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REMOTE DETECTION OF OCEAN FEATURES IN THE LESSER ANTILLES USING ERTS-1 DATA

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16. Abstract
Photographic data received from the ERTS-1 satellite over the Lesser Antilles Islands show distinct ocean features on the leeward side of each island. Attempts to relate these features to ocean eddy formations with the aid of ground truth data proved unsuccessful. However, surface and upper air wind data indicate a good correlation with the size, shape, and downwind extent of the ocean features.

Studies to date indicate strongly that these features result from horizontal differences in sea surface roughness due to the wind shadow effect of the islands. The results suggest that horizontal variations in the reflectance of the sea surface will make remote sensing of the ocean mixed layer more difficult than previously anticipated. The surface reflection seems to be large enough to mask the smaller horizontal variations in backscattered energy from the mixed layer.

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Figure 2. Technical Report Standard Title Page

FIGURES

ERTS-1 IMAGE IDENTIFICATION

FIGURE	OBSERVATION ID	CENTER POINT COORDINATES	MSS BAND
1	1082-13541	15.941N/60.278W	4-7
	1082-13544	14.492N/60.625W	4-7
	1082-13550	13.051N/60.973W	4-7
	1082-13553	11.621N/61.325W	4-7
	1083-14000	15.908N/61.770W	4-7
	1083-14002	14.474N/62.135W	4-7
	1083-14005	13.045N/62.489W	4-7
	1083-14011	11.605N/62.838W	4-7
2	1065-14000	14.465N/62.051W	5
3	1082-13541	15.941N/60.278W	5
	1082-13544	14.492N/60.625W	5
	1082-13550	13.051N/60.973W	5
	1082-13553	11.621N/61.325W	5
	1083-14000	15.908N/61.770W	5
	1083-14002	14.474N/62.135W	5
	1083-14005	13.045N/62.489W	5
	1083-14011	11.605N/62.838W	5
4	1119-14005	14.478N/62.166W	5
	1119-14012	13.032N/62.520W	5
	1119-14014	11.569N/62.866W	5
5	1209-14004	15.950N/61.867W	5
	1209-14010	14.517N/62.217W	5
	1209-14013	13.083N/62.467W	5
6	1244-13551	15.967N/60.550W	5
	1244-13553	14.533N/60.900W	5
	1244-13560	13.100N/61.250W	5
	1244-13562	11.667N/61.583W	5

TABLE

1. Observed wind speeds and directions and estimated direction of ocean surface features in the lee of the Antilles Islands.

1. INTRODUCTION

Investigations near Johnston Atoll by Barkley (1972) have shown that sufficient oceanic current flow produces a wake dominated by eddies on the leeward side of the island. Eddies with a cyclonic rotation bring deep water to the surface and, if the water is rich in nutrients, it could contribute significantly to the productivity of the area.

An example of this form of productivity enhancement was detected during a fishery oceanography survey of the eastern Caribbean near St. Vincent Island. Ingham and Mahnken (1966) found that tuna schools and bird flocks were concentrated in an area west of this Lesser Antilles island. They also noted that plankton and primary productivity in the mixed layer were higher in this area than the Atlantic, and that oceanographic data revealed the existence of horizontal temperature differences in the upper thermocline which might indicate the presence of eddy-like features in the ocean. They suggested the possibility that the increased productivity of this area is a consequence of downstream turbulence on the Caribbean side of St. Vincent Island.

The detection of eddy-like formations in the ocean is possible from satellite altitude because greater concentrations of chlorophyll and nutrients within the eddy cause horizontal variations in the backscattered solar radiation reaching satellite altitude. An ocean feature similar in size to those mentioned by Ingham and Mahnken was seen in a density sliced and color enhanced GEMINI VII photograph taken over Guadeloupe Island. The ocean feature was most clearly seen in the color enhancement of the green separation negative. (.450-.525 microns.) Because of the capability of the ERTS-1 camera system to simultaneously view the same area through several different band pass filters, we proposed to study the possibility of detecting such oceanic eddies with the use of ERTS images.

ERTS-1, launched in July 1972, collected six MSS (Multispectral Scanner) data sets over the Lesser Antilles region from September 1972-April 1973, when a recording system failure caused the termination of data collection in that area. ERTS-1 positive transparencies in the four MSS bands were obtained for the following dates: 26 Sept., 13-14 Oct., 1 Nov., 19 Nov. 1972, and 17 Feb. and 24 Mar. 1973. The satellite pass over the Lesser Antilles area occurs at approximately 1400 GMT. Each of these data sets indicates ocean surface features on the leeward side of many of the islands. They appear as areas of lower photo density in the ERTS-1 images but do not display the typical vortex pattern normally associated with eddies.

