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CETACEANS ASSOCIATED WITH GULF STREAM FEATURES OFF THE NORTHEASTERN USA SHELF

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ABSTRACT

Marine mammal surveys were conducted during summer 1990 and 1991 in shelf-edge and off shelf waters between Cape Hatteras and Georges Bank. Sperm whales were the most frequently sighted large whale in both years comprising 27.9% and 12.7 % of total sighting in 1990 and 1991. Bottlenose dolphins (13.5%) and pilot whales (13.3%) were the most frequently sighted small cetacean in 1990 and 1991, respectively. Rates of sperm whale sightings in 1990 that were within a 9.3 km buffer (5 nautical miles) of the Gulf Stream north wall and in the Gulf Stream were not significantly different ($x^2 = 2.86$, $P>0.05$). However, in 1991, significantly more ($x^2 = 51.1$, $P<0.05$) sighting were associated with shelf-edge areas where warm-core rings were located. Beaked and pilot whales, Risso's, bottlenose, spinner, saddleback, and Stenella dolphins were also sighted along the Gulf Stream north wall and along warm-core rings that coincided with the shelf break. Sightings data for these latter species were insufficient to examine correlations with Gulf Stream features.

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INTRODUCTION

Cetacean distribution and abundance relative to oceanographic features represent important ecological relationships that can be examined using satellite images of sea surface temperature (SST) and chlorophyll. For example, Smith et al. (1986) found a strong correlation between shipboard estimates of cetacean abundance in the California current and satellite imagery chlorophyll measurements; and Brown and Winn (1989) utilized SST data to correlate right whale distribution with thermal fronts in the Great South Channel region of Georges Bank.

Off the eastern U.S, the Gulf Stream and warm core rings are important oceanographic features that entrain and transport marine organisms in offshore waters off eastern North America (Flierl and Wroblewski 1984; Haney and McGillivary 1985; Myers and Drinkwater 1989; Olson and Backus 1985; Wishner and Allison 1986; and Wroblewski and Cheney 1984). Distinct fronts along the Gulf Stream north wall and warm core ring (WCR) edges contribute to the formation of ephemeral habitats and local prey concentrations that lure and sustain a variety of predators (Olson and Backus, 1985; Powers, 1987; and Nash et al., 1989). In addition, commercial fishing activity for large pelagics (i.e., swordfish, Xiphias gladius) is known to occur along frontal features (Podesta et al., In press).

Several studies have documented the spatial and temporal importance of shelf-edge bathymetric features, banks, and tidal or current-driven upwelling frontal processes off the northeast USA to cetacean populations (Hain et al. 1985; Kenney and Winn 1987; Payne et al. 1986; Wishner et al. 1988; and Mayo and Marx 1990). Although feeding is probably the singular most important activity that occurs in these habitats, several of these areas are critical nursery areas for endangered right and humpback whales (Megaptera novaeangliae) (National Marine Fisheries Service (NMFS) 1991a; NMFS 1991b).

Cetacean utilization of off-shelf (>2000m isobath) habitats off the northeast U.S., are not well documented. Prior to the late 1970's few marine mammal field studies were conducted in the northeast region, and since then most field programs have concentrated on coastal, shelf and shelf edge habitats (Cetacean and Turtle Assessment Program (CETAP), 1982; Hain et al., 1985; Kenney and Winn, 1987). Furthermore, we are unaware of any systematic marine mammal surveys conducted beyond the 2000 m isobath.

This paper examines cetacean distribution, sighting frequency, and group size in the waters between the shelf edge and Gulf Stream features based on shipboard surveys conducted during 1990 and 1991.

METHODS

During 5-18 August 1990 and 8 June to 16 July 1991 the National Oceanic and Atmospheric Administration (NOAA) 34m fisheries research vessel R/V CHAPMAN was used to conduct marine mammal sighting surveys in shelf-edge and offshore waters off the northeastern U.S. coast (Figures 1 and 2).

The objectives of these cruises were: 1) to investigate cetacean fine scale distribution and habitat use within WCRs, canyons, and the shelf/slope edge; 2) to determine whether the distribution of marine mammals is continuous between several major canyons and the Gulf Stream north wall; 3) to conduct line transect population surveys along the shelf/slope edge and out to the Gulf Stream; and 4) to determine how the variation in species composition is correlated with oceanographic features.

The 1990 track lines were not predetermined and a daily random starting position (i.e., overnight steaming position) was used. A predetermined cruise track was followed in 1991 although some changes were made when necessary (areal closures due to military activity, distribution of WCRs, and other factors).

Vessel speed under normal searching conditions was 9.5-10.5 knots. Marine mammal sightings were collected daily between 0700 and 1900 hours, conditions permitting, using standard line transect methods (Burnham et al. 1980).

The sighting team consisted of three observers (port, center, and starboard) that searched from the catwalk of the pilot house. Individuals were randomly assigned to each position at the start of each day. Observers maintained 45 minute watches with a 15 minute rest period and a 15 minute data recording period. Positions were rotated every 15 minutes. Primary searching was done with the naked eye, but binoculars were used to confirm initial sightings, and for determining species identification, group size, and swimming direction. Visual estimates were made of the radial distance to each sighting. Sighting angle was determined using a pelorus that was mounted at each observer station.

Sea surface bucket temperatures were taken every 15 minutes in the 1990 and 1991 ship surveys. In 1990, Expendable bathythermographs (XBT's), deployed to 460 m, were used in combination with satellite data to help determine the vessels position relative to WCRs and the Gulf Stream north wall. In 1991, a Seabird Electronics Conductivity, Temperature, Depth Recorder (CTD), deployed to 200 m, was used to define vessel position and some animal sightings relative to water column characteristics.

Sea surface temperature (SST) data were also collected using the advanced very high resolution radiometer (AVHRR) aboard the NOAA-11 satellite. These data are received twice daily, preprocessed at the University of Miami and routinely transmitted to the University of Rhode Island (URI) for further processing and analysis. Final analysis of these data was done by the NOAA Remote Sensing Group, NEFSC, Narragansett, RI.

Satellite processing was completed using methods described in Cornillon et al. (1987). Images were remapped to display the study area in a 512 x 512 pixel image. These images have a temperature resolution of 0.125°c (Schwalb 1978), temperature accuracy of 0.75°c (Cornillon and Stramma 1985) and spatial resolution of 1 km at nadir.

A digitizing program was used to outline the north wall of the Gulf Stream and the boundary of any warm core rings. The north wall and warm core rings were distinguished from other bodies of water by the marked temperature change between Gulf Stream and slope waters. The cruise periods were during the summer when diurnal warming makes the difference between the Gulf Stream and WCR less distinguishable. In order to minimize this effect only morning images were used. When the slope water temperatures became indistinguishable from the Gulf Stream /WCR water or cloud cover was too great, the image was not digitized. Complete digitized data were available for the north wall and WCRs for a total of four days in 1990 and 1991. Partial data were available for other days.

Sightings, transect data, and digitized positions of Gulf Stream features were incorporated into an Arc-Info Geographic Information System for mapping and data analysis. Since the Gulf Stream north wall and WCRs are variable features on spatial and temporal scales (Wiebe 1980; Carter 1985; and Cornillon 1985) (Figures 3 and 4), animal associations with these features were determined using daily satellite images. As noted above, daily images usually contained "cloud" gaps, but available pieces were sufficient for our analysis.

The Chi-Square statistic (Zar, 1974) was used to determine if there were significant differences in sperm whale sightings associated with Gulf Stream features. Although other species were sighted along and within Gulf Stream features, sperm whales were the only species that was frequently sighted in all habitats surveyed in both years.

RESULTS

Sighting Effort

In 1990, 1,399 km (67.7%) of searching effort was conducted in off-shelf waters (Figure 1). In addition, 96% of the effort was in Beaufort 3 or less (Table 1). This included approximately 18% within a 9.3 km (5 nautical mile) buffer zone of the Gulf Stream north wall and an additional 34% in the Gulf Stream. Nearly 7% of the total effort was associated with a WCR positioned southwest of Georges Bank. In addition, approximately, 30% of total searching effort was conducted along the shelf edge between Oceanographer and Gilbert Canyons on Georges Bank. In 1991 only 12% of searching effort was conducted in off-shelf waters, and nearly 82% (3,342 km) was conducted in shelf-edge waters principally between the 200 m and 2000 m isobaths. In addition, 82% of searching effort was conducted in Beaufort 3 or less (Table 1).

Sighting Summary

A total of 111 cetacean sightings were made in 1990, with 97% of the sightings made in Beaufort 3 or less (Table 2). Sperm whales (Physeter catodon) were the most frequently sighted cetacean (28%, n= 31/111), and solitary animals comprised 73% of these sightings (Table 3).

