X-590-73-248
PREPRINT

NASA TM X- 70717

OCEAN TIDES AND QUASI-STATIONARY DEPARTURES FROM THE MARINE GEOID INVESTIGATION

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(NASA-TM-X-70717) OCEAN TIDES AND QUASI-STATIONARY DEPARTURES FROM THE MARINE GEOID INVESTIGATION (NASA) 25 p HC $4.25 CSCL 08C

N74-31849

Unclas
G3/13 46715

JANUARY 1973

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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January, 1973

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OCEAN TIDES AND QUASI-STATIONARY DEPARTURES
FROM THE MARINE GEOID INVESTIGATION

1. Scientific/Technological Description of the Investigation

The proposed investigation is an exploratory one intended to be a companion to the Ocean Geoid Determination Investigation. The data generated in connection with the latter investigation will, it is anticipated, also contain some information which may permit initial detection of tides and/or currents.

The GEOS-C altimeter will provide information about the location of the sea surfaces. In order to infer the location of the geoid, i.e., the mean sea level, from these data, it will be necessary to develop information about the quasi-stationary and periodic departures of the sea surface from its mean position. Initially, predictive information will be used to estimate the quasi-stationary departures due, e.g., to currents and wind setup, and the periodic departures due to the tides. In the neighborhood of the western North Atlantic calibration region it is anticipated that the tracking of GEOS-C should yield the spacecraft altitude relative to the ground station configuration with accuracies of the order of half a meter. The GEOS-C altimeter operating in its localized mode is expected to have a half-meter accuracy capability. The M_2 semi-diurnal tidal component and the altitude increment across the Gulf Stream in this region are each estimated to be of the order of a meter. Accordingly, there exists the possibility that each of these features may actually be observed.

The principal objective of the investigation is to do this. Such determinations will be sought in connection with the Ocean Geoid Determination Investigation in order to find the geoid itself.

The largest tidal amplitude to be found on earth occurs in the Bay of Fundy. The GEOS-C altimeter system should easily be capable of observing it, provided it can operate close enough to land.

The importance of the anti-amphidromic regions has been emphasized by Hendershott and pointed out to one of us (Siry) by Zetler (8, 9, 28, 37, 38). The deployment of accurate tracking systems in the Caribbean and U.S. areas may permit an attempt to detect the anti-amphidromic region in the eastern Pacific, although the observing situation there is not the most promising.

The best opportunity to investigate these fundamental characteristics of the tides occurs in the eastern Atlantic. The operation of three ten-centimeter lasers in this area as discussed in a later section of this proposal would permit a serious attempt to study this key phenomenon.

The purpose of this investigation proposal is to indicate observing strategies designed to illuminate the tidal an' Gulf Stream features in western North Atlantic area, and to propose that the anti-amphidromic regions, particularly the one in Atlantic, be studied at or after the end of Phase I of the GEOS-C program. The Atlantic anti-amphidromic experiment, for example, would involve the redeployment of 10-cm lasers.

Discussions of some of these experiments have been presented at meetings concerned with these topics. (3, 30, 31, 32)

2. Background

The departure of the ocean surface from the geoid can be thought of in terms of tidal phenomena and the features of the general circulation, including current patterns and features associated with currents such as the meanders of the Gulf Stream.

Tidal phenomena have been studied by Hendershott, Munk and Zetler (8, 29, 37). Hendershott and Munk describe a model involving a number of amphidromic points which can be obtained by solving the Laplace Tidal Equations (LTE) in the case where coastal values are given. This model for the M_2 semi-diurnal tidal component appears in Figure 5.(8) Cotidal lines for the Atlantic Ocean which are due to Hansen appear in more detail in Figure 3.(27) Amplitudes of the order of a meter occur in the western North Atlantic.

Hendershott has pointed out that the regions separating the amphidromic points in which the tidal range is large and the phase is slowly varying are of greater interest than the amphidromes themselves because the tidal potential energy is largely to be found in these anti-amphidromic regions. He suggested that the most important of these regions have their centers at approximately 0°N, 15°W; 15°S, 75°E; 5°N, 135°W; 10°S, 115°W. (38). Zetler has also called the attention of one of us (Siry) to the importance of these regions (28). Their locations are indicated in Figure 5.

The possibility and importance of observing currents such as the Gulf Stream has been pointed out by Von Arx and his colleagues (19).

Considerable effort has been devoted to the study of the meanders of the Gulf Stream. This research is discussed by Hansen (26). The Gulf Stream proper can be thought of as a Kelvin wave. Departures from this model are also of interest here.

In the study described by Hansen, the position of the Gulf Stream between Cape Hatteras and approximately 60° west longitude was observed at intervals ranging from a few days to a month. The 15° isotherm was chosen as an index of the main thermal front at a depth of 200 meters, and hence as an indication of the Gulf Stream position (26).

Wavelike features having wavelengths of 200-400 km were observed. Hansen shows them in Figure 1.(26) The evolution of the meanders in terms of phase progression is indicated in Figure 2.(26) It is seen there that the meanders progress at a rate of the order of a mean wavelength, taken to be 300 km, each couple of months. This corresponds to about 5 km/day.

Altitude variations across much of the Gulf Stream due to the geostrophic effect are of the order of a meter.

Some information about its position will be available from sources other than GEOS-C.

The inclination of 65° also makes it possible to study the antarctic circumpolar current which is of interest for more than one reason. It is the only continuous current which corresponds to a closed circuit or curve on the globe. It is also the strongest current, being equivalent in terms of mass flux to five or six Gulf Streams.

3. Objectives

The objective of this investigation is to attempt to detect tides and/or currents through analysis of the data generated in connection with the Ocean Geoid Determination Investigation.

The short-term objectives involve the analysis of data from the first year of GEOS-C operation when precise lasers are located in the western North Atlantic and Caribbean areas and ATS-F is at 94°W. The aims are to detect the M_2 semi-diurnal tidal component and the altitude increment across the Gulf Stream in the western North Atlantic. Meanders of the Gulf Stream will probably also be noticeable, particularly if a 10-centimeter laser station is located somewhere in the Boston-Newfoundland region. The attempt will also be made to detect the anti-amphidromic region in the eastern Pacific.

The longer term objectives are to study more closely the anti-amphidromic regions, particularly the one in the eastern Atlantic. It is proposed to do this toward the end of Phase I of the GEOS-C program, when ATS-F is near 15°W, and at other times when precise lasers can be deployed to other locations.

