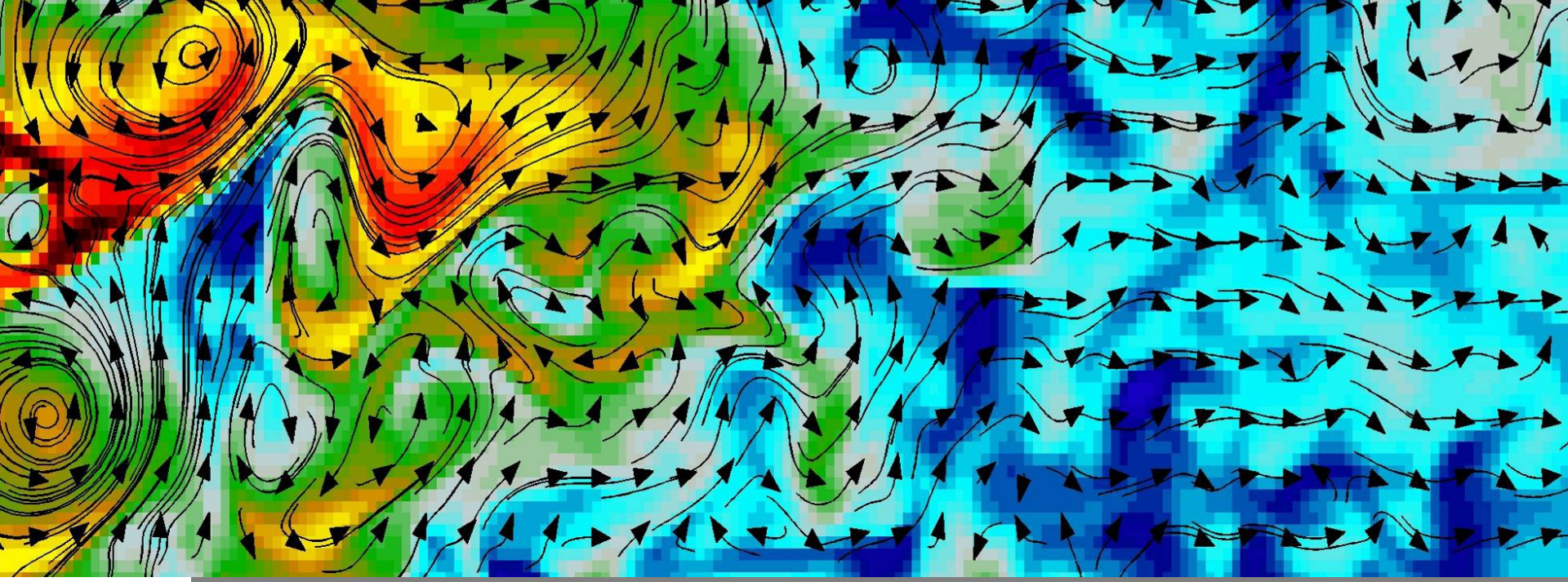


# Interoperability between observation and prediction systems function? - Example Argo

Peter Oke
CSIRO Environment


House of Ocean
Prediction


House of Ocean Prediction
Advice
Best Practices
Products
Ocean Data Assimilation
Ocean Model
Tools


**Real-Time Argo data***

**$$$ $$$ Research Funding $$$ $$$**

*Just one of many observational foundations

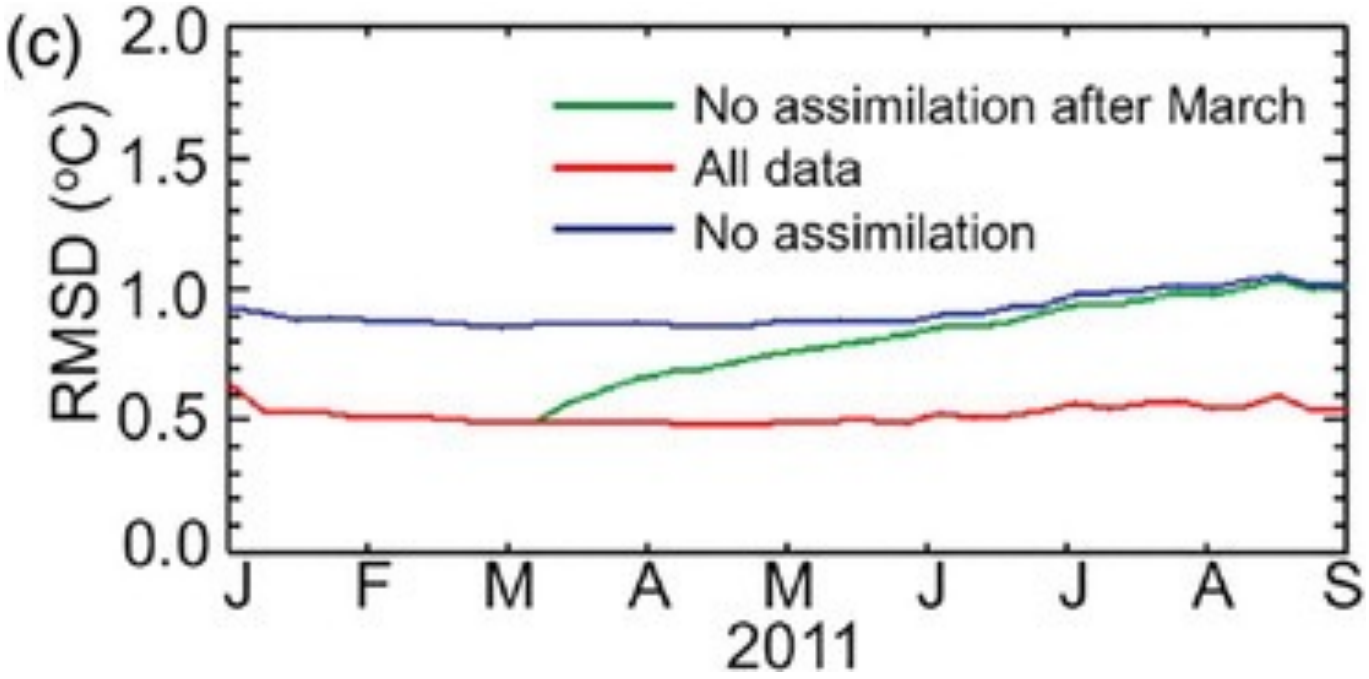

*Just one of many observational foundations

# A Simple OSE

One of the simplest Observing System Experiments ever published.
Courtesy of Greg Smith, Environment Canada.

*Q/ What happens if we have no observations to assimilate?*

*A/ Our systems forget all data in about 2 months* ☹




Oke, P.R., Larnicol, G., Fujii, Y., Smith, G.C., Lea, D.J., Guinehut, S., Remy, E., Balmaseda, M.A., Rykova, T., Surcel-Colan, D. and Martin, M.J., 2015. Assessing the impact of observations on ocean forecasts and reanalyses: Part 1, Global studies. *Journal of Operational Oceanography*, *8*(sup1), pp.s49-s62.

# Talk Outline

- Argo suitability for operational services
- Towards OneArgo:
  - the plan vs the reality
  - the challenges
  - typical costs
  - international coordination
- Using Argo data in real-time
- Using Argo data in delayed-mode
- Reminder of the impacts of Argo data on prediction systems

- **A plea for help!**

# Argo suitability for operational services

## What the Argo Program does well …

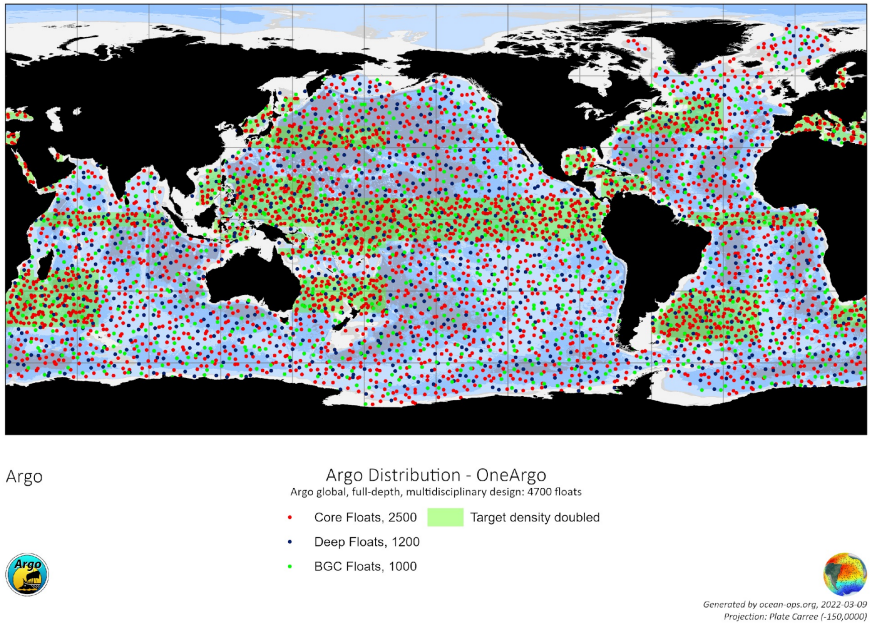
- Only in situ ocean observing program with near-global coverage
- Data retrieved, processed, automatic-QCed and delivered to the GTS and GDACs within 24 hours of measurement
- Vertical resolution of measurements exceeds operational needs
- Complimentary information to satellite altimetry
- Consistently-applied QC flags and grey list maintained
- Strictly enforced data formatting and metadata

## Where the Argo Program struggles …

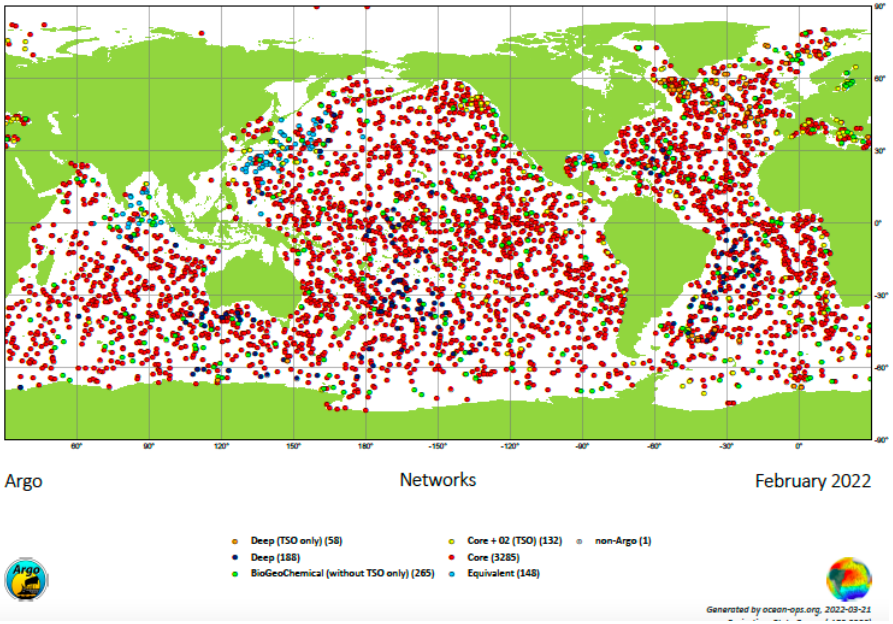
- Maintenance of array on research funding
- Horizontal resolution doesn't resolve mesoscales
- Temporal resolution doesn't resolve mesoscales
- Precision of Argo data is often poorly regarded by the broader observational community (considered uncalibrated data)
- Expansion to OneArgo hasn't been matched by required funding increase
- Real-time data processing usually not 24-7 supported

