THE USE OF AVHRR IMAGERY AND THE MANAGEMENT OF SEA TURTLE INTERACTIONS IN THE MID ATLANTIC BIGHT

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INTRODUCTION

Large-mesh gill nets used in the fishery for goosefish (monkfish), *Lophius* sp., have been documented to capture and drown sea turtles along the Mid Atlantic coast of the U.S. (NEFSC, unpubl. data). Significant stranding events have been associated with the operation of this fishery in its southern range (SEFSC, unpubl. data). The Fishery Management Plan mandated differential trip limits over time (4 yr) for vessels fishing the monkfish Southern Fishery Management Area (SFMA: includes North Carolina and Virginia) using trawl versus non-trawl (e.g., gillnet) gear, effectively reducing effort (Mid-Atlantic Fishery Management Council et al., 1998). The most recent Section 7 consultation was based on the plan as outlined and amended (NMFS, 2001). A recent court decision (Gary Hall et. al. v. Evans, 2001) has overturned these differential trip limits and there now is concern that fishing effort in the SFMA will increase. Consequently, the potential for interactions with sea turtles is much greater now than was considered in the consultation. Furthermore, the State of North Carolina has submitted an application for an Exempted Fishery Permit (EFP) to allow a few state fishermen without federal permits to enter the fishery, ostensibly to determine the relative proportion of *L. gastrophysis* (blackfin goosefish/monkfish) taken in the fishery. With the change in status of the fishery relative to the original consultation and in light of an EFP application, NMFS needed to evaluate the impact of the anticipated fishery on sea turtles.

As a strawman risk analysis we began with an evaluation of the sea turtle conservation measures proposed in North Carolina's Application for an EFP. The North Carolina Division of Marine Fisheries proposed five time-specific area closures. The northern boundary of the management area was 37/ 56' 00", which represents Chincoteague, Virginia. The southern boundaries, which change with time are as follows:

35/ 20' 30" Avon, NC
35/ 46' 00" Oregon Inlet, NC
36/ 22' 30" Currituck Beach Light, NC
36/ 55' 54" Cape Henry, VA
37/ 34' 36" Wachapreague, VA

The EFP proposed closing the waters to monkfishing south of the southern boundary at different times throughout the period. Our goal was to independently define closure dates for those same areas based on sea surface temperature imagery.

Sea surface temperature (SST) images acquired by the Advanced Very High Resolution Radiometer (AVHRR) sensor onboard NOAA polar orbiting satellites were used to evaluate the risk of sea turtles interacting with fisheries operating in the nearshore and offshore waters of North Carolina and Virginia. In order to determine if the dates proposed for closure were adequate to protect sea turtles, we analyzed sea surface temperature (SST) data between the southern boundary of each area.

Note that the analysis conducted only addresses warming waters in the spring. It does not address the risk to sea turtles associated with the fishery moving southward with the migrating fish stocks and cooling temperatures in the fall.

MATERIALS AND METHODS

Only SST images free from cloud cover or other obstructions were selected at approximately 2 week intervals beginning March 1 and ending June 30 for the years 1999-2001. We defined 5 areas based on the southern boundaries proposed in the EFP application. The boundaries of each Area are:

Area 1 - 35/ 20' 30" (Avon, NC) to 35/ 46' 00" (Oregon Inlet, NC)
Area 2 - 35/ 46' 00" (Oregon Inlet, NC) to 36/ 22' 30" (Currituck Beach Light, NC)
Area 3 - 36/ 22' 30" (Currituck Beach Light, NC) to 36/ 55' 54" (Cape Henry, VA)
Area 4 - 36/ 55' 54" (Cape Henry, VA) to 37/ 34' 36" (Wachapreague, VA)
Area 5 - 37/ 34' 36" (Wachapreague, VA) to 37/ 56' 00" (Chincoteague, VA)

Two different kinds of graphics were produced from the SST images. Initially, the image was imported into Windows Image Manager (WIM), a software that allows display and some analysis of SST images. For each image, the same lookup table (LUT) file, which associates certain colors with certain pixel values, was loaded to ensure all images had identical color codes. Each image was geo-rectified by shifting the image to match coastlines with a land mask overlay. We overlayed a graphic depicting each Area's north-south boundaries and used the coastline, 10 nm offshore, 35 nm offshore and 45 nm offshore as the east-west boundaries. The area between 10 nm offshore and 35 nm offshore encompassed the majority of observed monkfish trips occurring from 1996-1999 (NEFSC, 2000). WE used the 45 nm offshore boundary to represent the easternmost boundary of the fishery. A temperature bar depicting the temperature/color relationship of the image is included with each image, allowing a visual analysis of the SST.

Secondly, the image was imported into CoastWatch Data Analysis Tool (CDAT) to construct a frequency distribution of SST within an area drawn on the image. CDAT restricted our ability to extract SST data from the entire designated Area because it only allowed a rectangle to be drawn, not a parallelagram nor a polygon. We choose geocoordinates for this rectangle which we felt encompassed a representative sample of the entire designated Area (Figure 1).

From these temperature distributions, we determined the likelihood that a sea turtle might be found in a certain designated Area at different times of the fishing season. Each designated Area/date

was scored (somewhat subjectively since we had access only to the histogram graphic and not the raw data) as either too warm, indicating probable high risk to sea turtles, or not too warm (o.k.), indicating probability of a low risk. A score of too warm was assigned if a significant portion ($ 50%) of the pixels underlying each designated Area represented SST's $11°C . Epperly et al. (1995) reported that during the winter, turtles off the North Carolina shelf were most likely to occur in waters $11°C. Already NMFS has used that information along with historical SST imagery to regulate the winter trawl fishery operating south of Cape Charles, Va. (61 FR 1846, January 24, 1996). Also, of the 16 turtles observed taken in the monkfish fishery with large-mesh gillnets, all but 1 (94%) were taken in waters $11°C (NEFSC, unpubl. data).

For Areas 2, 3, 4, and 5, the rectangles evaluated were entirely over the continental shelf. The southeast portion of the rectangle for Area 1 included waters seaward of the shelf; consequently, high temperature values visibly associated with the off-shelf portion of Area 1 were censured from our analysis of the histograms to better reflect the area being fished.

To summarize the results, we partition the data temporally, dividing each month into 2 segments, by day: early (1-15) and late ($16). We then provide 2 dates, describing the range in levels of risk, for consideration to use in regulations to close a designated Area to large-mesh gillnet fishing: (1) a reasonable date to maximize sea turtle conservation, and (2) the latest date that possibly could be defended based on SST's. Risk increases with time corresponding to warming water temperatures.

RESULTS AND CONCLUSIONS

We present these results with caution since three years is a short time series to evaluate oceanographic conditions in such a dynamic area. Only after considered examination of a longer period could one more accurately predict the risk to sea turtles. Also, the areas defined herein do not encompass the full geographic range of the fishery. Unaudited logbook data indicate that throughout this region, the entire continental shelf is fished (NEFSC, 2000). Except for Area 1, the rectangles we analyzed did not extend seaward to the shelf break. Since the Gulf Stream influence likely is greatest over the outer shelf areas, our analysis of areas not extending to the shelf break did not consider the farthest extent of the fishery and would tend to underestimate the risk to sea turtles. Detailed results are presented in Table 1 and are summarized below. The WIM imagery and the CDAT results are contained in separate documents (PowerPoint presentations), by month.

Area 1

Based solely on these 3 years of imagery we found that Area 1 could never be open to unrestricted fishing without significant risk to sea turtles. In early March, three of four dates were too warm; in late March, two of four were too warm. Throughout the winter, the Gulf Stream appears to influence the nearshore waters intermittently as far north as Oregon Inlet and this has been documented in imagery from the early 1990's (Chester et al., 1994; Epperly et al., 1995). Fishing on the continental

shelf south of Oregon Inlet without turtle conservation measures poses a significant risk to sea turtles year round.

Area 2

In early March, two of four dates were too warm but during late March, none of four were too warm. In early April, two of four dates were too warm and by late April all were too warm. This is in contrast with imagery from the early 1990's when it was determined that during early March, fishing in the area north of Oregon Inlet probably would pose little risk to sea turtles. However, based on imagery from late March, NMFS determined that significant risk to sea turtles extended to waters north of Oregon Inlet and each year moves the TED line for the winter trawl fishery northward on Mar. 16 (61 FR 1846, January 24, 1996). Based on information provided below on Areas 3 and 4, we would recommend March 16 as the date to close Area 2 to unrestricted fishing to minimize risk. The area must be closed by April 16 when 100% of the dates examined thereafter were too warm.

Areas 3 and 4

We did not find the sea surface temperatures of Area 3 to be significantly different from Area 4 and therefore recommend the two areas be treated as a single unit. In both areas, one of four dates in early April was too warm, and by late April one of two dates was too warm. A reasonable closure date for maximum turtle protection is April 1. After April, 100% of all dates examined were too warm. May 1 is the latest date that the area could be closed without significant risk to sea turtles

Area 5

During early April, one date (April 9, 2001) was possibly too warm, but only about 1/3 of the area was warm and the maximum temperature observed was but 12°C. During late April, one date clearly was too warm. In May and in June all dates examined were too warm. April 16 is the most turtle-conservative date for closure in this area and May 1 is the latest date that the area could be closed without significant risk to sea turtles.

RECOMMENDATIONS FOR FUTURE ANALYSES

Since AVHRR imagery can be used to evaluate the risk of sea turtles interacting with fisheries operating in the Mid Atlantic area, we recommend NMFS evaluate imagery from over a decade and describe spatiotemporal boundaries in which turtle conservation measures should be required to minimize the risk to sea turtles. We can evaluate imagery in polygons described on the north and south by latitudes (we propose using 30 minute intervals), on the west by the shoreline, and on the east by the

200 m depth contour, approximating the shelf edge. Each of these polygons can be used to "cut" AVHRR imagery and export SST data, by pixel, for quantitative analysis. These results can be applied to a risk analysis of any perceived threat within the described shelf areas. NMFS SEFSC proposes to do this analysis and the results should be available by summer 2002.

LITERATURE CITED

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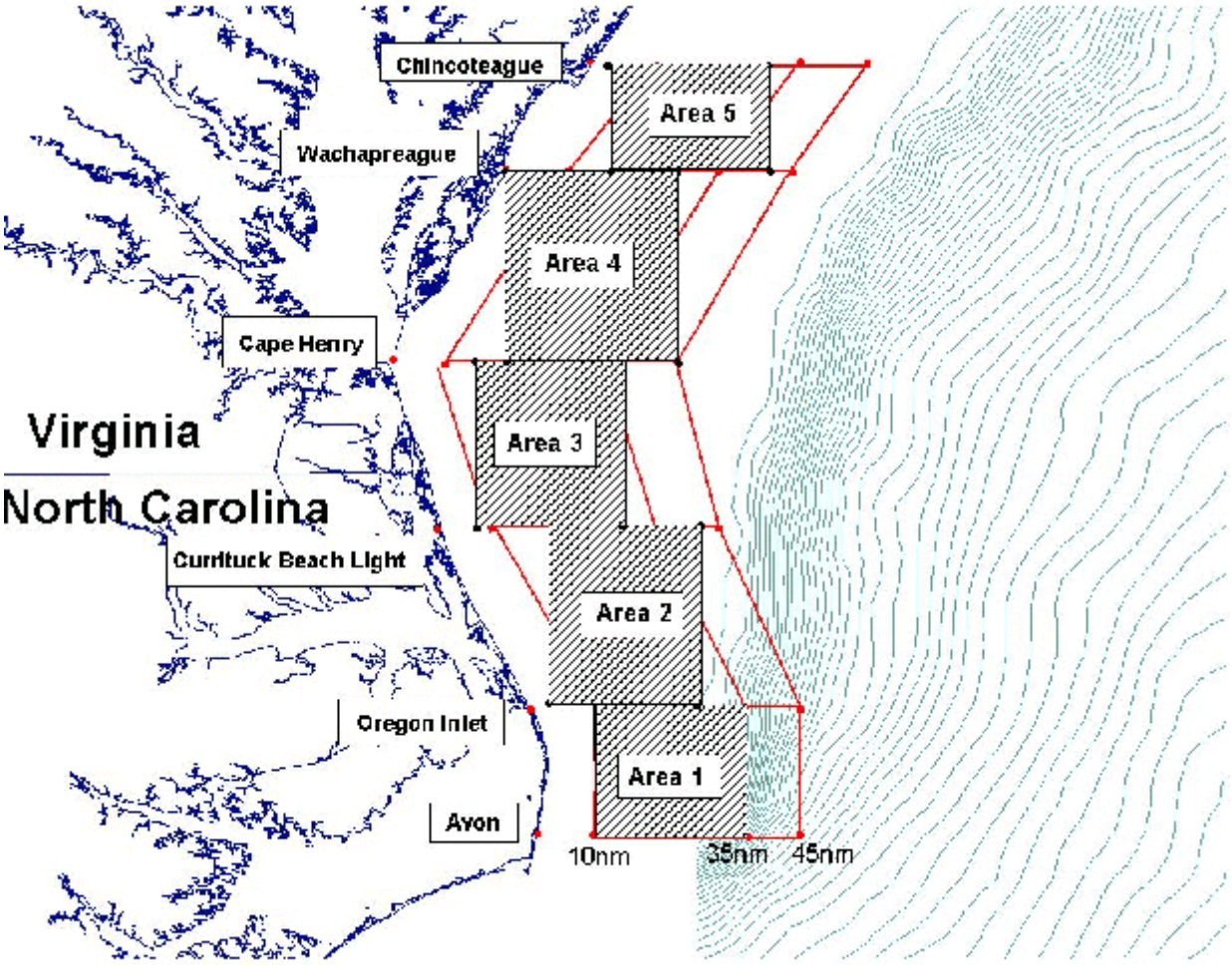
Northeast Fisheries Science Center. 2000. Report of the 31st Northeast Regional Stock Assessment Workshop (31st SAW): Stock Assessment Review Committee (SARC) consensus summary of assessments. Northeast Fish. Sci. Cent. Ref. Doc. 00-15.

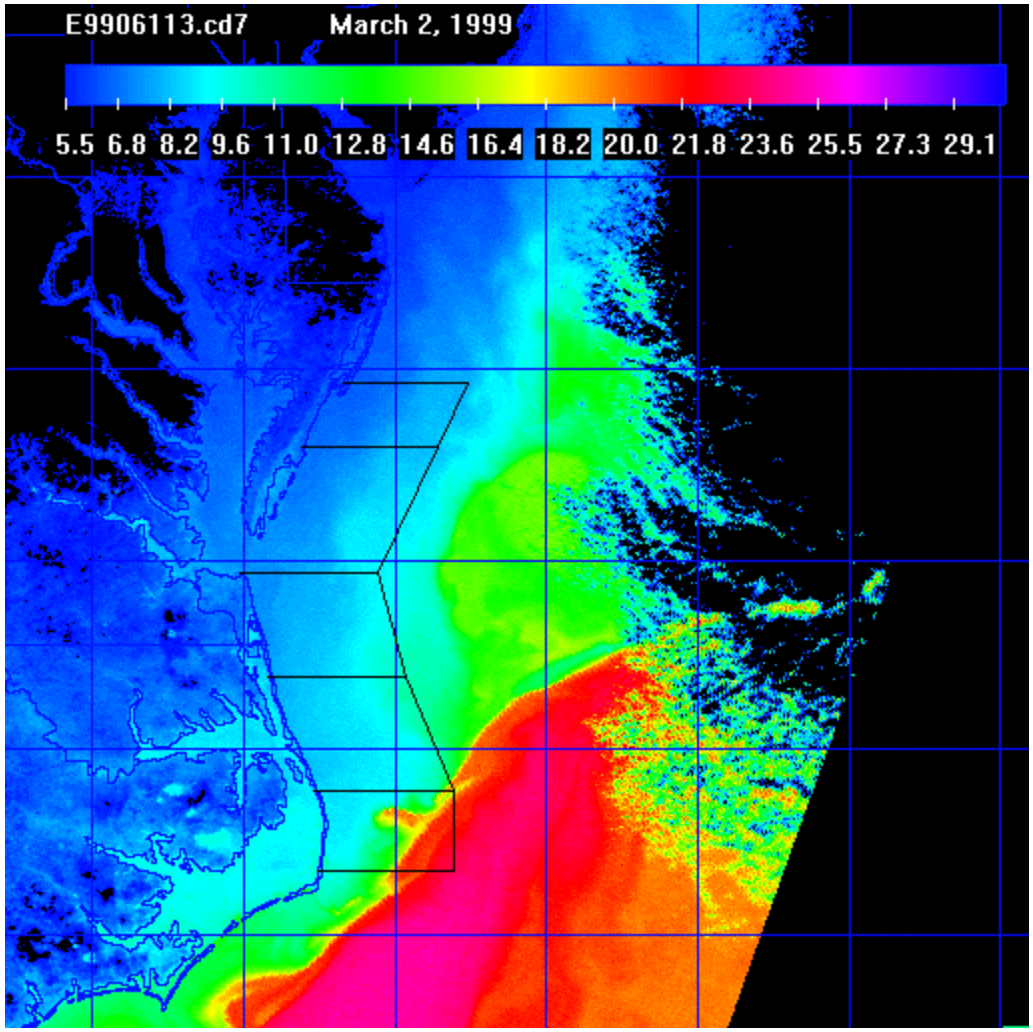
Table 1. Detailed scoring of daily imagery, 1999-2001, by area.. An "X" indicates that a detailed image for that area/date was not analyzed and hence, no histogram was produced but usually the cell could be scored based on WIM imagery; "o.k" denotes a significant number of pixels of the image represented temperatures < 11°C. "Warm" indicates that a significant number of pixels of the image represented temperatures $11°C and these cells are shaded.

Date	Area				
	1	2	3	4	5
MARCH					
March 1, 2000	Warm sign. amt. $11°C	Warm sign. amt. $11°C	ok	X - o.k. based on WIM image	X - o.k. based on WIM image
March 5, 1999	Warm all are $11°C	Warm most are $11°C	ok	ok	ok
March 10, 2001	o.k.	o.k.	o.k.	X - o.k. based on WIM image	X - o.k. based on WIM image
March 13, 2000	Warm most are $11°C	o.k. few $11°C	o.k.	X - o.k. based on WIM image	X - o.k. based on WIM image
March 16, 1999	o.k. warm off shelf	o.k.	o.k.	o.k.	o.k.
March 24, 2001	o.k. warm off shelf	o.k.	o.k.	o.k.	o.k.
March 29, 2000	Warm nearly all $11°C	o.k.	o.k.	X - o.k. based on WIM image	X - o.k. based on WIM image
March 30, 1999	Warm Gulf Stream over southern shelf	o.k.	o.k.	o.k.	X - o.k. based on WIM image
APRIL					
April 4, 2001	X-prob. o.k. based on WIM	o.k.	o.k.	o.k.	X - o.k. based on WIM image
April 9, 2001	X - warm based on WIM image	Warm	Warm	Warm	o.k. ~1/3 $11°C; max is 12°C
April 10, 2000	X - warm based on WIM image	Warm	o.k.	o.k.	X - o.k. based on WIM image
April 14, 1999	X - warm based on WIM image	o.k.	o.k.	o.k.	o.k.

Date	Area				
	1	2	3	4	5
April 23, 2001	X - warm based on WIM image	Warm	Warm	Warm	Warm ~50% $11°C
April 26, 2000	X - warm based on WIM image	Warm >50% $11°C	o.k.	o.k.	X - o.k. based on WIM image
MAY					
May 5, 1999	X - warm based on WIM image	Warm	Warm	Warm	Warm
May 5, 2001	X - warm based on WIM image	X - warm based on WIM image	Warm	Warm	Warm
May 9, 2000	X - warm based on WIM image	X - warm based on WIM image	Warm	Warm	Warm
May 13, 2001	X - warm based on WIM image	X - warm based on WIM image	Warm	Warm	Warm
May 17, 1999	X - warm based on WIM image	Warm	Warm	Warm	Warm
May 24, 2000	X - warm based on WIM image	X - warm based on WIM image	Warm	Warm	Warm
May 24, 2001	X - warm based on WIM image	X - warm based on WIM image	Warm	Warm	Warm
May 31, 1999	X - warm based on WIM image	X - warm based on WIM image	Warm	Warm	Warm
JUNE					
June 10, 2000	X - warm based on WIM image	X - warm based on WIM image	X - warm based on WIM image	Warm	Warm
June 10, 2001	X - warm based on WIM image	X - warm based on WIM image	X - warm based on WIM image	Warm	Warm
June 14, 1999	X - warm based on WIM image	X - warm based on WIM image	X - warm based on WIM image	Warm	Warm
June 20, 2000	X - warm based on WIM image	X - warm based on WIM image	X - warm based on WIM image	X - warm based on WIM image	Warm
June 26, 2001	X - warm based on WIM image	X - warm based on WIM image	X - warm based on WIM image	X - warm based on WIM image	Warm

Figure 1. Cross-hatched Area 1 - Area 5 represent rectangular boxes from which SST frequency distributions were extracted. Distance from shore (10, 35, and 45 nm) is shown as is bathymetry. The shallowest depth contour depicted is 200 m.

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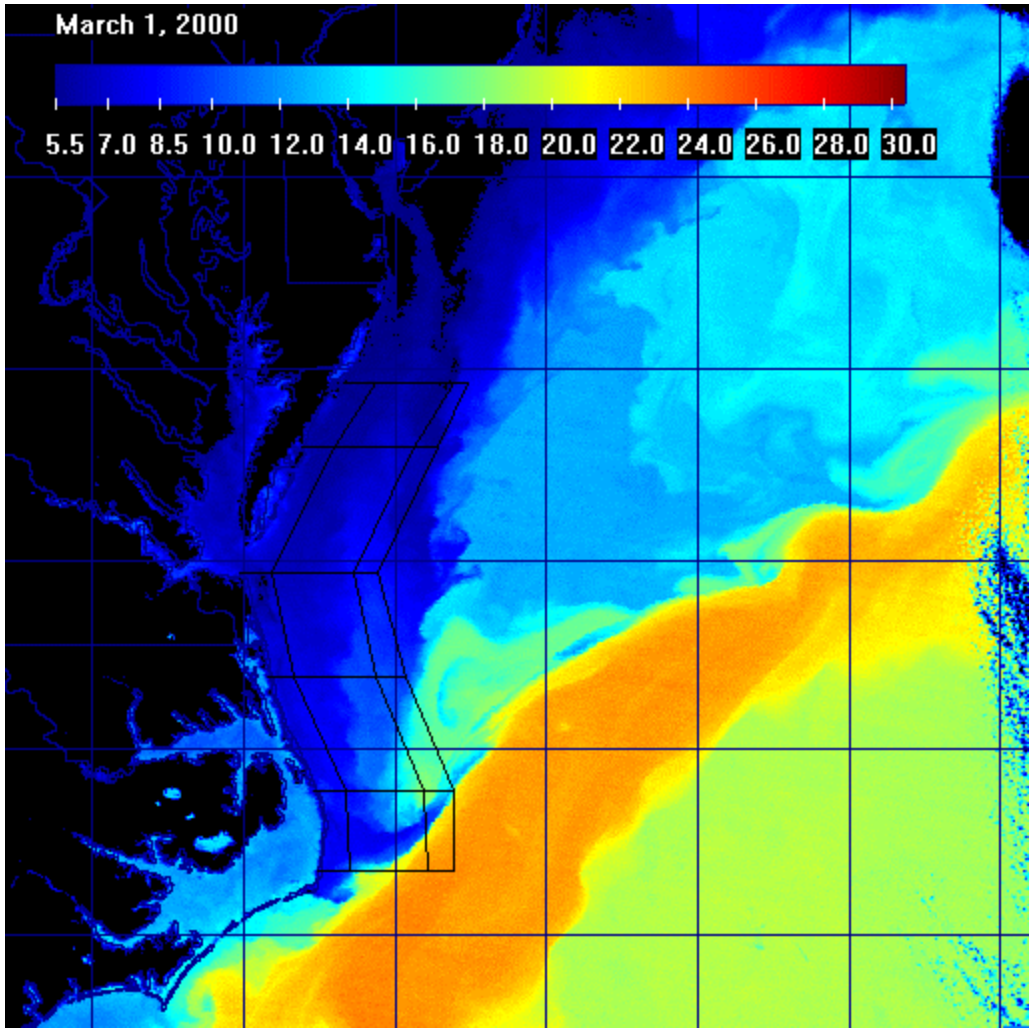
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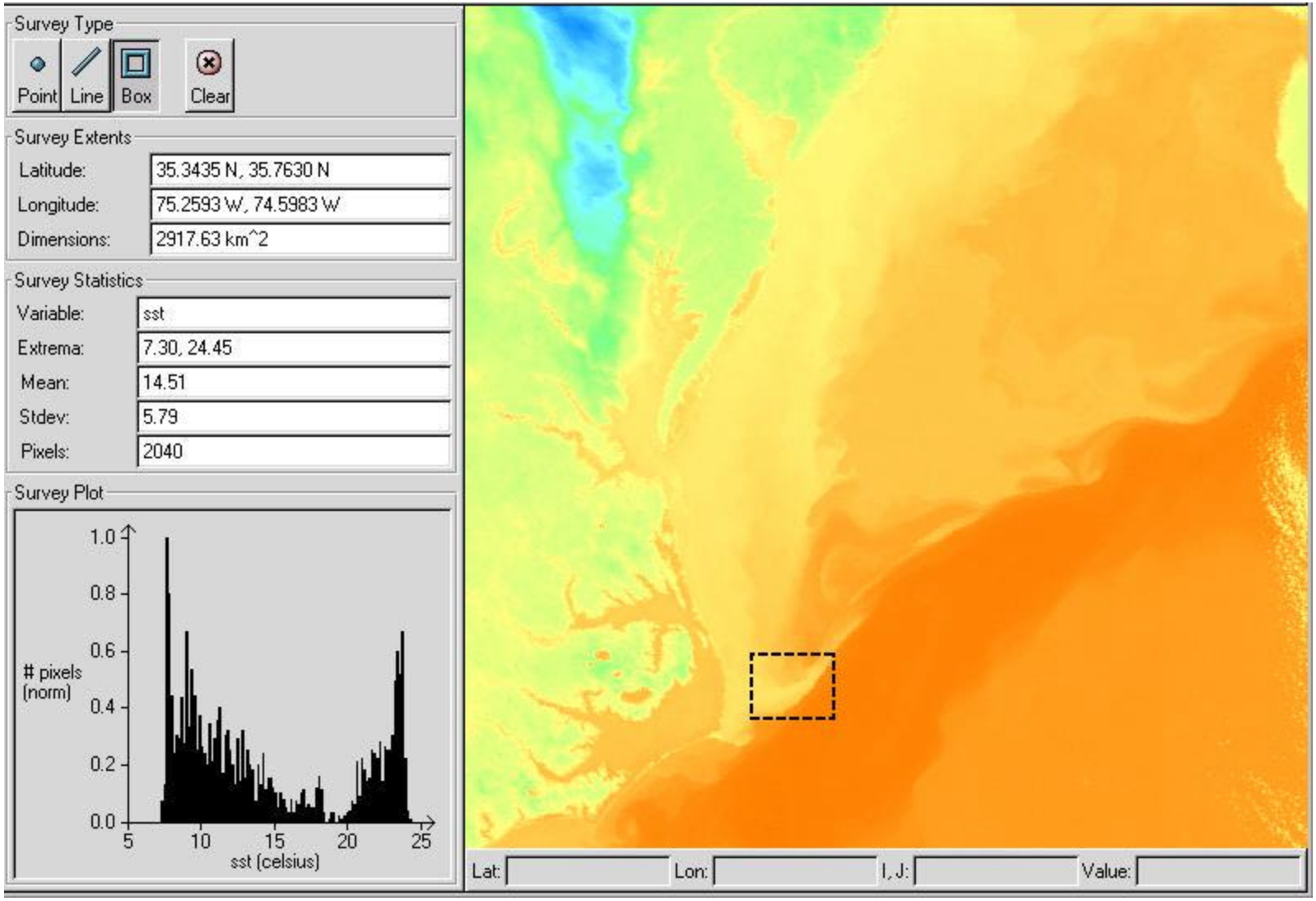
March 1, 2000 - Area 1



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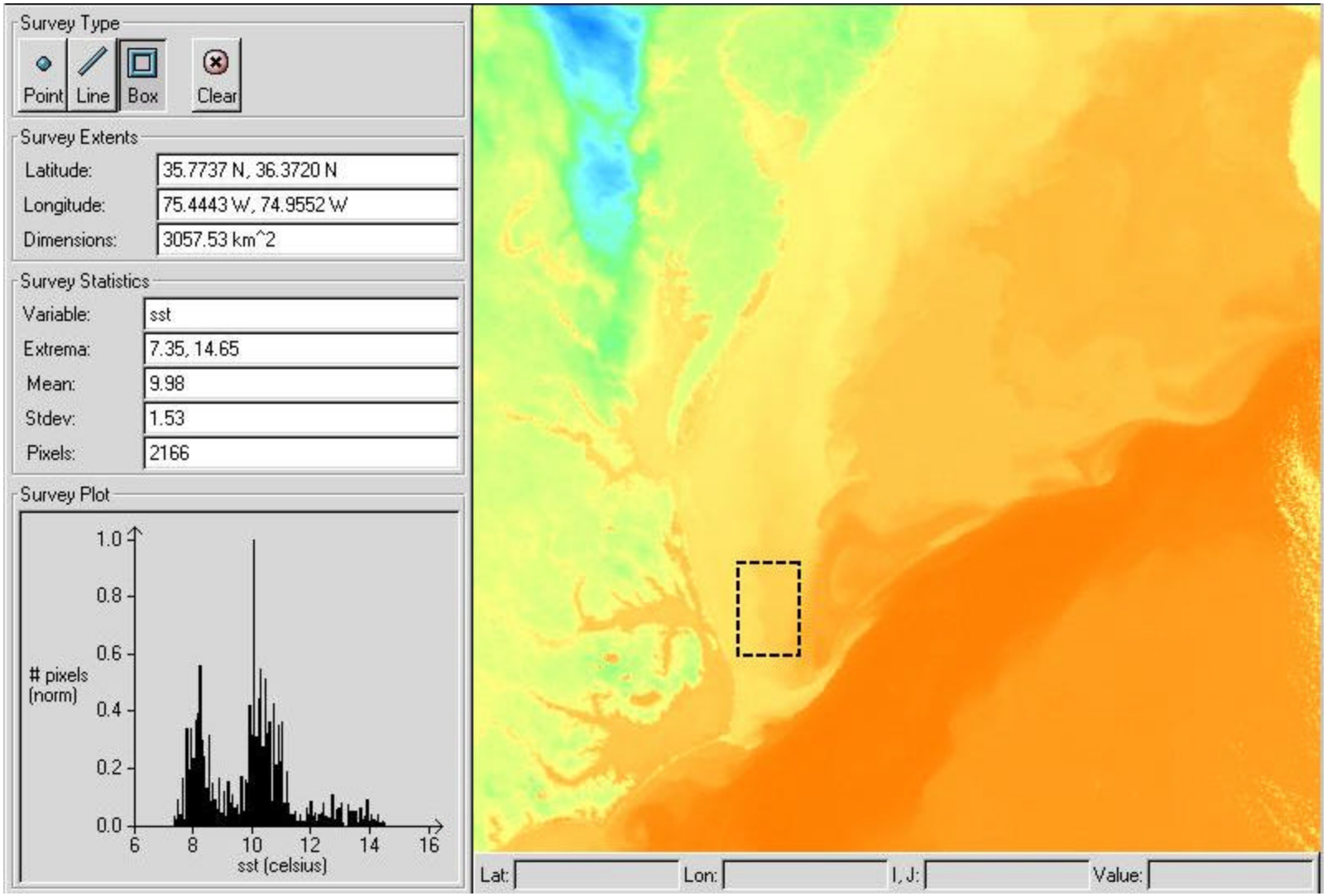

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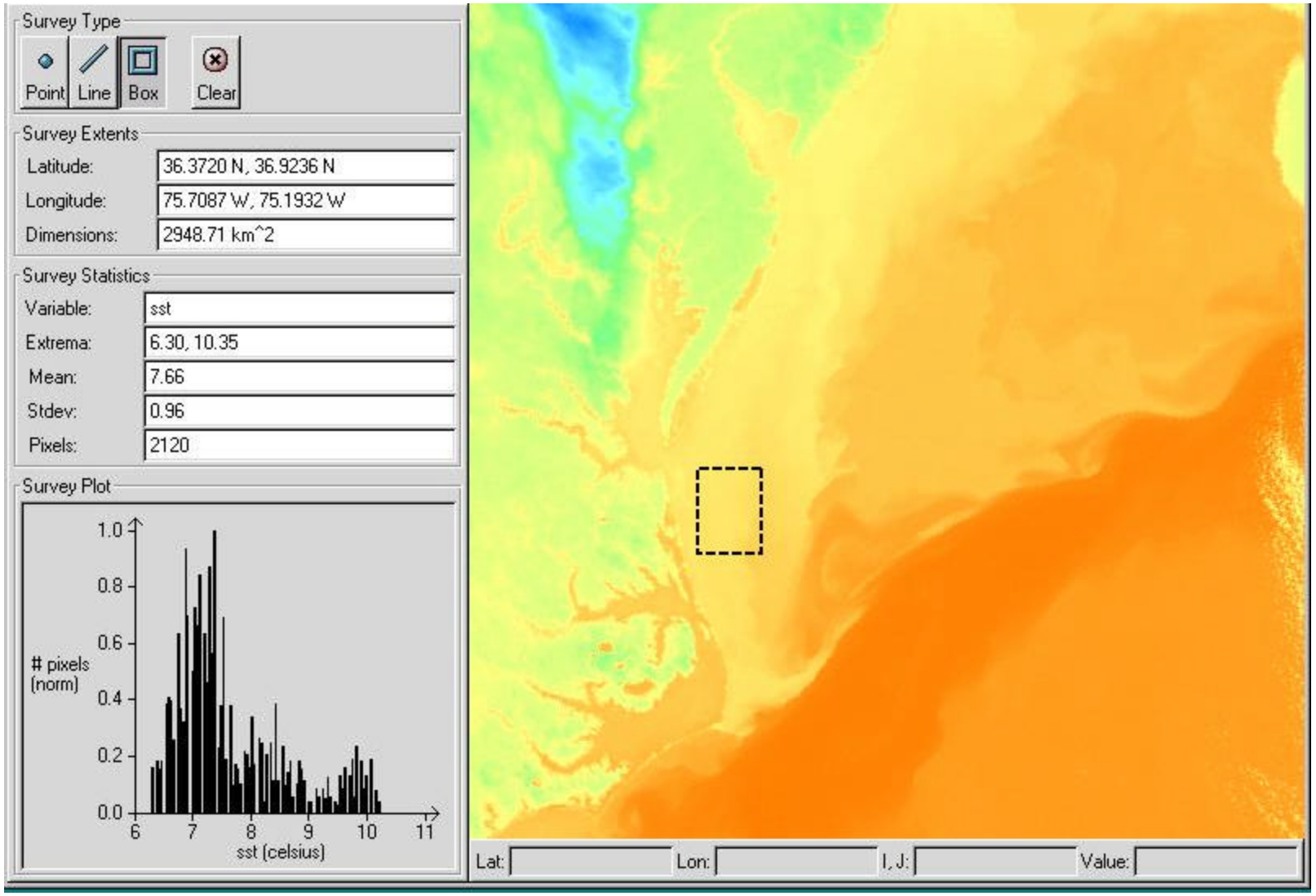

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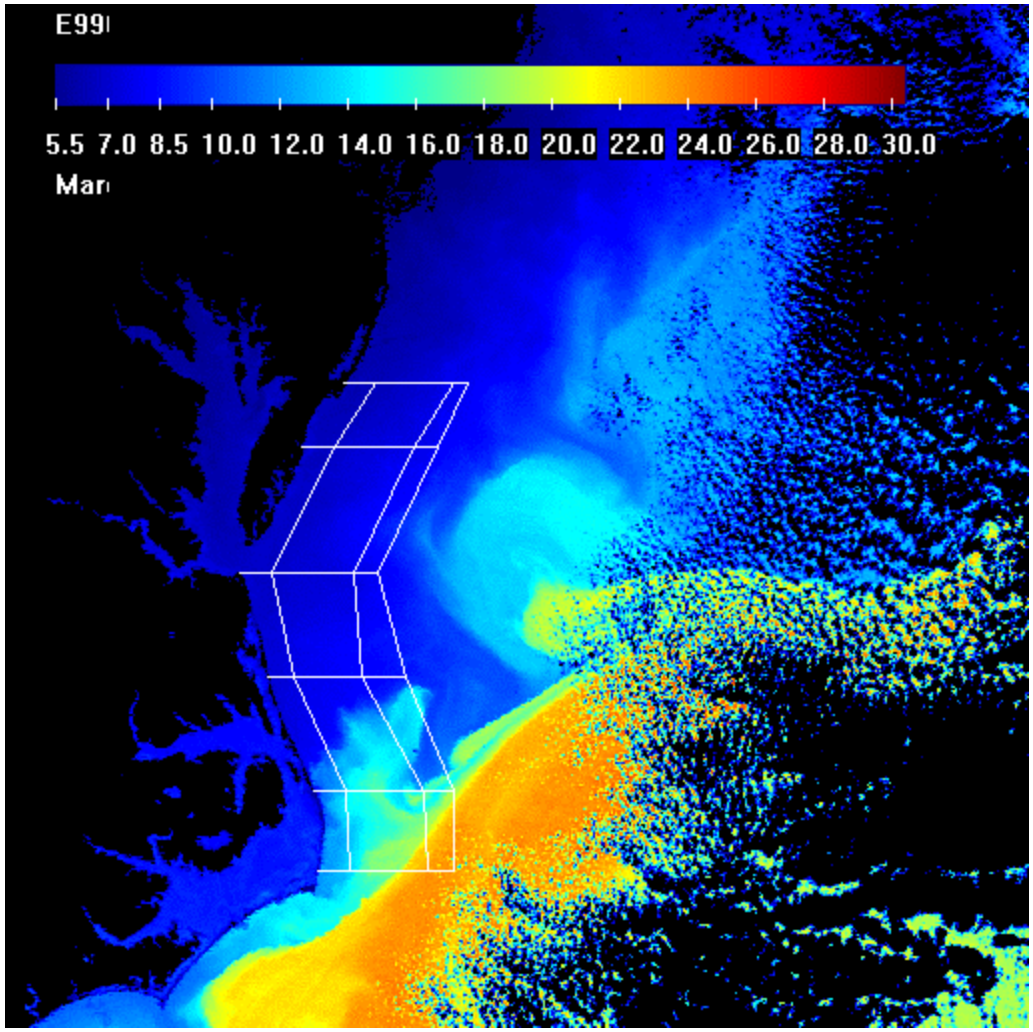

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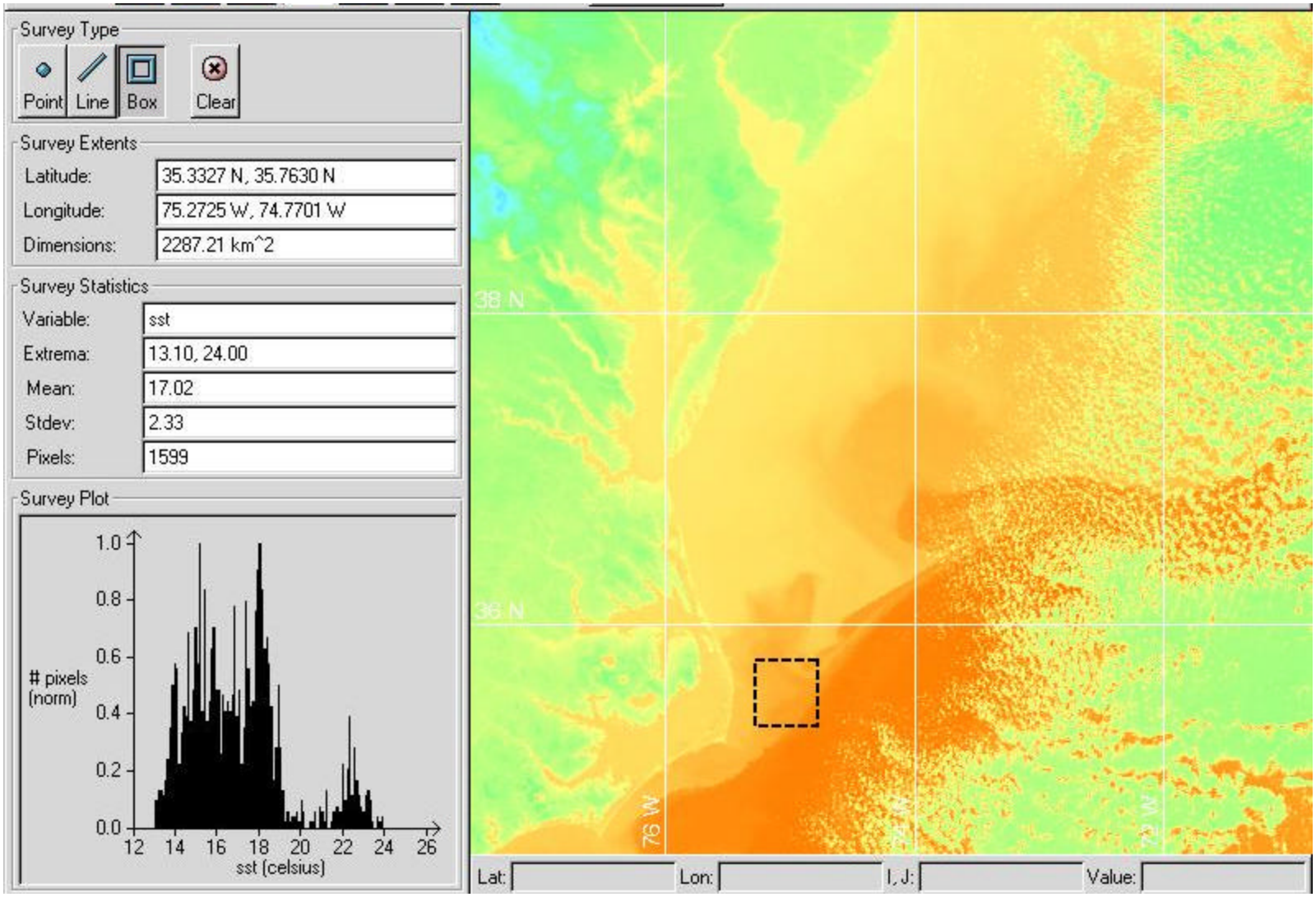

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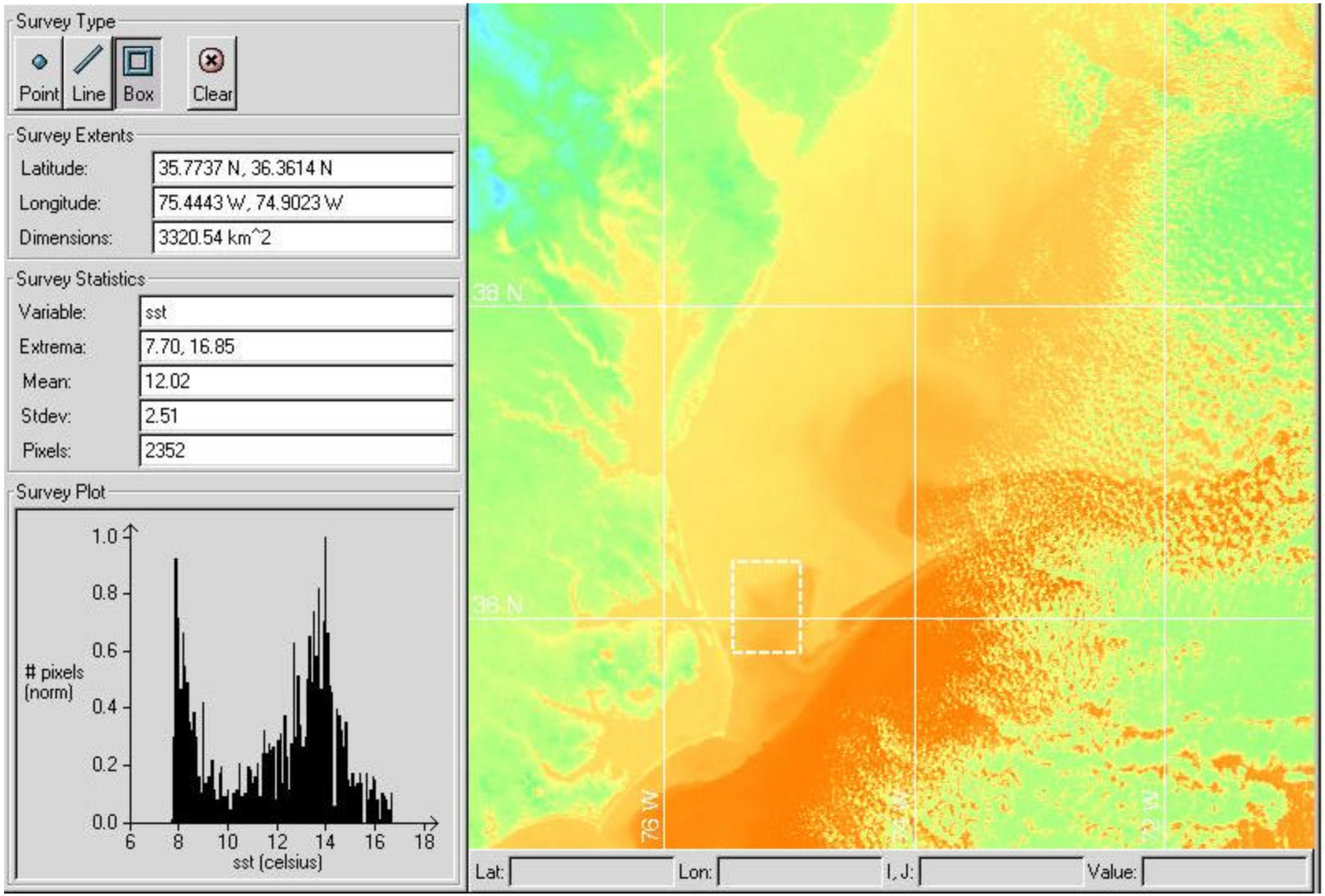

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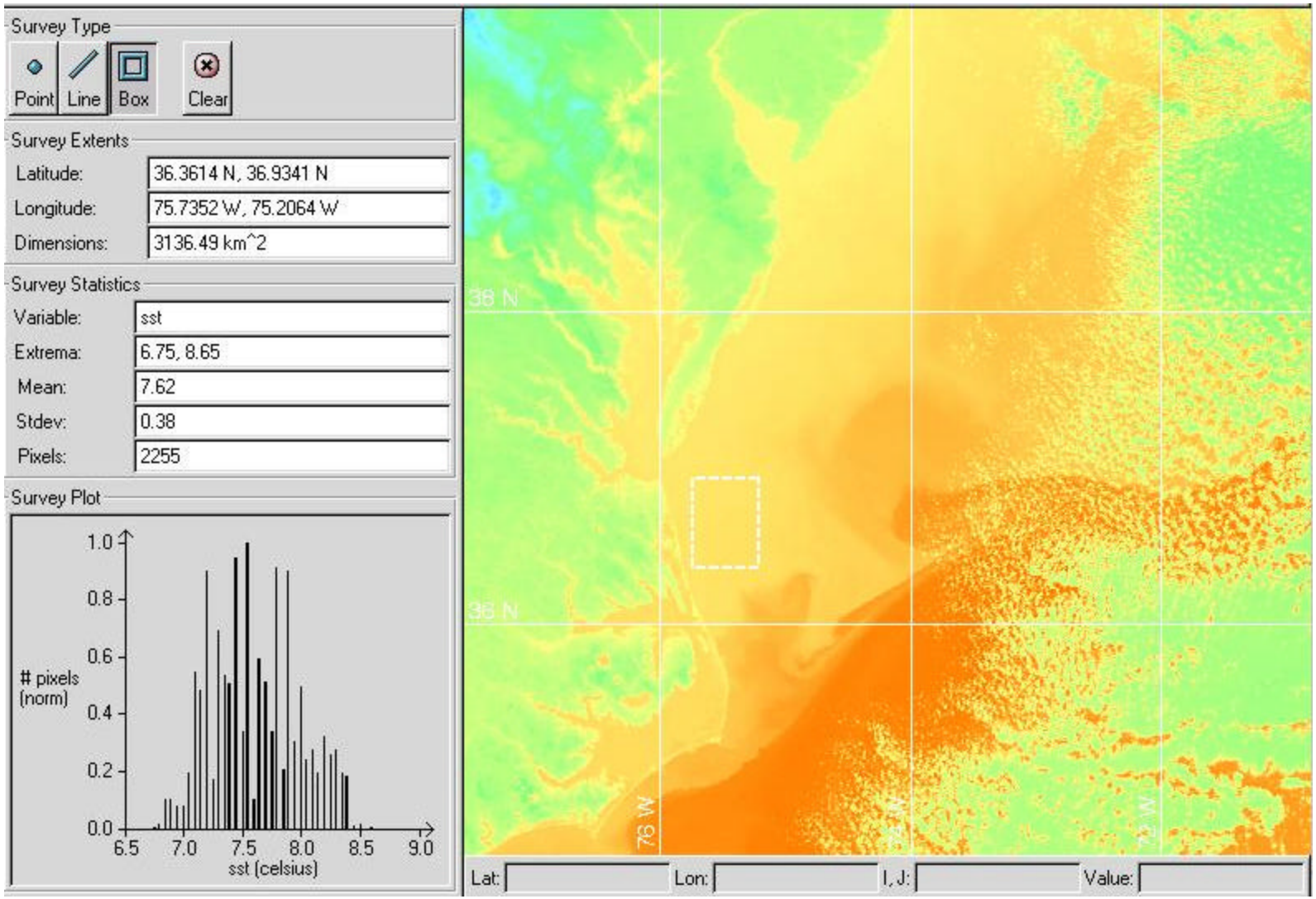

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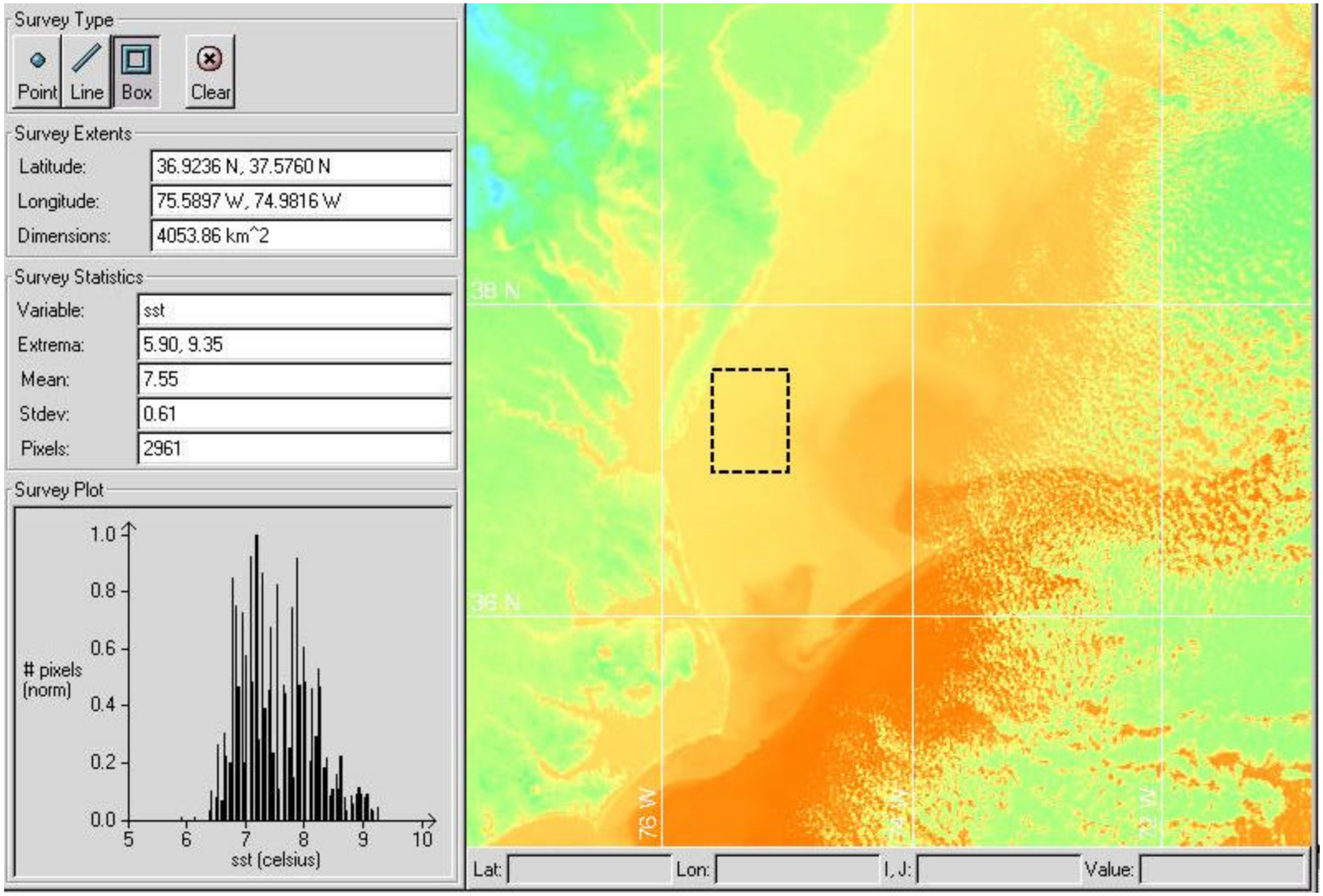

