

# Civilian application of infrasound IMS data: study vertical profiles of temperature and wind velocity in the atmosphere

**Sergey Kulichkov** <sup>(1)</sup>, Igor Chunchuzov <sup>(1)</sup>,  
Oleg Popov <sup>(1)</sup>, Elena Golikova <sup>(1)</sup>, Pierrick Mialle <sup>(2)</sup>,  
Elisabeth Blanc <sup>(3)</sup>, Alexis Le Pichon <sup>(3)</sup>,  
Laslo Evers <sup>(4)</sup>, Lars Ceranna <sup>(5)</sup>

(1) A.M. Oboukhov Institute of Atmospheric Physics RAS;

(2) CTBTO Preparatory Commission, Vienna, Austria

(3) Commissariat à l'énergie atomique et aux énergies alternatives (CEA), France

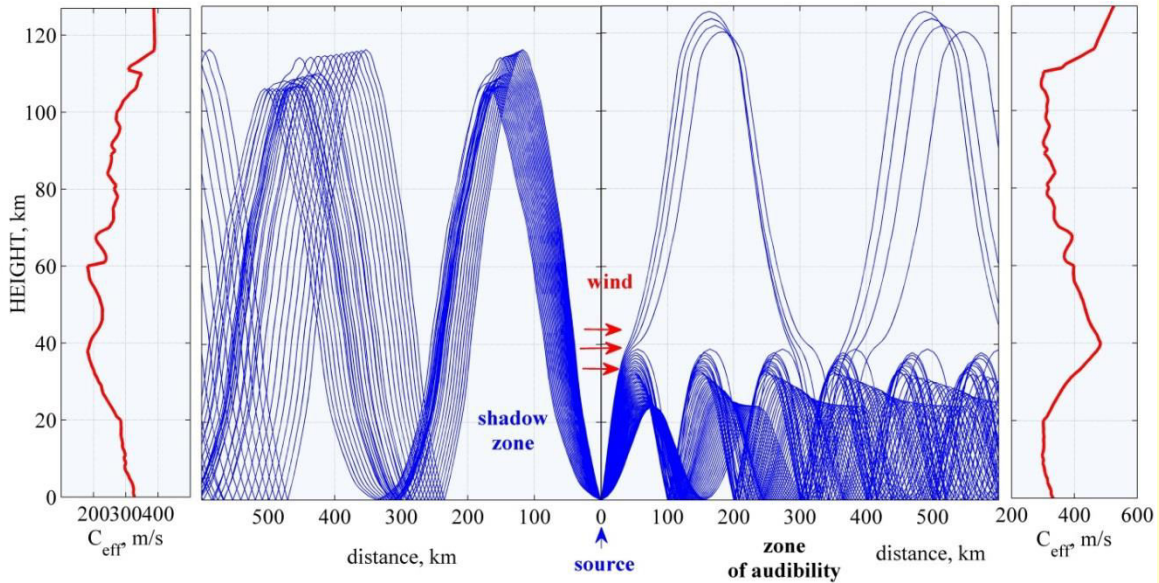
(4) Royal Netherlands Meteorological Institute (KNMI), De Bilt, Netherlands

(5) Federal Institute for Geosciences and Natural Resources (BGR), Hanover, Germany

# OUTLINE

- ◆ Introduction
- ◆ History
- ◆ Objectives
- ◆ Study of atmospheric structure by using of infrasound data obtained at IMS stations
  - *averaged vertical profiles of effective sound velocities (temperature + wind)*
  - *fine structure of the middle atmosphere ( $h=20\dots 130$  km) – anisotropic turbulence*
- ◆ Spatial and temporal stability of atmospheric structure
- ◆ Discussion
- ◆ Conclusions

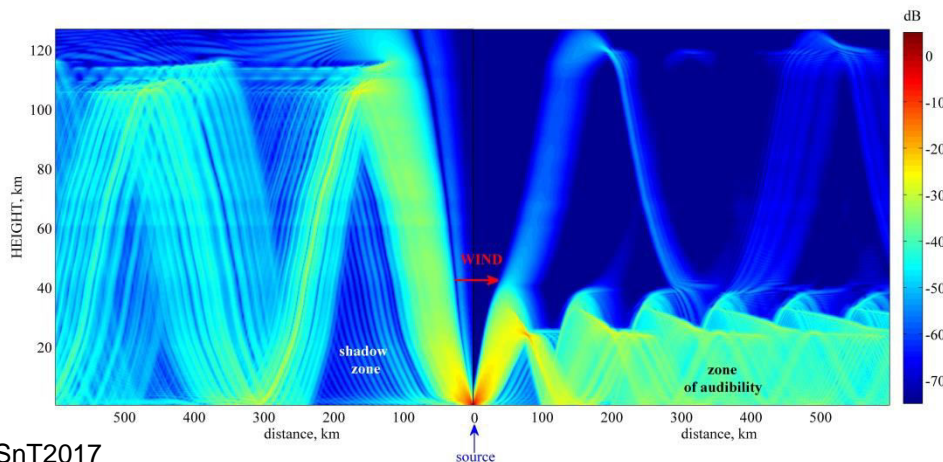
# INTRODUCTION



◆ the first experiments on using of acoustic method to study atmospheric structure by using of infrasound data obtained at IMS stations

- averaged vertical profiles of effective sound velocities (temperature + wind)

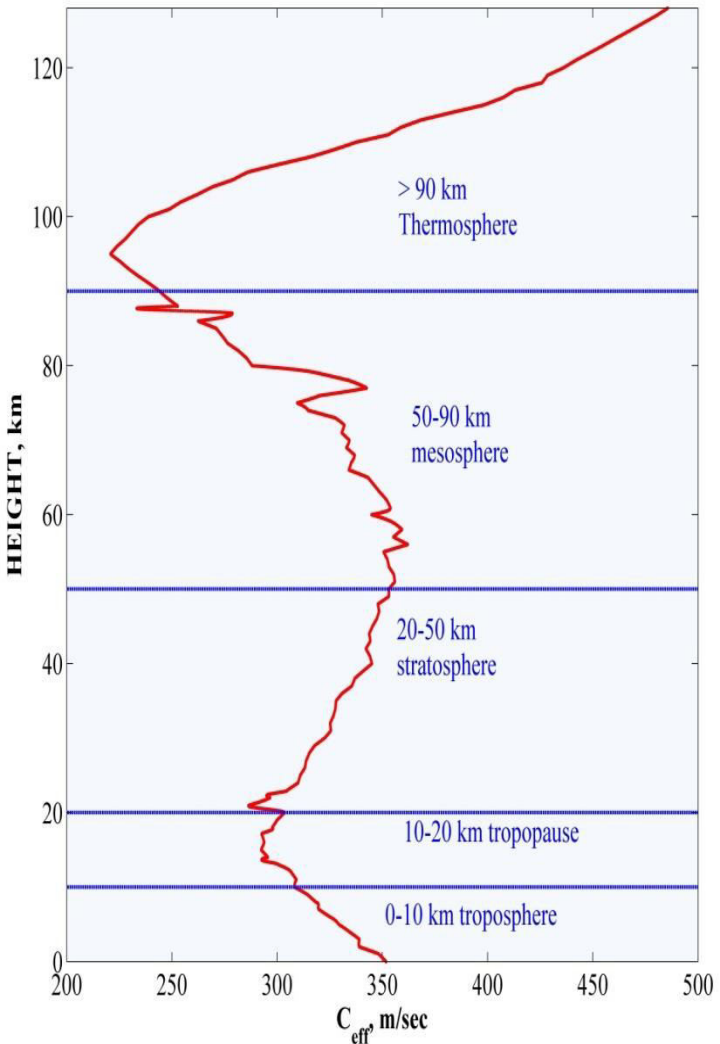
**infrasound data observed in the zones of audibility**



- fine structure of the middle atmosphere ( $h=20\dots130$  km) – anisotropic turbulence

**infrasound data observed in the zones of shadow**

# HISTORY



CTBTO SmT2017  
**Effective sound velocity**

## REMOTE INFRASONIC METHOD

(long-range infrasound propagation in the atmosphere)  
average profiles of wind and temperature stratification

- ◆ the stratosphere (temperature inversion) was discovered
  - **the beginning of the 20th century**
- ◆ the strong wind in the stratosphere was discovered
  - **the first half of the 20th century**
- ◆ the first data indicating the presence of the thermosphere
  - **the first half of the 20th century**
- ◆ network of national infrasound stations for detecting nuclear explosions
  - **the second half of the 20th century**
- ◆ **IMS (CTBTO) – the end of the 20th century**

**Renaissance of infrasound  
method**

# OBJECTIVES

## QUESTION :

- ◆ **What reason in using of the infrasound method to study the atmospheric structure, when there are many other very good methods: satellites, lidars, radars, missiles....**

## ANSWER :

- 1) **The more, the better ;**
- 2) **To monitoring temporal variability of the wind field in the lower thermosphere (90-130 km) .**  
**This layer is poorly studied by other remote sensing methods (radars, lidars and satellites).**
- 3) **To study fine structure (anisotropic turbulence) of the middle atmosphere (h=20...130 km)**  
***the vertical scales of such inhomogeneities caused by the internal gravity waves (IGW) -  $\Delta h \sim 10m \dots 10km$ ; the horizontal scales  $\Delta \ell = n \times \Delta h$  ( $n \sim 10-100$ ).***  
**Anisotropic turbulence also is poorly studied by other remote sensing methods (radars, lidars and satellites).**
- 4) **To study the statistical characteristics of the IGW perturbations (variances, vertical wavenumber spectra and structure functions).**

