

Atmospheric boundary layer as a laboratory for modeling infrasound propagation and scattering in the atmosphere

Igor Chunchuzov¹, Sergey Kulichkov¹, Oleg Popov¹,
Vitaly Perepelkin¹,
Aram Vardanyan² and Gagik Ayvazyan²

¹*Obukhov Institute of Atmospheric Physics,
119017 Moscow, 3 Pyzhevskii Per., Russia*

²*Barva Innovation Center, Talin, 0501 Armenia*

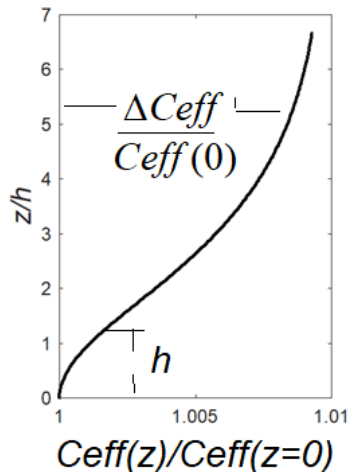
Presented at SnT, June 24-28, 2019, Vienna

C O N T E N T

- Physical modeling of the propagation of signals from explosions in the atmosphere
- Acoustic pulse propagation in the “shallow” wave guide. Lamb mode generated by nuclear explosions
- Using stably stratified atmospheric boundary layer (ABL) to model the propagation of acoustic pulses in the stratospheric wave guides
- Effect of scattering of acoustic pulses from a layered structure in the ABL. Similarity with the same effect in the upper atmosphere.

SIMILAR Ceff-profiles

Epstein layer over rigid boundary



$C_{eff}(z)/C_{eff}(z=0) = F(z/h)$ -nondimensional vertical $C_{eff}(z)$ -profile

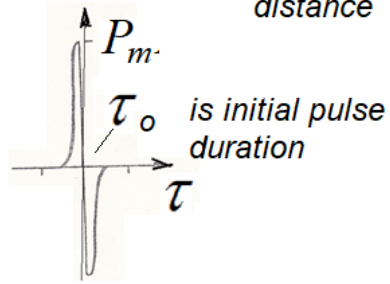
h -vertical scale of the inhomogeneous layer

ΔC_{eff} is the vertical jump in $C_{eff}(z)$.

$\varepsilon_0 = 2\Delta C_{eff} / C_{eff}(0)$ -relative jump in $C_{eff}(z)$.

Normal mode solution

Initial signal near point source at a distance R_0



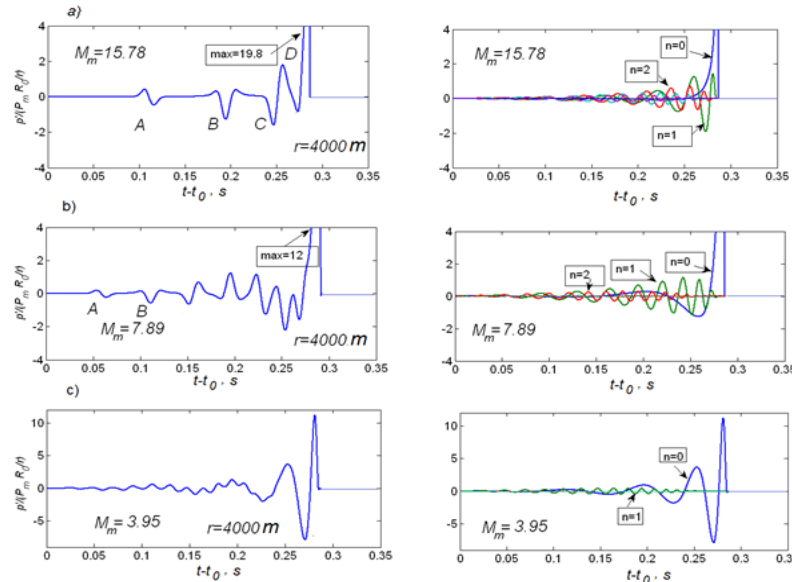
$\omega_m = 1/(2\pi\tau_0)$ is central frequency of the spectral maximum

At large distance r the wave form of the signal in the wave guide is a function of effective tickness of the wave guide $M_m = 2\varepsilon_0^{1/2}k_m h$ and normalized distance r/L_i , where

$k_m = \omega_m / c_0$ -wave number, $L_i \approx \frac{4\pi}{\varepsilon_0 k_m}$ is minimal interference spatial period for normal wave modes, $\tau = t - r/c_0$:

$$\frac{p'(r, \phi, z=0, t) \cdot r}{P_m R_0} = F(M_m, \frac{r}{L_i}, \omega_m \tau)$$

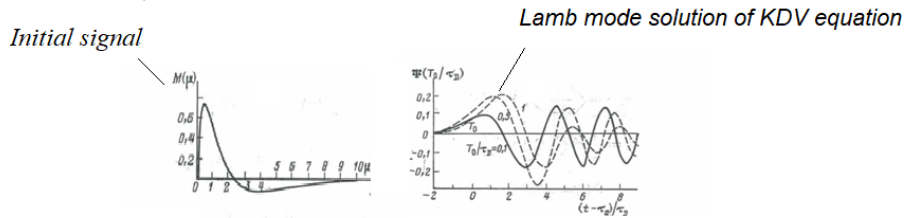
Evolution of the signal wave form in the Epstein layer when M_m decreases



Modeling of acoustic pulse propagation in the “shallow” wave guide ($M_m \ll 1$)

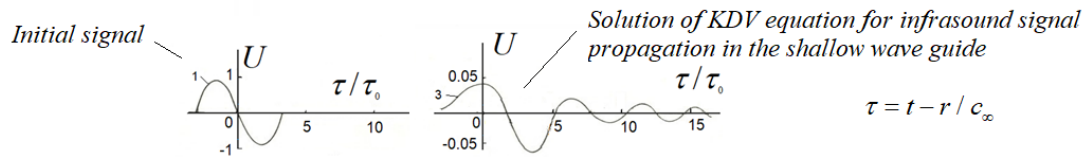
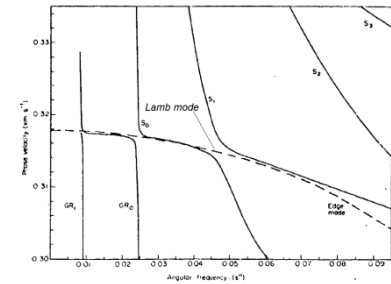
Modeling of Lamb mode propagation from nuclear explosion

