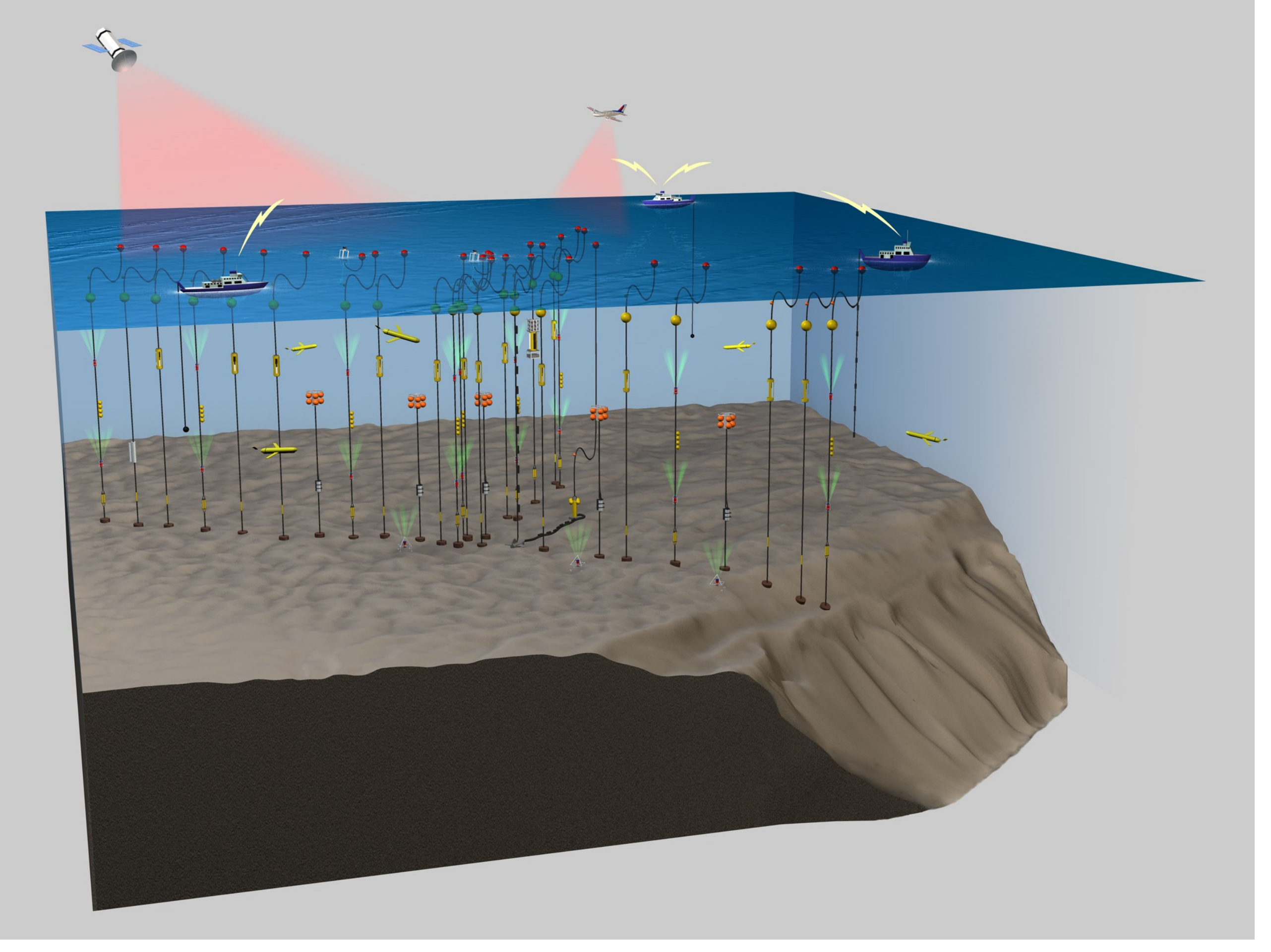
Acoustic ducting, refraction, and shadowing by curved (funky) internal waves in shallow water

Jim Lynch, Y.T. Lin, Tim Duda,

Art Newhall, and Glen Gawarkiewicz

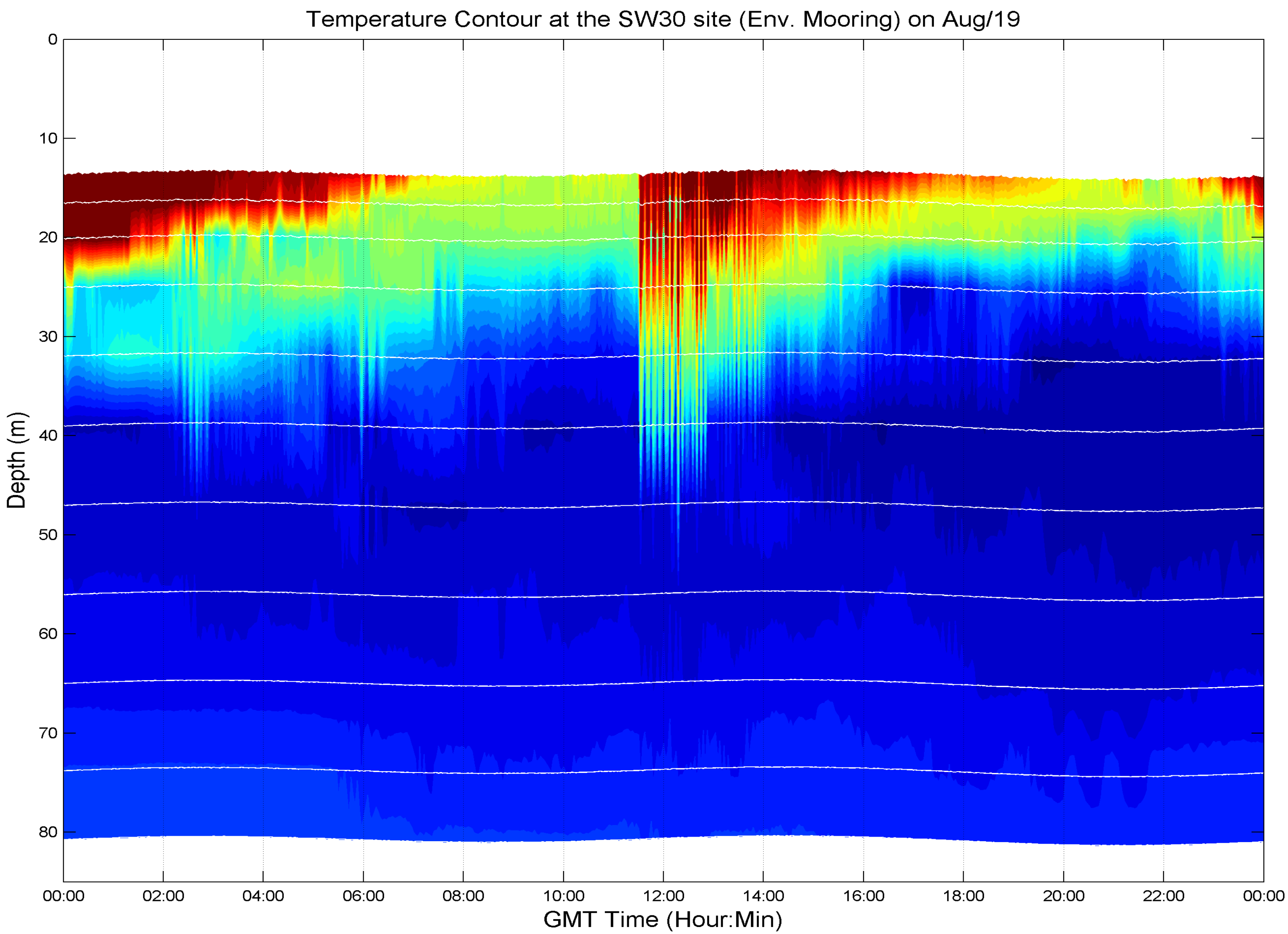
WHOI

SW06 3-D View

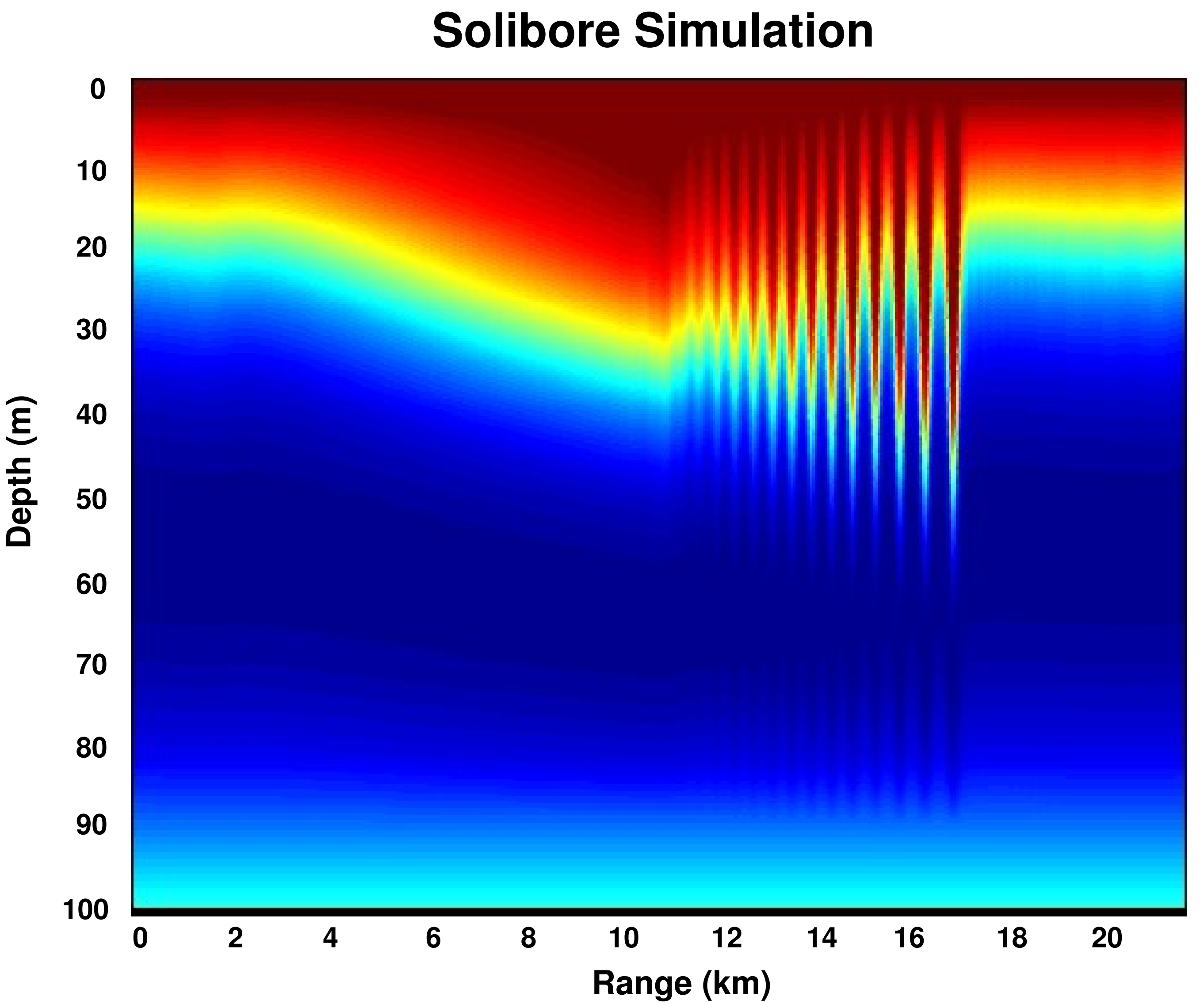


Why put all this stuff in the water?? Sea level is rising nicely without it. What are the big issues??

