# NEMO data assimilation and PDAF cooperation

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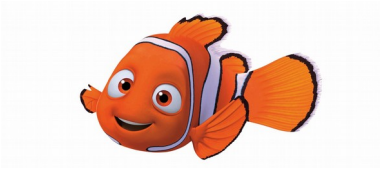
# Outline

- NEMO data assimilation
  - An introduction
  - NEMO DA
  - 3D/4D Var
  - 3D/4D EnVar
- PDAF
  - Different ensemble filters
  - NEMO-Nordic implementation
  - Cooperation



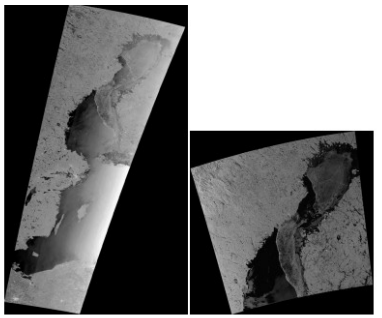
PDAF Parallel Data Assimilation Framework

# NEMO data assimilation: An introduction

- In general, to make good forecasts we need two things:
  - A good initial condition
  - A good model, used to integrate the initial condition forward in time (e.g. NEMO, HBM, GETM, … etc)
- A good initial condition is obtained from a combination of:
  - A first guess (normally a short forecast, e.g. +6H)
  - Observations
  - A data assimilation program

# NEMO data assimilation: NEMO DA

- Two methods can be used:
  - Modify the restart files (this method was used with HIROMB, and HBM in MyOcean projects; used by e.g. Mercator)
  - Produce an increment file for NEMO to read (NetCDF format; ”assim_background_increment.nc”; used operationally at SMHI)
- Increments are implemented in NEMO-3.6 for these variables:
  - S/T
  - U/V
  - SLA (sea level anomaly)
  - Ice concentration and ice thickness (implemented by SMHI)

# NEMO data assimilation: 3D/4D Var

- Variational techniques, meaning a cost function *J* is minimized:

$$J(w) = \frac{1}{2} w^T w + \frac{1}{2} \sum_{i=1}^{I} (H M_i U_i w - d_i)^T R^{-1} (H M_i U_i w - d_i)$$

$$\nabla_w J = w + \sum_{i=1}^{I} U_i^T M_i^T H^T R^{-1} (H M_i U_i w - d_i)$$

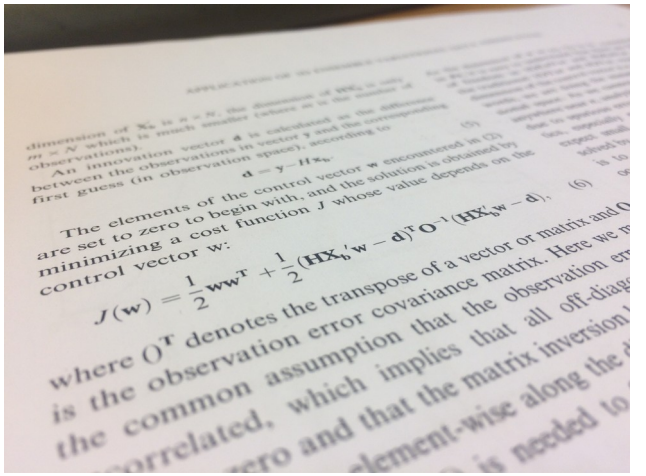
Tangent Linear model

Adjoint model

- NEMOVAR:
  - Developed by a European group; UK, France, …?
  - Not part of the NEMO distribution
  - Not tested at SMHI yet
- Normally requires a parameterization of horizontal and vertical structure functions (correlations); could introduce problems in the e.g. the thermocline
- 4D-Var requires tangent linear forward and backard versions of the full nonlinear model (high cost, both for development and running)

# NEMO data assimilation: 3D/4D EnVar

- ”Ensemble Variational data assimilation”
- Based on Liu et al. (2008; 2009); developed for the ocean by SMHI 2010-2018 (Axell and Liu, 2016; 2017)
- Produces an *increment file*
- Needs an ensemble of model states
- Used in MyOcean/Copernicus reanalyses with HIROMB
- Code parallelized with OpenMP
- Still rather heavy to run for reanalysis projects, better to use ensemble filter methods for speed!



# NEMO data assimilation: 3D/4D EnVar (cont.)

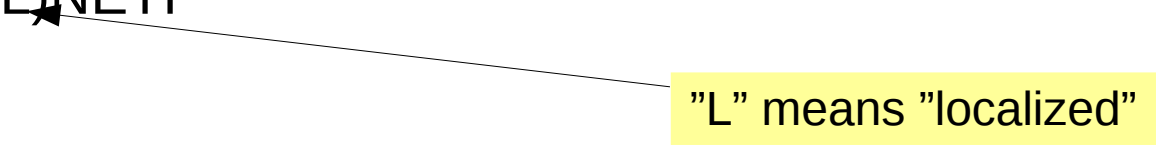
- Advantages of 4D EnVar (compared to standard 4D-Var):
  - Background error covariances are...
    - flow dependent (change with location and time)
    - updated daily
  - No tangent linear or adjoint model versions required!!!
  - Similar results, but much faster than standard 4D-Var (Gutafsson and Bojarova, 2014)
- Disadvantages, or pit falls:
  - Quality of results depends on ensemble used
  - The work of improving the ensemble never ends...

