FRESHENING OF THE DEEP NORTH ATLANTIC OVER THE PAST FOUR DECADES

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Motivation

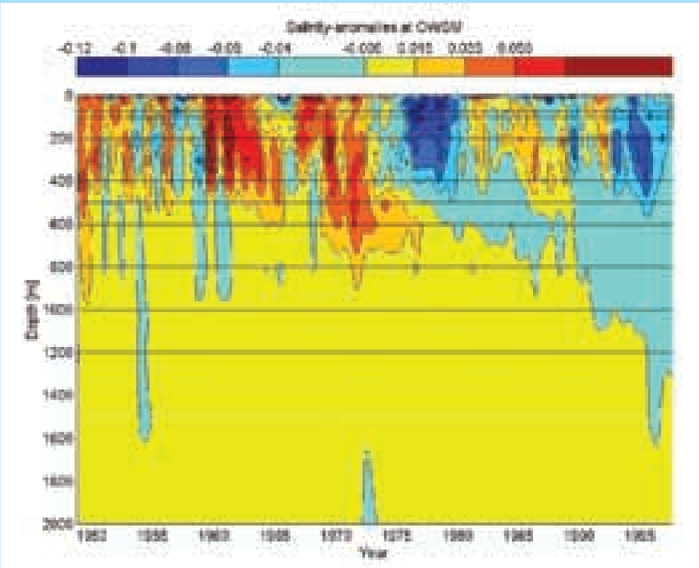


Figure 1: Nordic Sea Freshening

Many coupled climate models predict a slowdown of the global thermohaline circulation in response to increased freshening and warming in subpolar seas.

Salinity at Ocean Weather Station Mike in the Norwegian Sea shows a dramatic freshening over the past 4 decades (figure courtesy of S. Østerhus). Have multi-decadal changes in the Nordic Seas, source waters of overflow at the Greenland Scotland Ridge, been passed through the system of deep North Atlantic ventilation to the Labrador Sea?

The deep and abyssal layers of the Labrador Sea see the three components of NADW: Labrador Sea Water (LSW), North East Atlantic Deep Water (NEADW from the Iceland Scotland overflow) and Denmark Strait Overflow Water (DSOW). Can the strong freshening trends of NEADW and DSOW in the Labrador Sea really be traced back to the Nordic Seas and the Greenland Scotland Ridge?

The data set was selected to lie within the 3300m isobath of the Labrador Sea, and the plot represents the median values of vertical property profiles, binned according to σ_2 density intervals.

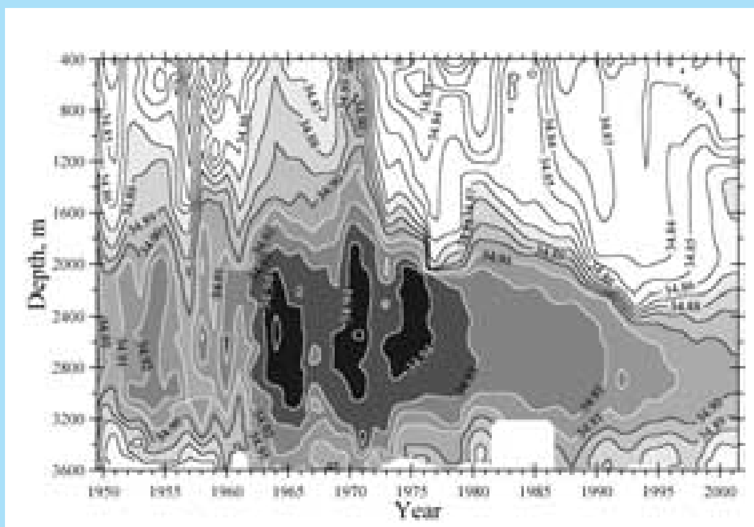
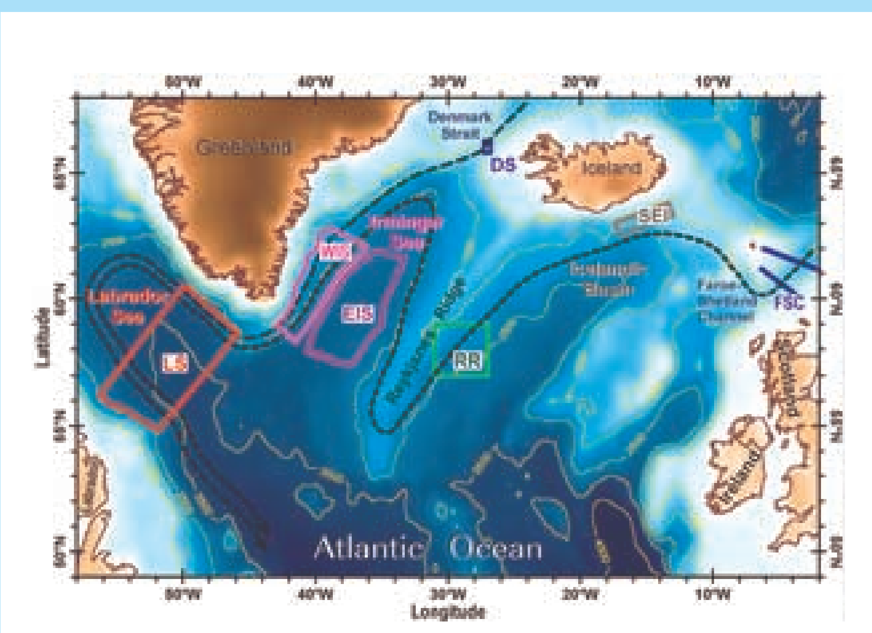


