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Assessment of the Global Argo Array Enhancements Using Observing System Simulation Experiments

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OUTLINE

1. Motivation/tools. Why impact studies are needed ?
2. Observing System Simulation Experiment
3. The doubling of Argo in WBC and along the equator
4. The Deep Argo network
5. Conclusion/Discussion

Motivations

Ocean analysis and forecasting systems have a high dependency on observations availability and quality.

Mercator Ocean has set up a dedicated team to work on observation impact assessment and analysis of the contributions of present / future observing systems (satellite and in-situ).

Observation impact studies are performed to:

- ✓ verify that observation information is « optimally » used in the analysis step and improve the assimilation components
- ✓ quantify the impact of the present observation network in ocean analysis and forecasts,
- ✓ demonstrate the value of an observation network for operational ocean analysis and forecasts,
- ✓ help defining and testing future observing systems from an integrated system perspective involving satellite and in-situ observations and numerical models.

Tools

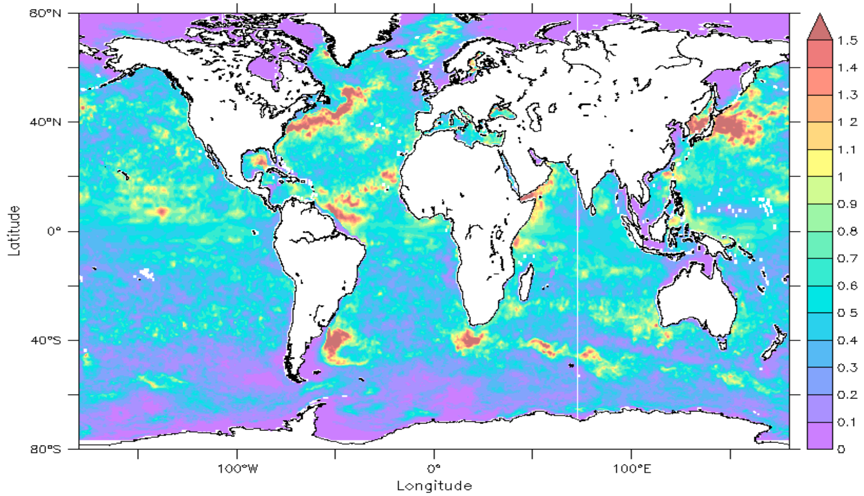
- OSEs allow assessing the impact of an existing data set on the performances of a modelling and data assimilation system (by withholding observations).

- OSSEs are powerful tools to help designing new observing systems and to perform preparatory data assimilation work.
  - OSSEs typically use two different ocean models. One model is used to perform a "truth" or nature run - and it is treated as if it is the real ocean.
  - The truth run is sampled in a manner that mimics either an existing or future observing system - yielding synthetic observations.
  - The synthetic observations are assimilated into the second model, and the model performance is evaluated by comparing it against the truth run.
  - OSSEs need to be "calibrated" with OSEs (real data). Choice of Nature run.

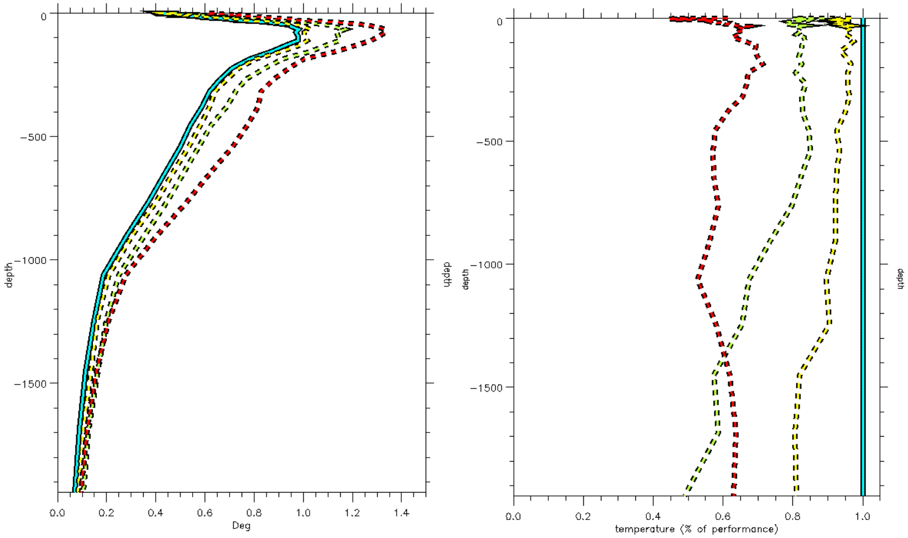
➢ *OSSEs and OSEs require heavy and dedicated infrastructure (running R&D versions of operational systems).* Other alternative approaches are explored (DFS, …)

1-year OSEs with the Mercator Ocean global ocean ¼° analysis and forecasting system (Turpin, Remy and Le Traon, Ocean Science, 2016)

Impact of the assimilation of Argo floats and their density. Reference run (all observations), run no Argo, run Argo/2. E-AIMS FP7 project.



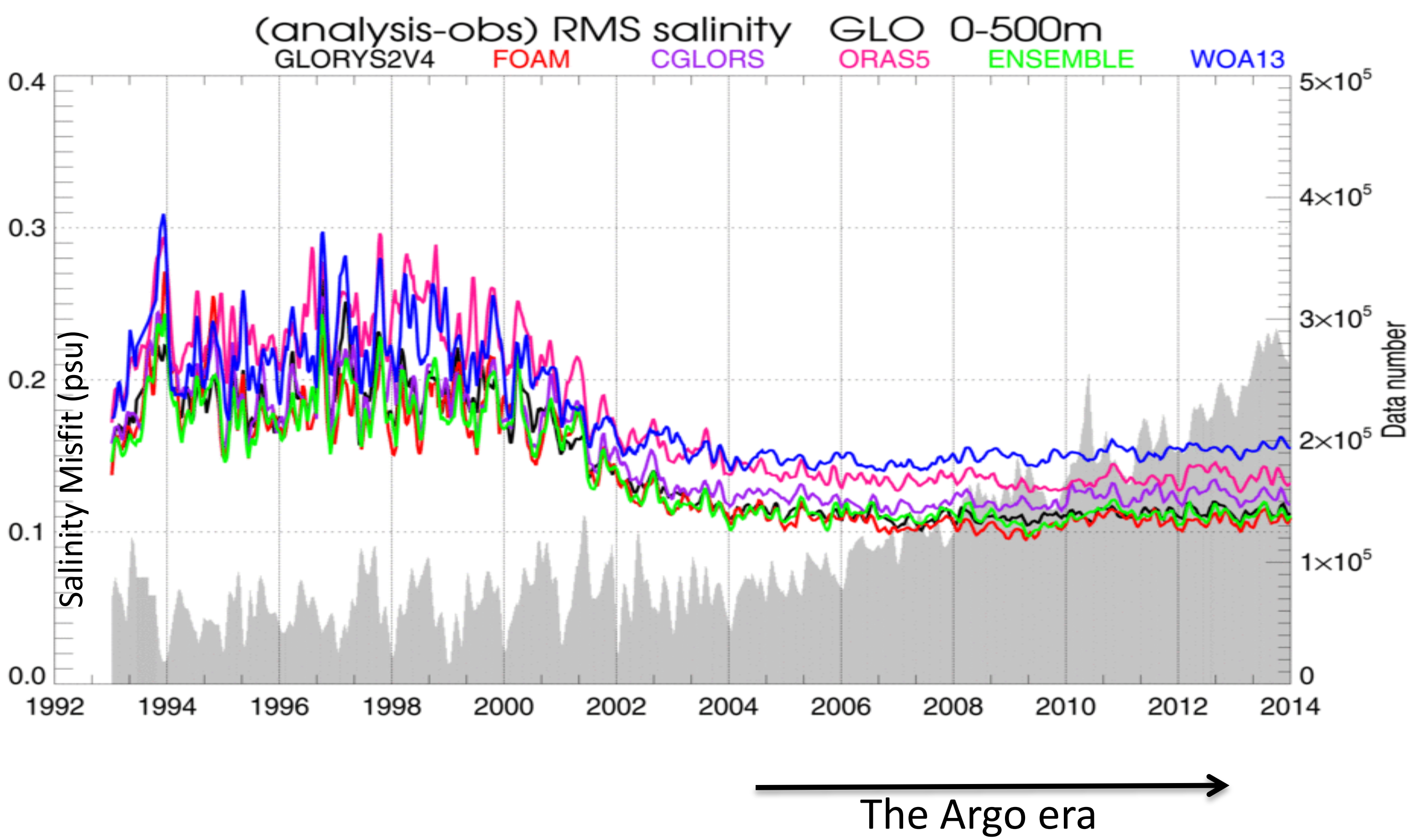
RMS of 0-300 m temperature differences between Run-Ref and Run-NoArgo



