Streamer Events from Wind Measurements: Method for the Rapid Detection of the Position

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Abstract

The circumpolar wind band (jet stream) represents a meridional barrier for air masses, but also energy fluxes. So-called "streamer events" are an example of how this barrier can be disrupted. During such events air masses from lower latitudes can irreversibly be mixed into the circulation at higher latitudes with various consequences for atmospheric chemistry, energy and momentum balance. Streamers are known as being the consequence of enhanced planetary wave (PW) activity or even wave breaking. It is assumed that increased atmospheric gravity waves and possibly also even infrasound can be generated by pronounced streamer events.

We present a simple but robust method based on wind measurements and related quantities (vorticity, divergence) that enables the automatic detection of streamers in large data sets. Three case studies are shown to demonstrate this approach. The work presented here is a pre-study for the analysis of ADM/AEOLUS observations within the ESA-project LISA.

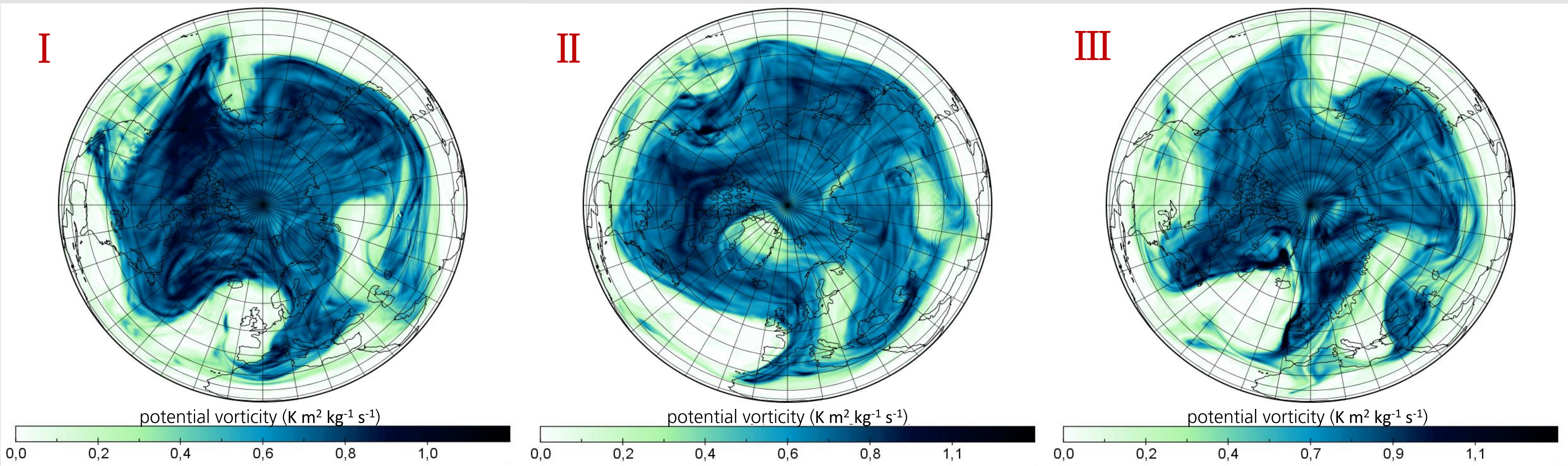

Fig. 1: Potential vorticity at 200 hPa height taken from ERA5-reanalysis at three selected dates (I Dec 18 2017, II Feb 09 2020, III Nov 04 2020) indicating strong streamer events over Northern Atlantic.

Data

For our investigations we use the global reanalysis ERA-5 by ECMWF. It is based on the 4D-Var data assimilation in CY41R2 of ECMWF's Integrated Forecast System (IFS). Detailed information about ERA-5 is given by [1]. The dataset is equidistantly gridded at 0.25° horizontal resolution. From the 137 non-equidistant levels from ground level (1012 hPa) up to the mesopause region (0.01 hPa) we chose the 200 hPa pressure level. ERA-5 has an hourly temporal resolution, but for our analysis four temporal steps per day (0 UTC, 6 UTC, 12 UTC, 18 UTC) are regarded. We analyzed zonal and meridional wind components, potential vorticity and divergence at selected dates (Dec 18 2017 12 UTC, Feb 09 2020 0 UTC and Nov 04 2020 0 UTC). The planetary wave analysis (DAI) is based on temperature data.