Several techniques to enhance the lower density range of the ERTS-1 positive transparencies have been investigated. Density slicing of the ERTS-1 images through the use of a color densitometer seemed to be the most promising procedure. Several tests showed that the camera system used to detect density differences does not have the precision necessary to improve the features seen in the ERTS-1 transparencies. Tests with multispectral viewers, designed specifically to view transparencies produced from narrow band energies,have indicated that near coastal or shallow water regions may readily be enhanced, but little success has been achieved in enhancing density differences across deep ocean features such as those in the lee of the Lesser Antilles.

The most effective photographic rendition of oceanic features is achieved by simple contact printing of the ERTS-1 positive transparencies, and arranging a spatial composite of the resulting negative prints. In this way the darker features in the lee of the islands appear in the prints as lighter areas. Figure 1 is a mosaic of negative prints for 13-14 Oct. in each of the four MSS bands:

ERTS Band	λ (microns)
MSS 4	.5-.6
MSS 5	.6-.7
MSS 6	.7-.8
MSS 7	.8-1.1

MSS 5 seems to have the optimum sensitivity for detecting these ocean features. The changes in photo density are much more clearly defined in MSS 5 than they are in MSS 4 and slightly clearer than MSS 6 and MSS 7.

2. ERTS-1 DATA INTERPRETATION

2.1 ERTS Photographic Data

Five of the six ERTS-1 data sets are presented in Figures 2-6. The sixth MSS data set, collected on 1 Nov., is not included due to extensive cloudiness over the Antilles arc.

Figure 2 shows the ERTS-1 coverage of the area west of Martinique. Although much of the region is covered with cirrus and small cumulus clouds, two lighter areas are visible near the top of the print. A narrow line extends to the southwest in the lee of the northern tip of Martinique. Another light feature can be seen at the top edge of the negative print to the northwest of Martinique which also extends in a southwest direction parallel with the feature at the northern tip of the island. This feature appears to be originating from the western side of Dominica.

Figures 3 and 4 show the data received for the 13-14 Oct. and 19 Nov. orbits, respectively. In the October data, bright areas can be seen to the west of all the islands from Guadeloupe to Grenada and Tobago. The brightest area is to the west of St. Vincent. The features extend in a west to west-northwest direction away from each island. On 19 November, only moderate indications of ocean features are evident. These features extend slightly south of west in the lee of Martinique, St. Lucia, and Grenada. The longitudinal extent of the 19 November features is much smaller than in the other cases.

Figures 5 and 6 show the remaining ERTS-1 data collected near the Lesser Antilles islands. On 17 February 1973, bright areas in the negative prints can be seen to the west of each island from Guadeloupe to St. Vincent even though several clouds are present. The features in this case extend slightly north of west as opposed to the component south of west noticed on 26 Sept. and 19 Nov. Similarly, on 24 March very bright features are seen on the leeward side of the island arc. These features have a component further north of west than that seen on 13-14 Oct. or 17 Feb.

2.2 Wind and Topography

The winds for each area displayed in Figures 2-6 were averaged to obtain a mean speed and direction for the region. The estimated direction of each ocean feature was also determined by measuring the angle between a meridian and a line drawn through the center of each feature. An average angle was calculated for each day. The resulting correlation between the wind and the direction of the ocean features is given in Table 1.

It can be readily seen from the table that the directions of the wind and ocean features are in agreement within a few degrees. Clearly, the winds and the ocean features detected by the ERTS-1 satellite are directly related.

It is also suggested in Table 1 that wind speeds between 10 kt. and 15 kt. produce very well defined features on the leeward side of the islands while speeds near 20 kt. greatly diminish the size and sharpness of the features as shown, for example, by the 19 Nov. features. Duntley (1964) and others have shown that the intensity of reflected light from the ocean surface varies with solar zenith angle as well as wind speed. For high solar zenith angles (20^{o}) the intensity of red light varies most rapidly with low wind speeds (3 to 13 kt.) while the opposite effect is seen for medium and low solar zenith angles; the greatest change in intensity occurring at wind speeds greater than 20 kt. At first glance, Duntley's work would seem to be contrary to the evidence presented in Table 1, where the 19 Nov. data, with higher wind speed and medium solar zenith angle (43^{o}), show only a slight indication of ocean features, while the 17 Feb. data with slower wind speed but the same solar zenith angle show very distinct features. The apparent inverse relationship between wind speed and feature size and clarity is most likely caused by the topography of each island, i.e., it appears that the height and orientation of the islands block the air flow most effectively when wind speeds are below 15 kt. At speeds greater than 15 kt. the islands