# Study of atmospheric structure by using of infrasound data obtained at IMS stations

- *averaged vertical profiles (temperature + wind)*

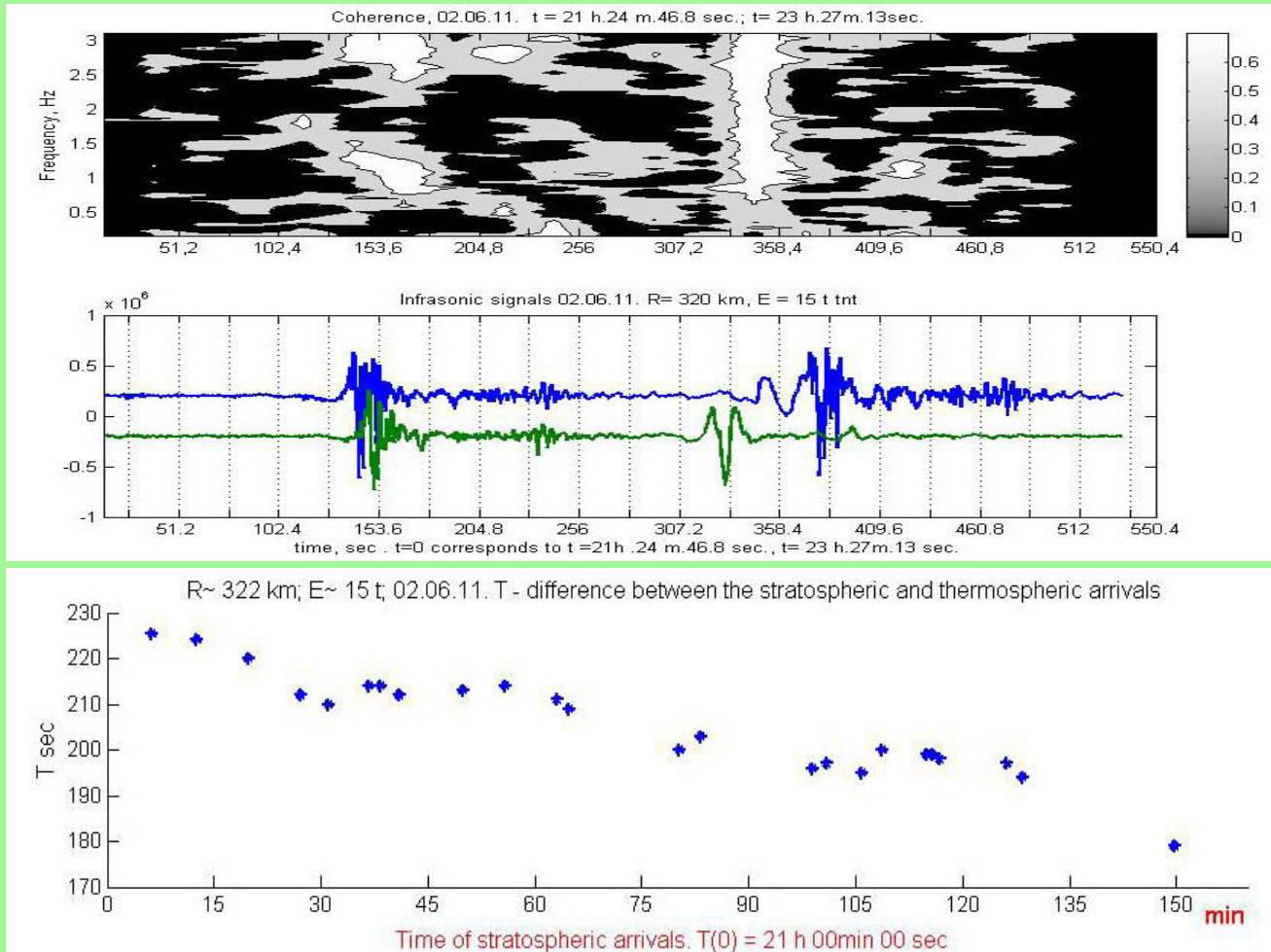
# **METHOD OF RECONSTRUCTION**

**(temperature; wind; direction of wind)**

**Well-known Nelder-Mead algorithm are used to correction of primary profiles of temperature and wind velocity in the atmosphere**

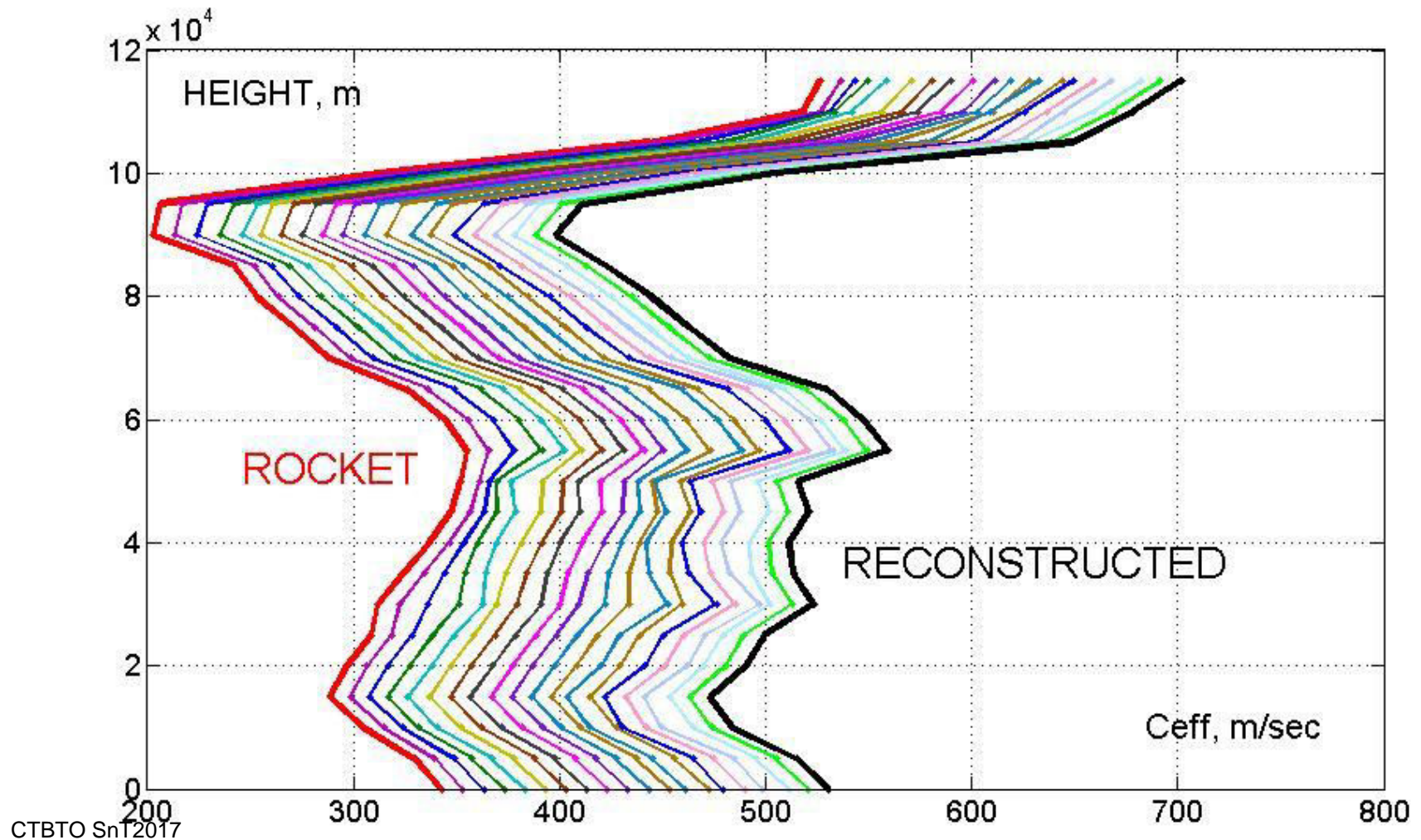
# INITIAL INFRASOUND DATA

(row of surface explosions;  $E \sim 10\text{-}15$  t tnt;  $R = 320$  km)



# RESULTS

(algorithm Nelder – MFA)

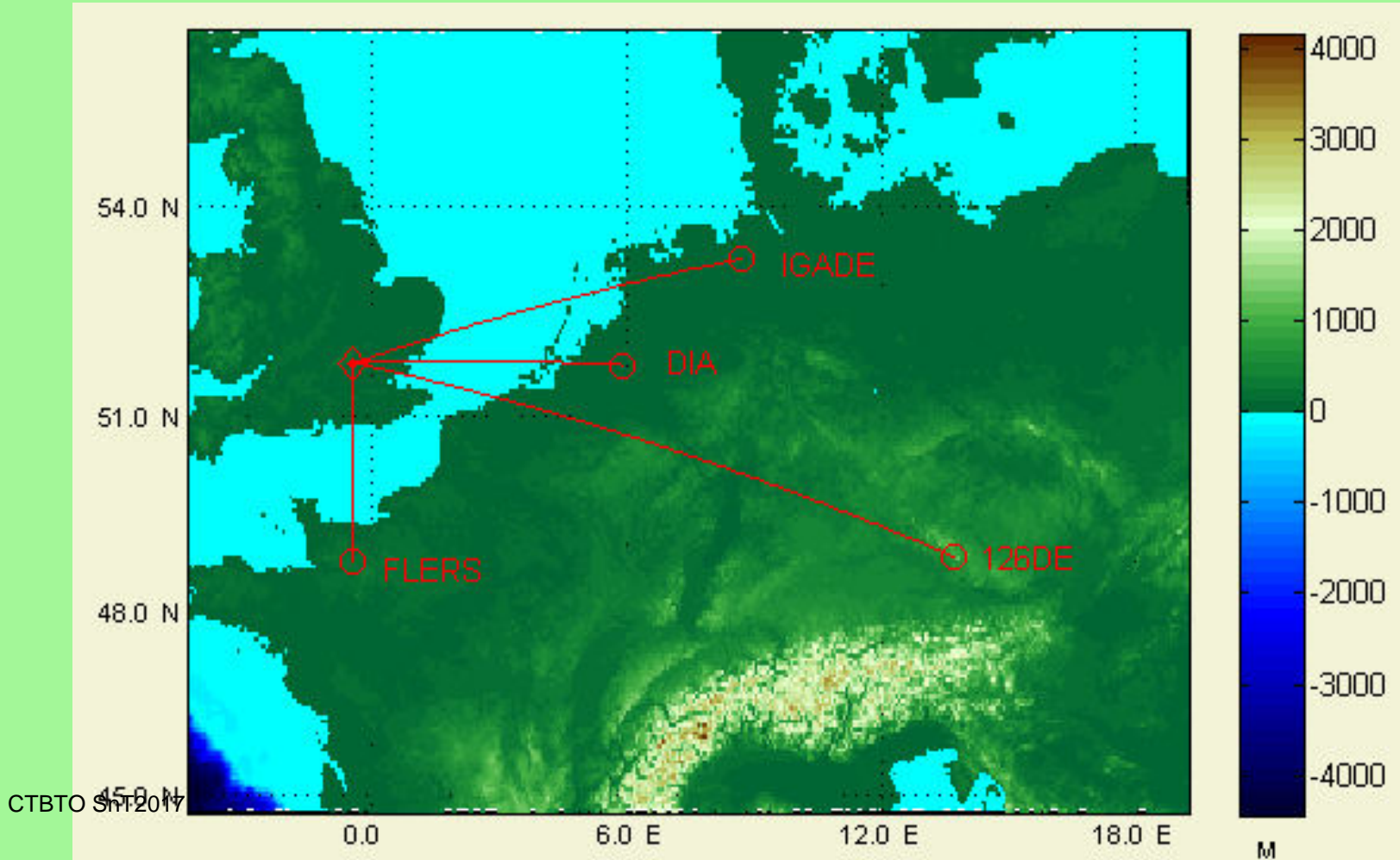


# INITIAL INFRASOUND DATA

vapor cloud explosion occurred on December 11, 2005 at an oil depot near Buncefield (UK)

