A JEDI Based Ocean Sea Ice Data Assimilation System for the UFS

JCSDA Core: Guillaume Vernieres, Travis Sluka, Hamideh Ebrahimi
EMC: Jong Kim & marine DA group
GMAO: Min-Jeong Kim
Contributors: JCSDA JEDI team, NOAA/EMC, NASA/GMAO, NOAA/ESRL

SOCA: Sea-ice, Ocean, and Coupled Assimilation

Who is JCSDA?

Joint Center for Satellite Data Assimilation

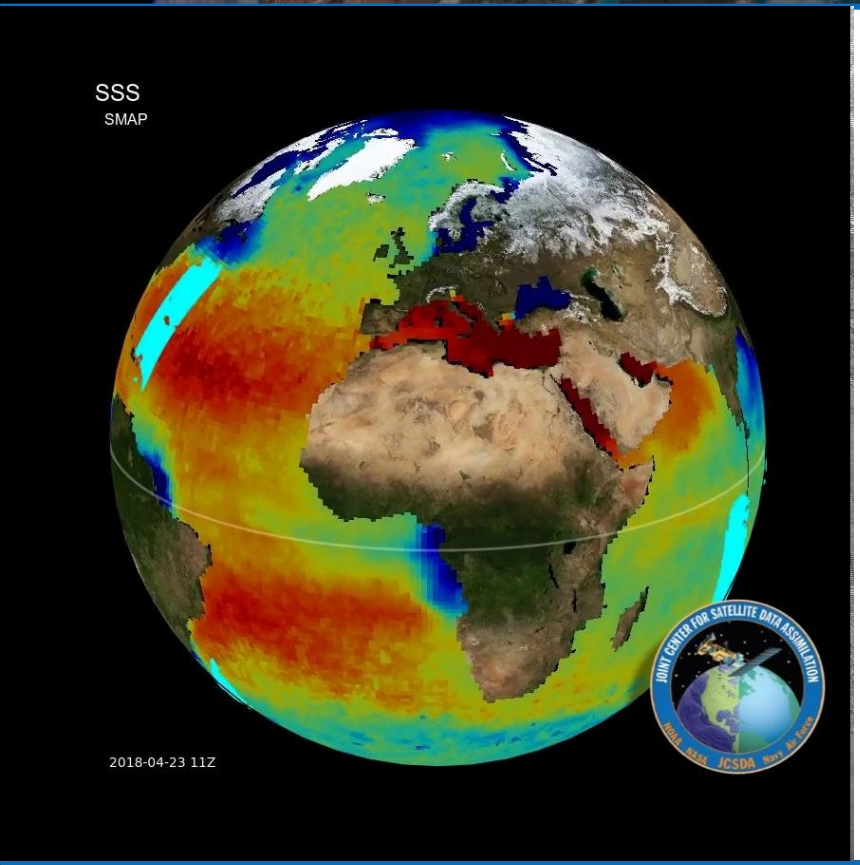
Interagency partnership hosted by UCAR dedicated to improving and accelerating use of research and operational satellite data in weather, ocean, climate and environmental analysis and prediction systems

Who is JCSDA?

JCSDA PROJECTS https://www.jcsda.org		
OBSERVATIONS	**ALGORITHM & INFRASTRUCTURE**	**APPLICATIONS**
• UFO • CRTM • Diagnostics • Observation database	• DA Algorithms (OOPS) • B Matrix (SABER) • Infrastructure • Coupling Methodology	• Marine (**SOCA**) • Land • Atm. Constituents • NWP (starting 2021)

Sea ice **O**cean **C**oupled **A**ssimilation

SOCA (Sea-ice, Ocean, and Coupled Assimilation)



- **marine data assimilation**
  (ocean, sea ice, coupled, ...)
- **Built within JEDI system**
  (Joint Effort for Data Assimilation Integration)
- **Coupled DA**
  for use with NOAA's UFS, NASA's GEOS

JEDI framework

Goals

- Next-generation **unified** DA system
- Increase **R2O/O2R** transition rate (academia/operations)
- Increase **science productivity** and **code performance**

Overview of JEDI:
https://doi.org/10.25923/rb19-0q26

Strategy

- **Modular code** for flexibility, robustness and optimization
- Mutualize **model-agnostic** component across:
  - **Applications** (atmosphere, ocean, NWP,...)
  - **Model & grids** (operational/research, regional/global)
  - **Observations** (past, current and future)
- Collective reduction of entropy

SOCA: Interface to JEDI

What we **interface with** JEDI

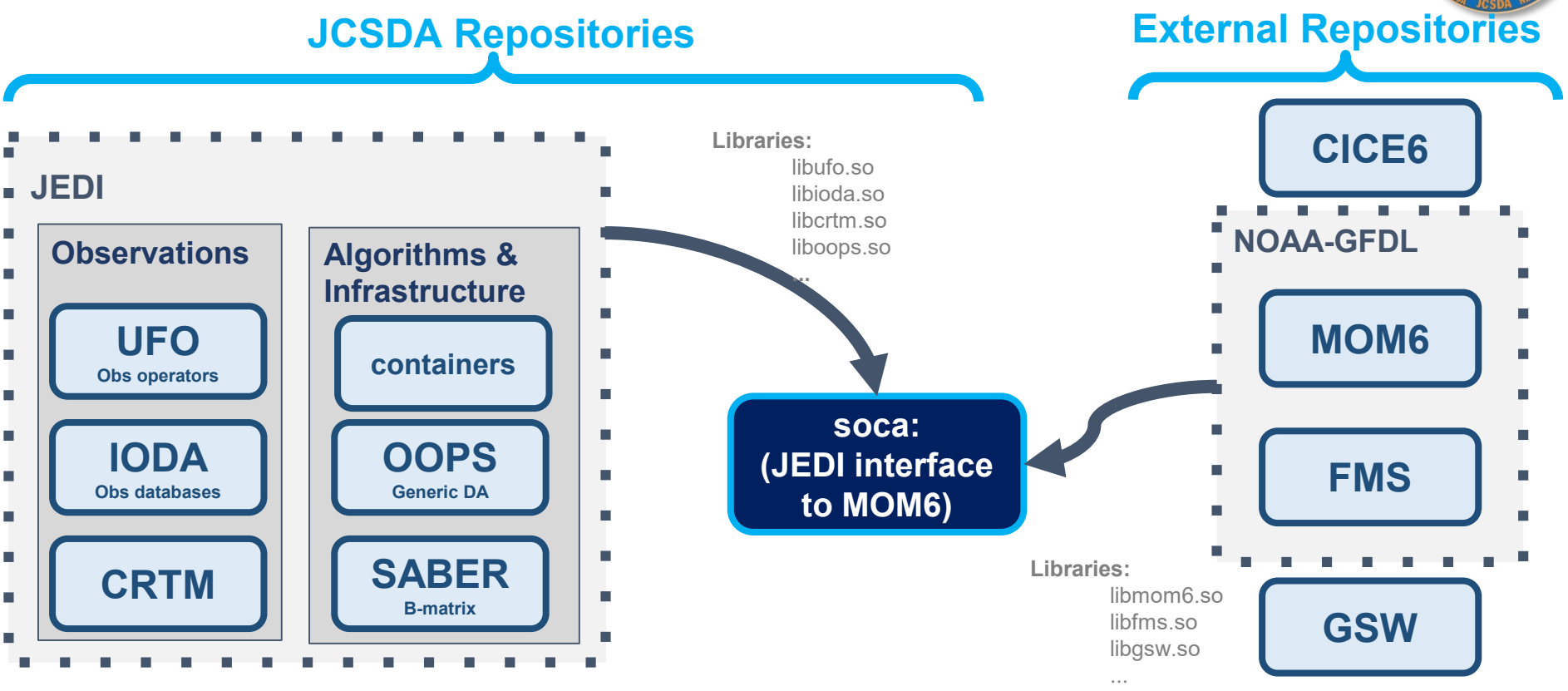
- **MOM6 (Travis & Guillaume)**
- **CICE6 (Jong Kim)**
- **ROMS (Hernan Arango)**
- **Observation operators** (within UFO)
- **Background error covariance** (using SABER)

What we get **from** JEDI

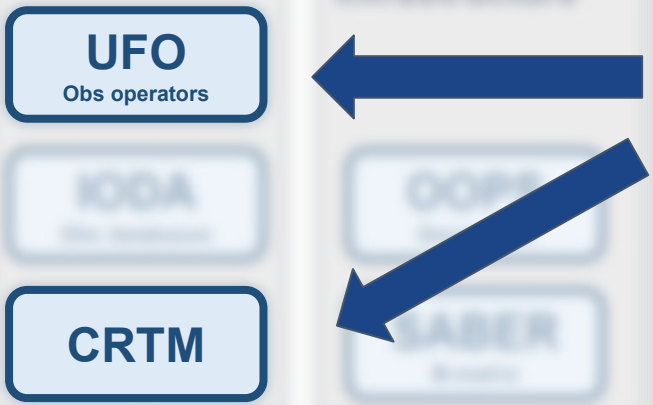
Generic applications:

- **DA algorithms** 3DVAR, 3DFGAT, “4DVAR”, Hybrid-EnVAR, LETKF
- **h(x):** Advance MOM6 over a time window and simulate observations using the generic UFO’s.
- **Perturbation of initial conditions:** B-matrix randomization.
- **Forecast:** Advance of MOM6 over a time window, driven by OOPS.
- ...

SOCA: Interface to JEDI



SOCA: Interface to JEDI



UFO: Unified Forward Operators

- SST/SSS retrievals
- insitu T/S
- altimetry
  (Absolute Dynamic Topography)
- sea-ice fraction/thickness
- SST/SSS direct assimilation
  GMI/SMAP brightness temperatures using CRTM

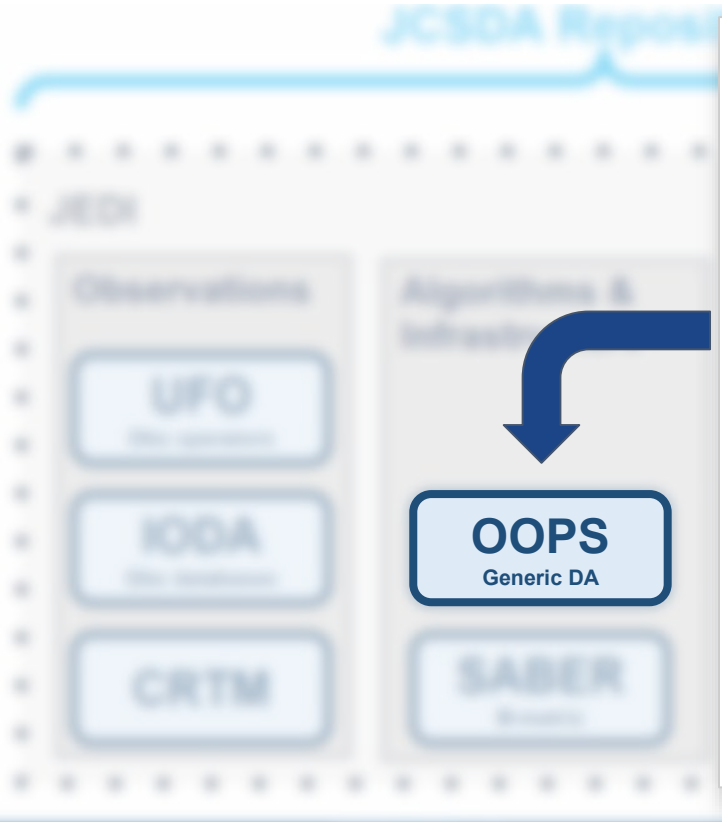
SOCA: Interface to JEDI

UFO: Generic Quality Control

- quality control filters
  (track check, background check, buddy check, …)
- thinning
  (Gaussian temporal / spatial …)
- variational bias correction
  (in development by JEDI team)

no coding required, just configuration files!

