# Structures of High- and Midlatitude Ionosphere in 23rd and 24th Solar Cycles: Results from Radio Tomography

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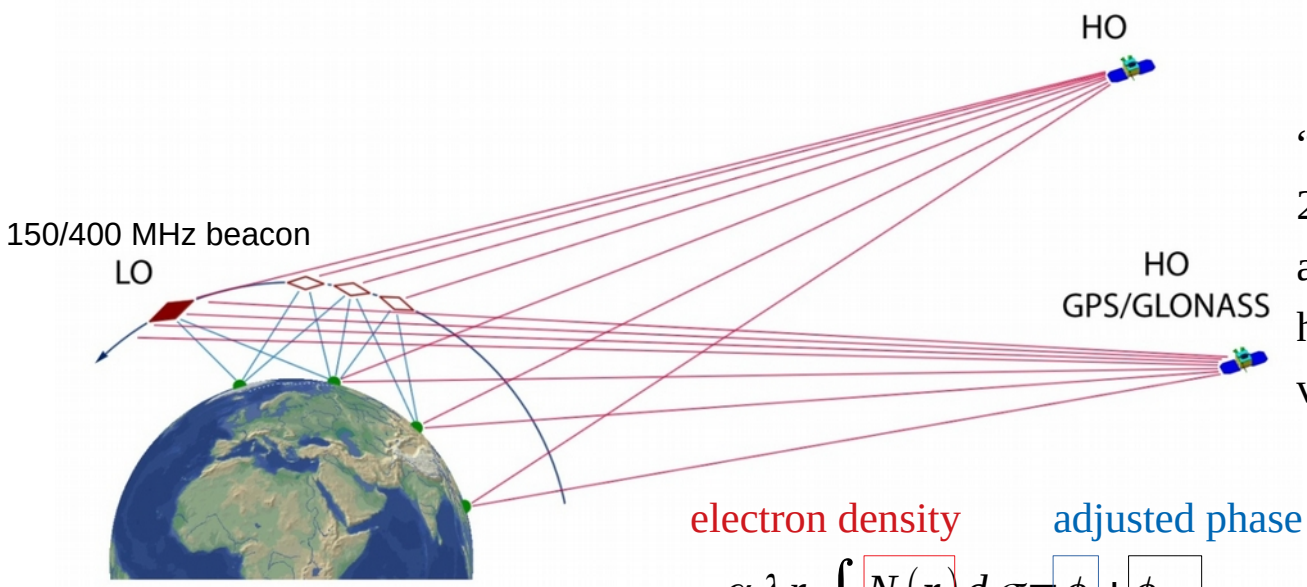
*URSI GASS, 2020*

# Low Orbital Radiotomography of Ionosphere




"instantaneous" (~5-10 minutes) 2D RT images of the ionosphere above the receiving chains
horizontal resolution **20-30 km**
vertical resolution **30-40 km**

electron density adjusted phase

$$\alpha \lambda r_e \int_{l_j} N(\mathbf{r})\, d\sigma = \phi_j + \phi_{0j}$$

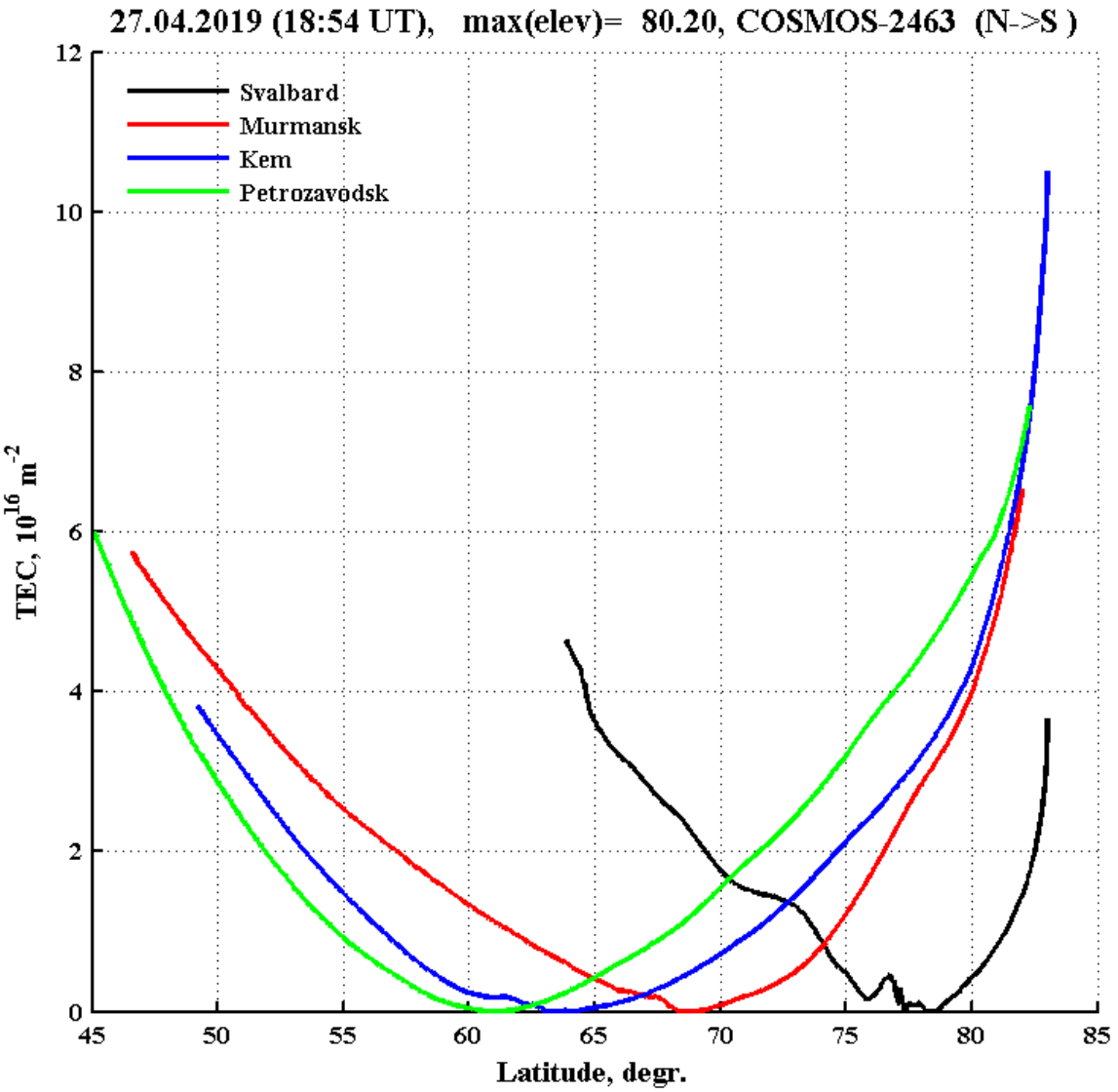
unknown initial phase

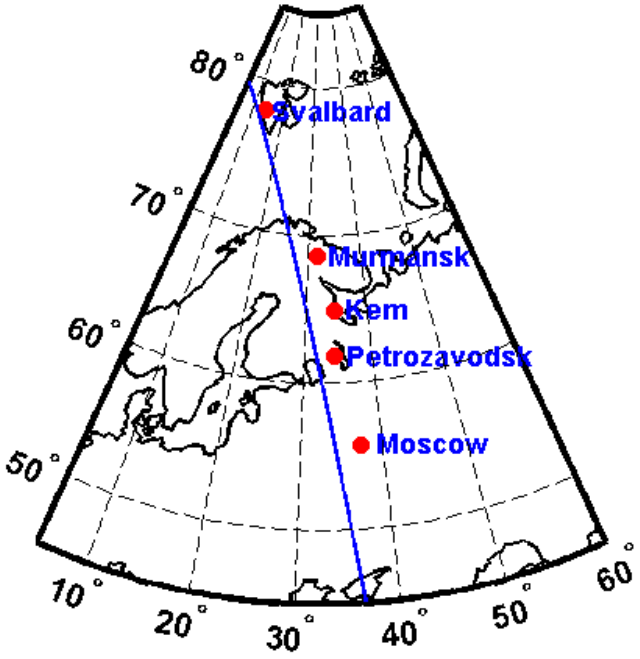
Approach to solution

- Discretization of the problem with expansion over system of basis functions
- Phase-difference approach to exclude unknown initial phase
- Iterative solvers (ART, DART, SIRT) for ill-posed SLE

