Remarks on the gravity-acoustic waves observed during thunderstorms

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Brunt-Väisälä or buoyancy oscillations

Dispersion relation for gravity acoustic waves

$$(\omega^2 - \omega_a^2) + \left(\frac{\omega_g^2}{\omega^2} - 1\right) k_s^2 c_s^2 - k_z^2 c_s^2 = 0$$

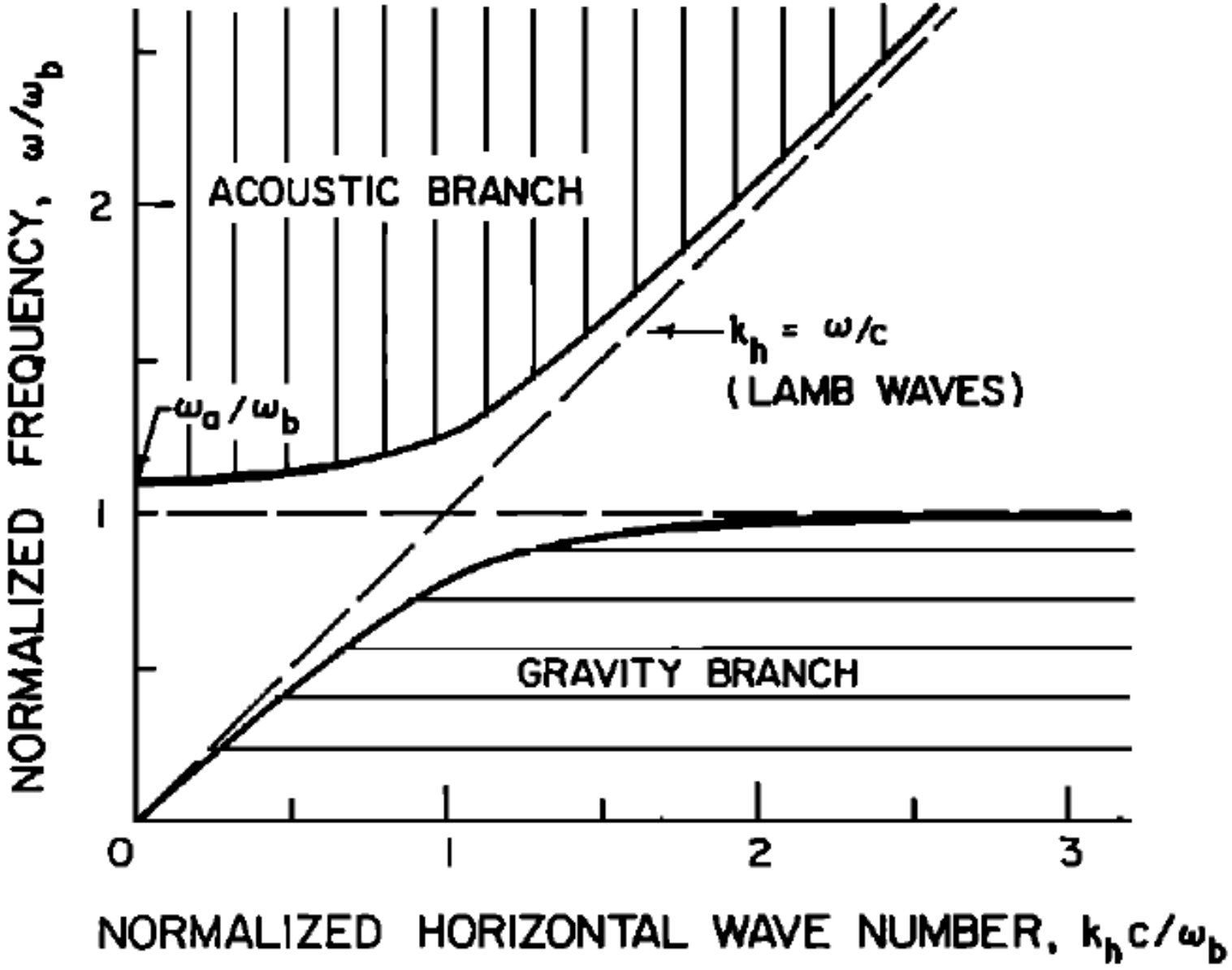
where

$$\omega_g = (\gamma - 1)^{1/2} \frac{g}{c_s}$$

is buoyancy frequency

$$\omega_a = \frac{\gamma}{2} \cdot \frac{g}{c_s}$$

and cut frequency of acoustic waves


NORMALIZED FREQUENCY, ω/ω_b
2
1
ACOUSTIC BRANCH
$k_h = \omega/c$
(LAMB WAVES)
ω_a/ω_b
GRAVITY BRANCH
0
1
2
3
NORMALIZED HORIZONTAL WAVE NUMBER, $k_h c/\omega_b$