SOCA: Interface to JEDI



OOPS: Assimilation methods

- 3DVAR & 3D Hyb-EnVAR
- 3DVAR-FGAT
- EDA
- LETKF
- 4D Hybrid EnVAR
- 4DVAR

SOCA Implementation at NOAA/EMC (NG-GODAS)

SOCA: Interface to JEDI

SABER: System Agnostic Background Error Representation

BUMP: (Background error on Unstructured Mesh Package)

calculation and application of univariate or multivariate correlation / localization

SOCA
Ongoing activities

OSSEs at NOAA/CPC

Jieshun Zhu

CPC/NCEP/NOAA and
ESSIC / UMD, College Park

Ocean observing system simulation experiments (OSSEs)

- Current configuration of in-situ observations (e.g., TAO, Argo)
- Proposed configurations by the TPOS 2020 project

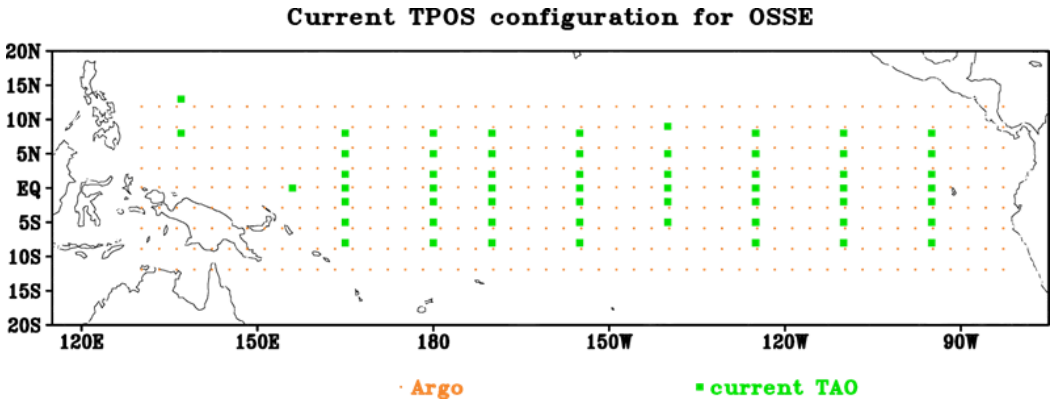
DA system: 1° MOM6 + **Marine JEDI** 3DVar

Atmospheric forcing: daily from Nature run

Synthetic Obs. sampling: TAO/Argo with current configurations; from Nature run

-*TAO is sampled every 24 hours (vs. 10min in reality)*

-*Argo is sampled every 3x3 box every 10 days within TP*



Biogeochemistry assimilation

Xiao Liu (NOAA/EMC)

- **SOCA/Marine JEDI** DA
- BLING coupled to MOM6
- Chlorophyll tracers
- ocean color observations from VIIRS and MODIS

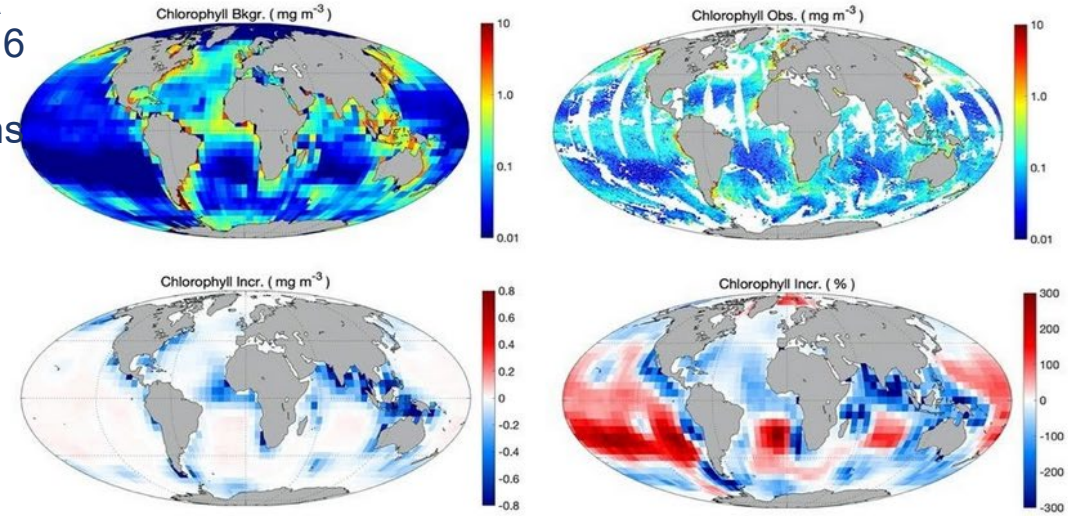
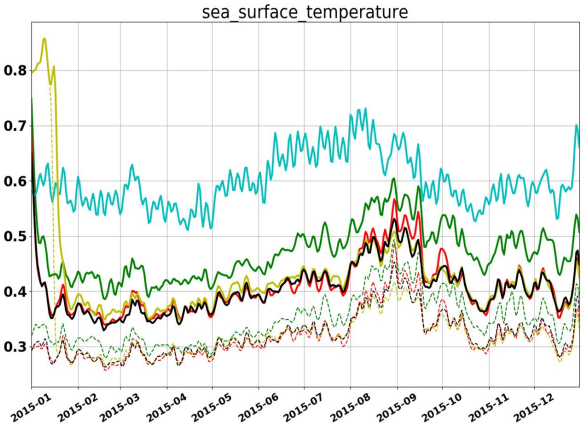


Figure 2. (upper panels) Simulated "background" chlorophyll in MOM6-BLING and Level-2 chlorophyll derived from NOAA-20/VIIRS imagery on 2018/04/15 used to create chlorophyll analysis; (lower panels) chlorophyll increments calculated based on the 3DVAR scheme in JEDI, shown as the absolute and percentage increments, respectively.

Multiple Implementations of SOCA

JCSDA/EMC/GMAO



UFS-3DVAR-02

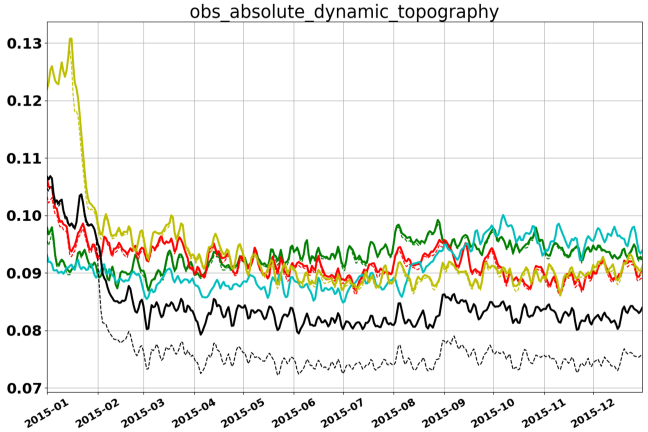
GEOS-3DVAR-02

M6S2-3DVAR-02

M6S2-3DVAR-03-beta

Several Implementations:

- **U**nified **F**orcast **S**ystem
  - NG-GODAS
  - HAFS
  - WCDA (Sergey Frolov)
- **G**oddard **E**arth **O**bserving **S**ystem
- MOM6-SIS2

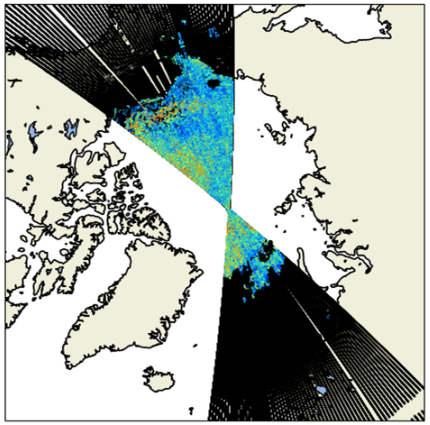


Sea Ice Freeboard Assimilation in GEOS-CICE4

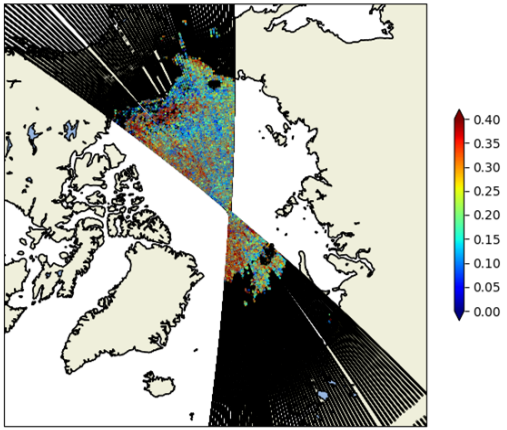
Min-Jeong, Bin Zhao, Guillaume, Jong Kim (GMAO/JCSDA/EMC)

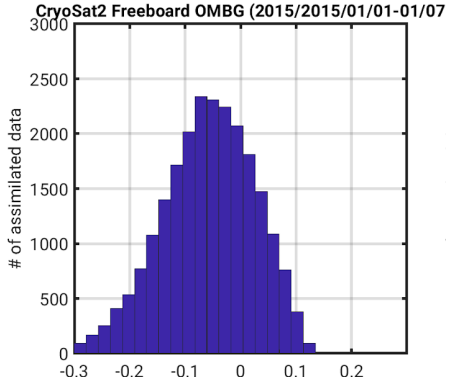
Sea ice Freeboard [m]

