FFI Forsvarets forskningsinstitutt

Finding acoustically stable areas through EOF classification

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Introduction

Objective

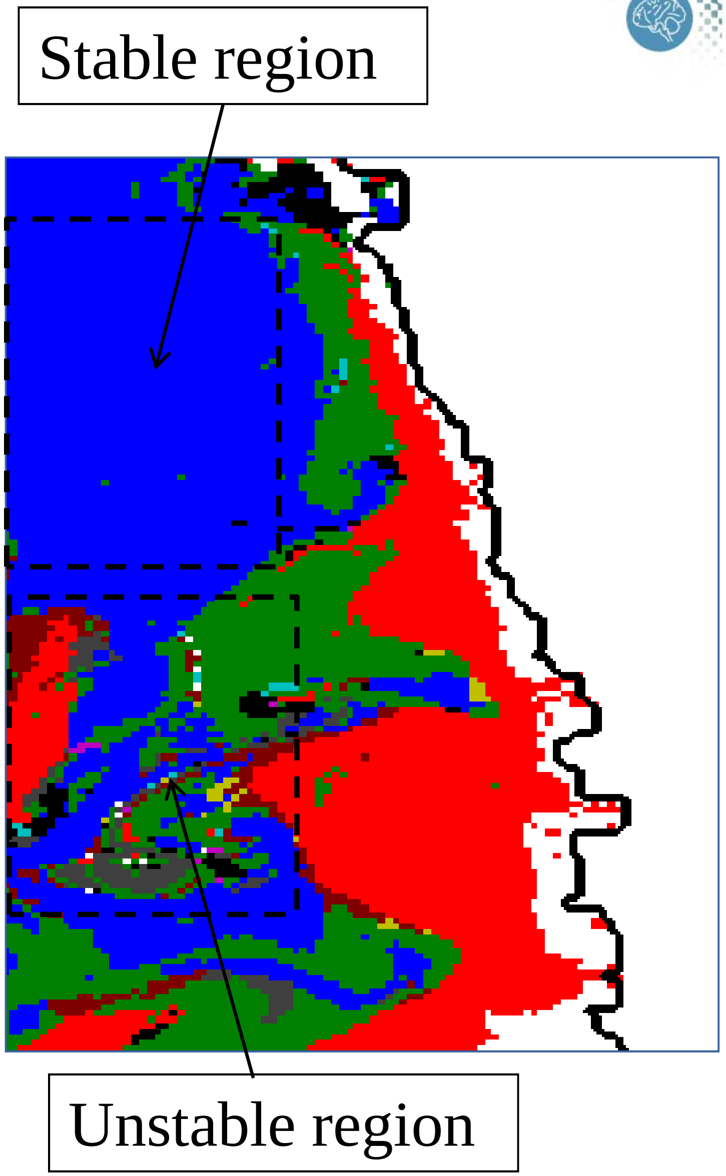
Split an area into smaller, acoustically stable areas.

Motivation

Planning aid for REA missions.

Requirement

An ocean model outputting spatio-temporal sound speed data.



Method

1. Find EOFs for the modelled sound speed profiles (SSPs).

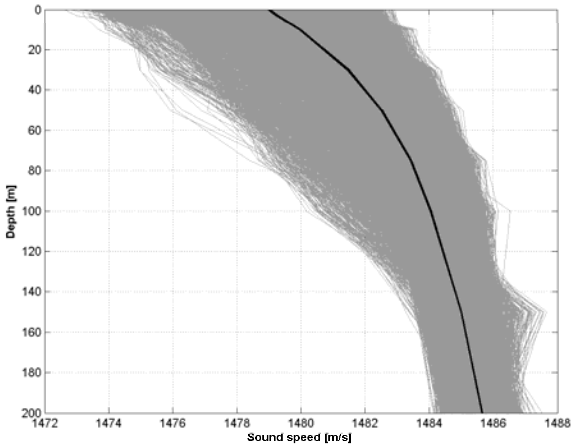
2. Group the SSPs with respect to the EOF coefficients.

3. Investigate the acoustically stability of the groups:
   a) If stable, keep the group.
   b) If not stable, repeat step 2 and 3 for the unstable groups.

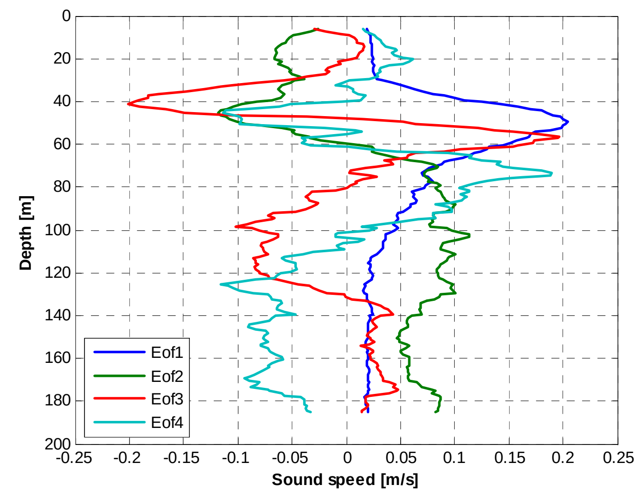
This is similar to methods used in seabed classification [1]

[1] S. Milligan, L. LeBlanc, and F. Middleton, “Statistical grouping of acoustic reflection profiles,” the Journal of the Acoustic Society of America, vol. 64, no. 3, pp. 795–807, 1978.

Empirical orthogonal functions



$$\mathbf{R_x u_k} = \lambda_k \mathbf{u_k}$$



u_k are EOFs (eigenvectors)
κ_k : EOF-coefficients
R_x : covariance matrix
λ_k are eigenvalues

$$c_i[n] - \bar{c}[n] = \sum_{k=1}^{N-1} \kappa_k u_k[n]$$

[2] C. W. Therrien, Discrete Random Signals and Statistical Signal Processing. Prentice Hall, 1992.

Grouping algorithms

- Two methods are tested:
  - Clustering of coefficients (CC)
  - Ordering of coefficient magnitude (OCM)

Clustering of coefficients (1)

EOF analysis will give you a set of coefficients κ_k that are unique to every single profile.

$$c_i[z_n] \approx \bar{c}[z_n] + \sum_{k=1}^{H} \kappa_k u_k[n]$$

Using the first H coefficients and basis functions to reconstruct sound speed ci at depth zn

Limiting ourselves to the dominant *H* set of coefficients, we use multivariate statistics *(cluster analysis)* to cluster together similar profiles.

- *H* is usually small

  H= 3 to 5 usually captures 95% of the variance.

[3] A. K. Jain and R. C. Dubes, Algorithms for Clustering Data, ser. Prentice Hall Advanced Reference Series. Prentice Hall, 1988.

Clustering of coefficients (2)

Each SSP is represented as a singular point in the *H* - dimensional coefficient space.

Cluster analysis is used to group those points into clusters based on distances within the coefficient space.