# PDAF:
# Applications at SMHI

- Recently used in Copernicus reanalysis
  - 1993-2016
  - V4
  - Assimilated variables:
    - S/T profiles and SST
    - Biogeochemical variables (in-situ)
- Ongoing project: Sea Level Anomalies
- Faster than 3D EnVar (used in V3 with HIROMB)

# PDAF: Different ensemble filters

- Parallell Data Assimilation Framework
  - developed at AWI
  - http://pdaf.awi.de/trac/wiki
- PDAF: not a data assimilation method, rather a package of ensemble-based filters:
  - SEEK
  - (L)SEIK ←used by SMHI!
  - (L)EnKF
  - (L)ETKF
  - (L)ESTKF ← used by BSH and DMI! Also reccommended by AWI
  - (L)NETF




- Localized often best for our applications

# PDAF:
# NEMO-Nordic implementation

- **NEMO-Nordic-PDAF**:
  - Localized Sequential Evoluative Interpolated Kalman Filter (**LSEIK**) algorithm.
  - Updated to the almost latest release of NEMO (V3.6)

- **Observation data**:
  The observation data is processed and quality controlled; super-observations applied (thinning in both horizontal and vertical direction) before the data assimilation

- **Ensemble model states generation**:
  Empirical orthogonal functions (**EOF**s) are applied to generate the Principal component analysis(**PCA**) for the ensemble model states (T, S, U, V and SSH). Currently, the PCA is based on a histroical model run
- **PROS & CONS**

  Computationally cheap.. One forward NEMO run, can assimilate most of the useful ocean data,Ensemble spans different seasons/years, No dynamical evolution of the error..

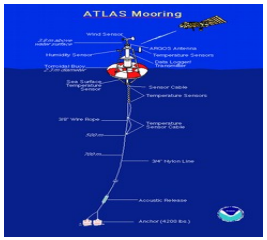
# Observations

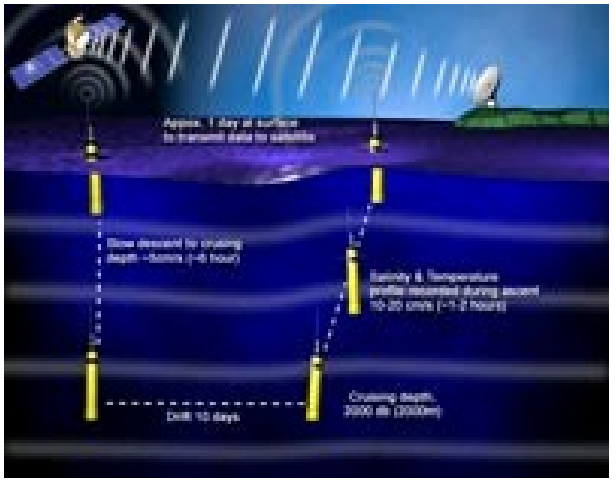
## Moorings

ICES (http://ices.dmi.dk )

