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ERA-CLIM2 WP2

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ERA-CLIM2 review, April 2016.

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- Deliverables status following approval of the 12 month extension
- Key achievements of the work in the past 9 months and progress against the deliverables
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WP2 objectives
Future coupling methods

- Research and development in coupled data assimilation for climate reanalysis, and work on development of the carbon component.
- Developments will be available for implementation in the CERA (Coupled ECMWF Reanalysis) framework developed at ECMWF.
- The work package will address the special requirements for the pre-satellite data-sparse era and the requirement to maintain a consistent climate signal throughout the entire reanalysis period.

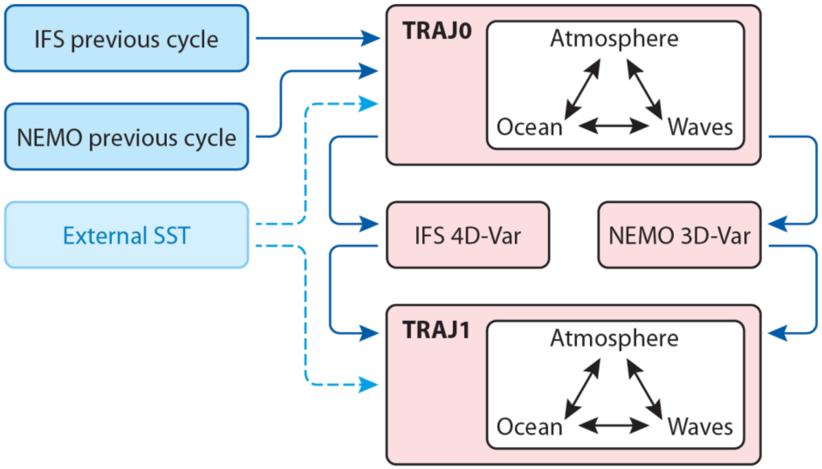
•T2.1: Coordination and management

•T2.2: To include SST and sea-ice assimilation in NEMOVAR

•T2.3: To improve the ocean analysis component including use of ensembles and 4D-VAR

•T2.4: Development of the carbon component of coupled earth system reanalysis

•T2.5: Towards development of fully coupled data assimilation



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WP2 status of deliverables

Deliverable number	Deliverable title	Delivery date	Type
D2.1	Assimilation of sea-surface temperature observations [METO]	27 => 39	Code + documented results
D2.2	Assimilation of sea-ice observations [MERCO]	27 => 39	Code + documented results
D2.3	Ensemble-based covariance estimates [CERFACS]	34 => 46	Code + documented results
D2.4	Ensemble-based covariances in coupled data assimilation [CMCC]	24 => 36	Report
D2.5	4D-Var in NEMOVAR [INRIA]	27 => 39	Report
D2.6	Optimised model parameters for the carbon cycle [UVSQ]	34 => 46	Report
D2.7	Alternatives for coupling ocean biogeochemistry [MERCO]	34 => 46	Report
D2.8	Weakly coupled assimilation methods [UREAD]	18	Report
D2.9	Covariances from weakly coupled data assimilation [METO]	18	Report
D2.10	Coupled-model drift [UREAD]	34 => 46	Report
D2.11	Fully coupled data assimilation [INRIA]	34 => 46	Report
D2.12	Status report WP2 [METO]	8	Report

- 3 deliverables complete.
- All others have been extended by 12 months in order to provide better quality deliverables.