Absolute (left) and normalized (right) RMS of temperature innovations for Run-Ref(blue), Run-Argo/2(yellow), Run-NoArgo (green) and Free Run (red)

- T&S 7-day forecast errors reduced by 20 to 60% when Argo data are assimilated.
- Higher impact is found:
  - in surface layers in the tropical band and energetic ocean regions (WBC,…),
  - at depth in outflow or deep convection regions.
- Keeping only half of the Argo floats degrades significantly the analysis.

Contribution of Argo : comparison between different global ocean reanalyses and observations (salinity)

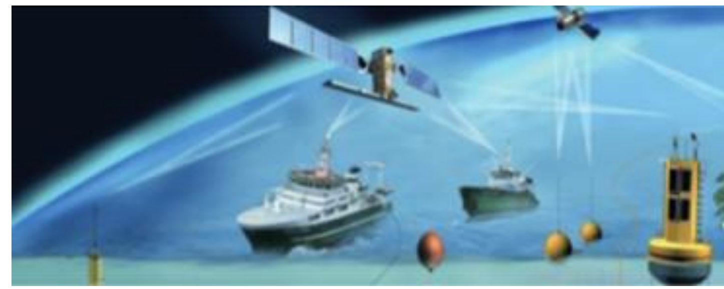


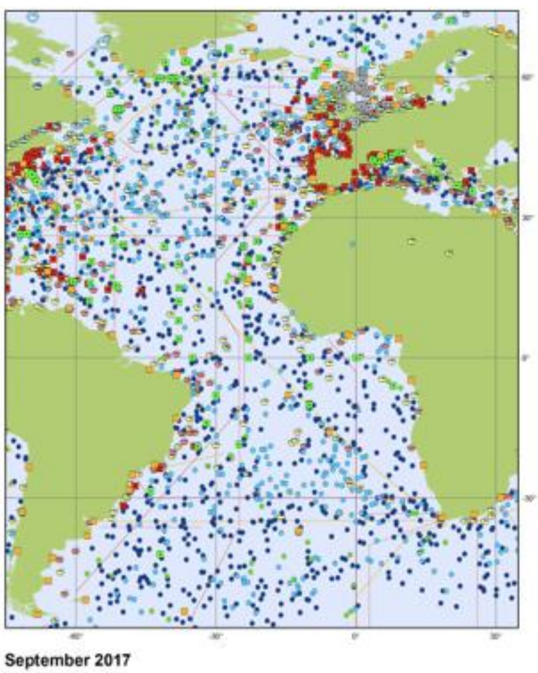
THE PROGRAM H2020 ATLANTOS

AtlantOS
EU Horizon 2020 project

Partners: 62 partners from 18 countries (13 EU & 5 non-EU)
Coordinator: GEOMAR
The project: Integration of ocean observing activities across all disciplines for the Atlantic

While space-based observations are better coordinated, the in situ observing networks are still somewhat fragmented.





Atlantic Ocean Observing System (2015)

Organised in 10 high-level work packages on:

- *Enhancement of ship-based and autonomous observing networks*
- *Interfaces with costal ocean observing systems*
- *Integrated regional observing systems (climate and fisheries)*
- *Cross-cutting issues and emerging networks*
- *Data flow and data integration*
- *Social benefits from observing/information systems*
- *System evaluation and sustainability*
- ***Observing system requirements and design studies (physics and BGC)***

2. Observing System Simulation Experiments in AtlantOS (physics)

➔ **Multi-models / multi-approaches** exercice considering the **same synthetic observations**

Nature Run

global HR Mercator Ocean - 1/12° - daily (CMEMS)
Forcing: 3h-ECMWF (operational)
Initialisation: EN4 climatology
No assimilation

Construction of **Synthetic Observations**

An ocean **data assimilation system**

CLS: ARMOR-3D multivariate ocean state (observations only)

