ON PARAMETRIZING SCALES THAT ARE ONLY SOMEWHAT SMALLER THAN THE SMALLEST RESOLVED SCALES, WITH APPLICATION TO CONVECTION AND OROGRAPHY[1]

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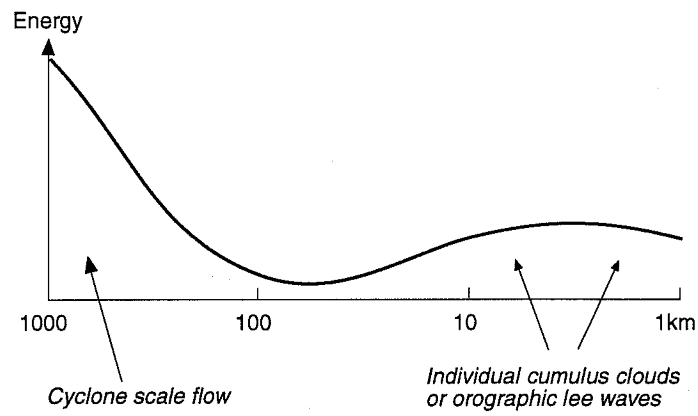
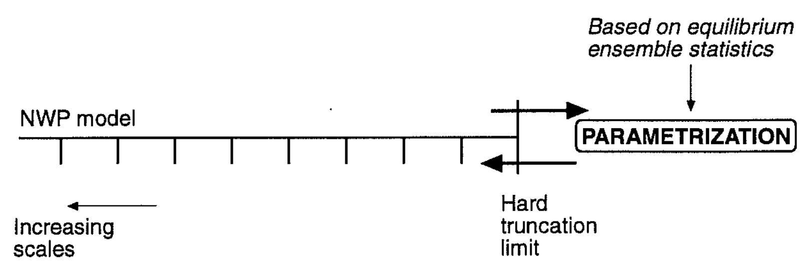
If the real world was like this:

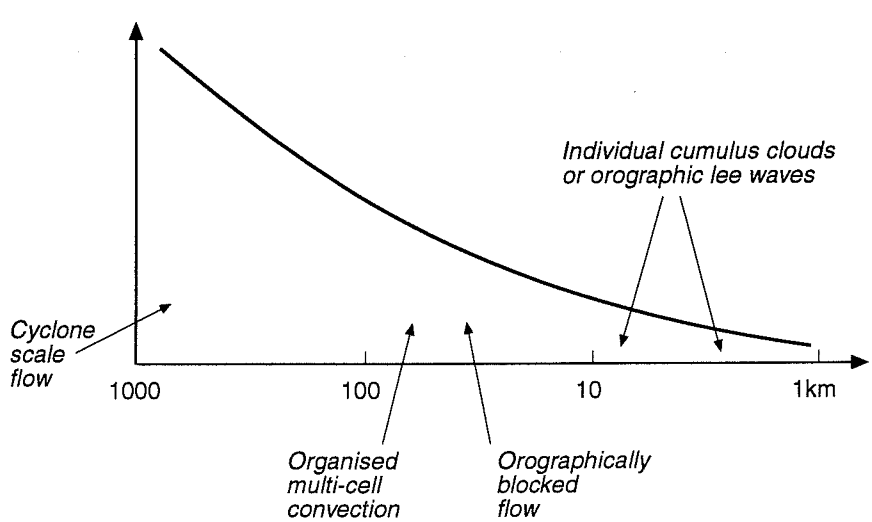


then conventional NWP formulation:



