Detection of Dynamic Fronts Using Satellite Altimetry

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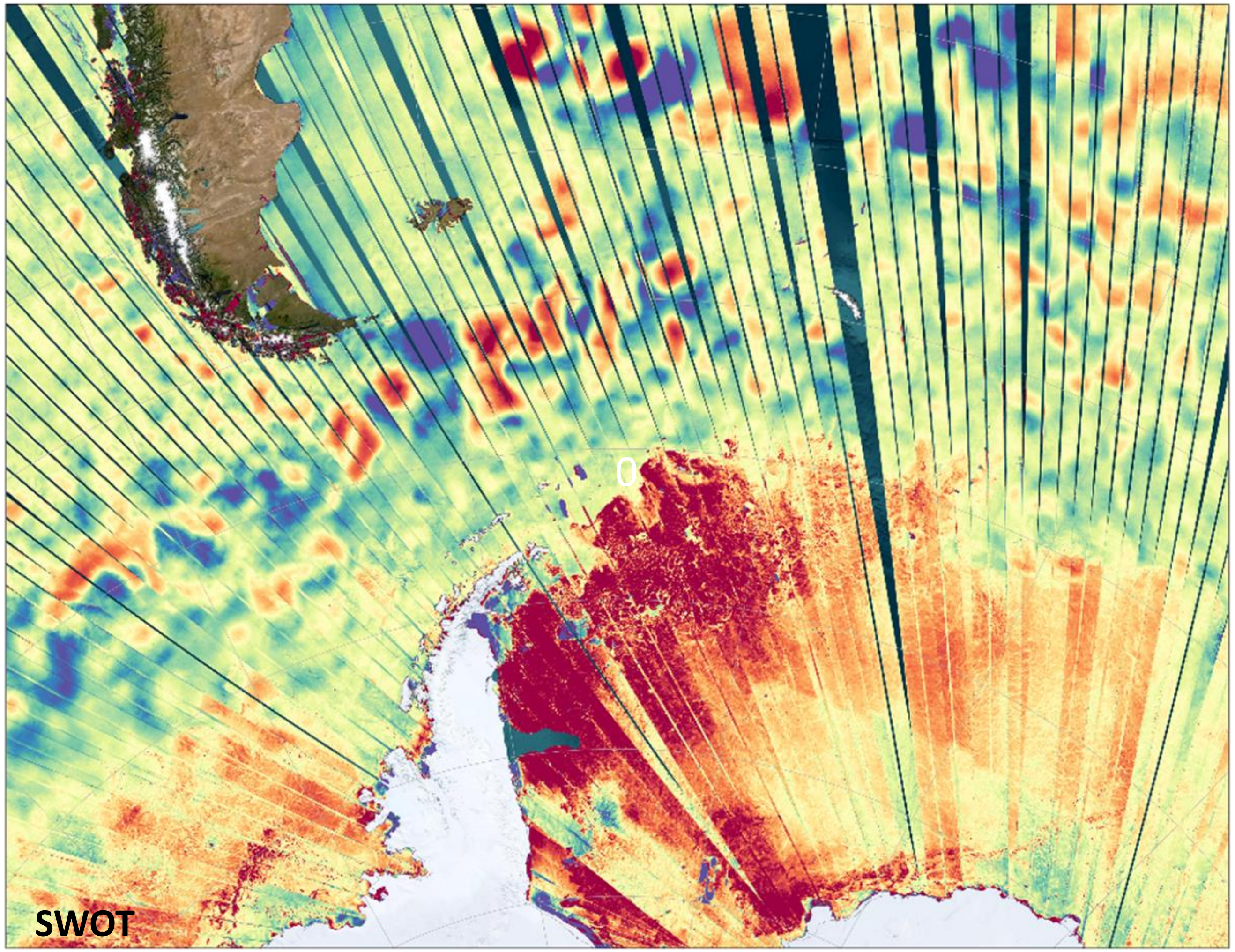

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Introduction

Marine fronts are narrow boundaries between two water masses with different physical properties. Fronts are dynamic, meaning they vary in space, time, and intensity. Therefore, their detection based on a fixed value of a physical variable such as Absolute Dynamic Topography (**ADT**) may not be the most optimal method. In order to detect the **spatial and temporal variations** of the most important fronts in the Drake Passage (DP), namely the Subantarctic Front (SAF), the Polar Front (PF), and the Southern Front of the Circumpolar Antarctic Current (SACCF), we proposed a methodology that utilizes 27 years of daily satellite altimetry maps (1993-2019).

