Intrinsic Hurricane Predictability

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Project Overview

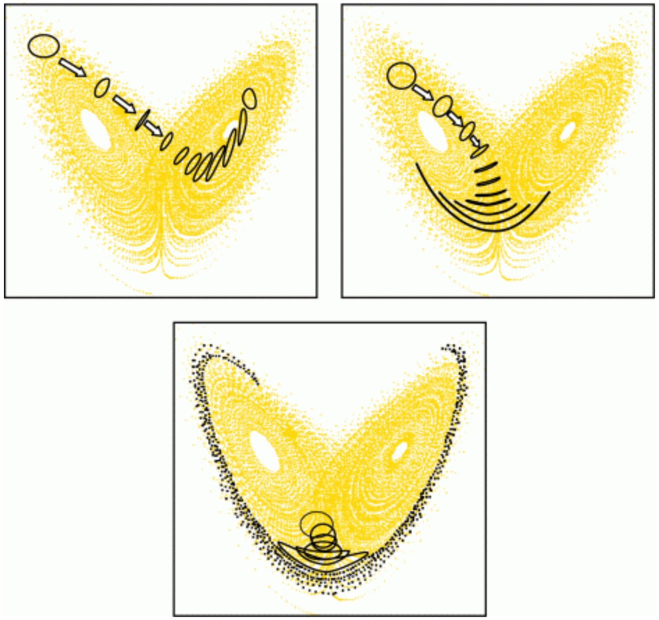
- Mainly concerned with understanding the limit of hurricane predictability
- It is unclear what improvements one should expect, since the fundamental predictability of tropical cyclone structure and intensity is essentially unknown
  - A limiting factor in intensity forecasts
- Knowing the "ceiling" is crucial for guiding improvements to future forecasts
- Critical for allocation of resources (i.e., targeting specific improvements more effectively)

- Goal: identify particular scales of motion that are the predominant limiting factors to improving forecasts

Three Limits on Predictability

1. Initial condition sensitivity ("chaos"): Lorenz (1963)

- Small initial errors grow ~ exponentially
- Fastest growing structures determine fate of forecast
    - May project across scales
    - Large time: Lyapunov vectors
    - Short time: singular vectors
- This is a <u>linear</u> perspective



Palmer (2006)

Three Limits on Predictability

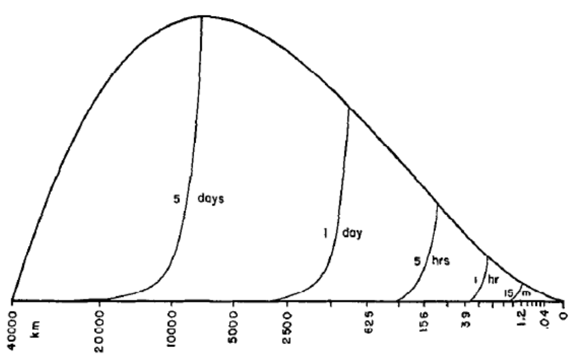
2. Turbulent cascades: Lorenz (1969)

- Upscale growth of errors limits predictability in time
- Depends only on shape of spectrum
  - Boundary between infinite and limited predictability is a characteristic slope of -3
  - Fundamentally nonlinear

The predictability of a flow which possesses many scales of motion

By EDWARD N. LORENZ, *Massachusetts Institute of Technology*[1]

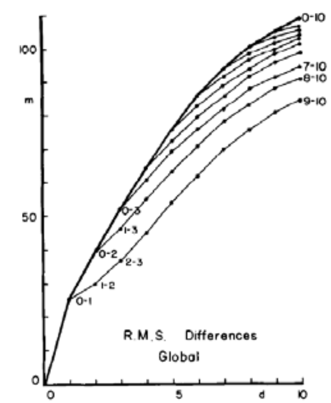
(Manuscript received October 31, 1968, revised version December 13, 1968)



Atmospheric predictability experiments with a large numerical model

By E. N. LORENZ,[1] *European Centre for Medium Range Weather Forecasts, Reading RG2 9AX, England*

(Manuscript received January 28, 1982)



Three Limits on Predictability

3. Boundary conditions and multiscale problems
   - "Predictability of the second kind"
     - Lorenz (1975); Charney and Shukla (1981)
   - Known forcing or slow component adds skill
     - E.g. ENSO, climate forecasting
   - Important beyond the weather "limit"

Predictability of First and Second Kind
(applied to tropical cyclone prediction)

- First kind: "intrinsic" TC-scale initial conditions
  - Internal storm dynamics
- Second kind: environmental "boundary conditions"
  - SST, shear, dry air intrusions, etc.

