Internal waves of abnormal heights: features of generation

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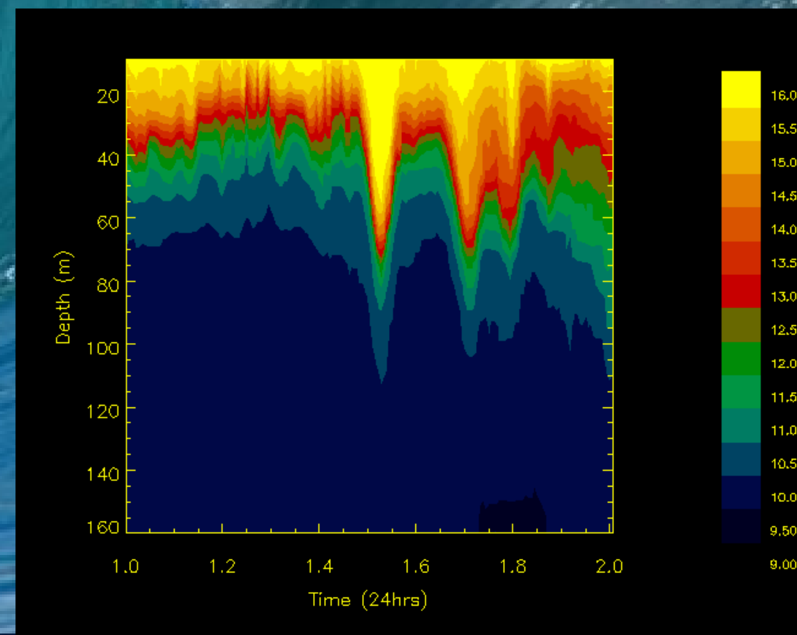


Do internal "killer" waves exist in the ocean?

US submarine Tresher April 10 1963

15 minutes after submerging the message came from Tresher to accompanied submarine Skylarke about unexpected problems. Submariners on Skylarke heard the sound "as air burst into tanks" and after that the silence came. The salvor found on the place of accident various debris including the pieces of inside panels. The abnormal large internal wave had been mentioned as one of the possible reasons of the catastrophe.

Internal waves on the ocean shelves

- **Most intensive IW had been observed on the ocean shelves**

- **Shallow water, long IW, vertical mode structure**

- **There is no the Garrett-Munk spectrum**

- **There is 90% of presence of the first mode**

Mechanizms

Most of mechanisms declared for generation of rogue surface waves are valid for internal waves + features valid only for stratified waters

The features are:

- **the nonlinearity in the first order for internal wave can have either sign (for surface wave it is only positive)**
- **the nonlinearity in the second order for internal waves can have either sign also (for surface wave it is only negative)**
- **horizontal variability takes place as for stratification as well depth (for surface waves only for depth) and coefficients are changed significantly on the wave way**

Modeling of long IW

The asymptotic theory model used for horizontally variable background is based on the Gardner equation

$$\frac{\partial \varsigma}{\partial x} + (\alpha \varsigma + \alpha_1 \varsigma^2)\frac{\partial \varsigma}{\partial t} + \beta \frac{\partial^3 \varsigma}{\partial t^3} = 0$$

Equation is written in the reference system *t, x-ct*

ζ **is vertical displacement of water particles on the mode** Φ **maximum level, coefficients** α, α_1 **and** β **are determined by horizontally variable stratification, depth and vertical mode structure.**

Eigenvalue problem for Φ and c

$$\frac{d}{dz}\left[(c - U(z))^2 \frac{d\Phi}{dz}\right] + N(z)^2 \Phi = 0,$$

$$\Phi(0) = \Phi(H) = 0 \qquad \Phi_{max} = 1$$

Nonlinear Correction to Mode Structure

$$\frac{d}{dz}\left[(c-U)^2\frac{dT}{dz}\right]+N^2T=$$

$$=\frac{3}{2}\frac{d}{dz}\left[(c-U)^2\left(\frac{d\Phi}{dz}\right)^2\right]-\alpha\frac{d}{dz}\left[(c-U)\frac{d\Phi}{dz}\right]$$

T = 0 ***where*** **z = 0, H**
T = 0 ***where*** **Φ(z) = 1**

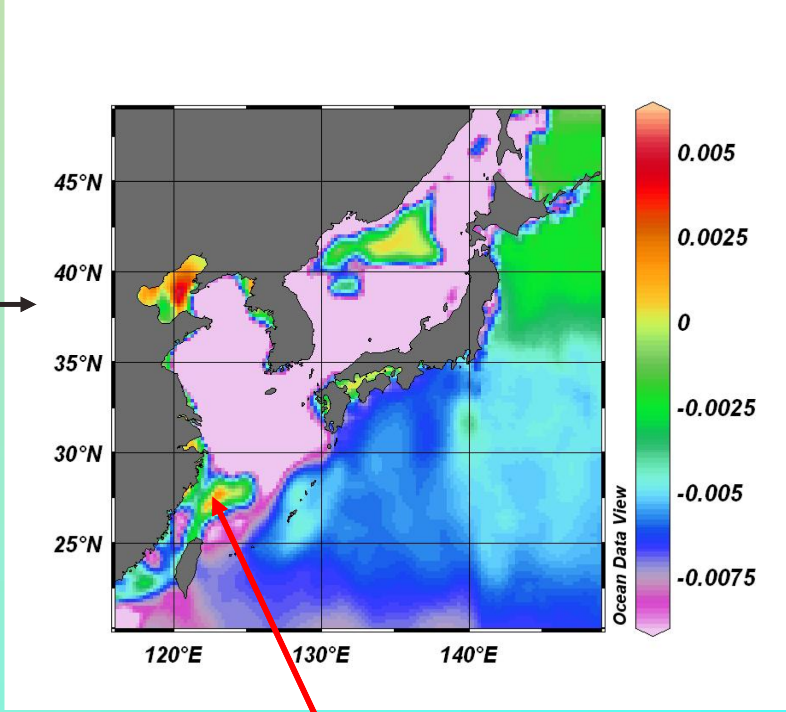
$$\zeta(z,x,t)=\varsigma(x,t)\Phi(z)+\varsigma^2T(z)$$

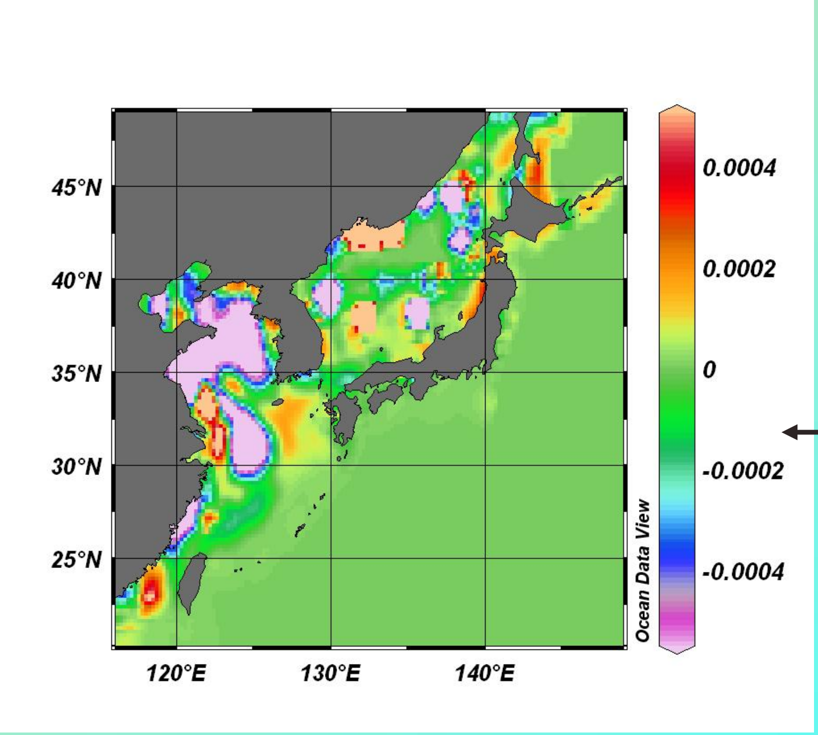
Coefficients for the ocean shelves

China seas, Japan Sea, Yellow Sea

Liu A.K., Y.S. Chang, V.-R. Hsu, N.K. Lang, Evolution of nonlinear internal waves in the East and South China Seas. J. Phys. Oceanography, 1998, 103, 7995-8008

