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Spatial and temporal stochastic cascade structure of deterministic numerical models of the atmosphere

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Statistical analyses of numerical models of the atmosphere have traditionally concentrated on classical turbulent fluxes especially the energy and enstrophy. Theoretically, this has been justified by isotropic theories and through hypothetical isotropic cascades. However due to gravity, the atmosphere and its models are strongly anisotropic (stratified) so that these theories are quite unrealistic.

Our starting point are empirical findings that the stratification is scaling so that the atmospheric dynamics (and as we show here, their models) can be governed by anisotropic cascades governed by nonstandard turbulent fluxes. In this generalized scaling framework we expect scaling relations of the (generalized) Kolmogorov form to hold:
F(L) = e(L) L**H
where F(L) is the fluctuation in a field at scale L and H is a scaling exponent and e(L) is the underlying resolution L flux. We use this approach to estimate e(L) and then to systematically degrade it to lower and lower resolutions. The cascade hypothesis predicts that
<e(L)**q> = (Louter/L)**K(q)
where here L is the resolution of the flux, Louter is the outer scale of the cascade (where it starts) and K(q) is a scaling exponent function describing all the statistical properties as a function of scale.

In this presentation we test this anisotropic cascade framework on the horizontal east-west wind, temperature, and humidity fields at 5 different pressure levels for both (three years of) the ERA40 reanalysis as well as (six months of) the Canadian Meteorological Centre Global Environmental Multiscale (CMC GEM) model. Our results indicate that over most of the range of scales (essentially planetary scales down to 2 – 3 pixels; below this the hyperviscosity breaks the scaling), that the spatial stochastic structure predicted by phenomenological cascade models is obeyed to within $\pm 1\%$. We also examine the cascade sructure in the temporal domain; we find that it has a break in the scaling between the meteorological (less than $\sim$20 days) and climate (greater than $\sim$ 100 days) regimes. The temporal behaviour is also discussed with the aid of space-time (Stommel diagrams) to which we give a rigorous interpretation. We discuss how to exploit stochastic cascade structure to improve current forecasting methods, including applications to stochastic parametrisations.