A Brief Gulf Stream Tutorial

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For the Newport-Bermuda racer the Gulf Stream is often considered a juncture as important as the start or finish of the Race. The location, structure and variability of this major ocean current combine to produce a particular challenge for every navigator/tactician. What is the nature of this challenge and how best might it be addressed ?

The Gulf Stream is a portion of the large clockwise current system affecting the entire North Atlantic Ocean. Driven by the average wind field over the North Atlantic and the associated distributions of water temperature and salinity, the Gulf Stream is an energetic boundary current separating the warm waters of the Sargasso Sea from the cooler continental shelf waters adjoining New England. The resulting thermal boundary represents one of the most striking features of this current and one that is most easily measured. From Florida to Cape Hatteras the Gulf Stream follows a reasonably well defined northerly track along the outer limits of the U.S. continental shelf. Beyond, to the north of Hatteras, Stream associated flows proceed along a progressively more northeasterly tending track with the main body of the current separating gradually from the shelf. Horizontal flow trajectories in this area, including the rhumb line to Bermuda, become increasingly non-linear and wavelike with characteristics similar to those observed in clouds of smoke trailing downwind from a chimney. The resulting large amplitude meanders in the main body of the Stream tend to propagate downstream, towards Europe, and grow in amplitude. On occasion these meanders will become so large that they will "pinch off" forming independent rotating rings or eddies in the areas to the north and south of the main body of the Stream. This combination of time variant features has the potential to affect a significant portion of the rhumb line between Newport and Bermuda well beyond the limits of the main body of the current. The extent of this influence necessarily varies significantly in space and time. This variability challenges the Race navigator and establishes some particular requirements for study sufficient to resolve Stream characteristics.

Given the strong thermal signature typically associated with the Gulf Stream, efforts to locate the Stream and map its primary features typically begins with the collection of satellite sea surface temperature (SST) images available at a number of web sites (see e.g. marine.rutgers.edu/mrs/ or fermi.jhuapl.edu/sat_ocean.html). These images are generally provided in one of two forms, instantaneous or composite. The instantaneous image represents the view from a single satellite pass taken at some discrete time. The composite represents what might be considered an average of multiple passes over an extended period of time (typically one day to one week). The instantaneous-single pass image tends to provide higher spatial resolution and more accurate detailing of Stream features and location but is often affected by the presence of clouds. By focusing on selected features over a number of passes, the process of compositing is able to reduce this sensitivity to cloud cover.

Examination of a typical composite satellite image (Fig.1) shows that on February 16, 2006 the main body of the Stream, approximately 60 nm in width, crossed the rhumb line to

Bermuda at a point ~ 240nm from Newport. The crossing proceeds from the southwest to the northeast and is part of a meandering pattern which rapidly increases in amplitude. Such meanders generally proceed to the east similar to a wave moving across the water's surface at speeds of approximately 10-20nm/day. This progression can significantly alter flow directions within the main body of the Stream.

Flow speeds vary across the main body with maxima occurring in the vicinity of maximum thermal gradients which are typically found approximately 20-30nm in from the northern edge of the Stream (Fig.2). Multiple surveys have shown these maxima to be remarkably constant with values of 4 knots +/- 0.5kt. Deviations from this tend to be associated with periods of high energy winds. It's interesting to note just how narrow the high speed core of the Stream is and that as one proceeds to the south and east across the Stream flow directions change from easterlies to westerlies (Fig.2). These counter flows were observed by several boats during the 2008 Race.

