Met Office

Stochastic parametrization of multi-scale processes using a dual grid and ‘real-time computer games physics’

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Contents

- review need for stochastic physics
- describe the latest ECMWF spectral stochastic backscatter scheme
- discuss the use of fluid motion emulators as enhanced pattern generators
- discuss the ‘dual-grid’ approach with examples and relate to ensemble prediction

Model error : physical parametrization deficiencies

- overly-simplified physics
- excessive numerical dissipation
- vertical column-based
  (missing horizontal structure)
- Quasi-statistical equilibrium assumption
  (incorrect diurnal cycle, missing fluctuations..)
- Numerical implementation problems
  (e.g. if-test intermittency, gridpoint storms..)

Stochastic representations

- account for unpredictable, near-gridscale statistical fluctuation (e.g. ECMWF 'stochastic physics' multiplicative noise)

- kinetic energy backscatter – inject 'lost' KE back into the model proportional to dissipation rate (e.g. ECMWF/UKMO SSBS and SKEB schemes)

- inherently stochastic parametrization schemes (e.g. convection scheme of Plant and Craig, 2007)

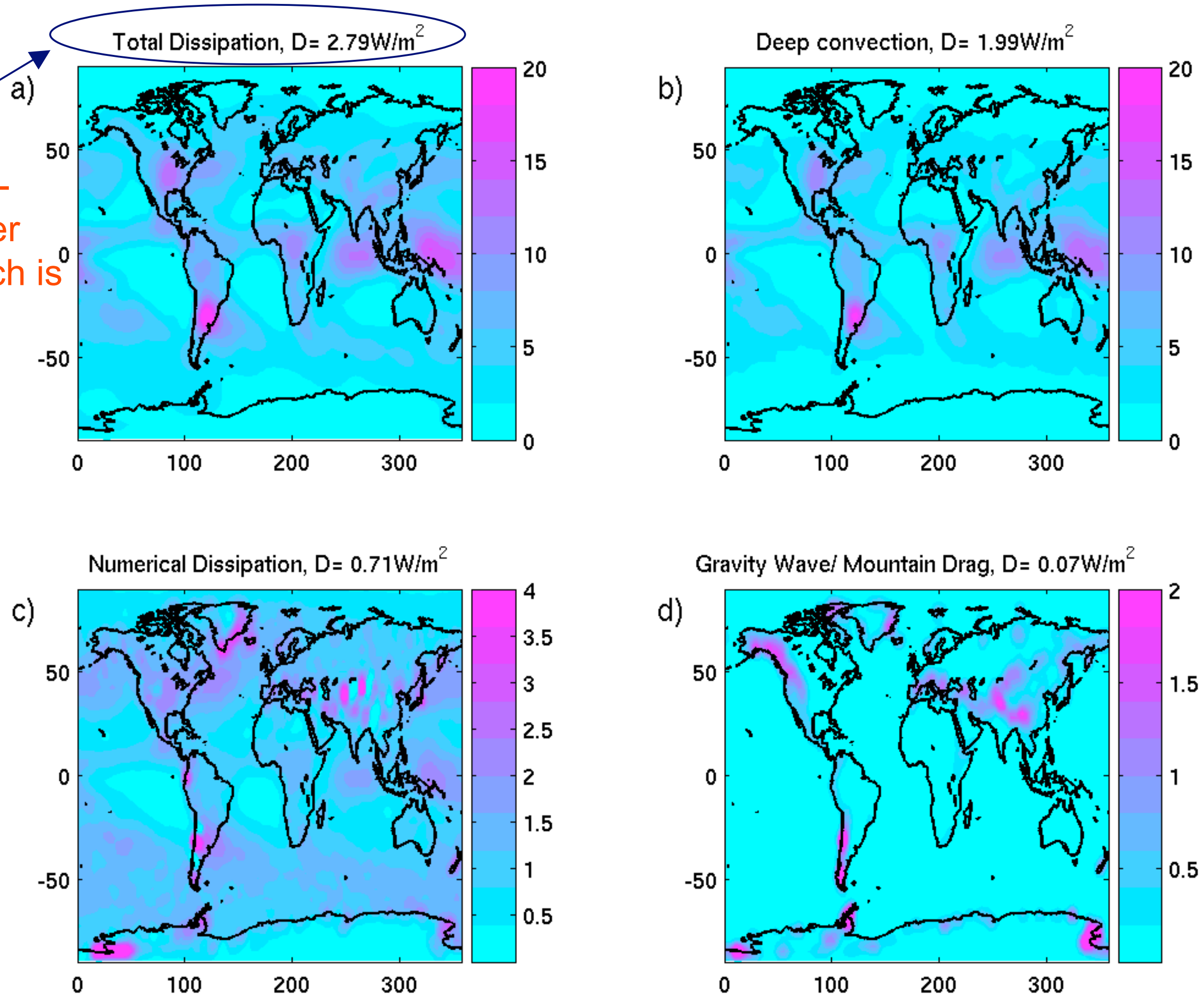
ECMWF Spectral Stochastic Backscatter Scheme
(developed by Judith Berner)

Where we are now…

- Streamfunction forcing pattern generator represented by a spherical harmonic expansion
- evolves spectral amplitudes as a 1st-order autoregressive process
- Streamfunction forcing is the product of the pattern maker and square root of a model dissipation rate
- ‘roll off’ of spectral power in the pattern generator tuned to match that deduced from big domain CRM simulations
- Backscatter ratio of about 2%

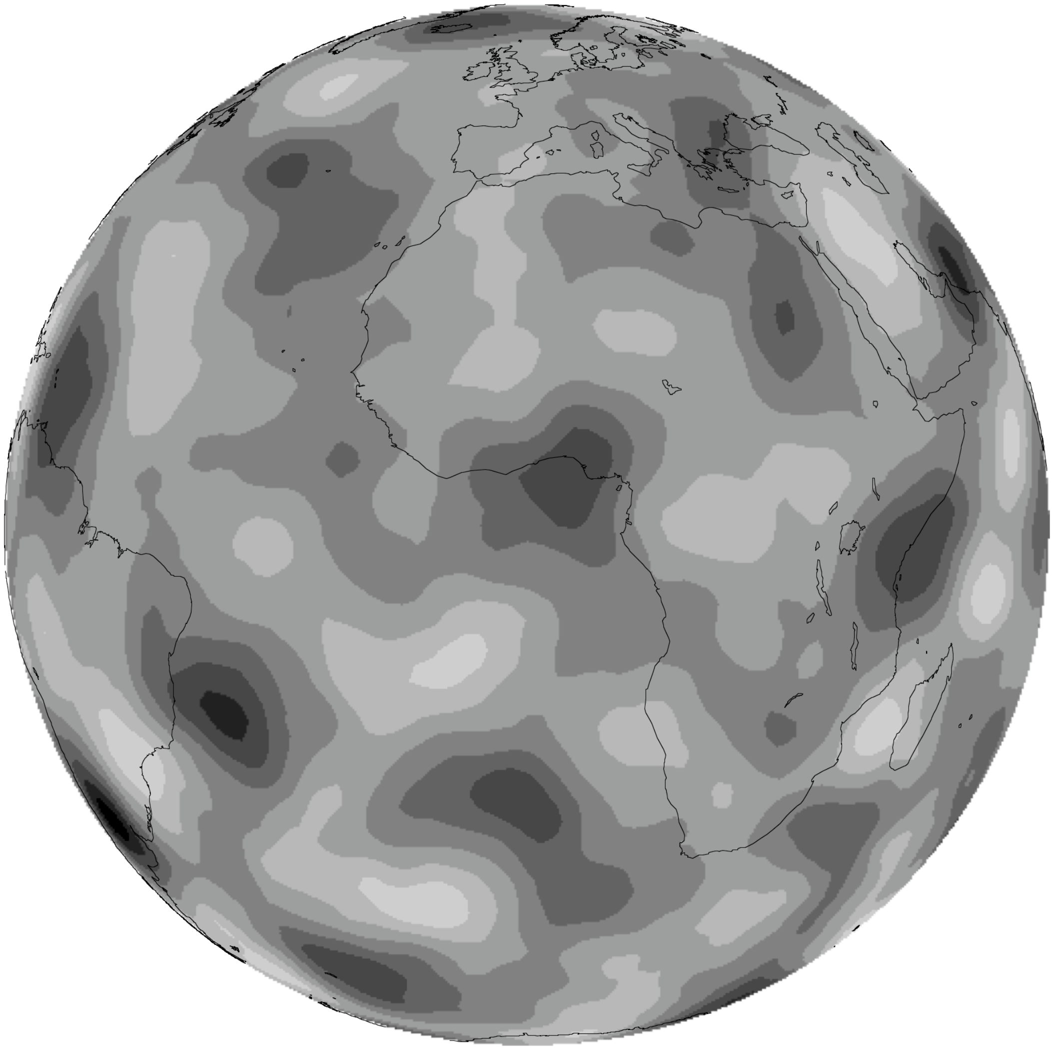
see: Berner, Shutts, Leutbecher and Palmer (2007)