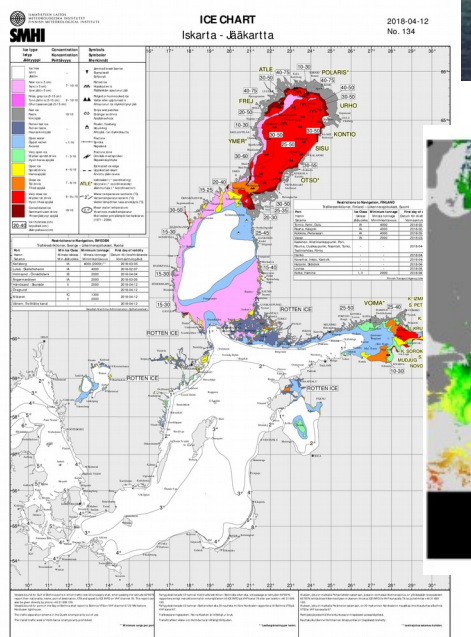
*SHARK (http://sharkweb.smhi.se)*

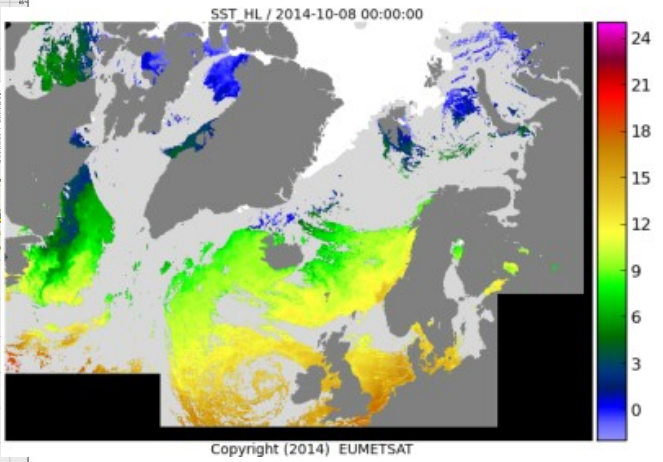
### Buoy



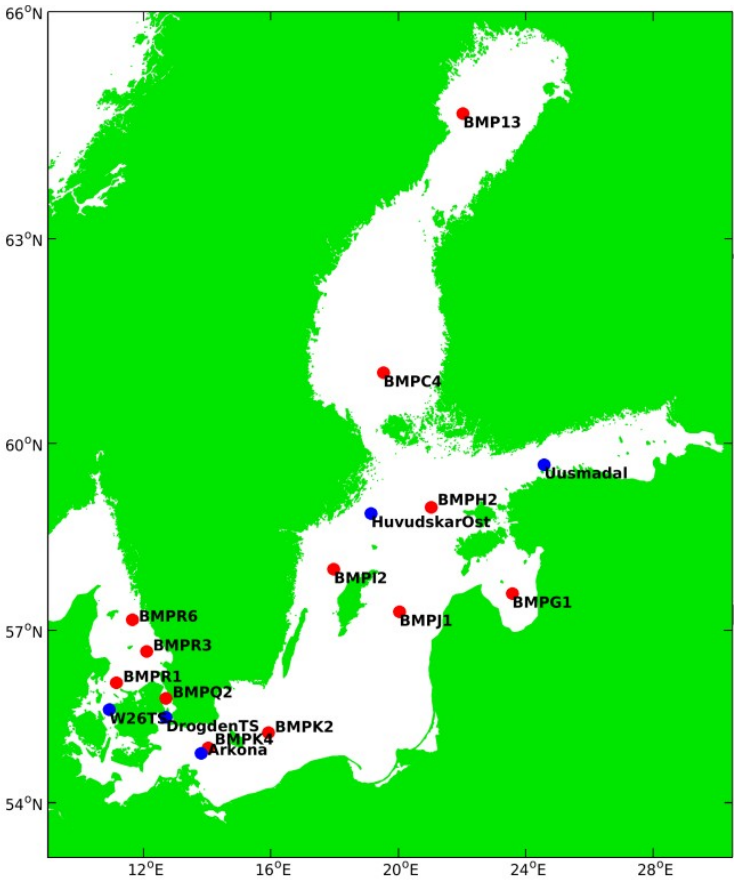



