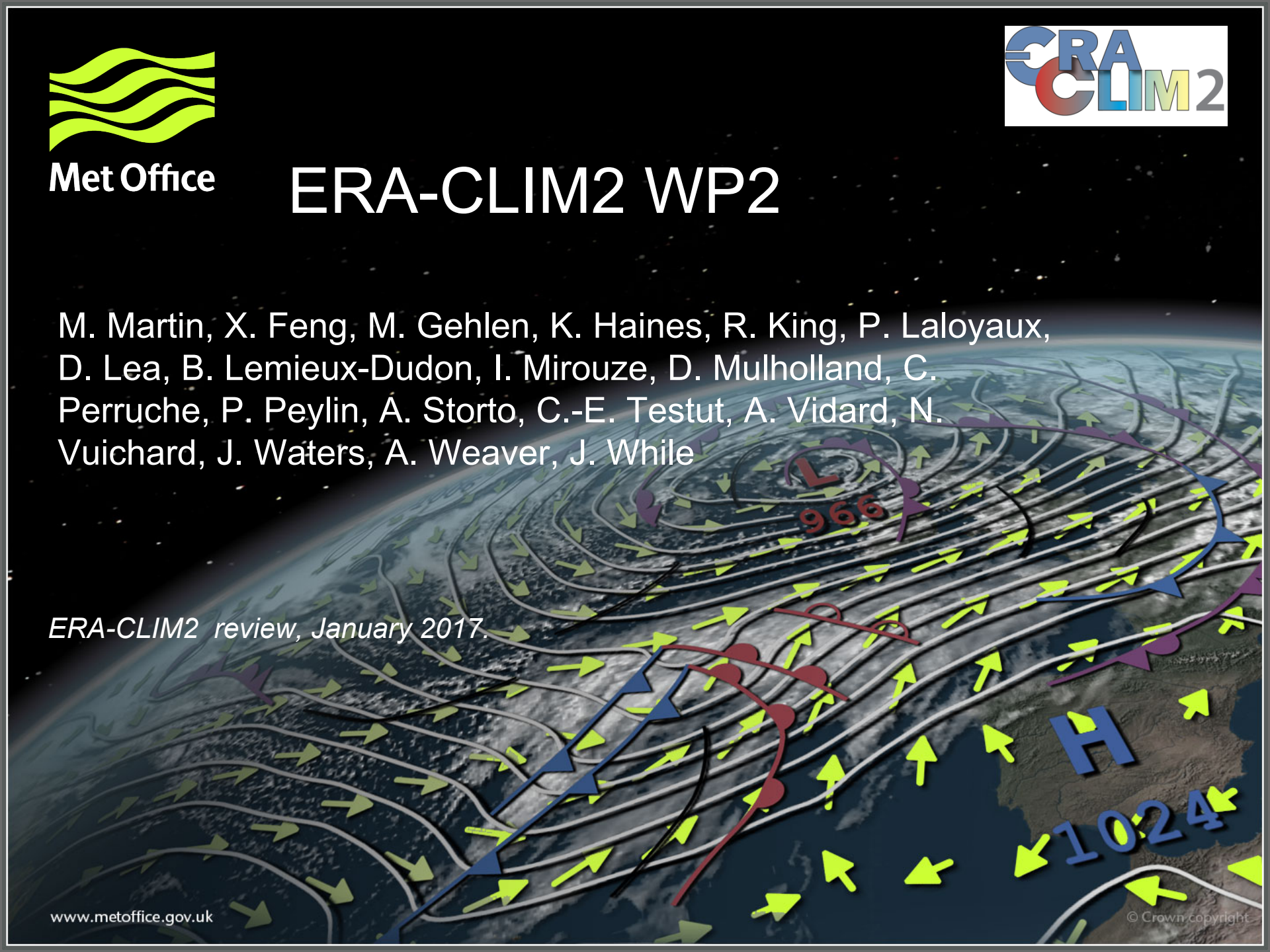
ERA-CLIM2 WP2

M. Martin, X. Feng, M. Gehlen, K. Haines, R. King, P. Laloyaux, D. Lea, B. Lemieux-Dudon, I. Mirouze, D. Mulholland, C. Perruche, P. Peylin, A. Storto, C.-E. Testut, A. Vidard, N. Vuichard, J. Waters, A. Weaver, J. While

ERA-CLIM2 review, January 2017.



