The Gulf Stream Near the Rhumb Line Newport-Bermuda May 13, 2016
An Analysis of Conditions

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With slightly more than a month to go until the start of this year's Newport Bermuda Race it's time for the diligent navigator to begin study of existing Gulf Stream conditions in combination with daily/weekly weather patterns and their evolution. This is recommended whether or not you plan to employ meteorological or oceanographic consultants before the Race. The above studies will make for a more informed client and will assist with evaluations of conditions during the Race when predictions provided before the Race have been known to deviate from those observed along the track.

Your study might begin by reviewing an article that I wrote several years ago describing the fundamental characteristics of the Stream and its inherent variability. This ***Gulf Stream Primer*** is posted with my tutorials on the Race website **(**www.Bermudarace.com) under the Resources tab (Gulf Stream & WX). The article ***Gulf Stream Analysis and Prediction*** in this year's Race Program builds on these fundamentals and provides an introduction to computer models used in the routing programs used by many competitors.

Recognizing that the Gulf Stream is a reasonably well defined warm water current which proceeds from Cape Hatteras towards Europe most studies of Stream position and dynamics begin by analyzing sea surface temperature (SST) patterns in the vicinity of the rhumb line. There are a number of web sites which provide satellite observations of SST but I favor the site maintained Rutgers University scientists at the Coastal Ocean Observation Laboratory (http://rucool.marine.rutgers.edu). Instantaneous and daily composite images of SST in the Gulf Stream region are available on this site by going to **DATA** on the Main Menu and then to "Real-time and Archived Satellite Imagery". Similar views are available on the Johns Hopkins University (JHU) site (http://fermi.jhuapl.edu/sat_ocean.html) by using the "**Real-Time NOAA AVHRR Imagery"** tab and then down to **"JHU Applied Physics Laboratory, Ocean Remote Sensing Group"**. Although no instantaneous images are available at this site the three day and seven day composites that are provided are often of particular value during periods of e xtended cloud cover which limit satellite views of the ocean's surface.

Scrolling through the archive of satellite imagery, both instantaneous and composite, maintained at the Rutgers site provides graphic illustration of the extent of northwestern

Atlantic cloud cover that has been present over the past five months. Clouds resulted in no clear images of Gulf Stream region SST for the entire month of January with conditions improving only slightly in February and March. April and May views are similarly limited by clouds with relatively few consecutive cloud free days. It should be evident why early study of the Stream is so often advised.

When observed in early February the northern edge, or north wall of the Gulf Stream, shown by a sharp increase in surface water temperature from approximately 66^{o} F 18^{o} C) to 76^{o} F (24^{o} C), crossed the Newport-Bermuda (NB) rhumb line at a point approximately 210 nm from Newport (Fig.1). The observed SST pattern suggests that the current across the rhumb line was proceeding from west to east at near right angles to the line. Maximum speeds would be found in an area approximately 20 to 30nm to the south of the north wall. From Cape Hatteras to this point the Stream appeared as a near linear feature with a gentle meandering pattern along its northern, inshore, edge. Immediately east of the rhumb line however, there was evidence of an abrupt change in position with flows proceeding to the southeast. Unfortunately details of this feature were obscured by clouds. These conditions would favor a route to Bermuda that went west of the rhumb line to get through the main body of the Stream as quickly as possible. The distance west would be dependent on the winds and potential boat speeds. The limited visibility due to cloud cover prevents accurate evaluation of conditions south of the main body of the Stream. What can be seen suggests that there may be cold core rings in this area requiring care in the selection of a course to Bermuda. We will look at methods to assist in this in a moment.

One month later the gentle meander observed in February had deepened significantly forming a nearly sinusoidal wave extending from Cape Hatteras to 62^{o} W (Fig.2). This deepening brought the north wall crossing of the rhumb line closer to Newport by approximately 25nm. The water temperature gradient was nearly the same as observed in February. The observed SST pattern favors flows proceeding from the northwest to the southeast across the rhumb line with maxima again located approximately 30nm to the south. Beyond the main body of the Stream (the area shown prominently in red) the SST pattern indicates an organized area of cooler water with a warmer perimeter. This is the characteristic signature of a cold core ring. As discussed in the *Primer,* cold core features produce a counterclockwise rotating current with maximum speeds of approximately 3kts. Because the cooler, higher density, water mass sometimes allows a “skin” of warmer water to accumulate over the ring they may be difficult to observe and accurately define in standard satellite images since satellite sensors only measure immediate surface temperatures. Fortunately we have available to us an alternative to the SST observations to assist in the evaluation of these features.

Since 1992 and the launch of the TOPEX/Poseidon satellite, NASA and partners have been measuring sea surface heights with great accuracy. Heights are directly correlated with the factors causing currents. These radar measurements are virtually insensitive to cloud conditions and provide a stream of data which serves as the basis for a computer model of global ocean circulation which is updated daily (http://www.aoml.noaa.gov/). Model output provides a comprehensive view of Stream structure both in and adjacent to the main body as well as indications of relative flow speeds. Actual flow magnitudes however, are slightly low due to model formulation. Over the past ten years I have used this model in a variety of applications including each of the Newport Bermuda Races and found it to be remarkably accurate. As discussed in my Race Program article there are a number of other models but this one allows easy selection of a small area for analysis which provides a more detailed view of flow conditions than the other NOAA or Navy models.

