NOTES AND CORRESPONDENCE

Surface Cyclogenesis over South America

MANOEL ALONSO GAN AND VADLAMUDI BRAHMANANDA RAO

Instituto de Pesquisas Espaciais, São José dos Campos-SP, Brazil

2 July 1990 and 3 November 1990

ABSTRACT

The frequency of surface cyclogenesis over South America (approximately the area enclosed by 15°–50°S and 30°–90°W) has been calculated using 10 years (1979–1988) of data. The frequency of cyclogenesis is more in winter than in any other season. Highest frequency (139) is found in the month of May and the lowest frequency (71) is found in the month of December. In addition to seasonal variation, the frequency of cyclogenesis shows interannual variation. The occurrence of cyclogenesis is more during the years of negative Southern Oscillation index (El Niño years) and less during the years of positive Southern Oscillation index. The years of higher (lower) cyclogenesis are found to be associated with higher (lower) rainfall. This explains the negative correlation between the precipitation over southern Brazil and the Southern Oscillation index.

1. Introduction

Several studies have been made regarding the cyclogenesis and the propagation of cyclones in the Northern Hemisphere (Petterson 1956; Palmen and Newton 1969; Whittaker and Horn 1981; and many others). These studies identified regions of preference of cyclogenesis and passage of cyclones. Except for a few, similar studies have been lacking for the Southern Hemisphere, particularly for the South American region.

Talajaard (1972), using International Geophysical Year (IGY) data, observed that a maximum of cyclogenesis occurred over Paraguay. Necco (1982) identified for the First GARP Global Experiment (FGGE) year about 119 cyclone centers; of which 70% formed over the region confined by 0°–90°W and 10°–55°S. Summer is the season of less cyclogenesis over South America. On the contrary, Satyamurty et al. (1990), using mostly satellite imagery for the period 1980–86, noted that summer is the season of highest cyclogenesis. Intrigued by the opposing conclusions of Necco and Satyamurty et al., we undertook the present study to verify the seasonal preference of surface cyclogenesis over South America. Satyamurty et al. used only two years of surface data; their study is mostly based on satellite imagery. A disadvantage of using satellite imagery is the lack of delineation of the level of cyclogenesis. Necco (1982) used only 1-yr data. We use in the present study 10 years of surface charts, January 1979–December 1988. In addition to determining the seasonal preference of cyclogenesis, we explore further the characteristics of atmosphere responsible for the seasonal and interannual variations of cyclogenesis.

2. Data source and methodology

The following data sources have been used in the present study.

- Four surface charts for each day for the period from January 1979–December 1988 were obtained from Instituto de Atividades Espaciais (IAE), Brazil. These charts were plotted and analyzed by the Brazilian Air Force. The charts extend from 0°–60°S and from 30°–100°W, and a total of 14 600 charts have been examined.
- Monthly mean data for eight radiosonde stations (see Table 1 and Fig. 1) were obtained from "monthly climatic data for the world" for the period from January 1978–December 1987.
- Monthly precipitation data for 12 surface stations (see Table 4 and Fig. 1) were obtained from Boletim Agroclimatologico of the Brazilian National Meteorological Institute (Inemet).

The method used to identify surface cyclogenesis is that at least one closed isobar around a low pressure should be found for an analysis of 2-mb intervals. Further, the low pressure center should persist for at least 4 consecutive map times. The initiation of cyclogenesis is the time of the first appearance of the closed isobar. The direction of the movement of the low pressure centers formed in the region of study (15°–50°S, 30°–90°W) is obtained taking the initial position and final position after 24 h.

3. Results and discussion

Table 2 shows the frequency of cyclogenesis for each month and for all 10 years. One can note interannual variation in this table, 1981 being the year of lowest

---

Corresponding author address: Dr. Manoel Alonso Gan, CPTEC/INPE, C. P. 515, 12201 Sao Jose dos Campos-SP, Brazil.

© 1991 American Meteorological Society

TABLE 1. List of eight radio-/(rawin-) sonde stations used to prepare cross sections of Richardson number and static stability.

Number	Station	Latitude (°S)	Longitude (°W)
1	Galeão	22.49	43.15
2	São Paulo	23.37	46.39
3	Curitiba	25.31	49.10
4	Porto Alegre	30.00	51.11
5	Ezeiza	34.49	58.32
6	Comandante Espora	38.44	62.10
7	Comodoro Rivadavia	45.47	67.30
8	Punta Arenas	53.02	70.51

frequency and 1983 the year of highest frequency. The 10-yr totals show seasonal variation with winter months showing higher frequency of cyclogenesis and summer months showing lower frequency. The highest frequency (134) of cyclogenesis is found in May and the lowest (71) is found in December. Further, a secondary maximum (105) is found in October. Table 3 shows the frequency of cyclogenesis for the 10 years separated into 4 seasons; summer (December, January, and February), autumn (March, April, and May), winter (June, July, and August), and spring (September, October, and November). Again in Table 3, one can note the preference for autumn and winter, summer being the season of lowest frequency of cyclogenesis. Interannual variation also can be noted in this table. Combining autumn and winter, the El Niño years 1983, 1986, and 1987 show high frequency of cyclogenesis, and 1983 shows the highest. The year 1981 shows the lowest frequency. It is interesting to note that during 1981 the Southern Oscillation (SO) index was positive (Kousky 1989), while the El Niño years—1983, 1986, and 1987—are known to be characterized by negative SO index.

