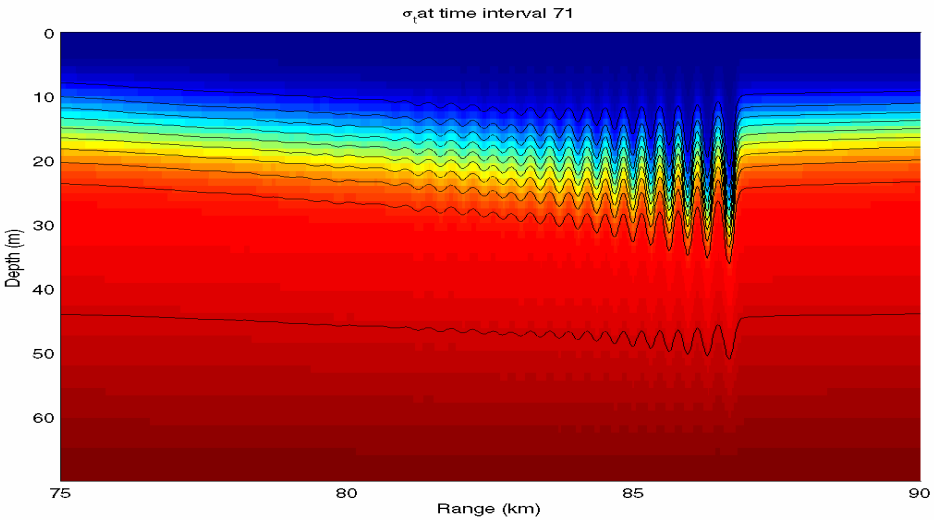
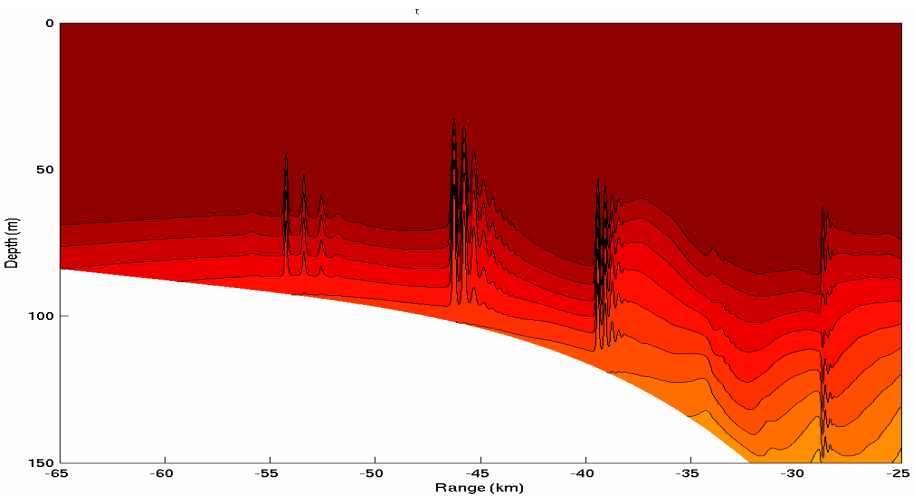
Ocean-acoustic studies of near-surface and near-bottom soliton packets.

A. Warn-Varnas, S. Chin-Bing , D. King, J. Hawkins, K. Lamb and J. Lynch

Yellow Sea



Winter Primer4



- **Issues**

  Generation, propagation, and characteristics of solitary waves.

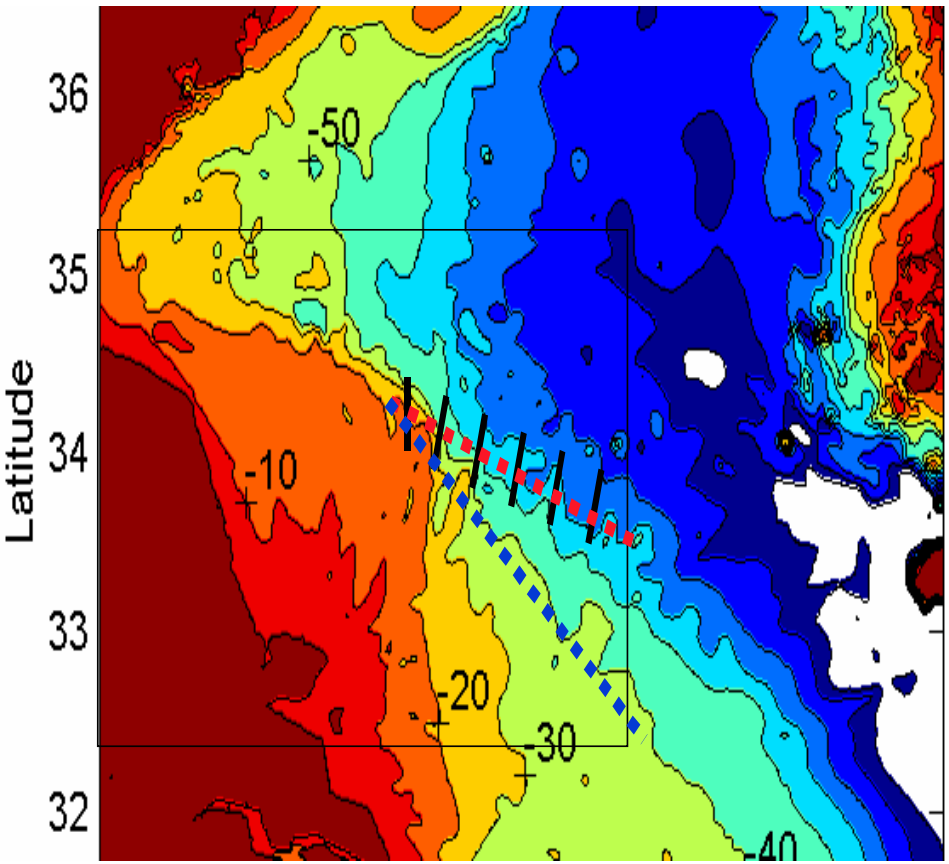
  Validation of solitary wave and acoustical field predictions with data.

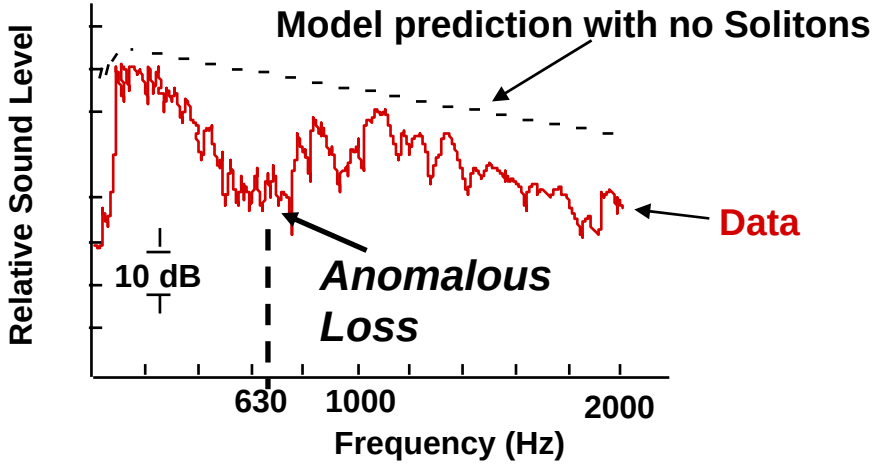
  Interaction mechanisms of soliton packets with the acoustical field.

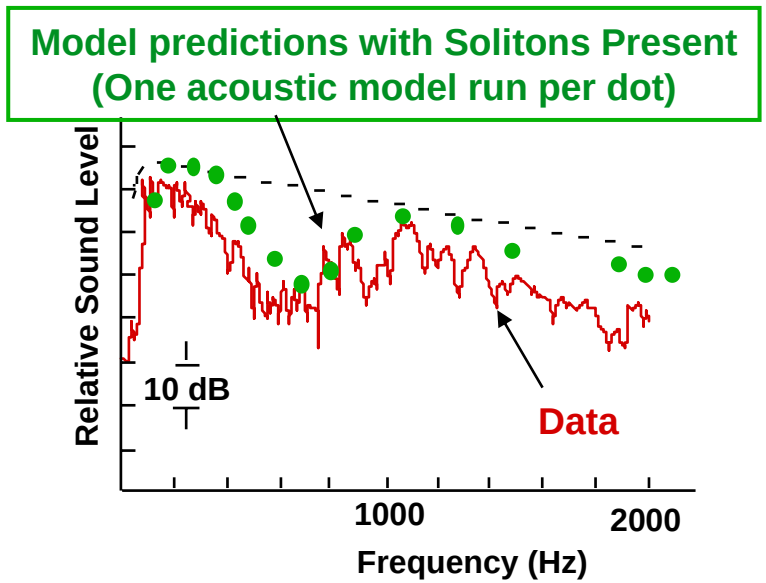
  Anomalous loss or gain of acoustical energy in presence of soliton packets.