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

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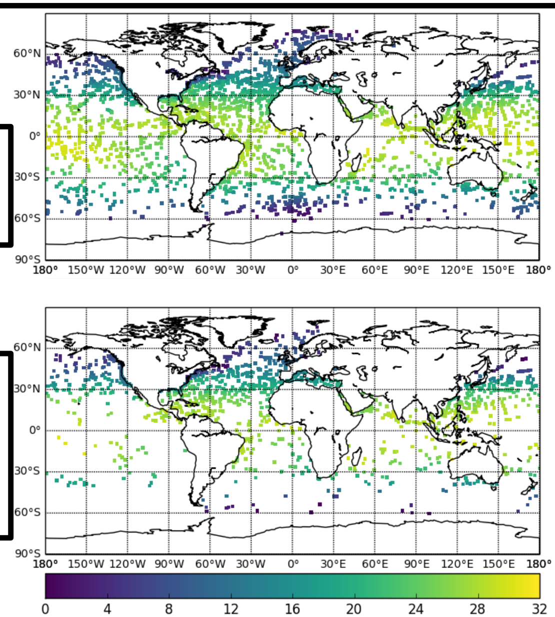
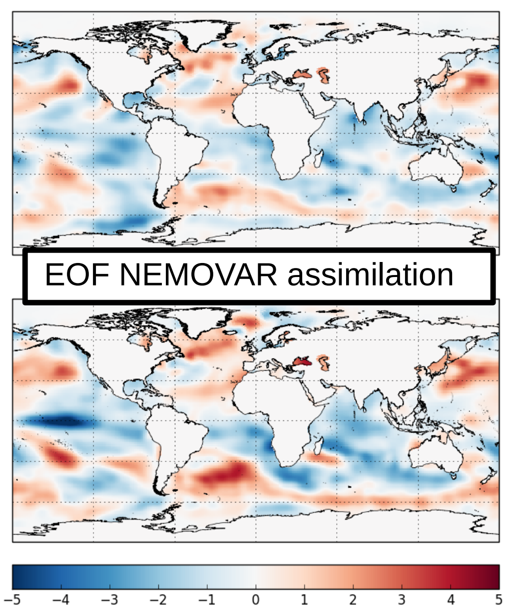
D2.1: SST bias correction and EOF error covariance developments [METO]

- Theoretical expressions and idealised experiments have supported the proposed improved ***SST bias correction*** scheme. Work to implement it in NEMOVAR making progress.
- EOFs have been calculated based on 20-year observation only (EN4), reanalysis (GloSea5), and coupled model (HadCM3) datasets. ***EOF-based error covariance model*** has been implemented in a recent version of NEMOVAR, utilising the code developments made at CERFACS for the ensemble error covariance model.
- An experimental framework is currently being developed to assess the use of EOFs on sparse observation networks, compared to the existing local error covariance model used in NEMOVAR.

