The Gulf Stream Near the Rhumb Line Newport-Bermuda May 2, 2008
An Analysis of Conditions

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Since March, 2008 the Gulf Stream in the vicinity of the Newport-Bermuda rhumb line has displayed a complex of sea surface temperature patterns including prominent meanders and a combination of warm and cold-core rings. The evolution of these features has been difficult to detail due to the nearly continuous cloud cover during this period. Cloud cover density has been sufficient to affect the quality of both instantaneous satellite views of the sea surface and the longer term composite images made up by combining a number of instantaneous views. These conditions provide clear indication of the value of early study of the Stream if an accurate picture of conditions is to be available for Race planning. Delays in the initiation of this process until a week or two before the Race could very well result in little useful data. I'll attempt over the next 50 days or so to assist you in this process. We'll share the results during the Navigator's Forum scheduled for Thursday June 26 at the RBYC.

As a start, let's briefly review what we are dealing with. The Gulf Stream represents the major boundary current in the North Atlantic Ocean. It is a part of the clockwise circulation pattern affecting the entire North Atlantic Ocean. This circulation is responsible for the transport of significant quantities of heat from the equatorial regions to the northern latitudes. As a result it should not be surprising that one of the Stream's principal features is its temperature. The Stream consists of a relatively warm mass of water which stands in sharp contrast to the cooler waters found along the continental shelf bordering the U.S. east coast. Stream temperatures even tend to be higher than those found in the interior of the Sargasso Sea surrounding Bermuda. These temperature contrasts or gradients affect the density of the water column just as differences in air temperature affects air column densities. And, just as differences in air column density results in horizontal gradients in barometric pressure sufficient to cause flows, i.e. winds, the differences in water column densities affect the oceanic pressure field and drive currents. The greater the temperature difference over a given distance the greater the speed of the flow. The direction of flow depends on the direction of the gradient. In the northern hemisphere an observer with warm water to his right and cold to the left will be facing downstream i.e. looking in the direction towards which the flow is going.

The waters that form the Gulf Stream leave the Straits of Florida and flow northerly in close contact with the continental margin of the southeastern states until they reach Cape Hatteras. Beyond this point the flow departs from the continental margin and proceeds offshore to the north and east. In addition to the change in direction, this point also marks the beginning of a substantial change in flow structure. Here the rather well ordered shore parallel flow found along the coast of Georgia and the Carolinas is replaced by a spatially variant meandering flow field similar in form to a stream of smoke in the wake of a chimney. These variations affect both the planview contours of the Stream as indicated by the sea surface temperature patterns and associated gradients and the proximity of the northern limits of the Stream to the coast of New England. Both of these characteristics have the potential to significantly affect a boat's track and rate of progress as it proceeds along the Newport-Bermuda rhumb line.

Viewed from aloft the meandering Gulf Stream to the north and east of Cape Hatteras displays a wavelike pattern with crests and troughs of varying frequency, wavelength, and amplitude. These features typically migrate to the northeast, or downstream, at rates of approximately 10 nm (nautical miles)/day. Migration is typically accompanied by an increase in amplitude which on occasion can lead to an instability resulting in the "pinching off" of a portion of the Stream and the formation of a new stand-alone feature or ring. The process is similar to that observed in meandering rivers leading to the formation of an oxbow lake. If the "pinch-off" occurs to the north of the main body of the Stream the ring will consist of a portion of warm water, from the adjoining Sargasso Sea, surrounded by Stream water. Such a WARM core ring is nearly circular with a diameter ranging from 60 to 180nm. If free of contact with the main body of the Stream , these rings will tend to migrate to the south and west at rates of approximately 0.05-0.1 knot and persist for six months or more before breaking up due to contact with the continental margin or entrainment in the main body of the Stream. The temperature contrasts between the inner core and outer boundary result in a clockwise (anti-cyclonic) flow with an average speed of approximately 2-2.5 kts. Maxima occur in the vicinity of the maximum thermal gradients typically found 10 to 30 nm or 1/3 of the radial distance in from the outer edge of the ring.