A.D. Pierce and J.W. Posey
Geophys. J. R. Astr. Soc. 26 341-368 (1971)



I.P. Chunchuzov, Izv. Atm. Ocean. Physics, V.22, №2, 114-119

Phase speed of Lamb mode vs frequency



$$\tau = t - r / c_\infty$$

$k_0(\omega) \approx \omega / c_\infty (1 + \alpha \cdot \omega^2 + \dots)$ -dispersion equation for the fundamental mode in the shallow tropospheric waveguide

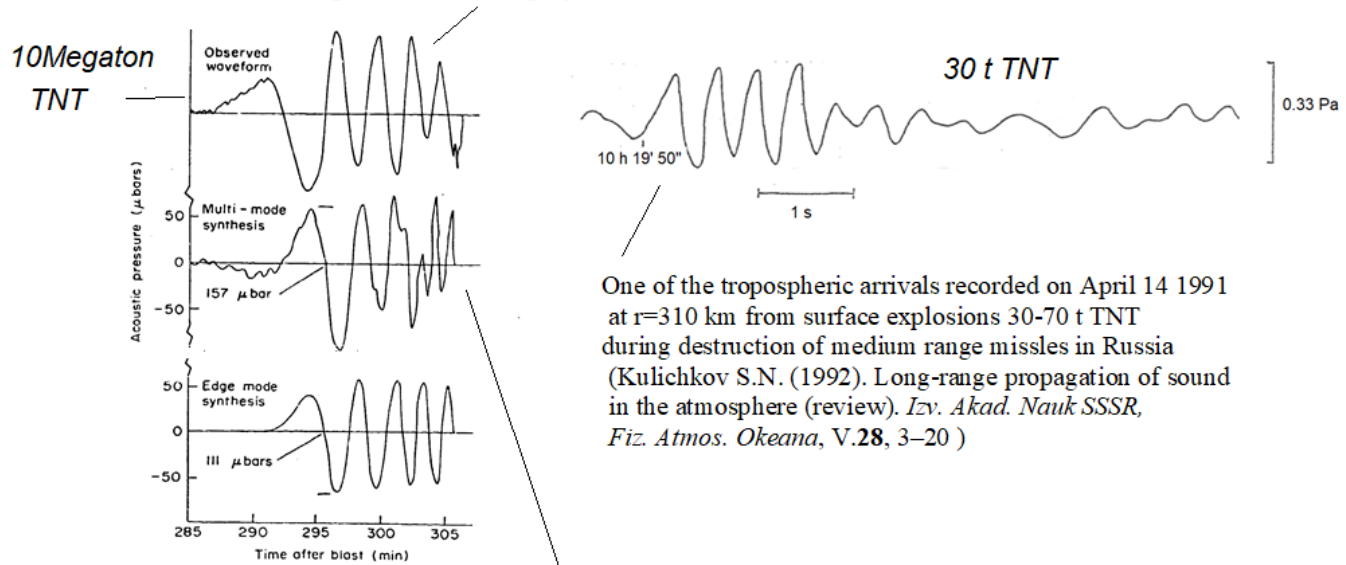
$$\alpha \equiv \frac{\varepsilon_0^2 h^2}{2c_\infty^2}$$

Korteweg–de Vries (KDV) equation

$$\frac{\partial U}{\partial r} - \frac{\bar{\varepsilon} P_0}{\bar{\rho} c_\infty^3} r_0^{1/2} U \frac{\partial U}{\partial \tau} - \frac{\alpha}{c_\infty} \frac{\partial^3 U}{\partial \tau^3} = 0 \quad \text{-KDV equation}$$

If $f_m=0.8$ Hz, $h=150$ m, $c=340$ m/s, $\varepsilon_0 = 0.016$ then $M_m \sim 0.5$

A.D. Pierce and J.W. Posey, Theory of the Excitation and Propagation of Lamb's Atmospheric Edge Mode from Nuclear Explosions, *Geophys. J. R. Astr. Soc.* 26 341-368 (1971)



One of the tropospheric arrivals recorded on April 14 1991 at $r=310$ km from surface explosions 30-70 t TNT during destruction of medium range missiles in Russia (Kulichkov S.N. (1992). Long-range propagation of sound in the atmosphere (review). *Izv. Akad. Nauk SSSR, Fiz. Atmos. Okeana*, V.28, 3-20)

Figure 14. Observed and theoretical pressure waveforms at Berkeley, California, following the Housatonic detonation at Johnson Island on October 30, 1962. The observed waveform is taken from Donn and Shaw [1967]. The energy yield assumed in the theoretical computations was 10 MT. The maximum peak to trough amplitude of the experimental waveform is about 350 μ bar.

Modeling of the propagation of signals from explosions in the stratospheric and thermospheric wave guides ($M_m \gg 1$) by studying the propagation of acoustic pulses from detonation source in stably stratified ABL

In stably stratified ABL we can control stratification of wind (SODAR), temperature (Profiler) and parameters of the initial signal from artificial pulsed source (detonation generator), therefore we can control M_m to study the dependence of the wave form as a function of M_m , distance $\frac{r}{L_i}$ and azimuth φ relative to the wind direction.



Detonation generator

RAY TRAJECTORIES ($M_m \gg 1$)