- TL and its fluctuations (Katznelson, Duda, Lynch, Badiey et al)
- Fully 3-D acoustics - not just slices of 3-D ocean – and direction of arrivals (Lin and Duda work)
- Array coherence (Duda et al)
- Inversion for bottom in presence of fluctuating ocean (Lin work)
- Others…

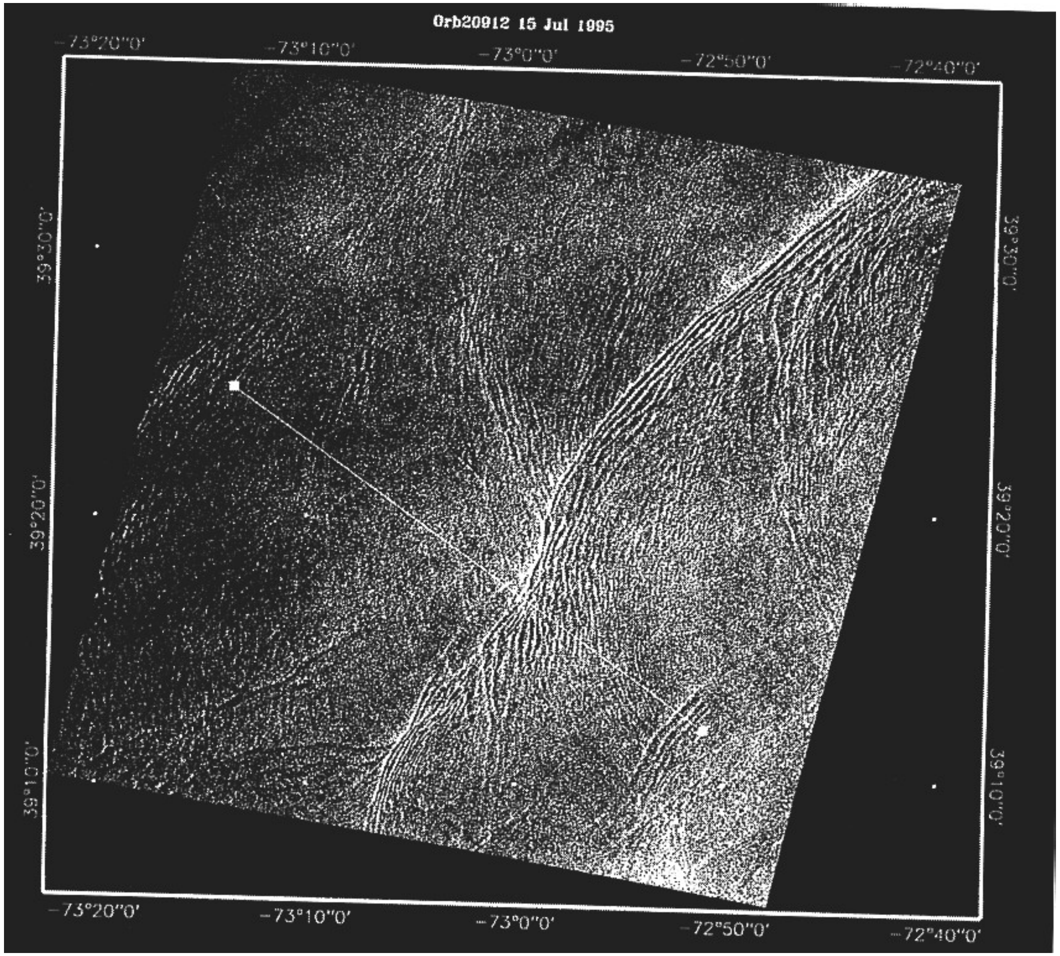

Temperature Contour at the SW30 site (Env. Mooring) on Aug/19
Depth (m)
0
10
20
30
40
50
60
70
80
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
GMT Time (Hour:Min)

Box 2



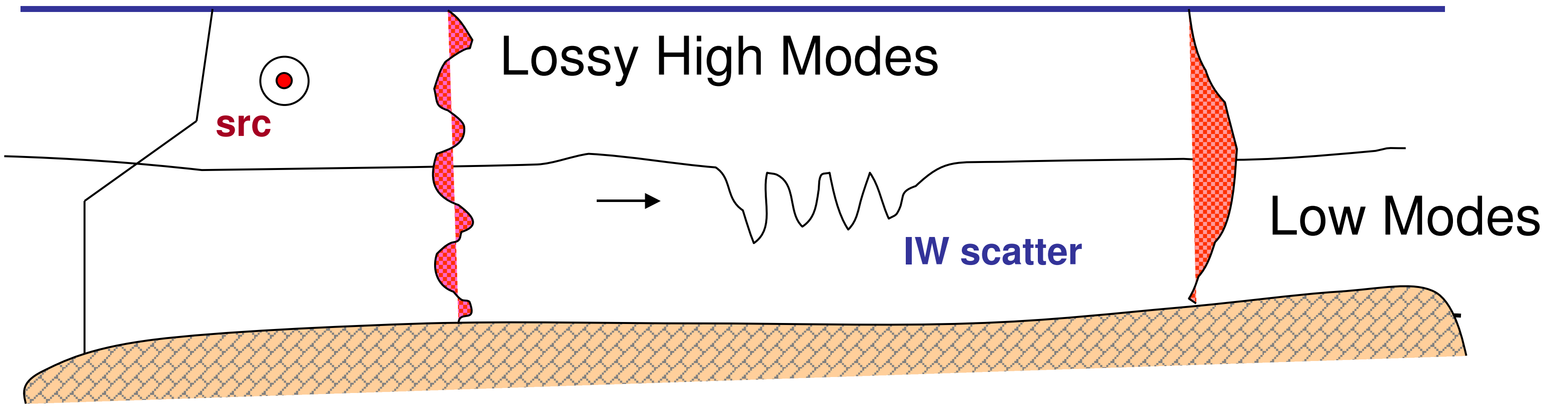
Solibore Simulation
Depth (m)
0
10
20
30
40
50
60
70
80
90
100
0
2
4
6
8
10
12
14
16
18
20
Range (km)

