Variability and changes of the stratospheric large scale circulation and possible consequences for ozone streamer events

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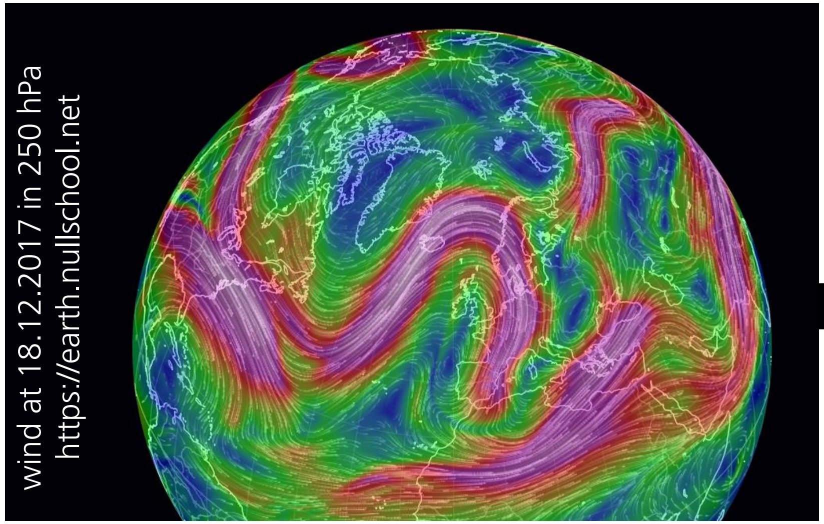
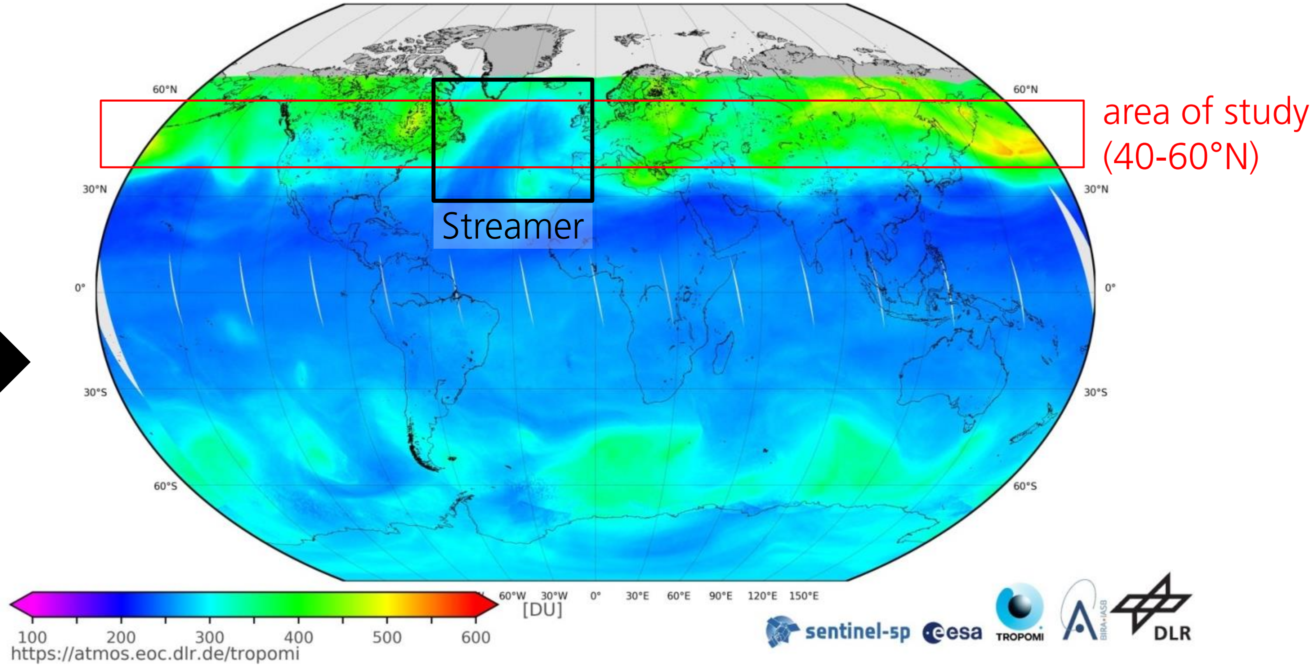
Motivation

