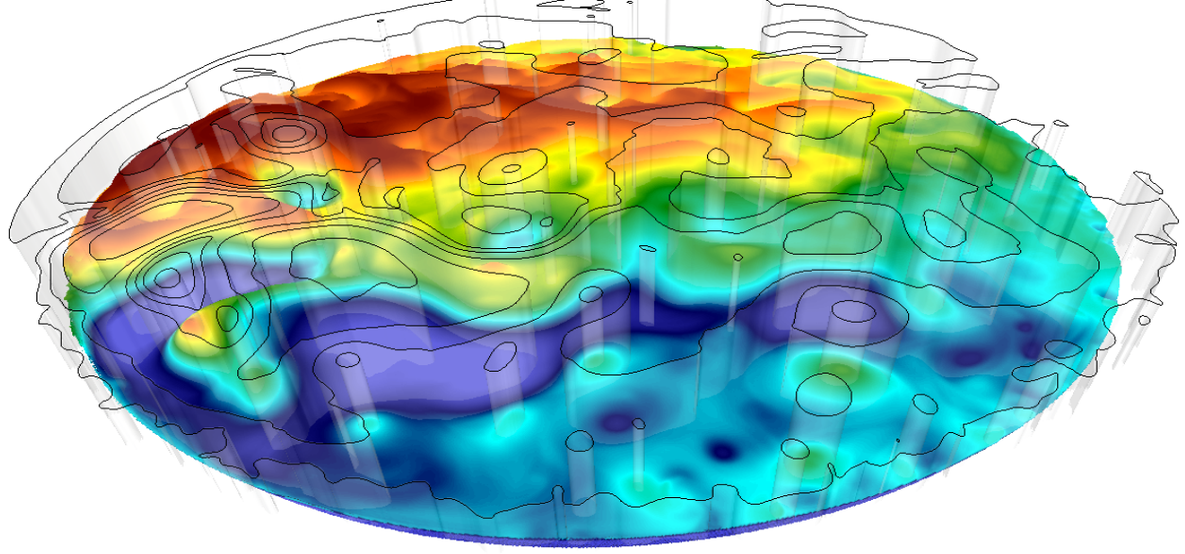

Computing Tensor Diffusivity from a Well-Resolved, Eddying Simulation

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LA-UR-15-20179

Climate, Ocean and Sea-Ice Modeling Project

Los Alamos NATIONAL LABORATORY EST. 1943

U.S. DEPARTMENT OF ENERGY | Office of Science

Motivation

Why tracer diffusivity [κ]?

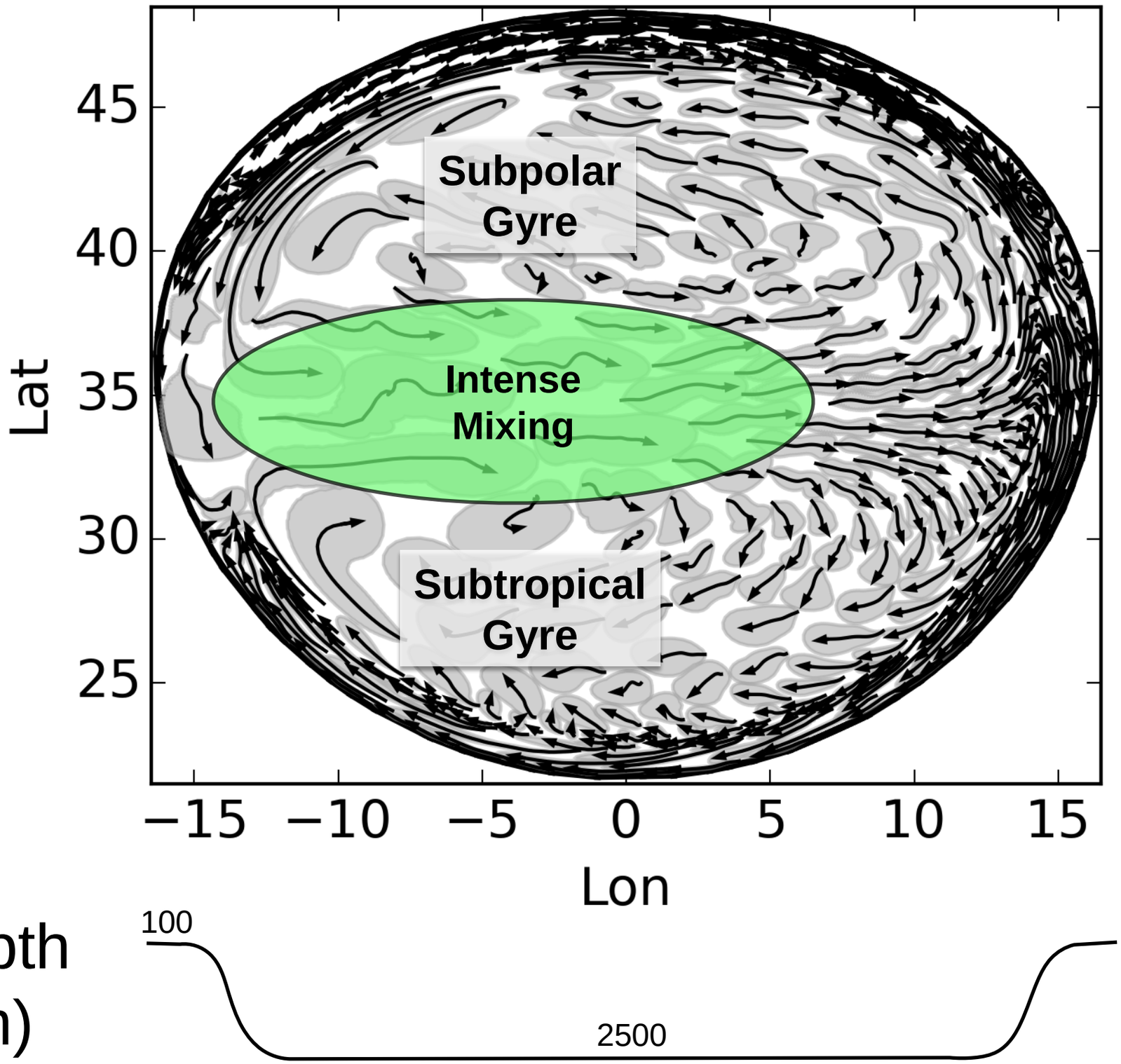
- Fundamental property of ocean circulation (observational estimates in progress)
- Isopycnal mixing key to ventilation of important climate system tracers:
  - Dynamically active tracers (temp, salinity)
  - Chemical and biological tracers
- Driven by mesoscale (baroclinic eddies)

