Joint assimilation of sea-ice concentration and thickness from remotely-sensed observations

Andrea Cipollone, D. S. Banerjee, D. Iovino, A. Aydogdu, S. Masina

ODA dept

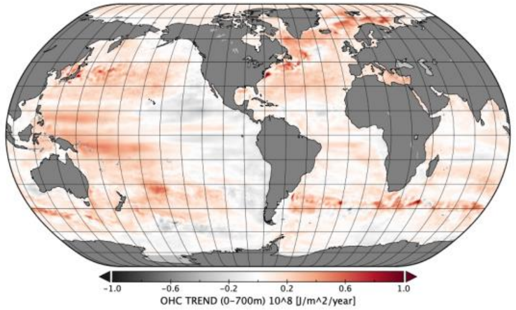
@ OceanPredict DA-TT meeting,
Rome, 9th May 2023

Present status of in-house DA systems

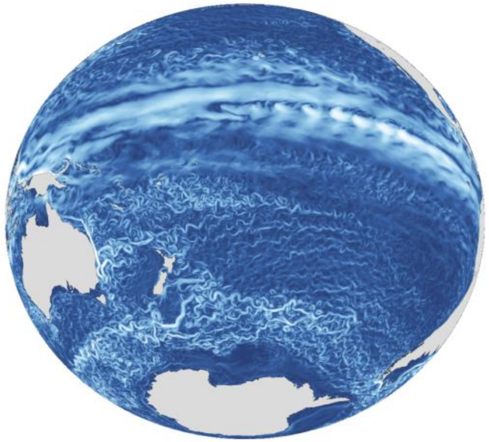
Ocean component

Global operational Reanalysis/Forecast products at CMCC are based on OceanVar, a 3dvar DA scheme that ingests ocean observations such as T/S/SLA (Dobricic & Pinardi 2008; Storto et al. 2011, etc.)

- Initialization of ocean component of the coupled seasonal prediction system (ensemble of Ocean Reanalysis)
- Consolidate series of eddy-permitting ocean Reanalyses C-GLORS (Storto et al, 2015) http://c-glors.cmcc.it/, member of the CMEMS GREP product)



- Initialization of eddy resolving short-term ocean forecast GOFS16 (Cipollone et al., 2020, https://gofs.cmcc.it/)



See Ali Aydogdu's talk

Same scheme is employed at regional scale (Black Sea and Med Sea)

Sea-ice component

Sea Ice variables (concentration and thickness) are currently constrained with univariate nudging procedures variables towards two different products OSISAF SIC (Lavergne, 2019) and PIOMAS SIT (Zhang & Rothrock, 2003)

INTRODUCING A SEA-ICE DATA ASSIMILATION SYSTEM

*A consistent multivariate sea-ice DA is crucial to improve the capability of Reanalysis/Forecast system to **predict diverse sea-ice characteristics** and to provide a realistic representation **of interannual/decadal signals.***

Sea-ice regulates the exchange of heat and gases (oce-atm), affects the local/global ocean circulation (DWF), impacts ecosystems, human activities ect

CHARACTERISTICS

Sea-ice thickness retrievals are very recent (~2010s, or ICESat in 2003/2004) and **available only during the freezing season** (due to meltpond interference).

Sea-ice variables are **highly non-gaussian** (i.e. SIC limited between 0-1) and the direct use in standard DA approach (based on normal distribution for pdf) must be treated with extra-care

NOVELTY

A new sea-ice (SIC/SIT) module is included in OceanVar based on anamorphosis transformation (Simon & Bertino, 2009) that moves the minimization in a gaussian space

ANAMORPHOSIS OPERATOR is the tangent linear of the algorithm from the SANGOMA project (http://www.data-assimilation.net/) that maps the different quantiles of the initial and final distributions (Brankart et al., 2012)

