Ensemble Data Assimilation in NEMO using PDAF

Lars Nerger[1], Yuchen Sun[1], Wibke Düsterhöft-Wriggers[2],
Yumeng Chen[3], and Dale Partridge[4]

1: Alfred Wegener Institute, Bremerhaven, Germany
2: Federal Maritime and Hydrographic Agency (BSH), Rostock, Germany
3: University of Reading / NCEO, Reading, UK
4: Plymouth Marine Laboratory, Plymouth, UK

PDAF Parallel Data Assimilation Framework

EGU Assembly 2023

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004032.

PDAF – Parallel Data Assimilation Framework

PDAF Parallel Data Assimilation Framework

A unified tool for interdisciplinary data assimilation …

- provide support for parallel ensemble forecasts
- provide assimilation methods (solvers) - fully-implemented & parallelized
- provide tools for observation handling and for diagnostics
- easily useable with (probably) any numerical model
- a program library (PDAF-core) plus additional functions
- run from notebooks to supercomputers (Fortran, MPI & OpenMP)
- ensure separation of concerns (model – DA method – observations – covariances)

Open source:
Code, documentation, and tutorial available at

http://pdaf.awi.de

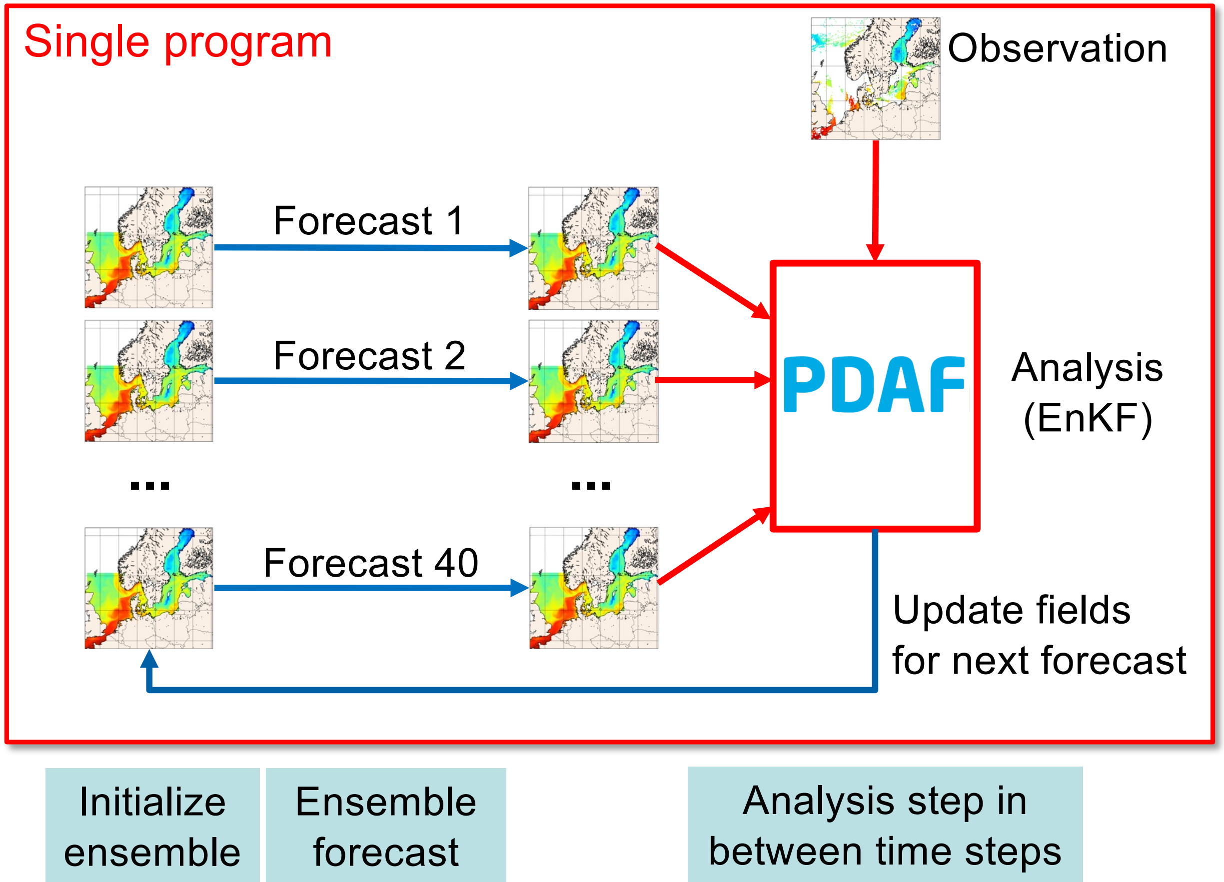
L. Nerger, W. Hiller, Computers & Geosciences 55 (2013) 110-118