In 1991, 463 marine mammal sightings were recorded and 88% were in Beaufort 3 or less (Table 4). Unidentified dolphins (26%, n= 119/463) and unidentified whales (11%, n= 52/463) accounted for a large percentage of total sightings (Table 4). The most frequently sighted identifiable cetaceans were pilot whales (Globicephala spp.) (13%, n= 61/463) and sperm whales (13%, n= 58/463) (Table 4). The majority of large whale sightings were solitary animals (Table 5). Furthermore, most of the delphinid groups, excluding pilot whales, contained six or more animals.

Baleen Whales

In 1990, very few baleen whale sightings were made (2 sightings of 1 animal each). One fin whale (Balaenoptera physalus) and a fin or sei (B. borealis) whale were seen along the continental shelf edge near Lydonia Canyon. In 1991, 45 fin whales were observed during 28 sightings, frequently in the areas where the bathymetric front coincided with the thermal front along the shelf/slope break, for instance along Georges Bank and in the Great South Channel. Fin whales were also seen along of the edge of a WCR and a WCR remnant near Wilmington Canyon, along the northern wall of the Gulf Stream off North Carolina, and near the 200m isobath of Atlantis and Hydrographer Canyons where no thermal gradient was obvious. It appears that balaenopterids are scarce in the offshore slope and Gulf Stream waters in agreement with eariler findings (CETAP 1982).

Beaked Whales

Although Ziphiidae are difficult to identify to species in the field, concentrated effort resulted in identification of several species. The species observed include True's beaked whale (Mesoplodon mirus), possible Antillean beaked whales (M. europaeus), possible North Sea beaked whales (M. bidens), goosebeaked whales (Ziphius cavirostris), and unidentified beaked whales. Based on the small samples sizes, however, analyses will be performed on the family in general, rather than each species.

In 1990, 15 beaked whales were observed during 6 sightings (Table 2, Figure 5). These were seen along the north wall (goosebeaked whales) and in the middle of the Gulf Stream (probably True's beaked whale), in the Sargasso Sea near the south wall of the Stream (possible Antillean beaked whale and unidentified beaked whale), and along the 2000m bathymetric contour of the shelf break (North Sea or True's beaked whale). In 1991, 29 beaked whales, which could not be identified to species, were observed in 7 sightings (Table 4, Figure 6). These occurred near Oceanographer Canyon between the 200m and 2000m isobaths which did not coincide with a noticeable thermal gradient, and along the 2000m isobath which coincided with the edge of a large warm-core ring near southeastern Georges Bank. No beaked whales were recorded in the southern portion of the 1991 surveys.

Sperm Whales

Sperm whales (Physeter catadon) were the species most frequently sighted during these surveys. During 1990, 31 sightings of 47 sperm whales were made (Table 2, Figure 5). The vast majority of these sightings were made along the north wall of the Gulf Stream, with scattered sightings in the slope waters, in the Stream, and along the south wall of the Stream. Fifty-eight sightings of 129 sperm whales were recorded in 1991, with sperm whales generally sighted between the 200m and 2000m isobaths, including an area where the remnant of a warm-core ring was located (Table 4, Figure 6). Sightings were also made along the north wall of the Gulf Stream. Few sperm whales were observed in the slope waters between the shelf break and the Gulf Stream.

In 1990, sperm whale sightings within 9.3 km buffer of the Gulf Stream north wall and in the Gulf Stream were not significantly different (X^2 = 2.86, 2 df, $P>0.05$) (Table 6). However, in 1991 significantly more (X^2 = 51.1, 2 df, $P< 0.05$) sperm whale sightings were associated with areas where WCR interact with shelf-edge bathymetric features, than with either shelf-edge or WCR (Table 7, Figure 6).

Small Cetaceans

Risso's dolphins (Grampus griseus) were observed during 7 sightings of 36 animals in 1990 (Table 2, Figure 7). Sightings were generally confined to the north wall of the Gulf Stream and the area of Oceanographer Canyon along the shelf break. Scattered sightings were also made in the outer edge of a warm-core ring. No sightings were made west of approximately 71° W. During 1991, 17 sightings of 333 Risso's dolphins were made, with the majority occurring along the shelf break, scattered from Baltimore to Lydonia Canyons, in the area of a warm-core ring remnant near Hydrographer Canyon, and in the shelf waters shoreward of the 200m isobath (Table 4, Figure 8). Often, the Risso's dolphins were found in areas of strong bathymetric fronts where no associated thermal front was noticeable.

In 1990, 68 pilot whales (Globicephala spp.) were observed during 14 sightings (Table 2, Figure 7). Atlantic pilot whale (G. melaena) and short-finned pilot whale (G. macrorhynchus) are grouped at the generic level since these species are difficult to separate at sea (CETAP 1982). These sightings occurred principally along the north wall of the Gulf Stream, along the shelf break, and near Oceanographer Canyon, with a couple of sightings recorded in the mid-portion of the Stream near Cape Hatteras. Pilot whales were observed during 61 sightings, accounting for 724 pilot whales during the 1991 survey (Table 4, Figure 8). The vast majority of these sightings occurred along the shelf break, including in canyons (principally Oceanographer, Hydrographer, and Corsair canyons) along the southern edge of Georges Bank, both in areas where a thermal front coincided with the bathymetric front, as well as where this co-occurrence was lacking. Some sightings were also made along the north wall of the Gulf Stream, which coincided with the bathymetric break near Cape Hatteras, and along a warm-core ring and ring remnants, which were also near bathymetric fronts.

No saddleback dolphins (Delphinus delphis) were recorded during the 1990 surveys, though these were the most commonly seen dolphins during 1991, with 43 sightings of 3493 dolphins recorded (Table 4, Figure 9). These dolphins were observed along the north wall of the Stream which coincided with the shelf break, in Oceanographer, Hydrographer and Block Canyons of southern Georges Bank and near Hudson Canyon where no thermal front was detectable, on Georges Bank shoreward of Oceanographer Canyon along a noticeable thermal front, and along the edge of a warm-core ring which was in close proximity to the southeastern bathymetric edge of Georges Bank.

Bottlenose dolphins (Tursiops truncatus) were observed during 15 sightings of 138 dolphins in 1990 (Table 2, Figure 10). Sightings were made throughout the Gulf Stream, along the north wall, in the middle of the Stream, and near the south wall. Sightings were also made in the vicinity of a warm-core ring, and in Oceanographer Canyon. In 1991, 40 sightings of 588 bottlenose dolphins were made (Table 4, Figure 11). Numerous sightings were made along the bathymetric shelf break, in areas both with, and without, an accompanying thermal front (Figure 11). Bottlenose dolphins were also seen in the Gulf Stream, along the north wall, in the canyons of the southern edge of Georges Bank, and along the edge of a warm-core ring.

Bottlenose dolphins were commonly sighted in both years. No definitive distinction was made between "near-shore" and "off-shore" stocks (Kenney, 1990), though it was noted that all animals observed were large dolphins, with the exception of a confirmed single sighting of a coastal form along the southern periphery of Georges Bank. In addition to bottlenose dolphins sightings made during transects, dolphins were in sighted inlets near Wilmington, NC. Dolphins observed very near the coast appeared to be significantly smaller than the bottlenose dolphins observed during the 1990 and 1991 offshore surveys, and thus we presume the bottlenose dolphins described here to be from the putative "off-shore" stock (Mitchell 1975).

Three Stenella species were observed during these surveys, including spotted dolphins (S. frontalis), striped dolphins (S. coeruleoalba), and spinner dolphins (S. longirostris). Because of the small sample size recorded for each species, all three species are condensed together.

During 1990, 9 sightings of 93 spotted dolphins, 2 sightings of 56 striped dolphins, and 2 sightings of 2 spinner dolphins were made (Table 2, Figure 10). Stenella spp. were sighted along the north wall and middle of the Gulf Stream, and along the edge of a warm-core ring. In 1991, 6 sightings of 392 spotted dolphins, 7 sightings of 916 striped dolphins, and 2 sightings of 21 spinner dolphins were made (Table 4, Figure 11). These species were observed along the north wall of the Gulf Stream, which coincided with the shelf edge bathymetric front, along the shelf break which also coincided with a thermal front, along the edges of a warm-core ring remnant near the shelf break and a WCR near the southern edge of Georges Bank, in a Gulf Stream shingle, and in the slope waters near a relatively weak thermal front. Results of the 1990 and 1991 surveys indicate that Gulf Stream features are important habitats for several shelf-edge and slope water species, although the exact use of these features could not be discerned.

