The role of the Pacific-Antarctic Ridge in establishing the northward extent of Antarctic sea-ice

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Monitoring the Antarctic sea-ice is essential for improving our knowledge of the Southern Ocean (SO) and its role in the climate system. We used passive microwave-derived sea-ice concentration (SIC) data for the 2002-2020 period to retrieve sea-ice extent and analyse its year-to-year variability in the Pacific sector of the Southern Ocean. Results provide observational evidence of the recurring formation of a sea-ice protrusion that anomalously extends to 60°S at about 150°W during the winter season. The importance of the Pacific Antarctic Ridge - PAR (a tectonic plate boundary located in this area) to this phenomenon is explored and discussed in this study. A special focus is devoted to the role played by oceanic mesoscale eddies' presence and characteristics in the study area. To this aim we used the multi mission altimetry-derived eddy trajectories data distributed by AVISO.

The combined analysis of co-located sea-ice observations and altimetric information confirm that the PAR acts as a barrier, deflecting to the north the Antarctic Circumpolar Current (ACC) flow and limiting eddies' interaction with the sea-ice edge. This action has an evident impact on the local SIE variability. To provide an estimation of this phenomenon, we divided the Pacific sector of the SO into three longitudinal bands, each 25 degrees wide (i.e., 175° E - 160° W, 160° W - 135° W and 135° W - 110° W), and calculated the maximum ice area that forms in each latitudinal sector. As expected, the sector that includes the PAR (i.e., 160° W - 135° W) is characterized by a larger sea-ice area (104537 km²) that is approximately twice those observed in the neighbouring western (43720 km²) and eastern (58244 km²) sectors.

Antarctic sea ice variability

To analyse Antarctic sea-ice variability we retrieved the sea ice concentration for each month from May to December, averaged over the 2002-2020 study period. These maps highlight the recurrent formation of a sea-ice protrusion in the Ross sea sector that extends up to 60°S at about 150°W