CMCC: Ensemble NEMO simulations

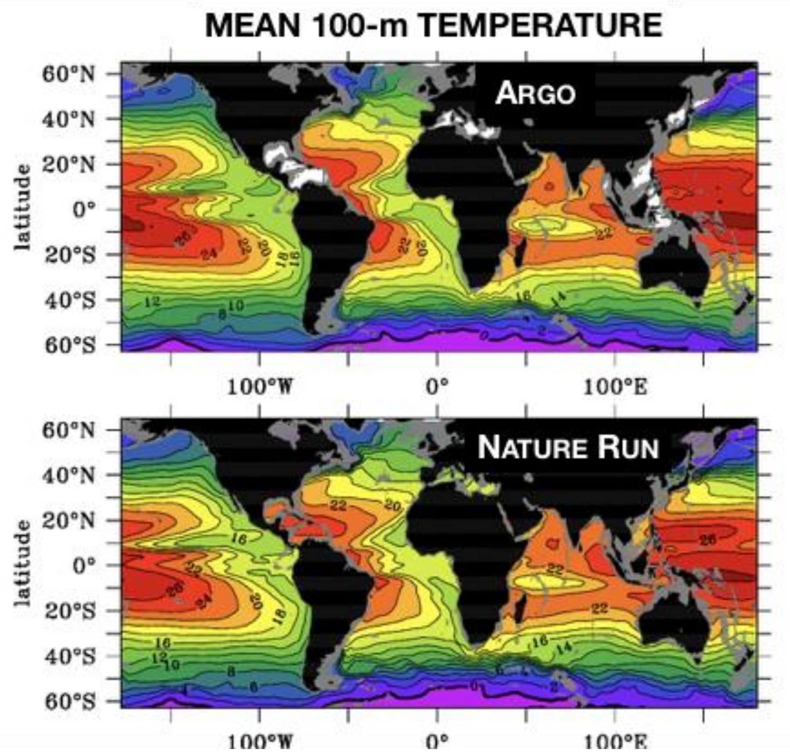
Met-Office: 1/4° global - NEMO/NEMOVAR

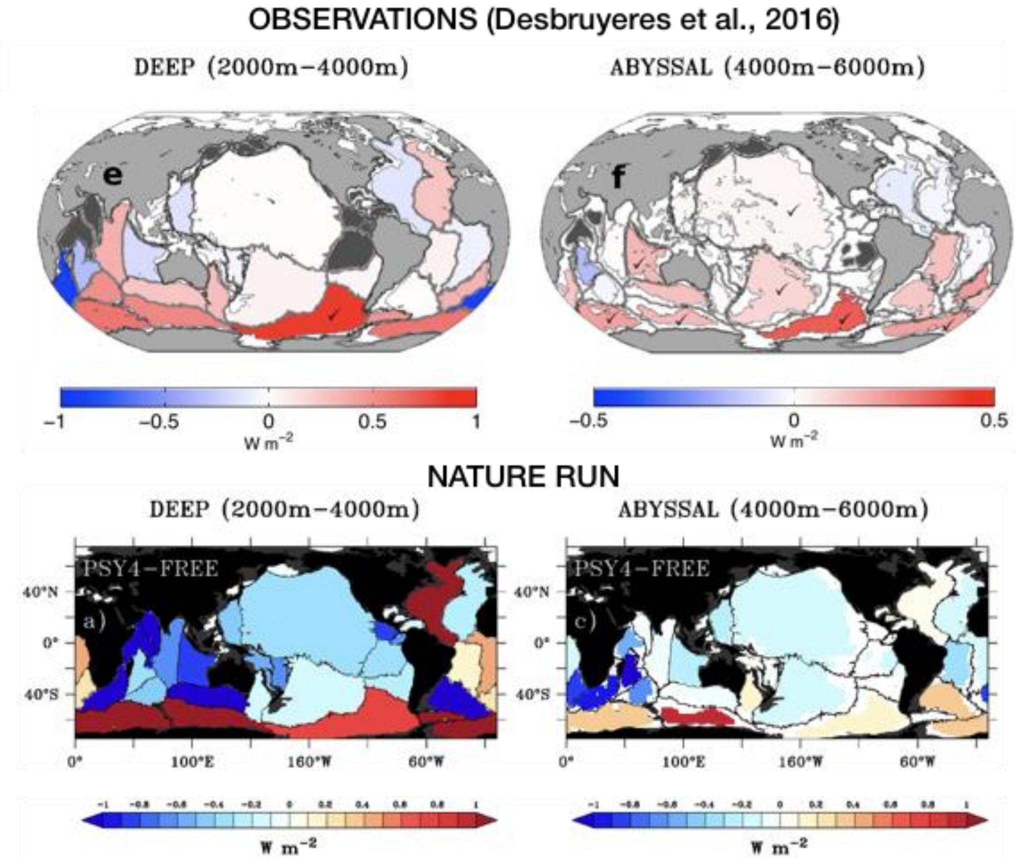
Mercator-Ocean: 1/4° global
System: NEMO/SAM2
Forcing: 3h-ERA-Interim
Initialisation: Levitus13 climatology

OSSE have an ocean state reference (=NATURE RUN)

THE QUESTION IS HOW DO OSSE SIMULATIONS REPRODUCE THE NATURE RUN ?

A "REALISTIC" NATURE RUN





- The mean and climatology is similar with Argo (Roemmich and Gilson, 2009)
- Limitations concerns the spatial position of the main structures

- Temperature long-term trends in the deep ocean are regionally consistently regionally with observations

➔ Gasparin, et al., 2018: *A global view of the 2007-2015 oceanic variability in the global high resolution monitoring and forecasting system at Mercator-Ocean, In review in Journal of Marine Systems.*

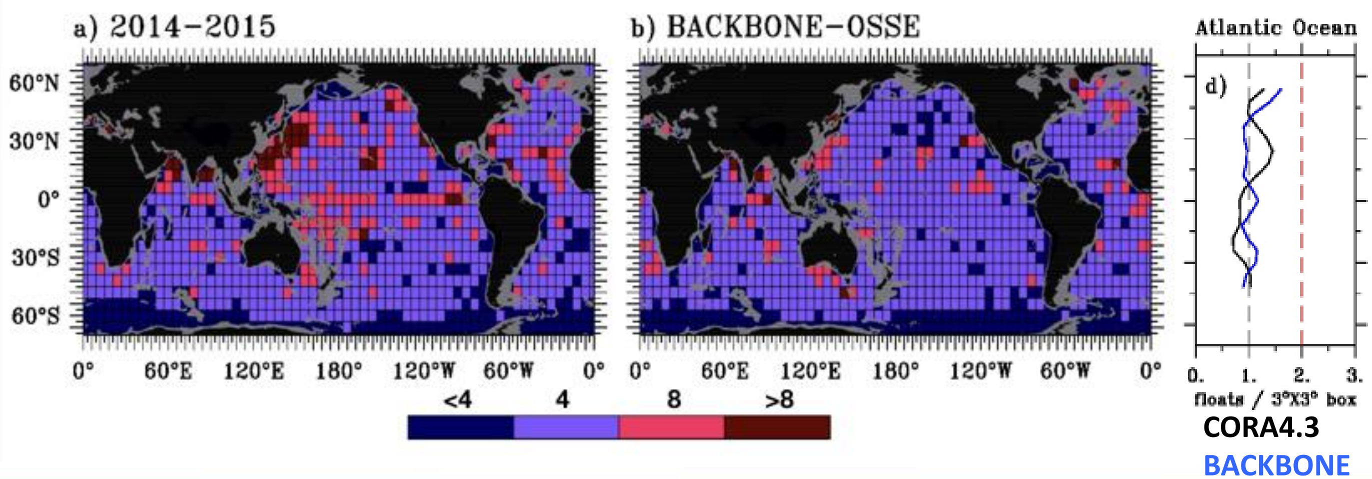
A SET OF 3-YEAR OSSE EXPERIMENTS

OSSE1 – BACKBONE (Satellites+Argo+Mooring+XBT)
OSSE2 – ARGO2X (BACKBONE + Enhancing WBC and Equatorial regions)
OSSE3 – DEEP4000 (BACKBONE + Extension to 4000m)
OSSE4 – DEEP6000 (BACKBONE + Extension to 6000m)

1. Construction of **synthetic observations** by subsampling the Nature Run at the space and time location of each observation (SSH, SST, Argo, Mooring, XBT)
2. Addition of **realistic errors** on synthetic observations (instrumental + representativity errors) following observing network recommendations

➔ OSSE1: Experiment **BACKBONE (SSH, SST, Argo, Mooring, XBT)**

Number of floats per 6ºx6º square from the CORA4.3 data set, and from the synthetic BACKBONE design

