An approach to deep convective organization using cellular automata

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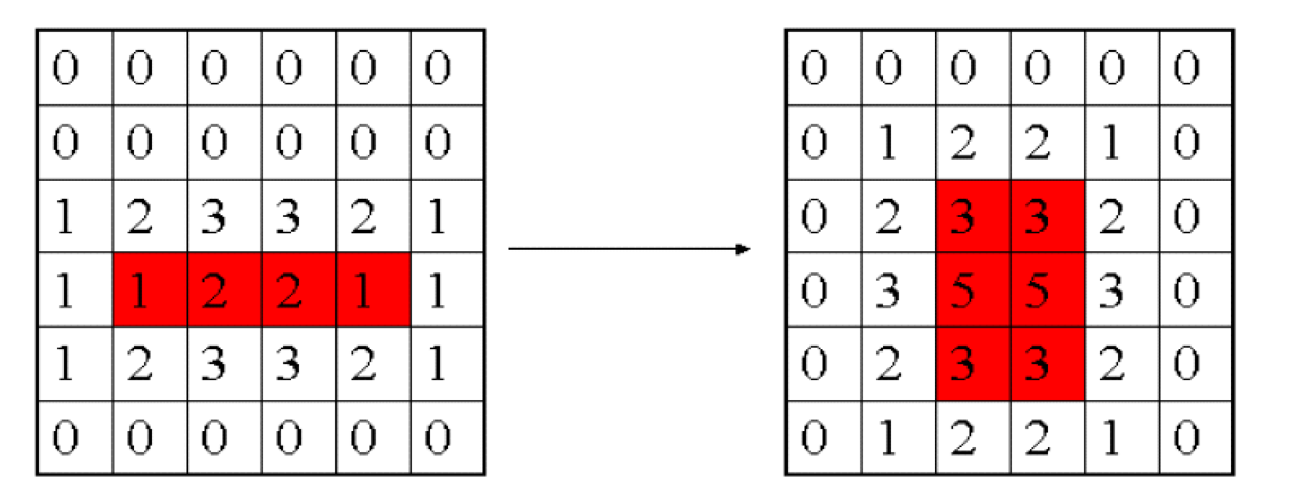
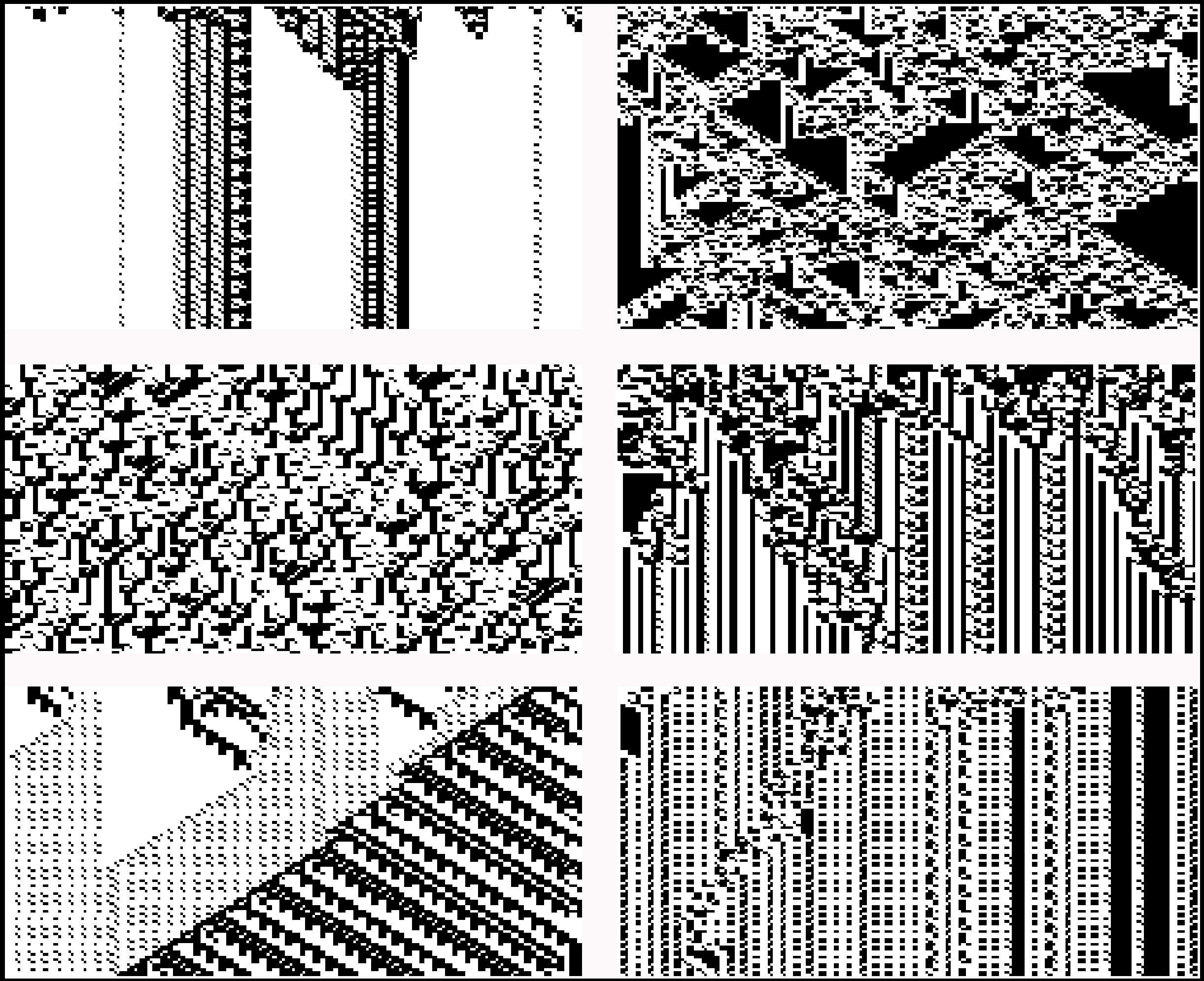
What is cellular automata

An elementary cellular automata (Wolfram 1983) is a dynamical system with a state vector which takes on a number of discrete states determined by a given rule. This rule relates the state at one point in space and time to the state of the neighbouring CA grid-cells at the previous time-step.