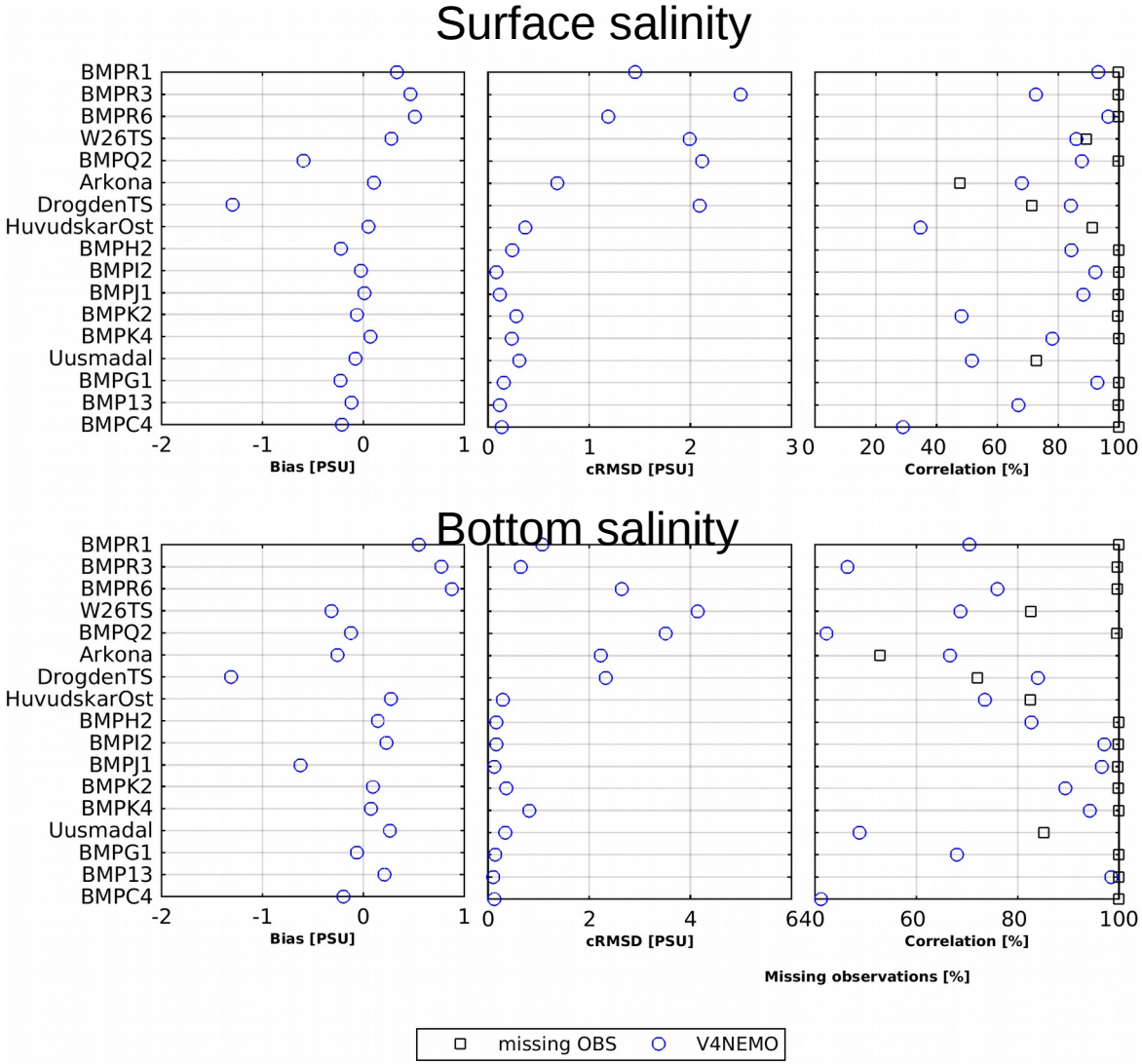
### CTD



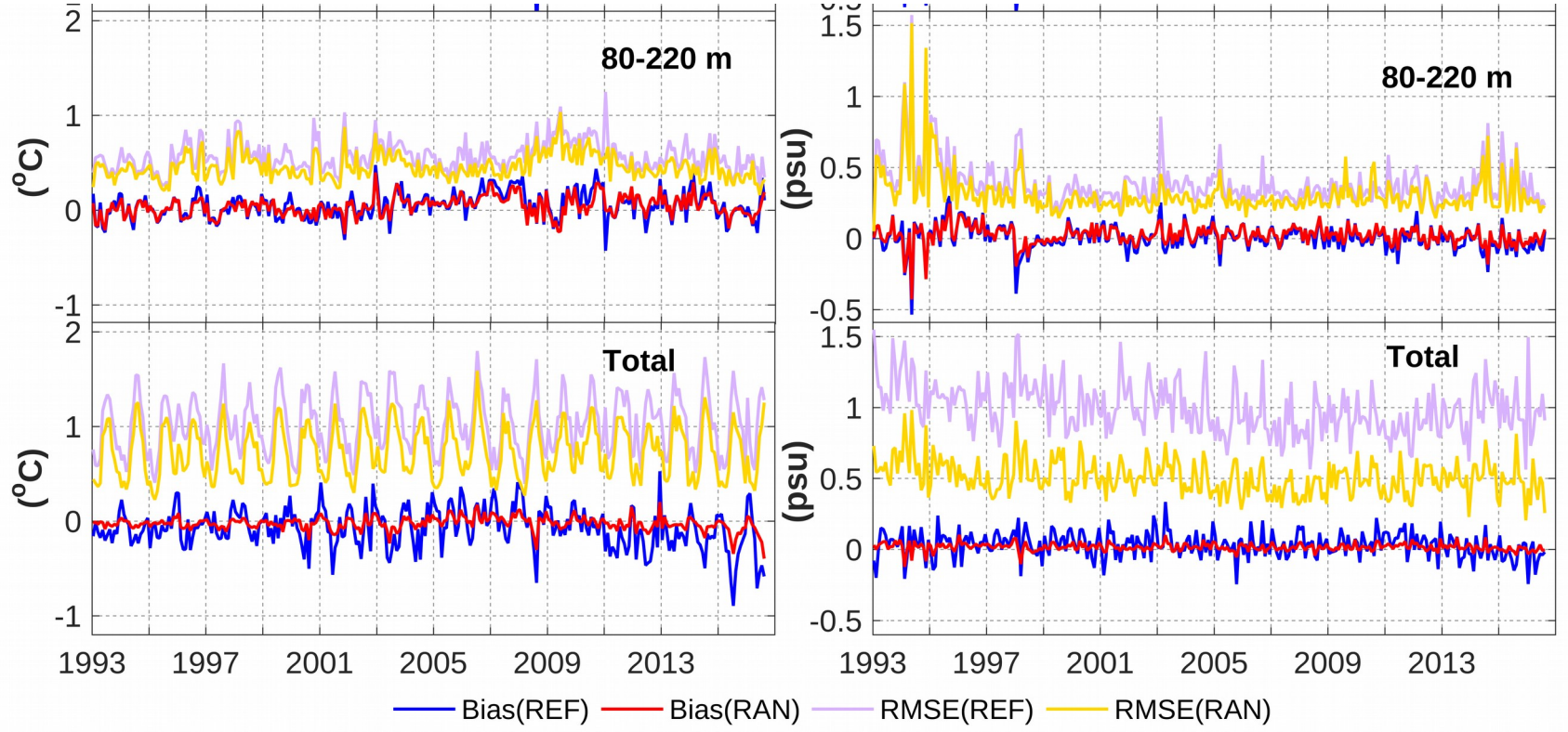



# Surface and bottom salinity (V4) VS. independent observation

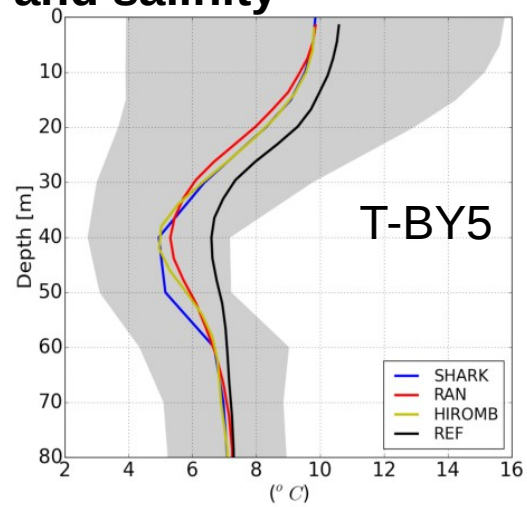