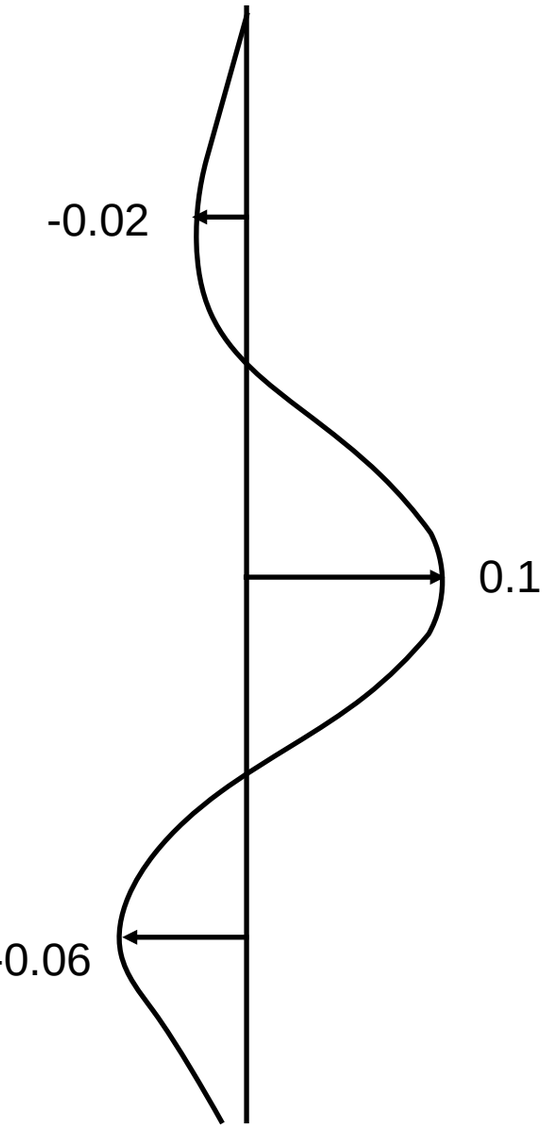
Outline

1. SOMA: **S**imulating **O**cean **M**esoscale **A**ctivity
2. Computation of diffusivity via LIGHT: **L**agrangian **I**n-situ **G**lobal **H**igh-performance particle **T**racking
3. SOMA Experimental design
4. SOMA Diffusivity
   A. Spatial structure
   B. Resolution dependence
   C. Scales of mixing
5. Summary

"Diagnosing isopycnal diffusivity in an eddying, idealized mid-latitude ocean basin via Lagrangian In-situ, Global, High-performance particle Tracking (LIGHT)", *Journal of Physical Oceanography,* in review.

Dynamics of the SOMA wind-driven double gyre system



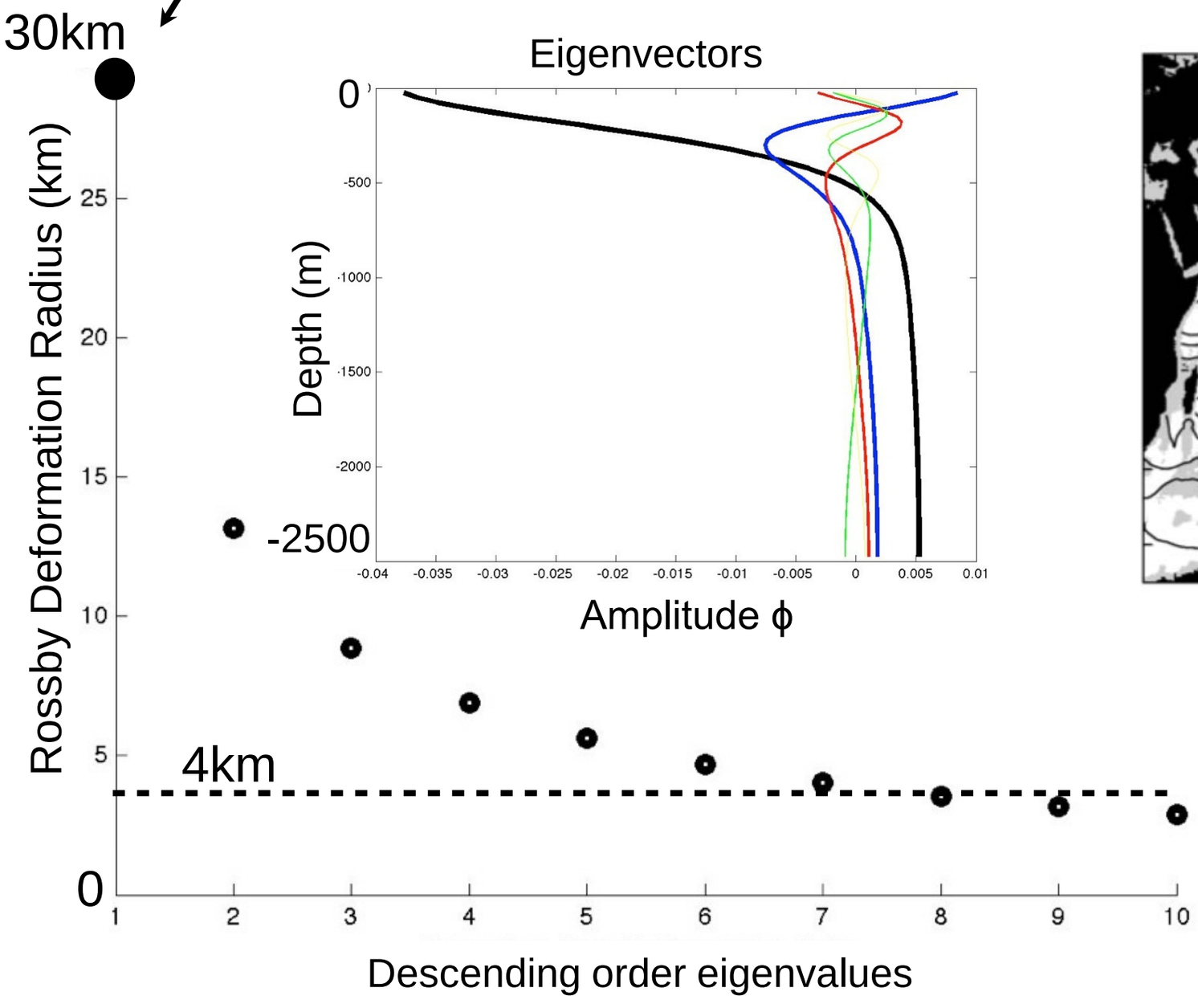


Wind Stress
(N m^{-2})

Depth
(m)

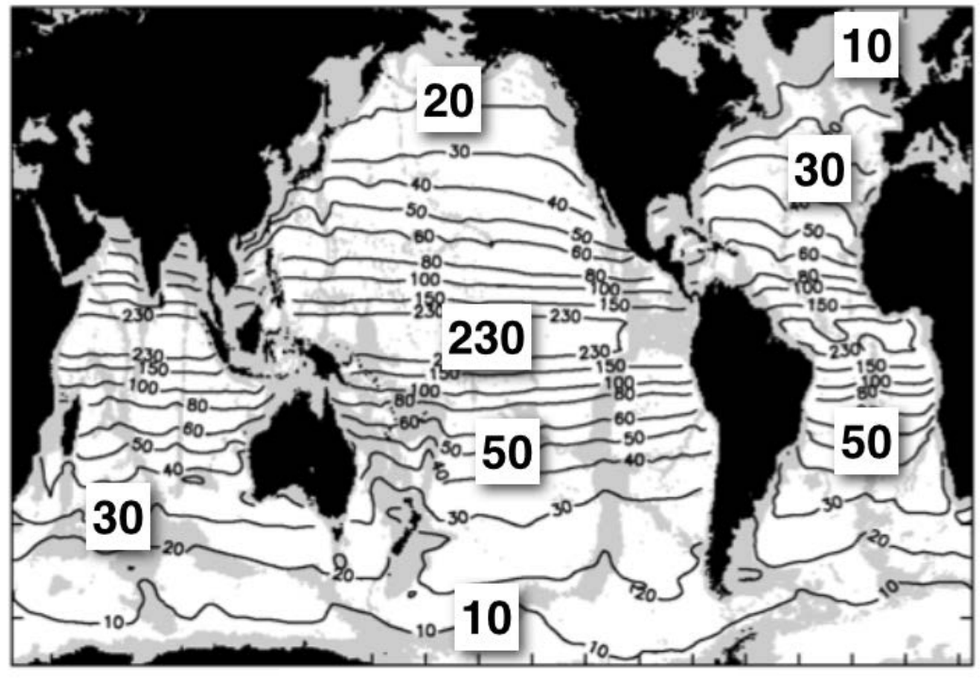
SOMA: Rossby radius of deformation spectrum