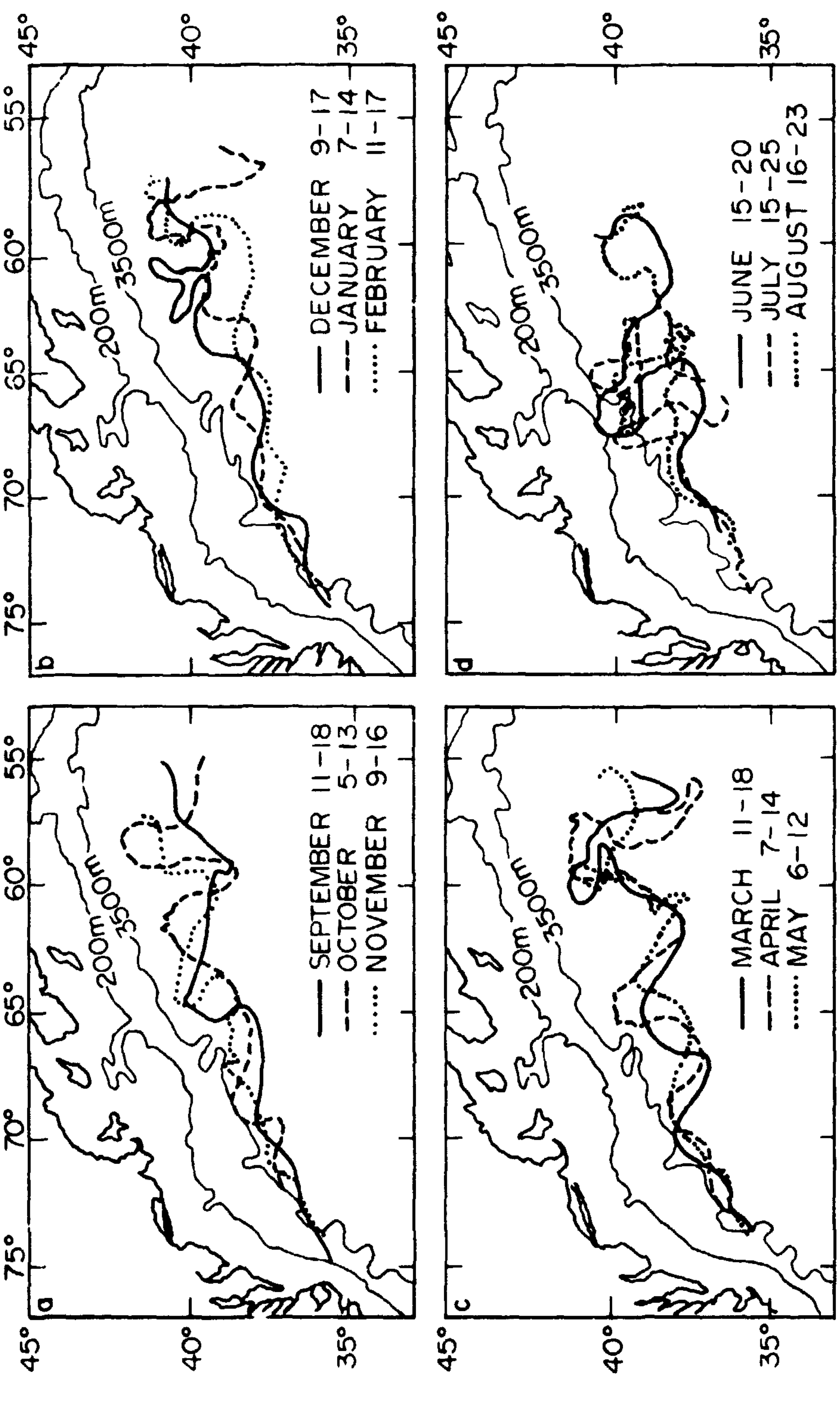

a
b
c
d
200m
3500m
SEPTEMBER 11-18
OCTOBER 5-13
NOVEMBER 9-16
DECEMBER 9-17
JANUARY 7-14
FEBRUARY 11-17
MARCH 11-18
APRIL 7-14
MAY 6-12
JUNE 15-20
JULY 15-25
AUGUST 16-23
75°
70°
65°
60°
55°
45°
40°
35°

Figure 1

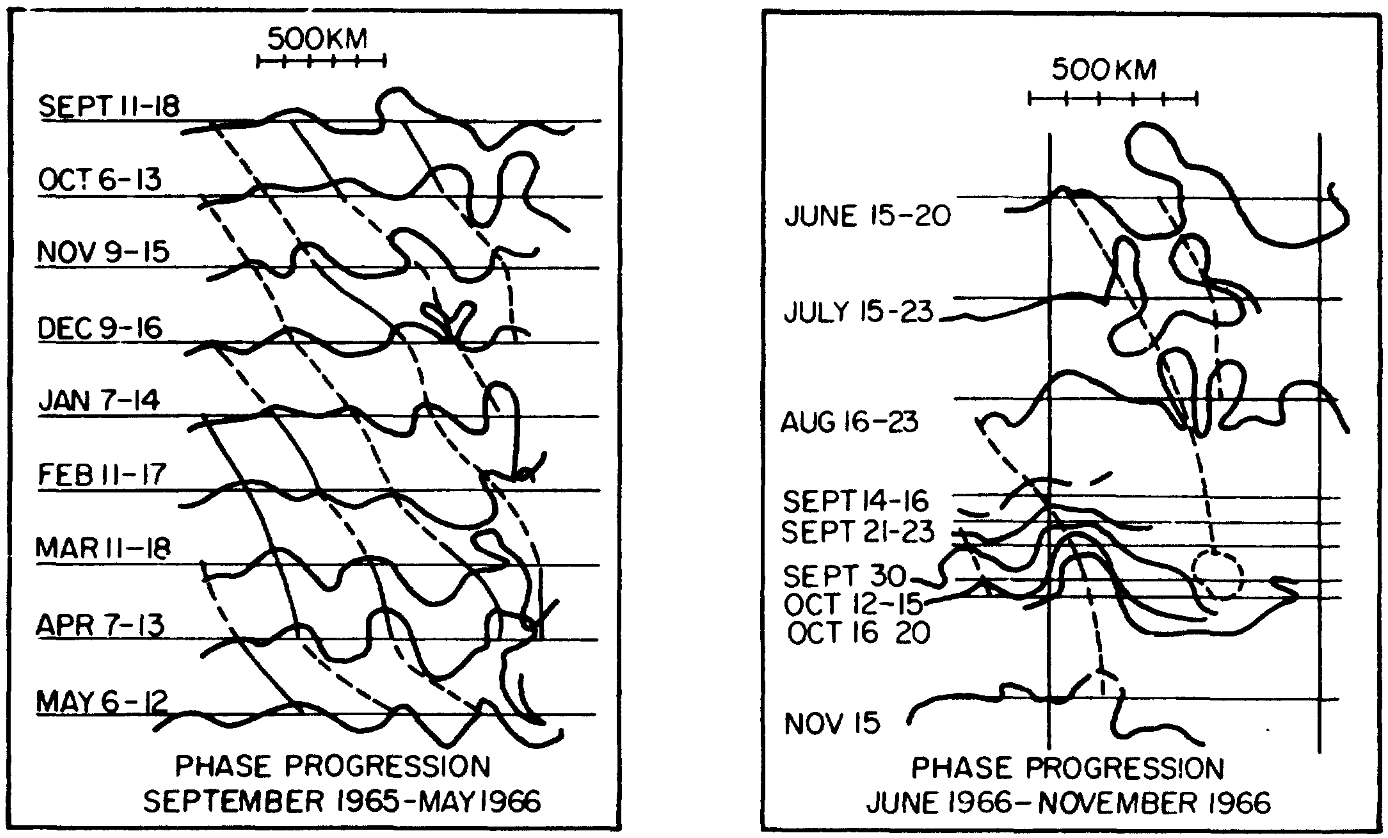

500KM
SEPT 11-18
OCT 6-13
NOV 9-15
DEC 9-16
JAN 7-14
FEB 11-17
MAR 11-18
APR 7-13
MAY 6-12
PHASE PROGRESSION
SEPTEMBER 1965-MAY 1966
500 KM
JUNE 15-20
JULY 15-23
AUG 16-23
SEPT 14-16
SEPT 21-23
SEPT 30
OCT 12-15
OCT 16 20
NOV 15
PHASE PROGRESSION
JUNE 1966-NOVEMBER 1966

