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IDENTIFICATION AND CHARACTERIZATION OF POLAR LOW OVER THE ANTARCTIC PENINSULA AND ADJACENT SEAS

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1. INTRODUCTION

Polar Lows (PL) are intense mesoscale marine cyclones (Rasmussen and Turner, 2003) with a short lifetime (usually between six and 36 hours) and occurring preferentially in high latitude regions in both hemispheres. It is a phenomenon with a horizontal extent of less than 1000 km and usually develops in the background of extratropical cyclones.

Before having a specific nomenclature, the phenomenon had names like "Arctic Low" and "Arctic Hurricane". However, it is worth pointing out that despite these nomenclatures, polar lows are not restricted to the polar latitudes or to the Northern Hemisphere.

In the EPLWG (The European Polar Lows Working Group), in addition to a universal nomenclature, it has been defined that a Polar Low is an intense maritime cyclonic vortex that develops in the rear of a polar front, whose horizontal scale does not exceed 1000 km and which has a surface wind speed greater than 15m.s-1.

Polar Lows are associated with severe weather due to intense winds, heavy rain, or even heavy snow. And due to their short lifetime (compared to synoptic cyclones, for example), they are difficult to predict, making a better understanding of these systems even more necessary.

The study of these phenomena over the Antarctic continent is still very recent and the lack of meteorological data in the region makes it difficult to better study and understand the characteristics of the Antarctic Polar Lows.

There are several theories regarding the forcing mechanisms that lead to the development of these systems.

The first hypotheses that attempted to explain the formation of a Polar Low advocated the theory of thermal instability, which proposes instability within a cold air mass flowing over the warmer sea as the main mechanism (Dannevig, 1954).

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Dierer and Schluenzen (2005), in a study of the parameters that may influence the development of these mesocyclones, through numerical modeling simulations, found that regions with less dense sea ice cover (75% ice cover) and with intense winds produce favorable condition for sea ice breaking. The wind field creates a divergence in the drift of this ice, creating favorable conditions for the development of Polar Lows. Furthermore, they realized that for the average heat fluxes at the surface, the distribution of sea ice may be more important than the absolute amount of sea ice in the area, since a lower concentration will increase the air temperature over this ice cover, and thus the temperature difference between air and water during sea ice flow will be smaller and the heat flux over water, reduced.

Emanuel (1989) states that other disturbances, such as topographically generated cyclones, can also act as initial disturbances, while Sardie and Warner (1983) showed that some Polar Lows tend to be mainly baroclinic, while others show strong convective features.

Despite the multiplicity of these theories on the development of Polar Lows, they still remain too complex to be explained by just one of the theories. This difficulty has led to the acceptance of several mechanisms acting simultaneously in triggering and intensifying a Polar Low and a spectrum between extremely baroclinic cases (Bracegirdle and Gray, 2008).

2. OBJECTIVE

This work aims to identify the regions of higher density of Polar Lows, as well as the preferred regions of genesis and their trajectories, using the year 2020 as the study period. Another important feature analyzed are the types of cloud signatures associated with these systems and the frequency of shallow, medium, and deep vortices associated with the Polar Lows (PL).

3. BIBLIOGRAPHIC REVIEW

The Antarctic Continent

The Antarctic Continent comprises the entire territorial strip below 60ºS and is the most isolated region on the planet, separated from the other continents by stormy seas. Because it is located at higher latitudes, it receives little solar energy. In addition, due to the low temperatures and consequent large ice cover, the continent has a high albedo value. Thus, much of the incoming energy is reflected back into the atmosphere.

Ice not only covers the Antarctic continent, but also surrounds it. During the winter months, a belt of about 1000 km is formed around the continent, increasing the ice-covered region by approximately 18 million km^2. In the summer months, this belt of sea ice retreats practically to the coast, with the exception of the Weddell and Ross Seas, which have permanent ice shelves.

