Implementation Plan for the Hybrid Ocean Modeling Environment HOME

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1. Executive Summary

Recent advances in simulating the ocean through the use of generalized hybrid coordinate modeling techniques have led to a modest proliferation of such models (HIM, HYCOM, HYPOP, Poseidon, and POSUM, among others). These models exploit certain inherent properties of nearly adiabatic flow in the interior of the ocean while attempting to seamlessly transform to more appropriate coordinates near boundaries and in other special regions of interest, such as the coastal zones. While the separate models have made significant advances by exploiting advanced numerical techniques and enhanced physical parameterizations in different ways, it has become apparent that the intellectual diversity fostered through these several efforts is not easily captured or shared to improve models across the board.

HOME will develop a new ocean modeling environment for generalized, hybrid, vertical coordinate models. HOME will:

Accelerate the improvement of ocean models by

- Unifying the nation's existing isopycnic and hybrid ocean models into a single common code base, based on powerful frameworks such as ESMF. This code base will permit diversity while developing a common language and mechanism for absorbing novel methodologies.
- Exploring the merits of different approaches to representing important ocean dynamics within the generalized vertical coordinate context, leading to best practice recommendations.
- Assessing the prospects for a larger unification of ocean models, including the use of common algorithms for applications that currently utilize geopotential or sigma coordinates.
- Engaging the wider ocean modeling community to collaborate and assist with the examination and development of best practices.

Provide a consolidation of models and a path toward a longer-term vision of ocean modeling, including

- Stable, maintainable, production-level code for robust applications using the generalized hybrid coordinates.
- A single taxonomy and semantic framework for users and developers.
- A framework that may evolve to accept novel numerical descriptions of ocean dynamics.
- A single framework for interfacing with biology, geochemical, or other Earth system models.

HOME will provide dramatically more user- and developer-friendly models and will be an indispensable staging point toward a longer-term vision of ocean modeling.

This implementation plan lays out the rationale and vision for HOME and details how it can be developed within a 3-year timescale with an annual budget of roughly $1.5 million, presumably to be distributed among the 5 federal agencies with significant interests in furthering the nation’s ocean modeling capabilities.

2. Introduction

Ocean circulation models are essential tools for understanding, assessing and predicting the global oceans, their role in climate and the Earth system. Much of the uncertainty associated with the prediction of climate can be ascribed to an imperfect knowledge of the oceans and their mechanisms for mitigating or exacerbating changes in the atmosphere and cryosphere. The oceans operate in the climate system to transfer information (heat, salt, chemical constituents) over large distances and long times. Skillful models of the ocean circulation need to transport and preserve these properties correctly. Short-term ocean predictions rely both on the ability to initialize a model to agree with observed conditions, and on the ability of that model to accurately propagate the ocean's state. There is undeniable value in using the same model for prediction as is widely used for long-term simulation and study of the ocean circulation, because it enables each effort to leverage the development and understanding derived from the others.

Ocean model development has a long history of being primarily the fruit of individual efforts, rather than a cohesive community effort. While this was appropriate for a previous era when ocean modeling was a smaller enterprise and computer architectures were very heterogeneous, the limitations of this approach are increasingly apparent. This traditional mode of development has led to a great difficulty in evolving ocean models to more proficiently capture the fundamental aspects of the ocean dynamics. Intercomparison has been largely restricted to whole models, and interchange of specific capabilities has been slow and limited to those instances where the benefits are abundantly obvious. Shockingly, potentially valuable ocean modeling capabilities have been lost when primary developers left the field (e.g., J. Oberhuber's OPYC) or in the transition between computer architectures (e.g., the NCAR Ocean Model). This mode of development is no longer viable in an era when increasingly diverse demands are being placed upon ocean models. The time has come for the development of ocean modeling capabilities to become a coherent community effort. In the near term, a consolidation and evaluation of the diverse range of existing practice will be of tremendous value, while in the longer term the community must systematically explore promising options for extending the skill and applicability of our ocean models.

Generalized hybrid vertical coordinate ocean models are currently used for an increasingly diverse suite of applications, from high resolution now-casting and short-term prediction of the regional ocean state, to global tidal simulations, to ENSO forecasting, to multi-century climate simulations, to theoretical studies of the ocean's dynamics. The various individual decisions to use this class of model were made independently, based on its inherent strengths.

There is now general agreement among ocean modelers that generalized vertical coordinates are desirable for skillful simulations of the ocean (Griffies et al., 2000a). There are well known deficiencies of each of the commonly used vertical coordinates – excessive spurious mixing with sigma- and geopotential-coordinates; lack of resolution and difficulties with the nonlinear equation of state in very weakly stratified interior regions with isopycnal coordinates; pressure gradient errors with sigma-coordinates; and difficulties representing downslope bottom flows with geopotential coordinates. The appropriate generalized vertical coordinate ocean model would minimize each of these liabilities, while providing the flexibility to tailor the model to the specific application.

Vertically Lagrangian solution techniques are well established in the ocean for using an isopycnic vertical coordinate (e.g. Bleck and Smith, 1990, Oberhuber 1993). This combination is uniquely able to avoid spurious diapycnal mixing, even in the limit of geostrophic turbulence

(Griffies et al., 2000b) – a critical consideration given the extremely adiabatic nature of the interior ocean and the long timescales upon which the ocean circulation evolves. Isopycnal coordinates are also uniquely valuable for simulating the ocean because both the continuous and vertically discrete forms exactly exhibit the potential vorticity dynamics that are thought to govern the large-scale inviscid and adiabatic ocean circulation[1]. In addition, these techniques have been combined with the ALE (Arbitrary Lagrangian-Eulerian) technique (Hirt et al., 1974, Margolin, 1997) to produce hybrid vertical coordinate models (Schopf and Loughe, 1995, Bleck, 2002). In the atmosphere, essentially the same techniques have proven highly skillful in a range of simulations that include terrain-following (sigma-) coordinates (Lin, 2004) and in operational predictions (Bleck & Benjamin, 1993). The Lagrangian vertical coordinate approach should be able to emulate the (non-ALE) hybrid depth-sigma coordinates, the hybrid density-pressure coordinates, or any one of the single coordinates in wide use, but should also go beyond these specific choices to enable the use of a truly general vertical coordinate. A vertically Lagrangian formalism would thus appear to be the most promising avenue for the development of a flexible, state-of-the-art community ocean modeling environment.

This recognition calls for the development of HOME: a **versatile, open-source, community Ocean Modeling Environment using a generalized hybrid vertical coordinate and Lagrangian solution techniques**. The HOME development effort must also identify and refine best practices or describe trade-offs between alternatives for simulating a range of important ocean processes. The outcome of the HOME development effort would not be a single ocean model, but rather a community collection of ocean modeling code and algorithms from which optimal ocean models for specific applications can be constructed, along with a systematic effort to evaluate the various options. HOME will replace five existing hybrid ocean modeling codes with a single code-base.

2.1. WHAT ARE THE ADVANTAGES OF THIS APPROACH?

The development of HOME presents several outstanding opportunities for research, applications and education. The key benefits can be summed up as

- Community Cohesion
- Ingenuity
- Technology
- Flexibility
- Education

Community Cohesion

The advantages of a vertically Lagrangian formalism have led several groups to develop what have turned out to be similar models for the ocean circulation. While coming from various applications and differing roots, these models have more commonality than difference. An active community of investigators meets regularly to share concepts and results, and experience with one model is sometimes carried forth to other codes. However, it has become apparent that too much time is being spent by each group on mundane, replicated and redundant coding, and that the benefits of collaboration far outweigh those of code "ownership". Sharing a common Ocean Modeling Environment will minimize the model development overhead, maximize the usability, and provide a means for harnessing the individual talents of the scientific community on the problem areas each is best suited to address.

[1] Of course, with the ocean's nonlinear equation of state, there is no materially conserved quantity like potential vorticity. Despite this fact, it is still extremely valuable to use a numerical representation of the ocean that would conserve potential vorticity if the equation of state were simpler, as the approximate conservation of potential vorticity provides a powerful constraint on the ocean circulation on timescales of minutes to decades.