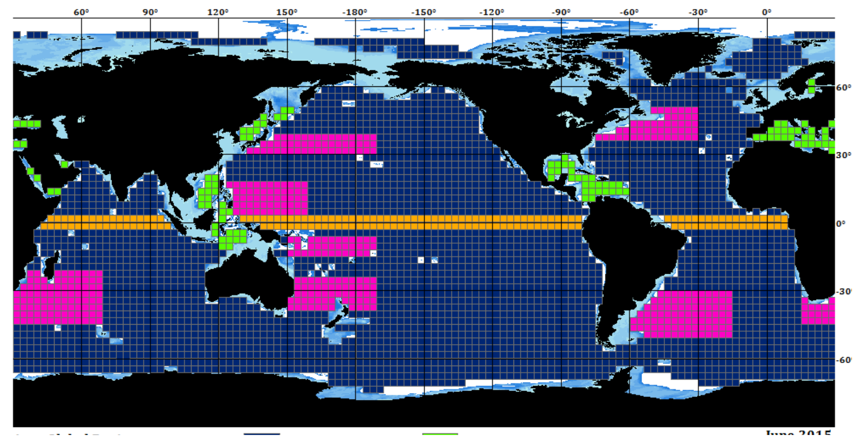


3. The Doubling of Argo in WBC and EQUATORIAL (3s-3n) regions

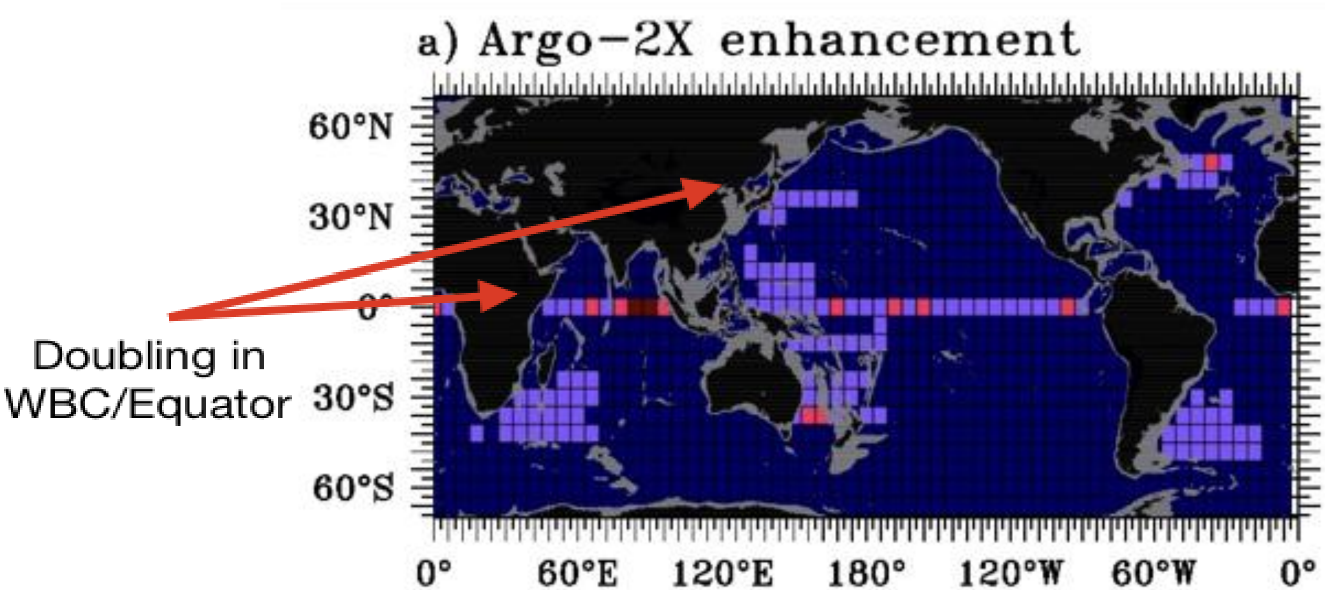
➔ OSSE2: Experiment **ARGO2X**

= Backbone + doubling Argo WBC/ Equator

- Target density 2 x global design = 2 floats every 3°x 3° in high energy regions.
- Adding T/S profiles according to Argo trajectories of year N+1 in JCOMMOPS regions



(JCOMMOPS)



Equivalent-number of floats added in the JCOMMOPS regions

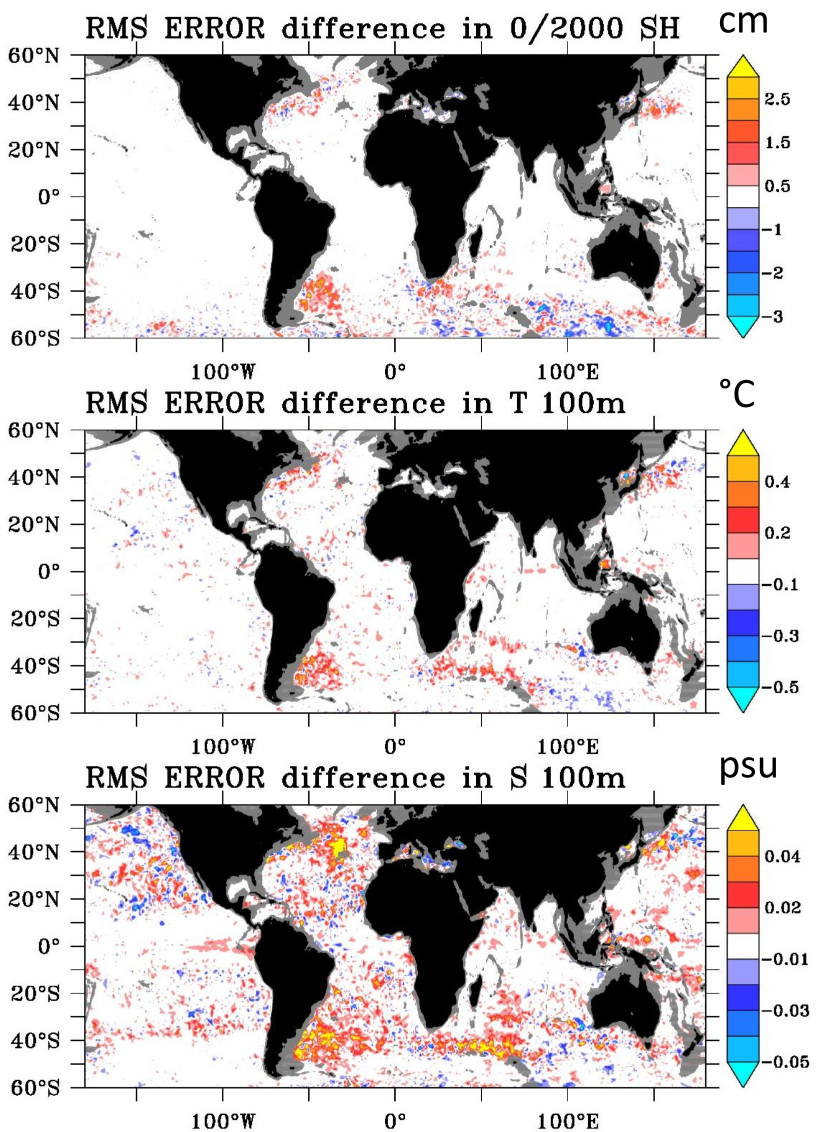
3. The Doubling of Argo in WBC and EQUATORIAL (3S-3N) regions

Improvement of the 2009-2010 daily variability for the 0/2000 SH, 100-m Temperature and 100-m Salinity

« RMS diff of BACKBONE minus RMS diff of ARGO2X relative to the Nature Run »

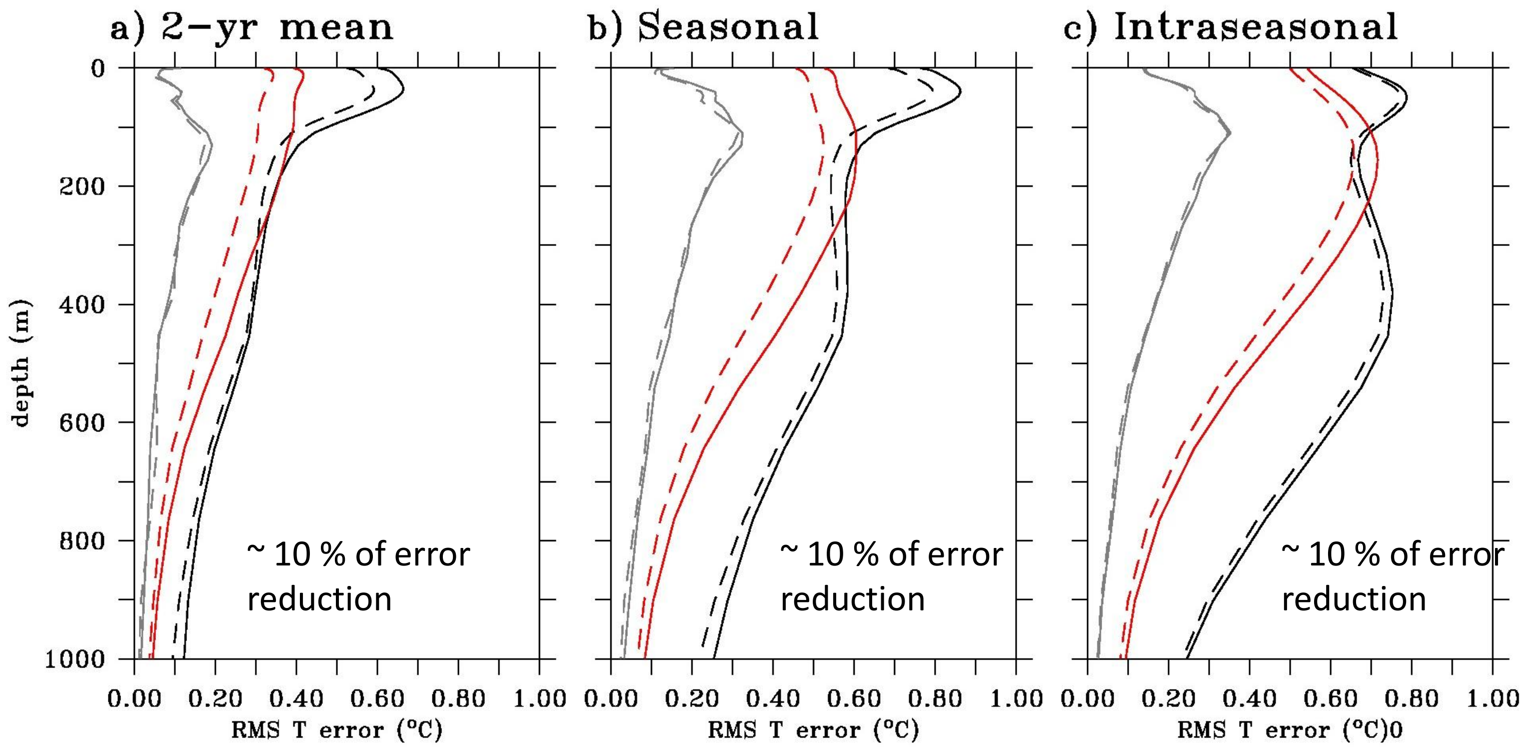
(red = improvement, blue = deterioration)