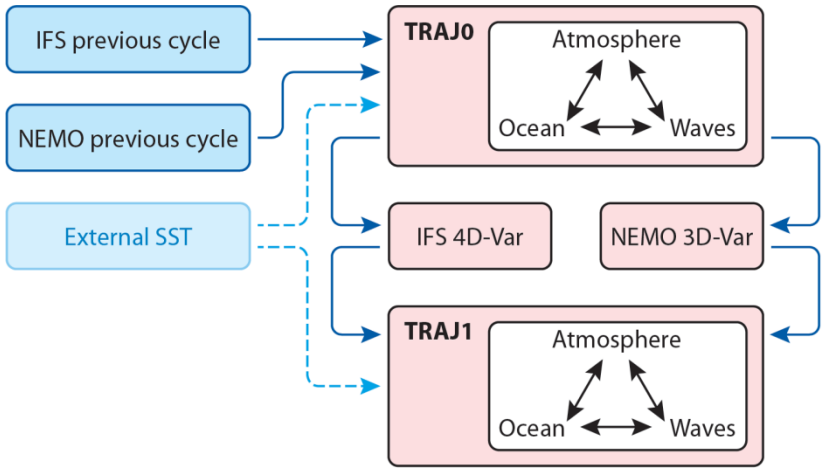
Contents

- Objectives of WP2
- Deliverables' status
- Key achievements of the work in the past 9 months and progress against the deliverables
- Work planned for the rest of the project
- Outreach

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



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

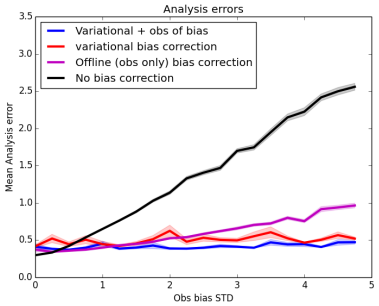
- 4 deliverables complete. The latest is the D2.4 report.
- 3 deliverables are due soon (month 39). They are expected to be delivered on time.
- 5 deliverables are due at month 46.

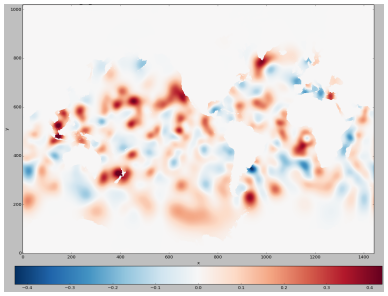
T2.2 to include SST and sea-ice assimilation in NEMOVAR

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. The scheme has been implemented in the NEMOVAR Git repository and is now available to ECMWF. Demonstration of the impact of the scheme is underway.

Idealised experiments show benefits from proposed scheme

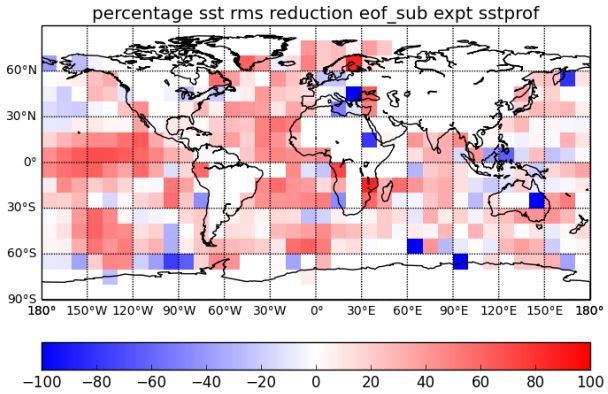




Example SST bias field for NOAA/ AVHRR from NEMOVAR

- EOFs have been calculated based on a 20-year reanalysis (GloSea5) of the satellite era. The ***EOF-based error covariance model*** has been implemented in a recent version of NEMOVAR. Experiments demonstrating the benefits of the developments in the data sparse period have been carried out, by sub-sampling the present day network, and comparing results to the withheld obs.