Figure 2

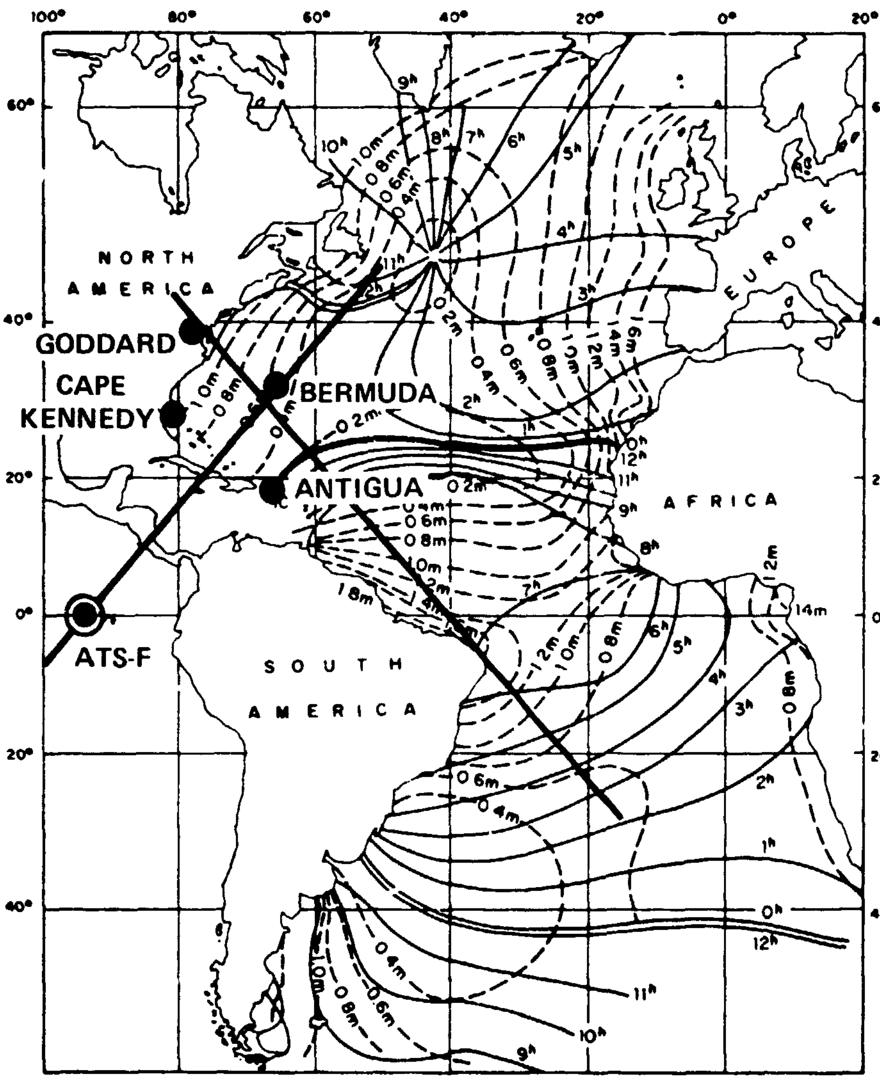
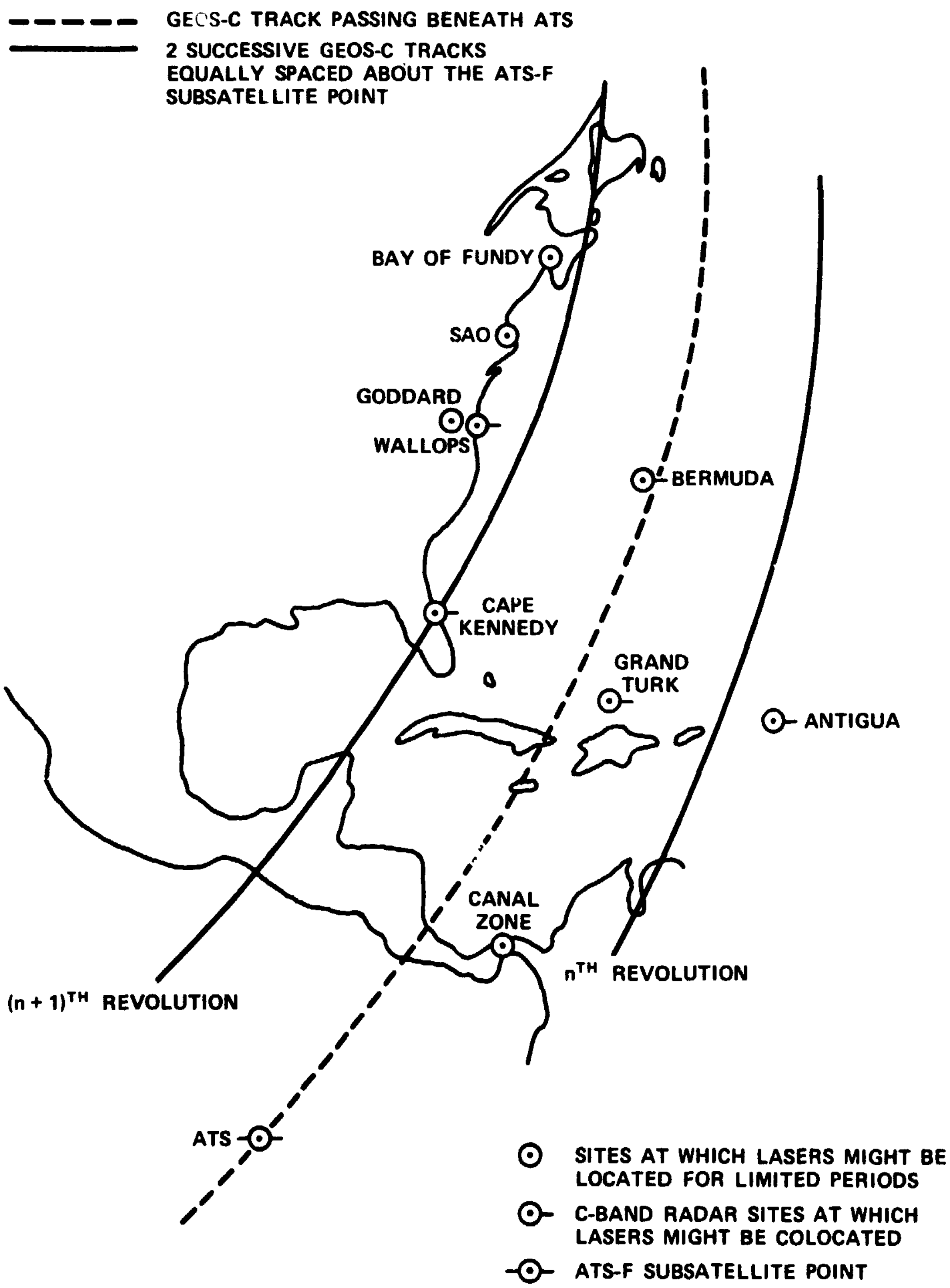


FIG. 3. THEORETICAL TIDES OF ATLANTIC OCEAN. FULL LINES: CO-TIDAL LINES REFERRED TO MOON-TRANSITION THROUGH MERIDIAN OF Grw., DASHED LINES: CO-RANGE LINES OF THE SEMI-DIURNAL TIDE M_2 IN m (ACCORDING TO HANSEN).

