

SECTION 90

REGIONAL STUDIES USING SEA SURFACE TEMPERATURE
FIELDS DERIVED FROM SATELLITE INFRARED MEASUREMENTS

by

Alan E. Strong
National Oceanic and Atmospheric Administration
Washington, D. C. 20031INTRODUCTION

With the launching of several earth-orbiting satellites carrying infrared (IR) radiometers, it has now become possible to detect structure in sea surface temperature (Tss) distributions under relatively clear sky conditions. A number of studies (Rao, 1968; Curtis and Rao, 1969; Smith et al., 1970; Warnecke et al., 1971; Rao et al., 1971) have shown Tss distributions over both small and large areas by means of satellite IR information. This report shows three informative examples of Tss distributions over the western Atlantic which were detected by means of data from the scanning radiometer on the Improved TIROS Operational Satellite-1 (ITOS-1). This satellite series, replacing the ESSA series, became operational with NOAA's environmental satellite NOAA-1, launched in December 1970.

DIRECT READOUT INFRARED (DRIR) OCEANOGRAPHIC DISPLAY

ITOS-1, launched 23 January 1970, was designed to provide 12-hr coverage (day and night) of the entire surface of the earth, principally for meteorological purposes. The scanning radiometer (SR) has a visible and an IR channel, the latter measuring radiation in the 10.5-12.5 μ m wavelength region. When the radiometer is looking straight down at the Earth's surface, the area instantaneously viewed is about 7.5 km in diameter.

These radiation measurements are temporarily stored on board the satellite for later transmission to the ground and for subsequent global mapping. For the convenience of those within transmission range of the satellite, the SR also transmits data for immediate local use directly to Automatic Picture Transmission (APT) ground stations. The IR transmission is known as Direct Readout Infrared (DRIR). Data obtained from the DRIR can be displayed on a photofacsimile recorder

to produce a continuous strip image of infrared radiance over the local area. When used properly this pictorial display can be very useful for immediate qualitative interpretation of thermal conditions. The two examples presented here have been processed to make visible the horizontal temperature gradients on the ocean surface. The gray-scale representation chosen encompasses only temperatures ranging from 0 to 30C. All cooler surfaces, such as clouds, snow and ice and much of the land surface, appear white (less radiant energy reaching the satellite), while warmer surfaces appear progressively darker. Quantitative values can be obtained by generating a calibrated gray scale wedge and comparing it with the picture, or by using a computer printout of the calibrated temperature values at grid points. In the examples presented here, each gray scale interval represents a temperature change of approximately 1C.

A GULF STREAM MEANDER OFF CAROLINAS

Figure 1 is a DRIR image obtained about 0900 GMT 15 February 1971 from ITOS-1. Some of the prominent features of this thermal image are the Florida Peninsula and the Gulf Stream. The main thermal front on the northern edge of the Gulf Stream, and the meanders along the thermal front between Charleston, S. C., and Cape Hatteras are dramatic. Three distinct gray shades, indicative of three thermal regions, can be seen as far south as the coast of Georgia. Farther south only two such regions are discernable. A similar separation in the Middle Atlantic bight region, showing three different water masses, has been shown by Rao et al. (1971), using October 1970 ITOS-1 DRIR data. The near-black area corresponds to the Gulf Stream, and the dark gray and light gray areas, just north of the Stream, correspond to the intermediate slope water mass the cooler shelf water mass, respectively. Clouds obscure the warm water of the Stream in the Florida straits. Meanders in the Gulf Stream boundary are evident just east of Cape Romain and Cape Lookout. The same features, seen in the ITOS-1 DRIR data on the following day, persisted until late February.

The analyzed Tss over a portion of the area depicted in Fig. 1 is shown in Fig. 2. Some appropriate geographic locations and gridding has been provided.

EDDIES FORM AS THE MEANDER BREAKS DOWN

Two weeks later a dramatic change occurred in the meander region of the Gulf Stream. Through breaks in overlying clouds, it was noticed in the satellite pictures that a cold eddy had started to detach from the colder water. Following the passage of a cold front the area became free of clouds on 5 March 1971. Figure 3 shows the ITOS-1

DRIR image for this day. The DRIR analysis, shown in Fig. 4, shows 18-20°C slope water being injected into 24-25°C Gulf Stream water. Three break-off eddies are visible along the northern edge of the Gulf Stream. Two, immediately east of Cape Romain and Cape Fear, are very well defined; the northernmost eddy is small and barely visible.