TABLE 1

Average	26 Sept.	13 Oct.	14 Oct.	19 Nov.	17 Feb.	24 Mar.*
Wind Speed	10	10	13	19	12	10
Wind Direction	60°	110°	103°	85°	99°	116°
Estimated Direction of Ocean Features	57°	105°	101°	83°	102°	114°
Solar Zenith Angle	32°	35°	36°	43°	43°	32°

*The mean wind for 24 March does not include the two ship reports southwest of Barbados which are due to local weather conditions.

seem to lose their effectiveness to retard the wind; wave forms within the island wake become similar to those in unprotected areas. Thus, the intensity of reflected energy is nearly the same and only slight contrasts are produced in the ERTS-1 negative prints.

The Lesser Antilles are volcanic islands and therefore very mountainous with only a few low, relatively flat areas. Guadeloupe, Dominica, St. Lucia, St. Vincent, and Grenada have mountain ranges extending north-south with heights above 1000 meters on most islands. When the wind is nearly perpendicular to the mountain ranges, the ocean features have almost the same width as the islands. However, when the wind direction is at an acute angle to the north-south mountain ranges, as in the 26 Sept. case, the ocean features become more narrow. Furthermore, Martinique, which has mountains at its northern end over 1300 meters and relatively low lands under 500 meters at the southern end, causes the ocean feature to be only as wide as the northern half of the island, even when the wind is perpendicular to the mountains.

Further evidence that the influence of topography on the air flow is the main cause of these ocean features can be seen by studying the area in the ERTS-1 prints to the west of Barbados. Barbados is a relatively flat island; its highest peak is approximately 400 meters in height. The ERTS-1 orbits of 13 Oct. and 24 Mar. pass sufficiently close to Barbados so that any ocean feature extending from that island would be seen on the eastern edge of the ERTS-1 image. However, there is no feature visible in either ERTS-1 print, suggesting that the topography of Barbados is too low to produce an extensive wind induced feature on its leeward side.

2.5 Surface Reflectance

It is apparent from the ERTS-1 data that changes in wind speed greatly affect the amount of backscattered energy due to the variation in surface roughness. As a result, it appears that remote sensing of the mixed layer will be more difficult than previously anticipated because the energy reflected from the ocean surface must be taken into account. Since the ERTS-1 multispectral scanner senses the same area in four separate energy bands at the same time, it may be possible to minimize in the data the effect of energy reflected from the surface by taking energy differences between two spectral bands. Thus, the difference between bands 4 and 7, for example, would be more representative of the energy reflected from below the ocean surface.

By superimposing two ERTS-1 transparencies, one being a positive and the other a negative, the energy reflected from the surface would be minimized and the resulting image would tend to enhance the radiation backscattered from the subsurface. This photographic differencing technique was employed in an attempt to detect changes in the backscattered energy patterns, indicative of subsurface eddy formations. Unfortunately, there was no noticeable change in the pattern after applying this method to the 13-14 Oct. data. More research in the area of minimizing the energy reflected from the ocean surface is needed before the detection of subsurface features can be achieved from satellite height.

3. CONCLUSIONS

The results of studies with ERTS-1 photographic data of the Lesser Antilles Island arc have shown that changes in sea state have a large effect on the amount of backscattered solar radiation reaching a satellite sensor. Smoother seas cause a decrease in the solar radiation reflected from the ocean surface. This is immediately apparent from the negative ERTS-1 prints (Fig. 1-6) which display much lower photo densities in the wind shadow of each island than in the open ocean, unprotected from the wind. It is evident from this study that horizontal variations in the reflectance of the sea surface will make remote sensing of the ocean mixed layer more difficult.

Preliminary attempts to remove the surface reflectance by photographic differences have not yielded positive results. Further studies are needed to produce a method to minimize the effect of surface reflectance and qualitatively describe horizontal variations in particles in the ocean mixed layer through remote sensing.