YELLOW SEA STUDIES

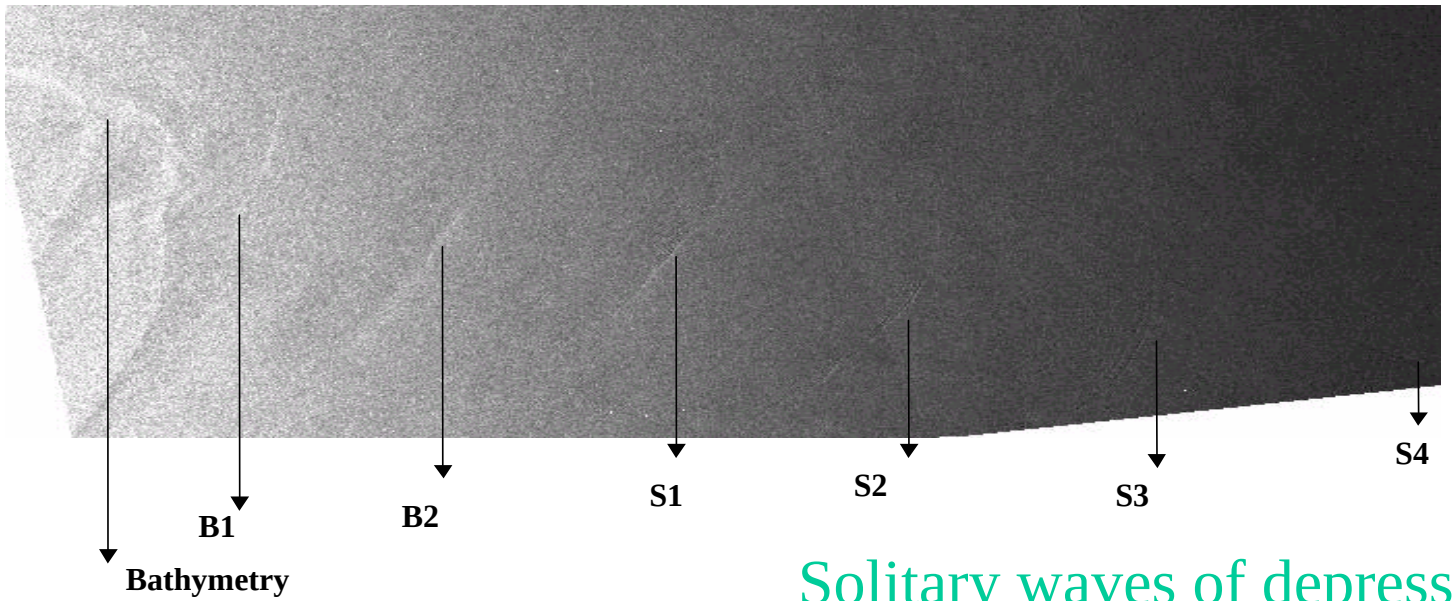
Shandong region



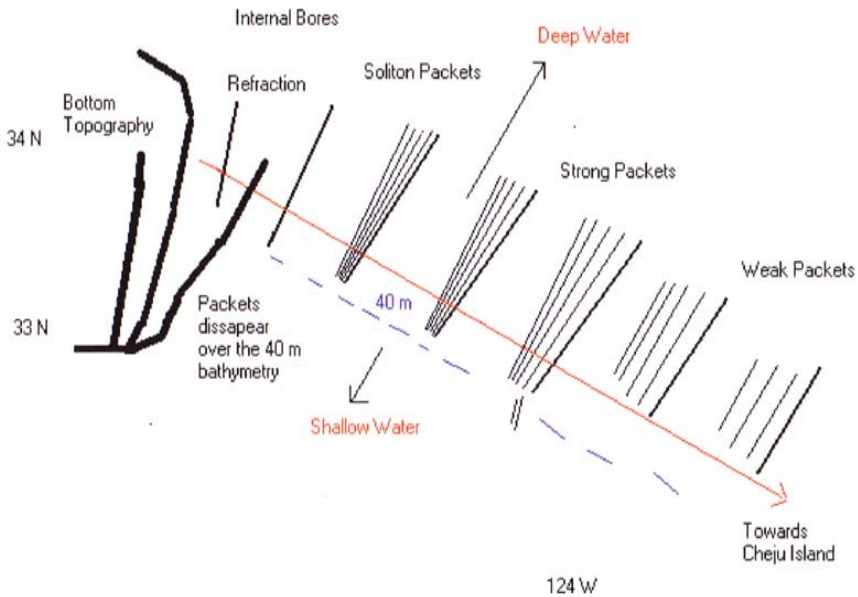


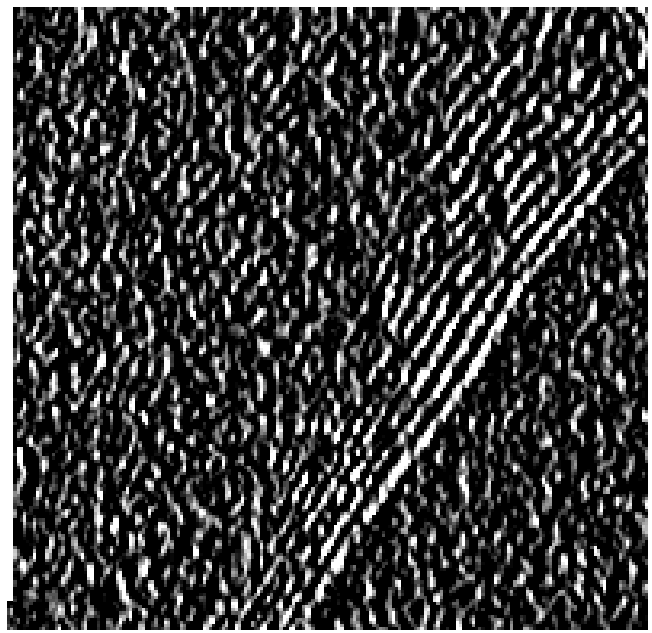


RADARSAT-1 SAR IMAGE 8/22/1998



Solitary waves of depression





LAMB 1994 NH MODEL

2.5 D inviscid equations

Sigma-coordinate grid

Incompressible Boussinesq:

