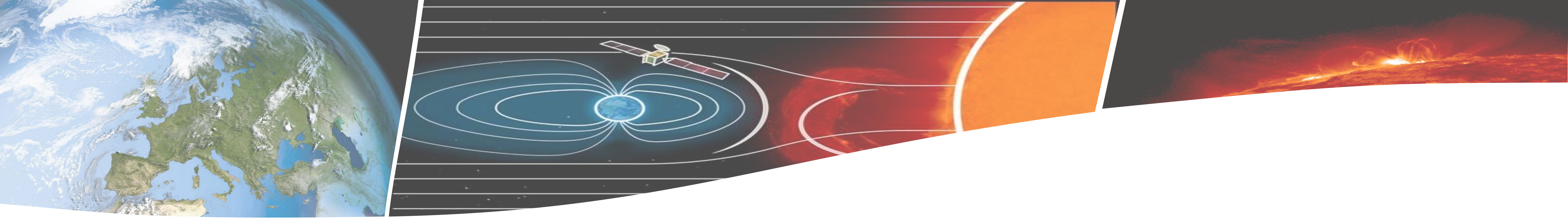

Impact of Sudden Stratospheric Warmings and Elevated Stratopause events on the VLF signal in high latitudes

Helen Schneider[1], Vivien Wendt[1], Daniela Banys[1], and Mark Clilverd[2]

1 Institute of Solar-Terrestrial Physics, German Aerospace Center, Neustrelitz, Germany, 2 British Antarctic Survey (UKRI-NERC), Cambridge, UK

Introduction

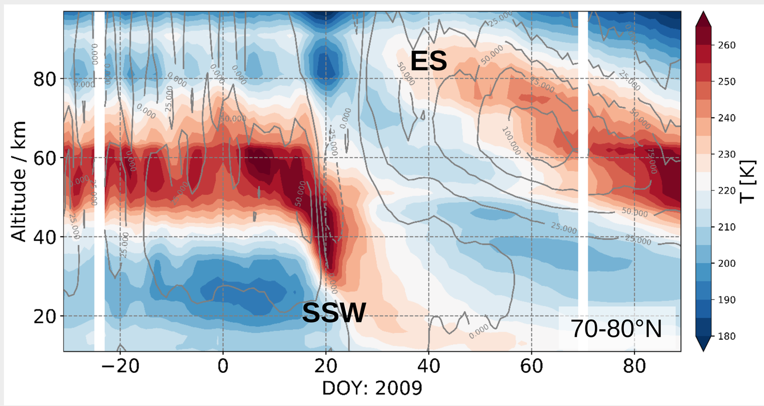

Fig. 1: Zonal mean temperature (colors) and zonal mean zonal wind (contours), both from MLS data onboard Aura satellite

- **S**udden **S**tratospheric **W**arming**:** reversal of zonal wind to westward directions, warming/cooling in stratosphere/mesosphere
- **E**levated **S**tratopause**:** very strong eastward winds in mesospheric heights, cooling/warming in stratosph./mesosph.
- Enhanced upward/downward transport during SSW/ES -> changes in neutral chemistry
- SSW / ES induced changes influence D-region ionization
- D-region is also upper reflection boundary for the Very Low Frequency (VLF) Transmission, used for long distance communication -> ***Is there a SSW/ES impact on VLF signal?***

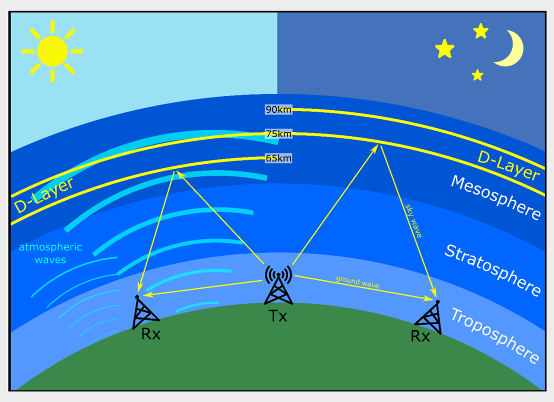

Fig.2: Principle VLF signal propagation from transmitter to receiver with different reflection heights during day and night time [courtesy of V. Wendt]