Characteristic scale for baroclinic instability



Eigenvectors

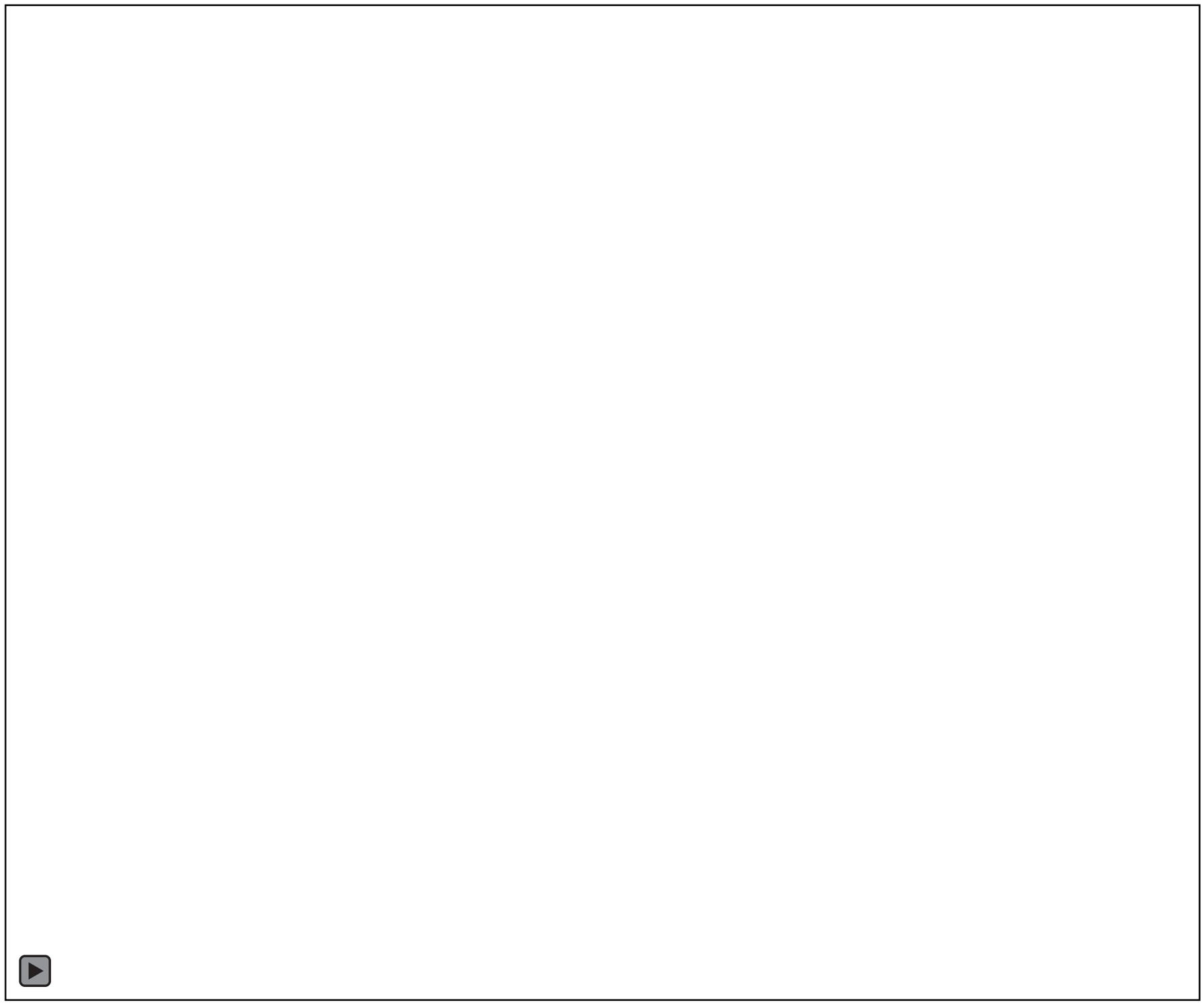
First Rossby deformation radius (km) in global ocean



Chelton et al. (1998)

MPAS-O: 4 km grid resolution

Relative vorticity at 100 m depth with one frame every 15 days.

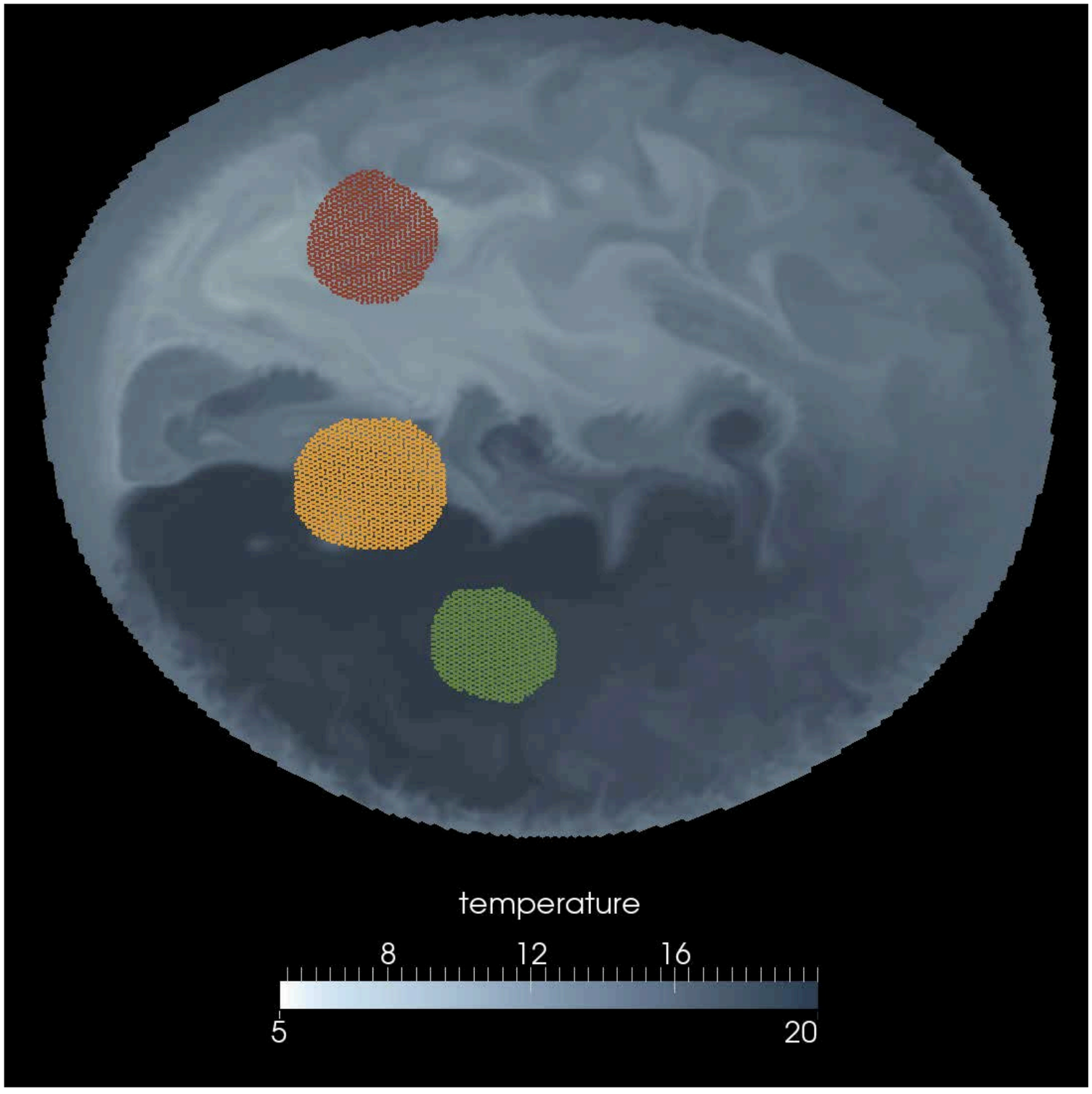


movie here: https://www.dropbox.com/s/q2unhxi51rpz243/SOMA_4km.mov

Lagrangian **I**n-situ **G**lobal **H**igh-performance **T**racking (LIGHT)