The altimetry based model results for March 11 (two day delay required for data reduction) indicates that the flows adjoining the rhumb line on March 9 (Fig.2) are influenced first by the meander and then by an evident cold core ring centered near 38^{o} 15’ N 68^{o} 30’ W (Fig.3). The ring diameter is approximately 180nm consistent with the SST pattern. This combination of factors favors a track proceeding to a point approximately 50-60nm west of the rhumb line near 37^{o} N in the northern limits of the ring. Currents in this area would initially set to the west followed by an increasing southerly set along the westerly margin of the ring. Depending on wind directions the course being steered would also progressively change to maintain CMG towards Bermuda. The model results also show two additional rings south of 35^{o} N (Fig.3). The northern one of the pair, just south of 35^{o} N provides a favorable set towards Bermuda for boats west of the rhumb line. The southern one centered near 32^{o} 50’ N 66^{o} 30’ W will produce adverse currents to the west of the rhumb line which cannot, under the usual wind conditions and the proximity of Bermuda, be easily avoided. Adverse effects can be minimized by proceeding east to the rhumb line.

Both Stream meanders and rings can be expected to evolve with time and change position. The meanders are expected to proceed downstream towards Europe at rates of approximately 10nm/day. Both warm core and cold core rings will drift to the west at rates near 2-3nm/day. Since these movements can substantially affect flow patterns along the course it’s important to become familiar with the actual drift rates. That’s the real value of time series observations and one of the primary reasons for starting your study of the Stream as early as possible. In addition these studies often provide clear indication that Stream evolution does not always occur as predicted.

By mid-April the orderly meander observed in March had not simply migrated to the east but rather had abruptly deepened west of the rhumbline and broken in pieces to the east (Fig.4). The SST pattern also indicates the continuing presence of a cold core feature near 36^{o} N 68^{o} W although the fragmented SST patterns suggest that this is more likely an artifact resulting from the compositing process used to produce this image. This conclusion is supported by the altimetry based model results (Fig.5) which show that the ring observed in March (Fig.3) was essentially absorbed by the reorganization of the meander. The single organized area of counter clockwise rotation is centered near 33^{o} N 68^{o} W and may be the result of the consolidation of the pair of cold core rings observed in March south of 35^{o} N(Fig.3). The flow pattern resulting from these changes continues to favor a track to the west of the rhumb line for boats heading to Bermuda and east for those returning to New England. Overall the strategic choices are simpler in April than they were in March.

Over the next three weeks into early May clouds continued to limit satellite views but those that were available showed only minor change in the Stream structure near the rhumb line from that observed on April 19 (Fig.4). The western limb of the meander proceeded to move slowly to the east and by May 9 was in close contact with the rhumb line (Fig.6). The pattern indicates a dominance of flow from the northwest to the southeast in the area west of the rhumb line and ultimately across the line. To the east the trough formed in April remained unchanged but for the development of a large circular pool of warm water near 40^{o} N 66^{o} 30'W . This progression indicates that the meander is slowly moving to the east and may over the next month undergo some "interesting" changes both in terms of position and structure. Portions may also detach forming rings with the potential to affect the region of the rhumb line and strategic decisions for boats going to and coming back from Bermuda.

To the south of the main body of the Stream clouds again obscure the SST patterns. Examination of the output from the altimetry based model for May 11 (Fig.7) indicates that the flows in this area are more complicated than indicated by the SST image. In particular, the cold core feature observed in March has reformed and is now centered near 35^{o} 45' N 68^{o} 30' W affecting an area 120nm in diameter. Simple reliance on the SST composite image would have resulted in selection of a track that would very likely have encountered an extended area of adverse currents south of 37^{o} N. Use of the altimetry based model favors entry of the Stream near 38^{o} 30' N 70^{o} W approximately 30-40nm west of the rhumb line for boats enroute Newport to Bermuda. This south southeasterly track would continue to a point at least 60nm west of the rhumb line along the western perimeter of the ring. Only south of 35^{o} 30' N would the track be directed to Bermuda. Once clear of the ring the altimetry based model shows no significant adverse flows affecting the route to Bermuda. A cold core ring is shown centered near 34^{o} N 65^{o} 30' W just to the east of the rhumb line. Since the drift of these features tends to be to the west this ring may come to affect the track to Bermuda over the next few weeks. We will look to follow its evolution in the next Note.

To summarize:

- The Gulf Stream is a dynamic ocean current characterized by significant spatial and temporal variability. Early study is recommended to develop an understanding of existing Stream structure and its potential evolution.
- Cloud cover complicates evaluations of Stream characteristics that rely on satellite SST observations. This can be overcome to some extent by the use of selected computer models such as the altimetry based model to supplement SST observations. We are fortunate today to have so many options available to us on the web.
- Observations over the past four months provide clear evidence that Stream evolution including the migration of meanders and the position and drift of rings does not always follow simple rules. This sometimes chaotic behavior is best understood using a variety of data from both direct observations (e.g. satellites) and computer models
- At present the Stream in the vicinity of the rhumb line is dominated by a large amplitude meander and a cold core ring. The combination affects approximately 240nm of the rhumb line. It's important to realize that this influence includes both current characteristics and the regional weather. The Gulf Stream is a known as a "weather breeder" affecting winds and sea state. Routing must take both of these factors into account.
- As you study the Stream in anticipation of the Race to Bermuda remember that the understanding gained can also be of use during the return to the United States.

