Atmospheric Predictability

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Initial-Condition Errors: Scale Sensitivities

Consider two different questions

- Is upscale error growth important?
  - (even if it is not exactly a “spectral cascade”)

- Given initial errors of fixed absolute magnitude, does their horizontal scale influence predictability?
Lorenz’s 1969 Answer: Experiments A & B

Modified spectral turbulence model (Durran and Gingrich 2014)

“Evidently when the initial error is small enough, its spectrum has little effect upon the range of predictability.”

Implications of Experiment B were largely overlooked.
Small *relative errors* in the large-scales can destroy predictability.
Influence of Scale: Lorenz Model

- Small *relative* errors in the large scales rapidly propagate down to the smallest resolved scale.

- Those small-scale errors subsequently propagate back upscale as if they had simply originated in the small scales.
  - Upscale growth is responsible for the finite limit to intrinsic predictability

- No easy way to diagnose the scale of the “original errors”.
How relevant is the Lorenz model?

- It does not include
  - Baroclinic instability
  - Deep convection
  - Inhomogeneity and nonstationarity

- Nonlinear effects are incorporated only crudely.
- Incorrectly assumed $k^{-5/3}$ slope for the background KE spectrum at large-scales.

- Deep Convection?
Error Growth in Observed Convective Systems

• Four cases: both weakly and strongly forced systems
  • 24-hr control simulations
  • WRF model, 2.5 km horizontal grid spacing
  • GFS analysis for initial conditions
  • Six ensemble simulations branch off each control at hour 6

• Different *background* perturbations among ensemble members in the near-surface moisture field
  • Monochromatic square wave in horizontal, random phase
    • **Small-scale ensemble**: $x$ & $y$ wavelengths 20 km ($\lambda = 14$ km)
    • **Large-scale ensemble**: $x$ & $y$ wavelengths 200 km ($\lambda = 140$ km)
  • Perturbation amplitude of *1% of control moisture field*
  • 1-km e-folding decay scale away from the surface
Synoptic Overview

- Sea-level pressure
- 500 hPa heights
- 500 hPa vertical velocity (contours)
Control Simulations

- Simulated composite reflectivity
- 12 hours after initialization from GFS
- Hour 6 in the ensembles
- 2.5 km horiz. resolution
Perturbation KE Growth: April 2017 Case

\[ \lambda = 14 \text{ km} \]
\[ \lambda = 140 \text{ km} \]
Fractions Skill Score

- **1 mm/hr precip threshold**
- **5, 20, 80 km verification radii**
- **Weak forcing:** 14-km perturbations grow faster than 140-km perturbations
Influence of Scale – Convective Systems

- Equal amplitude 1% humidity errors at 14 and 140 km produce:
  - Similar losses in predictability in strongly forced cases
  - More rapid error growth in weakly forced cases

- Short-wavelength errors influence convective initiation
  - Important in weakly forced cases

- Long-wavelength errors influence convective organization
  - Important in strongly forced cases
Implications for data assimilation on the mesoscale

- Characteristic velocities at wavelengths of 200-400 km are 5 times larger than those at 2-4 km.

- Equal improvements:
  - (> 6-hr forecast) from reducing IC errors at
    2-4 km below 50%
    200-400 km below 10%
  - (equal absolute errors in KE')
Predictability and Microphysics

Fine-scale rain gauge network across ridge
MM5 vs Rain Gauges

Black: observations
Gray: MM5 forecast
MM5 vs Rain Gauges
WY 2005

Black: observations
Gray: MM5 forecast
Predictability and “Physics”

Don’t test a family of physics parameterizations in simulations using single deterministic initial condition!


Another measure of predictability

Fractions skill score

(Roberts and Lean, *MWR*, 2008)
Strong/Moderate Forcing

Synthetic radar reflectivity
Weak Forcing

Synthetic radar reflectivity
Implications for data assimilation: I

Parseval’s relation

\[
\int_S u^2(x) \, dx = \int_{-\infty}^{\infty} \hat{u}(k)\hat{u}^*(k) \, dk
\]

KE in wavenumber band \((k_1, k_2)\)

\[
E(k_1, k_2) = \int_{k_1}^{k_2} \hat{u}(k)\hat{u}^*(k) + \hat{v}(k)\hat{v}^*(k) \, dk
\]
Implications for data assimilation: II

- $k^{-5/3}$ KE spectrum

$$\frac{E(k_1, k_2)}{E(k_3, k_4)} = \frac{\lambda_1^{2/3} - \lambda_2^{2/3}}{\lambda_3^{2/3} - \lambda_4^{2/3}}$$

- Ratio of velocities in 200-400-km band to those in 2-4-km band is 0.21

- Which is the easier goal?
  - Reduce errors at 200-400 km below 10%
  - Reduce errors at 2-4 km below 50%
Error saturation (KE’/KE) in layer 10 < z < 12 km

- Similar errors at 12 hr in all cases
- Small-scale errors produce more saturation at 6 hr in the weakly forced cases
  - More variation in CI