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DATA NOTE

Wind envelope amplitude data at 300 hPa for the study of atmospheric waves in the Southern Hemisphere during austral summer

[version 1; peer review: awaiting peer review]

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Abstract

Background: Understanding the atmospheric processes linked to the development of weather extremes like heatwaves, extreme rainfall, *etc*, is key to mitigate future damages caused by these phenomena. One of the atmospheric processes associated to the development of these events are Rossby wave packets, which are meanders of the strong westerly winds that travels in the upper atmosphere.
Methods: In order to track and characterize these wave packets, the wind envelope amplitude of the packet is calculated. In this document we describe two wind envelope amplitude at 300 hPa (V_{300env}) datasets obtained from ERA 5 and NCEP-DOE2 reanalyses for the Southern hemisphere during the austral summer, as well as the methodology followed to obtain the datasets.
Conclusions: We expect that this database will help the study of atmospheric waves in the southern hemisphere, thus, facilitating studies that focus on understanding atmospheric dynamical processes associated to extreme weather events development.

Keywords

Rossby Wave Packet, Wind envelope amplitude, ERA 5, NCEP-DOE2

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Plain language summary

In order to improve the detection of intense weather events such as heatwaves, cold spells or extreme rainfall, we first need a better understanding of the atmospheric and oceanic processes that cause these events in the first place. One of these processes are the Rossby wave packets, which are deviations of the strong wind currents that appear in the upper atmosphere of mid-latitudes. In order to study the Rossby wave packets, we need to use data from simulations that represent the wind circulation in the upper-levels of the atmosphere, which is the altitude where these packets propagate. Nonetheless, the presence of noisy fluctuations in the atmosphere increases the difficulty of observing and analysing the characteristics of these wave packets. Therefore, we need to process the data in order to detect and track Rossby wave packets and their trajectory effectively. Therefore, in this document we describe two data sets in which we transformed meridional wind speed into a variable, called wind envelope, which is used to characterize and study Rossby wave packets, as well as the methodology applied to obtain it.

Introduction

Heatwaves and cold spells, among other extreme events, are phenomena that even if they do not occur very often, they cause severe destruction and casualties in the affected areas. Also, several studies have shown that the frequency of occurrence and intensity of these extremes will increase in the nearby future (Skansi *et al.,* 2013; Stott *et al.,* 2016). Therefore, we need to enhance the detection of these extreme events in the sub-seasonal scale (10–90 days in advance) in order to reduce human casualties and mitigate future damages. Nonetheless, in order to achieve this, first we need a better understanding of the phenomena that trigger the development of these events in the first place. One of this processes are the atmospheric Rossby wave packets.

Rossby wave packets are meanders, deviations of the strong westerly winds that circulate in the upper troposphere (Rossby, 1945) and have been linked to extreme rainfall, heatwaves and extratropical cyclone development (Chang, 2005; O'Brien & Reeder, 2017; Wirth *et al.,* 2018). When Rossby wave packets propagate in the atmosphere, they manifest as a series of troughs and ridges confined in a certain latitudinal sector, which travel mainly eastwards during austral summer (Chang, 1999). Consequently, it is possible to characterize the Rossby wave packets by computing the envelope of the meridional wind speed at the altitude where these packets propagate (Zimin *et al*., 2003).

Nonetheless, the computing and noise filtering of the wind envelope can be a little tricky. Therefore, the aim of this datanote is to describe two datasets which contain wind envelope amplitude data from the southern hemisphere during austral summer, as well as to describe the methodology applied to obtain the mentioned datasets. This will be useful to facilitate the study of atmospheric waves in the southern hemisphere, as well as the understanding of dynamical processes associated with extreme weather events.

Data and methods

Brief description of V_{300env} data

Wind envelope amplitude at 300 hPa or V_{300env} (measured in m/s) quantifies the intensity and size of the meanders of the jet stream. This is, the bigger and more intense the meanders of the jet stream are (which manifest as a series of troughs and ridges showing negative and positive V_{300} cells), the more energetic the Rossby Wave Packet is. Since the atmosphere presents variability in many spatial and time scales, low amplitude values of V_{300env} are not associated to Rossby Wave Packet activity, but to small scale variability which we consider here as noise. Therefore, we need to filter out low values of V_{300env} before the analysis of these atmospheric waves. The threshold between noise and signal is not obvious because there are not physical properties that separate one packet from another (Souders *et al.,* 2014a). Thus, there is no optimal threshold to filter out low intensity V_{300env} values, and if the threshold is too low, we might follow noise, but if it is too high, we will lose Rossby wave packets.

