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# STUDY OF THE BRAZIL AND FALKLAND CURRENTS USING THIR IMAGES OF NIMBUS V AND OCEANOGRAPHIC DATA IN 1972 TO 1973

Y.C. Tseng, H.M. Inostroza V. and R. Kumar

Instituto de Pesquisas Espaciais (INPE)
Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq)
12.200 - S.J. dos Campos, SP, Brazil

## ABSTRACT

An oceanographic study of the Western Edge of the Sub-tropical Convergence of the Southwestern Atlantic Ocean, called the Front, which is a thermal discontinuity between the Brazil and Falkland Currents, was done utilizing the Temperature Humidity Infrared Radiometer (THIR) of Nimbus V in the 10.5 to 12.5 μm channel and historical oceanographic data in the period of 1972 to 1973. Some important results obtained are: the oceanographic Front could be detected from Nimbus V THIR data: oceanographic charts clearly showed that the transition zone where the Brazil and the Falkland Currents meet, was the Front detected from satellite data; ocean current speeds calculated with THIR data were of the same order of magnitude as those calculated oceanographically; fisheries statistics for Pargo Rôseo showed that the maximum catches were in September of 1973, in the period when the Front was observed most distinctly and clearly. The results showed the great potentiality of satellite data to study surface thermal structures, surface currents and oceanic fisheries.

## I. INTRODUCTION

The area of study is located at the western edge of the South Atlantic Sub-tropical Convergence, where the boundary (also called the Front) between the Brazil and Falkland Currents has been observed. The approximate coordinates are from 25° to 45°S latitude, and from 45° to 65°W longitude, whose oceanic part was estimated to be 2.5 x $10^6$ $km^2$ (Fig. I.1). The Brazil Current, carrying water of high temperature and high salinity, is a southern branch of the South Atlantic Equatorial Current. The Falkland Current, which sometimes is considered a branch of the South Atlantic West Wind Drift Current, extends northwards along the Coast of Argentina to about 35°S, where it meets the southwestern moving Brazil Current. The Falkland Current carries water of low temperature and low salinity of the Subantarctic region.

The boundaries between the cold and the warm currents have been found to be good fishing areas (Uda, 1936 and 1952; Zusser, 1958; Laevastu and Hela, 1970; Hynd, 1968). The Falkland Current maintains a high phytoplankton biomass and has been found to be one of the most productive areas of the world's oceans (Mandelli and Orlando, 1966). The greatest abundance of demersal fish exists in the southern Brazil at latitudes of more than 28°S (Yesaki, 1973). Besides, the Brazil and Falkland Currents are, at present, very poorly described in the existing literature. For these reasons it seemed that studying this current system could contribute significantly to fisheries and oceanography.

Many investigators have found that the surface boundary between warm and cold currents can be detected through remote sensing by studying the cloud-free images, either in the infrared and/or in the visible wavelength region, (Allison and Kreins, 1970; Maul, 1972 and 1974; Maul and Gordon, 1973; Stevenson et.al., 1974; Stevenson and Miller, 1972; Szekielda, 1972; Szekielda and Mitchell, 1974). With the Temperature Humidity Infrared Radiometer (THIR) OF Nimbus V satellite, 10.5 to 12.5 μm channel, it has been possible to detect the pronounced temperature gradient of the surface boundary between the warm Brazil and the cold Falkland Currents; sometimes to observe clearly the difference of the two water masses associated with them and in some cases to visualize the complexity of their mixing. The objectives of the study are summarized as follows:

1 - To visually interpret the available cloud-free Nimbus V THIR (10.5 to 12.5 μm channel) images from the end of 1972 to the end of 1973 in the study region.
2 - To describe the most outstanding features of the boundary and the two water masses of the Brazil and Falkland Currents.
3 - To describe possible displacement of the currents and attempt to visualize the Mixing processes of the associated water masses from the comparison of successive images.

4 - To compare the Nimbus THIR data with the oceanographic data available from the Data Bank of INPE.

## II. METHODOLOGY

152 cloud-free images of Nimbus V (see Table II.1), Temperature Humidity Infrared Radiometer (THIR), 10.5 to 12.5 μm channel, were used for this study. The boundary of the Brazil and Falkland Currents was primarily determined by visual interpretation of enlarged photographs. In this way a boundary line (or Front line) was obtained for every image. 75 boundary lines, obtained from enlarged photographs rated as excellent, were superimposed in Mercator map into 12 groups according to 12 time periods of the year, i.e. four seasons and each season being subdivided into three time periods called the first, the second and the third periods respectively. Each period was further subdivided into three shorter periods called early, middle and late periods. Each short period covered approximately 10 days. Image-100 (General Electric Company, 1975) was used to help the visual interpretation, in those cases indicated in Table II.1.

The oceanographic data of temperature, salinity and dynamic height were used to supplement the interpretation of the boundary. More than two thousand oceanographic stations distributed over ten time periods were selected for this study. The first two variables - temperature and salinity - were considered as the ground truth (sea truth) and compared with the results obtained from image studies. The dynamic height was used to calculate the geostrophic current in order to get an idea of the possible movement of the boundary. The study was done at first to describe the outstanding characteristics of the Front in each period, and then to compare these with the oceanographic data. Due to the time and the scale differences between these two approaches (satellite and conventional oceanographic data) and the errors (measurement, assumptions, approximations) involved, only the comparison of the order of magnitude of the quantities was emphasized, rather than their absolute values.

In order to better describe the Front, the study area was divided into three regions as defined in the previous work (Tseng, 1974), i.e. the northern region, the central region and the southern region. The northern region extends from 30$^o$ to 34$^o$S latitude and from 48$^o$ to 54$^o$W longitude; the central from 34$^o$S to 38$^o$S latitude and from 51$^o$W to 56$^o$W longitude and the southern from 38$^o$S to about 46$^o$S latitude and from 50$^o$W to 60$^o$W longitude.

Some terms used in Section III have been defined in order to compare oceanographic and satellite data:

Mean Front (or mean boundary or mean): the arithmetic mean of the Fronts (obtained from Nimbus V THIR data) in each period.
Eastern Envelope: the line connecting the easternmost peaks (more oceanic part) of the individual boundary (obtained from Nimbus V THIR data) lines.
Western Envelope: the line connecting the westernmost peaks (close to the coast) of the individual boundary (obtained from Nimbus V THIR data) lines.
Eastern peakline: the line connecting the peaks of the (surface) isotherms (obtained from oceanographic data) in the eastern part (more oceanic part) of the study area.
Western peaklines: the line connecting the peaks of the (surface) isotherms (obtained from oceanographic data) in the western part (close to the coast) of the study area.
Transition zone: the zone lying between the Eastern and the Western peaklines.

## III. STUDY OF THE FRONT WITH THIR IMAGES AND WITH OCEANOGRAPHIC DATA

Natural oceanographic phenomena such as the boundary between the Brazil and Falkland Currents is so important to oceanography and fisheries that, from space data, a cartographic description in 6 out of the 12 periods is given in this Section III. In this description, features such as the position of the Front in the various periods of the year, its geographical extension, its apparent East-West motion and its meanders, are discussed. An attempt was also made to compare the order of magnitude of the East-West possible displacement of the Front with respect to geostrophic currents. A comparison of the Front with oceanographic charts was done for those periods where oceanographic as well as satellite data were available. More detailed description of the Front and its comparison with oceanographic data can be found in Tseng (1976).