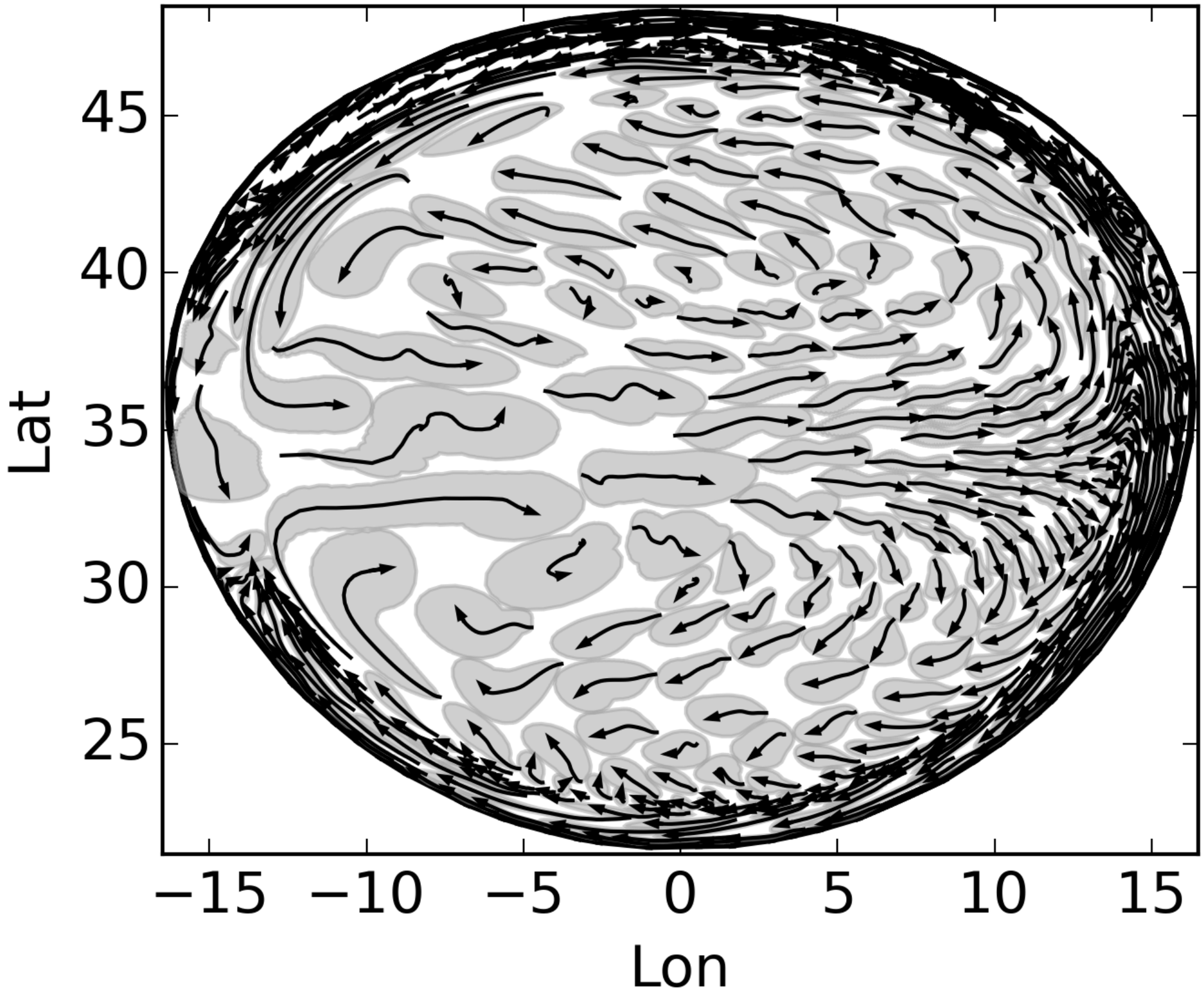
- *in situ* HPC Lagrangian particle tracking
  - same time step and velocity field as dycore
  - particles communication pattern similar to dycore
  - particles stored in flexible doubly linked lists on each processor
- Extensible
  - housed in MPAS-O analysis member
  - particle metadata generated from registry
  - communication routines independent of metadata (flexible variable addition)

LPT cluster mixing



Each frame represents a day of simulation

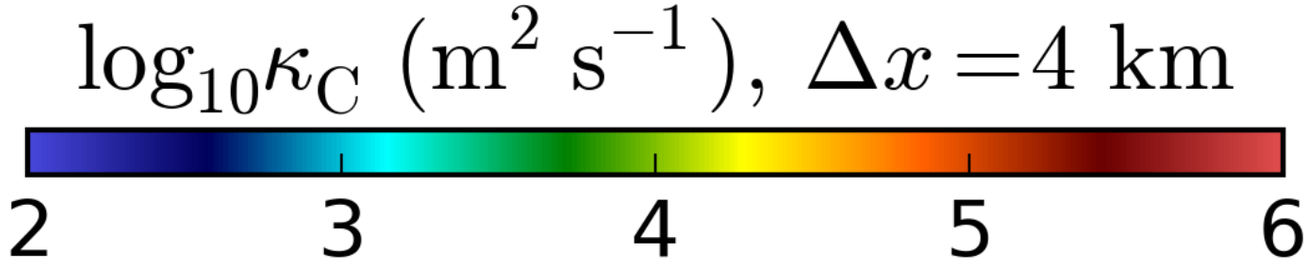
LPT cluster statistics: $\kappa_{ij} = \frac{1}{2}\frac{d}{dt}\Sigma_{ij}$