The cost function in the incremental formulation is used, where a control variable transformation (CVT) is used to precondition the minimization problem and where **V** corresponds to the "left square root" of **B**

$$J(\delta \boldsymbol{x}) = \frac{1}{2}\delta \boldsymbol{x}^{\mathrm{T}} \boldsymbol{B}^{-1} \delta \boldsymbol{x} + \frac{1}{2}(\boldsymbol{H}\delta \boldsymbol{x} - \boldsymbol{d})^{\mathrm{T}} \boldsymbol{R}^{-1} (\boldsymbol{H}\delta \boldsymbol{x} - \boldsymbol{d})$$

$$\delta \boldsymbol{x} = \boldsymbol{V}\boldsymbol{v}$$

Control space

model space

CVT ("square root" of B)

Operator that shapes **B** are : cross-cov SIC/SIT, horizontal diffusion, anamorphosis

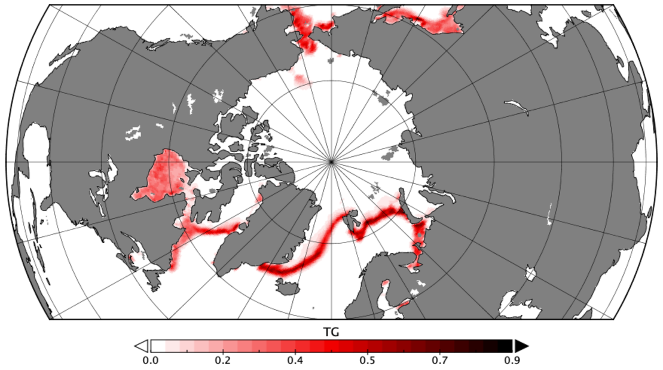
$$\delta \boldsymbol{x} = (\delta \mathrm{SIC}, \delta \mathrm{SIT}) = \boldsymbol{V}_{\mathrm{gICE} \rightarrow \mathrm{ICE}} \boldsymbol{V}_h \boldsymbol{V}_{(\mathrm{gSIC:gSIT})} \boldsymbol{v}$$

Tangent of Anamorphosis op (around the background field)

Horizontal corr.

Cross-cov gSIC/gSIT

December representation of the tangent $V_{gSIC\text{->}SIC}$ (around the background field)



Approximations

The tangent approx. is correct when increments are not so high, i.e. extreme events (that pass the BQC) lead to increments that are treated with coefficient around the background (as any other linear operator)

Background value must inside the range of values used to construct the transformation, otherwise increments are zero.

Cipollone et al., submitted to OC (2023)

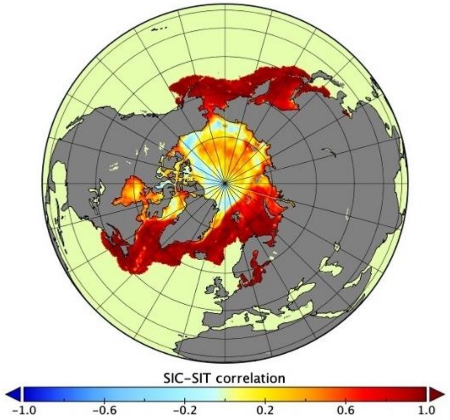
DATA ASSIMILATION SCHEME

ANAMORPHOSIS IMPACT

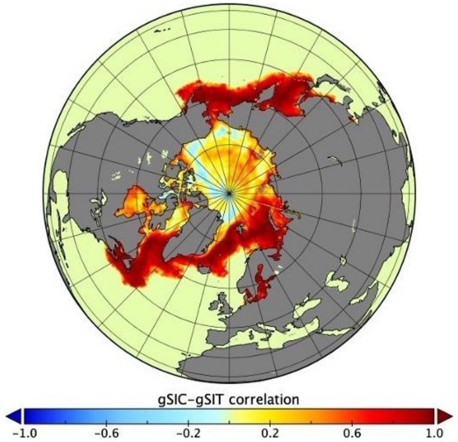
The operator is applied in each grid point, the initial distribution is constructed from the statistics of a 31y simulation (NEMO-LIM2), enriched with values from neighbouring points, using 21 quantiles for the mapping

- ☑ Cross Covariance between SIC and SIT is (almost) preserved by the transformation.

