ERA-CLIM2 Project
Mercator Ocean Contributions to WP2.2

Task 2.2 : Development of assimilation techniques

Mercator Ocean
Ocean Forecasters

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…

Mercator Activities in the ERA-CLIM2 Project
Contribution to the development of assimilation techniques

WP2 task2.2 : Development of assimilation techniques for improved use of surface observations

MO Sub task : Assimilation of Sea Ice Concentration

Objective: to improve coupled ocean/sea-ice data assimilation.
Developing and testing a scheme that transforms sea-ice concentration to a Gaussian variable during the assimilation process.

Deliverable D2.2 (t0+27+12):
Results from a study
Documented code and library.

Mercator activities in the ERA-CLIM2 Project
General Work Plan for WP2 task2.2

1 - Production of reference reanalysis without the use of Gaussian transformation in the sea ice analysis

→Development of a multivariate sea ice analysis vs univariate sea ice analysis (used in operational)

⇒ **Well posed to demonstrate the interest of the Gaussian transformation due to the presence of wrong extrapolation**

→Use the Arctic-Northern Atlantic Configuration at 1/4°(75lev,CREG4/NEMO3.6/LIM3) coupled with the Mercator Assimilation System (SAM2) and the multivariate/univariate sea ice analysis.

⇒ **a low-cost and recent model configuration centred on the Arctic Sea is more efficient for this study**...
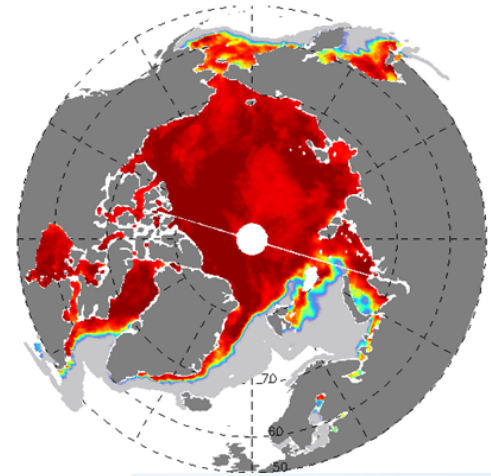
We have realized various multi-years reanalysis using different tuning for the state vector and we have identified a first robust set up for a multivariate sea ice analysis.

Multivariate Sea Ice Reanalysis
Main characteristics

Sea Ice Concentration (OSI-SAF)

Model
- **Nemo 3.6, LIM3/Multi-categories(1:15)**
- **CREG ¼, 75 levels**

Assimilation

- **Analysis based on a 2D local multivariate SEEK/LETKF filter**

- **Weakly-coupled DA system using 2 separate analyses :**

- **Ocean Analysis (SLA, InSitu Data from CORA3.2, SST) , IAU on (h,T,S,U,V)**

- **Sea Ice Analysis**

    - 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 Model anomalies

- **Unidata/Multivariate Sea Ice analysis**

    - **CREG4 reanalysis using multivariate state vector [SIC, SICONCAT(1:15), SIVOLUCAT(1:15)]**

Multivariate Sea Ice Reanalysis
CREG4 reanalysis assimilating OSI-SAF SIC Observations

Mercator Ocean — Ocean Forecasters

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 Concentration RMS misfits to OSISAF
- Free run
- Forecast
- Analysis

Sea Ice Concentration misfits average to OSISAF
- Free run
- Forecast
- Analysis
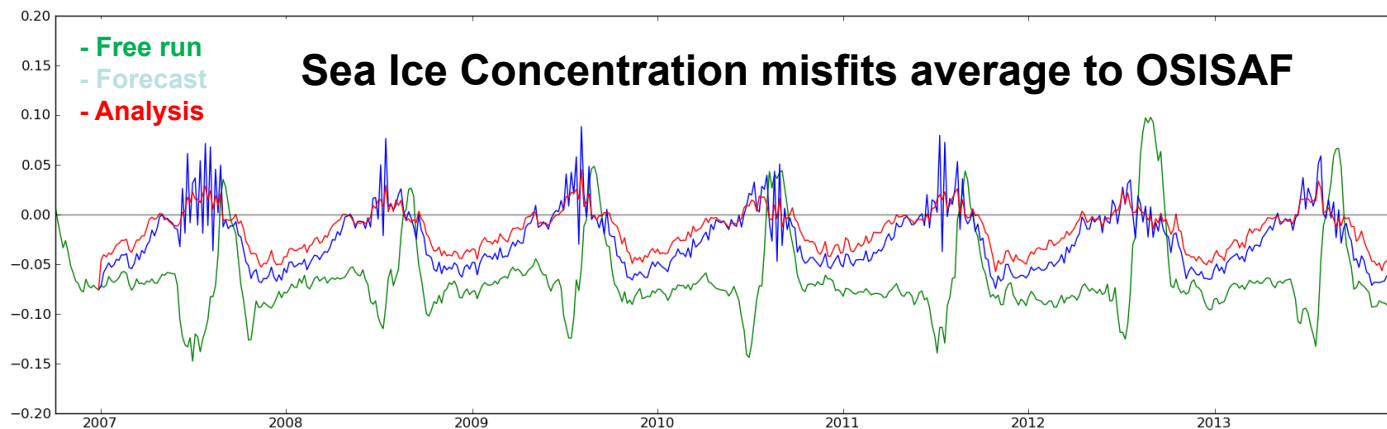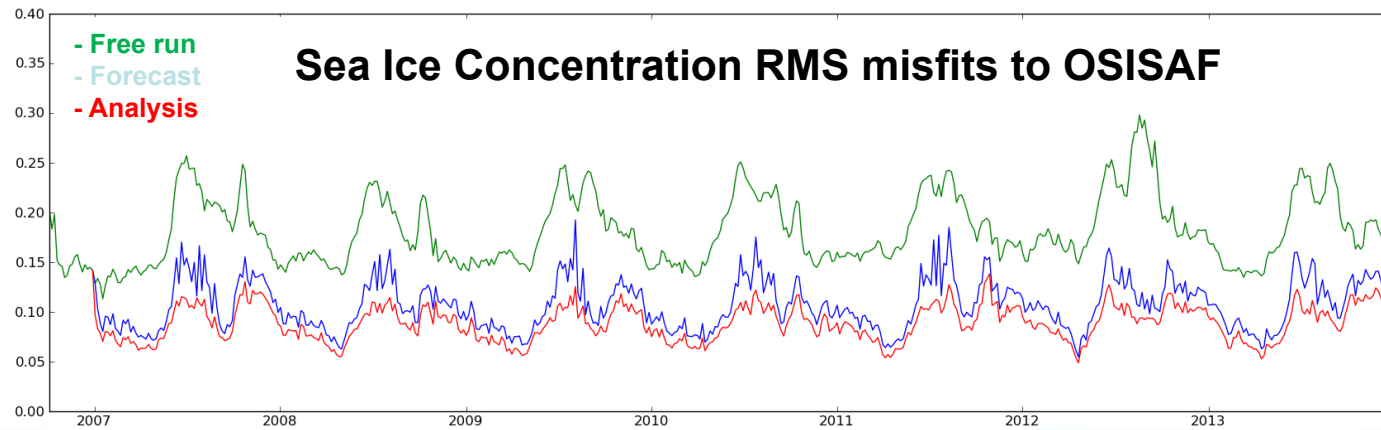
Multivariate Sea Ice Reanalysis
CREG4 reanalysis assimilating OSI-SAF SIC Observations