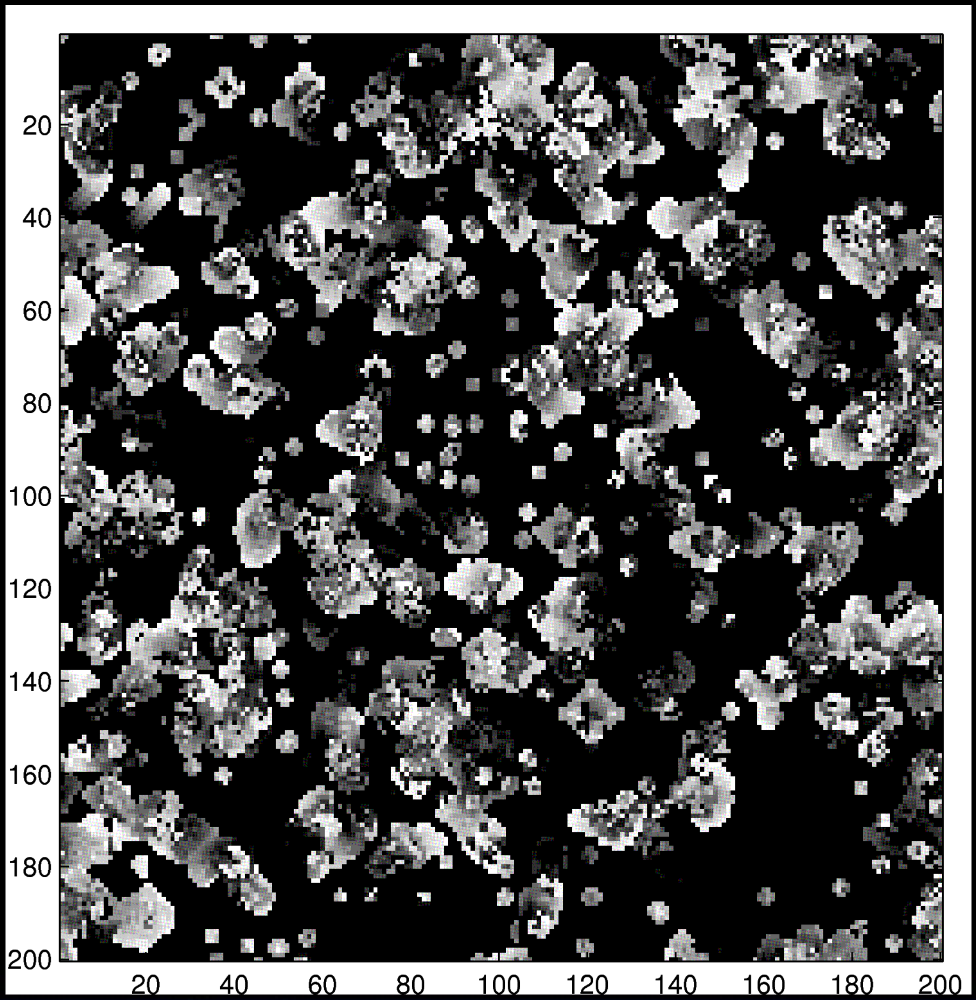
What is cellular automata

- Complex patterns can be generated

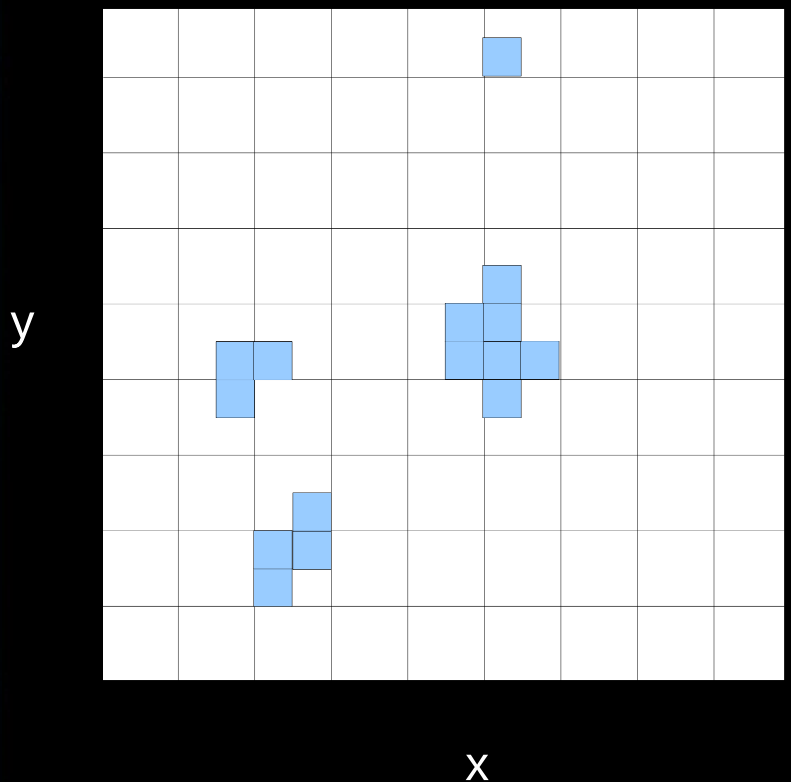


What is cellular automata

- Example Conway's Game of Life (GOL)



Interesting for organization of deep convection



- Auto-correlation in space and time
- Spatial and temporal scales of deep convection
- Inherent memory
- Lateral communication, organization.
- Stochastic statistical representation of sub-grid variability

CA acting on a higher resolution than that of the model grid.

Atmospheric Variability

- Within EPS, stochastic representation of errors arising from sub-grid scale variance is becoming more and more frequent. (Maybe even standard). Buizza, 1999, Palmer, 2001, Shutts, 2005.
- Want to ensure that the model is not under-dispersive, and saturates towards the atmospheres characteristic variability at the limit of deterministic predictability.
- A typical example of sub-grid variability arises from deep convection in the atmosphere.
- Idea from Palmer, 2001, Shutts, 2005 and Berner, 2008 to use a cellular automaton in order to replace a mere "noise maker", by stochastic physics on space and time scales larger than the truncation scale of the model.

Atmospheric Variability

- Question is, should such “noise” be added within the EPS, or if the model itself is lacking in variability should we aim to construct parameterizations in the deterministic model which have stochastic elements? i.e. Lin and Neelin (2002, 2003), Shutts (2005), Teixeira and Reynolds (2008), Plant and Craig (2008)

Deep convection organization

- Many “organizing mechanisms” in the atmosphere.
- Examples of such processes are vertical wind shear, underlying sea surface temperature (SST) gradients, cold pool dynamics and water vapour feedbacks (Tompkins 2001).
- Also, ducted gravity waves, initiated from deep convection, act to organize convective clusters and meso-scale convective systems (Huang 1998).
- Fast moving gravity waves are either damped, or not resolved in time in most NWP models.

Idealized study of CA parameters

- Design neighbourhood rules that govern the CA to achieve a statistical representation of the sub-grid scale motions.
- In particular the horizontally propagating gravity waves.
- Study impact of CA parameters in an idealized setup.

