First insights into the project LISA:
Lidar measurements to Identify Streamers and analyze Atmospheric waves (Aeolus+Innovation)

Lisa Küchelbacher[1], Jaroslav Chum[2], Oleg Goussev[1], Peter Križan[2], Michal Kozubek[2], Jan Laštovička[2], Katerina Podolska[2], Tereza Šindelářová[2], Franziska Trinkl[1], Sabine Wüst[1], Michael Bittner[1]

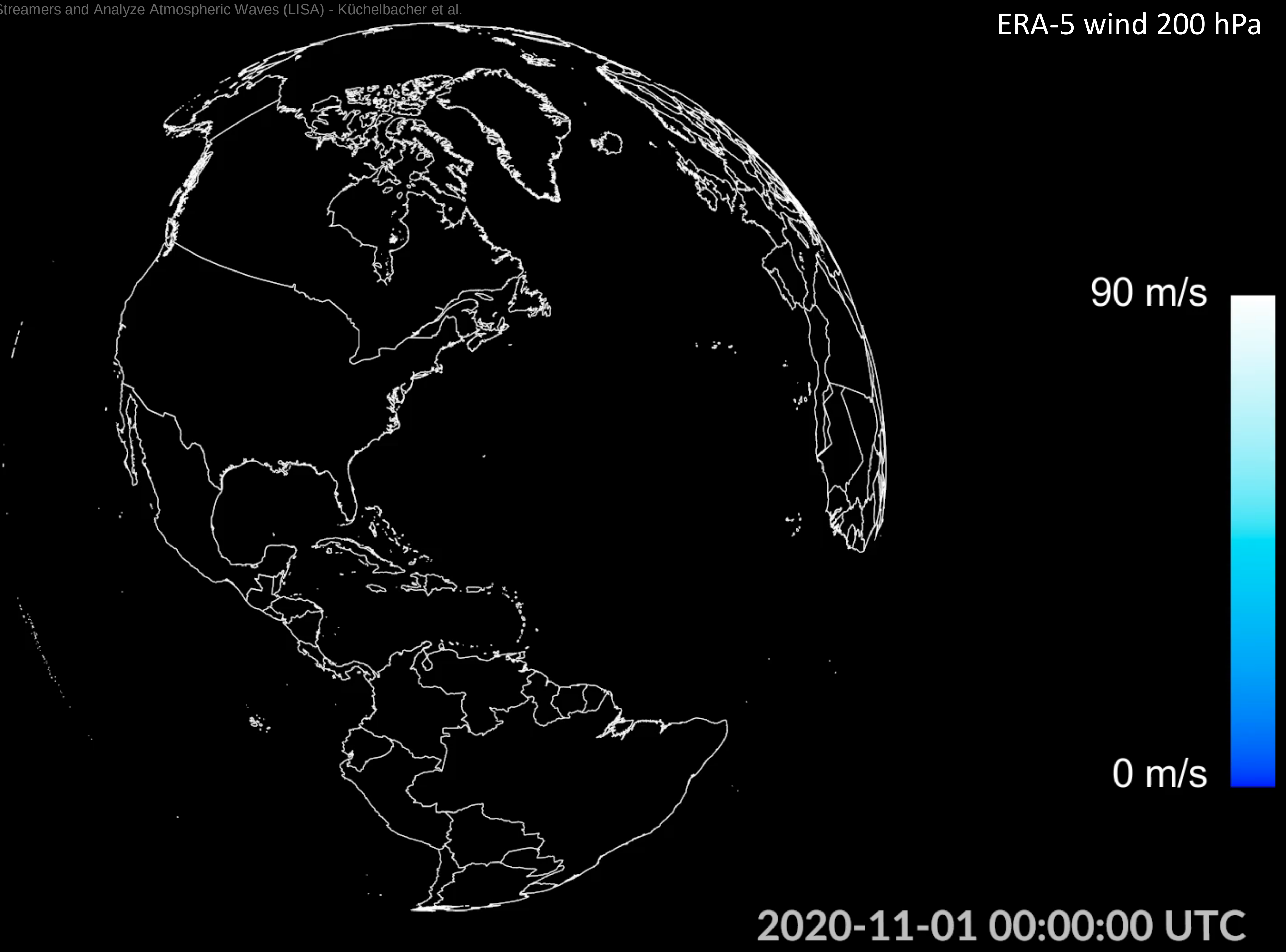
1 German Aerospace Center, DLR-EOC-DFD, Oberpfaffenhofen, Germany
2 Institute of Atmospheric Physics, CAS-IAP, Prague, Czech Republic

INSTITUTE OF ATMOSPHERIC PHYSICS
CAS

PW are the main drivers of the large-scale weather patterns of the mid-latitudes.

Breaking of PW leads to large-scale tongue-like structures (streamer events) and cut-offs of air masses, such as high- or low pressure cells.

Poleward breaking PW lead airmasses into the higher latitudes. Such streamer events are considered in the project.



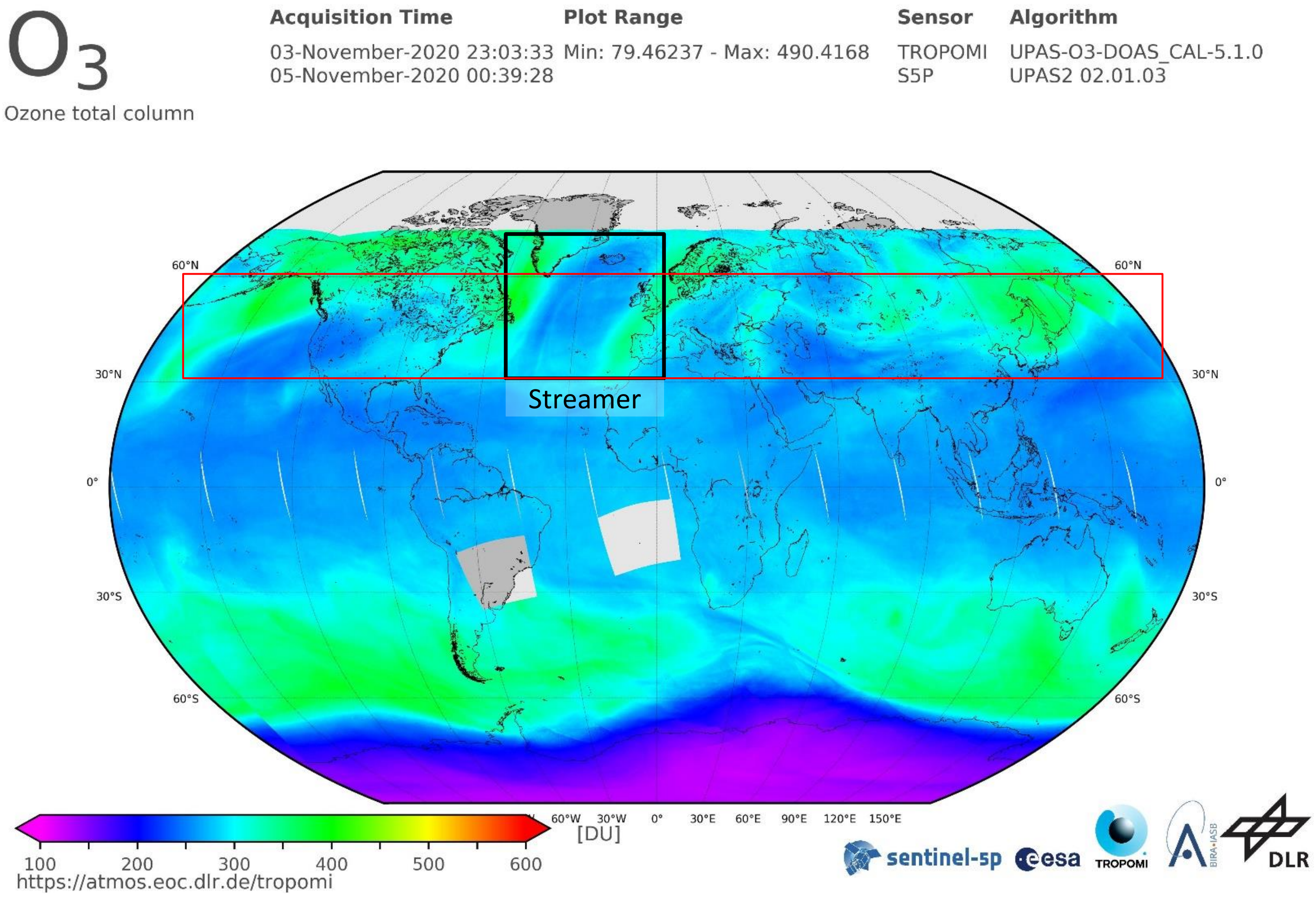
Streamer events in TO3

Streamer events

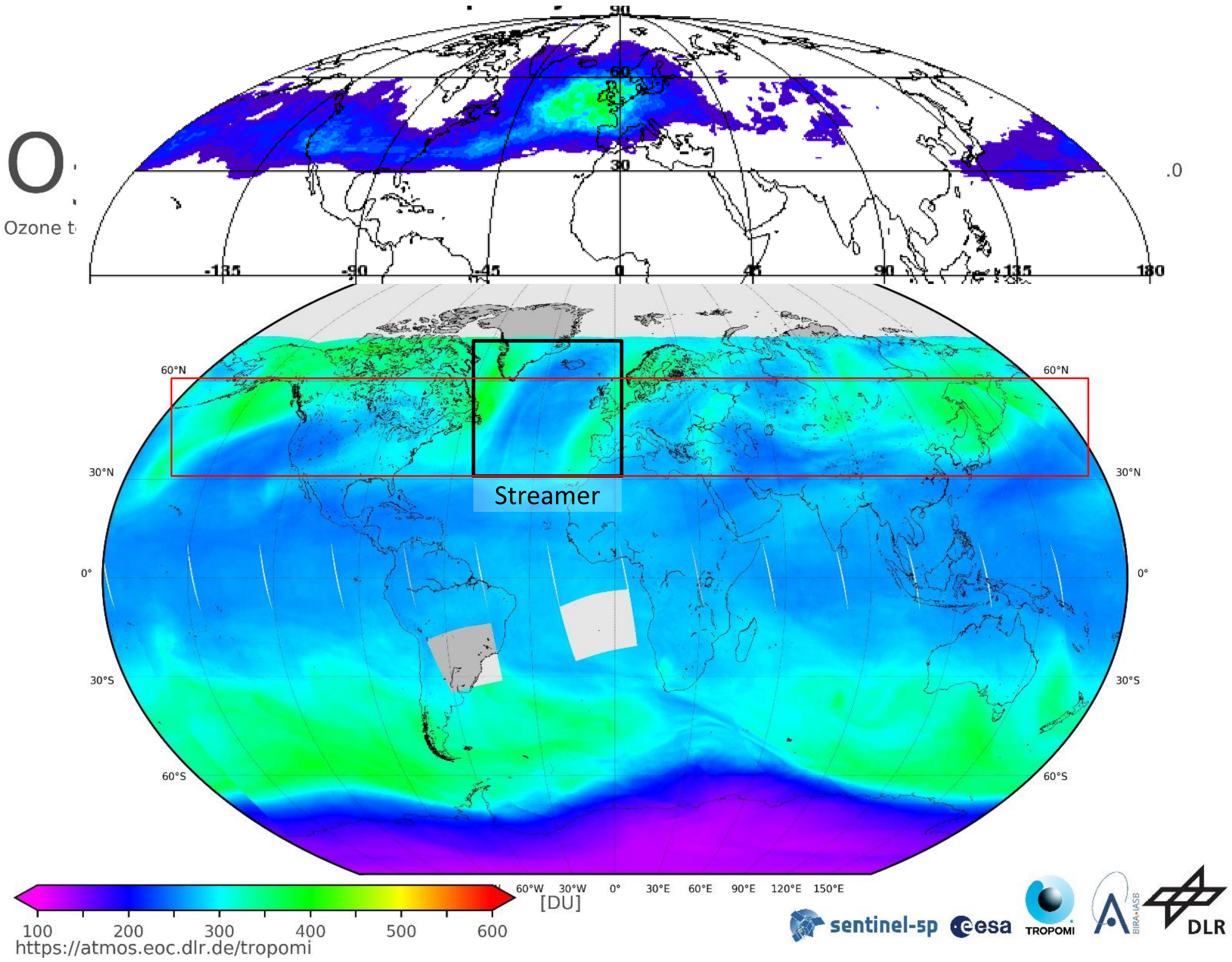
PW dominate the meridional Brewer-Dobson circulation in the stratosphere and thus the large-scale mass transport of ozone.