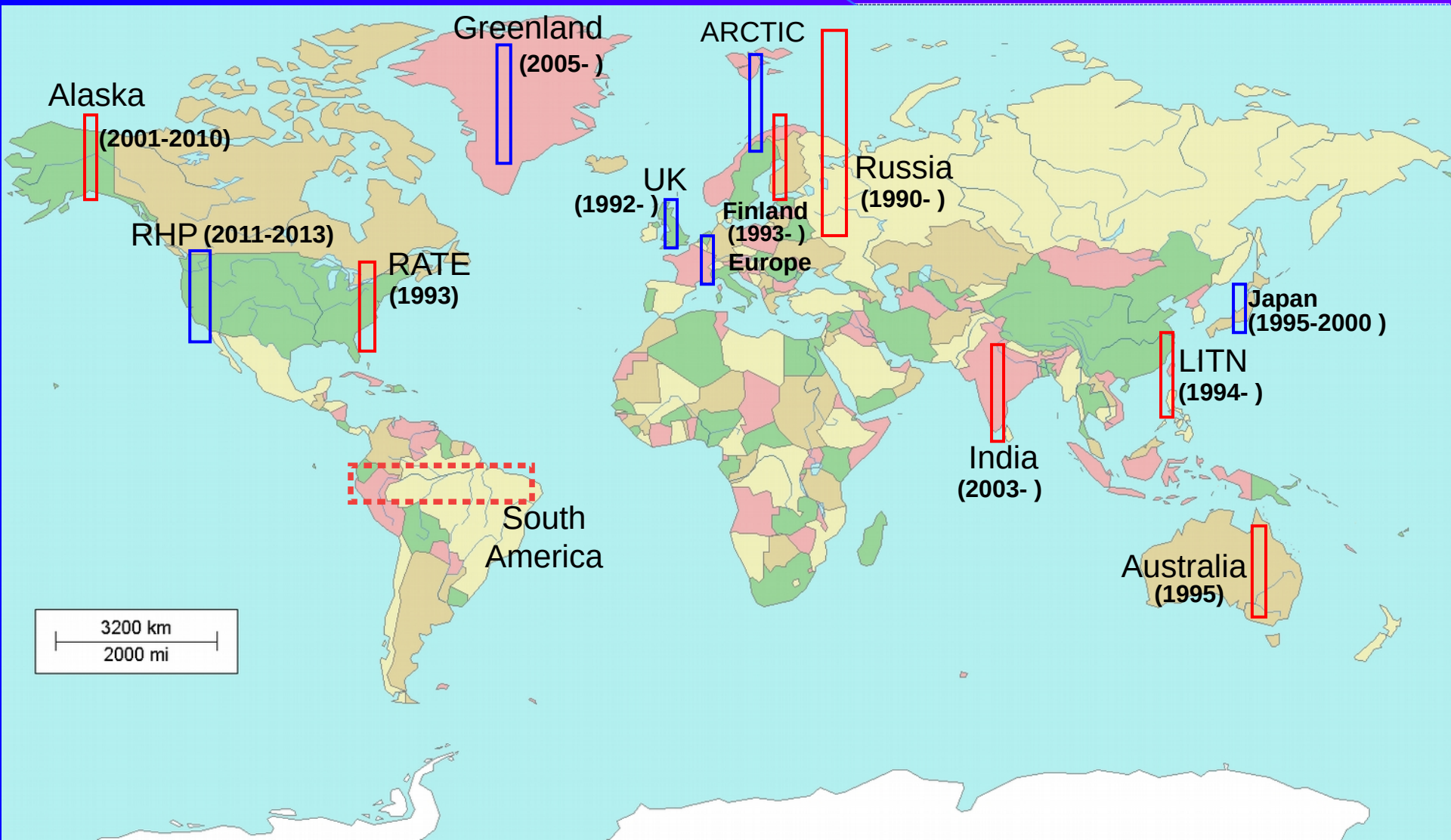
see [Kunitsyn&Tereshchenko, Ionospheric Tomography, Springer 2003]

# Low Orbital Radiotomography: Example of experimental raw data from Moscow – Karjala – Kola Peninsula – Svalbard receivers

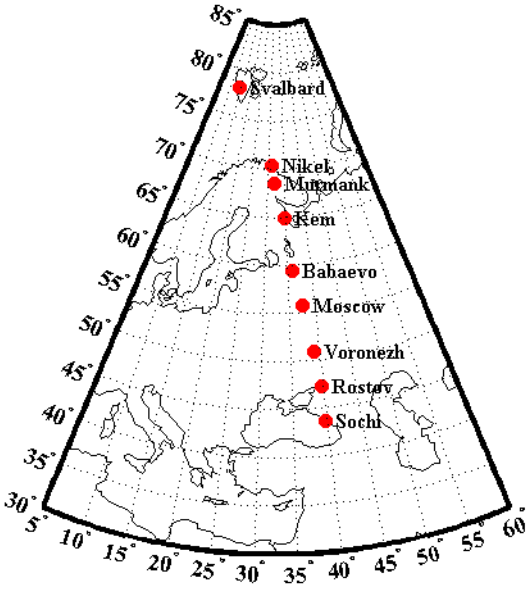


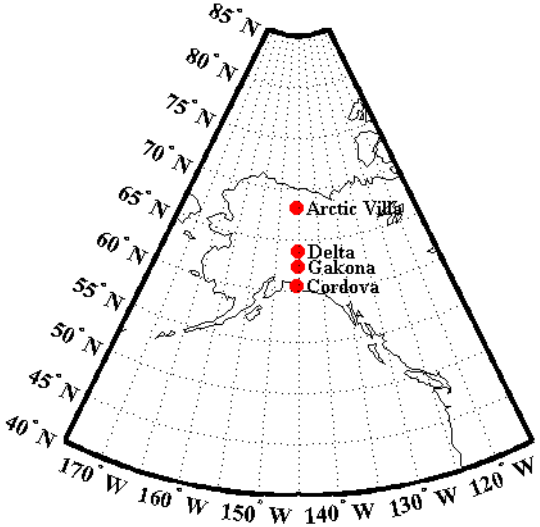
# LORT Systems (legacy)



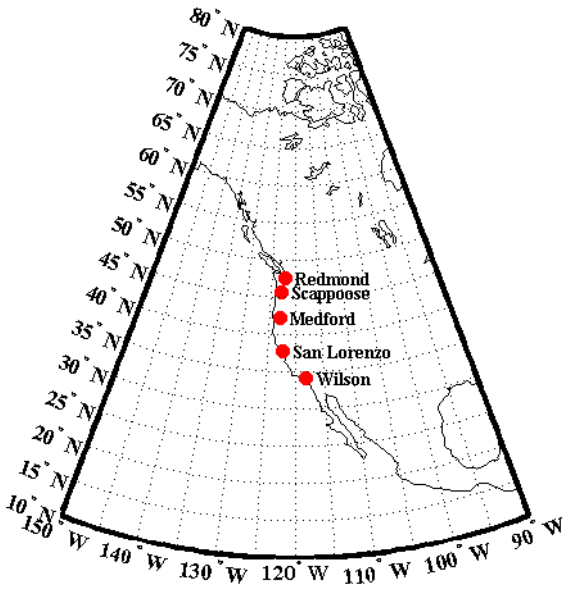
# LORT Systems considered in current work




