Assimilation of CryoSat-2 radar Freeboard data in a global ocean-sea-ice modelling system

Aliette Chenal[1,3], Charles-Emmanuel Testut[1], Florent Garnier[2], Gilles Garric[1], and Laurent Parent[1]

[1] Mercator Ocean International, Toulouse, France

[2] Legos, Toulouse, France

[3] CNES, Toulouse, France

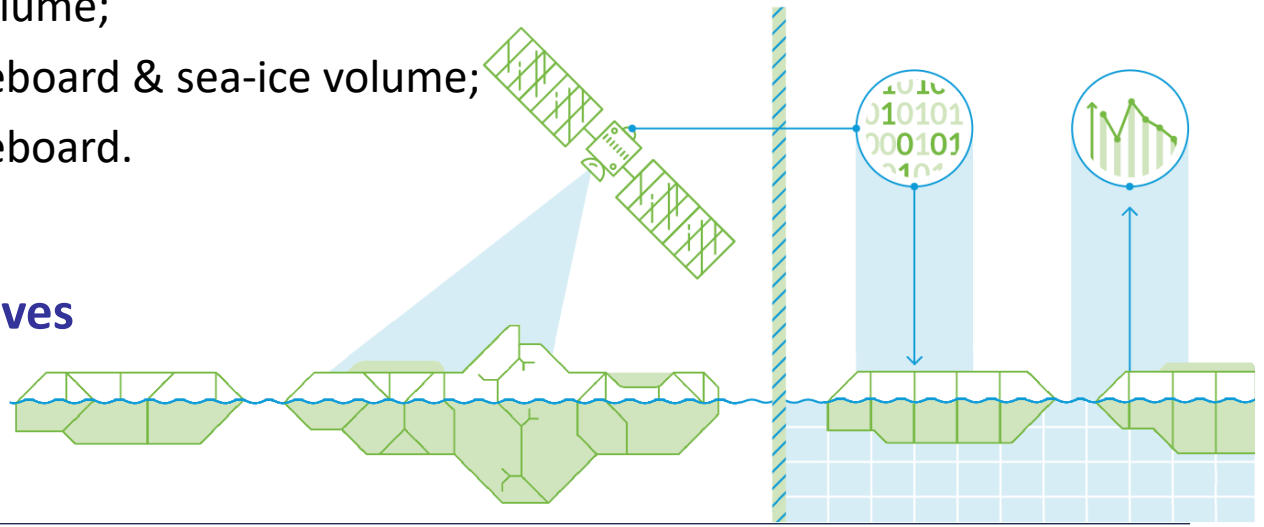
Table of contents

➢ Objectives

Development of a multidata/multivariate sea-ice analysis (operational purposes).

➢ Assimilation of CryoSat-2 Radar Freeboard products :

- **Method 1** : Sea-ice volume;
- **Method 2** : Radar freeboard & sea-ice volume;
- **Method 3** : Radar freeboard.



➢ Summary and perspectives

Objectives

Model

Ocean: Nemo 3.6	Sea-ice: LIM3/Multi-categories	Global ¼° grid	ERA5 atmospheric forcing (1h)

Assimilation (Kalman filter)

- Analysis based on a 2D local multivariate Singular Evolutive Extended Kalman Filter (SEEK)
- 7-days cycle ;
- 2 separate analyses :

1. Ocean Analysis

● Sea level anomaly, sea surface temperature, in situ data.

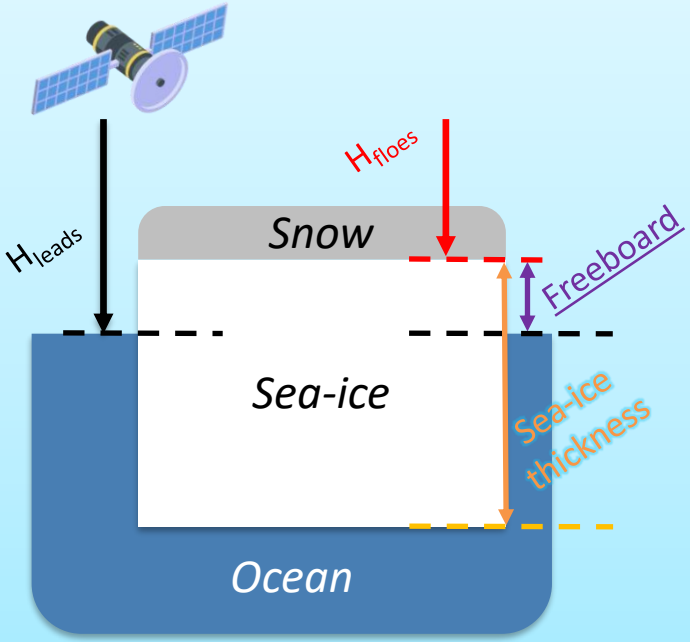
2. Sea Ice Analysis

● Assimilation of sea-ice concentration from the OSISAF products (Ocean and Sea Ice Satellite Application Facility)

● **Objective:** add a **constraint on the SEA-ICE VOLUME**

NEW!