Estimated dissipation rates – breakdown of physical contributions



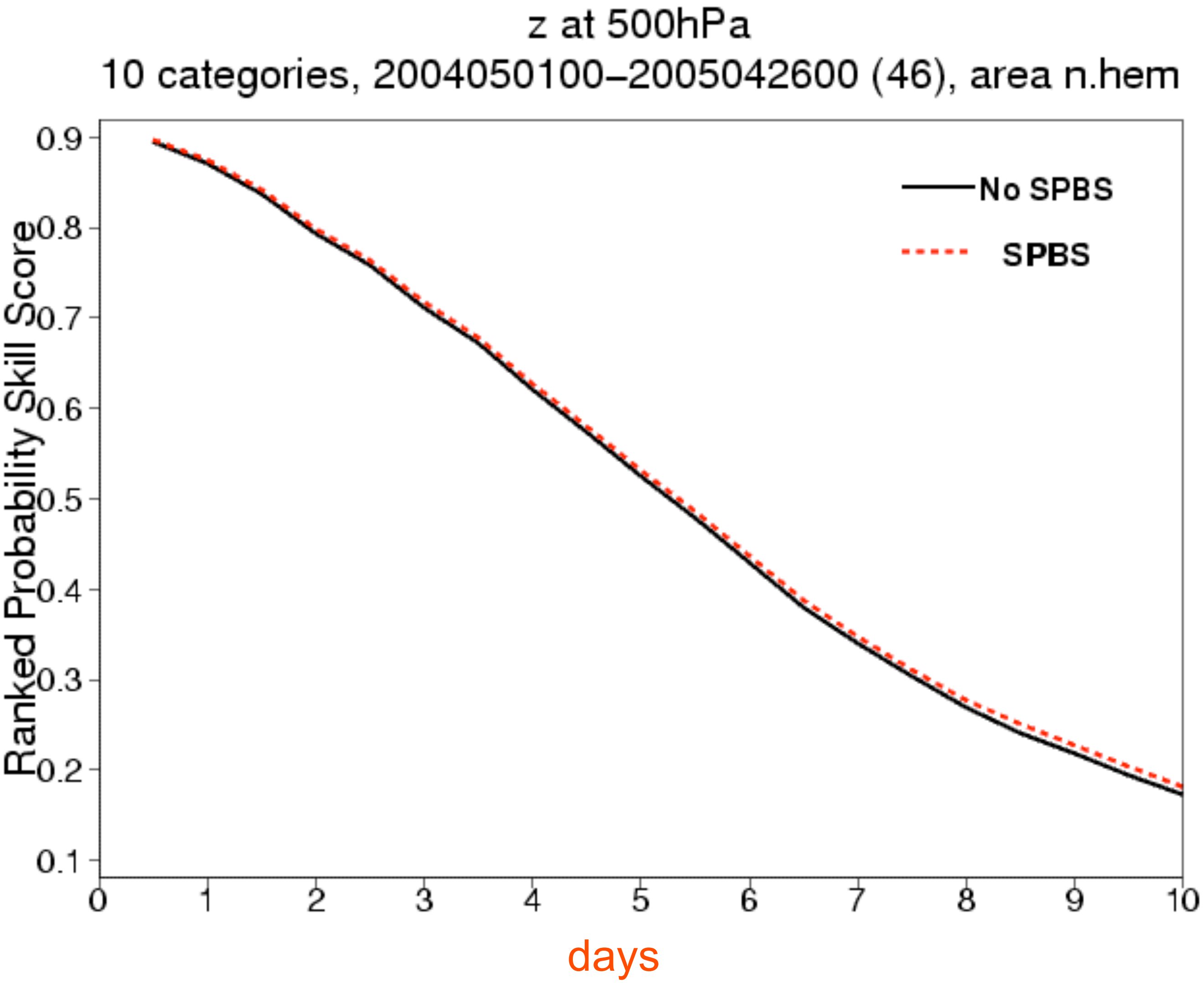
Similar to the global-mean boundary layer dissipation rate which is excluded

