1999

Scientific development of a massively parallel ocean climate model

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https://hdl.handle.net/10945/52657

FINAL REPORT ON CHAMMP-SUPPORTED RESEARCH (9/1/94 - 2/28/98) DE-AI03-94ER61928
"Scientific Development of a Massively Parallel Ocean Climate Model"
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Research activities are grouped in fifteen categories and summarized below:

1. Exploration of global ocean circulation at 1/2-degree on vector computers

By exploiting the power of the multi-processor CRAY Y-MP/8, it was possible to represent global ocean circulation at length scales close to the Rossby radius of deformation for the first time. A series of decadal calculations explored the effects of progressive improvements in surface atmospheric conditions using observed winds from analyses of the European Centre for Medium-range Weather Forecasts (ECMWF). Relevant publications include McCann et al. (1994) and Chervin et al. (1997).

2. Algorithmic improvement of the Parallel Ocean Climate Model (POCM)

Interactions with Los Alamos modellers Smith, Dukowicz, and Malone brought to our attention model improvements in the forms of pressure averaging, reduced diffusion at high latitude, and a somewhat more accurate equation of state. The POCM configuration is algorithmically comparable to the model developed at Los Alamos National Laboaratory (LANL); but it is more conserving of memory, particularly if SSD is available. It continues to be more efficient on parallel-vector machines than other models derived from the Modular Ocean Model, which is widely applied to climate problems.

3. Global simulations of 1987-96 with 1/4-degree grid spacing, unsmoothed bathymetry, high-frequency ECMWF winds, and ECMWF heat fluxes

Limited memory of CRAY Y-MP machines at the National Center for Atmospheric Research (NCAR) dictated using a 1/4-degree grid on a latitudinal average (along with 20 levels). Smoothing of bathymetry was not needed for stability, and geometry was specified quite accurately. ECMWF wind stresses were obtained from Anthony Craig at NCAR; and ECMWF heat fluxes came from Bernard Barnier in Grenoble. A simulation of the period 1987-94 was reported in Semtner (1995) and Stammer et al. (1996).

4. Collaboration with Los Alamos on eddy-resolving global simulations of 1985-95 using the Parallel ocean Program (POP).

Beginning in 1993, Smith and Malone (and later Maltrud) of Los Alamos undertook massively parallel simulations with POP on a CM-5. Collaboration consisted in jointly planning the experiments, providing bathymetry, wind stress, heat flux, and initial conditions, and jointly examining the output of the simulations. A grid spacing of 1/6-degree (averaged between latitudes 77 S and 77 N) was possible. Early results were reported by Semtner (1995); and comprehensive results are found in Maltrud et al. (1997).

5. Detailed comparison of model output with satellite and in-situ data

NPS personnel evaluated the models against observations, using the 1/4- and 1/6-degree results and often collaborating with observationalists. Robin Tokmakian and Julie McClean conducted comparisons with TOPEX altimeter data, WOCE hydrography, surface drifter data, and low frequency tidal records. These can be found in Stammer et al. (1996), Tokmakian (1996), Ramp et al. (1997), McClean et al. (1997), McClean and Semtner (1996), and Gordon and McClean (1997). The papers demonstrate that ocean models can now reproduce the detailed time variations that are observed, as well as depicting eddy effects and boundary transports at their observed length scales and with magnitudes only slightly smaller than observed.

6. Development of a stand-alone Arctic ocean model in POCM and POP forms

DISCLAIMER

DISCLAIMER

Wieslaw Maslowski came to NPS in 1994 as a NOAA Global Change Postdoc with Arctic modeling expertise (Maslowski, 1996). He and a PhD student, LCDR Rost Parsons, built a high-resolution POCM-based model of the Arctic Ocean and subpolar North Atlantic, in order to complete the global domain relative to earlier modeling studies. The new model has 18-km grid spacing and 30-levels; and it can smoothly join to near-global models at the equator or simply overlap them in a portion of the North Atlantic. The model has been validated on both regional and local spatial scales (Parsons, 1995; Maslowski et al., 1997a,b). Also, Maslowski collaborated with Craig of NCAR to produce a version for massively parallel machines using POP.

7. Implementation of a sea-ice model and coupling to the POCM Arctic and the 1/4-degree global ocean models for 1990-94 simulation studies

Yuxia Zhang also came to NPS in 1994 as a NOAA Global Change Postdoc with experience in sea-ice modeling and interests in coupled climate modeling. Using efficient Hibler ice dynamics, she produced an 18-km ice model with thermodynamics as well. She conducted stand-alone tests with ECMWF atmospheric forcing, and joontly with Maslowski, coupled the sea ice model to the ocean model for simulations of 1990-94. These exhibited many features found in recent observations, resulting from the high resolution and ocean-ice interactions, as described in Semtner (1996) and Zhang et al. (1997a,b). Also, Zhang joined southern hemisphere ice to the 1/4-degree near-global ocean and ran it with 1990-94 ECMWF forcing (Semtner, 1997a).

8. 100-year parallel simulation of Arctic ocean and sea-ice circulation

Maslowski, Zhang, and Craig collaborated to produce a coupled ice-ocean model for the massively parallel T3D at the Arctic Region Supercomputing Center. In addition, eight tracers were introduced at river inflow sites into the Arctic, in order to be able to understand the overall freshwater balance of the Arctic. A century-long integration is complete (Maslowski, 1997).

