PN-ABI-233

APPLICATION OF SATELLITE IMAGERY TO MANAGEMENT OF COASTAL FISHERY RESOURCES FOR PERU AND ECUADOR

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Washington, D.C.
August 1985

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1. Objective

The Agency for International Development(AID) has ongoing programs to increase the effectiveness of industry and development in developing countries. This document reports on the AISC response to a request by AID for a feasibility study of the application of satellite imagery to fishery resources off Ecuador and Peru.The Participating Agency Servicing Agreement (PASA) is BOF-0000-P-CC-3062-02 which has been in effect beginning 31 December 1983.

Satellite imagery is a logical approach to evaluation of regional resources in the marine environment where local data are expensive to acquire and limited in time or space. The region off Ecuador and Peru from the Gulf of Guayaquil to the Chilean border is the same linear distance as from Miami, Florida, to Cape Cod, Massachusetts . Coverage of such a region in detail using only surface platforms is an impossible task. Satellite imagery interpreted with the aid of selected ground truth and models is a viable alternative.

The Marine Environmental Assessment Division elected to examine satellite imagery from 1985 to evaluate the feasibility of using such imagery for monitoring and developing coastal marine resources in Ecuador and Peru.

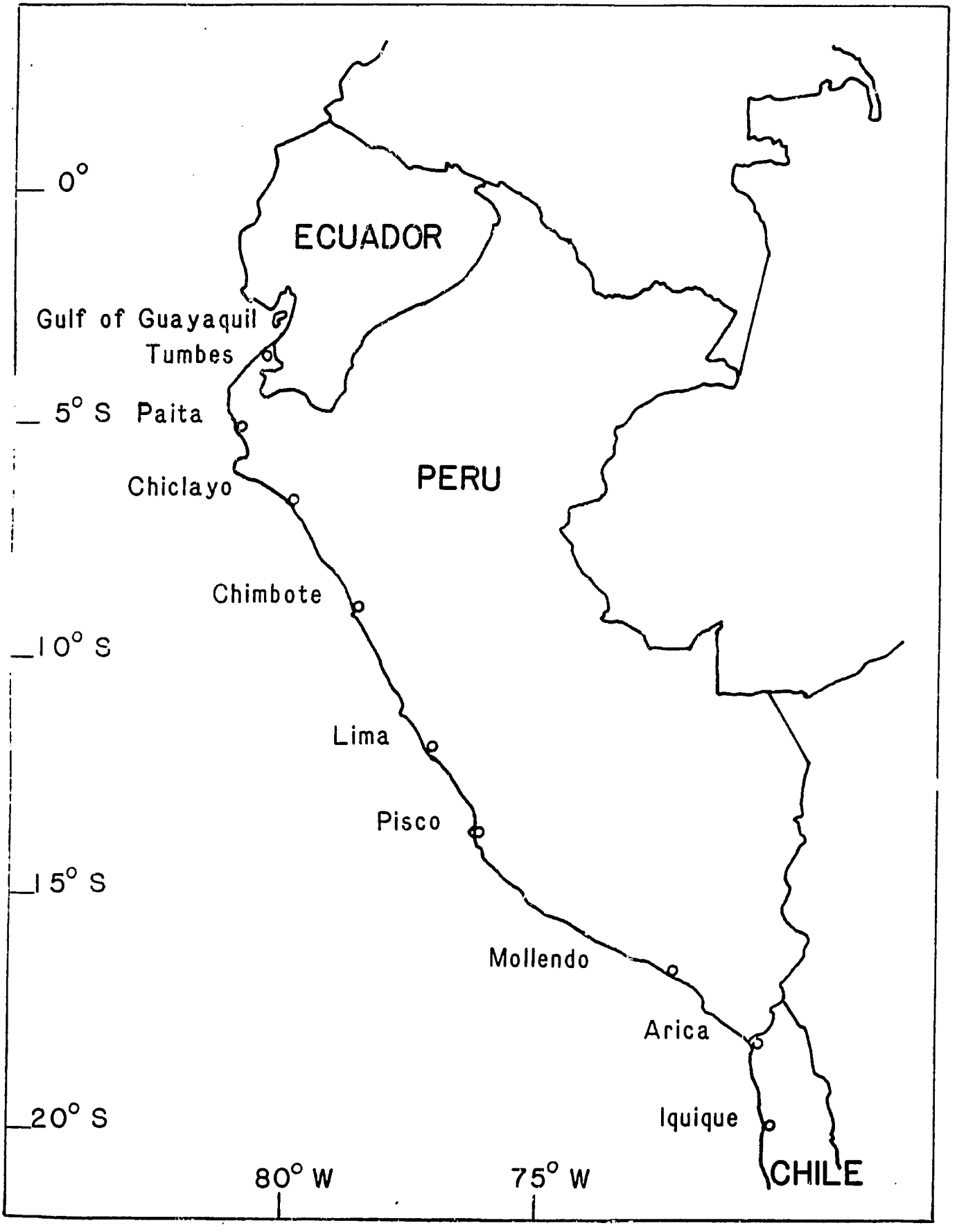
2. Background

The region off the coast of Peru and Ecuador (Figure 1) is a region of intense upwelling and like all such regions is extremely rich in fish populations. The Peruvian upwelling ecosystem has been especially productive of the small fish, anchoveta. The distribution of this species is highly dependent upon the temperature distribution of the offshore waters since the anchovy feeds preferentially on the phytoplankton associated with the rich upwelled water immediately off the coast. Development and monitoring of the natural resource of this ecosystem requires understanding of the dynamics of the environment, knowledge of the life cycles of the species in the ecosystem, and a method for identifying with some precision the critical upwelling regions for both harvest and control.

2.1 The Oceanography

Although the dynamical theory of the region is still incompletely understood, an excellent description can be given of the observational data for the coastal current regime off Peru and Ecuador. The system comprises four distinct current structures. Two surface currents are present, each flowing northward toward the equator. The larger of these is the Humboldt current which expands and recedes seasonally. The Humboldt Current flows from the Circumpolar current north along the coast being narrower during the months of December through May and broadening considerably during the months of June through October. At all times the flow is broad (100 km or wider) and slow, a kind of gentle drift of fresher and cooler water toward the equatorial region,

Figure 1 - Map of Ecuador/Peru Region



ECUADOR - PERU COASTAL REGION

The Peru Coastal Current must be distinguished from the Humboldt Current since a primary constituent of the coastal current is upwelled water from mid-depths to the surface in a very narrow equatorward flow immediately next to the coast. The Peru Coastal Current remains mostly less than 50 km wide immediately adjacent to the coast and provides the coldest surface water temperatures of the area.

Beneath the two surface currents flow two poleward currents. The larger of these, the Peru Countercurrent flows beneath the Humboldt Current and the Peru Coastal Current, occasionally surfacing between the two surface currents. The smaller is the Peru Undercurrent which flows along the bottom beneath the Peru Coastal Current adjacent to the coast. This undercurrent is of the type usually associated with upwelling along the west coasts of continents.

Aperiodically the general atmospheric circulation is perturbed and produces in turn a transequatorial eastward flow at the surface of the Pacific. This flow in turn creates a flooding of the surface waters off Peru and Ecuador with higher-than-normal water temperatures, suppressing the upwelling of the Peru Coastal Current. The phenomenon is known as El Nino. Records exist for seventy-seven El Nino events since 1726, an average of one every three years or so. Certain of these events have proven catastrophic in intensity, including the 1940-41, 1957-58, 1972-73, and most recently, 1982-83 events. The El Nino events affect the anchoveta and other species of the region, as well as marine birds and coastal shrimp fisheries and mariculture. Several authors have given comprehensive reviews of the phenomenon or of specific El Nino events (Rasmussen,1985;...). The present study will not address the El Nino phenomenon as a specific problem. Rather, we will examine the use of satellite imagery for environmental information in general, assuming that most of the use will be during normal periods. Any intrusion of equatorial waters will of course also be detectable through the use of the imagery, but those times represent only the crisis periods for the fishery management problem.

In other years the Peru Coastal Current may intensify as in 1950 (Figure 2) and flood the ocean coastal surface area with colder-than-normal water. At these times the conditions may be exceptionally beneficial for anchoveta spawning and growth. Detection of such episodes could be valuable for fishery management decisions for harvest areas or amounts.

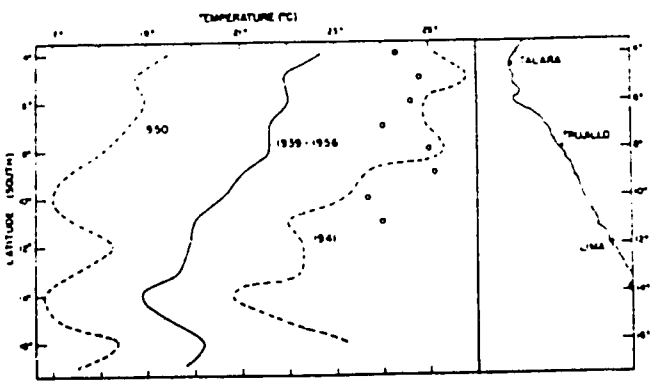


Figure 2 - Coastal Sea Surface Temperature for Ecuador/Peru Region

Scientists have documented that the maximum values of productivity in the region are immediately adjacent to the coast(Guillen,1973). This region of the ocean is among the most productive regions of the world with primary productivity values well in excess of 100mg C/mg Chlorophyll-a/day. Guillen, Rojas de Mendiola, and Rondan(1973) have reported surface production values exceeding 700mg C/square meter/day associated with the strongest upwelling.

Guillen and Rondan(1973) further documented the chlorophyll-a concentrations appeared in pockets along the coast, four cells being evident in their data which exceeded 4.0ug/L of chlorophyll. They noted the highest values of chlorophyll-a corresponded with the prime fishing grounds. Rojas de Mendiola and N.Ochoa(1973) further support the evidence with documentation of the anchovy feeding preferences. Primary diet for the anchovies of their survey appeared to be the cool water plankton Chatoceros species and Schroderella delicatula. The findings of some specimens with Thalassiothrix Schroderella delicatula. The findings of some specimens with Thalassiothrix longissima and Planktoniella sp.in their stomachs is explained through the intrusion of surface oceanic waters close to shore with a thickness of at least 80 meters.

The problem in application of the satellite imagery to the problem of fishery development and conservation would then be to define the areas of intense population of the anchovy through imagery of either temperature or turbidity(chlorophyll-a).

2.2 The Fishery

Although the coastal upwelling system provides habitat to several species of marketable fish, only after 1954 did the nations in the area begin to capitalize on the natural resource potential of the marine environment. Beginning in that year Peru built a fishing fleet designed to harvest the anchoveta. During the next ten years their fishing fleet of purse seiners increased more than tenfold. Concurrently the catch increased from 43,000 metric tons in 1954 to a record 12,227,000 metric tons in 1970. From 1966 through 1971 the Peruvian anchoveta stock supported a catch of more than 10,000,000 metric tons each year (Table 1).