Experimental design

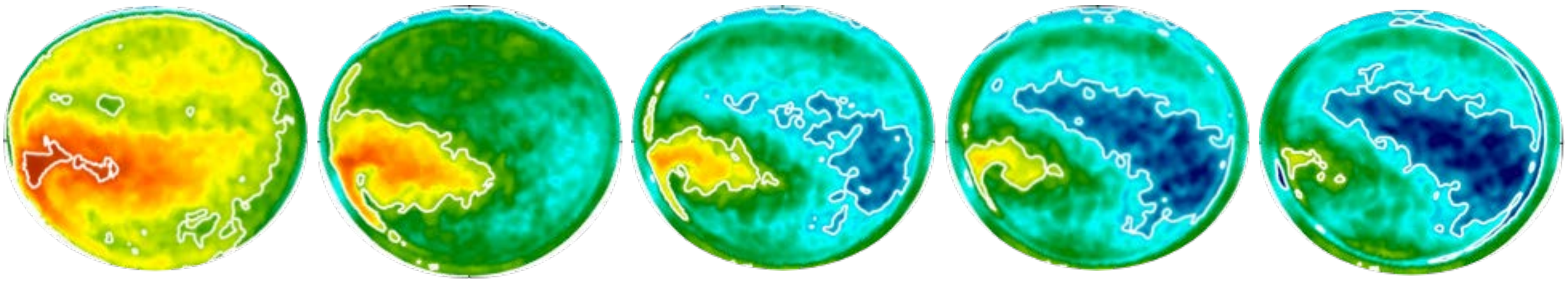
- *in situ* HPC Lagrangian particle tracking via LIGHT
- Particles seeded on potential density surfaces
- Ensemble of 30 LPT realizations with diffusivity computed as mean time-rate of change of cluster dispersion tensor (covariance) from 10 - 12 days
- 4km, 8km, 16km, and 32km grids (30km Rossby radius is dominant scale)
- Velocity filter width of 8Δx utilized (4km - 8Δx approx. grid scale of 32’ km & 32km - 8Δx approx. grid scale of 256’ km)

Diffusivity vertical structure at 4 km resolution



Mean depth (m)