North-West Russia




Alaska



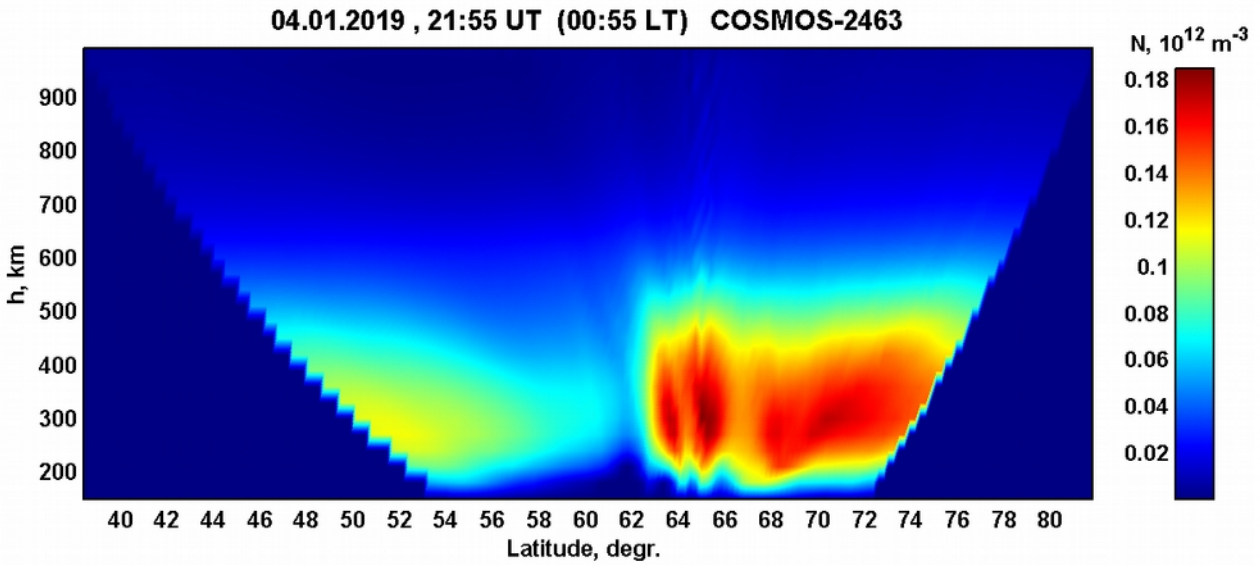

U.S. West Coast

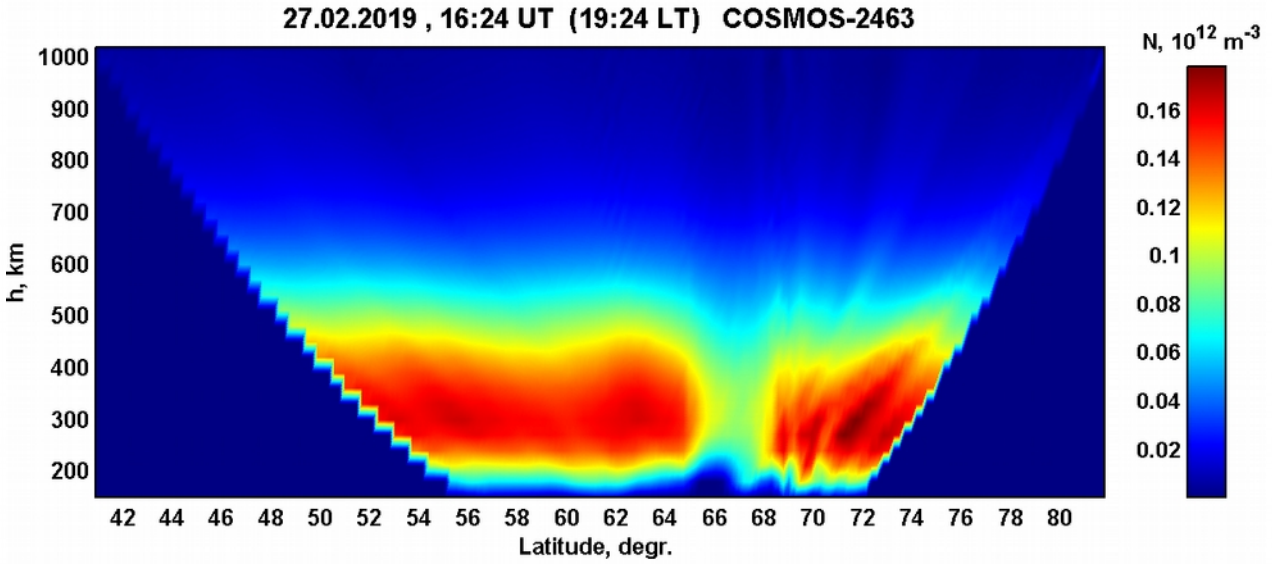
**Note rapid degradation of LO beacon satellites constellation**

