Impact of 4D-Var assimilation on transport estimates of pelagic eggs

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Introduction

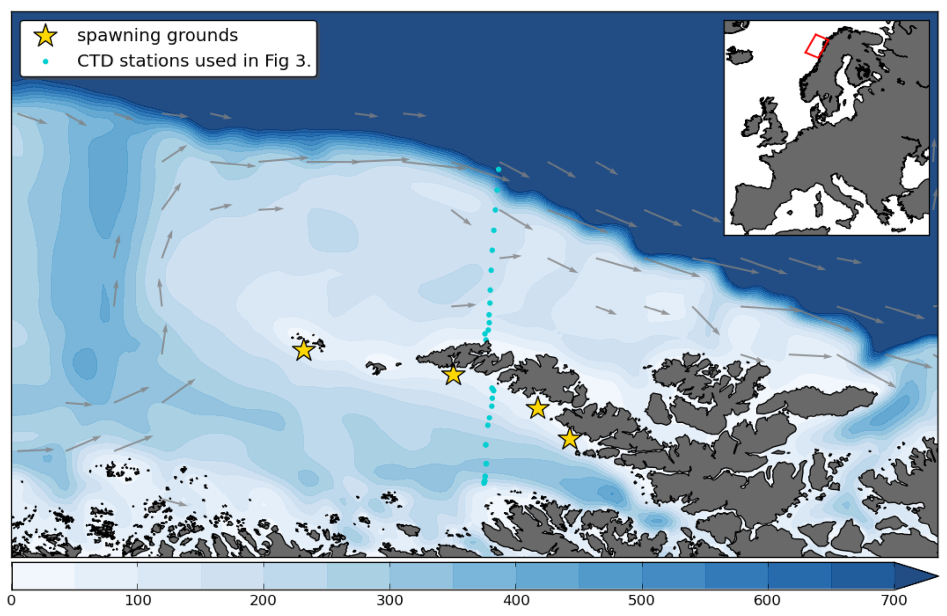

Figure 1: The model domain. The blue shading represents bathymetry (meters), while the yellow stars marks release sites for cod eggs in the particle tracking model. The gray arrows indicate the dominating currents.

In situ observations still provide the most accurate estimation of ocean hydrography, but the number of sub-surface observations are usually too sparse to properly resolve the density structure of the ocean. In 1984 and 1985, during the spawning season of the Northeast Arctic cod in March and April, the Institute of Marine Research (IMR) carried out extensive field experiments around the Lofoten archipelago, collecting a large number of CTD profiles as well as egg samples. This data set provide an excellent basis for studying how improved representation of the density field through assimilation may affect the associated circulation patterns.

The water properties around the Lofoten archipelago are strongly dependent on the Norwegian Coastal Current which carries fresh water from the Baltic northwards, while additional freshwater is added from the fjords. The coast of Norway is very long and errors in freshwater influx at model boundaries and river runoff will accumulate and may have a large detrimental impact in the far north.

Two independent spring season re-analyses for the years 1984 and 1985 have been made using ROMS 4D-Var. To study the effect of assimilation on transport of Northeast Arctic cod eggs and larvae from their spawning grounds towards their nursery grounds in the Barents Sea, the output from ROMS is used by the Lagrangian advection and diffusion model, LADIM, to calculate trajectories of cod eggs spawned at four major spawning sites in Vestfjorden [1].

Grid

- 2.4 km horizontal resolution
- 35 vertical layers

Model Input

- Six hourly atmospheric forcing from NORA10 (downscaling of ERA-40) [2]
- Nested in BaSIC4km hindcast [3]

ROMS IS4DVAR configuration

- Assimilation window: 72h
- 10 inner, 2 outer loops

Experiments

- Hindcast simulation (no assimilation) Jan. 1983 - May 1985
- Two spring season re-analyses
  - Jan. 1984 - Apr. 1984
  - Jan. 1985 - Apr. 1985