## MAP of experiment

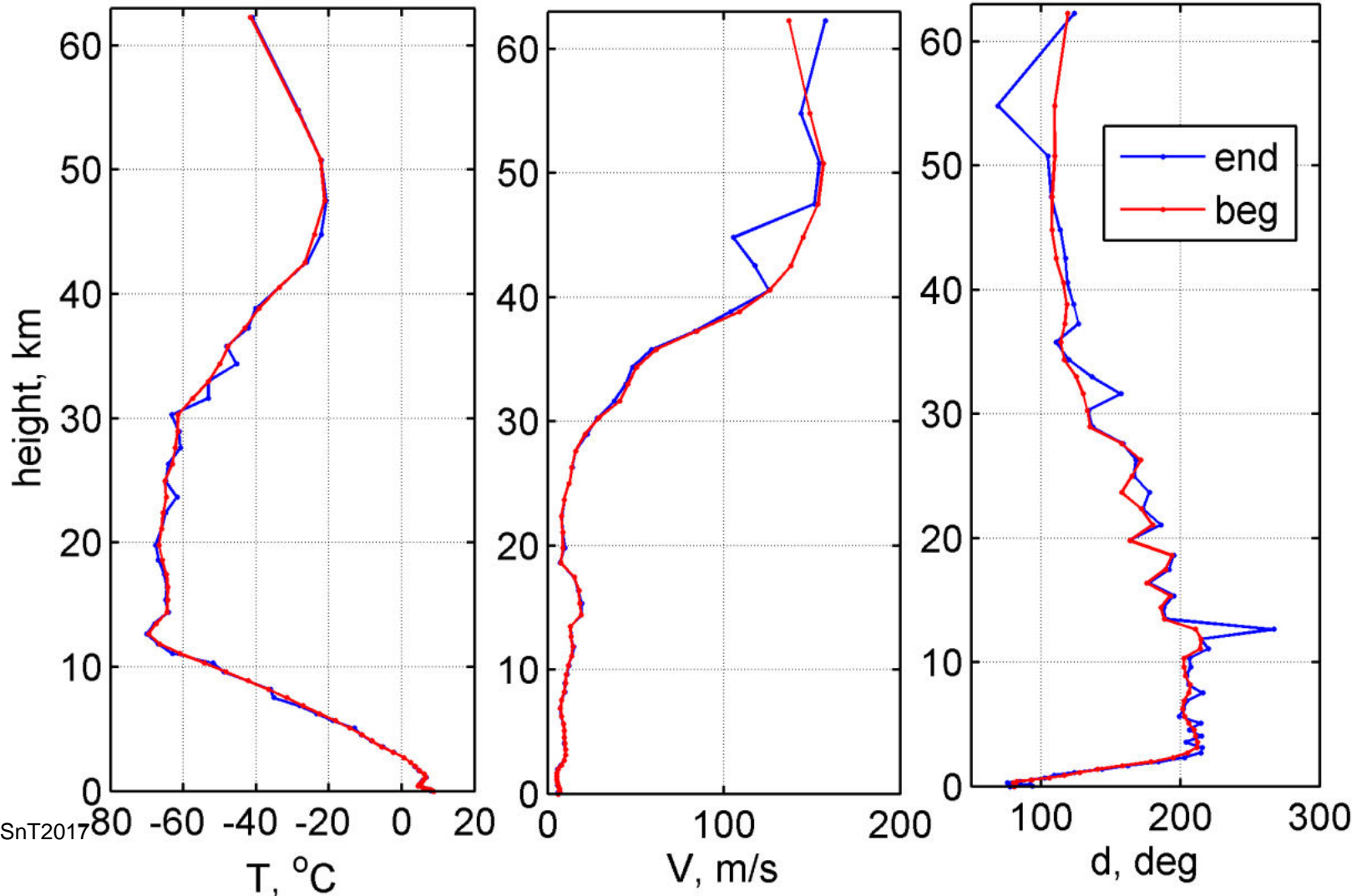
Source ( $\diamond$ ); receivers ( $\circ$ ), routes of infrasound propagation



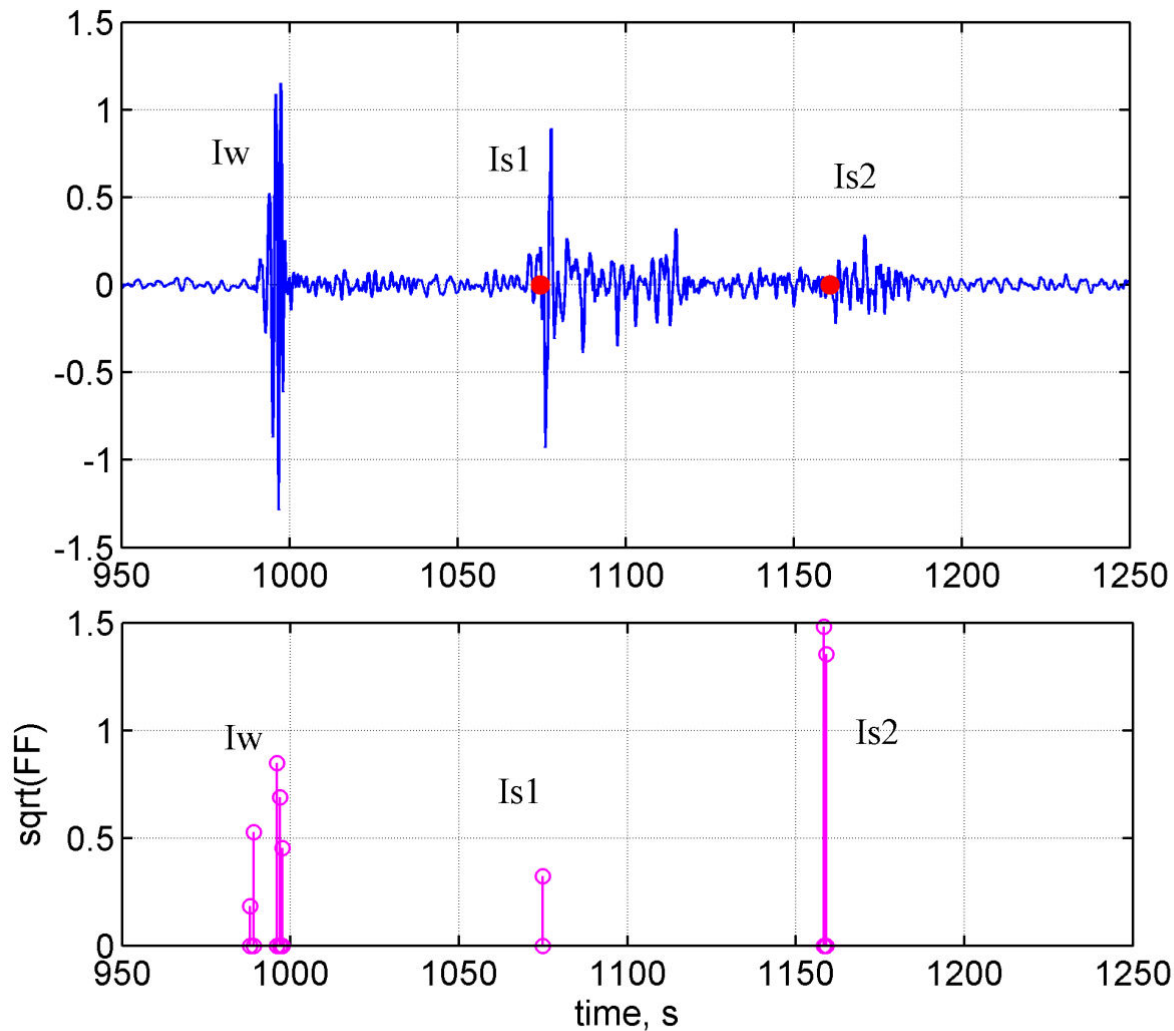
# Two stations

(FLERS + DIA; stratospheric arrivals)

primary ecmwf profile (red) modified profile (blue)



# Infrasound signal observed in FLERS – top. Structure of infrasound signal calculated by ray theory for modified **ecmwf** profile (two stations) – bottom.