Due to poleward breaking PW air masses with low ozone concentration are irreversible mixed into the mid-latitudes.

→ **Streamer are efficient processes for meridional mixing**



Streamer events in TO3



Streamer events

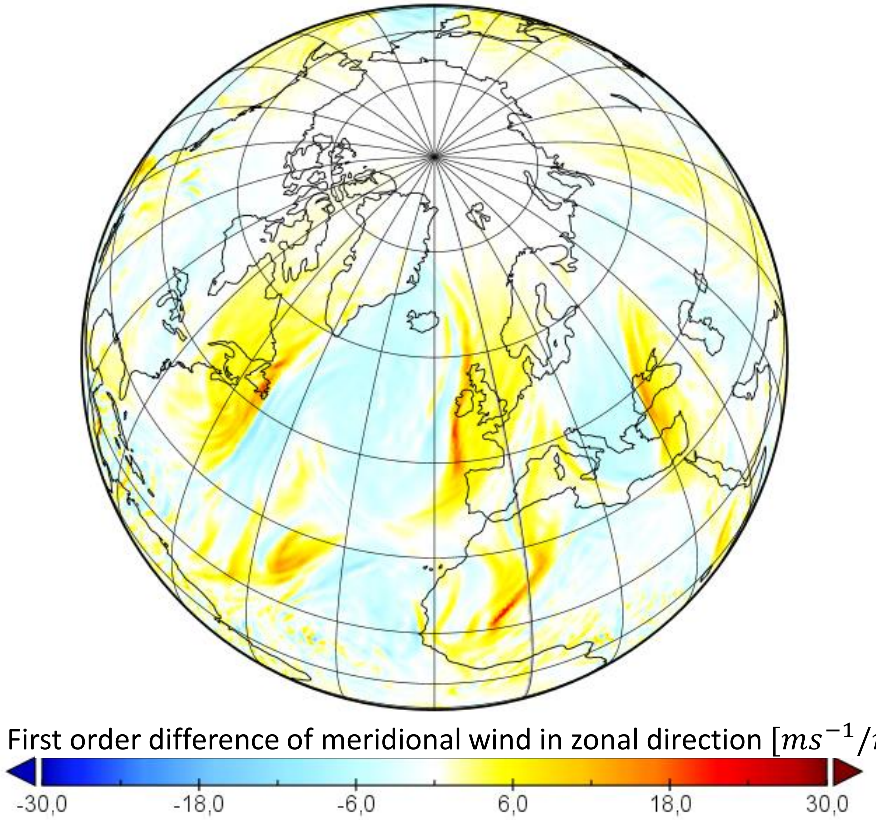
PW dominate the meridional Brewer-Dobson circulation in the stratosphere and thus the large-scale mass transport of ozone.

Due to poleward breaking PW air masses with low ozone concentration are irreversible mixed into the mid-latitudes.

PW predominantly break at Northatlantic / Europe (James 1998)

→ ***very interesting region for studies of atm. dynamics!***

Wave dynamics due to streamers



First order difference of meridional wind in zonal direction $[ms^{-1}/m]$

- Link between poleward breaking planetary waves exciting gravity waves (Zülicke & Peters 2008)
- Observations of anticyclones which excite GWs (e.g. Kramer et al, 2015, 2016)
- Substantial deviation between the model and observation due to wave links across scales (Hocke et al. 2017)
- Aeolus uniquely enables studies of waves at different scales in detail over the Northern Atlantic were wind measurements are still sparse

$\hookrightarrow$ Identification of the source regions and quantification of the different wave parameters (period, wavelength, amplitude) required.

Project idea and main goals

Characterization of the dynamical situation of the atmosphere with respect to streamer events by Aeolus measurements

Demonstration of products in case studies with respect to **streamer events**

Data comparison
- Comparison of ERA-5 data and Aeolus measurements

Aeolus data
- Planetary wave activity
- Gravity wave activity

Supplement data
- Gravity waves

Comparison of ERA5 and AEOLUS

- Comparison of zonal wind at 100, 150 and 200 hPa from AEOLUS and ERA5 show a systematic difference between Aeolus and ERA5 (AEOLUS shows stronger winds)
- The difference between ERA5 and Aeolus differs per zonal band (largest for higher latitudes)
- The main features (variability or structure of time series) are very similar

Average (max) in m/s	65°-60°N	60°-55°N	55°-50°N	50°-45°N
100 hPa	1 (3.5)	0.3 (1)	-2.5 (4.3)	2 (4)
150 hPa	0.8 (1.8)	0.9 (2.7)	0.5 (2.1)	1.1 (1.9)
200 hPa	1.5 (3)	0.5 (2.5)	1 (4)	1.8 (4)

Planetary waves: Calculation of Dynamical Activity Index (DAI)

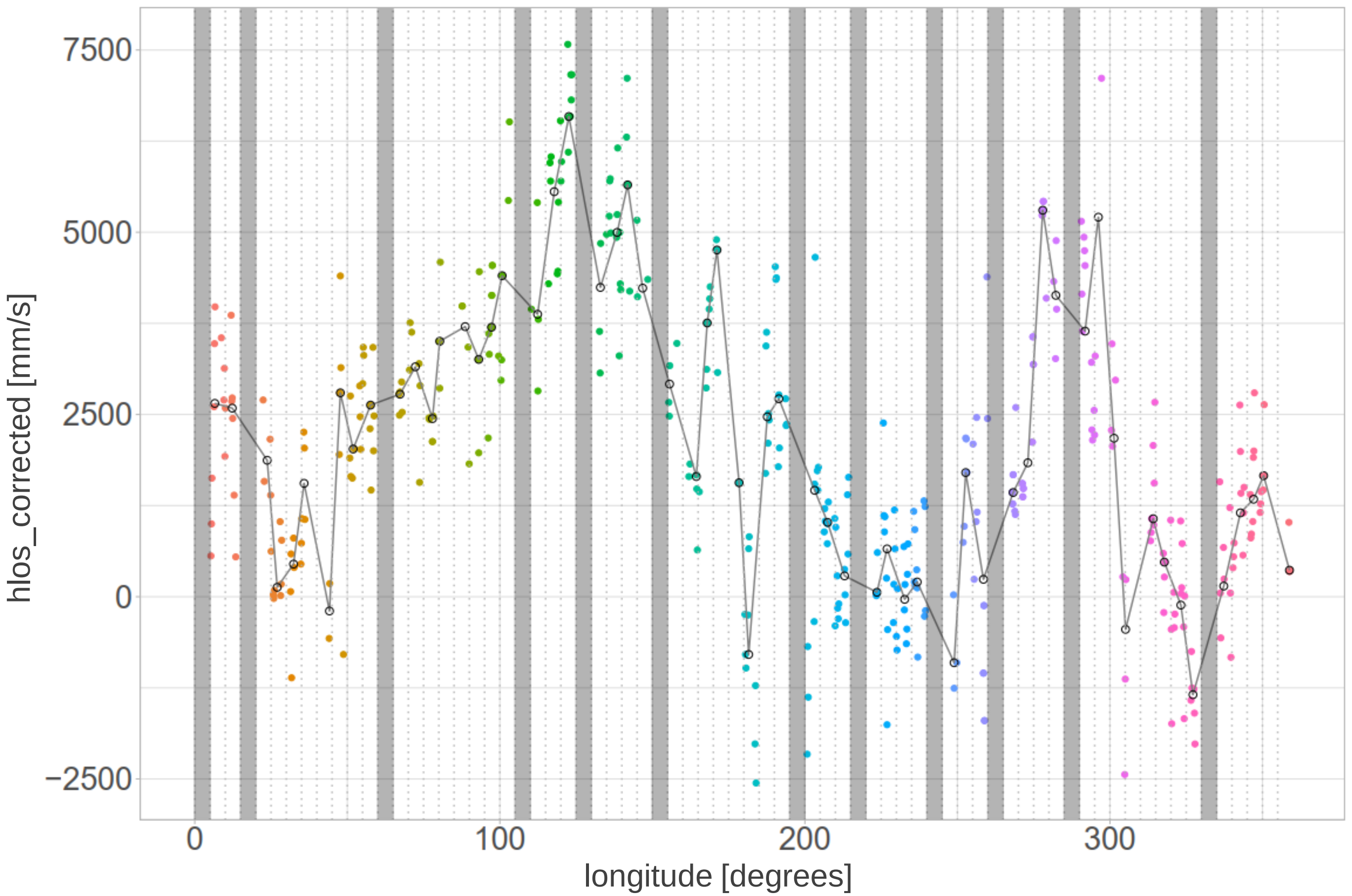
Bittner et al. 1997, Erbertseder et al. 2006

- hlos_corrected integrated over **5 days**
- **Median** hlos_corrected is calculated on equidistant lon, lat grid (black circle)
- If no median hlos value is available in grid **NaN values** are created (grey shade)
- If more than 85% of data is available for one latitude interval,
- Residuals of all median hloc_corrected values will be analyzed by HA.

$$hlos'_{cor}(\lambda)|_{\phi,t} = \left[\sum_{i=1}^{9} \boldsymbol{A_i} \sin\left(\frac{2\pi}{\lambda_i}\ \lambda\ + \varphi_i\right)\right]_{|\phi,t}$$