Satellite measurement : **Radar Freeboard** from CryoSat-2 (Laforge et al. 2020).



Freeboard = a · H_{ice} + b · H_{snow}

(a and b depending on the water, sea-ice and snow densities).

Objectives

Model

Ocean: Nemo 3.6	Sea-ice: LIM3/Multi-categories	Global ¼° grid	ERA5 atmospheric forcing (1h)

Assimilation (Kalman filter)

- Analysis based on a 2D local multivariate Singular Evolutive Extended Kalman Filter (SEEK)
- 7-days cycle ;
- 2 separate analyses :

1. Ocean Analysis

● Sea level anomaly, sea surface temperature, in situ data.

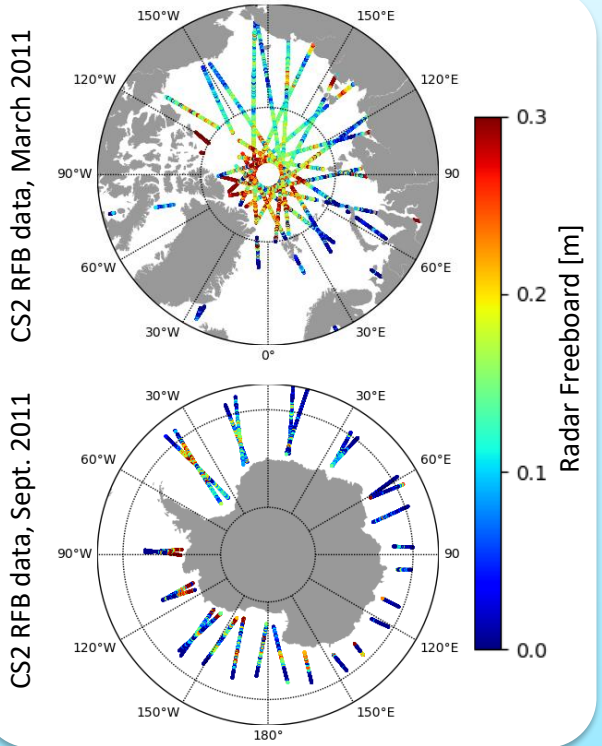
2. Sea Ice Analysis

● Assimilation of sea-ice concentration from the OSISAF products (Ocean and Sea Ice Satellite Application Facility)

● **Objective:** add a **constraint on the SEA-ICE VOLUME**

NEW!

Satellite measurement : **Radar Freeboard** from CryoSat-2 (Laforge et al. 2020).



METHODS : Assimilation of radar freeboard

METHOD 1

Multidata :

- Assimilation of sea-ice concentration
- **Assimilation of SEA-ICE VOLUME**

build from along-track CryoSat-2 Radar FreeBoard & OSISAF sea-ice concentration & Warren99 climatology snow data.

Multivariate analysis :

- Multivariate state vector :

$$\left[\begin{array}{c} sea-ice \\ concentration \end{array} ; \begin{array}{c} sea-ice \\ volume \end{array}\right]$$

METHOD 2

Multidata :

- Assimilation of sea-ice concentration
- **Assimilation of RADAR FREEBOARD VOLUME & SEA-ICE VOLUME**

build from along-track CryoSat-2 Radar FreeBoard & OSISAF sea-ice concentration data.

