Long-term trends in mesospheric winds and gravity waves extracted from meteor radar measurements and Gaia simulations

Jason Müller

August 14, 2020

Overview

Some basic theory

Methods

Results and Discussion

- Kiruna
- Collm
- Tavistock
- Rio Grande
- Davis Station

Comparison to Wilhelm et al. (2019)

Conclusion

Some basic theory

Circulation driving processes

- 75 km—100 km Mesosphere and lower Thermosphere
- Around Mesopause
- Inversion of temperature gradient from positive to negative
- Eddies keep atmosphere well mixed
- Ionisation does not yet play a major role, the atmosphere is mainly neutral
- Evaporation of meteors occurs here - Plasma in neutral environment

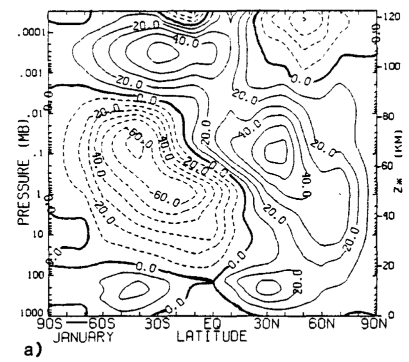
Circulation driving processes

- Radiative heating and cooling
- Gravity-inertia-waves (GWs)
- Tidal waves
- Planetary waves

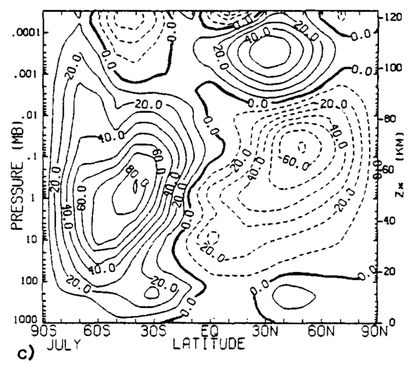
Gravity-inertia-waves

- Produced in lower atmosphere for example by deep convection, storms, flow over mountains...
- Amplitude grows exponentially as density decreases with altitude
- If GWs pass a layer where the horizontal wind is equal to their phase-speed $\rightarrow$filtering
- Momentum deposition by breaking of filtering

Mean circulation



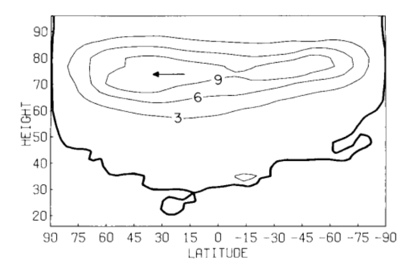
Zonal mean zonal wind distribution in January



Zonal mean zonal wind distribution in July

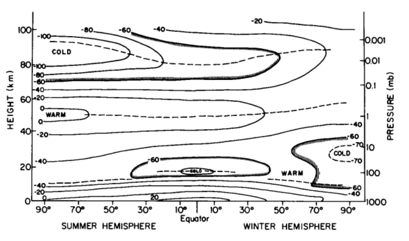
(Chandra et al., 1990)

Mean circulation



Zonal mean meridional wind for Northern-Hemisphere winter solstice

(Andrews et al., 1987)



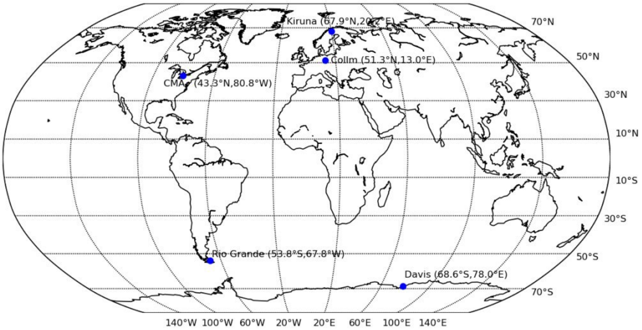
Zonal mean temperature for Northern-Hemisphere winter solstice

Aim of this project

Are there long-term changes in the MLT wind field?
Do they get reproduced by Gaia-model simulations?

Methods

Stations



Kiruna (67.9°N,20.2°E)
Collm (51.3°N,13.0°E)
CMA (43.3°N,80.8°W)
Rio Grande (53.8°S,67.8°W)
Davis (68.6°S,78.0°E)
70°N
50°N
30°N
10°N
10°S
30°S
50°S
70°S
140°W 100°W 60°W 20°W 20°E 60°E 100°E 140°E

Meteor radar

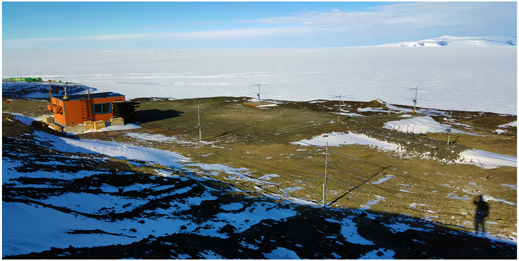
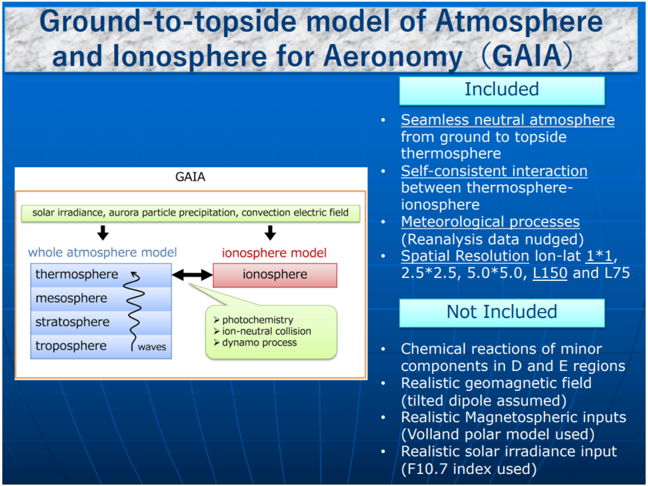


Photo: University of Colorado, Boulder; `https://ccar.colorado.edu/meteors/instrument`

- Meteor radar measures radar signal reflected by plasma
- When Plasma moves with neutral background, wind speeds can be derived

The Gaia Model



Slide: Huixin Liu, Kyushu University, Japan, `https://www.dropbox.com/s/sxaem3cl9vykpis/Huixin_IAP2019.pdf?dl=0`

Data processing

Station	Start	End
Kiruna	01.08.1999	31.12.2019
Collm	01.08.2004	06.03.2019
Tavistock	01.01.2002	31.12.2018
Rio Grande	01.02.2008	31.12.2019
Davis-Station	01.01.2005	31.12.2019