The Antarctic climate is very dynamic, as it has a series of extratropical cyclones that act in the coastal regions and in the seas adjacent to the continent, carrying out energy exchanges between the middle and polar latitudes in the Southern Hemisphere.

Figure 1. Topographic map of Antarctica
Source: REMA

The action of extratropical cyclones allows the coastal regions to reach even positive temperature values, so the most extreme values are linked to the interior of the continent and the large mountain ranges. In **Figure 2**, Antarctica can be seen surrounded by extratropical cyclones, showing the dynamics that exist on the continent.

Unlike the Arctic, where Polar Lows occur exclusively in the winter months, in Antarctica, there are episodes of Polar Lows throughout the year, and they are most frequent in summer and least frequent in winter. Moreover, they occur at all latitudes and longitudes around the continent (Carrasco *et al*., 2003). This is due to the fact that the Antarctic continent is a year-round source of cold air, unlike its opposite, which warms up in the summer months, losing its ice cover over land areas.

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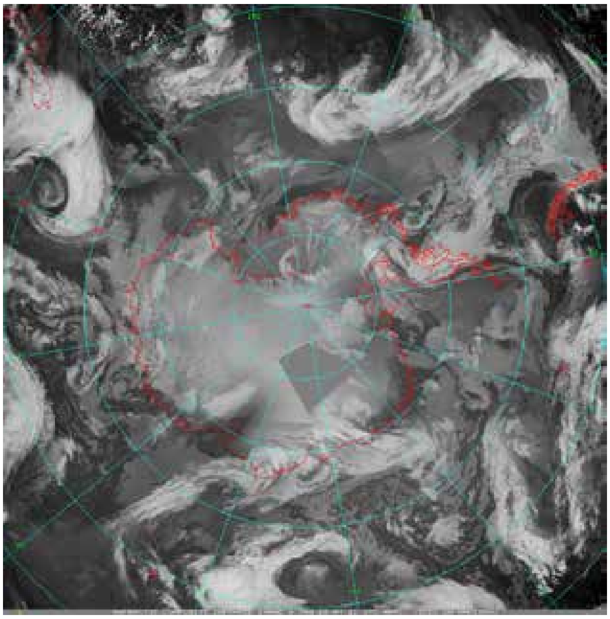


Figure 2: Mosaic produced by several polar orbiting satellites produced by the infrared channel on January 4, 2020 at 11 UTC
Source: AMRC & AWS

Antarctic Peninsula

The Antarctic Peninsula is a mountainous barrier that extends northward from the base of the continent and separates the Weddell (east of the Peninsula) and Bellinghausen (west of the Peninsula) seas, acting as a barrier to airflow.

Cloud Signature

Polar Lows have vortices with various cloud signatures. The most commonly observed are "comma-like" clouds and spiral clouds.

Comma-like cloud

Comma-shaped clouds are usually found at mid-latitudes near the main baroclinic zone. However, they can also be seen at higher latitudes.

The tail of this cloud type often marks the front of a cold air mass with cumulus cloud, sometimes in the form of cloudy streets behind it, and is often represented on synoptic charts as a short "secondary" cold front, a trough, or even an occluded system. This type of mesoscale cloud vortex is the most frequently observed PL signature.

It is worth noting, however, that polar lows with a comma-like cloud signature are not truly comma clouds. In fact, they are shaped similarly to such systems since comma clouds are presented as weak surface systems. Occasionally, however, these systems can develop strong surface circulations, i.e., Polar Lows.