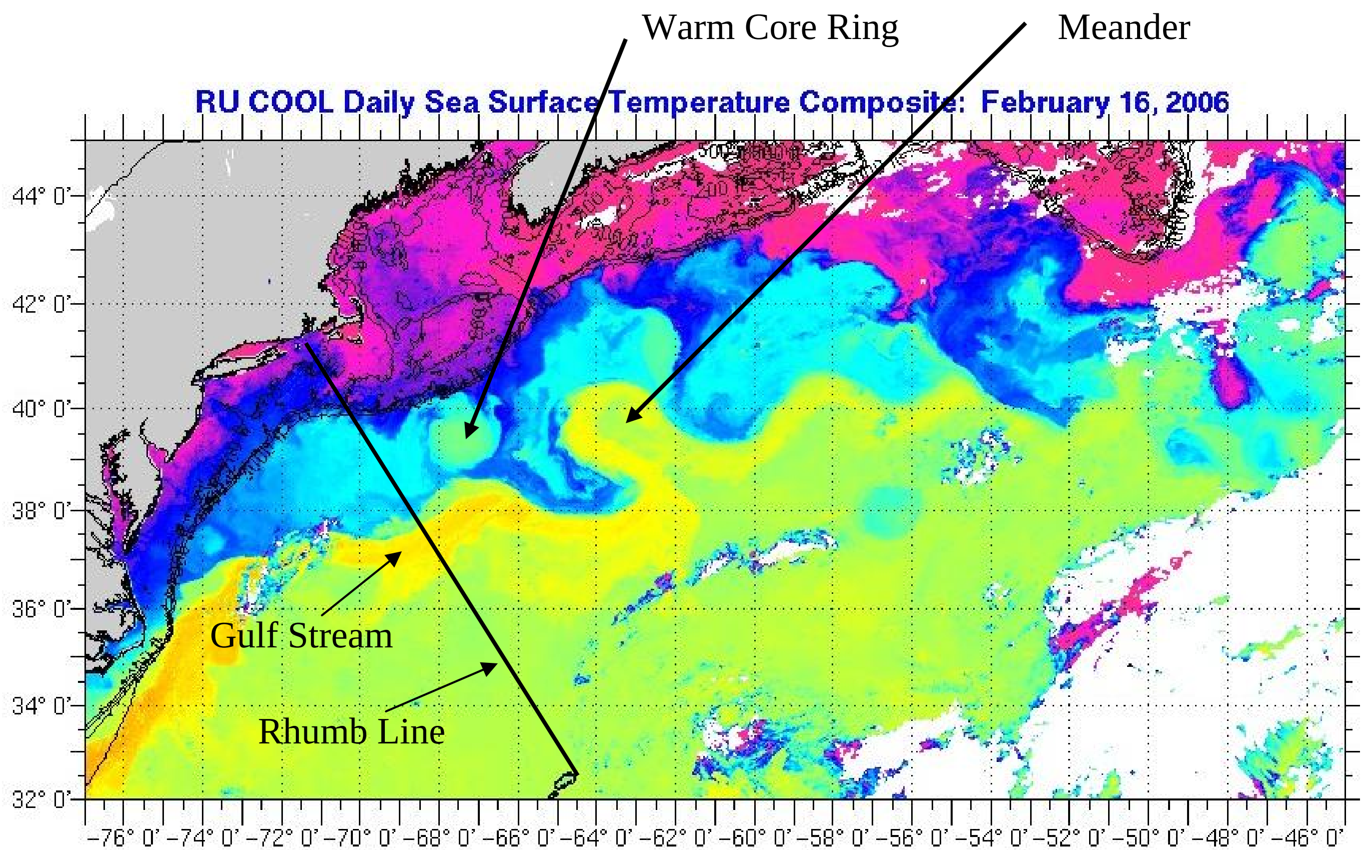
In addition to the location and form of the main body of the Stream, the satellite SST image shows a warm core ring to the north of the Stream east of the rhumb line (Fig.1). Typically such features are formed when meanders "pinch-off" trapping a parcel of warm Sargasso Sea water. The meander observed to the east near 40^{o}N 67^{o}W may in time result in another similar ring. Alternatively, the deep meander in the main body of the Stream crossing 38^{o}N may "pinch-off" to the south of the Stream trapping a parcel of cooler continental shelf water as a "cold core" ring within the Sargasso Sea. These classes of rings each display unique circulation characteristics with the warm core rings rotating clockwise while the cold core ring rotates counterclockwise. Maximum speeds, on the order of 2 knots, are again found in the vicinity of the maximum thermal gradients approximately 20nm in from the edge of the ring. Both warm and cold core rings tend to drift to the west southwest at speeds of approximately 0.1knot if clear of direct Stream influence. Warm core rings often are affected by shoaling along the edge of the continental shelf and have significantly shorter lives (~5-6 months) than cold core rings (~ 1-2 years). Both can significantly affect small boat set and drift over an area extending well to the north and south of the main body of the Stream.