Started with SWARM Cross Shelf

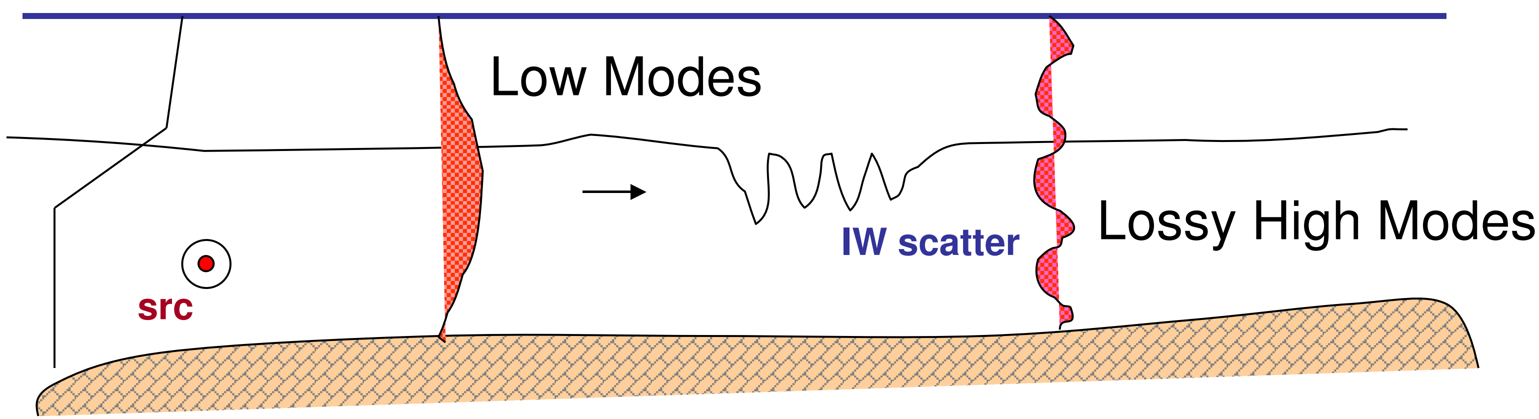


And a mouse…

IW Induced Coupled Propagation Gain/Loss Cases



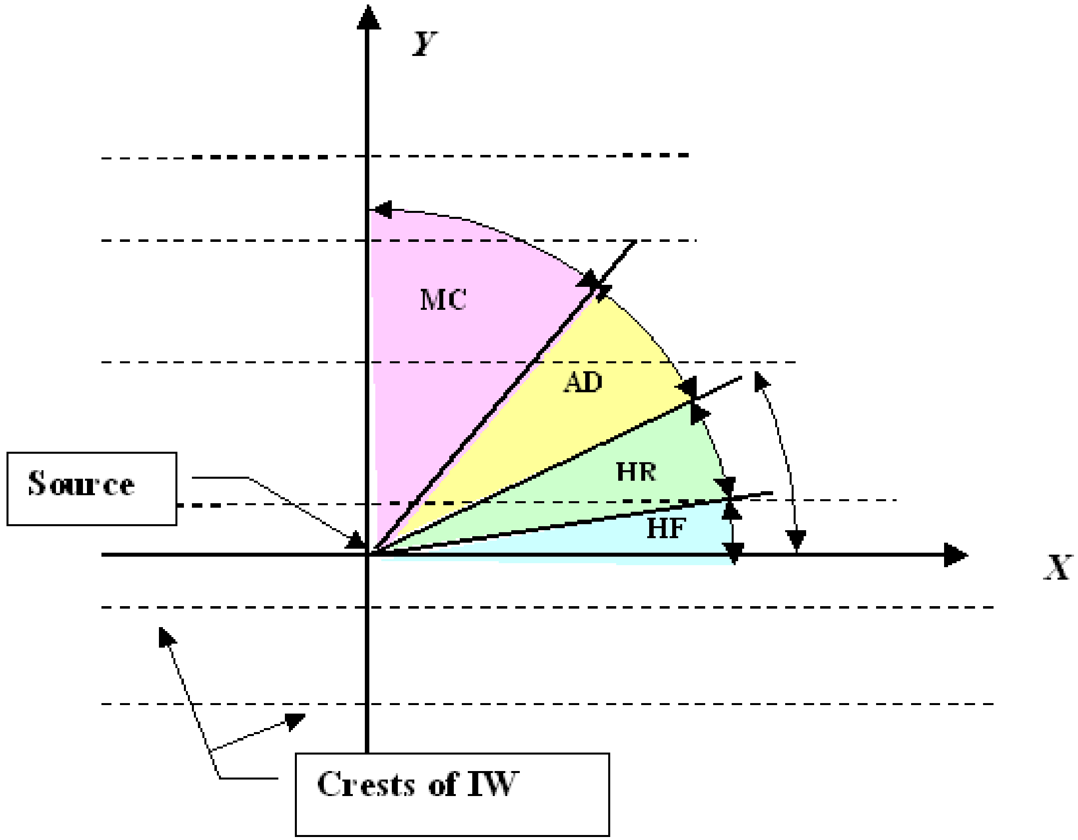
PRIMER Noise Case – Net Amplification



Zhou Yellow Sea Case – Net Attenuation

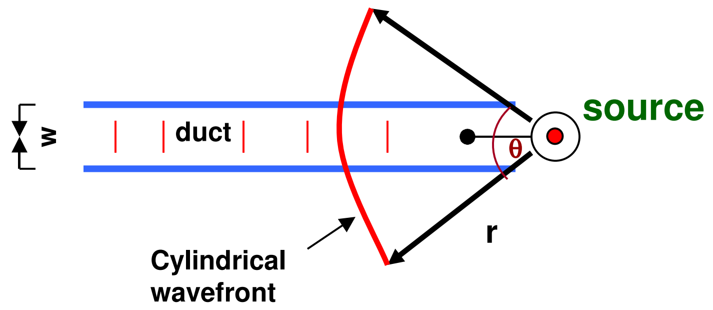
Evolution - Boris' Master Plan!

Oops – Boris *Katznelsons* IW Master Plan!



Mean intensity increase due to ducting (no spreading vs. cylindrical spreading)

For IW duct, have geometry



R = Ratio of areas = $r\theta_c/w$

IW duct (r_1=20 km, w = 1 km, θ_c = 7.5°)

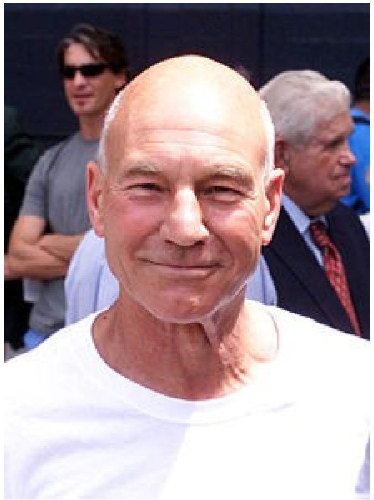
10 log R = 7.18 dB

7-8 dB is a lot for sonar systems!! (And is observed))

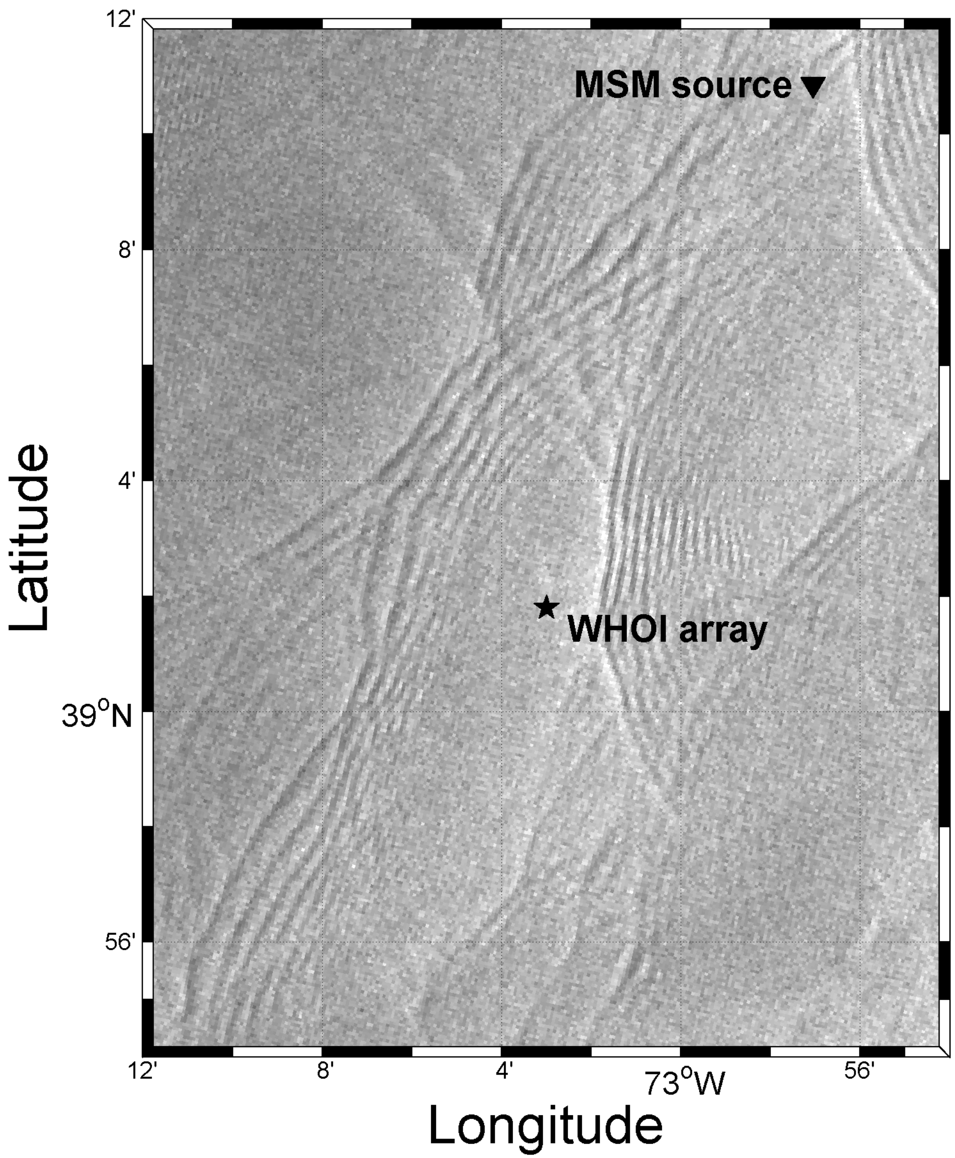
IW Trek – The Next Generation

New IW Features to Include….funkier!

Curved IW's
Terminating IW's
Field of IW's with
  horizontal decorrelation
Crossing Wave Trains



