Building Ensemble-Based Data Assimilation Systems for Coupled Models

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Overview

How to simplify to apply data assimilation?

1. Extend model to integrate the ensemble
2. Add analysis step to the model
3. Then focus on applying data assimilation

PDAF: A tool for data assimilation

PDAF - Parallel Data Assimilation Framework

- a program library for ensemble data assimilation
- provide support for parallel ensemble forecasts
- provide fully-implemented & parallelized filters and smoothers (EnKF, LETKF, NETF, EWPF … easy to add more)
- easily useable with (probably) any numerical model (applied with NEMO, MITgcm, FESOM, HBM, TerrSysMP, …)
- run from laptops to supercomputers (Fortran, MPI & OpenMP)
- first public release in 2004; continued development
- ~200 registered users; community contributions

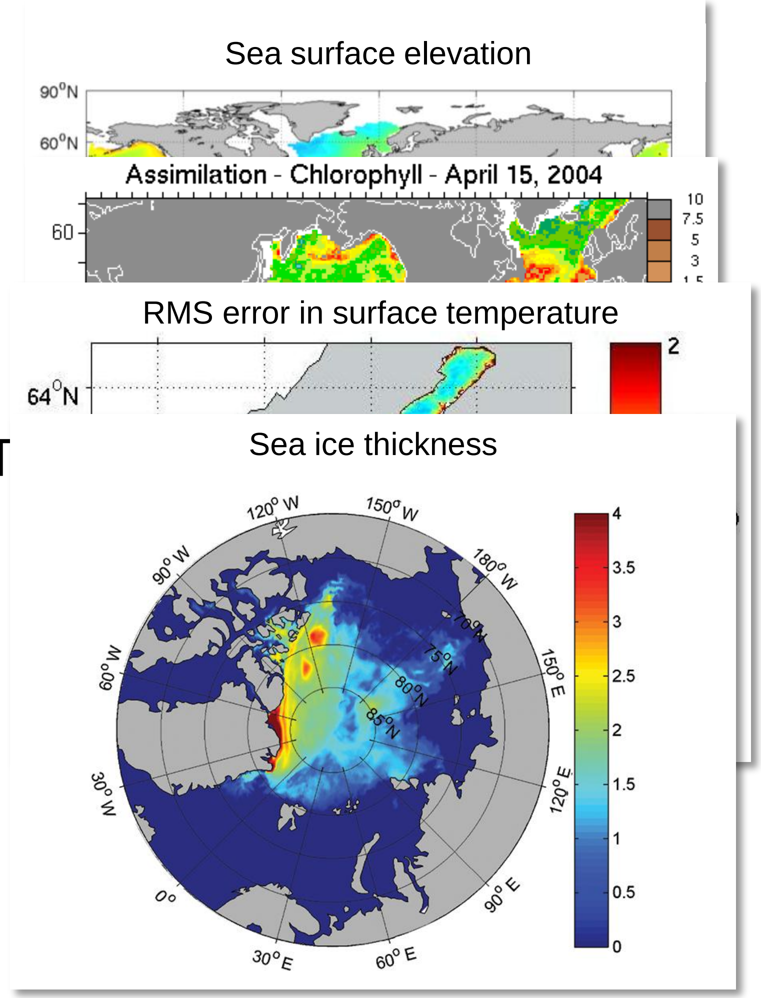
Open source:
Code, documentation & tutorials at

http://pdaf.awi.de

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

Application examples run with PDAF

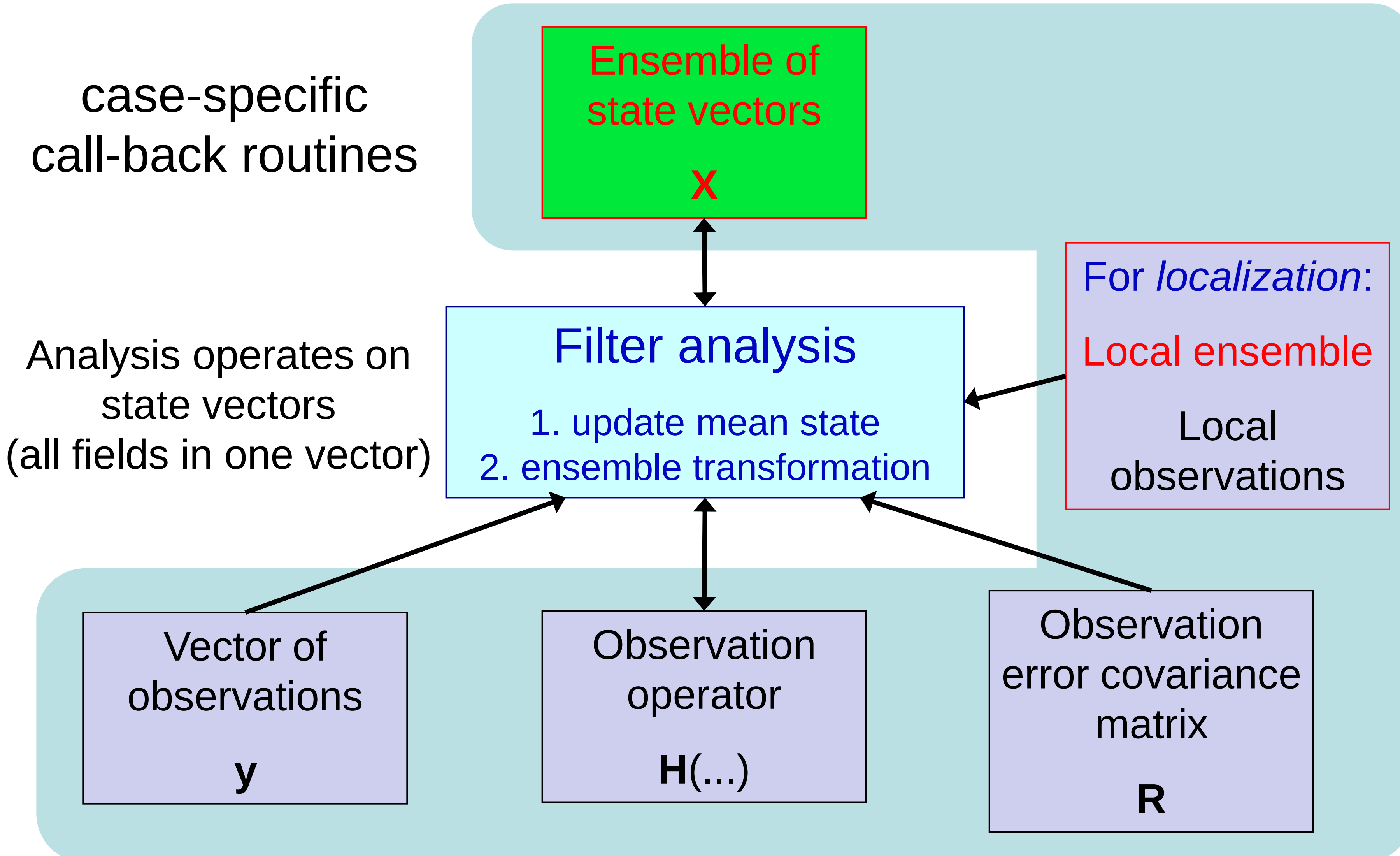
- FESOM: Global ocean state estimation (Janjic et al., 2011, 2012)
- NASA Ocean Biogeochemical Model: Chlorophyll assimilation (Nerger & Gregg, 2007, 2008)
- HBM-ERGOM: Coastal assimilation of SST & ocean color (S. Losa et al. 2013, 2014)
- MITgcm: sea-ice assimilation (Q. Yang et al., 2014-16, NMEFC Beijing)