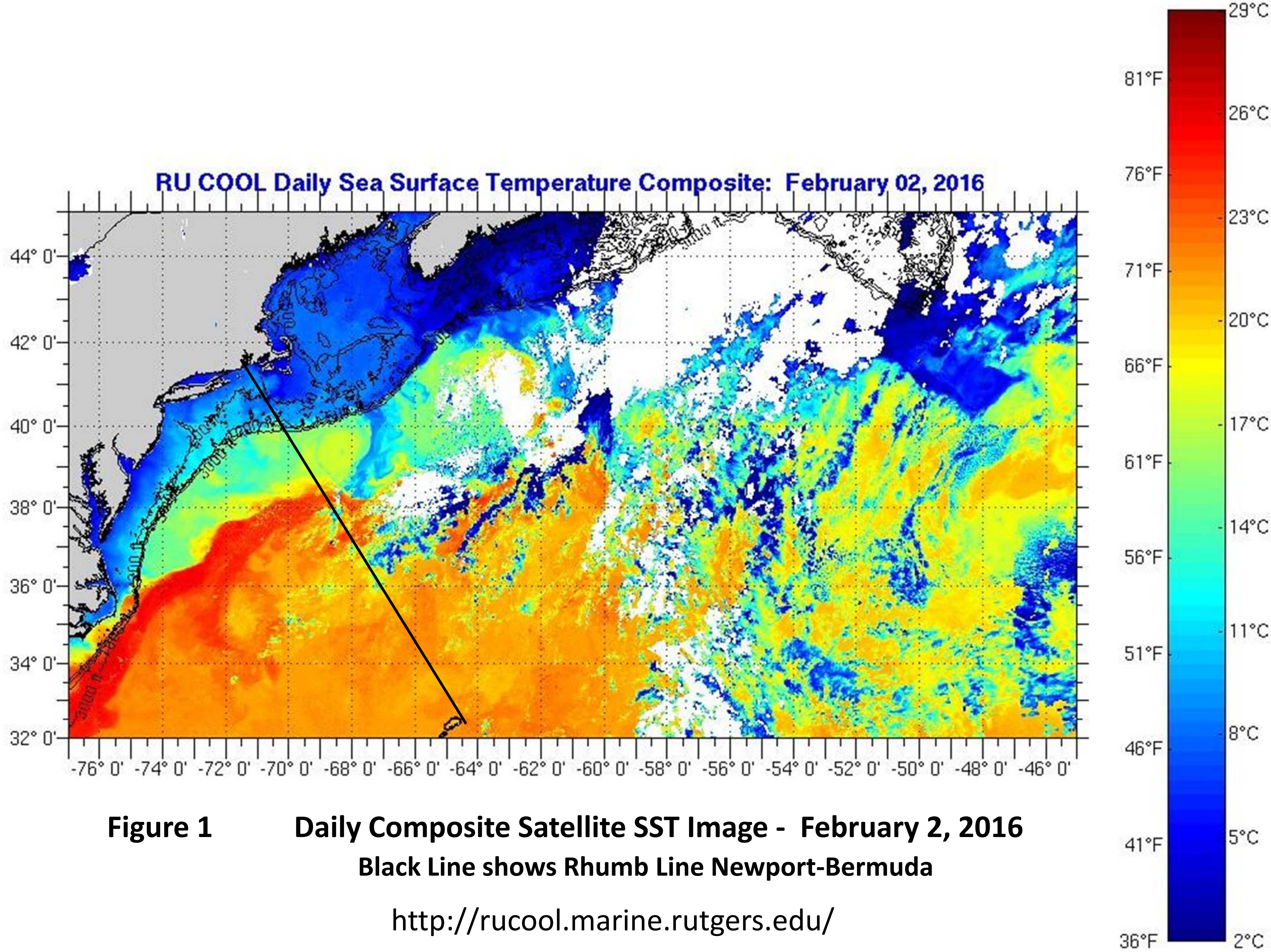
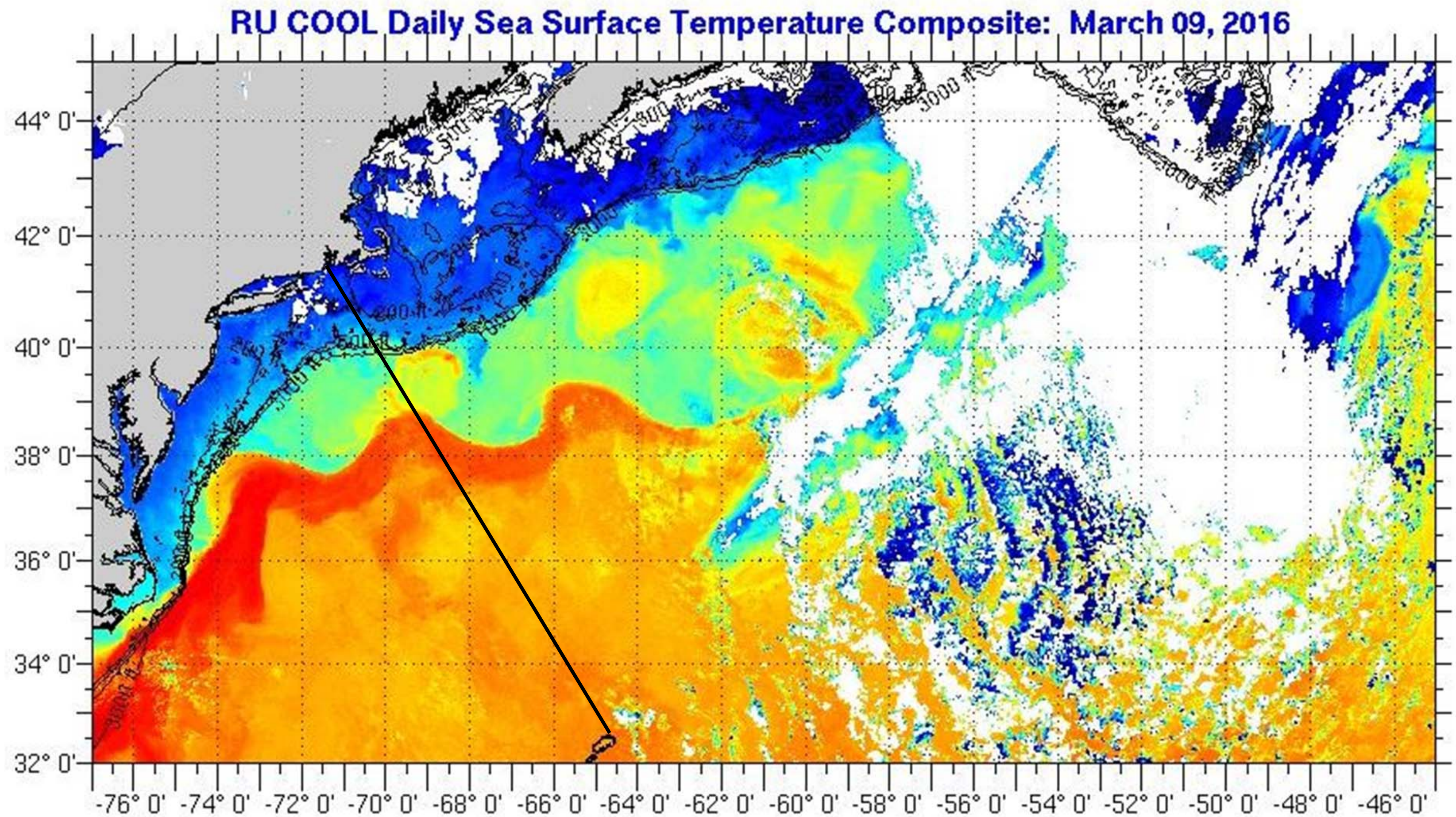


