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ENSEMBLES

Deliverable D1.9

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Due: month 34

Report on the production of OPA/NEMO analyses and initial conditions for use in seasonal to decadal Stream 2 hindcasts

1. Introduction

This report briefly describes two ocean data assimilation systems built for the OPA/NEMO general circulation model, as well as their results on the 1960-2005 period. These reanalyses were produced to provide ocean state estimates and initial conditions for the Stream 2 seasonal to decadal hindcast experiments of the ENSEMBLES project. They both use the same forcing fields, derived from ERA40, assimilate the same set of ocean temperature and salinity profiles produced for ENSEMBLES (Ingleby and Huddleston, 2007), following a similar spin up procedure defined previously for the FP5 ENACT project. Early results of ocean variability are shown for each system and a brief intercomparison of ocean heat content variability is presented at the end.

2. Ensembles of reanalyses produced by the CERFACS OPAVAR system

An incremental 3-dimensional variational assimilation system for the OPA/NEMO model (3D-VAR version of OPAVAR, OPA8-2_VAR3-0, Weaver et al., 2005) has been used to produce ensembles of ocean reanalyses over the 1960-2005 period. The incremental algorithm scheme uses one outer loop and forty inner loops. Assimilation window of 10 days was used. The observational error covariance model includes a representativeness error estimate to reduce the weight of observations collected in areas where eddy activity is important. The EN3 oceanographic data base of Ingleby and Huddleston (2007) is used in the assimilation. The 9-member ensemble of analyses is defined as follows: a non-perturbed member, four members with positive surface forcing perturbations and four with negative surface forcing perturbations. Each perturbed experiment is forced by the standard ERA40 fields plus a combination of perturbations to the following fields: SST, wind stress and freshwater flux. Some minor differences with the standard ENSEMBLES perturbations have been introduced. First, freshwater flux perturbations are applied, which can have an influence on the thermohaline circulation on decadal and longer time scales. Second, the SST perturbations are applied daily, with a de-correlation time scale of about one week. The observations were not perturbed, as initially planned, to avoid introducing instabilities in the vertical density profiles[1]. The experiments start in January 1960, and the perturbations are applied continuously to each integration. From September 2002 onwards, when ER40 terminates, ECMWF operational surface fluxes were used as forcing.