Despite the value of the satellite SST image its ultimate utility is often affected by cloud cover as a brief viewing of the past few weeks of data clearly demonstrates (see Rutgers site e.g.). If these conditions were to persist the navigator would most likely be forced to develop estimates of the Stream related current field based on his last view of the Stream in combination with some computer simulations (http://www7320.nrlssc.navy.mil/global_nlom32/gfs.html) and/or satellite altimetry (http://www.aoml.noaa.gov/phod/dataphod/work/trinanes/INTERFACE/index.html). Of these, the altimetry plots are often most useful best reproducing both the main body of the Stream and the attendant rings (e.g. compare Fig. 3 to Fig.1). They also are often uniquely able to provide indication of the presence of cold core rings such as the one shown near 35^{o}30'N 66^{o}30'W not evident on the SST image (Fig.1) most probably due to the sinking of cold ring waters below a thin surface layer of lower density warm water. This sinking does little to reduce the effect of the ring on surface currents making an understanding of ring location essential to route planning.

Beyond consideration of set and drift the Gulf Stream also exerts significant influence on weather and sea state. The sharp thermal boundary along the northern limits of the Stream drives warm moist air aloft favoring cloud formation and the intensification of advancing pressure systems over a large portion of the North Atlantic. Intensification is particularly pronounced in fast moving cold fronts. Encountering the warm waters of the Stream these fronts increase the rate at which moisture laden warm air moves aloft favoring formation of intense thunderstorms replete with wind, rain and sometimes hail. The horizontal extent and duration of these events can vary significantly as a function of frontal trajectory and the concurrent position and form of the Stream. The combination often complicates forecasting due to model limitations leaving the navigator to be the best judge of probable wind conditions.

Assessment of conditions to be encountered must also consider Stream effects on sea state. Energetic current flows against the wind can result in marked wave steepening and an increase in the frequency of breaking. The resulting “rough” seas may occur both within the main body of the Stream and the attendant rings with sea roughness depending entirely on wind speeds and relative current directions. The prevailing southwesterlies acting on the 16^{th} of February (Fig.1) for example, may favor reduction in wave heights within the main body of the Stream while producing a noticeably rough sea along the southern margin of the warm core ring due to the countering northeasterly flows in this area. Boats will be more or less affected by these conditions depending on hull characteristics and speeds.

This variety of features and effects in combination with the significant spatial and temporal variability of both forms the challenge that is the Gulf Stream. Resolution of these characteristics sufficient to optimize routing is best realized by early study. For many these efforts and the subsequent test of results are an essential part of the special attraction of the Newport to Bermuda Race.