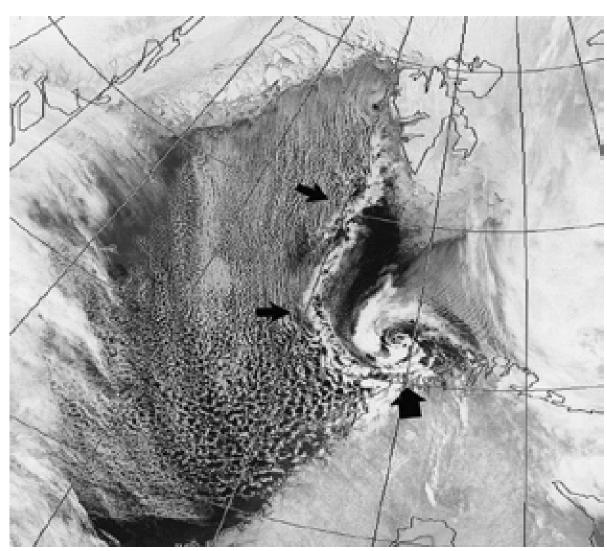
Spiral Cloud

The spiral-shaped signature has bands of convective cloud elements curving inward toward the circulation center of the polar low. These types of signatures are characterized by one or more spiral bands of convective clouds around the circulation center. Generally, spiral-type Polar Lows have a cloud-free eye in the region of the center of the low.

4. METHODOLOGY

TRACK algorithm

Mesocyclones were tracked using the TRACK automated tracking algorithm (HODGES, 1994, 1995), utilizing the relative vorticity field at the 850 hPa level from the ERA 5 reanalysis of the European Centre for Medium-Range Weather Forecasts (ECMWF) as input data. Relative vorticity was used because unlike the Mean Sea Level Pressure field, relative vorticity is effective in detecting weak and fast moving systems. In addition, this parameter can be altered to reduce the major and minor spatial scales and focus on the mesoscale, making the identification and tracking process easier.



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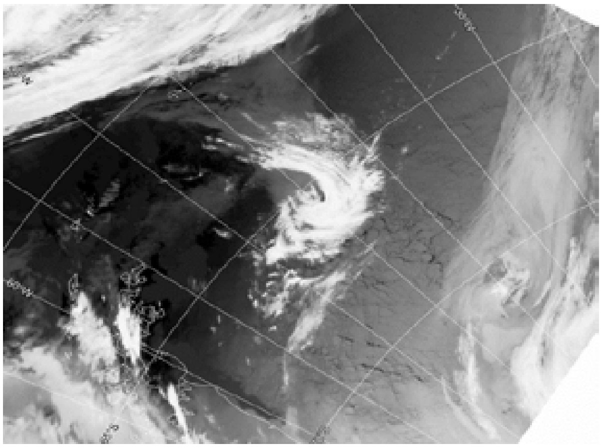

Figure 3. Thermal infrared image of a comma (a) and spiral (b) "type" Polar Low
Source: Rasmussen and Turner, 2003

The threshold -2.0 x10 -5 s-1 was used to identify the local minima. Tracking is performed using the nearest neighbor technique, thus also determining the course of the identified cyclones.

Table 1. ERA 5 Reanalysis Information

Reanalysis	Resolution	Time Series	Data Frequency
ERA5	0.25º x 0.25º	1979 - Currently	Time

The vorticity was spectrally altered by converting to spectral representation and truncating to T40-T100. The background at planetary and synoptic scales, defined by total wave number ≤ 40, and the smaller spatial scales defined by wave number ≥ 100, were then removed.

These mesocyclones are identified by determining local minima (cyclones have negative vorticity in the Southern Hemisphere) on a polar stereographic projection.

As a result, the algorithm provides a spreadsheet with all cyclones found, as well as their position (latitude and longitude) and relative vorticity value at each 1-hour time step (time frequency of the input data).

Validation

Of the results obtained through TRACK, a filtering was performed following these steps:

i. Duration time - only events that corresponded to the usual lifetime of Polar Lows (between six and 36 hours) were considered;

ii. Region of occurrence - since the input data is global and the entire southern hemisphere was considered in the tracking step to avoid cyclone retaliation, it was necessary to select from all tracked systems those that occurred in the area of interest. In addition, since the goal of the paper is to also analyze mesocyclogenesis regions, it was chosen to consider only those events that were included in the study region during their entire life cycle. This step eliminated about 95% of all tracked cyclones;