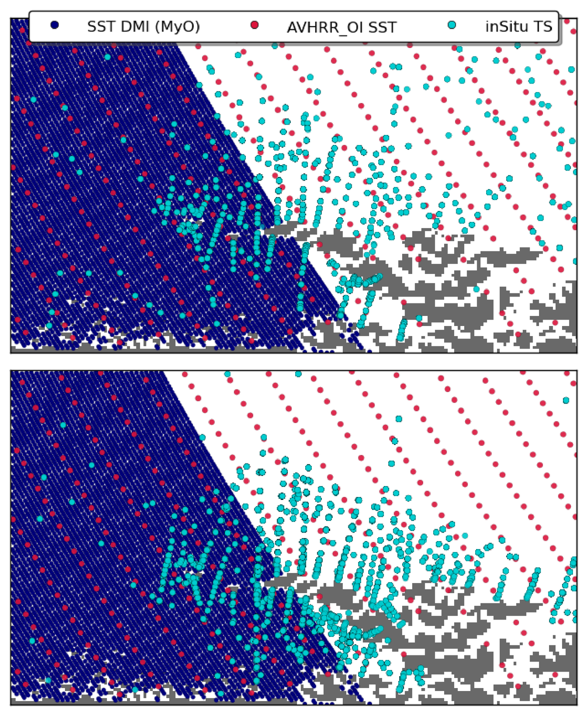

Figure 2: The upper panel shows the observation distribution in 1984 and the lower panel show the same for 1985.The total number of in situ observations are nearly doubled from 84 to 85.

Assimilated data

- Daily fields of blended sea surface temperature (SST) with 0.25° resolution from GHRSST
- Daily fields of analyzed SST with 0.03° resolution from MyOcean.
- In situ data retrieved from the Hadley Center. The data set mainly consists of CTD profiles collected during IMR's cod assessment cruises.

Water Properties

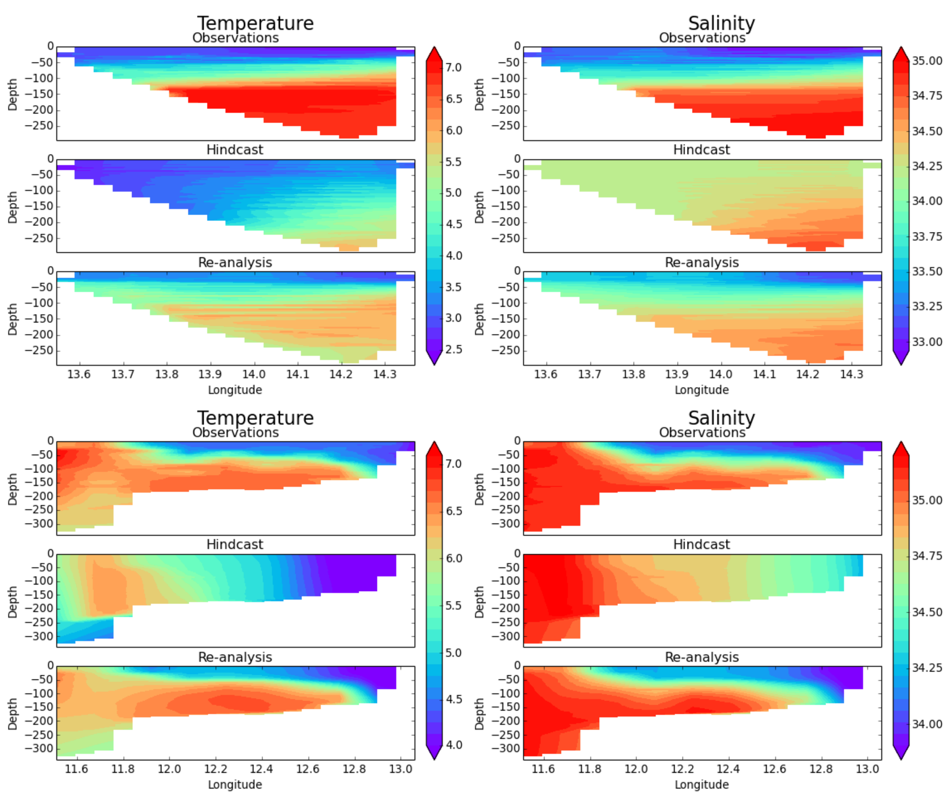

Figure 3: The upper two panels show cross sections of temperature and salinity inside Vestfjorden , while the two lower panels are from a cross section outside of Lofoten. The locations of the cross sections are shown in Fig. 1.

Figure 3 shows temperature and salinity along two different cross-sections in observations, hindcast and re-analysis background estimates (thus the observations used for comparison have not yet been assimilated). It is clear that the coastal water is too saline and that the stratification is generally to weak in the hindcast simulations. The water properties are greatly improved by data assimilation, providing a much better representation of the mixed layer and coastal water.

For a large-scale evaluation of the distribution of different water masses, we calculate the freshwater height:

$$FWH = \frac{1}{S_{ref}} \int_{z}^{0} max[S_{ref} - S(z), 0] dz, \qquad (1)$$

Maps of mean freshwater height for the months March and April are shown for both spring seasons. In a similar manner, a climatology of freshwater height for these months have been calculated from all available in situ profiles taken during the period 1983-1989. Similar to the climatology, the re-analyses show a higher content of freshwater both inside Vestfjorden, as well as over the continental shelf outside the archipelago. The maps also reveal a problem with too high freshwater content in the Lofoten basin, stemming from the boundary conditions, which is only slightly reduced by assimilation.

