

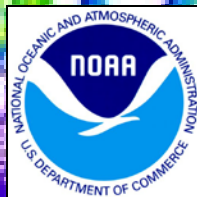
Assimilating Coherent Structures

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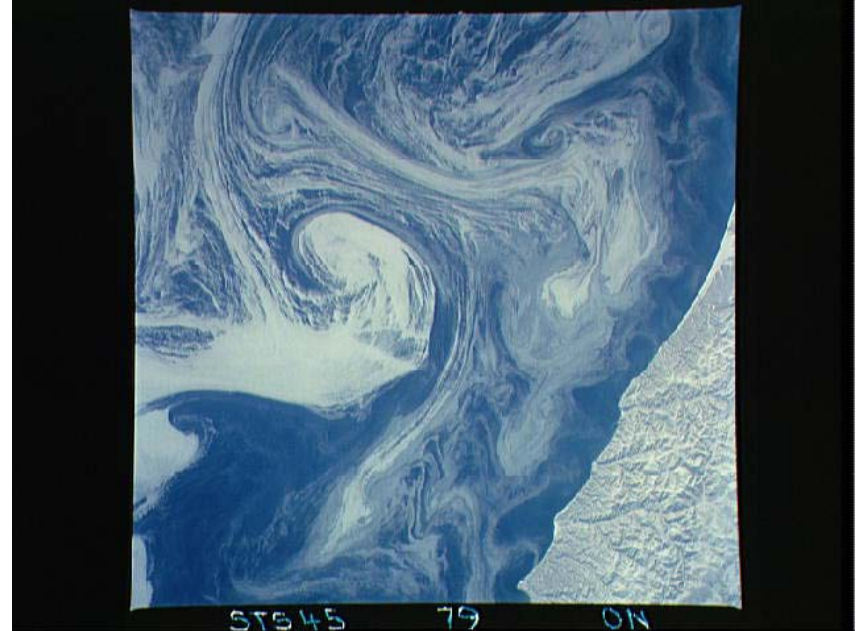
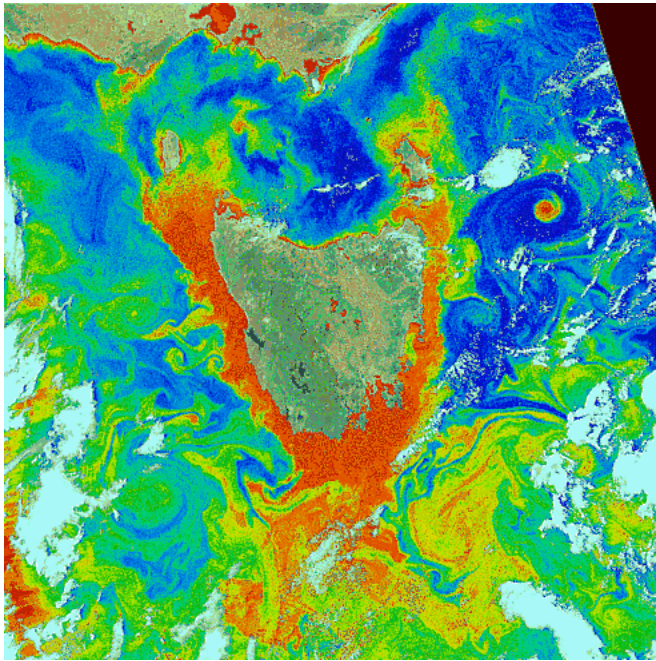
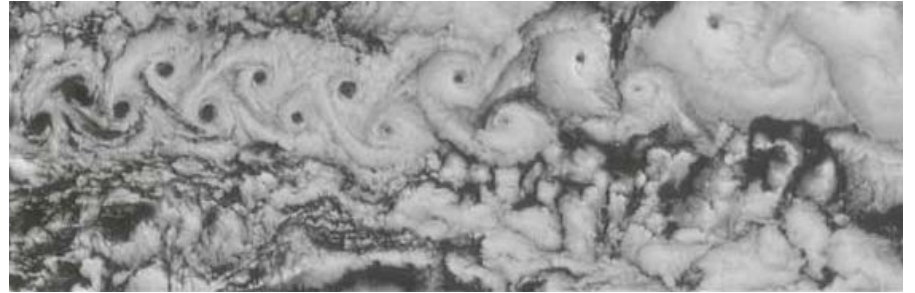
(Beechler et al 2010)



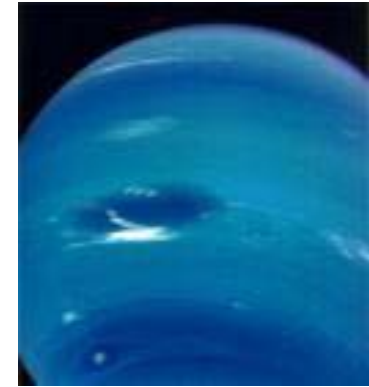
Outline

- Coherent structures in atmosphere and ocean
- Structure assimilation in weather forecasting
- Speculations on climate