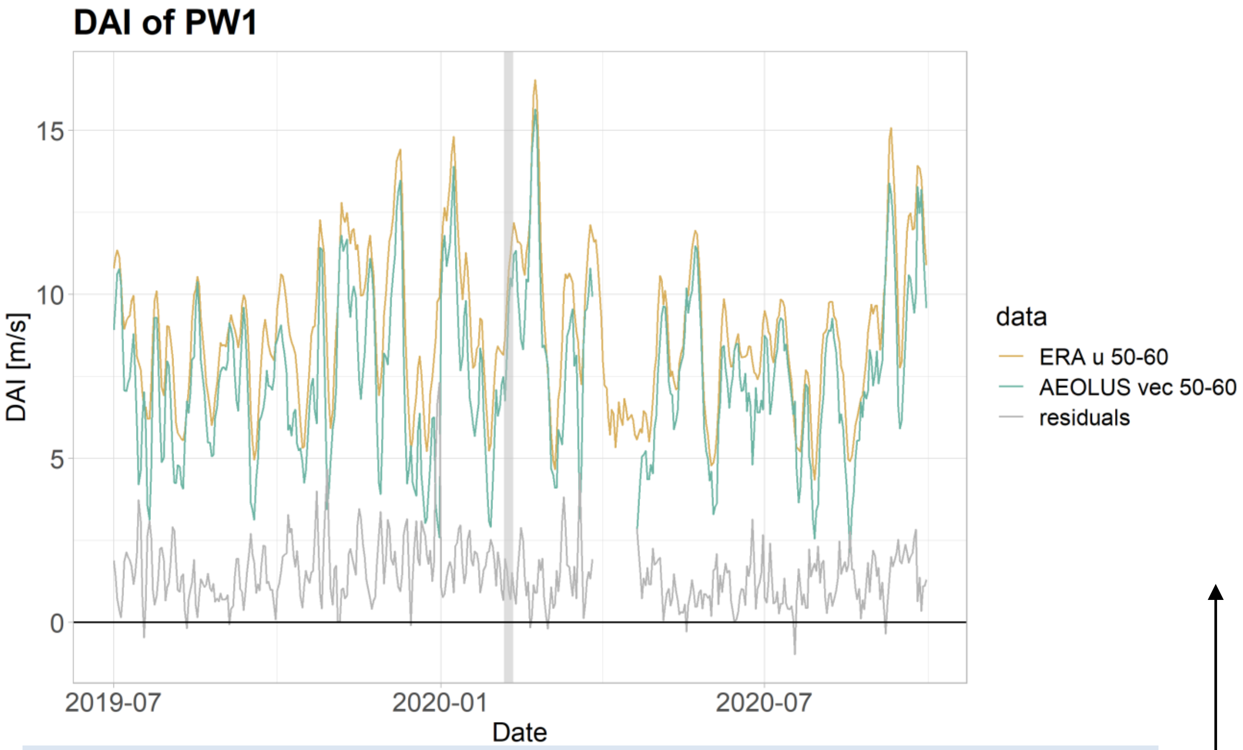
- DAI represents the mean amplitude 30-70°N

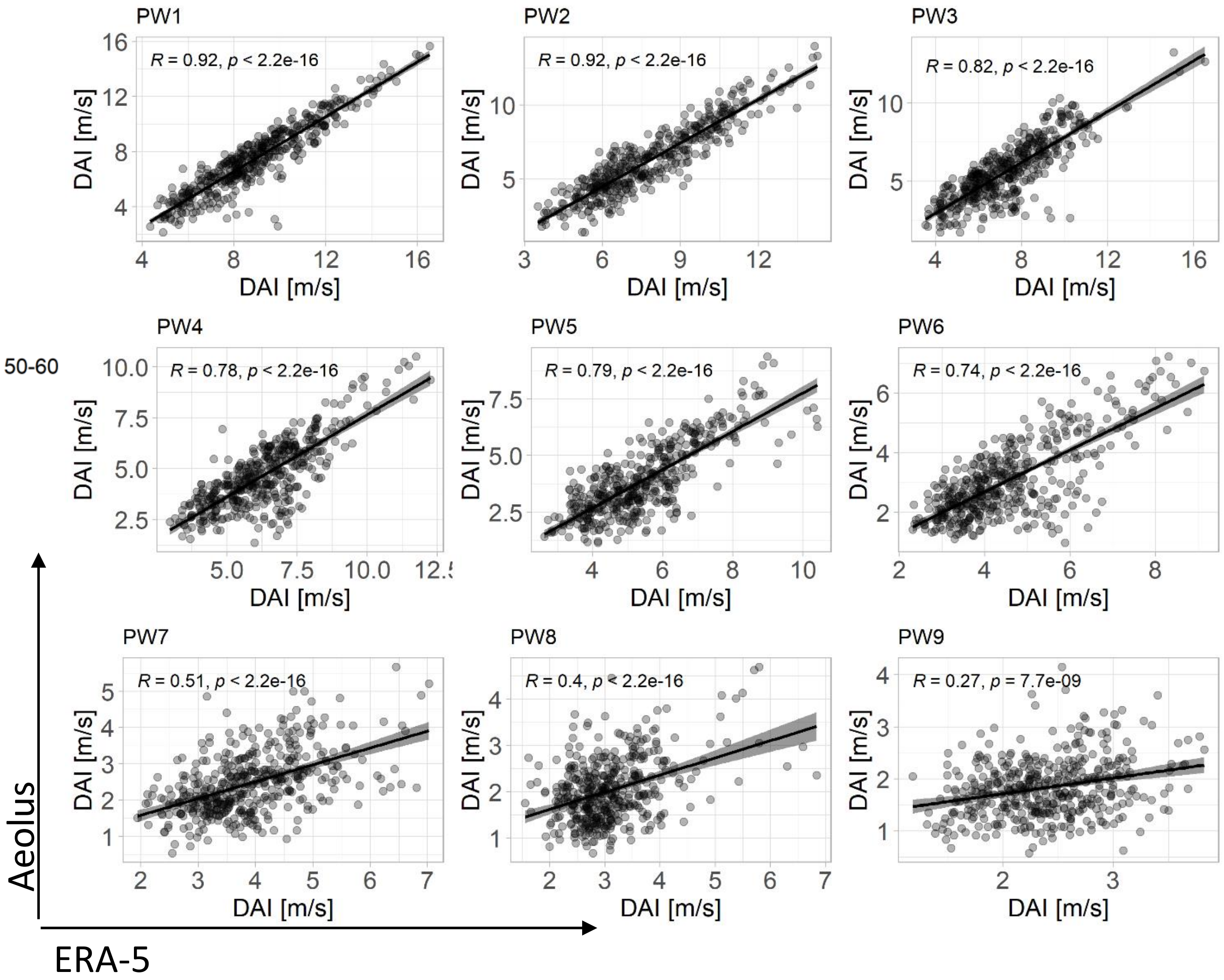
2020-10-02 5 days 37.5° to 40°N



Planetary waves: Comparion of the DAI based on ERA-5 and Aeolus data

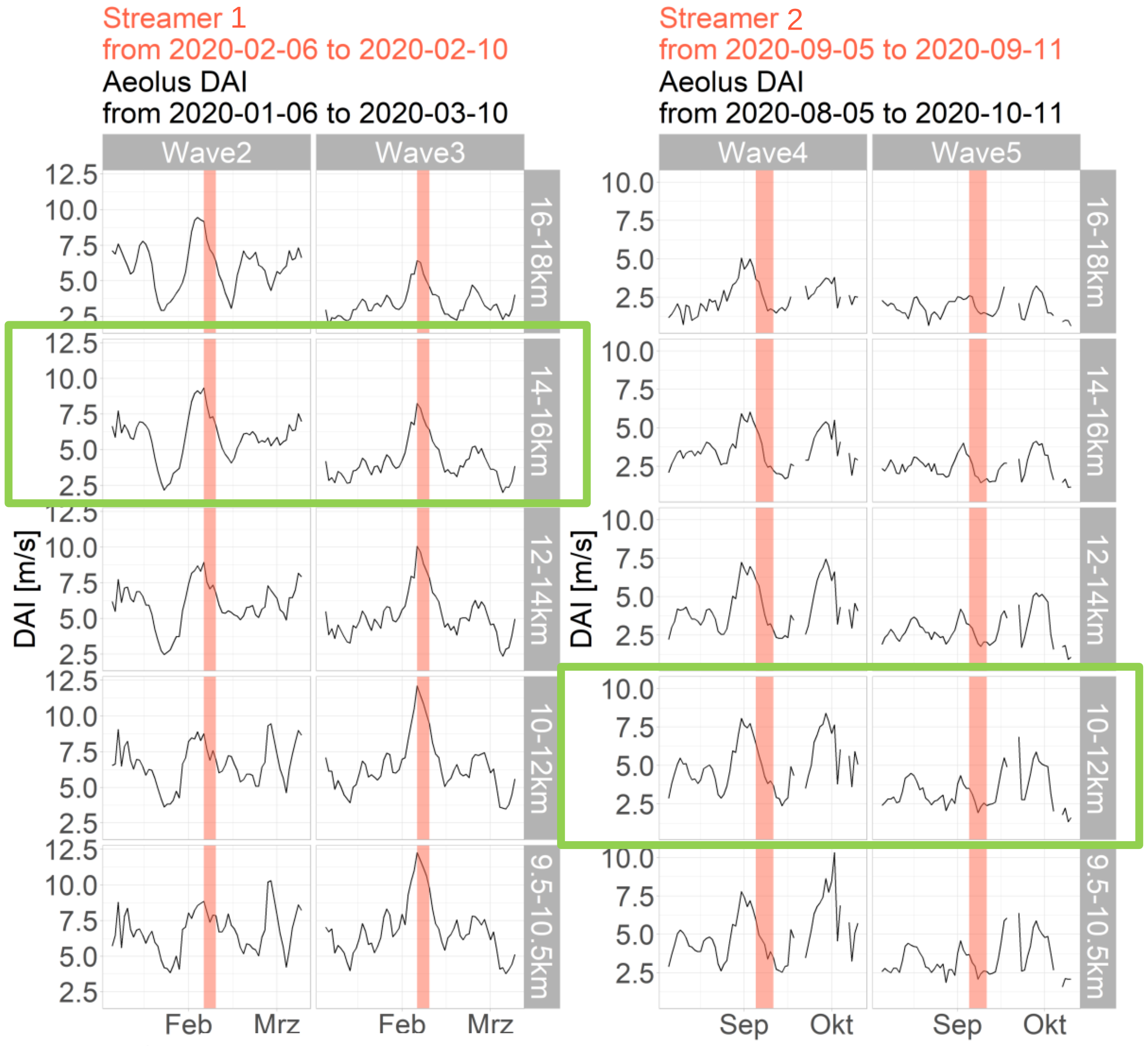
ERA-5-250 u vs Aeolus hlos_corrected,(9500-10500m) $(50 - 60°N)$, 5 day mean





- Overall courses are similar, correlations of PW1 and PW2 very good
- Good correlations up to PW6
- Higher wavenumbers low correlations (PW7-PW9)
    - Stationarity assumption of HA
    - Low amplitudes of PW with high wavenumbers (noise)

Streamer in Aeolus-DAI in 2020

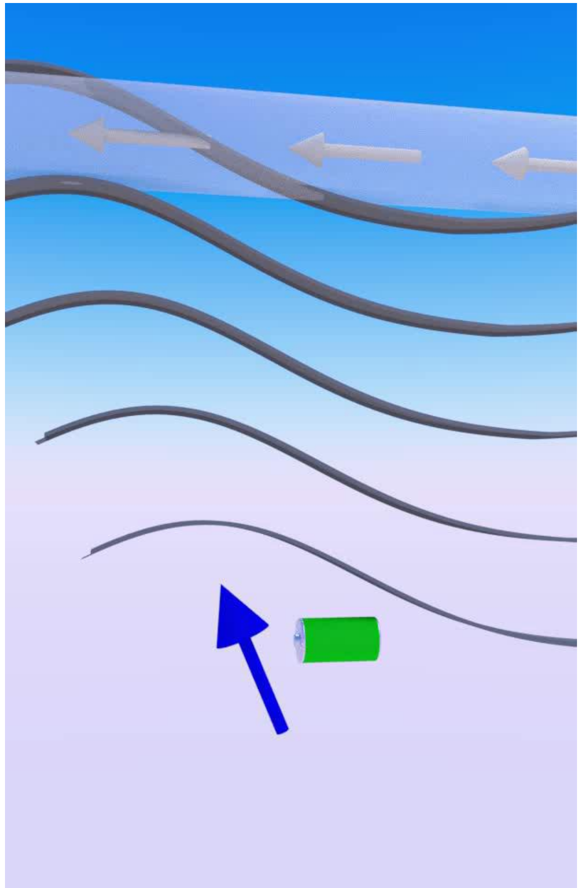


- Strong increase of DAI before and decrease of DAI while streamer occurs
  → wave breaking
- Streamer occurs in different heights
- Different combinations of wavenumbers explain wavebreaking before streamer
  - Different wavenumbers shows the typical behavior
    → Wave-wave-interaction

Gravity waves: What are GW and why to consider?