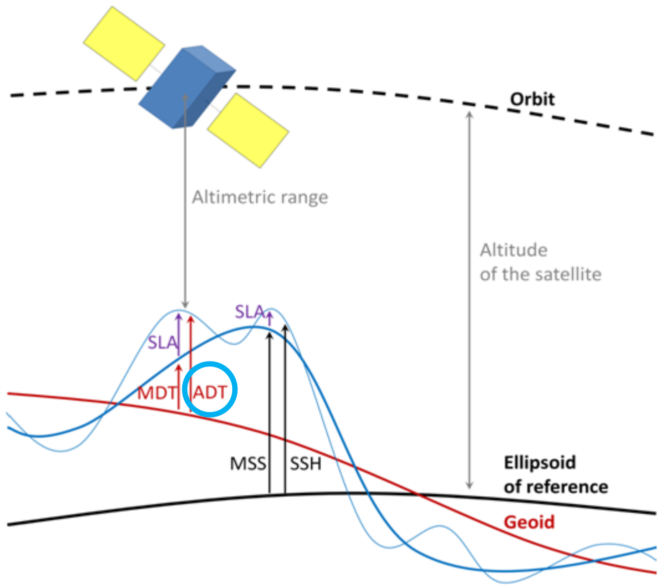


Figure 1. Overview of the different fields used in altimetry (credit: CLS, https://duacs.cls.fr/)

Methodology

The methodology involves calculating the probability density function (**PDF**) of daily **ADT** in a polygon with a fixed area (5° width x 12.5° length), systematically advancing eastward every 3° from 73°W to 53°W (Fig. 2).

Water masses are identified as relative maximas in the PDF associated with a value of ADT, while the frontal zone is represented by a minimum located between these maximas (Fig. 3).

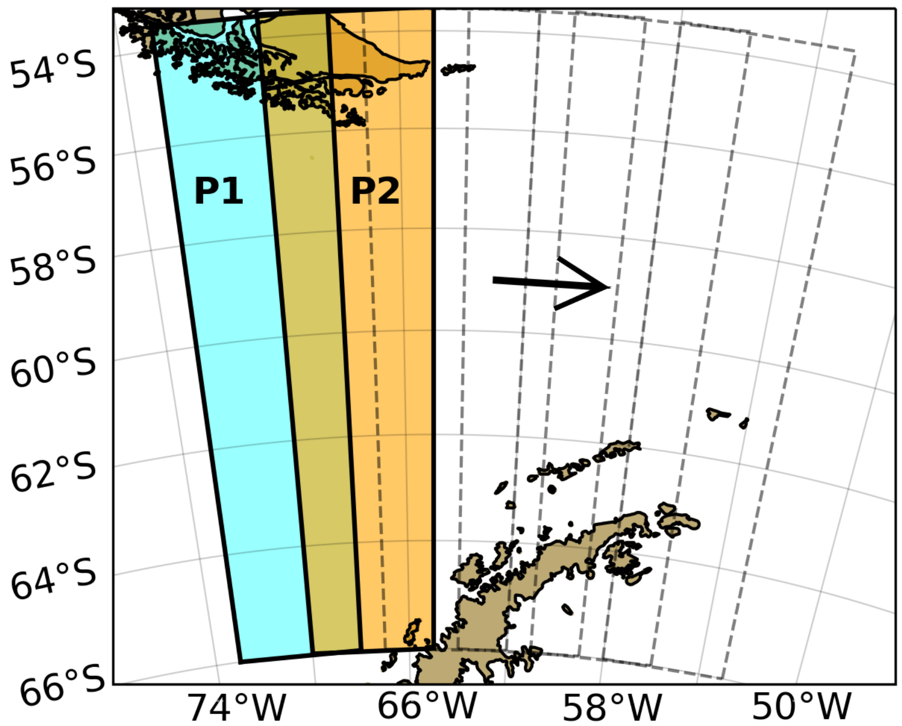


Figure 2. Displacement scheme of the fixed area polygon in the study area.