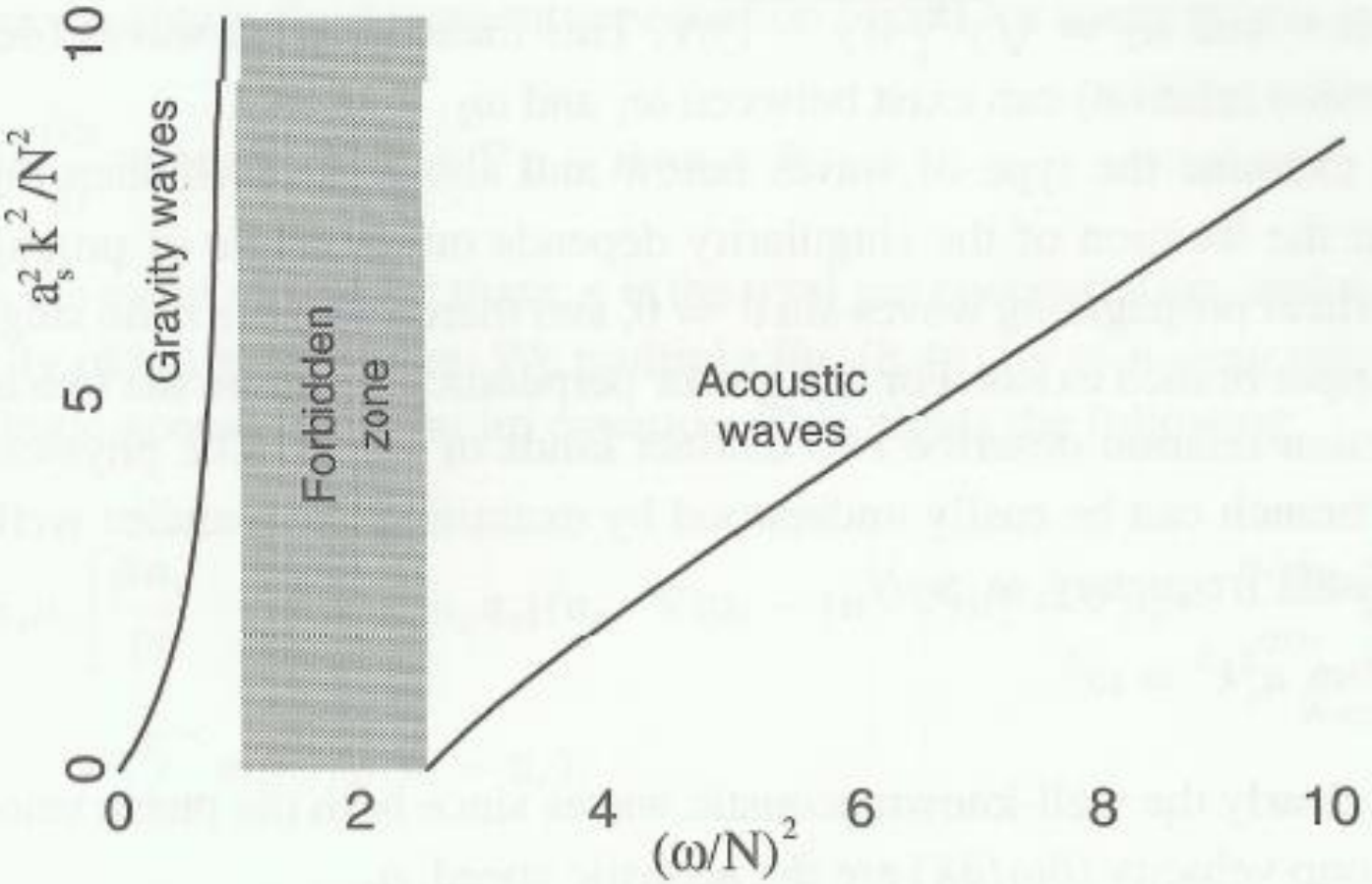
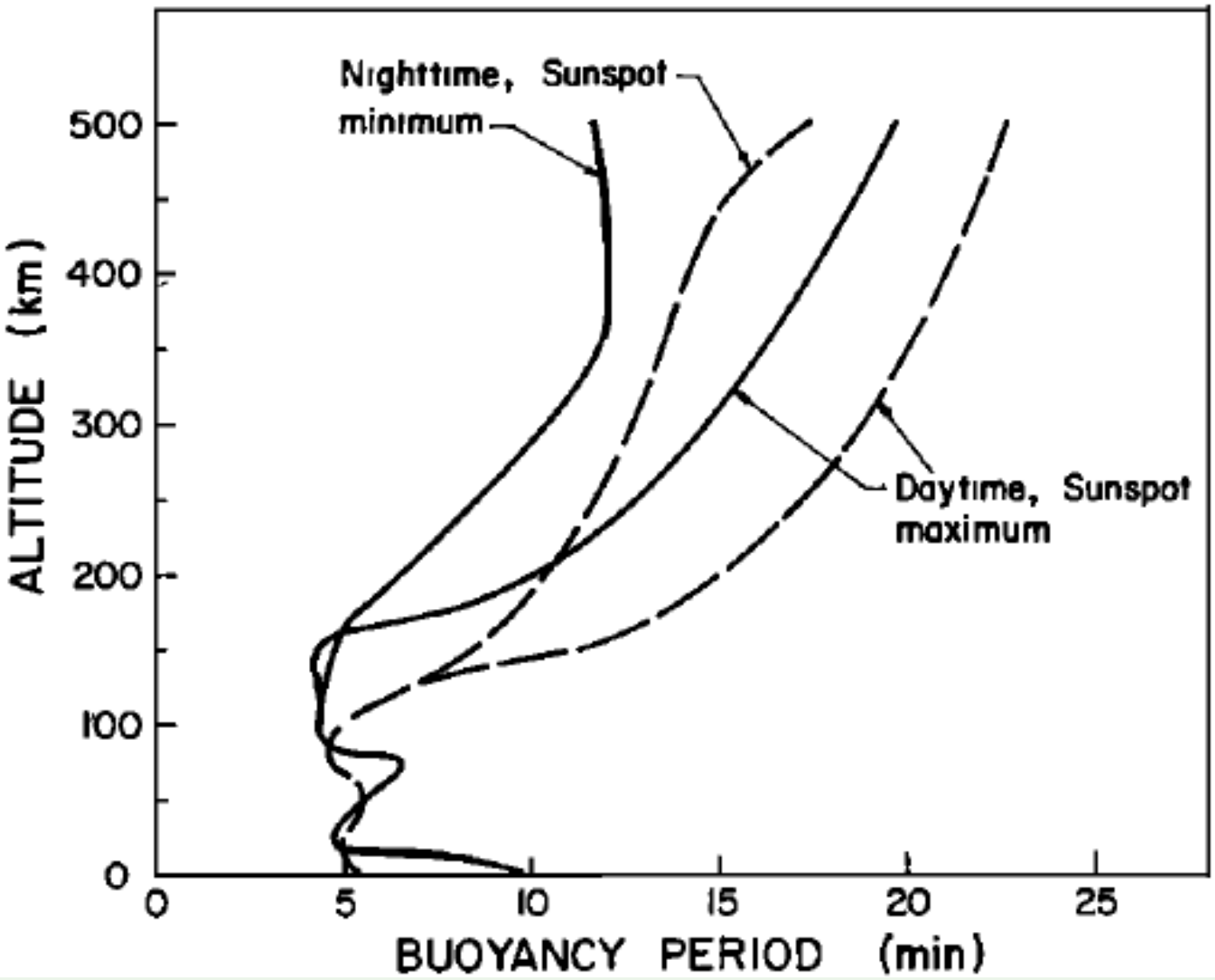