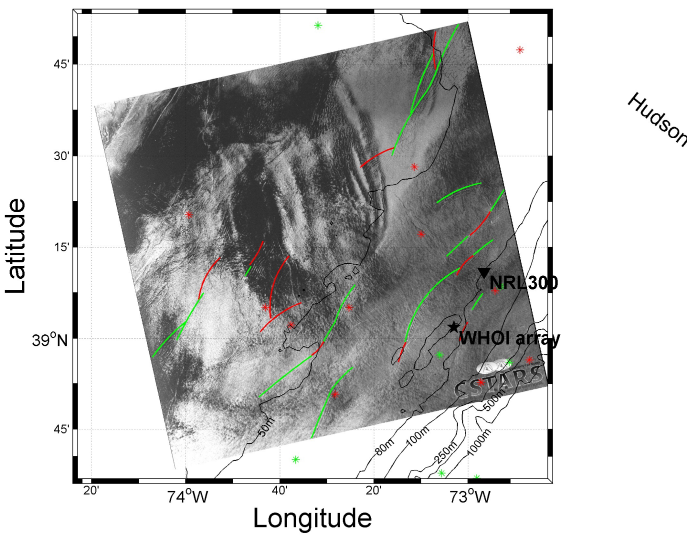
Capt Nick Witzell



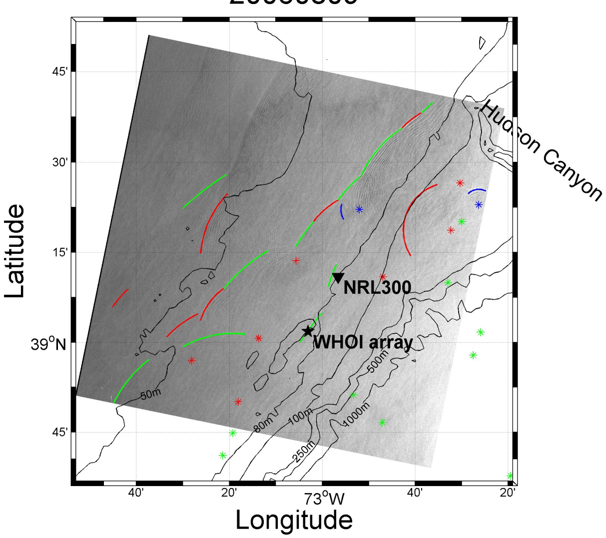
So much for infinite plane waves…

Satellite Image Analysis

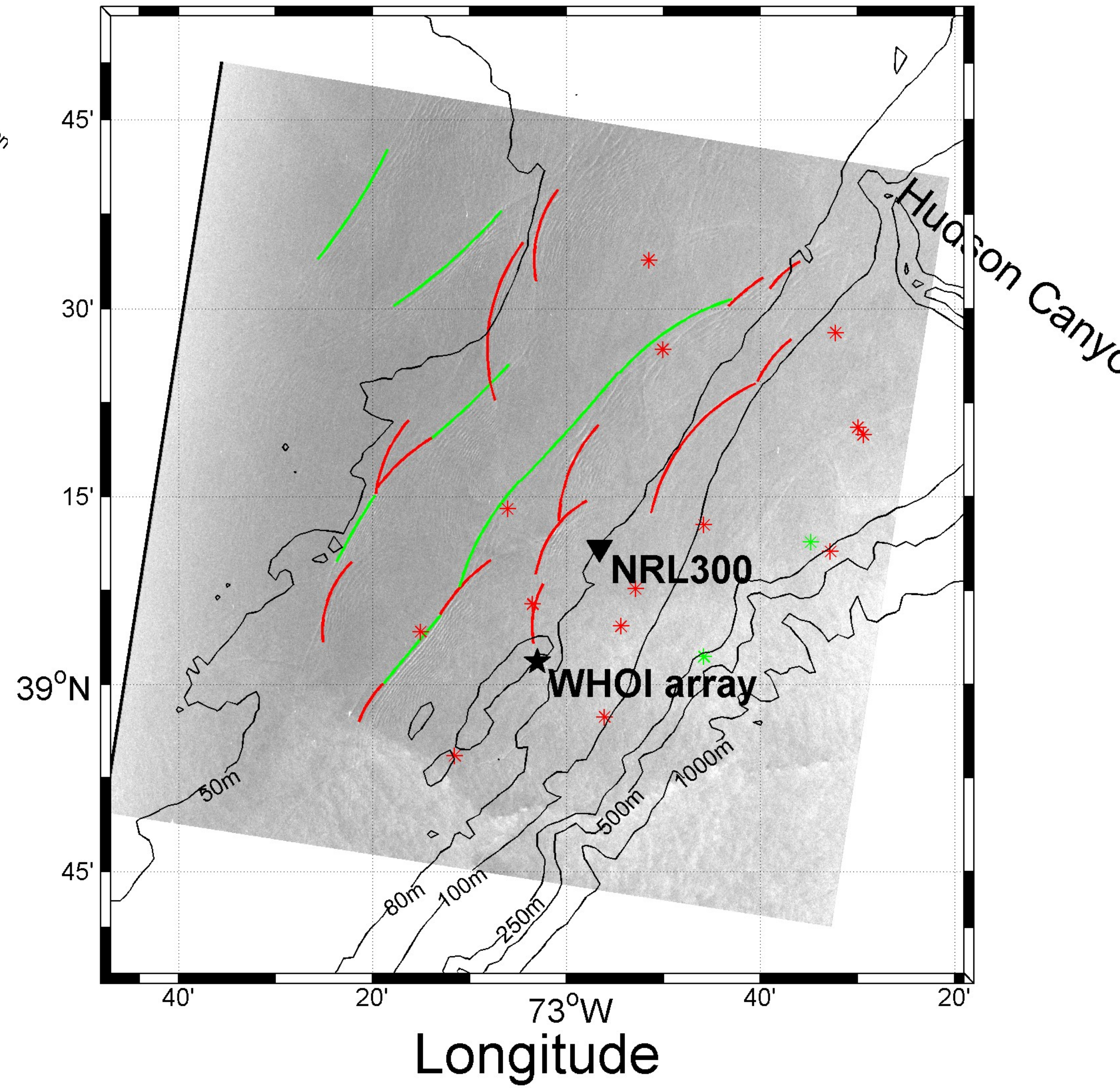
20060805



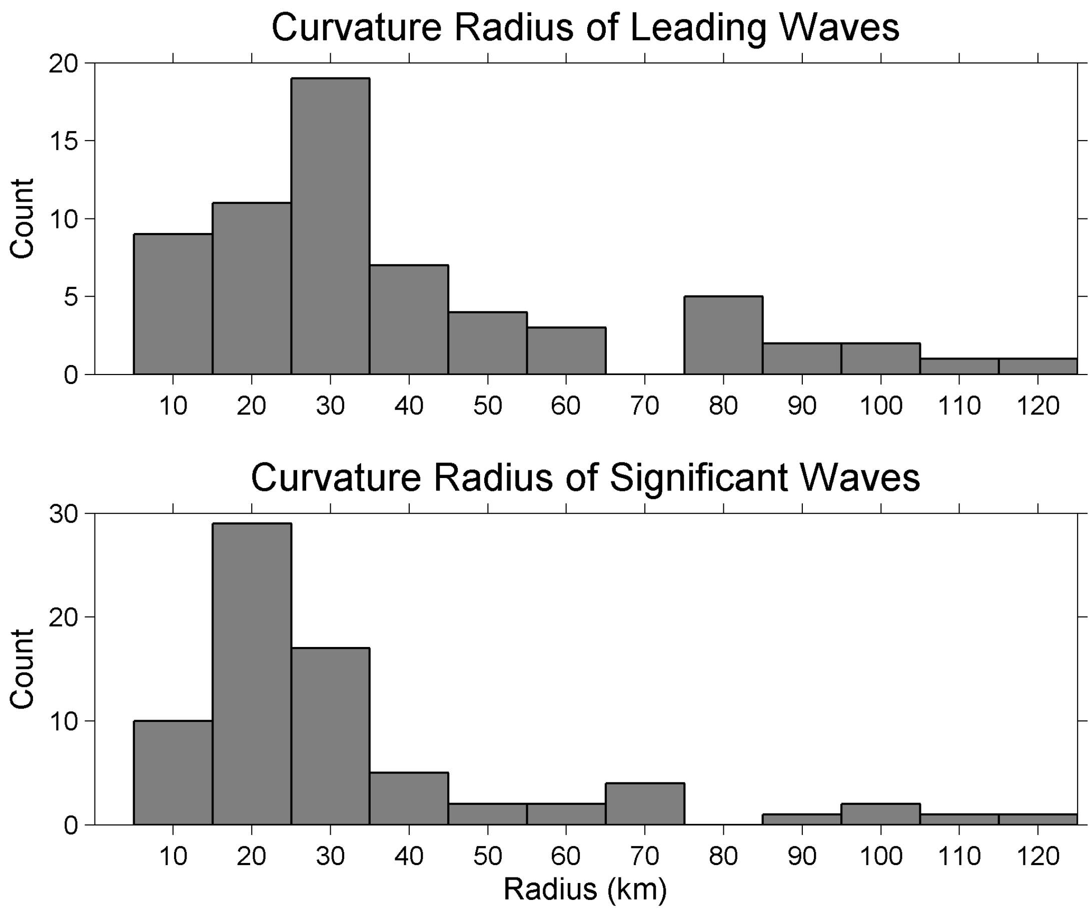
20060809



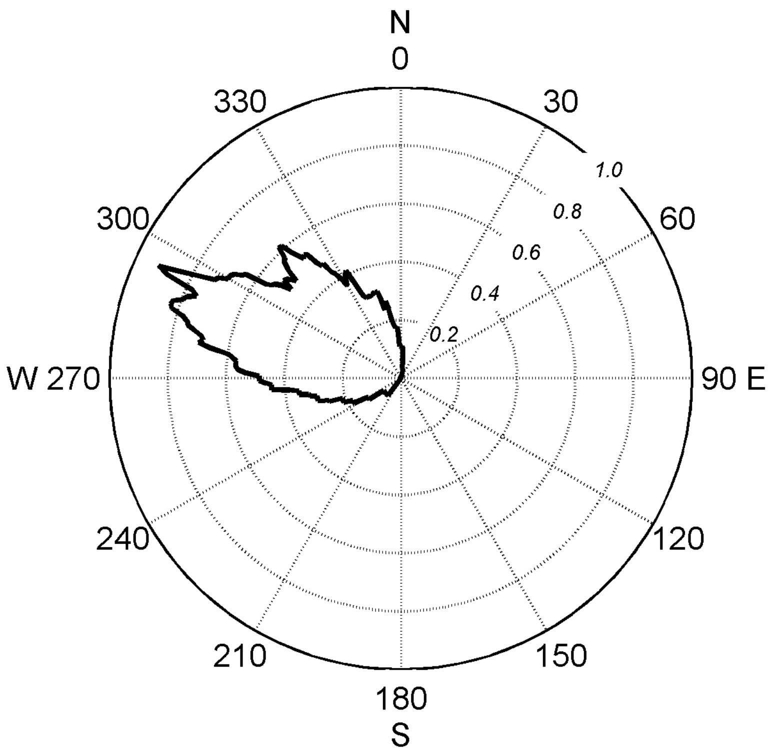
20060813



It's this curvy!

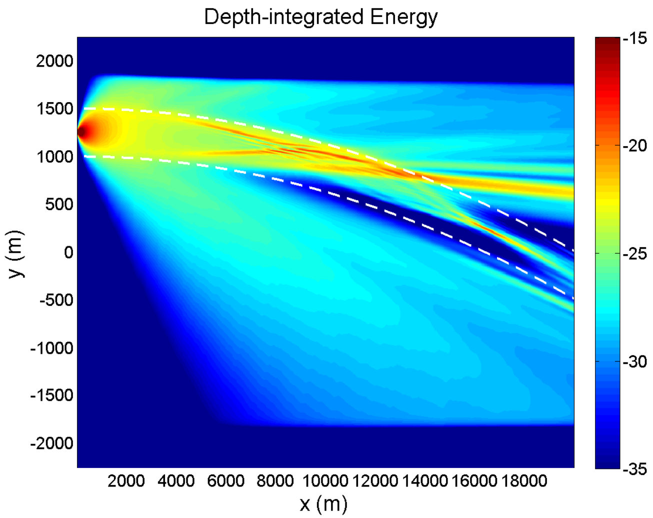


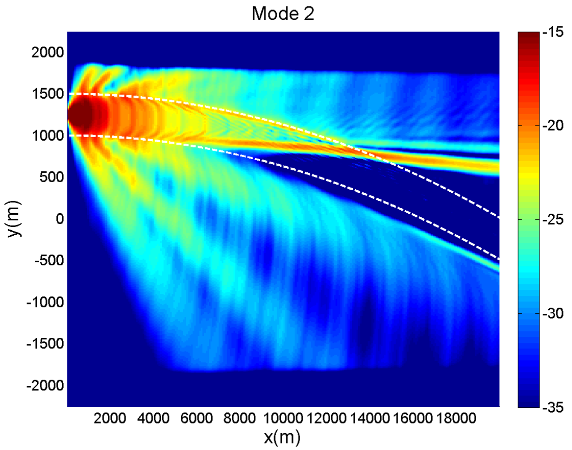
And OMG it's heading for New Jersey!