- Each cluster is tested for acoustic stability.
  - If test fails => that cluster is subdivided into more clusters.
  - There is a threshold for how small a cluster can be.

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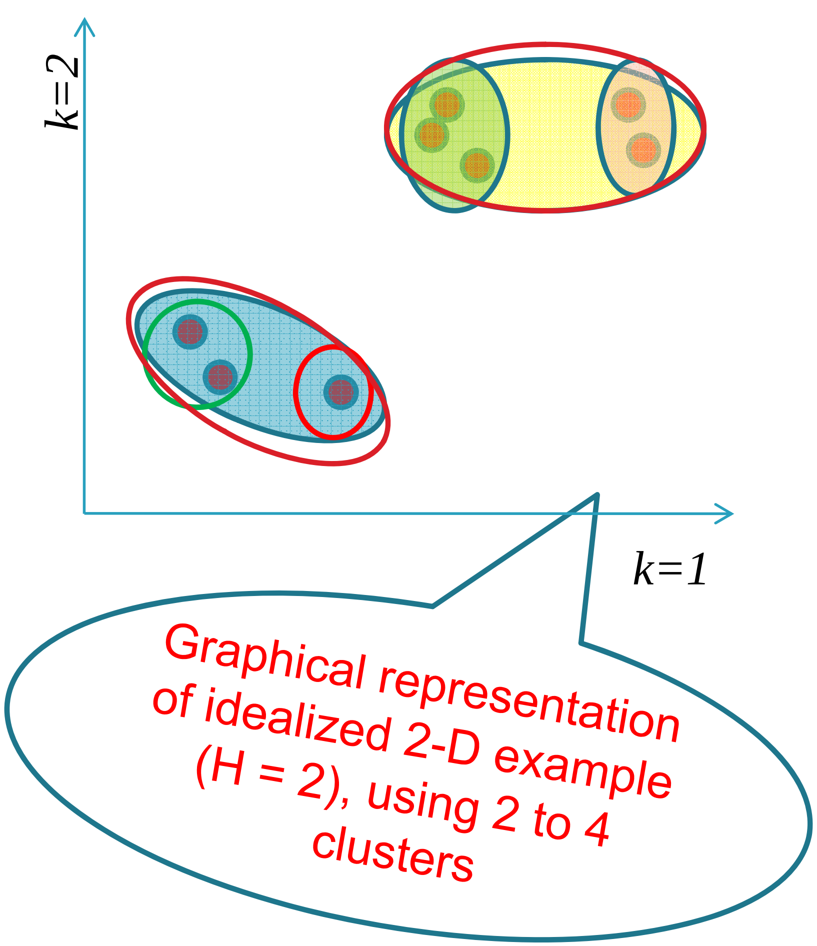

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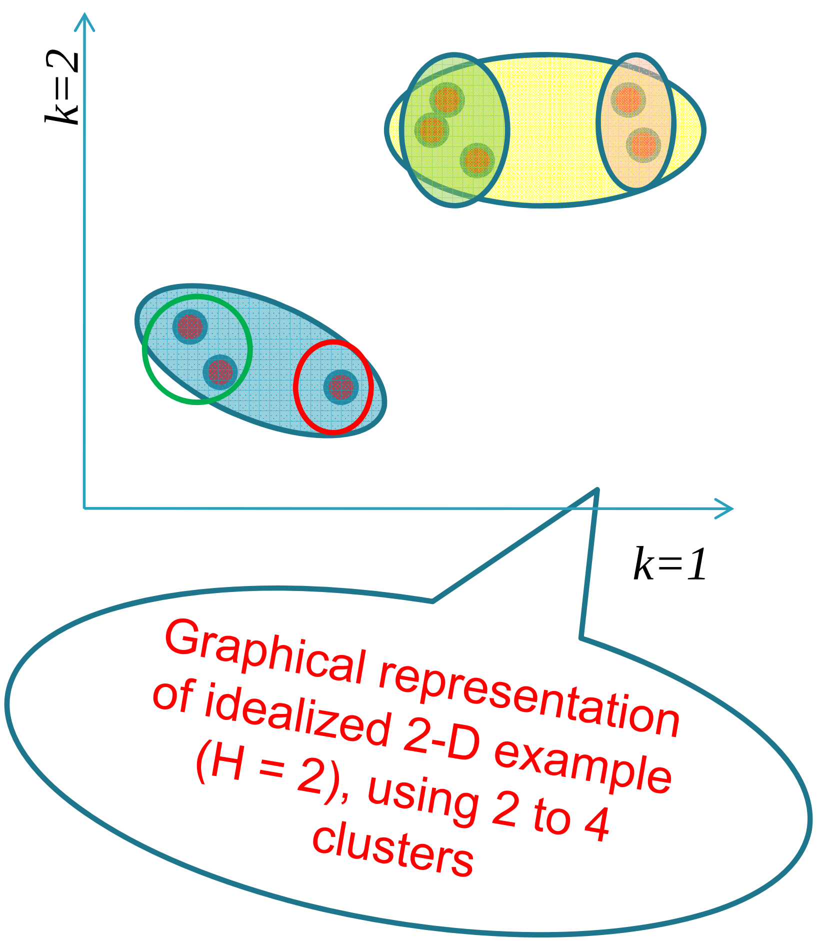


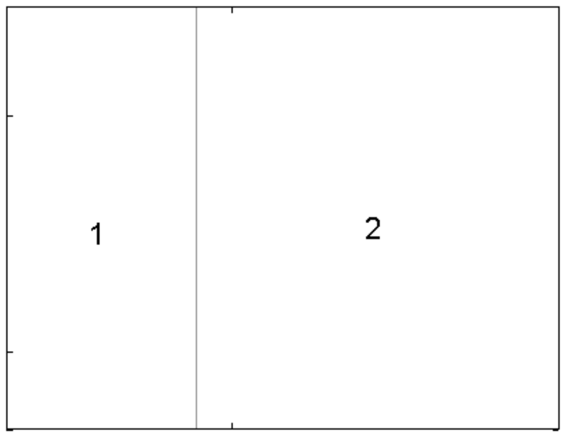
Ordering of coefficient magnitude (1)

- Group the data set with respect to the absolute value of the strongest coefficient for each SSP.

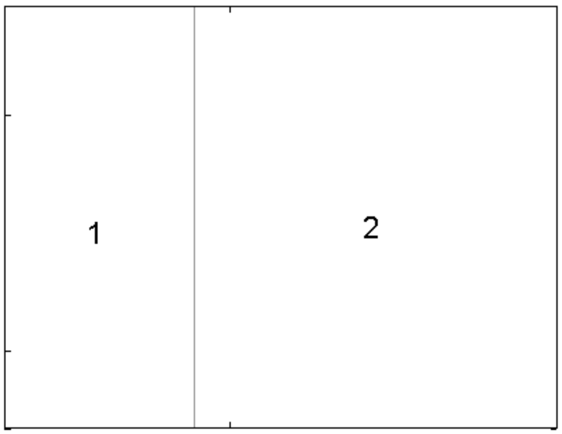
- Split the groups with respect to the sign of the coefficient.

