The Gulf Stream in the Vicinity of the Rhumb Line Newport to Bermuda April 18, 2011
An Analysis of Conditions

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Anyone interested in studying Gulf Stream characteristics over the past month or so must be thoroughly impressed, if not depressed, by the persistence of a relatively dense cloud cover and the associated difficulty in detailing sea surface temperatures along the rhumb line to Bermuda. This is not terribly unusual for this time of year and very often carries on into June and beyond. It provides clear indication of the reason why it's important to begin studies of the Stream early so that the presence of clouds during the weeks immediately prior to race time does not force reliance on models or consultant advice in which the user has little confidence. That said, it's not at all too late to start if one is planning a June departure. The features developing in and around the Stream at the moment have the potential to produce a very "interesting" challenge to racers and cruisers heading for Bermuda this June. We can define the beginnings of the probable evolution of these conditions by reviewing recent conditions.

Our review proceeds on the assumption that readers have taken a moment to look at my *Brief Gulf Stream Tutorial* posted on the homepages of the Bermuda 1-2, Marion-Bermuda, and Newport- Bermuda Races. This article provides a description of the primary characteristics of the Stream with particular emphasis on the distributions of sea surface temperature (SST) and the relationships between SST, flow speeds and directions. This leads to a discussion of altimetry and the associated numerical modeling of currents along the entire rhumb line across the Stream to Bermuda. This was intended simply as an introduction to the variety of subjects and techniques used in the analysis of Gulf Stream conditions. My analyses between now and race time will serve to further illustrate the utility of these techniques and may in fact add a few more tools of use in strategic planning.

When first viewed in mid-March (Fig.1) the main body of the Gulf Stream crossed the rhumb line at a point approximately 180nm from Newport. Flows were essentially perpendicular to the line proceeding from the southwest to the northeast. Water temperatures at the crossing were rising rapidly from approximately 17^{o} C in the north to 20- 23^{o} C to the south. While substantially warmer than the water temperatures inshore, which for this late winter period look to be around 5^{o} C, these Stream temperatures are somewhat less than those that will be encountered in June. The spatial gradients in temperature however are approximately the same found in June implying similar current speeds.

In looking at SST it's important to realize that these gradients affect water densities and associated water column pressures. The resulting spatial gradients in pressure have the potential to produce water flows just as atmospheric variations in pressure can cause winds. This implies that flows may be produced <u>at any point</u> along the track affected by local temperature gradients.

Proceeding from Newport, for example, the SST data (Fig.1) show a variety of warm water "patches" well to the north of the main body of the Stream. In each of these, warmer waters to the right of the track will find the boat heading with the current (rule of thumb). A particularly abrupt change in temperature illustrating this is observed at a point approximately 120 nm from Newport where water temperatures increase from 10^{o} C to nearly 17^{o} C , a difference similar in magnitude to that observed in the main body of the Stream. Despite this similarity however, the flows associated with this boundary will be less than those found in the Stream due to a more gradual spatial gradient. Speeds might approach +/- 2 knots with flows proceeding from the southwest to the northeast.

From Cape Hatteras to the rhumb line and beyond, the March SST data show that the main body of the Stream follows a sinuous, meandering course. Such features typically progress to the northeast at rates of 10 to 20 nm/day producing a progressive change in the direction of flows crossing the rhumb line. On occasion the meander will deepen and "pinch off" forming eddies or rings. The composite satellite image issued on April 18 provides graphic illustration of this process and the extent to which deepening and migration can affect flow speeds and directions in the vicinity of the rhumb line. In March, direct Gulf Stream affects were confined to a well defined region of the rhumb line with a total width of approximately 60 nm (Fig.1). By mid-April deepening and the progressive northeast displacement of the main body meander had increased the extent of direct Stream influence on the rhumb line to nearly 210 nm (Fig.2). A significant portion of this area is affected by flows proceeding from the southeast to the northwest towards Newport. Avoidance of these adverse flows for boats enroute Bermuda in these conditions would most likely require selection of a course well to the east of the rhumb line until clear of Stream influence unless some particular wind conditions justify the significant increase in distance associated with a westerly track to enter the Stream at a point ~ 120nm west of the line near 36^{o} 30' N 71^{o} 20' W.