# Towards OneArgo

## Argo Plan




## Argo Reality




*OneArgo array design*

*2500 Core*

*1200 Deep*

*1000 BGC*

*4700 total*

*OneArgo array status*

*3285 Core*

*188 Deep*

*265 BGC*

*3738 total*

# Towards OneArgo

- OneArgo is an ambitious plan
- The Core Argo Program costs about US$100M/year
- The OneArgo Program will cost about $400M/year

… we're struggling

- **Main challenges**:
  - Raising the funds … most National Argo Programs are supported by research funding
  - New sensors mean more fail modes, more power consumption, and shorter float life
  - New data types mean more data to process, require new processing methods, …
  - Competing interests mean more tension … it's not easy

# Costs of a National Program (e.g., Australia)

- In most countries, Argo funding is from *research funding*
- Ongoing costs include floats purchases, telecoms, and people

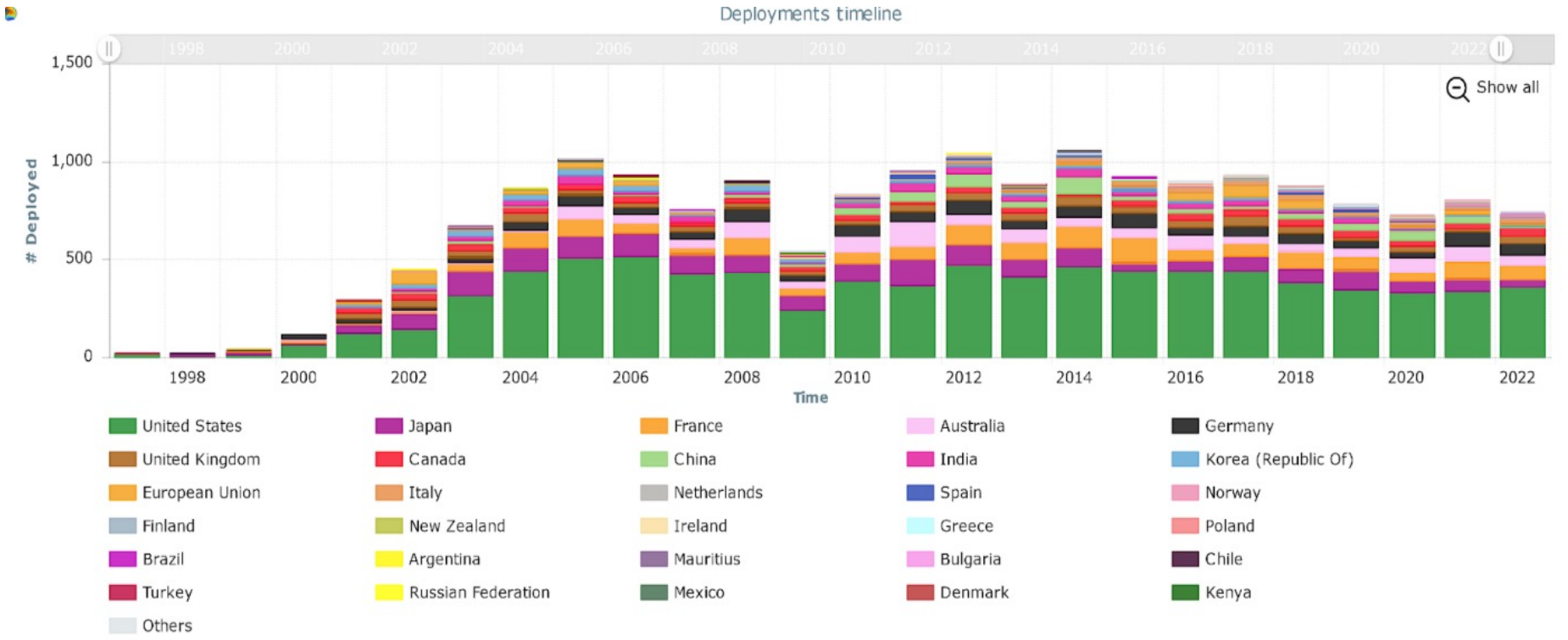
- Annual costs for Australia (AUD):
  - Annual float purchases: ~$3M
  - Annual telecommunications: ~$500K
  - Annual salaries: ~$1.5M
  - Annual budget: ~$5M  *… all from research grants*

- Australia maintains about 5-10% of the global array

- Per float: Core, AUD$30K; Deep, AUD$100K; BGC, AUD$180K

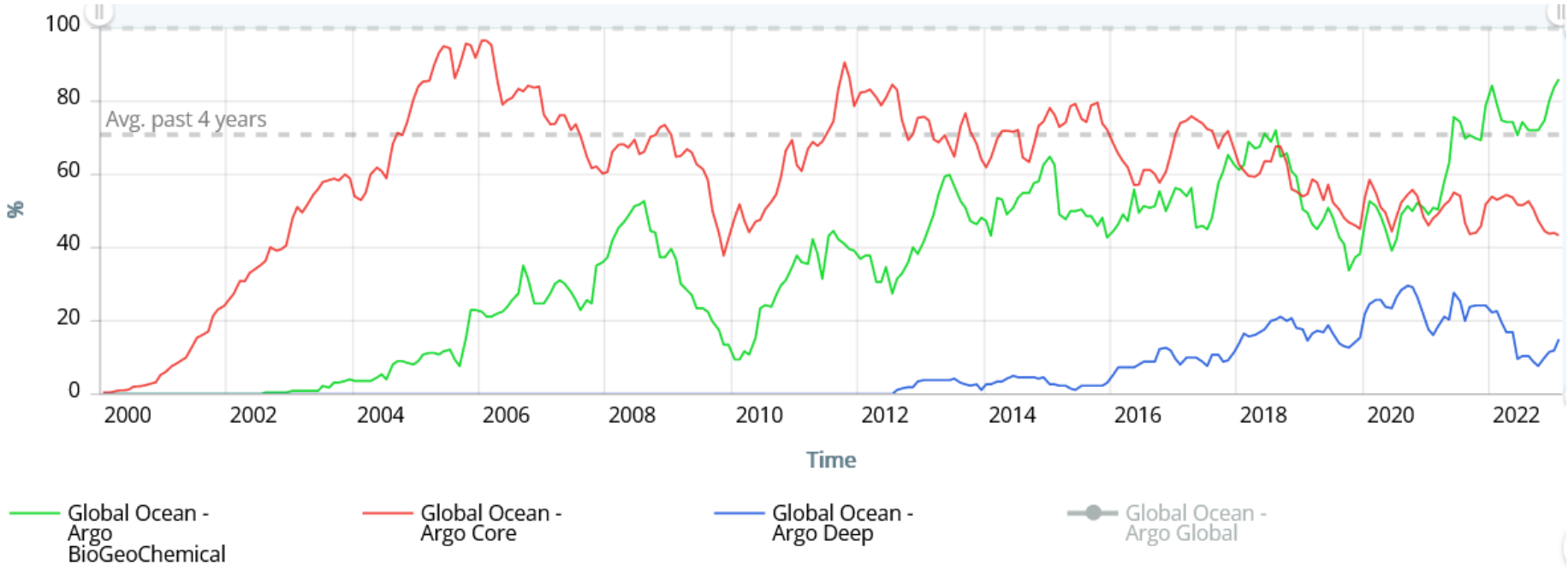
# Argo – working together

- Argo is an international effort with many countries contributing.
- Together, we deploy about 800 floats per year



# Argo – working together

- Argo is an international effort with many countries contributing.
- Together, we deploy about 800 floats per year
- Deployment of core floats are being replaced by BGC floats
- But BGC floats are often operated differently, cost more, and don't last as long (*Core float ~5 years; BGC float ~3 years*).



# Using Argo data

# Using Argo data in real-time

**Use the QC flags!**

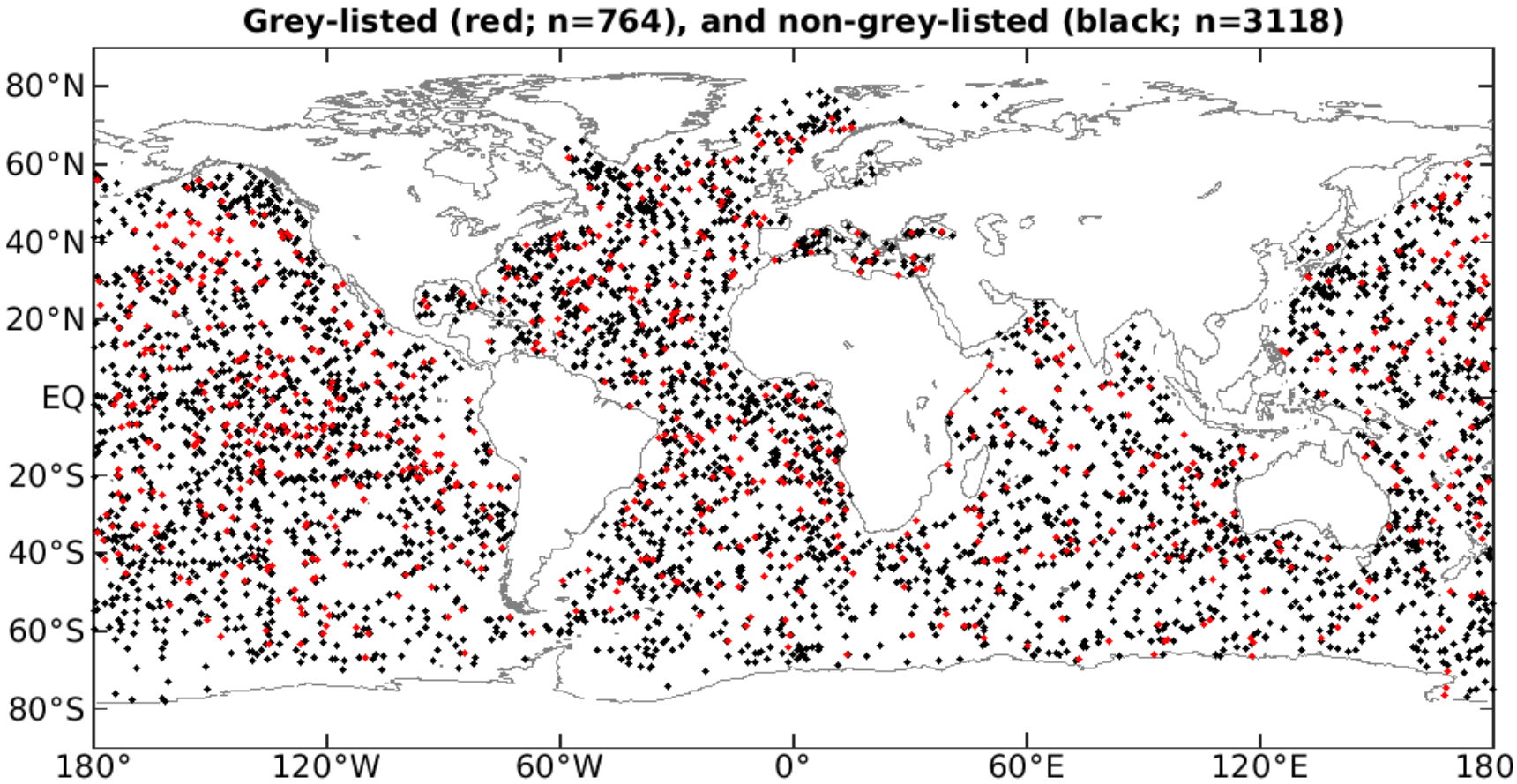
**… and always use the "adjusted" variables**