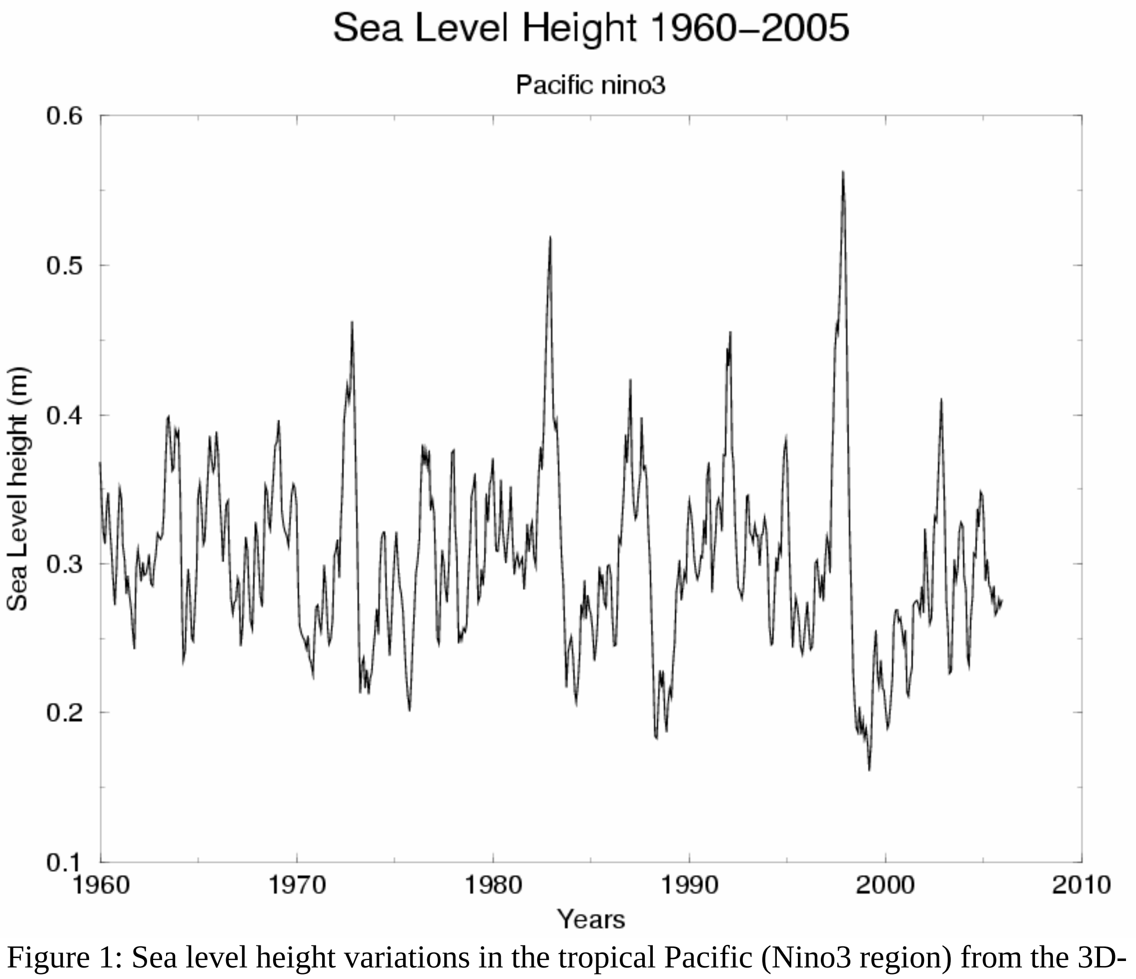

Figure 1: Sea level height variations in the tropical Pacific (Nino3 region) from the 3D-Var reanalysis

[1] More details of the way these experiments were constructed as well as a sensitivity investigation to the different sets of perturbations can be found at http://www.cerfacs.fr/globc/publication/technicalreport/2007/rapport_ensemble .

As an illustration of the results of these reanalyses we show in Figure 1 the sea level variations in the tropical “Nino3” Pacific region, indicative of ENSO intensity. We can see the series of highs and lows associated with warm and cold events. Comparison with observations from satellite altimetry from 1992 onwards is under way and will provide a useful external validation of the reanalysis.

As the system is able to provide not only one, but an ensemble of reanalyses, we present in Figure 2 a first illustration of how the ensemble spread behaves. This figure shows the mean ensemble spread, as a function of depth and latitude along the equator, over two distinct periods, before and after 1980. These two periods were chosen since the perturbations introduced in the system were computed from two different datasets (see http://www.ecmwf.int/research/EU_projects/ENSEMBLES/exp_setup/ini_perturb/index.html) to reflect the evolution of the climate observing system, and in particular the availability of satellite observations after 1980. We can see from Figure 2 that this has a significant impact on the tropical ocean initial condition spread (here, only November is shown, but the other seasons show similar results), reflecting a much more uncertain ocean state during the first period, especially at the thermocline level. Note that this higher spread before 1980 may also reflect the poorer observation coverage in the tropical oceans.