Figure 8.2 Plot of dispersion relation (8.42) for perpendicular propagation ($\vartheta = \pi/2$ and $\gamma = 5/3$).

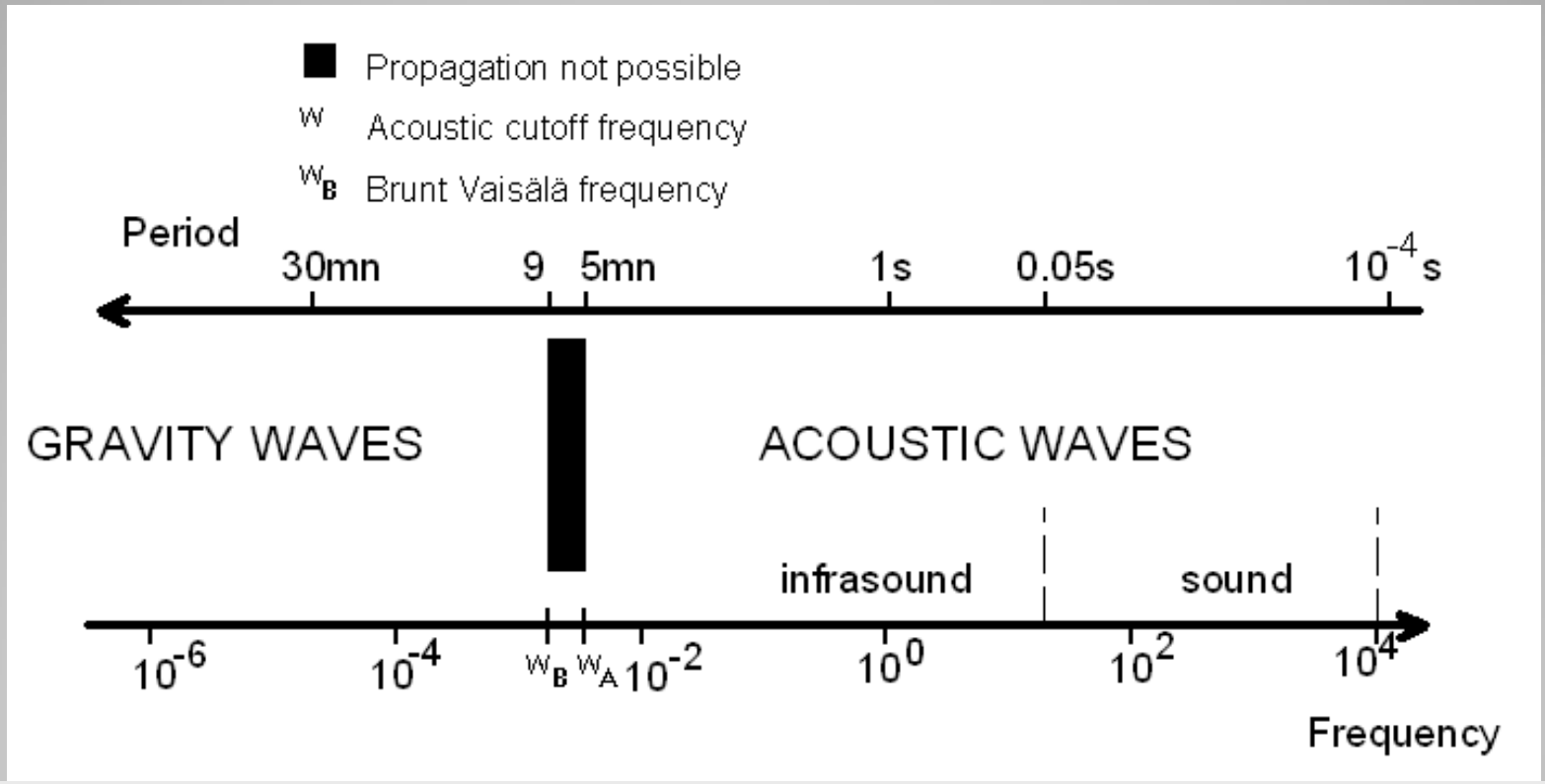


a nonisothermal atmosphere (solid lines), an isothermal atmosphere (dashed lines)