| QC flag | Meaning | Real-time comment (applicable to <PARAM>_QC in "R" mode and <PARAM>_ADJUSTED_QC in "A" mode) | Delayed-mode comment (applicable to <PARAM>_ADJUSTED_QC in "D" mode) |
|---|---|---|---|
| "0" | No QC is performed | No QC is performed. | No QC is performed. |
| "1" | Good data | Good data. All Argo real-time QC tests passed. These measurements are good within the limits of the Argo real-time QC tests. | Good data. No adjustment is needed, or the adjusted value is statistically consistent with good quality reference data. An error estimate is supplied. |
| "2" | Probably good data | Probably good data. These measurements are to be used with caution. | Probably good data. Delayed-mode evaluation is based on insufficient information. An error estimate is supplied. |
| "3" | Probably bad data that are potentially adjustable | Probably bad data. These measurements are not to be used without scientific adjustment, e.g., data affected by sensor drift but may be adjusted in delayed mode. | Probably bad data. An adjustment may (or may not) have been applied, but the value may still be bad. An error estimate is supplied. |
| "4" | Bad data | Bad data. These measurements are not to be used. A flag "4" indicates that a relevant real-time QC test has failed. A flag "4" may also be assigned for bad measurements that are known to be not adjustable, e.g., due to sensor failure. | Bad data. Not adjustable. Adjusted data are replaced by FillValue. |
| "5" | Value changed | Value changed | Value changed |
| "6" | Not used | Not used | Not used |
| "7" | Not used | Not used | Not used |
| "8" | Estimated value | Estimated value (interpolated, extrapolated, or other estimation) | Estimated value (interpolated, extrapolated, or other estimation) |
| "9" | Missing value | Missing value. Data parameter will record FillValue. | Missing value. Data parameter will record FillValue. |
| " " | FillValue | Empty space in NetCDF file. | Empty space in NetCDF file. |

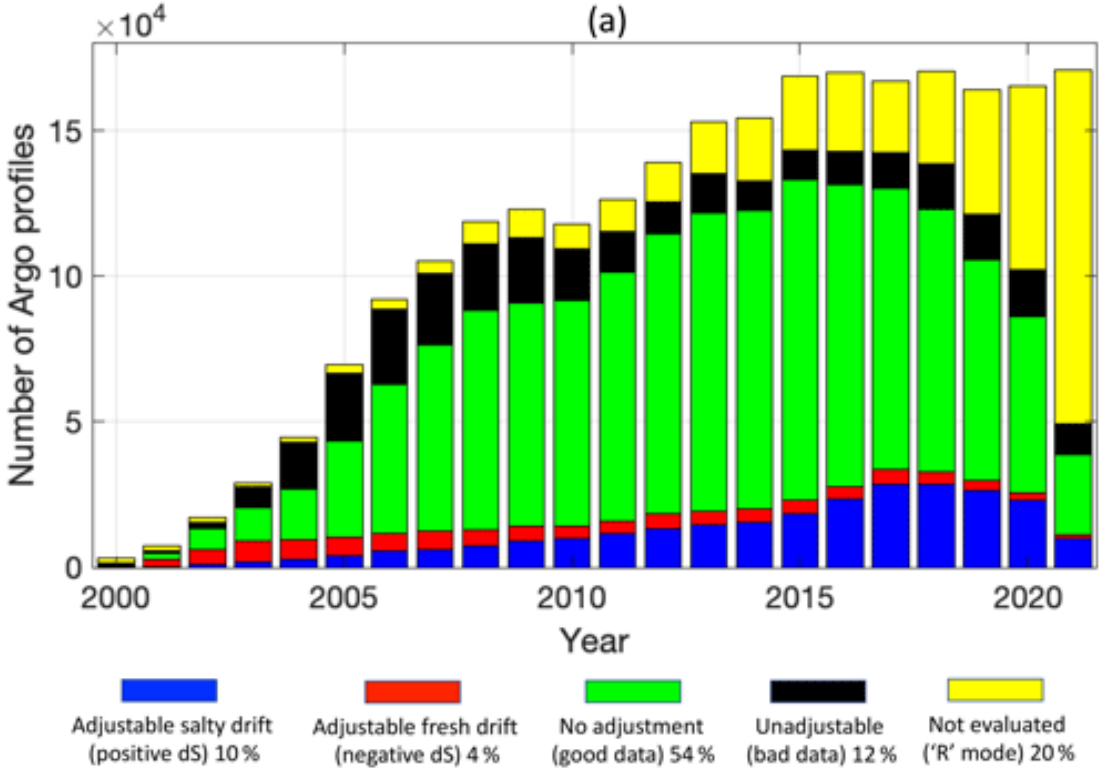
Wong, A. P. S., Gilson, J., and Cabanes, C.: Argo salinity: bias and uncertainty evaluation, Earth Syst. Sci. Data, 15, 383–393, https://doi.org/10.5194/essd-15-383-2023, 2023.

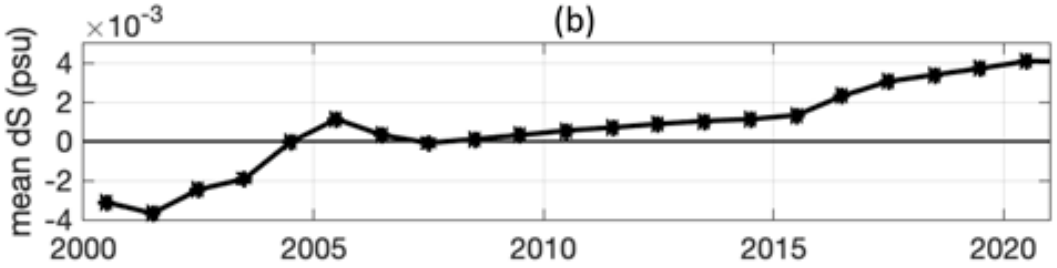
# Using Argo data in real-time - the Grey list

- The grey list includes float IDs that appear to be returning bad or suspect data.
- A significant percentage of floats are grey-listed.



# Using Argo data in delayed-mode




Be aware that delayed-mode quality control on Argo data is … *pause* … **delayed**

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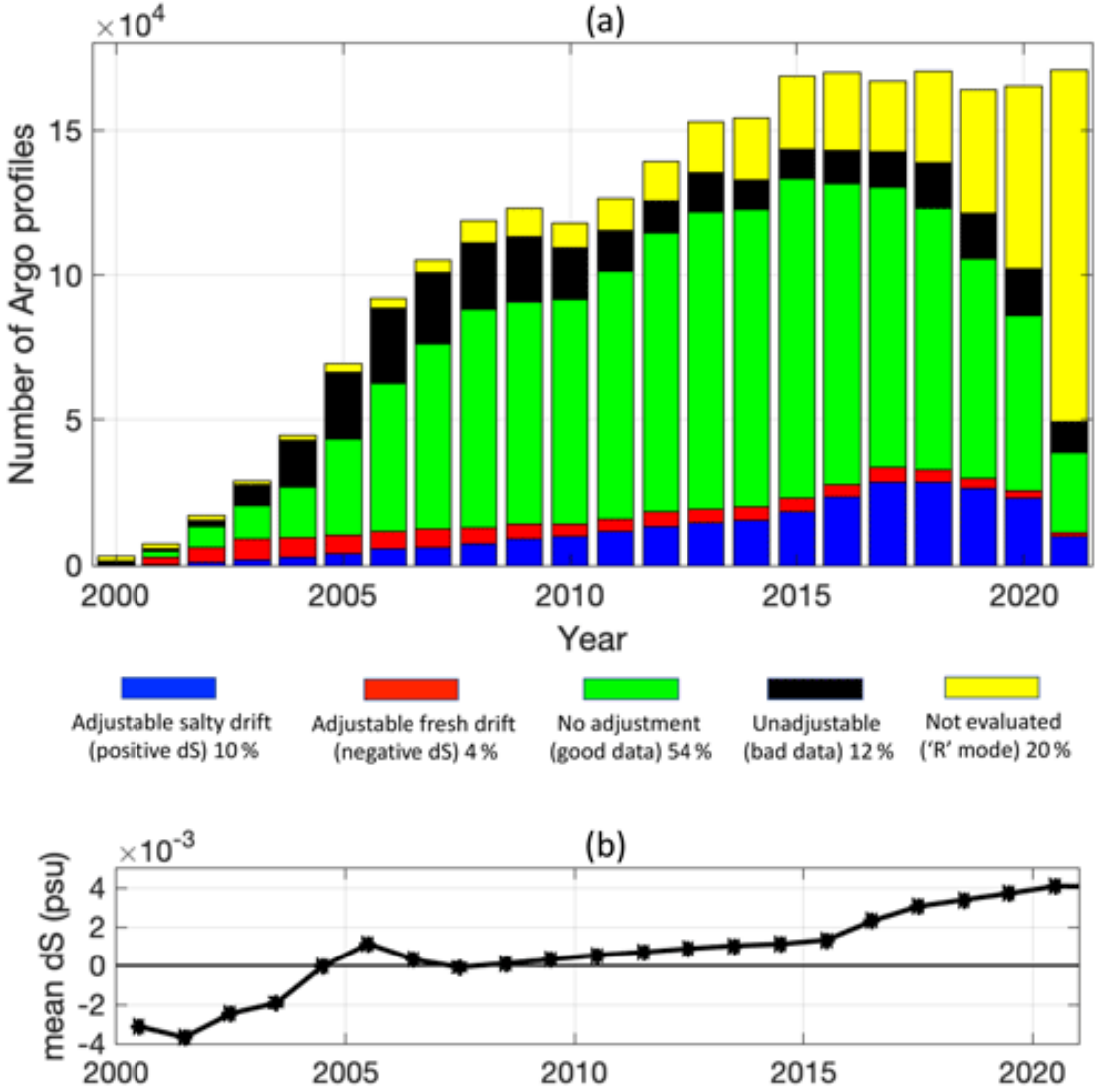


Be aware that delayed-mode quality control on Argo data is … *pause* … **<u>delayed</u>**

… so if you want the most up-to-date data, re-sync your Argo database before every reanalysis.

Community datasets (e.g., EN4, CORA) may not always be up to date. But the GDACs are always up to date.

Wong, A. P. S., Gilson, J., and Cabanes, C.: Argo salinity: bias and uncertainty evaluation, Earth Syst. Sci. Data, 15, 383–393, https://doi.org/10.5194/essd-15-383-2023, 2023.