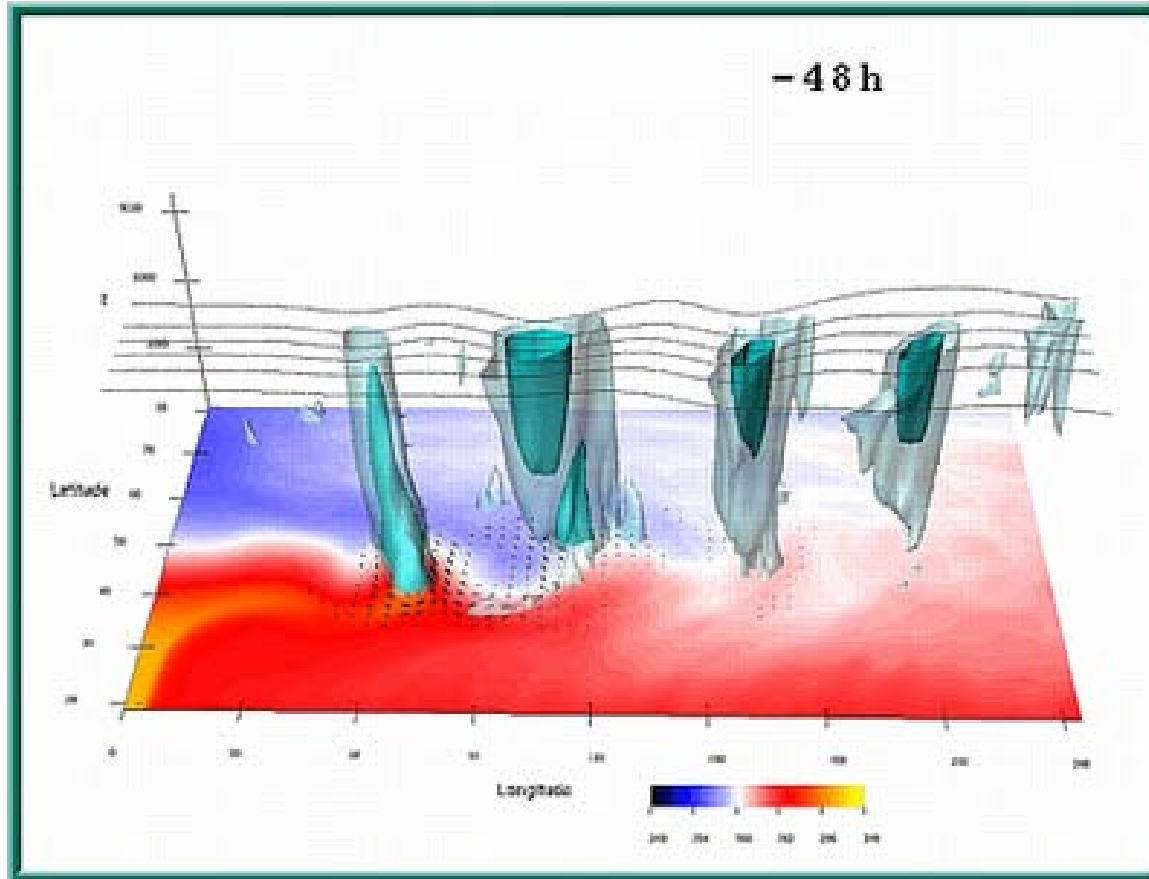
1. Structures Ubiquitous



atmospheric vortices

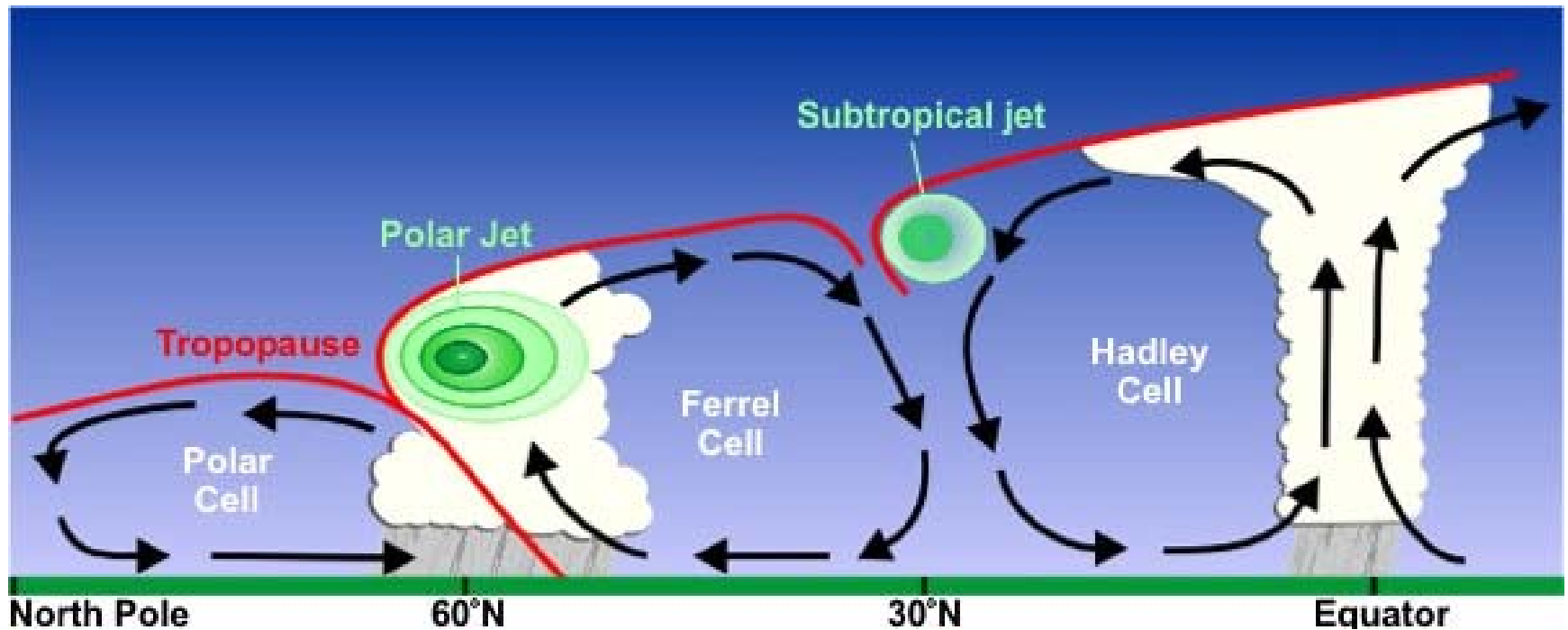


baroclinic lifecycle

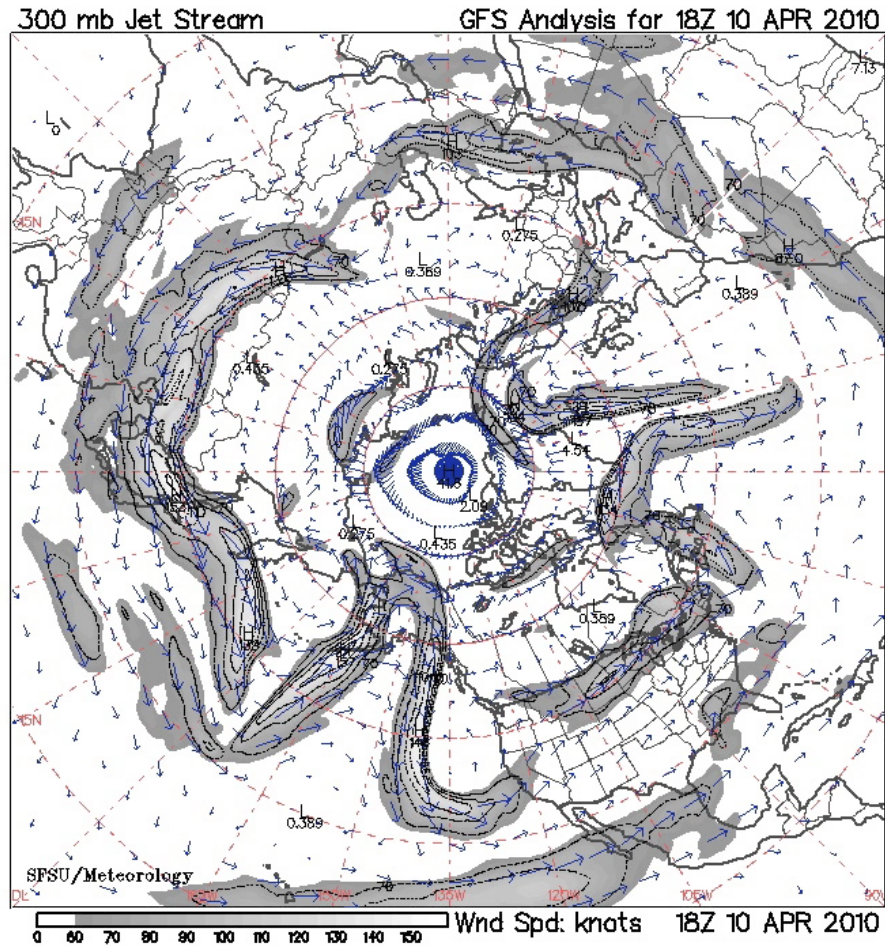


Orlanski and Gross, 2000

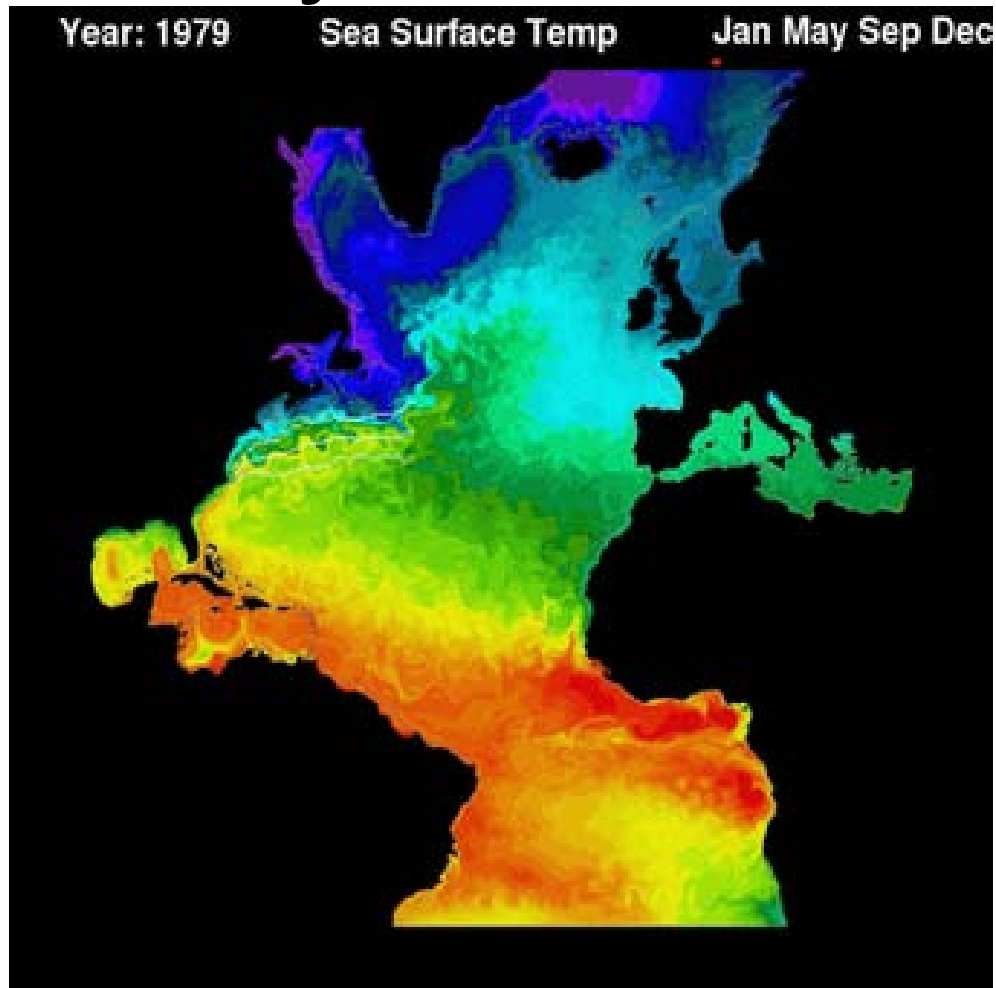
Atmospheric jet stream



10 days of the Jet stream



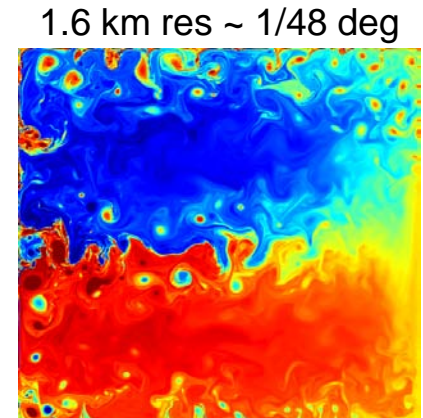
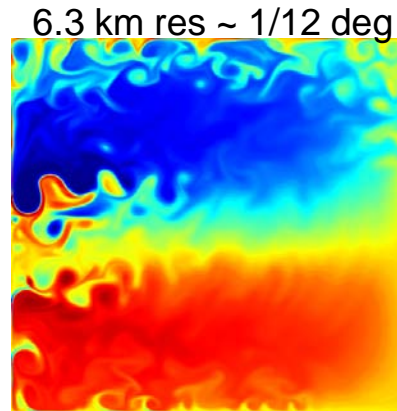
ocean jets and vortices



MICOM Ocean GCM

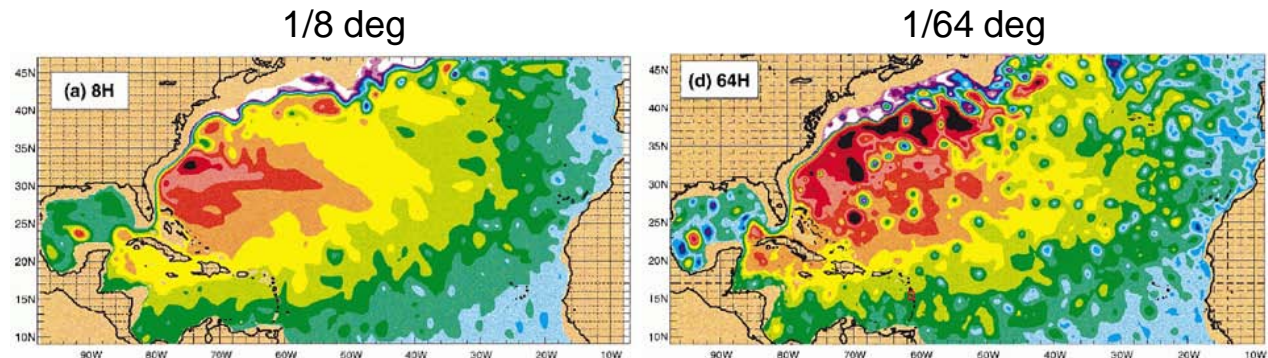
ocean coherent vortices

- Evidence for an “explosion” in coherent vortex population as Re increases
- QG ocean gyre



(Siegel, et al, 2001)

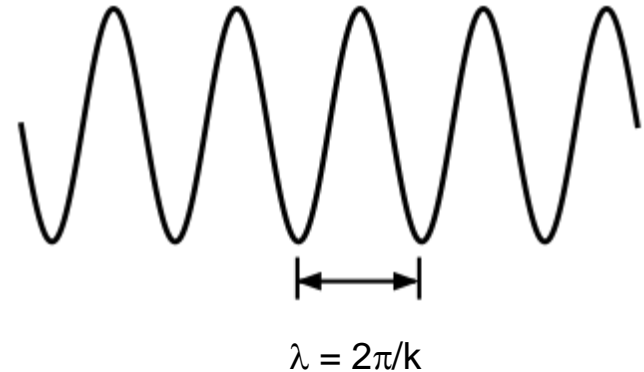
- NRL NLOM



“a basin-wide explosion in the number and strength of mesoscale eddies” (Hurlbert and Hogan, 2000)