In addition to the deepening and migration of the meander, the April 18th composite shows a parcel of discrete cold water surrounded by warmer waters centered near 36^{o} 40' N 68^{o} 15' W or approximately 15 nm west of the rhumb line. This cold core ring will produce counterclockwise flows over an area of 60 to 90 nm. Unless entrained by the main body of the Stream, such rings will typically drift to the west at speeds of 0.1 knot or so.

A slightly more detailed view of the main body Stream on April 18th is provided by an instantaneous satellite SST image permitted by a short period of cloud free views (Fig.3). In the absence of the averaging associated with the compositing process, this higher resolution image provides clear indication of the cold core ring and additional detail within the meander. The latter area appears to be approaching some instability (similar to a breaking wave) and may "pinch-off". The evolution of the ring remains a question due to its close proximity to the main body of the Stream and the potential for entrainment. Both of these features bear close watching over the next few weeks.

It's interesting to note that in addition to the features observed on the 3 day composites (Figs 1&2), the instantaneous SST image also shows a large area of cooler water in the vicinity of 35º N 72º W (Fig.3). Such a distribution favors a counterclockwise flow that could adversely affect the advance of boats that chose the westerly track with entry into the Stream at a point 120 nm west of the rhumbline and certainly requires consideration if such a “flyer” is being considered. This points to the value of the higher resolution instantaneous images vs composites particularly when potentially costly options are being considered.

The presence of clouds will necessarily prevent detailing of surface water temperatures since the IR sensors on the satellites cannot “see through” the moisture laden clouds. Under such circumstances the navigator is forced to rely on alternative depictions of the Gulf Stream. A few years ago the best alternative was provided by the Naval Oceanographic Office in the form of sea surface temperature images based on aerial flight data as interpreted by an analyst. These now appear to be supplemented by additional model data and possibly selected satellite data. The result is an image that closely resembles the satellite composites but lacks similar spatial resolution (Fig.4). Overall the major features of the Stream appear to be adequately resolved, including the cold ring just west of the rhumb line along 36º N, although there are some substantial differences in the position of the western limits of the Stream along 38º N indicated on the Navy image relative to that shown on the instantaneous satellite image (compare Fig.4 to Fig.3). This difference may be the result of the criteria used by the analyst to specify the outer limits of the main body of the Stream. Study and comparison over a period of time would allow resolution of this. Despite these differences the Navy maps (updated MWF of each week) represent a valuable tool in the absence of direct satellite imagery and warrant a bit of study to build confidence.

In addition to the SST images, the Naval Oceanographic Office also issues the results of computer based numerical models detailing a variety of flow features including sea surface temperatures in the north Atlantic (Fig.5). Comparison of the model SST results to concurrent satellite SST data shows only partial similarity suggesting that the model has limited utility as a small boat navigational tool due primarily to the spatial resolution. However, since daily maps are provided and archived it’s possible to run a series of images sequentially as a “film loop” providing clear indication of the evolution of Gulf Stream features. These provide a useful indication of the time rate of change of the Stream which may represent the primary value of these model data.

Possibly the most valuable tool to use in the evaluation of Gulf Stream characteristics during periods of dense cloud cover is NOAA’s model of Stream flows based on satellite altimetry (Fig.6). Over the past six years or so in a variety of races these data have proven to be of great value in the determination of Gulf Stream position and flow directions. Flow speeds indicated by the altimetry based models are generally lower than observed due to model specifications. In contrast, comparisons of the model based definition of Stream location as well as the location of associated features, such as the cold core ring to the west of the rhumb line, show excellent similarity with the added benefit of detailing of the areas to the north (along the NE shelf) and to the south (in the Sargasso Sea) of the main body of the Stream (compare Fig.3 to Fig.6).

Examination of the altimetry based model results provides something of a new perspective on several of the Stream features inferred from the satellite SST images. In particular, the flows within the meander, the position of the cold ring relative to the main body of the Stream and the presence of a counter clockwise rotating feature, similar to a cold core ring, centered near 36^o 40' N 71^o W. Each of these have potential strategic significance.