Table 1. Peruvian Anchoveta Catch 1951-1983
(Million Metric Tons)

Year	Catch	Year	Catch	Year	Catch	Year	Catch
1951	7.4	1961	5010.9	1971	10276.8	1981	1225.2
1952	15.7	1962	6691.5	1972	4447.8	1982	1725.7
1953	37.2	1963	6634.8	1973	1513.0	1983	118.2
1954	43.1	1964	8863.4	1974	3583.5		
1955	58.8	1965	7242.4	1975	3078.8		
1956	118.9	1966	8529.8	1976	3863.0		
1957	325.6	1967	9824.6	1977	792.1		
1958	737.0	1968	10262.7	1978	1156.6		
1959	1942.4	1969	8960.5	1979	1362.8		
1960	3310.2	1970	12277.0	1980	720.1		

In 1972 the fishery catch was reduced to only 40 percent of previous years due to overfishing, and the remaining fishery stock was estimated to have been only 2,000,000 tons. After 1972 although catches remained in the range of 1.5 to 3.5 million tons, recruitment was very much reduced, and by 1977, a minor El Nino year, the harvest was less than a million tons ofanchoveta. Cushing (1981) points out that a spawning stock of less than 5 million metric tons appears to result in reduced recruitment and that despite a short-lived recovery to 10 million tons or more in total stock in spring of 1975, the continued large harvesting, combined with smaller recruitment in El Nino years, reduced spawning stock to no more than 3 million tons in early 1977.

Catches and stocks have continued to decline. In the most recent years prior to 1983, annual catches were less than a million tons of anchoveta. The 1982-83 El Nino event reduced catches even more disastrously than prior events. Peruvian maritime fish catch (all species) declined 58 percent between 1982 and 1983, falling from 3.5 million metric tons to 1.45 million metric tons. The anchoveta landings declined 93.2 percent between the two years from 1,726,000 metric tons in 1982 to only 118,000 metric tons in 1983. This figure is less than one percent of the record catches of 1970, a truly devastating decline for what was once the largest single fishery in the world and which represented fully one-fifth of the total world's fish catch by weight.

Changes have been taking place with other species, however. With the intrusion of warmer waters during El Nino events, warm water species such as mackerel become available to the fishermen. And the decline in the anchoveta population of the coastal current ecosystem has seen an increase in the population of the sardine. Catches of sardines during the years prior to 1973 averaged 6000 metric tons per year. Since then the catch has grown steadily until 1982 yielded 1.4 million metric tons. The sardine fishery was not as severely affected by the El Nino. Catches declined only 30 percent following the severe 1982-83 event.

2.3 The Economic Impact

The recent history of the economic situation in Peru and Ecuador is intimately tied to the coastal marine environment and its resources. The region is one of the few areas in the world naturally suited to the culture of shrimp, and the nearshore dynamics provide the habitat for the valuable anchoveta.

The Peru fishmeal industry is a classic example of primary export industry leading to growth in the country with backward linkages directly stimulating other Peruvian industry. Following a change in policy of the Peruvian government toward the export sector in 1950, the economy performed vigorously through the next twenty years. In 1950 the agriculture and fishing industries in Peru produced 23 percent of the gross national product (GNP) and employed 59 percent of the labor force. By 1967 this same sector produced only 18 percent of the GNP and employed 50 percent of the labor. The fishery portion of the total however grew from 0.2 percent of GNP in 1950 to 2.1 percent in 1967. As a fraction of export value in 1950, fish and fish products accounted for 2.9 percent of total export value, while by

1967 these products brought in 27 percent of the total exports, the single largest share of all commodities.

The fishmeal market, although enormously beneficial to Peru and having expanded during the 1960s, is small ($418 million) compared to the other major agricultural commodity markets (wheat-$4500 million; coffee-$2500 million; cotton-$2500 million). However, fishmeal is a protein-rich ration for hogs and chickens and is used for nutrition as well as a growth stimulating factor which saves time and cost prior to marketing the poultry and livestock.

As the industry grew and the agriculturally advanced nations purchased their production, Peru contributed more than 60 percent of the world market in fishmeal in the late 1960s, benefiting commensurately from higher and higher fishmeal prices. Fishmeal processing plants were built along the coast and boat building industries flourished. By 1970 more than 2000 bnoats were seining for anchoveta in the coastal waters off Peru.

Scientific agencies at that time were beginning to express concern for overfishing, but fishery and environmental statistics were not sufficient to make convincing demonstrations of overfishing. As early as 1970, however, Roemer(1970) expressed the opinion that economic arguments did impy strongly that overfishing had been occurring.

Following a high mortality of anchoveta young in 1971 and 1972, the El Nino of 1972-73 produced disastrous declines in the anchoveta catch (Cushman,1981). This decline has continued to the present and brought ruin to much of the related industry and contributed to enormously increased prices on the world commodity markets. During the height of the guano industry success, Peru exported more than 200,000 tons of guano each year. Following the competition for the anchoveta between the fishermen and the birds, and with the indirect effect of poor recruitment following strong El Nino events, the bird population declined drastically. Guano exports in 1982 were only 15,364 tons, a figure lower than in 1909, seventy-three years earlier. More than 2,000 purse seiners operated in the coastal areas during the peak years of anchoveta harvest; in 1983 there were only 249 operable and empty holds were common following cruises. In 1968 up to 120 fishmeal processing plants were operating along the coast of Peru; in 1982 this number had declined to 36, of which 30 were closed the next year following the 1982-83 El Nino.

The indirect effect of the failure of the anchoveta fishery can be seen in prices of Figure 3. The prices of fishmeal, soybean meal, and pork all have been affected by the catch of anchoveta. The prices of the end product (hogs) has a multiplier of 10 compared to the prices at the primary commodity level and appear to lag the feed prices by about two years.

While the fishmeal industry is salient when considering economic benefits of the Peru/Ecuador coastal marine resources, the shrimp industry is also important. Shrimp and other fish products are second only to petroleum in Ecuador's export list. The shrimp industry accounted for nine percent of all Ecuador exports in 1983. That country is second only to Mexico in world volume of shrimp exports.

ANCHOVETA CATCH AND WORLD COMMODITY PRICES

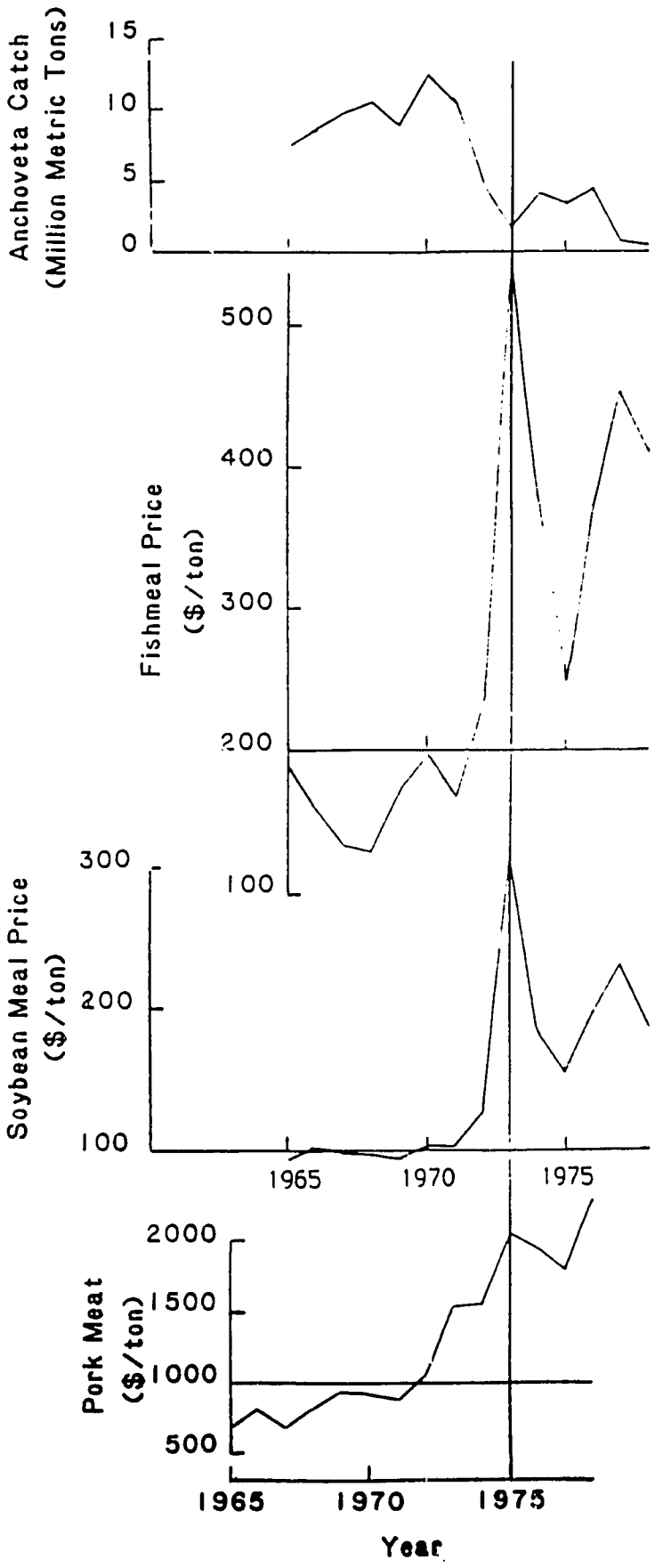


Figure 3 - Anchovy Catch and World Commodity Prices

Altogether the marine resources of Peru and Ecuador probably can provide at least $500 million dollars of foreign exchange each year to those countries with proper resource development and management.

3. Satellite Datasets

Satellite imagery are available from the NOAA-n series of satellites which offer data from the Advanced Very High Resolution Radiometer(AVHRR). This sensor allows calculation of radiance data in five spectral bands (Table 2). Sea surface temperature is computed using established equa-

Table 2. NOAA-9 Advanced Very High Resolution Radiometer Spectral Bands

CHANNEL	1	2	3	4	5
WAVELENGTH	0.58-0.68	0.72-1.0	3.5-3.9	10.2-11.3	11.4-12.4

tions with channels 3, 4, and 5 from the AVHRR. There are equations available for day or night imagery and corrections apply for atmospheric effects. SST values from this source have absolute accuracy of near 1.0 degree Celsius. Relative accuracy on any particular image is better than 0.5 degrees C.

The NASA Nimbus-7 satellite offers in addition a Coastal Zone Color Scanner which provides direct imagery of chlorophyll and other pigments. The LANDSAT satellite provides extremely high resolution imagery for certain coastal applications but are not applicable to the problem at hand in the open ocean.