Sharing a common modeling environment is only possible in a community with a strong foundation of trust and mutual respect. The Lagrangian vertical coordinate ocean model community has been meeting annually for the past decade to discuss the challenges, experiences and breakthroughs in developing and using the isopycnic and hybrid (pressure-density) coordinate ocean models. The community as a whole has had to grapple with the unique difficulties of isopycnic models, for example striving so that such complications as the ocean's nonlinear equation of state are handled almost as gracefully as with other classes of ocean models. This challenge to the community as a whole has had to be addressed before this class of models could gain wide-spread acceptance, and there has been extensive intellectual cross-fertilization between models. This long experience has led to a strong web of collaborations, many evidenced in publications, and out of it has emerged a community with a strong base of mutual trust and respect, and the ability to critically and candidly examine the virtues and faults of various approaches without endangering the community's cohesion. In this respect, the Lagrangian-vertical coordinate ocean modeling community is ideally suited for the transition to a community modeling environment.

The ideals of a community based ocean modeling environment have been long promoted, but this is perhaps the first truly community-generated initiative to consolidate modeling efforts and share ownership and development of a significant computing resource for the nation's and the world's oceanographic community.

Ingenuity

HOME will be a base for the future exploration of novel modeling concepts, the more rapid improvement of large scale circulation models, and a stable base for the development of new application services built around a core model framework that can be maintained at the cutting edge of the science. It will provide a framework for experimentation and rapid implementation of improvements in the representation of physical processes in ocean models.

For example, innovative features that HOME models might explore include, but are not limited to:

- Multi-level refinements to the representation of surface mixed layers
- alternative vertical coordinates (orthobaric or iso-neutral surfaces)
- effects of nonlinearities in the equation of state, such as thermobaricity and cabbeling
- explicit resolution and modeling of bottom boundary currents,
- direct calculation of internal and external tides
- multi-model ensembles and interactive ensembles
- active biogeochemical models

HOME will furnish the capability to interchange, combine, and modify choices of vertical coordinate, physical parameterizations, algorithms, parameter settings, and so on. This is in contrast with the usual single model consisting of a fixed set of parameterizations and algorithms, perhaps with some restricted freedom in the setting of parameters, but with very limited user options to experiment with the model architecture. HOME will not merely be a collaboration of several groups to consolidate the options of various hybrid vertical coordinate models into a single code. Though this by itself would make a significant contribution to ocean modeling, it would miss a far larger opportunity to explore new combinations of ideas.

It is essential to maintain and extend the diversity of available algorithms. The diverse collection of techniques is the gene pool of future ocean models. A rich pool provides the best prospect for selecting the models that are optimal for answering specific questions about the ocean. By comparing the performance of a rich array of configurations, the community will be able to breed ocean models that are most generally skillful at representing the broad assortment of physical processes that are important in the simulation of a system as complicated as the ocean circulation. The danger of code proliferation - that it may lead to modeling camps isolated from each other - is counteracted by the provision of an overarching Ocean Modeling Environment.

The grand idea driving HOME is that it should foster the ingenuity and innovativeness of the user, rather than restricting it into well-worn channels.

Technology

Another significant factor in the development of HOME is the ability to exploit the deployment of new technology rapidly and effectively. Foremost among these are the Earth System Modeling Framework (ESMF). These technologies work together to provide the models insulation from hardware architecture (via ESMF's infrastructure level) and performance issues and to provide a powerful and effective means for building robust and portable model systems that can easily be coupled to atmosphere models, sea-ice models, and data assimilation systems (via ESMF's superstructure level). This development effort would be one of the first model systems whose code is built from the ground up on ESMF, and should be compliant with the emerging standards for model interoperability, such as the PRISM standards in Europe.

The common software framework will also permit the new community ocean models to be developed with mature data assimilation and initialization methods, such as those currently used at NASA GMAO (and incorporated into ESMF) and NRL Stennis. The use of a common framework will facilitate further research into ensemble Kalman filter and other data assimilation techniques and application of remote sensing for model initialization and verification. Rich nesting capabilities would also accrue directly from using ESMF.

The commitment to ESMF and development through a large community would ensure that ocean modeling applications can be built and maintained for the long-term. Whether the application is coastal coupled forecast systems, or IPCC global climate assessments, it demands stability and long-term support. The open-source software movement has shown that a committed team of interested investigators representing a number of large institutions can provide a secure and long-lasting basis for support.

Flexibility

The development of a generalized-Lagrangian vertical coordinate HOME will facilitate the development of model systems having depth, pressure, fractional depth (sigma), density or combinations of these as the basis for vertical discretization. For example, it might prove valuable to have a model that includes deep ocean regions in isopycnal coordinates and coastal and shelf regions in sigma or pressure coordinates. While there are special challenges to any of these more exotic combinations of choices, the reward may be great, and the exploitation of a common ocean modeling environment will mean that developments by one group for a specialized application can be readily shared with all users. Moreover, the experience in atmospheric models has been that sigma- and pressure-coordinate models based upon Lagrangian vertical coordinate techniques are competitive with, or even superior to, models using the traditional Eulerian techniques (e.g. Lin, 2004; Benjamin et al., 2004). There is every reason to expect that the oceanic situation will be similar.

Education

The emergence of a common modeling environment for generalized Lagrangian coordinate ocean modeling should provide concrete benefits to the nation's need to develop the next generation of scientists. The full ocean models that are used for oceanic predictions or climate studies are much more complicated than is often appropriate for many pedagogical purposes or for idealized studies. As a result, many students are not exposed to the models that are used in practice. If a simplified selection of the full code-base for illustrative or idealized simulations can be included along with a very user-friendly interface, one can envision the widespread use of the base code in graduate oceanographic education. For developing a proficient ocean modeling community, for maintaining community cohesion, and for speeding the integration of recent graduates into the scientific modeling workforce, there is no substitute for training students with the same code-base as is used for real applications.

3. Vision

There are several reasons why HOME should be developed now: (1) Hybrid vertical coordinate ocean models are being used for an increasingly large array of oceanic studies and applications; (2) The Earth System Modeling Framework (ESMF) will enable ocean modeling code to be written with greater flexibility while isolating the models from the details of the hardware upon which they are run; (3) All of the potential predecessor models are committed to adopting ESMF, and simultaneously converting to the common code base will mean much less disruption for both the model users and developers than if the transition to ESMF and the transition to the shared code base were to happen separately; and (4) Most importantly, virtually the entire hybrid vertical coordinate ocean model development community is genuinely interested in channeling their currently disparate efforts into a community Ocean Modeling Environment, HOME.

The vision that is presented here is one of an initial merge of hybrid (isopycnal) models into a common code-base. Such a framework could be envisioned to embrace sigma- and geopotential-based coordinate models into a single environment. While we embrace an eventual goal of accommodating many models into the framework, a close examination of the hybrid coordinate models reveals that there are many scientific issues specifically facing layered ocean models. On the three-year timescale of this proposal, we will incorporate important capabilities from sigma- and geopotential-coordinate models, and aggressively explore the prospects for the application of HOME-based models to the applications that have traditionally used these other formulations. However, our over-riding goal is to replace five existing hybrid vertical coordinate models with HOME by the end of this three year effort. We do not anticipate that sigma- and geopotential-coordinate models will necessarily be replaced by HOME on this time scale. The mature ocean modeling system must have associated with it rich data assimilation capabilities; drawing upon and extending current practice, HOME will deliver this. The impetus for the current effort centers on a desire to capture the best practices and differences between the extant layered models in order to accelerate the development of improvements to the models and to cull non-competitive options. For the next few years, such focused work on readily achievable consolidations and extensions of current practice through a succession of viable models is a prudent staging strategy toward the more challenging broad consolidation of ocean modeling practice.

Long term goal

The 10-year vision is to have a broad unification of ocean modeling practice by collecting the expertise of the current sigma-, geopotential-, and isopycnic/hybrid- coordinate models in a single software framework. This will allow the greatest possible flexibility for users and synergies for model developers.

There are currently efforts to unify the terrain-following (sigma-) models through the TOMS effort. In addition, there are ongoing efforts to promote much tighter coordination between the GFDL/MOM and MIT model groups over the next 3 years. HOME is a complementary effort to unify the generalized hybrid coordinate development teams into a single code base within 3 years, while also importing critical capabilities developed for these other model classes (see later sections for details) and aggressively exploring how to make a larger unification of ocean modeling across the three classes a reality in a time-frame of 5-10 years.

The next step is to unify all of the three model classes into a generalized ocean modeling environment, within a time-frame of 5-10 years. Even beyond this goal, HOME should lead to a future in which untraditional ocean modeling approaches are made readily available for routine and widespread use as they become available. Nonhydrostatic models already are indispensable for certain oceanic applications, and unstructured or partially spectral approaches continue to be developed. Through HOME and successor efforts, these techniques can be delivered to the users of ocean models with substantially reduced disruption of their studies.