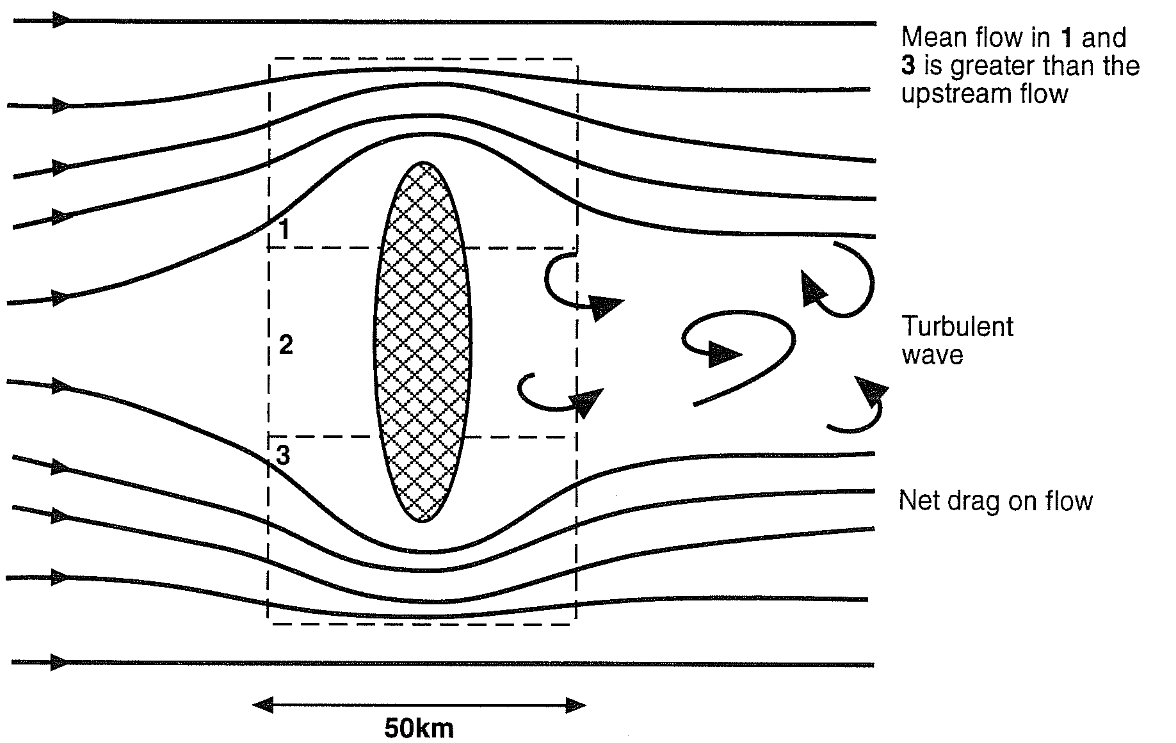
where truncation limit ≈ spectral gap, would be well founded.

Unfortunately there is no obvious spectral gap, i.e.