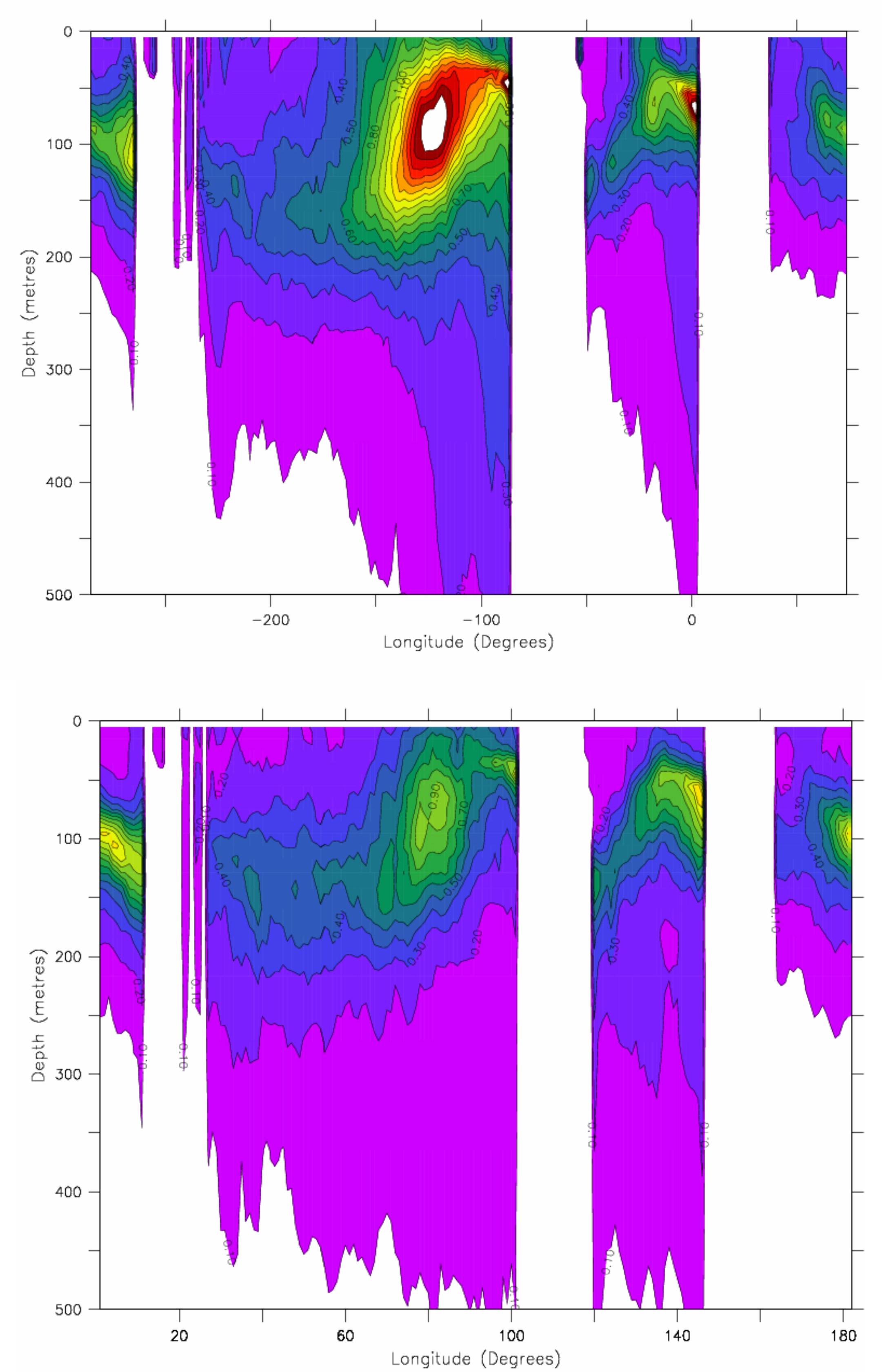

Figure 2: mean temperature spread along the equator of the 3D-Var November 1st initial conditions, for the 1960-1979 period (top panel), bottom for the 1980-2005 period (bottom panel).