DISCUSSION

Distribution of cetaceans seen along the shelf-edge in the 1990 and 1991 surveys were generally similar to those reported by CETAP (1982). Latitudinal gradation in species composition in 1991 and CETAP surveys is likely related to distribution patterns of higher preference prey, foraging strategies, or thermal preference. The shelf-edge is a high-use cetacean habitat, and as Kenney and Winn (1987) have hypothesized it is likely associated with elevated productivity resulting from complex oceanographic processes. Gulf Stream ring features probably enhance shelf-edge productivity, thus attracting large predators. Seasonally, these habits are utilized by migratory species of fish and squid that support important commercial and recreational fisheries (NMFS, NEFSC, unpublished data).

Ten cetaceans (fin, sperm, beaked and pilot whales, Risso's, bottlenose, saddleback, and Stenella dolphins) were also distributed along the Gulf Stream north wall which indicates this feature is also an important habitat. All of these species except fin whales were also seen associated with warm-core rings. In addition, the low number of sightings in slope waters suggests limited movements, or discontinuity in habitat desirability between the shelf-edge and north wall features. However, additional spatial and temporal sighting effort, mid-water fishing and acoustic surveying are required prior to quantifying species abundance potential prey resources along this feature.

Only beaked and sperm whales, bottlenose and Stenella dolphins were sighted within the Gulf Stream, which is consistent with the oceanic distribution of these species and the Stenella preference for warm waters (Leatherwood et al. 1976).

Sperm whale utilization of deeper shelf-edge waters, principally along the 2000m isobath, off the northeast has been documented in diverse scientific studies, and opportunistic sighting (CETAP 1982; Hain et al. submitted for publication; Lee and Socci 1989; Mitchell 1974; and Watkins, pers. comm., Woods Hole Oceanographic Institution). In addition, distribution of October 1968 through May 1990 sperm whale sightings (Hain et al., submitted for publication) indicates use of Gulf Stream waters. These authors also examined seasonal utilization of on-shelf waters (<200m) off New England and southwestern Nova Scotia and related it to inshore movement of likely prey (i.e., long-finned squid, Loligo pealei). However, sperm whale association with Gulf Stream features as reported herein has not previously been documented. Based on the 1990 and 1991 data we hypothesize that Gulf Stream features are high-use habitats for sperm whales because these are areas of high productivity (Nash et al. 1989). However, in Townsend's maps (Townsend 1935) waters off the northeast U.S. shelf were not designated as sperm whaling grounds. This suggests that whaling did not occur in this region.

In addition, elevated productivity along the shelf-edge may be amplified by the presence of warm-core rings. This may explain the numerous sperm whale sightings at the mouth of Hudson Canyon in 1991 as compared to the sparse sightings in the CETAP data base. The Gulf Stream north wall, warm-core rings and shelf-edge play important roles in the ecology of squids (Coelho 1985; Maurer and Bowman 1985; and Rowell et al. 1985) which are a principal sperm whale food item. However, since sperm whales feed well below surface waters (Watkins, pers. comm., Woods Hole Oceanographic Institution, Woods Hole, MA.), we cannot confirm that this activity occurred in the vicinity of the sightings. In addition, several Grampus dolphin sightings were associated with the WCR located off Hudson Canyon. This delphinid is also considered to feed almost exclusively on squid (Kenney et al. 1985).

Although 1990 sightings rates for sperm whales along the north wall and within the Gulf Stream were not significantly different, the analyses may be biased since the digitized position of the north wall was based on SST data. Vertical water column temperature and salinity profiles would have helped establish the precise water type where sighting were made. The use of a CTD profiler in 1991 was very valuable in establishing water type, particularly in the vicinity of warm-core rings. Furthermore, 1990 and 1991 surveys demonstrated the need for real time shipboard acquisition of SST data that in combination with CTD casts can be used to document cetacean mesoscale use of oceanographic features. In addition, the ability to collect acoustic data and conduct mid-water fishing will enable researchers to examine possible trophic relationships between cetaceans and pelagic prey, particularly along Gulf Stream features.

Based on the very low abundance estimates contained in the CETAP (1982) data base for several of the shelf-edge species reported in this paper (i.e., beaked and sperm whales, spotted, spinner, and stripped dolphins), future abundance surveys for these species need to consider waters beyond the 2000m isobath. These surveys should be conducted on research platforms capable of conducting mid-water fishing, oceanographic, and plankton operations. Likewise, additional studies along Gulf Stream features will increase our knowledge of cetacean deep-water (>2000m) habitat use and movement between shelf-edge and these features.

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Table 1. Survey effort (km) by Beaufort scale.

Year	Beaufort 0	1	2	3	4	5	Total
1990	320	976	435	243	78	15	2067
1991	154	606	1172	1483	453	264	4032

Table 2. Number of sightings by Beaufort scale in 1990.

Species	Beaufort 0	1	2	3	4	5+	Total
Beaked whale	1	2	3	0	0	0	6
Fin whale	0	1	0	0	0	0	1
Sperm whale	13	13	3	2	0	0	31
Unid. whale	0	3	3	1	0	0	7
Pilot whale	2	6	6	0	0	0	14
Bottlenose dolphin	4	5	2	4	0	0	15
Risso's dolphin	3	1	1	0	0	2	7
Spinner dolphin	2	0	0	0	0	0	2
Spotted dolphin	0	5	3	0	0	1	9
Striped dolphin	1	1	0	0	0	0	2
Unid. dolphin	5	10	1	1	0	0	17
Total	31	47	22	8	0	3	111

Table 3. Frequency of sightings by group size in 1990.

Species	Group Size 1	2-5	6-10	11-20	>20	Total Sighting	Total # Animals	% Total Sightings
Beaked whale	3	3	0	0	0	6	15	5.4
Fin whale	1	0	0	0	0	1	1	0.9
Sperm whale	23	8	0	0	0	31	47	27.9
Pilot whale	3	8	1	2	0	14	68	12.7
Bottlenose dolph.	1	3	8	2	1	15	138	13.5
Risso's dolphin	0	5	2	0	0	7	36	6.3
Spinner dolphin	2	0	0	0	0	2	1	1.8
Spotted dolphin	1	2	4	1	1	9	93	8.1
Striped dolphin	0	0	1	0	1	2	56	1.8
Unid. dolphin	3	8	4	1	1	17	154	15.3
Unid. whale	7	0	0	0	0	7	7	6.3

Table 4. Number of sightings by Beaufort scale in 1991.

Species	Beaufort						
	0	1	2	3	4	5+	Total
Beaked whale	0	3	2	2	0	0	7
Fin whale	0	10	3	10	3	2	28
Humpback whale 0	3	1	2	6	0	12	
Minke whale	0	0	0	1	0	0	1
Sei whale	0	0	0	2	0	0	2
Sperm whale	1	6	21	21	8	1	58
Unid. whale	2	11	20	13	9	2	57
Pilot whale	0	16	23	19	3	0	61
Pygmy sperm whale	0	0	1	0	0	0	1
Bottlenose dolphin	0	11	10	14	4	1	40
Risso's dolphin	0	2	9	3	3	0	17
Saddleback dolphin	1	6	18	16	0	2	43
Spinner dolphin	0	1	1	0	0	0	2
Spotted dolphin	0	0	3	0	0	3	6
Striped dolphin	0	1	2	3	1	0	7
Whitesided dolphin	0	0	2	0	0	0	2
Unid. dolphin	1	19	45	45	7	2	119
Total	5	89	161	151	44	13	463

Table 5. Frequency of sightings by group size in 1991.

Species	Group Size							
	1	2-5	6-10	11-20	>20	Total Sightings	Total # Animals	%Total Sightings
Beaked whale	1	4	2	0	0	7	29	1.5
Fin whale	21	6	1	0	0	28	45	6.1
Humpback whale	8	2	2	0	0	12	24	2.6
Minke whale	1	0	0	0	0	1	1	0.2
Sei whale	1	1	0	0	0	2	3	0.4
Sperm whale	30	25	1	2	0	58	129	12.7
Pilot whale	4	23	15	11	8	61	724	13.3
Pygmy sperm wh.	1	0	0	0	0	1	1	0.2
Bottlenose dolph.	4	8	9	10	7	40	588	8.7
Risso's dolphin	0	4	7	2	3	17	333	3.7
Saddleback dolph.	1	3	4	8	27	43	3493	9.4
Spinner dolphin	1	0	0	1	0	2	21	0.4
Spotted dolphin	0	1	0	2	3	6	392	1.3
Striped dolphin	0	1	0	0	6	7	916	1.5
Whitesided dolph.	0	0	0	0	2	2	925	0.4
Unid. dolphin	20	20	22	17	40	119	4344	26.0
Unid. whale	45	7	0	0	1	52	64	11.4

Table 6. Observed and expected sperm whale sightings associated with Gulf Stream features in 1990.

