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**16. Summary/Notes**

*The results presented in this paper are a synthesis of the researches carried out in the coast of Rio Grande do Sul (Brazil), with the main purpose of testing the feasibility of using repetitive orbital images in the study of coastal processes in the Brazilian coast. From a collection of information gathered during a long period, through the orbital plataforms SKYLAB and LANDSAT, it was possible to establish a method for the systematic study of the dynamical regime of lagoon and marine surface waters, on the coastal plain of Rio Grande do Sul. The series of multispectral images analyzed by visual and automatic techniques have put in evidence spatial and temporal variations reflected in the optical properties of waters, which carry different loads of materials in suspension. The identified patterns offer a synoptic picture of phenomena of great amplitude, from which trends of circulation can be inferred, correlating the atmospheric and hydrologic variables simultaneously to the overflight of orbital vehicles.*

**17. Remarks**

*Presented in the Thirtheenth Symposium on Remote Sensing of Environment, Ann Arbor, April 1979, U.S.A.*

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## 1. INTRODUCTION

The lagoon and coastal environments of the coast of Rio Grande do Sul, present hydrological problems of great interest for the study of coastal processes, in consequence of their complexity and dimensions. It is, undoubtedly, the most complete and widest coastal lagoon system of the whole American continent, being extremely important as a natural resource for this southern part of the Brazilian coast.

The direction of this coastal zone, between 28$^o$S and 34$^o$S, runs NE-SW, covering 47.150 Km$^2$, including both Brazilian and Uruguayan territories (Delaney, 1965).

This coast presents, as a regular feature, holocenic sand structures strongly influenced by coastal currents, which are controlled by the action of winds, whose prevailing directions coincides with the main axis of the coastal plain.

In consequence of its paleogeographic evolution (Jost & Herz, 1975) a complex lagoon system was established in this plain, in which the Patos Lagoon (10.360 Km$^2$) and Mirim Lagoon are outstanding.These two largest basins have their origins related to glacio-eustatic processes which have defined a sequence of terraces, starting from the Upper Tertiary.

Interlinked by the São Gonçalo channel and connected to the open sea by the Rio Grande channel the Patos Lagoon has, particularly, the characteristics of a lagoon, due to the frequent penetration of salt wedges to its body, through its southeastern outlet.

An extensive region encompasses the coastal plain of Rio Grande do Sul, with greatly diversified physical conditions, that are a function of the hydrological role of the fluvial basins, which drain 197.770 Km$^2$ of highlands which, in the average, are 300 m high over the Rio Grande Shield, and 900 m over the plateau, being, in addition under the marine influence of the Brazil's and Falkland's Currents, covering the adjacent continental shelf over approximately 200.000 $Km^2$, according to the system depicted by Herz (1977) (Figure 1).

The climate, of a subtropical character, is basically influenced by the action of the Atlantic Polar Mass centers, which are constantly acting over the region, causing high levels of rainfall during the winter periods, following a progression (1200 to 2250 mm/year), which the geographic distribution of the relief of the north-northwest hill slopes, until reaching the highest point near the Serra Geral, on the Plateau, at 1400 m (Figure 2).

The hydrographical basins which drain the geomorphological compartment named "Planalto" (Plateau), transport large amounts of clay-minerals withdrawn from thick soils deriving from basalt alterations (Jurassic).

This material is discharged into the Patos Lagoon through the Guaîba estuary, together with gondwanic sediments (Permian and Triassic) of the Peripheric Depression.

Other streams, which cross the Rio Grande Shield, collected mainly silt and lesser amounts of clays,since the production of decomposed materials is attributable to the climatic action on the rocky base.

All the particulate matter of continental origin transported by river and marine waters in different concentrations alter the optical properties of the same. In this way these suspended particles act as natural tracers of the surface circulation water trends, when observed through the multispectral sensors systems, in the region of the visible spectrum. (Polcyn & Rollin, 1969; Ritchie et al., 1976).

This fact becomes evident when analysing the LANDSAT (MSS) images in the orbit base 237 between the latitudes of 28°S and 38°S. The repetitive coverage of these satellites have accumulated important data concerning the coastal process in action on the eastern coast of the

Southern Atlantic during the last five years. The overflights of LANDSAT satellites have demonstrated that it is possible to carry out systematical work of visual and automatic interpretation, having in view obtaining a synoptic understanding of coastal phenomena, of temporal/spatial ,beyond the reach of the conventional direct observation techniques.

A series of dynamical behavior models are proposed for the surface waters of the lagoon and adjacent coast, of the studied region, supported by ground truth hydrometeorological data, including variation of tide ranges, fluviometry and surface wind direction and speed, obtained from fixed stations located in suitable positions, for the accurate evaluation of the hydraulic regime of the hydrologic system (Herz, 1977).