3. Reanalyses using the INGV data assimilation system

The latest INGV data assimilation system implemented during the second year of ENSEMBLES has been used to update the production of global ocean analyses and extend them to the present.
Temperature and salinity profiles are taken from the EN3 package released by the MetOffice during the ENSEMBLES project (Ingleby and Huddleston, 2007). This data set covers the period 1950-2006. Due to a delay in the release of the last year of the EN3 data set, for this year only we used data taken from the CORIOLIS data centre.
A problem with SOLO, FSI Argo floats was reported on 16 Feb 2007, and in the EN3 data set these data have been rejected.
The analysis is produced using the OPA8.2 OGCM, and a Reduced Order Optimal Interpolation (ROOI) scheme for the assimilation of vertical Temperature and Salinity profiles. The ROOI scheme uses a seasonal dependent set of bi-variate T/S EOF applied at each model grid point and obtained from a forced control run (Bellucci et al., 2007).
Model setup and operating strategy are very similar to the ones used during the ENACT project. Ocean surface is forced with daily fields of heat, freshwater fluxes and wind stresses taken from ECMWF ERA40 reanalysis. From September 2002 onwards, ECMWF operational fluxes and wind stress fields are used. Temperature and salinity fields are blandly damped over the water column to the Levitus 2001 climatology, but strongly damped poleward of 60S/ 60N in order to prevent the onset of a numerical instability in the Southern Ocean. Sea surface temperatures are relaxed to Reynolds SST from 1982 onward, linearly interpolated to daily values. From January 2003 ECMWF operational SST fields are used.
Also the spin-up strategy is similar to the one previously defined for the ENACT project: 5 year run (starting from still oceans) forced with ERA40-derived climatological fluxes and wind stresses, and damped to ERA40 SST climatology and to Levitus 2001 temperature and salinity along the whole water column. Interannual daily forcing and assimilation of vertical profiles start at Jan 1958.
A global analysis covering the period 1958-2006 has been produced with this system. The updated time series of monthly mean heat content anomalies calculated over the upper 300 m and averaged globally confirms the long-term rate of ocean warming, even if after 2002 the trend seems to level off. The heat content calculated separately for the three different oceans reveals that the global warming rate after 2000 is mainly due to the Atlantic component, which also shows a similar slowdown during the most recent years. Furthermore, the time series of heat content in the three basins confirm that large part of the variability is due to interdecadal variability.