Computation of V_{300env}

Initial data. The starting data is meridional wind speed at 300 hPa (V_{300}) from the ERA5 reanalysis (Hans *et al.,* 2020), with a horizontal resolution of 0.25° x 0.25°, and the NCEP-DOE Reanalysis 2 (NOAA/OAR/ESRL) (Kanamitsu *et al*., 2002), with a horizontal resolution of 2.5° x 2.5°. Both datasets were regridded to a spatial resolution of 2.5x2.5° and to a daily timestep using the Climate Data Operators software (Schulzweida, 2022), which is a tool that enables the regridding of datasets. The datasets cover the entire longitudinal sector, and with a latitudinal range between 90°S to 30°N.

The period of study chosen is the austral summer, here considered as December, January, February and March (DJFM) from 1979–2020 thus retaining data corresponding to 41 summer seasons.

Measurement of V_{300env}

In this section we will describe the steps followed to obtain V_{300env}. from V_{300}. Nonetheless, before describing the process it is important to highlight that this methodology requires that Rossby wave packets travel mainly in the zonal direction (Zimin *et al.,* 2006). This condition is fulfilled during southern hemisphere summer, when the jet stream is centred around 50°S and shows a narrow and approximately zonally symmetric wind flow (Chang, 1999).

After removing the 29th of February during leap years, we transform V_{300}. to V_{300env}. the methodology is at follows: first, we subtract the climatological variability from V_{300}. Second, we retain the V_{300} data corresponding to our period of study (between December–March) and extracted the seasonal variability. Third, we apply the methodology of Zimin *et al.* (2003) to find the wind envelope. The procedure used in Zimin *et al.* (2003) consists in four steps. First, we selected V_{300} data for a given latitude and applied the fast Fourier transform; second, we retained data with wavenumbers between 4 and 11, which correspond to travelling transient waves in the southern Hemisphere

(Trenberth, 1981). Third, the magnitude of the envelope is computed by applying the inverse Fourier transform to the data (multiplied by two and retaining the absolute values). As a result, we obtain V_{300env} for a given latitudinal section. Then we repeat the same process for the remaining latitudes. A Python (RRID:SCR_008394) script describing the methodology of Zimin *et al.*, 2003 is available in Perez (2021a).

Choosing an appropriate V_{300env} threshold

In order to choose the most suitable threshold to filter noise, we follow the methodology used in Sagarra and Barreiro (2020): first, we apply a seven day running mean value of V_{300env} in order to filter out synoptic structures, and second, we measure the frequency distribution of the values of V_{300env} in the area of study. As a result, we obtain a Gaussian distribution which indicates the frequency of occurrence of finding V_{300env} for a certain value. Lastly, we round V_{300env} values to the first decimal number, and the most frequent value of the distribution is chosen as the threshold (which also matches with the median of the distribution).

In the case of the NCEP dataset, Grazzini & Vitart (2015) considered a threshold value of 16 m/s, Souders *et al.* (2014b) 14 m/s, and Sagarra & Barreiro (2020) and Perez *et al.* (2021) 15 m/s. Nonetheless, for ERA 5 dataset, Perez *et al.*, 2021 used a threshold of 19 m/s. The reason to apply a higher threshold for ERA 5 datasets relies on the fact that this dataset has larger mean values of V_{300env}, indicating that the jet stream meanderings are stronger, which could be attributed to the higher resolution of ERA 5 compared to NCEP-DOE2 (Perez *et al.*, 2021).