## 2. HYDROMETEOROLOGICAL CHARACTERS OF THE SYSTEM

The hydrographic basins, which form the Patos/Mirim complex, show large seasonal variations. Considerable river and lagoon flows occur in the period from July to September, during the rains of winter/spring, and this may still be associated to the piling up of waters in the southwestern sector of the Patos Lagoon on the Rio Grande channel, due to the action of the northeasterly winds created by the displacement of the low pressure centers, originated in the tropical Atlantic region. In periods of low waters, when fluviometric levels are generally reduced, the lagoon waters go down, which cause an hydraulic compensation by the intrusion of marine waters, especially in the northeastern direction. Some cases of saline intrusions in the lagoon are conditioned to the action of southerly and southwesterly winds, which pile up the shelf waters against the entrance of the channel which links the lagoon system to the sea.

The astronomical tides in the Rio Grande channel generally of the diurnal type, presenting variations of little amplitude, 0.47 m on the average. The height of the largest high tide ever recorded was 1.25 m in the Port of Rio Grande, and the smallest ebb-tide -0.22m, which are phases of level oscilations, in accretion to the astronomical effect, caused by the piling up of waters in consequence of the wind action of the enlarged volume of stream waters discharged into the lagoon, under intense rainfall.

The intrusion of the saline water mass, in the estuarine region through the Rio Grande channel shows a seasonal variation, being regulated by the system. During periods of low waters, of lags in run-off, these currents of hydraulic compensation penetrate deeply, raising the salinity in the lagoon environment. Systematic surveys, carried out during 56 years, have shown that the greatest frequency of salt water inflow occurs during April, with 76% of probability, and a periodicity of these years for the more expressive occurrences (Figure 3).

The tide-prism, at the lowest water levels, can extend itself for 66 Km to the interior of the sailing waterway, when it is associated with southerly and southeasterly winds.

At the inversion of the flux, in the ebb-tide, the volume of running waters can reach 2.400 $m^3/s$ at a speed of 0.27 m/s, which, in a period of 12 hours, can transport through the channel 103 x $10^6$ $m^3$ of water (Malaval, 1916).

The records of flow produced by tides rarely go beyond the banks located at the southwestern sector of the lagoon, existing a predominance of situations of ebb-flow, which can reach 2/3 of the yearly period, owing to the higher levels of lagoon waters which cause slope currents that the tides seldom can overcome, in normal conditions.

Although the hydrographical regimes present a great rythmical identify in the system, it must be pointed out that the fluviometric variation, which express the rivers activity from north/northeast to southeast, suffer a gradual lessening of the pluviometric distribution influenced by the energy of relief.

The Mirim Complex is evalueted directly at its connection with the São Gonçalo channel to the southwestern part of the Patos Lagoon, in the Laranjal embayment.

For this point the Commission of the Mirim Lagoon has recorded values of maximum outflow reaching 3.000 $m^3/s$ , presenting averages of 700 $m^3/s$ in a cross section of 1.200 $m^2$, with ebb-flow speeds averaging 0.6 m/s.

From the Patos Complex the rivers which flow into the Guaíba estuary, are those which contribute with the largest volume of fresh water, the largest basin being that of the Jacuí/Taquari rivers, with an average outflow of 13.000 $m^3/s$ and maximum values of 25.000 $m^3/s$ during the winter (Rochefort, 1958). During the periods of low waters, the outflow can reach values as low as 41 $m^3/s$.

The Camaquã river, second in importance within the system, flows over a smoother relief and shows, during the spring, a maximum outflow of 5.300 $m^3/s$, and 6 $m^3/s$ during the longest periods of draught, in summer, when a great water deficiency within the soils of the region also occurs.

If the estimates of average outflow are added together, the total obtained sums up to 23.300 $m^3/s$ which corresponds, approximately, to the estimates of exceptional winter outflow, mentioned by Duprat (1941), with 22.674 $m^3/s$ for an average cross section of 9.000 $m^2$ in the mentioned channel.

Malaval (1916), observed, during six years, the ebb and flood tides regime in Rio Grande, arriving at the conclusion that during a year, 108 days show a flood situation, with an average flux of 6.767 $m^3/s$ (0.76 m/s), and 205 days of ebb-flow, with 865 $m^3/s$ (0.96 m/s) on the average and 52 days of slack water. In addition, it was demonstrated that the fluxes of flood tide last in the average from 18 to 24 hours, and in cases of prolonged low waters in the continent, this effect may last from 5 to 9 days (Figure 3). In winter the ebb-tides happen to last from 10 to 19 days according to favourable conditions of winds and tides. It is interesting to note that, in general, the replenishing of ebb-flow is in excess of 200% over the duration of flood tide periods.

Such dynamical behavior presents multiple aspects as detected by LANDSAT MSS images and complementary information obtained through simultaneous ground thuth. It must be pointed out, however, that among the several models analysed, the general trends identified are absolutely coherent with the bathymetric, morphological and sedimentary data. These parameters, processed through a program of Trend Surface Analysis (Herz & Amaral, 1976), produced a series of maps with a distribution of the regional trends of granulometric character of the bottom sediments (Figure 4). In this way, the general transport patterns and source areas of sedimentary matter, introduced in the Patos Lagoon, were identified.

