Eddy and seasonal variability of surface dynamics and fluxes in the Nordic Seas in a 1/12º global ocean model, forced and coupled to the atmosphere

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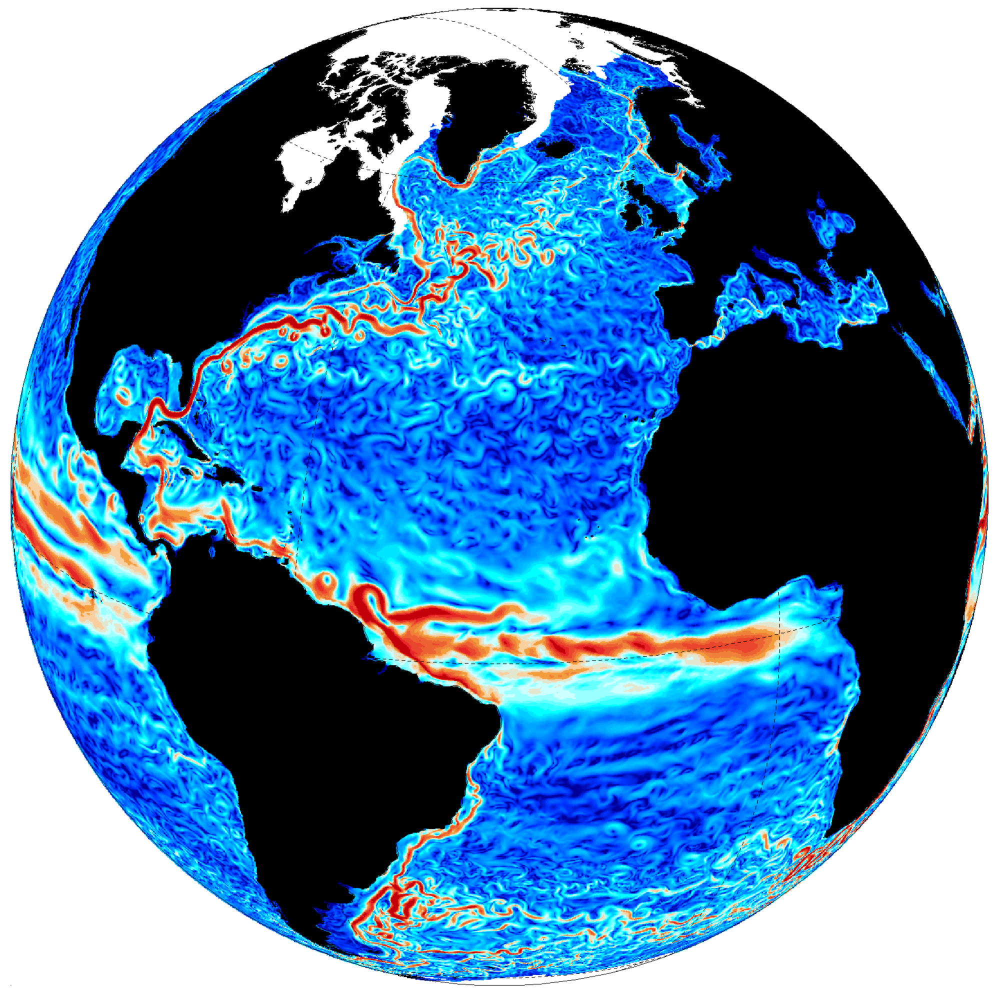


The Nordic Seas are a region of deep water formation, a major control of the Atlantic Meridional Overturning Circulation and thus very important for climate scenarios. In the west, the Greenland Sea is partially covered with sea ice, advected from the Arctic ocean or formed locally. In the east, the Norwegian sea is much warmer, due to the inflow of Atlantic Water from the North Atlantic subpolar gyre. The warm Atlantic water exhibits complex dynamics, notably interactions with topography and eddy mixing.

How are these dynamics represented in a global ocean model at 1/12º resolution?

We use a coupled simulation performed at the Met Office, with the Global Coupled model version 3 (GC3; Williams et al., 2017). It includes the 1/12° NEMO ocean model ORCA12, the sea ice model CICE, the MetUM atmosphere at 25 km resolution and the JULES land model (Hewitt et al., 2016). The coupled simulation is multidecadal. The forced simulation uses the same ocean-ice model and the CORE forcing (Griffies et al., 2016), for the years 1976 to 1995.

