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The East Greenland Spill Jet as an important component of the Atlantic Meridional Overturning Circulation

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ABSTRACT

The recently discovered East Greenland Spill Jet is a bottom-intensified current on the upper continental slope south of Denmark Strait, transporting intermediate density water equatorward. Until now the Spill Jet has only been observed with limited summertime measurements from ships. Here we present the first year-round mooring observations demonstrating that the current is a ubiquitous feature with a volume transport similar to the well-known plume of Denmark Strait overflow water farther downslope. Using reverse particle tracking in a high-resolution numerical model, we investigate the upstream sources feeding the Spill Jet. Three main pathways are identified: particles flowing directly into the Spill Jet from the Denmark Strait sill; particles progressing southward on the East Greenland shelf that subsequently spill over the shelfbreak into the current; and ambient water from the Irminger Sea that gets entrained into the flow. The two Spill Jet pathways emanating from Denmark Strait are newly resolved, and long-term hydrographic data from the strait verifies that dense water is present far onto the Greenland shelf. Additional measurements near the southern tip of Greenland suggest that the Spill Jet ultimately merges with the deep portion of the shelfbreak current, originally thought to be a lateral circulation associated with the sub-polar gyre. Our study thus reveals a previously unrecognized significant component of the Atlantic Meridional Overturning Circulation that needs to be considered to understand fully the ocean's role in climate.

1. Introduction

Strong air–sea heat exchange in the Nordic Seas leads to the formation of dense water which is exported to the Atlantic Ocean through the Faroe Bank Channel and the Denmark Strait. These overflows form the headwaters of the Deep Western Boundary Current (DWBC) (Dickson and Brown, 1994), which constitutes the abyssal limb of the Atlantic Meridional Overturning Circulation (AMOC). The largest and densest overflow plume emanates from Denmark Strait and entrains ambient water from the Irminger Sea. During this process energetic cyclones are formed that rapidly propagate with the overflow water southward along the East Greenland continental slope (Spall and Price, 1998; Käse et al., 2003; von Appen et al., 2014). Recently, a narrow current transporting intermediate density water equatorward was discovered inshore of the Denmark Strait overflow plume. This feature was termed the East Greenland Spill Jet (hereafter referred to simply as the Spill Jet), owing to the hypothesis that its formation is associated with dense water spilling off the shelf and forming a gravity current south of Denmark Strait (Pickart et al., 2005). Model simulations and subsequent observations support this hypothesis (Magaldi et al., 2011; Harden et al., 2014).

To date the Spill Jet has only been observed from a small number of quasi-synoptic shipboard velocity sections, all of them

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occupied during the summer months near 65°N (labeled the "Spill Jet section", Fig. 1). From these limited data it has been suggested that the Spill Jet is located on the upper slope and transports between 3 and 7 Sv (1 Sv$=10^6$ m^3/s) equatorward (Brearley et al., 2012). For the most part, its density is lighter than 27.8 kg/m^3 (all densities in this paper are potential densities referenced to the surface), which is commonly taken as the upper limit of Denmark Strait overflow water (DSOW). However, hydrographic measurements (Rudels et al., 1999; Macrander et al., 2005; Brearley et al., 2012; Falina et al., 2012) and numerical simulations (Koszalka et al., 2013) suggest that dense water cascading off the shelf south of Denmark Strait can at times contribute to the deeper DSOW plume. Basic questions thus remain about the existence and importance of the Spill Jet and its relation to the circulation of the North Atlantic Ocean (Fig. 1). After describing the data and methods employed in the study, we demonstrate the ubiquity of the Spill Jet, investigate its formation region and mechanisms, and close with an assessment of its contribution to the AMOC.

2. Data and methods

2.1. Mooring array

Seven moorings were deployed along the Spill Jet section (named consecutively from "EG1" on the shelf in 248 m at 65°30.0'N 33°8.8'W to "EG7" on the slope in 1585 m at 65°7.3'N 32°41.1'W, Fig. 1) from 4 September 2007 to 4 October 2008 (von Appen et al., 2014). The moorings contained conductivity–temperature–depth (CTD) moored profilers operating between the bottom and ≈100 m depth. On the outer three moorings (EG5–7) the profilers included an acoustic current meter. Acoustic Doppler current profilers (ADCPs) measured velocity on all moorings between ≈100 m and the surface, and also between ≈100 m and the bottom on the inner four moorings (EG1–4). Some of the moored profilers stopped working prematurely, but the mean section is robust (see von Appen, 2012).