If the "pinch-off" occurs to the south of the main body of the Stream a COLD core ring is formed. These features, with diameters similar to the warm core rings, also tend to migrate to the southwest at a speed of less than 0.1 kt and, due to the absence of the continental margin influence, are typically longer lived than warm core rings. The temperature distribution characteristic of a cold core ring favors counter clockwise (cyclonic) currents around the core with average speeds approaching 3 knots. Again maxima are located some distance in from the outer edge of the ring in the vicinity of the maximum thermal gradients. The evident dependence of current speeds and directions on thermal gradients make the continuous monitoring of sea surface water temperatures an absolute necessity within Race strategic planning. These data also complement analyses and predictions of surface wind conditions.

To determine the extent to which this variety of Gulf Stream features may affect the track of a vessel heading for Bermuda it's only necessary to obtain a current map of sea surface temperatures for the northwestern Atlantic. These are available from several sources with my favorites given on the Race web site (bermudarace.com) under the Logistics and Resources link. I generally start by examining the satellite image file at the Rutgers University site (marine.rutgers.edu/mrs/). This graphically illustrates the extent of the cloud cover over the past month. It isn't until April 23-24 that the composite image represents a relatively "uncontaminated" view of the sea surface. The majority of the prior images are distorted to some extent due to cloud and water vapor effects. Selecting the 24th composite since it covers a large portion of the Stream we see that the main body of the Stream will (on this day) be encountered at a point approximately 200 nm from Newport (Fig.1). Water temperatures will be approximately 25^{o} C (77^{o}F) showing a marked increase on entry. The Stream appears to be relatively narrow (~40nm) with flows proceeding to the east. Maxima should be found approximately 10-15 nm to the southeast of the northern limits of the main body of the Stream in the region marked by maximum thermal gradients.

Although the satellite image shows that the limits of the main body of the Stream will be found 200nm down the Rhumb Line it also indicates that surface water temperatures will be on the increase much earlier with an evident boundary at a point approximately 120 nm from Newport. Temperatures at this point increase from shelf values of 10-15^o C to 20^o C +/- . The temperature gradient associated with this boundary favors flows proceeding to the east to northeast with some slight indication of a southerly component due to an inflection point in the temperature boundary as it crosses the Rhumb Line.