Planetary waves (PW) dominate the meridional Brewer-Dobson circulation in the stratosphere and therewith, the large-scale mass transport of ozone. As PW break, ozone poor air masses are irreversibly mixed into mid-latitudes. Due to the disproportionate warming of the North Pole, an increase in PW activity (PWA) is expected. This should also have consequences for ozone streamer events.



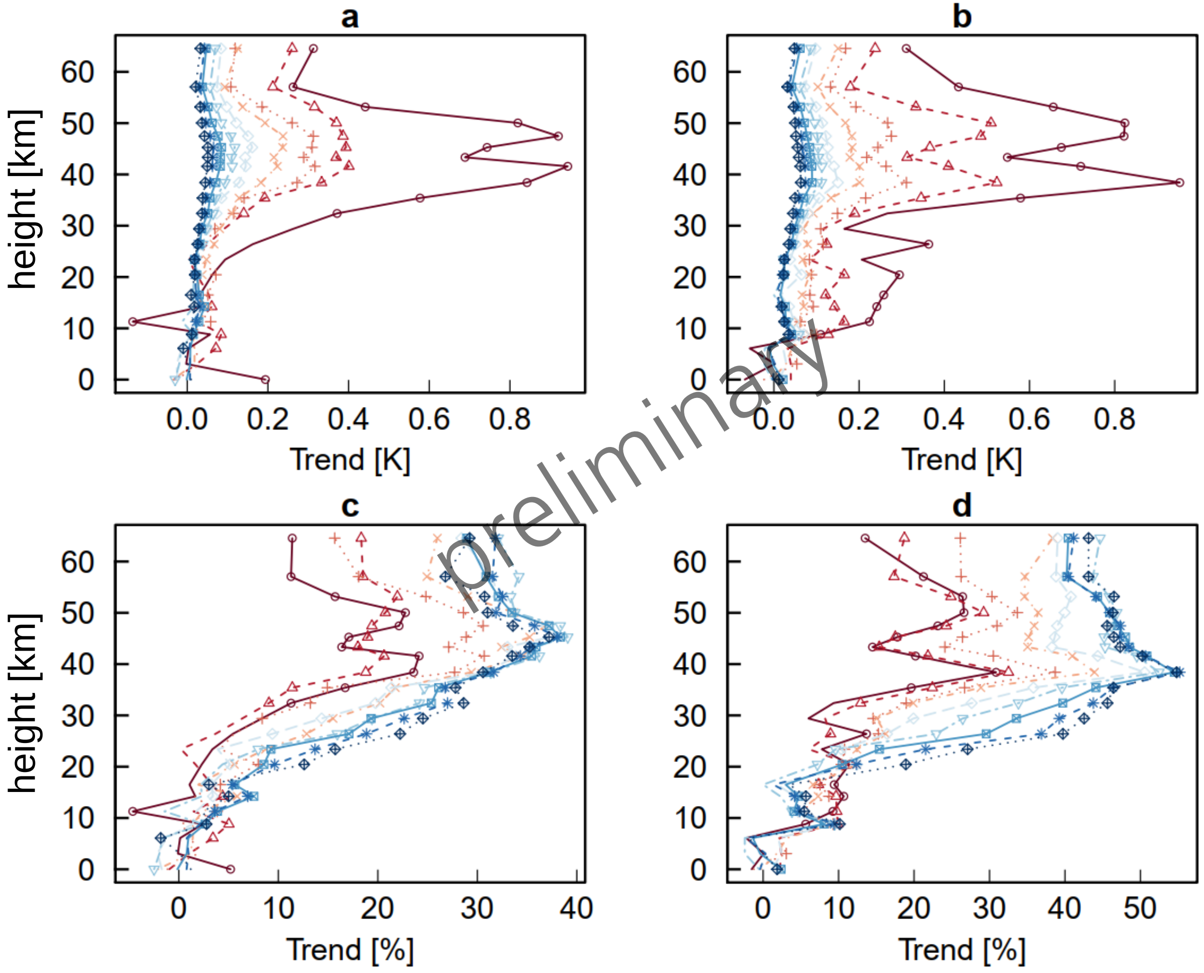
Strong meridional winds above North Atlantic due to high PWA transports ozone poor airmasses into mid-latitudes



