ASSESSING THE REALISM OF OCEAN SIMULATIONS AGAINST HYDROGRAPHY AND ALTIMETRY

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Introduction

Future climate prediction systems will include ocean models at eddy-admitting to eddy-resolving resolution, i.e. ¼° on the horizontal or finer. The development and calibration of such models requires the use of more accurate numerical schemes, and the improvement of physical subgrid-scale parameterizations for the ocean interior and its boundaries, including air-sea interactions that drive the global ocean circulation and its feedbacks to the atmosphere. The DRAKKAR consortium is developing a hierarchy of basin-scale to global ocean models (Barnier et al, this issue) to simulate and study the ocean variability driven by realistic atmospheric conditions over the last 50 years without data assimilation. These oceanic hindcasts should help understand the nonlinear interactions between fine scale processes and large-scale ocean dynamics, better interpret and take advantage of satellite and in situ observations (see Penduff et al, 2006, for an overview). However, numerical simulations require quantitative model-observation mismatch evaluations to guide dynamical studies and further model improvements, and careful dynamical assessments

This paper presents an assessment method of model solutions against two complementary datasets: the ENACT-ENSEMBLES hydrographic profile database[1] which covers the period 1956-present and includes 7.4 million temperature/salinity (T/S) reports from hydrographic sections, moored arrays, floats, ARGO and XBT observations; and the Ssalto/Duacs multimission Sea Level Anomaly (SLA) weekly maps from altimeter measurements[2] available since 1993. DRAKKAR models simulate the evolution since the late 1950's of T, S, velocity, sea-surface height (SSH), sea-ice characteristics, and oceanic concentrations of two tracers (CFC11, ^{14}C) released in the atmosphere over that period. These variables are stored as successive 5-day averages during the integrations. Dynamical outputs are then collocated with real observations for comparison purposes. This paper focuses on the 1958-2004 global ¼° ORCA025-G70 simulation (Barnier et al, this issue), and its 2°-resolution counterpart driven by the same surface forcing.

Data preprocessing

The collocation procedure linearly interpolates model T/S fields at the geographical locations, depths, and instants when real T/S profiles where collected. Only quality-checked (unflagged) observations are considered. Model profiles are stored in the same format as observed ones to facilitate their dissemination. Collocated profiles are then processed jointly to characterize the structure of T/S model biases in space and time. Model SSH fields are interpolated as observed SLA maps, i.e. weekly and on a 1/3x1/3° Mercator grid, from 1993 to 2004. Collocated SLA databases are obtained by masking them where and when (either real or simulated) sea-ice is present, by removing at each grid point their respective 1993-1999 mean, and by removing their global spatial average every week. Lanczos filters may then be applied to split collocated SLA fields (and thus evaluate the model skill) into distinct wavenumber-frequency ranges. We focus here on the interannual SLA variability, i.e. with timescales longer than 18 months.

Upper ocean heat and salt contents

The upper ocean, which varies and interacts with the atmosphere on a wide range of time and space scales, requires a dedicated assessment in terms of heat and salt content (HC and SC). Each color dot in Figure A shows, for the 50-450m layer and the period 1998-2004, a collocated bias (¼° global simulation minus ARGO) of HC and SC. A cold fresh bias, whose median reaches -3°C at 250m and -0.5 psu at the surface, can be seen north of the simulated North Atlantic Current. Indeed, this current progressively tends to block over the Mid-Atlantic Ridge, like in many models at this resolution, and lets cold and fresh subpolar waters invade the region off the Grand Banks. Two other shifts are revealed in the Antarctic Circumpolar Current (ACC), which locally departs from its observed route near 45° and near 90°E. Another significant T/S bias (reaching +2°C and +0.2 psu at 200m), not fully understood yet and subject to present investigations, is revealed in the Kuroshio region. The warm and salty bias visible in the northwestern Indian Ocean is due to a spurious mixing of the Red Sea overflow; our present work on bottom boundary layer parameterizations will hopefully reduce it. The DRAKKAR group is also working on improving the surface forcing function to limit the warm and salty equatorial bias seen in the tropical Indian and Atlantic basins. Over the rest of the global ocean, collocated model and ARGO profiles show smaller biases after several decades of integration.

The black and green lines in Figure B illustrate in the Sargasso Sea how ARGO is being used to assess the mixed layer annual cycle simulated at ¼° resolution, in terms of monthly heat content (MLHC), depth (MLD), and temperature (MLT). The median MLHC simulated there over 1998-2004 appears overestimated

[1] http://www.mersea.eu.org/Insitu-Obs/1-Insitu-Data-ENACT.html

[2] http://www.aviso.oceanobs.com/html/donnees/welcome_uk.html

between November and April, by up to a factor of 2 in winter. The lower panels show that this substantial bias is due to a winter MLD that is twice as deep as observed, and not to a warm bias (ARGO and simulated MLTs are almost identical). This approach also helps evaluate hydrographic sampling errors: our results shows that, in this region, ARGO accurately samples the distributions (median, percentiles) of monthly MLHC, MLD and MLT: blue lines (full model) and black lines (subsampled model) are remarkably similar. Hydrographic sampling error evaluation and model-observation intercomparisons are presently being extended at global scale.