		RMS	Mean	N
No assim	SST	1.0918	0.2415	1228915
EOF	**SST**	**0.8630**	**-0.0588**	
Standard	SST	0.9793	-0.0462	

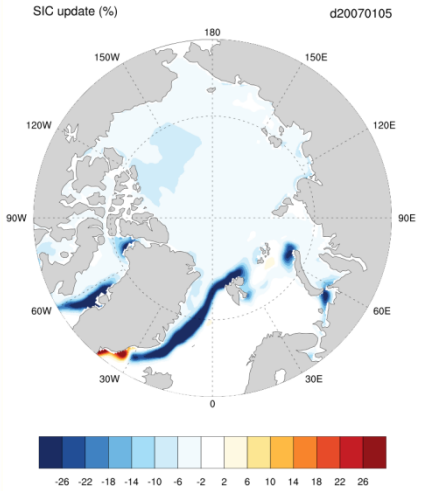


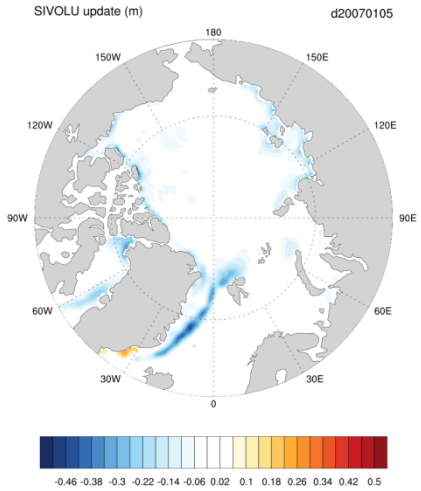
% reduction in SST error compared to background

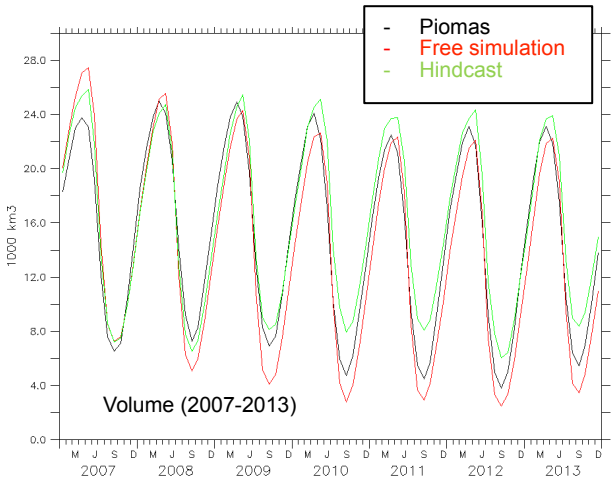
T2.2 to include SST and sea-ice assimilation in NEMOVAR

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 free 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 vector including Concentration and Volume is used for the sea-ice analysis.
- Multi-year hindcast experiments assimilating OSI-SAF SIC products have been performed in order to identify an optimal set up for the multivariate sea-ice analysis.







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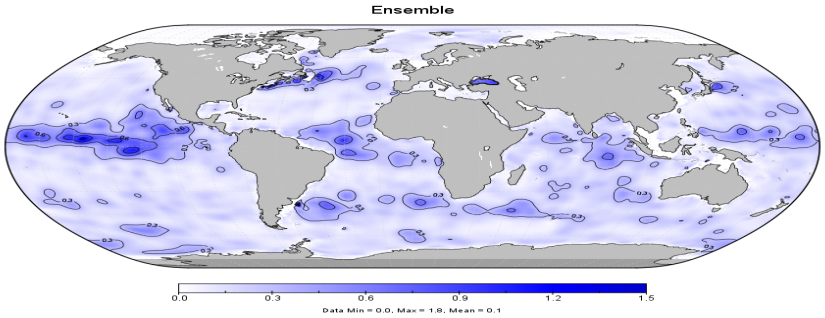
T2.3 to improve the ocean analysis component including use of ensembles and 4D-VAR

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

- Code required to use ensemble perturbations to define the background error covariance matrix (**B**) is complete and has been integrated into the trunk of the NEMOVAR central repository.
- Two methods have been developed to use ensemble perturbations to define **B**.
  1. Estimate parameters (variances and correlation length scales) of the covariance model.
  2. Define a low-rank sample estimate of the covariance matrix and localize it using a Schur product.
- **Hybrid formulations** of both 1. and 2. have also been developed in which the ensemble component is linearly combined with a “modelled” (climatological) component.
- 1. and 2. include optimally-based algorithms for filtering parameters and estimating hybridization weights and localization scales.
- Preliminary expts with hybrid variances have been conducted in collaboration with ECMWF.