**more than 10 satellites in early 2000s**

**very few possibilities nowadays (ePOP/Cassiope) especially at high latitudes**

# Examples of ionization troughs (North-West Russia)



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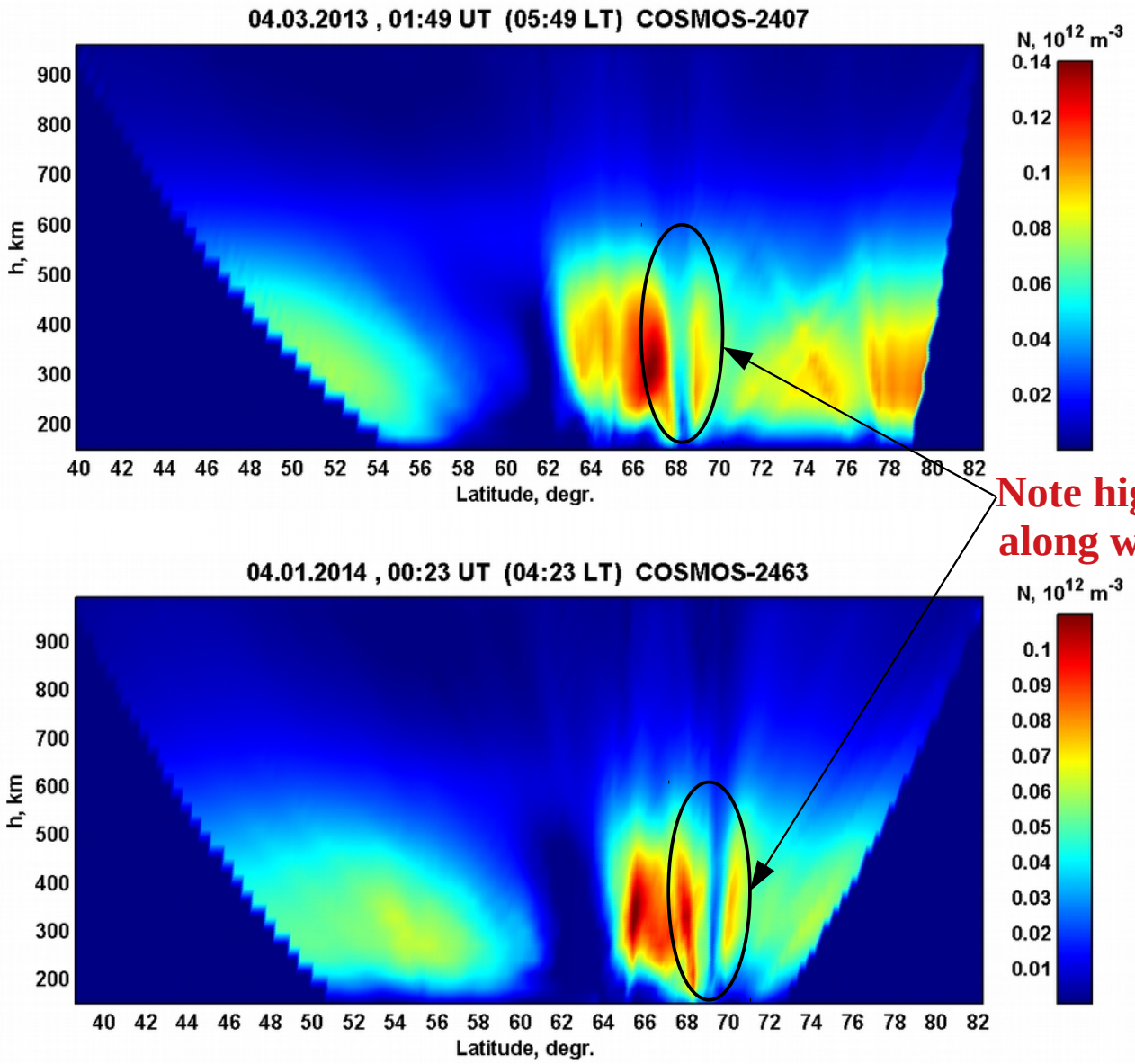
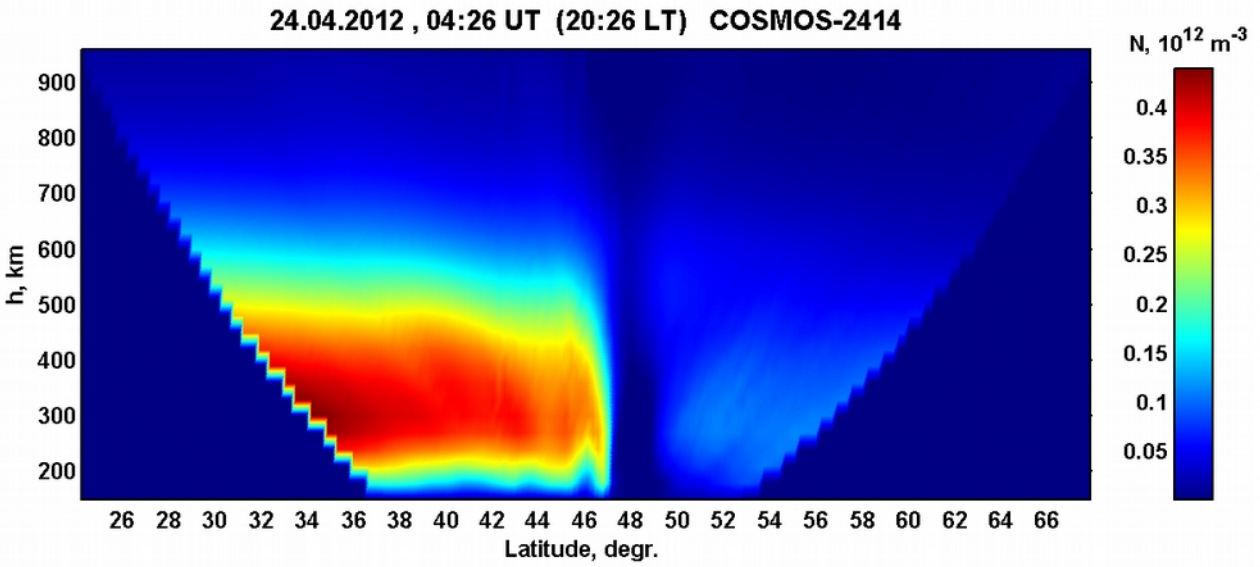
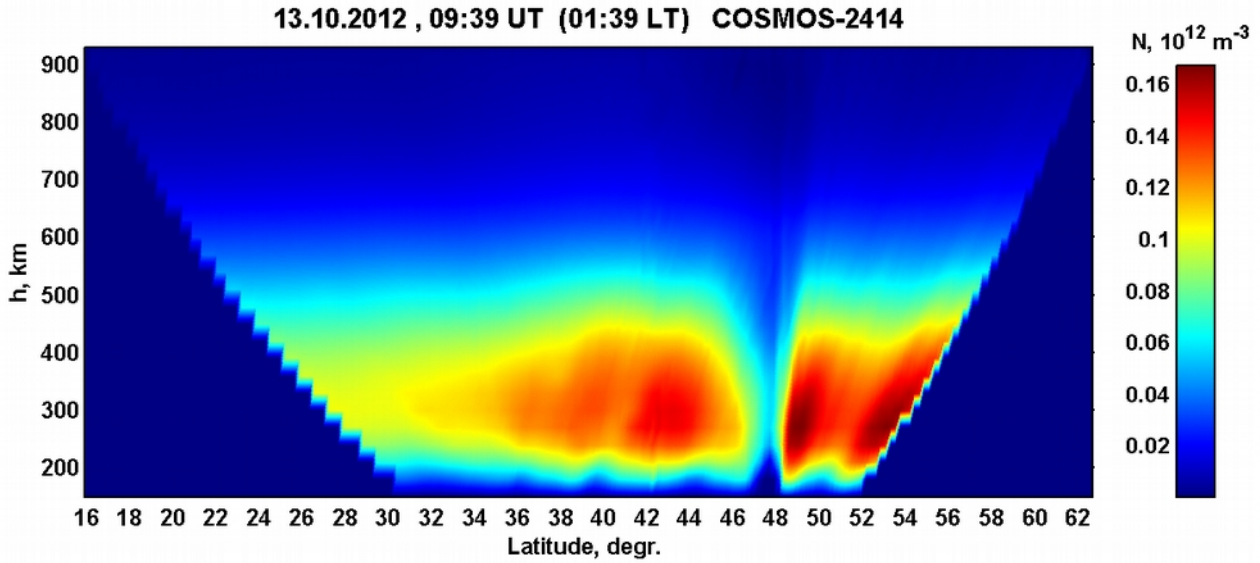