iii. Identification criteria - the criteria of Zappa et al. (2014) were used to differentiate Polar Lows from other mesoscale systems. These are: relative vorticity; near-surface wind intensity; difference, in modulus, between air temperature at 500 hPa and sea surface temperature difference, in modulus, between air temperature at 500 hPa and sea surface temperature

iv. Observation of satellite images - the satellite images of the infrared and water vapor channel (AMRC & AWS) were observed for each event, validating and noting the type of cloud signature and depth of the tracked systems based on the color scale. Because satellite images of the infrared channel are displayed on a black-to-white scale, shallow clouds appear darker or gray while medium and high clouds appear white. Thus, dark clouds identify shallow vortices and white clouds identify deep vortices.

5. RESULTS AND DISCUSSIONS

Figure 4a shows the monthly distribution of the 42 Polar Lows that were tracked and matched the established criteria throughout the study area. With the exception of May that did not record any Polar Low events, occurrences were noted in all months, with March being the month with the highest frequency of these mesocyclones.

Since the time series of the study comprised only one year, the seasons were defined as summer (January, February, and March), fall (April, May, and June), winter (July, August, and September), and spring (October, November, and December).

The study period showed a maximum frequency in the summer season and a minimum in the fall (**Figure 4b**). These results are opposite to those usually found over the Arctic. In the high latitudes of the northern hemisphere, Polar Lows are most frequent during the winter months and least frequent during the summer months, in agreement with previous work (Carleton, 1996). This is due to the geographical differences and the different seasonal patterns of warming and cooling between the two hemispheres.

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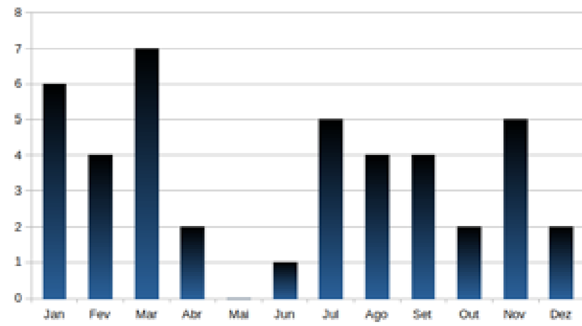
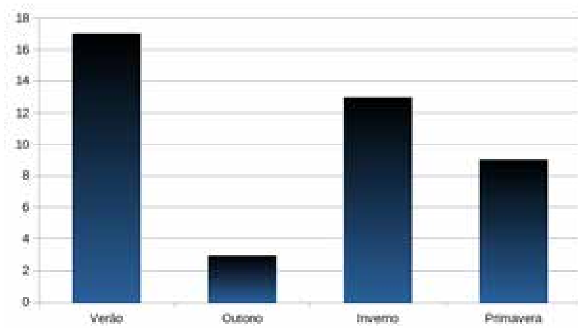


(a)



(b)

Figure 4. (a) Monthly and (b) seasonal distribution of the amount of tracked Polar Lows

Figure 5 shows the annual time series of occurrences of these mesoscale vortices that were tracked during 2020 over the Weddell Sea, Bellingshausen Sea, and Amundsenm Sea sectors, establishing the Weddell Sea as having the highest density of mesocyclones (24 Polar Lows) and the Amundsen Sea (1 Polar Low) the lowest density. The Bellingshausen Sea (10 Polar Lows) showed a higher amount than the Weddell Sea only in September. And it is possible to see that the occurrence of these mesocyclones over Bellingshausen are restricted to the summer and winter months. Thus, the Weddell Sea is the only region with the presence of Polar Lows during the whole year.

Although it is not one of the study regions, the Drake Passage was analyzed and during the study period, the Drake Passage presented seven polar lows.

