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Cyclonic vortices over South America

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ABSTRACT

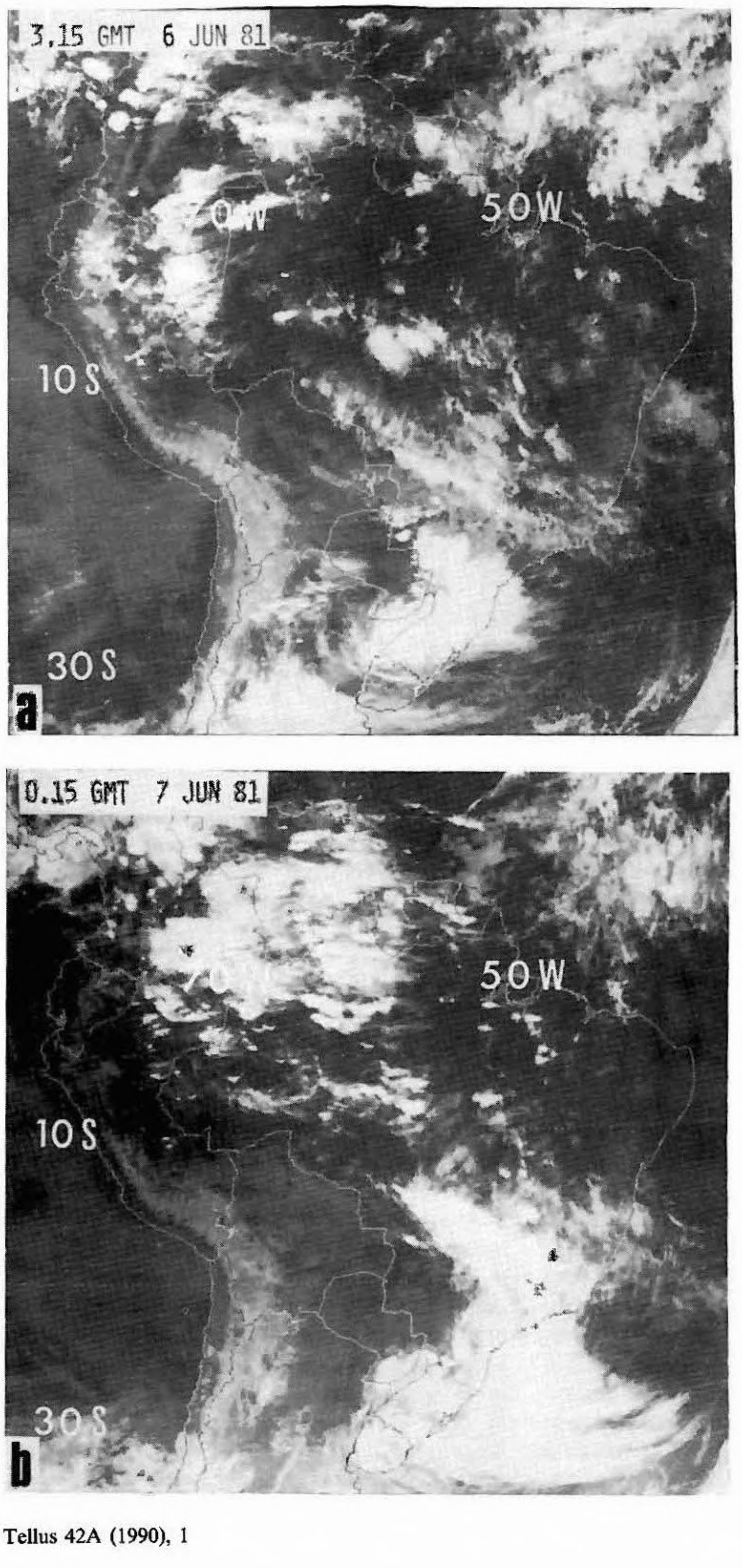
It is observed from satellite cloud imagery that about 100 neutral vortices per year cross the South American continent between 15–60°S, and almost as many are generated or intensified in the same latitude belt between 30–70°W. There are more cyclogeneses in summer than in winter in contrast to the common idea that winter is the season of maximum extratropical cyclogenesis. The frequency of neutral vortices is higher in the transition seasons than in summer and winter. Neutral vortices move toward the east with a speed of about 20 m s^{-1}, while the cyclones which develop over the region move southeastward more slowly with an average speed of 12.5 m s^{-1}. Vortices crossing the Andes with cyclonic vorticity in excess of 2×10^{-5} s^{-1} have a 40% probability of producing intense convective systems near the east coast of the continent.