α →





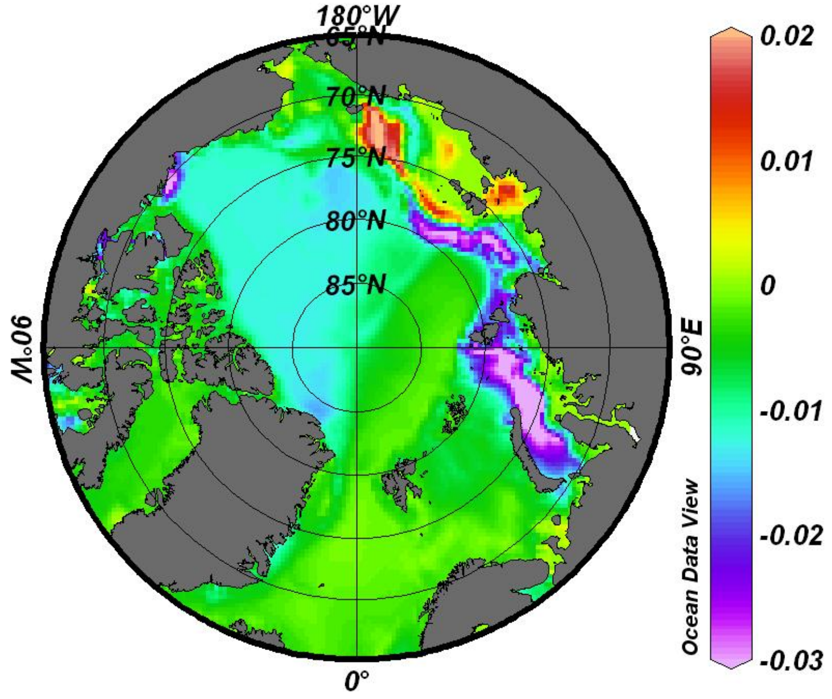
← α_1

The change of polarity of internal solitons had been observed and explained as change of sign of α

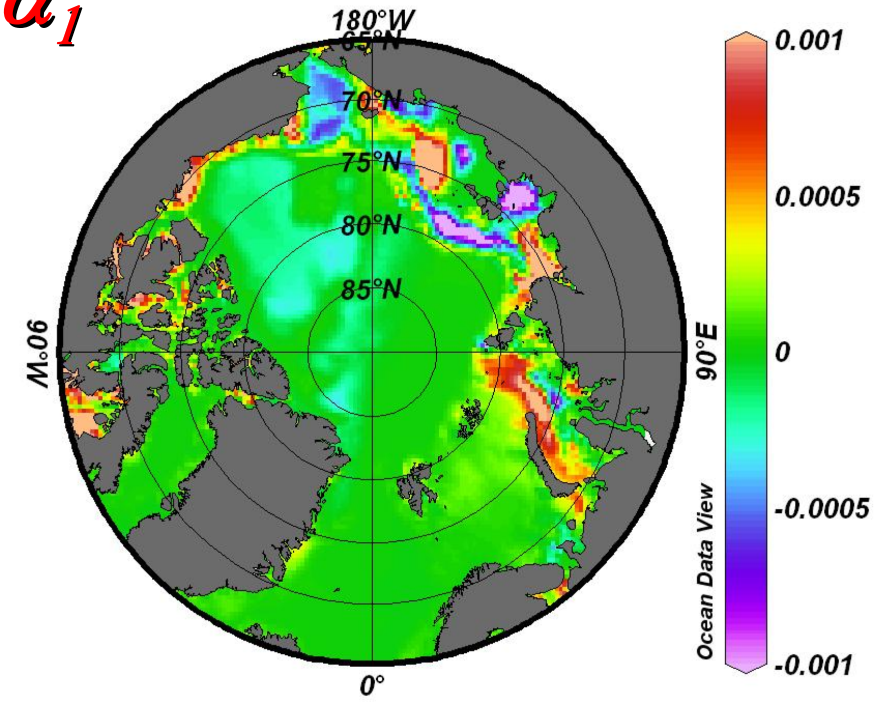
Russian Arctic

Sign variability for quadratic nonlinearity is ordinary occurance on the ocean shelves

α



α_1

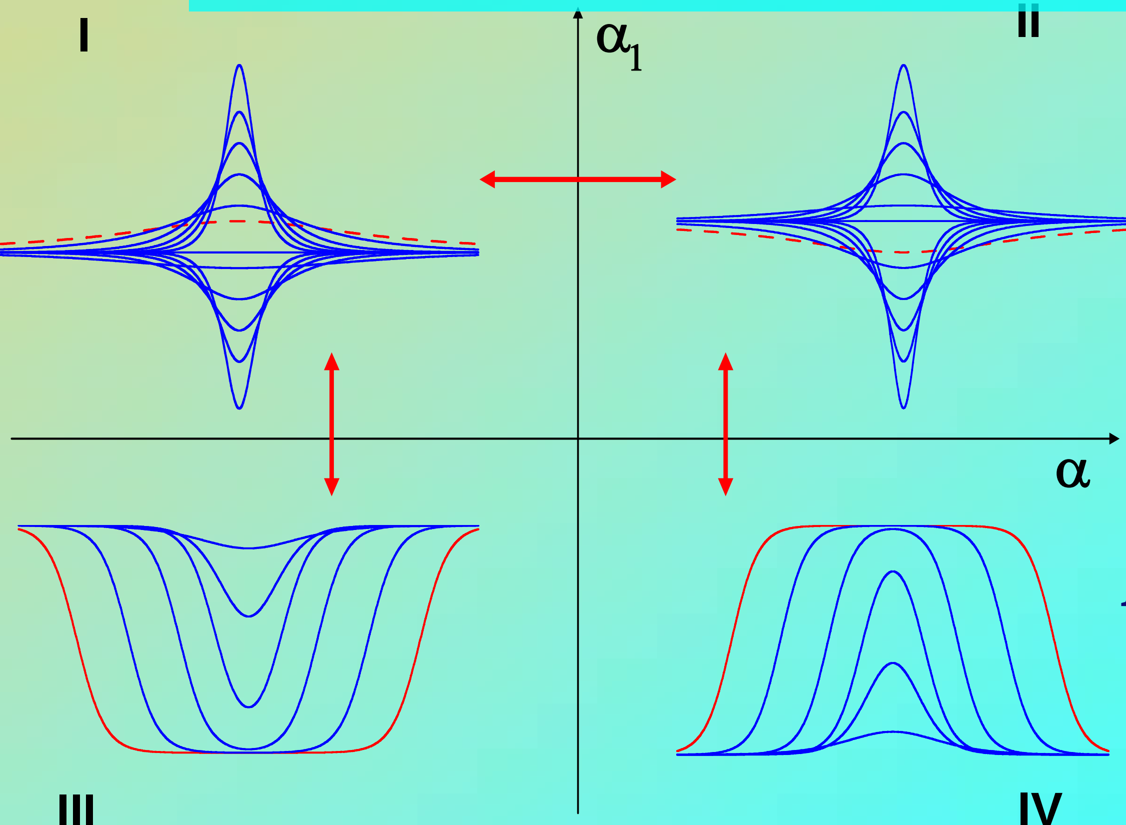


Positive values for the cubic nonlinearity are not too exotic on the ocean shelves