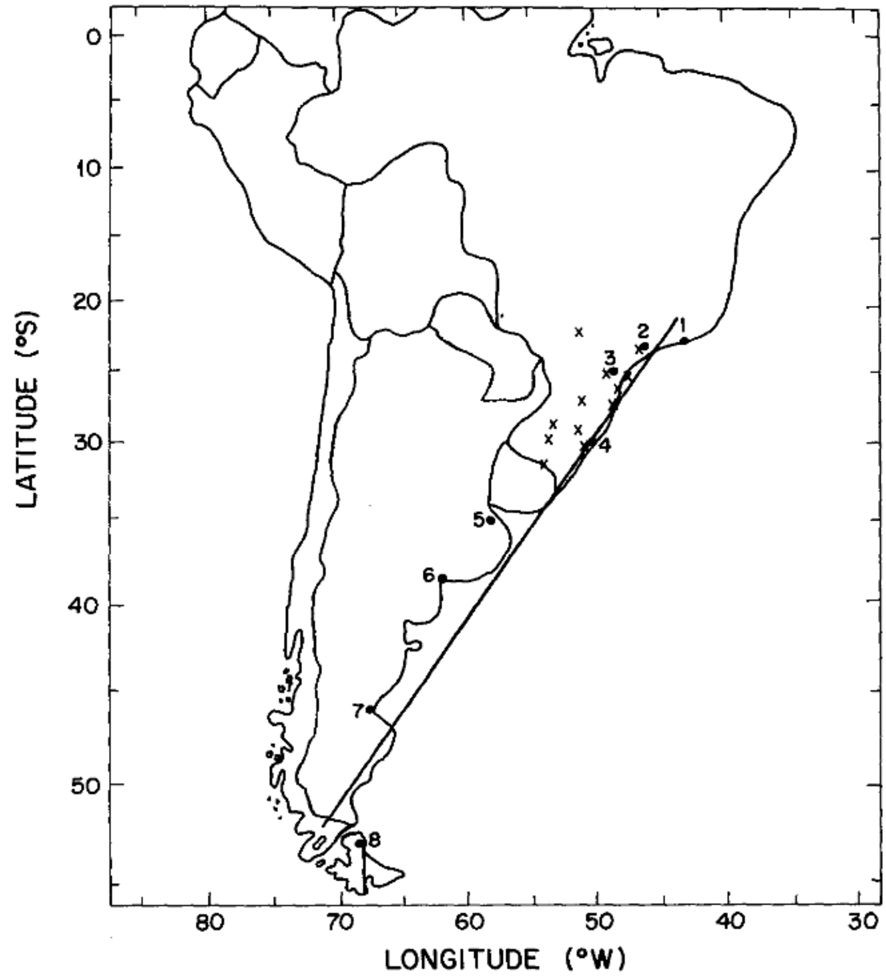

FIG. 1. Location of 8 radio-/(rawin-) sonde stations along the east coast of South America. Also shown are the raingage stations in Southern Brazil. The cross denotes the raingage stations and the point radiosonde stations.

TABLE 2. Frequency of cyclogenesis for each month.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1979	4	9	7	4	18	3	9	11	4	9	9	6	93
1980	8	11	5	9	7	10	12	11	9	8	12	9	111
1981	7	7	8	13	4	5	8	6	6	6	9	7	86
1982	7	7	8	5	13	12	10	3	11	11	2	8	97
1983	8	4	12	9	14	14	14	13	12	15	11	9	135
1984	7	7	7	6	20	15	13	4	12	12	8	8	119
1985	11	10	7	11	15	11	10	6	10	15	4	4	114
1986	8	6	10	11	20	11	7	14	6	7	5	4	109
1987	3	6	7	9	7	11	17	19	13	12	6	7	117
1988	10	5	9	11	16	9	7	10	7	10	7	9	110
Total	73	72	80	88	134	101	107	97	90	105	73	71	1091

In order to find out whether the interannual variation of the frequency of cyclogenesis is consistent with rainfall variation, we calculated rainfall anomalies for select southern Brazil stations (see Fig. 1 for location) for the winter months of the years 1981, 1983, and 1987. These are shown in Table 4.

It can be seen from Table 4 that the rainfall anomalies during the winter of 1981 were all negative except over one station. This is in agreement with the lowest frequency of cyclogenesis during that year noted earlier. During the intense El Niño year 1983 we find high positive rainfall anomalies over all the stations. Over several stations the rainfall anomalies were more than 100% of the normals. The El Niño event of 1986–87 was not as intense as the 1983 event (Kousky and Leetma 1989). However, the rainfall anomalies over several stations were positive, particularly most of the southernmost stations show positive anomalies during 1987. Thus the interannual variation of the frequency of cyclogenesis is consistent with the interannual variation of rainfall anomalies. Recently Aceituno (1988) and Rao and Hada (1990) have confirmed that the rainfall over southern Brazil shows strong negative correlation with the SO index. The present study shows that this negative correlation is because of higher cyclogenesis and higher rainfall during the years of negative SO index (El Niño years), and lower cyclogenesis and lower rainfall during the years of positive SO index.

TABLE 3. Frequency of cyclogenesis for the four seasons.

Year	Summer	Autumn	Winter	Spring
1979	13*	29	23	22
1980	25	21	33	29
1981	23	25	19	21
1982	21	26	25	24
1983	20	35	41	38
1984	23	33	32	32
1985	29	33	27	29
1986	18	41	32	18
1987	13	23	47	31
1988	22	36	26	24
Total	207	302	305	268

* Only cyclogeneses of January and February 1979 are included.