- How to separate? Very difficult with real storms
  - Simultaneous influences
  - Small sample size
  - Incompletely observed (verification difficult)

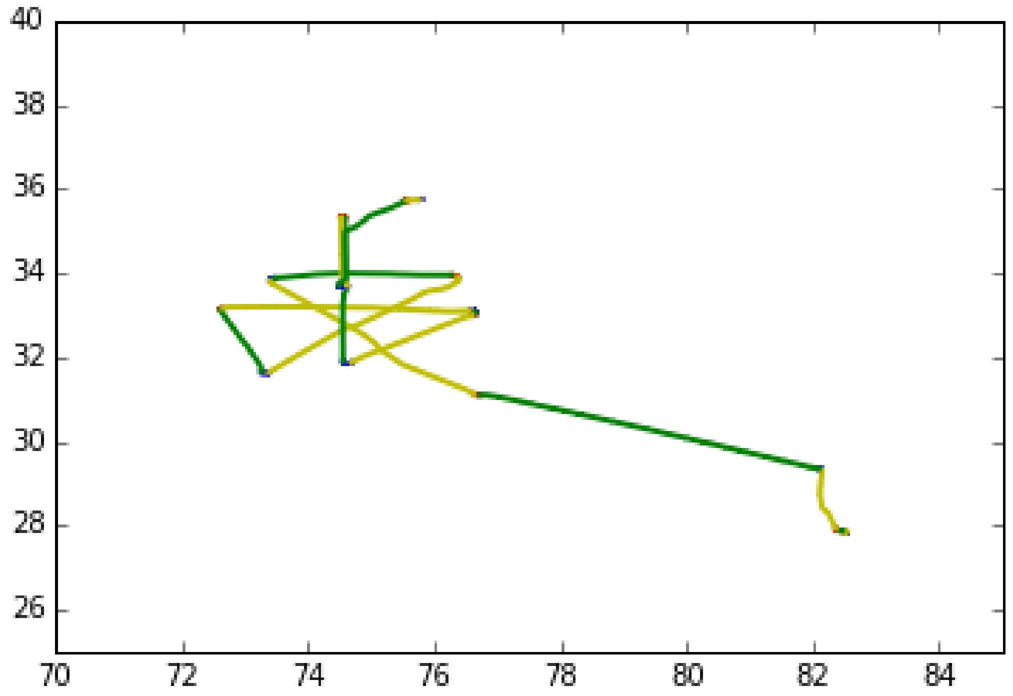
- Here, investigation is performed in two ways:
  1) Through estimation of the kinetic energy spectrum for hurricanes using only aircraft observation ("Type-1 predictability")
  2) Idealized numerical experiments simulating only the diurnal cycle ("Type-2 predictability")

Aircraft Observations
(Type-1 predictability)

- Analyze 1-second flight-level data for spectra
- Similar to, e.g., Nastrom and Gage (1985)
  - for the real atmosphere a -3 power law exists at large scales
  - transitions to a -5/3 power law around 300-500 km
  - -3 power law is boundary for predictability