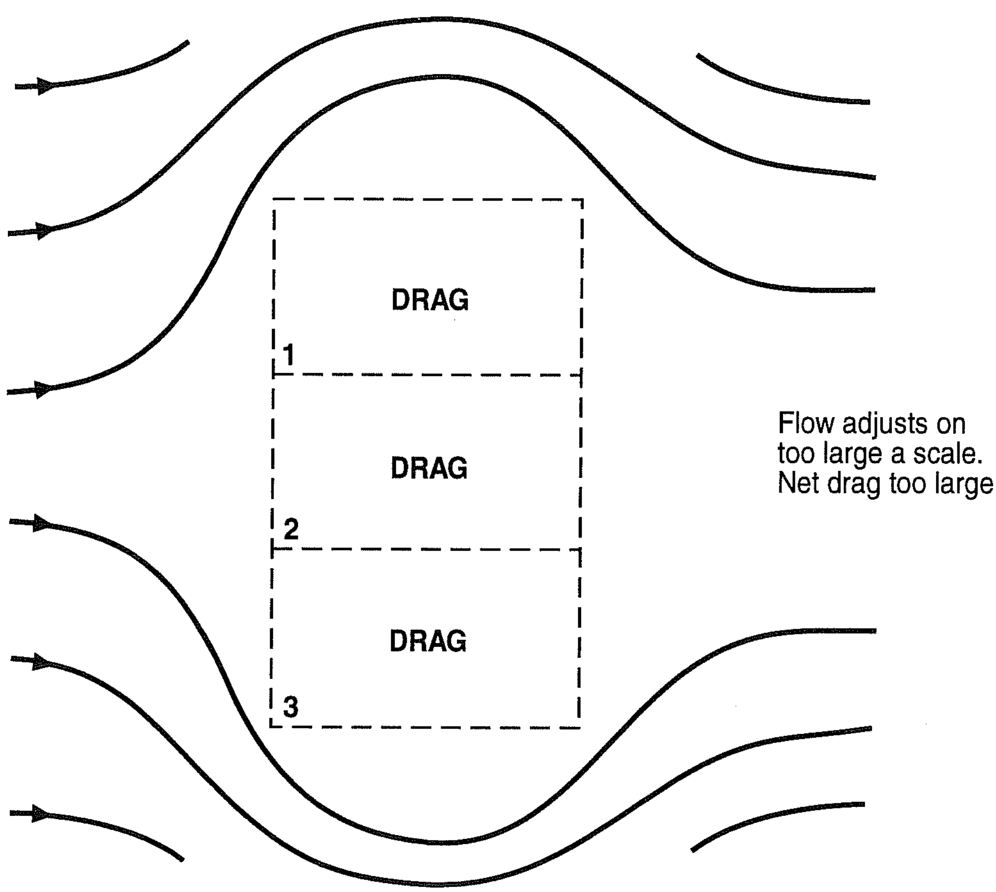


[1]Proceedings of the ECMWF Workshop on Convection (1997)

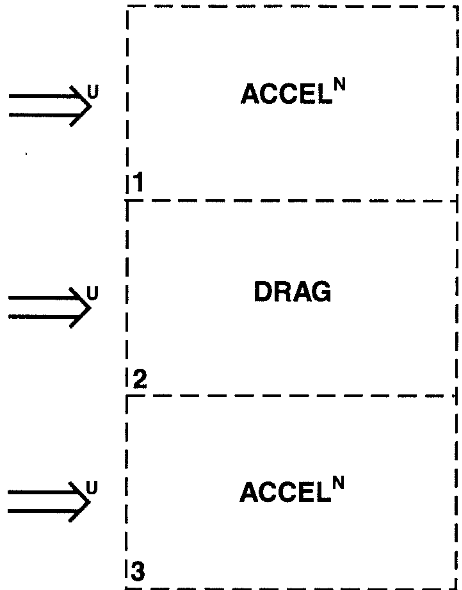
So what?! Consider (2-D) flow blocked by a long, tall, thin obstacle. Let **1, 2, 3** denote typical gridboxes.



Let μ^2 = subgrid orographic variance, U = upstream velocity. Current ECMWF subgridscale orographic parametrization blocks flow if $N\mu/U \geq 1$. Suppose $N\mu/U \geq 1$ in grid boxes **1, 2** and **3**. Then strong parametrized drag in all 3 boxes, i.e.

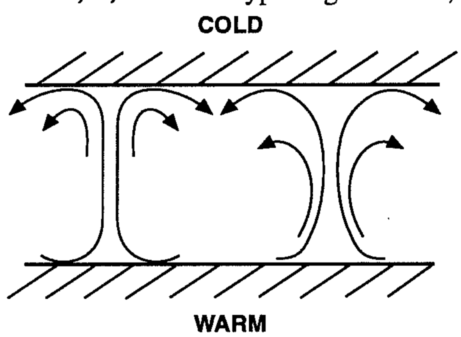


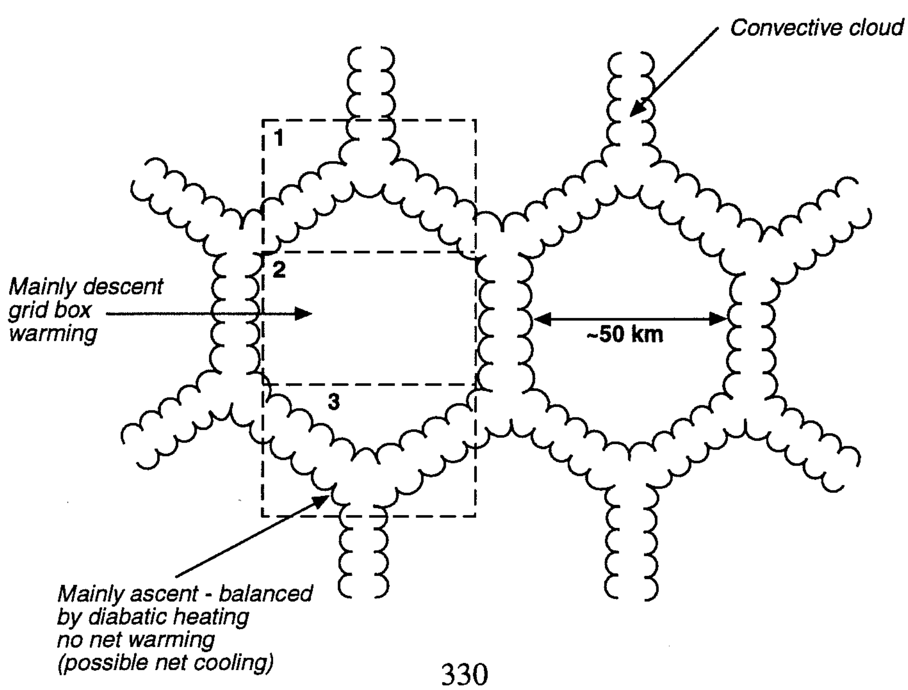
Parametrized tendency should be:



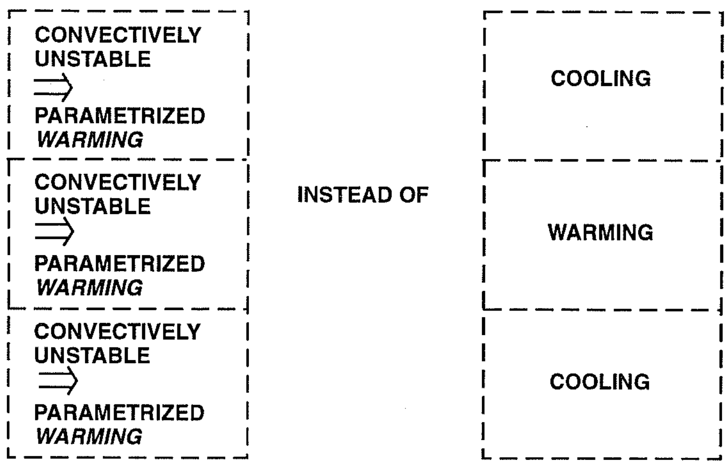
In NH, acceleration is stronger in **1** than **3** because of Coriolis effect. Resulting transverse pressure gradient implies " lift force". See also Durran, 1995.

Similar situation for organised convection e.g. Rayleigh-Bénard convection, such as occurs in midlatitude cold-air outbreaks behind cold fronts. Let **1, 2, 3** denote typical grid boxes, as before





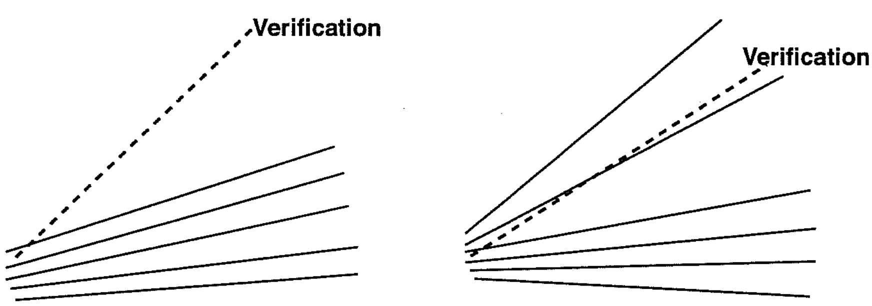
Conventional parametrization tendency will give



Related problem (*Lander and Hoskins*, 1997). Parametrization is driven by the smallest resolved scales. But there is substantial model error in smallest resolved scales because of an inappropriate hard truncation limit. Therefore there is potential positive feedback of error from parametrization.

Does this type of error near the truncation limit matter for cyclone-scale forecasts?

- In quasi-2D flow there can be a strong inverse energy cascade from sub-cyclone to cyclone scales (cf singular vector analysis).
- It is important to try to quantify these types of small-scale spatially coherent model error in order to assess their impact on the predictability of cyclone-scale forecasts.
- What is the pdf of model error associated with the misrepresentation of coherent structures near the truncation limit?
- Should this pdf be represented in an ensemble forecast? Is it possible that, on occasion,