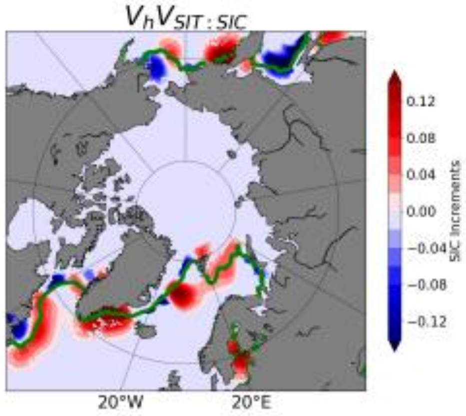
March SIC/SIT Correlation $V_{\mathrm{SIC:SIT}}$

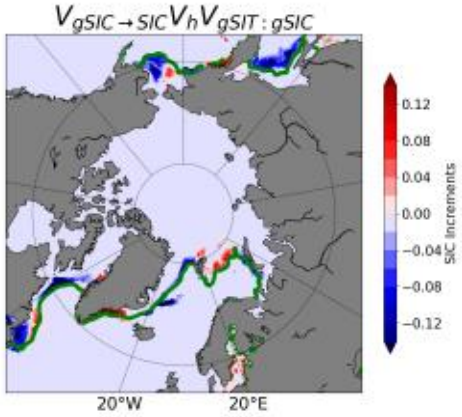


March gSIC/gSIT Correlation $V_{\mathrm{gSIC:gSIT}}$



- ☑ Increments preserve the strong anisotropy close to the sea-ice edge (weighted by the local variability) rather than be spread isotropically (standard case)





Spatial correlation ~150km

EXPERIMENT CONFIGURATION AND DATA

- Five-year long experiments with identical initial condition (CGLORSv5 reanalysis) and model set up: NEMO v3.6 and sea-ice model LIM2 (one thickness category) with a global grid at ¼° resolution (ORCA025) but different sea-ice DA configuration and dataset:

Sea ice thickness

CS2SMOS SIT Data fusion: Weekly merged l4 CryoSat-2/SMOS (Ricker et al, 2017).

CRYOSAT-2 (Thick) SIT data: Weekly meas. from polar-orbiting CryoSat-2(Hendricks et al., 2020).

SMOS (Thin) SIT data: Daily measurements of Thin Sea Ice Thickness from SMOS sensor

Sea ice concentration:

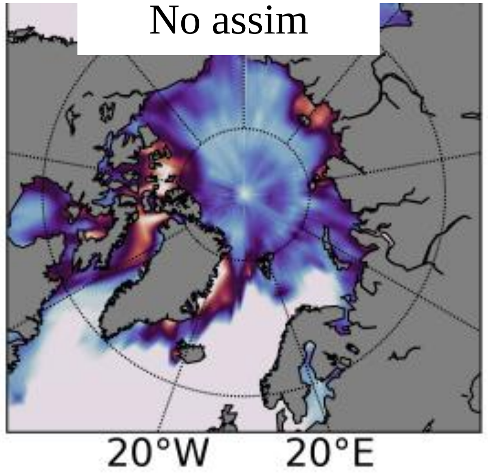
OSISAF SIC data: Daily reprocessed measurements of concentration (Lavergne et al.,2019)

Data assimilation configuration

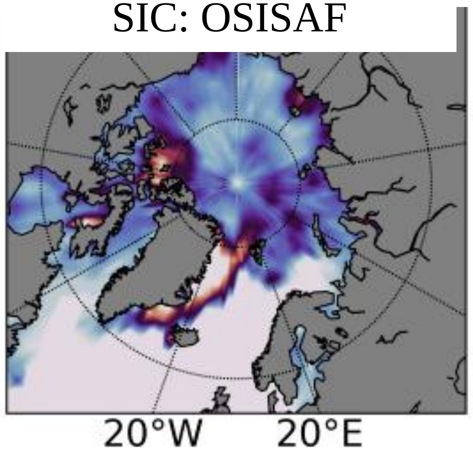
Exp Name	SIC data	SIT data	subsampling range	Desroziers' OE (multiplication factor)
CTRL	None	None	None	None
L4DE1	OSISAF	L4 CS2SMOS	None	1
L4DE30	OSISAF	L4 CS2SMOS	None	30
L4SUB	OSISAF	L4 CS2SMOS	SIT ~100km	1
L3CR2	OSISAF	L3 CryoSat-2	None	2
L3CR2&SM	OSISAF	L3 CryoSat-2 & SMOS	None	2;2
SICDE1	OSISAF	None	None	1
SICDE02	OSISAF	None	None	0.2