The winter maximum in the frequency of cyclogenesis in our results is in agreement with Necco's (1982)

TABLE 4. Rainfall anomalies (mm) for select stations in Southern Brazil.

Station	1981	1983	1987	Normal
Presidente Prudente (22°–07°S, 51°–23°W)	−10.4	+17.8	−12.8	125.1
São Paulo (23°–30°S, 46°–37°W)	+9.8	+162.9	+102.3	121.4
Curitiba (25°–20°S, 49°–14°W)	−150.0	+247.0	−36.2	249.8
Paranagua (25°–31°S, 48°–31°W)	−34.9	+208.2	+41.6	238.6
S. F. do Sul (26°–15°S, 48°–39°W)	−43.7	+438.8	−2.6	257.7
Campos Novos (27°–24°S, 51°–12°W)	−75.6	+602.1	−45.9	431.3
Floranópolis (27°–36°S, 48°–38°W)	−44.2	+556.6	+32.1	230.1
Cruz Alta (28°–38°S, 53°–36°W)	−237.6	+308.1	+144.2	403.3
Caxias do Sul (29°–10°S, 51°–12°W)	−70.5	+421.4	+218.5	425.1
Santa Maria (29°–42°S, 53°–42°W)	−65.2	+99.7	+325.2	399.3
Porto Alegre (30°–01°S, 51°–13°W)	−94.1	+184.1	+216.1	363.4
Bagé (31°–20°S, 54°–06°W)	−86.0	+88.2	+175.0	344.5

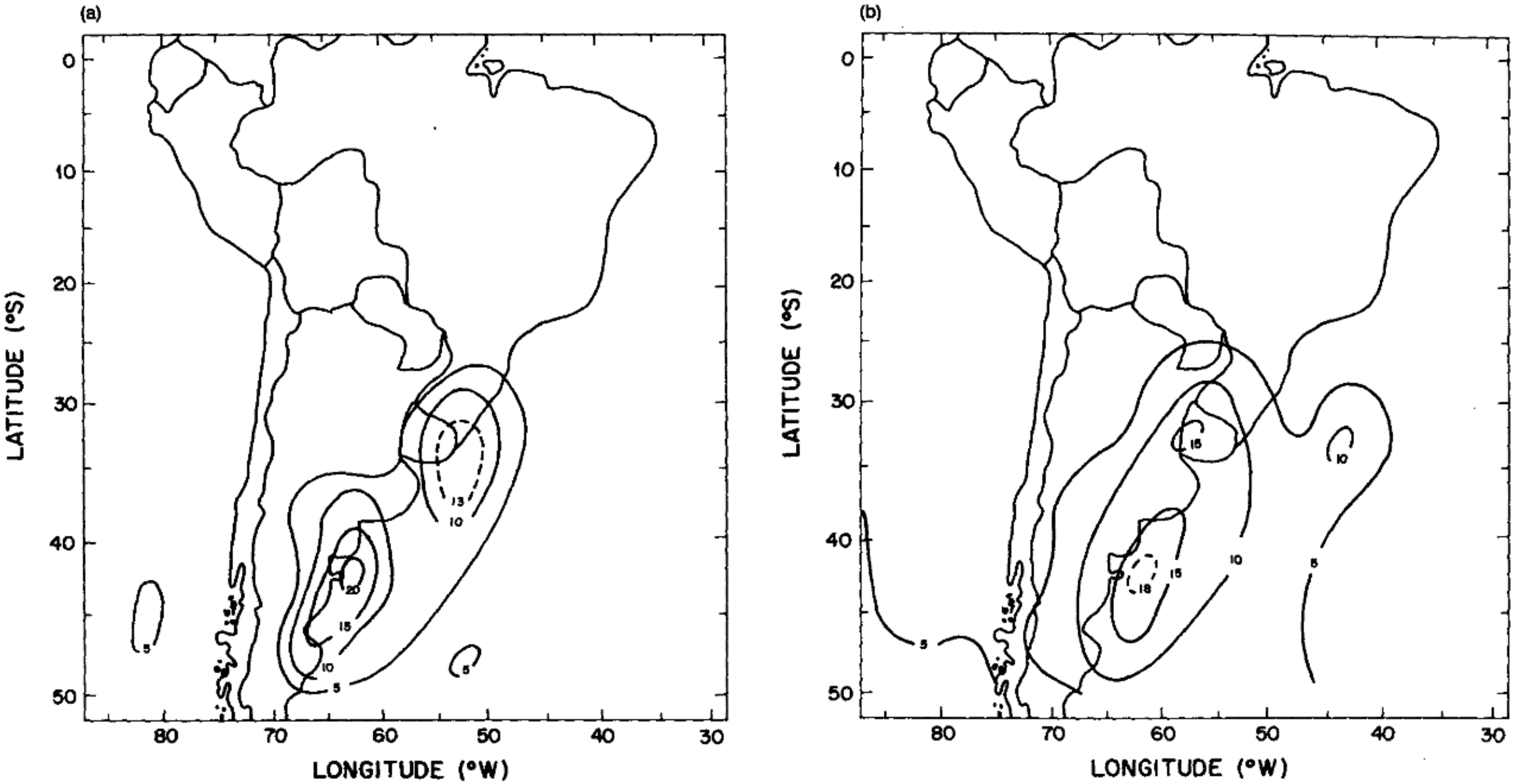

FIG. 2. Isolines of frequency of cyclogenesis: (a) summer (December, January, and February); (b) autumn (March, April, and May); (c) winter (June, July, and August); (d) spring (September, October, and November).