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
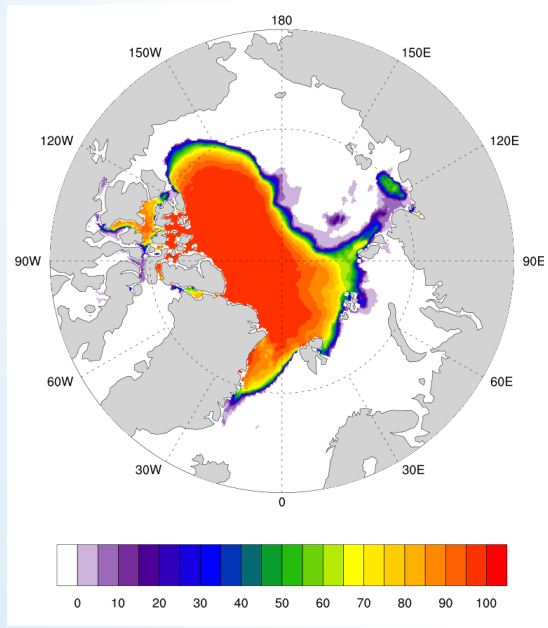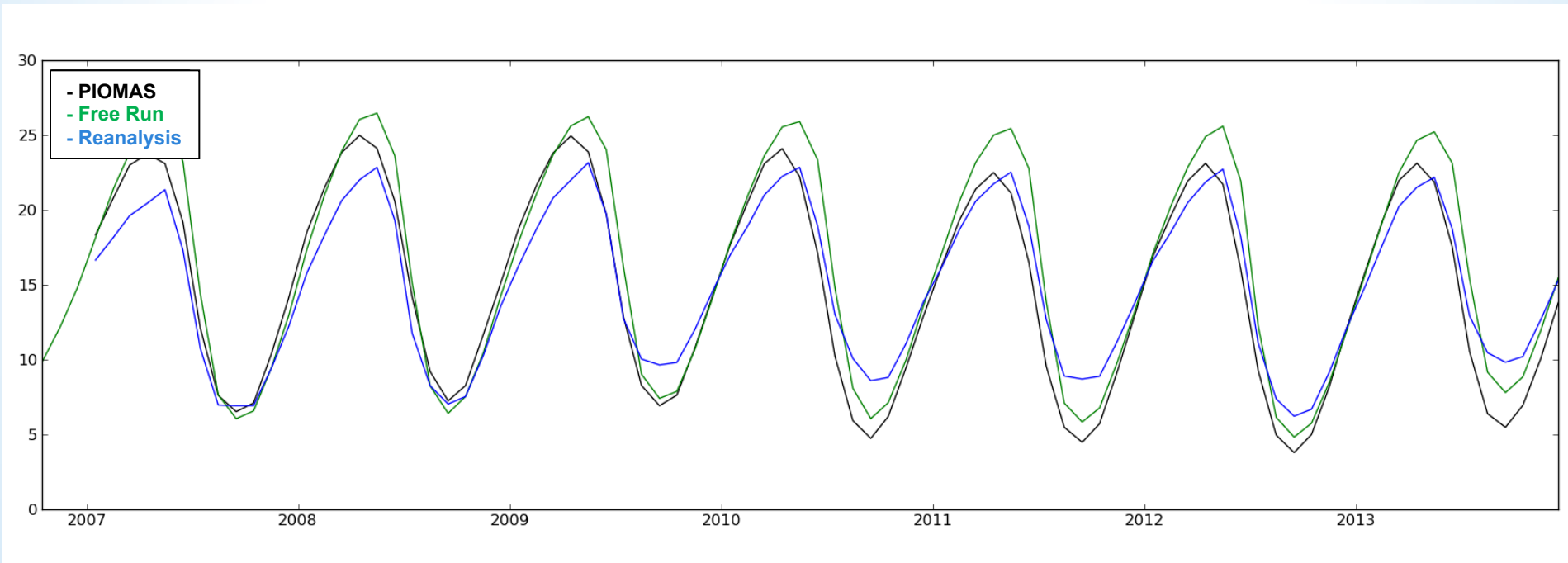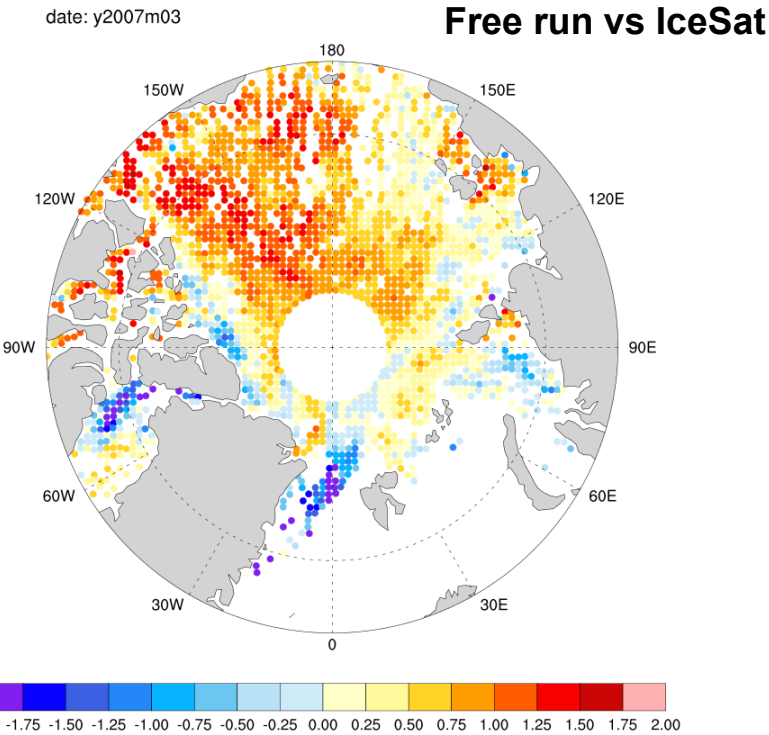
CREG4 free run
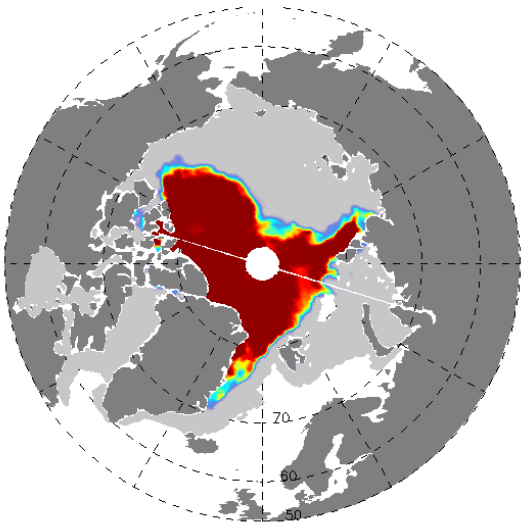
OSI-SAF
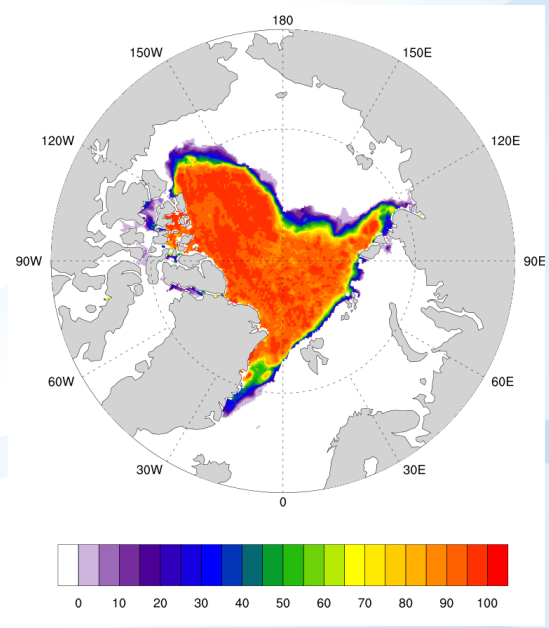
CREG4 reanalysis