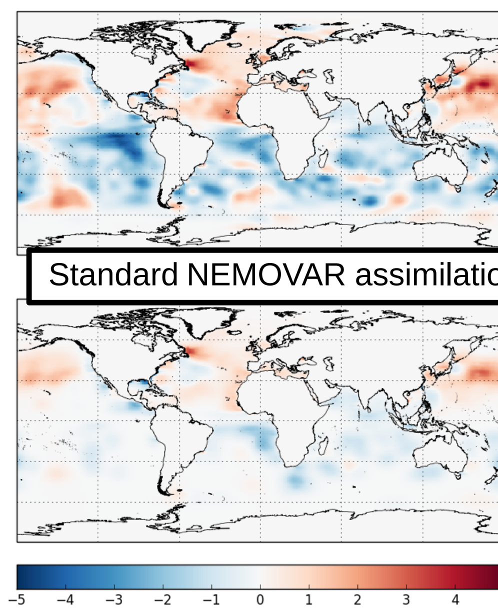
Full in situ SST data from Jan 2010

Sub-sampled data from Jan 2010 to simulate Jan 1960





EOF NEMOVAR assimilation



Standard NEMOVAR assimilation

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

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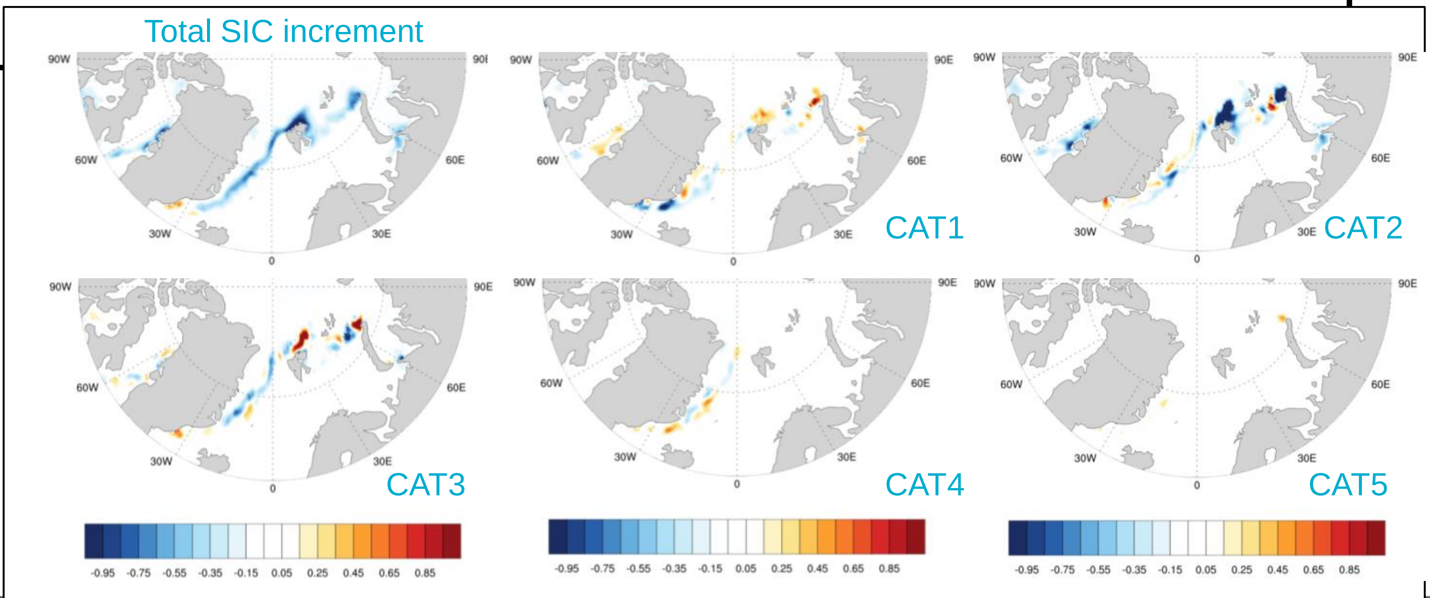
D2.2: Develop multivariate sea-ice assimilation [MERCO]

- A system coupling the NEMO3.6/LIM3 model and the Mercator Assimilation System (SAM2) has been developed. Arctic-Northern Atlantic Configuration at 1/4°(CREG025) has been implemented in SAM2.
- A 7-year simulation has been produced for the estimation of the uncertainties of the SAM2 analysis where the background error is represented by a prior ensemble of model states.
- Multivariate sea-ice state vectors for the sea-ice analysis are being evaluated and short hindcast experiments assimilating OSI-SAF SIC products have been completed, exploring how to estimate statistically the SIC update of each category of the SIC.



T2.3 to improve the ocean analysis component including use of ensembles and 4D-VAR

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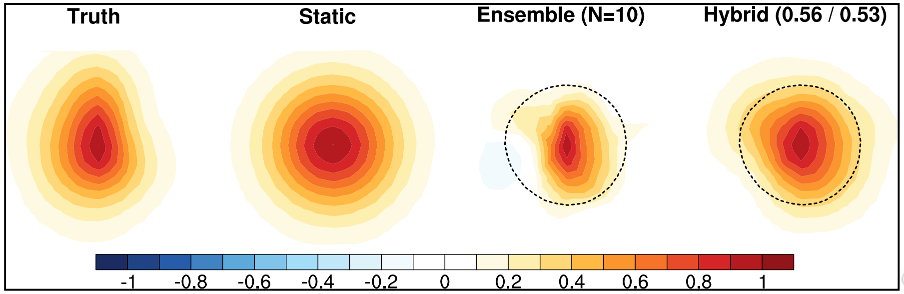
D2.3: Using ensemble-estimated background error variances and correlation scales in NEMOVAR [CERFACS]

