Met Office

WP2

T2.2: Development of assimilation techniques for improved use of surface observations

Matt Martin, Rob King, Dan Lea, James While, Charles-Emmanuel Testut

November 2014, ECMWF, Reading, UK.

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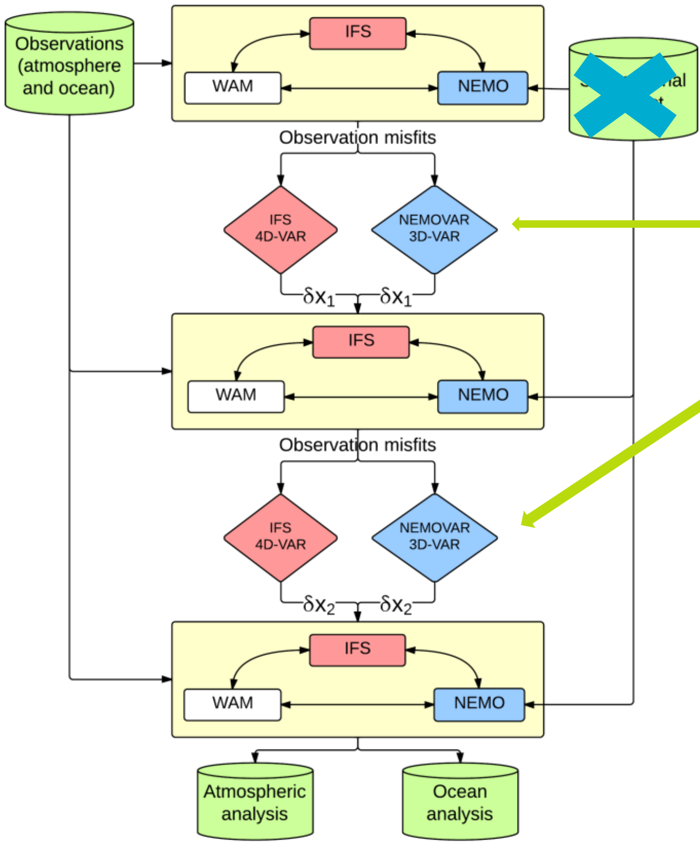
- Direct assimilation of SST observations [Met Office]
- Improvement of coupled ocean/sea-ice data assimilation [Mercator Ocean]

Introduction



- Current CERA system

T2.2 to include SST/sea-ice assimilation in NEMOVAR

- Current CERA system uses external information on SST and sea-ice.
- Coupling between atmosphere, ocean and sea-ice is therefore not as strong as it could be because of the constraint of the external observation-based estimates.
- Aim of this task is to develop schemes which can be applied in NEMOVAR to assimilate SST and sea-ice data directly.

Direct assimilation of SST observations

Direct assimilation of SST observations
Overview

D2.1 : Documented code with test results for assimilation and bias correction of satellite SST observations, and for assimilation of sparse in-situ SST observations, in NEMOVAR. [month 27]

- Assimilation of SST data directly by NEMOVAR developed at the Met Office in the FOAM system

  -> Waters et al. (2014).

- Aspects of the scheme need to be developed in order for the system to be more useful for climate reanalysis:

  1. Dealing with sparse historical SST observations.

     -> use techniques similar to those applied in HadISST2 (Kennedy et al., 2014).

  2. Ensuring stability of system during different data regimes (e.g. different satellite biases).

     -> testing and improving the SST bias correction used in FOAM and OSTIA (Donlon et al., 2012).

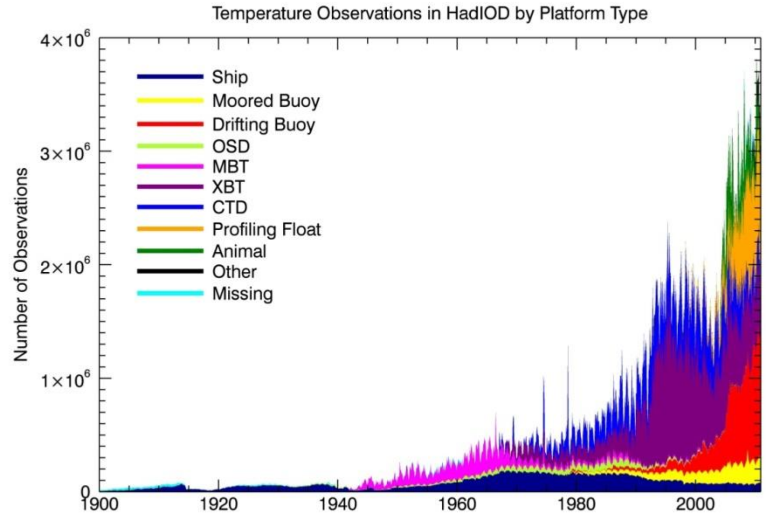
  3. Assessing impact of SST assimilation and the above improvements through data impact studies in coupled DA framework.

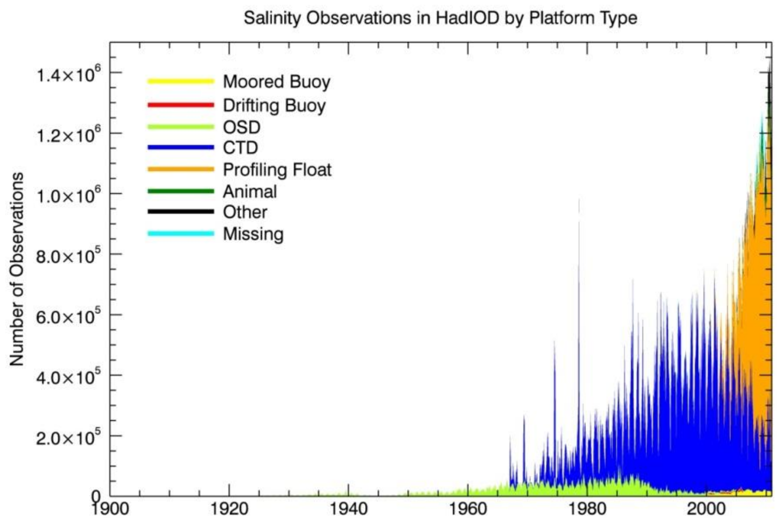
Dealing with sparse historical observations

Dan Lea

Dealing with sparse historical SST observations
Motivation

- Observations sparse with inhomogeneous sampling, particularly before the satellite period.
- Observations now much less sparse and more globally homogeneous, but still sparse sampling at depth.
- How can assimilation make best use of the sparse historical data while still doing a good job with today's data?
- The key thing which gives data assimilation its power is the background error covariance which allows us to spread information from the observation locations.
- Can we improve the error covariance structures to allow us to correctly spread sparse observation information over greater distances in order to fill in the gaps?