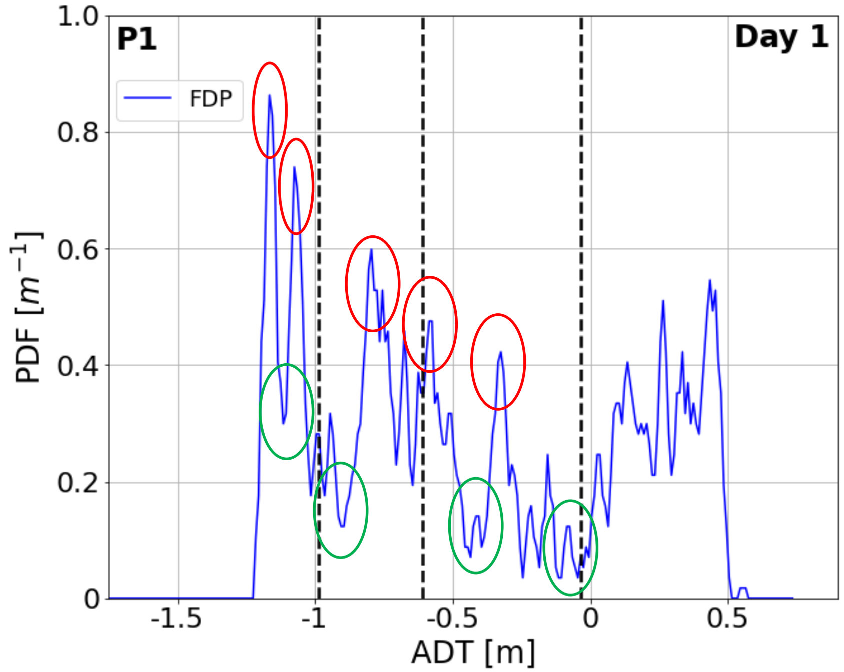


Figure 3. Example of ADT PDF for day 1 on P1. The dotted lines indicate the values of ADT -0.985, -0.610 and -0.035 m associated with the SACCF, PF and SAF respectively according to Kim & Orsi (2014).

Within each designated area, the minimum of the PDF and the associated ADT value were detected, and inter-box connectivity is established by identifying the ADT value closest to that of the preceding box. We employed ADT because it integrates the entire water column, that is, it is influenced not only by surface processes but also by subsurface processes (Chapman et al., 2020). The SL-TAC multi-mission altimeter data processing system was extracted. It is the grilled product provided in deferred time. These products are available from 01/01/1993 to 31/12/2020 and have a horizontal resolution of 0.25° x 0.25° with L4 processing level (https://resources.marine.copernicus.eu/product-detail/SEALEVEL_GLO_PHY_L4_MY_008_047/INFORMATION).

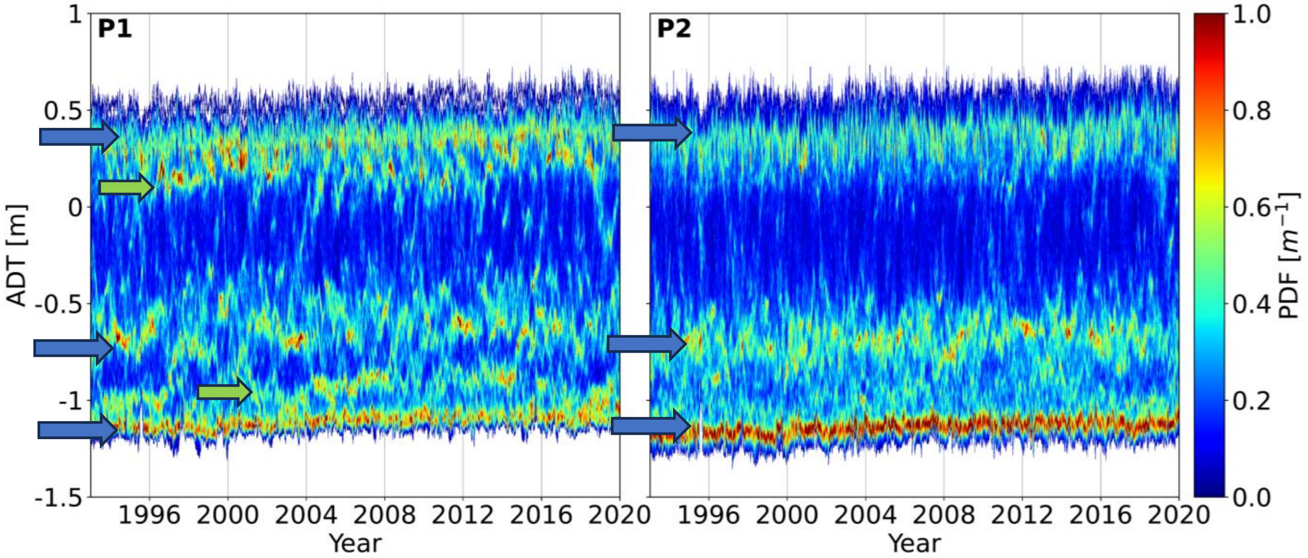


Figure 4. Daily time series of the ADT PDF in P1 and P2 of the DP.

