# MEXUS-Gulf Remote Sensing and Technology Research 1977-84

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## Introduction

The Remote Sensing Working Group of MEXUS-Gulf was organized because of an interest in remote sensing shared by the fisheries organizations of Mexico and the United States. This interest was due to an appreciation by both nations of the contributions that remote sensing could make to increased understandings of the fisheries and ecology of the Gulf of Mexico.

Numerous efforts were made beginning in 1979 to initiate a cooperative remote sensing study from which both countries could benefit. Mexico's interest, however, initially was focused on hydroacoustics and interest in the United States was directed primarily at aerospace forms of remote sensing. Unfortunately, neither country had the capability to initiate a meaningful exchange of information related to the Gulf of Mexico in the initial phases of MEXUS-Gulf.

In 1981, an advanced state-of-the-art digital image processor was installed within the Mississippi Laboratories of the Southeast Fisheries Center (SEFC) of the National Marine Fisheries Service (NMFS), and work began in Mexico by the Instituto Nacional de Pesca (INP), Departmento de Pesca, to apply high resolution acoustics to problems related to plankton assessment. These remote sensing technologies may provide a basis from which cooperative efforts and exchanges now can spring to further the goals of MEXUS-Gulf.

The Technology Working Group of MEXUS-Gulf was one of the later working groups formed and has not had sufficient time to fully develop mechanisms for effective exchanges of information or cooperative research programs. In 1981, the Remote Sensing and Technology Working Groups combined efforts to initiate meaningful research in 1982. Plans were developed for information exchanges primarily related to fishing and fuel efficiencies in commercial shrimp fleets.

This paper summarizes initial efforts directly or indirectly stimulated by MEXUS-Gulf in remote sensing and technology. These efforts fall into three general areas: Radio and satellite tracking of sea turtles, fuel efficiencies in shrimp fisheries, and analyses of satellite imagery for derived chlorophyll patterns and concentrations. This paper provides a basis for more comprehensive summaries jointly authored by investigators from Mexico and the United States.

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## Radio and Satellite Tracking

### Radio Tracking

Radio tracking of sea turtles by NMFS was done to judge the success or failure of the initial phase of releases of headstarted Kemp ridley turtles, *Lepidochelys kempi*. The headstarting was initiated jointly by Mexico and the United States in 1978 when turtle eggs were collected from nesting grounds near Ranch Nuevo, Tamaulipas, Mexico, for rearing at the SEFC Galveston Laboratory in Texas. The first few months after release were considered especially critical for the turtles, and it was this period which formulated the basis for radio tracking. Subsequently, however, radio tracking capabilities were expanded to include more than just headstarted sea turtles.

Steps to develop a radio tracking capability included a series of controlled experiments to optimize attachment procedures and to evaluate effects on turtle behavior. No significant effects were noted in surfacing or feeding behavior when the transmitters were trailed behind the animals on lanyards roughly-two-thirds the carapace length. The transmitters (8 g) were enclosed in triangular wooden pyramidal floats with a total air weight of 28 g. The advantage of the lanyard attachment method was that it allowed full exposure of the transmitter antenna every time the turtle surfaced. The radiated power of the transmitter in saltwater averaged −7 dbm with a capability of 45 days of continuous operation (Timko and De Blanc, 1981).

The turtles were tracked by an aircraft equipped with a high-gain (130 db) battery powered receiver. The receiver could be manually tuned to differentiate and receive signals from up to 100 different turtles. Three-element yagi antennas were mounted on the wings and a dipole quarter-wave antenna was installed on the underside of the aircraft. The yagi antennas provided directional capability for tracking and the dipole was used for initial detection. Detection range was about 50 km. A Loran-C navigation system was used to help position the turtles.

Three demonstrations of the tracking system were conducted before it was considered operational. All three were conducted in the eastern Gulf of Mexico. The first demonstration was relatively unsuccessful due to fatigue or corrosion of stainless steel lanyards used to attach the transmitters to an initial group of ten headstarted ridley turtles. The stainless steel lanyards were replaced with nylon monofilament for the subsequent demonstrations which were successful. Selected turtles were tracked for periods of up to 30 days following

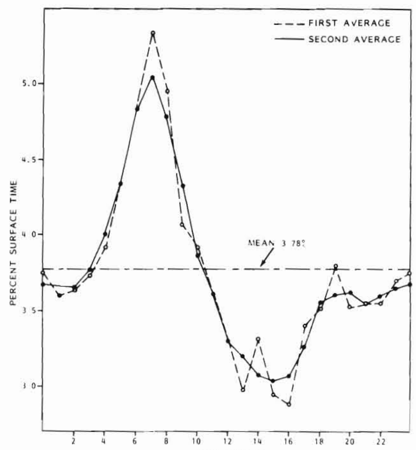


Figure 1.—Time averaged diurnal surfacing pattern (percent surface time) of loggerhead sea turtles. Averaging done by combining data from adjoining hours of an hour with data from that hour. Second average done similar to first, but with average values from the first averaging. After Kemmerer et al., text footnote 1.

release, with some of them traveling as far as 240 km offshore.

A cooperative demonstration of the radio tracking system was completed by representatives of INP and SEFC in 1981. Transmitters and a receiver were provided for a tracking experiment off Mexico.