The flows of the main body of the Stream in the meander west of the rhumb line shown in the altimetry based images look to be more nearly south to north than might be inferred from the SST data. In addition the model flows show minimal western excursion beyond 70^o W apparently differing from the SST plots by 30-60nm. These differences illustrate the difficulties inherent in attempts to infer flow from SST data alone. Recall that the flow speeds are a function of spatial gradients in water temperature and that typically maxima are to be found at some distance (on the order of 30 nm) in from the evident thermal boundary. This fact favors the direct measurement of sea surface heights (altimetry) over visual interpretation of satellite images since it's practically impossible to accurate define temperature gradients using these images whereas the heights measured by the altimetry are directly related to them. This would at least imply that the altimetry results are a more accurate representation of the actual flows than those that might be inferred simply using the SST images. Experience has indicated that this is generally the case.

With regard to the cold core ring, the altimetry based model shows this feature to be in close contact with the main body of the Stream (Fig.6). This implies that the normal western drift of the ring may be impeded by the north going Stream which could in time bring the ring in close contact with the rhumb line. Alternatively, the ring might be entrained and destroyed within the main body of the Stream. Time will tell. It's evident that this feature bears watching over the next month or so.

Finally, the counter clockwise rotating feature shown in the altimetry based model results represents an additional factor that would have to be considered in the evaluation of any potential western track. It would appear that at this moment the position of this feature, its size and the associated flows effectively eliminate any reasonable western track from consideration in the absence of some very unusual wind conditions.

To summarize, the main body of the Gulf Stream currently in the vicinity of the rhumb line is dominated by a deep meander that may be bordering on unstable. A cold ring resides to south of the main body just to the west of the rhumb line. Each of these features have the potential to significantly affect small boat set and drift enroute to Bermuda. Their evolution should be carefully monitored over the next few weeks.