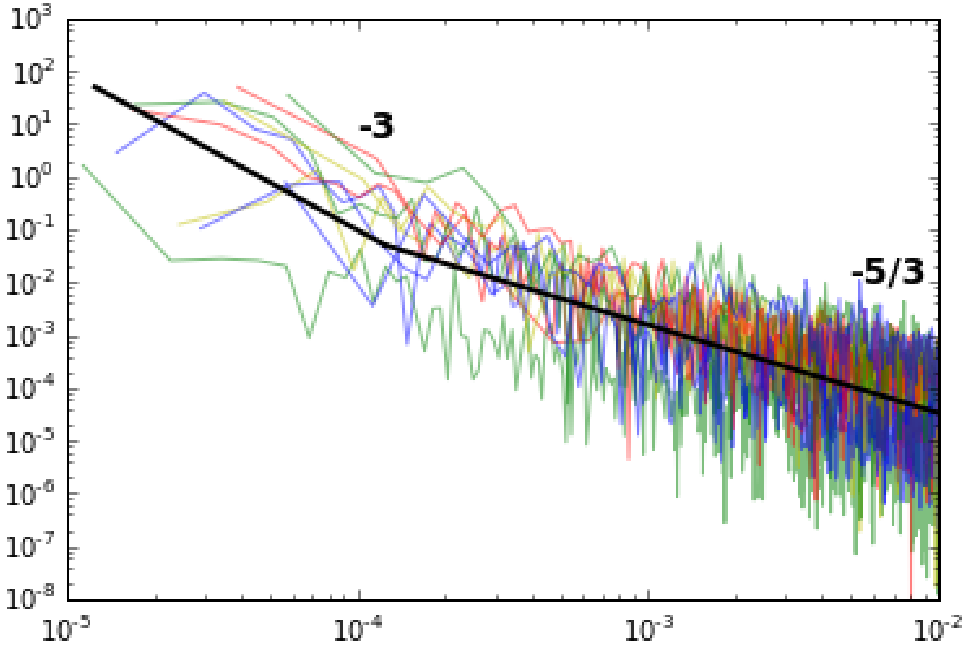
- Hypothesis for hurricanes: the kinetic energy spectrum has a -3 power law that extends to smaller scales (owing to the rapid rotation)
  - The larger scales are more predictable

Example Track Identification (Earl 2010)



Analyze flight data along tracks.

KE Spectrum



Transition shown at 100 km. Could be at shorter length scales.

Tropical Cyclone Diurnal Cycle
(Type-2 “predictability”)

- Solar cycle is a known forcing
  - Longwave radiation, clouds, etc. are not
- Diurnal “pulses” have been observed in real storms (Dunion et al., 2015)
  - Spatially coherent and highly predictable