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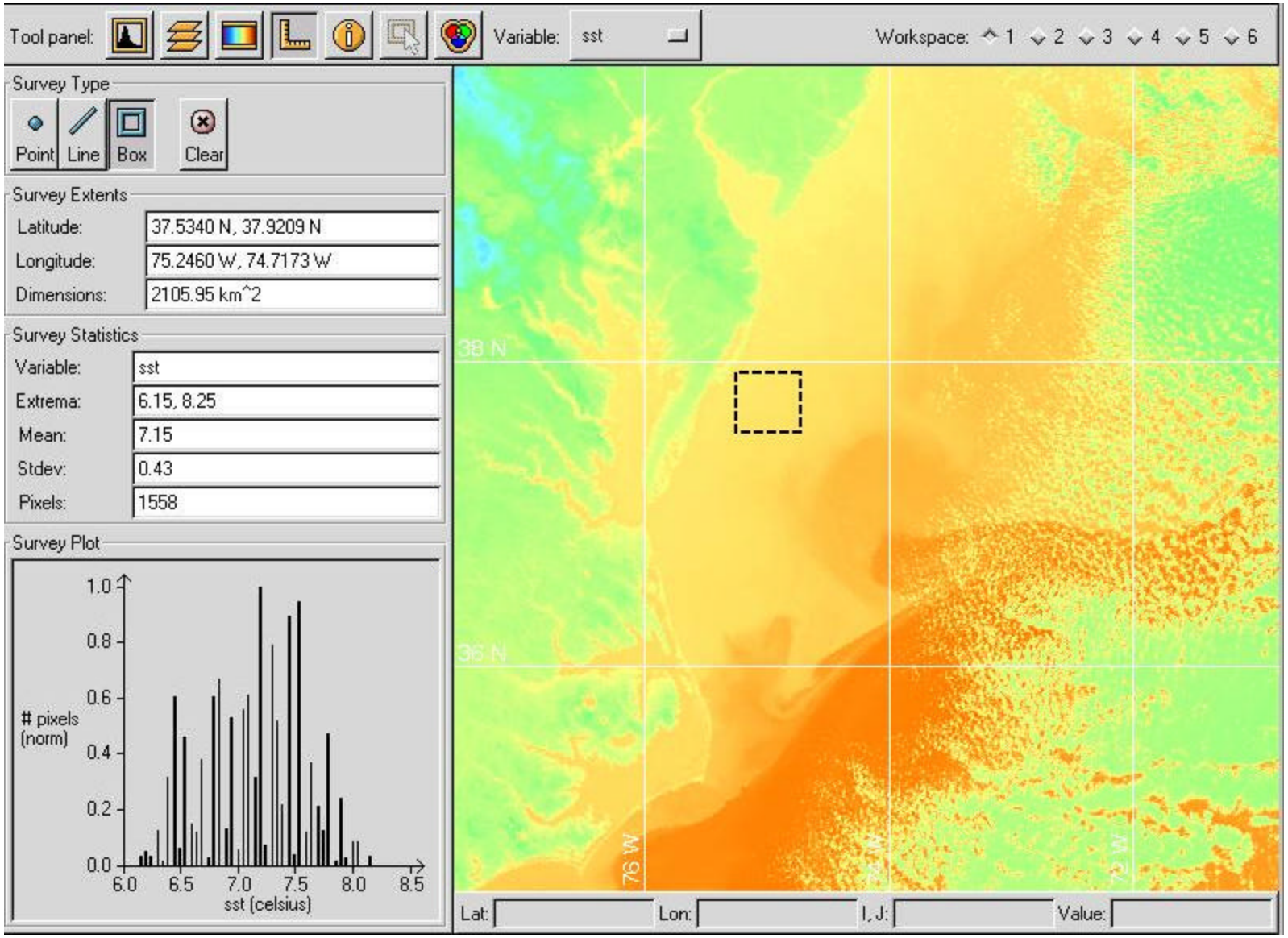

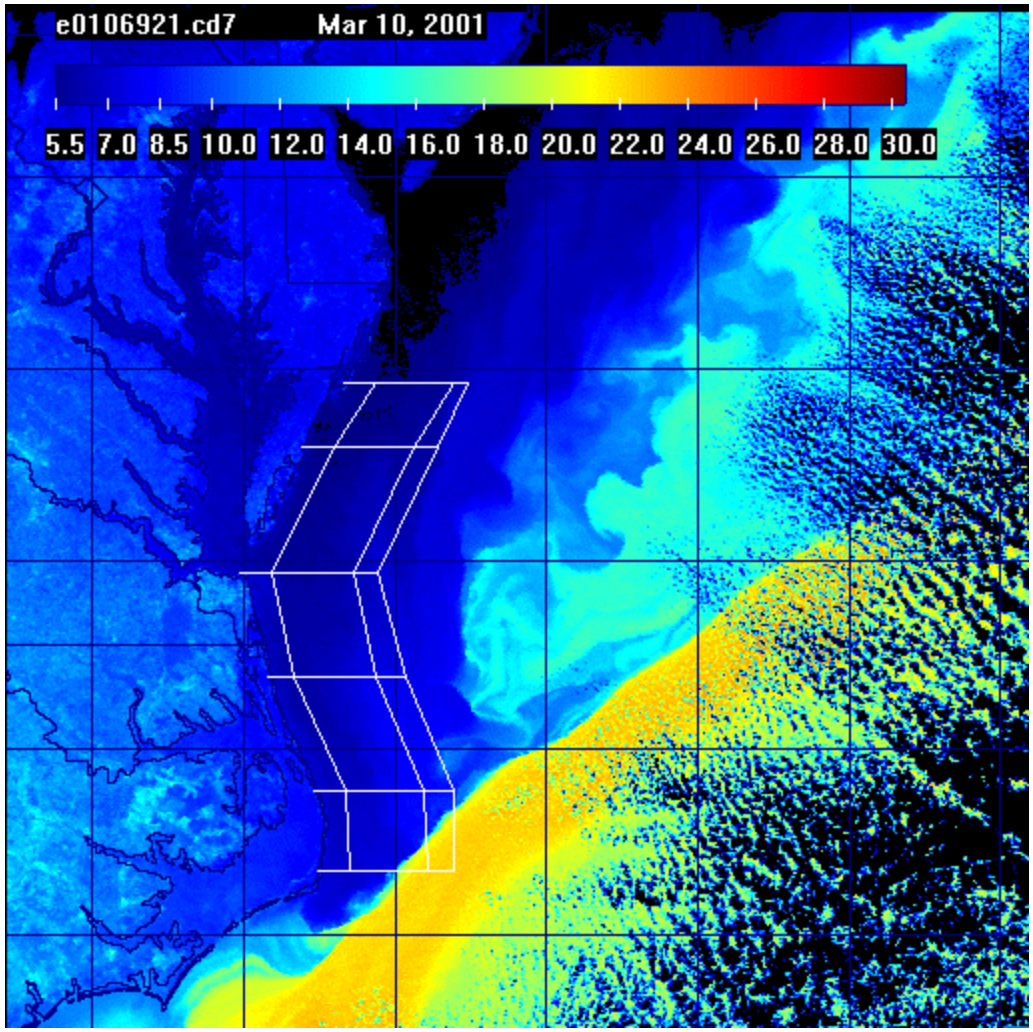
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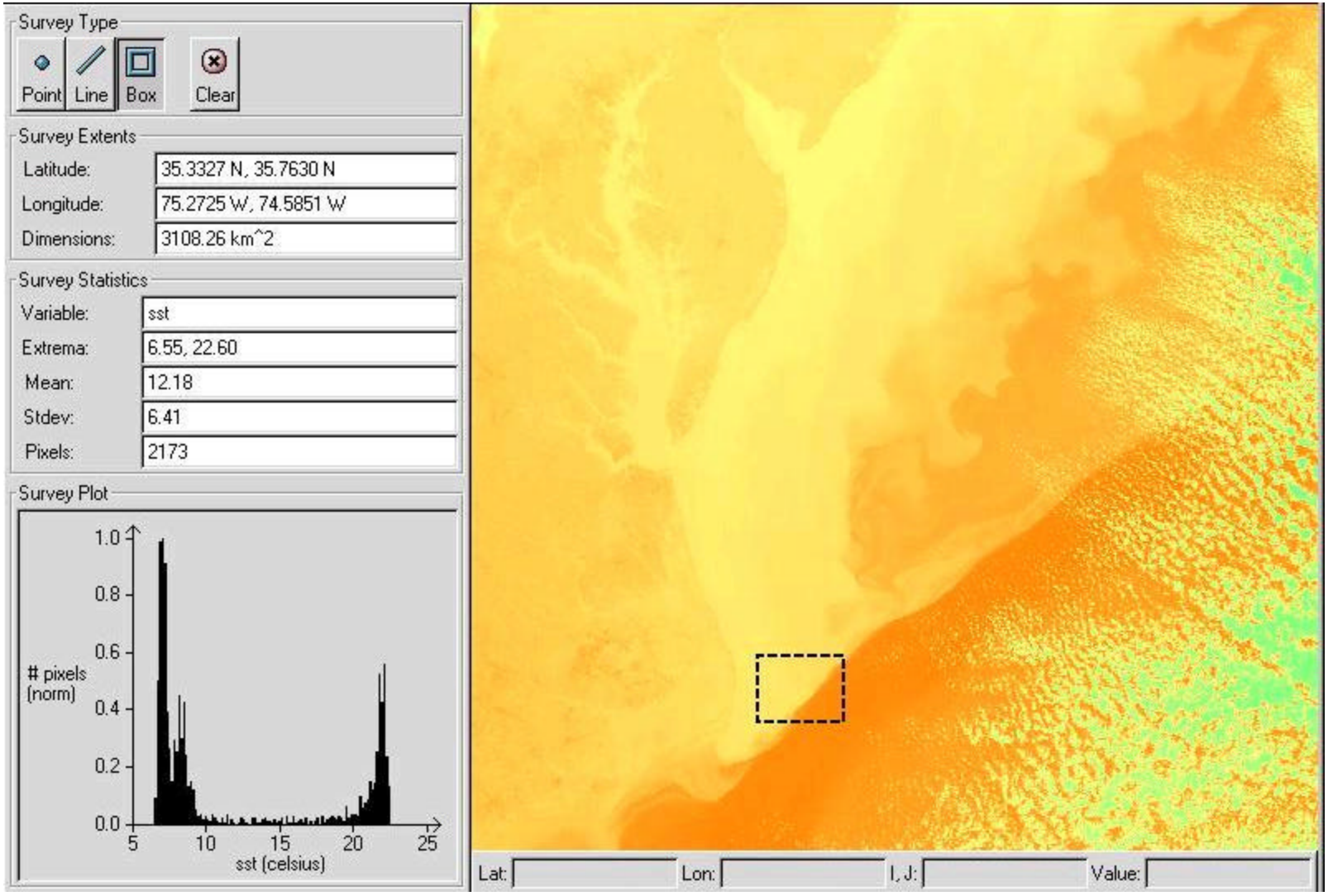

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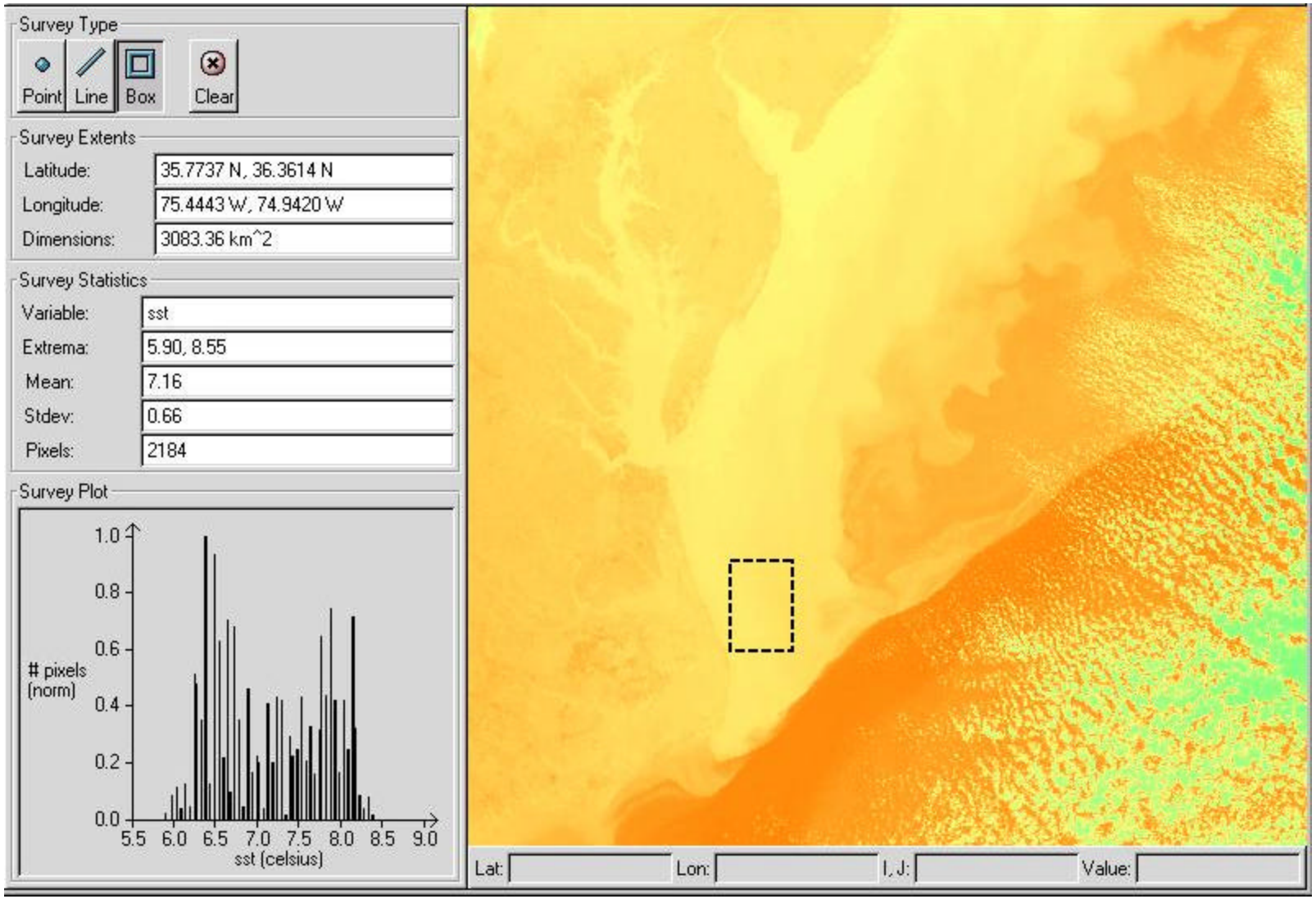

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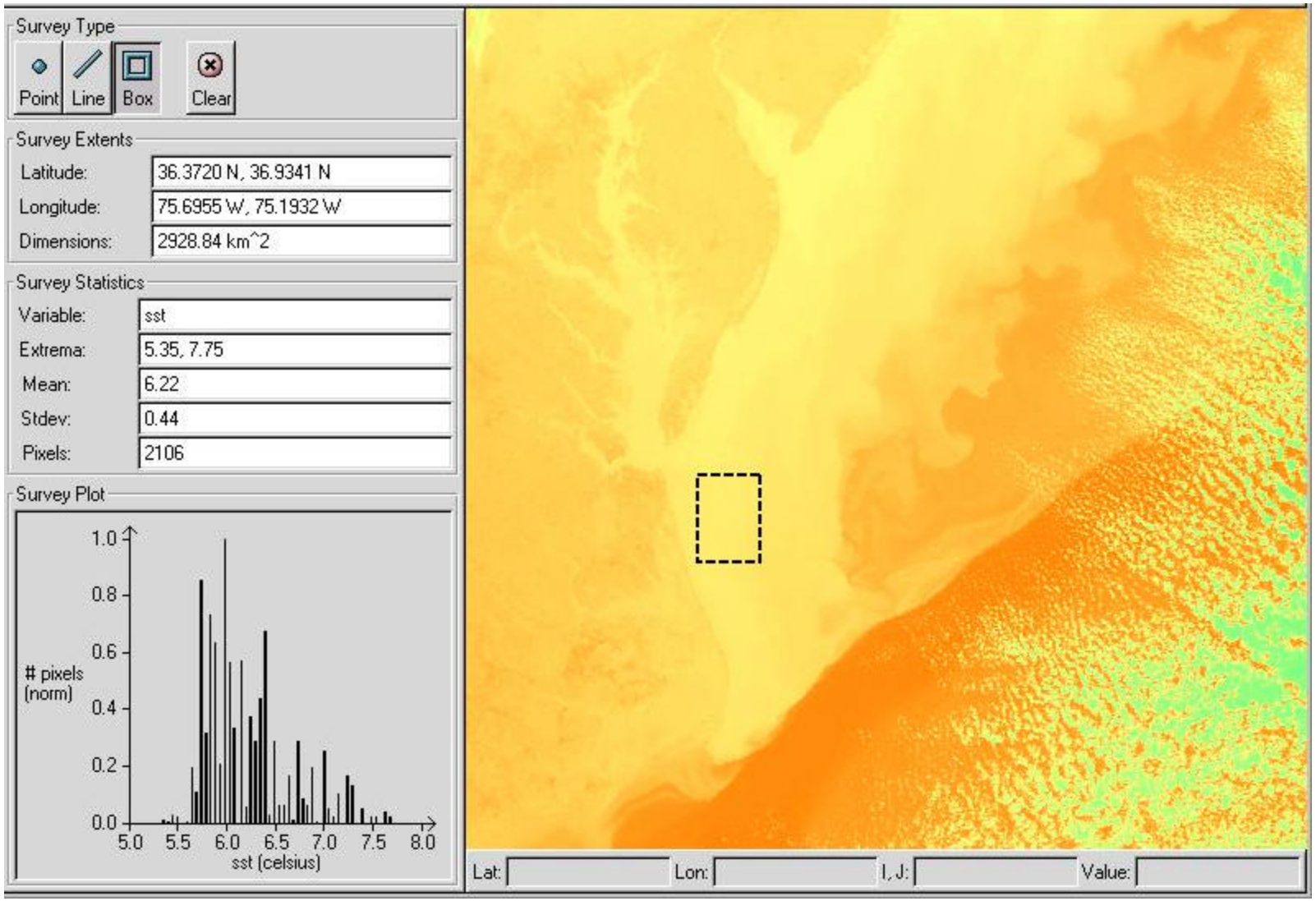

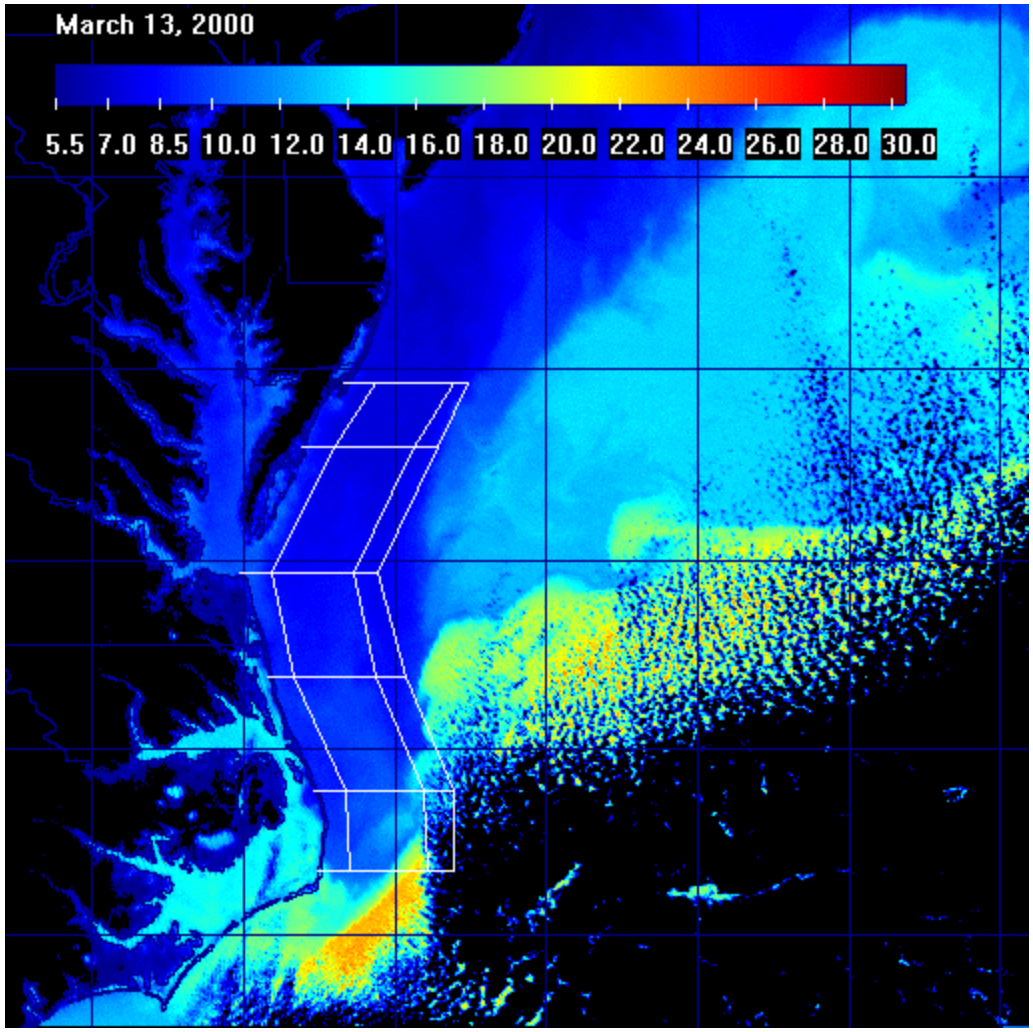
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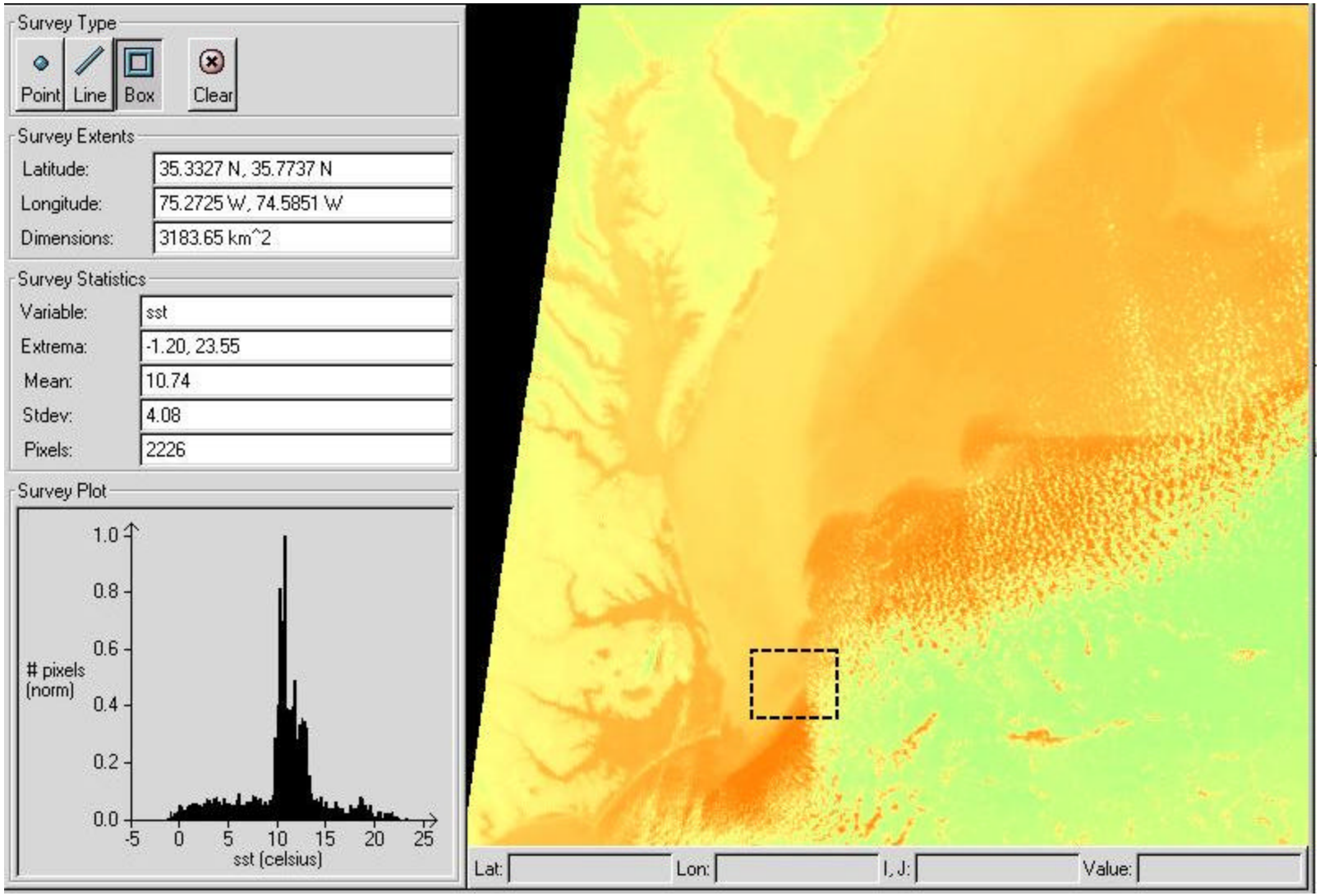

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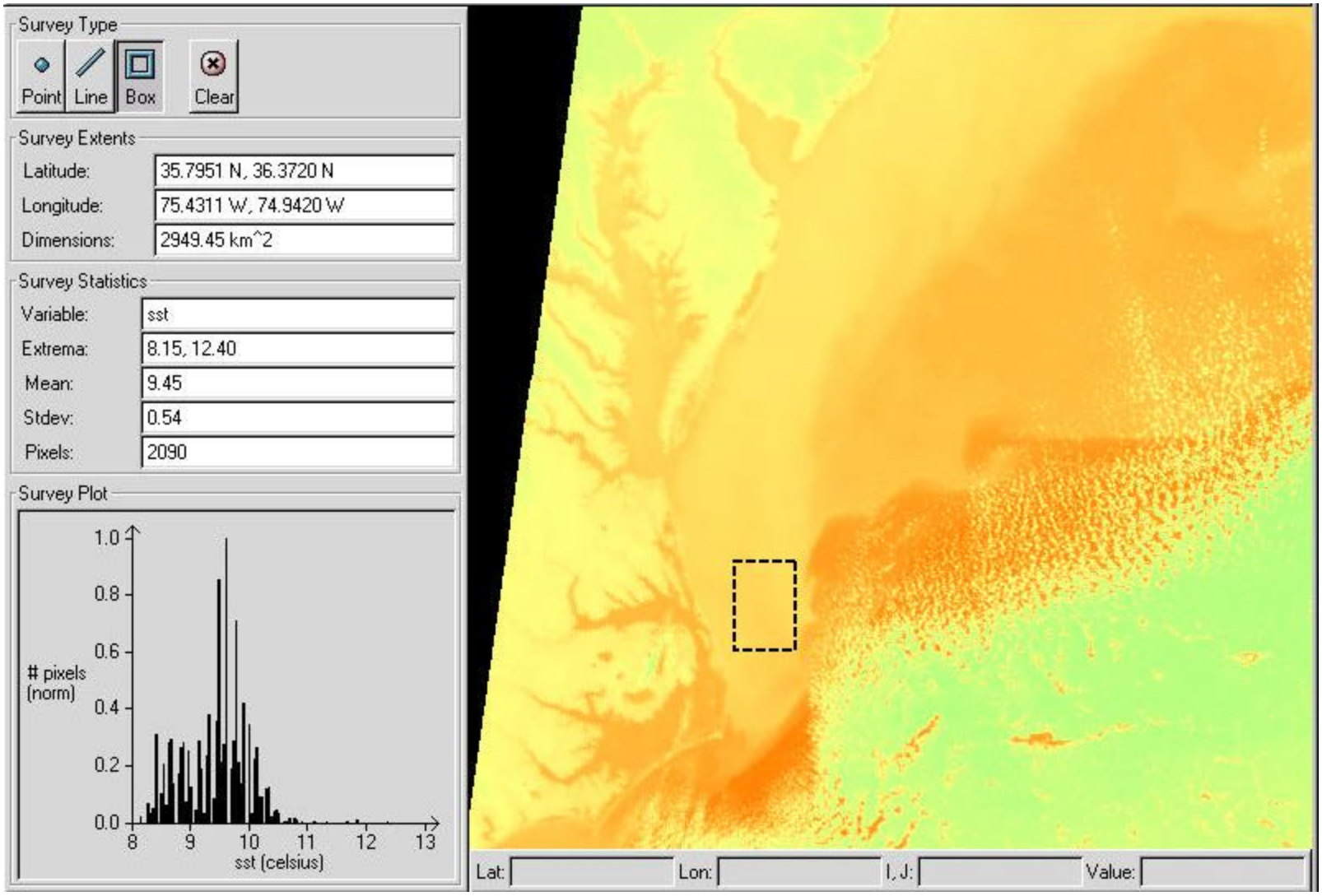

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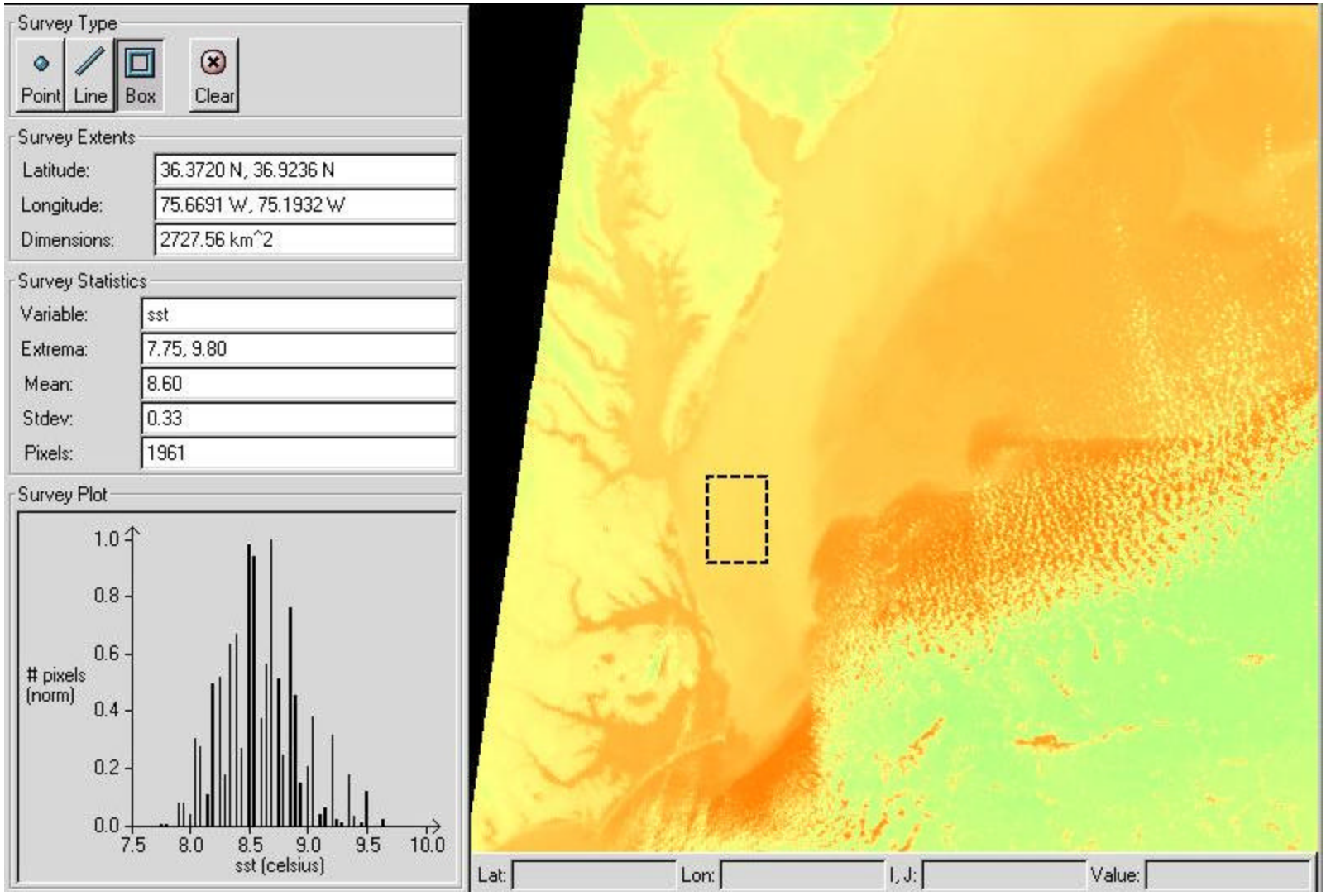

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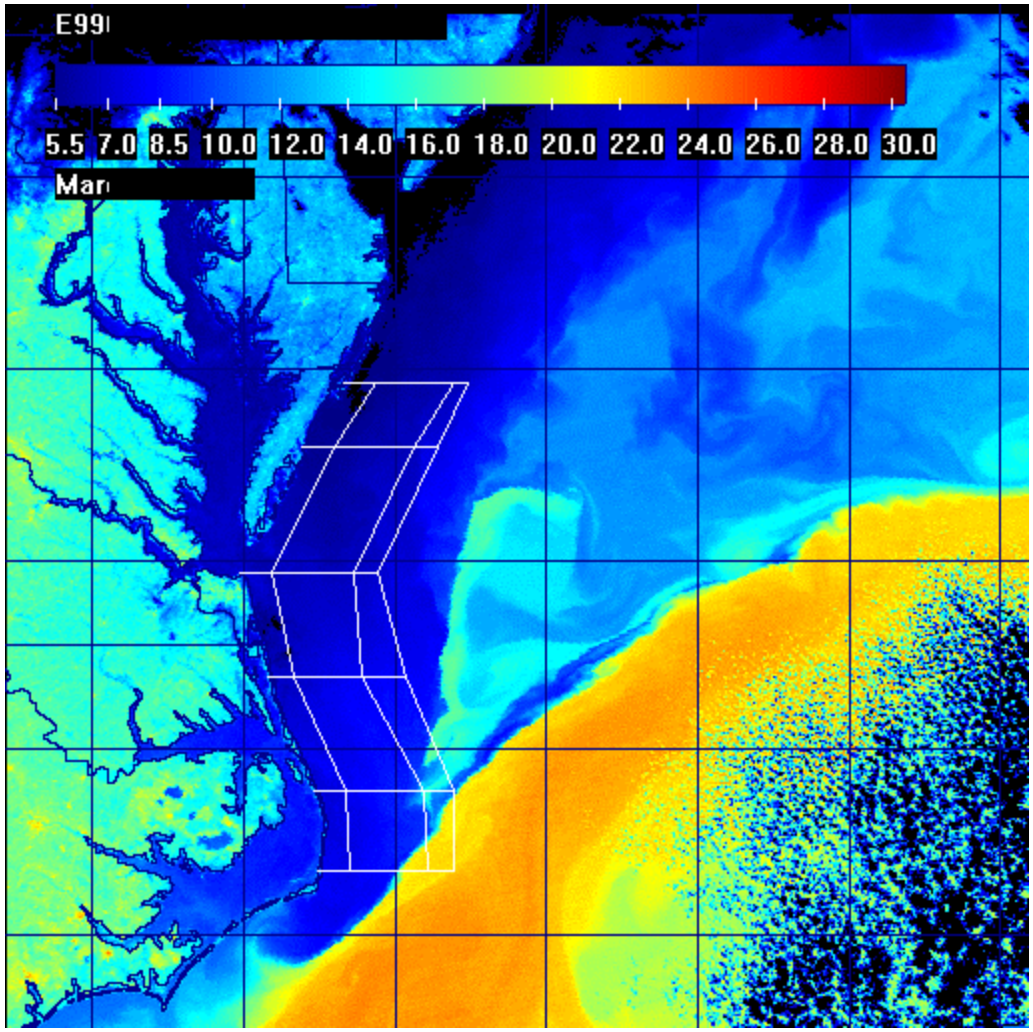

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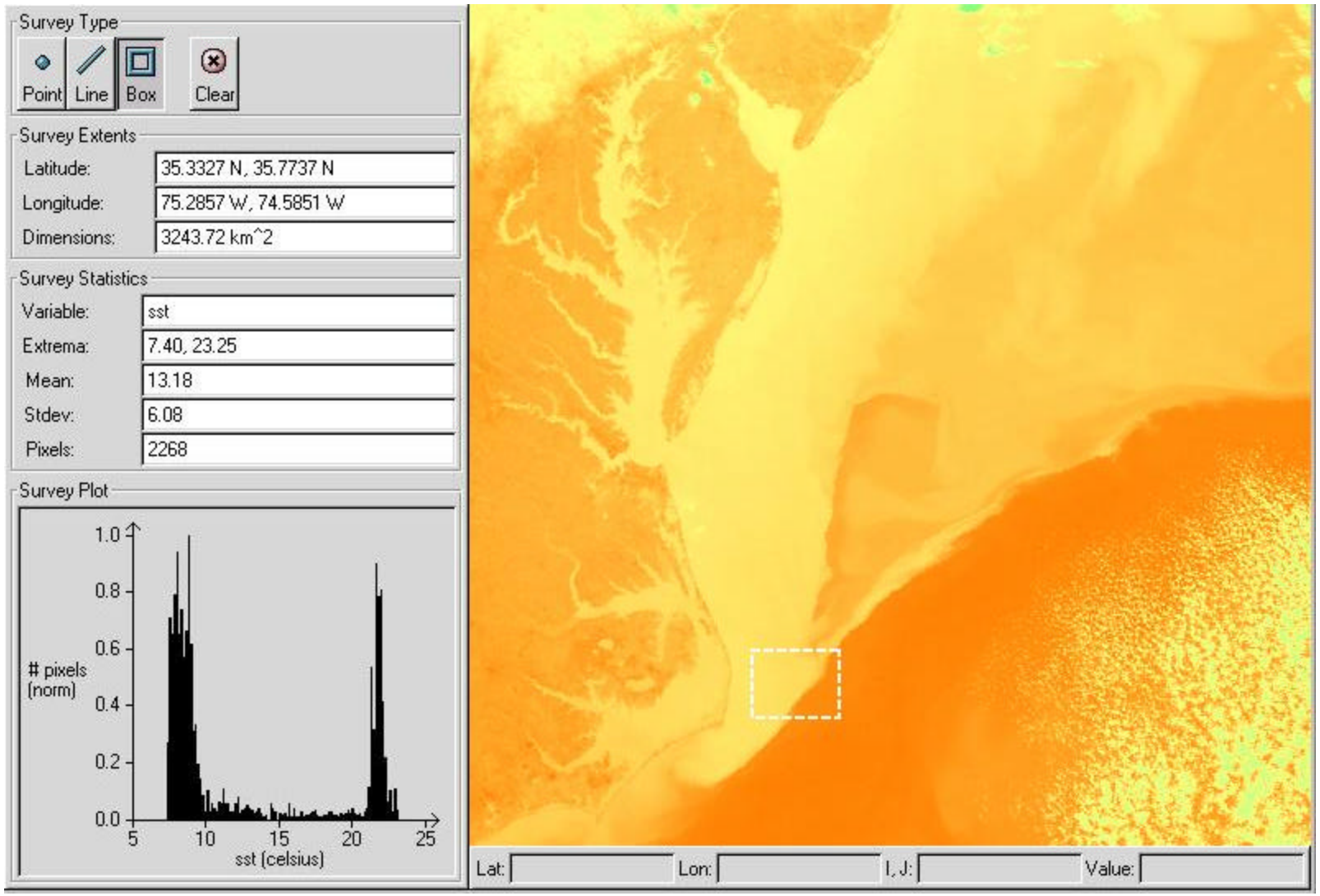

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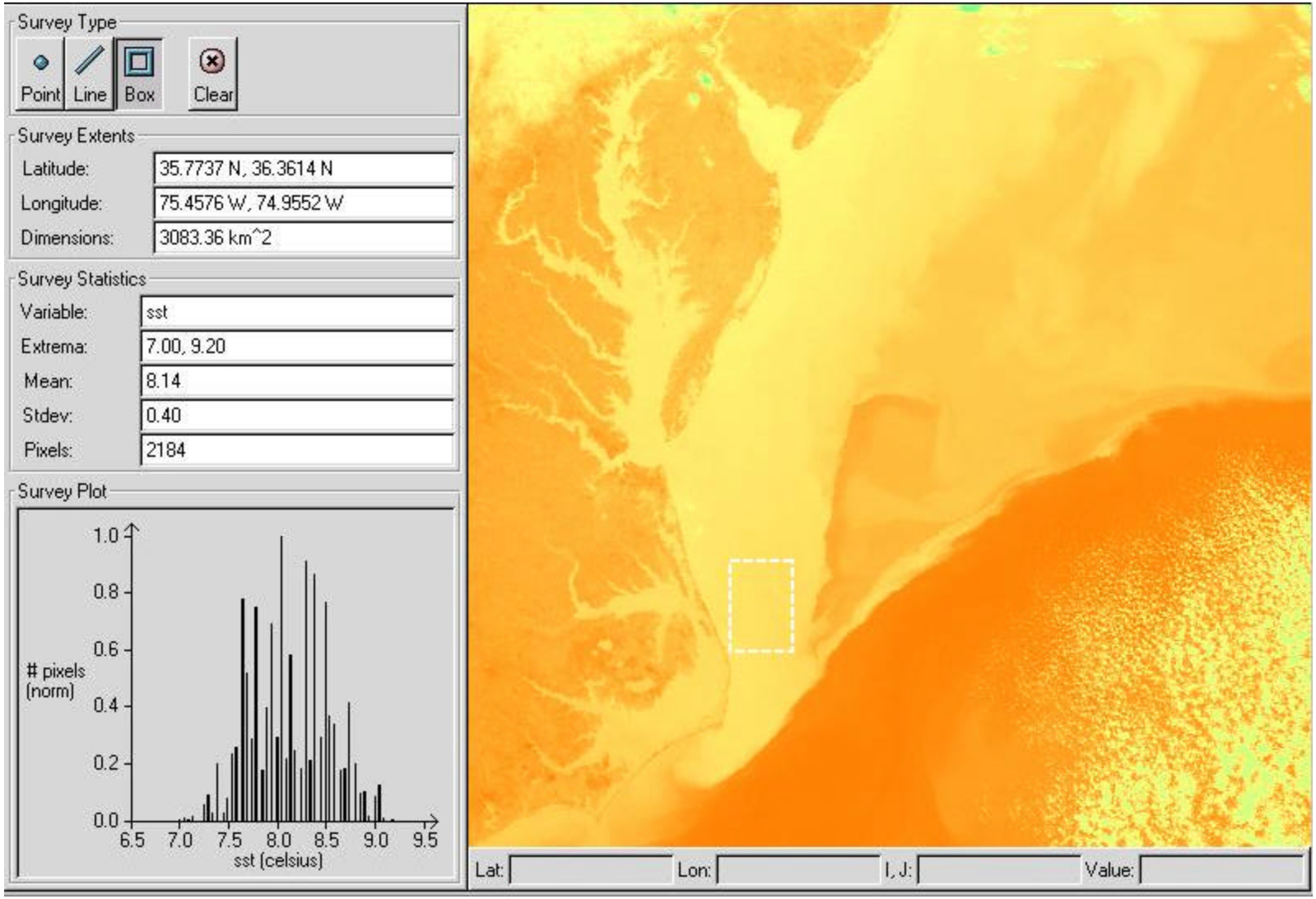

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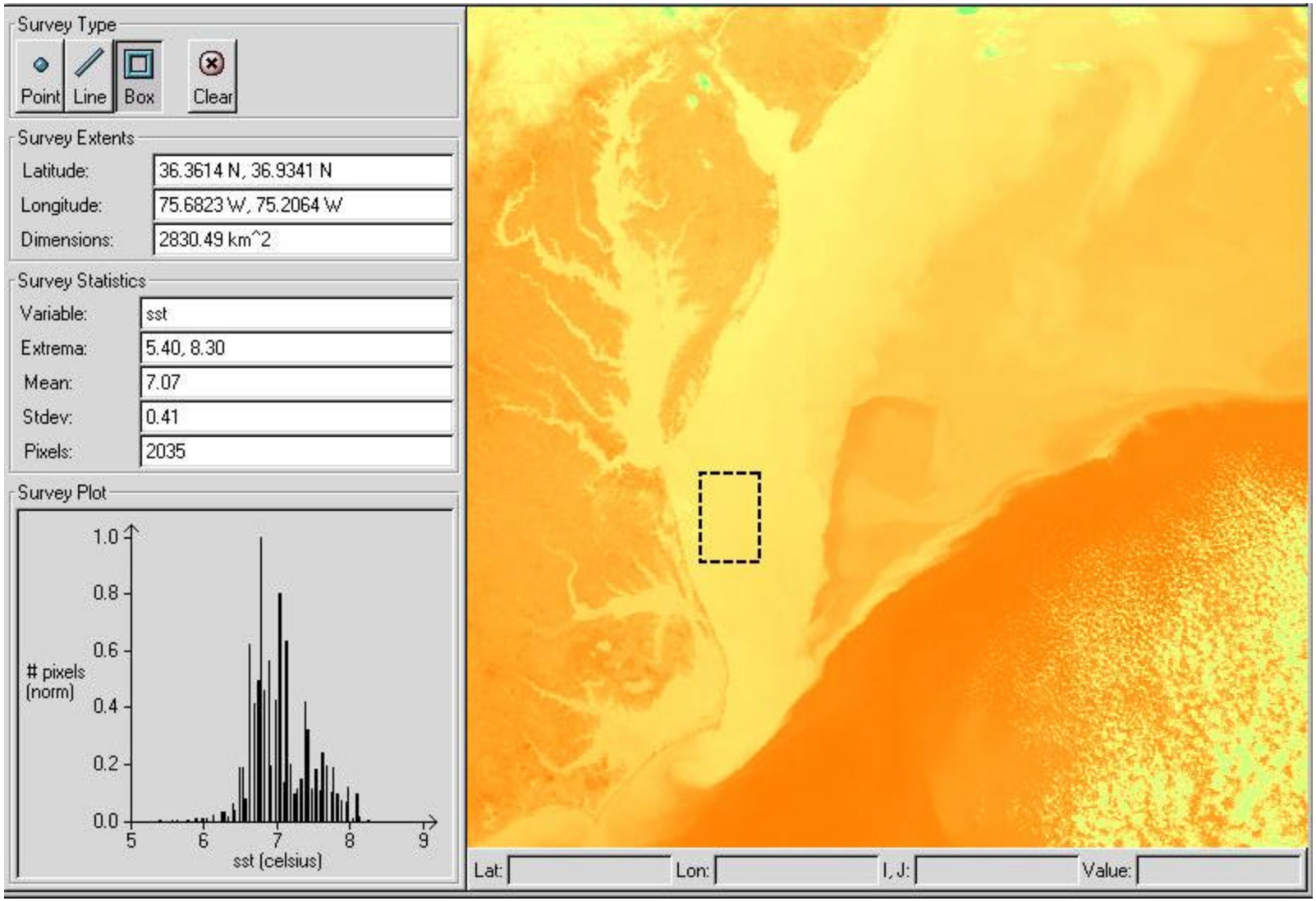

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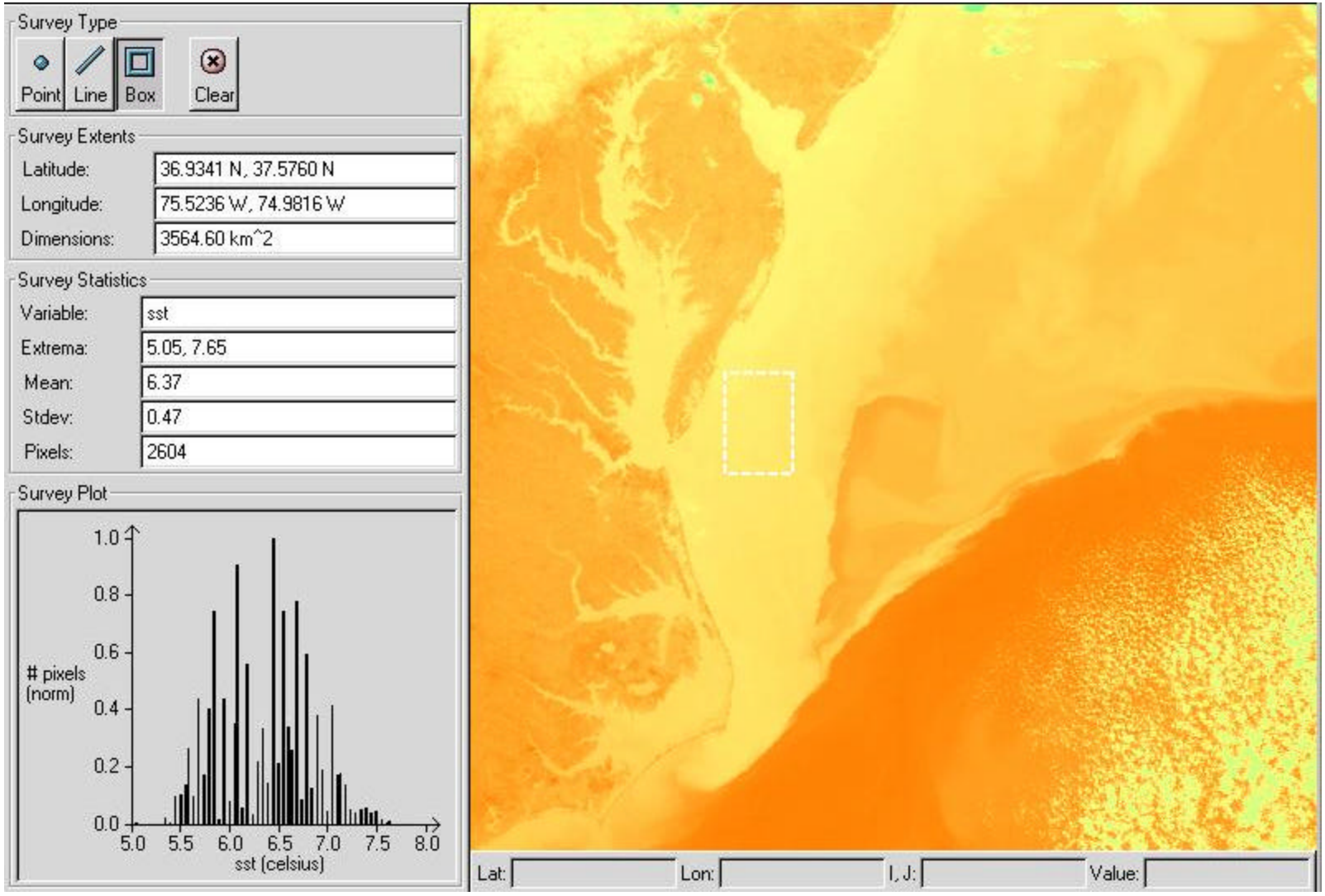