NOAA satellite data are interpreted in two forms by National Environmental Satellite Service and available from the Satellite Data Service Division. These two routine products are available for the region of interest. The first is the GLobal Ocean Sea Surface Temperature Computation (GOSSTCOMP). The second is the special preparation for the Equatorial Pacific Ocean Climate Study(EPOCS). The resolution of the GOSSTCOMP temperture maps is only one degree or about 100 km. The detail of the EPOCS product is better but still is only 50 km. Since the coastal current off Peru where the upwelling is intense and where the primary fishery occurs is only on the order of 50 km at its widest, imagery of the coastal waters must be delivered in product which retains the detail of close-in coastal variations. Neither of the SDSD map products fulfills the requirements for monitoring of the Peru Coastal Current fisheries. The SST maps of SDSD are quite useful for evaluating the overall regional effect and extent of the Humboldt current or for possible early detection of El Nino events.

This first study is limited to the exploration of applying NOAA-n AVHRR imagery to the tracking of upwelling zones along the Peruvian coast. We compare the relative usefulness of satellite derived maps from SDSD and the higher resolution AISC color imaging of LAC data for the austral winter period May to August, 1985.

3.1 Description of Satellite Data Availability

NOAA-n series AVHRR data are available from the Satellite Data Services Division of the National Environmental Satellite Data and Information Service (NESDIS) in digital form on magnetic tapes or as maps of sea surface temperature derived from those tapes. Imagery may be Local Area Coverage (LAC) with a pixel resolution of 1.1 km or GLobal Area Coverage(GAC) which has been subsampled from the LAC data and gives resolution of only about 10 km per pixel. The interpreted data for the maps published by SDSD are averaged over the basic digital imagery in larger areas.

MEAD has evaluated data of both digital and interpreted map form for the period of study, May thorugh July 1985.

3.2 Sea Surface Temperature Maps from SDSD

Wrytki (1977) suggested using satellite derived surface temperature maps for analysis and monitoring changes in the large scale thermal features in the Ecuador/Peru region. Through a series of maps redrawn from National Environmental Satellite Service maps he illustrated the progression of the Humboldt Current in its development from January 1975 through July 1976.

MEAD has developed similar illustrations for weekly charts of 1985 (Figures 4 through 8). The earliest map, 16 April 1985, shows mild upwelling off Pisco, Peru. Minimum temperatures shown are 19C. The Humboldt Current is weakly developed carrying water of 22C north of Gulf of Guayaquil. The map of 23 April shows much the same situation.

Data on the maps of 30 April and 07 May begin to show 19C water at Chiclayo and 17C water off Pisco. The Humboldt current has intensified and is carrying 20C water north of Guayaquil, but remains the same width. By 14 May we see 16C water in the main upwelling cell off Pisco. Note the 25C isotherm during this period has remained north of the equator.

Beginning 21 May we see no 25C water in the southern region off Peru, although there is a flow southward out of the Gulf of Panama to 2 S. At this time only 18C water is recorded in the upwelling pockets. By 04 June we obtain 17C water in the upwelling and the southerly flow of warmer water from Panama has extended a further 90 km down the coast. On 11 June we see minimum temperatures of 17C in the upwelling and the Humboldt current has begun to spread at 20 S.

In the middle of June and later the Humboldt Current has begun to develop strongly through the broadening in the southern portion. During this period the maps show only a minimum of 17C water in the upwelling areas close to the coast. Early July water of 15C is shown on the map near