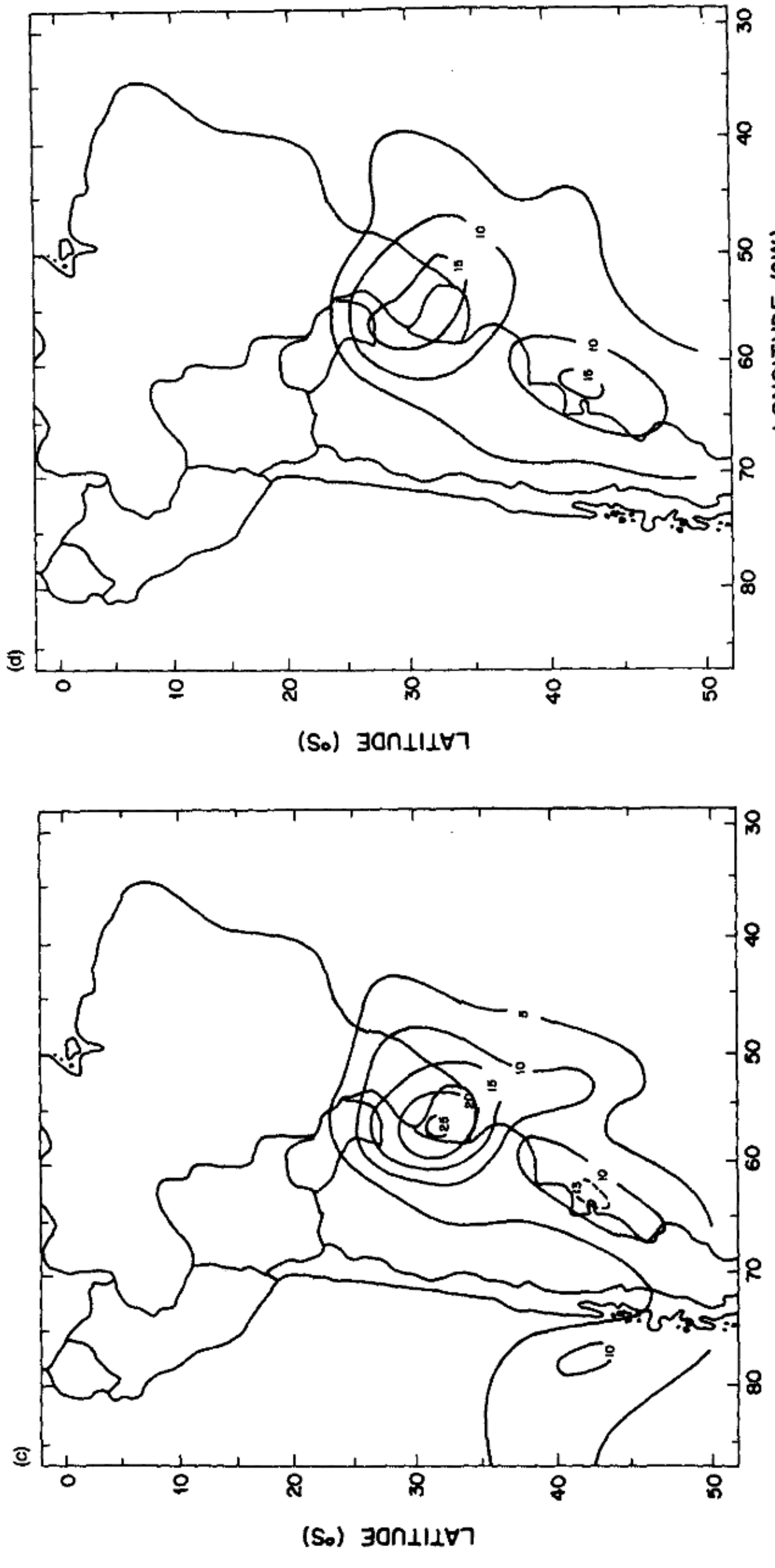

FIG. 2. (*Continued*)

result and is in contrast with the conclusion of Satyamurty et al. (1990), who found a maximum in summer. Our results also agree with what is found in the Northern Hemisphere (Ziska and Smith 1980). Since Satyamurty et al. used mostly satellite imagery, they could not distinguish the level of cyclogenesis, and consequently they included upper-level cyclogenesis also.

Figures 2a–d show the isolines of frequency of cyclogenesis for the four seasons, respectively, and Fig. 3 shows the annual distribution. The count of centers was for each 5° lat × 5° long square. In these figures we can note two maxima, one over the Gulf of San Matias (42.5°S, 62.5°W) and the other over Uruguay (around 31.5°S, 55°W). It can also be seen that in the chart of the transition seasons and in the annual chart, the two maxima have the same intensity. However, in winter the Uruguay center is more intense and in summer the Gulf of San Matias center is more intense. Satyamurty et al. (1990) obtained a maximum near the Gulf of San Matias, but they did not discuss the seasonal variation of the center.

In Fig. 3 two centers of high frequency of cyclogenesis are noted. The explanation for the formation and location of these centers should await theoretical and numerical studies. However, one can form a conclusion about the possible physical mechanisms involved. Basically two cyclogenetic processes are involved, namely, local baroclinic instability of westerlies and lee cyclogenesis due to the Andes mountains. Theoretical study of Hayes et al. (1987) suggests that lee cyclogenesis is the result of superposition of a moving baroclinic disturbance and a mountain forced stationary wave. Considering the position of lee trough (Satyamurty et al. 1980), the northern center over Uruguay might be due to the mountain effect. The formation of the southern center over the Gulf of San Matias seems to be due to local baroclinic instability of westerlies.