Region relative to GS Features	Observed Frequency	Expected Frequency	X^2
9.3 km north of GS north wall	5	3.9	0.31
9.3 km south of GS north wall	9	5.9	1.63
In GS beyond 9.3 km	15	19.2	0.92

$X^2 = 2.86$, 2 df, $p>0.05$

Table 7. Observed and expected sperm whale sightings associated with Gulf Stream features in 1991.

Region relative to GS features	Observed Frequency	Expected Frequency	X^2
Within 9.3 km of GS ring feature	5	14.5	6.22
Within 9.3 km of GS ring and 2000 m isobath	22	6.0	42.67
Within 9.3 km of 2000 m isobath, no ring present	14	20.5	2.06

$X^2 = 42.67$, 2 df, $p < 0.05$

FIGURE LEGENDS

Figure 1. Transect lines during NOAA R/V CHAPMAN 1990 marine mammal survey.

Figure 2. Transect lines during NOAA R/V CHAPMAN 1991 marine mammal survey.

Figure 3. Variability in Gulf Stream north wall and warm-core ring positions during 5-18 August 1990 marine mammal survey based on satellite images for August 6, 10, 14, and 18.

Figure 4. Variability in Gulf Stream north wall and warm-core ring positions during 8 June to 16 July 1991 marine mammal survey based on satellite images for June 9, 14, 15, and 25.

Figure 5. Distribution of beaked (BEWH) and sperm (SPWH) whale sightings during 1990 survey, sightings in box correspond to August 5-10 period used for composite image.

Figure 6. Distribution of beaked (BEWH) and sperm (SPWH) whale sightings during 1991 survey, sightings in box correspond to June 7-8 period used for composite image.

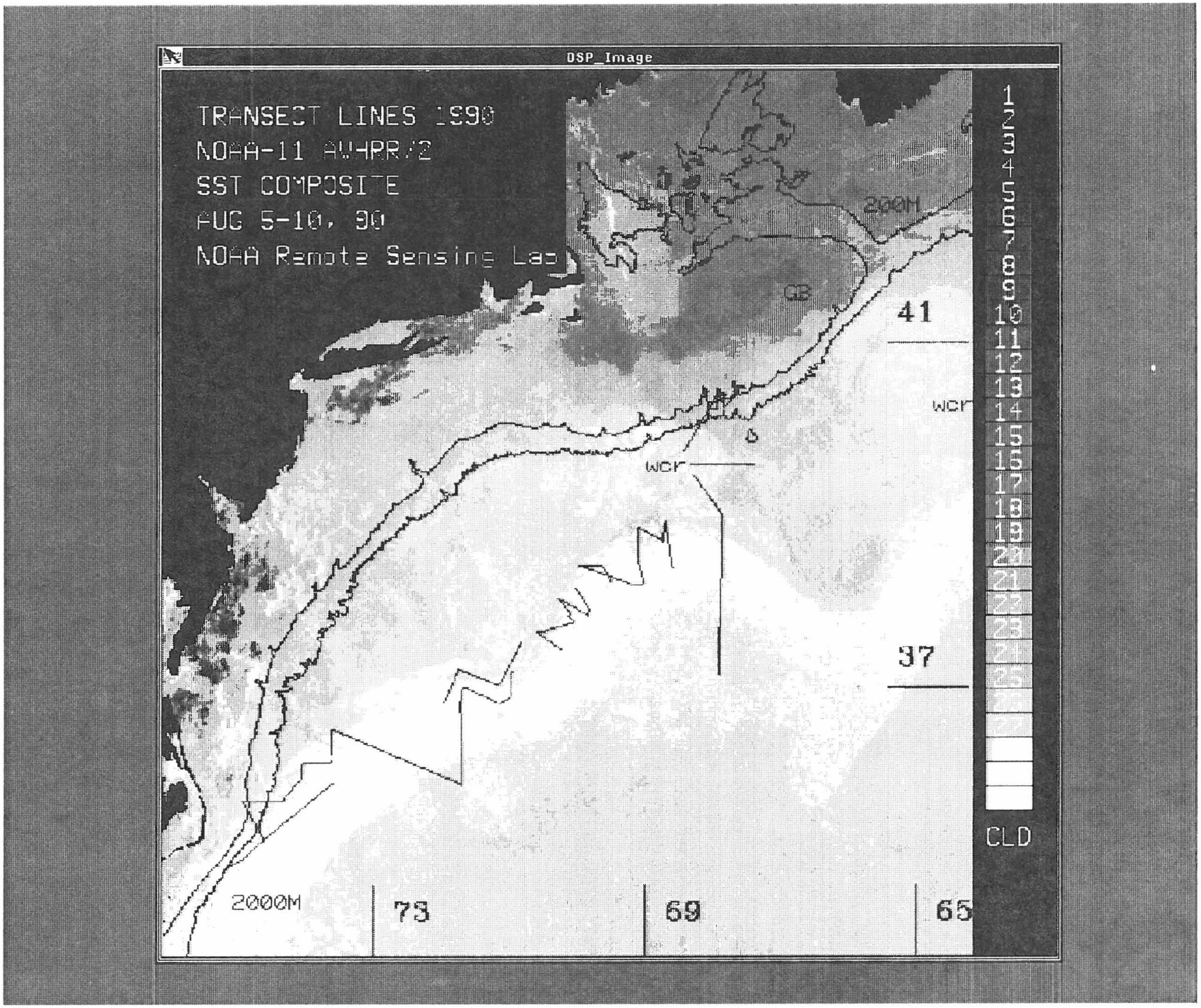
Figure 7. Distribution of Risso's (GRAMPUS) dolphin and pilot whale sightings during 1990 survey, sightings in boxes correspond to August 5-10 period used for composite image.

Figure 8. Distribution of Risso's (GRAMPUS) dolphin and pilot whale sightings during 1991 survey, sightings in box correspond to June 7-8 period used for composite image.

Figure 9. Distribution of saddleback (SADO) dolphin sightings during 1991 survey, sightings in box correspond to June 7-8 period used for composite image.

Figure 10. Distribution of bottlenose (BODO), spinner (SNDO), spotted (SPDO) and striped (STDO) dolphin sightings during 1990 survey, sightings in boxes correspond to August 5-10 period used for composite image.

Figure 11. Distribution of bottlenose (BODO), spinner (SNDO), spotted (SPDO) and striped (STDO) dolphin sightings during 1990 survey, sightings in box correspond to June 7-8 period used for composite image.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NOAA-11 AVHRR/2
SST COMPOSITE
AUG 5-10, 90
NOAA Remote Sensing Lab
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GB
41
wcr
wcr
37
2000M
73
69
65
1
2
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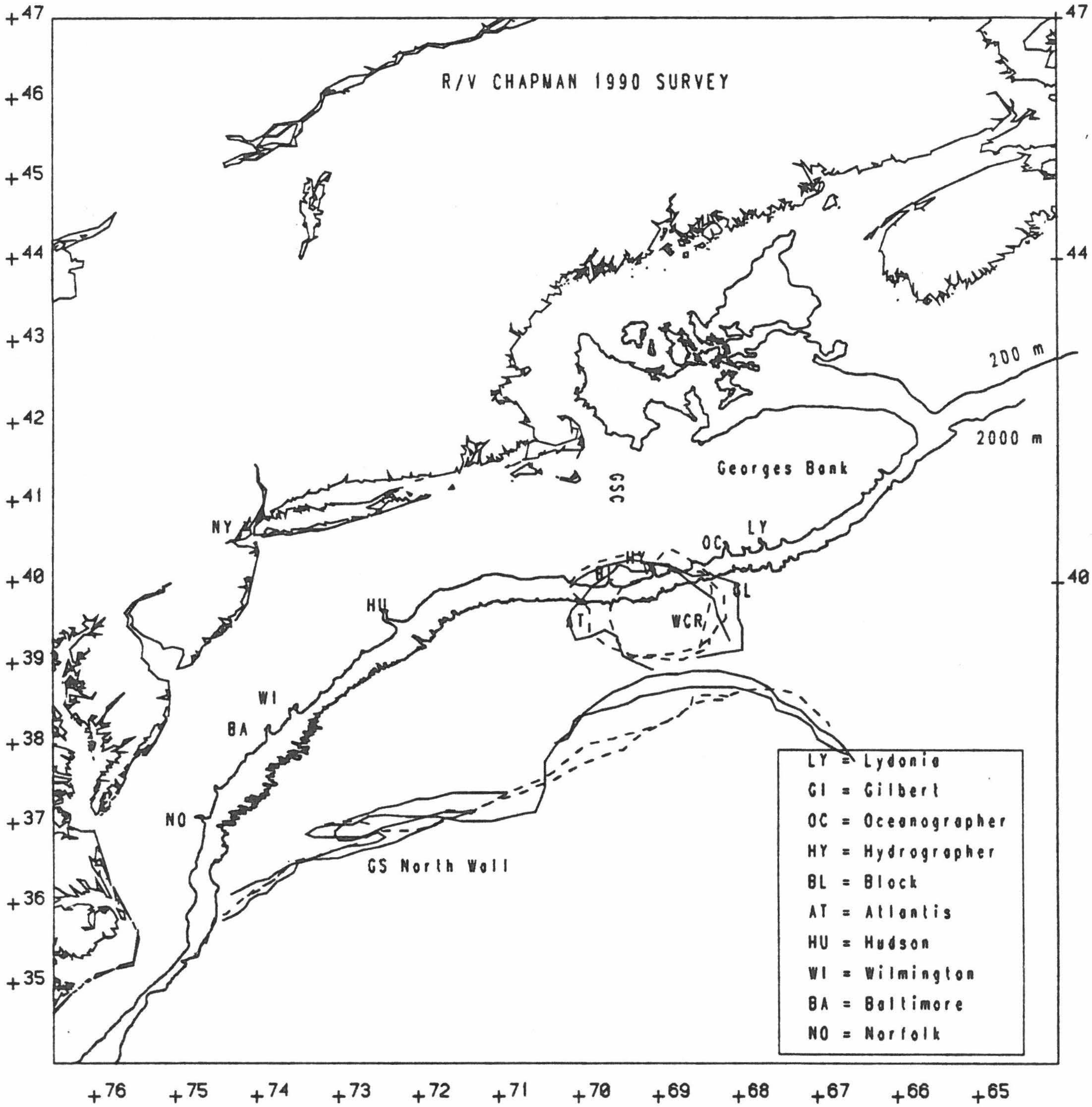
18
19
CLD