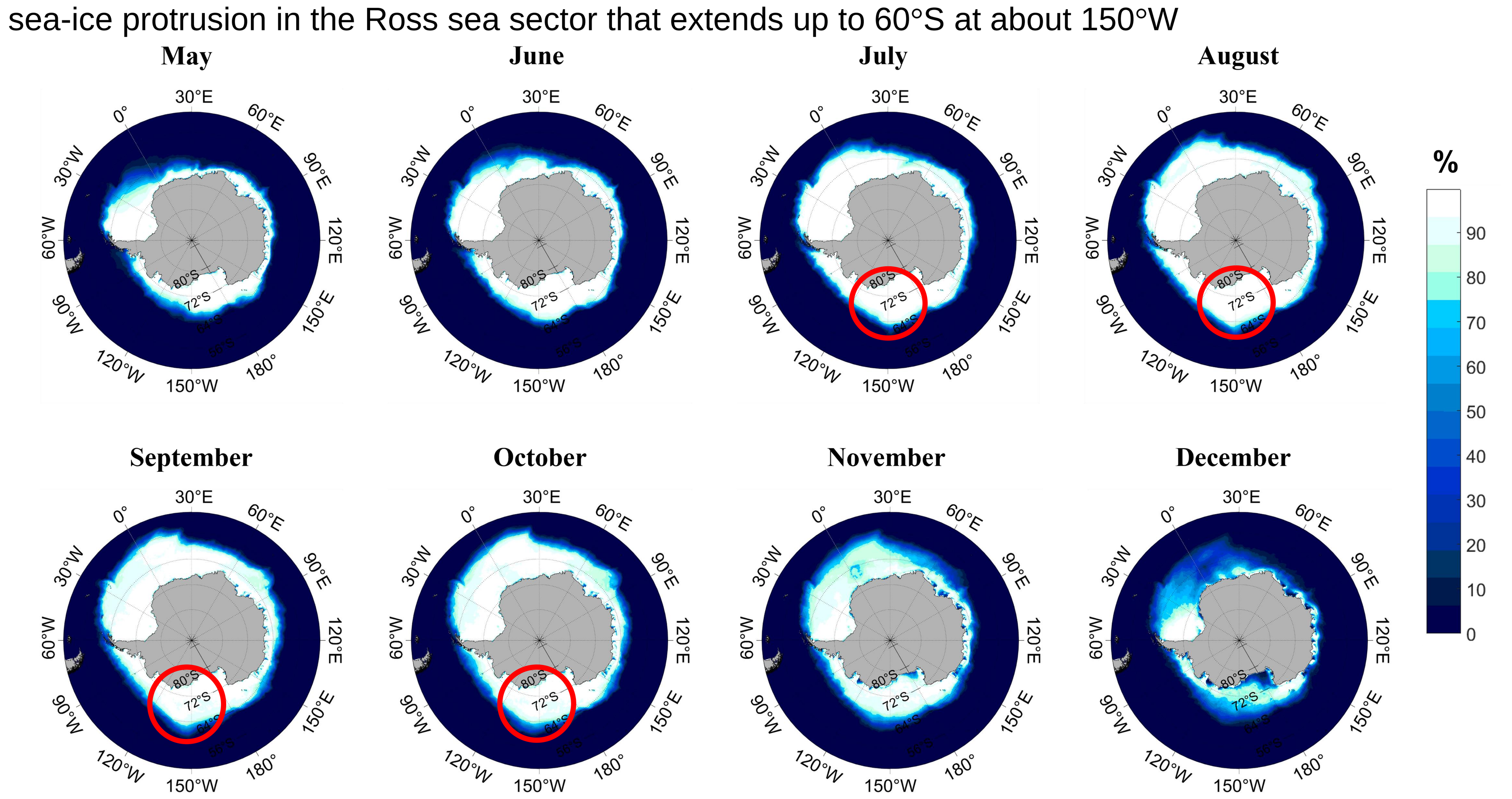


Figure 1. Sea ice concentration averaged over the period 2002-2020 for the months from May to December. The concentration is expressed as a percentage (shown in colour).

Pacific Sector of the Southern Ocean sea-ice variability

We specially focused our study on the Pacific sector of the Southern Ocean, and therefore we extracted the median SIE (0-90%) to describe the sea ice edge position for each climatological month. The monthly averaged median sea ice extent is represented by the different contour lines, which are superimposed to the bathymetry map of the study area. The contour lines of the median SIE corresponding to the western side of the identified ice protuberance are aligned to the Pacific Antarctic Ridge (red circle). At approximately 150°W, the ridge reaches lower latitudes moving from about 66°S at 180° to 60°S at 150°W. This allows the maximum SIE to be identified immediately further east of its position.