- Doubling Argo in WBC shows clear improvements, but still small compared with the total variability (not shown)



3. The Doubling of Argo in WBC and EQUATORIAL (3s-3n) regions

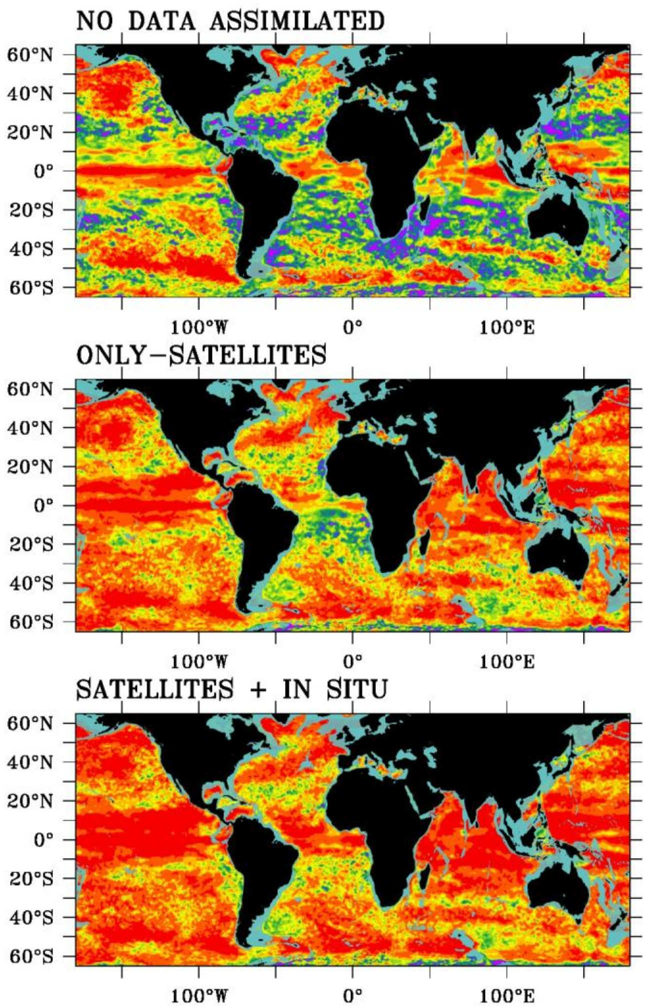
Temperature RMS diff. area-averaged in **the Gulf stream**, **the Brazil Current**, and **the Equatorial Atlantic** for representing the 2-yr mean, and seasonal and intraseasonal variability



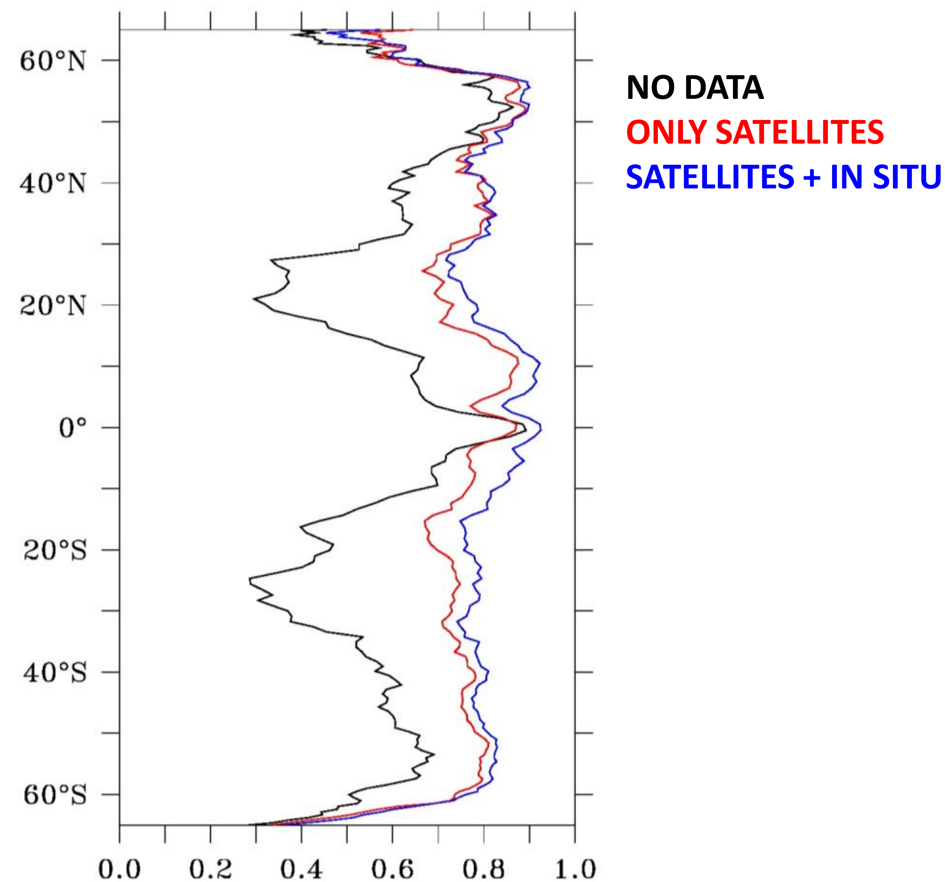
- Impact limited along the equator possibly reflecting (i) statistics on a too short period, (ii) a “simple” dynamic mostly controlled by atmospheric forcing, (iii) altimetry consideration.
- Effective impacts in WBC for 0/2000 SH, Temperature and salinity at different time scales
- Brazil Current region is more affected by doubling Argo floats

