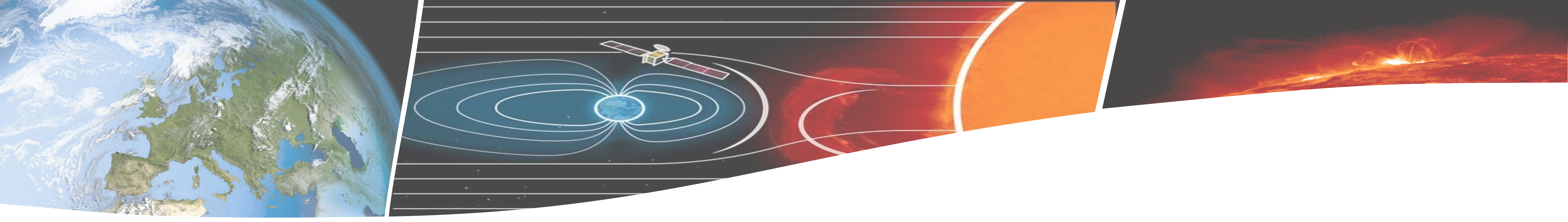

Impact of Sudden Stratospheric Warmings and Elevated Stratopause events on the VLF signal in high latitudes

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Introduction

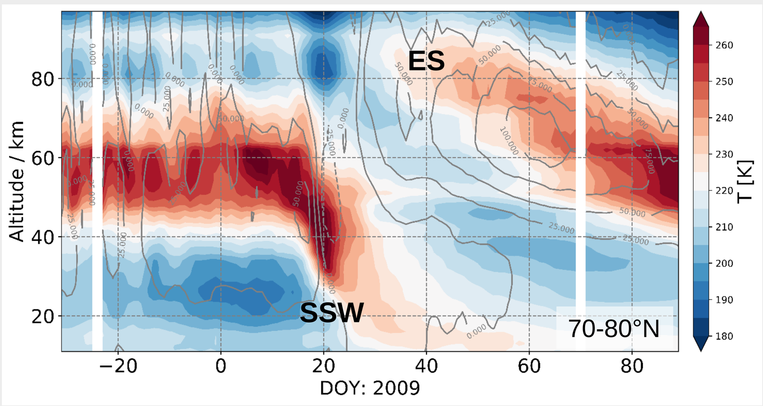

Fig. 1: Zonal mean temperature (colors) and zonal mean zonal wind (contours), both from MLS data onboard Aura satellite

- **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?***

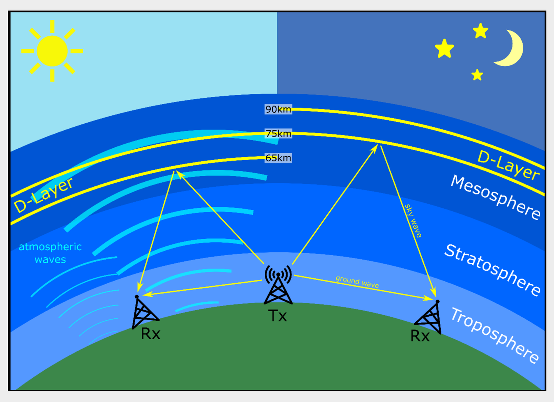

Fig.2: Principle VLF signal propagation from transmitter to receiver with different reflection heights during day and night time [courtesy of V. Wendt]

Data Preparation

Leveling with PELT

- VLF amplitude **level 0 data** (10 min median of 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**)

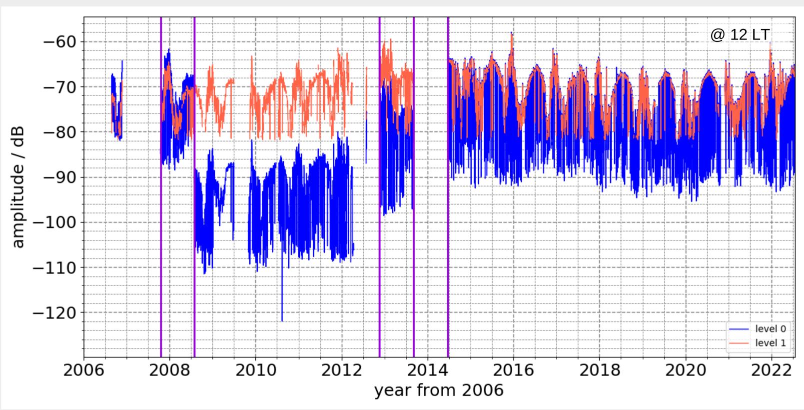

Fig. 3: VLF amplitude for link NAA-NyAlesund. Vertical purple lines mark segments determined with PELT method.