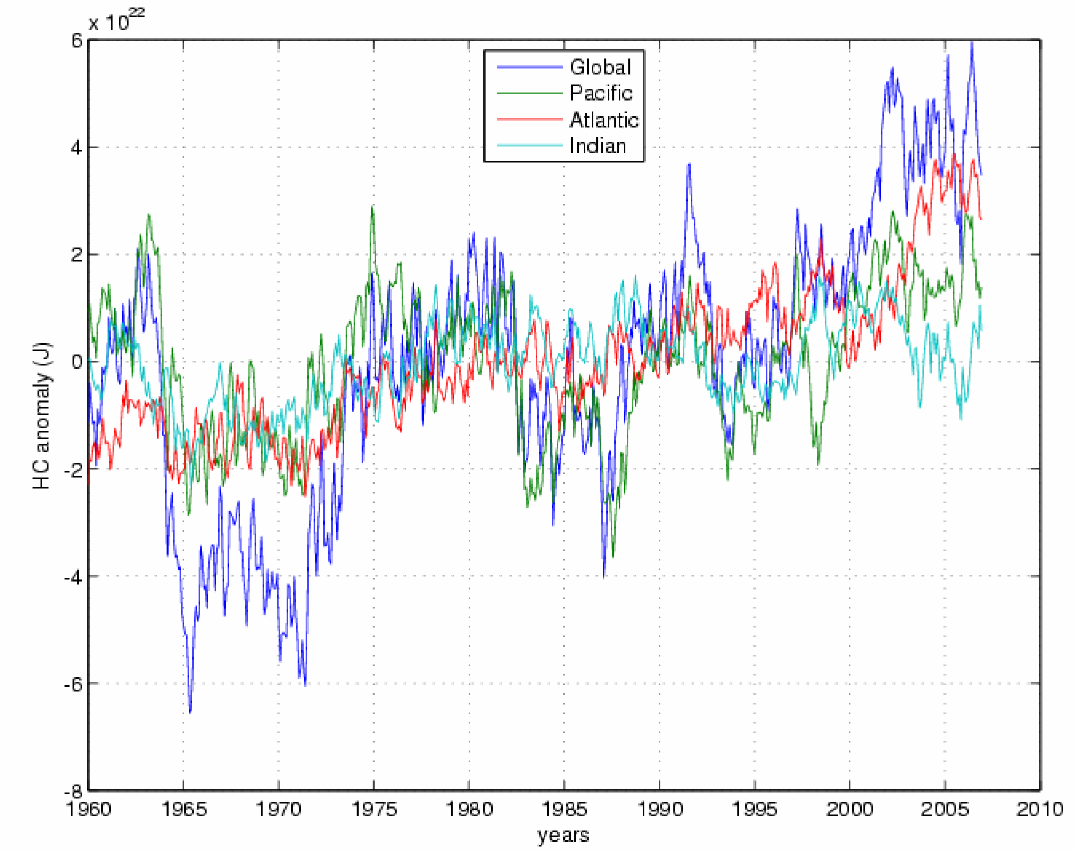

Figure 3: Heat Content anomalies (J) in different regions of the world ocean as seen by the INGV reanalysis.

4. Preliminary intercomparison of both reanalyses

As a first step towards a more complete intercomparison of both reanalyses presented above, we present in Figure 4 interannual anomalies of ocean heat content of the upper 300 meters over the 46-year period computed, for three regions (global ocean, northern hemisphere and tropical belt). It can be seen that the main features are captured by both reanalyses, and show a significant warming trend in the global ocean heat content. This can be compared to recent studies (e.g. as quoted in the chapter 5 of the fifth IPCC Assessment report; Levitus et al. 2005). The agreement is rather good between both reanalyses, even at high frequencies. At those frequencies, it seems that the CERFACS reanalyses have more pronounced peeks, which is probably due to differences in the details of the assimilation methods (e.g. background and observation error specifications). However, some lower frequency differences are obvious, and particularly the large difference between around 1981 and 1989, and in a weaker amplitude after 2000. The comparison between the three figures shows that the large difference in the eighties is located in the southern oceans. Investigations to better understand this are under way. Note also that both reanalyses clearly show a decrease of the global heat content of the oceans after 2000. This may be questionable as this is not consistent with altimeter measurements, and more precisely with estimations of thermosteric sea level variations made possible by a combination of altimeter measurements and gravity measurements (Lombard et al., 2007). Recently, problems with ARGO floats have been discovered [2], but those data are not included in the ENSEMBLES data base compiled by the Met-Office. Another possible explanation would be that climatologies used to validate and constrain models (such as Levitus) have a warm bias due to an inappropriate sampling of the ocean, especially of the southern ocean. Addressing this issue goes beyond the scope of this report. In any case, a regional validation with independent sea level data from altimetry should bring additional information.