In Figs. 2a–d seasonal variation is also noted. A comparison of Figs. 2a,c shows the equatorward displacement of the maximum from summer to winter. A similar displacement is also seen in the Northern Hemisphere (Figure 3.15, Palmén and Newton 1969).

In order to find out the atmospheric state responsible

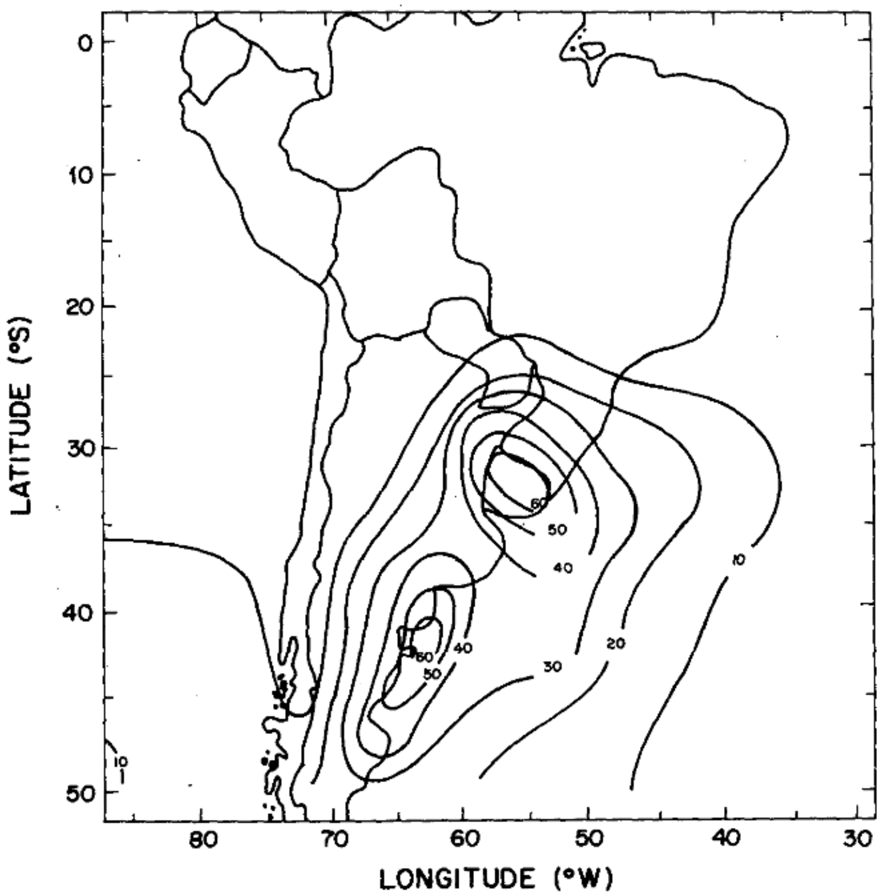

FIG. 3. Annual distribution of isolines of frequency of cyclogenesis.

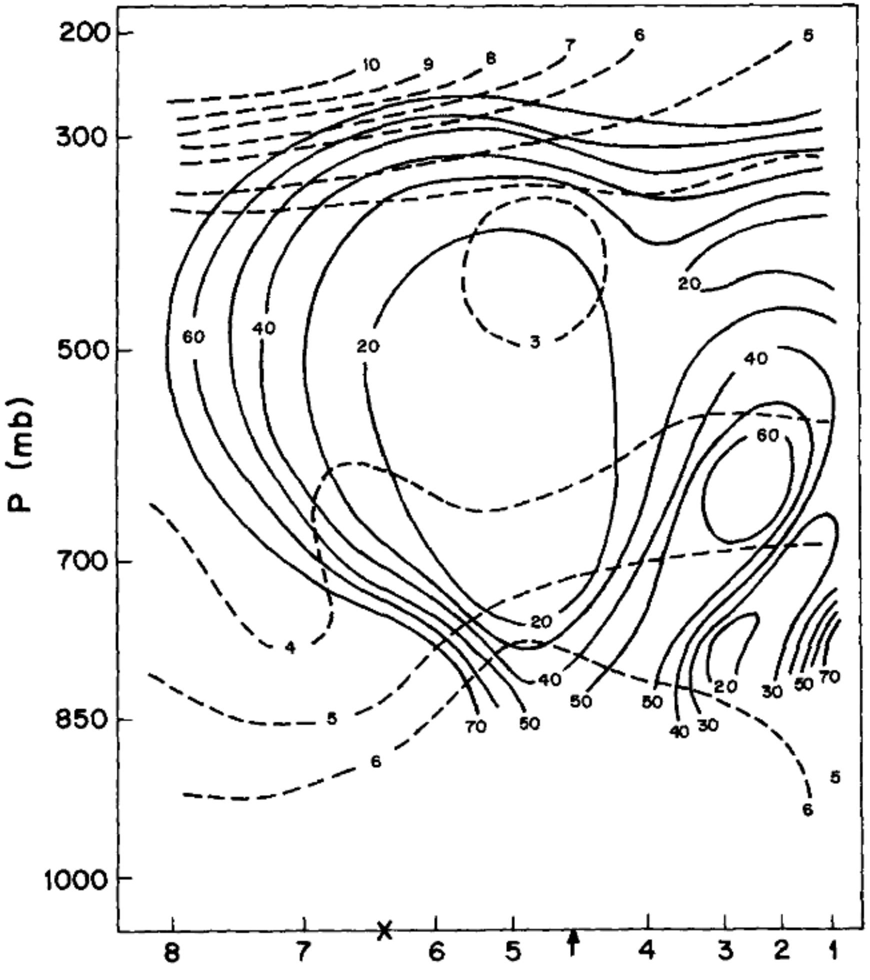

FIG. 4. Cross sections of static stability (dashed lines °C km^{-1}) and Richardson number (solid lines). Winter—10-yr mean. The arrow shows the position of principal center of maximum frequency of cyclogenesis and the cross denotes the secondary center.