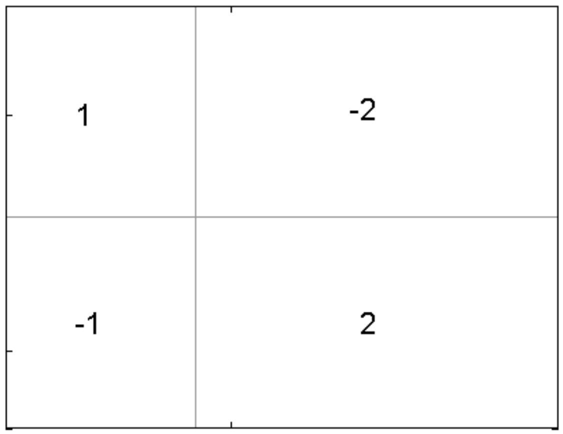
- If a group is not acoustically stable, the two steps above are repeated with the second strongest coefficient for the group.

Ordering of coefficient magnitude (2)

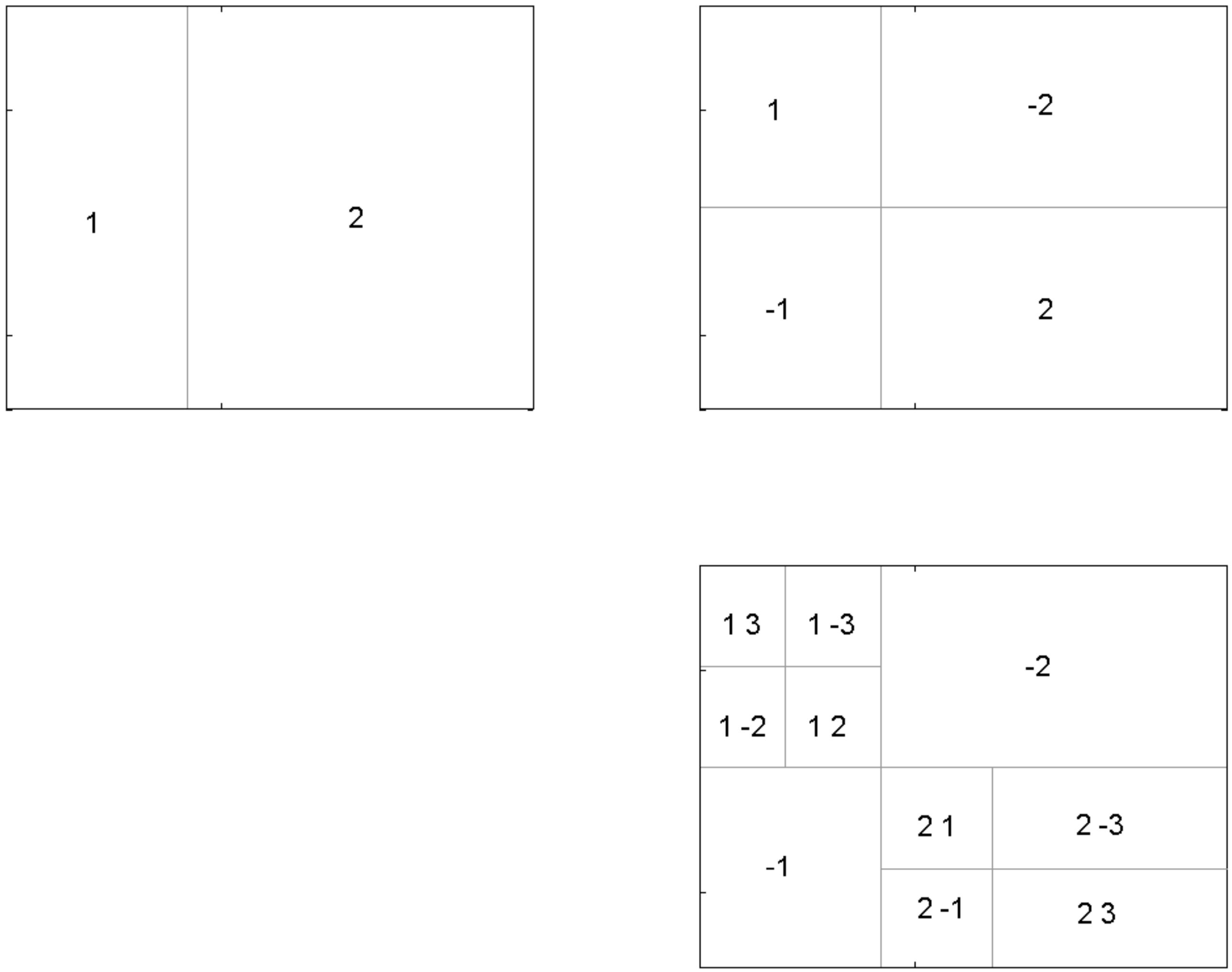


Ordering of coefficient magnitude (2)

