Phase front fluctuations due to internal waves in Shallow Water 2006 experiment

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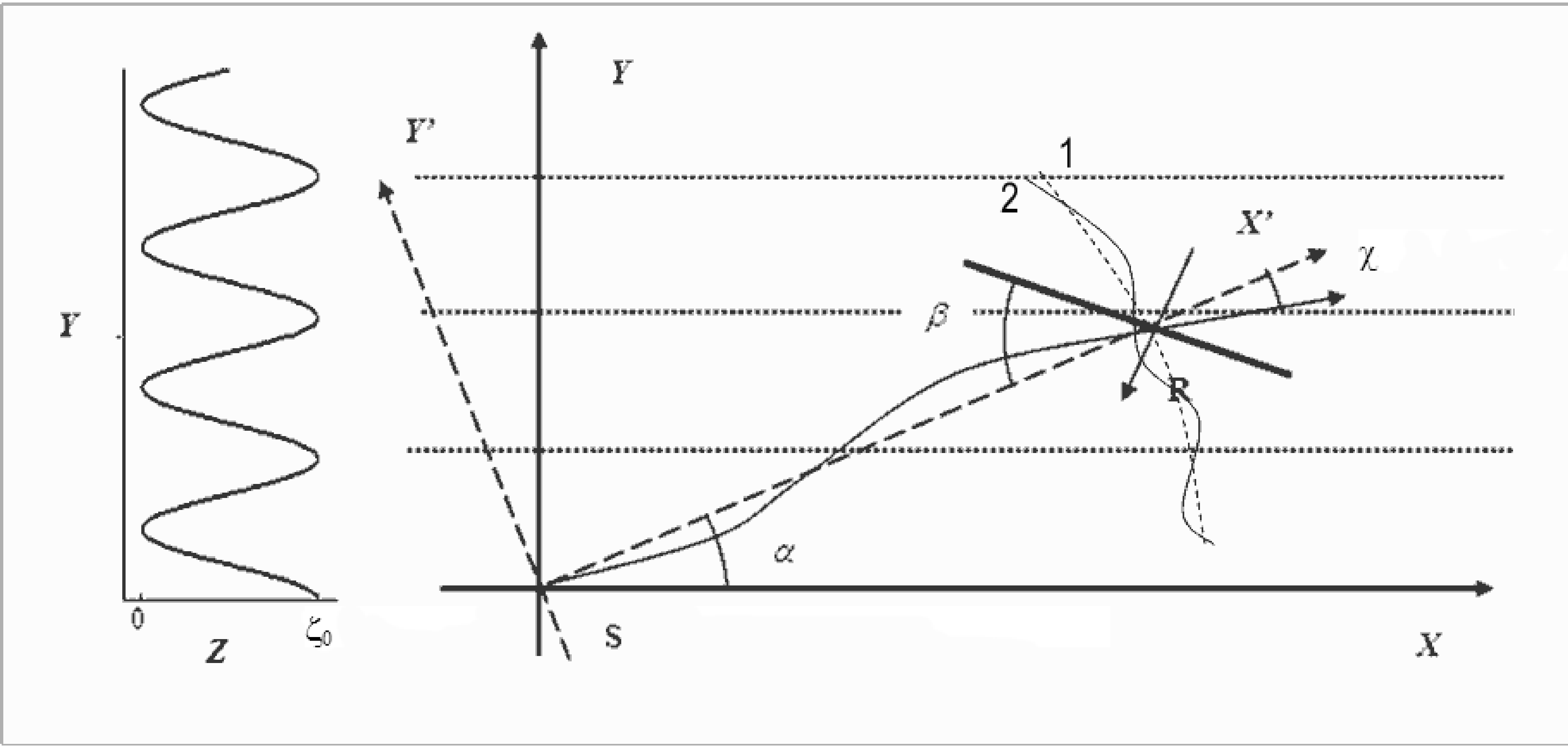
General scheme