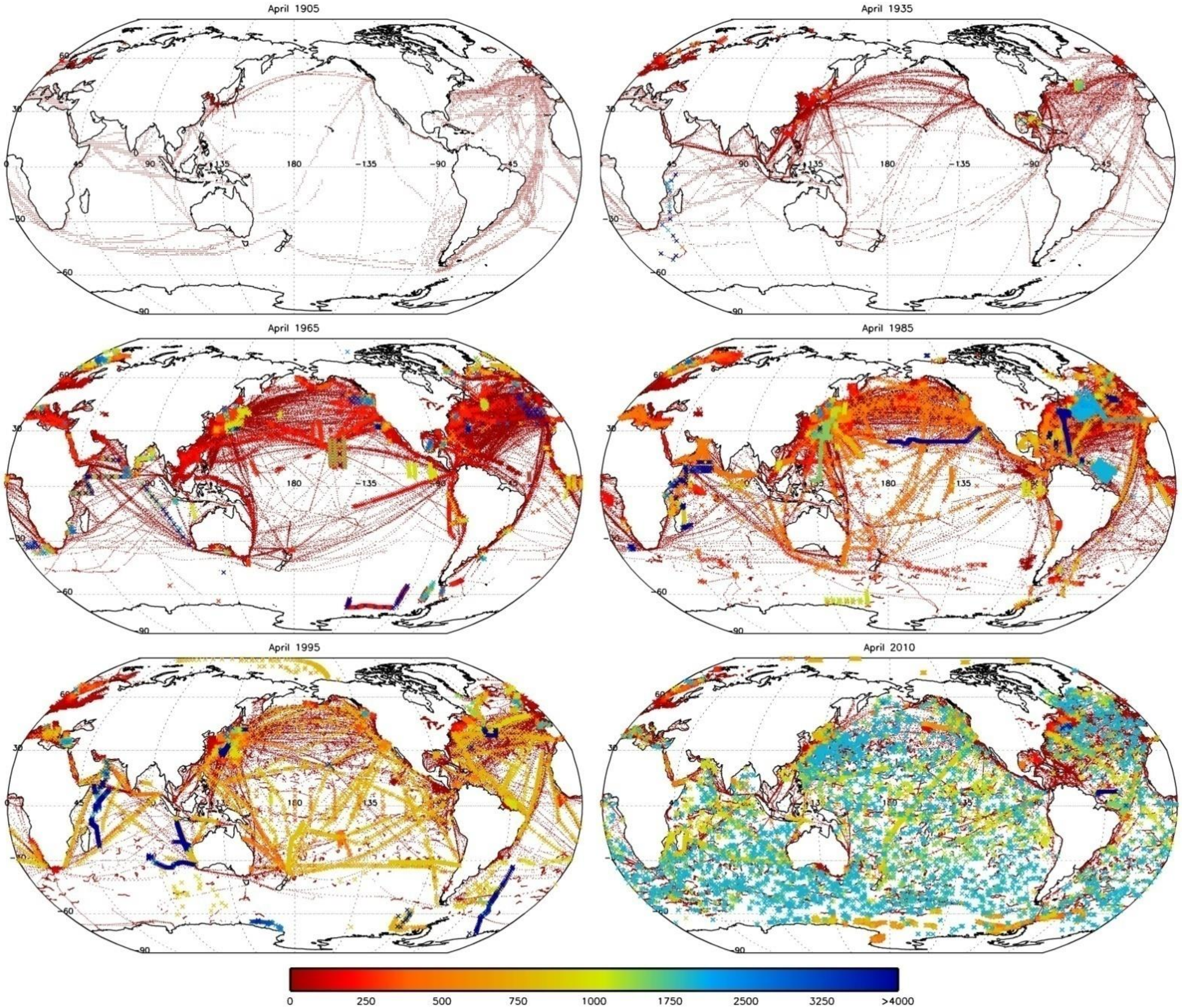




HadIOD: Atkinson et al. 2014, JGR, in press, DOI: 10.1002/2014JC010053

Observation locations – temperature profiles

- From Atkinson et al. 2014, JGR, in press, DOI: 10.1002/2014JC010053
- Location and maximum depth (if a profiling instrument) of temperature observations



Simon Good. Met Office Oceanography course 2014

Dealing with sparse historical SST observations
Building on other work

Various ocean systems at the Met Office already do ocean reanalysis in different forms:

- GloSea (seasonal forecasting system) reanalysis – uses the FOAM set-up of the NEMOVAR data assimilation system (Waters et al., 2014).
- **DePreSys** (decadal prediction system) uses the scheme of Smith et al. 2007.
- EN4 analysis system for sub-surface profiles (Good et al., 2013).
- **HadISST2** SST analysis system for climate purposes (Kennedy et al., 2014).
- OSTIA SST analysis system focussing on the satellite era (Merchant et al., 2014).

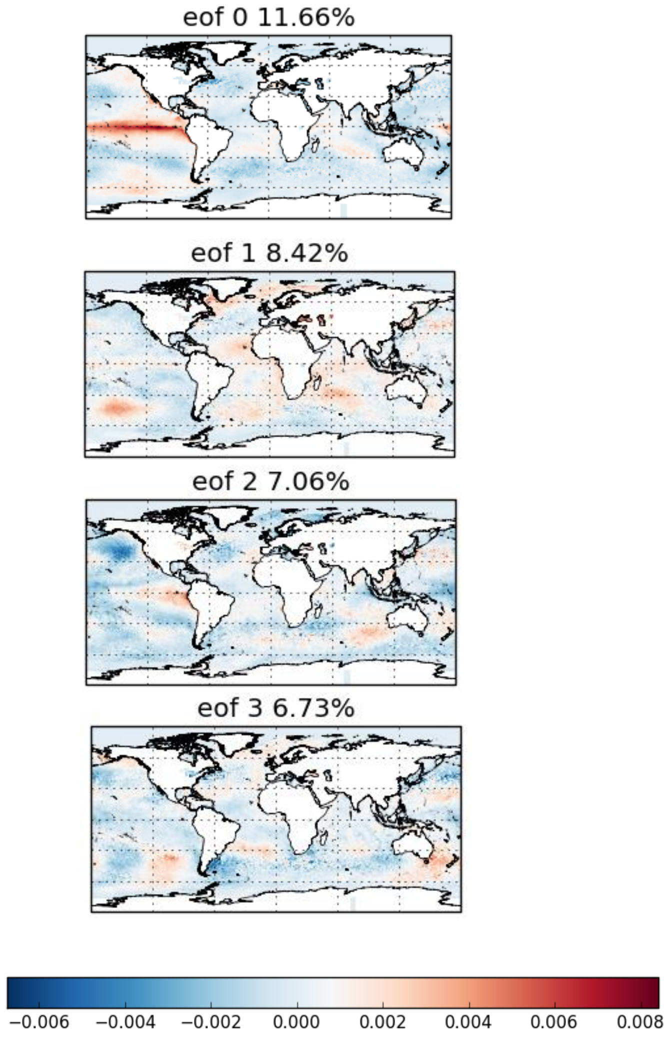
Work done to understand pros/cons from these various existing systems.

Dealing with sparse historical SST observations

Generating some initial EOFs

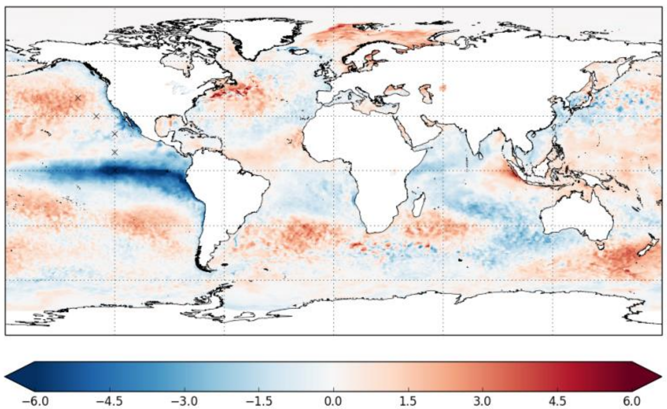
Two sets of monthly EOFs have been generated to help understand various issues:

1. Using the GloSea5 reanalysis: →
    - 1993-2013
    - ORCA025L75 NEMO configuration
    - using NEMOVAR 3DVar-FGAT data assimilation of SST, SLA, T&S profiles, sea-ice concentration.
    - Results will be affected by model biases.
2. Using the EN4 objective analysis data:
    - 1993-2013
    - 1 degree gridded objective analysis of the available T& S data.
    - Results will be affected by details of the objective analysis.



Dealing with sparse historical SST observations
EOF assimilation in test python system

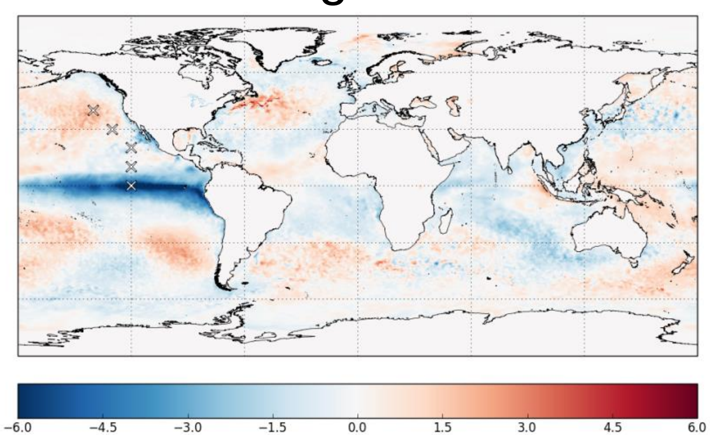
Difference from Truth (2005-1997)



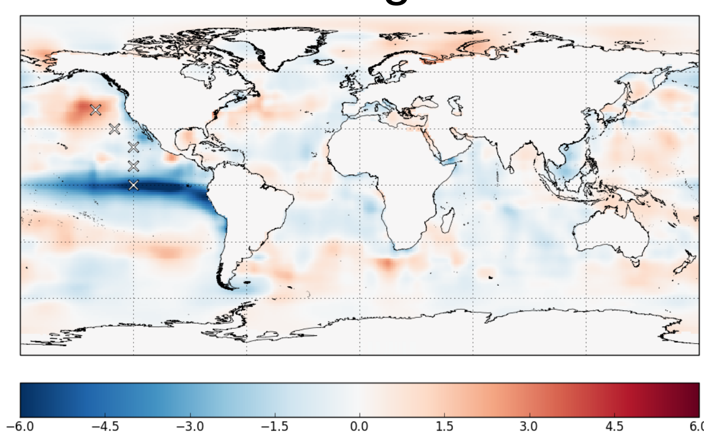
- System based on Reduced-Space OI.

