Satellite Altimetry and Seagliders: observing high-latitude ocean climate

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Global climate variability is extreme at the rim of the Arctic.

Ocean water masses are modified here, transports of liquid freshwater, ice and heat are strong, atmosphere-ocean interaction is strong, and yet direct observations are sparse.

Here we combine satellite altimetry with deep diving autonomous Seagliders to observe key elements of the ocean circulation and water-mass production.

ONR, NOAA, NSF and NASA components have given this observing program unprecedented coverage.

Results:

Western subpolar Atlantic

- 1 Seagliders have shown that offshore flow from Greenland controls deep convection and Labrador Sea Water production, as well as controlling the principal spring plankton bloom of the western subpolar Atlantic.

Low-salinity source waters from Greenland and the Arctic are likely to accelerate with global warming. Identification is through glider sections, altimetry, ocean color and SST imagery.

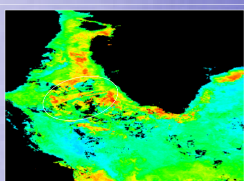
- 2 Altimetry combined with deep Seaglider sections reveals the 3-dimensional structure of the mesoscale anticyclonic eddies that dominate the Labrador Sea and the altimetric map of eddy kinetic energy.

Eastern subpolar Atlantic

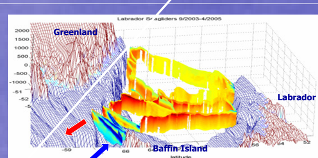
- 3 Current deployments of Seagliders between Iceland and Norway are providing intensive hydrographic surveys and velocity information revealing sites of deep, dense overflows southward into the Atlantic. Together with altimetric maps of EKE and anomalous velocity we have identified intense jet-like northward flow of warm, saline Atlantic water feeding the Faroes Current.
- 4 Continuing study of the downward trend in subpolar gyre surface circulation identified by Häkkinen & Rhines (2004), Hatun *et al.* (2005), includes the warming and increase in salinity of the Atlantic inflow to the Nordic Seas, and begins to connect this striking 15-year trend with other datasets and detailed altimetrically observed behavior of the North Atlantic Current.

1.

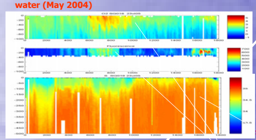
5 Seagliders carried out about 10,000 km of sections with 4200 vertical profiles during October 2003-April 2005



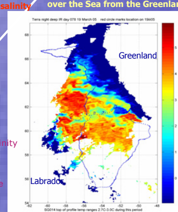
SeaWIFS ocean color showing intense spring chlorophyll bloom in Labrador Sea, connected with offshore advection of low-salinity water (May 2004)



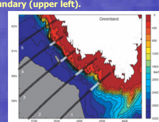
Potential temperature sections along Seaglider tracks, Labrador Sea, 2003-2005, viewed from northwest. Arctic water (cold, blue) flows through Davis Strait. The thin surface layer (greenish) is the cold, low-salinity water sweeping over the Sea from the Greenland boundary (upper left).

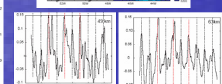


Seaglider section (spring 2005) passing through low-salinity 'cap' (seen also upper right ribbon section): chlorophyll, oxygen and salinity are all correlated



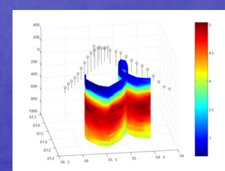
SST image superimposed on Seaglider track. The cold plume flowing off the Greenland coast contains the anticyclonic eddy shown in box 2.



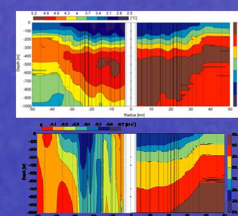


Altimetery based boundary current amplitude for sections 1 and 5 above. *This is the source of the offshore advection that controls both deep convection and primary productivity in the central Labrador Sea*

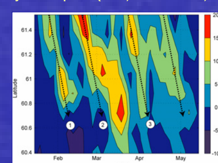
2.



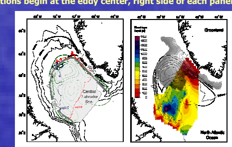
Combined altimetric and Seaglider section of an intense anticyclonic eddy in the offshore jet seen in panel 1 (*Hatun, Eriksen & Rhines, JPO 2007)*



Seaglider/altimeter cross-section of the intense eddy, giving a composite section of azimuthal velocity (lower left) , density (lower right), potential temperature (upper left) and salinity (upper right) (Sections begin at the eddy center, right side of each panel)

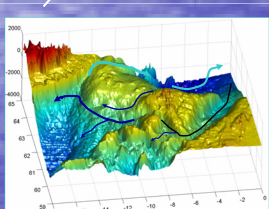


Hovmoeller plot of offshore movemnt of eddy and jet SSH anomalies relative to he Greenland boundary current