Other elements established by numerical models confirmed the trend patterns of circulation proposed in some distinct situations, identifying mainly the cellular eddies with suspended matter that can be seen in detail in the MSS-5 images.

## 3. METHOD OF INTERPRETATION

The techniques for identification of the circulation patterns and trends of the lagoon coastal waters, using orbital images, were based, essentially, on the optical properties of the several types of waters interacting differentially with the eletromagnetic radiations of the spectrum band (Polcyn & Rollin, 1969). A number of lagoon and coastal processes, which could be well understood by conventional methods of field research, were put in evidence by orbital imagery, which shows clearly the suspended particles in waters acting as natural tracers.

The visual recognition of particle dispersion phenomena, transported by waters in multispectral images at the orbital level , was carried out with the help of paper copies and transparencies at scale of 1:1.000.000. The visual pattern identification control was based on the

Reflex Step Wedge (Agfa-Gevaert, constant 0.10) and a densitometer Macbeth T-504, a few themes being prepared with the help of the scanning microdensitometer Datacolor-720 (Spatial Data). For some details CCT tapes were processed taking advantage of the resources of the interactive analysing system IMAGE-100 (G.E.) using special algorithms and a series of pre-processing programs integrated to the associated computer PDP 11/45.

All the organized themes through this procedure are absolutely corretable with the environmental variables collected almost simultaneously, the hydrometeorological data in particular. The correlation product is identified with data obtained indirectly by numerical modelling (Herz & Amaral, 1976; Brebbia, 1975).

The different suspended material concentration patterns are closely linked to the optical properties already discussed by Ritchie et al. (1976) and Lankes (1970).

## 4. SPATIAL AND TEMPORAL VARIATIONS IDENTIFIED ON THE ORBITAL IMAGES

Until present, scarce information has been produced concerning the lagoon and coastal processes related to the coast of Rio Grande do Sul, with the assistance of director measurements methods. Having in view the extension of the region, the problem of the lagoon surface water circulation has not been dealt with, widely, excepting a few particular data.

The available research work in sedimentology has however demostrated a few important factors in the interpretation of transport trends of particulate matter, starting with the recognition of the distribution patterns of the bottom sediments (Martins, 1963; Martins & Gamernann, 1967; Martins, 1971; Villwock, 1972; Villwock & Martins, 1972; Villwock et al., 1972; Villwock, 1977).

The temporal/spatial variations of the dispersion processes of suspended matter, detected by the multispectral images, revealed a great consistency with the distribution of the waters and atmosphere physical parameters. Owing to the Patos Lagoon moderate bathymetry (maximum depth 8 m, average 5 m), these hydrometeorological factors seem to influence greatly the circulation processes, which are also conditioned by the shape of the lagoon basin itself, a fact that was checked by the presence of holocenic structures observed on the lagoon shores (Jost & Herz, 1975 and Herz, 1977).

The three analysed episodes belong to high fluviometric levels periods, due to the predominance of rains, which marked the year of 1973 with very heavy precipitations during the winter all over the region, and consequent heavy concentrations of suspended matter in the Jacuī/Taquari river-basins of steeper gradient slope (Figure 2).

From the LANDSAT overflight of June 26th of the same year (orbit 237, points 33 to 35) it was possible to carry out a first appraisal of the MSS product used for the systematical observation of coastal processes.

It was found, in this case, that the trends of surface water circulation, under the influence of the flood tide and moderate southerly winds, have a tendency, inside the lagoon, at distributing themselves in cellular clockwise eddies, a hindering effect caused by saline intrusions in the lagoon due to the pilling up of the waters in the Northeast direction (Herz, 1975). In the south-western extremity of this basin (Figure 5) there is no difficulty in identifying the rather dark contrasts caused by the presence of marine waters in the estuarine zone of the lagoon. These waters, which are sufficiently transparent, show some light gray streaks that correspond to the lagoon waters contaminated by high concentrations of suspended matter, its turbidity depth being 0.1 to 0.3 m (measured by Secchi disc) (Herz et al., 1979).

This situation can be examined with the help of hydrometeorological support data as we can see in the Figures 6 and 7; the wind action being perfectly evident in the three synoptic periods prior to the taking each image sequence, the fluviograms and the tide levels show its effects in the São Gonçalo channel with the corresponding uprise of the water level (+ 110 cm), with a change in the circulation, from flood to neap tide (Herz, 1977).

In the second case, which deals with the multispectral image analysis of camera S-19)A, of SKYLAB SL-4 mission gathered in September, 1st, 1973, in orbit 21, the mapped patterns were discriminated more outstandingly, not only due to the greater resolution power of the sensors (28 m), in relation to the MSS scanner (80 m), but also due to the great stability of atmospheric conditions, existing at that time over the region (50% relative moisture and $10^{o}$C temperature).

