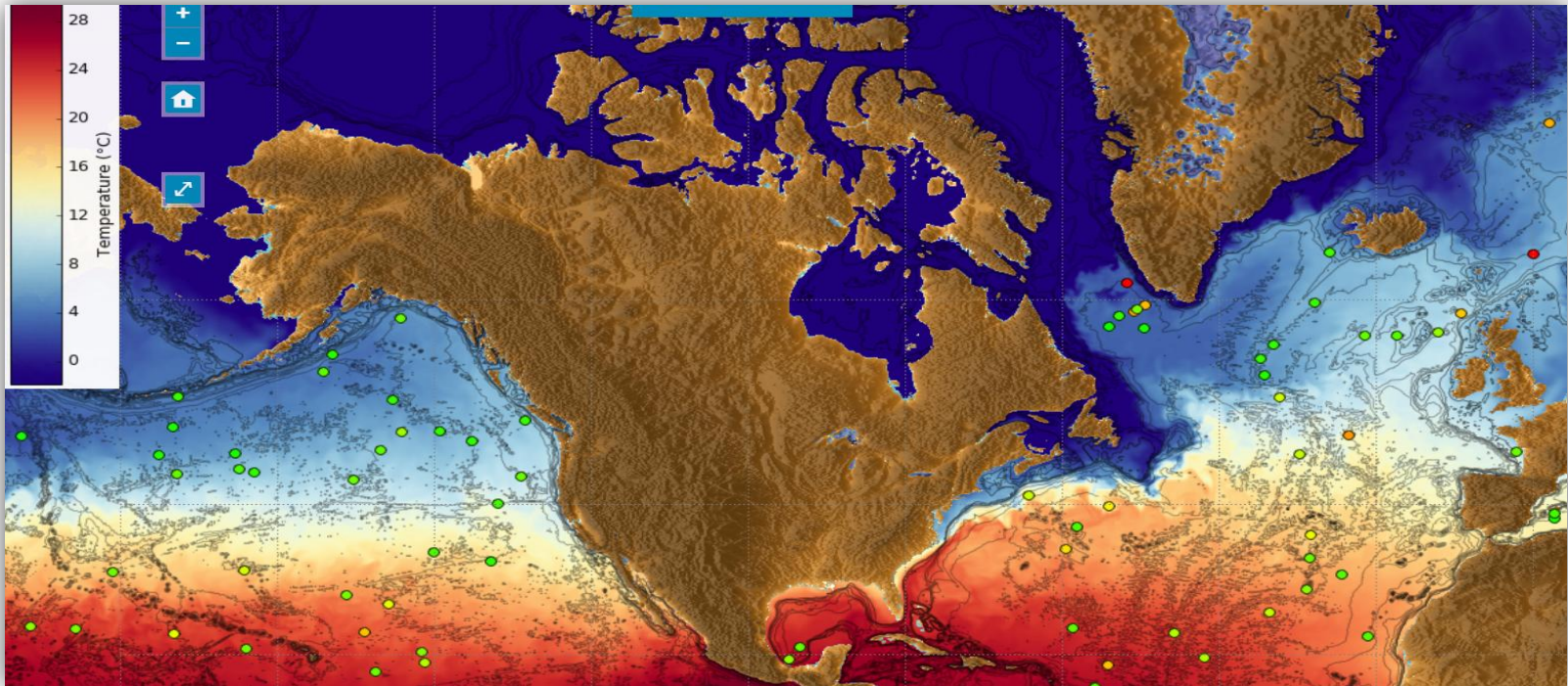


# What Operational Oceanography can do for ARGO?



## What can ARGO can do for Operational Oceanography?

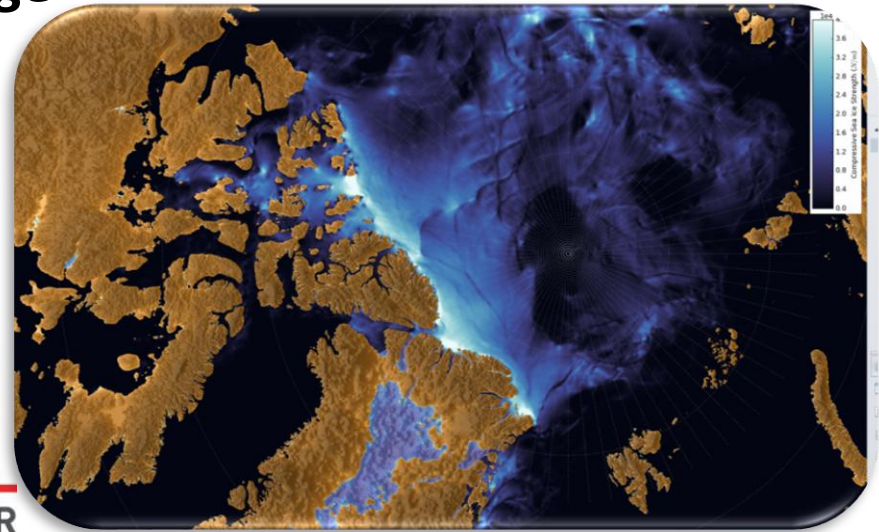
# CONCEPTS Ocean Ice Forecasting

## Canadian Operational Network of Coupled Environmental Prediction Systems

- Fisheries and Oceans Canada
- Environment and Climate Change Canada
- National Defense

Partner and collaborate with

- Mercator Ocean
- GODAE Ocean View



**GODAE** OceanView



Canada

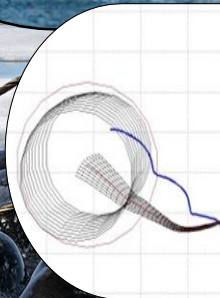
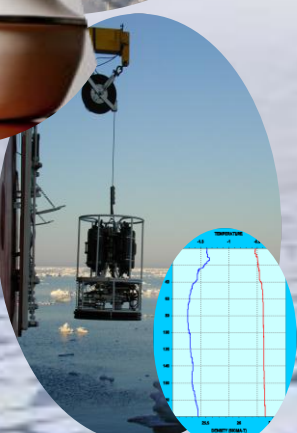
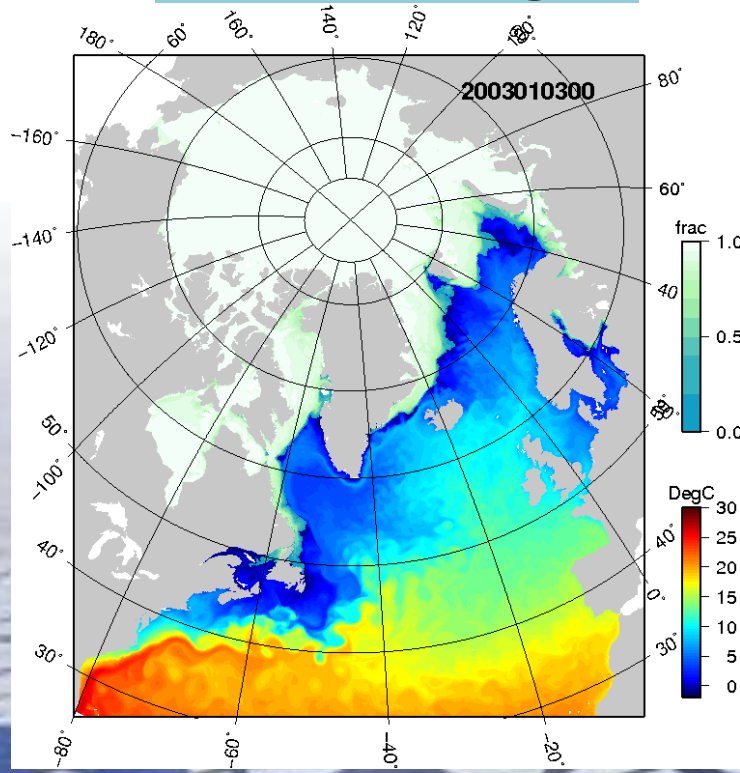


# Oceanographic Information Provision

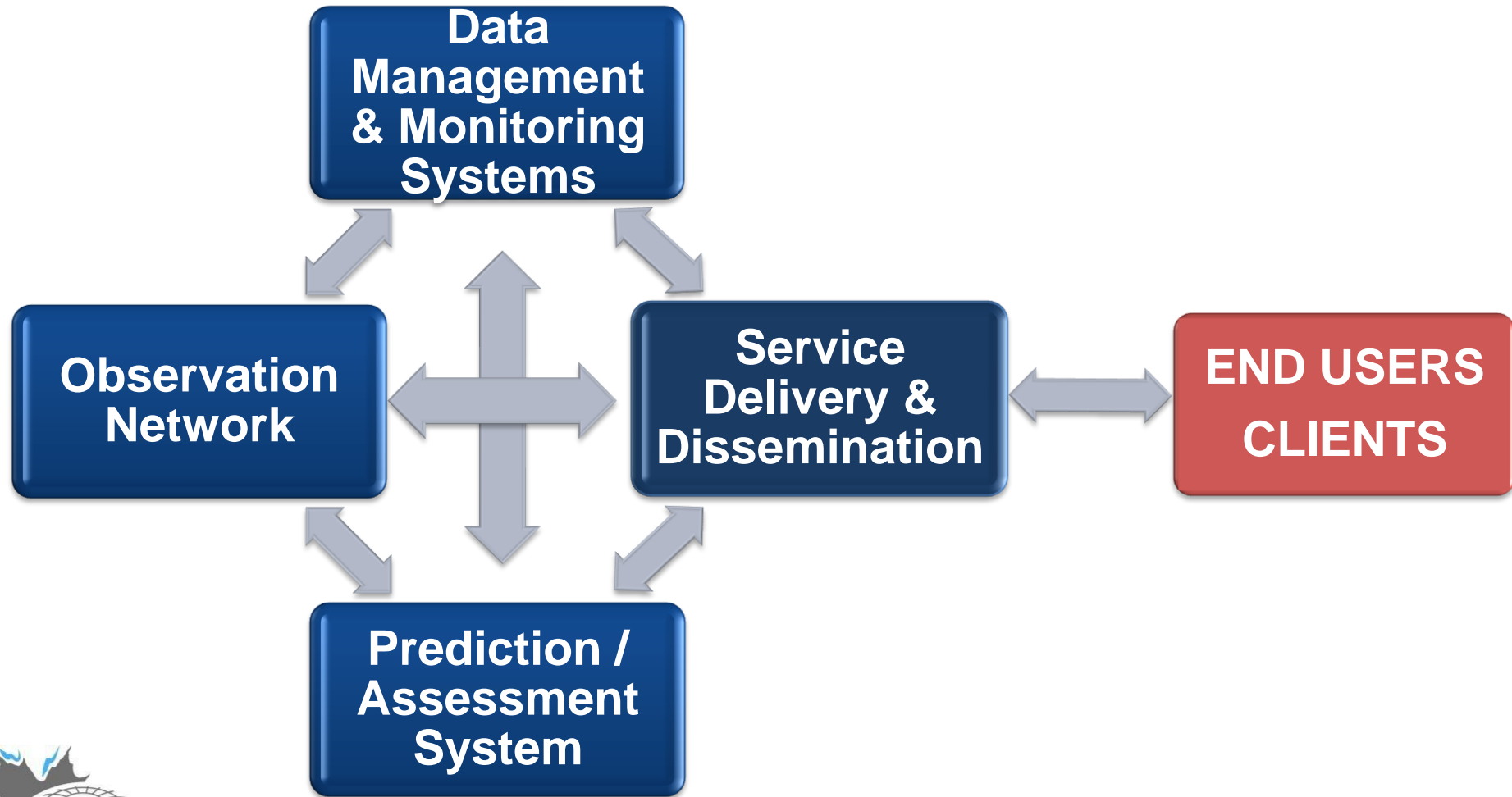
Observations

Information

Ocean  
Modelling



# Operational Oceanography supply Chain



Fisheries and Oceans  
Canada

Pêches et Océans  
Canada



Environment  
Canada

Environnement  
Canada



National  
Defence

8  
Défense  
nationale



# International partner

Ocean forecasting requires a large breadth of expertise

CONCEPTS accelerates it's ocean forecasting R&D by collaborating with: **Mercator- Océan, France** the world leading ocean forecasting center

A rich research exchange and inter-dependency is developing into strong long term partnership



Fisheries and Oceans  
Canada

Pêches et Océans  
Canada



Environment  
Canada

Environnement  
Canada



National  
Défense

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# International collaborations

GODAE Ocean View (GOV) is a Multi country network of leaders in operational oceanographic research



Through GOV:

CONCEPTS leads and participates in common research endeavours across international ocean forecasting centers from US, India, UK, Japan, Brazil, France, Italy,, Australia and Canada

CONCEPTS builds knowledge, expertise and relations with space agencies of the world (CNES, ESA, NASA....) .. And ARGO



Fisheries and Oceans  
Canada

Pêches et Océans  
Canada



Environment  
Canada

Environnement  
Canada



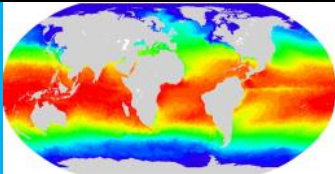

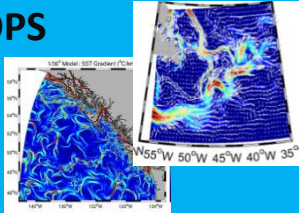
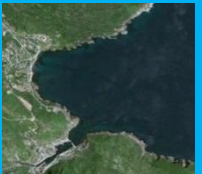
National  
Défence

10  
Défense  
nationale

# CONCEPTS

## Canadian Operational Network of Coupled Environmental Prediction Systems

Suite of oceanographic prediction systems that will be coupled to Atmospheric and Waves Forecasts or run as standalone systems.

ICE- Ocean Prediction Systems	 GIOPS	RIOPS 	CIOPS 	Near Shore 
Operational Start	2014	2016	2017 and beyond 2016 for Great Lakes	2018 Beyond
H Resolution	25 km	2-6 km	2 km	500m or less

Computing Power increasing faster than ocean observing capacity

Not enough data to evaluate and constrain fine scale features in Ocean prediction system



# Increasing Capability

## DFO Operational Oceanography Desk

**3 DFO staff at CMC since Sept 2017**

Monitoring, **In situ observation QC**, Product Dissemination

## Ocean Protection Plan

DFO 14 permanent new staff, ECCC 3 new Research scientists and 2 postdocs

Near-shore NEMO modelling

Improving drift prediction capacity (DFO and ECCC COSMOS)

Probabilistic forecasting

## YOPP

Coupled RIOPS-CAPS (2.5km Pan-Arctic GEM) + RIOPS Ocean Assimilation

CREG12-SAM2: Coastal In situ and SLA, under ice

## GIOPS

Coupled DA, ice thickness assim

## Sea ice

Address issue of overactive summer melt, land fast ice, MIZ processes



Fisheries and Oceans  
Canada

Pêches et Océans  
Canada



Environment  
Canada

Environnement  
Canada

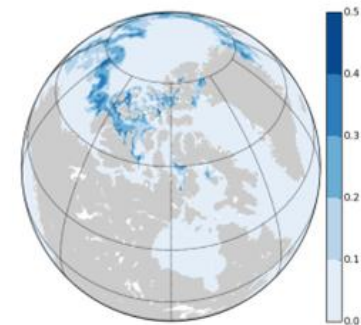
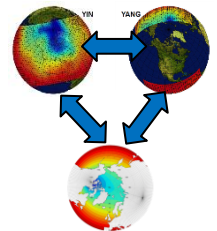
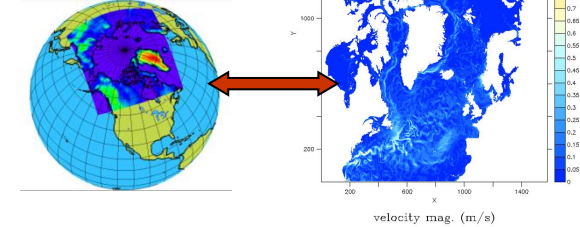