Simple theory

Complex sound field

$$\Psi(r,z) = \sum_l \psi_l(0,0;z_1)\psi_l(x,y;z)A_l(x,y)\exp[i\theta_l(x,y)]$$

$$(\nabla_r \theta_l)^2 = (q_l^0)^2 n_l^2$$

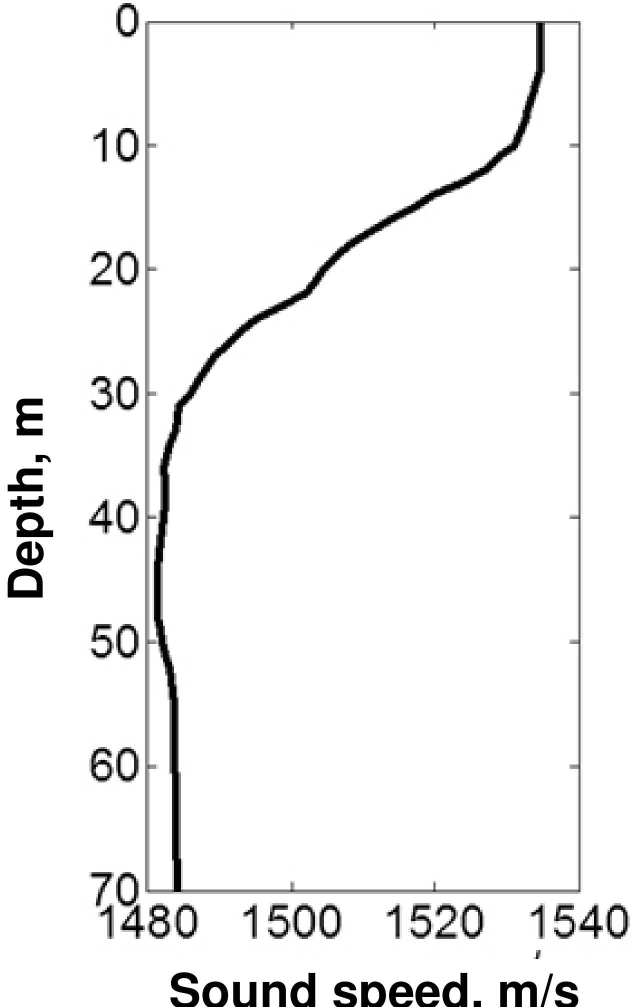
Refraction index for horizontal rays can be found in perturbation theory

$$n_l^2 = 1 + \mu_l, \ |\mu_l| << 1 \qquad \mu_l(y) = -\nu_l(\omega)\zeta_s(y)$$

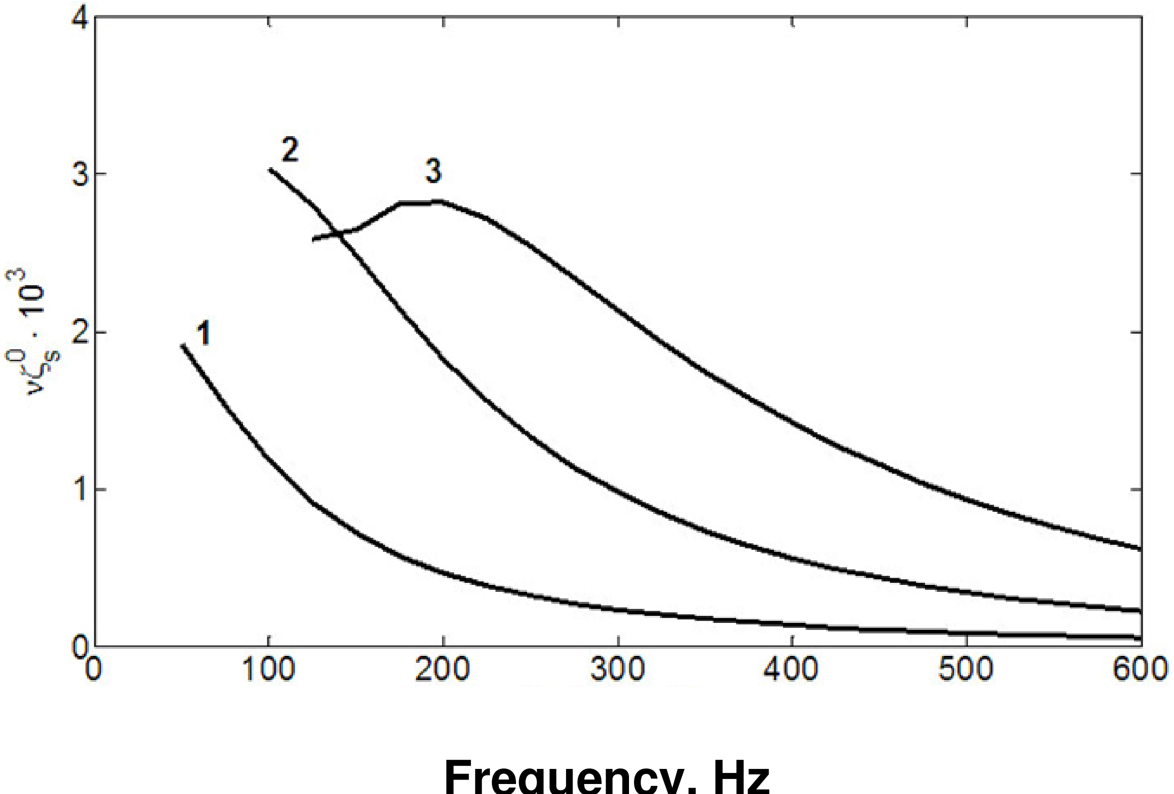
$$\nu_l(\omega) = \frac{2Qk^2}{(q_l^0)^2}\int_0^H [\psi_l^0(z)]^2 N^2(z)\Phi(z)dz$$