3.1 SUMMER SECOND PERIOD (FROM JANUARY 22 TO FEBRUARY 21, 1973)

Nine Front lines were selected from 20 cloud-free THIR images. Four of them were in the early as well as in the late period; one was in the middle period (Fig. III.1).

In the northern region, the Front was found on its mean position in the middle of the early period at an approximate distance of 160 km from the coast (curve 1), and reached its westernmost position (curve 5) in the middle period, with the minimum distance of 100 km from the coast. In general, the Front had a tendency of being more oceanic during the early and the late periods and was closer to the coast at the end of the early period and in the middle period. In almost all cases studied, its northern tip was hardly seen north of 32°S.

In the central region, the Front was found more oceanic in the middle of the early and the late periods (curves 1 to 2 and 6 to 7); while in the rest of the periods, it was much closer to the coast (curves 8 to 9). An outstanding meander existed in front of Rio de La Plata at about 37°S, throughout the whole interval of the study, having its radius of curvature of 400 km to its eastern side.

In the southern region, the Front was observed on its easternmost position with its southern tip reaching the longitude of 50°W in the early period (curve 1). In the rest of the period, its northern part stayed around the mean (curves 2 to 9), having small oscillations. However, its southern part had very wide fluctuations, especially at the latitude of 41°S. An outstanding meander existed around 53°W and 40°S with a radius of curvature of approximately 200 km on its western side.

The two Peaklines obtained from the oceanographic data were superimposed on the Front lines. The Envelopes and the Mean were properly located between the East and the West Peaklines in the northern and the central regions and showed a reasonable agreement between the satellite and oceanographic data (Fig. III.2). Some general characteristics of the Front obtained from both satellite and oceanographic data are outlined in Table III.1.

3.2 AUTUMN FIRST PERIOD (FROM MARCH 22 TO APRIL 21, 1973)

Nine Front lines were chosen from 20 THIR images studied in this period. Five of them were in the early period, one in the middle and three in the late periods (Fig. III.3).

In the northern region, only three Front lines appeared. The Front was found at its Mean in the early period (curve 1); at the end of the middle period, it was on its easternmost position (curve 6), and at the beginning of the late period, it reached the closest position from the coast with a distance of 90 km from it (curve 7).

In the central region, the Front was observed on its Mean in the early period (curve 1), was in the easternmost position with its southern edge still touching its Mean at the end of the early period (curve 5) and in its westernmost position at the end of the late period (curve 9). In general, the Front apparently had a tendency of being more oceanic at the end of the early period and in all the middle period, while it was closer to the coast in the late period.

In the southern region, the Front was observed at its Mean (curve 1) and was on its easternmost position at the end of the early period. Early in the late period, the Front reached its westernmost position (curve 8). Two meanders were observed throughout all of the period: one was centered at 38°30'S, with the center of curvature on the eastern side of the Mean; the other at 41°S with the center of curvature on the western side. Generally, the Front stayed more oceanic at the end of the early and middle period and closer to the coast in all of the late period.

The Mean and the two Envelopes also stayed between the Peaklines, up to 39°S, indicating a good agreement between the satellite and oceanographic data (Fig. III.4).

3.3 WINTER

3.3.1 WINTER SECOND PERIOD (JULY 22 TO AUGUST 21, 1973)

Four Front lines were chosen from seven THIR images studied. One of them was in the middle period; the other three in late period (Fig. III.5).

In the northern region, the Front was found at its Mean (curve 1) at the beginning of the middle period, maintaining a distance of 180 km from the coast and was on its easternmost position at the beginning of the late period (curve 2). A meander was found in front of Rio de La Plata, with its center of curvature to its western side and lasted for all of this period. The shift of the bending point of the Front Lines seemed to form an ellipse of 160km in the East-West direction and 50 km in the North-South direction, suggesting the presence of a counter clockwise oceanic eddy in this period (Fig. III.5).

In the southern region, the Front was observed on the west of the Mean (curve 1) at the beginning of the middle period, and on its easternmost position in the late period. Three meanders could be observed around 39$^{o}$S, all with their centers of curvature to the east of the Mean. The southern tip of the Front could not be observed clearly south of 40$^{o}$S. This was the shortest Front observed in the twelve periods of 1973 (See Table III.1). A comparison between satellite and oceanographic data was shown in Fig. III.6. The Eastern Peakline was not available in this case.

3.3.2 WINTER THIRD PERIOD (AUGUST 22 TO SEPTEMBER 21, 1973)

Twelve Front lines were chosen from 22 THIR images studied. Six of them were in the early period, two in the middle period, and four in the late period (Fig. III.7).

In the northern region, the Front was found at its mean position at the beginning of the early period (curve 1), on its westernmost position at the end of the early period (curve 5) and reached its easternmost position at the beginning of the middle period. The northern tip could be observed very clearly and distinctly down to 31$^{o}$S in most of the cases studied.

In the central region, the Front was found on the easternmost position at the end of the middle period (curve 4) and on its westernmost position at the end of the late period (curve 12). Many meanders could be observed in front of Rio de La Plata in all of the period. In most of the cases, their centers of curvature stayed on the western side of the Mean.

In the southern region, the characteristics of the Front were quite similar to those in the central region, showing the complexity of the East-West oscillations and the meandering at the Front in all this period.

A comparison between satellite and oceanographic data was made, as shown in Fig. III.8. It was found that the Mean Front and the Envelopes stayed between the two Peaklines shown in this Figure. The calculated speeds of the geostrophic current in the East-West direction were, roughly, 0.7 and 0.4 km/hr at 34$^{o}$ and 36$^{o}$S respectively: the same order of magnitude as those calculated from the Front lines (Table III.1).

3.4 SPRING

3.4.1 SPRING SECOND PERIOD (FROM OCTOBER 22 TO NOVEMBER 21, 1973)

Eight Front lines were chosen from nineteen THIR images studied. Five of them were in the middle period and three in the late period (Fig. III.9).

In the northern region, only one boundary line could be seen at distance of about 90 km from the coast. The northern tip could not be seen clearly in the latitudes north of 34$^{o}$S.

In the central region, the Front was found on its westernmost position at the beginning of the middle period, and reached its easternmost position at the end of the late period (curve 7). A meander could be observed in the front of Rio de La Plata with its center of curvature to the eastern side of the Mean lasting for the whole period.

In the southern region, the Front was found on its easternmost position at the beginning of the early period (curve 2), and on its westernmost position at the end of the late period (curve 7). A meander could be observed at 40$^{o}$S with the center of curvature to the west of the Mean. The fluctuations of the position of the Front were much wider in this period. The Mean and the two Envelopes did not lie between the two peaklines (Fig. III.10). This is the only exception from the six periods studied.

3.4.2 SPRING THIRD PERIOD (FROM NOVEMBER 22 TO DECEMBER 21, 1973)

Five Front lines were identified from eight THIR images studied. One of them was in the early,one in the middle and three in the late periods (Fig. III.11).

In the northern region, the Front was found on its easternmost position at the end of the early period (curve 1) and reached its westernmost position at the beginning of the late period (curve 3) to a distance of 110 km from the coast. The fluctuations of the position of the Front were especially smaller when compared to other periods studied.