In Figure 7, from the vector distribution obtained by interpolation of the directions and wind speed values, it was found that the surface dynamics could be considered calm, in contrast with the usual wind gusts of 0.2 m/s. This fact is of the utmost importance, since it distinghishes a completely different situation from the first mentioned, and it can be said that the resulting water circulation inside the Patos Lagoon is a consequence of the effects of gravity run off and seiche phenomena, basin shape and level oscillations due to astronomical tides (Figure 6).

The trends structure marked by the natural tracers which are discharged into the Guaĩba estuary does not propose, in the interpretation, any cellular eddies, but instead, one of a gradual run off in the direction northeast-southwestern which follows along the spits and points of the lagoon shores, where a more intensive flux is observed on the occidental margin, where the depth is more accentuated.

The water level variations were measured at the point of Itapuã (Guaĩba estuary) during a period of marked atmospheric stability and their multiple periodicity are explained by seiches movements.

However, completing a cicle between 24 and 25 hours (Instituto de Pesquisas Hidrãulicas - IPH), can be associated to the hypothesis of Azevedo (1945), who calculated, in simplified form, a period of longitudinal oscillations for the lagoon, in a little over 24 hours. This could explain the existence of intermittent arcs of sediment concentration with alternating contrasts, caused by the discontinuous flow of the waters into the Guaíba estuary, which rises the water level about 20 cm, at each period of a lagoon surface oscillation, starting probably from the triggering effect of the tides.

For the third case the overflight LANDSAT of September 24, 1973 (Figure 3) recorded one more episode of strong winds from the northeast (Figure 7) and a large overflow in the basins of the Patos hydrographic complex (Figure 6), defining circulation patterns together with high intensity surface currents in a northeast-southwest direction, pilling up a large volume of fresh water over the estuarine zone of the lagoon, there having no signs whatsoever of the cellular circulation interpreted in the previously described photomosaics. In the São Gonçalo channel the water level went through + 1.60 m from flood to neap tide.

The water accumulation on the Rio Grande channel promotes a very strong flow of the lesser dense waters over the coastal waters, which are similarly influenced by the same surface squalls (Figure 5), the dilution and dispersion of suspended matter being spread in a anti-clockwise eddy of about 80 Km to the south, in addition to the concentrated stream which flowed offshore along the piers of the mentioned channel.

## 5. CONCLUSION

The results of the interpretation here presented were developed during the researches carried out for the Project Rio Grande do Sul (CNPq-INPE/IOUSP), which had the objective of finding a methodology of application of LANDSAT images to the study of coastal processes.

From the preliminary qualitative phase, it is now being attempted, through the integration of institutions belonging to the area itself, to carry out a survey of the waters physical data, having in view a future correlation in the quantitative phase, which is already being carried on (Herz et al., 1979).

It was however demonstrated (Herz, 1977) that the information gathered by orbital multispectral sensors are indispensable for the quasi-synoptic observation of dynamical processes, presenting great variability in time and space.

Regions like the one focused in this investigation, present problem that hardly could be precisely surveyied by conventional methods of measurements "in situ", and in the particular case of the Patos Lagoon there would be great difficulties in surveying, at short term, its 10.360 $Km^2$, and, moreover, observe sucessfully its possible interactions with the coastal waters.