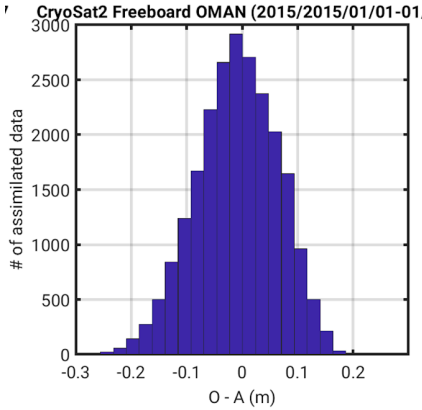
L2 Cryosat-2 Observations



GEOS background



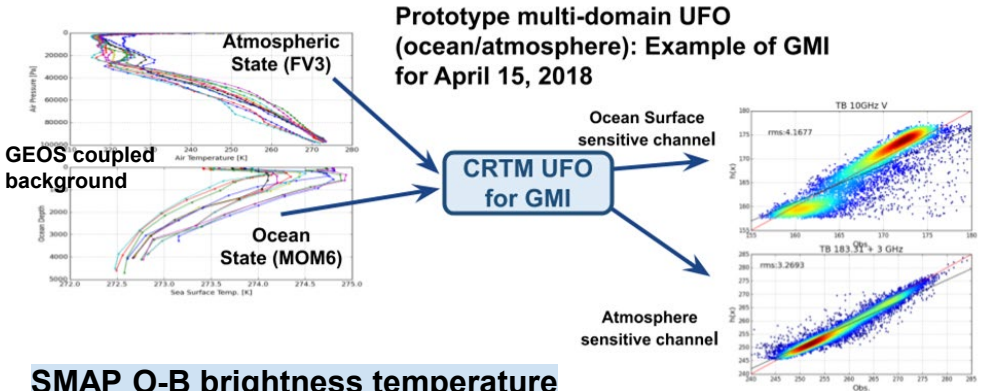




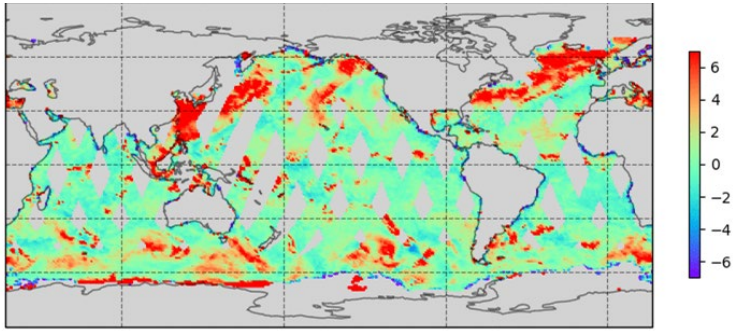
Radiance Assimilation in GEOS

Hamideh Ebrahimi (JCSDA)

- direct assimilation of MW brightness temperatures
  - SST (**GMI**)
  - SSS (**SMAP**)
- using CRTM with 2 domains (atmosphere & ocean)



SMAP O-B brightness temperature



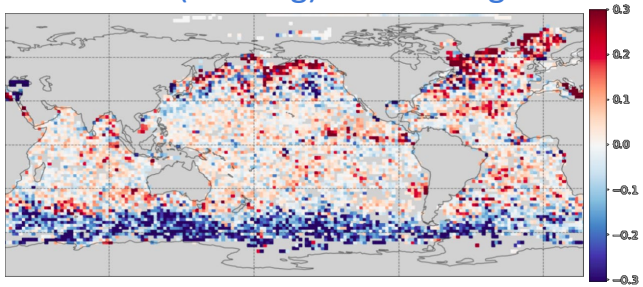
2015-01-01 01Z to 2015-01-01 23Z

JCSDA ioda-plots

AI Salinity Retrievals from SMAP

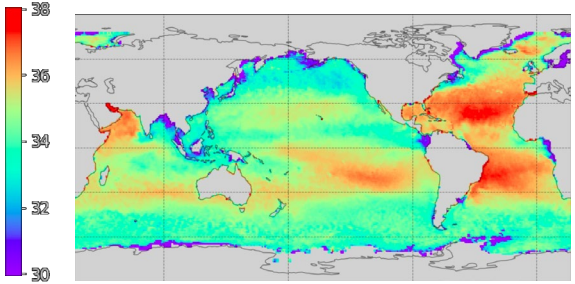
Francois Chabannes, Hamideh Ebrahimi (JCSDA)

OSE for JPL SSS and ML SSS
Comparison of the 24 hour forecast at insitu salinity above 5 m depth
ML RMSD(obs-bkg) - JPL ombg rmsd

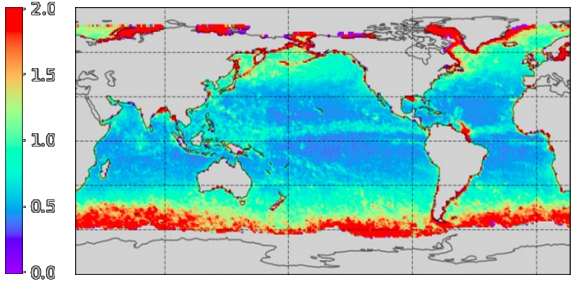


JPL retrieval :

SSS - Monthly Average

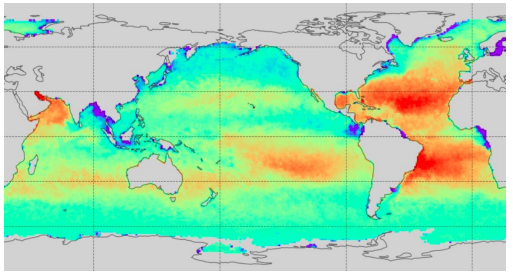


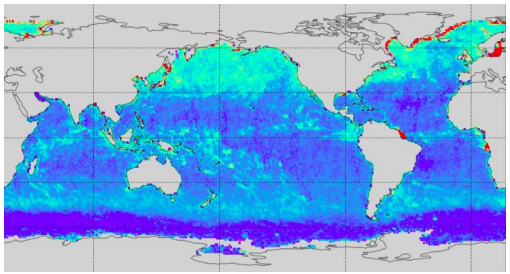
STD - Monthly Average



ML retrieval :

initial 321,728 weekly binned samples sanity checked with the Rain-Filtered RSS product



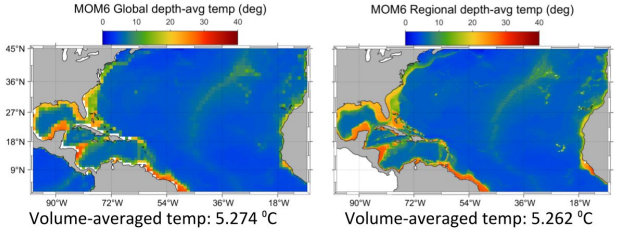


Regional Marine DA

Kriti Bhargava, Travis Sluka, Guillaume Vernieres, Hernan Arango and EMC marine DA group (JCSDA/EMC/Rutgers)

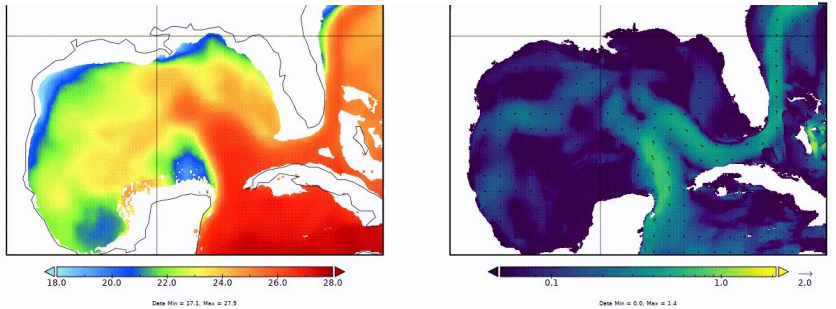
- Initialization of the marine component of the EMC Hurricane Analysis and Forecast System (HAFS)
- Based on the MOM6 interface to JEDI (SOCA)
- Development and support of the **ROMS**' interface to JEDI (Hernan Arango)

Downscaling application in JEDI (**Yi-Cheng Teng** NOAA/EMC)



Relative Difference: -0.50% (-0.06% if using 0.25 deg)
(0.7% from k=75 to k=41)

1/25 degree GoM MOM6 model run tests (**Travis Sluka** JCSDA)



JEDI Based Initialization of the Marine component of the UFS

JEDI-GODAS

JEDI-GODAS: First implementation

- 1 degree **Unified Forecast System**: MOM6-CICE6 Data Atmosphere (GEFS Forcing) provided by **EMC**
- Data Assimilation: **JEDI** based 3DVAR provided by the **JCSDA** with contributions from **EMC** and the **GMAO**
- Ready by March 31, 2021

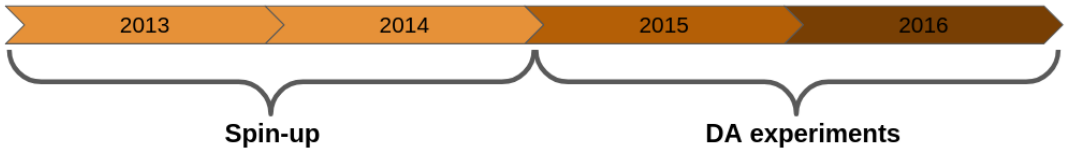
Model resolution and DA algorithm constrained by the available compute resources for a 40 year reanalysis

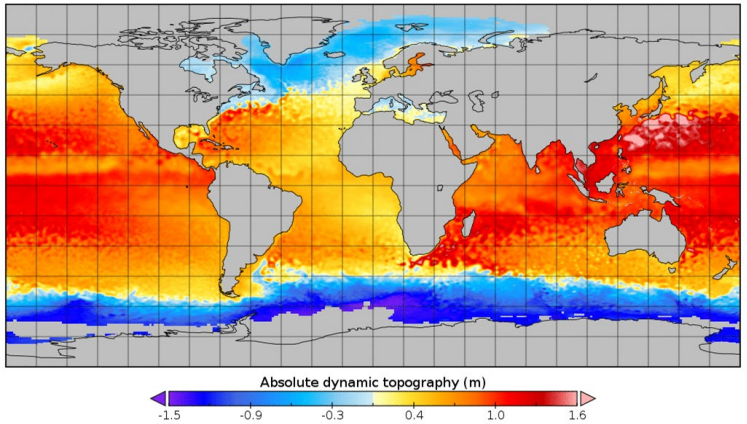
JEDI-GODAS: Development/Testing

- ❑ Reference experiment
- ❑ Observation subset
- ❑ DA algorithm (3DVAR and Hybrid EnVAR)
- ❑ Covariance modeling
- ❑ Preliminary results

JEDI-GODAS: Development/Testing

- 3DVAR with parametric background error and balance operators
- Sanity check for covariance modeling: 3D Hybrid EnVAR (LETKF for perturbation)
- Observations:
  - Insitu: Argo (T,S), Conductivity TD (T,S), XBT (T), TAO (T), PIRATA (T,S), RAMA (T,S) , Ship tracks (SST)
  - Satellite retrievals
- 24H DA window



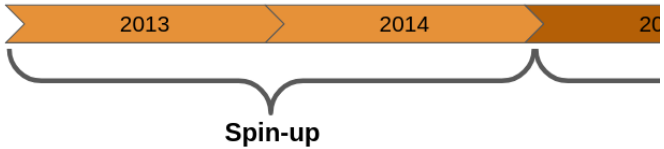


Experiment	Configuration	UFS	MOM6-SIS2	GEOS
Baseline/h(x)/spin-up	Forced only, no DA	Done	Done	In progress (spinup only)
Benchmark-01	Ocean only, 3DVAR	✕	Done	✕
Benchmark-02	Ocean only, 3DVAR	Done	Done	In progress (~ year 2)
Benchmark-03	Ocean & Sea-ice	In progress	In progress	In progress

