“Hybrid model”

“Composite flow model”

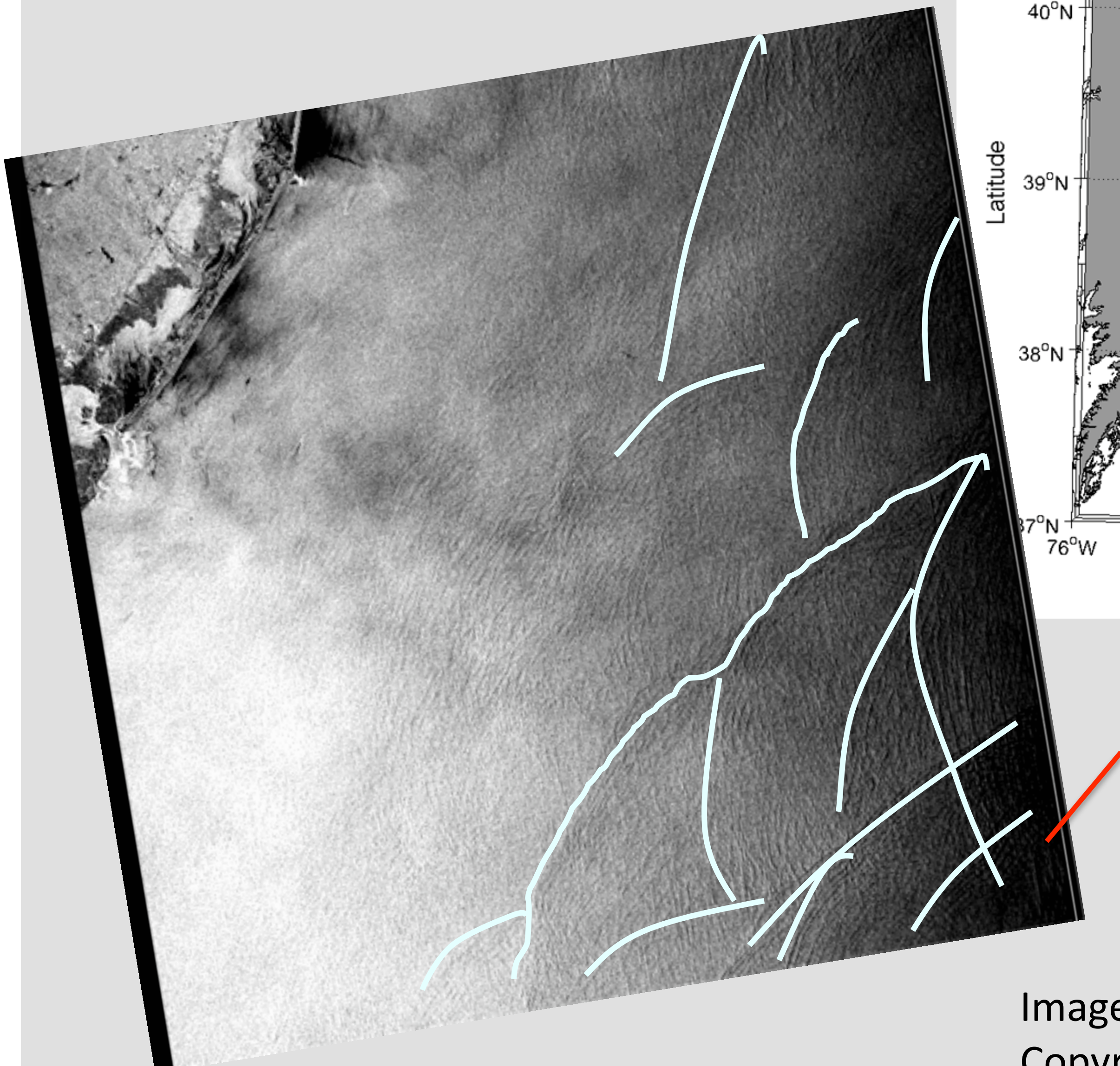
A fast alternative to the full computational solution (including NHP waves and bores)

A use: Identify areas of interest, for full simulations

Ensemble studies of uncertainty

Uncover physical effects of complex bathymetry etc.

