# Surface circulation in the Nordic Seas from clustered drifters


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## Abstract


We compare two methods for estimating mean velocities and eddy diffusivities from surface drifter observations in the Nordic Seas. The first is the conventional method of grouping data into geographical bins. The second relies on a "clustering" algorithm, and groups velocity observations according to nearest-neighbor distance.
Bins with a length scale of $\sim$ 50km capture the spatial variability of the mean velocity field. However, because many bins have few observations, the statistical significance varies substantially between estimates in bins. Clustering yields sets with approximately the same number of observations, so the significance is more uniform. At densely sampled regions, clusters can be used to construct the mean flow field with $\leq$ 10km resolution. Clustering also excels at estimation of eddy diffusivities, mapping them at an average resolution of 80km. Taking bathymetry into account in the clustering process further improves mean estimates where the data is sparse.
Clustering the available surface drifter data reveals a large anticyclonic vortex in the center of the Lofoten Basin and two permanent anticyclonic recirculations in the southern Norwegian Sea. Clustering also yields maps of the eddy diffusivities at unprecedented resolution. Diffusivities are suppressed at the core of the Norwegian Atlantic Current, whereas they are elevated in the Lofoten Basin and along the Polar Front.

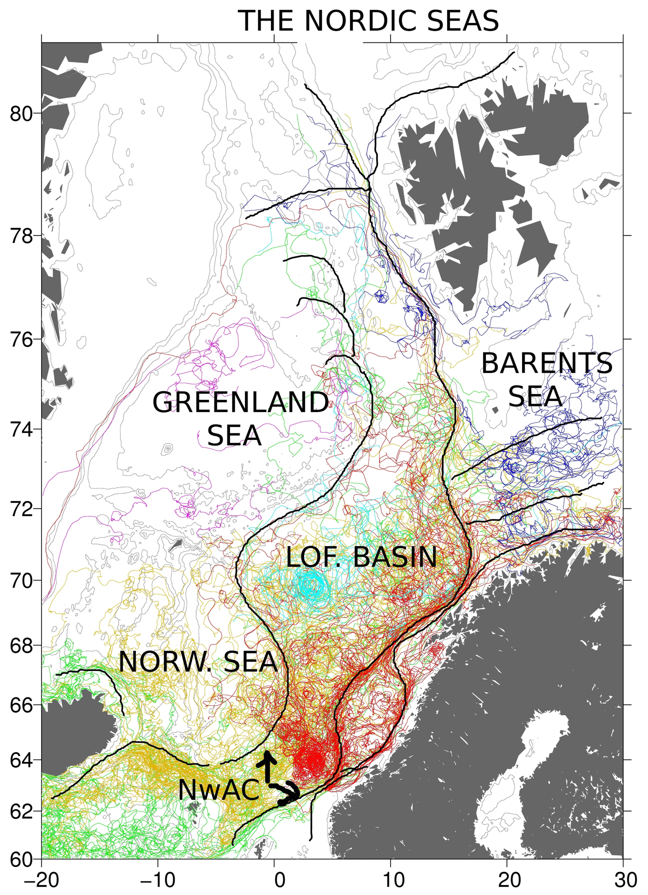

## Problem

Evolution of a tracer field $\theta$ is described by the generalized transport equation:

$$\frac{\partial}{\partial t}\langle\theta\rangle = -\mathcal{U}\nabla\langle\theta\rangle + \nabla\big(\kappa\nabla\langle\theta\rangle\big)$$

Mapping of ocean transport processes with Lagrangian data involves estimation of mean velocity $\mathcal{U}(x,y)$ and eddy diffusivity $\kappa(x,y)$. This is difficult because oceanic flows are inhomogeneous and drifter data distribution is non-uniform in space and in time.