● SITES AT WHICH LASERS MIGHT BE LOCATED FOR LIMITED PERIODS

◉ ATS-F SUBSATELLITE POINT



GEOS-C TRACK PASSING BENEATH ATS
2 SUCCESSIVE GEOS-C TRACKS EQUALLY SPACED ABOUT THE ATS-F SUBSATELLITE POINT
BAY OF FUNDY
SAO
GODDARD
WALLOPS
BERMUDA
CAPE KENNEDY
GRAND TURK
ANTIGUA
CANAL ZONE
(n + 1)TH REVOLUTION
nTH REVOLUTION
ATS
SITES AT WHICH LASERS MIGHT BE LOCATED FOR LIMITED PERIODS
C-BAND RADAR SITES AT WHICH LASERS MIGHT BE COLOCATED
ATS-F SUBSATELLITE POINT

Figure 4

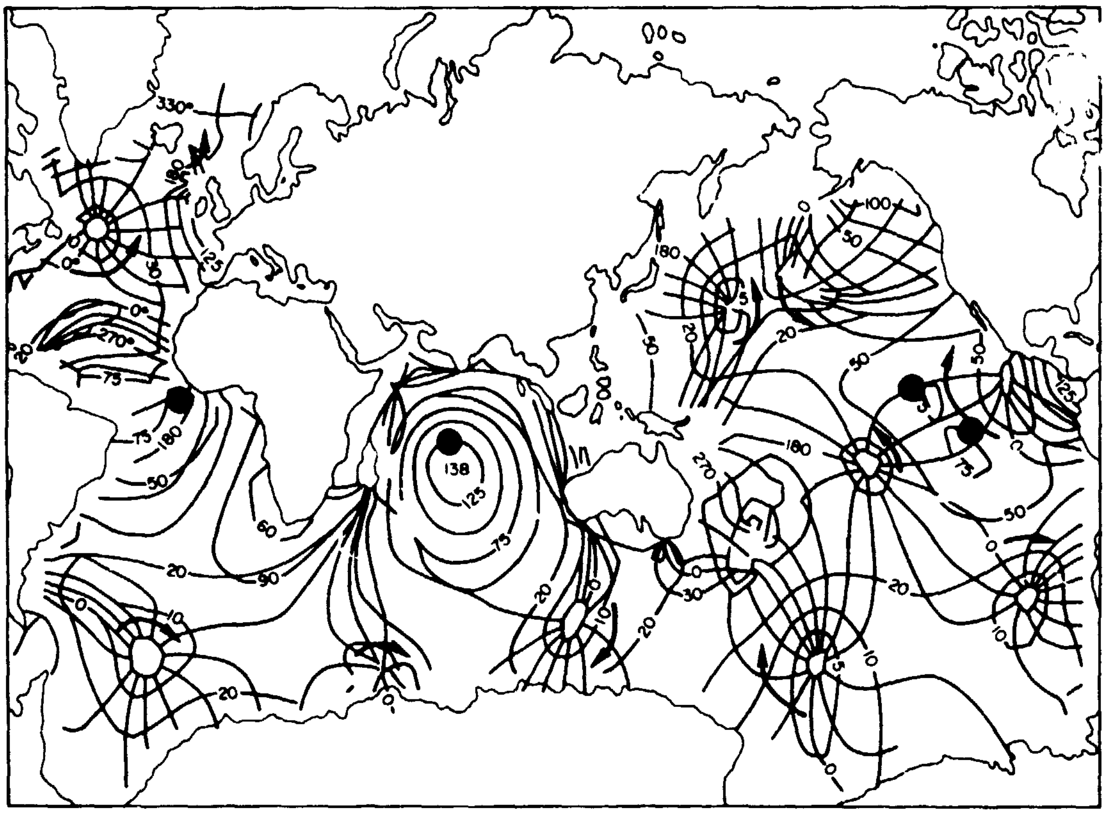


FIGURE 5. COTIDAL AND CORANGE LINES FOR THE M_2 TIDE OBTAINED BY SOLVING LTE WITH COASTAL VALUES SPECIFIED. COTIDAL LINES RADIATE FROM AMPHIDROMIC POINTS, CORRESPONDING TO THE PROGRESSION OF TIDAL CRESTS IN THE SENSE INDICATED BY THE HEAVY ARROWS AROUND THESE POINTS OF VANISHING TIDAL RANGE. HIGH TIDE OCCURS ALONG THE COTIDAL LINES LABELED 0° JUST AS THE MOON PASSES OVER GREENWICH MERIDIAN. SUCCESSIVE COTIDAL LINES DELINEATE TIDAL CRESTS AT LUNAR HOURLY INTERVALS. (FOR CLARITY, ONLY SELECTED COTIDAL LINES ARE LABELED, 30° CORRESPONDS TO A DELAY OF ONE LUNAR HOUR.) CORANGE LINES (5, 10, 20, 50, 75, 100, 125 cm) CONNECT LOCATIONS OF EQUAL TIDAL AMPLITUDE (NOT DOUBLE AMPLITUDE). THEY SURROUND AMPHIDROMIC POINTS (WHERE RANGE VANISHES AND PHASES VARY RAPIDLY) AND RANGE MAXIMA (WHERE RANGE IS LARGEST AND PHASES NEARLY CONSTANT).

● CIRCLES INDICATE APPROXIMATE LOCATIONS OF CENTERS OF ANTI-AMPHIDROMIC REGIONS

The discussion of detailed aspects of the objectives is included together with the discussion of the approach.

This investigation can help lay the ground work for the EOPAP.

4. Approach

The Atlantic region off the coast of the Northeastern United States is of particular interest from the standpoint of the Gulf Stream meanders as was indicated in Figure 1 which is given by Hansen (26). These features have amplitudes on the order of a meter. Tidal variations in this same region, while not quite as large as those found elsewhere, are nevertheless of considerable size, i.e., of the order of a meter also. This is indicated in Figures 3 and 5 where certain tidal components are seen.