Multi-Agency Support

Different agencies have differing but complementary ocean modeling interests in such areas as short-term ocean forecasting and nowcasting, state estimation, seasonal to interannual forecasts, interpretation of satellite data, global and regional climate prediction, and basic studies of the ocean's dynamics, as well as in the use of ocean models as educational tools. A broad base of agency support will both ensure that these varied interests will be addressed, and it will lessen the burden on any one Federal agency. Also, a broad base of agency support may be indispensable for fully engaging all of the relevant existing Federal activities; these activities currently exist within Navy, NOAA, DOE, and NASA labs.

Perhaps a more compelling reason for multi-agency support lies with the human dynamics of community model development. Centralized support will reinforce the concept of a team effort, and reward individuals for continuing cooperation, rather than providing incentive for withdrawing from the project.

Finally, we estimate that a viable effort would cost roughly $1.5 million/year, in addition to the in-kind support from key institutions. Funding of this magnitude can be achieved most easily with multi-agency support.

Long-term Support

The present implementation plan covers the 3-year cost of developing the HOME code base and assessing how it can best be used to simulate the ocean. In the long-term, this code base will require on-going support to ensure that it remains relevant. As a part of the HOME effort, a number of existing codes will lapse into legacy status as the efforts are shifted into the HOME code-base, including several that are currently supported by Federal research institutions. As the HOME use patterns evolve, we anticipate that a viable long-term support agreement can be achieved between NOAA/GFDL, Navy/NRL, and DOE/LANL to collectively provide user support that is more robust than for any of the predecessor models, but at smaller cost to each institution, out of the efforts that are currently expended to support these predecessor models. As such, we do not foresee the need to request open-ended support from the various Federal agencies' research budgets.

Measures of Success

There are a number of specific objectives by which the success of HOME will be measurable:

(1) The voluntary participation of a substantial portion of the nation's existing isopycnal and Lagrangian vertical coordinate model development community in contributing to and transitioning to a shared, open source community HOME.
(2) Collaboration from the nation's broader ocean model development community to consult on software design and to partner in the assessment of algorithmic best-practices for ocean modeling and refinement and extension of existing algorithmic capabilities.
(3) Contributions of new capabilities or algorithmic alternatives from beyond the circle of the key developers of existing models.
(4) The development of a code base that is easy to configure and use for a variety of applications. The documentation accompanying this code base must be clear, consistent, and explicit. The continued quality of this code base must be assured by and effective and sustainable HOME governance structure.
(5) Widespread adoption of the code-base for ocean applications.
(6) The development of extensive best-practice guidance for representing important processes to guide the construction of specific ocean modeling applications. This would include critical evaluation of previously unavailable algorithmic combinations, and it would almost certainly lead to improvements to oceanic applications based on these new combinations.
(7) The development and adoption of a selection of pedagogically useful examples derived from the HOME code base.

If successful, this initiative will go far toward transforming ocean models into the "handy, graceful tools, easily and promptly applicable to any well posed scientific question about the ocean, usable by anyone anywhere, and with well established uncertainty estimates" that are called for in the WOCE final report (Hallberg and McWilliams, 2001). The greatest value to accrue from developing HOME will be in dramatically reducing the human costs of developing and using ocean models.

4. Project Description

HOME will provide a versatile community open-source, ocean modeling environment using a predominantly Lagrangian vertical coordinate. The HOME development effort will also identify and refine best practices or describe trade-offs between alternatives for simulating a range of important ocean processes.

This proposal represents an agreement among several of the nation's most proficient ocean model development groups to leverage our combined efforts and knowledge, promoting greater collaboration and eliminating redundancies. The proposers include the principal developers of HYCOM and MICOM (Bleck, Chassignet, and Wallcraft), GMU/NASA/COLA's Poseidon (Schopf), NOAA/GFDL's HIM (Hallberg), DOE/LANL's HYPOP (Jones), and OSU's POSUM (deSzoeke and Springer) which represent the nation's foremost active primitive equation isopycnic- and hybrid-isopycnic coordinate ocean models. The active participation of the key developers of GFDL's MOM4 (Griffies), MITgcm (Adcroft), and ROMS (McWilliams and Shchepetkin) bring extensive experience with modern geopotential-coordinate and terrain-following ocean model techniques. This group has a long-standing collaboration through the Layered Ocean Modeling workshops, yet the current proposal will vastly accelerate the exchange of ideas within this group, removing barriers to collaboration on model development both with the core HOME team and within the broader oceanographic community.

Among the broad group of experienced ocean model developers participating in HOME, the existing ocean models can be classified in two groups. The HOME predecessor models are all predominantly isopycnal coordinate models; the developers behind these models have all expressed an intention for these models to disappear as distinct code-bases. The algorithms, applications, and even development activities of the predecessor models will persist, but be expressed through the common HOME code-base. The HOME predecessor models include HIM, HYCOM, HYPOP, Poseidon, and POSUM. The HOME contributing models are world-class z- and sigma-coordinate models. The collaborating developers of these models will be contributing expertise and techniques to HOME, but it is premature to commit to the end of these distinct code bases, as it is not yet certain whether models drawn from the HOME codebase will be as skillful as the existing models. However, the active collaboration of the HOME contributing model developers is an invaluable and concrete step toward a future in which the artificial fault lines between the current classes of ocean models have been erased.

We will create a new, efficient, modular, Fortran-95 code base, built upon the Earth System Modeling Framework (ESMF), that consolidates the algorithms of the existing models into a single interchangeable modeling environment. We will then design and carry out a series of tests to discriminate among the collected algorithmic choices, and provide best practice recommendations for accurately modeling set of oceanographically relevant situations. This project will vastly increase the diversity of explored hybrid-Lagrangian vertical coordinate model options, while reducing the software-induced incompatibilities.

The HOME code base will be written assuming that the hydrostatic primitive equations are being solved with a generalized Lagrangian vertical coordinate and generalized orthogonal horizontal coordinates. The Boussinesq approximation will not be made. Non-material vertical coordinates will be emulated through vertical remapping. Only one of the HOME contributing models (MITgcm) has nonhydrostatic capabilities, and it is an open research question how to successfully solve the nonhydrostatic equations with a Lagrangian vertical coordinate. Introducing nonhydrostatic capabilities into HOME goes beyond the scope of what can realistically be delivered in just three years, although we will strive not to preclude the addition of this capability later. As most large-scale ocean simulations capture only processes with very small aspect ratios, making the hydrostatic approximation will not severely hinder the utility of models derived from the HOME code-base.

In addition to consolidations within the existing ocean model development community, we expect HOME will provide a target for ocean model development with the widest acceptance. HOME will provide a user-friendly capability to use multiple ocean model formulations in coupled climate modeling studies. With a single code-base, we will be able to provide user-friendly interfaces for the entire suite of capabilities. This should facilitate the use of ocean models by inexperienced users, and will be invaluable for using state-of-the-art ocean models in outreach to students and other non-practitioners.

HOME will be built upon the Earth System Modeling Framework (ESMF). ESMF makes HOME particularly feasible at this time for two reasons. First, ESMF will hide many computer-specific coding choices and eliminates the need for a substantial portion of the specialized supporting software that comes with any ocean model; ESMF code should run well on all of the computer systems being used by the participants. Second, and more importantly, each of the models represented in this proposal is tentatively committed to transitioning to ESMF. There is enormous disruption any time that a project substantially changes the model code that it is using.

Although there may be a substantial effort to coordinate the transition of each of the predecessor models simultaneously to HOME and ESMF, there is likely to be minimal additional disruption to the projects that use the models. The impending ESMF transition provides a window of opportunity in which the merger of efforts into HOME will lead to minimal additional disruption to the existing model users.

4.1. HOME PREDECESSOR MODELS

The tremendous potential for HOME to enable science and skillful ocean simulations is best illustrated by contrasting the algorithmic approaches of the predecessor models and by highlighting some of the applications for which these models have been used.