Spectral streamfunction pattern generator

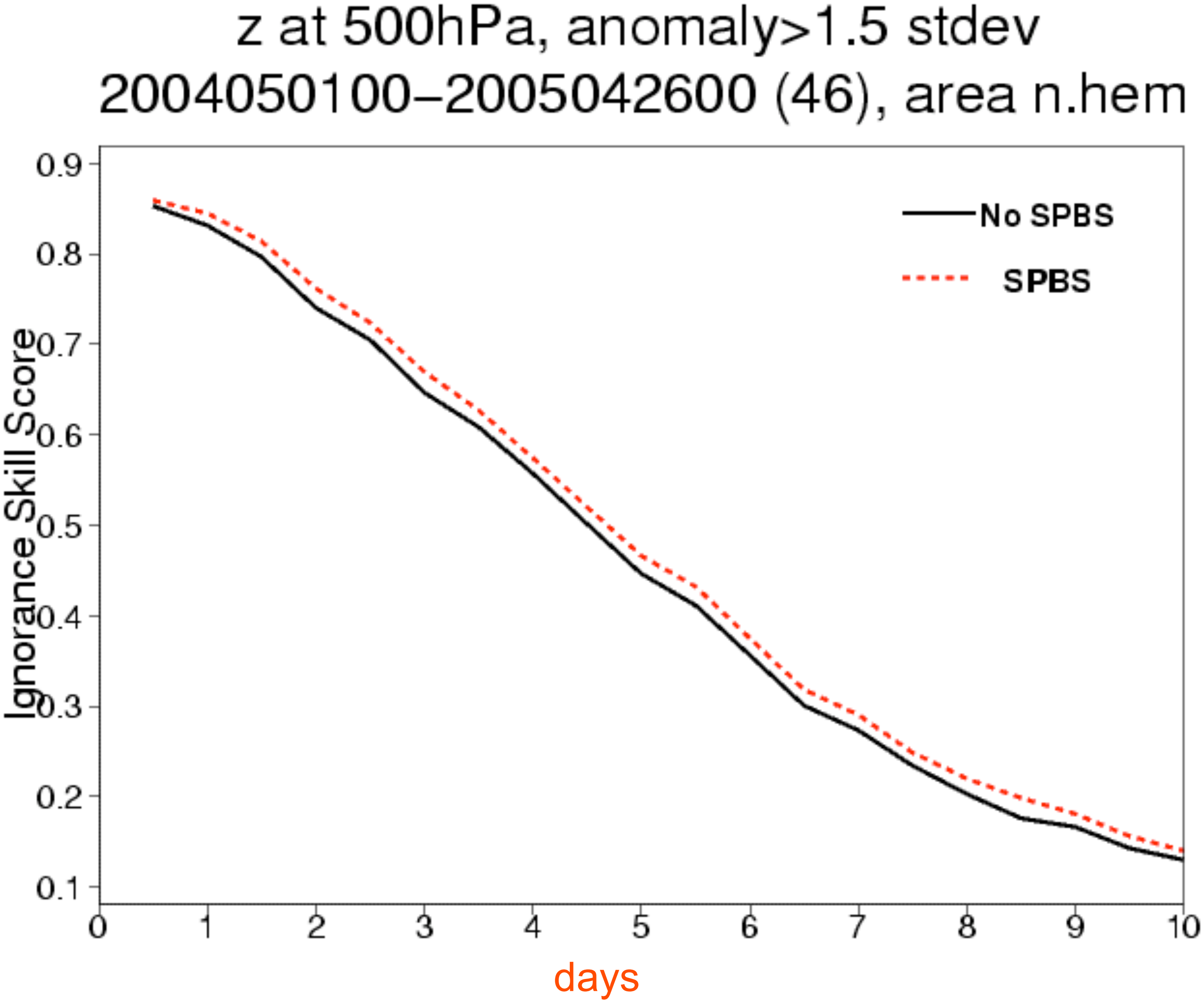


Rank Probability Skill Score 500 hPa geopotential height

50-member ensemble forecasts for 10 days started every 8th day in a one-year period

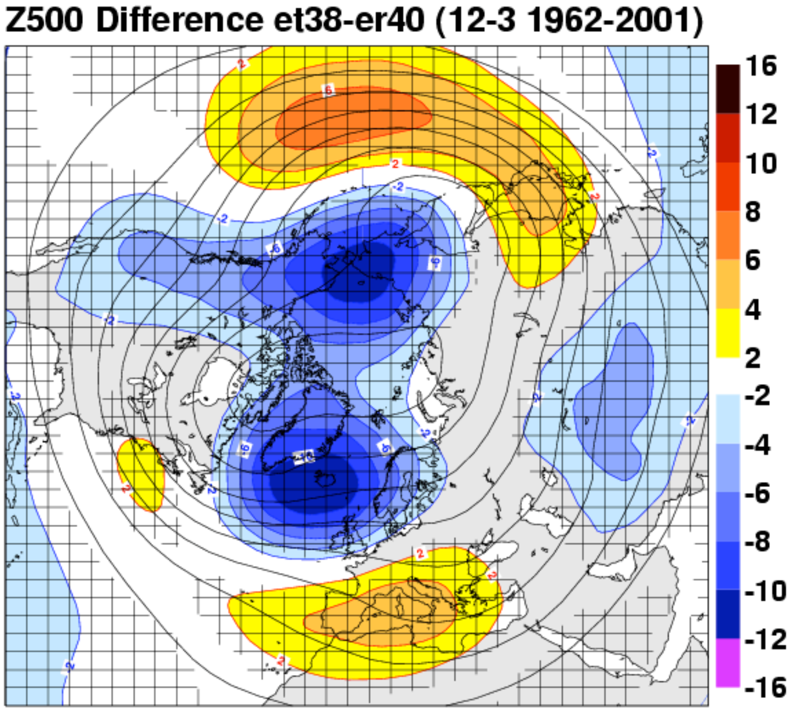


Ignorance Skill Score based on *anomaly > 1.5 std. devs.* for 500 hPa geopotential height

