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The Gulf Stream
Structure and Strategy

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For the Newport-Bermuda racer the point at which the Gulf Stream is encountered 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 and its effects presents 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 wind field over the North Atlantic and the associated distributions of water temperature and salinity, the Gulf Stream is an energetic western 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 sensed. 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, which includes the rhumb line Newport 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 begin with the collection of satellite sea surface temperature (SST) images available at a number of web sites (see e.g. http://rucool.marine.rutgers.edu or https://ocean.weather.gov/Loops/ocean_guidance.php?model=GOES&area=MidAtl&plot). 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 four days). 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 May 8, 2010, about a month before the start of the 2010 Newport –Bermuda Race, 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 west to east and is preceded by a narrow filament of warm water shed from the main body along 38ºN. The northern limit of the Stream displays a prominent meandering pattern which increases in amplitude to the east. Individually, 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 and the angle at which the Stream crosses the rhumb line. In recent years this rate of progression has displayed significant variability ranging from little to no movement to more than 20nm each day. Rates are best determined using satellite images extending over 10 to 20 days.

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 4-5 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, how it consists of regions of high and low speeds (i.e. a Filamentous structure), 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 are often observed by Newport-Bermuda racers.

In addition to the location and form of the main body of the Stream, the satellite SST image shows a warm core feature 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 or when coherent masses of warm water are shed to the north from the main body of the Stream. The segment crossing the rhumb line may in time produce a similar feature. Alternatively, to the east, the satellite image shows an evident mass of isolated cold water near 38ºN 62ºW. The image suggests that this cold core ring, or feature, was formed by the consolidation of adjoining meanders which served to trap the cooler continental shelf water. 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 3 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, all too often occurring during the period immediately preceding the Race. Under such conditions the navigator is forced to develop estimates of the Stream based on his last view of the Stream in combination with some computer simulations which are becoming increasingly accurate (e.g. https://polar.ncep.noaa.gov/global/fronts/) and/or satellite altimetry based models (https://cwcaribbean.aoml.noaa.gov/CURRENTS/index.html). Of these, the plots of the modeled current field based on altimetry (Fig.3) are often the most useful. Experience gained from both racing and cruising over the past ten years indicates that these plots accurately depict positions of the main body of the Stream and the attendant rings. They also are often uniquely able to provide indication of the presence of cold core rings such as the one shown near 34ºN 67º30'W (Fig.3) which are often obscured on the satellite image due to the sinking of cold ring waters below a thin surface layer of lower density warm water which results in the loss of the thermal IR signature sensed by satellites.

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 in person observations of the navigator being the best way to forecast 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 8^{th} of May (Fig.1), for example, may favor reduction in wave heights within the main body of the Stream near the rhumb line while producing rough seas 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. Examination of I-Boat tracks from the 2010 Race shows substantial differences in the way individual boats handled the conditions presented to them (Fig.3). For example *Carina*, the overall winner, sailed a near rhumb line course, with apparently minimal concern for currents, diverging only to accommodate wind conditions. In contrast, *Lindy* and *Sinn Fein*, smaller Class 1 competitors (the latter being the winner of the past two Newport Bermuda Races), sailed evidently longer and quite different courses seeking to optimize both current and wind conditions. They finished well behind Carina but within two hours of each other and close to the top of Class 1. The differing tactics illustrate the care required in design of strategy and the need to consider much more than simple analytical data describing Gulf Stream and/or wind and wave conditions. Boat type, condition and crew matters. The successful integration of all of these factors is the challenge that represents the particular attraction of the Newport Bermuda Race.