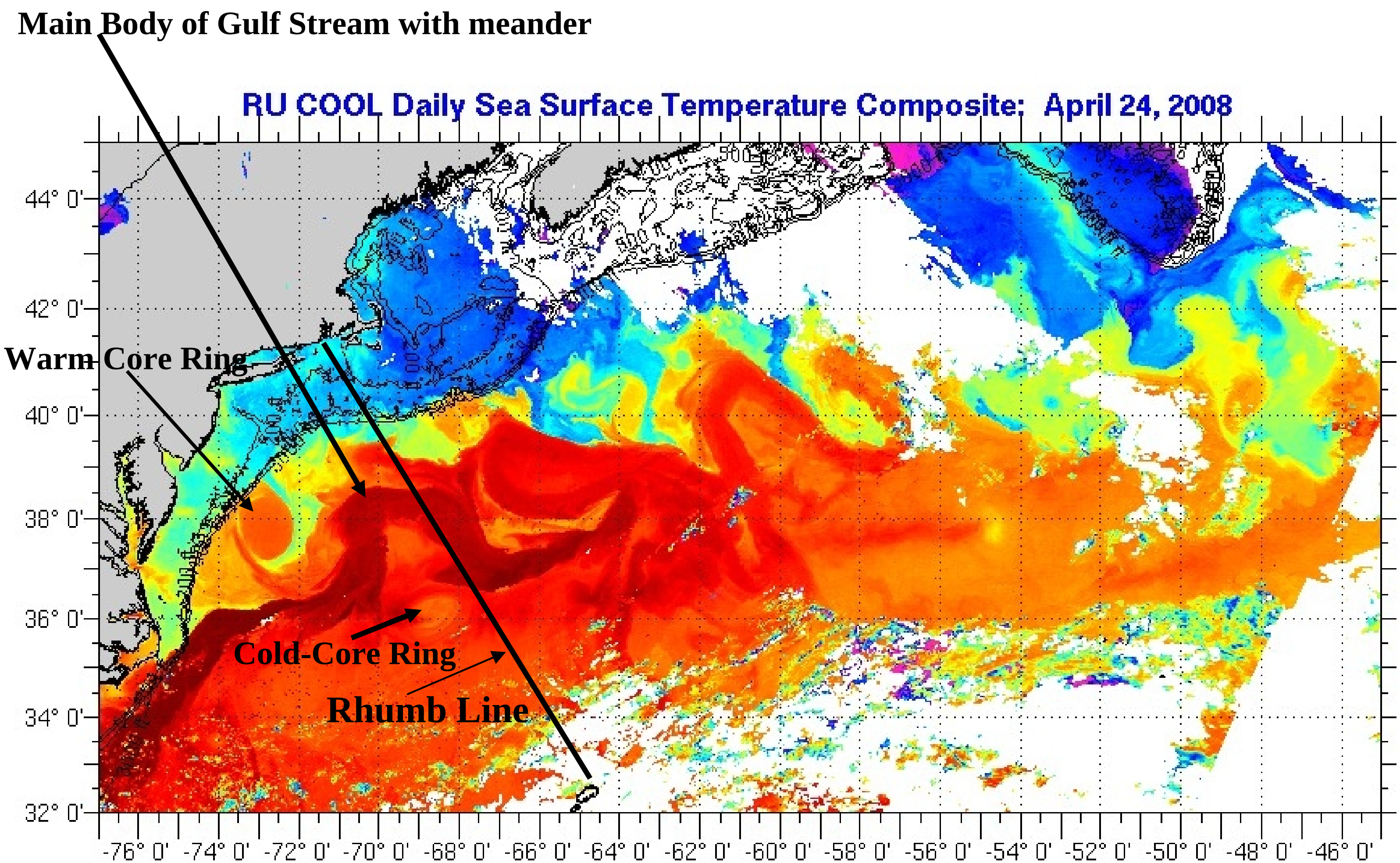
To the east and west of the Rhumb Line the main body of the Stream displays a significant sinuous meander with a portion of its eastern limb lying along the Rhumb Line. This favors a south going current down the Rhumb Line for nearly 120 nm. It also may result in a moderately rough sea state depending on wind conditions. Remember, however, that this meander is expected to progressively migrate to the east.

Beyond the southern limits of the main body meander the satellite image shows a well defined cold core eddy centered near 36^o 30' N 68^o 15' W. The eastern limits of this feature grazes the Rhumb Line resulting in north-northwest currents along a small section of the track. The presence of this ring has obvious implications to those favoring the west side of the course to Bermuda. This feature is expected to migrate to the west-southwest.

By May 2nd several of the features observed on April 24 have changed form and/or position (Fig.2). The three day composite image from Johns Hopkins shows a change in form but little easterly migration of the meander in the main body of the Stream providing clear indication of the time variability of the rates of meander migration as well as another indication of the value of extended study of Stream characteristics prior to departure. The change in shape of the meander results in flows across the Rhumb Line now proceeding to the south of east. Associated with this there is some slight displacement of the easterly limb of the meander favoring limited contact with the Rhumb Line. The initial thermal boundary located 120nm from Newport on April 24 has migrated to the southeast and is now located approximately 150-160 nm down the track. Flows along this boundary are proceeding to the south of east and there is no indication of any inflection point. Finally, the cold core ring remains evident in the image being now centered at 36^o N 68^o 45' W with a diameter of approximately 90nm. As a result of this southwesterly migration current maxima are now displaced west of the Rhumb Line by approximately 30nm.