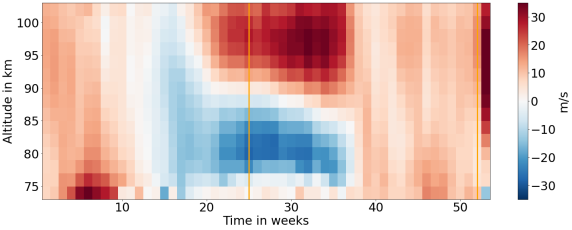
- Relatively short observation periods
- Periods range from 20 years in Kiruna to only 11 years in Rio Grande

Data Processing

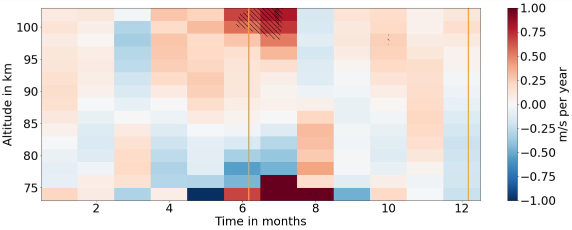
- Data processing via Xarray and Numpy and Scipy
- Climatologies: weekly mean
- Linear trends: monthly mean for more reliable trends
- Regression analysis performed using Scipy
- The linear regression is checked, using a hypothesis test. The results are p-values. Areas with p-values smaller than 0.05(0.01) are marked in the plot
- for further information on the statics used: `https://docs.scipy.org/doc/scipy/reference/generated/scipy.stats.linregress.html`

Results and Discussion

Kiruna 67° N, 20° O

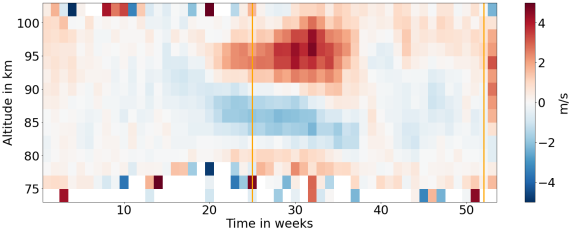


Zonal wind; climatology

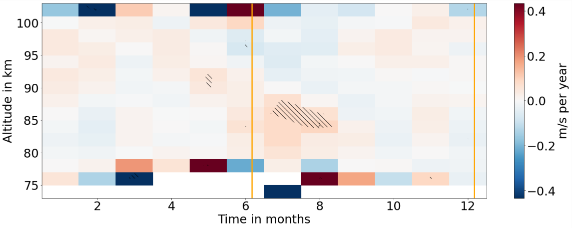


Zonal wind; linear trend

Kiruna 67° N, 20° O

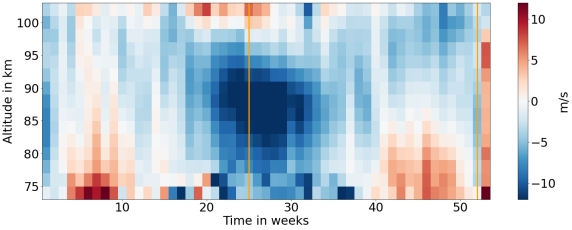


Zonal GW component; climatology

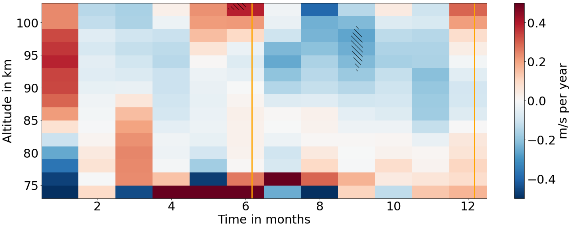


Zonal GW component; linear trend

Kiruna 67° 51' N, 20° 13' O

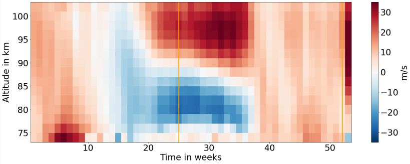


Meridional wind; climatology

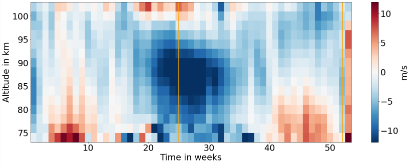


Meridional wind; linear trend

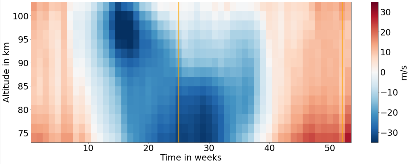
Kiruna 67° N, 20° O



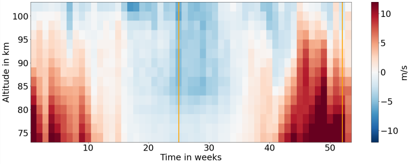
Measured climatology of the zonal wind



Measured climatology of the meridional wind



Simulated climatology of the zonal wind

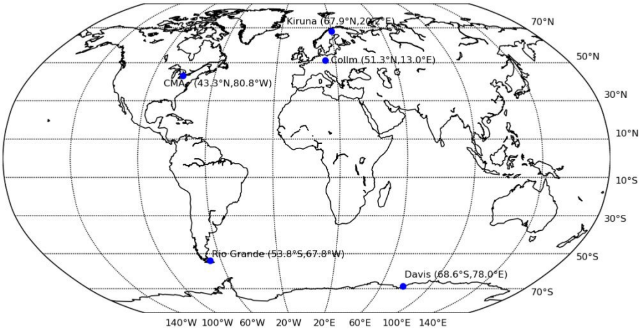


Simulated climatology of the meridional wind

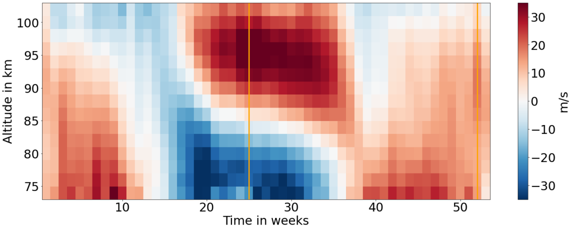
Kiruna 67° N, 20°

- Weak and spatially limited trends
- Existing trends do not seem to be connected to trends in GWs
- Gaia could roughly reproduce the climatology