Goal: Compute location and some properties of the internal wave field



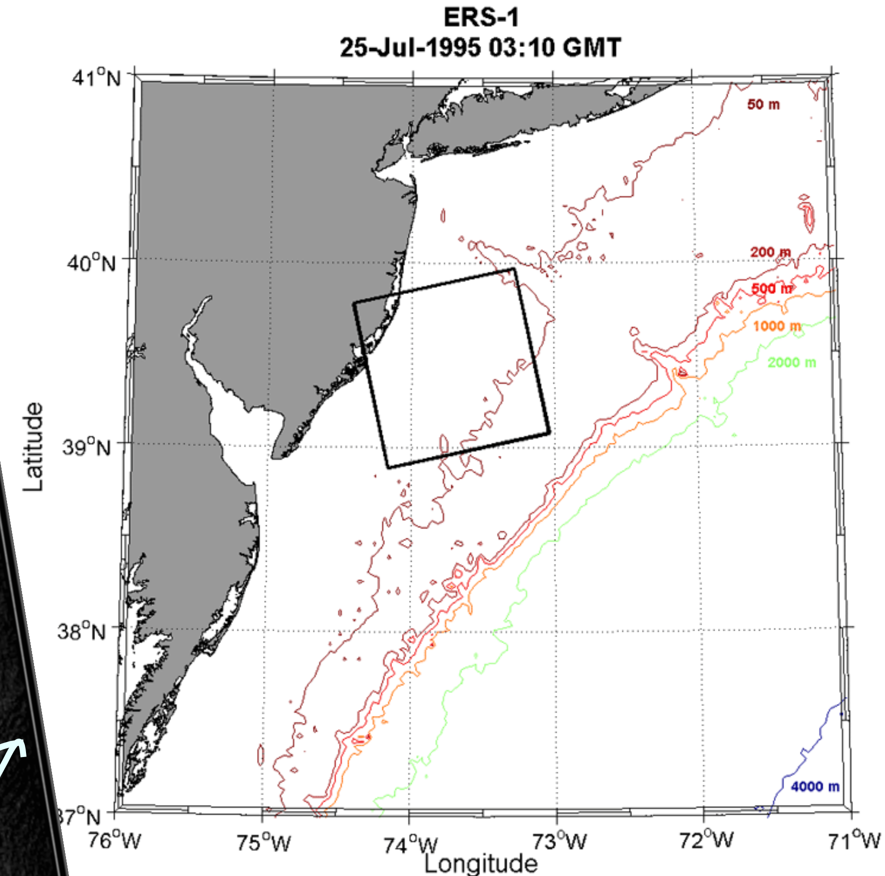
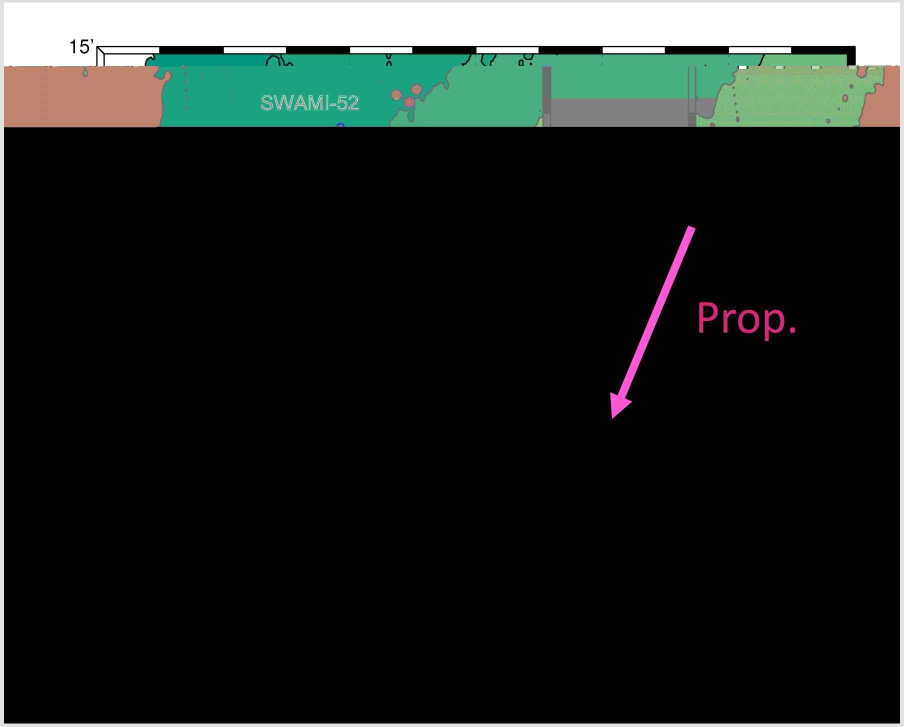