Online-Coupling – Assimilation-enabled Model

Couple a model with PDAF

- Modify model to simulate ensemble of model states
- Insert analysis step/solver to be executed at prescribed interval
- Run model as usual, but with more processors and additional options

- EnOI and 3D-Var also possible:
  - Evolve single model state
  - Prescribe ensemble perturbations or covariance



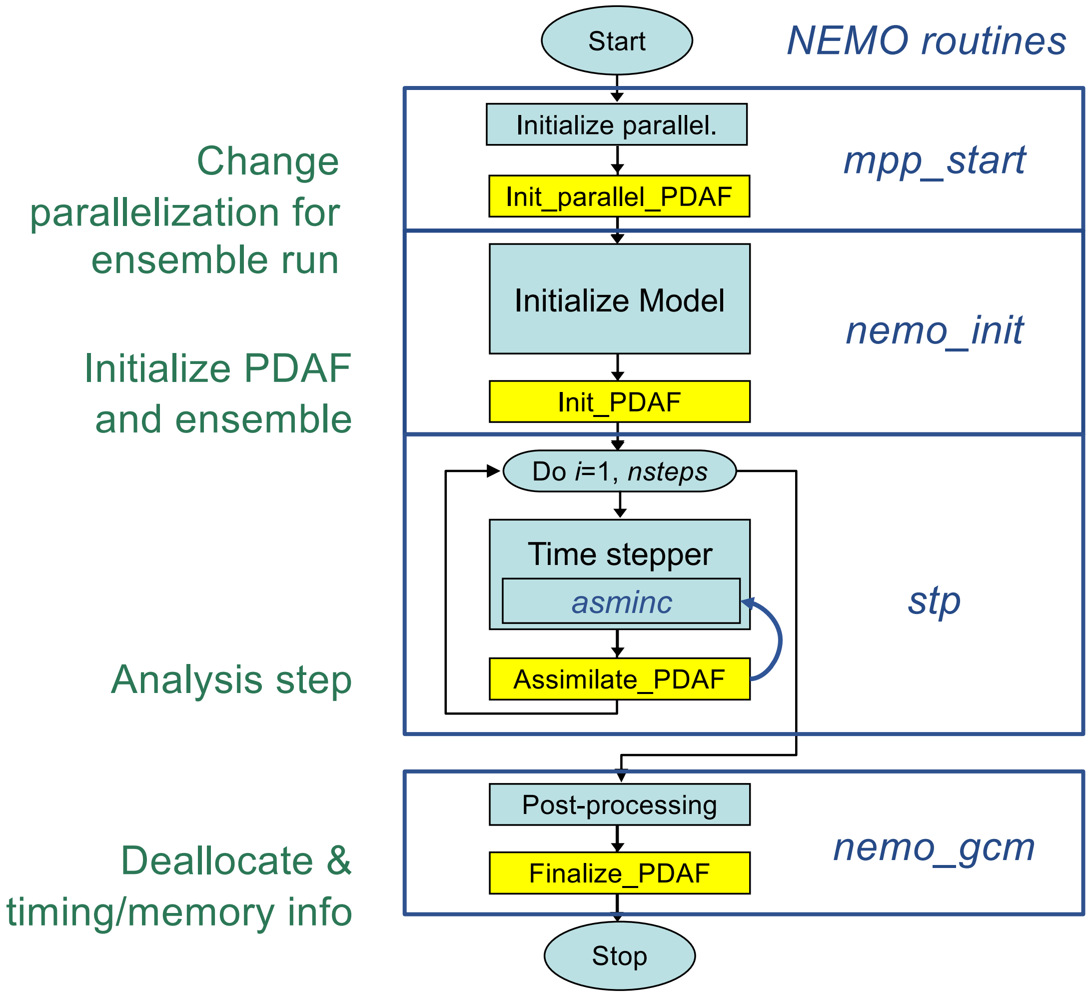
NEMO-PDAF Online Coupling

Model code | DA code

PDAF Parallel Data Assimilation Framework

Augment NEMO with DA functionality

- Insert 4 subroutine calls
- Modify parallelization for ensemble mode
- Transfer data between model and PDAF in memory
- Adapt NEMO's ASM module:
  PDAF provides increments in memory