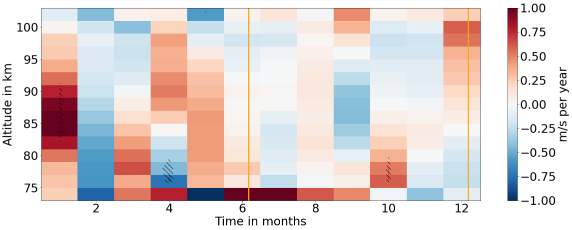
Collm 52° N, 15° O



Collm 52° N, 15° O

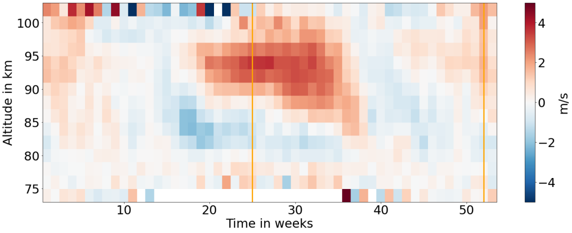


Zonal wind; climatology

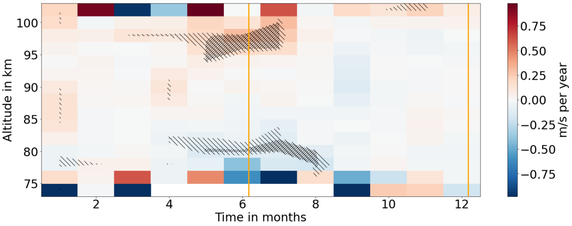


Zonal wind; linear trend

Collm 52° N, 15° O

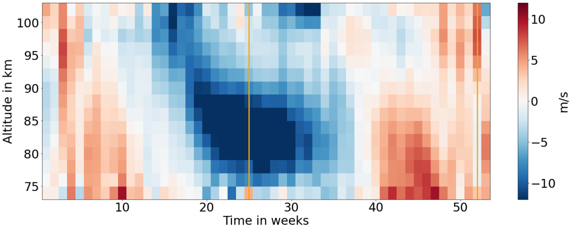


Zonal GW component; climatology

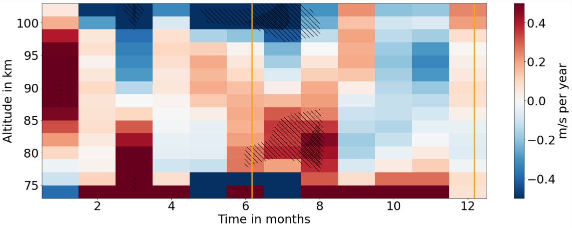


Zonal GW component; linear trend

Collm 52° N, 15° O

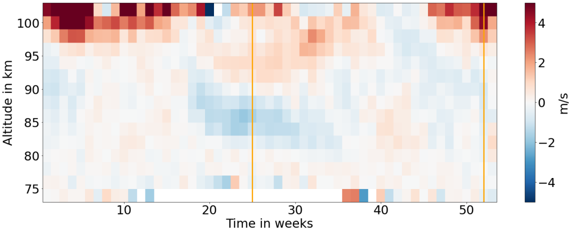


Meridional wind; climatology

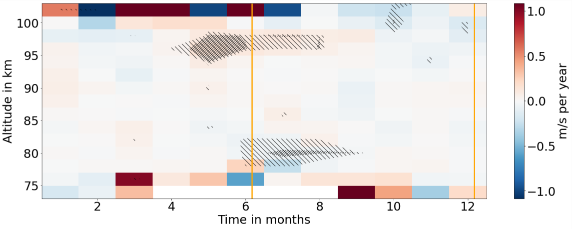


Meridional wind; linear trend

Collm 52° N, 15° O

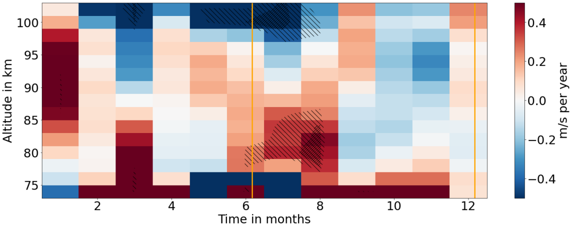


Meridional GW component; climatology

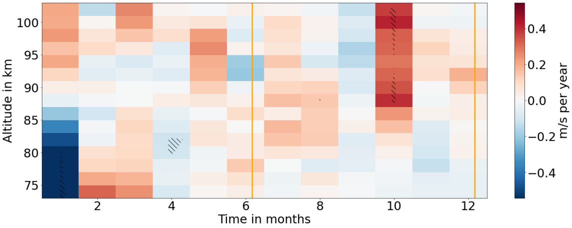


Meridional GW component; linear trend

Collm 52° N, 15° O



Measured meridional wind; linear trend

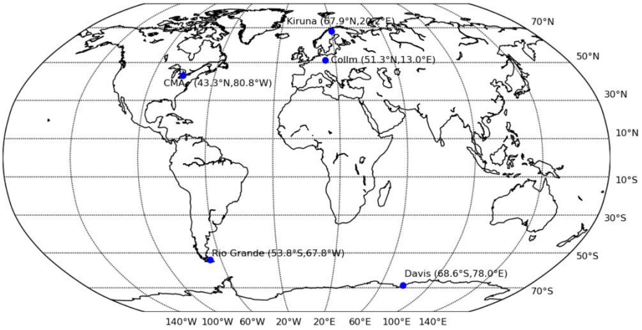


Simulated meridional wind; linear trend

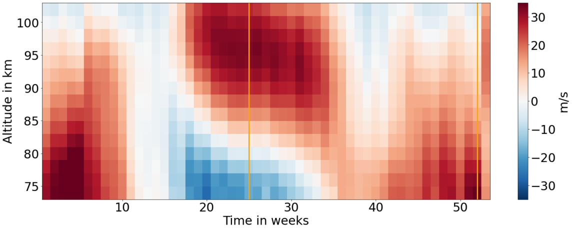
Collm 52° N, 15° O

- Zonal wind does not show any significant trend although there should be a forcing due to changing GW activity
- Meanwhile, the meridional wind does show a significant trend in the particular regions
- Gaia does not simulate the measured trends