Algorithms:

The HOME predecessor models are qualitatively similar in many regards, but differ in detail (often substantially) in the representation of essentially every term in the equations of motion. With the current codes, the implications of these differences are very difficult to assess in detail. Such an assessment will be one of the major benefits to be derived from the HOME project. As an illustration, the range of differences for two specific points is considered:

Ocean models typically use time stepping schemes that split the barotropic gravity wave dynamics from the internal ocean dynamics because of the factor of order 100 difference in the speed of external gravity waves and the next fastest mode in the system (sound waves having been filtered out by the hydrostatic approximation). HYCOM uses the Bleck and Smith (1990) split time stepping scheme, based on a leapfrog time step and a simple definition of the external mode. Following the identification of a coupled instability that can occur with that scheme when temporal filtering is reduced (Higdon and Bennett, 1995), Higdon and deSzoeke (1997), Hallberg (1997), Higdon (1999) , and Higdon (2002) have developed alternate split schemes that include the influence of internal stratification on the external mode speed; these schemes are used in HIM, Poseidon, and POSUM. Beyond the fundamental linear schemes, there are substantial differences between the models in the way that the two estimates of the free surface height (internal from the sum of layer thicknesses and directly from the barotropic solver) are reconciled. In addition, there are schemes in the literature that promise to be superior to those currently in use in the HOME predecessor models (e.g., Shchepetkin and McWilliams, 2004, which has demonstrated it virtues in ROMS). These schemes likely differ in the degree of conservativeness of energy and tracers, computational efficiency, formal temporal accuracy, and the propensity to excite spurious gravity waves. HOME will make it tractable to analyze and understand the implications of these various options.

The pressure gradients in the interior of pure isopycnal coordinate models or of pressure coordinate models are straightforward to evaluate. However, the ocean’s nonlinear equation of state and large-amplitude topography add significant complexity. There are at least three distinct approaches for ameliorating the effects of compressibility in introducing spurious pressure gradients in isopycnal coordinate models (Sun et al., 1999; deSzoeke et al., 2000; and Hallberg, 2004). Similar issues arise from thermobaricity in sigma-coordinate models as well (Shchepetkin and McWilliams, 2003). Near the bottom, there are several approaches currently used in the isopycnal coordinate predecessor models for handling the pressure gradients where layers vanish into sloping topography – either by vertical extrapolation of pressure gradients, horizontal extrapolation (Bleck and Smith, 1990), or using vertical viscosity to arrest unphysical downslope flows (Hallberg and Rhines, 1996). In addition, it is worth examining when the approaches developed for assessing the pressure gradients in sigma-coordinates (see Ezer et al. (2002) for an overview, or Shchepetkin and McWilliams (2003) for a newer example) will be more skillful.

These are just two examples of important parts of an ocean model where the predecessor models exhibit substantial variations. As shown in the tables in the second appendix, there are 9 distinct forms of the Coriolis terms, multiple forms of the surface mixed layer dynamics, at least 6 discretizations of the continuity equation, and 6 forms of horizontal tracer advection, and 4 approaches to vertical diapycnal mixing and remapping. Of particular importance for study are the implications of the specific choice of vertical coordinate. This is not intended to be an exhaustive list of the differences that will be studied as a part of HOME, but rather to give a sense of the likely fruitfulness of comparisons between currently available techniques, both for refining the selection among these techniques and for guiding the development of improved techniques.

HOME Predecessor & Contributing Model Applications:

HIM: HIM has been used principally for idealized geophysical fluid dynamics studies. HIM is now being configured for use in IPCC-class coupled climate studies at GFDL including the full nonlinear equation of state. In addition, HIM has been used for accurate global tidal simulations.

HYCOM: HYCOM has been used primarily for global ocean climate simulations and for eddy resolving ocean simulations and nowcast/forecasts. The next generation of global/basin-scale high resolution ocean circulation and forecasting systems at both the Navy (NAVO) and NOAA (NCEP) will be based on HYCOM.

HYPOP: HYPOP is being developed as the successor to the z-coordinate POP model. It is therefore being developed as a public model for climate change prediction, eddy-resolving ocean simulations, and ocean biogeochemistry.

MICOM: MICOM has been used for idealized, realistic basin-scale and global ocean simulations, with both purely adiabatic and more realistic physical parameterizations.

MITgcm: The finite volume MITgcm has been used to study ocean motions on a range of scales from molecular to global with a depth coordinate. Its optional nonhydrostatic capability allows it to address small-scale processes, such as convection and mixing over topography. MITgcm’s well-developed adjoint capability enables state estimation and parameter sensitivity studies.

MOM4: MOM4 has been used primarily for global ocean climate simulations, seasonal/interannual predictions, ocean reanalysis via data assimilation, and idealized process studies. This code is used by hundreds of researchers worldwide.

Poseidon: Poseidon has been used extensively for seasonal-to-interannual climate prediction at NASA/GSFC, and uses a variety of data assimilation methods. It has also proven valuable for coupled climate simulations, particularly for studying the long term variations in ENSO and TAV. Poseidon runs in either a barotropic or reduced gravity mode.

POSUM: POSUM features a generalized thermodynamic variable as its vertical coordinate. It has been used primarily for idealized studies fo the influence of thermodynamics on ocean dynamics.

ROMS: ROMS has been used for both idealized process studies and realistic simulations on basin and smaller scales. It is designed to work well in the regime of highly turbulent eddies, fronts, and jets.

5. HOME Implementation

5.1. PROJECT STRUCTURE

HOME will follow a "Spiral Development" strategy. Namely, there will be a series of releases of essentially complete working code (with important, realistic applications as test cases) with a timescale of roughly 1 year, and potentially all parts will be subject to subsequent coordinated iteration to extend and refine capabilities, more smoothly integrate contribution from various groups, and apply our findings from the best practice studies. The best practice studies will start immediately, and strive to make sense of the newly available options as the unified code base evolves. The two aspects of the implementation – code base development and best practice studies – will be closely coordinated and highly complementary.

5.2. CONSTRUCTION OF CODE-BASE

We will strive for a symmetrically smooth transition from projects using each of the 5 Lagrangian vertical coordinate predecessor models (HIM, HYCOM/MICOM, HYPOP, Poseidon, and POSUM). In addition we will strive to make choices about the structure and specifics of the HOME code base that will facilitate incorporation of ideas and techniques from the contributing models (MOM4, MITgcm, and ROMS).

We anticipate some conflict between maximizing performance and flexibility; however we have the advantage of being unfettered by past coding practice, with several legacy (predecessor) models but no legacy code base. If performance and flexibility come into conflict, we will favor flexibility but we anticipate that our performance goal of no more than 10% slower than predecessor models should still be attainable. Once we have established consensus coding standards, we will start with an exact conversion of selected applications based on all of the Lagrangian vertical coordinate predecessor models to the HOME structure and standards as a way of ensuring continuity, minimizing debugging efforts, and rapidly exposing any difficulties with the HOME design.

As a complementary effort, we will flesh out issues regarding the best approach to meld the best capabilities of the MOM, MIT, and POP Z-coordinate models into HOME (e.g., rotated mixing tensors). We will explore how to best extend HOME into the coastal areas, and how to structure the HOME code-base to enable coastal modeling activities to be expressed through the HOME code base, particularly through comparisons with ROMS simulations and the incorporation of capabilities from ROMS into HOME (e.g. careful evaluations of the pressure gradient accelerations). For the Z- and sigma-coordinate models, we will develop HOME-code-based approximations to reference solutions, but we are not certain that we will be able to devise algorithmically identical models.

There will be several consensus documents that we will write to guide the HOME development. Each of these documents will be prepared within the first 6 months that HOME is funded, and presented at an open public session at the 2005 LOM Workshop in Miami, February 2005. Each of these documents will be accepted by consensus of the HOME design team, and will potentially be revised twice based upon our experience within the three-year span of the proposed implementation. The revisions of most of these documents will tentatively occur in February 2006 and February 2007, i.e. these documents will arrive 6, 18, and 30 months into the HOME project.

- Memorandum of Understanding: This document will explicitly spell out such issues as ownership (shared), rights and responsibilities, governance, etc. R. Hallberg will lead in the preparation of this document.
- HOME Coding Standards: This document will describe the coding constructs, code documentation protocols, data movement strategies, and stylistic conventions that will be encouraged or required for HOME software. These coding standards will be designed to facilitate data-assimilation and grid nesting via ESMF. P. Schopf will lead the preparation of this document.
- HOME Functional Decomposition: This document will describe how the primitive equations will be broken into software modules, including a description of the input and output arguments. The input arguments will tend to be inclusive enough to accommodate the broadest range of techniques. Consensus is particularly important for this document, as it is a level where the components from different predecessor and contributing models will be exchanged. R. Bleck will prepare a first draft based upon an existing document; others will then prepare alternate versions in the same format, based on experience with existing models, this will lay the groundwork for a consensus document.
- HOME Methodology for Code Collaboration: This document will cover the HOME version control, review strategies and protocols, and the quality assurance strategies. This document will be relatively short. S. Springer will lead in the preparation of this document.
- HOME Model Definition: This document will define the equations that the models will be solving, and the approximations that will be applied and avoided, what the code-base will be capable of describing, and what will not be available in the common design. R. Hallberg will lead the preparation of this document.
- HOME Evaluation Strategy: This document will address how the HOME team will design tests to discriminate among the algorithmic techniques that will be collected into the HOME code-base. This document will include both examples of tests that we will use and our strategy for developing additional evaluative measures. A. Wallcraft will lead in the preparation of this document.
- HOME Variable Names and Units: This document will define a common set of variable names, sign conventions, and units, both for use in the documentation and for use in the code. These conventions are recommendations intended to promote a more seamless use of the HOME code base. This document will follow first drafts of the “Model definition” and the “Functional decomposition” documents, and those documents will be reconciled with the definitions and terminology in the “Names and Units” document.