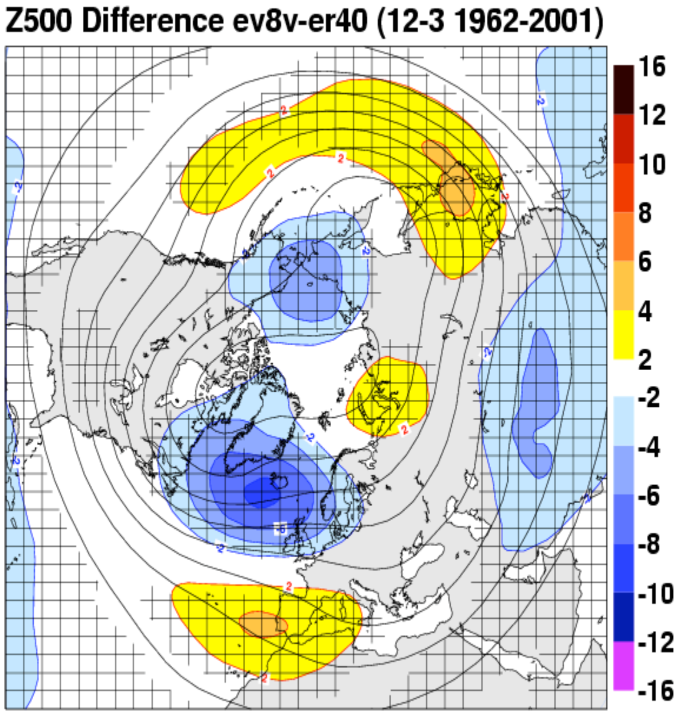


Reduction of systematic error of z500 over North Pacific and North Atlantic

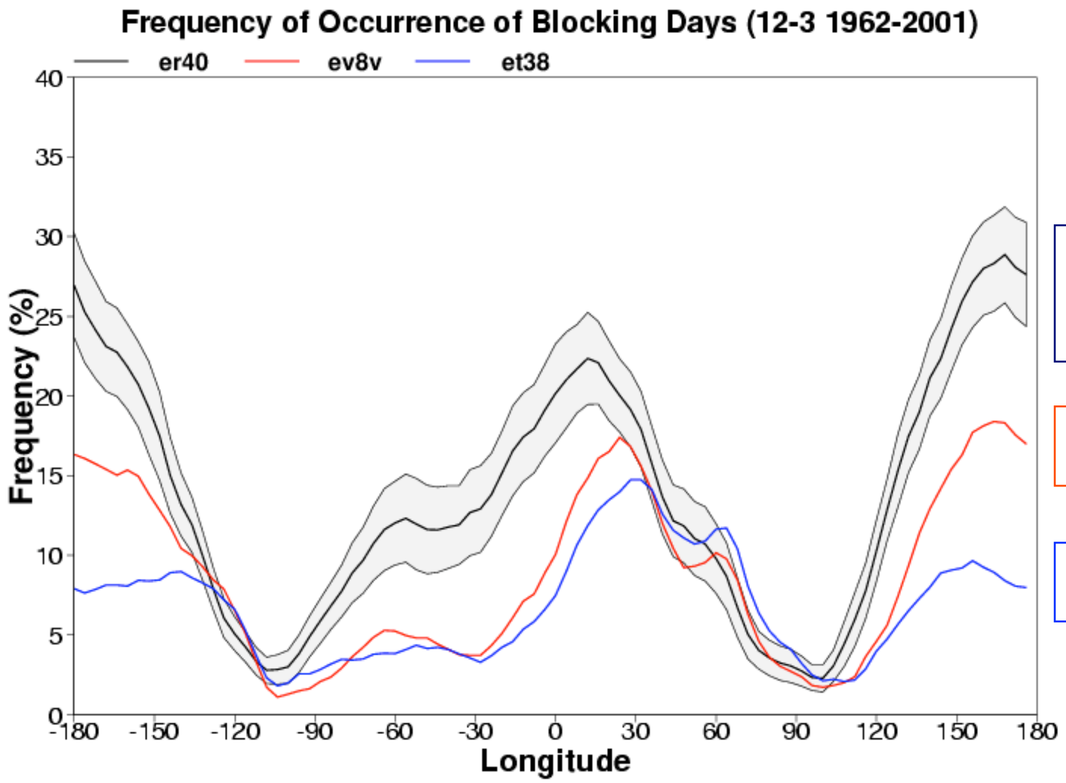
No Stochastic Backscatter


Z500 Difference et38-er40 (12-3 1962-2001)

Stochastic Backscatter


Z500 Difference ev8v-er40 (12-3 1962-2001)

Increase in occurrence of Atlantic and Pacific blocking



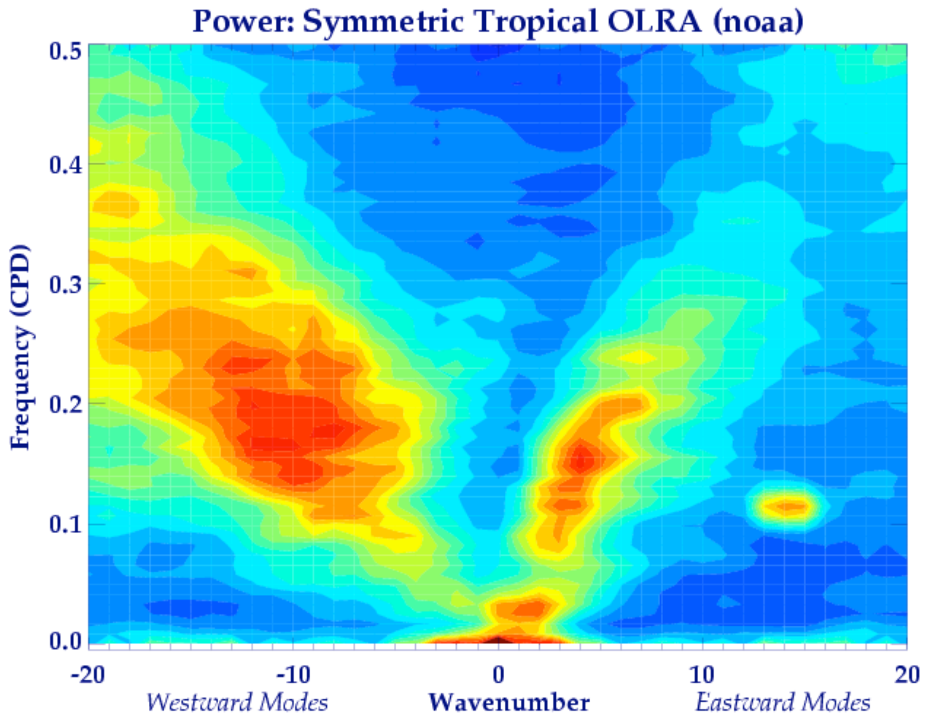
ERA40 + confidence interval

Stochastic Backscatter

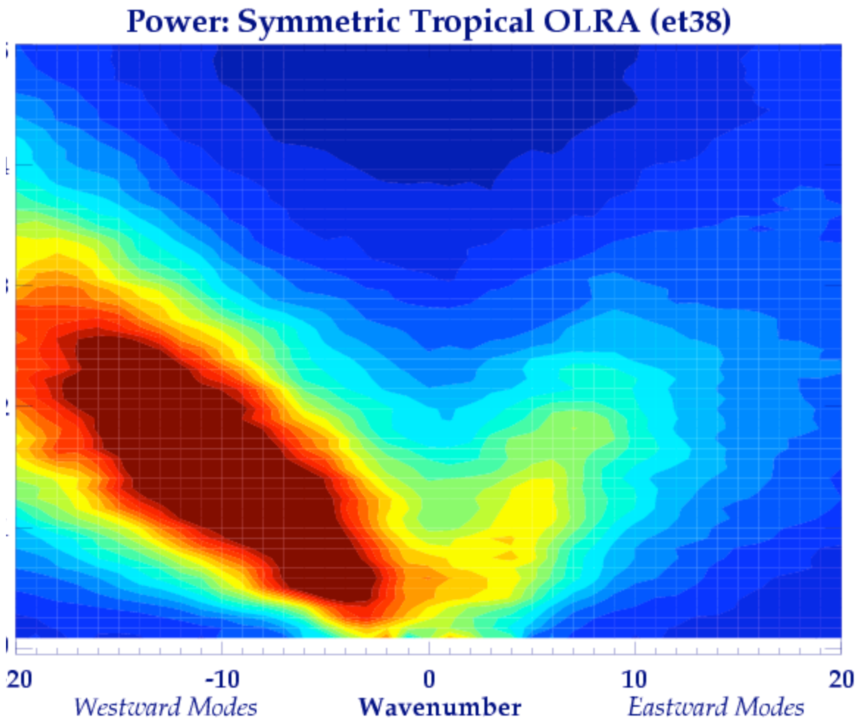
No Stochastic Backscatter

Wavenumber-Frequency Spectrum Symmetric part, background removed (after Wheeler and Kiladis, 1999)

Observations (NOAA)



