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RE	Restricted to a group specified by the consortium (including the Commission Services)	
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Summary

The main objective of this task has been to provide initialization schemes for the ocean and sea-ice components of the different COMBINE models. The initial conditions are needed for the decadal forecasts carried out in WP6. To this end, a variety of initialization schemes have been implemented in the different models. This first objective has been satisfactorily achieved.

New ocean re-analyses have been conducted using the most up-to-date quality-controlled observation data sets and forcing fluxes from improved atmospheric re-analysis. The new ocean re-analyses produced under this COMBINE work-package are an important upgrade with respect to those produced in the ENSEMBLES project, in that i) they are not affected by the spurious decadal variability due to errors in the assimilated observations (XBTs), and ii) they can be brought closer to present time due to the availability of ERA-INTERIM fluxes.

1. Background

The initialization of the ocean is at a quite mature state, largely due to the activities on the seasonal forecasting and ocean re-analysis, which, in most cases are based on similar ocean data assimilation methodology. The results of ocean data assimilation tend to be model and resolution dependent, implying that not all the COMBINE models had easily available ocean initial conditions. There was also the question of whether the seasonal forecast initialization strategy (or “Real World initialization”) is adequate for decadal forecasts, since, in the case of model error, it can lead to undesirable initialization shocks. An alternative approach, so-called anomaly initialization, had been used by the MetOffice decadal system, producing encouraging results. This second strategy has the additional advantage of being able to use existing ocean re-analyses produced by a model/data assimilation system to initialize a different model.

In any case, regardless of whether the initialization of the ocean is done in direct or anomaly mode, a base line gridded ocean re-analysis is needed. The production and provision of ocean re-analysis has been the target for this milestone, thus ensuring that all the models used in WP6 have viable ocean initial conditions, following either strategy.

A matter of concern was that the decadal variability in ocean re-analysis available before COMBINE was contaminated by errors in XBT (eXpandable BathyThermograph) observations. Recently, better quality controlled observational data set has been produced by the MetOffice, which also includes more up-to-date archive (it covers 2009, for instance). Equally, there have been important developments in the availability of forcing fluxes. The

ERA-INTERIM fluxes, available since 1989, are considered superior to those of ERA40, and they are continuously updated (running about 3-6 months behind real time), which allows the production of improved and more up-to-date initial conditions. This is quite relevant for the decadal forecasts.

This document describes the work carried out in the production of new ocean re-analyses at ECMWF/CERFACS and CMCC. It also describes the efforts at MPG to use existing re-analysis products in anomaly initialization mode, and it provides a brief report of the work at the MetOffice.

2. ECMWF/CERFACS: The NEMOVAR-COMBINE ocean re-analysis.

ECMWF and CERFACS have produced a new ocean re-analysis, based on NEMOVAR (Weaver et al 2005, Mogensen et al 2009). This reanalysis, that we called NEMOVAR-COMBINE, assimilates temperature and salinity only. The reanalysis spans the period 1958-2009. NEMOVAR-COMBINE will be used to initialize the decadal forecasts using EC-EARTH. A subset of data from NEMOVAR-COMBINE is also publicly available at (http://www.klimacampus.de/easy_init_ocean0.html?&L=0).

The NEMOVAR reanalysis assimilates profiles of temperature and salinity from a version of the quality controlled EN3_v2a data set, which contains corrections to the XBTs as in Table 1 of Wijffels et al (2008). The first guess is given by the NEMO model forced by ERA40 fluxes from 1957 until 1988 and by ERA-Interim thereafter. The ERA40 fluxes are from the original ERA-40 product (Uppala et al 2005) except for the precipitation field, which has been corrected as in Troccoli and Kalberg (2004). Details of the NEMOVAR-COMBINE re-analysis are given in a COMBINE technical report (Balmaseda et al, 2010: <http://www.combine-project.eu/Technical-Reports.1668.0.html>).

Some aspects of the climate variability of ORAS3 (Balmaseda et al 2008) and NEMOVAR-COMBINE have been compared and discussed. Both reanalyses show a consistent shallowing trend of the thermocline in the Equatorial Pacific, a feature also noticeable in ocean-only simulations. The decadal variability in the upper ocean heat content differs between the two reanalyses, and these differences are largely attributed to the quality of the observations assimilated, in particular the errors in the XBTs and the SOLO/FSI Argo floats that affected ORAS3 variability. Results show that the assimilation of ocean data is effective in constraining the upper thermal field, reducing the uncertainty arising from ocean models and forcing fluxes. However, it does not constrain the ocean circulation. For instance, the difference in the AMOC at 26N between NEMOVAR-COMBINE and ORAS3 is larger than the differences between the HOPE and NEMO ocean-only simulations. NEMOVAR weakens the values of the AMOC with respect to NEMO ocean-only simulation, while in ORAS3 the assimilation strengthens the AMOC with respect to the HOPE ocean-only. The AMOC in NEMOVAR-COMBINE is weaker than in ORAS3.