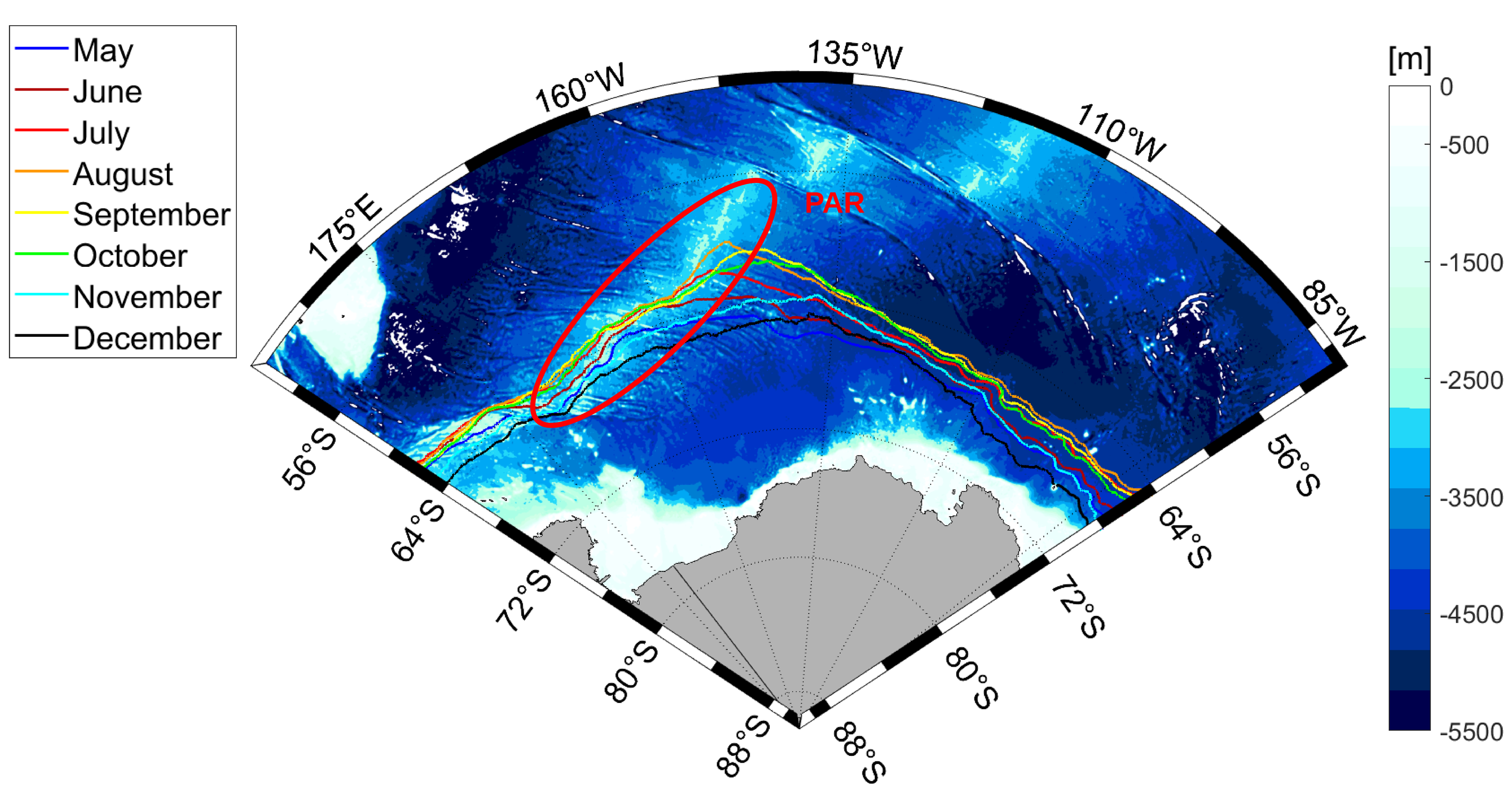
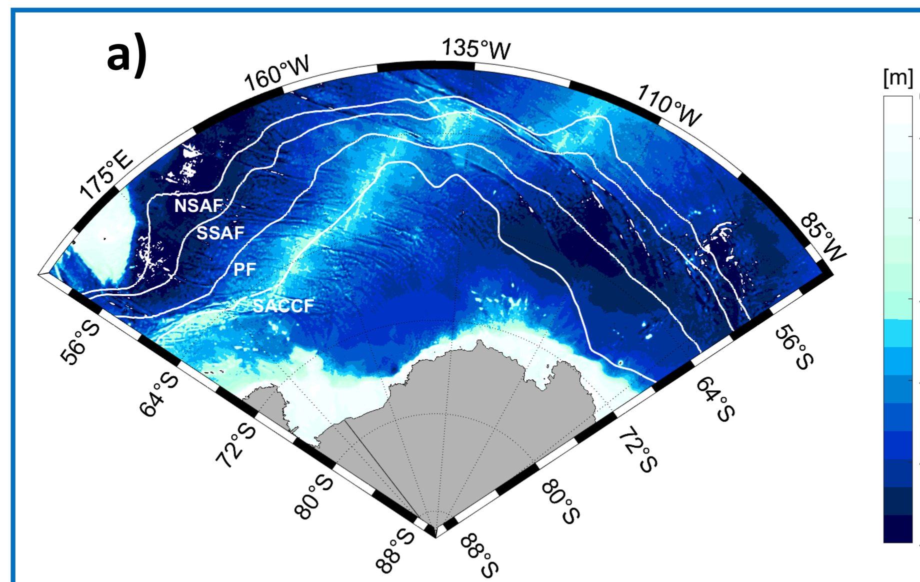


Figure 2. Median sea ice extent (0–90% ice concentration) for the months between May and December (colour coded), obtained through SIC data over the period 2002-2020.
The bathymetry of the Pacific sector of the Southern Ocean is represented and expressed in metres.