Eddy kinetic energy in the Norwegian Sea

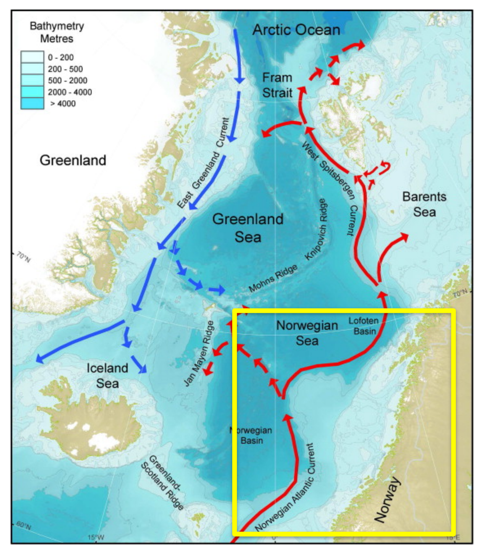


Figure 1 : Map of the Nordic Seas, with the circulation of Atlantic water (red) and Arctic water (blue) indicated (Isachsen et al, 2014).

Eddies generated along the warm Norwegian Atlantic Current cool the current by fluxing heat laterally into the interior. The eddy cooling is comparable to the surface heat loss to the atmosphere (Isachsen et al, 2012). These authors compared a forced ROMS simulation at 4km resolution with the rms velocity from surface drifters. The drifters clearly reveal the penetration of eddies into the interior.

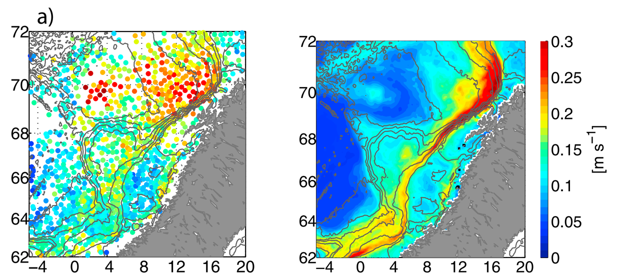


Figure 2 : a) rms velocity from surface drifters; b) rms velocity from a simulation with ROMS (from Isachsen et al, 2012, fig 4).

Their model has a level of eddy energy similar to observations in the Norwegian Atlantic current but underestimates the eddy activity in the interior, perhaps due to an excessive topographic control (Isachsen et al 2012). The same result was found by Wekerle et al (2016) using the FESOM finite element model at a similar resolution (4.5km).

RMS velocities from the global drifter database (Fig. 3a) are compared with the rms surface velocity in the forced ocean model (Fig. 3b) and in the coupled run (Fig. 3c). Eddy activity patterns are very similar, although the rms velocity is larger in the coupled model. Eddy activity is strong in the boundary current but too weak in the interior, consistent with the ROMS and FESOM models at similar resolution.