2. CMCC

CMCC has provided two sets of global ocean re-analyses to initialize the decadal prediction system designed to produce hindcast and forecast simulations for the 1960-2035 period, using the CMCC-CM global climate model (see WP6). The two re-analyses differ by both assimilation methodology and amount of assimilated data. More specifically, one of the two re-analyses was performed using an Optimal Interpolator (OI) assimilation scheme which assimilates only temperature and salinity. In particular, this re-analysis is part of a set of global ocean re-analyses produced at CMCC for climate applications (Masina et al., 2011), among which is seasonal forecast initialization (Alessandri et al. 2010, 2011), and it has been validated against a set of high quality in situ observations and independent data. The data assimilated are the EN3_v2a data set which does not implement any kind of time varying XBT corrections (<http://www.metoffice.gov.uk/hadobs/en3>).

A 3D-Variational approach (3DVAR) was used to produce the other re-analysis. In 3DVAR, besides the above mentioned hydrographic EN3_v2a data set but with the time-dependent fall rate correction (Wijffels et al. 2008) applied to the XBTs, along-track sea-level anomaly (SLA) observations were also assimilated from 1992 onward (Storto et al., 2010). Along-track SLA observations are assimilated via a local hydrostatic adjustment scheme, which splits the sea-level increment proportional to the water-column integrated density increment, into thermo- and halo- steric contributions, provided that the increment is spread into vertical profiles of temperature and salinity according to the local structure of the bivariate background-error vertical covariances. The dataset of along-track data is currently provided by AVISO and is the one in delayed time. We have investigated the impact of the altimeter data and the use of different Mean Dynamic Topographies (MDT) by comparing the re-analyses with observed temperature, salinity and velocity observations. One of the MDT used comes from Rio and Hernandez, (2004). Another MDT has been derived from the model long-term mean SSH from analyses and forecasts initialized by assimilating in-situ data only and then adjusted through output assimilation diagnostics (Dobricic, 2005).

In all the re-analyses produced we used the free-surface version of the ocean model OPA 8.2 (Madec et al., 1999), which is also the same version of the model used as ocean component by the coupled climate model CMCC-CM. We have started to investigate the impact of the different ocean re-analyses to initialize the decadal prediction system designed to produce hindcast and forecast simulations for the 1960-2035 period, using the CMCC-CM global climate model (Gualdi et al., 2008) (see WP6). The full set of decadal prediction experiments consists of 3-members ensembles of 30-years simulations, starting at 5-years intervals from 1960 to 2005, using CMIP5 historical radiative forcing conditions (including green-house gases, aerosols and solar irradiance variability) for the 1960-2005 period, followed by RCP4.5 scenario settings for the 2005-2035 period. The ocean state is initialized with the CMCC global ocean re-analyses covering the 1960-2005 period. The use of alternative ocean re-analyses is the criterion adopted to perturb the full three-dimensional ocean state, so as to generate the spread of the ensemble

members. The two perturbing elements, assimilation method and data amount and typology, are used to sample the uncertainties associated with the reconstructed state of the ocean.

3. MPG

MPG has investigated the impact of three state-of-the-art ocean reanalyses products or “ocean state estimates” on decadal predictability in one particular coupled forecast system. The ocean state estimates are ORA-S3 (Balmaseda et al, 2008), GECCO (Köhl and Stammer, 2008a,b), SODA (Carton and Giese, 2008). The forecast system is the MPI-M Earth System Model ECHAM5/MPI-OM (Jungclauss et al, 2006) in a coarse resolution T31L19/GR30. For all ocean states, an assimilation experiment was performed by nudging temperature and salinity anomalies into the coupled model. Each assimilation run delivered the initial condition for a set of hindcast experiments. Each set of hindcasts consists of a yearly initialization for a common period of 1970-2001, one ensemble member and 10 yr of hindcast. We assessed decadal prediction skill by computing correlations and root mean square errors (rmse) of various climate parameters such as spatial means of modeled sea surface temperature (SST) and upper-levels ocean heat content (OHC) with respect to observations. Furthermore, potential prediction skill of the Atlantic meridional overturning circulation (MOC) is provided.

