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The 1992–2009 transport variability of the East Greenland-Irminger Current at 60°N

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[1] The East Greenland Irminger Current (EGIC) decadal transport variability likely influences deep convection intensity in the Labrador and Irminger Seas but is poorly known yet. The EGIC transport west of the 2000 m isobath was estimated, for the first time, between 1992 and 2009 by combining surface geostrophic velocities derived from altimetry with an estimate of the vertical structure of the transport variability statistically determined from a moored array deployed in 2004–2006. The reconstructed 17-year time series of the EGIC transport was then validated against independent estimates confirming that, indeed, the vertical distribution of the EGIC variability has not changed significantly over the last two decades. The 1992–2009 mean transport is 19.5 Sv with a standard error of 0.3 Sv (1 Sv = 10^6 m^3 s^{-1}). In 1992–1996, the EGIC transport was close to the average. Over the following decade (1997–2005), the EGIC transport declined by 3 Sv (15%) so that the 2004–2006 mean transport inferred from the moored array is 2.2 Sv (10%) less than the 1992–2009 mean. It was followed by a period of higher transport. The seasonal to interannual transport variability is coherent with the variability of the windstress curl at the center of the Irminger Sea.

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1. Introduction

[2] The East Greenland Irminger Current (EGIC) flows south-westward along the east Greenland coast [*Pickart et al.*, 2005, Figure 1]. It advects Arctic waters and Atlantic waters previously densified in the eastern subpolar gyre towards the convection regions in the Labrador and Irminger Seas [*Holliday et al.*, 2007]. Knowledge of the decadal variability of the EGIC is of paramount importance since it might influence the Meridional Overturning Circulation (MOC) through its impact on the intensity of the deep convection [*McCartney and Talley*, 1982]. Based on 2 years of current measurements obtained from a moored array deployed, as part of the OVIDE project, at the south east tip of Greenland from June 2004 to June 2006 (Figure 1), *Daniault et al.* [2011, hereafter DLM] found a mean EGIC transport of 17.3 ± 1 Sv (1 Sv = 10^6 m^3 s^{-1}) between the 200 m and the 2000 m isobaths. Given the recently reported spin-down of the surface subpolar gyre [*Hakkinen and Rhines*, 2009], which northern rim is the EGIC, the question arises whether this value is consistent with a transport averaged on a longer period. To infer the EGIC transport from 1992 to 2009, we combined altimetry-derived surface geostrophic velocities with the first Empirical Orthogonal Function (EOF) of the EGIC transport variability computed from DLM's time series.

2. A 1992–2009 EGIC Transport Time Series

[3] We followed DLM and considered the EGIC between 59.87°N; 42.49°W and 59.60°N; 41.66°W (Figure 1). Hence defined, the width of the EGIC is about 100 km and its western and eastern limits coincide with the 200 m and 2000 m isobaths, respectively. The EGIC transport referred to in the following is perpendicular to the OVIDE mooring section and was integrated from the surface to the bottom. The water masses found in the EGIC are discussed by DLM.

[4] The vertical structure of the EGIC transport variability was approximated by the first EOF (EOF1) of the EGIC transport time series $T_m(z, t)$ computed by DLM. z is depth and t is time. EOF1 captures 85% of the total transport variance and represents ≃90% of the variance from the sea

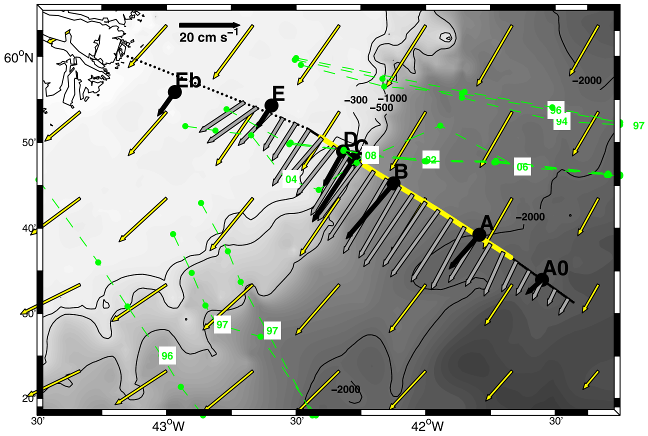

Figure 1. Bathymetric map and comparison of velocities from: Vessel Mounted Acoustic Doppler Current Profiler (grey arrows, 50–250 m layer), moorings (black arrows, 200 m), altimetry (yellow arrows, surface). All velocities were averaged over June 2002 (except moorings), June 2004 and June 2006. The EGIC transport is computed between the 200 m and 2000 m isobaths as indicated by the yellow line. AR7E and Ovide hydrographic sections are reported (green dotted lines).