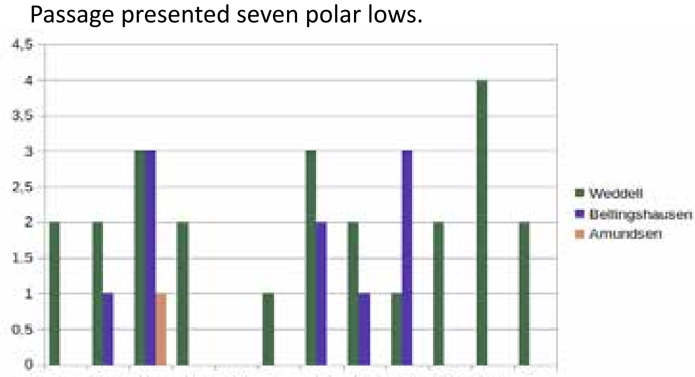


Figure 5. Monthly distribution of Polar Regions by sector: Weddell Sea (green), Bellingshausen Sea (purple), Amundsen Sea (pink)

Figure 6 shows the trajectory of all the tracked Polar Lows in the study region. The Weddell Sea, despite having the highest occurrence of Polar Lows, has vortices with minimal or no displacement, i.e., the systems that occurred in this region developed and decayed in almost the same location. On the other hand, in the Bellingshausen Sea sector there were both systems with short displacement, similar to the Weddell Sea, and systems with a larger displacement. There is also a tendency of east-northeast displacement of these systems. The mesocyclones with the largest displacements occurred in the Drake Passage, and five of the seven observed occurred in the summer season (image not shown).

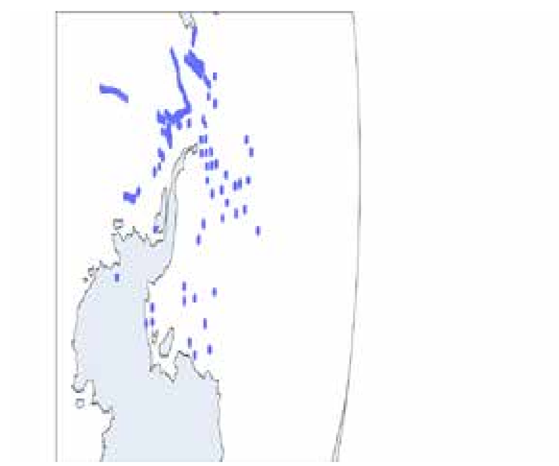


Figure 6. Trajectory of the Polar Lows

Figure 7 shows the mesocyclogenesis regions of all recorded Polar Disasters, i.e., the source areas of the Polar Lows. It is possible to observe a cyclogenetic region over the Weddell Seas, mainly over the Filchner-Ronne ice shelf, and Bellingshausen, as well as at the southern end of South America. Nevertheless, there is certain homogeneity in the spatial distribution of these mesocyclogenesis.

With respect to cloud signatures, the vast majority of comma-type clouds were recorded. Only 5% of the Polar Lows showed a spiral type signature and were recorded only over the Drake Passage and the Weddell Sea during the summer.

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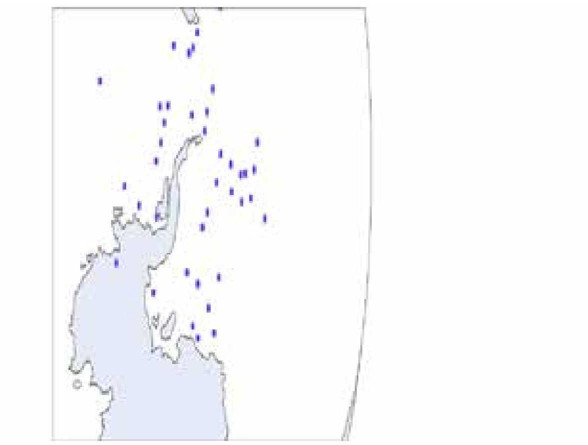

Figure 7. Regions of mesocyclogenesis

Figure 8 shows the seasonal distribution of the number of shallow, medium, and deep Polar Lows recorded over each Sea of the study area. In all seasons, a dominance of medium and deep systems was observed. Nevertheless, in autumn and spring there is a very small difference between the amounts of medium/deep and shallow vortices. On the other hand, summer presents a dominance of medium/deep vortices, and winter exhibits a similar behavior, although in smaller quantities.

