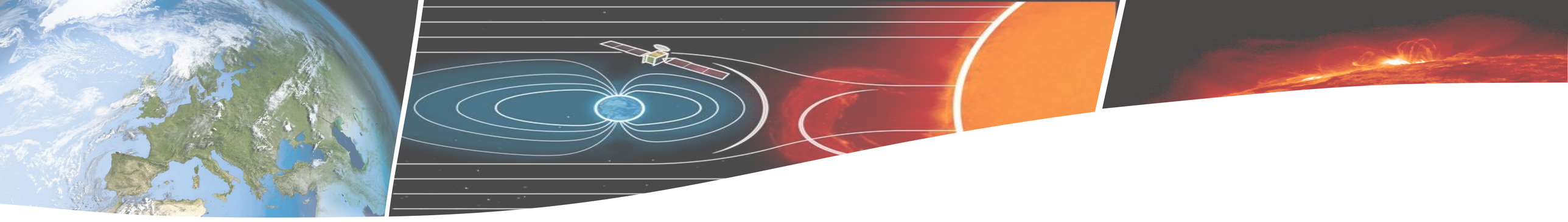


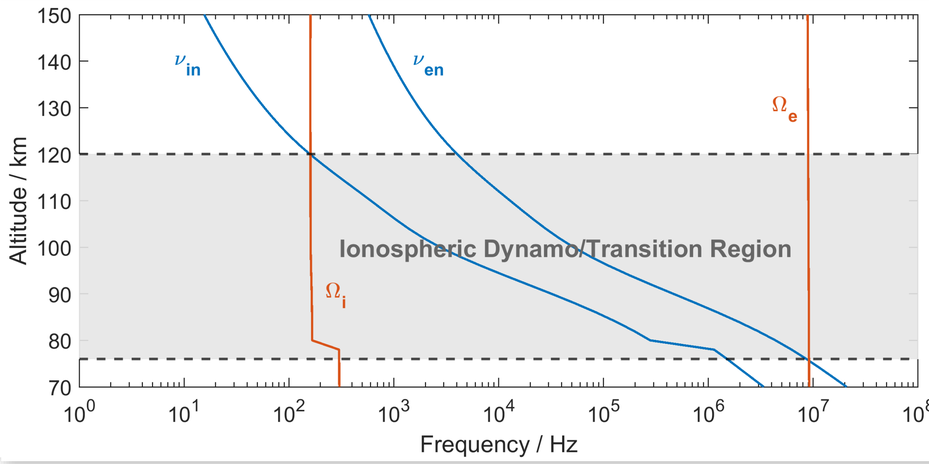
Ion-Neutral Coupling in the Ionospheric Dynamo Region – Measurements, Application and Impact on Ionospheric Variability

Florian Günzkofer[1], Gunter Stober[2], Dimitry Pokhotelov[3], and Claudia Borries[1]

[1] Institute for Solar-Terrestrial Physics, German Aerospace Center (DLR), Neustrelitz, Germany

[2] Institute of Applied Physics, University of Bern, Switzerland [3] Institute of Physics, University of Greifswald, Germany

The Ionospheric Dynamo/Transition Region



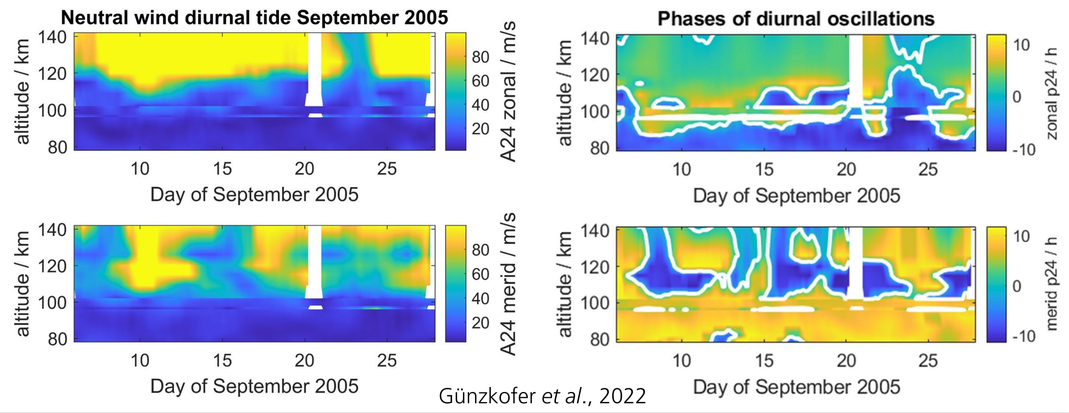
following Baumjohann and Treumann, 1997

- transition from highly-collisional plasma $\nu_{xn} \gg \Omega_x$ to collision-less plasma $\nu_{xn} \ll \Omega_x$
- electrons de-couple at ~ 80 km altitude and ions de-couple at ~ 120 km altitude ➔ **"transition region"**
- Pedersen and Hall conductivity maxima ➔ **"dynamo region"**
  - ➔ Joule heating by Pedersen currents
  - ➔ geomagnetic disturbances by Hall currents
- neutral dynamo $\boldsymbol{u}(z) \times \boldsymbol{B}$ can have an important impact on ionospheric dynamics and variability