Solitary waves of the Gardner equation

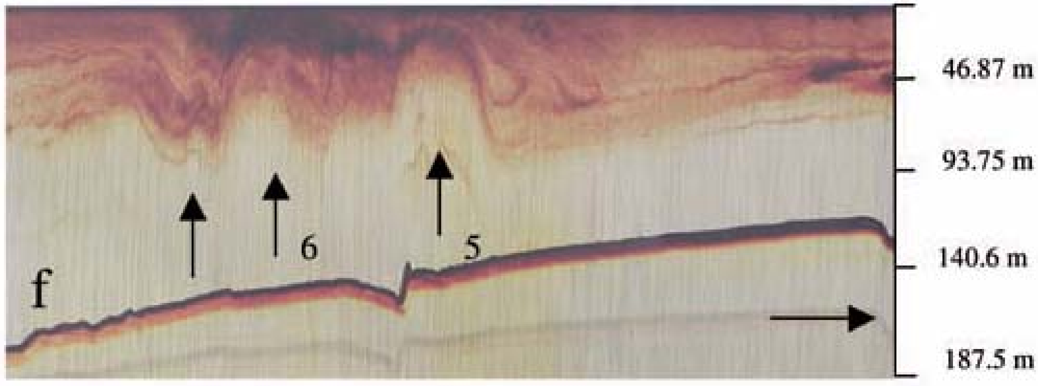
$$\eta(x,t)=\frac{A}{1+B\cosh(\gamma(x-Vt))},\qquad a=\frac{A}{1+B}$$

$$A=\frac{6\beta\gamma^2}{\alpha},\qquad B^2=1+\frac{6\alpha_1\beta\gamma^2}{\alpha^2},\qquad V=\beta\gamma^2$$



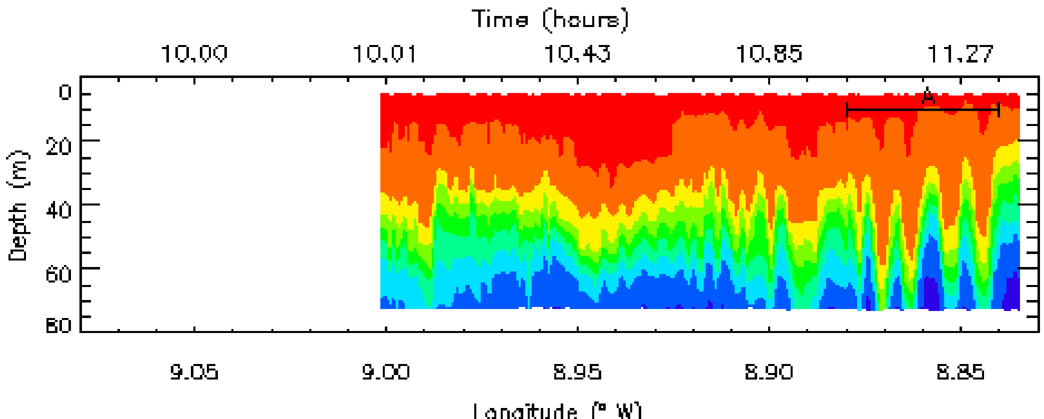
$$A_{sol} = -\alpha/\alpha_1$$

Observations



Marshall H. Orr and Peter C. Mignerey,

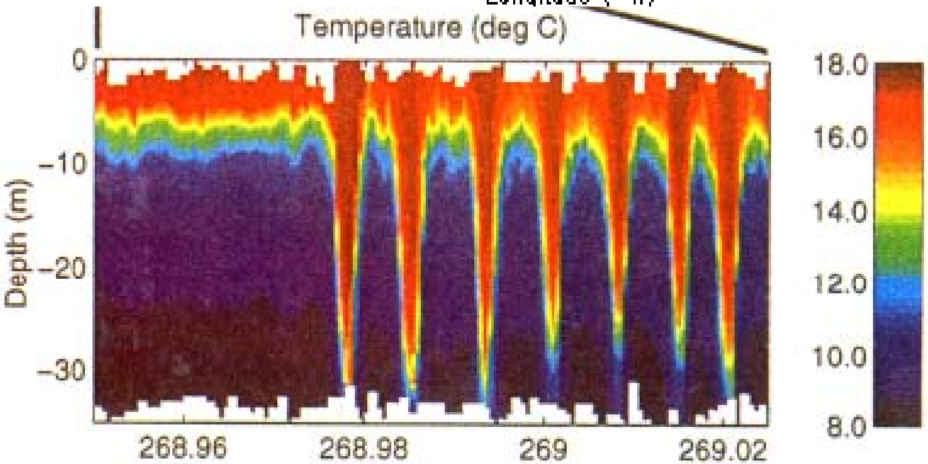
South China sea



J Small, T Sawyer, J.Scott,

SEASAME

Malin Shelfe Edge

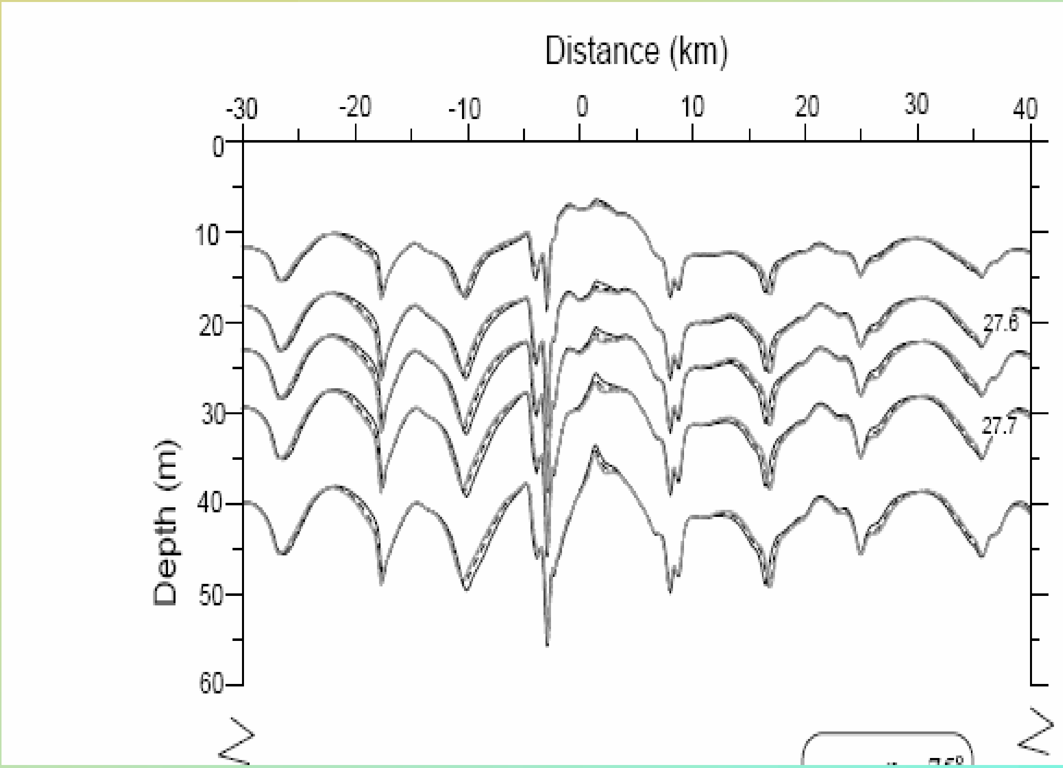


STANTON AND OSTROVSKY:

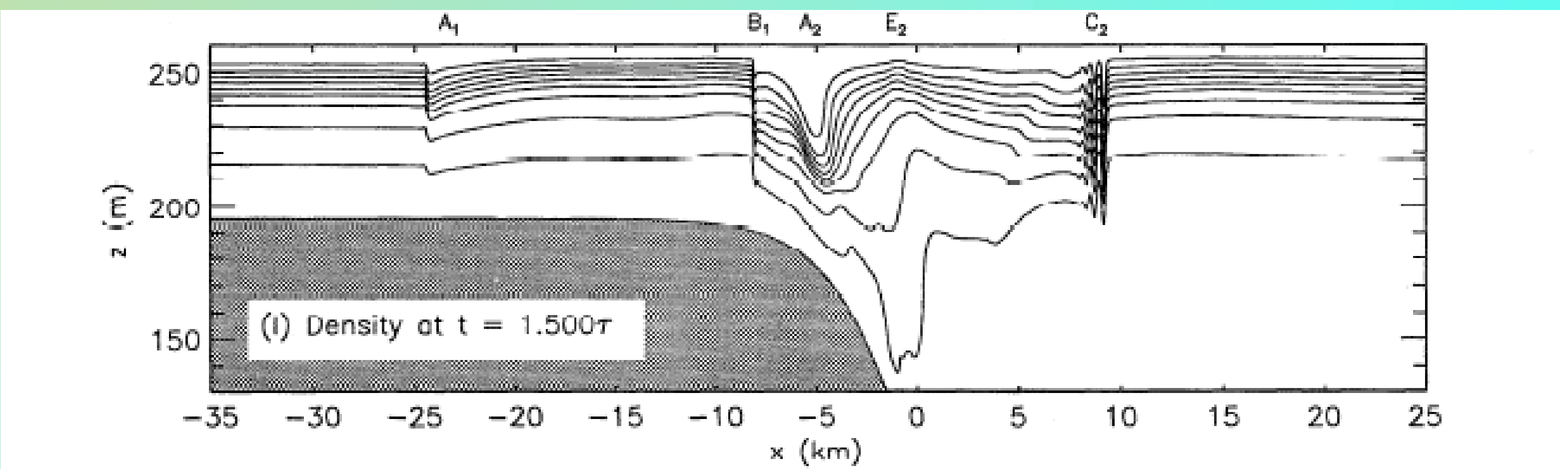
Nothern Oregon

Numerical modeling for Euler equations

Vlasenko et al, 2003



Lamb, 1994



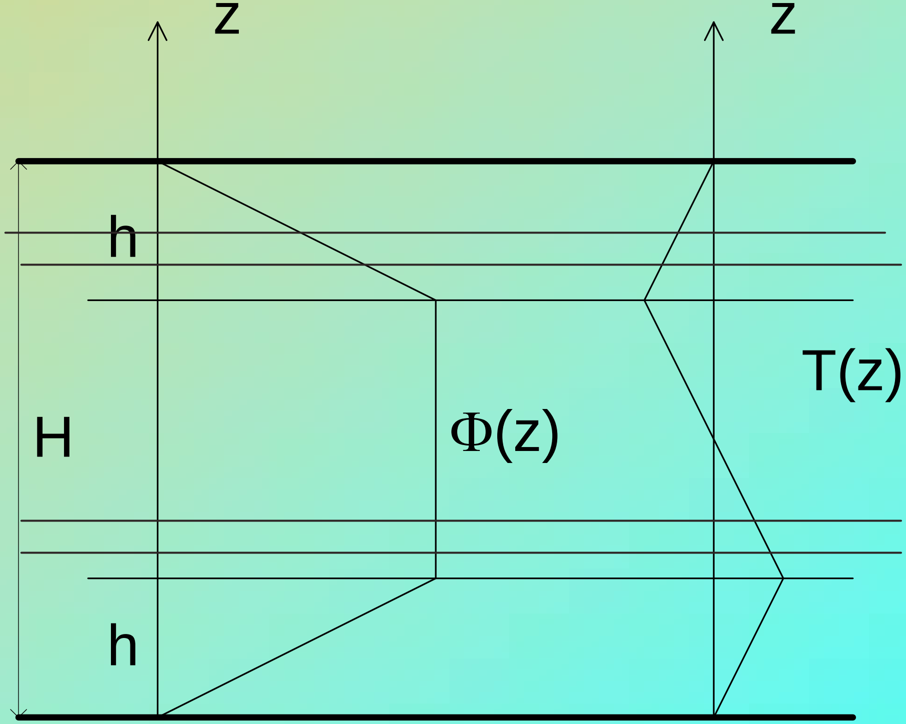
Internal Breathers

No observations!