- Generation: flow over mountainous regions, convection, wind shear, …
- GW can propagate vertically and horizontally
- GW transport energy & momentum through the atmosphere without transporting mass
- Deposition of energy & momentum → influence on temperature & wind

  (e.g. cold mesopause summer pole, warm mesopause winter pole)



Video courtesy of Patrick Hannawald,
DLR & University of Augsburg

Gravity waves: Calculation of the kinetic energy density

Aeolus data allow calculation of lower bound for kinetic energy density

- Needed: GW fluctuations

  → Removal of the superimposed wind background from each wind profile (approach: repeating spline, Wüst et al., 2017)

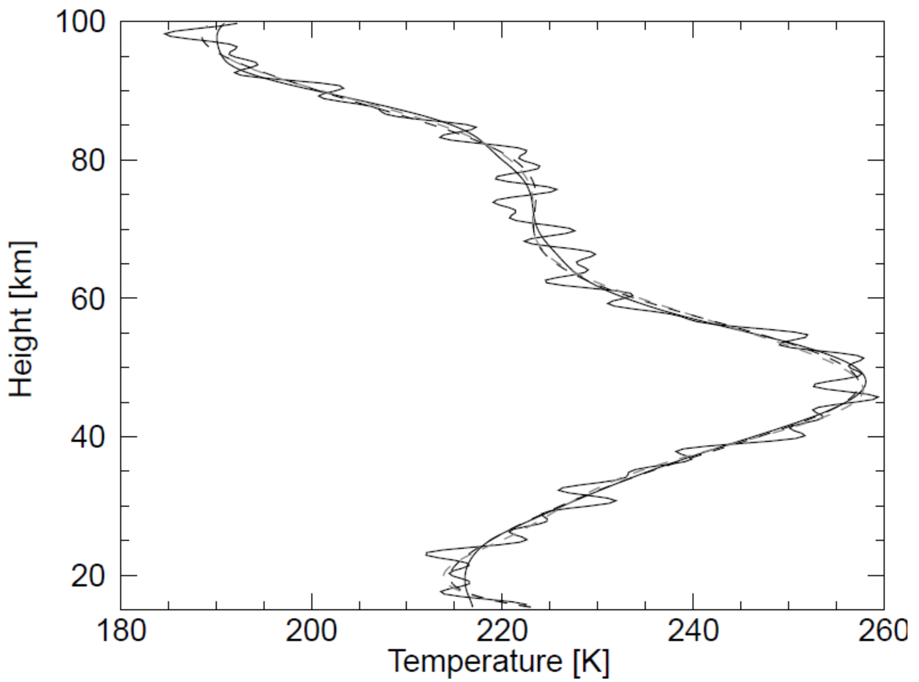
  → Derivation of zonal and meridional wind fluctuations

Not delivered by Aeolus

- Kinetic energy density: $$E_{kin} = \frac{1}{2}\left(\overline{u'^2} + \overline{v'^2} + \boxed{\overline{w'^2}}\right)$$

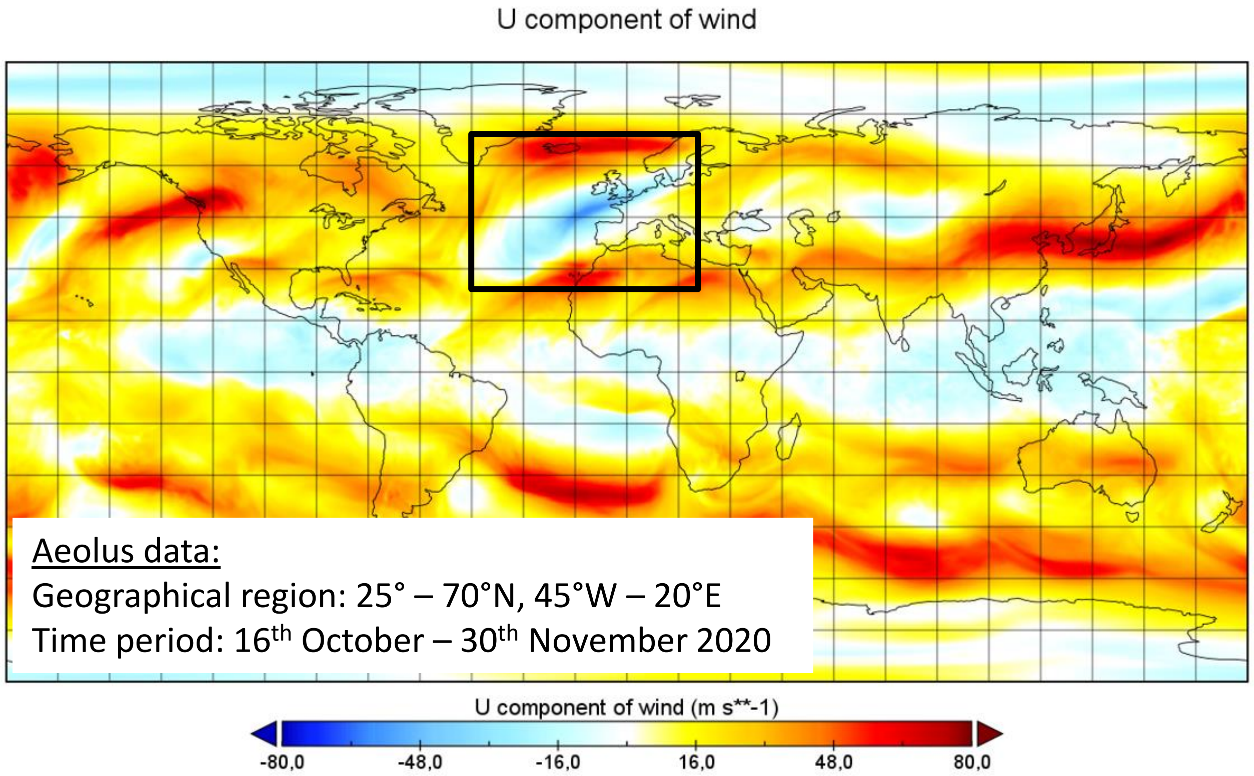
1. Squared residuals
2. sum over height range to be analysed
3. division through length of profile (not all profiles are of equal length)

→ Lower bound for the normalized kinetic energy density: $\frac{J}{kg \cdot m}$

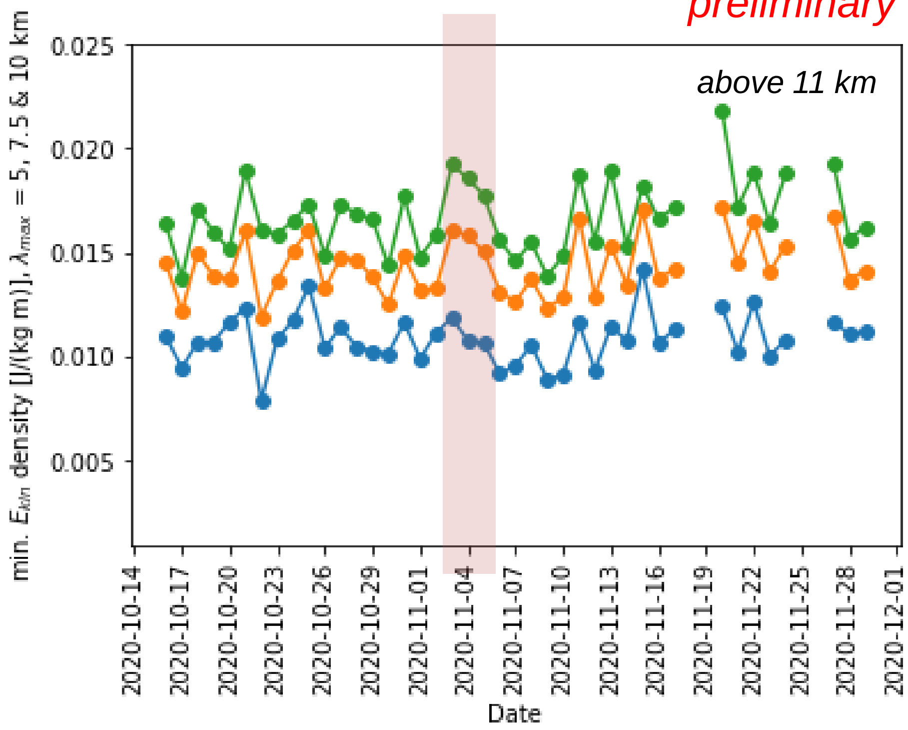


Wüst et al., 2017

Gravity waves:



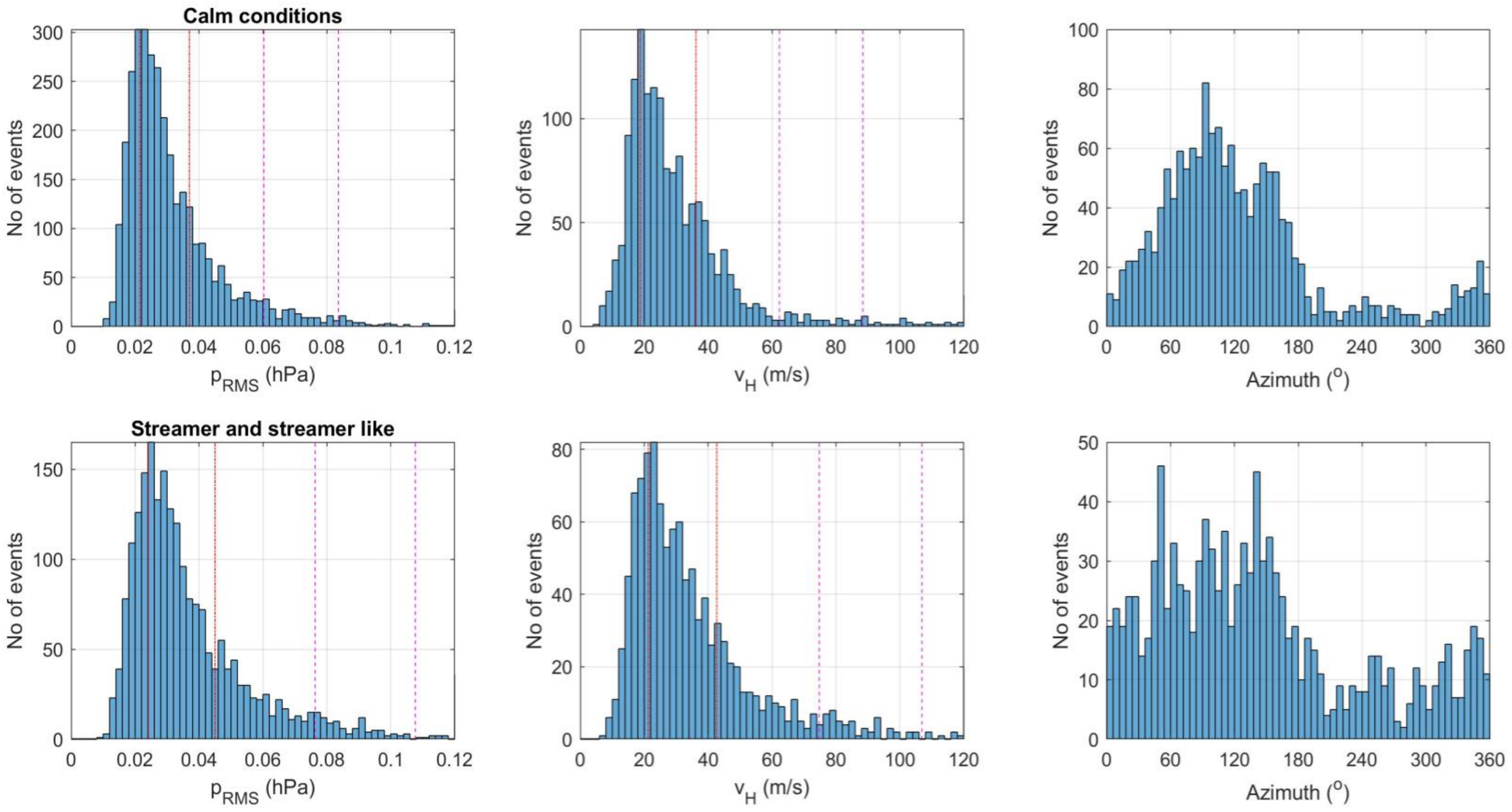
Aeolus data:
Geographical region: 25° – 70°N, 45°W – 20°E
Time period: 16th October – 30th November 2020



Main results:

- Possible streamer signal in GW (not extraordinary high but local maximum over some days, more pronounced for l_{max} = 7.5 and 10 km)
- Only stratosphere shows signal (stratosphere stably stratified → meets expectations)
  → next wind mission should also reach stratosphere

Gravity waves in the troposphere



Measurements by the microbarometer array

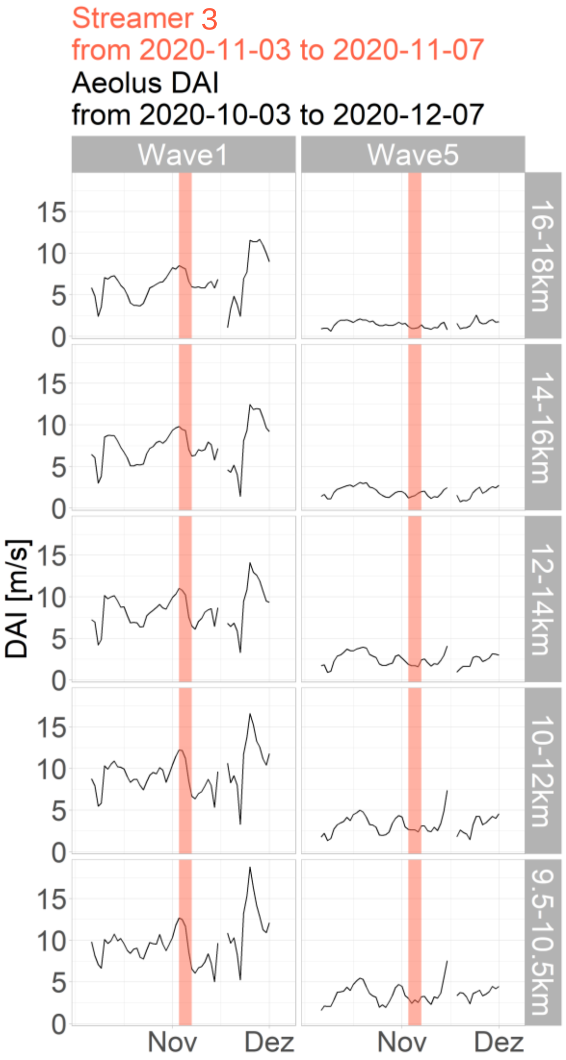
(West of the Czech Republic, 50.25N 12.44E)

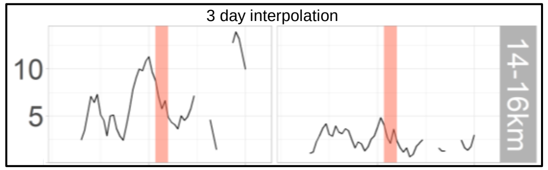
- GWs observed in the troposphere by the WBCI microbarometer array
  - The pressure fluctuations have larger amplitudes.
  - Wave propagation with different azimuths.

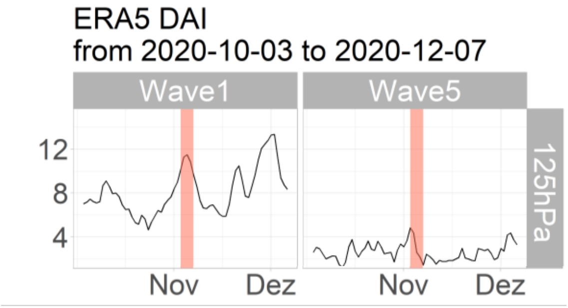
Summary

Data comparison	• Comparison of AEOLUS and ERA5 zonal wind show a difference between Aeolus measurements and ERA5 (AEOLUS shows stronger winds)
Aeolus data	• Derivation of PW up to wavenumber 6 is possible • Aeolus DAI shows wavebreaking with respect to two (of three) streamer events • Derivation of GW kin energy density is possible • GW kin energy density is increased in the lower stratosphere while streamer occurs
Supplement data	• GWs in the troposphere propagated with different azimuths and higher pressure fluctuations amplitudes during streamer events

Streamer in Aeolus-DAI in 2020







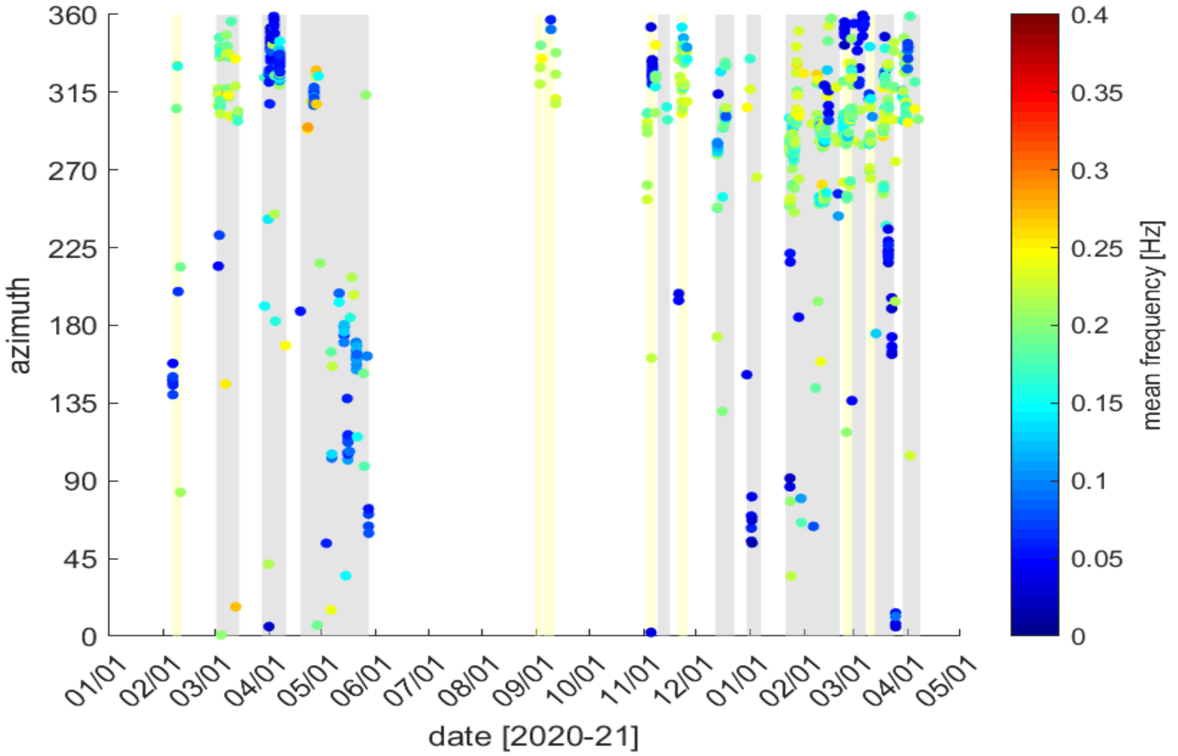
- No clear signals in Aeolus DAI considering 5 days for calculation
- PW1 in Aeolus DAI considering 3 days for calculation
- PW1 and PW5 in ERA5 DAI show signal (1 day resolution)

→ Duration of streamer too short for Aeolus DAI

INSTITUTE OF ATMOSPHERIC PHYSICS
CAS

Infrasound in the ionosphere

- Infrasound propagation controlled by temperature and winds in the atmosphere.
- Can we find signatures of streamer events in infrasound arrival parameters at WBCI?



Main results:

- Significant first order effects undoubtedly related to streamer events were not identified:
  - Streamers not a well-defined infrasound source
  - Circulation at 40-50 km stable – no break down of the stratospheric waveguide
- Can effects of streamers be of a lower order of significance or manifested only in near-regions?
  - Using a dense network of infrasound stations covering various distances and directions from a streamer.