The dominant signal in the mooring records was the passage of Denmark Strait Overflow Water (DSOW) cyclones every few days. These features contain lenses of dense overflow water on the bottom with a strong azimuthal flow in the water column above (von Appen et al., 2014). We identified the DSOW cyclone passages based on a set of criteria involving their velocity signal (translational and azimuthal), their density signature (the presence of anomalously dense water), and mooring motion (the strong flow near the centers of the cyclones resulted in mooring blow-down). It was found that the influence of the cyclones extended less than 18 h before and after their centers passed by the array. In order to isolate the Spill Jet signature, we identified the time periods when cyclones were present and excluded them from consideration. The mean potential density section in the absence of cyclones (≈35% of the record) was computed using a Laplacian spline interpolator with tension (Pickart and Smethie, 1998). Thermal wind was used to provide the geostrophic shear which was referenced to the mean cyclone-free along-slope velocities at the moorings (in the middle of the water column, the velocity records are complete enough to calculate the means). This absolute geostrophic velocity was then gridded with the same spline interpolator. The standard error of the Spill Jet transport is estimated using an integral time scale of several hours (von Appen et al., 2014). At least 25 independent realizations went into the Spill Jet quantification and most locations are defined by many more realizations. Dividing the standard deviation by the square root of the minimum number of degrees of freedom gives a standard error of <0.7 Sv. Instrument errors, assumed to be uncorrelated across the array, add <0.1 Sv uncertainty (Nikolopoulos et al., 2009).

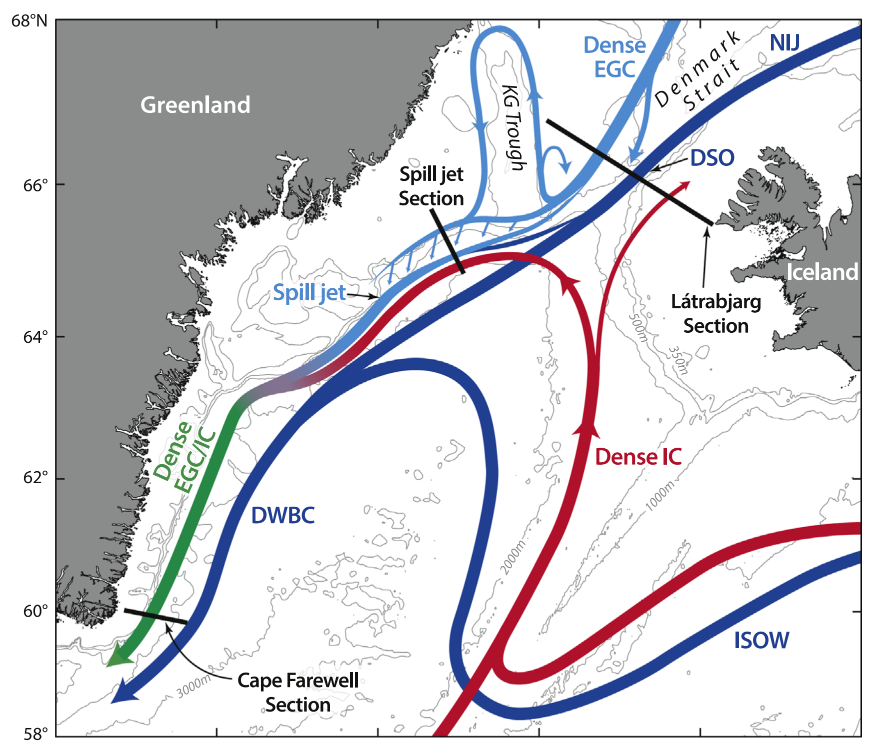

Fig. 1. Schematic of the dense water pathways in the Irminger Sea. This roughly corresponds to waters with density >27.6 kg/m^3. The abbreviations are as follows: EGC, East Greenland Current; NIJ, North Icelandic Jet; DSO, Denmark Strait Overflow; IC, Irminger Current; ISOW, Iceland Scotland Overflow Water; DWBC, Deep Western Boundary Current; and KG Trough, Kangerdlugssuaq Trough. Note that the less dense surface circulation of the IC, the EGC, and the East Greenland Coastal Current is not shown.