Progress Meeting Swarm4anomaly, 26.06.2019, Warszawa

Atmospheric waves related to thunderstorms

The waves can be generated : sound waves - infrasound - gravity waves



Gravity waves : Frequencies ***less*** than the Brunt-Vaisala frequency ⇨ periods ~ 5 min ~ several hours

Atmospheric waves from thunderstorms Observations at ground

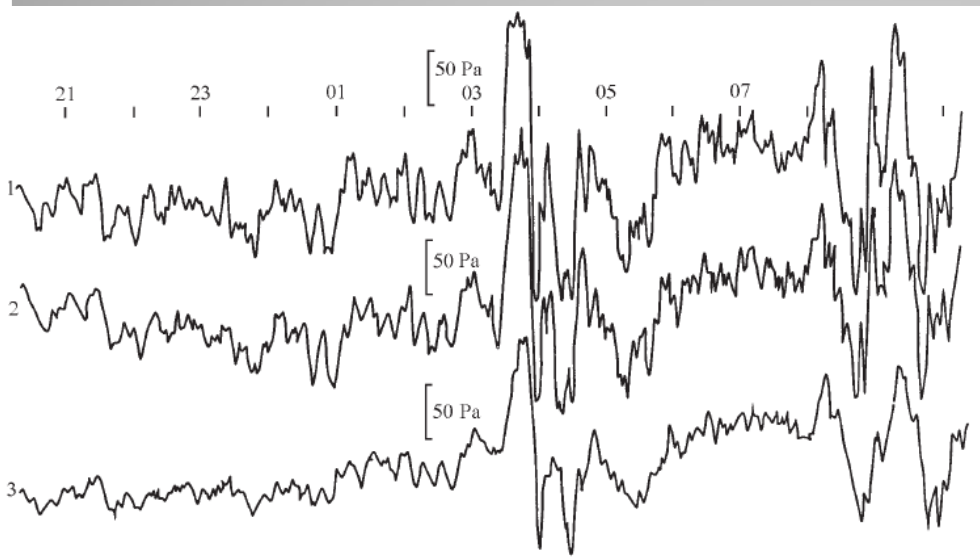
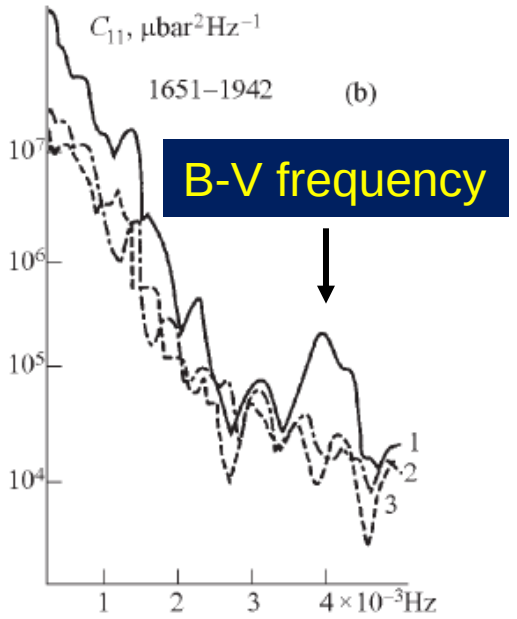


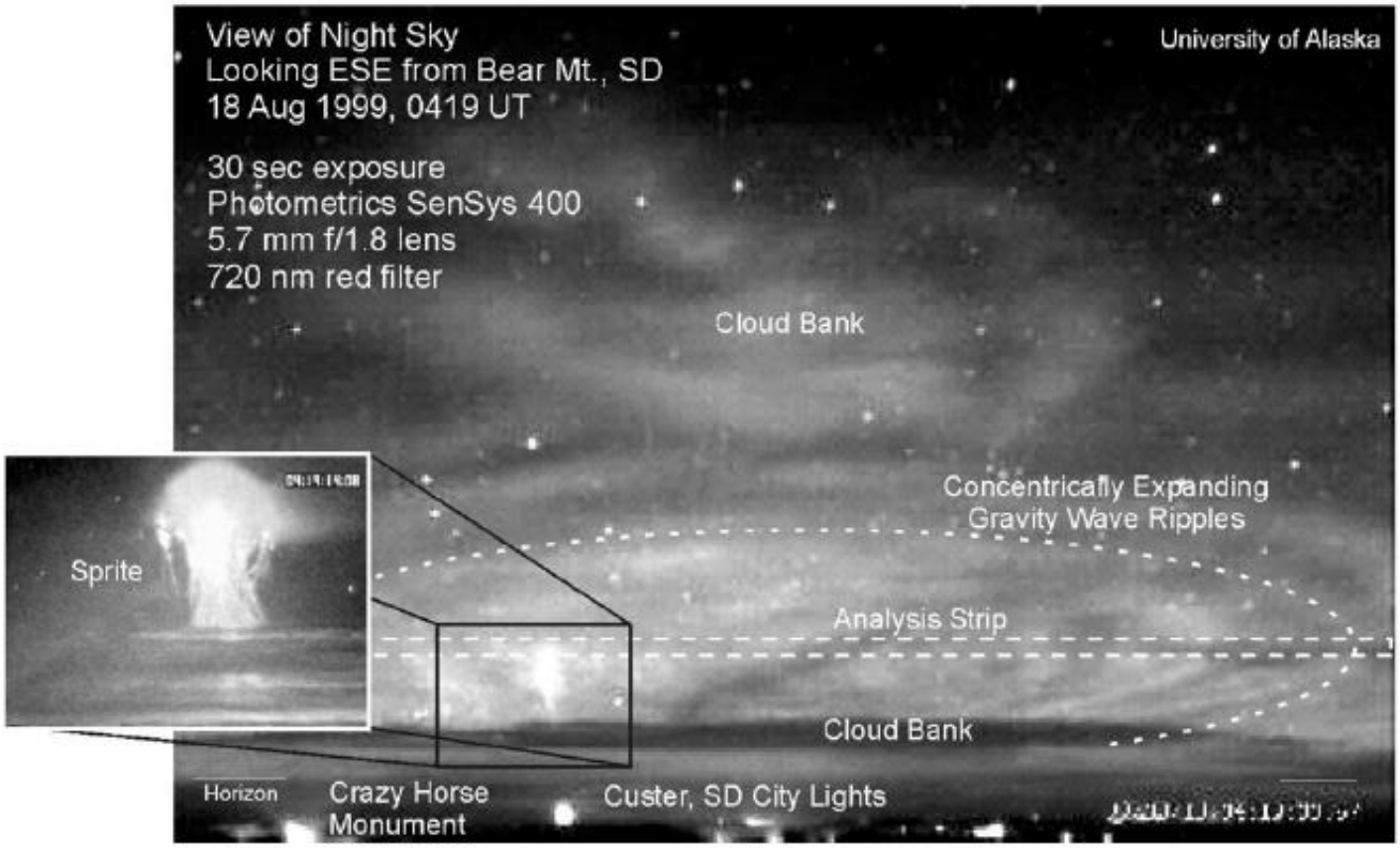
Figure 1. Pressure realizations from 2030 on August 7, 1991, to 1030 on August 8, 1991 (Moscow time), at sites (1) Sharapovo, (2) Pokrovskoe, and (3) Zvenigorod Scientific Station.