The ADT PDF in P1 show 5 relative maximas along the 27-year period that 3 out of 5 are permanent. In P2, 3 peaks are evident, indicating the spatial variability (Fig. 4).

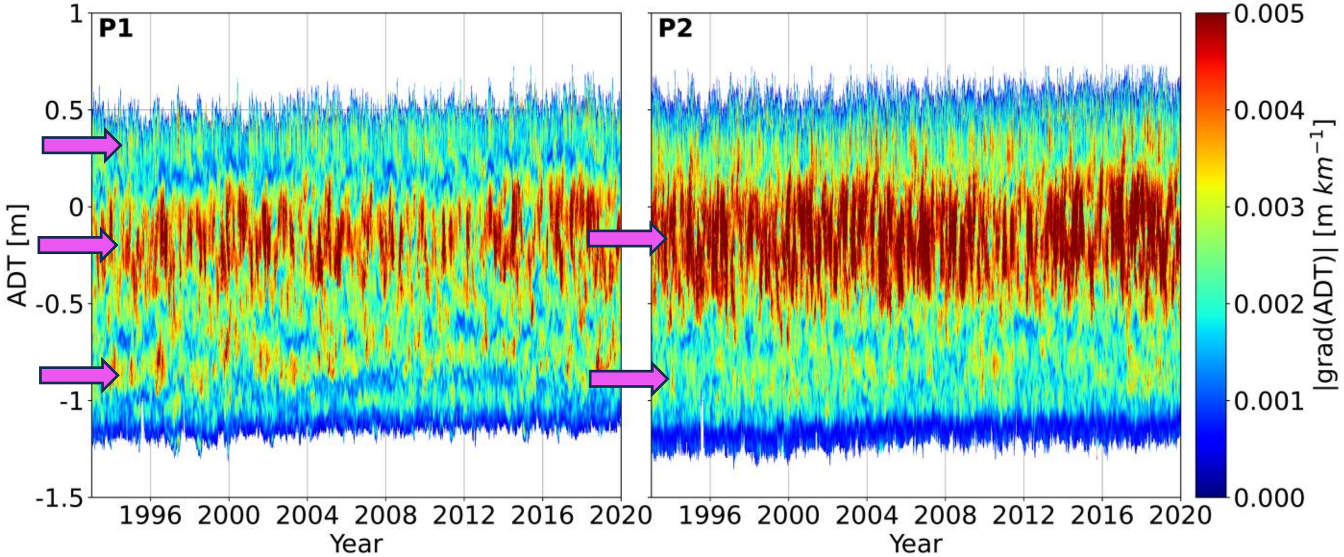


Figure 5. Daily time series of the |grad(ADT)| as a function of ADT in P1 and P2 of the DP.

The time series of the magnitude of the gradient of ADT (|grad(ADT)|) unveiled that a relative maximum value corresponds to a relative minimum value of PDF at a given ADT and conversely (Fig. 5).

Estimation of the climatological position of SAF, PF and SACCF

1) Calculate the monthly mean of daily PDF and |grad(ADT)|.