No Stochastic Backscatter



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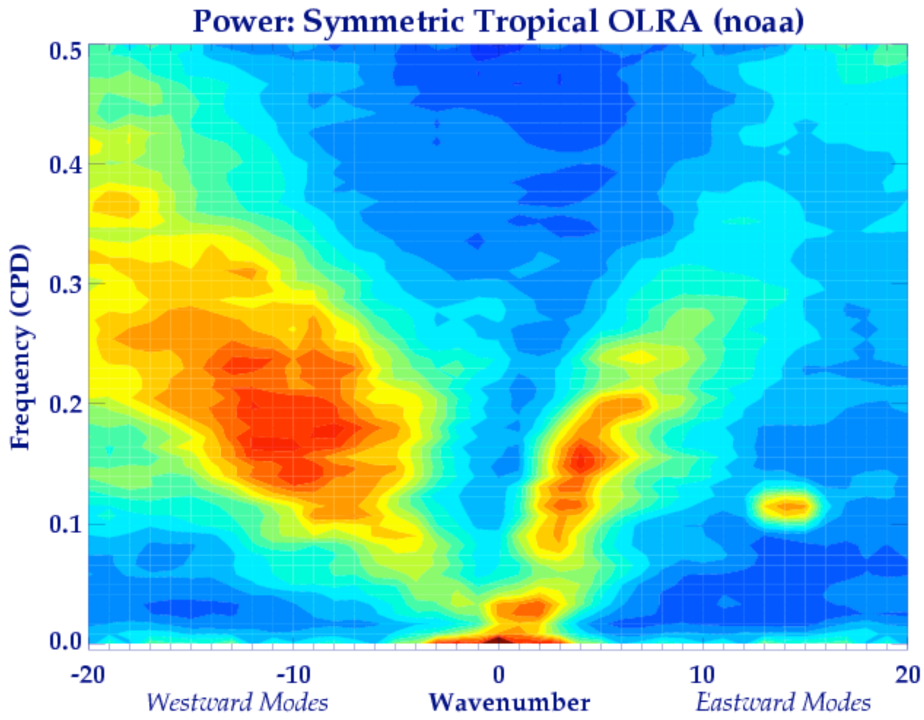
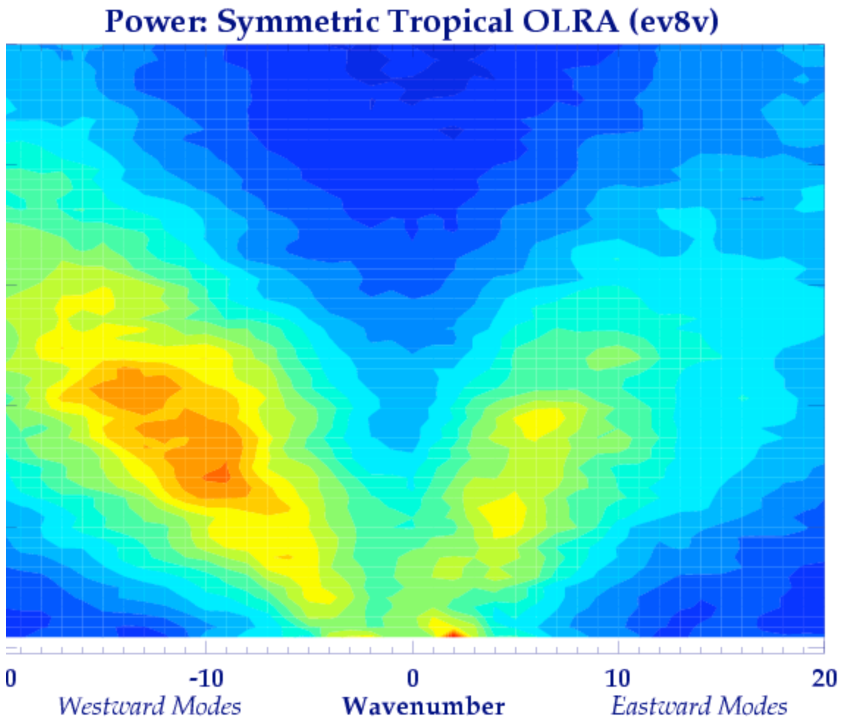


Power: Symmetric Tropical OLRA (noaa)

Stochastic Backscatter



Power: Symmetric Tropical OLRA (ev8v)

- Backscatter scheme reduces erroneous westward propagating modes

Pattern generators in stochastic physics

time

- smoothed random numbers (LES backscatter; Mason and Thomson, 1992)
- Cellular Automata (Palmer, 1997; 2001; Shutts, 2005)
- spectral AR1 (Berner et al, 2007)
- fluid motion emulators with coupling ?

View from the world of computer games animation

- animators need to do real-time rendering of fluid motion (e.g. smoke movement) and cloudscapes

- ‘accuracy’ in the predictive sense not important : speed is

- animators use the same physical equations as atmospheric modellers

- Why not use this approach to create a class of fine-scale physics ‘emulators’ ?

Cloud rendering in flight simulators

From Harris, 2003

(PhD thesis sponsored by NVidia Corporation)

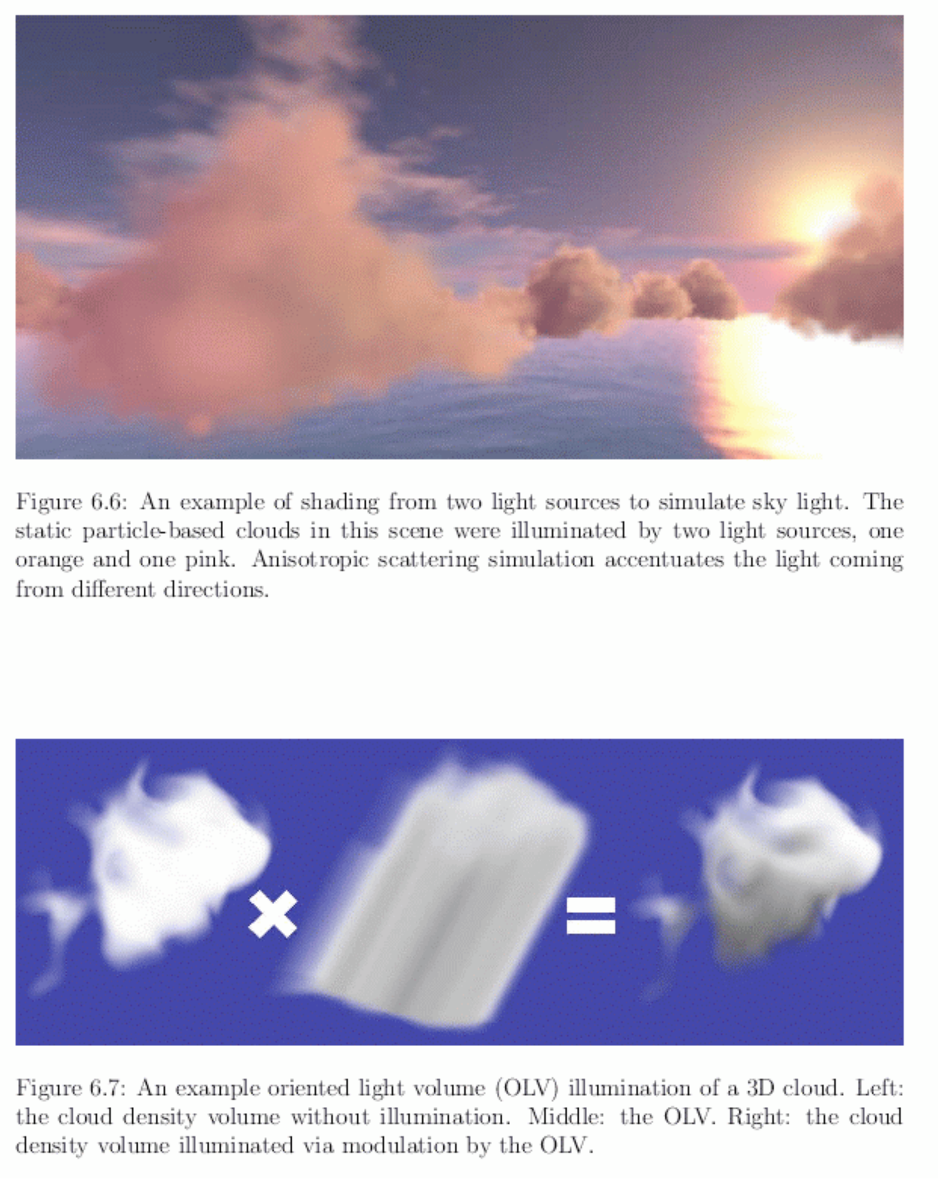


Figure 6.6: An example of shading from two light sources to simulate sky light. The static particle-based clouds in this scene were illuminated by two light sources, one orange and one pink. Anisotropic scattering simulation accentuates the light coming from different directions.