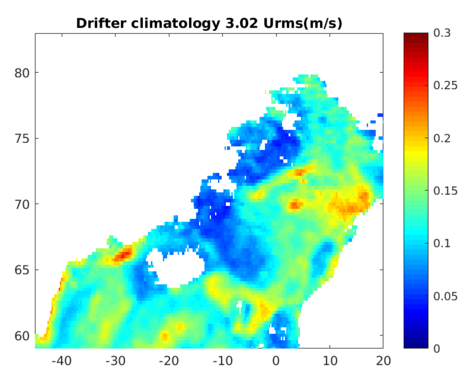


Figure 3a: rms velocity, drifters

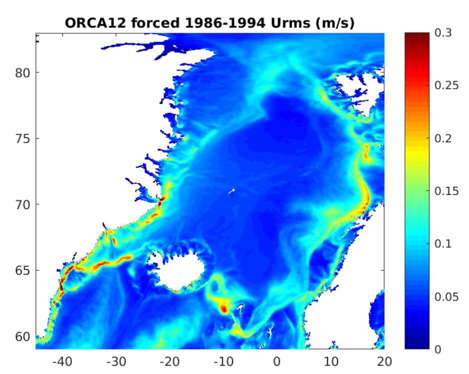


Figure 3b: rms velocity, forced model

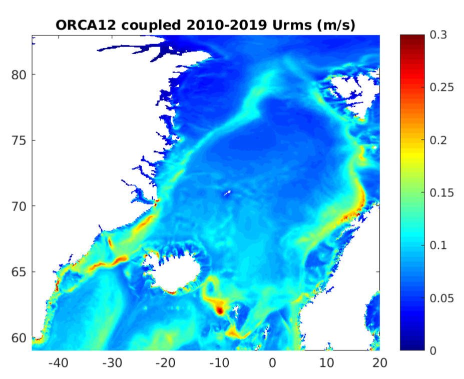


Figure 3c : rms velocity, coupled model

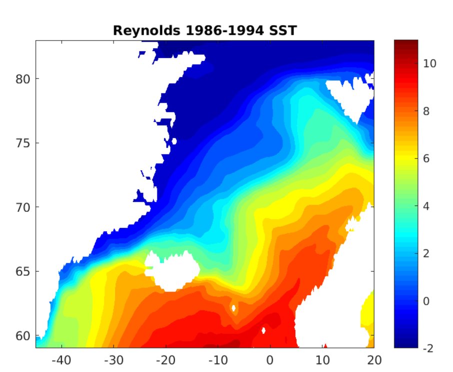


Figure 4a : Observed SST (Reynolds) averaged over years 1986 to 1994

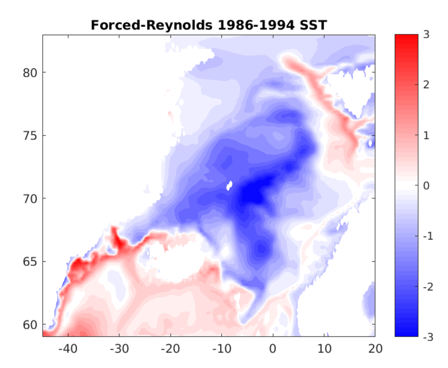


Figure 4b : Difference between the SST in the forced ocean model (1986 to 1994 average) and Reynolds SST.

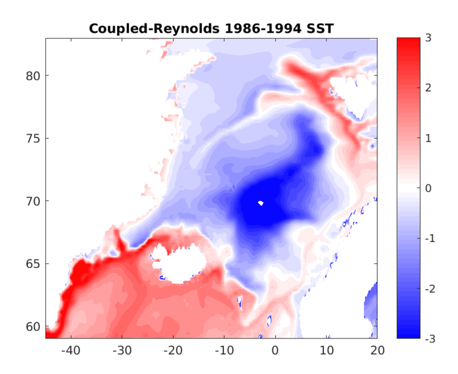
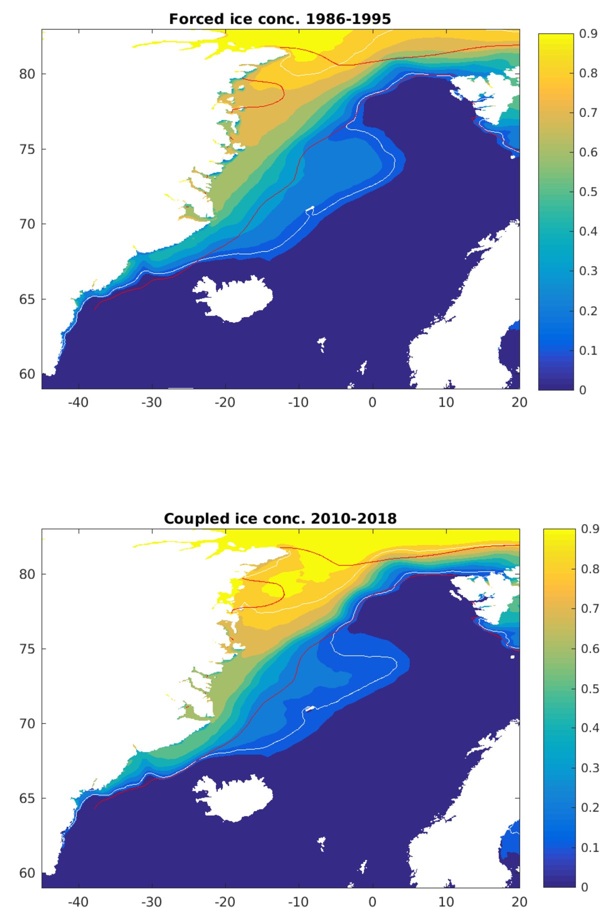


Figure 4c : Difference between the SST in the coupled ocean model (average over 10 years) and Reynolds SST.