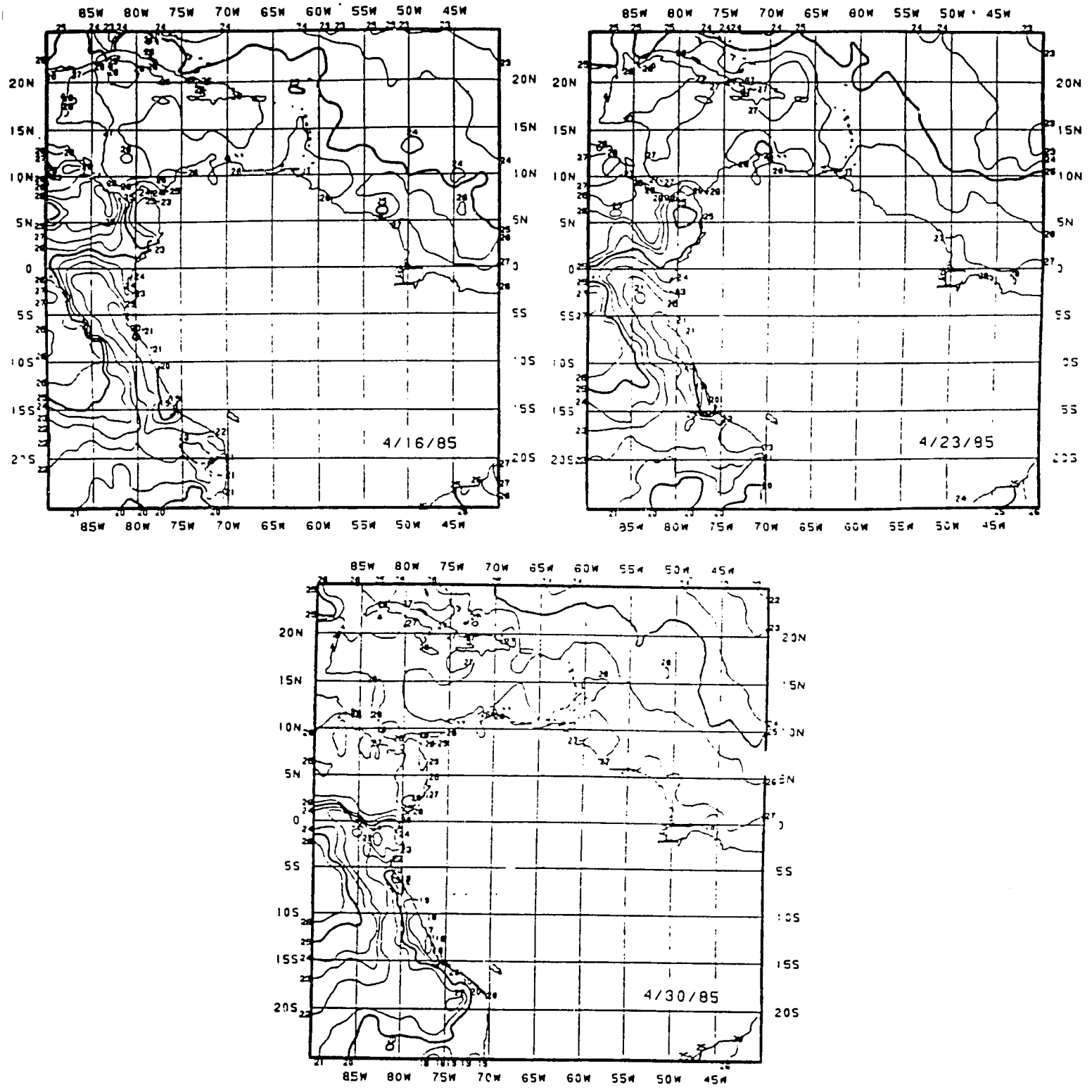


Figure 4 – Sea Surface Temperature(GOSSTCMP), 16 April-30 April 1985

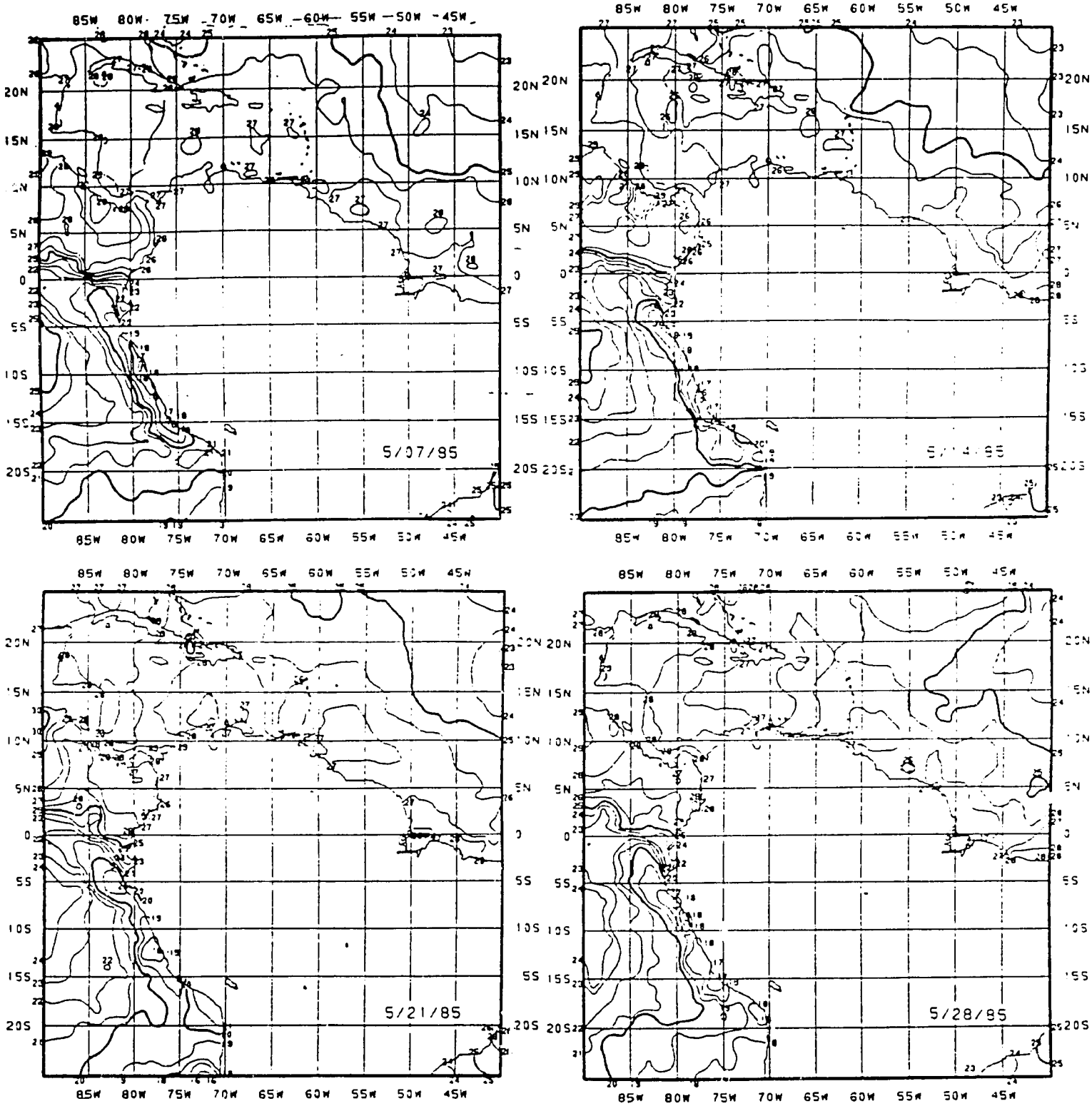


Figure 5 - Sea Surface Temperature(GOSSTCMP), 07 May-28 May 1985

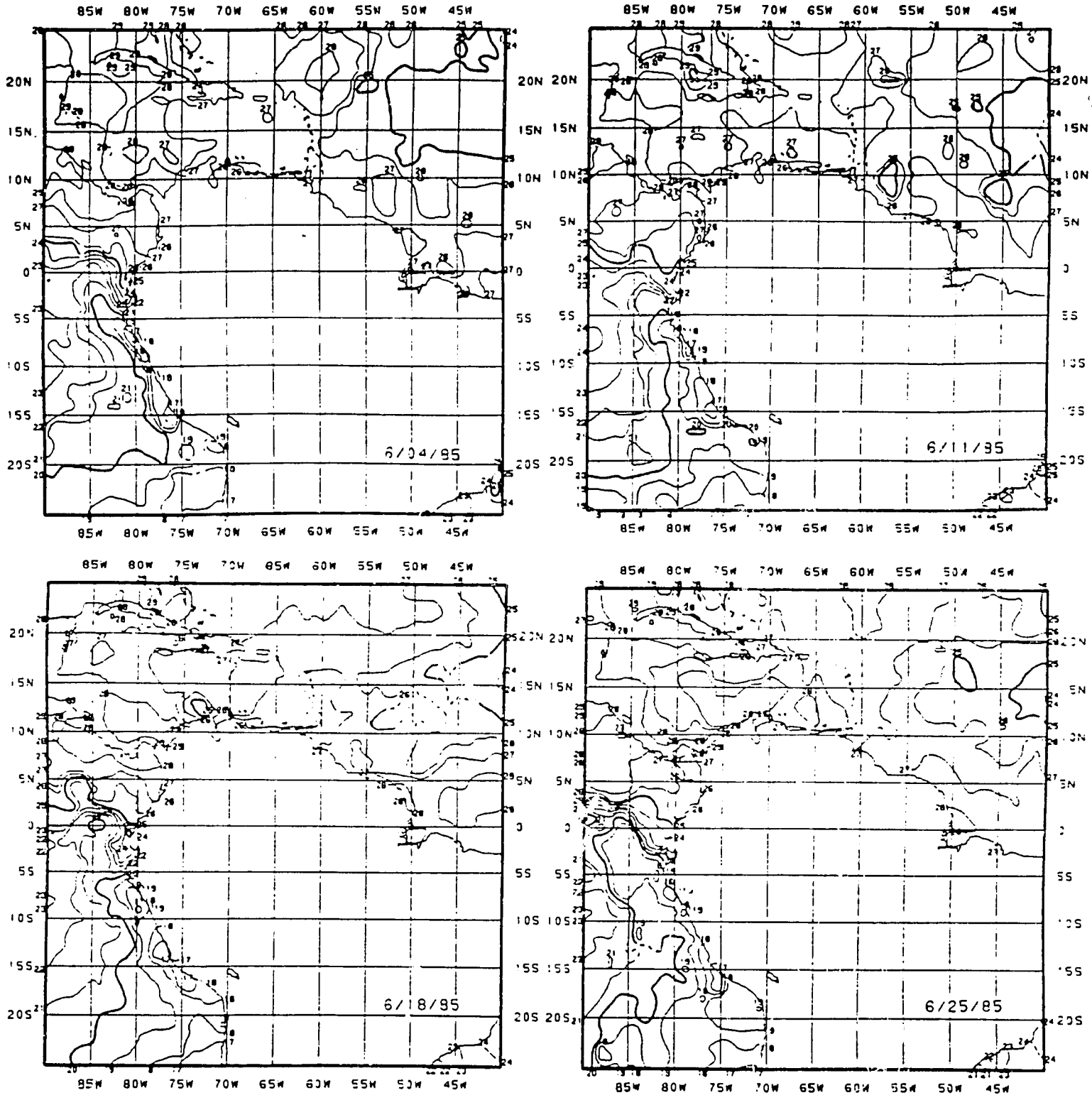


Figure 6 - Sea Surface Temperature(GOSSTCMP), 04 June-25 June 1985

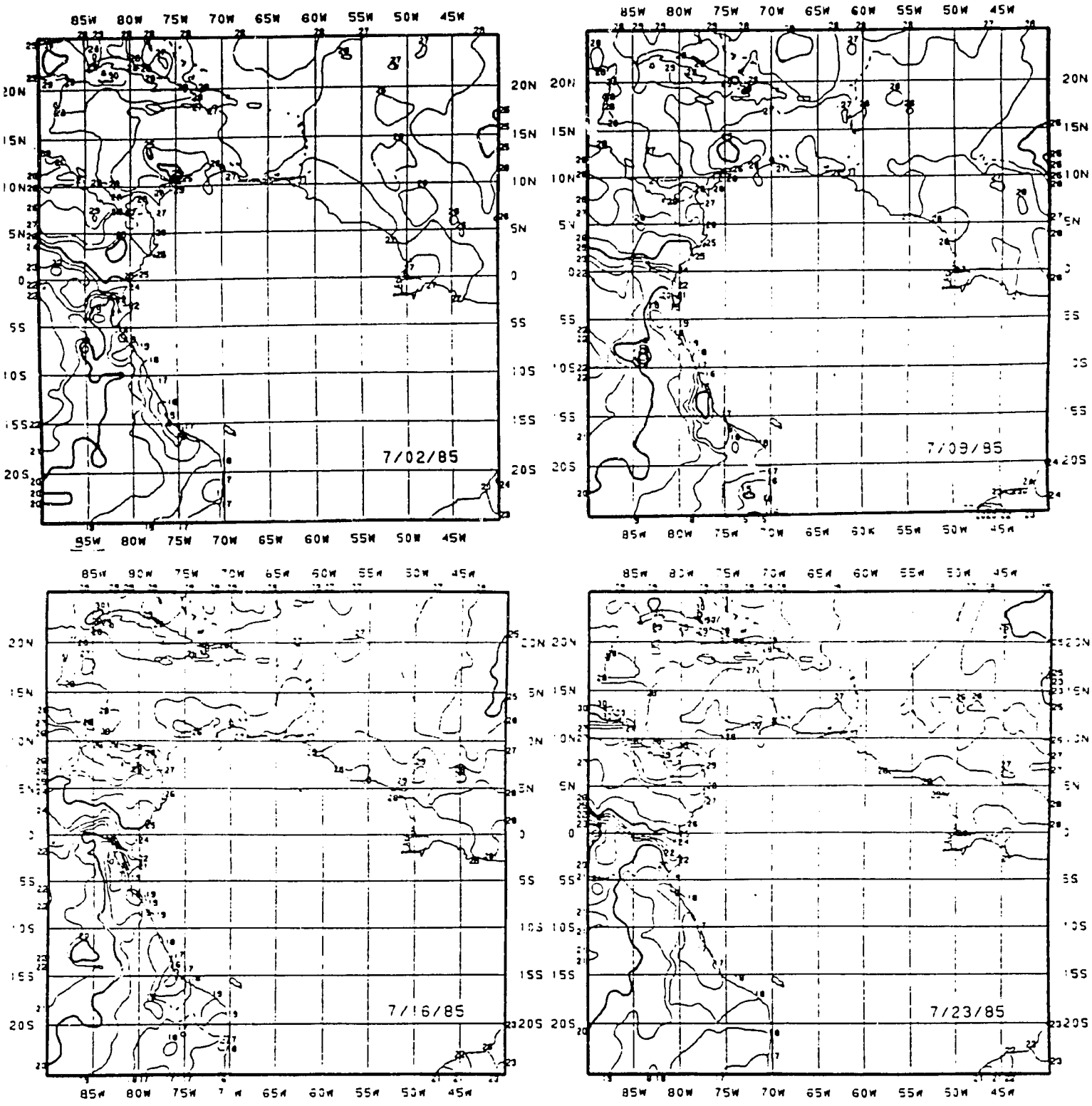


Figure 7 - Sea Surface Temperature(GOSSTCMP), 02 July-23 July 1985

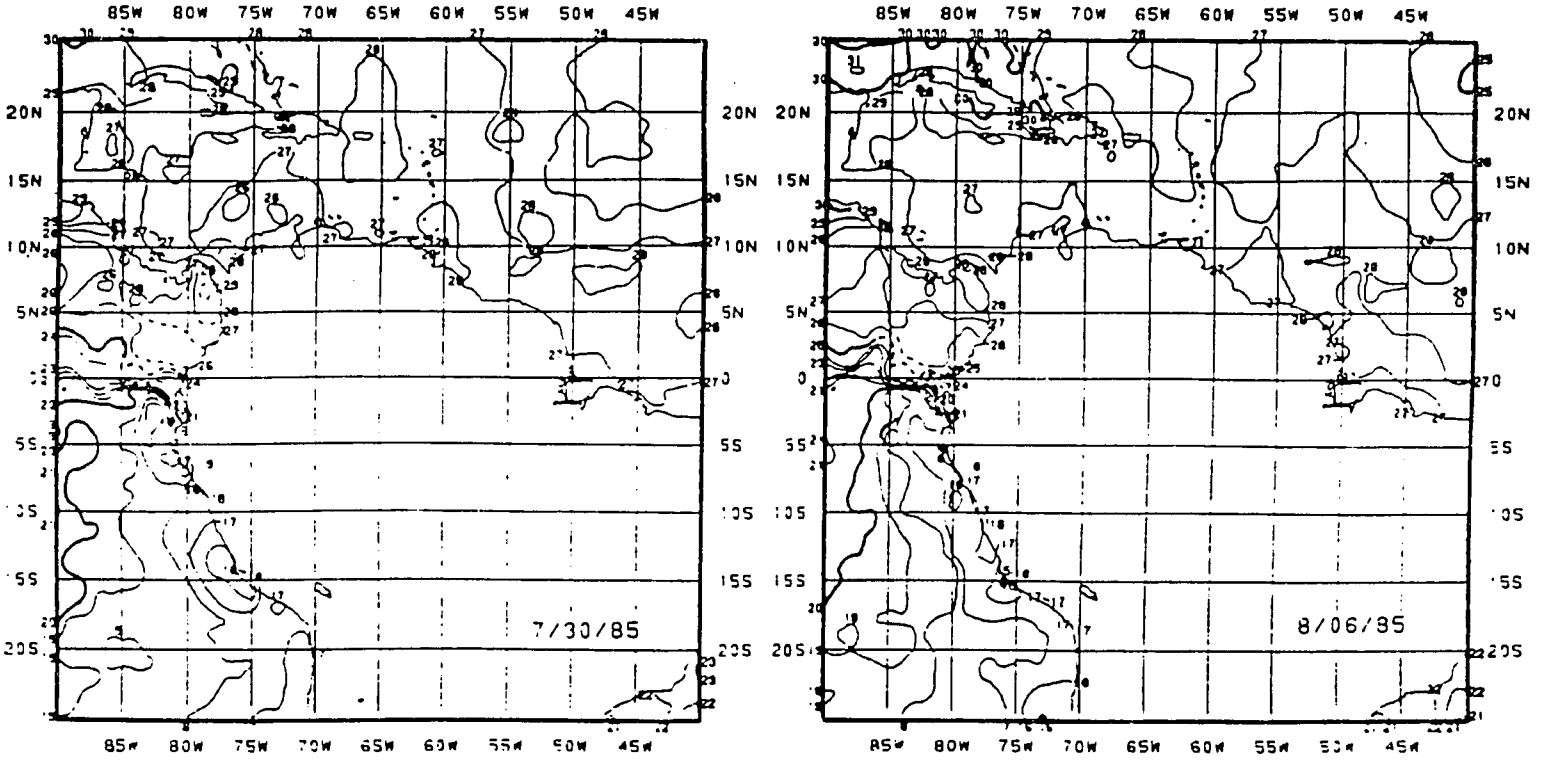


Figure 8 - Sea Surface Temperature(GOSSTCMP), 30 JUly-06 August 1985

Pisco, but this increases to 16C on maps of 09 July and 16 July. The Humboldt Current has reached a width of moe than 500 km. The map for 16 July shows a tongue of upwelling off the mouth of the Gulf of Guayaquil with water of 17C with water of 22C filling the GUlf itself.