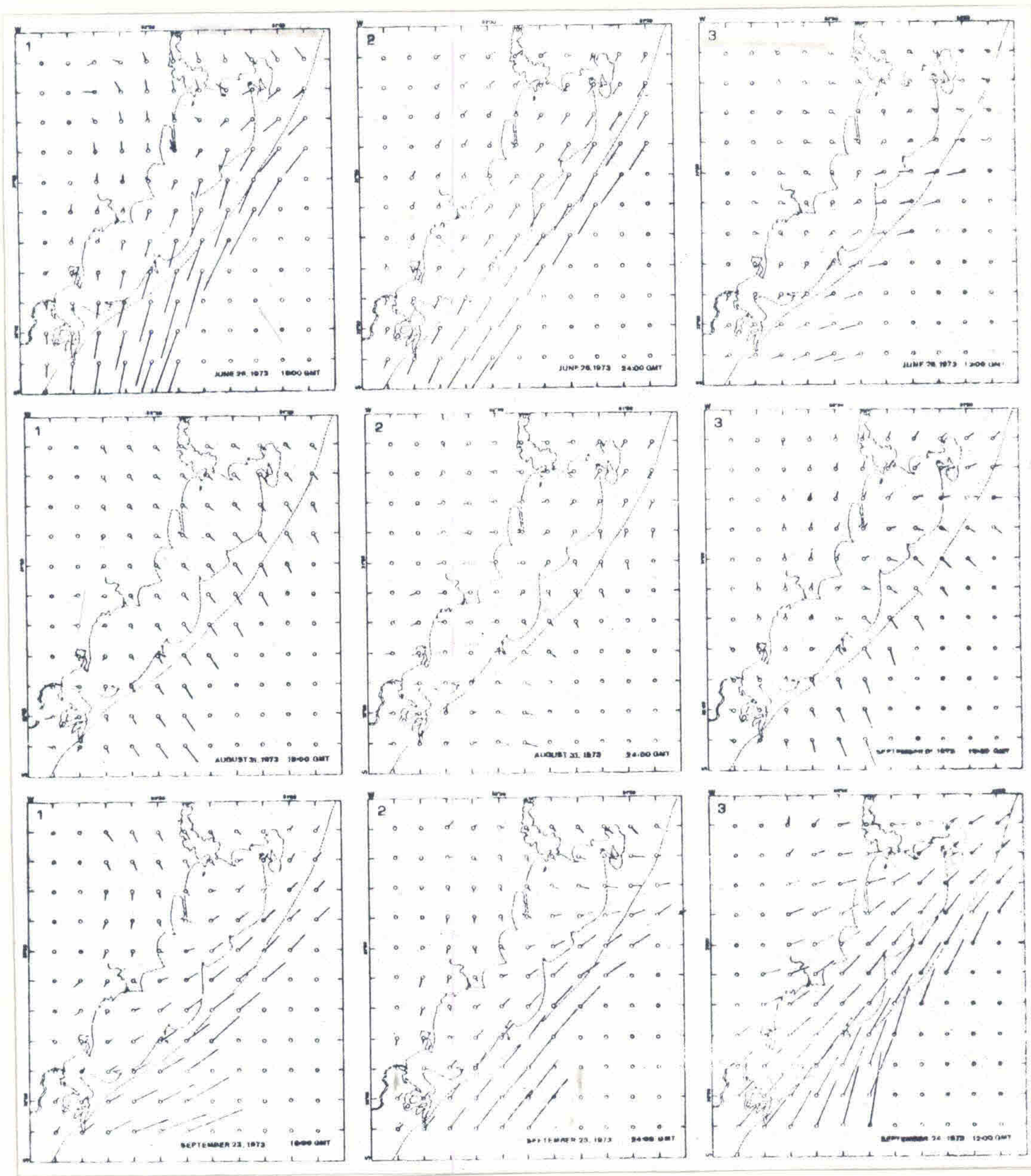


Fig. 1 - Surface Winds

(Geographic distribution of winds over Patos lagoon surface in Rio Grande do Sul Coastal Plain)