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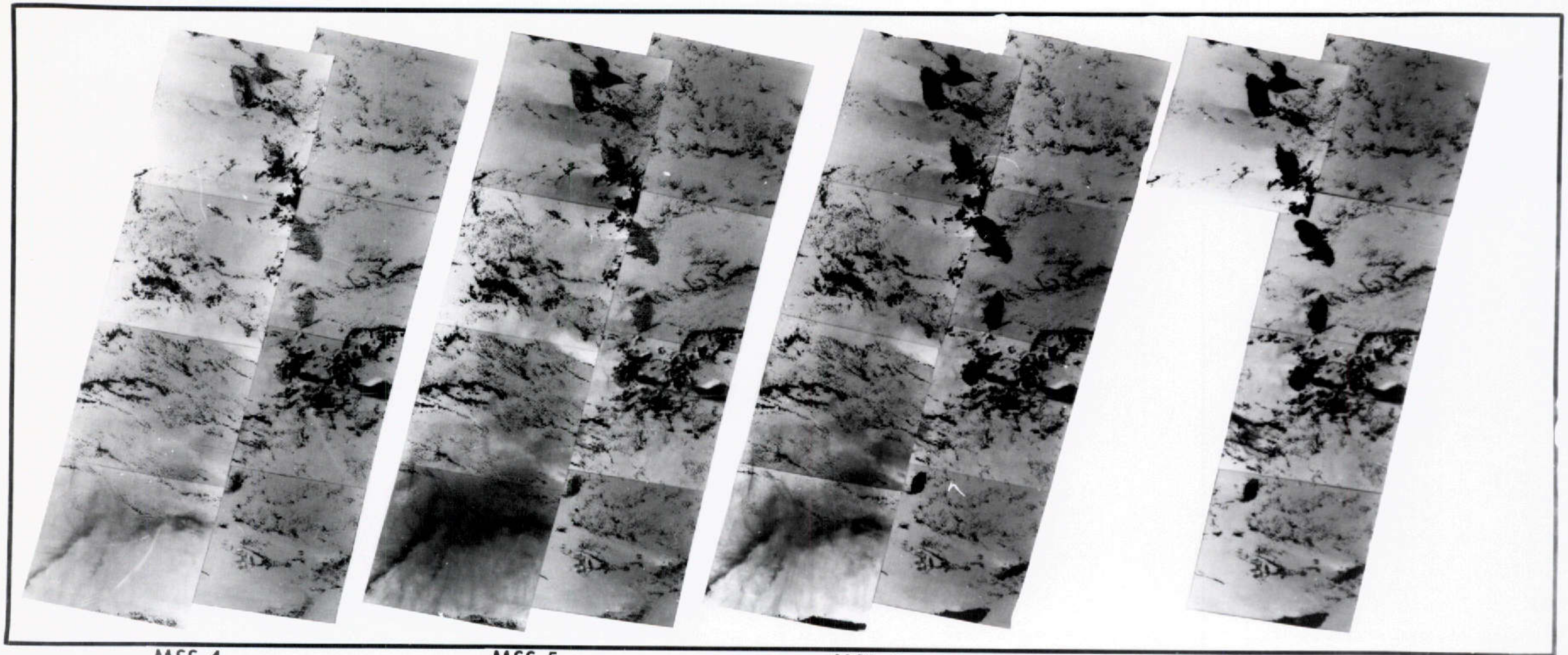