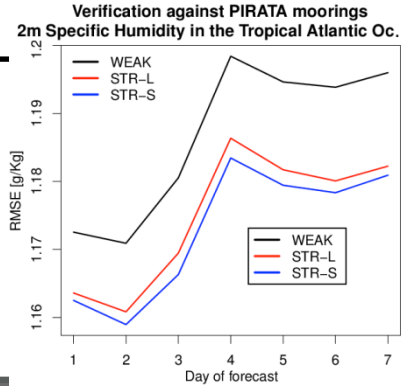
Example of optimally filtered T error standard deviations at 100m, estimated from the ECMWF 5-member ensemble of ocean reanalyses



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

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 were 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 specific humidity RMSE vs observations from PIRATA as a function of forecast range, for weakly (WEAK) and strongly coupled data assimilation experiments

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, and some further simplification of the TAM dynamics allowed to cancel this problem.
- In parallel, experiments have been performed with a higher resolution configuration at ¼°, where 4D-VAR were expected to have a greater impact.
  - Even at this resolution, assimilation windows of length at least several days are necessary to make a significant difference with the 3D-VAR.
  - Developments of multi-grid techniques that were primarily designed for making 4D-VAR affordable are now modified to improve the 3D-VAR performances as well (inversion of implicit B). In particular this require Nemovar to handle several grids at the same time (for 4Dvar purpose, off-line tranfert operators were used)

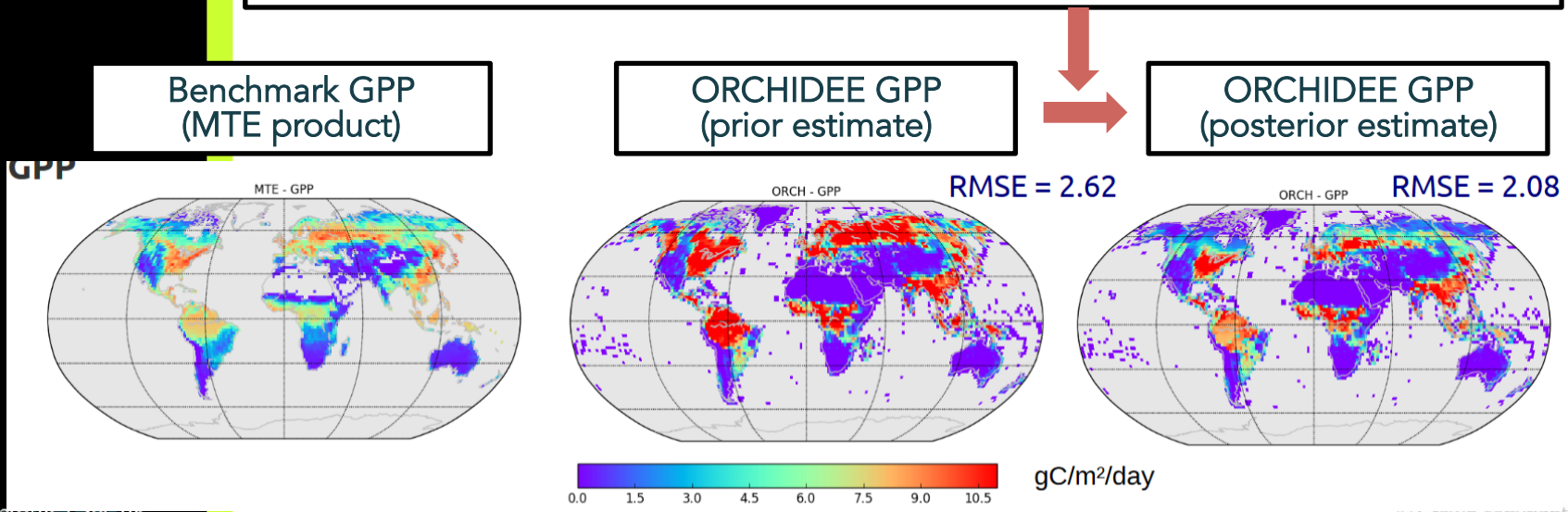
T2.4 Development of the carbon component coupled earth system reanalysis