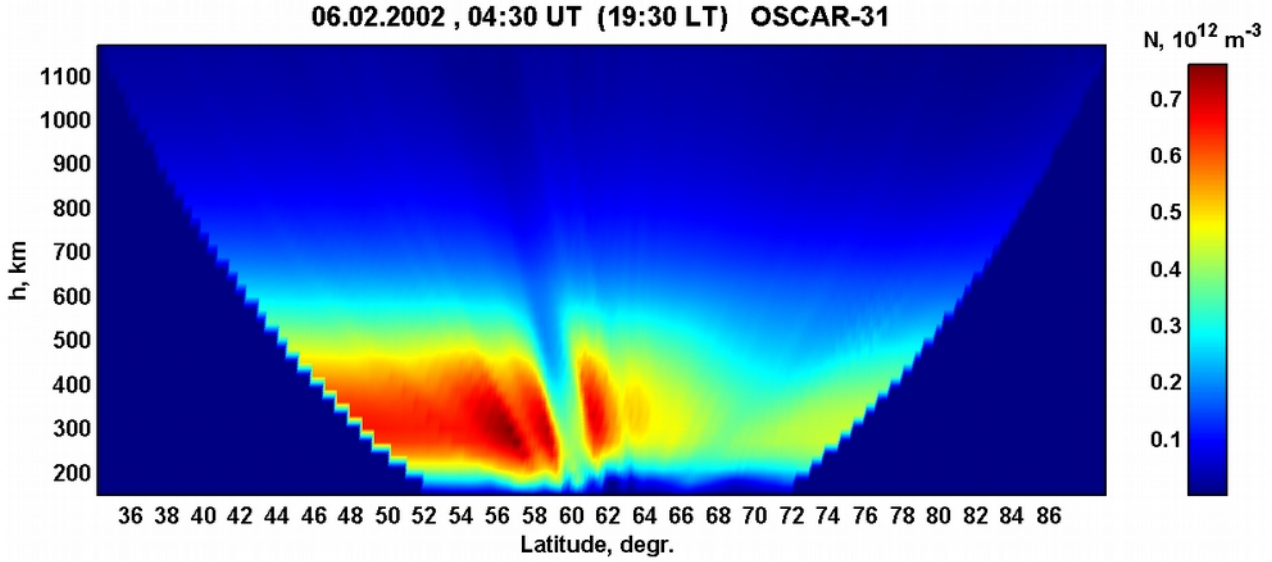

**Note high-latitude ionospheric trough along with main (mid-latitude) trough**

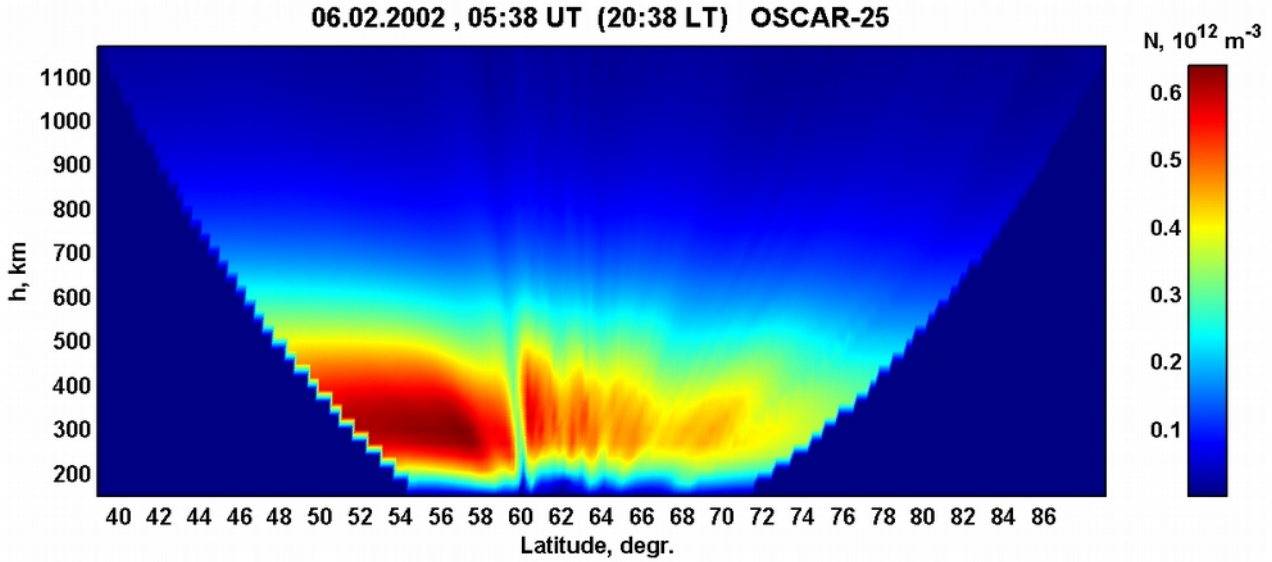
# Examples of mid-latitude troughs (U.S. West Coast)



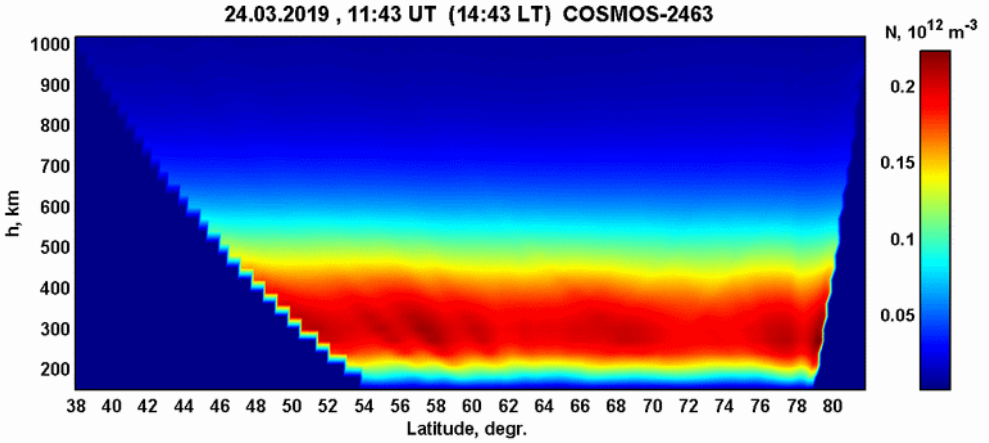



# Examples of high-latitude troughs (Alaska)

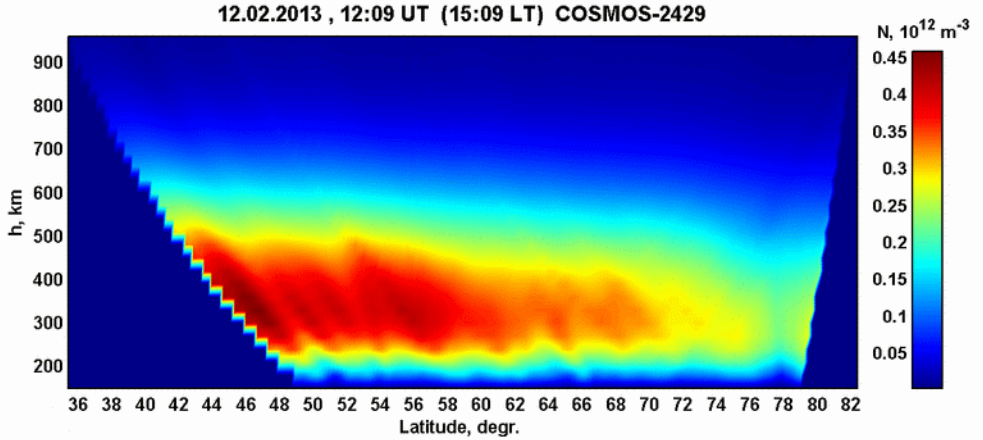


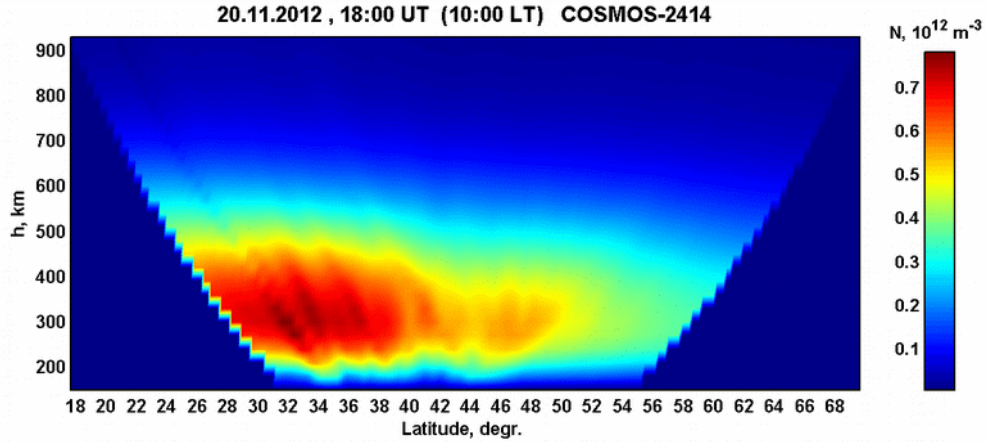
# Examples of traveling ionospheric disturbances