Figure 1 **Daily Composite Satellite SST Image - February 2, 2016**

Black Line shows Rhumb Line Newport-Bermuda

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



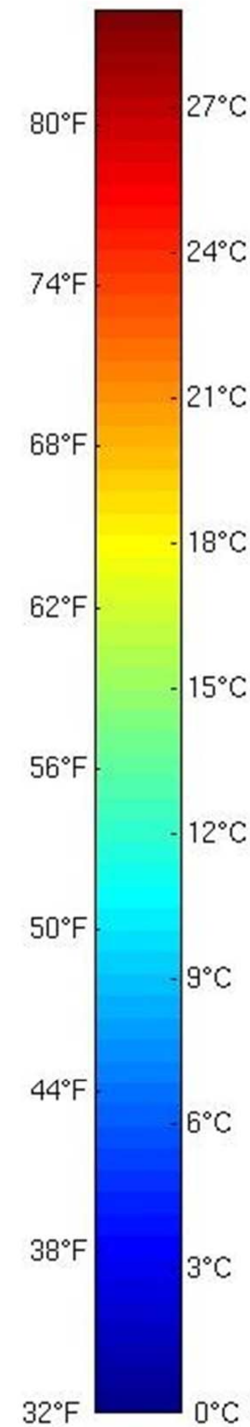