SURFACE
EXPLOSIONS 20-70 t TNT

DETONATION
GENERATOR

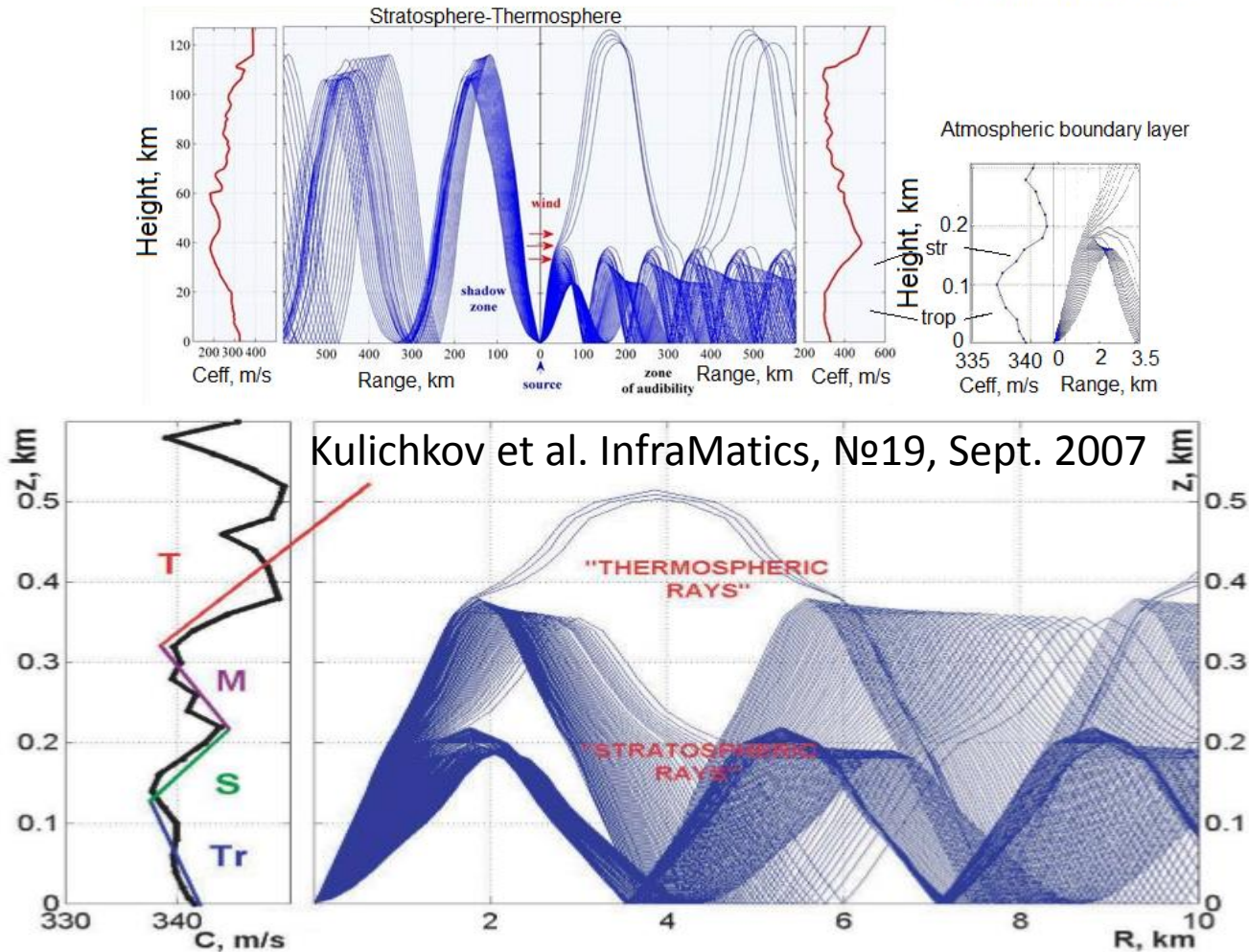
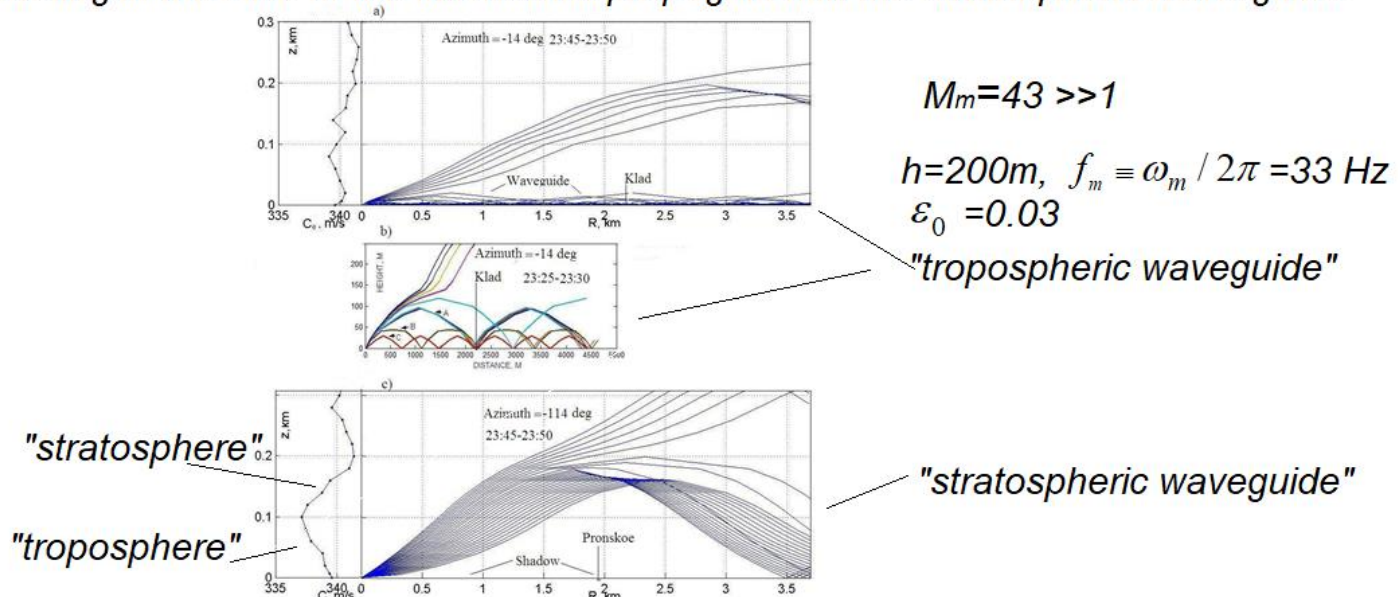
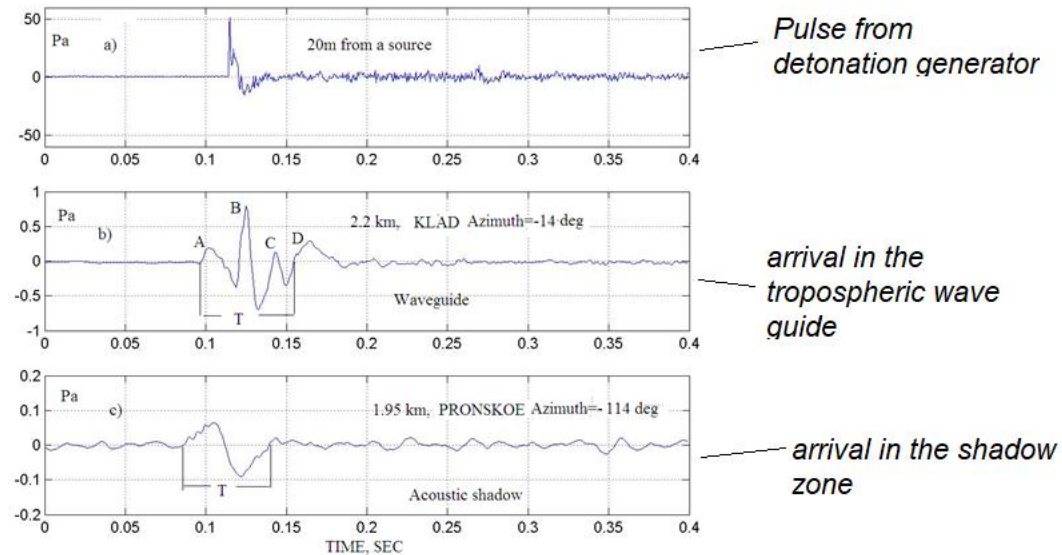