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nationale

# ECCEC polar forecasts for YOPP

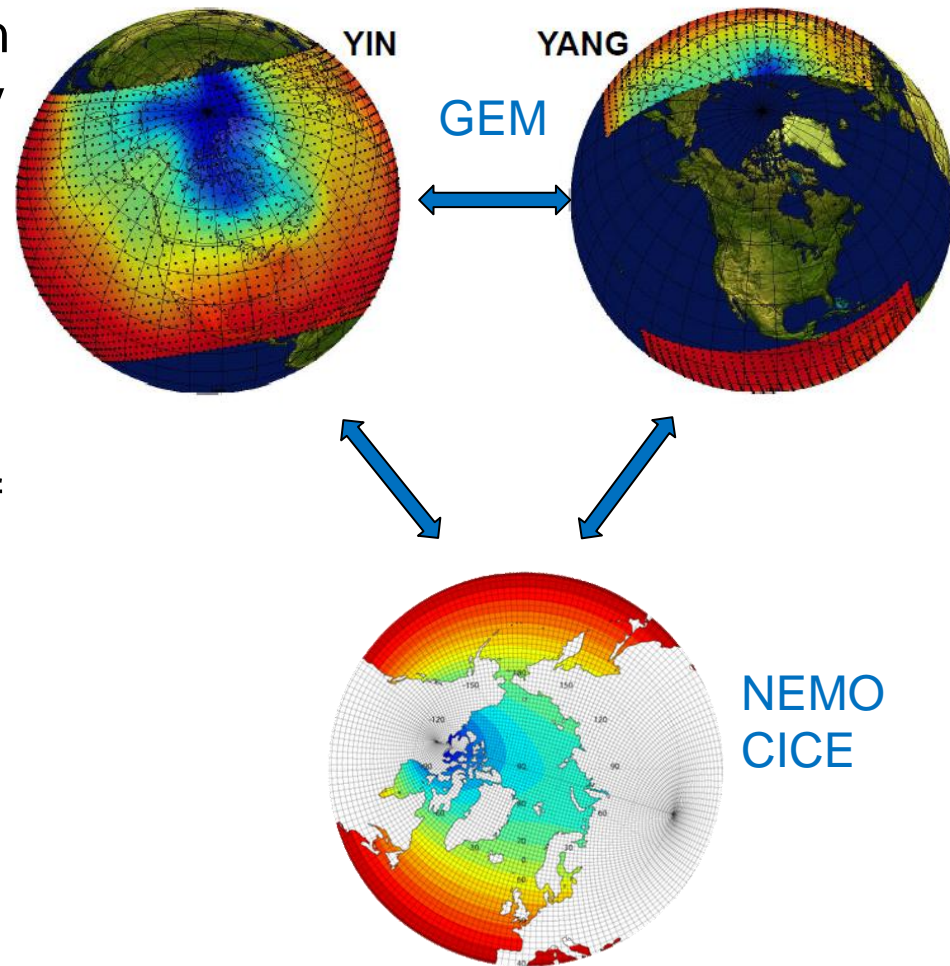
- Coupled CAPS-RIOPS
  - Arctic/N.Atl., fully-coupled A-I-O, 3km(A)-3-8km(IO), 2day
- GDPS-GIOPS
  - Global, fully-coupled A-I-O, 15km(A)-1/4deg(IO), 10day
- GIOPS Ensembles
  - Global, 1/4deg, 32 day, 20 member
- Seasonal Predictions
  - CanESM & GEM-NEMO-CICE
  - Global, 1deg, 2x20 member



# Global Coupled Medium-range Deterministic Forecasts



- Coupled NWP system running in operations at CCMEP since July 2016 (**Operational Nov1, 2017!**).
  - GDPS coupled to GLOPS
  - Global, fully-coupled A-I-O, 25 km(A)-1/4deg(IO),
  - 10 day forecast (2/day)
- Horizontal resolution increase of atmosphere to 15 km in 2018
- Available on GeoMet and RPNWMS:
  - E.g. [www.meteocentre.com/plus](http://www.meteocentre.com/plus)
- MSC datamart
  - [dd.weather.gc.ca](http://dd.weather.gc.ca)
  - Atm: GRIB2,
  - Ocean/Ice: Netcdf4



Smith et al., MWR, in review

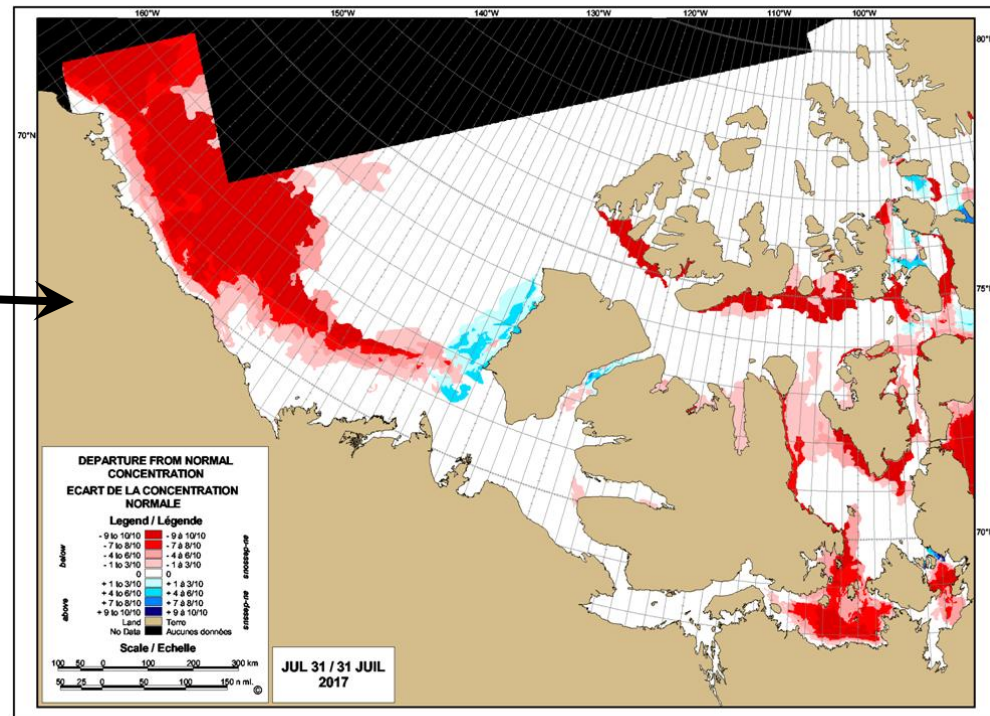
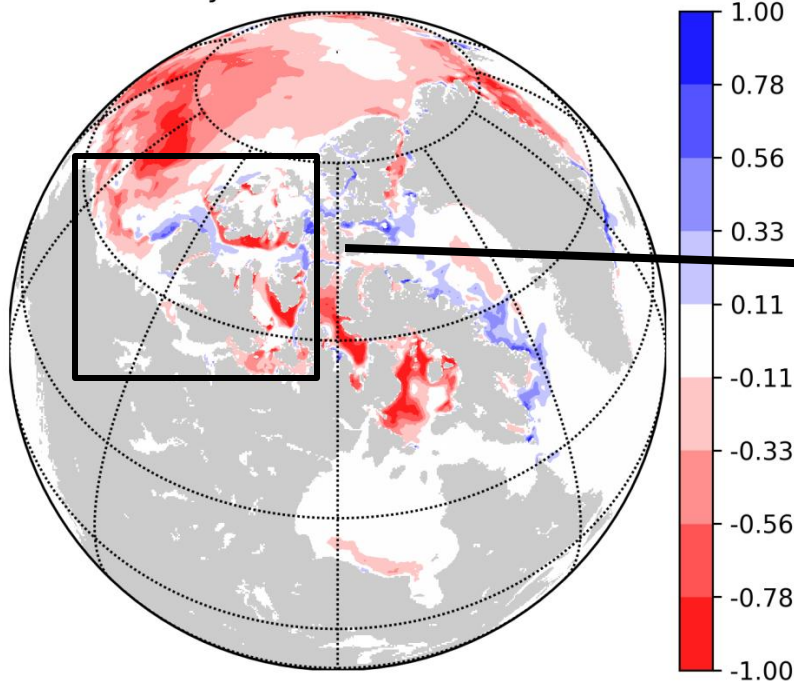


# 32 day Ensemble GLOPS forecasts

- Forced by Global Ensemble Prediction System (50km)
  - Coupling to be introduced winter 2018

## Canadian Ice Service Regional Analysis

Anomaly 2017-07-06+504 hours



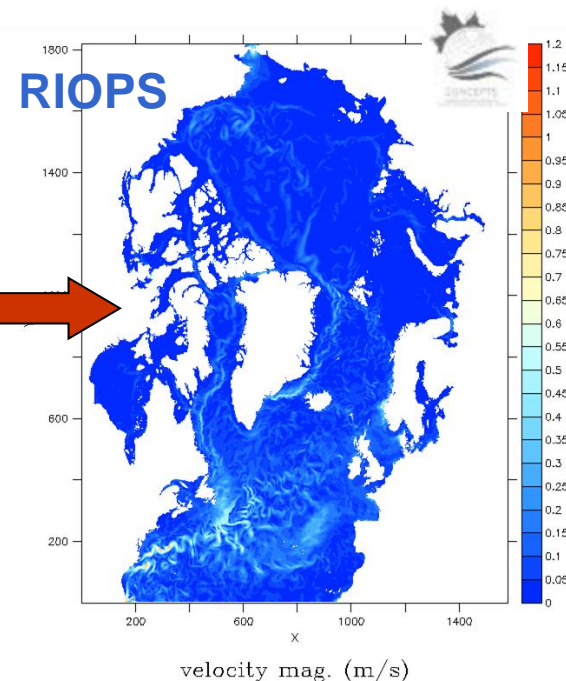
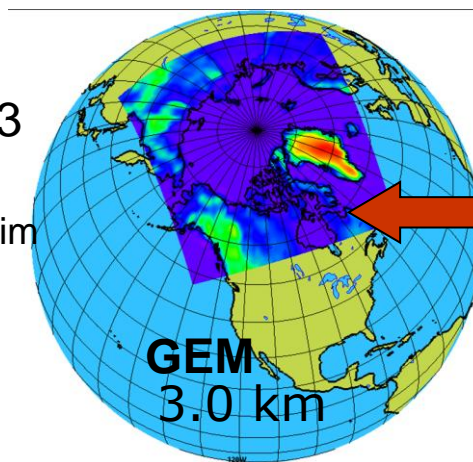
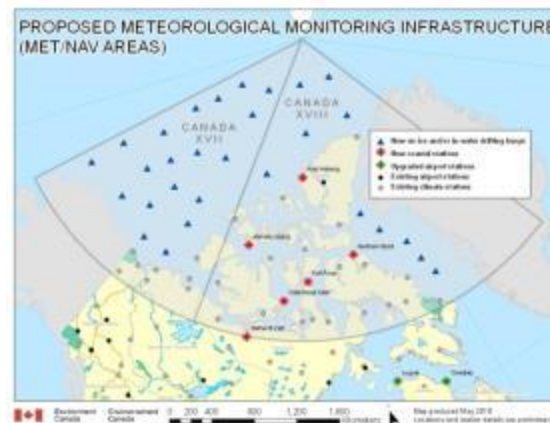
STATISTICS BASED UPON 1981-2010  
LES STATISTIQUES BASÉES SUR 1981-2010

# Canadian Arctic Prediction System (CAPS)

An ECCC contribution for YOPP

High-resolution coupled atmosphere-ice-ocean prediction system

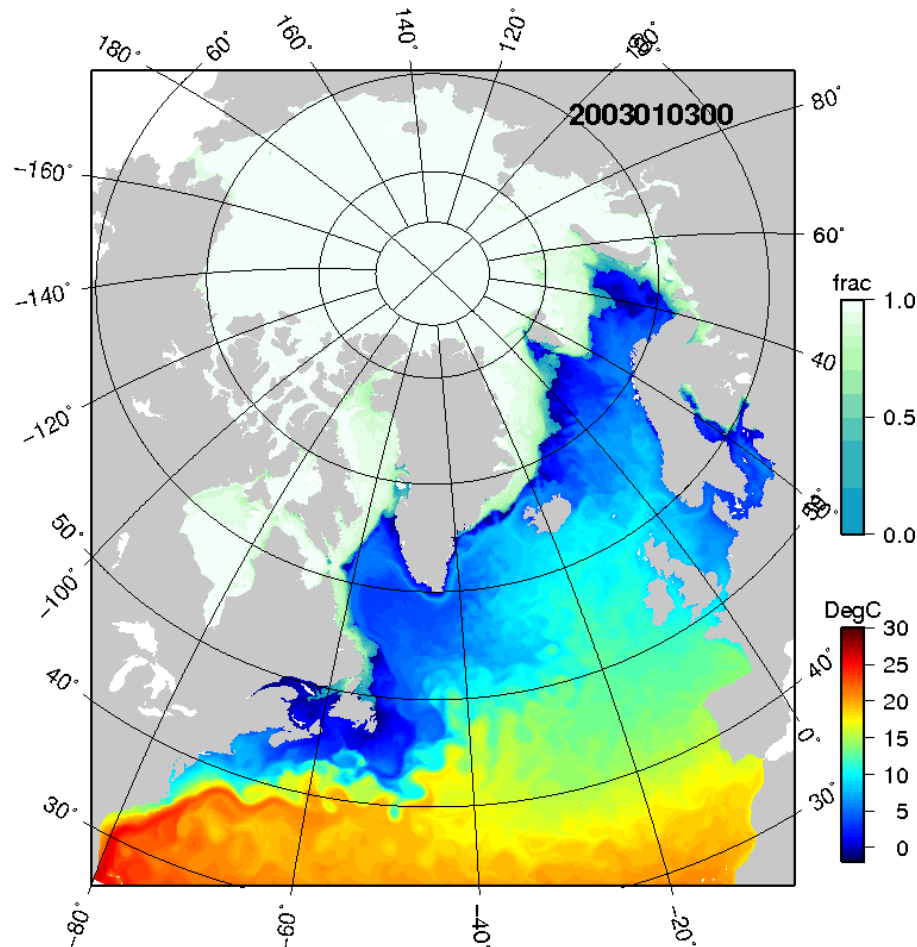
- In support of :
  - Weather prediction for northern Canada
  - EC METAREAs Services
  - Marine emergency response
- Coupled atmosphere-ice-ocean model
  - GEM (3.0 km)
    - Improved microphysics
  - NEMO-CICE (3-8 km)/WW3
    - Tides, landfast ice
    - Improved ice-ocean assim
  - 48 h forecasts (2/day)





CONCEPTS  
CANADIAN OPERATIONAL NETWORK OF  
COUPLED ENVIRONMENTAL PREDICTION SYSTEMS

# The Regional Ice-Ocean Prediction System (RIOPS)



Lemieux et al., QJRMS, 2015

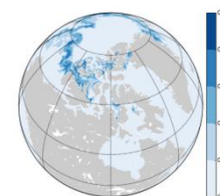
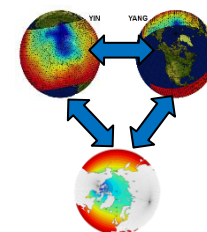
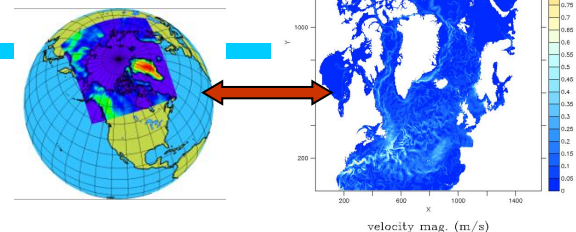
Dupont et al., GMD, 2015

- **Purpose:**
  - METAREAs 17&18
  - CIS support
  - Iceberg drift
  - Fisheries and aquaculture management
  - YOPP Coupled system CAPS
- 3-5km resolution in the Arctic
- 4x48hr ice-ocean forecasts
- 3DVar ice analysis
  - SSMI, SSMI/S
  - AVHRR, ASCAT, AMSR2
  - CIS charts, Radarsat analyses
- Improved ice model physics
  - Lanfast ice, tensile strength
- Spectral nudging to GLOPS ocean analyses; Assimilation soon on 1/12<sup>th</sup>
- Expanding to pan Canadian Domain: 3 Oceans



# ECCEC polar forecasts for YOPP

- Coupled CAPS-RIOPS
  - Arctic/N.Atl., fully-coupled A-I-O, 3km(A)-3-8km(IO), 2day
- GDPS-GIOPS
  - Global, fully-coupled A-I-O, 15km(A)-1/4deg(IO), 10day
- GIOPS Ensembles
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- Seasonal Predictions
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  - Global, 1deg, 2x20 member