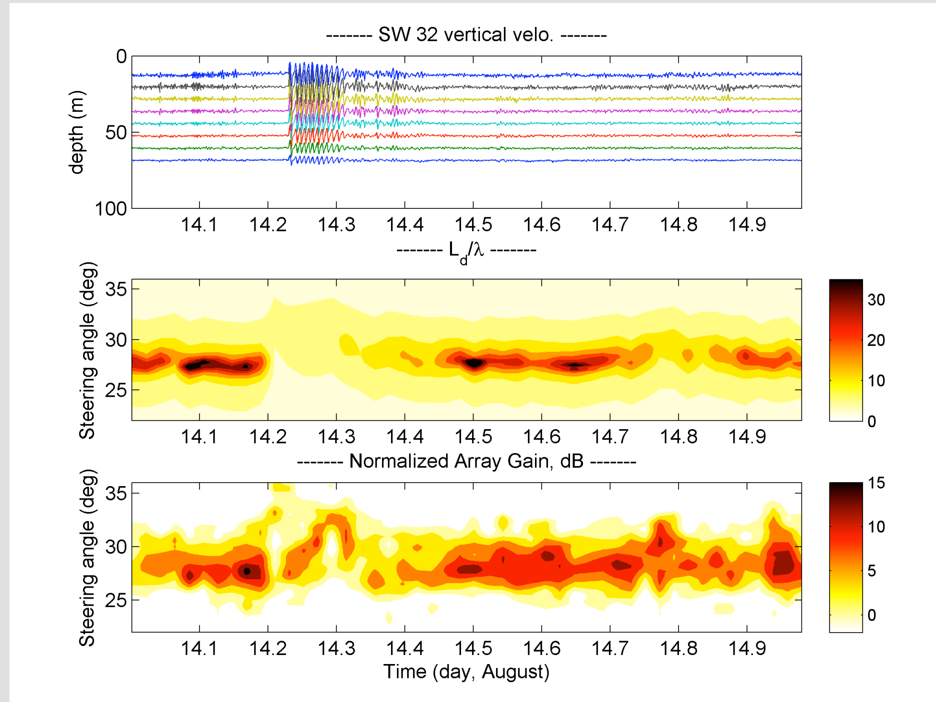
Image from Global Ocean Associates

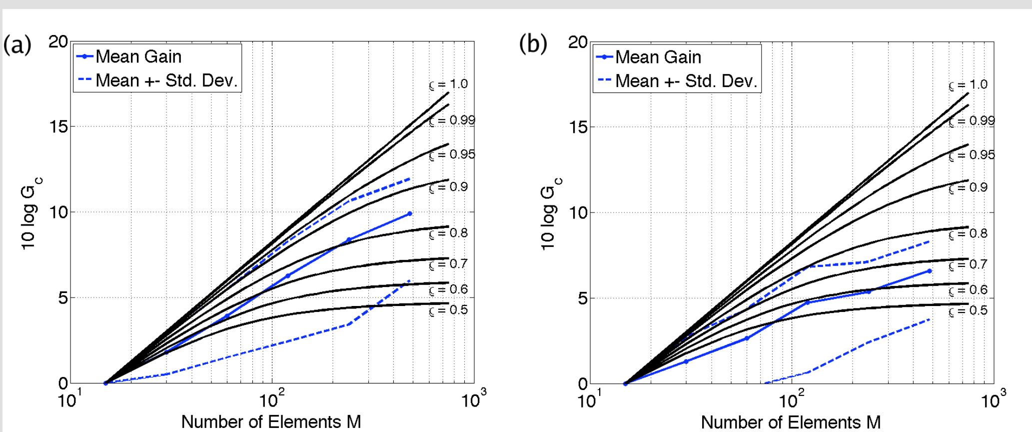
Acoustical effects of internal waves

- **Non-linear internal gravity waves (NLIWs) create strong anomalies of sound speed at the thermocline. Major effects:**
  - Shadowing
  - Focusing
  - Mode content alteration
  - Mode multipath
  - Mode 'splitting' (y-modes of z-modes)
  - Apparent bearing shifts
- **Advantages of localizing (predicting) the wave locations and parameters:**
  - Predict event arrivals at fixed locations
  - Make evolving maps of fluctuation statistics
  - Predict major/minor axes of anisotropic conditions
  - Predict strength of fluctuation effects
- **Nonlinear wave details are sensitive and by nature not entirely predictable, nor are the acoustic effects of the waves.**