INTEGRATED SYSTEM : COMPLEMENTARY ROLE OF IN SITU AND SATELLITE OBSERVATIONS

Correlation of the 100-m temperature
with the Nature Run from 3 experiments



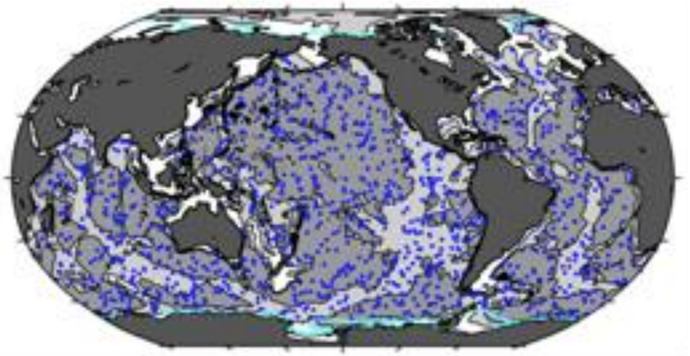
Zonal average



4. The Extension of Argo into the DEEP/ABYSSAL ocean

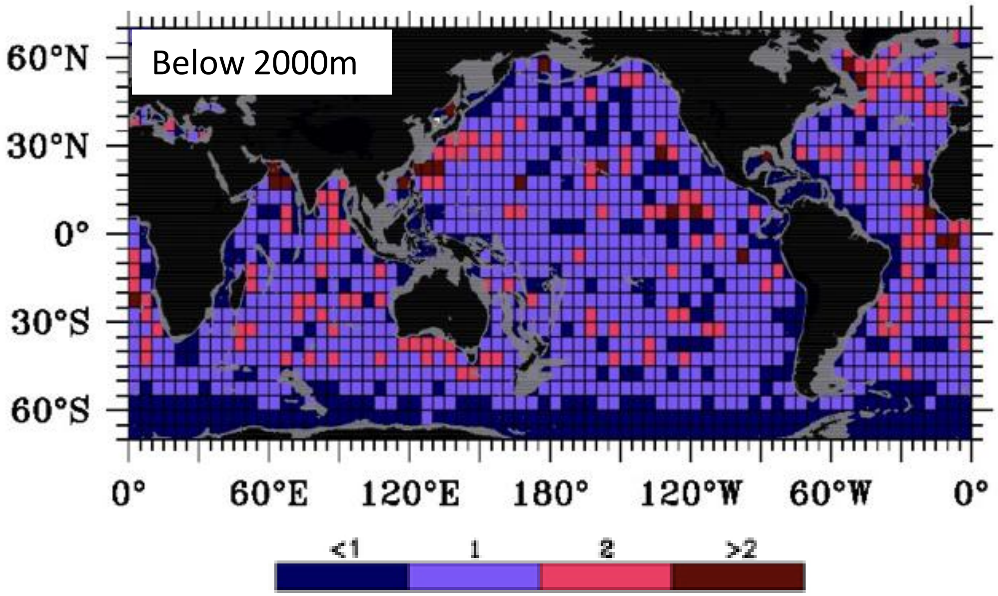
➔ OSSE3/4: Experiments **DEEP4000 / DEEP 6000**
= Backbone + deep extension

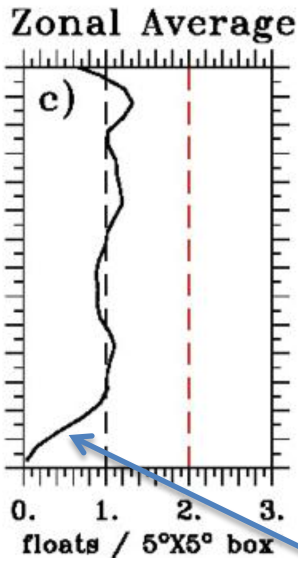
- Extension of 1/3 of core-Argo floats monthly at 4000m (DEEP4000) / 6000m (DEEP6000)
- Target density of Johnson et al., 2015 = 1 float every 5°x 5° monthly



(Johnson et al., 2015)
~1200 floats

Monthly extension of a 1/3 of core-Argo floats





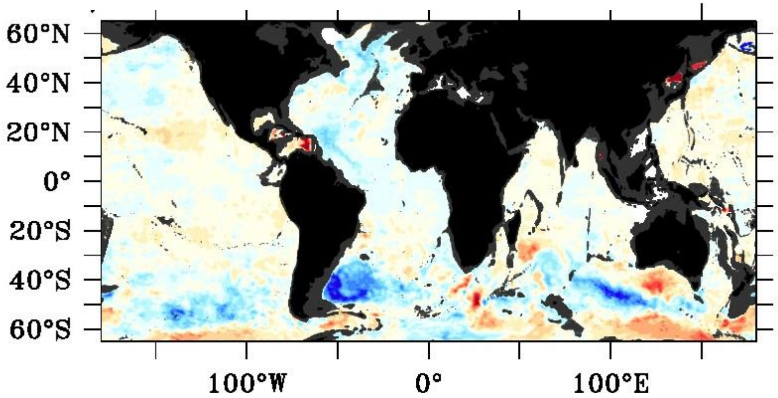
Equivalent-number of floats monthly sampling into the deep ocean

Deep extension reflects core-Argo = The Southern Ocean is undersampled

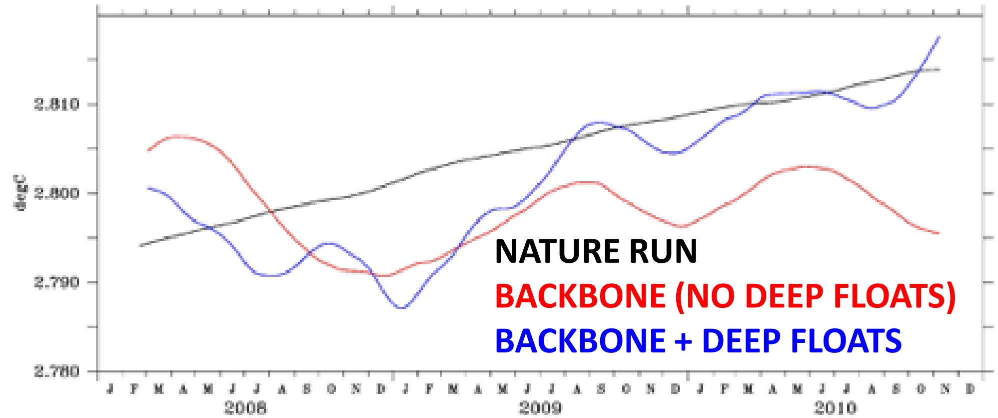
4. The Extension of Argo into the DEEP/ABYSSAL ocean

Error on mean 2000/4000 SH for the year 2010

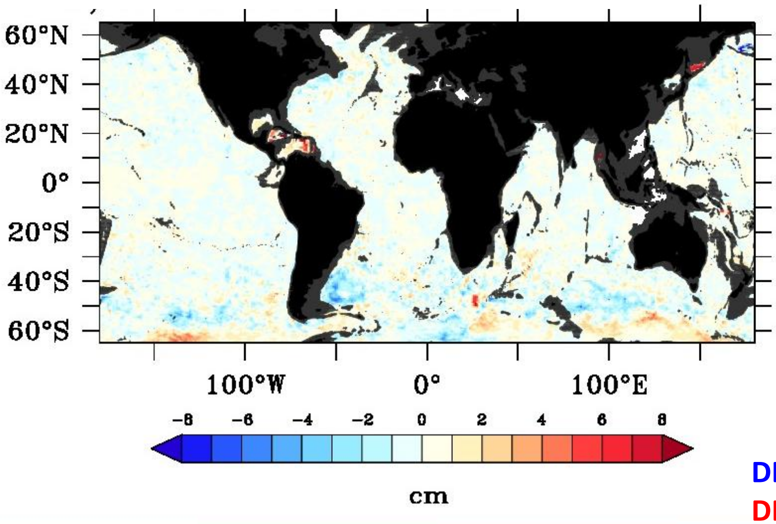
BACKBONE



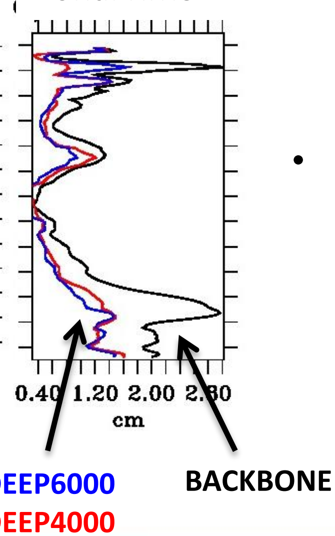
2000m-3000m Temperature in the North Atlantic