This region is also a reasonably attractive one from the standpoint of some of the practicalities of short arc tracking. Good advantage could be taken of lasers which are usually available at Goddard, Wallops Island, and possibly also at SAO. Other possible locations for lasers include Florida, Bermuda, the Canal Zone, and the Antilles, at Antigua and/or Grand Turk. C-band radars are also located at Wallops Island, Cape Kennedy, Bermuda, Antigua and Grand Turk. It would be valuable also to have an additional site near the point on the Bermuda meridian which is as far north of Goddard as Goddard is north of Bermuda. A laser at this location which is near the coast of the Bay of Fundy would be of interest not only from the point of view of oceanographic studies but also for earth dynamics studies. A site at this point, which is in Canada, or in nearby Maine would be suitable. It is anticipated that lasers will be located at some of the continental US sites shown in Figure 4 and that at least a couple of portable lasers will be available at times for use at some of the other sites indicated there. Three of these lasers in any of the triangular configurations in that map operating at the 10 cm accuracy level would make it possible to determine the altitude of GEOS-C with a relative accuracy of the order of half a meter or better in the neighborhood of the triangle. A Fourth laser nearby would provide the important checks on the instrumental biases by furnishing the redundant information. It would also reduce the impact of the cloud cover problem.

A. Gulf Stream Meander Studies

The altimeter tracking patterns are also good for observing the Gulf Stream meanders in this region. Shown in Figure 9 are surface tracks of the 65° orbit with 6° daily spacing. It is seen that the northward and southward going tracks cross the two principal branches of a typical Gulf Stream meander nearly orthogonally, providing almost ideal geometry for studying the behavior of these interesting features. Each ground track seen in Figure 9 will be followed four days later by one removed a degree or two from it, hence it will be possible to observe each feature once every four days. This frequency is well matched to the observational needs of a Gulf Stream meander experiment, as can be seen from inspection of Figures 1, 2 and 9. (26) The mean wavelength of a meander is often of the order of 300 kilometers, as was indicated above in the discussion associated with Figures 1 and 2. A typical meander moves a distance equal to its own wavelength in about a couple of months. This interval might be thought of as a characteristic time constant which can be associated with the Gulf Stream meanders in this sense. Observations every four days are well suited for a Gulf Stream meander experiment. In fact observations every ten days or so would be most welcome, as Hansen has already pointed out (26). This also allows a margin for gaps in the observing program which might be due to such things as weather conditions or operational factors.

Similar studies of the Kuroshio current could be conducted by means of lasers similarly placed in Japan and nearby islands such as Iwo Jima, say.

B. Tidal Studies

i. An Anti-Amphidromic Region Tidal Study

The anti-amphidromic region in the Sierra Leone Basin area which is indicated in Figure 6 is perhaps potentially the most suitable for study by means of the GEOS-C altimeter and orbit determination system since it is adjacent to island and coastal sites at which tracking lasers might be located. A US tracking facility is on Ascension Island. The French already have had a laser at Dakar and operated ground terminal facilities at Ouagadougou. The Syncom satellites were tracked by a radio range and range rate system from a ship at anchor in the harbor of Lagos, Nigeria. These would be suitable sites from the scientific standpoint for tracking by means of 10 cm lasers. A set of three lasers at Freetown, Abidjan and Ascension might be even somewhat better from the geometric standpoint. No arrangements have been made at the present time for 10 cm laser tracking from any of these sites. The location in the Lagos/ Abidjan area will be referred to simply as the Gulf of Guinea site.

Tracks of GEOS-C in this Sierra Leone Basin anti-amphidrome laser triangle region are seen in Figure 6. Twice each day the ground track passes through or very close to this triangle. At least one northbound track of the type seen, for example, would occur each day in the neighborhood of the triangle. These tracks are seen to be nearly orthogonal to the co-range lines of the semi-diurnal tide. Southbound tracks, nearly parallel to the co-range lines also

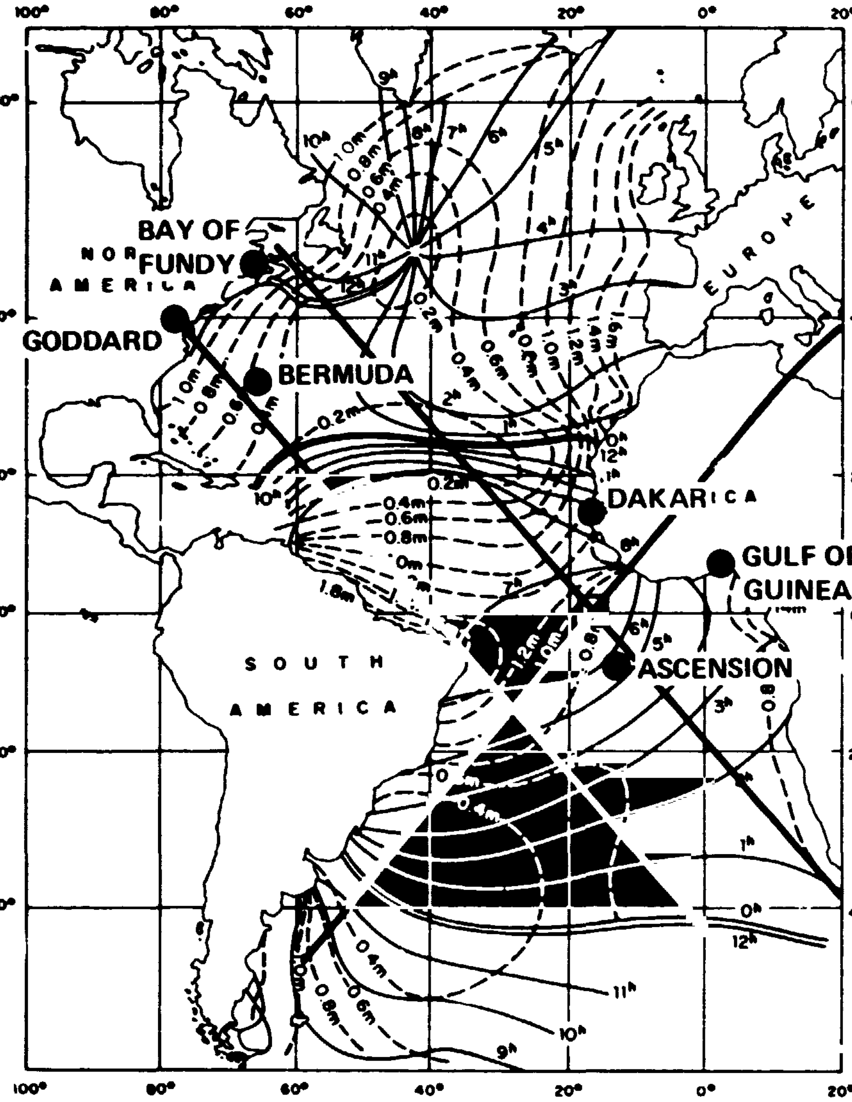


FIG. 6. THEORETICAL TIDES OF ATLANTIC OCEAN. FULL LINES: CO-TIDAL LINES REFERRED TO MOON-TRANSITION THROUGH MERIDIAN OF Grw., DASHED LINES: CO-RANGE LINES OF THE SEMI-DIURNAL TIDE M_2 IN m (ACCORDING TO HANSEN).

☐ APPROXIMATE CENTER OF ANTI-AMPHIDROMIC REGION

● SITES AT WHICH LASERS MIGHT BE LOCATED FOR LIMITED PERIODS occur daily in useful locations. The orbit of GEOS-C will have the property of moving about 10.5 degrees each day relative to the moon. A complete cycle of the semi-diurnal lunar tide can be observed by GEOS-C about once every 17 days. The daily observations of GEOS-C in the Sierra Leone Basin anti-amphidrome region would thus occur about 10.5° apart in this cycle, and hence provide ideal data for sampling this important tidal component. The interval between one day and the next can be thought of as corresponding to a bit over two-thirds of an hour in terms of the semi-diurnal cycle.