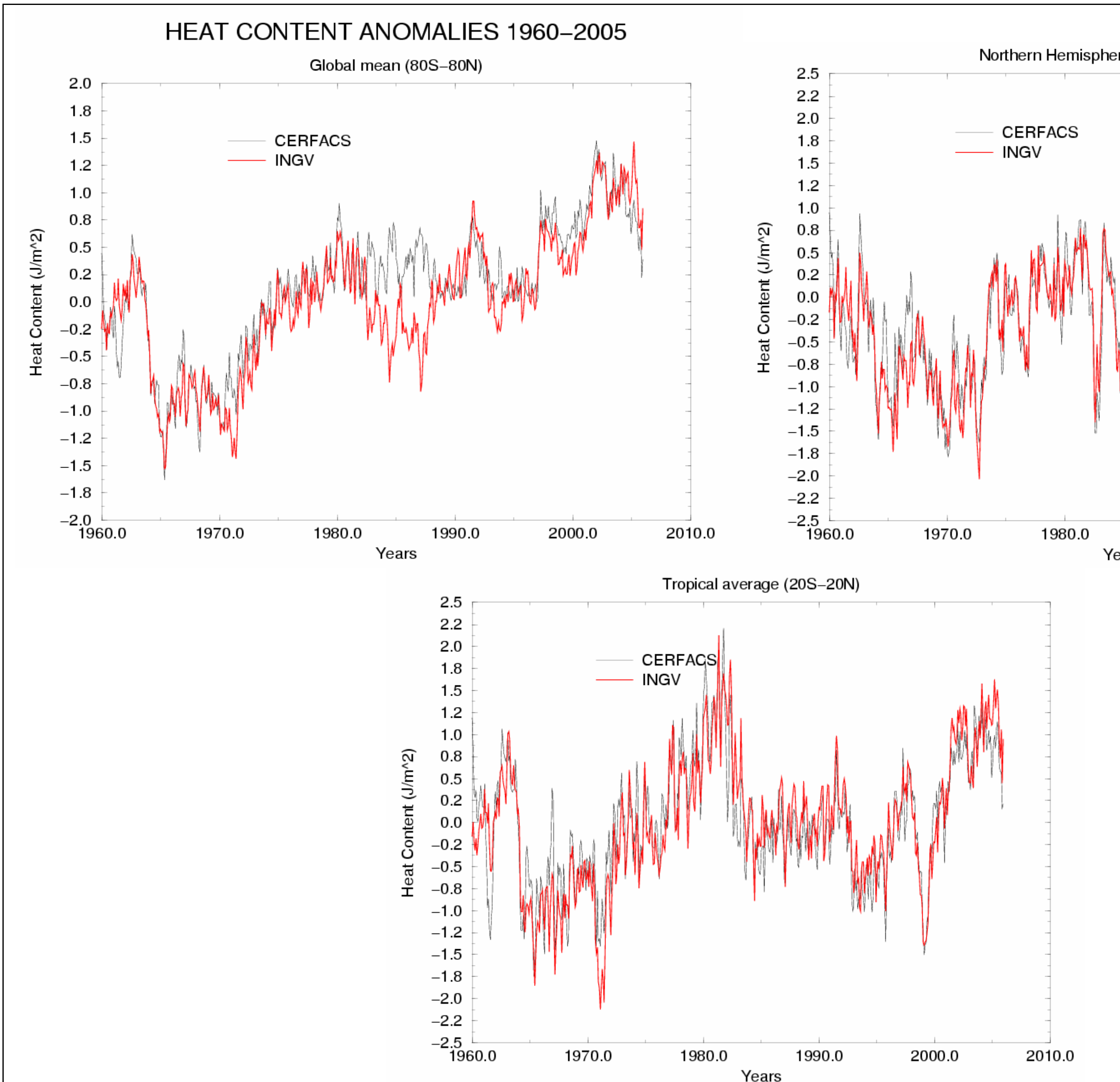

Figure 4: Comparison of the upper 300 meters heat content anomalies of both ocean reanalyses, averag middle: in the northern hemisphere; bottom: in the tropical belt.

[2] See for instance the revised version of Lyman et al., GRL, 2006 at http://oceans.pmel.noaa.gov/Pdf/heat_2006.pdf .

Conclusions

Two 46-year long (1960-2005) reanalyses have been produced for the OPA ocean general circulation model, one of which includes 8 additional perturbed members allowing to investigate uncertainties. Early results have been shown in this report, but more analyses will go on until the end of the project. In addition to the initial conditions produced for seasonal to decadal hindcasts, monthly mean variables from these reanalyses will be commonly archived at ECMWF and should constitute a useful database for ocean and climate variability research.

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