Fig. 1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+45
+44
+43
+42
+41
+40
+39
+38
+37
+36
+35
47
44
40
200 m
2000 m
Georges Bank
GSC
NY
OC
LY
HY
BL
WCR
HU
WI
BA
NO
GS North Wall
LY = Lydonia
GI = Gilbert
OC = Oceanographer
HY = Hydrographer
BL = Block
AT = Atlantis
HU = Hudson
WI = Wilmington
BA = Baltimore
NO = Norfolk
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+74
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+72
+71
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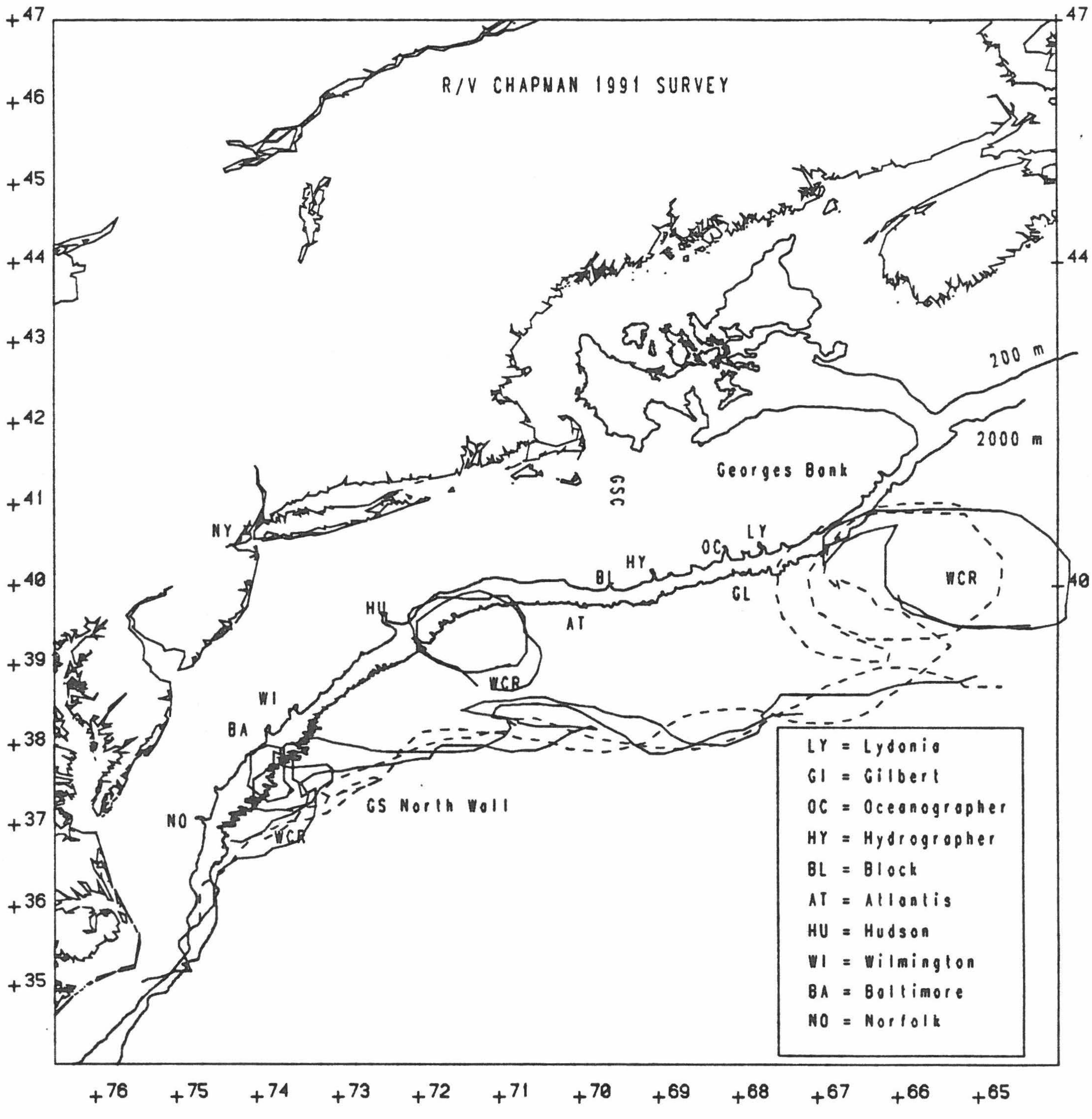
+68
+67
+66
+65

Fig. 3


R/V CHAPMAN 1991 SURVEY
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+39
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+37
+36
+35
47
44
40
200 m
2000 m
Georges Bank
GSC
NY
LY
OC
HY
BL
GL
AT
HU
WCR
WI
BA
NO
GS North Wall
LY = Lydonia
GI = Gilbert
OC = Oceanographer
HY = Hydrographer
BL = Block
AT = Atlantis
HU = Hudson
WI = Wilmington
BA = Baltimore
NO = Norfolk
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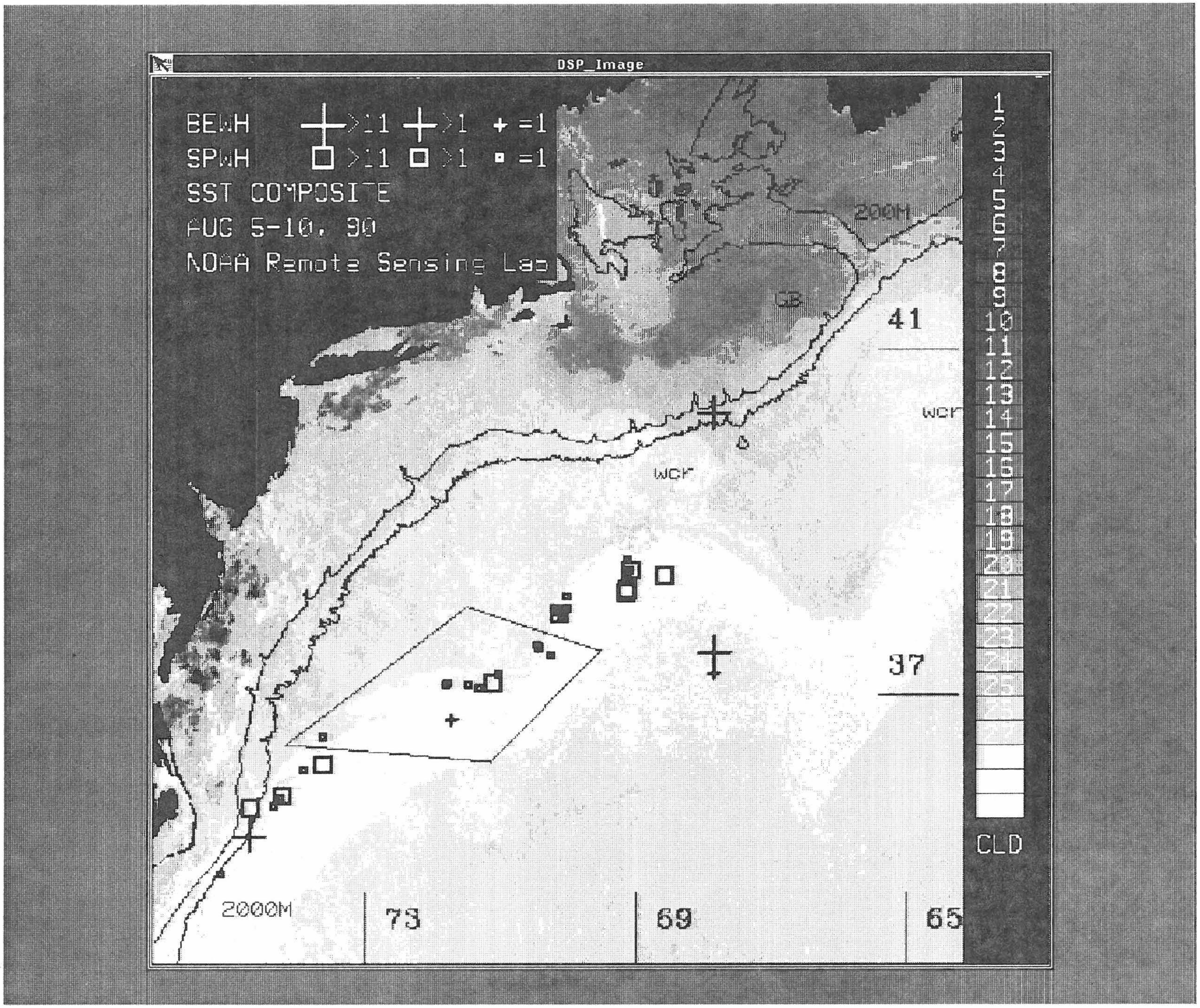
+75
+74
+73
+72
+71
+70
+69
+68
+67
+66
+65