Figure 1. Profile of stratification of effective sound speed in the atmospheric boundary layer which may be used to model the atmosphere from the land surface up to thermospheric heights of about 150 km (**Tr** – “troposphere”, **S** – “stratosphere”, **M** – “mesosphere”, **T** – “thermosphere”) – on the left. Calculation of ray paths – on the right.

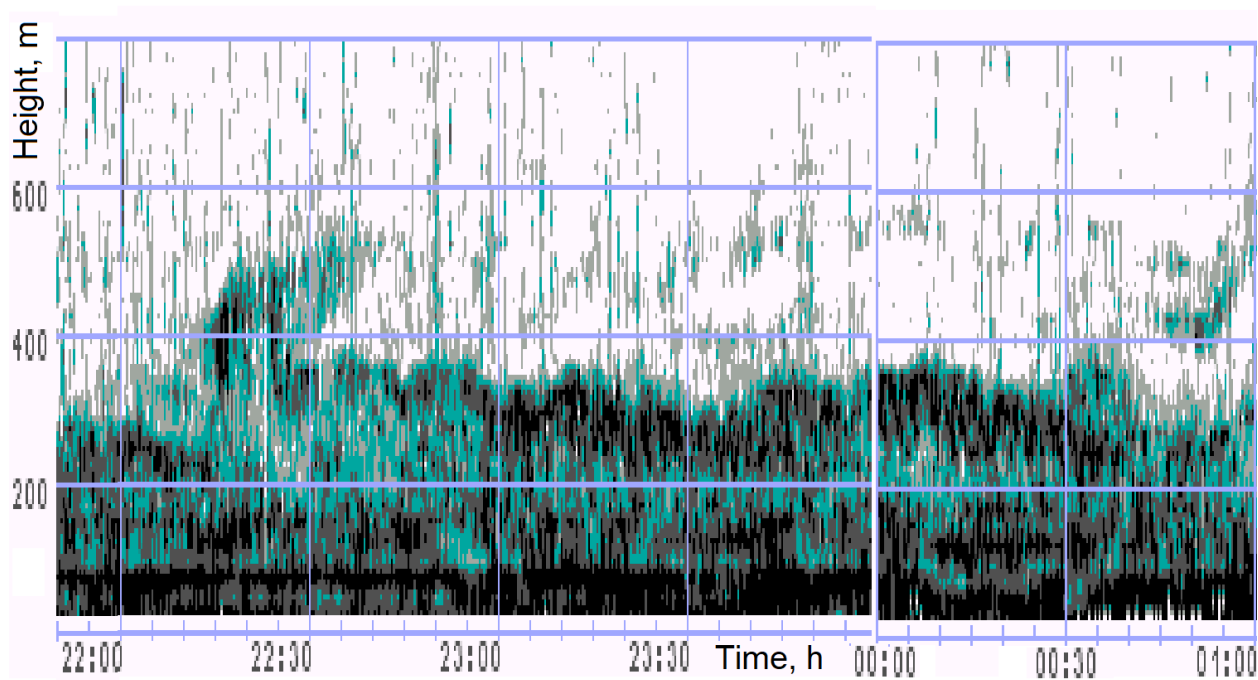
Modeling in the ABL of the infrasound propagation in the stratospheric wave guide



Signals from detonation source detected in two directions



CONTROL OF THE ABL STRATIFICATION BY SODAR



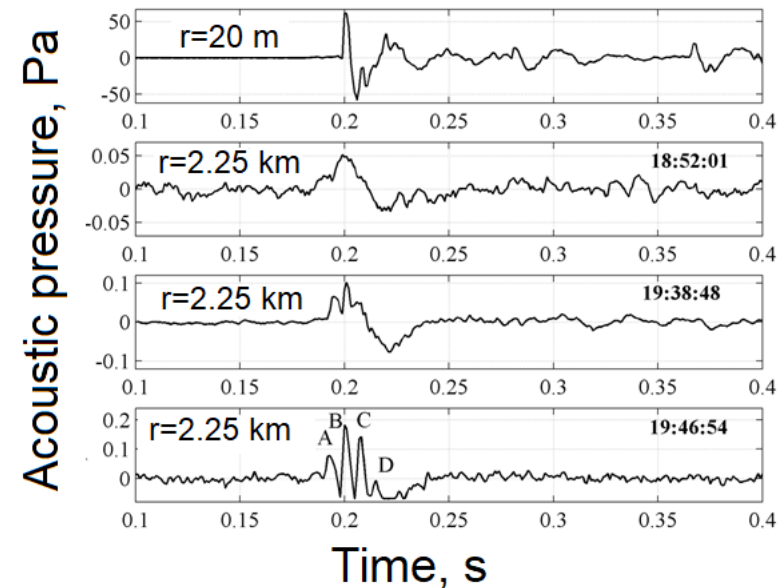
Recording of the scattered echo signal of SODAR from 22:00 MST on August 13 to 01:00 MST on August 14, 2002 (Zvenigorod). The blackening layers located in the height ranges of 100–150 m and 300–350 m are caused by the scattering of a SODAR echo-signal by layers of intense turbulence within a stably stratified ABL. The displacements of such layers are caused by atmospheric gravity wave-like structures. High gradients in C_{eff} exist at the boundaries between layers of turbulence and stably stratified layers.

Modeling of the effect of atmospheric gravity wave perturbations and coherent structures in the atmosphere on infrasound propagation by using acoustic pulsed generator in Armenia

Chunchuzov I.P., Perepelkin V.G., Popov O.E., Kulichkov S.N., Vardanyan A.A., Ivazyan G.E., Khachikyan Kh.Z.. Study of the characteristics of the fine-scale layered structure of the lower troposphere by using acoustic pulse remote sensing. Izvestiya Atmospheric and Oceanic Physics, 2016, Vol. 53, No. 3, pp. 279–293.