SW06 Along-shelf Acoustic Observations: Transiting NLIW Groups





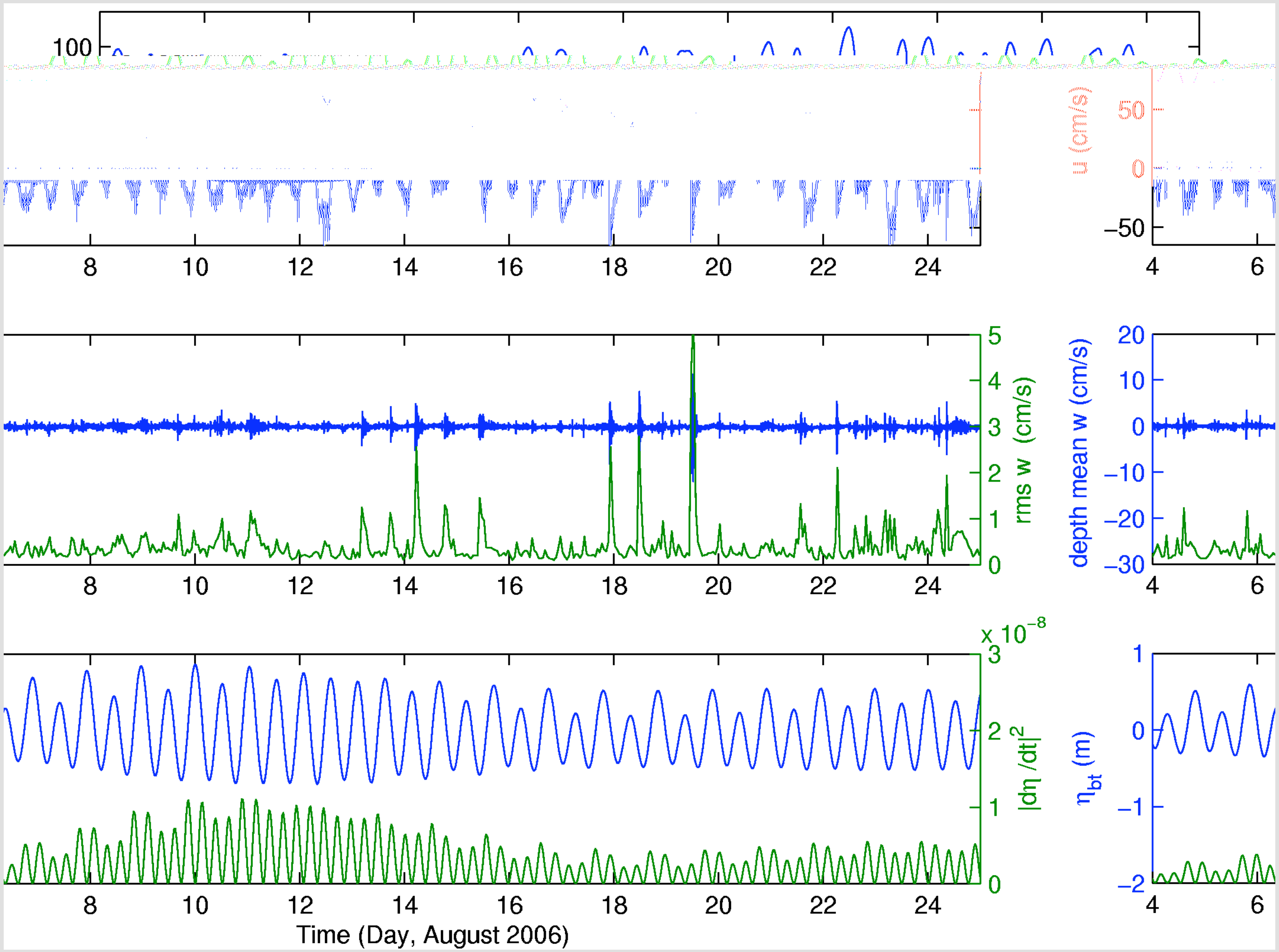


Above: Beam deflection and shortening of horizontal field coherence length (30 to 5 wave-length) at horiz. array as IW's pass. Array gain changes also.

Left: Typical max and min array gain curves vs aperture size. (w/o and with NLIW)

Collis, Duda, Lynch, DeFerrari, 9/2008 JASA EL.