Because of general overcast conditions in the area, it was not possible to establish a good history on the development of these eddies during the 18-day period between the days on which these two DRIR images were acquired. Continued monitoring of ITOS-1 IR data indicated no evidence of these eddies in the same general area during a 10-day period subsequent to 5 March, nor did the meander pattern become re-established.

These eddies along the Gulf Stream boundary occur in a region of strong shearing action between the relatively slow moving slope water and the fast moving main Gulf Stream. It is possible that they are related in some way to the bottom topography or the coastline configuration. Strong, 50-kt westerly winds, associated with an intense storm that crossed the region on 4 March 1971, were reported by two ships in the vicinity of these eddies. It seems likely that these winds caused extreme stress on the ocean surface and so played a major role in the thermal structure shown in Fig. 4. The occurrence of these eddies downwind of the Carolina Capes may be more than just coincidence.

A STRONG CYCLONIC EDDY IS DISCOVERED

IN THE WESTERN SARAGASSO SEA

SATELLITE OBSERVATIONS

On 12 April 1971 the NOAA-1 satellite's early morning pass (approximately 0900 GMT) viewed the Eastern United States. Much of the Eastern Seaboard was cloudfree. The scanning-radiometer provided thermal infrared imagery that revealed an intricate Gulf Stream structure, including a large meander to the north off Cape Hatteras. The DRIR data from the satellite has been displayed as above for the higher temperatures of the ocean scene in Fig. 5. The analysis of Tss accompanies the imagery in Fig. 6.

Most interesting is the meandering Gulf Stream that is present with not only a strong multi-stepped northern gradient but also a moderate thermal gradient on the Saragasso side. Another stream of warm water appears to joint (or diverge from) the Gulf Stream just southeast of Cape Hatteras. Although this structure is interesting to investigate of itself, as it may be related to the eddy, we were concerned with the cooler regions of water on the Saragasso side, primarily the cool area centered at approximately 33N, 73W.

During the following two days additional NOAA-1 DRIR data were acquired. They showed virtually an identical system. From Fig. 6 it can be seen that surface temperatures in the cooler area were near 16°C whereas the Gulf Stream to the west was running approximately 8°C warmer.

SHIP OBSERVATIONS

In May 1971 the existence of the suspected eddy was confirmed on cruise 98 of the University of Rhode Island R/V TRIDENT. This work was coordinated by Chief Scientist Philip L. Richardson. On May 11 the eddy was found 180 miles southeast of Cape Hatteras at 32° 47'N, 73° 27'W, in the area indicated by the satellite. It was characterized by a strong surface cyclonic circulation, cooler surface temperatures and a cold deep core. This feature appears similar to Gulf Stream rings that have been reported by Parker (1972). In the center of the eddy, surface temperatures were about 19°C, three degrees cooler than normally found in this location and time. Surface temperatures were warmer than the April measurements in Fig. 6. The May satellite data, however, are in agreement with this increase in temperature. The ship surface temperatures were measured with a bucket thermometer.

The surface current speeds in the eddy ranged from near zero in the central region to a maximum of 3.0 knots at a distance of 50 miles from the center. As a comparison to these note that the Gulf Stream has speeds of 4.0 knots. Thus, there was an apparent decrease in surface velocity from the time the eddy broke from the Gulf Stream.

The subsurface features of the eddy were explored by bathythermographs (BT) and hydrocast. Fig. 7 shows a BT cross-section that is a composite of March 1971 soundings along the track AB shown in Fig. 8. Although the March cross section is fortuitous, since there was no knowledge of the feature then, the cross section is similar to the more intensive survey results from the TRIDENT. These results will be published soon.

In May shape of the eddy appeared to be elliptical with the major axis at about 025° true. The ellipticity is apparent in the satellite data, the surface bucket data and from the BT data. The size of the eddy based on the location of the 15C isotherm at 500 meters was approximately 35 by 65 miles. The diameter based on the distance from the center of the eddy to the zero velocity line between the Gulf Stream and the eddy was 85 miles.

TRACKING THE EDDY

We are attempting to continue the observations of this eddy by use of satellite, plane and ship. The observations to date can be seen in Fig. 8 and indicate the eddy is moving southwest at about one mile per day. The eddy was relocated in October 1971 on the TRIDENT and again in January 1972 by the USNS WILKES. A search of all available surface temperatures and BT data is continuing. Several cruises are scheduled during early 1972 into the eddy as it drifts onto or along the edge of the Blake Plateau.