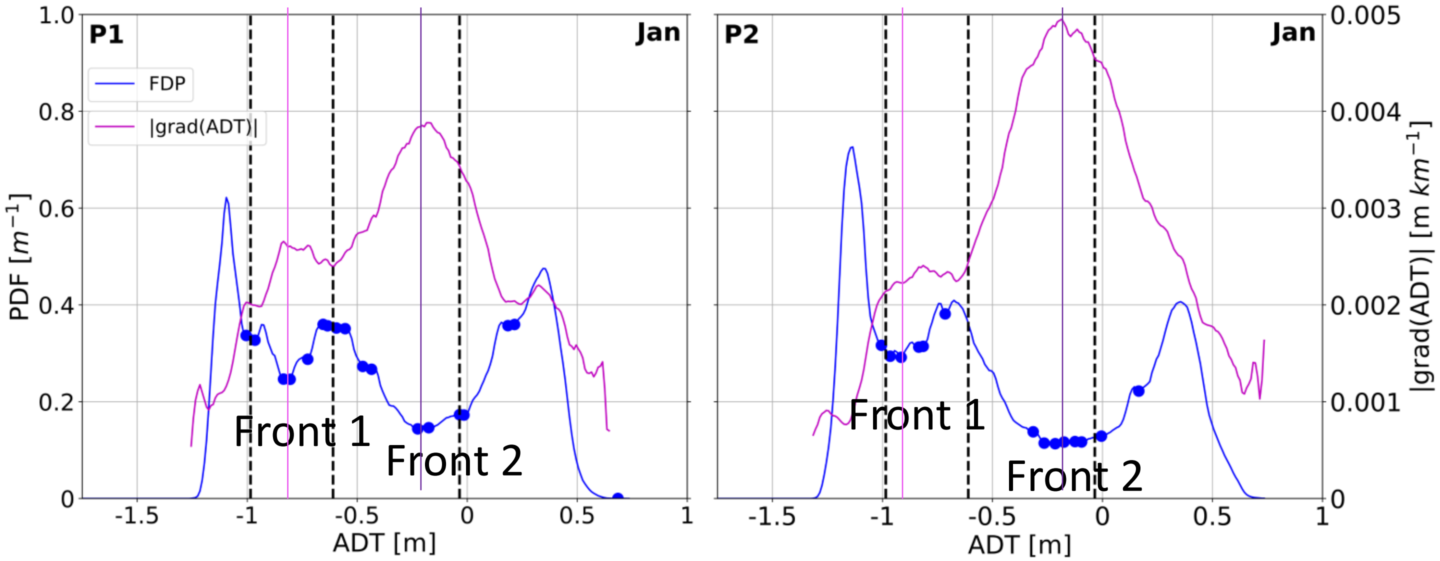


Figure 6. ADT PDF January climatology and |grad(ADT)| on P1 and P2. The dotted lines indicate the values of ADT -0.985, -0.610 and -0.035 m associated with the SACCF, PF and SAF respectively according to Kim & Orsi (2014). The blue dots indicate the minima relative to PDF.

Idem to Figs. 4 and 5, high values of |grad(ADT)| correspond to low values of ADP PDF and conversely. This confirms that PDF serves as a robust indicator of ADT fronts.

The relative minimum values identified for PDF exhibit slight variations across different regions. Since these values correspond to an associated ADT, which could represent a front, the findings underscore that employing a fixed ADT contour to define a front in an extensive region is not an appropriate approach.

We conducted a climatological analysis of fronts by averaging the PDF and the |grad(ADT)| over a 27-year period (1993-2019).

i) Front identification: starting from the initial polygon (P1), the selected ADT value associated with the PDF minimum is the closest to the ADTK&O (Kim & Orsi (2014)) value (|ADT – ADTK&O| < 0.2 m). If this condition is not met, the ADT value associated with the maximums of |grad(ADT)| that has a minimum difference with the value of ADTK&O is selected. If neither of these two conditions is fulfilled, the selected ADT value is the closest to the ADTK&O mean value for each front.

ii) Spatial tracking: to ensure the longitudinal tracking of a given front from one polygon to the next, we selected the ADT values associated with the PDF minimums to the ADT value of each front found in the previous polygon. Alternatively, we selected the ADT value associated with the maximum |grad(ADT)| that have minimal discrepancy with the ADT value of the previous polygon. If both conditions would fail, we selected the ADT value closest to the ADTK&O value for each front in each polygon.

Estimation of the yearly position of SAF, PF and SACCF

1) Calculate the yearly mean of daily PDF and |grad(ADT)|.