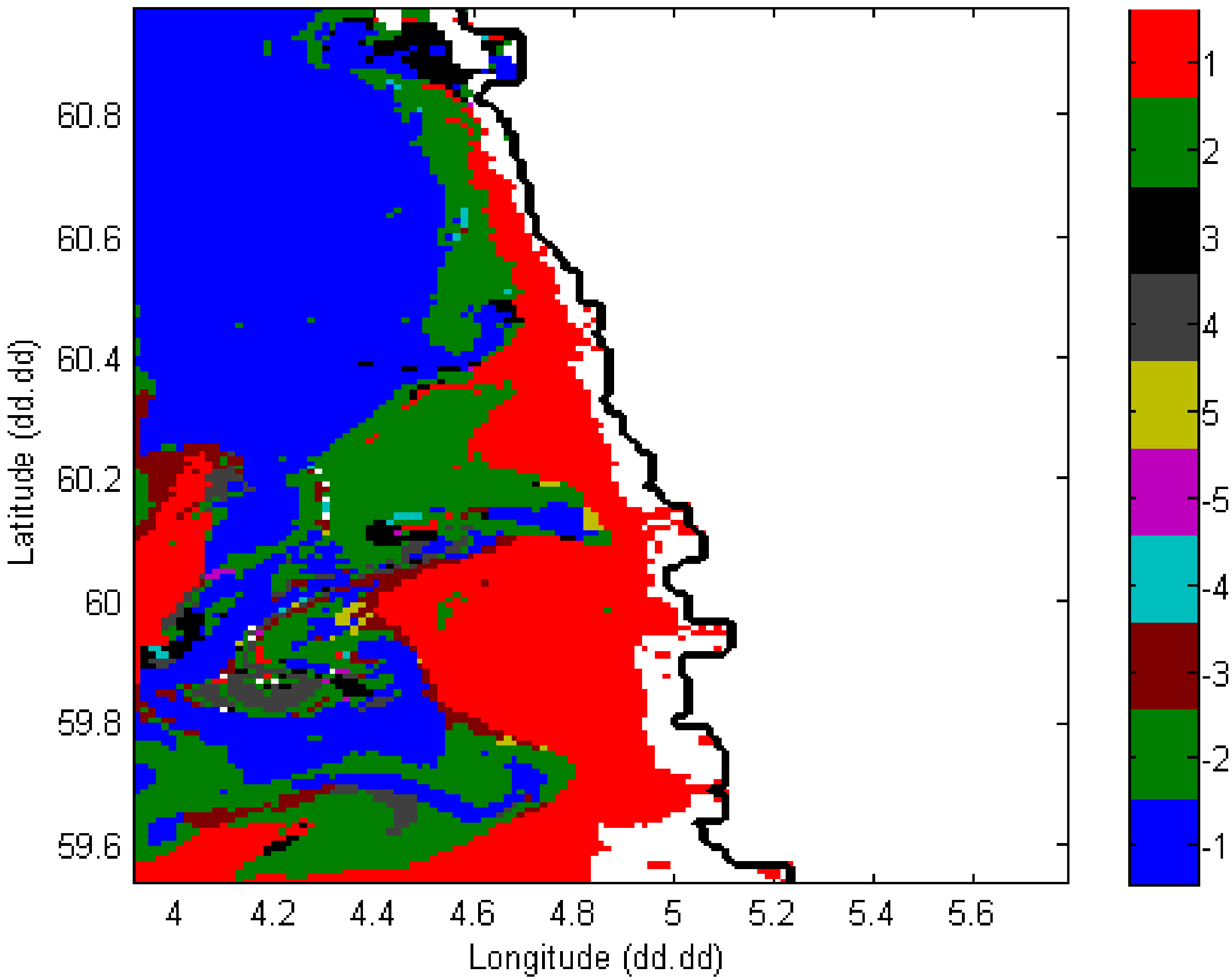




Ordering of coefficient magnitude (2)



Ordering of coefficient magnitude



Acoustic stability (1)

Signal excess (SE) is estimated using an acoustic model for a set of SSPs. The expected SE is estimated:

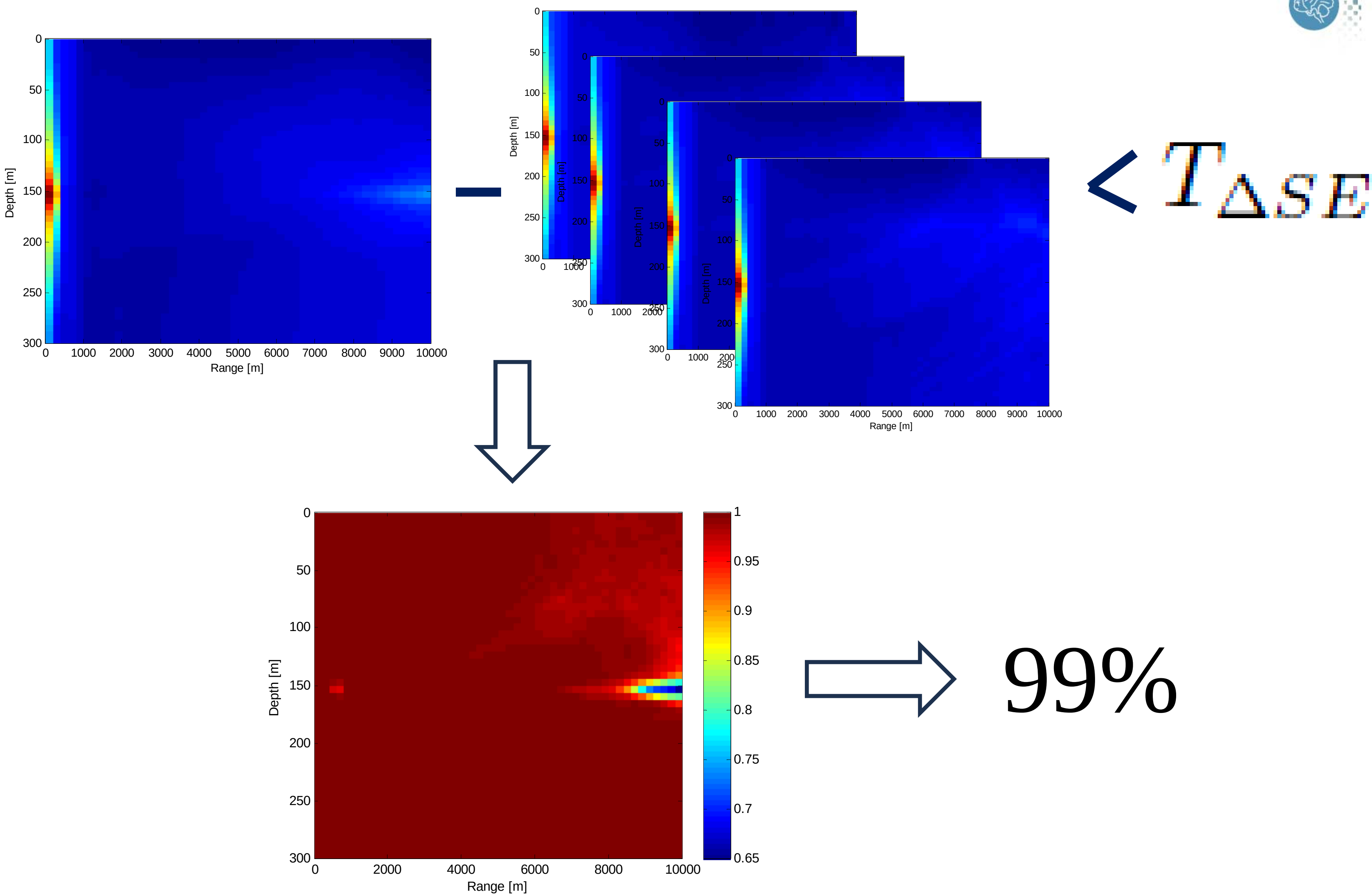
$$m_s(r,z,\phi) \quad = \quad \frac{1}{N}\sum_{n=0}^{N-1} s_n(r,z,\phi)$$

Assuming that the acoustic model is flawless and that all SSPs have an equal probability of being the true SSP at a given time and location, then:

$$P(T_{\Delta SE}) \quad = \quad \int_0^{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} P_{SE}(r,z,\phi,T_{\Delta SE})g(r,z,\phi)r\mathrm{d}r\mathrm{d}z\mathrm{d}\phi$$

$$P_{SE}(r,z,\phi,T_{\Delta SE}) \quad = \quad Pr\left\{|10\log_{10} m_s(r,z,\phi) - SE_t(r,z,\phi)| \leq T_{\Delta SE}\right\}$$