- The main code modifications required to allow the use of ensemble perturbations to define the background error covariance matrix (**B**) are complete.
- The code has been integrated into a common reference version of NEMOVAR based at CERFACS and made available to ECMWF, including significant improvements to the "diffusion" algorithm used extensively in NEMOVAR (Weaver et al. 2016).
- Two methods have been developed to use ensemble perturbations to define **B**:
    1. use ensembles to estimate parameters (variances and correlation length scales) of the NEMOVAR covariance model.
    2. use ensembles to define a sample estimate of the covariance matrix. Optimally based techniques have been developed to filter the covariance model parameters and to localize the sample covariances.
- A *hybrid* formulation of **B**, involving a linear combination of the covariance model and the localized sample covariance matrix, has also been developed, as well as a procedure to optimally determine the weights given to each term.

Idealised example from NEMOVAR of the impact of the optimal tuning procedure and the resulting hybrid covariances



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T2.3 to improve the ocean analysis component including use of ensembles and 4D-VAR

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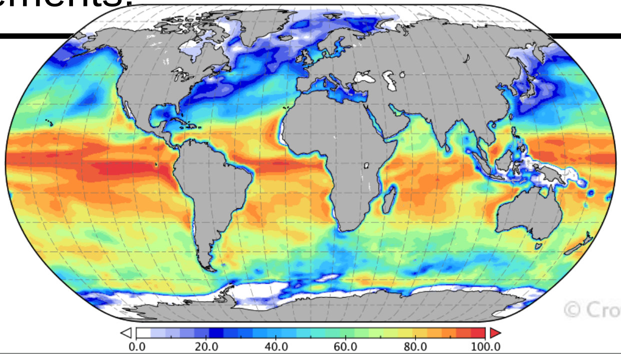
D2.4: Investigate the impact of air-sea coupled background-error covariances for use in strongly coupled data assimilation and use ensemble-derived information to construct the covariances [CMCC]

- An atmospheric boundary layer (ABL) model (CheapAML) has been coupled to NEMO.
- Monthly climatological coupled covariances have been estimated with different strategies:

  1. A linearized balance operator mapping ocean state perturbations to balanced ABL parameter perturbations which is essentially the tangent-linear version of the CORE bulk formulae.
  2. Purely statistical covariances between ocean state and ABL parameters are calculated: (a) from ensemble simulations with perturbed wind forcing and (b) from de-trended anomalies with respect to the long-term monthly climatology.

- Experiments are being performed to investigate the benefits of strongly coupled data assimilation where the ocean observing system is allowed to correct air temperature and humidity at 2 meters through coupled analysis increments.

2m air temperature background-error variance explained by the linearized air-surface balance (January)



T2.3 to improve the ocean analysis component including use of ensembles and 4D-VAR

D2.5: Test impact of 4D-VAR in NEMOVAR and develop a more computationally efficient implementation [INRIA]

- 4D-VAR in the ocean has been implemented and tested:
  - With the CERA settings (1° resolution and 1 day assimilation window) it showed only a modest impact compared to 3D-VAR.
  - Because of its importance for biogeochemical models, the impact of 4D-VAR respect to 3D-VAR on the vertical velocities has been investigated. With the CERA settings, the improvement on vertical velocities is barely noticeable; moreover 4D-VAR shows a strange behaviour on the equatorial band. A digital filter has been added to NEMOVAR, but with little impact on this particular problem - investigations are still on-going.
- In parallel, preliminary experiments have been performed with a higher resolution configuration at ¼°, where 4D-VAR is expected to have a greater impact.
  - At such resolution 4D-VAR iterations computing cost makes it difficult to run on medium size clusters. To address this issue multi-grid capability has been added to NEMOVAR.
  - Despite very encouraging results on an academic configuration, the transfer operator prototype is not efficient enough to handle realistic fine resolution global configurations and is undergoing a rewrite.