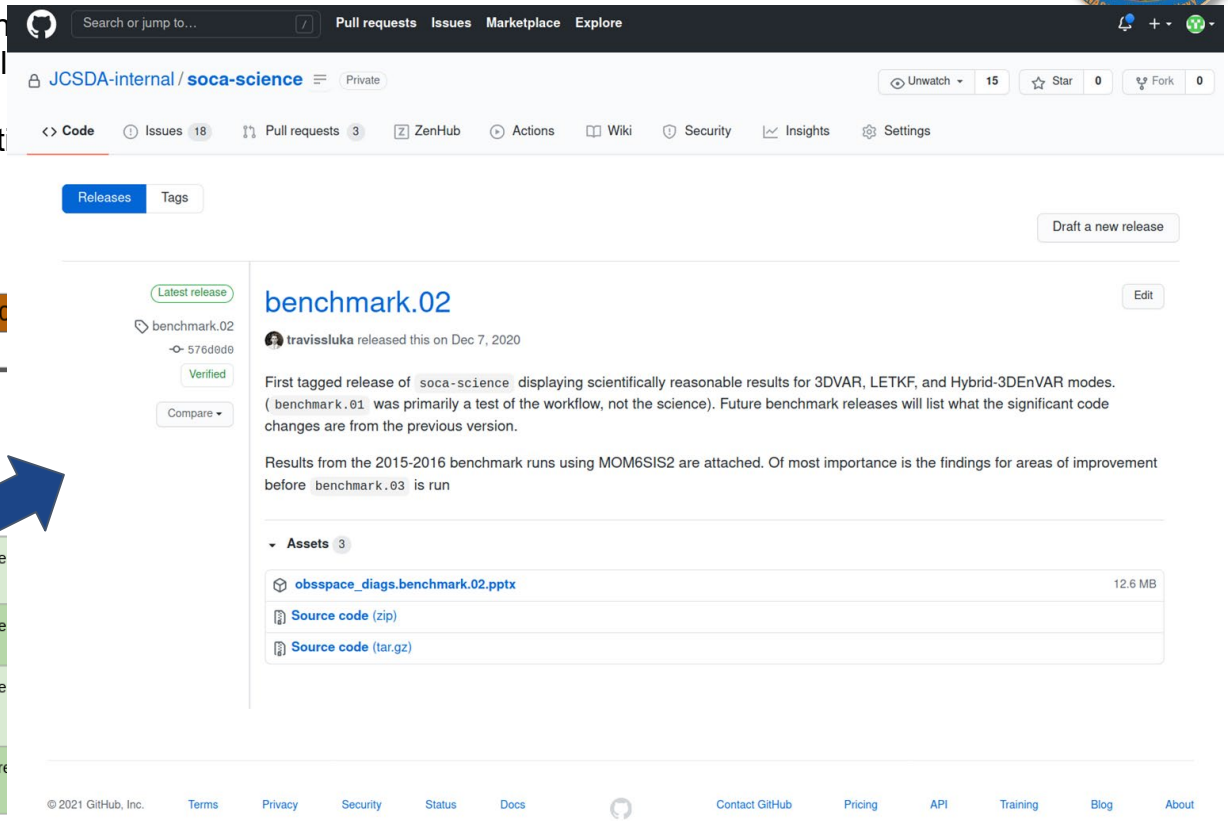
Due mid-March 2021

JEDI-GODAS: Development/Testing

- 3DVAR with parametric backgroun
- Sanity check for covariance model
- Observations:
  - Insitu: Argo (T,S), Conduct (T,S) , Ship tracks (SST)
  - Satellite retrievals
- 24H DA window

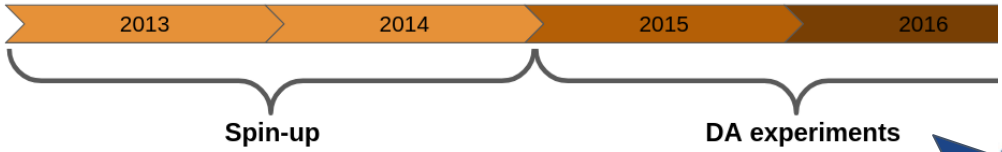


Experiment	Configuration	UFS	M
Baseline/h(x)/spin-up	Forced only, no DA	D	Done
Benchmark-01	Ocean 3D	✕	Done
Benchmark-02	ean only, 3DVAR	Done	Done
Benchmark-03	Ocean & Sea-ice	In progress	In progr



JEDI-GODAS: Development/Testing

- 3DVAR with parametric background error and balance ope
- Sanity check for covariance modeling: Hybrid EnVAR
- Observations:
  - Insitu: Argo (T,S), Conductivity TD (T,S), XBT (T),
    (T,S) , Ship tracks (SST)
  - Satellite retrievals
- 24H DA window



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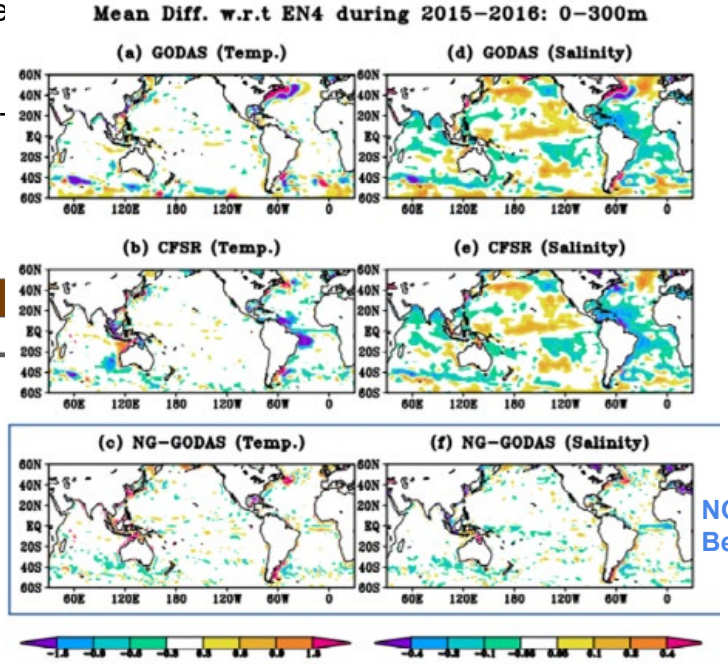
Benchmark-03	Ocean & Sea-ice	In progress	In progress	In progress



NG-GODAS Benchmark-02

*Analysis by **JieShun Zhu**, CPC*

JEDI-GODAS: Observations

Observation	Data Provider	Sensor/Satellite	Count/24hrs	% used
Sea Surface Temperature (IR)	GHRSST (L3)	AVHRR - NOAA19	200,000	96
		AVHRR - METOPA	220,000	96
Sea ice concentration	EMC (Robert Grumbine) L2	SSMIS - F18	3,700,000	16-20
Sea ice thickness	GIOMAS L4	N/A	63,319	20-30
Absolute Dynamic Topography	NESDIS RADS L2	Jason-2	48,000	70
		Cryosat-2	46,000	70
		Sentinel 3A	43,000	70
Insitu T&S	WOD	Argo, CTD, XBT, TAO, RAMA, PIRATA, ...	50,000	85-99

Superobed and pre-QC'ed

Superobed and pre-QC'ed

1.1M - 1.3M observations per 24 hour cycle

JEDI-GODAS: Observations

Observation	Data Provider	Sensor/Satellite	Count/24hrs	% used
Sea Surface Temperature (IR)	GHRSST (L3)	AVHRR - NOAA19		
		AVHRR - METOPA		
Sea ice concentration	EMC (Robert Grumbine) L2	SSMIS - F18		
Sea ice thickness	GIOMAS L4	N/A	63,319	20-30
Absolute Dynamic Topography	NESDIS RADS L2	Jason-2	48,000	70
		Cryosat-2	46,000	70
		Sentinel 3A	43,000	70
Insitu T&S	WOD	Argo, CTD, XBT, TAO, RAMA, PIRATA, ...	50,000	85-99

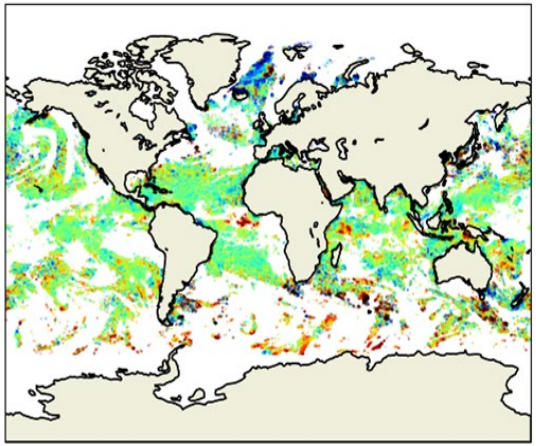
Superobed and pre-QC'ed

1.1M - 1.3M observations per 24 hour cycle

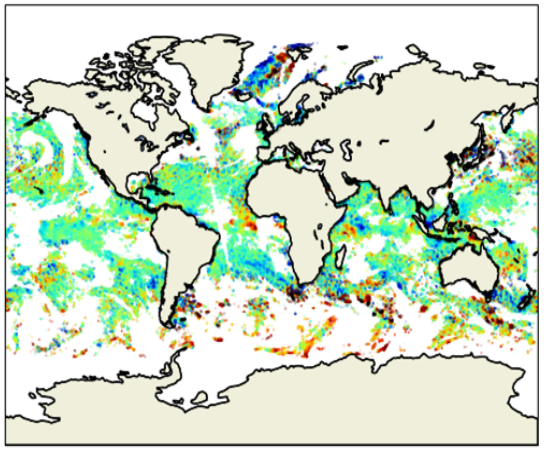
JEDI-GODAS: Observations

Spatial Coverage, 24 hour window

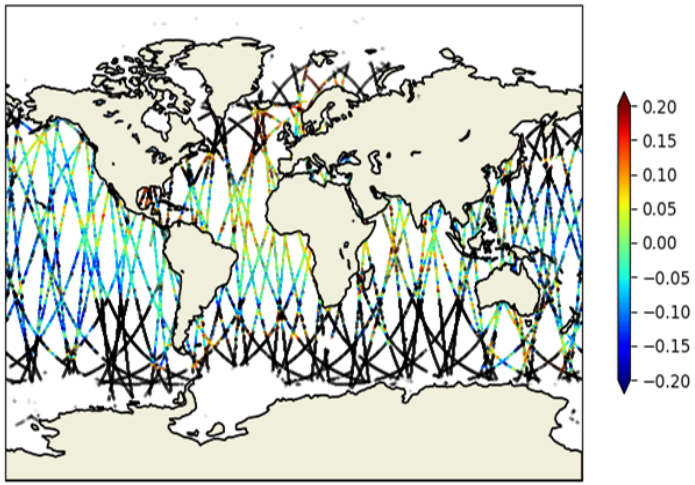
NOAA-19
Obs-Background [K]
2015-12-31 12Z



METOPA
Obs-Background [K]
2015-12-31 12Z



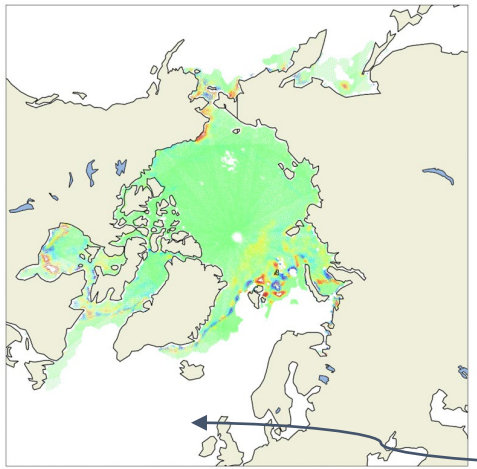
Jason-2, Cryosat-2, Sentinel 3A
Obs-Background [m]
2015-01-01 12Z