- Quasi-monochromatic waves at the local Brunt Väisälä frequency
- Propagation over hundreds of km

Curry Murty 1974, Grachev et al., 1995

Gravity waves produced by thunderstorms
Mesospheric observations



- Gravity wave period of 10-11 min and wavelength 50-40 km.
- The gravity wave could be caused by quasi-periodic ringing at the tropopause due to pumping by the buoyant air column in the convective cell below.

Gravity wave from thunderstorms in the upper atmosphere and ionosphere

- Penetration of gravity waves up to altitudes higher than 150 km
- When the clouds developed sufficiently in the vertical direction to reach the height of the tropopause, gravity-wave oscillations in the vertical velocity above the tropopause would develop.

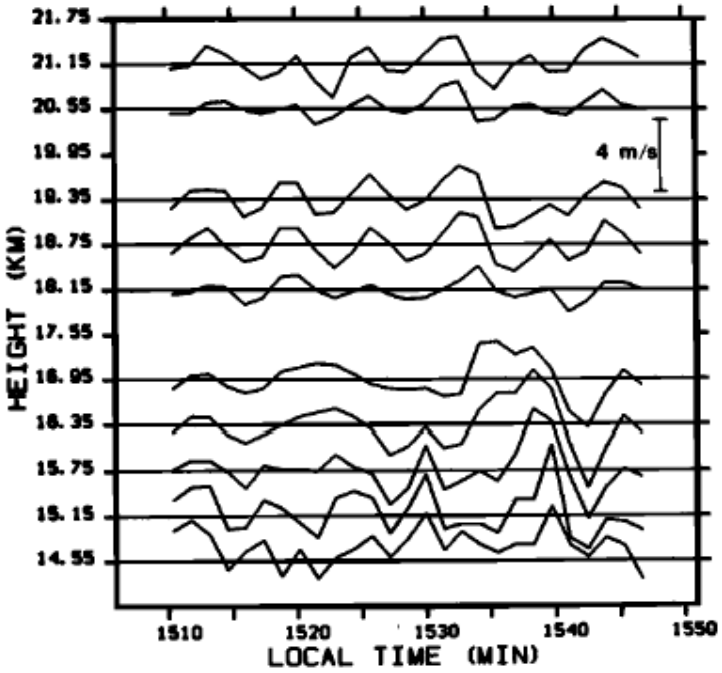
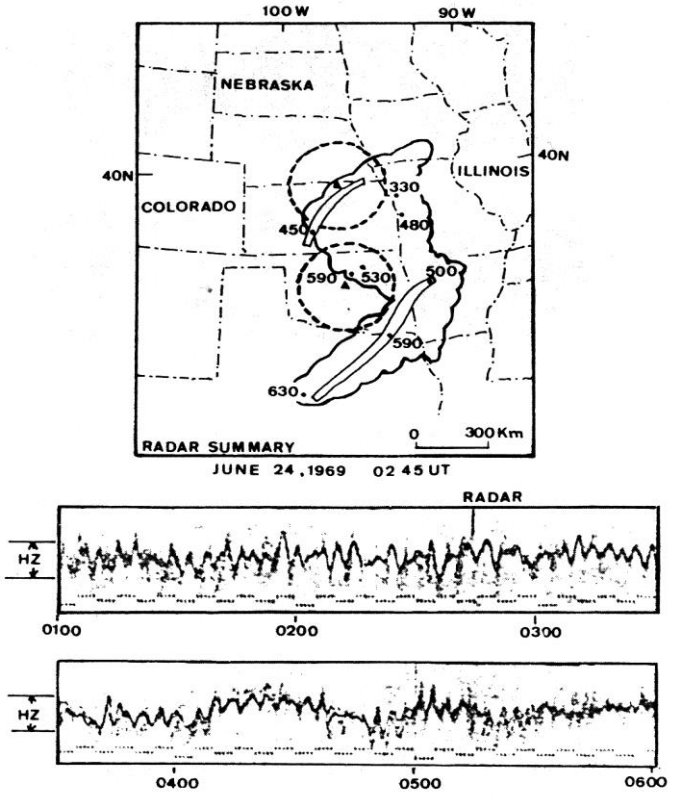


Figure 3. Vertical velocities as a function of time at ten heights. The vertical bar at right shows the reference velocity scale.