Figure 6.7: An example oriented light volume (OLV) illumination of a 3D cloud. Left: the cloud density volume without illumination. Middle: the OLV. Right: the cloud density volume illuminated via modulation by the OLV.

Speed ‘tricks’ for realistic pattern generation

- inaccurate advection e.g. simple semi-Lagrangian advection with bi-linear interpolation
- elliptic pressure solver accuracy comprised for speed e.g. small fixed no. of iterations
- over-simplified physics e.g. relaxation with different time constants

Vorticity confinement – J. Steinhoff, 1992

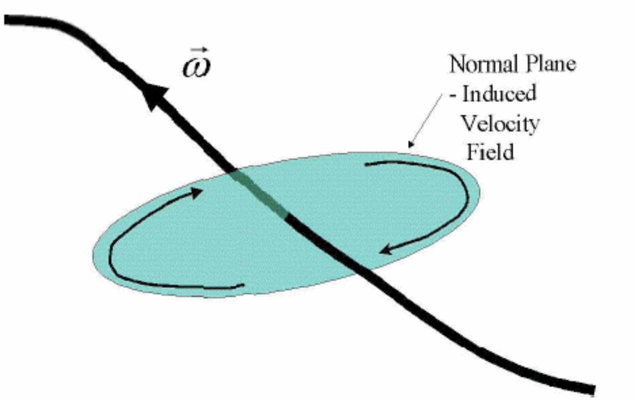
- Stam and other computer games animators use this technique to counteract excessive diffusion associated with low-order interpolation in SL advection scheme

$$\frac{\partial \mathbf{V}}{\partial t} + \mathbf{V}\cdot\nabla\mathbf{V} + \frac{1}{\rho}\nabla p = \mu\nabla^2\mathbf{V} - \epsilon\mathbf{S}$$

confinement term

includes numerical dissipation in this context

$$\mathbf{S} = \mathbf{n} \times (\nabla\times\mathbf{V})$$

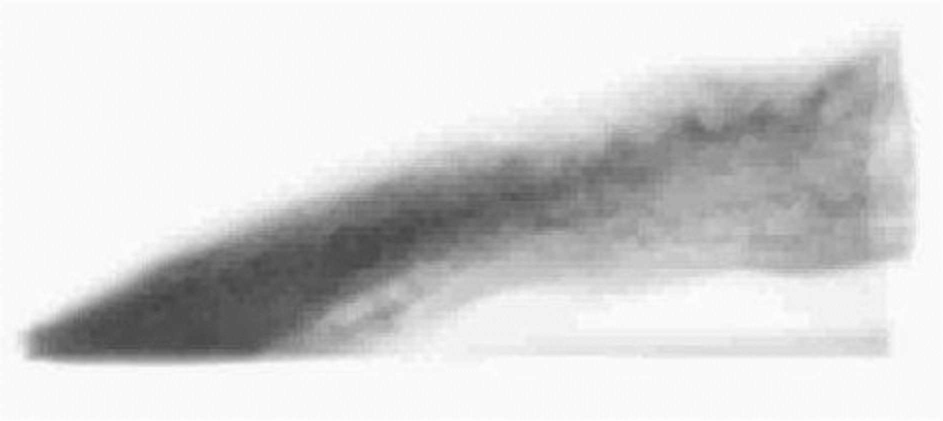


$$\mathbf{n} = \frac{\nabla\eta}{|\nabla\eta|}$$

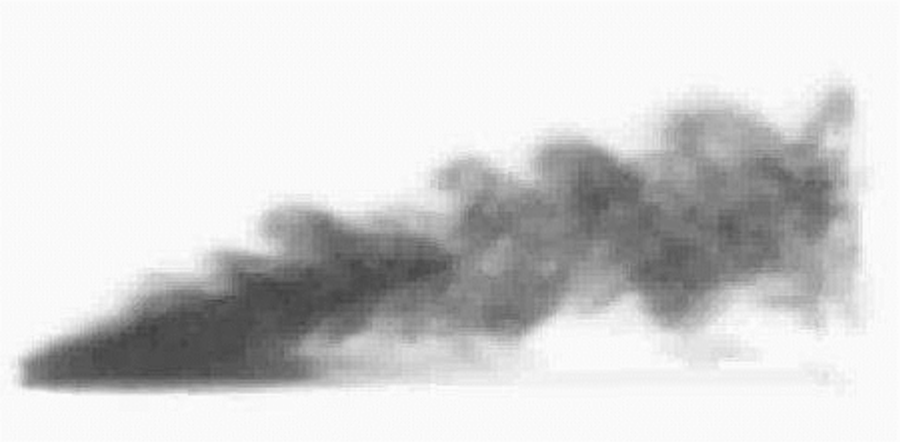
$$\eta = |\nabla\times\mathbf{V}|$$

Effect of vorticity confinement in a simulation of turbulent jet

Steinhoff et al, 2005



Jet Plume Without Vorticity Confinement



Jet Plume With Vorticity Confinement

3D simulation of jet emerging from a flat plate (Steinhoff, 2003)

