Two Gyres revisited: Branches, bifurcations, and retroflections over the Tail of the Grand Banks of Newfoundland

Mike McCartney & Paula Fratantoni
Woods Hole Oceanographic Institution

Work sponsored by the National Science Foundation

Historical Context

Thirty-two years ago, Worthington published his classic *On the North Atlantic Circulation*. A central feature of his synthesis of circulation estimates and interpretations was his "Two Gyre hypothesis," described from a concept he put forward in 1962.

His idea was that the large transport he estimated for the eastward flow of the Gulf Stream south of New Scotia was wholly retroflected west of the Tail of the Grand Banks and that the large northerly recirculation that he estimated for the northward Current water north of the Grand Banks was wholly recirculated back to the North Atlantic Current, which became the focus of controversy.

There has been much work since then. In 1993 Schmitz and Mike McCartney undertook a synthesis of the whole North Atlantic, to update Worthington’s original estimate of the transport of the gyres and to make a more definitive statement about the circulation. They estimated the eastward flow of the Gulf Stream south of New Scotia was 150 Sv (Sverdrup transports). The Tail of the Grand Banks remained an area of great uncertainty.

In this paper, we build on the idea that the Tail of the Grand Banks is the site of a significant northerly recirculation, now termed the Tail of the Grand Banks of Newfoundland. We explore the implications of new measurements since Worthington and McCartney synthesized the circulation of the Tail of the Grand Banks.

I. A definitive measurement (A. Clarke, C. Mein and colleagues) of North Atlantic Current (NAC) transport as 145 Sv, even stronger than Worthington’s original estimate of the 160 Sv. Due to appreciable northward airflow within the latter, its contribution to the North Atlantic Current is included, which became the focus of controversy. There has been much work since then. In 1993 Schmitz and Mike McCartney undertook a synthesis of the whole North Atlantic, to update Worthington’s original estimate of the transport of the gyres and to make a more definitive statement about the circulation. They estimated the eastward flow of the Gulf Stream south of New Scotia was 150 Sv (Sverdrup transports). The Tail of the Grand Banks remained an area of great uncertainty.

II. Equiflow follow-up along the western boundary is dominated from north of New Scotia south to Cape Hatteras, spanning bathymetric depth from the shelf break, across the inshore region, and through the Western Boundary Current (WBC). How does that system, the Continental Slope Current (CSC) negotiate the "sheer encounter" with Gulf Stream branches crossing the Tail of the Grand Banks? There is growing evidence that not all the flows are flowing southward east of the Grand Banks. Flow west across the NAC. Can we estimate that the retroflection of the Continental Slope Current (CSC) Recent DCMW measurements (A. Clarke, H. Schott, J. Fisher and colleagues) near 47.5°W confirm the DCMW transporting the approach the Tail from the north.

III. Constraining the Regional Circulation

Integrating the measurement of 140 Sv for the North Atlantic Current strength into the circulation of Grand Banks regional recirculation brings significant uncertainty to the strengths of branches, bifurcations and retroflections over the Tail of the Grand Banks. These can be reduced to two unexplored questions:

What is the eastward flow of Gulf Stream south of New Scotia that bifurcates and retroflects across the Tail of the Grand Banks, and what can we infer from these?

What is the southward flow over the continental slope that bifurcates and retroflects across the Tail of the Grand Banks, and what can we infer from these?

IV. The Structural Stability of Worthington’s "Trough"

The eastward-flowing Gulf Stream approaches the Tail of the Banks with the character of an inertial spiral flow. However, at the Tail, significant changes occur (refer to the inflection point at the top of page 32):

1. Portions of the Gulf Stream diverge, retroflecting northward and southward to field recirculation gyres adjacent to the Stream.
2. A branch of the Gulf Stream flows seaward northward across the Tail, feeding the North Atlantic Current, and
3. A residual transport continuous eastward feeds the Azores Current.

V. The Schematic of the calculated circulation

Schematic of the estimated circulation south and east of the Grand Banks of Newfoundland

VI. Key Transport estimates and measurements constraining the regional circulation.

West of the Tail of the Grand Banks, the Gulf Stream transports 150 Sv towards the Tail. Northeast of the Tail, the North Atlantic Current transports 140 Sv away from the Tail. East of the Tail the Azores Current transports 10 Sv across the Mid-Atlantic Ridge. Between the North Atlantic Current and the Grand Banks, the Continental Slope Current transports 30 Sv southward.

Between the Gulf Stream and the Nova Scotia continental shelf, the Continental Slope Current transports 45 Sv eastward.

Each of the above water columns transport can be subdivided into separate contributions to the thermohaline mass transport, so the estimates require transport consistency across the three layers as well as the full water column. The meridional transport circulations are estimated to be about 15 Sv (10 Sv), requiring a net southward flow of deep water of that strength east of the Grand Banks.

VII. The Tail-induced Bottleneck hypothesis

The low pressure Trough over the Tail of the Grand Banks represents a Tail-induced bottleneck to the currents approaching the Tail from the west and north. The Trough most significantly support the northeast turning branch of the Gulf Stream and the northeast flowing branch of the Continental Slope Current. This limits the sustainable strengths of the across-Bank transports.

Our plan of attack on this hypothesis involves working on existing ocean observations to refine circulation estimates that underlie the quantitative schematic, and, in parallel, to develop a model of the currents. In this poster we describe some aspects of the regional measurements that our new analysis work has revealed, and describe a first look at HYCOM model output for this region.

The maps show the Trough as it appears in climatological averages of hydrographic data. The Tail’s axis is overlaid. Shown are the depth of the 10°C isotherm, which is a proxy for thermocline, and theta at 1000, 2000 and 3000 m. Data coverage ≤ 2000 m is dominated by the NASA ISS data between 1982 and 1991. These surveys represent 39 well-distributed synoptic surveys in the domain during that period. Individual sections have larger numbers of repeats.