1. Introduction

South-central South America (SA) is one of the regions affected by the passage, intensification, decay and genesis of cyclonic vortices. Very often, vortices approaching from the South Pacific after crossing the Andes intensify near and east of Paraguay. Sometimes they initiate intense convection in the region (Velasco and Fritsch, 1987). The winds and rain that accompany such systems occasionally cause heavy damage to the urban and rural properties. Many authors have studied the frequency of development and propagation of the cyclonic vortices in the Northern Hemisphere (NH) (see Palmén and Newton, 1969). These studies have identified the regions preferred for cyclonic development and cyclone passages. Whittaker and Horn (1984) have reaffirmed that there is a high frequency of extra-tropical cyclones in the western North Pacific, the region just east of the Rocky Mountains and in the Gulf stream region off North America. Their study has also shown the changes in tracks and genesis areas of the cyclones in the NH from season to season.

There are few similar studies for the Southern Hemisphere (SH) using conventional synoptic charts for limited periods. Three distinct types of depression occurring in South America, namely, thermal, coastal and subpolar lows identified by K. Wolcken in 1923 are described in Necco (1982a). Taljaard (1972) used IGY (International Geophysical Year) data and showed that the region around Paraguay has a maximum frequency of cyclones of more than 20 in a 4-month period, and that they move toward the southeast. Carleton (1981) adapted the extra-tropical vortex classification of Troup and Streten (1972) and studied the frequency and seasonal variations for the SH as a whole. Necco (1982a, b) identified 119 cyclonic centers during the FGGE (First Global GARP Experiment) period in the area between 0–90°W and 10–55°S, of which 70% initiated over the area and 20% approached from the South Pacific.

We will investigate more closely the frequency of the cyclones and cyclonic development as well as preferred areas and seasons of their generation over the South American region. We base our study on satellite cloud imagery and synoptic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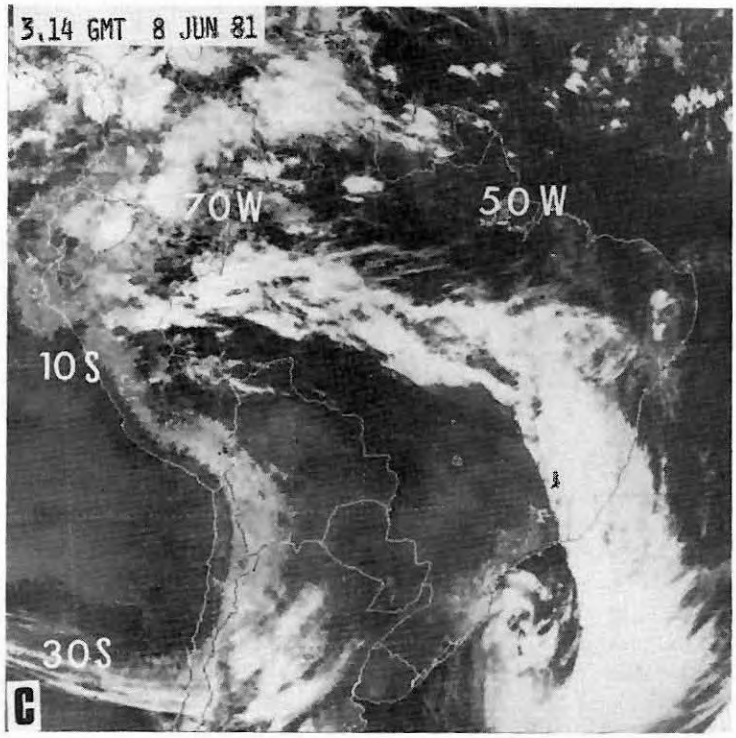

Fig. 1. Infrared cloud imagery showing a typical case of cyclogenesis over east-central South America during 6–8 June 1981.

charts. We also attempt to determine the threshold value of the mid-tropospheric vorticity necessary for winter development over the continent with a view to providing hints for the forecasters.