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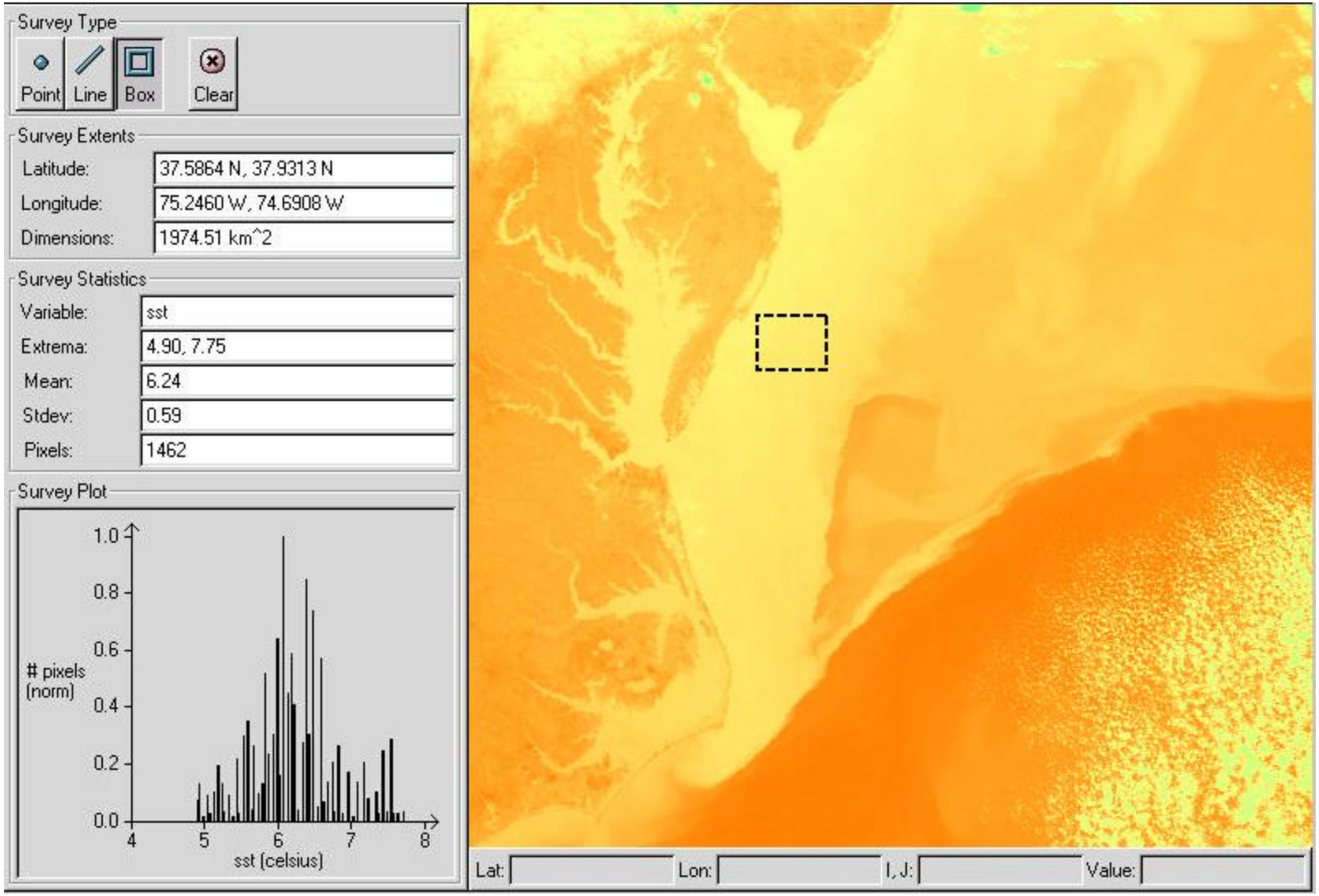

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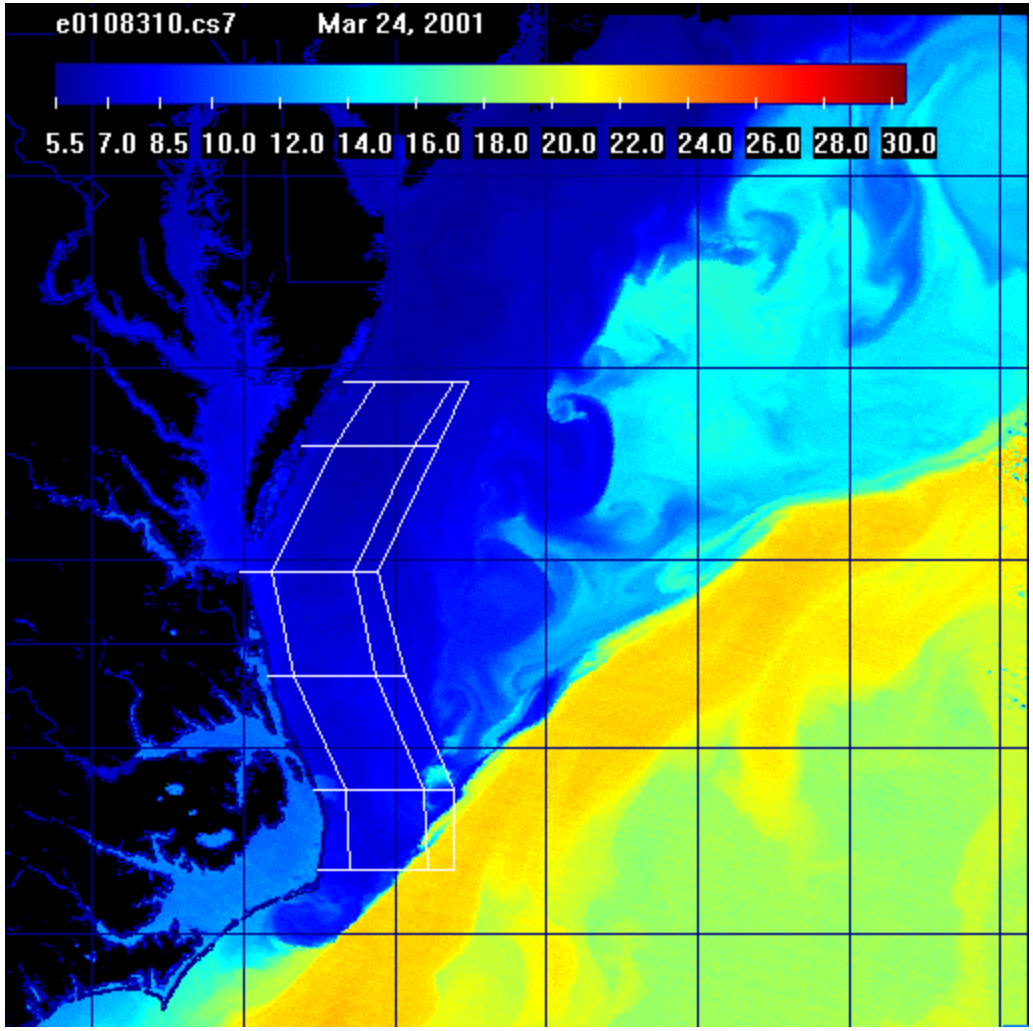
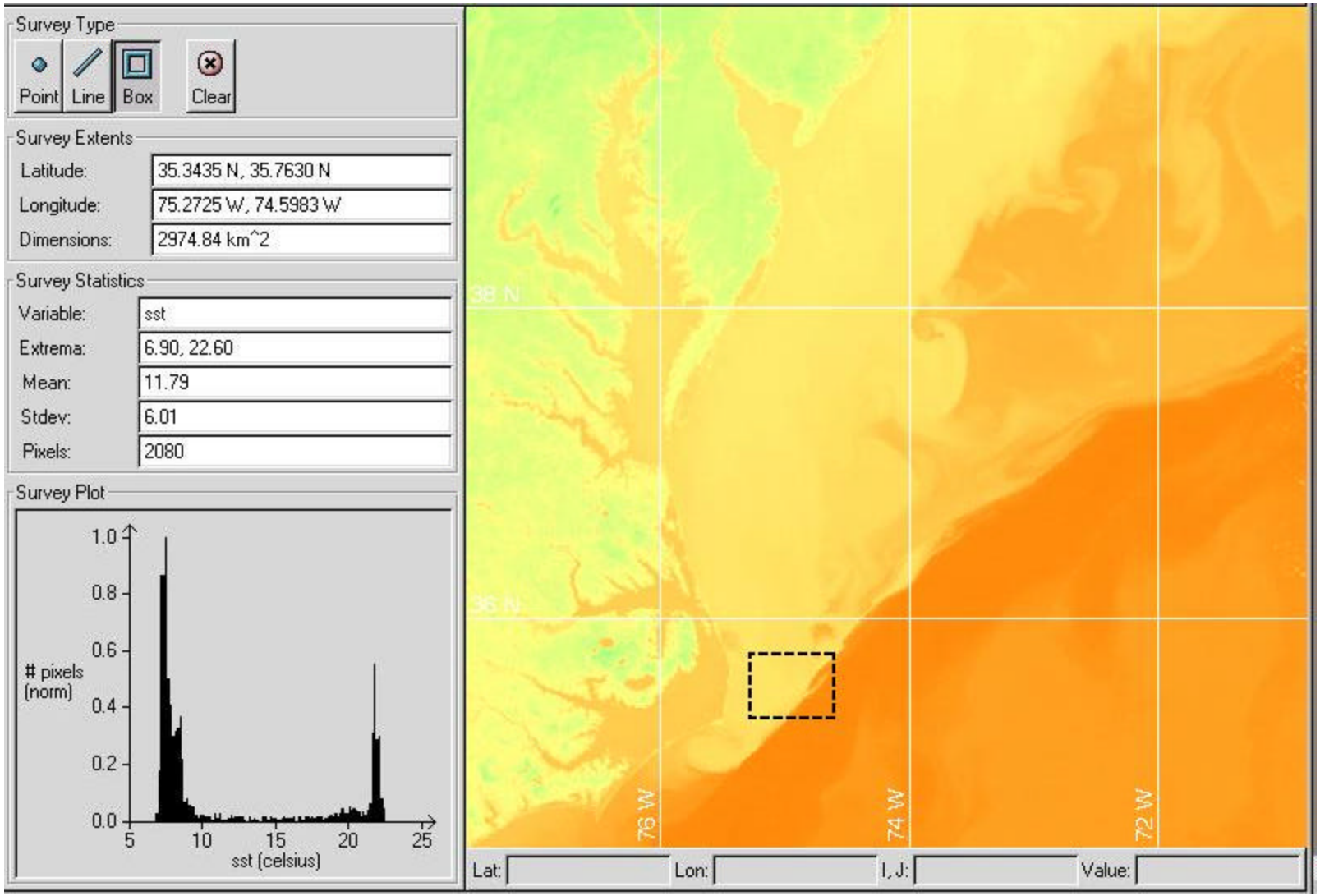


March 24, 2001 - Area 1



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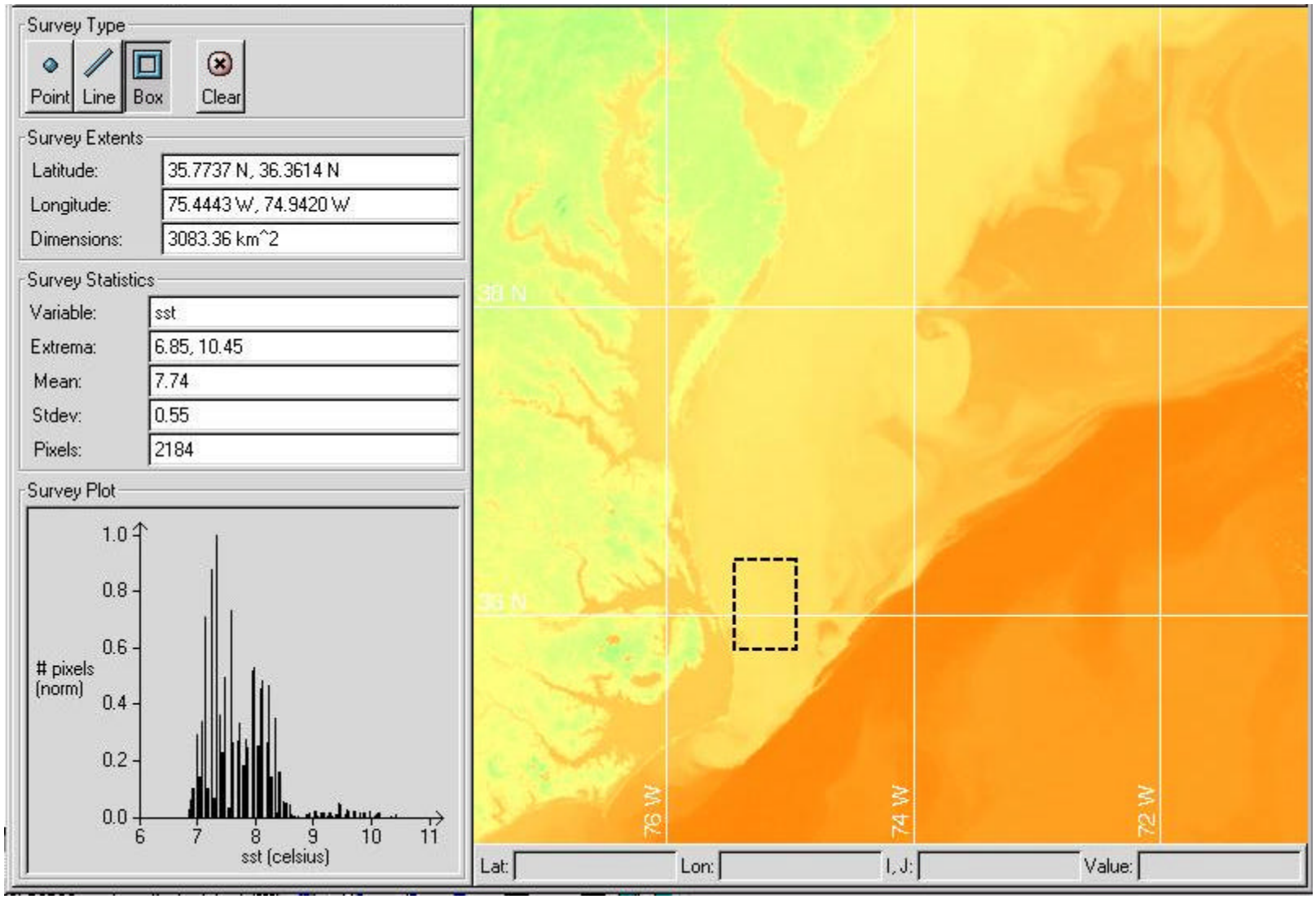
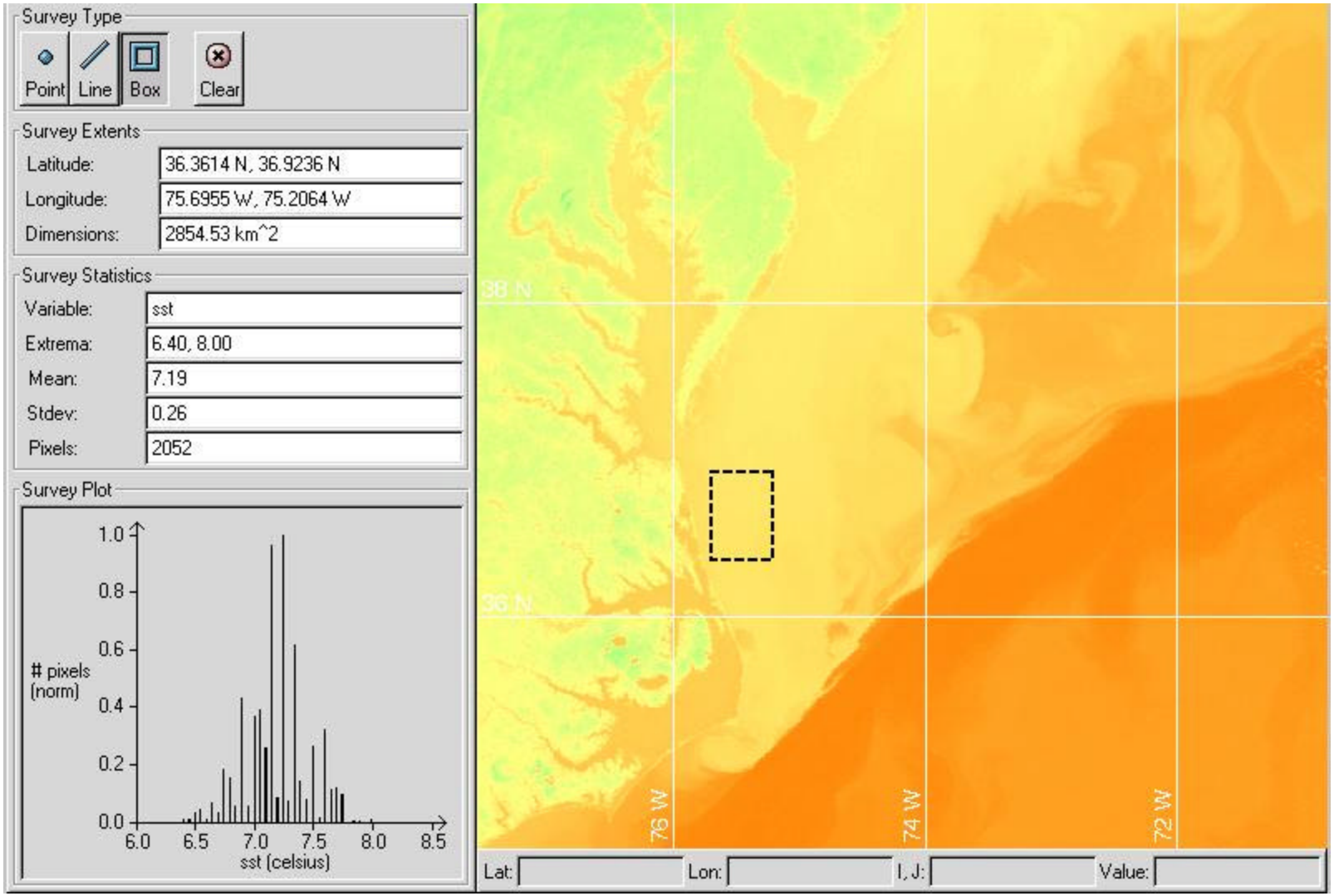
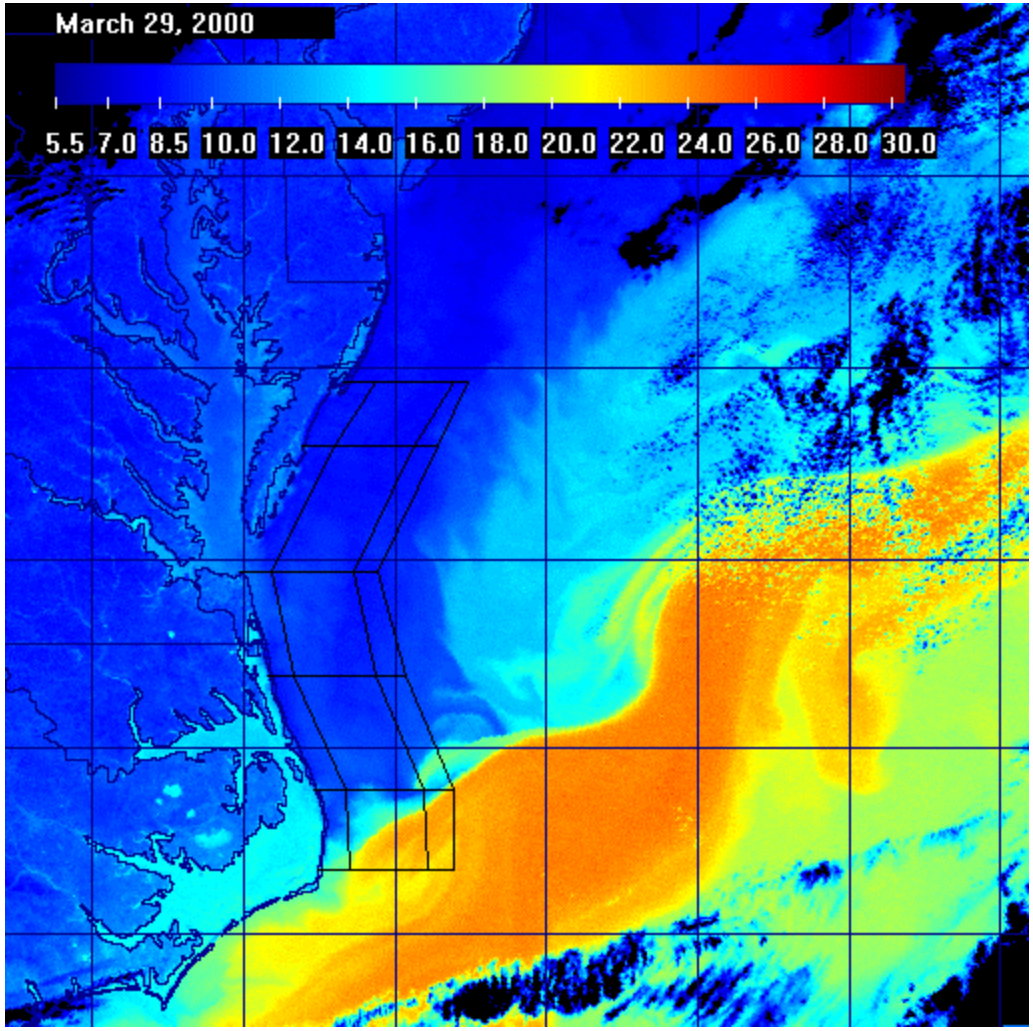


March 24, 2001 - Area 3



March 29, 2000



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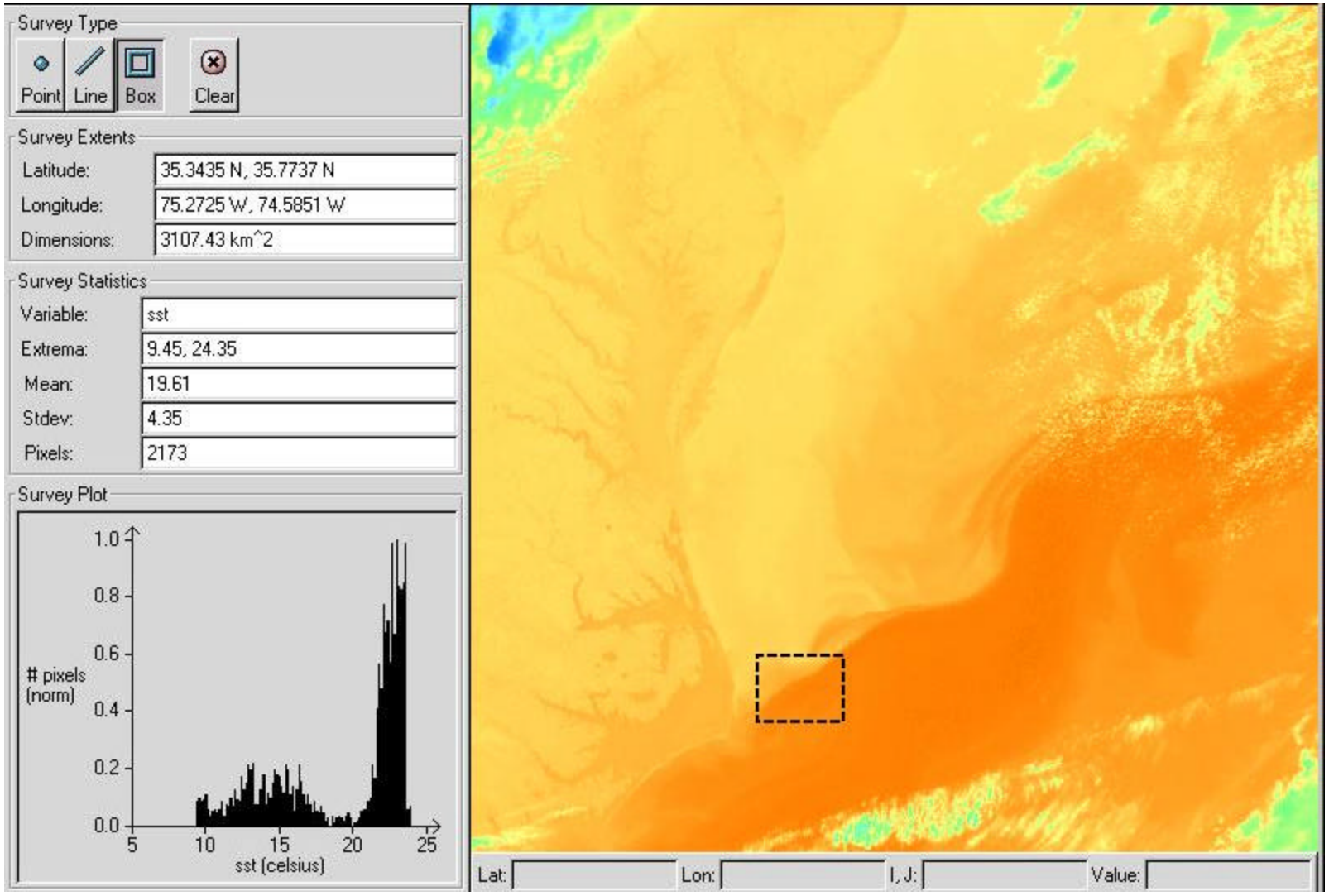

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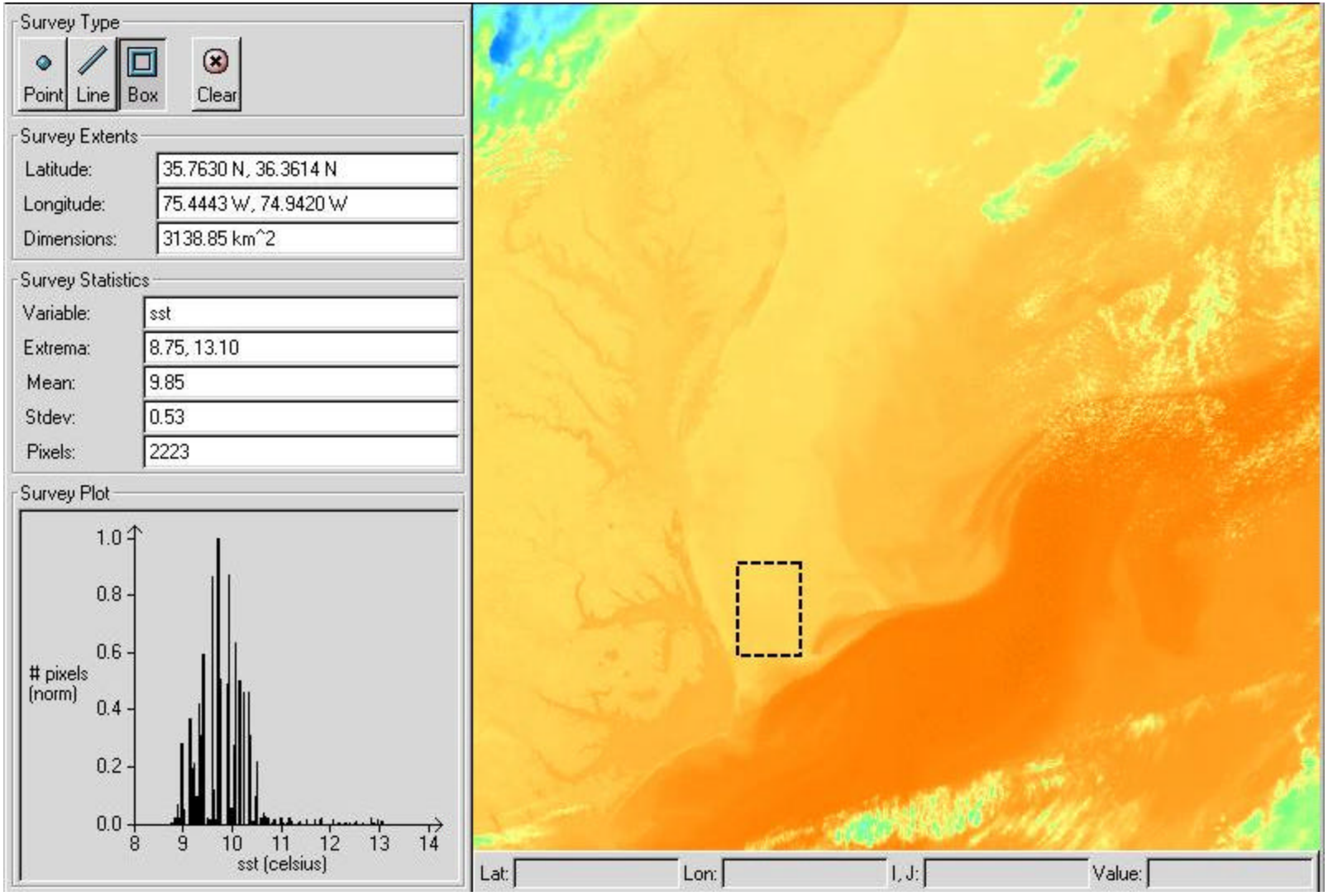

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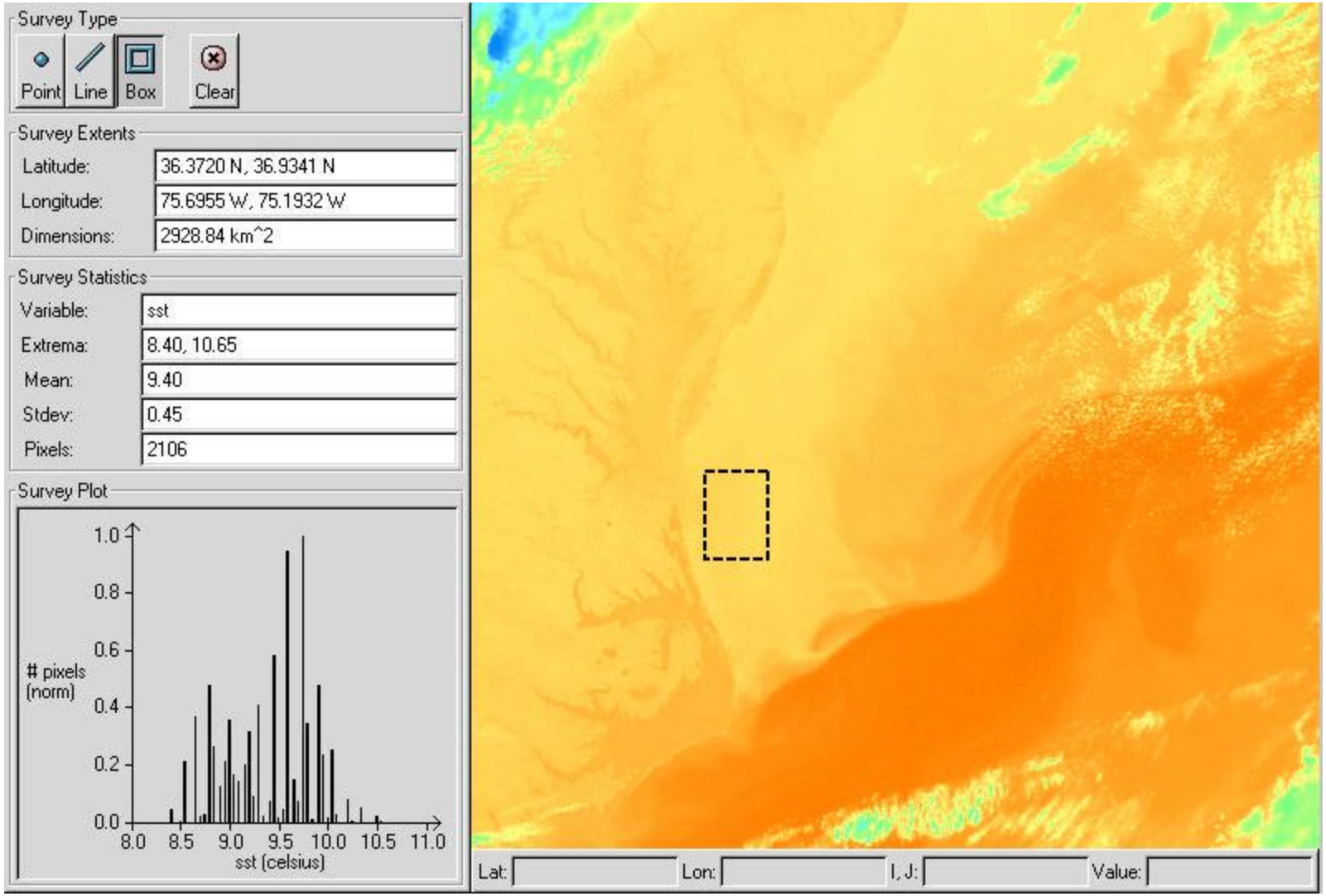
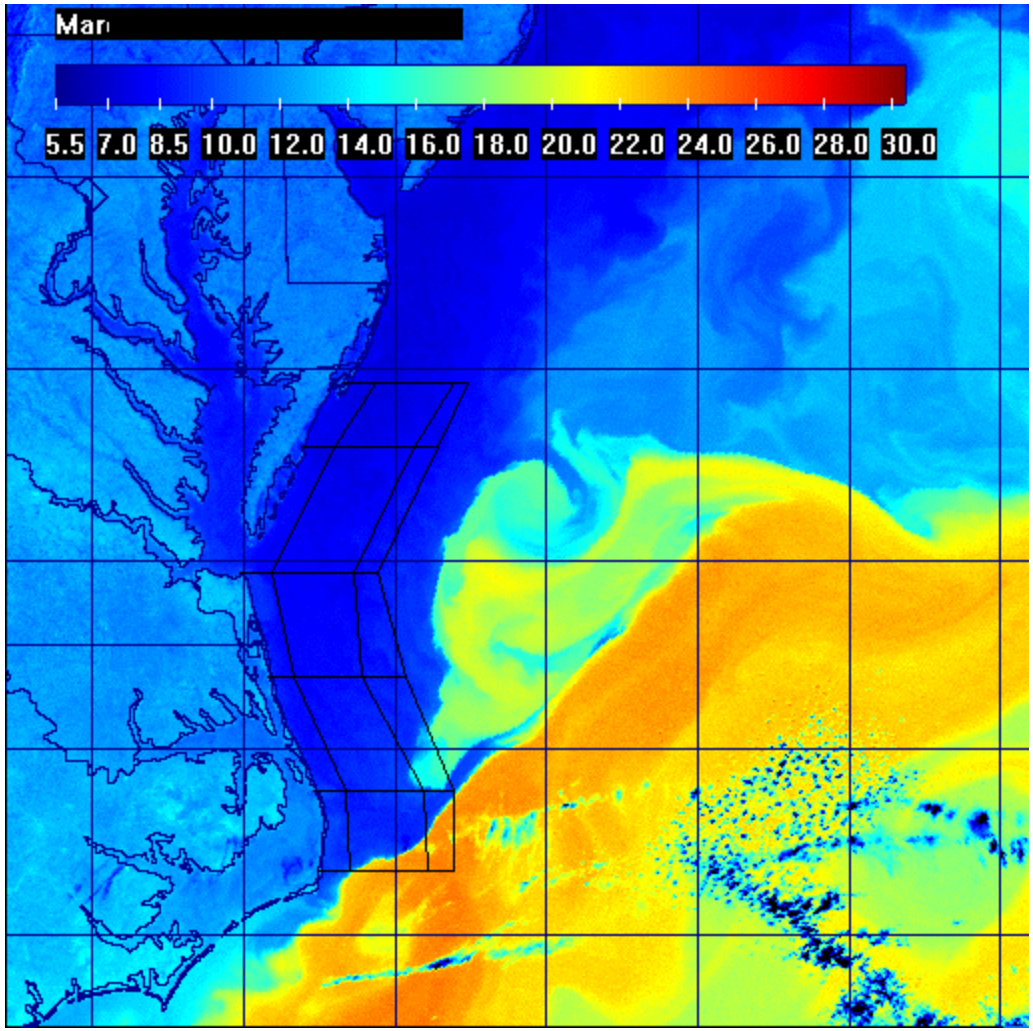
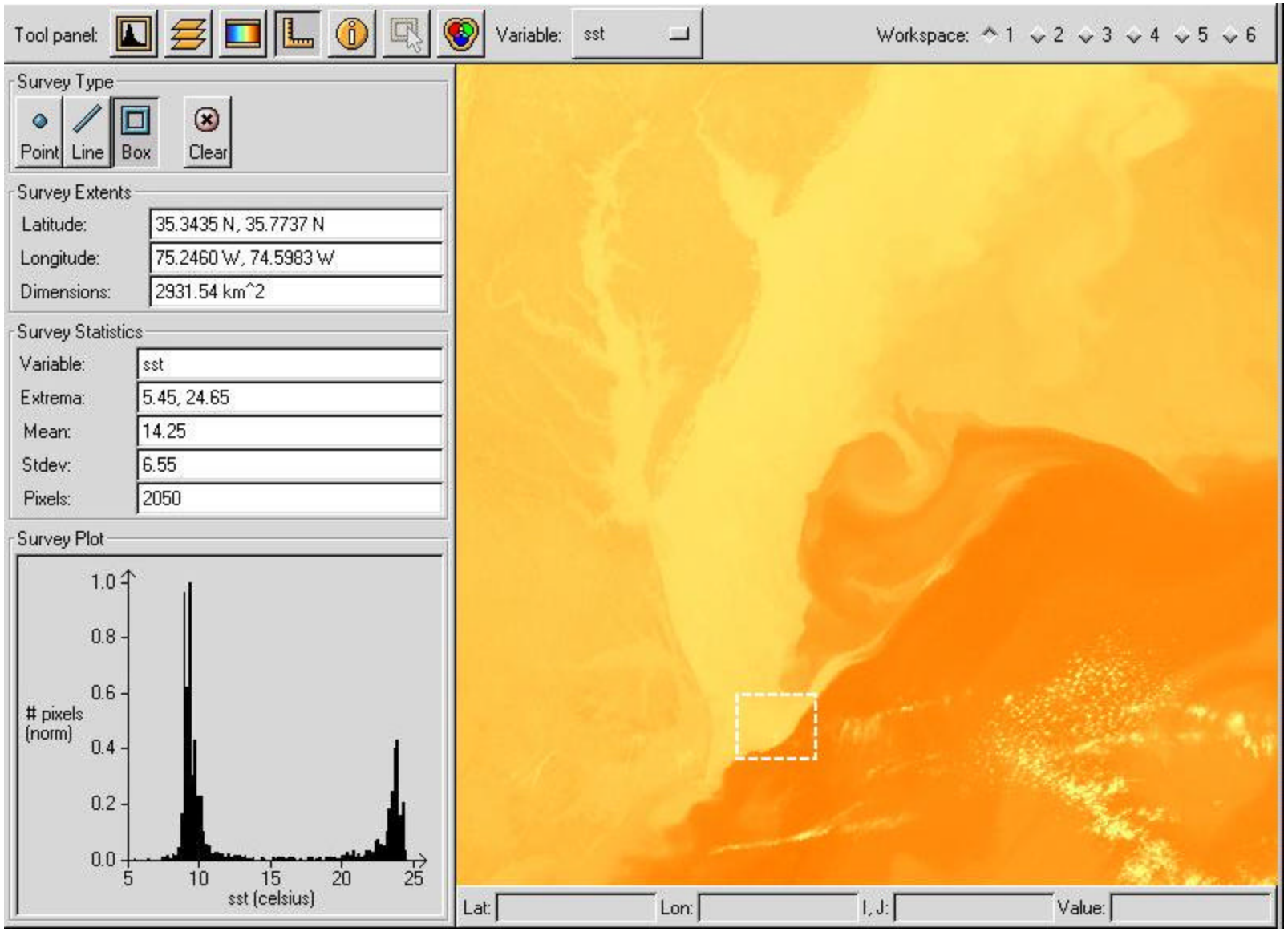


March 30, 1999



March 30, 1999 - Area 1



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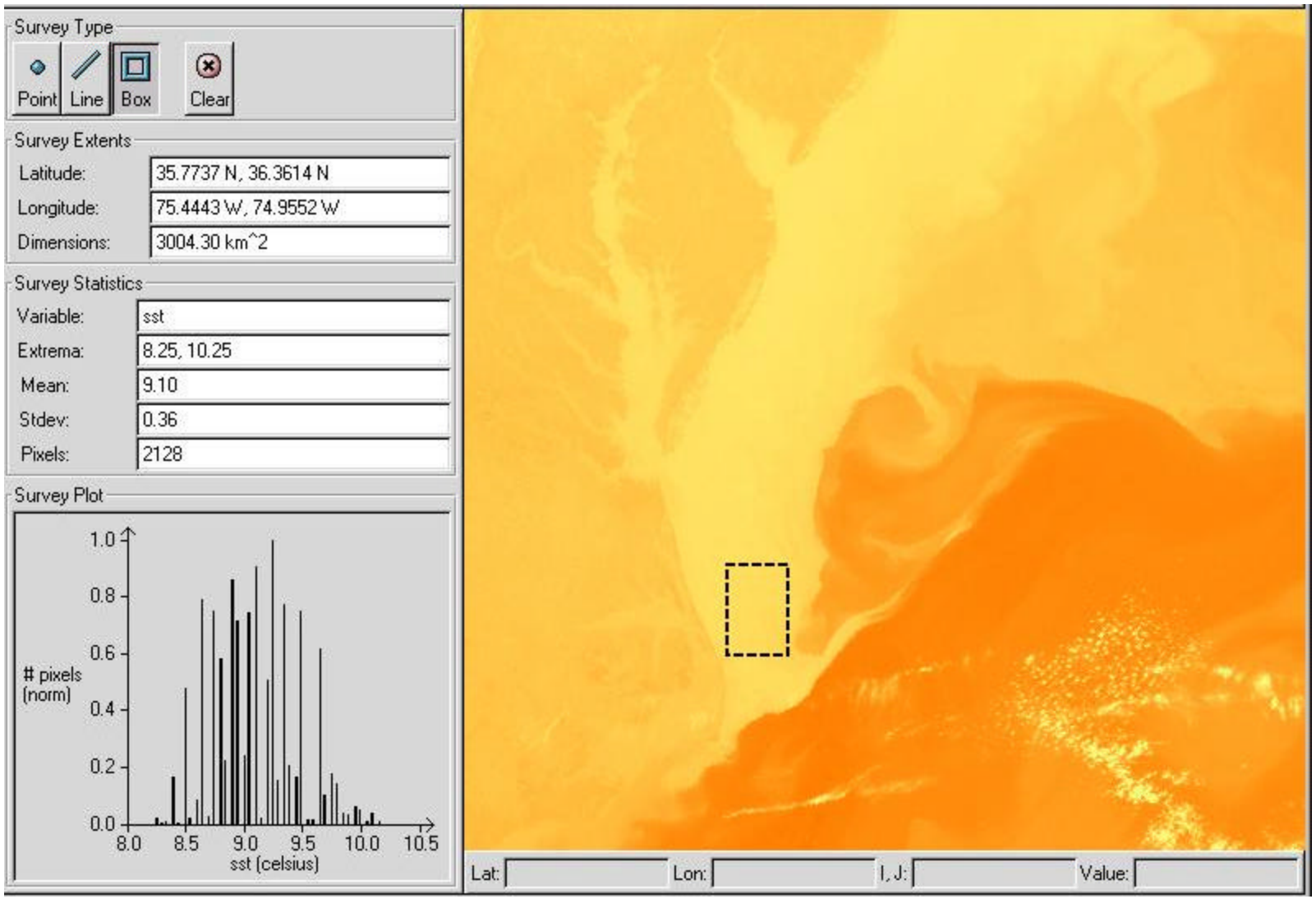

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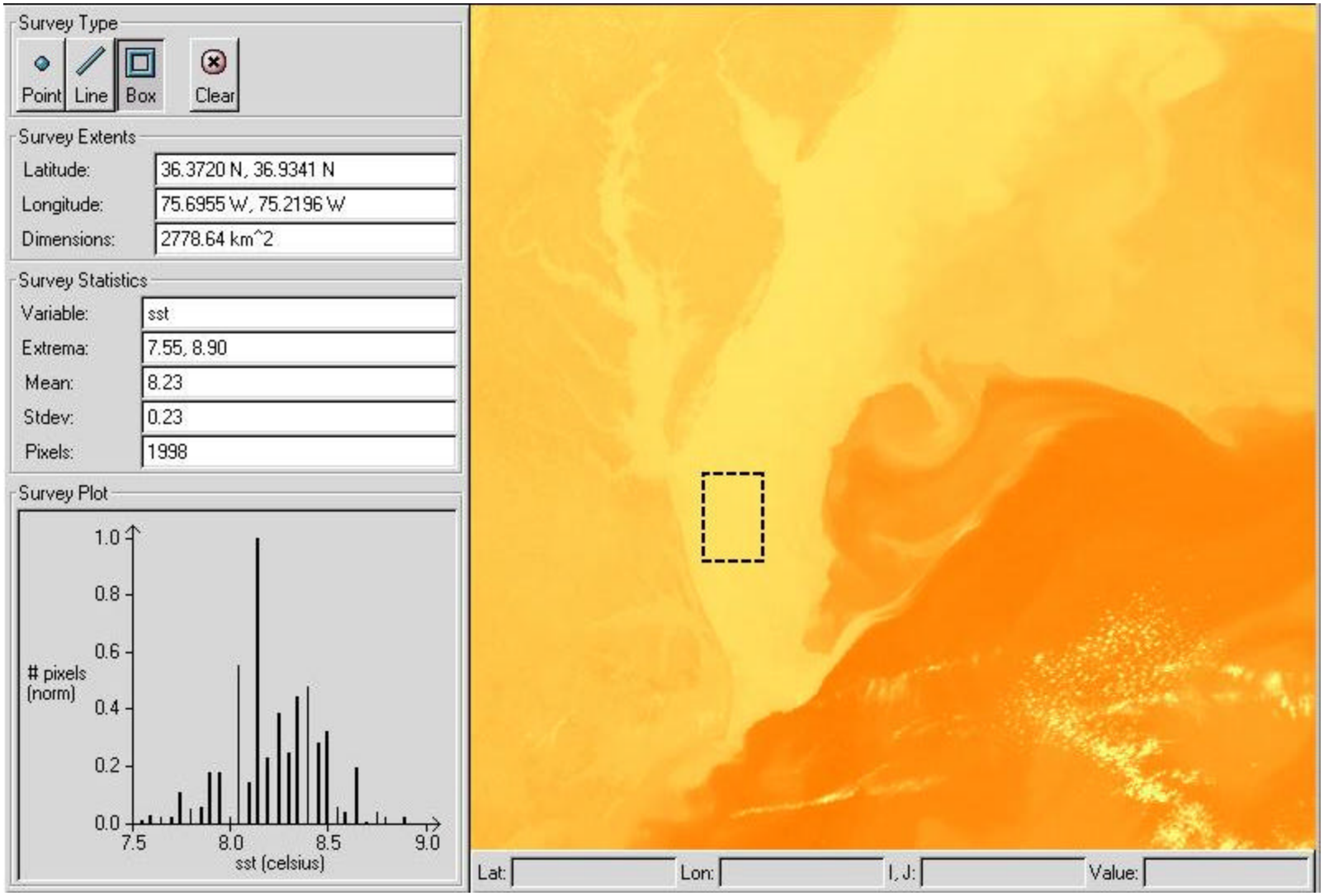

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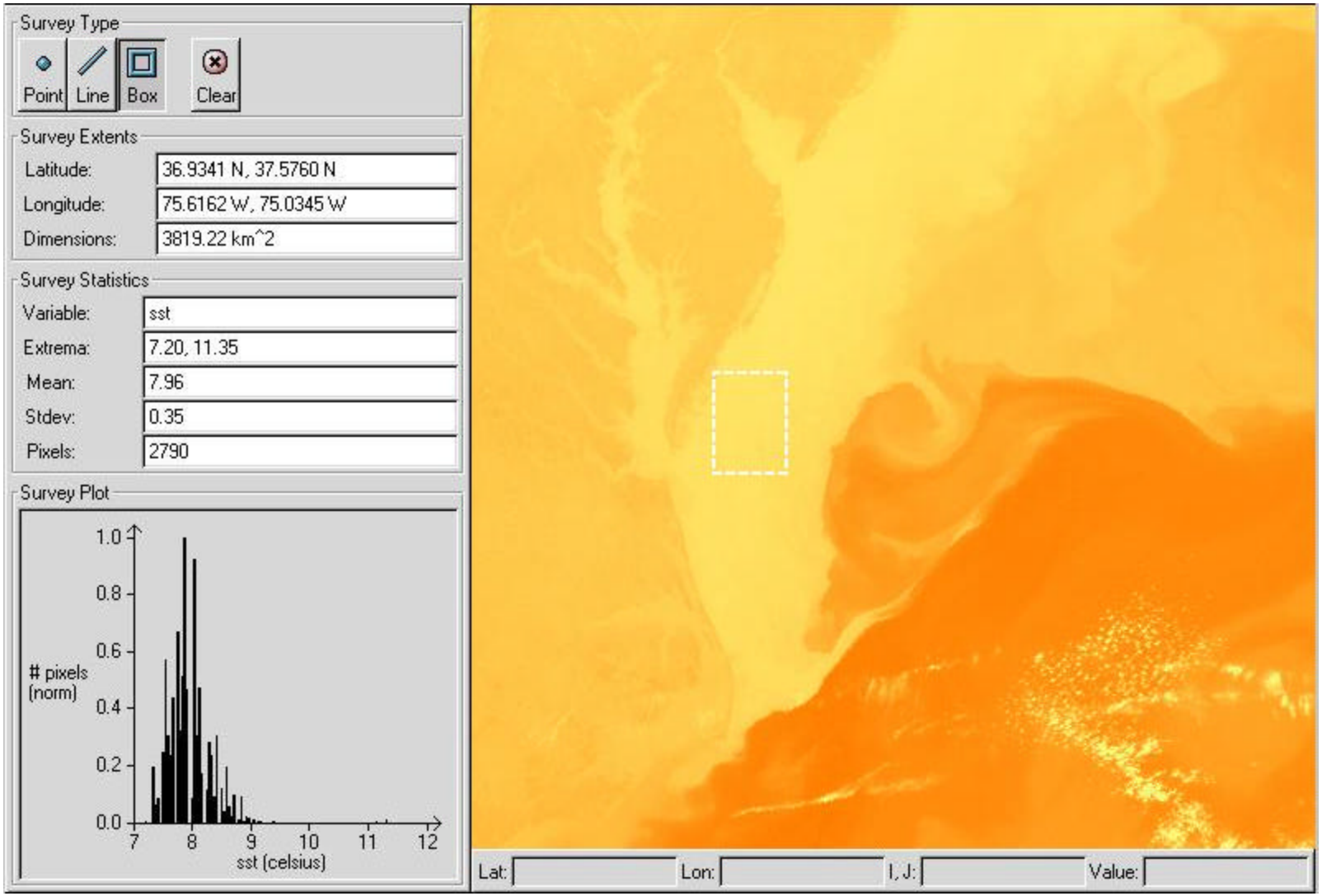
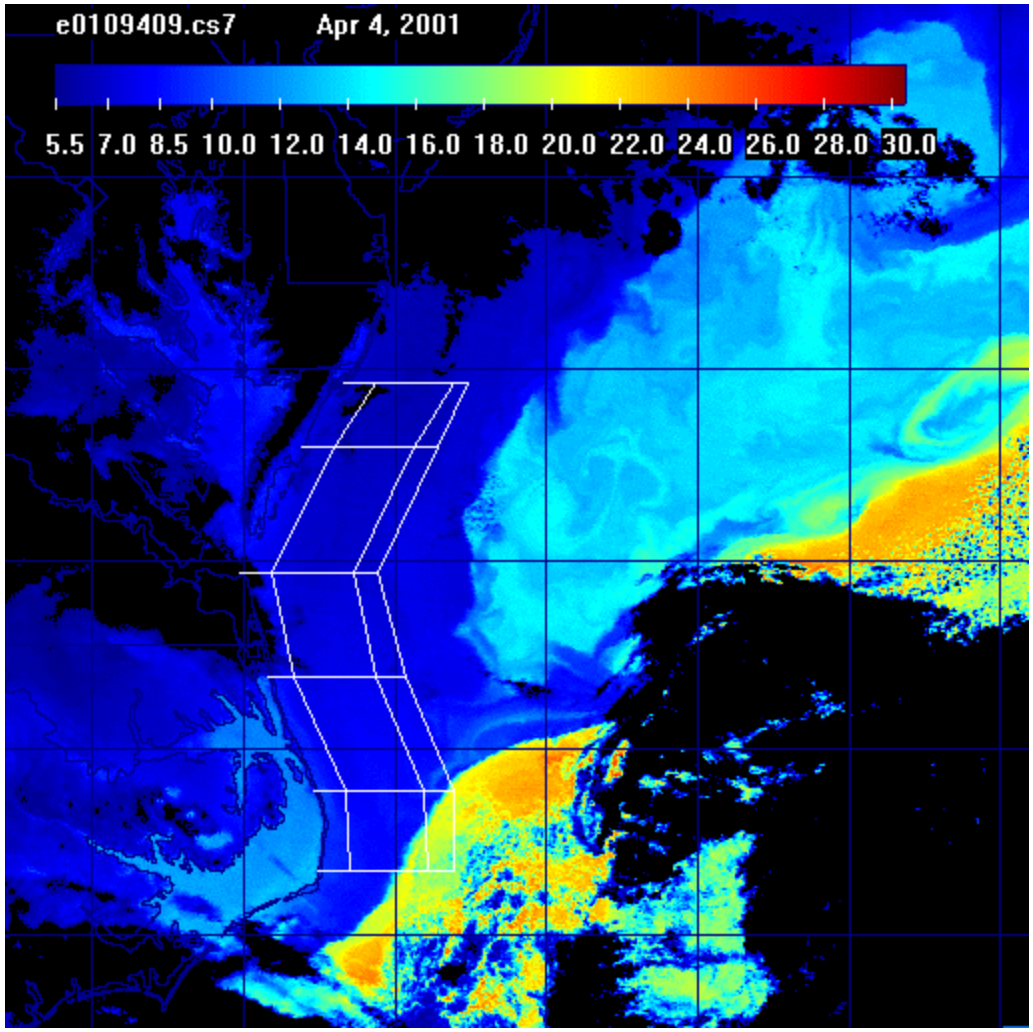