SW06

Sound speed profile



Correction to refraction index for horizontal rays
As a function of frequency



Estimation for phase shift and variation of horizontal angles

$$\theta_l(x,y) = q_l^0 r\left[1 - \frac{1}{2y}\int_0^y \mu_l(y)dy\right]$$

$$dq_l \sim q_l^0 r m_l^0 / 4$$

As a result of internal waves phase front can be shifted Along the horizontal ray up to 15-20 m, eikonal shift can be ~ 5-6 rad (depends on mode number and frequency)

$$\chi \approx \frac{\cos\alpha}{2\sin\alpha}\left[\mu_l(r\sin\alpha) - \frac{\mu_l^0}{2}\right]$$

$$\Delta\chi \sim \frac{\mu_l^0}{\alpha}$$

Horizontal angle also depends On mode number and frequency and can be ~ 0,5-5 degrees

Determination of refraction angle using horizontal array

HLA response

$$u(\gamma) = \int_{-L/2}^{L/2} \Psi(\vec{R} + \vec{\rho}, z) e^{-ik\rho\cos\gamma} d\rho$$

Complex sound field from PE

$$\Psi(r,z) = \sum_l P_l(r)\psi_l(r;z) \qquad P_l(r) = F_l(x,y)\exp(iq_l^0 x),$$

$$\frac{\partial F_l}{\partial x} = \frac{i}{2q_l^0}\frac{\partial^2 F_l}{\partial y^2} + \frac{iq_l^0}{2}(n_l^2(x,y) - 1)F_l$$