The radio tracking capability was expanded in 1981 to monitor movements and surfacing behavior of adult loggerhead sea turtles, *Caretta caretta*, near the Canaveral Channel, Florida (Kemmerer et al.[1]). The same tracking and attachment rationale used for the headstarted turtles was used with the addition of shore-based spectrum analyzer to continuously monitor absence or presence of radio signals. Data from 20 days of continuous monitoring of 20 radio-equipped turtles suggested that about 3 days were needed for the animals to normalize surfacing behavior patterns (i.e., adjust to capture, handling, and tagging). The mean time spent by a turtle during a surfacing was 2.20 minutes, and the turtles averaged 1.03 surfacings an hour. The turtles spent an average of 3.78 percent of their time at the surface and a trend analysis indicated diurnal periodicity in surfacing behavior (Fig. 1).

[1] Kemmerer, A. J., R. E. Timko, and S. B. Burkett. Movement and surfacing behavior patterns of loggerhead sea turtles in and near Cape Canaveral Channel, Florida (September and October 1981). Manuscr. on file at National Marine Fisheries Service, Southeast Fisheries Center, Mississippi Laboratories, NSTL Station, Miss.

## Satellite Tracking

Long-term tracking studies of far-ranging sea turtles were considered to be practically impossible with traditional radio tracking techniques primarily because of cost constraints. These constraints led SEFC investigators to consider the use of satellite systems whose feasibility had already been demonstrated for tracking elk (Craighead et al., 1972) and polar bears (Kolz et al., 1980).

Transmitters originally developed to track polar bears were modified for use with sea turtles (Timko and Kolz, 1982). The transmitters were designed to operate through the Nimbus-6 satellite which carries a data collection and transmitter location system capable of handling random transmissions from up to 1,000 transmitters worldwide. Data are transmitted to the satellite as 401.2 MHz radio frequency pulses. The pulses have a duration of about 1 second and occur at a rate of about one per minute. Each pulse contains an unmodulated carrier and a phase-modulated section for data synchronization and transmitter identification. The unmodulated portion of the carrier is used to measure the doppler frequency shift and to calculate the latitude and longitude of the transmitter. Location accuracy is about $\pm$ 5 km.

The transmitter was designed to operate for 1 year with a duty cycle of an 8 hour transmission period every 4 days to conserve battery power. It was completely enclosed in 16 cm diameter PVC pipe 28 cm in length. The transmitter package weighed about 3.2 kg in air and floated 40 percent exposed or 1.8 kg positively buoyant. A secondary radio beacon also was included in the PVC pipe to continuously radiate 165 MHz radio frequency pulses. The secondary beacon was added to allow the turtle to be located by search aircraft. A complete description of the transmitter is given by Timko and Kolz (1982).

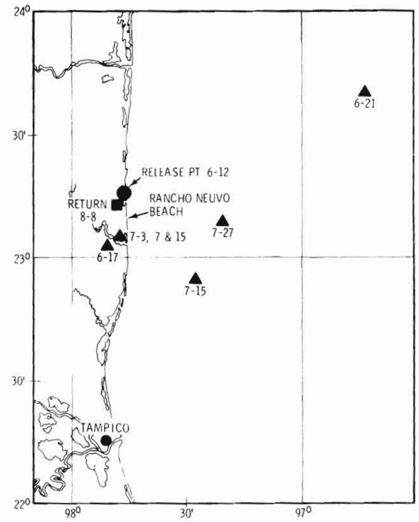


Figure 2.—Satellite derived positions for cooperative MEXUS-Gulf Kemp ridley sea turtle tracking equipment (1980).

After a series of captive animal tests, the first field demonstration of a satellite tracking capability for sea turtles was conducted. A 96 kg female loggerhead turtle, nicknamed "Dianne", was outfitted with a Nimbus-6 transmitter and released off the coast of Mississippi in October 1979. The transmitter was attached to the trailing edge of the turtle's carapace with a lanyard about two-thirds the length of the carapace. Dianne was successfully tracked for 8 months over a distance exceeding 2,200 km (Timko and Kolz, 1982).

The success of the satellite tracking demonstration prompted a cooperative effort between INP and SEFC investigators to track a Kemp ridley turtle. In June 1980, a 67.3 cm carapace length female ridley was tagged with a Nimbus-6 transmitter at Rancho Nuevo, Mexico. The transmitter was attached after the turtle deposited her clutch of eggs. She was allowed to return naturally to the sea and to swim through the surf.

The first returns from the satellite indicated the ridley turtle had moved a short distance off the nesting beach (Fig. 2), but later returns from a position roughly 25 km south of the release site in Barre del Tordos, an inland lagoon, indicated a detachment problem. After an extensive search, the transmitter was located in a fishing camp being used as a float on a gill net. No evidence of what had happened to the female ridley was found, although it was generally assumed she had been caught by a fisherman. The conclusion from the experiment was the transmitter probably was too large for the ridley turtle and may have led to her capture.

Partly because of the presumed failure with tracking the Kemp ridley, but primarily because of a phasing down of the Nimbus-6 system by the National Aeronautics and Space Administration (NASA), engineering research and development shifted to a new satellite—TIROS-N. This satellite carries a data collection and platform location system similar to the one aboard Nimbus-6 but with expanded capabilities. The system, referred to as ARGOS, represents a cooperative effort by the United States and France, with France providing the hardware and data processing and the United States providing the space vehicles and support systems. ARGOS is proposed to be operational on all NOAA series satellites.