Multivariate Sea Ice Reanalysis
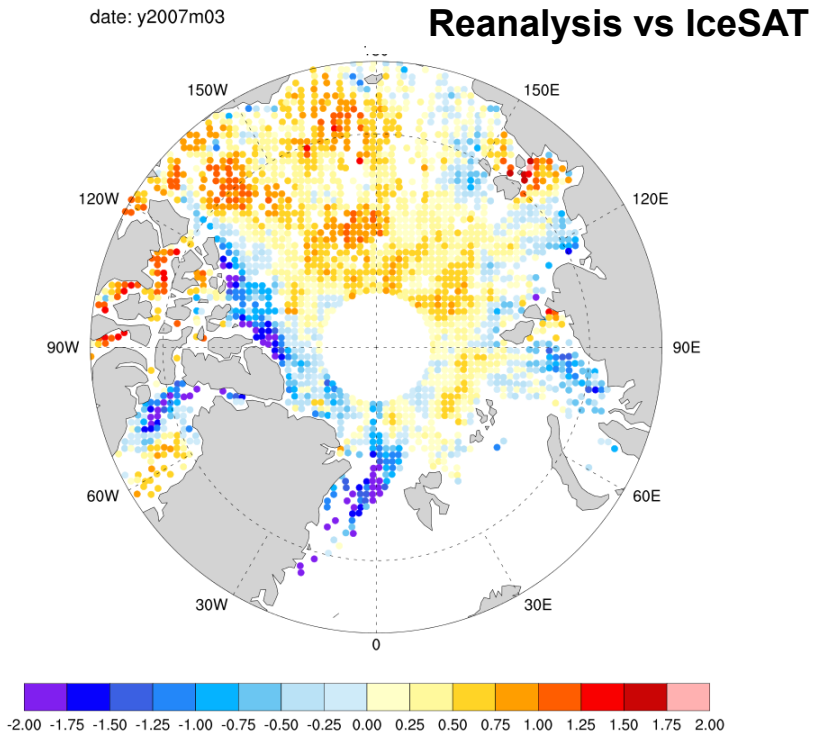## CREG4 reanalysis assimilating OSI-SAF SIC Observations

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)

Multivariate Sea Ice Reanalysis
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 thickness difference at y2007m03 — Free run vs IceSat

Sea ice thickness difference at y2007m03 — Reanalysis vs IceSAT

Mercator activities in the ERA-CLIM2 Project
General Work Plan for WP2 task2.2

1 - Production of reference reanalysis without the use of Gaussian transformation in the sea ice analysis

→Development of a multivariate sea ice analysis vs univariate sea ice analysis (used in operational)

⇒ **Well posed to demonstrate the interest of the Gaussian transformation due to the presence of wrong extrapolation**

→Use the Arctic-Northern Atlantic Configuration at 1/4°(75lev,CREG4/NEMO3.6/LIM3) coupled with the Mercator Assimilation System (SAM2) and the multivariate/univariate sea ice analysis.

⇒ **a low-cost and recent model configuration centred on the Arctic Sea ismore efficient for this study**…

We have realized various multi-years reanalysis using different tuning for the state vector and we have identified a first robust set up for a multivariate sea ice analysis.

2 - Investigate the role of the Gaussian anamorphic transformation on the sea-ice data assimilation problem

→ Idealized exercises with ensemble background error in order to evaluate the efficiency of sea-ice analysis

→ realistic test case with the CREG4/NEMO3.6/LIM3 model using 256 members

⇒ **1D multivariate (SIC,VOL) sea ice analyses assimilating SIC only provided by a nature run**

The Gaussian Anamorphosis approach

Anamorphic Transformation based on

2006-2013 CREG4 Free simulation model states

SIC   SIC percentiles   Anamorphic SIC

SIC Percentile map

Min (-3)

Median (0)

Max (+3)
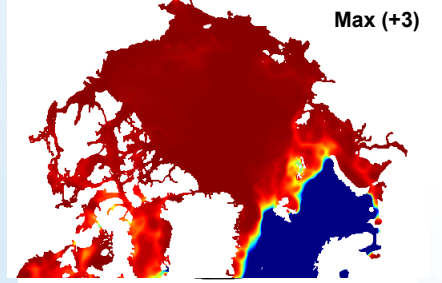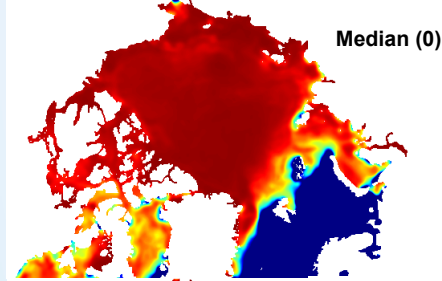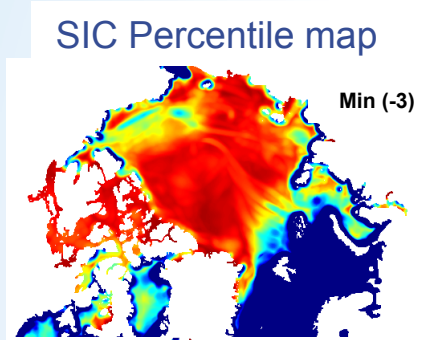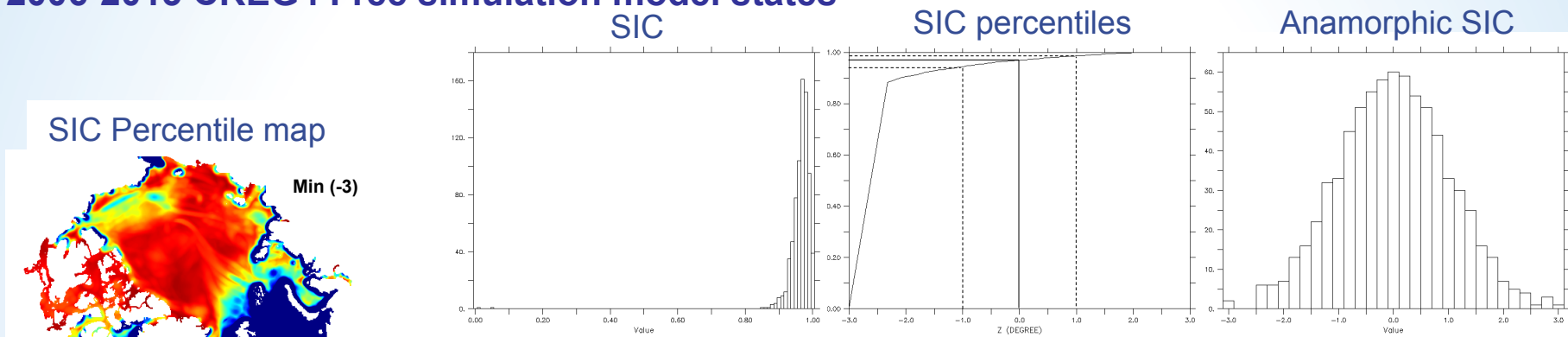
We build local (space and time) transformation for each variable of the state vector (SIC, SIVOLU, SICONCAT(1:15), SIVOLUCAT((1:15))