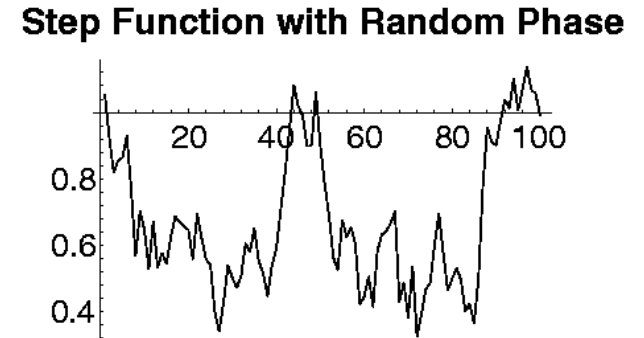
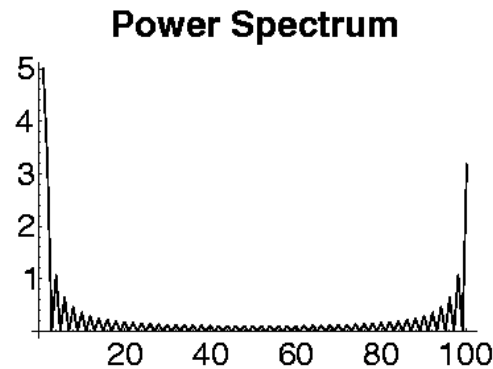
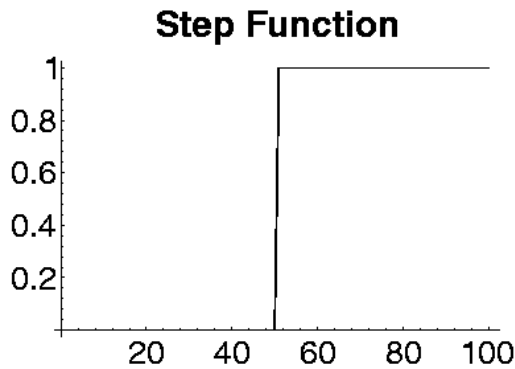
traditional turbulence theory

- treats fluid as random
- focus on Fourier space
 - “eddies” with scale $k \sim \cos(kx)$
 - but waves are not structures
- main concern is spectra
 - $E(k) \sim k^{-5/3}$ in 3d homogeneous isotropic
 - $E(k) \sim k^{-3}$ in 2d



phases are not random

- traditional theories of turbulence:
 - wavenumber space: $A(k)e^{i\phi(k)}$
 - random phase approx. common
- structures:
 - local in physical space
 - random phase approximation fails

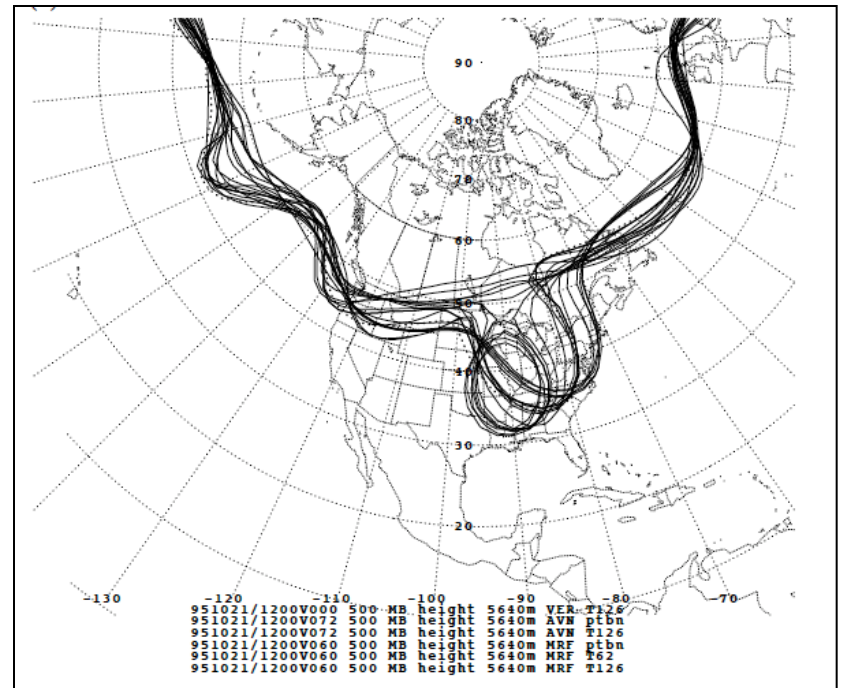


structures and human impact

- structures have enormous human impact
 - hurricanes
 - tornados
 - storms
 - jet stream path
 - Gulf stream