The 1960 to 2001 sea surface temperature (SST) signal in the North Atlantic (NA) sector (80W-0, EQ-60N) is highly correlated among observations and all assimilation experiments with the exception of the interannual variability in the GECCO nudged run (not shown). The representation of the MOC at 26N however differs remarkably in the ocean state estimates regarding both the long-term mean from 1960 to 2001 and the transient behavior (Figure 1, upper). The particular MOC signatures around 26N in ORA-S3 have already been documented in recent studies from Balmaseda et al (2007).

The MOC signals in our coupled model after nudging anomalies of ocean temperature and salinity from the respective ocean state estimates reveal differing degrees of degeneration. A strong amplification of the interannual variability is apparent in the SODA and GECCO assimilation runs (SODA-ASSIM and GECCO-ASSIM) whereas the variability appears much more conserved in the case of nudging with ORA-S3 (ORA-S3-ASSIM) (Figure 1, lower). Furthermore, in GECCO-ASSIM, a strong upward trend is introduced that amounts to an increase of about 6 Sv within 40 years. The long-term mean MOC in the assimilation runs are virtually the same with values ranging from 15.5 to 15.8 Sv which corresponds to the climatological mean of the coupled model since we assimilate only anomalies.

Figure 2 provides an overview of long-term means and standard deviations (stdev) of the MOC in the Atlantic basin from 30S to 65N, again comparing the ocean state estimates and the respective assimilation runs. The long-term mean MOC in the assimilation runs is set by the coupled model and peaks with more than 16 Sv at about 30N and 1000 m in all runs (Figure 2, lower). In

the ocean state estimates, on the other hand, the signatures and the magnitudes of the overturning differ strongly (Figure 2, upper). The MOC peaks in GECCO between 45N and 50N at about 1000 m with a value exceeding 12 Sv. In SODA we find a maximum overturning of more than 20 Sv at about 35N and 1000 m. In ORA-S3 the highest value lies over 24 Sv and is located at 40N well below 1000 m and above 1500 m.

The stdev after nudging the ocean state estimates into the coupled model is highly increased over almost the entire basin in GECCO-ASSIM and SODA-ASSIM, whereas it is much more retained in ORA-S3-ASSIM. In all assimilation runs, strongest amplifications up to a factor of 4 can be found on and slightly north of the equator and in subsurface layers down to about 2500 m depth. North of 40N and about below 1000 m, both GECCO-ASSIM and ORA-S3-ASSIM reveal a decrease in stdev which is the opposite case in SODA-ASSIM. Overall, the representation of the MOC is quite diverse in both the ocean state estimates and the assimilation runs. Closest matches are found for initializing the model by ORA-S3.

