INVESTIGATION OF THE ATMOSPHERIC GRAVITY WAVE IMPACT ON THE IONOSPHERIC DYNAMO REGION WITH THE EISCAT INCOHERENT SCATTER RADAR

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AGW-TID dispersion relation and observations

Gravity wave dispersion relation:
[Hines, 1960; Vadas and Fritts, 2005; Nicolls and Heinselman, 2007]

$$\boldsymbol{k}^2 = \frac{N^2 k_H^2}{\omega_I^2} \cdot \gamma - \frac{1}{4H^2}$$

Internal wave frequency:

$$\omega_I = 2\pi/\tau - k_H \cdot U$$

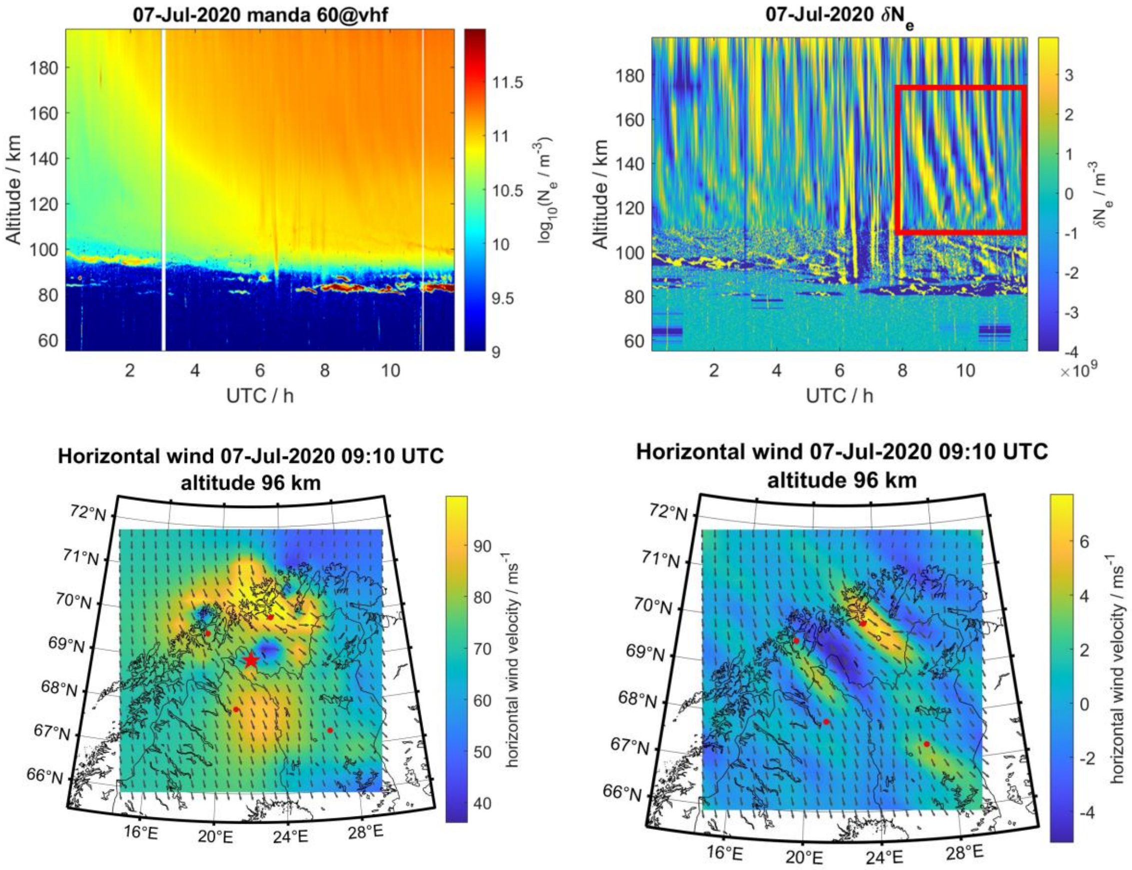
vertically resolved measurements:

EISCAT ISR

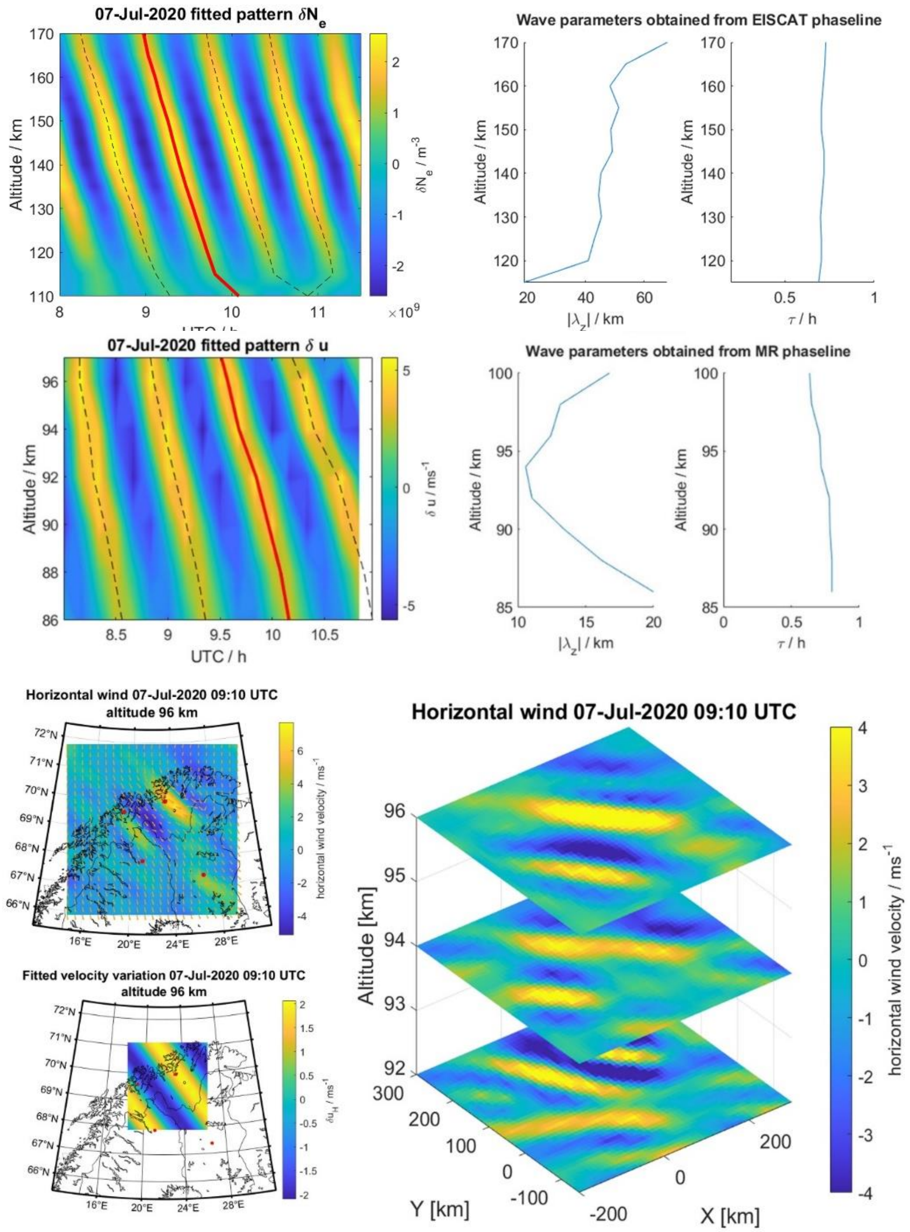
horizontally resolved measurements:

Nordic Meteor Radar Cluster

- wave parameters k_z, k_H and τ are coupled to background atmosphere
  ➔ ionospheric waves provide information on neutral atmosphere
- vertical and horizontal dimension difficult to measure at the same time



Wave filtering and wave parameter determination



2D Fourier filters are applied on vertical (τ, λ_z) and horizontal (λ_x, λ_y) measurements

1. **vertical**: $dN_e = A \cdot \cos(2\pi t/\tau + \delta)$ ➔ $\tau(z)$ and $\delta(z)$

   $t_{max}(z) = -\frac{\delta(z)\cdot\tau(z)}{2\pi} + t_0 + n \cdot \tau$ ➔ phase line

   $k_z = \frac{2\pi}{\tau} \cdot \frac{dt_{max}}{dz} = 2\pi/\lambda_z$

2. **horizontal:** $\delta v = A \cdot \sin\left(\cos\alpha \cdot \frac{2\pi}{\lambda_H} \cdot x + \sin\alpha \cdot \frac{2\pi}{\lambda_H} \cdot y + \delta\right)$

$\boldsymbol{\lambda_z}$	**$\sim 10 - 70$ km**
$\boldsymbol{\lambda_H}$	**230 km**
$\boldsymbol{\tau}$	**~ 43 min**
$\boldsymbol{\alpha}$	**$0.644\ (= 37.9°)$**

Inferred wind velocity profile

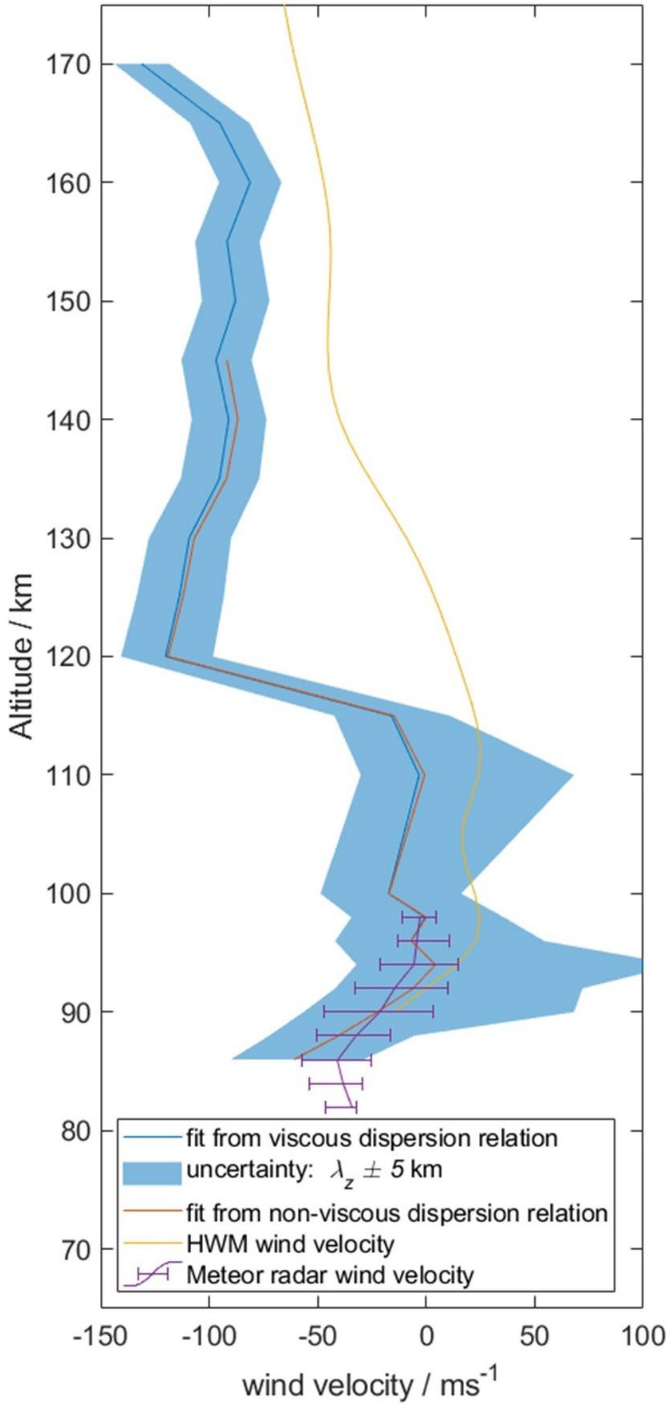
- GW dispersion relation includes wind velocity along the propagation direction
- apply wave parameters and NRLMSISE-00 background atmosphere
- perform non-linear least square fit of the viscous and non-viscous dispersion relations