Measurements of the total ozone column (TO3) on 18.12.2017 show a region with low TO3 (streamer event) over the North Atlantic

Long-term changes of planetary wave activity (PWA)

data: ERA-Interim (1979-2018)



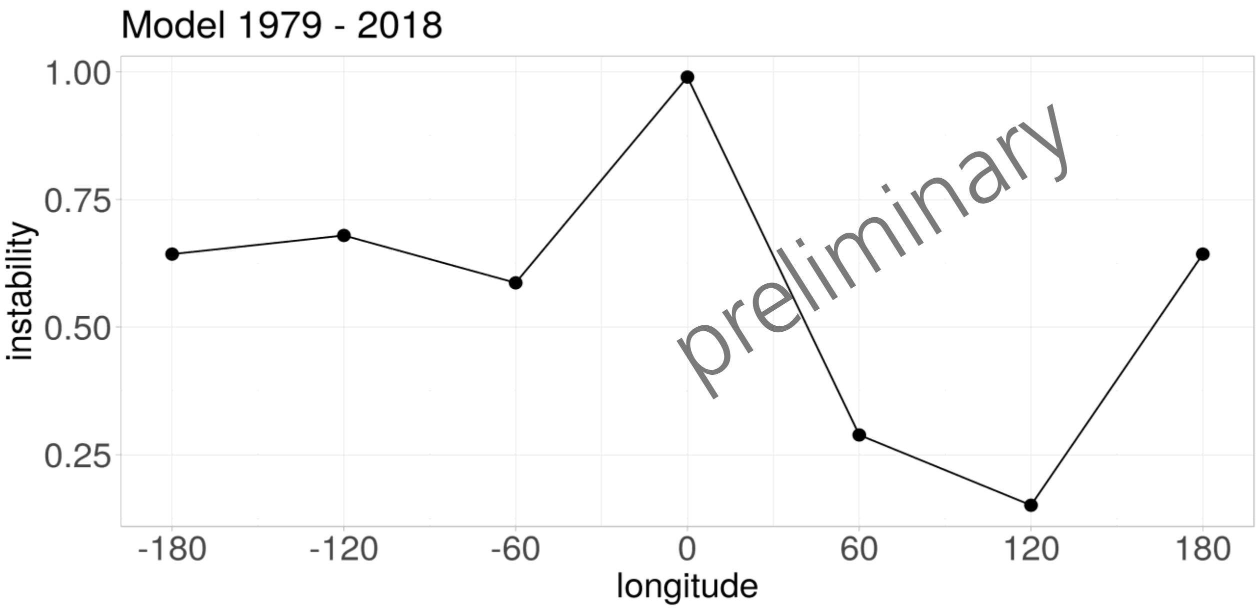
Analysis 1: The PWA, given by the dynamic activity index (DAI, Bittner et al., 1997, Erbertseder et al., 2006), is calculated on a routine basis. Nine sinusoidal oscillations are adjusted to the temperature at each circle of latitude with a least square approach, the harmonic analysis. The mean amplitude of each oscillation averaged from 0-90°N serves as a measure of each PW.