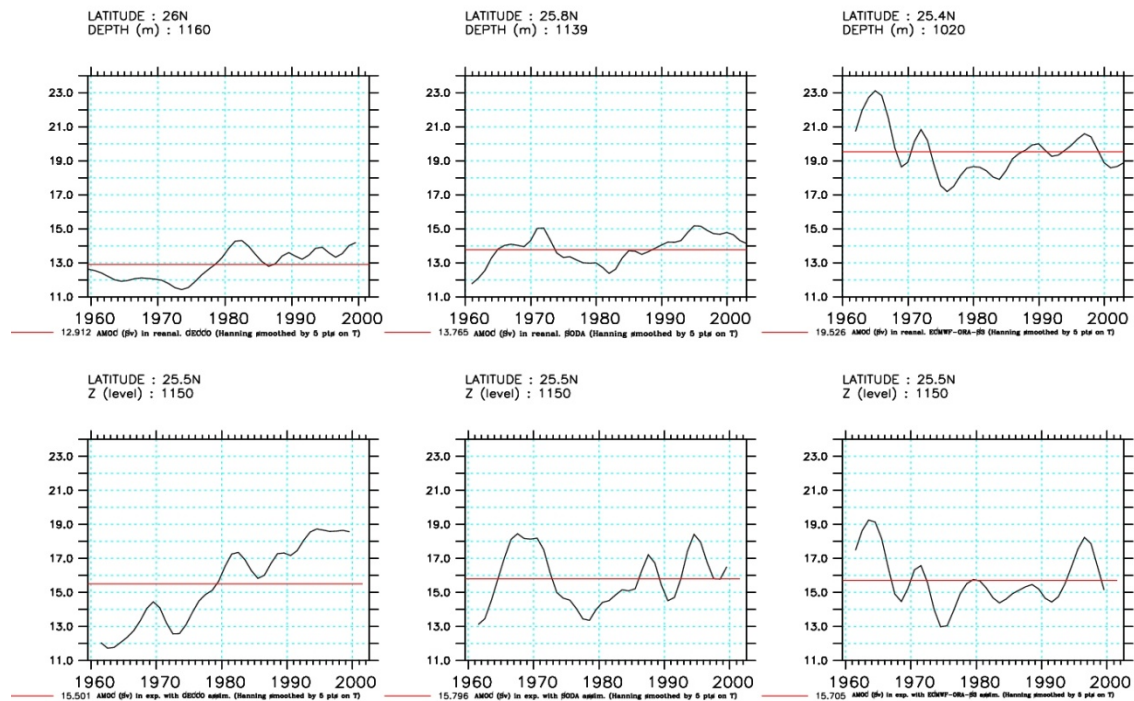


Figure 1: Long-term mean (red) and variability (black) of the Atlantic meridional overturning circulation (MOC) at 26N and 1000 m depth from (left) GECCO, (center) SODA, (right) ORA-S3: zonally-integrated flow field [Sv] in (upper) the ocean state estimates and (lower) the assimilation runs.

4. METO

METO has completed the CMIP5 hindcast experiments using both full field and anomaly initialization. These two strategies will also be compared in the latest Hadley Centre coupled model, HadGEM3. To this end, transient integrations of the 20th century using HadGEM3 have also been started.

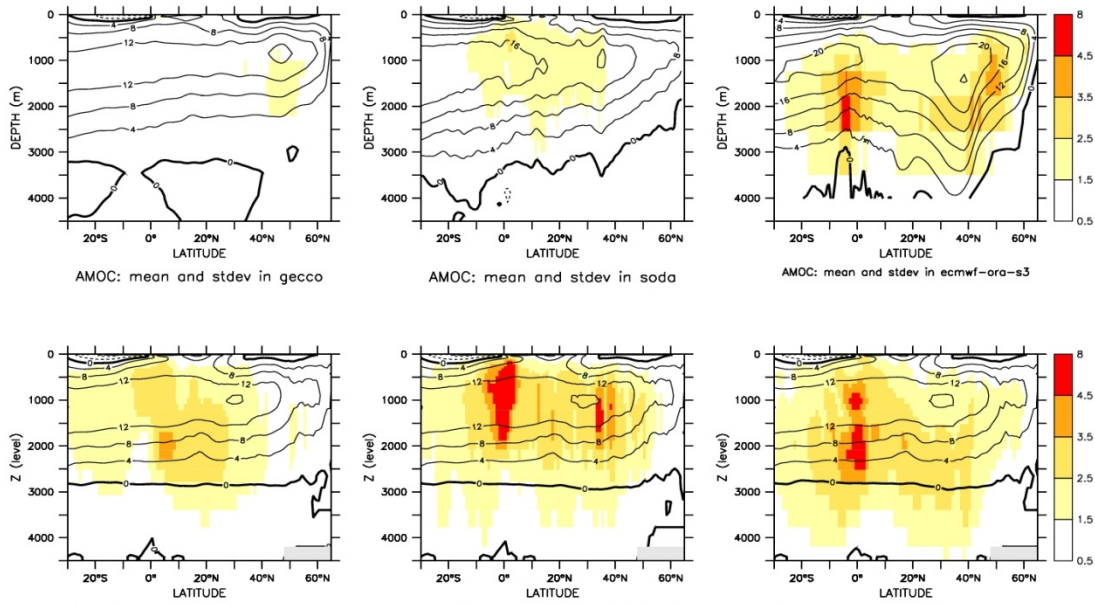


Figure 2: Long-term mean (contours) and stdev (shading) of the Atlantic meridional overturning circulation (MOC) from (left) GECCO, (center) SODA, (right) ORA-S3: zonally integrated flow field [Sv] in (upper) the ocean state estimates and (lower) the assimilation runs.

The CMIP5 hindcasts consist of 10 ensemble members starting on 1st of November every 5 years between 1960 and 2005. The hindcast experiments are generally 10 years long with an additional extension of 20 years for those starting in 1960, 1980, and 2005. The initial conditions are created by relaxing the coupled model to analyses of ocean temperature and salinity and atmospheric wind, temperature and surface pressure. The 10 ensemble members are created by randomly perturbing the SSTs with white noise. The external forcings follow the CMIP5 protocol, i.e. historical concentration of greenhouse gases and aerosol concentrations are used until 2005 and those of the RCP4.5 scenario thereafter. An uninitialized comparison (transient) experiment is performed, which employs the same model and the same external forcings and consists also of 10 ensemble members. Figure 3 shows first results for the global ensemble mean temperature. Due to model errors drift is present especially in the full-field initialized hindcasts. The drift can be corrected, a posteriori, by using a simple bias correction, leading to similar root-mean-square (rms) errors as for the anomaly initialized system. The effect of the bias correction on the correlation skill or the rms skill of the anomaly initialized system is very small (negligible). The initialization is of advantage for the surface air temperature especially for predictions with lead time of one year, but regionally the advantage is quite noisy due to the limited number of start dates (only 10). Further detailed assessment is ongoing and will be reported later.