Figure 2: The deep Labrador Sea



The two main overflows across the Greenland-Scotland Ridge, their spreading pathways to the Labrador Sea (- - - -), the data-sources used to describe their changing characteristics en route (identifiers and colours as in Figure 5) and selected place names.

Figure 3: Overflow pathways and time-series locations

WOCE sections A1/AR7 W & E show a 'snapshot' in 1994 of the along path evolution of deep water around the northern Atlantic basins. The dilution of LSW core characteristics with distance from its source in the Labrador Sea (LS) into the Irminger Sea (IS) and Iceland Basin is illustrated along a full-ocean vertical section from Labrador - Cape Farewell-Reykjanes Ridge - Porcupine Bank.

The along path change of the core overflow from the Faroe Shetland Channel can be seen, first as it flows southward on the southern flank of the Reykjanes Ridge (labelled FSCO-Faroe Shetland Channel Overflow), then on the northern flank as Charlie Gibbs Fracture Zone Overflow (CGFZO) and as North East Atlantic Deep Water in the Labrador Sea.

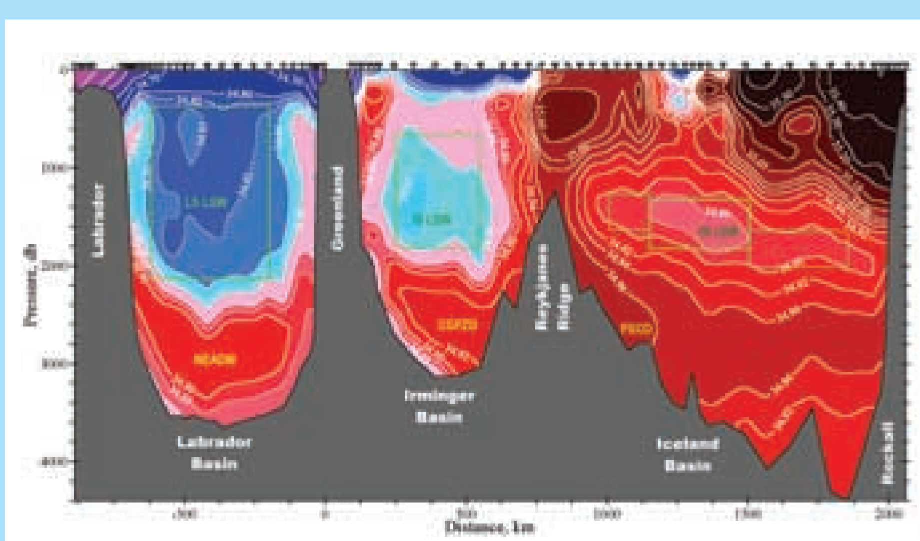


Figure 4: North Atlantic Salinity section

Evidence that a rapid and sustained freshening has occurred during the past four decades in both of the cold dense overflows which cross the Greenland-Scotland Ridge and along their spreading-pathways to the Labrador Sea. The salinity time-series shown are plotted to a common scale (with the exception of SEI at half scale), and the mean freshening rates in ppm per decade listed against each curve are calculated for the common period 1965-2000.