Figure 1: The slope of the linear regression per decade of PW1 to 9 in Kelvin from 10 m to 65 km altitude on the northern hemisphere in winter (October to March) left (a, c) and summer (April to September) right (b, d) indicates long-term changes of the PWA. The absolute PWA change in Kelvin is shown above (a, b), the relative PWA change, related to the mean value of the time series, is shown below (c, d). Significant trends (t-test) are marked with symbols at the individual heights.

Conclusion 1: Long-term changes indicate that the PWA has already increased in the stratosphere, while the situation in the troposphere is found to be not conclusive yet. In the stratosphere especially PW with higher zonal wave numbers increase strongest.

Spectral model of planetary induced meridional wind shear with height

data: ERA-Interim temperature (30°-70°N)



Analysis 2: We derive the structure function of PW for each day from 1979 until 2018 (see analysis of DAI slide 3). The structure function for all latitudes between 30°-70°N at 11 km heigth is implemented in the thermal wind shear equation. Therewith, we derive the PW induced vertical shear of meridional wind. The difference of two regions (each 60° x 60°) gives an indication of the instability of the atmosphere due to PW in this region.

$$\frac{\partial v}{\partial z} = \frac{g}{f} \cdot \frac{1}{T(\lambda)} \frac{\partial T}{\partial \lambda}$$

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

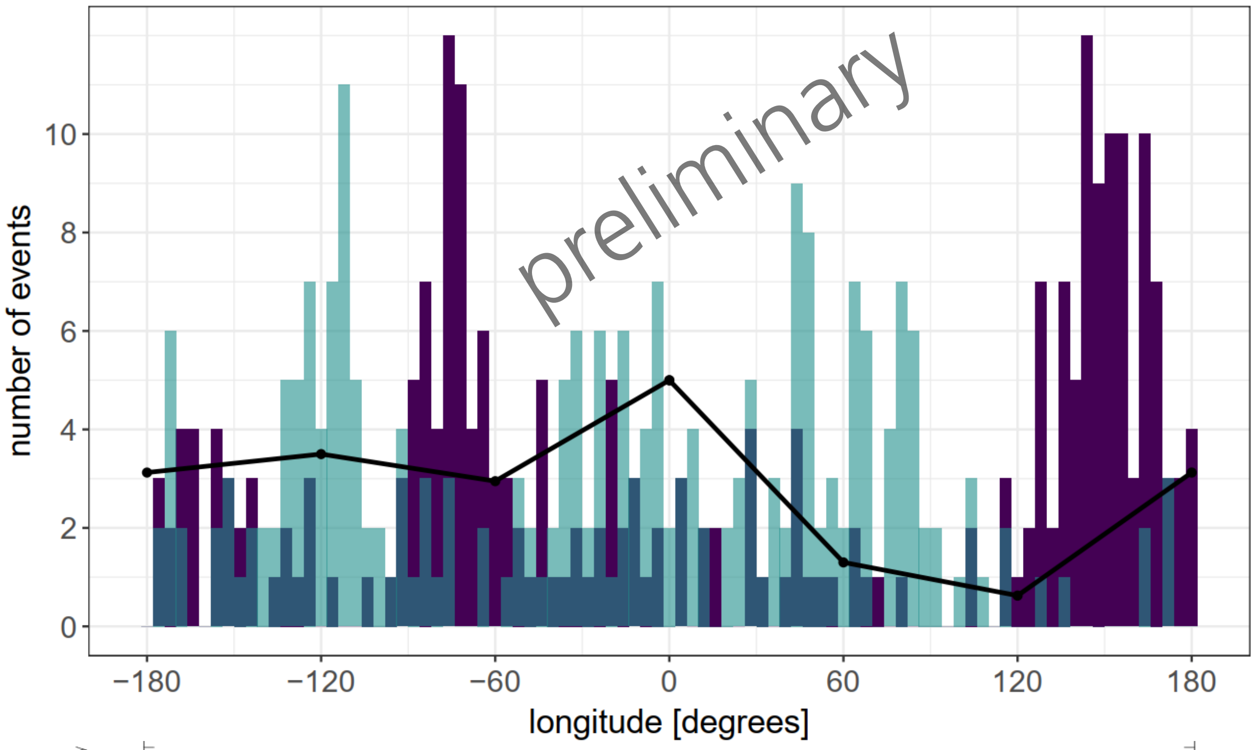
$$\boxed{\frac{\partial T}{\partial \lambda} = \sum_{i=1}^{n} A_i \cdot cos\left[\frac{2\pi}{\lambda_i} \cdot \lambda + \varphi_i\right] \cdot \frac{2\pi}{\lambda_i}}$$