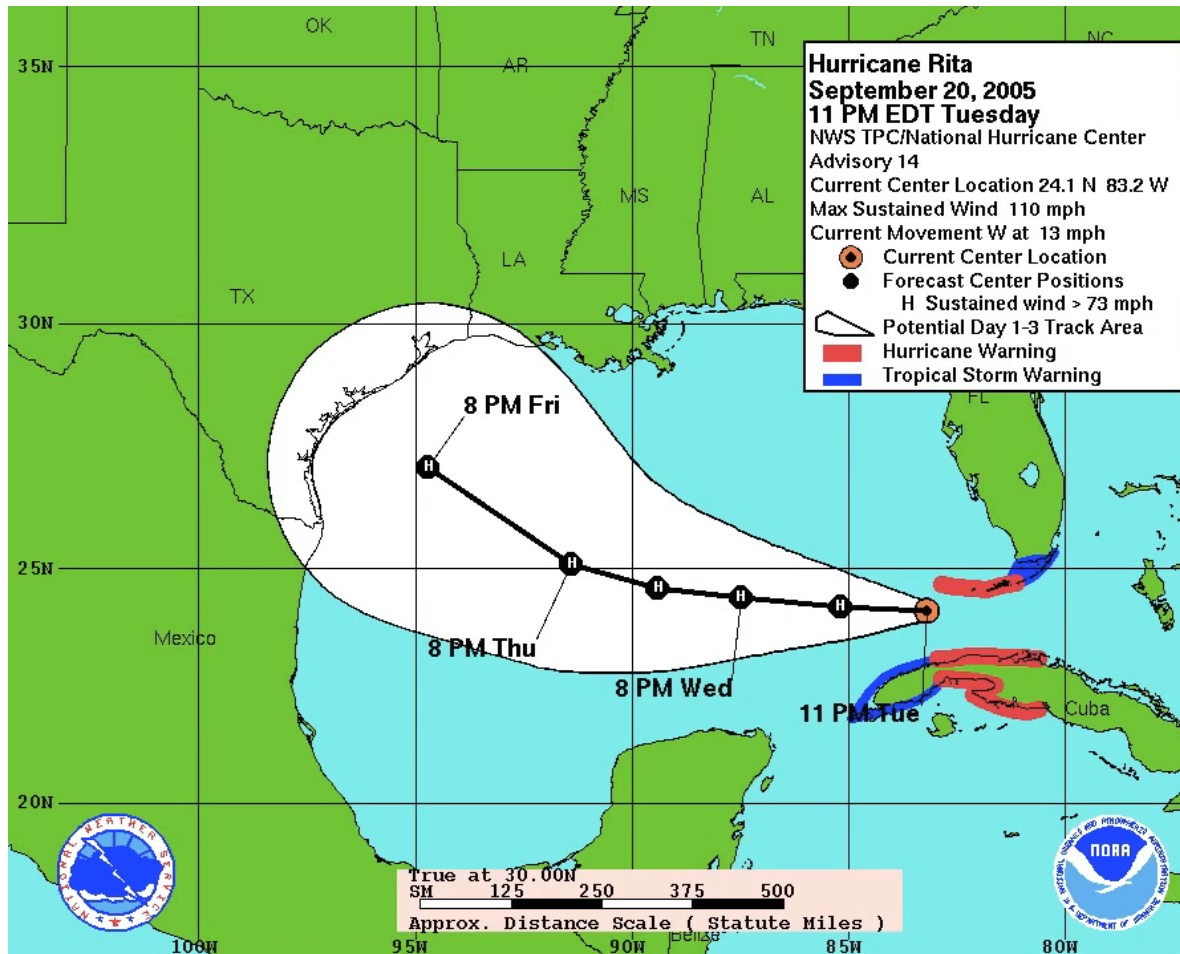
2. Forecasting structures

- Models often fail at predicting path of structures
 - Storm in wrong place
 - Hurricane track
 - Jet stream position