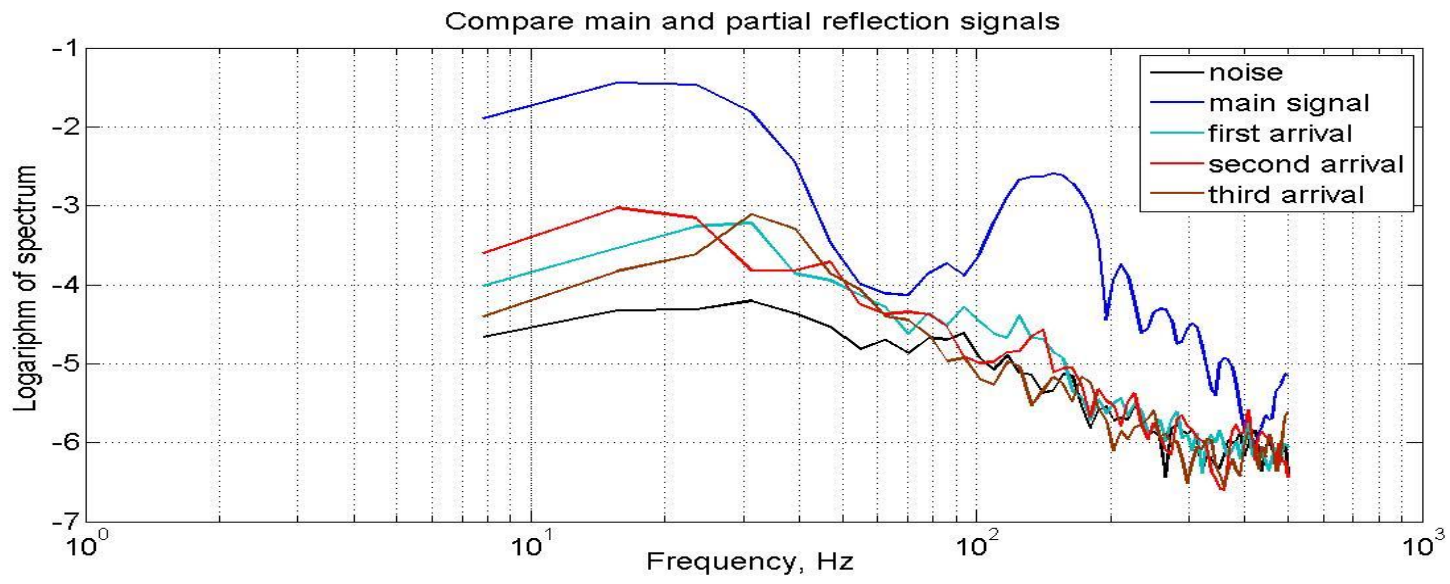
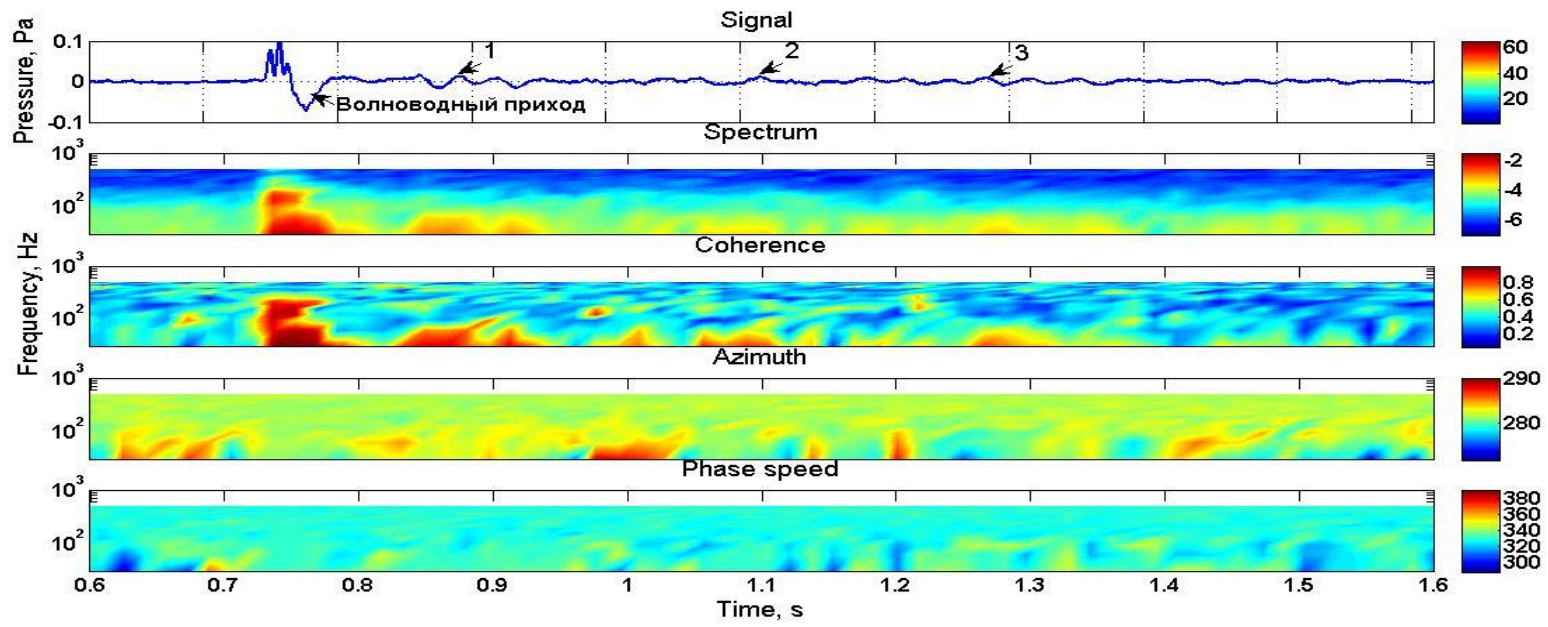
Anti-hail acoustic cannon