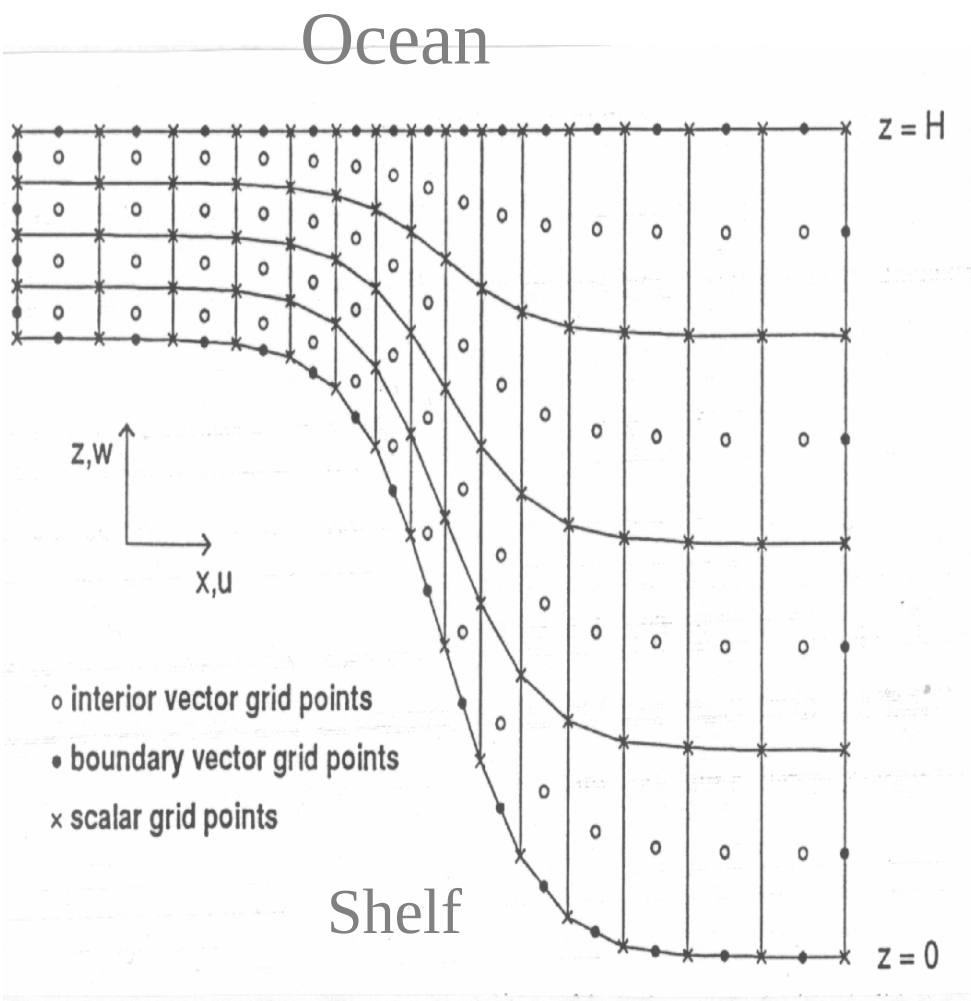
$$U_t + U \bullet \nabla U - fv\vec{i} = -\nabla p - \rho g$$