April 4, 2001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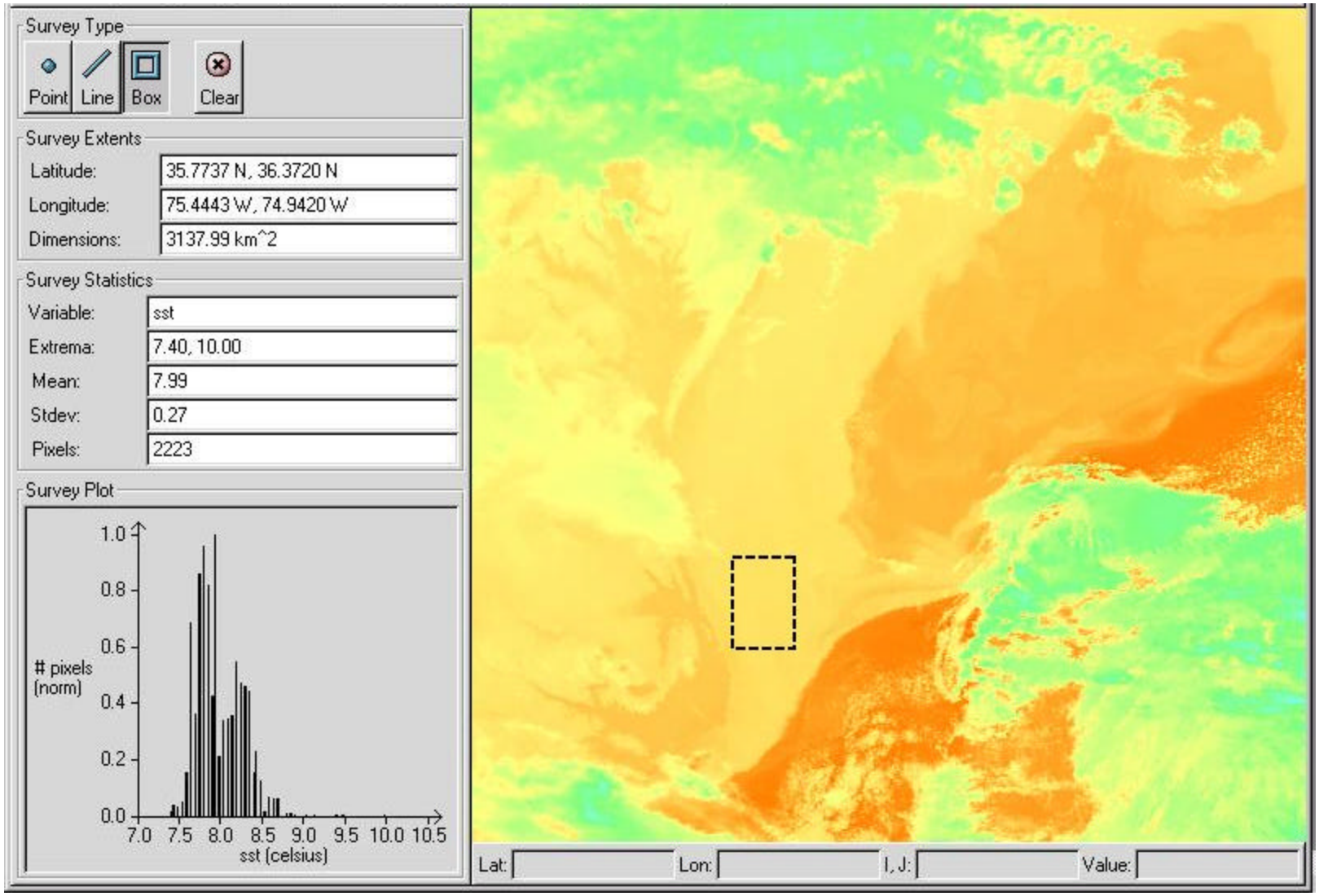
April 4, 2001 Area 2



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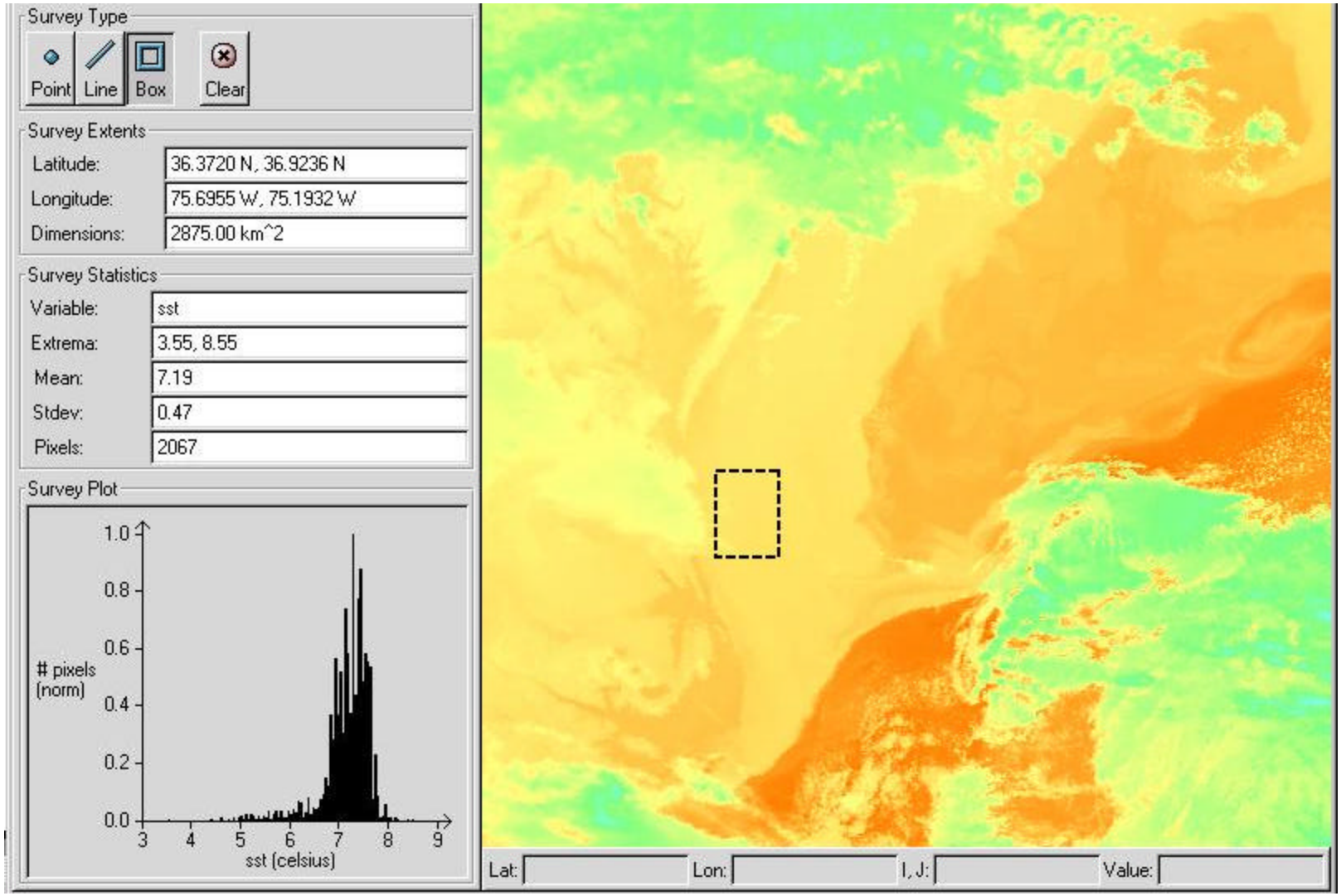
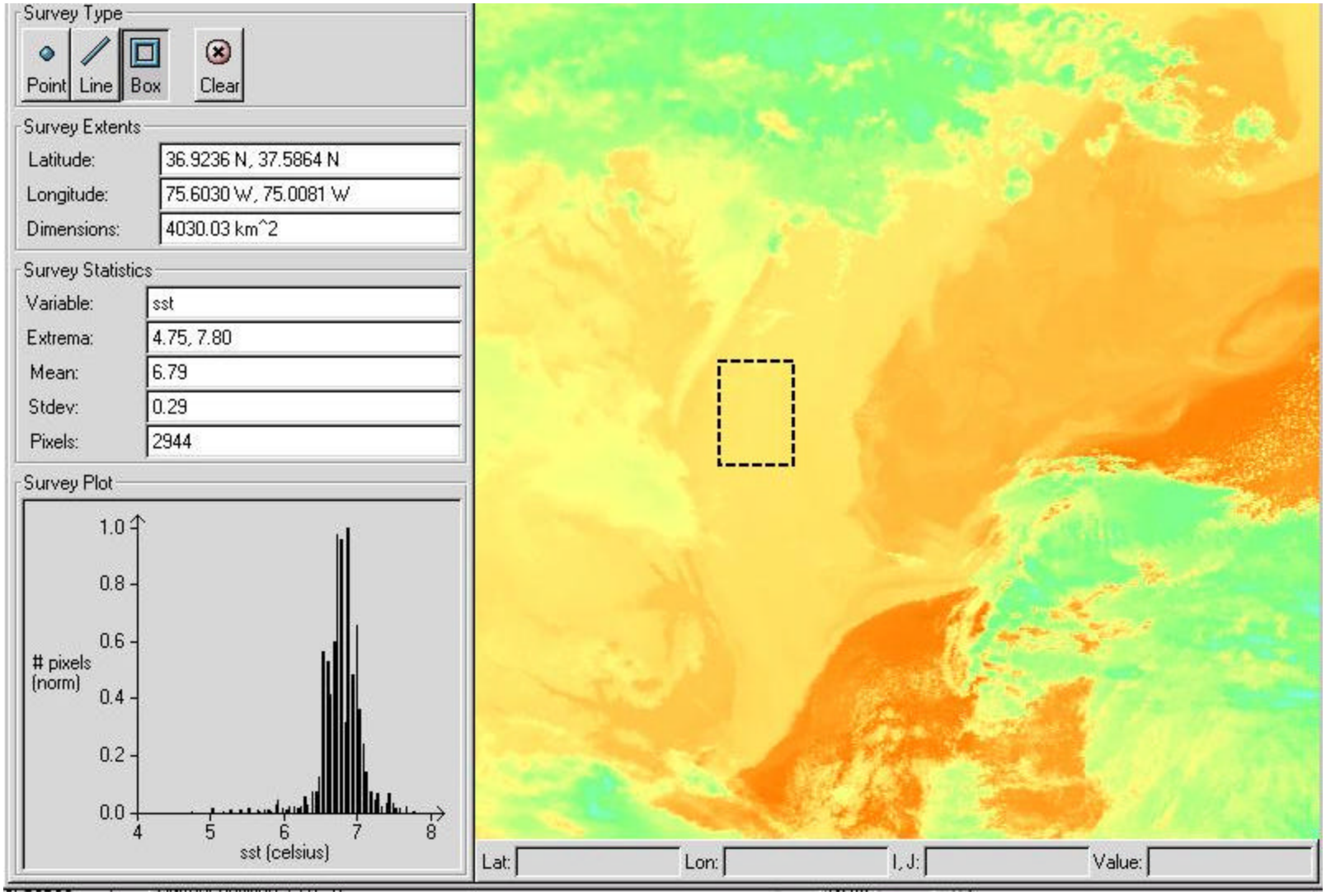
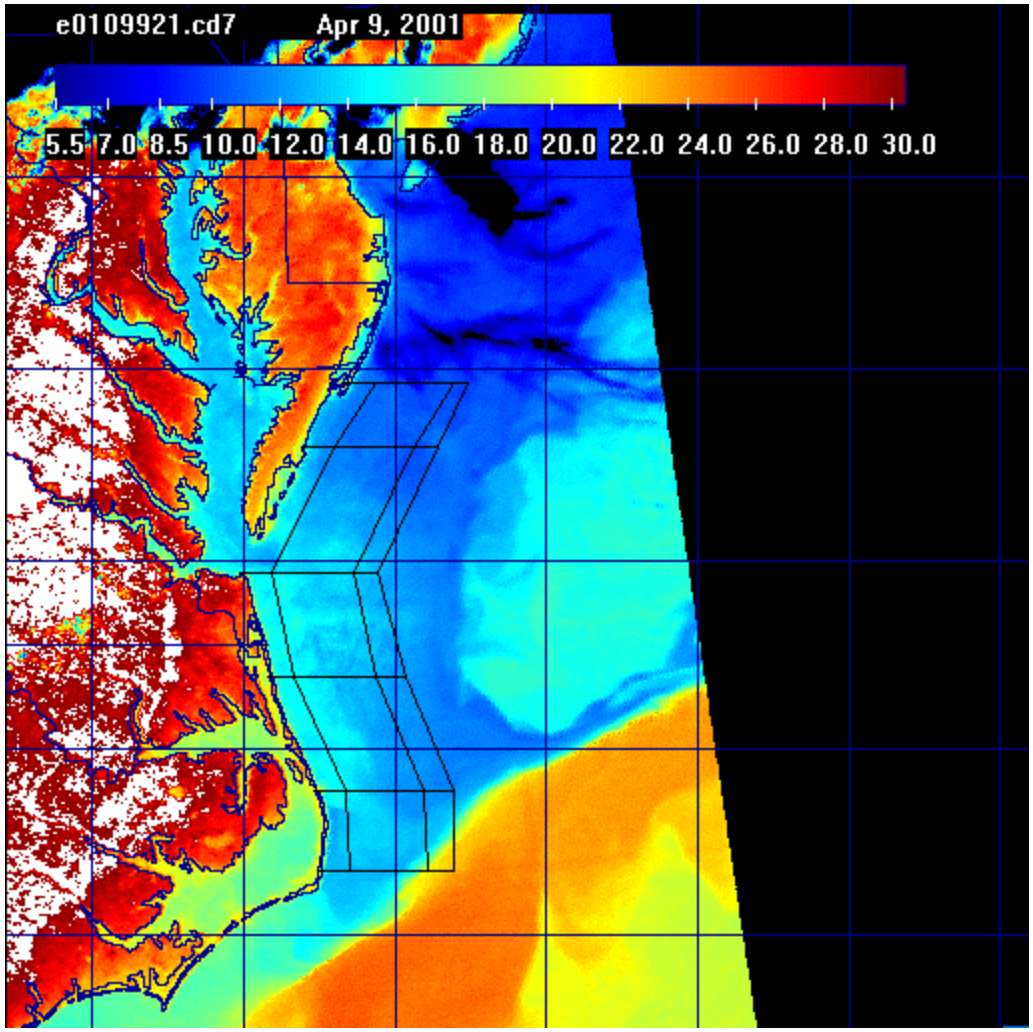


April 4, 2001 Area 4



April 9, 2001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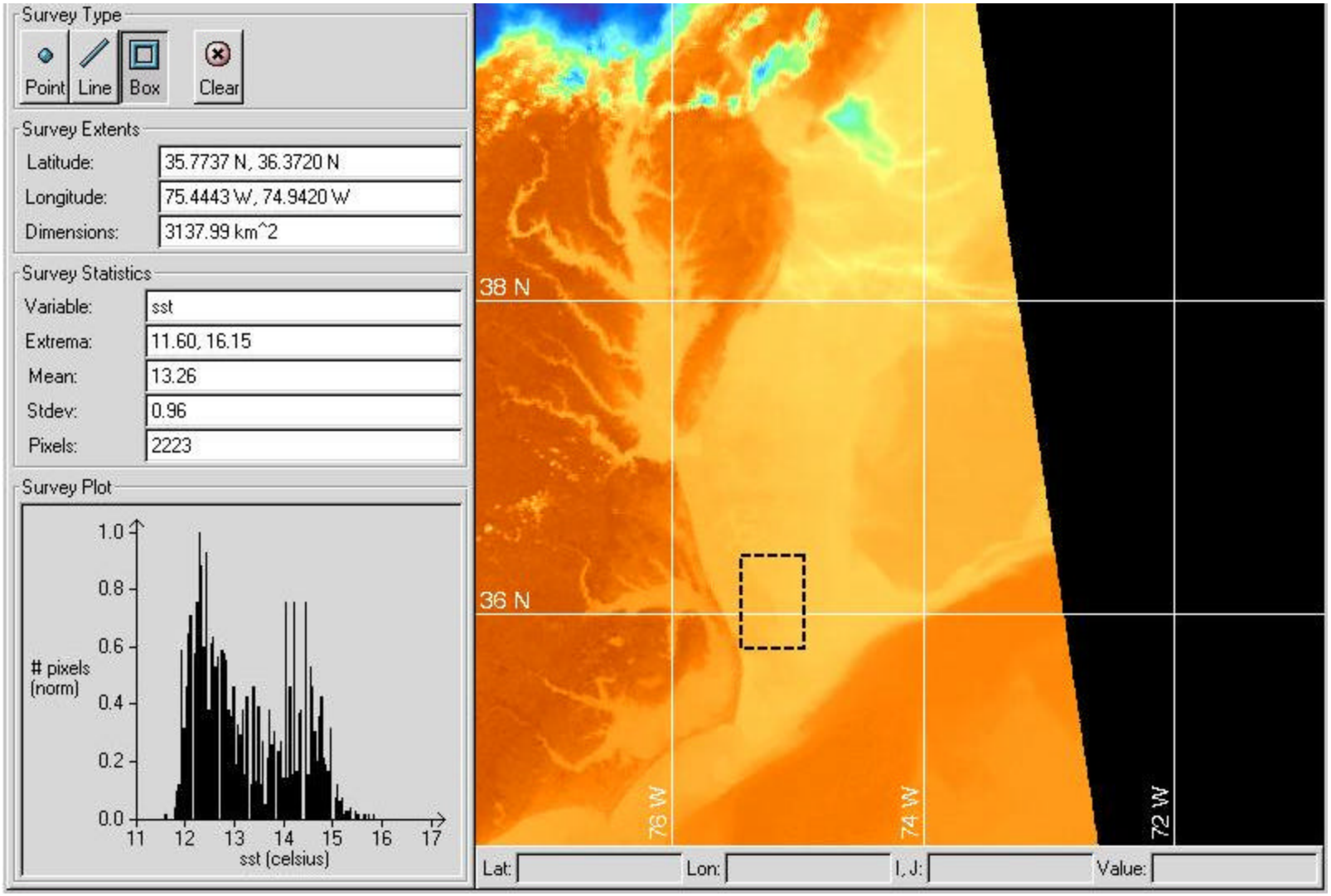
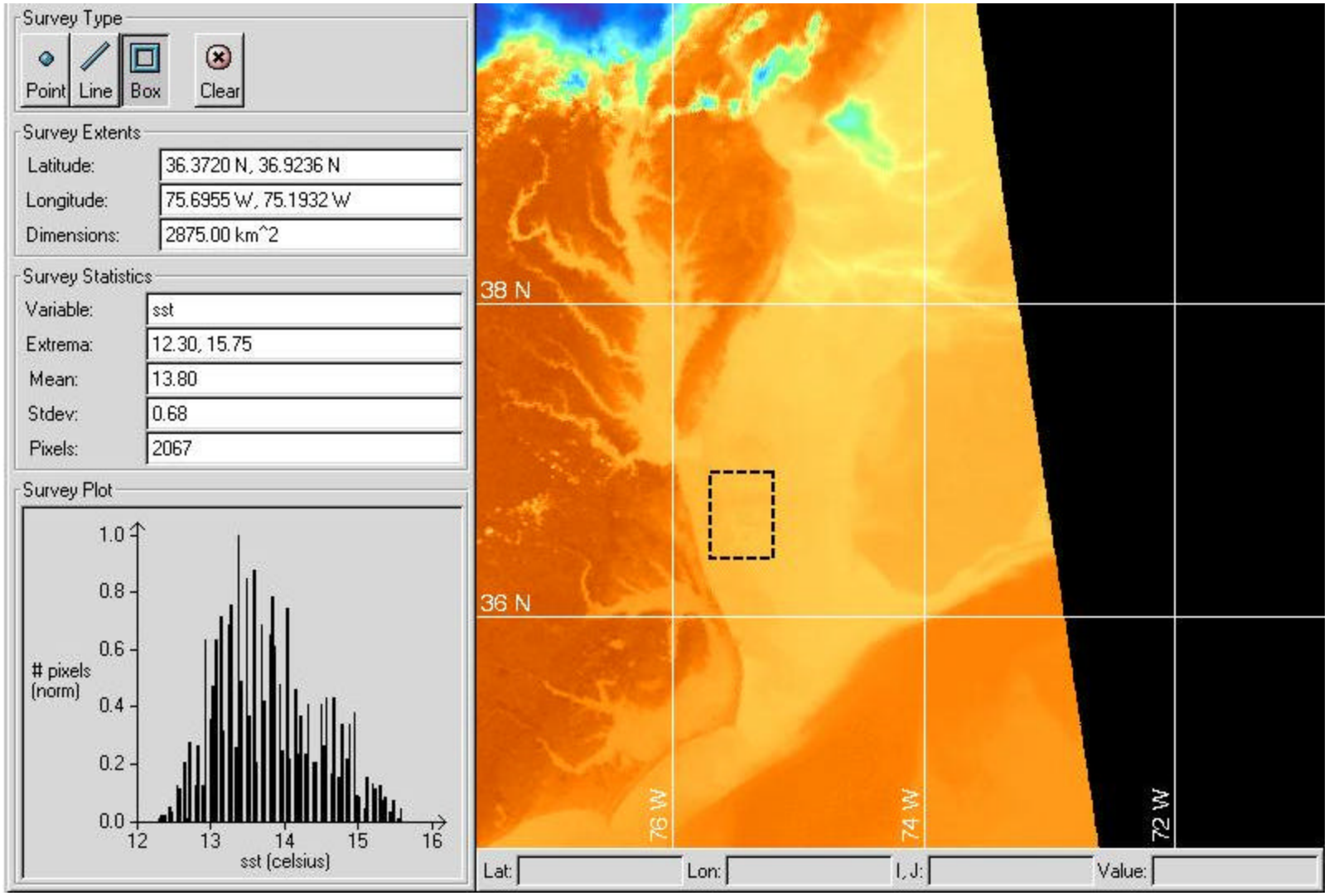
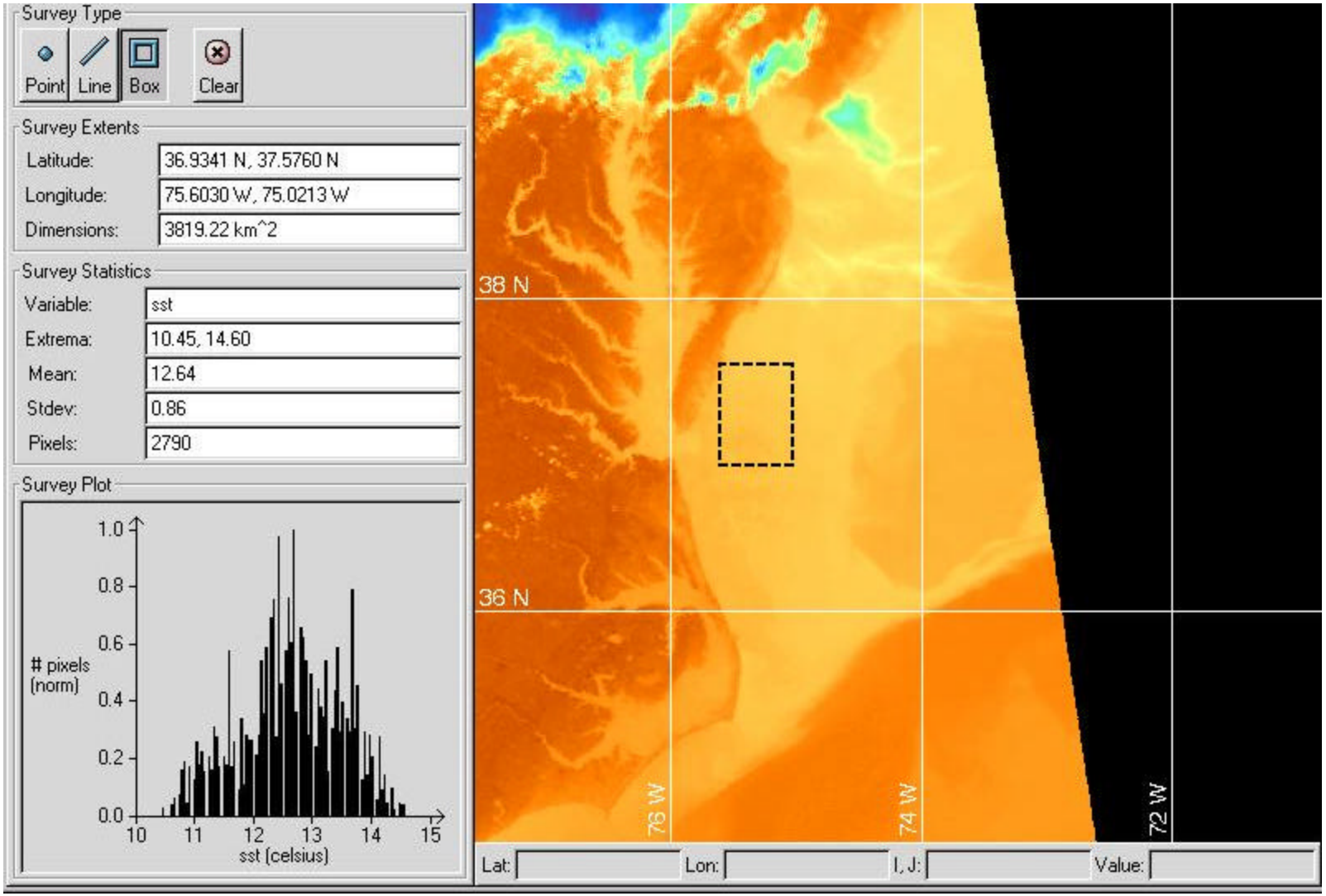
April 9, 2001 Area 2



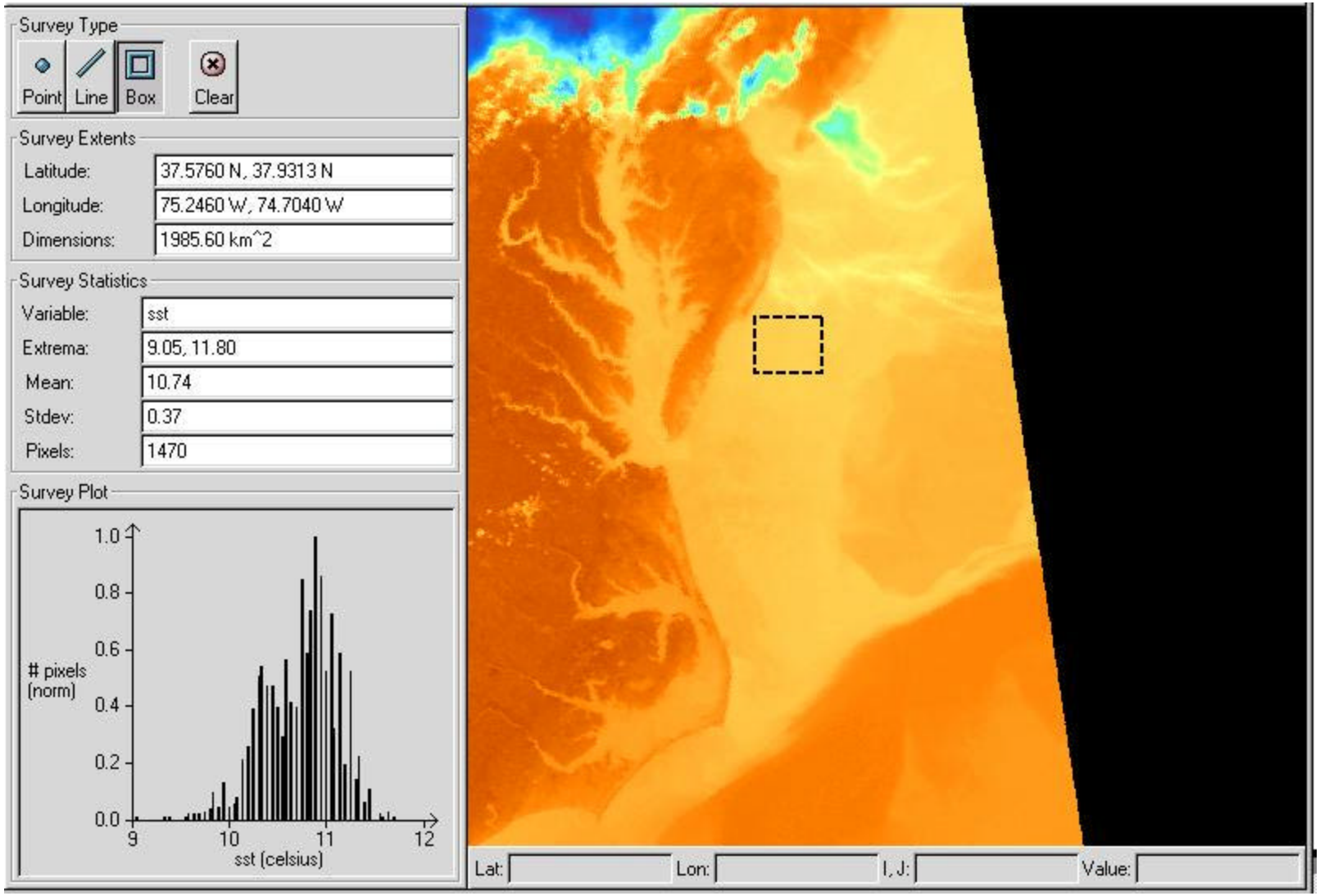
April 9, 2001 Area 3



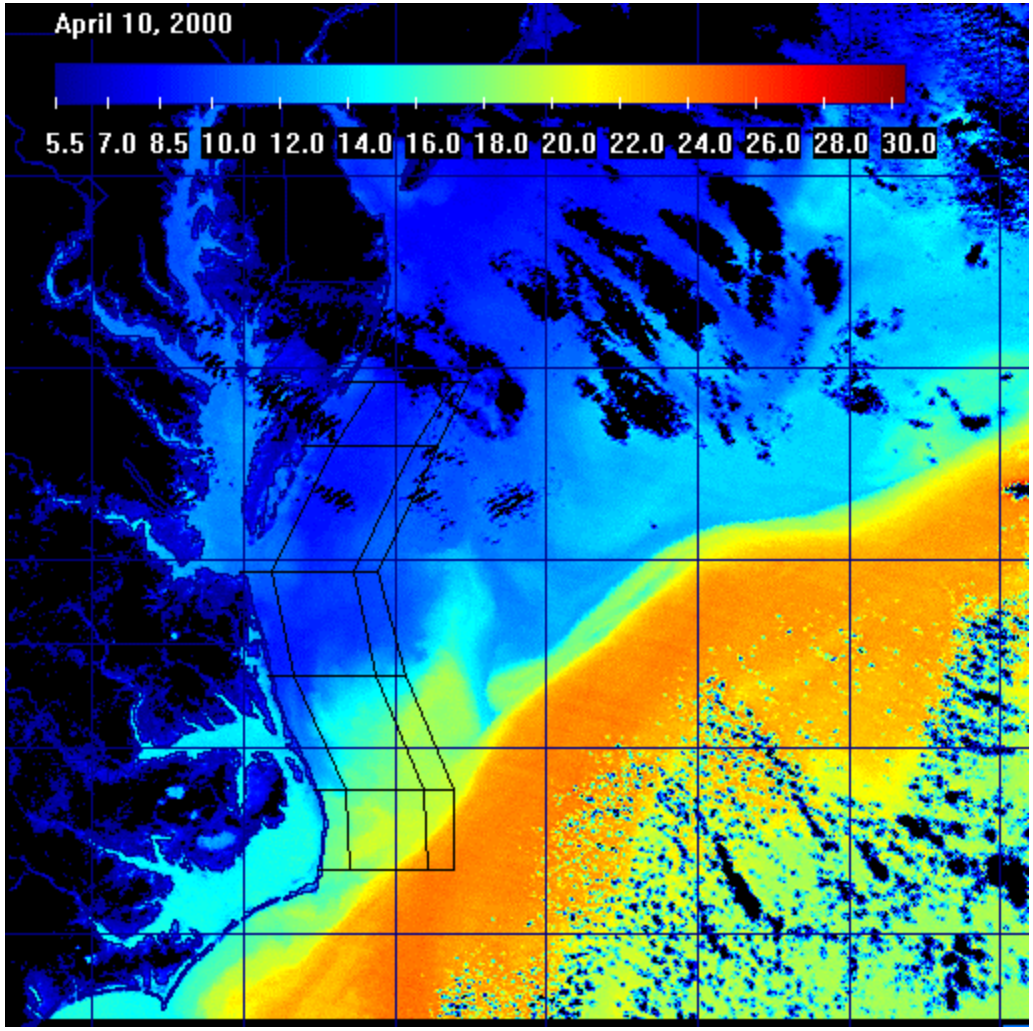
April 9, 2001 Area 4



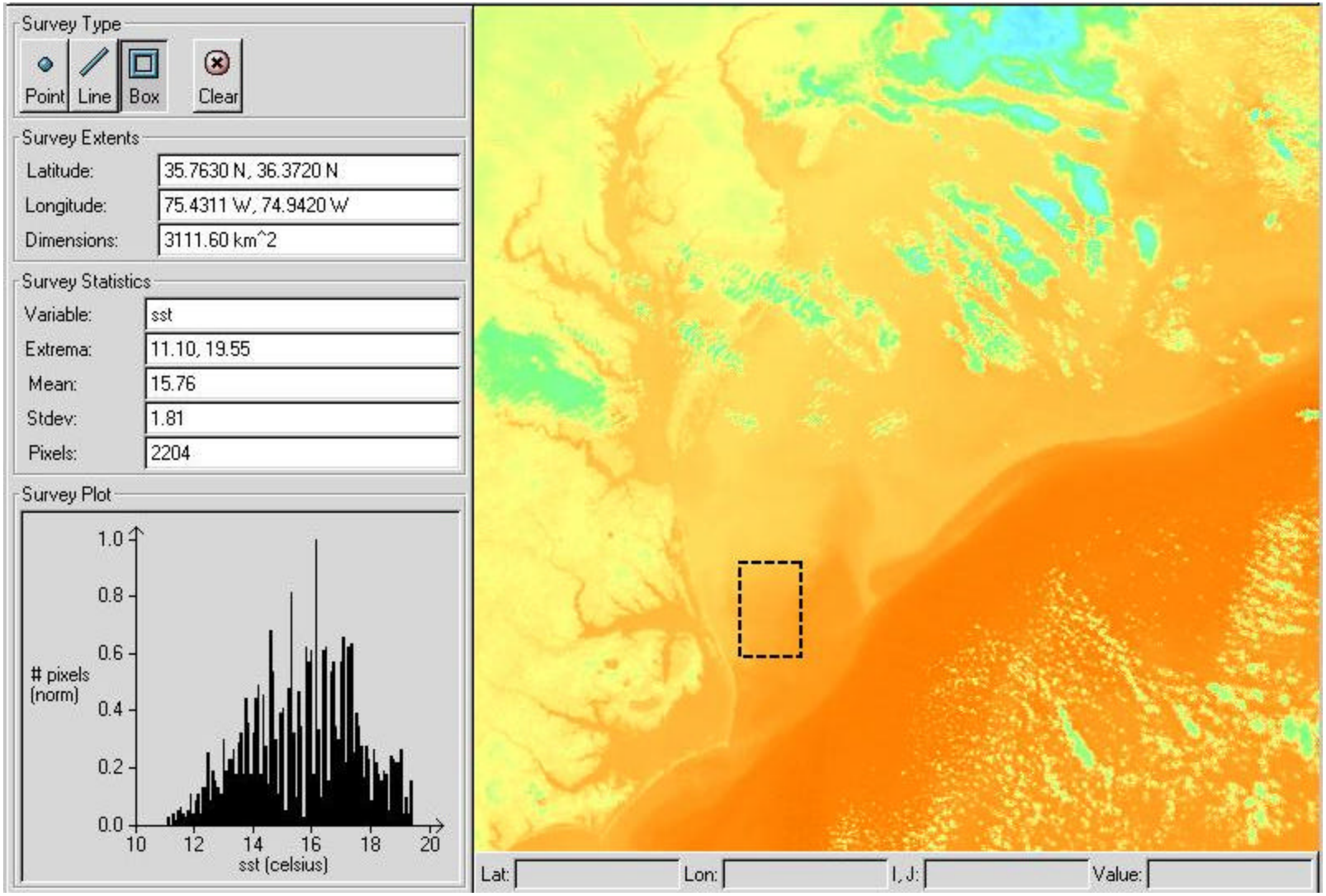
April 9, 2001 Area 5



April 10, 2000



April 10, 2000 - Area 2



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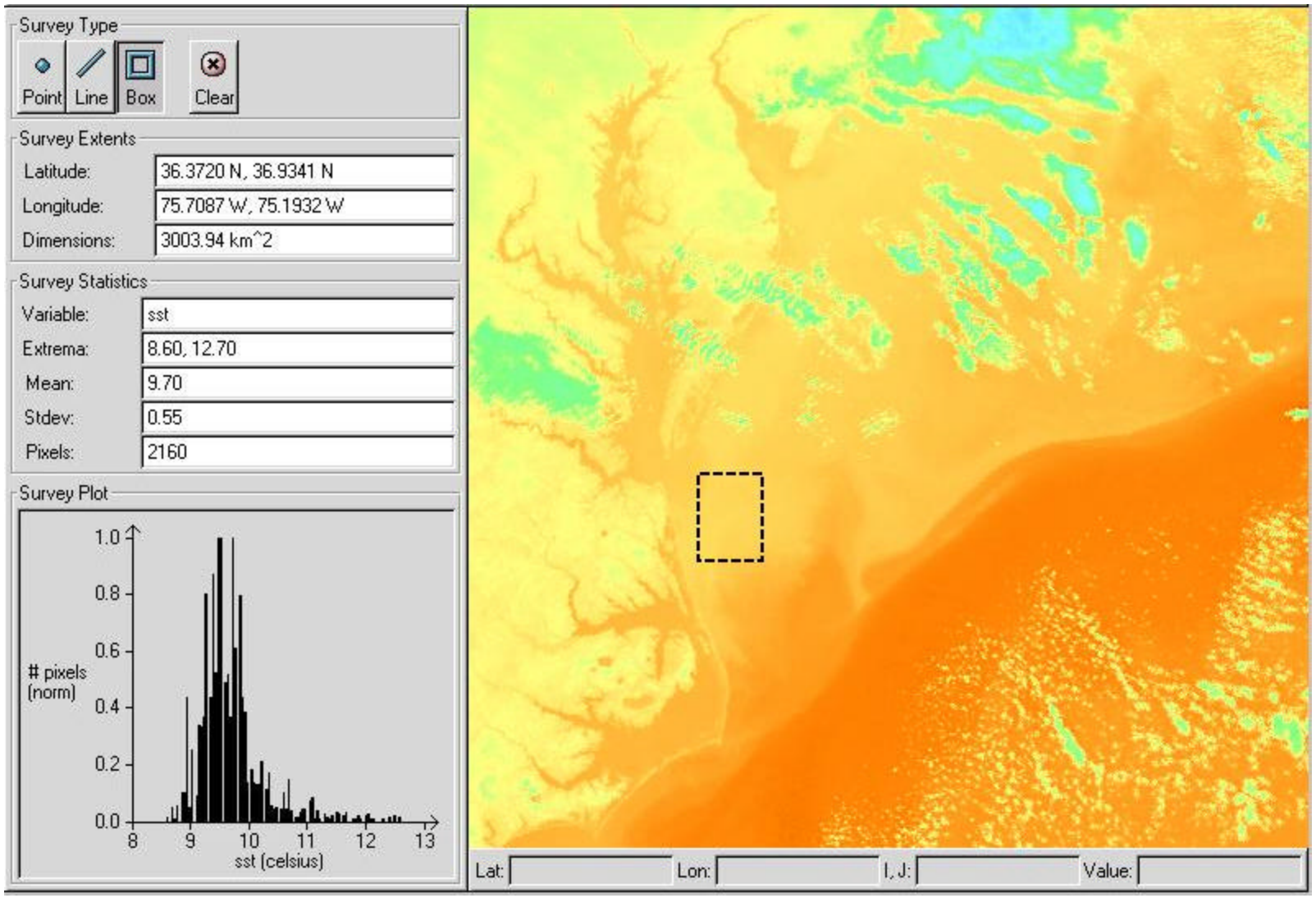

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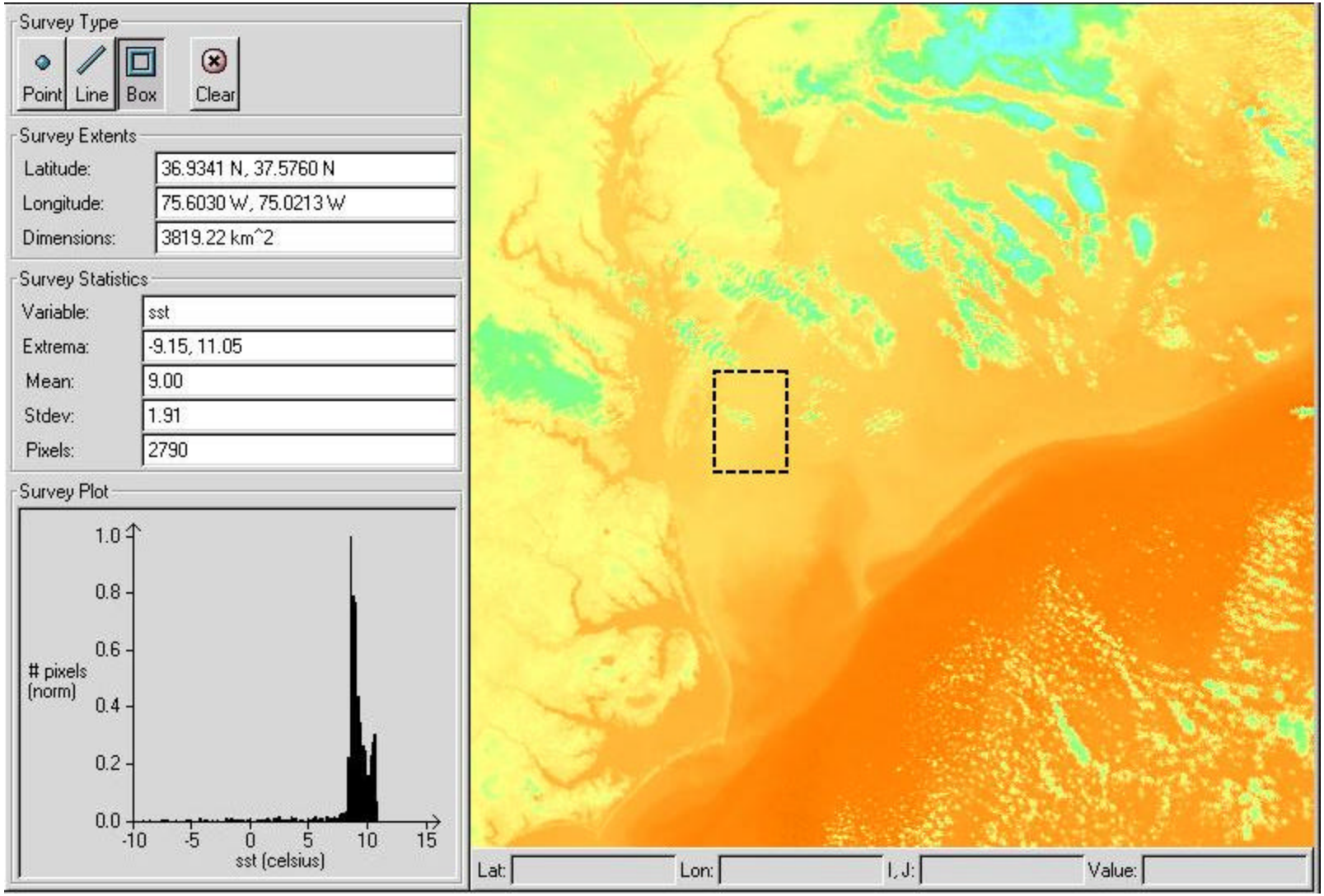
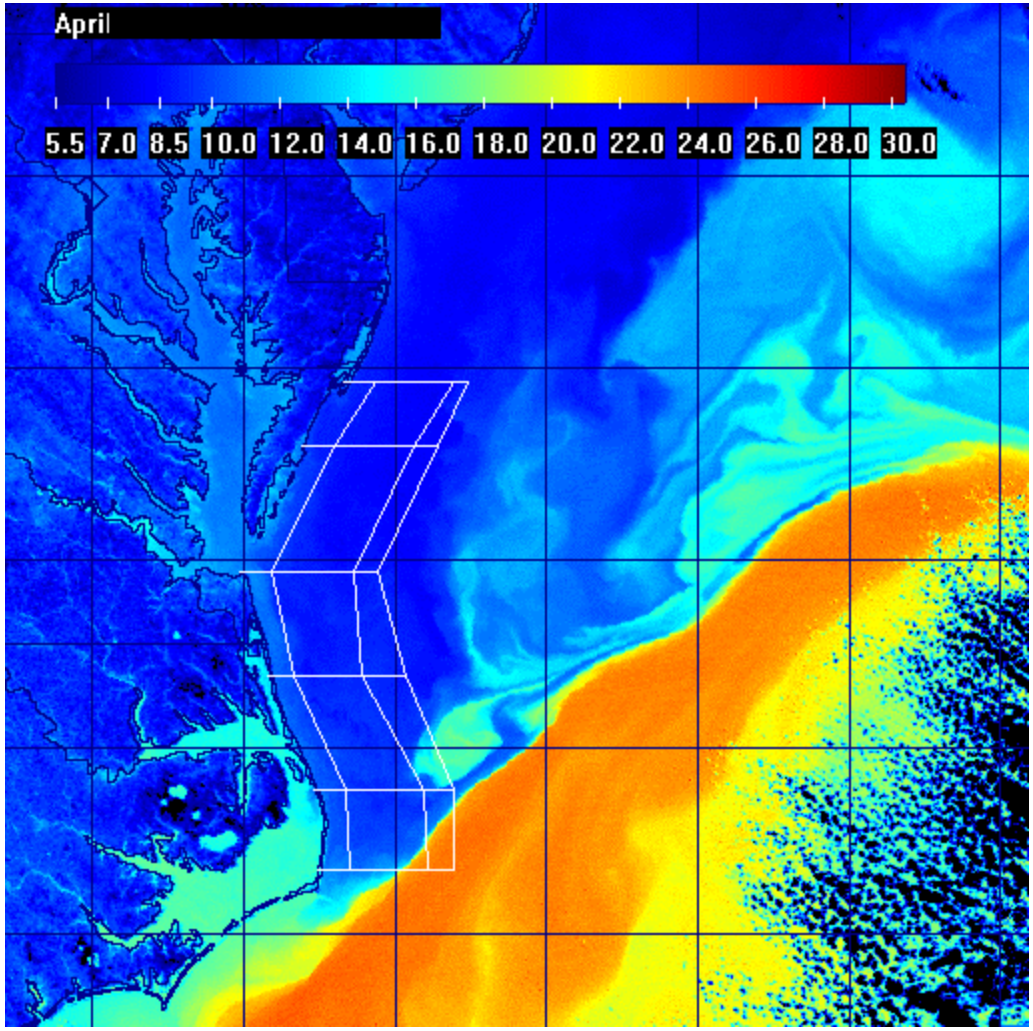


April 14, 1999



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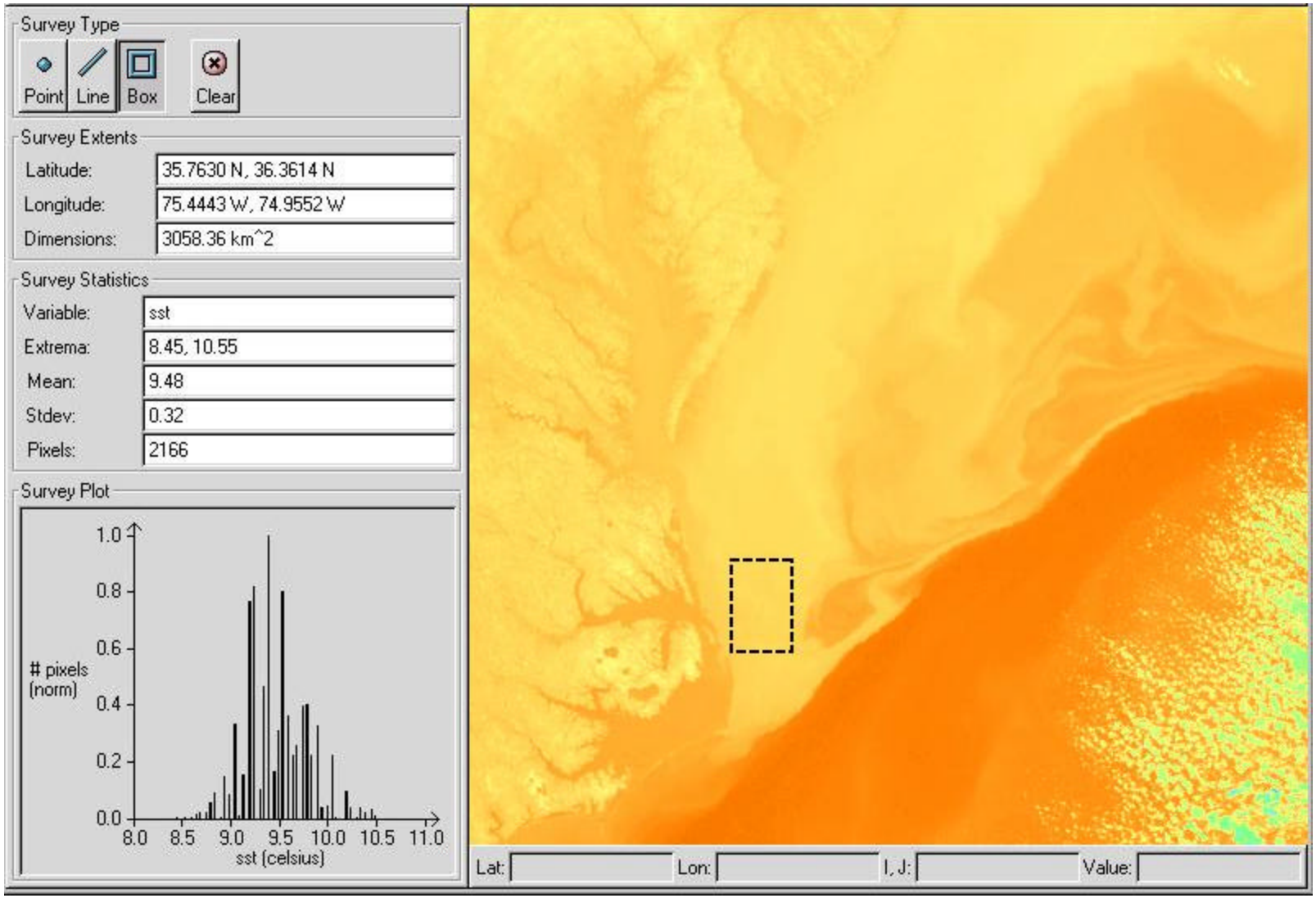