The Sea Surface Temperature (SST) in the interior of the Norwegian sea is too cold in the models compared with the observations (Fig. 4). On the other hand, the temperature of the Atlantic current along Svalbard is too high in the models. This is consistent with an underestimated lateral eddy mixing between the boundary current and the interior.

Despite their different atmospheric forcings, the two ocean simulations behave similarly.

Sea ice concentration



The ice concentrations averaged over 9 years in the forced and coupled models are very similar (Fig. 5). In both models the marginal sea ice zone (MIZ, outlined by the white contours) covers a larger area than in the observations (red contours). In March, the sea ice often forms a tongue extending into the center of the Greenland sea, called the Odden. The Odden is more frequent and more pronounced in the model than in the observations, hence a larger sea ice concentration in the multi-year average. This probably results from a misrepresentation of processes in the ocean or ice model, rather than from the atmospheric forcing. Although its amplitude is too strong in the models, the seasonal cycle of ice area (Fig. 6) is in phase with observations. Both forced and coupled model exhibit a strong interannual variability.

Figure 5 : time-mean ice concentration. White lines: 0.15 and 0.85 contours in the models; red: same contours in NSIDC data, for the same years ar the forced model. Year numbers for the coupled model are arbitrary.

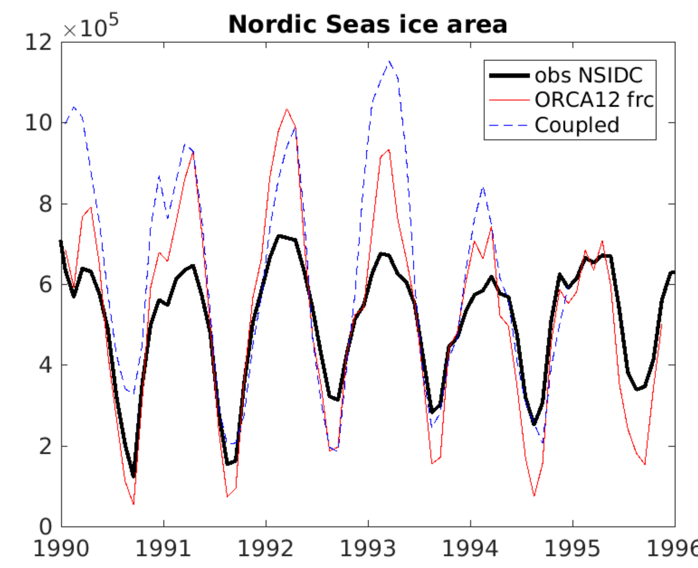


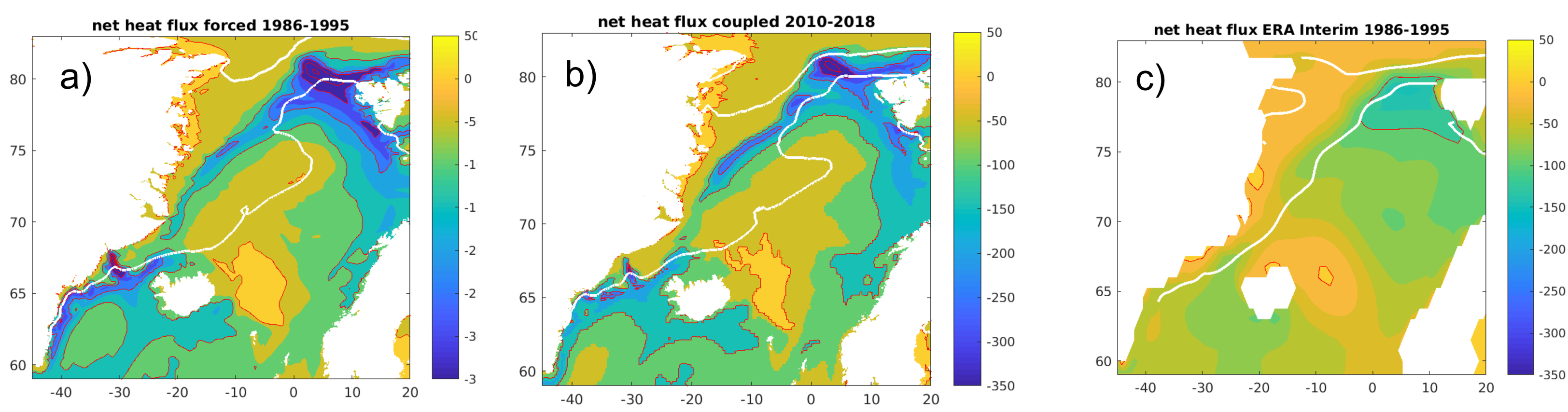
Figure 6 : Time series of ice cover in the Nordic seas (Greenland to 15ºW, 64ºN to 82ºN) for observations and models. Year numbers for the coupled model are arbitrary.