Important working test cases from the various predecessor models will be used to ensure continuity of scientifically value in the model code bases. At each step, an effort will be made to ensure that any differences in the solutions arise from the order of operations, and that the solutions retain their scientific utility. These test cases will be most valuable during the initial code conversion, and will be supplemented by other, more idealized tests for the ongoing code development. The test cases for ensuring the algorithmic continuity from the various predecessor models will include the following:

HIM:

- 1-degree, 48 layer global climate model with fully nonlinear equation of state used at GFDL for climate studies
- 2-layer idealized adiabatic wind-driven gyre model, as a simple example emphasizing the dynamic core only – this should be especially valuable for rapid prototyping and for ensuring the value of HOME for simple, pedagogically tractable simulations.

HYCOM:

- 20-layer 1/12 degree Gulf of Mexico nested (off-line) inside 1/12 degree Atlantic HYCOM.
- 28-layer 0.72, 0.24 and 0.08 fully global ocean model, both with and without data assimilation.
- Two dimensional (infinite *f*-plane) upwelling/downwelling test case.

HYPOP:

- 3 degree, 26-layer global test case.
- 1 degree, 40 layer global ocean/ice model.
- Assorted unit-tests of communication, equation of state, etc.

Poseidon:

- 1 degree, 20 layer global reduced gravity hybrid coupled model
- Data assimilation system for ENSO forecasts.

POSUM:

- A thermobaric soliton solution.

The test cases for approximating the Z- and sigma-coordinate contributing models will be as follows:

MITgcm:

- The global 2-degree, 20 level model used by the ECCO project.

MOM4:

- GFDL's 1-degree, 50 level "OM3" global ocean model, currently in use for IPCC climate simulations.

ROMS:

- Pacific basin 0.5 degree resolution 30 level decadal simulation with reanalysis meteorological forcing.

Several of the above need an associated ice model. We will only use ice models that are in the ESMF framework, and will couple to them via ESMF; no recoding of the ice models should be necessary.

There are a number of design considerations that will be balanced in defining the specifications for the HOME code-base. User-friendliness will be paramount in specifying parameters and initial conditions; this will rely on clear documentation, many examples, and enough options to accommodate the diverse needs of highly idealized and fully realistic simulations. The APIs of the component interfaces will emphasize the algorithmic flexibility that is essential for the best practice studies to be practical. At the top level HOME will be designed around ESMF objects and their initialize, run, and finalize methods, but at the lower levels we will avoid the use of opaque types where they would add significant overhead. The lower levels of HOME will be organized around modular and interchangeable functional pieces, with all information passed via arguments. The internal component coding style will emphasize performance across a range of computer platforms, with user friendliness deriving from disciplined documentation and consistency in style and variable naming conventions. In addition, bit for bit reproducibility (on the same machine across any number of processors) and algorithmic symmetry have proven themselves as indispensable debugging tools, and will be encouraged and documented.

PERFORMANCE GOALS

Moore's Law implies that a factor of two in performance can be made up in about 18 months, i.e. comparable computer systems 18 months apart in age will differ in performance by a factor of about two. This is a strong argument for emphasizing flexibility over performance. However, ocean modelers don't typically have the option of waiting for a new faster computer system to run their application and an inefficient ocean model is clearly "wasting" computer cycles. It has been our experience that user's of an ocean model will definitely not switch to a new implementation if it provides better functionality but is 2x slower than the original. They usually will switch to a new implementation if it provides better functionality and no more than about 10% degradation in performance. Since our goal is to replace five predecessor models, we will generate scalability and performance test cases based on actual applications of the predecessor models with a target of less than 10% degradation in performance across a range of platforms and processor counts. Note that this also implies that scalability will be essentially as good as or better than the predecessor models. We anticipate that this goal can be reached, even with ESMF overhead, because we can standardize on a coding style that performs better than that in the legacy codes. We expect to use ESMF for both superstructure (top level and coupling to other components) and infrastructure (low level scalability). We believe that the risk associated with depending on the viability of ESMF is easily mitigated; if ESMF infrastructure has too much overhead to achieve the 10% performance degradation goal we can switch to an alternative API for low level scalability. This could either be a custom API just for HOME, or we could adapt an existing API such as GFDL's Flexible Modeling System.

INPUT/OUTPUT AND PRE/POST-PROCESSING

A large fraction of the software associated with an ocean model is for pre-processing and post-processing. In the past this has been model-specific and highly dependent on the choice of model file formats (e.g. netCDF, HDF, GRIB, raw binary, or ASCII text). The ESMF I/O API will to some extent allow the choice of file formats to be made at run time. A self describing data format is clearly needed, and ocean modelers have typically used netCDF. However the current version of netCDF is an old design with substandard large file support. A new version of netCDF is in development and it may allow us to continue using netCDF for HOME. For performance, we expect to implement an ESMF-based asynchronous I/O capability for HOME (dedicating a subset of the processors to I/O). ESMF will also be used for HOME-specific pre-processing and post-processing programs. This automatically makes then scalable to multiple processors and allows some I/O format flexibility. In the short term we will need compatibility with pre-processing and post-processing programs from predecessor models, and perhaps also contributing models. This can either be accomplished by converting HOME files to the predecessor model format, or by converting predecessor model files to the HOME format. In the long term, converting predecessor files to HOME will clearly be the appropriate method, but initially converting in the other direction may be necessary to gain access to pre-processing and post-processing programs not yet available in HOME.

5.3. BEST-PRACTICE STUDIES AND APPLICATIONS OF HOME

The HOME project will include an extensive effort to identify the best techniques for capturing the fundamental dynamics of specific phenomena and global properties of the ocean that are most pertinent to a variety of ocean simulations. In doing this, we will attempt to breed the best possible ocean model from the existing capabilities, and to provide invaluable guidance to make the best use of the wide range of capabilities that will be collected in the HOME code-base.

The HOME best-practice efforts will deviate from current practice, in that we will not be devising the tests to affirm the virtues of a particular technique (as is all too often the case with papers describing new numerical developments), but rather to objectively assess the strengths and weaknesses of many techniques. We will use a diversity of tests to ensure that various techniques' skill in a broad range of oceanographically relevant situations is assessed. Finally, by engaging such a diverse group of ocean modelers in an objective assessment, it is our expectation that each of us will, of our own volition, select those techniques that are most promising, effectively leading to the relegation of inferior techniques to a legacy status, but without any need for a unilateral enforcement mechanism. We see the HOME best-practice studies as a critical step in moving ocean model development from being the heroic effort of isolated individuals and institutions to being a coherent and systematic community endeavor.

The HOME Best Practice Team (BPT) will identify the most important processes to consider, taking into account the current state of understanding and the importance of the processes to key applications. One member of the BPT will be identified as the Project Leader on a specific question, with the rest of the team acting as collaborators and consultants, contributing to the experimental design of the tests and interpretation of the results, and helping determine the algorithmic combinations to be evaluated. The Project Leader will take the lead in writing up the results of these studies, as publications in the peer-reviewed literature. In addition, the Project Leader will prepare bimonthly written progress reports to the BPT, call teleconferences as needed, and lead the discussions of the Project at the HOME meetings.

Even before the predecessor models' algorithms have been converted to HOME, we will start designing a set of tests to assess the range of algorithmic options and to establish best practice recommendations. The initial projects will devise tests to address such areas as:

- The optimal choice of vertical coordinates for selected applications.
- The degree to which eddy-rich simulations are acceptably adiabatic. This particular test is relatively mature; it will draw heavily upon the analysis in Griffies et al. (2000) of the extent to which MOM is adiabatic in several relevant situations.
- The treatment of compressibility and thermobaricity.
- The treatment of pressure gradients near topography.
- Comparison of available tracer advection schemes.
- The importance of differences in the discretization of the Coriolis terms (e.g. topographic wave propagation, PV conservation in turbulent flow).
- There will be a special focus on mixed layer physics and near surface dynamics in evaluating and refining choices.
- Coastal applications of HOME.