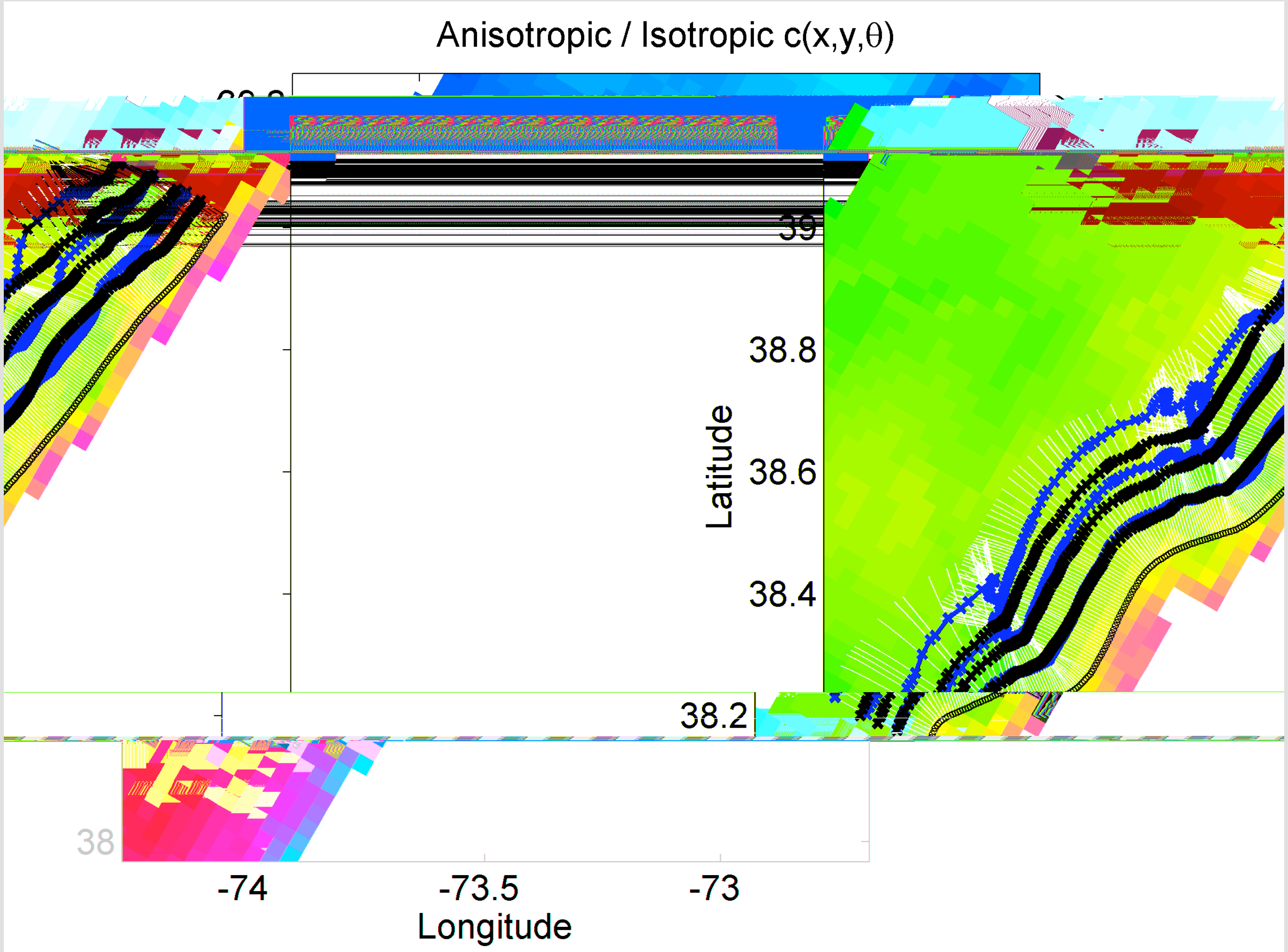
Strong nonlinear waves not appearing when tidal forcing is strongest; one field program



SW06 Location SW30, ~ 80 m isobath

Original vision

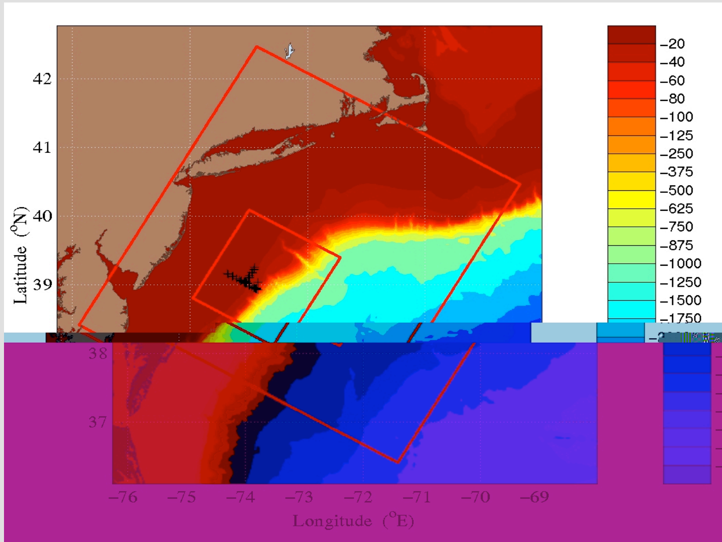
- Best possible data-driven predictive regional flow model,
  - Hydrostatic pressure (HP) physics
  - Tidal forcing
  - Includes best possible HP internal tides
- Paste on smaller-scale NHP features such as nonlinear internal waves and bores, N by 2D approach.
- Map out locations of the internal waves, estimate their characteristics. Number of waves, size of waves, direction of waves, etc.
- Pass this information to acoustic prediction models