DEEP6000

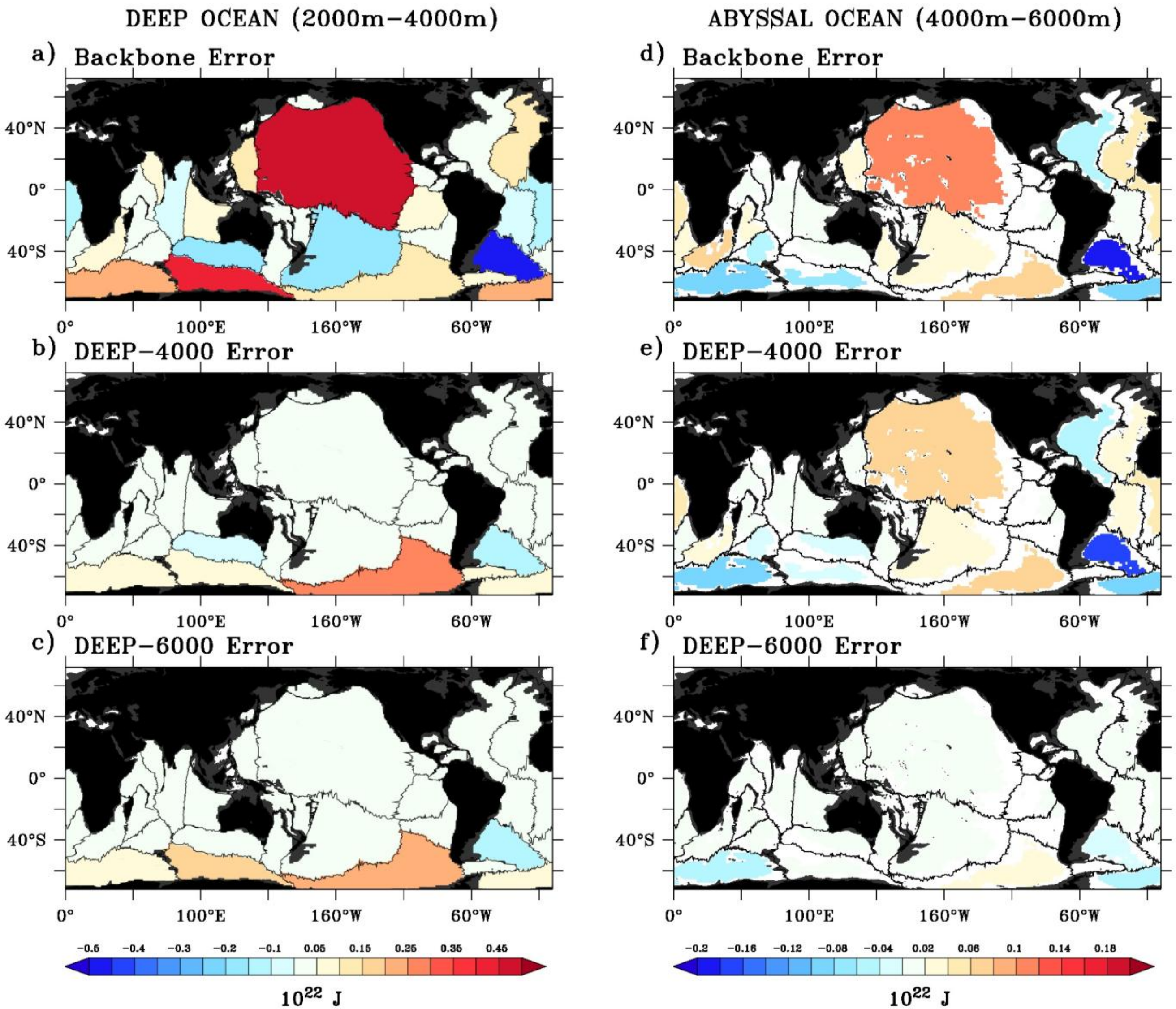


Zonal RMS



- Deep Argo significantly reduces biases, especially in the Southern Ocean

4. THE EXTENSION OF ARGO INTO THE DEEP/ABYSSAL OCEAN

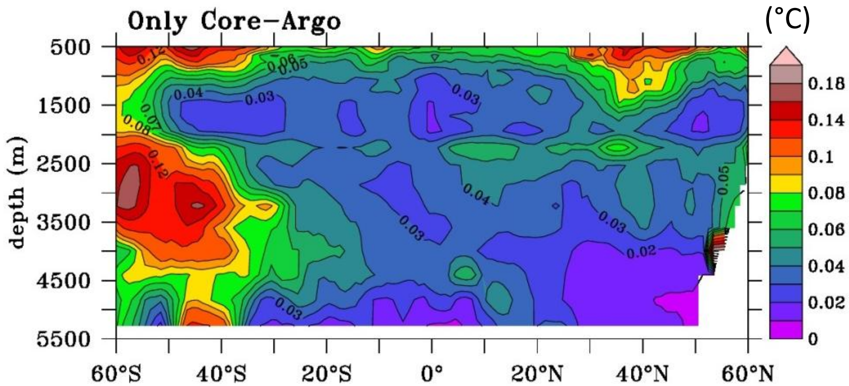


2010 OHC error in the deep and abyssal oceans for the Backbone, DEEP4000 and DEEP6000 experiments

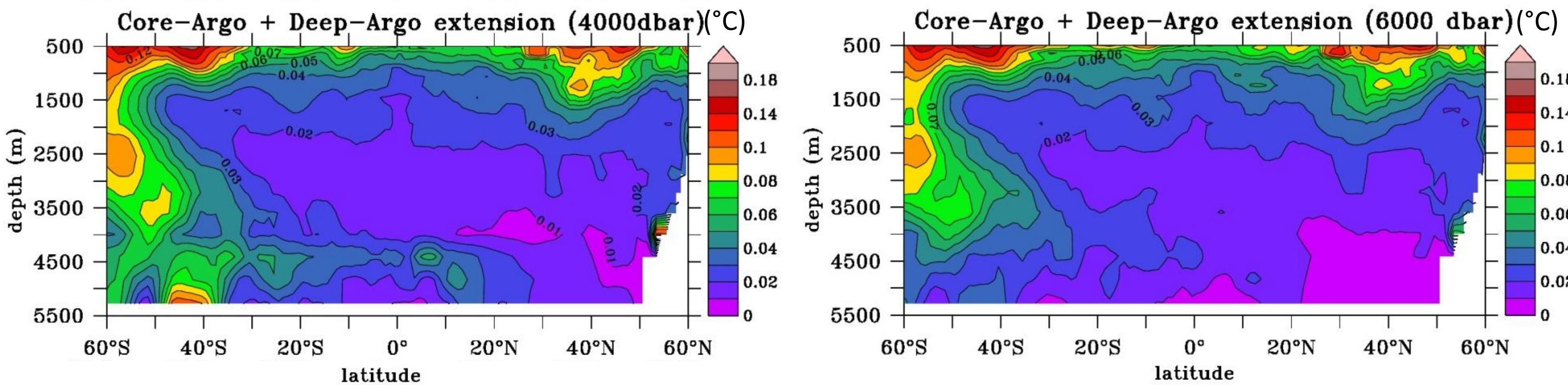
Impact of deep-Argo is evident on the 2010 mean in the 2000-4000m layer, the Southern Ocean remains undersampled

Compared with DEEP4000, DEEP6000 significantly reduces biases in the 4000-6000m layer

Impact of Deep-Argo enhancement on 2-year mean temperature fields



Temperature zonal RMS diff. compared with the realistic simulation for representing a 2-yr mean for only core-Argo (0-2000dbar, top panel), for core-Argo + deep-Argo extension (0-4000dbar, bottom left panel), for core-Argo + deep Argo extension (0-6000dbar, bottom right panel)



CONCLUSION

SUMMARY OF RESULTS :

1. Observation impact studies are needed to support the evolution of global ocean observing system, but also refine data assimilation schemes in operational systems (e.g., Deep Argo).
2. OSSE dedicated to *in situ* obs. provide complementary elements for observing networks by assessing their future contribution on operational systems in an integrated view (with altimetry)
3. Doubling core-Argo (0-2000m) improves the representation of WBC and equatorial variability, by reducing Temperature and Salinity error of around 10% of in these regions.
4. The extension of Argo into the deep ocean shows significant improvement for representing the mean of the deep ocean. More investigations are needed for estimating impact on the long-term trends.