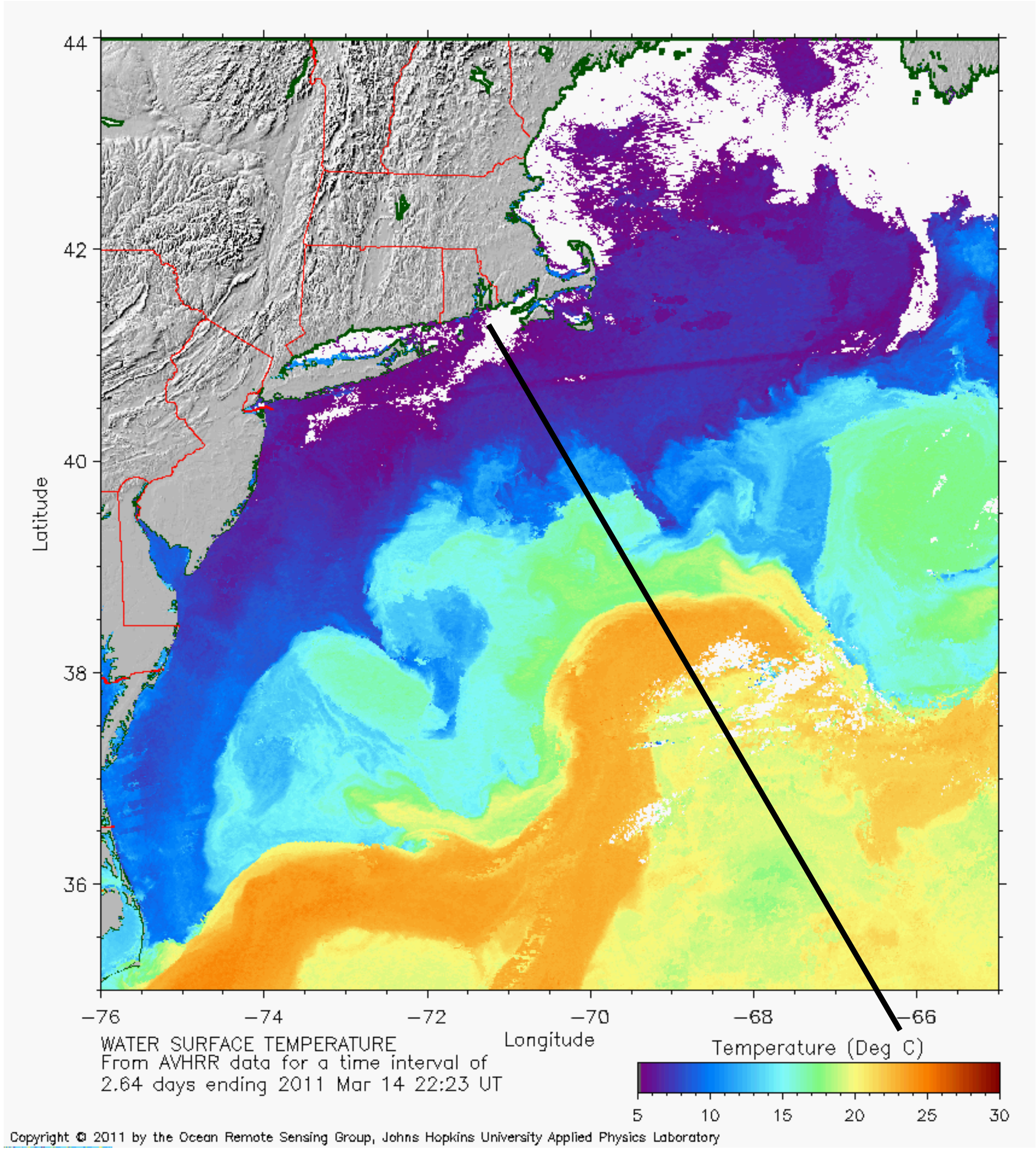

Figure 1 Three Day Composite Satellite Image SST - Issued March 14, 2011

Source : http://fermi.jhuapl.edu/avhrr/

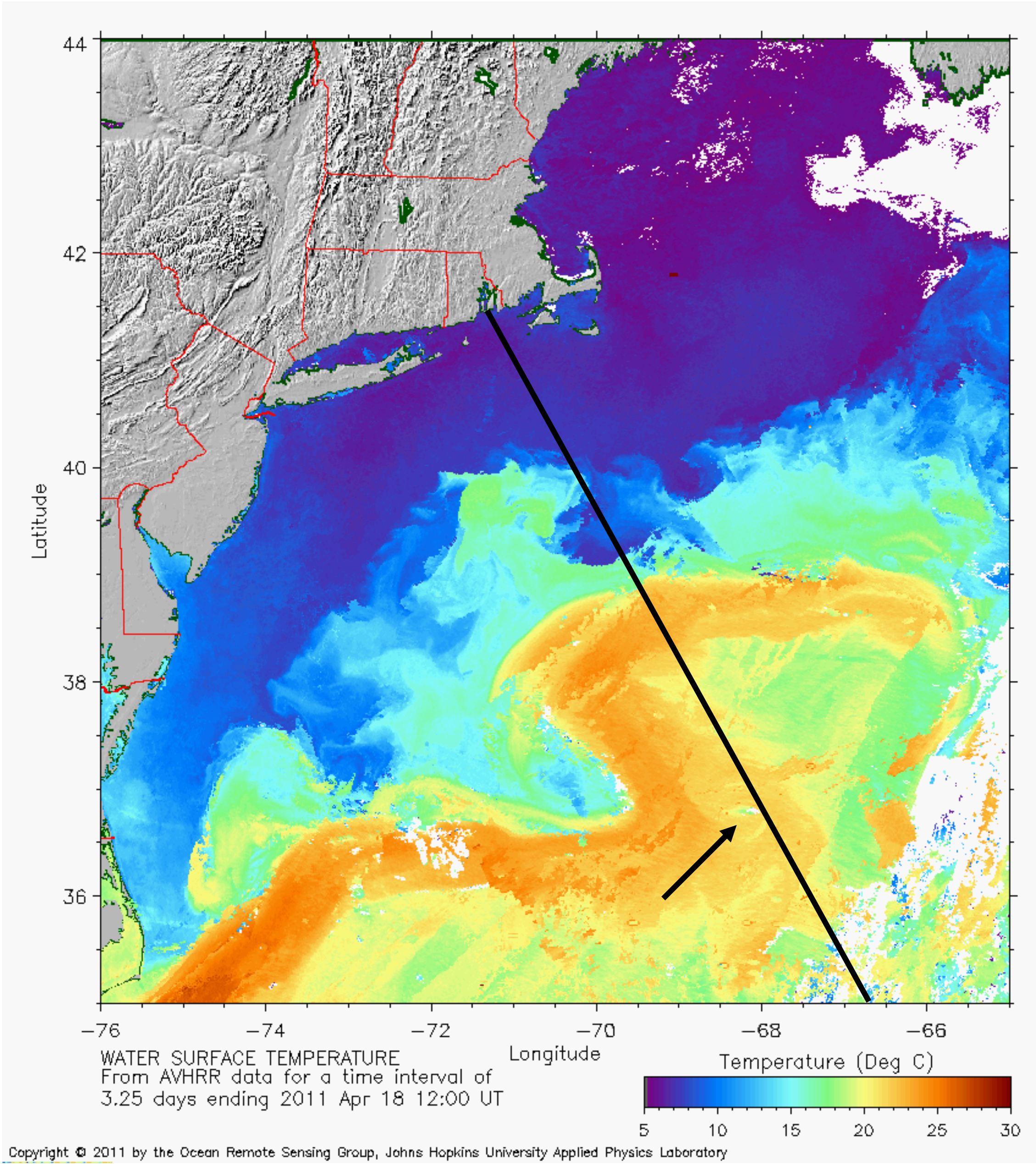

Figure 2 Three Day Composite Satellite Image SST – Issued April 18, 2011
