Deep-Sea Research II 98 (2013) 244–256

Contents lists available at ScienceDirect

Deep-Sea Research II

journal homepage: www.elsevier.com/locate/dsr2

Thermal front variability along the North Atlantic Current observed using microwave and infrared satellite data

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ARTICLE INFO

Available online 28 August 2013

Keywords:
Oceanic fronts
Remote sensing
North Atlantic Current
Ocean currents
Ocean circulation
SST
Mid-Atlantic Ridge
Charlie Gibbs Fracture Zone
Altimetry

ABSTRACT

Thermal fronts detected using multiple satellite sensors have been integrated to provide new information on the spatial and seasonal distribution of oceanic fronts in the North Atlantic. The branching of the North Atlantic Current (NAC) as it encounters the Mid-Atlantic Ridge (MAR) is reflected in surface thermal fronts, which preferentially occur at the Charlie Gibbs Fracture Zone (CGFZ) and several smaller fracture zones. North of the CGFZ there are few thermal fronts, contrasting with the region to the south, where there are frequent surface thermal fronts that are persistent seasonally and interannually. The alignment of the fronts confirms that the shallower Reykjanes Ridge north of the CGFZ is more of a barrier to water movements than the ridge to the south. Comparison of front distributions with satellite altimetry data indicates that the MAR influence on deep ocean currents is also frequently exhibited in surface temperature. The improved spatial and temporal resolution of the front analysis has revealed consistent seasonality in the branching patterns. These results contribute to our understanding of the variability of the NAC, and the techniques for visualising oceanic fronts can be applied in other regions to reveal details of surface currents that cannot be resolved using satellite altimetry or *in situ* measurements.

1. Introduction

Upper ocean flow in the northern North Atlantic is dominated by the several-branched, northeast-flowing North Atlantic Current (NAC). This flow, an extension of the Gulf Stream, is the northern arm of the subtropical gyre and transports warm water towards higher latitudes as part of the global thermohaline circulation. The Mid-Atlantic Ridge (MAR) is a major topographic barrier to the NAC (Fig. 1), the branches of which tend to be guided across the MAR by a number of deep fracture zones between 45°N and 53°N. The northern branch of the NAC passes through the Charlie-Gibbs Fracture Zone (CGFZ) at 52°N (Rossby, 1996; Bower et al., 2002), providing a distinct northern edge to the subpolar front (SPF), the boundary between the subpolar and subtropical waters. The remaining branches are more variable and loosely tied to the Faraday, Maxwell and Bight Fracture Zones (Bower et al., 2002; Bower and von Appen, 2008). Understanding the seasonal and interannual variability of the NAC pathways is important for ocean and climate predictions.

The aim of the Ecosystems of the Mid-Atlantic Ridge at the subpolar front and CGFZ project (ECOMAR) was to understand how physical and biogeochemical factors influence the distribution and structure of deep-sea communities, focusing on the fauna of the MAR. In particular the project sought to determine whether productivity and biodiversity associated with the ridge were enhanced compared with adjacent open ocean areas (Priede et al., 2013b). Abundant and diverse marine life requires enhanced nutrient availability and it was hypothesised that the presence of the MAR would increase mixing, elevate nutrient concentrations and provide the ideal conditions for increased marine productivity and biodiversity (Priede et al., 2013a).

The objective of this paper is to use Earth observation (EO) data to investigate thermal fronts across the MAR, their variability and longevity, and to relate these to the deeper oceanic structure through comparison with sea surface height measurements. A thermal front can indicate several aspects of surface structure. It may delineate a strong jet, representing a density gradient of significant vertical extent; it may show local enhancement of a weak gradient by mesoscale shear and strain; it may be due to enhanced mixing breaking through the seasonal stratification; or it may represent a shallow structure with little dynamical significance.

New front detection methods (Miller, 2009), based on merged microwave and infrared data, are used to identify surface thermal fronts. Infrared measurements of sea surface temperature are limited by cloud cover that prevents remote observations being made.

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http://dx.doi.org/10.1016/j.dsr2.2013.08.014

