Application, Data assimilation: A perspective from Norway

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Initialization of Ocean & sea-ice

OBS: SSTA + ICE C.

Need for strongly coupled initialisation:

- Dynamical consistency
- Better exploit sparse & inhomogeneously distributed observations
Strongly coupled data assimilation with the Ensemble Kalman Filter

Ocean bottom

Surface

Sea-ice

Ice concentration

Ice thickness

OBS: SSTA + ICE C.

ML

T, S

Ocean

Member 1

Member N

Member 29

Member 30

Propagation

Correction
Coupled assimilation
Ocean & sea-ice

Lisæter et al. 03

Ice-conc increment

Salinity increment
Coupled assimilation
Ocean & sea-ice

Sakov et al. 2012
TOPAZ System:
European marine forecasting system for the Arctic Region

- HYCOM + 1 thickness (EVP) sea-ice model
- EnKF data assimilation method
- ECMWF forcing
- Provides
  - daily 10-day forecast
  - Reanalysis (1989-2014)

http://marine.copernicus.eu/


Other EnKF-based ocean sea-ice forced systems:
- NEMO-LIM+EnKF (Matthiot et al. 2012, Massonnet et al. 2014; Barth et al. 2016)
- MIT+SEIK (Yang et al. 2014, 2016)
Assimilation in TOPAZ

- DEnKF, asynchronous
  - 100 members
  - Local analysis (~90 km radius)
  - Rfactor/kfactor inflation
  - Weak SSS nudging

- Observations:
  - Sea Level Anomalies (CLS)
  - SST (NOAA, OSTIA)
  - Sea Ice Concentr. (OSISAF)
  - Sea ice drift (CERSAT/OSISAF)
  - T/S profiles (Coriolis, IPY)
  - 400,000 observations per week
  - ~100 in each local radius

DFS: Degrees of Freedom for Signal

\[ DFS = \text{tr}(\frac{\partial \hat{y}}{\partial y}) = \text{tr}(\frac{\partial H X^a}{\partial y}) = \text{tr}(KH) \]
Relative impacts of different observations in March 2014

Xie et al. 2016 TC
Assimilation of thick ice thickness: e.g. ICE-Sat; Cryosat-2

We follow the recipe of Lisæter et al. 2007 (assimilation of synthetic ice thickness)

[ P. Sakov 2013 ]
Conclusion
Initialization for short time forecast

• EnKF can provide cross covariance between ocean & sea ice
  ➔ Skillful initialization for short time forecast
  Daily RMSE (e.g. ~6 cm SLA; 0.66 °C for SST; < 5% for Ice concentration)
  *Xie et al. Ocean science discussion sub*

• Observations of ice concentration, thickness, ITP are most effectives in the Arctic (not sea-ice drift)

Remaining Challenges:
• Model has bias:
  • Thickness (up to 2 m); deep ocean
  • Thermodynamics (meltpond, heat capacity, …)
  • Dynamic (VP for high resolution ?)

TOPAZ ongoing developments:
• Test assimilation of CRYOSAT2
• Change to CICE-5 multicategory and increase resolution (~6 km)
• implementation of NextSIM in TOPAZ (**long term objective**)
Next generation sea-ice forecast

next generation sea ice model (neXtSIM):
• Elasto brittle rheology including a new “damage” variable for sea ice
• Finite element lagrangian mesh

Rampal et al. 2016 (TC); Bouillon & Rampal 2015 (OM)

Data assimilation in such model is:

- Challenging:
  • How to handle the lagrangian mesh (i.e. remeshing)
  • How to handle and preserve the non-gaussian distribution

- Promising:
  • Reduced model bias (especially regarding the drift)
  • Can ingest new data type (e.g. deformation rates)

Ongoing development in DASIM project (Rabatel, Carrassi, Rampal, Jones)
Strongly coupled assimilation in fully coupled ESM

How to constrain sea-ice in fully coupled ESM, without external constraint (SSS nudging, atmospheric forcing) and for long simulations (> 30 years)

Main source of observation in the Arctic is ice concentration

Perfect twin experiments:
- Synthetic observations created from the model at different time:
  - Use pre-industrial forcing
  - Test 10 year reanalysis with monthly assim of ice concentration

- Experiments:
  - **Free**: Free ensemble run
  - **Twin-A**: Estimate ice quantity with EnKF and diagnosed the ocean
  - **Twin-E**: strongly coupled ocean (ML only)-sea-ice (multi-category) + post-process ocean+sea-ice (similar to Massonnet et al. 2014)
Norwegian Climate Prediction Model (NorCPM)

Earth System model (NorESM1-M)
- Atmospheric chemistry
- CAM
- CICE
- CLM
- River routing
- NorESM-O
- HAMOCC

Data assimilation (EnKF)
- 30 members
- atm 2°; ocean+ice 1°

Long term objectives:
- Long term reanalysis (1850 – present)
- Seasonal-to-decadal prediction
  - CMIP6 DCPP

Stochastic observations
HadISST2 (SST+Ice conc)

Counillon et al. 2014, 2016; Wang et al. 2015
Strongly coupled assimilation in fully coupled ESM

Can EnKF initialise fully coupled ESM, without external constraint (SSS nudging, atmospheric forcing) and for long simulations (> 30 years)

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Assimilation with multicategory sea-ice

Massonnet et al. 2014: assimilation with multicategory sea ice (LIM)

Use EnKF to update ice concentration & thickness for each category and apply post-processing for handling non-physical values
Strongly coupled assimilation
Ocean & sea-ice: (OSSE)

Using flow dependent cross covariance (i.e. EnKF) performs better than post processing

M. Kimmritz
Strongly coupled assimilation
Ocean & sea-ice: (OSSE)

But degradation builds over time:
- Ice accumulate in wrong cat.
- Drift in the ocean

M. Kimmritz
Assimilation of sea-ice in fully coupled ESM

Primary conclusions:
• Assimilation of ice concentration implemented in NorCPM (with CICE4 multicategory)
• Improvement for ice concentration, thickness and initially for ocean T,S but degradation builds with time

How to annihilate (or minimize) the drift?
• Identify variables that should be updated/diagnosed?
• Should we update each category independently or stretch?
• Organization/transformed variables so that cross covariance is reasonably linear:
  • Anamorphosis (Bertino 2003, Barth et al. 2015)
  • Aggregation method (Wang et al. 2016)
• How to construct the localisation radius (horizontal, vertical, cross compartment)