- Twin experiment:
  - Truth: Dec 2005 from GloSea5.
  - Background is Dec 1997.
  - Assimilate 5 obs from 2005.
  - Recreate the Dec 2005 fields

Increments using Glosea 5 EOFs



Increments using EN4 EOFs



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EOF assimilation in test python system

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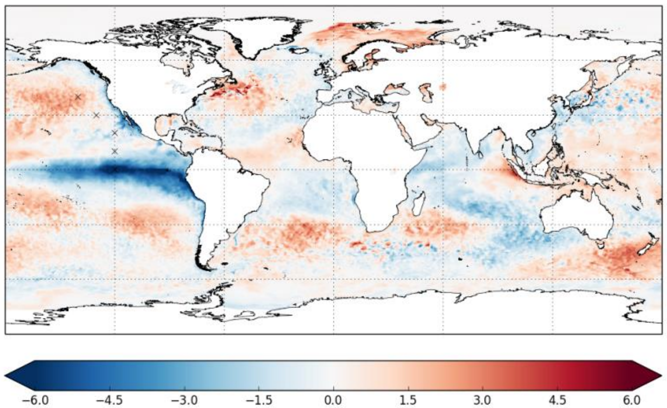
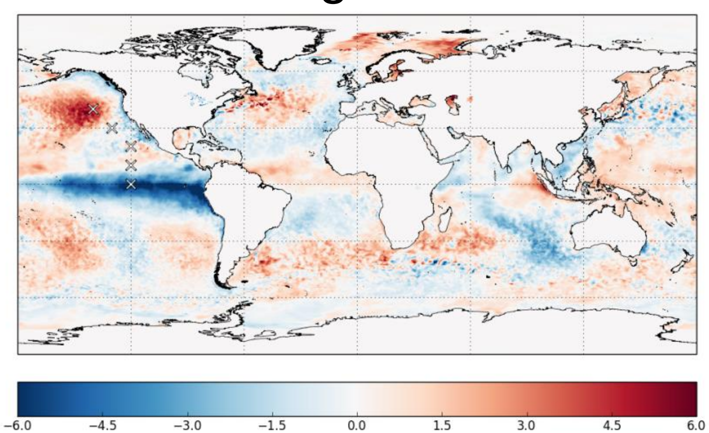


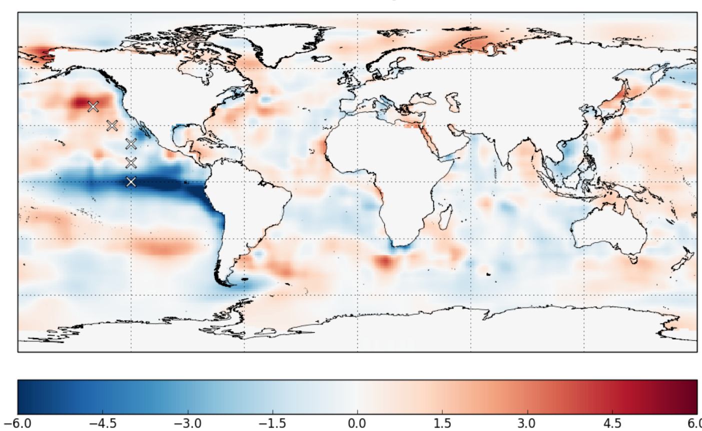
- Obs errors of 2°C

  -> sensitivity of analysis to obs errors implies need to be careful about spreading information globally.

Increments using Glosea 5 EOFs



Increments using EN4 EOFs



Dealing with sparse historical SST observations

Next steps

- Further investigations of EOFs:
  - How to combine model and observation-based EOFs.
  - Investigating use of Variational Bayesian Principal Component Analysis (VBPCA) method used in HadISST2.
  - How to combine the EOF based error covariance model with the existing NEMOVAR error covariances (modelled using the diffusion operator).

- Adapting NEMOVAR ensemble error covariance code:
  - Work by Anthony Weaver on the use of ensemble information in NEMOVAR
  - There is the potential to adapt some of this framework for the large scale covariance work
  - In effect a past climate run is a large ensemble of possible ocean states

- Assessing the system in idealised test cases.

SST bias correction development

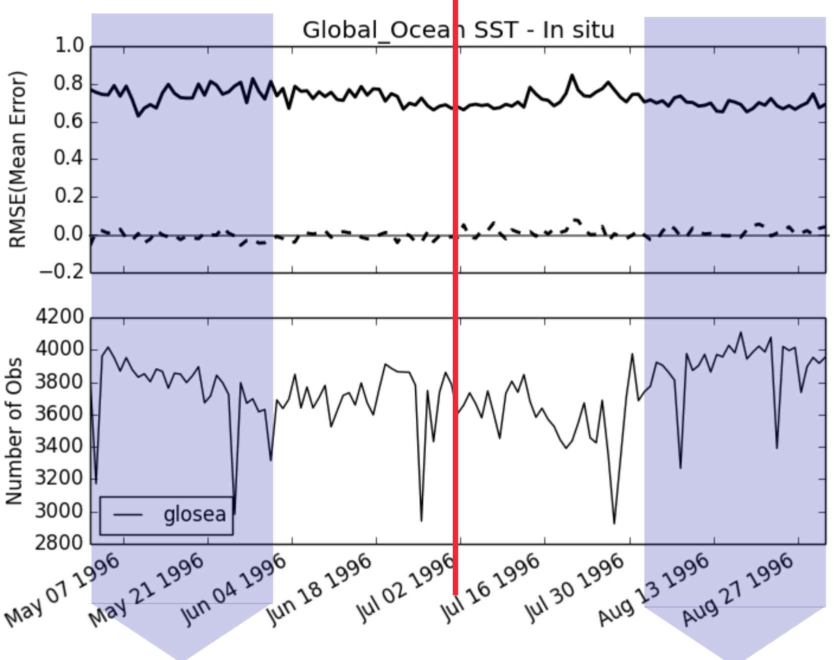
James While

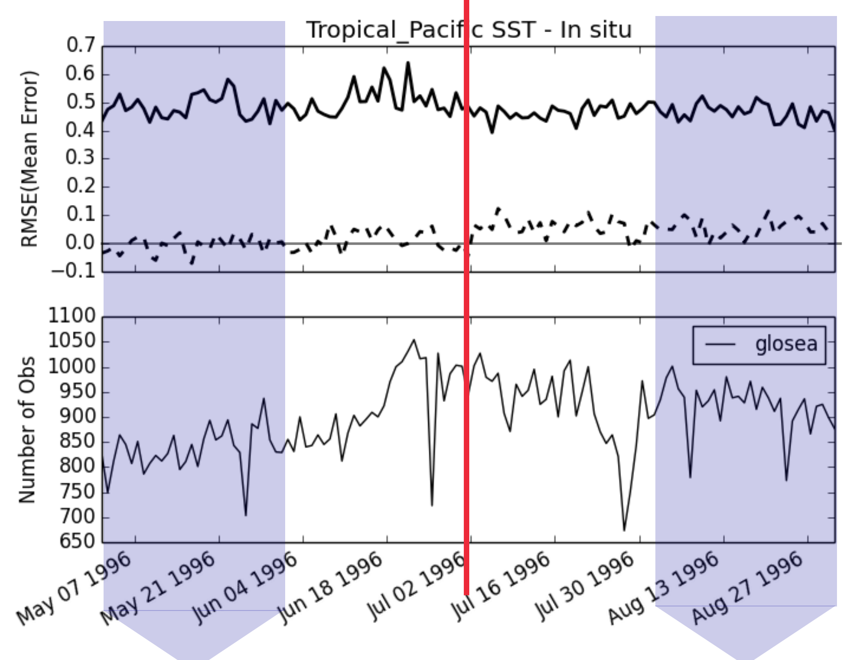
SST Bias correction

Motivation

The current Met Office SST bias correction system, based on matchups to ‘unbiased’ reference data, is significantly affected by changes in the observing system. Example from GloSea5 reanalysis:

Start of ATSR-2 data
(used as reference in bias correction)





RMS: 0.75K
Mean: -0.01K

RMS: 0.693K
Mean: 0.013K

RMS: 0.487K
Mean: -0.006K

e: mean obs-bac
RMS obs-back

RMS: 0.466K
Mean: 0.054K

SST Bias correction

Developing the system

We plan to develop the bias correction scheme so that it contains a variational part that does not depend on reference data. This system should be less sensitive to changes in the observing system and more suitable for long climate runs.

In essence the new system will consist of a merged version of two bias correction methodologies:

1. A bias correction system that uses matchups between biased and unbiased reference data sets to calculate the SST bias (already implemented).

2. A variational system where the SST bias is explicitly included in the assimilation cost function. This is similar to how we currently bias correct altimetry data

We will adaptively merge the two systems based upon their relative errors
Variational system - > to improve the system when reference data is sparse
Matchup system -> Better when reference data is abundant

SST Bias correction
Work plan

Initial work completed to:

- Find examples where the SSTs are not completely stable, even with the existing bias correction scheme (as used in OSTIA/GloSea5).
- Think about methods for improving the bias correction.