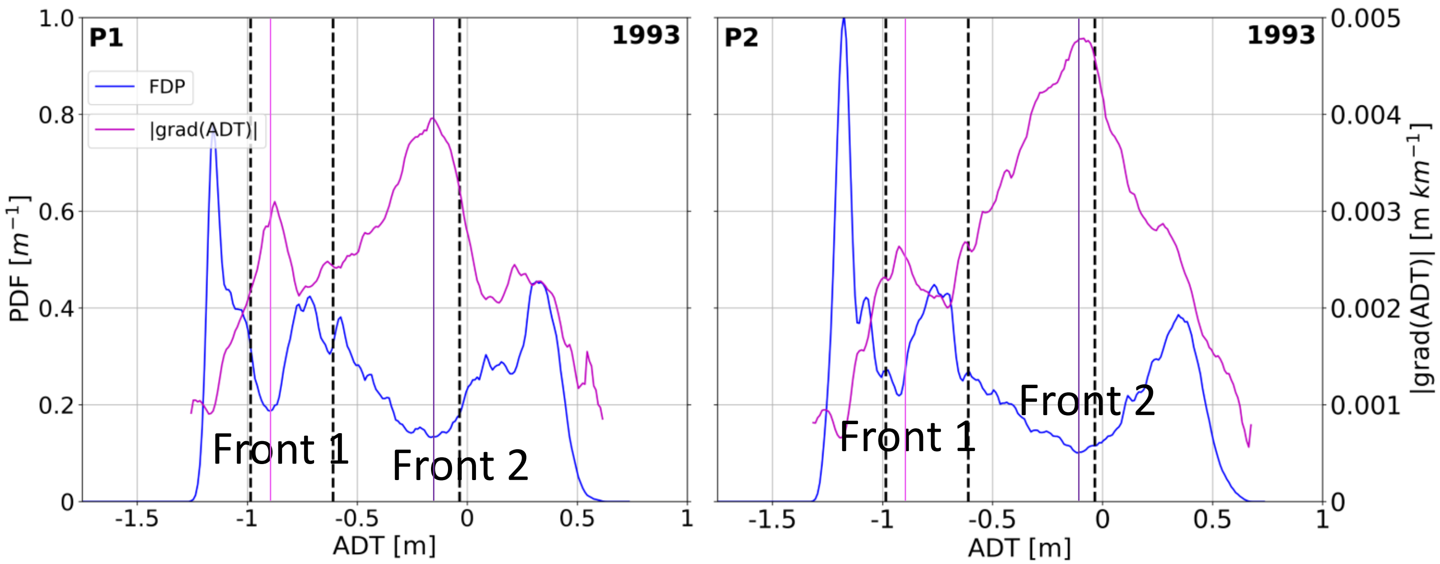
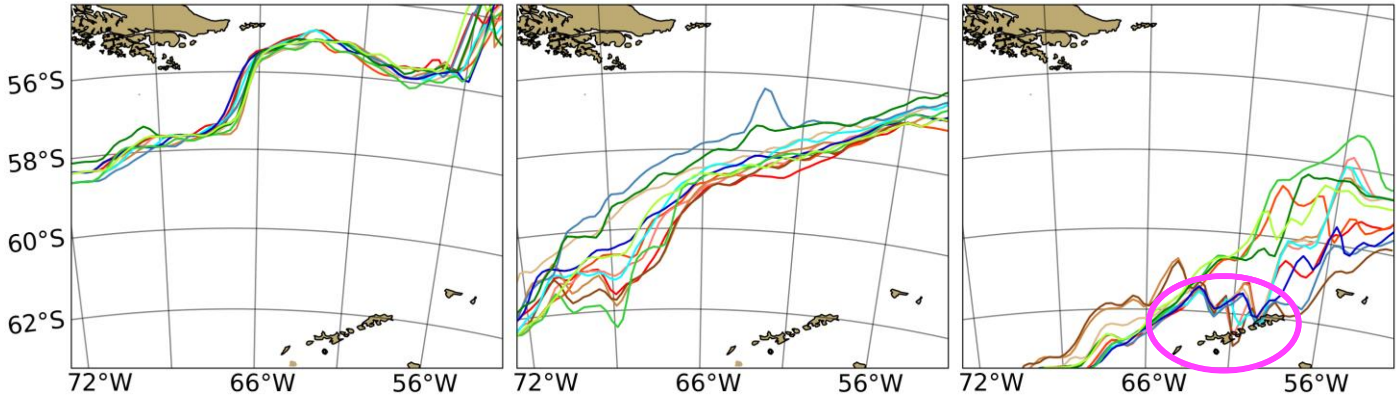


Figure 7. ADT PDF 1993 climatology and |grad(ADT)| on P1 and P2. The dotted lines indicate the values of ADT -0.985, -0.610 and -0.035 m associated with the SACCF, PF and SAF respectively according to Kim & Orsi (2014).