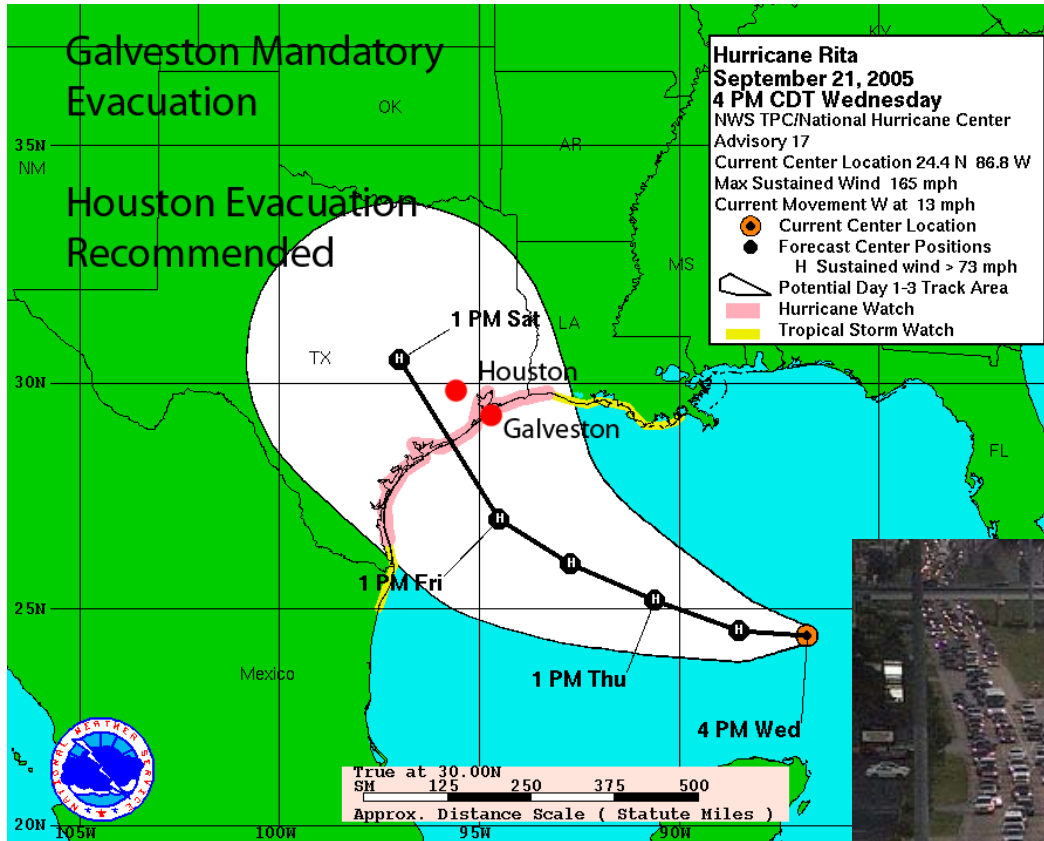


Kalnay et al 1998

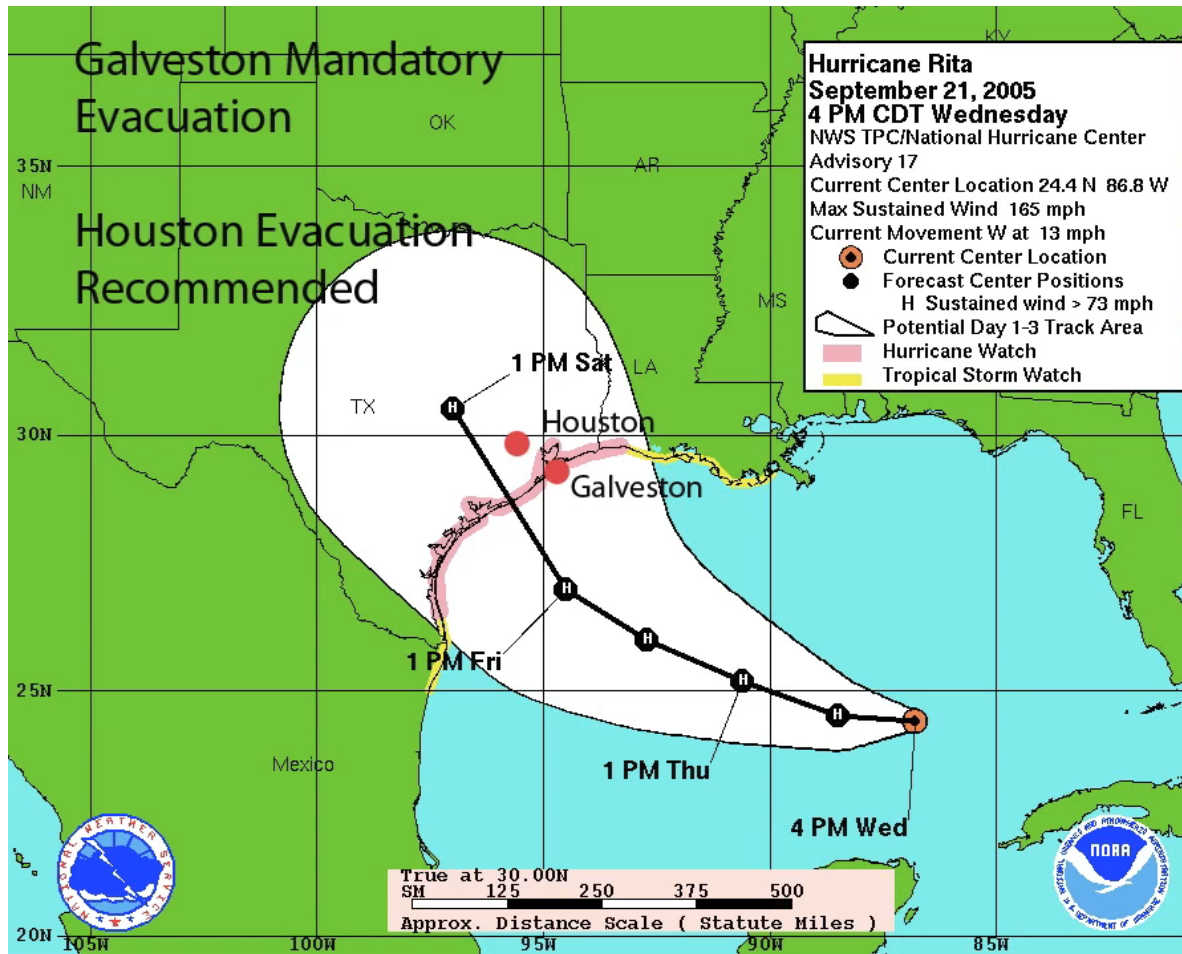
Hurricane Rita



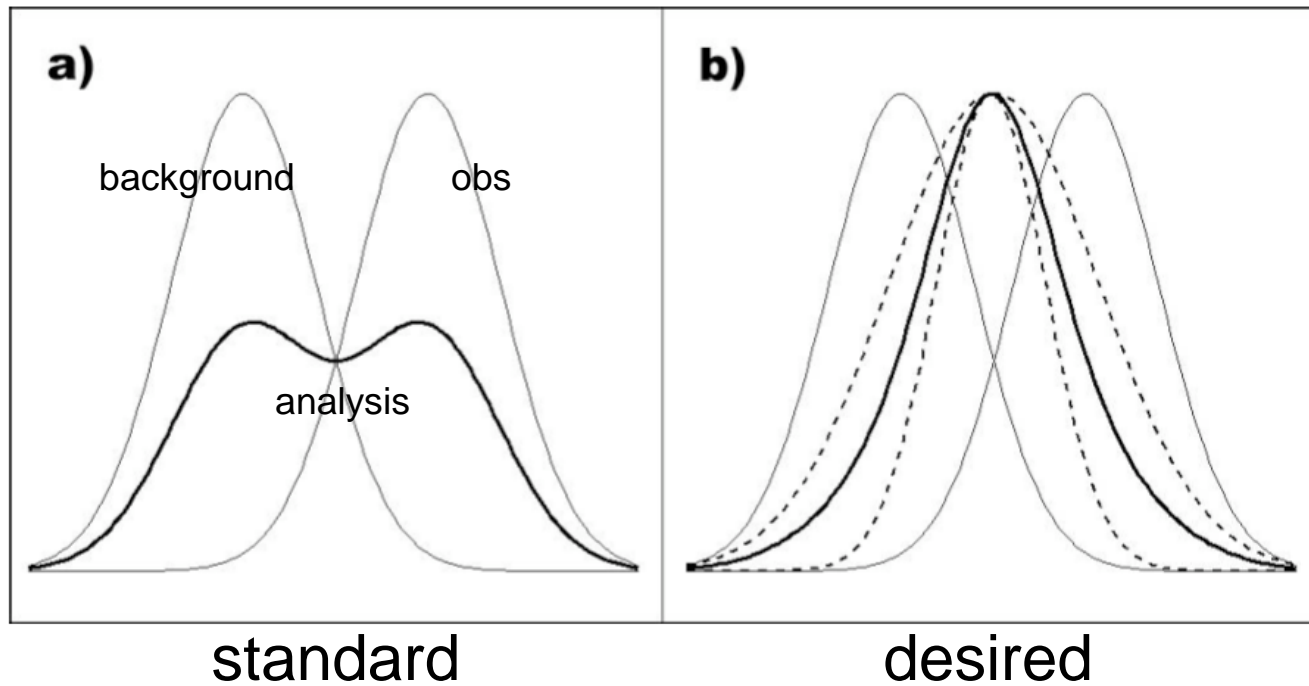
Hurricane Rita



Hurricane Rita



- Standard assimilation techniques smear structures



Structure based assimilation

(Beechler, et al 2010)

- Assimilate location and properties of physically localized structures
- propose methodology
- implement in idealized model
- Example: Gaussian bump $u(x) = Ae^{-(x-x_0)^2/2\sigma^2}$
 - Structure variables:
 - Amplitude A
 - location x_0
 - width σ

modular method

- desire technique that can work in many scenarios
 - variety of structures
 - variety of assimilation strategies
- partition into three independent steps
- follow with traditional assimilation

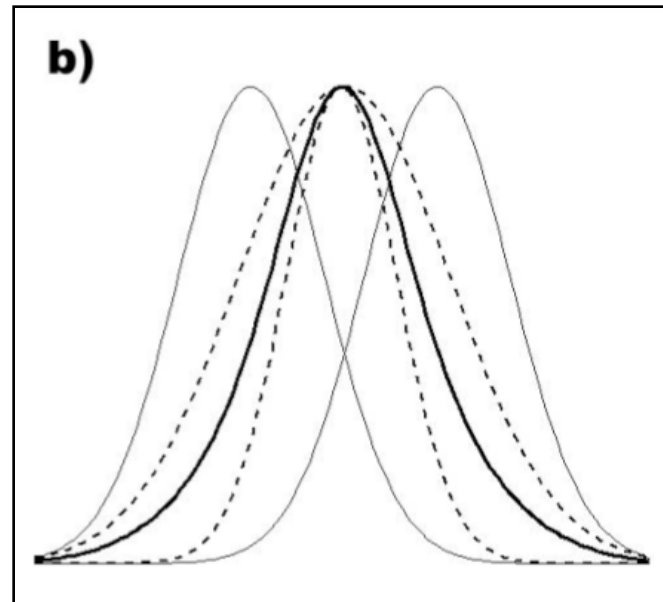
Step 1. Identify structure

- many different structure identification techniques
 - subjective techniques
 - wavelets
 - manifolds
- successfully used in many fields
- output: variables describing the structure
- which structures are important?
- which variables give most improvement?