SIC (20070105)
physical space

=>

SIC (20070105)
anamorphic space

0.9   1.0

0.   1.0

-3   +3
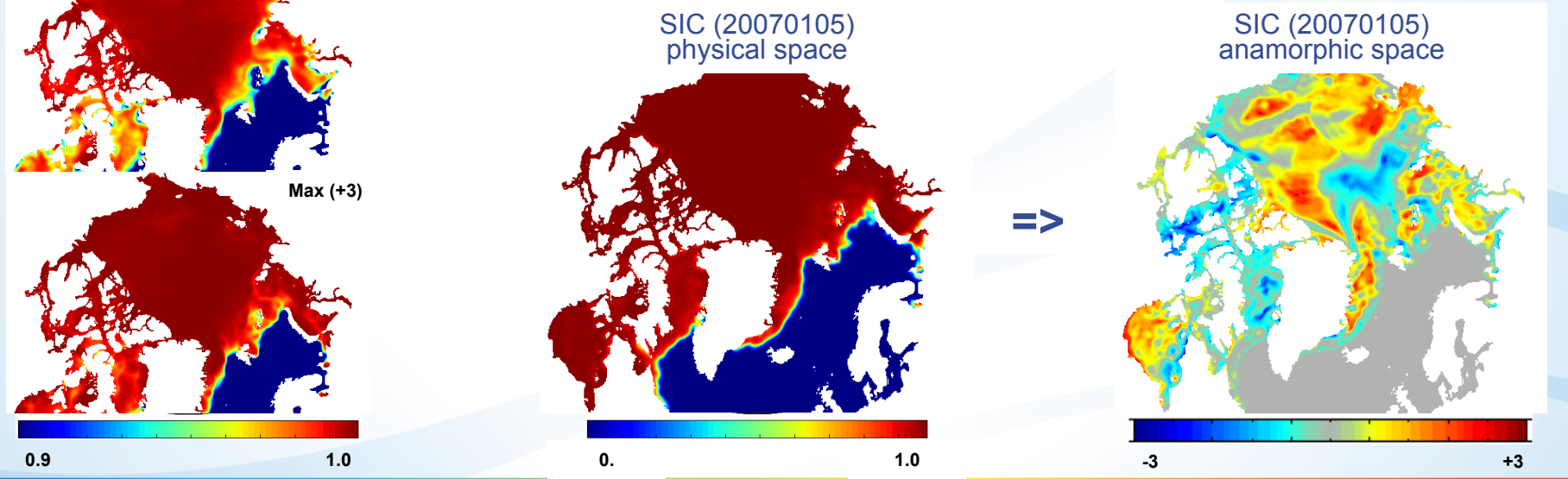
Bayesian Data Assimilation aims to find the probability of the system state x given observations y of the system using the Baye's theorem:

$$p(x|y) = p(y|x) \cdot p(x)$$

y|x N(0.5, 0.04) and E[x] = 0.5 and Var [x] = 0.12
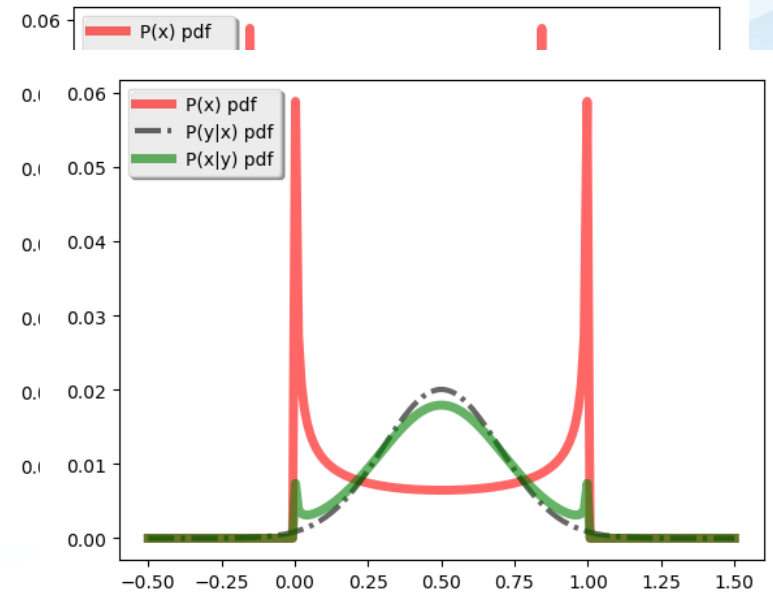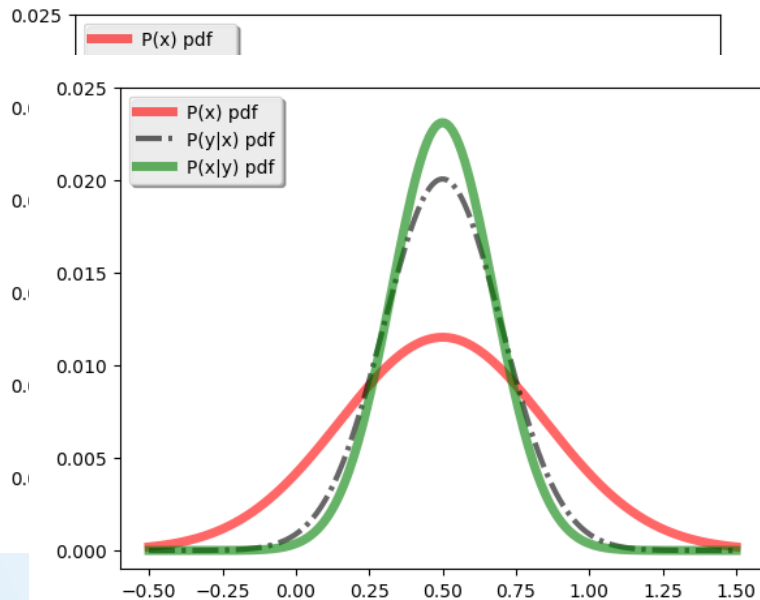
Build idealized exercices comparing EnKF solution to the Bayesian solution
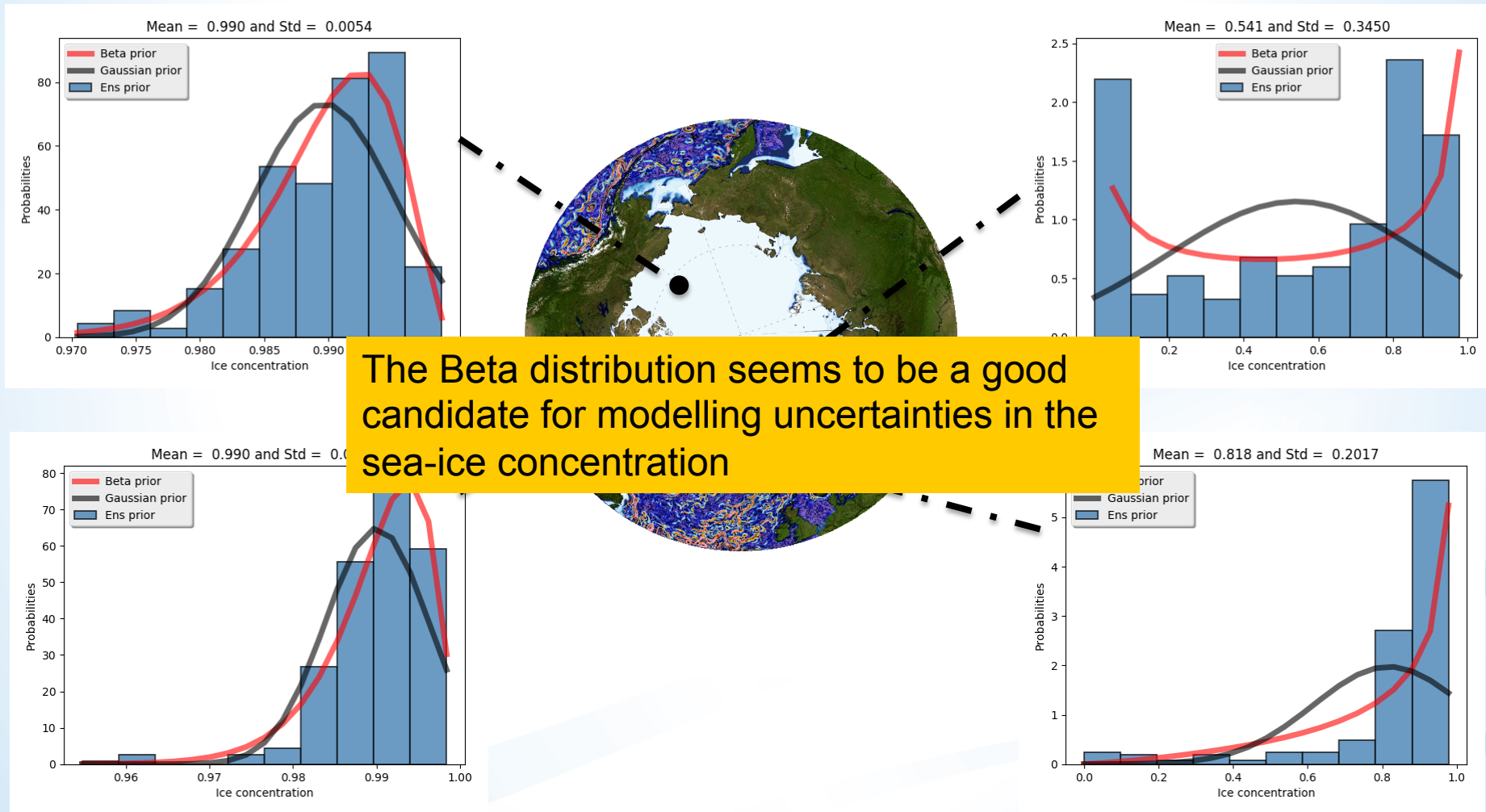
Realistic test case with CREG4/NEMO3.6/LIM3
Sea-ice concentration prior distribution