The ATS-F satellite will pass directly over the Sierra Leone Basin anti-amphidrome region as it moves from 94° west longitude to 34° east longitude. It will be within about 30° of the nominal center of the region on the equator at 15° west longitude for the duration of the 17-day interval in which GEOS-C can sense a complete cycle of the semi-diurnal lunar tidal component. Satellite-to-satellite tracking between ATS-F and GEOS-C would certainly augment the laser capability. It may make it possible to conduct a useful investigation with a smaller number of lasers. Its value would be enhanced if it remained within about 13° of the center of the region for the entire 17 day cycle. Such a drift rate in this region, which is about half the one currently planned, would provide an observing interval of some 26°. This is comparable with the characteristic GEOS-C observing span which is associated with the fact that its equator crossings in the neighborhood of a given point from day-to-day range over a 26° longitude interval.

The GEOS-C altimeter operating in the 0.5 meter accuracy mode with the relative orbital altitude determined to about half a meter should permit tidal observations to about a meter or better. The GEOS-C systems thus offer the possibility of conducting an initial, exploratory tidal experiment in the Sierra Leone Basin anti-amphidrome region.

Satellite-to-satellite tracking from ATS-F at 94°W together with laser tracking from American and Pacific sites would open up the possibility of studying the anti-amphidrome regions in the Pacific as is indicated in Figure 7.

Satellite-to-satellite tracking from ATS when it is located at 35°E combined with laser tracking from Indian Ocean sites would make possible an attempt to observe the anti-amphidromic region in the Eastern Hemisphere. This possibility, which is indicated in Figure 8, is perhaps somewhat less favorable than the others.

The result presented in Figures 5 and 8 indicates that this region may have the largest oscillation amplitude. The predicted amplitudes vary somewhat as functions of the assumptions. The study of each of the major anti-amphidromic

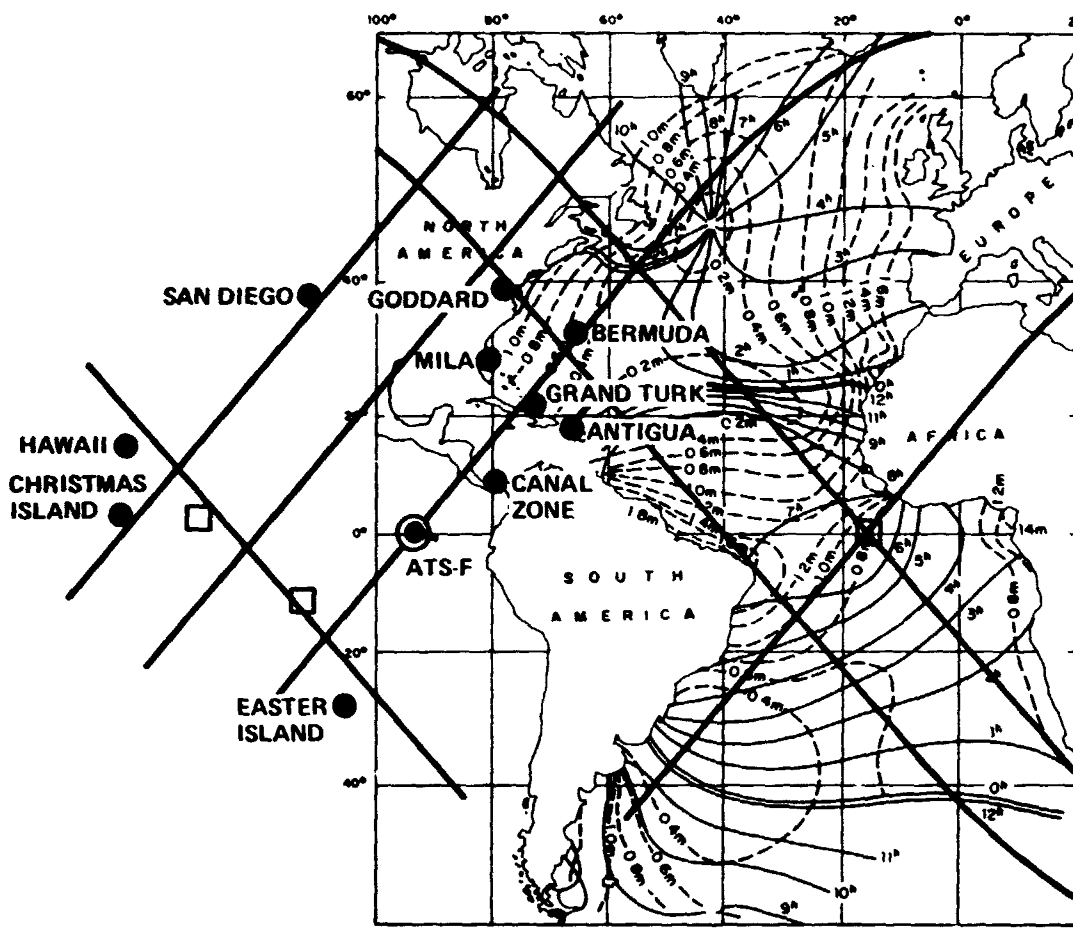


FIG. 7. THEORETICAL TIDES OF ATLANTIC OCEAN. FULL LINES: CO-TIDAL LINES REFERRED TO MOON-TRANSITION THROUGH MERIDIAN OF Grw., DASHED LINES: CO-RANGE LINES OF THE SEMI-DIURNAL TIDE M_2 IN m (ACCORDING TO HANSEN).