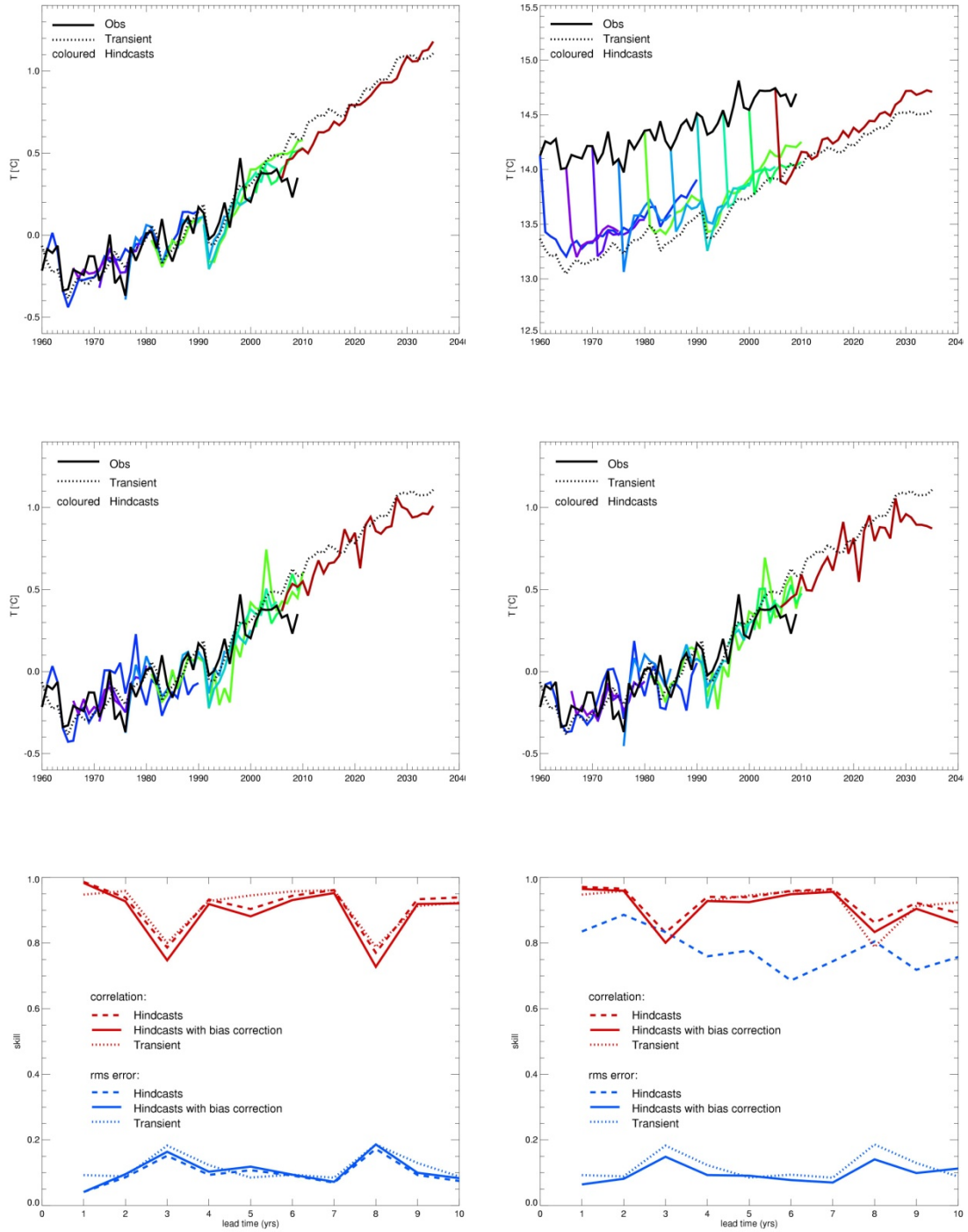


Figure 3: Time series of global mean surface air temperature from observations (black) and the ensemble means of the hindcasts (coloured with a different color for each start date) and the uninitialized experiment (black dotted) for DePreSys CMIP5 using anomaly (left) or full-field (right) initialization technique. Middle: Same as top after the bias correction. Bottom: Correlation (red) and rms-error (K, blue) prediction skill for the hindcasts (full), hindcasts with bias correction (dashed), and transient (dotted) experiments for different lead times.

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