The surface thermal data allow definition of the position of the Gulf Stream, the primary directions of flow and the influence of such features as meanders and rings. They cannot in themselves define current speeds. This requires calculation of the influence of temperature (acting in combination with the salt content or salinity of the water) on the density of the water column and ultimately on the pressure field that drives the currents. An alternative method makes use of the height of the water column over a given reference pressure surface. Oceanographers define a “standard ocean” with a specified distribution of water column temperature and salinity (i.e. density) to define heights and then study departures from this ideal, or anomalies, displayed by the real ocean. These anomalies are defined using a combination of direct satellite observations of sea surface elevation and computer based models. Direct current measurements show that the results of this technique are becoming increasingly precise and accurate particularly for ocean current systems such as the Gulf Stream characterized by a large change of water column density over relatively short distances. An example of the results of this method is shown in Figure 3.

The altimeter data indicate that the marked changes in surface temperature displayed in Figures 1 and 2 are accompanied by a significant change in sea surface elevation over the reference surface. Following the Rhumb Line from 40^o N to 38^o N elevation changes by nearly 1meter indicating that we’re sailing uphill to Bermuda ! The data also show that elevations can be expected to display significant spatial variability. This should come as no surprise given the spatial variability of the temperature field. These patterns favor a spatially variant flow field with magnitudes and directions governed by the water column highs and lows. The vectors (blue arrows) shown in Figure 3 represent model estimates of the current field produced by the spatially variant water column elevations. They provide a clear indication of the main body of the Stream and the character of the flow to be expected prior to the main body. Further south the eastern limb of the meander stands well away from the Rhumb Line as does the cold core ring. Flows along the Rhumb Line are generally south going until a northeasterly flow is encountered for a short time in the vicinity of 36^o 30'N 67^o 40' W. This, in combination with the form of the main body of the Stream and with due consideration of wind and forecast, might be taken to favor a track slightly east of the Rhumb Line. Further south, within 60-90 nm of Bermuda the model indicates that westerly flows develop. Of course, these favor progressive return to the Rhumb Line of those that departed to the east and some slight adverse current for those closing from the west. Overall, an interesting set of data worth some study in combination with the surface thermal data. We’ll continue this exercise next time. If there are any questions don’t hesitate to contact me.



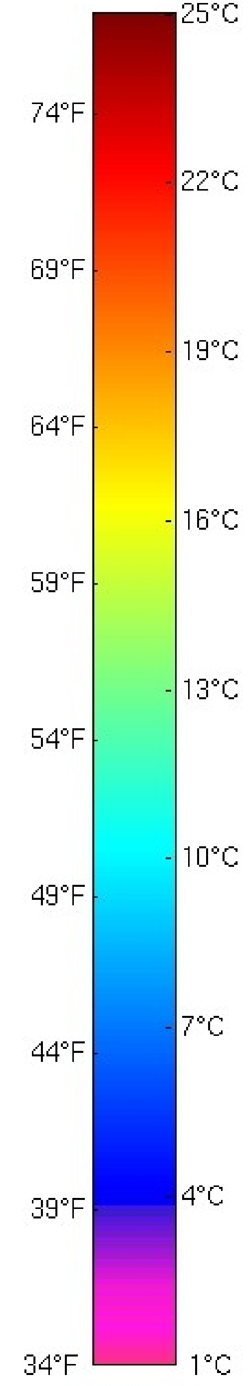


Figure 1 Composite Satellite Image of Sea Surface Temperatures – Northwest Atlantic Ocean
From: marine.rutgers.edu