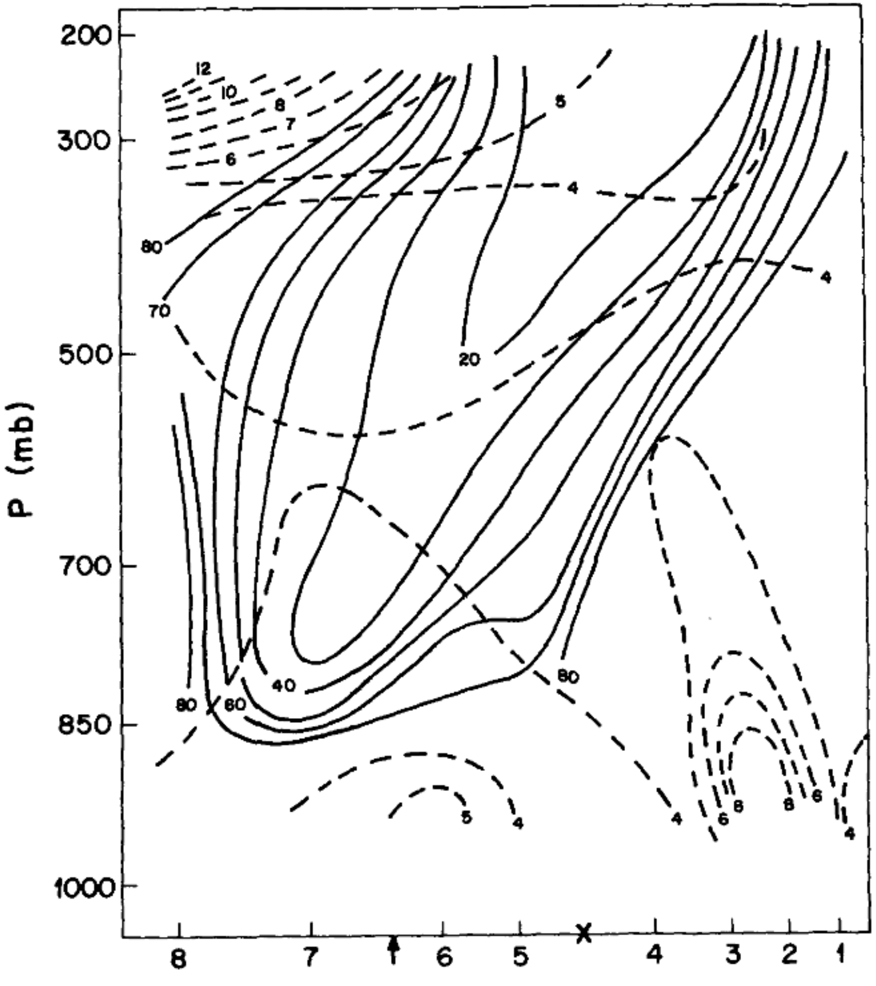

FIG. 5. Same as Fig. 4 but for Summer.