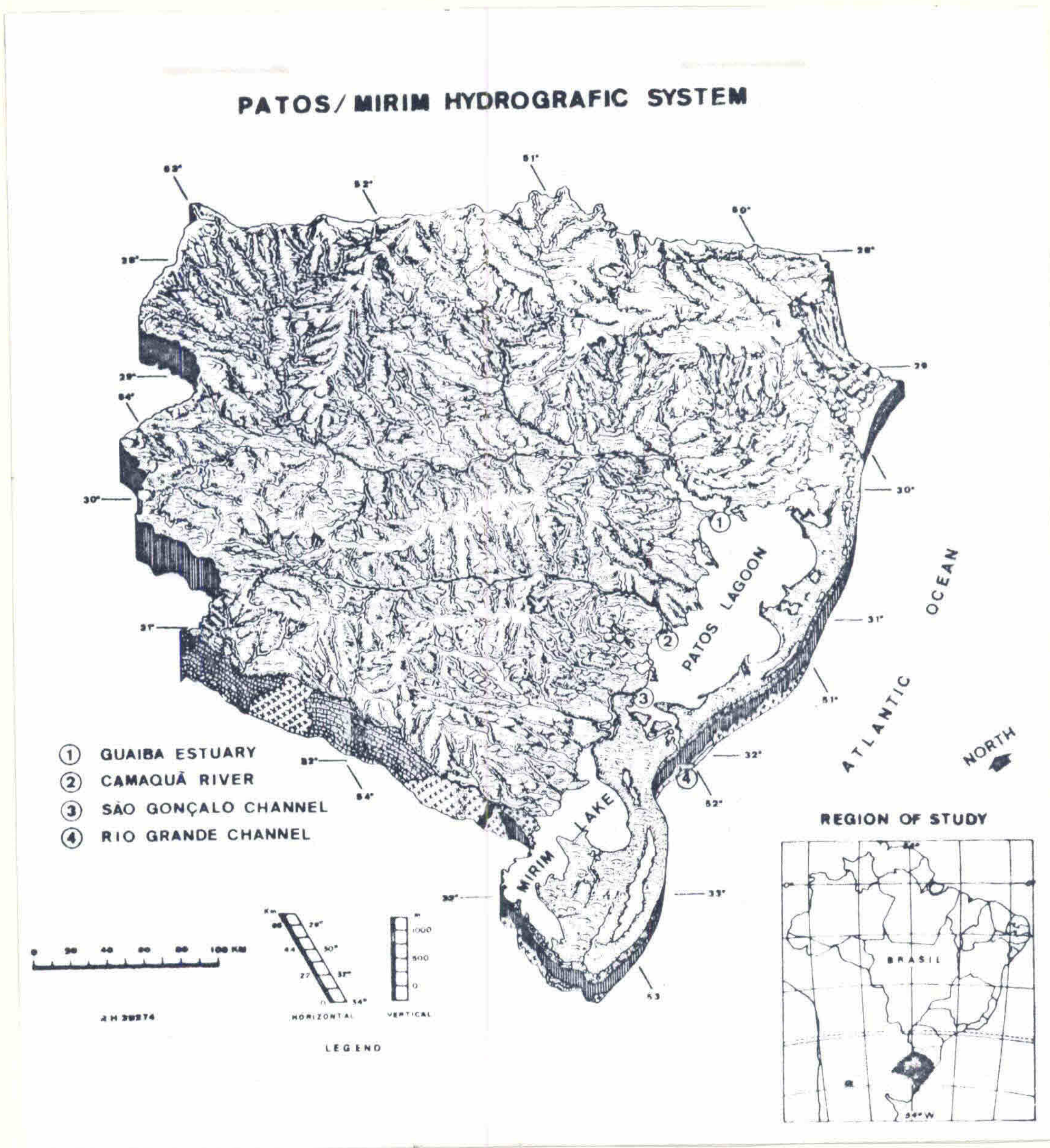



Fig. 2 - Region of Study

(Isometric projection of Patos-Mirim hydrographic system. In this partial view of the region Jacuí/Taquari rivers (79.770 Km2) are the main hydrographic basin of Patos complex)

Fig. 3 - SKYLAB and LANDSAT Information

(Circulation patterns deduced from a SKYLAB 1:300.000 photomosaic (left)(September 1, 1973) LANDSAT information from August 18, 1975 (right), showing a dry season situation with saline intrusion inside the lagoon)