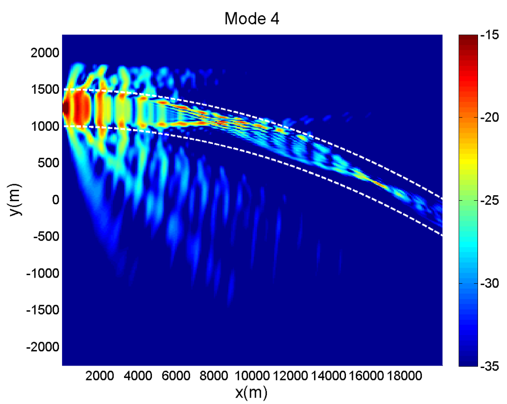


Put this curvature into a numerical model, see neat stuff. For instance, higher modes trap better—hmmm!

- **Case 2 : curvature=135km, frequency = 200Hz**

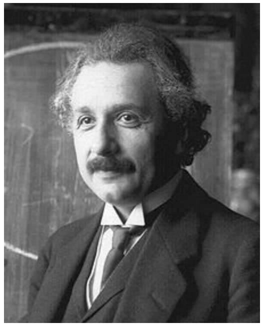






- Modes 1 and 2 penetrate through internal wave duct, but modes 3 and 4 focus in the duct.

Some Simple Theory



- Previous work clearly displays frequency and mode dispersion effects, light piping (and leakage from curved pipe), etc.
- But doesn’t have simple physical insight into how parameters of problem (frequency, mode number, IW strength, background waveguide structure, etc.) affect trapping and leakage of modes.
- Looking to a simple theory picture is useful?!
- Lynch an excellent choice for *very* simple stuff

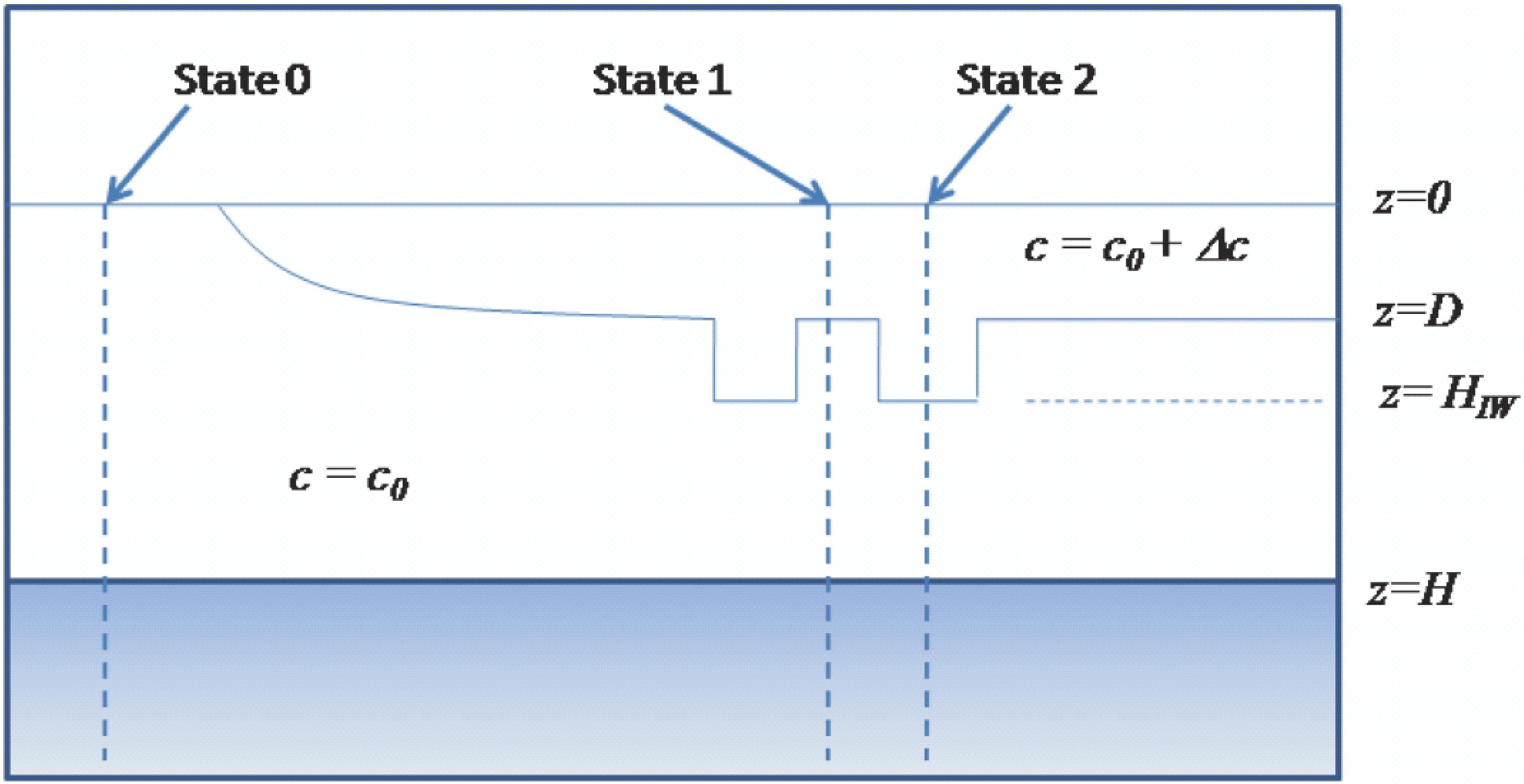
Start with Weinberg/Burridge 3-D horizontal ray/verticalmode theory

- Have a local horizontal index of refraction for each mode at a given frequency

$$n_n(x, y, \omega) = k_n(r)/k_n(0).$$

- After get the index of refraction field by computing the modes at all x,y, then trace rays in the horizontal
- Product of the ray (horizontal) and mode (vertical) gives acoustic field !!!

Trivializing IW's 101



Simple modal waveguide model

$$\gamma_n H = (m + 1/2)\pi$$

$$k_n = (k^2 - \gamma_n^2)^{1/2}$$

$$Z_n(z) = \frac{2}{H}\sin(\gamma_n z)$$

$$\Delta k_n = \frac{1}{2k_n}\int_0^D \frac{\Delta q Z_n^2(z)dz}{\rho(z)}$$

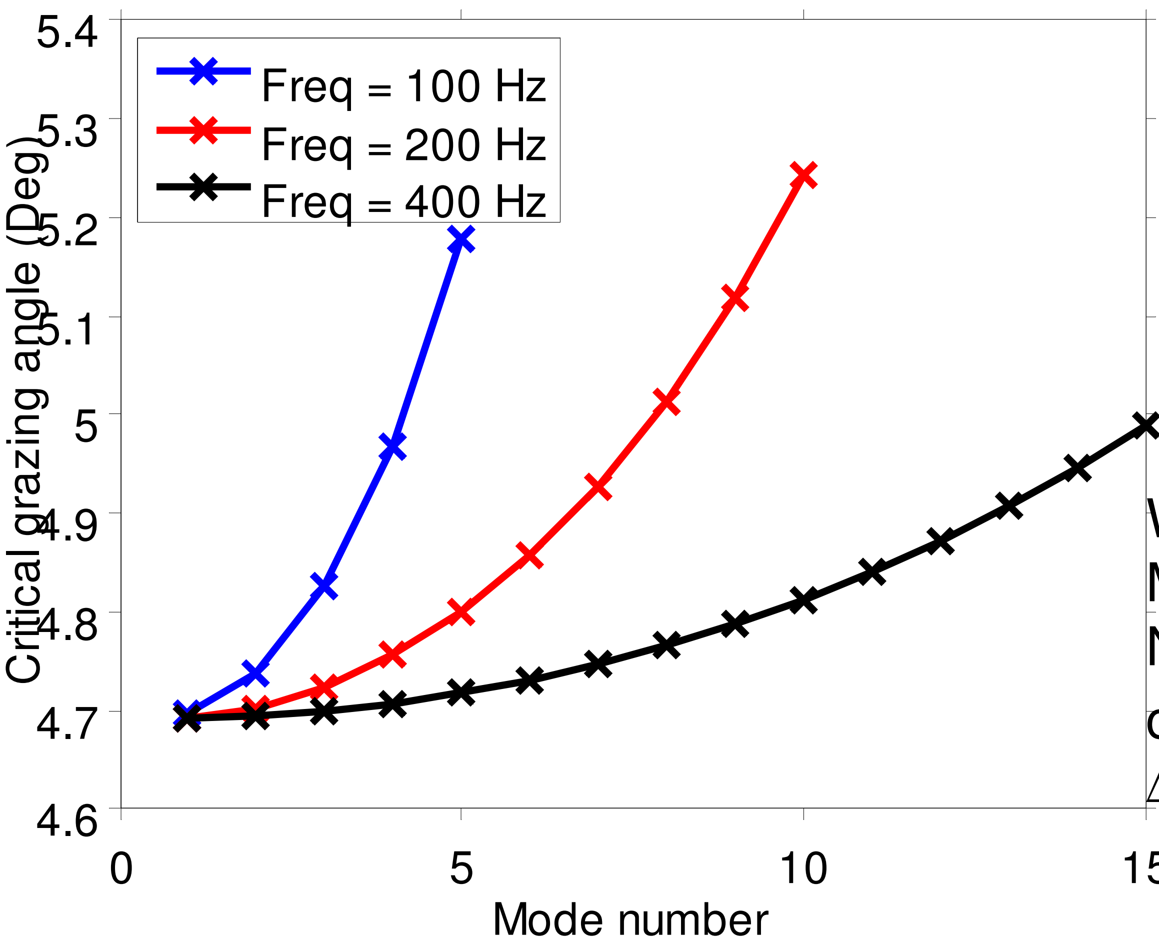
$$\Delta q = -2\Delta c(z)\frac{\omega^2}{c_0^3(z)}$$

$$\Delta k_n = \frac{2}{k_n H}\frac{\omega^2}{c_0^2}\frac{\Delta c}{c_0}\int_0^{D,H_{IW}} \sin^2(\gamma_n z)dz$$

- Simple model – rigid bottom background waveguide plus ML, IW perturbations
- The background eigenvalue plus the appropriate perturbation is what we want -> eigenvalue at each point in (x,y)