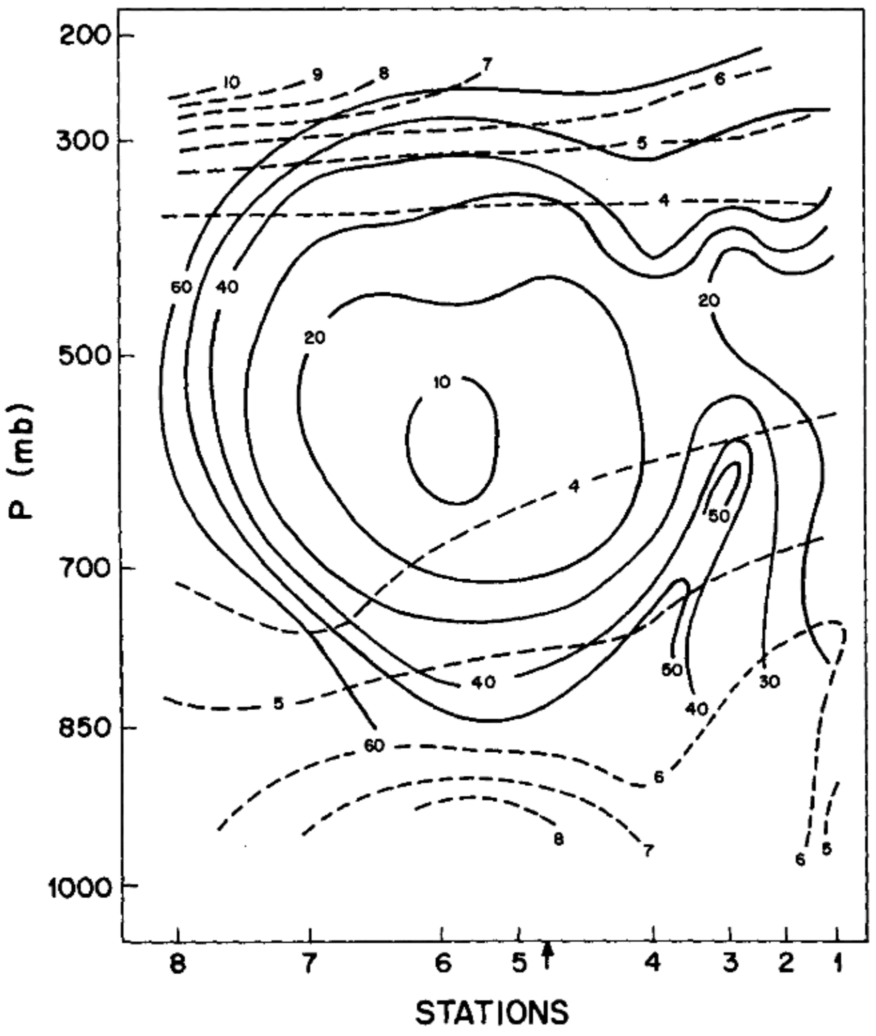

FIG. 6. Same as Fig. 4 but for Winter 1981.

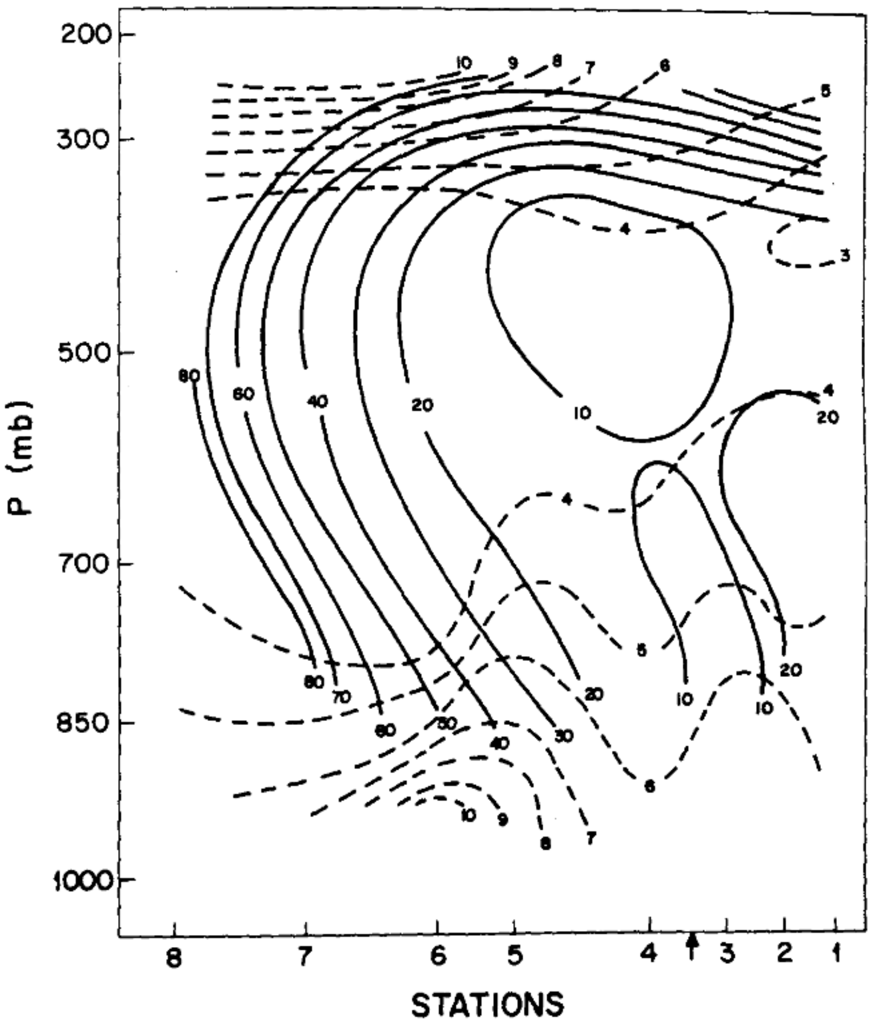

FIG. 7. Same as Fig. 4 but for Winter 1983.

for the seasonal and interannual differences in the frequency of cyclogenesis, we examined the Richardson number field

$$\mathrm{Ri} = \frac{g(\partial\bar{\theta}/\partial z)}{\bar{\theta}(\partial\bar{u}/\partial z)^2}$$

and the static stability field $S = \partial\bar{\theta}/\partial z$. Symbols have the usual meaning and a bar denotes time average. It is known that static stability and wind shear are principal factors responsible for the origin of extratropical cyclones (Holton 1979). The data were given at standard pressure levels in the vertical and for the eight radiosonde stations mentioned earlier. Finite differences are used to calculate Ri and S. Figures 4 and 5 show vertical cross sections of these two fields for the average of ten winters and ten summers, respectively. Figures 6 and 7 show the corresponding fields for the winter season of minimum frequency of cyclogenesis, 1981, and for the winter season of maximum cyclogenesis frequency, 1983, respectively. It can be seen in Figs. 4 and 5 that the principal centers are located in the region of low Ri in the lower troposphere. Also the Ri minimum is lower in winter than in summer. Earlier we noted that the frequency of cyclogenesis is more in winter than in summer. The differences are much more pronounced in Figs. 6 and 7. During the winter of 1983, both Ri and static stability are lower in the lower troposphere in the region of cyclogenesis compared to the values during the winter of 1981. The lower values of Ri are due to higher wind shear and slightly lower static stability. It is known that the westerlies become stronger over southern Brazil during the El Niño years (Kousky and Leetmaa 1989; and Aceituno 1989). Thus the combination of static stability and the wind shear seems to explain, at least partially, some of the differences in the frequency of cyclogenesis noted earlier.