The U. S. Naval Oceanographic Office reports one BT in the eddy in July 1971. It is suggested that all of these observations are of the same eddy and that this might possibly be the same eddy as reported near 36.5°N , 69.0W in October 1970 by the U.S. Naval Oceanographic Office (Gemmill and Gotthardt, 1971). Thus there exists the possibility that the eddy has been followed for at least ten months and perhaps as long as 15 months.

CONCLUSIONS

Gulf Stream associated eddies and meanders have been discovered and tracked through the coordinated use of satellite and ship. The concerted use of ship and satellite has provided an excellent method of studying large scale thermal features and offers a system approach to oceanographic pursuits that makes for much more effective use of expensive ship operations.

REFERENCES

1. Rao, P. K., 1968: Sea surface temperature measurements from satellites. *Mariners Wea. Log*, 12, 152-154.
2. Curtis, W. R., and P. K. Rao, 1969: Gulf Stream thermal gradients from satellite, ship and aircraft observations. *J. Geophys. Res.*, 74, 6984-6990.
3. Smith, W. L., P. K. Rao, R. Koffler and W. R. Curtis, 1970: The determination of sea-surface temperature from satellite high resolution infrared window radiation measurements. *Mon. Wea. Rev.*, 98, 604-611.
4. Warnecke, G., L. J. Allison, L. McMillin and K. H. Szekiolda, 1971: Remote sensing of ocean currents and sea surface temperature changes derived from the Nimbus II satellite. *J. Phys. Oceanogr.*, 1, 45-60.
5. Rao, P. K., A. E. Strong and R. Koffler, 1971: Gulf Stream and middle Atlantic bight: Complex thermal structure as seen from an environmental satellite. *Science*, 173, 529-530.
6. Parker, C. E: Gulf Stream rings in the Saragasso Sea. *Deep Sea Research*, in press, 1972.
7. Gemmill, W., and G. A. Gotthardt: Formation and movement of a Gulf Stream meander. Paper presented at the April 1971 American Geophysical Union Meeting in Washington, D.C.

