Freshening and stratification in the subpolar North Atlantic: Possible effects on Chlorophyll-a concentrations and NPP

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Freshening in the North Atlantic

- Examination of a range of objective analysis products collectively suggests widespread freshening of the North Atlantic from mid-2000 to the present.
- Fig. 1 shows the spatial distributions of the linear trend from four objective analysis products calculated from 2004 to 2015.
- The spatial distributions of the salinity trend show a general decrease in salinity in the northern North Atlantic, especially in the central North Atlantic and western subpolar gyre, including the Labrador Sea.
- As can be seen in Fig. 2, the linear trends in salinity are significantly different from zero for most of the North Atlantic.

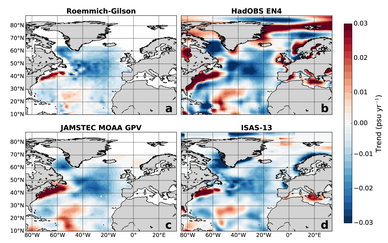

Fig. 1: Spatial distributions of linear trend in upper salinity seasonal anomaly for 2004-2015 using monthly mean fields of (a) Roemmich and Gilson, (b) HadOBS EN4, (c) JAMSTEC MOAA GPV, (d) ISAS-13.

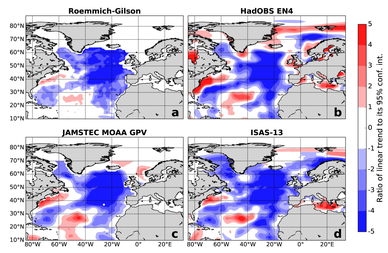

Fig. 2: Ratio of linear trend to its 95% confidence interval using monthly mean fields from 2004 to 2015 with seasonality removed as given by (a) Roemmich and Gilson, (b) HadOBS EN4, (c) JAMSTEC MOAA GPV, and (d) ISAS-13. The ratio indicates the significance of the trend, with significant trends corresponding to ratios with magnitudes larger than 1.0.

Trends in Stratification

- The BOA-Argo product (Li et al., 2017) has been used to compare the spatial trends of temperature and salinity in the upper 20 m (Fig. 3) for 2004-2006.
- Both temperature and salinity are decreasing in the subpolar North Atlantic, where colder surface layers contribute to higher and fresher surface layers to lower surface densities.
- The spatial distributions of stratification (Fig. 4) shows that there is a general increase in stratification both in terms of density difference between surface and deeper ocean and the buoyancy frequency (N^2) of the upper 100 m.

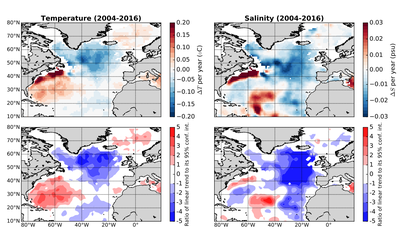

Fig. 3: Spatial distributions of linear trend in (a) temperature and (b) salinity of the upper 20 m. Corresponding significance of the trends are shown in (c) and (d) for temperature and salinity, respectively.

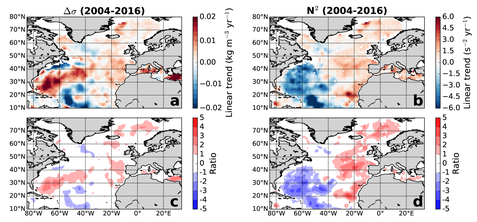

Fig. 4: (a) Spatial distributions of linear trend in stratification for 2004-2016 defined as the density difference between the upper 20 m and 100-500 m. (b) Spatial distribution of linear trend in N^2. Corresponding significance of the trends are shown in (c) and (d) for density difference and N^2, respectively.

Trends in Nitrate and Chlorophyll-a

- Nitrate fields from the biogeochemistry reanalysis product based on the PISCES model (Aumont et al., 2015) reveal a decline in the surface nitrate concentration in the subpolar and Nordic seas from 2004-2014 (Fig. 5a).
- Spatial trends from the NASA Ocean Biogeochemical Model (NOBM) of nitrate and total chlorophyll-a show coherent patterns (Fig. 5b&c).
- Negative trends in the Labrador Sea, Northwest Atlantic and parts of the Nordic Seas.
- Given the variability in the reanalysis products, these trends are significant (Fig. 5d-f).