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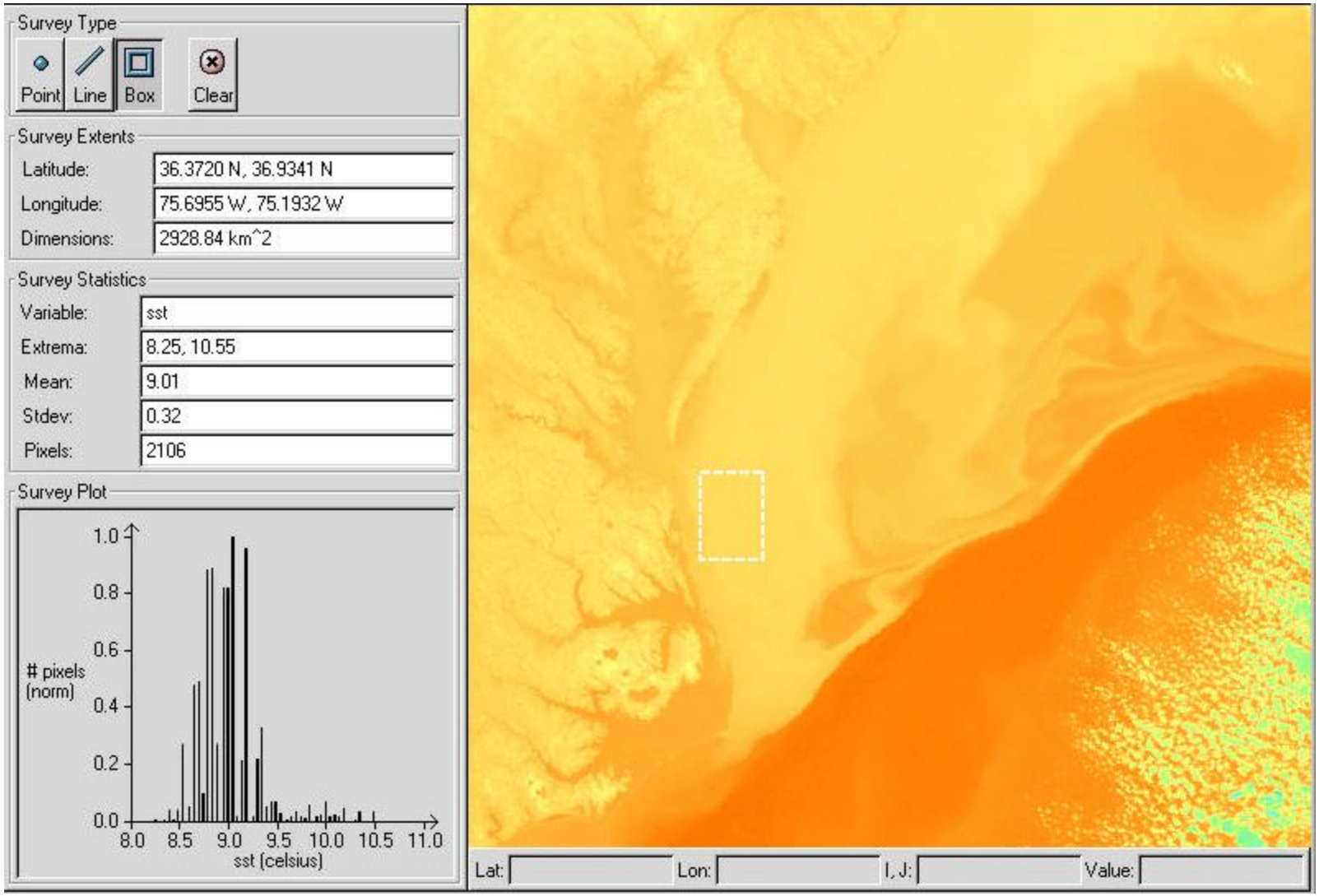

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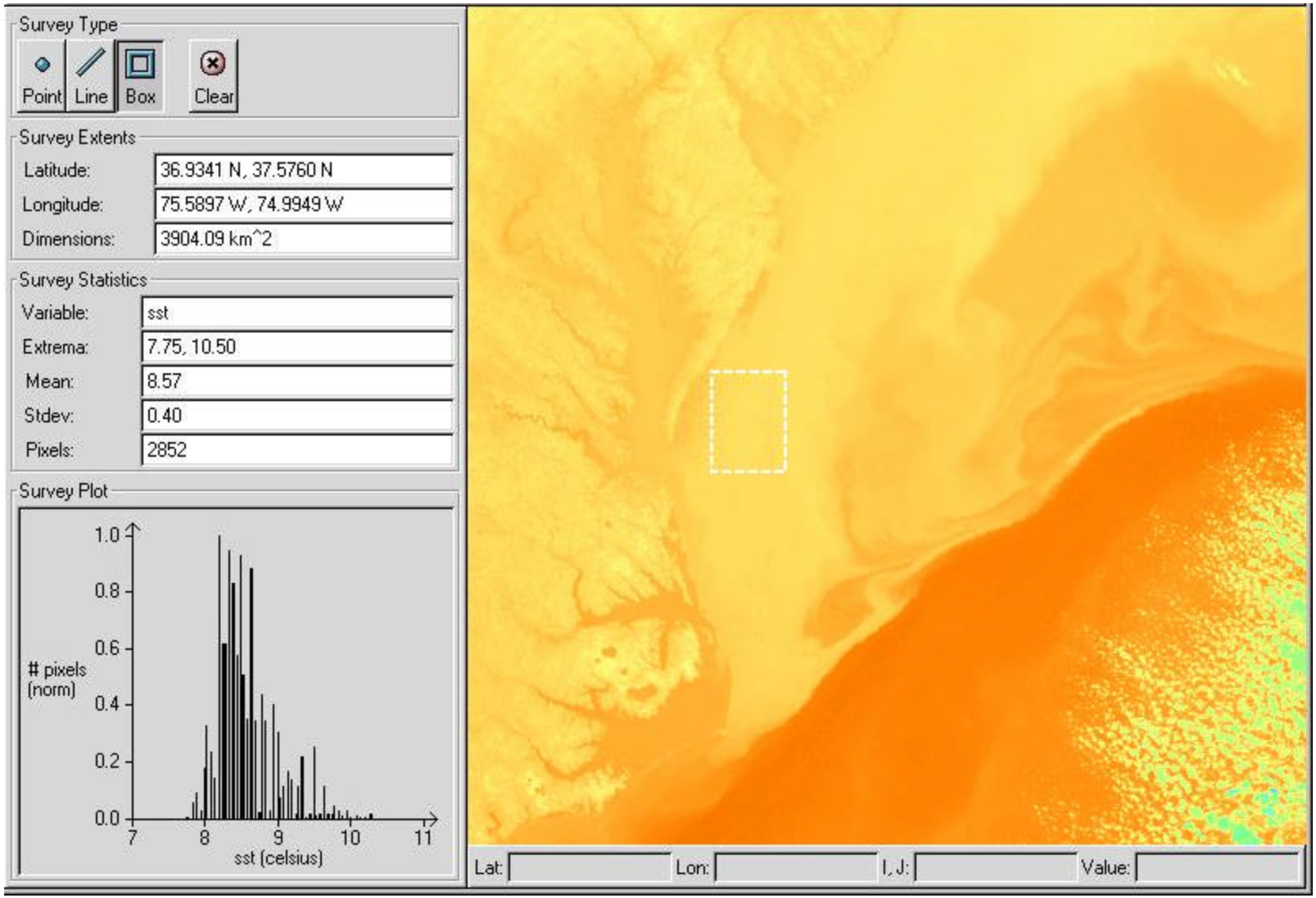

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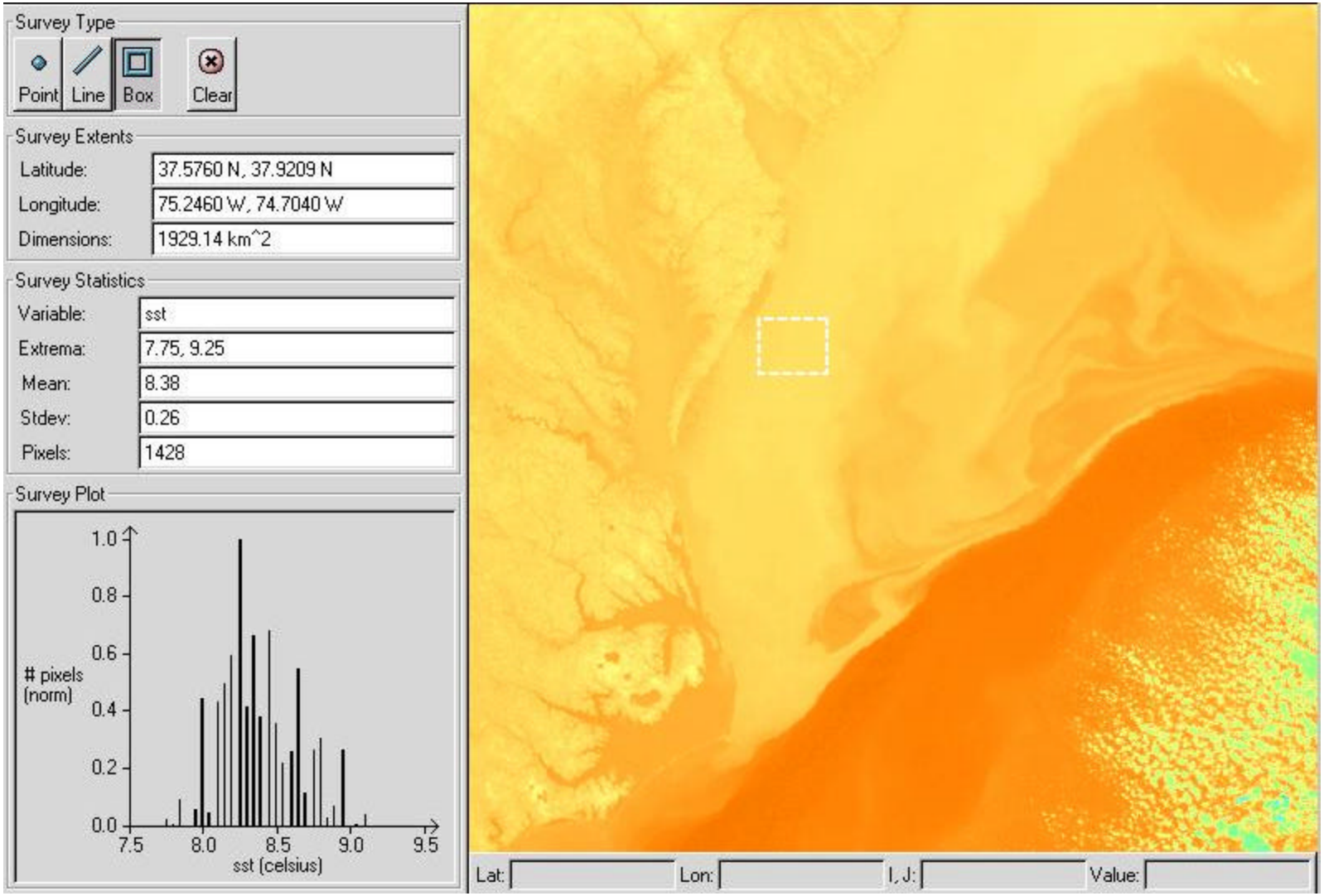
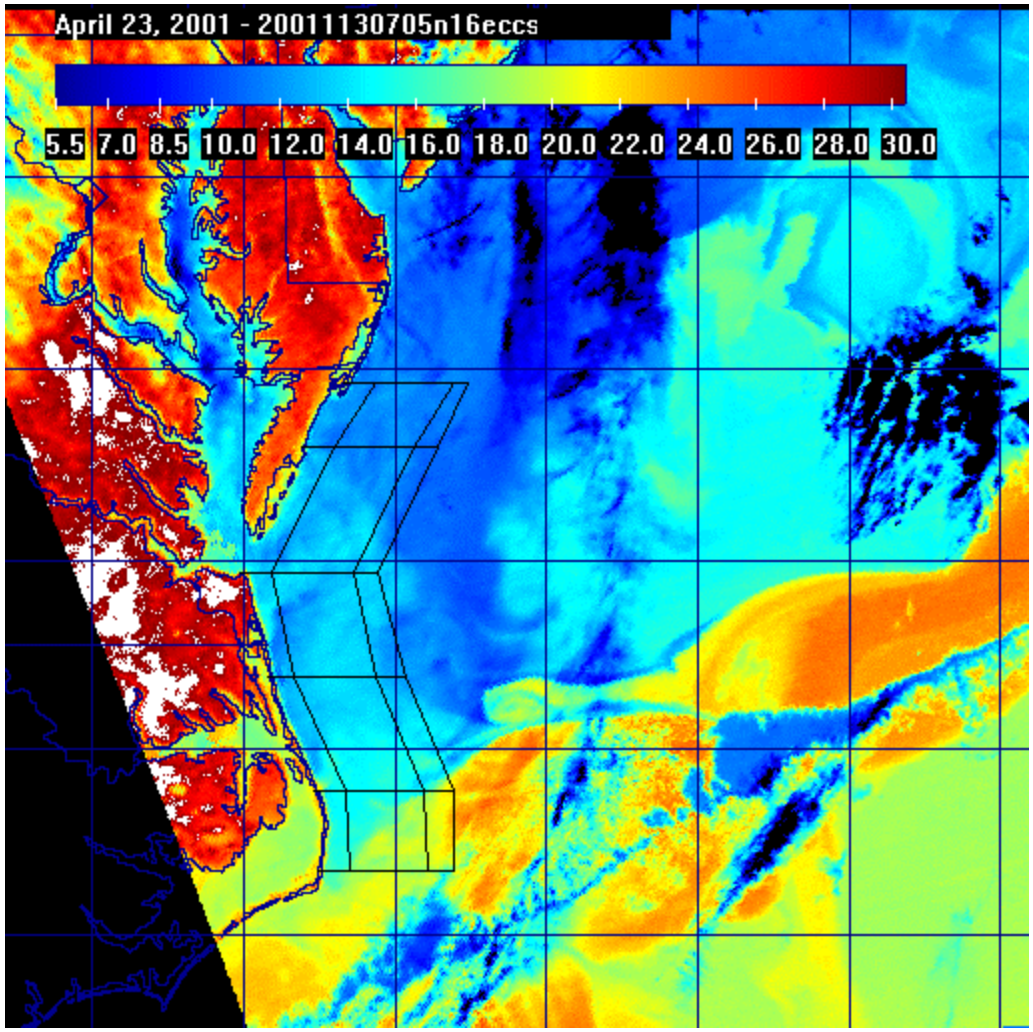


April 23, 2001



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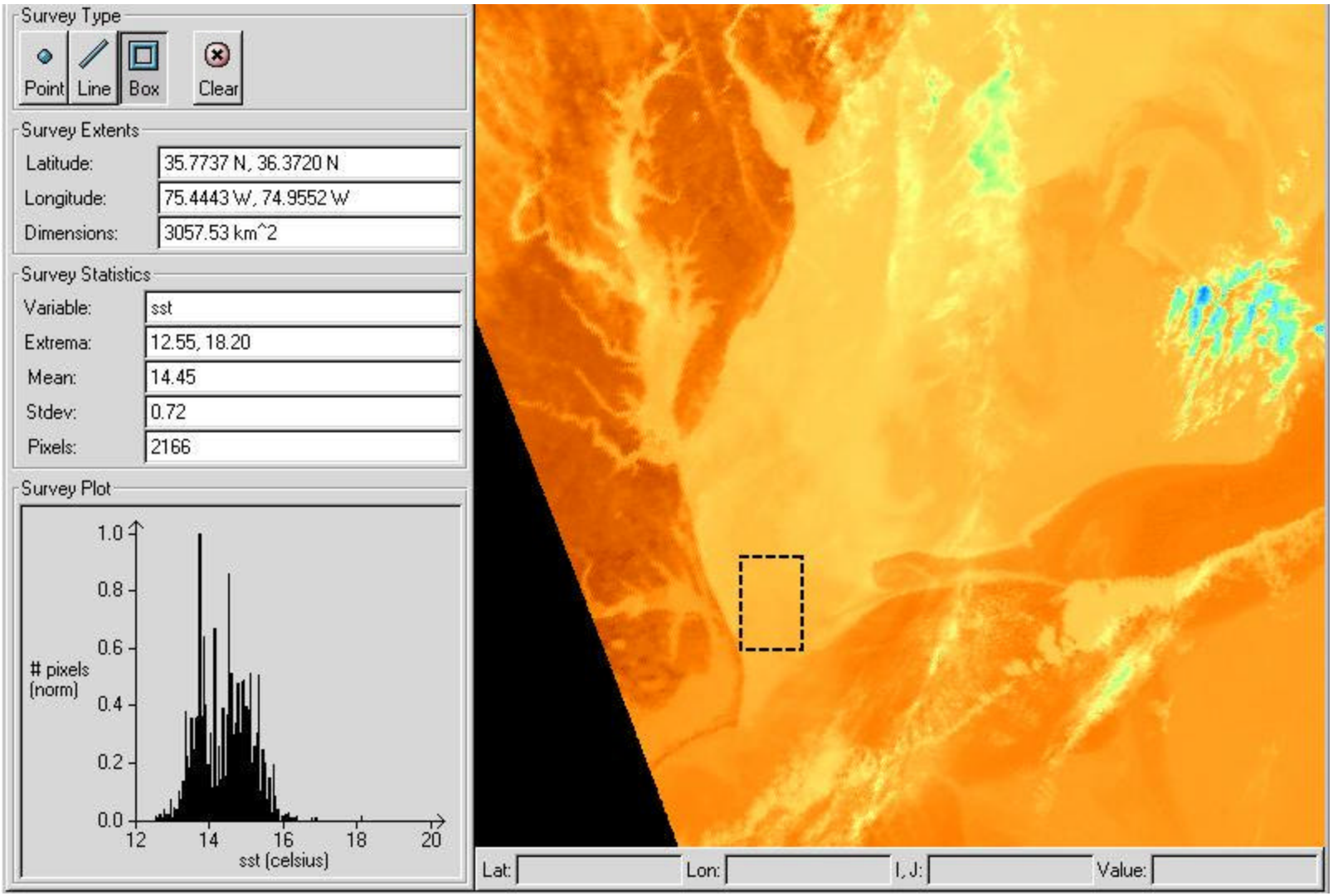

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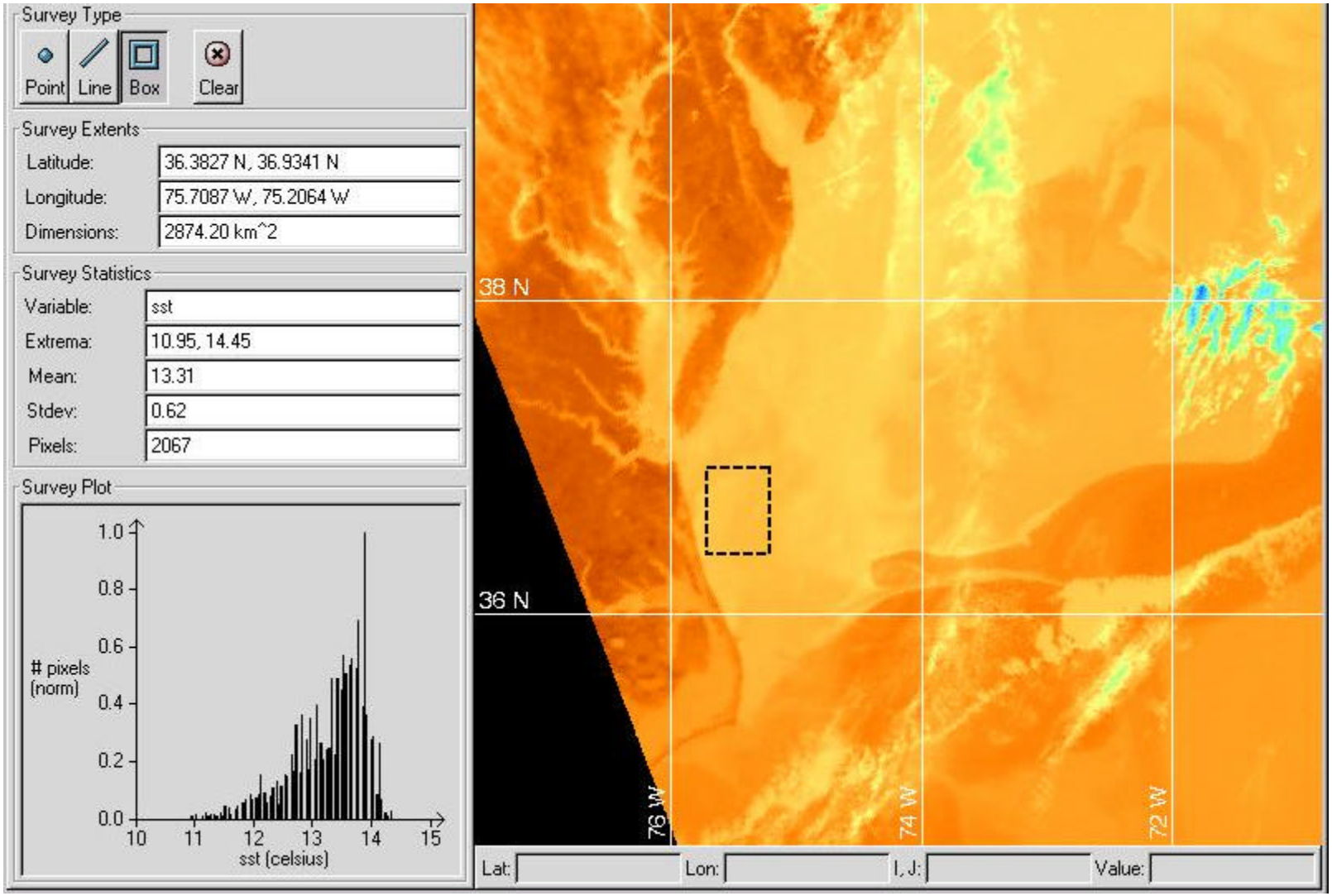

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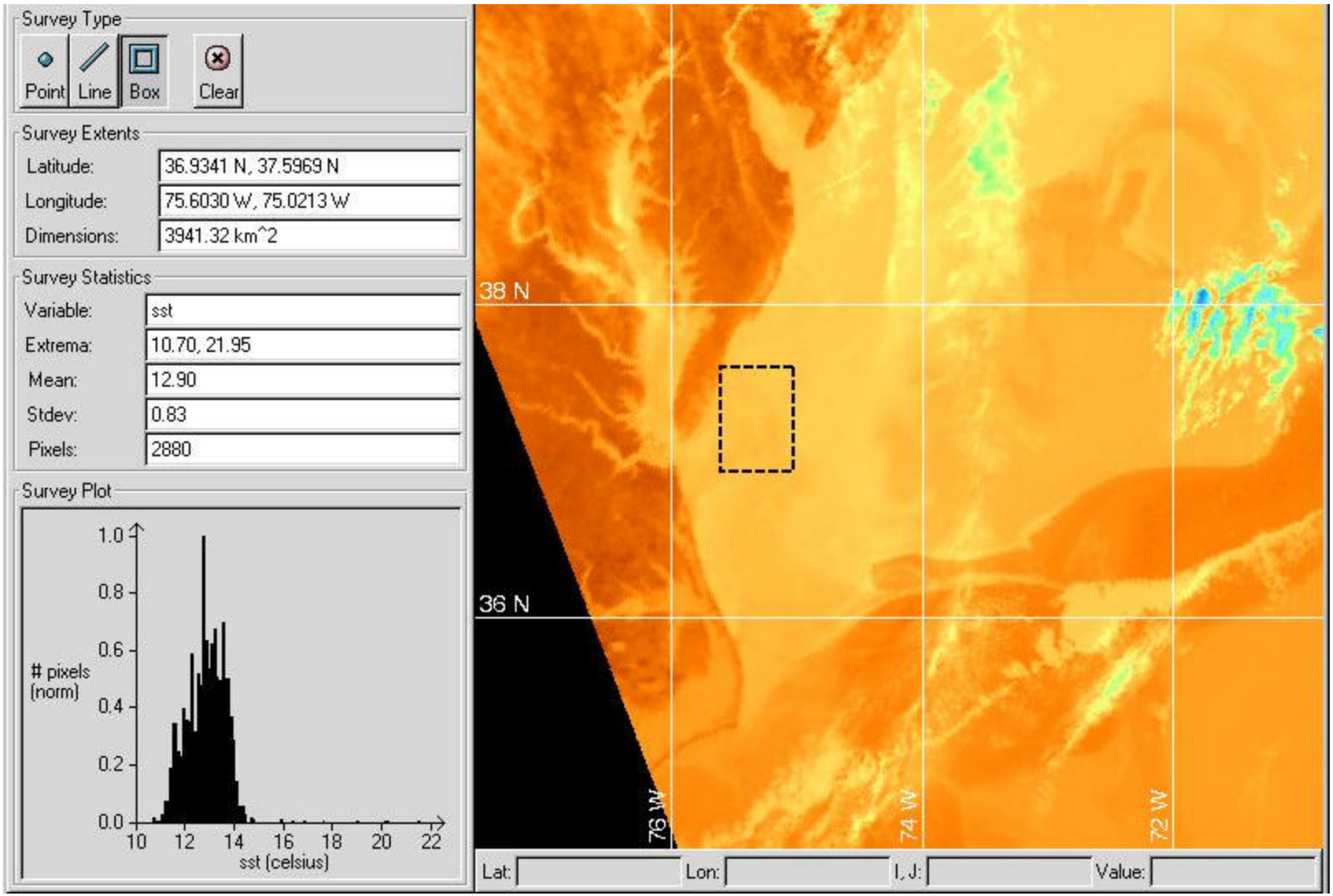

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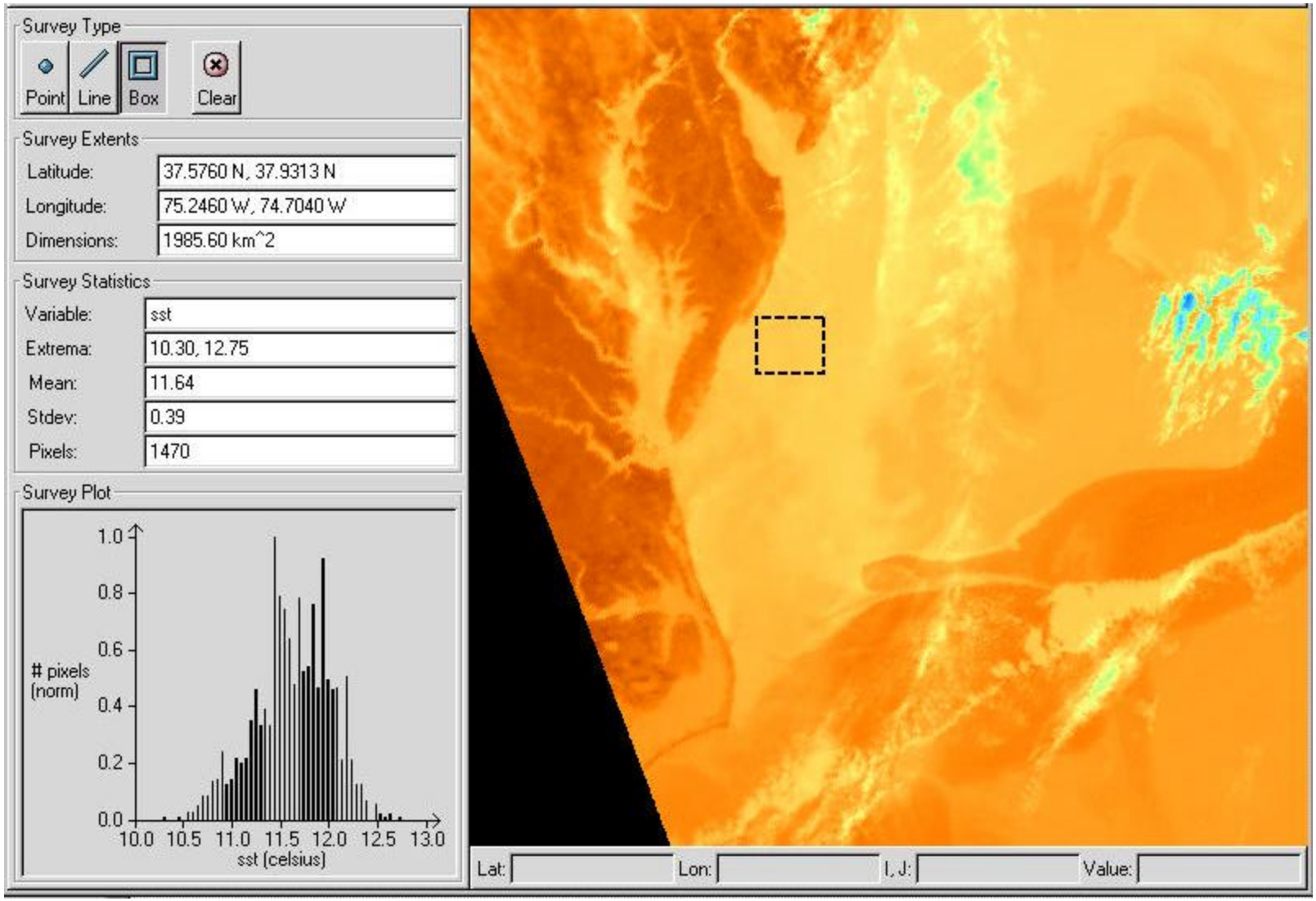
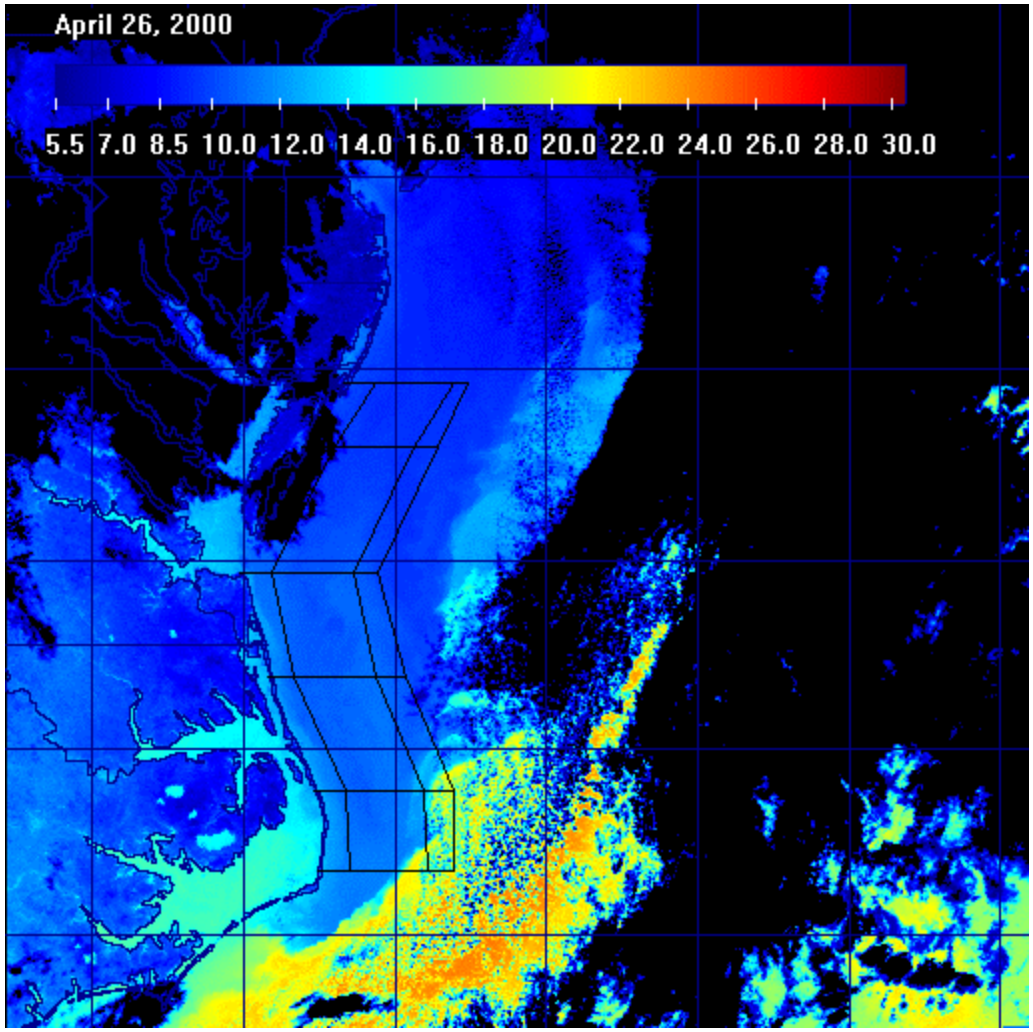


April 26, 2000



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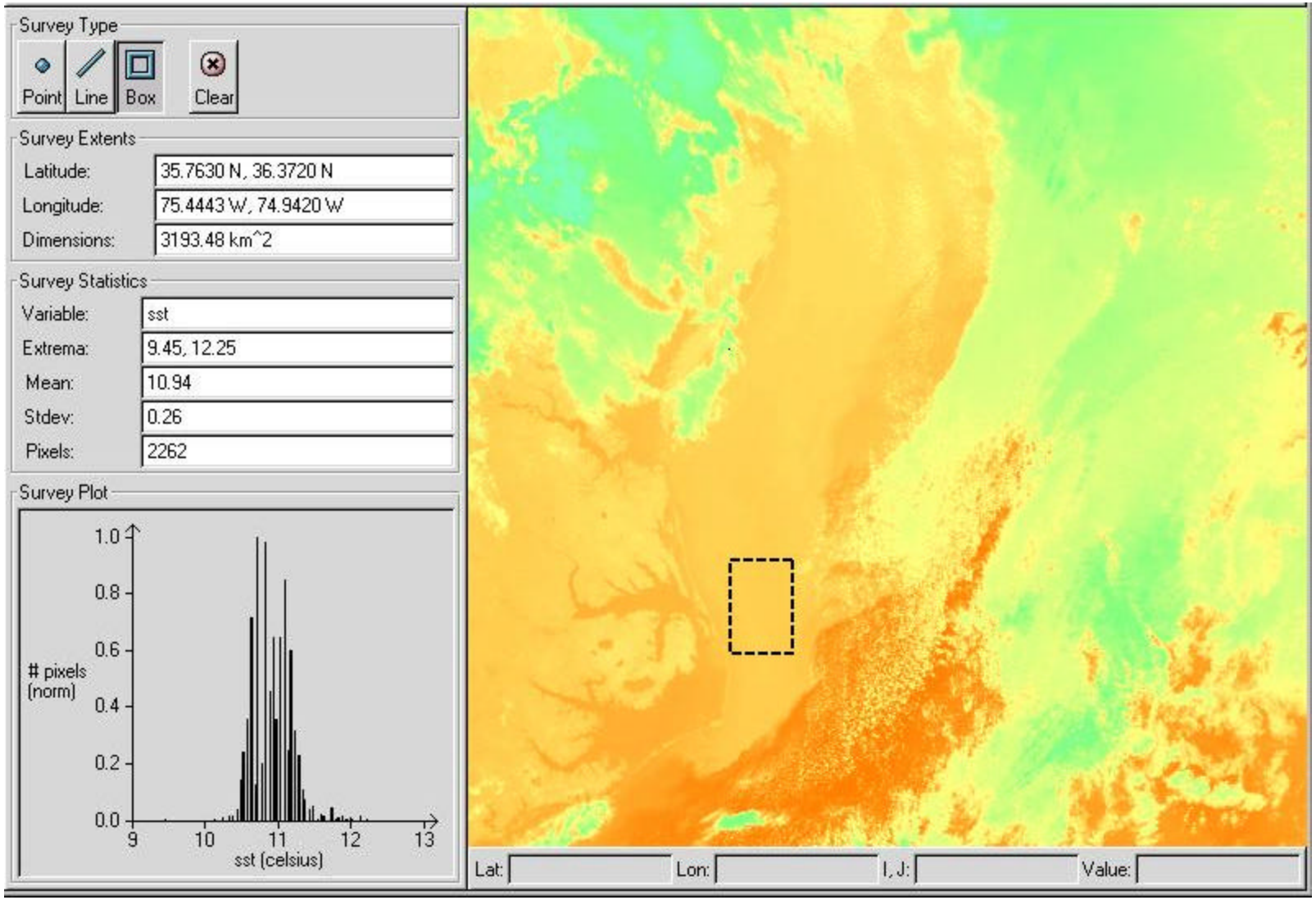

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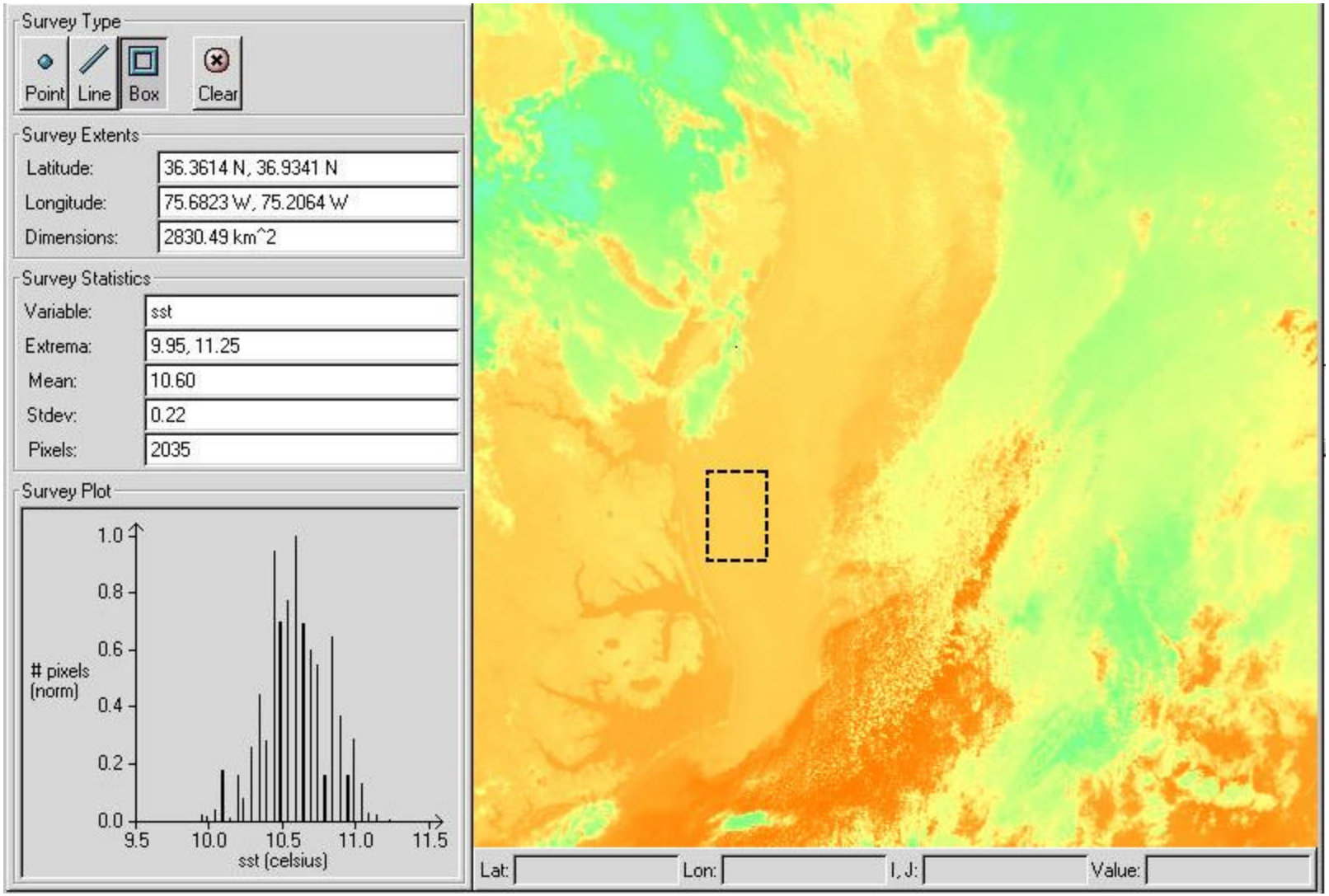

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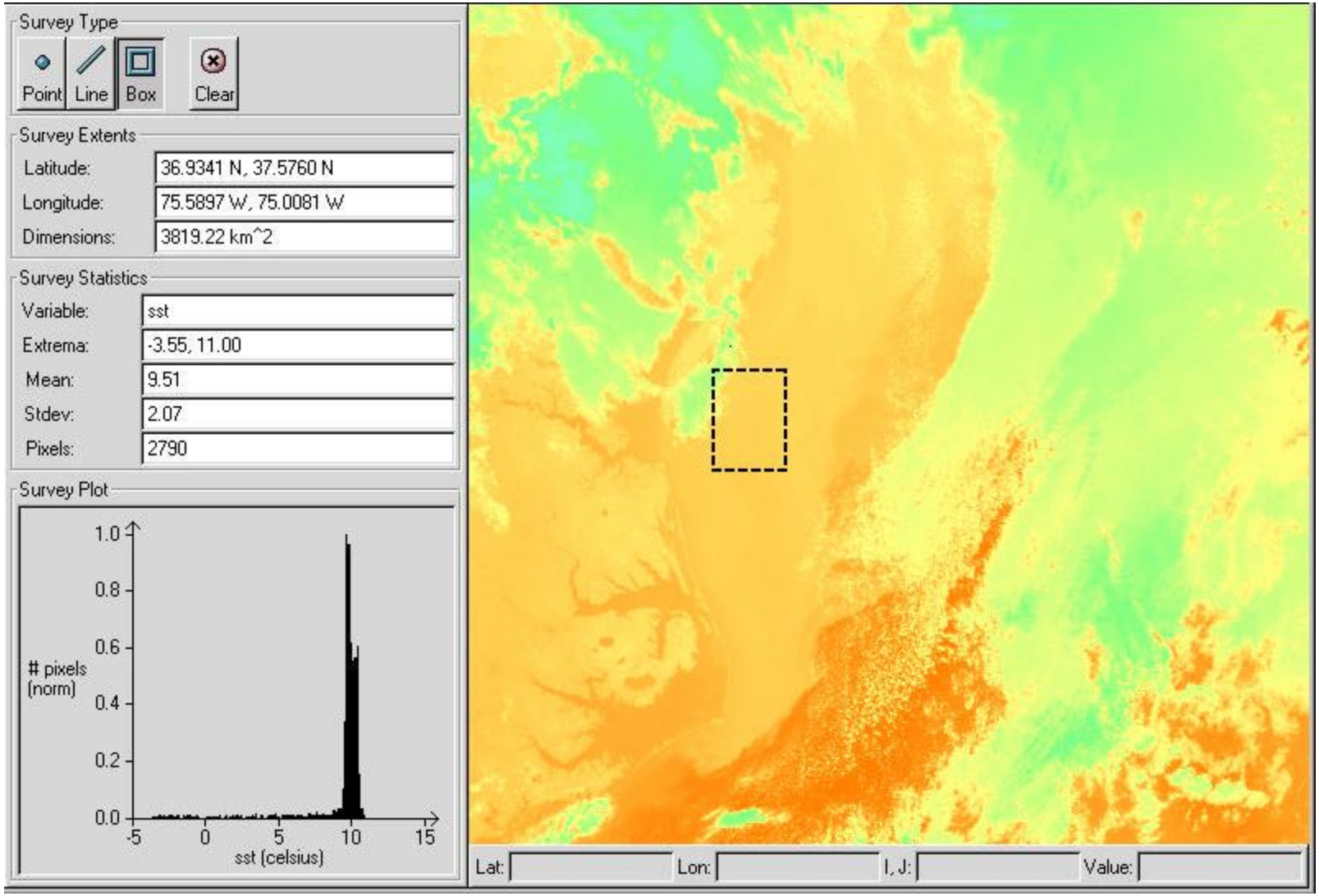
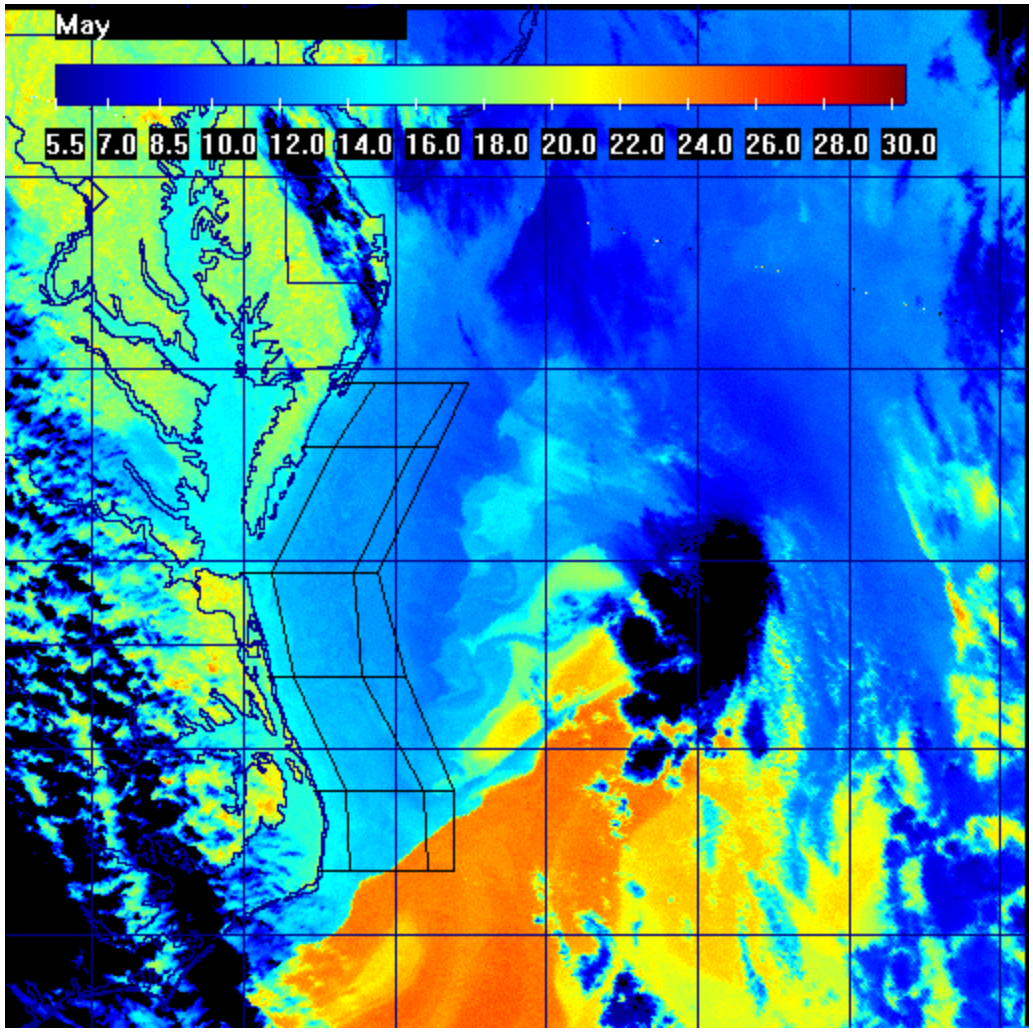


May 5, 1999



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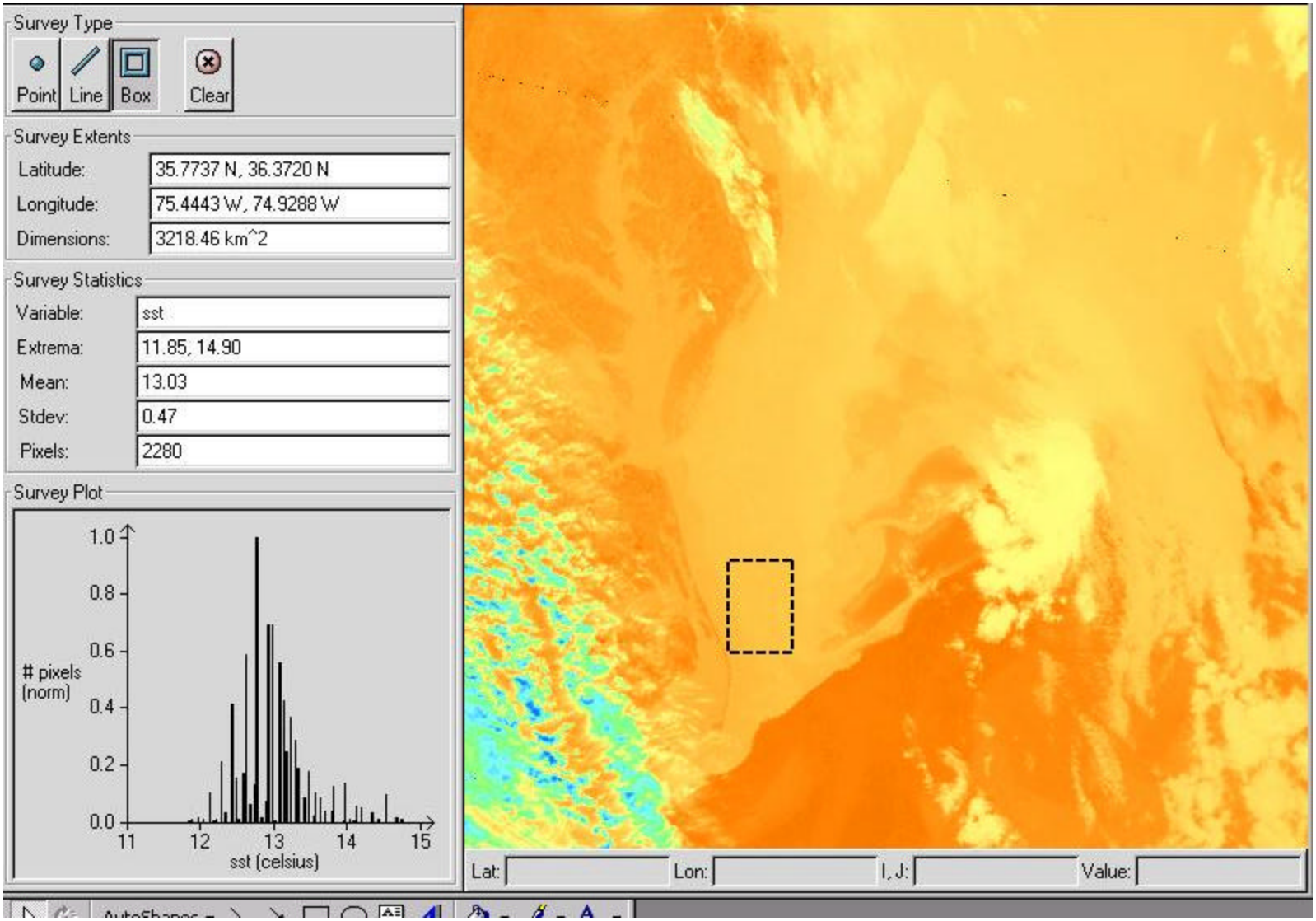

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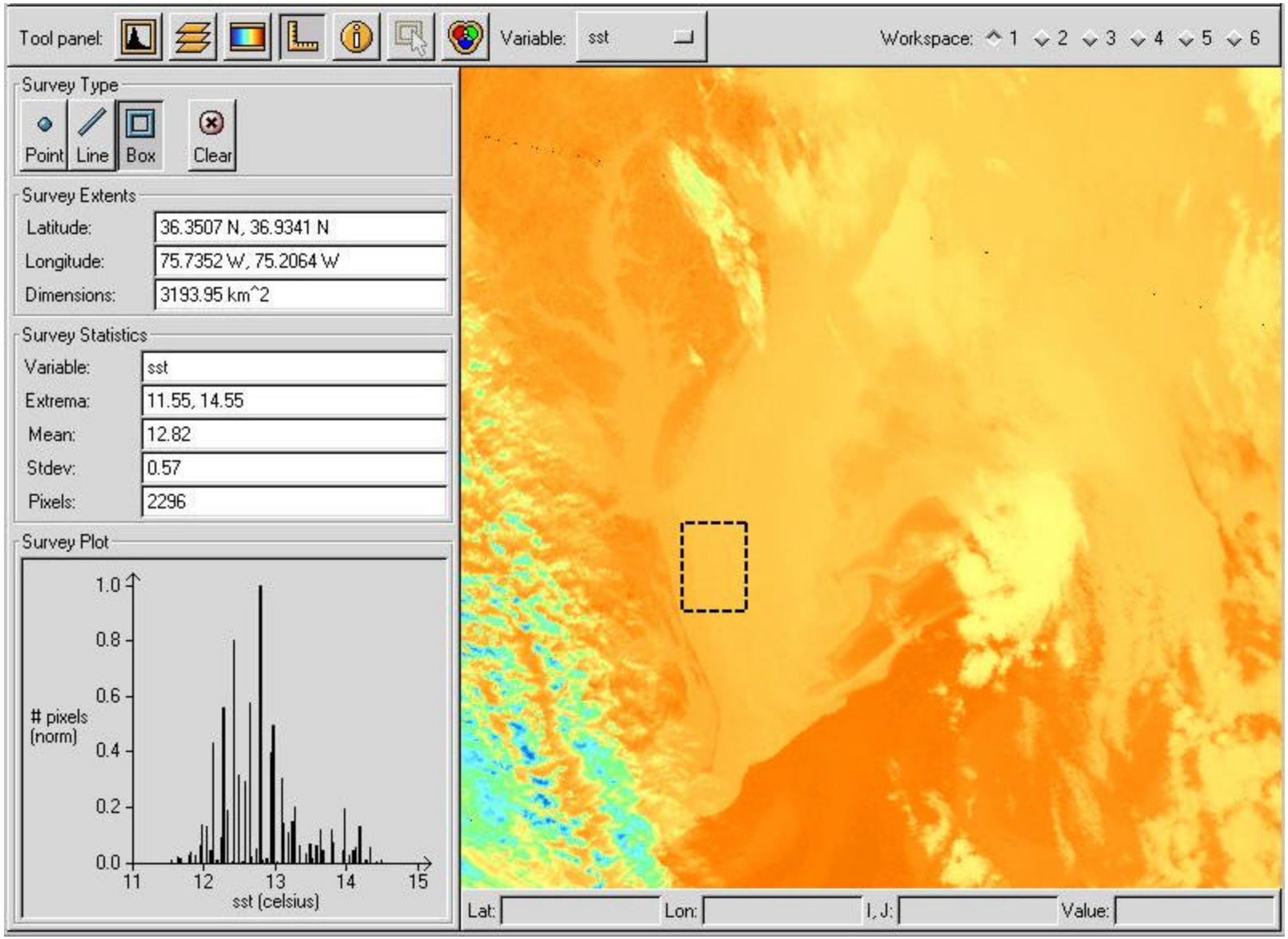