Arrow indicates possible cold core ring
Source : http://fermi.jhuapl.edu/avhrr/

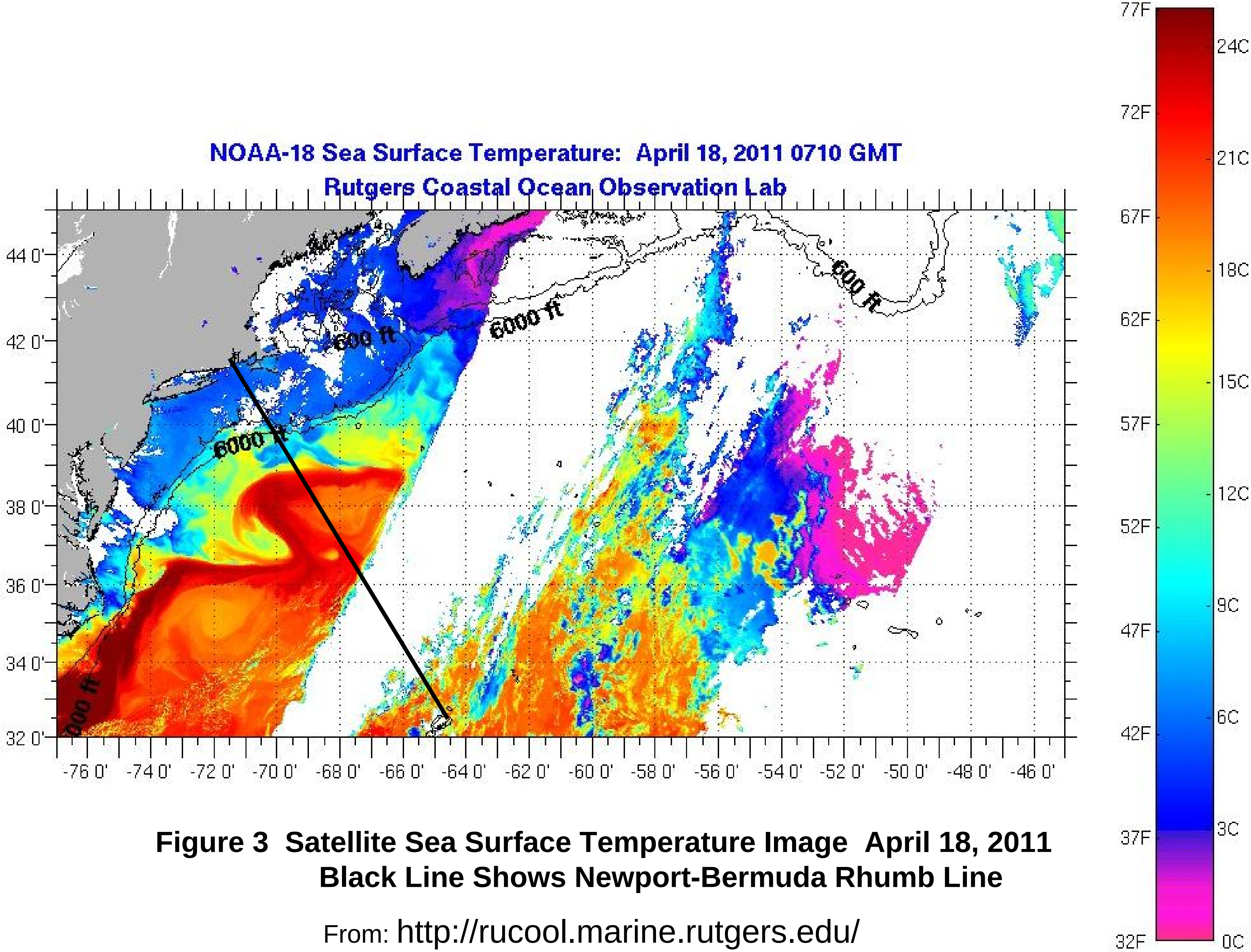

Figure 3 Satellite Sea Surface Temperature Image April 18, 2011
Black Line Shows Newport-Bermuda Rhumb Line