The ARGOS data collection and platform locationing system is capable of providing precise location and data retrieval from fixed or mobile transmitter platforms worldwide. The platforms transmit a coded message at 401.65 MHz which includes an unique identification code, sensor data, and an unmodulated carrier. The unmodulated carrier is used to calculate platform positions which tests by NMFS engineers indicate can be as accurate as 21 m. Message duration depends on the quantity of data to be transmitted, but is always less than 1 second.

Major advantages of the ARGOS system are that it has two satellites in orbit, compared to the single Nimbus-6 system, and its planned long-term operational capability. All transmitters must provide a minimum of 7 uplinks to be located. These uplinks, however, can be with one or both satellites which overall should increase the probability of tracking briefly surfacing marine animals.

Two prototype ARGOS sea turtle transmitters were recently developed by NMFS. The transmitters are similar in design to the ones used for tracking the loggerhead and Kemp ridley turtles. A major advantage of these transmitters is their greatly reduced size, which is roughly 22 percent displacement volume, 41 percent air weight, and 13 percent buoyancy of the Nimbus-6 transmitters (Table 1). While they are probably still too large for tracking most juvenile turtles, they appear to have significant potential for tracking all adult sizes of the five sea turtle species endemic to the Gulf of Mexico.

**Table 1.—Comparison of Nimbus-6 and ARGOS sea turtle tracking transmitters.**

| Parameter | Nimbus-6 | ARGOS |
|---|---|---|
| Air Weight (kg) | 3.2 | 1.3 |
| Buoyancy (kg) | 1.8 | 0.23 |
| Length (cm) | 28 | 50.8 |
| Diameter (cm) | 16 | 5.1 |
| Displacement volume ($cm^3$) | 5,444 | 1,207 |

The turtle transmitters have been certified by ARGOS and a semicontrolled captive animal test was completed with one of the transmitters attached to a loggerhead turtle. The transmitter operated perfectly even though the turtle escaped from captivity after several weeks, and the transmitter had to be used for location and recovery. The first wild animal test was planned to begin in September 1982 with release of a transmitter tagged adult loggerhead turtle in the northcentral Gulf of Mexico.

## Technology

Technology efforts in the United States related to MEXUS-Gulf have concentrated on characterizations of fishing and gear efficiencies in the Gulf of Mexico shrimp fleet. Scientific observers aboard cooperating offshore shrimp trawlers have recorded information on time and fuel budgets since 1980. Twenty vessels in the Gulf were monitored for time budgets covering 119 trips ranging in length from 6 hours to 17 days. An additional three monitored vessels ranging in length from 19.2 to 25.9 m and powered with diesel engines from 275 to 520 mhp were equipped with microprocessor fuel flow and tachometer systems.

Most significant of the findings from the observer monitoring is that while the vessels spent only slightly more than 50 percent of the time fishing, this activity consumed almost 70 percent of the fuel. Running time to and from fishing grounds and between fishing grounds accounted for 19 percent of the time and 28 percent of the fuel budgets, respectively. Roughly 25 percent of the time budget was used without the main propulsion unit operating. Very little time, about 1 percent, was spent fishing with try-nets alone and accounted for less than 1 percent of the fuel consumed. Gear handling also accounted for very small portions of the time and fuel budgets representing about 1 and 2 percent of the two budgets, respectively. A comprehensive review of findings from this study is given by Veal et al.[2]

Review of shrimp trawls indicated that since 1970 there have been numerous changes, but most of the changes have remained with the basic balloon, semiballoon, and flat trawl design. The two most recent changes have been with development of the twin and tongue trawls. The development of the twin trawl, however, is more a development in rigging than in trawl design. The twin trawl essentially consists of two smaller trawls tied together with an extra door, sled, or bullet between the nets. The primary advantage of the twin trawl is an increase in horizontal spread without an accompanying increase in drag. The development of the tongue trawl was an attempt to combine advantages of twin and single trawls into a single net. The distinguishing feature of the tongue trawl is a section of webbing that extends forward from the top of the net and connects to a central and extra trawl bridle. The rationale of the design was to increase horizontal spread of the net by reducing total load on the doors. This was done by transferring a portion of the load to the tongue and central bridle.

A series of underway measurements on a selected group of shrimp trawls was made by SEFC scuba divers to evaluate spread efficiencies (Table 2). Each trawl

[2]Veal, D. D., M. V. Rawson, and W. Hosking. 1981. Structure, strategy and fuel consumption in the Gulf shrimp fleet. Paper presented at Fishing Industry Energy Conservation Conference, Soc. Naval Archit. Mar. Engr., Seattle, Wash., Oct. 26-27, 1981.

was 18.3 m headrope length (webbing to webbing) and was constructed by a commercial trawl manufacturer. The trawls were rigged identically with standard loop chains and without floatation. Chain wooden doors 2.4 by 1.0 m were used to spread the nets and the trawls towed in 9 m of water using 15.2 m bridles and 22.9 m warps.