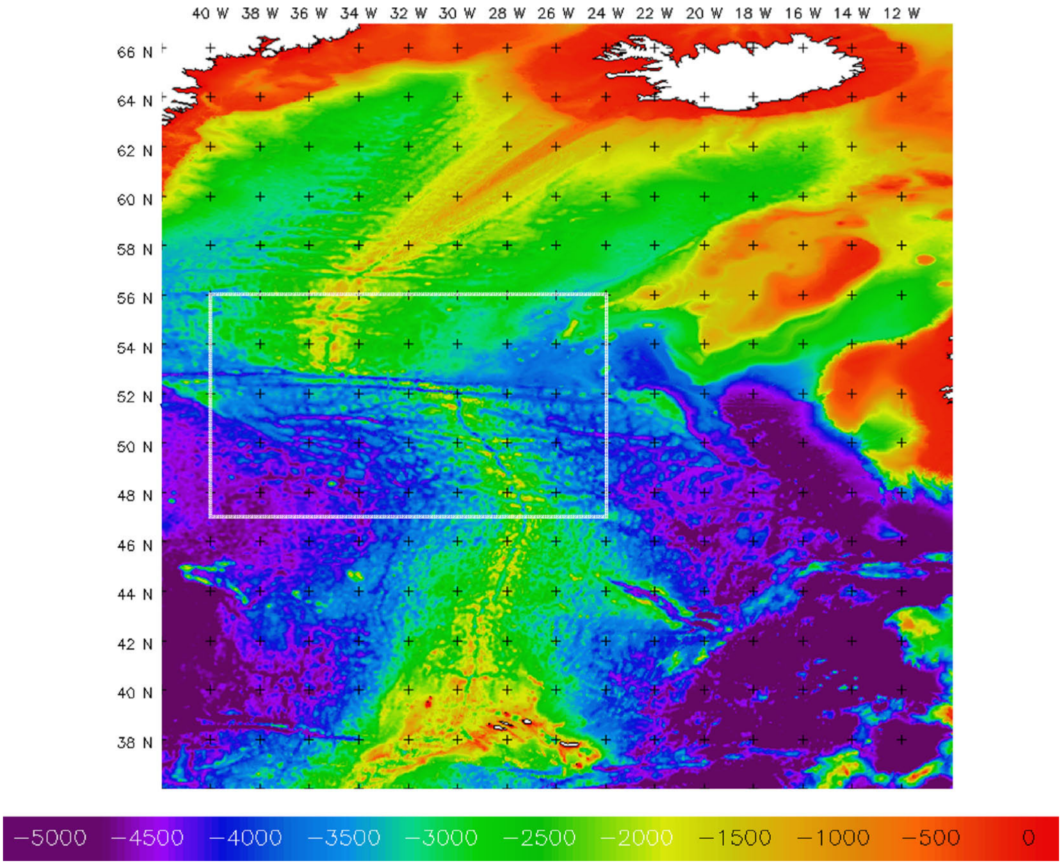

Fig. 1. Bathymetry of MAR region, derived from GEBCO. The box (white line) indicates the subregion analysed for AVHRR thermal fronts.

This is a particular problem over frontal regions such as the subpolar front, which have therefore only rarely been studied using satellite infrared data (Flatau et al., 2003). Such data have been used to map the long-term mean position of fronts in large marine ecosystems (Belkin et al., 2009). Passive microwave sensors can now estimate sea surface temperature through cloud cover, although at a lower resolution. The new, combined dataset exceeds the spatial and temporal resolution possible with previous gridded products, providing improved resolution of surface thermal fronts. Here we investigate whether this combined dataset can extend our knowledge of the seasonal and interannual variability of the NAC pathways and their relationship to the bathymetry of the MAR. Comparisons are drawn with studies of the surface topography and upper-ocean currents obtained from satellite altimetry and drifters (Bower and von Appen, 2008).

2. Methods

2.1. Sea-surface temperature data

The initial source of data for this frontal analysis was the Advanced Very High Resolution Radiometer (AVHRR) archive acquired by Dundee Satellite Receiving Station, comprising several passes per day over the North Atlantic continuously since August 1981 (Miller et al., 1997). The maximum spatial resolution is 1.1 km, sufficient for detection of all scales of fronts relevant to the MAR. Twenty eight years of data were processed to encompass the interannual variability, from August 1981 to December 2008.

The first stage was to convert the raw infrared AVHRR data into sea surface temperature (SST) maps. The Panorama system (Miller et al., 1997) enabled the data to be calibrated into SST values, navigated, cloud-masked and mapped consistently for the MAR region. For the sequence, over 24,000 AVHRR passes were processed. The SST data were mapped into Mercator projection, with a spatial resolution of approximately 1.1 km/pixel.

The second stage was to detect ocean fronts on every individual SST scene and combine them to generate monthly front maps. Algorithms enable fronts to be located accurately and objectively. The criteria for detecting a front are that there are distinct cold and warm modes of the temperature histogram within a local window (32 × 32 pixels); a minimum step of 0.4 °C across the front; and the cold and warm pixels form contiguous areas. The selected window size provides sufficient pixel samples to allow sensitive detection of a bimodal distribution, while limiting the inclusion of more than two water masses in the window; and this has been found to be applicable to different resolutions. The minimum step of 0.4 °C identifies most genuine fronts without confusing the map with too many weaker structures. The composite front map technique combines the location, gradient, persistence and proximity of all fronts observed over a given period into a single map (Miller, 2009). Despite the severe cloud cover in the NE Atlantic, this approach combines the available evidence for fronts without blurring dynamic features, an inherent problem with conventional time-averaging methods. It is important to emphasise that fronts are not detected on monthly SST composites, but rather on individual SST ‘snapshots’ that reveal the detailed thermal structure without averaging artefacts.

Eight-day composite front maps were also derived from daily merged microwave and infrared SST data from 2006 to 2011 provided by Remote Sensing Systems, USA. These SST maps improve upon the 25 km resolution of the microwave sensors (AMSR-E, TMI and WindSAT) by merging with all cloud-free 1 km infrared SST data using optimal interpolation onto a 9 km grid