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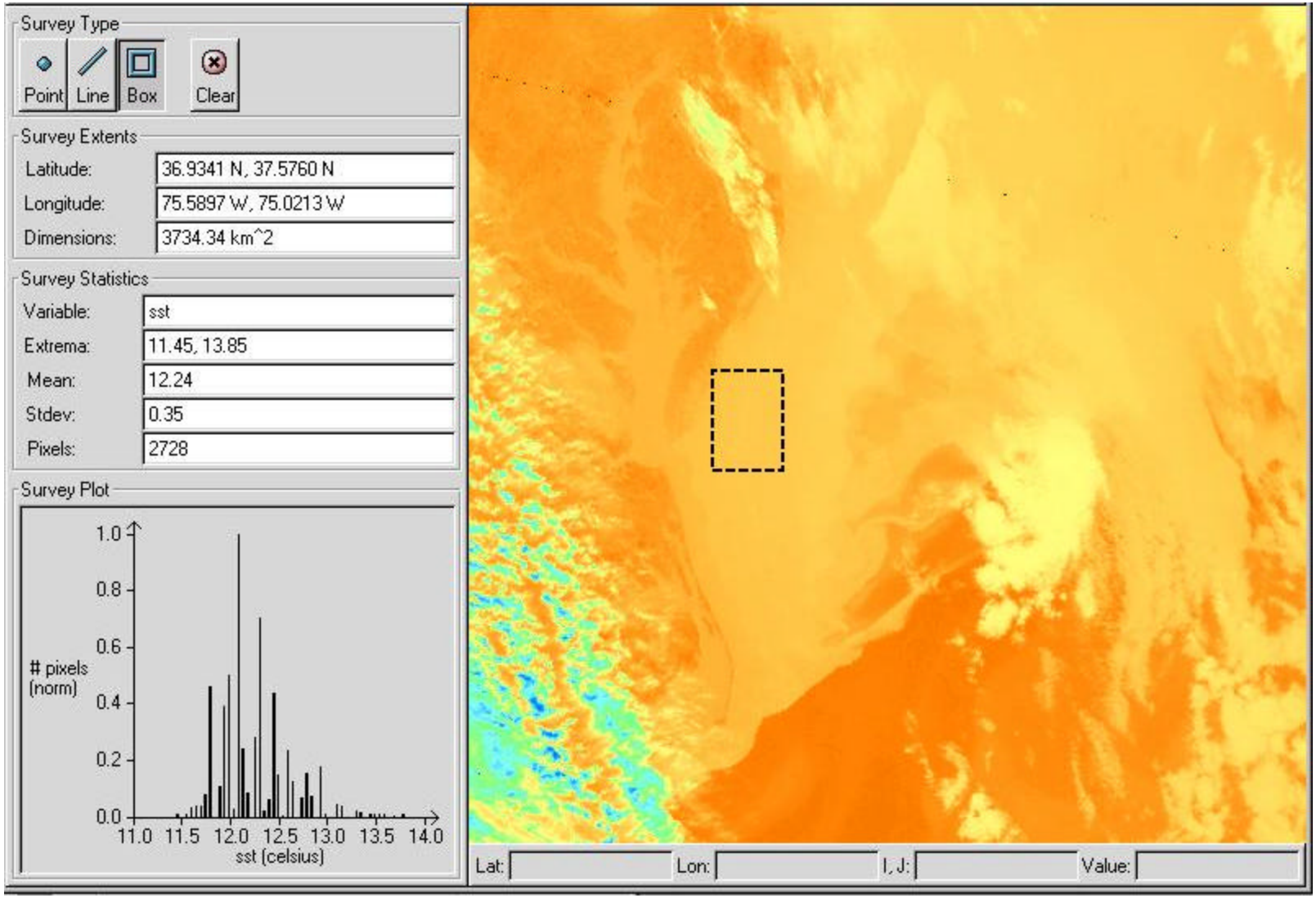

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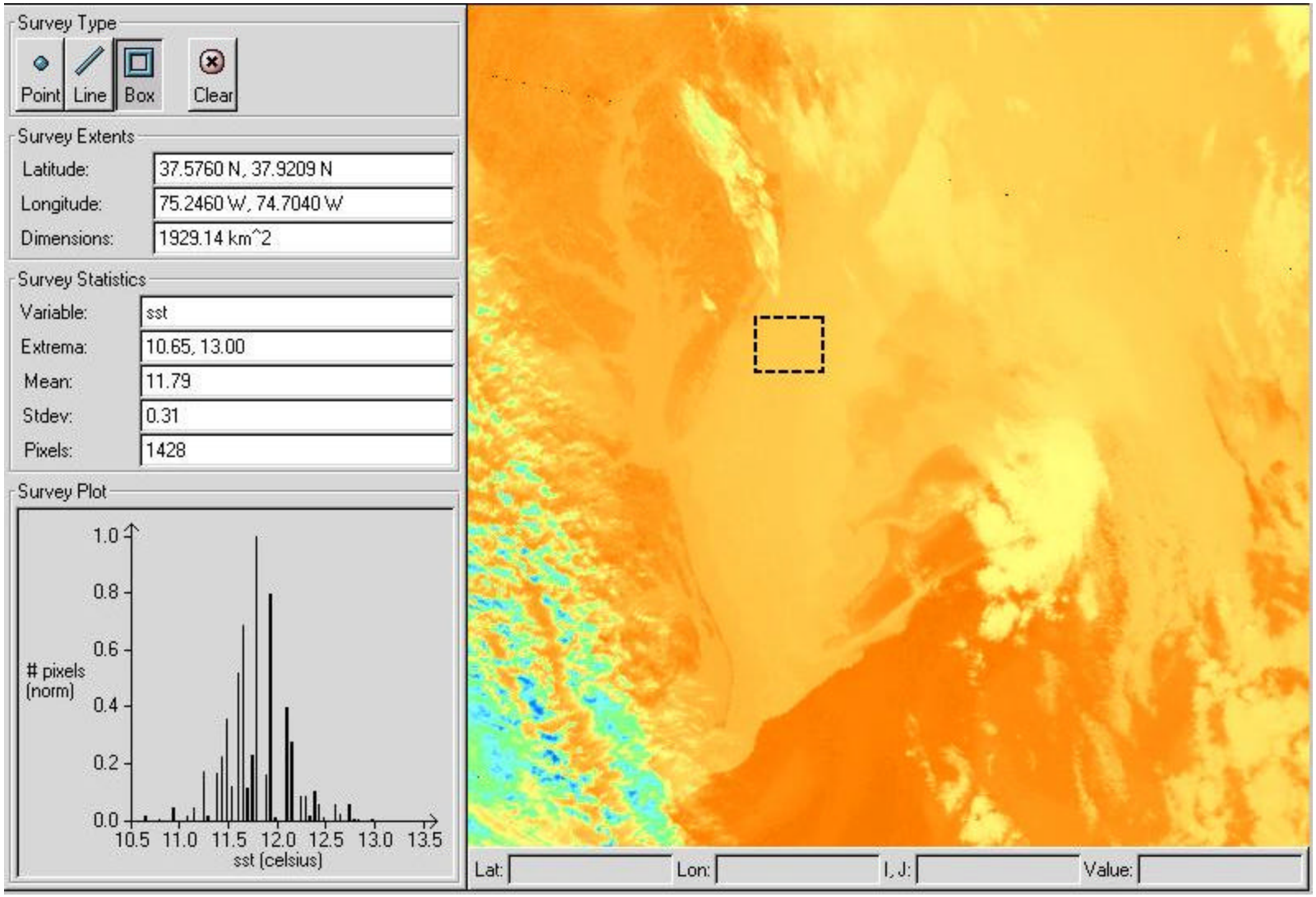

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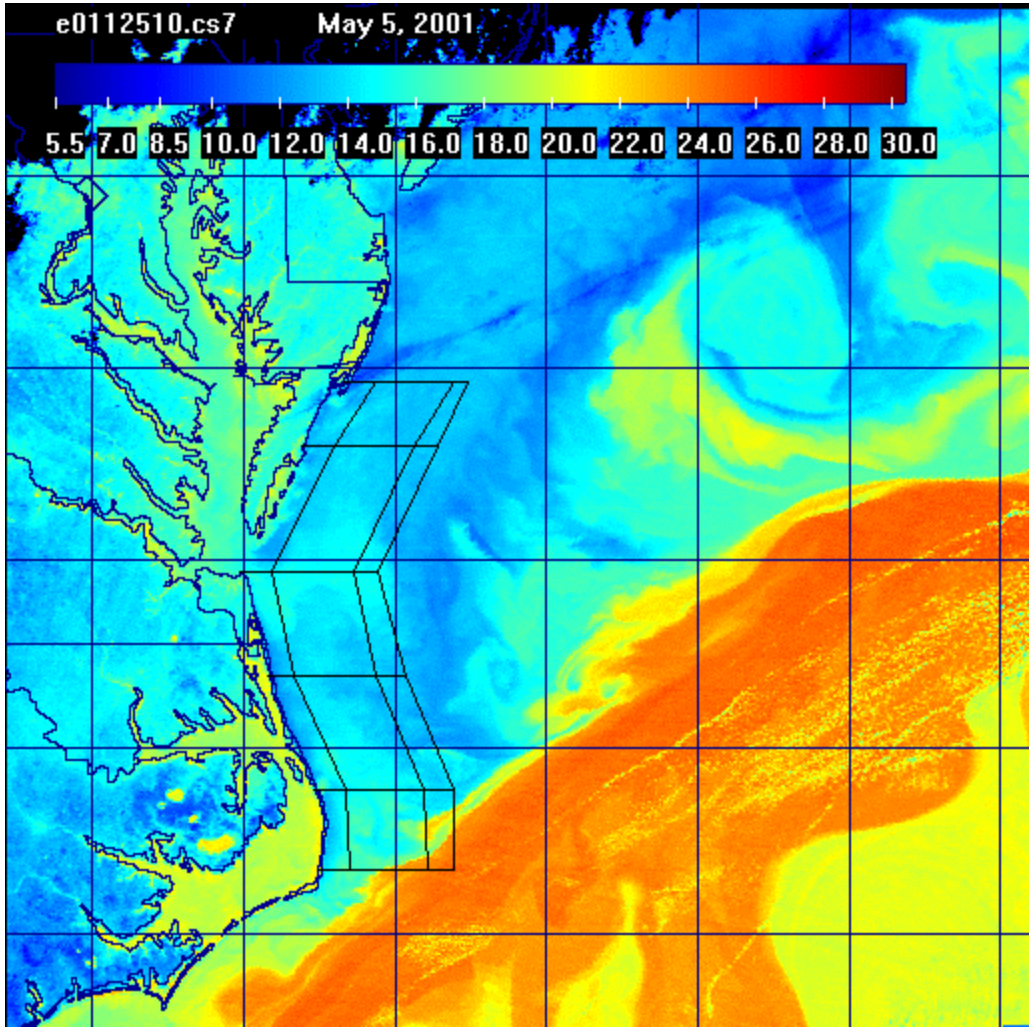
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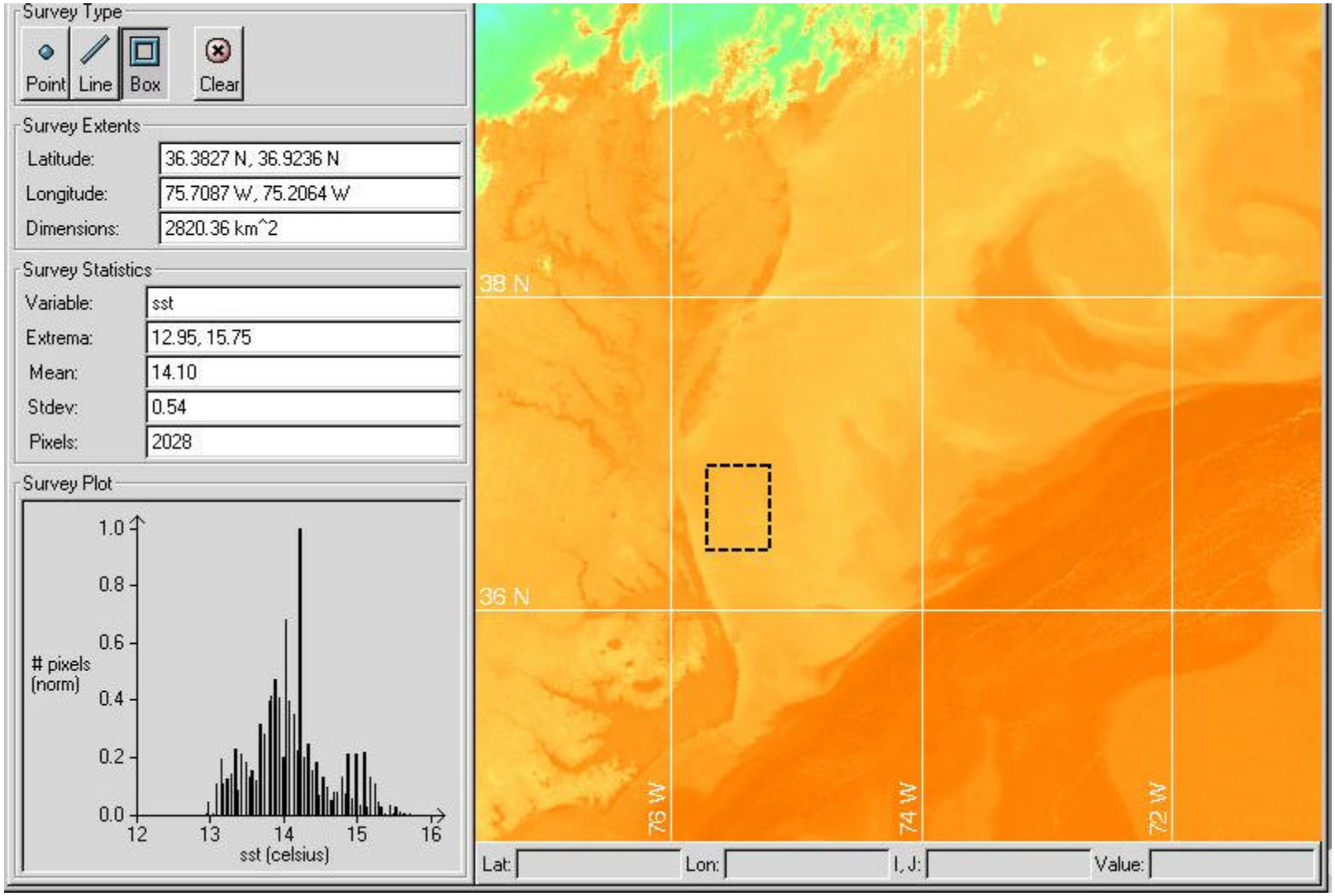

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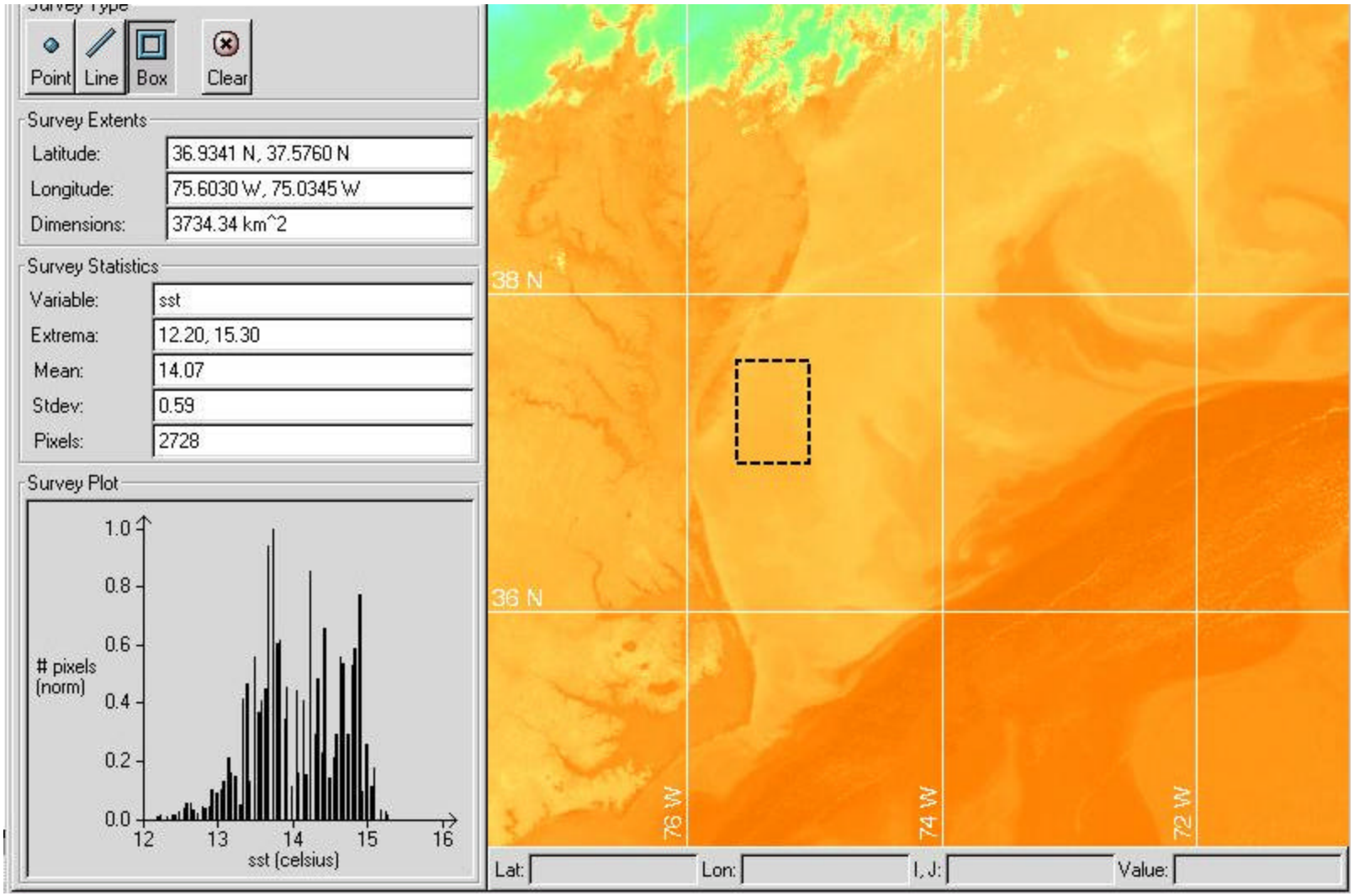

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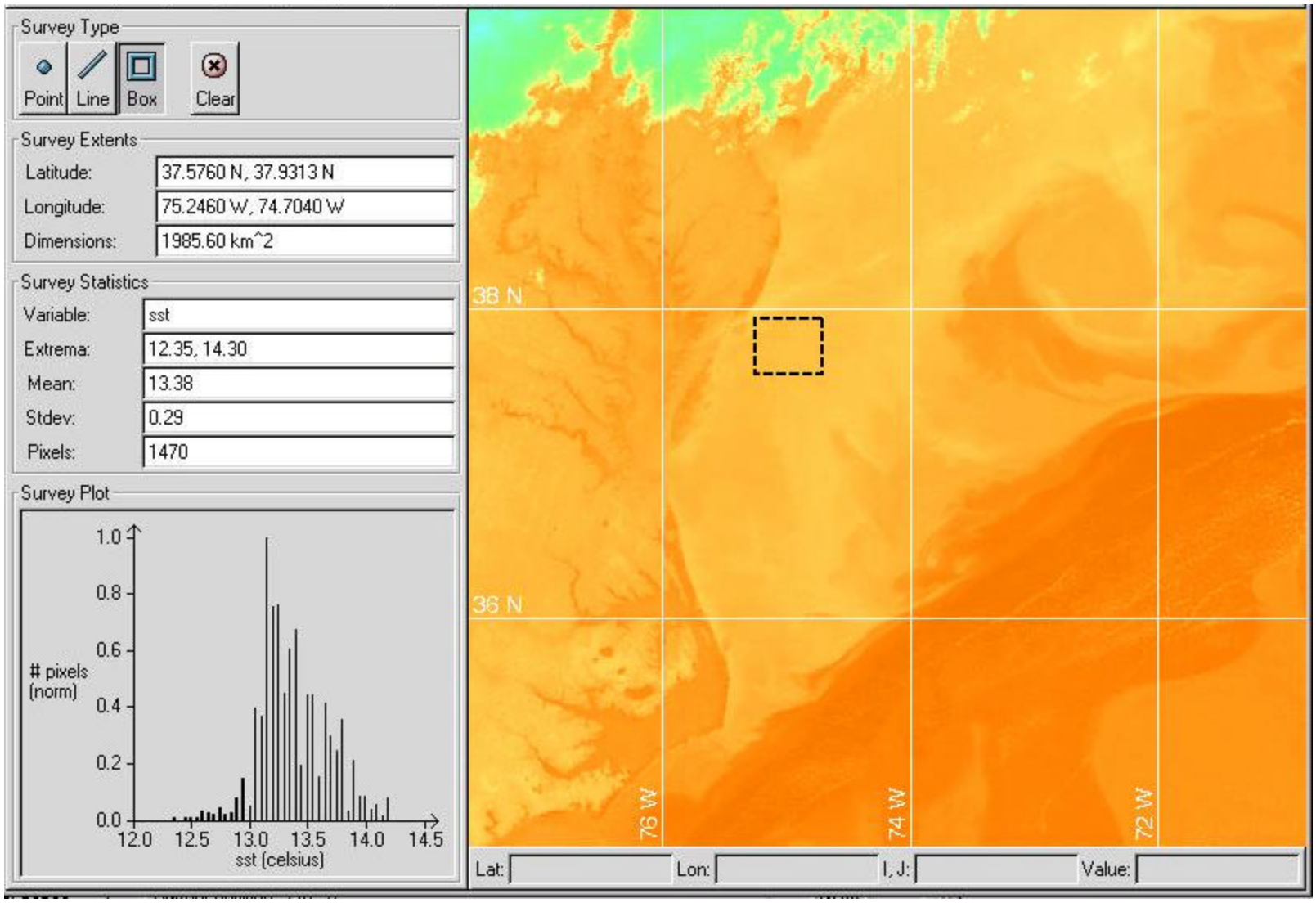

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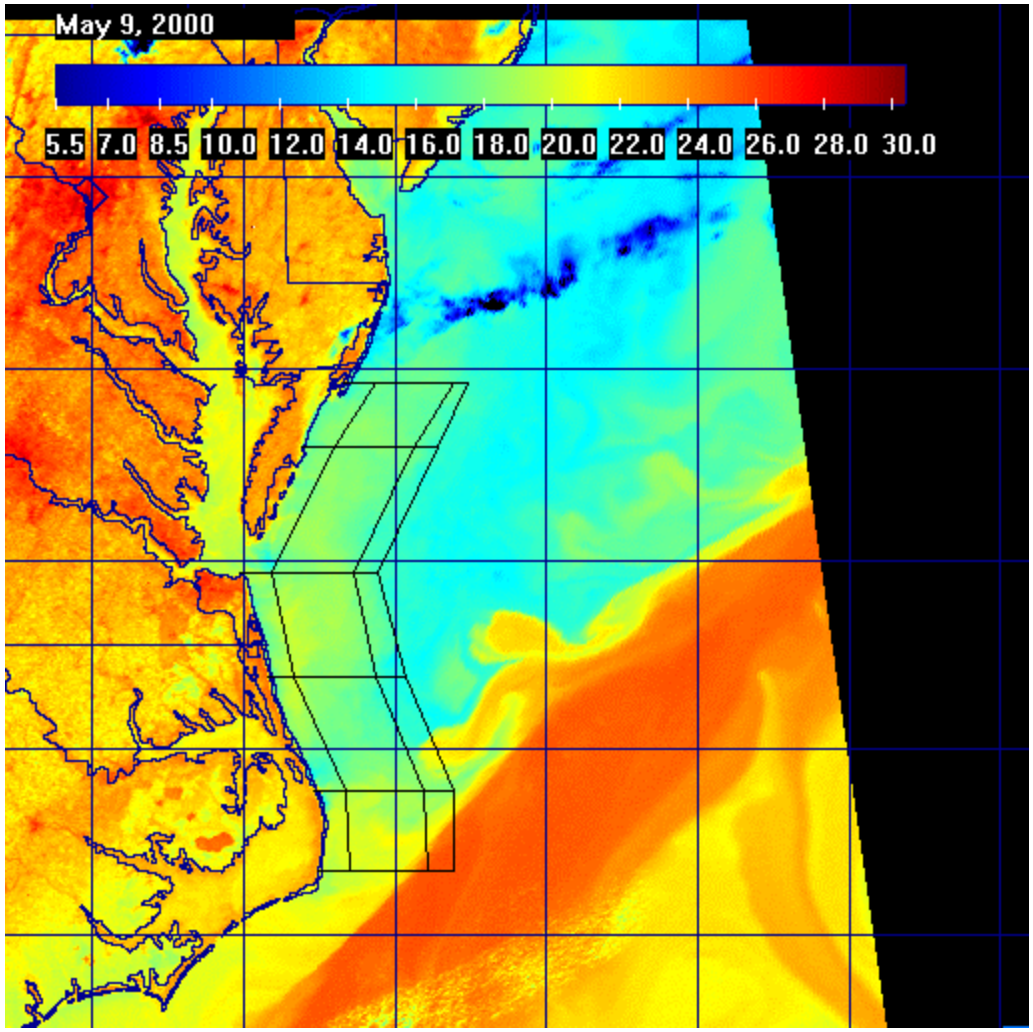

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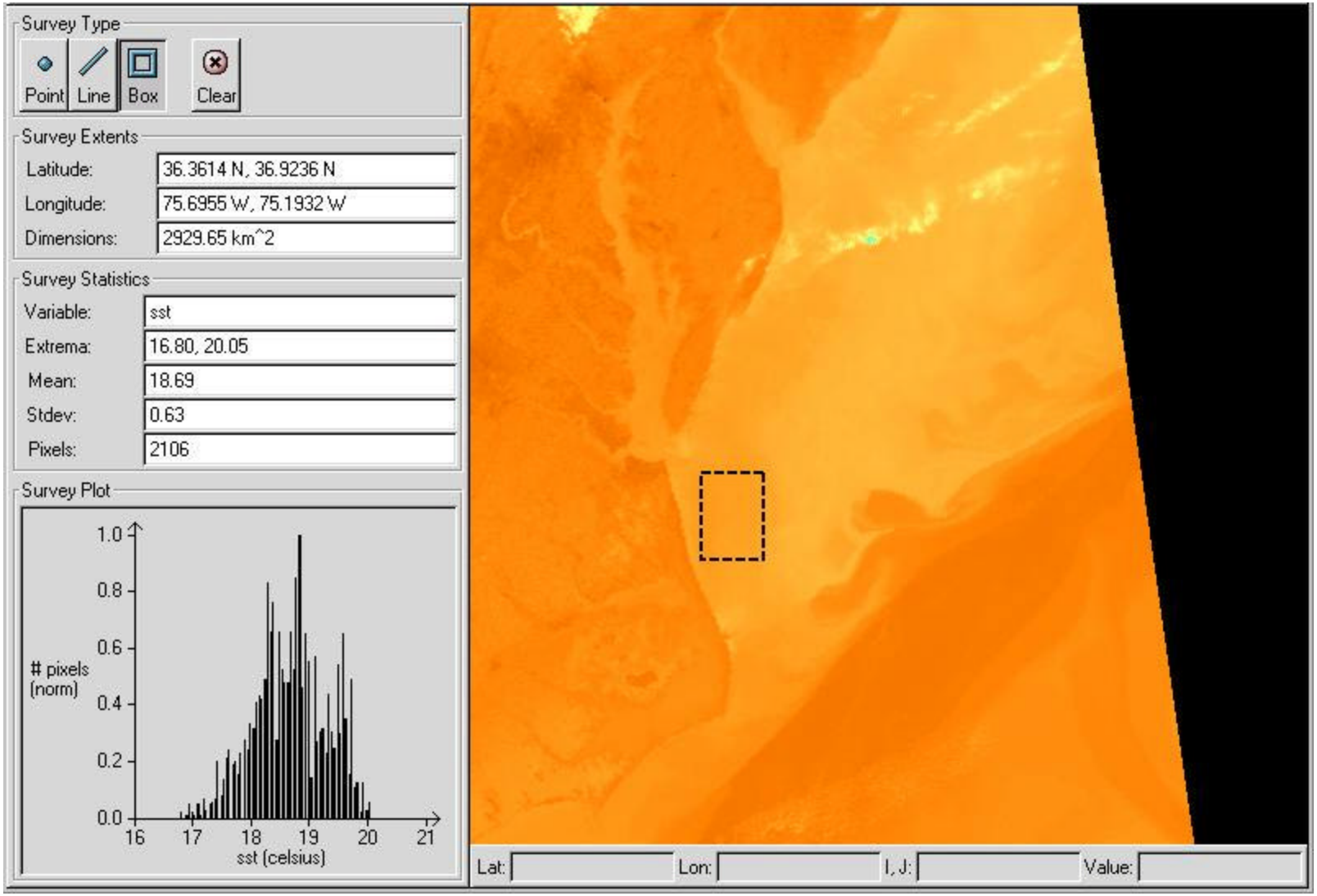

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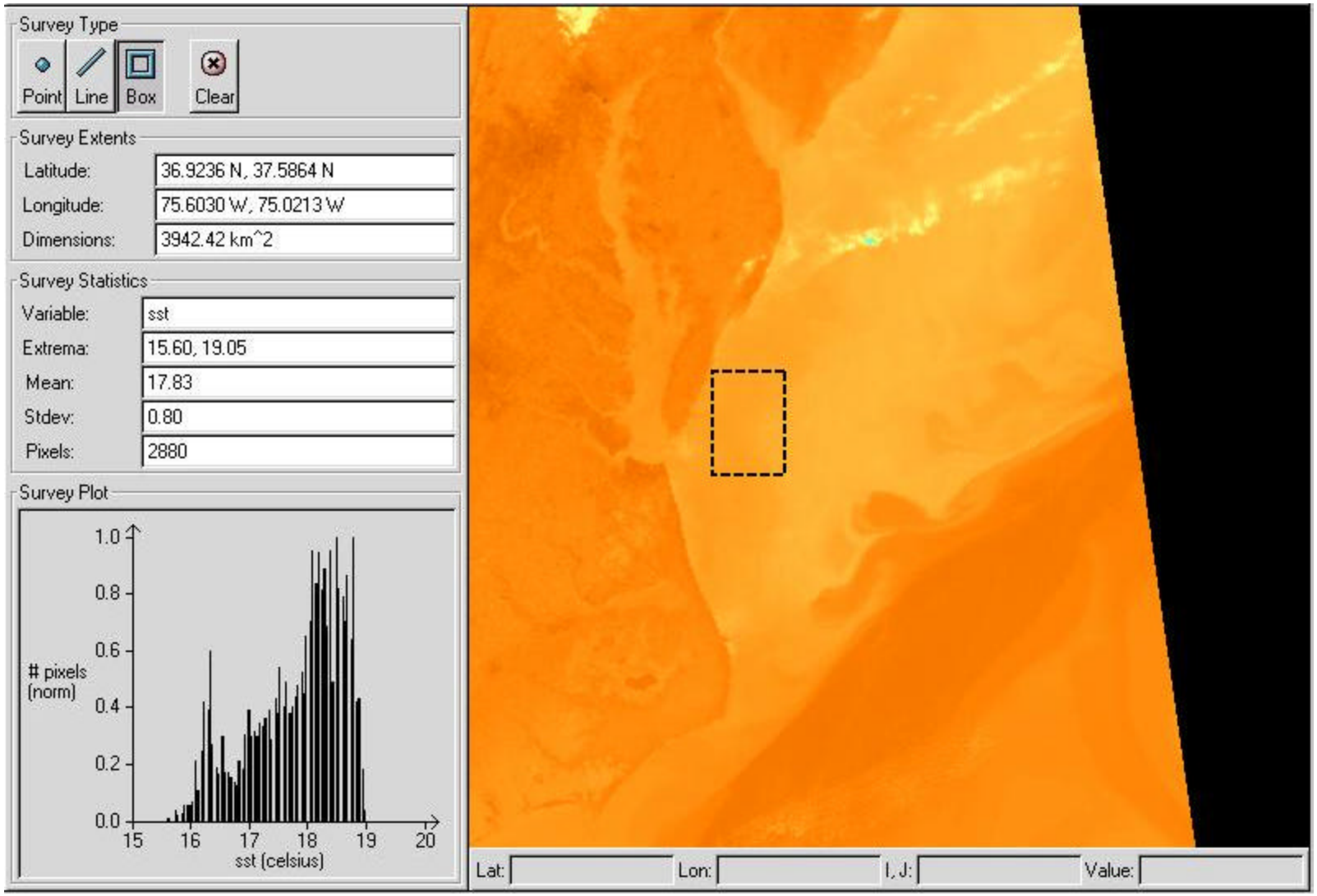

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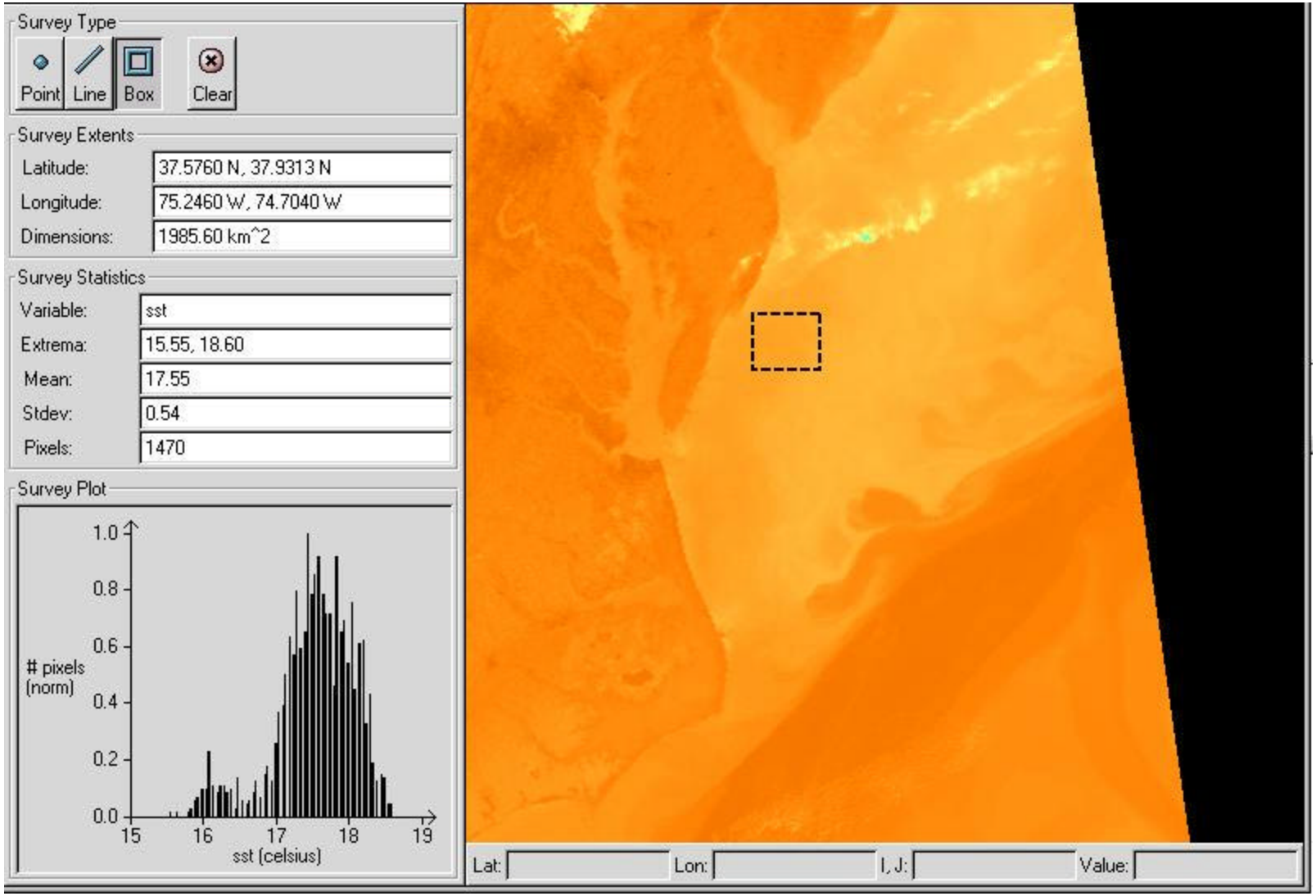

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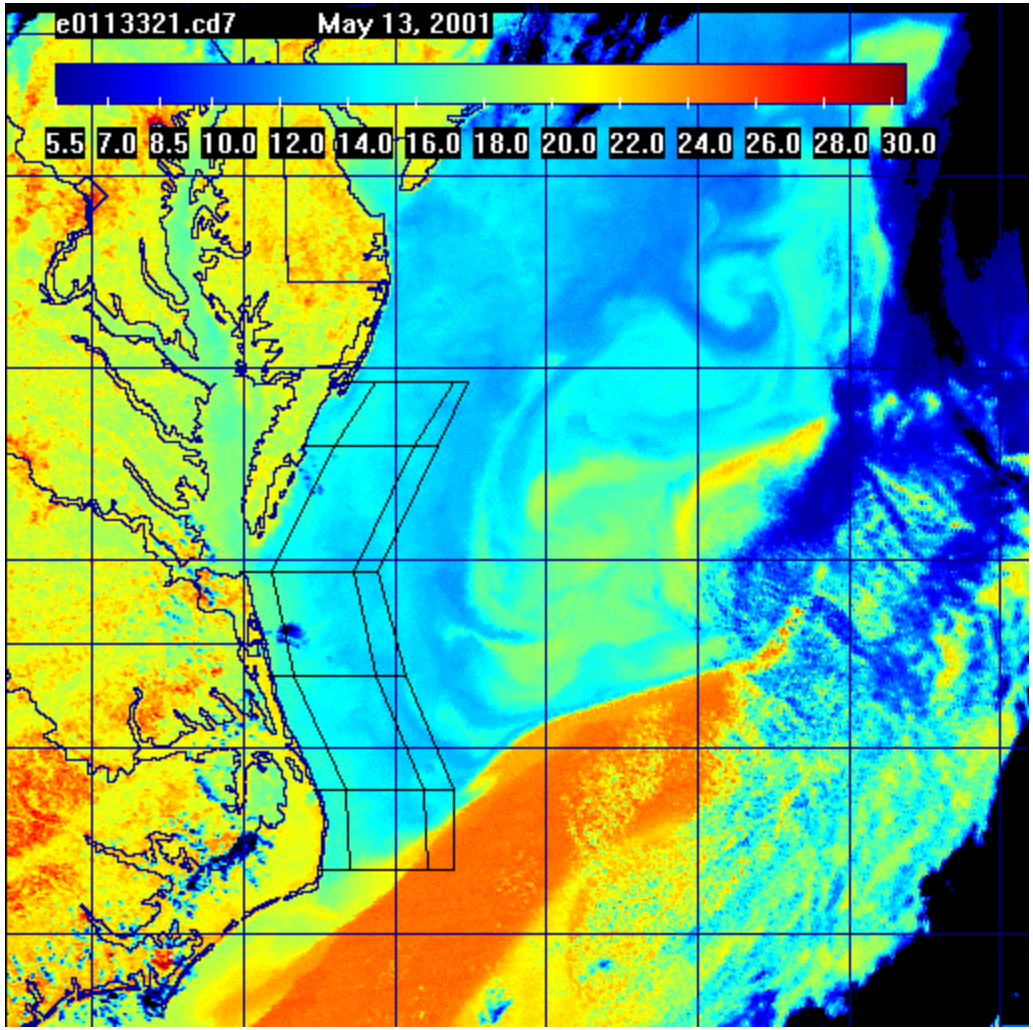
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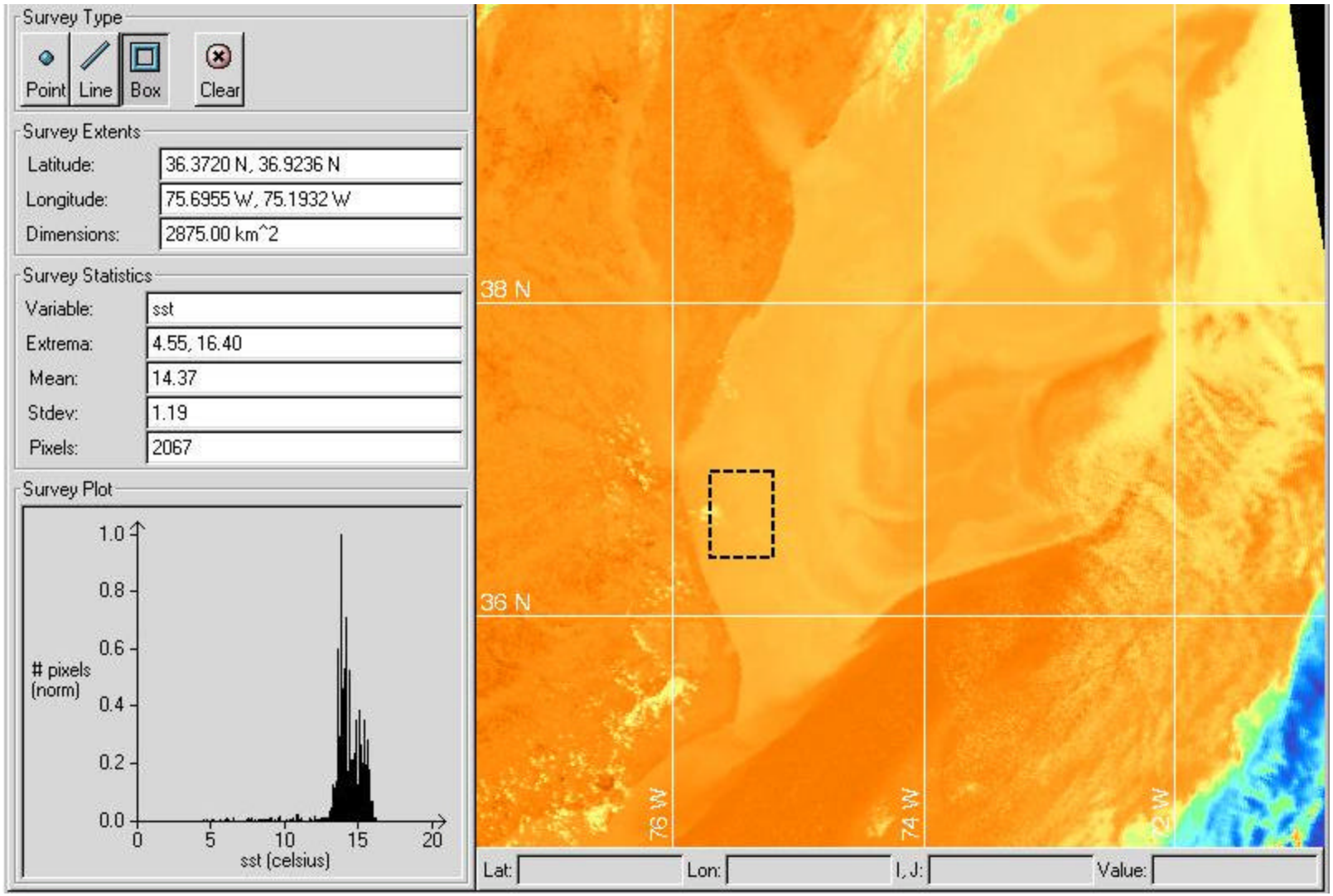
May 13, 2001 - Area 3



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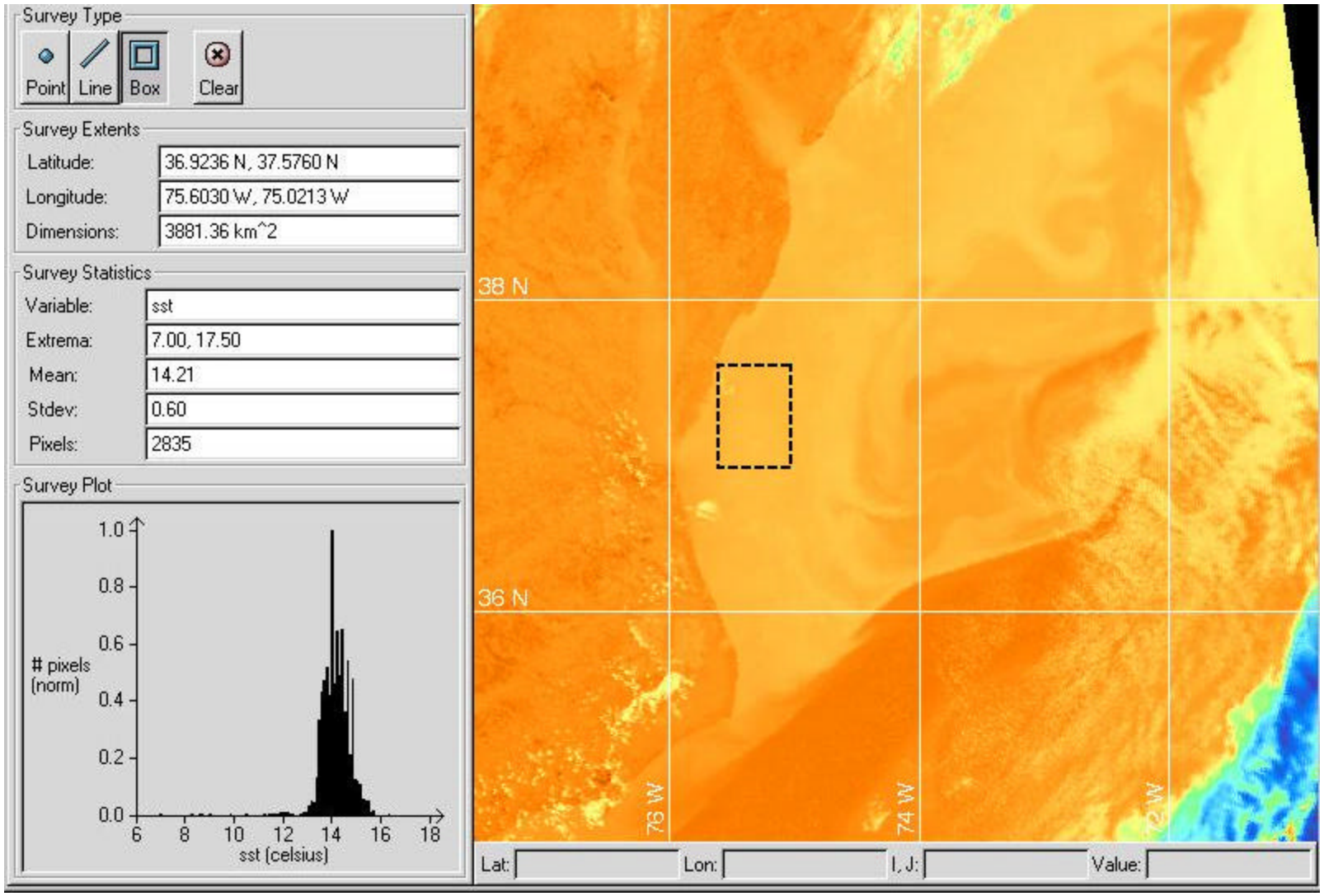