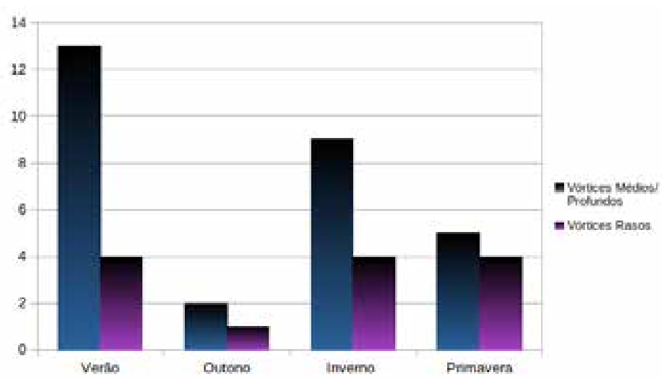

Figure 8. Seasonal distribution of the number of shallow, medium, and deep clouds over each sector

In the upper row of **Figure 9**, the seasonality of the sea ice belt around the Antarctic continent is observed. The lowest concentration can be seen during the summer season when the ice cover retreats almost to the coastline except for the permafrost shelves such as the Ross and Weddell Seas. During autumn, the ice begins to extend further into the ocean, especially in the seas mentioned above. In winter, the belt reaches its maximum, and in extreme cases can cover much of the Drake Passage. During spring, this coverage recedes again. However, it is observed that during this season, the ice still covers a large area (slightly smaller than in winter), but this ice cover, if compared to winter, is much thinner.

The lower concentration of sea ice over the ocean during summer, and the consequent larger ice-free area, is shown to be a very important factor for the higher concentration of Polar Lows over the region, because the rate of latent heat transfer from the ocean to the atmosphere, by bringing the boundary layer to saturation, increases convection intensity. This may also be a factor that explains why the mesocyclones with the greatest displacement occur during the summer and at slightly lower latitudes, but other factors, such as the relationship of these Polar Lows with their parent cyclones, still need to be analyzed for such a statement.

Although the smaller layer of sea ice is a determining factor, in spring and winter, despite this coverage, it is possible to observe vortices over ice-covered regions. It is noted that the Polar Lows that developed in these regions, for the most part, had short displacement and life span (usually around six hours). Moreover, in the spring, the ice sheet had less thickness, which provides a greater likelihood of ice breaking and the appearance of polynyas, and it is known that during the winter there is a greater concentration of cyclones passing through the region and can provide a favorable environment for the development of Polar Lows in their rear.

The autumn season recorded the least amount of Polar Lows. The vast majority of them tended to develop over ice-free sea in all seasons.

6. CONCLUSIONS

The high frequency of Polar Lows recorded in the summer season agrees with previous work. This reinforces the importance of moisture supply from the ocean for their development and maintenance. When the cold air mass moves from the continent or ice-covered region to a much warmer and wetter environment that is the open ocean, sensible and latent heat fluxes from the ocean to the boundary layer can develop convection in the cold air mass, triggering and/or enhancing mesoscale cyclonic disturbances.

Comma-type clouds were the most frequently found in the study area, which agrees with the results found by Turner et al. (1996).

The mesocyclogenesis tended to develop over sea ice, except for winter, which had vortices over the sea ice that covered the Weddell Sea, and spring, which had much of the study area covered by ice, but it was thinner.

The summer and winter months showed more homogeneity in the amount of Polar Discharge over the Weddell and Bellingshausen Seas. And in the transition months (fall and spring), vortices were only observed over the Weddell Sea.

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The Polar Lows over the Drake showed the largest displacements, in contrast to the Weddell Sea, whose systems emerged and decayed in nearly the same region. In addition, the surface charts were also observed. When the studied system was marked on them, it appeared in the form of secondary cold fronts and cavities.