Step 2: Assimilate Structure

- structure variables in background and obs
- use your favorite data assimilation technique to create structure variables for analysis
- example

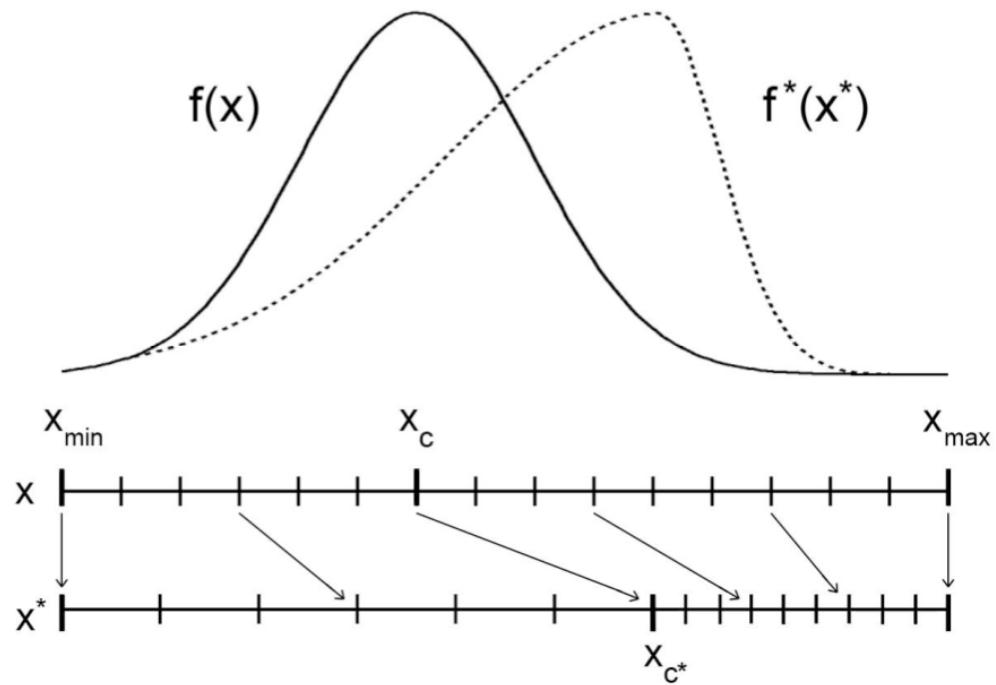
$$x_0^{analysis} = \frac{x_0^{background} + x_0^{observations}}{2}$$



Step 3: Create analysis

- Steps 1 and 2 use well developed ideas
 - room for improvement, particularly in identification
- difficulty: structure variables are not model variables
- propose: morph structures in background field to match analysis
 - move underlying model grid
 - remap onto original model grid

- example: move bump by 1D grid morphing



Nonlinear Data Assimilation

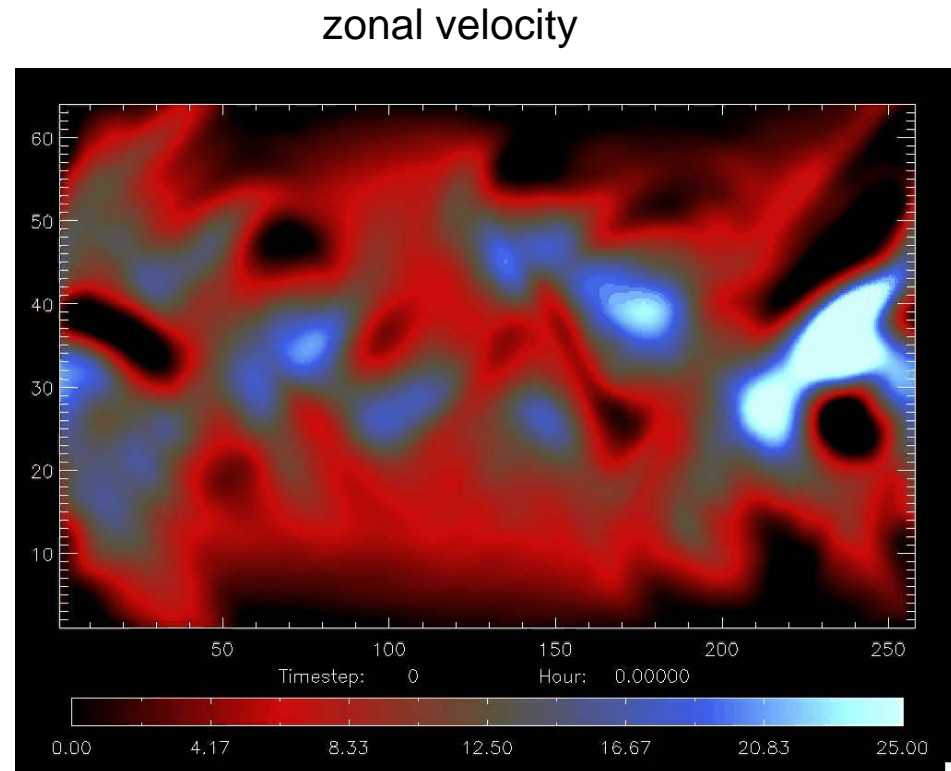
- “The study of non-linear physics is like the study of non-elephant biology.”

- Stanislaw Ulam

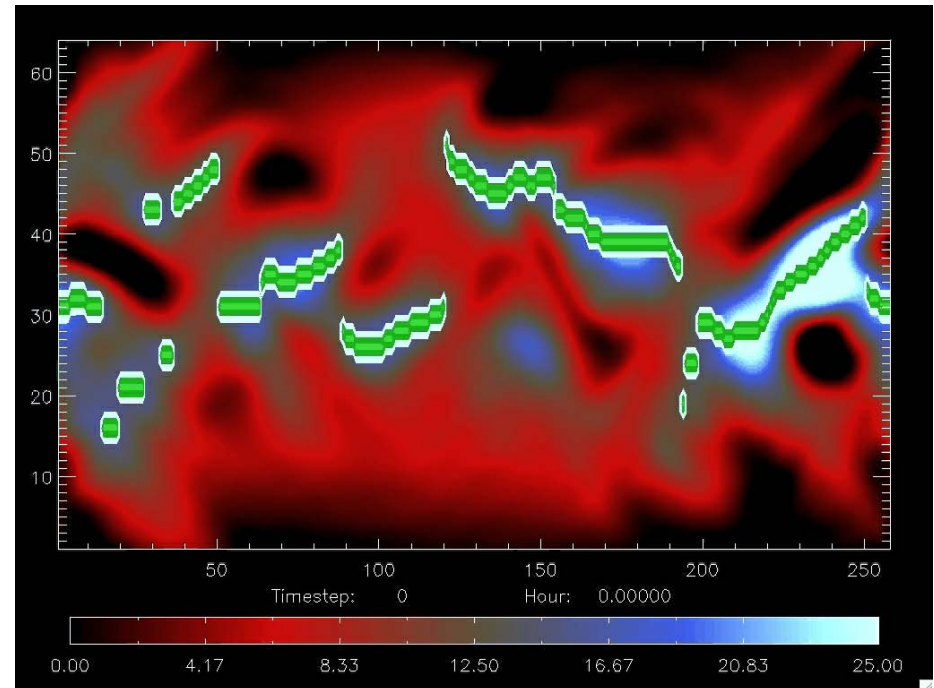
- Structures are empirical
 - rarely derived from equations
 - explore by observations, experiments, simulations
- Define nonlinear coordinate transformation
 - nonlinear transformation to structure coordinates
 - linear data assimilation of structure coordinates
 - nonlinear grid morphing creates analysis