$$q_l \cos\beta = k\cos\gamma_l$$

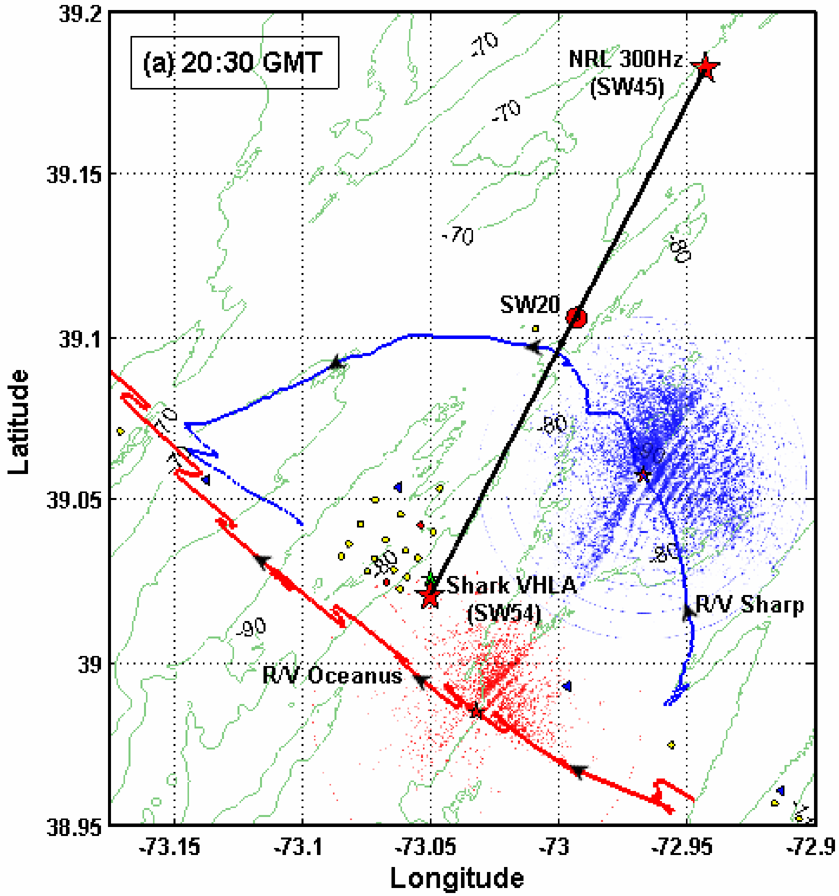
In absence of IW

$$\chi(\omega,\beta) = \arccos\left(\frac{k\cos\gamma}{q_l}\right) - \beta$$

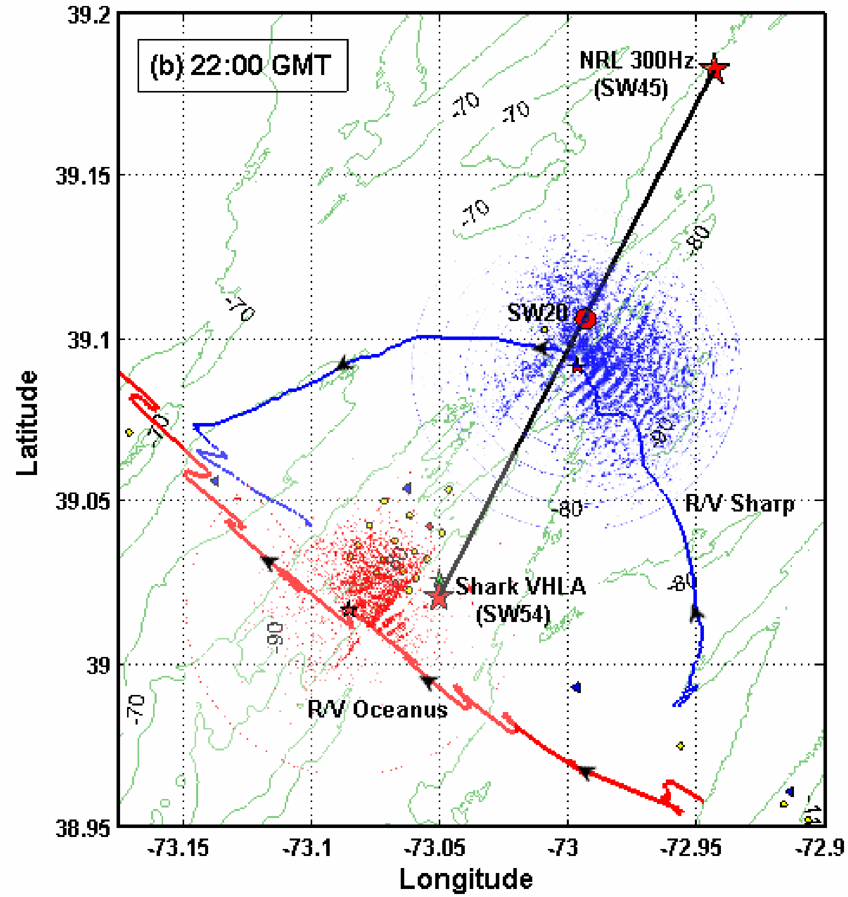
Calculation of angle of horizontal refraction