Multivariate analysis :

- Sea Ice assimilation experiment using multivariate state vector

$$\left[\begin{array}{c} sea-ice \\ concentration \end{array} ; \begin{array}{c} freeboard \\ radar\ volume \end{array} ; \begin{array}{c} sea-ice \\ volume \end{array} ; \begin{array}{c} snow \\ volume \end{array}\right]$$

METHOD 3

Multidata :

- Assimilation of sea-ice concentration
- **Assimilation of RADAR FREEBOARD VOLUME**

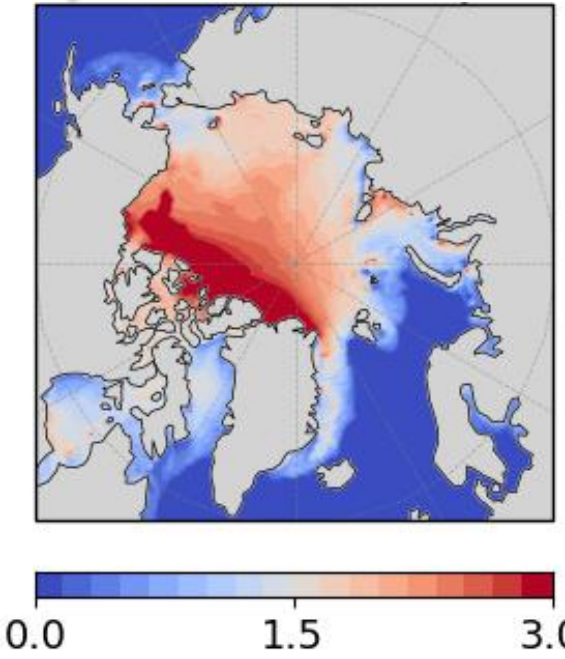
build from along-track CryoSat-2 Radar FreeBoard & OSISAF sea-ice concentration data.

METHOD 1 : Assimilation of sea-ice volume

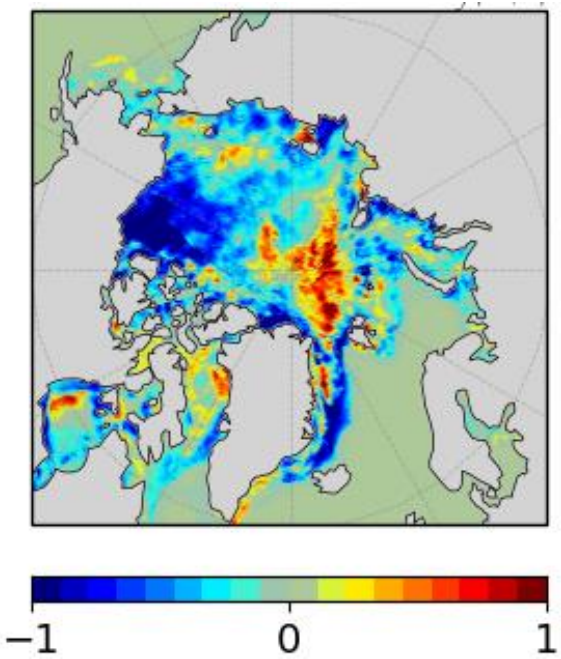
RESULTS

Sea Ice Volume [m]

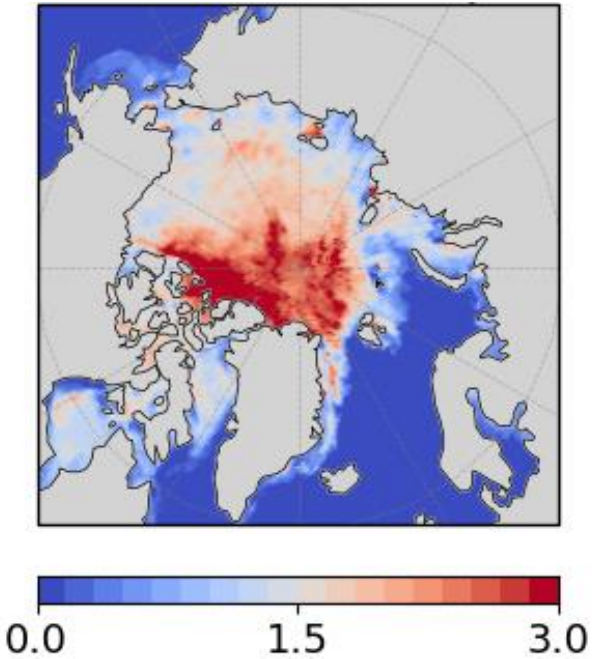
7-day cycle (March) after 3 months of simulation (Jan -> March 2011)



Run without assimilation



Impact of the assimilation
(difference left – right)



Run with assimilation (sea-ice concentration & volume)