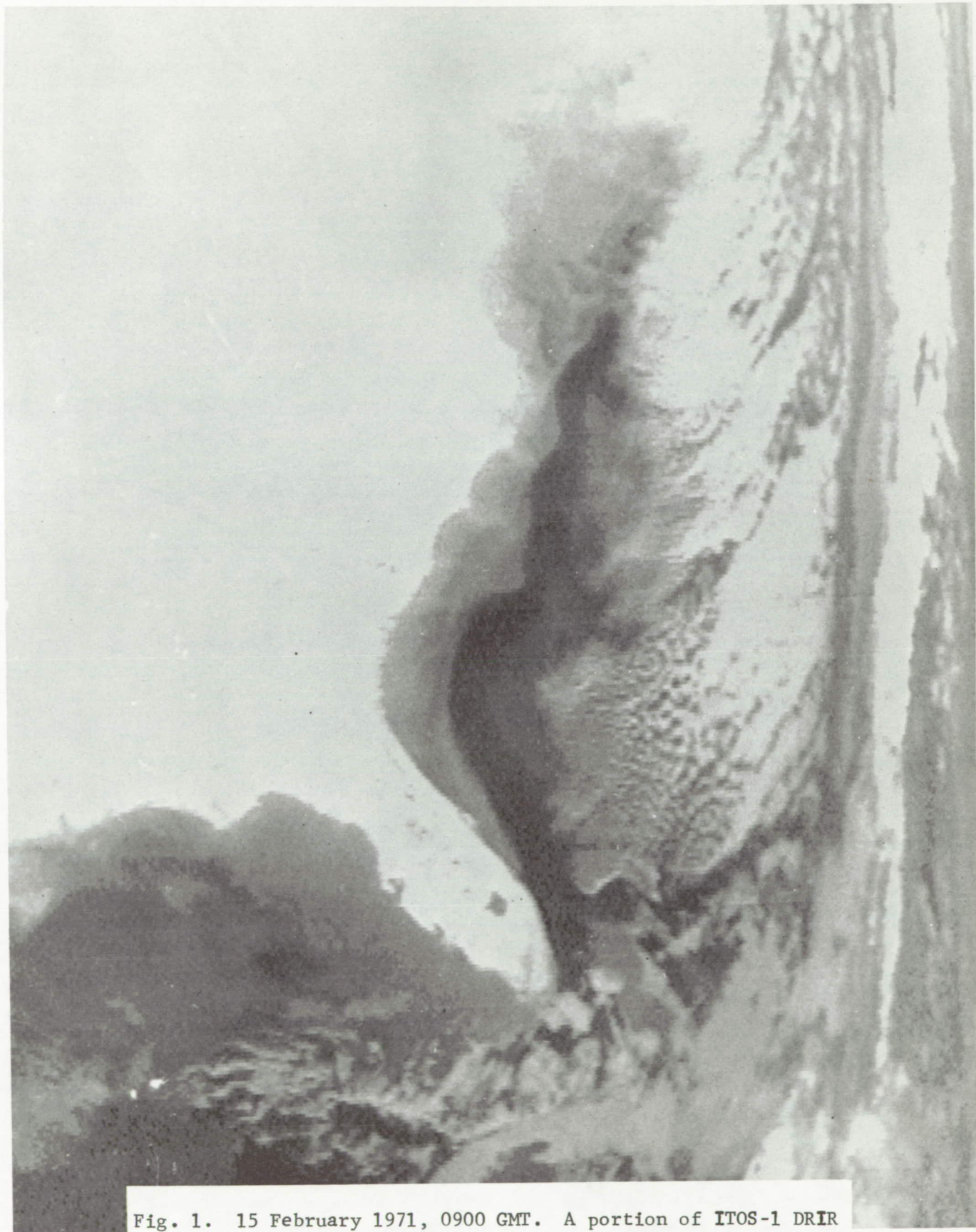


Fig. 1. 15 February 1971, 0900 GMT. A portion of ITOS-1 DRIR imagery showing a gulf stream meander off the Carolina Coast.