North-West Russia

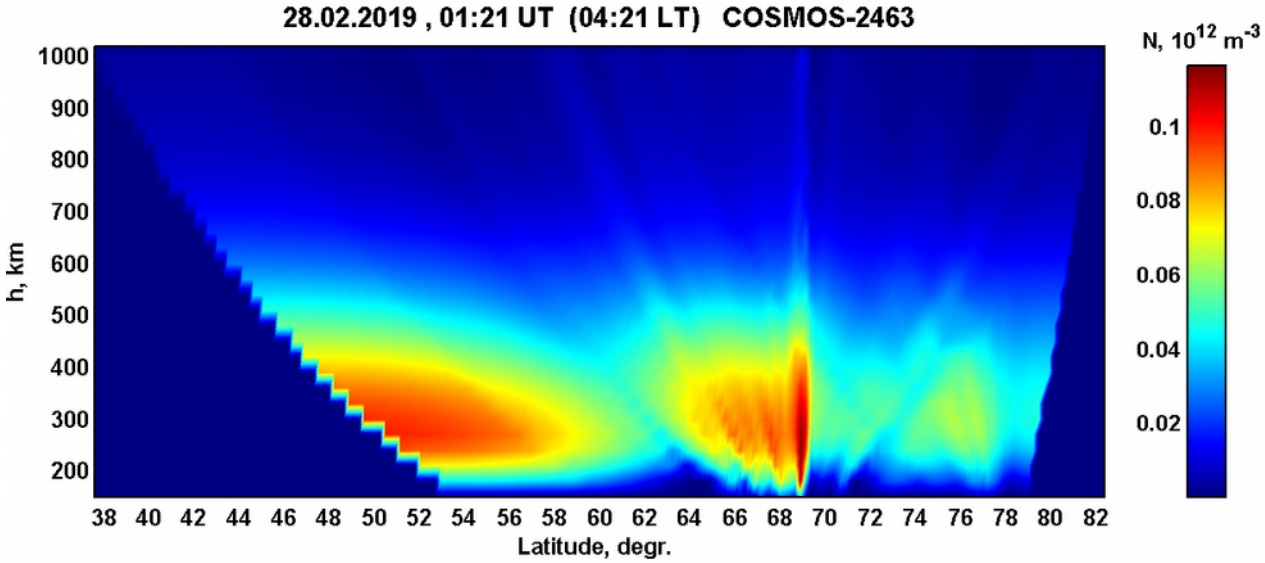


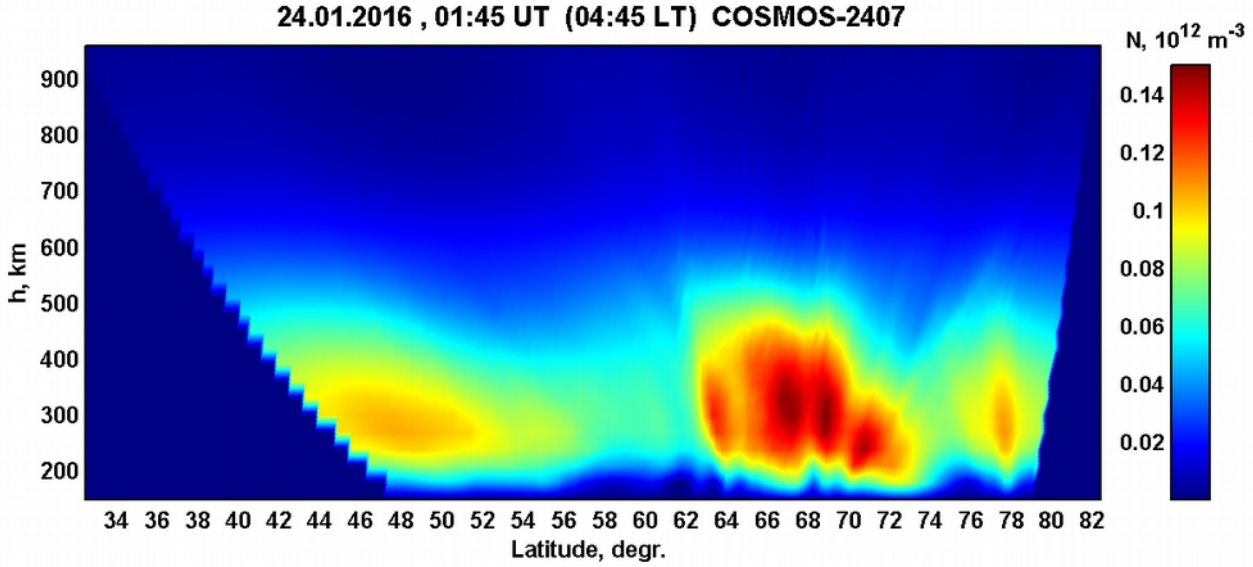

Inclination of wave packets shows typical southward propagation



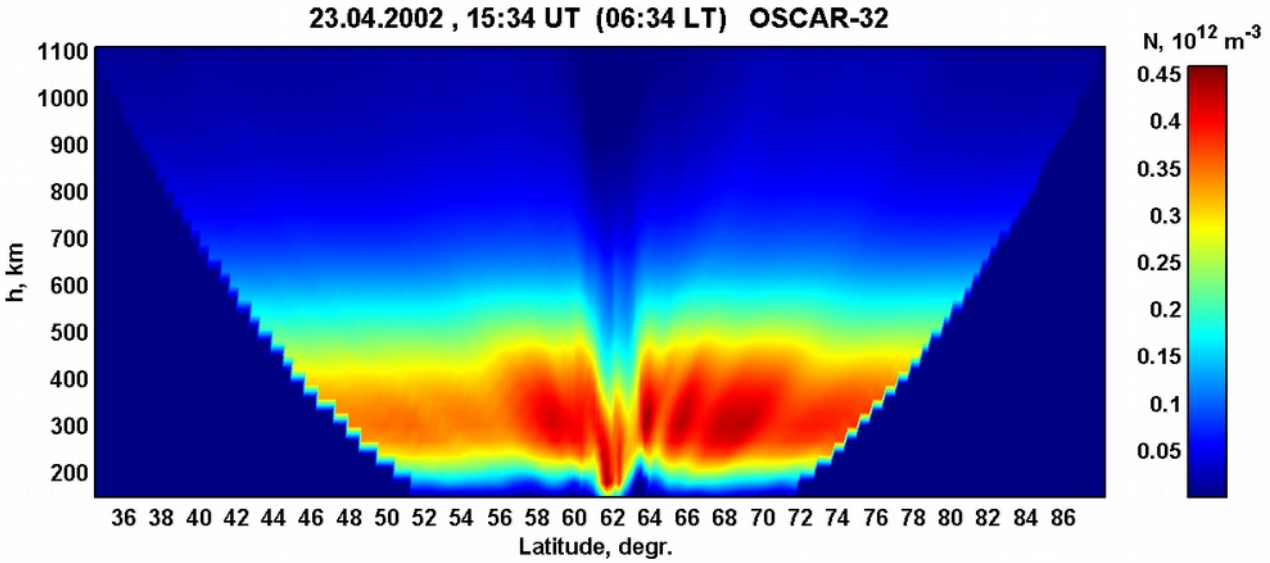

U.S. West Coast

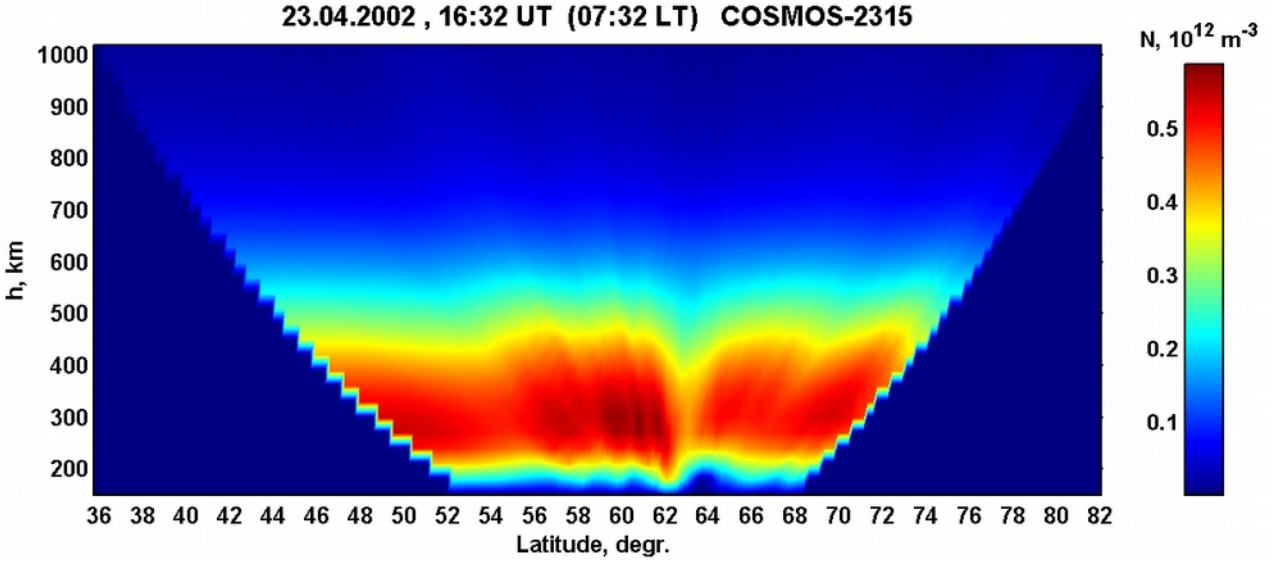
# Wave-like structures (North-West Russia)