Fisheries and Oceans  
Canada

Pêches et Océans  
Canada



Environment  
Canada

Environnement  
Canada



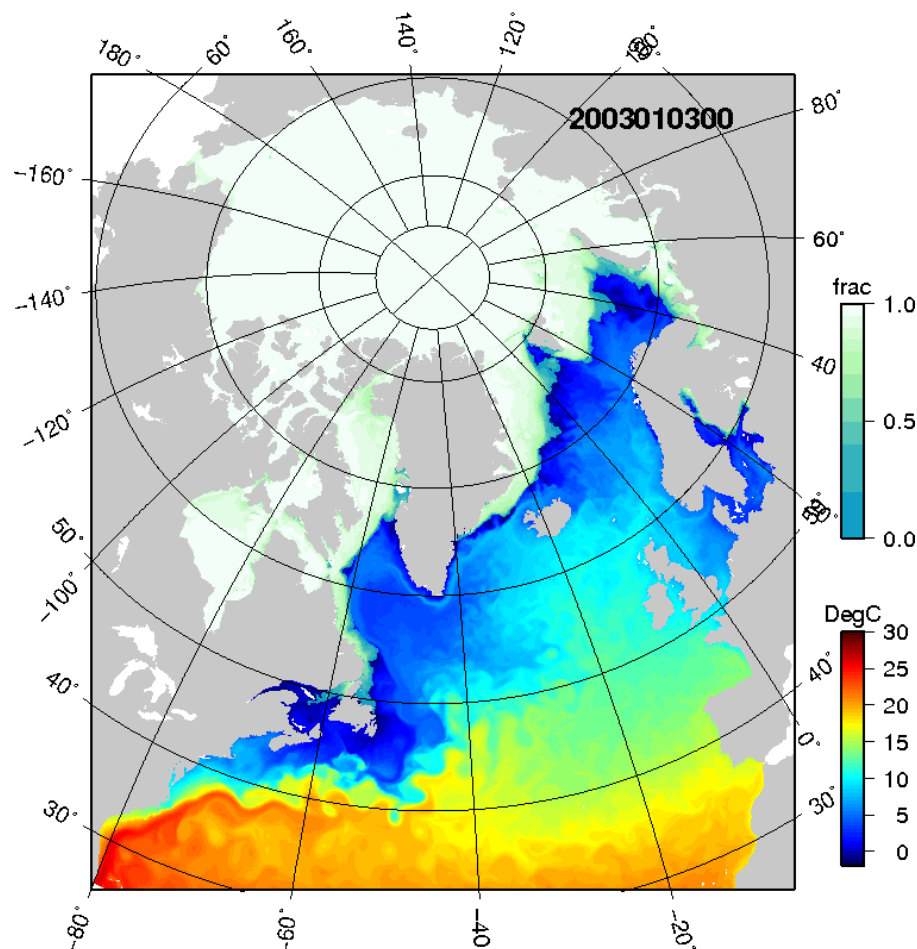
National  
Defence

Défense  
nationale



CONCEPTS  
CANADIAN OPERATIONAL NETWORK OF  
COUPLED ENVIRONMENTAL PREDICTION SYSTEMS

# The Regional Ice-Ocean Prediction System (RIOPS)



Lemieux et al., QJRMS, 2015  
Dupont et al., GMD, 2015

- **Purpose:**
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- 3-5km resolution in the Arctic
- 4x48hr ice-ocean forecasts
- 3DVar ice analysis
  - SSMI, SSMI/S
  - AVHRR, ASCAT, AMSR2
  - CIS charts, Radarsat analyses
- Improved ice model physics
  - Lanfast ice, tensile strength
- Spectral nudging to GLOPS ocean analyses
- Real-time production since April 2016



Fisheries and Oceans  
Canada

Pêches et Océans  
Canada



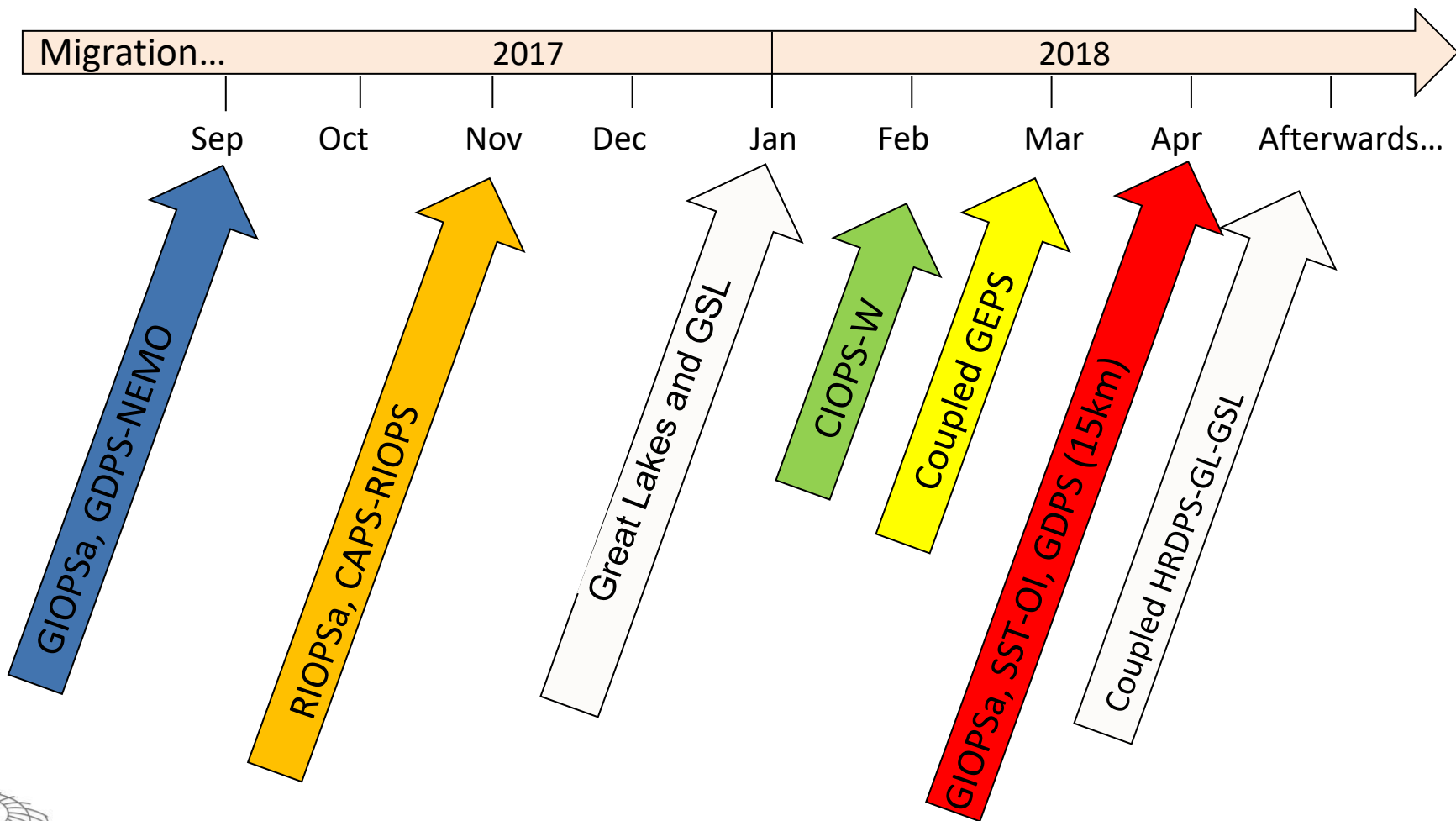
Environment  
Canada

Environnement  
Canada



National  
Defence

Défense  
nationale



Fisheries and Oceans  
Canada

Pêches et Océans  
Canada



Environment  
Canada

Environnement  
Canada

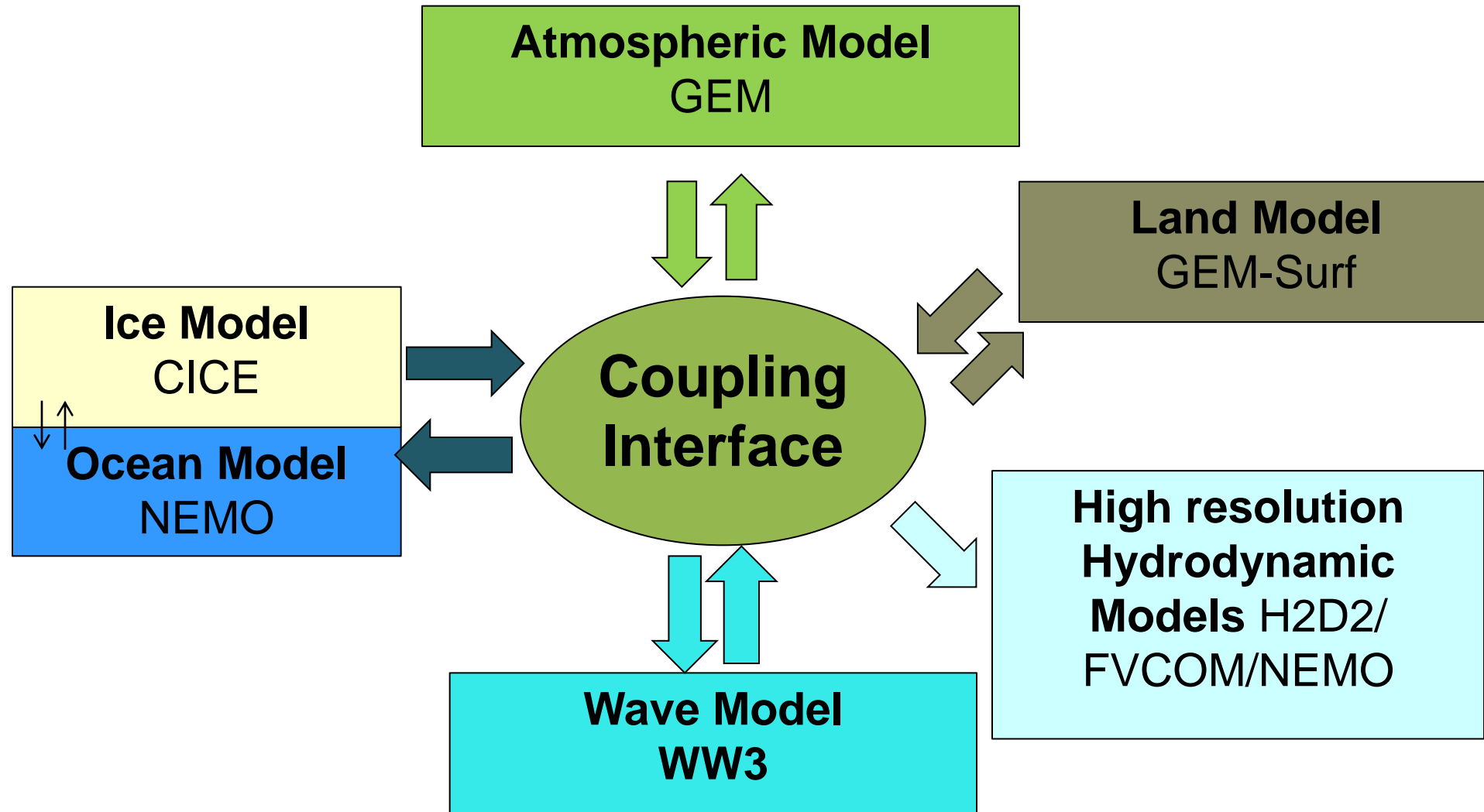


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Défense  
nationale

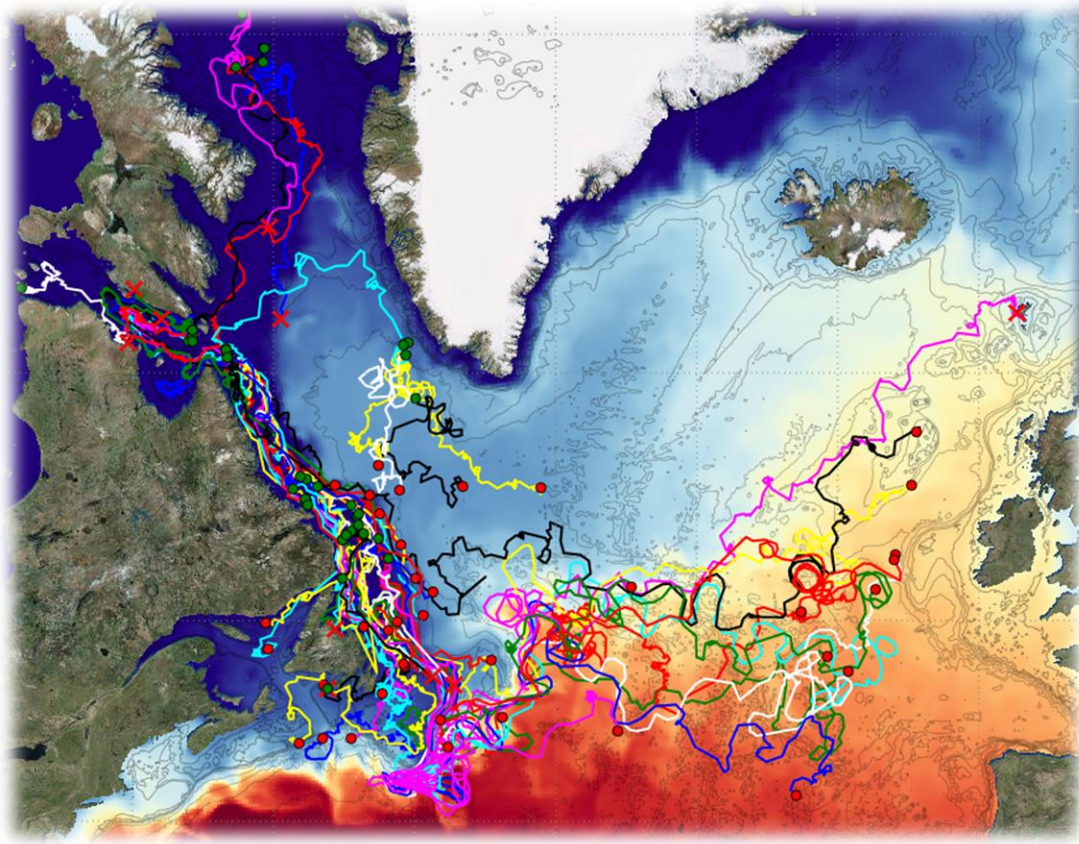


# Towards Comprehensive Environmental Prediction



# Increase in Collaboration with CCG Metocean iSVP Could be used for Argo Equiv.

- 50 drifters deployed



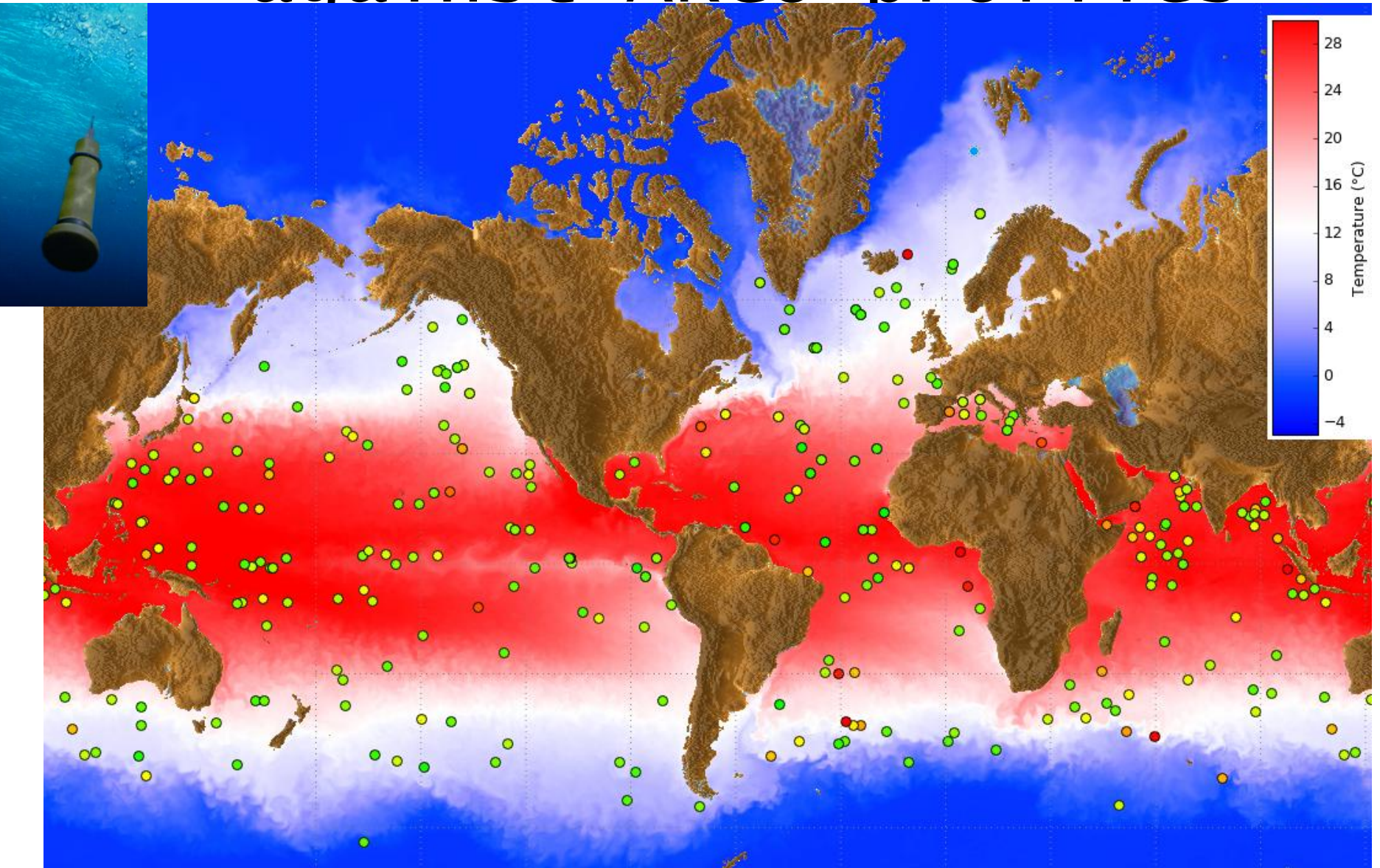
# CONCEPTS Observations

## Arctic Plans 2018

- 5 ARGO floats: daily profile BEAUFORT/ Arctic
- 2 ARGO floats Hudson
- METAREA ice drifter deployment (Herc deployment)
- 3 surface drifters Hudson Strait
- Using operational CCG Ice Breakers
- New ARGO profiler standing offer: NKE
- DND purchasing ALAMO floats (4) for air deployment in Arctic.