Larsen et al. 1982



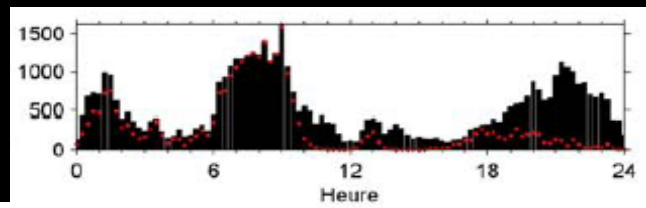
Davies et al. 1977

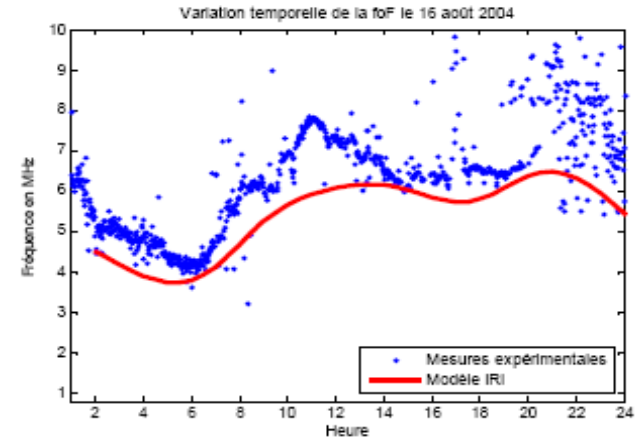
Gravity waves in the ionosphere 08/16/2004

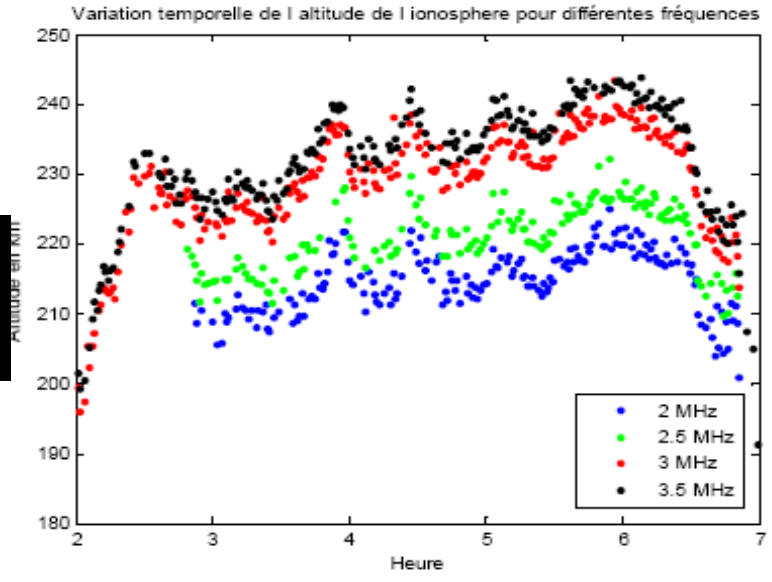
Increase of the critical frequency of the F2 region when the number of lightning flashes increases

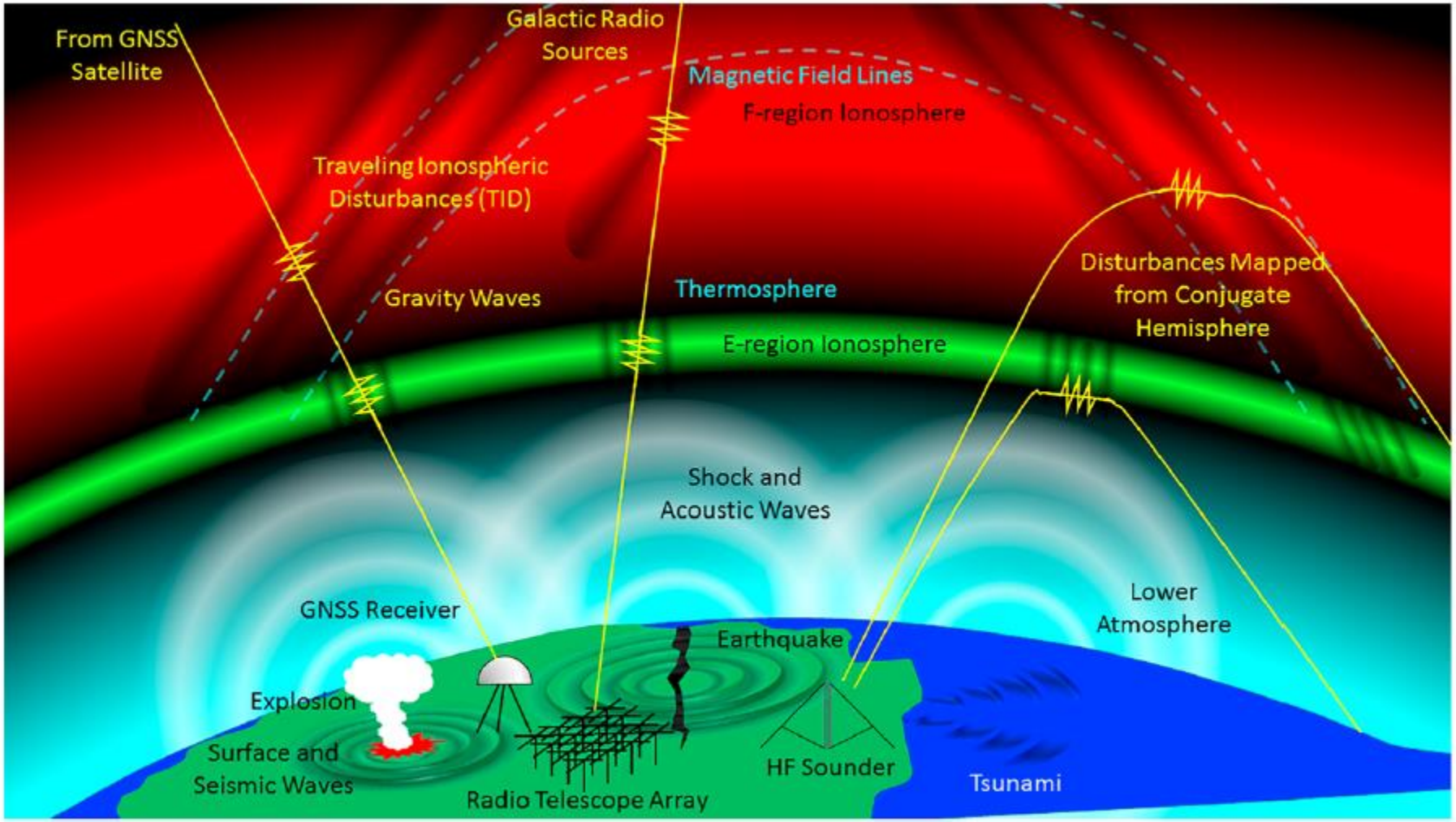
Gravity waves with periods of about 30 min at altitudes in the range 210-240 km