Fig. 4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SPWH >11 >1 =1
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AUG 5-10, 90
NOAA Remote Sensing Lab
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GB
WCR
WCR
41
37
2000M
73
69
65
1
2
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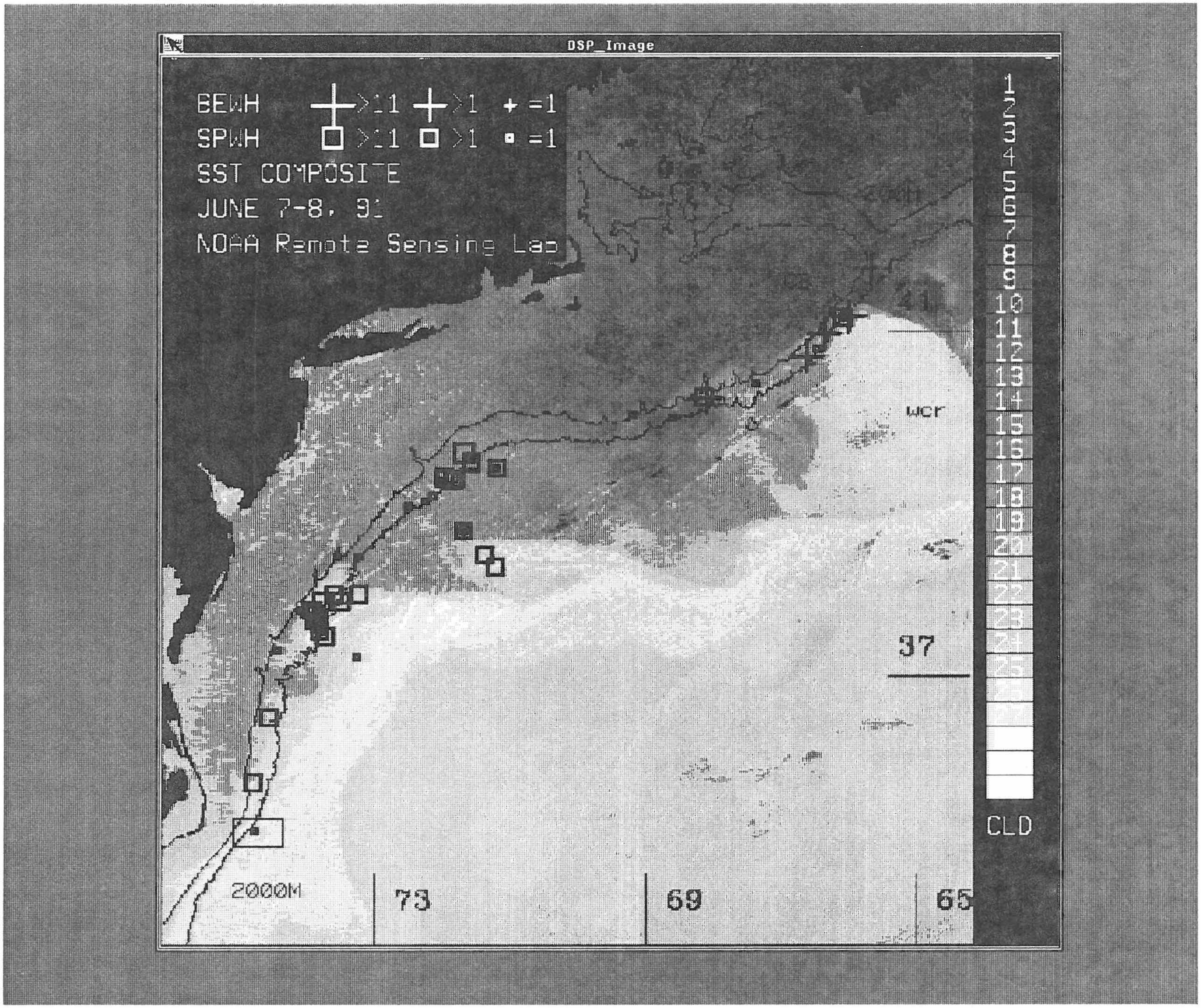
25
CLD

Fig. 5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JUNE 7-8, 91
NOAA Remote Sensing Lab
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2000M
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69
65
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2
3
4
5
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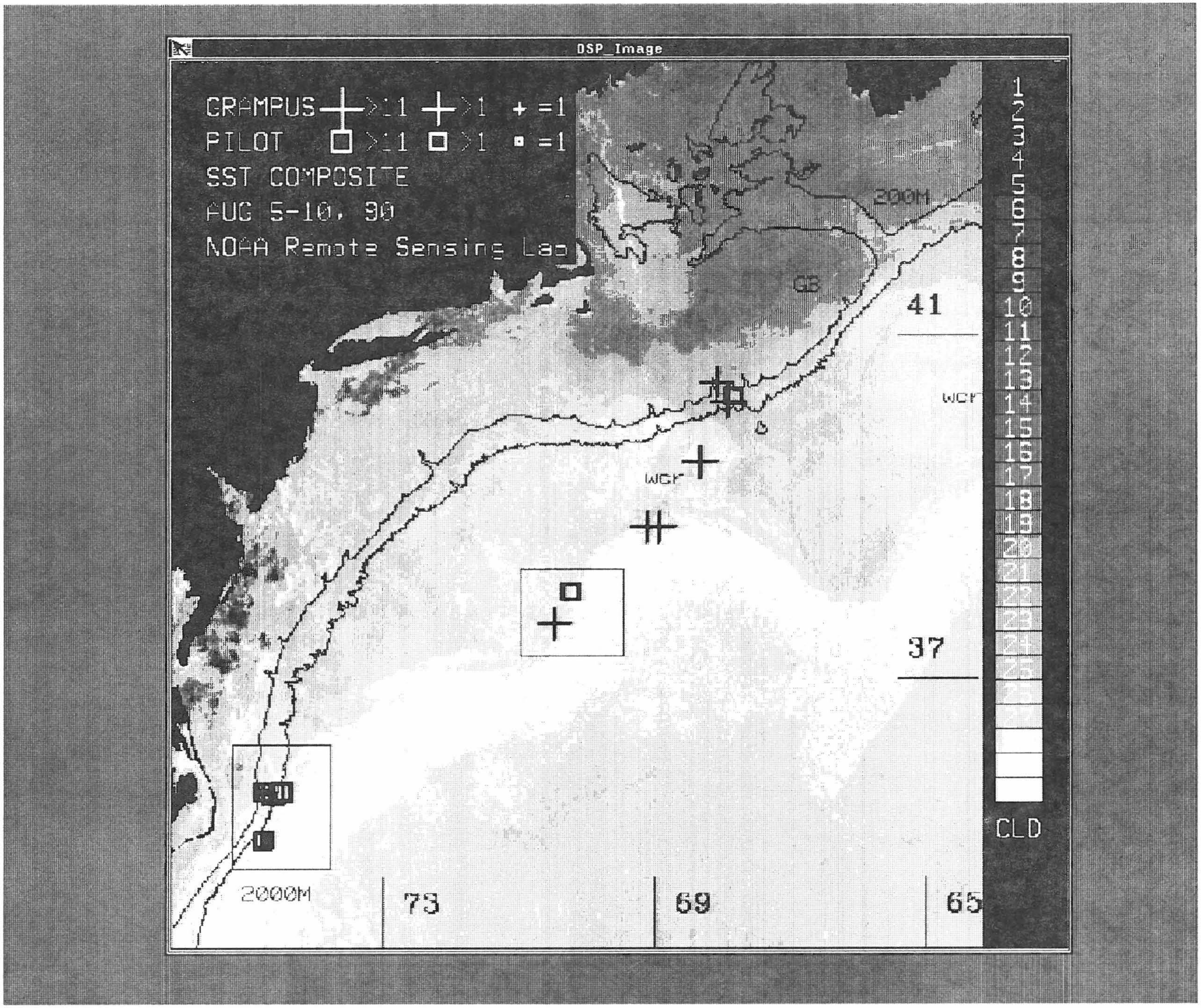
25
CLD