Data Preparation

Leveling with PELT

- VLF amplitude raw data timeseries show amplitude steps caused by maintenance actions or technical disturbances (Fig. 3)
- Segment wise leveling of amplitude steps with help of **P**runed **E**xact **L**inear **T**ime method [Killick et al. 2012]
- First outlier filtration step with a low-pass filter (**level 1 data**)

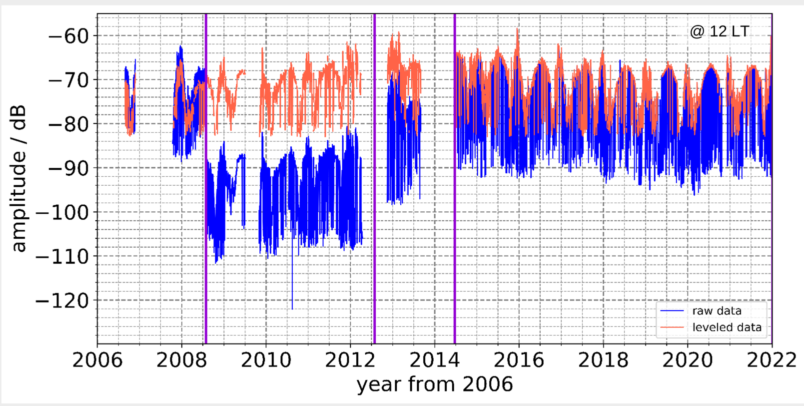

Fig. 3: VLF amplitude for link NAA-NyAlesund. Vertical purple lines mark segments determined with PELT method.

Outlier Detection with MAD

- Outlier detection with **M**edian of all **A**bsolute **D**eviations [Rousseeuw, P. and Hubert, M., 2011]:

$$\mathrm{MAD} = 1.483 \; \underset{i=1,\ldots,n}{\mathrm{median}} \left| x_i - \underset{j=1,\ldots,n}{\mathrm{median}}(x_j) \right|$$

$$z_{score} = \left(x_i - \underset{j=1,\ldots,n}{\mathrm{median}}(x_j)\right) / \mathrm{MAD}$$

- 1. dim: running MAD (60 days) along the time vector
- 2. dim: year wise MAD for each daytime bin
- Only outliers are considered, which match for both dimensions (**level 2 data**)

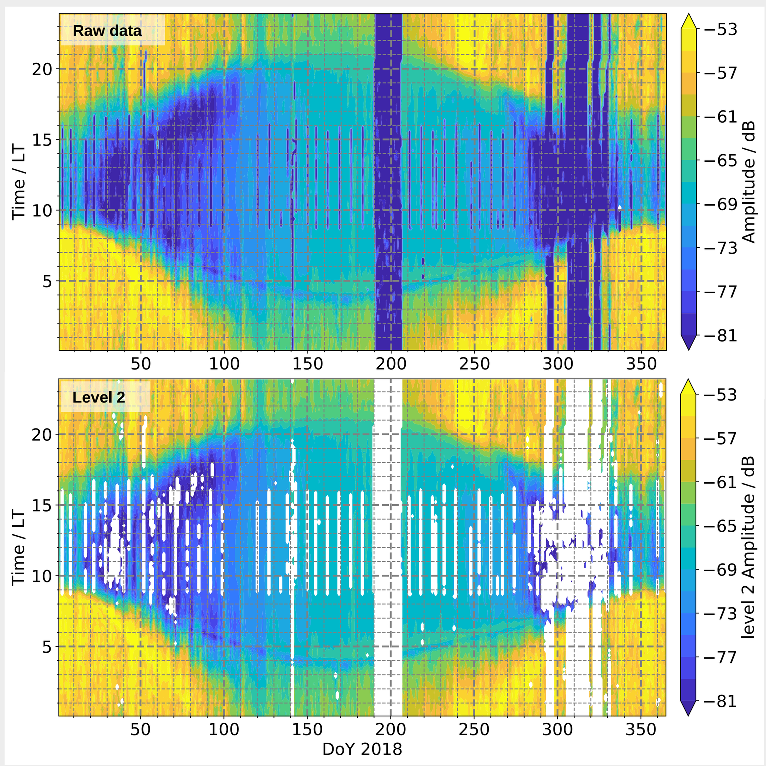

Fig. 4: Diurnal and seasonal variation of VLF amplitude for the link NAA-NyA (Fig. 8).