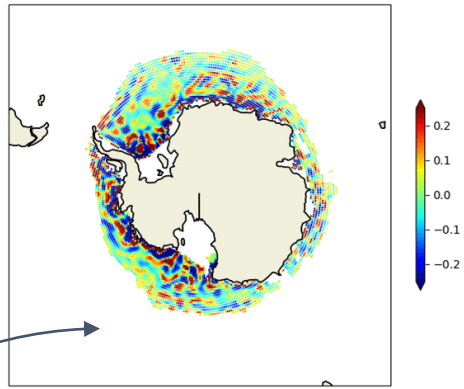


JEDI-GODAS: Observations

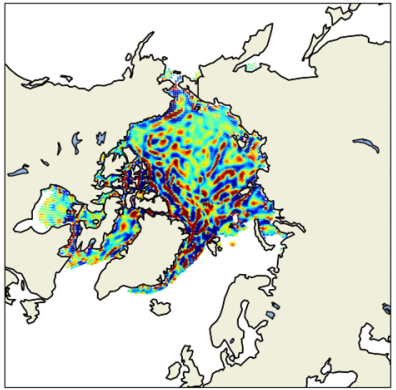
Spatial Coverage, 24 hour window

SSMI ice concentration
Obs-Background
2015-12-15 12Z





GIOMAS ice thickness
Obs-Background [m]
2015-12-15 12Z



- Rejected ice observations

JEDI-GODAS: Observations

Generic Quality Control: No coding!

```
obs filters:
- filter: Domain Check
  where:
  - variable: {name: sea_area_fraction@GeoVaLs}
    minvalue: 0.9
- filter: Domain Check
  where:
  - variable: { name: sea_surface_temperature@GeoVaLs}
    minvalue: 5.0
- filter: Background Check
  absolute threshold: 0.2
- filter: Bounds Check
  minvalue: -2.0
  maxvalue: 2.0
  action:
    name: assign error
    error function:
      name: LinearCombination@ObsFunction
      options:
        variables: [mesoscale_representation_error@GeoVaLs,
                    obs_absolute_dynamic_topography@ObsError]
        coefs: [0.1,
                0.01]
- filter: BlackList
  where:
  - variable:
      name: latitude@MetaData
    minvalue: -65
    maxvalue: -30
  - variable:
      name: longitude@MetaData
    minvalue: -125
    maxvalue: -90
- filter: BlackList
  where:
```

Land mask

Reject ADT obs if SST<5°C

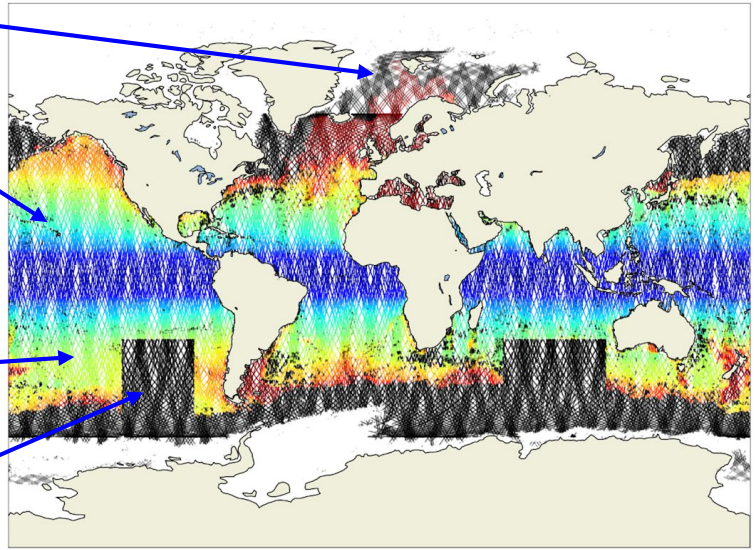
Reject ADT obs if |Obs-Bkg|<0.2 m

Reject ADT obs outside of [-2.0m, 2.0m]

Assign ADT obs error [m]

Reject ADT obs in specific region

- Rejected observations

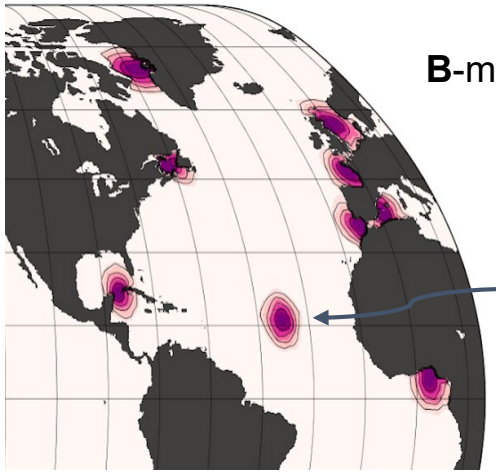


JEDI-GODAS: Covariance Modeling

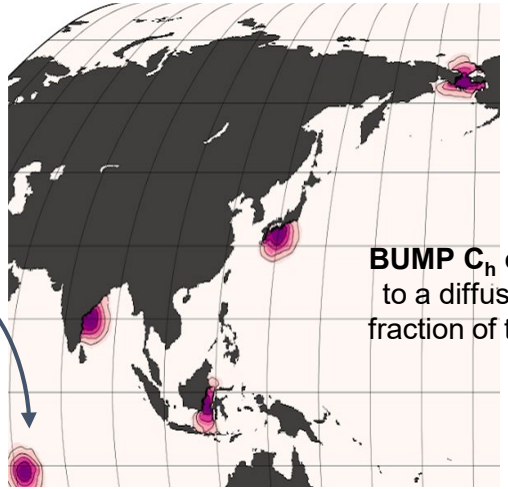
Static Covariance Model

$$B = K F_h^{\frac{1}{2}} D_p D_f C_v^{\frac{1}{2}} C_h C_v^{\frac{1}{2}T} D_f D_p F_h^{\frac{1}{2}T} K^T$$

B-matrix on **U**nstructured **M**esh **P**ackage
(BUMP, Benjamin Menetrier)



Impulse response of $\mathbf{C_h}$ to dirac delta functions



BUMP $\mathbf{C_h}$ operator is similar to a diffusion operator at a fraction of the computational cost

JEDI-GODAS: Covariance Modeling

Static Covariance Model

$$B = K F_h^{\frac{1}{2}} D_p D_f C_v^{\frac{1}{2}} C_h C_v^{\frac{1}{2}^T} D_f D_p F_h^{\frac{1}{2}^T} K^T$$

Vertical correlation operator (convolution)

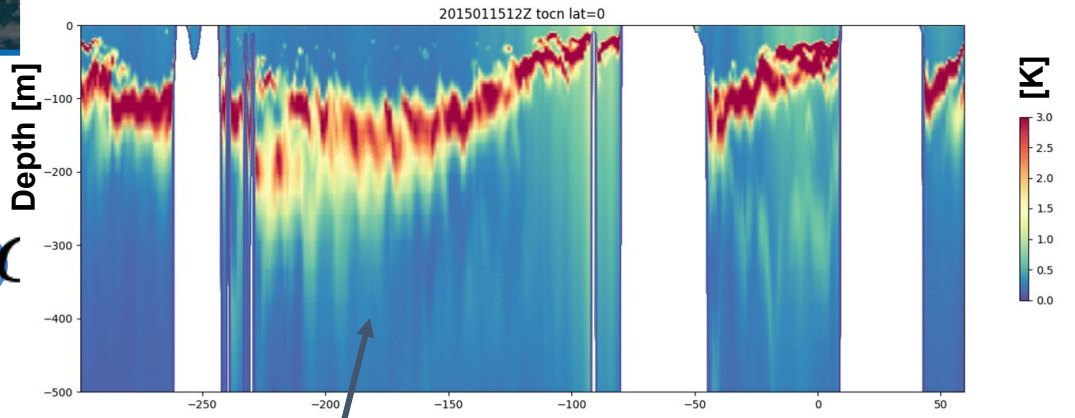
3D Correlation operator could be handled by BUMP

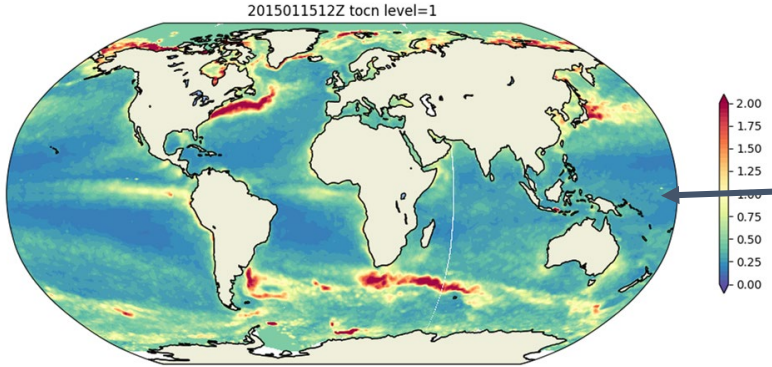
JEDI-GODAS: Covariance Model

Static Covariance Model

$$B = K F_h^{\frac{1}{2}} D_p D_f C$$

Equatorial Temperature background error





Parametric standard deviation of the background error

Ocean:

- Temperature
  - Based on dT/dz Below mixed layer
  - Climatology of SST obs - background within mixed layer (Hybrid-GODAS, Travis Sluka)
- Unbalanced Salinity, currents

Sea ice:

- Ice concentration
- Ice thickness

JEDI-GODAS: Covariance Modeling

Static Covariance Model

$$B = K F_h^{\frac{1}{2}} D_p D_f C_v^{\frac{1}{2}} C_h C_v^{\frac{1}{2}T} D_f D_p F_h^{\frac{1}{2}T} K^T$$

Vertical convolution

Parametric standard deviation of the background error

Ocean:

- Temperature
  - Based on dT/dz Below mixed layer
  - Climatology of SST obs - background within mixed layer (Hybrid-GODAS, Travis Sluka)
- Unbalanced Salinity, currents

Sea ice:

- Ice concentration
- Ice thickness

Horizontal filter

JEDI-GODAS: Covariance Modeling

Static Covariance Model

$$\boldsymbol{B} = \boldsymbol{K} \boldsymbol{F}_h^{\frac{1}{2}} \boldsymbol{D}_p \boldsymbol{D}_f \boldsymbol{C}_v^{\frac{1}{2}} \boldsymbol{C}_h \boldsymbol{C}_v^{\frac{1}{2}^T} \boldsymbol{D}_f \boldsymbol{D}_p \boldsymbol{F}_h^{\frac{1}{2}^T} \boldsymbol{K}^T$$