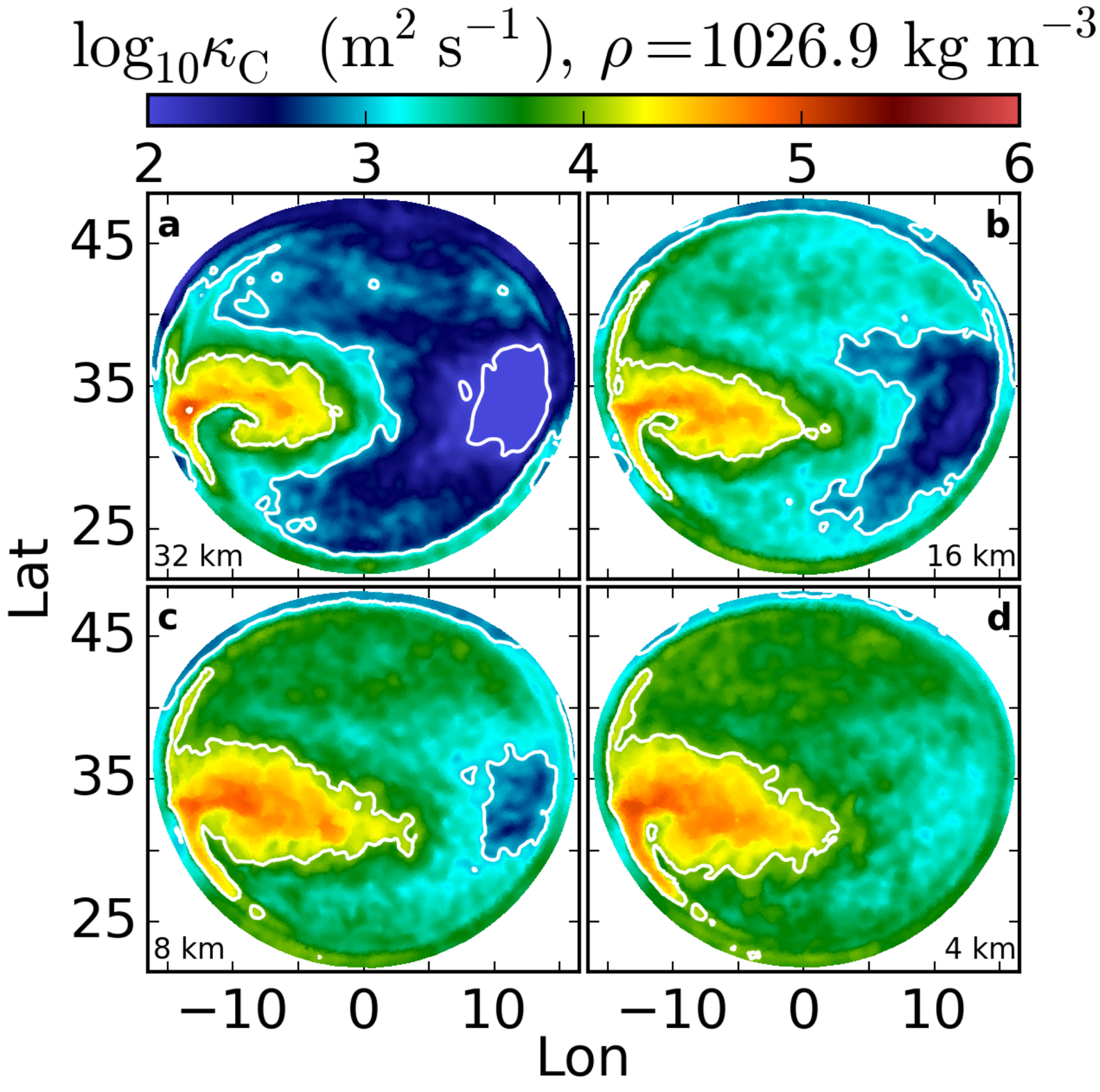
100	250	400	600	1000



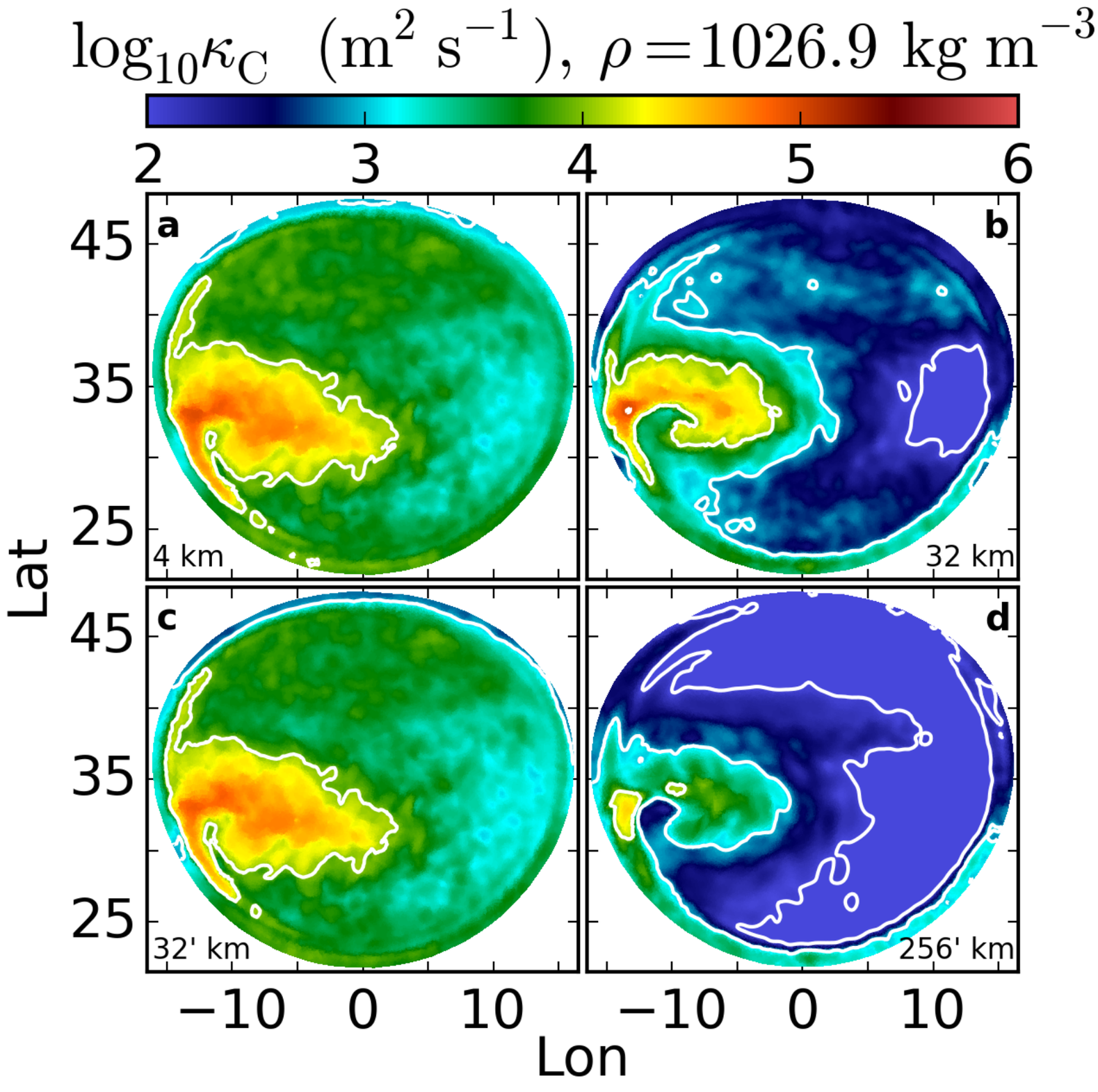
1025.6	1026.9	1027.4	1027.7	1028.1

Potential density surface (kg m^{-3})

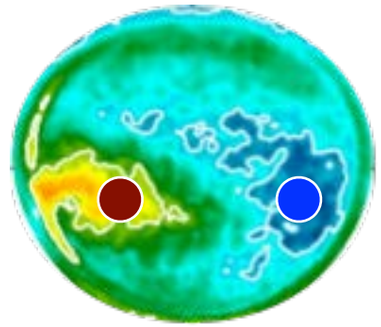
Diffusivity dependence on model resolution