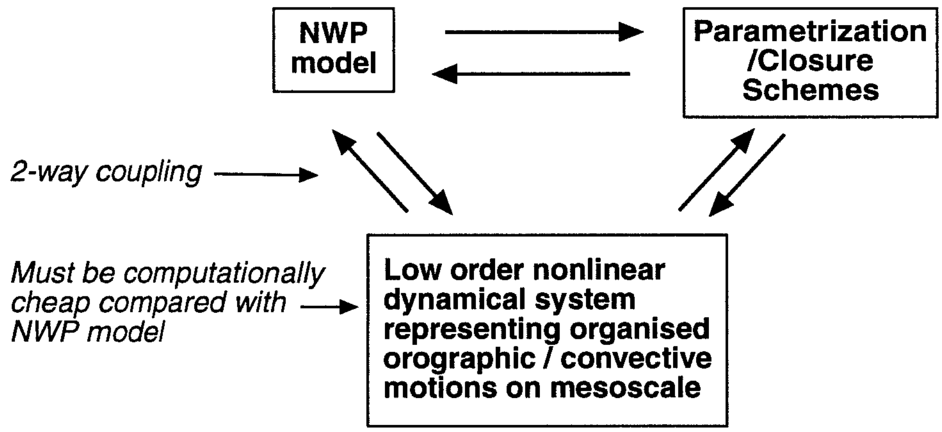


HYPOTHETICAL ensemble with initial perturbations only

HYPOTHETICAL ensemble with initial and model perturbations

Is there an alternative to conventional parametrization to deal with this type of model error?

A possible approach



Two possible low-order dynamical systems:

1. Nonlinear coupled ODE model based on Galerkin projection of equations of motion onto EOF basis defined from a high resolution (e.g. orographic, cloud-resolving) model.
2. Cellular automaton model with rules learnt from a high resolution (e.g. orographic, cloud-resolving) model.

EOF MODELS

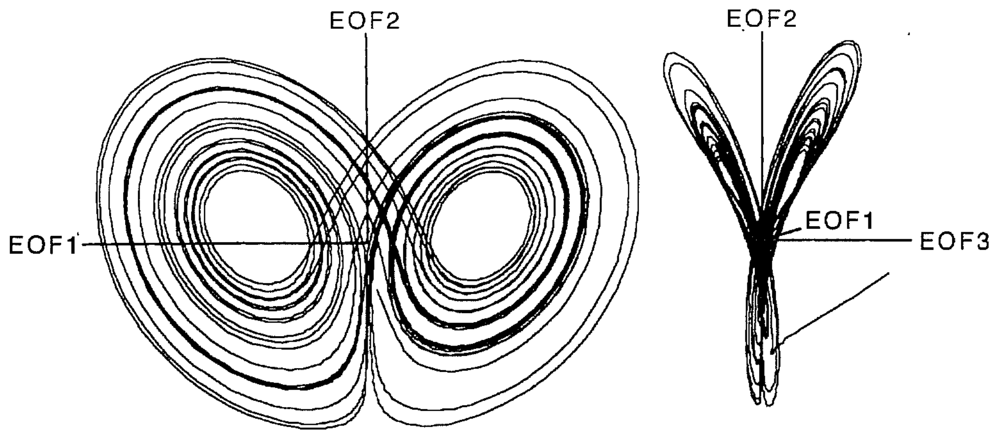
Nb EOF = POD (Proper Orthogonal Decomposition) used in probability theory
= Karhunen - Loève expansion used in turbulence theory

Use of EOF models

Lorenz (1956)	first made suggestion
Sellers (1957)	application to 500 mb height prediction
Rinne and Karhila (1975)	predictive skill of model with 57 EOFs as good as grid point model with 1080 grid points
Cazemier et al (1994)	80 EOF model could simulate short and long term evolution of 2D turbulent flow simulated by 10^8 grid point
Selten (1995)	EOF model of global circulation
Zuang (1996)	15 EOF model to study dynamical evolution of convective plumes in atmospheric boundary layer.