Quiet time line with composite

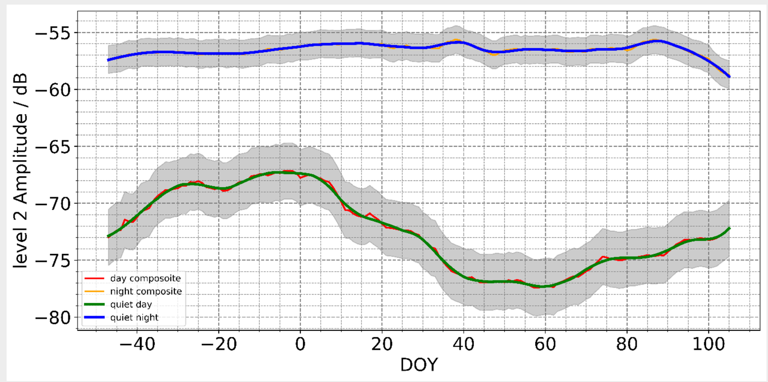

Fig. 5: Quiet time daytime (green) and nighttime (blue) line of VLF signal amplitude for the link NAA-NyAlesund, computed by polynomial fit of daytime composite (red) and nighttime composite (yellow) .

- Composite of 16 day running median values
- Daytime: median (12 LT +- 1h)
- Nighttime: median (22 LT - 24 LT)
- Smoothing with Savitzky-Golay filter (17,3)
- To distinguish between typical seasonal variation and disturbances of VLF amplitude

Results

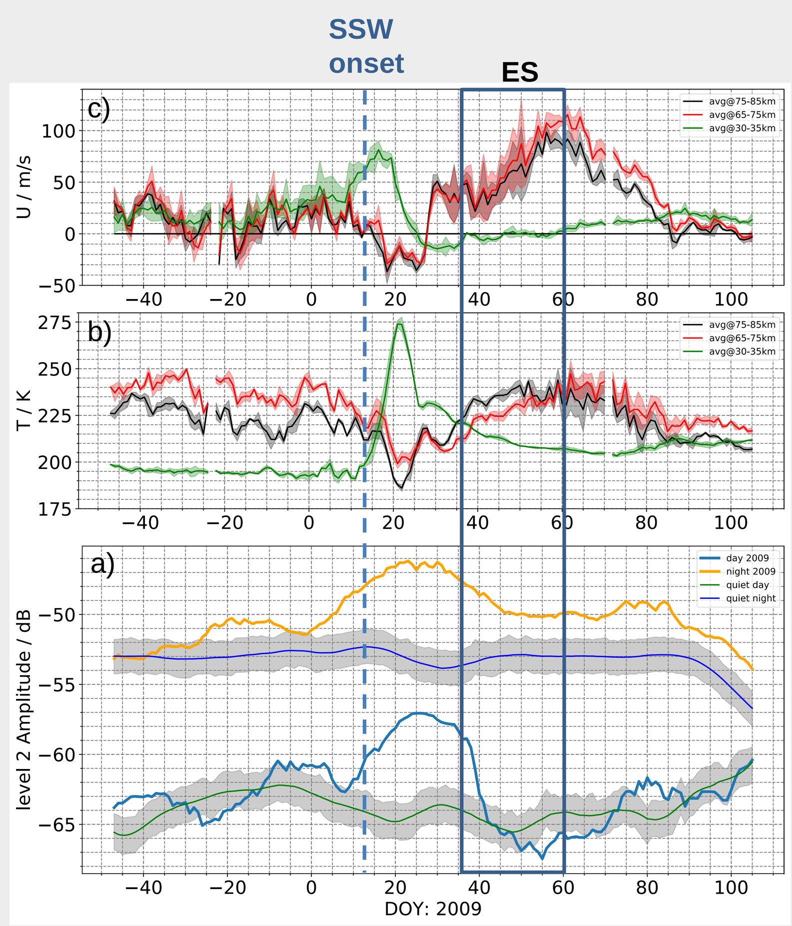

Fig. 6: a) VLF daytime and nighttime amplitude for winter 2009 and the quiet time lines, both for the link ***NRK-NyAlesund.*** *b) temperature and c) zonal wind, both averaged over the 3 segments along the path (****orange boxes*** *in Fig. 8).*