➔ **neutral atmosphere dynamics in the dynamo region are highly important for space weather research**

Tidal Oscillations in the Dynamo Region

- classical view on tidal neutral wind oscillations in the dynamo region at high latitudes:
  - below ~ 110 km: upward propagating semidiurnal atmospheric tide ➔ **12 h**
  - above ~ 120 km: forced via ion drag by the polar plasma convection ➔ **24 h**
- measurements: EISCAT UHF campaign from September 2005 (Nozawa *et al.*, 2010) and Kiruna meteor radar
  - ➔ **meridional wind shows strong 12 h oscillations above 120 km altitude**
- models: GAIA, WACCM-X(SD), and TIE-GCM; varying plasma convection, atmospheric forcing, and EUV flux
  - ➔ **strong semidiurnal osciallations above 120 km found; measurements confirmed**
  - ➔ **most likely *in situ* forcing by polar plasma convection and EUV absorption**



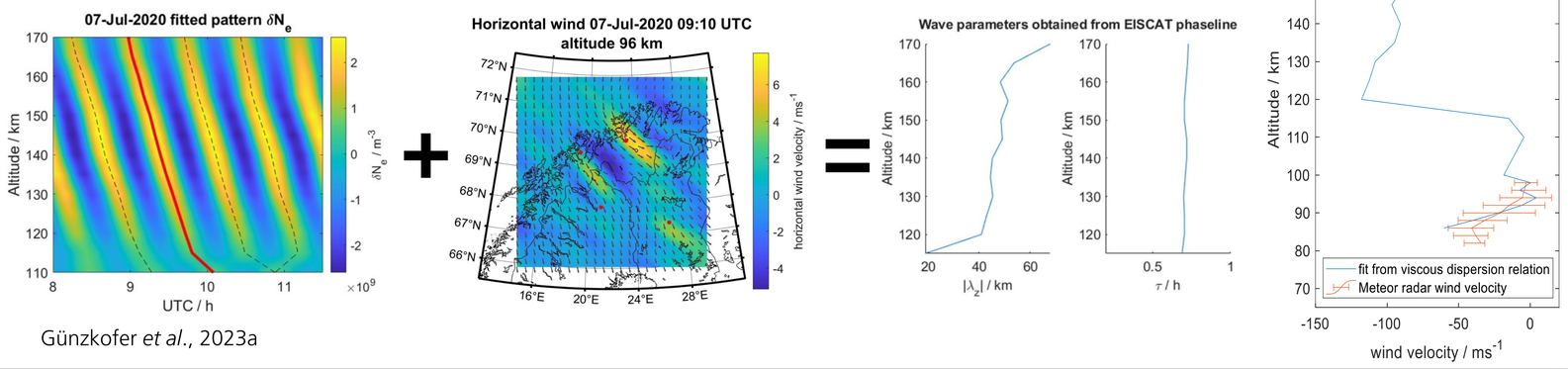
Günzkofer *et al.*, 2022

3D AGW-TID Observations

- neutral wind velocities can be inferred from observations of atmospheric gravity waves (AGWs)
- AGWs can be observed in the ionosphere as travelling ionospheric disturbances (TIDs)
- combined observations with the EISCAT VHF radar and the Nordic Meteor Radar Cluster
  - ➔ Fourier filter to determine 3D wave parameters (vertical/ horizontal wavelength, wave period, and propagation direction)
  - ➔ neutral wind velocity inferred from anelastic dissipative GW dispersion relation

➔ **neutral winds fit meteor radar measurements; validation above 100 km required**

EISCAT VHF radar + **Nordic Meteor Radar Cluster** = **wave parameters and neutral wind**