# Verification against ARGO profiles





# The Task Teams (TT) of GOV

## → Development of new capabilities

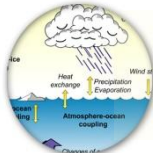
TTs address specific topics of particular interest to GOV

## → International collaboration

TTs work in collaboration with international programmes and research groups



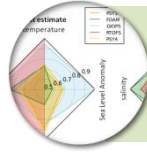
**COSS-TT:** Coastal Ocean and Shelf Seas



**CP-TT:** Coupled Prediction



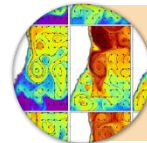
**DA-TT:** Data Assimilation



**IV-TT:** Intercomparisons and Validation



**MEAP-TT:** Marine Ecosystem Analysis and Prediction

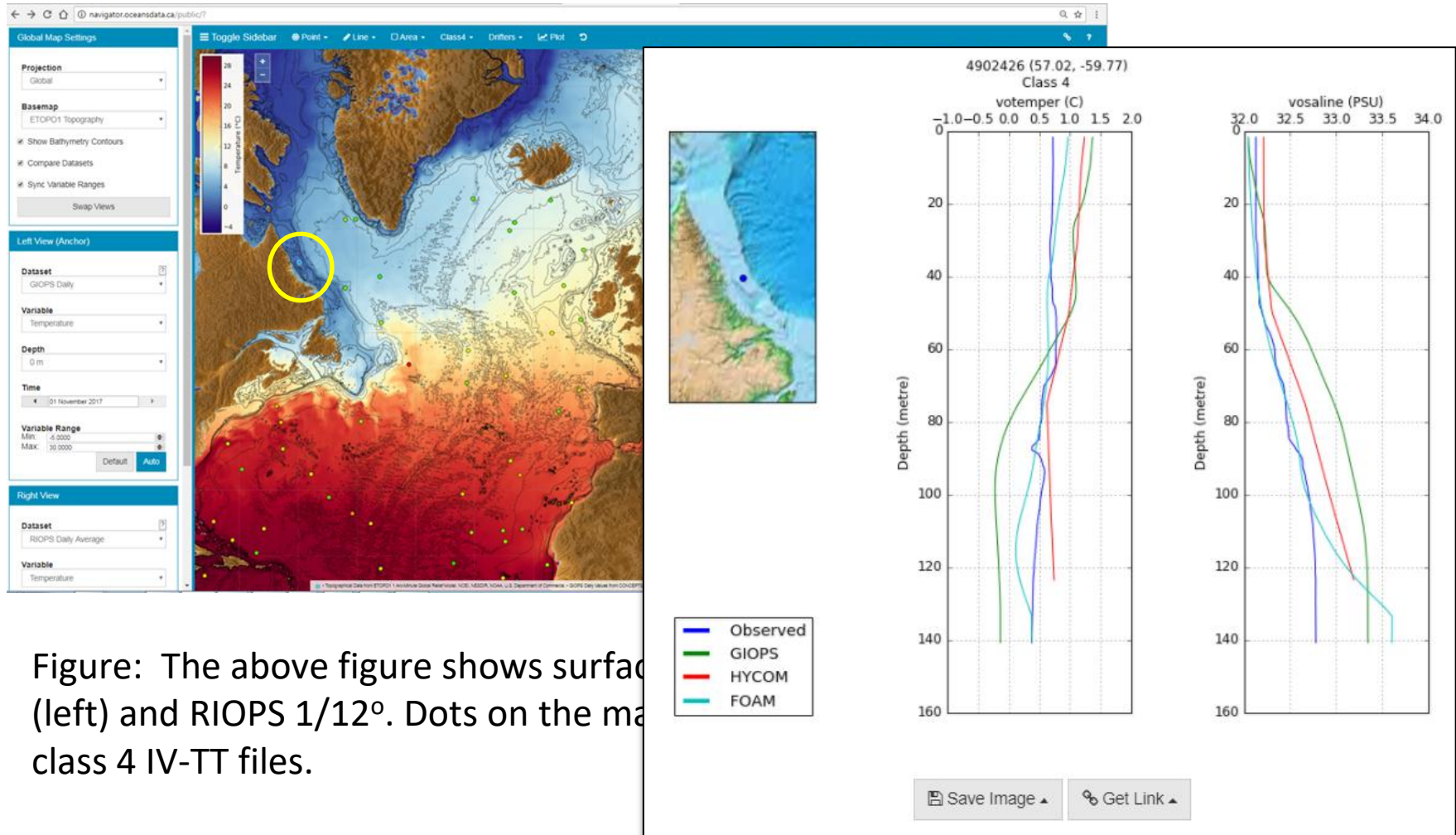


**OSEval-TT:** Observing System Evaluation

Will include GOV general presentation for AST 2019 document archive

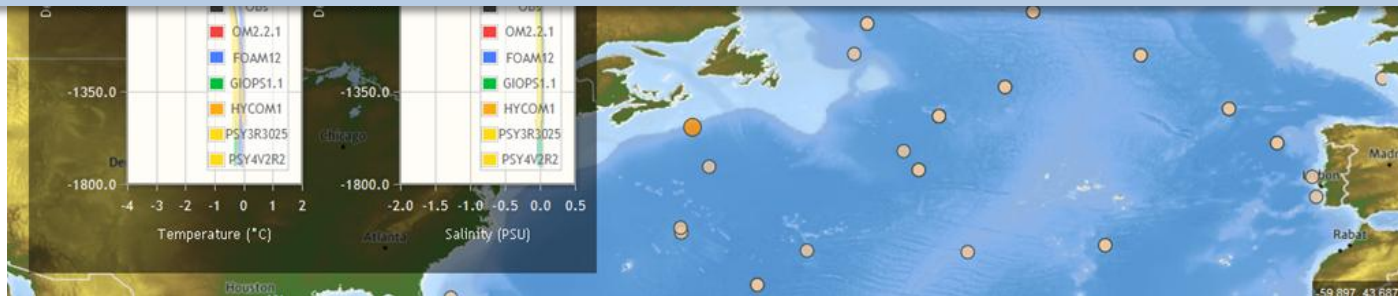
# Dynamic web viewers

CONCEPTS OceanNavigator: <http://navigator.oceansdata.ca>



# BoM Website

- <http://130.56.244.252/monitoring/index.php?pg=class4>
- Allows **specific monitoring** in parallel to IV-TT annual report or GOV monitoring website
  - *Do not replace operational postprocessing of each OOFs*
- Foster coordination among GOV task teams
- Targets experts audience: GOVST members
  - *Broader audience subject to policy decisions from contributing OOFs*

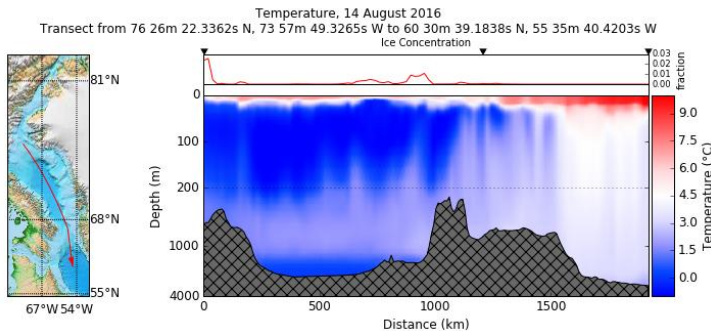
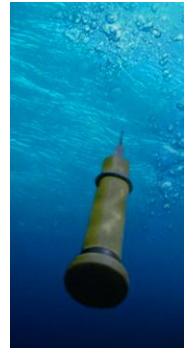
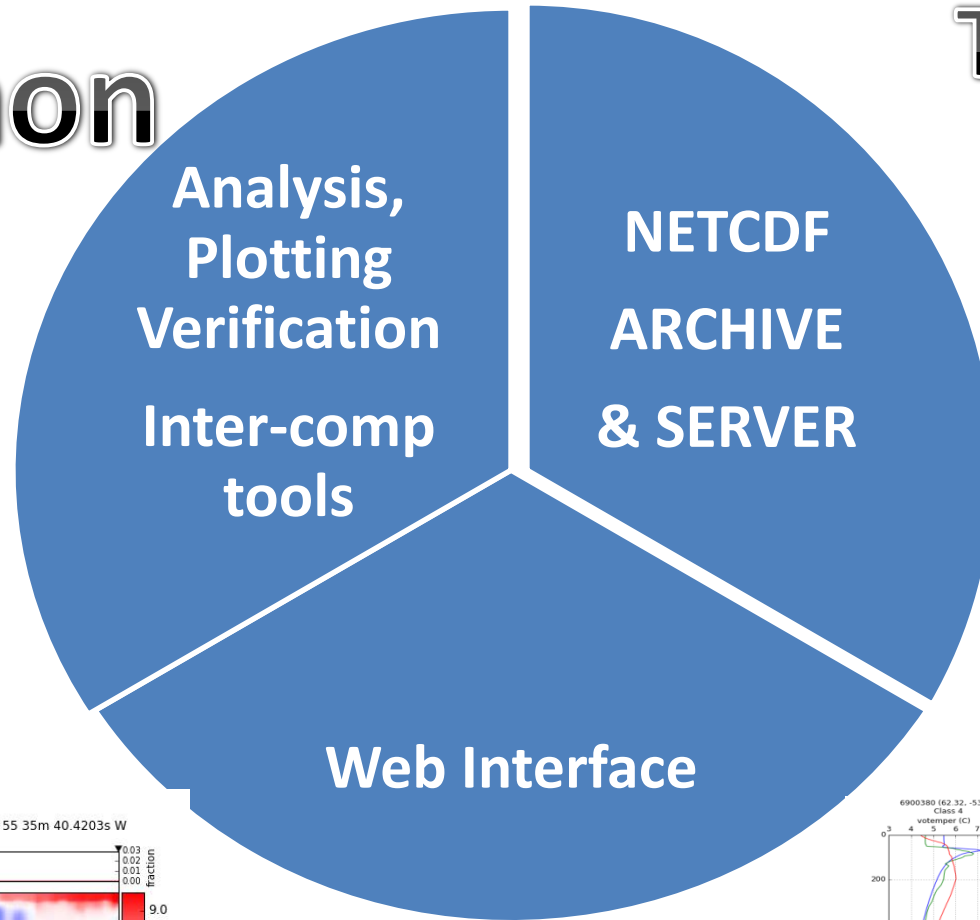


Prasanth Divakaran's contribution

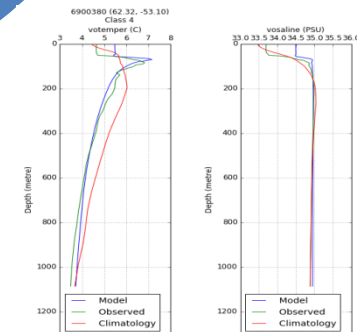
# CONCEPTS Ocean Navigator

Python

THREDDS

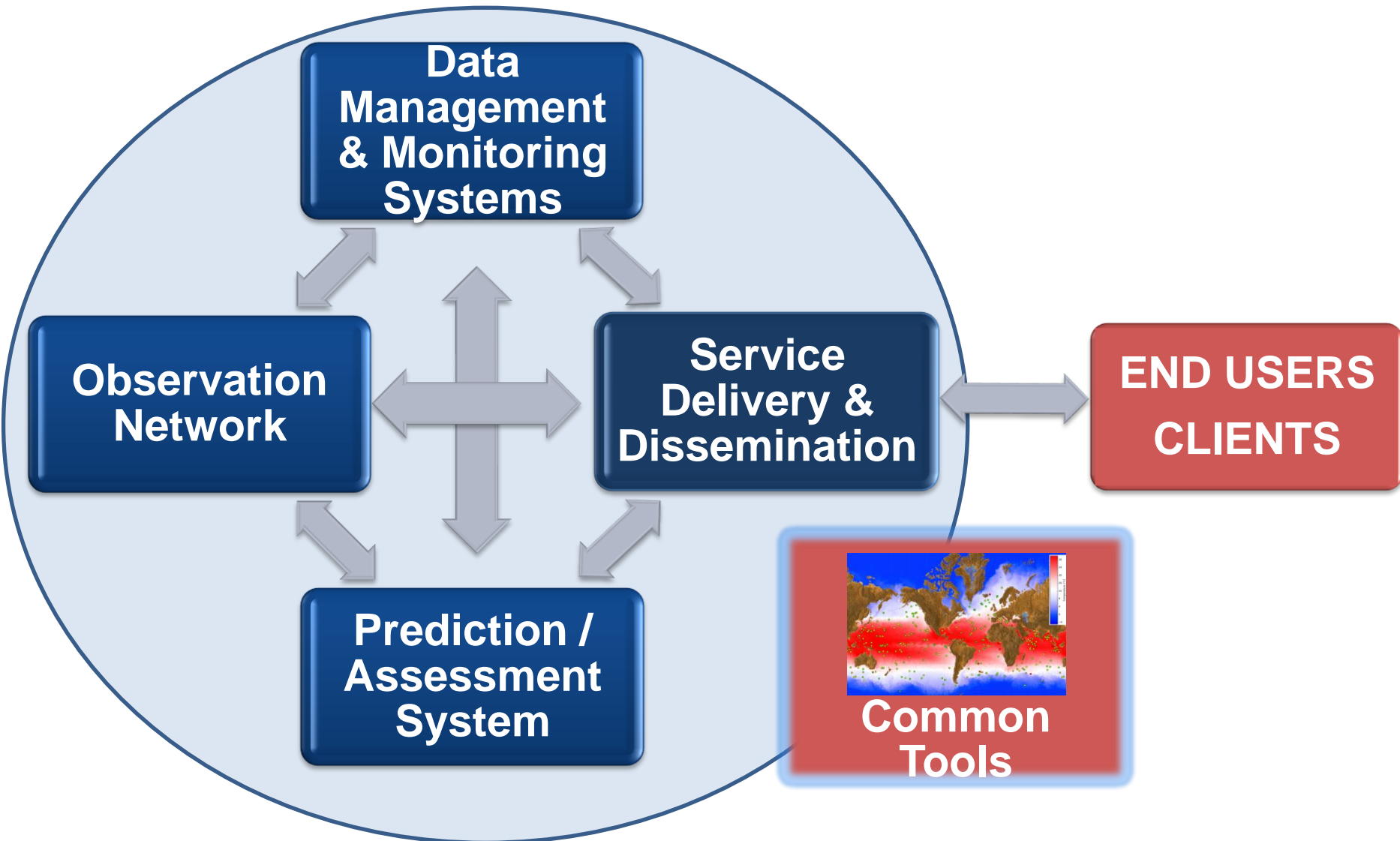


Java Script





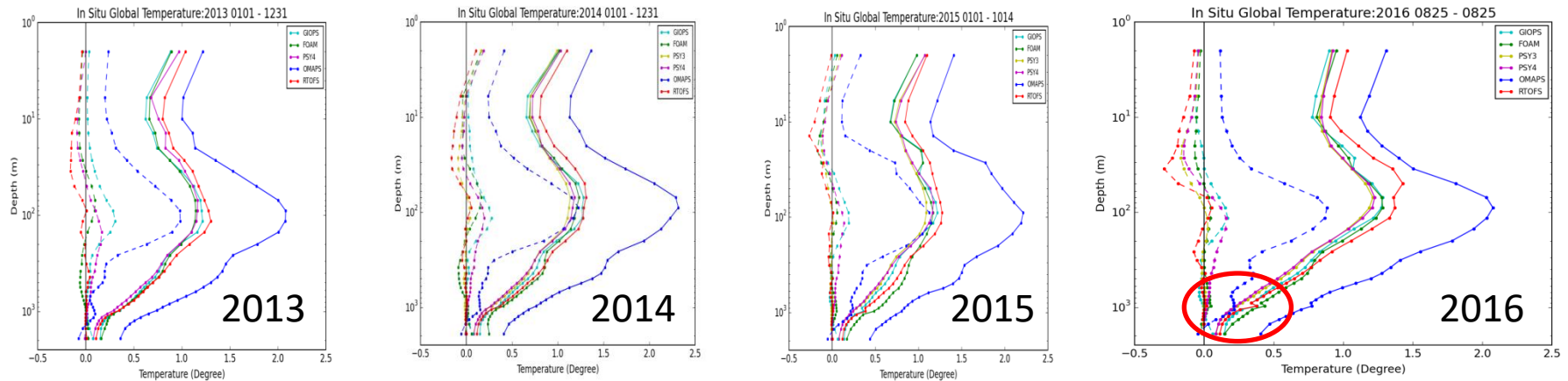
# GODAE Class 4, Verification, Accessibility