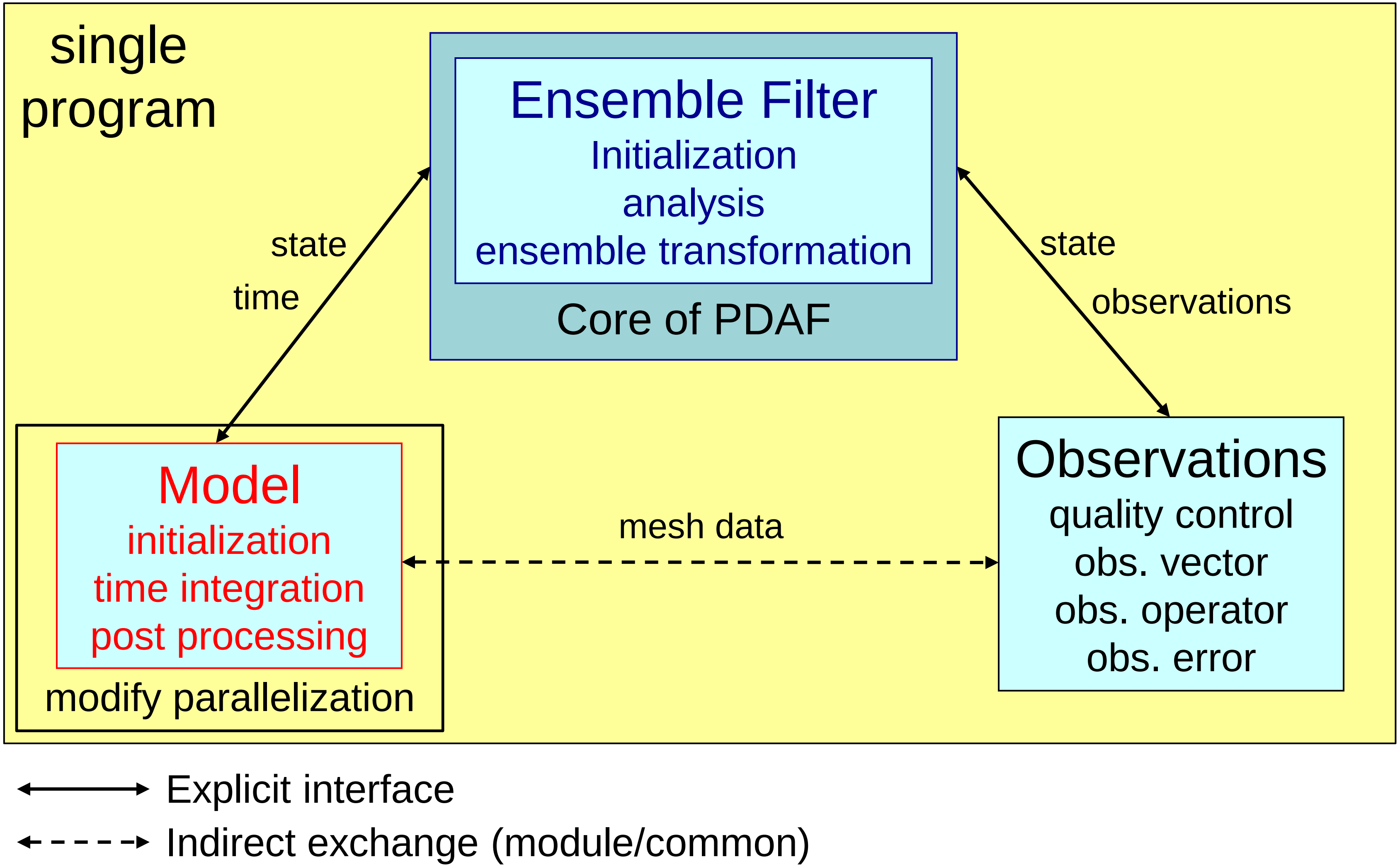
+ external applications & users, e.g.

- Geodynamo (IPGP Paris, A. Fournier)
- MPI-ESM (coupled ESM, IFM Hamburg, S. Brune) *-> talk tomorrow*
- CMEMS BAL-MFC (Copernicus Marine Service Baltic Sea)
- TerrSysMP-PDAF (hydrology, FZJ)

Ensemble filter analysis step



Logical separation of assimilation system



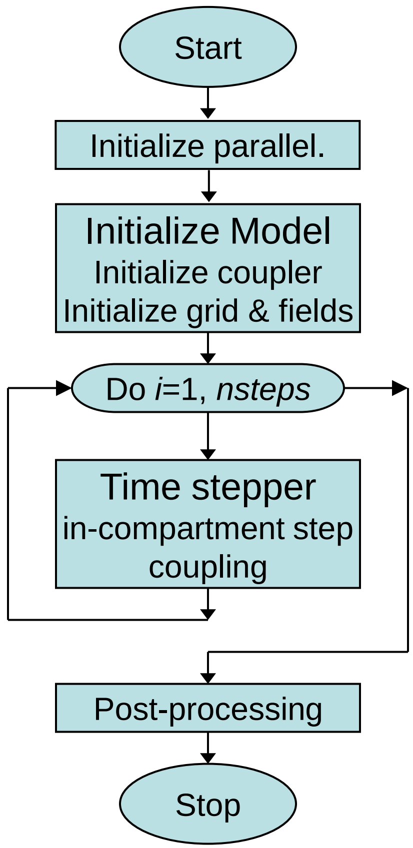
Nerger, L., Hiller, W. Software for Ensemble-based DA Systems – Implementation and Scalability. Computers and Geosciences 55 (2013) 110-118