Each member generates
4 new members

64 member
Init. Clim.

2006/10/04   2007/02/21   2007/06/30
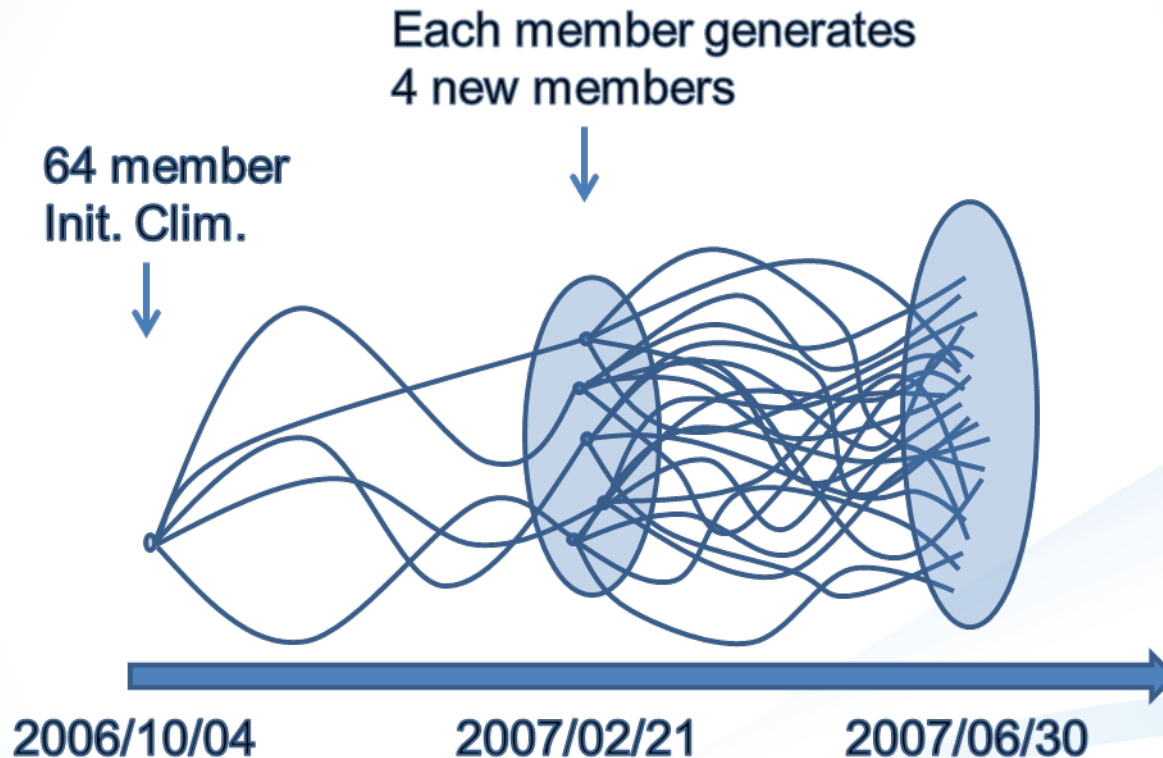
A 256-members CREG4/NEMO3.6/LIM3 has been performed using perturbed rheology parameters and perturbed atmospheric fields and validated against distributions obtained using satellite observations.