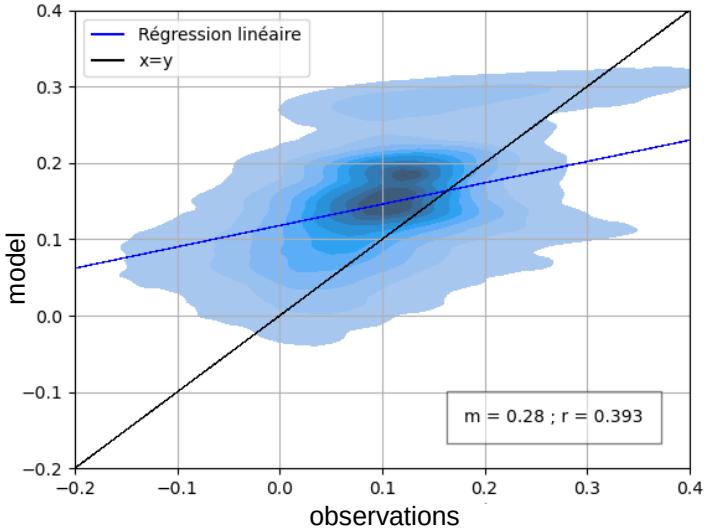
METHOD 1 : Assimilation of sea-ice volume

RESULTS

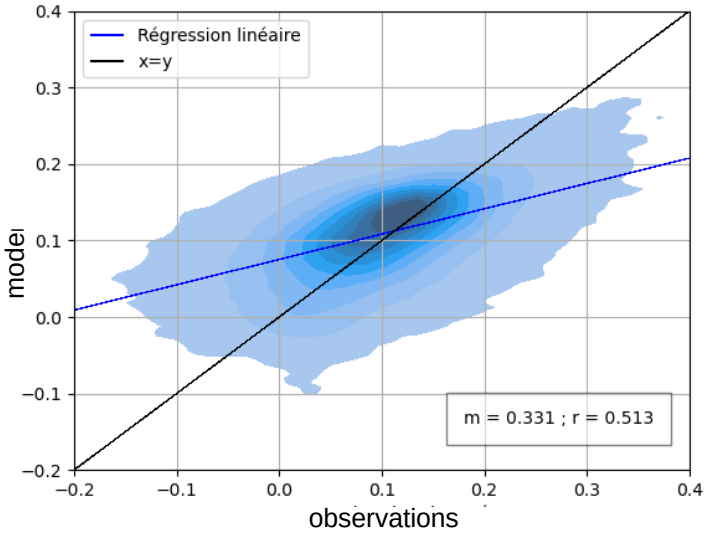
Comparison with assimilated dataset :

CryoSat-2 Radar Freeboard [m]

Without assimilation



With assimilation



METHODS : Assimilation of radar freeboard

METHOD 1

Multidata :

- Assimilation of sea-ice concentration
- **Assimilation of SEA-ICE VOLUME**

build from along-track CryoSat-2 Radar FreeBoard & OSISAF sea-ice concentration & Warren99 climatology snow data.

Multivariate analysis :

- Multivariate state vector :

$$\left[\begin{array}{c} sea-ice \\ concentration \end{array} ; \begin{array}{c} sea-ice \\ volume \end{array}\right]$$

METHOD 2

Multidata :

- Assimilation of sea-ice concentration
- **Assimilation of RADAR FREEBOARD VOLUME & SEA-ICE VOLUME**

build from along-track CryoSat-2 Radar FreeBoard & OSISAF sea-ice concentration data.

Multivariate analysis :

- Sea Ice assimilation experiment using multivariate state vector

$$\left[\begin{array}{c} sea-ice \\ concentration \end{array} ; \begin{array}{c} freeboard \\ radar\ volume \end{array} ; \begin{array}{c} sea-ice \\ volume \end{array} ; \begin{array}{c} snow \\ volume \end{array}\right]$$