$$v_t + U \bullet \nabla v + fu = 0$$

$$\nabla \bullet U = 0$$

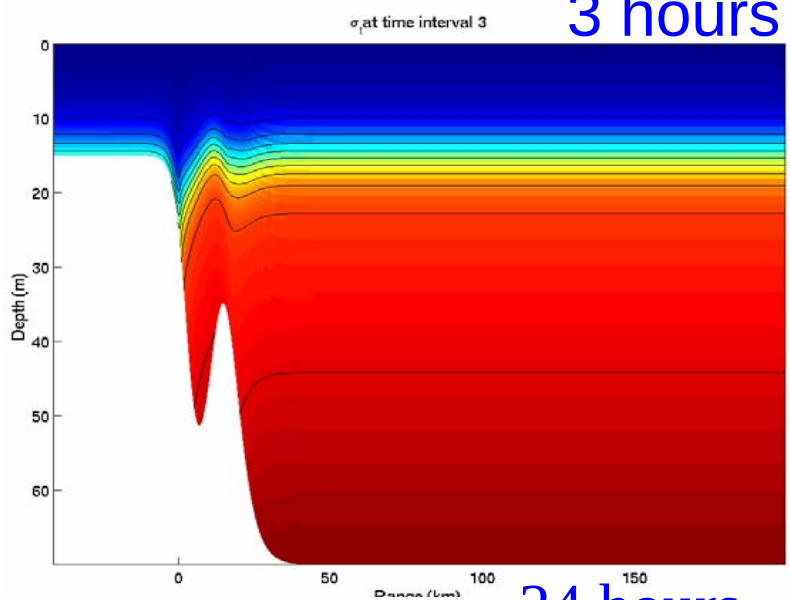
$$\rho_t + U \bullet \nabla \rho = 0$$

$$\nabla = \vec{i}\,\partial/\partial x + \vec{k}\,\partial/\partial z$$

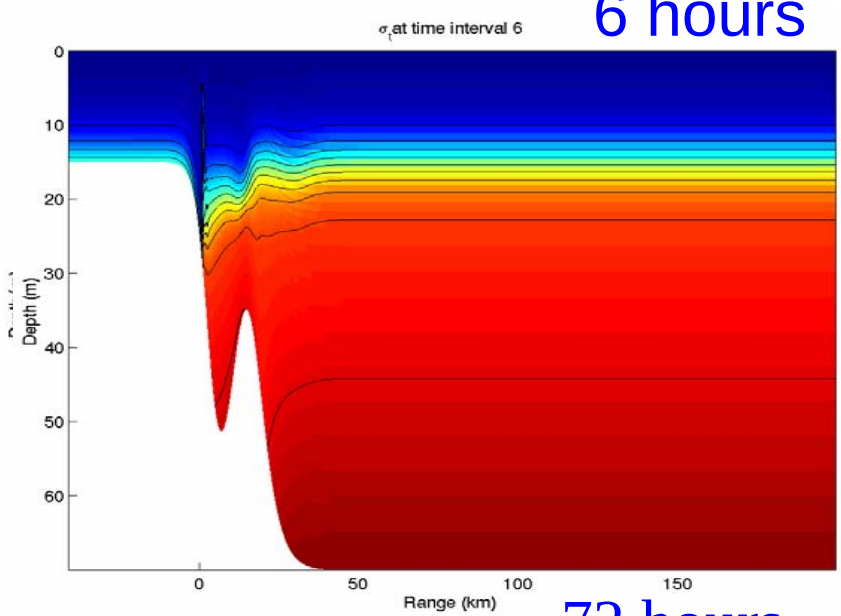


GENERATION OF SOLITARY WAVES

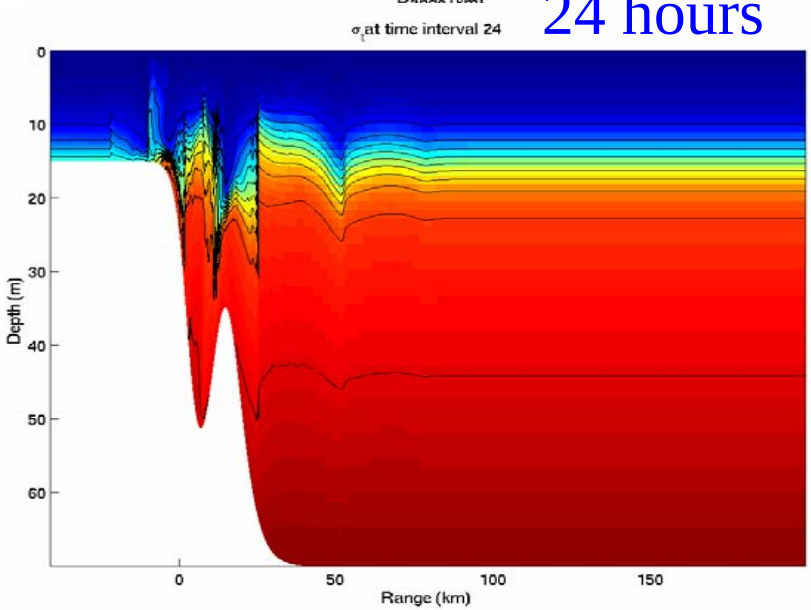
3 hours



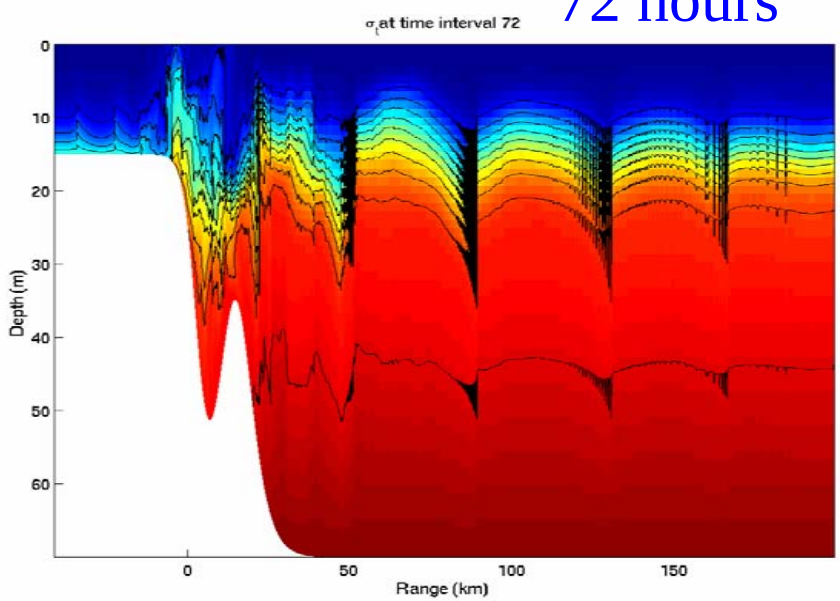
6 hours

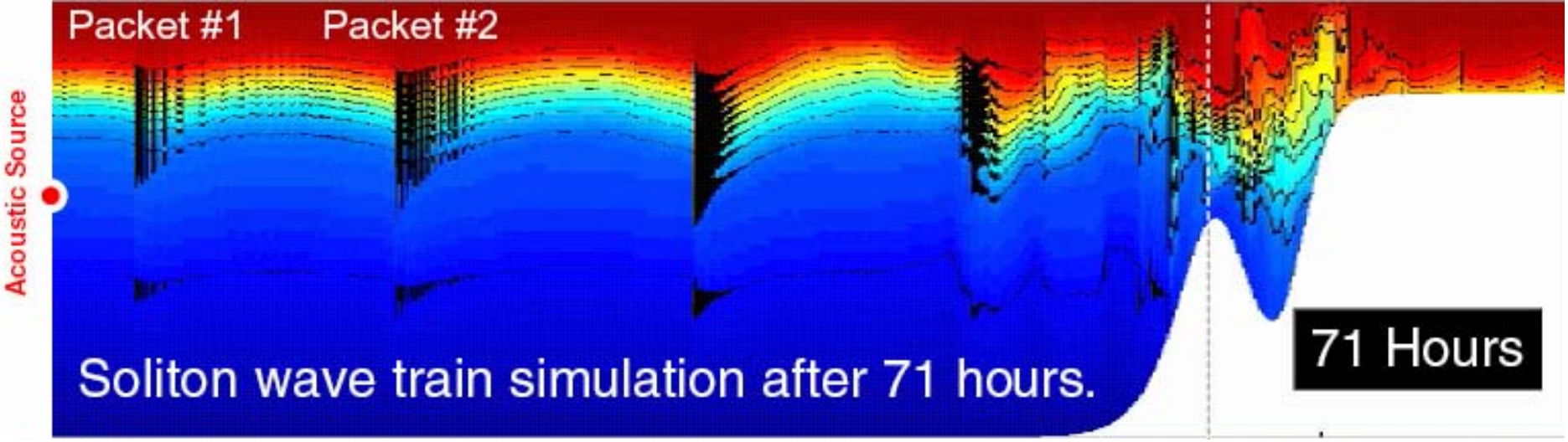


24 hours



72 hours





Helmholtz Eq. $\nabla^2 P(\vec{r}) + k^2 P(\vec{r}) = 0$, *where* $k(\vec{r}) = 2\pi f / C(\vec{r})$

$$\frac{\partial^2 P(r,z)}{\partial r^2} + \frac{1}{r}\frac{\partial P(r,z)}{\partial r} + \frac{\partial^2 P(r,z)}{\partial z^2} + k_0^2 n^2(r,z) P(r,z) = 0$$

with $k(r,z) = k_0 n(r,z)$, $k_0 = 2\pi f / C_0$

Define $P(r,z) = p(r,z)/\sqrt{r}$,

and remove the cylindrical spreading term

$$\frac{\partial^2 p(r,z)}{\partial r^2} = -\left(k_0^2 n^2(r,z) + \partial^2/\partial z^2\right) p(r,z)$$

$$\left[\frac{\partial}{\partial r} + ik_0\sqrt{(1+X)}\right]\left[\frac{\partial}{\partial r} - ik_0\sqrt{(1+X)}\right] p = 0$$

where $X = k_0^{-2}\left(\partial^2/\partial z^2 + k^2 - k_0^2\right)$

$$\frac{\partial p}{\partial r} = ik_0\sqrt{(1+X)}\,p \quad \textit{Parabolic (Outgoing) Wave Eq.}$$

Remove the common phase term, $\exp(ik_0 r)$

$$\frac{\partial p}{\partial r} = ik_0\left(-1 + \sqrt{(1+X)}\right)p \quad \textit{One-way PE}$$

Approximate the pseudo-differential operator by a

n-order Pade' series: $-1 + \sqrt{(1+X)} \cong \sum_{j=1}^{n} a_{j,n} X / (1 + b_{j,n} X)$

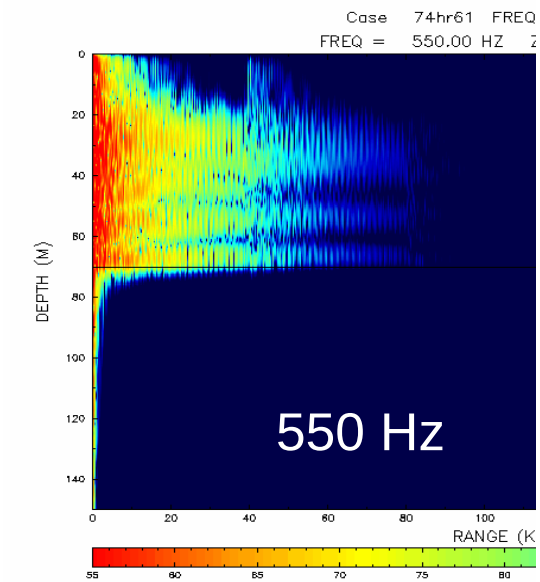
$$\frac{\partial p}{\partial r} = ik_0 \sum_{j=1}^{n} \frac{a_{j,n} X}{1 + b_{j,n} X} p \quad \textit{FEPE model solves this equation.}$$

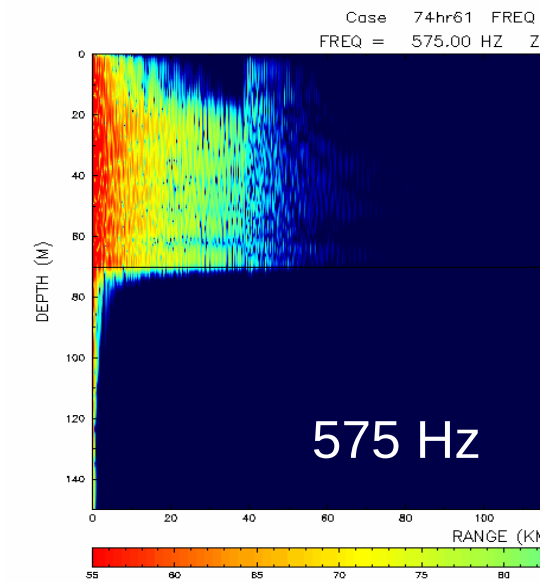
$n = 7$ *gives propagating angles* $> 150^{\circ}$

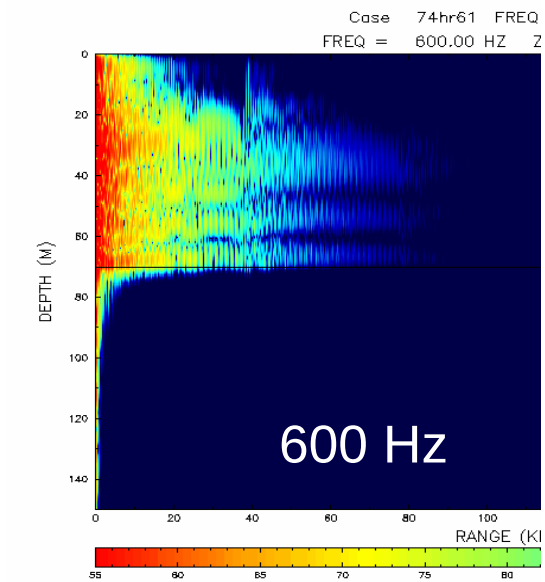
$$p(r+\Delta r) - p(r) = \frac{1}{2} ik_0 \Delta r \frac{a_{j,n} X}{1 + b_{j,n} X}\left[p(r+\Delta r) + p(r)\right]$$