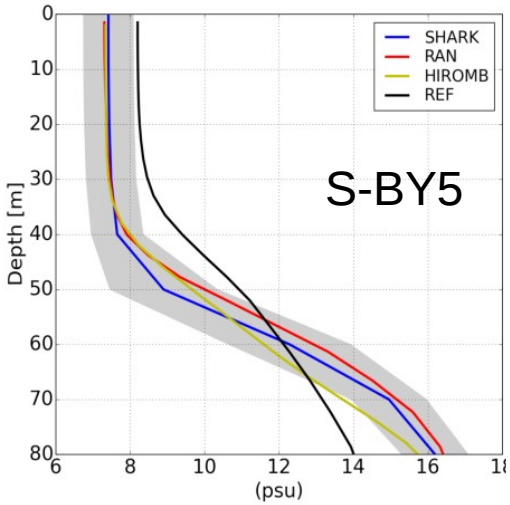



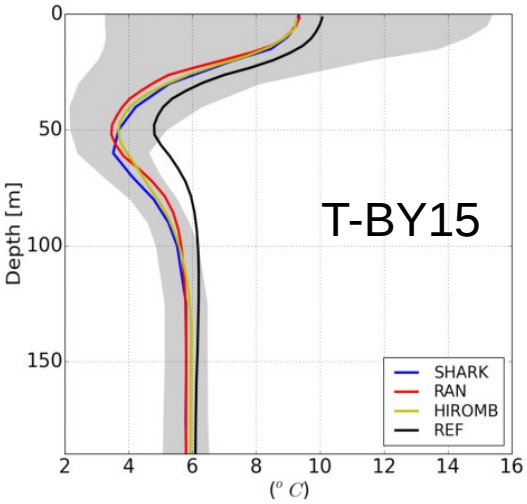
# Monthly-averaged bias and RMSE of temperature (left) and salinity (right).