256 members test case with CREG4/NEMO3.6/LIM3
Sea-ice concentration prior distribution

The Beta distribution seems to be a good candidate for modelling uncertainties in the sea-ice concentration

Data assimilation with a Beta distributed Prior

- **How does the EnKF solution compares to the Bayesian solution?**
- **Can Gaussian anamorphosis help to partially restore bayesianity?**

$$CRPS = \sum_{i=1}^{nbins} (cdf^B - cdf^F)^2$$

Analysis using Pf (beta Xf,ns=1024)

CRPS(Xa)=0.021

ERA-CLIM2 General Assembly, December 12-15, 2017, Bern, Swiss
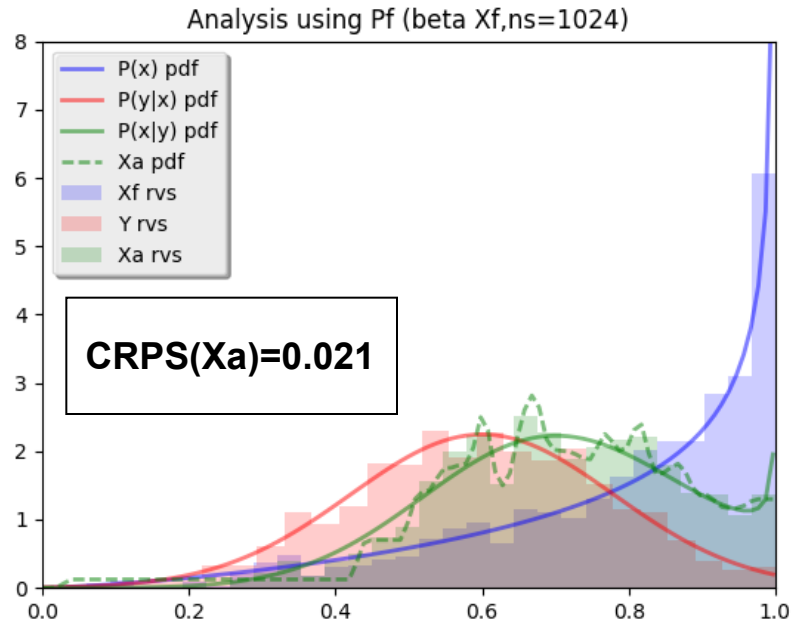
Idealized exercises

Data assimilation with a Beta distributed Prior

- **How does the EnKF solution compares to the Bayesian solution?**
- **Can Gaussian anamorphosis help to partially restore bayesianity?**

Etkf — Analysis using ETKf (beta Xf,ns=1024)
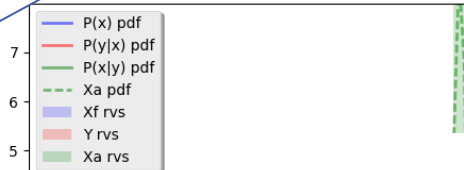
CRPS(Xa)=0.451

Enkf — Analysis using EnKf (beta Xf,ns=1024)

CRPS(Xa)=0.282

Enkf Tx — Analysis using EnKf_Tx (beta Xf,n...)
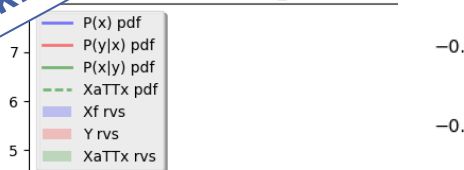
CRPS(Xa)=0.072
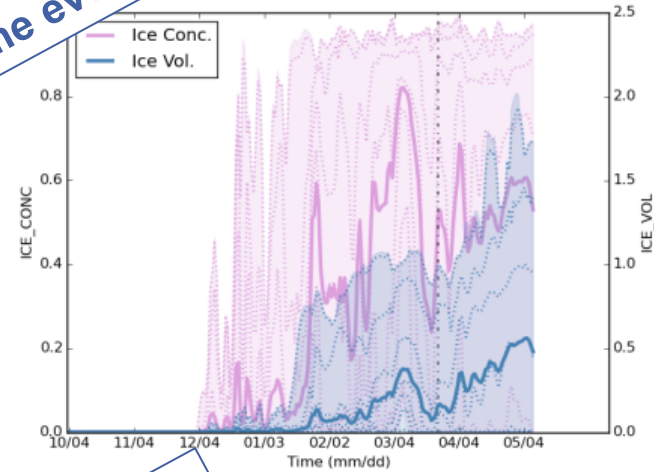
Analysis using Pf (beta Xf,ns=1024)

CRPS(Xa)=0.021

Mean-Meanref (beta Xf)
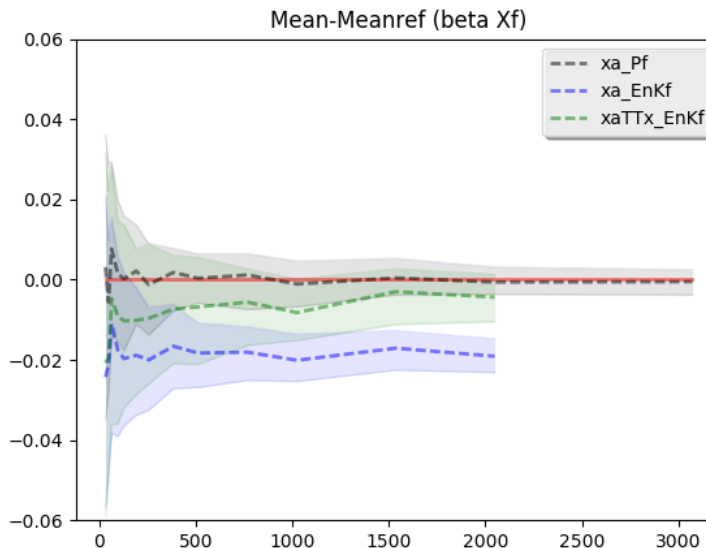
Realistic test case CREG4/NEMO3.6/LIM3
Concentration and Volume (256 members)

Prior
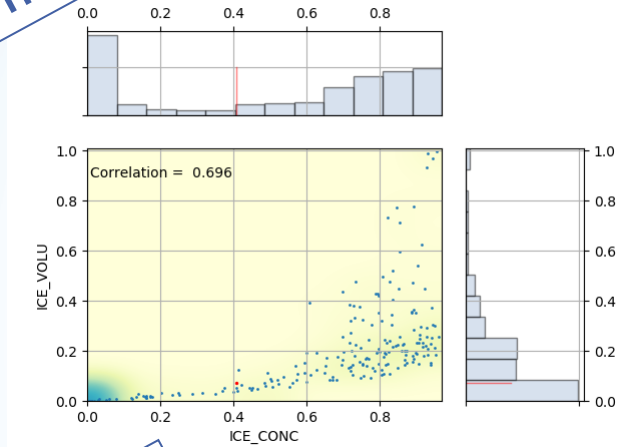
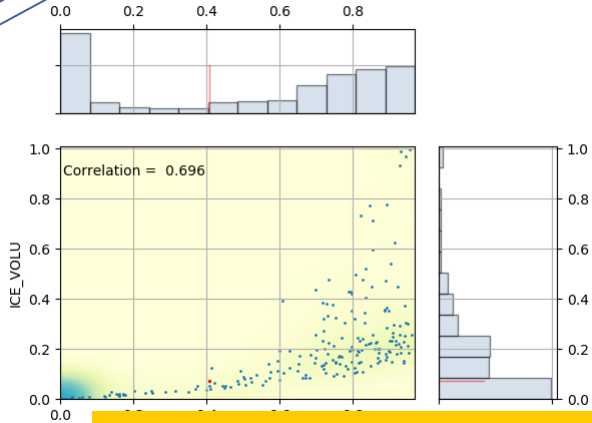Time evolution