Where possible, projects addressing different questions will use common test simulations, both to reduce the overhead of the effort and to maximize the understanding. These tests will emphasize large-scale oceanographic questions, even though this means that analytic solutions will often not be available, complicating the interpretation of the tests. All of the projects will exploit the flexibility of the HOME code-base to carry out tests using a broad collection of algorithmic combinations that are deemed likely to influence the performance on these tests, including existing combinations from multiple predecessor models and novel combinations.

R. Hallberg will chair the Best Practice Team as a whole. This role will include leading the discussions of the whole team to identify those phenomena that are of sufficient interest to initiate projects studying them, and to determine when sufficient progress has been made on a project to shift efforts to other projects. The Chair will also coordinate the collection of reports on the various BPT projects and synthesize these reports. The other members of the BPT include A. Adcroft, R. Bleck, E. Chassignet, R. deSzoeke, S. Griffies, M. Iskandarani, P. Jones, J. McWilliams, P. Schopf, A. Shchepetkin, S. Springer, A. Wallcraft and the postdocs who are to be hired at GFDL and Miami. Given the notable stature and proven capabilities of the members of BPT, the organization into coordinated and collaborative but autonomous projects would seem to be the only viable organizational structure.

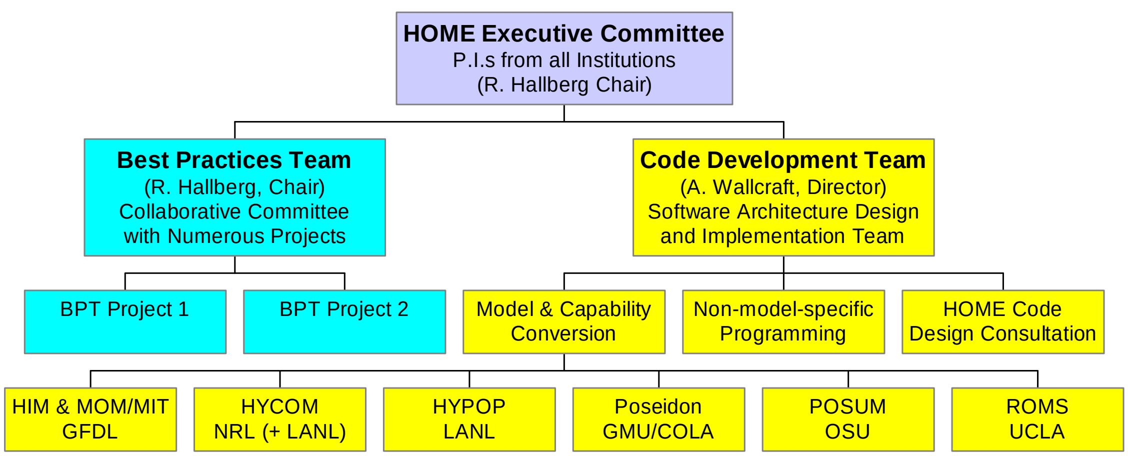
In addition to the phenomenological projects, the BPT will also explore the prospects for HOME to be extended into additional capabilities as a part of the longer term vision of a broader unification of ocean modeling capabilities. Areas to be explored include nonhydrostatic simulations and alternate, irregular, or unstructured horizontal discretizations. Although this exercise may not lead to significant applications within the 3-year scope of this implementation plan, it will be a critical fertilization for algorithmic exploration. The resulting mutual influence and coordination of diverse avenues of potential improvement make HOME an indispensable platform for the development of truly generalized ocean modeling code within a timeframe of five to ten years.

5.4. PROJECT MANAGEMENT

We seek funding to start in the time-frame of October, 2004, and anticipate funding for an initial period of 3 years. The tentative budget, roughly $1.5 million per year, can be found in the table in the appendix.

Over the three years, we will divide the efforts among the various institutions to ensure a viable distributed project management plan, while still engaging in enough cross-team synchronization to ensure a viable, cohesive project as a whole. The project will be organized into 2 teams – a "Code Development Team" (CDT) and a "Best Practices Team" (BPT) – and an executive committee of the P.I.s to deal with all governance issues. Alan Wallcraft will lead the CDT, while Robert Hallberg will chair both the BPT and the executive committee. This structure is shown in the organizational chart below.

HOME Organizational Chart



All of the HOME participants will meet twice a year; one meeting will be synchronized with the annual "Layered Ocean Model User's Workshop", that is held every February in Miami, while the other meeting will be held in roughly September/October, starting immediately after the initiation of funding, at one of the other participating institutions. In addition, both the CDT and BPT will have conference calls as needed, but at least monthly.

Much of the coordination underpinning the CDT will initially revolve around achieving an explicit (written) consensus of the specifications for each software module (including the APIs), and on the overarching documents (listed above) to achieve a common look-and-feel for the software, but the exact implementation will be left to the individual writing the module, subject to a formalized cross-institutional peer review. Much of the initial code development will be distributed according to the predecessor model being worked on, with the work roughly collocated with the original developer. Later development will emphasize common capabilities, and will be assigned to a CDT member by mutual agreement between that CDT member, CDT leader Wallcraft, and the HOME P.I. at the CDT member's institution.

The BPT will distribute its work by process, rather than by the predecessor model. For example, one member of the team will take responsibility for leading the assessment of the evaluation of pressure gradients near topography – designing meaningful test cases, analyzing simulations using a variety of algorithmic options, and writing up the results (preferably for publication in the peer-reviewed literature). All of this will be done in consultation with the rest of the BPT, but might be essentially an individual research project. The BPT as a whole will coordinate these efforts to ensure that the HOME project as a whole provides a coherent evaluation of the most pertinent aspects of ocean modeling, and provide feedback on the relevancy of the tests. These tests will build upon the smaller-scale studies that Dale Haidvogel and colleagues have developed (see http://www.imcs.rutgers.edu/po/index.php?model=test-problems), but will extend to larger-scale problems and will certainly include many tests for which an analytic solution is unavailable.

5.5. USER INTERFACE TO HOME:

HOME is intended to be an open, community model, and an inviting user interface to HOME is particularly important. We will rely upon a detailed web-portal and freely accessible code repository as the principle point of contact by external users. Outside collaborators will be encouraged to contribute new capabilities, subject to a similar peer-review process to that used for internal contributions. User questions can be directed to the HOME bulletin board; experience from MOM4 has shown that this can be a very effective vehicle for quickly addressing users' queries. In a broader sense, user support will continue to rely upon the major modeling centers, even as it does now, but their shift to a common code base will allow user support to be distributed between them and HOME will not require substantially greater resources for user support beyond what will naturally follow the major modeling centers' shift away from the predecessor codes.

With the great diversity of algorithms, it will be particularly important to provide users with tools to make sense of this diversity and select the options that best suit their particular application. In addition to the best practice write-ups (both as preprints/reprints of peer reviewed publications and technical notes), we will offer several ways for users to start from model configurations that are close to the intended application: 1. We will establish a library of model configurations that have been used in specific peer reviewed model studies of the ocean; 2. We will offer configurations that reproducing existing named models (e.g. HYCOM, v2.1); 3. We will offer specific applications that are routinely used, such as GFDL's 1° global climate model; and 4. We will provide simplified examples that reproduce selected pedagogically useful ocean circulation solutions, such as wind-driven gyres in simple basins.