METHOD 3

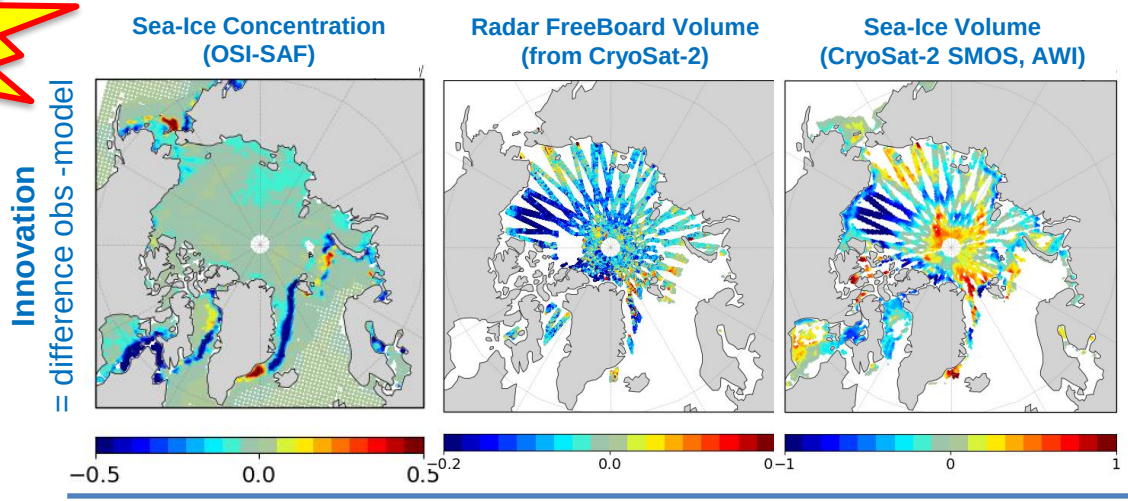
Multidata :

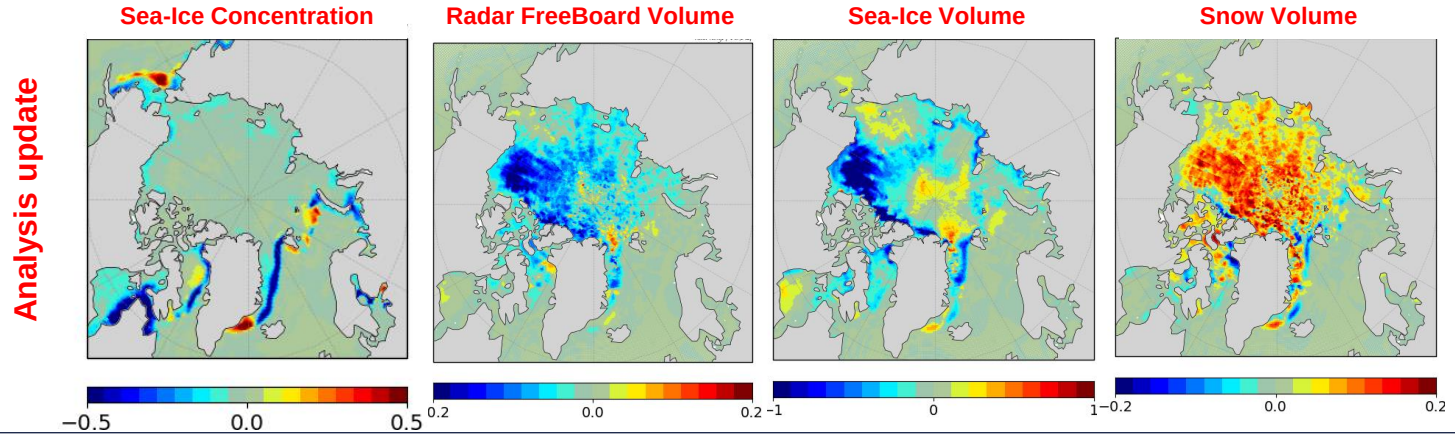
- Assimilation of sea-ice concentration
- **Assimilation of RADAR FREEBOARD VOLUME**

build from along-track CryoSat-2 Radar FreeBoard & OSISAF sea-ice concentration data.

METHOD 2 : Assimilation of radar freeboard and sea-ice volume

RESULTS





Sea Ice Analysis
7-day Cycle
3-10 jan. 2011

Radar Freeboard =
$a \cdot H_{ice} + b \cdot H_{snow}$

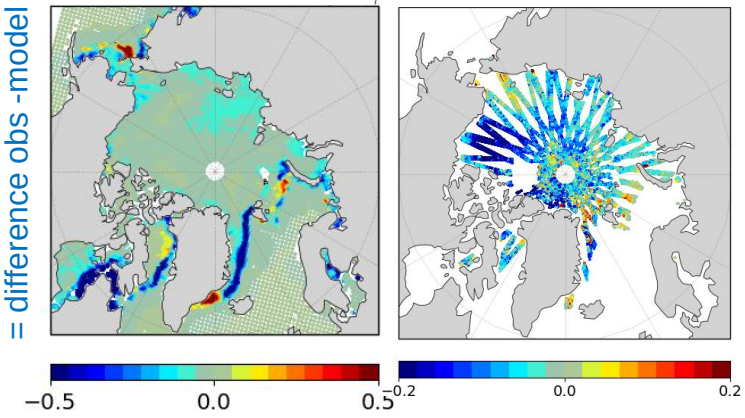
METHOD 3 : Assimilation of radar freeboard