Experiment SW06, event 50

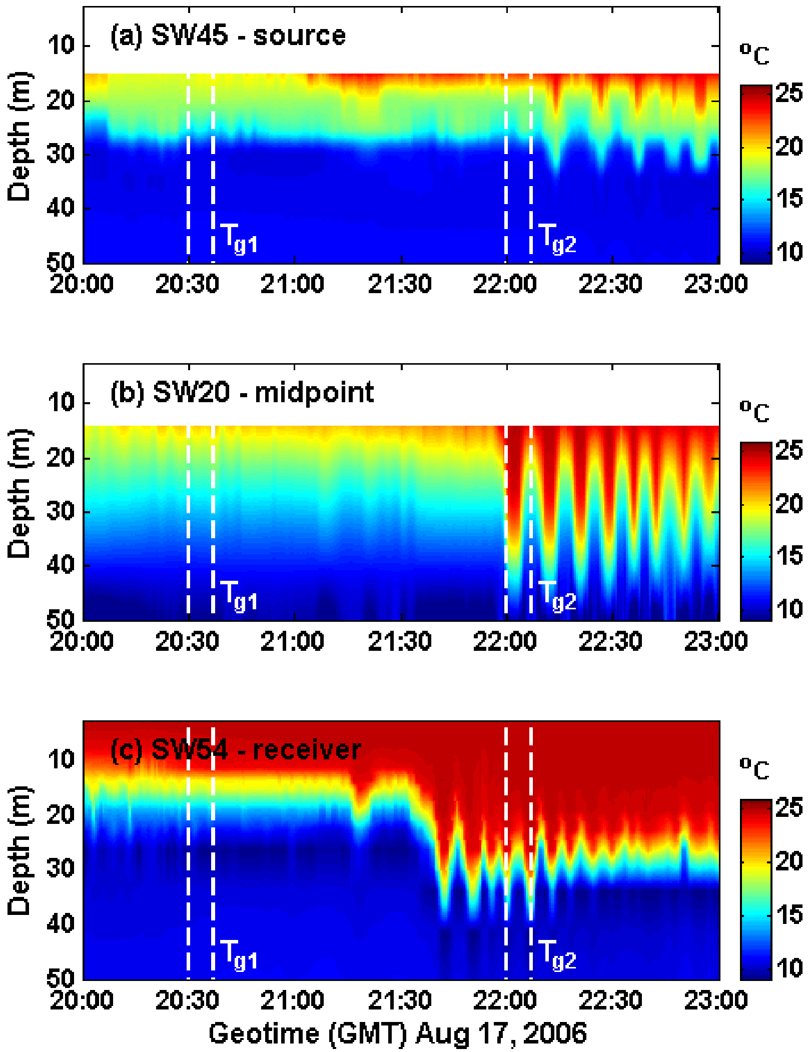
Before IW , Tg1 (20:30)



IW at the track, Tg2 (22:00)



Sound speed profiles

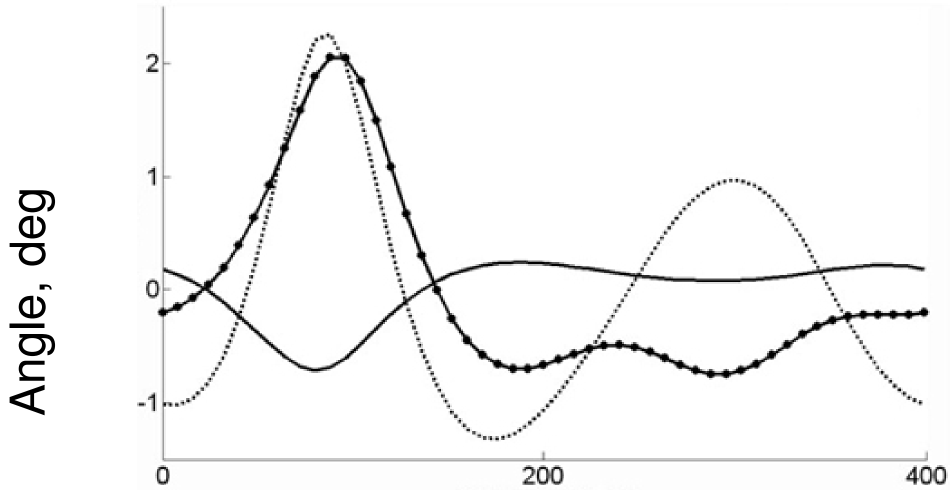


Sound speed profile
Near the source

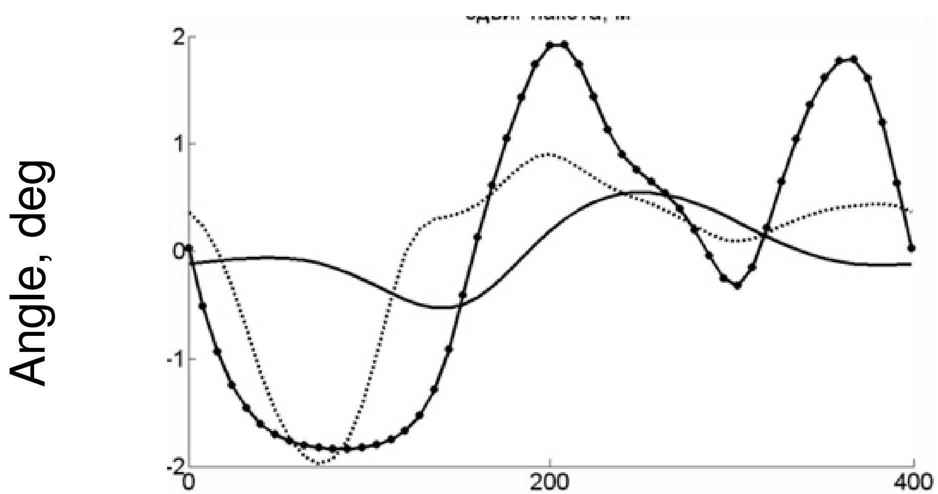
Sound speed profile
In the middle
Of the acoustic track