Figure 2 Daily Composite Satellite SST Image - March 9, 2016

Black Line shows Rhumb Line Newport-Bermuda

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

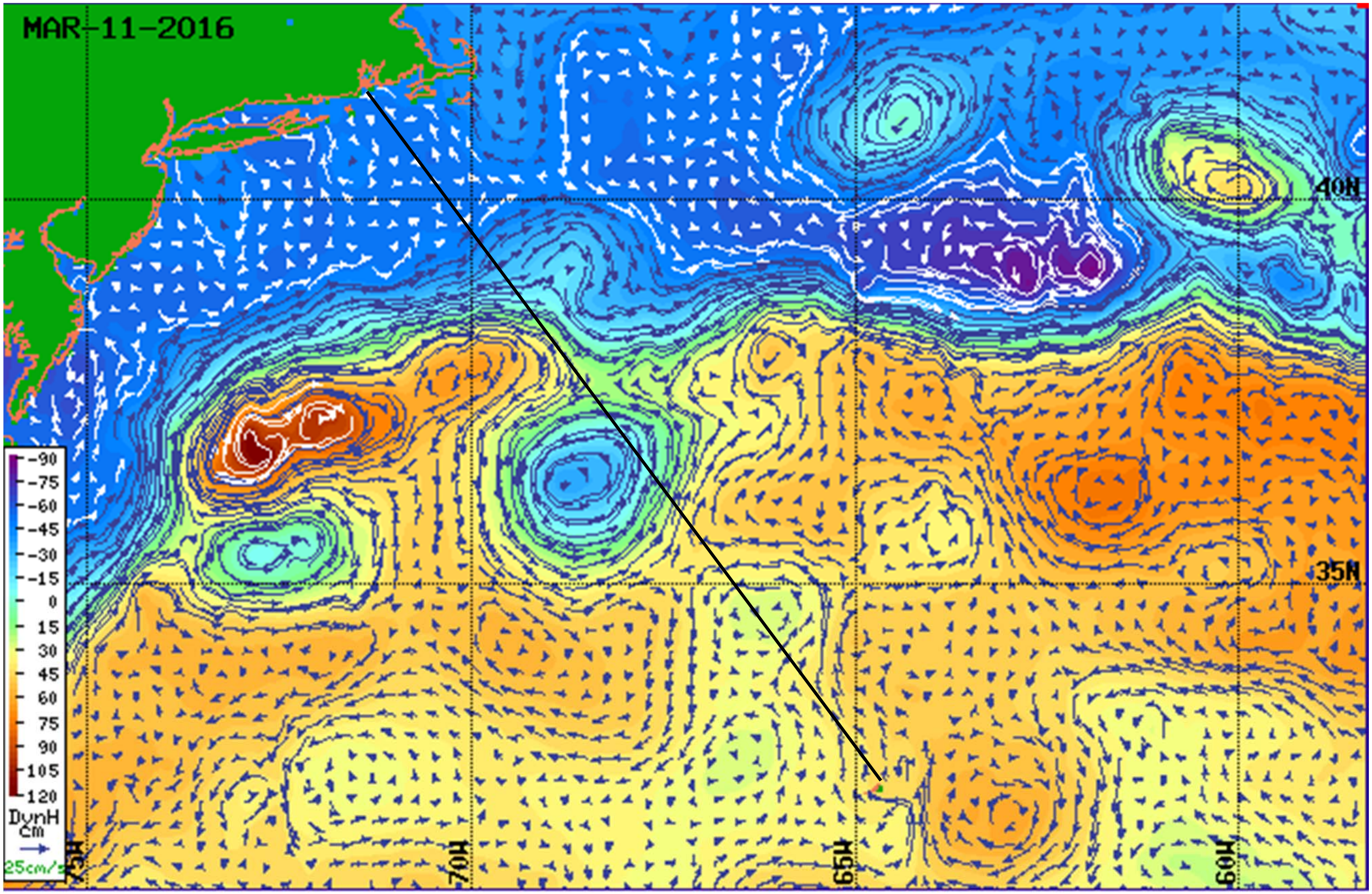
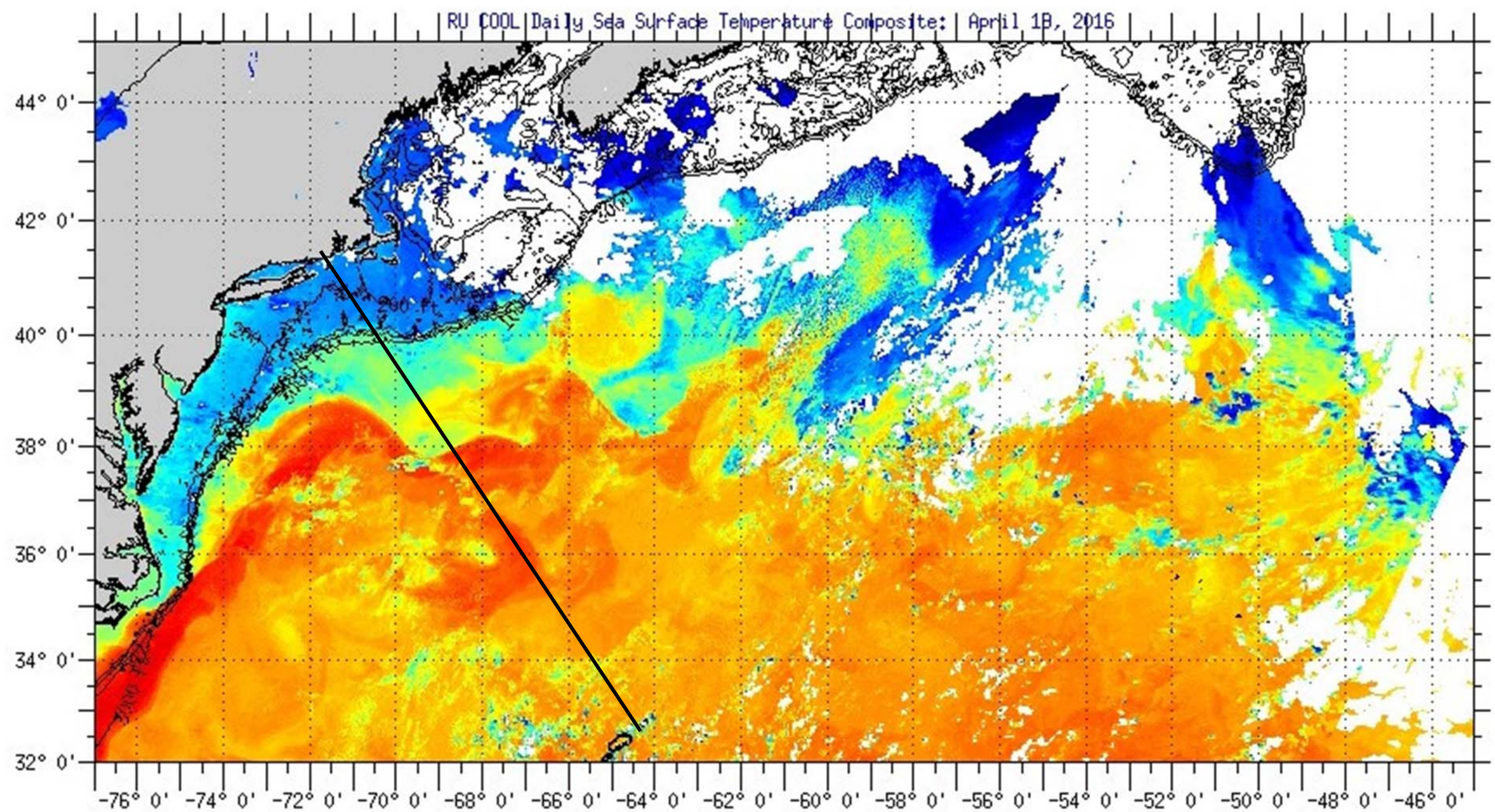