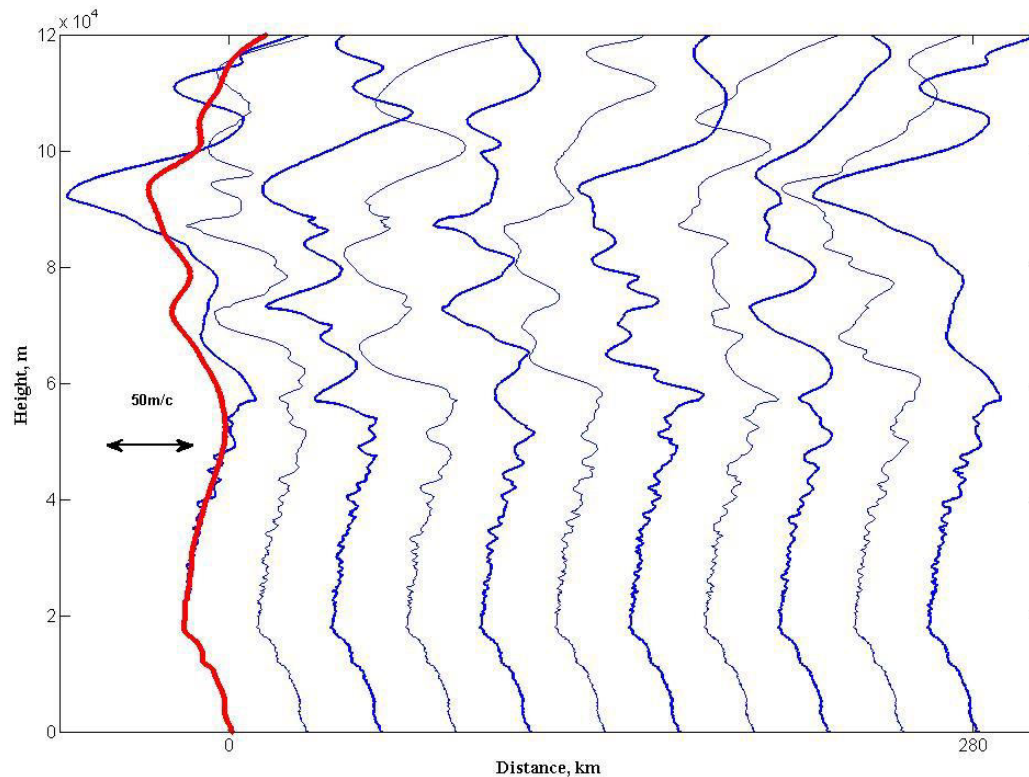


# **Study of atmospheric structure by using of infrasound data obtained at IMS stations**

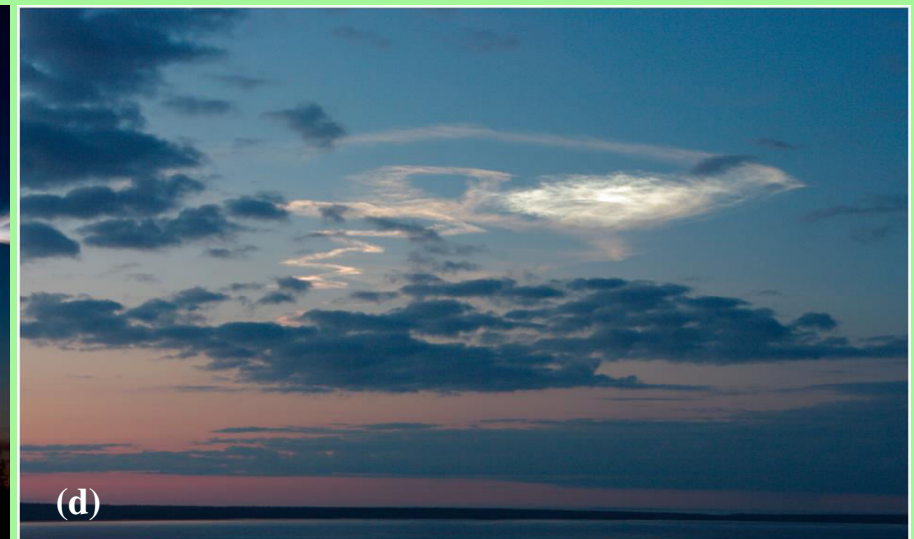
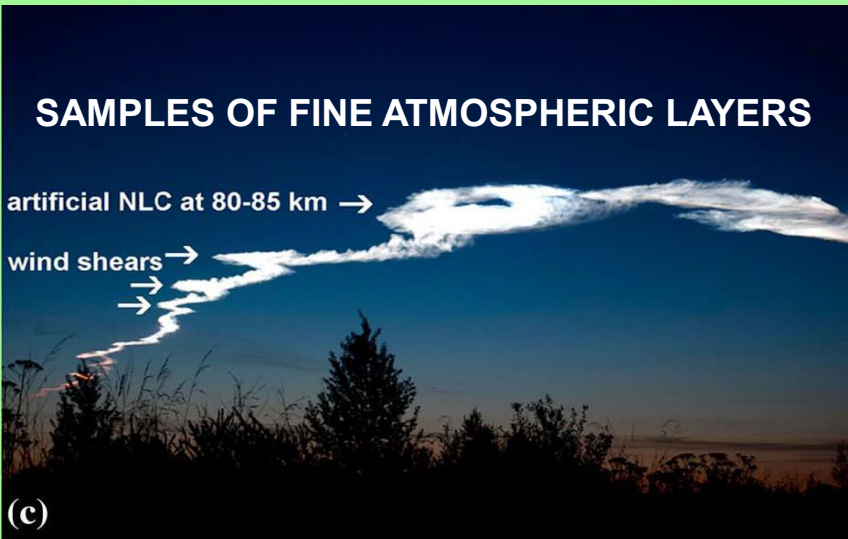
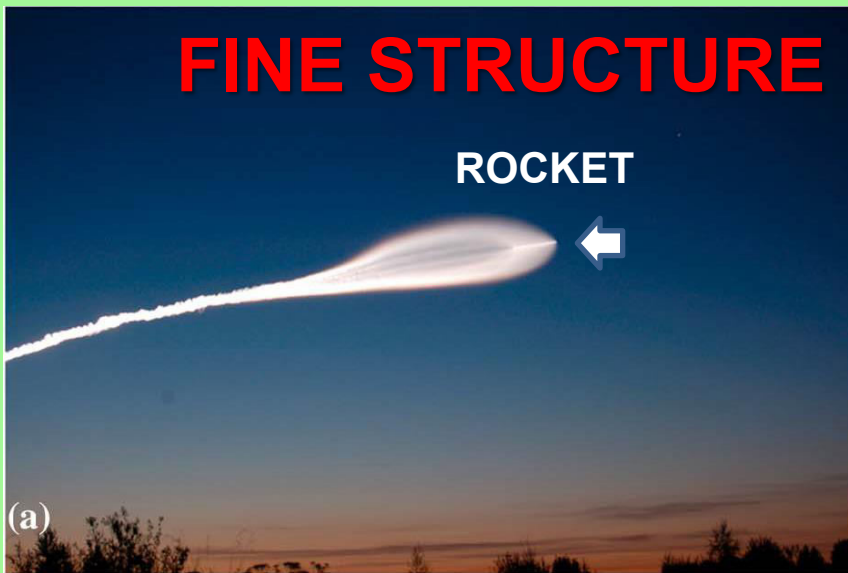
- ***fine structure of the middle atmosphere  
( $h=20\dots 130$  km) – anisotropic turbulence***

# Fine inhomogeneous structure of the atmosphere (theory; Chunchuzov, 2009-2015)

- ◆ the vertical scales of inhomogeneities caused by the internal gravitational waves -  $\Delta h \sim 10\text{m} \dots 10\text{km}$
- ◆ the horizontal scales of inhomogeneities  $\Delta \ell = n \times \Delta h$  ( $n \sim 10-100$ )

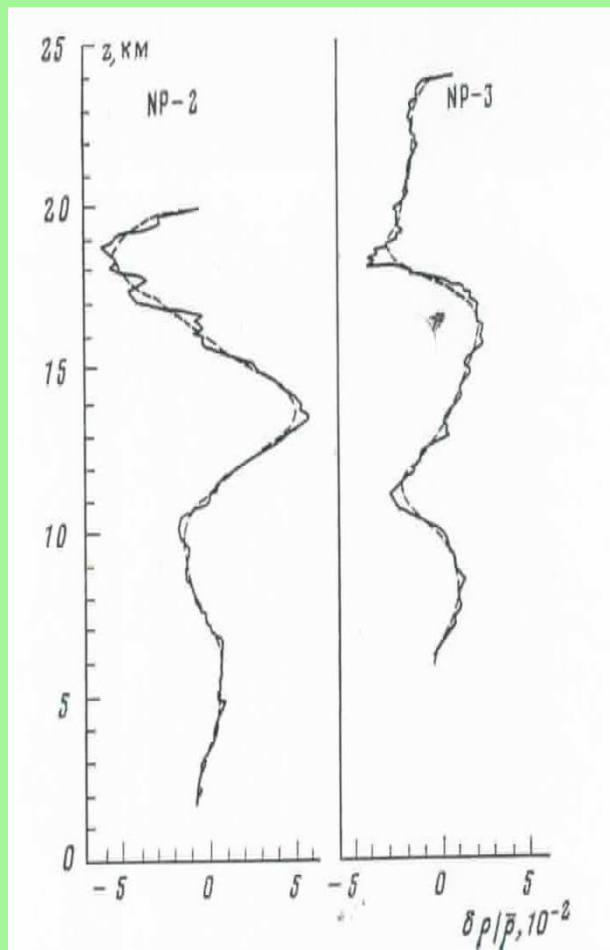
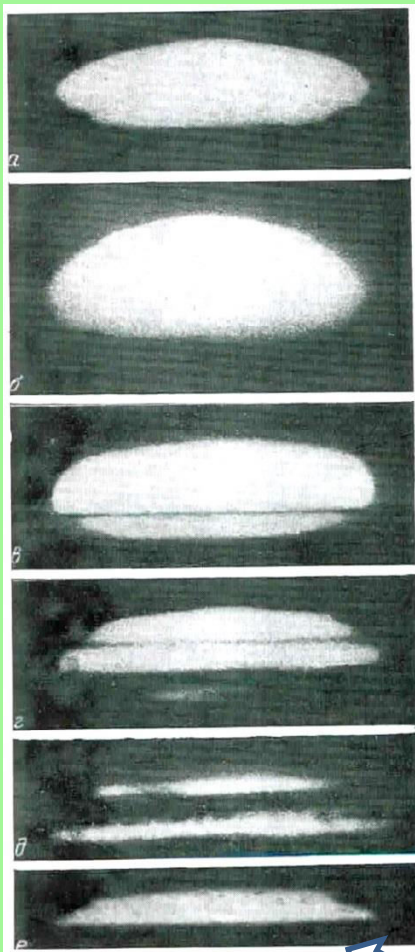


# FINE STRUCTURE OF THE ATMOSPHERE



The rocket exhaust trail left by the Soyuz rocket launched at 2153:53 UT on 21 May 2009 from Plesetsk. Images were taken after the launch: (a) 204 s, (b) 253 s, (c) 610 s, (d) 19min 39 s

# FINE STRUCTURE OF THE ATMOSPHERE



**GRECHKO G.M., GURVICH A.S.,  
LYAKHOV V.A., SAVCHENKO S.A.,  
SOKOLOVSKY S.V.**

**INVESTIGATION OF REFRACTION IN THE  
THIRD EXPEDITION ON THE ORBITAL  
STATION "SALYUT-6"**

**IZVESTIYA, ATMOSPHERIC AND  
OCEANIC PHYSICS, 1981.V.17, №11.  
P.1123-1133**



**GRECHKO G.M., GURVICH A.S., ROMANENKO Ju.V., SOKOLOVSKY S.V., TATARSKAYA M.S.**

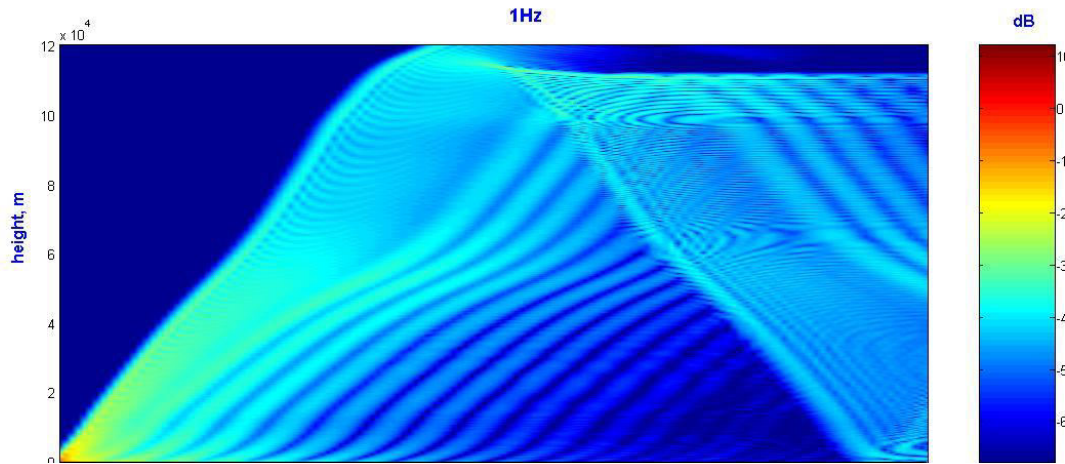
**THE STRATIFIED STRUCTURE OF TEMPERATURE DISTRIBUTION IN ATMOSPHERE BY REFRACTION  
MEASUREMENTS FROM SALJUT -6**