Methods

We select three streamer events at occasions where the angle between the eastern flank of the steamer and the latitudes is as close to 90° as possible. The zonal gradients were calculate from the ERA5 reanalysis data at these dates at 200 hPa height. For this purpose, the first order difference of the zonal and meridional wind component (u and v), the wind divergence (d) and the potential vorticity (ς_{pot}) between 45° and 55°N is calculated. The product of these meridional averaged quantities is finally the parameter to detect the streamer position P_{zG}.

To characterize the dynamical situation of the atmosphere we derive the DAI; a measure for PW [2]. We analyze the DAI for zonal wavenumbers 1 to 9 (PW1 to PW9) for the selected dates, here only results up to PW6 are shown.

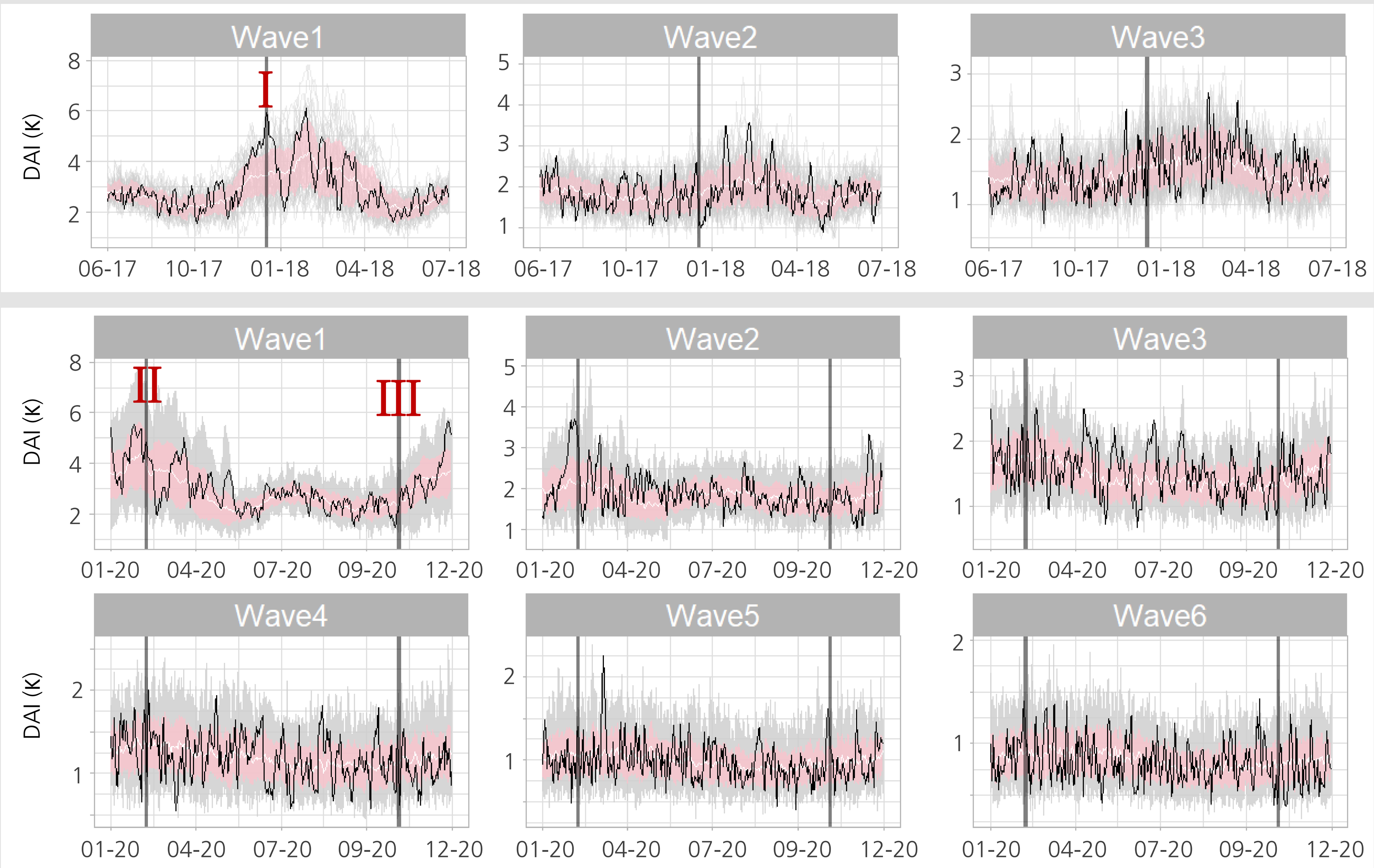

Fig. 3: Dynamic activity index DAI at 200 hPa height. This climatology compares the DAI during a year (black curve) with all values (light grey area) and the mean (white line) of the years 1979 to 2021 and two times standard deviation (red area). The vertical dark grey lines mark the time periods of the selected streamer events (I Dec 18 2017, II Feb 09 2020 and III Nov 04 2020).