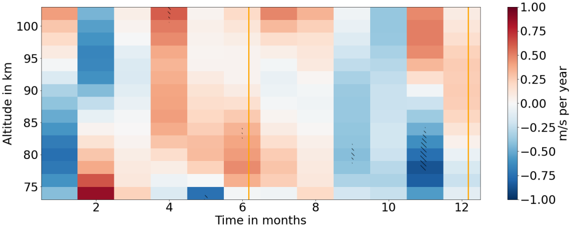
Tavistock 43° N, 81° W



Tavistock 43° N, 81° W

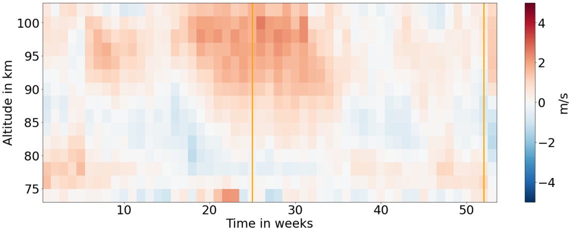


Zonal wind; climatology

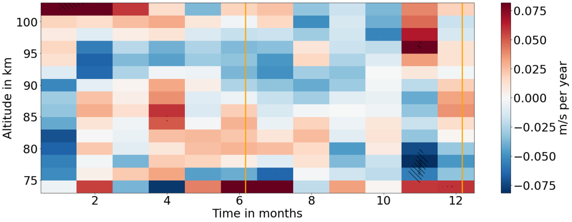


Zonal wind; linear trend

Tavistock 52° N, 15° O

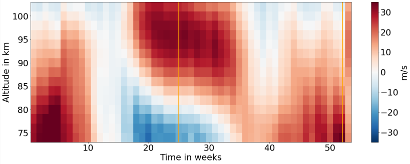


Zonal GW component; climatology

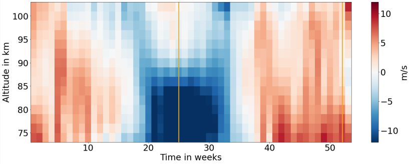


Zonal GW component; linear trend

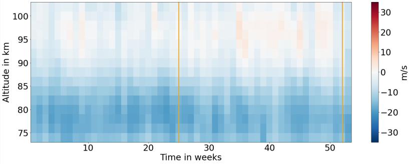
Tavistock 43° N, 81° W



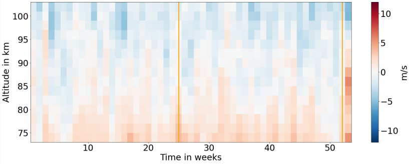
Measured climatology of the zonal wind



Measured climatology of the meridional wind

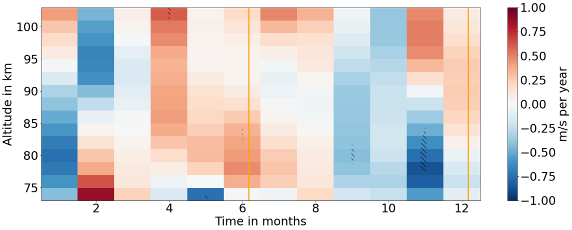


Simulated climatology of the zonal wind

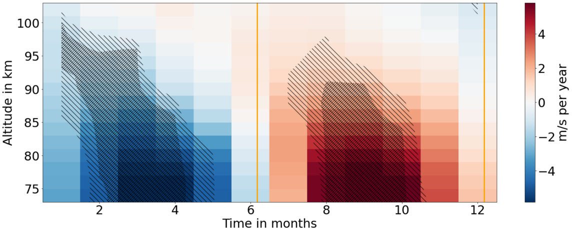


Simulated climatology of the meridional wind

Tavistock 43° N, 81° W

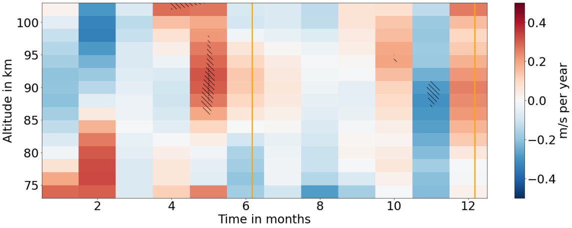


Measured zonal wind; linear trend

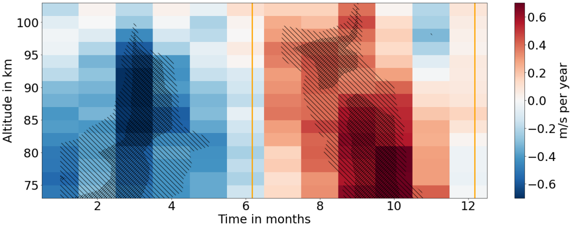


Simulated zonal wind; linear trend

Tavistock 43° N, 81° W

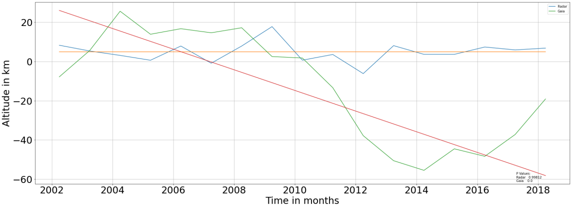


Measured meridional wind; linear trend

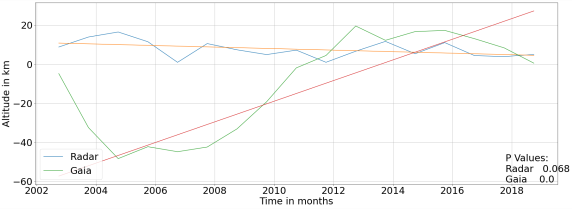


Simulated meridional wind; linear trend

Tavistock 43° N, 81° W



Simulated monthly mean zonal winds in March, 84 km

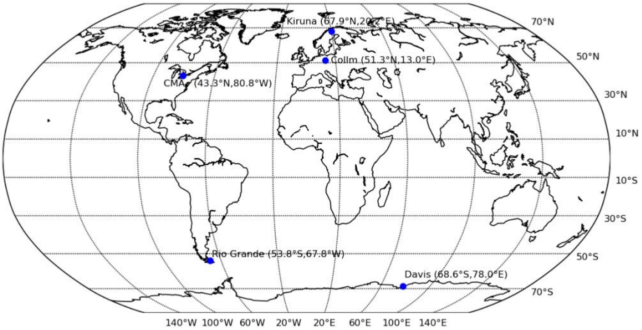


Simulated monthly mean zonal winds in September, 84 km

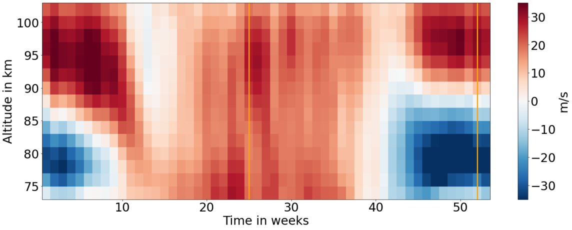
Tavistock 43° N, 81° W

- Weak trends in zonal and meridional winds, each with an corresponding trend in their GWs component
- Extreme differences between measured and simulated climatology and wind trends
- Gaia simulations show wave-like structure of monthly mean wind in spring and autumn with periods of 20 Years.
- Longer time series and data verification required