Next steps:

- Investigate methods in a simplified system.
- Develop the scheme to carry out variational bias correction of SST in NEMOVAR.
- Combine the match-up based method with the variational method in NEMOVAR
- Assess the scheme using two periods, one in the early satellite period (e.g. start of ATSR-2), and one during the later period (e.g. using MetOp reference data).

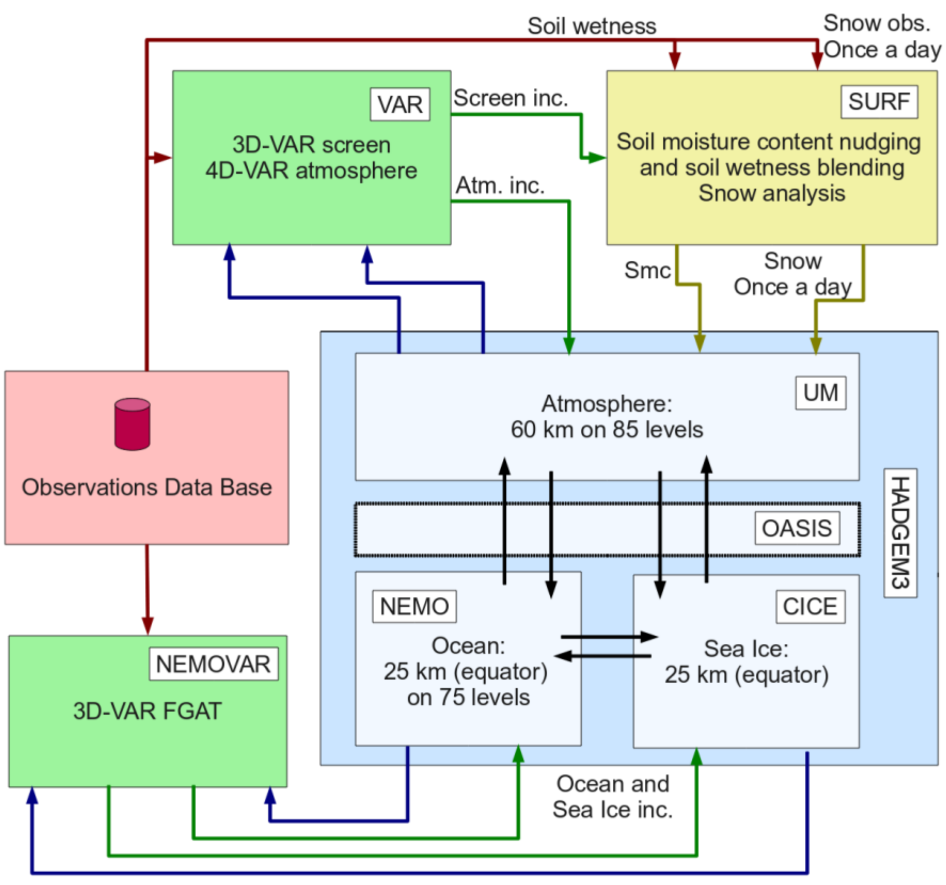
Assessment of developments and data impact studies

Rob King

Assessment of developments

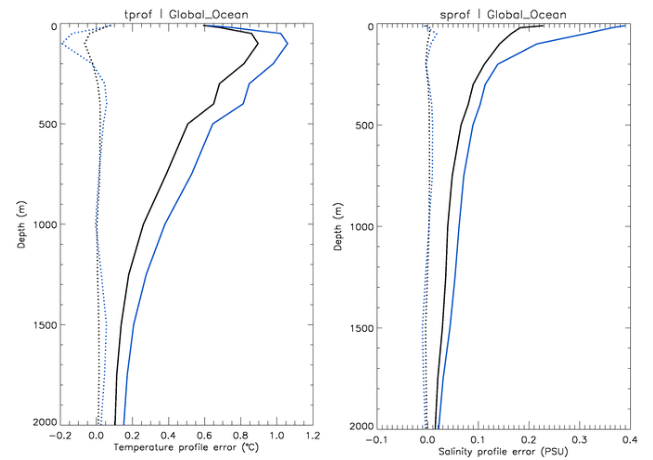
Observing System Experiments

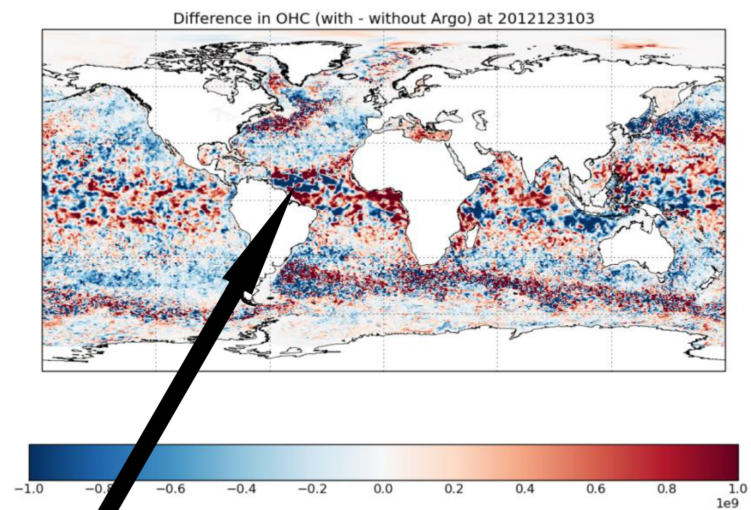
- Aim 1: to investigate the impact of assimilating SST observations in coupled prediction systems on weather-forecasting timescales.
- Aim 2: to assess the impact of the SST assimilation improvements planned as part of this WP.
- Will be performed with the UKMO weakly-coupled system
  - UM atmosphere (60km) and NEMO ocean (ORCA025) with hourly coupling
  - 6-hour data assimilation window.
  - 4DVAR assimilation for atmosphere observations (plus assimilation of land surface observations).
  - 3DVAR assimilation for ocean observations, including SST, SLA, sea-ice concentration, and T/S profiles.



Assessment of developments
Planned integrations

- Initial run with existing system:
  - Deny specific SST sources (all satellite data).
  - Compare with existing control and an OSE run to assess impact of Argo (already done for E-AIMS project).
- Once EOF and bias correction improvements implemented
  - Repeat above experiment (control & OSE) for part of the chosen period (2009-2010) to assess impact of improved bias correction.
  - To test the use of EOFs, run a further experiment with 2009-observations sub-sampled to emulate the sparse sampling of the historical period.
  - To assess the improvements over the existing use of SST, if time allows, run a final experiment with the system modified to emulate the treatment of SST in the ECMWF coupled system (SST nudging)





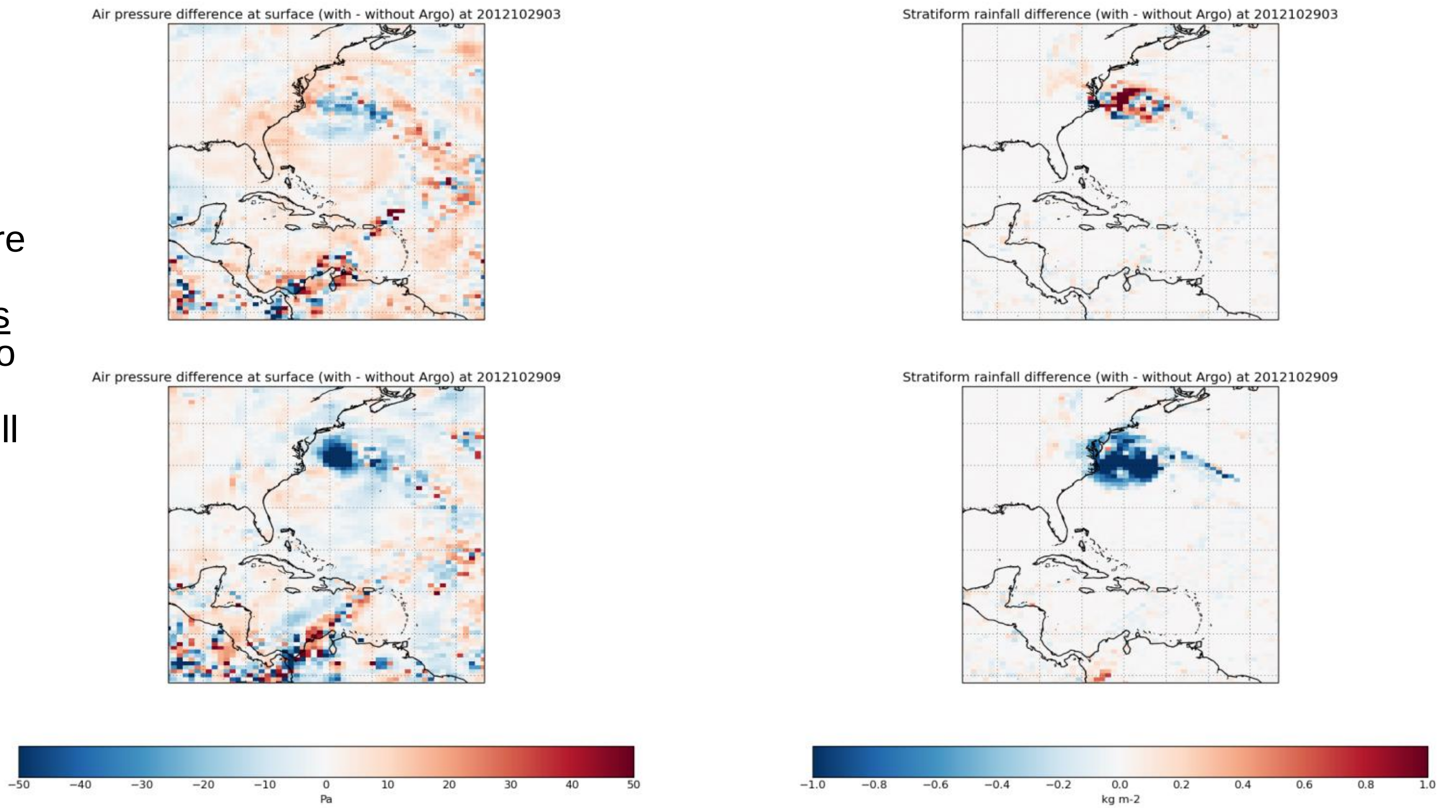
Semi-static differences in ocean-heat content (top 300m) which may affect progress/intensity of storms.