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

LSCE has UPDATED its Carbon Cycle Data Assimilation System (CCDAS) with a new version of the ORCHIDEE land surface model (CMIP6).
Main areas of work:

- define a framework/tool to update automatically the Tangent Linear model of ORCHIDEE
- Summary of different strategies to minimize the cost function for the CCDAS: gradient-based vs Genetic algorithm (Bastrikov et al., to be submitted).
- Comparison of simultaneous vs Stepwise data-stream assimilation
- Investigation of the potential of new C-cycle data streams for the use in the CCDAS : fluorescence data & atmospheric COS concentrations; ice core CO2 data

Impact of the Assimilation of Solar Induce Fluorescence (SIF from GOME-2 data) on the Gross Primary Production (GPP)



Peylin, et al. 2016.

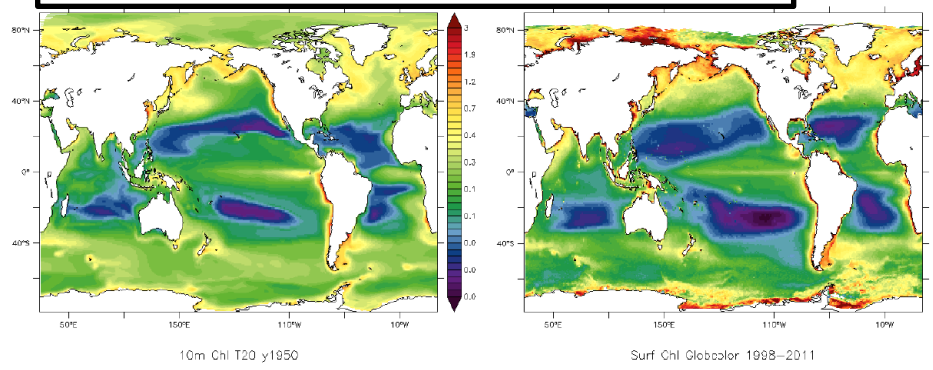
T2.4 Development of the carbon component coupled earth system reanalysis

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

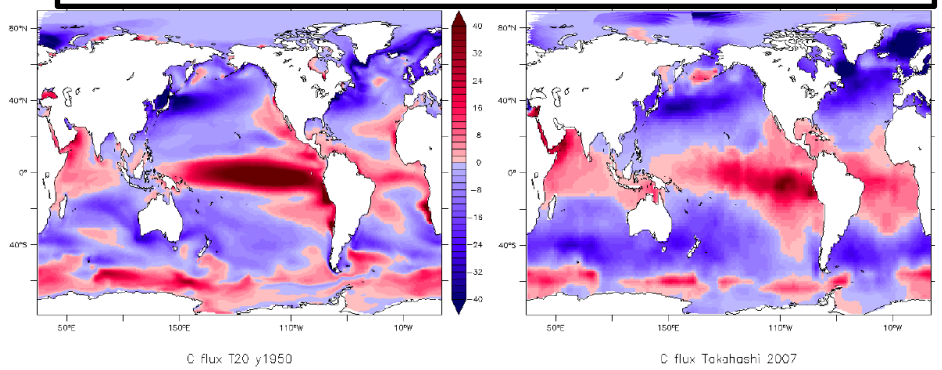
Previous work focused on designing method for running the BGC reanalysis, and for generating initial conditions.

The focus of MERCO in this area has been on production work in WP1, so no recent progress in WP2 on this deliverable.