RESULTS

Sea-Ice Concentration (OSI-SAF)

Radar FreeBoard Volume (from CryoSat-2)

Innovation = difference obs -model

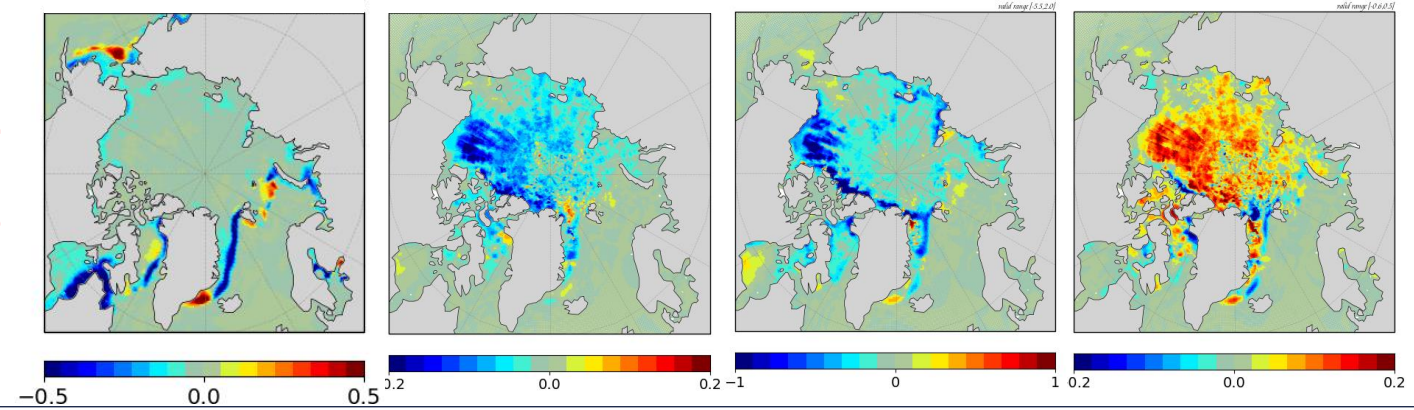


Sea Ice Analysis
7-day Cycle
3-10 jan. 2011

Freeboard Radar =
$a \cdot H_{ice} + b \cdot H_{snow}$