**ITOS 1 SRIR DIRECT
15 FEBRUARY 1971
0900 GMT**

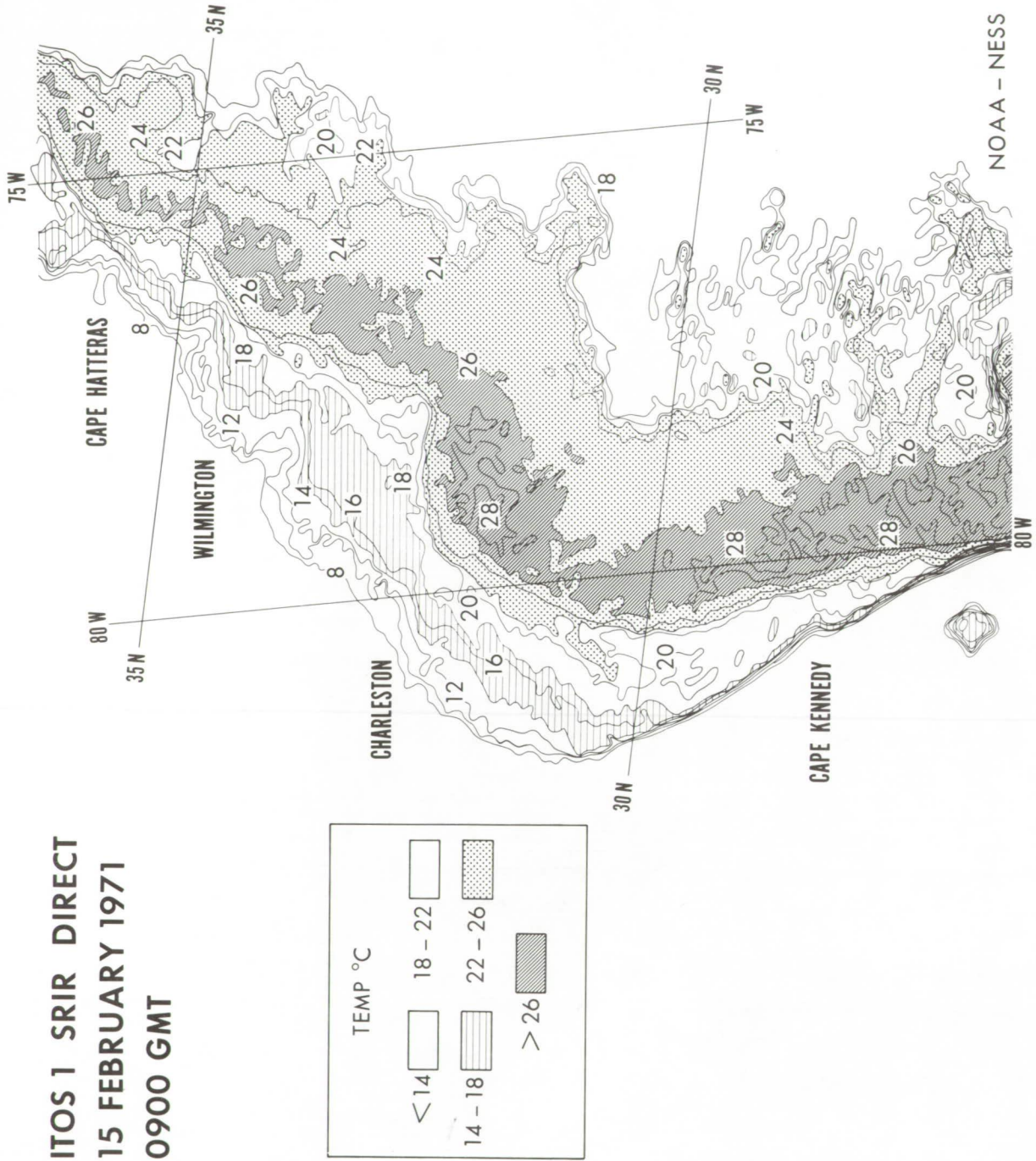


Fig. 2. Tss analysis of a portion of Figure 1.

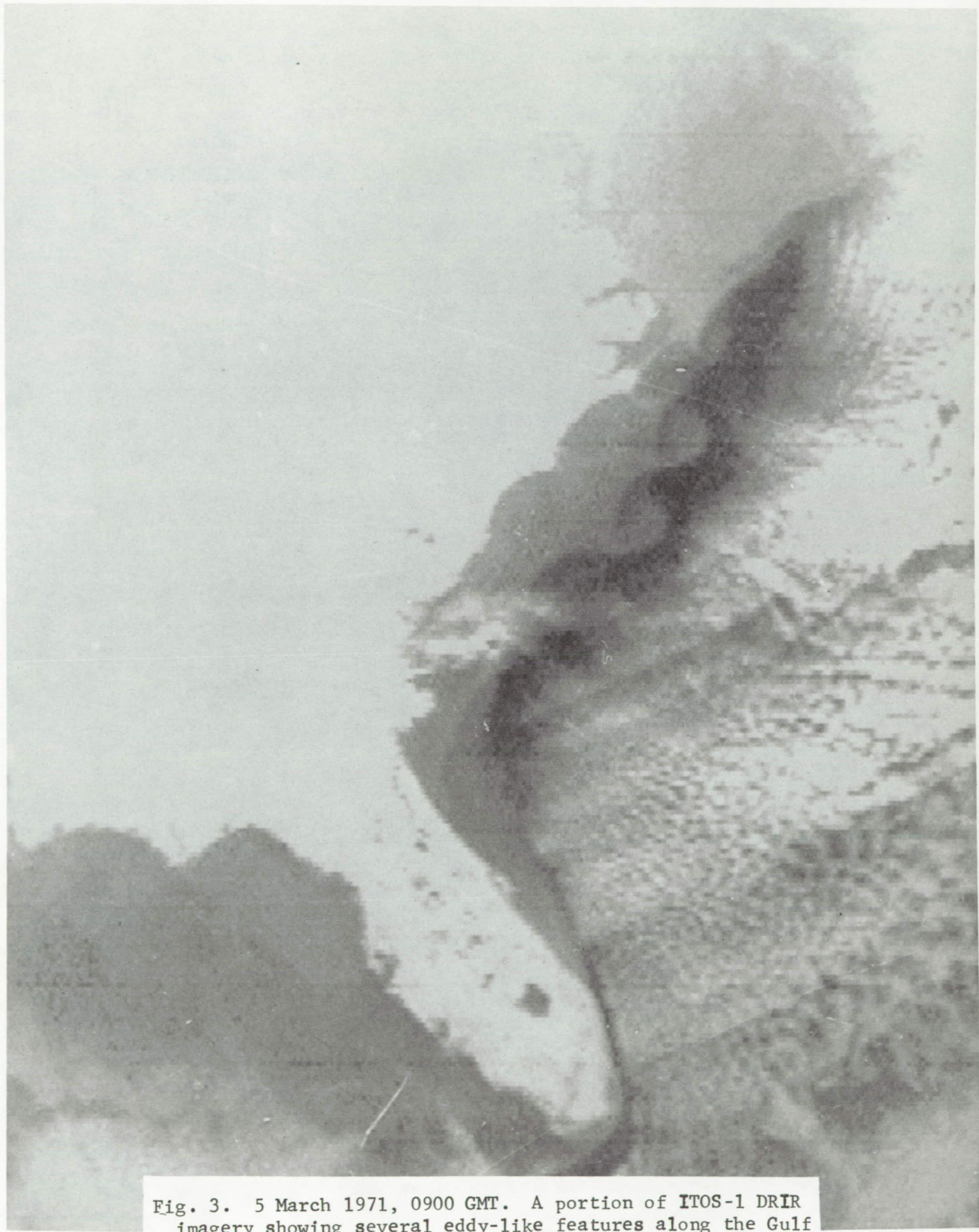


Fig. 3. 5 March 1971, 0900 GMT. A portion of ITOS-1 DRIR imagery showing several eddy-like features along the Gulf Stream front of the Carolina Coast.