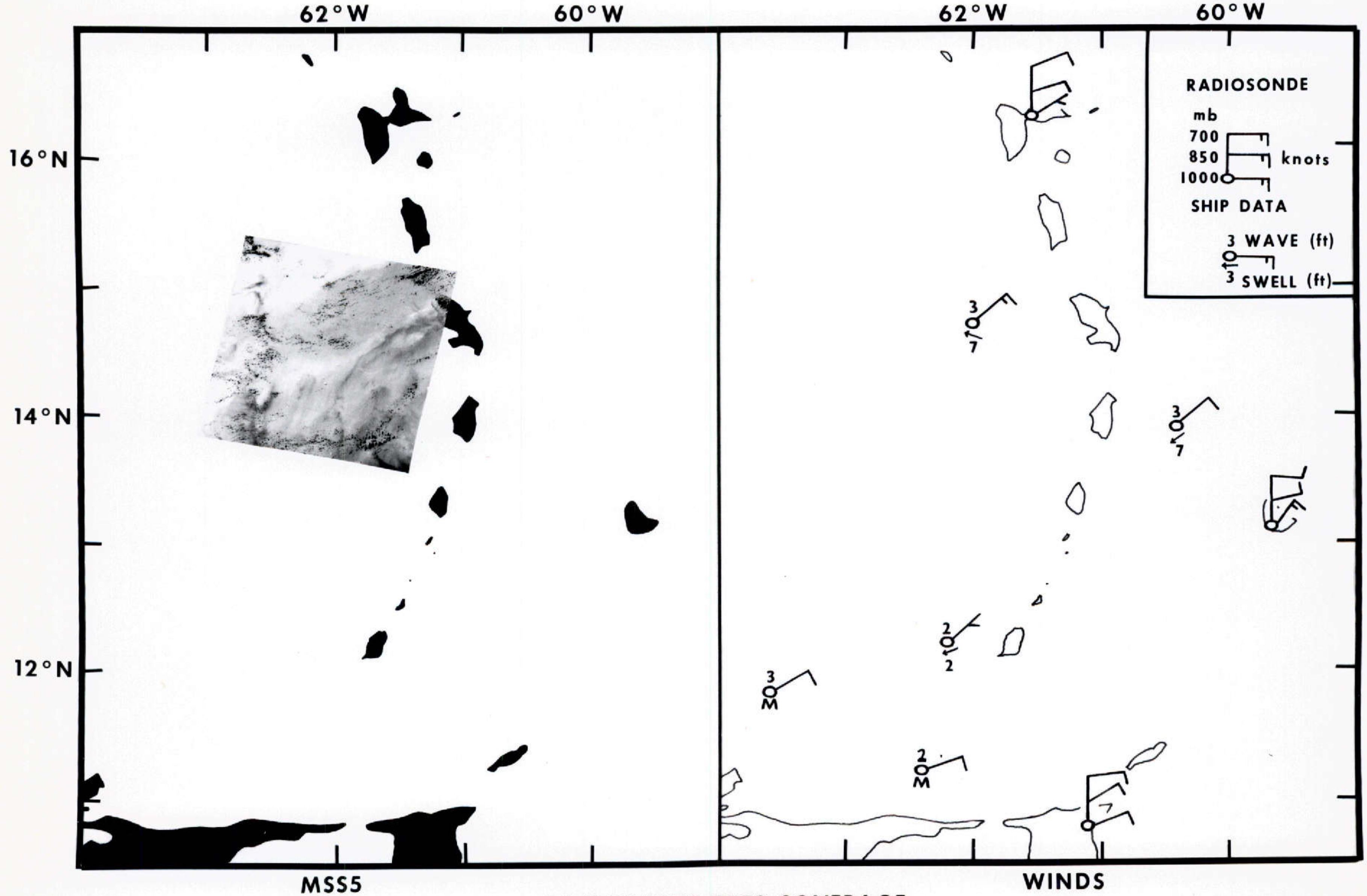
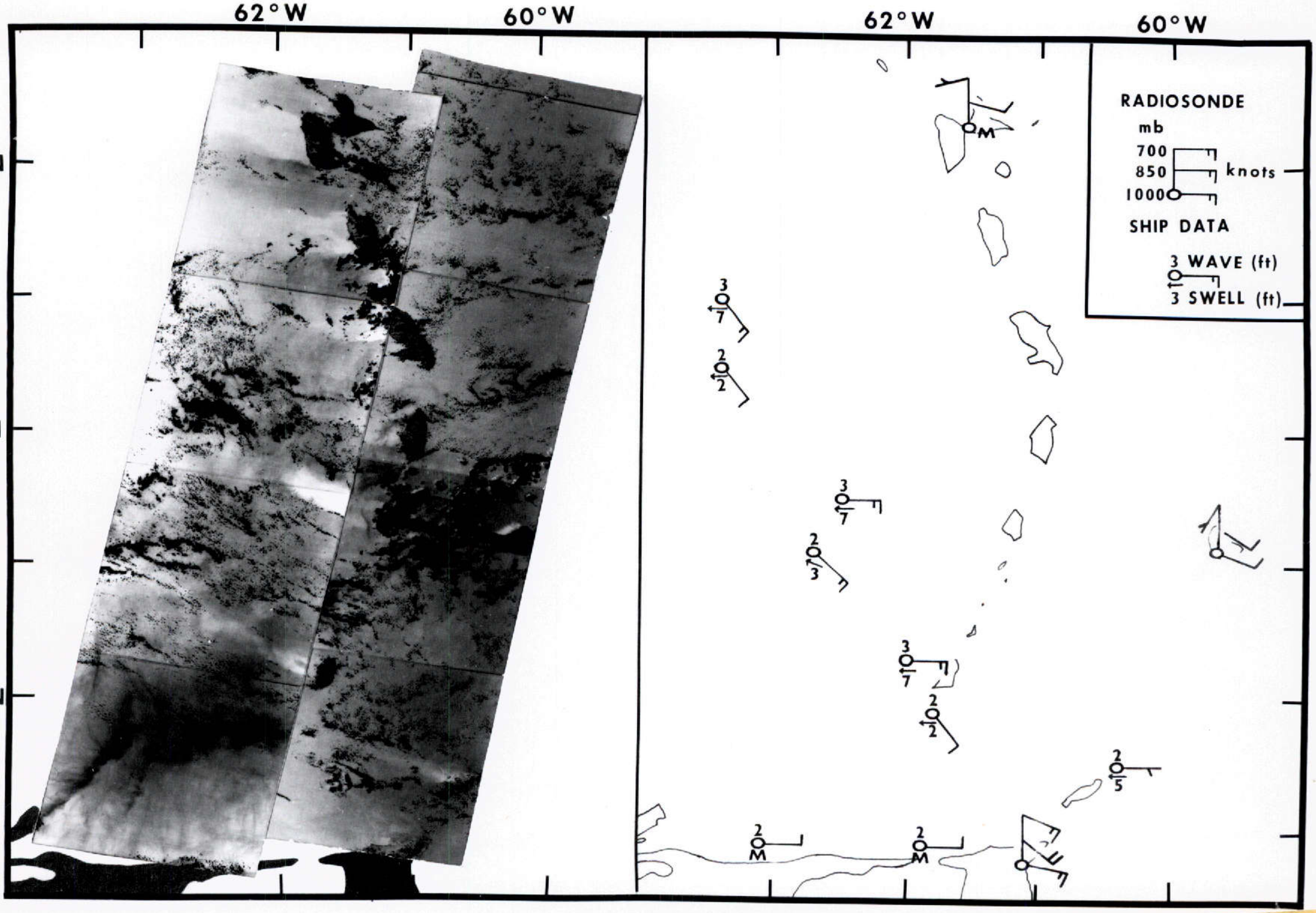