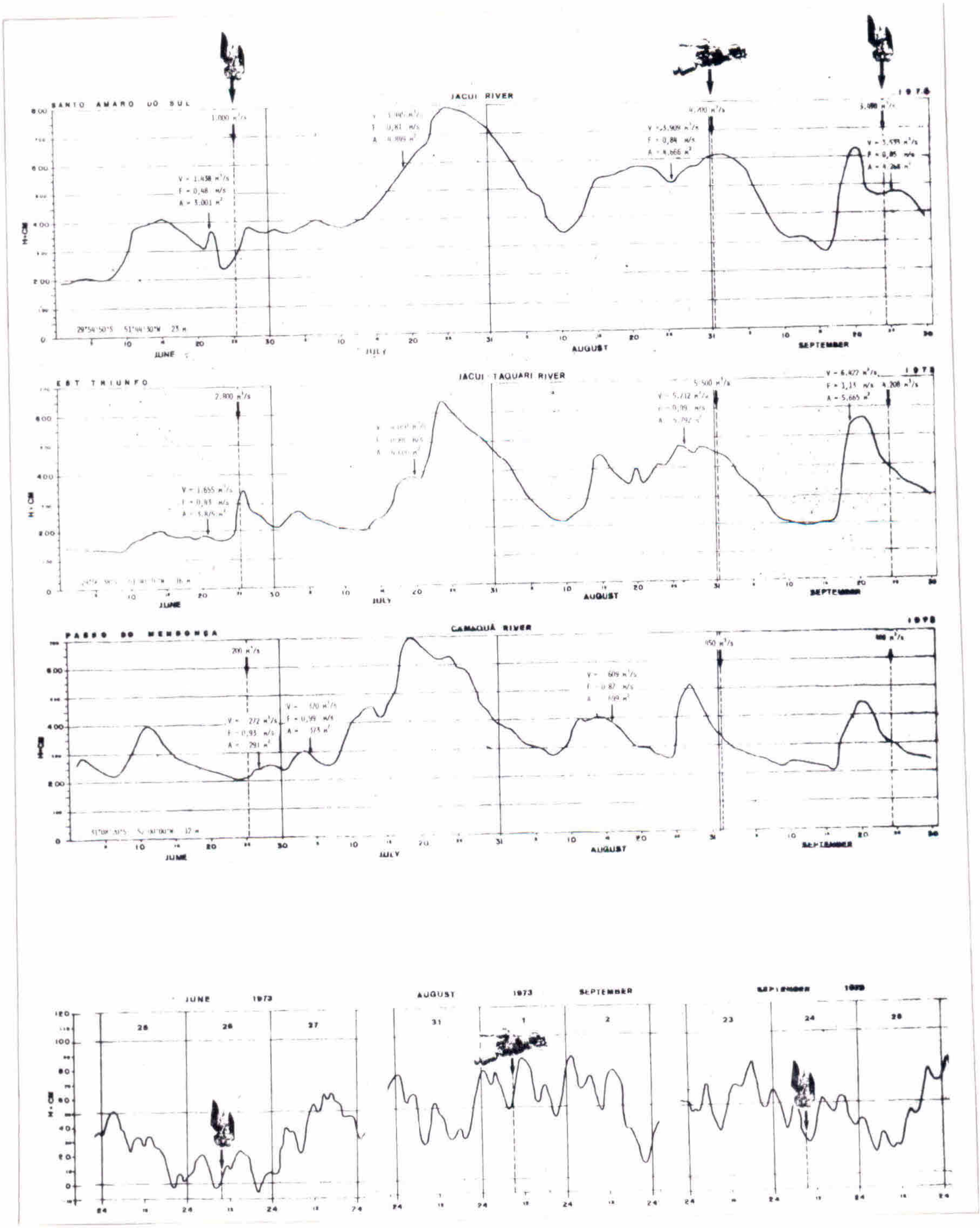



Fig. 4 - Fluviometric Levels and Tide Levels

(Fluviometric curves from Jacuí/Taquari and Camaquã rivers covering the period of LANDSAT and SKYLAB overpasses; tide levels variation in June 26, 1973; September, 1 and September 24, 1973 in Rio Grande channel)

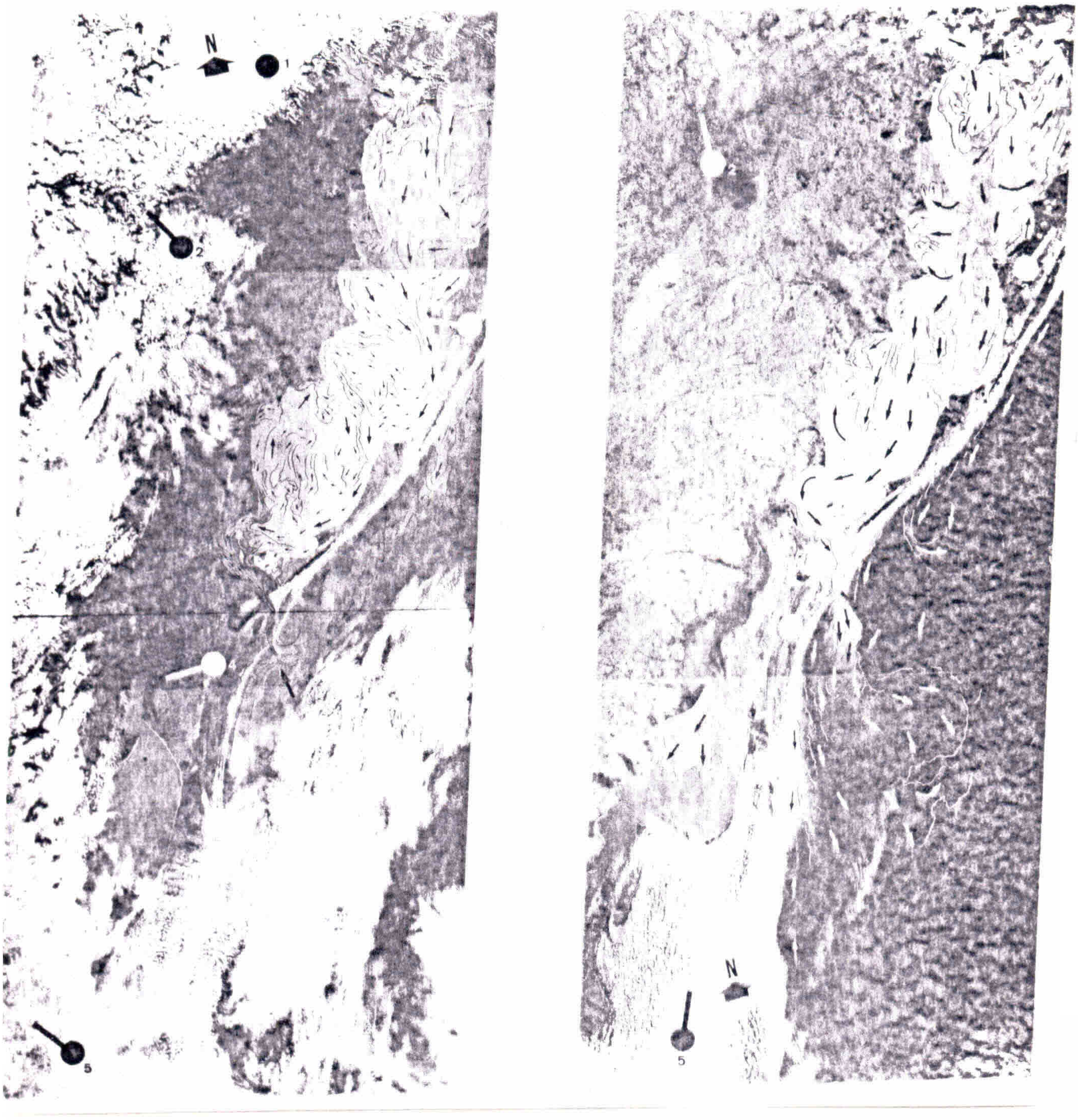
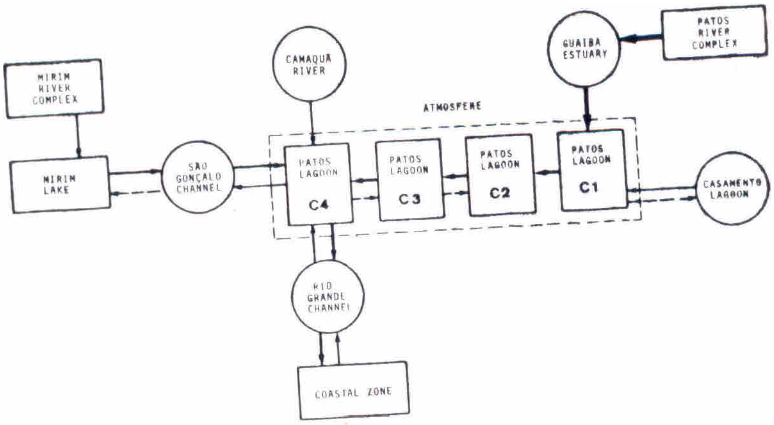