The map of 23 July shows upwelling of 17C water. The Humboldt Current is now over 900 km wide at 15 S. During the next two weeks the maps show intensification of upwelling with water of 15C off Pisco in early August. The maps delineate three cells of upwelling - one at Chiclayo, another off Lima, and one below Pisco. The Humboldt Current flow is very clear with the northward drift wider than 1200 km at 15 S.

The obvious limitation to these maps is that isotherm values are averaged over such a large scale that only broad features are discernible. Any small intense upwelling pockets close to the coast are smeared by the averaging process. We now use Local Area Coverage (LAC) imagery to see if we can see the smaller upwelling features suspected to be the major fishery areas.

3.3 Satellite Processing at AISC

AISC has image processing equipment which can utilize NOAA-n data and produce false-color maps of temperature and/or turbidity at high resolution. We first use the channel 2 data to distinguish between water pixels and land pixels. Water absorbs virtually all incident near IR radiation, hence water pixels appear quite dark in channel 2. Soil, vegetation, and clouds reflect some or most near IR radiation and appear very bright in channel 2. Certain types of clouds such as thin cirrus and some cumulus as well as fog or mist may produce brightness radiance measures similar to water. Care must be taken to avoid over-interpreting imagery which may be contaminated with these cloud types.

In order to give the images in this report a more realistic appearance a special masking was used which gives exact water temperatures from the SST algorithms and displays land and cloud masses in white, gray, and black. The land/cloud mask was created using channel 2 data, but scaling the gray tones between white for the cloud areas of maximum brightness and black for the darkest land areas or cloud-contaminated areas.

In all the images we used AVHRR Local Area Coverage (LAC) data. These data have an initial resolution of approximately 1.1 km X 1.1 km at nadir. Because of the size of the area to be viewed and the limitations of the AISC image processor, we subsetted these data by selecting only every fourth pixel and only every fourth scanline. The resolution of the images in this report is 4 km X 4 km for each pixel. None of the images have been corrected for geographic distortion.

3.4 Discussion of Satellite Imagery

The first image chosen for study is taken from the NOAA-9 satellite on 05 May 1985. The region is relatively cloud-free and reveals a very narrow band of upwelling along the Peru coast from Mollendo in the south to Chiclayo in the north. The upwelled surface water is predominantly

around 15C but there are a few small areas showing 14C. The Gulf of Guayaquil is covered with very warm water (22C), but offshore of the Gulf we can see patches of upwelling. The offshore region is dominated by complex dynamic formations reflecting the interface of the upwelled Peru Coastal Current water and the equatorial surface waters. The far offshore area reveals an extremely large area covered by the very warm equatorial water above 22C. Some of these waters extend south as far as 20 degrees south latitude off the coast of Chile.

The second image for the study period is of 07 May 1985. In this shot we see the narrow band of upwelling mostly less than 50 km wide along the coast from north of Mollendo to the southern portion of the Gulf of Guayaquil. The temperatures fall as low as 14C in certain local patches south of Pisco. At this early date the offshore cloud masses due to the convergence of the upper air flow are not so dominant as they are later in the season. We see immediately the detail achieved through AISC procedures exceeds the information available from the 50 km processing required for the EPOCS program objectives. Another featue to note is the irregular form of the boundary between the oceanic waters at temperatures of 18-19C and the cooler 17C water. The movement of these features could account for the oceanic plankton species found in several samples of anchovy.

In the third image, taken 08 May 1985 we see much the same general features but with significant changes in detail. the band of cool upwelled waterbetween Pisco and Lima has become more uniformly 15C with some pixels showing 14C where the day before the non-uniform pixels were more likely to be at 16C. The migrating cloud masses shield the boundary interfaces between the 16C water and the 17C water so some of the instability patterns are less obvious. Upwelling appears to be occurring as far south as Iquique and possibly farther since our image ends at that point.

The next image for 15 May 1985 has more obscuring by clouds over the upwelling region. Some clear areas indicate the upwelling has become more consistent over the surface along the northern Peru coast. The image interpretation for this date may be subject to error due to cloud contamination of the pixels. However, even without firm absolute temperature values, the evidence of waves along the coast is clear from the patterns of the 17C and 18C interface.

By the next day 16 May 1985, we see the upwelling suppressed in several areas along the upper half of Peru. From Lima to Paita only isolated cells of 14C or 15C water are evident. At the coastal curve below Pisco there is still stongly upwelled water with one tongue extending almost 100 km offshore. There is a suggestion of water as cool as 12C surfacing just off Punta Carretas. In the image the zone of the 16C to 18C water is very clear and the instability patterns quite obvious. Many pools and tongues of alternately cool and warm water appear indicating vigorous mixing and advection processes, some of these associated with verical motions and some associated with coastally trapped waves.

The image for 24 May 1985 is too cloud-filled to interpret any surface water temperatures in detail but near coast pixels indicate the continued presence of strong upwelling. The image for the next day 25 May 1985 has similar cloud cover but with the area right next to the

coast clear. The picture shows upwelling dominant along the coast from north of Mollendo to Chiclayo with much of the narrow band at 14C. Note the contrast with the Gulf of Guayaquil which shows waters of 22C or warmer even at Tumbres, while around Punta Mancora at Paita there are pixels showing 15C water.

During the two days before the next picture we see little change in the general structure of the surface but there is a suggestion of cooling of the southern waters south of Mollendo where 19C water pixels are no longer visible. The extreme cloud cover in this image limits useful interpretation.

The image of 03 June 1985 has cleared somewhat in the northern area but is still masked with massive cloud cover through the lower southern portion. Upwelling is again consistent from south of Pisco to Paita, but the waters from Chiclayo to Paita have been mixed to mostly 17C.

By 12 June 1985 very warm waters have moved to cover the entire Gulf of Guayaquil and extend south below Paita. Immediately south of Paita the upwelling regime continues as before. Offshore of Pisco we see a spreading of cooler 17C water possibly the beginning of the intrusion of the Humboldt Current which achieves its maximum effect in August of most years.

The images of 15 June and 23 June 1985 are not generally interpretable due to the extreme cloud cover. Beneath the few clear area we can see the upwelling very near the coast continuing south to Mollendo. The image of 03 July reveals offshore waters at 17C over wide regions despite excessive cloud formations. Nearshore south of Pisco we see the clear beginning of very strong upwelling with considerable areas of 13C water and patches of 12C water. The very-near-shore upwelling strip extends almost to Chile in this picture.

By 22 July 1985 we can see a large extent of clear imagery which reveals the northern movement of the Humboldt Current well offshore of both Chile and Peru. The area is dominated by 17C water with pools of 16C and even 15C water embedded in the flow. Large eddies appear where the Humboldt current itself borders the near coast Peru Coastal Current with its strong upwelling. cloud cover prevents examination of the norhtern portion of the region.

The entire coast of Peru below Talara is dominated by water less than 15C by 31 July 1985. Several clear pools of water at 12C appear between Pisco and Arica and much of the coast north of Pisco may have a very narrow band of 12C water right at the coast. The offshore region appears to be predominantly cooled to at least 15C by the northward establishment of the Humboldt Current. Note the band of coastal upwelling extends north to isolate the warmer waters of the Gulf of Guayaquil.

The imagery from 01 August has too many clouds for interpretation in detail, but the clear area off southern Peru show the large extent at this time of the pool of very cool upwelled water. The picture shows clearly a large amount of 12C water and possibly cooler cells in the center of this pool.

4. Comparative Analysis of SST Maps and LAC Imagery

We learn a great deal about the responses of the satellite processing methods through comparison of the LAC color enhanced images with the standard derived sea surface temperature maps and their respective utility for environmental monitoring.