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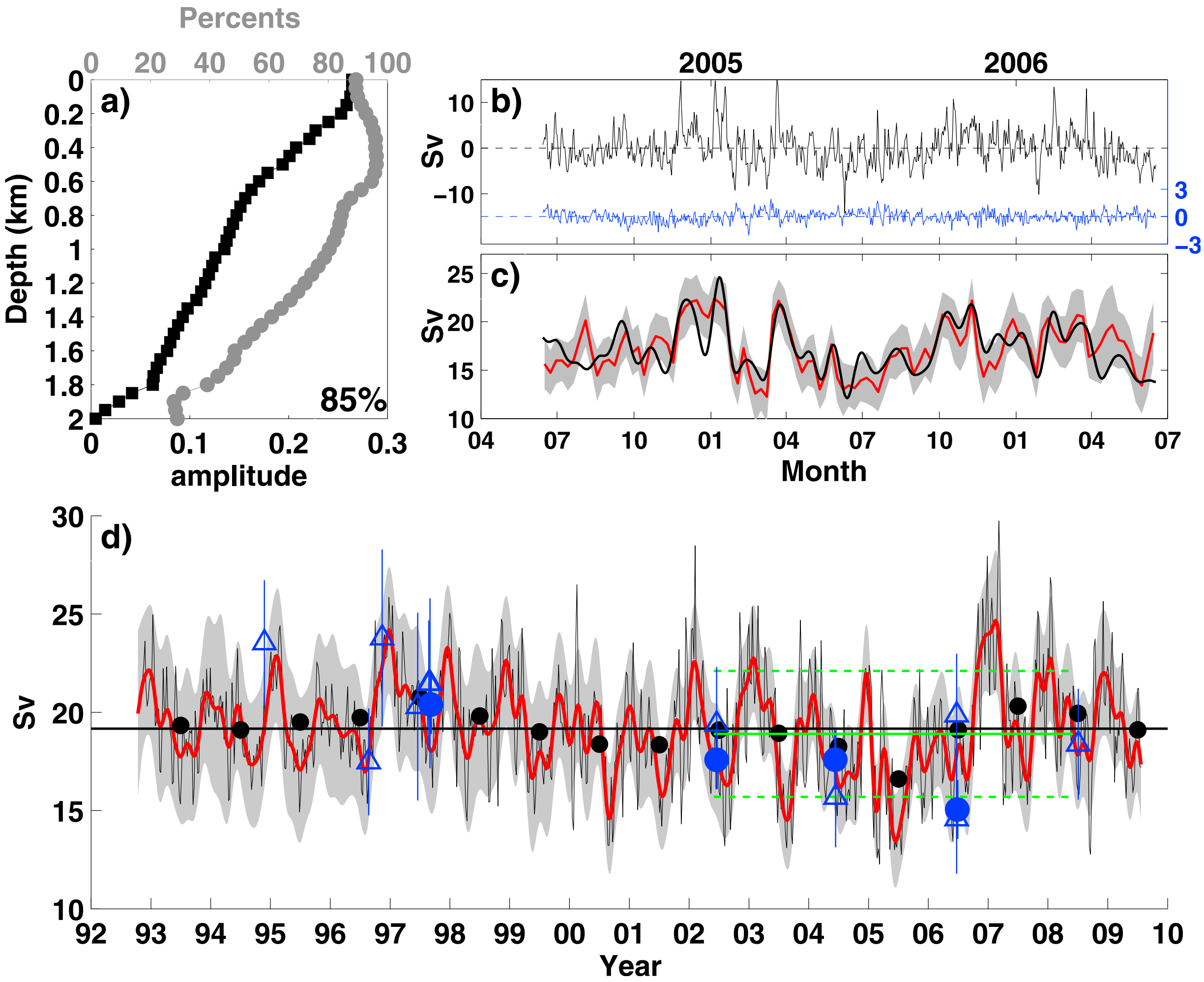