modeling in the Euler equation system

Talipova, Lamb, Polukhina, Kurkin Oct. – Nov. 2005

Three-layer model: H = 100m, h = 30m

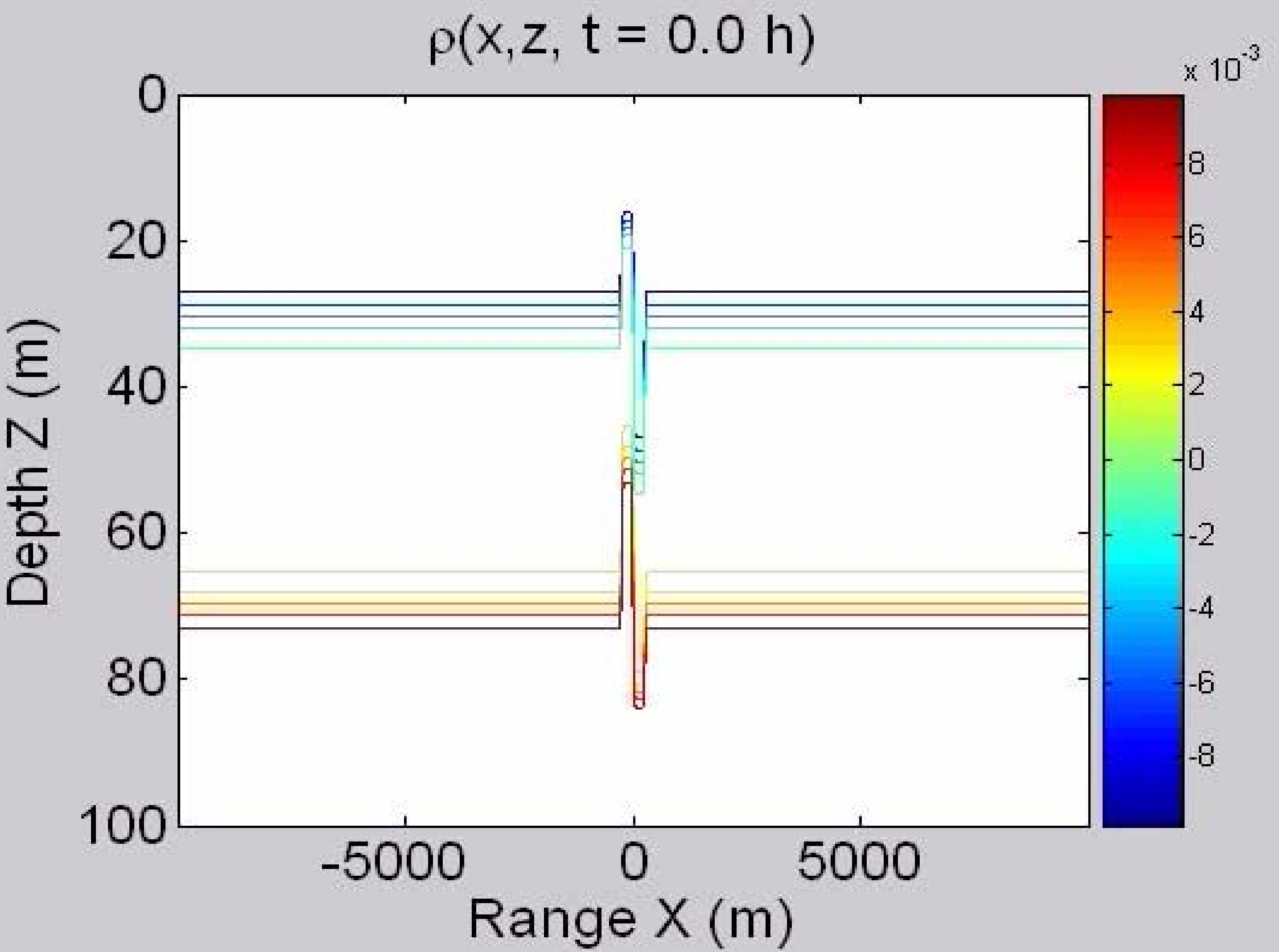


Δh

$\Delta\rho/\rho$ **= 0.005**

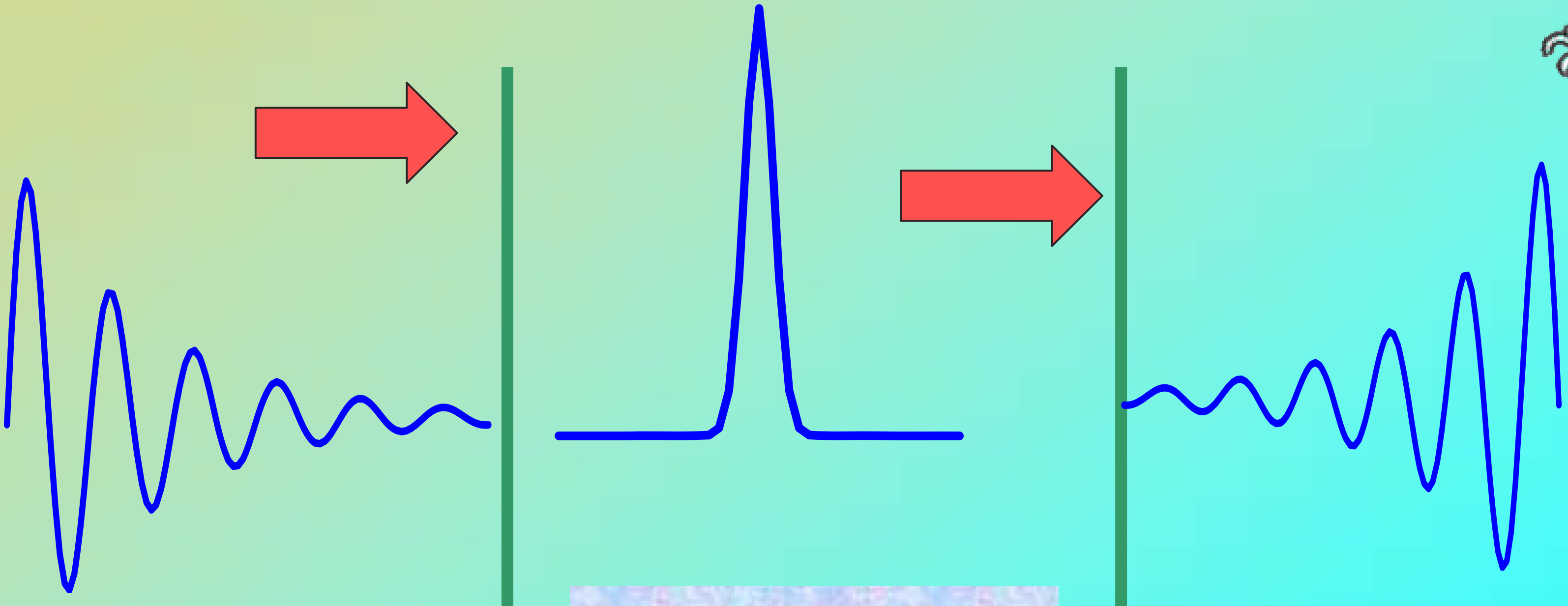
Δh **= 4m**

Numerical modeling



Dispersion Focusing

Physics: *Phase speed is c(k)*

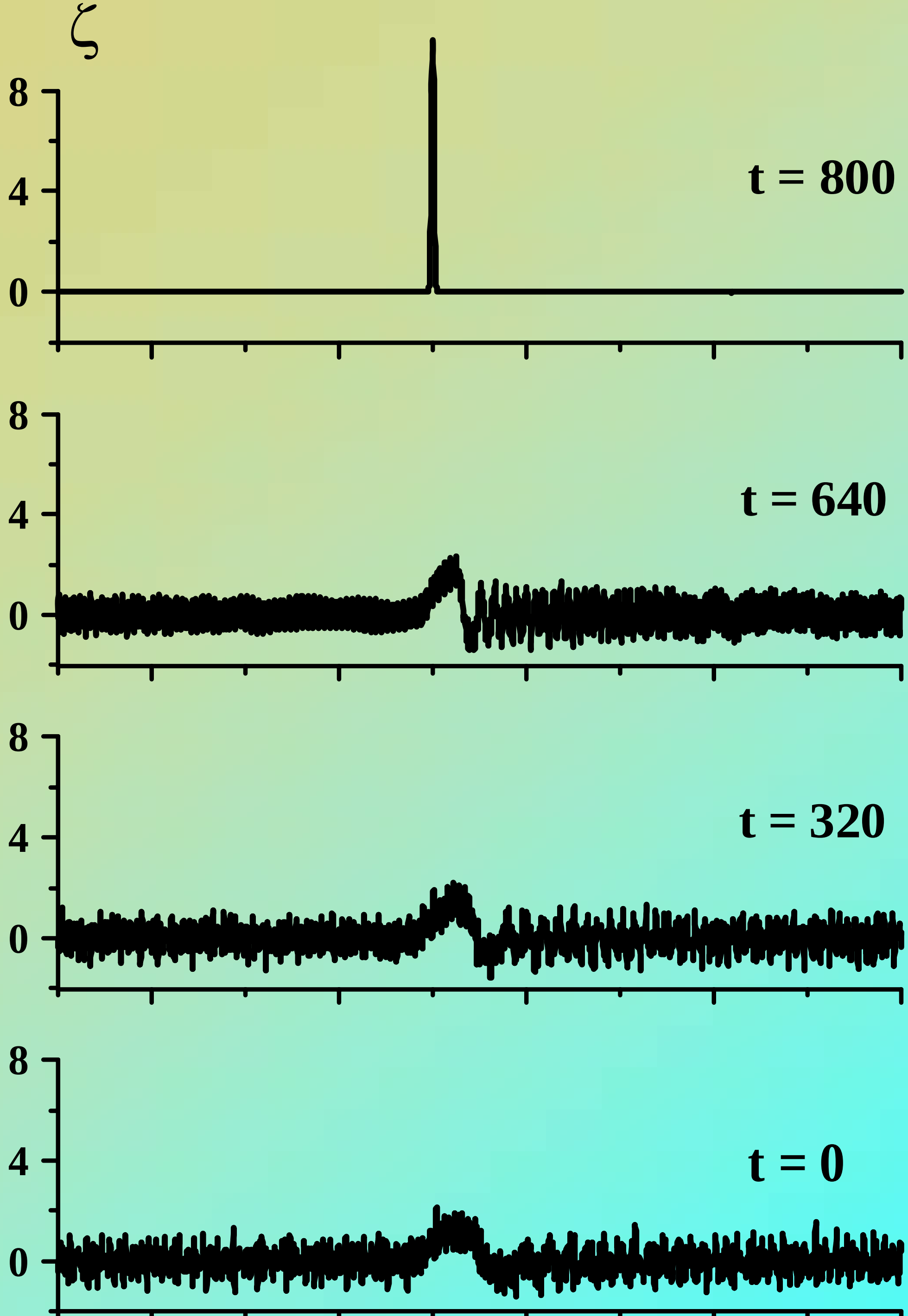


negative time

t = 0
(wave focus)