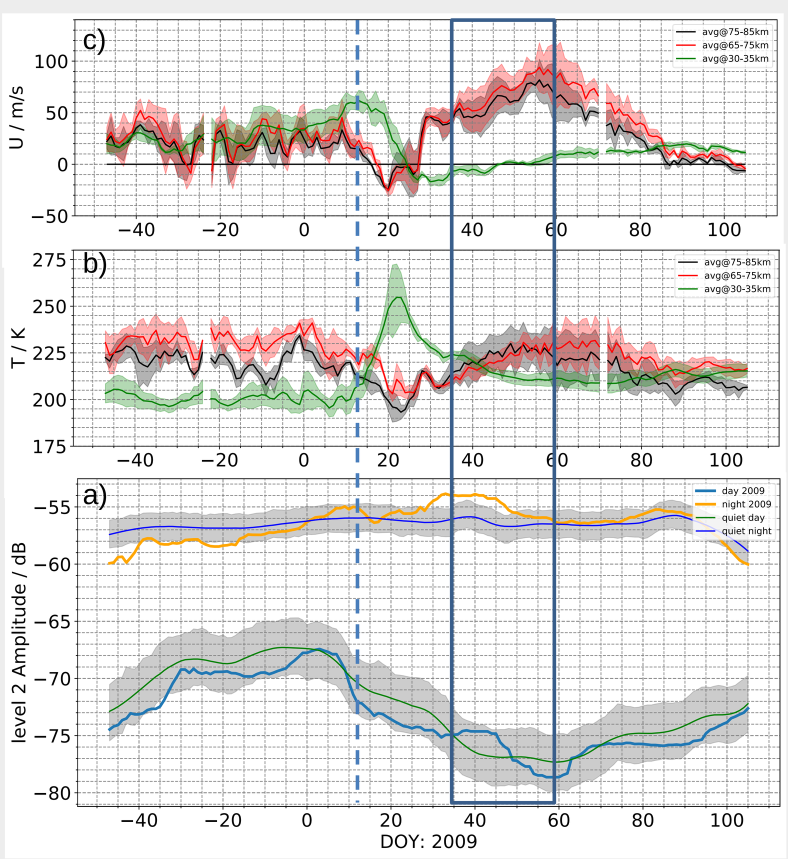

Fig. 7: a) same as in Fig. 6, but for link ***NAA-NyAlesund*** *. b) temperature and c) zonal wind, both averaged over 3 segments along the path (****magenta boxes*** *in Fig. 8)*

- Low solar and geomagnetic conditions during winter 2009 (not shown) -> perturbation have atmospheric origin
- 2 different transmitter-receiver links from the AARDDVARK network (fig. 8)
- Both links are located in high latitudes, but distinguish in pathway, length and path characteristics (ice, water, solid ground)

NRK-NyA (Fig 6.):

- Significant variation in VLF amplitude during SSW and ES (day- and nighttime)
- VLF variation seems to be anticorrelated with mesospheric temperatures and zonal wind (red and black line, 6b,c) durng SSW/ES event
- Anticorrelation not observable before and after SSW/ES event

NAA-NyA (Fig 7):

- VLF amplitude (day- and nighttime) does not show same strong variation as for the NRK-NyAlesund link
- VLF amplitude shows wave signature, but variation keeps within standard deviation.