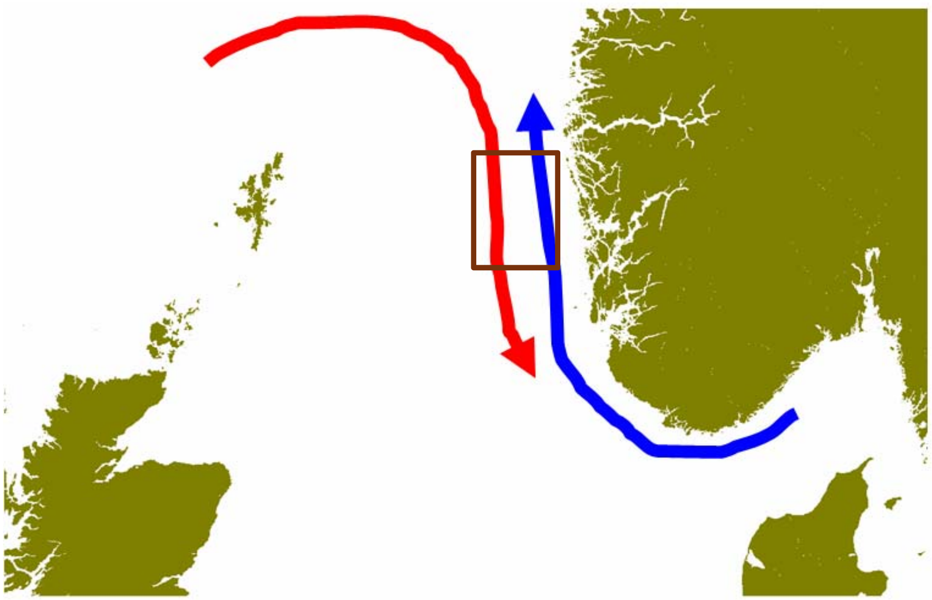
Acoustic stability (2)



Area of investigation

Coastal water

Atlantic water



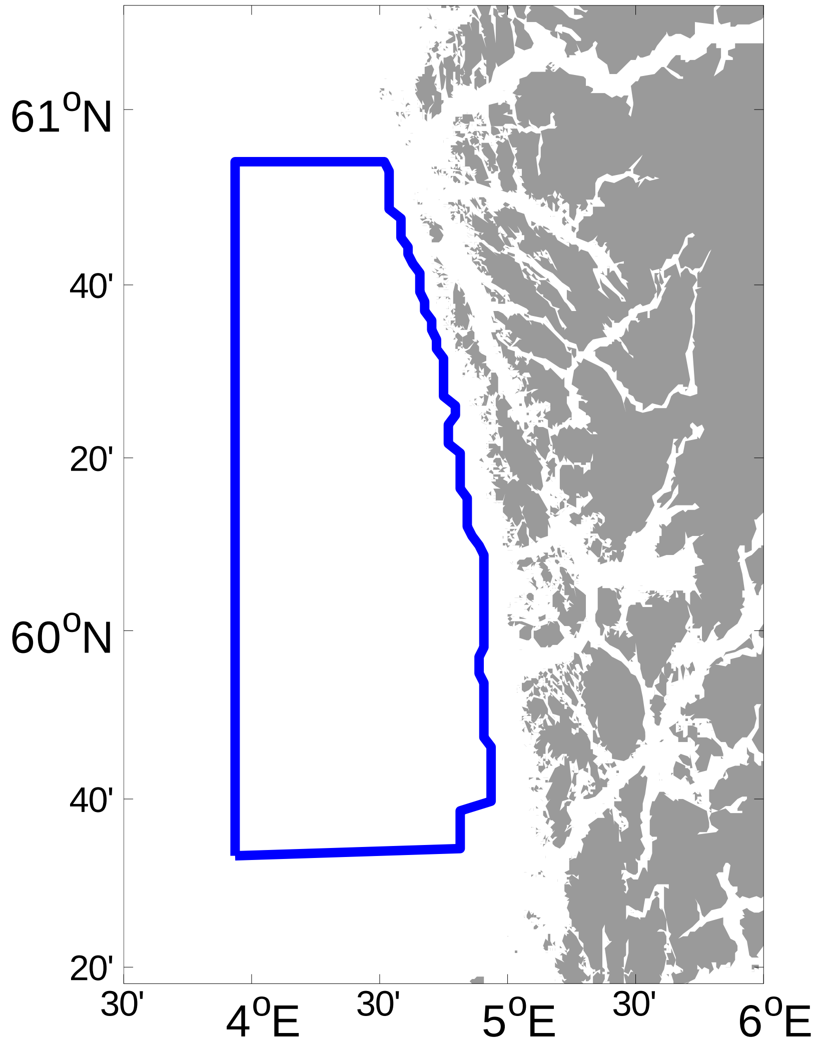
[4] R. Sætre, The Norwegian Coastal Current - Oceanography and Climate. Tapir Academic Press, 2007.

Data set

- Data set from Norwegian Meteorological Office's (met.no) numerical model Westcoast (MI POM).

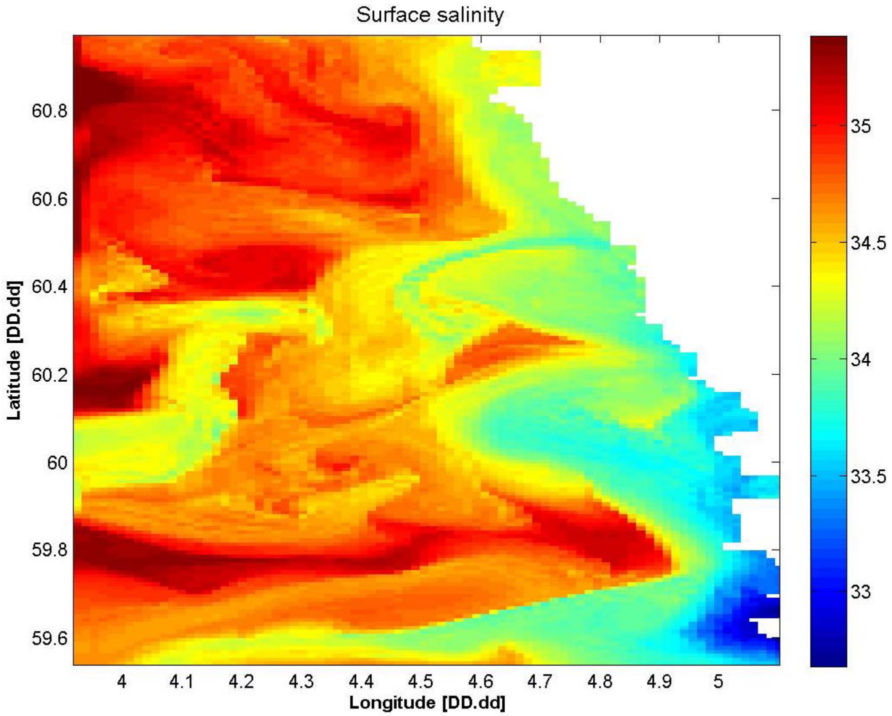
- Blue area is a chosen subset to avoid fjords and inlets. All profiles cut at 200 m (9 depths).

- Contains 10000 SSPs per timestep and 11 timesteps in all.



May EOFs be used to classify areas as oceanographically or acoustically stable?