## Study area and Data



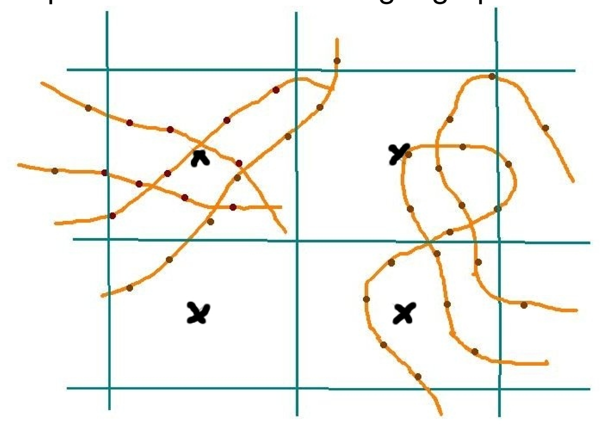

The study area is the eastern Nordic Seas: The Norwegian Sea with the Lofoten Basin, and the Barents Sea Opening. The Norwegian Atlantic Current system (NwAC) conducts warm and saline waters into the Arctic. These waters loose heat and gradually subduct while transversing the Nordic Seas. Largest heat loss occurs in the Lofoten Basin and in the Barents Sea.
Data: Drifter trajectories (drogued at 15m depth). Source: Global Drifter Program database, enhanced by recent deployments from the POLEWARD project. Temporal span: 1990-2009. Here the trajectories from 2000s are shown, color-coded by the deployment site.

## Averaging of drifter data

Traditionally, Lagrangian observations are grouped in geographical bins and then averaged. We use clustering algorithm to group them.

## Averaging by binning

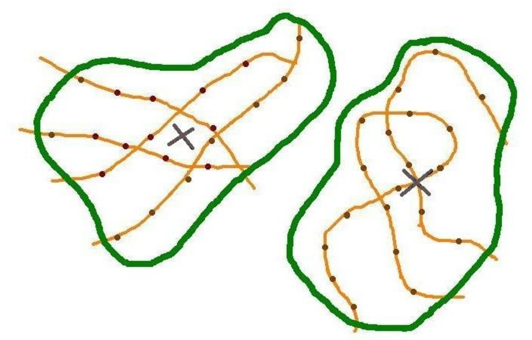
- Group observations into geographical bins



- A-priori chosen length scale
- Unequal number of data in bins $\rightarrow$ nonuniform statistical accuracy
- Large bins $\rightarrow$ a significant estimate $\rightarrow$ too smooth fields

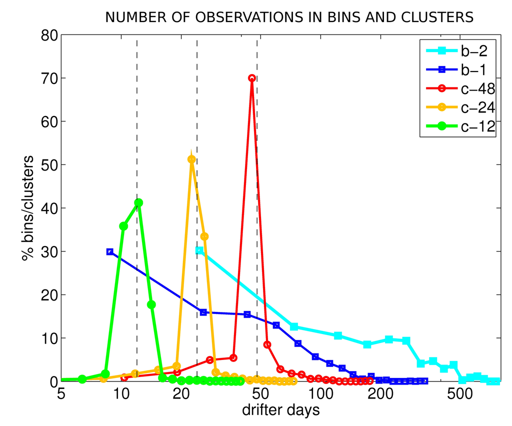
## Averaging by clustering

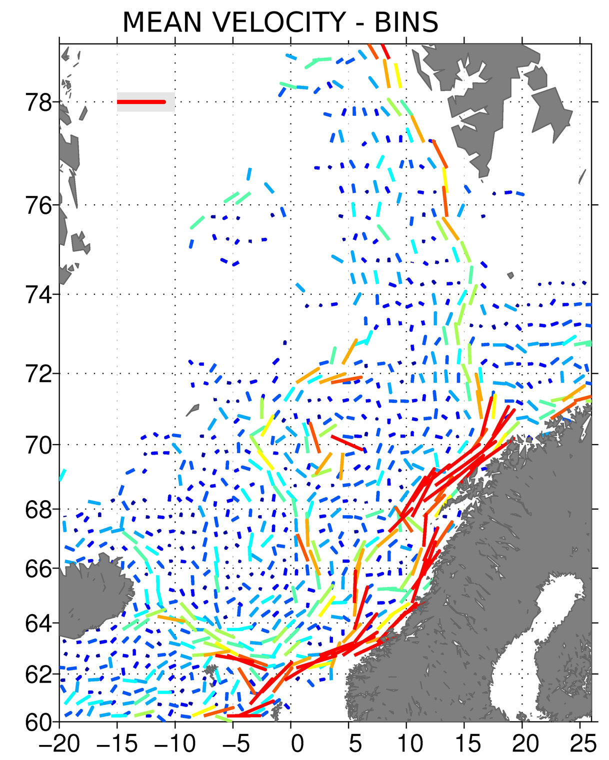
- Group equal number $m$ of nearest observations
- Iteractively: $\min \sum_{i=1}^{k} \sum_{\mathbf{x}_j \in S_i} ||\mathbf{x}_j - \mu_i||^2$