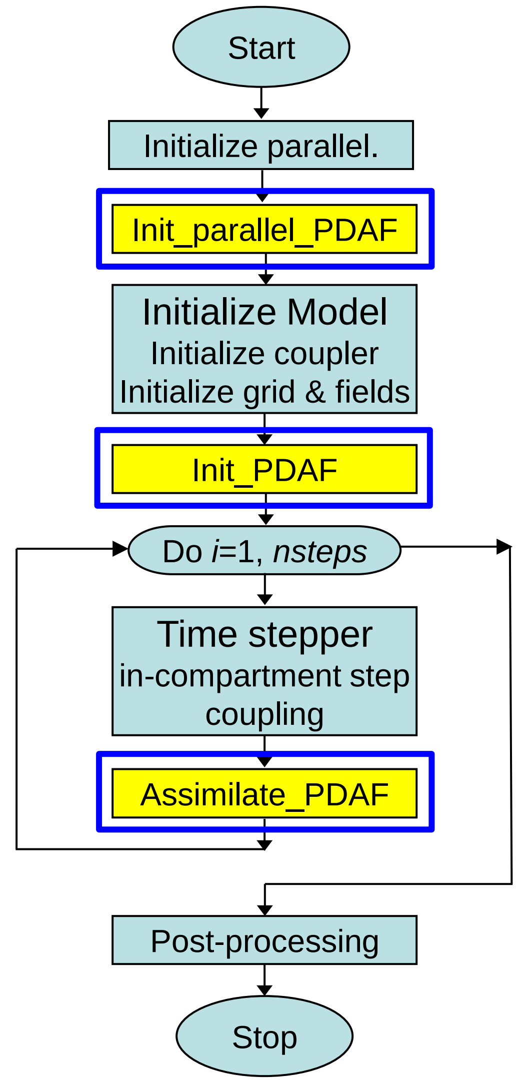
Extending a Model for Data Assimilation

Model

single or multiple executables

coupler might be separate program





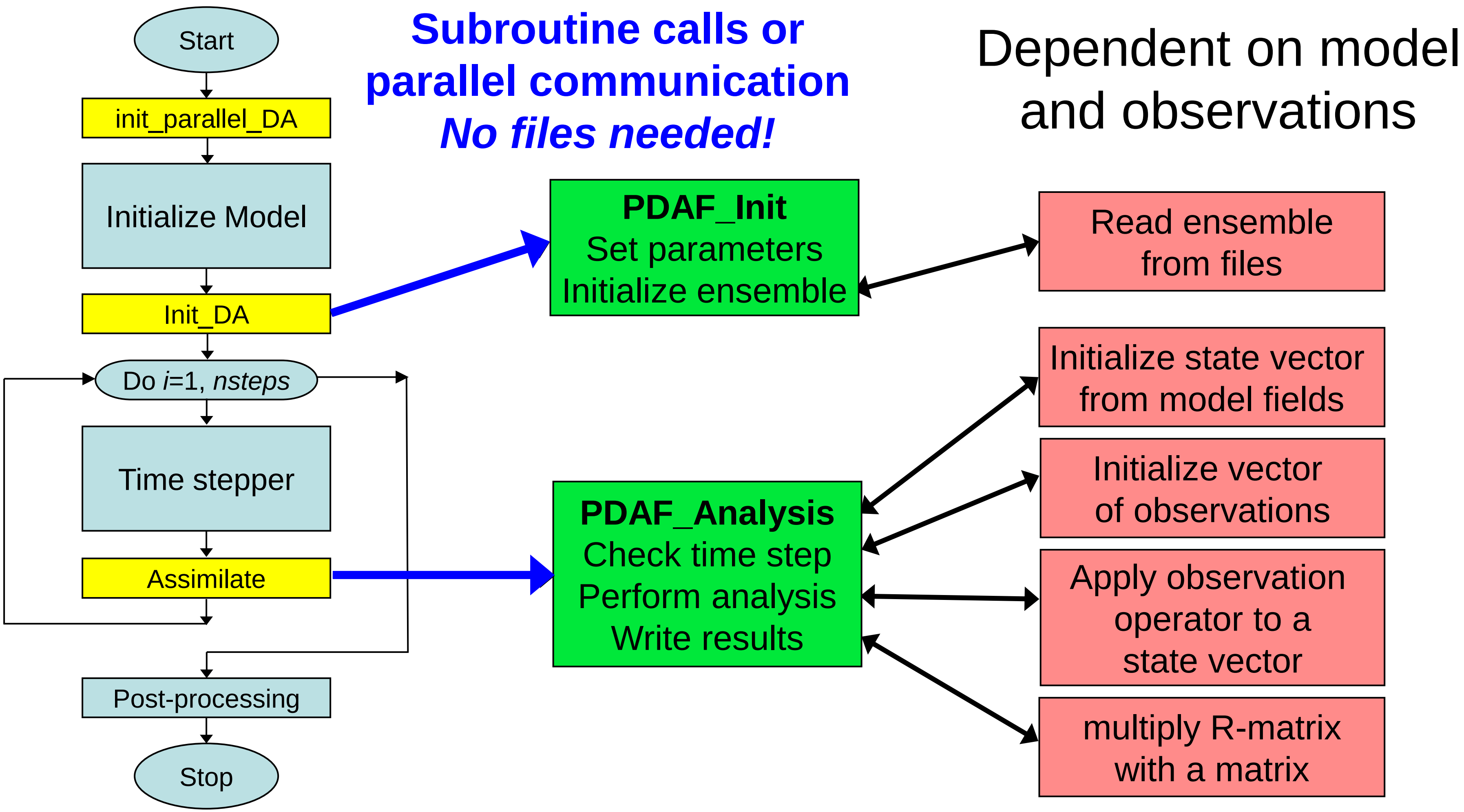
Extension for data assimilation

plus:
Possible model-specific adaption

Possible adaption of coupler (e.g. OASIS3-MCT)