In the central region, the Front was found on its easternmost position at the end of the early period (curve 1) and it reached its westernmost position at the beginning of the late period (curve 3). A meander occurred in front of Rio de La Plata, with its center of curvature in the eastern side of the Mean, lasting for almost all the period. The amplitude of the oscillations of the Front was the smallest as compared to the other periods in 1973.

In the southern region, the Front was found on its westernmost position at the beginning of the late period (curve 3) and reached its easternmost position at the end of the late period (curve 5). A meander was found at about 40°S with its center of curvature on the western side of the Mean lasting for almost the whole period.

The Mean Front and the two Envelopes stayed completely between the two Peaklines showing a good agreement between the satellite and the oceanographic data (Fig. III.12).

## IV. DISCUSSION

To study oceanographic current boundaries would need a large number of images and a lot of oceanographic data. The number of good quality images is limited by such factors as excessive cloud cover, noise in the spectral channel and/or detector,telemetry problems, grid point errors, etc. For these reasons, some periods in this study had a lot of good quality images, and others did not have enough. Besides the possible errors mentioned, two more factors should also be taken into account. The one is called microsurface effect; the other is the time difference between the measurements made by oceanographic methods and with satellites.

With respect to the first, it is known that a layer of less than 1 mm of water is opaque to infrared radiation from 8 to 14 μm, and 98% of the absorption occurs in the first 0.1 mm of the layer (Ewing, et.al. 1960). This means that the observed infrared radiation emerges from the very top of the air - water interface (the microsurface), where transfer processes like evaporation, reflection etc., take place and also where microsurface properties, such as protein monolayer and dust or oil films, are significant. The sea surface temperature is defined by conventional methods as the mean temperature of a well-mixed layer at least several decimeters deep, which is in reasonable agreement with the nature of conventional sea surface temperature observations. Experiments have shown (Ewing, et.al. 1960) that the microsurface is approximately 0.6°K colder than the layer of 15 cm under the surface. It has also been observed that the microsurface is remarkably stable. Thus, under clear-sky conditions, radiometric measurements of sea surface temperature generally should be approximately 0.6°K lower than conventional measurements.

With respect to the second factor, it can be said that the THIR sensor scans the large area of the boundary in approximately ten minutes. In such a short period of measurement, not a single oceanographic station could possibly be taken. For oceanographic vessels to cover the same boundary area, they would have to stay months in sea, running distances of more than one thousand kilometers to make oceanographic stations. When these cruises end, oceanographers have to plot the data in a single chart for every property measured for the whole area. After that, a chart showing average conditions is issued. This chart, however, contains probably a larger distortion of the ocean structure than that obtained from the satellites for the same area.

The oceanographic information of this area, in a scale adequate to compare with satellite data (1:3500000 in this case), was poor and fragmentary. For this reason, an Atlas of oceanographic structure (Inostroza and Tseng, in preparation) was prepared, and was used as a basic historical document for the image study. This Atlas consists of 150 charts of temperature, salinity, oxygen and nutrients in four levels: surface, 50m, 100m and 150m. These charts represented the average monthly conditions, and were used as the ground truth for this study, because simultaneous ground observations corresponding to the satellite passages were not available. Since the average conditions of the open ocean do not change very much in this scale (almost in steady state, Pickard, 1963), the average monthly temperature charts could reasonably represent the ground truth data.

The results from the comparative studies between oceanographic and satellite data have been quite stimulating. Because not only the Mean Fronts, but also their Envelopes were located between the Eastern and the Western peaklines obtained from the oceanographic data. The zone between these two peaklines, defined as the Transition Zone, was the zone where all the oscillations of the Fronts during the period of 1972 to 1973, occurred. The Peaklines represented a permanent oceanographic reality of the southwestern Atlantic Ocean at the boundary of the Brazil and Falkland Currents (not yet described in the existing literature). The Eastern and the Western Envelopes were fully obtained from the satellite Nimbus THIR data. Why the positions of the Envelopes stayed practically between these two peaklines in almost all the cases and not out of them? The authors believe that the Fronts obtained from the satellite data in this region are in the zone where they belong to, that is to say, in the Transition Zone, because in this zone the temperature gradient, as measured by the sensor, exists. Then it could be stated that in spite of the errors involved in the present sensor capabilities and the variables in oceanographic and satellite data including time differences between the two data sets, oceanographic charts show that the sensors give the positions of the Fronts, where they should be, i.e., where the temperature gradients obtained from oceanographic data are.

Another idea, developed to correlate the oceanographic characteristics and the satellite data, was to estimate the current speed. The authors believe that to study the movement of the current is not easy at present, because the capabilities of the present sensors are limited. For this reason, charts of geostrophic currents were made, and their speeds were calculated and compared with those obtained from the satellite data (see Table III.1). Speeds of the currents obtained from the pilot charts cannot be properly compared with those obtained from the satellite and the geostrophic currents (the scale of pilot charts was $5^{\circ} \times 5^{\circ}$, while that of the satellite and the geostrophic currents was $1^{\circ} \times 1^{\circ}$). A careful comparison of the current speeds (E-W or W-E direction) calculated from the satellite and the oceanographic data showed that, at least at $34^{\circ}$S, they were practically equal in each corresponding period. Now, from the seven periods studied and nineteen individual values of speed (Table III.1), it was found that eighteen of them were between 0.2 km/hr (0.1 knot) and 1.7 km/hr (0.9 knot) (close to 95% of the cases studied), and only one value was 2.4 km/hr (1.4 knot). It can be said that the current speeds calculated from the satellite data are of the same order of magnitude from 0.2 to 1.8 km/hr (0.1 to 1 knot). As those calculated from the conventional oceanographic methods (in 95% of the cases) and, in some latitudes, these values are practically equal (in the case of $34^{\circ}$S, for instance).

A study of the commercial fisheries of Pargo Rõseo in the coast of Rio Grande do Sul demonstrated that the catches of this fish were maximum in September of 1973, with 5 million kilograms and, in the other months, the catches were much smaller (Yesaki and Barcellos, 1974). As the Front lines of the third period of winter, obtained from the satellite data, were very active and much wider in their fluctuations, the Front lines and their characteristics could be important factors that affected, directly or indirectly, those September catches. This would mean that detecting the Front might be an important subject to study in the future, that would give useful information for fisheries in this region.

## V. CONCLUSIONS

Some important conclusions obtained from this study are summarized as follows:

1. Detailed analysis of seventy five THIR images (interpreted visually and some with Image-100) have shown clearly the existence of oceanographic Fronts in this study area.
2. The surface temperature charts obtained from the historical oceanographic data showed the existence of a series of peaks, associated with each isotherm in the west, as well as a series of peaks, associated with each isotherm in the East. The Western and the Eastern peaklines could be observed in all the periods studied. Obviously, the first (Western) is associated with the Falkland Current and the second with the Brazil Current. These Peaklines, which have not been described in the present literature, were considered as the permanent oceanographic reality in the study region. They were obtained completely from the <u>pure oceanographic data</u>. The Transition Zone was also obtained from the pure oceanographic data.
3. The Envelopes and the Mean Fronts were obtained from <u>pure satellite data</u>. In comparison with the oceanographic data, it was shown that these Envelopes and the Mean Front were practically located between the Western and the Eastern peaklines in each period. This is encouraging and useful as it shows similarity between the results obtained from conventional and from space oceanography.