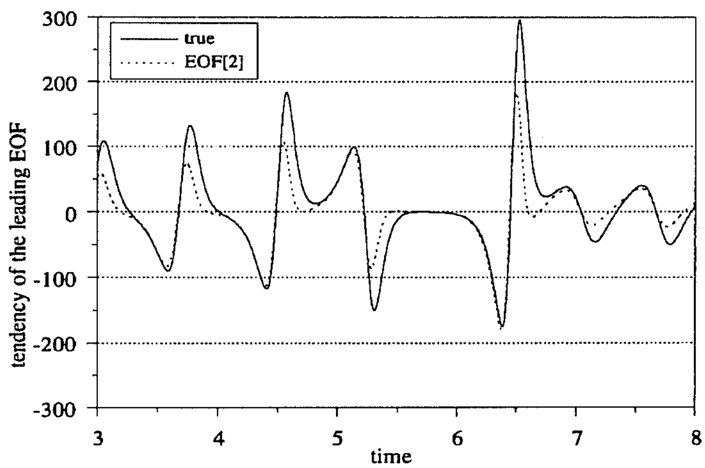
e.g. *Lorenz* (1963)

$$\dot{z}_1 = -10z_1 + 10z_2$$
$$\dot{z}_2 = -z_1 z_3 + 28z_1 - z_2$$
$$\dot{z}_3 = z_1 z_2 - 8/3 z_3$$



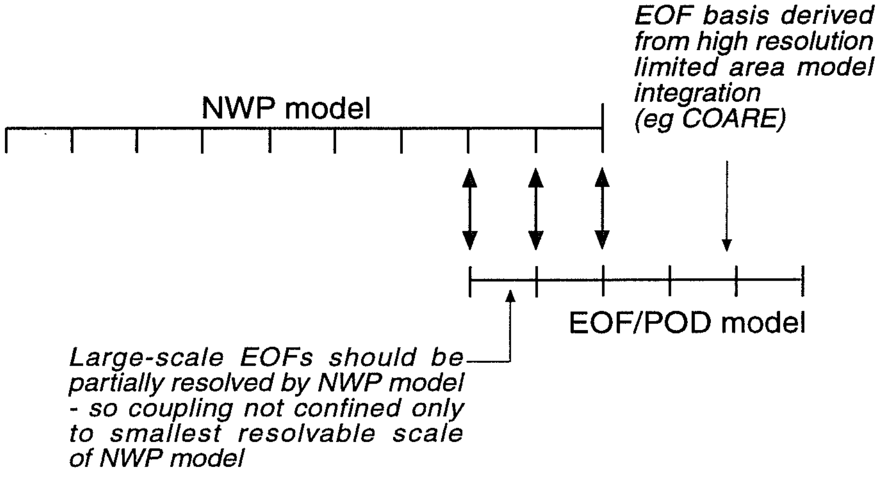
when projected onto dominant 2 EOFs becomes: (*Selten*, 1995)

$$\dot{a}_1 = 2.3a_1 - 0.49a_1a_2$$
$$\dot{a}_2 = -62 - 2.7a_2 + 0.49a_1^2$$



The figure above shows a timeseries of the tendency of the leading EOF as given by the Lorenz equations and the approximated tendency by the EOF model with two EOF's

Consider coupling the NWP and EOF model



Let u_{EOF}, T_{EOF} denote wind and temperature projection of EOF-model state vector onto NWP model grid:

NWP model

$$\frac{\partial u}{\partial t}+(u.\nabla)u=\ldots-\kappa(u-u_{EOF})$$

$$\frac{\partial T}{\partial t}+(u.\nabla)T=\ldots-\kappa(T-T_{EOF})$$

Let a_n^{NWP} denote projection of NWP model state vector onto n^{th} EOF

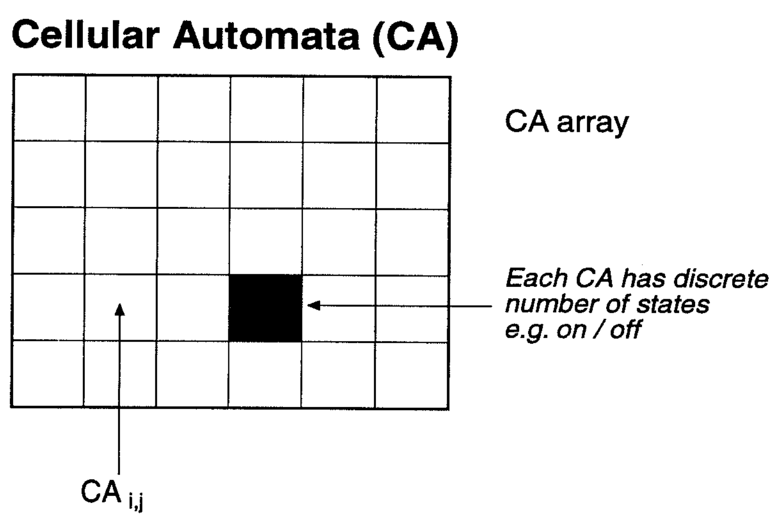
EOF model

$$\frac{da_n}{dt}=\ldots-k(a_n-a_n^{NWP})$$

EOF models representing adjacent spatial domains should be coupled together to ensure consistent common boundary conditions. Nb EOF basis could be adaptive i.e. dependent on large-scale flow and stability conditions.