revised parallelization enables ensemble forecast

Framework solution with generic filter implementation

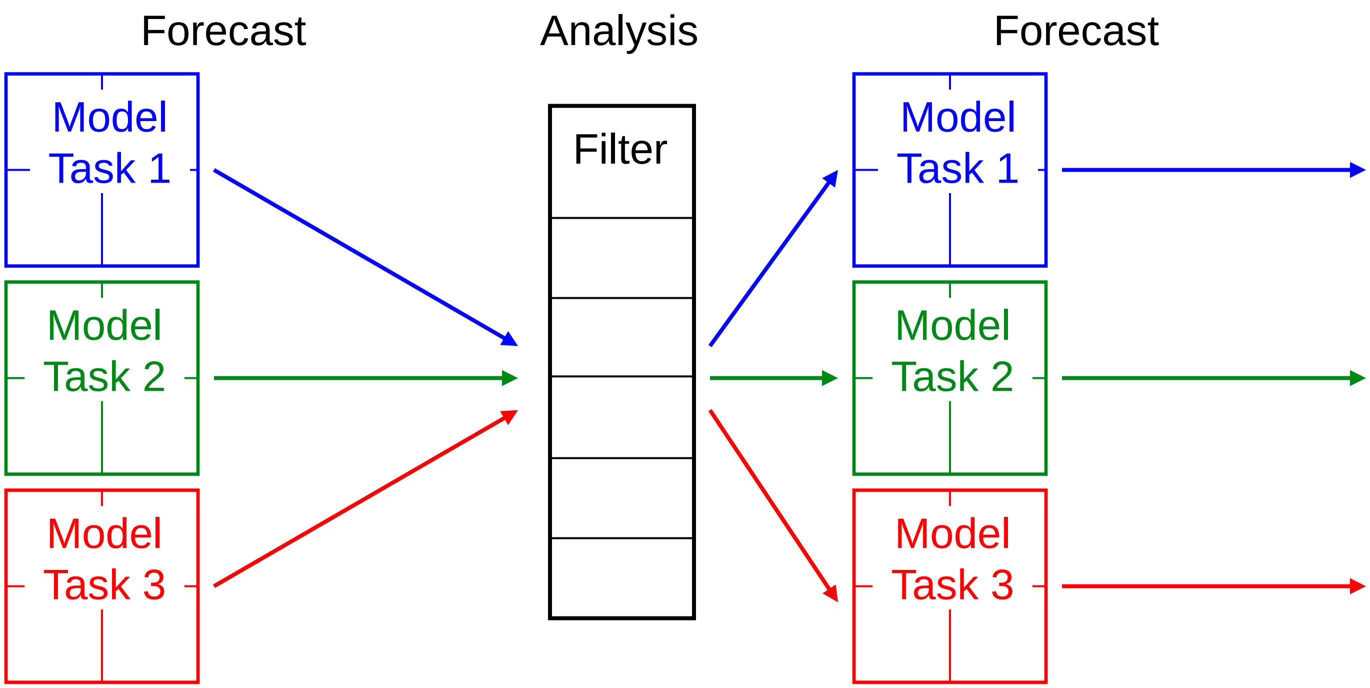


Model with assimilation extension

Core-routines of assimilation framework

Case specific call-back routines

2-level Parallelism



1. Multiple concurrent model tasks
2. Each model task can be parallelized

- ➢ Analysis step is also parallelized
- ➢ Configured by “*MPI Communicators*”

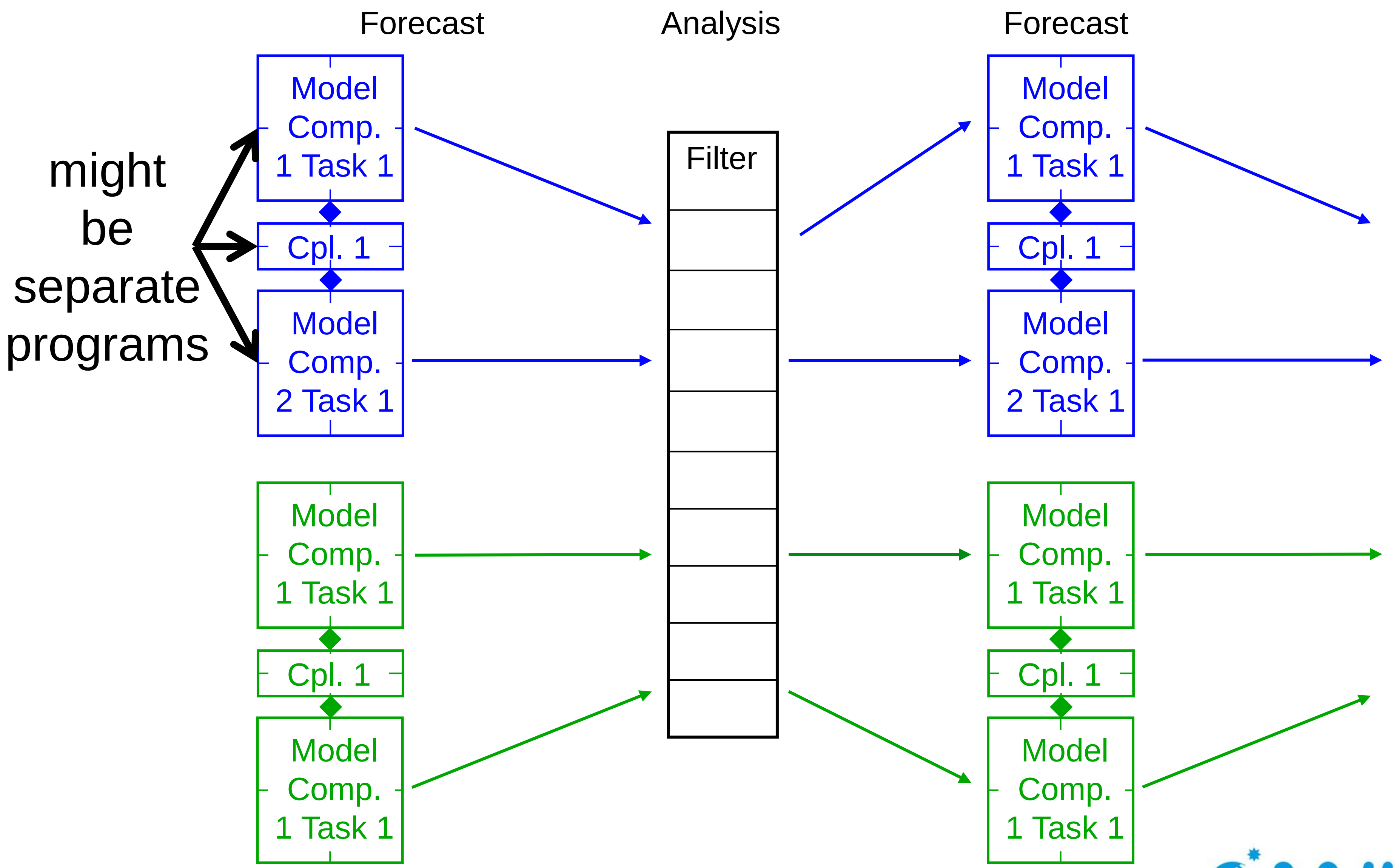
Building the Assimilation System

Problem reduces to:

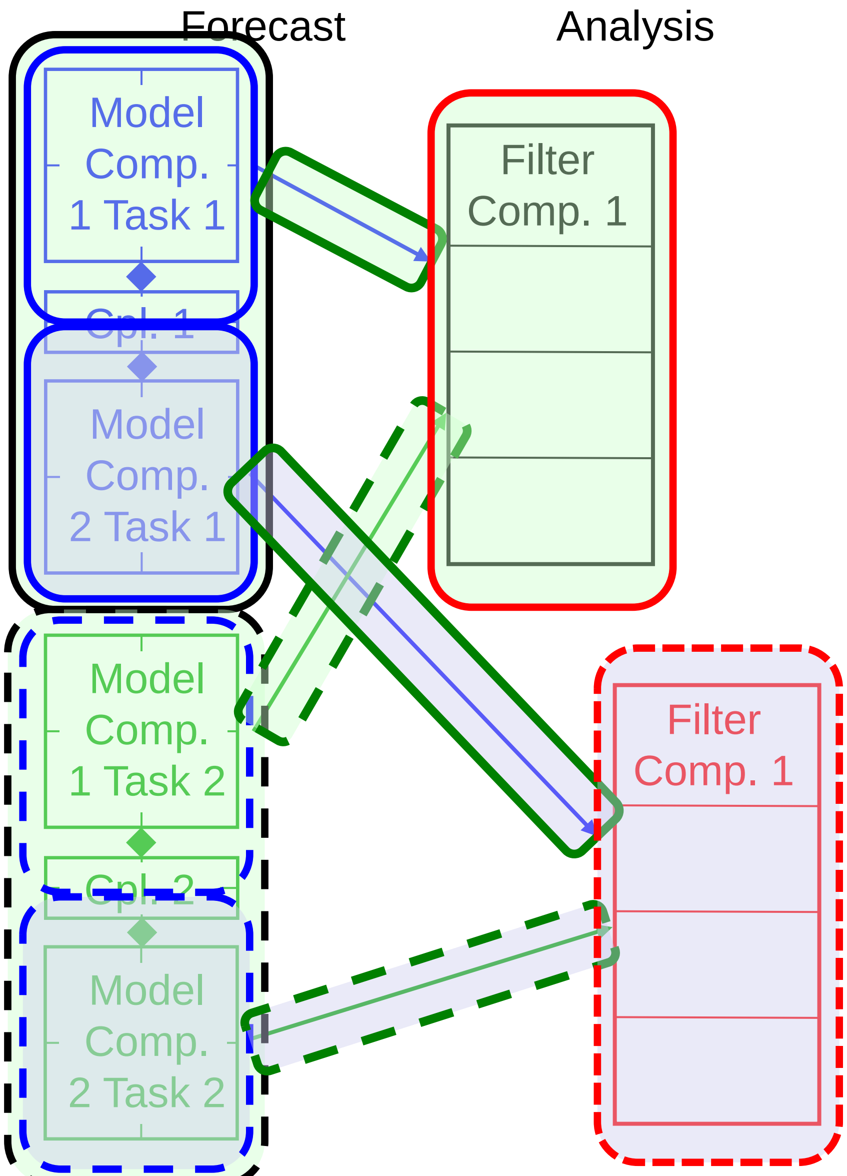
1. Configuration of parallelization (MPI communicators)

2. Implementation of compartment-specific user routines and linking with model codes at compile time

2 compartment system – strongly coupled DA



Configure Parallelization – weakly coupled DA



Logical decomposition:

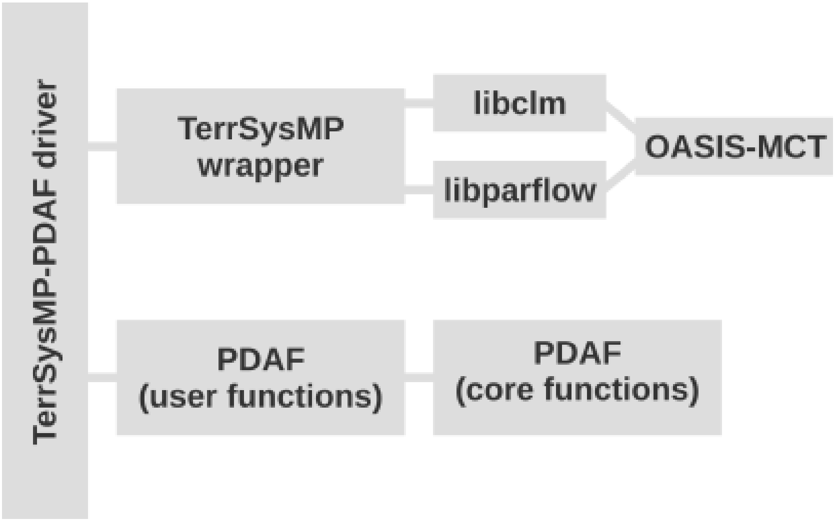
- Communicator for each
  - Coupled model task
  - Compartment in each task (init by coupler)
  - (Coupler *might want to split MPI_COMM_WORLD*)
  - Filter for each compartment
  - Connection for collecting ensembles for filtering

- Different compartments
  - Initialize distinct assimilation parameters
  - Use distinct user routines

Example: TerrSysMP-PDAF (Kurtz et al. 2016)

TerrSysMP model

- Atmosphere: COSMO
- Land surface: CLM
- Subsurface: ParFlow
- coupled with PDAF using wrapper
- single executable
- driver controls program