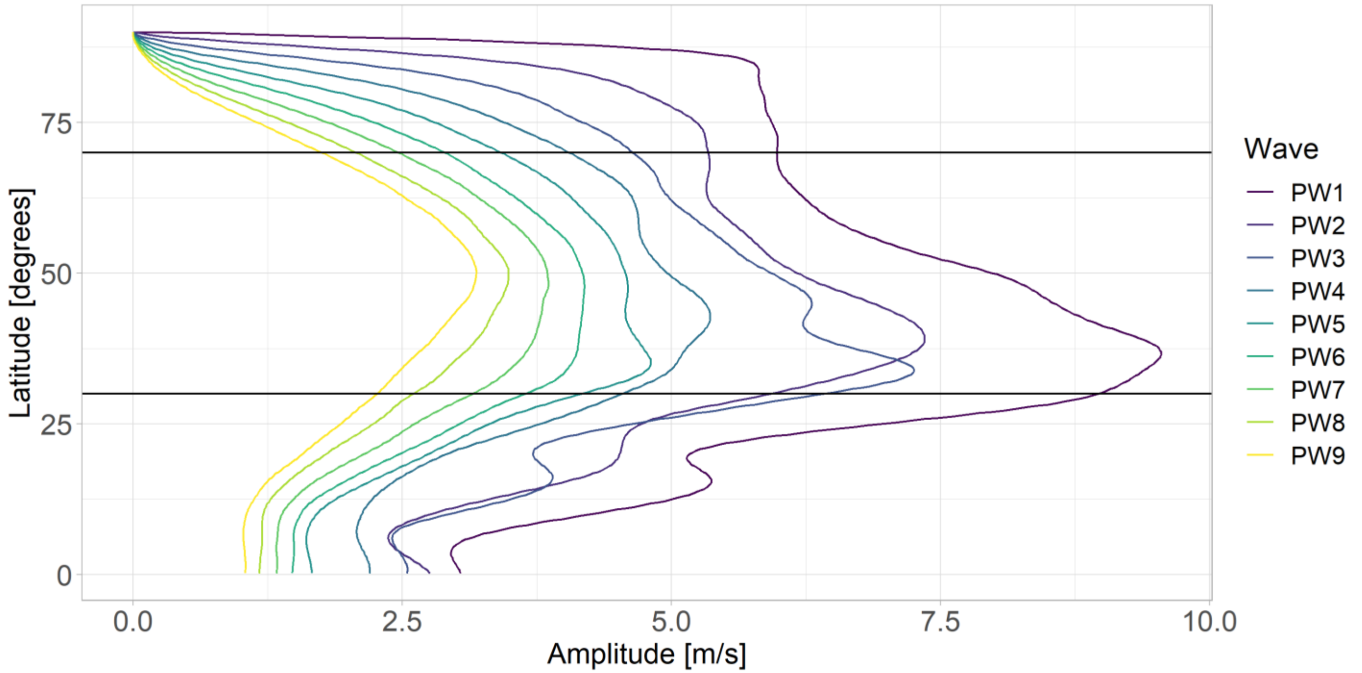
	median	$Q_{0.1}$	$Q_{0.9}$
Frequency streamer events	0.18 Hz	0.04 Hz	0.23 Hz
Frequency calm days	0.16 Hz	0.05 Hz	0.23 Hz
RMS amplitude streamer events	0.03 Pa	0.01 Pa	0.05 Pa
RMS amplitude calm days	0.03 Pa	0.01 Pa	0.06 Pa

Infrasound detections were processed using the DTK-GPMCC software kindly provided by CEA/DASE, Arpajon, France

DLR
INSTITUTE OF ATMOSPHERIC PHYSICS CAS

Dynamical Activity Index: Climatology of PW
ERA-5 1979-01-01 to 2021-07-30 250 hPa

Amplitude by latitude and wavenumber



If the amplitude of the PW is larger than the error of the AEOLUS measurement, the PW signal can reliably be extracted.

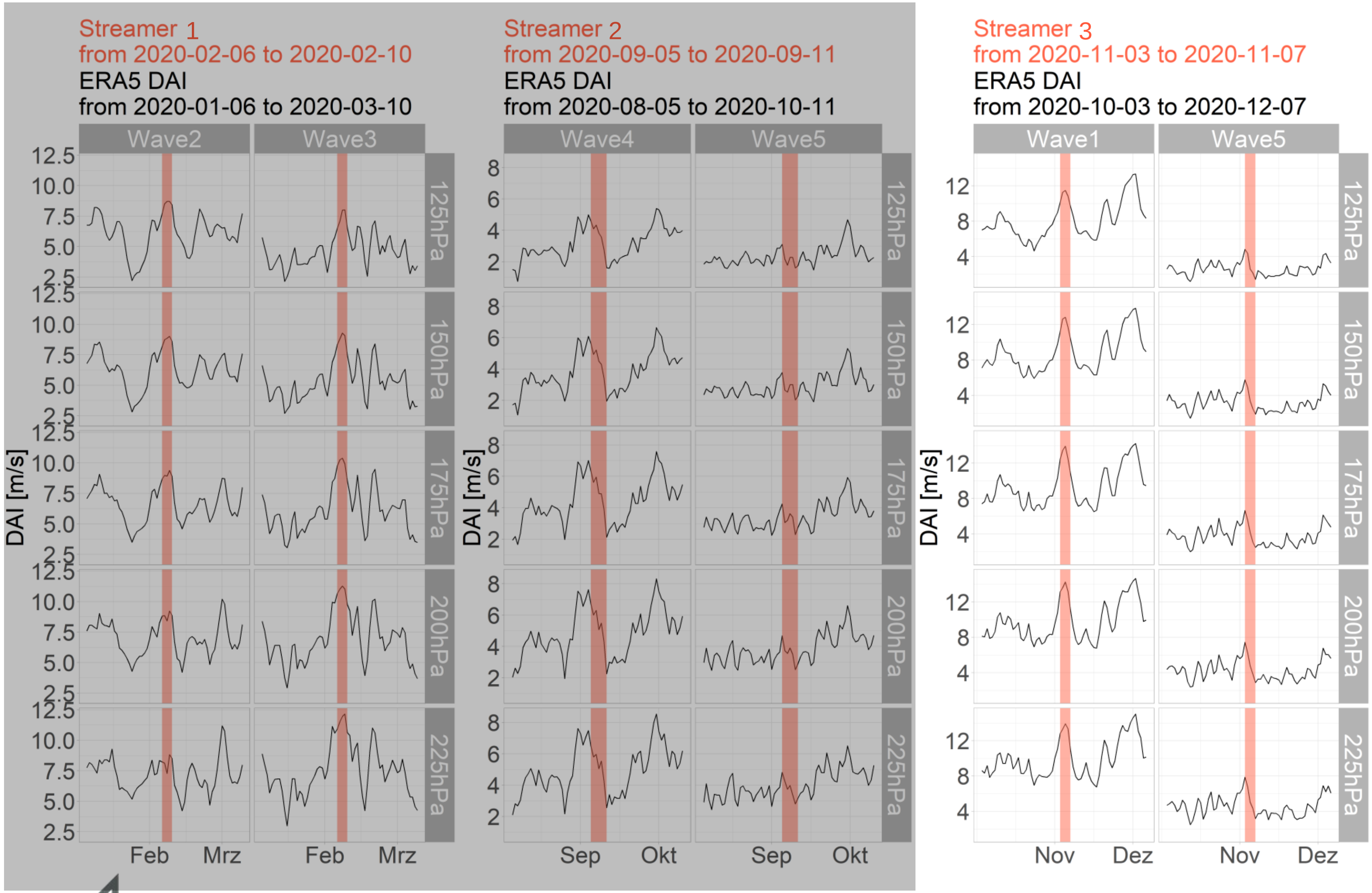
From ERA5 wind analysis the amplitude of PW1 is approx. 8 m/s, whereas the amplitude of PW9 is about 2 m/s.

Measurements with errors of >= 5 m/s are not considered

To find out up to which wavelengths a derivation of PW activity is possible based on Aeolus measurements is part of the project.

→ Highest amplitudes of PW with low wavenumbers in mid-latitudes

Streamer in ERA5-DAI in 2020



Comparison with ERA5-DAI

- For streamer 1 and 2, the results of Aeolus-DAI correspond to the ERA5-DAI curves, especially with regard to the relevant wave numbers and the basic course of the height profiles.
- For streamer 3, only the observation for wave 1 coincides.

Attention: Altitudes and pressure levels do not refer to the same height steps:

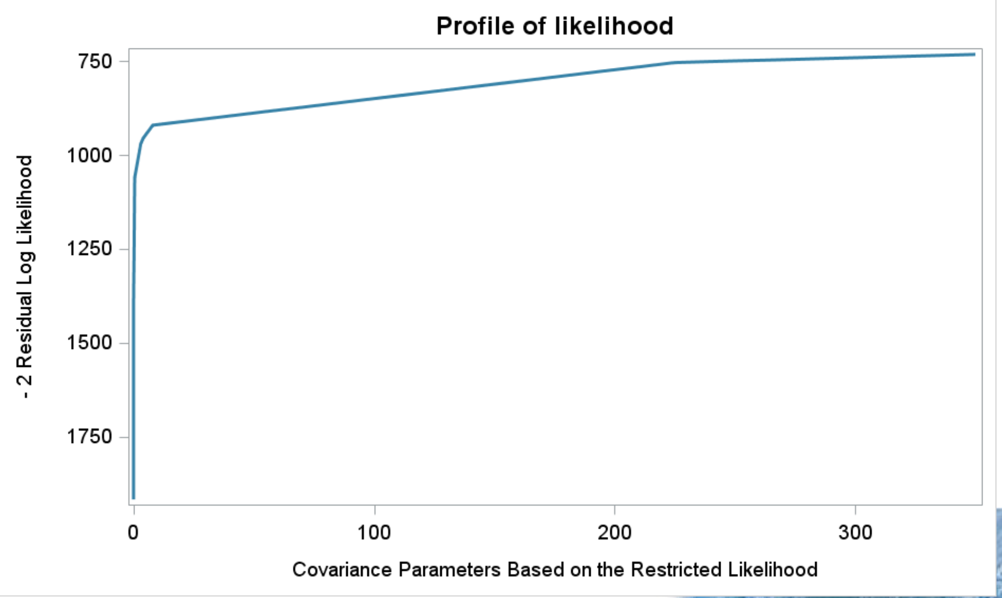
- 18 km ~ 70 hPa
- 16 km ~ 100 hPa
- 14 km ~ 125 hPa
- 13 km ~ 150 hPa
- 12 km ~ 200 hPa
- 10 km ~ 250 hPa

ERA5 dataset homogeneity testing, using AIC (Akaike's information criterion)

AIC = - (maximumlog - likelihood) + 2(number of free parameters) statistics for whole AEOLUS measurements period but the comparison will be applied mainly on the streamer events.