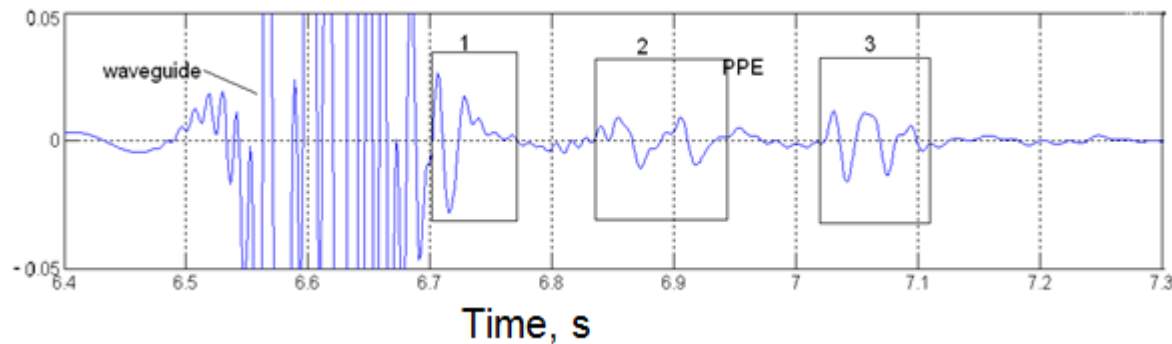
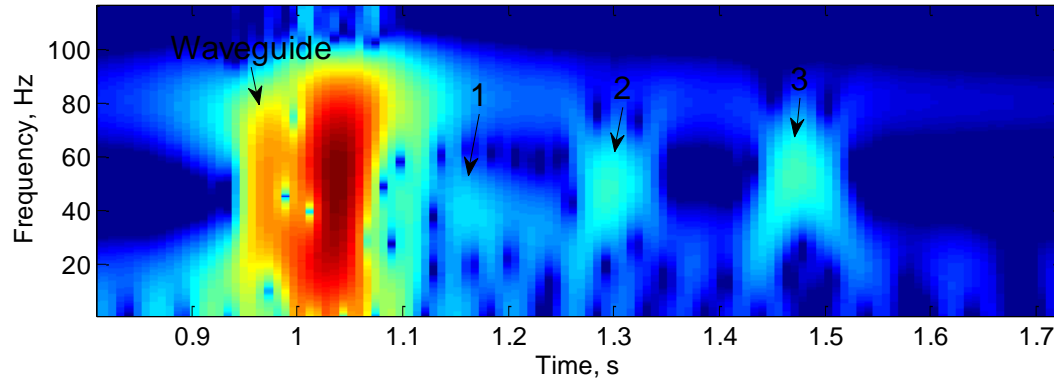
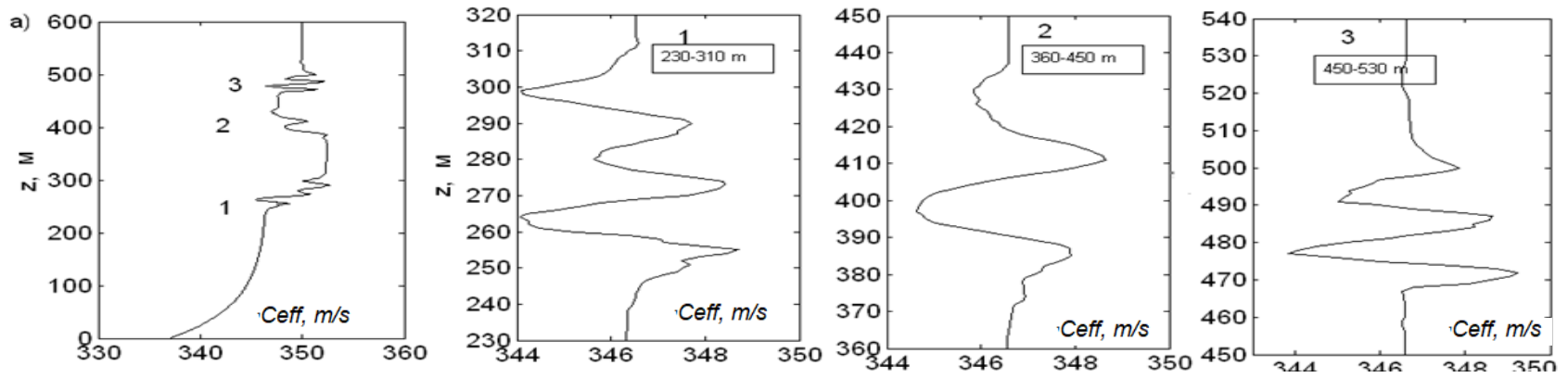
The evolution of the waveform of the signals from the detonation generator during formation of stable stratification from 18:52 to 19:47 LT., September 17, 2015. The signal near the source ($r = 20\text{ m}$, $z = 0\text{ m}$) is shown on the top panel.

Waveforms at a distance $r = 2.25\text{ km}$ from the source at different times (three lower panels).

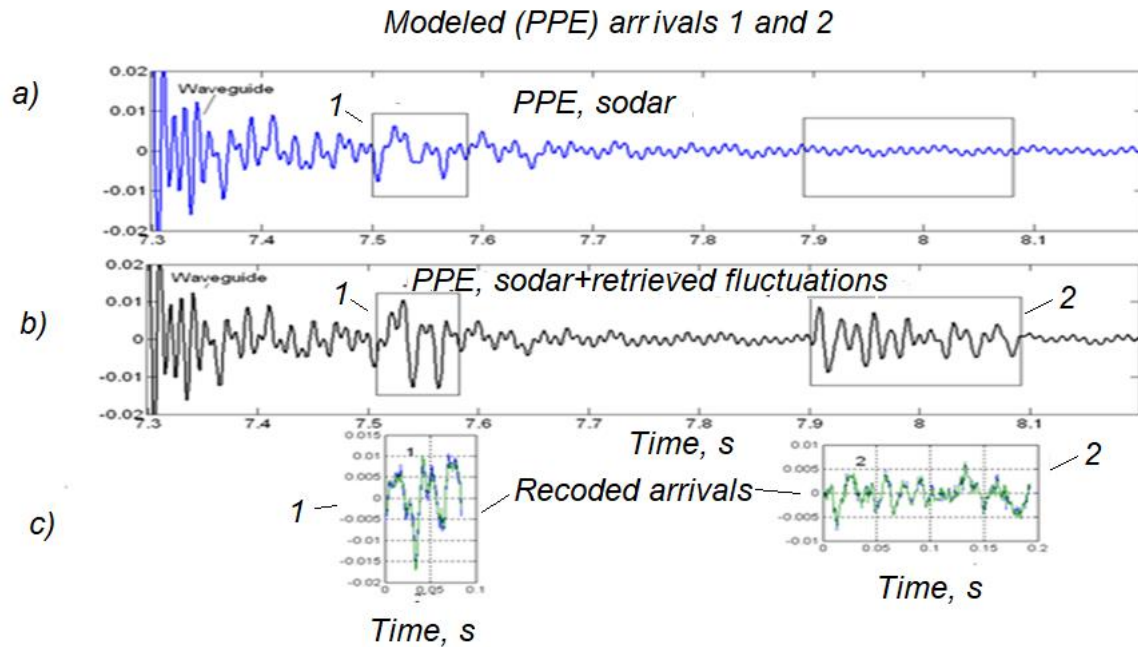
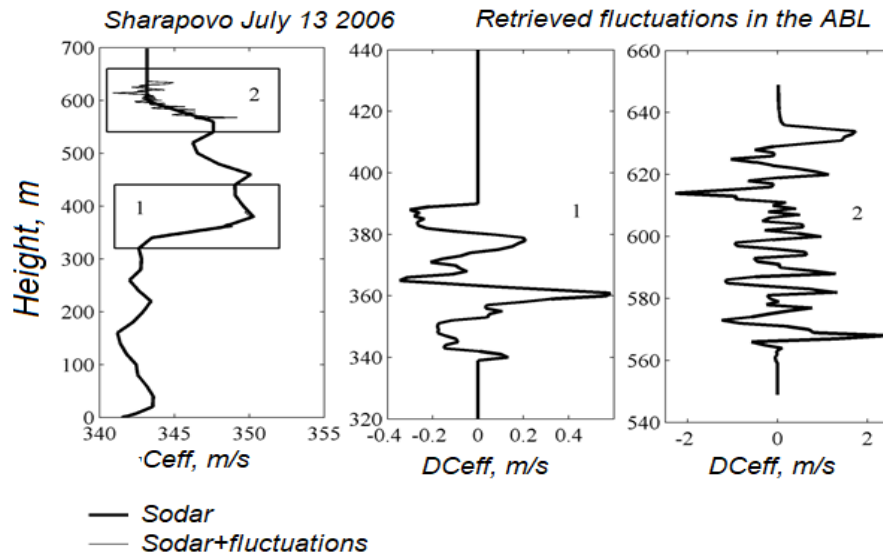
Top: One of the signals recorded at a distance of $r = 2.25$ km from the source. The top panel shows the waveguiding signal (waveguide) (a), and the arrivals 1, 2 and 3, are detected at the “tail” of the signal using the correlation analysis of signals at the triangular antenna receivers