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)

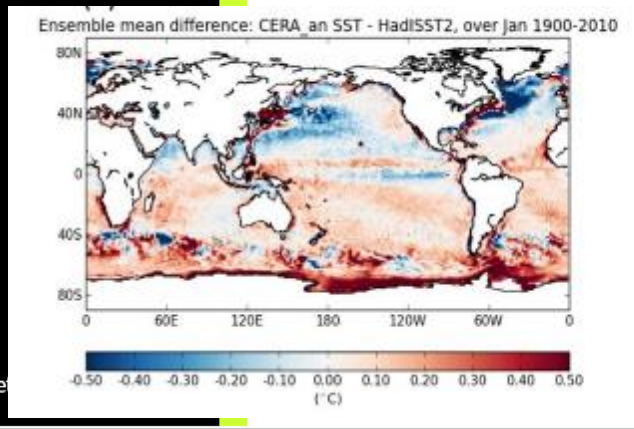


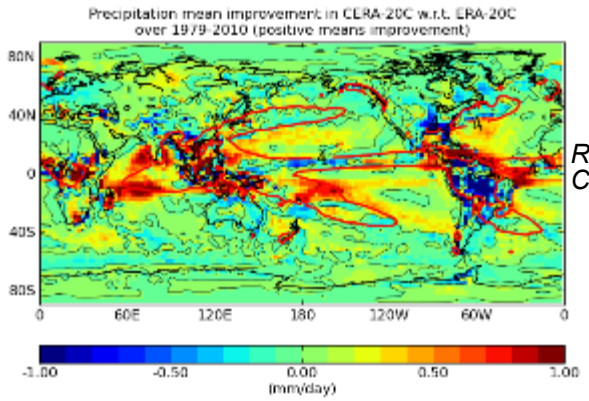
T2.5 Towards development of fully coupled data assimilation

D2.8 [UREAD] and D2.9 [METO] delivered in month 18

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 (period 4-5 days) 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 (ACC) at lead times of a few months (Mullholand et al 2016).
- SST bias and ocean T bias in CERA-20C has also been diagnosed with temporal variability. Approaches are being developed and will be applied in CERA to reduce the bias.
- Precipitation bias is also being analysed due to better coupling processes in CERA-20C.





Red contour is high P regions
Climatological P>12cm/month

T2.5 Towards development of fully coupled data assimilation

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 accepted as a paper to the CARI2016 conference and presented in the Coupled Data Assimilation Workshop.
- Following the OOPS training school organised at Grenoble in February 2016, this approach has been implemented using OOPS, and the results mentioned above has been reproduced. Additionally, a more realistic toy coupled system mimicking the ocean-atmosphere behaviour (ocean vertical mixing-bulk-ABL) has been implemented, is being tested and will soon be interfaced with OOPS.

WP2 plans for the rest of the project

- Continue to make progress against deliverables. Next WP2 deliverables are due in Mar 2017 [METO, MERCO, INRIA], then Oct 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.
- Coordination of code deliverables from METO, CERFACS and INRIA is on-going through the NEMOVAR steering group.
- METO/INRIA/CERFACS are now using directly the central NEMOVAR git repository hosted by ECMWF so ERA-CLIM2 NEMOVAR code developments will therefore be directly accessible by ECMWF.
- How to provide and integrate code developments by MERCO needs further discussions.
- Plan between METO and ECMWF to implement and test SST data assimilation capability in CERA.

WP2 outreach (1)

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.
- Mulholland, D. P., Haines, K. and Balmaseda, M. A. (2016), Improving seasonal forecasting through tropical ocean bias corrections. Q.J.R. Meteorol. Soc., 142: 2797–2807. doi: 10.1002/qj.2869
- 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 stepwise carbon cycle data assimilation system using multiple data streams to constrain the simulated land surface carbon cycle, Geosci. Model Dev., 9, 3321-3346, doi: 10.5194/gmd-9-3321-2016
- Conference paper: Toward variational data assimilation for coupled models: first experiments on a diffusion problem. Rémi Pellerej, Arthur Vidard, Florian Lemarié. CARI 2016, Oct 2016, Tunis, Tunisia. 2016

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

- *Uncertainties of sea surface and air temperature in the CERA-20C coupled reanalysis ensemble (Feng et al), submitted to QJRMS.*
- SST bias correction theory, idealised experiments and realistic implementation (While et al)
- EOF error covariance developments in NEMOVAR (Lea et al)
- Strongly coupled assimilation using linearised ocean-atmosphere balance relationships (Storto et al)

WP2 outreach (2)

WP2 participants involved in the GODAE OceanView Data Assimilation Task Team meeting in Santa Cruz, USA, July 2016:

- https://www.godae-oceanview.org/outreach/meetings-workshops/task-team-meetings/joint-da-meap-tt-workshop/
- ERA-CLIM2 presentation from P. Laloyaux; ensemble ocean DA from A. Weaver; EOF-based error covariances from D. Lea; sea-ice assimilation work from C.-E. Testut; ocean biogeochemistry from C. Perruche.