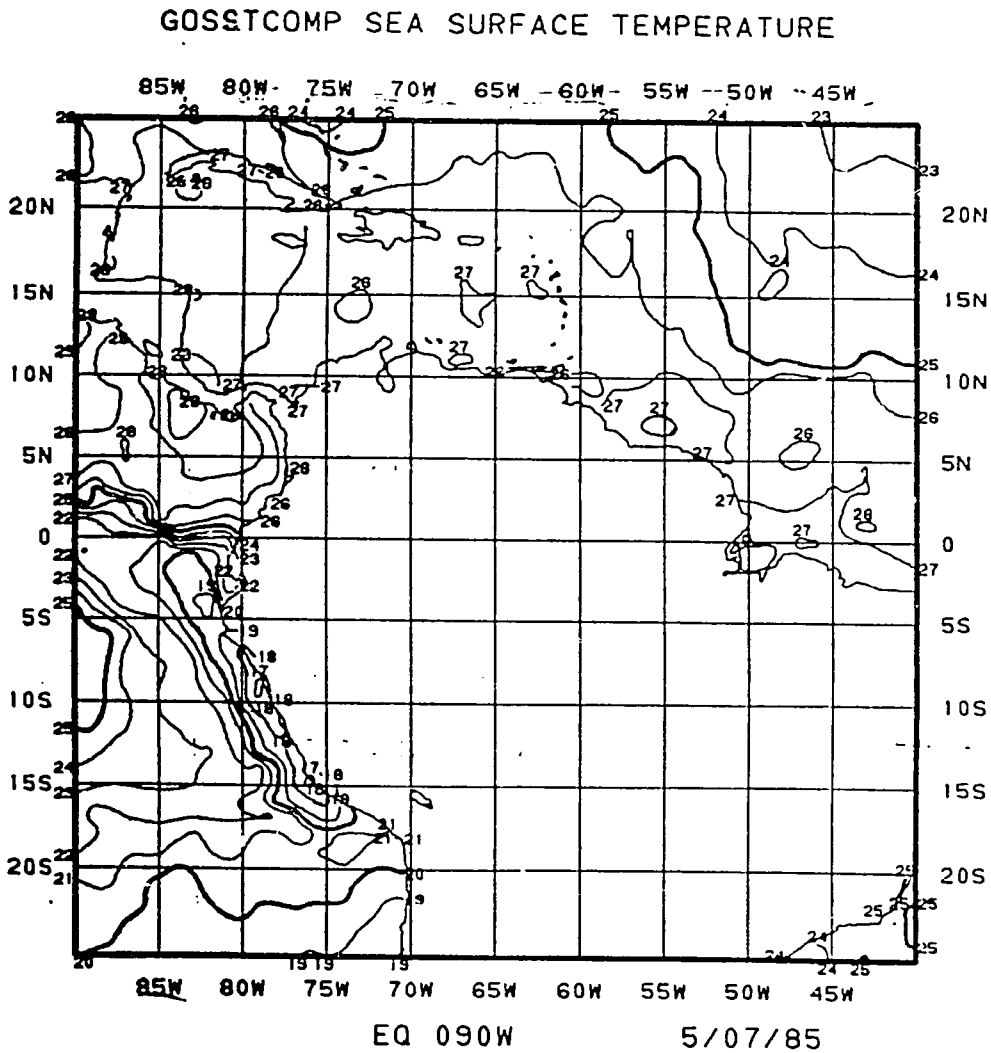
In the GOSSTCMP map of 07 May 1985 we see the upwelling areas with a minimum surface temperature of 17C. The special product at higher resolution for EPOC has the same minimum temperatures, but shows a little different pattern in the isotherms. Both methods for the maps, however show fairly smooth contours for the 20C, 19C, and 18C isotherms. The LAC data processed at AISC show on the other hand, intense activity in the surface waters giving rise to complex wedges and fingers along the 20C, 19C, and 18C isotherms. The LAC data also reveal upwelling with minimum surface water temperatures of 14C in the Peru Coastal Current. GOSSTCMP averaging process yields a closed 19C isotherm off the mouth of the Gulf of Guayaquil. The detail of the LAC processing imagery show predominantly 17C water off the Gulf with significant areas of 16C and even 15C water at the southern tip of the Gulf. The AISC LAC results show a very strong front intersecting the surface at the mouth of the Gulf with temperature falling from 22C over much of the surface of the Gulf of Guayaquil to 16C or 17C in the open ocean.

In the image for 03 July 1985, the AISC LAC image shows large coastal areas of 15C water extending from Arica possibly all the way to Chiclayo. Several excellent indications of 14C and 13C water are evident with a few pixels even showing 12C upwelled water. The GOSSTCMP map show only one area of upwelling with minimum surface tempertures of 15C in a timy pocket north of Pisco. The special EDPOCS process map shows more structure in the coastal region, indicating two or three pockets of upwelling. The minimum surface temperatures given by the EPOCS map are 15C in the pocket south of Pisco and 18C in the two more northern pockets. The SDSD averaging methods and the AISC LAC procedure thus give very different pictures of both the intensity and the distribution of the upwelling in the Coastal Current.

AISC LAC imagery for 22 July 1985 shows strong interplay at the surface of the Peru Coastal Current with the broader Humboldt Current. Large masses of 14C and15C water appear in eddies formed by coastally trapped waves. None of this detailed structure is seen in either the GOSSTCMP or the EPOCS averaged maps. The temperatures are smoothed such that users of the maps see only minimum surface water temperatures of 17C.

Maps for 30 July 1985 show two or three distinct pockets of upwelling with minimum surface water temperatures of 16C. Despite severe cloud cover offshore the AISC LAC imagery shows much more intense upwelling giving surface temperatues of 12C. Much of this intense upwelling is within 50 km of the coast, so it would not appear in the GOSSTCMP or EPOCS maps.

We see then the major differences in the two satellite products lies in the scale of detail which is available in each method. The GOSSTCMP and EPOCS map procedures allow broad scale vision of the region with clear depiction of the planetary and synoptic scales of motion and events. The AISC LAC processing allows closer inspection of details of the temperature fields, especially close to the coast.



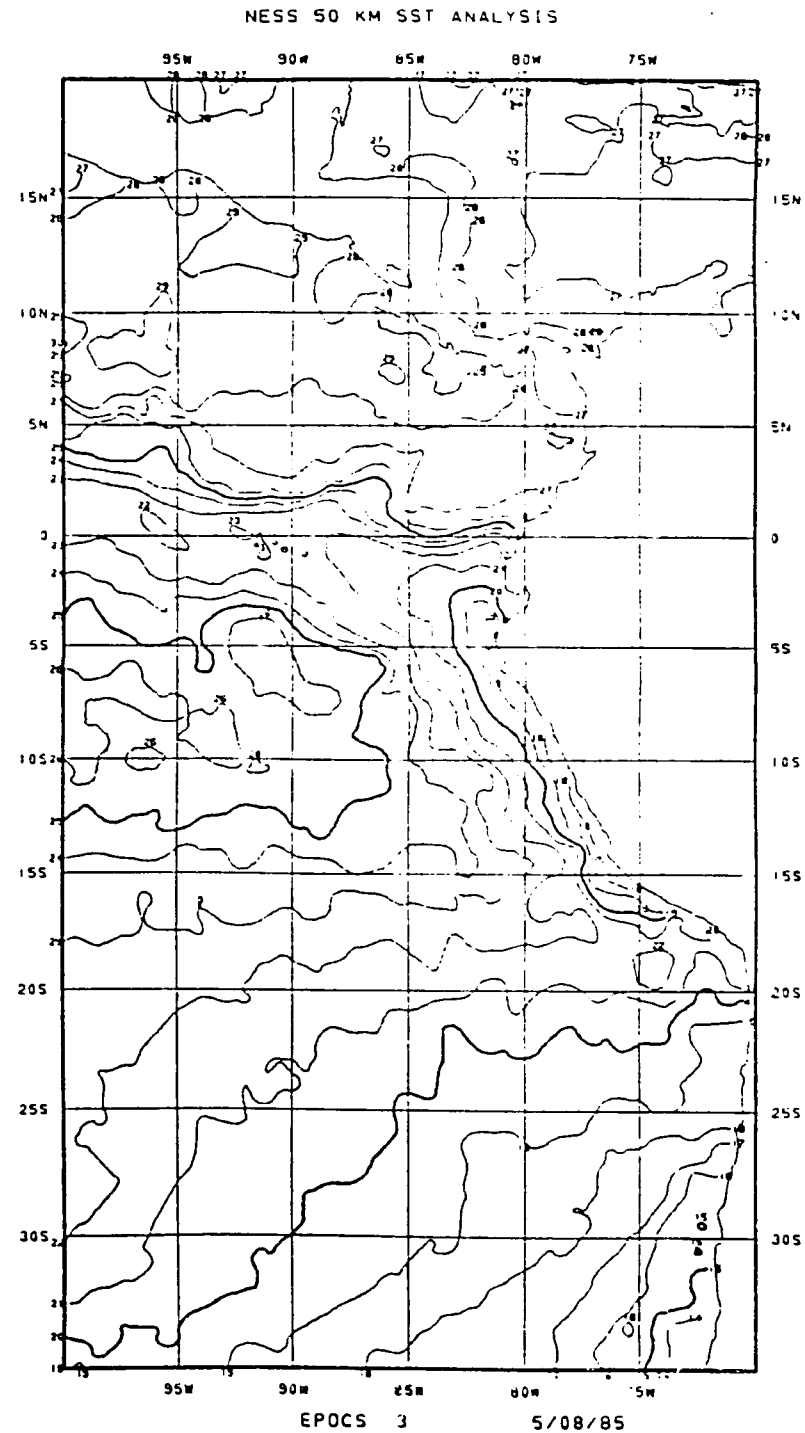
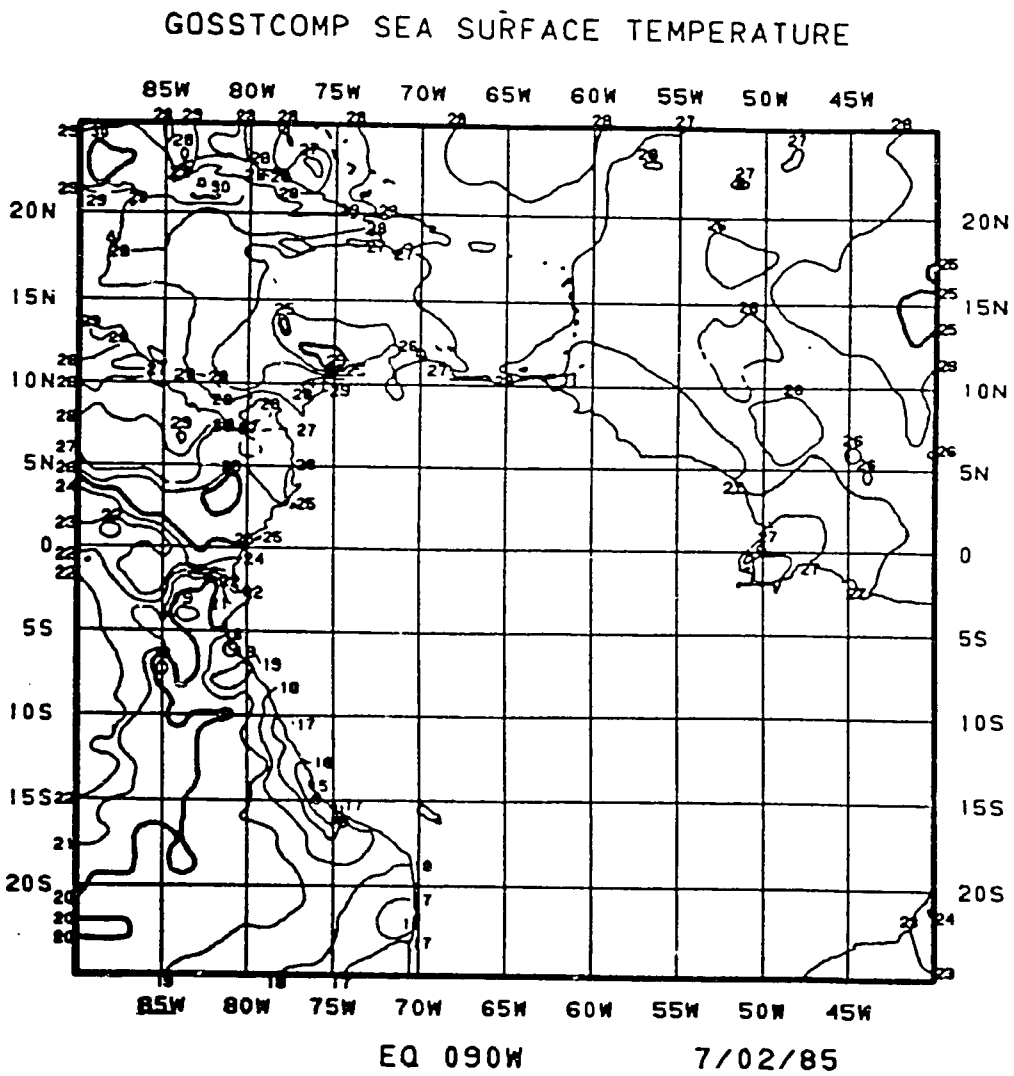