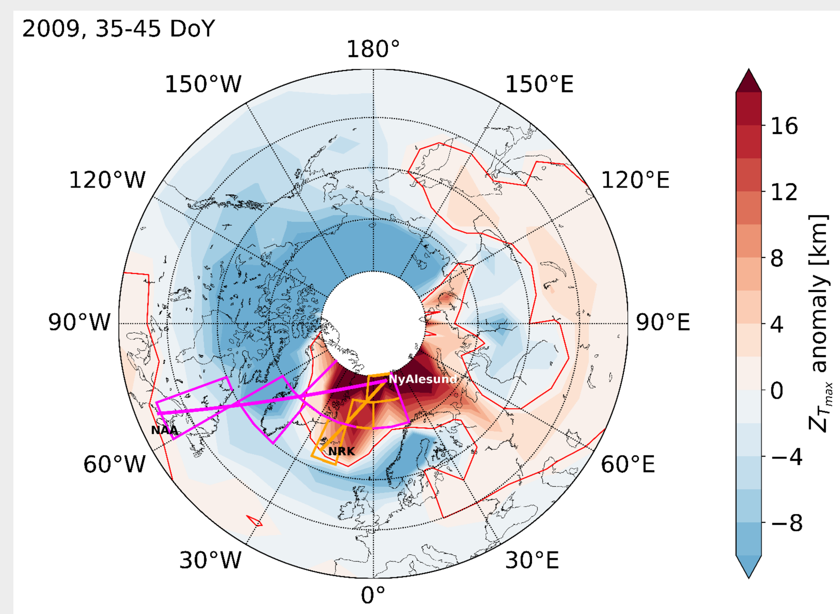

Fig. 8: Stratopause altitude anomaly averaged over period 35-45 DOY 2009. The colored boxes represents segments, used for T und u computation in Fig. 6 and 7. Global satellite data from MLS onboard Aura satellite were used.

Conclusion

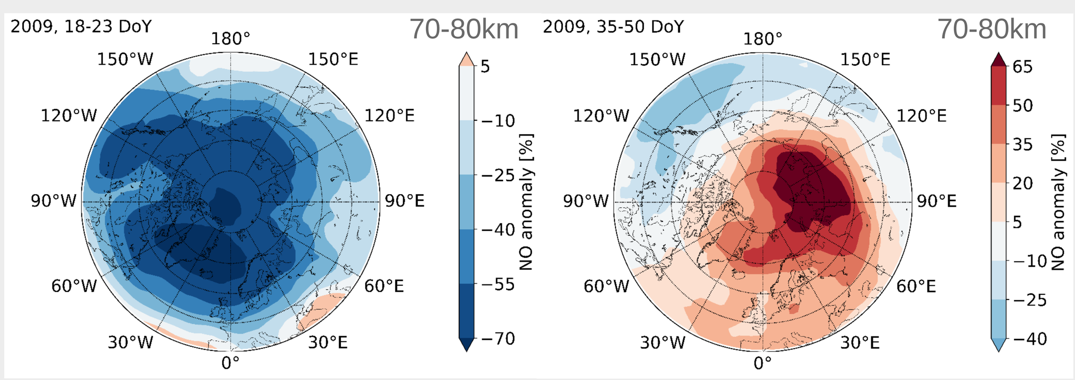

Fig. 9: NO (SD-WACCM-X) anomaly in percentage for SSW (a) and ES period (b) compared to quiet winter conditions.

- **NRK-NyAlesund**: temperature and zonal wind changes indirect responsible for VLF amplitude variation as anticorrelation cannot be observed continuously
- Changes in temperature, wind and NO concentration during SSW/ES indicate a change in global circulation responsible for the perturbation of the VLF signal
- **NAA-NyAlesund:** no significant changes during SSW/ES event, might be stronger effected by Lyman-α variation (pending task)
- **Longitudinal dependency of SSW/ES effects on VLF signal, due to longitudinal and latitudinal differences in strength of SSW/ES and the accompanying modified NO concentration (fig. 9)**

Outlook

Identification of dominant drivers for VLF signal perturbations during SSW/ES events

Comparison with other SSW / ES events and links:

- atmospheric dynamics
- minor constituent concentration (NO, O_3)
- wave activity
- solar and geomagnetic activity

References:

Killick, R., Fearnhead, P., Eckley, I. A. (2012): Optimal detection of change points with a linear computational costs, JASA, 107, https://doi.org/10.48550/arXiv.1101.1438

Rousseeuw, P. and Hubert, M. (2011): Robust statistics for outlier detection, WIREs Data Mining and Knowledge Discovery, Volume 1, January/February, DOI: 10.1002/widm.2

Schneider, H., Wendt, V., Banyś, D. and Clilverd, M. (2023): A new approach on VLF signal processing, in preparation

Wendt, V., Schneider, H., Banyś, D. and Clilverd, M. (2023): Why can the October Effect not be observed during nighttime?, in preparation

Deutsches Zentrum DLR für Luft- und Raumfahrt

Acknowledgments:
We thank Marc Hansen for helpful discussions, the Jet Propulsion Laboratory/NASA for providing access to the Aura/MLS level 2 retrieval products and the NCAR Climate Data Gateway for providing SD-WACCM-X datasets.

H. Schneider
DLR, Institute for Solar-Terrestrial Physics,
Kalkhorstweg 53, 17235 Neustrelitz
Tel.: +49 3981 480 298, Email: helen.schneider@dlr.de