Figure 3 Satellite Altimetry Derived Surface Currents- NW Atlantic Region- March 11, 2016

Black Line shows Rhumb Line Newport-Bermuda

http://www.aoml.noaa.gov/



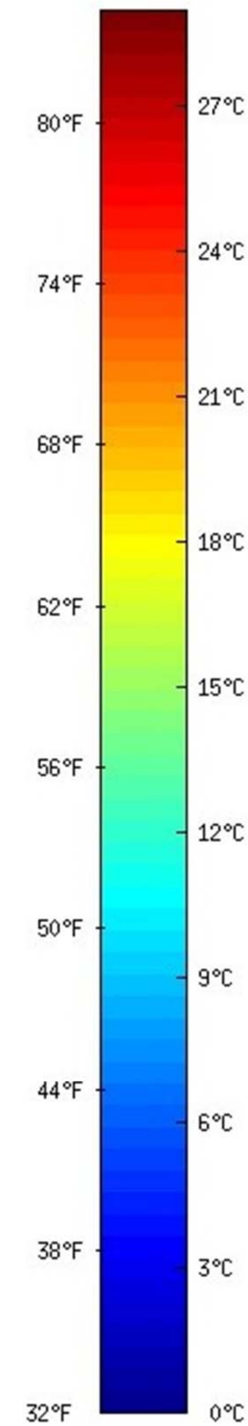


Figure 4 Daily Composite Satellite SST Image - April 19, 2016
Black Line shows Rhumb Line Newport-Bermuda