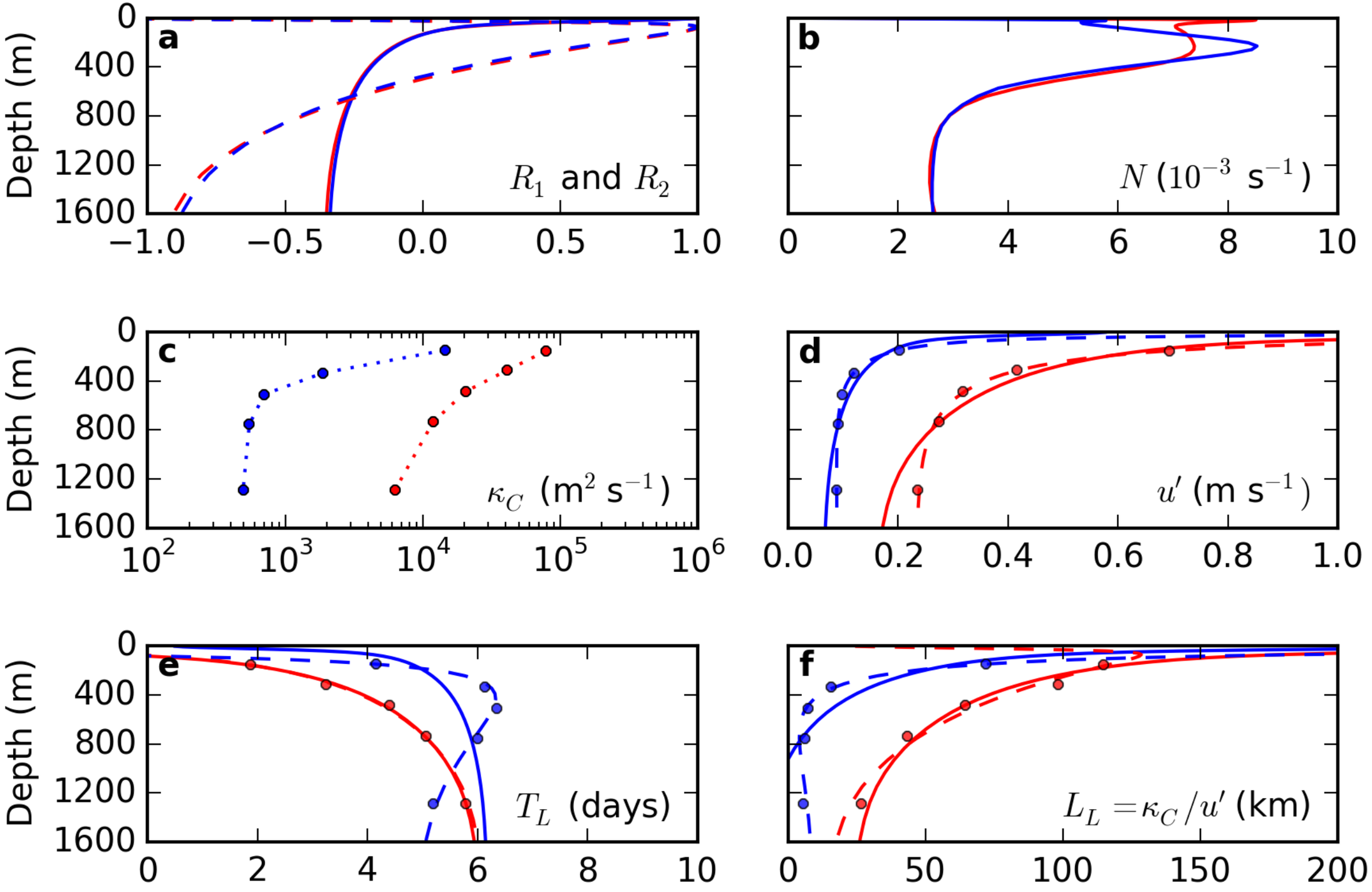


Diffusivity dependence on velocity filter scales



Western and Eastern profiles





Summary

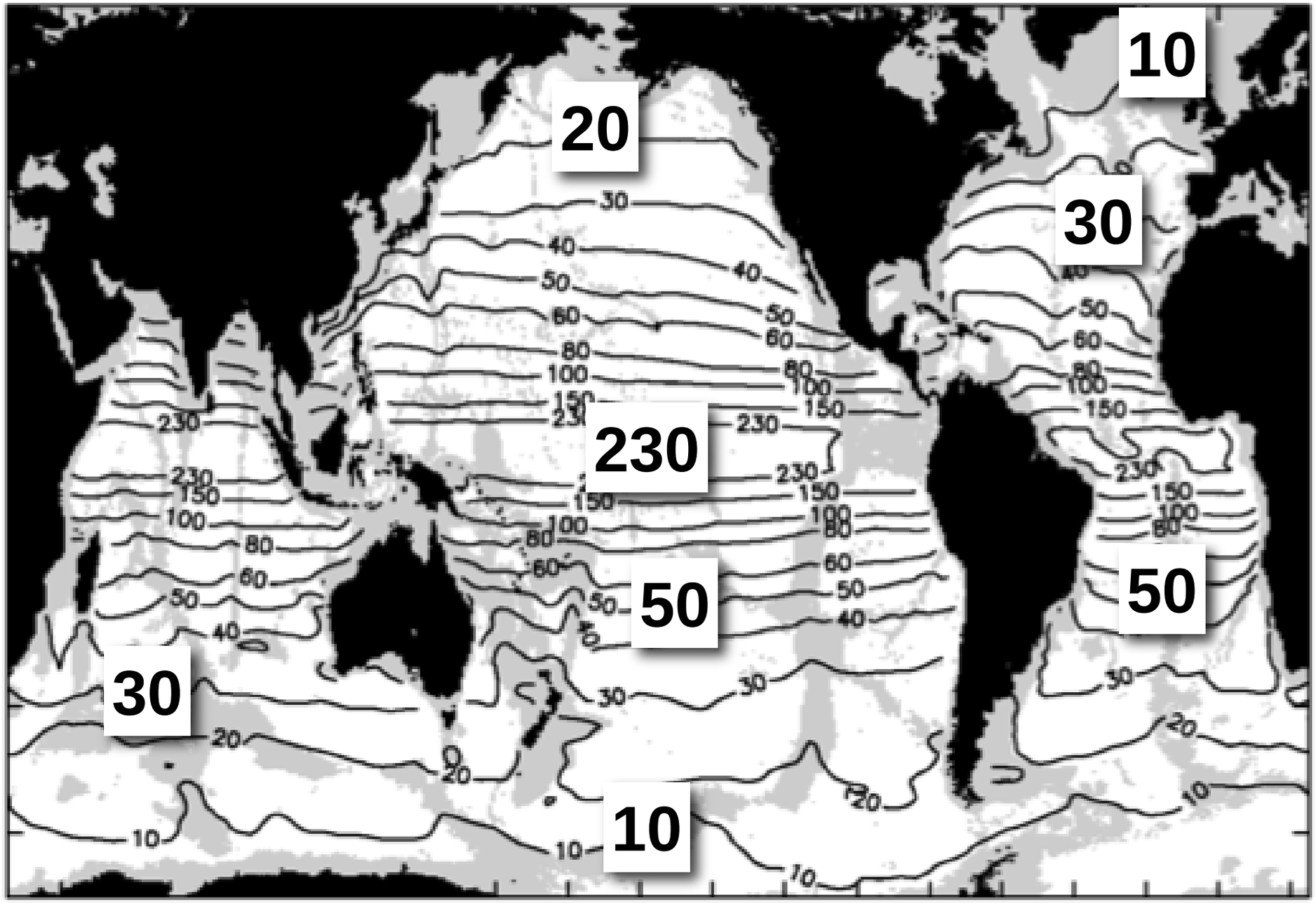
- LPT measures high resolution fluid diffusivity
- Wide range of spatial diffusivity (10^5 to 10^2 $m^2\,s^{-1}$) with attenuation at depth and away from jet
- Characteristic mixing scale is 3 to 4 times first RRD, but sub-RRD scales necessary to resolve the diffusivity, e.g.,

$$\Delta x \leq \frac{L_d}{4}$$

- Mixing occurs at range of spatial scales $\gtrsim$ RRD
- Diffusivity strongly dependent on grid resolution

Questions & comments?

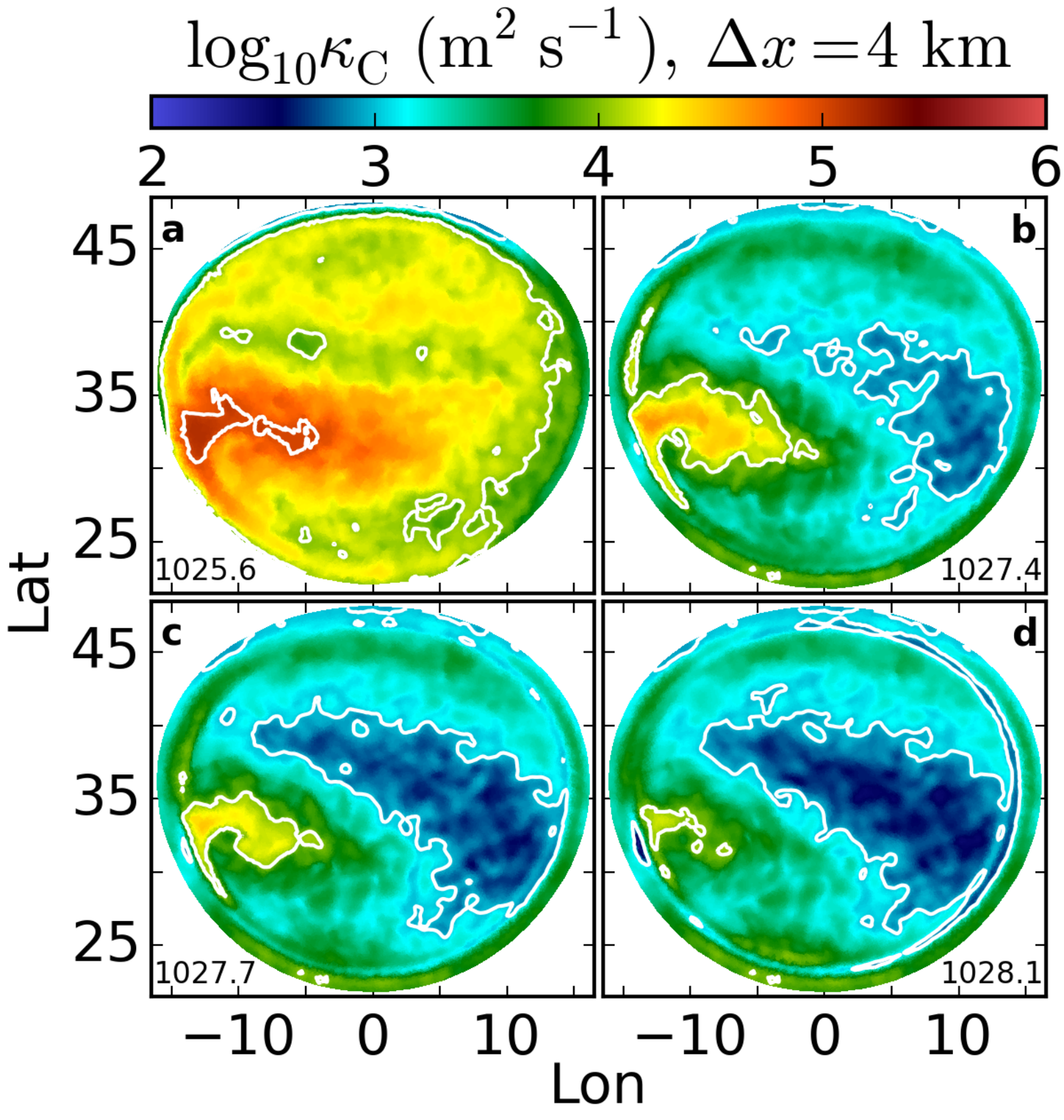
First Rossby deformation radius (km) in global ocean