CELLULAR AUTOMATA (CA)

See e.g. *Adamatzky* (1996) for background. First applied by von Neumann to biological problems. Local evolution rule:



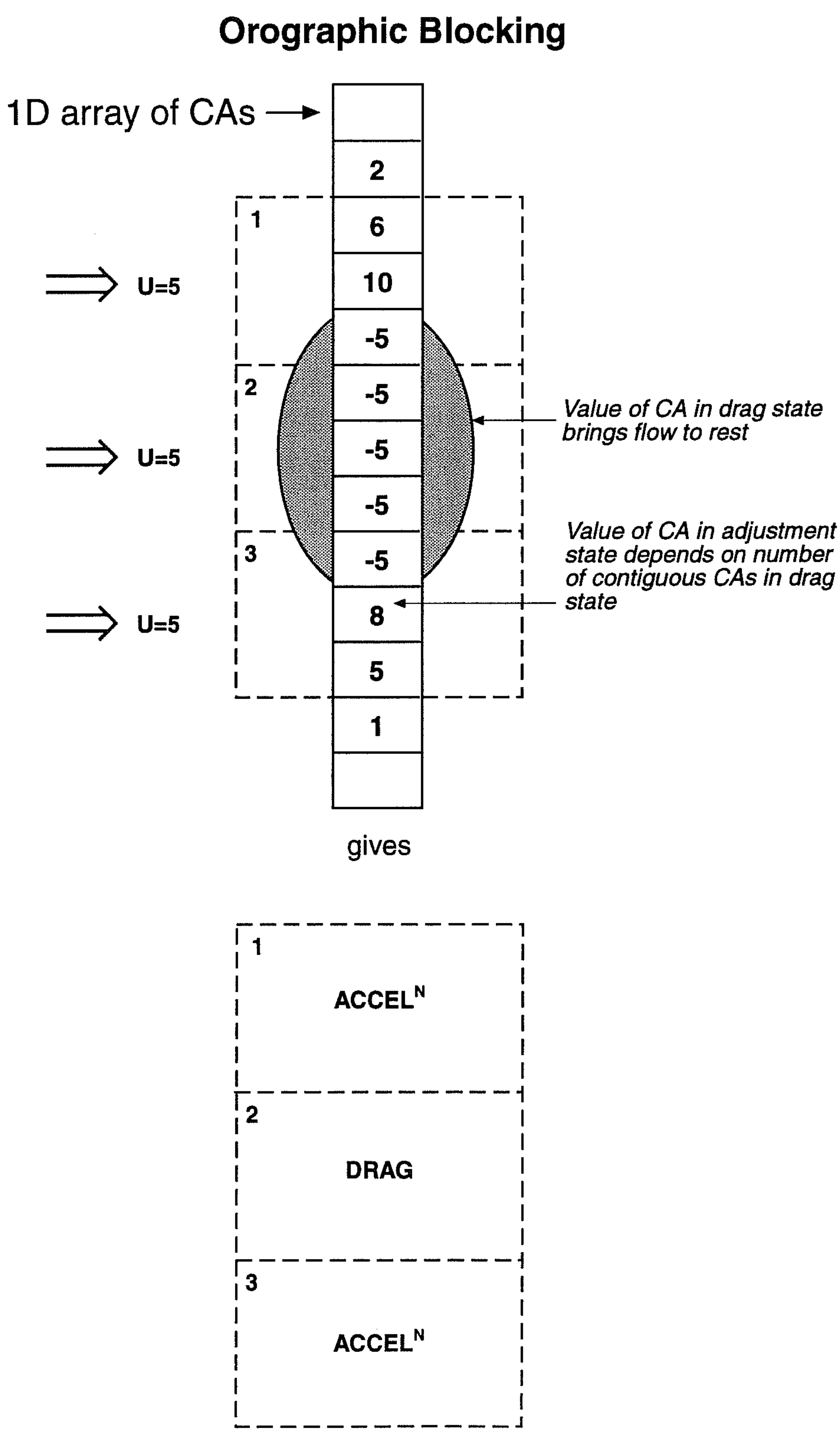
e.g.