positive time

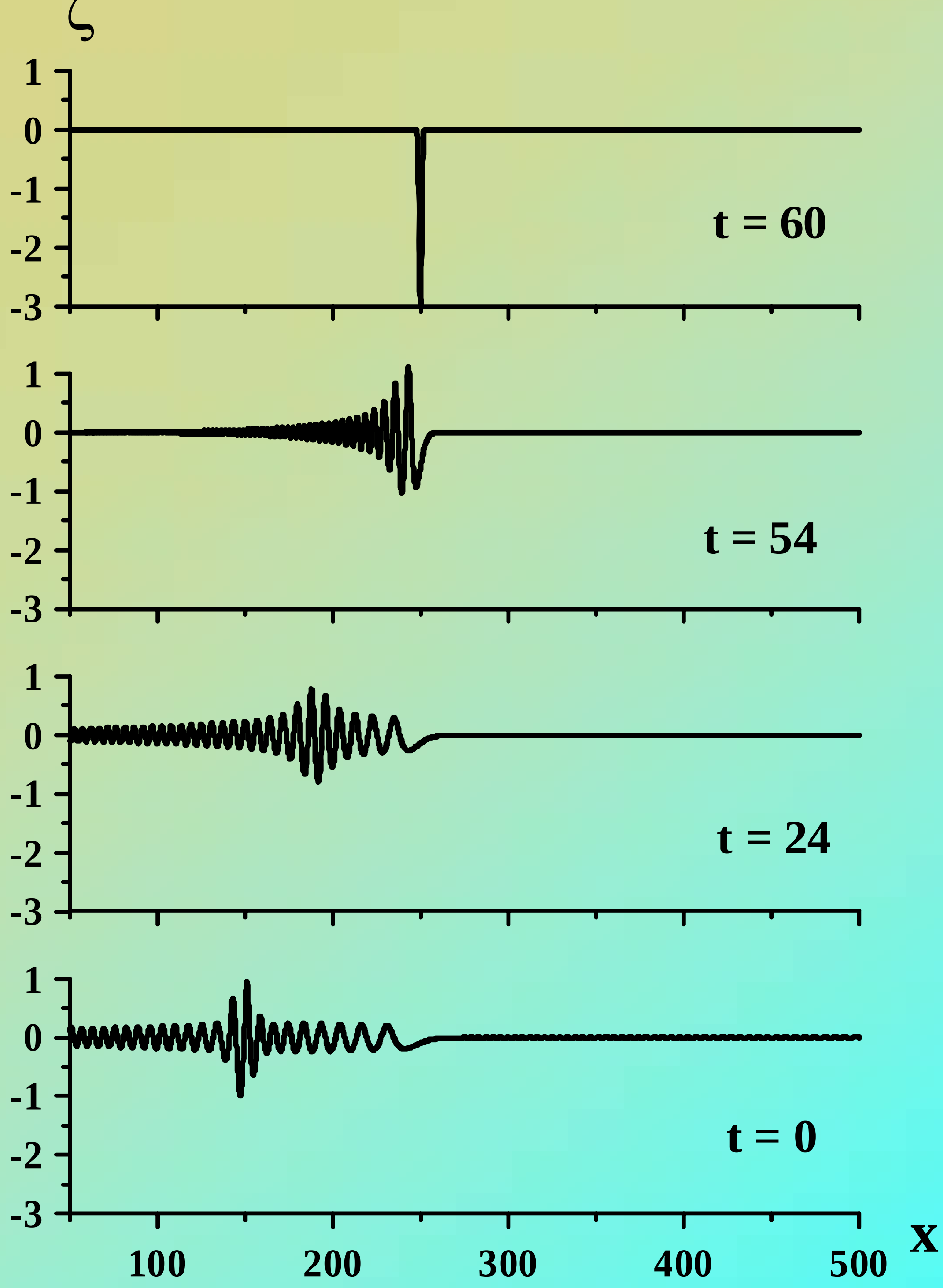
Dispersion Enhancement



$\alpha > 0$

$\alpha_1 < 0$

thick soliton and tail



$\alpha > 0$

$\alpha_1 > 0$

Breather and wave tail

NLS for internal waves

Grimshaw R., Pelinovsky D., Pelinovsky E., Talipova T. *Physica D*, 2001, 159,1-2, 35-57

$$i\frac{\partial A}{\partial \tau} = 3\beta k\frac{\partial^2 A}{\partial \xi^2} + k\delta\left|A^2\right|A$$

$$\delta = \alpha_1 - \frac{\alpha^2}{6\beta k^2}$$

for Bengamin – Fair instability

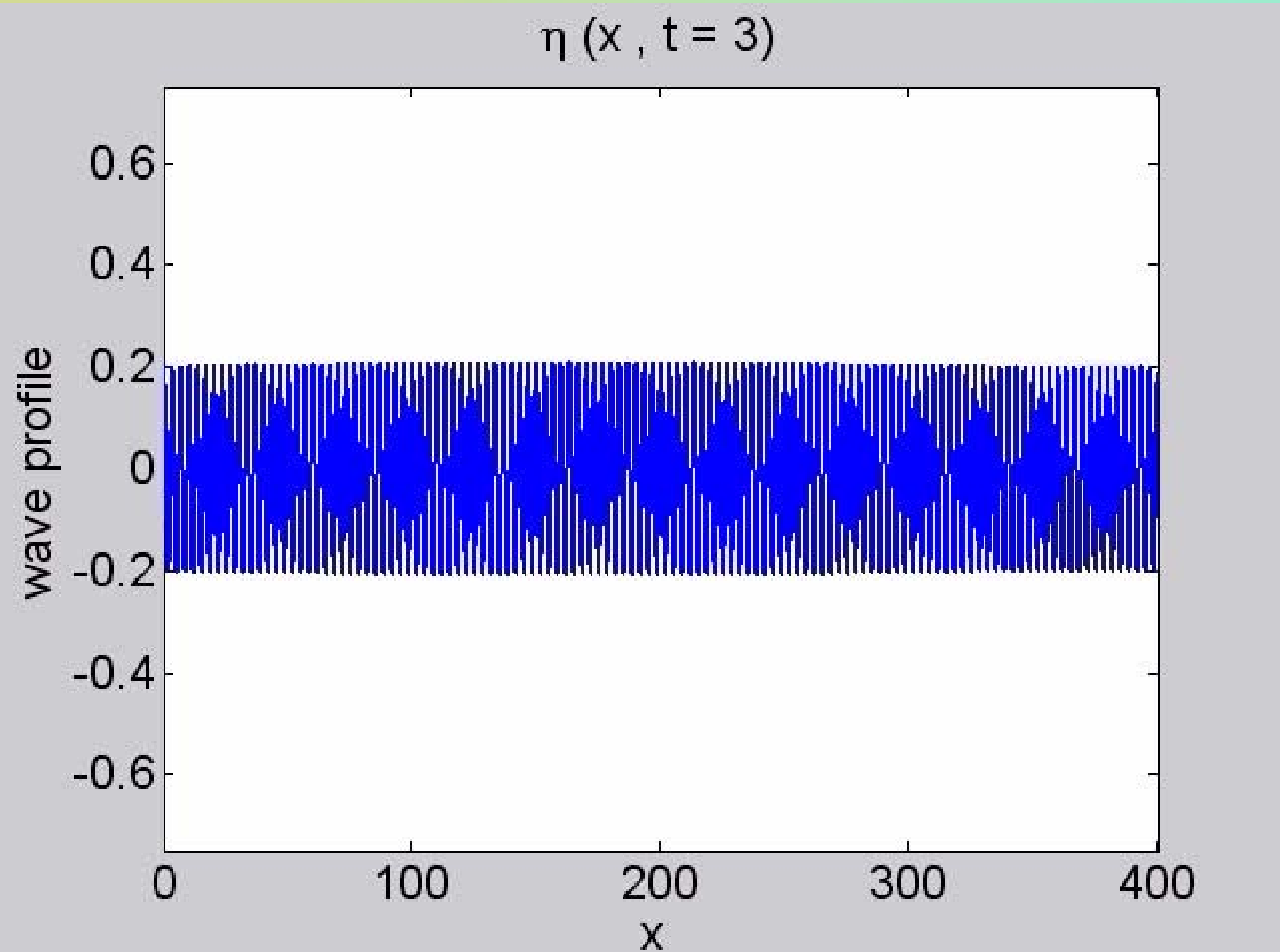
$$L = 3\beta\delta k > \mathbf{0} \longrightarrow \boldsymbol{\alpha_1 > 0}; \quad k > \frac{|\alpha|}{\sqrt{6\alpha_1\beta}}$$