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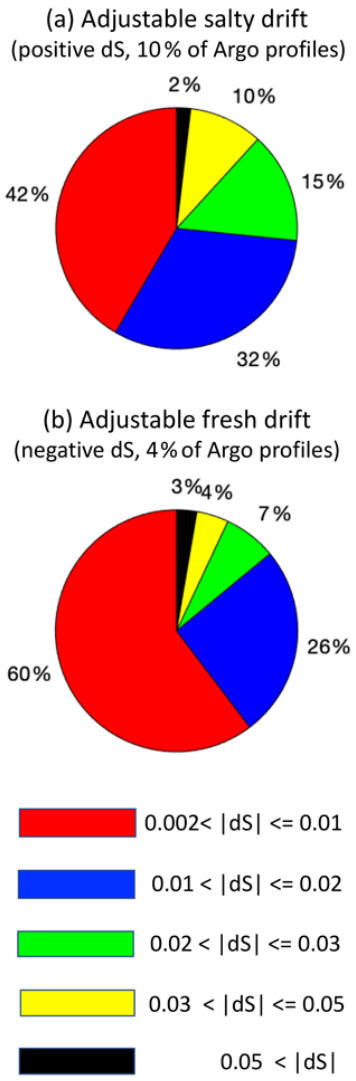
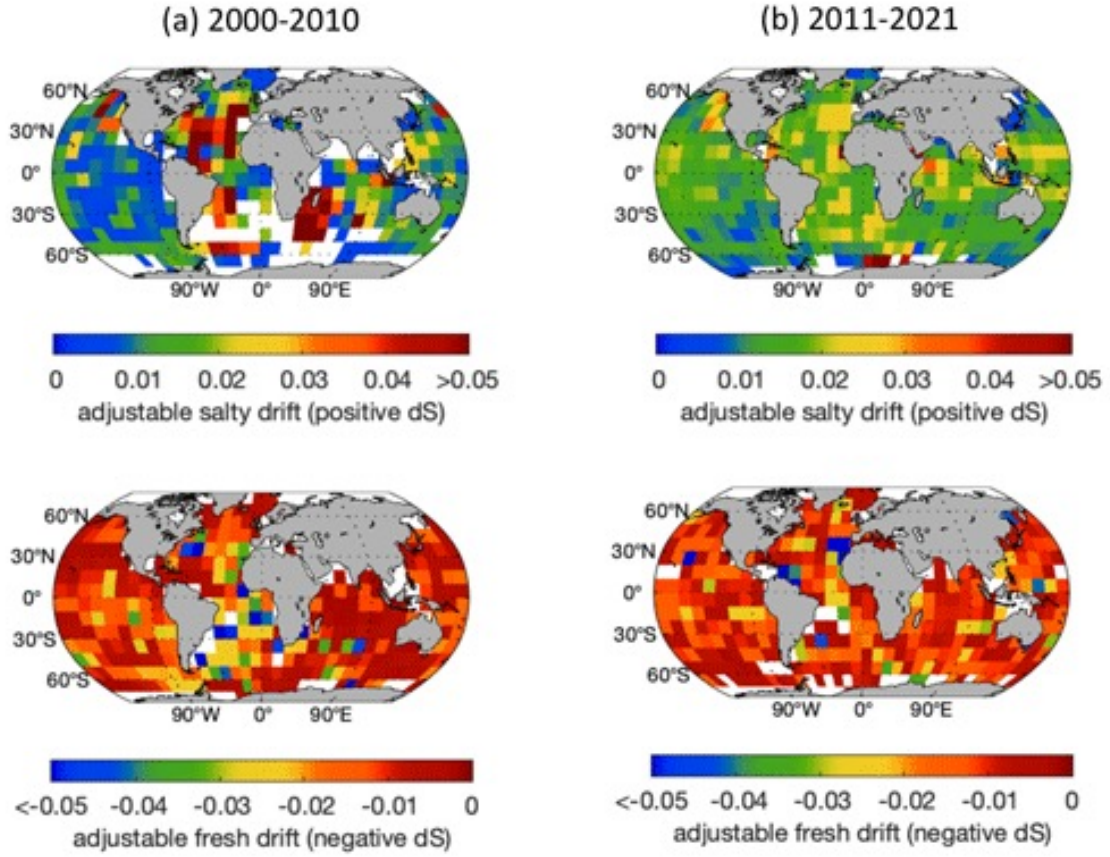



- Most corrections to Delayed-mode data are to salinity.
- Corrections are generally small … but are often systematic (may introduce global or regional biases)

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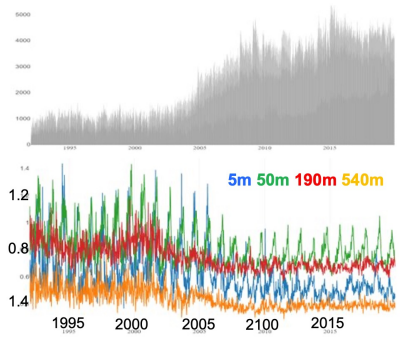
# Impacts on ocean predictions

*Contributors: Remy, Hao, Turpin, Oke*

- Argo always has more impact than every other platform on reanalyses ***subsurface*** ocean properties.
- Impacts pre- and post-Argo are always very clear.

## Impact of Argo data on a 1/12°-res ocean reanalyses

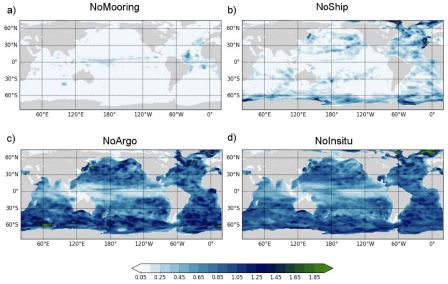
*Remy et al. (Mercator Ocean)*




## Impacts on ocean, sea-ice reanalysis

*Hao et al. (ECMWF)*

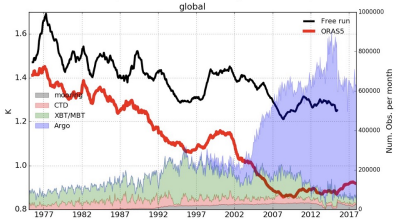
- Maps of normalized RMSD of Temperature (upper 700m) in OSEs with different data with-held. RMSD w.r.t a reference reanalysis, in which all in-situ assimilated.
- Using ECMQF 1/4°-res ocean-ice reanalysis system




## Impacts on ocean, sea-ice reanalysis

*Hao et al. (ECMWF)*

Temperature RMSE (0-1000 m)




Mean: 2005-2014

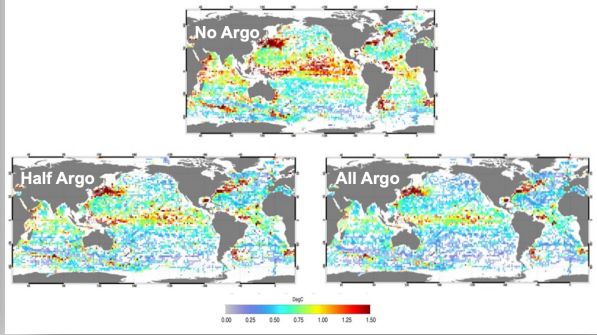
| | T RMS reduction | S RMS reduction |
|---|---|---|
| In-situ | 65% | 90% |
| Bias-corr. | 14% | 10% |
| SST | 18% | negative |
| Altimeter | 3% | neutral |

Assimilation of ocean in-situ observations helps to constrain the 3D ocean, therefore providing better estimation of the ocean initial condition for the coupled forecasting system

## Impact of Core Argo on a 1/4°-res ocean reanalysis

*Turpin, Remy et al. (Mercator Ocean)*

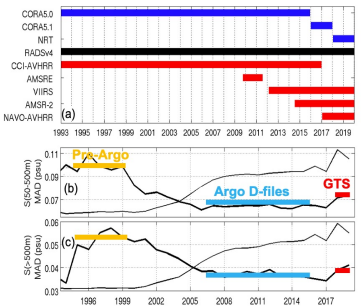
Observing System Experiments (OSEs), showing the RMS misfits of 0-300m temperatures, between *in situ* temperature and analyses from GLORYS




## Impact of R-files on an ocean reanalysis

*Oke, Chamberlain et al (CSIRO)*

- BRAN2020, CSIRO's latest ocean reanalysis.
- In 2017, we switched from D-files to R-files.
- The performance of the reanalysis degraded by about 30%.
- *Using archived data from the GTS, instead of D-files from the GDACs, could degrade your reanalysis by 1/3rd of the improvement gained by assimilating data from all available Argo floats.*



# Impacts on coupled predictions

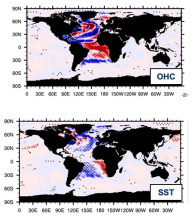
*Contributors: Balmaseda, Fujii, Hao*

- Impacts on coupled systems are often non-local … e.g., with-holding data in the Atlantic, impacts predictions in the Pacific.
- Loss of performance when Argo data are with-held is equivalent to 15-years of system development.

## Impact of ocean observations on atmospheric forecasts

*Balmaseda et al. (ECMWF)*

**May Ocean Initial Conditions**

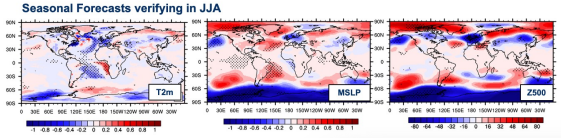



Comparison of OSEs with and without ***in situ data*** in the Atlantic Ocean.

The atmosphere responds to large scale SST gradients. As a consequence, at seasonal time scales, differences in Atlantic SST are felt by the atmosphere at a global scale:

- Note the significant impact on MSLP in the Tropical Pacific, the impact on T2m at the Pacific mid-latitudes.
- There are also some significant impact on the Southern hemisphere subtropical jet by Australia

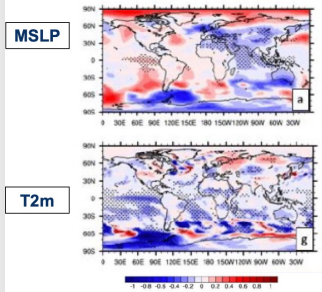
**Seasonal Forecasts verifying in JJA**




## Impact of ocean observations on mean atmospheric state

*Balmaseda et al. (ECMWF)*

**NoArgo-REF**



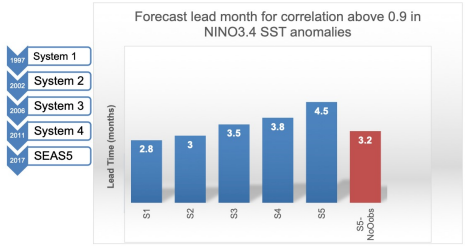

May start 2005-2015, JJA verification

- Tropical Pacific: increased MSLP over cold tongue area, La Nina like conditions, associated with dryness in precipitation.
- Tropical Indo-Atlantic: decrease in MSLP likely due to large-scale SST gradients

## Impact of Argo data on seasonal predictions

*Balmaseda et al. (ECMWF)*

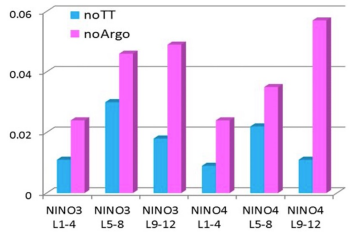
- Demonstration of the improvements of ECMWF's seasonal prediction system … plus a result using the latest system, without *in situ* ocean data.
- Sustained development over 25 years has extended the lead time of useful forecasts by 1.7 months.
- *Without in-situ ocean observations, we'd lose ~15 years of progress.*




## Impacts of Core Argo on seasonal predictions

*Fujii et al. (JMA)*

Observing System Experiments (OSEs), showing the reduction of anomaly correlation for NINO3 and NINO4 at different lead times, with and without data from Argo (magenta) and the Tropical Mooring array (blue)