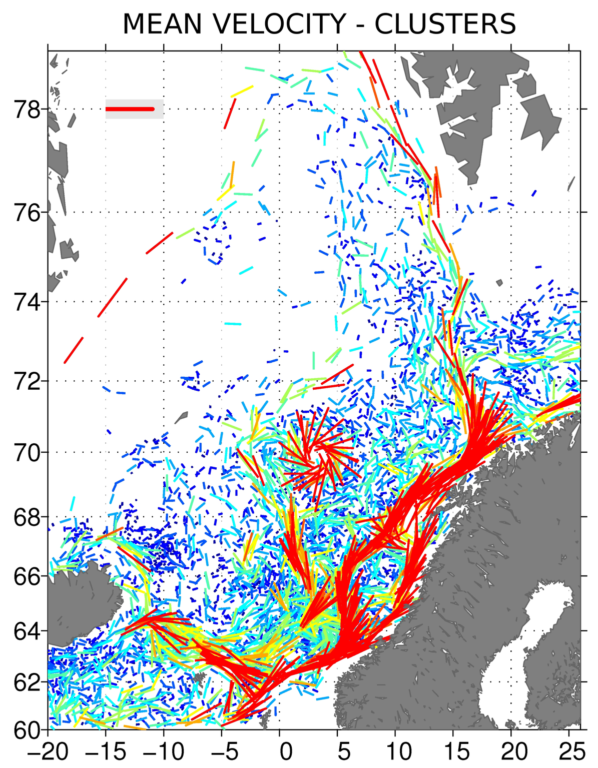


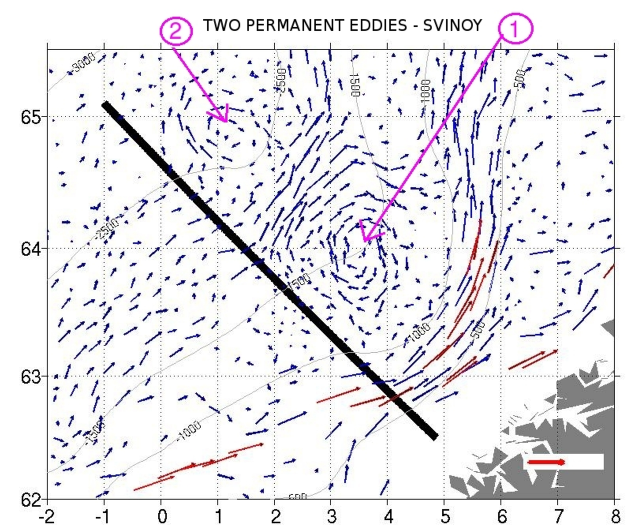
- No assumptions on the length scale
- Equal number of data in bins $\rightarrow$ uniform statistical accuracy
- Estimates are defined on an irregular grid
- The main currents are topographically steered $\rightarrow$ including the depth parameter further improves the resolution of the estimate