4. Another relationship between the conventional and space oceanography became evident from the calculation of current speeds. The results showed that 95% of the current speeds, calculated from both methods, were of the same order of magnitude, and in one case, at 34°S latitude, the calculated speeds were practically equal in all the periods.
5. As pointed out earlier, the position as well as the characteristics of the Front lines can be important factors that might affect, directly or indirectly, the concentration of the fish. This fact supports the conclusion that the boundaries between the cold Falkland Current and the warm Brazil Current in the Southwestern Atlantic ocean are good fishing areas.

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REFERENCES

Allison, L.J. and E.R. Kreins (1970), Color Enhancement of Nimbus High Resolution Infrared Radiometer Data, Applied Optics, 9: 681-686.

Anding, D., R. Kauth, and R. Turner (1971), Atmospheric Effects on Infrared Multispectral Sensing of Sea Surface Temperature from Space, NASA, Washington,D.C.,(NASA Contractor Report CR-1858).

Ewing, G.C. and E.D. McAlister (1960), On the Thermal Boundary Layer of the Ocean, Science, 131:1374 - 1376.

General Electric Company (1975), Image 100 User Manual, Daytona Beach, Florida.

Hynd, J.S. (1968), How Sea Surface Temperature Maps Aid Tuna Fishermen, Australian Fisheries Newsletter, pp. 23-29.

Inostroza V., H. M. and Y.C. Tseng (in preparation), Atlas de Estruturas Oceanográficas do Rio Grande do Sul, INPE, S.J. Campos, SP, Brasil.

Laevastu, T. and I. Hela (1970), Fisheries Oceanography, London, Fishing News Books, pp. 25-32.

Mandelli, E.F. and A.M. Orlando (1966), La producción Organica Primaria de las Caracteristicas Fisioquímicas de la Malvinas, Presented at Third Session CARPAS, CARPAS/3D. Tech. 10, Buenos Aires, Argentina, pp.25-29.

Maul, G.A. (1972), Remote Sensing of Ocean Currents Using ERTS Imagery, Symposium on Significant Results obtained from the Earth Resources Technology Satellite 1, NASA-GSFC, Greenbelt, Maryland, pp. 1365-1375.

Maul, G.A. (1974), Preliminary Assessment of Oceanic Observations from SKYLAB, NASA Technical Memorandum TMX-58 142, NASA-Lyndon B. Johnson Space Center, Houston, Texas, pp. 18.1-18.8.

Maul, G.A. and H.P. Gordon (1973), Relationships between ERTS Radiances and Gradients across Oceanic Fronts, Third Earth Resources Technology Satellite Symposium, NASA, Washington, D.C., pp. 1279-1308.

Maul, G.A. and D.V. Hansen (1972), An Observation of Gulf Stream Surface Front Structure by Ship, Aircraft and Satellite, Remote Sensing of Environment 2: 109-116.

Pickard, G.L. (1963), Descriptive Physical Oceanography, Pergamon Press, Oxford, London p. 74 and 130.

Sabatini, R.R., G.A. Rabchevsky, and J.E. Sissala (1971), Nimbus Earth Resources Observation, NASA-GSFC, Greenbelt, Maryland, p.122.

Stevenson, M.R. and F.R. Miller (1972), Application of High Resolution and Visual Data to Investigate Changes in and the Relationship between Sea Surface Temperature and Cloud Patterns over the Eastern Tropical Pacific, Inter-American Tropical Tuna Commission, La Jolla, California.

Stevenson, R.E., L.D. Carter, and V. Haar (1974), Preliminary Report on Visual Observation of the Oceans from SKYLAB, NASA Technical Memorandum TMX-58 142, NASA-Lyndon B. Johnson Space Center, Houston, Texas, pp. 17.1 - 17.15.

Szekielda, K.H. (1972), Upwelling Studies with Satellite, J. Cons. Int. Explor. Mer. 34(3): 379-388.

Szekielda, K.H. and K.F. Mitchell (1974), Oceanographic Application of Color-Enhanced Satellite Imageries, NASA-TMX-651-71-53, NASA-GSFC, Greenbelt, Maryland.

Tseng, Y.C. (1974),Study of the Surface Boundary of the Brazil and Falkland Currents ,Seminar on Space Applications of Direct Interest to Developing Countries, INPE, S.J. Campos-SP, Brasil, V.2.

Tseng, Y. C. (1976), Estudo do Extremo Oeste da Convergência Sub-Tropical do Oceano Atlântico Sul Usando Imagens do Satélite Nimbus V e Dados Oceanográficos, no Período de 1972 a 1973. INPE-940-TPT/038, S.J. Campos-SP, Brasil, 93 p.

Uda, M. (1936), Fishing Centre of "Sanma" (Cololabis Saira Breevert) Correlated with the Head Oyashio Cold Current (In Japanese with English Summary), Bull. Jap. Soc. Scient. Fish. 5:236-238.

Uda, M. (1952), On the Relation between the Variation of the Important Fisheries Conditions and the Oceanographical Conditions in the Adjacent Waters of Japan, J. Tokyo Univ. Fish. 38: 363-389.

Yesaki, M. (1973), Sumário dos Levantamentos de Pesca Exploratória ao Largo da Costa Sul do Brasil e Estimativa da Biomassa de Peixe Demersal e Potencial Pesqueiro, Programa de Pesquisa e Desenvolvimento Pesqueiro do Brasil, PNUD/FAO, Ministério da Agricultura/SUDEPE, Rio de Janeiro, Brasil.

Yesaki, M. and B. Barcellos (1974), Desenvolvimento da Pesca do Pargo-Róseo ao Largo da Costa Sul do Brasil, FAO/SUDEPE, Rio de Janeiro, Brasil.

Zusser, S.G. (1958), A Contribution to the Study of Fish Behavior, Symposium on Fish Behavior, S.l, IPFC.

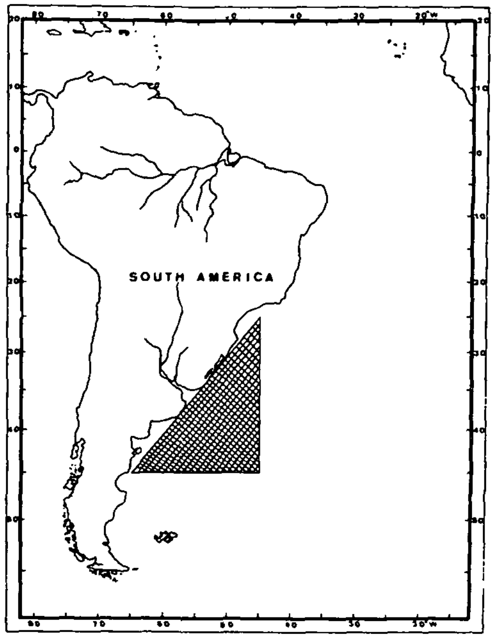


FIG. I.1 - AREA OF STUDY.