Figure 2. (a) Vertical structure of the first EOF (black squares) of the EGIC transport and percentage of variance explained by this EOF as a function of depth (grey circles). (b) In situ EGIC transport anomaly (black line) and difference between in situ transport anomaly and transport anomaly reconstructed from EOF1 (blue line). (c) Zoom over 2004–2006 of the EGIC transport filtered with a 1/27 days^{-1} cut-off frequency: from the altimetry (red) and mooring (black) transports. (d) Thin black curve: weekly altimetric transport; thick red curve: altimetric transport filtered with a 1/90 days^{-1} cut-off frequency; black bullets: annual means; blue-filled circles: OVIDE transports; green horizontal line: average transport across the 60°N section over 2002–2008 [*Sarafanov et al.*, 2010a]; blue triangles: AR7E transports. Grey areas represent the errors (see text for details).

surface to 600 m depth (Figure 2a); 50% of the mean transport is found in this depth range. Below, EOF1 representativity decreases and it only explains 30% of the variability at 2000 m, where current variability is mostly at high frequency and uncorrelated with the lower frequency variability found closer to the surface (see DLM). Nevertheless, the time series reconstructed from EOF1 is highly correlated with $T_m(t)$ (correlation coefficient r = 0.99, rms difference of 0.57 Sv), where $T_m(t)$ is the depth-integrated mooring transport (Figure 2b). We checked that computing EOF1 over shorter one-year periods led to similar results.

[5] A time series $T_{alt}(0, t)$ of the EGIC surface transport, was constructed from the surface absolute geostrophic velocities derived from the multi-mission altimetry products provided by AVISO (ADT gridded delayed time products). The surface velocities available on a 1/3° grid, with data every 7 days since October 1992, were interpolated at regularly spaced locations, before being integrated along the mooring line to give $T_{alt}(0, t)$. Over the 2004–2006 mooring period, the surface transport anomaly $T^{*}_{alt}(0, t)$ was projected onto EOF1 to give $T^{*}_{alt}(z, t)$, a depth-dependent transport anomaly. Since we only used altimetry transport anomalies our results are not affected by errors on the mean dynamic topography. Absolute transport $T_{alt}(z, t)$ was then obtained by adding the time-averaged mooring transport $\overline{T}_m(t)$ to $T^{*}_{alt}(z, t)$. The surface to bottom integrated altimetry transport $T_{alt}(t)$ compares well with the mooring transport $T_m(t)$ once the high frequencies, not resolved by the weekly altimetry products and potentially smoothed out by the processing of altimetry data, have been filtered out (Figure 2c). The correlation between the two time series is at a maximum ($r = 0.71$, $p_{value} < 10^{-15}$) when $T_m(t)$ is filtered with a cut-off frequency of 1/27 days^{-1}. The rms difference between the two time series is then 1.9 Sv. The method is thus best suited for reconstructing transport variability at periods equal to or longer than one month. The EGIC transport was finally extended over the entire altimetry period (Figure 2d) with the underlying assumption that the vertical structure of the

EGIC variability inferred from the 2004–2006 mooring can represent longer time scales and did not vary considerably over the 1992–2009 period. In the following sections, the good agreement between T_{alt}(t) and independent estimates validates this assumption.

[6] The estimation error was calculated considering both the time-dependent altimetry mapping error from AVISO, scaled by the standard deviation of the altimetry velocities, and the representativity error due to our approximate vertical structure (0.57 Sv).Averaged over the 17-year altimetry period, it equals 3.2 Sv. The error was larger at the beginning of the period when less altimeter were flying. During the 2004–2006 mooring deployment, we found 2.6 Sv, which compares favorably with the 1.9 Sv rms error resulting from the direct comparison of T_{alt}(t) with T_m(t).