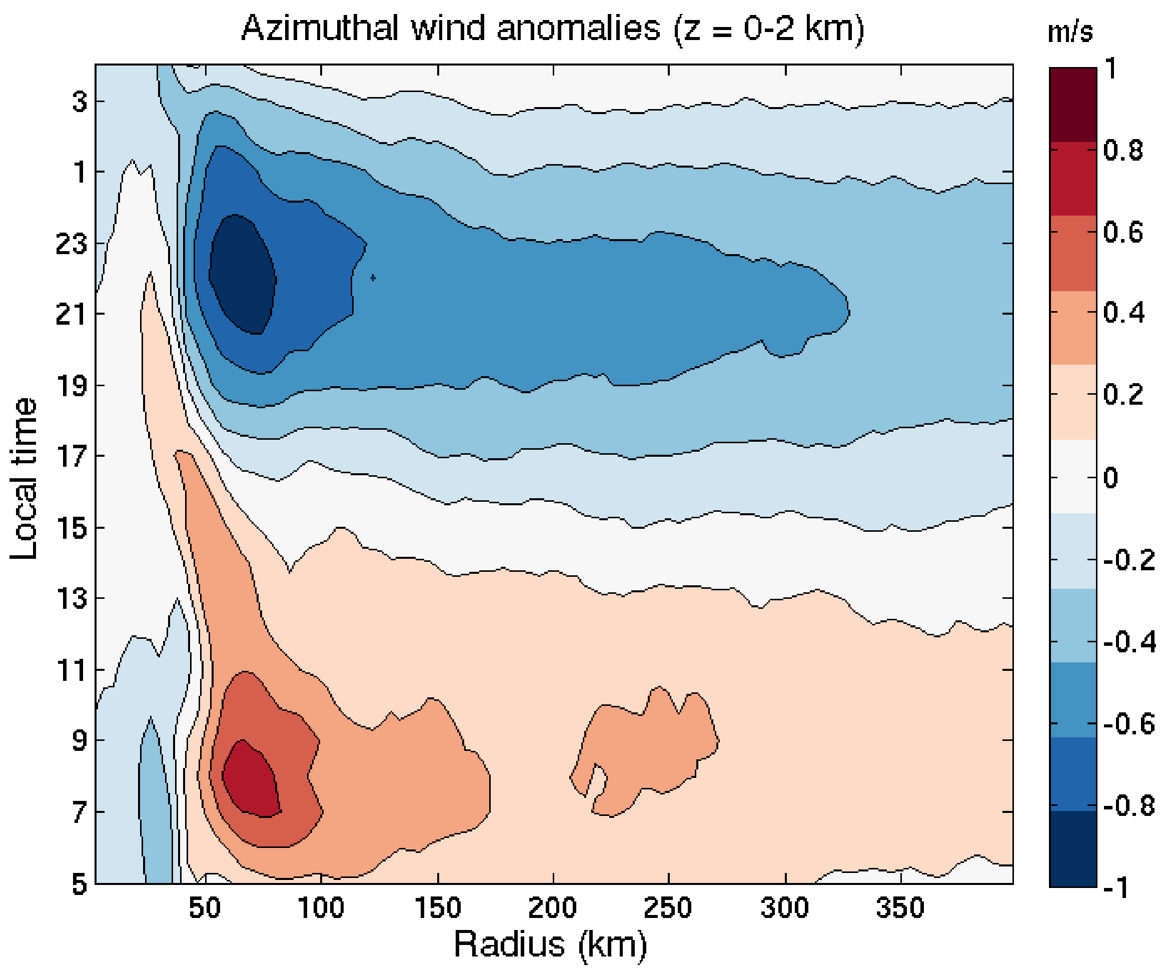
- Hakim (2011, 2013) and Brown and Hakim (2013) – radiation plays a critical role in tropical cyclone (TC) variability

- Although a signal in the high cloudiness