- Tested using 65536 processor cores

W. Kurtz et al., Geosci. Model Dev. 9 (2016) 1341

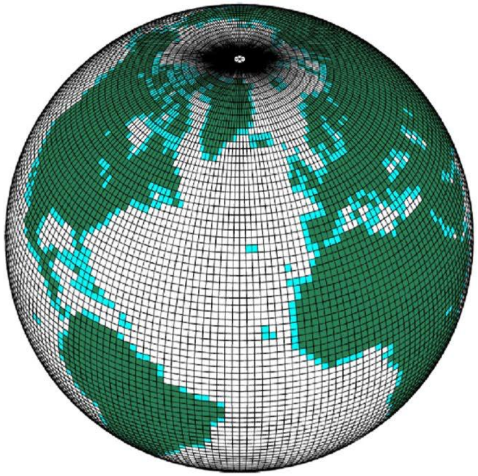
Example: ECHAM6-FESOM

Atmosphere
- ECHAM6
- JSBACH land

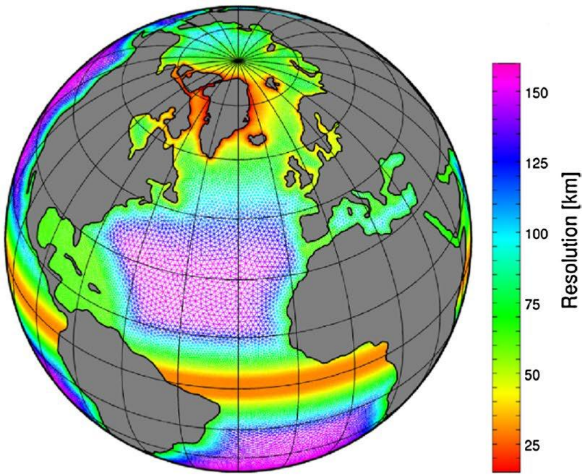
Ocean
- FESOM
- includes sea ice

Coupler library
- OASIS3-MCT

Atmosphere



Ocean



Separate executables for atmosphere and ocean

Data assimilation (FESOM completed, ECHAM6 in progress)
- Add 3 subroutine calls per compartment model
- Replace MPI_COMM_WORLD in OASIS coupler
- Implement call-back routines

Model: D. Sidorenko et al., Clim Dyn 44 (2015) 757

Summary

- Software framework
  simplifies building data assimilation systems
- Efficient online DA coupling
  with minimal changes to model code
- Setup of data assimilation with coupled model
  1. Configuration of communicators
  2. Implementation of user-routines
     - for interfacing with model code and
     - observation handling

References

- http://pdaf.awi.de
- Nerger, L., Hiller, W. *Software for Ensemble-based DA Systems – Implementation and Scalability*. Computers and Geosciences 55 (2013) 110-118
- Nerger, L., Hiller, W., Schröter, J.(2005). *PDAF - The Parallel Data Assimilation Framework: Experiences with Kalman Filtering*, Proceedings of the Eleventh ECMWF Workshop on the Use of High Performance Computing in Meteorology, Reading, UK, 25 - 29 October 2004, pp. 63-83.

Thank you !

Changes to FESOM

Add to *par_init* (gen_partitioning.F90) after MPI_init

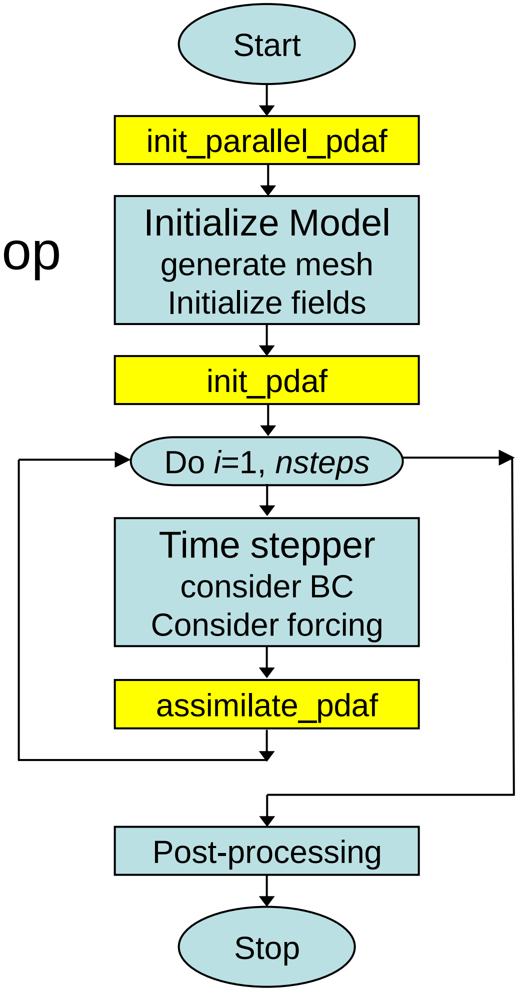
```
#ifdef USE_PDAF
  CALL init_parallel_pdaf(0, 1, MPI_COMM_FESOM)
#endif
```

Add to *main* (fesom_main.F90) just before stepping loop

```
  CALL init_pdaf()
```

Add to *main* (fesom_main.F90) just before 'END DO'

```
  CALL assimilate_pdaf()
```



OASIS3-MCT

Assumes to split MPI_COMM_WORLD in *oasis_init_comp* (mod_oasis_method.F90)

- Needs to split COMM_FESOM

Changes to ECHAM6

Add to *p_start* (mo_mpi.f90) after MPI_init

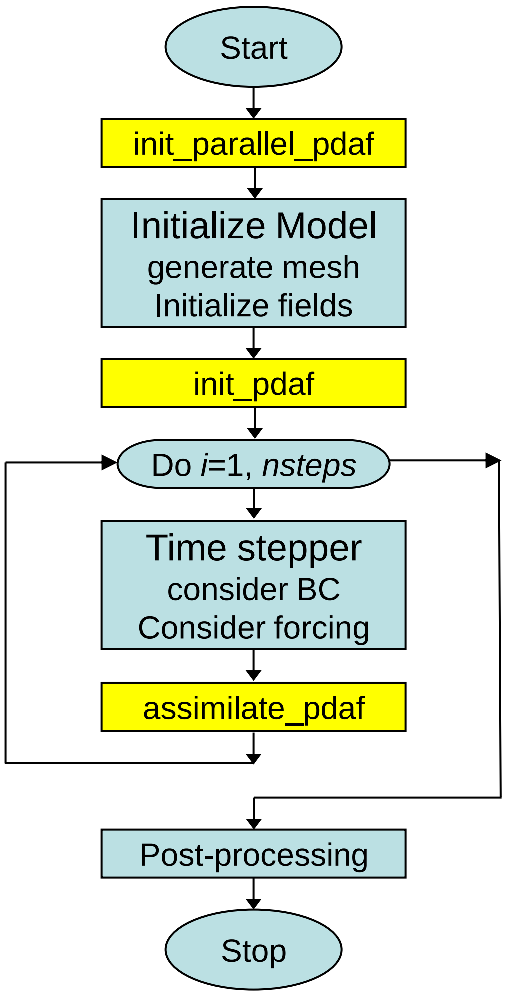
```
#ifdef USE_PDAF
  CALL init_parallel_pdaf(0, 1, p_global_comm)
#endif
```