Outlier Detection with MAD

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

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

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

- 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**)

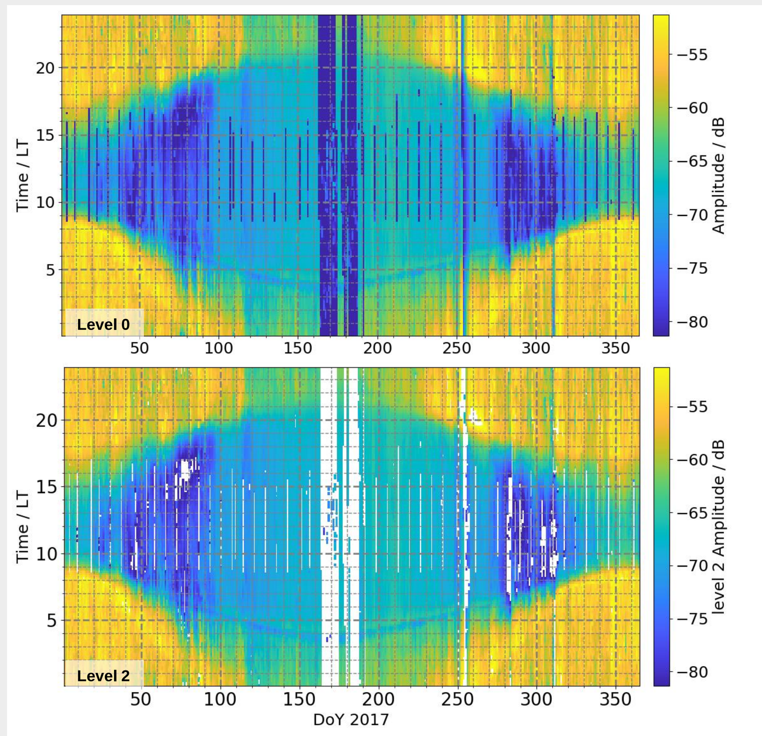

Fig. 4: Diurnal and seasonal variation of VLF amplitude for the link NAA-NyA (Fig. 8).

Quiet time line with composite

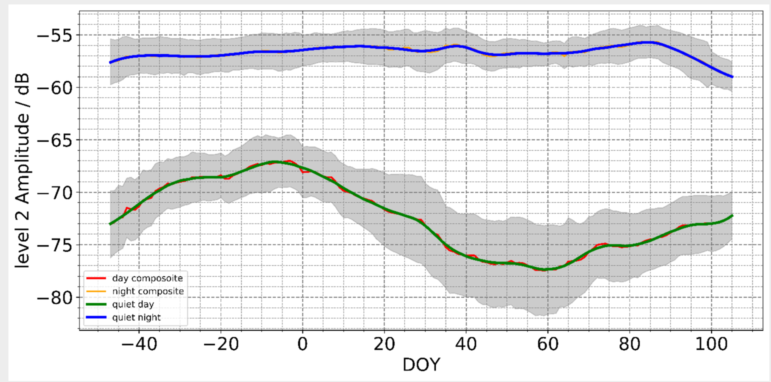

Fig. 5: Quiet time daytime (green) and nighttime (blue) line of VLF signal amplitude for the link NAA-NyAlesund, computed by polynomial fit of daytime composite (red) and nighttime composite (yellow) .