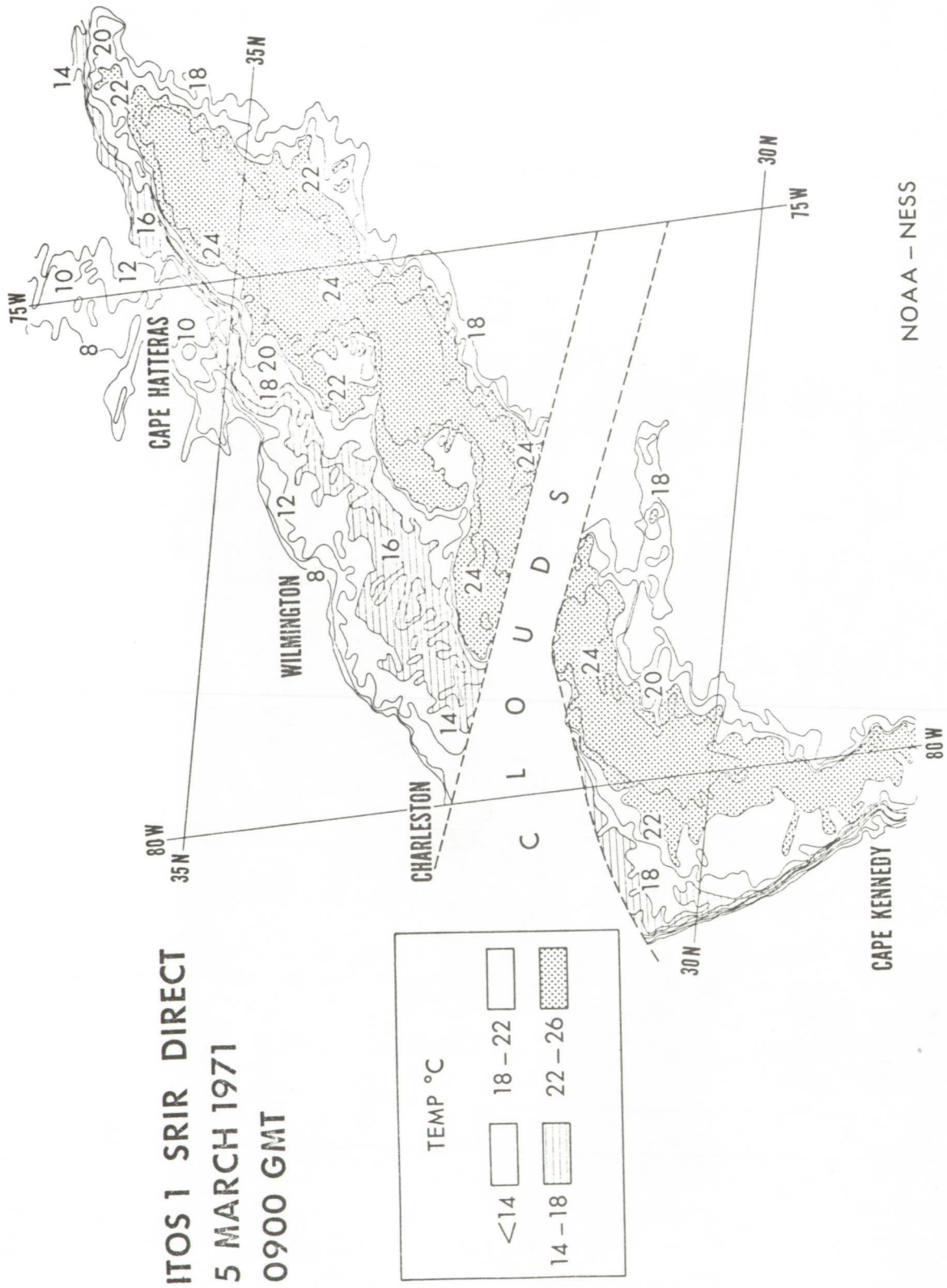


Fig. 4. Tss analysis of a portion of Figure 3.



Fig. 5. 14 April 1971, 0900 GMT. A portion of NOAA-1 DRIR imagery revealing a cold eddy circulation across the Gulf Stream southeast of Cape Hatteras.