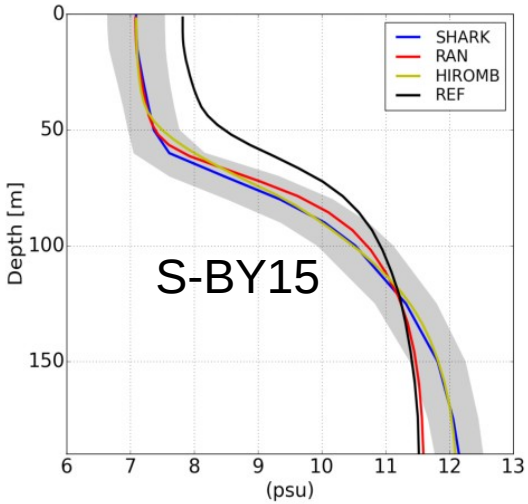


# Average (1993-2016) vertical profiles for temperature and salinity

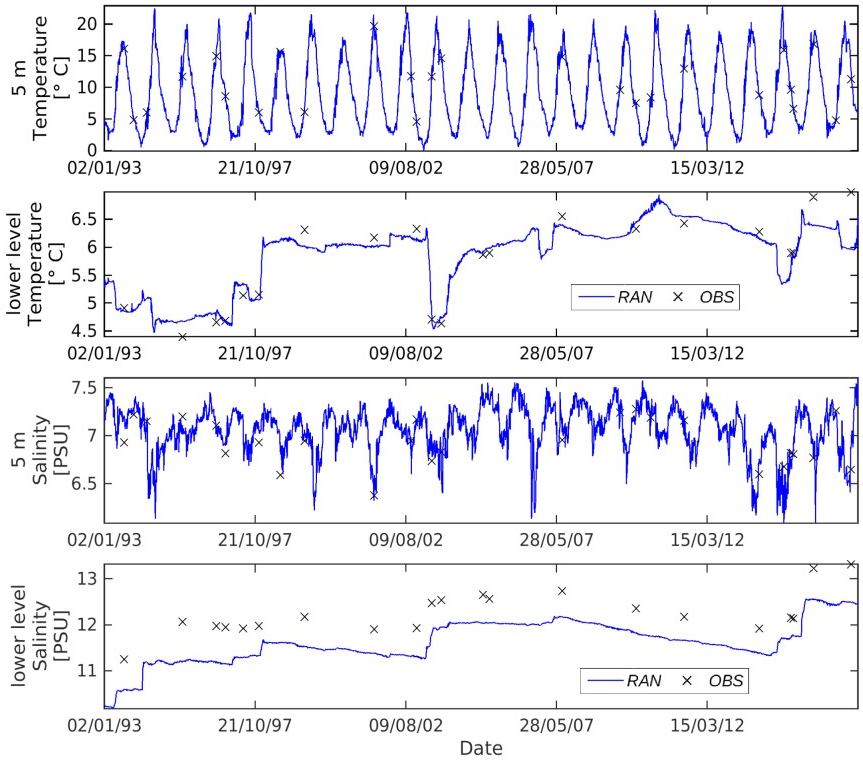


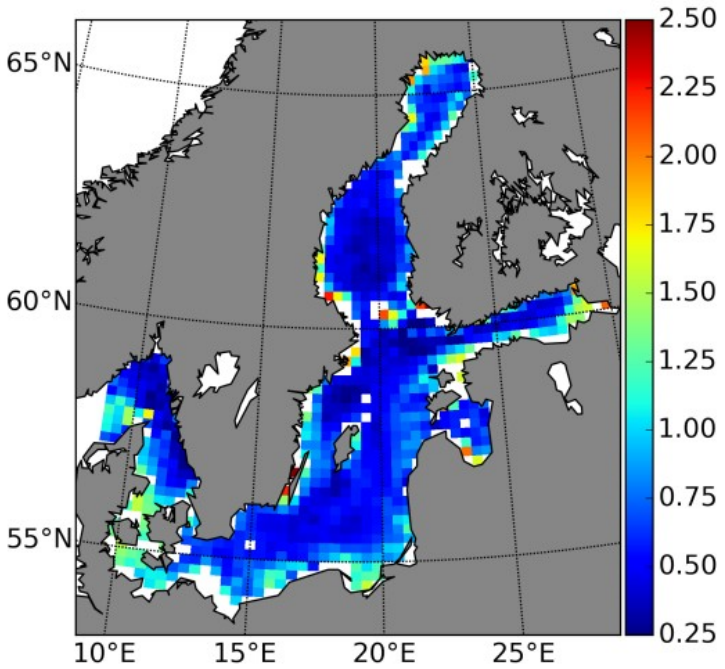



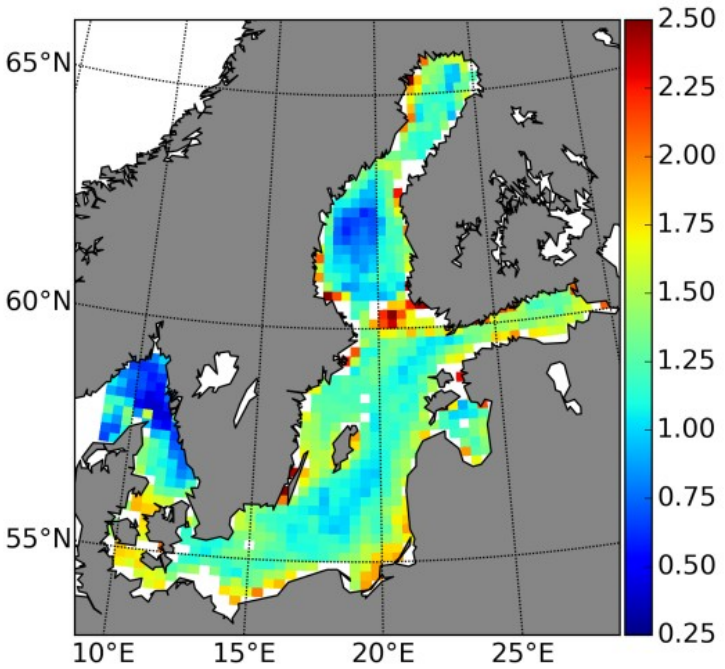



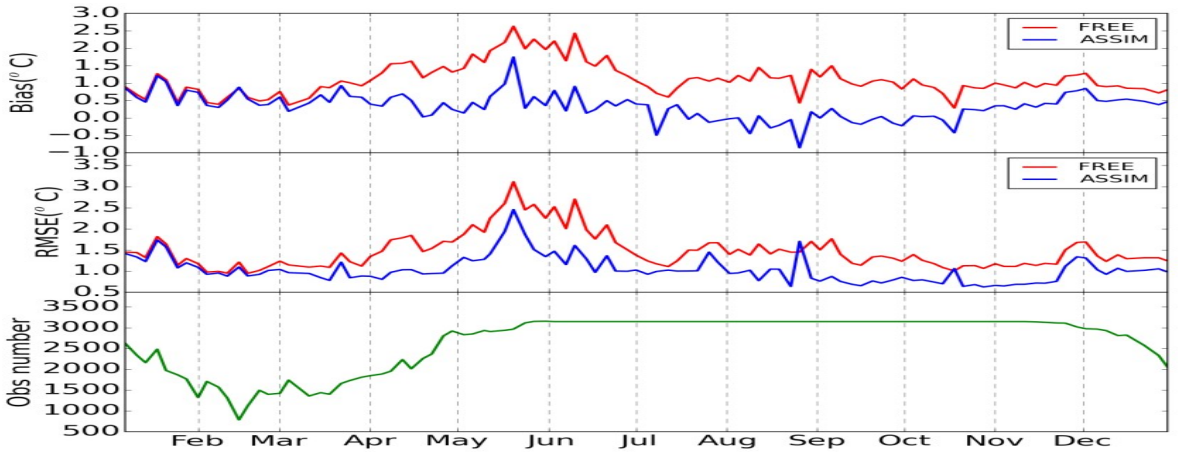

# Time series of temperature and salinity at top (5m) and bottom level of BMJP1



# Map of the RMSE of SST from ASSIM run (left ) and FREE run (right ) calculated against IceMap SST in 2010, respectively.