Fig. 5 - LANDSAT MSS-5 Images

(Photomosaic of MSS images June, 26 (left) and September, 24 (right) showing circulation patterns in Patos lagoon and coastal zone in 1973)



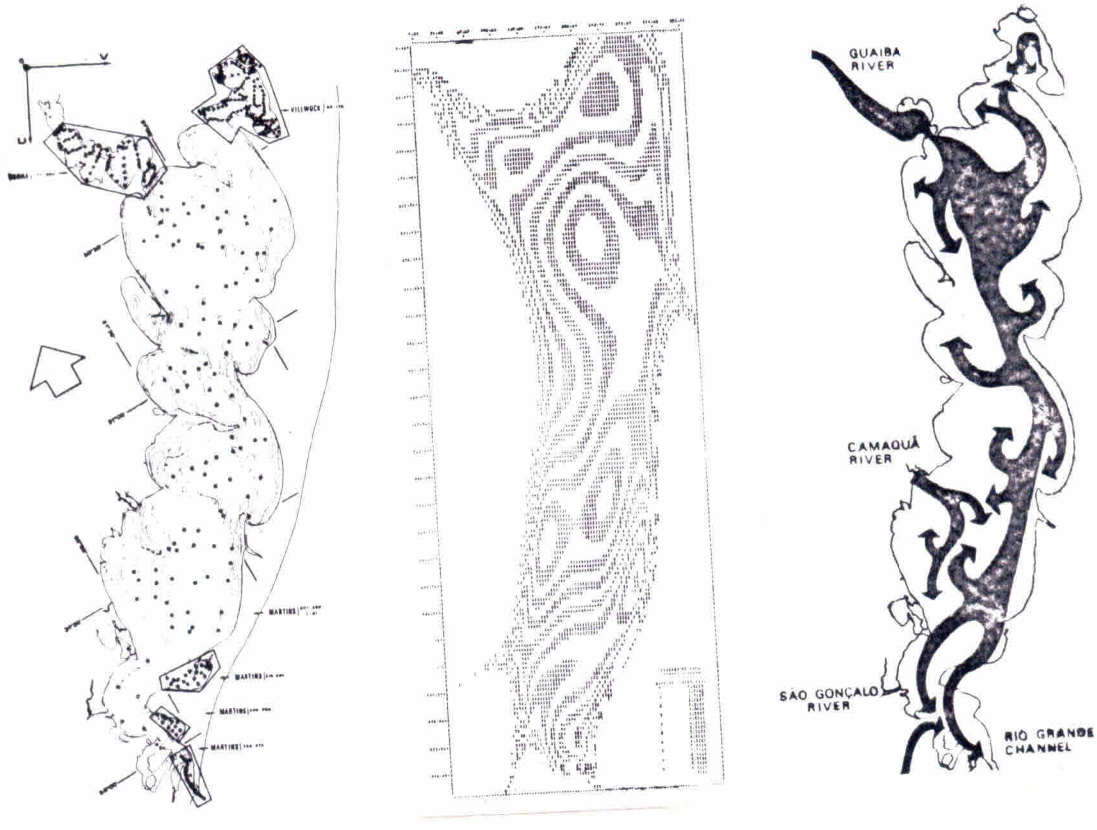




Fig. 6 - General Circulation Model

(Figurative esqueme of the hydrographic system (above). Bottom sediment samples in Patos lagoon and the proposition of a general circulation model from correlation of trend surface analysis and image

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