has been well documented in the past, the impact of diurnal cycle on storm dynamics remains unknown

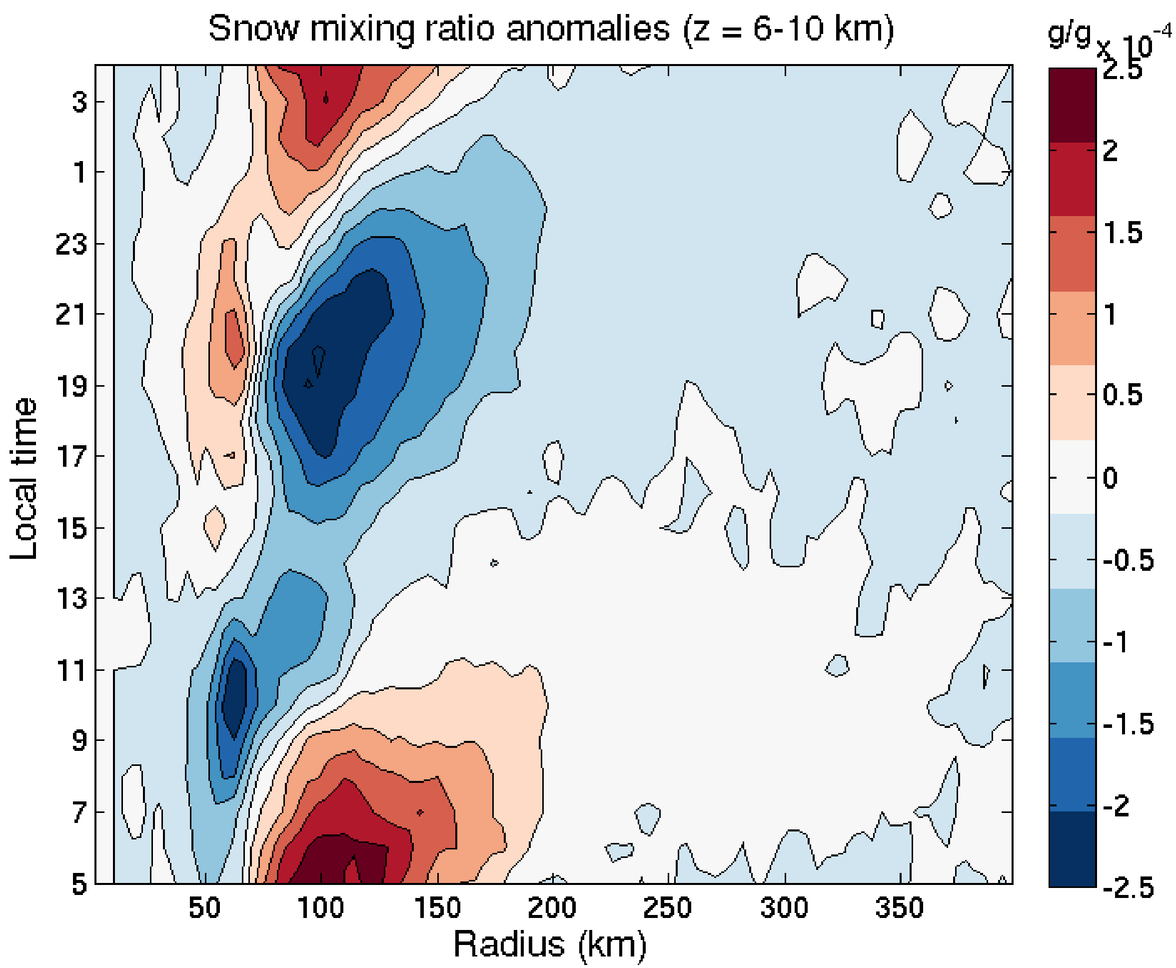
- Does this add any skill to structure and intensity forecasts?