Sound speed profile
Near the receiving array

Modeling of angles of horizontal refraction for SW06 conditions



Frequency 100 Hz,

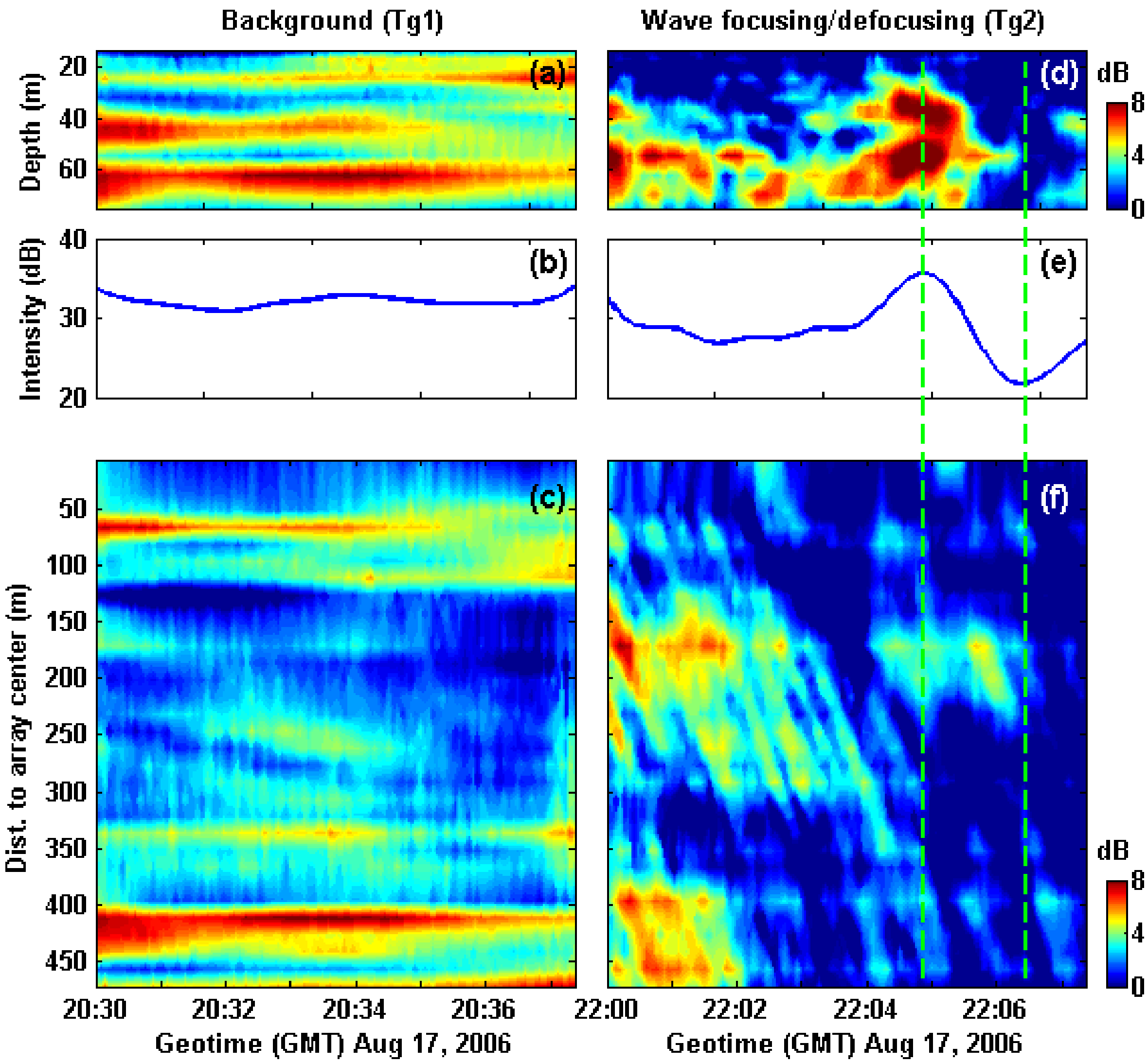


Frequency 300 Hz

Shift of train, m

Mode 1
Mode 2
Mode 3

Intensity fluctuations

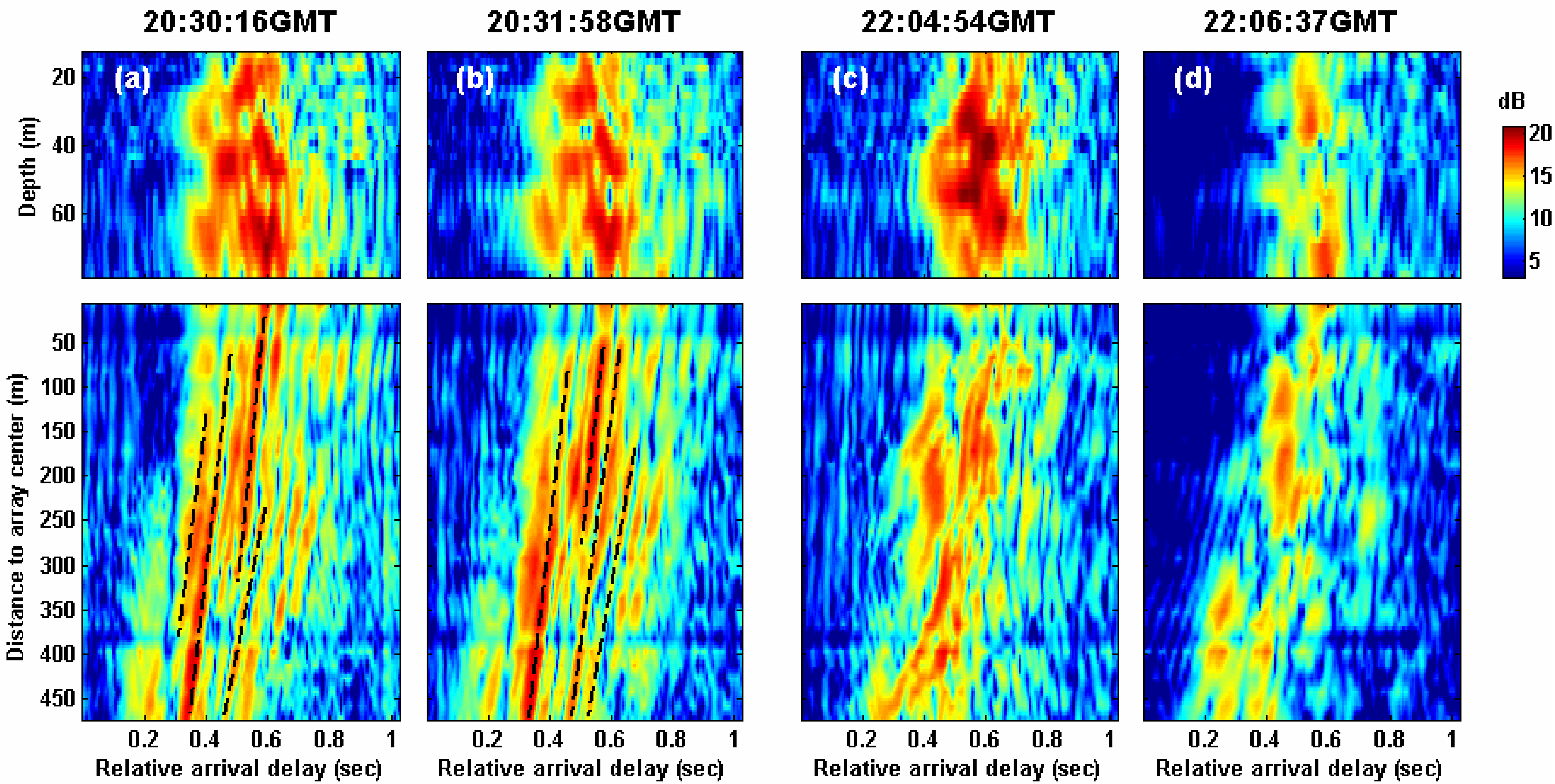


Vertical array