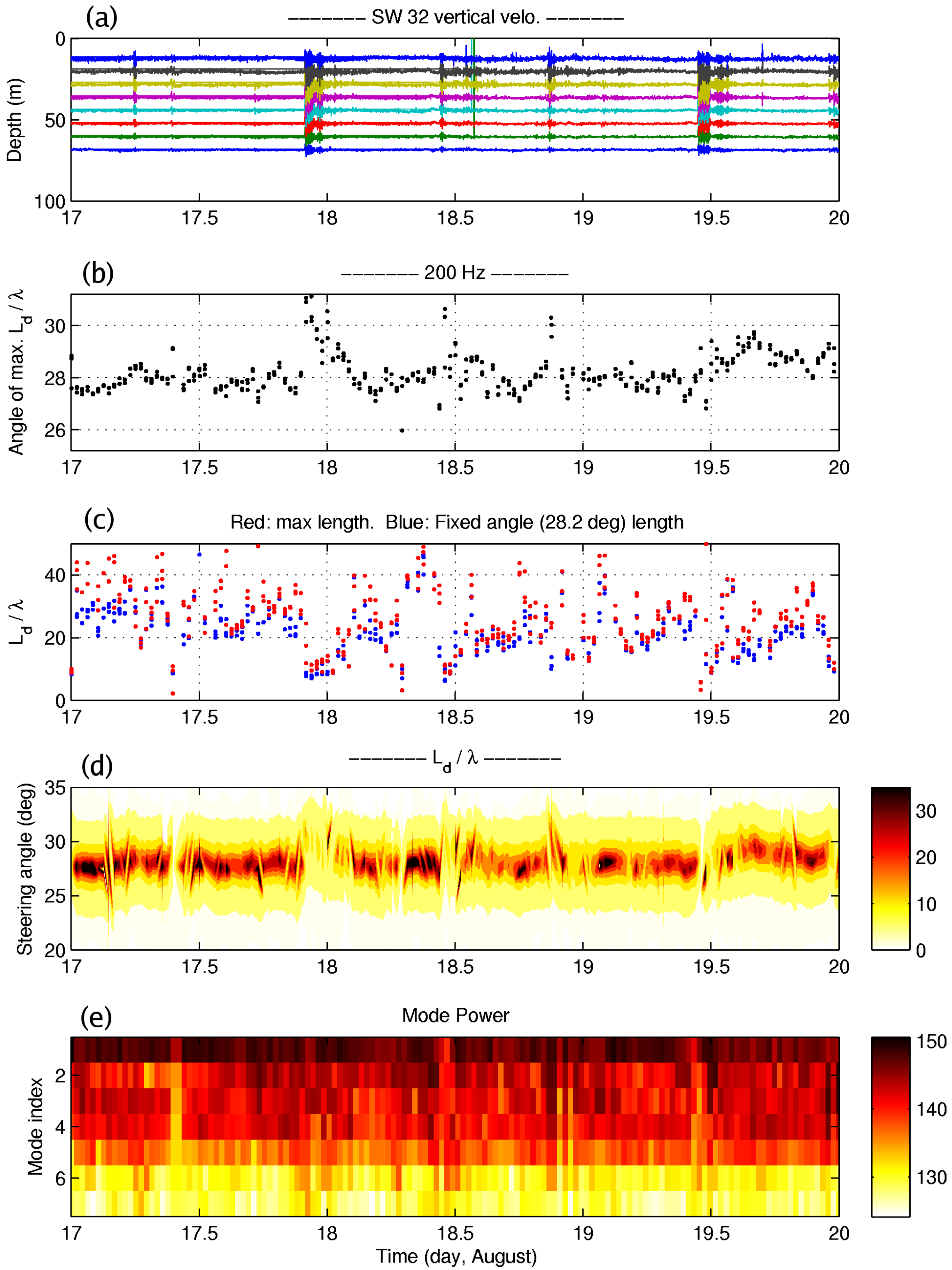
Frequency dependence of normal mode critical grazing angle

- Perturbative formulation for critical angle



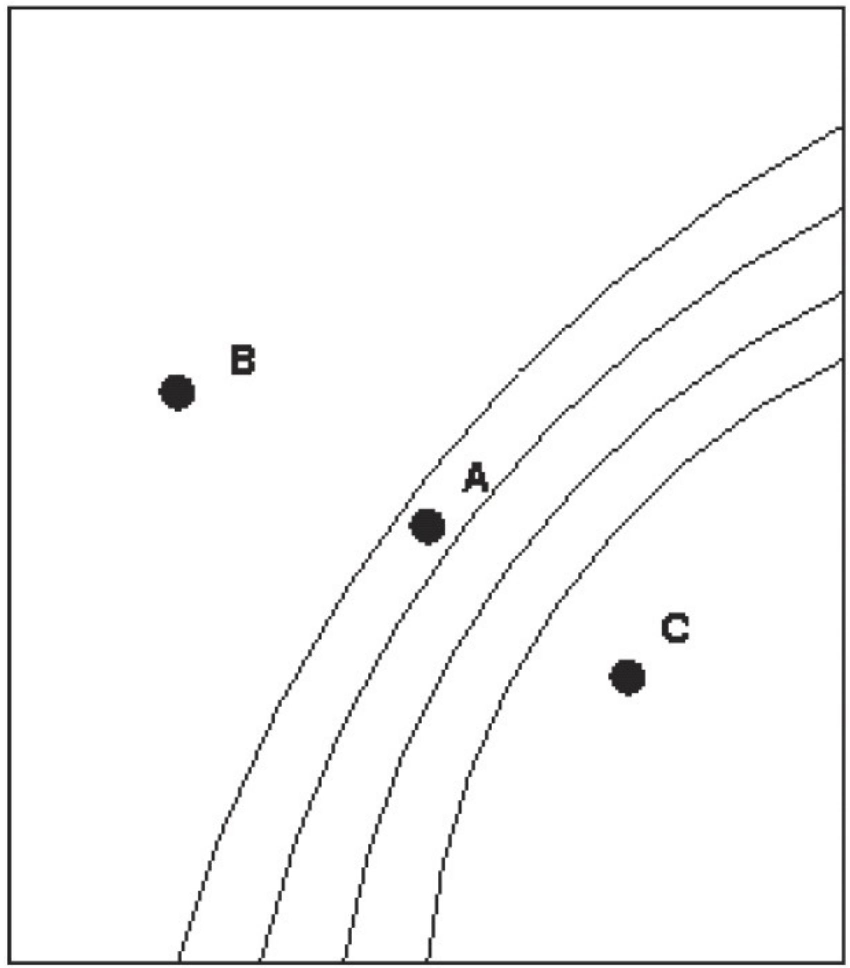
$$\theta_{n,crit} = sin^{-1}\left[\frac{\left[k^2 - \left[\frac{\left(n+\frac{1}{2}\right)\pi}{H}\right]^2\right]^{\frac{1}{2}} - \frac{H_{IW}\Delta c\omega^2}{k_n c_0^3 H}}{\left[k^2 - \left[\frac{\left(n+\frac{1}{2}\right)\pi}{H}\right]^2\right]^{\frac{1}{2}} - \frac{D\Delta c\omega^2}{k_n c_0^3 H}}\right]$$

Water Depth (H) = 80m
Mixed Layer Depth (D) = 15m
NLIW Depth (H_{IW}) = 25m
c0 = 1500 m/s
Δc = 40 m/s

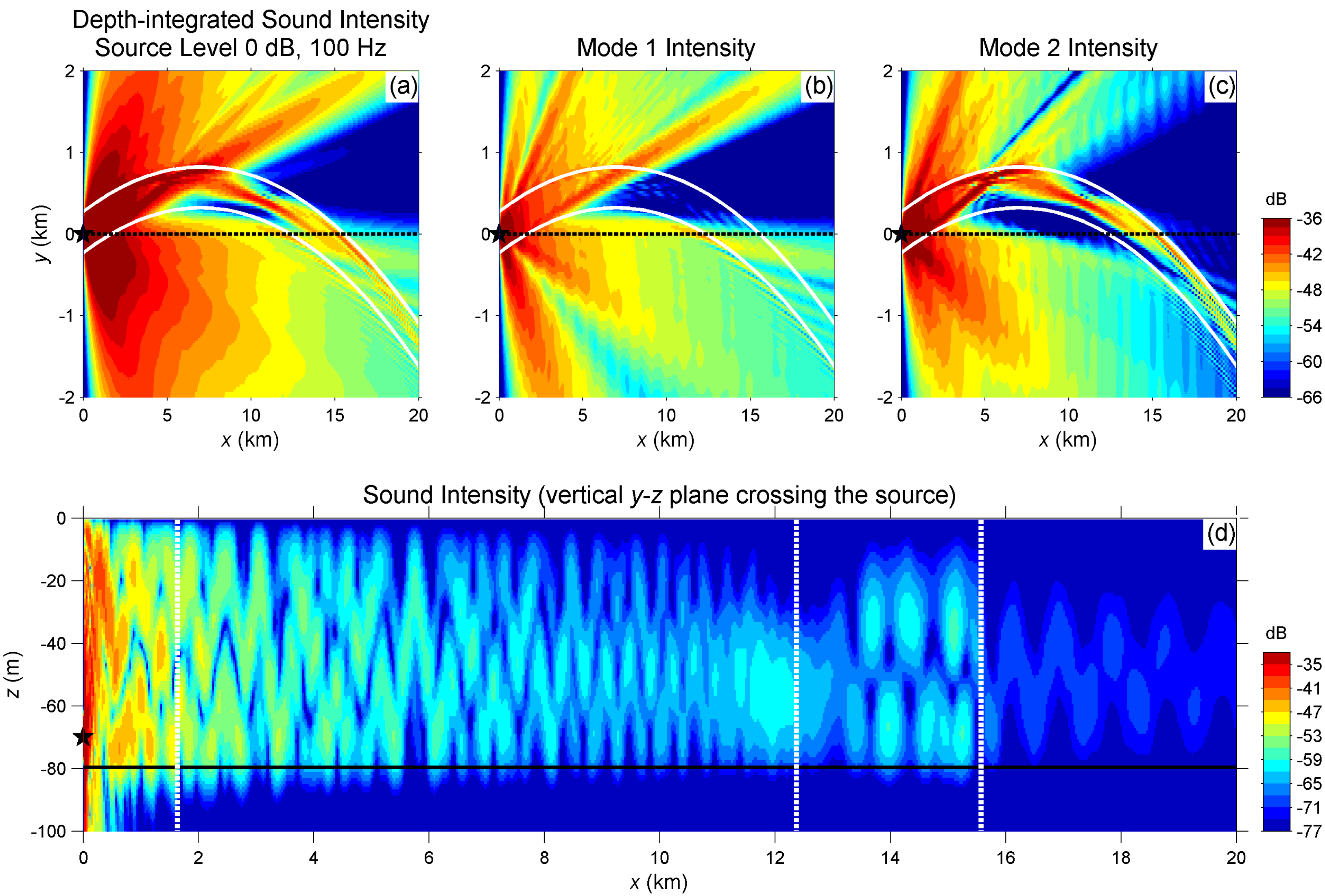


What does Mr. Data say??