Sea level interannual variability

The 2° and ¼° DRAKKAR simulations are assessed in terms of interannual SLA variability (ISV) after collocation onto altimetric maps. Because the 2° grid is refined meridionally to 1/3° at low latitudes, both models simulate the ISV observed there with realistic and comparable amplitudes (Figure C). At higher latitudes, the ISV magnitude gets more realistic at ¼° resolution, especially in the eddy-active Gulf Stream (GS), North Atlantic Current and ACC (both shifted as mentioned), Kuroshio, and Agulhas region. A space-time analysis of the ISV is shown for the GS region in Figure D. SLA fields from both simulations are projected on the 1st EOF of the observed ISV in this area. Its spatial structure $\mathbf{E_o}$ and associated principal component $\mathbf{P_o}$ show that the GS latitude follows the NAO index in the real ocean with a 9-month lag (right panel). The ¼° model represents 19% of this mode's variance, which is modest but much greater than in the 2° model (2%). Moreover, the ¼° model captures much better the delay between the NAO forcing and the GS's response (7.8 months instead of 3.2 months at 2° resolution), yielding a better correlation with the observed ISV (0.59 instead of 0.49). Investigations of this kind are being extended to other key areas and basins of the World Ocean.

Conclusion

This quick overview of our "collocated" assessment approach has highlighted certain strengths and weaknesses of 50-year DRAKKAR simulations with respect to complementary (and recent) observations. More complete assessments are underway in other regions, depths and time ranges, and should contribute to guide model improvements. Our next multi-decadal climate-oriented simulations will be compared against the same observational databases, to precisely quantify the model sensitivities (e.g. time-mean state, various modes of variability, drifts) to thermal and mechanical surface fluxes, to resolved physical processes (e.g. mesoscale turbulence, nonlinearities, scale interactions, etc.), and to numerical choices (e.g. resolution, schemes, parameterization of non-hydrostatic, mixing or diffusive processes). These tools can also help evaluate existing or future ocean observing systems in terms of sampling errors, and strengthen the link between the observational and numerical oceanographic communities. Ocean observations, especially prior to the recent ARGO-plus-altimeter "golden age", are both rare with respect to typical scales of motion (the Rossby radius) and dispersed in time and space. On the statistical side, model-observation mismatches can always be computed, but estimating the robustness or significance of these skills may be difficult. Besides the extension of our evaluations to various regions, timescales, periods and depth ranges, advantage should thus progressively be also taken of complementary observational datasets (e.g. satellite SSTs, current meters, tide gauges, lagrangian trajectories, etc).