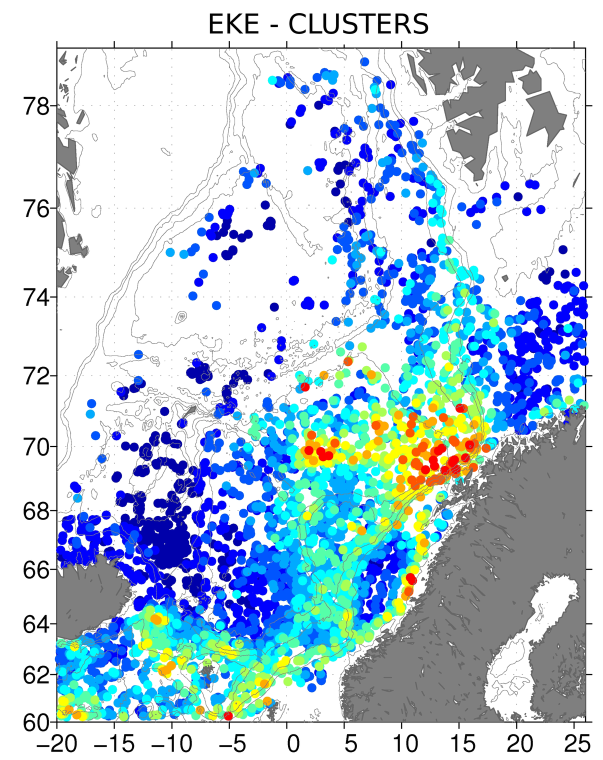
## Results - Mean surface velocities



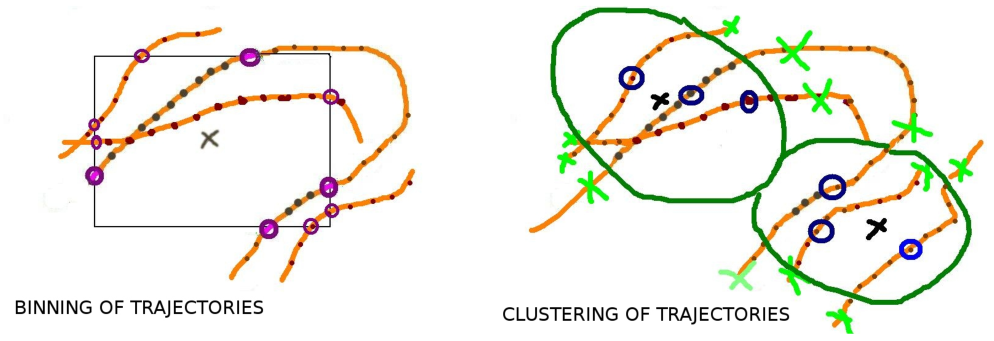

Binning estimates must be at least $\sim$ 50km scale to be significant, whereas clustering estimates can be $\sim$ 10km at densely sampled Svinøy section, revealing permanent eddy features. Eddy variability is intensified in the Lofoten Basin, and its pattern is in very good agreement with model results by Røed et. al. (2011).

## Results - Eddy diffusivites

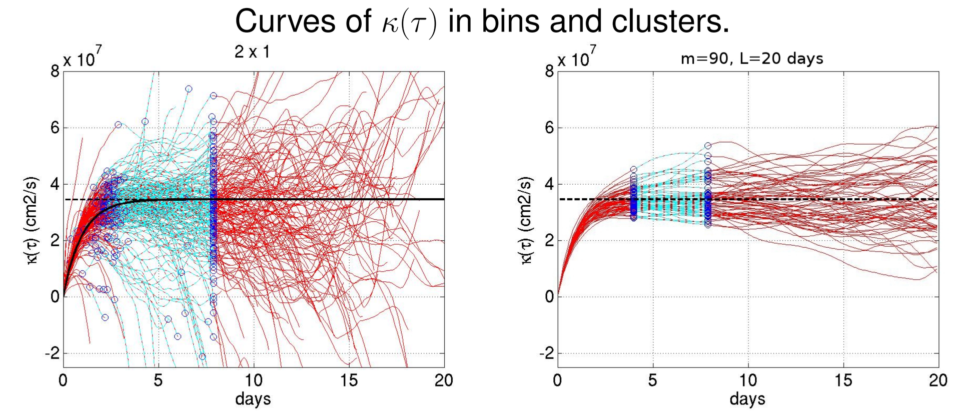
Eddy diffusivities are estimated from the eddy velocity autocorrelation:

$$\kappa(x,\tau) = < u'(t_o|x,t_o)u'(t_o+\tau|x,t_o) > = \int_0^t P(\tau)\,d\tau$$