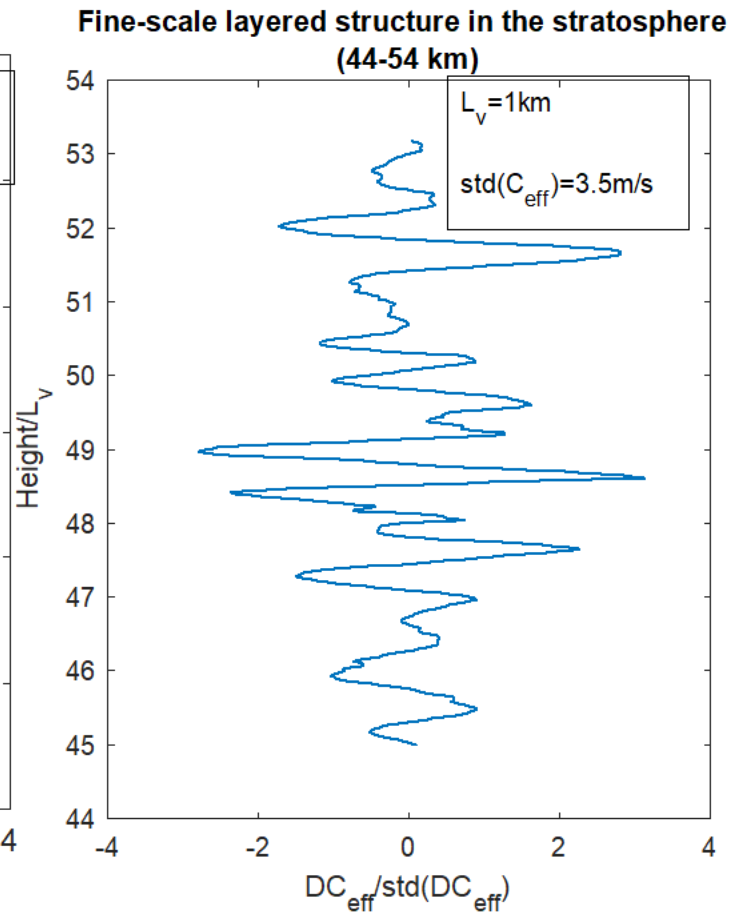
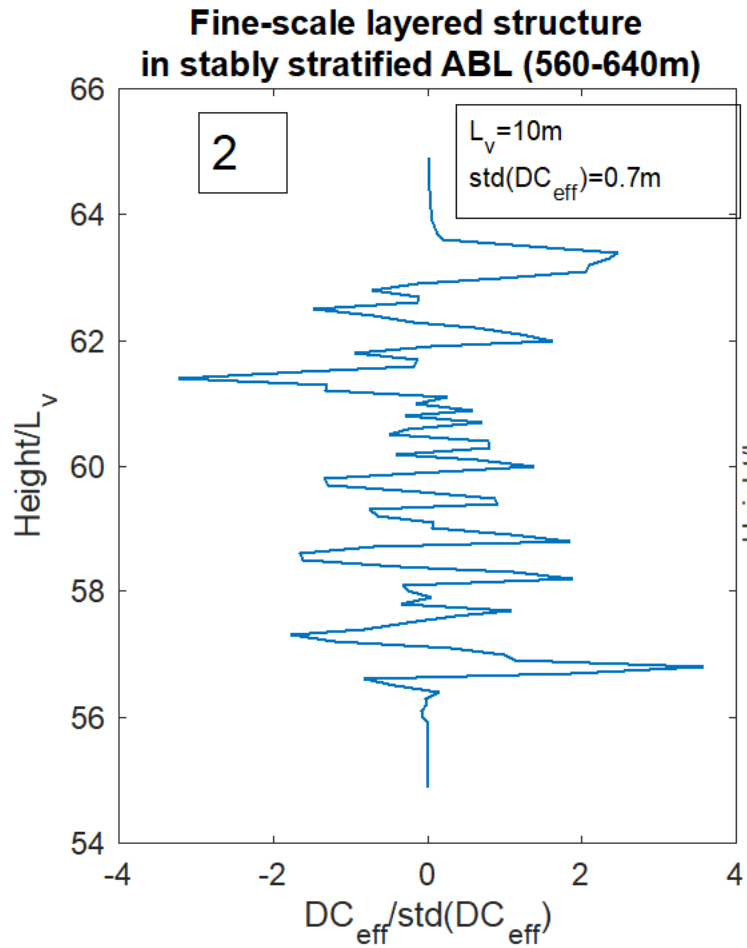
Upper panels: Vertical profiles of the effective sound speed fluctuations retrieved from the arrivals 1,2 and 3. Lower panel: Calculation of the signal and its spectrum as a function of time (middle panel) by pseudo-differential parabolic equation method (PPE)