Add to *control* (control.f90) before call to *stepon*

```
  CALL init_pdaf()
```

Add to *stepon* (step.f90) before 'END DO'

```
  CALL assimilate_pdaf()
```



OASIS3-MCT

Assumes to split MPI_COMM_WORLD in *oasis_init_comp* (mod_oasis_method.F90)

- Needs to split p_global_comm

Minimal changes to NEMO

Add to *mynode* (lin_mpp.F90) just before init of myrank

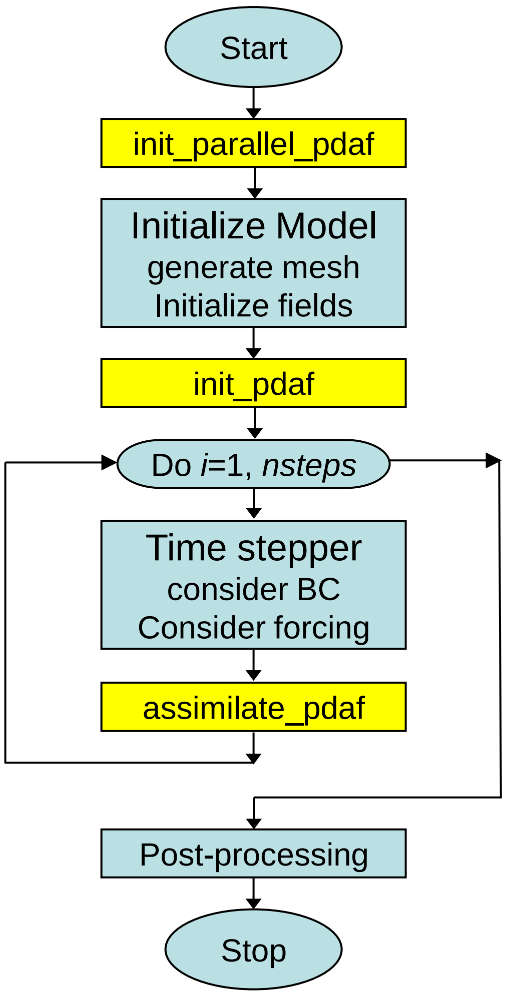
```
#ifdef key_USE_PDAF
  CALL init_parallel_pdaf(0, 1, mpi_comm_opa)
#endif
```

Add to *nemo_init* (nemogcm.F90) at end of routine

```
  CALL init_pdaf()
```

Add to *stp* (step.F90) at end of routine

```
  CALL assimilate_pdaf()
```



For Euler time step after analysis step:

Modify *dyn_nxt* (dynnxt.F90)

```
#ifdef key_USE_PDAF
  IF((neuler==0 .AND. kt==nit000) .or. assimilate)
#else
```

Current algorithms in PDAF

PDAF originated from comparison studies of different filters

Filters

- EnKF (Evensen, 1994 + perturbed obs.)
- ETKF (Bishop et al., 2001)
- SEIK filter (Pham et al., 1998)
- SEEK filter (Pham et al., 1998)
- ESTKF (Nerger et al., 2012)

G

- LETKF (Hunt et al., 2007)
- LSEIK filter (Nerger et al., 2006)
- LESTKF (Nerger et al., 2012)

Localized filters

Smoothers for

- ETKF/LETKF
- ESTKF/LESTKF
- EnKF

Global and local smoothers

Not yet released:

- serial EnSRF
- particle filter
- EWPF
- NETF

Parallel Performance

Parallel Performance

Use between 64 and 4096 processor cores of SGI Altix ICE cluster (HLRN-II)

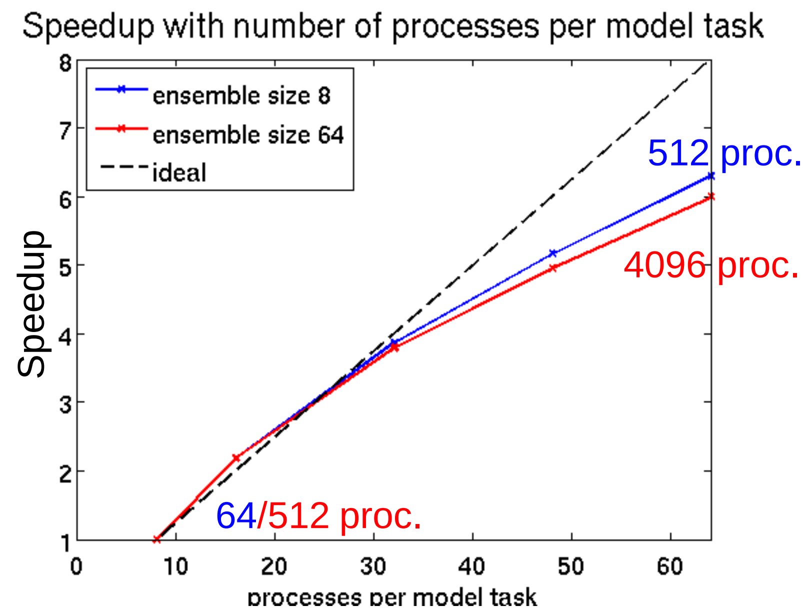
94-99% of computing time in model integrations