Bouchelit , 2007



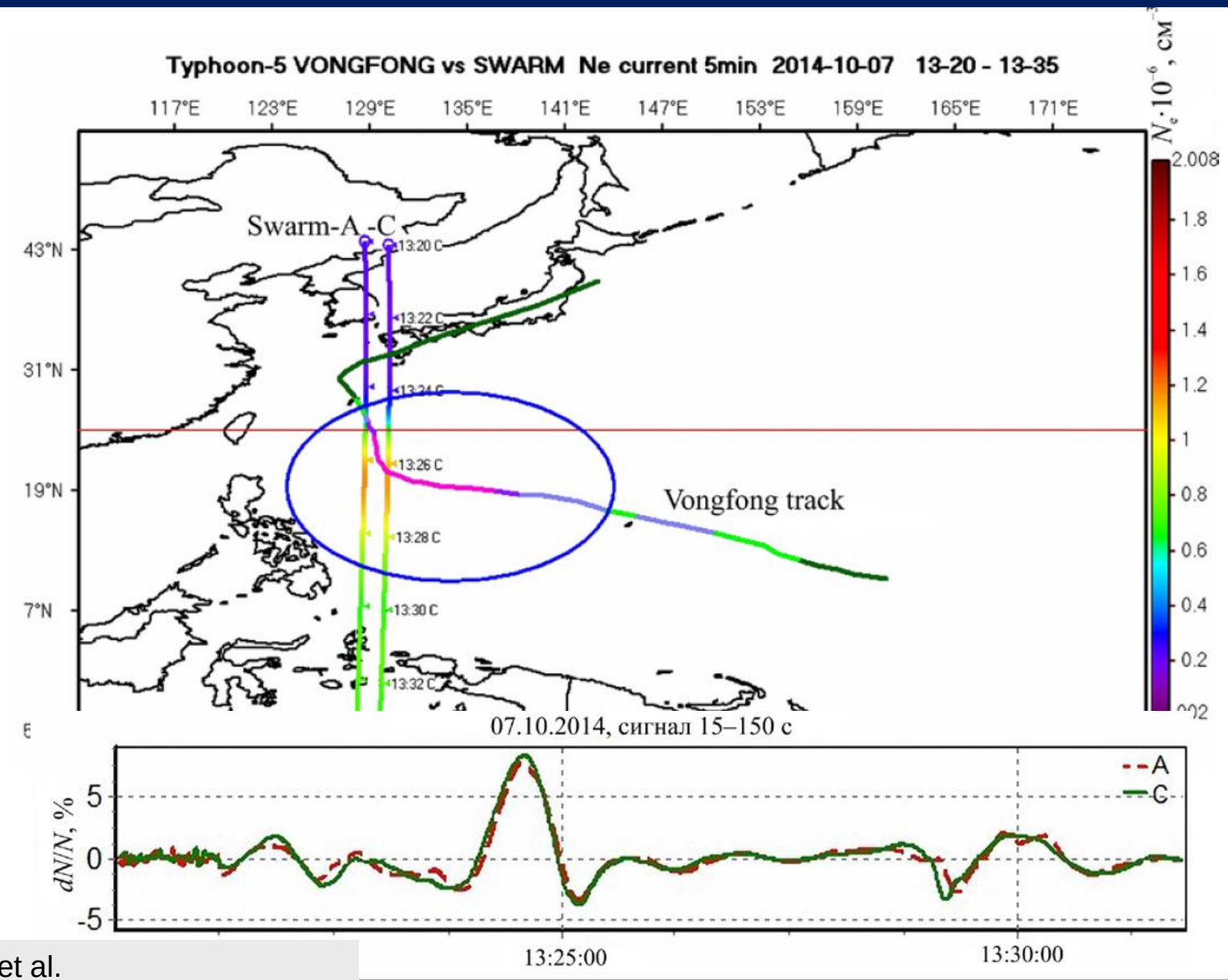






HUANG ET AL.
Reviews of Geophysics,2017

IMPACT OF TyPHOON VONGFONG 2014 ON THE IONOSPHERE WAVE DISTURBANCES OF IONOSPHERIC PLASMA



Zakharov et al.
Solar-Terrestrial Physics. May 2019.