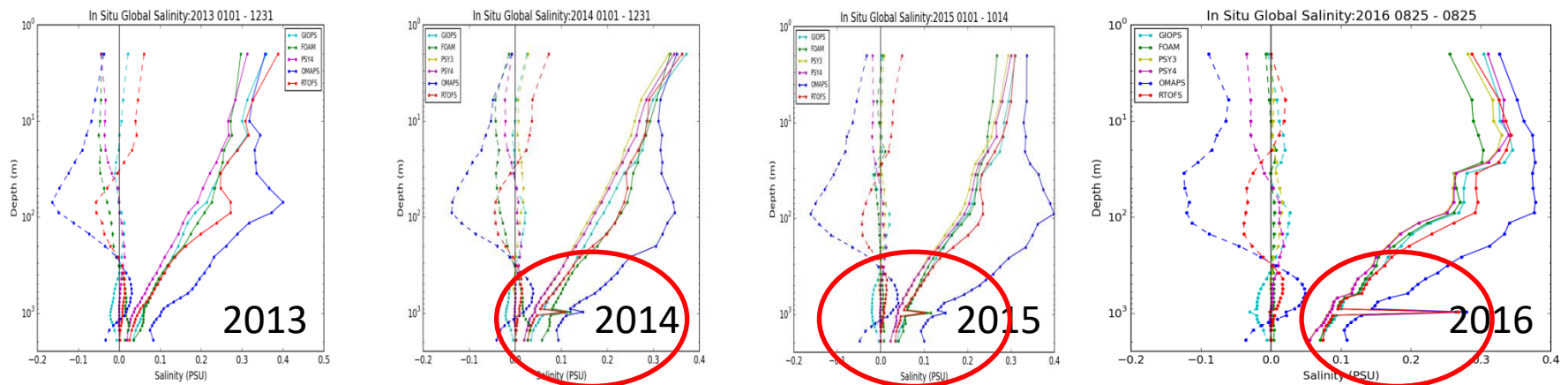
# Mean annual T&S profiles



## Temperature



## Salinity

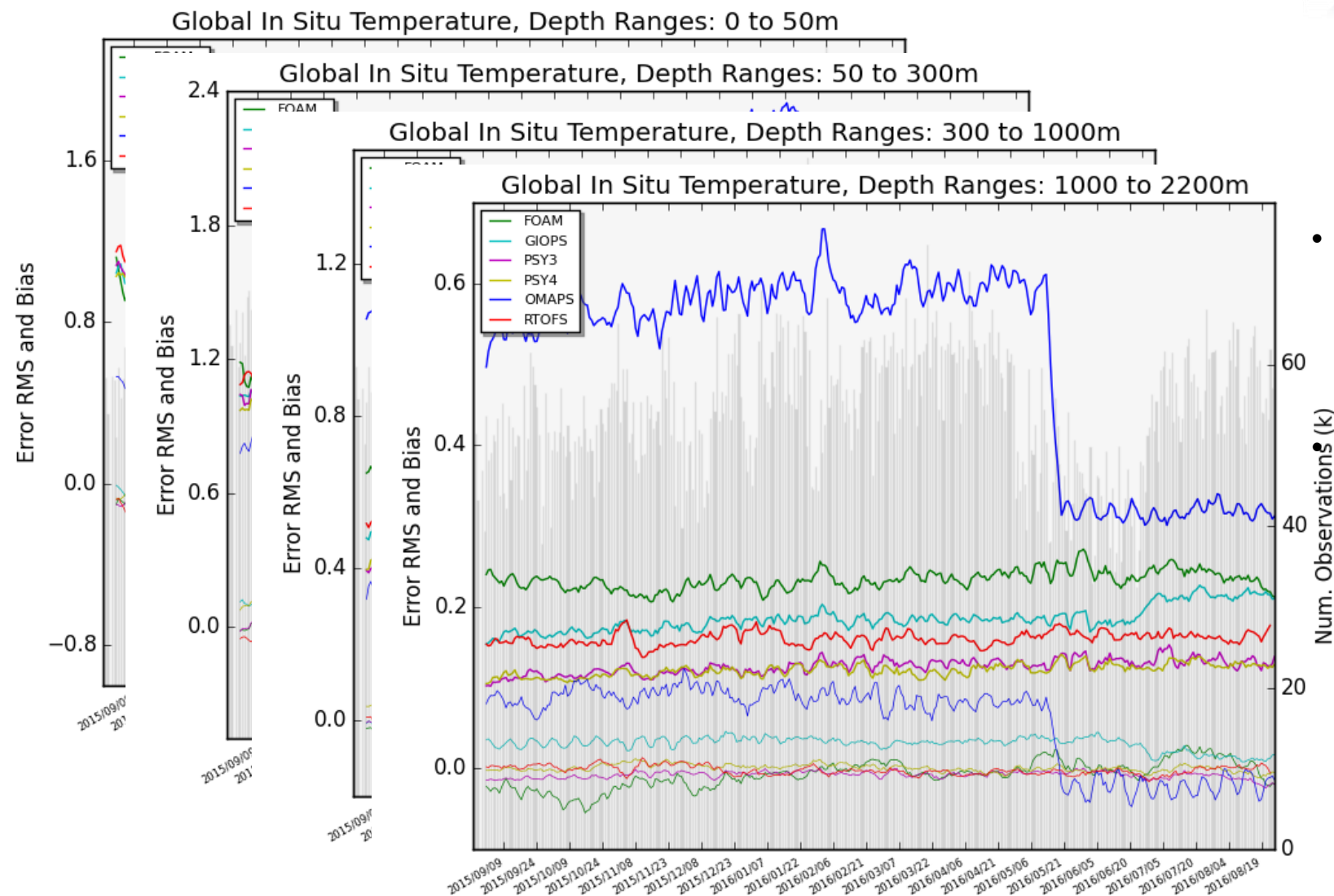


**Adopt common QC practices during assessment**

GOV-ST-8, Bergen, Norway, November 6-10, 2017



# Temperature timeseries



- OMAPS update, all depth, still oscillations

May 2016, change #obs, not affecting OOFs



# Salinity multiyear timeseries

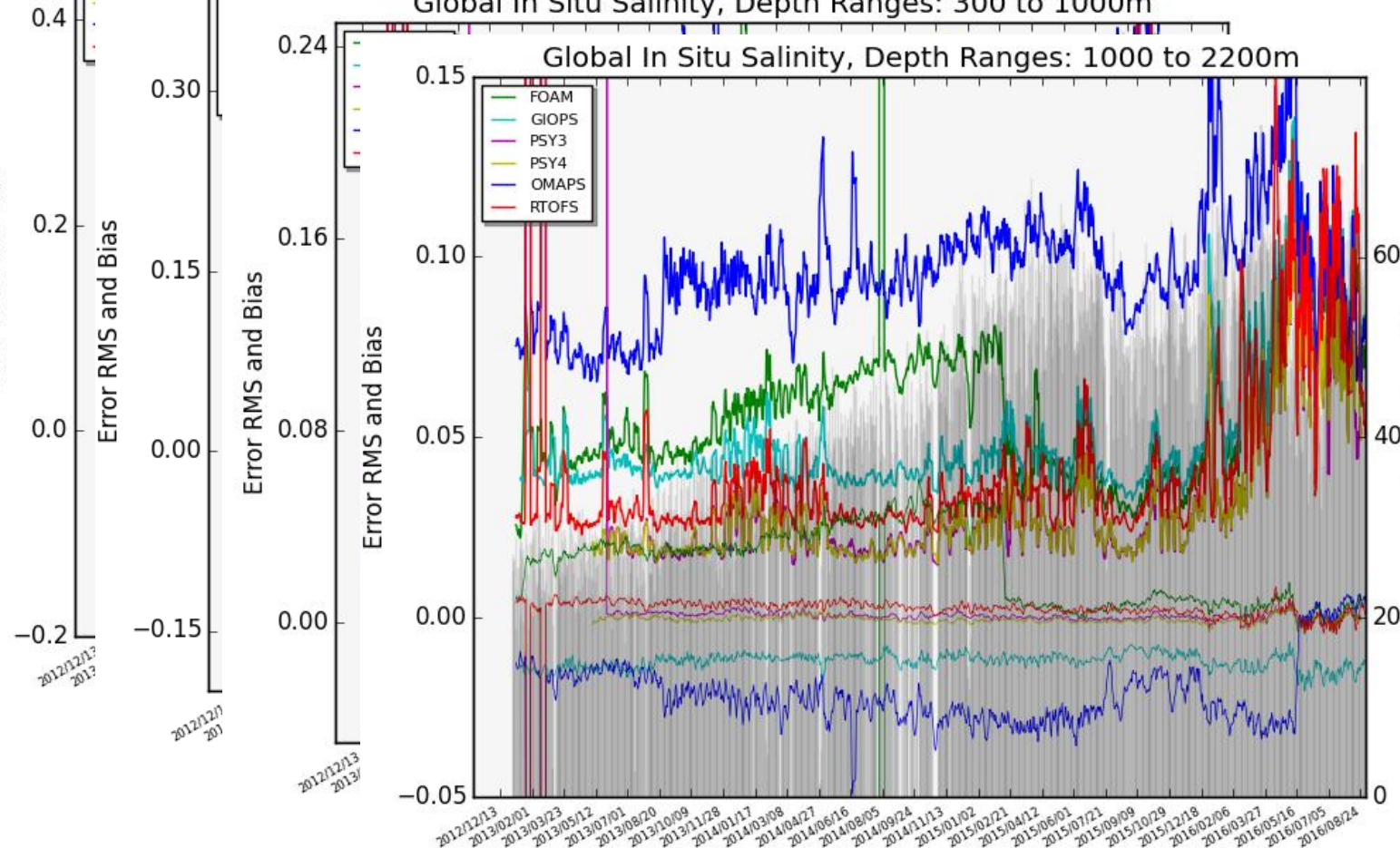
Global In Situ Salinity, Depth Ranges: 0 to 50m

Global In Situ Salinity, Depth Ranges: 50 to 300m

Global In Situ Salinity, Depth Ranges: 300 to 1000m

Global In Situ Salinity, Depth Ranges: 1000 to 2200m

Error RMS and Bias

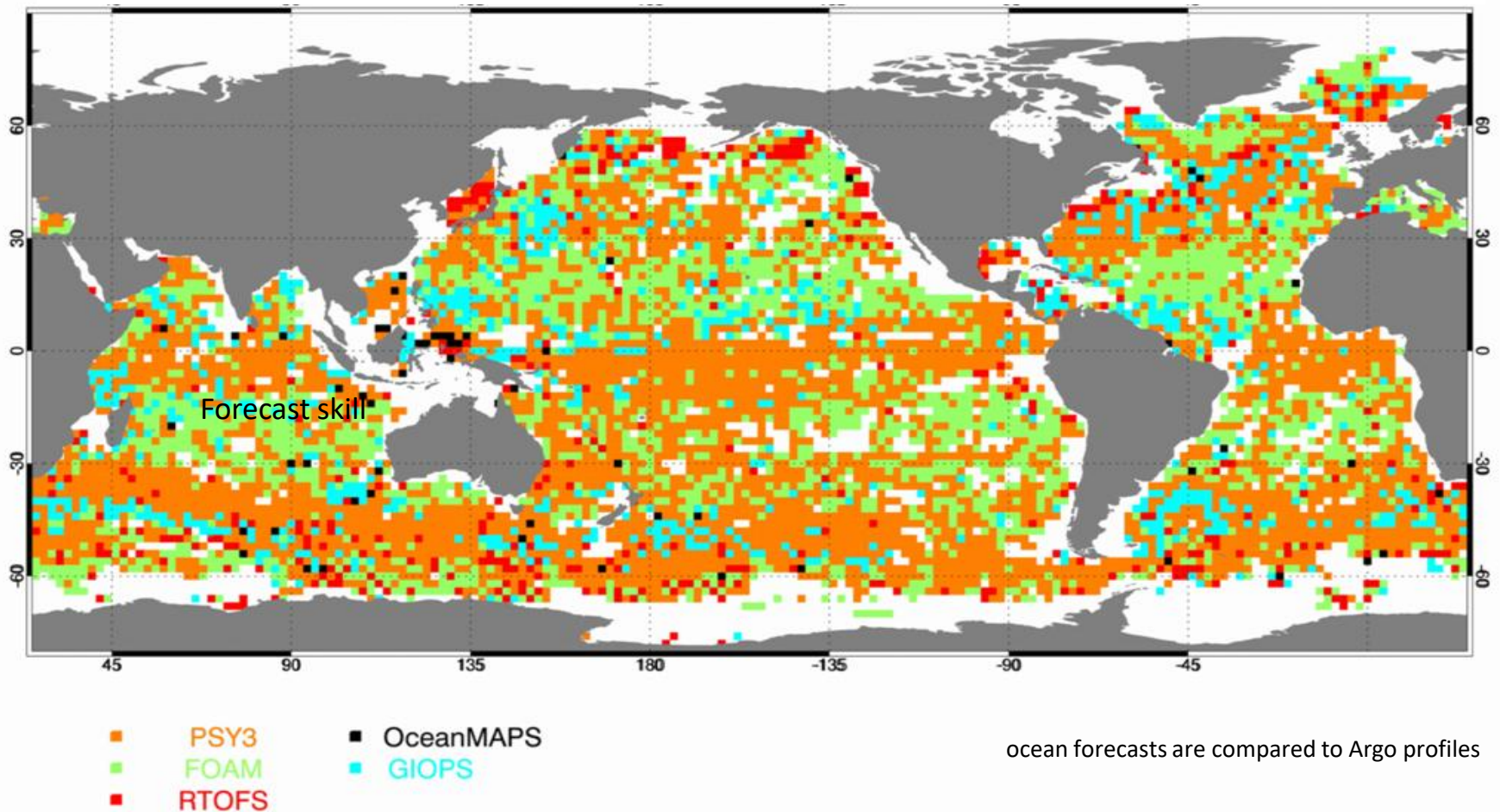


- Change in salinity obs. System ? Argo with other cycling?
- Most OOFs affected



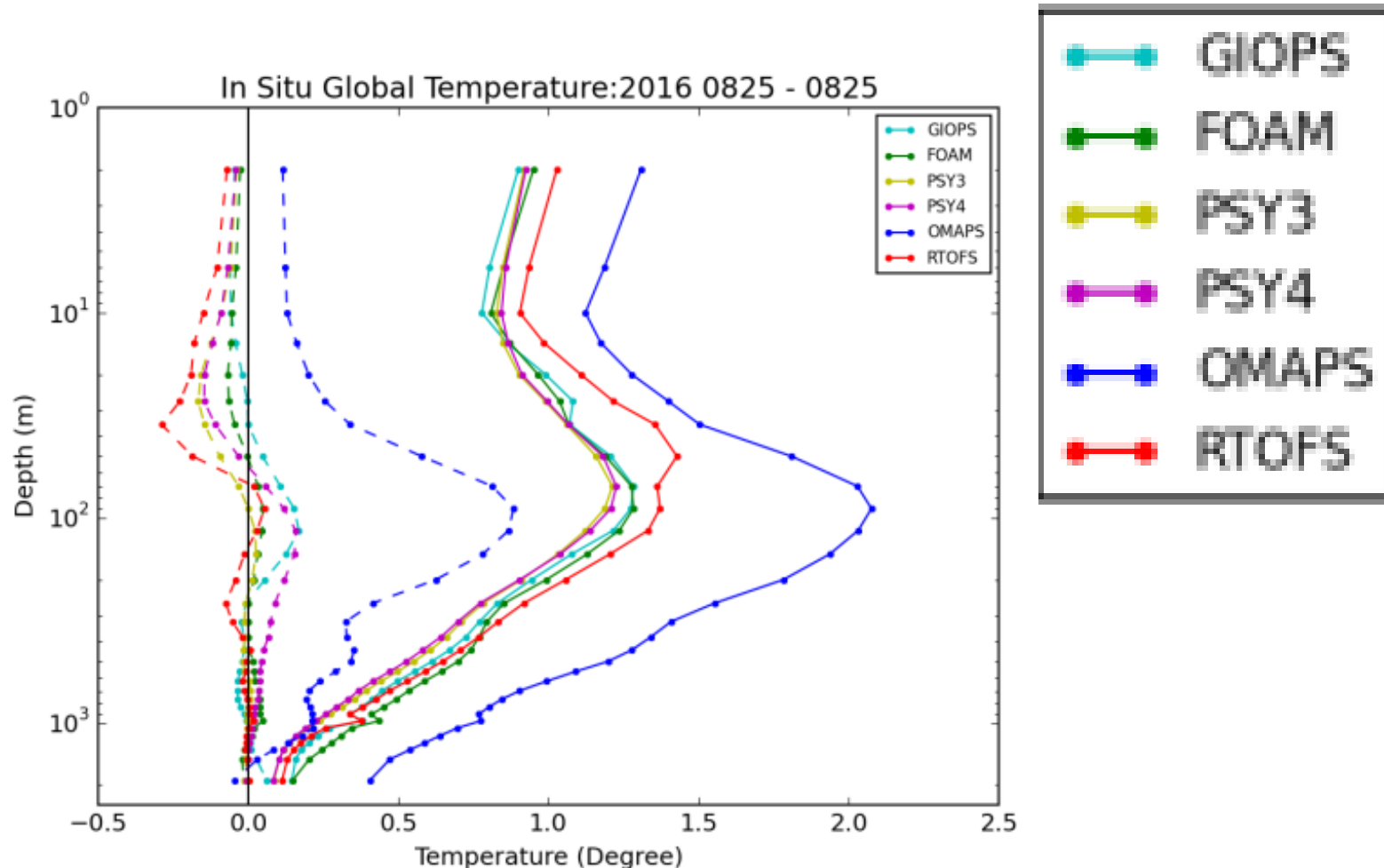
# GOV Real time Multi-assessment, inter-comparison: started in 2013