Many contributions from WP2 participants to the Coupled Data Assimilation Workshop organised by WMO (and sponsored by ERA-CLIM2) in Toulouse, October 2016:

- http://www.meteo.fr/cic/meetings/2016/CDAW2016/index.html
- Patrick Laloyaux presented the CERA-20C system.
- Daniel Lea presented work on coupled DA at METO, and WP2 work on EOF error covariances.
- Andrea Storto presented work on strongly coupled DA at CMCC.
- Xiangbo Feng presented work on estimating coupled error covariances at UoR.
- James While presented work on SST bias correction developments at METO.
- Arthur Vidard presented work on strongly coupled DA research at INRIA.
- Anthony Weaver was on the organising committee.
- Anthony Weaver and Matt Martin chaired a breakout discussion on the challenges and future direction of coupled reanalysis.

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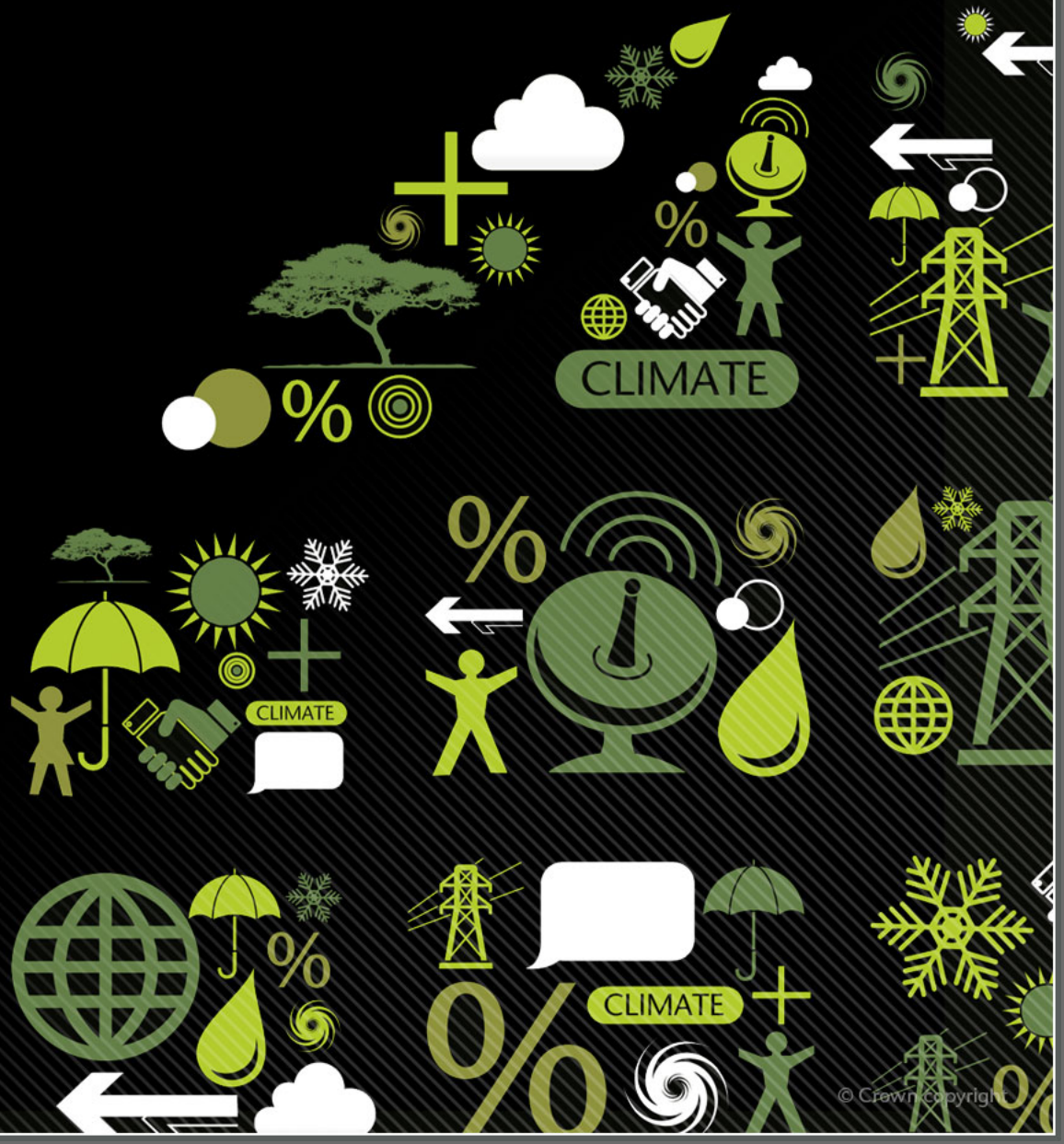