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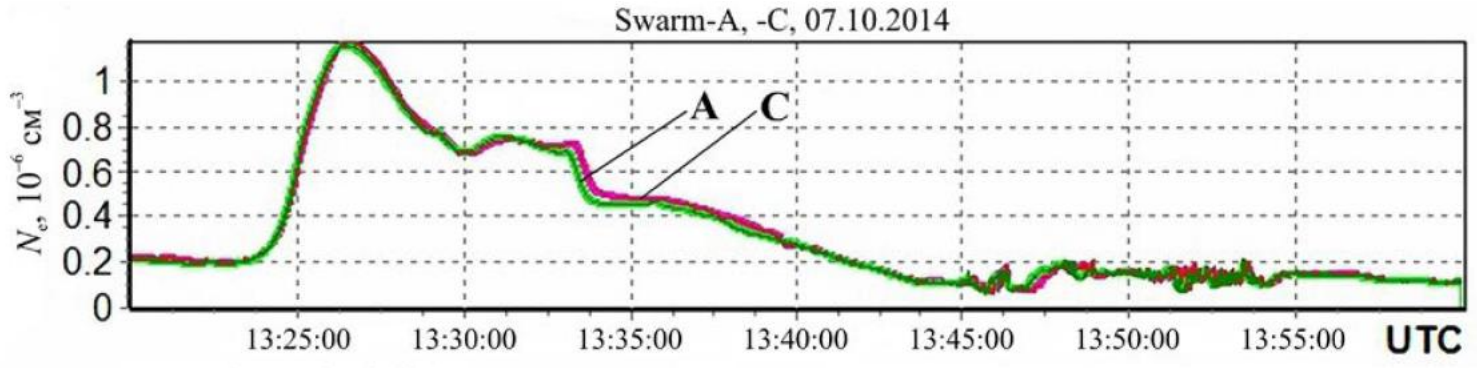

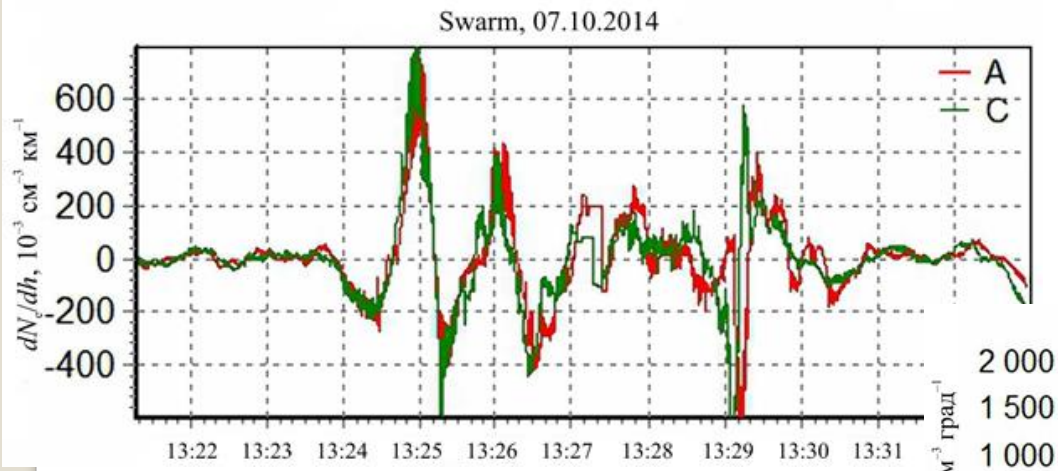

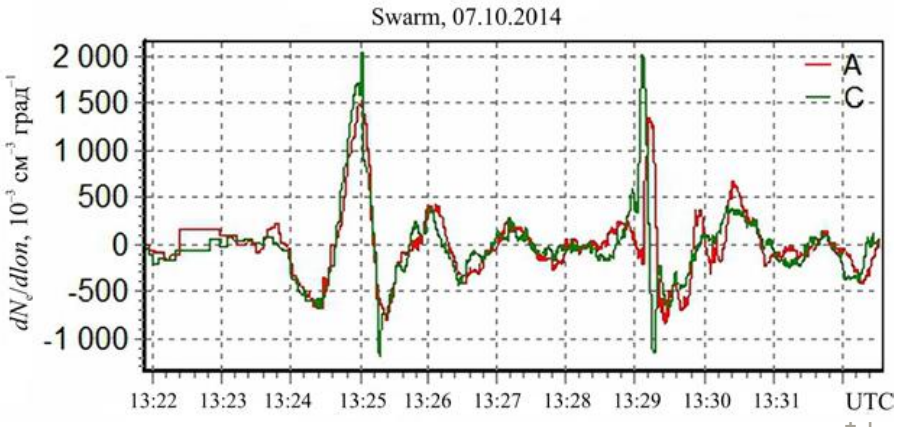

Zakharov et al.
Solar-Terrestrial Physics. 2019.

Conclusions and discussion

Gravity waves have been registered in the neutral atmosphere as well as in the ionosphere.

Origin of them can be very different, but common feature is the impulsive character of them.

The registrations have been done with ground based and satellite techniques.

The waves associated with impulsive events have periods of several minutes, from 3 to 30 in published case studies.

Group velocity from around 50 m/s through 300 up to 1000 m/s .

Main problem of the correlation of the events with satellite registrations is time delay, which can be even up to tens of minutes.