  ➔ good agreement with Meteor Radar measurements (9 – 11 UTC)

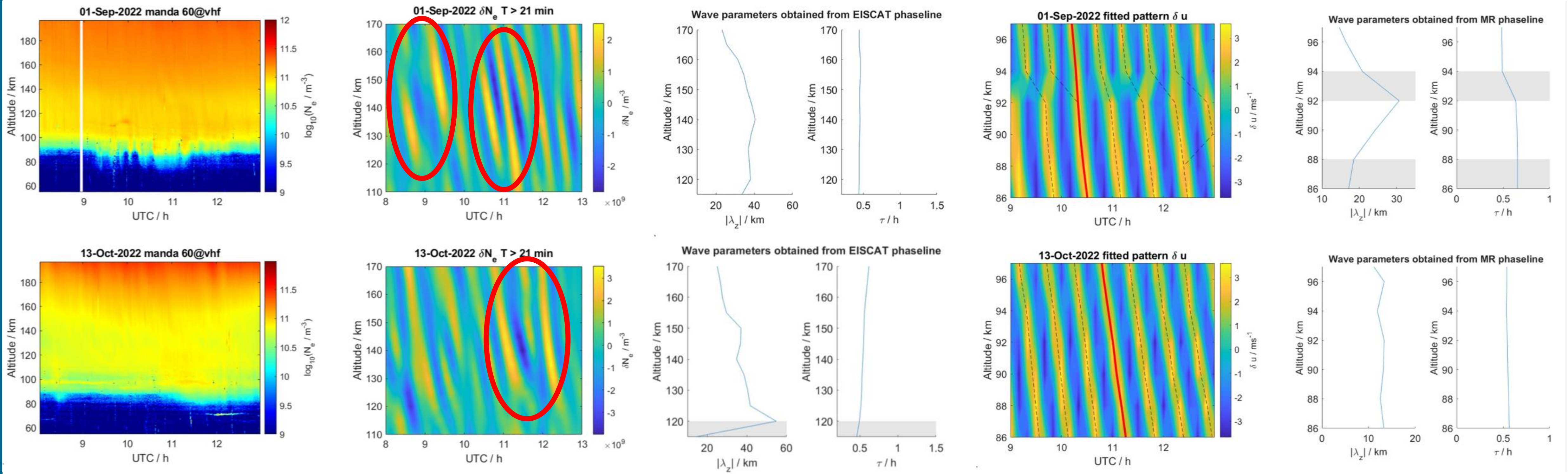
  ➔ general trend follows HWM climatology

  ➔ fit of non-viscous dispersion relation does not converge at altitudes > 145 km

- vertical wavelength uncertainty of ± 5 km has a significant impact on the wind profile