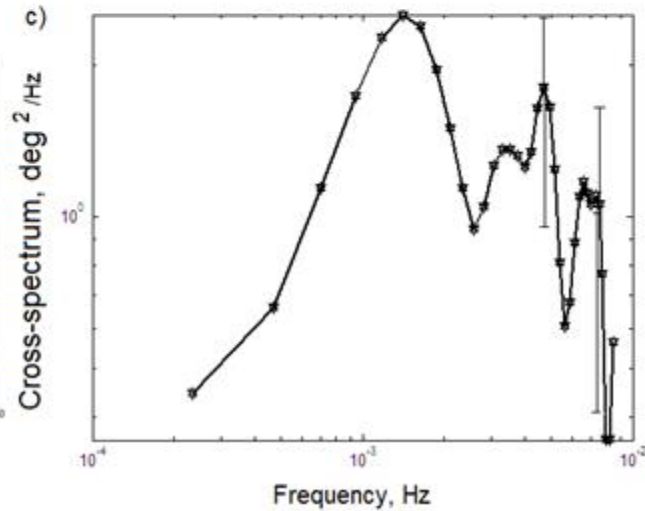
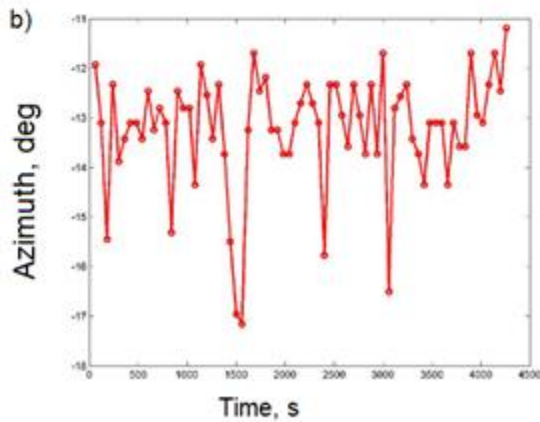
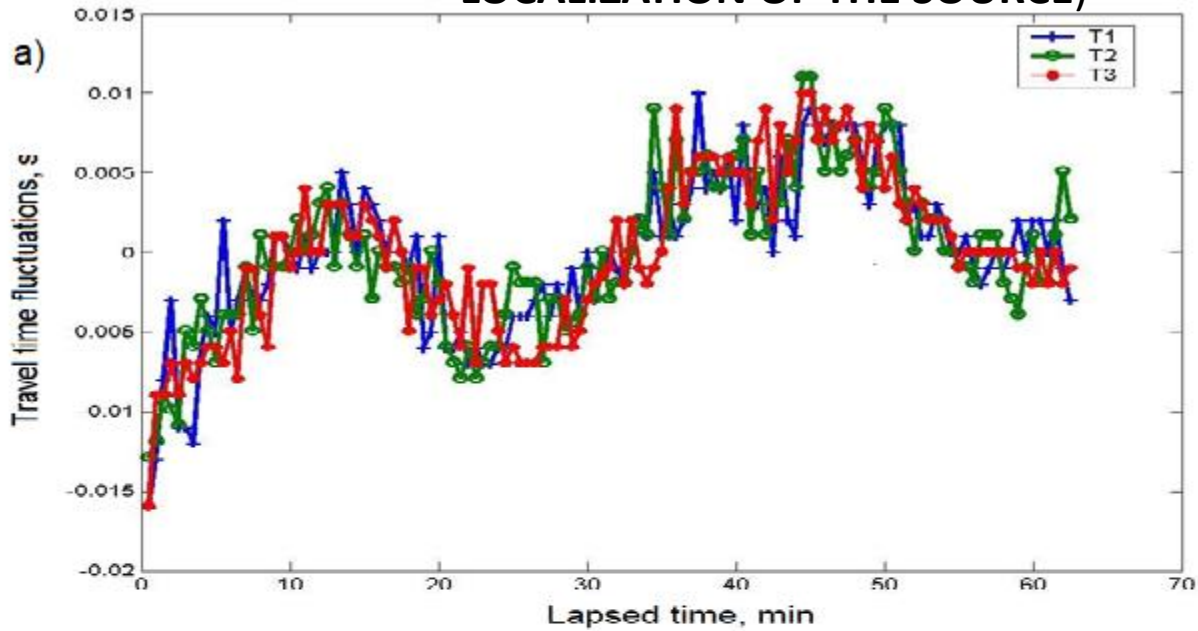
Retrieved profiles $DC_{eff}(z)$ obtained from the arrivals 1 and 2 of the signal (middle and right panels) superimposed on the mean profile (left) obtained from sodar and temperature profiler data on Aug 13 2006 near Moscow (ZNS)



MODELING FINE-SCALE LAYERED STRUCTURE IN THE STRATOSPHERE USING STABLE ABL



MODELING THE EFFECT OF ATMOSPHERIC GRAVITY WAVE PERTURBATIONS IN STABLY STRATIFIED ABL ON SOUND TRAVEL TIME AND AZIMUTH OF ARRIVAL (ERROR IN LOCALIZATION OF THE SOURCE)



CONCLUSIONS

1. We showed the possibility for physical modeling of the propagation of signals from explosions of different power in the atmosphere by studying the propagation of acoustic pulses from artificial detonation sources in stably stratified ABL. The stratification of the ABL was controlled by SODAR and temperature profiler.
2. The similarity between the propagation of the infrasound signals from surface explosions (20-70 t TNT) in the "shallow" tropospheric wave guide and propagation of Lamb mode from nuclear explosions was found.
3. The propagation of acoustic pulses in the "stratospheric" wave guides in stable ABL was studied as a function of the azimuth of propagation.
4. The effect of scattering of acoustic pulses from a fine-scale layered structure in stably stratified ABL was found. This effect was shown to be similar to the scattering of infrasound signals from gravity wave perturbations and coherent structures in the upper atmosphere.
5. The effect of temporal fluctuations of C_{eff} on the azimuth of propagation of acoustic pulses from detonation source was studied. This effect leads to the error in localization of acoustic sources similarly to the effect of gravity wave perturbations in the upper atmosphere on localization of infrasound sources (explosions, volcanoes)