*L1-4 → 1-4 month lead time*

*L5-8 → 5-8 month lead time*

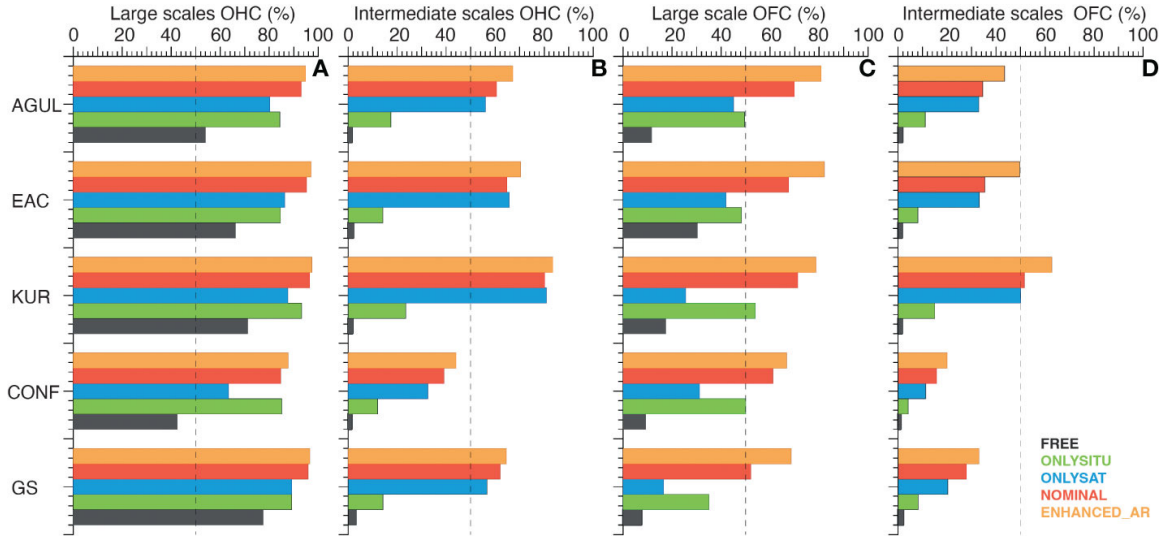
# Impacts of WBC-enhanced Argo (OSSE)

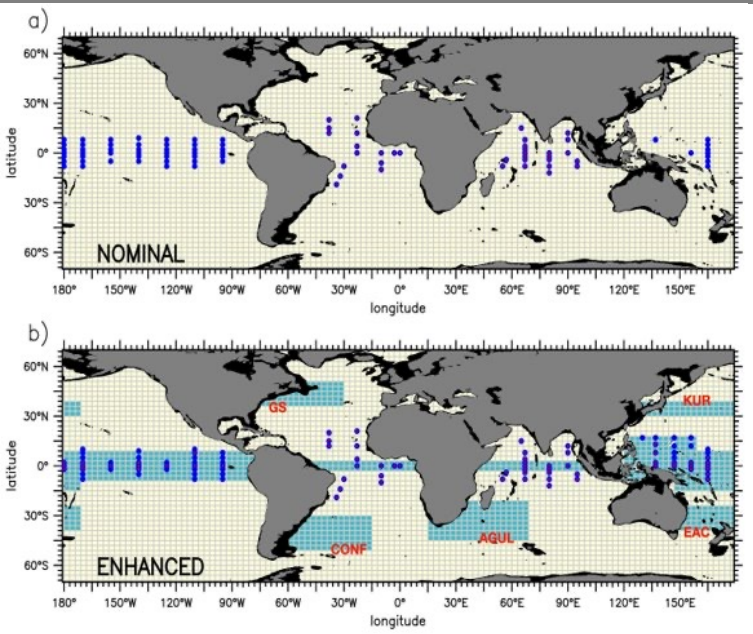
*Gasparin et al*

OSSEs showing the % variance of OHC and OFC in WBCs.

Analyses separated by scales (large-scale and intermediate-scale), using the 1/4º-res GLORYS system

In situ delivers most improvement on large scales; and satellite data delivers most improvement on intermediate scales.




**Enhanced AR** *(double Argo in WBCs and tropics)*

**Nominal** *(3x3 Argo)*

**Only Satellite**

**Only In Situ**

**No data**

On the control of spatial and temporal oceanic scales by existing and future observing systems: An observing system simulation experiment approach


Florent Gasparin[1,2*], Jean-Michael Lellouche[1], Sophie E. Cravatte[3], Giovanni Ruggiero[1], B. Rohith[1,2], Pierre Yves Le Traon[1] and Elisabeth Rémy[1]

[1]Mercator Ocean International, Toulouse, France, [2]Université de Toulouse, LEGOS (IRD/UPS/CNES/CNRS), Toulouse, France, [3]Université de Toulouse, LEGOS (IRD/UPS/CNES/CNRS), Nouméa, New Caledonia


*Frontiers in Marine Science, 2023*

# Impacts of WBC-enhanced Argo (OSSE)

*Gasparin et al*

OSSEs s… OFC in W…

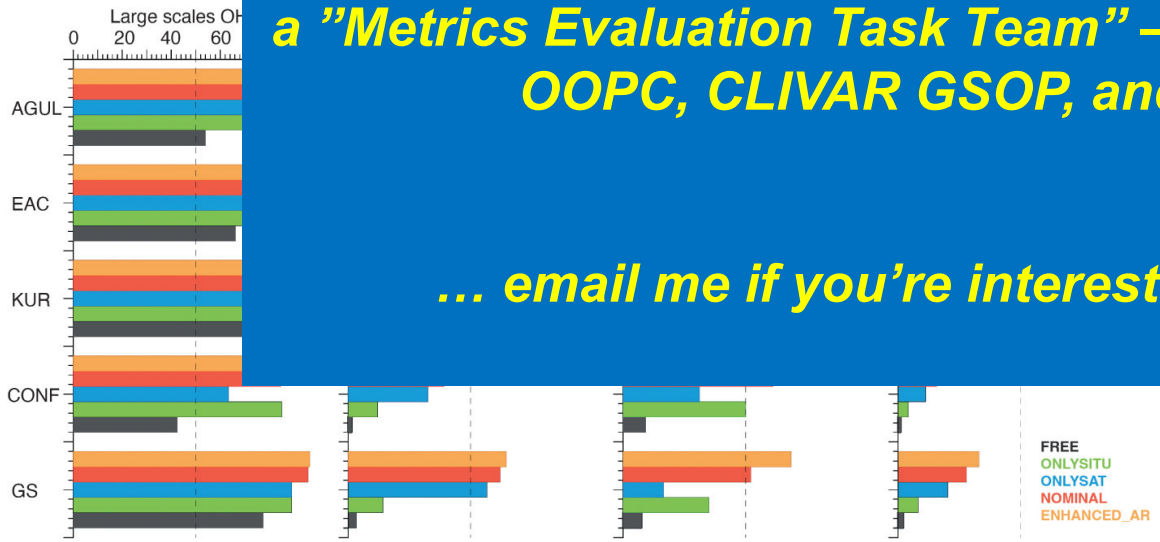
Analyses se… using the 1/…

In situ de… scales; a… improve…

***An excellent paper!***

***The evaluation of the OSSEs at different scales was particularly insightful. We need more thoughtful analyses like this. To accelerate this, we are setting up a "Metrics Evaluation Task Team" – a joint TT between OOPC, CLIVAR GSOP, and SynObs***

***… email me if you're interested in joining.***

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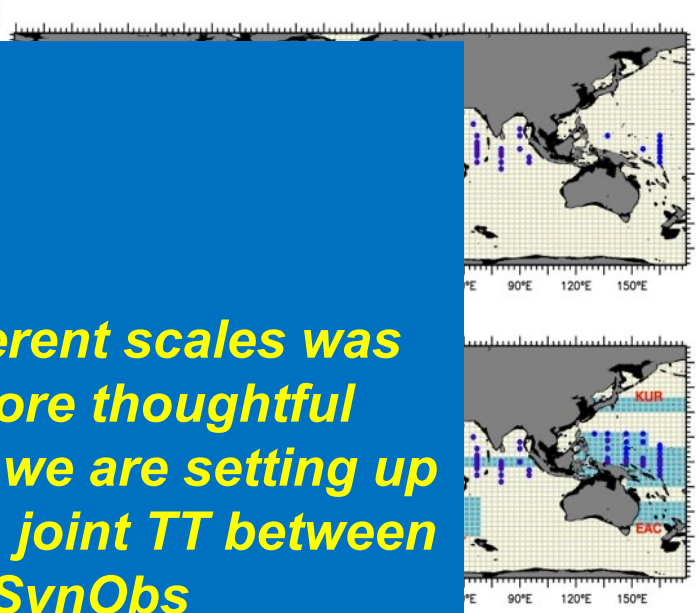


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*Frontiers in Marine Science, 2023*

# A plea for help

- Please continue to demonstrate the impact of Argo data on prediction systems

- Clear demonstration of impacts on coupled systems may be the key to help move the Argo Program onto a secure footing

  … by showing impact on NWP

  … and possibly attracting secure, operational funding from policy changes at NWP-centres

Special Issue of Frontiers in Marine Science, on “Demonstrating Observation Impacts for the Ocean and Coupled Prediction”

*(Topic Editors: YosukeFujii, Elisabeth Remy, Peter Oke)*

*… soliciting submissions by February 2024*

SynObs

UN Ocean Decade Project

# Summary

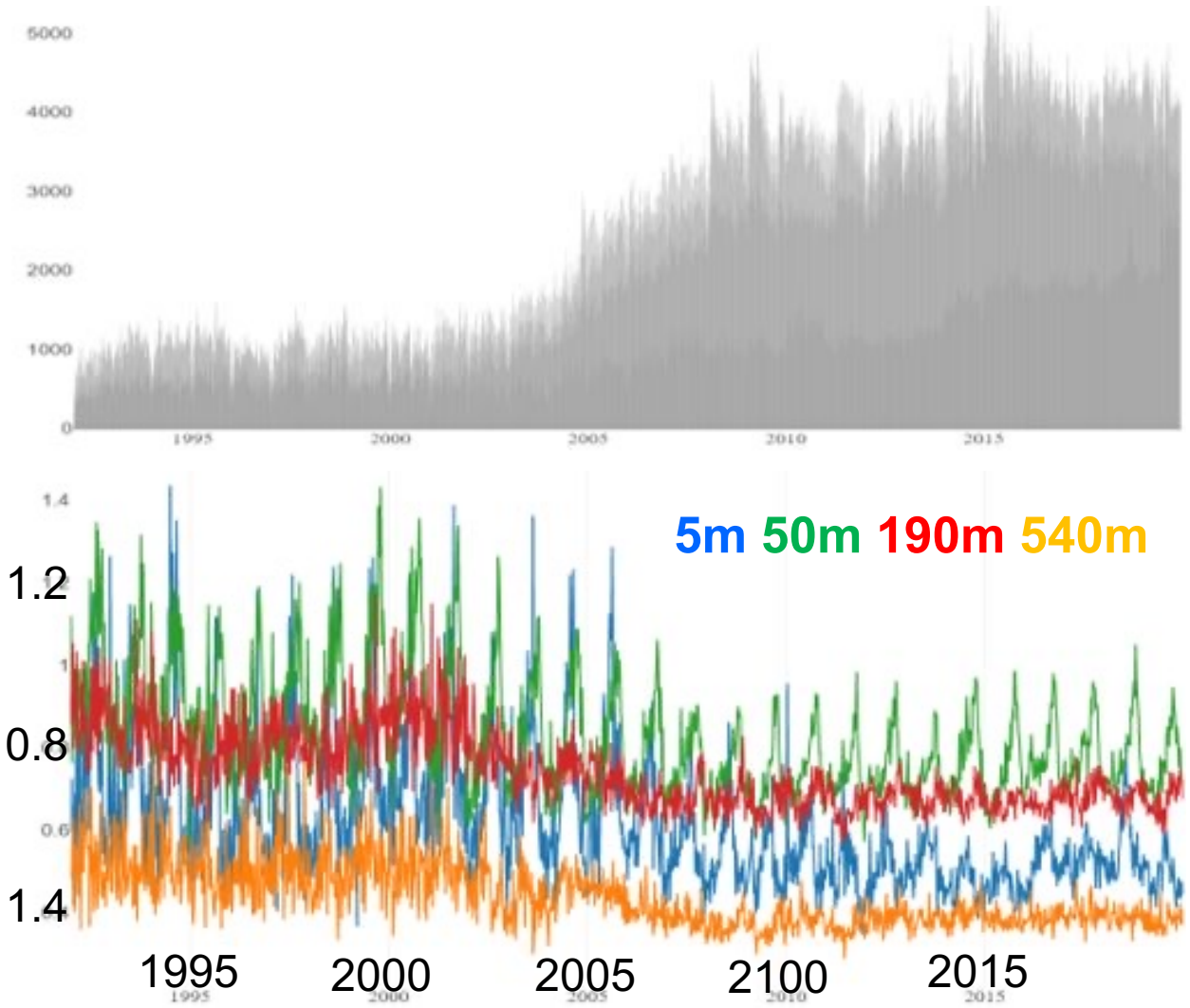
- Delayed-mode Argo data is … delayed – so update every time.
- Real-time data comes with QC flags … but they only help if you use them.
- Observation impacts studies are highly valued by the Argo community. Please persist. Please be creative. Please try to really understand the impacts … don't settle for RMSD ☹

- The Argo Program is facing some challenges.
- OneArgo is an ambitious plan … but not yet a reality.