The tongue trawls outperformed the other trawls in spread efficiency, ranging from 80 to 85 percent. Efficiency is the horizontal spread of the net expressed as a percentage of headrope length. Based on these measurements, the tongue trawls appear best suited for the bottom dwelling brown shrimp, *Penaeus aztecus*, and pink shrimp, *P. duorarum*. The Mongoose trawl may be the best overall tongue-type of trawl because of its greater vertical opening and relatively good spread efficiency, although less than the other two tongue trawls. The greater vertical opening would be especially important for white shrimp, *P. setiferus*, and at times for the other two species when for reasons related to currents or behavior they are off the bottom. A comprehensive review of these measurements together with measurements from other nets with and without tongues, with and without floats, and with different door sizes is given by Watson et al.[3]

A series of instrumented tows of a Mongoose trawl were made to judge performance characteristics under simulated fishing conditions. Preliminary measurements indicated that during a relatively long trawl tow, vessel speed through the water and engine rpm would decrease with an accompanying increase in the rate of fuel consumption even though throttle settings were fixed. Additionally, the horizontal spread of the net decreased, all presumably due to increased net loadings. In one series of measurements, the swept area efficiency of the net was found to decrease 40 percent over a 150-minute tow which together with a 4 percent increase in the rate of fuel consumption suggested the tow was 44 percent less efficient when the last measurements were made than when the trawl was first put over the side of the trawler (Kemmerer et al.[4]).

[3]Watson, J. W., I. K. Workman, D. W. Taylor, and A. F. Serra. Configurations of common shrimp trawls employed in southeastern United States waters. Manuscr. on file at National Marine Fisheries Service, Southeast Fisheries Center, Mississippi Laboratories, Pascagoula, Miss.

**Table 2.—Comparisons between eight common shrimp trawls. Measurements were made while being towed 1.3-1.5 m/seconds. Headropes were all 18.3 m (after Watson et al., text footnote 3).**

| Trawl | Spread (m) | Vertical opening (m) | Spread efficiency (%) |
|---|---|---|---|
| Flat | 12.2 | 1.2 | 67 |
| Semiballoon | 12.2 | 1.2 | 67 |
| Western jib[1] | 12.5 | 1.1 | 68 |
| Balloon | 12.8 | 1.1 | 70 |
| Super X-3[2] | 13.4 | 1.1 | 73 |
| Super X-3 tongue | 15.5 | 0.6 | 85 |
| Cobra/hood tongue[3] | 14.9 | 0.8 | 82 |
| Mongoose tongue[4] | 14.6 | 1.2 | 80 |

[1]Similar to flat trawl with major difference in construction of the corner pieces.
[2]Similar to western jib, but with differences in the corner pieces.
[3]Similar to semiballoon trawl with addition of a tongue added to the top body panel.
[4]Similar to Cobra trawl with major difference being the tongue is designed into the trawl.

In another series of instrumented trawl tows, several types of nets were evaluated for swept area fishing efficiency as a function of fuel consumption. The twin trawl was found to be 38 percent more efficient than were any of the single trawls tested at vessel speeds through the water comparable to commercial fishing operations (Kemmerer et al.[4]). A 50 percent increase in area swept by the twin trawl, which was provided by increasing towing speed, required roughly a 400 percent increase in fuel consumption. Increases of 40 percent in area swept by single trawls similarly required nearly 400 percent increases in rates of fuel consumption.

## Satellite Remote Sensing

Availability of the SEFC satellite image processor and discussions with INP investigators in 1981 prompted efforts to process selected images provided by the Coastal Zone Color Scanner (CZCS). This particular remote sensing system was stressed because it is the only color sensor in orbit specifically designed for application to the oceans of the world. Rather than attempting to process all available CZCS data available for the Gulf of Mexico, an area off the coast of Mexico which experienced several periods of significant meteorological perturbations in 1979 was examined for a time series of chlorophyll patterns and concentrations (Fig. 3).

[4]Kemmerer, A. J., W. R. Seidel, C. D Veal, and W. Hosking. 1982. Fuel relationships in southeastern United States shrimp fisheries. Rep. to Int. Counc. Explor. Sea, Copenhagen.

### Satellite System

The CZCS system is carried by Nimbus-7 which was launched in October 1978. The spacecraft is a research platform of the NASA Goddard Space Flight Center with a threefold monitoring mission: Atmospheric pollution, oceanography, and atmospheric sciences. Two instruments are dedicated to oceanography, the CZCS and a scanning microwave radiometer. The spacecraft is in a sun-synchronous, near-polar (99.28°), 955 km altitude orbit with an ascending-node equator crossing near local noon (Hovis et al., 1980). Repeat coverage at the equator is every 3 days with at least daily coverage about 60°N.

The CZCS has four high resolution (20 nm) spectral bands in the visible spectral region and two in the nonvisible region. Center wavelengths are 443, 520, 550, 670, 750, and 11,500 nm. The spectral characteristics of the CZCS were governed by the spectra of phytoplankton (Morel and Prieur, 1977) while the radiometric sensitivity of the sensor was determined by the magnitude of expected radiances from the sea surface (Gordon et al., 1980). Bands 1 and 4 of the sensor (centered at 443 and 670 nm, respectively) span spectral regions of strong chlorophyll-*a* absorption. Band 3, centered at 550 nm, falls in a region of minimum chlorophyll-*a* absorption while Band 2, center at 520 nm, is near a point where subsurface upwelling radiance is nearly independent of the concentration of chlorophyll-*a* (Gordon et al., 1980). Band 5 (700 to 800 nm) is used primarily for discriminating between land, clouds, and water, and Band 6 (10,500 to 12,500 nm) is a thermal infrared detector for monitoring sea-surface temperature. All 6 bands are perfectly coregistered.