Impact of DA in February SIT RMSE

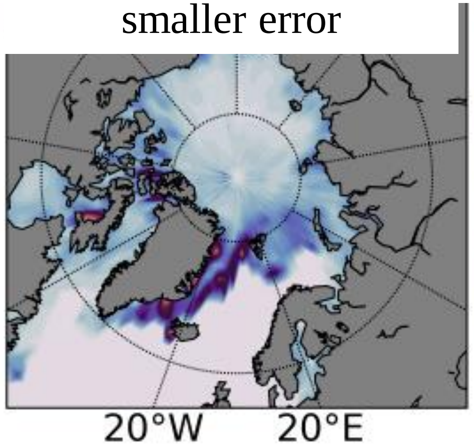
No assim



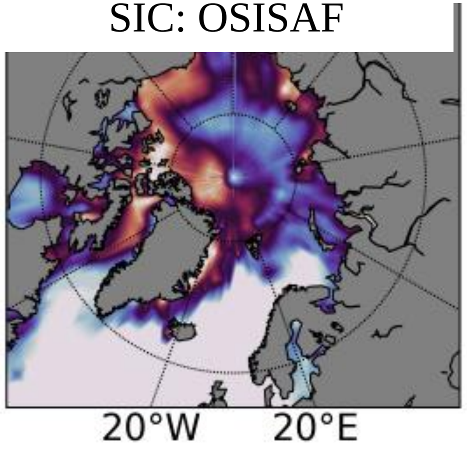
SIC: OSISAF

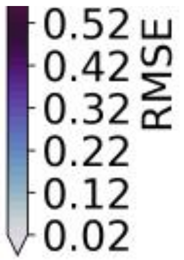


SIC: OSISAF
smaller error

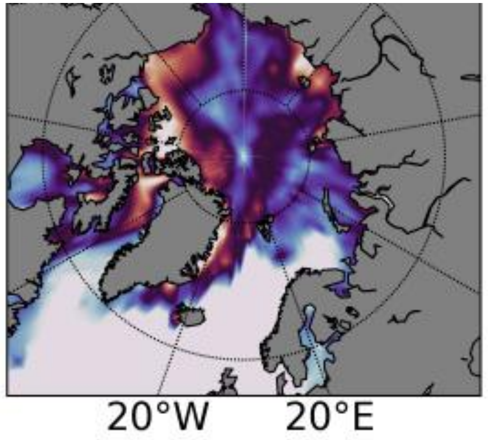


SIT: L3 Cryosat-2
SIC: OSISAF

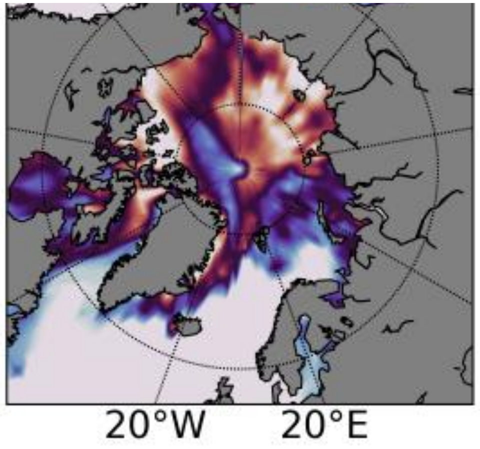




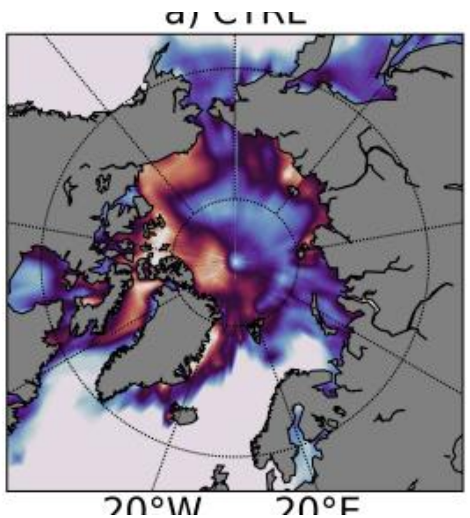
SIT: L3 Cryosat-2 & SMOS
SIC: OSISAF



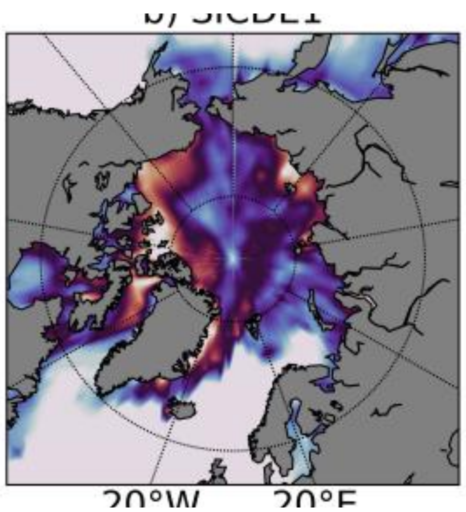
SIT: L4 CS2SMOS
SIC: OSISAF

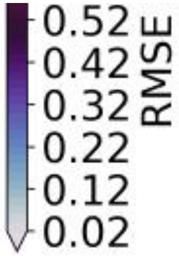


SIT: L4, larger error