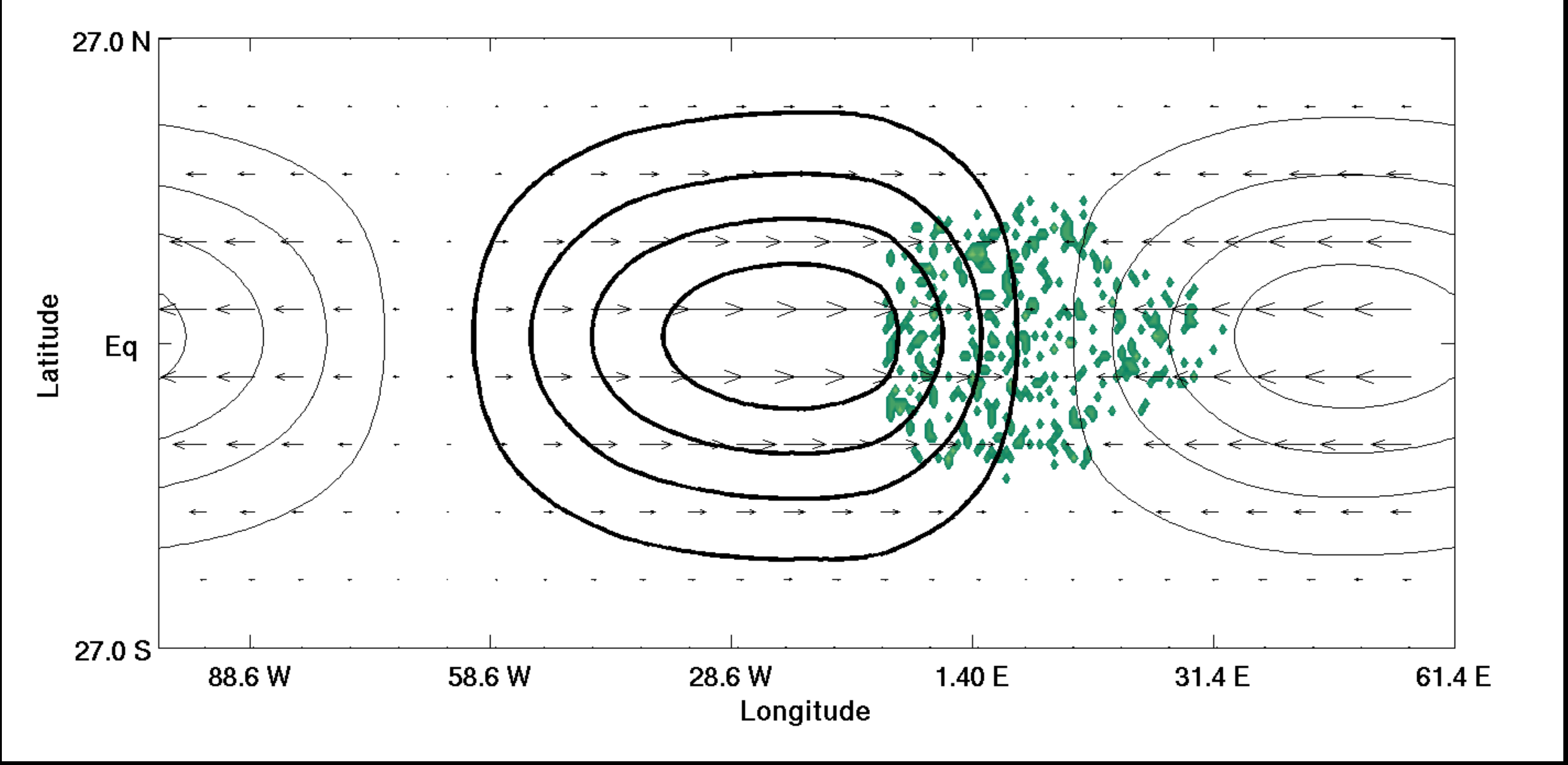
$$\frac{du}{dt} + \mathbf{V}\cdot\nabla u - fv = -g\frac{\partial h}{\partial x} + K_u$$

$$\frac{dv}{dt} + \mathbf{V}\cdot\nabla v + fu = -g\frac{\partial h}{\partial y} + K_v$$

$$\frac{dh}{dt} + \mathbf{V}\cdot\nabla h + h\nabla\cdot\mathbf{V} = Q + K_h$$

Q(x,y,t)=fraction of CA

Forget about physical processes of deep convection for a moment, and look only at scale interaction between different atmospheric scales. i.e how large-scale waves interact with the convective scales.