Animation without vorticity confinement

Simulation with vorticity confinement

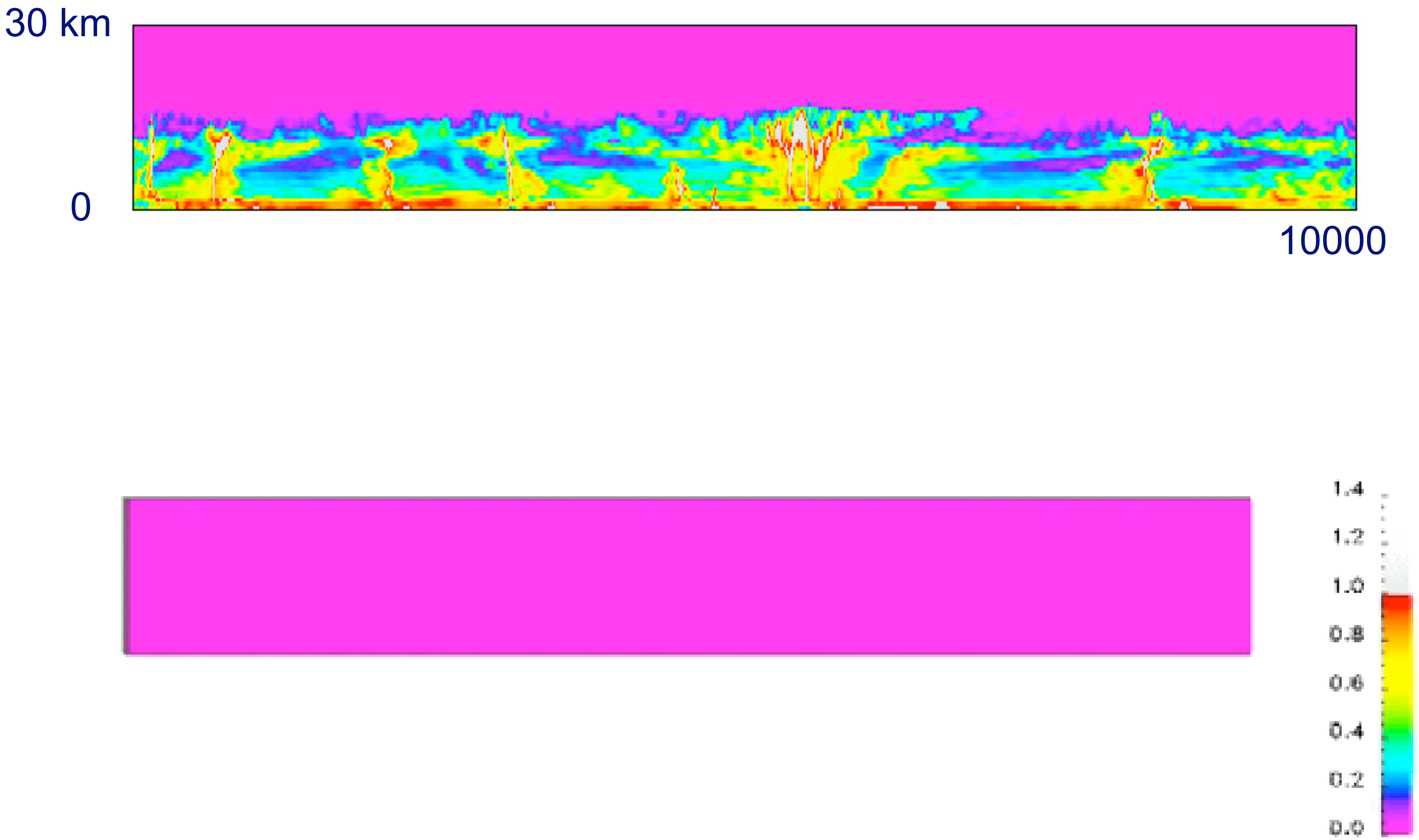
Animation with vorticity confinement

Convective cloud emulator

Approximations used in moist physics:

- Two water mixing ratios only: precipitating (q_R)and non-precipitating water (q)
- Define cloud water to be q – qsat and relax to zero at a rate proportional to the supersaturation
- rate of evaporation of q_R proportional to subsaturation
- Fall speed of precipitation given by Kessler formula for droplets
- Mixed qsat formula for liquid water and ice with transition between 0 C and -15 C.