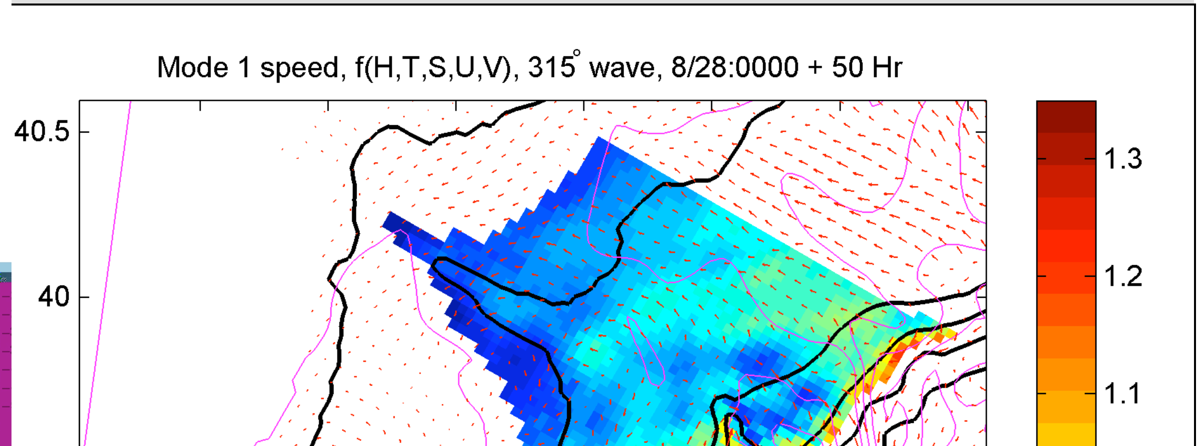
Ray tracing of internal tides. We won't need to do this if we can properly compute internal wave generation and propagation. Studies of effects like this can guide in the development of sufficient computational models.

- The smaller-scale model needs to include nonhydrostatic pressure physics (NHP in our proposal)
- Mode-one internal waves
- Some options:
  - Two-layer model (only mode one)
  - Continuous stratification
  - High order of nonlinearity
  - Include rotation

End; extra slides



HOPS two-way nested modeling domains.
3km and 1km grids. Tides included.



Mode-1 internal tide speed. Anisotropic in variable current field [u(x,y,z), v(x,y,z)]

Speed at one heading plotted.

Explanation forthcoming.

Anisotropic wave speed: Taylor-Goldstein equation

Used often for stability analysis of viscid and inviscid plane-parallel shear flow. (Find 'fastest growing modes', high imaginary speed component, i.e. exponential growth, with *c = ω/k*)

Earth's rotation neglected. (Need to fix that and re-derive.)

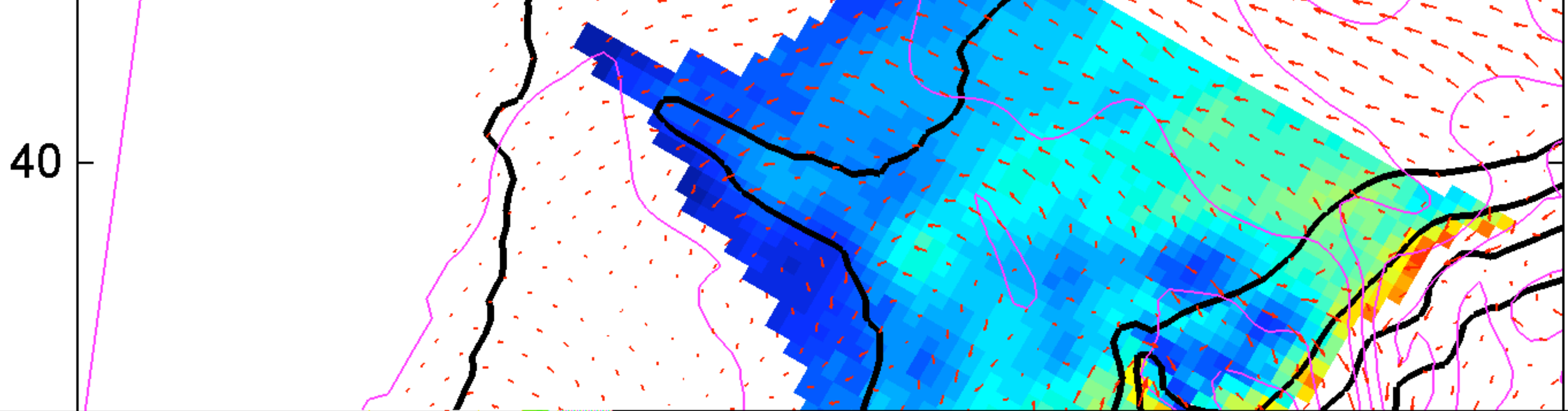
We analyze the eigenmode with fastest real speed, having (essentially) zero imaginary speed component.