2. Data and analysis

Infrared (IR) cloud imagery at intervals of 3 h and visible cloud imagery at irregular intervals during daytime taken by GOES-EAST over a period of 7 years from January 1980 to December 1986 were used. The cloud images were examined visually to identify cloud patterns associated with cyclonic centers and vortices. The subjective identification is based on the description given by Anderson et al. (1966). The intensification, if any, and successive positions of cyclone centers were noted, and their tracks were calculated over the area between 15–60°S and 30–70°W, which is divided into several latitude bands of 5° width. This area covers the subtropical and extratropical regions of South America. The classification was done by month and for the four seasons, summer (Dec–Jan–Feb), autumn (Mar–Apr–May), winter (Jun–Jul–Aug) and spring (Sept–Oct–Nov) for the 7 years. An example of the passage of an intensifying cyclonic center is shown in Fig. 1. It can be seen that the cyclone moved southeastward from South Paraguay to the Atlantic Ocean. The associated frontal cloud band also intensified and moved northeastward. Vortices which do not show appreciable intensification in the cloud imagery during their passage over the region are loosely classified as neutral in this study.

The advantage of examining cloud photographs is that they provide an integrated picture of the meteorological conditions in the troposphere as a whole, and that very weak systems are not taken into account. With the availability of three-hourly images, the identification and determination of the places of genesis and the tracks of cyclones become reliable, especially over data-sparse regions. The disadvantage is that the distinction between the lower, middle and upper tropospheric features is partially lost.

To complement and to check the statistics, six-hourly surface synoptic analysis of two years 1980 and 1986, was also undertaken. Low-pressure centers with at least one closed standard isobar (i.e., isobar with a value of $1000 + 4n$ hPa, where n is a positive or negative integer) were counted month by month in 5° latitudinal bands in the same South American region mentioned above. The threshold vorticity was evaluated from wind data, analysed by the National Meteorological Center, Washington at 500 and 300 hPa levels. The wind data are given at 5° longitude and approximately 5° latitude intervals in the region north of 48°S. These data are fairly good in the upper troposphere because the analysis took into account satellite winds. The criterion used for identifying the occurrence of Intense Convective Systems (ICS) is that the duration of convection be more than 12 h and the maximum area covered by convection be not less than a 3° latitude by 3° longitude box.

The vertical component of the relative vorticity was calculated by using centered differences:

$$\zeta(i,j) = (v(i+1,j) - v(i-1,j))/2\Delta x - (u(i,j+1) - u(i,j-1))/2\Delta y,$$

where $\zeta(i,j)$ is the relative vorticity calculated at the point $x = i\Delta x$ and $y = j\Delta y$ in which Δx and Δy are grid distances. As an example, the vorticity distribution at 700 hPa corresponding to the case shown in Fig. 1 is given in Fig. 2. The trajectories of the vortex center shown in the cloud imagery and the vorticity fields agree fairly well. The case considered in this example is a sufficiently large vortex and could be described well by the wind data coverage; however smaller and weaker vortices can often not be delineated by the existing data coverage.

3. Climatology of vortices and cyclogenesis

3.1. Cloud imagery

The total number of cyclonic vortices that formed in the region between 30–70°W and