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References

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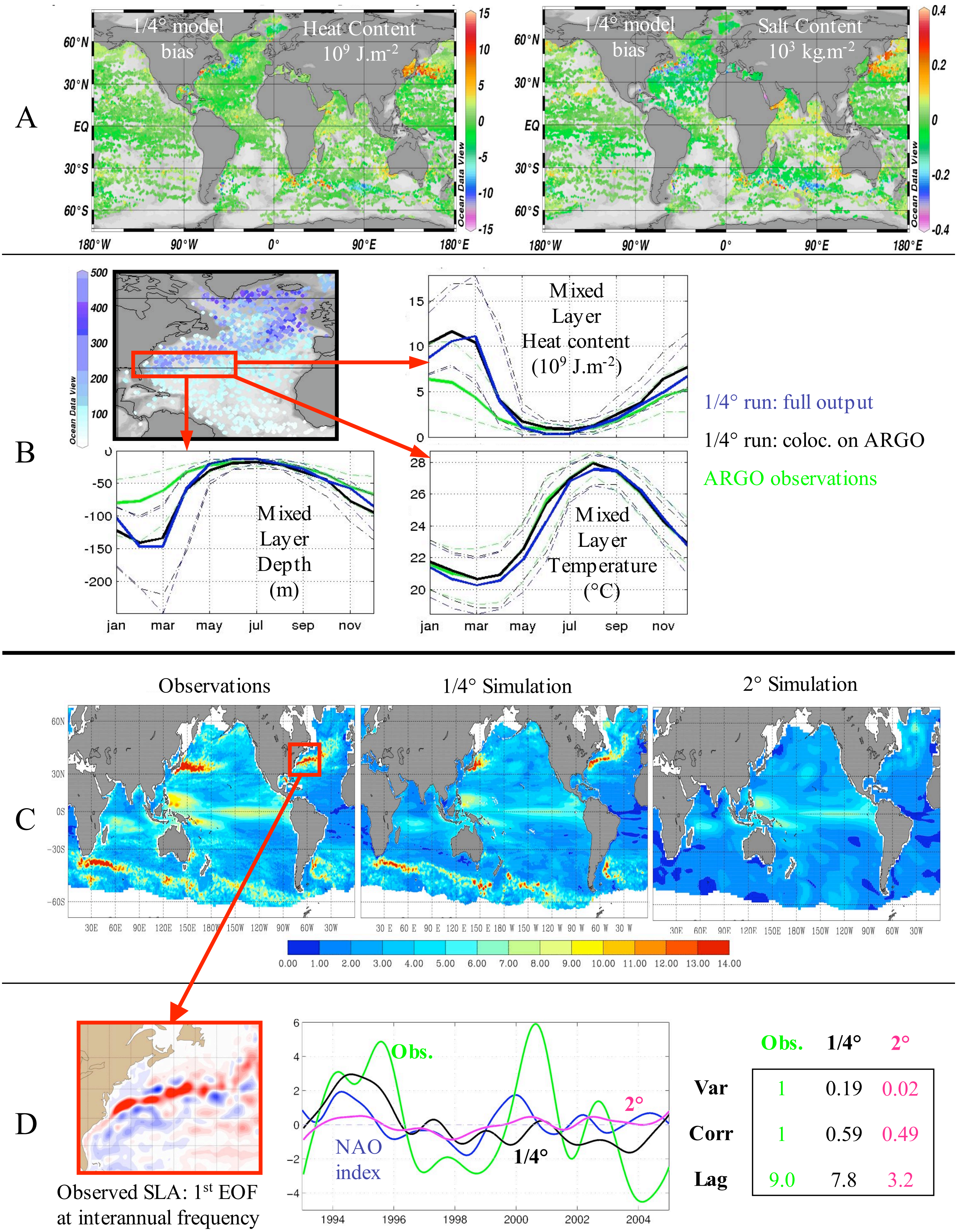
Figure A. Mixed layer heat and salt content biases from the ¼° simulation collocated with ARGO profiles over 1998-2004. Each color dot quantifies a synoptic model bias.

Figure B. Top left: Local mixed layer depth (MLD) estimates from ARGO in February (1998-2004). The MLD corresponds to a 0.2°C temperature change (Montegut et al, 2004). Other panels: Monthly mixed layer statistics (heat content in 10^9 J/m^2, depth in m, temperature in °C) over 1998-2004 in the Sargasso Sea from the full ¼° simulation (blue), ARGO (green), and the model collocated with ARGO (black). Medians (thick lines) and 17%/83% percentiles (dashed) characterize monthly distributions.

Figure C. 1993-2004 standard deviations (cm) of observed and simulated low-frequency (LF) SLAs.

Figure D. Left: normalized 1st EOF $\mathbf{E_o(x,y)}$ of the observed LF SLA in the Gulf Stream region. Center: Principal component $\mathbf{P_o(t)}$ in cm associated with $\mathbf{E_o}$ (green), low-passed filtered NAO index $\mathbf{N(t)}$ (blue), projection of simulated SLAs on $\mathbf{E_o}$ ($\mathbf{P_{1/4}(t)}$ in black for the ¼° model, $\mathbf{P_2(t)}$ in magenta for the 2° model). Right panel: variances of $\mathbf{P_o}$, $\mathbf{P_{1/4}}$, and $\mathbf{P_2}$ scaled by the variance of $\mathbf{P_o}$ (line 1). Correlation of $\mathbf{P_o}$, $\mathbf{P_{1/4}}$, and $\mathbf{P_2}$ with $\mathbf{P_o}$ (line 2). Lag between $\mathbf{N}$ and $\mathbf{P_o}$, $\mathbf{P_{1/4}}$, $\mathbf{P_2}$ in months (line 3).


A
1/4° model bias
Heat Content
10^9 J.m^{-2}
1/4° model bias
Salt Content
10^3 kg.m^{-2}
60°N
30°N
EQ
30°S
60°S
180°W
90°W
0°
90°E
180°E
Ocean Data View
B
Mixed Layer Heat content (10^9 J.m^{-2})
Mixed Layer Depth (m)
Mixed Layer Temperature (°C)
jan
mar
may
jul
sep
nov
1/4° run: full output
1/4° run: coloc. on ARGO
ARGO observations
C
Observations
1/4° Simulation
2° Simulation
0.00 1.00 2.00 3.00 4.00 5.00 6.00 7.00 8.00 9.00 10.00 11.00 12.00 13.00 14.00
D
Observed SLA: 1st EOF at interannual frequency
Obs.
NAO index
1/4°
2°
1994
1996
1998
2000
2002
2004
Obs. 1/4° 2°
Var 1 0.19 0.02
Corr 1 0.59 0.49
Lag 9.0 7.8 3.2