0-100m salinity 1-day forecast: which system performs best in 2013



# Evaluation with International Systems

## GODAE Ocean View Class 4 Example



# T/S : control of Water masses

Diagram TS KUROSHIO  
PSY4V2 hdest vs In situ Coriolis

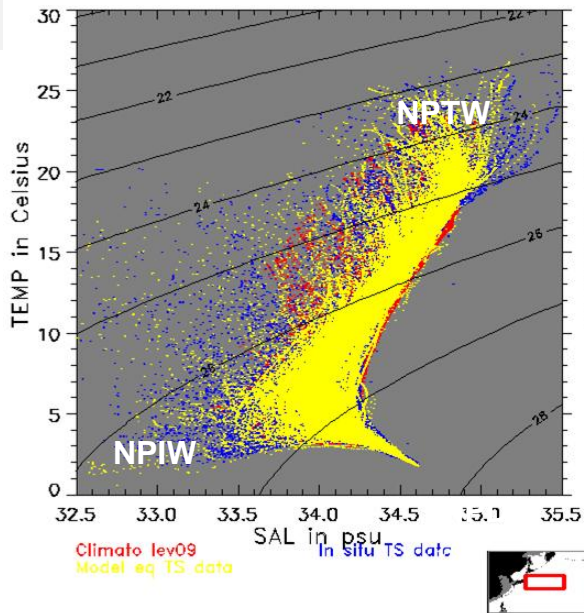


Diagram TS GULF\_CADIZ  
PSY4V2 hdest vs In situ Coriolis

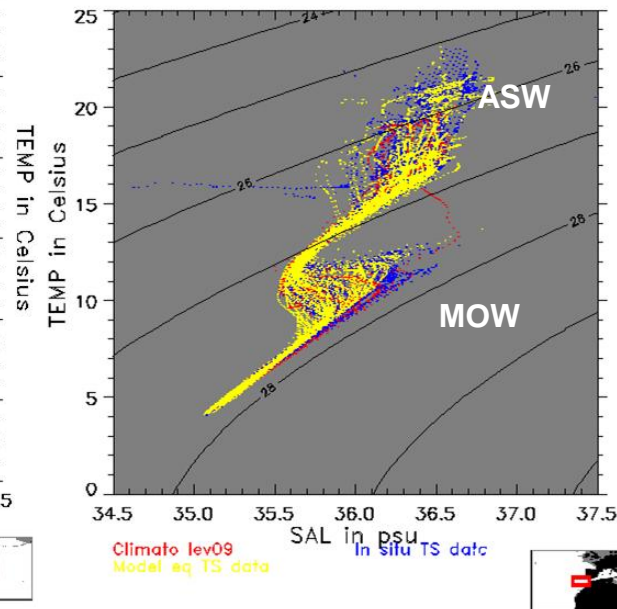
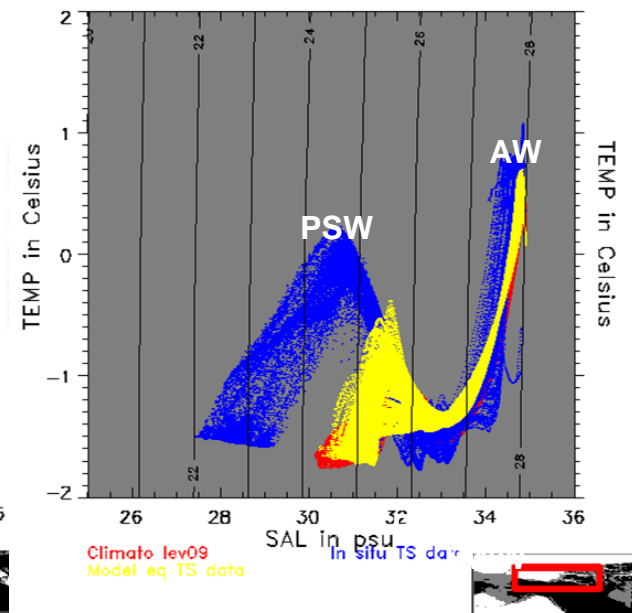


Diagram TS BEAUFORT  
PSY4V2 hdest vs In situ Coriolis



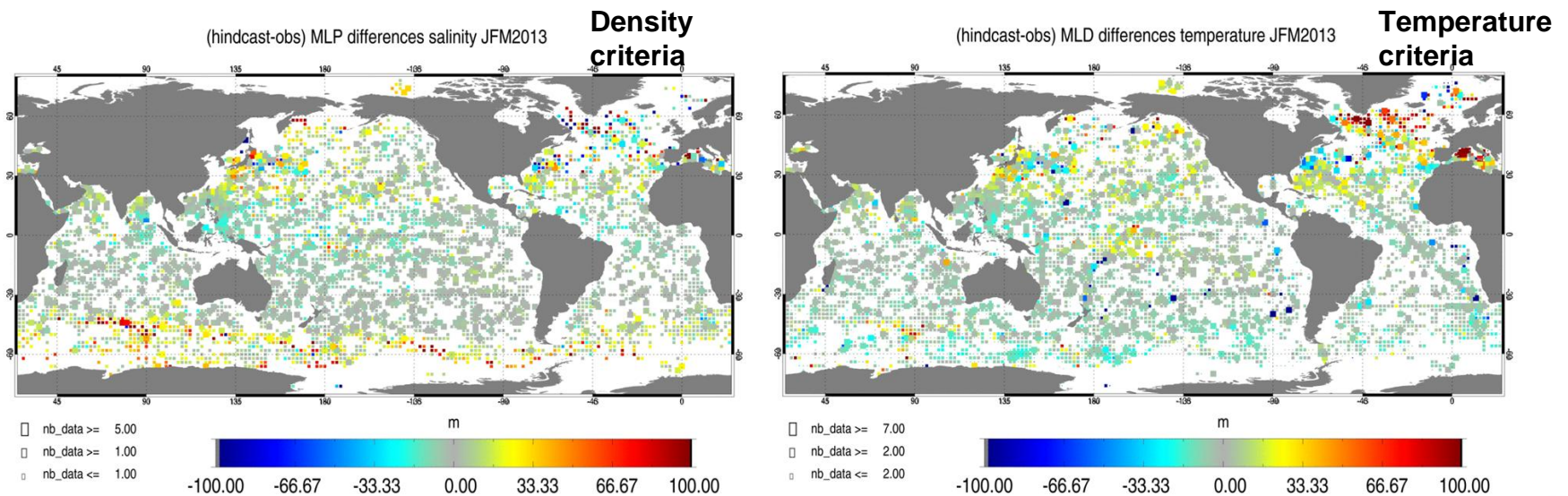
- T/S diagrams of well known water masses
- Identify some missing or not well represented water masses in operational systems

Charly Regnier's contribution



# Evaluation with derived quantities

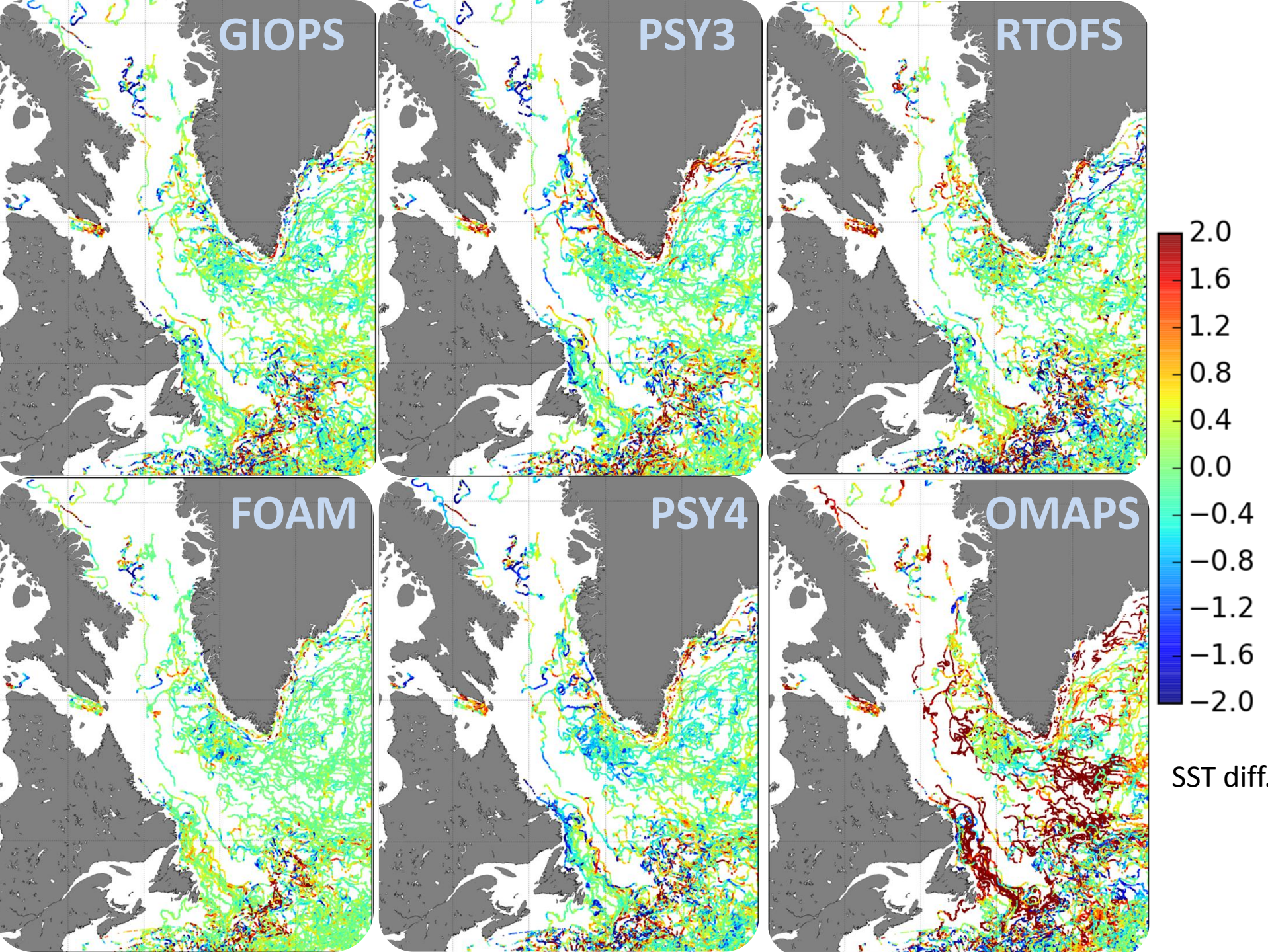
We can compute the MLD in the Argo profiles and in the systems



Compare with basics 2D maps or pdf by regions

Charly Regnier's contribution

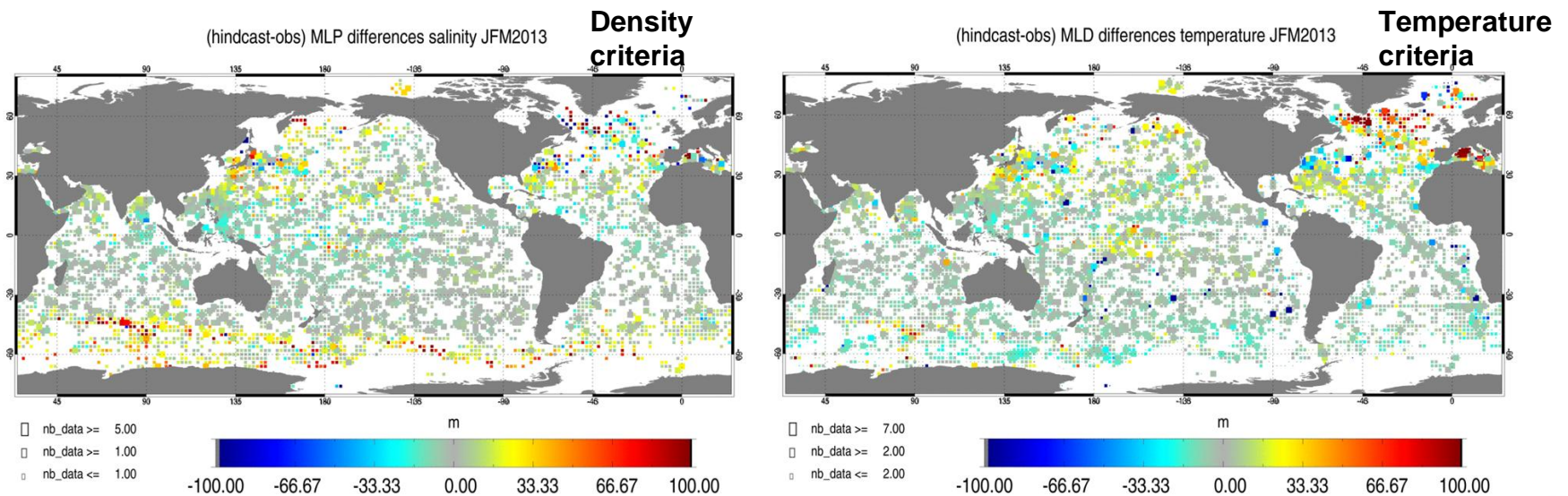






# Evaluation with derived quantities

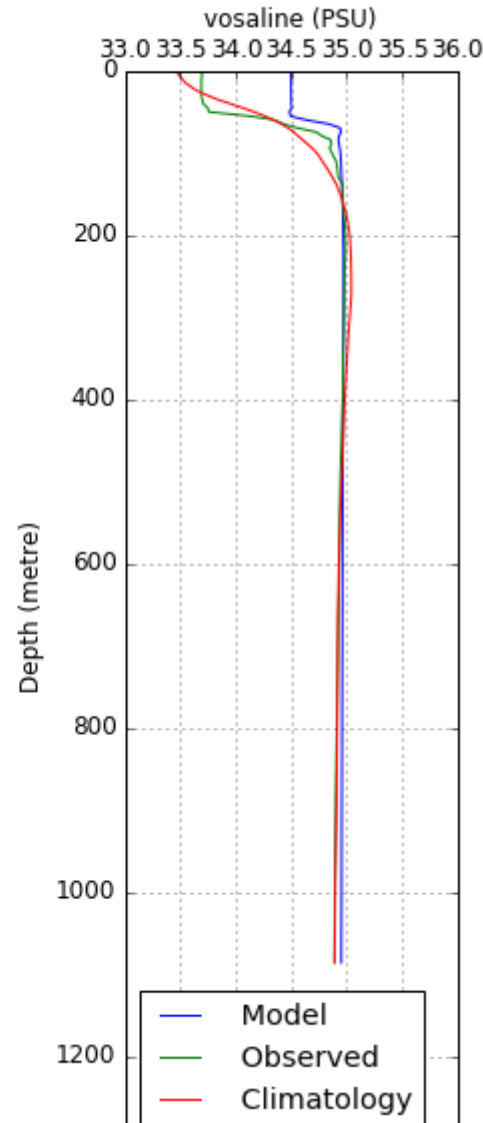
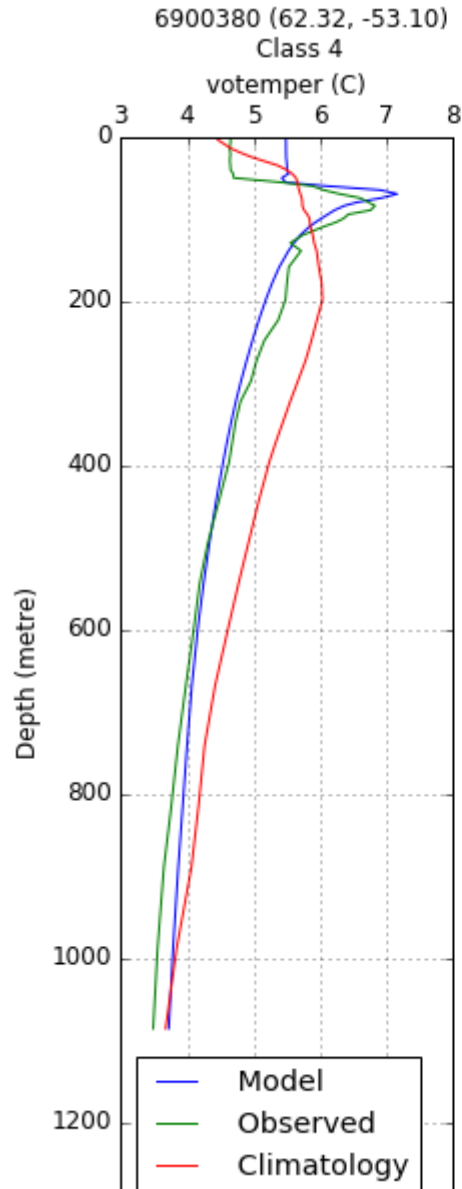
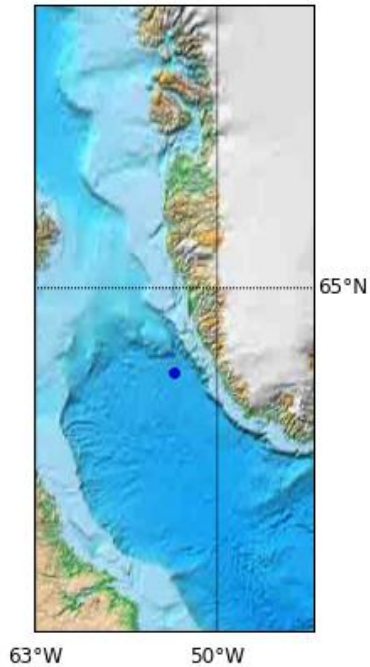
We can compute the MLD in the Argo profiles and in the systems