3. Comparison With Independent Estimates

[7] Fourteen synoptic estimates of the EGIC transports were obtained from hydrographic lines intersecting the EGIC close to the mooring section (Figure 1). First we considered the absolute EGIC transports available for August 1997, June 2002, June 2004 and June 2006 [*Lherminier et al.*, 2007, 2010] and referred to as "Ovide transports" in the following (Figure 2d). DLM discussed in details the good agreement of those estimates, independent from altimetry, with the mooring transports for June 2004 and June 2006. Second for the A1E/AR7E hydrographic sections that run to the coast with a sufficient spatial resolution (see http://cchdo.ucsd.edu/search?query=ar07), EGIC transports ("AR7E transports" in the following) were computed by adjusting the relative velocity profiles to surface absolute altimetry velocities (Figure 2d). They are not totally independent from T_{alt} since both transports are referred to altimetry at the surface, but the vertical structure of the transports are estimated from two independent data sets. Errors on those transports are estimated based on the altimetry errors (Figure 2d). The rms difference between T_{alt} and the Ovide and AR7E transport estimates is 2.5 Sv. It is lower than the 3.1 Sv error in T_{alt}, indicating that, within error bars, those transports are compatible. In addition, with a difference of 0.17 Sv between the two estimates, our 2002–2008 mean EGIC transport compares well with that reported by *Sarafanov et al.* [2010b] (see Figure 2d). These results validate our hypothesis of no substantial change in the vertical structure of the EGIC transport variability over 1992–2009.

4. Discussion

[8] We estimated 19.5 ± 0.3 Sv for the 17-year mean of the EGIC altimetric transport T_{alt}, a value 2.2 Sv larger than the 2004–2006 mooring transport T_m mean. Hence, we conclude that the moored array was deployed during a period of weak EGIC transport. In 1992–1996, the EGIC transport was close to the average. After an increase in 1997, the EGIC transport decreases by 3 Sv between 1997 and 2005 (linear trend, significantly non-zero at the 95% confidence level). This result is in general agreement with the variability between 1992 and 2006 of the first EOF of the sea surface height in the Subpolar Gyre discussed by *Hakkinen and Rhines* [2009]. After 2006, the EGIC transport is slightly larger than the mean, indicating a strengthening of the subpolar gyre. Beyond this decadal variability, no significant trend is evidenced in the 1992–2009 EGIC transport time series.

[9] *Han et al.* [2010] estimated the decadal variability of the Labrador Current between the 600 m and the 3400 m isobaths, north of the Hamilton Bank, by combining altimetry measurements with the AR7W hydrographic sections. Similarly to our results they found no significant trend between 1993 and 2004. They also noted a decline of the Labrador Current transport in the second half of the 1990's followed by a partial rebound.

[10] Our analysis relies on the assumption that the vertical structure of the EGIC transport variability inferred from the 2004–2006 mooring records is adequate and that the vertical structure of the EGIC transport did not vary considerably on a decadal time scale. The close agreement of the inferred transport time series with independent estimates, that also show a decrease of the EGIC transport between 1997 and 2005, suggest that this assumption is reasonable. Finally, the agreement with the two AR7E estimates in 1996 confirms the ability of the method to account for the seasonal variability.

[11] The 2.9 Sv standard deviation of the altimetry transport is smaller than the 3.8 Sv estimated from the current meter time series since part of the energetic high frequency variability observed from the current meter data cannot be resolved by the altimetry. A seasonal signal of 1.8 Sv amplitude is evidenced with a maximum (minimum) amplitude in January (July). This confirms the result of DLM who found a similar amplitude (1.5 Sv) and phase for the seasonal signal from the analysis of the 2-year mooring time series. Since DLM found that the seasonal signal mainly affects the 0–600 m layer, as observed in the Labrador Current by *Fischer et al.* [2004], the slight increase in amplitude compared to DLM might be due to the EOFs reconstruction that propagates the seasonal signal down to the ocean floor.

[12] DLM found that the EGIC transport variability at intra-seasonal time scales is coherent, at the 95% significance level, with the wind stress curl variability over the Irminger Sea. Our extended EGIC transport time series allowed us to assess the correlation for longer time scales. Based on 27-day low-pass filtered time series, the correlation between the wind stress curl in the Irminger Sea from the NCEP Reanalysis [*Kalnay et al.*, 1996] and the EGIC transport (r = 0.5) is statistically significant at the 95% confidence level. Interestingly, the low EGIC transport period in 2005–2006 corresponds to a persistent anomaly in the wind stress curl (not shown). As the EGIC closes the cyclonic circulation gyre in the Irminger Sea, this result was expected from the model analysis of *Spall and Pickart* [2003]. In addition, boundary waves, eddies and recirculations likely contribute to the observed variability. However, to better understand the underlying mechanisms, dedicated numerical studies are needed. In particular, a joint study of the EGIC, West Greenland Current and Labrador Current variability would illustrate the correlation between the surface circulation variability in the Labrador and Irminger Seas reported by *Hakkinen and Rhines* [2009].

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