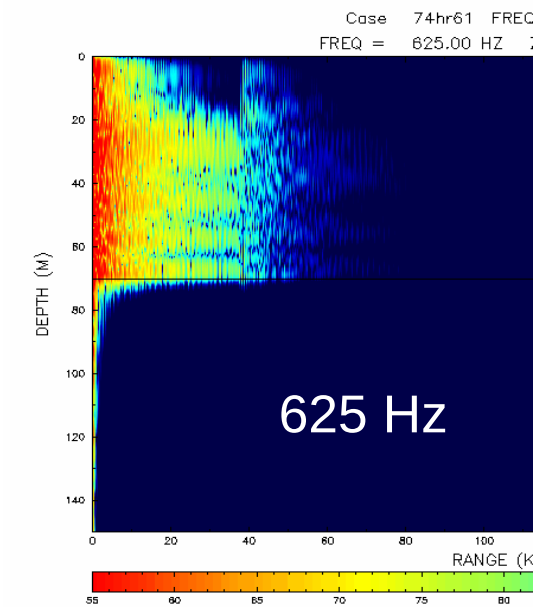
$$p(r+\Delta r) = \frac{1 + \left(b_{j,n} + ik_0 \Delta r a_{j,n}/2\right)X}{1 + \left(b_{j,n} - ik_0 \Delta r a_{j,n}/2\right)X}\, p(r)$$

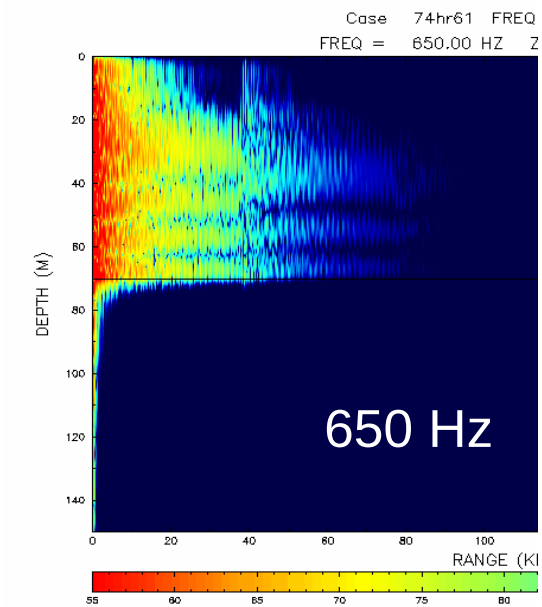
Multiple Acoustic Losses Hour 74 Tidal Forcing 0.7 m/s