Air-sea heat fluxes

Due to the inflow of warm Atlantic water, the Nordic seas are a sink of heat for the ocean. In the models (Fig. 7a and 7b), the heat flux out of the ocean displays a high spatial variability with a large heat loss northwest of Svalbard, in the marginal sea ice zone (cooling > 400 W/m²). The pattern of cooling is similar in the forced and in the coupled model. The spatial pattern is different from the atmospheric flux derived from reanalyses. Fig 7c shows that the ocean heat loss is much lower in ERA Interim (less than 150W/m² of cooling everywhere in the interannual average).

The net heat flux experienced by the ocean is the sum of the ocean-atmosphere flux and the ice-ocean flux. Could the strong cooling in the model be due to the ice-ocean flux? Indeed, the maximum heat loss near Svalbard and the band of heat loss along the path of the East Greenland current are partly due to melting of ice advected by the ocean currents, probably mostly coming through Fram strait.

The ocean-atmosphere flux, computed without the ocean-ice flux, is shown in Fig 7d and 7e. It is still larger than ERA Interim but more comparable. The forced model loses more heat than the coupled model even though its SST anomaly is lower than the coupled model (Fig. 4).



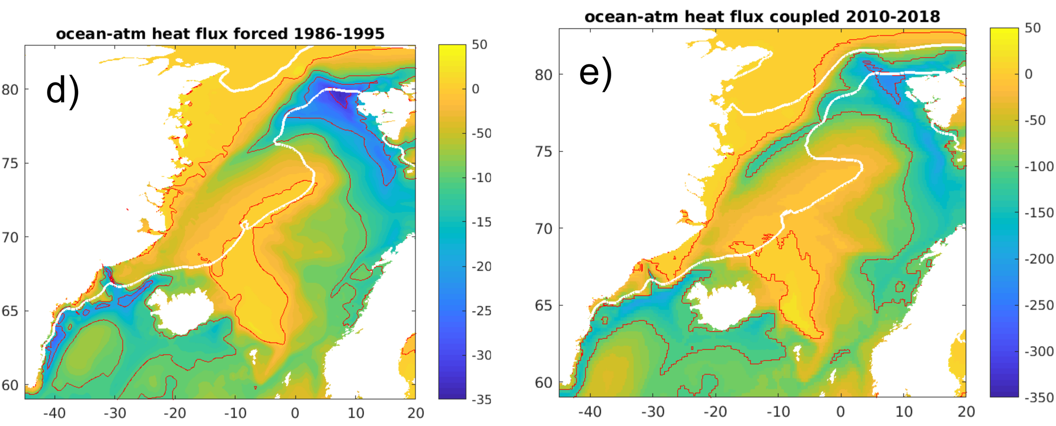


Figure 7 : Time-mean surface heat flux, negative out of the ocean (colorscale saturated at -350 W/m², and red contours every 100W/m²). The marginal sea ice zone is outlined in white (concentration 0.85 and 0.15). a: forced model total ocean heat flux. b: same for the coupled simulation. c: averaged surface heat flux from the reanalysis ERA Interim, with NSIDC ice concentration. d) and e): same as a) and b) but for the ocean-atmosphere flux only (ocean-ice flux removed).

Conclusions

- The global 1/12º coupled and forced models exhibit the same biases in eddy-kinetic energy in the Nordic seas. The low eddy kinetic energy in the center of the Norwegian Sea is a bias shared by other ocean-only models at 4km resolution.
- The lack of lateral transport of heat into the interior may be the cause of the excessive temperature in the West Spitsbergen current, south and west of Svalbard.
- Sea ice area is overestimated in the Greenland sea, in the coupled and forced models.
- Overall, the quality of the ORCA12 coupled simulation is remarquable (Hewitt et al, 2016). Nevertheless, common biases in forced and coupled simulations suggest that progress in simulating ocean-topography interactions, ocean dynamics and sea ice dynamics could improve future climate scenarios at high resolution.

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