Compare with basics 2D maps or pdf by regions

Charly Regnier's contribution

# ARGO Drifter Verification



- Compare with Climatology



# Navigator Example

- Kuroshio Current

**Class 4 Settings**

☒ Show Location

☒ Show Climatology

**Additional Models**

HYCOM

FOAM

BLK

**Show Error**

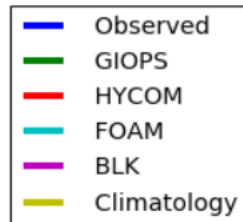
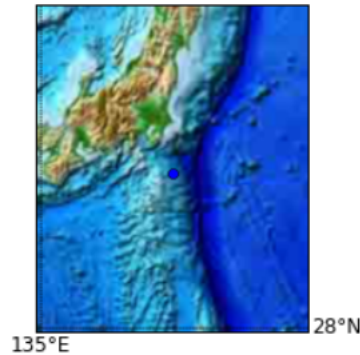
None

**Saved Image Size**

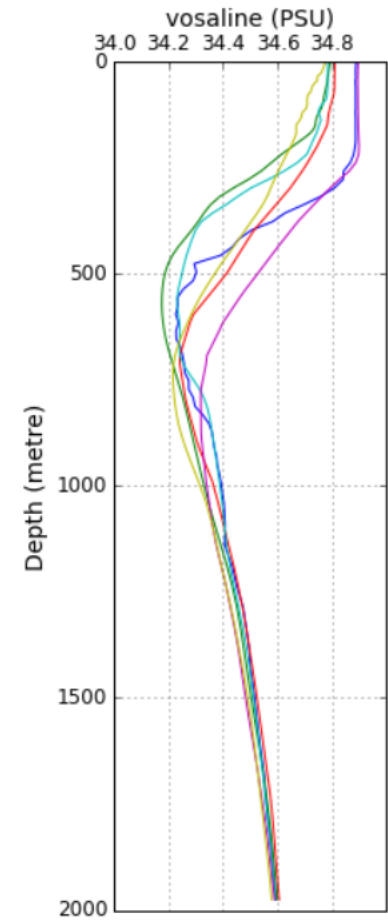
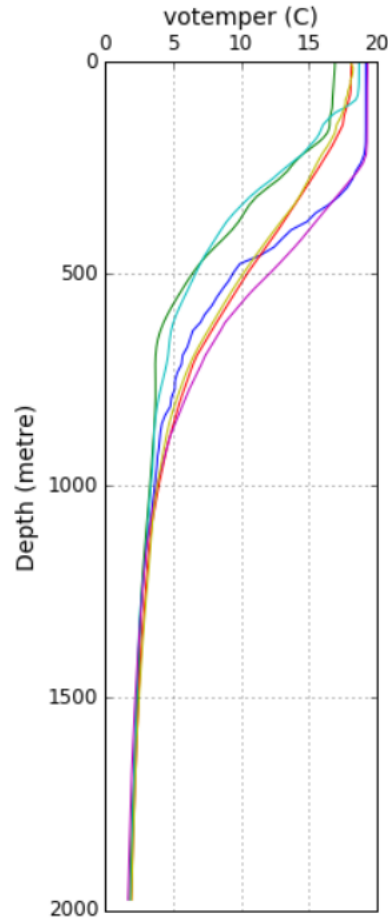
Width: 12.00 inch

Height: 7.50 inches

DPI: 144



2902980 (33.89, 140.80)  
Class 4



Save Image

Get Link



# Navigator Example

2902980 (33.89, 140.80)  
Class 4

## Class 4 Settings

- ☒ Show Location
- ☒ Show Climatology

### Additional Models

HYCOM  
FOAM  
BLK

### Show Error

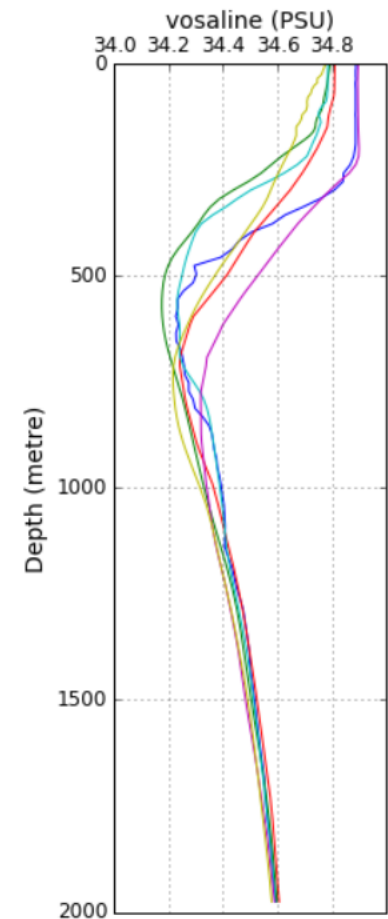
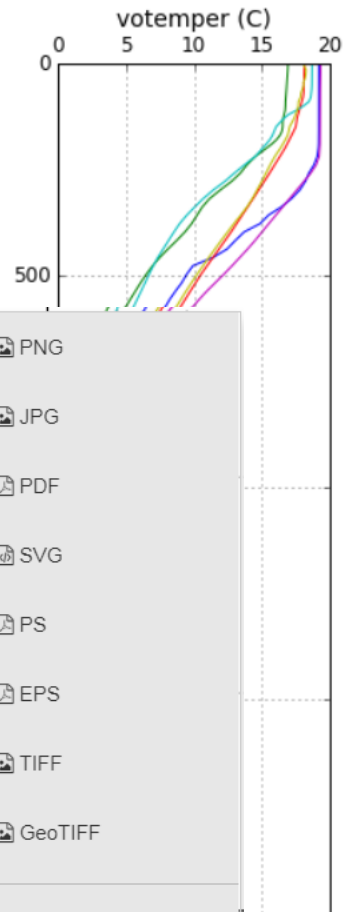
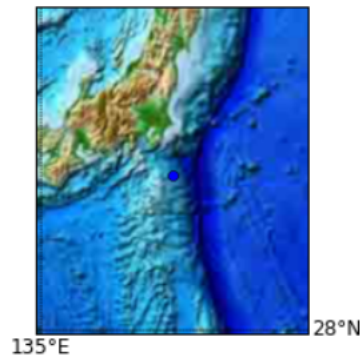
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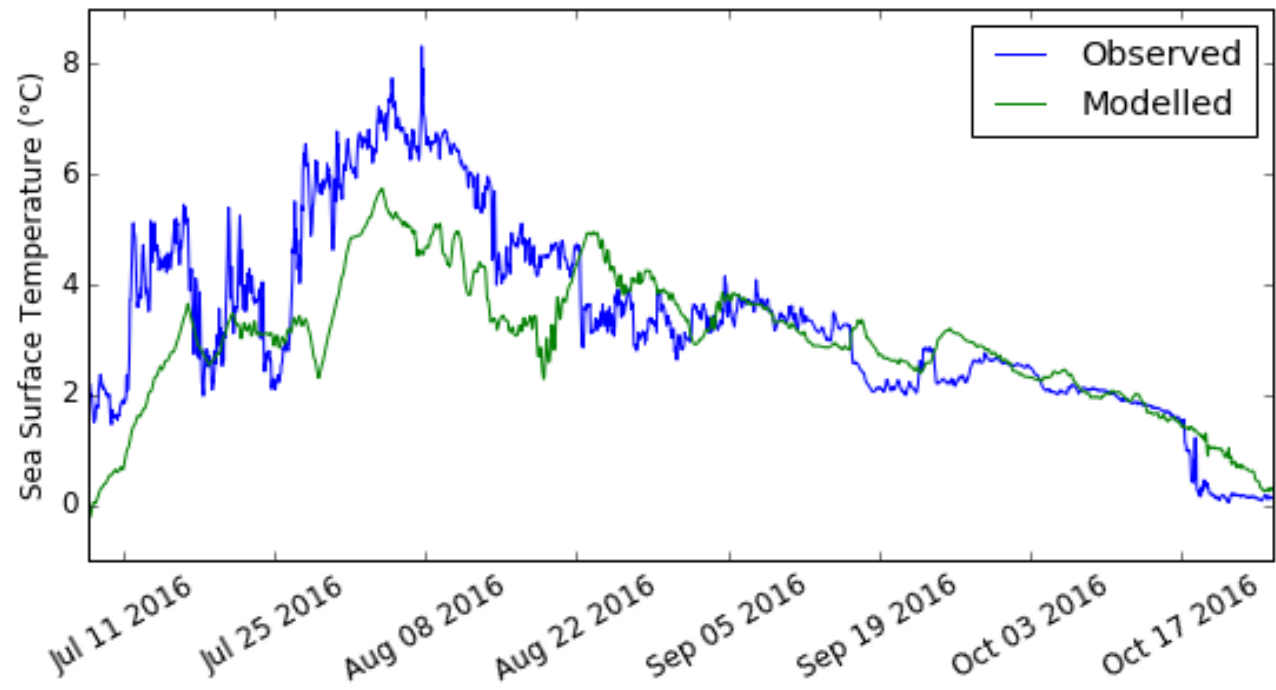
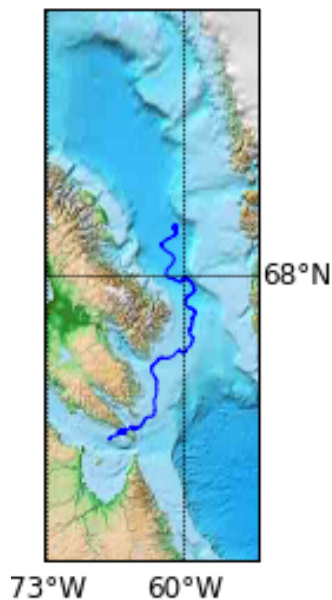
PNG  
JPG  
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SVG  
PS  
EPS  
TIFF  
GeoTIFF