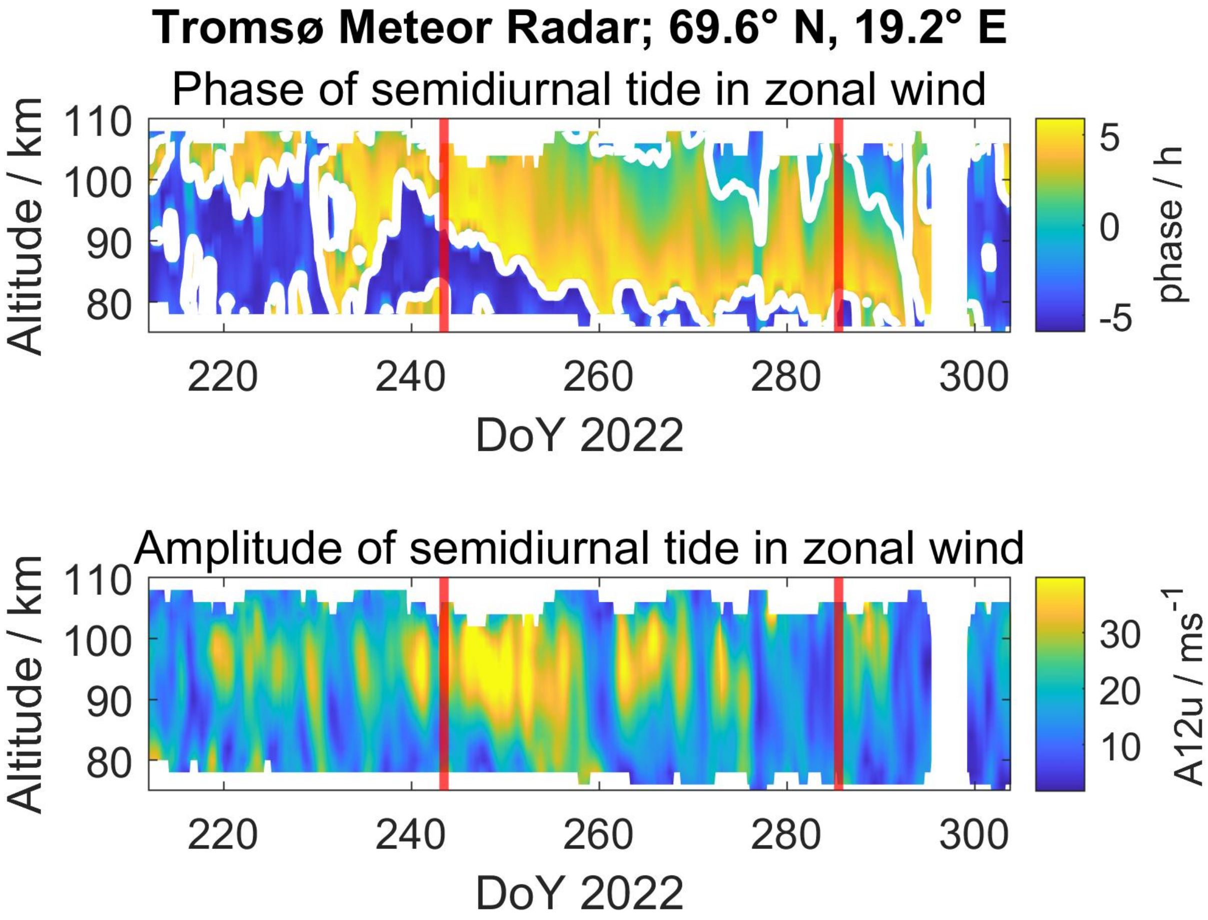
Seasonal variations – Autumn equinox

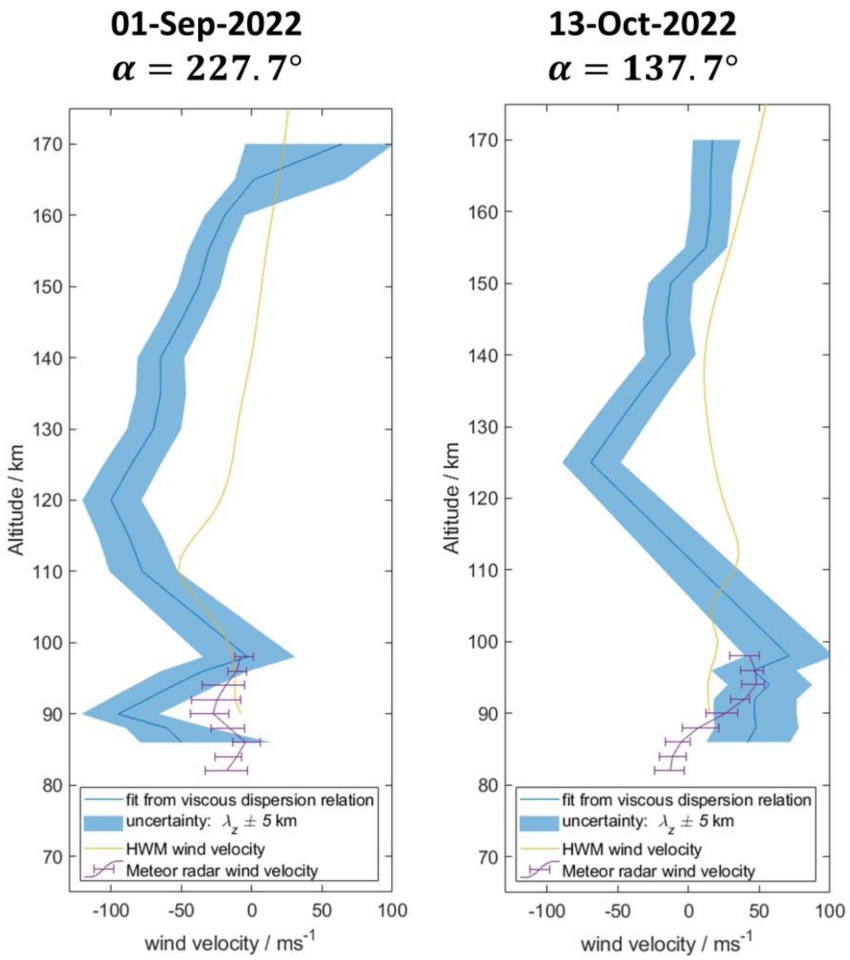


Date	1 September 2022	1 September 2022	13 October 2022
Time	08:00–10:00 UTC	10:00–12:00 UTC	10:00–12:00 UTC
τ [min] from EISCAT (110–170 km)	69.2 ± 1.4	26.9 ± 0.4	33.5 ± 2.0
τ [min] from meteor radar (86–98 km)	–	32.9 ± 7.1	32.9 ± 0.7

- two EISCAT campaigns conducted on Sep 01 and Oct 13, 2022, to show seasonal changes around the equinox
- MS-TIDs and AGWs detected in both measurements at 10-12 UT
- distinct transition of wave parameters of Sep 01 AGW-TID at approximately 92 – 94 km altitude

Tidal activity during autumn 2022





- general trend agrees with climatology
- strong deviations from meteor radar measurements during wave parameter transition on Sep 01
- else: wind profile agrees with meteor radar measurements within uncertainties

Summary:

1. Atmospheric gravity waves significantly impact the ionospheric variability

2. Studying plasma-neutral coupling requires combined investigations with ionosphere (e.g. EISCAT, EISCAT_3D) and neutral atmosphere (e.g. Nordic Meteor Radar Cluster) instruments

3. Better understanding of plasma-neutral coupling will allow for improving the parameterization of atmospheric processes in Ionosphere models

4. AGW-TID observations are an additional option for neutral wind measurements in the lower thermosphere

5. For complete results:
   F. Günzkofer *et al*., „Inferring neutral winds in the ionospheric transition region from AGW-TID observations with the EISCAT VHF radar and the Nordic Meteor Radar Cluster“, *Annales Geophysicae*, **41**, 409-428, (2023).

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