- 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

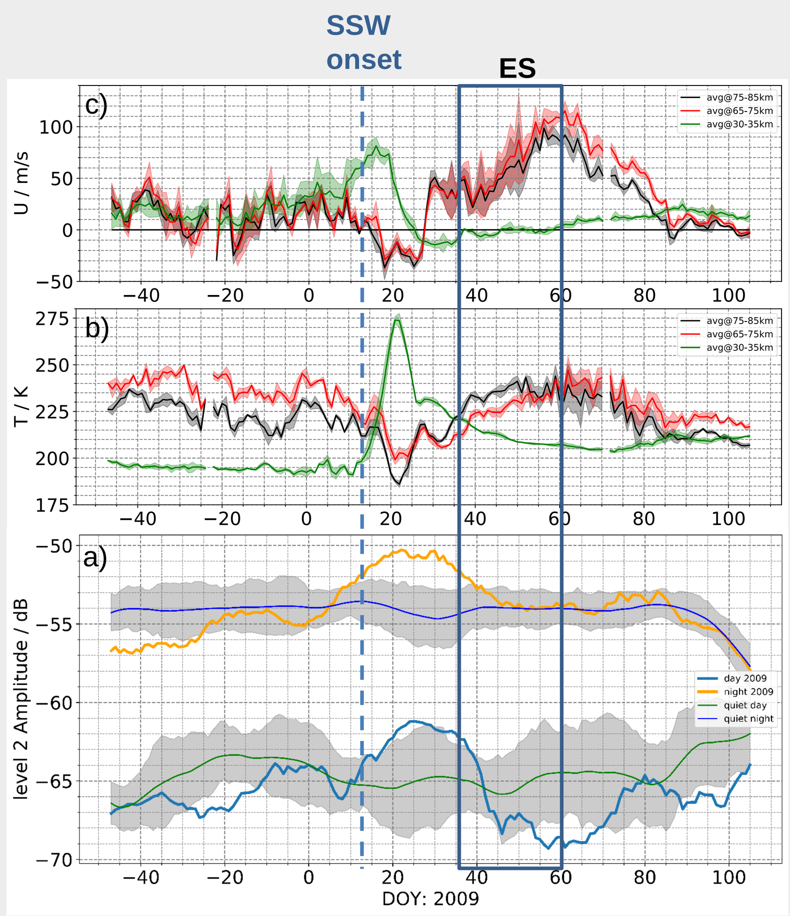

Fig. 6: a) VLF daytime and nighttime amplitude for winter 2009 and the quiet time lines, both for the link ***NRK-NyAlesund.*** *b) temperature and c) zonal wind, both averaged over the 3 segments along the path (****orange boxes*** *in Fig. 8).*

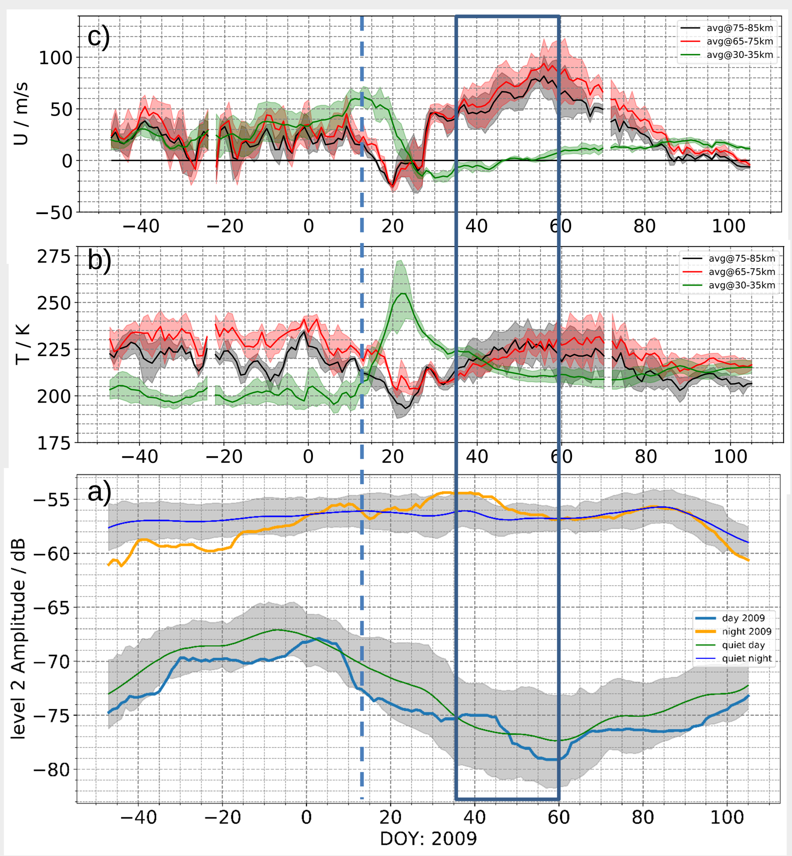

Fig. 7: a) same as in Fig. 6, but for link ***NAA-NyAlesund*** *. b) temperature and c) zonal wind, both averaged over 3 segments along the path (****magenta boxes*** *in Fig. 8)*

- 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) during 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.