- Conduct very long, idealized numerical experiments in Cloud Model 1 (CM1) with no exterior environment to determine the tropical cyclone diurnal cycle

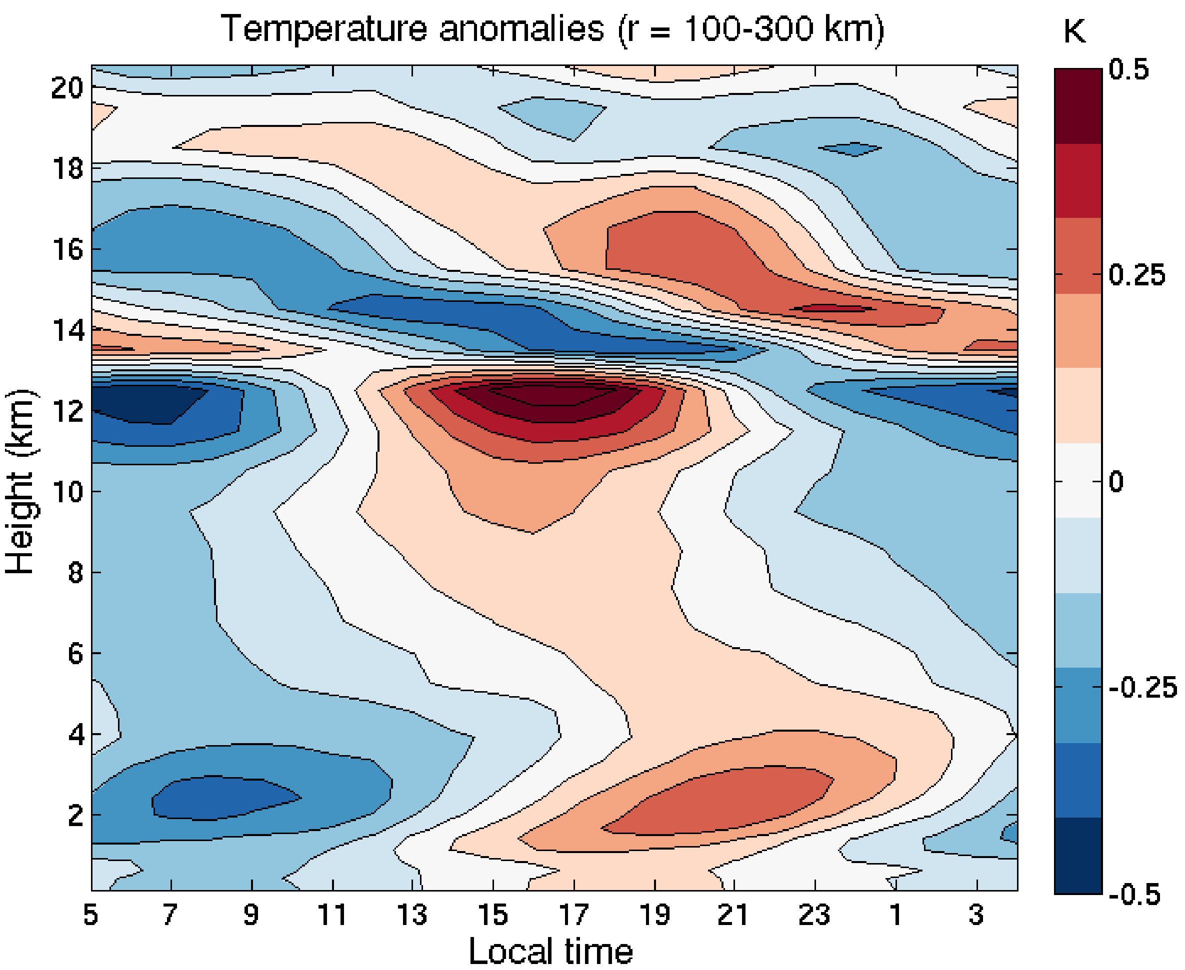
Idealized Experiments



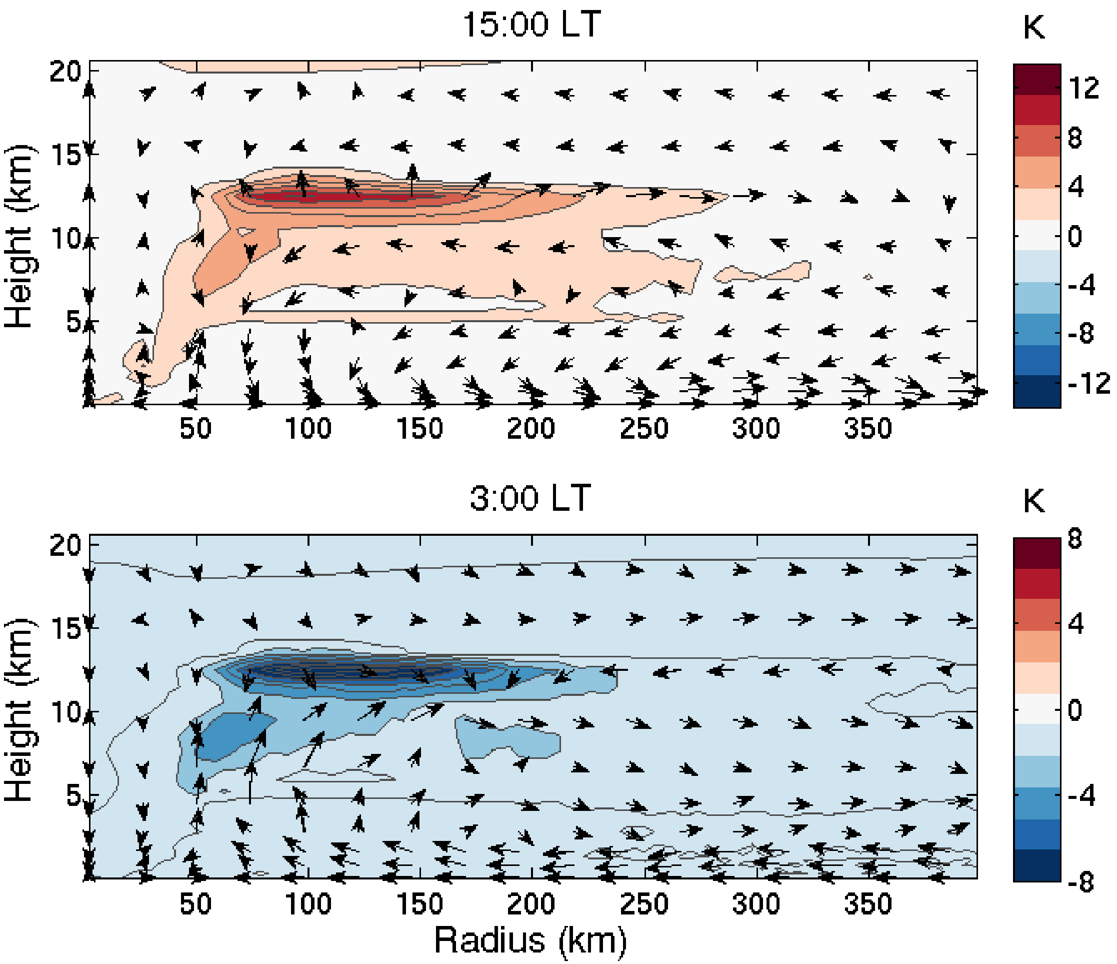
Idealized Experiments



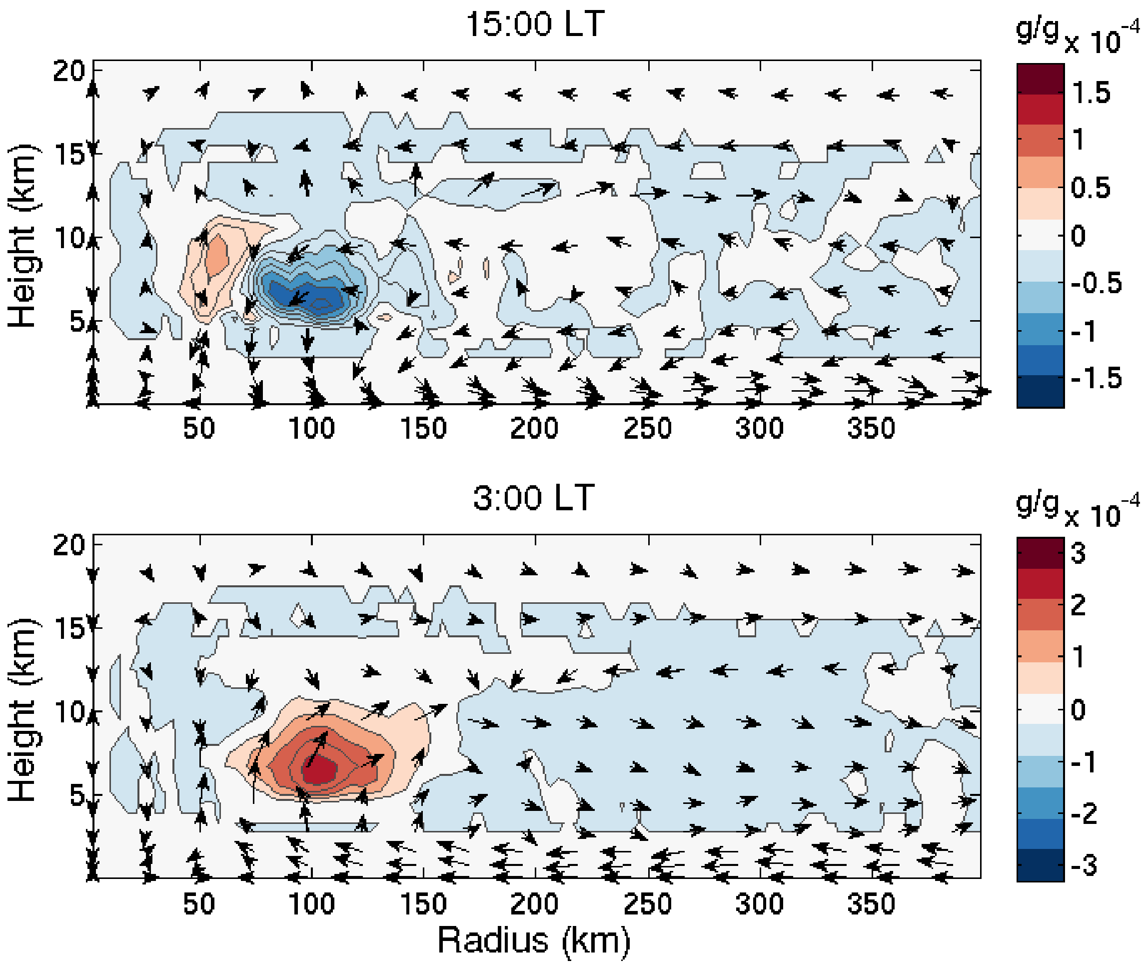
Idealized Experiments



Idealized Experiments



Idealized Experiments



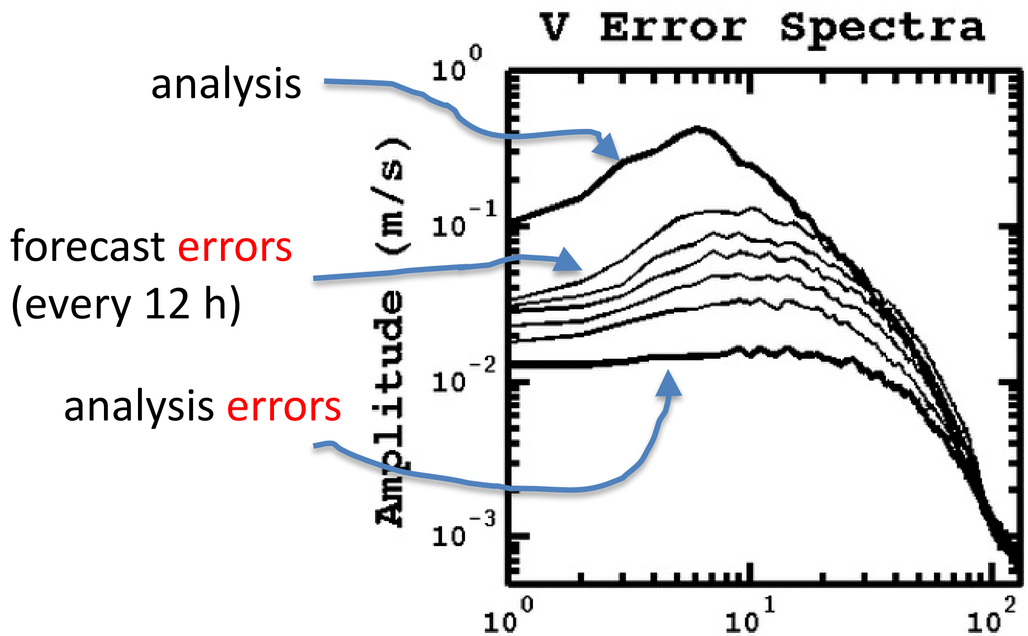
Summary

- The upper limit of tropical cyclone predictability is essentially unknown
- Knowing this limit is crucial for guiding improvements to our current TC forecasts
- This work seeks to identify this limit and determine the scales responsible for error growth in TCs
  - Performed (1) by evaluating the kinetic energy spectrum for hurricanes via aircraft observations ("Type-1 predicability") and (2) idealized experiments of the tropical cyclone diurnal cycle ("Type 2 predictability")

- Key Results:
  - (1) Kinetic energy spectrum of hurricanes shows an observable -3 and a -5/3 slope structure
    - Inflection point exists at smaller wavelengths (near 100~km) as compared to that of the global atmosphere
  - (2) Solar radiation adds predictability through an observable tropical cyclone diurnal cycle
    - Coherent signal in the wind and cloud fields that drives a local response within the storm
    - Impacts storm intensity

Thanks!

Which Process Dominates in Reality?



Hakim (2005)
From small ensemble of operational forecast systems
Applies to 40°N

- Synoptic-planetary analysis error larger than saturation on mesoscale
- Rapid growth on synoptic scale, suggestive of linear instability
- Peak migrates only slowly upscale

What does these spectra look like for tropical cyclones?