TABLE II.1 - LIST OF THE NIMBUS V THIR USED

| ORBIT | DATE (DAY,MO.,YR) | SEASON | RATING | ORBIT | DATE (DAY,MO.,YR.) | SEASON | RATING | ORBIT | DATE (DAY,MO.,YR.) | SEASON | RATING | ORBIT | DATE (DAY,MO.,YR.) | SEASON | RATING |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0220 D | 27.12.72 | Summer 1 | E | 0945 D | 19.02.73 | Summer 2 | P | 2864 D | 12.07.73 | Winter 1 | G | 4045 D | 08.10.73 | Spring 1 | P |
| 0260 D | 30.12.72 | " | G | 0977 N | 22.02.73 | Summer 3 | P | 2883 N | 14.07.73 | " | E | 4059 D | 09.10.73 | " | G |
| 0273 D | 31.12.72 | " | E | v*1025 D | 25.02.73 | " | E | 3138 N | 02.08.73 | Winter 2 | P | 4078 N | 11.10.73 | " | P |
| 0287 D | 01.01.73 | " | E | v*1052 D | 27.02.73 | " | E | v 3159 D | 03.08.73 | " | E | 4091 N | 12.10.73 | " | E |
| 0346 N | 06.01.73 | " | G | 1119 D | 04.03.73 | " | P | 3259 N | 11.08.73 | " | G | 4099 D | 12.10.73 | " | G |
| 0354 D | 06.01.73 | " | E | 1334 D | 20.03.73 | " | P | 3267 D | 11.08.73 | " | E | 4112 D | 13.10.73 | " | G |
| 0367 D | 07.01.73 | " | G | 1339 N | 21.03.73 | " | P | v 3334 D | 16.08.73 | " | E | v 4118 N | 14.10.73 | " | E |
| 0373 N | 08.01.73 | " | P | 1365 N | 23.03.73 | Autumn 1 | G | 3353 N | 18.08.73 | " | G | v 4126 D | 14.10.73 | " | E |
| 0381 D | 08.01.73 | " | E | *1374 D | 23.03.73 | " | E | 3374 D | 19.08.73 | " | E | 4131 N | 15.10.73 | " | G |
| 0394 D | 09.01.73 | " | E | 1420 N | 27.03.73 | " | P | 3420 N | 23.08.73 | Winter 3 | P | v 4139 D | 15.10.73 | " | E |
| v* 0421 D | 11.01.73 | " | E | 1428 D | 27.03.73 | " | G | 3468 D | 26.08.73 | " | E | 4145 N | 16.10.73 | " | E |
| 0467 N | 15.01.73 | " | P | 1433 N | 28.03.73 | " | E | v 3487 N | 28.08.73 | " | E | 4260 D | 24.10.73 | Spring 2 | P |
| v* 0475 D | 15.01.73 | " | E | *1441 D | 28.03.73 | " | E | v 3495 D | 28.08.73 | " | E | *4287 D | 26.10.73 | " | G |
| * 0480 N | 16.01.73 | " | G | 1447 N | 29.03.73 | " | G | 3508 D | 29.08.73 | " | E | 4300 D | 27.10.73 | " | P |
| v 0488 D | 16.01.73 | " | E | 1455 D | 29.03.73 | " | E | 3514 N | 30.08.73 | " | G | 4386 N | 03.11.73 | " | G |
| 0534 N | 20.01.73 | " | G | *1460 N | 30.03.73 | " | E | 3522 D | 30.08.73 | " | G | 4394 D | 03.11.73 | " | E |
| 0542 D | 20.01.73 | " | E | 1468 D | 30.03.73 | " | G | v 3527 N | 31.08.73 | " | E | 4413 N | 05.11.73 | " | E |
| 0609 D | 25.01.73 | Summer 2 | E | 1581 N | 08.04.73 | " | P | v 3535 D | 31.08.73 | " | E | 4421 D | 05.11.73 | " | E |
| 0622 D | 26.01.73 | " | E | 1602 D | 09.04.73 | " | E | 3554 N | 02.09.73 | " | G | 4440 N | 07.11.73 | " | G |
| 0628 N | 27.01.73 | " | G | 1608 N | 10.04.73 | " | P | v 3562 D | 02.09.73 | " | E | 4448 D | 07.11.73 | " | E |
| 0636 D | 27.01.73 | " | E | 1616 D | 10.04.73 | " | P | 3575 D | 03.09.73 | " | G | 4461 D | 08.11.73 | " | G |
| 0649 D | 28.01.73 | " | E | 1629 D | 11.04.73 | " | E | v 3629 D | 07.09.73 | " | E | 4467 N | 09.11.73 | " | E |
| 0735 N | 04.02.73 | " | G | v 1648 N | 13.04.73 | " | E | 3656 D | 09.09.73 | " | G | 4475 D | 09.11.73 | " | G |
| 0743 D | 04.02.73 | " | P | v 1656 D | 13.04.73 | " | G | v 3710 D | 13.09.73 | " | E | 4488 N | 10.11.73 | " | G |
| 0749 N | 05.02.73 | " | P | 1702 N | 17.04.73 | " | P | 3729 N | 15.09.73 | " | P | 4494 N | 11.11.73 | " | E |
| 0757 D | 05.02.73 | " | G | 1729 N | 19.04.73 | " | E | 3750 D | 16.09.73 | " | E | 4542 D | 14.11.73 | " | G |
| 0762 N | 06.02.73 | " | G | 1742 N | 20.04.73 | " | P | 3782 N | 19.09.73 | " | P | 4582 D | 17.11.73 | " | E |
| v* 0770 D | 06.02.73 | " | E | 1836 N | 27.04.73 | Autumn 2 | P | 3796 N | 20.09.73 | " | E | 4588 N | 18.11.73 | " | E |
| 0824 D | 10.02.73 | " | G | 1863 N | 29.04.73 | " | P | 3804 D | 20.09.73 | " | G | 4609 D | 19.11.73 | " | G |
| 0877 D | 14.02.73 | " | E | 1970 N | 07.05.73 | " | E | 3809 N | 21.09.73 | " | G | 4628 N | 21.11.73 | " | G |
| 0878 D | 14.02.73 | " | G | 2051 N | 13.05.73 | " | E | 3817 D | 21.09.73 | " | E | 4722 N | 28.11.73 | Spring 3 | P |
| *0883 N | 15.02.73 | " | G | 2064 N | 14.05.73 | " | P | 3831 D | 22.09.73 | Spring 1 | G | 4730 D | 28.11.73 | " | E |
| v*0891 D | 15.02.73 | " | E | 2091 N | 16.05.73 | " | P | 3836 N | 23.09.73 | " | E | 4864 D | 08.12.73 | " | E |
| 0904 D | 16.02.73 | " | E | 2118 N | 18.05.73 | " | P | v 3844 D | 23.09.73 | " | E | 4910 N | 12.12.73 | " | E |
| 0905 D | 16.02.73 | " | G | 2252 N | 28.05.73 | Autumn 3 | E | v 3857 D | 24.09.73 | " | E | 4958 D | 15.12.73 | " | E |
| *0918 D | 17.02.73 | " | G | 2480 N | 14.06.73 | " | E | 3871 D | 25.09.73 | " | E | 4971 D | 16.12.73 | " | P |
| v*0931 D | 18.02.73 | " | E | 2722 N | 02.07.73 | Winter 1 | E | 3898 D | 27.09.73 | " | E | 5012 D | 19.12.73 | " | P |
| 0937 N | 19.02.73 | " | G | 2730 D | 02.07.73 | " | G | 3903 N | 28.09.73 | " | P | 5025 D | 20.12.73 | " | E |

REMARKS: (1) - D: Daytime; N: Nighttime

(2) - Rating was divided into three classes: excellent (E), good (G) and poor (P). Those of the excellent were chosen to study the Fronts in 1972 to 1973.

(3) - "v" Image-100 was applied.

(4) - "*" Grid Print Maps were applied.