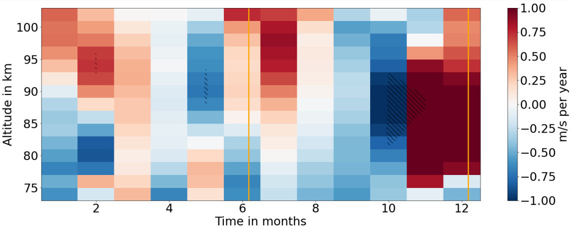
Rio Grande 53° S, 67° W



Rio Grande 53° S, 67° W

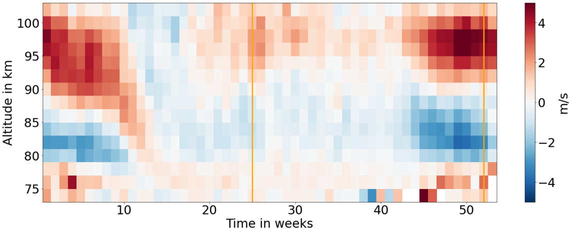


Zonal wind; climatology

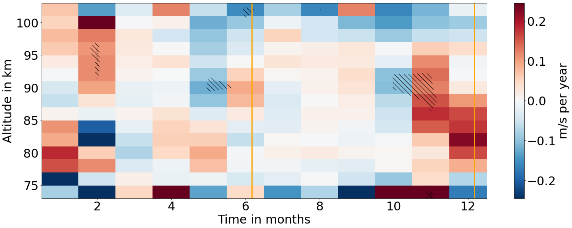


Zonal wind; linear trend

Rio Grande 53° S, 67° W

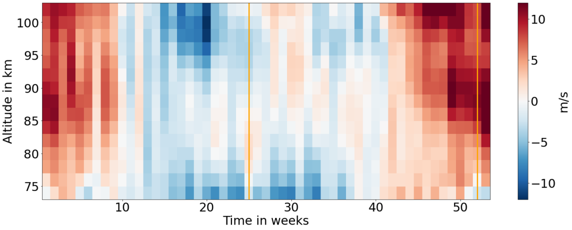


Zonal GW component; climatology

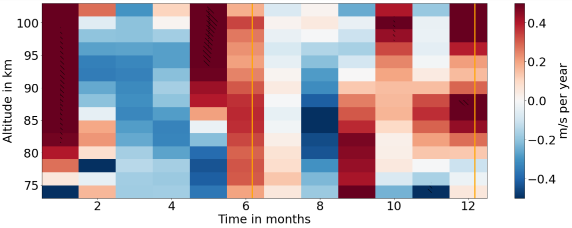


Zonal GW component; linear trend

Rio Grande 53° S, 67° W

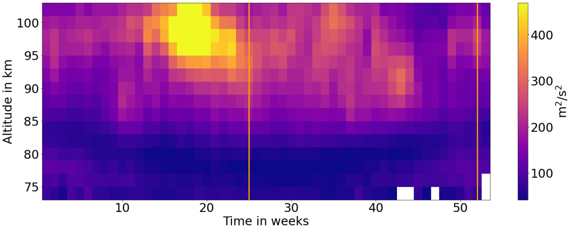


Meridional wind; climatology

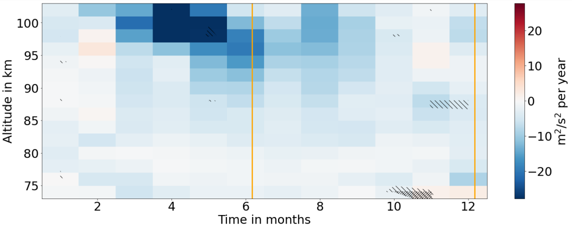


Meridional wind; linear trend

Rio Grande 53° S, 67° W



Gravity wave(GW) kinetic energy; climatology

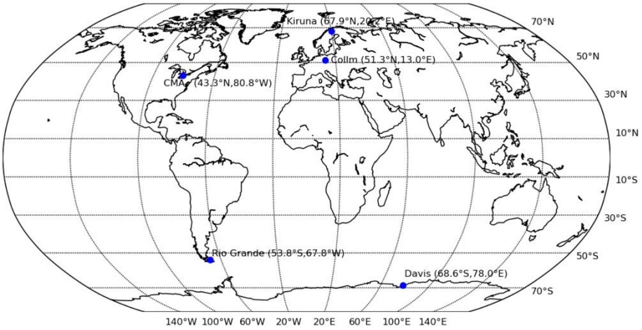


Gravity wave(GW) kinetic energy; linear trend

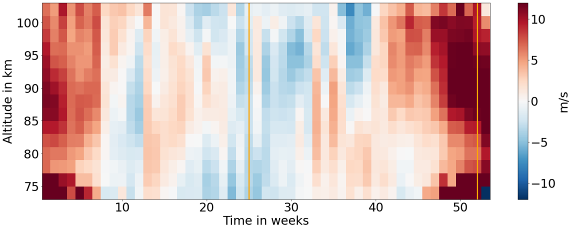
Rio Grande 53° S, 67° W

- Zonal and meridional wind show significant trends which correspond to trends in GWs
- Meridional wind shows pronounced minimum in Spring in about 100 km altitude. This region corresponds very well to an maximum of GW kinetic energy
- Gaia does not reproduce any of the measured significant trends