Weaver et al, 2006

$$\boldsymbol{K} = \begin{bmatrix} I & 0 & 0 & 0 \\ K_{ST} & I & 0 & 0 \\ K_{\eta T} & K_{\eta S} & I & 0 \\ K_{cT} & 0 & 0 & I \end{bmatrix}$$

$$\delta S_B = \frac{\partial S}{\partial T} \delta T$$

Troccoli and Haines, 1999

$$\delta \eta_B = -\int_{Bottom}^{0} \frac{\delta \rho(T,S,z)}{\rho_0} dz$$

Cooper and Haines, 1996

$$\delta c_B = \frac{\partial c}{\partial T} \delta T$$

JEDI-GODAS: Covariance Modeling

Static Covariance Model

$$B = K F_h^{\frac{1}{2}} D_p D_f C_v^{\frac{1}{2}} C_h C_v^{\frac{1}{2}T} D$$

Weaver et al, 2006

$$K = \begin{bmatrix} I & 0 & 0 & 0 \\ K_{ST} & I & 0 & 0 \\ K_{\eta T} & K_{\eta S} & I & 0 \\ K_{cT} & 0 & 0 & I \end{bmatrix}$$

$$\delta S_B = \frac{\partial S}{\partial T}\delta T$$

Troccoli and Haines, 1999

$$\delta \eta_B = -\int_{Bottom}^{0} \frac{\delta \rho(T,S,z)}{\rho_0} dz$$

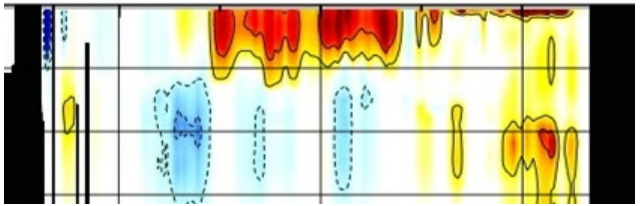
Cooper and Haines, 1996

$$\delta c_B = \frac{\partial c}{\partial T}\delta T$$

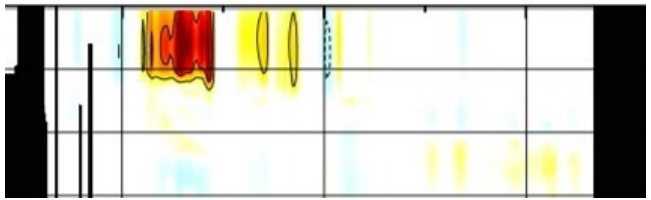
Application example: Altimeter assimilation

Multivariate increment for T and S using balance operators in the B-matrix

Temperature increment at 0N



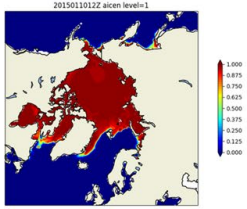
Salinity increment at 0N



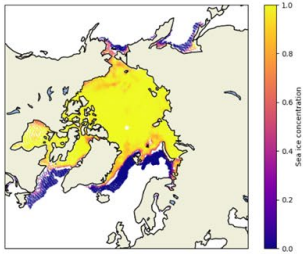
JEDI-GODAS: Covariance Modeling

Hybrid Covariance Model

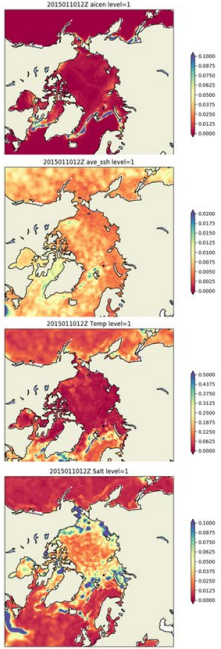
Ice concentration Background



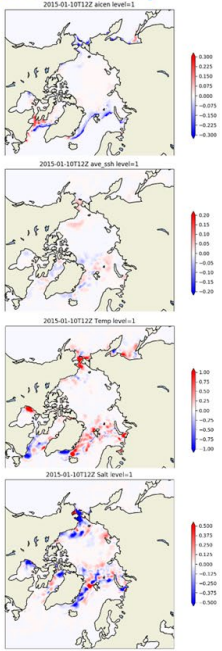
L2 Ice concentration observations (SSMI/SSMIS)



Spread



EnVAR increment (20 members)



$$B = \alpha B_{static} + \beta B_{ens}$$

Ice concentration

Sea surface height [m]

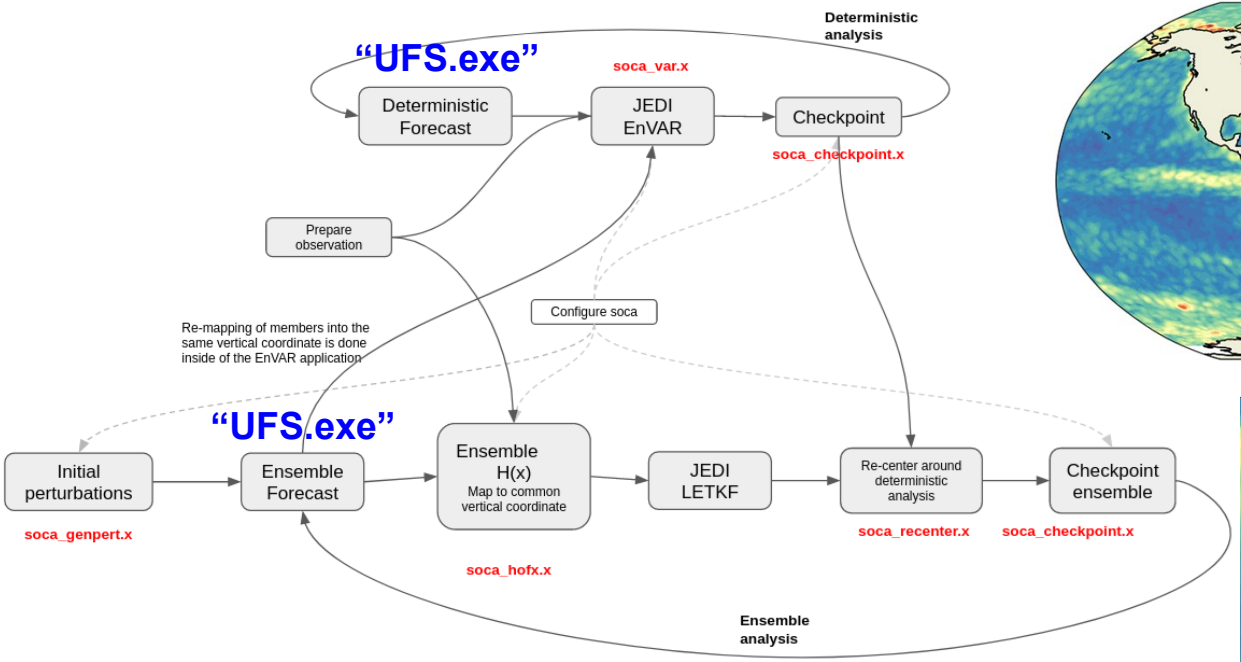
Sea surface temperature [K]

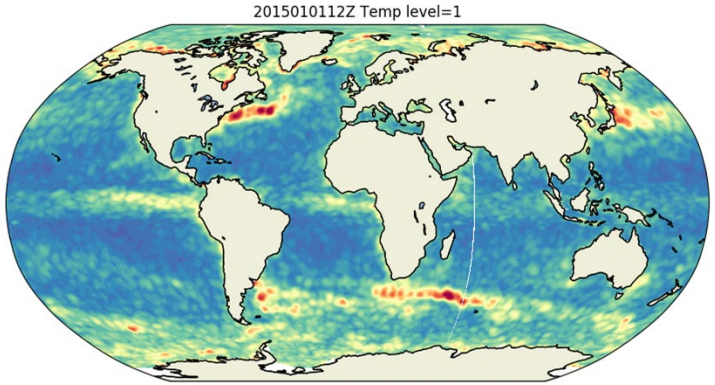
Sea surface salinity [psu]

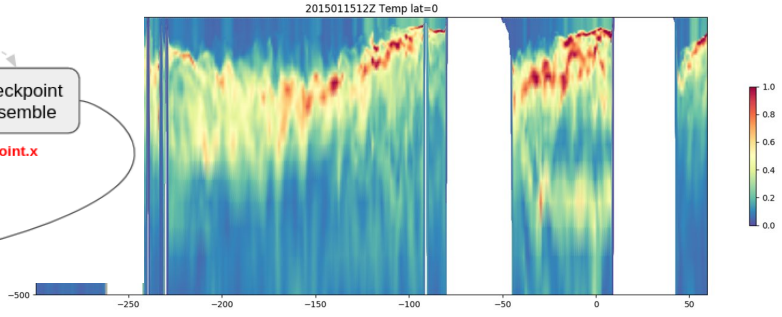
Ensemble B provides cross-covariances between the ocean and sea ice state

Hybrid EnVAR with LETKF perturbations

3D Hybrid EnVAR workflow, consistent with the GSI implementation.
Currently used as benchmark for the development of the 3DVAR