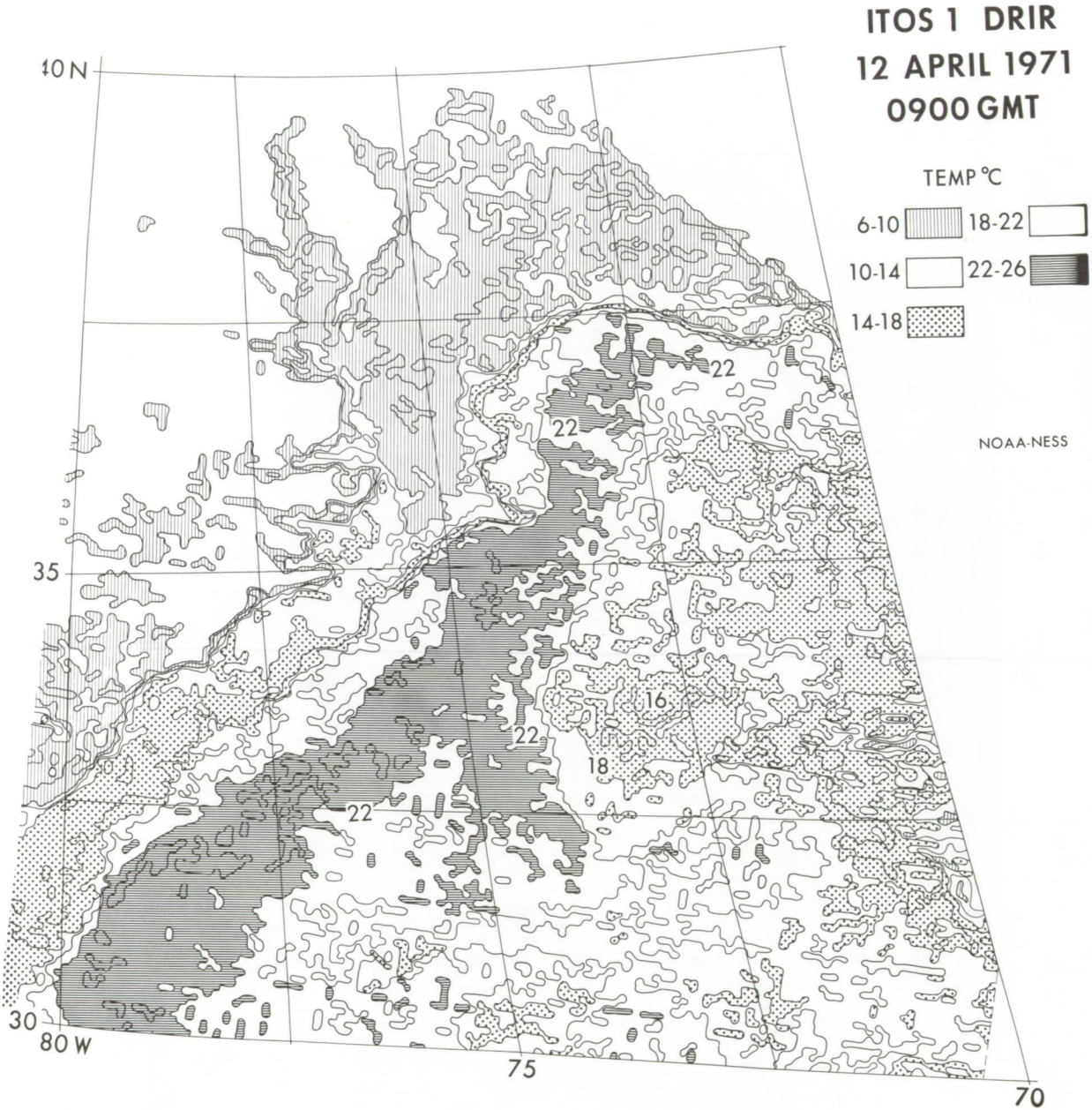


Fig. 6. T_{SS} analysis of a portion of Figure 5.