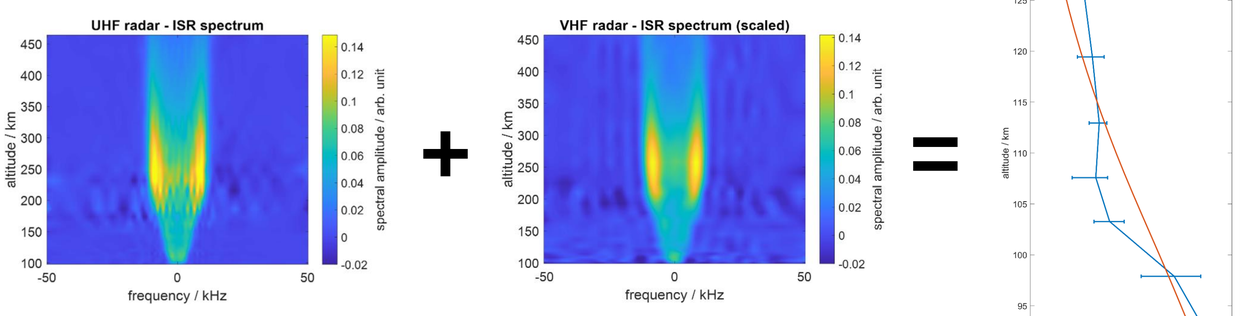
Günzkofer *et al.*, 2023a

Direct Ion-Neutral Collision Frequency ν_{in} Measurements

- direct measurement of ν_{in} possible with dual-frequency EISCAT experiments (VHF/UHF radar)
- different methods to analyze dual-frequency ISR experiments proposed by Grassmann, 1993
- infer ν_{in} from the ***difference spectrum*** based on standard ISR analysis software, e.g. GUISDAP
  - ➔ VHF spectrum is scaled to UHF frequencies; scaled spectrum is equivalent to UHF spectrum with collision frequency $\xi \cdot \nu_{in}$ where $\xi = f_{UHF}/f_{VHF}$
  - ➔ β factor is introduced to compensate technical differences of UHF and VHF radar

➔ **ν_{in} profile shows distinct deviations from climatology but recovers general trend**

➔ **boundaries of ionospheric dynamo region and altitudes of conductivity maxima vary**



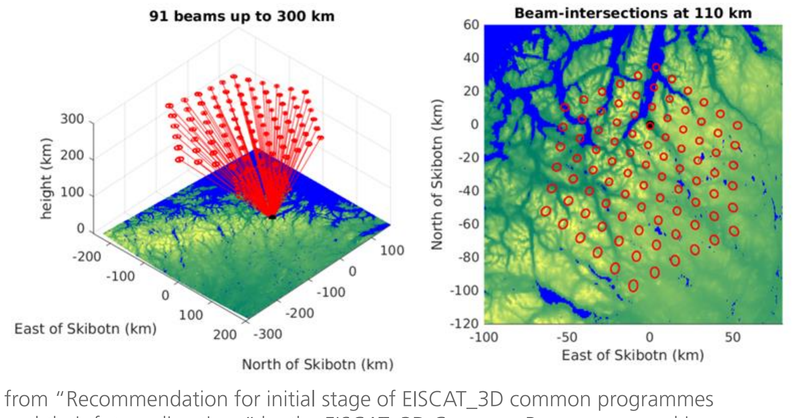
Günzkofer *et al.*, 2023b

Conclusion

1. Tidal oscillations in the dynamo region show a complex mixing of tidal modes from different forcing mechanisms
   - ➔ semidiurnal oscillations can be forced *in situ* in addition to upward-propagating atmospheric tides
   - ➔ possible impact on semidiurnal variability of the ionosphere via neutral dynamo effect
2. 3D observations of AGW-TIDs allow to infer neutral wind velocities in the dynamo region
   - ➔ combination of two instruments with sufficient horizontal and vertical coverage required
   - ➔ obtained neutral winds agree well with meteor radar measurements, further validation required
3. Ion-neutral collision frequency profiles can be measured with dual-frequency ISR experiments
   - ➔ *difference spectrum* method only requires minor modification of standard ISR analysis software
   - ➔ direct measurement of collision frequencies possible without further assumption as other methods (e.g., $T_e = T_i$, $u_z = 0$)

Outlook – EISCAT_3D

- **phased array ISR EISCAT_3D** currently under construction
- electronic steering of radar beam allows multi-beam experiments
  - ➔ measurement of 3D ion velocities (and neutral winds) at high time resolution; potentially continuous measurements possible
  - ➔ multi-beam measurements might allow to obtain vertical and horizontal wave parameters
  - ➔ no dual-frequency capability planned



from "Recommendation for initial stage of EISCAT_3D common programmes and their future directions" by the EISCAT_3D Common Programme working group

References:

Günzkofer F. *et al.*, *accepted to Atmospheric Measurement Techniques*, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2023-1495, 2023b

Günzkofer F. *et al.*, *Annales Geophysicae*, **41**, 409-428, 2023a

Günzkofer F. *et al.*, *Journal of Geophysical Research: Space Physics,* **127**, e2022JA030861, 2022

Nozawa S. *et al.*, *Journal of Geophysical Research*, **115**, A08312, 2010

Baumjohann W. and Treumann R., "*Basic Space Plasma Physics*", Imperial College Press, 1997

Grassmann V., *Journal of Atmospheric and Terrestrial Physics*, **55**, 573-576, 1993

Deutsches Zentrum für Luft- und Raumfahrt

Acknowledgments:
I would like to gratefully acknowledge contributions by: H. Liu, H.-L. Liu, A. Tjulin, N. J. Mitchell, I. Mann, S. L. Vadas, E. Becker, A. Kozlovsky, M. Tsutsumi, N. Gulbrandsen, S. Nozawa, M. Lester, E. Belova, J. Kero, and Y. Miyoshi.

Contact: Florian Günzkofer
Institute for Solar-Terrestrial Physics, DLR
Kalkhorstweg 53, 17235 Neustrelitz
Tel.: +49 3981 480-118, **Email: florian.guenzkofer@dlr.de**