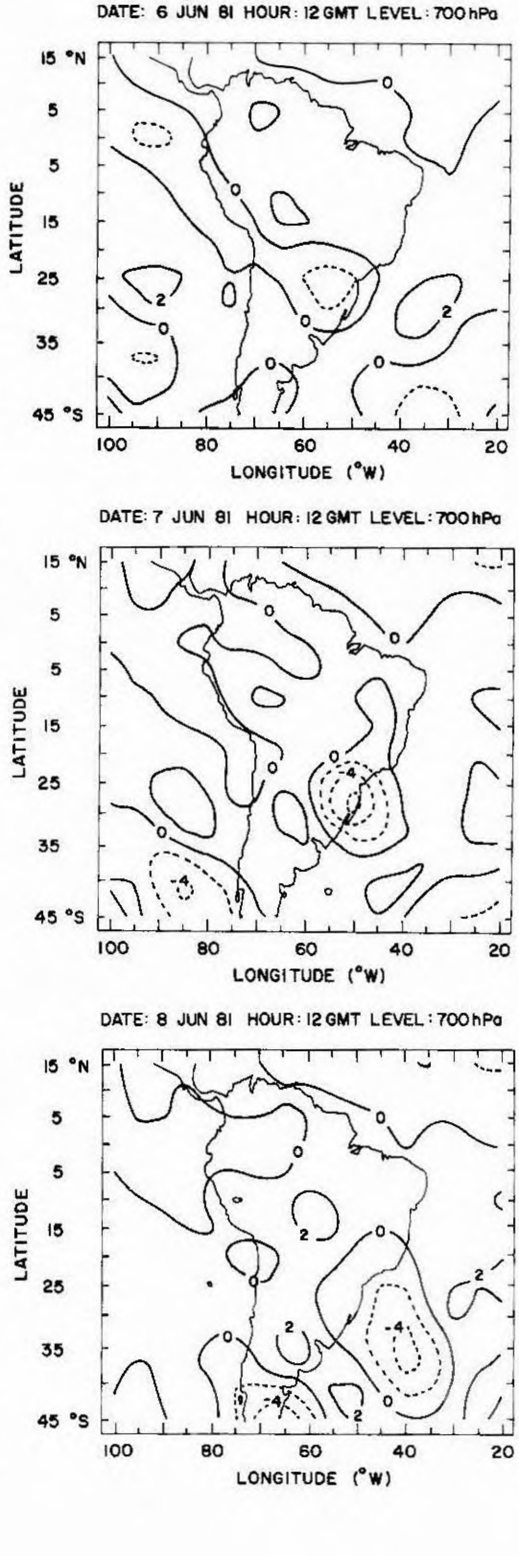

Fig. 2. The vorticity distribution at 700 hPa corresponding to the satellite photos shown in Fig. 1.

15–45°S observed in the cloud imagery for the 7-year period, 1980–1986, is about 750, of which about 280 formed north of 30°S. Table 1 shows interannual variation and seasonal distribution of vortex formations in the region. The frequency per year is about 100. However, in the El Niño year, 1983, the number increased by 25%. The increase occurred mainly north of 30°S, which is consistent with the above normal precipitation observed over extreme South Brazil during this year (Kousky et al., 1984). Although the vortices are seen to form in all seasons, which is in agreement with Chung's (1977) observation, a significant preference is shown for summer (Dec–Jan–Feb), winter (Jun–Jul–Aug) being the season of minimum frequency. This is in contrast to the finding that the cyclogenesis in the NH over North America is more frequent in winter (Zishka and Smith, 1980).

Table 2 shows the preferred directions of movement of the vortices that formed north of 45°S. Only a small fraction (around 8%) dissipated without any appreciable movement while a large fraction (56%) moved southeastwards and about 22% eastwards. This preference in the movement is the same for all seasons. However, it is interesting to note that no stationary vortices developed over the area in winter (Jun–Jul–Aug). The vortices forming south of 45°S preferred to move eastwards (not shown).

The locations of frequency of cyclogenesis and cyclone development in the South American region is shown in Fig. 3. It can be seen that there are preferred locations south and slightly east of Paraguay over the continent.

Table 1. *Frequency of formation of cyclonic vortices in the region 15–45° S; 30–70° W during the period 1980–86*

Season Year	Summer	Autumn	Winter	Spring	Total
1980	28	20	31	36	115
1981	50	25	16	24	115
1982	26	23	28	30	107
1983	34	35	18	39	126
1984	38	20	17	25	100
1985	30	22	15	30	97
1986	21	30	18	20	89
total	227	175	143	204	749

Table 2. *Direction of movement of the vortices generated in the region 15–45° S; 30–70° W during the period 1980–86*

Season Direction	Summer	Autumn	Winter	Spring	Total
SE	135	101	78	110	424
E	47	33	47	48	175
NE	17	15	8	18	58
N	2	2	0	2	6
NW	1	0	0	0	1
W	1	0	0	0	1
S	5	7	5	5	22
stationary	34	11	0	17	62
total	242	169	138	200	749