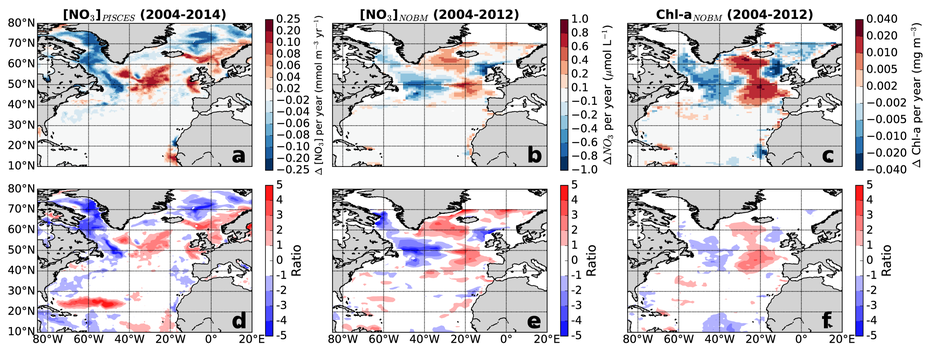

Fig. 5: (a) Spatial distribution of the linear trend in sea surface nitrate concentration ((NO_3)) between 2004 to 2014 from PISCES. Spatial distributions of linear trend in (b) (NO_3) and (c) chlorophyll-a for 2004-2012 from NOBM reanalysis product. The corresponding significance of the trends are shown in (d) (e) and (f).

Trends in Ocean Productivity

- Monthly maps of primary productivity from two different algorithms (Behrenfeld and Falkowski (1997): VPGM, Westberry et al. (2008): CbPM2) were used to calculate the annual production in the subpolar North Atlantic from February to October (Fig. 6).
- The yearly time series of total production in the North Atlantic show different trends depending whether the VPGM or CbPM2 algorithm is used.
- Whereas VPGM-derived production shows a slight increase in total production over the last 10 years, CbPM2-derived production shows a decline.
- Despite the difference in the total North Atlantic production, the spatial distribution of the linear trend is similar whether using the VPGM or CbPM2 algorithms (Fig. 7).
- Overall, VPGM-derived production shows a more positive trend, except for the western Labrador Sea and parts of the Northwest Atlantic, as well as a region in the northeast Atlantic (Fig. 7a).
- Comparatively, the CbPM2-derived production results in recent trends that are more negative (Fig. 7c).
- Regions where the VPGM algorithm results in a negative trend correspond to regions that have negative trends with the CbPM2 algorithm, though the latter is much larger in magnitude.
- In terms of significance, the trends in VPGM-derived production are significant for the increases in the central and eastern regions of the North Atlantic (Fig. 7b).
- The largely negative trends in CbPM2-derived production are significant throughout the western and eastern North Atlantic (Fig. 7d), though there is a positive significant trend in parts of the Greenland Sea.

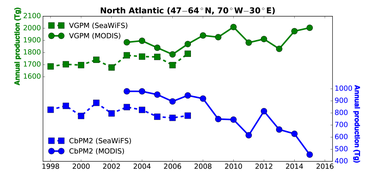

Fig. 6: Annual production (Feb-Oct) in the subpolar North Atlantic derived from VGPM and CbPM2 using SeaWiFS and MODIS data.

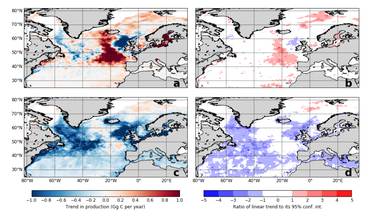

Fig. 7: Spatial distributions of linear trends for annual summer (June-August) production evaluated over 2003-2015 using MODIS data for (a) VPGM-derived summer production, and (c) CbPM2-derived summer production, alongside the ratios of the linear trend to its 95% confidence interval for (b) VPGM and (d) CbPM2.

- There are mismatches in total production depending on the model used, but the spatial pattern of the trend remains consistent regardless of the model.
- The spatial trends in NPP match observed patterns of freshening, stratification, nitrate and chlorophyll-a in recent years.

Conclusions

Spatial trends of surface salinity reveal large-scale freshening, with the largest trends in western subpolar gyre and Labrador Sea.

There is a general increase in stratification in the North Atlantic.

A biogeochemistry reanalysis product indicates an overall negative trend in sea surface nitrate over the same time period.

Analysis of satellite derived productivity, along with maps of chlorophyll-a, shows that total production in the same region is reduced, starting in the mid-2000s.

The results suggest that the observed freshening in the subpolar region, and associated changes to stratification, have limited nutrient inputs from below, thereby limiting productivity.

Regions such as the Labrador Sea that have experienced a decline in surface salinity have experienced changes in stratification and a decline in nutrient inputs from below, which would explain the recent negative trend in primary production.

These trends need to be further investigated using other algorithms as well as estimates of primary productivity independent of those used so far.

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