The CZCS has an active scan of 78° centered on nadir and a ground resolution of 825 nm. A normal complete

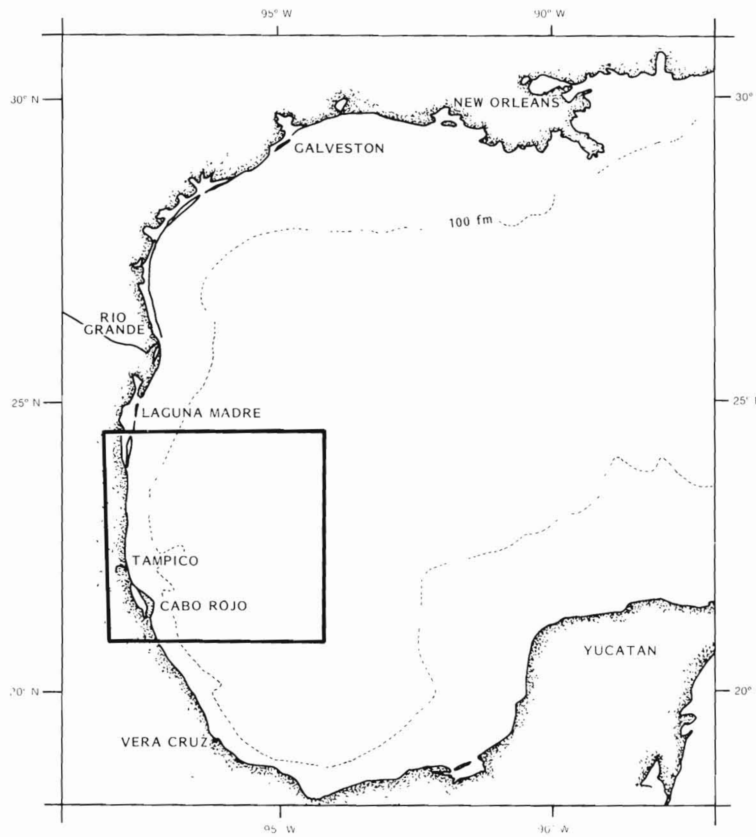


Figure 3.—Study area showing approximate CZCS coverage area (outlined rectangle) for Figure 4A-D.

scene requires about 2 minutes to acquire and is about 800 km along the satellite track and 1,600 km across track. The scan plane of the sensor can be tilted ±20° from nadir along track to minimize sunglint.

## Algorithms

Before CZCS imagery is used to compute chlorophyll concentrations, the digital data must be corrected for atmospheric scattering by air molecules and aerosols. Typically, the desired water-leaving radiance is only 10-20 percent of that actually measured at satellite altitude with the majority of the radiance due to atmospheric scattering (Gordon and Clark, 1981). Several techniques are available for the correction and the one used is based on the concept of clear-water radiance (described by Gordon and Clark, 1981). The advantage of this technique is it does not require surface truth information.

Essentially, the clear water radiance correction technique is based on a demonstrated capability to compute radiances at 520, 550, and 670 nm for very clear oceanic waters (i.e., chlorophyll concentrations less than 0.25 mg/m$^3$), knowing only the solar zenith angle (Gordon and Clark, 1981). As Rayleigh scattering can be computed from theory with information on spacecraft-pixel geometry and solar elevation and azimuth, the scattering from aerosols can be inferred directly from spacecraft radiance measurements given certain assumptions are satisfied (Gordon and Clark, 1981). Water radiances can then be extracted from the data and are assumed to represent absolute intensities from just below the sea surface.

The majority of CZCS chlorophyll algorithms are based on linear regression models where the logarithm of chlorophyll concentration is computed from a logarithm of the ratio of radiances from two CZCS bands. Smith and Baker (1982) review a number of these regression algorithms, noting that $r^2$ values from four separate studies were all above 0.90 for cholorphyll concentrations ranging from 0.01 to 10 mg/m$^3$.

Chlorophyll concentrations presented in this paper were inferred from atmospherically corrected CZCS radiances applied to a chlorophyll algorithm currently used by NASA to process CZCS data to the derived product stage. The algorithm is in two equations where the logarithm of chlorophyll concentrations less than 1.5 mg/m$^3$ is estimated from a ratio of CZCS radiances from bands centered at 443 and 550 nm, and concentrations between 1.5 and 32 mg/m$^3$ are estimated from a ratio of radiances from bands centered at 520 and 550 nm. The expected accuracy of the estimate is 0.25-0.50 the logarithm of the chlorophyll concentration (Gordon and Clark, 1980).

