Recent advances in the Mercator ocean and sea-ice reanalysis system:
Modelling of sea-ice forecast error statistics.

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Univariate Sea Ice Analysis in the operational applications

- The Mercator ocean and sea-ice reanalysis system PSY4V3

Development of a multivariate Sea Ice Analysis

- Reanalysis using multivariate state vector
- New background error based on Ensemble modelling

Summary and Plans
The Mercator ocean and sea-ice system PSY4V3
Main Characteristics

Model
- Nemo 3.1, LIM2-EVP(mono-category)
- Global 1/12°, 50 levels, IFS
- Oct. 2006 to near real-time

Assimilation
- Analysis based on a 2D local multivariate SEEK/LETKF
- Weakly-coupled DA system using 2 separate analyses:
  - Ocean Analysis (SLA, InSitu Data from CORA3.2, SST), IAU on (h,T,S,U,V)
  - Unidata/univariate Sea Ice Analysis
    - Sea Ice Concentration (OSI-SAF)
    - SIC Error: 1% open ocean, linear from 25% to 5% for SIC values between 0.01 and 1
    - Forecast error covariances are built from a prior ensemble of Sea Ice Concentration anomalies => Fixed basis background error
Mercator Data Assimilation System (SAM2):
Pf: Fixed Basis Background error covariances
Representation by a prior ensemble of anomalies

- We generate a pseudo-ensemble from a forced simulation

- We use these anomalies to compute Pf in the analysis
The Mercator ocean and sea-ice system PSY4V3
Model restarting using the sea ice model update

Restart Strategy: IAU on SIC + …
- … nothing using an implicit concept of thickness conservation
\[ \Delta \text{SIC}_i, \Delta h_i = 0, h_i = \text{cte} \Leftrightarrow \Delta V_i = h_i \cdot \Delta \text{SIC}_i \]

Analysis of Sea Ice Concentration (y2011m10d12, 7 days cycle)

Innovation
OSISAF – PSY4V3/LIM2noEVP

Model update

Residual
Innovation – Model update
The Mercator ocean and sea-ice system PSY4V3
2006-2017 hindcast experiment
assimilating OSI-SAF SIC Observations

CERSAT SIC Misfits

Residual vs innovation
OSI-SAF (Feb 2012)

OSI-SAF SIC Innovation

CERSAT SIC Residu

Oct.2006 Jan..2015

OSI-SAF SIC Residu
The Mercator ocean and sea-ice system PSY4V3
2006-2017 hindcast experiment
assimilating OSI-SAF SIC Observations

OSI-SAF SIC Innovation
(PSY4V3)

OSI-SAF SIC Residu
(PSY4V3)

OSI-SAF SIC Misfits
(Run using Ocean Bias only)

Sept 2011

March 2012
The Mercator ocean and sea-ice system PSY4V3
2006-2017 near real-time simulation
assimilating OSI-SAF SIC Observations

RMS Diff PSY4V2R2 Ice fraction 2016-09-01_2016-09-30
Old system

RMS Diff PSY4V3R1 Ice fraction 2016-09-01_2016-09-30
New system

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La Spezia, Italy, October, 2017
The Mercator ocean and sea-ice system PSY4V3
2006-2017 near real-time simulation
assimilating OSI-SAF SIC Observations

Proportion Correct Total: \( PCT = \frac{a+d}{n} \)

<table>
<thead>
<tr>
<th></th>
<th>AMSR Ice</th>
<th>AMSR Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast Ice</td>
<td>Hit ice (a)</td>
<td>False Alarm (b)</td>
</tr>
<tr>
<td>Forecast Water</td>
<td>Miss (c)</td>
<td>Hit water (d)</td>
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Objectives of a multivariate Sea Ice State Vector

- To assimilate various sea ice data sets (Sea Ice Drift, Thickness, SI Temperature, …)
- To update unobserved variables (Thickness or Volume, …) in order to increase the control of the sea ice state using more consistent sea ice model update

We need

- To identify and activate an appropriate sea ice state vector according to the used data sets and the used sea ice model (LIM2-EVP_monocat, LIM3_multi-category)
- To use relevant background error covariance based on the physics of the days in order to obtain good extrapolation from observed to unobserved space

=> Ensemble approach using stochastic perturbations

Development Framework:

- NEMO3.6/LIM3 multi-category
- Use of an Arctic-Northern Atlantic Configuration at 1/4° (CREG4/NEMO3.6/LIM3)
Toward a Multivariate Sea Ice Analysis 
assimilating multi-observations and updating multi-variables

Sensitivity hindcast experiment using CREG4 with NEMO3.6/LIM3_5categories

Multivariate state vector for multivariate sea ice analysis: [SIC,SIC_CAT1, SIC_CAT2,SIC_CAT3,SIC_CAT4,SIC_CAT5] with OSI-SAF SIC observations

Multivariate Sea Ice Model update (y2006m12d28) 
(after 2 months of hindcast experiment)
Toward a Multivariate Sea Ice Analysis
assimilating multi-observations and updating multi-variables