**The evolution of the simulation SST bias, error and number of IceMap SST in 2010.**

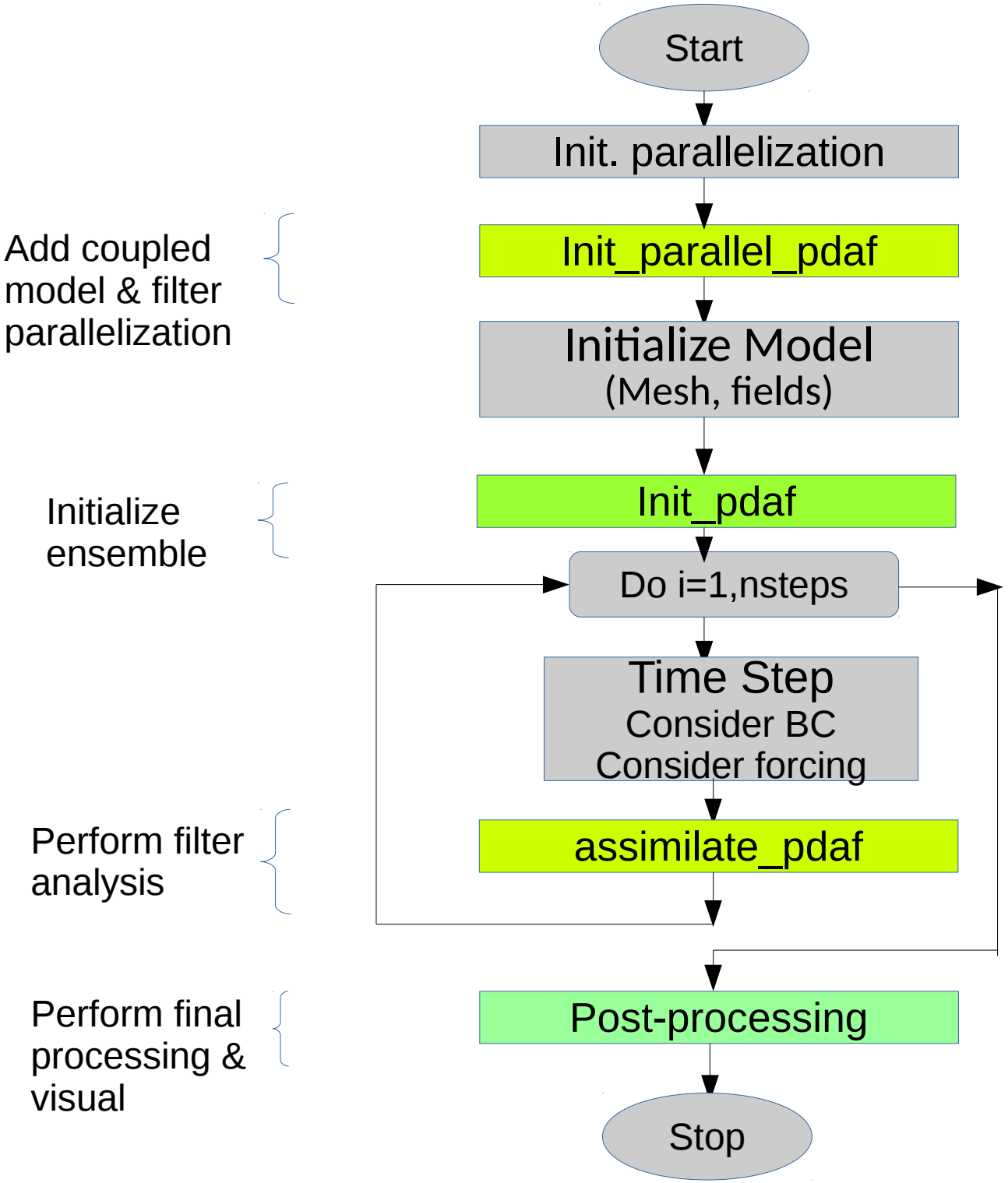
# PDAF: Cooperation

- Comparison on-line vs. off-line versions; different?
- Comparison of different ensemble filters:
  - LSEIK Filter
  - LESTK Filter
  - ...
- Development of ensemble generation techniques
- Technical implementation for NEMO-Nordic?
- Test implementations for sea ice, SLA, chlorophyll-a, ...