Concentration Correlation

Volume Correlation

ERA-CLIM2 General Assembly, December 12-15, 2017, Bern, Swiss
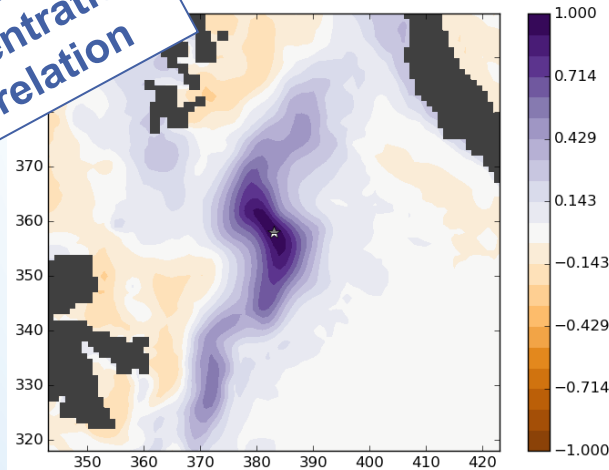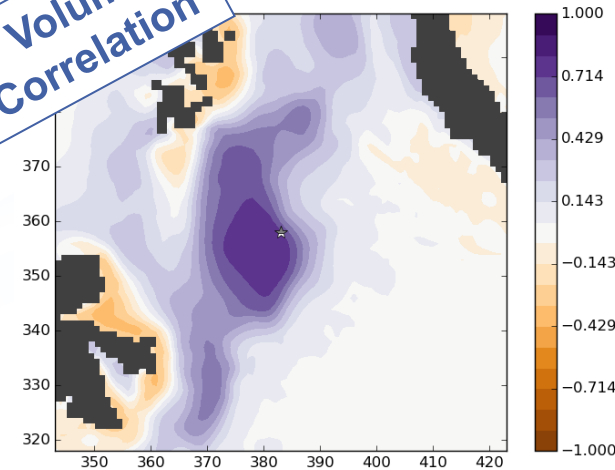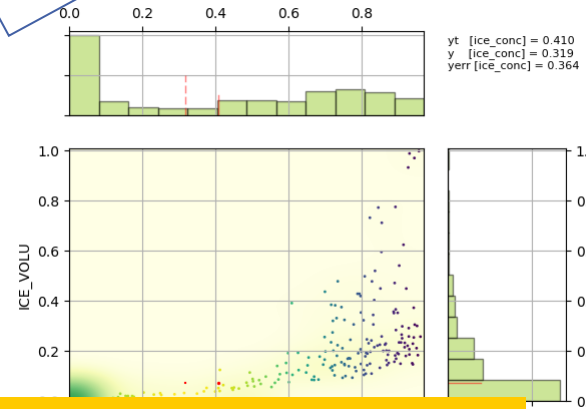
Realistic test case CREG4/NEMO3.6/LIM3

Bi-variate Concentration and Volume (256 members)

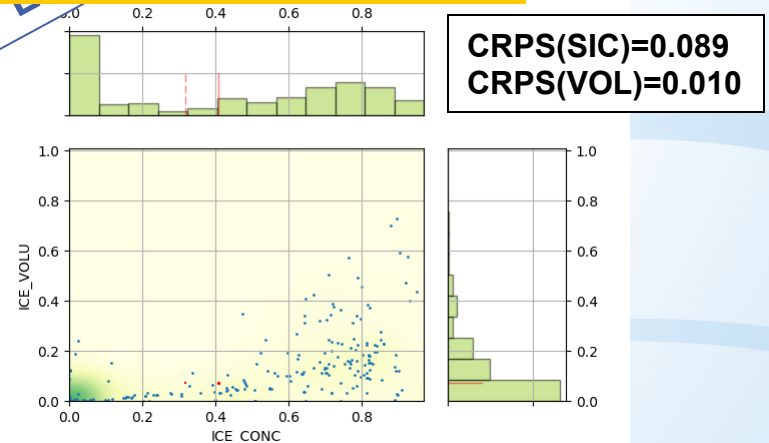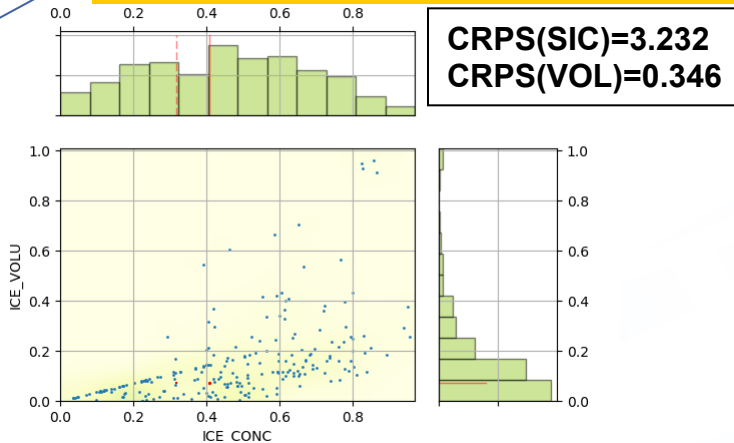**1D multivariate sea ice analysis assimilating SIC only provided by a nature run**

Gaussian anamorphosis improves the posterior distribution in particular in the sea ice extent

CRPS(SIC)=3.232
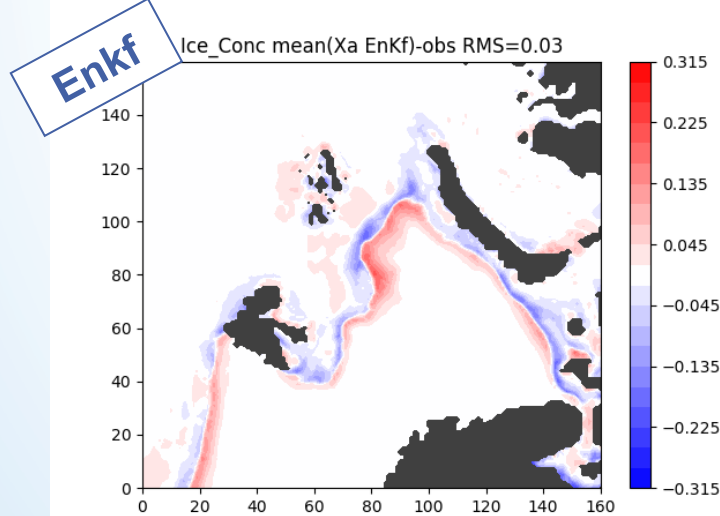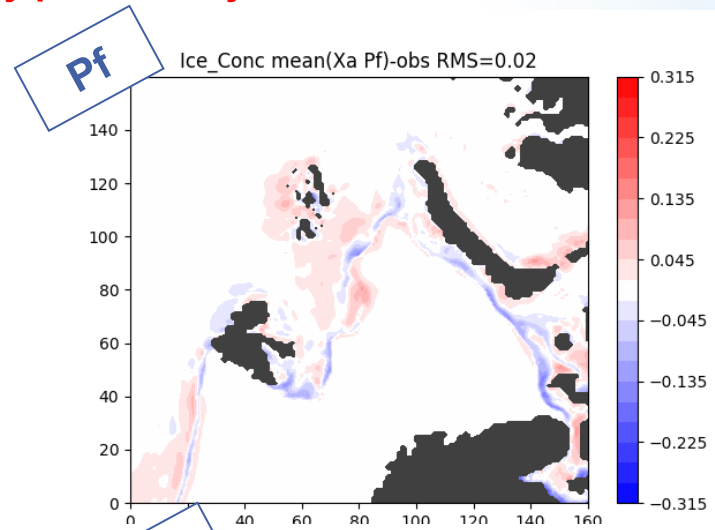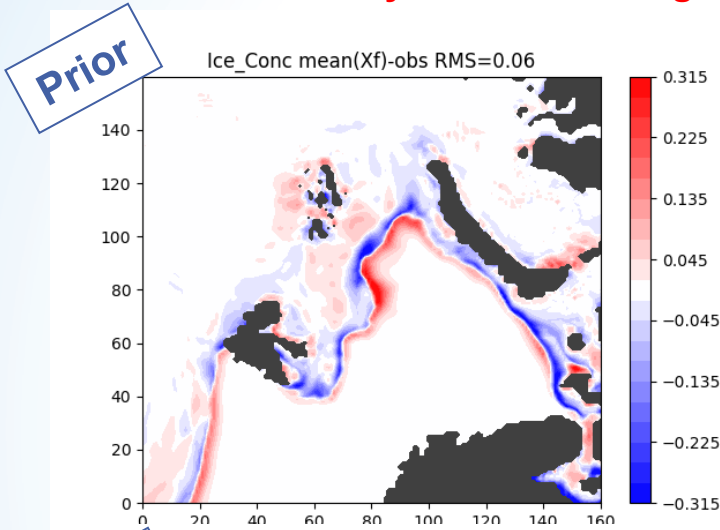CRPS(VOL)=0.346