The TSM-Temperature criterion at 500 hPa > 43K was not met and the Polar Lows showed a difference between 28 and 40K. Therefore, this criterion was disregarded. It is known that Antarctica and the Arctic have similar characteristics, but not entirely the same. The criteria used by Zappa et al. (2014) were defined for Polar Lows at high latitudes in the Northern Hemisphere. Thus, larger time series analysis is still needed for a better understanding of these systems over the high latitudes of the Southern Hemisphere.

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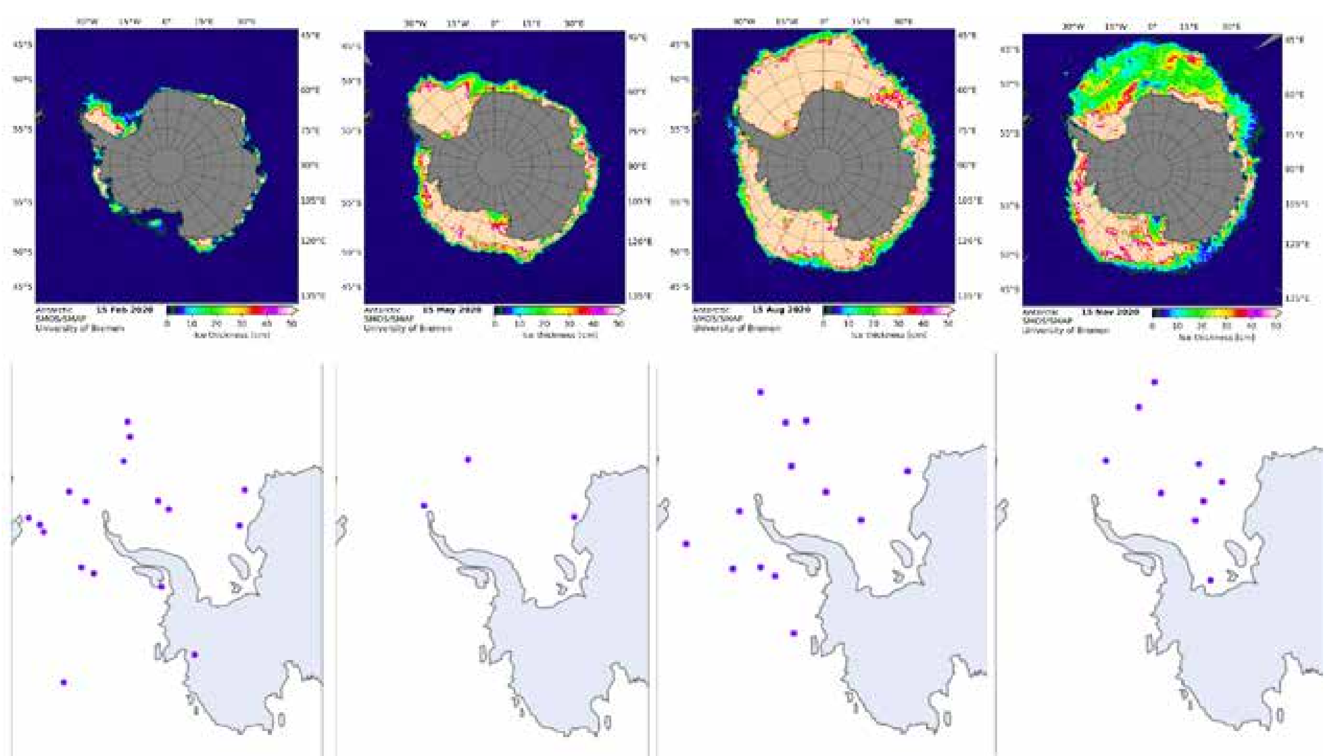

Figure 9. Seasonal distribution of mesocyclogenesis regions (summer, fall, winter, and spring) on the left. Seasonal variation of sea ice concentration over Antarctica on the right

Source: University of Bremen

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