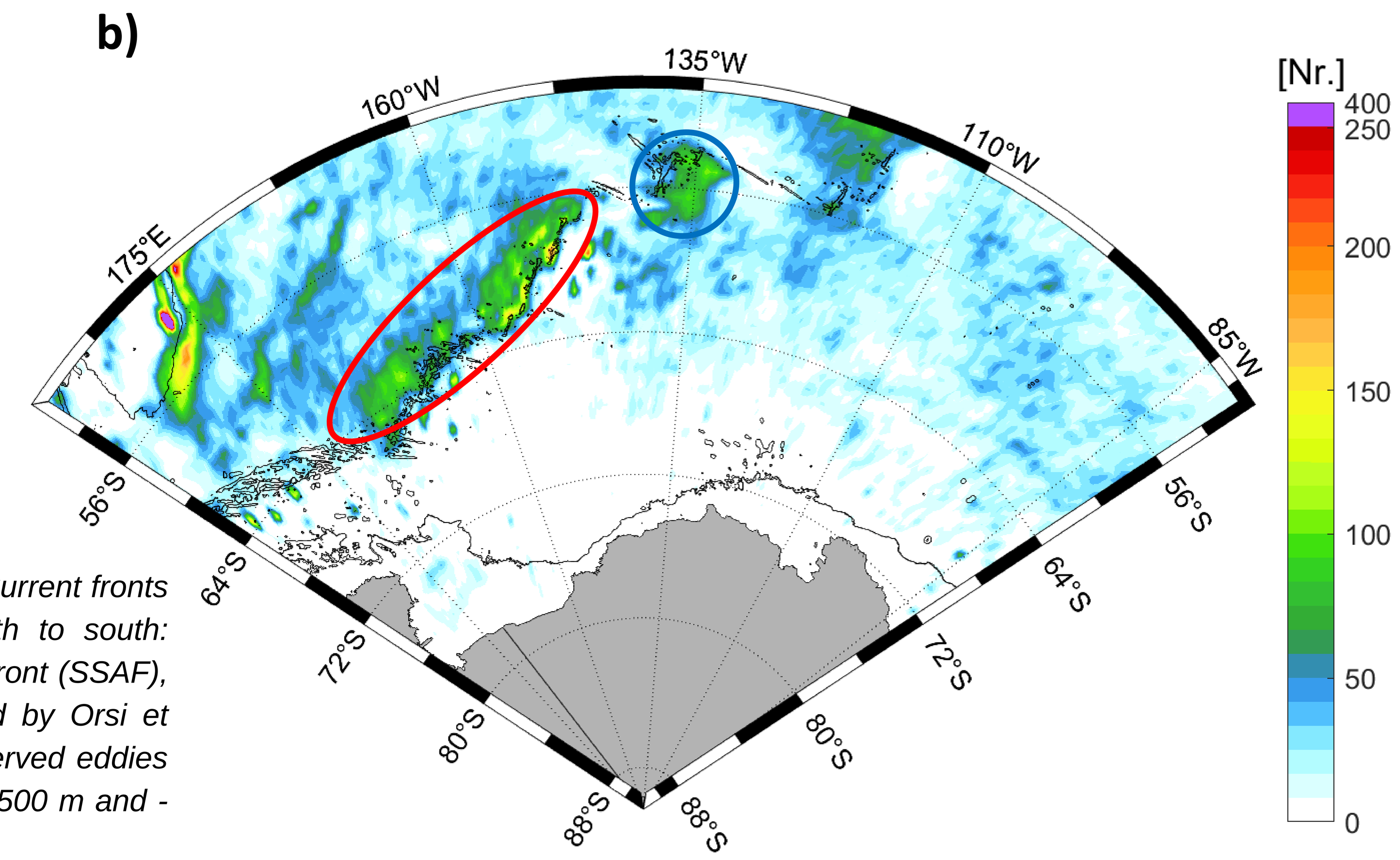


*Figure 3. **a)** Mean positions of the main Antarctic Circumpolar Current fronts (white lines), adapted from Menna et al. (2020). From north to south: Northern Sub-Antarctic Front (NSAF), Southern Sub-Antarctic Front (SSAF), Polar front (PF) and Southern ACC Front (sACCf) as defined by Orsi et al.(1995); Sallée et al.(2008). **b)** Frequency map of all the observed eddies during the 1993-2020 period within 0.5 × 0.5° grid cells. The -2500 m and -2600 m bathymetric contour lines are represented in black.*

Eddies' Dynamics

We investigated sea ice variability shaped by ocean circulation and the role played by regional bathymetric constraints. Figure 3a shows the northward deflection of the ACC and its fronts due to the PAR presence, that certainly constitutes a first contribution to the northward extent of the sea ice. Additionally, we explored the effect on the SIE of the interactions between ACC eddies and the PAR. Eddy observations have been used to produce a frequency map (Figure 3b) from 1993 to 2020 within 0.5 × 0.5° grid cells. The western (red circle) side of the PAR (identified by the 2500 and 2600 m depth isolines) is characterized by higher concentration of eddies than the eastern side.