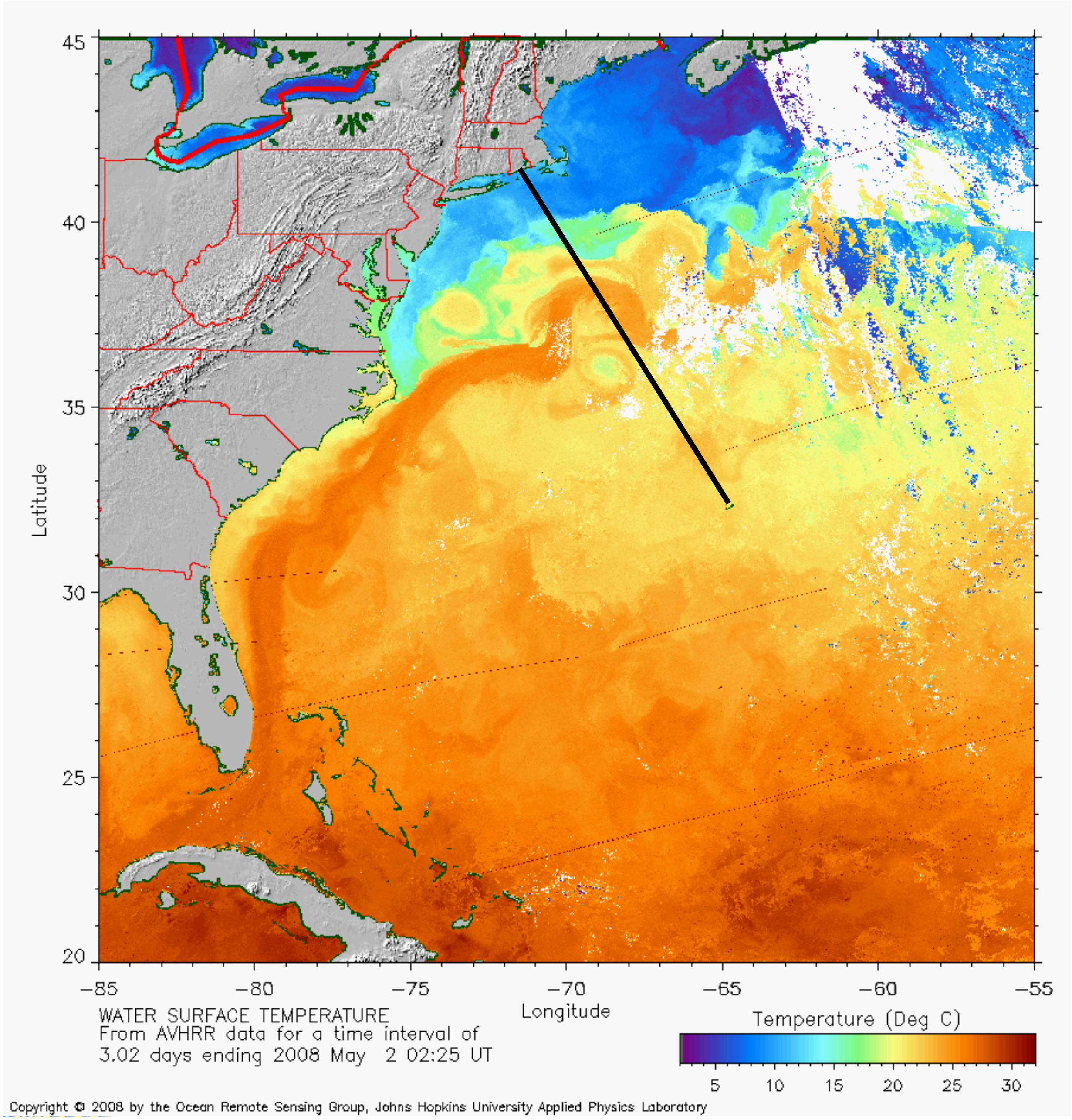


Figure 2 Three Day Composite Satellite Image of Sea surface Temperatures From:http://fermi.jhuapl.edu/sat_ocean.html