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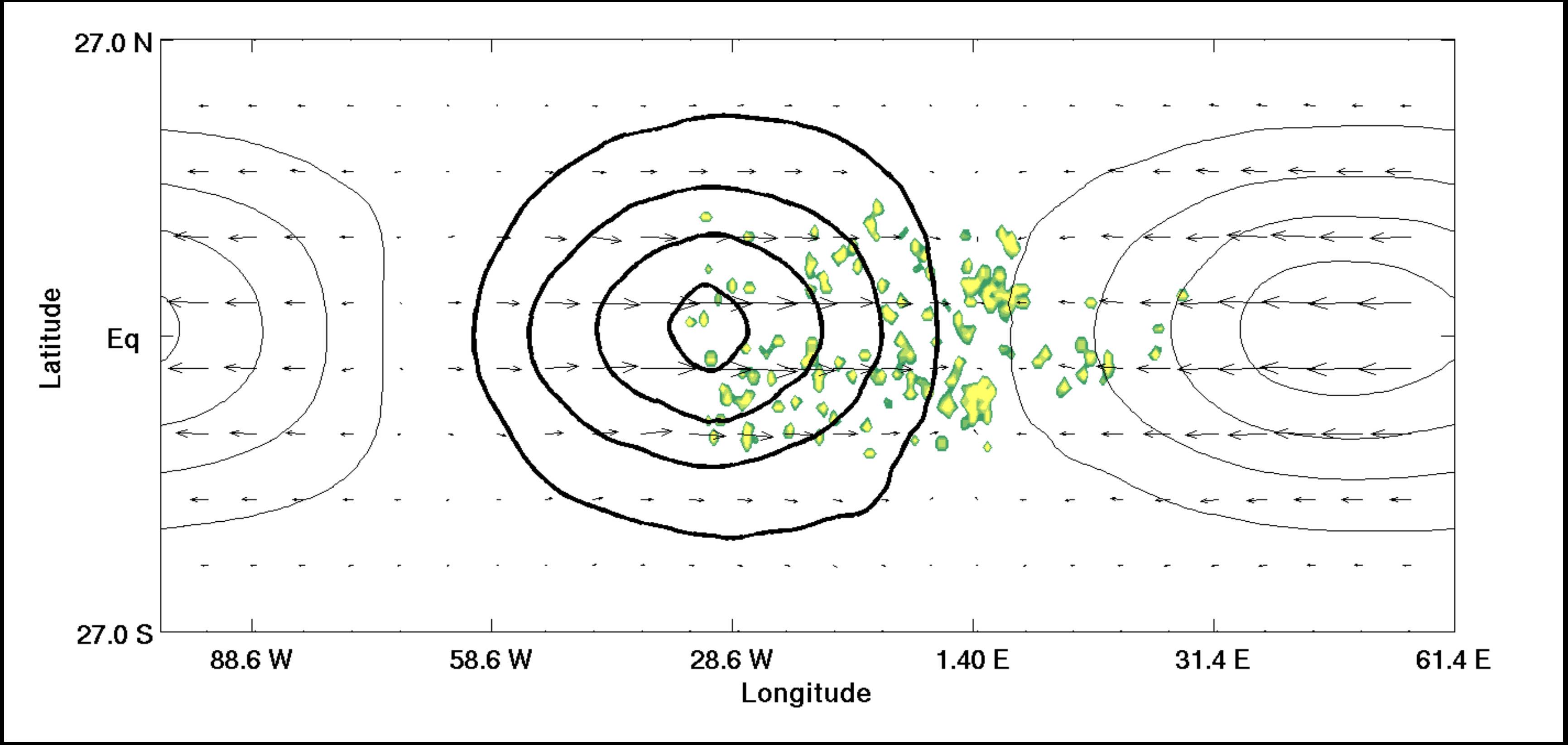
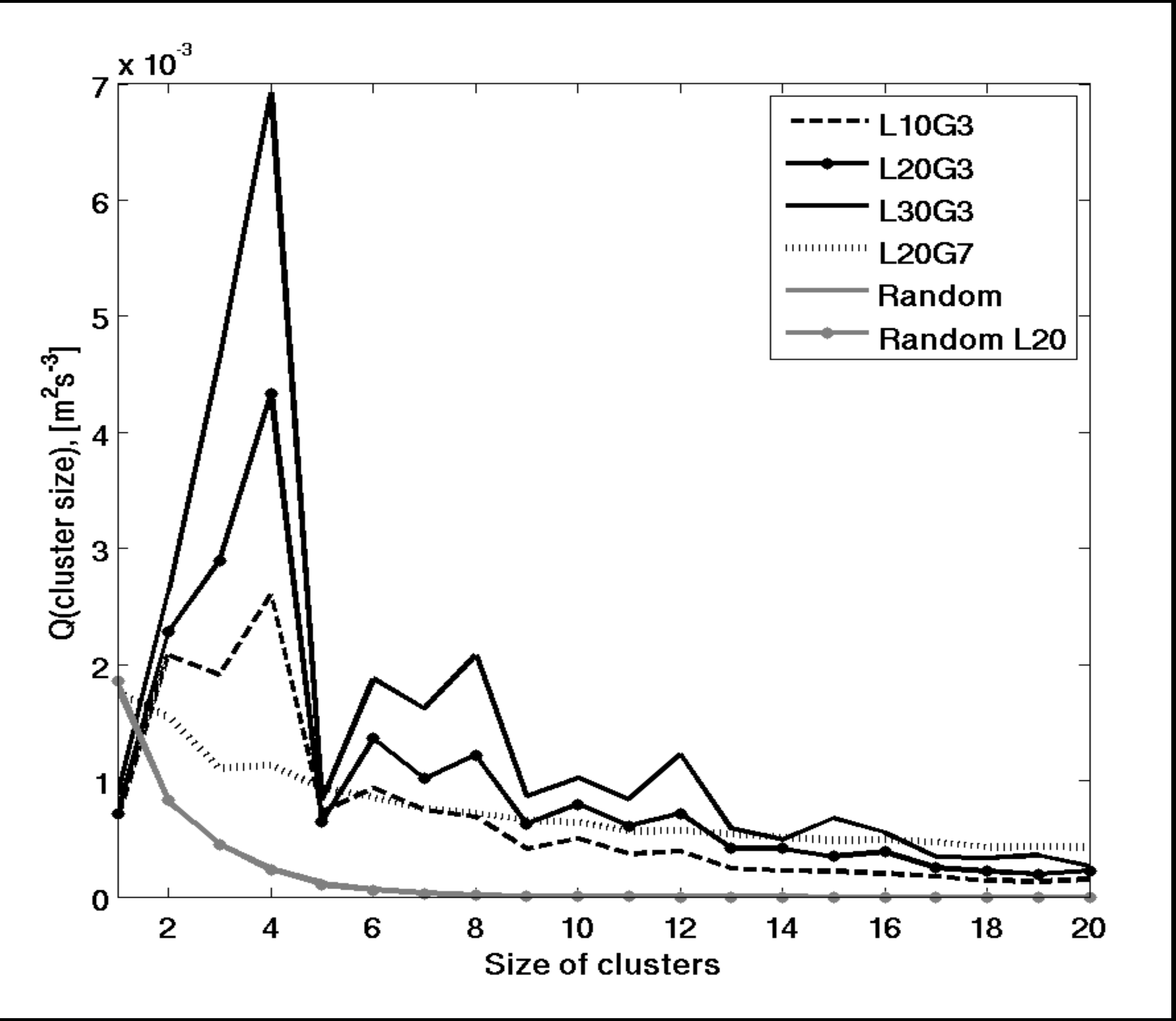
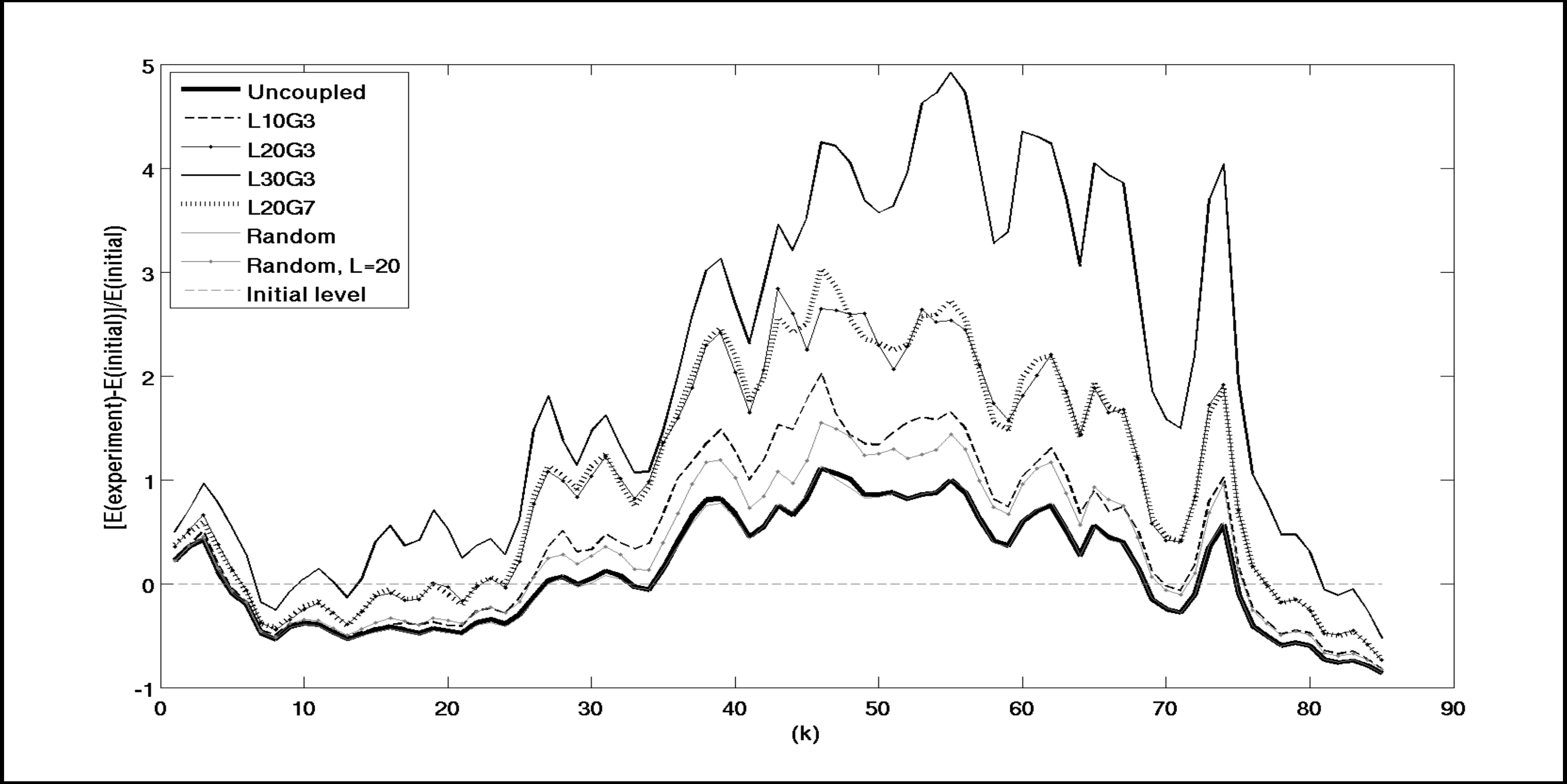


Spatial and temporal scales generated by the CA scheme depends on the horizontal resolution of the CA grid, and given memory.



Even if different horizontal resolutions generate different sizes of convective structures, the time-scale is the most important for how much energy is back-scattered to the larger scales



Using a CA in a 3D model with full physics.

- Thus far, we've studied scale interaction using a CA to generate "clusters" mimicking organization through atmospheric gravity waves.
- The structures generated by the CA yields a greater back-scatter to the larger scales than that of pure random noise.
- The amount of energy back-scattered to the larger atmospheric scales depends on the parameters of the CA scheme, and the memory is the most important.
- We've seen that a CA encompasses several components which are of interest for deep convection organization, such as lateral communication, memory and stochasticity.
- Want to explore in a state-of-the-art NWP model.