CTBTO SnT2017

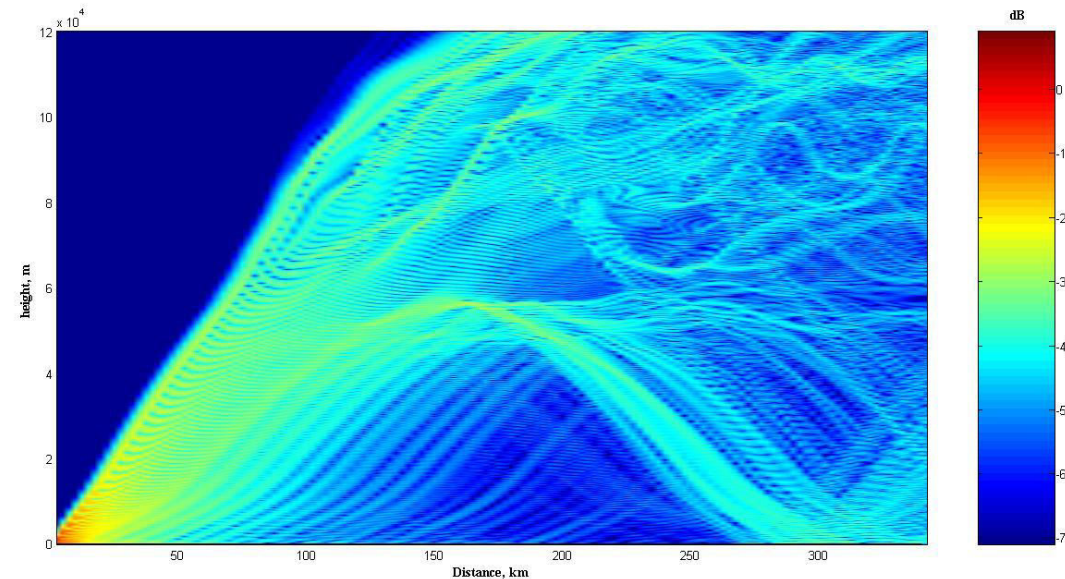
**IZVESTIYA, ATMOSPHERIC AND OCEANIC PHYSICS, 1981.V.17, №2. P.115-122**

# The acoustic field of a point source

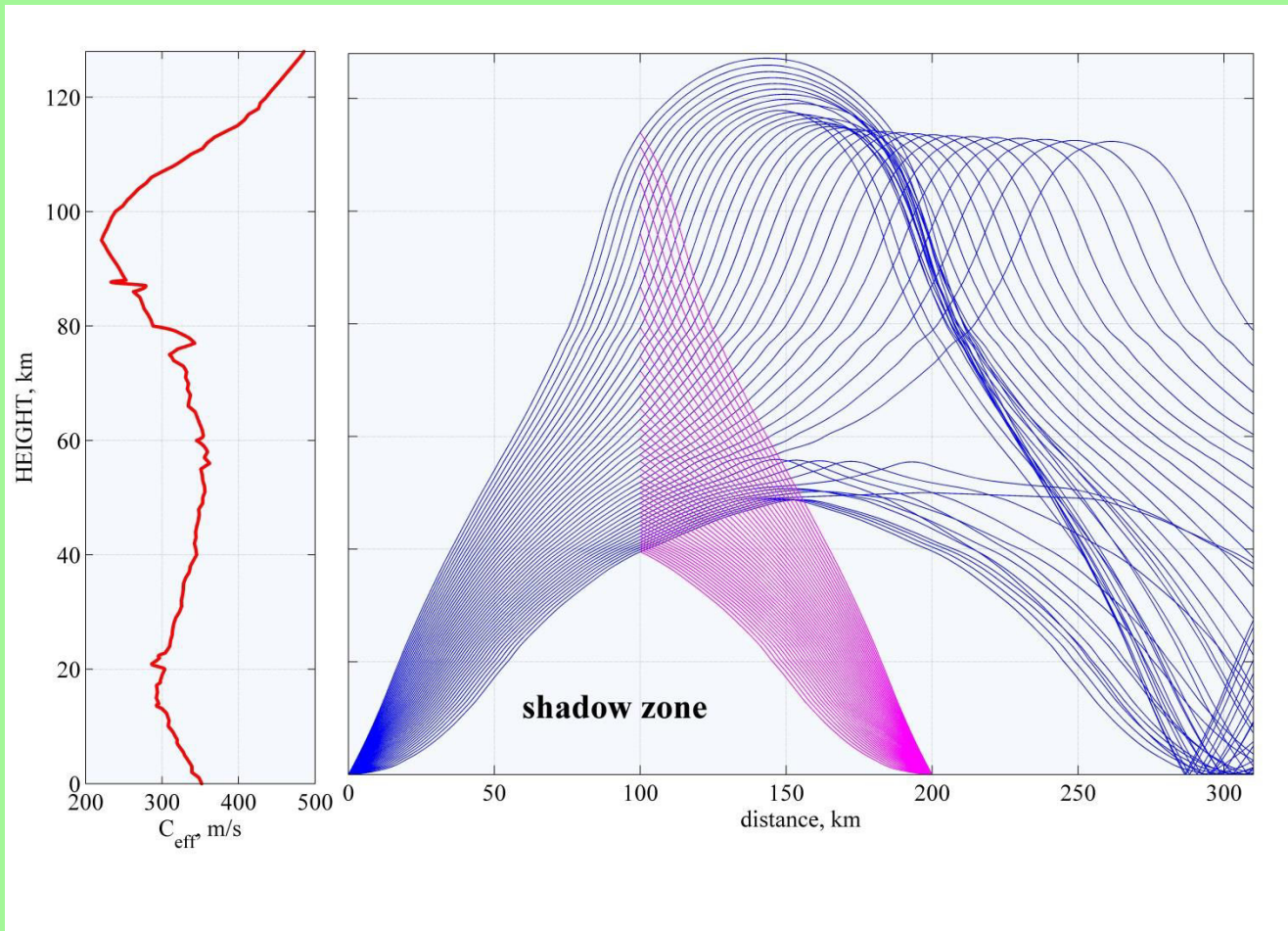
averaged  
profile



averaged  
profile +  
fine  
structure



# Scheme of the illumination of acoustic shadow zone

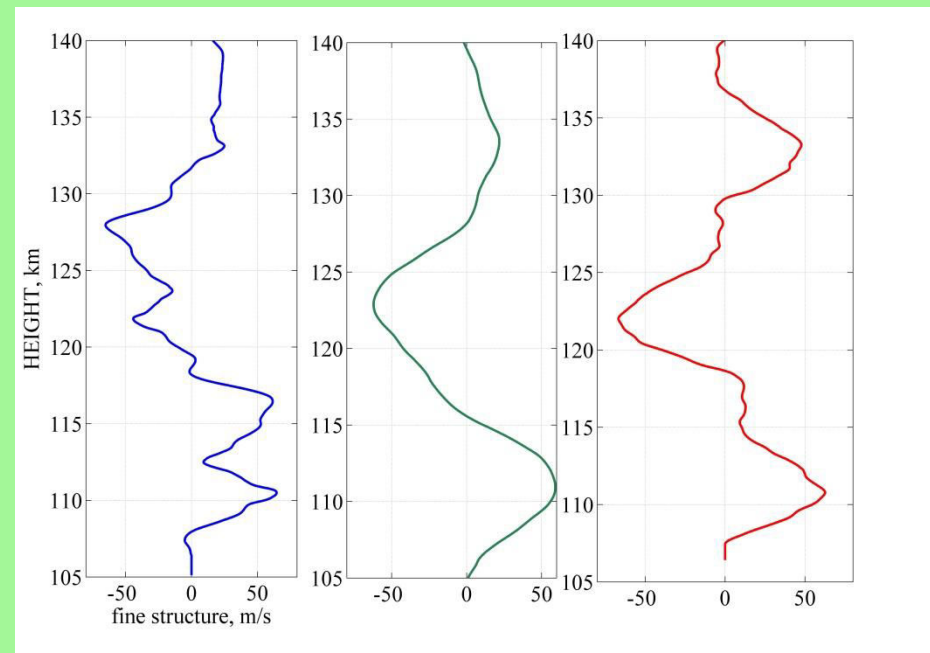
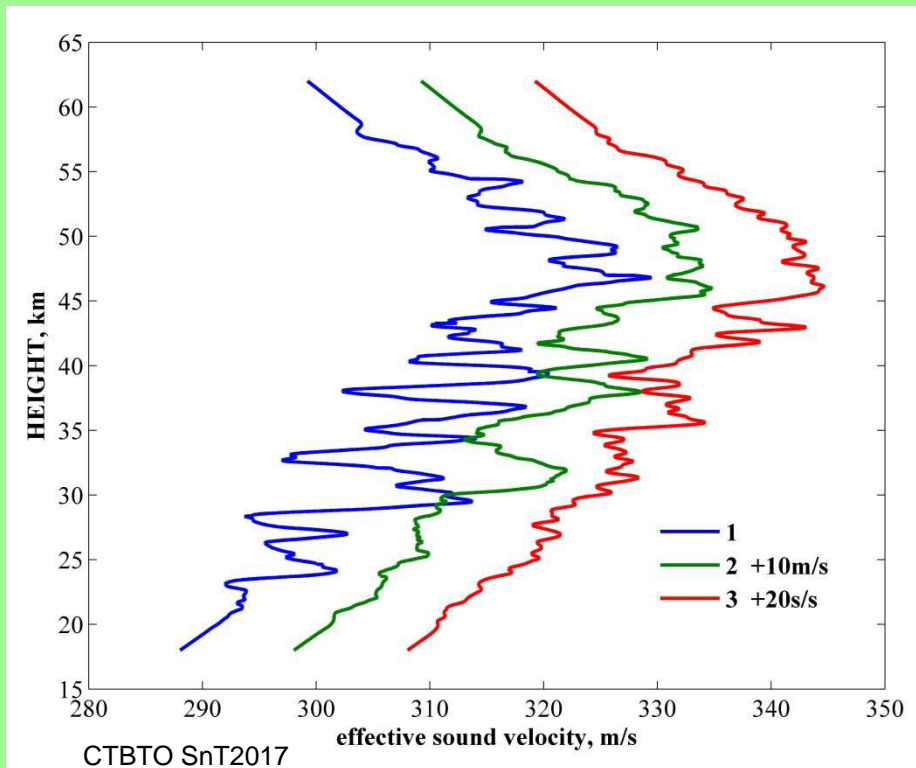


# Study of fine-scale atmospheric structure

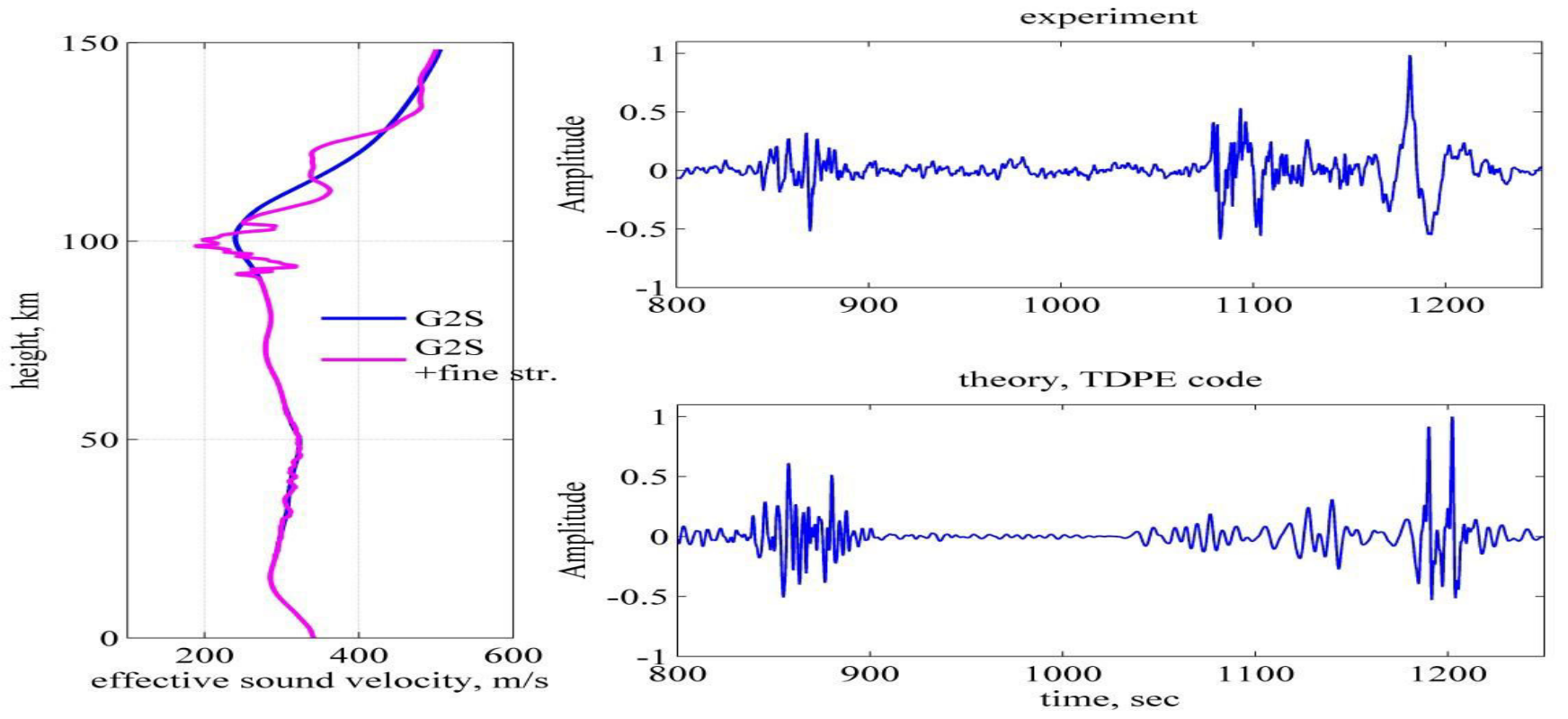
- ◆ the scattering of infrasound from anisotropic wind velocity inhomogeneities in the middle atmosphere leads to the penetration of the infrasound field into acoustic shadow zones;
  - ◆ to retrieve vertical profiles and vertical wavenumber spectra of the wind velocity fluctuations in the middle atmosphere (up to a height of 130 km above ground) we used:
    - the relation found between the wave forms of infrasound arrivals in the shadow zone and the vertical profiles of the wind velocity and temperature inhomogeneities;
    - the travel times and relative amplitudes of the stratospheric and thermospheric arrivals detected in the shadow zones for volcano eruptions;
- (I. Chunchuzov, S. Kulichkov and P. Firstov, *Izvestiya, Atmospheric and Oceanic Physics*, 2013, V.49(3), 258-270.)