- No changes to XIOS, but to file_def*.xml



- Very efficient & highly scalable
- Direct access to model grid and fields through Fortran modules
- File output kept to minimum
- No model restarts for cycled assimilation

PDAF interface structure

PDAF Parallel Data Assimilation Framework

- **Model-sided Interface:** Defined calls to PDAF routines
  (called by driver program for offline coupling)

- **Case-related Interface:**
  User-supplied call-back routines for elementary operations:
  - transfers between model fields and ensemble of state vectors
  - observation-related operations

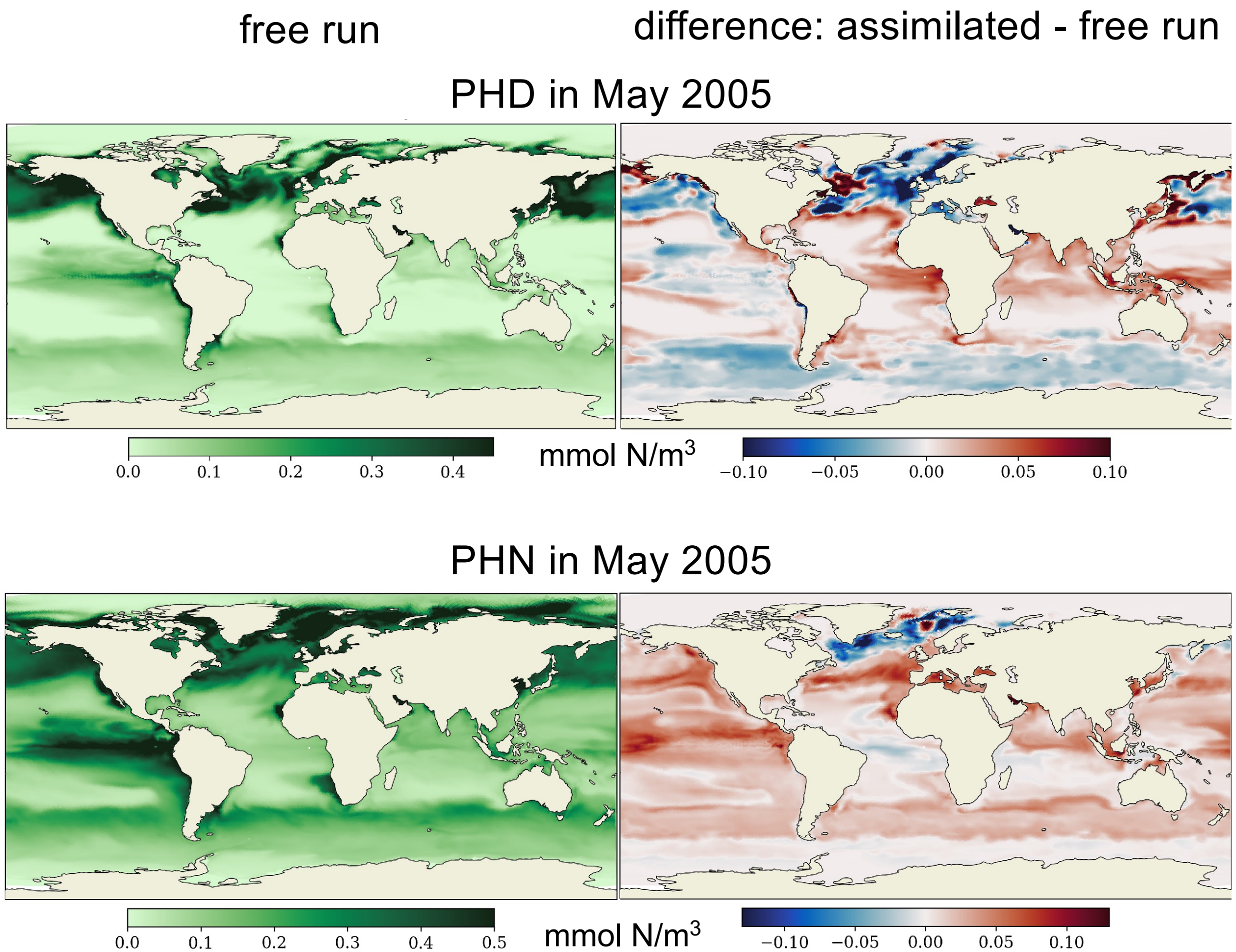
- User-supplied routines can be implemented as routines of the model and can share data with it (low abstraction level)