Updraught mesh-fraction in 3MT

$$\underbrace{\frac{\partial \sigma_u}{\partial t}\int (h_u-\overline{h})\,\frac{dp}{g}}_{\mathrm{I}} = \underbrace{L\int \sigma_u \omega_u^{*}\frac{\delta q_{ca}}{g}}_{\mathrm{II}} + \underbrace{\alpha_{cvg} L \int CVGQ\frac{dp}{g}}_{\mathrm{III}} + \underbrace{\frac{\sigma_{CA}-\sigma_u}{\tau} * \left(\int (h_u-\overline{h})\,\frac{dp}{g}\right)}_{\mathrm{IV}}$$

Storage =
Increase of mesh
fraction

Sink =
Gross
condensation
(consumption
by updraft)

Source =
resolved
moisture
convergence

Source/(sink)
organization by
CA

I

II

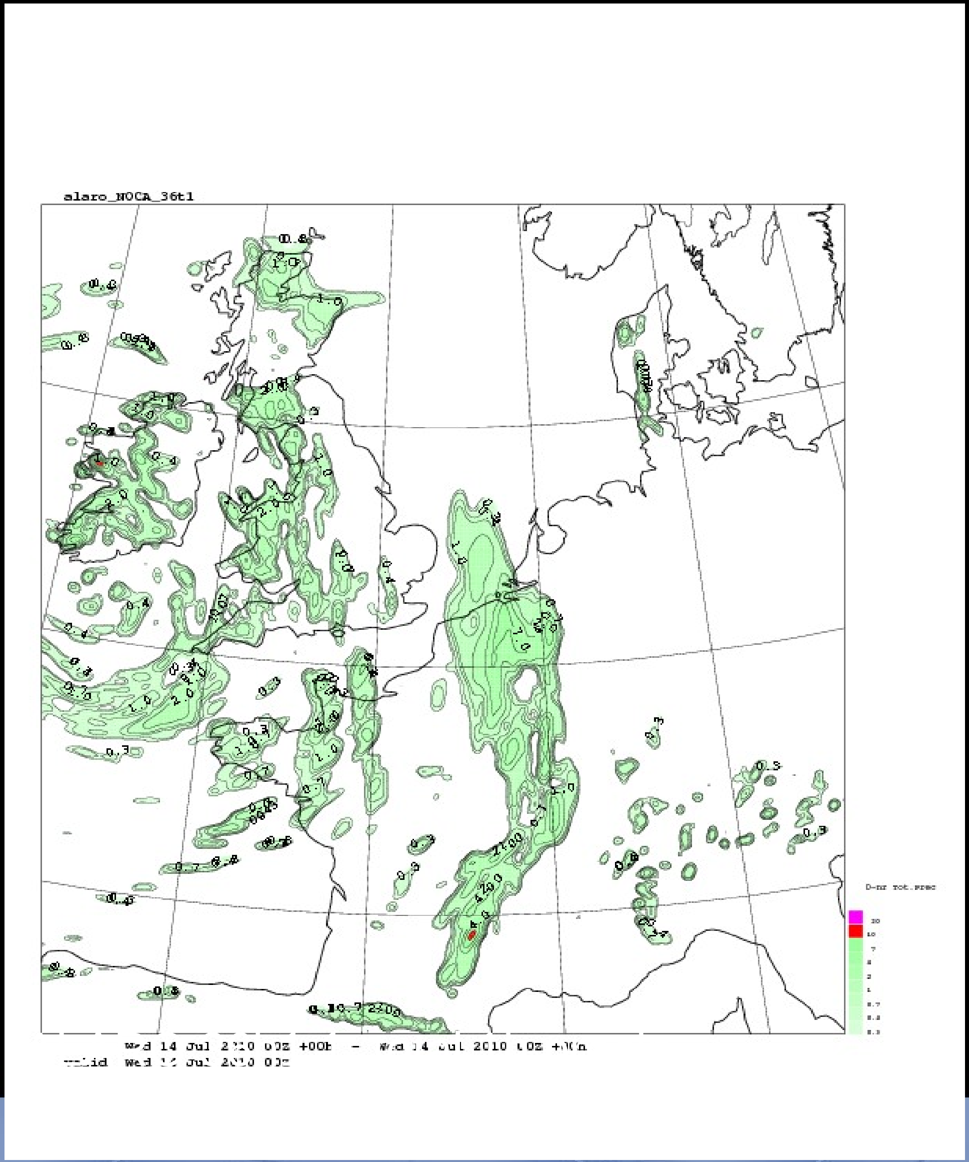
III

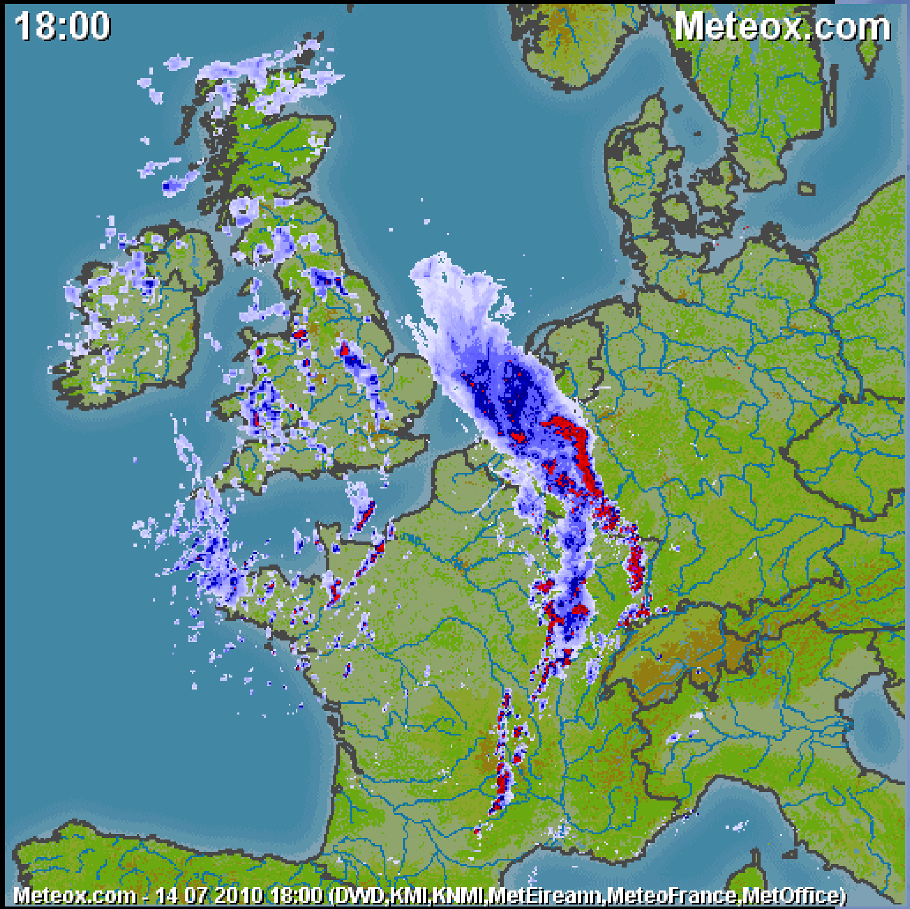
Function of
CAPE
or/and
Low level
moisture
convergence