Is this stable?



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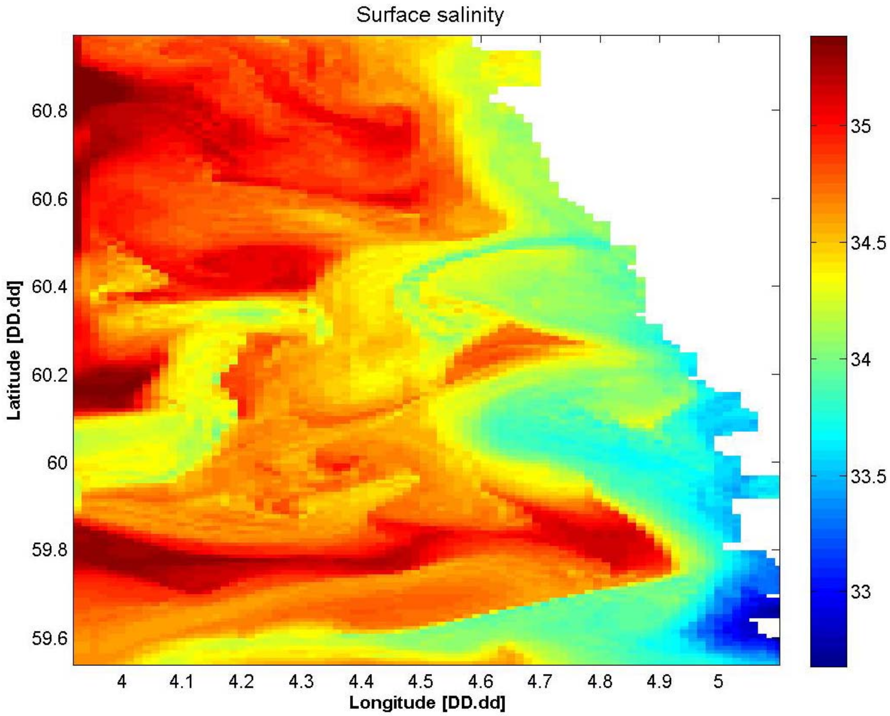
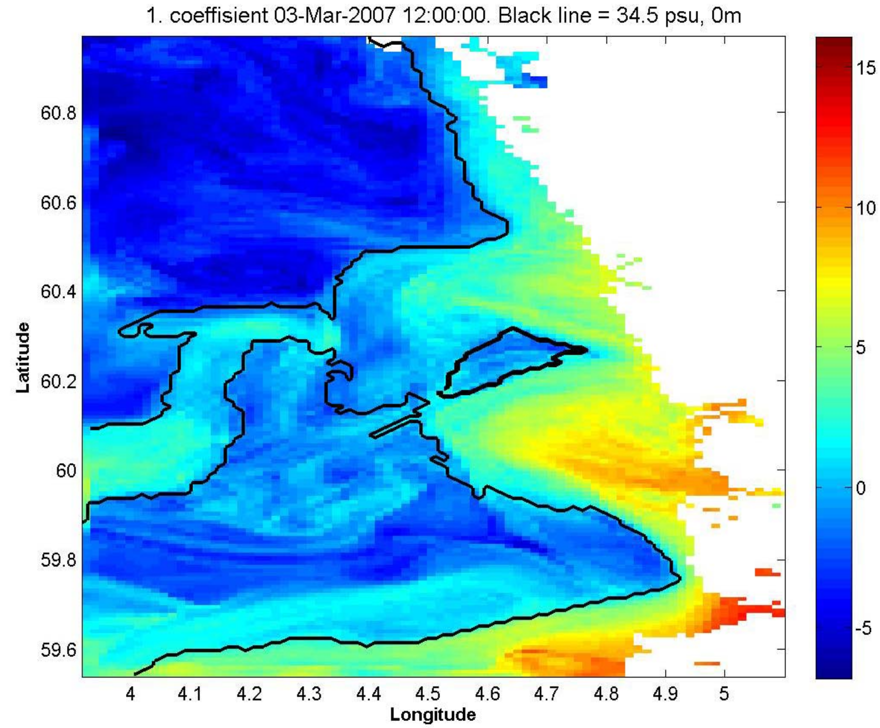
Is this stable?