# SAMPLE OF THE RETRIEVED FLUCTUATIONS OF THE EFFECTIVE SOUND SPEED IN THE STRATOSPHERE (left) and THERMOSPHERE (right)

- ◆ Tungurahua volcano (R~ 251 km, Ecuador)  
(3 profiles;  $\Delta t = 30$  min.) (I. Chunchuzov, et al. 2013)



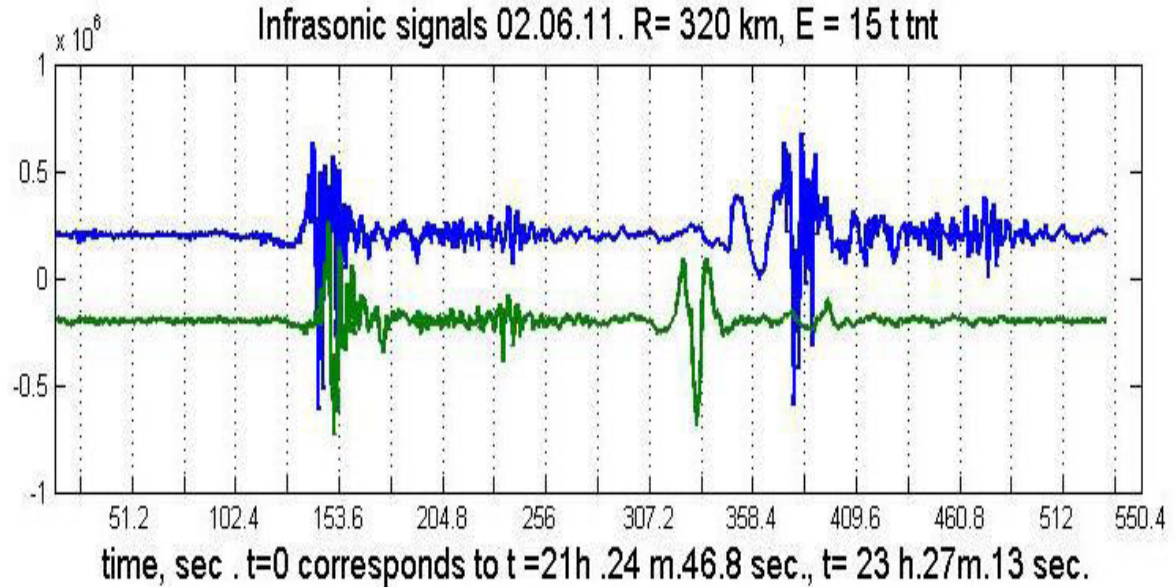
# EXAMPLE OF RETRIEVED FLUCTUATIONS OF THE EFFECTIVE SOUND SPEED BY USING INFRASONIC SIGNALS FROM A VOLCANO IN ECUADOR (R= 250,5 km)



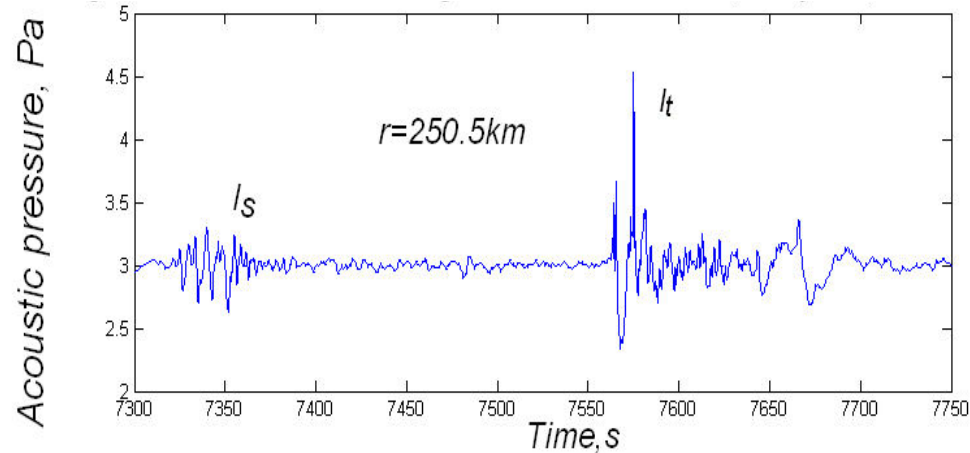
# Spatial Variations

- ◆ explosions (RUSSIA)
- ◆ volcano (EQUADOR)

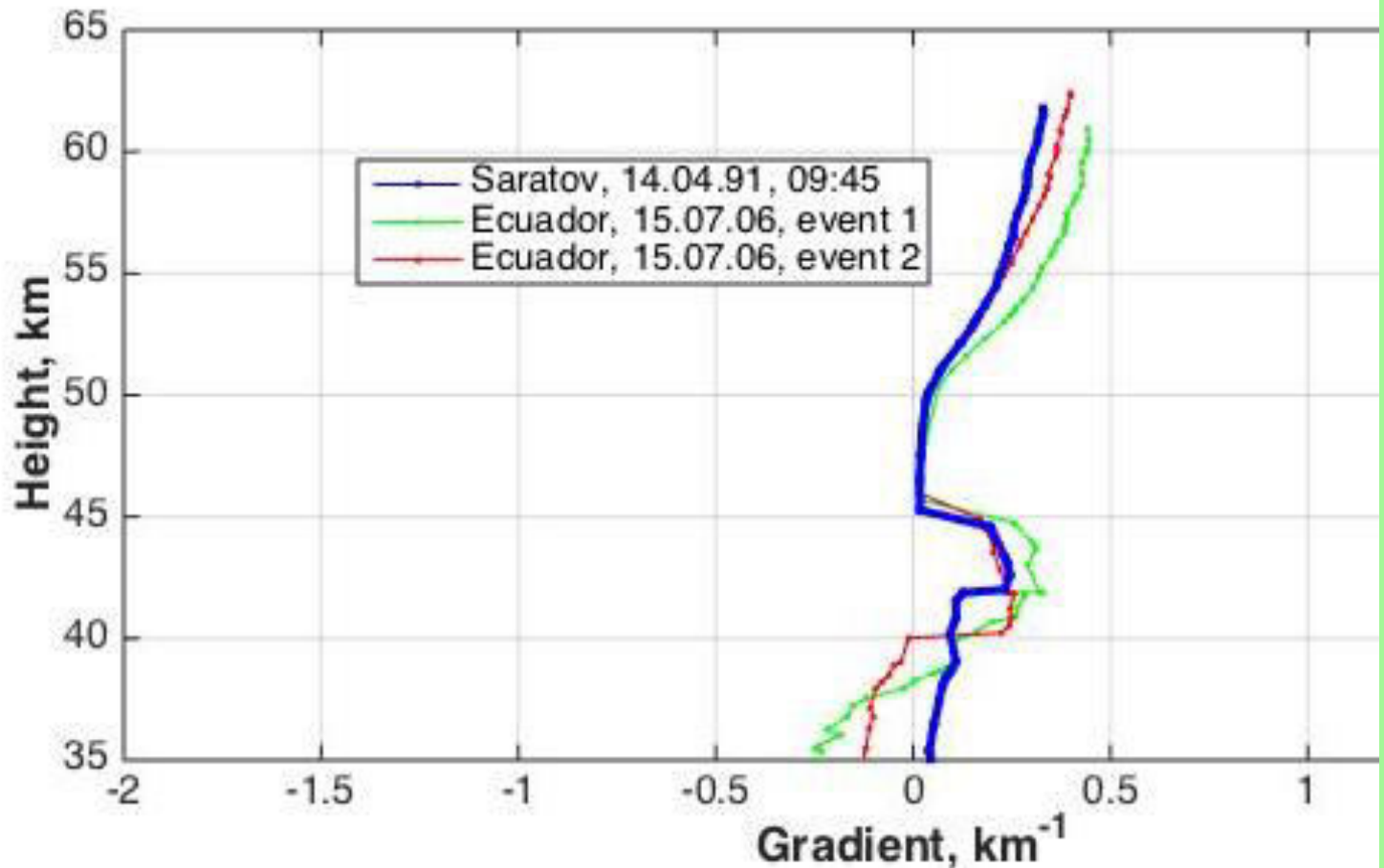
explosions



volcano



# Vertical gradients ( $q$ ) (obtained for Ecuador and Russia)



CTE O Snt 2017  $q \sim 0,31 \text{ km}^{-1}$  corresponds to  $\partial c_{\text{eff}} / \partial z \sim 50 \text{ m/s/km} !!!$

# Temporal Variations

The stability of infrasonic signals reflected from the layer of “wind corner” ( $H \sim 70$  km)