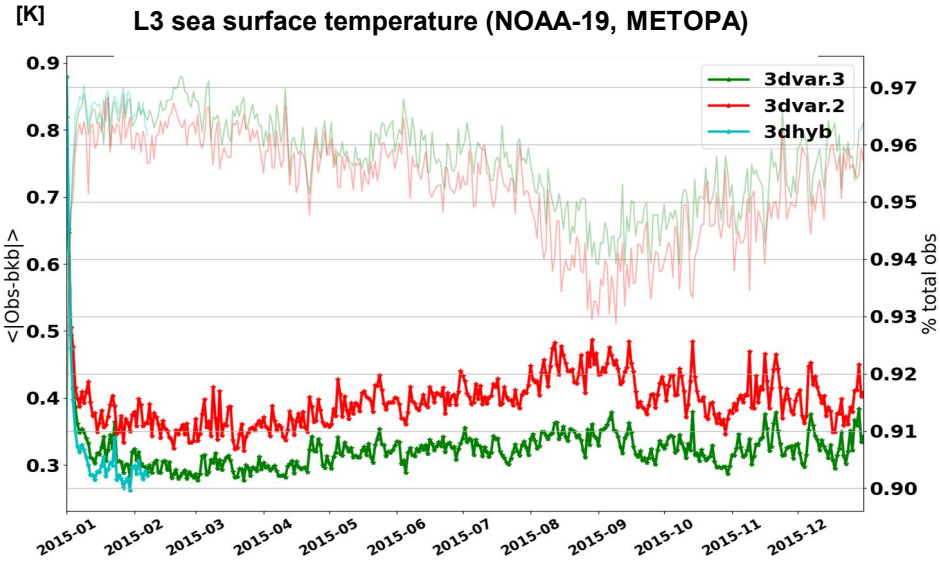


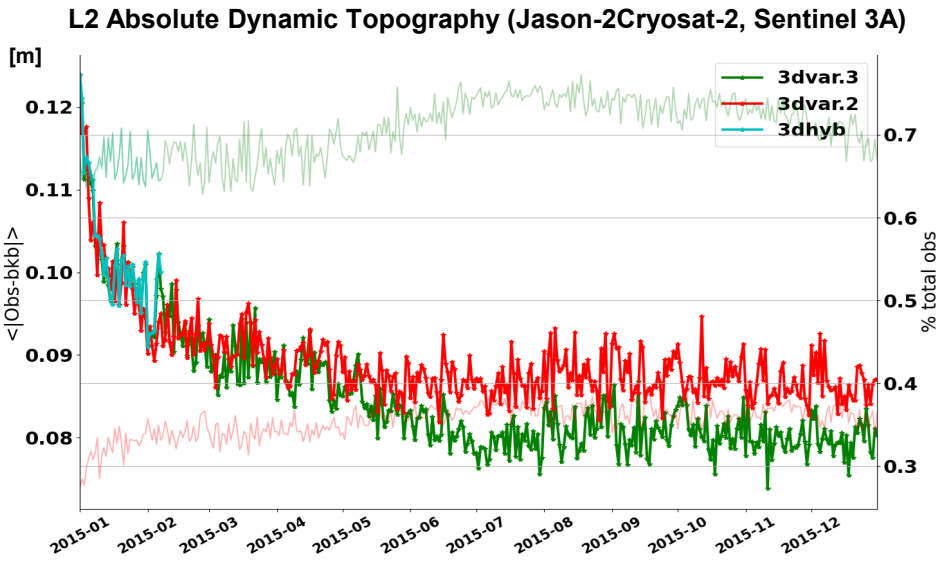


Travis Sluka, Guillaume Vernieres, Stylianos Flampouris, Rahul Mahajan

JEDI-GODAS: Preliminary Results

Global MAE of Obs-Bkg for SST and ADT

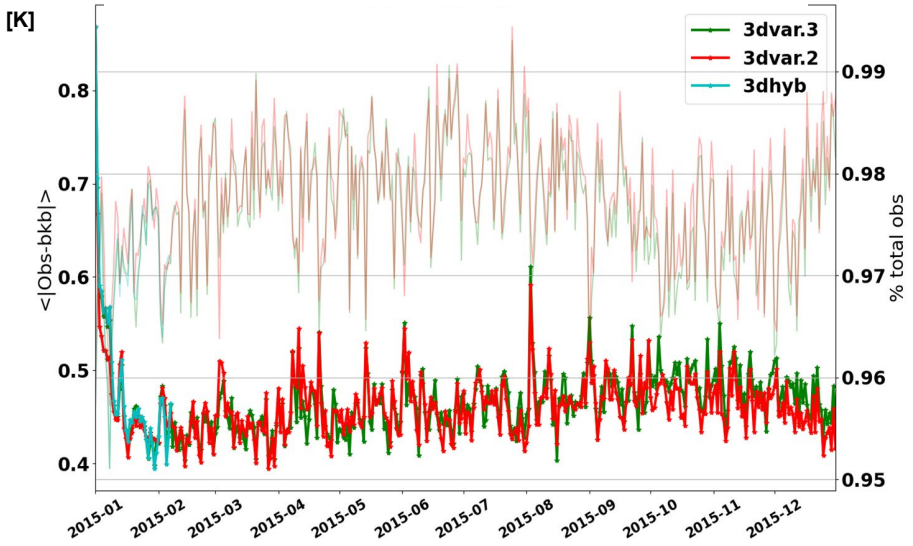




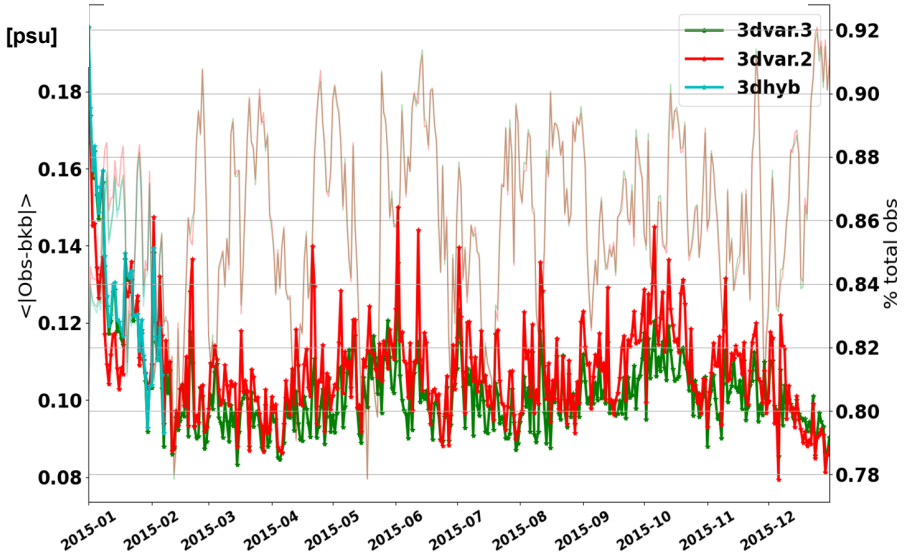
JEDI-GODAS: Preliminary Results

Global MAE of Obs-Bkg for in situ Temperature and Salinity

Argo, CTD, XBT, TAO, PIRATA, RAMA, ...



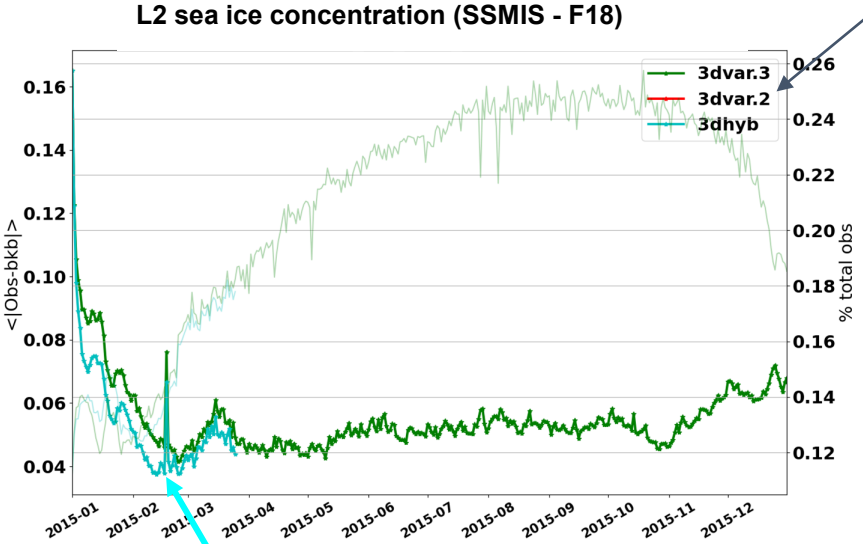
Argo, CTD, PIRATA, RAMA, ...