Table 5 shows the frequency of cyclones moving in different directions for different latitude belts. Only those cyclones that formed and remained in the region of study (15°–50°S, 30°–90°W) are included. It can be seen that in the latitude belts 15°–30°S and 30°–40°S, the predominant direction of movement of the cyclones is southeast in all the seasons of the year. In the latitude belt 40°–50°S, the predominant direction of movement is east in all the seasons of the year.

TABLE 5. Frequency of cyclones moving in different directions.

a) 15°S–30°S

	Summer	Autumn	Winter	Spring
E	7	12	13	10
SE	12	15	30	18
S	—	1	4	3

b) 30°S–40°S

	Summer	Autumn	Winter	Spring
NE	—	—	—	4
E	20	21	28	30
SE	30	35	46	37
S	—	1	2	6

c) 40°S–50°S

	Summer	Autumn	Winter	Spring
NE	1	3	—	—
E	18	24	19	30
SE	15	19	14	14
S	1	1	2	—

4. Summary and concluding remarks

In the present study the frequency of occurrence of surface cyclogenesis over South America has been obtained. During the 10-yr period from January 1979 through December 1988, 1091 cases of cyclogenesis have been observed. The frequency of cyclogenesis is more in winter than in any other season. Highest frequency (134) is found in the month of May and the lowest (71) is found in the month of December. The higher frequency of cyclogenesis in winter is in agreement with the results of Necco (1982) and is in contradiction with the conclusions of Satyamurty et al. (1990). The disagreement with the results of Satyamurty et al. (1990) is due to the fact that they used mostly satellite imagery in their analysis of cyclogenesis.

In addition to seasonal variation, the frequency of cyclogenesis shows interannual variation also. The incidence of cyclogenesis is more in El Niño years such as 1983 and 1987. An examination of the Richardson number field showed that during the El Niño years the lower atmosphere is characterized by lower Richardson number, which seems to favor baroclinic instability.

In the spatial distribution of the frequency of cyclogenesis we noted two centers of preference of cyclogenesis, one around Uruguay and the other near to Gulf of San Matias in Argentina. The values of the frequency of these two centers vary with the seasons; the Uruguay center being stronger in winter and the other center being stronger in summer. Further studies are necessary to explain the formation and location of these centers.

Acknowledgments. The present article forms part of the Ph.D. thesis of the first author. Thanks are due to the official reviewers and Prof. Frederick Sanders for useful suggestions. Thanks are also due to Nilda Costa Alves Moreira da Silva for typing the manuscript.

REFERENCES

Aceituno, P., 1988: On the functioning of the Southern Oscillation in the South American sector. *Mon. Wea. Rev.*, **116**, 505–525.

——, 1989: On the functioning of the Southern Oscillation in the South American sector. Part II: Upper-air circulation. *J. Climate,* **2,** 341–355.

Hayes, J. L., R. T. Williams and M. A. Rennick, 1987: Lee cyclogenesis. Part I: Analytic studies. *J. Atmos. Sci.,* **44,** 432–442.

Holton, J. R., 1979: *An Introduction to Dynamic Meteorology.* Academic Press, 391 pp.

Kousky, V. E., 1989: The global climate for September–November 1988: High Southern Oscillation index and cold episode characteristics continued. *J. Climate,* **2,** 173–192.

——, and A. Leetmaa, 1989: The 1986–87 Pacific warm episode: Evolution of oceanic and atmospheric anomaly fields. *J. Climate,* **2,** 254–267.

Necco, G. V., 1982: Behavior of the cyclonic vortices in the South American region during FGGE: Cyclogenesis. (Comportamiento de vortices ciclonicos en el area Sudamericana durante el FGGE: Ciclogenesis). *Meteorologica,* **Vol. VIII,** 7–20.

Palmen, E., and C. M. Newton, 1969. *Atmospheric Circulation Systems.* Academic Press, 603 pp.

Petterson, S., 1956: *Weather Analysis and Forecasting. Motion and Motion Systems.* McGraw-Hill, 498 pp.

Rao, V. B., and K. Hada, 1990: Characteristics of rainfall over Brazil: Annual variations and connections with the Southern Oscillation. *Theoretical and Applied Climatology,* **42,** 81–91.

Satyamurty, P., R. P. Santos and M. A. M. Lemes, 1980: On the stationary trough generated by the Andes. *Mon. Wea. Rev.,* **108,** 510–519.

——, C. C. Ferreira and M. A. Gan, 1990: Cyclonic vortices over South America. *Tellus,* **42,** 194–201.

Taljaard, J. J., 1972. Synoptic meteorology of the Southern Hemisphere. *Meteor. Monogr.,* **13,** 139–214.

Whittaker, L. M., and L. H. Horn, 1981: Geographical and seasonal distribution of North American cyclogenesis, 1958–1977. *Mon. Wea. Rev.,* **109,** 2312–2321.

Zishka, K. M., and P. J. Smith, 1980: The climatology of cyclones and anticyclones over North America and surrounding ocean environs for January and July 1950–77. *Mon. Wea. Rev.,* **108,** 387–401.