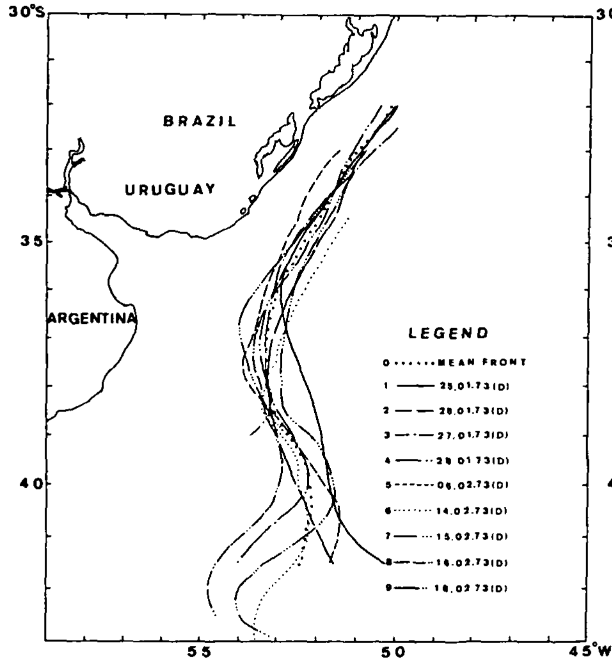


FIG. III.1 - FRONT LINES OF SUMMER SECOND PERIOD OF 1973.

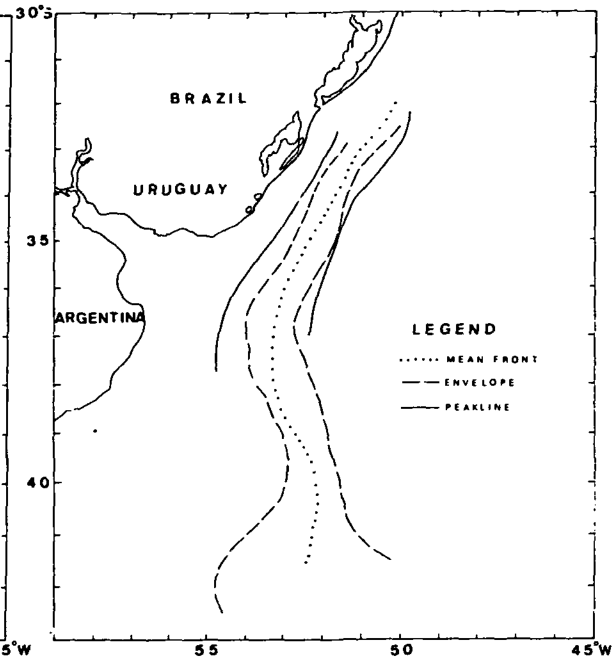


FIG. III.2 - MEAN FRONT, ENVELOPES AND PEAK-LINES OF SUMMER SECOND PERIOD OF 1973.

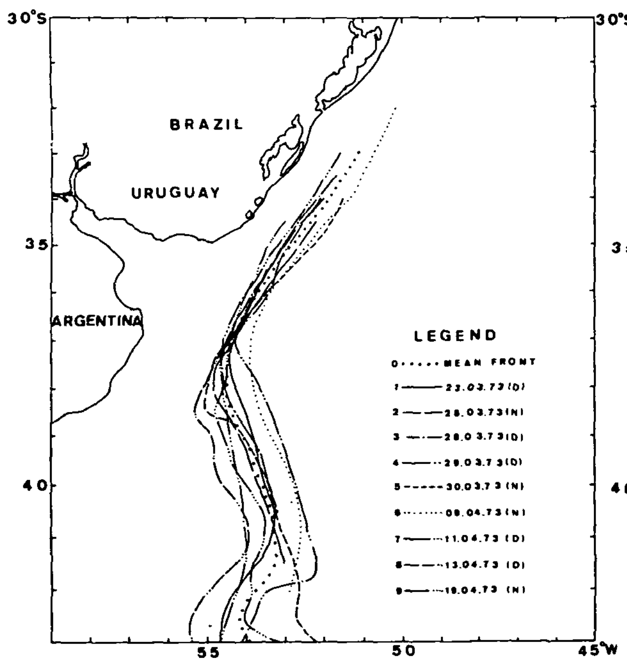


FIG. III.3 - FRONT LINES OF AUTUMN FIRST PERIOD OF 1973.

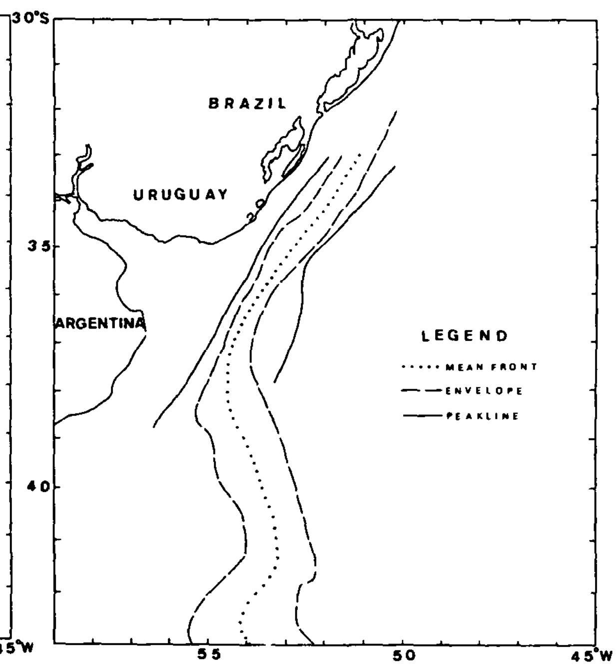


FIG. III.4 - MEAN FRONT, ENVELOPES AND PEAK-LINES OF AUTUMN FIRST PERIOD OF 1973.

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TABLE III.1 - SOME GENERAL CHARACTERISTICS OF THE FRONT.