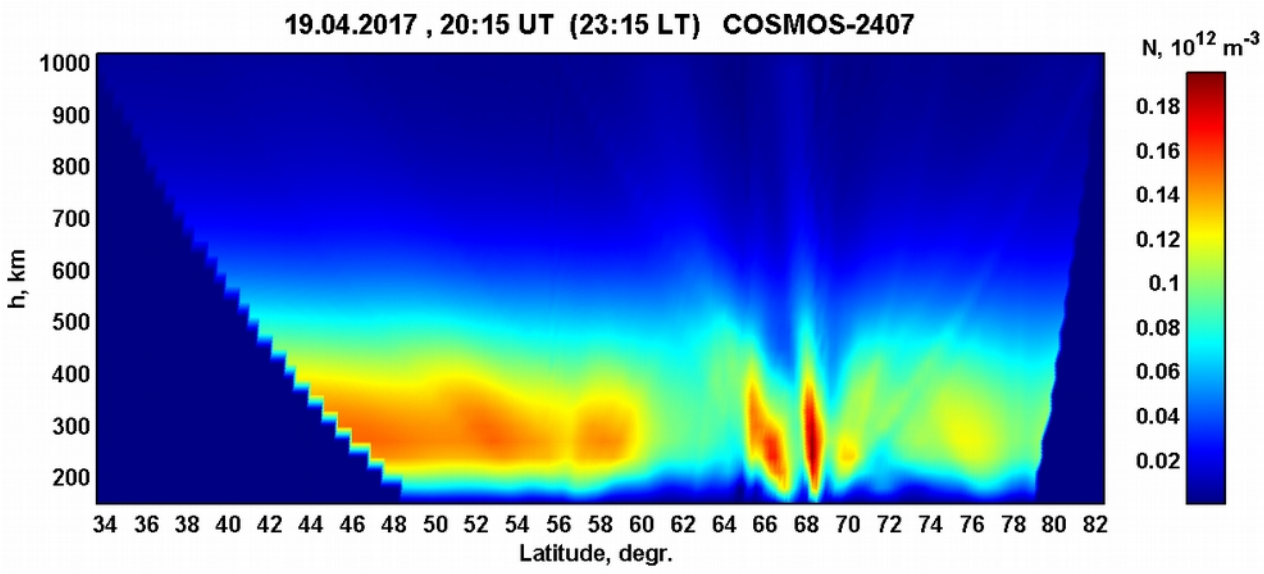



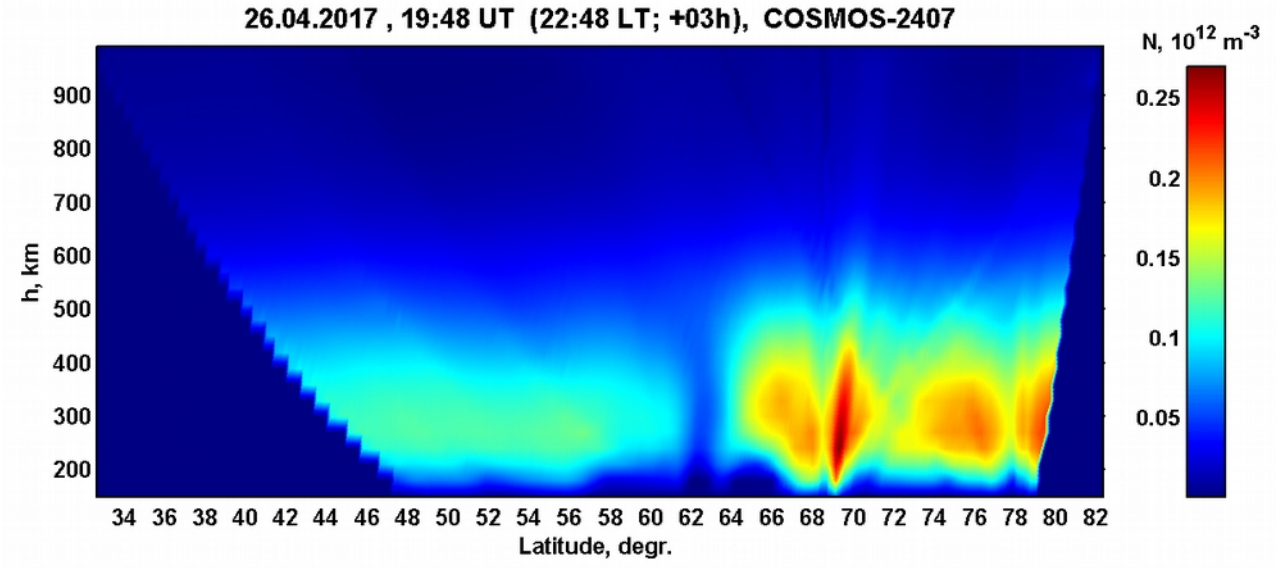
# Wave-like structures (Alaska)



# Examples of narrow isolated structures



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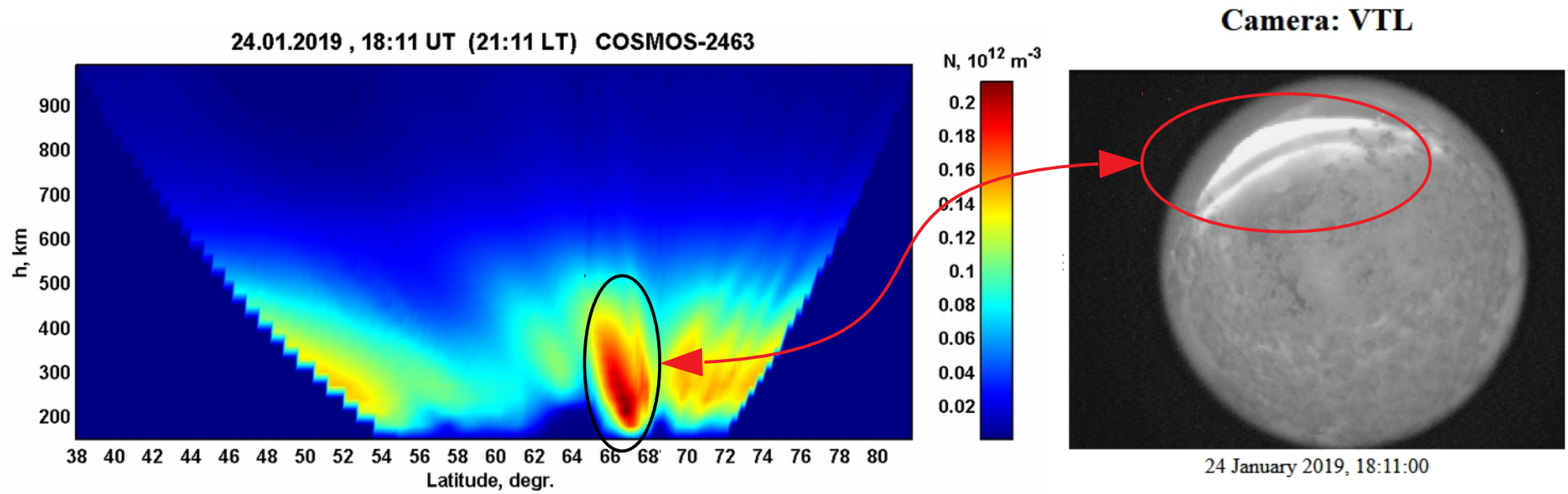
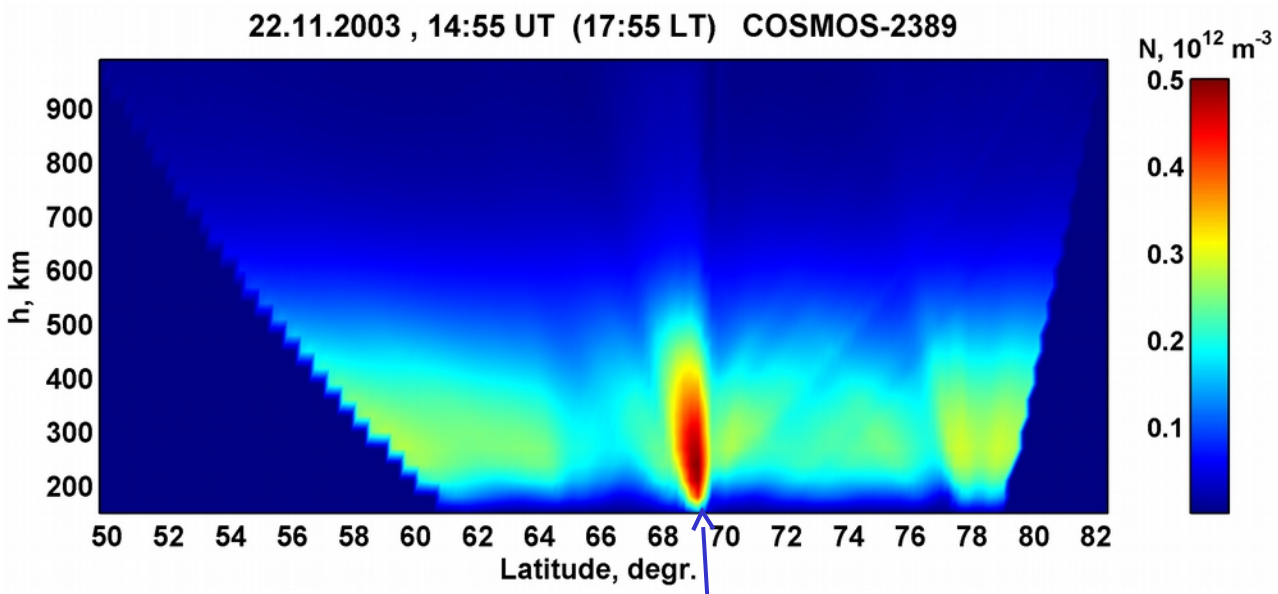