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

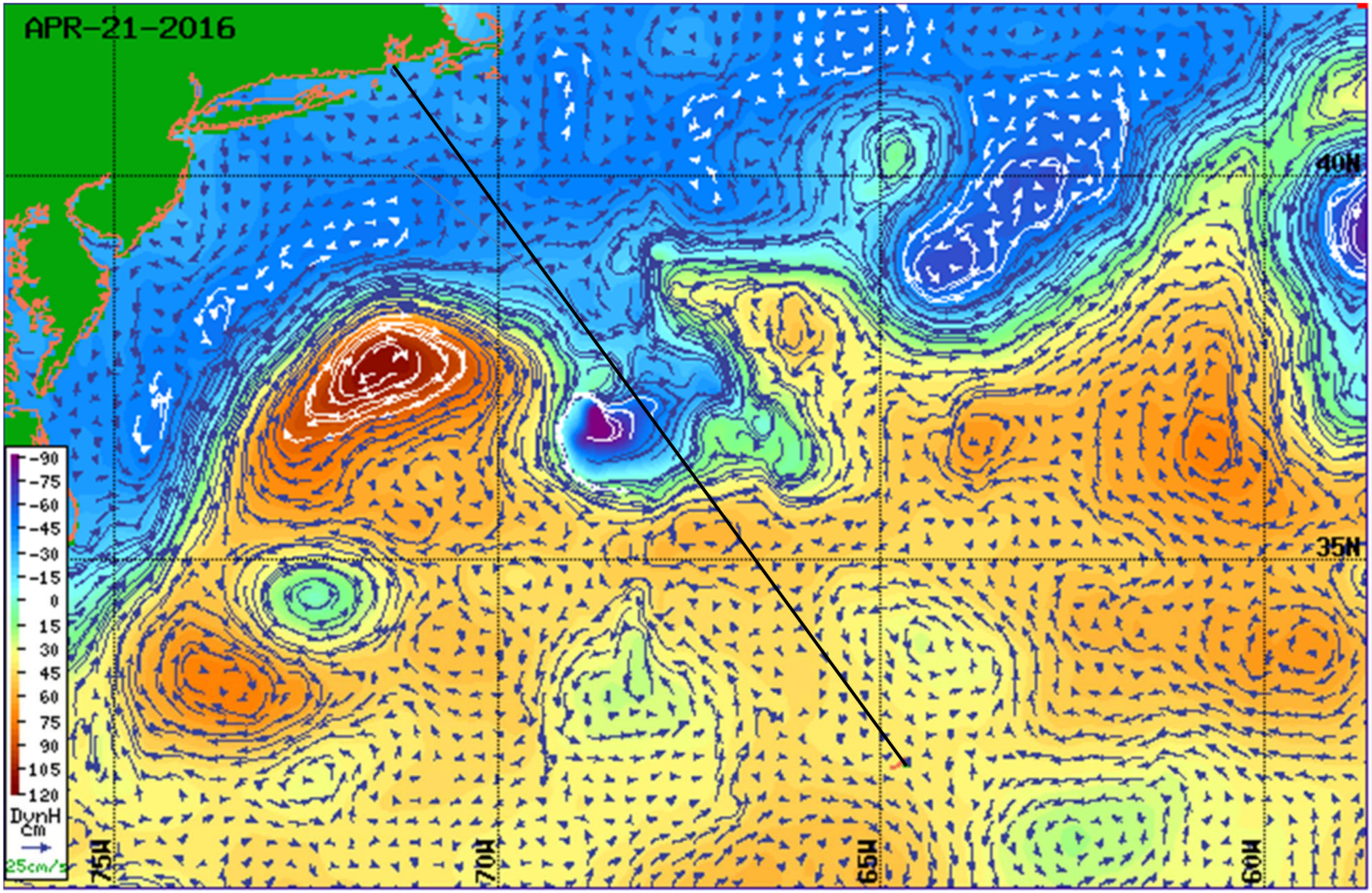


Figure 5 Satellite Altimetry Derived Surface Currents- NW Atlantic Region- April 21, 2016