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T2.4 Development of the carbon component coupled earth system reanalysis

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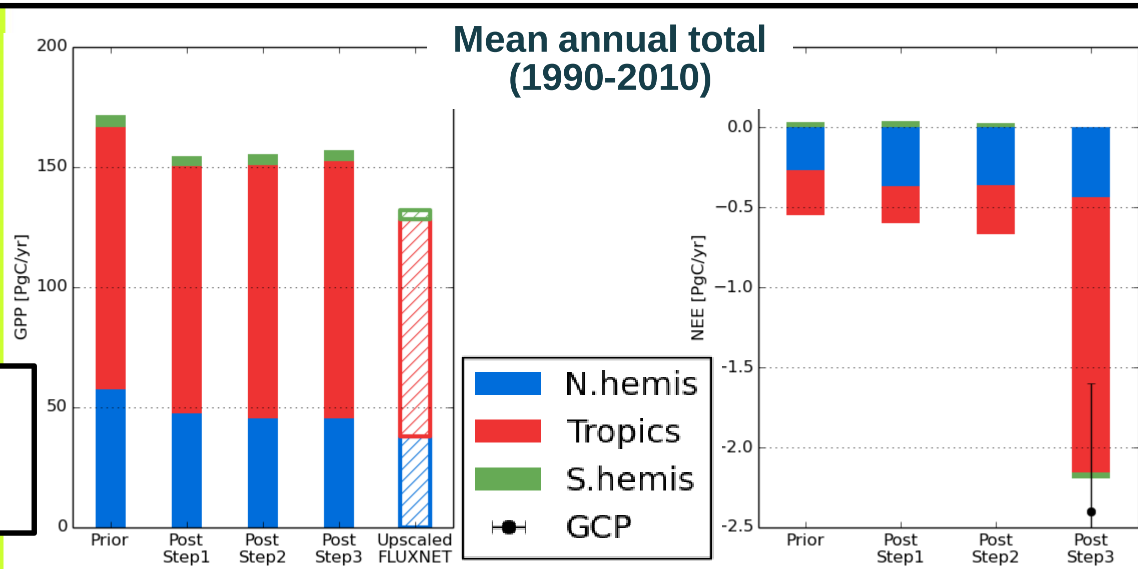
D2.6: Optimize terrestrial model parameters and carbon fluxes for the 20th century [UVSQ]

LSCE has finalized its Carbon Cycle Data Assimilation System (CCDAS) built around the ORCHIDEE land surface model (i.e. parameter optimization using multiple data streams). Main areas of work:

- Investigation of two different strategies to minimize the cost function: gradient-based vs Monte Carlo. A paper is in preparation (Bastrikov et al., 2016).
- An analysis of the carbon fluxes obtained with the current CCDAS based on a sequential assimilation of (i) MODIS-NDVI data, (ii) FluxNet carbon and water fluxes at 70 sites, and (iii) atmospheric CO2 concentrations at 50 sites over 3 years (see fig). The results are under review in GMD (Peylin et al. 2016).
- Preparation of the input data for the application of the CCDAS over a longer period, i.e. assimilation of atmospheric CO2 data covering the past 50 years in a first step the full century in a second step (using ice core data).

Impact on net and gross C budgets



Gross Primary Productivity

→ (C assimilation)

Net Ecosystem Exchange

→ (net CO_2 flux)

Peylin, et al. 2016.