6. Timelines

Year 1:

- Code Design Team (CDT) will establish preliminary consensus coding and documentation standards, and a methodological decomposition of the models. These standards will include specification of the nature of the data flow and appropriate Fortran 95 concepts. The initial document release will be in February 2005 (assuming an October 2004 project start date). The new code base that will be developed will be built upon the Earth System Modeling Framework (ESMF).
- Programmers at NRL and LANL will convert existing HYCOM and MICOM applications to conform to the HOME standards; the programmer at GFDL will convert first an idealized GFD simulation and later GFDL's HIM-based global ocean climate model to code following HOME standards; the programmer at OSU and the programmer at GMU will do the same with POSUM and Poseidon, respectively. All of this work will be overseen locally by various P.I.s and coordinated through Wallcraft at NRL. The initial conversion test cases will be simple but realistic, followed by increasingly complex instantiations that have been used for scientifically interesting studies.
- GFDL programming support (actually several people, collectively contributing 6 months per year of effort) will coordinate the development of a HOME web page, bulletin board, and a G-Forge code repository, providing both a restricted-access medium for exchange between HOME participants and a public interface to HOME. Reflecting the multi-institutional nature of HOME, these web sites and repositories will be mirrored at other HOME institutions.
- The first common code-base release will occur in June 2005, focusing on the dynamic cores and common HOME infrastructure such as the interfaces to the ESMF and/or PRISM frameworks. Each of the existing dynamic cores will work, and efforts will be made to achieve as much interchangeability of specific parts of the dynamic cores.
- There will be a supplemental code-base release in September 2005, focusing on diabatic processes (including diapycnal mixing, mixed layer and boundary layer dynamics, and vertical remapping). This supplemental release will be delayed relative to the release of the cores to ensure early interchangeability of the diabatic processes between the cores.
- The coding standards will be iterated by the CDT based on our experience with the conversion exercises.
- The Best Practices Team (BPT) will begin devising tests that will be used to evaluate the behavior of various algorithmic combinations and refining these tests using predecessor models. There will be a focus on those features that will be captured with the simplest initial HOME code base, and especially the dynamic cores.

Year 2:

- Continued refinement of the coding standards documents, with particular emphasis on data assimilation and issues that arise from emulating non-isopycnal coordinate systems. This effort culminates in the release of a revised set of documents in February, 2006.
- All of the code base will be brought up to the February 2006 standards in a June, 2006 code release. This release will strive to fully eliminate any remaining barriers to interchange of pieces of the dynamic cores and to facilitate the use of the cores in skillfully emulating non-isopycnal coordinate systems.
- Programmers at various institutions will provide HOME code capturing adequate functionality to replicate fully realistic simulations. Also, the CDT will use a range of

interoperability tests to ensure that the HOME base can work seamlessly across applications inherited from several predecessor models.

- The CDT will achieve a consensus on the range of available pre- and post-processing capabilities to be provided by HOME, and ease-of-use considerations for model initialization and analysis.
- BPT will perform tests addressing issues pertaining to the dynamic cores. Specifically, BPT studies will report on the following issues:
    - The representation of pressure gradients near topography, as indicated by the quality of wave simulations and deep boundary-current spinup (topographic bores).
    - The issues pertaining to the barotropic-baroclinic mode splitting paradigm used to step the models. Based upon an initial examination of the existing options, we anticipate that there may be distinctions in property conservation, stability, computational efficiency, and "noisiness" of the internal and external gravity wave fields. Both idealized and realistic cases will be used, but large amplitude topography will be used in all of these studies to emphasize situations where distinctions are likely to be greatest. These studies may also make concrete recommendations regarding the overall choice of time stepping schemes.
- The BPT will also extend and refine the test suite to include thermodynamic questions, in preparation for reports to be released in year 3.
- By the end of year 2, at least 2 significant applications, derived from different predecessor models, will have completely migrated to the HOME code-base.

Year 3:

- Programmers at GFDL and LANL focus on converting Z-coordinate capabilities from MITgcm, MOM4 and (HY)POP.
- Programmers at GMU and Stennis will focus on adopting data assimilation capabilities to HOME.
- Programmer at GFDL focuses on implementing the consensus ideas about a range of ease-of-use issues and pre- and post-processing capabilities.
- BPT develops more quantitative measures of tests, further extension and refinement of test suite.
- At least 2 (and presumably all 5) of the predecessor codes will have become Legacy codes by the end of the third year, with the subsequent ocean model development by these groups channeled through the HOME code base. This is a continuation, as needed, of efforts from years 1 and 2 by the relevant programmers at all the institutions.

Target after 1 year:

At least one idealized test case from each predecessor models is running under HOME.

An initial suite of test cases will be available, all running on predecessor and contributing models (where appropriate) with many also running in HOME.

Target after 2 years:

A major application from each of two predecessor models is fully running under HOME and meeting the performance target.

An interim suite of test cases will be available, all running on HOME and on predecessor and contributing models (where appropriate).

Target after 3 years:

There will be a single HOME code base replacing all of the predecessor models. Known algorithmic combinations will be available (or replaced with superior combinations), but there is no guarantee that all possible combinations will work.

We will have established a test suite that can be used to assess the strengths and weaknesses of various algorithmic approaches. Many of the test cases will also be applicable to non-hybrid models.

7. Position Descriptions

GFDL Position descriptions:

A. R. Hallberg (GFDL P.I.): Will spend roughly 3 weeks per year on work in support of the Executive committee; 3 weeks per year on CDT work – assisting with the preparation of the consensus documents and oversight of the GFDL programmer on HIM conversion and other tasks; and 6 weeks per year working on BPT projects and advising the GFDL postdoc.

B. GFDL Postdoc (Whit Anderson): Will spend 10 months per year on BPT projects and 2 months per year on CDT work – especially the consensus documents.

C. GFDL Programmer (To be hired): Will work 12 months per year for the CDT – prototyping coding constructs, converting HIM, converting capabilities from MOM4 and the MITgcm, and pre- and post-processing capabilities at successive times in the evolution of HOME.

D. Misc. Programming (various people): Several people already at GFDL will contribute an aggregate 6 months per year on such programming and support issues as code repository preparation and ADA compliant web-page design.

E. A. Adcroft: Will spend roughly 1.5 weeks per year advising the CDT (especially regarding the conversion of MITgcm capabilities) and 2.5 weeks per year collaborating in BPT projects. HOME has synergies with other efforts Adcroft is engaged in.

F. S. Griffies: Will spend 1.5 weeks per year advising the CDT (especially regarding the conversion of MOM4 capabilities) and 1.5 weeks per year collaborating in BPT projects. HOME has synergies with other efforts Griffies is engaged in.

GMU/COLA Position Descriptions:

A. P. Schopf (GMU P.I.): Will spend roughly 1 week per year on Executive Committee commitments; 3? weeks per year on CDT work – assisting with the preparation of the consensus documents and oversight of the GMU programmer on Poseidon conversion and other tasks; and 4? weeks per year on BPT projects.

B. GMU Programmer (To be hired): Will work 12 months per year for the CDT – prototyping coding constructs, converting Poseidon, and data assimilation capabilities at successive times in the evolution of HOME.

LANL Position Descriptions:

A. R. Bleck (LANL P.I.): Will spend roughly 1 week per year on Executive Committee commitments; and 3 weeks per year on BPT projects and oversight of the LANL programmer.
B. LANL Programmer (To be hired): Will work 3 months per year on algorithmic developments directed by Bleck and conversion of HYCOM developments used primarily in HYCOM at LANL.
C. P. Jones: Will work 2 months per year as a part of the CDT, mainly on conversion of HYPOP to HOME and 2 months per year on BPT projects.

U. Miami Position Descriptions:

A. E. Chassignet (U. Miami P.I.): Will spend roughly 1 week per year on Executive Committee commitments; and 7 weeks per year on BPT projects and oversight (along with Iskandarani) of the U. Miami post-doc.
B. M. Iskandarani: Will spend 2 weeks per year advising the CDT, particularly in the preparation of the consensus documents and 6 weeks per year collaborating in BPT projects, including oversight (along with Chassignet) of the U. Miami post-doc.
C. U. Miami Postdoc: Will spend 12 months per year on BPT projects.

Oregon State U. Position Descriptions:

A. R. deSzoeke (OSU P.I.): Will spend roughly 1 week per year on Executive Committee commitments; and 7 weeks per year on BPT.
B. S. Springer: Will spend 3 months per year on CDT efforts, including the conversion of POSUM, and 3 months per year on BPT projects.

NRL/Stennis Position Descriptions:

A. Wallcraft (NRL/Stennis P.I.): Will spend roughly 1 week per year on Executive Committee commitments; 5.5 months per year directing a variety of CDT activities, including the conversion of HYCOM and oversight of the Stennis programmer; and 1 week per year consulting with the BPT.
B. Stennis Programmer: Will work 12 months per year for the CDT – prototyping coding constructs, converting HYCOM, and nesting and pre- and post-processing capabilities at successive times in the evolution of HOME.

U. California, Los Angeles Position Descriptions:

A. J. McWilliams (UCLA P.I.): Will spend roughly 3 weeks per year on the BPT.
B. Shchepetkin: Will spend 2 months per year on CDT efforts, including providing prototypes of code constructs and the conversion of ROMS capabilities, and 2 months per year on BPT projects.