9. Testing of new physics (modified forcing, deep convection, mixed layer)

Better physical treatments continue to be implemented in NPS modeling studies. Methods of specifying wind stresses and preprocessing history files to minimize the aliasing of high-frequency inertial waves have been explored by Jayne and Tokmakian (1997). Surface boundary conditions on bouyancy are being better specified through efforts by Zhang. Methods of deep convection are being implemented via collaboration with Terri Paluszkiewicz and Eric Skyllingstad of Pacific Northwest Laboratories. A Kraus-Turner mixed-layer model has been implemented by Semtner in the 1/4-deg. model. Finally, the Cox-Redi isopycnal mixing tensor is installed, if future applications should require a sub-grid scale closure scheme based on isopycnal mixing and third-order advection.

10. Participation in the development of a massively parallel climate model (with Warren Washington's group at NCAR), especially regarding sea ice

An objective of the NPS research for 1994-97 was to participate in the construction of a coupled model of the atmosphere, ocean, and sea ice for use on massively parallel computers. Given the availability of POP and the parallelization of the Community Climate Model Version 3 (CCM-3), the missing component of ice was supplied by Yuxia Zhang at NPS and Anthony Craig at NCAR. Collaborative visits between NPS and NCAR led to the formulation of appropriate coupling strategies to be used in single partitions of CRAY machines. Over fifteen months, the model was brought to full production status by the group effort. This is the first global parallel climate model to our knowledge -- and one with sufficiently high resolution in both atmosphere (T42) and ocean (2/3-degree) to portray climate states and climate variability with greater accuracy than previously possible.

11. Extensive distribution of ocean output to an international user base

Oceanographers believe global high-resolution simulations are of sufficient interest and value to many scientists that the results of the calculations should be made widely available. This has guided the NPS approach; and through the efforts of Robin Tokmakian, many research groups had obtained the model output by 1994. New users have continued to materialize in subsequent years, and many published papers have resulted.

12. Participating in (sometimes organizing) modeling workshops/meetings

Members of the NPS project participated in numerous working groups, workshops, symposia, and forums. To name only a few: a workshop in September 1994 for the International WOCE Numerical Experimentation Group was organized at LANL by Semtner. McClean organized a session on model/data comparisons at the 1996 Ocean Sciences Meeting. Maslowski served as host for a 1996 Arctic modeling meeting. Service to DOE included NPS participation in a Review of Large Computational Projects in 1994.

13. Communication of results of simulations not only by means of published papers but also through video and Web animations, distributed worldwide

Global ocean simulations with resolved turbulence produce massive amounts of material that can be easily appreciated through animation techniques. Michael McCann, Shirley Isakari, and Peter Braccio produced videotapes of 1/2-degree, 1/4-degree, and 1/6-degree (POP) results in both NTSC and international PAL formats. Hundreds of tapes have been distributed, mainly in response to specific requests. Many animations and selected output files are available on the Web at sites vislab-www.nps.navy.mil/~braccio and vislab-www.nps.navy.mil/~rtt , which are mirrored in Europe at no cost.

14. Resource leveraging through complementary funding from other sources

The NPS project has been successful in obtaining funding from multiple sources in order to conduct various complementary studies of global ocean circulation. Leveraging has also occurred from an NCAR/University computing pool, from the Arctic Region Supercomputing Center at the University of Alaska, and from the Climate Simulation Laboratory (CSL) at NCAR. Little DOE direct computing support has been required except in collaboration with LANL scientists on 1/6-degree global modeling.

15. Construction of a fully global ocean and ice model for studies of ocean circulation and decadal variability using ECMWF reanalyzed data

The latest allocation of computer time to NPS from the CSL allows multidecadal integrations to be run on a CRAY C-90 machine. Still taking advantage of solid-state-disk message passing to minimize memory and maximize computational efficiency, the Arctic and 1/4-degree global models have been run with continual exchanges of lateral boundary information in the region of overlap (the subpolar North Atlantic). The ice models from both the Arctic and Antarctic are included, making this a fully global ocean-ice model for climate-related simulations. Data from the ECMWF reanalysis project are available at NCAR for the years 1979-93; and together with the operational analyses of 1993-96, eighteen years of forcing data are being used in ensembles of experiments.

In summary, the NPS CHAMMP project has advanced numerical modeling of ocean circulation in a climate context by developing models with improved numerics, physics, extent, and resolution. Simulations with increasingly realistic atmospheric forcing of 1985-96 provide invaluable records for analysis, interpretation, and distribution, which have facilitated many scientific discoveries and further model improvements. New understanding of the thermohaline circulation and of many types of oceanic variability are paving the way for future research on decade to century time scales, in order to quantify climate predictability and anticipate climatic changes.

NPS PUBLICATIONS RELATED TO CHAMMP

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Semtner, A.J., 1997b: Very high-resolution estimates of global ocean circulation, suitable for carbon-cycle modeling. Proceedings of the 1993 Snowmass Global Change Institute on the Global Carbon Cycle, Ed: T. Wigley. Cambridge University Press, United Kingdom, in press.

Stammer, D., R. Tokmakian, A. J. Semtner, and C. Wunsch, 1996: How well does a 1/4 degree global circulation model simulate large-scale oceanic observations? J. Geophys. Res., 101, 25779-25811.

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Zhang, Y., W. Maslowski, and A.J. Semtner, 1997b: High-resolution Arctic Ocean and sea ice simulations: Part II, Ice model and early coupled results. J. Geophys. Res., submitted.

Most recent products delivered:

Stammer, D., R. Tokmakian, A. J. Semtner, and C. Wunsch, 1996: How well does a 1/4 degree global circulation model simulate large-scale oceanic observations? J. Geophys. Res., 101, 25779-25811.

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Zhang, Y., W. Maslowski, and A.J. Semtner, 1997: High-resolution Arctic Ocean and sea ice simulations: Part II, Ice model and early coupled results. J. Geophys. Res., submitted.

Most recent notes concerning the project:

Final report is included in the section above for progress reports, including publications.

Other Project Information Sources:

Project URL

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