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### Climate variability in the North Atlantic, causes and consequences

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Physical circulation and ocean biology interact in many ways. From the global pattern of nutrient upwelling pathways/meridional overturning circulation (MOC) to microscopic interactions between ocean turbulence and foraging/feeding strategies, ecosystems must deal with basics of stratification of temperature and buoyancy and shearing/straining/vertical&horizontal advection by ocean currents. Here we describe the surges of circulation that have brought (a) unusually warm, saline waters to the subpolar Atlantic Nordic Seas in episodes, particularly in the early 2000s, the late 1980s, the 1960s and the extended pre-Greenhouse warm-period extending from late 1920s to 1950s (Hakkinen & Rhines, *J. Geophys. Res*. 2011; *Science,* 2011 submitted); and, (b), episodes of invasion by buoyant, low-salinity waters overtop of the subpolar Atlantic, from orgins in the Arctic. The warm episodes (a) are linked to atmospheric forcing patterns, the famous NAO but also long periods of repeated atmospheric blocking anticyclones and their effect on wind-stress-curl. These are large, stalled meanders of the jet stream occupying either the Greenland region or the European sector. The cold, low-salinity surface waters (b) are enhanced Arctic outflow which has contributed to recent decline of sea-ace in the Arctic basin.

MOC is usually represented as the maximum streamfunction of the zonally averaged north/up velocity plotted against latitude. This is an incomplete icon-isation. Bergen, Norway and UK oceanographers provide analysis of the MOC in terms of *water-mass transformation* rather than a simple index of velocity. They give this more dynamically informative picture of vertical mixing, lateral transport and air/sea exchange, which has strong connections with ecosystem geography and intensity.

Finally, robotic glider platforms return fine-scale observations of bio-optical profiles coordinated with vertical velocity, shear, temperature and circulation. Relating to water-mass transformation, mode-water production and deep convection, we have shown from Seaglider deployments (Frajka-Williams & Rhines, *Deep-Sea Research,* 2009, 2010, see also Wu *et al.* Mar. Eco. Prog. Ser. 2008) that advection of buoyant low-salinity waters from Greenland boundary currents exerts strong control over primary production: the dominant spring bloom of the western subpolar Atlantic.

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