Figure 2: atmospheric instability measure; calculated as described above.

Conclusion 2: At the transition from the North Atlantic to Europe, the atmospheric instability is maximum due to PW. Here, PW deform the the jet stream strongest which leads also to an enhanced probability of breaking PW. As one consequence, ozone-poor air masses (streamers) are cut-off from the equatorial region to mid-latitudes. An increase in PWA is expected to further increase the occurrence frequency of streamer events.

Occurrence of high and low TO3 concentration depending on the longitude

data: TO3 GOME-2 (40-60°N, 2013 - 2020)



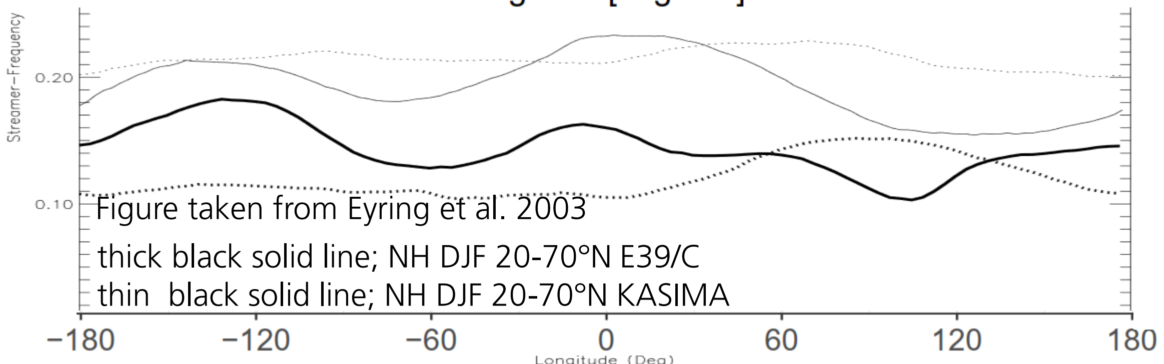


Figure taken from Eyring et al. 2003
thick black solid line; NH DJF 20-70°N E39/C
thin black solid line; NH DJF 20-70°N KASIMA

Analysis 3: Based on the daily longitudinal mean TO3 from 2013 to 2020, O3 poor and rich air masses are identified for the latitudes 40-60°N, which exceed or fall below twice the standard deviation. Events persistent longer than five days are shown left dependent from longitude.

Figure 3: Deviations from the longitudinal mean value of assimilated TO3 concentrations from 2013 to 2020 for a latitude mean value of 40-60°N are identified with a twofold standard deviation. Positive (negative) anomalies that persist longer than five consecutive days indicate an anomal high (low) TO3 concentration. Low (high) anomalies are plotted with petrol (purple) colors.

Conclusion 3: Low (high) TO3 concentration are linked to (anti-) cyclonic pressure cells, as due to PW breaking northern (southern) air masses are led into the mid-latitudes. There is a characteristic longitudinal variation which indicates that streamer events occur mainly at approx. 120°E and between 30°E to 100°W whereas O3 rich air events occur mainly in between at approx. 70°E and 150°W. The maxima of O3 poor events fit well to the derived instability measure (black line) and a streamer climatology found in Eyring et al. 2003 (plot below).