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8. Appendix: Draft Budget

Draft Budgets for HOME: (Dollar amounts in thousands, including benefits & overhead)
(Salaries & benefits increase 5%/year.)

		Yr 1	Yr 2	Yr 3	Total
NOAA/GFDL					
	Postdoc (12 mo.)	$82.0	$86.1	$90.4	$258.5
	Programmer (12 mo.)	$120.0	$126.0	$132.3	$378.3
	6 mo/yr Misc. Programmin	N/C	N/C	N/C	$0.0
	Hallberg (12 wk.)	N/C	N/C	N/C	$0.0
	Adcroft (4 wk.)	N/C	N/C	N/C	$0.0
	Griffies (3 wk.)	N/C	N/C	N/C	$0.0
	Travel, computer, misc.	$20.0	$20.0	$20.0	$60.0
	Subtotals:	$222.0	$232.1	$242.7	$696.8
GMU/COLA					
	Programmer (12 mo.)	$110.0	$115.5	$121.3	$346.8
	Schopf (8 wk.)	$40.0	$42.0	$44.1	$126.1
	Misc.	$15.0	$15.0	$15.0	$45.0
	Subtotals:	$165.0	$172.5	$180.4	$517.9
LANL					
	Programmer (3 mo.)	$70.0	$73.5	$77.2	$220.7
	Bleck (4 wk.)	$25.0	$26.3	$27.6	$78.8
	Jones (4 mo.)	$80.0	$84.0	$88.2	$252.2
	Misc.	$20.0	$20.0	$20.0	$60.0
	Subtotals:	$195.0	$203.8	$212.9	$611.7
U. Miami					
	Postdoc (12 mo.)	$90.0	$94.5	$99.2	$283.7
	Chassignet (8 wk.)	$40.0	$42.0	$44.1	$126.1
	Iskandarani (8 wk.)	$30.0	$31.5	$33.1	$94.6
	Misc.	$20.0	$20.0	$20.0	$60.0
	Subtotals:	$180.0	$188.0	$196.4	$564.4
Oregon State					
	Springer (6 mo.)	$90.0	$94.5	$99.2	$283.7
	deSzoeke (8 wk.)	$40.0	$42.0	$44.1	$126.1
	Misc.	$20.0	$20.0	$20.0	$60.0
	Subtotals:	$150.0	$156.5	$163.3	$469.8
Stennis					
	Programmer (12 mo.)	$190.0	$199.5	$209.5	$599.0
	Wallcraft (6 mo.)	$135.0	$141.8	$148.8	$425.6
	Misc.	$20.0	$20.0	$20.0	$60.0
	Subtotals:	$345.0	$361.3	$378.3	$1,084.6
UCLA					
	McWilliams (3 wks.)	$25.0	$26.3	$27.6	$78.8
	Shchepetkin (4 mo.)	$60.0	$63.0	$66.2	$189.2
	Misc.	$10.0	$10.0	$10.0	$30.0
	Subtotals:	$95.0	$99.3	$103.7	$298.0
Non-Institution specific					
	HOME Meeting Budget	$60.0	$60.0	$60.0	$180.0
Total:		$1,412.0	$1,473.4	$1,537.8	$4,423.1

Budget explanation:

- Each of the dollar amounts listed here are approximate, and assume a 5% increase in personnel costs after the first year – the exact rates will be specified with the formal proposal but should differ by no more than 10%, with less than 5% change in the aggregate.
- All of the significant computer-time required for HOME development will be provided by the various host institutions from existing resources.
- Each of the line-items labeled "Misc." includes such items as HOME-related travel, personal computers, and publication page charges – the specific balance varies between institutions and will be explicitly specified with the formal proposal.
- We are requesting a HOME meeting budget to support such expenses as invitational travel to the HOME meetings to facilitate international and domestic collaborations; the travel budget for each of the participating institutions is listed with each of the individual institutions.

9. Appendix: Comparison of Algorithms

The following table provides a rough comparison of the algorithms currently in use in the HOME predecessor models. It is intended to give some sense of the diversity of capabilities that will be drawn together by HOME.

		Poseidon	HIM	HYCOM	Posum	MITgcm	MOM4	POP	HYPOP	ROMS	
Coriolis											
			x		x	x					Sadourny Energy conserving 2nd order
			o	x	o	x					Sadourny Enstrophy conserving
		x	x								Arakawa-Hsu 2nd order
			o							x	Arakawa-Lamb Energy conserving 2nd order
		x	o			x					Suarez-Takacs 4th order
									x		Dukowicz C-grid Energy Conserving
		x									Oberhuber B-grid 2nd order
						x					Semi-implicit C/D-grid 2nd order
							x	x			Semi-implicit B-grid (unstaggered)
Nonlinear Momentum Terms											
			x	x	x	x					Included with Coriolis
		x				x					Same as Coriolis, computed separately
		x									Oberhuber B-grid 2nd order
						x	x	x	x	o	2nd order centered advection of momentum
										x	3rd order upstream advection of momentum
										x	4th order centered advection of momentum
Pressure Gradient Evaluation											
		x								x	Lin Jacobian (or equivalent)
			x	x	x				x		Montgomery potential + non-isopycnal correction
		x	x		x					(x)	use dM/deta to link ext + internal modes
						x	x	x			2nd order B-grid or C-grid in z-coordinates
										x	4th order monotonized Jacobian
	Thermobaricity					N/A	N/A	N/A			
			x	x							Sun et al (& Hallberg)
					x						de Szoeke et al orthobaric density
										x	Neutral density gradients extracted
Vertical Advection/Remapping											
			x	x	x	o	o			o	Upstream 1st order remapping/advection
				x						o	van Leer remapping in z subdomain
		x								x	Quadratic spline remapping
									x		Cubic spline remapping
						x	x	x		o	2nd order advection (with various limiters)
						x	x				3rd order advection (with various limiters)
						x	x			x	4th order advection (with various limiters)
Vertical Viscosity / Diffusion											
		x	x	x	x	x	x	x	x	x	Implicit Ri-dependent
			x	x		x	x	x	x	x	Bottom drag law
		x	x	x	x	x	x	x	x	x	Surface turbulent mixing
				x							inviscid
				x	x	x	x	x	x	x	KPP interior mixing
Horizontal Viscosity											
		x	x		x	x	x	x	x	x	Laplacian
		x	x	x		x	x	x	x		Biharmonic
		x	x	x			x	x	x		Smagorinsky shear-dependent coefficients
						x					Leith shear-dependent coeffients
		x				x					Shapiro filter
							x	x	x		Anisotropic options

	Poseidon	HIM	HYCOM	Posum	MITgcm	MOM4	POP	HYPOP	ROMS	
Interface Smoothing / Isopycnal Surface Smoothing (e.g. Gent-McWilliams)										
	x	x	x		x	x	x	x	x	Laplacian
	x				o					Shapiro filter
Equation of State										
	x	x	x	x	x	x	x	x	x	Simplified
	x	x	x	x	x	x	x	x	x	International EOS / Realistic funtional fit
Thickness Advection					N/A	N/A	N/A		N/A	
	o	o	o	o						1st order donor cell
	o	x	x	o	(x)	(x)	(x)		(x)	2nd order centered (with limiters)
	x	x								3rd order upstream (with limiters)
	o									4th order centered (with limiters)
		x	x	x						MPDATA
								x		Incremental remapping
Tracer Advection										
	o		o	o	o	o				1st order donor cell
	o		x	o	x	o	x		x	2nd order centered (with limiters)
	x	x			x	x	x		x	3rd order upstream (with limiters)
	o				x	o	x		x	4th order centered (with limiters)
			x	x						MPDATA
								x		Incremental remapping
	x	x								Time split from wave dynamics
Coordinate Systems										
horizontal										
	o	o	o	x	o	o	o	o	o	Spherical polar
	o	o	o	o	o	o	o	o	o	Cartesian
	x	x	x		x	x	x	x	x	Orthogonal curvilinear
vertical										
		x	x							isopycnal (choice of reference pressure)
				x						thermobaric specific volume
	x		x					x		generalized
					x	x	x			geopotential / pressure
									x	terrain-following
Barotropic/baroclinic split										
	x	x								Hallberg
			x	x						Bleck, et al
				x						ADI barotropic solver (Higdon et al)
					x		x			Projection method rigid lid or implicit free surface
						x				Griffies et al explicit free surface
								x		Dukowicz explicit free surface
									x	Schepetkin & McWilliams
Key:	**x - commonly used**							**(x) - effectively used**		
	o - little-used available option or available as a special case of another option									