SIC: OSISAF

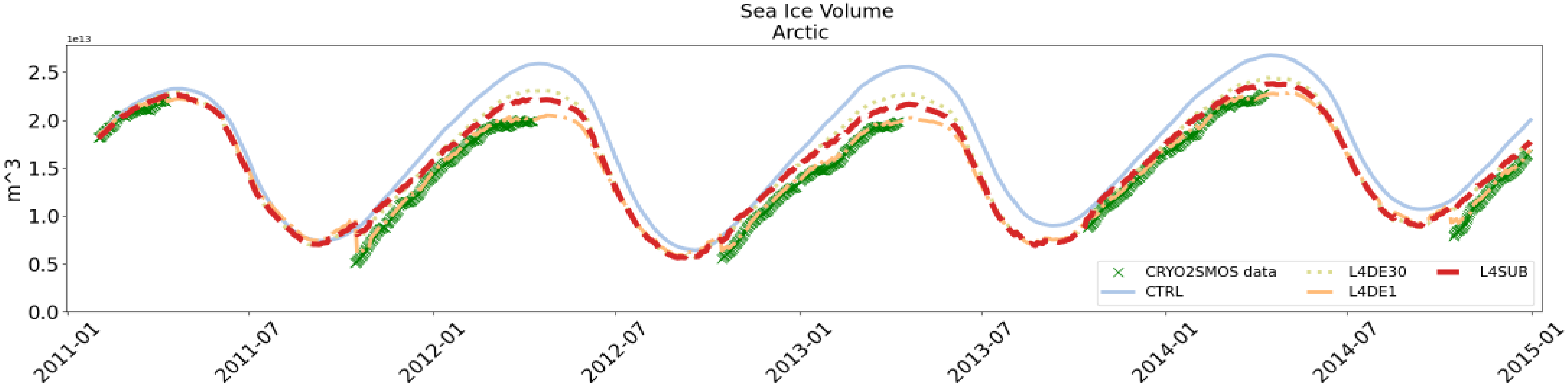


SIT: L4 ~100km SUBSAMP
SIC: OSISAF

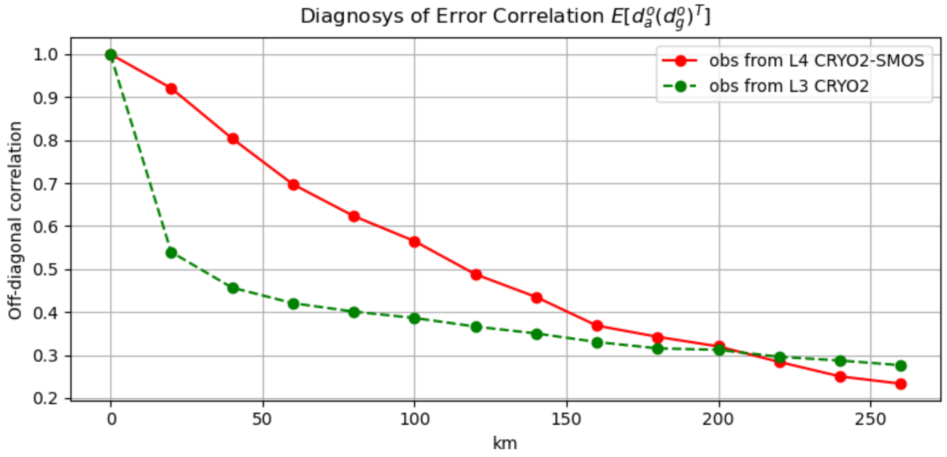




- ☑ Assimilation of L4 CS2SMOS data (**L4DE1**) generates jumps in the total volume at the onset of the freezing period. **L4SUB** recovers the correct seasonality by subsampling the data as well as **L4DE30** (Obs Err. is increased w.r.t Desroziers' extimate).

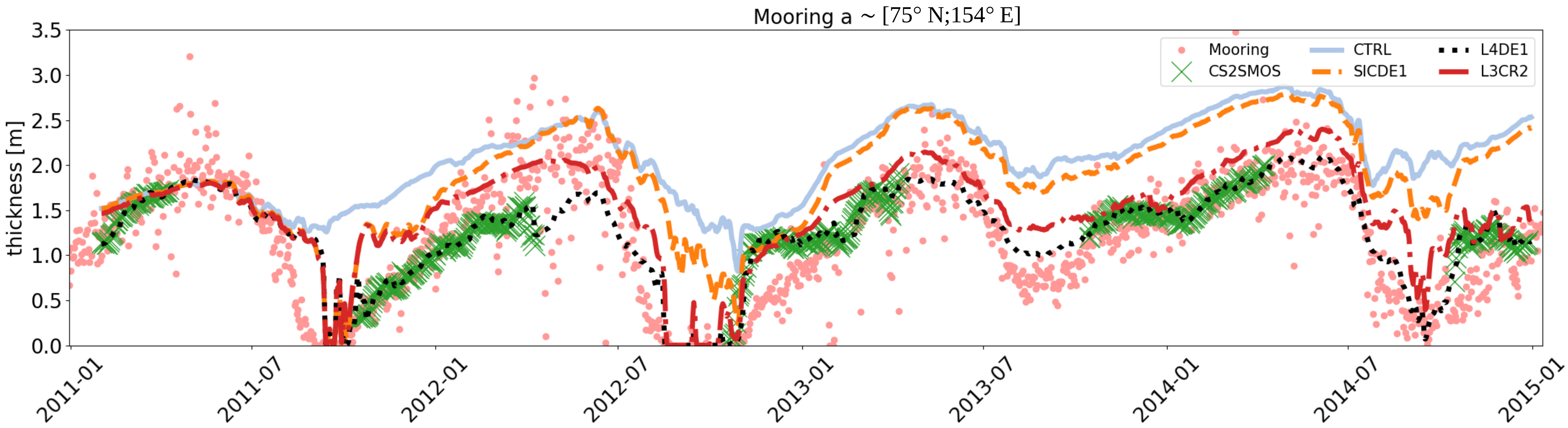


Such overconfidence in the observations (too small error) is likely to be caused by the absence of correlation between observation error **(zero off-diagonal element in the R matrix)**



IMPACT OF DA ON INITIAL CONDITIONS

- Independent validation against thickness mooring data in Beaufort Gyre (Beaufort Gyre Exploration Project, www.whoi.edu/beaufortgyre) (pink dots). Assimilation of SIC data only (**SICDE1**) slightly improves the SIT estimates especially during summer-time w.r.t. **CTRL**. **L4DE1** assimilates L4 CS2MOS and reproduces SIT evolution in summer (no SIT data) better than **L3CR2** where only Cryosat-2 data are assimilated.