First hints of slight changes of the main characteristics of streamer events ?

data: TO3 GOME-2 (40-60°N, 2014 – 2019*)

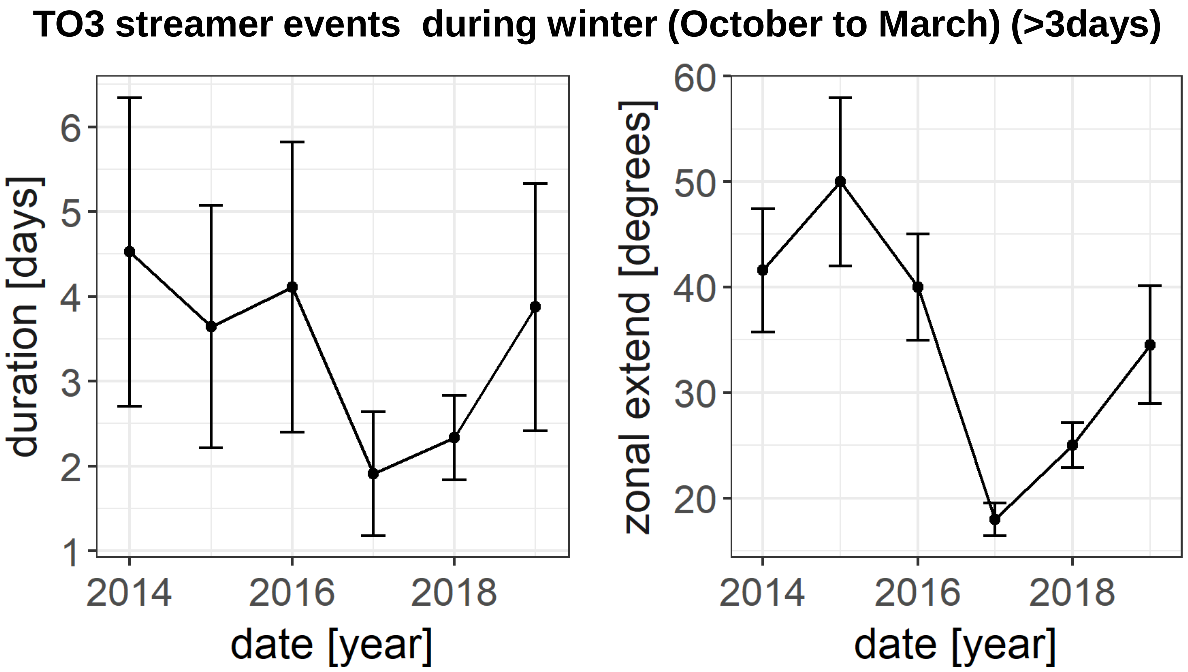


Figure 4: From 2014 to 2019 87 streamer events are detected. The mean values of duration (left) and zonal extend (right) of streamer events during winter (from October until March) which persist for more than three days are given in the figure. Uncertainty intervals are calculated by the RSME.

Conclusion 4: The duration and zonal extend of streamer events during winter is very variable from year to year. So far, changes cannot be detected, as the time series is too short.

Outlook: As PW with higher wavenumbers increased strongest during the last four decades, we tentatively speculate that smaller scale waves could lead to smaller streamers.

*** 2013 and 2020 are not included because the dataset of the years is incomplete**

Summary and Conclusion

ΔPWA

- PWA derived of ERA-Interim temperatures (1979-2018)
- PWA has already increased in the stratosphere
- those PW with higher zonal wave numbers increased strongest.

PW induced wind shear

- **PW induced wind shear** is strongest at the transition zone from North Atlantic to Europe
- Here, streamer events occur most frequently

Streamer

- The duration and zonal extend of streamer events during winter is very variable from year to year. So far, no changes can be observed; next step: extension of the time series

Expected future consequences

- Due to significant long-term increases of the PWA in the stratosphere, ozone streamer events are likely to occur more often in the future.

Ideas and comments welcome

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