## Derived Chlorophyll

Chlorophyll charts derived from four CZCS coverages of the study area off Mexico are presented in Figure 4. Figure 4A shows chlorophyll concentrations from 21 August 1979. Coastal concentrations averaged about 0.50 mg/m$^3$, and for the complete scene, less land and cloud pixels, the arithmetic mean concentration was 0.18 mg/m$^3$. A frequency analysis of the scene with cumulative percent curves for area and chlorophyll concentration is presented in Figure 5A. This scene is assumed to represent normal conditions for the area with the highest chlorophyll concentrations immediately adjacent to the coast.

Coverage by the CZCS about a month after the first image on 29 September 1979 showed a major phytoplankton bloom had or was occurring (Fig. 4B). The bloom was generally confined to an area from the coast out to a depth of about 180 m. Chlorophyll concentrations in the region of the bloom averaged about 2.5 mg/m$^3$ which increased the mean for the entire scene to 0.66 mg/m$^3$. This increase represents roughly a 266 percent increase in the amount of chlorophyll from the first to the second CZCS scene. The frequency analysis for the scene (Fig. 5B) shows two

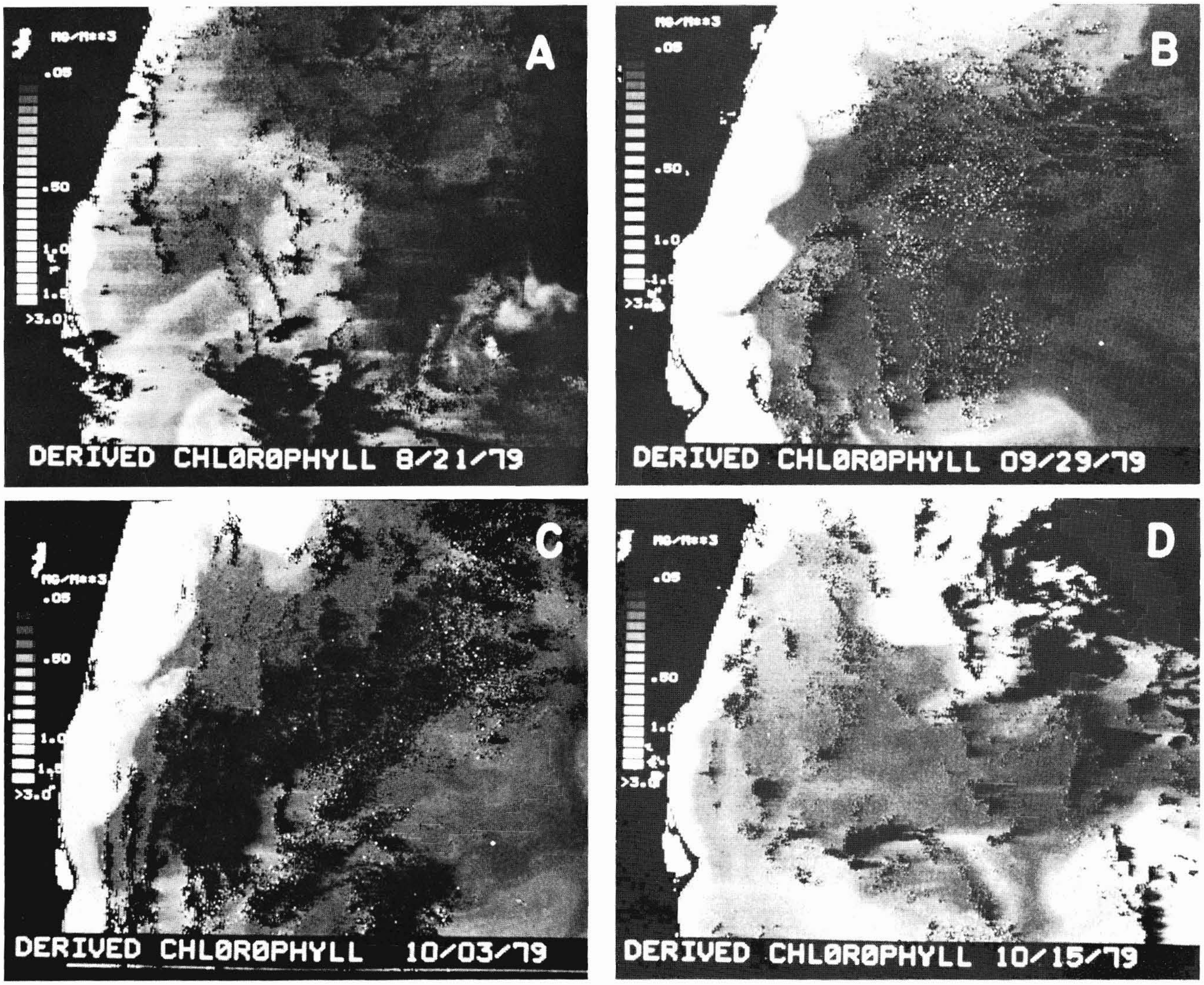


Figure 4.—Chlorophyll charts derived from CZCS digital data. The images consist of 512 × 512 picture elements (pixels), each representing a surface area of about 825 × 825 m. Chlorophyll concentrations in mg/m$^3$ are depicted according to the gray scale. Black areas are land or clouds: A, 21 August 1979; B, 29 September 1979; C, 3 October 1979; and D, 15 October 1979.

peaks in chlorophyll concentration. The first peak at about 0.14 mg/m$^3$ is characteristic of chlorophyll concentrations in clear oceanic waters while the second at about 2.5 mg/m$^3$ defines concentrations associated with the bloom.