Figure 9 - Sea Surface Temperature(GOSSTCMP and EPOCS), 08 May 1985



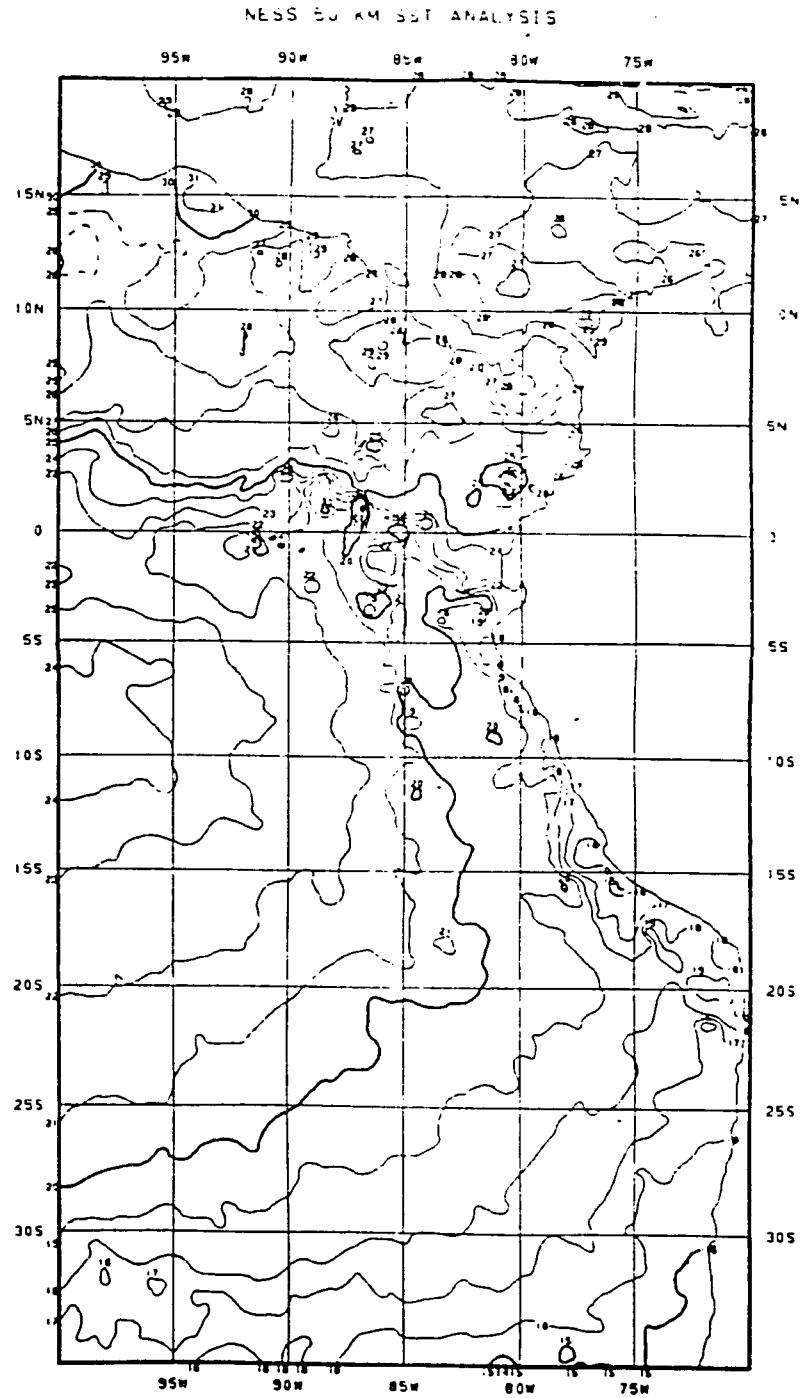
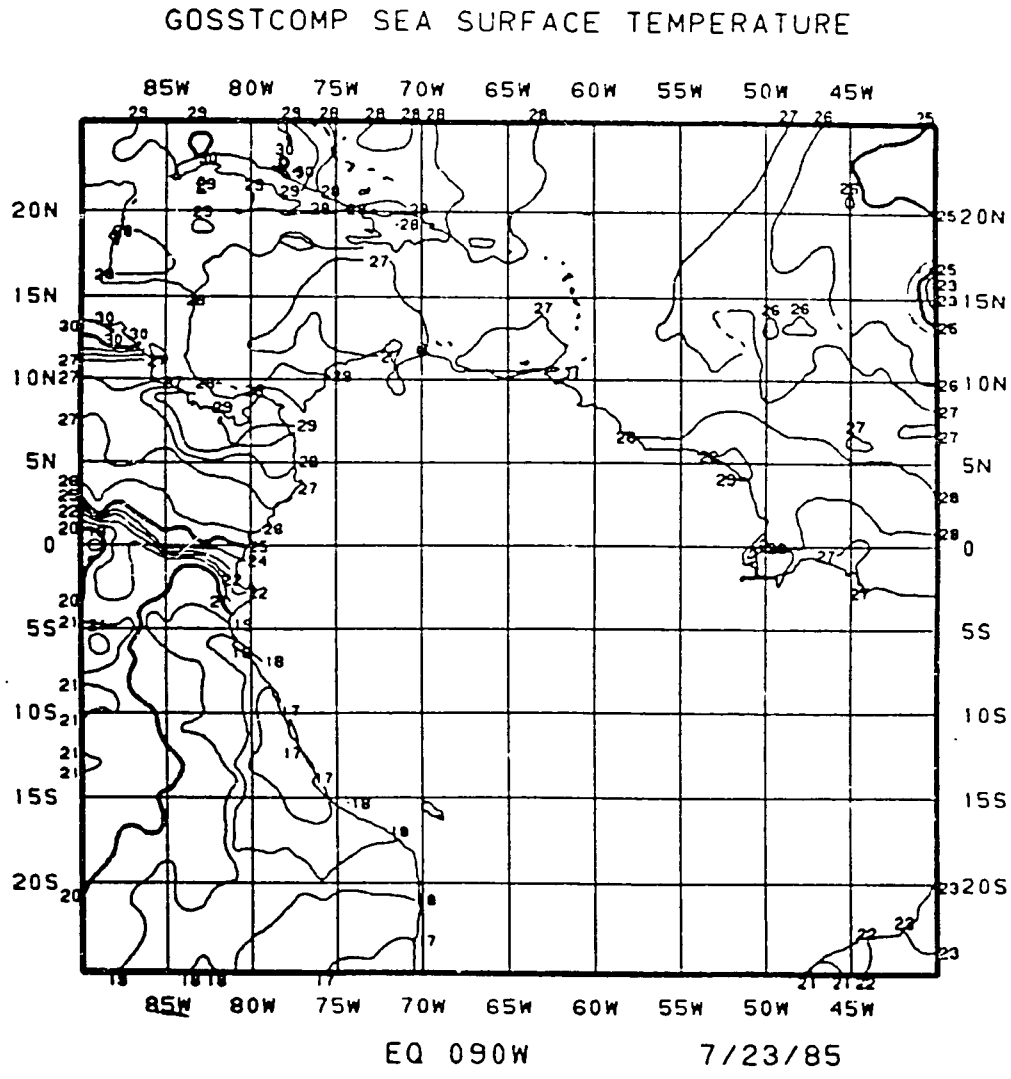