Black Line shows Rhumb Line Newport-Bermuda

http://www.aoml.noaa.gov/

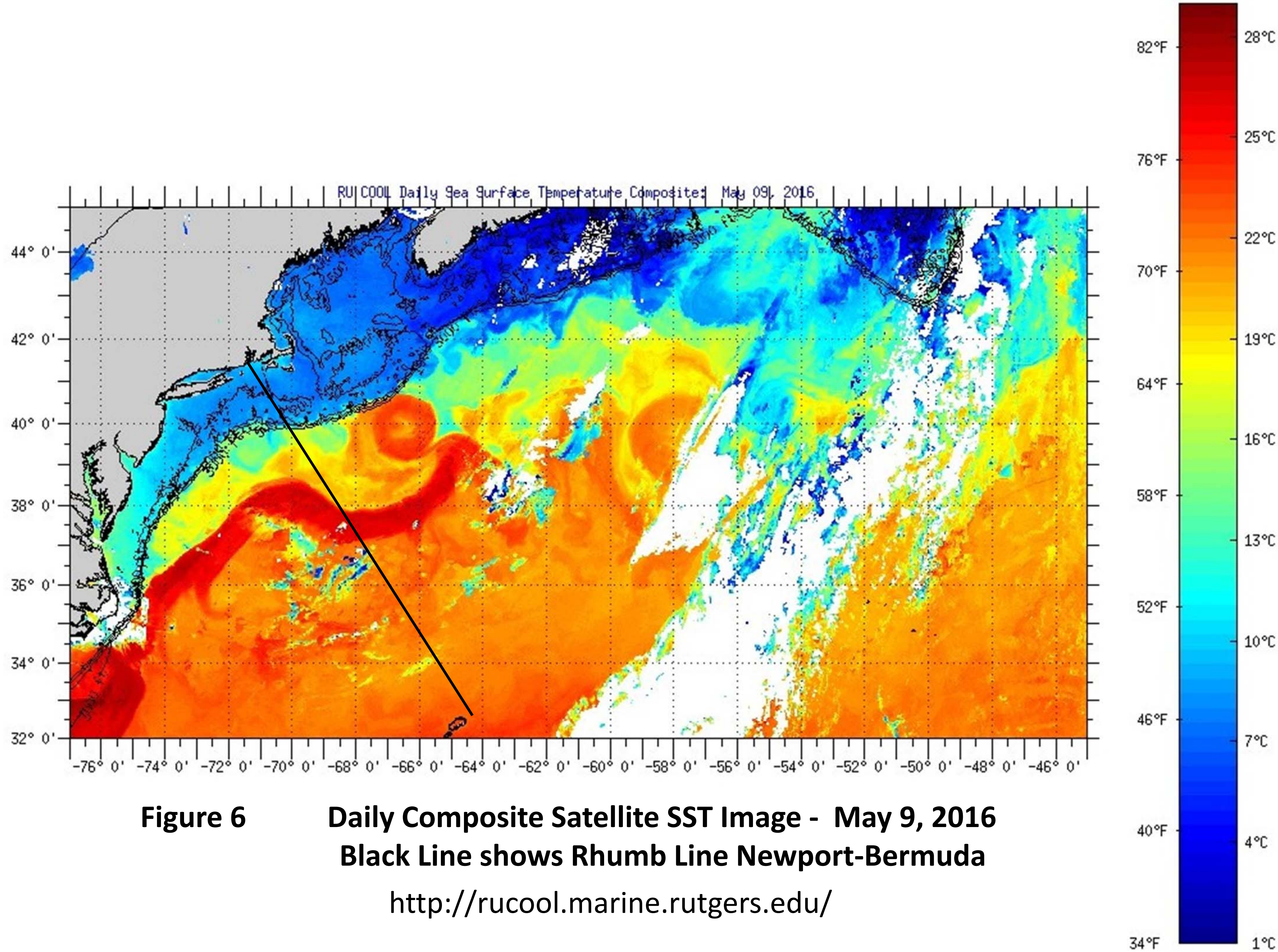


Figure 6 Daily Composite Satellite SST Image - May 9, 2016
Black Line shows Rhumb Line Newport-Bermuda

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

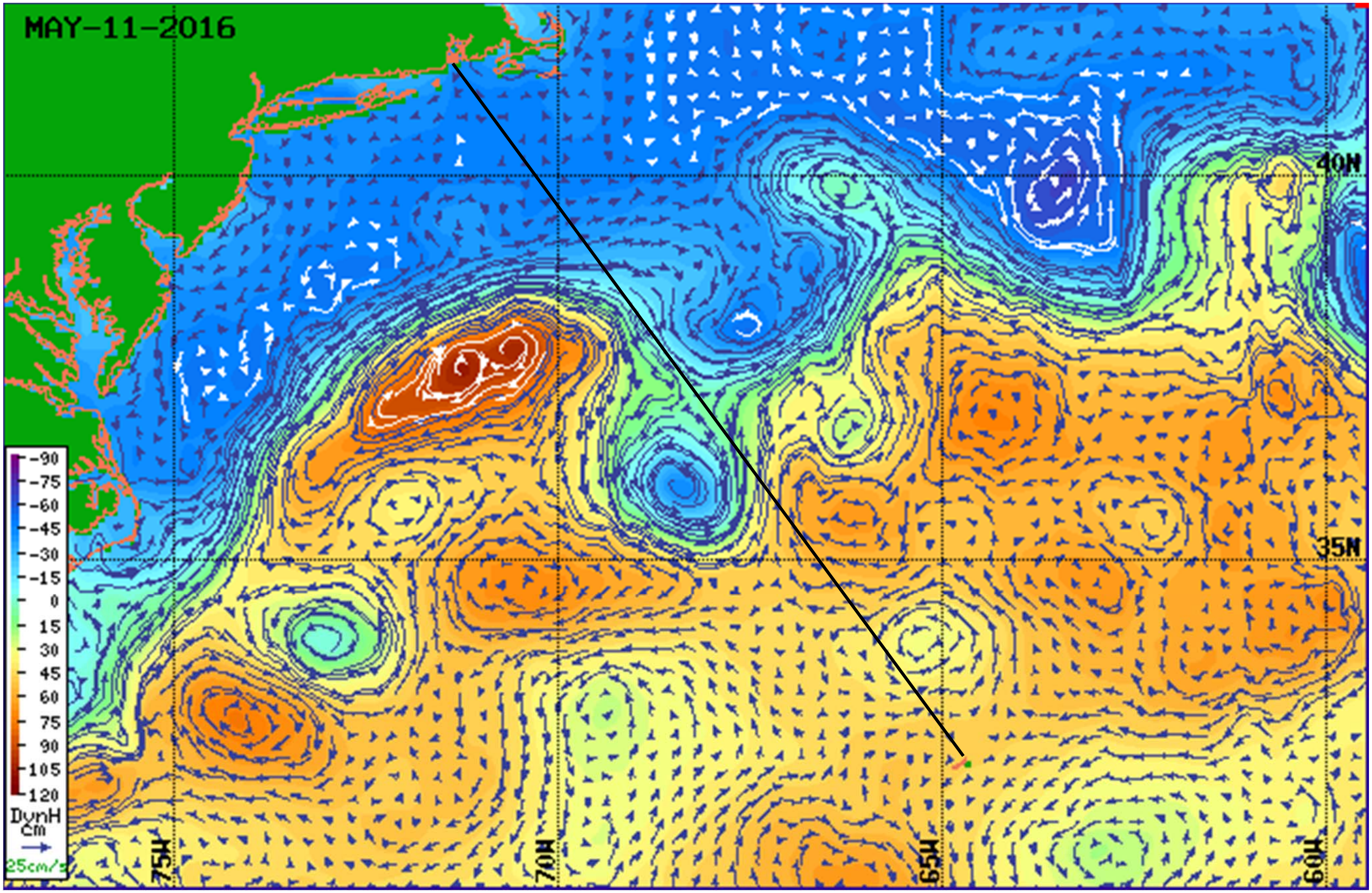


Figure 7 Satellite Altimetry Derived Surface Currents- NW Atlantic Region- May 11, 2016

Black Line shows Rhumb Line Newport-Bermuda

http://www.aoml.noaa.gov/