Observation influence

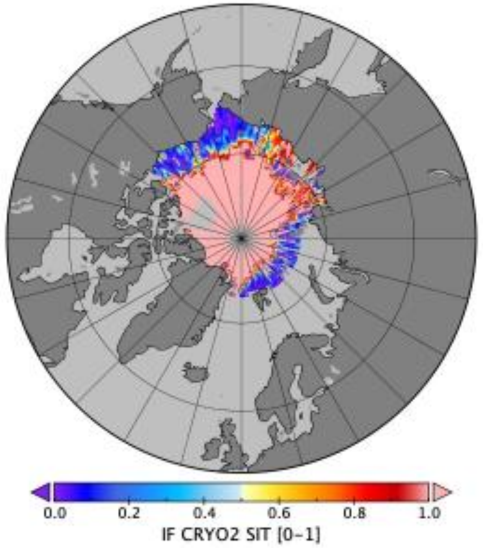
A measure of the relative influence of different observation types into the model dynamic/thermodynamics, follows the evaluation of the Degrees of Freedom for Signal (DFS, Cardinali et al. (2004) and the impact factor index (IF):

$$\mathrm{IF}_j = \frac{\overline{\mathrm{DFS}_j}}{\sum_o \overline{\mathrm{DFS}_o}}$$

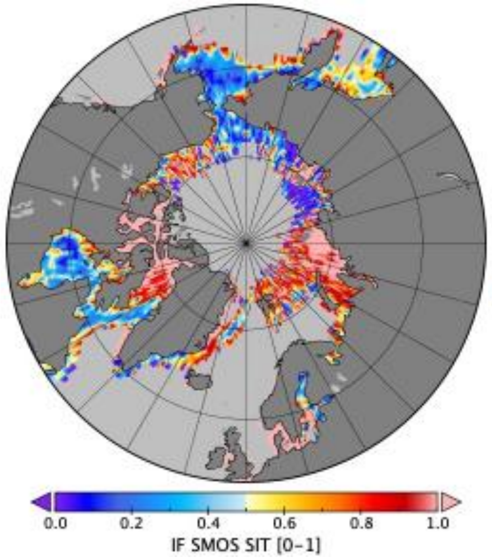
Experiment analyzed:
SIT : L3 Cryosat-2 & SMOS
SIC: OSISAF

IF compares the influence of different observation datasets and quantify the relative impact of each single dataset

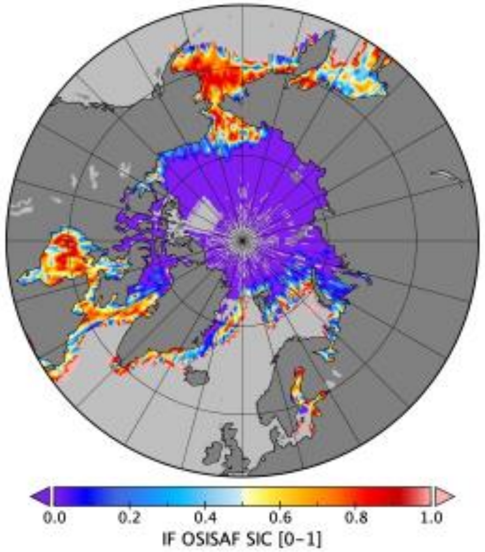
Influence of Cryosat-2 SIT



Influence of SMOS SIT



Influence of OSISAF SIC



Cryosat-2 data largely impact the Eurasian basin while most of the Siberian coast is influenced by the SMOS data as well as west Greenland rift basin. Moving toward the sea-ice edge a competitive behaviour is shown between SMOS and SIC data.

CONCLUSIONS

- Anamorphosis transformation of sea-ice variables in their Gaussian counterparts can help to include specific physical constraints in final increments (i.e. strong spatial anisotropy close to sea-ice edge) and to ease the coupling with other variables in a multivariate approach.

- SIT data are dense and not continuous in time (available only during the accretion period). This can generate discontinuities at the onset of the growing season that are to be avoided to preserve a realistic seasonal variability in a Reanalysis product.

- The ingestion of SIT data in winter (Cryosat-2 and SMOS) provides much better initial conditions for SIT prediction in spring compared to experiments without SIT or with the Cryosat-2 only assimilation

THANK YOU !!