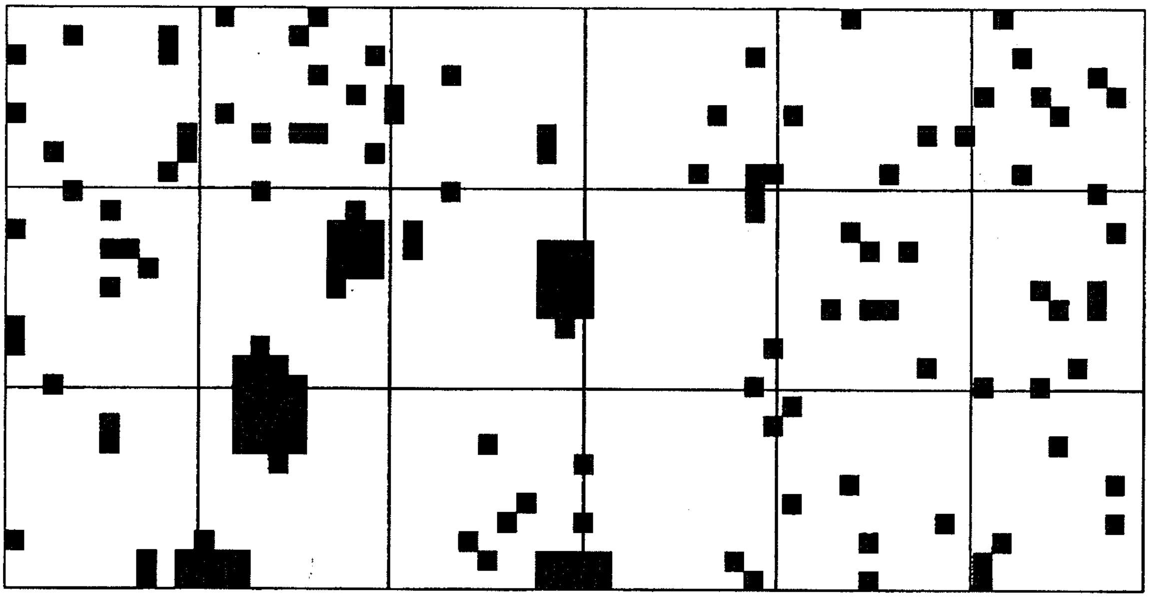
$$CA_{i,j}(t+1)=f(CA_{i-1,j-1}(t),CA_{i+1,j+1}(t),\ldots)$$

CA model is a dynamical system with discrete space - discrete time - discrete state vector.
There are many CA model representations of PDEs in physics e.g. *Frisch et al* (1986) a lattice gas automata for the Navier Stokes equations
CAs are able to simulate hexagon-like patterns (cf Rayleigh-Bénard convection above)

Application of CA method to subgridscale orographic blocking

- Let h = mean orographic height within CA. If $Nh/U \geq 1$, CA is in 'drag state'.
- For CAs in a non-drag state, but within a neighbourhood of a drag state CA, the CAs are in an 'adjustment state'. Value and extent of neighbourhood of adjustment CAs determined by CA representation of $\phi = \nabla^{-2} h$
- Gridbox mean tendency given by counting CA values





The Figure above is a snapshot of an example of a possible cellular automaton model of organised convection. The grid is presumed to be equivalent to a GCM grid. At initial time the CAs are set 'on' according to a random number generator. (For NWP, the individual CAs could be initialised using high resolution satellite imagery). The probability of being 'on' can be thought of as being proportional to the magnitude of the convective closure parameter. The probability of a CA remaining 'on' at the next time step is a function of the number on surrounding 'on' cells. Isolated CAs die very quickly; the illustrated 'blobs' have a much longer timescale. The function that gives the lifetime of a CA can be thought of as being determined by grid-scale wind shear. The CAs can be made to advect with the ambient wind. (I am grateful to Bernd Becker for help in producing this example.)

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