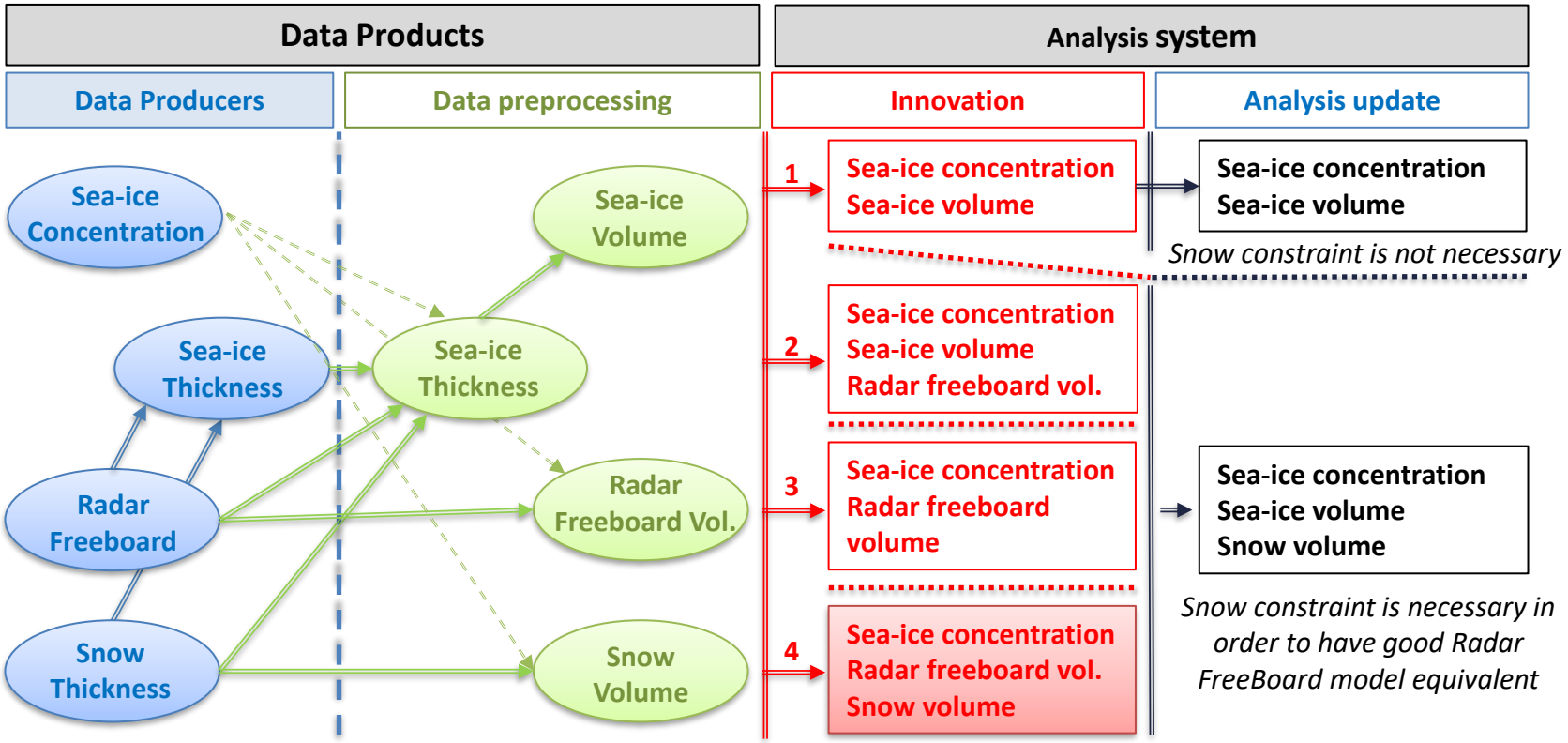
Analysis update

Sea-Ice Concentration | Radar FreeBoard Volume | Sea-Ice Volume | Snow Volume



Summary and perspectives

Various set of data products are possible

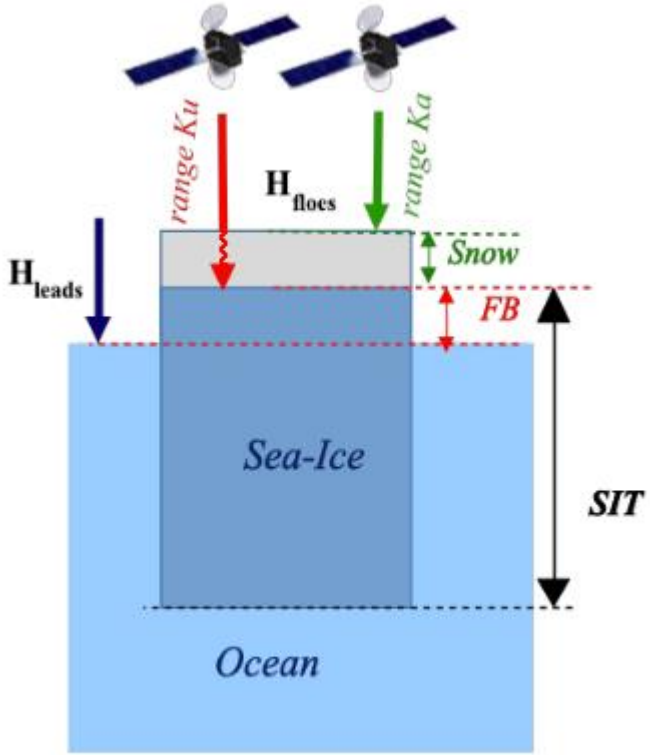


Thank you !