Fig. 6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PILOT >11 >1 =1
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AUG 5-10, 90
NOAA Remote Sensing Lab
200M
GB
41
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WCR
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2000M
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69
65
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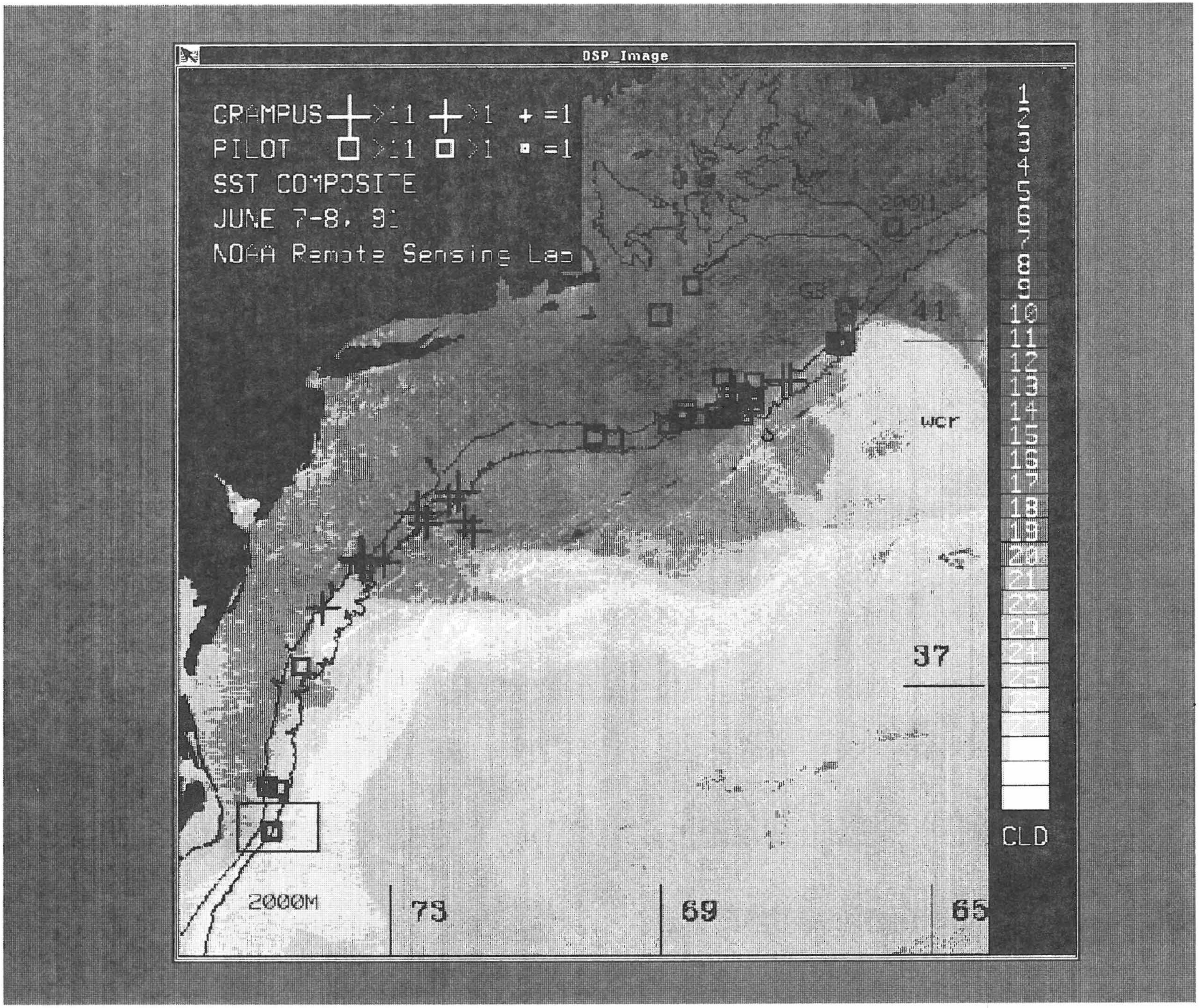
CLD

Fig. 7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JUNE 7-8, 91
NOAA Remote Sensing Lab
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2000M
73
69
65
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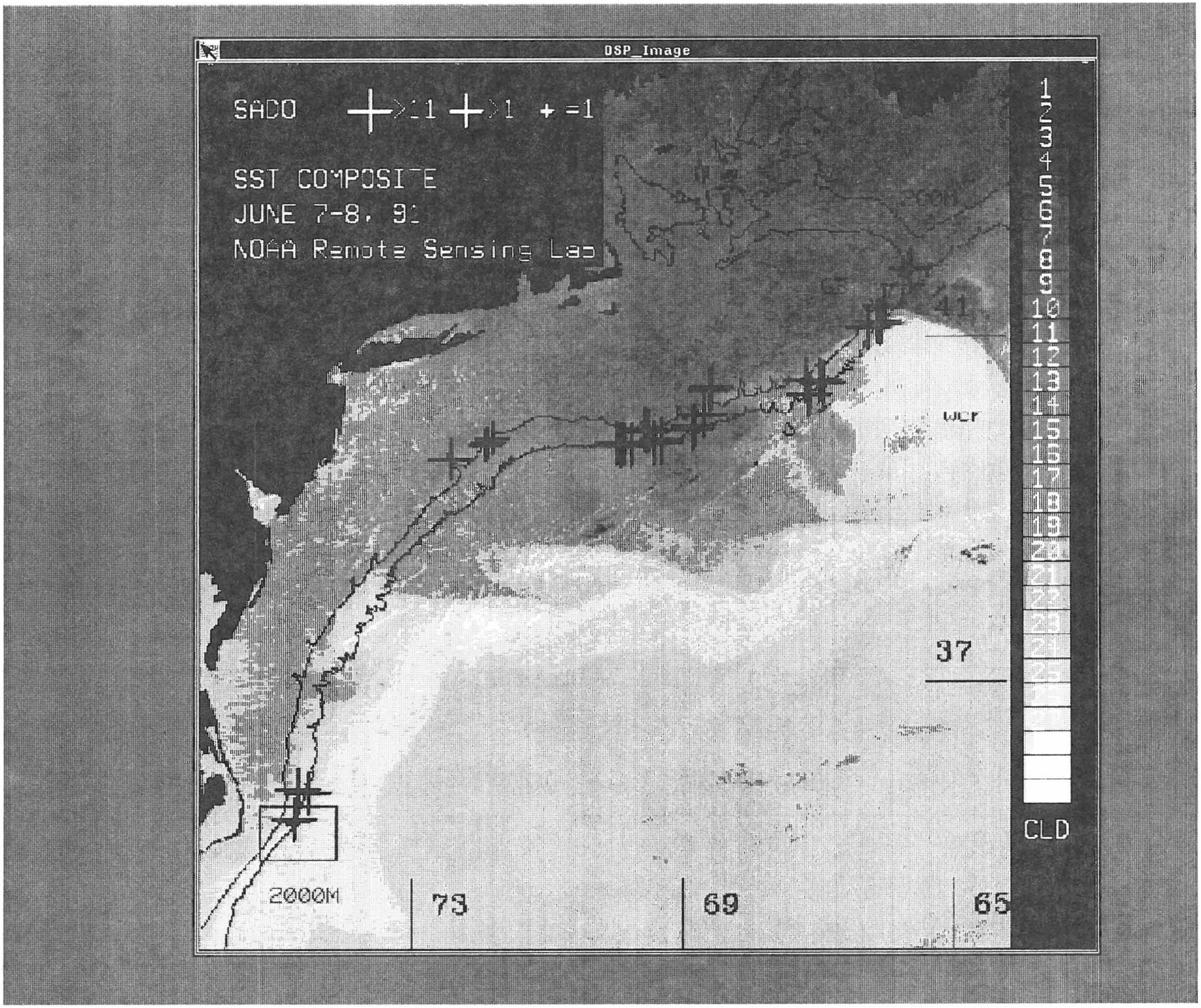
CLD