Met Office

NoArgo OSE – preliminary results

- Global verification statistics for the atmospheric fields show negligible differences between the control and NoArgo runs, but specific case studies show greater impact.
  - Plots below show sea-level pressure difference (left) and rainfall difference (right) for 03Z (top) and 09Z (bottom) on 29/10/2012 as Hurricane Sandy makes landfall.

These differences are between the control and NoArgo analysis runs. We also plan to run test case forecasts, but are still investigating these differences.



WP2 task2.2 : Development of assimilation techniques for improved use of surface observations

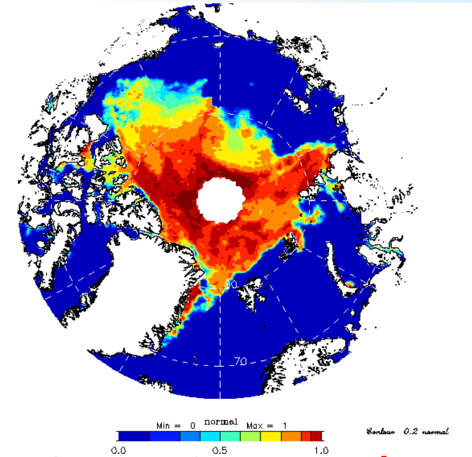
MO Sub task : Assimilation of Sea Ice Concentration

Objective: to improve coupled ocean/sea-ice data assimilation.
Developing and testing a scheme that transforms sea-ice concentration to a Gaussian variable during the assimilation process.

Deliverable D2.2 (t0+27):
Results from a study
Documented code and library applicable in the context of NEMOVAR.

C.-E. Testut

Assimilation of Sea Ice Concentration :
Current status of the Mercator Reanalysis (G2V3)



Sea Ice Concentration from CERSAT (IFREMER)

Model

- Nemo 3.1, LIM2-EVP
- Global ¼, 75 levels
- 1992-2012

Assimilation

- Analysis based on a 2D local multivariate SEEK/LETKF filter
- Weakly-coupled DA system using 2 separate analyses :
- Ocean Analysis (SLA, InSitu Data from CORA3.2, SST) , IAU on (h,T,S,U,V)
- **Unidata/univariate sea ice analysis (SIC), IAU on (SIC)**
- **SIC Error: 1% open ocean, linear from 25% to 5% for SIC values between 0.01 and 1**
- **Forecast error covariances are built from a prior ensemble of Sea Ice Concentration anomalies => Fixed basis background error**

Assimilation of Sea Ice Concentration :
Current status of the Mercator Reanalysis (G2V3)

Assimilation of the Sea Ice Concentration (SIC) in the global ¼° configuration.

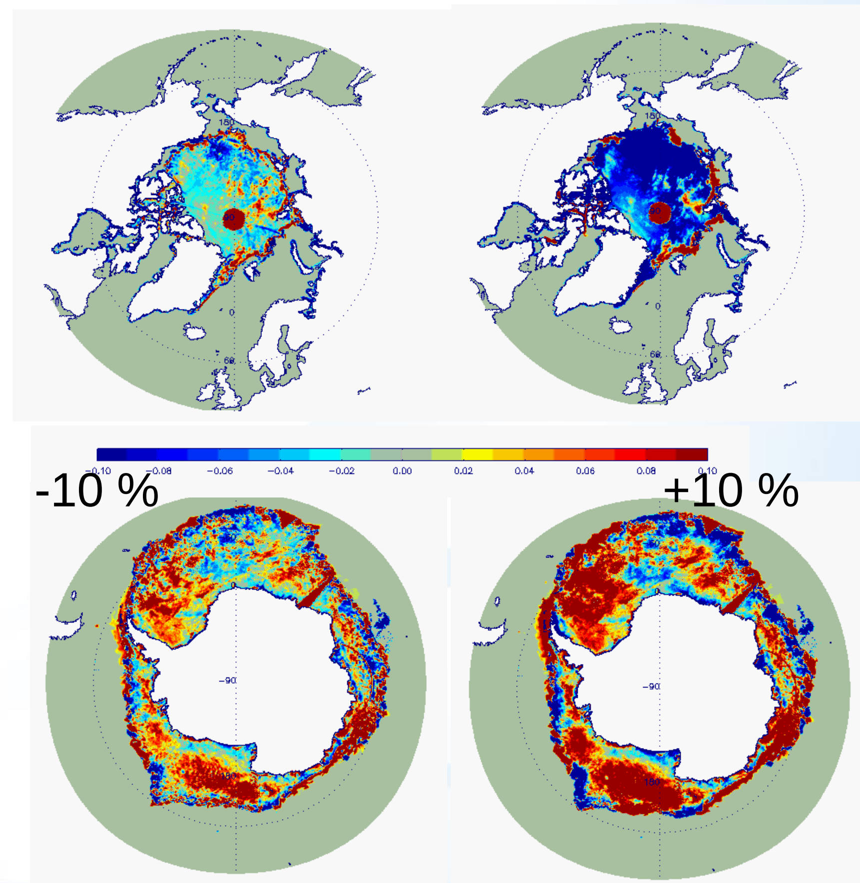
- Univariate assimilation of the SIC in the sea ice model
- Improvment of SIC representation in Arctic and Antarctic oceans.

Obs - Model for SIC

With Assimilation of SIC | Without Assimilation

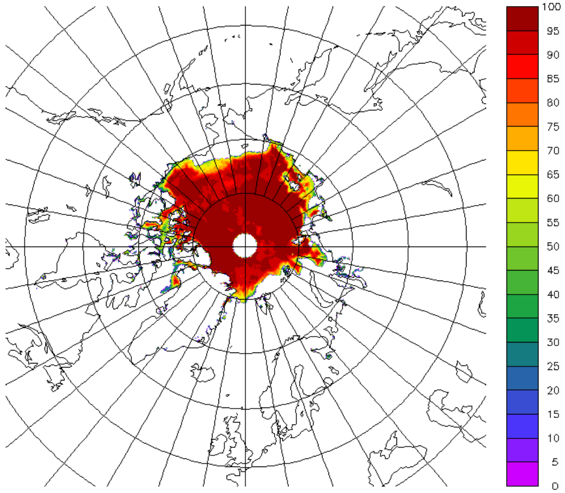
Minimum extension in Arctic in september

Maximum extension in Antarctic In september



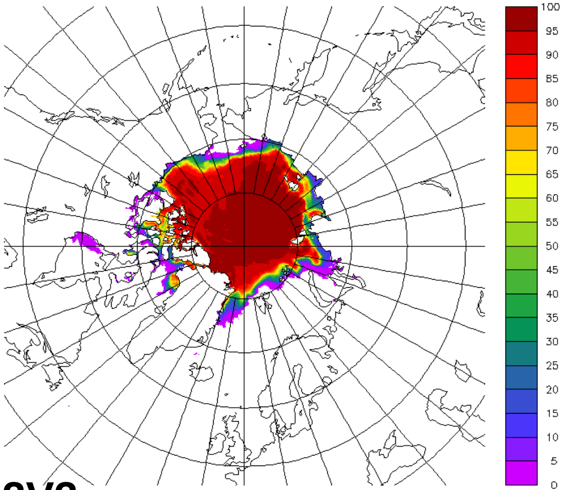
Assimilation of Sea Ice Concentration :
Current status of the Mercator Reanalysis (G2V3)