(In case there are questions)

Additional slides

Freeboard Radar definition



$FB_{ice} = H_{ice} - H_{oce}$

$FB_{ice} = h_{ice} .(1 - \rho_{ice}/\rho_{oce}) - h_{snow} . \rho_{snow}/\rho_{oce}$

$FB\ Radar = FB_{ice} - h_{snow} . (c/c_{snow} -1)$

$c_{snow} = c.(1+0.51. \rho_{snow}/1000)^{-1.5}$ (from Ulaby, 1986)

$Radar\ FB = a(\rho_{ice},\rho_{oce},\rho_{snow}).h_{ice} + b.(\rho_{ice},\rho_{oce},\rho_{snow})h_{snow}$

In NEMO3.6, we use

$\rho_{oce} = 1026$ $\rho_{ice}=917$ $\rho_{snow}=330$ (kg/m^3)

=> **$FB\ Radar = 0.106\ h_{ice} - 0.584\ h_{snow}$**

FBRVOLU = FBR.SIC = a.SIVOLU + b.SNVOLU

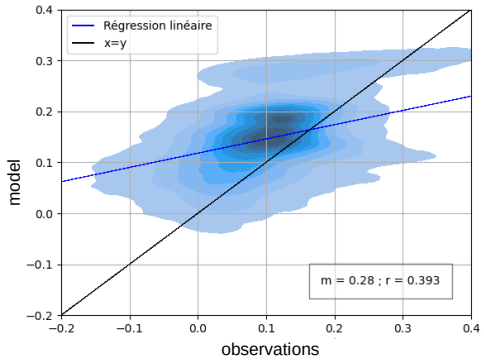
METHOD 1 : Assimilation of sea-ice volume

RESULTS

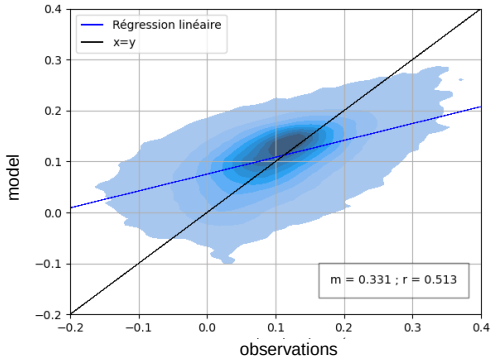
Comparison with assimilated datasets :

Radar freeboard [m]

Without assimilation



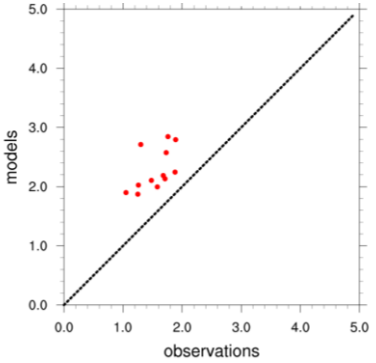
With assimilation

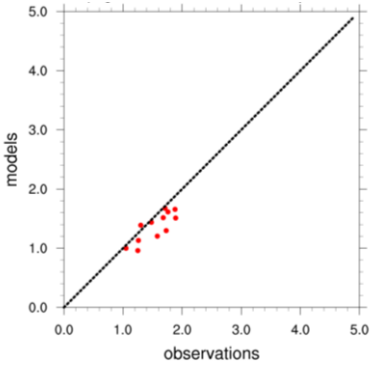


Comparison with independent datasets :

Beaufort Gyre Exploration Project

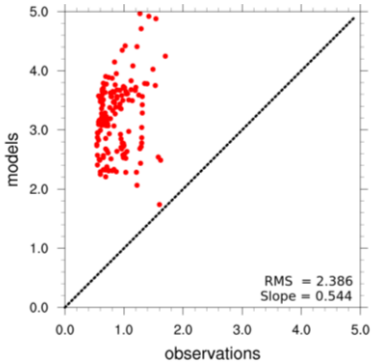
Sea-ice draft [m]

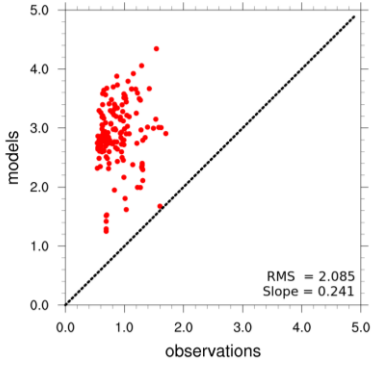




Operation Ice Bridge

Sea-ice thickness [m]





Summary and perspectives

Multivariate and multidata sea-ice analysis ☑

Assimilation of along-track CryoSat-2 data ☑

Next developments of this study:

- Adaptation to the **new sea-ice NEMO model SI3**;
- Production of a short reanalysis 2011-2020 with assimilation in **Antarctica**;
- Implementation and tests of a Snow Volume data assimilation with altimetry bi-band **KaKu data** (Garnier et al. 2021).