Fig. 8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SST COMPOSITE
JUNE 7-8, 91
NOAA Remote Sensing Lab
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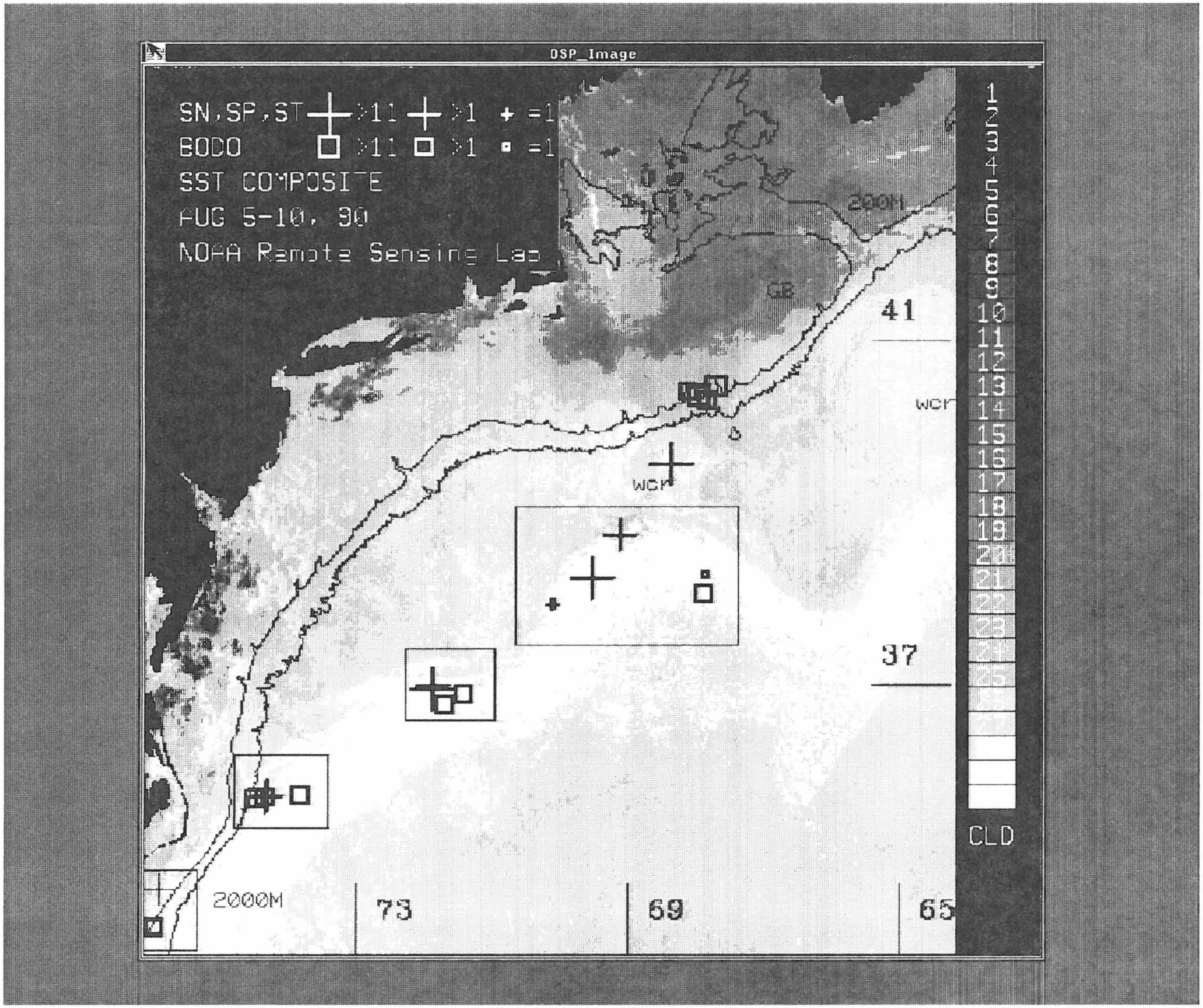
CLD
41
37
2000M
73
69
65

Fig. 9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BODO >11 >1 =1
SST COMPOSITE
AUG 5-10, 90
NOAA Remote Sensing Lab
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GB
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WCR
WCR
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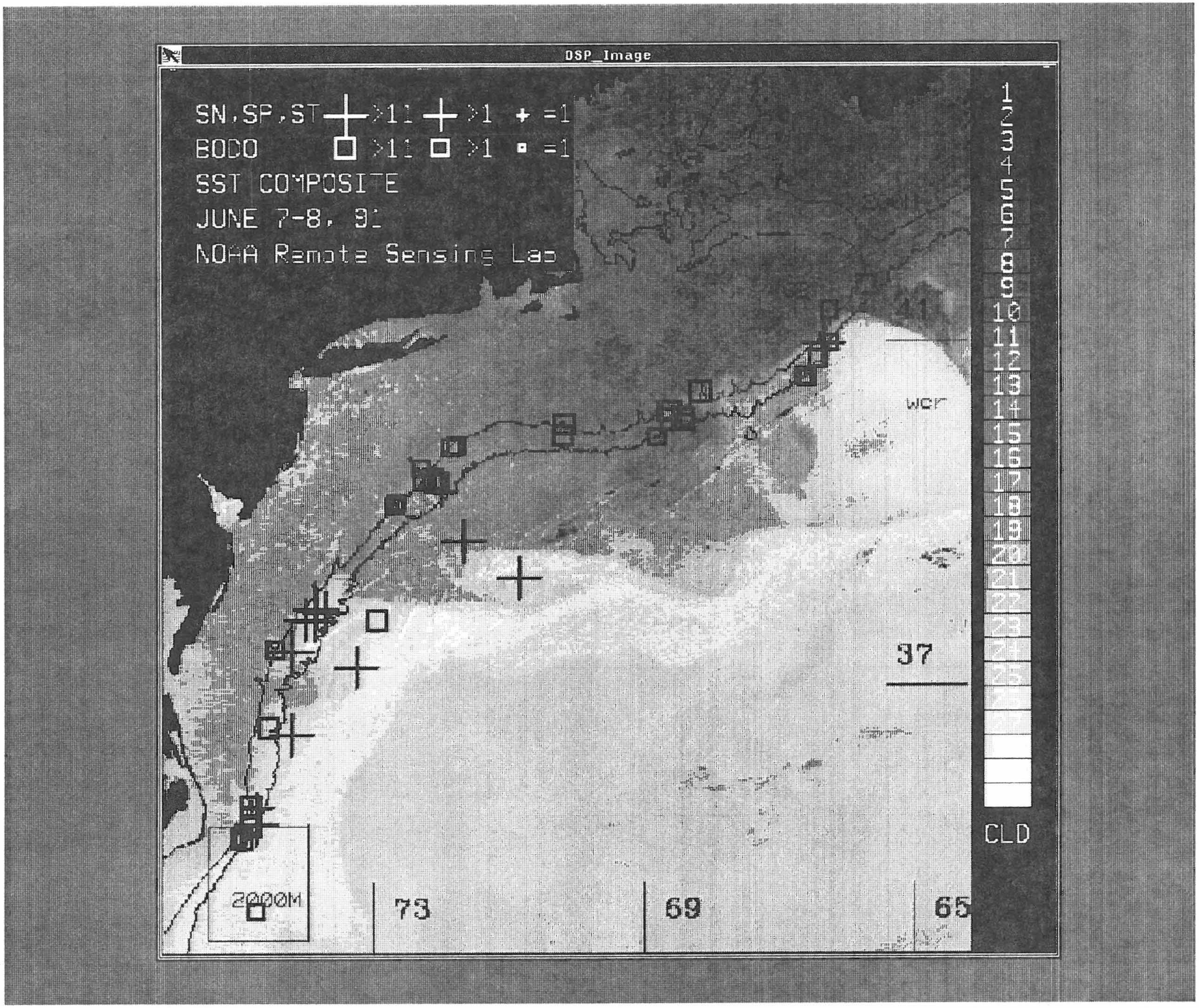
2000M
73
69
65
CLD

Fig. 10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SST COMPOSITE
JUNE 7-8, 91
NOAA Remote Sensing Lab
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2000M
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27
CLD

Fig. 11