Brief description of the data sets

ERA 5 and NCEP-DOE2 V_{300env} data are stored in NetCDF-4 format (readable in Python), and each file contains V_{300env} data stored in four dimensions (Pérez, 2021). The first dimension indicates the day of the DJFM season, and ranges from day 1 to 121, being 1 the 1st of December and day 121 the 31th of March (the 29th of February of leap years were excluded from the study). The second dimension signals the year of analysis, which begins in December, for example, the first (last) year corresponds to the season that begins the 1st of December of 1980 (2020), and finishes the 31th of March of 1981 (2021). Lastly, the third and fourth dimension are the latitude and longitude coordinates respectively.

Examples

In this section we display two examples of how to use the described datasets to detect the formation and behaviour of atmospheric Rossby wave packets using mainly ERA 5 data.

Example 1: composite maps of V_{300} and V_{300env} during the propagation of Rossby wave packets: the goal of this example is to show that using V_{300env} data we can detect and follow Rossby wave packets. Figure 1 shows the composite maps of V_{300} and V_{300env} the 6th and 8th of January of 2003. As we can observe in Figure 1, high values of V_{300env} match with areas where troughs and ridges manifest (represented as strong positive and negative centers of V_{300}). Also, areas with a local maximum of $V_{300env.}$ indicate the center of activity of the propagating packets. We observe that during the 06/01/2003 there are two wave packets, one located at the east of South America, and another one located at the center of the Indian basin. Two days later, during the 08/01/2003, the packets propagated eastward, and now we observe one wave packet at the eastern South Atlantic basin, and the other one between the eastern Indian basin-Western Pacific basin.

Example 2: Hovmoller diagram of V_{300env} during the propagation of Rossby wave packets: in this example we display the evolution of $V_{300.}$and V_{300env} in a Hovmoller diagram during the propagation of a Rossby Wave Packet. Figure 2 displays the evolution of V_{300} (Figure 2a), V_{300env} (Figure 2b) and filtered V_{300env} (Figure 2c) in the longitudinal section between mid latitudes (40–65°S) from the 6th to the 26th of January of 2003. As in Figure 1, we can observe the manifestation of troughs and ridges during the propagation of Rossby wave packets and the V_{300env} captures it. Nevertheless, as we previously stated, it is difficult to track Rossby wave packets in Figure 2b if we do not filter out the noise. Hence, in Figure 2c we present the same diagram as in Figure 2b, but filtering V_{300env} values below 19 m/s (as in Perez *et al.*, 2021). As expected, it is now

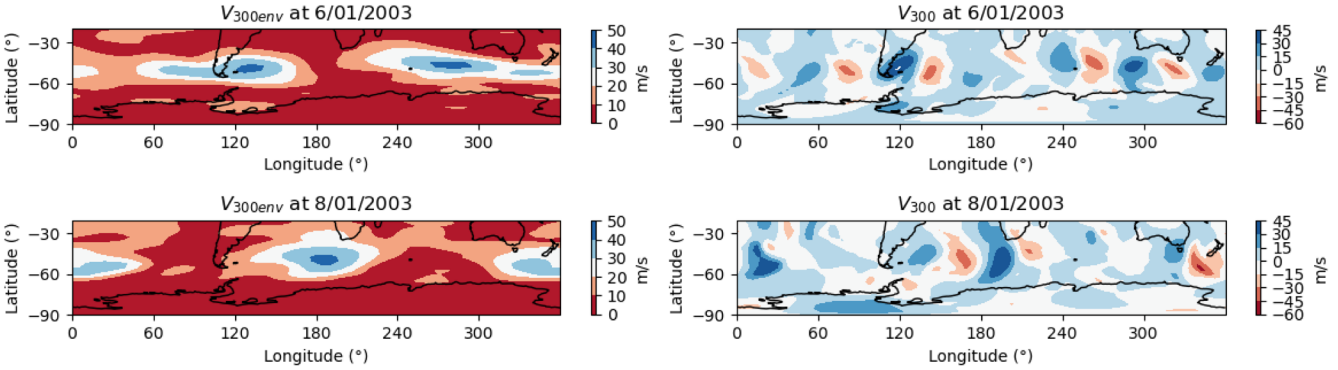

Figure 1. Composite map of V_{300env} (left figures) and V_{300} (right figures) during Rossby wave packets