Leading coefficient

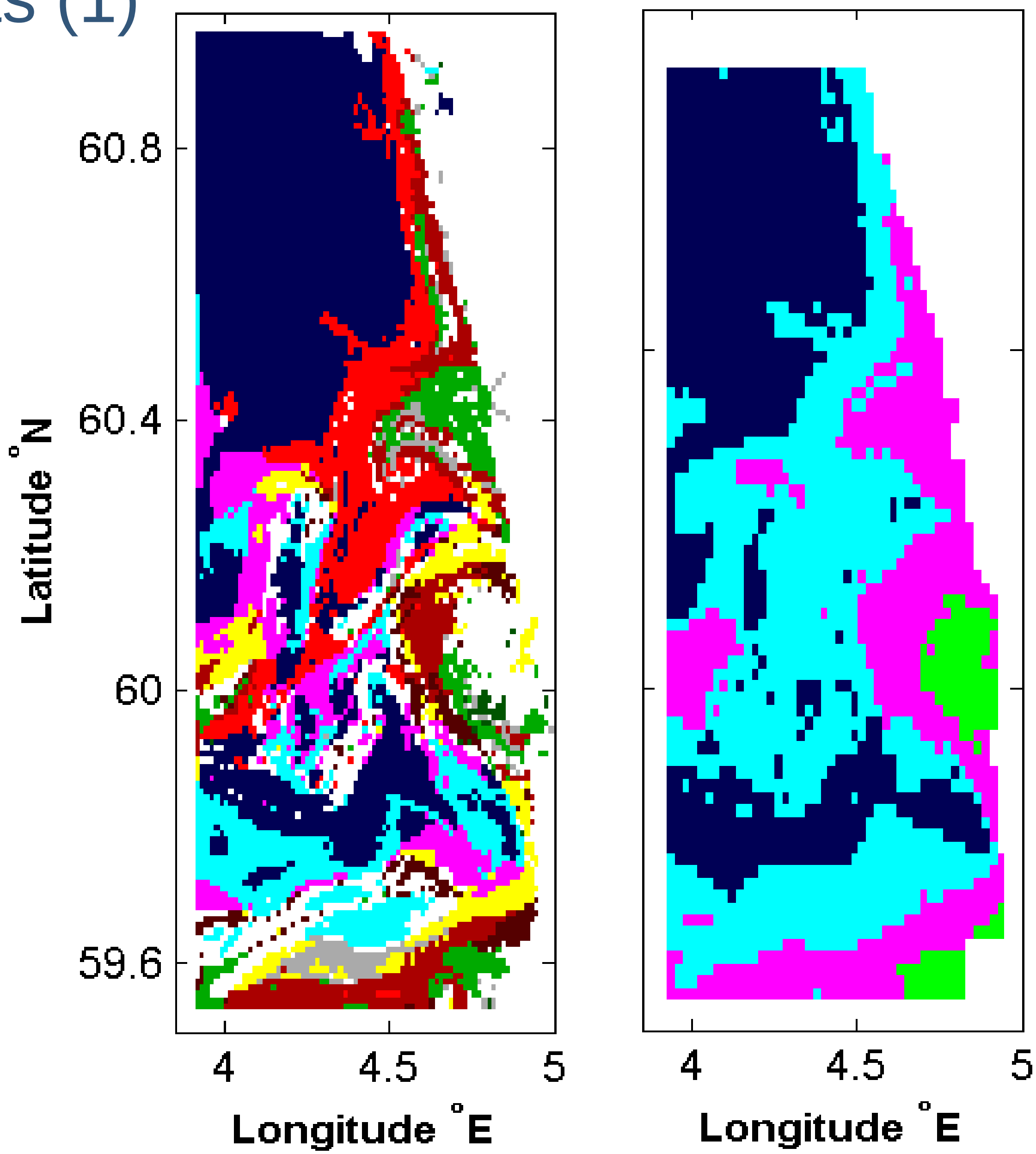
+ salinity contour at 34.5 psu





Results (1)

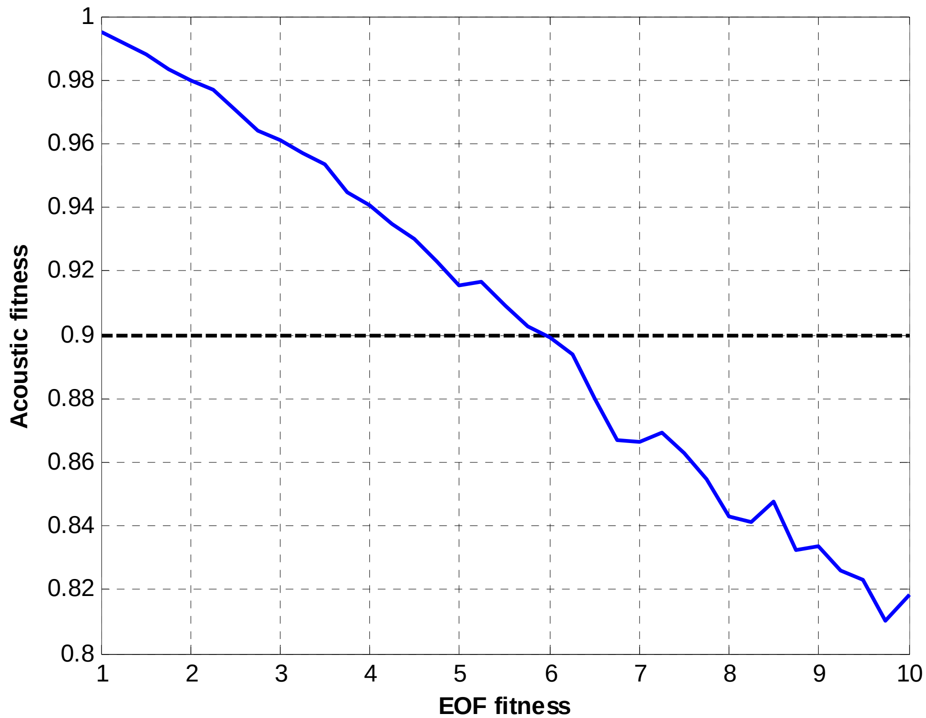
OCM



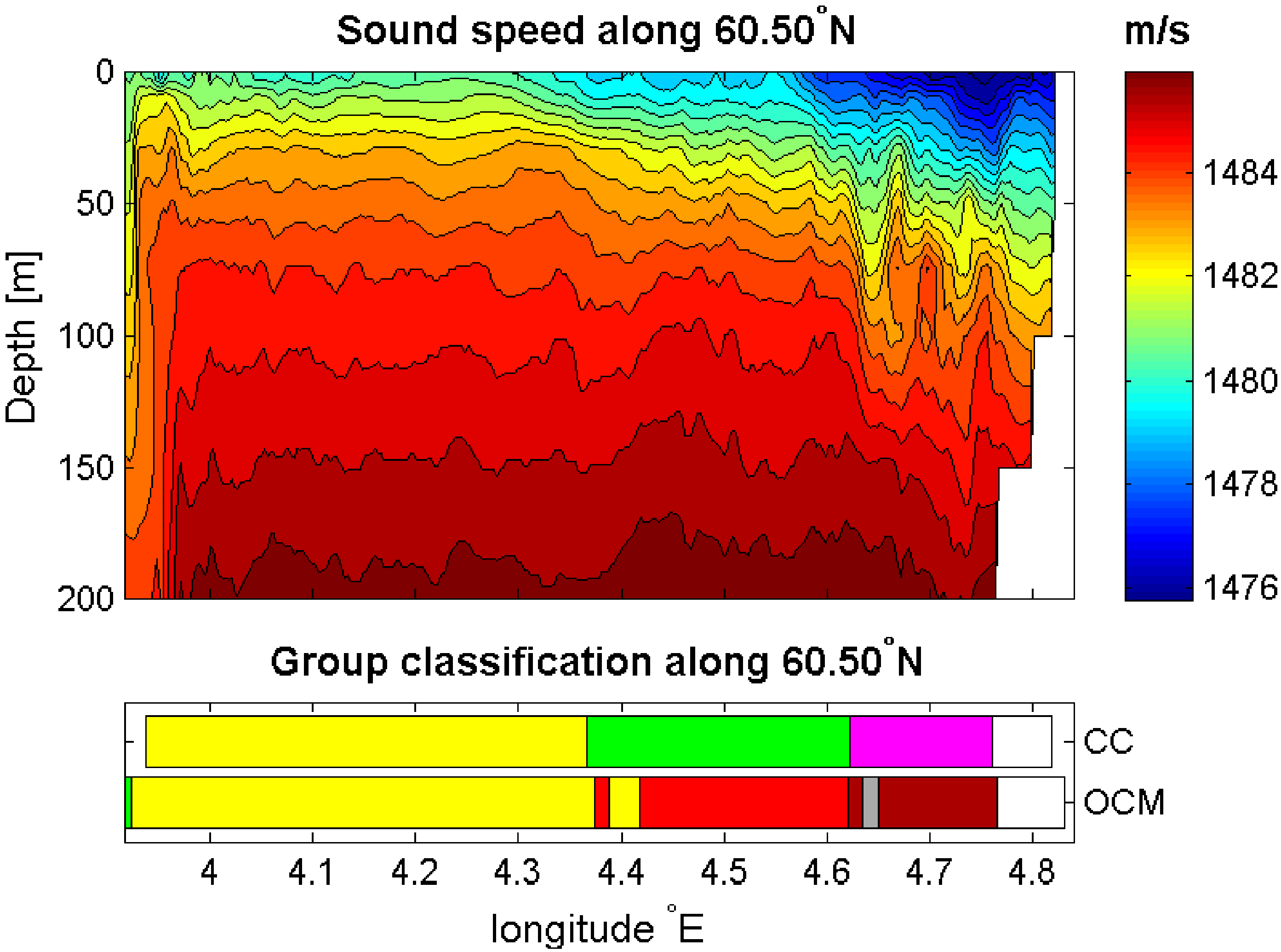
CC

Alternative stability measure

The oceanographic variability within a set of SSPs can be measured by simply summing the eigenvalues of the EOFs representing the group assessed, this is equivalent to summing the SSP variance over all depths.