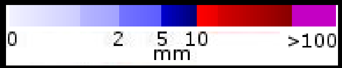
IV

$$\frac{\sigma_u^{+}-\overline{\sigma_u}}{\Delta t} = \frac{\sigma_{CA}-\sigma_u^{+}}{\tau}$$

Radar image, squalline 14/7-10
16 UTC (or 18 CET)

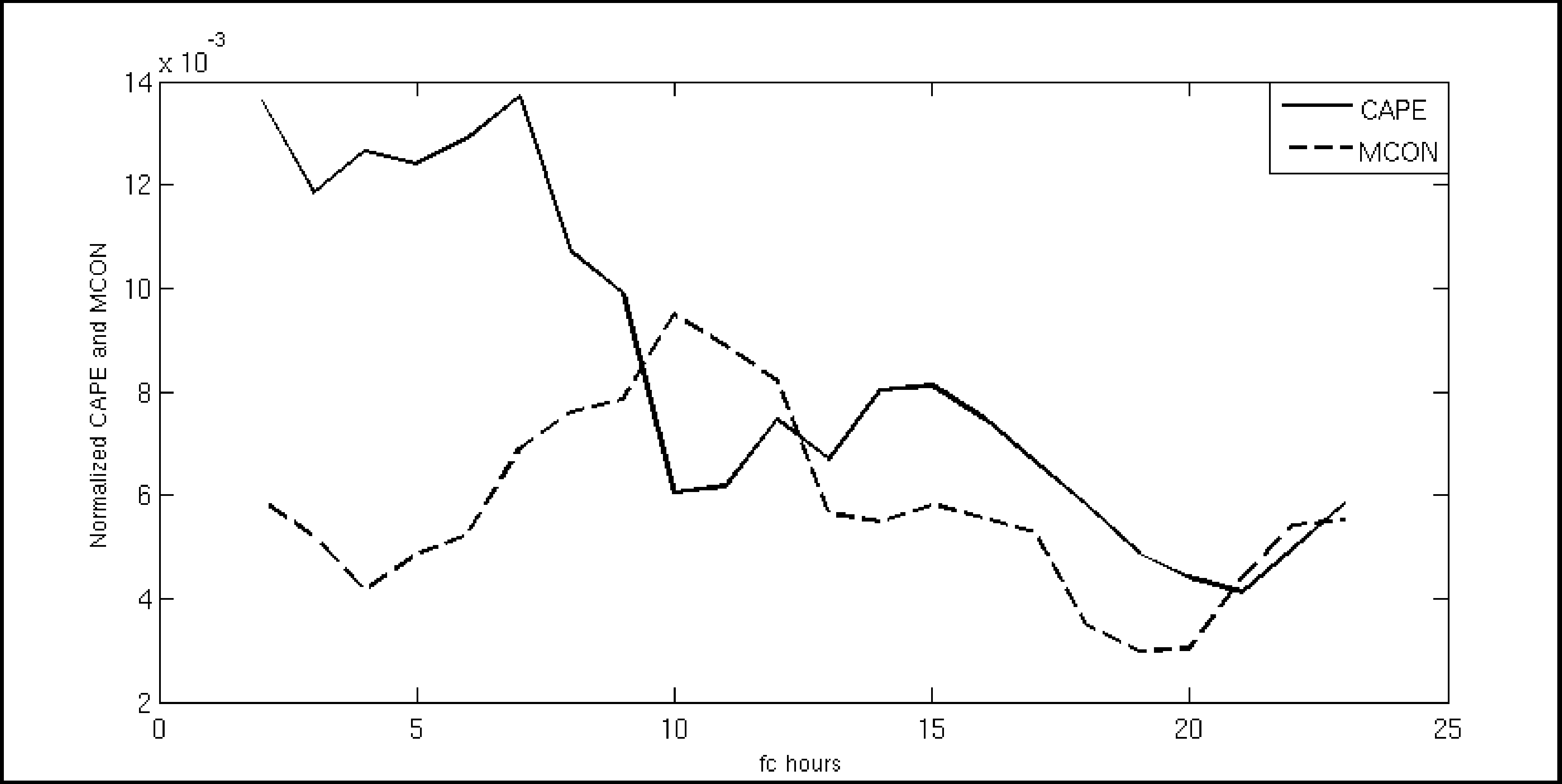






1 hour precip from radar image.

Time evolution of normalized CAPE and moisture convergence (term III).



Probabilistic/Deterministic rules

- Probabilistic

  (+): Can update the CA on a more physical basis

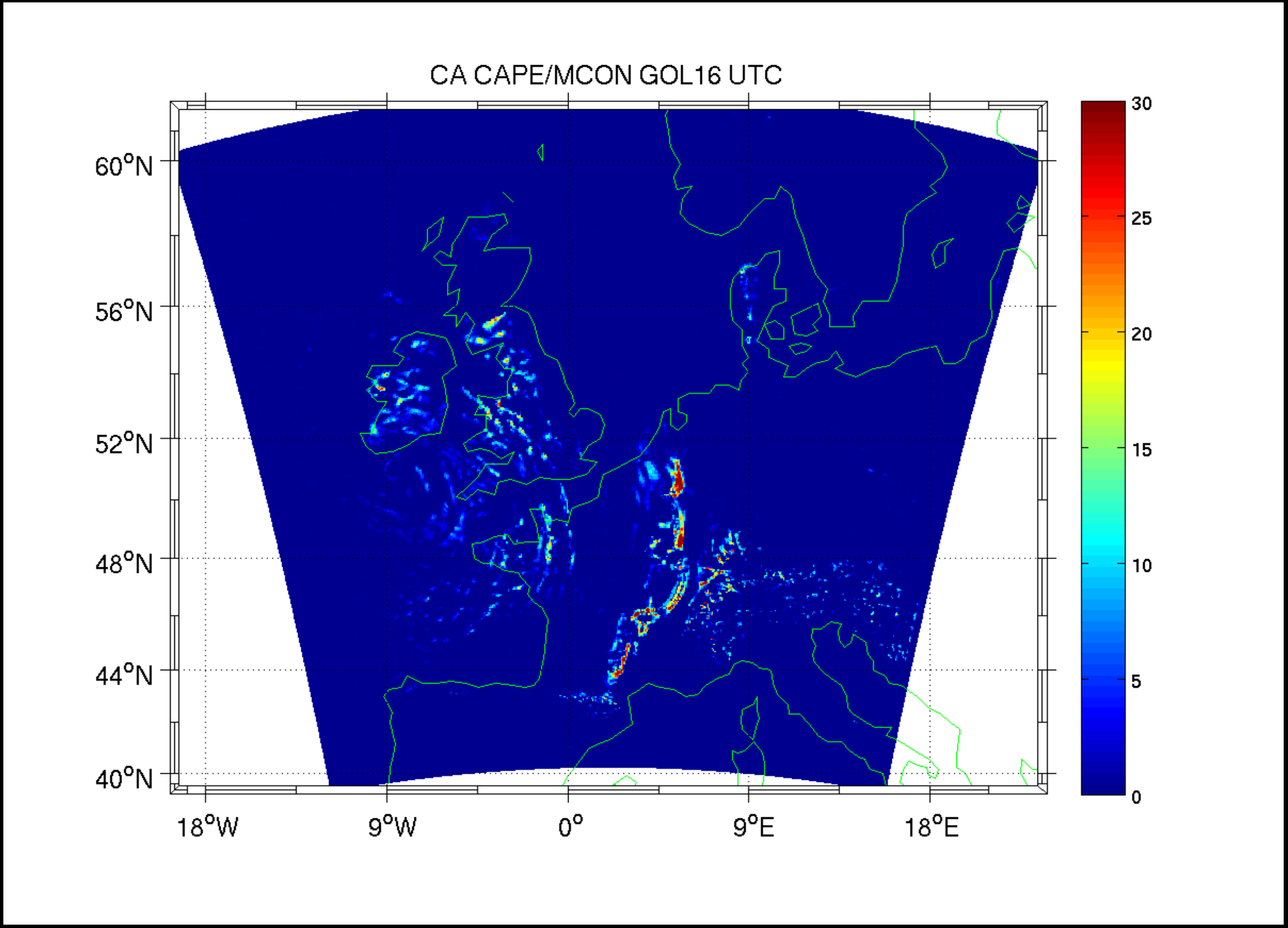
  (-) : Does not necessarily remain active (i.e all cells can "die"). Needs to be seeded more frequent, strong dependence on the "convective input fields"

- Deterministic (GOL)

  (+): Designed with rules such that the CA remains active throughout the forecast period (without seeding new cells). Inherent autocorrelation in space and time, through self-organization, allowing for communication between grid-boxes -> larger spatial scales.