◆ EXPLOSIONS,  $E=20-70$  t tnt (Kulichkov, et al, 2002)- left

◆ VOLCANO, EQUADOR

(Assink et al, JGR VOL. 117, 2012; Assink et al, JGR under review 2013) - right

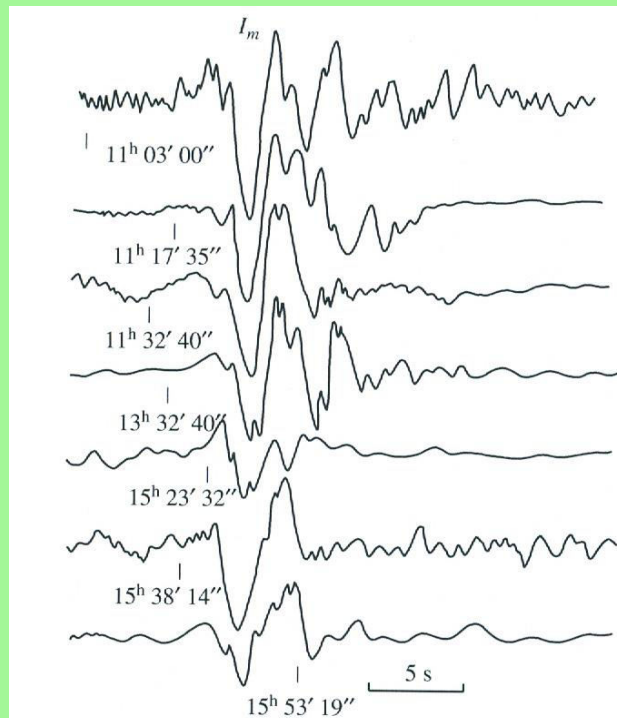
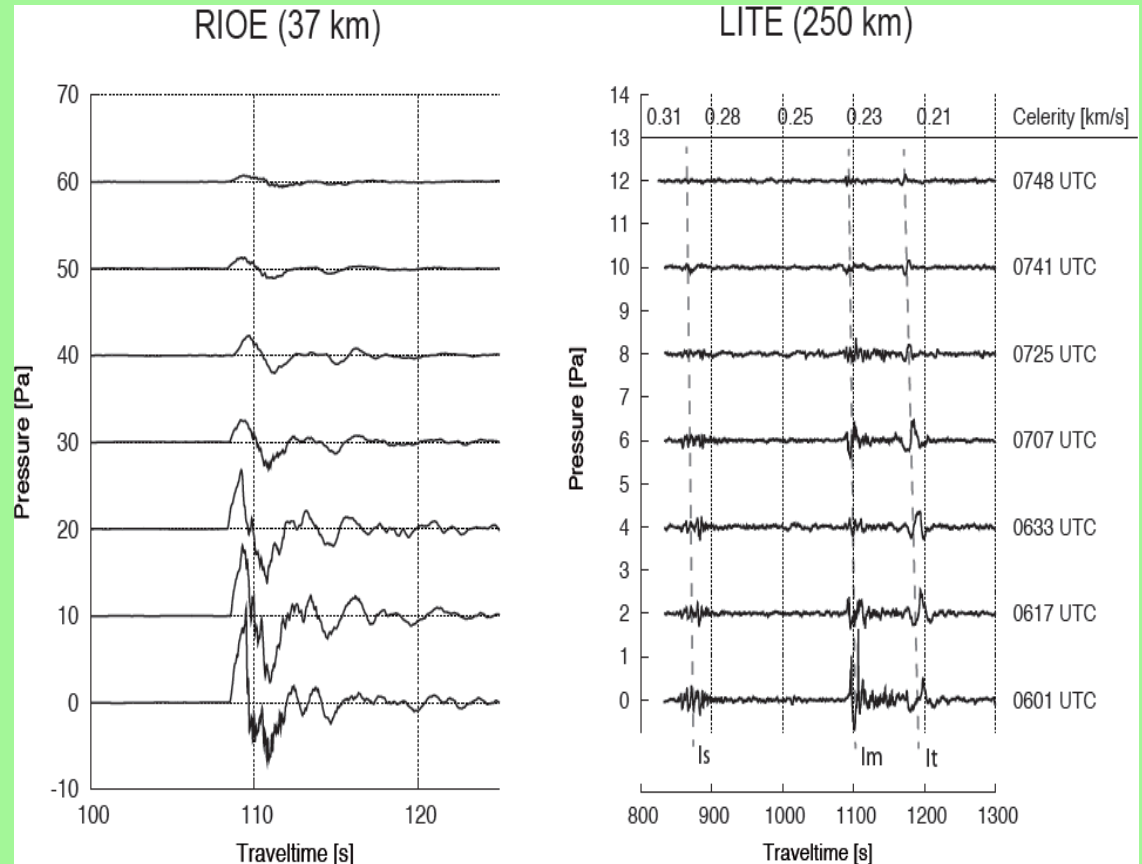


Fig. 5. Localized (pulsed  $I_m$ ) infrasonic signals recorded in the geometric shadow zone at a distance of 300 km from the explosions equivalent to 20–70 t of TNT implemented on October 20, 1990.



# Temporal Variations

◆ wave form of infrasonic signal depends on “instant” profile (averaged + fine structure) of effective sound speed;

◆ “instant” profile of effective sound speed can vary significantly due to effects of internal gravity waves;

## QUESTION ?

◆ within what time “instant” profile of effective sound speed (averaged + fine structure) can be stable?

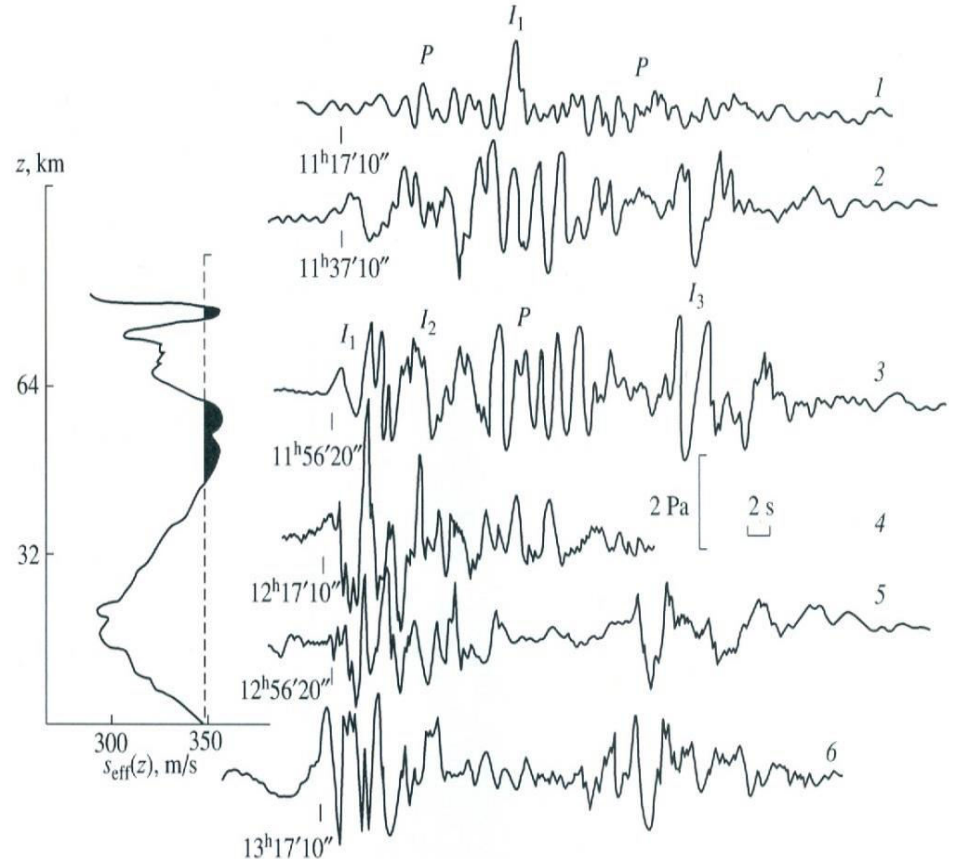


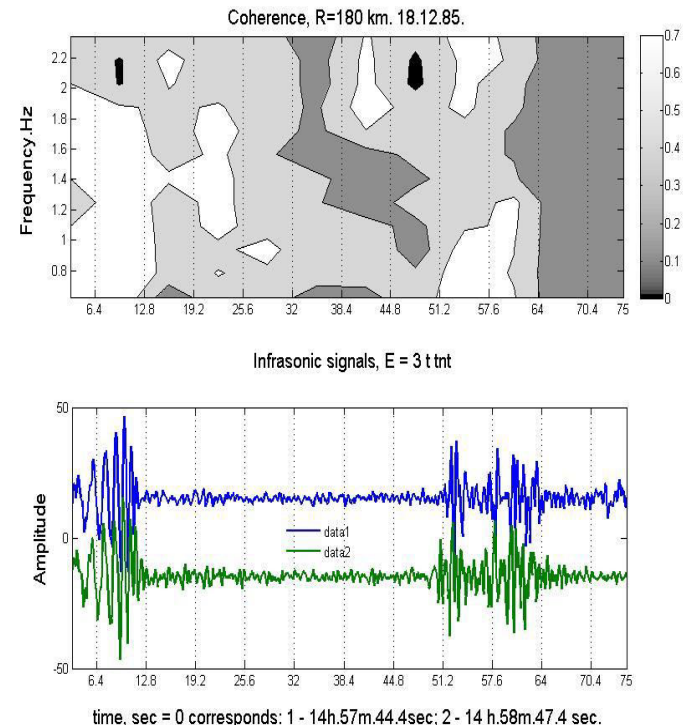
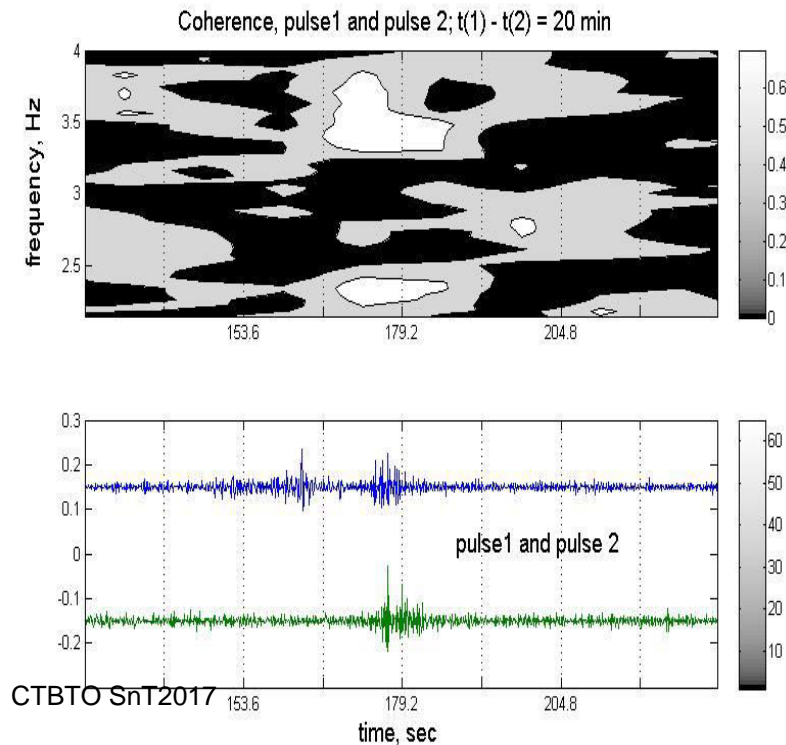
Fig. 3. Records of infrasonic arrivals in the zone of refractive acoustic audibility at a distance of 300 km from six explosions (1–6) equivalent to 20–70 t of TNT implemented at a 20-minute interval during daylight hours on July 7, 1990 (on the right). Profile of the effective acoustic speed  $s_{\text{eff}}(z)$  (on the left; the region of ray turning is shaded).

# Temporal Variations

Stability of infrasound signals scattered on the fine structure of the atmosphere for explosions of different yields

◆ explosions; E= 20 kg tnt;  $\Delta T = 20$  min.; R = 340 km - left

◆ explosions; E = 3 t tnt;  $\Delta T = 1$ min.; R= 180 km - right

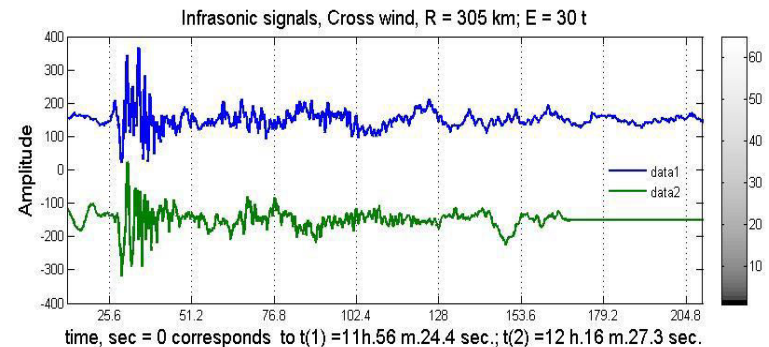
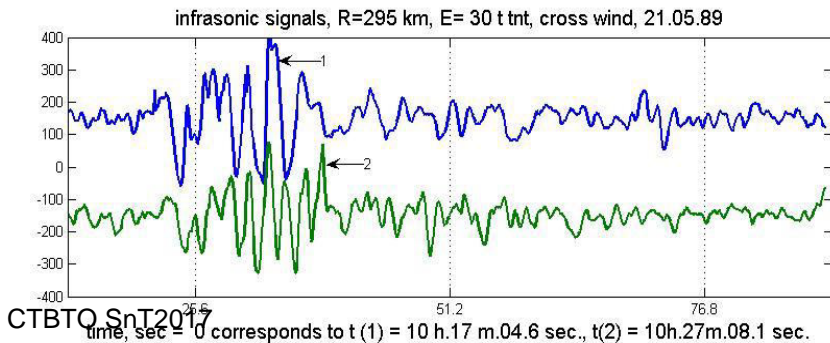
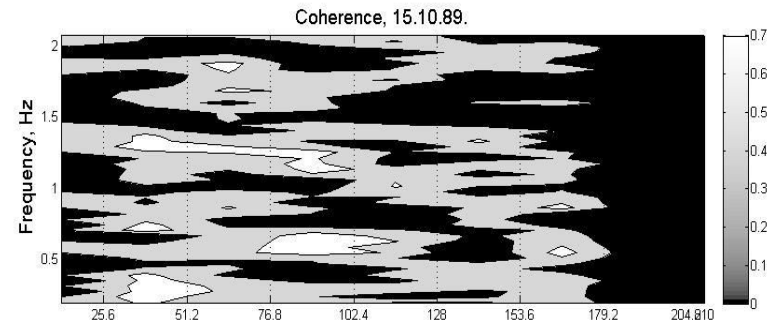
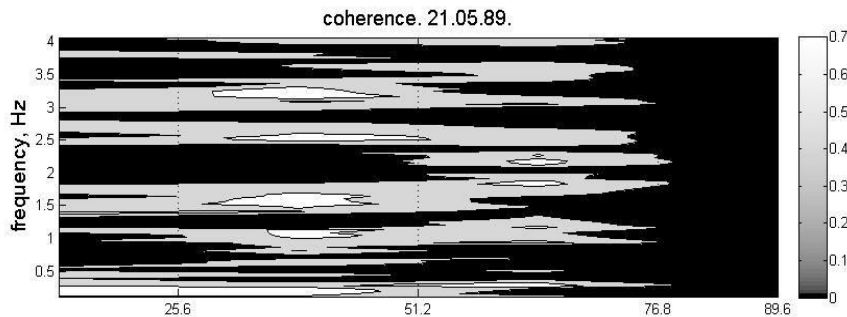