CERSAT data | **GLORYS2V3**

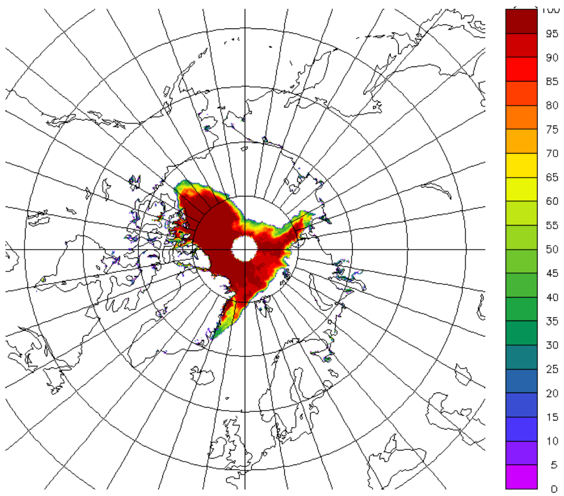


Extreme Events

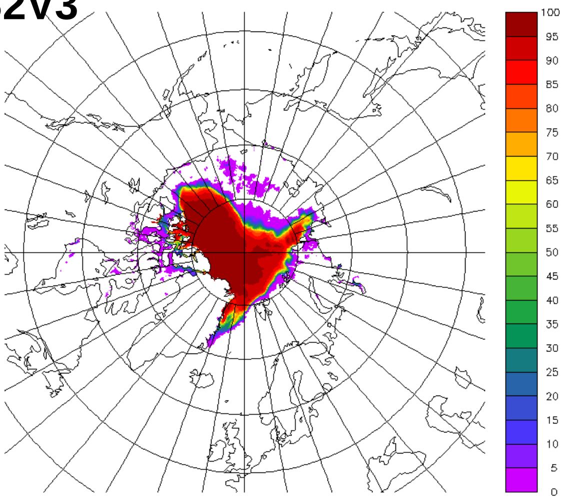
Sept 1996



Good behaviour of GLORYS2V3 during extreme events



Sept 2007



Mercator activities in the ERA-CLIM2 Project
General Work Plan for WP2 task2.2

Mercator Ocean
Ocean Forecasters

1 - Production of reference simulation without the use of Gaussian transformation in the sea ice analysis

→Development of a multivariate sea ice analysis in the Mercator Reanalysis system

=> Well posed to demonstrate the interest of the Gaussian transformation due to the presence of wrong extrapolation

… Work in Progress…

→Use of an Arctic-Northern Atlantic Configuration at 1/4° (CREG4/NEMO3.6) which is in development in partnership with Canada (Env. Can. and Fisheries and Oceans) and coupling with the Mercator Assimilation System (SAM2) and the multivariate sea ice analysis.

=> a low-cost and recent model configuration centred on the Arctic Sea will be more efficient for this study

… Work in Progress…

→Production of reference simulation using **multivariate sea ice analysis**

2 - Development of libraries dedicated to the anamorphosis approach :

→Coupling with the Mercator Assimilation system

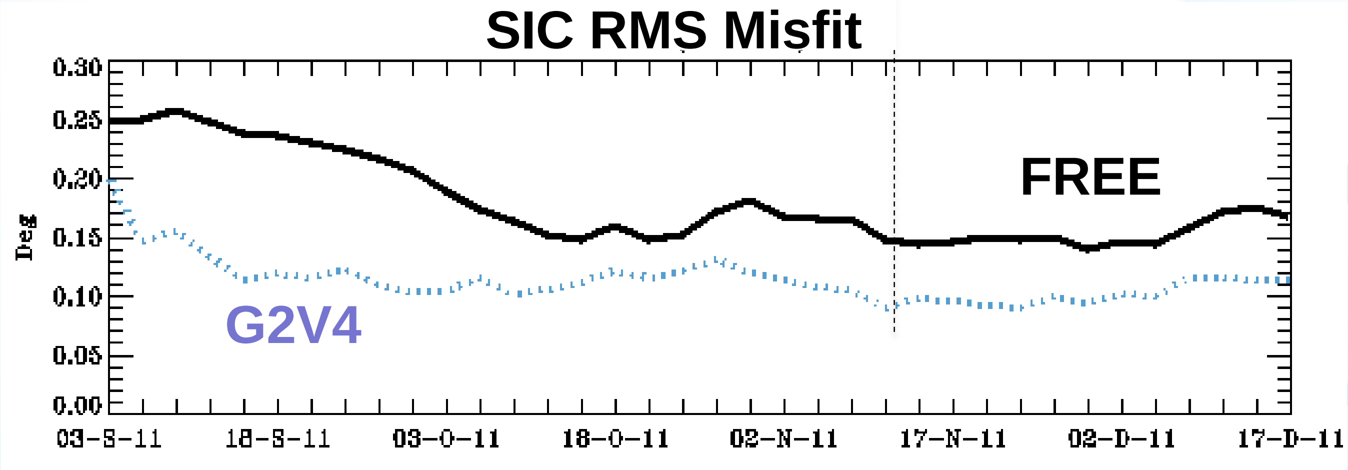
→Hindcast using the Anamorphosis approach

Development of a multivariate sea ice analysis

…Work in progress…

Mean features of a multivariate sea ice analysis

- based on a 2D local multivariate SEEK/LETKF filter
- Fixed basis background error
- **Multivariate state vector :** [SST,SIC,Thickness]
- **Assimilated data** : SIC and SST restricted to open ocean close to the marginal zone
- **Corrected Variables** : SIC and Thickness



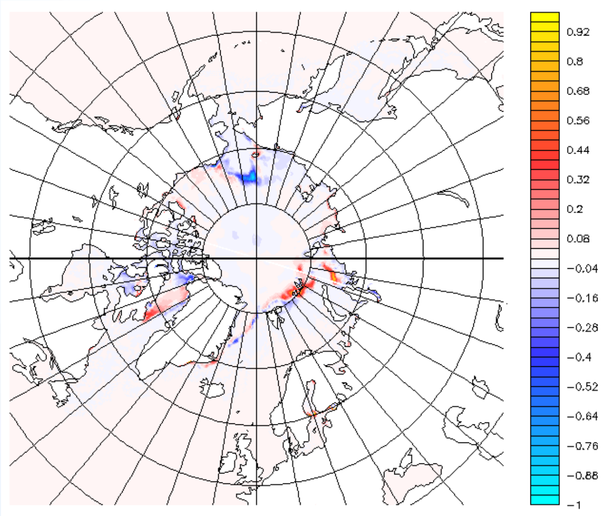
Development of a multivariate sea ice analysis

…Work in progress…

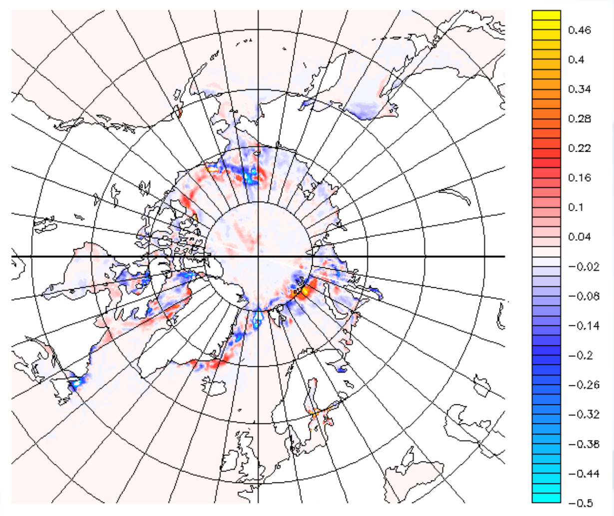
Multivariate state vector for G2V4 sea ice analysis
[SST,SIC,Thickness] with (SST,SIC) observations
SST restricted to open ocean close to the marginal zone

Test_G2V4 Sea Ice Model update (y2011m11d11)

(after 2 months of hindcast experiment)