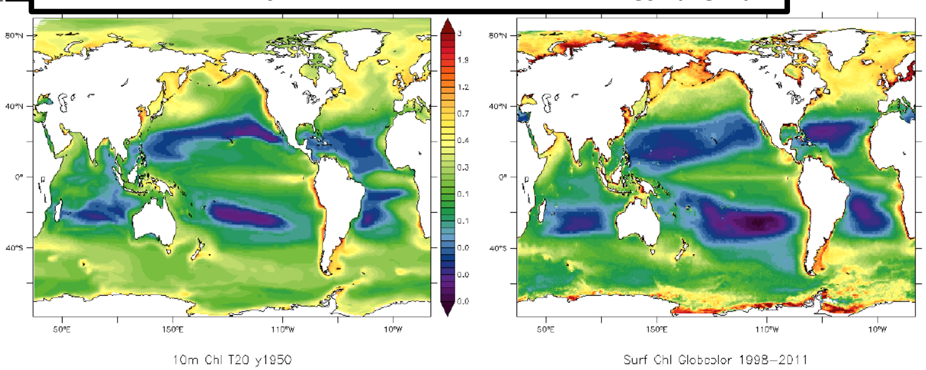
T2.4 Development of the carbon component coupled earth system reanalysis

D2.7 : Report on assessments of alternative methods for coupling ocean biogeochemistry in future Earth system reanalysis [MERCO]

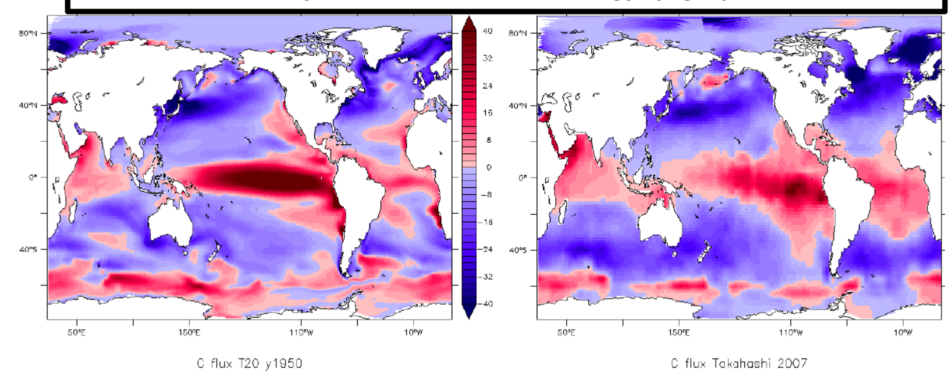
CERA-20C system not available until 2017 so current work aims to get the best 20th century reanalysis for biogeochemistry forced by ERA-20C.

- System for BGC reanalysis updated: coupled NEMO-PISCES simulation with NEMO 3.6, ORCA1 with 75 vertical levels, vvl parameterization included. BGC tracers initialized in 1870 using the output of the 100th year of a simulation produced in IPSL in July 2015 (used COREII climatological forcings and preindustrial atmospheric CO2).
- Spin-up phase from 1870-1900 taking a variable atmospheric CO2 concentration into account. Daily climatology of ERA-20C forcings generated in order to be used as forcings for this spin-up phase.
- 20th century run completed, forced by the interannual ERA-20C forcings and variable atmospheric CO2.

Surface Chl (mg/m^3) from simulation in 1950 (left) and observed by GLOBCOLOR climatology (right)



Sea-air carbon fluxes (gC/m^2) from simulation in 1950 (left) and observed by Takahashi climatology (right)