| SEASON | PERIOD | LATITUDE | APPROXIMATE SPEED OF CURRENT (KM/HR) IN EAST-WEST OR WEST-EAST DIRECTION: FROM NIMBUS V THIR | FROM OCEANOGRAPHIC DATA | FROM PILOT CHART | APPROXIMATE NORTHERN AND SOUTHERN TIPS FROM NIMBUS V THIR (°S) | APPROXIMATE LENGTH OF FRONT FROM NIMBUS V THIR (KM) |
|---|---|---|---|---|---|---|---|
| SUMMER | 1 | 31 | - | - | 1.1 | 32-43 | 1,220 |
| | | 34 | 0.6 | - | - | | |
| | | 36 | 0.6 | - | 1.3 | | |
| | | 38 | 0.7 | - | - | | |
| | | 40 | 0.6 | - | - | | |
| | 2 | 34 | 0.4 | - | - | 32-43 | 1,220 |
| | | 35 | - | - | 1.1 | | |
| | | 36 | 0.6 | - | - | | |
| | | 38 | 0.4 | - | - | | |
| | | 40 | 0.7 | - | - | | |
| | 3 | 32 | - | - | 0.7 | 32-41 | 1,000 |
| | | 34 | 0.4 | 0.4 | 0.9 | | |
| | | 36 | 1.7 | 0.4 | - | | |
| | | 38 | 2.6 | 0.6 | - | | |
| | | 40 | 3.1 | - | - | | |
| AUTUMN | 1 | 32 | - | - | 0.7 | 32-43 | 1,220 |
| | | 34 | 0.6 | 0.2 | 0.9 | | |
| | | 36 | 0.4 | 1.1 | - | | |
| | | 38 | 0.9 | 0.7 | - | | |
| | | 40 | 0.7 | - | - | | |
| | 2 | 31 | - | - | 0.6 | 34-43 | 1,000 |
| | | 32 | - | - | 0.6 | | |
| | | 34 | 0.2 | 0.2 | - | | |
| | | 35 | - | - | 1.1 | | |
| | | 36 | 0.2 | 1.1 | - | | |
| | | 38 | 0.2 | 0.7 | - | | |
| | | 40 | 0.4 | - | - | | |
| | 3 | 31 | - | - | 1.1 | 33-43 | 1,110 |
| | | 33 | - | - | 0.9 | | |
| | | 34 | 0.2 | 0.2 | - | | |
| | | 36 | 0.2 | - | - | | |
| | | 38 | 0.2 | 1.1 | - | | |
| | | 40 | 0.2 | 0.7 | - | | |
| WINTER | 1 | 31 | - | - | 1.3 | 33-43 | 1,110 |
| | | 34 | 0.2 | - | - | | |
| | | 36 | 0.2 | - | 0.6 | | |
| | | 38 | 0.2 | - | - | | |
| | | 40 | 0.4 | - | - | | |
| | 2 | 34 | 0.6 | - | - | 32-40 | 890 |
| | | 35 | - | - | 0.9 | | |
| | | 36 | 0.7 | - | - | | |
| | | 38 | 0.7 | - | - | | |
| | | 40 | 0.7 | - | - | | |
| | 3 | 33 | - | - | 0.9 | 30-43 | 1,450 |
| | | 34 | 0.6 | 0.7 | - | | |
| | | 36 | 0.6 | 0.4 | 1.1 | | |
| | | 38 | 0.9 | - | - | | |
| | | 40 | 1.1 | - | - | | |
| SPRING | 1 | 34 | 0.7 | - | 1.1 | 31-43 | 1,330 |
| | | 36 | 0.4 | - | 1.1 | | |
| | | 38 | 0.7 | - | - | | |
| | | 40 | 0.6 | - | - | | |
| | 2 | 31 | - | - | 1.1 | 33-43 | 1,110 |
| | | 34 | 0.6 | 0.4 | 1.1 | | |
| | | 36 | 1.3 | 0.6 | 1.1 | | |
| | | 38 | 1.5 | 0.7 | - | | |
| | | 40 | 1.7 | - | - | | |
| | 3 | 32 | - | - | 1.1 | 32-41 | 1,000 |
| | | 34 | 0.4 | 0.4 | 1.1 | | |
| | | 36 | 0.2 | 0.6 | 1.1 | | |
| | | 38 | 0.2 | - | - | | |
| | | 40 | 0.4 | - | - | | |

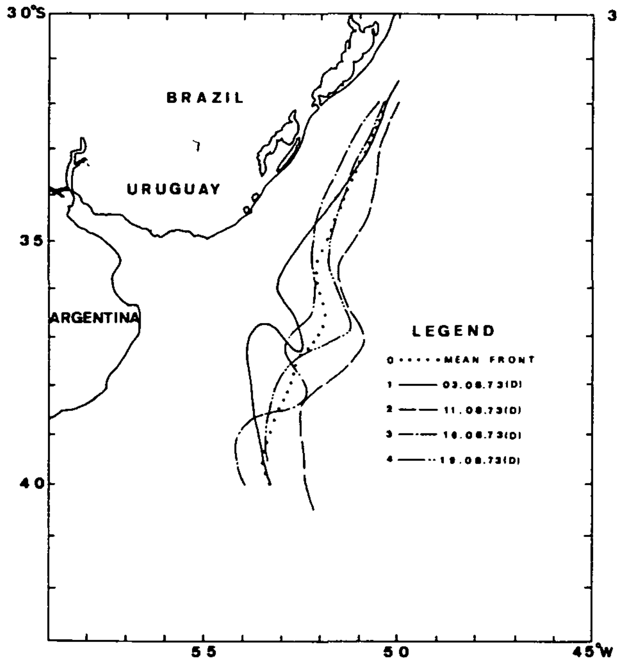


FIG. III.5 - FRONT LINES OF WINTER SECOND PERIOD OF 1973.

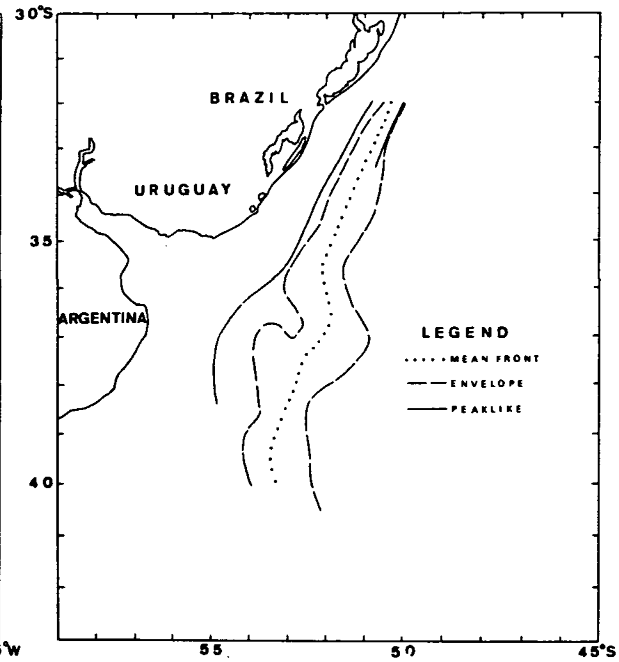


FIG. III.6 - MEAN FRONT, ENVELOPES AND PEAK-LINES OF WINTER SECOND PERIOD OF 1973.

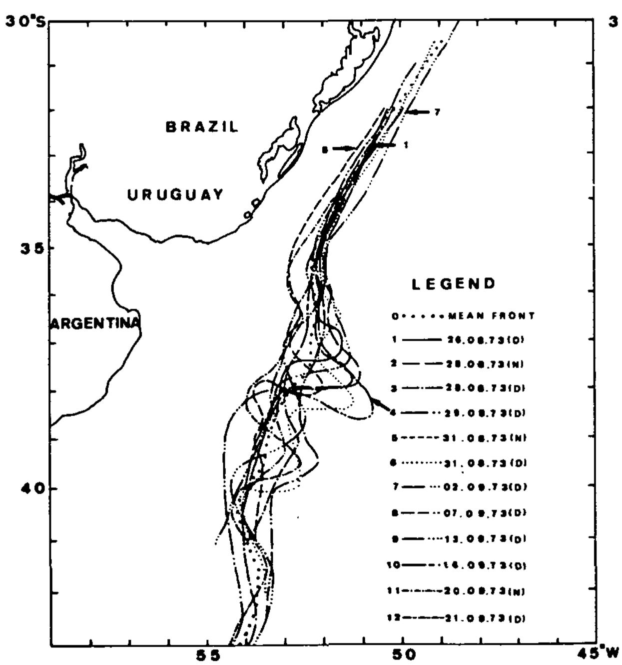


FIG. III.7 - FRONT LINES OF WINTER THIRD PERIOD OF 1973.