Relative humidity in 2D run with cloud emulator

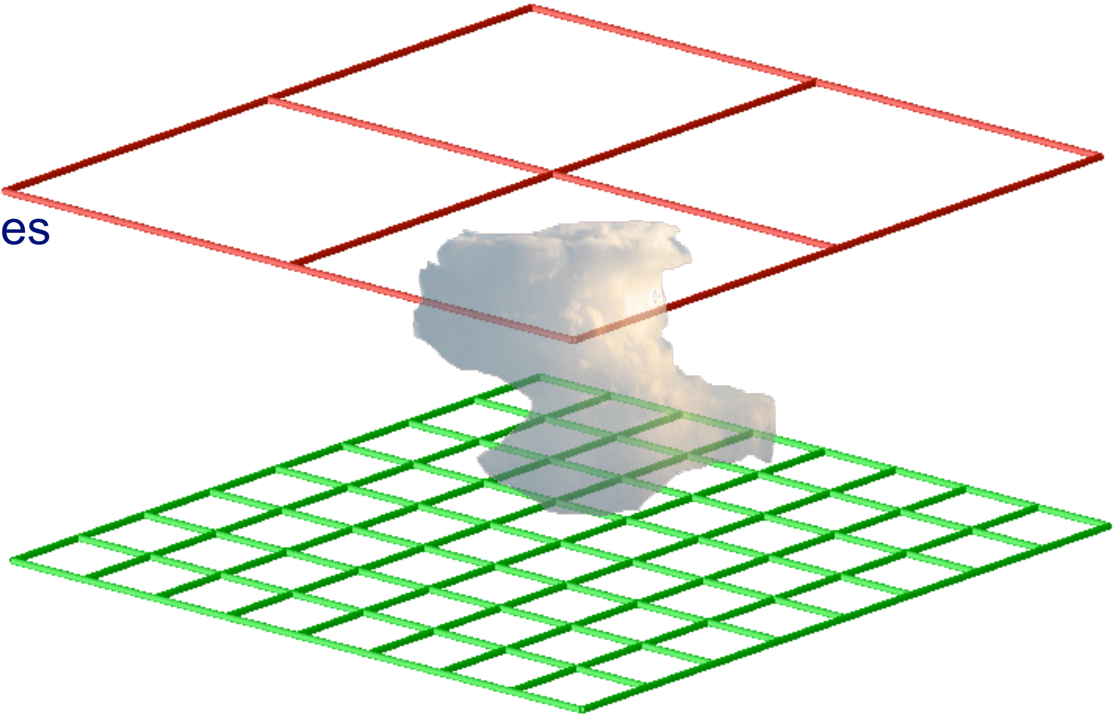


Dual-grid strategy

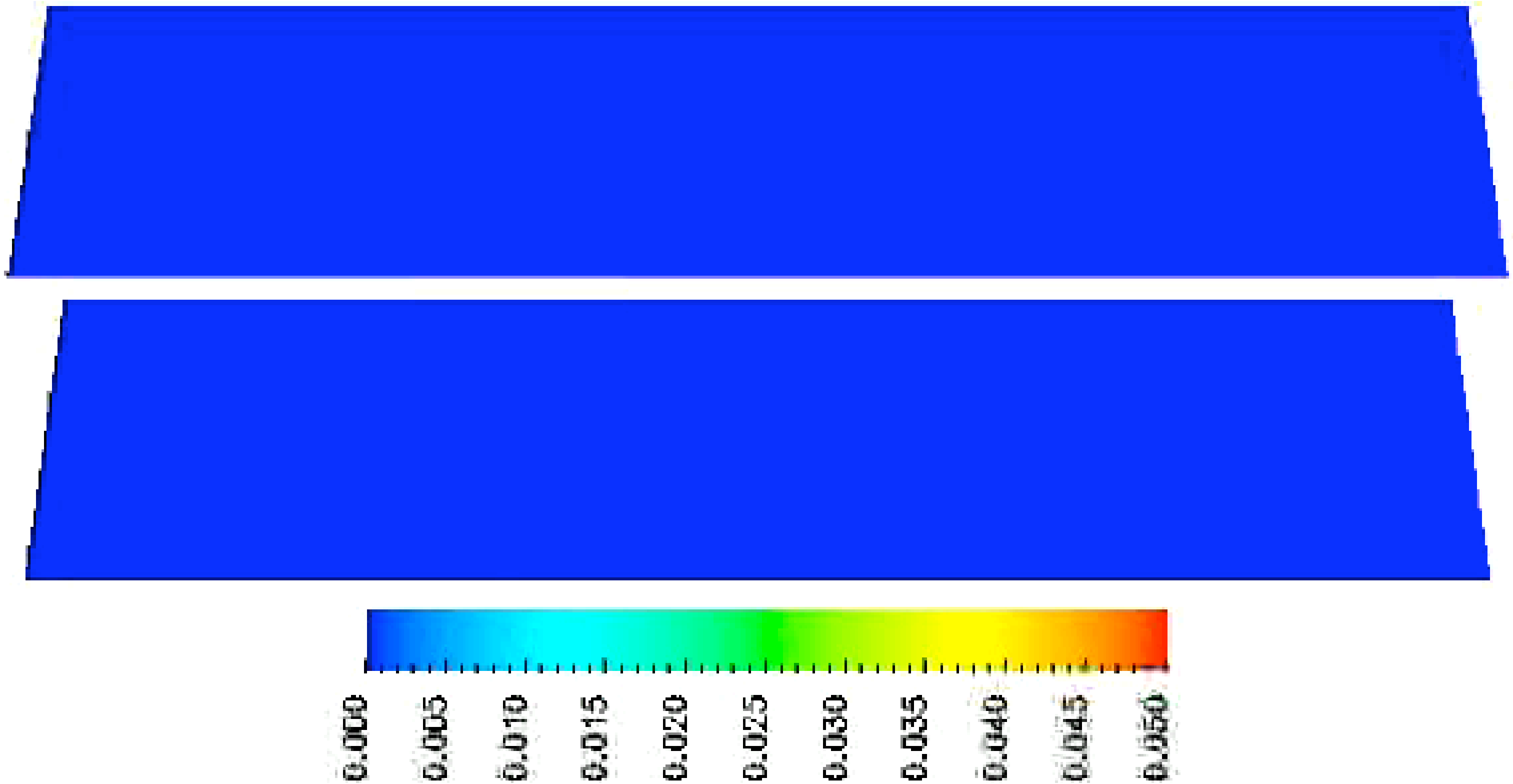
- if the emulator is based on same equations as the forecast model why not couple the two together as a dual-grid model ?
- the ‘accurate’ coarser NWP grid acts as a large-scale forcing field for an underlying ‘inaccurate’ fine-grid model with severely-approximated physics
- resembles super-parametrization/Multi-Model Framework (Randall et al, 2003)
- lower computational cost achieved by relaxing the requirement for numerical accuracy
- Nature of the coupling between the two grids will be crucial

Dual grid representation

Couple grids through eddy fluxes computed on fine grid and two-way relaxation



Tom Allen’s dual-grid simulation of dry convection

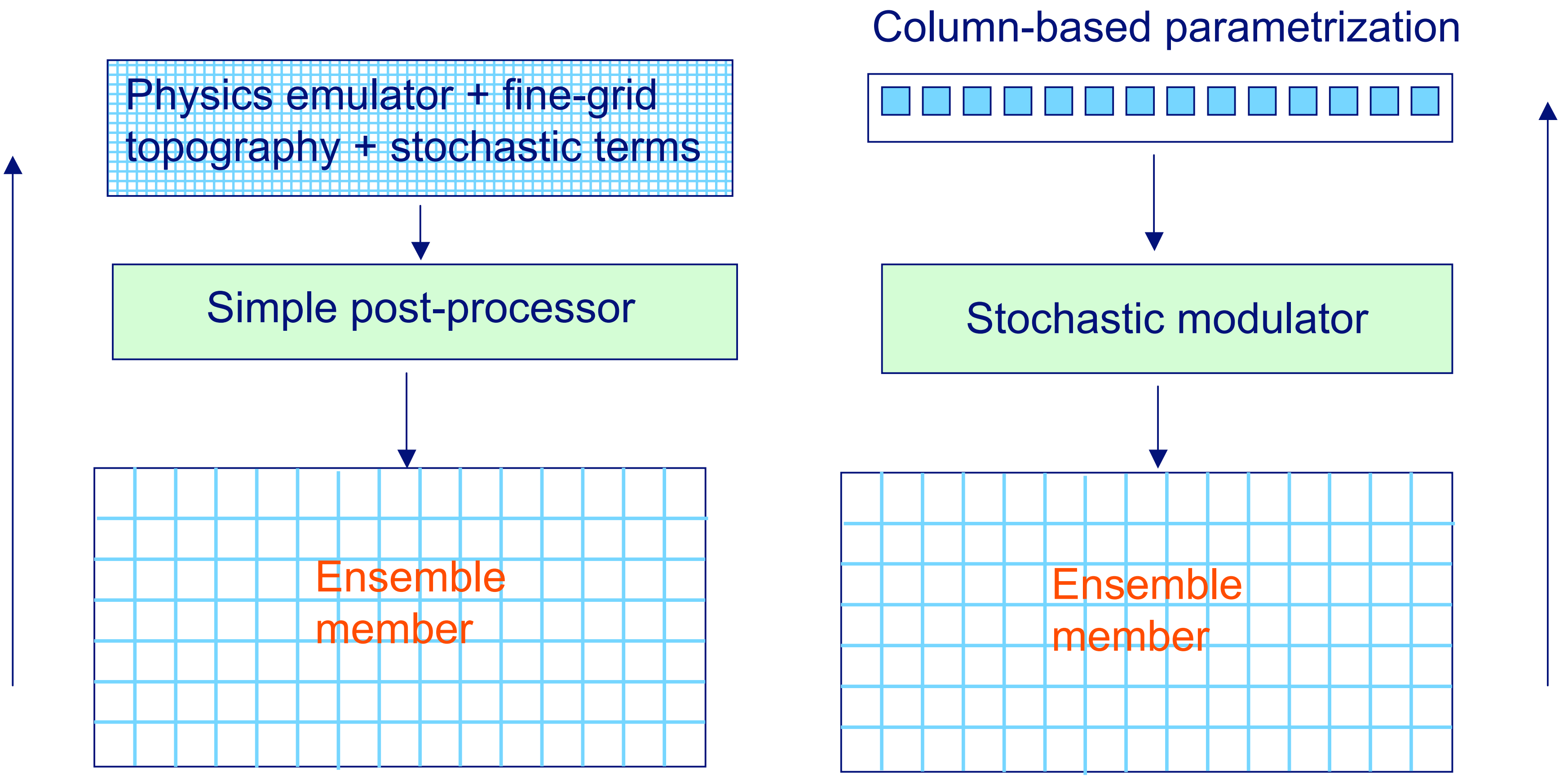


Dynamics and physics grids

- Compute physical parametrizations on a different resolution grid from the dynamics in the ECMWF model
- coarse physics and fine dynamics ?

Fine physics and coarse dynamics gives better skill (Hortal and Salmond, unpublished)

Parametrization strategies



Column-based parametrization

Physics emulator + fine-grid topography + stochastic terms

Simple post-processor

Stochastic modulator

Ensemble member

Ensemble member

Comments on dual-grid method

- generates its own flow-sensitive quasi-stochastic fluctuations
- solution convergence as numerical and physical accuracy is improved
- fine grid computation of orographic drag
- surface fluxes integrated over fine-grid surface type specification
- accuracy compromises set by what is computationally affordable

Summary

- replace pattern generators that underpin ‘stochastic physics’ with emulators

- physics emulators attempt to mimic high resolution simulation models (e.g. CRMs) at a fraction of the cost

- each ensemble member would use a stochastically-perturbed physics emulator coupled to the forecast model fields