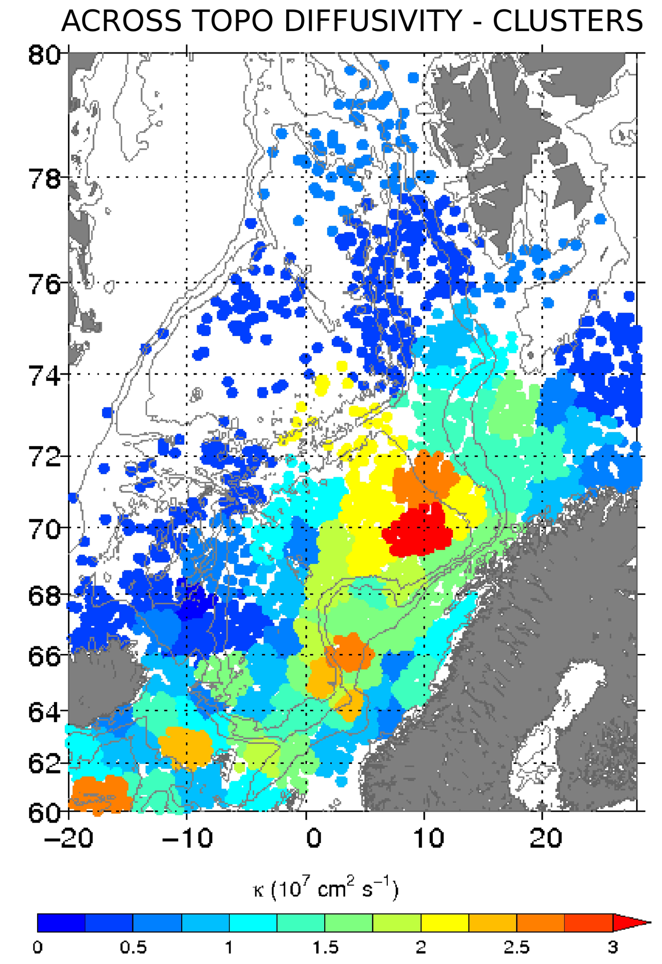
Bins have varying number of trajectory segments of different length. This leads to non-convergent velocity autocorrelations and diffusivity estimates and large errors. Clusters group a predefined number of segments of equal length (e.g., 20 days). This improves the convergence of the estimate and reduces the error.




Curves of $\kappa(\tau)$ in bins and clusters.




Optimal parameters in the Nordic Seas are found to be $m$=60 trajectory segments, 10 days long, in each cluster. The mean autocorrelation function from these segments is integrated to obtain the time series of $\kappa(\tau)$. A cluster estimate $< \kappa >$ is the average value of $\kappa(\tau)$ over 6-10 day period, and pertains to the cluster center. The currents in the Nordic Seas are topographically steered so we also project the eddy velocities relative to the underlying topography, and calculate the across-isobath eddy diffusivity avoiding the bias due to mean current shear.




A map of the cross-isobath eddy diffusivity obtained by clustering. It is intensified in the Lofoten Basin and along the western branch of NwAC (Polar Front), whereas it is reduced in the main core of the Norwegian Atlantic Current system along the shelf break.

## Conclusions

- For irregularly distributed drifter data in the Nordic Seas, clustering method is more successful at capturing spatial variability of the mean velocity and variance than averaging in geographical bins
- Clustering improves convergence of the eddy diffusivity estimates yielding maps of $\kappa$ at 80km resolution on average
- The across-isobath (across flow) eddy diffusivity is intensified in the Lofoten Basin and along the Polar Front, whereas it is reduced in the eastern core of the Norwegian Atlantic Current system along the shelf break.

## References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L. P. Røed and N. M. Kristensen (2011): Eddy generation and cross shelf mixing off Lofoten, Norway, sub. JPO
The POLEWARD project: http://folk.uio.no/ingako/my_files/POLEWARD_WEBPAGE_MAIN.html