FSC Sill and ***FSC-NSAIW*** describe the freshening deep outflow through the Faroe Shetland Channel at sill depth and in the Arctic Intermediate Water layer respectively (Turrell *et al.*, 1999).

SEI shows the depth-mean anomaly of salinity in the 500-1000m layer at the head of the S. Icelandic Basin and so represents the salinity of the watermasses likely to be entrained into the eastern overflow as it leaves the Faroe Bank Channel. (The short term spike of the Great Salinity Anomaly of the mid-70s has been omitted).

RR represents the product of that mixing, describing the salinity trend in the deep salinity maximum which marks the core of ISOW against the deep eastern flank of the Reykjanes Ridge at 57-59°N, 27-31°W.

EIS-NEADW, ***WIS-NEADW*** and ***LS-NEADW*** describe salinity time-series at successive stages in the spreading of the eastern overflow as it continues into the Irminger Sea, shoals and alters along the Greenland Slope and ultimately forms the Deep Water of the Labrador Sea.

DS, ***WIS-DSOW*** and ***LS-DSOW*** describe the salinity trends of the Denmark Strait overflow at the sill (depths of 500-550m at T<0°C), in the 0-200m near-bottom layer where the overflow plume descends the Slope off S.E. Greenland, and in the abyssal layers of the Labrador Sea respectively. The observed annual mean ice flux through Fram Strait (Vinje, 2001), 1990-97, is shown for comparison (scale inverted) as a possible remote cause of the enhanced freshening along this path in the mid-'90s.