From: http://rucool.marine.rutgers.edu/

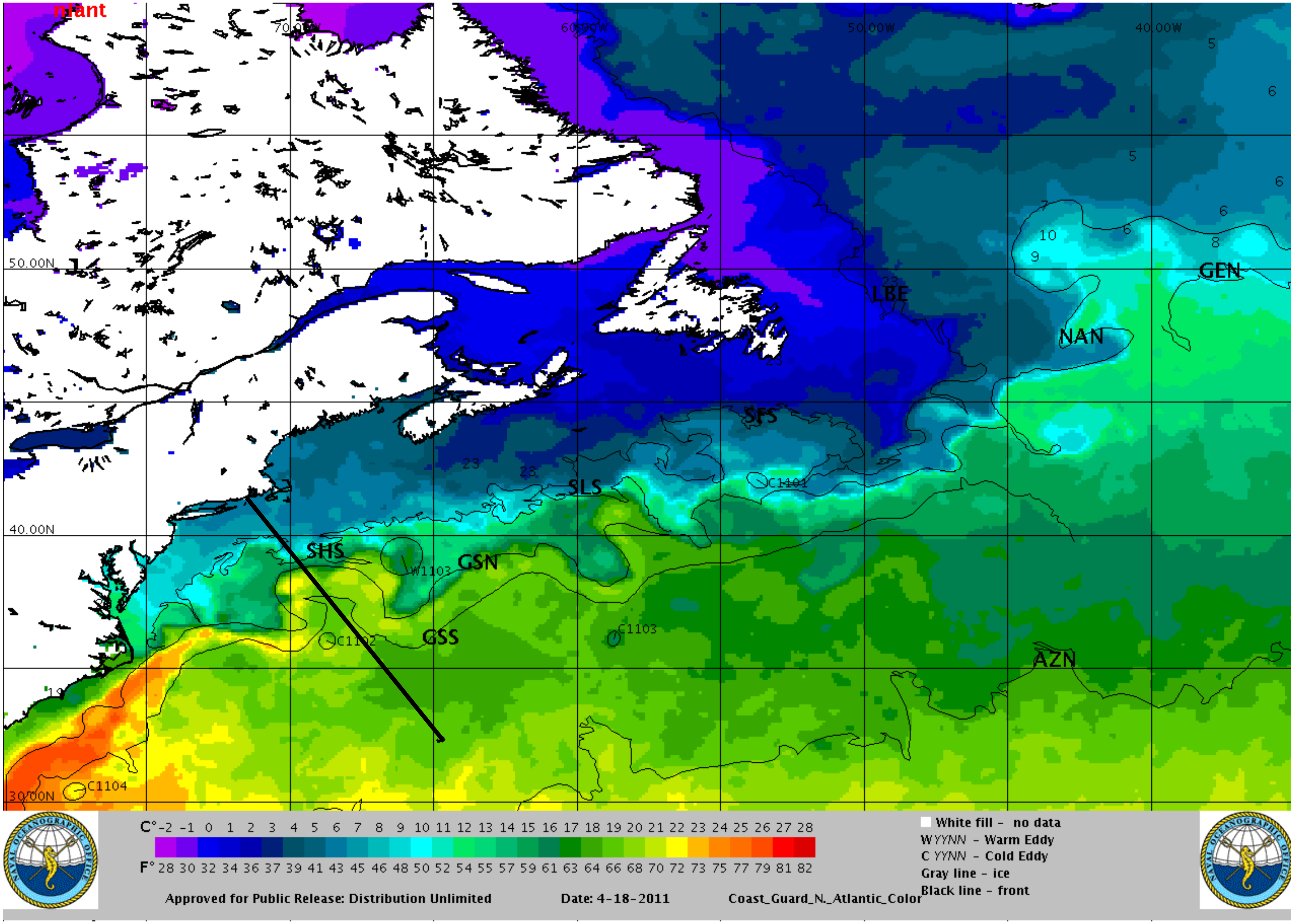

Figure 4 Northwest Atlantic Sea surface Temperatures – April 18, 2011

From: http://ecowatch.ncddc.noaa.gov/JAG/Navy/