By 3 October 1979 the intensity of the chlorophyll bloom had subsided (Fig. 4C). Concentrations along the coast were still high, but had fallen to an average of about 1.0 mg/m$^3$. The mean for the scene was 0.30 mg/m$^3$. The area frequency analysis for the scene indicated a peak in chlorophyll concentration at about 0.18 mg/m$^3$, with two smaller peaks at 0.80 and 1.58 mg/m$^3$ (Fig. 5C). Sensor coverage almost two weeks later showed chlorophyll concentrations along the coast had fallen back to levels roughly the same as before the bloom (Fig. 4D). Significant concentrations of oceanic chlorophyll, however, were apparent in the northcentral and southeastern portions of the image which resulted in a leveling out of the mean chlorophyll concentration at 0.29 mg/m$^3$. The area frequency analysis showed the major chlorophyll concentration peak at about 0.19 mg/m$^3$ with a secondary substantial peak at 0.40 mg/m$^3$ (Fig. 5D).

## Discussion of the Chlorophyll Bloom

A completely satisfactory explanation for the chlorophyll bloom sensed by the CZCS on 29 September 1979 is not possible due to the lack of accompanying surface truth information. However, a plausible explanation is available from meteorological data provided by the National Climatic Clenter of the National

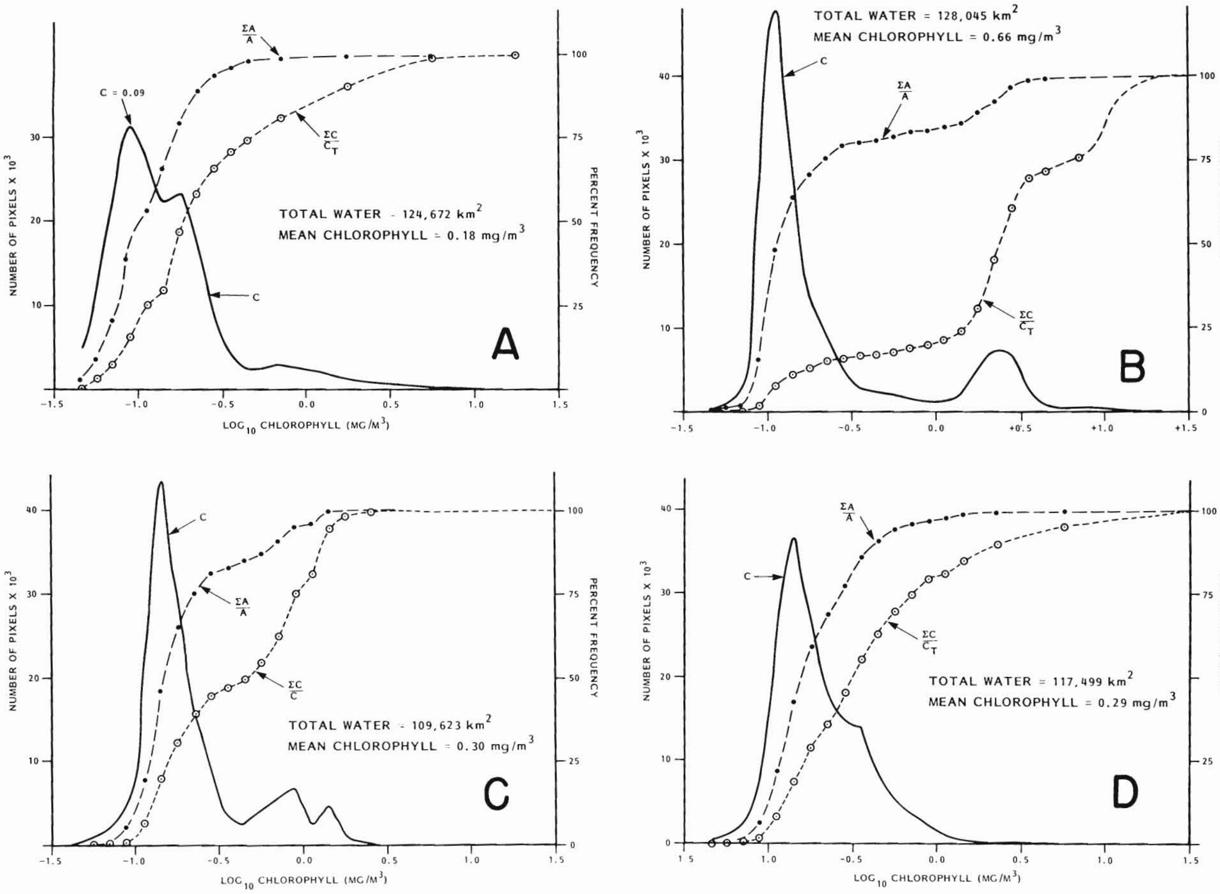


Figure 5.—Statistical analysis of water pixels of Figures 4A-D. Solid lines are frequency distributions of number of pixels (area) vs. chlorophyll concentration. Dashed lines are cumulative chlorophyll distributions as a percentage of total chlorophyll. Dotted lines are corresponding cumulative area distributions as a percentage of total water area.