CRPS(SIC)=0.089
CRPS(VOL)=0.010

Realistic test case CREG4/NEMO3.6/LIM3

Misfit of sample mean to nature run

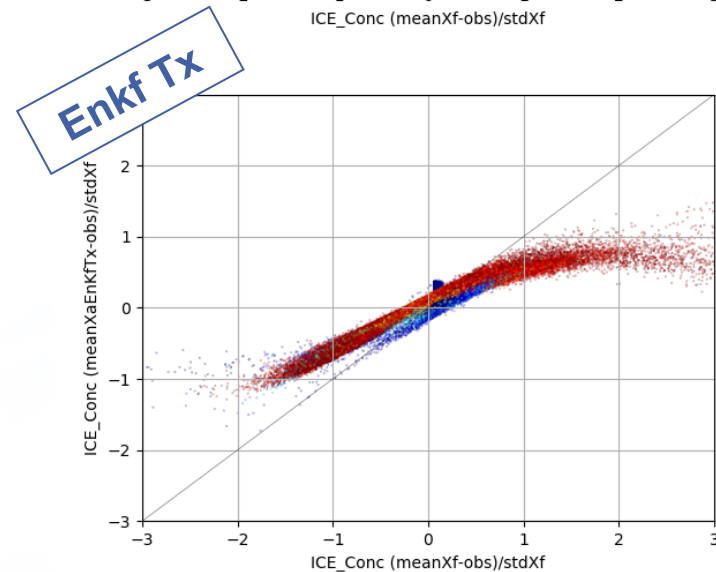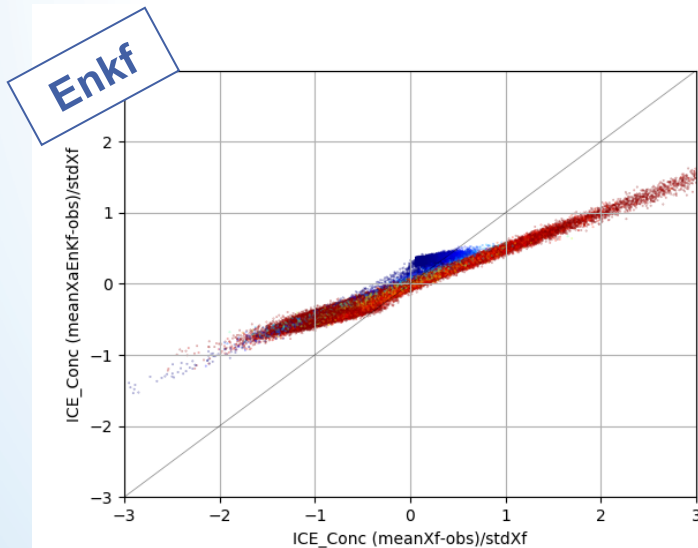**1D multivariate sea ice analyses assimilating SIC only provided by a nature run**

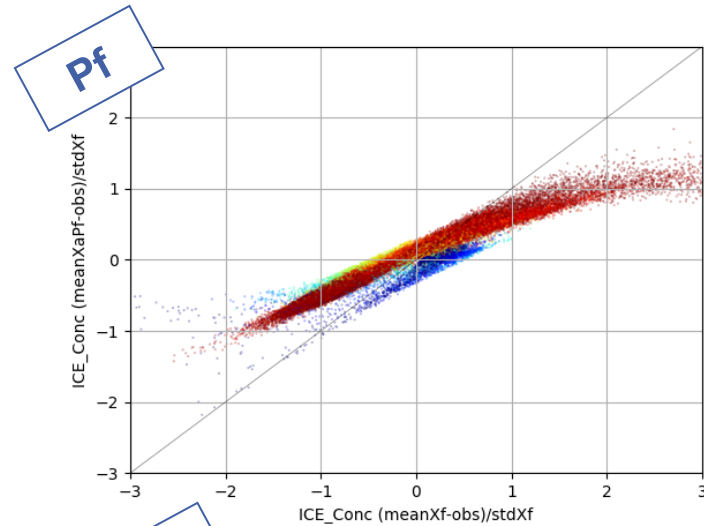ERA-CLIM2 General Assembly, December 12-15, 2017, Bern, Swiss
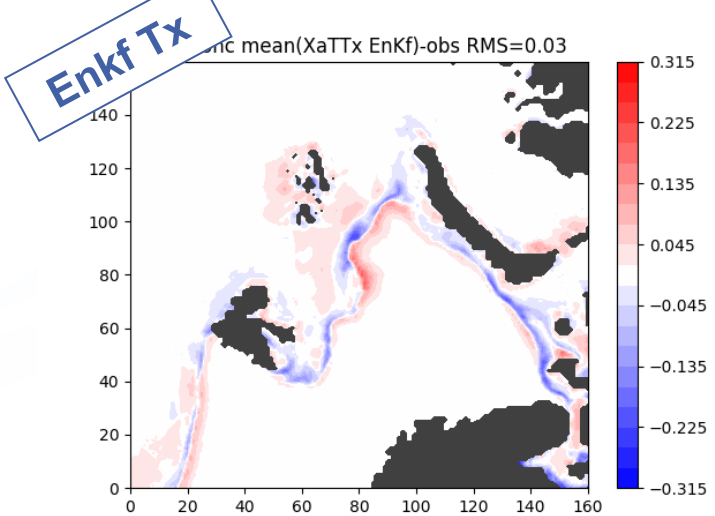
Realistic test case CREG4/NEMO3.6/LIM3
Reduced misfit of sample mean to nature run
Posterior vs Prior

**Sea Ice Concentration
for all the domain**

Blue : low values of SIC
Red : High values of SIC

Conclusions

- Sea-ice concentration priors are strongly non-Gaussian;

- Using very simple examples it was possible to demonstrate the benefit of using Gaussian Anamorphosis in the assimilation of sea-ice concentration
- In particular, Gaussian Anamorphosis seems to improve reliability and the representation of the posterior pdf;

- In a more realistic framework bias is an important component of the DA system, then observations tend to be outside the ensemble pack limiting the analysis correction;
- in addition the estimation of the observation error in the anamorphic space is not straitghtforward and could deteriorate the efficiency in case of wrong estimation.

- this study provides preliminary encouraging results but this work must be continued before an implementation in an operational system. In particular, tests of this method on a 3D analysis tools have not been done.