Conversely, an increase in the number of eddies in the eastern side of the PAR (56°S and 135°W, blue circle), next to the Udintsev fracture zone. Here the ACC and the eddies overcome the influence of the PAR and move southward.

Eddy observations have been used to produce monthly anticyclonic (in red) and cyclonic (in green) eddy trajectories and distribution maps over the SO during the study period (Figure 4). The median SIE contours for the month of August (left) and December (right) are also superimposed on the eddy distribution map. Compared to the surrounding areas, the concentration of both types of eddies on the eastern slope of the PAR is considerably lower than on the western slope.

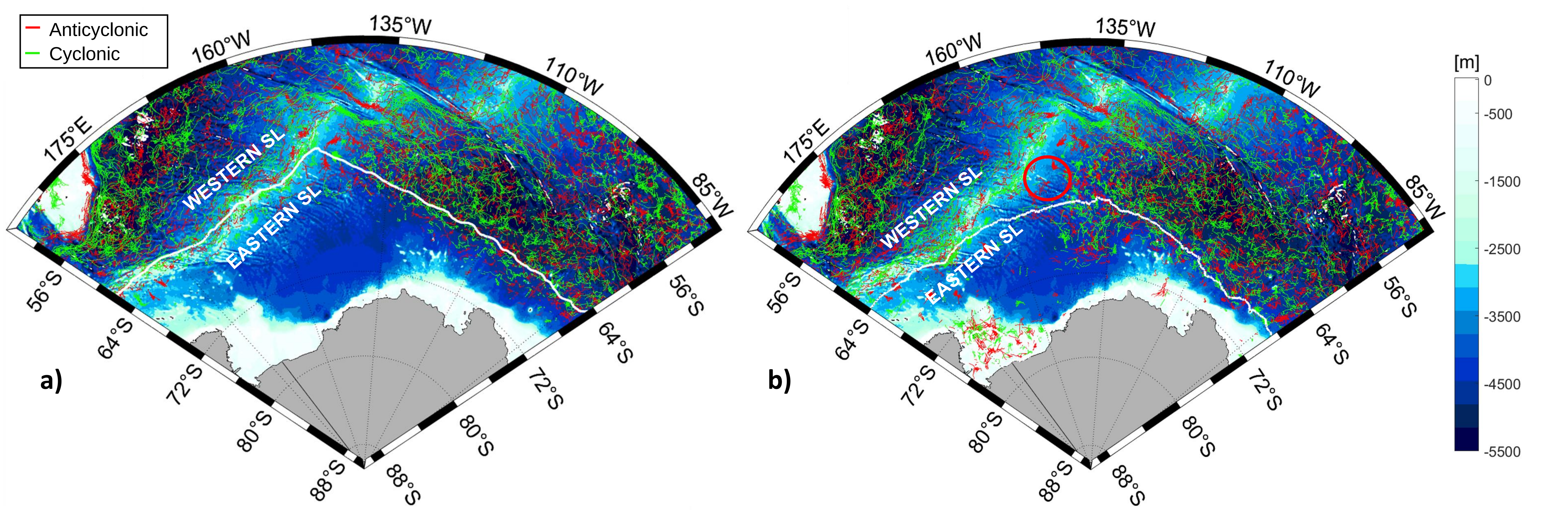


*Figure 4. **a)** August and **b)** December anticyclonic (red) and cyclonic (green) eddies distribution maps overlapped on the respective median ice extent (0-90%), relative to the 2002-2020 period. The bathymetry is expressed in metres (see colour bar).*

According to our results, the ridge act as a strong barrier that prevents cold and warm core eddies from propagating eastward and forces them to move northward together with the ACC, limiting their interaction with the marginal ice zone. This allows the SIE contours to generally follow the submarine relief itself during all the months analysed. The effect of the PAR is also demonstrated by the absence of eddies on the eastern slope of the ridge even during the summer months when SIE is limited to higher latitudes. Consequently, this mechanism favours SIE exceptional growth at 150°W.

Acknowledgments

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