SIC Model update



Thickness Model update

⇒ The thickness model update is statistically extrapolated

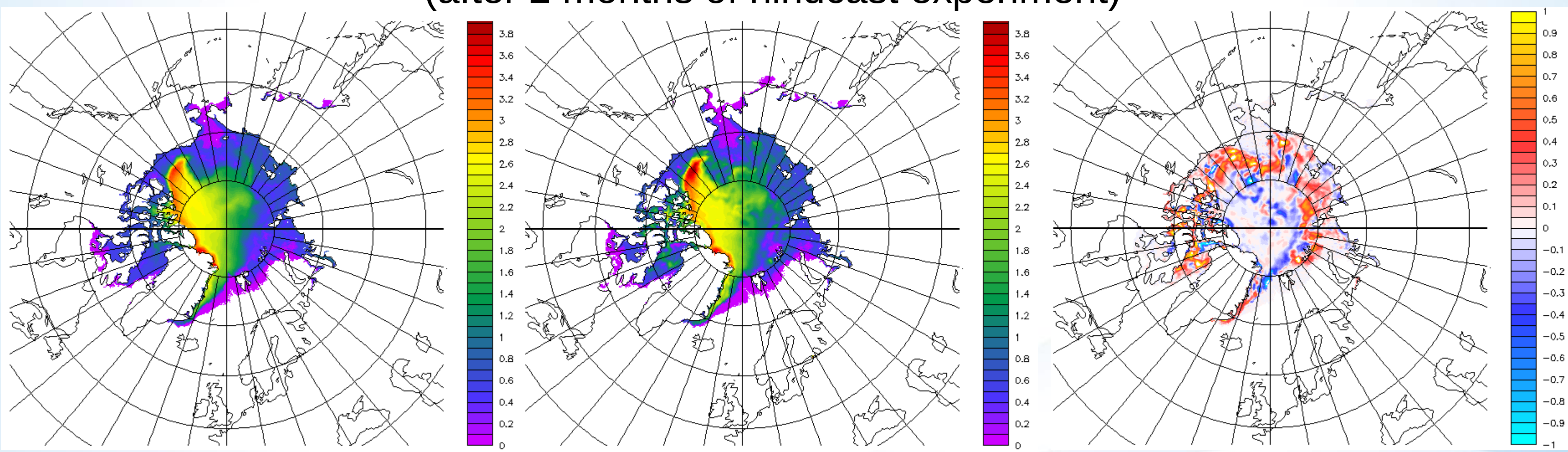
⇒ The sign of the thickness model update seems to be consistent but the magnitude is probably wrong due to non Gaussian properties of SIC and Thickness

Development of a multivariate sea ice analysis

…Work in progress…

Multivariate state vector for G2V4 sea ice analysis
[SST,SIC,Thickness] with (SST,SIC) observations
SST restricted to open ocean close to the marginal zone

Thickness (y2011m11d11)
(after 2 months of hindcast experiment)



G2V3
SIC correction

TEST_G2V4
SIC & Thickness corrections

TEST_G2V4 – G2V3

⇒ Strong impact of the the use of Thickness model update
⇒ But need Thickness data in order to validate TEST_G2V4 simulation

An Arctic-Northern configuration dedicated to the development of an advanced sea ice analysis

…Work in Progress…

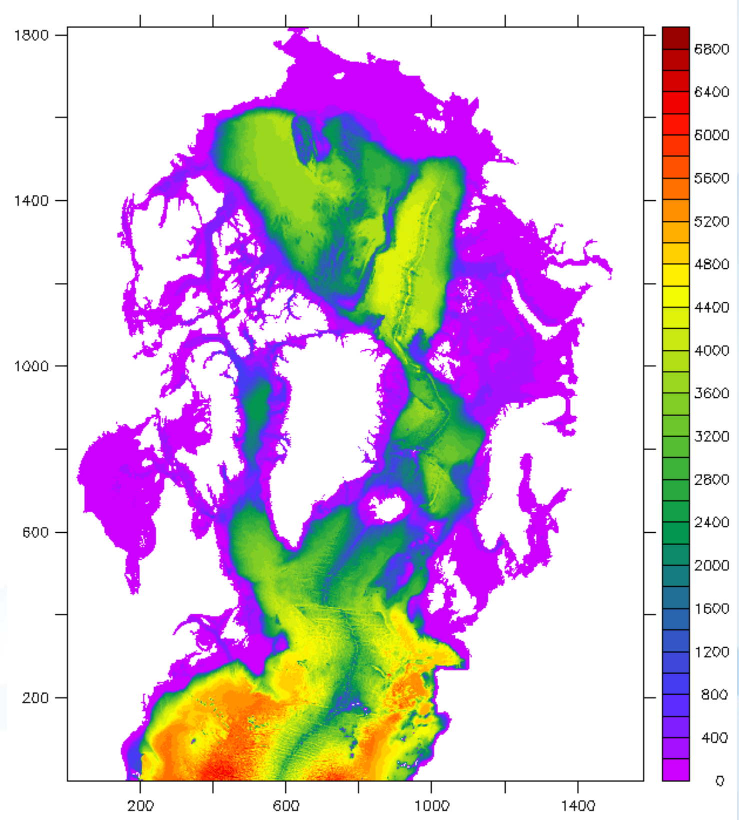
To develop an advanced sea ice analysis (multidata, multivariate, Gaussian Anamorphosis parameterization, ensemble, LIM3, …), it is more efficient to use a recent and low-cost model configuration centred on the Arctic Sea

=> Use of an Arctic-Northern Atlantic Configuration at 1/4° (CREG4/NEMO3.6) which is in development in partnership with Canada (Env. Can. and Fisheries and Oceans)

Technical work in progress (by the end of 2014)

→ Coupling with the Mercator Assimilation System (SAM2) and multivariate sea ice analysis.

NB: This development is a technical step which is not directly linked to the ERACLIM2 project



Source: G. Smith, Env. Canada, Montréal

Mercator activities in the ERA-CLIM2 Project
Future steps for WP2 task2.2

Mercator Ocean
Ocean Forecasters

1 - Production of reference simulation without the use of Gaussian transformation in the sea ice analysis

→Development of a multivariate sea ice analysis in the Mercator Reanalysis system
=> stabilize a robust tuning **(by the end of 2014)**

→Use of an Arctic-Northern Atlantic Configuration at 1/4° (CREG4/NEMO3.6)) and coupling with the Mercator Assimilation System (SAM2) and the multivariate sea ice analysis.
=> Technical step under development **(by the end of 2014)**

…

In 2015

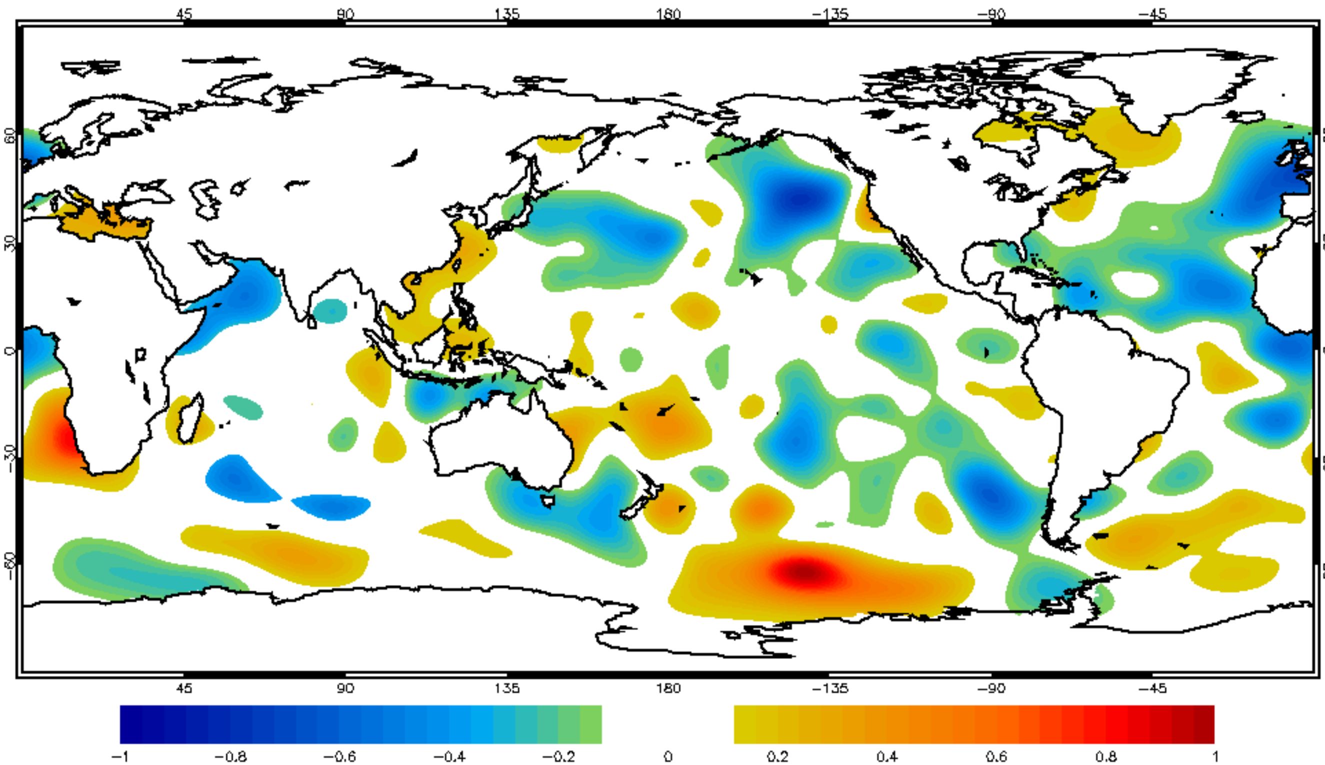
→Production of reference simulation using **multivariate sea ice analysis** (June 2015)

2 - Development of libraries dedicated to the Anamorphosis approach :

→Coupling with the Mercator Assimilation system
→Hindcast using the Anamorphosis approach (by the end of 2014)

SST Bias correction
Matchup method

Example Bias field for AVHRR



Sources of reference data are:

In-situ data (excluding ships)
(A)ATSR series satellites
METOP (but only from the centre of the swath)

The matchup method uses assumed 'unbiased' observations as a reference to calculate a bias field.