Chelton et al. (1998)

$$\Delta x \leq \frac{L_d}{4}$$

Diffusivity vertical structure

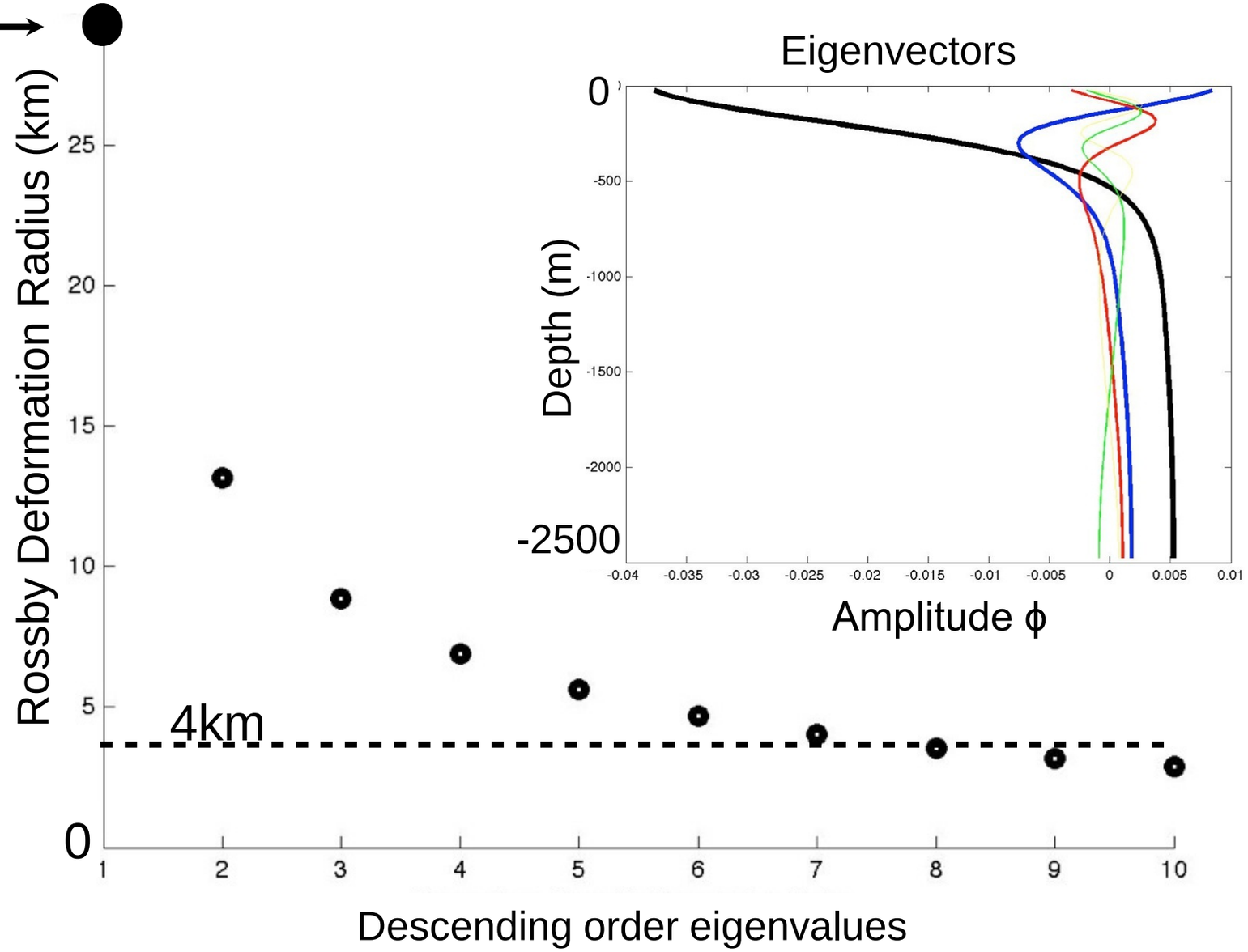


SOMA: Rossby radius of deformation spectrum

Characteristic scale for baroclinic instability

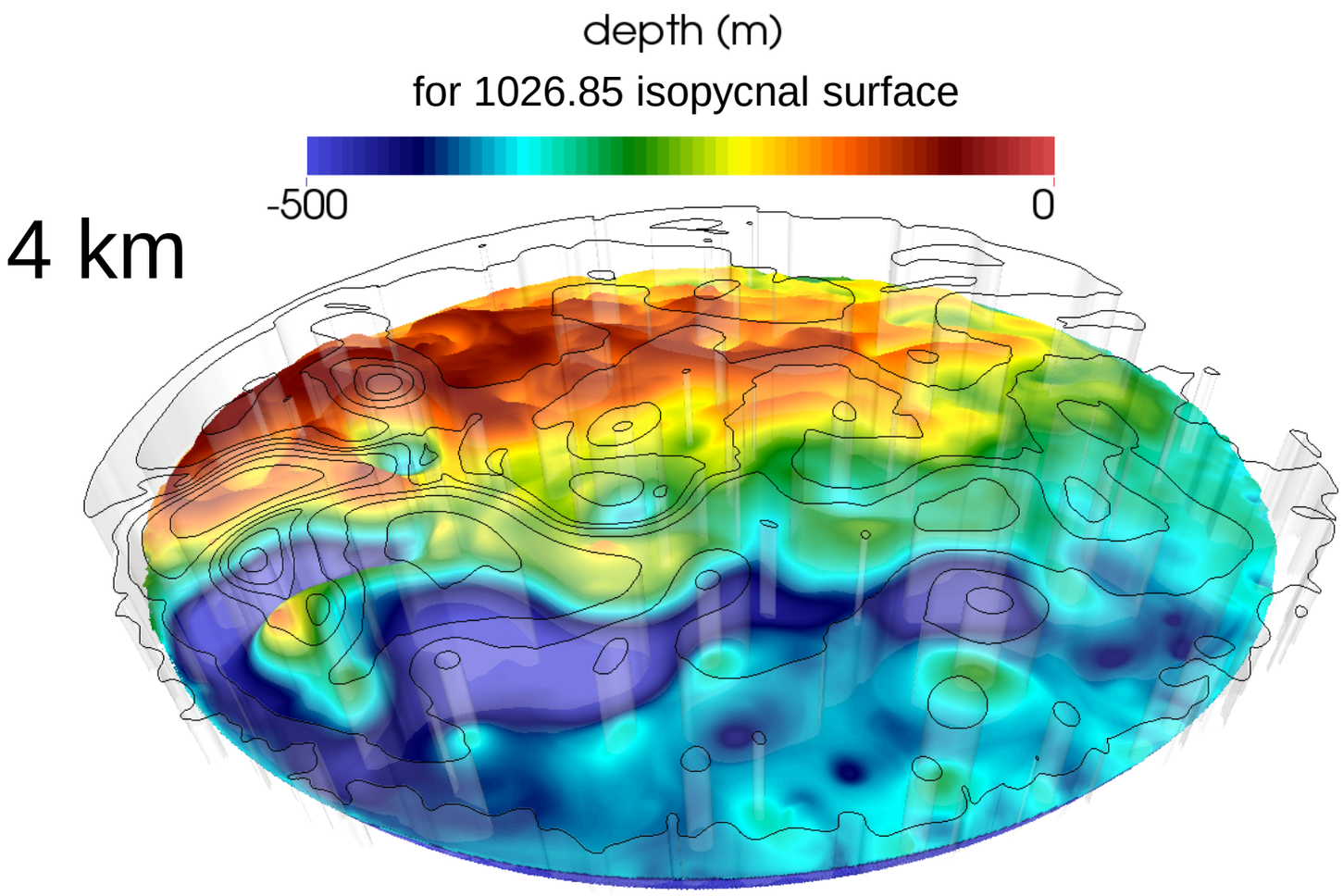
30km

$$L_d = \frac{c}{f}$$



$$\frac{\partial^2 \phi}{\partial z^2} + \frac{N^2(z)}{c^2}\phi = 0,\ \phi = 0 \text{ at } z = 0 \text{ and } z = -H$$

Snapshots of depth at 1026.85 potential density buoyancy surface with SSH contours



Diffusivity anisotropy