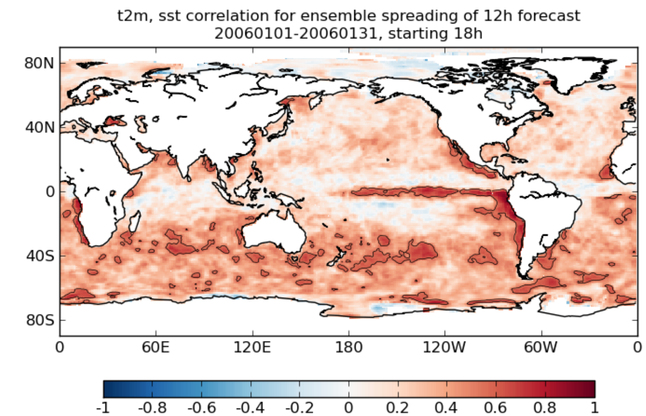


T2.5 Towards development of fully coupled data assimilation

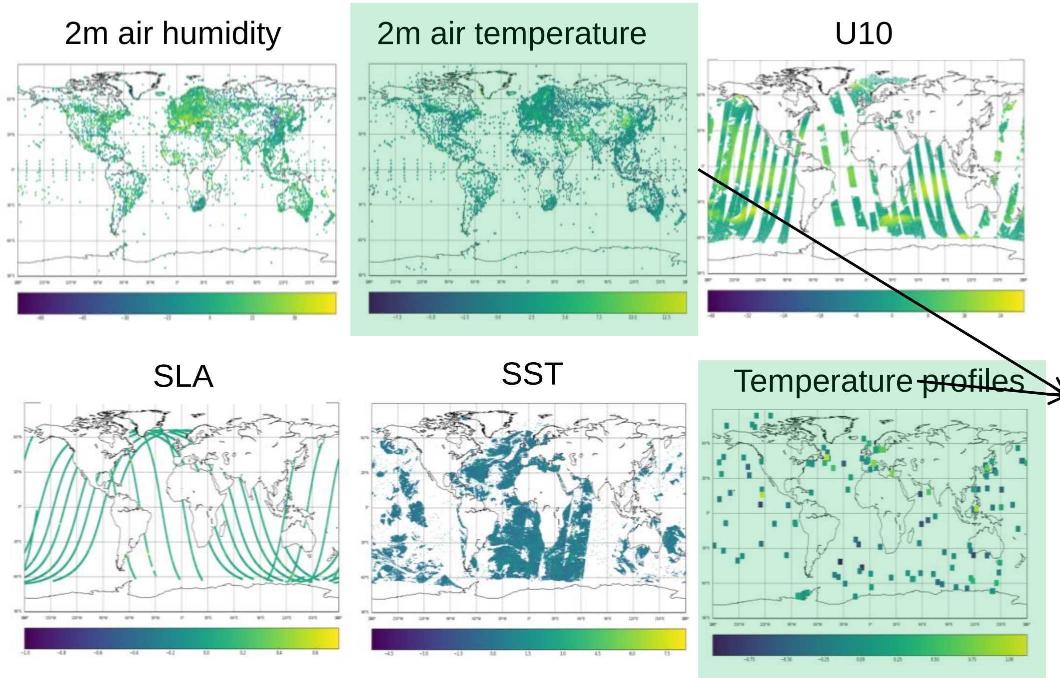
D2.9: Techniques for calculating coupled error covariances from outputs of a weakly coupled data assimilation experiment [METO, UREAD]

- UREAD work has taken CERA ensemble outputs and used these to estimate coupled error covariances.
- Results from innovation-based method using METO coupled DA system for Jan-March 2009. Atmos/ocean innovations match-ups within 0.1 degrees and 6 hours.

Ensemble based background error correlations from CERA

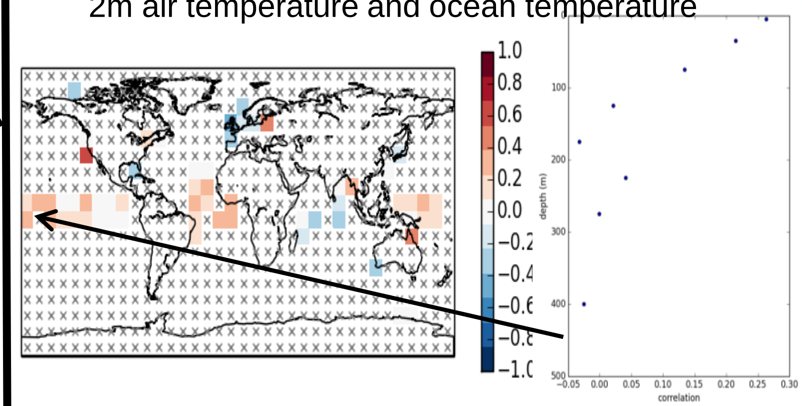


Ocean & atmosphere innovations from coupled DA run every 6-h



Innovation based background error correlations

2m air temperature and ocean temperature



T2.5 Towards development of fully coupled data assimilation

D2.10 : Report on assessment of coupled-model drift and approaches for obtaining consistent ocean and atmospheric bias corrections. [UREAD]

- The impact on seasonal forecasts of the use of equatorial bias correction in the ocean has been analysed. Initialisation shocks have been clearly detected in coupled forecasts initialised from ORAS4.
- Initialisation shock can be minimised by slowly removing the bias correction field during the forecast which is found to have a positive impact on forecast SST skill at lead times of a few months (Mullholand et al 2016).