- Argo is mostly on research funds … if we can demonstrate impacts on coupled predictions, including NWP systems, we have a chance to move Argo to a sustainable footing. Please help.

# Impact of Argo data on a 1/12°-res ocean reanalyses

*Remy et al. (Mercator Ocean)*



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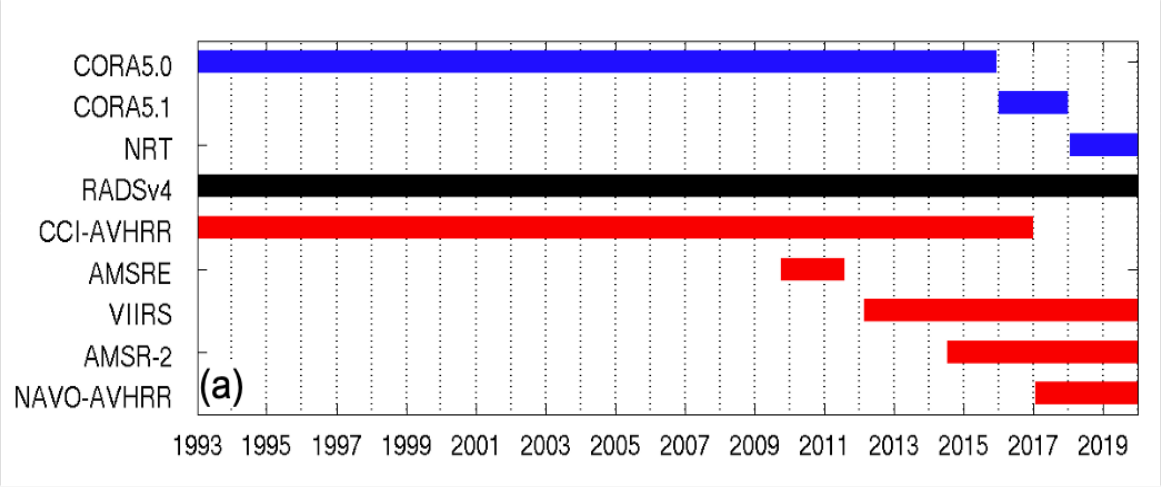
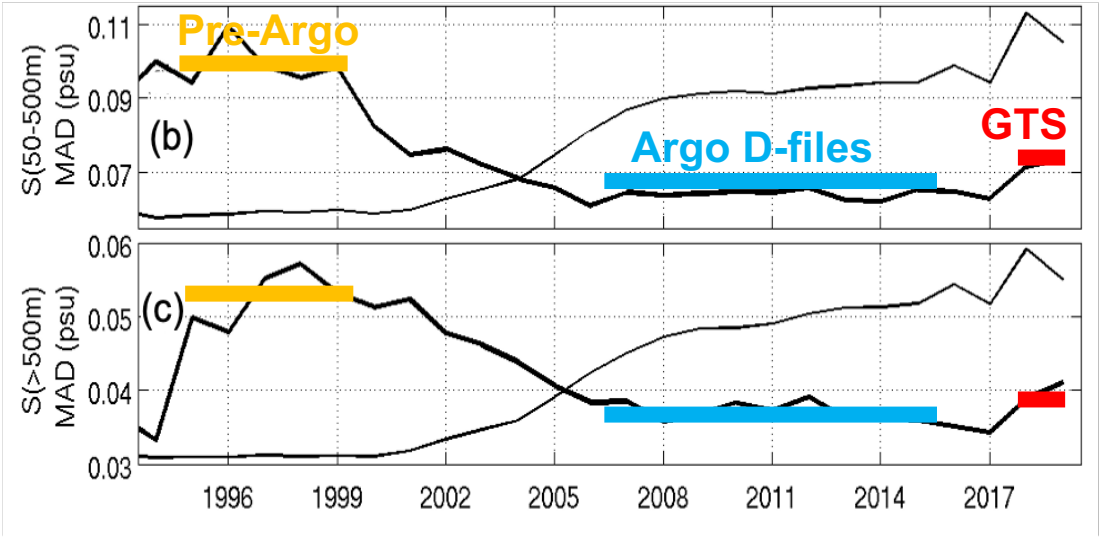


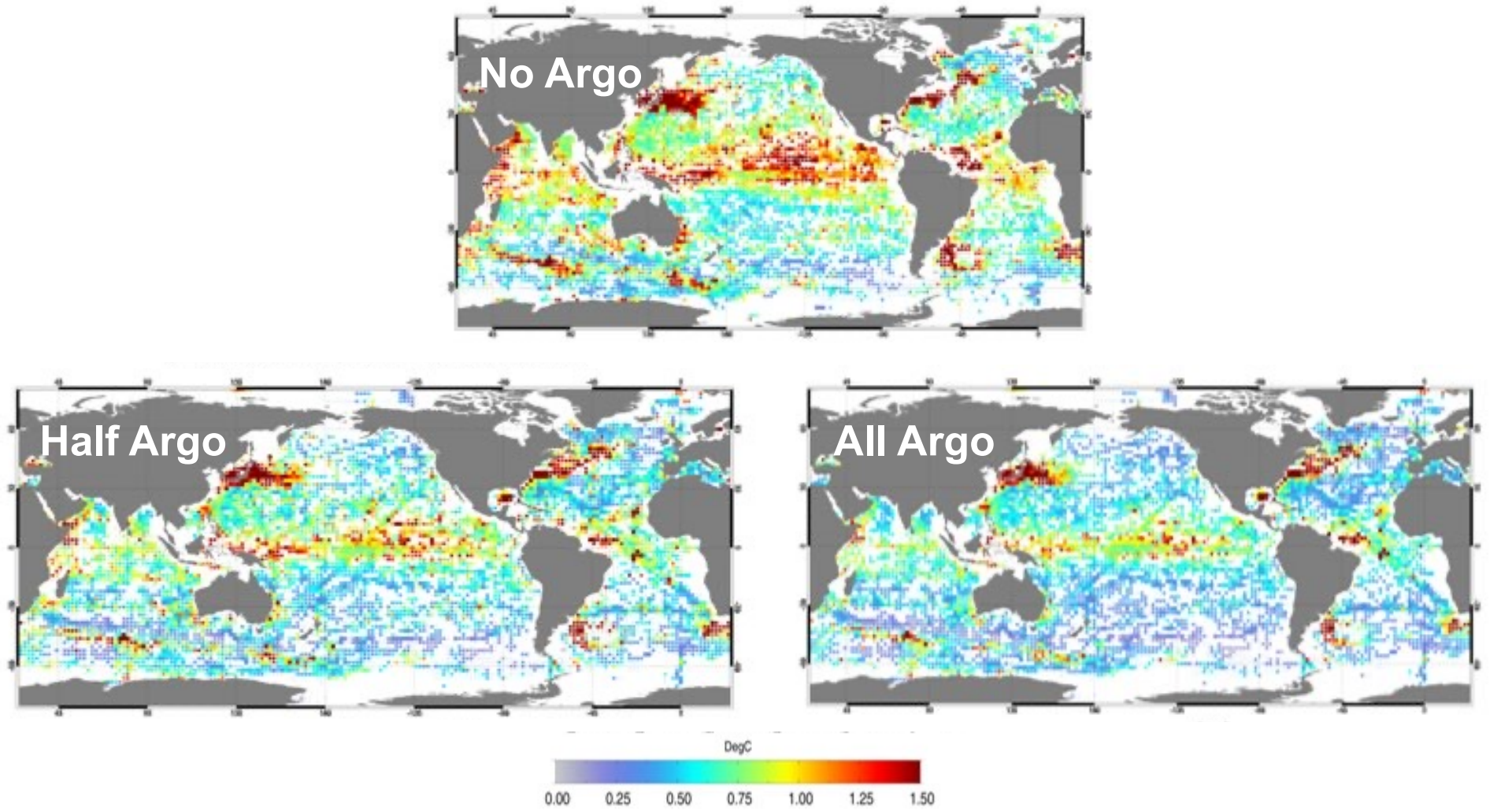




- *Using archived data from the GTS, instead of D-files from the GDACs, could degrade your reanalysis by 1/3rd of the improvement gained by assimilating data from all available Argo floats.*