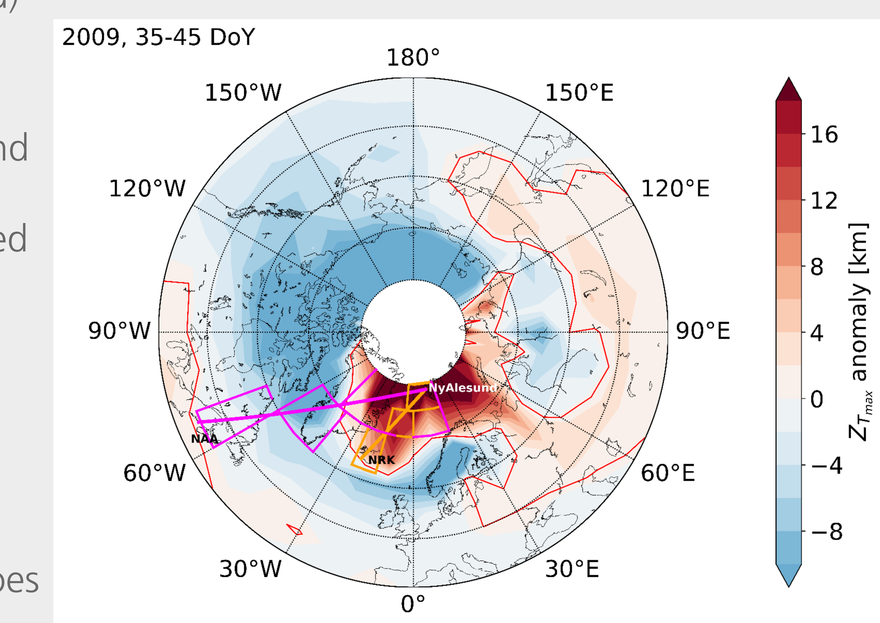

Fig. 8: Stratopause altitude anomaly averaged over period 35-45 DOY 2009. The colored boxes represents segments, used for T and u computation in Fig. 6 and 7. Global satellite data from MLS onboard Aura satellite were used.

Conclusion/Outlook

NRK-NyAlesund:

- temperature and zonal wind changes indirectly responsible for VLF amplitude variation as anticorrelation cannot be observed continuously
- changes in T, u and minor constituents (NO, H_2O, O_3) during SSW/ES indicate a change in global circulation responsible for the VLF perturbation (e.g., NO in Fig. 9b)
- water vapor as a tracer for vertical transport shows strong correlation with daytime signal (R=0.75; see Fig. 9a)

NAA-NyAlesund:

- wave signature which mostly relates to Lyman alpha radiation variation (not shown)

Two links with different pathways showed different VLF signal variation for the same SSW/ES event:

- **NRK-NyAlesund** signal is more affected by the dynamical changes during SSW/ES
- **NAA-NyAlesund** does not show SSW/ES influence, VLF variation relates more due to Lyman alpha variation

➢ **Role of water vapor needs to be clarified!**

➢ **Is the reason for the difference 1) different pathway itself or 2) the long. and lat. differences in strength of SSW/ES and the accompanying minor constituents concentration?**

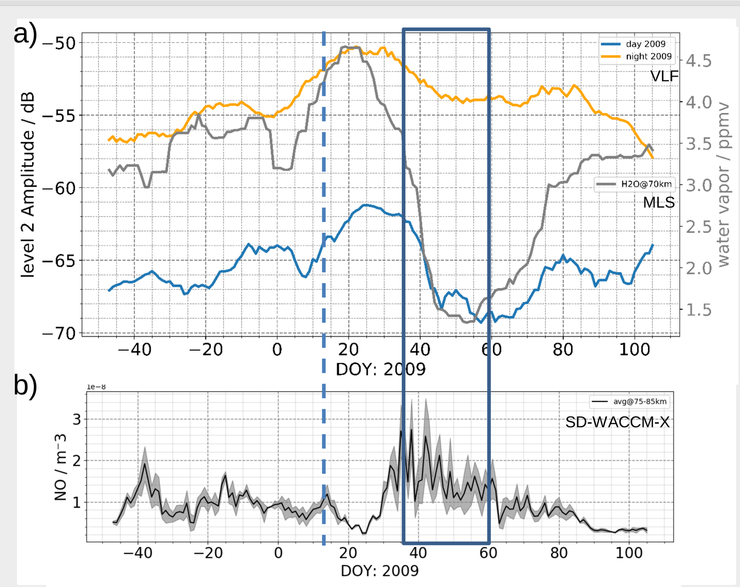

Fig. 9: a) VLF daytime and nighttime amplitude for winter 2009 for ***NRK-NyAlesund*** *and water vapor at 70 km along the path b) NO concentration at 75-85 km along the NRK-NyAlesund path.*

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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.

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