Implement and test technique

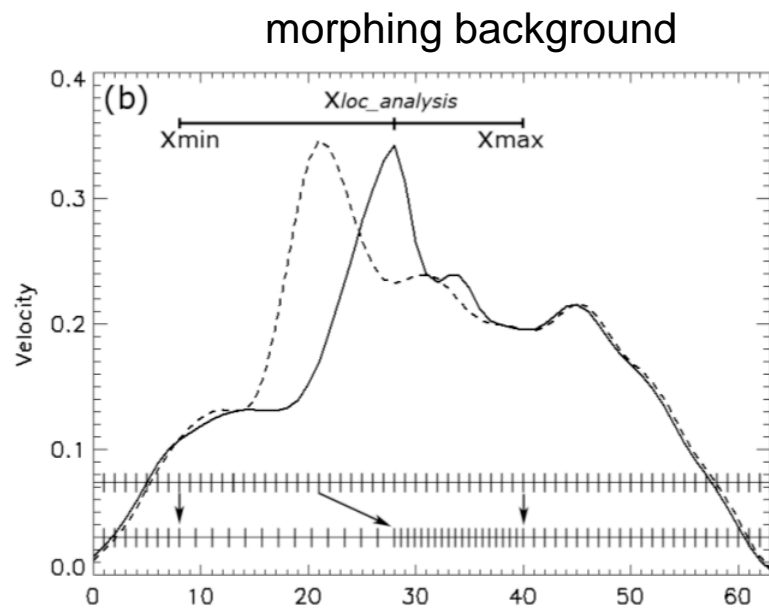
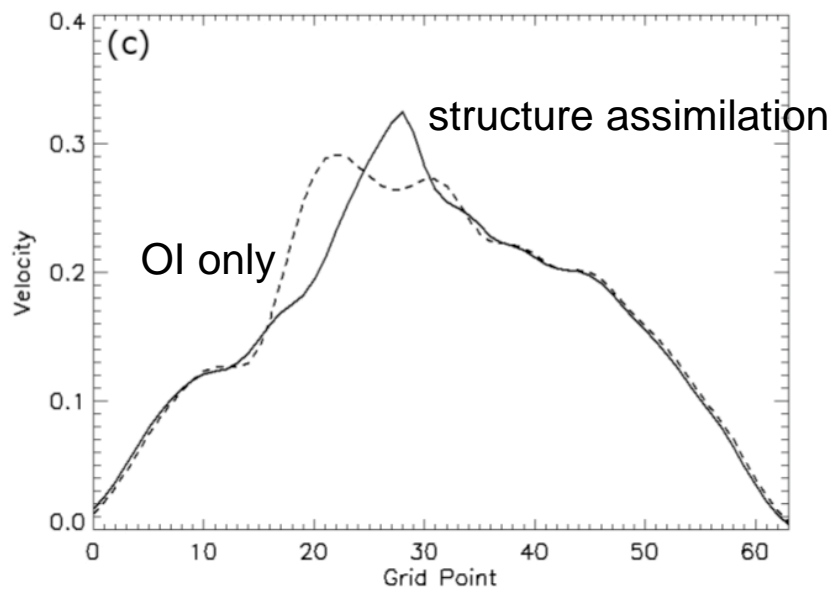
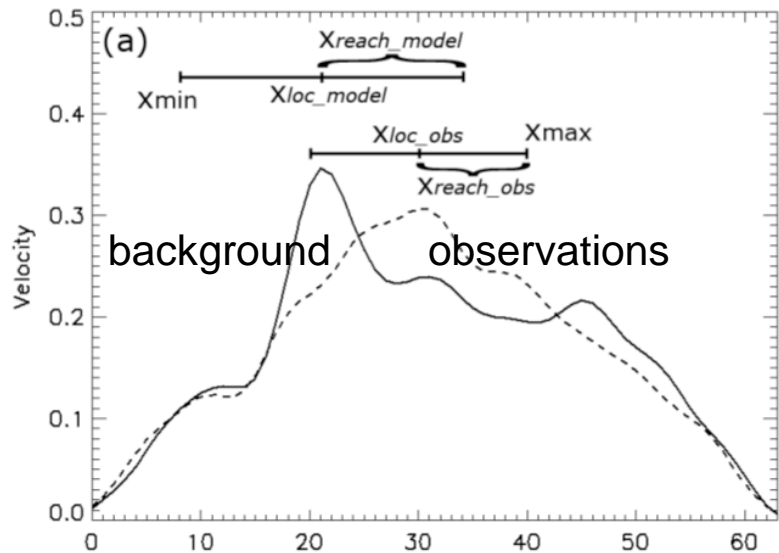
- Idealized atmospheric model with jet stream
- 2-layer
- quasi-geostrophic dynamics
- channel geometry
- perfect model scenario
- model twin configuration
 - truth
 - forecast



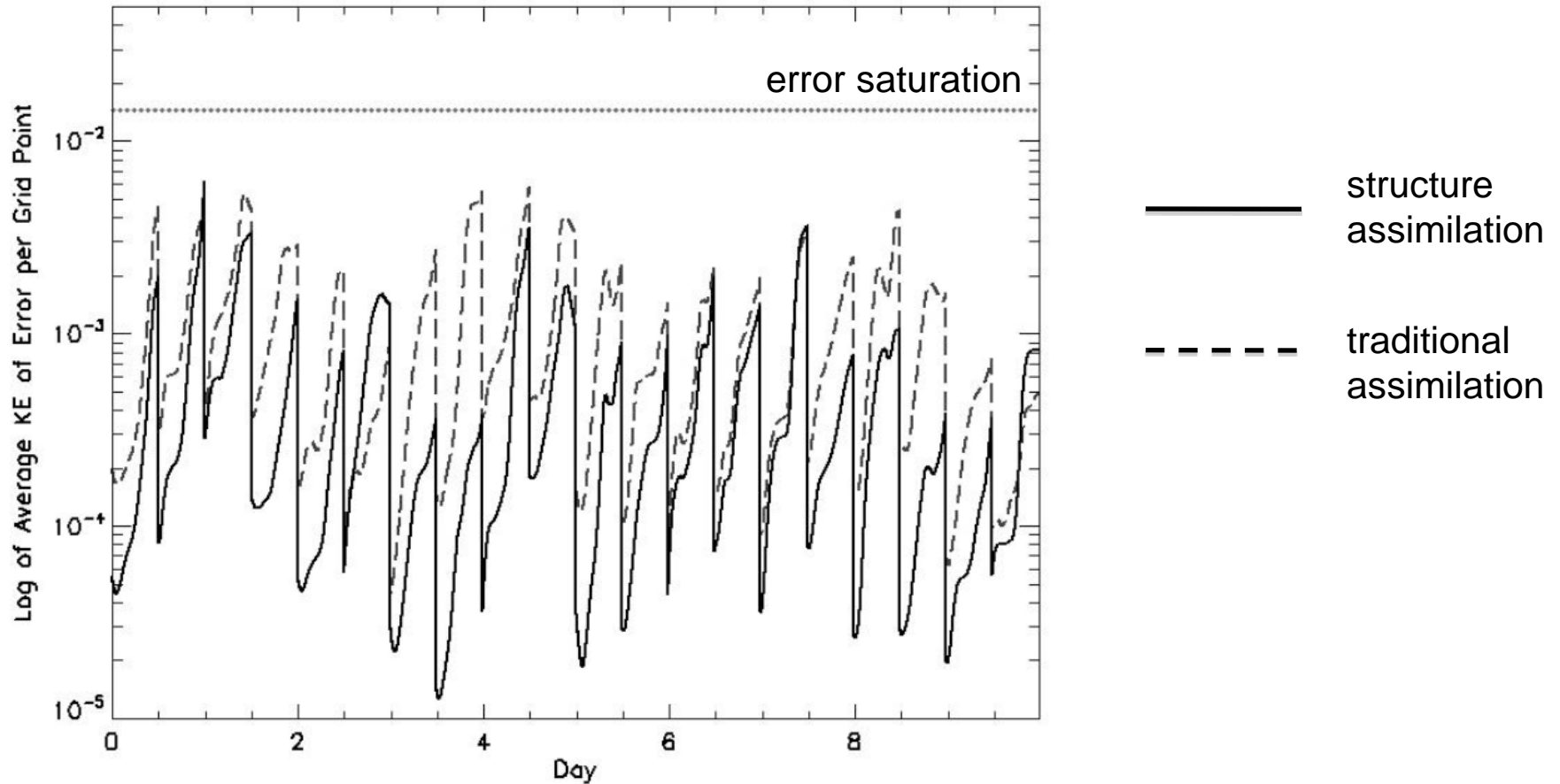
- Philosophy and experience: Simple inclusion of structure often gives significant improvement
- Step 1: 1D structure identification
 - at each longitude, identify latitude of jet
 - maximum of zonal velocity
 - only assimilate jet latitude



- Step 2: obtain analyzed jet latitude by optimal interpolation
- Step 3: 1D grid morphing
- test with 12hr forecasts