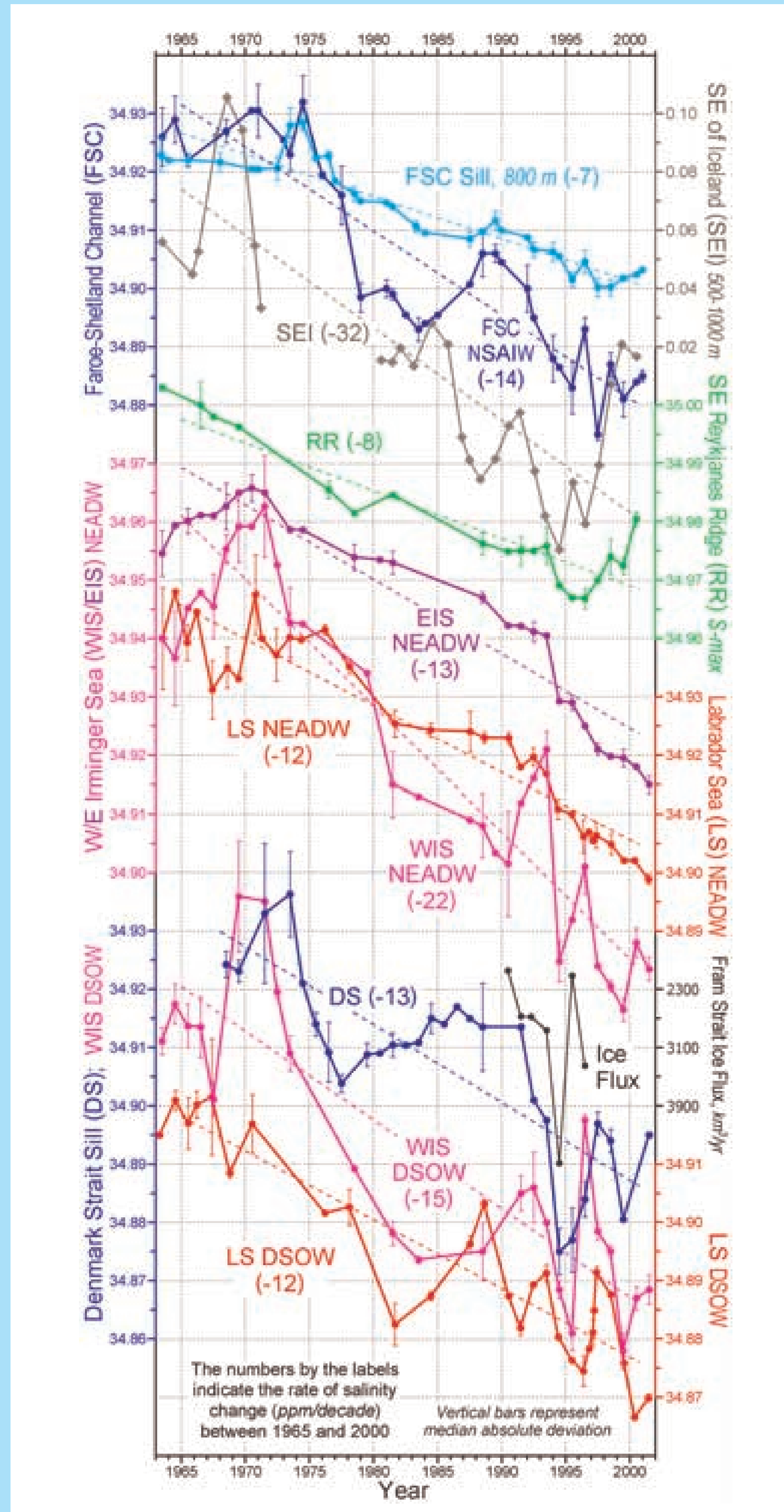


Figure 5: Along path overflow salinity time-series

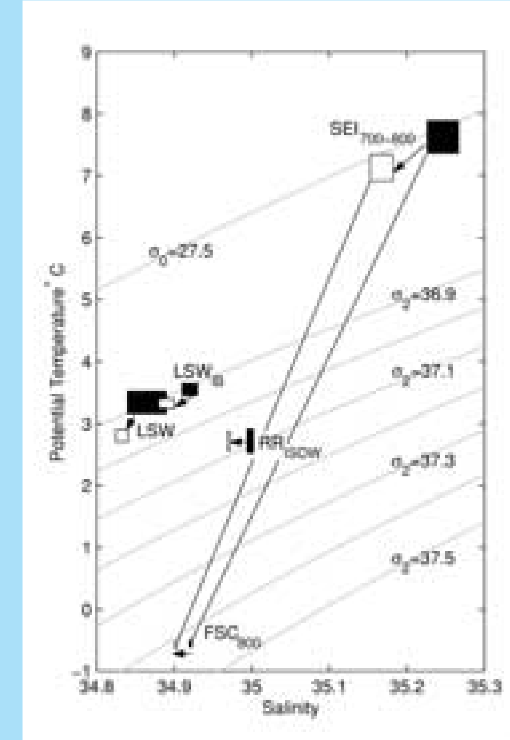


Figure 6: Simple mixing in ISOW formation

This potential temperature-salinity diagram describes the mixing relations in the S. Iceland Basin between overflow, entrainment and LSW, and takes account of the changing character of each of these three end-members between the 1960s (black rectangles) and late 1990s (open rectangles). Cold, dense water crossing the sill of the Faroe-Shetland Channel at 800m depth (FSC_{800}) will initially entrain the warm salty resident water at around that depth as it passes westward along the Iceland-Faroe Slope. That end member ('$SEI_{700-800}$') is water at 700-800m depth from immediately above the permanent thermocline in this region.

The product of any simple mixing between these two water-types cannot explain the relative freshness of the ISOW core (RR_{ISOW}) encountered further south against the Reykjanes Ridge. That freshening can only derive from mixing with a component of LSW. [Note that since data to describe the changing LSW-derivative in the S. Icelandic Basin is sparse, we show the locus of that modified LSW (LSW_{IB}), and that of LSW at source, 5 years earlier].

Concluding Remarks

The freshening rate of the eastern overflow was maintained downstream by mixing with waters that were themselves freshening at an equal or greater rate. A similar conclusion applies to the overflow from the Denmark Strait as it descends the Greenland Slope to the abyssal Labrador Sea. As its volume rapidly doubles by entrainment south of the sill, its relatively uniform freshening rate is not simply the result of a short spreading-path but must reflect mixing with overlying waters of a similar or greater rate of freshening ------- LSW at -13 ppm or WIS-NEADW at -22 ppm per decade.

There has been a widespread, sustained, rapid and surprisingly uniform freshening of the deep and abyssal North Atlantic, south of the Greenland-Scotland Ridge, over the past 4 decades. Since the freshening affects both overflows and their spreading pathways downstream, it seems to confirm that subarctic change can be rapidly transferred to the deep Atlantic, and has already directly affected the abyssal limb of the Atlantic MOC.

Questions

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Further Reading

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Acknowledgements

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