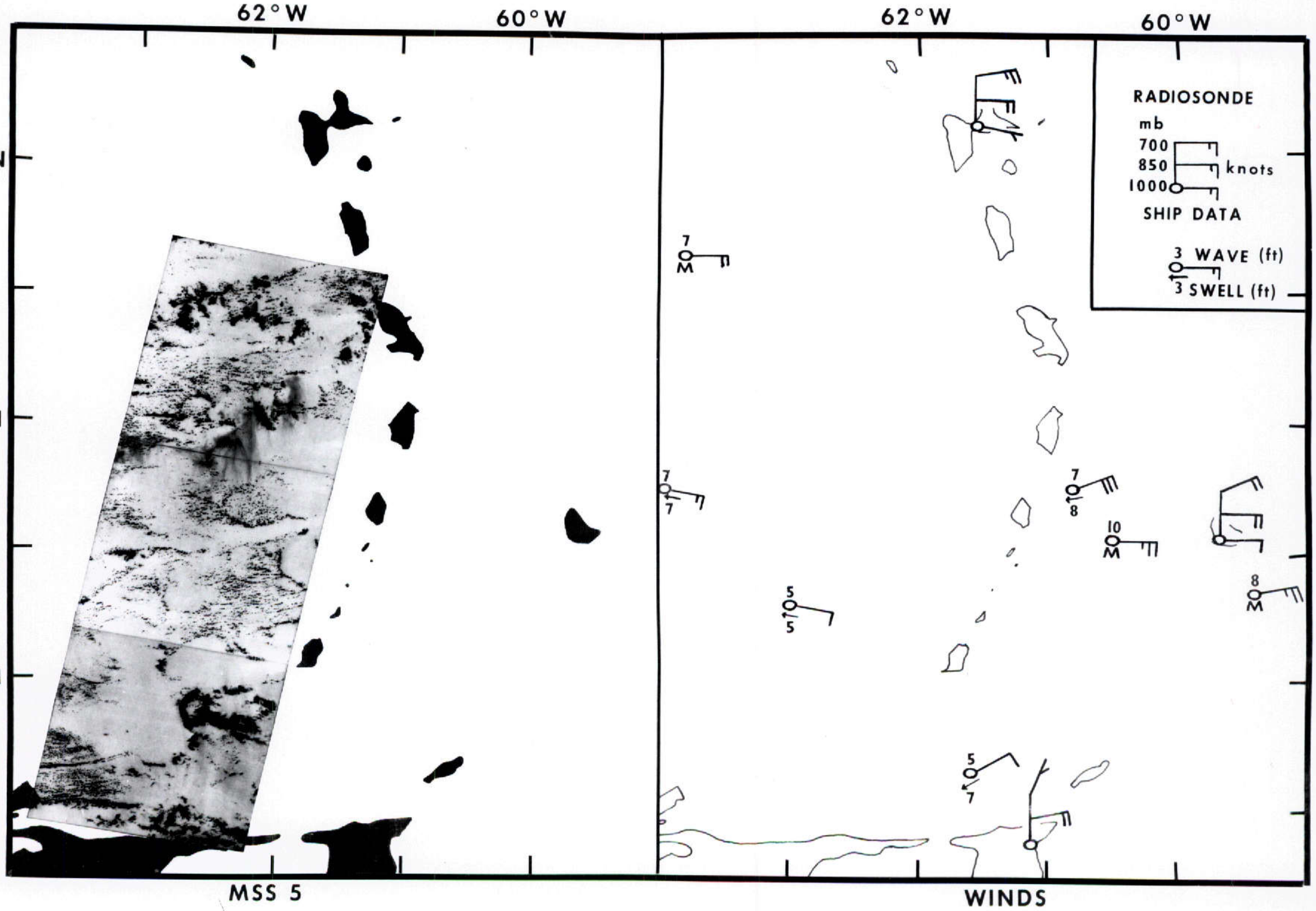
ERTS COVERAGE OF THE LESSER ANTILLES
13–14 OCT 1972