Results & Discussion

To better understand non-linear transport processes in the atmosphere the observation and characterization of steamer events is important [3]. At Dec 18 2017 (I), Feb 09 2020 (II) and Nov 04 2020 (III) large-scale elongated air masses from the tropics are led into the mid-latitudes above the Northern Atlantic along the edge of the polar vortex (see potential vorticity in Fig. 1).

The product P_{zG} of all derived parameters of the wind quantities serves as a suitable quantity for the identification and localization of streamer events. The product of the magnitudes results in approx. zero along almost all longitudes. Only within the longitude range of the streamer a clear signal occurs. This criterion thus allows identifying the streamer event. Extremes in the zonal difference of the meridional wind component occur at the location of the flanks of the streamers, indicating strong meridional air mass transport. This is the reason why the product is most sensitive to the meridional wind component; but with this parameter alone the steamer identification is not distinct. Particularly noteworthy is the fact that the transport direction of the air masses becomes clear via the sign of the product at the events at I and III, but only partially at II. Further events need to be analyzed.

The identification of the streamer events is best when the flanks of the steamer are quasi-parallel to the longitudes. This is due to the zonal derivation of the parameters. From our analysis it became clear, that within the spatio-temporal evolution of the steamer there is always a timestep, where this criterion is fulfilled. To further improve our measure, also the meridional derivation should be considered. This becomes more and more important if the streamer shall be traced in time.

Steamers are a direct consequence of PW-breaking [4]. We created a climatology of PWA for the period January 1979 to February 2021 and plotted the DAI of the PW1 to PW3 for the streamer event, and PW1 to PW6 for the streamer events in 2020 (Fig. 3). It becomes clear, that at the 200 hPa pressure level PW1 shows the highest activity, followed by PW2. PWA with higher zonal wavenumbers strongly decreases, which is to be expected [4]. It can be seen on Dec 18 2017 (streamer I) the activity of PW1 and PW2 is unusual high, until it then clearly collapses. Similar behavior of PW1 and PW2 can be observed at II (Feb 09 2020). Hocke te al [3] note that the polar vortex edge is often shifted toward the European sector by a zonal wave 1 in winter. Therefore, it is not surprising, that PW1 seems to have let to these events. On Nov 04 2020 (streamer III) Fig. 1 indicates, that the polar vortex is quasi-circumpolar, which indicates a weak contribution of PW1. Moreover, the polar vortex edge is much stronger disturbed by waves with higher wavenumbers (PW5). Here, PW5 is strong before it collapses at the occasion of the steamer. These case studies show, that PW dynamics of each event need to be analyzed individually, but highlight the importance of PW1 and PW2. Next to the DAI, the phase should be further evaluated.

On Dec 12 2017 at the 50 hPa pressure level (not shown here) the activity of PW1 collapses a few days later compared to 200 hPa. We tentatively interpret this as an indication that the stationary PW1 propagates vertically from bottom to top in the atmosphere. While it already breaks further down at the 200 hPa pressure level, we tentatively speculate that a residual energy remains in PW1, which continues to propagate vertically. Due to the exponential density decrease with height, the amplitude continues to grow until PW1 breaks again at 50hPa.

Summary & Outlook

In our study we analyze three selected streamers which obviously are a consequence of poleward breaking PW. At the flanks of the steamers changes of the zonal and meridional wind components and also vorticity and divergence in zonal direction are enhanced. The parameter P_{zG} helps to decisively identify the longitudes of the flank of the streamers. At the occasion of the steamer the activity of PW strongly decreases which we interpret as an indication of PW breaking. At two of three examples PW1 and PW2 play a key role.

Due to PW breaking gravity waves might be excited at the flanks of streamer. The project LISA will further evaluate atmospheric waves on different scales based on Aeolus wind measurements aiming at deriving kinetic energy density of gravity waves and therefore providing information about the energy transfer from PW to gravity waves.