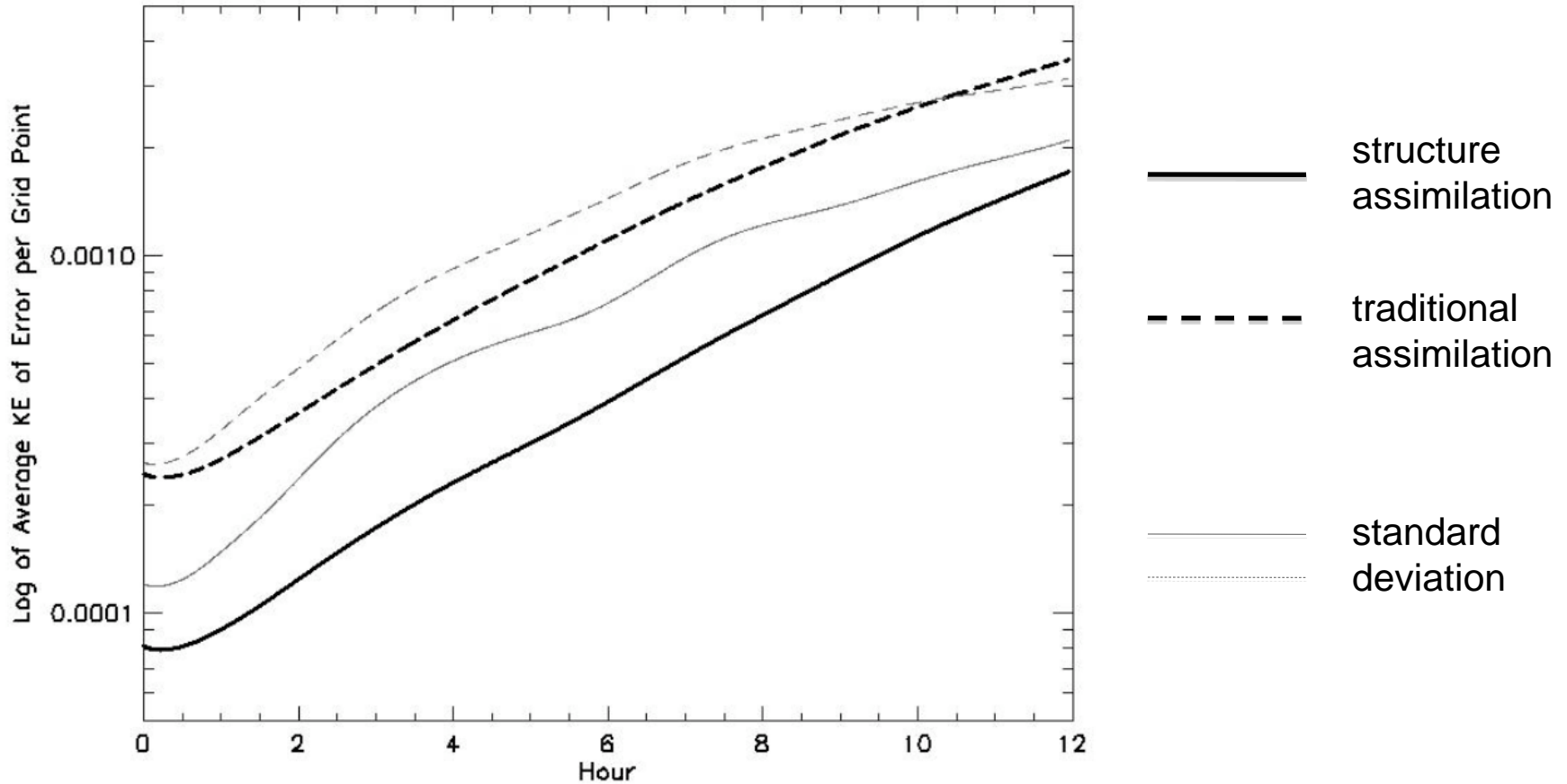
10 days of forecasts



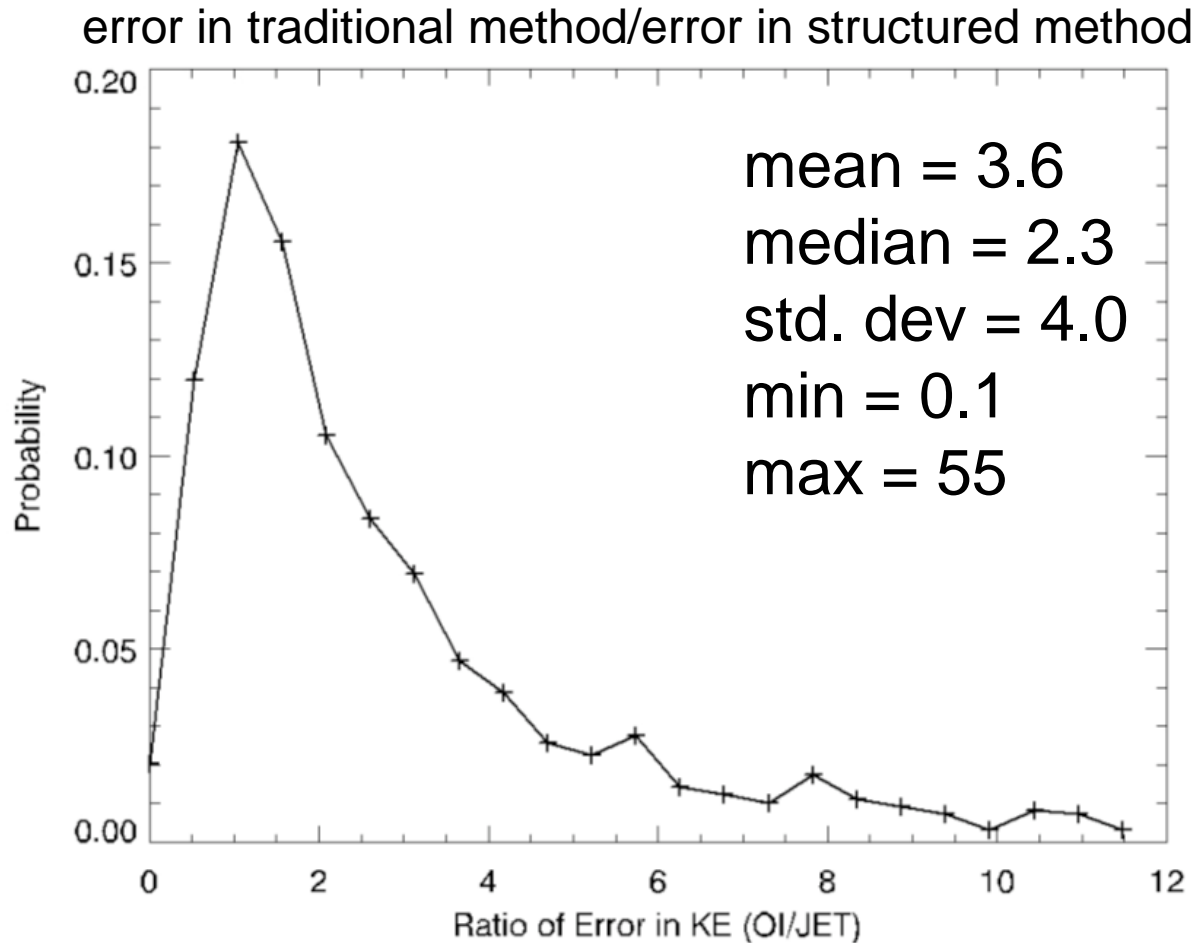
Structure assimilation has less error

Average improvement

10,000 forecasts



Distribution of improvement



3. Application to climate

- Context: seasonal to decadal and longer forecasts
- Assimilating structures improves initial condition
- Improves forecasts as long as memory of initial conditions matters
- Expect improvements when location and coherence of features important

- Model must be realistic enough to capture features
- Obs must capture features
- If assimilation destroys features, model must rebuild
- Jets: Monthly to ??
 - Gulf Stream, Kurishio, Antarctic Circumpolar Current
- Mesoscale eddies: Monthly to ??
- Thermocline: ENSO timescales, 5 years?

- Deep convection sites?
- Ice sheet margins?
- annular modes:
 - morph hemispheric grid N/S?
 - topography/coastlines?
- apply to time averaged features?

Summary

- Proposed modular method to assimilate structures in forecast models
- Implemented in idealized numerical weather forecast system
- On average, forecasts are significantly better
 - Spectacular successes and failures
- Much to do
 - Implement in more realistic models
 - 2D and 3D morphing: computer science community
 - Include other structures