Source can be exterior to wave train, inside waves, or interior to wave train – lets look at!



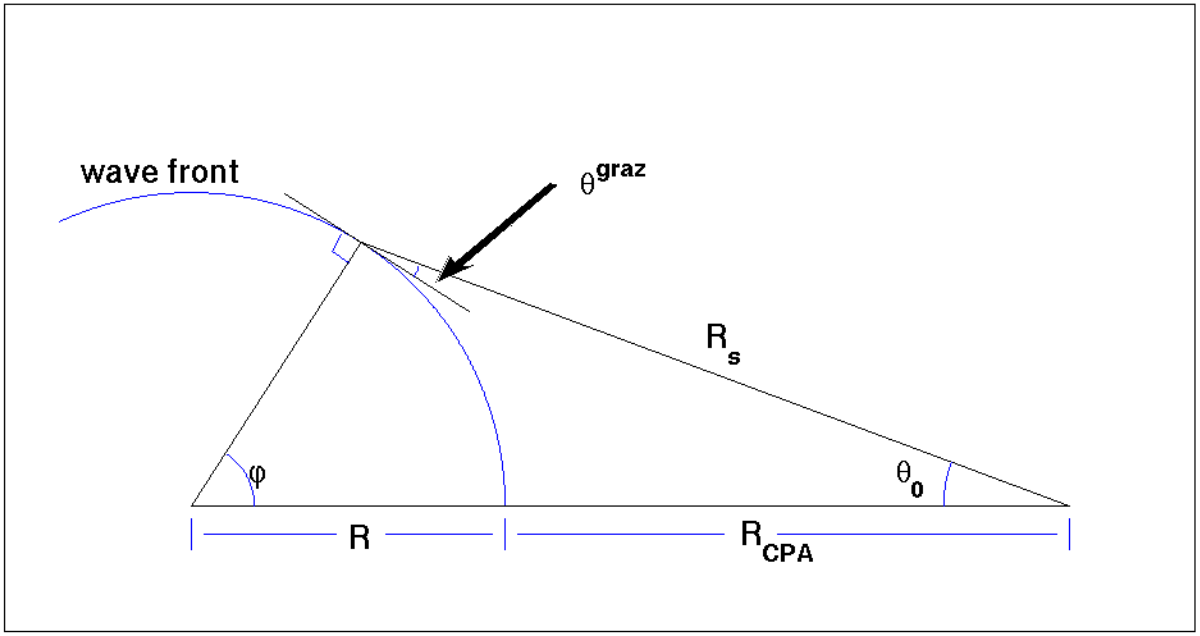
Already saw interior case



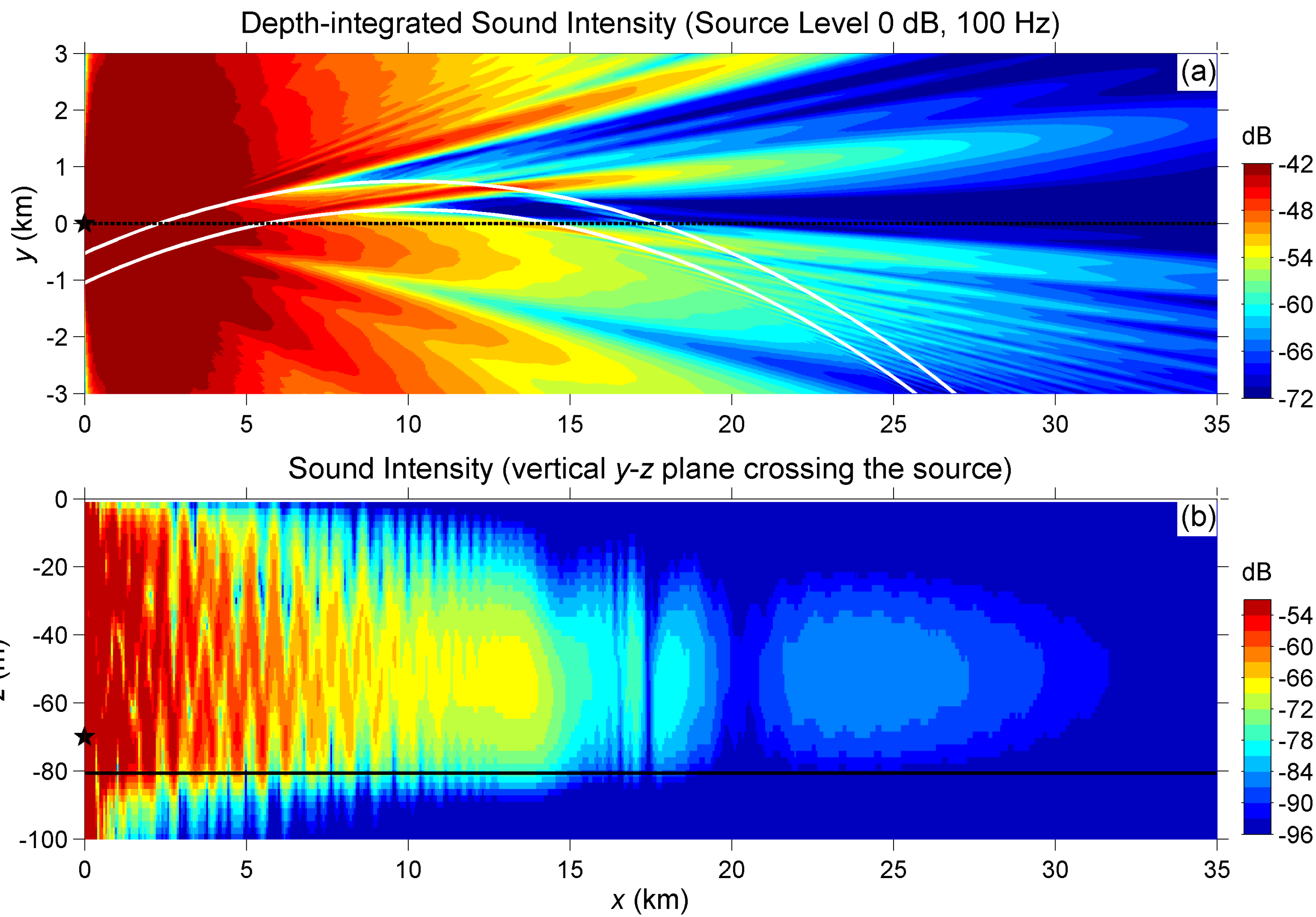
Exterior gives Shadowin g

- IW has critical angle of ~5 degrees (max)
- Can give a shadow behind a linear IW, but only if source is within 1-2 km of IW front
- Curved IW's allow one to see shadowing for source considerably further away
- Might be an observable effect in data..???

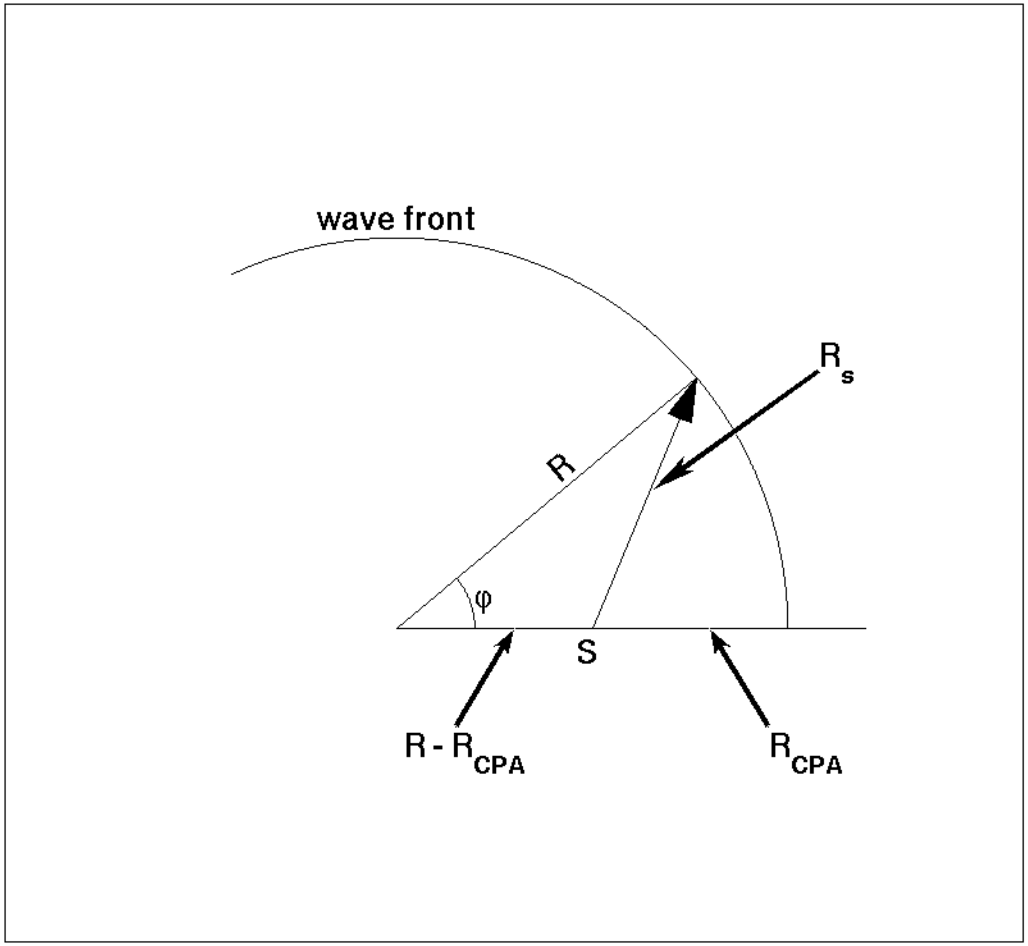
Exampleof how “falling away horizon”gives critical angle before the tangent point, and thus a shadow region behind the IW