Matchups between biased data and the reference are assimilated into a background field of bias using a long (7^0) length-scale.
This is similar to how OSTIA woks.

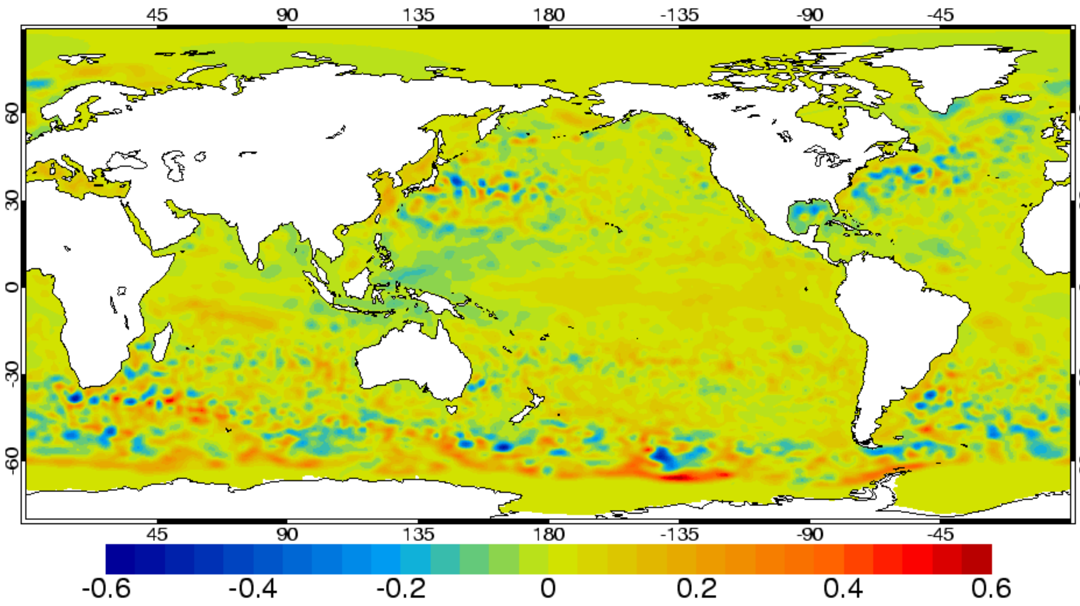
The calculated bias field is removed from the biased data

This system is used operationally in FOAM.

SST Bias correction

Variational method

Example Altimetry Bias field (100km length-scale)



Bias included as part of the cost function:

$$J = \tfrac{1}{2}\,(\mathbf{d}-\mathbf{H}(\delta\mathbf{x}+\mathbf{b}))^T\mathbf{R}^{-1}(\mathbf{y}-\mathbf{H}(\delta\mathbf{x}+\mathbf{b}))$$

$$+ \tfrac{1}{2}\,(\delta\,\mathbf{x})^T\mathbf{B}^{-1}(\delta\,\mathbf{x}) + (\mathbf{b}-\mathbf{b}^f)^T\mathbf{O}^{-1}(\mathbf{b}-\mathbf{b}^f)$$

The bias is updated when assimilating, based on the innovations (obs-bg).

Need to estimate the length-scale and errors of the bias field.

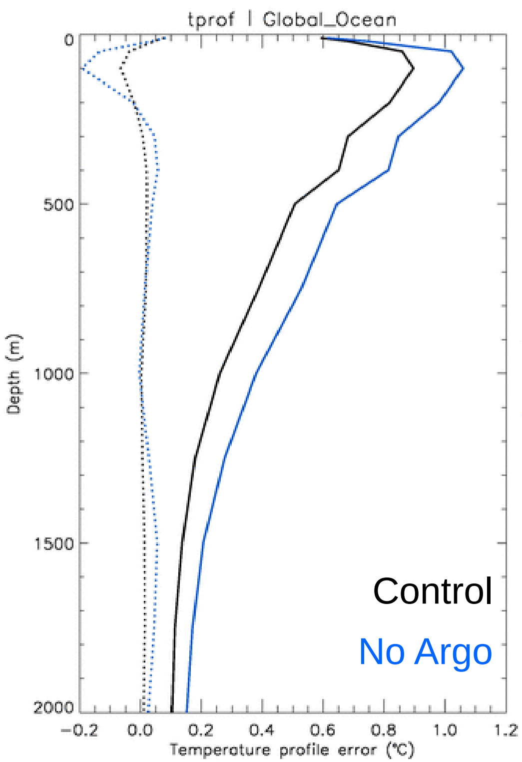
Need to distinguish model and observation biases.

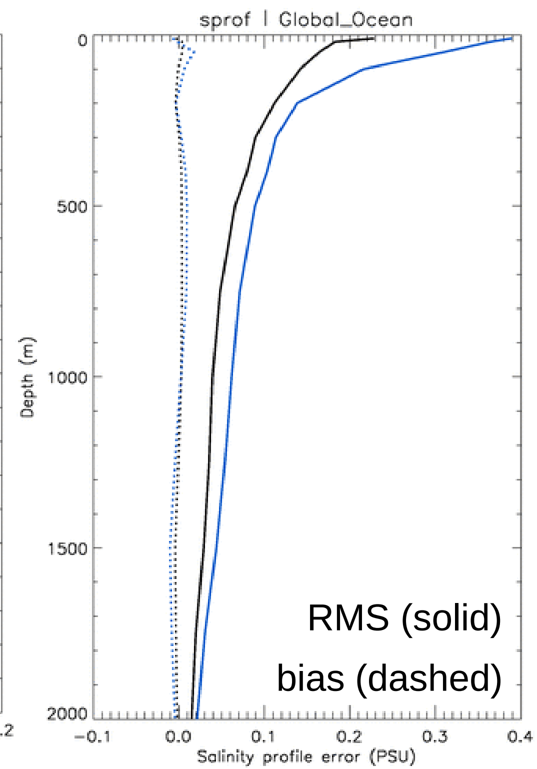
A similar system is currently used at the Met Office for altimetry data.

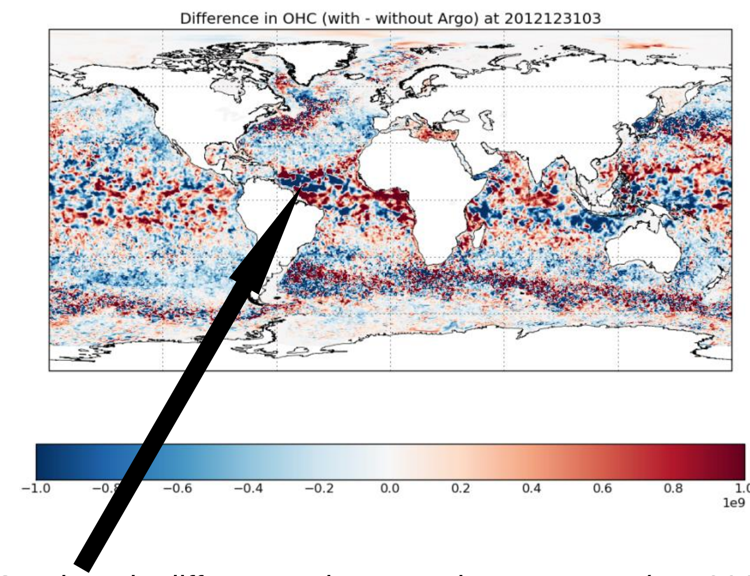
NoArgo OSE - preliminary results

Met Office

- There is a clear (and expected) degradation in the mean ocean profile statistics over the 13-month analysis run when Argo is removed.
  - Temperature profiles are degraded at all layers, except the surface layer where SST assimilation (in both runs) constrains the temperature.
  - However, some significant and temporally-static differences are seen in the ocean fields, e.g. differences in the upper ocean heat content (bottom-right plot)







Semi-static differences in ocean-heat content (top 300m) which may affect progress/intensity of storms.

NoArgo OSE – <u>preliminary</u> results

- Global verification statistics for the atmospheric fields show negligible differences between the control and NoArgo runs, but specific case studies show greater impact.
  - Plots below show sea-level pressure difference (left) and rainfall difference (right) for 03Z (top) and 09Z (bottom) on 29/10/2012 as Hurricane Sandy makes landfall.

These differences are between the control and NoArgo <u>analysis</u> runs. We also plan to run test case forecasts, but are still investigating these differences.