# Temporal Variations

Stability of infrasound signals scattered on the fine structure of the atmosphere for explosions of different yields

◆ explosions; E= 30 t tnt;  $\Delta T = 20$  min.; R = 295 km - left

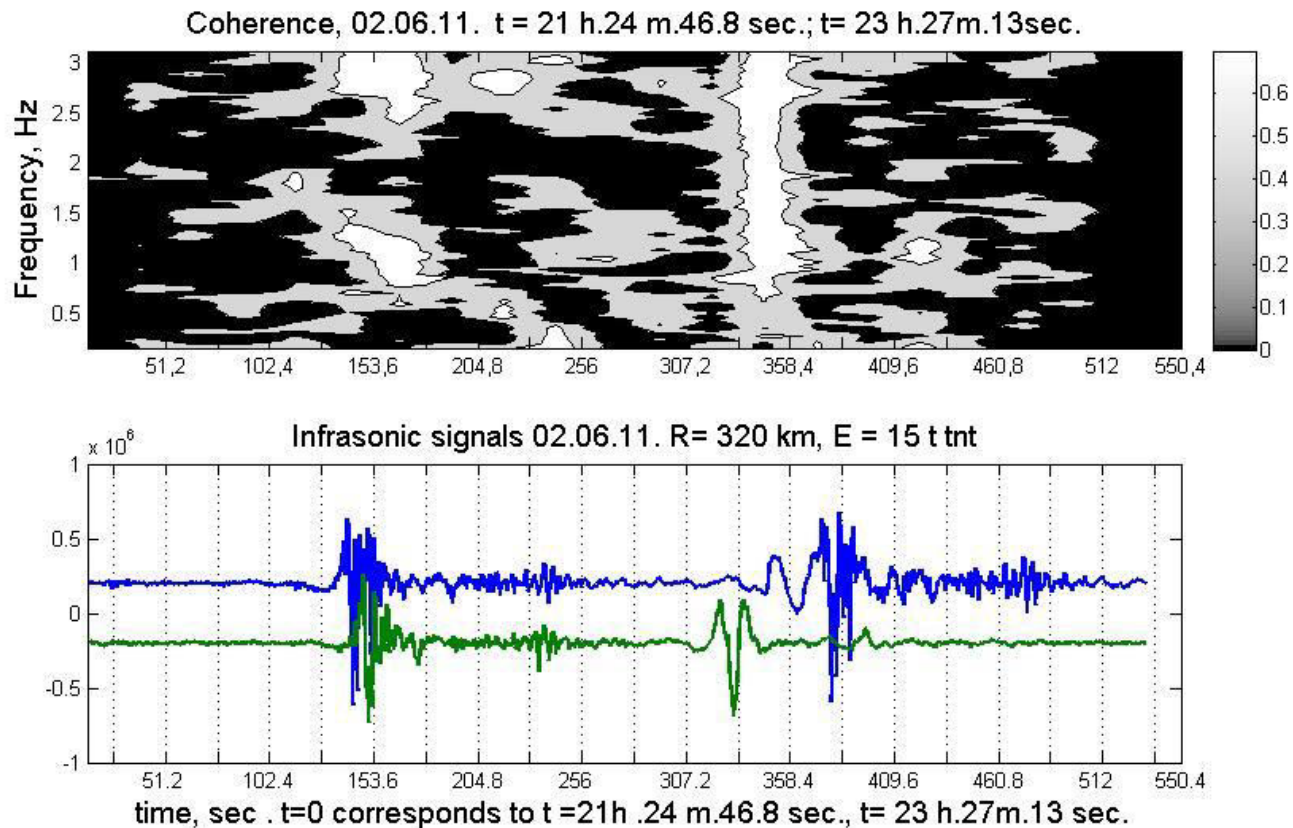
◆ explosions; E = 30 t tnt;  $\Delta T = 20$  min.; R= 305 km - right



# Temporal Variations

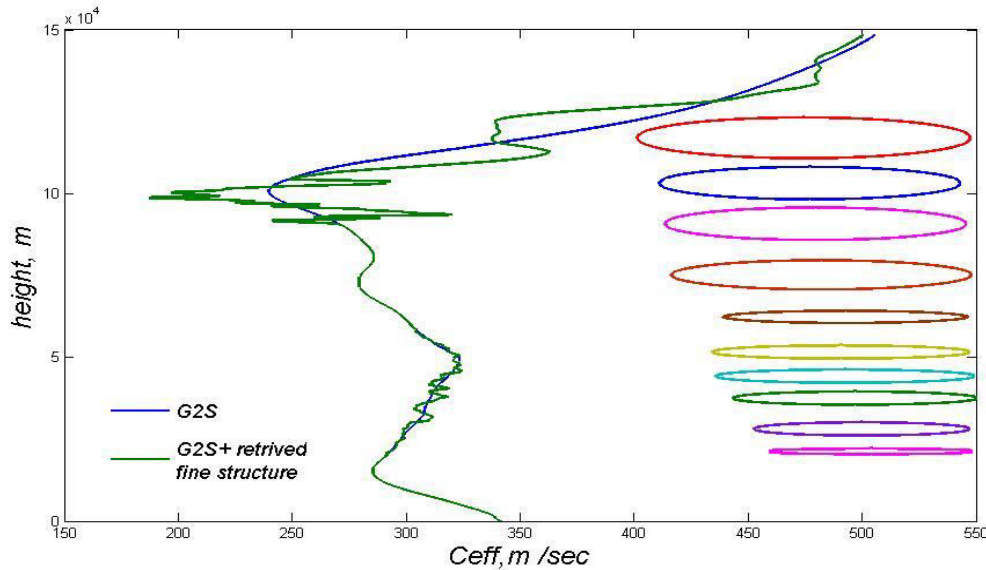
Stability of infrasound signals scattered on the fine structure of the atmosphere for

◆ explosions;  $E = 15 \text{ t tnt}$ ;  $\Delta T = 2 \text{ h } 3 \text{ min.}$ ;  $R = 320 \text{ km}$

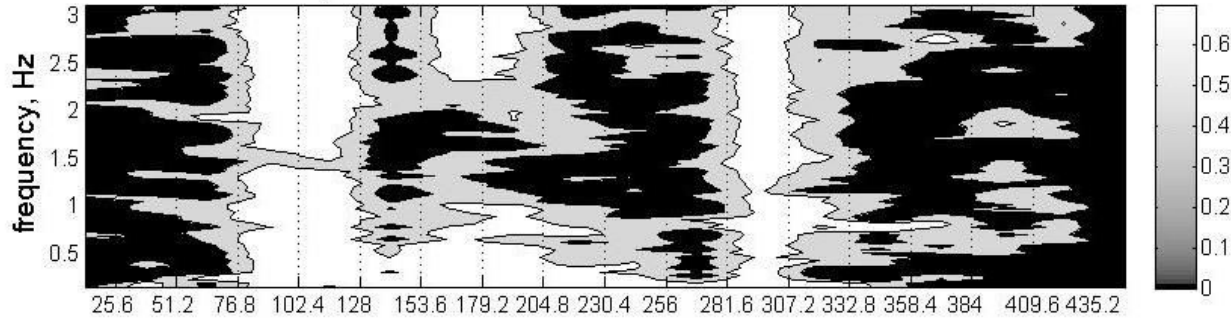


# DISCUSSION

- ◆ fine layered structure of the atmosphere
- ◆ cross-coherence between successive signals (4-min time interval between signals)
- ◆ stability of the fine layered structure in the middle atmosphere:



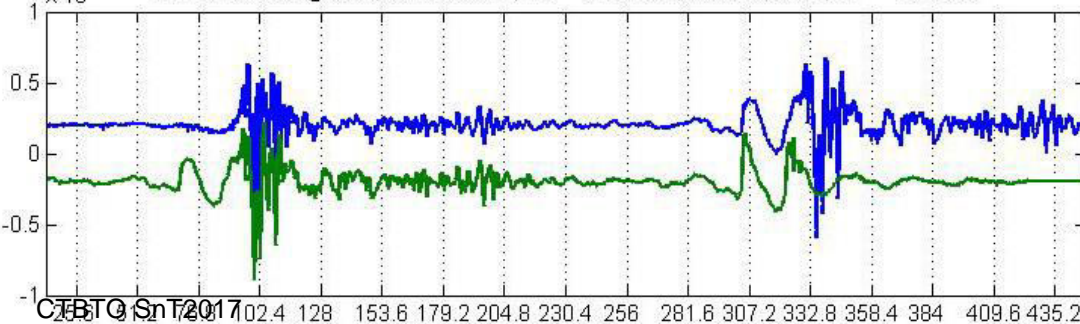
Coherence, 02.06.11. t = 21h.25m.30sec., t = 21 h.29 m.25.4sec.



■ *in general;*

■ *“instant “parameters;*

Infrasonic signals, 02.06.11.; R = 320 km; down wind; E ~ 15 t tnt



time, sec., t=0 corresponds to t= 21 h.25 m.30sec., and t = 21 h.29 m.25.4 sec.

# CONCLUSIONS

- ◆ **A**coustic method is an effective tool for probing atmosphere.
- ◆ **R**enaissance in the acoustic sounding method of the middle atmosphere (20...130 km).  
*averaged profiles (daily; seasonal, etc. variations; climate change)*
- ◆ **T**he methodological grounds for probing of a fine layered structure of the atmosphere by using infrasound from explosions are developed.
- ◆ **F**ine structure ( $\Delta h \sim 10\text{m} \dots 10\text{km}$ ;  $\Delta \ell = n \times \Delta h$ ;  $n \sim 10-100$ ) of the atmosphere can keep its stability *in general and in detail within time intervals* not less than **4 min** and for the horizontal scales not less than 300 km.
- ◆ The middle atmosphere may be **COHERENT** structure in the **range of vertical scales 20...130 km.**

# THANK YOU FOR ATTENTION