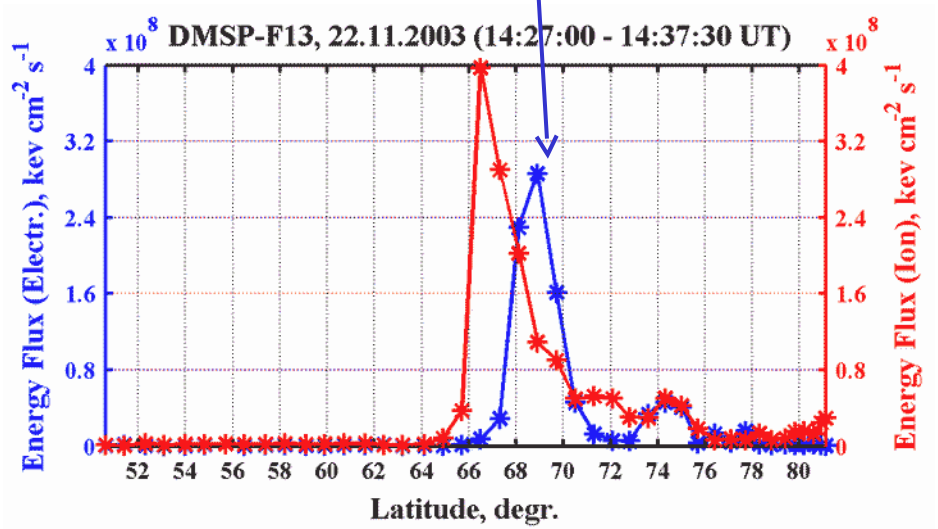

note good correspondence between tomographic and optical data
note that LORT tends to overestimate the height of corpuscular ionozation

Significant amount of narrow isolated structures on LORT reconstructions at high latitudes can be associated with energetic precipitating particles

It can be seen from the comparison of LORT reconstruction and SSJ/4 (Precipitating Plasma Monitor) onboard DMSP satellites for close in space (300km) and time (~0.5h) passes

# Comparison of LORT and DMSP SSJ/4 data



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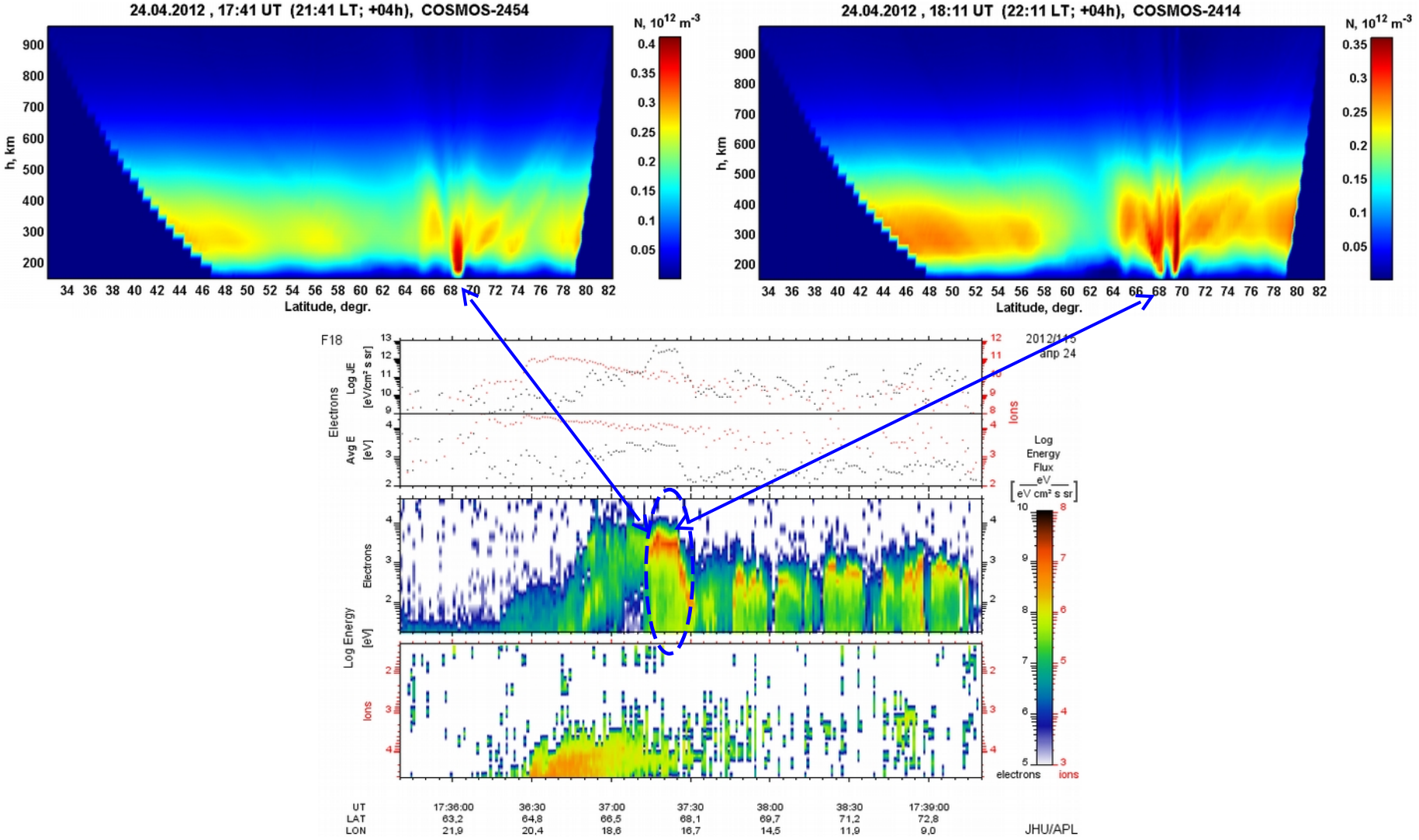

# Concluding remarks

LORT images of the ionosphere at mid and high latitudes show a great variety of structures (TIDs and wave-like structures, troughs, narrow localized structures, associated with energetic particle precipitations, etc).

Strong variability of high-latitude ionosphere according to LORT persists even in undisturbed geomagnetic conditions.

The comparison of LORT and DMSP SSJ/4 data shows that the spatial structure of additional corpuscular ionization on RT reconstructions qualitatively corresponds to the spatial distributions of ionizing particle fluxes.

LORT images can’t be analyzed successfully without additional information from other instruments. Optical measurements at high latitudes can provide significant additional information, especially about ionization of lower ionosphere in case of particle precipitations.

New beacons at polar orbits are needed to study complex processes in high-latitude ionosphere, since GNSS data is not sufficient in Arctic region due to significant orbit limitations, especially  for studying small-scale ionospheric structures.