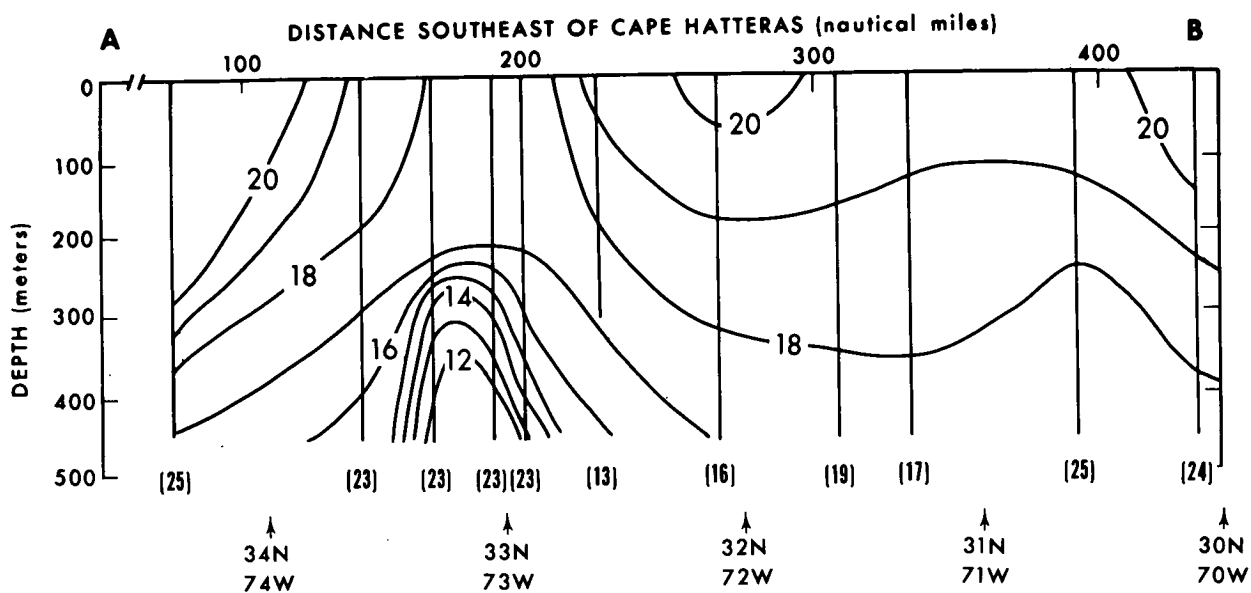


Fig. 7. BT composite cross-section for mid-March 1971 along the AB transect shown in Figure 8. BT depths are shown by vertical lines. Date for each cast is noted at bottom of sounding.

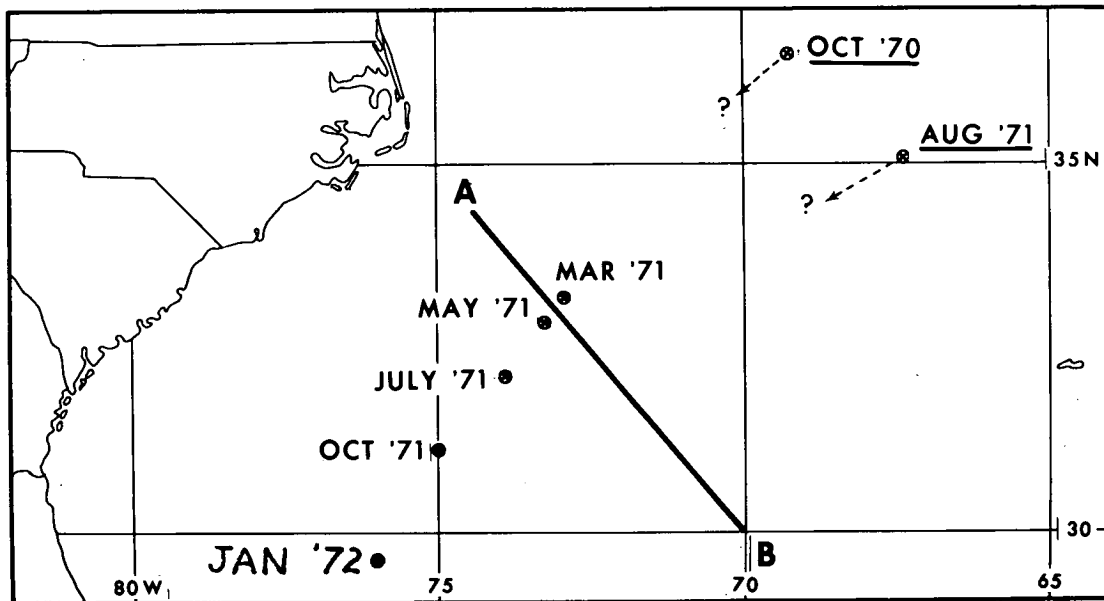


Fig. 8. Cold eddy history 1970-72. In addition, another eddy location is shown for August 1971. AB transect is shown in Figure 7.