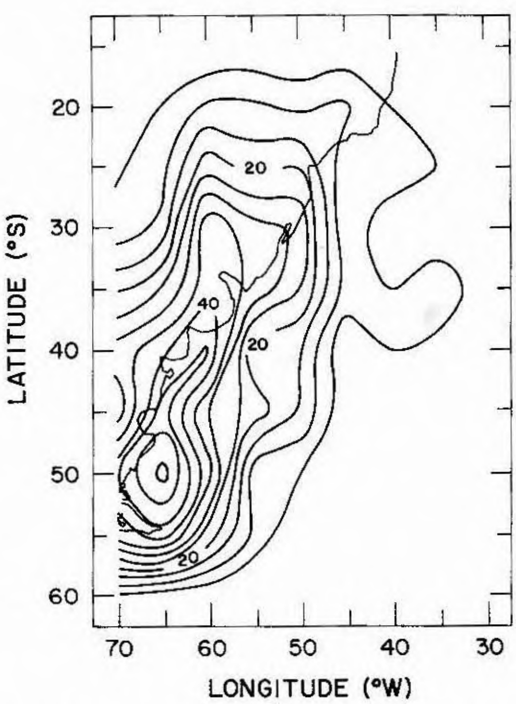

Fig. 3. Frequency of cyclogenesis. The contours represent the number of cyclones in a 5° longitude × 5° latitude box during the 7-year period 1980–86. The contour interval is 5.

The total number of neutral vortices which passed without any development or visible intensification over the region between 15–60°S and 30–70°W is about 800 in the 7-year period. That is, there are as many vortices crossing the region without intensification as there are cyclones developing in the region. Table 3 shows the yearly and seasonal distribution of the passage of vortices. They have a small preference for the transition seasons (Mar, Apr, May and Sep, Oct, Nov). The cyclone passages were very few in the zonal belt 25–35°S. This means that practically all the vortex activity observed north of 35°S is either generated or developed over the continent. About 63% of all the neutral vortices move eastward and the rest are equally divided between northeasterly and southeasterly tracks.

Table 4 shows the seasonal distribution of the speed of propagation of neutral and developing vortices along with their duration of development. One important observation is that the neutral systems move faster (~ 20 m s^{-1}) than the developing ones (~ 12.5 m s^{-1}). The mean duration of development is about 14 h in summer (Dec–Jan–Feb) and about 21 h in winter (Jun–Jul–Aug).

3.2. Surface synoptic charts

The number of days with a surface low-pressure center in the region 15–60°S, 30–70°W observed on the surface charts of 00, 06, 12 and 18 GMT are, respectively, 708, 659, 751 and 691, during 1980. It is important to note that if, on a particular day, there are *n* centers in the region, the day is counted *n* times. There are more observations in the region at 12 GMT and therefore slightly more low-pressure centers are identified at this hour. Table 5 shows the latitudinal and seasonal distribution of the days with surface lows at 12 GMT. About 30% of the total are observed in the latitudinal band 50–55°S. One interesting feature is that the latitudinal distribution has a smaller but a clear maximum between 15 and 30°S in addition to the one south of 50°S. The same is also observed in the other 3 synoptic hours (not shown here). This subtropical maximum is mainly due to increased frequency in summer and autumn (Nov to Apr). Such a maximum was also observed by Taljaard (1972) during the IGY for the whole Southern Hemisphere.

Table 3. *Passage of vortices without development in the region 25–60° S; 30–70° W during the period 1980–86*

Season Year	Summer	Autumn	Winter	Spring	Total
1980	24	13	13	14	64
1981	29	15	13	33	90
1982	38	40	18	25	121
1983	17	31	45	39	132
1984	38	45	25	35	143
1985	23	29	16	28	96
1986	29	34	38	37	138
total	198	207	168	211	784

Table 4. *Velocity and duration of cyclonic vortices (7-year mean)*

	Summer	Autumn	Winter	Spring
cyclones without development (m s^{-1})	20.5	17.1	23.3	21.1
cyclones with development (m s^{-1})	12.6	11.1	13.9	13.2
duration of development (h)	14.2	17.6	21.1	18.6

Table 5. *Number of days with surface lows at 12 GMT in the region 15–55° S; 30–70° W during the year 1980*

Season Latitude	Summer	Autumn	Winter	Spring	Total
15–20°S	34	19	18	24	95
21–25°S	32	30	19	24	105
26–30°S	26	23	10	26	85
31–35°S	17	20	5	13	55
36–40°S	19	11	4	12	46
41–45°S	14	14	11	9	48
46–50°S	15	13	20	10	58
51–55°S	59	64	57	82	262
total	216	194	144	200	754

The mean speed of movement of the surface low-pressure centers varies between 13 m s^{-1} in winter and 9 m s^{-1} in autumn with an annual mean around 11 m s^{-1}. It is interesting to note that these speeds are comparable to those obtained for the intensifying vortices and are rather less than the speeds of the neutral vortices presented in Subsection 3.1.