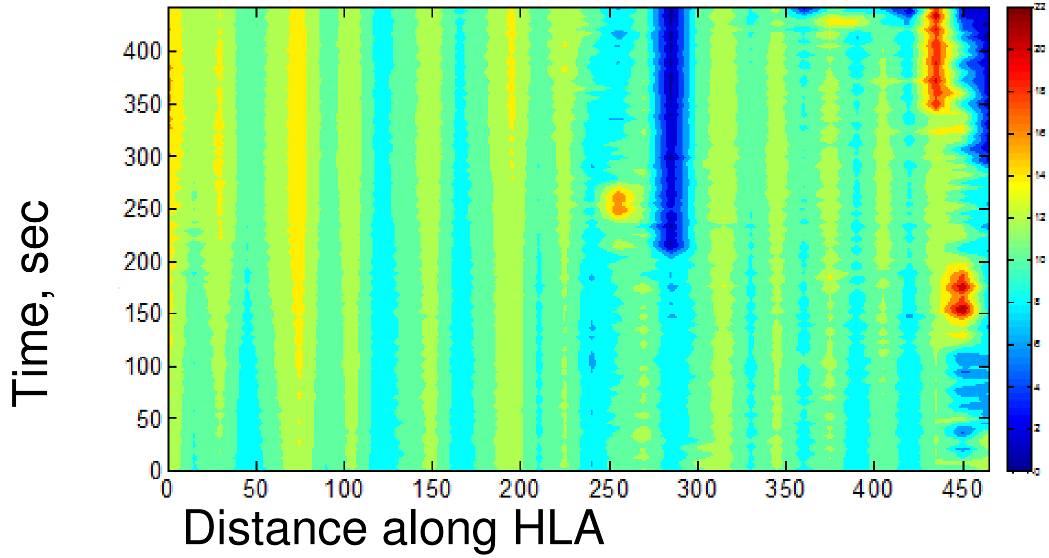
Total intensity Summarized over depth

Horizontal array

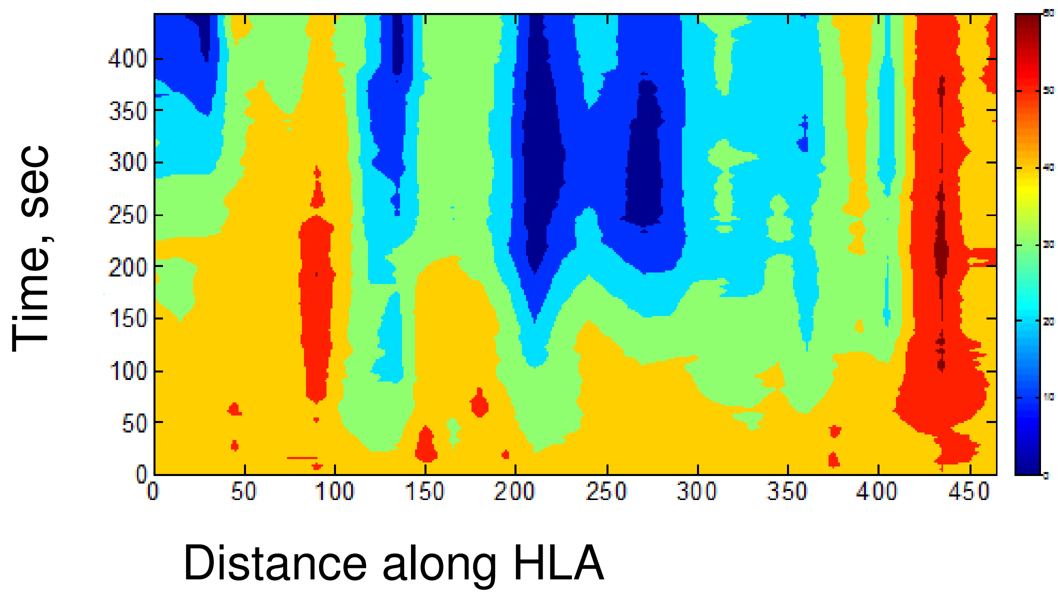
Arrival time fluctuations



Signal's phase at the horizontal array



No IW



In presence of IW

Angle of horizontal refraction

conclusion

- Phase variations and angle of horizontal refraction depend on mode number and frequency
- For experiment SW06 (event 50) we have periods with no IW at the acoustic track and with IW at the acoustic track.
- Phase and amplitude variations correspond to theory of horizontal refraction explaining amplitude and phase fluctuations