● SITES AT WHICH LASERS MIGHT BE LOCATED FOR LIMITED PERIODS

◉ ATS-F SUBSATELLITE POINT

□ APPROXIMATE CENTERS OF ANTI-AMPHIDROMIC REGIONS

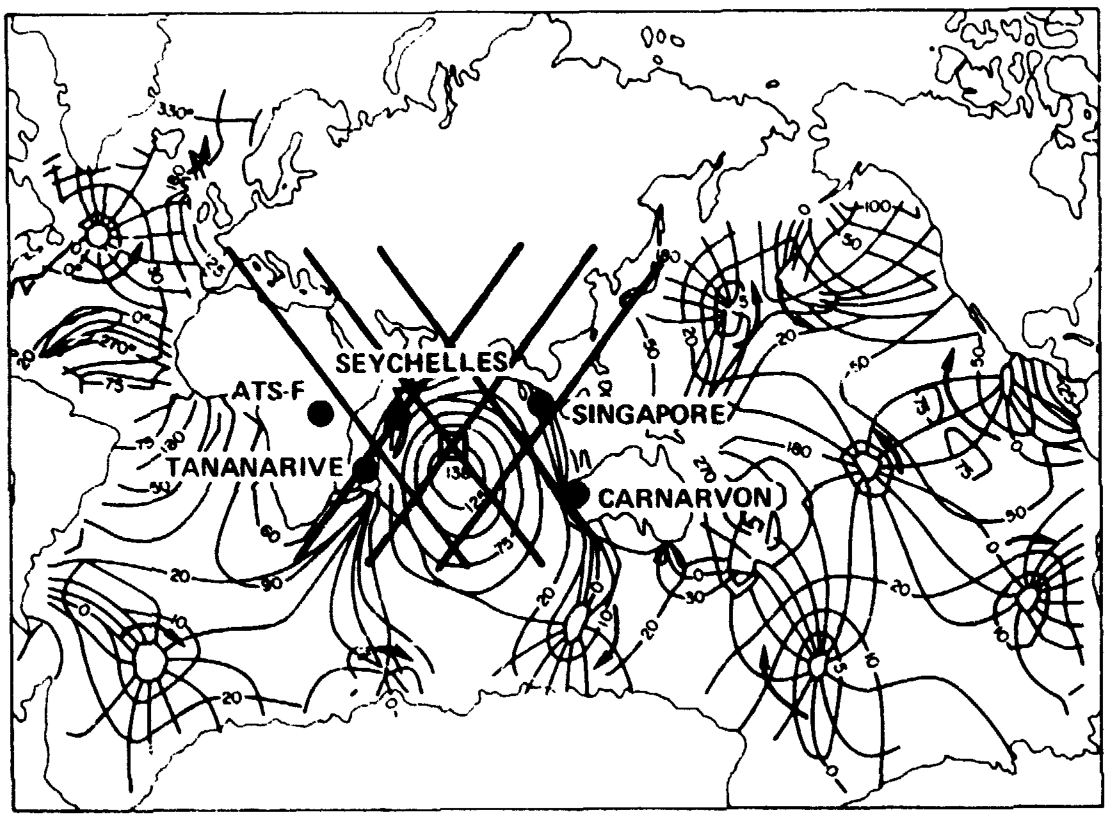


FIGURE 8. COTIDAL AND CORANGE LINES FOR THE M_2 TIDE OBT^INED BY SOLVING LTE WITH COASTAL VALUES SPECIFIED. COTIDAL LINES 'DIATE FROM AMPHIDROMIC POINTS, CORRESPONDING TO THE PROGRESSıJN OF TIDAL CRESTS IN THE SENSE INDICATED BY THE HEAVY ARROWS AROUND THESE POINTS OF VANISHING TIDAL RANGE. HIGH TIDE OCCURS ALONG THE COTIDAL LINES LABELED 0° JUST AS THE MOON PASSES OVER GREENWICH MERIDIAN. SUCCESSIVE COTIDAL LINES DELINEATE TIDAL CRESTS AT LUNAR HOURLY INTERVALS. (FOR CLARITY, ONLY SELECTED COTIDAL LINES ARE LABELED, 30° CORRESPONDS TO A DELAY OF ONE LUNAR HOUR.) CORANGE LINES (5, 10, 20, 50, 75, 100, 125 cm) CONNECT LOCATIONS OF EQUAL TIDAL AMPLITUDE (NOT DOUBLE AMPLITUDE). THEY SURROUND AMPHIDROMIC POINTS (WHERE RANGE VANISHES AND PHASES VARY RAPIDLY) AND RANGE MAXIMA (WHERE RANGE IS LARGEST AND PHASES NEARLY CONSTANT).

○ SITES AT WHICH LASERS MIGHT BE LOCATED FOR LIMITED PERIODS

● ATS-F SUBSATELLITE POINT

□ APPROXIMATE CENTER OF ANTI-AMPHIDROMIC REGION

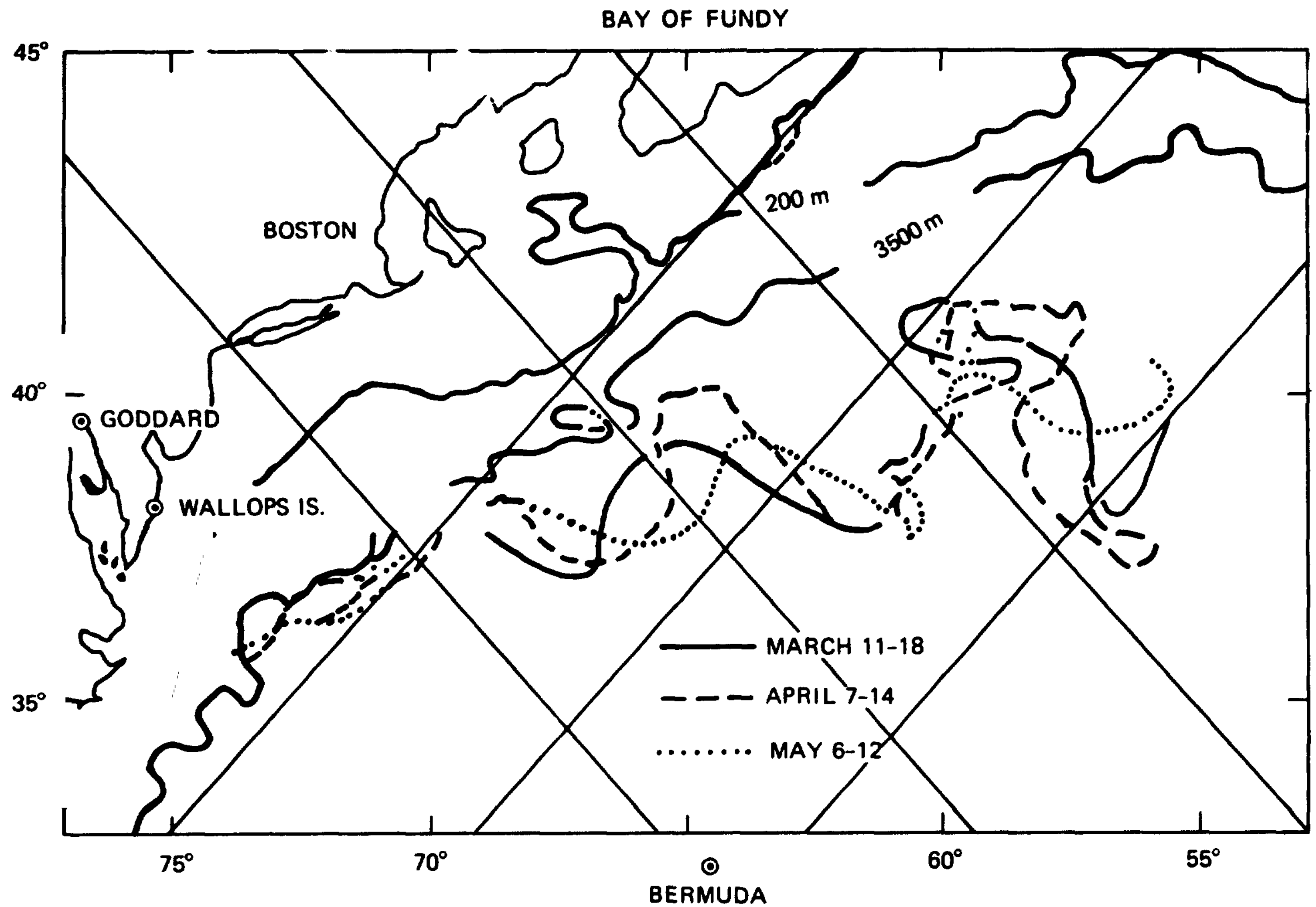

BAY OF FUNDY
45°
40°
35°
BOSTON
GODDARD
WALLOPS IS.
200 m
3500 m
MARCH 11-18
APRIL 7-14
MAY 6-12
75°
70°
60°
55°
BERMUDA

Figure 9

regions is accordingly of interest since information about all of them taken together should help to discriminate between the various models which the theory allows.