D2.11 : Report on fully coupled data assimilation in simplified systems with implications for Earth system reanalysis. [INRIA]

- Aim is to mimic a Schwarz iterative method to improve coupling convergence within the 4D-VAR framework. To test this idea, a very simple 1D linear coupled system has been implemented and several formulations of the variational scheme have been proposed. They go from strongly coupled to weakly coupled with additional terms in the cost function. This work has been submitted as a paper to the CARI2016 conference.
- Following the OOPS training school organised at Grenoble in February 2016, this approach is currently under implementation using OOPS. Additionally, a more realistic toy coupled system mimicking the ocean-atmosphere behaviour is being finalised.

WP2 plans for coming 12 months

- Continue to make progress against deliverables (specific plans for each deliverable have been made). Next WP2 deliverables are due: Jan 2017 [CMCC], Apr 2017 [METO, MERCO, INRIA], then Nov 2017 [CERFACS, MERCO, UVSQ, UREAD, INRIA].
- Monitor deliverables and expect drafts of reports or test documentation at least one month before due dates to allow for review.
- Plan to have a WP2 meeting in Autumn 2016 to check on progress of deliverables and to coordinate the work.
- Coordination of code deliverables from METO, CERFACS and INRIA is on-going. METO/INRIA are now using directly the central NEMOVAR git repository hosted by CERFACS.

  -> ERA-CLIM2 NEMOVAR code developments will therefore be directly accessible by ECMWF.
- How to provide and integrate code developments by MERCO will need further discussions.

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WP2 outreach

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Published papers related to ERA-CLIM2 WP2 work:

- Mulholland, D. P., P. Laloyaux, K. Haines and M.-A. Balmaseda. Origin and impact of initialisation shocks in coupled atmosphere-ocean forecasts. Mon. Wea. Review, http://dx.doi.org/10.1175/MWR-D-15-0076.1.
- Weaver AT, Tshimanga J, Piacentini A, 2016. Correlation operators based on an implicitly formulated diffusion equation solved with the Chebyshev iteration. *Q. J. Roy. Meteorol. Soc.,* **142**: 455-471.
- Lea, D. J., I. Mirouze, M. J. Martin, R. R. King, A. Hines, D. Walters, and M. Thurlow, 2015: Assessing a New Coupled Data Assimilation System Based on the Met Office Coupled Atmosphere–Land–Ocean–Sea Ice Model. Monthly Weather Review, 143, 4678–4694, doi: 10.1175/MWR-D-15-0174.1.
- Peylin, P., Bacour, C., MacBean, N., Leonard, S., Rayner, P. J., Kuppel, S., Koffi, E. N., Kane, A., Maignan, F., Chevallier, F., Ciais, P., and Prunet, P.: A new step-wise Carbon Cycle Data Assimilation System using multiple data streams to constrain the simulated land surface carbon cycle, Geosci. Model Dev. Discuss., doi:10.5194/gmd-2016-13, in review, 2016..

Encourage papers to be drafted on various other aspects, e.g.:

- SST bias correction theory and idealised experiments (While et al)
- EOF error covariance developments in NEMOVAR (Lea et al)
- Coupled error covariances calculated using innovations from weakly coupled DA (Waters et al)
- Coupled error covariances calculated using ensemble information from weakly coupled DA (Feng et al)
- Strongly coupled assimilation using linearised ocean-atmosphere balance relationships (Storto et al)

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