$$w_{zz} + \left[\frac{N^2}{(c-U)^2} + \frac{U_{zz}}{c-U} - k^2 \right] w = 0$$

$$\mathbf{u}' = (u', 0, w')$$

$$w' = (x, z, t) = w(z) e^{i(kx - \omega t)}$$

$$U(z) = \text{background current; project [U,V]}$$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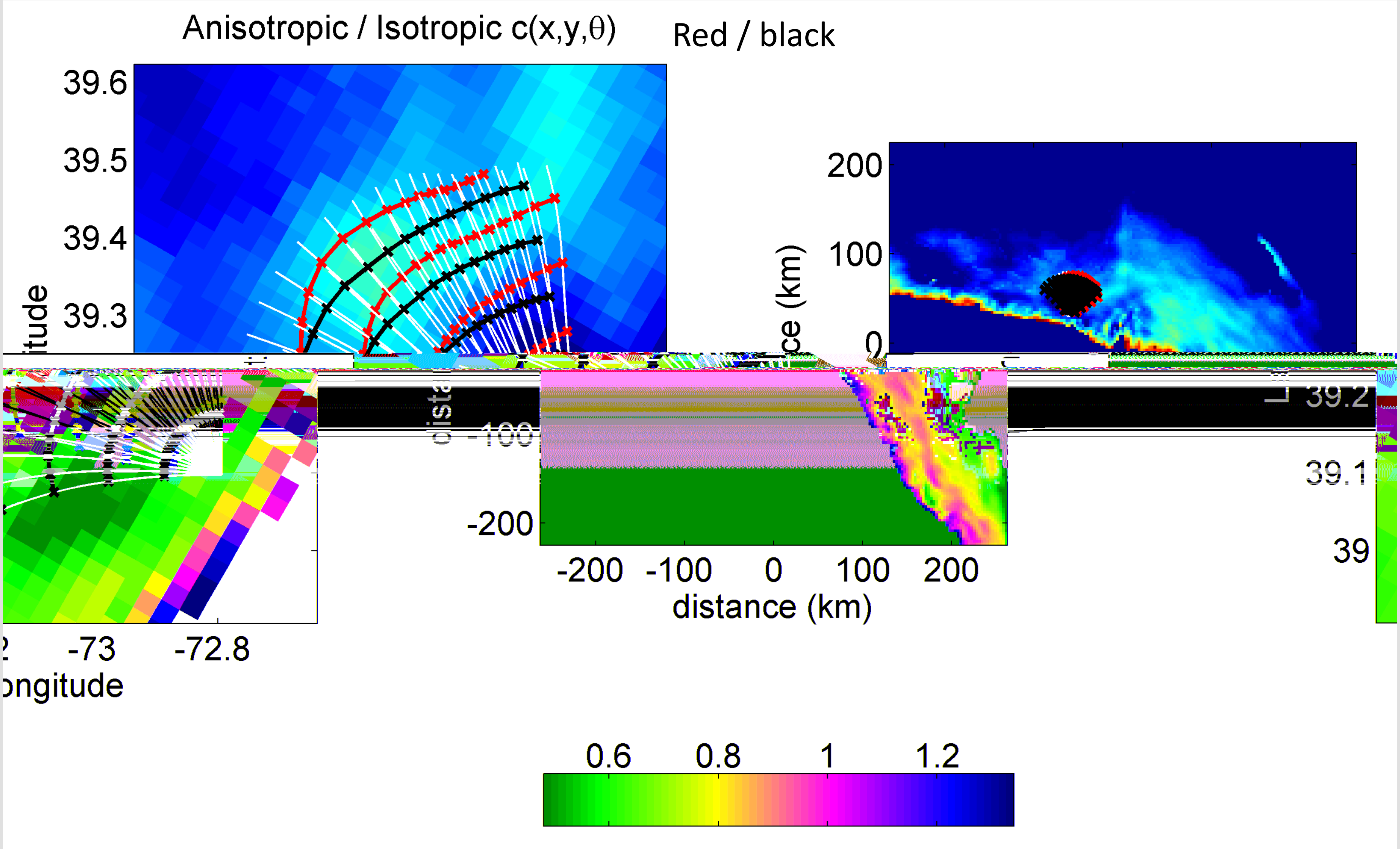
Anisotropic / Isotropic wave speed comparison