CSV  
ODV

Save Image

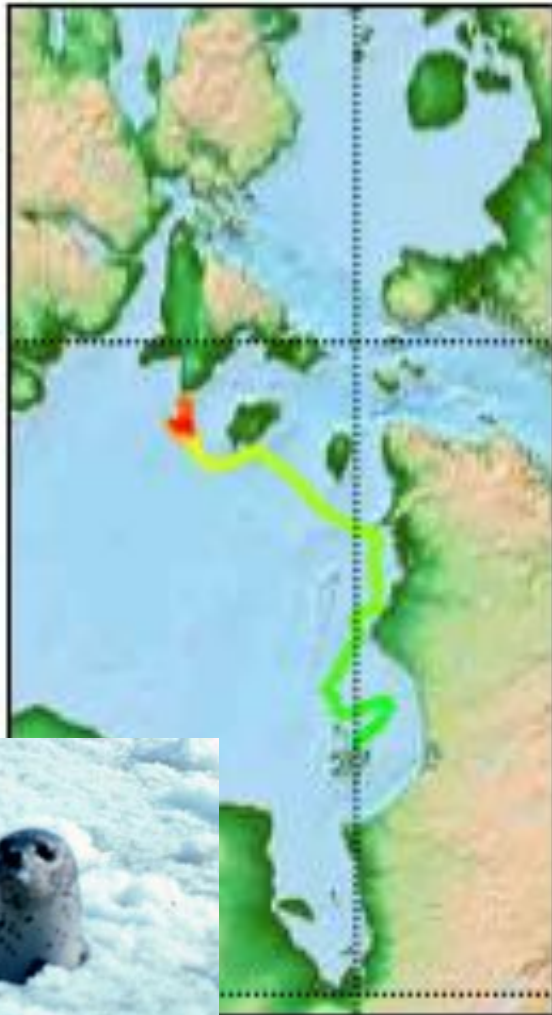
Get Link

# Along Drifter track RIOPS Temperature Forecast Verification

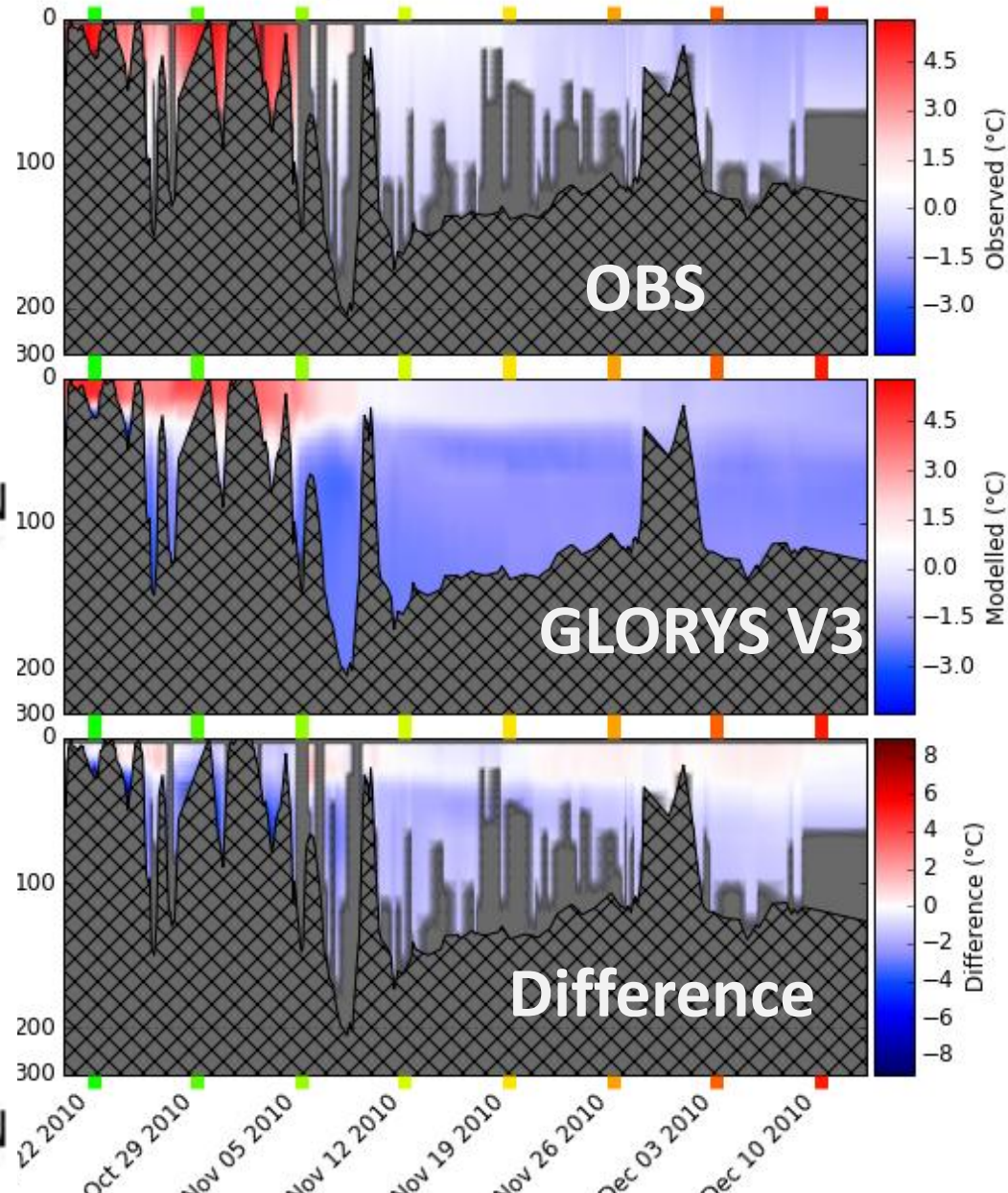


# Verification against Ring Seal TD observations

Data Courtesy Steve Ferguson



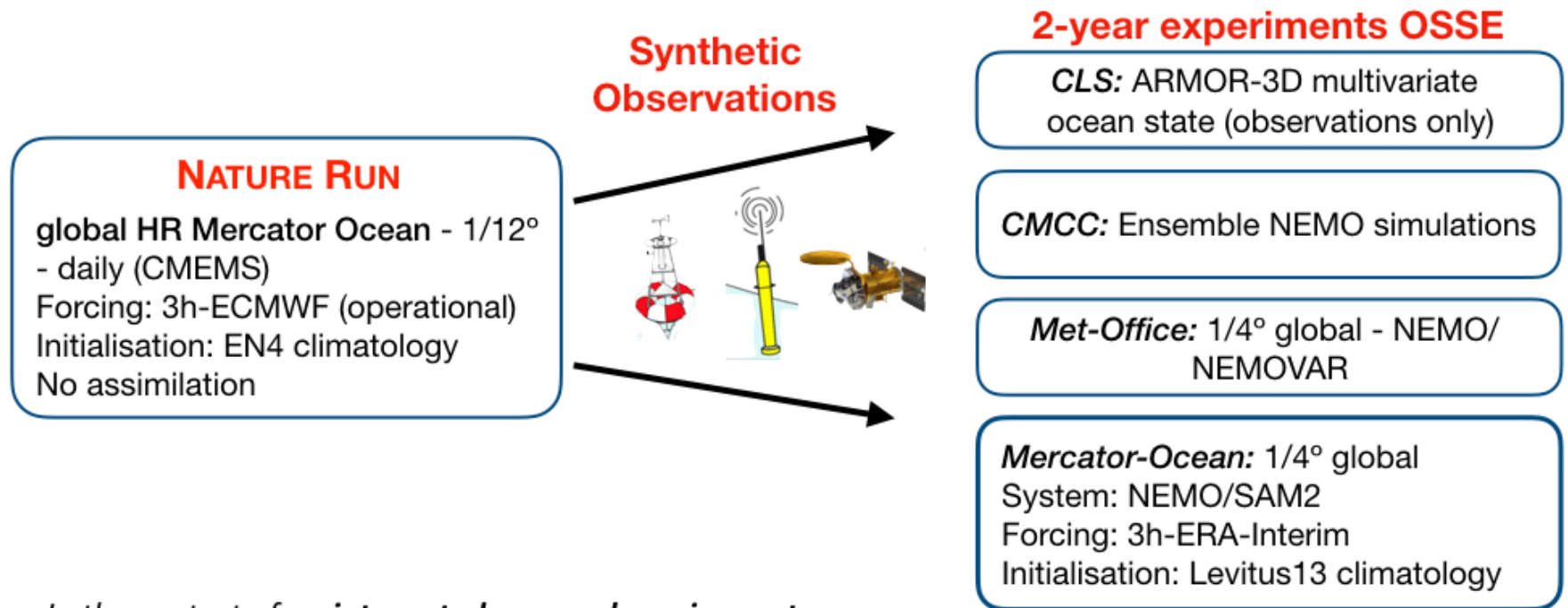
Animal Track Temperature  
rs6-16-10\_ODV.txt



# Optimizing and enhancing the integrated Atlantic Ocean Observing Systems

## OBSERVING SYSTEM SIMULATION EXPERIMENTS IN ATLANTOS

→ Multi-models / multi-approaches exercise considering the same synthetic observations



*In the context of an **integrated ocean observing system** ...*

- What is the added-value of XBT lines for AMOC transport ?
- What is the impact of doubling Argo in WBC and along equatorial regions ?
- How deep Argo (down to 6000m) will improve ocean state estimate ?
- How sparse high-frequency moorings impact on ocean analysis and forecasting systems ?
- What is the potential impact of an extension to 150m of drifters thermistor chain ? etc ...

**AtlantOS**

EU Horizon 2020 project



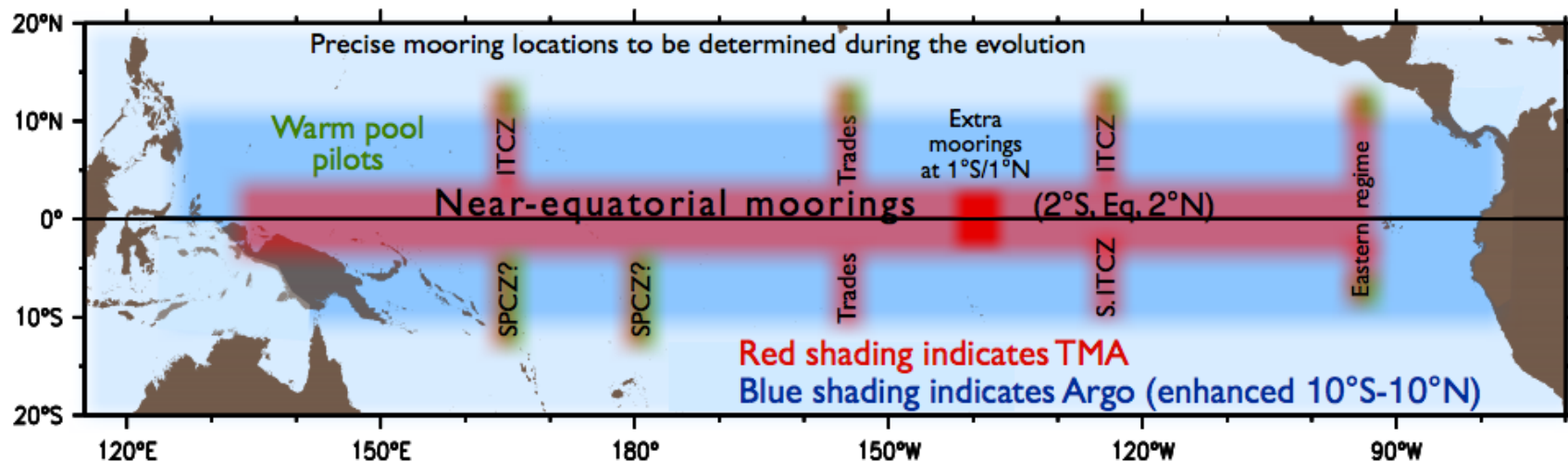
# OMOC/OSSE System Configuration

- **Nature Run (NR)** – free running
  - HYbrid Coordinate Ocean Model (HYCOM) run at high resolution (3-4 km)
  - Multi-year unconstrained simulations
- **Forecast Model (FM)** – with Data Assimilation (fraternal twin system)
  - The FM has to be substantially different from the NR
- **Ocean Data Assimilation (DA) procedure**
  - In-house statistical interpolation system designed specifically for HYCOM
- **Synthetic Observation Simulation Toolbox**
  - Realistic errors added on synthetic observations (*uncertainties in actual observations vs FM eg., instrument noise, representation of different scales in FM/obs.*)

➤ Halliwell et al, 2014; Oke et al, 2015; Kourafalou et al, 2016

**System fully validated** (Kourafalou et al., 2016; Androulidakis et al., 2016; Halliwell et al., 2017)

- Launched in 2015 according to the recommendation in La Jolla workshop.
- Purpose: Propose an efficient and sustainable design of TPOS for its reorganization
- First report was published in 2016 (see <http://tpos2020.org>)
- **New design of TPOS is proposed (evaluation is requested).**
  - Moorings : Mainly 2°N-2°S. Enhanced sampling of the mixed layer.
  - Argo floats: Doubling in 10°N-10°S
- Extension of Real-Time MultiORA/sharing of information on observational data and their influence (QC flags, increments, innovation, etc.) and forcing data is suggested.



# Annual community OSEs

- ✓ **Proposed in the TT meeting in 2014**
- ✓ Perform one study per year; duration: 6 months
- ✓ One study includes 3 OSEs
  - ALL: OSE that assimilates “all” observations
  - NONE: OSE that assimilates no observations
  - COSE: OSE that with-holds an agreed set of observations

## ◆ *Proposed Schedule*

Initial time	End time	Data with-held	Due date
7/2013	12/2013	Degraded Argo array (-20%)	4/2015
7/2014	12/2014	X altimeter(s) of the constellation (TBD)	4/2016
7/2015	12/2015	Tropical moorings	4/2017
7/2016	12/2016	X% of Argo (TBD)	4/2018
7/2017	12/2017	X altimeter(s) of the constellation (TBD)	4/2019

## **Community OSE has not been conducted due to following issues:**

- ✓ **How can it attract international people with limited financial support?**
- ✓ **How can it communicate among international people?**
- ✓ **Who lead the processing of the results?**

# Lessons learned from the past

## *From NRT OSEs (Met Office 2011)*

Significant benefits from running them

Significant overhead to run them (human, supercomputer, storage)

- funding

- cheaper (alternative ?) techniques

- community experiment: Shall be relevant if more than one system to do it

One month experiment probably not long enough to see full impact

## *From annual community OSEs*

It's hard to motivate members to work for free ... 😊

- Prepare funding is favourable.

- Plan for publishing OIS gives members a clear target.

Although community activities, i.e., **applying multiple systems to equivalent experiments**, is a way of establishing system-independent, robust results, we have experienced difficulty of it this 8 years.



# Observing Impact Statement (OIS) published

## Observation Impact Statement for Argo

July 2011

D. Lea, Met Office, Exeter, UK

For GODAE OceanView

### Summary

A parallel version of the FOAM operational system was run, during July 2011, withholding all Argo temperature and salinity observations in order to assess the impact of these data on the system. Argo data form 75% of the total subsurface temperature and 85% of salinity observations assimilated into FOAM. Withholding Argo data results in a 5% increase in the RMS observation-minus-background differences. We also see impacts on other model variables. For instance, there are large scale changes of  $\pm 5$ cm in SSH.

### Disclaimer

The results are derived only from the FOAM system. Any statements about the information content of an observing system may be strongly dependent on the model and data assimilation system. The impact of the observations may also be underestimated due to the short time over which the experiment was run.

### System description

FOAM (Forecasting Ocean Assimilation Model) is the Met Office's short range (0-6 day) operational global open ocean forecasting system. Remotely sensed satellite SST (sea surface temperature) and in-situ SST data, profile temperature and salinity data, satellite altimeter SLA (sea level anomaly) data and sea ice concentration data are assimilated in the NEMO (Nucleus for European Modelling of the Ocean) model.

- ✓ Change the method of publishing in a more internationally collaborated manner
- ✓ Include contributions from many TT members
- ✓ Open to the public from GOV web pages (?)

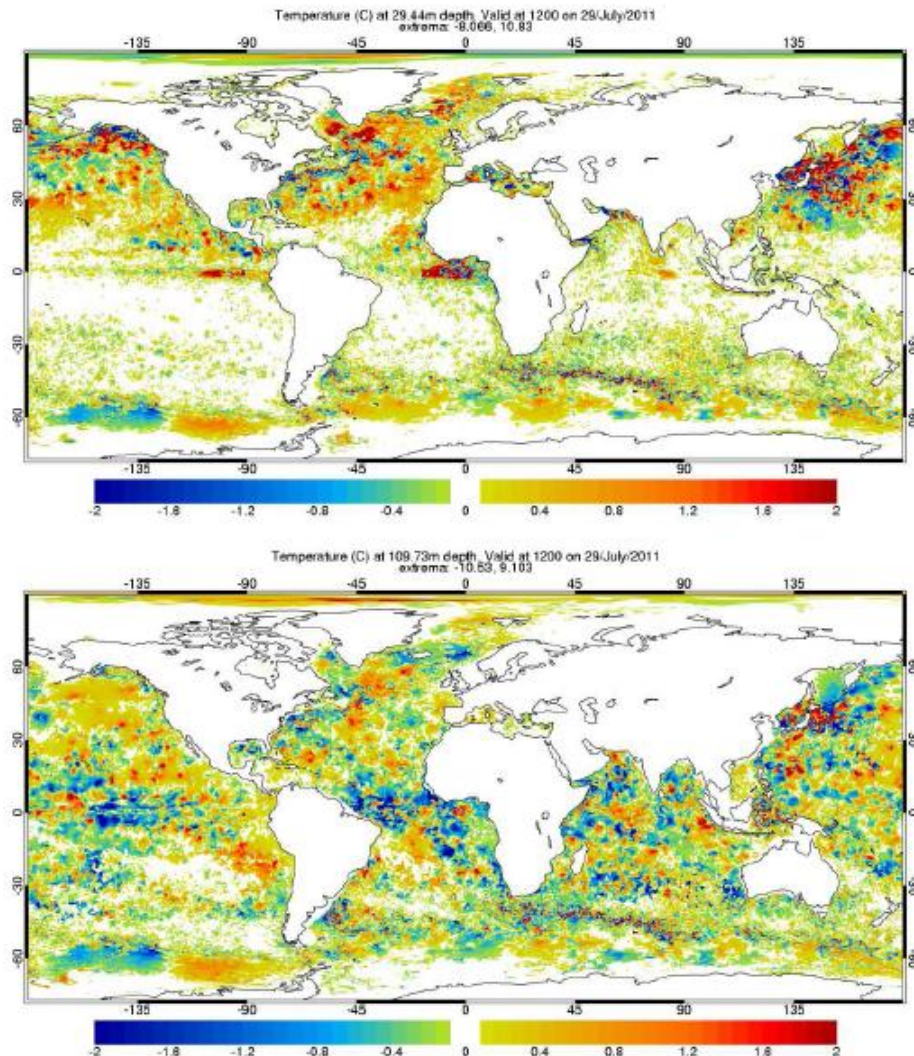


Fig 2. Map of the temperature difference (Operational minus "No Argo") in °C at (a) 29.44 m depth and (b) 109.73 m depth. Derived from daily average fields at the end of Argo OSE period.

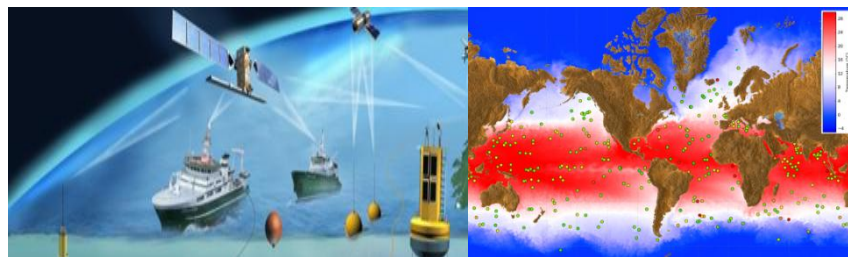
# GOV and OSS/OSSE

- ✓ Considering publishing OIS with a better international community defined approach.
- ✓ Pull skill/tools and contributions from task team members
- ✓ Should we develop web accessibility open to the public from GOV web pages (?)

# Questions for AST 2019

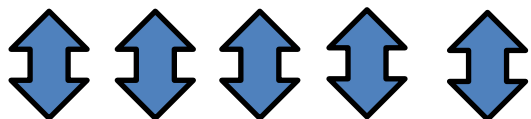
- What do you want to see in real time from OOFS?
  - Class 4 metrics vs ARGO
  - Along track ARGO verification
- What info do you want to see in delayed mode from OOFS?
  - OSSE's , OSE, other type verification
  - How to develop more ARGO/GOV collaboration/projects
- Collaboration on common projects?
  - Deep ARGO
  - BioGeochem ARGO...
  -

# Example of end goals in OO



**Archive**

Ocean Ice Atm, Waves, BGC  
+  
THREDDS/ERRDAP

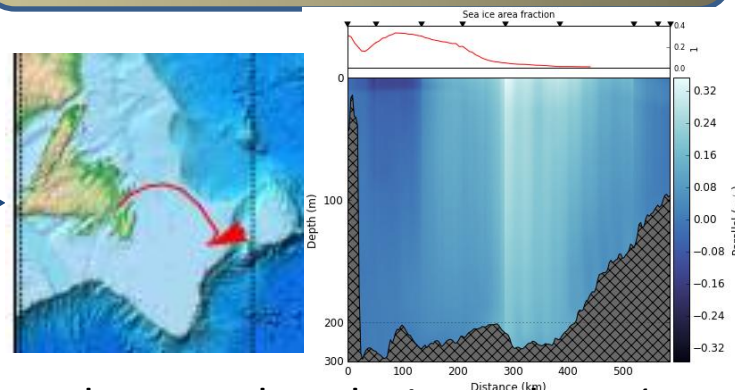


**Generic Information Server  
& WEB INTERFACE**

<http://navigator.oceansdata.ca>



**Value Added  
Downstream Provider**



Along Track Velocity and Ice %  
for tow out