Online: Access model information through modules / static variables
offline: initialize model information from files

Assimilating Phytoplankton Carbon in NEMO-FABM-MEDUSA

PDAF Parallel Data Assimilation Framework

- DA setup
  - Kalman filter: LESTKF
  - Localisation radius: 200 km
  - Forgetting factor: 0.95
  - Ensemble size: 30
- Model setup
  - FABM-MEDUSA
  - ORCA1 grid
  - Year: 2005
- Observation
  - The phytoplankton carbon products from BICEP project
- State
  - Diatom phytoplankton nitrogen (PHD)
  - non-diatom phytoplankton nitrogen (PHN)



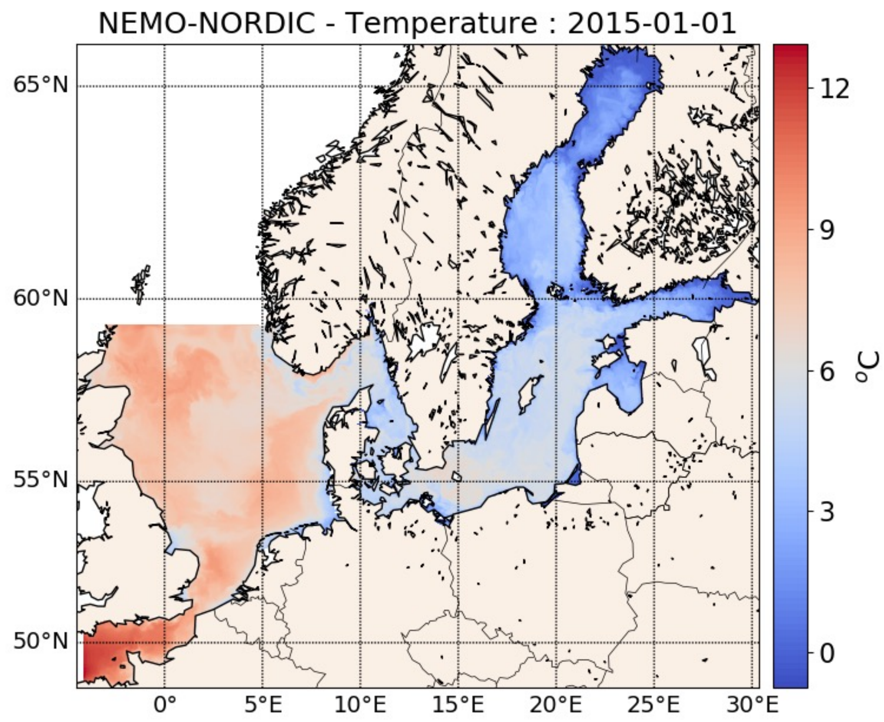
National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL
University of Reading
PML Plymouth Marine Laboratory