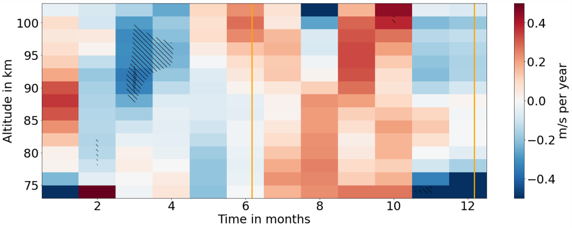
Davis 68° S, 77° O



Davis 68° S, 77° O

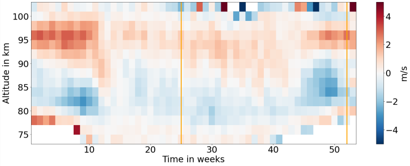


Meridional wind; climatology

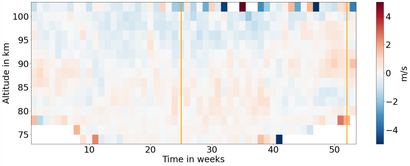


Meridional wind; linear trend

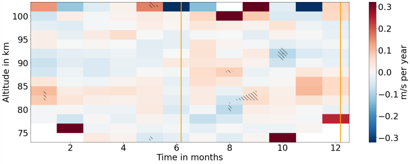
Davis 68° S, 77° O



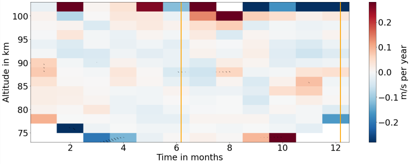
Zonal GW component; climatology



Meridional GW component; climatology

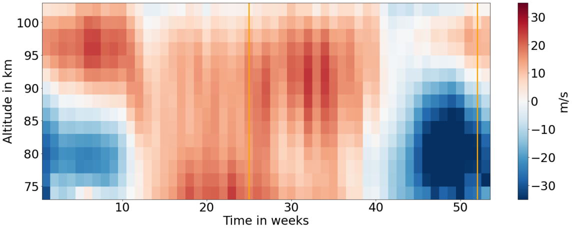


Zonal GW component; linear trend

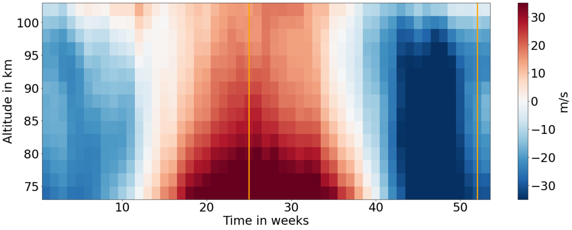


Meridional GW component; linear trend

Davis 68° S, 77° O

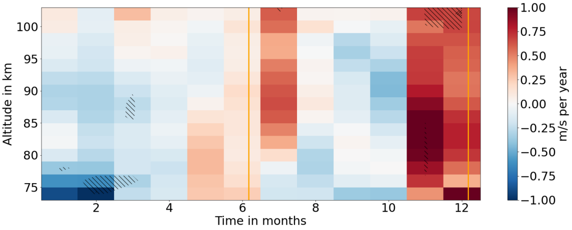


Measured zonal wind; climatology

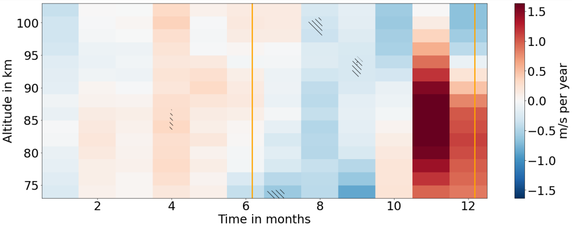


Simulated zonal wind; climatology

Davis 68° S, 77° O

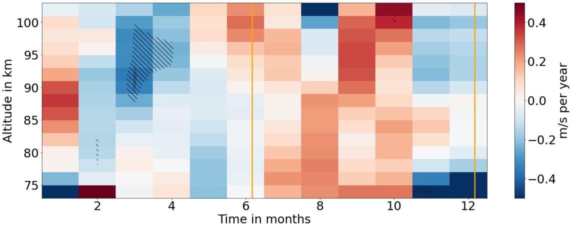


Measured zonal wind; linear trend

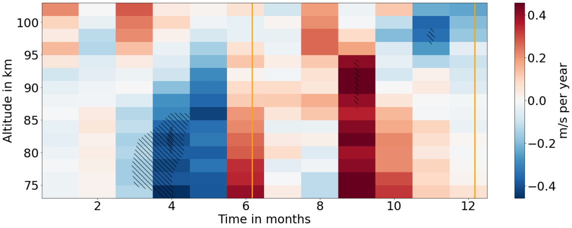


Simulated zonal wind; linear trend

Davis 68° S, 77° O

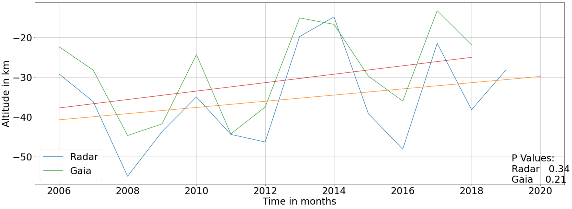


Measured meridional wind; linear trend



Simulated meridional wind; linear trend

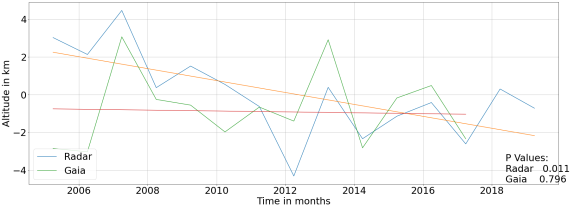
Davis 68° S, 77° O



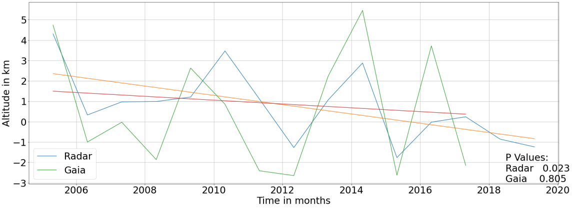
Simulated monthly mean zonal winds in December, 84 km

Simulated monthly mean zonal winds in December, 88 km

Davis 68° S, 77° O

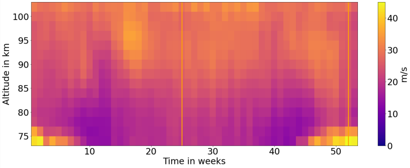


Simulated monthly mean meridional winds in March, 94 km

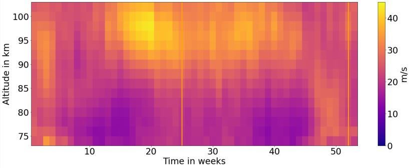


Simulated monthly mean meridional winds in April, 94 km

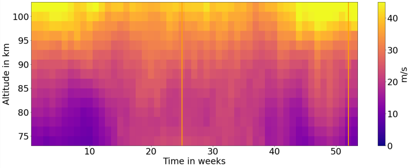
Davis 68° S, 77° O



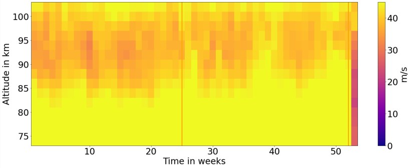
Measured standard deviation of u in Davis



Measured standard deviation of u in Rio Grande



Simulated standard deviation of u in Davis



Simulated standard deviation of u in Rio Grande

Davis 68° S, 77° O

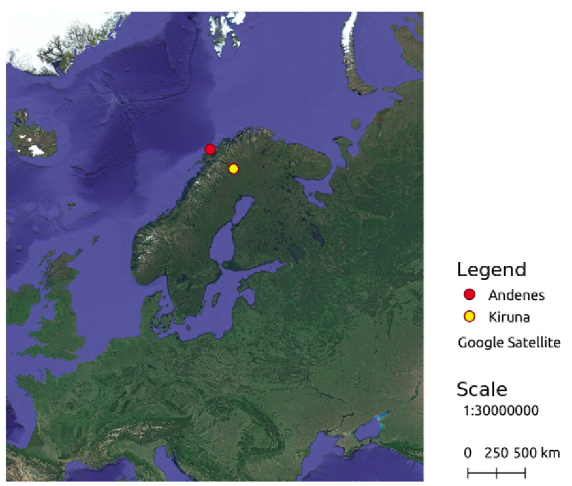
- Both, the zonal and meridional wind show strong and significant trends
- GWs are very weak and do not show any significant trends
- The circulation in Davis is most probably not driven by GWs
- Gaia simulates the climatology and the long-term changes exceptionally well
- This might be a hint to some problems of Gaia with GWs