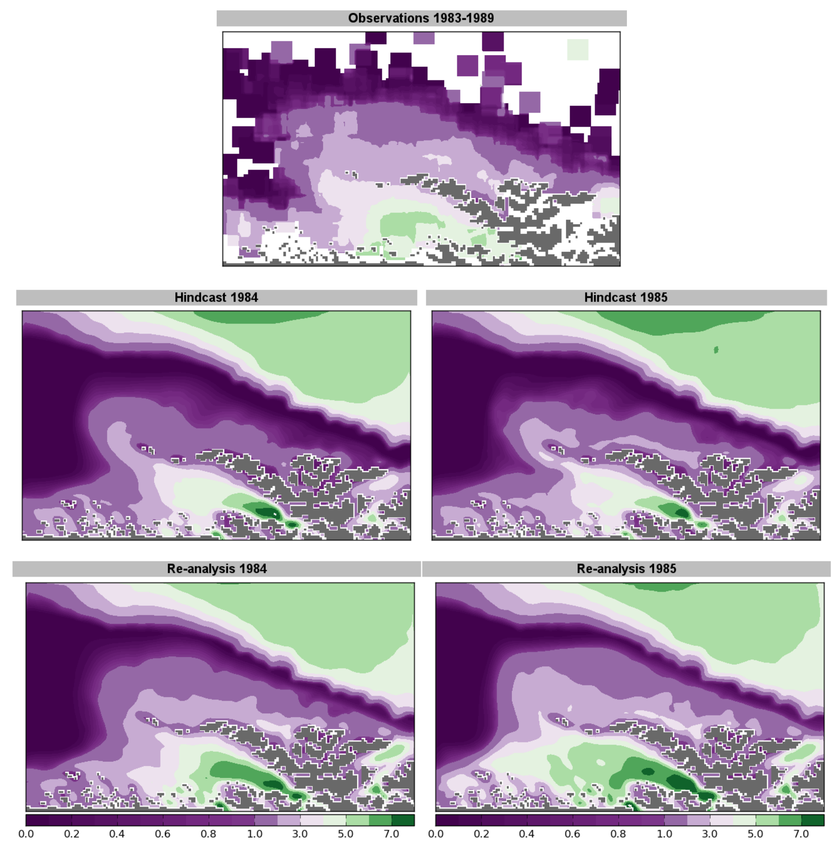

Figure 4: Mean freshwater height during March-April 1984 (*left*) and 1985 (*right*) as calculated from observations, hindcast and re-analysis simulations. High values indicate high freshwater content.

Transport of cod eggs

The output of the ROMS simulations are used as forcing in a particle tracking model (LADIM). LADIM is initiated on 15 March both years, and run throughout April. Cod eggs are released every other night at the four spawning grounds depicted in Figure 1 during the first 30 days of the simulations. The cod eggs are slightly buoyant in sea water, and thus remain in the upper part of the water column throughout the simulation. The preliminary results exhibits large differences in spread.

In particular, the concentration of eggs in the interior of Vestfjorden and further offshore on the shelf is increased in the simulations forced by the re-analyses. This is in accordance with observations, but the results remains to be validated with in situ egg samples. The overall effect on number of eggs that leave Vestfjorden is opposite in 1984 and 1985 with more eggs being retained in the fjord in 1985, most likely due to difference in prevailing wind directions.