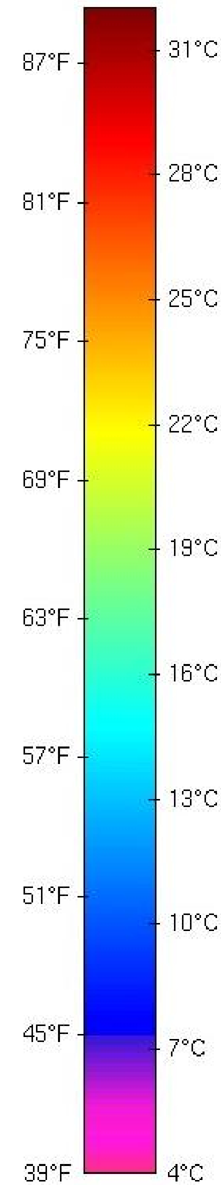
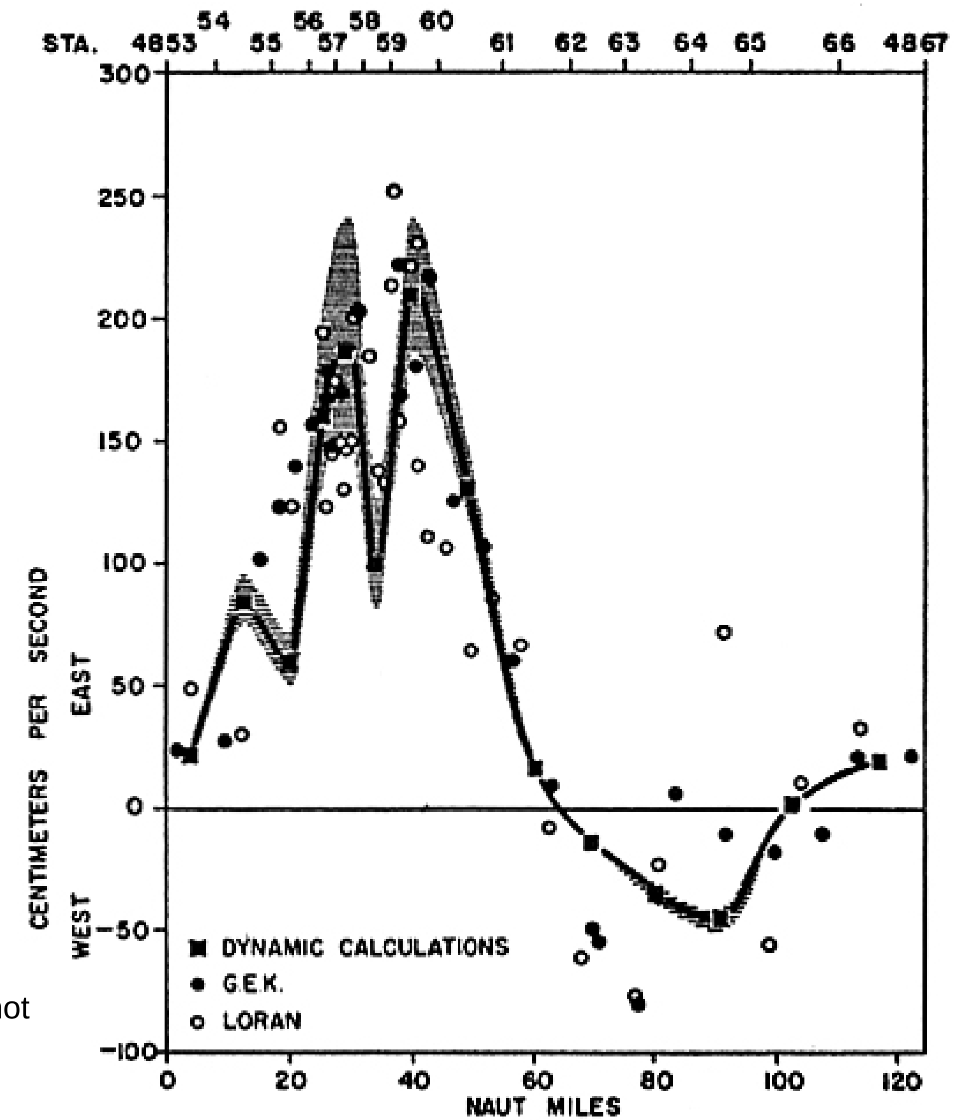


Figure 1 Daily composite Satellite Image – Northwest Atlantic Ocean Showing Gulf Stream and Associated Features