Yellow Sea

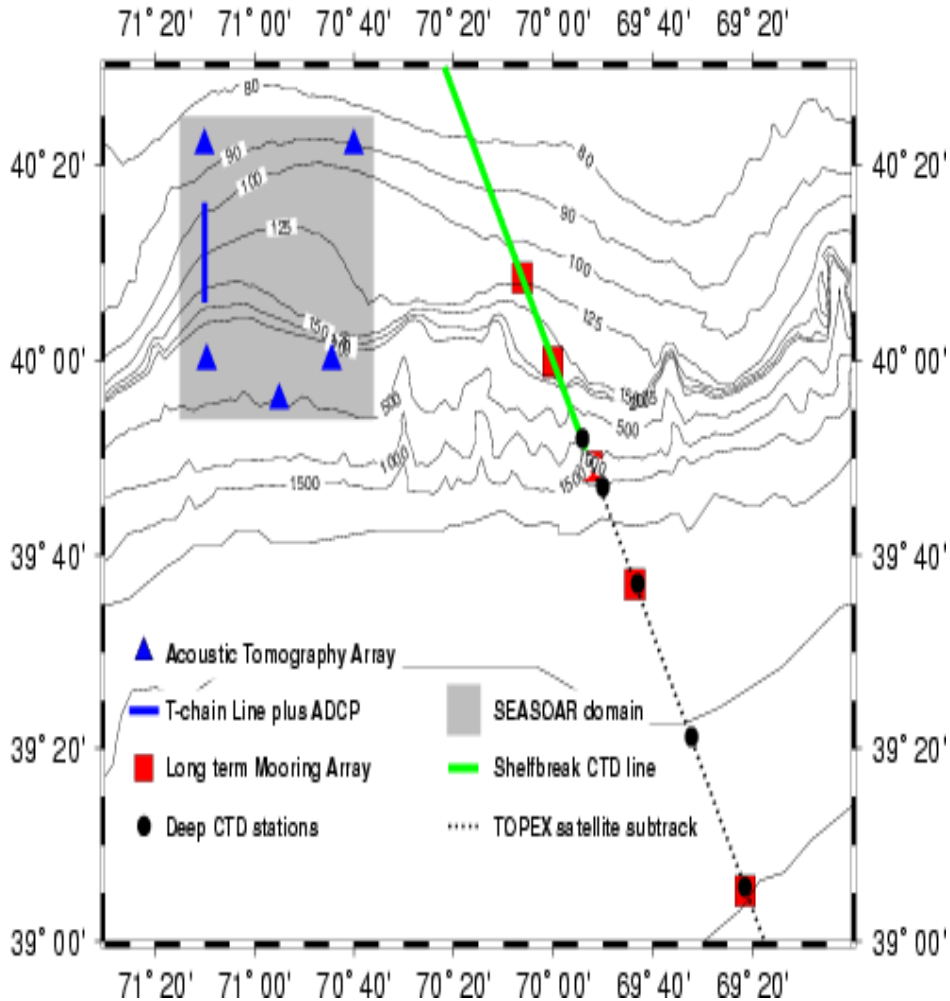
Hour 74

Forcing .70m/s

Note Loss of Propagation at 575 Hz and 625 Hz

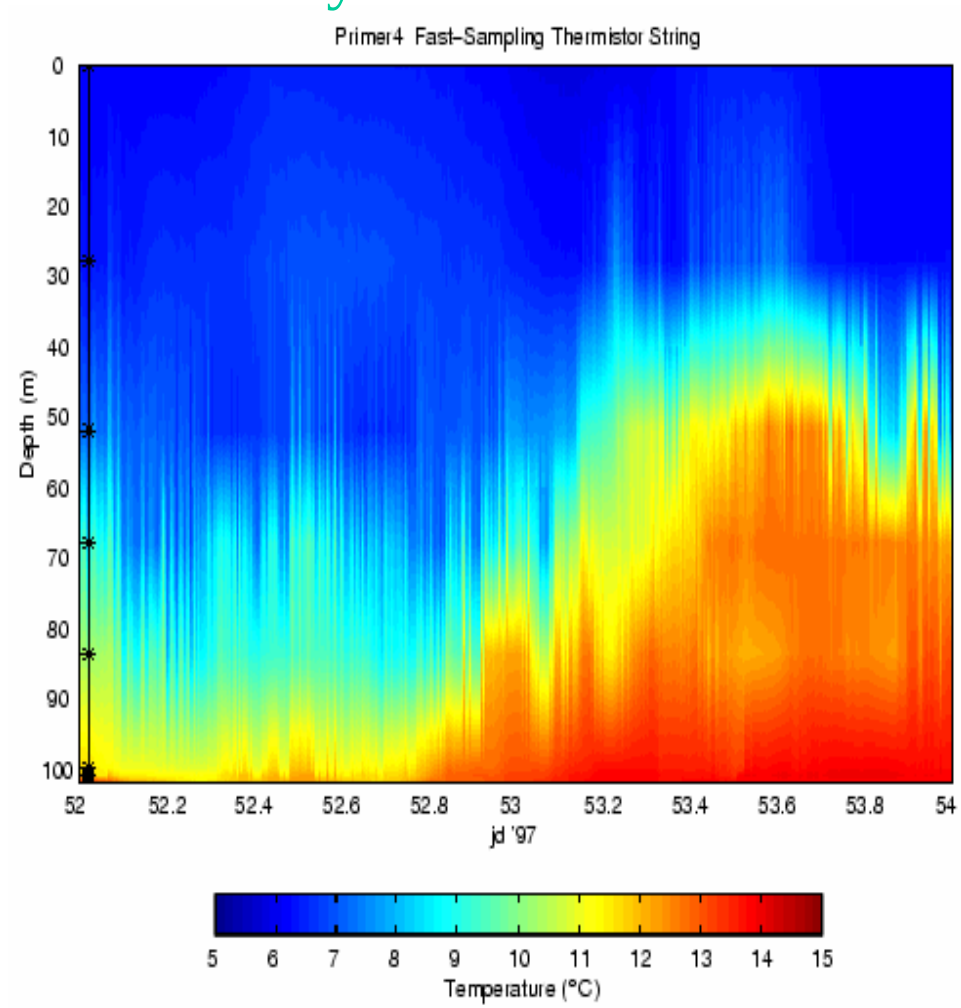
WINTER PRIMER FEB 97

Events



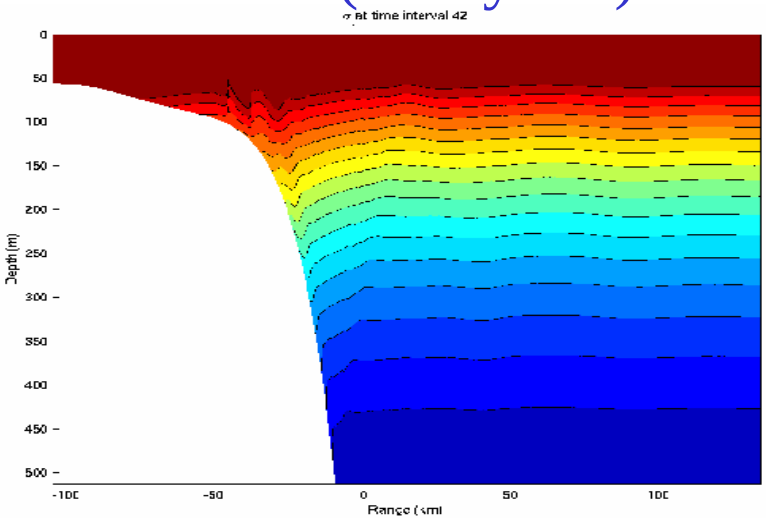
Thermiston chain data

Solitary waves of elevation

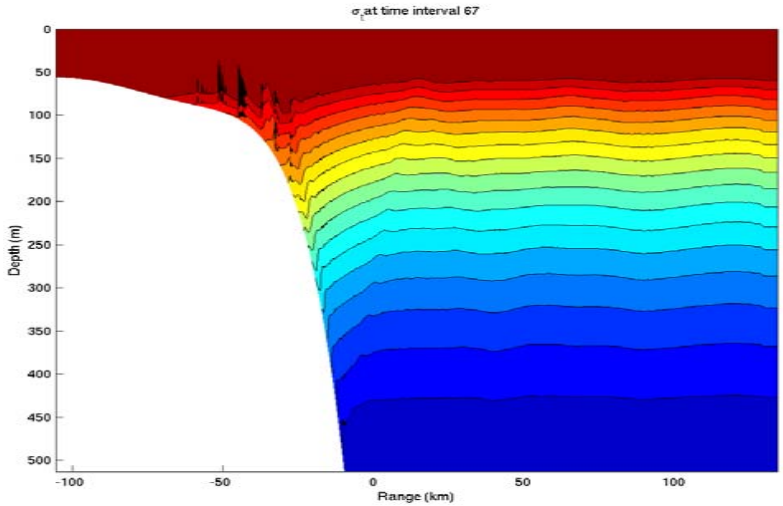


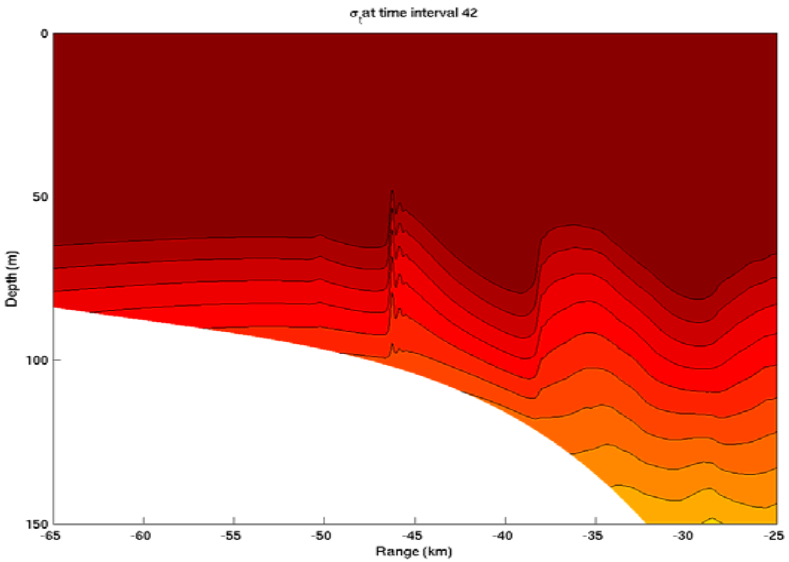
ON SHELF SOLITARY WAVE GENERATION (case 1 & MLD 50 meters)

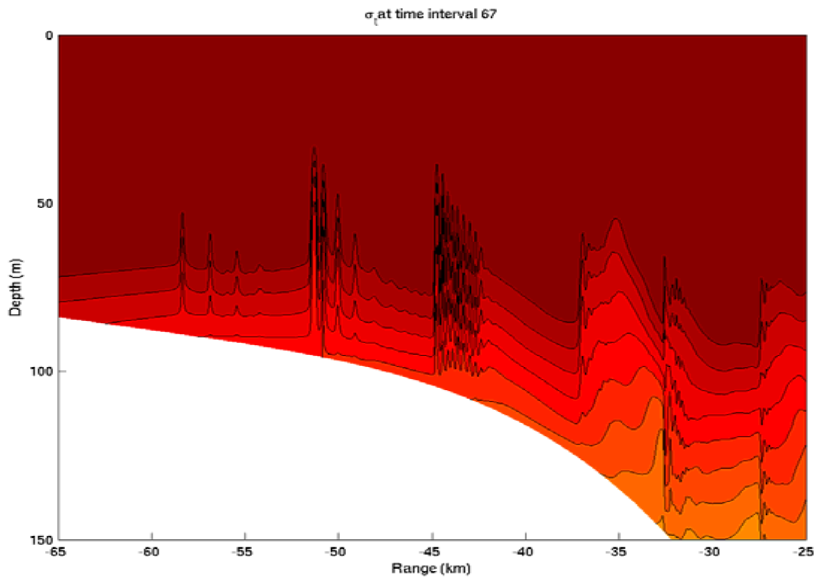
42 hours (3.5 cycles)



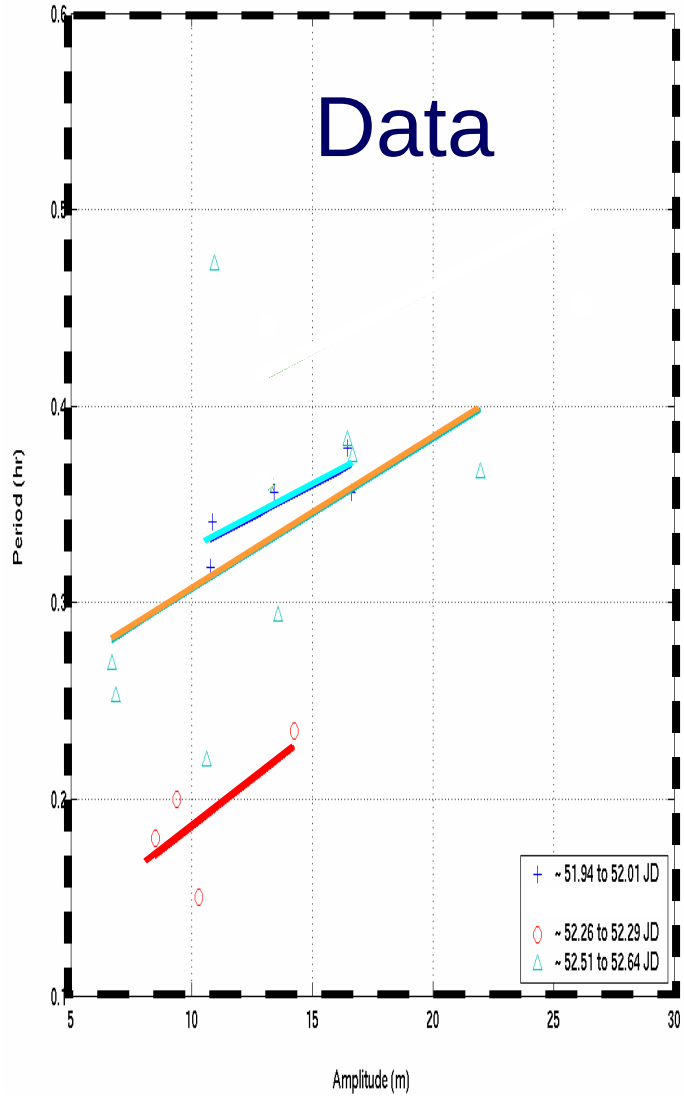
67 hours (5.5 cycles)