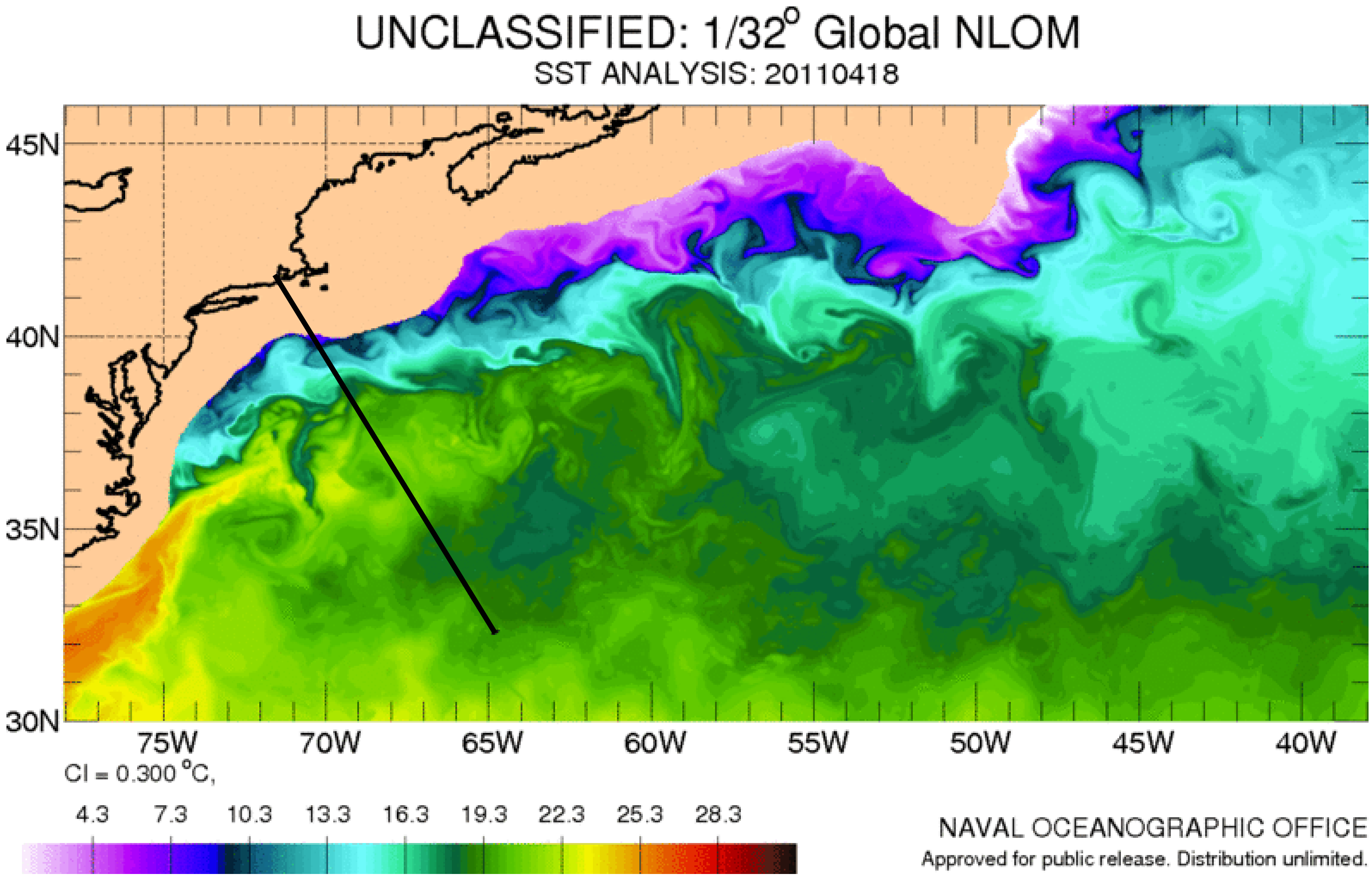

Figure 5 Gulf Stream – Numerical Model Results - April 18, 2011

From: http://www7320.nrlssc.navy.mil/global_nlom32/navo/GFSTRSST.gif

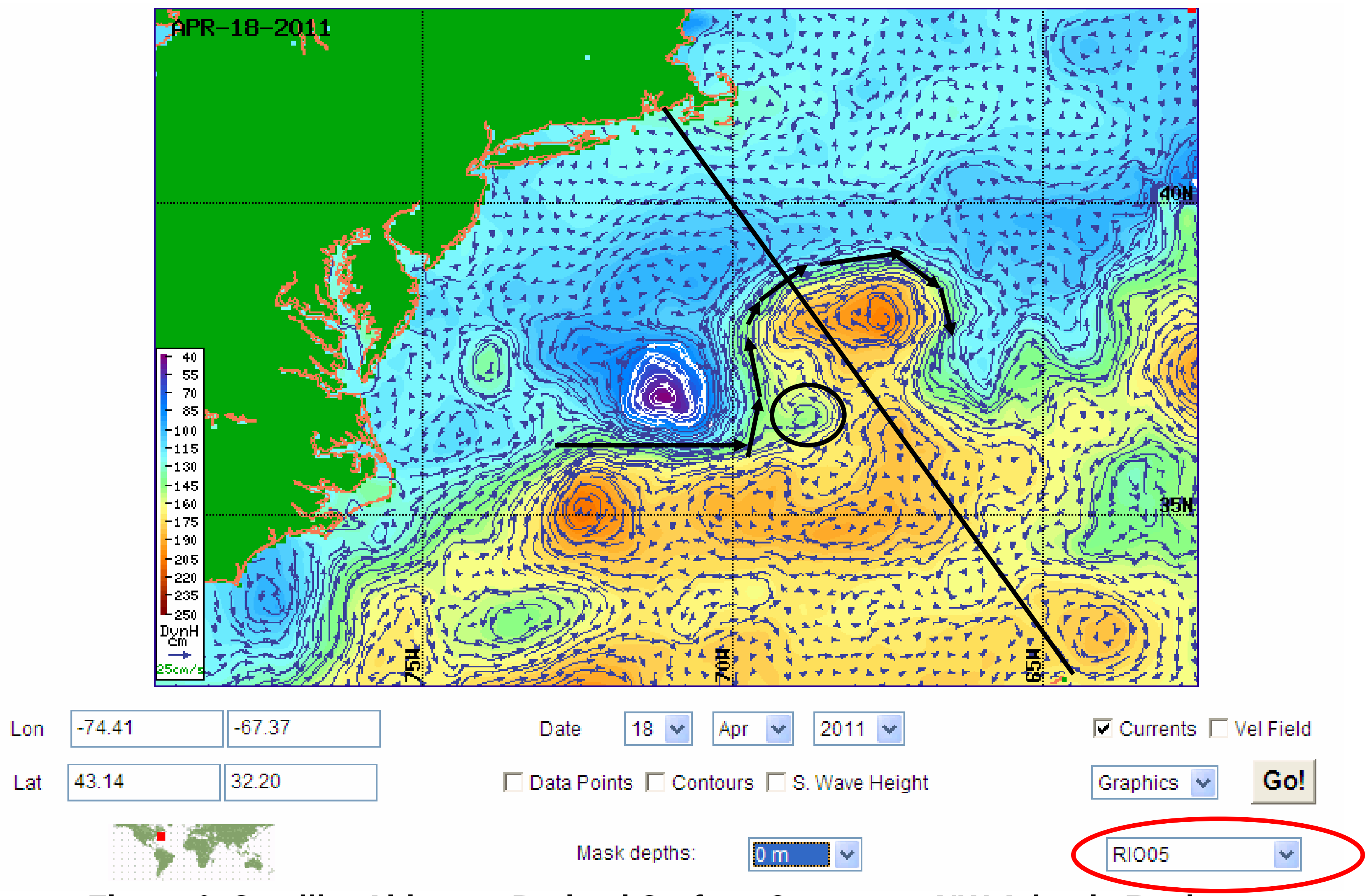

Figure 6 Satellite Altimetry Derived Surface Currents – NW Atlantic Region

Note: Black detailing of Stream boundary and ring added for clarity

From: http://www.aoml.noaa.gov/phod/dataphod/work/trinanes/INTERFACE/index.html