3.3. *Intense winter convective activity*

Sanders (1987) studied 96 events of 500 hPa vorticity maxima crossing the Rockies in winter (Oct to Mar) 1985 to determine the threshold vorticity necessary for producing, what he called, "bombs" or explosive cyclogenesis near the east coast of North America. He found that 38 events produced bombs and in 26 cases, the absolute vorticity was equal to or more than 22×10^{-5} s^{-1}. In the present study, the 500 and 300 hPa wind data for the 6-month period April to September 1979 in the region 15–48°S and 45–75°W are used. It is important to note that in the case of the South American region, the upper wind data are obtained from very sparse observations, and therefore the vorticity maxima are reduced in their intensities compared to the North American vortices.

The total number of ICS observed in the 6-month period in the South American region is 39 and all of them except one occurred following a vortex of intensity exceeding 2×10^{-5} s^{-1} crossing the Andes.

Table 6 shows the number of the cyclonic centers and the number of ICS initiated by them, according to their intensity. We note that there were 71 cyclonic vortices with magnitude in excess of 4×10^{-5} s^{-1} and 29 of them produced ICS. When relative cyclonic vorticity in excess of 5×10^{-5} s^{-1} is considered, there were 54 centers, of which 50% produced ICS. A surprising result is that a smaller % of vortices with relative cyclonic vorticity in excess of 6×10^{-5} s^{-1} produced ICS. These results mean that although approach of a 500 hPa cyclonic vortex is crucial, it is not sufficient for the development of ICS. The month-wise separation of the events (not shown here) indicates that a larger % of the vortices with relative cyclonic vorticity in excess of 5×10^{-5} s^{-1} triggered ICS in the month of August, mostly south of 25°S.

Table 6. *Intense convective systems (ICS) generated by 500 hPa vortices over eastern South America during the period April–September 1979*

Absolute value of relative cyclonic vorticity (10^{-5} s^{-1})	Number of vortices	Number of ICS	(%)
>2.0 (total)	90	38	43
>4.0	71	29	41
>5.0	54	27	50
>6.0	33	14	42

4. Summary

Southern South America is one of the regions preferred for cyclonic vortex passages and cyclogenesis (Taljaard, 1972). On average, 100 neutral vortices per year cross the continent in the latitude band between 15 and 60°S and almost as many are either generated or intensify in the region. In the El Niño year 1983, however, there were about 25% more vortex formations, the increase mostly occurring in the subtropical latitudes north of 30°S. In all the years between 1980 and 1986, it is seen that a large % of the vortices observed north of 30°S are locally developed or intensified. The frequency of neutral vortices is more in the transition seasons while there is more cyclogenesis in summer. This last observation is in contrast to the Northern Hemisphere case, where cyclogenesis occurs more frequently in winter. This indicates that although baroclinity is an indispensable factor, there are other essential agents such as the water vapour convergence and the sensible heating, which are more active in the development of cyclones over South America in summer.

The preferred course of movement of the neutral cyclonic vortices without appreciable or visible development over the region is easterly while the vortices that form or intensify in the region take a more southeasterly course. One important observation is that the slow-moving vortices develop over the region and the fast moving ones tend to cross the region without appreciable intensification.

The occurrence of surface lows in the region is very frequent. Their latitudinal distribution shows a large peak south of 50°S and a secondary peak in the subtropics around 25°S, especially in summer. This is due to the frequent formation of what are known regionally as "chaco lows". The surface lows on average move with speeds equal to those of regionally developing vortices.

The threshold cyclonic vorticity at 500 hPa for generation of an intense convective system (ICS) near the east coast of South America in winter is around $2 \times 10^{-5}\ s^{-1}$, with a 40% chance. However, if the vorticity is around $5 \times 10^{-5}\ s^{-1}$, the chances increase to 50%. The present study is important for subjective prediction of the ICS in the region and it must be extended to several winters and summers to establish more precise statistics.

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