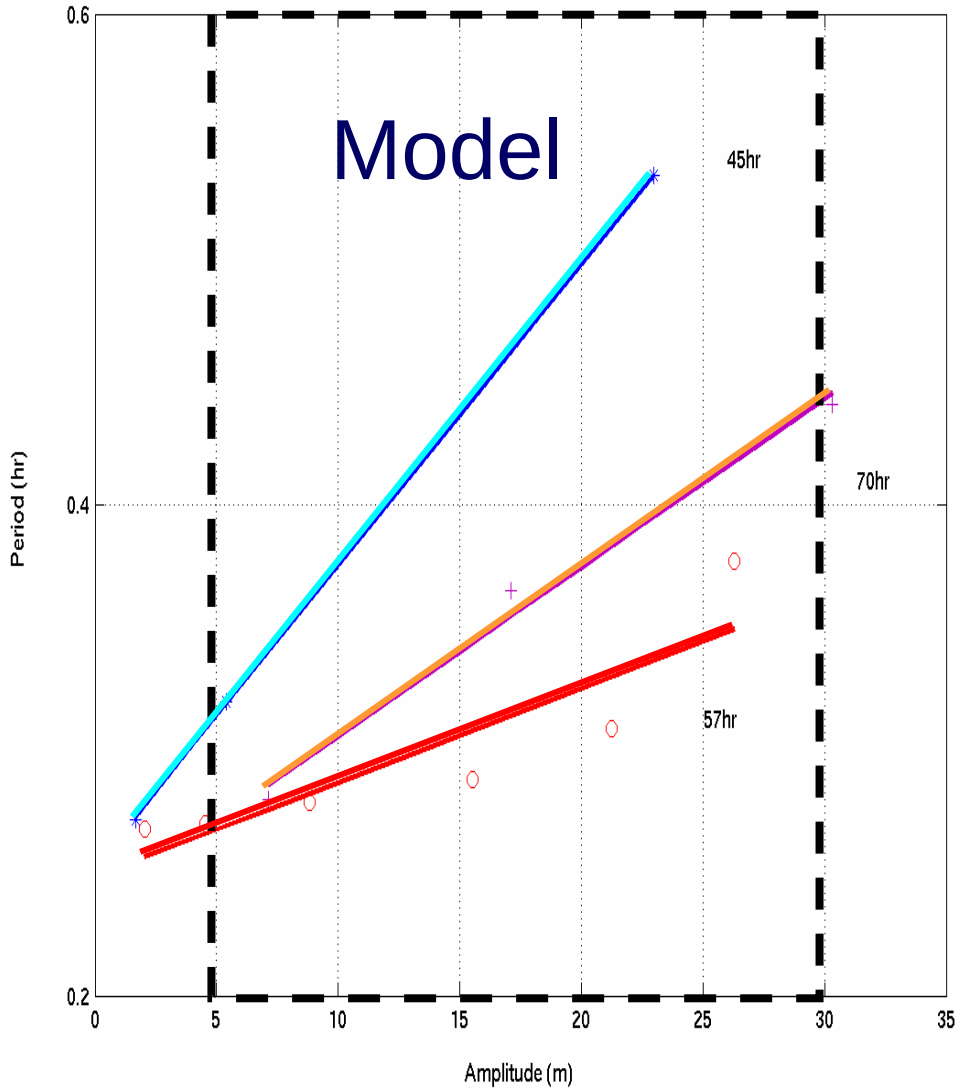


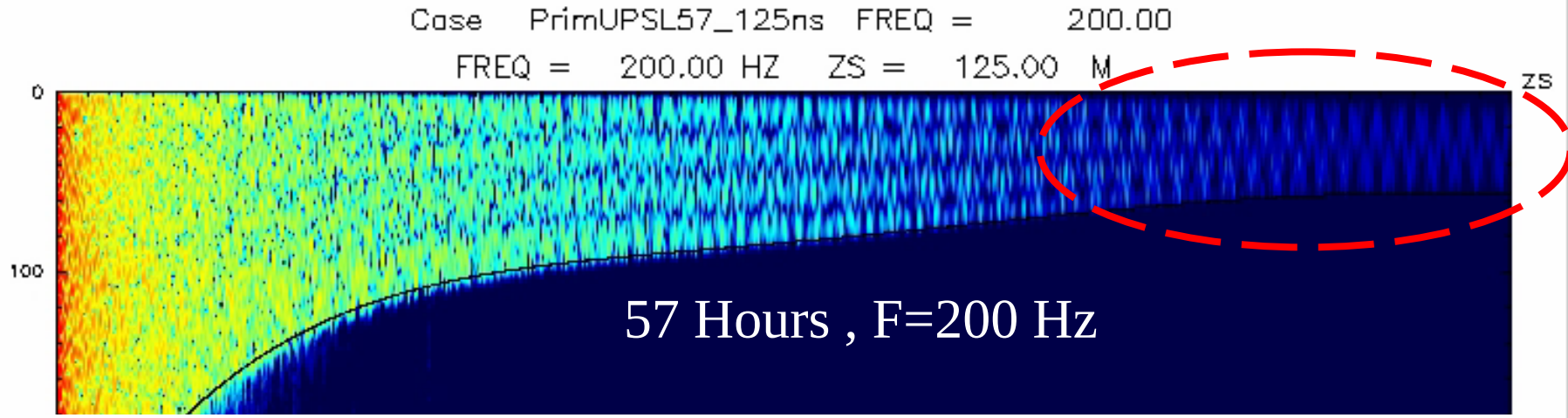


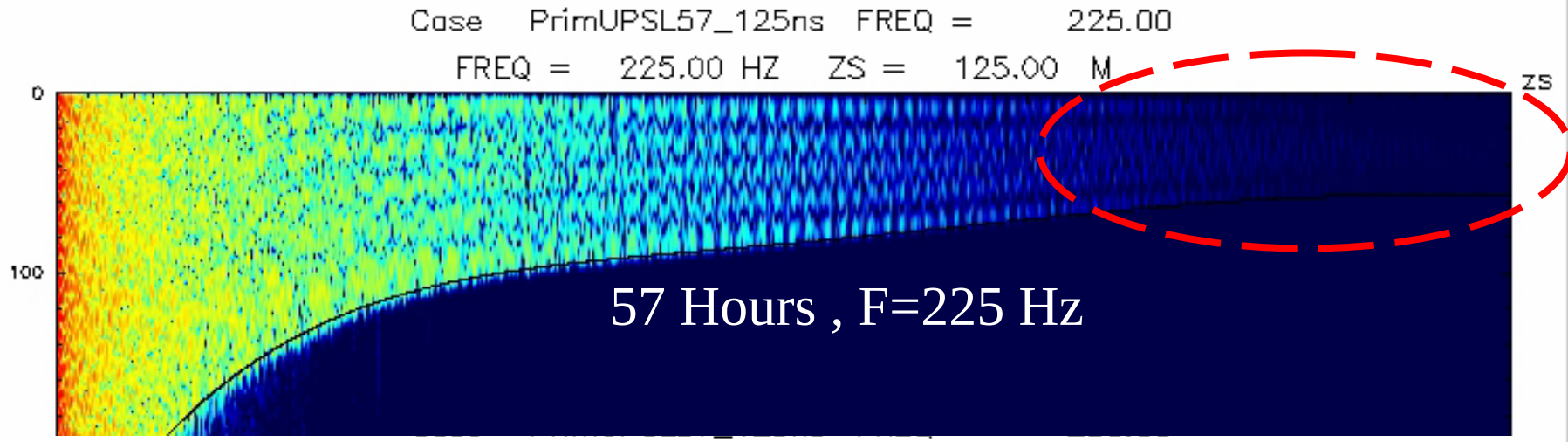


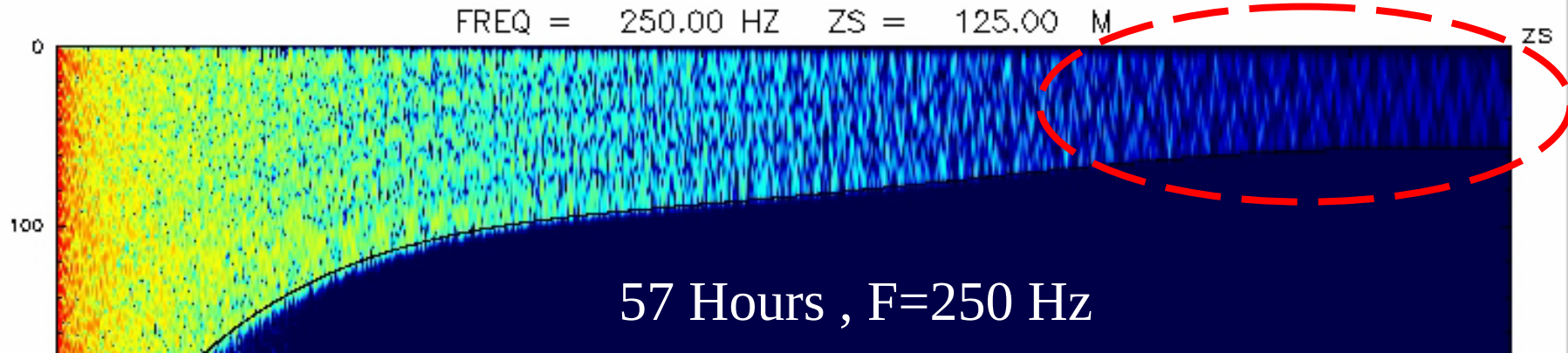
DISPERSION OF MODEL & DATA





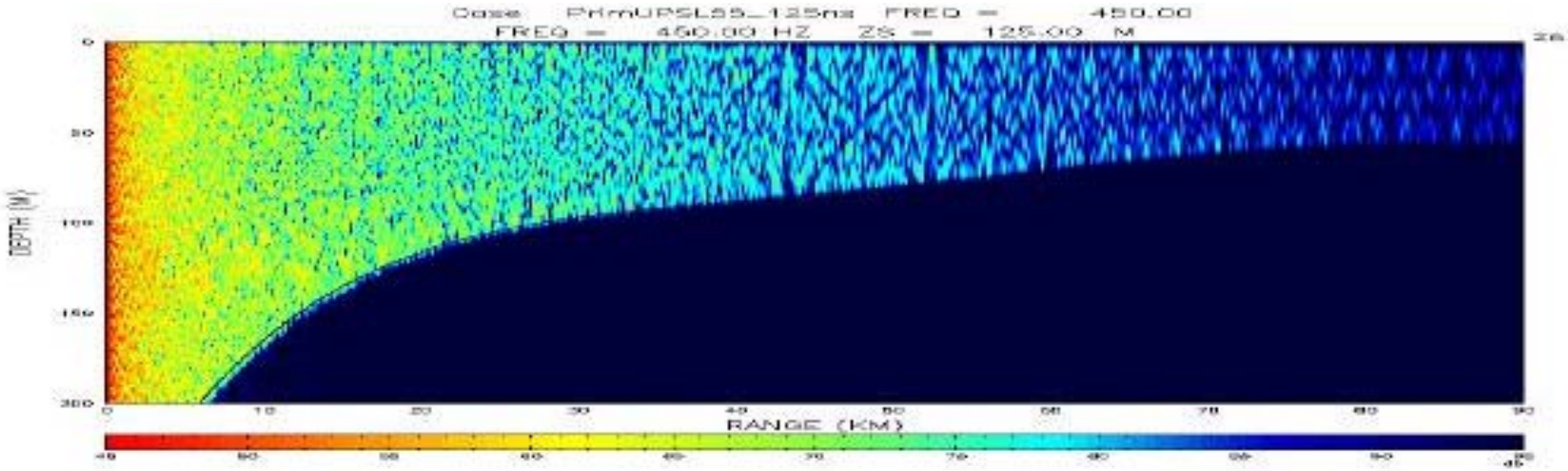

Case PrimUPSL57_125ns FREQ = 200.00
FREQ = 200.00 HZ ZS = 125.00 M
0
100
ZS
57 Hours , F=200 Hz


Case PrimUPSL57_125ns FREQ = 225.00
FREQ = 225.00 HZ ZS = 125.00 M
0
100
ZS
57 Hours , F=225 Hz

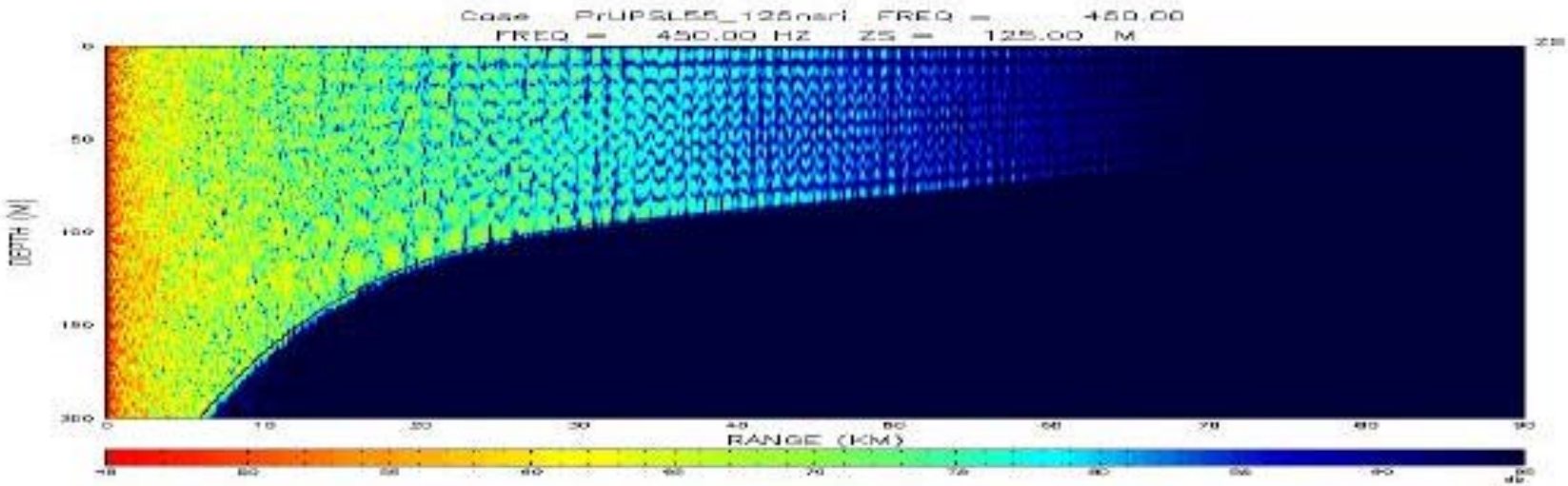

FREQ = 250.00 HZ ZS = 125.00 M
0
100
ZS
57 Hours , F=250 Hz

Anomalous gain with soliton packets

With soliton packets



Without soliton packets



SUMMARY

•Winter Primer4 simulations showed that near-bottom solitary waves of elevation propagate only on the shelf. No solitary waves are formed off the shelf.

•Simulated amplitudes and periods of near-bottom solitary waves of elevations for winter Primer4 overlapped with thermistor chain measurements.

•Yellow Sea ,near-surface solitary waves, simulations with tuned model, agree with SAR data within factors of 2 (or less) in wavelength and deduced amplitude.

• Near-Surface Solitons

Mode Conversions: if source is below themocline, results in signal loss below the thermocline.
Magnitude of Signal Changes can be large (~ 10 dB)
Conversion Mechanisms are complex:
Major: trapped-to-trapped modes;
Minor: trapped-to-continuous (lossy); trapped-to-backscatter

• Near-Bottom Solitons

Mode Conversions: if source is below themocline, results in signal gain above the thermocline.
Magnitude of Signal Changes are moderate large (~ 3-5 dB)
Conversion Mechanisms: only trapped-to-trapped modes have been seen by us