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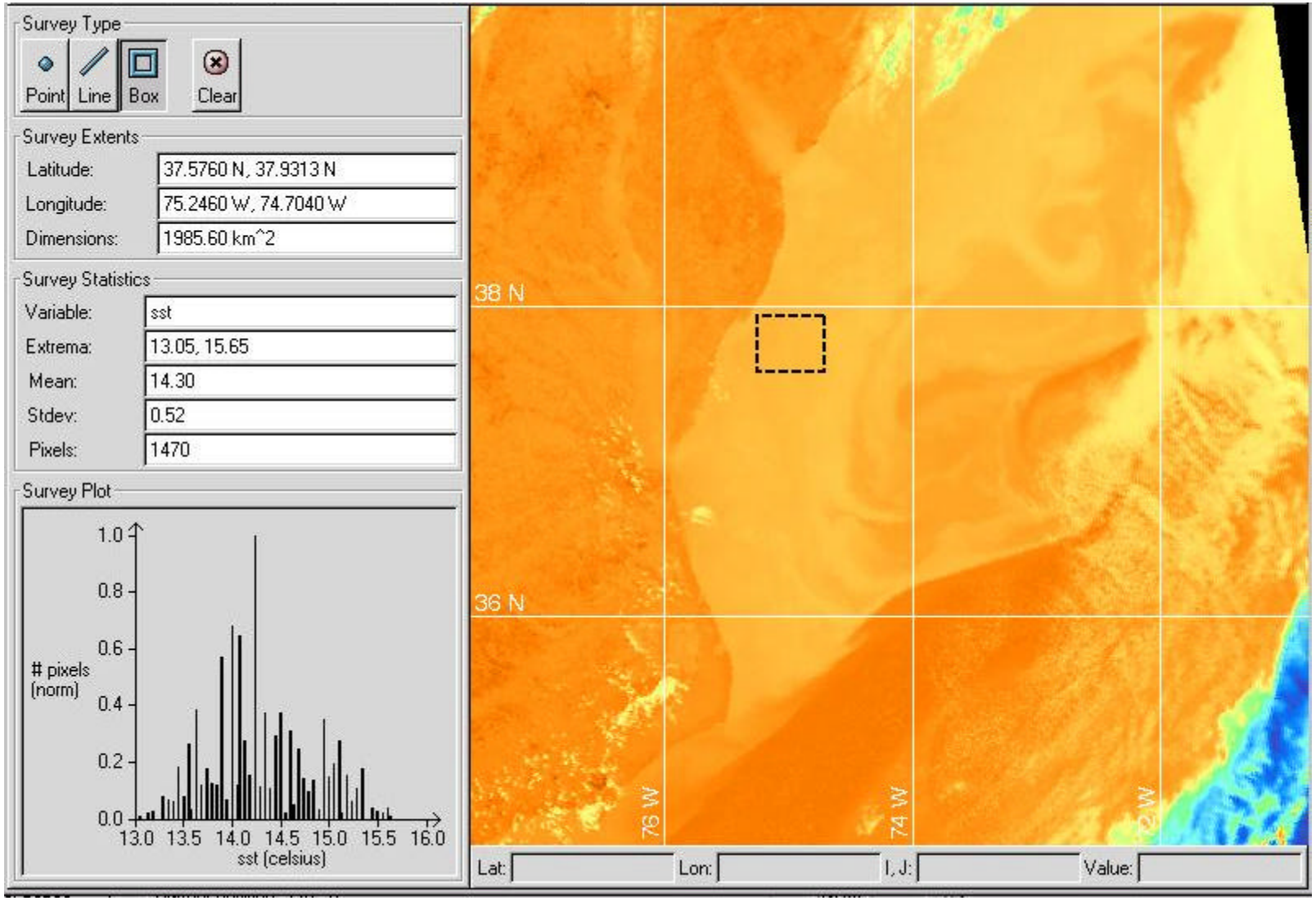
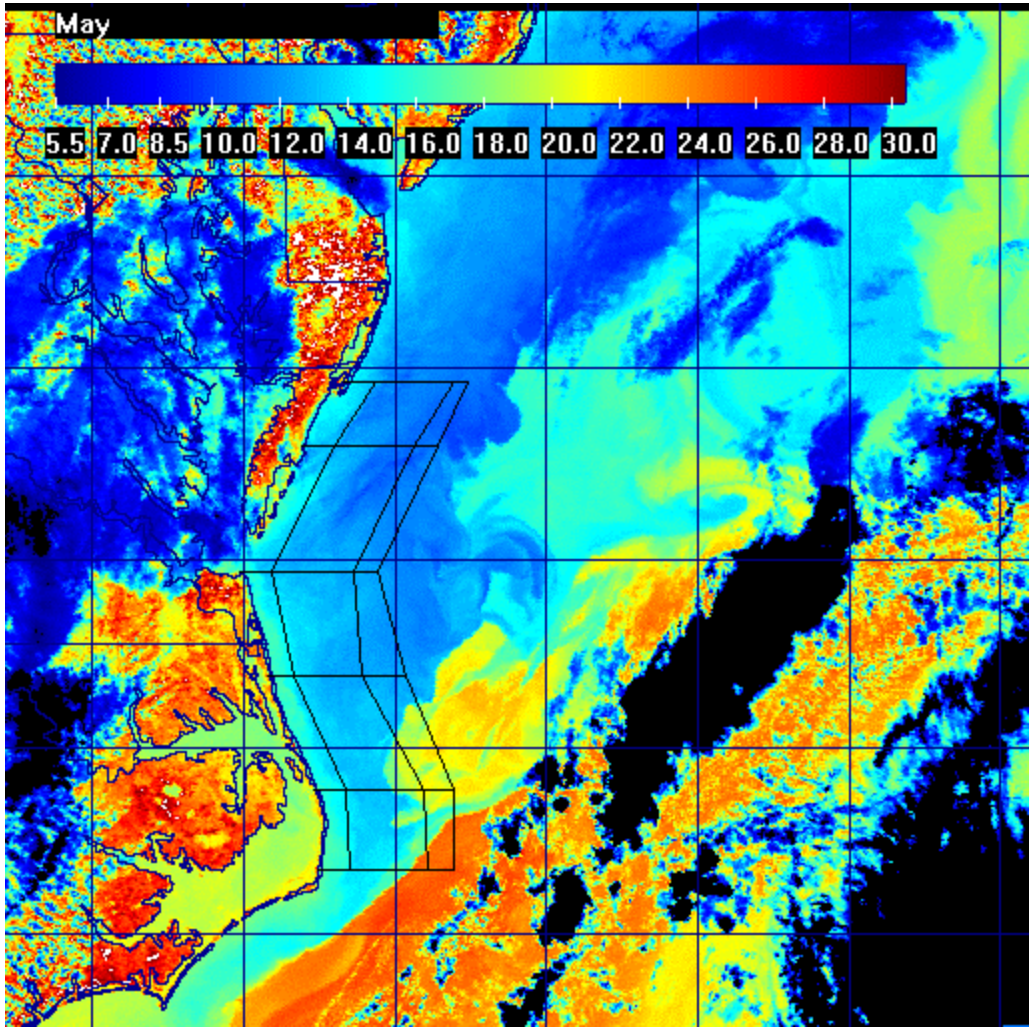
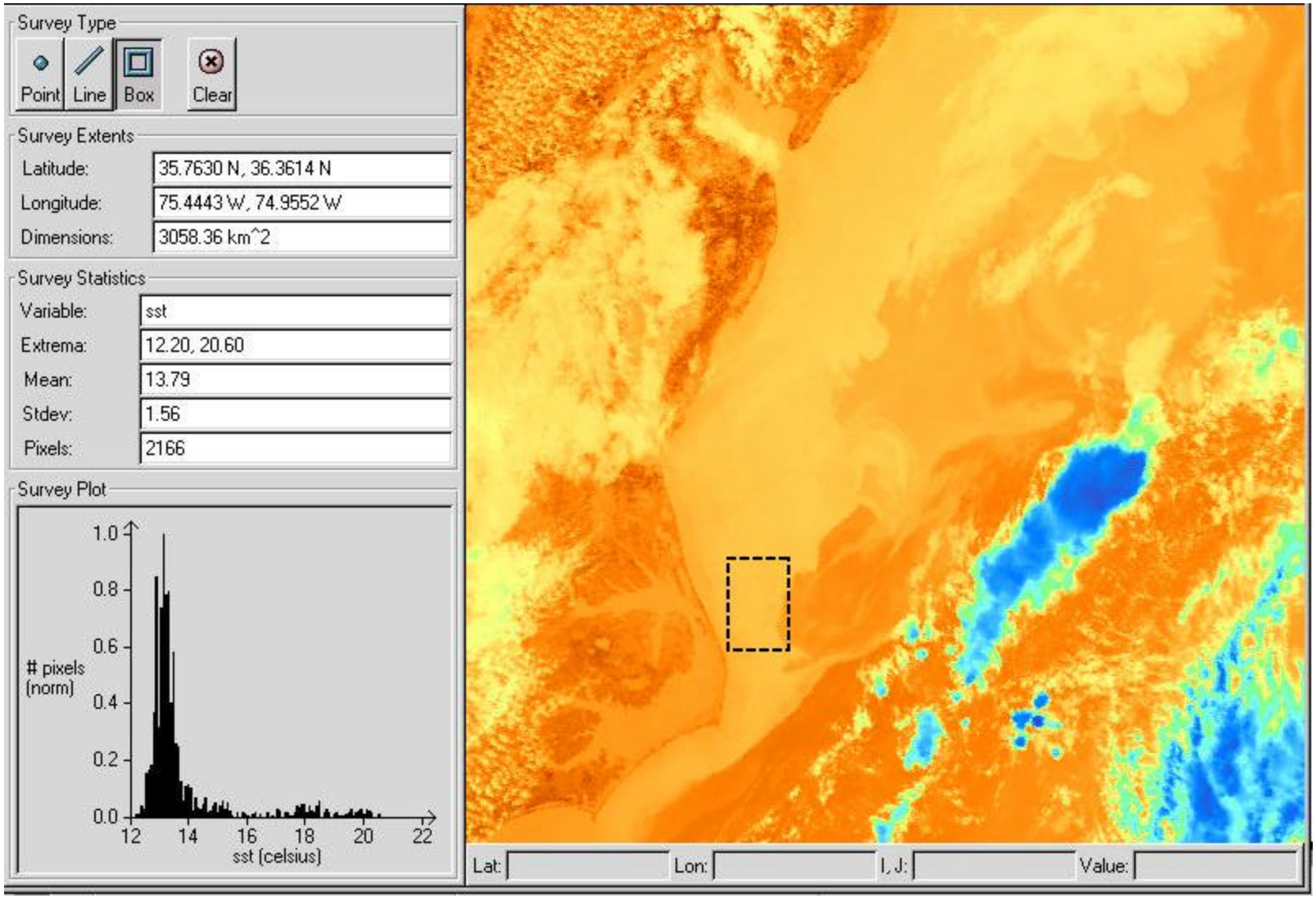


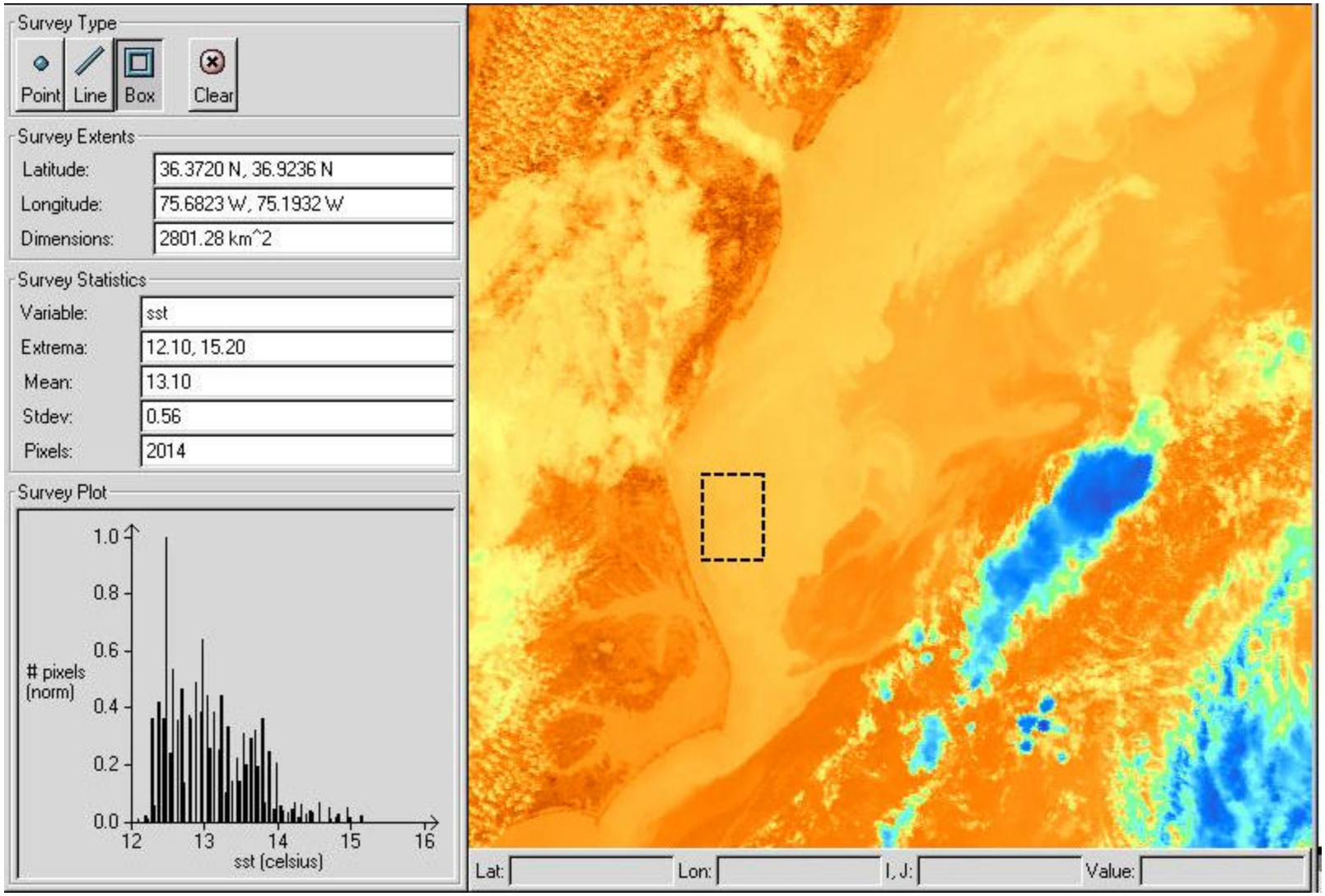
May 17, 1999



May 17, 1999 - Area 2



May 17, 1999 - Area 3



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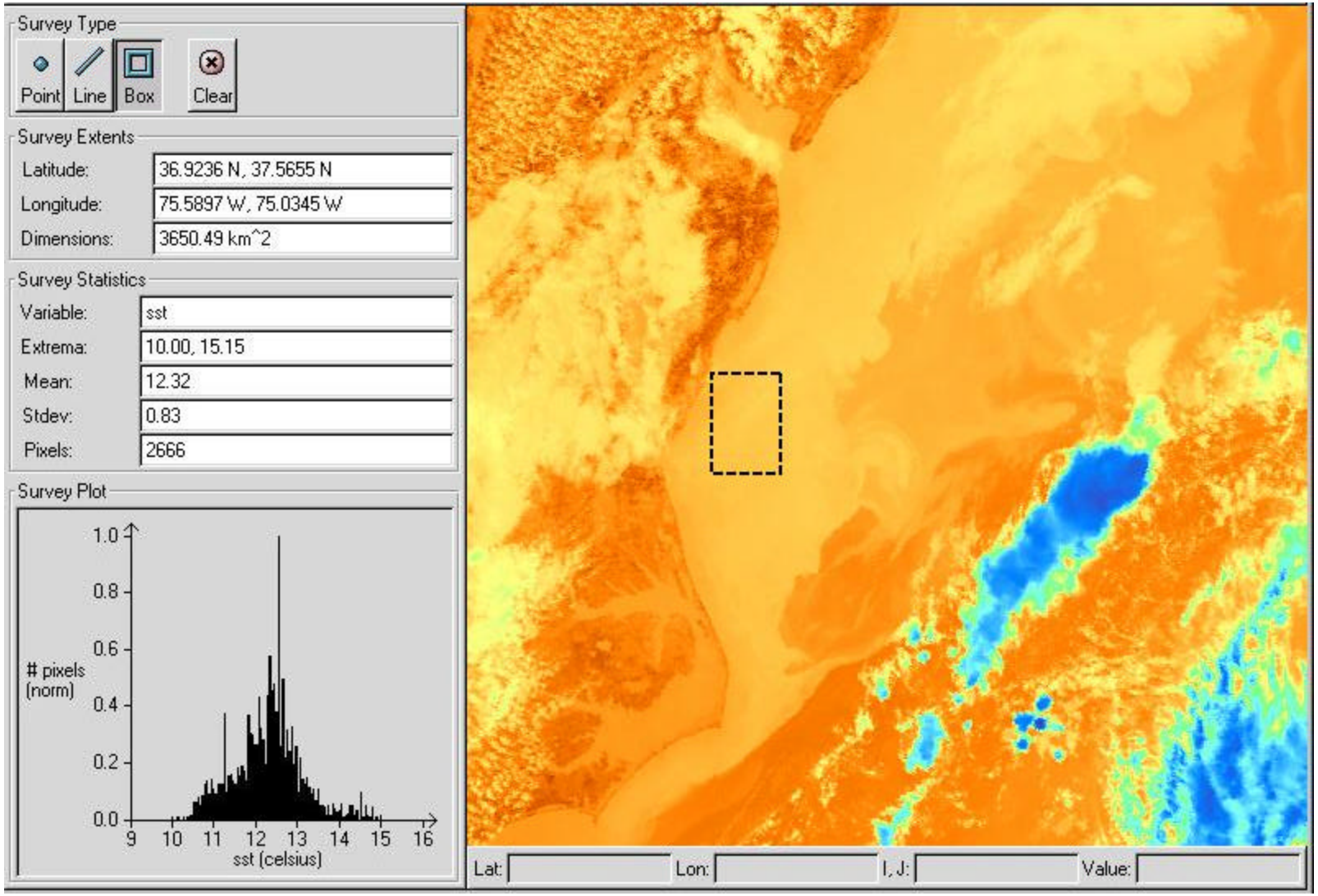
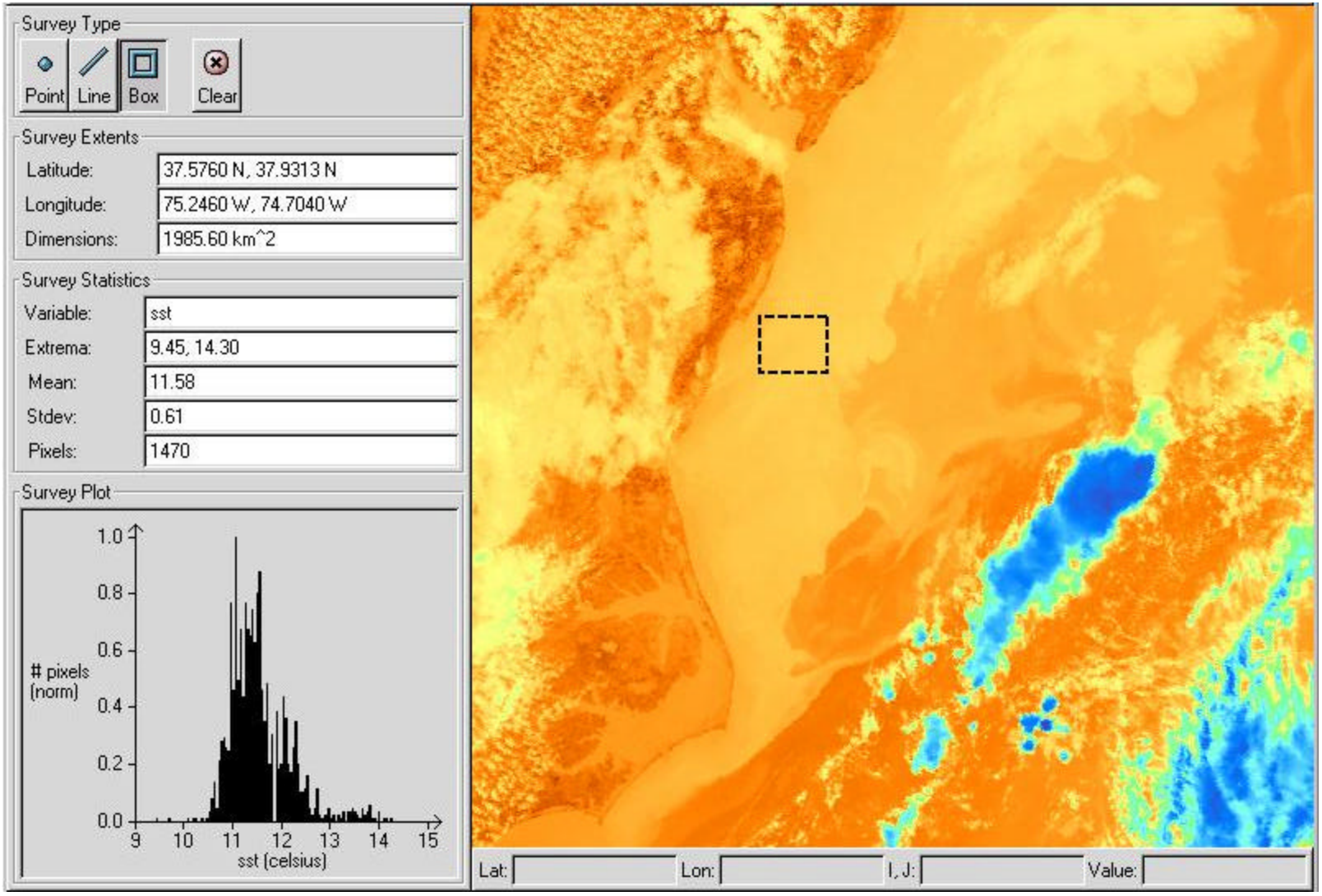
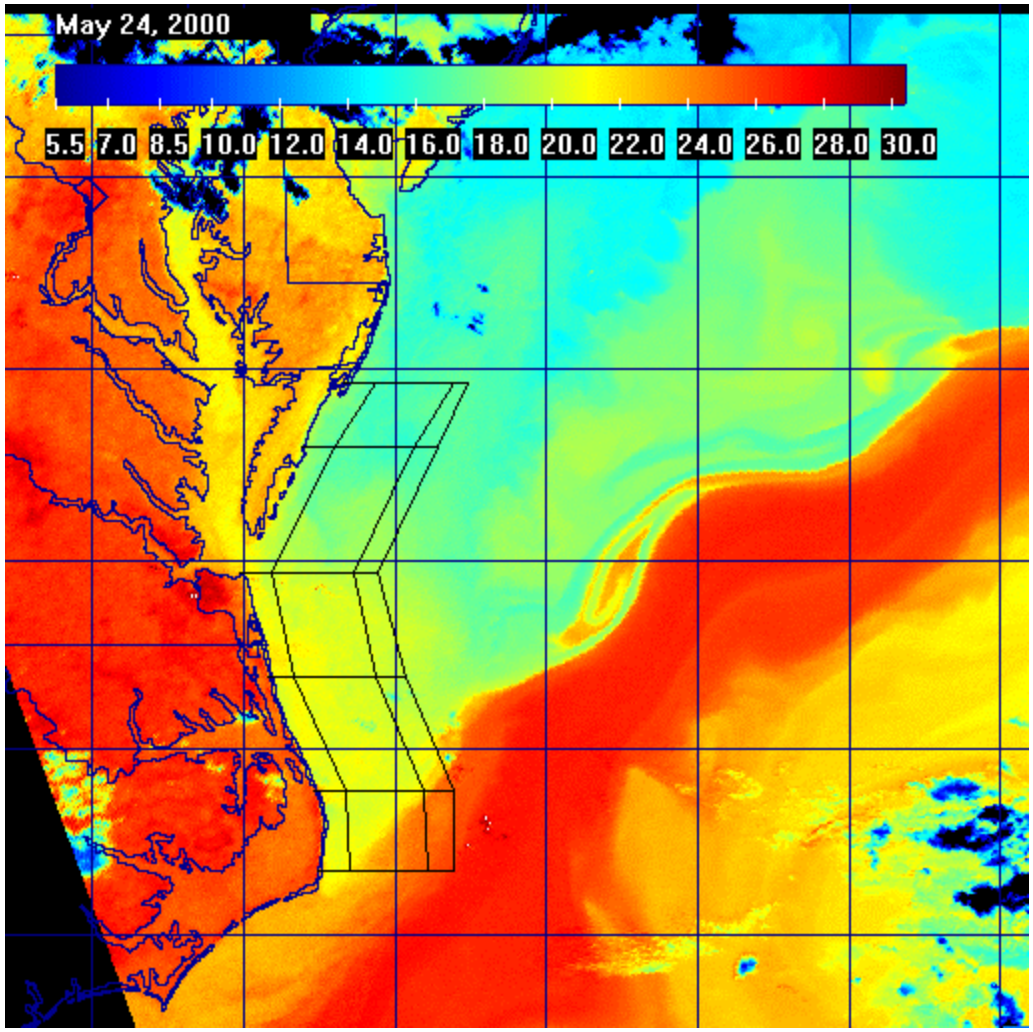


May 17, 1999 - Area 5



May 24, 2000



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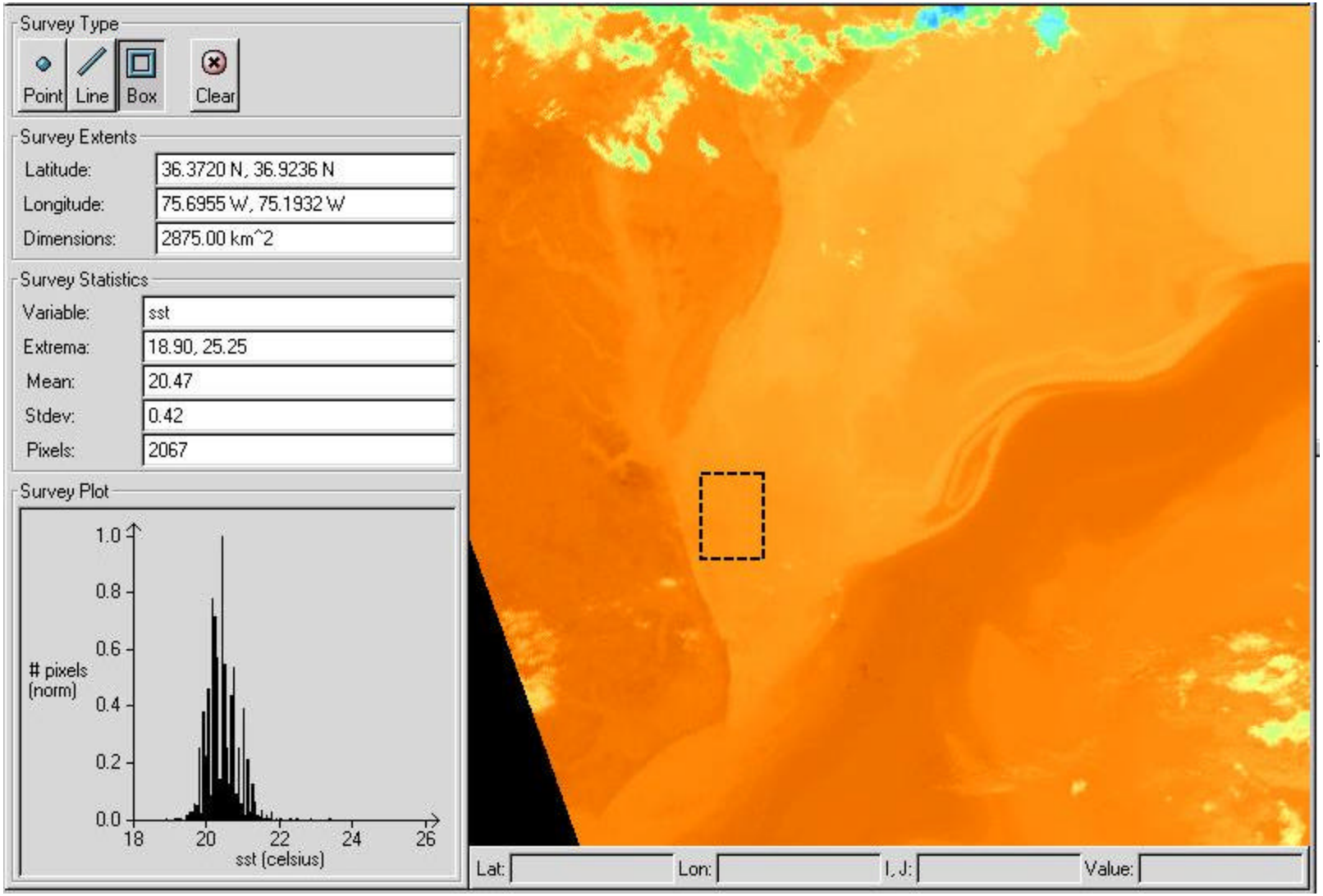

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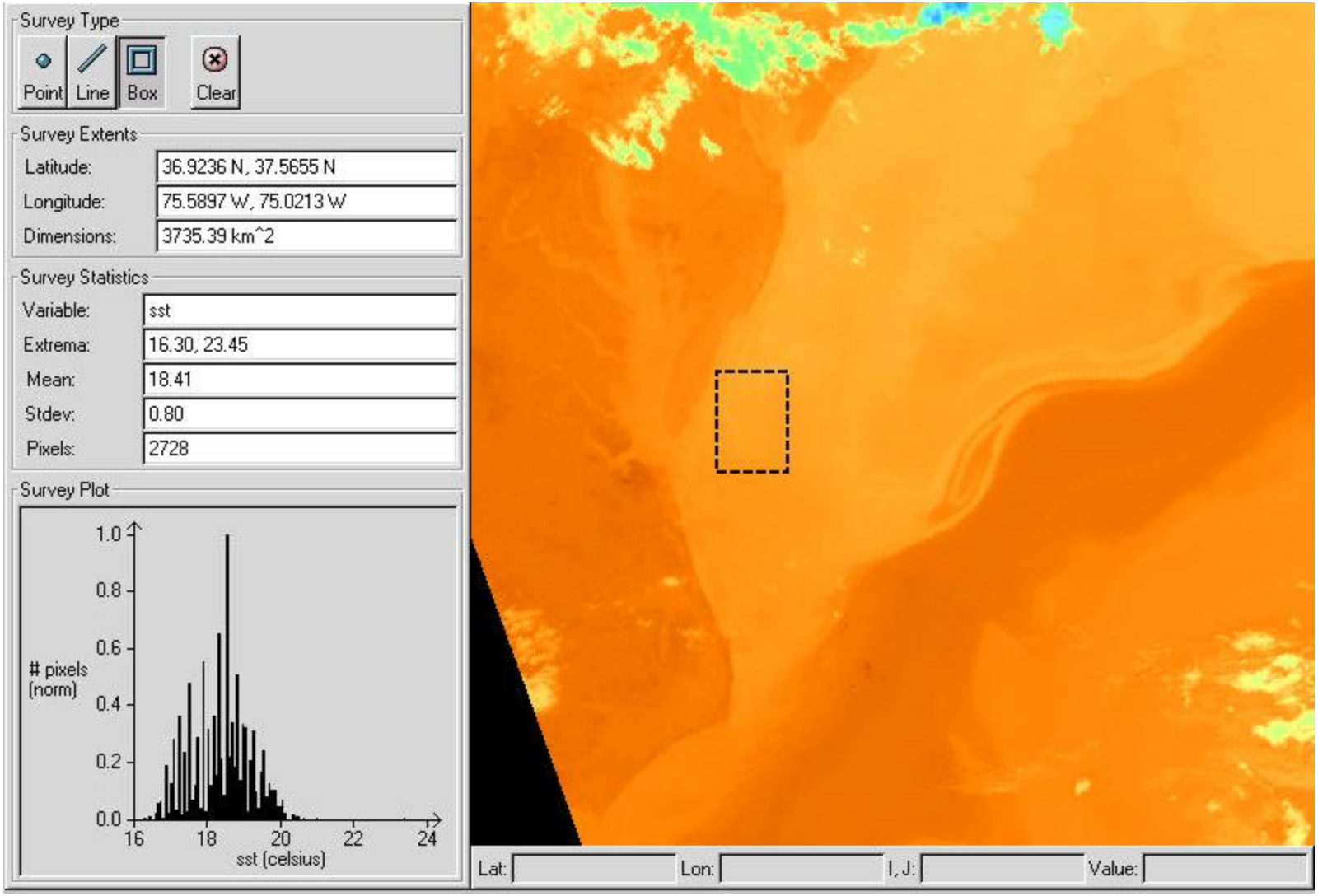
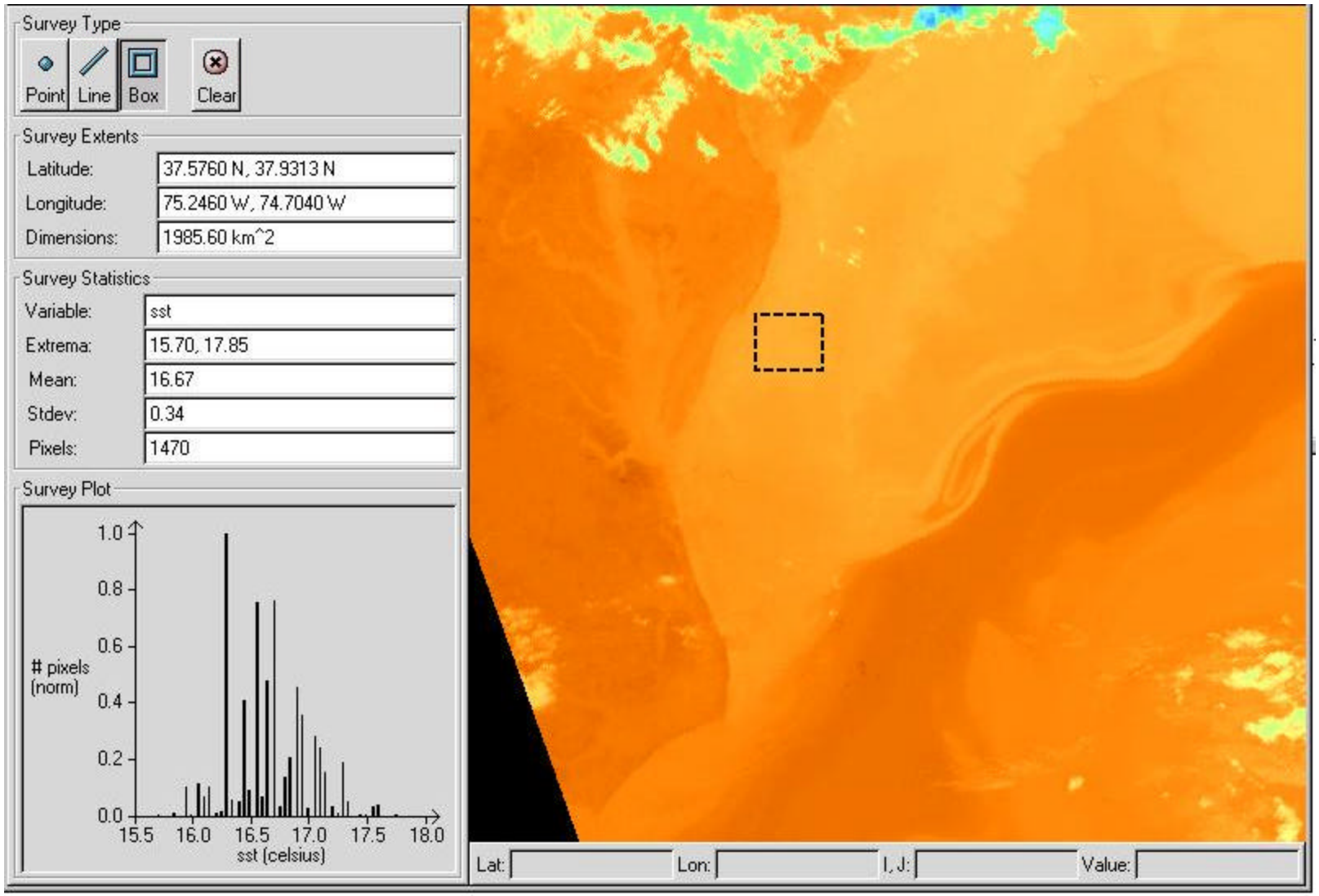


May 24, 2000 - Area 5



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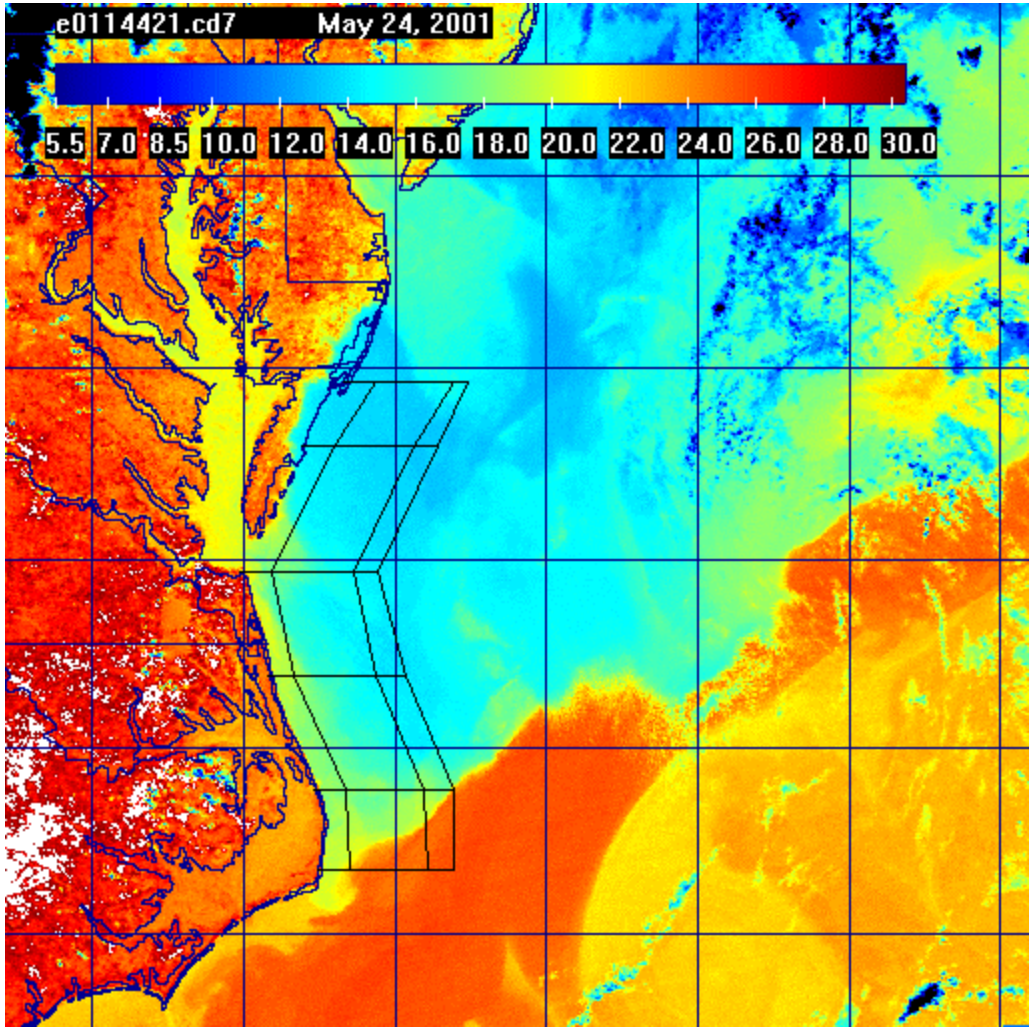
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May 24, 2001
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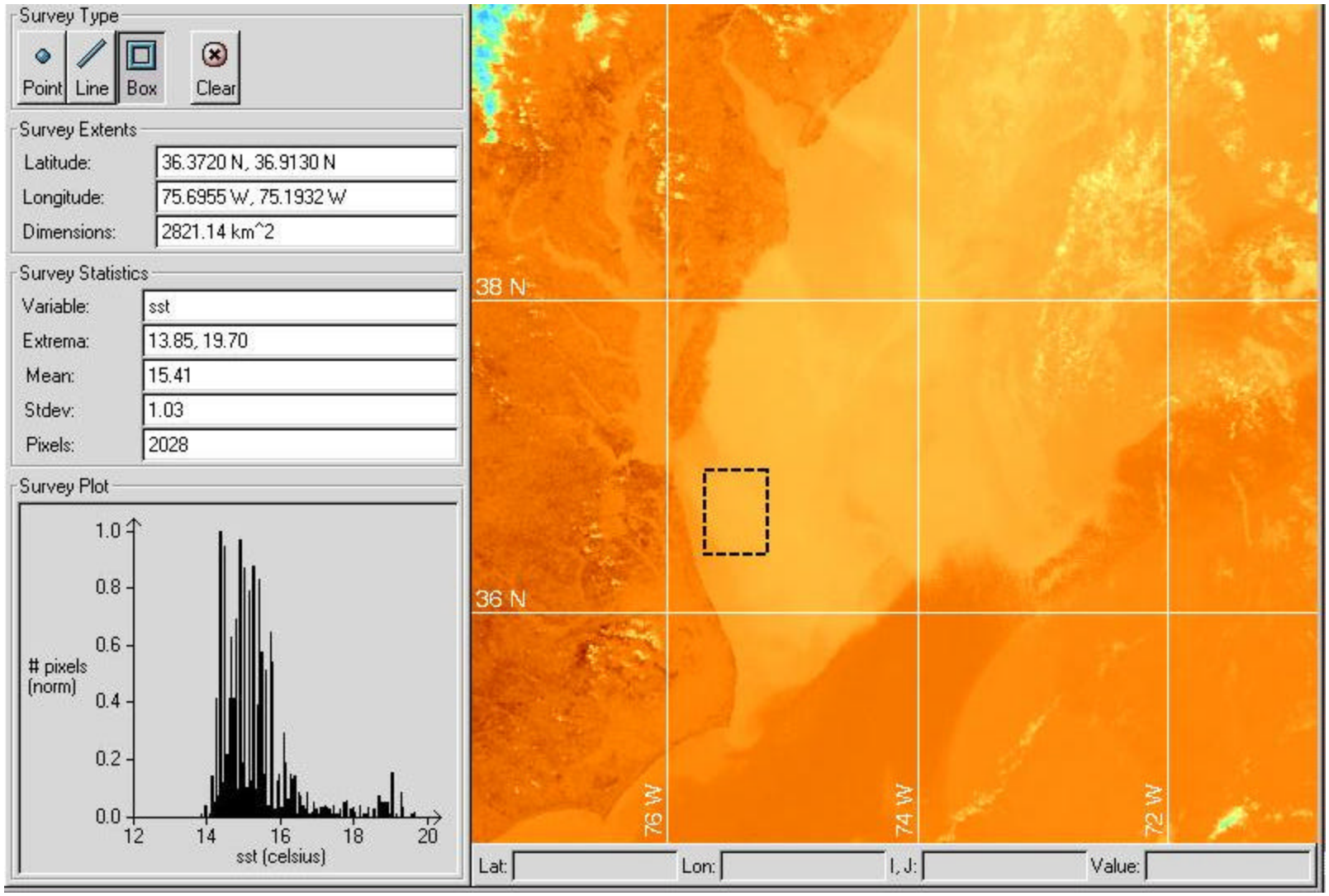
May 24, 2001 - Area 3



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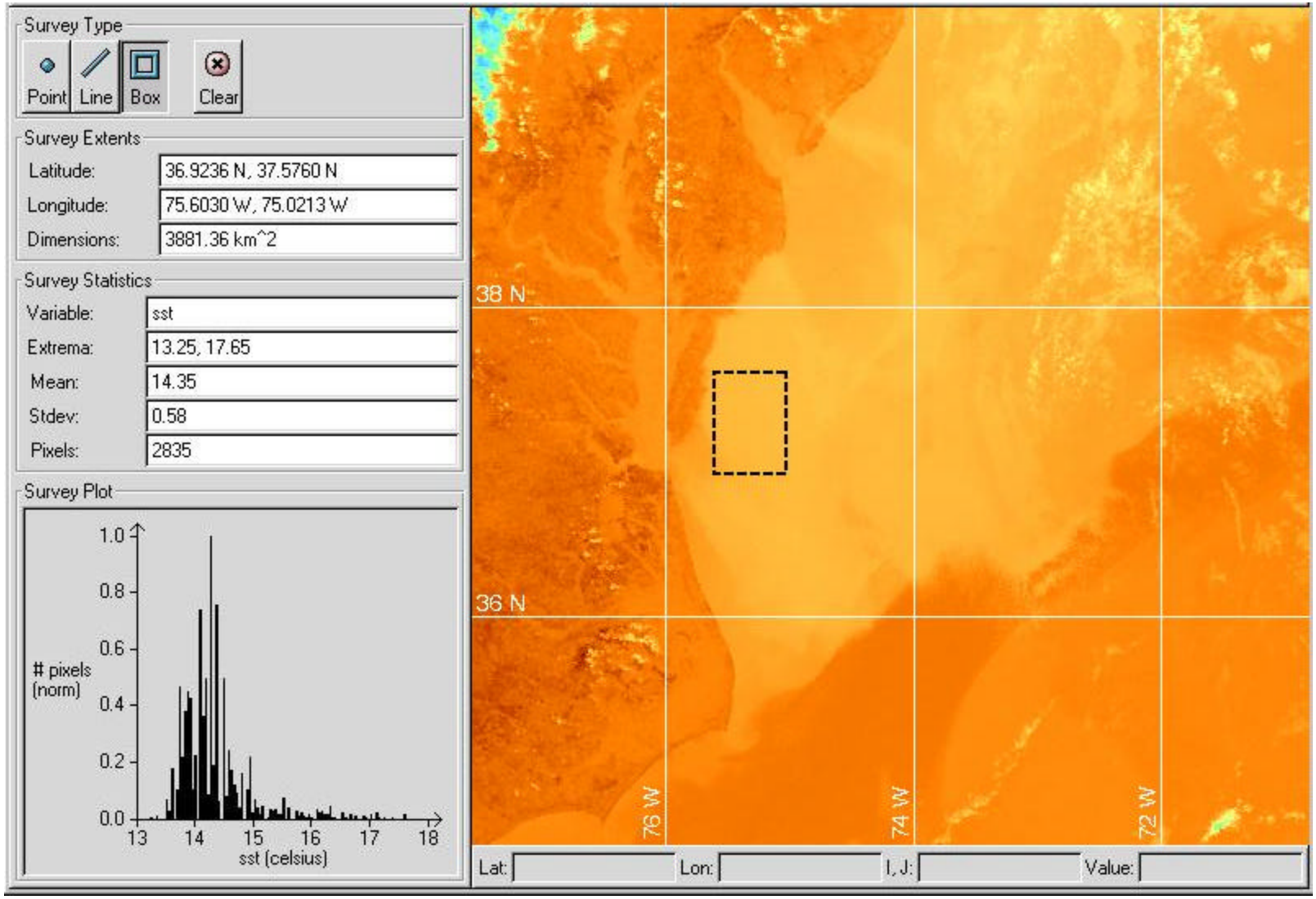
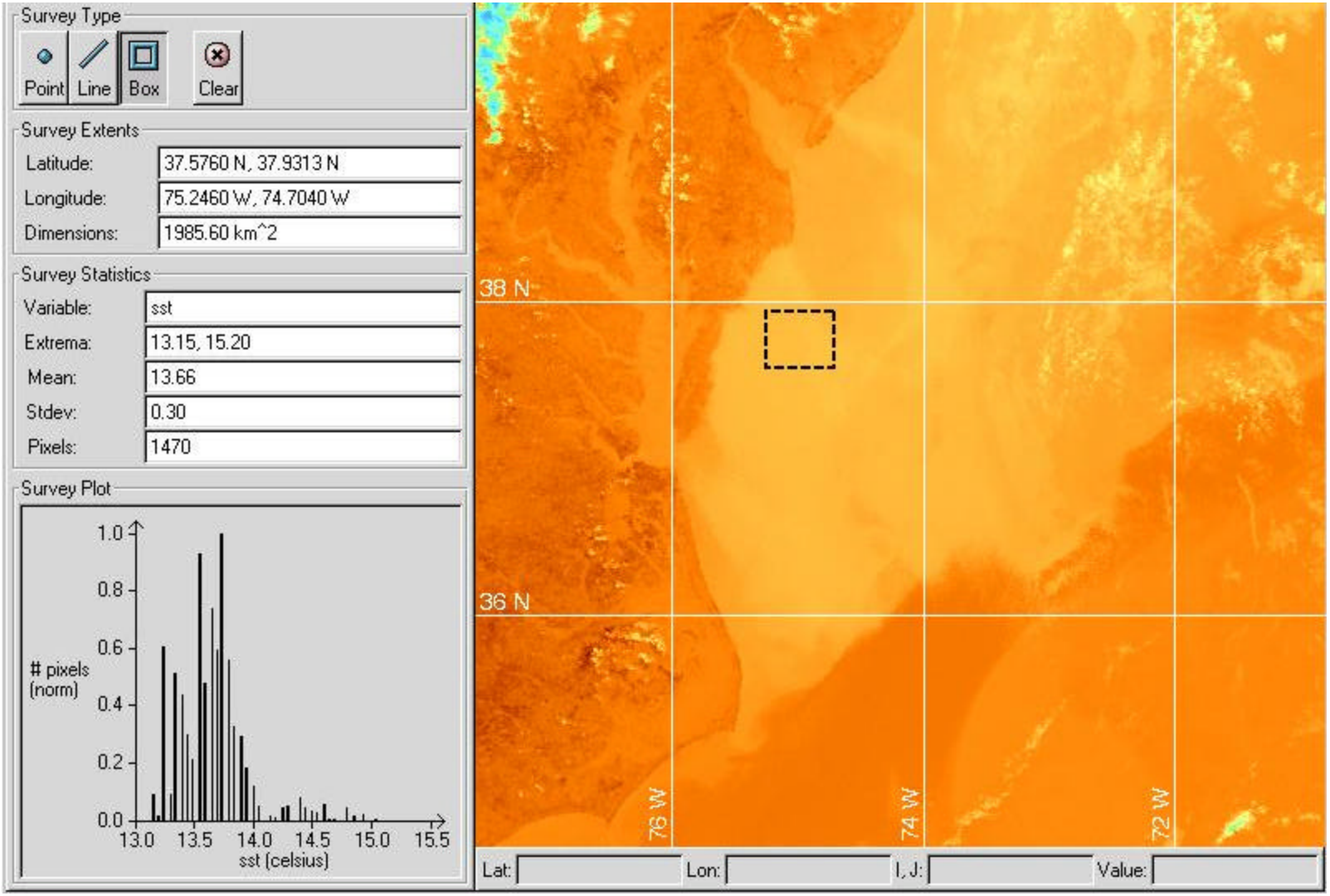
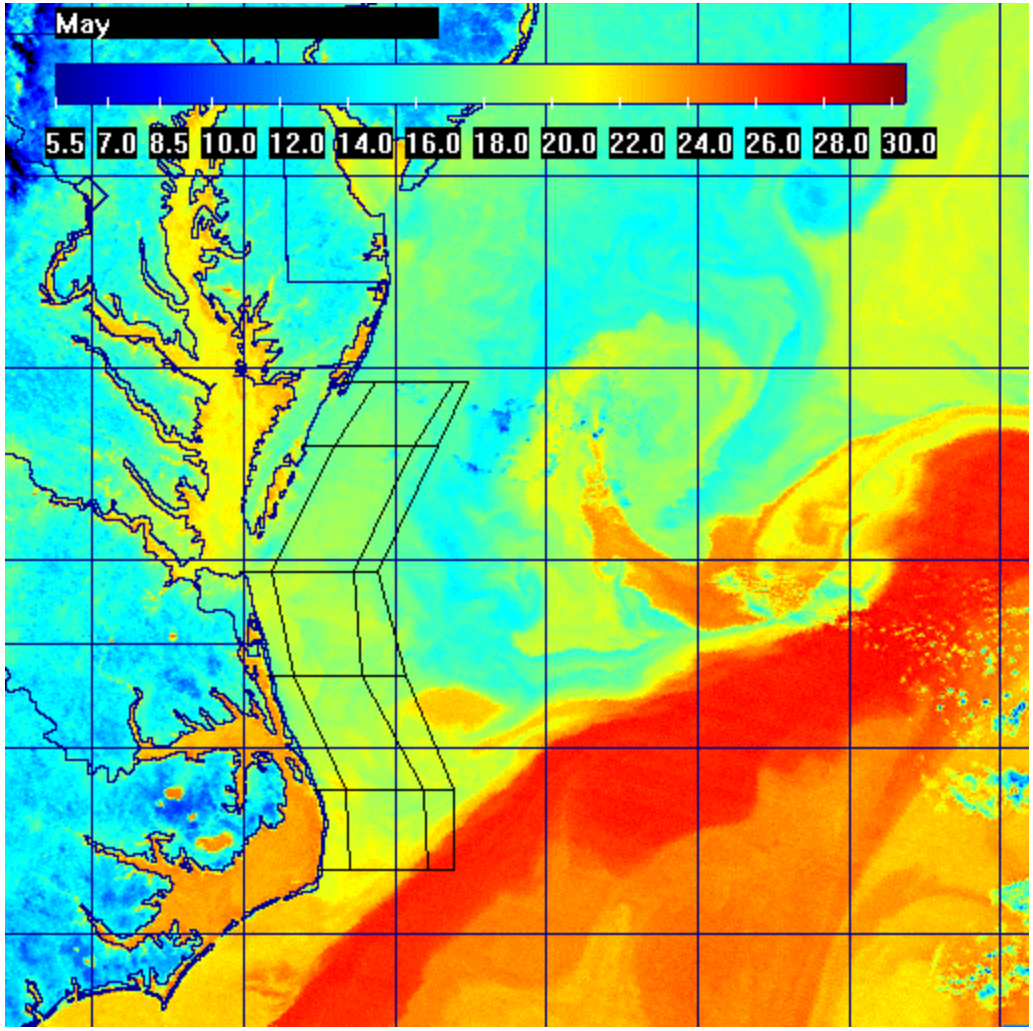