Source: Rutgers University



50 cm/sec = ~ 1 knot

Figure 2 Near Surface Current Speeds Along a Gulf Stream Transect

From: Stommel,H. 1965 The Gulf Stream – Univ. of California Press

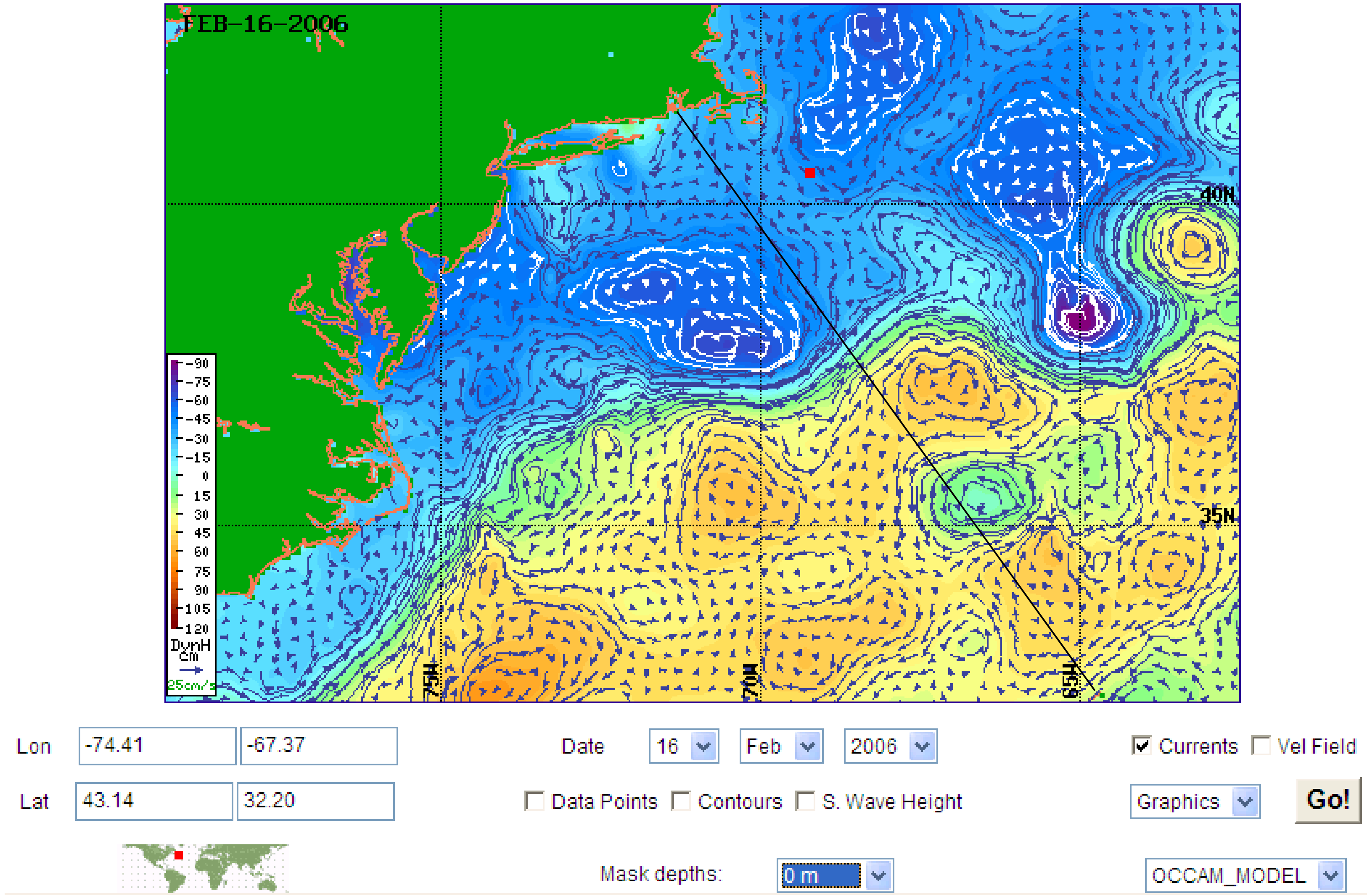


Figure 3 Satellite Altimetry Derived Surface Currents – NW Atlantic Region

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