NEXT STEPS:

- Results can be model-dependent, multi-model approach is required to assess the robustness of the results (AtlantOS exercise, Mercator Ocean/MetOffice/CLS/CMCC)
- Gasparin, F., Hamon, M., Remy, E., and Le Traon P.Y., 2018: *Assessing the Global Argo Array Enhancements Using Observing System Simulation Experiments*, In preparation

Atlantos Argo BGC OSSEs
(Met Office, CNRS/LGGE)

- Perform OSSEs to assess different BGC-Argo deployment strategies
- Assess:
  - the sampling coverage required to constrain the biogeochemistry
  - where assimilating BGC-Argo would have greatest impact
  - how BGC-Argo data would complement existing ocean colour data

- Align with physics OSSEs (same model and Argo trajectories)

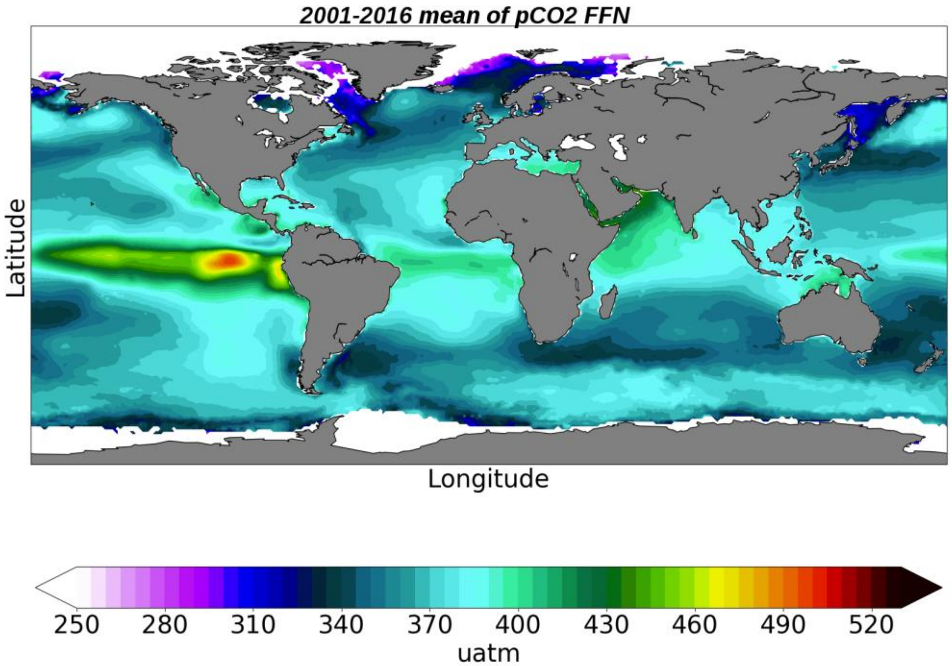
- Model runs (global ¼° NEMO)
  - Nature run (used to generate “ocean colour” and “BGC-Argo”)
  - Perturbed run
    - OSSE 1: Assimilate “ocean colour” into perturbed run
    - OSSE 2: Assimilate “ocean colour” and ¼ “BGC-Argo” into perturbed run
    - OSSE 3: Assimilate “ocean colour” and full “BGC-Argo” into perturbed run

- Simulated observations
  - Ocean colour: daily surface chlorophyll
  - BGC-Argo: profiles of chlorophyll, nitrate, oxygen, pH

Observing System Design Studies : pCO2 and pH

Partners: LSCE/CNRS, University of Exeter

- **Reconstruction of pCO2 through statistical methods (Feed-Forward Neural network Model applied globally** and **Vector Generalized Additive Model at the ocean basin scale)**
- **Estimation of air-sea flux CO2 and pH from FFNN and VGAM**
- **Time period : 2001-2016**



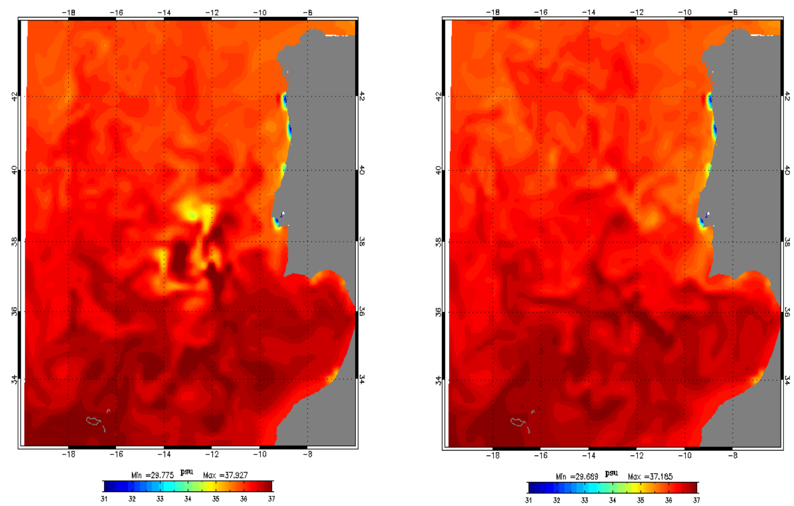
Network simulation experiments:

1. Existing network of *in situ* obs: VOS + moorings
2. Addition of all Argo floats with pCO_2 (pH)
3. Addition of 30% of Argo foats with pCO2 (pH)
4. Combination of VOS + Argo + moorings

Iidentification of an improved observational network for air-sea flux of CO2 and pH monitoring.

Experiment activities are conducted to clarify benefits of existing and enhancements of the Argo network on operational systems

SSS FIELDS (03/01/2008)



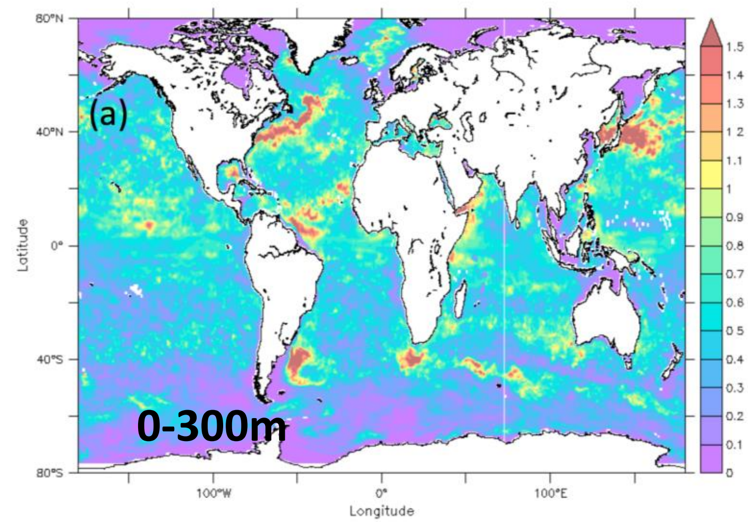
Before background check *After background check*

- Erroneous measurements clearly impact on the operational system
- Quality profile checks have been implemented

Major contribution of the existing Argo network
(E-AIMS project - 2013-2015)

- Removing all or part of **existing Argo floats** in a data assimilation system has strong impacts on upper-ocean representation
- Higher impact is found in the tropical band and energetic ocean regions, where high eddy activity drives a lower signal/noise ratio
- Keeping only ½ of Argo floats degrades significantly the analysis.

Temperature RMS diff. Operational-minus-NoArgo.



(Turpin et al., 2016)