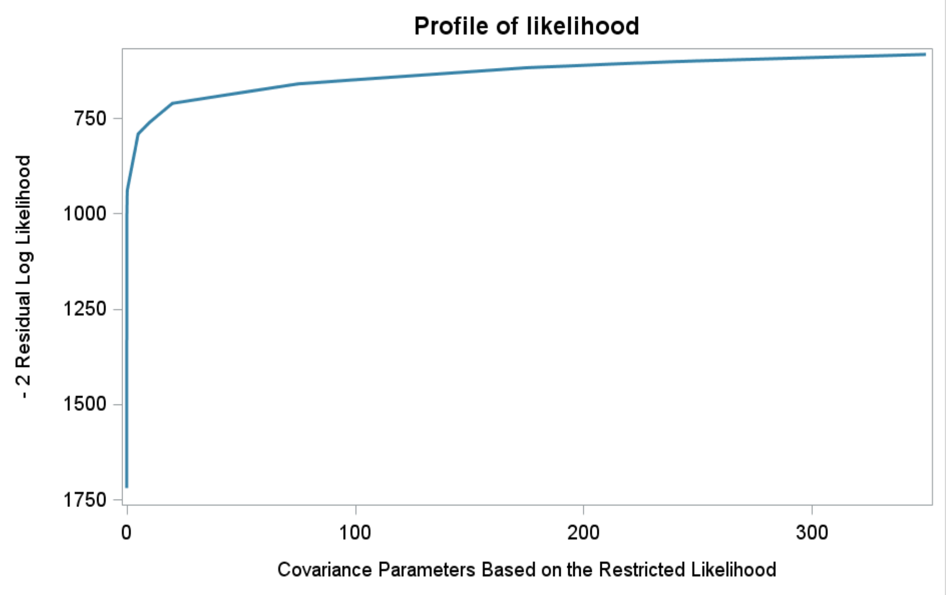
Streamer event 1 (2-10. 11. 2020)

Fit Statistics Streamer event 1		
-2 RLL (Res Log Likelihood)		915.50
AIC (Akaike's information criterion)		913.50
AICC (Corrected AIC)		913.48
BIC (Bayesian information criterion)		915.50
Covariance Parameter Estimates		
Cov Parm	Estimate	Standard Error
Var (RSmooth)	137.23	42.7830
Residual	4.453	0.3628

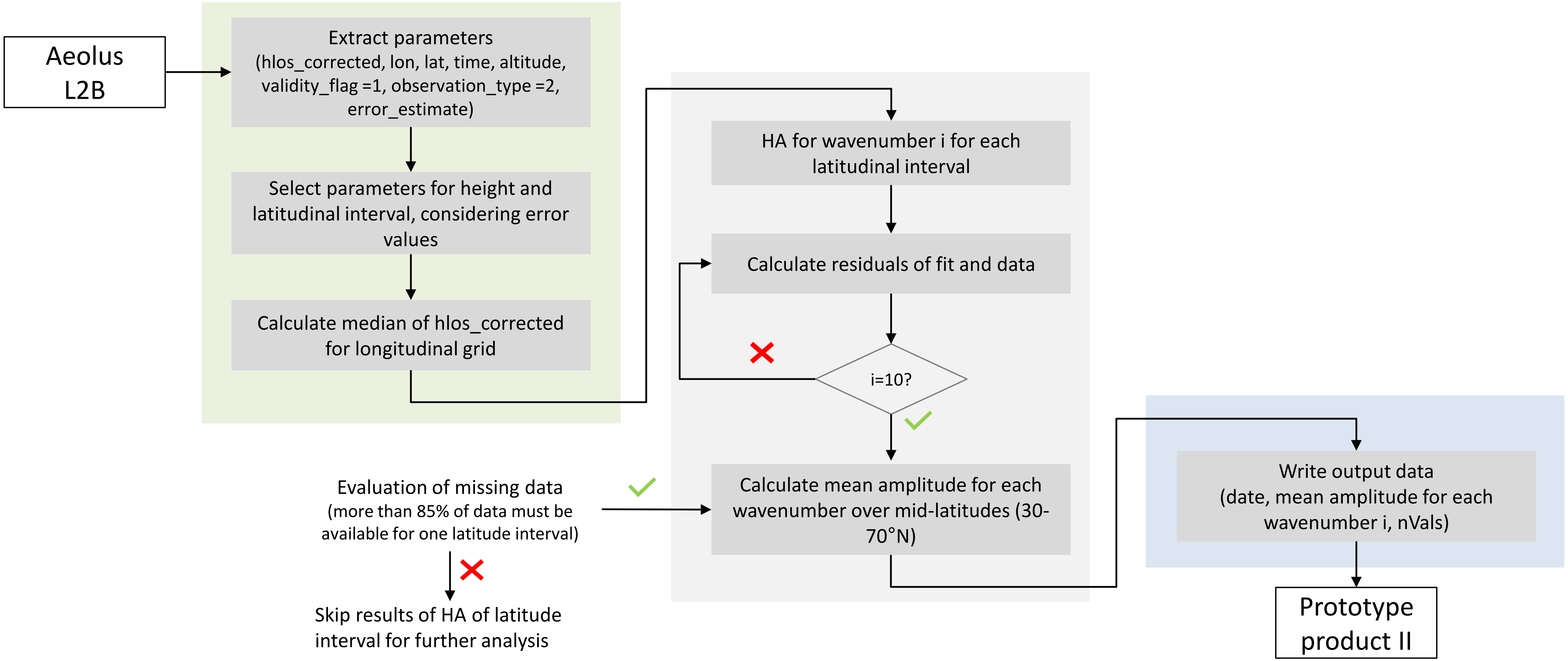


Streamer event 2 (4-12. 2. 2020)

Fit Statistics Streamer event 2		
-2 RLL (Res Log Likelihood)		940.58
AIC (Akaike's information criterion)		938.12
AICC (Corrected AIC)		938.17
BIC (Bayesian information criterion)		940.58
Covariance Parameter Estimates		
Cov Parm	Estimate	Standard Error
Var (RSmooth)	166.02	55.3400
Residual	5.682	0.6423

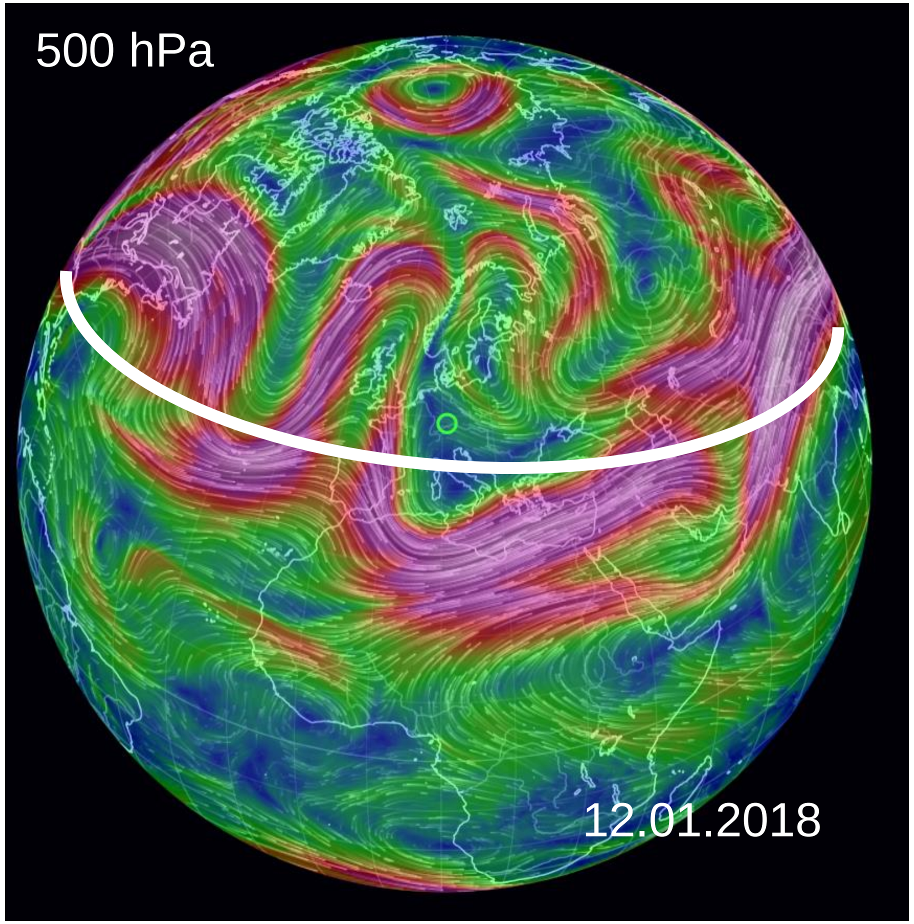


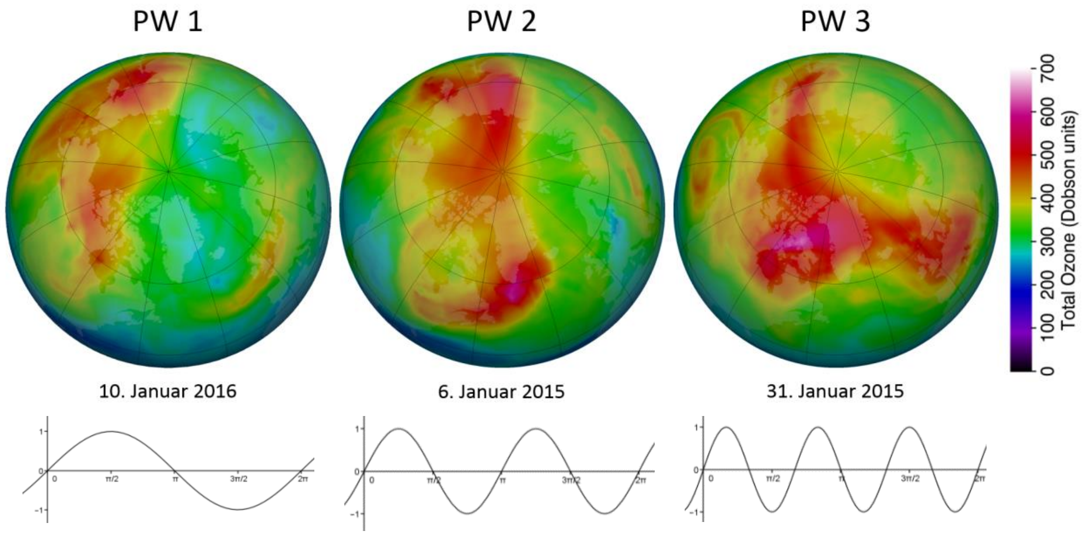
Planetary waves: Calculation of Dynamical Activity Index (DAI)



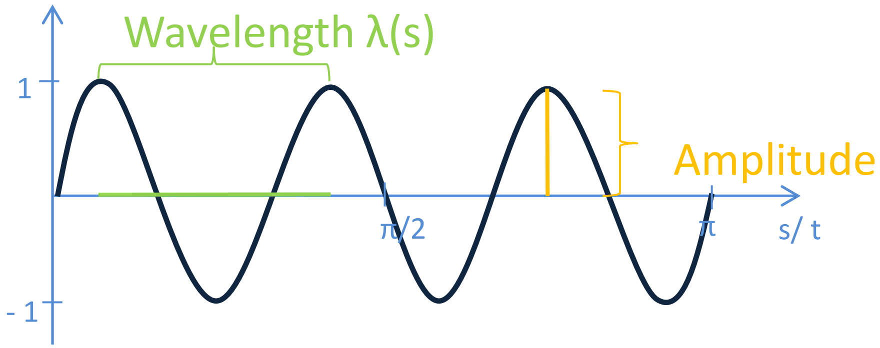
Bittner et al. 1997, Erbertseder et al. 2006