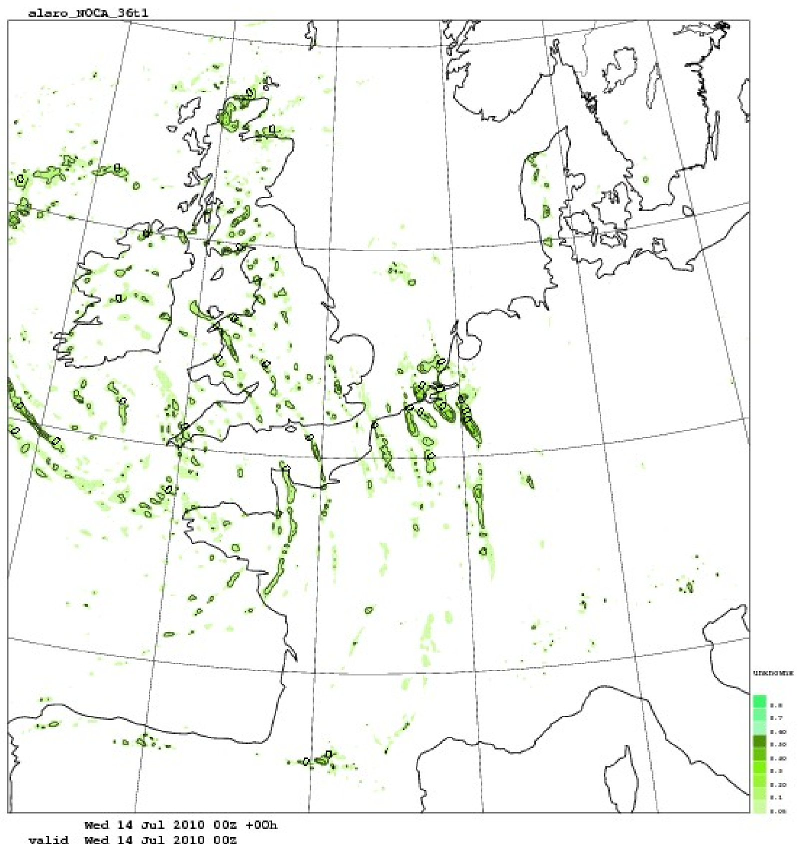
  (-) : No physical basis for the rules. (However, accurate space/time scales (through clustering) can be achieved, depending on tuning parameters of the scheme).

CA field


CA CAPE/MCON GOL16 UTC
60°N
56°N
52°N
48°N
44°N
40°N
18°W
9°W
0°
9°E
18°E
30
25
20
15
10
5
0

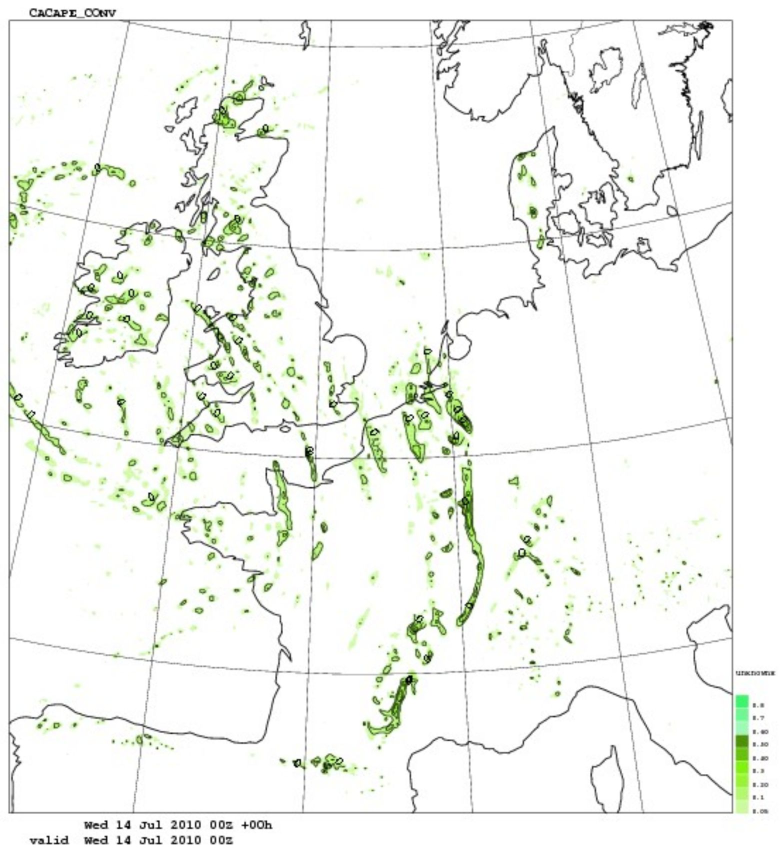
Updraught mesh fraction, 2010-07-14, 16 UTC