ii. A Continental Shelf Tide Study

A tidal experiment in the neighborhood of a continental shelf could be conducted in the western North Atlantic in the region covered by the tracking sites indicated in Figure 4. Amplitudes of the order of a meter are indicated, for example, in Figures 3 and 6. It is anticipated that the behavior indicated there may be modified by the shelf itself. It is anticipated that lasers having 10 centimeter accuracy will be located at sites in this region in connection with the altimeter calibration and the Gulf Stream studies outlined above. Data taken in connection with these activities would also be useful in connection with such a tidal study. Additional observations specifically designed for the tidal investigation would also be needed. We see from Figures 6 and 7 that, again. the GEOS-C Altimeter satellite ground track passes through or very close to the laser tracking region once each day. At least one of the northbound tracks of the type seen in Figure 7 for example, would occur every day. These tracks, are, again, nearly orthogonal to the co-range lines of the semi-diurnal tide as is also apparent from the figure. Southbound tracks, nearly parallel to the co-range lines, also occur daily in useful locations in similar fashion. The GEOS-C orbit will, again, sample of whole semi-diurnal cycle in about two and a half weeks.

iii. A Bay of Fundy Tide Study

Tidal amplitudes in the Bay of Fundy region are the largest on earth. Ranges as high as fifteen meters are found. They should be amenable to direct measurement by the GEOS-C altimeter system. They should provide what may well be the first opportunity for an actual tidal observation by the GEOS-C. They will also furnish a continuing opportunity for a kind of validation or calibration of the ability of the GEOS-C altimeter system to observe tides. (Cf. Figures 4, 6 and 9)

iv. Global Tidal Studies

The use of altimeter data gathered over extended periods of time has been studied by Zetler (29). He finds the prospects to be promising.

5. Data Requirements

Data requirements have been discussed in earlier sections. In particular, the following procedures are proposed.

A. <u>A Continental Shelf Tidal Study</u>

This study requires all altimeter tracks occurring in the GEOS-C calibration region in both directions, i.e., north-south and south-north, for at least one complete lunar tidal cycle, i.e., about two and a half weeks, and preferably for two such cycles. (Cf. Figure 3) A set of tracks which do not occur in an uninterrupted sequence can, in principle, be used to study the phenomenon. Effects of obscuring factors are, however, minimized if a continuous sequence spanning an entire lunar cycle is available. A second such set provides redundancy. The attempt should be made to obtain all possible tracks since weather problems will tend to interrupt the sequences in any event.

B. <u>A Gulf Stream Meander Study</u>

This study requires tracks in both directions, i.e., north-south and south-north, at least once every four days and preferably once every two days, in the Gulf Stream meander region indicated in Figure 9. Again, if the attempt is made to observe on at least one pair of passes, i.e., north-south and south-north, each day, a reasonable set of data will be obtained in spite of weather problems. These tracks should be obtained at least over a complete cycle, i.e., over a two-month period. The term period is used somewhat more loosely in the case of this phenomenon, hence, a longer period of observation, say four months, would be very valuable.

The geometry of the situation calls for a 10 cm laser somewhere in the Boston-Newfoundland region. A site with relatively good weather conditions would be most desirable.

C. <u>An Eastern Pacific Anti-Emphidromic Region Study</u>

This experiment, while not an optimum one for studying anti-amphidromic regions, can, nevertheless, be attempted with ATS-F located at 94°W and the 10-cm lasers located in the GEOS-C calibration region in the Caribbean, U.S., and western North Atlantic areas.

Each day for at least a two and half week period, and preferably for two such periods, the two GEOS-C north-south ground tracks which are closest to the ATS-F subsatellite point at 94°W should be tracked throughout a revolution pass. Every SST pass should span the entire period of continuous visibility from ATS-F in a given revolution. The range rate integration interval should be 10 seconds. Range data should be taken at least once each 5 minutes at 1 second intervals for at least 20 seconds.

Each altimeter data pass should be accompanied by ground tracking, during a two revolution interval centered on the mid-time of the second of these altimeter passes, from all laser and Tranet Doppler stations and, as power permits, all C-band and USB stations whenever GEOS-C is above 5° elevation. Laser data should be taken at 1 second intervals or the shortest convenient interval, which ever is longer. Tranet data should be taken at the shortest convenient interval. C-band and USB data should be at intervals of about 6-10 seconds, or as power resources permit. Altimeter passes in this interval should be tracked by both 10-cm lasers and collocated C-band radars throughout each pass whenever laser visibility occurs in any part of the pass.

It is anticipated that the addition of one 10-cm laser at Easter Island while ATS-F is at 94°W would materially increase the likelihood of conducting an anti-amphidromic tidal investigation in the eastern Pacific area. Satellite-to-satellite tracking from ATS-F would then span the gap between Easter Island and the Caribbean complex of 10-cm lasers, making possible direct observation of the southernmost of the two Pacific anti-amphidromic regions on north-south passes. (Cf. Figure 7) Similarly, ATS-F would bridge the span between Easter Island and Hawaii making possible direct observation of both of the eastern Pacific anti-amphidromic regions in the same south-north pass. The lunar laser at Hawaii, operating in a fixed pointing or non-tracking mode, might serve as the northern anchor point of such an observation line.

D. An Eastern Atlantic Anti-Amphidromic Region Study

This experiment can best be conducted by locating three ten-centimeter lasers in the Sierra Leone Basin anti-amphidrome region in the equatorial Atlantic area off the west coast of Africa which is indicated in Figure 6. Such an experiment would presumably occur after Phase I. Again, all tracks in both directions in the appropriate neighborhood of the laser triangle region should be tracked for at least one two-and-a-half week period and preferably for two such periods. When ATS-F is drifting over this region on its journey from 94°W to 35°E, satellite-to-satellite tracking data from it together with tracking from a smaller number of lasers might contain enough information to make a study.

An ATS-F longitude drift rate of about a degree and a half a day would let it stay reasonably close to this region for one 17-day period. A drift rate half this large would permit fairly good observing over two such periods. This type of experiment will be studied further.

E. An Indian Ocean Anti-Amphidromic Region Study

The study of this region, too, would involve the redeployment of 10-cm lasers to take advantage of the eastern location of ATS-F. The data requirements would be analogous to those for the Eastern Pacific region. They would be keyed, say, to the two GEOS-C south-north passes occurring just east of the ATS-F subsatellite point at 35°E, as is indicated in Figure 8.

The details of the tidal models tend to vary as the tidal researches continue and additional effects are taken into account. The planning of a specific experiment involving the redeployment of lasers in some later period will be based on the then current estimates concerning the locations of the anti-amphidromic regions and the amplitu..es and other characteristics associated with them. The above discussion is included to indicate general directions for future GEOS-C research activities which appear to be promising.

It is requested that all data formats to be used be specified as far in advance of the launch as is practicable.

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