Zonal wavenumber of PW





$$\sum_{i=1}^{n} A_i \sin\left(\frac{2\pi}{\tau_i}\lambda + \varphi_i\right)$$



$$\text{Wavenumber } k = \frac{2\pi}{\lambda} = \frac{360°}{60°} = 6$$

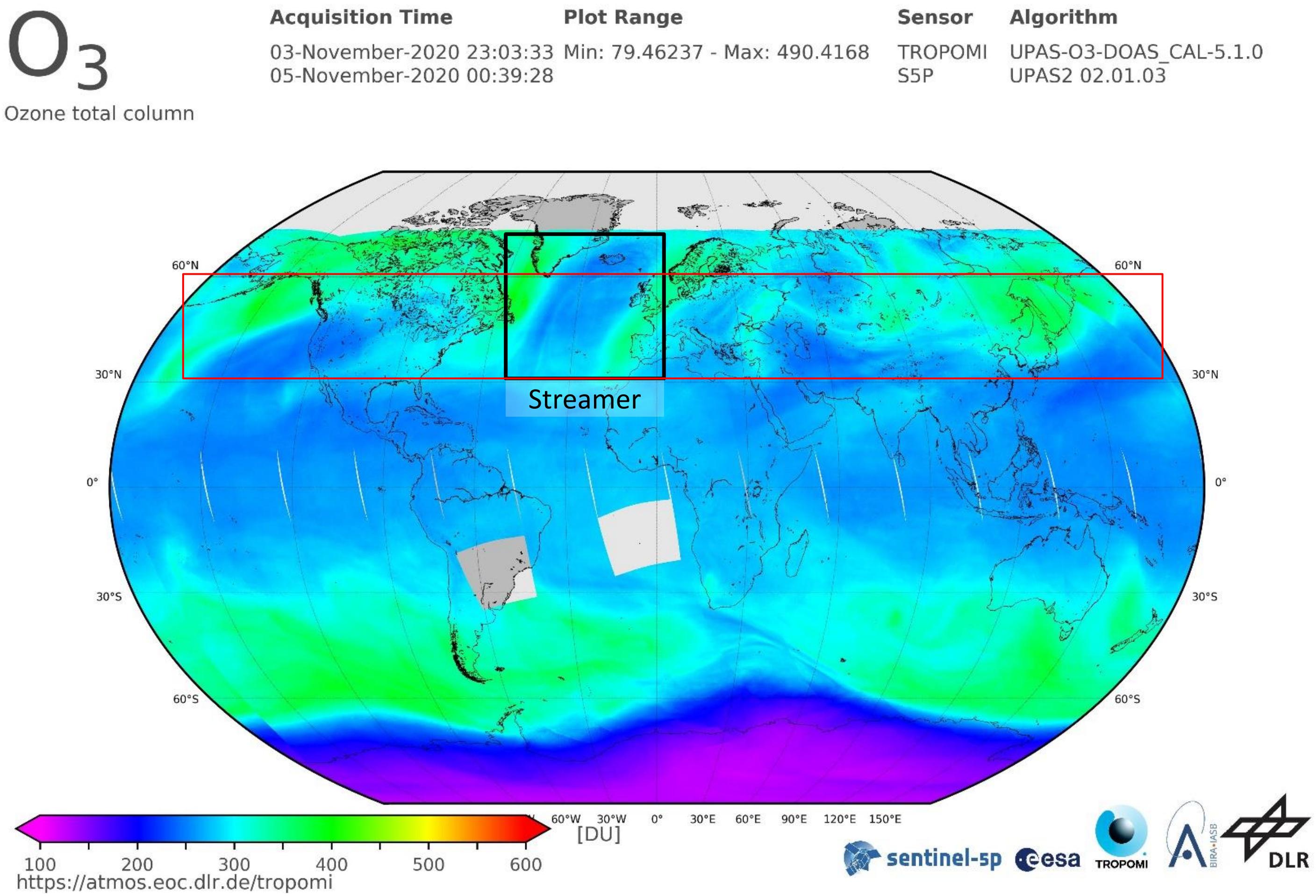
DLR

Streamer events in TO3

Streamer events

PW dominate the meridional Brewer-Dobson circulation in the stratosphere and thus the large-scale mass transport of ozone.

Due to poleward breaking PW air masses with low ozone concentration are irreversible mixed into the mid-latitudes.



Mass flux density in ~10 km

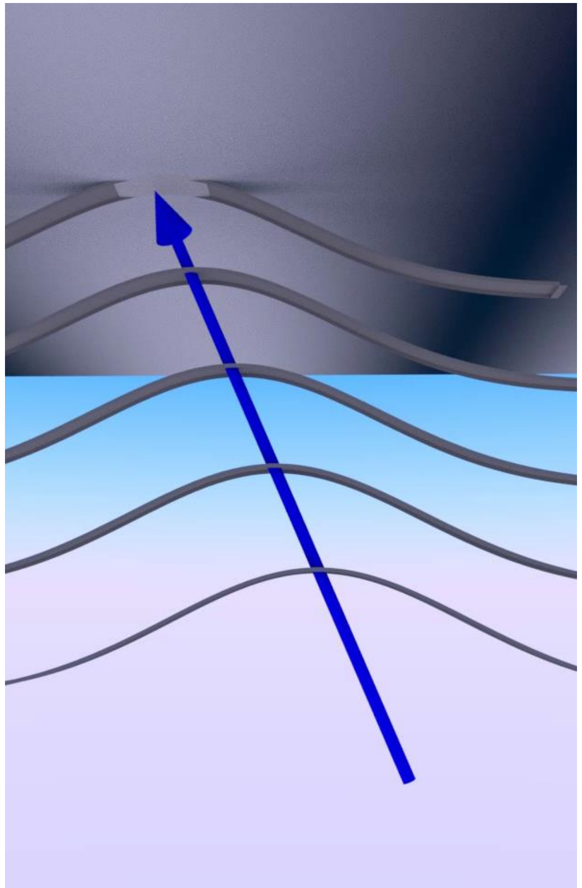
Mean state $v \cdot \rho \approx \;\; 1 \frac{m}{s} \cdot 0{,}4 \frac{kg}{m^3} \approx \;\; 0{,}4 \frac{kg}{s \cdot m^2}$

Streamer $v \cdot \rho \approx 50 \frac{m}{s} \cdot 0{,}4 \frac{kg}{m^3} \approx 20 \frac{kg}{s \cdot m^2}$

differs in one to two orders of magnitude

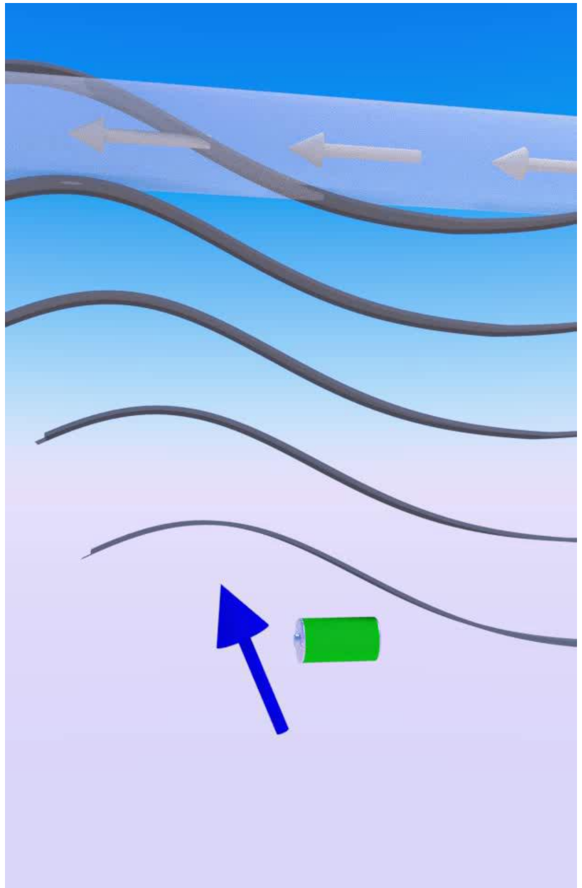
→ **Streamer are efficient processes for meridional mixing**

Gravity waves: What are GW and why to consider?



Video courtesy of Patrick Hannawald,
DLR & University of Augsburg

- Generation: flow over mountainous regions, convection, wind shear, …
- GW can propagate vertically and horizontally
- GW transport energy & momentum through the atmosphere without transporting mass
- Deposition of energy & momentum → influence on temperature & wind (e.g. cold mesopause summer pole, warm mesopause winter pole)



Video courtesy of Patrick Hannawald,
DLR & University of Augsburg

Gravity waves: Calculation of the kinetic energy density

Aeolus data allow calculation of lower bound for kinetic energy density

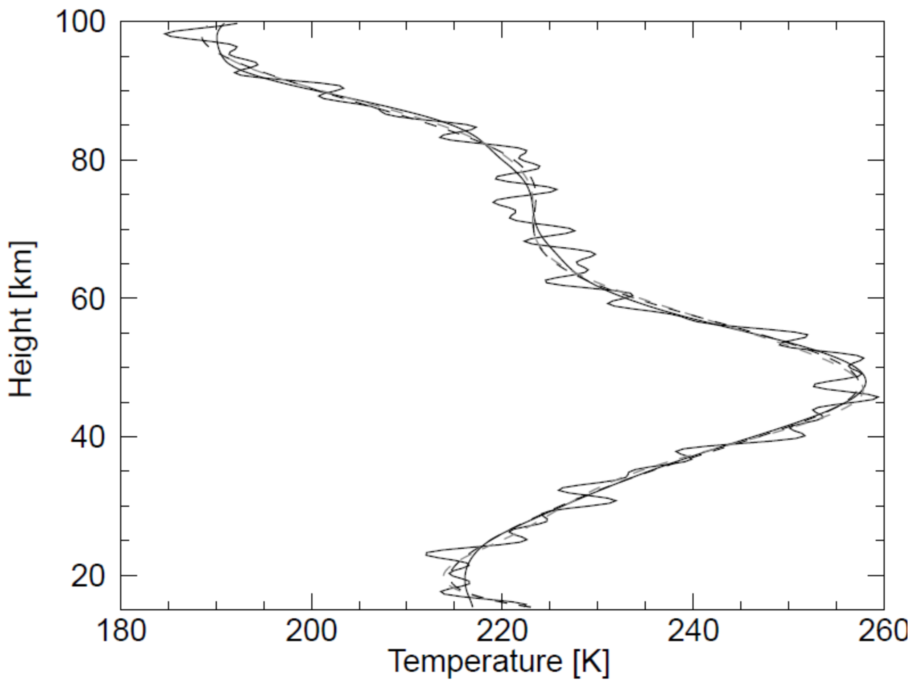
- Needed: GW fluctuations → Removal of the superimposed wind background from each wind profile (approach: repeating spline, Wüst et al., 2017) → Derivation of zonal and meridional wind fluctuations

Not delivered by Aeolus

- Kinetic energy density: $E_{kin} = \frac{1}{2}\left(\overline{u'^2} + \overline{v'^2} + \boxed{\overline{w'^2}}\right)$
- Unit:

$$\frac{m^2}{s^2} = \frac{kg}{kg} \cdot \frac{m^2}{s^2} = \frac{1}{kg} \cdot \frac{kg \cdot m}{s^2} \cdot m = \frac{1}{kg} \cdot N \cdot m = \frac{J}{kg}$$

- Squared residuals, sum over height range to be analysed, division through length of profile (not all profiles are of equal length) → Lower bound for the normalized kinetic energy density: $\frac{J}{kg \cdot m}$



Wüst et al., 2017