ALARO reference, 36h1.1



16 UTC

ALARO CA-CAPECONV, 36h1.1

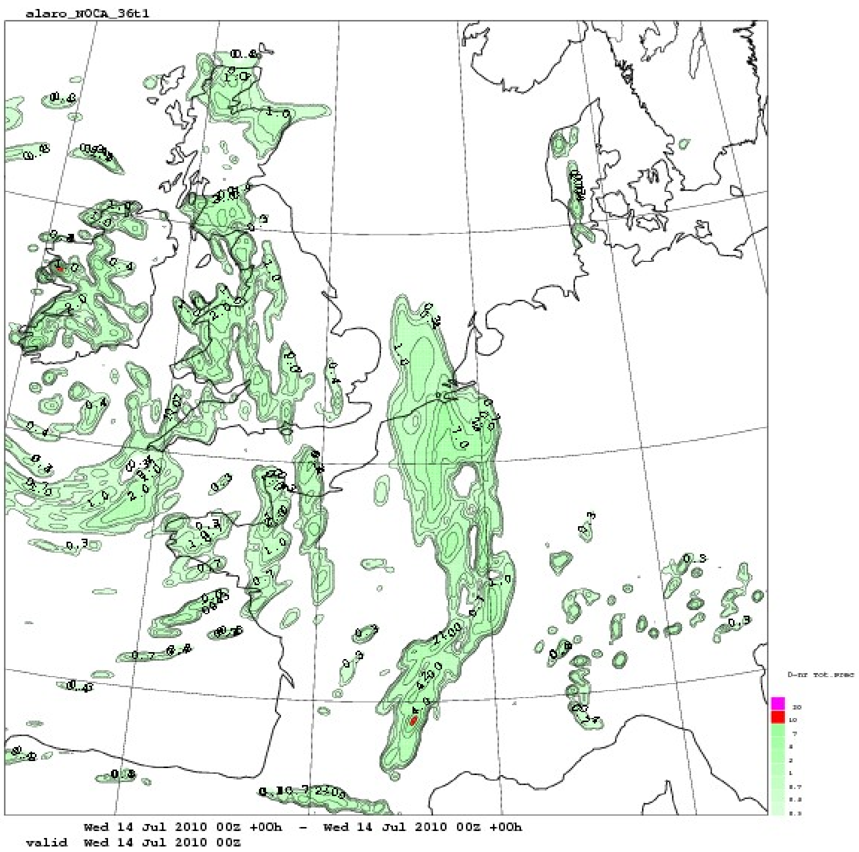


16 UTC

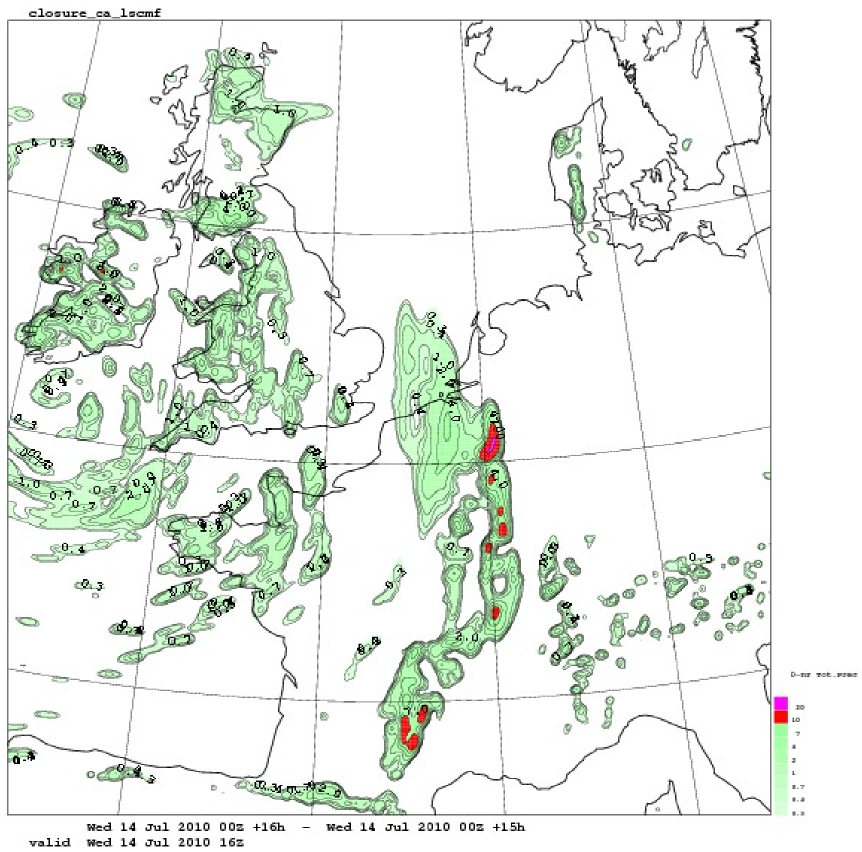
Total precipitation, 2010-07-14, 16 UTC

ALARO reference, 36h1.1

ALARO CA-CAPECONV, 36h1.1

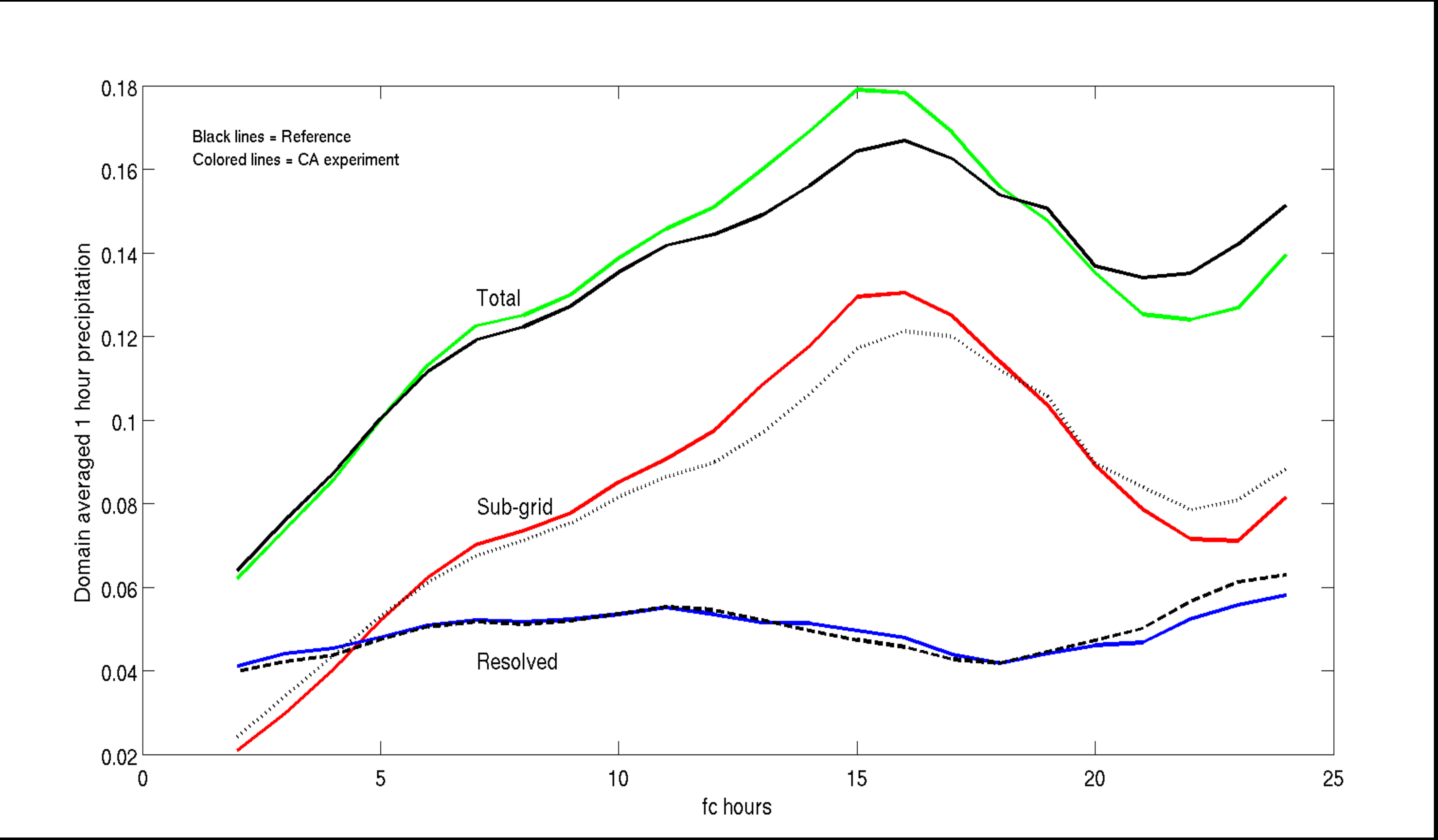


16 UTC



16 UTC

Time evolution of precipitation



Seems to be an increase in total amount, as a result of an increase of the sub-grid

Outlook

- Look more at internal variability of model runs
- Investigate closer the impact of LSCMF on/off
- Other cases, verification, validation