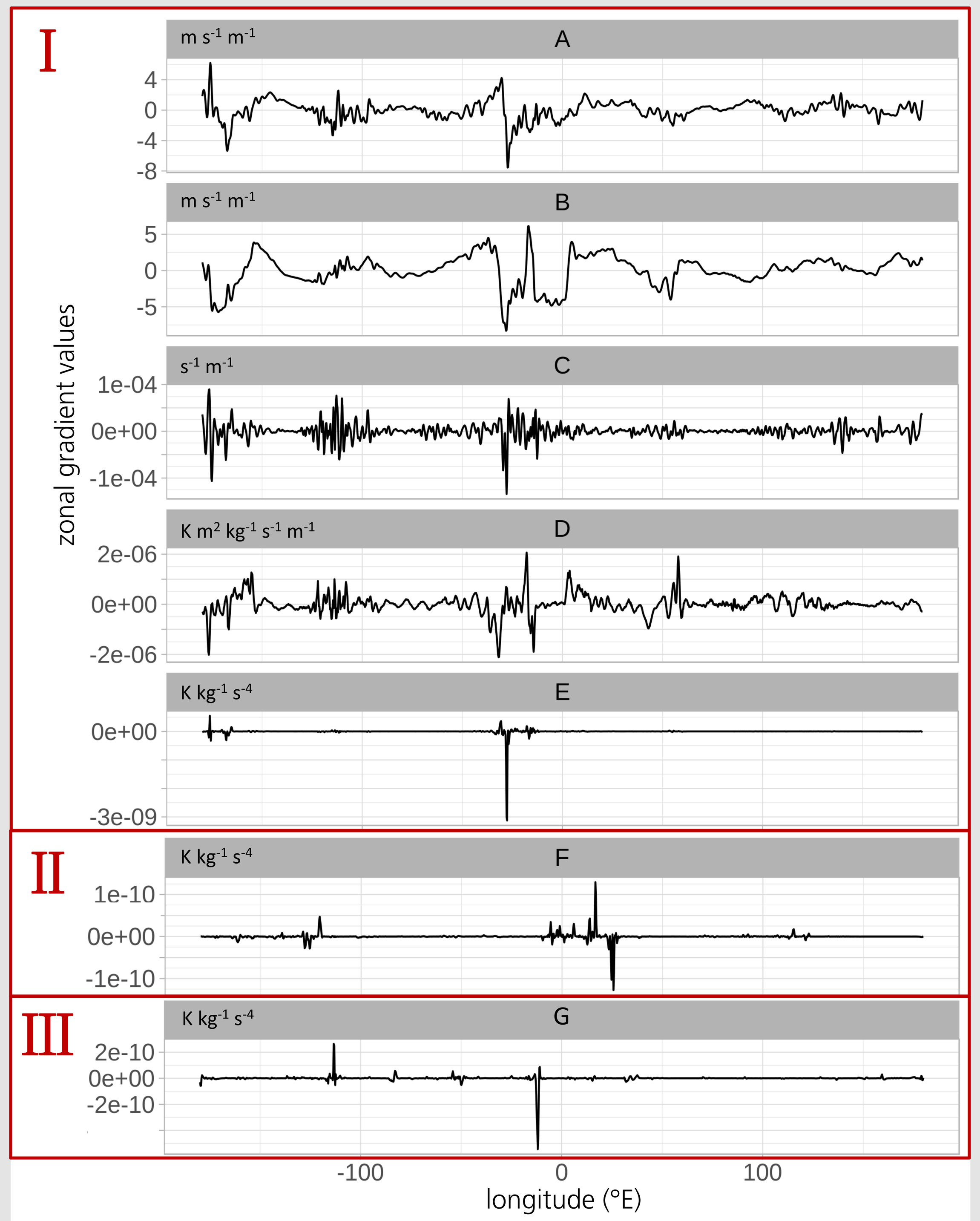

Fig. 2: First order difference in zonal direction of wind and related parameters at Dec 18 2017: A zonal wind component, B meridional wind component, C divergence, D potential vorticity, and E product of all zonal gradients. F product of all zonal gradients at Feb 09 2020, G product of all zonal gradients at Nov 04. 2020. All figures relate to 200 hPa. The products of the zonal gradients at the selected times detect the position of streamer events at Northern Atlantic.

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DLR Deutsches Zentrum für Luft- und Raumfahrt