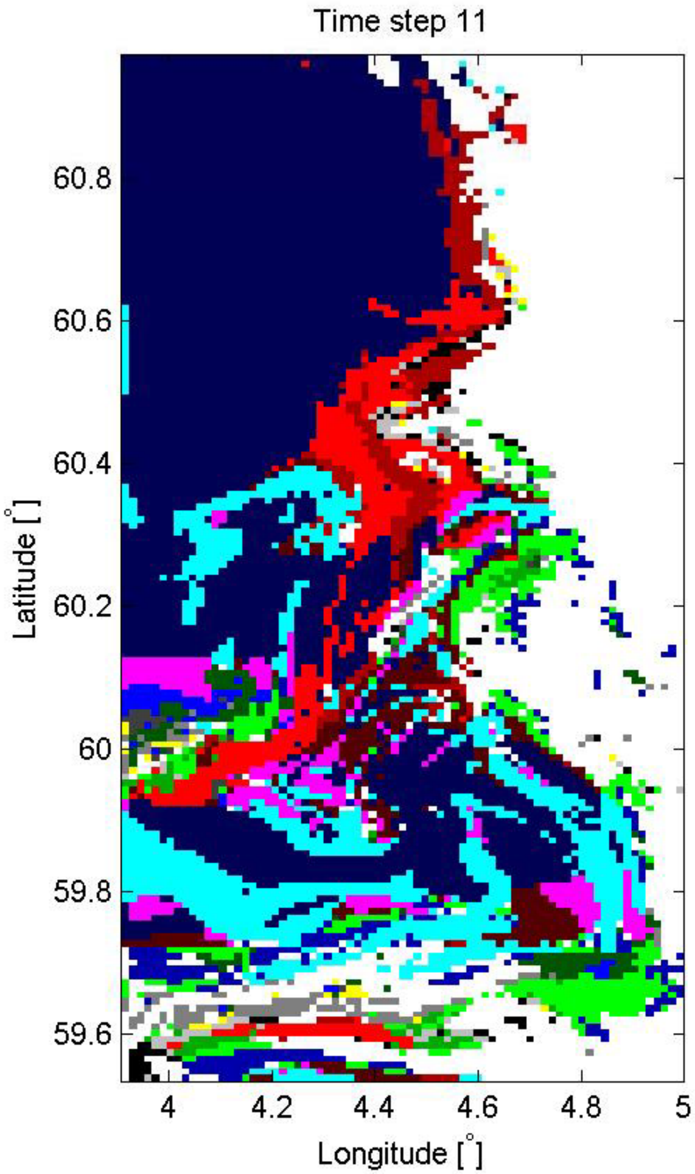


Results (2)

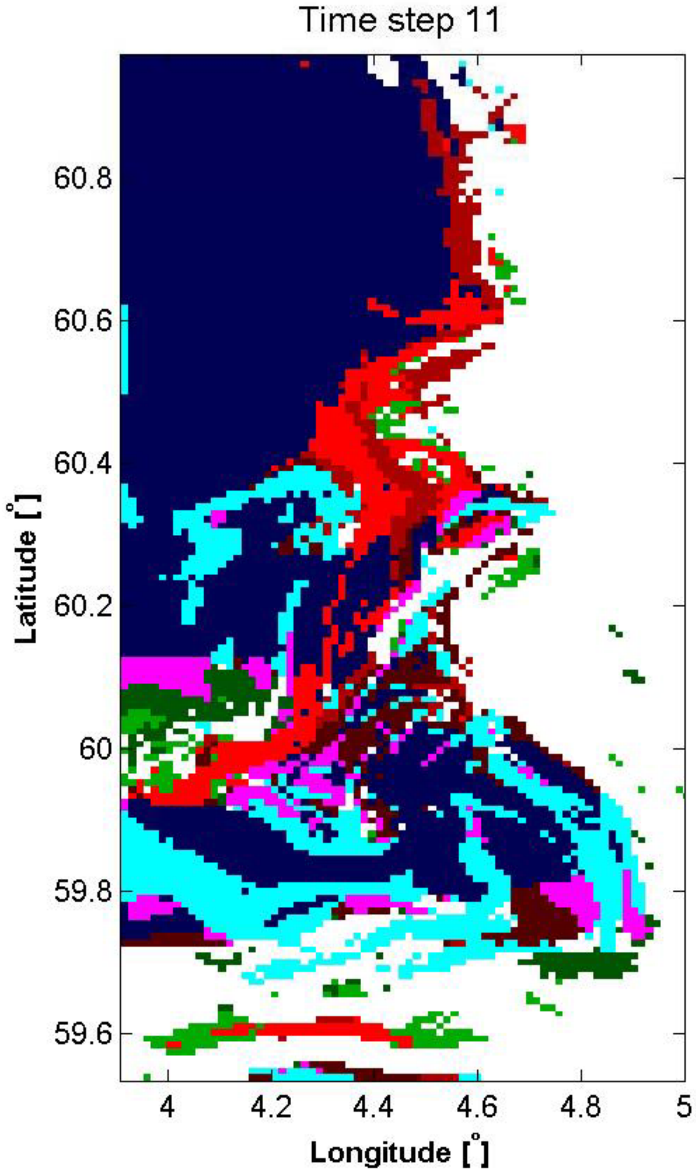


Sound speed along 60.50°N
m/s
0
50
100
150
200
Depth [m]
1484
1482
1480
1478
1476
Group classification along 60.50°N
CC
OCM
4
4.1
4.2
4.3
4.4
4.5
4.6
4.7
4.8
longitude °E

Acoustic stability measure



Non-acoustic stability measure



Conclusion

- The proposed method divides a large area into smaller acoustically stable areas
  - Slow and accurate version
  - Fast and less accurate version
- Useful for planning deployment of REA assets such as gliders.
- May determine how often SSPs should be measured during sonar operations.
- Single SSP represents each area. Useful for fast optimalisation of sonar parameters.

Conclusion

- We have developed a method for classifying groups of SSPs as either acoustically stable or unstable.
  - The method combines EOFs with clustering and acoustic modelling, and is exceedingly slow and sometimes disfunctional for very large data sets (hours).
  - A variant of the method uses a self-developed ”clustering”-algorithm and a non-acoustic stability measure and runs in seconds.
- Possible applications include:
  - Stability maps showing what regions frequent SSP measurements are necessary or unnecessary.
  - Useful for determining areas in which to conduct sonar tests that require stable sonar conditions.
  - May be combined with methods for determining optimal sonar parameters since each stable area may be represented by a single SSP.