Assimilating SST and Chlorophyll in NEMO-ERGOM

PDAF Parallel Data Assimilation Framework

- Model setup
  - NEMO-NORDIC + ERGOM biogeochemistry
  - 1 nm resolution (ca. 1.8km); 56 layers
  - Year: 2015
- DA setup
  - Kalman filter: LESTKF
  - Localisation radius: 15 km
  - Forgetting factor: 0.95
  - Ensemble size: 30
  - Daily assimilation
- Observations
  - SST and Chlorophyll from CMEMS
- State
  - 5 physics variables
  - 16 ERGOM prognostic variables + 4 diagnostic variables
  - State dimension: $704 \cdot 10^6$

Poster:
Sun & Nerger
Today OS4.11
Board X5.306



SEAMLESS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004032.

AWI

Summary – NEMO-PDAF

- Coupled NEMO and PDAF for (ensemble) data assimilation
  - state vector can include ocean physics / sea ice / BGC …
  - easy addition of observation types
  - supports cycled DA without model restarts
  - utilize NEMO's ASM-module: IAU and direct initialization
  - Currently for NEMO 4.0.x – NEMO 4.2 in progress

- Code will be made open source

PDAF is open source:
Code, documentation, and tutorial available at

http://pdaf.awi.de

PDAF package: DA Algorithms and Models

PDAF Parallel Data Assimilation Framework

PDAF originated from comparison studies of different filters

Ensemble Filters and smoothers - *global and localized*

- EnKF (Evensen, 1994 + perturbed obs.)
- (L)ETKF (Bishop et al., 2001/Hunt et al. 2007)
- ESTKF (Nerger et al., 2012)
- NETF (Toedter & Ahrens, 2015)
- Particle filter
- *EnOI mode*

Model bindings

- MITgcm
- AWI-CM / FESOM

Toy models (full implementations with PDAF)

- Lorenz-96 / Lorenz-63
- Lorenz-2005 models II and III

3D-Var schemes
(incremental with control variable transformation)

- 3D-Var with parameterized covar.
- 3D Ensemble Var
- Hybrid 3D-Var

Community:

- pyPDAF (Python-coded models)
- TerrSysMP-PDAF

In progress

- SCHISM/ESMF (VIMS)
- GOTM/FABM "EAT" (BB ApS)

References

PDAF Parallel Data Assimilation Framework

- https://pdaf.awi.de (The website also provides a list of studies using PDAF)
- https://github.com/PDAF

- Nerger, L., Hiller, W. (2013). Software for Ensemble-based Data Assimilation Systems - Implementation Strategies and Scalability. Computers and Geosciences, 55, 110-118. doi:10.1016/j.cageo.2012.03.026
- Nerger, L., Hiller, W., Schröter, J.(2005). PDAF - The Parallel Data Assimilation Framework: Experiences with Kalman Filtering, Use of high performance computing in meteorology : proceedings of the Eleventh ECMWF Workshop on the Use of High Performance Computing in Meteorology, Reading, UK, 25 - 29 October 2004 / Eds.: Walter Zwieflhofer; George Mozdzynski, Singapore: World Scientific, 63-83. doi:10.1142/9789812701831_0006
- Nerger, L., Tang, Q., Mu, L. (2020). Efficient ensemble data assimilation for coupled models with the Parallel Data Assimilation Framework: Example of AWI-CM. Geoscientific Model Development, 13, 4305–4321, doi:10.5194/gmd-13-4305-2020

pdaf@awi.de