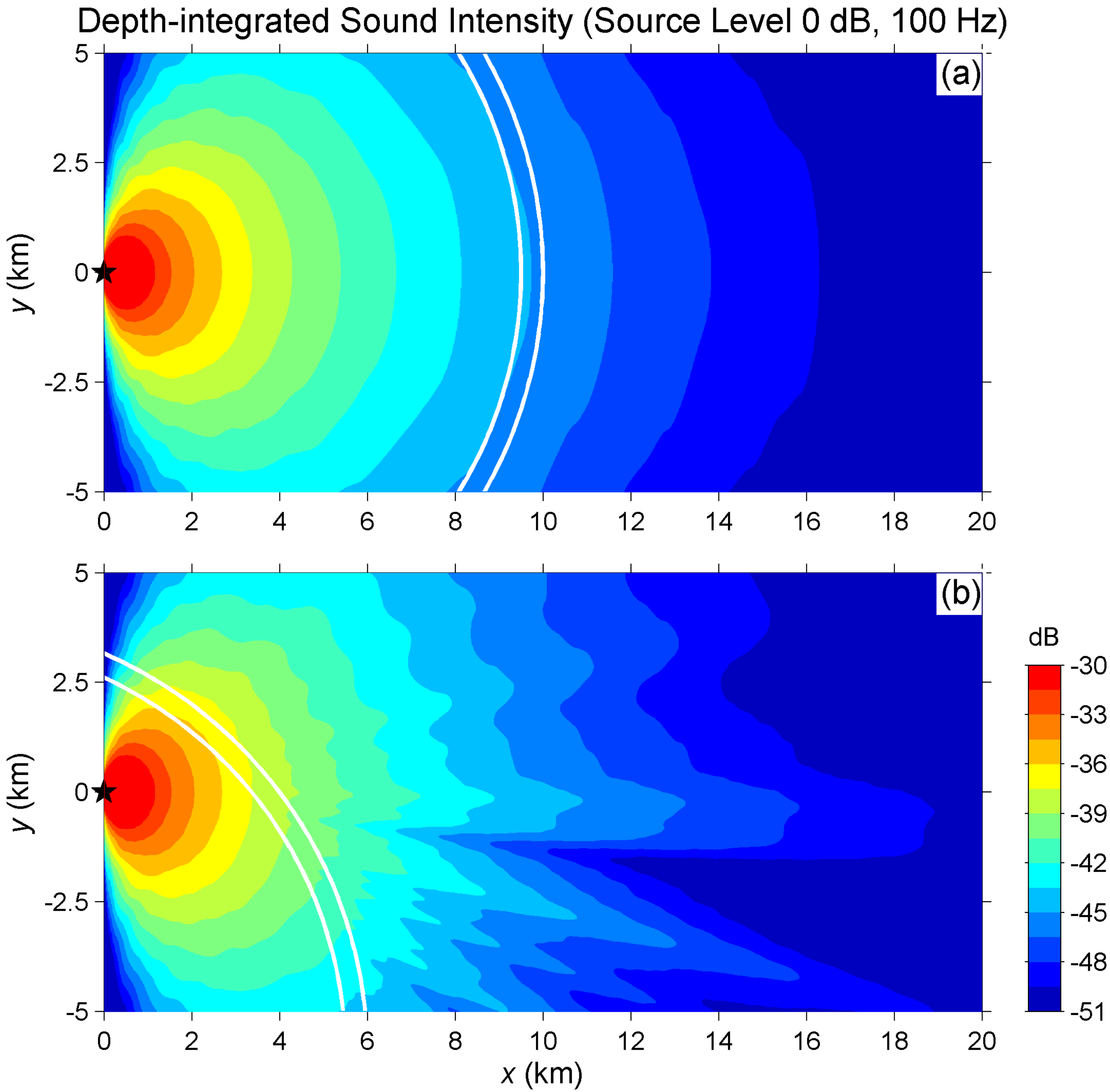


Exterior shows the shadow… and more

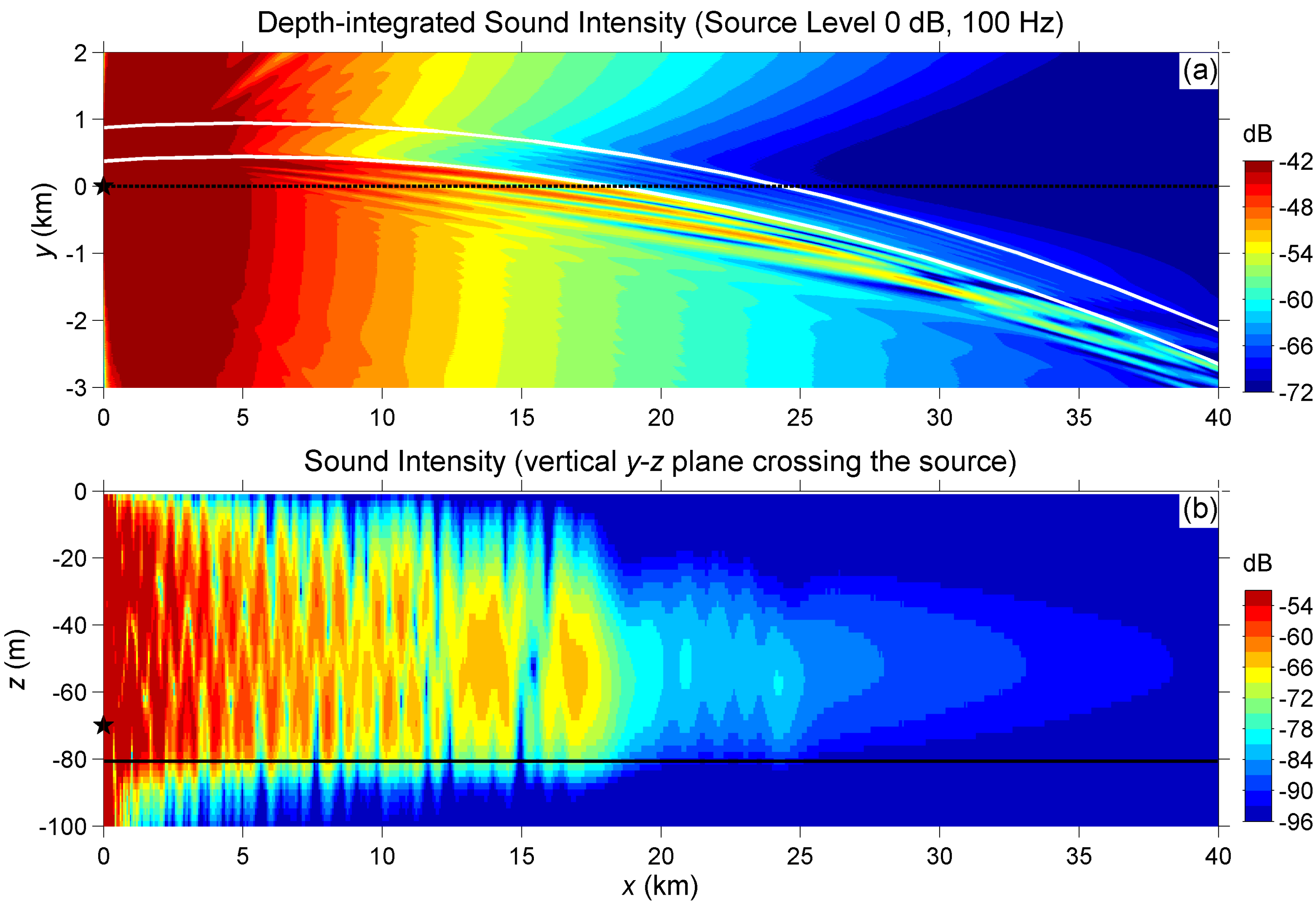


Interior case - most sound penetrates



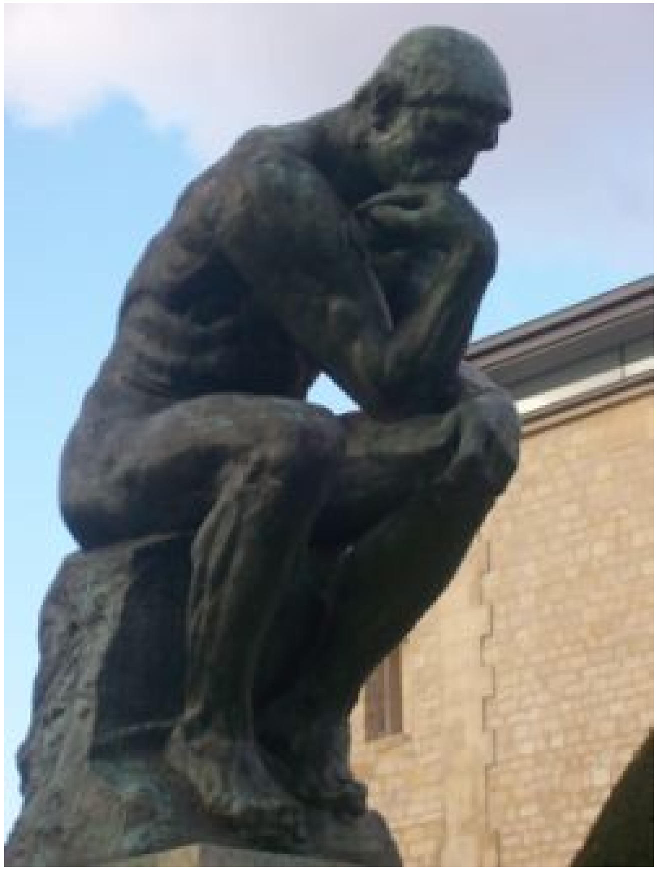

Depth-integrated Sound Intensity (Source Level 0 dB, 100 Hz)
(a)
(b)
y (km)
x (km)
dB
-30
-33
-36
-39
-42
-45
-48
-51
5
2.5
0
-2.5
-5
0
2
4
6
8
10
12
14
16
18
20

Interior – when near IW, get… whispering gallery, horizontal Lloyd's mirror, and neat shadow zone!



Quo Vadis ?

- What does one see with *all* of this stuff present? (for sure it's Funky !)
- Are there distinct signals/signatures from each "process" we've examined, [time, angle, frequency, intensity,..]or do they produce similar, "additive" effects?
- How to describe this mess - with random medium approach…?!?
- What does this mean for naval and other ocean acoustics applications?



Questions??