Oceanic and Atmospheric Administration. These data show that the western Gulf of Mexico experienced severe changes in meteorological conditions during the CZCS coverage period (Fig. 6).

On 21 August 1979, the date of the first CZCS coverage, surface winds were light and easterly or southeasterly in the southwestern Gulf of Mexico (Fig. 6A). From 10 to 15 September 1979, wind circulation in the entire Gulf was dominated by Hurricane Frederick (Fig. 6B) which passed through the central Gulf and made landfall near Pascagoula, Miss. Hurricane Henri was spawned in the southwestern Gulf on 17 September 1979, and on 18 September 1979 was only about 200 km east-southeast of Cabo Rojo (Fig. 6C). Winds along the coast north of Cabo Rojo were northeasterly at about 20.5 m/second (40 knots) while maximum winds near the eye of the hurricane were near 38.6 m/second (75 knots). While these wind directions are not favorable for coastal upwelling, their magnitude coupled with the low atmospheric pressures associated with Hurricane Henri could cause extreme vertical mixing bringing cooler water and nutrients into the surface layers. Presumably, it was this vertical mixing which led to the chlorophyll bloom sensed by the CZCS on 29 September 1979. Hurricane Henri was downgraded to a Tropical Depression on 19 September 1979, and remained in the southwest Gulf for nearly 3 days before drifting to the northeast and dissipating on 24 September 1979.

By 29 September 1979, the date of the chlorophyll bloom sensed by CZCS, all traces of Hurricane Henri had vanished and winds were generally light and northerly along the east coast of Mexico (Fig. 6D). These winds would not have been conducive to coastal upwelling. Offshore winds near Yucatan were also light, but could have tended to drive surface waters toward the north. On 3 October 1979, surface winds were still light and variable, but generally northerly in the southwestern Gulf (Fig. 6E). Winds in this direction could have led to downwelling along the coasts of Mexico and Yucatan. Between 3 and 15 October 1979, the winds turned to northeasterly and intensified to between 5.1 and 12.9 m/second (10-25 knots). Wind driven transport would have caused a

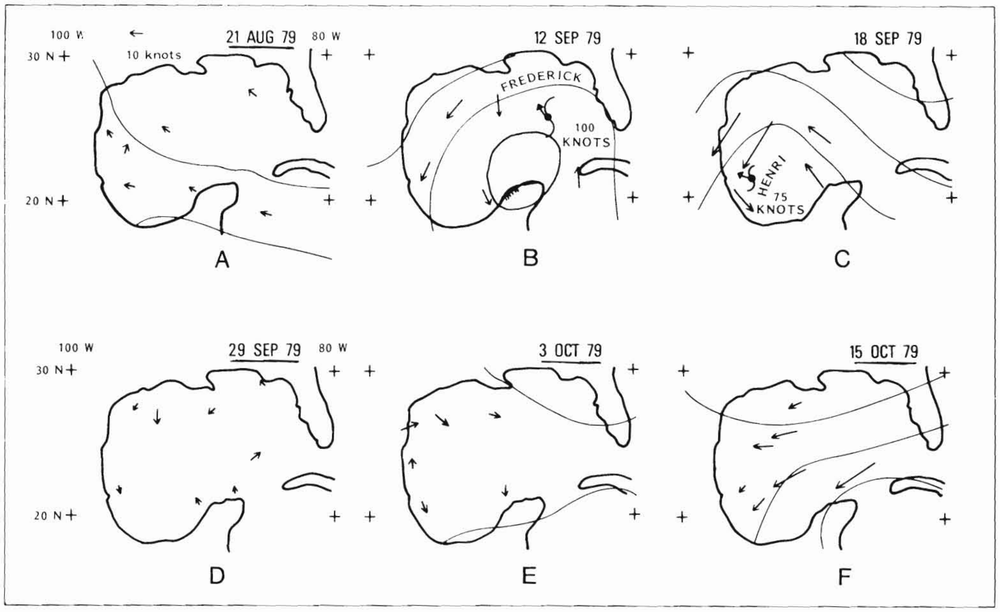


Figure 6.—Selected meteorological surface analysis charts for the Gulf of Mexico. Underlined dates are those for CZCS images in Figure 4A-D. Arrows are relative wind velocity vectors and solid lines are surface isobars.

piling up of water along the east coast of Mexico and strong downwelling would be expected (Fig. 6F). The same winds also would be expected to drive surface waters away from the Yucatan coast toward the central Western Gulf. These winds may have been the reason for the relatively chlorophyll-rich waters in the southeastern corner of the 15 October 1979 CZCS image.

## Conclusions and Recommendations

The Remote Sensing and Technology Working Groups of MEXUS-Gulf have been relatively inactive since the inception of MEXUS-Gulf. Even with a low level of activity, however, significant progress has been achieved primarily in areas related to animal tracking and satellite remote sensing. The progress in these areas suggest the working groups should concentrate more of their efforts in these two areas to develop associations which ultimately could lead to a broadening in the scope of cooperative research by Mexico and the United States. Efforts should be intensified to train Mexican scientists in satellite image processing and then to seek out means so these scientists could have time available to them on image processing systems already in Mexico. The possibility of a cooperative tracking study of a Kemp ridley sea turtle with the newly developed ARGOS transmitters also should be explored.

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