Comparison to Wilhelm et al. (2019)

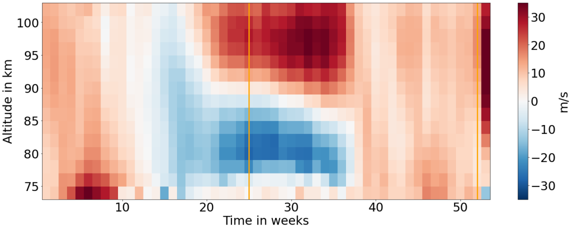
Comparing Kiruna to Andenes

- Similar (meteor) radars used
- Homogenisation of data to prevent errors, caused by changes at the radars
- Adaptive spectral filtering of time series applied, resulting in a mush smoother timer series with clearer trends
- Stations: Andenes, Juliusruh, Tavistock (CMA) between 2002 and 2018
- Trends with p-values of 0.1 (0.05) are accepted

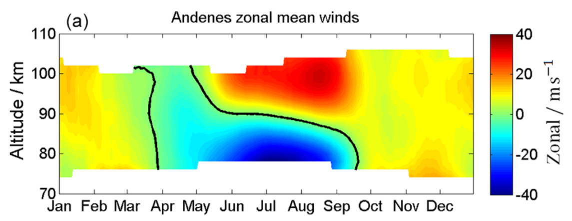
Comparing Kiruna to Andenes



Comparing Kiruna to Andenes

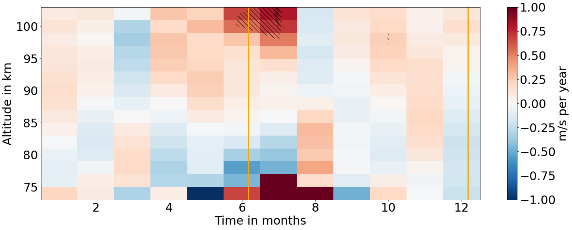


Zonal wind climatology; Kiruna

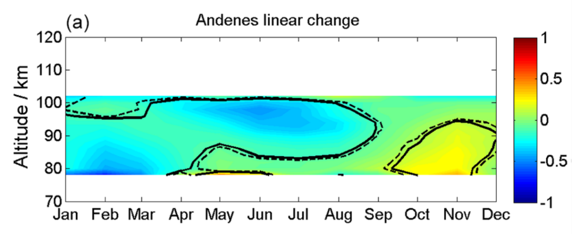


Zonal wind climatology; Andenes

Comparing Kiruna to Andenes

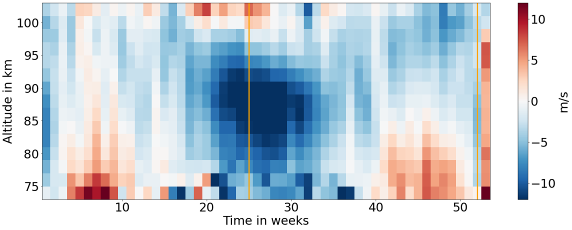


Zonal wind trends; Kiruna

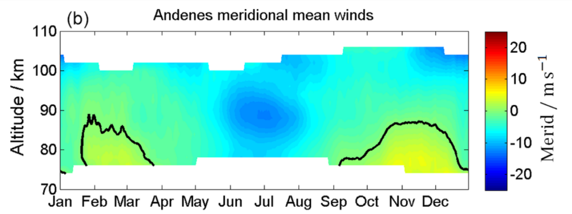


Zonal wind trends; Andenes

Comparing Kiruna to Andenes

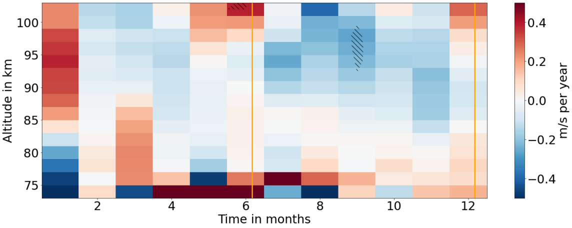


Meridional wind climatology; Kiruna

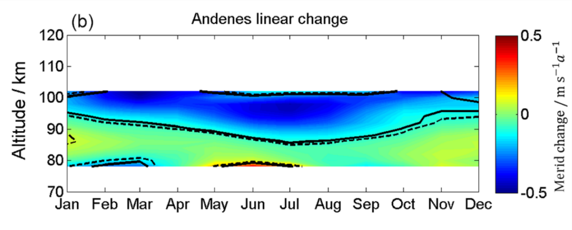


Meridional wind climatology; Andenes

Comparing Kiruna to Andenes

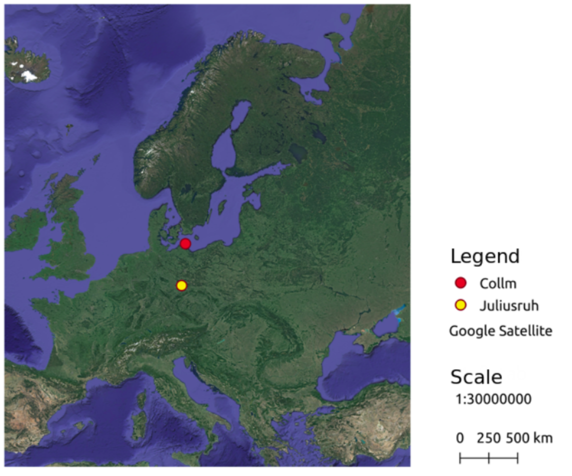


Meridional wind trends; Kiruna

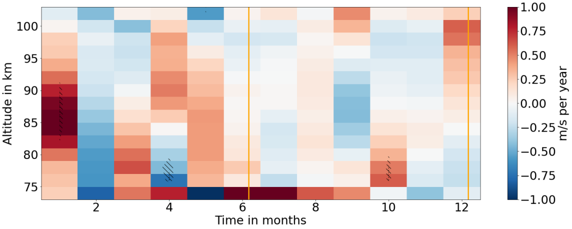


Meridional wind trends; Andenes

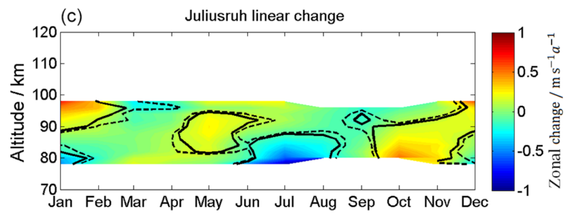
Comparing Collm to Juliusruh



Comparing Collm to Juliusruh

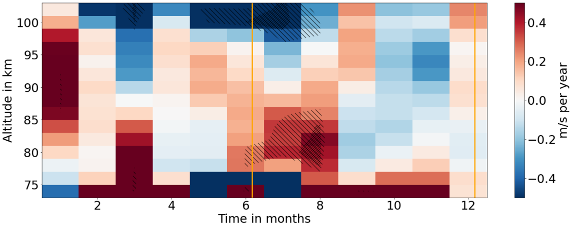


Zonal wind trends; Collm

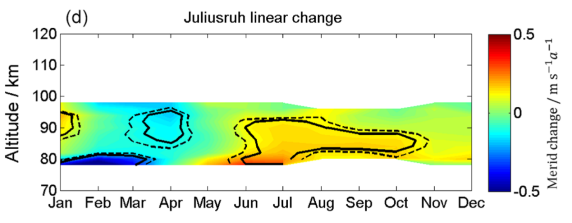


Zonal wind trends; Juliusruh

Comparing Collm to Juliusruh



Meridional wind trends; Collm



Meridional wind trends; Juliusruh

Comparison to Wilhelm et al. (2019)

- Very similar climatologies
- Trends show large differences, even significant trends with reversed sign e.g. zonal wind in June in Andenes/Kiruna or March in Collm/Juliusruh
- Difference might be due to very local effects, differences in the preprocessing of the data or statistical errors due to the short time periods

Conclusion

Conclusion