Sensitivity hindcast experiment using CREG4 with NEMO3.6/LIM3_5categories

Multivariate state vector for multivariate sea ice analysis:
[SIC, SIC_CAT1, SIC_CAT2, SIC_CAT3, SIC_CAT4, SIC_CAT5] with OSI-SAF SIC observations
CRED4 Reanalysis starting at 20070102
Model update from analysis: [siconc, siconcat, sivolucat]
($\Delta$siconcat(1:15), $\Delta$sivolucat(1:15)) estimated from analysis based on OSI-SAF SI and null innovations on SICONCAT(15) and SIVOLUCAT(15)
Toward a Multivariate Sea Ice Analysis
CREG4 reanalysis assimilating OSI-SAF SIC Observations

CREG4 Reanalysis starting at 20070102
Model update from analysis: [siconc, siconcat, sivolucat]

(Δsiconcat(1:15), Δsivolucat(1:15)) estimated from analysis based on OSI-SAF SI and null innovations on SICONCAT(15) and SIVOLUCAT(15)

SIC(%) 20070915

CREG4 free run
OSI-SAF
CREG4 reanalysis
Toward a Multivariate Sea Ice Analysis
CREG4 reanalysis assimilating OSI-SAF SIC Observations

CREG4 Reanalysis starting at 20070102
Model update from analysis : [siconc,siconcat,sivolucat]

(Δsiconcat(1:15), Δsivolucat(1:15)) estimated from analysis based on OSI-SAF SI and null innovations on SICONCAT(15) and SIVOLUCAT(15)

Sea Ice Volume (Arctic)
Toward a Multivariate Sea Ice Analysis
CREG4 reanalysis assimilating OSI-SAF SIC Observations

CREG4 reanalysis starting at 20070102
Model update from analysis: [siconc, siconcat, sivolucat]
\( \Delta \text{SICONCAT}(1:15), \Delta \text{SIVOLUCAT}(1:15) \) estimated from analysis based on OSI-SAF SI and null innovations on SICONCAT(15) and SIVOLUCAT(15)

Sea ice thickness difference at y2007m03

CREG4 reanalysis

Date: y2007m03

Sea ice thickness difference at y2007m03

Free run

Date: y2007m03
Various sensitivity tests to identify a relevant tuning giving appropriate spread

- 6 months Ensemble simulations (26 members) using Global ¼° (NEMO3.6/LIM3)
  - Start from ensemble spinup (4months)
  - Forcing pert. + stochastic pert. on (P*, drag ocean-ice, drag ice-atm, albedo, ocean parameters,...)

- 14 months Ensemble simulations (30 members) using CREG4 (NEMO3.6/LIM3)
  - Start from climatology in oct.2006
  - Forcing pert. + stochastic pert. on (P*, drag ocean-ice, drag ice-atm, albedo, ocean parameters,...)

- 12 months Ensemble simulations (256 members) using CREG4 (NEMO3.6/LIM3)
  - Start from climatology in oct.2006
  - Forcing pert. + stochastic pert. on (P*, drag ocean-ice, drag ice-atm, albedo, ocean parameters,...)
Toward an Ensemble approach for the background error
Free Ensemble simulations using stochastic perturbations

6 months Ensemble simulations (26 members) using Global ¼° (NEMO3.6/LIM3)

Sea Ice Concentration, February, 2012 (after 4 months)

Observation - Ensemble Mean

Ensemble Spread
Toward an Ensemble approach for the background error
Free Ensemble simulations using stochastic perturbations

6 months Ensemble simulations (26 members) using Global ¼° (NEMO3.6/LIM3)

Sea Ice Concentration, February, 2012 (after 4 months)

Observation - Ensemble Mean
Observation Rank
Ensemble Spread
Toward an Ensemble approach for the background error
Free Ensemble simulations using stochastic perturbations

14 months Ensemble simulations (30 members) using CREG4 (NEMO3.6/LIM3)

Sea Ice Thickness, March-April, 2007 (after 6 months)

Observation - Ensemble Mean
Observation (Ice sat)
Ensemble Spread

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Toward an Ensemble approach for the background error
Free Ensemble simulations using stochastic perturbations

14 months Ensemble simulations (30 members) using CREG4 (NEMO3.6/LIM3)

Sea Ice Thickness, March-April, 2007 (after 6 months)

Percentile 25% of the ensemble  
Observation (Ice sat)  
Percentile 75% of the Ensemble

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Toward an Ensemble approach for the background error
Sea-ice statistics (CREG4 - 256 members)

Conc vs Conc

Vol correlation

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Toward an Ensemble approach for the background error
Sea-ice statistics (CREG4 - 256 members)

Conc vs Conc | Vol correlation

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Summary and Plans

➢ The Univariate Sea Ice Analysis in the Mercator operational applications is able to well represent the SIC but fails to constraint the volume.

➢ A multivariate Sea Ice Analysis is in development for the future Mercator operational system. Different sea ice state vector are and will be explored depending of the assimilated observations.

➢ A background error based on Ensemble modelling is probably necessary to well extrapolate the information. An Ensemble Kalman filter is in preparation and will be tested on the CREG4 system in 2018.
Thank You!!