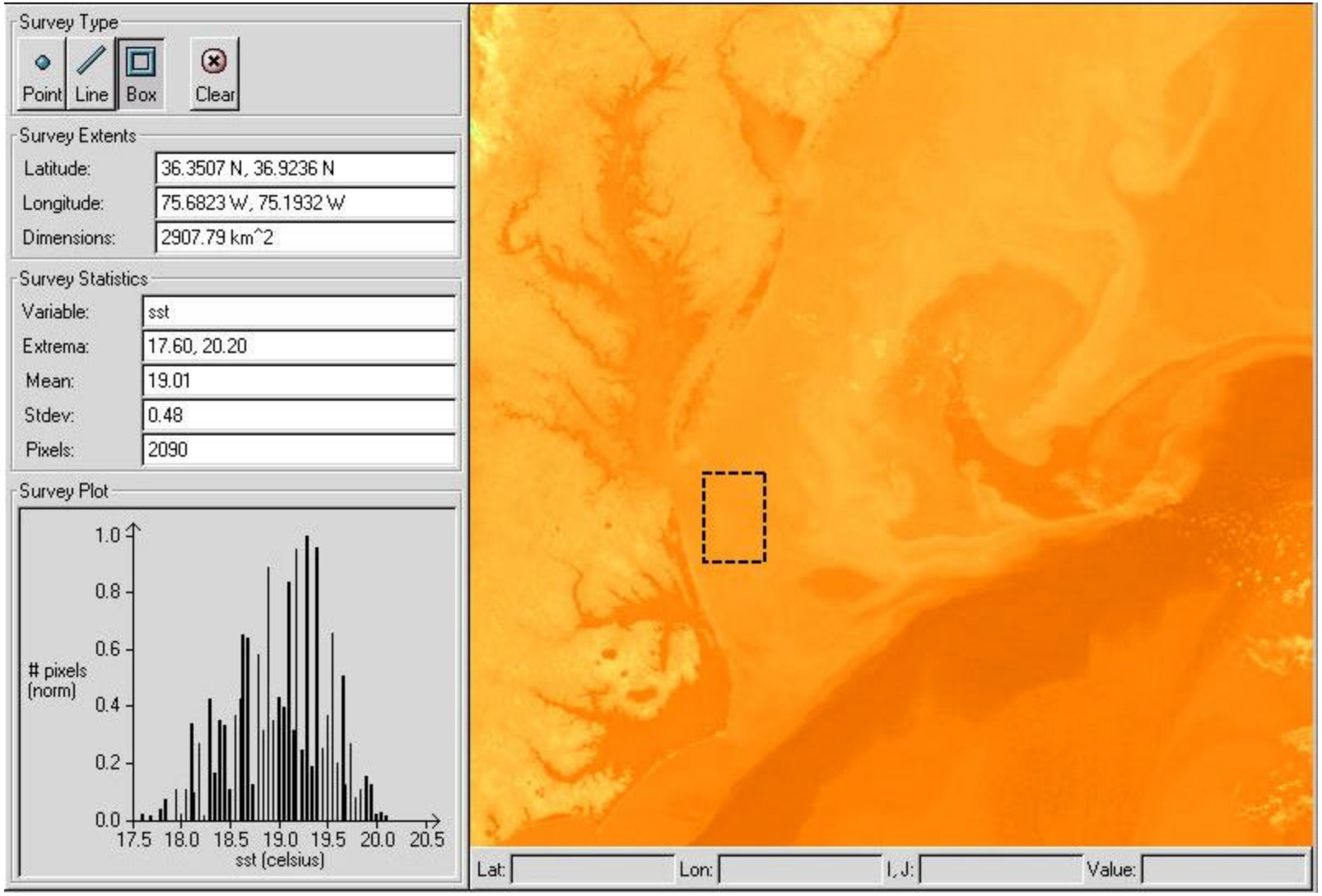
May 24, 2001 - Area 5



May 31, 1999



May 31, 1999 - Area 3



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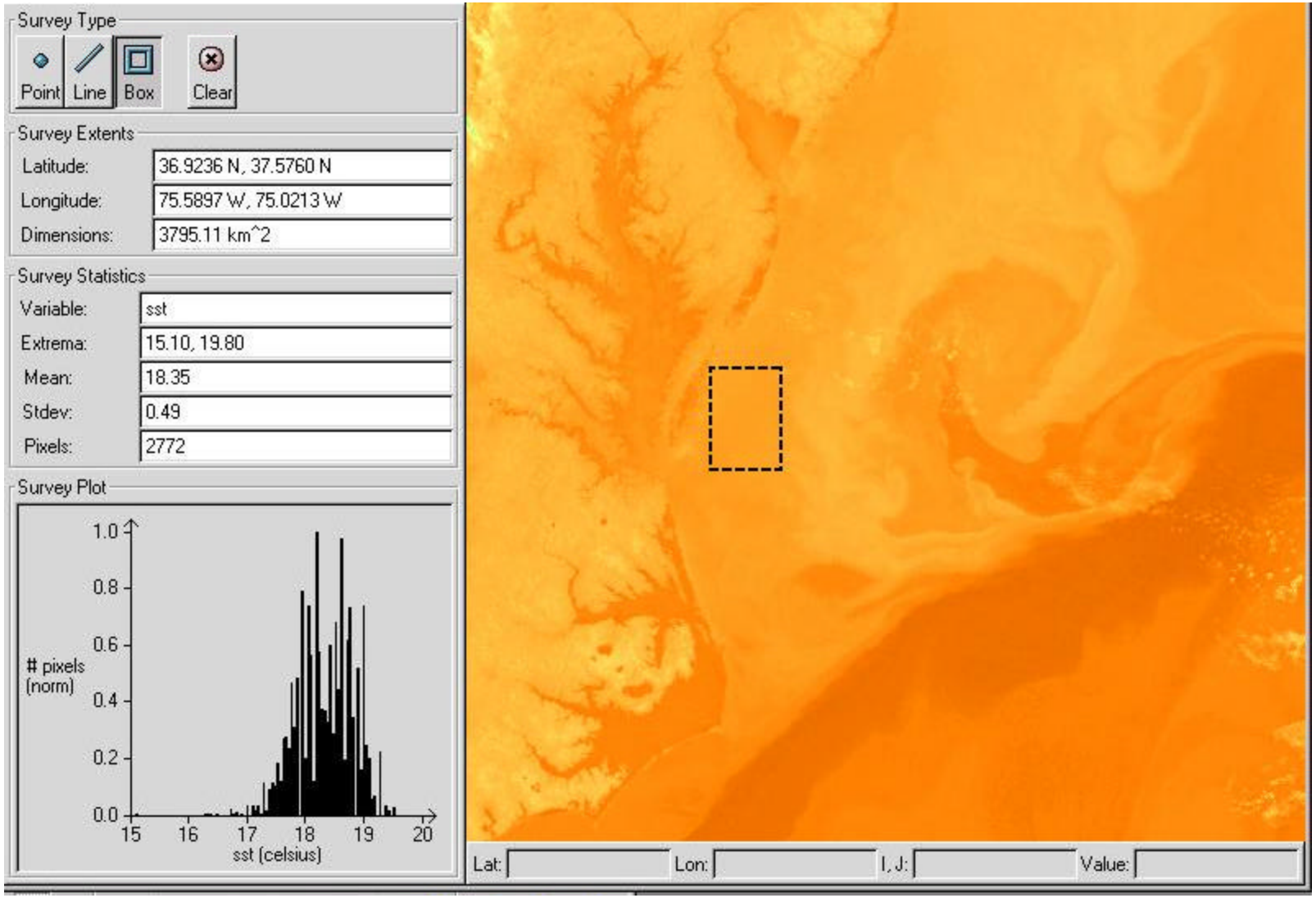
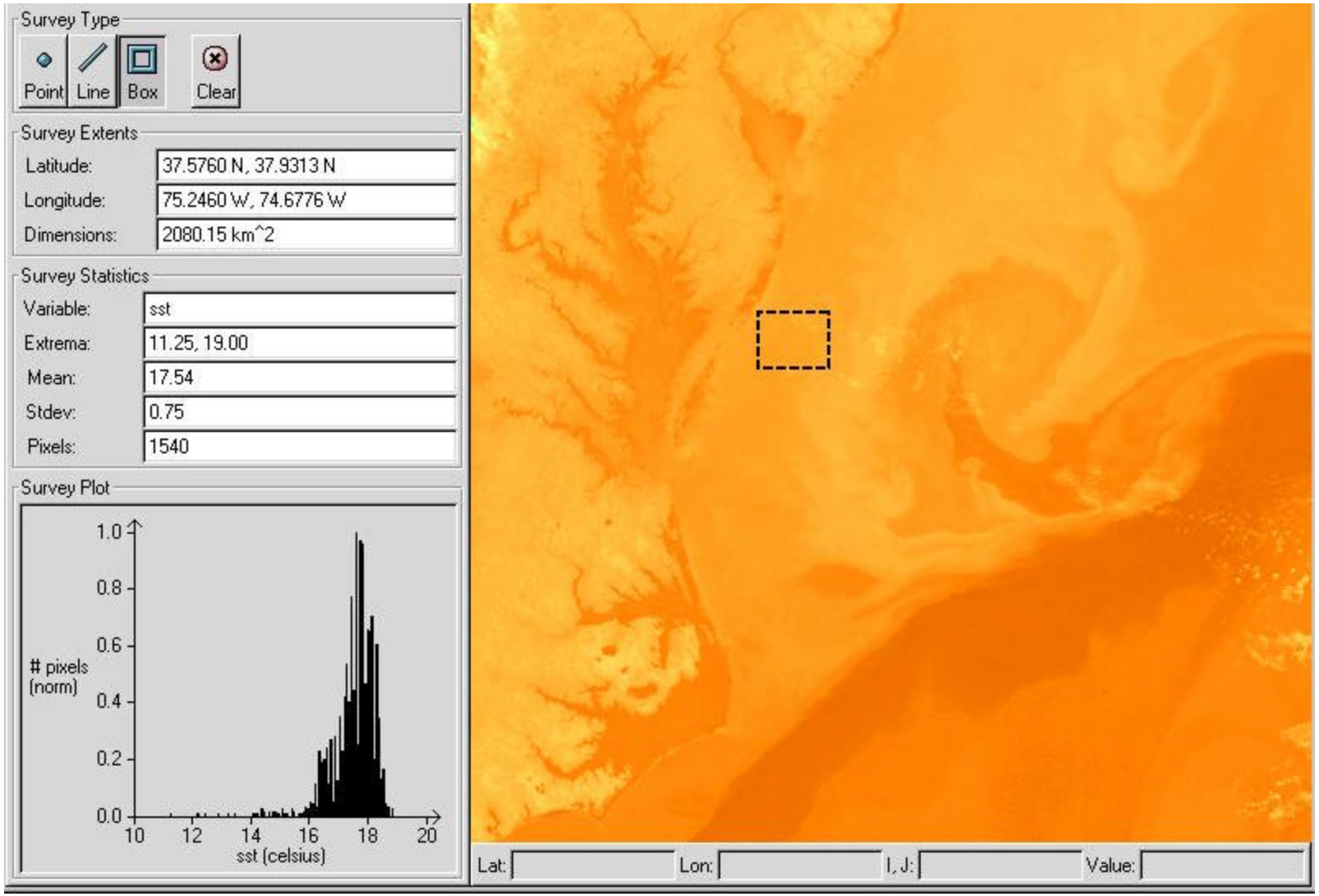
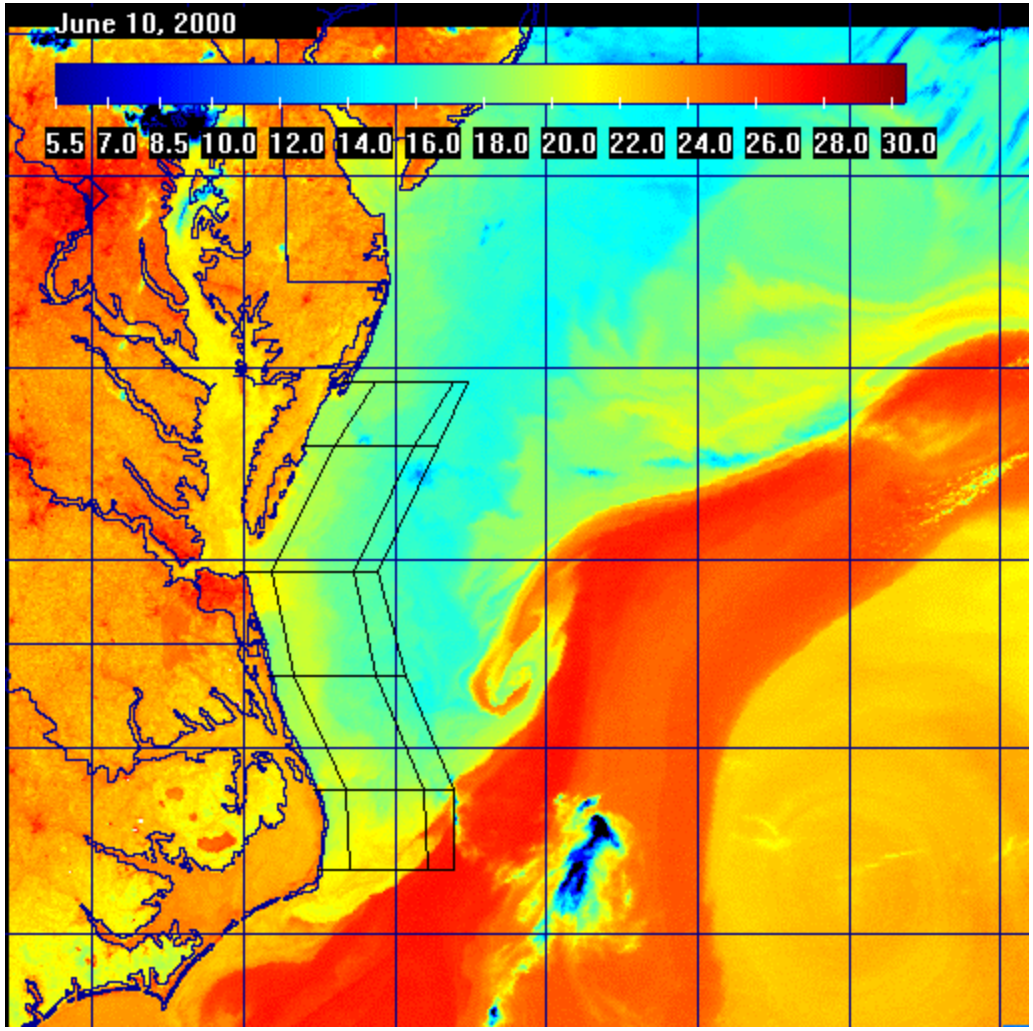


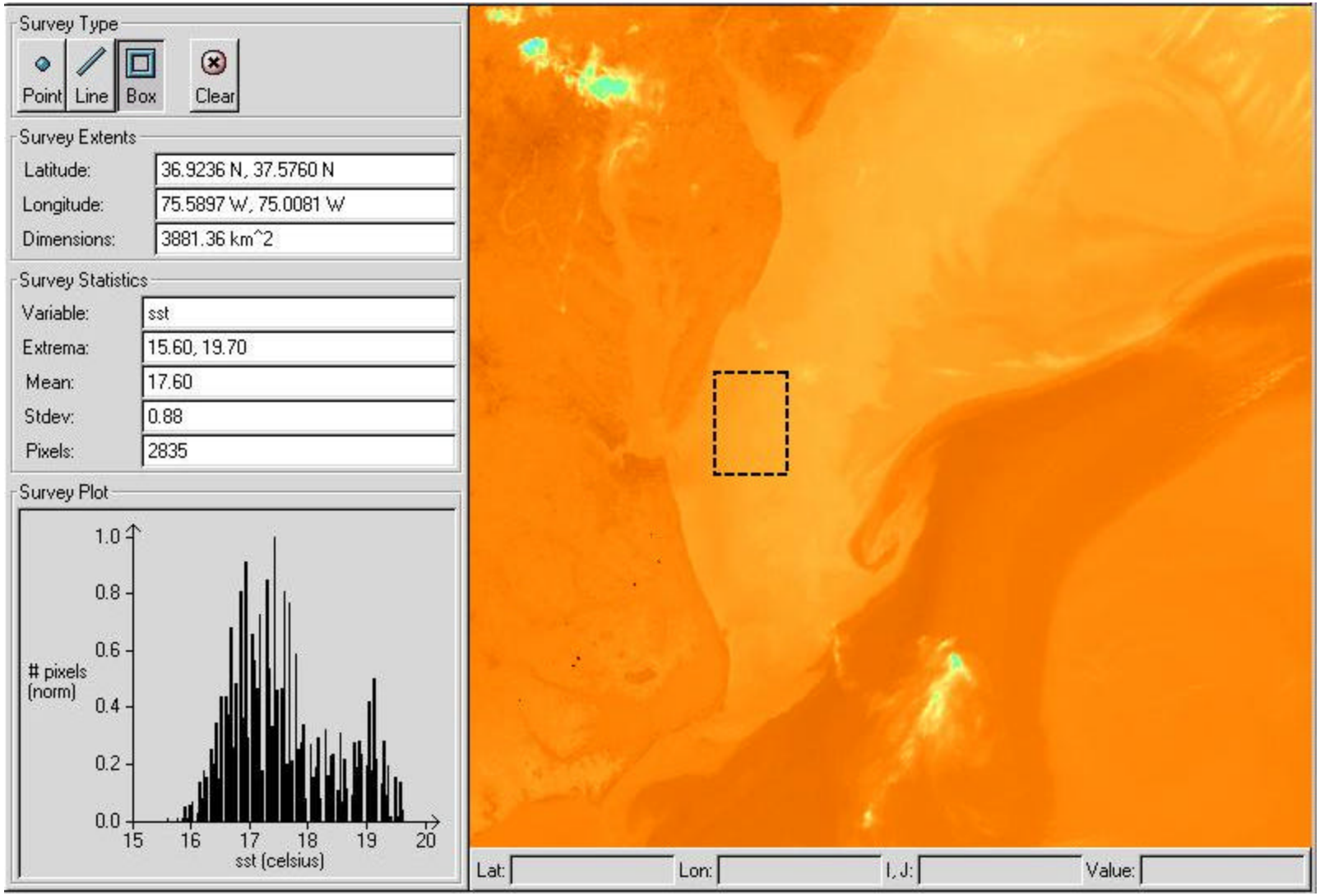
May 31, 1999 - Area 5



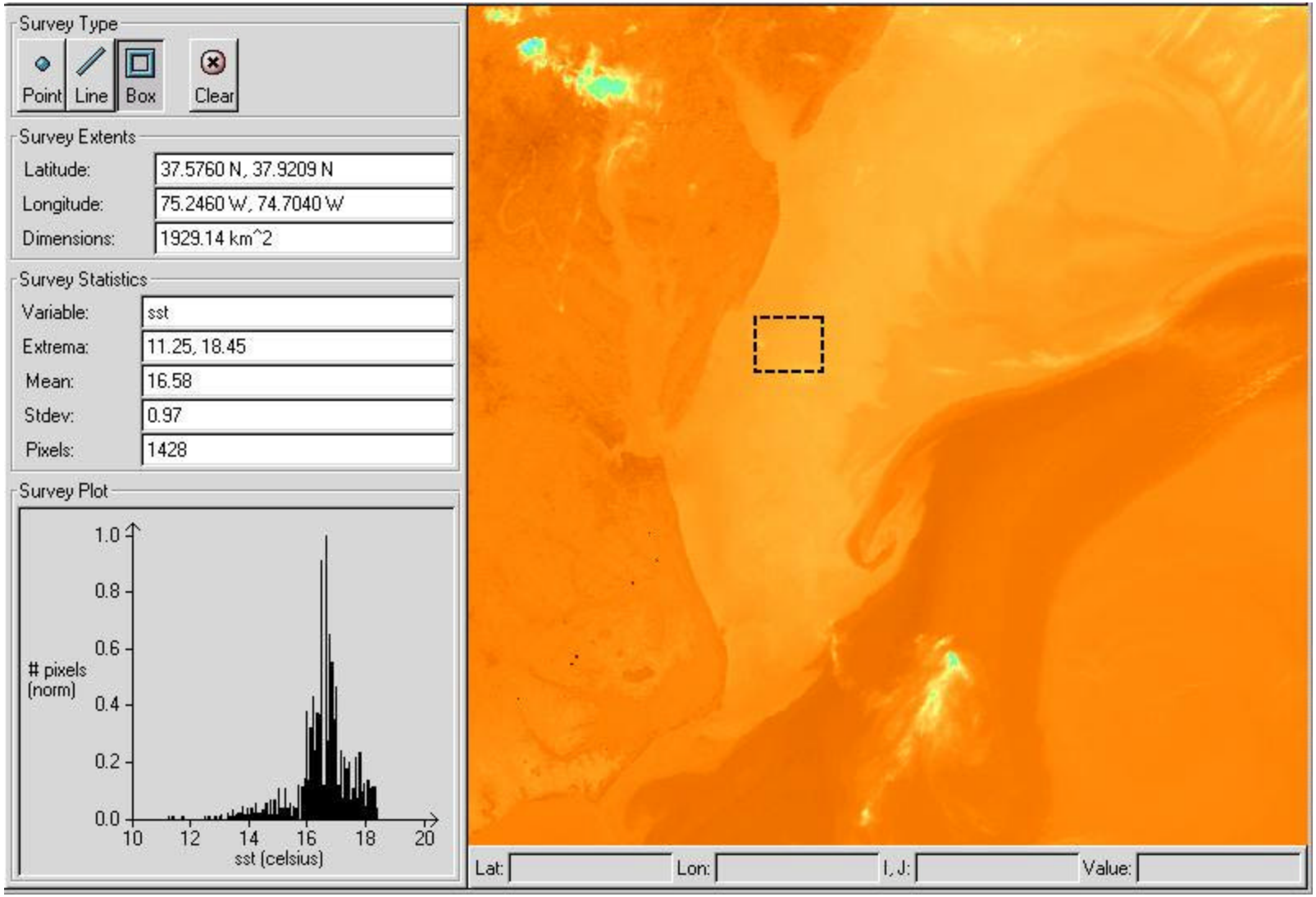
June 10, 2000



June 10, 2000 - Area 4



June 10, 2000 - Area 5



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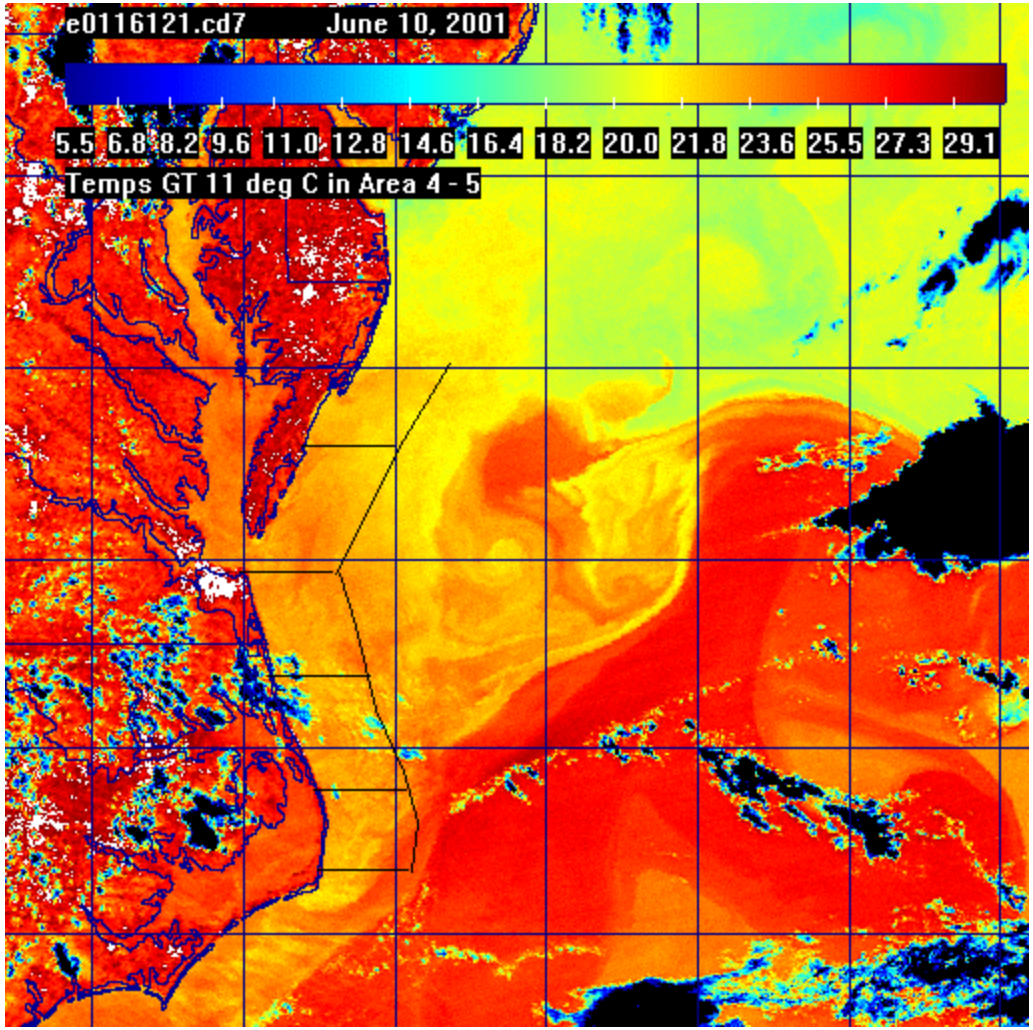
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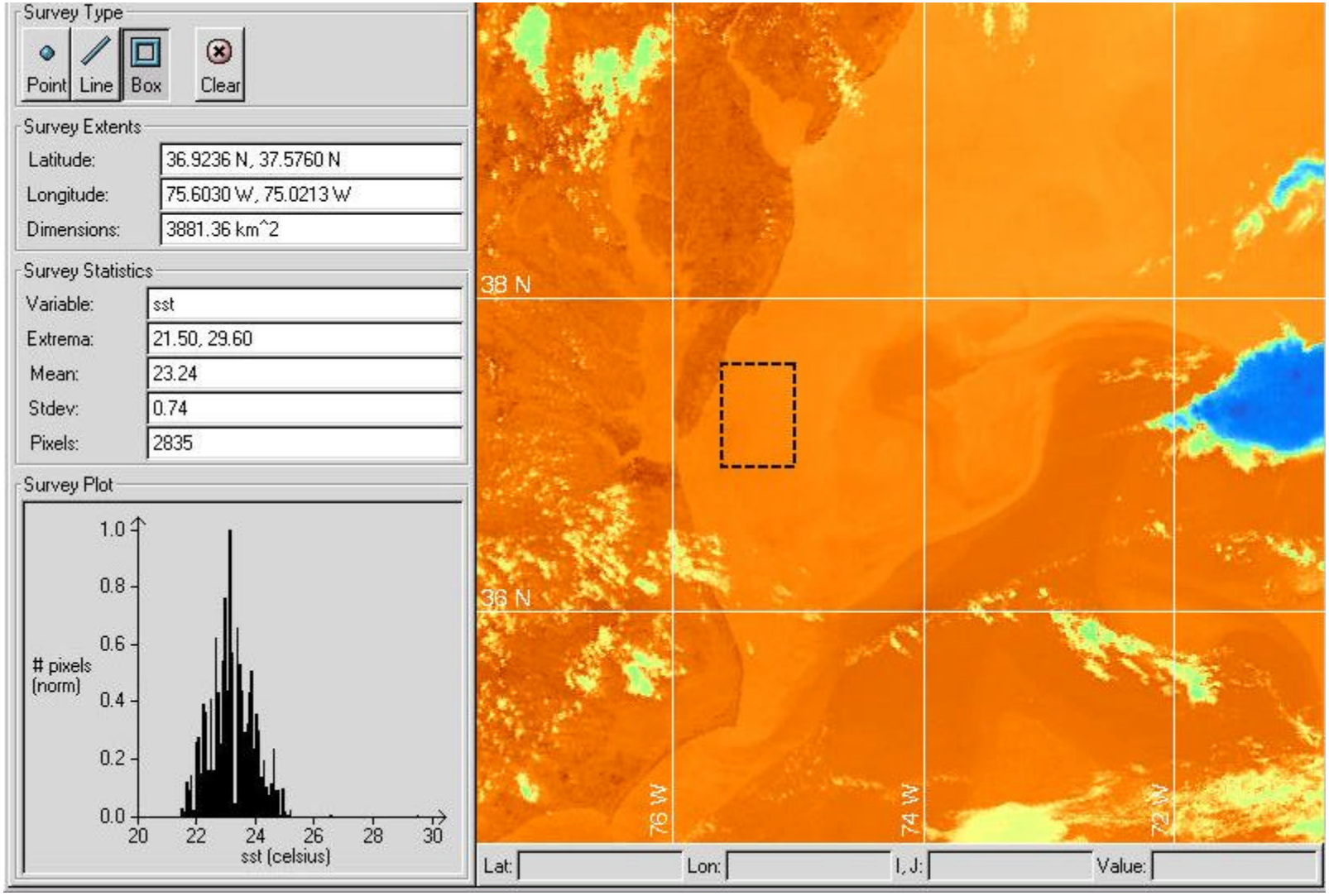
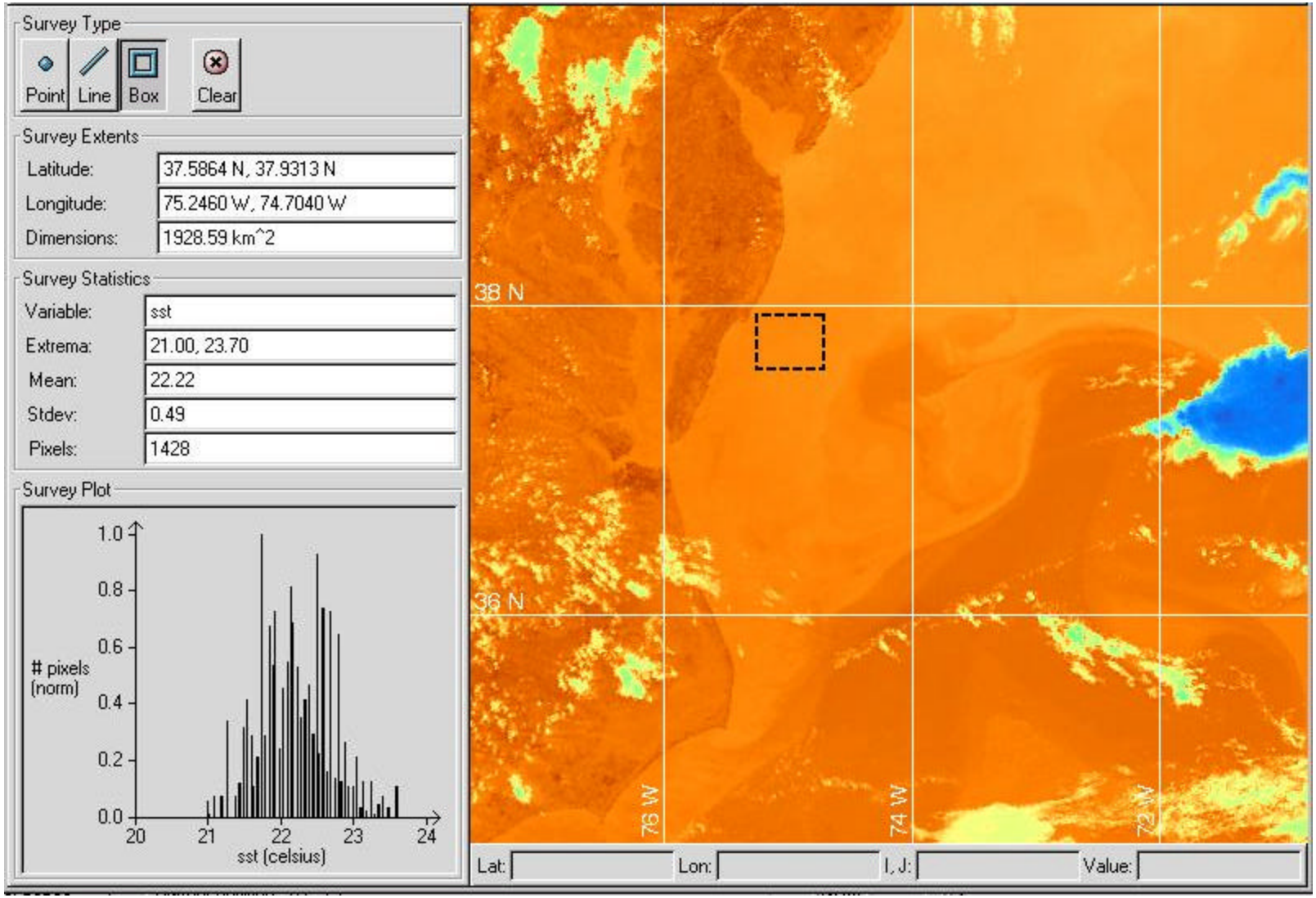
June 10, 2001
5.5 6.8 8.2 9.6 11.0 12.8 14.6 16.4 18.2 20.0 21.8 23.6 25.5 27.3 29.1
Temps GT 11 deg C in Area 4 - 5

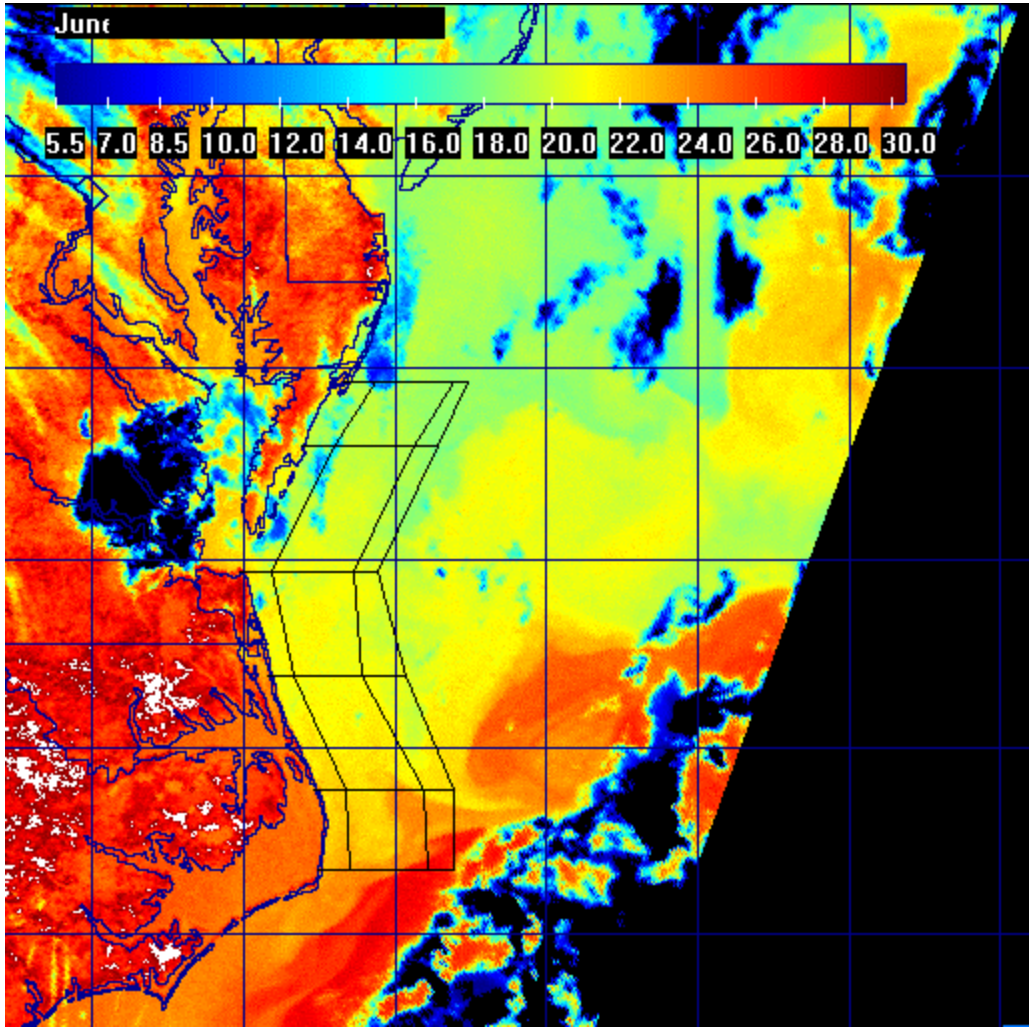
June 10, 2001 - Area 4



June 10, 2001 - Area 5



June 14, 1999



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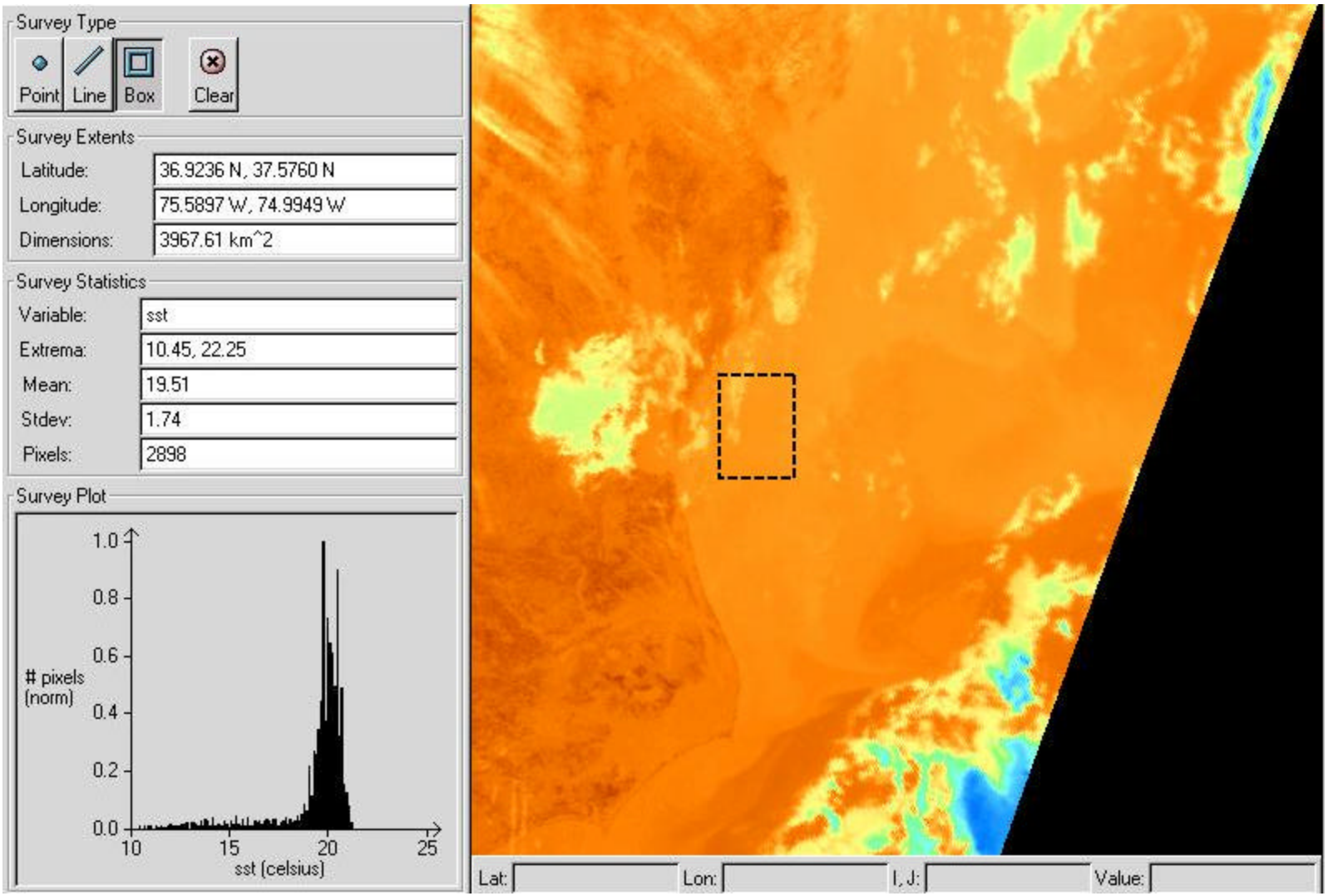

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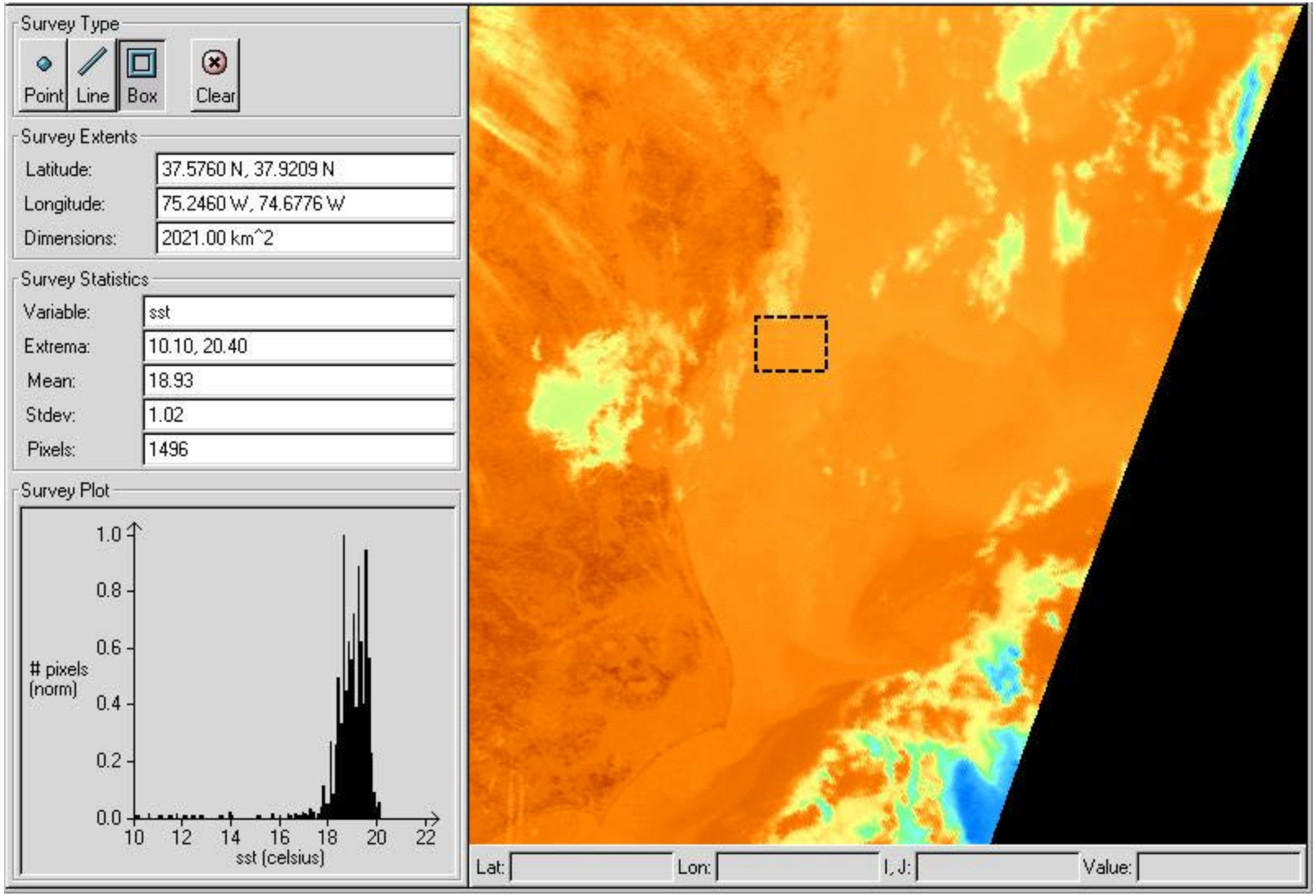
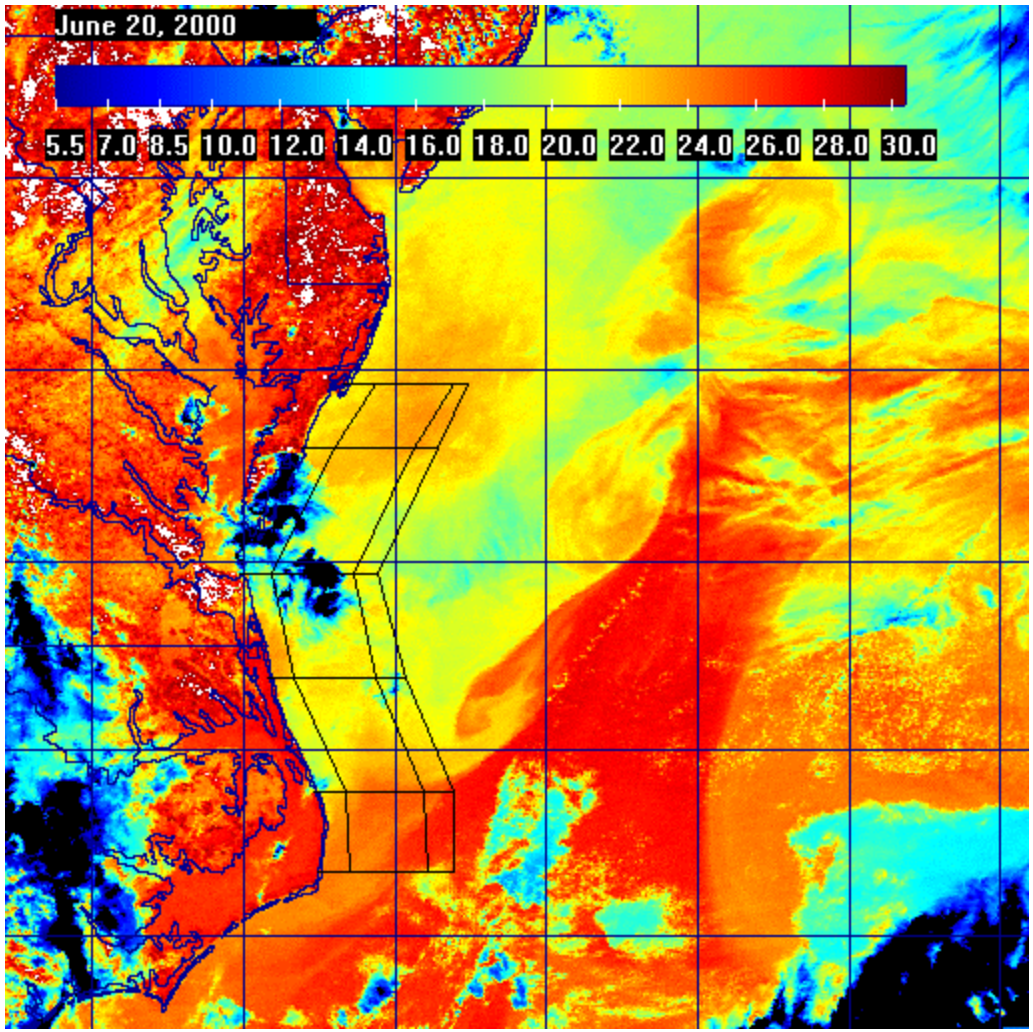


June 20, 2000



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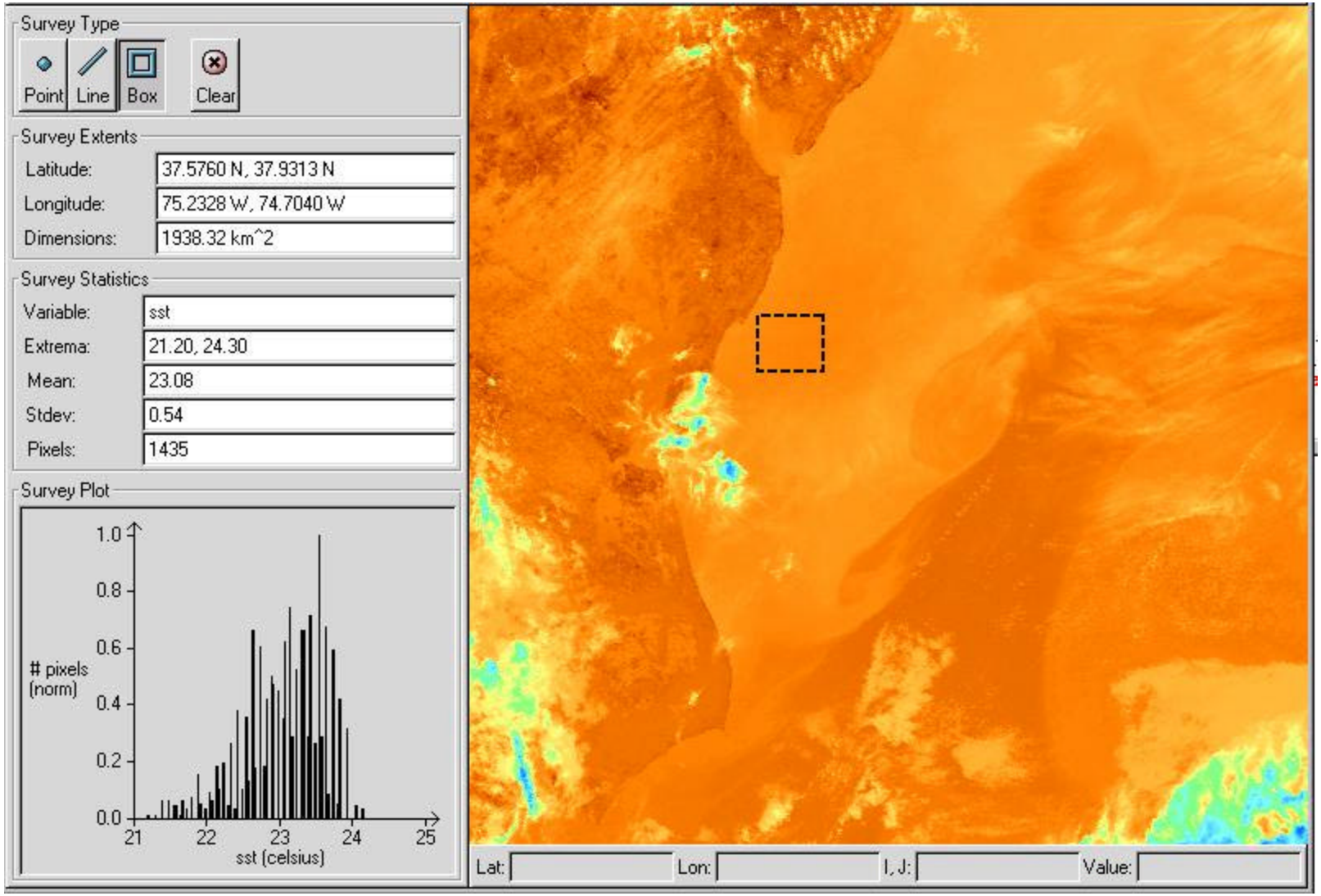
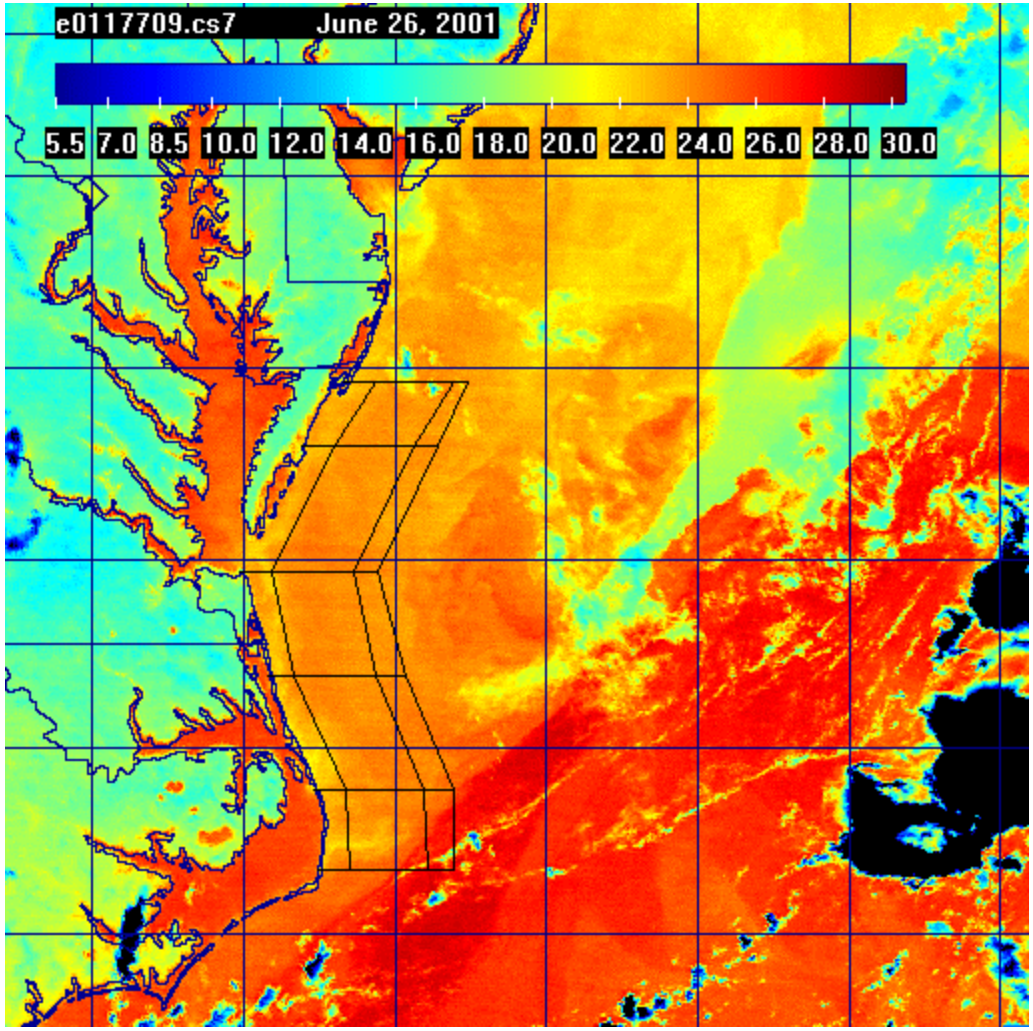


June 26, 2001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June 26, 2001
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June 26, 2001 - Area 5