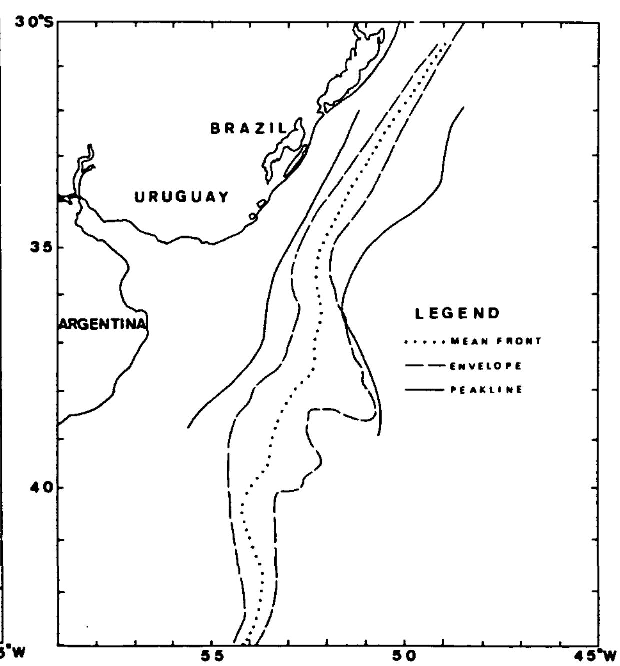


FIG. III.8 - MEAN FRONT, ENVELOPES AND PEAK-LINES OF WINTER THIRD PERIOD OF 1973.

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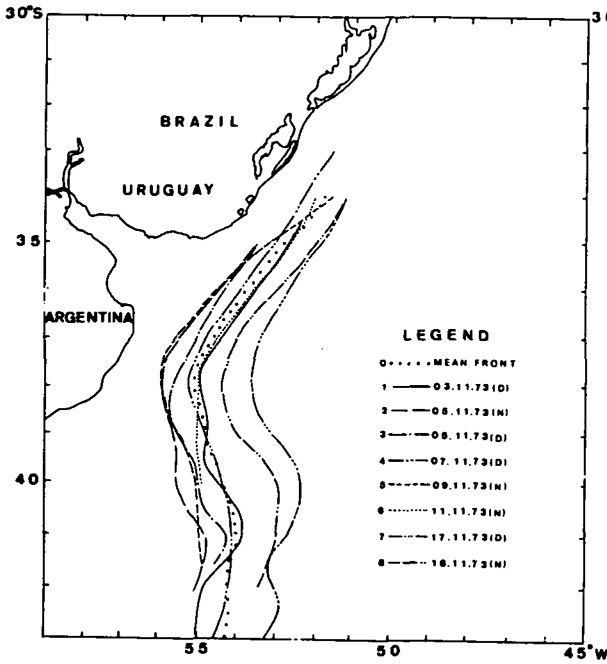


FIG. III.9 - FRONT LINES OF SPRING SECOND PERIOD OF 1973.

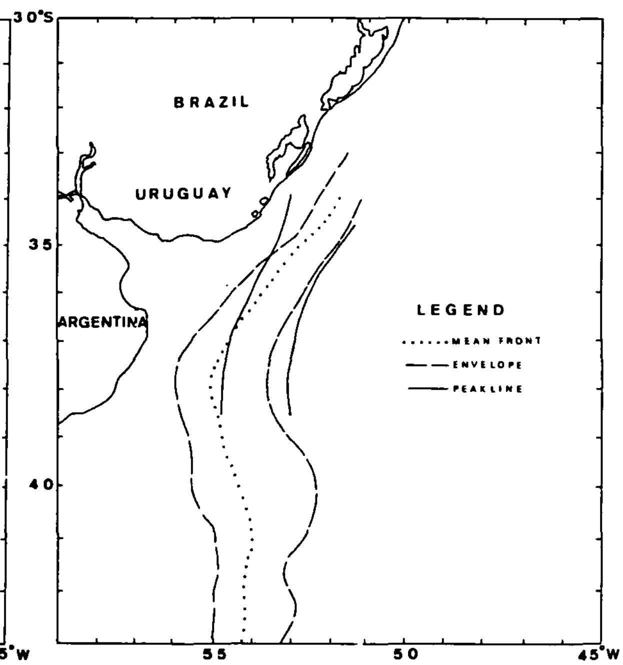


FIG. III.10 - MEAN FRONT, ENVELOPES AND PEAK-LINES OF SPRING SECOND PERIOD OF 1973.

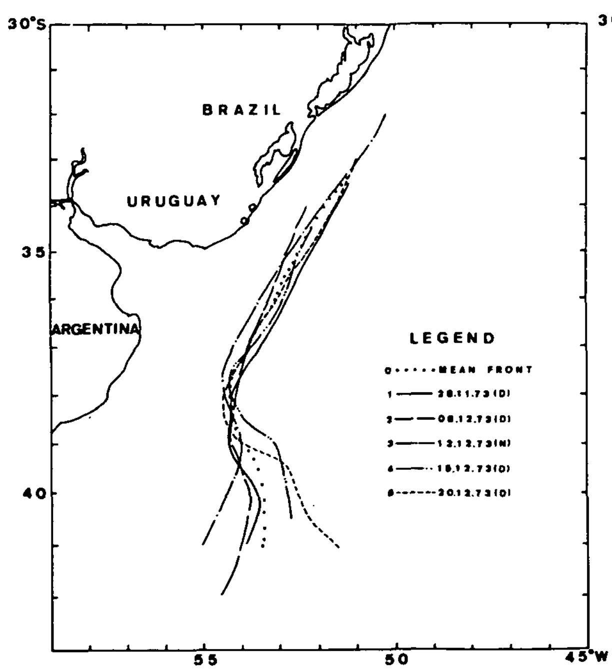


FIG. III.11 - FRONT LINES OF SPRING THIRD PERIOD OF 1973.

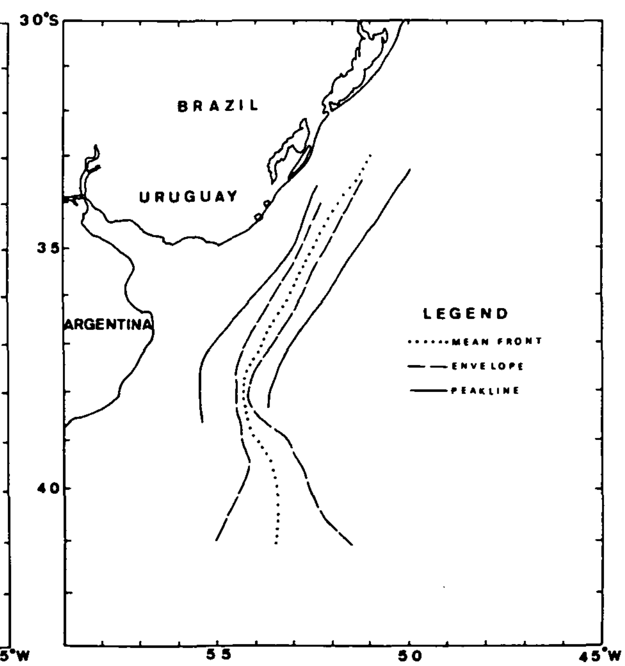


FIG. III.12 - MEAN FRONT, ENVELOPES AND PEAK-LINES OF SPRING THIRD PERIOD OF 1973.