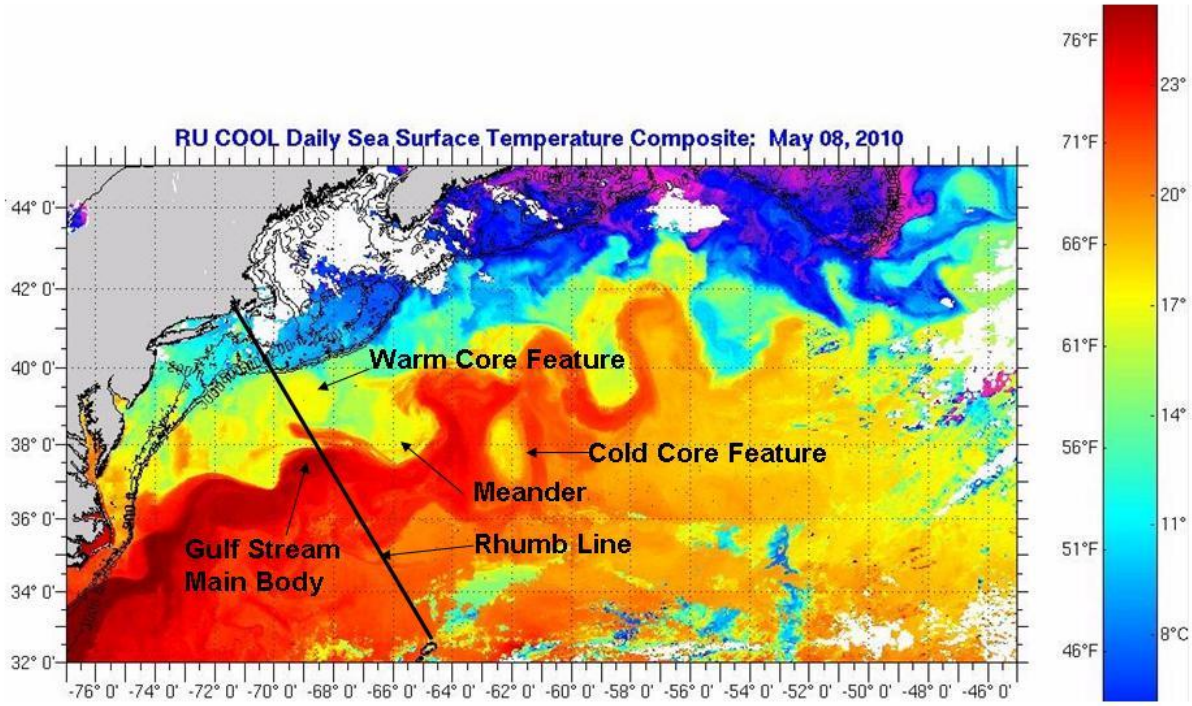
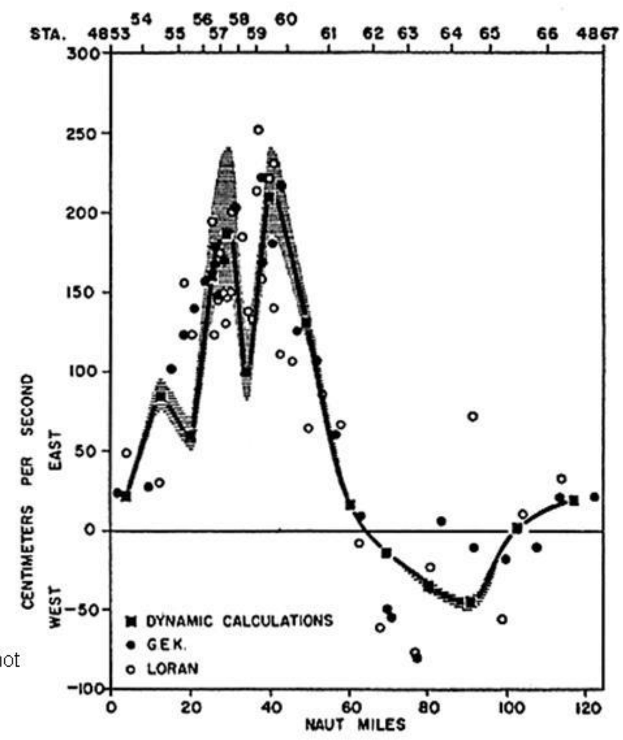


Figure 1 Daily Composite Satellite Image – Northwest Atlantic Ocean Showing Gulf Stream and Associated Features

Source: Rutgers University - http://rucool.marine.rutgers.edu



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

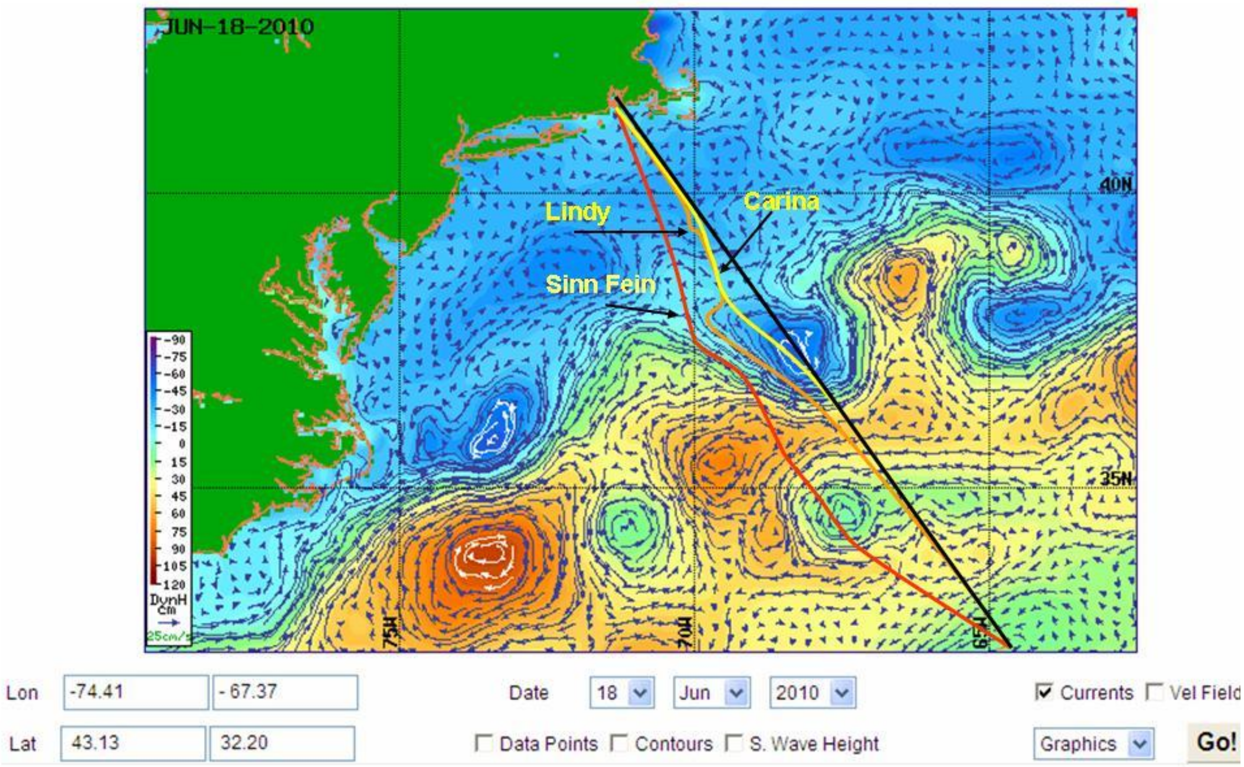


Figure 3 Satellite Altimetry Derived Surface Currents – NW Atlantic Region

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