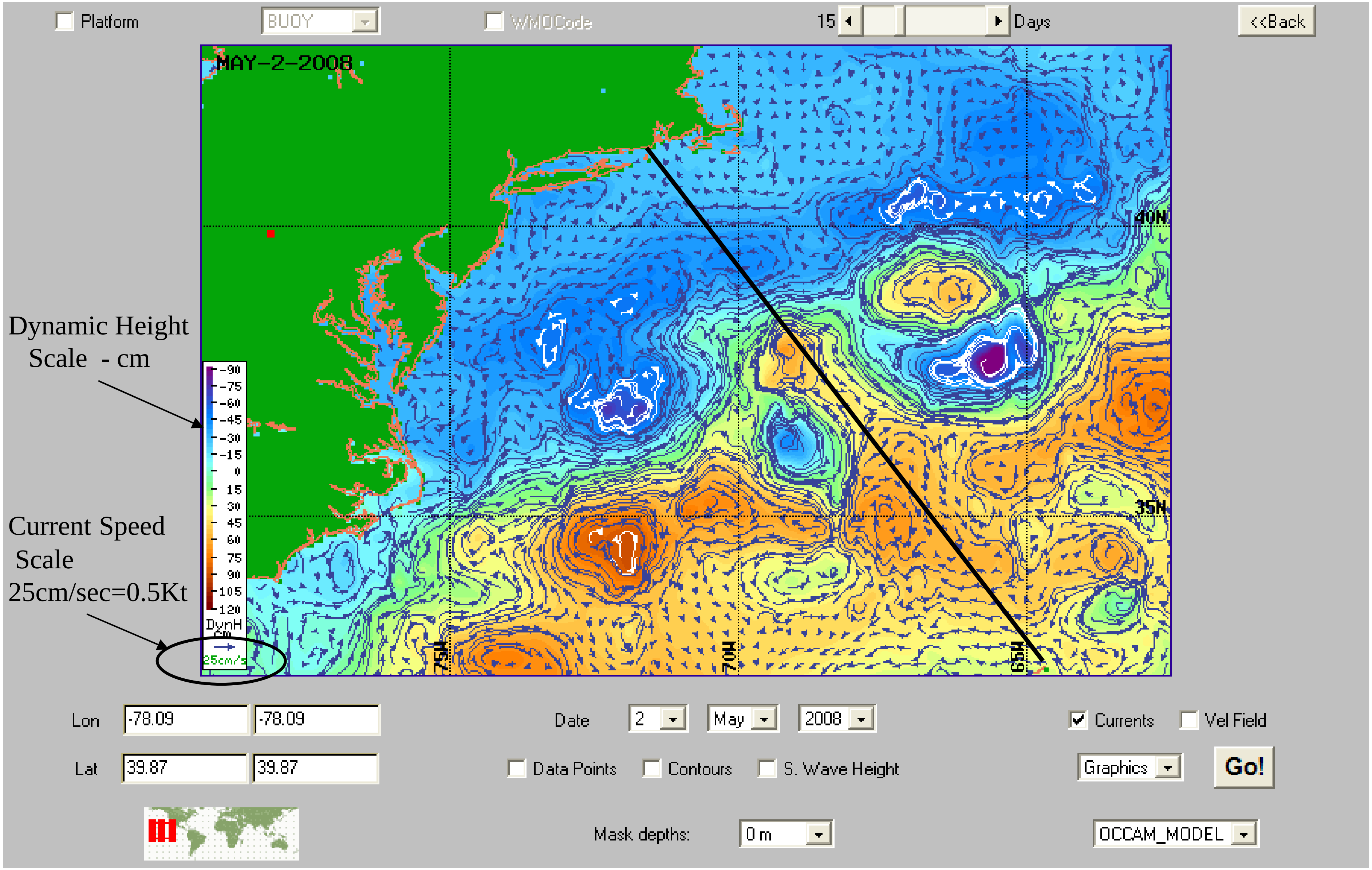


Figure 3 Current Speeds and Directions in the Vicinity of the Newport-Bermuda Rhumb Line Based on NOAA/AOML Altimeter Data May 2, 2008

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