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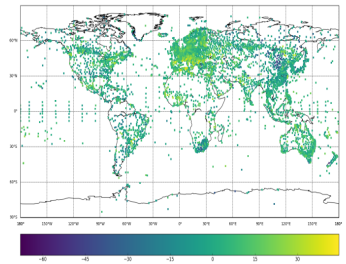
T2.5 Towards development of fully coupled data assimilation

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

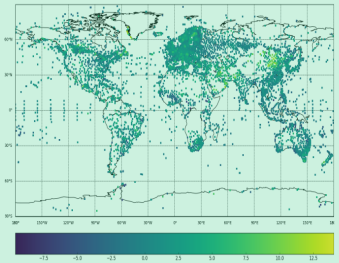
- UREAD work has taken CERA ensemble outputs and used these to estimate coupled error covariances.
- Results from innovation-based method using METO coupled DA system for Jan-March 2009. Atmos/ocean innovations match-ups within 0.1 degrees and 6 hours.

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

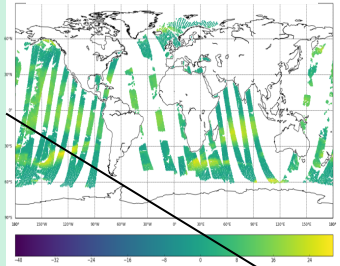
2m air humidity



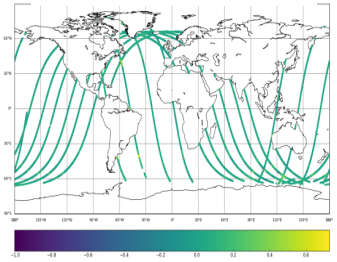
2m air temperature



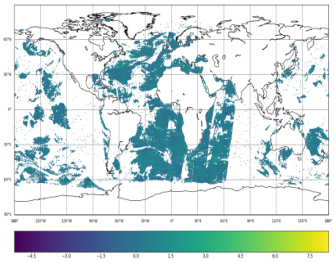
U10



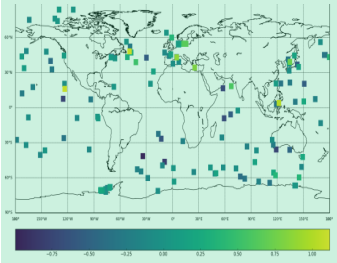
SLA



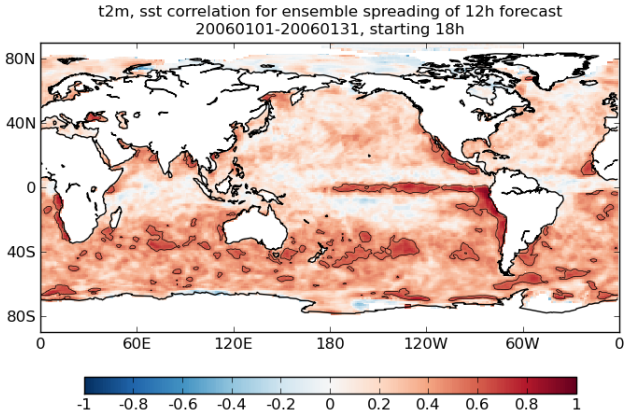
SST



Temperature ~~profiles~~



Ensemble based background error correlations from CERA



Innovation based background error correlations

2m air temperature and ocean temperature