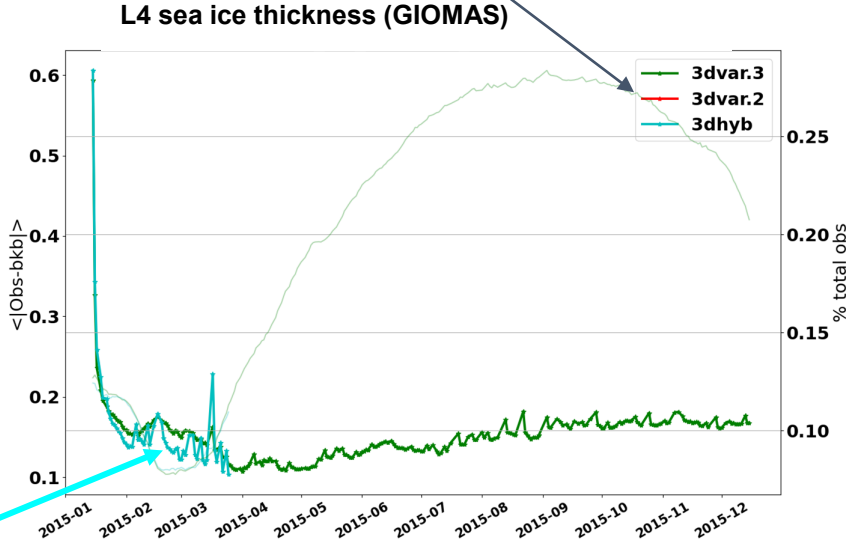


JEDI-GODAS: Preliminary Results

Antarctic sea ice MAE of Obs-Bkg for ice concentration and thickness

Switch from CICE5 to CICE6, no sea ice DA in benchmark 2

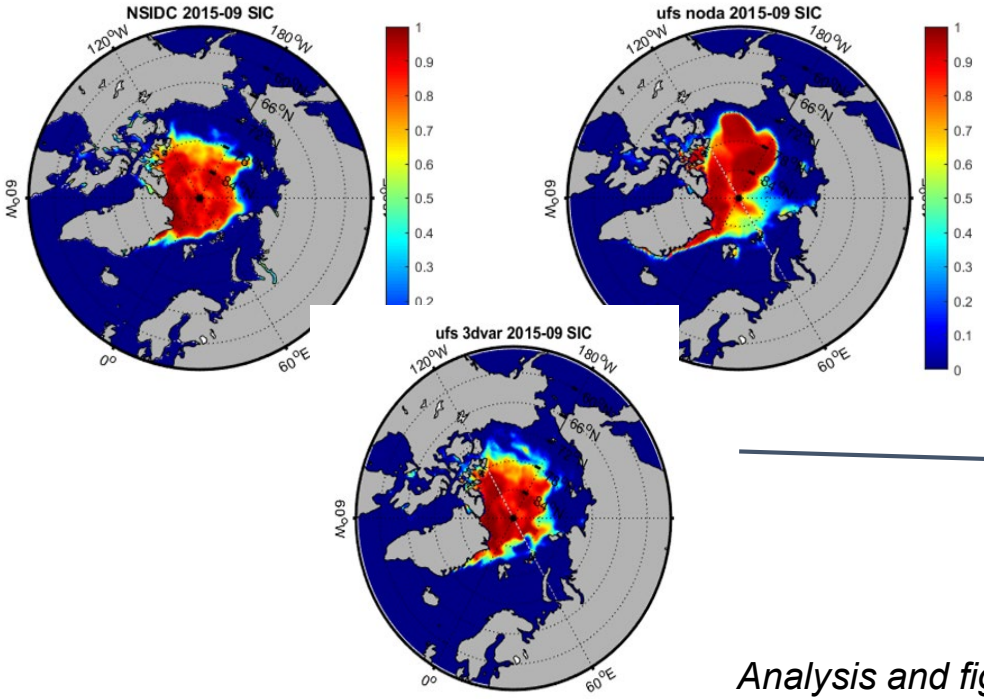


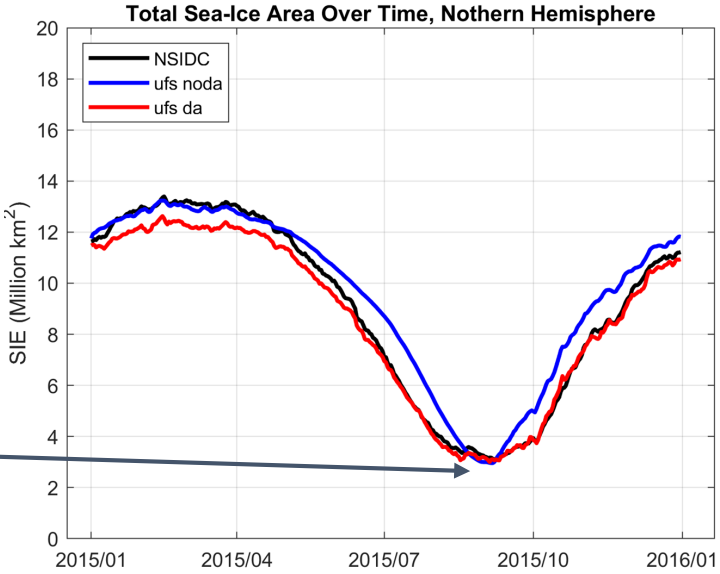


Strongly coupled through $\mathbf{B}_{ens}$

JEDI-GODAS: Preliminary Results

Arctic sea ice extent



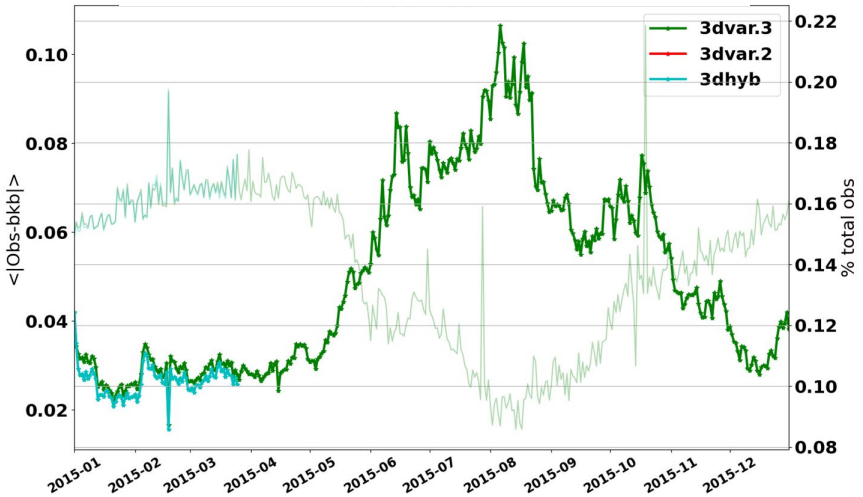


Analysis and figures: ***Yi-Cheng Teng*** *(EMC)*

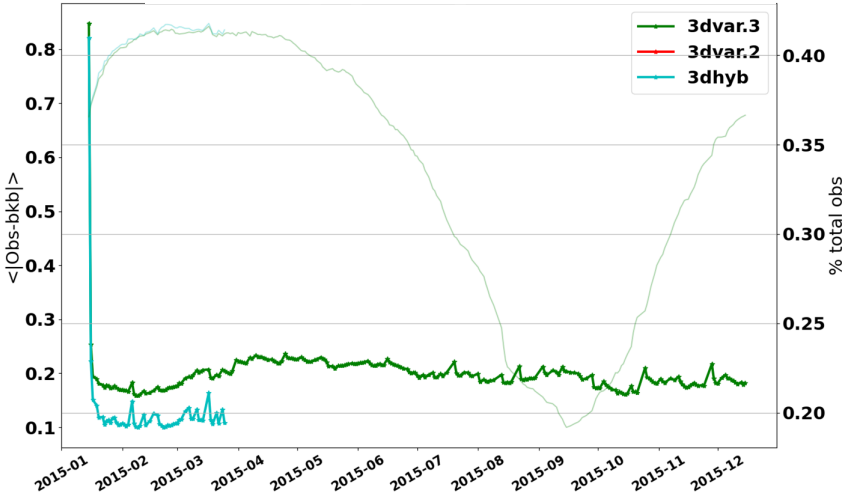
JEDI-GODAS: Preliminary Results

Arctic sea ice MAE of Obs-Bkg for ice concentration and thickness

L2 sea ice concentration (SSMIS - F18)



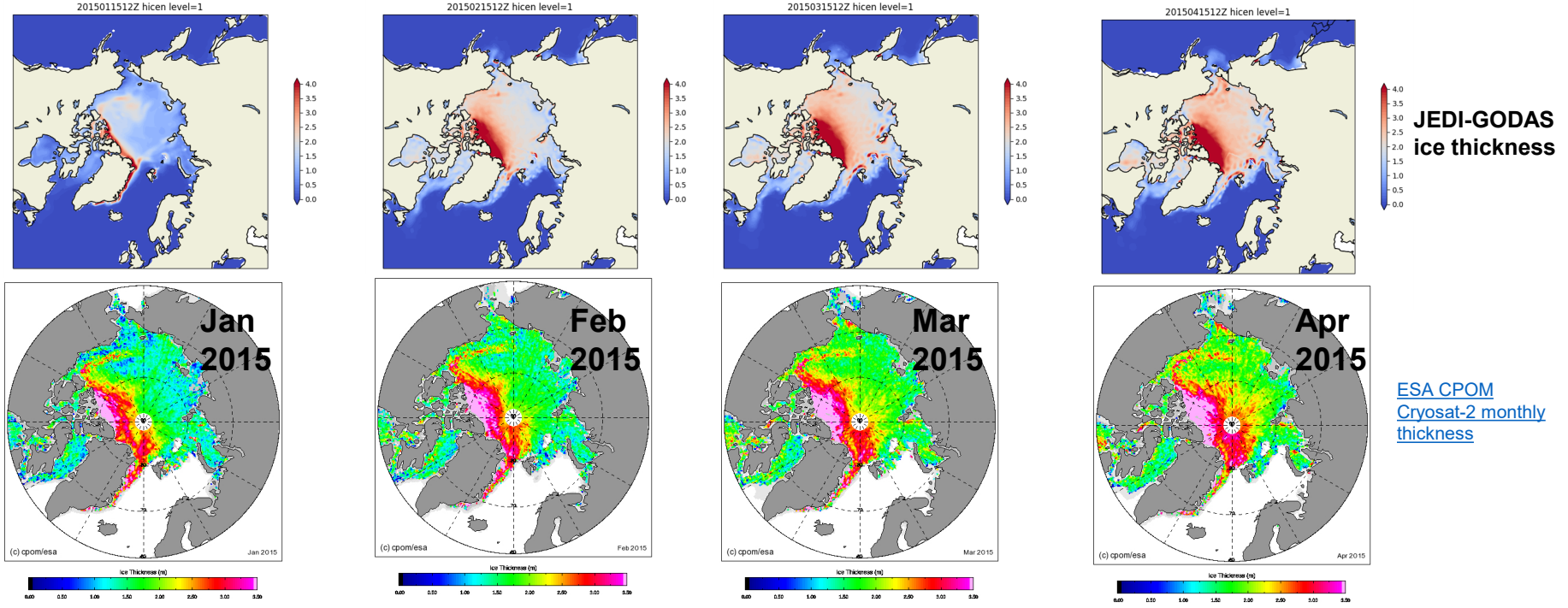
L4 sea ice thickness (GIOMAS)



JEDI-GODAS: Preliminary Results

Arctic sea ice thickness

Qualitative comparison with [ESA CPOM Cryosat-2 monthly thickness]

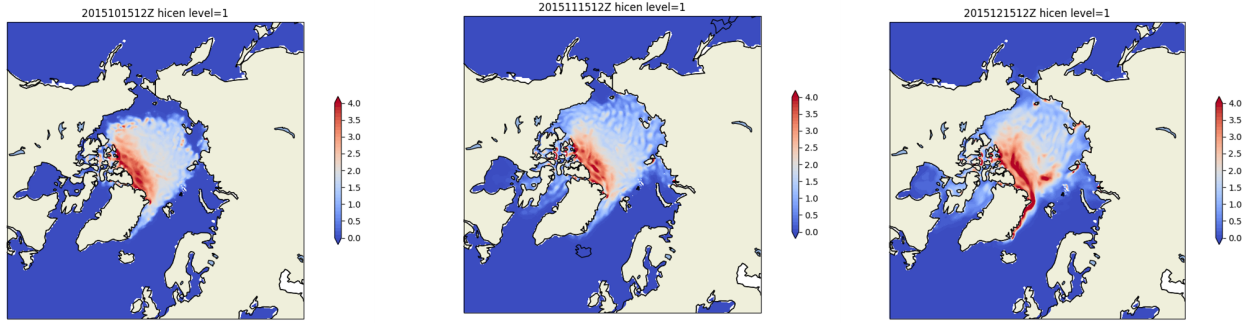


JEDI-GODAS: Preliminary Results

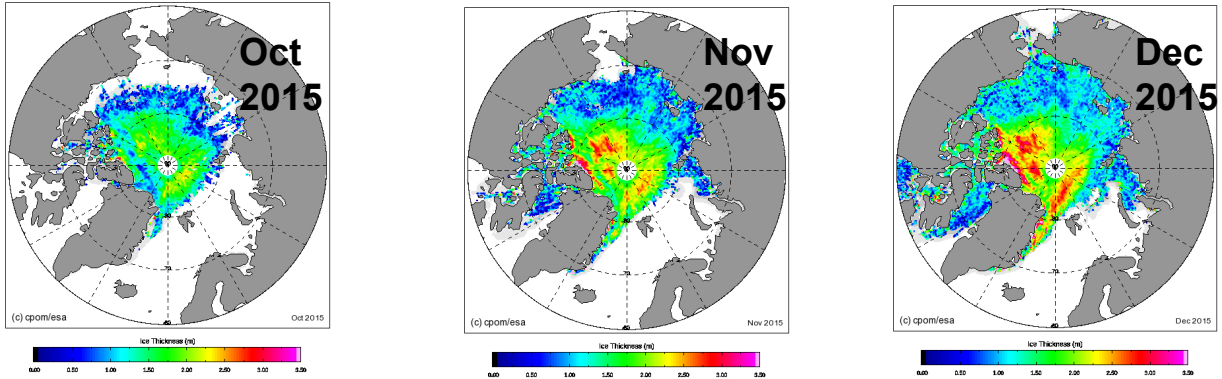
Arctic sea ice thickness

Qualitative comparison with [ESA CPOM Cryosat-2 monthly thickness]

JEDI-GODAS ice thickness



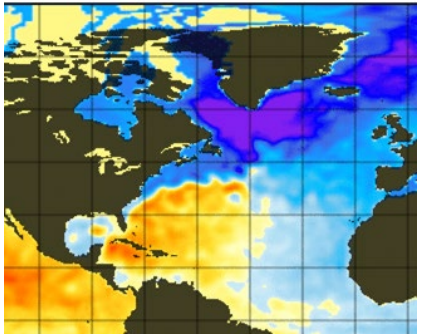
[ESA CPOM Cryosat-2 monthly thickness]



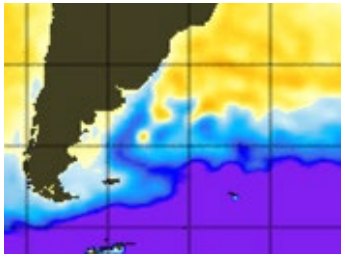
JEDI-GODAS: Preliminary Results

Background SSH (06/24/2016) vs objective analysis of ADT (AVISO), offset adjusted visually.

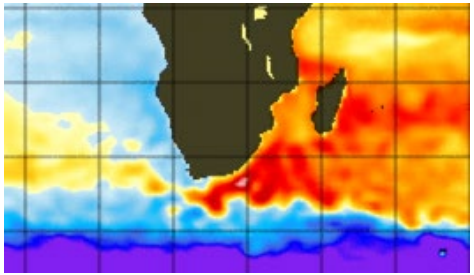
North Atlantic & Gulf of Mexico



Falkland Current

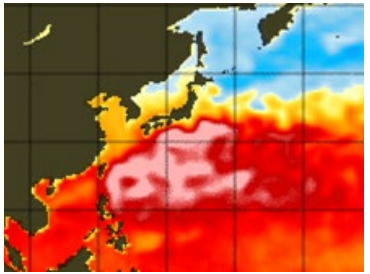


Agulhas Current



Absolute dynamic topography [m]

Kuroshio, large meander state



Experiment shown is for MOM6-SIS2, not the UFS

What's Next? Questions?

- Ocean sea ice reanalysis for CPC and EMC (**NG-GODAS**)
- Other applications of SOCA/Marine JEDI:
  - S2S initialization (¼ degree)
  - Regional MOM6 for HAFS
- More observations through careful OSE
- DA algorithm refinement (4D)