- Winds in the Mesosphere and lower Thermosphere heavily depend on latitude, longitude, altitude and time
- Many stations show significant long-term trends. However, magnitude, time of year and altitude differ widely between the each of the stations
- While some significant trends appear to be connected to GWs, other trends do not
- Trends in the meridional wind component and in lower latitudes seem to be closer related to trends in GWs than trends of the zonal wind component and higher latitudes.
- In large parts, Gaia can not reproduce trends of the MLT winds. However, this is not true for the Davis-Station, where the simulations reproduce the winds very well.

Possible improvements

- Longer time series
- More stations
- Analysis of tidal components and planetary waves

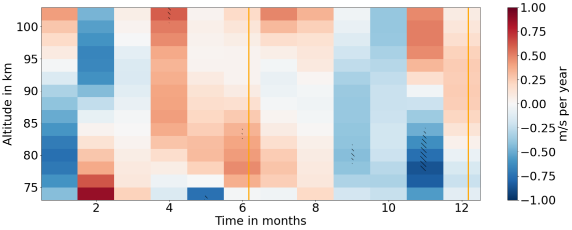
References

Andrews, D. G., Leovy, C. B., and Holton, J. R. (1987). *Middle atmosphere dynamics*. Academic press.

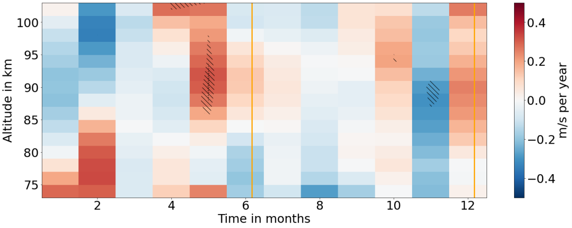
Chandra, S., Fleming, E. L., Schoeberl, M. R., and Barnett, J. J. (1990). Monthly mean global climatology of temperature, wind, geopotential height and pressure for 0–120 km. *Advances in Space Research*, 10(6):3–12.

Wilhelm, S., Stober, G., and Brown, P. (2019). Climatologies and long-term changes in mesospheric wind and wave measurements based on radar observations at high and mid latitudes. In *Annales Geophysicae*, volume 37, pages 851–875. Copernicus GmbH.

Backup

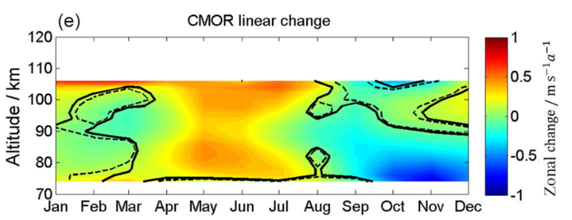


CMA zonal wind trend

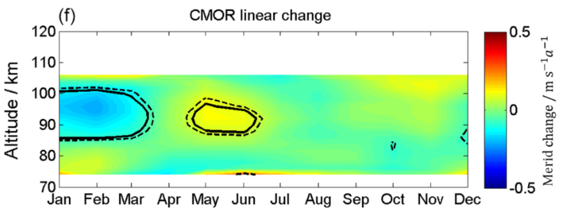


CMA meridional wind trend

Backup

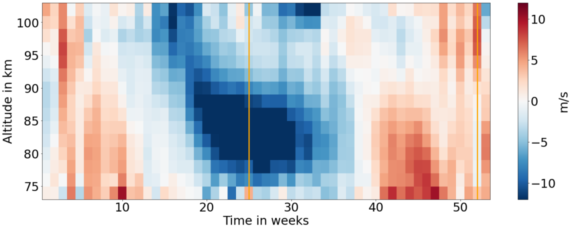


CMA zonal wind trend

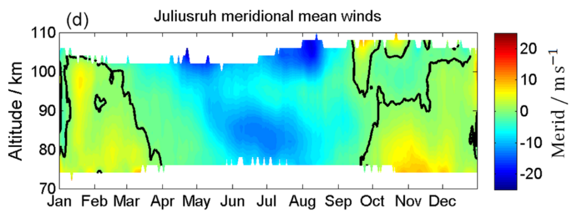


CMA meridional wind trend

Comparing Collm to Juliusruh

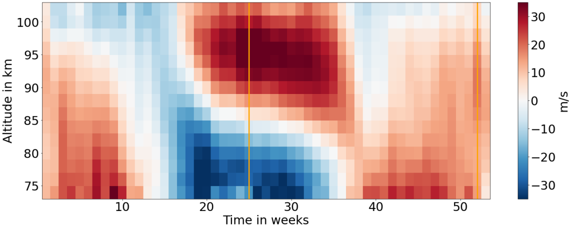


Meridional wind climatology; Collm

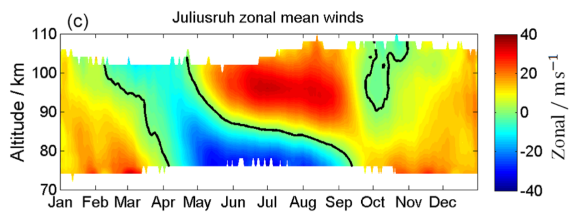


Meridional wind climatology; Juliusruh

Comparing Collm to Juliusruh



Zonal wind climatology; Collm



Zonal wind climatology; Juliusruh