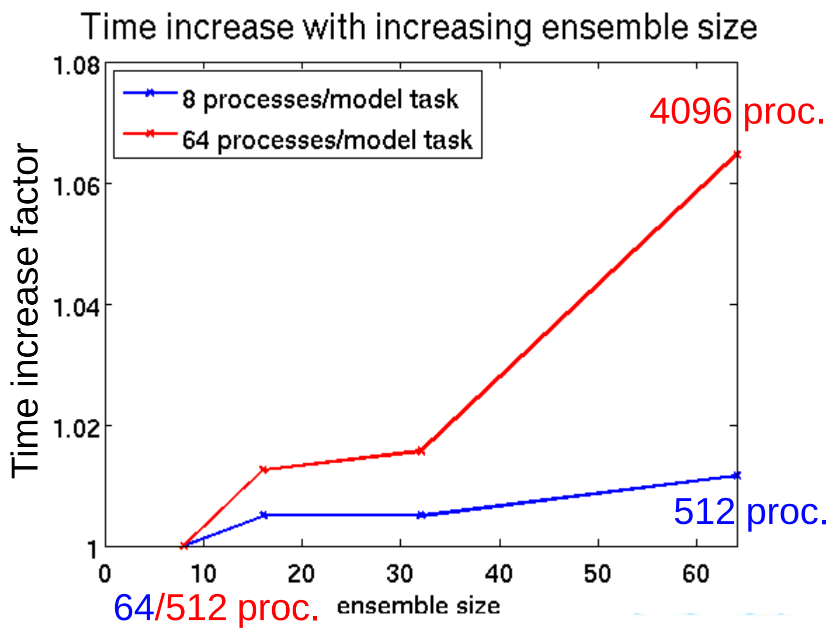
Speedup: Increase number of processes for each model task, fixed ensemble size

- factor 6 for 8x processes/model task
- one reason: time stepping solver needs more iterations

Scalability: Increase ensemble size, fixed number of processes per model task

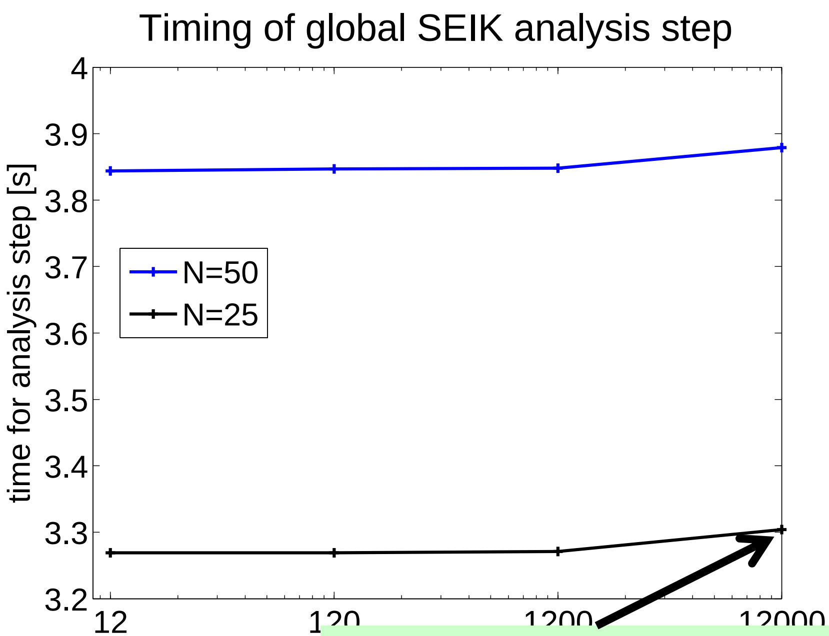
- increase by ~7% from 512 to 4096 processes (8x ensemble size)
- one reason: more communication on the network





Very big test case

- Simulate a “model”
- Choose an ensemble
  - state vector per processor: 10^7
  - observations per processor: $2 \cdot 10^5$
  - Ensemble size: 25
  - 2GB memory per processor
- Apply analysis step for different processor numbers
  - 12 – 120 – 1200 – 12000



State dimension: 1.2e11

Observation dimension: 2.4e9

- Very small increase in analysis time (~1%)
- Didn’t try to run a real ensemble of largest state size (no model yet)

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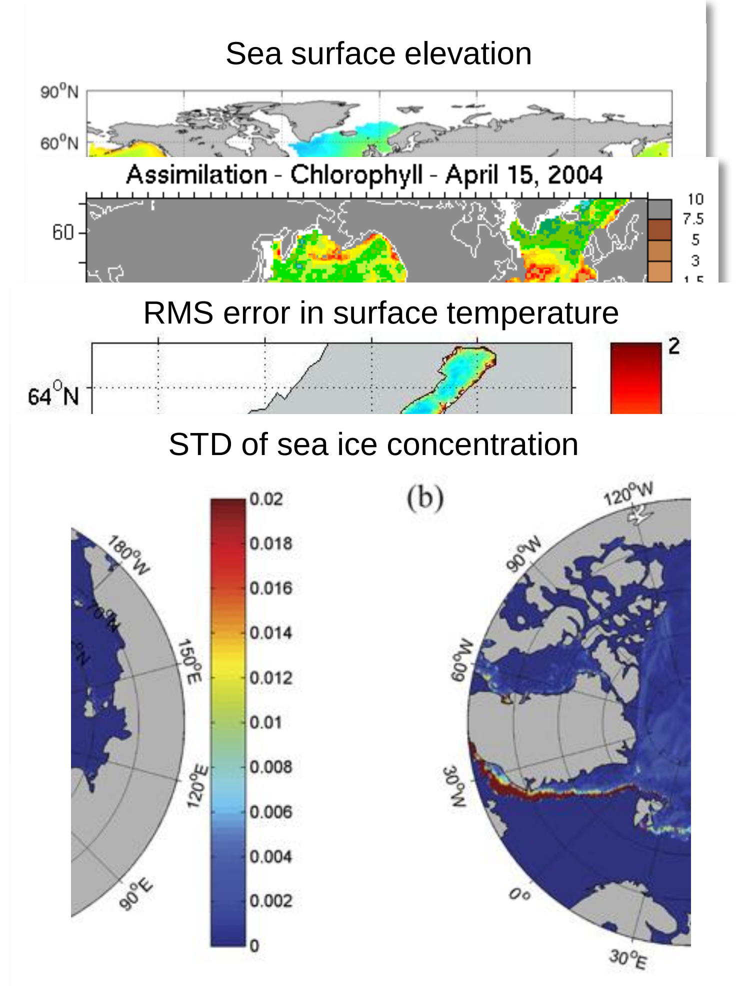

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