# Impact of Core Argo on a 1/4°-res ocean reanalysis

*Turpin, Remy et al. (Mercator Ocean)*

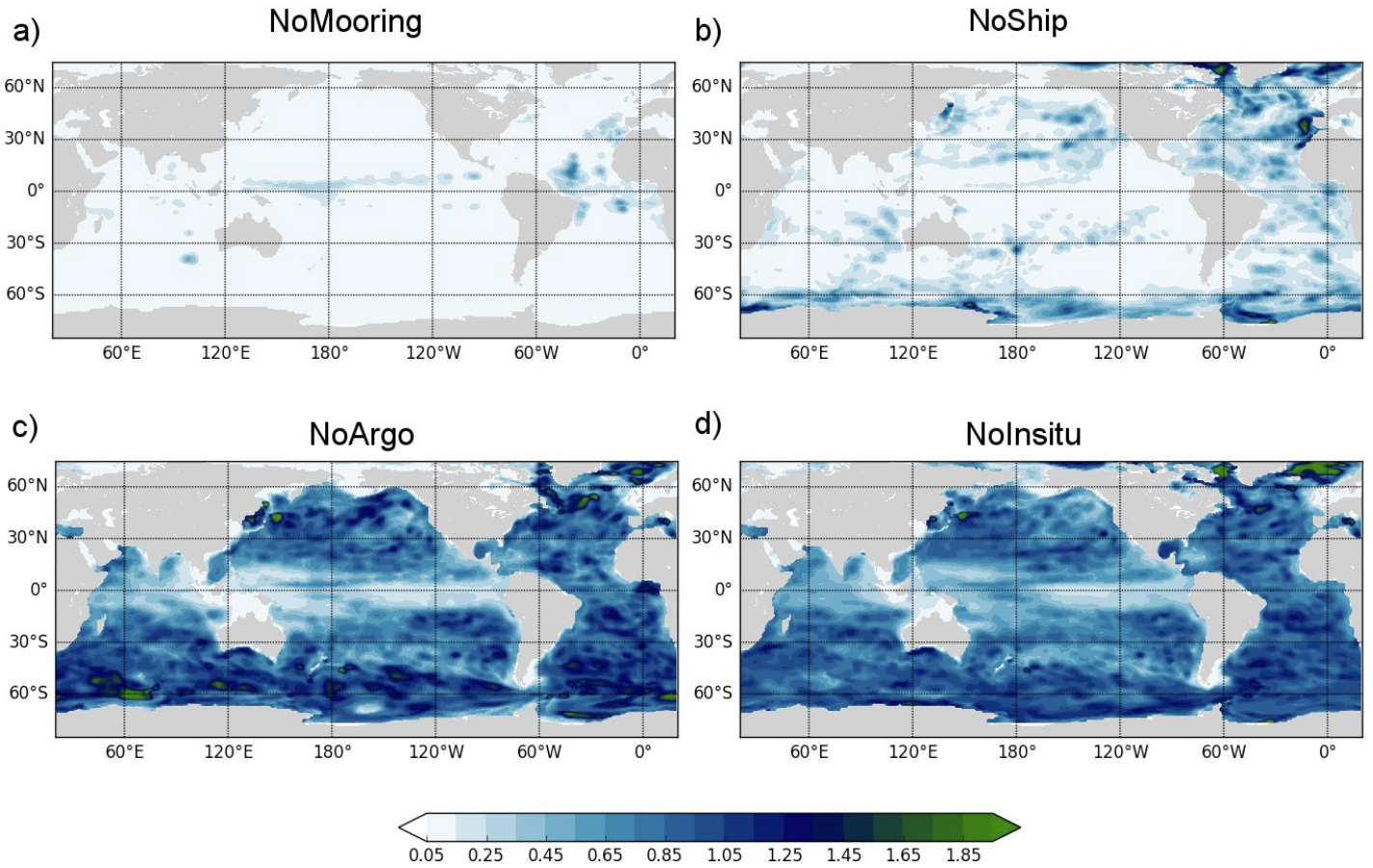
Observing System Experiments (OSEs), showing the RMS misfits of 0-300m temperatures, between *in situ* temperature and analyses from GLORYS



# Impacts on ocean, sea-ice reanalysis

*Hao et al. (ECMWF)*

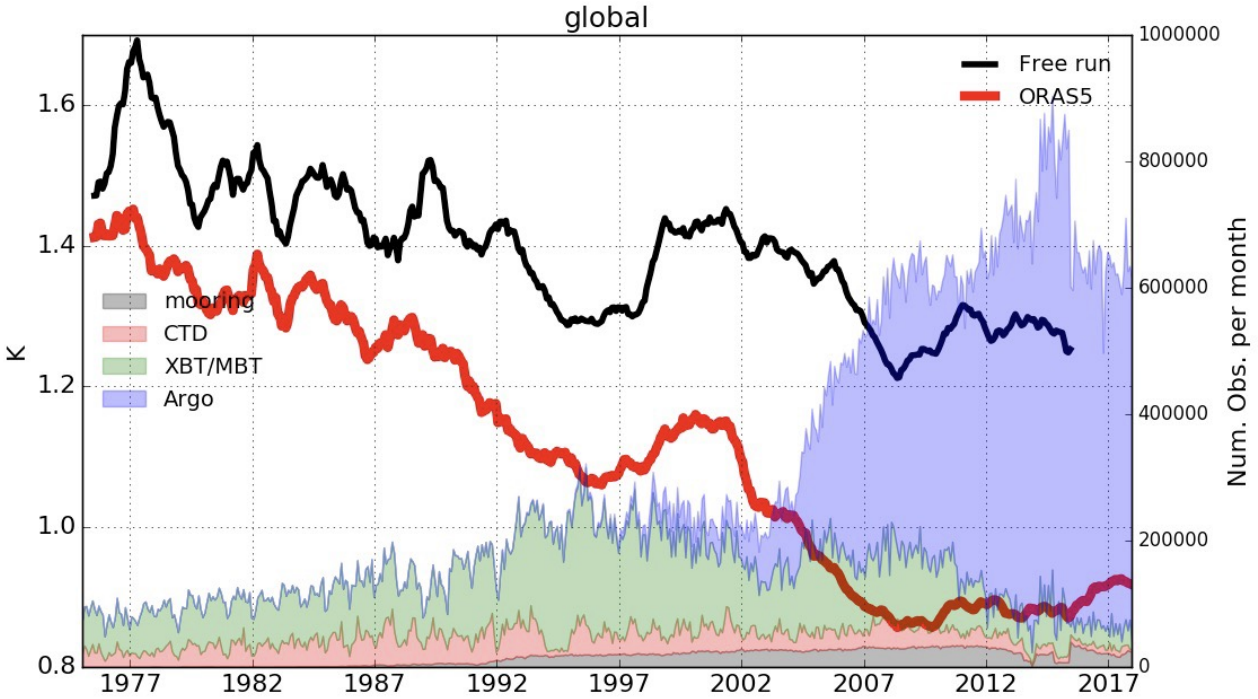
- Maps of normalized RMSD of Temperature (upper 700m) in OSEs with different data with-held. RMSD w.r.t a reference reanalysis, in which all in-situ assimilated.
- Using ECMQF 1/4º-res ocean-ice reanalysis system



# Impacts on ocean, sea-ice reanalysis

*Hao et al. (ECMWF)*

## Temperature RMSE (0-1000 m)




Mean: 2005-2014

| | T RMS reduction | S RMS reduction |
|---|---|---|
| In-situ | 65% | 90% |
| Bias-corr. | 14% | 10% |
| SST | 18% | negative |
| Altimeter | 3% | neutral |

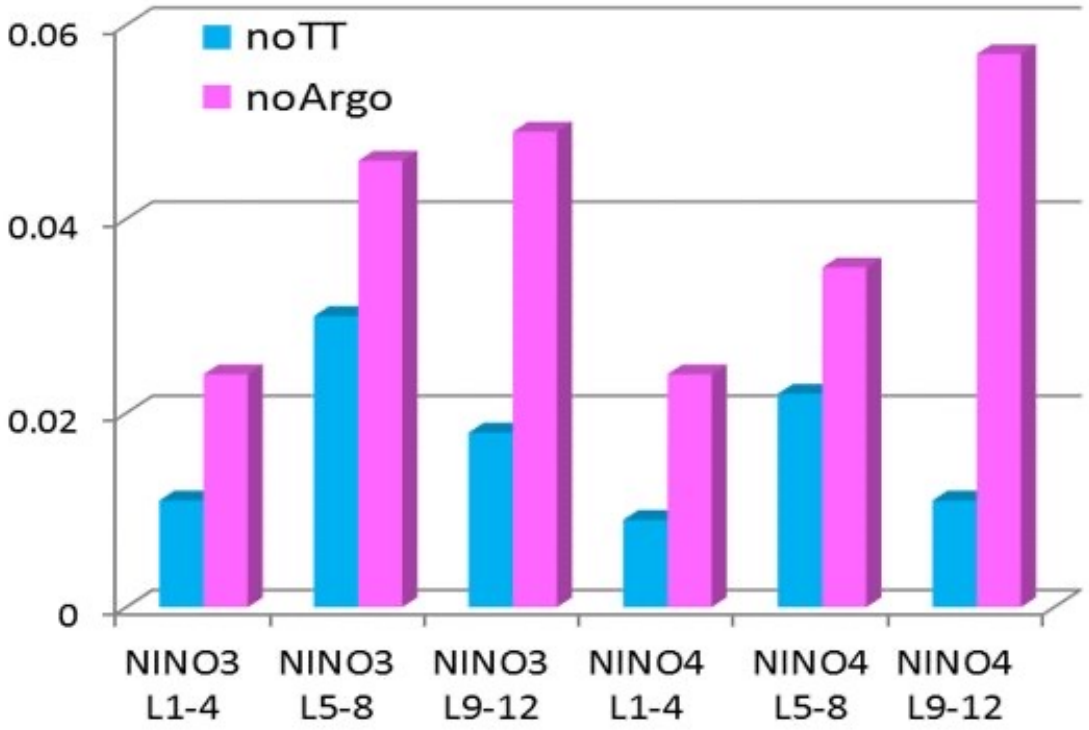
Assimilation of ocean in-situ observations helps to constrain the 3D ocean, therefore providing better estimation of the ocean initial condition for the coupled forecasting system

# Impacts on seasonal predictions

# Impacts of Core Argo on seasonal predictions

*Fujii et al. (JMA)*

Observing System Experiments (OSEs), showing the reduction of anomaly correlation for NINO3 and NINO4 at different lead times, with and without data from Argo (magenta) and the Tropical Mooring array (blue)



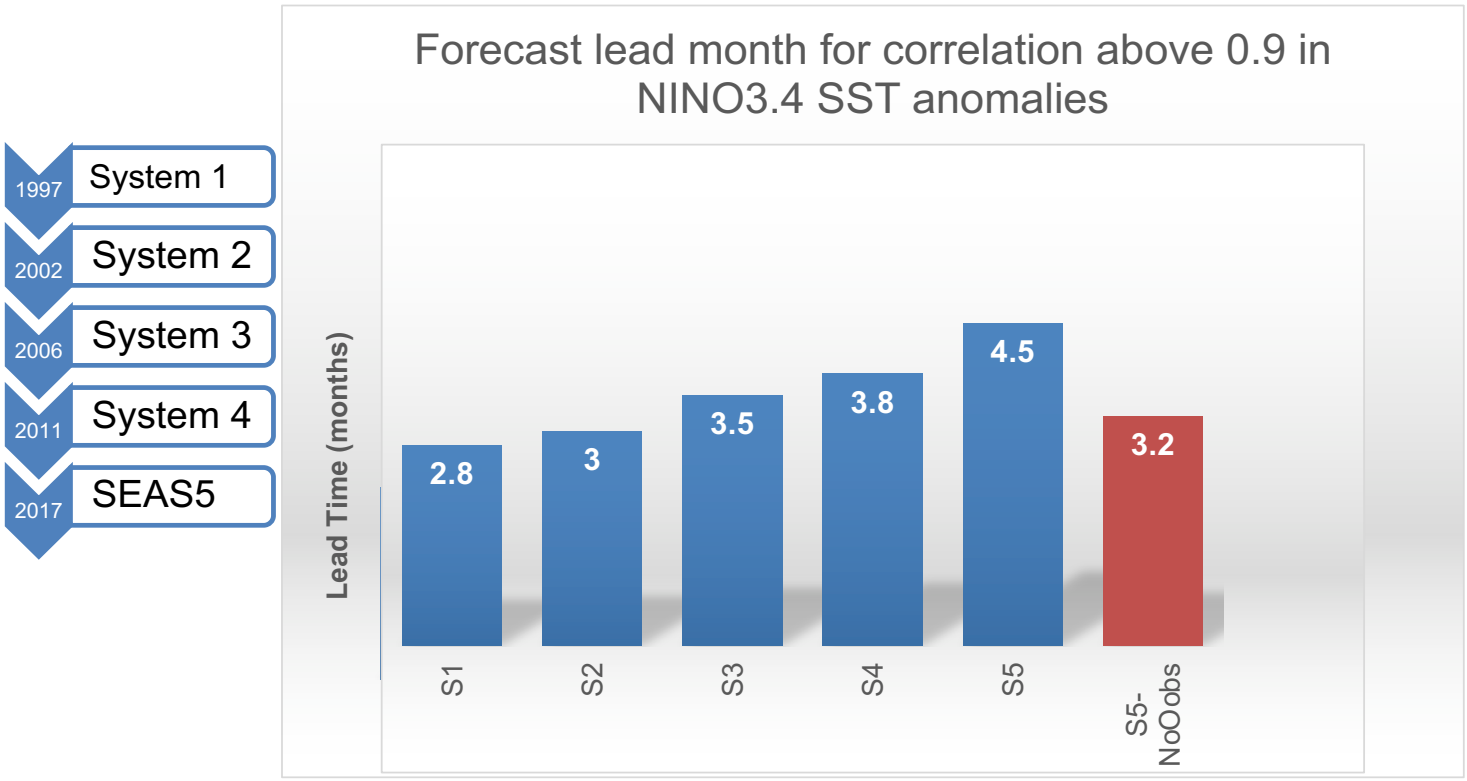

*L1-4 → 1-4 month lead time*

*L5-8 → 5-8 month lead time*

# Impact of Argo data on seasonal predictions

*Balmaseda et al. (ECMWF)*

- Demonstration of the improvements of ECMWF's seasonal prediction system … plus a result using the latest system, without *in situ* ocean data.
- Sustained development over 25 years has extended the lead time of useful forecasts by 1.7 months.
- *Without in-situ ocean observations, we'd lose ~15 years of progress.*