Bendjamin- Feir instability in the Gardner (mKdV) model

$\alpha = 0$

$\alpha_1 > 0$

$\eta(x,0) = a(1+m\cos Kx)\cos kx$



a = 0.2

m = 0.05

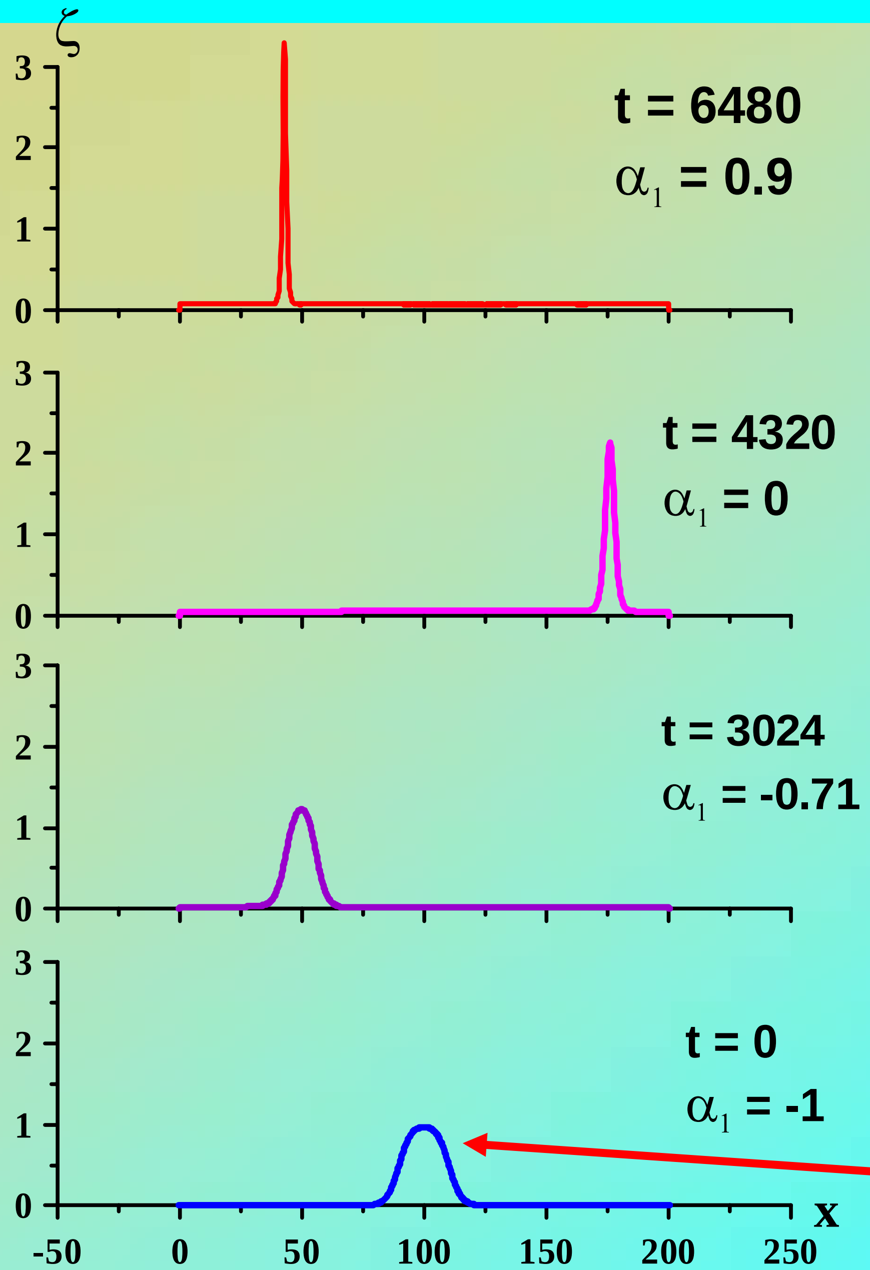
k = 1.884

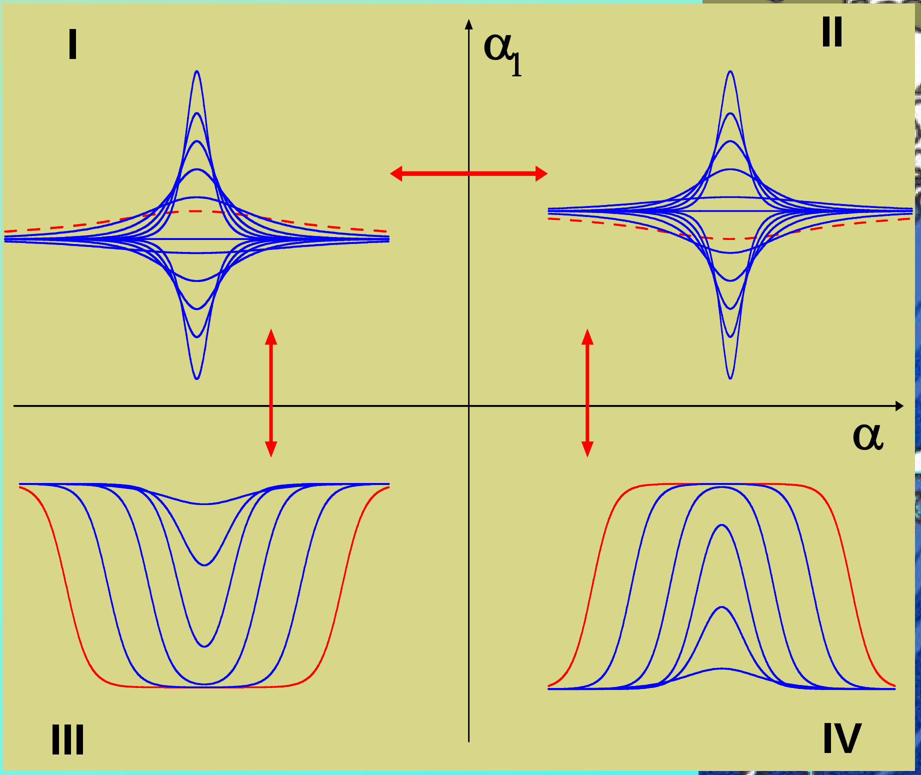
K = 0.00785

amplification factor is between 3 to 3.5

Transformation through transition zone

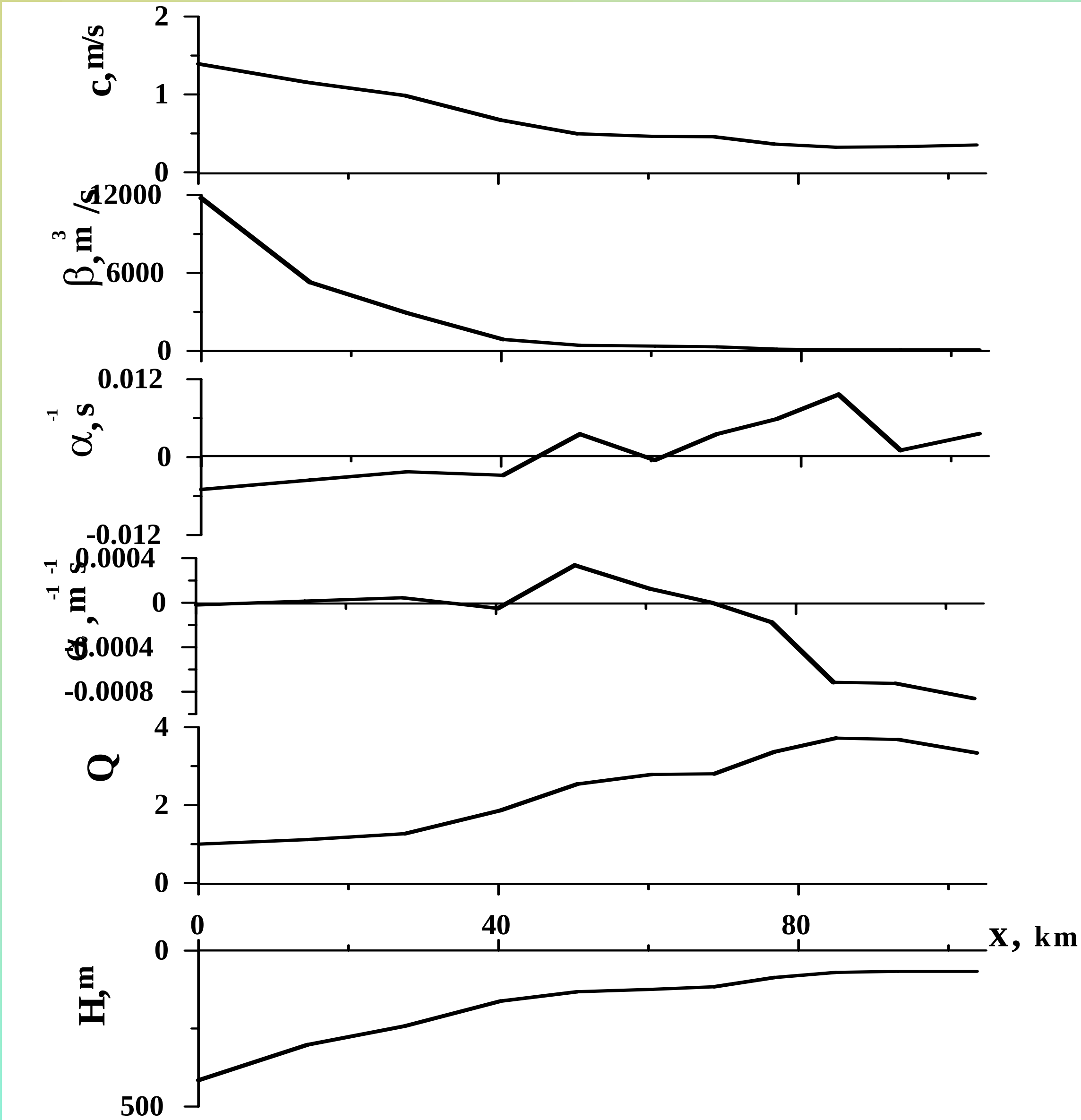
$\alpha = 1, \; \beta = 1$



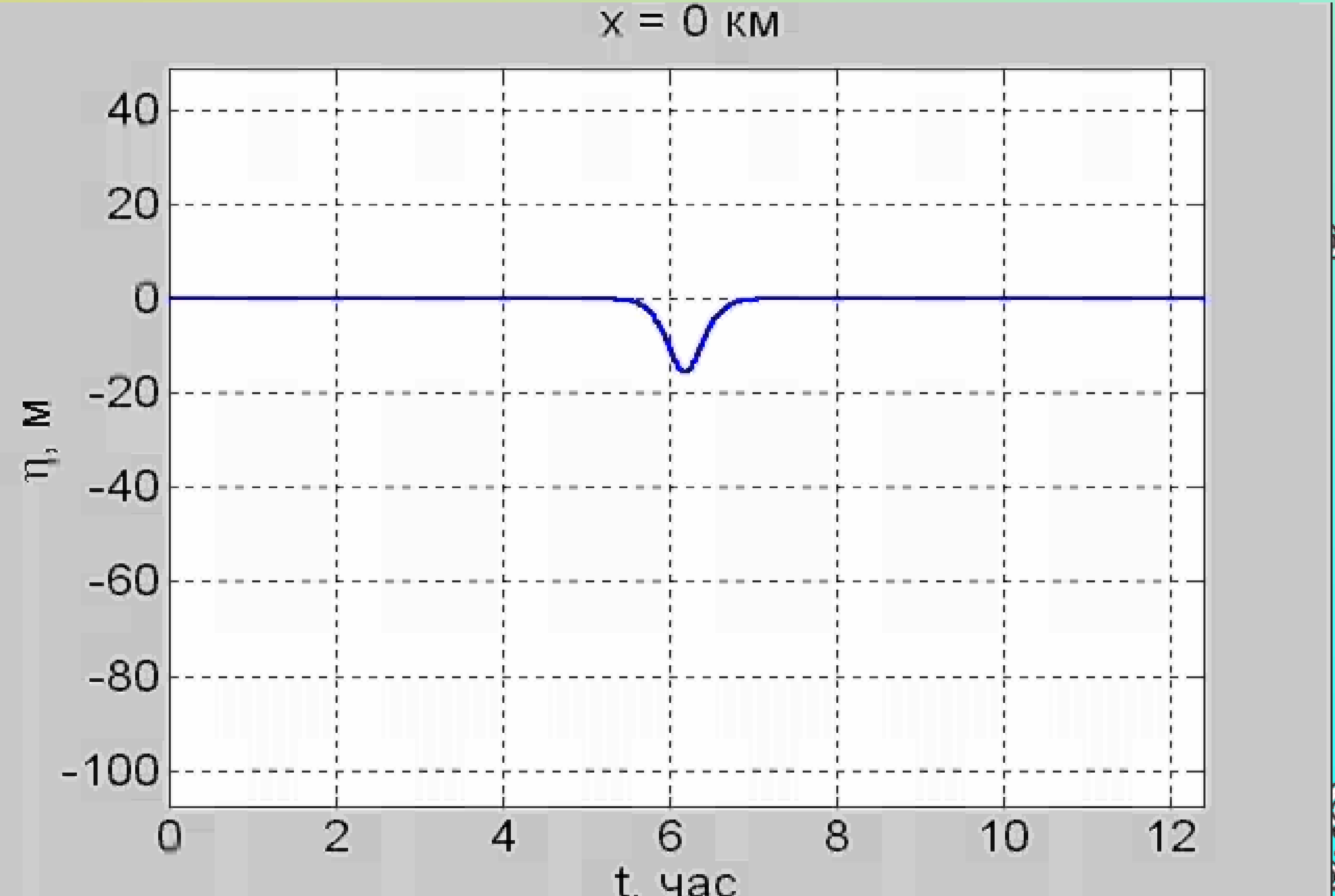


$A_{sol} = -\alpha / \alpha_1$

Model parameters on the North West Australian shelf



Internal soliton transformation on the North West Australian shelf



CONCLUSIONS

- Mechanisms of surface rogue wave formation can be applied for internal rogue wave formation

- Dynamics of internal waves is more various than dynamics of surface waves

- Additional mechanisms of internal rogue wave formation connected with variable water stratification are exists