Figure 10 - Sea Surface Temperature(GOSSTCMP and EPOCS), 02 July 1985



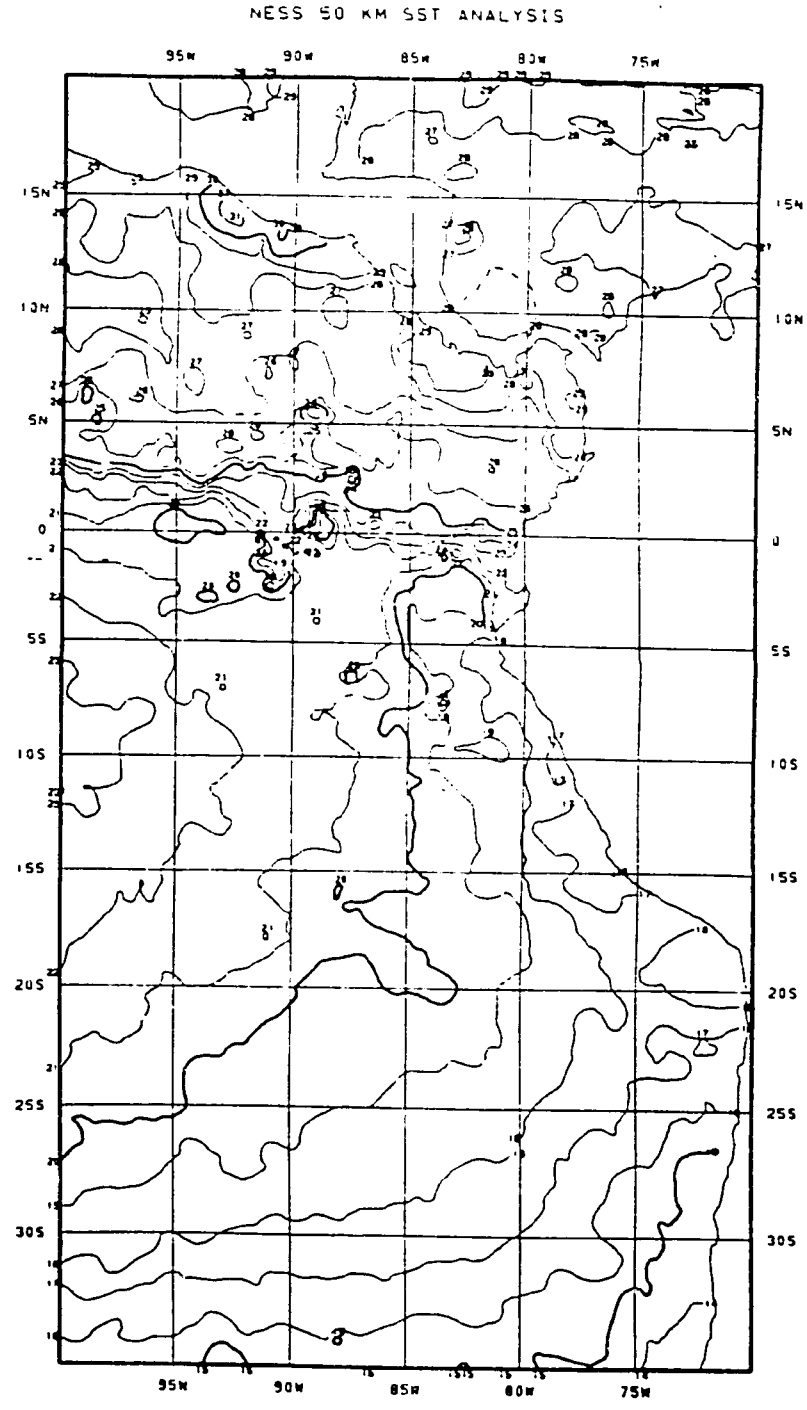
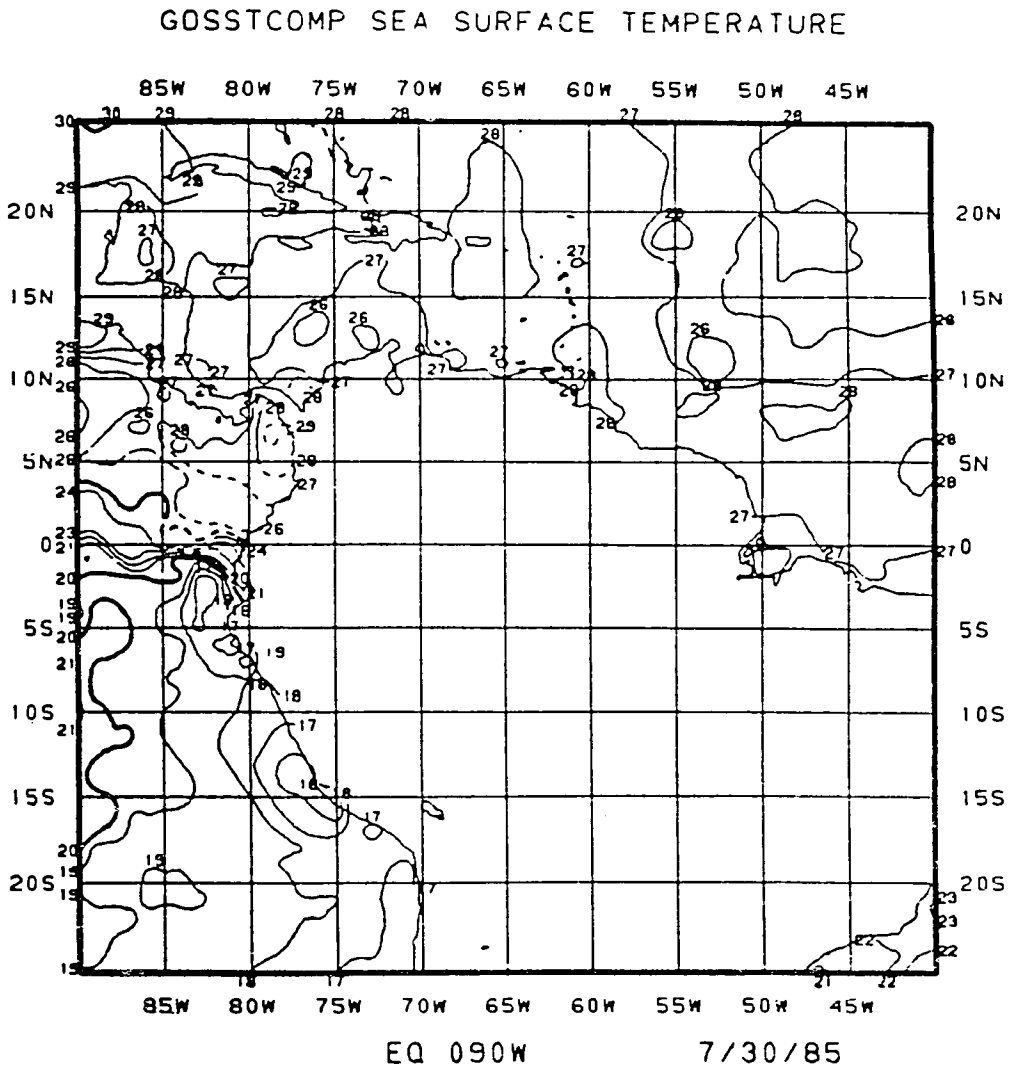


Figure 11 -- Sea Surface Temperature(GOSSTCMP and EPOCS), 23 July 1985



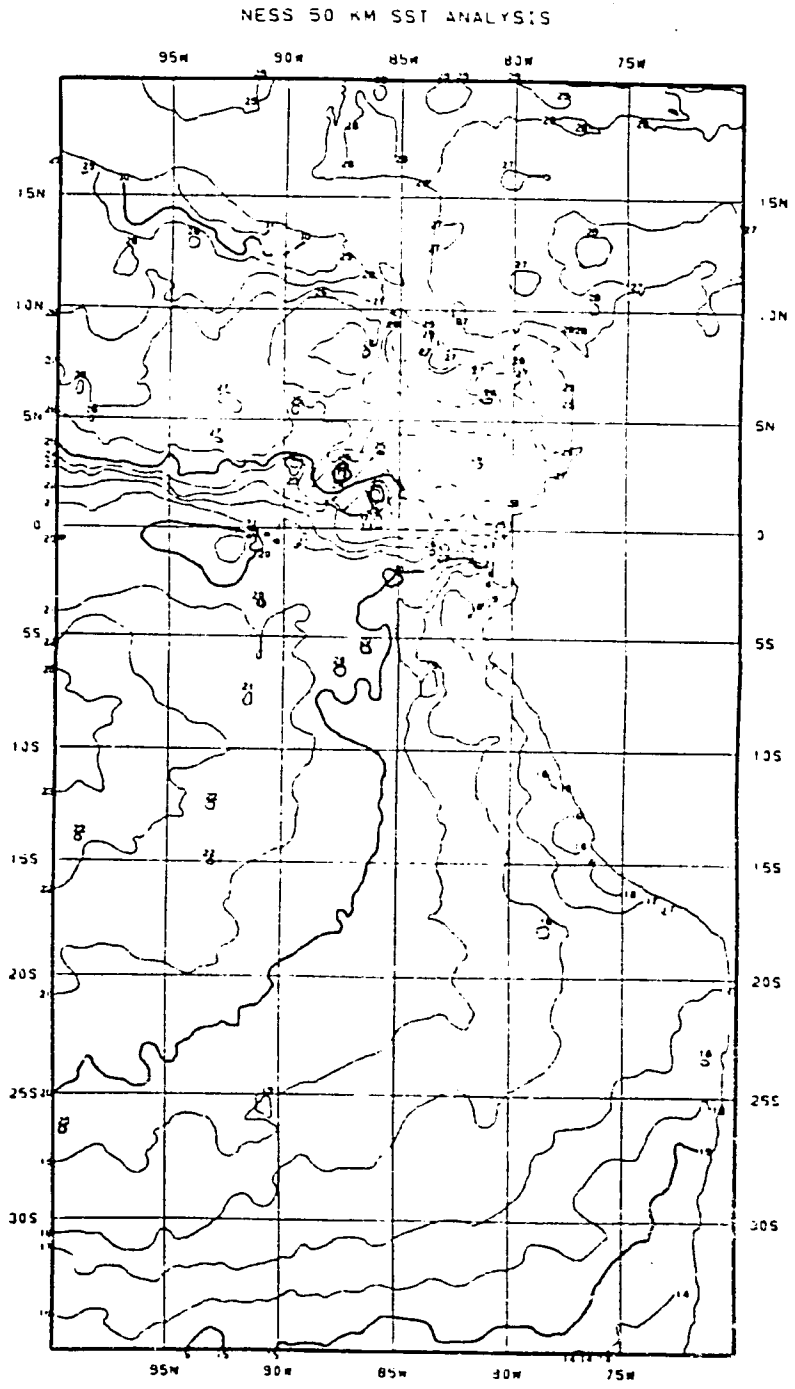


Figure 12 Sea Surface Temperature(GOSSTCMP and EPOCS), 30 July 1985

5. Conclusions and Recommendations

We have demonstrated the utility of satellite data for monitoring coastal and offshore processes for 1985. Literature has been cited which illustrates further application of remote sensed ocean surface data for a multitude of oceanographic and management uses. The more precise knowledge which is available relating sea surface temperature, turbidity, wave patterns, or other sensible parameters to fishery, shipping, or other economic activities, the better will be the relationship between the interpretation of satellite imagery and derived economic benefits.

The relative merits for the type of satellite data product to be used in the tracking or development of fishery resources off the coast of Ecuador and Peru are clear. For large scale offshore events the maps derived by SDSD integrating data over 50 -100 km grids are excellent and easily accessible. Events such as the development of an El Nino or the evolution of the Humboldt Current are clear in these products. Validation of circulation models for the regional ocean would be easily accomplished using these maps.

For the evaluation or monitoring of the coastal current and the associated coastal fisheries, the more detailed LAC data are required. The fisheries are concentrated in a narrow (50 km) zone along the coast in small pockets of intense upwelling. The LAC data enhanced with color processing gives clear and accurate pictures of the processes and distributions of the coastal waters. If the spawning volume and success for the anchoveta or other species can be related to the intensity or distribution of upwelling, fishery managers might be able to evaluate conservation measures based on satellite derived estimates of these parameters. Fishermen may be able to track fishing zones more precisely if LAC interpretations could be provided at a reasonable cost.

AISC recommends continued exploration of the application of this LAC processing technology in the following arenas:

1) compositing techniques to minimize cloud interference with scientific interpretations;

2) develop imaging methods for stand-alone microcomputers for application in the developing nations;

3) explore possible establishment of a receiving station in the Ecuador-Peru-Chile region for retaining more frequent images of the region;

4) explore relationships of fishery with details of upwelling features to improve economic impact of the technology;

5) routinely apply geographic corrections to standard projection (Mercator or Plate Carree) to each image for easier direct intercomparison of images.

Good environmental data are not alone sufficient to ensure an economically viable fishery. A policy balancing the harvest of anchoveta and guano, combined with appropriate debt practices for fishery-related industry from the

banks in Peru must be enacted with provision for acquisition and dissemination of appropriate data. The availability and ease of access of current and detailed comprehensive environmental data, such as satellite imagery would provide security to the policy and finance decisionmakers.

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7. Acknowledgments

This report is based on the effort of many individuals in addition to the author. The image procesing algorithms were developed by Fred G. Everdale and Dr. Richard Stumpf. Anne Wilburn processed the images and produced the color prints. Karl Pechmann helped with the graphics. Dr. Celso Barrientos and Dr. Kenneth Turgeon provided valuable discussion and review.