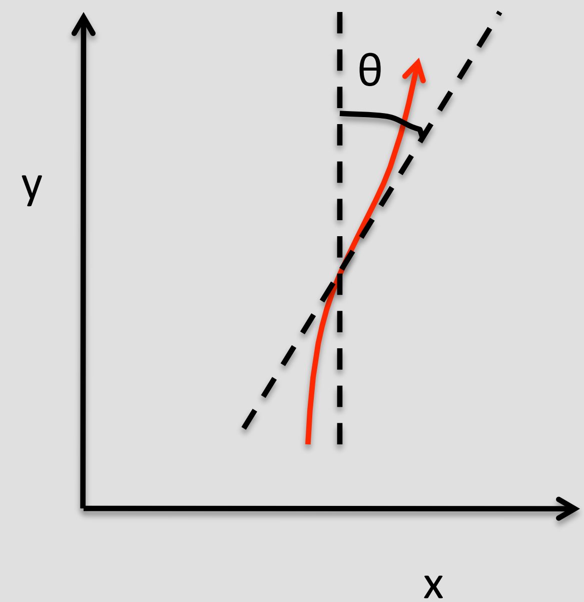


Non-canonical form of raytrace equations

$$\frac{d\theta}{dy} = \frac{1}{c}\frac{\partial c}{\partial y}\tan\theta - \frac{1}{c}\frac{\partial c}{\partial x}$$

$$\frac{dx}{dy} = \tan\theta$$

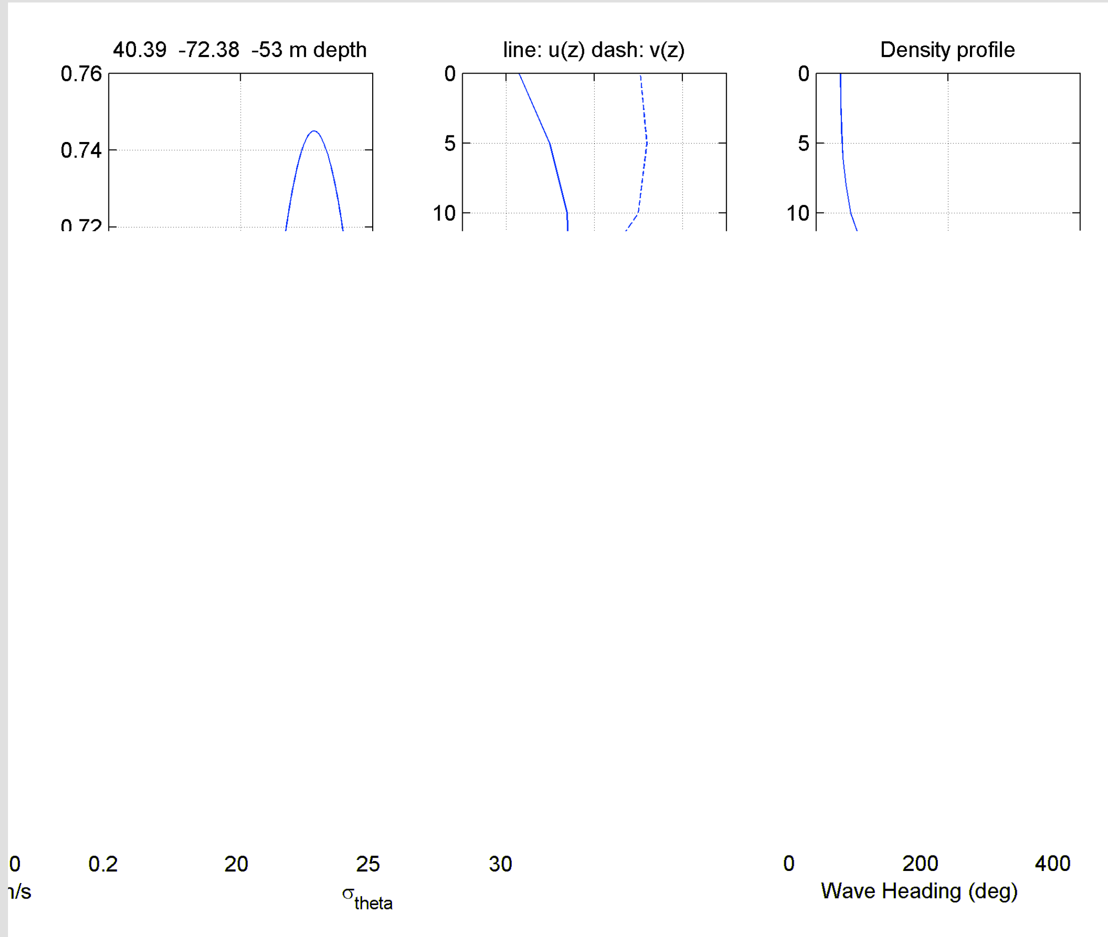
$$\frac{dt}{dy} = \frac{\sec\theta}{c}$$



$$c_I = c(x,y)$$ Isotropic wave speed

$$c_A = c(x,y,\theta)$$ Anisotropic wave speed

$$w_{zz} + \left[\frac{N^2}{(c-U)^2} + \frac{U_{zz}}{c-U} - k^2\right] w = 0$$



$U(z) =$ background current; project [U,V]

Project current onto all directions to solve for eigenmodes at all points of the compass.