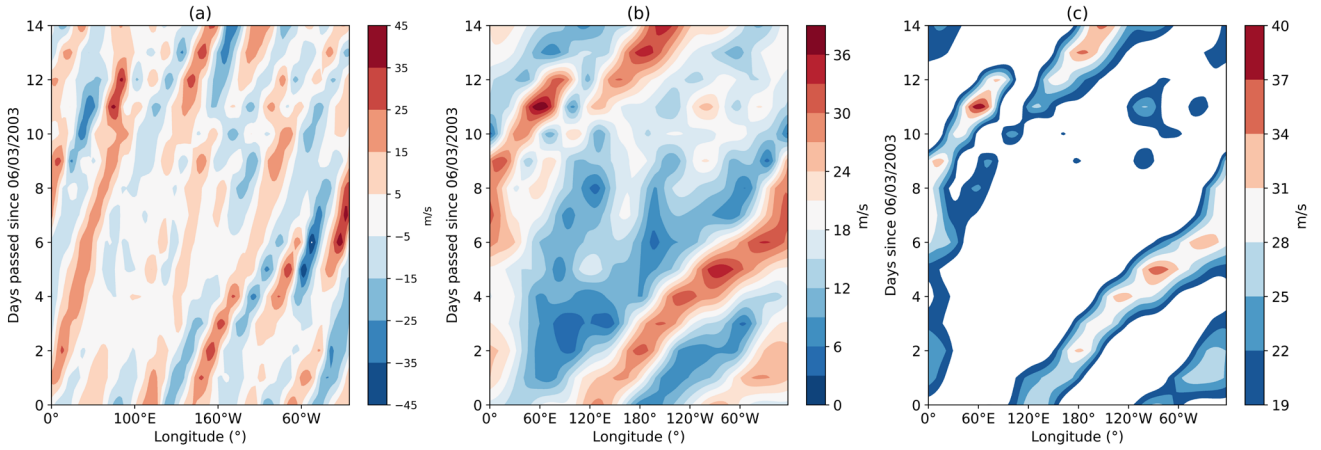

Figure 2. Hovmoller diagram of the temporal evolution of V_{300} (left figure), V_{300env} (middle figure) and V_{300env} (right figure) above the threshold of 19 m/s, (as in Perez *et al.*, 2021), between 40–65°S.

much easier to observe where these packets appear, their propagation, as well as the areas where they lose their stability and disappear.

Limitations

As we mentioned earlier in the document, this methodology requires that the Rossby wave packets travel mainly in the zonal direction, and this pattern is only observed during southern hemisphere summer (Chang, 1999). As a result, the datasets only covers the time period in which this methodology is effective to observe these atmospheric waves, which is the austral summer of the southern hemisphere

Data availability

Source data

ERA5 reanalysis data are freely available in the Copernicus Climate Data Store https://cds.climate.copernicus.eu. NCEP/DOE Reanalysis 2 can be downloaded at the websites: https://psl.noaa.gov/data/gridded/data.ncep.reanalysis2.html. ENSO and SAM indexes are available at https://origin.cpc.ncep.noaa.gov/. The amplitude of the envelope of the RWPs is publicly available at https://doi.org/10.5281/zenodo.5714192, as well as a script to obtain wind envelope data from meridional wind speed at https://doi.org/10.5281/zenodo.5724656.

Underlying data

Zenodo: Wind envelope at 300 hPa in the Southern Hemisphere during austral summer between 1979–2020. https://doi.org/10.5281/zenodo.7341912, (Pérez, 2021)

This project contains the following underlying data:

- V300_env_1979_2020_ERA_5_v1.1.nc (V_{300env} data from December 1979 to March 2020 obtained using V_{300} ERA 5 data).
- V300_env_1979_2020_NCEPDOE2_v1.1.nc (V_{300env} data from December 1979 to March 2020 obtained using V_{300} NCEP-DOE2 data)

The described data is available in a NetCDF-4 format

Data are available under the terms of the Creative Commons Attribution 4.0 International license (CC-BY 4.0).

Software availability

The source code in this article has been previously used and cited in Perez *et al.*, 2021

Archived source code: https://doi.org/10.5281/zenodo.5724656. (Pérez, 2021a)

License: MIT

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