As in Figure 6, the ADT values associated with relative minimum PDF exhibit slight variations across different regions. The |grad(ADT)| values also change. Thus, the intensity of the fronts vary spatially.

Repeat steps i) and ii) explained in previous slide.

Results



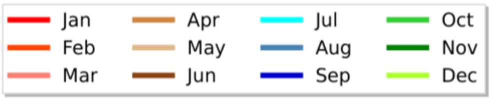


Figure 8. Mensual climatological positions of the primary fronts within the DP determined using the aforementioned methodology, respectively. From left to right: FSA, FP, and FSCCA.

The position of the fronts within the DP exhibited significant spatial variability throughout the annual cycle (Fig. 8). This variability was particularly pronounced in the PF and the SACCF. Nevertheless, a distinct seasonal variation was not observed.

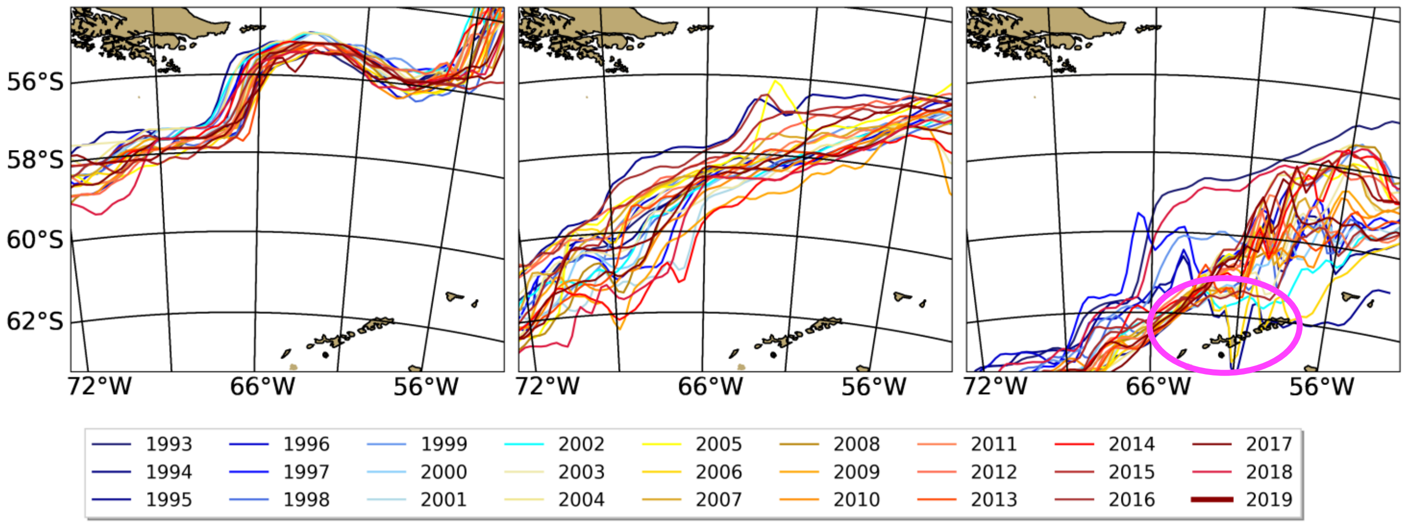


Figure 9. Annual climatological positions of the primary fronts within the DP determined using the aforementioned methodology, respectively. From left to right: FSA, FP, and FSCCA.

The position of the fronts within the DP exhibited significant interannual variability (Fig. 9). The long-term trend is not as pronounced. It is noticeable that the SAF and SACCF tend to shift southward over the years.

Marine fronts should not traverse over land. The region highlighted in magenta serves as an area warranting closer scrutiny and examination. The algorithm encounters a failure in this specific area, compounded by the presence of sea ice during certain periods of the year in addition to land.

Conclusions

• The implemented methodology unveiled that the position of the fronts is not static, it exhibits considerable spatial and temporal variability. This variability was particularly pronounced in two out of the three studied fronts (Polar Front and Southern Front of the Circumpolar Antarctic Current).

• A subtle southward displacement of the SACCF and PF is evident. Frontal detection requires enhancement, as there are instances where SACCF is positioned over land. One approach to ameliorate this could involve leveraging machine learning and/or incorporating model data with a 1/2-degree spatial resolution.