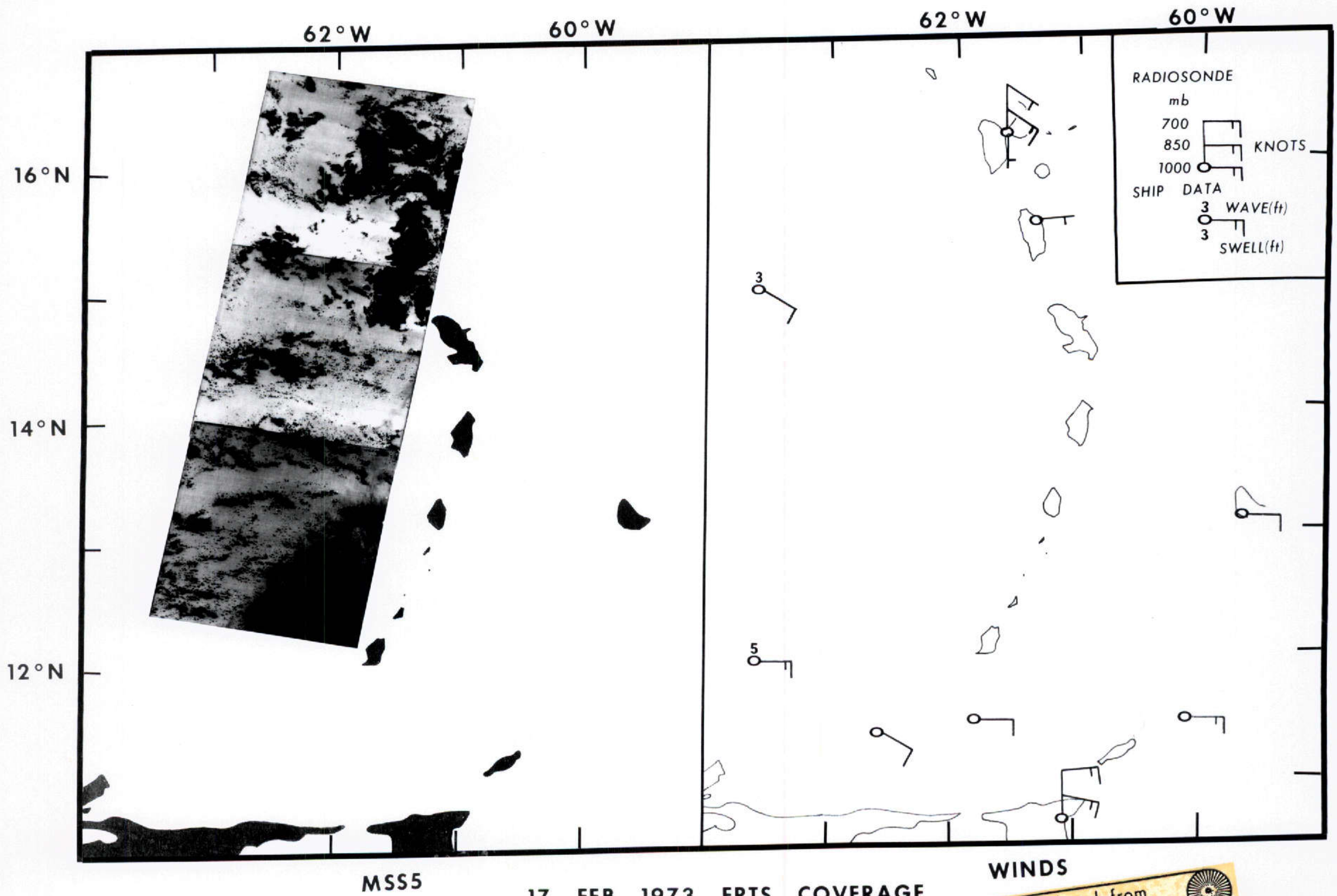
26 SEPT 1972 ERTS COVERAGE



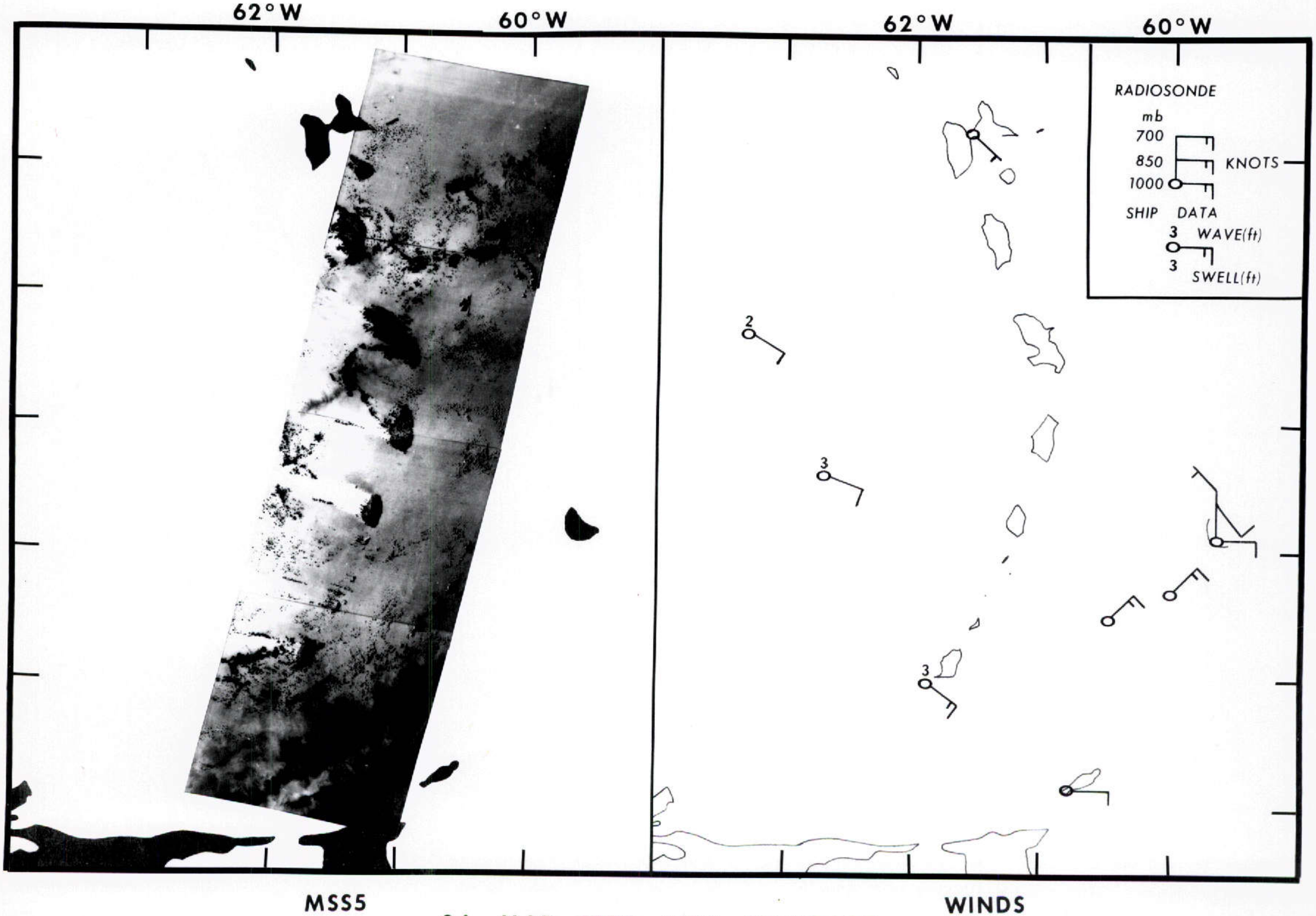
MSS 5 13–14 OCT 1972 ERTS COVERAGE WINDS



19 NOV 1972 ERTS COVERAGE



17 FEB 1973 ERTS COVERAGE



24 MAR 1973 ERTS COVERAGE