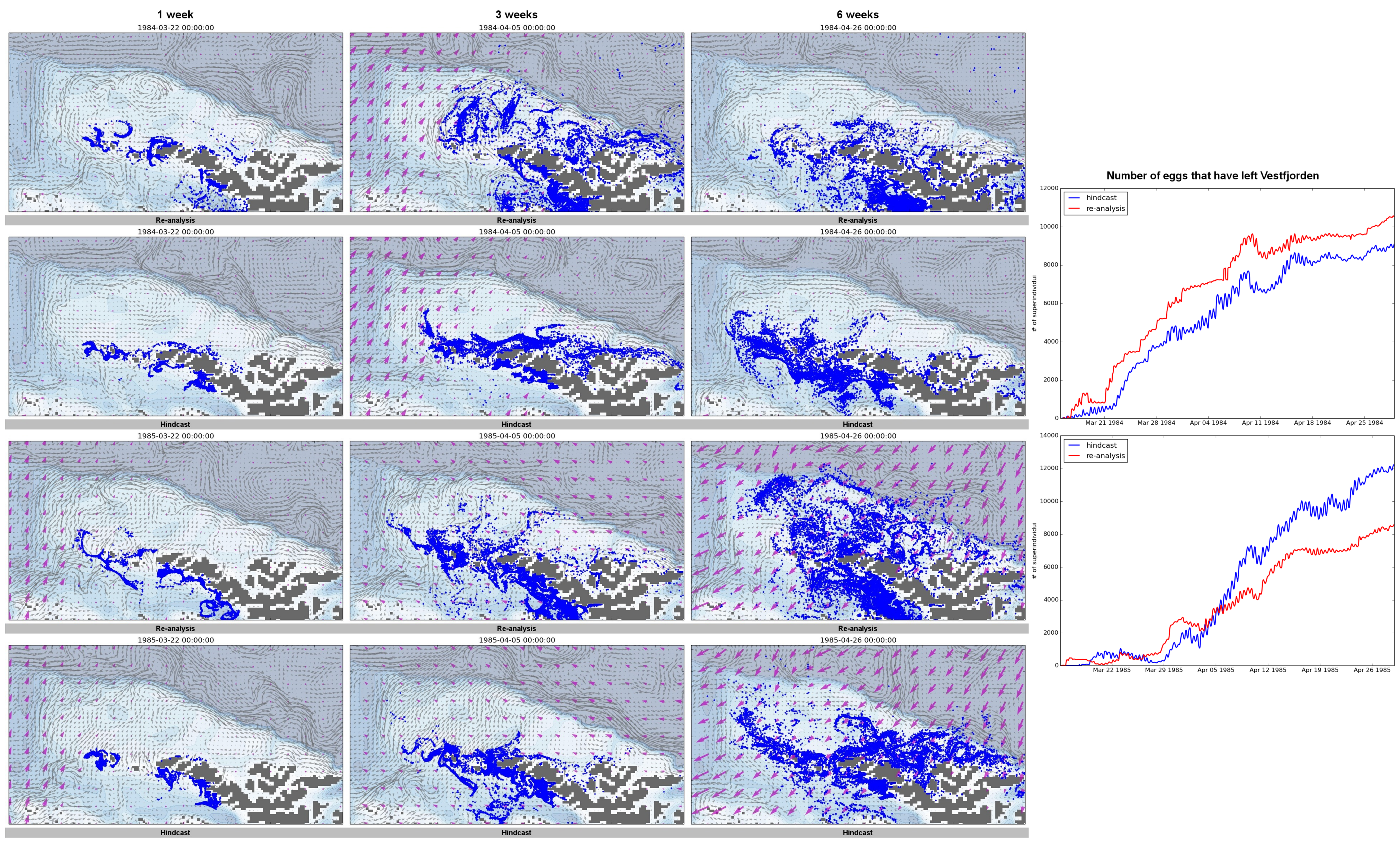

Figure 5: Distribution of cod eggs after 1 , 3 and 6 weeks after initialization on 15 March. The panels on the right show number of eggs that have been transported out of Vestfjorden. Blue dots represent cod eggs, gray arrows currents at 1 meter depth, purple arrows represent wind stress.

Summary and future work

- Assimilation of hydrography profiles has profound effect on the distribution of freshwater, and implicitly on the circulation.
- The egg transport model results differ widely between hindcast and re-analysis. A direct comparison with in situ egg samples will be carried out to validate our results.
- A reduction of the salinity bias in the Lofoten basin is desirable. Inclusion of boundary conditions in the control vector should help.
- We plan to expand the assimilation experiments to also allow for changes to the surface stress and fluxes and extension of the re-analyses to cover May as well, to allow for longer transport simulations.
- The transport through the two straits in the outer part of Vestfjorden are particularly important for advection of eggs out of Vestfjorden. Adjoint impact studies on these transports are therefore of particular interest in this context.

Figure 6: The cod egg movie!

References

[1] : Ådlandsvik, B. and S. Sundby: *Modelling transport of cod larvae from the Lofoten area.*, ICES Mar. Sci. Symp., 198, 379-392, (1994).

[2] : Reistad, M. Ø. Breivik, H. Haakenstad, O. J. Aarnes, B. R. Furevik and J.-M. Bidlot: *A high-resolution hindcast of wind and waves for the North Sea, the Norwegian Sea, and the Barents Sea*, Journal of Geophysical Research: Oceans. 116,2156-2202, (2011).

[3] : Kristensen, N. M., A. Melsom, Y. Gusdal, L. P. Røed, B. Ådlandsvik and J. Albretsen: *BaSIC Validation - Addendum 2*, met.no Report 11/2014 (2014).