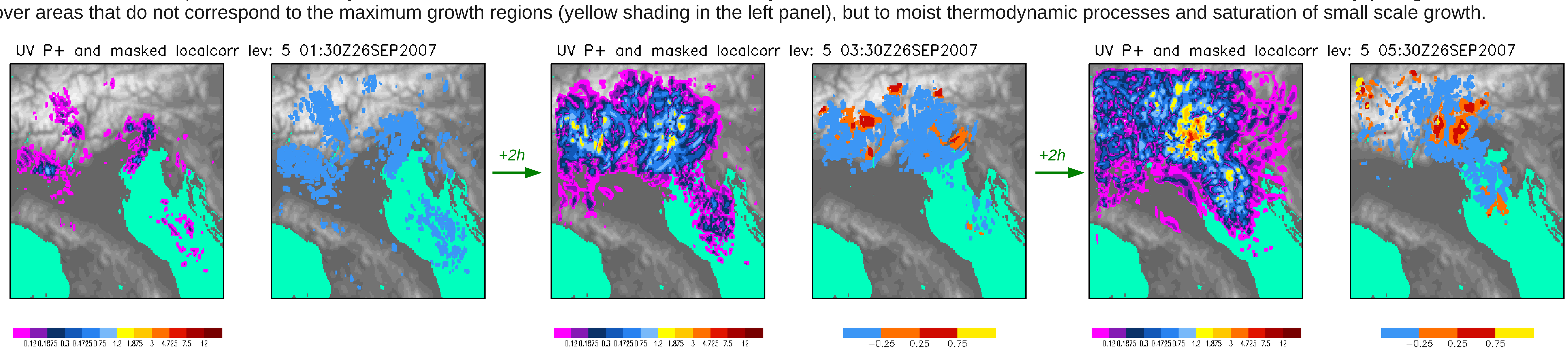
T_d 1st exp:



T_d 2nd exp:



B) Non-linear evolution. At 01h30 (initial time), 03h30 (+2h), 05h30 (+4h): perturbation 1 (left) and **local spatial correlation** (right) for horizontal velocity at level 5. Both fields are masked for small values of the perturbation velocity module. At 01h30 the local correlation is -1 everywhere. At later times, the local correlation field shows loss of linearity (orange and red shading) over areas that do not correspond to the maximum growth regions (yellow shading in the left panel), but to moist thermodynamic processes and saturation of small scale growth.

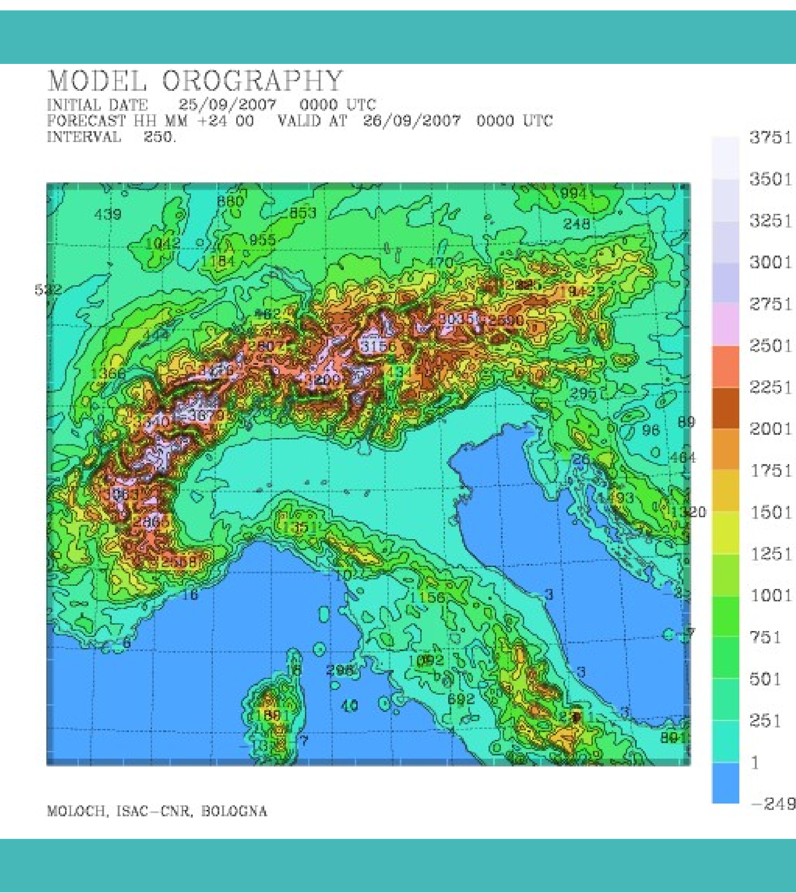


Preliminary results:

➔ Bred vectors quickly get organized in spatially coherent structures. The growth of small errors in the linear regime is not immediately disrupted by strongly non-linear processes present in moist convection.

➔ Strongly non-linear(*izable*) processes (moist thermodynamics, phase transitions during convection) seem to affect predictability when they succeed in determining non-linearity in the evolution of the horizontal velocity field. Other variables (temperature, pressure, vertical velocity, humidity and concentrations of condensed phases) are more directly affected. Wind seems then to be the best candidate as a control variable.

➔ Estimated values of T_{lin} and T_d also lead to some optimism, at least for very short prediction range. Estimates, though, are dependent on the amplitude of the initial perturbation. A larger perturbation amplitude requires a larger domain to avoid (delay) the stabilizing effect of boundary forcing: we are currently working with the larger domain shown on the right.



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