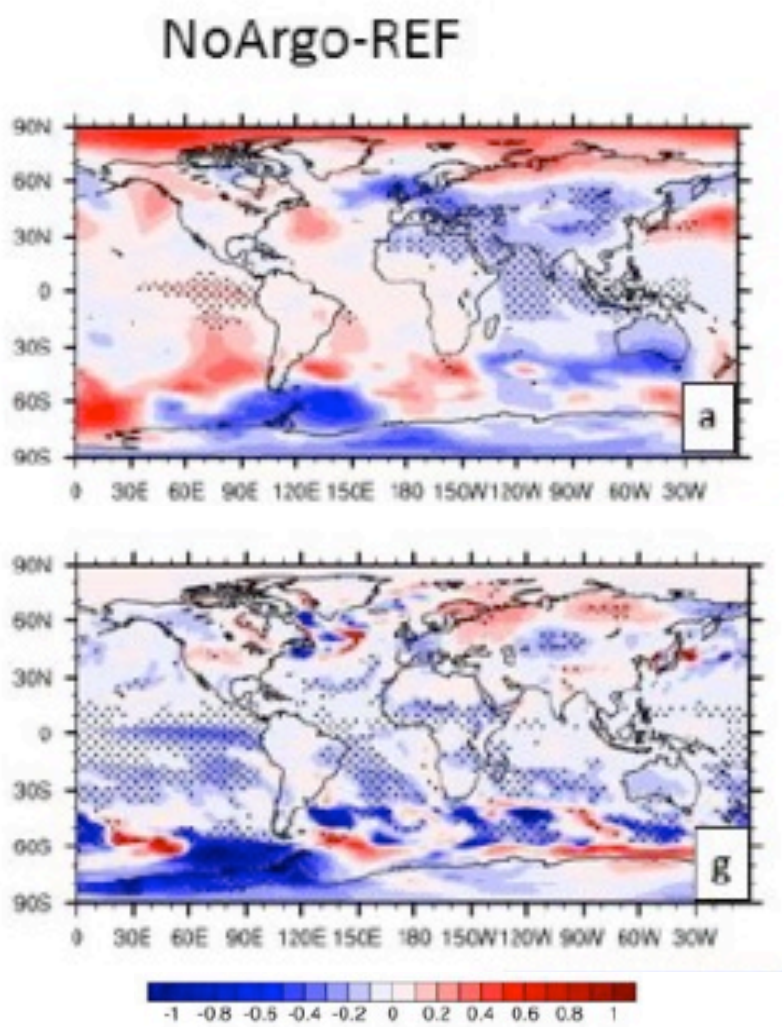
# Impacts on coupled predictions

# Impact of ocean observations on mean atmospheric state

*Balmaseda et al. (ECMWF)*

**MSLP**

**T2m**



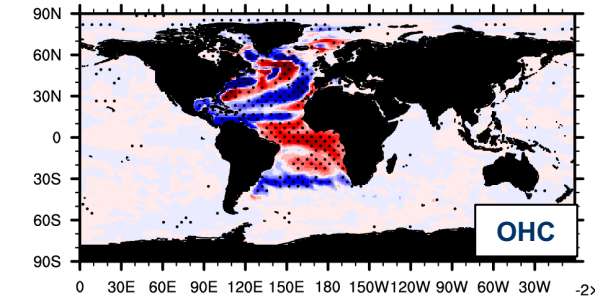

May start 2005-2015, JJA verification

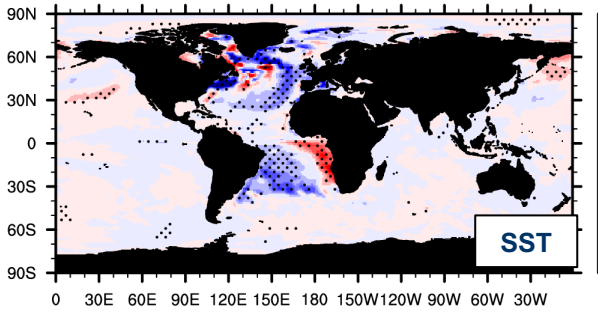
- Tropical Pacific: increased MSLP over cold tongue area, La Nina like conditions, associated with dryness in precipitation.
- Tropical Indo-Atlantic: decrease in MSLP likely due to large-scale SST gradients

# Impact of ocean observations on atmospheric forecasts

*Balmaseda et al. (ECMWF)*

### May Ocean Initial Conditions



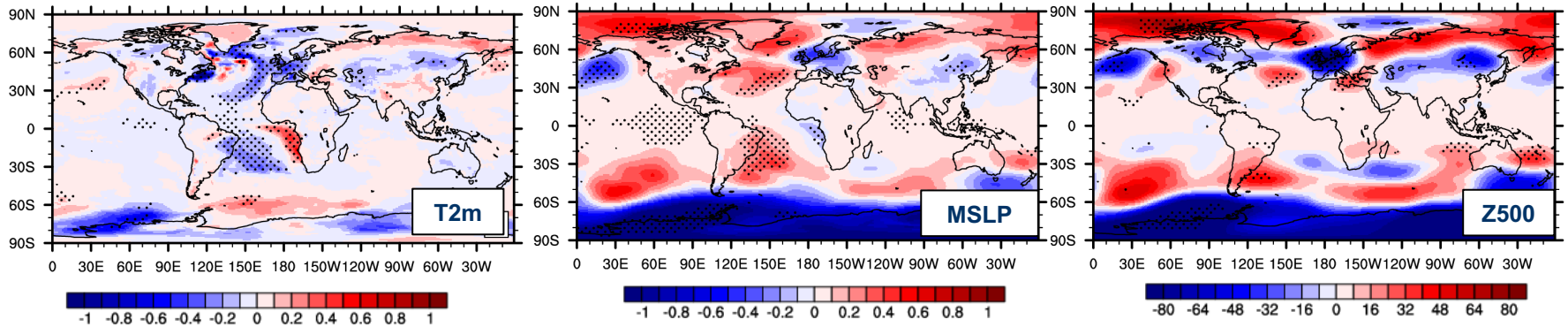




## Comparison of OSEs with and without ***in situ data*** in the Atlantic Ocean.

The atmosphere responds to large scale SST gradients. As a consequence, at seasonal time scales, differences in Atlantic SST are felt by the atmosphere at a global scale:

- Note the significant impact on MSLP in the Tropical Pacific, the impact on T2m at the Pacific mid-latitudes.
- There are also some significant impact on the Southern hemisphere subtropical jet by Australia

### Seasonal Forecasts verifying in JJA



# UKMet-led studies on Argo impacts

*Martin (UKMet)*

- Assimilation into ocean forecasting systems:
  - Previous studies reporting the impact of Argo (and other observing systems) include Lea et al. (2014)
  - Investigations into potential impact of expanding the Argo array (more data in western boundary currents, deep Argo) carried out [Mao et al., 2020]

- Assimilation into our global coupled NWP system:
  - implemented operationally 2022
  - Argo observations directly impact the operational coupled weather forecasts (on both ocean and atmosphere)
  - impact of Argo data in the coupled NWP system was reported in King et al., 2019.
  - coupled NWP analyses also used to initialise coupled seasonal forecasts

- Impact of BGC Argo on assimilation in coupled physical-biogeochemical models [Ford, 2020]

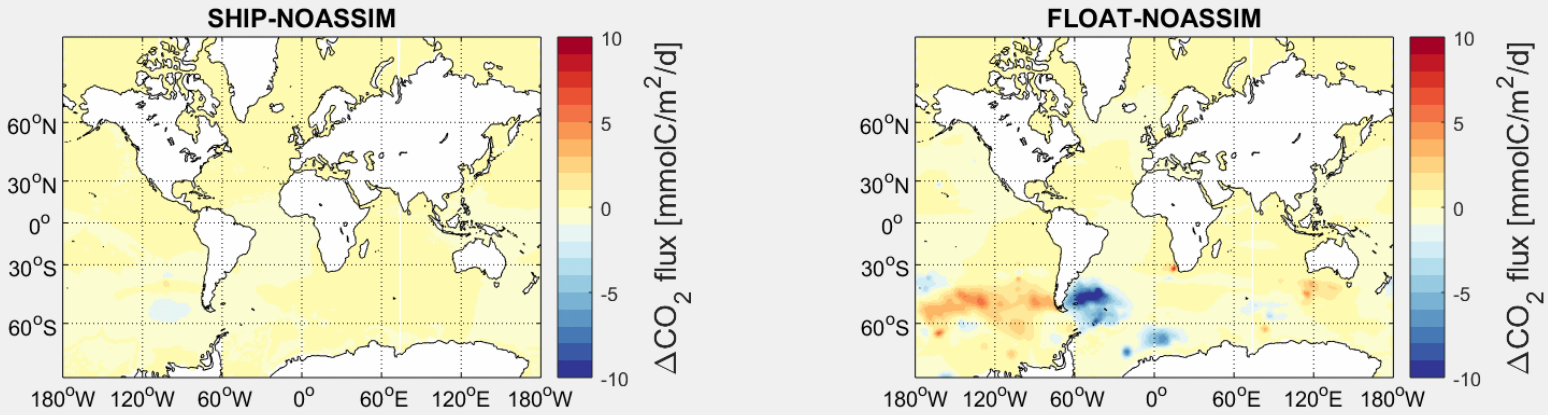
# Assimilating *in situ* BGC data from ships and Argo

*Andrea Rochner (U Exeter, UKMet)*

- Data assimilation experiments using simulations with NEMO-MEDUSA and NEMOVAR 3DVar scheme
- Compare the impacts on air-sea $CO_2$ flux

Δ>0: Less ocean uptake in DA

Jan 2017




NOASSIM = No data assimilation (DA)

SHIP = DA experiment with ship-based data from GLODAPv2 and SOCAT data sets (carbon variables, nutrients, oxygen)

FLOAT = DA experiment with BGC-Argo float data (pH, nitrate, oxygen)

Δ<0 More ocean uptake in DA

Preliminary results from Andrea Rochner, a PhD candidate from Exeter University.

SHIP → assimilates ship-based BGC data; FLOAT → assimilates BGC-Argo data into a coupled model with BGC.

Differences in SHIP and FLOAT are often related to the distribution of observations. But when ship-based and Argo data are co-located (eg summer in the Southern Ocean) , the impacts on CO2 flux can be opposite … this may point to inconsistencies between the data types, or a dependence on which variables are assimilated, which needs more investigation.

# *The tall poppy syndrome*

*… one of our biggest challenges ☹*