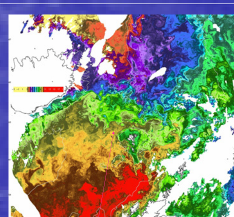


The deep convection region in the Labrador Sea (blue, right pane, Pickart 1998 cruise) is conditioned by the offshore flows described here The EKE maximum (grey shading) and ARGO float derived streamfunction (solid curves) show how this region is 'protected' from the low-salinity cap advecting from west Greenland

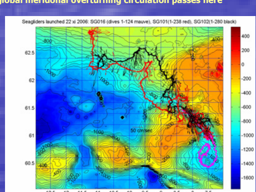
3.



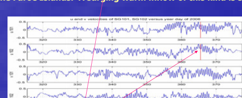
Topography of the Iceland-Faroe Ridge and Faroe-Shetland Channel, showing sites of dense, deep southward flows and warm, saline upper ocean flows into the Nordic Seas. 2/3 of the deep circulation feeding the global meridonal overturning circulation passes here



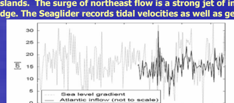
SST image showing warm Atlantic Water moving north on both sides of the Faroe Islands. A surging warm inflow of this kind is seen in the fig. below



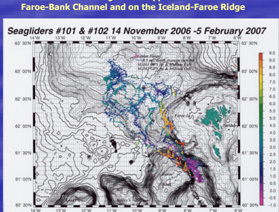
Seaglider tracks (Nov 2006-Feb 2007 with depth-averaged ocean currents. The gliders mapped the dense overflows in Faroe-Bank Channel and on the Iceland-Faroe Ridge



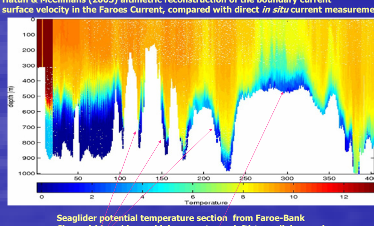
Ocean currents (depth-averaged u and v components) observed by Seagliders between Iceland and Faroe Islands. The surge of northeast flow is a strong jet of inflow of Atlantic Water across the Ridge. The Seaglider records tidal velocities as well as geostrophic currents.



Hatun & McClimans (2003) altimetric reconstruction of the boundary current surface velocity in the Faroes Current, compared with direct *in situ* current measurements



Bottom potential temperature for all Seaglider dives (~2500 profiles), between Nov 06 and Feb 07 The deep blue/purple waters are overflowing from the Norwegian Sea, south through narrow valleys. Section view seen at right



Seaglider potential temperature section from Faroe-Bank Channel (deep blue, cold dense water on left) to muliple crossings of the Channel connecting to the Atlantic, and then excursions into the dense (deep blue) water plumes on the Iceland-Faroe Ridge

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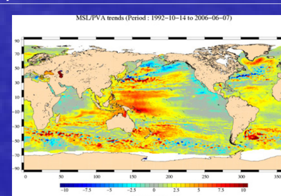
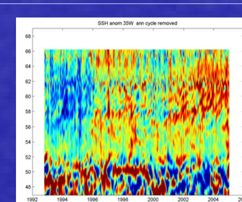
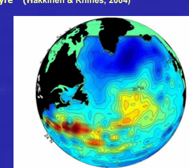


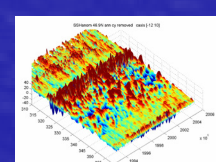
SSH trend 1992-2006, showing both global ocean warming/expansion and dynamical change. The rise in sea-level in the subpolar Atlantic corresponds to the slowing of the surface circulation of the cyclonic subpolar gyre (Häkkinen & Rhines, 2004)



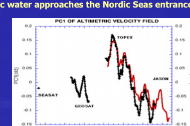
Hovmoeller plot of SSH anomaly along 35W The North Atlantic Current (NAC) passes through Charlie-Gibbs Fracture Zone at 52N. The years 1996 and 2000 mark abrupt changes in SSH of the gyre north of the NAC, with apparent change in Atlantic Water inflow to the Nordic Seas (Hatun et al 2005)



Leading EOF of SSH explains about 70% of the subpolar variance. Note structure in eastern end of gyre where northward flow of warm Atlantic water approaches the Nordic Seas entrance



Hovmoeller plot of SSH anomaly at 46.9N. Here the North Atlantic Current approaches its separation latitude; intense eddy activity is seen to its east



Time-series of leading EOF of altimetric velocity field showing continuation of declining circulation discussed by H&R (2004) to 2005, and suggestion of levels in Seasat and Geosat eras.

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www.ocean.washington.edu/research/gfd/gfd.html