- Regular meetings within a data assimilation working group; Who? How? How often?
- …?

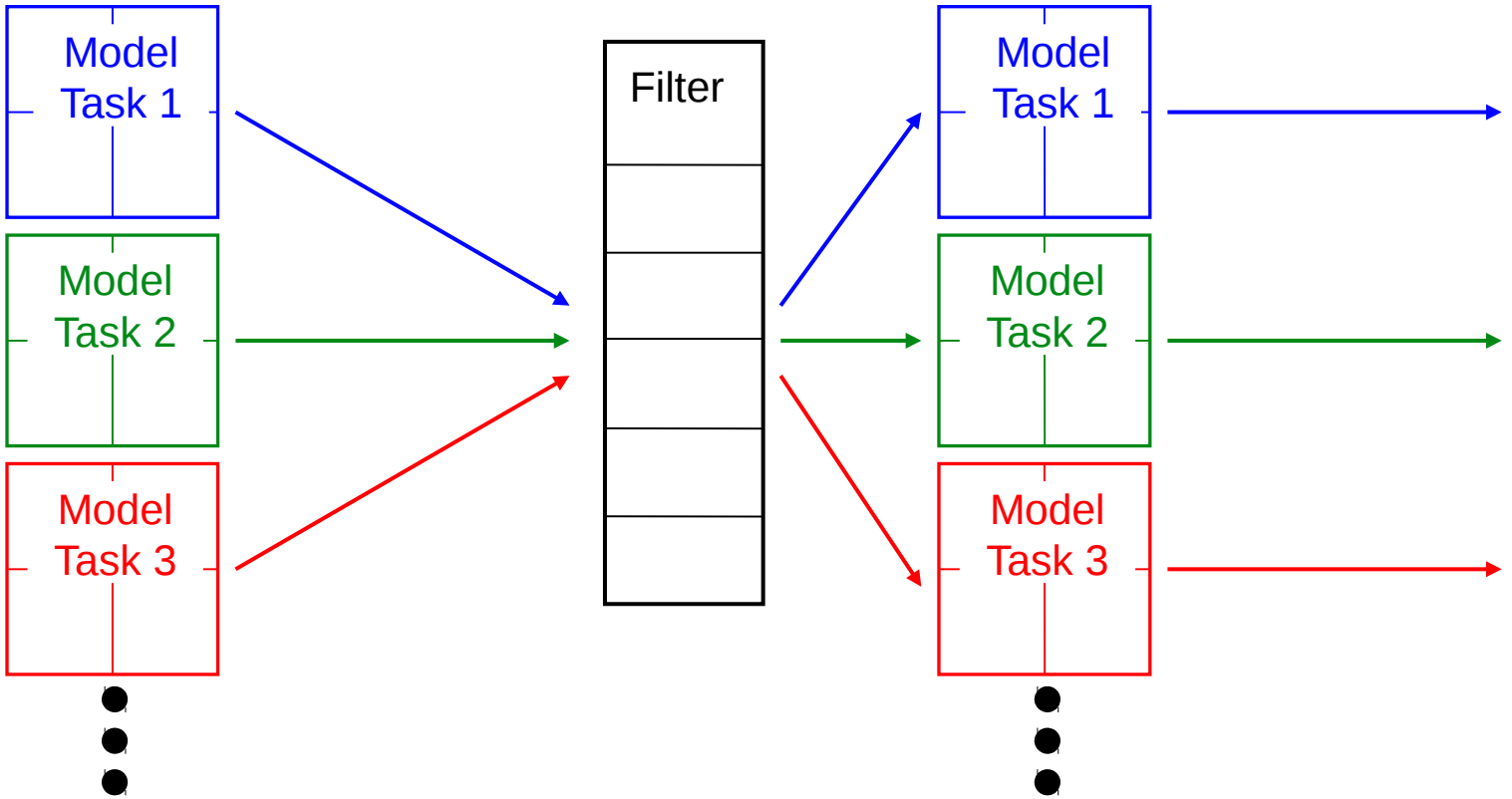
*The end...*

# About on-line version of PDAF

# Online coupled NEMO with PDAF



# 2-level parallelization of the assimilation system




MPI and OpenMP are used for parallelization:

- OpenMP is used for parallelization of NEMO
- MPI is used to distribute the ensemble members