Completion Report

For subcontract between NOAA Fisheries Service and the IPRC, SOEST, UH

1. Introduction

A major issue of coral reef ecology is determining the extent to which planktonic propagules disperse away from natal reefs instead of remaining to reseed them. The question whether reefs of the Northwestern Hawaiian Islands (NWHI) serve as recruitment sources for the main Hawaiian Islands (MHI) is important to ecosystem (fisheries) management, especially the designation of no-take marine protected areas (MPAs) and other types of reserves. Evidence supporting or refuting this assumption is lacking. General inability to detect genetic differences between NWHI and MHI populations has been wrongly interpreted as evidence that species comprise single archipelago-wide stocks. Recent evidence challenges the notion that the NWHI are a source of reef fish populations in the MHI; endemic species are disproportionately abundant at the northernmost atolls compared to the rest of the NWHI and the MHI. Ocean data further suggest that ocean currents are dominated by eddy variability but generally tend to flow from the MHI toward the NWHI.

A key step in addressing this issue is a better estimation of upper ocean circulation and associated archipelago connections; best made through hydrodynamic (numerical) modeling. An archipelago scale model could provide crucial information on planktonic dispersal and connectivity among reef fish metapopulations; information needed to identify the stocks necessary for developing scientifically based management strategies and for establishing the numbers, sizes, and spacing of no-take MPAs within the Hawaiian Archipelago. Additionally, hydrodynamic models' predictive capability could be used to estimate changes in circulation due to climate variability and climate change, providing scenarios both of changes in connectivity as well as other important issues, such as forecasted degradation of corals reefs due to increasing temperatures.

The subcontract between NOAA Fisheries Service and the IPRC has been to extend IPRC's existing Hawaii ocean model domain, which is used at the IPRC to study the transports and eddy formation around the MHI, to include the NWHI. The whole archipelago model can then be used to conduct passive larval dispersion modeling experiments along the Hawaiian Archipelago.

Five deliverables, as detailed below, were proposed initially. Four have been completed. Because of technical difficulties with the model code there was no time in that allotted to the contract to tackle the fifth deliverable, namely a comparison of dispersion characteristics with other flow models. This task would require coordination with researchers from NOAA Fisheries Service who use other flow models.

- Configuration of HYCOM regional model for the Hawaiian Archipelago
- Implementation of particle tracking routines in the HYCOM model
- Preliminary analysis of flow and transport
- Preliminary passive larval dispersion modeling

- Initial comparisons of dispersion characteristics with other flow models

The rest of this report provides details on each of the completed deliverables.

2. Deliverables

2.1 Configuration of HYCOM regional model for the Hawaiian Archipelago

The Hybrid Coordinate Ocean Model (HYCOM, Bleck (2002)) is a fully three-dimensional ocean circulation model, with a hybrid vertical coordinate system that is isopycnal (along constant potential density surfaces) in the stratified ocean interior, level (along constant geopotential levels) in the ocean upper layer where water properties are near well-mixed, and sigma (terrain-following) for shelf-seas. This coordinate system is designed to best represent the different dynamic regimes within a single framework.

The HYCOM (version 2.2, the most recent) implemented for the Hawaiian Archipelago is obtained from the HYCOM Consortium for Data Assimilative Modeling (http://hycom.rsmas.miami.edu) whose goal is to develop an eddy-resolving, real-time global ocean prediction system with the objectives of depicting three-dimensional ocean state, provision of boundary conditions for coastal and regional models, and provision of oceanic boundary conditions for a global coupled ocean-atmosphere prediction model. This system is due to be transitioned for operational use by the US Navy and by NOAA at NCEP. By configuring the Hawaii regional HYCOM in line with the global system allows a regional prediction system to be readily developed in due course.

The domain for the Hawaiian Archipelago is 175ºE-150ºW, 15º-35ºN as shown in Fig. 1 which is the model bathymetry from the Smith-Sandwell database. The horizontal resolution is 1/12º (~8 km). There are 32 layers in the vertical but only the top 28 are active in the Hawaii region. In this domain, the top 4 layers are generally on a fixed level coordinate with spacing from 3m to 6m, and the deeper layers are in isopycnal coordinate as depicted in Fig. 2 for potential temperature along 158ºW in the top 200m. As a test experiment, the regional model is initialized with fields on January 1, 2003 from a global hindcast simulation provided by the HYCOM Consortium. The experiment is then run for years 2003 and 2004, and the solutions are stable. The lateral boundary conditions come from the same hindcast simulation. For this test experiment, no downscaling is performed, that is, the regional model and the global model are at the same horizontal resolution. However, downscaling has been done with an earlier version of HYCOM to 1/25º (4 km) for a domain encompassing the MHI and 1/100º (1 km) for a single island domain (Oahu). Similar downscaling will be carried out with the latest version of HYCOM in support of a SOEST-wide activity to establish an ocean observing system around the Island of Oahu.

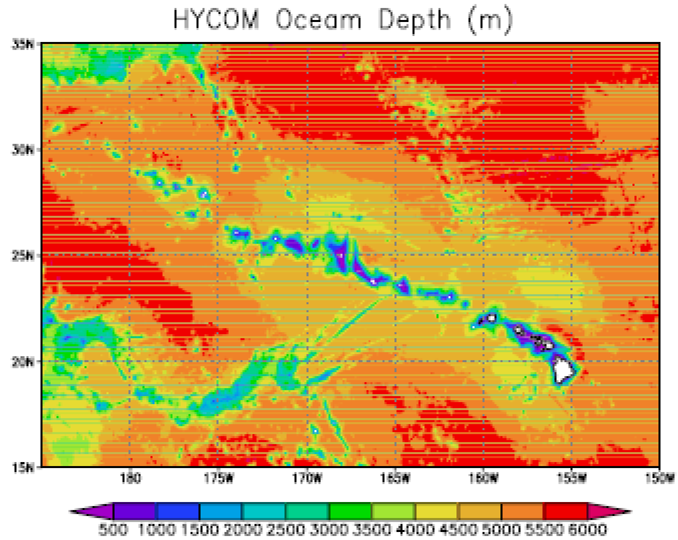


Fig.1. Bathymetry for HYCOM Hawaii Archipelago domain.

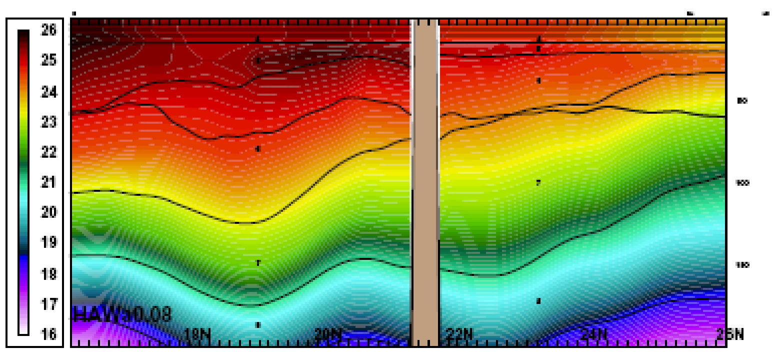


Fig. 2. Vertical section of potential temperature (°C) along 158°W from 16°N (left) to 26°N (right) for the top 200 m. Layer interfaces and numbers are marked. The thick black line indicates a diagnosed mixed layer depth.

The surface wind and heat and freshwater fluxes are from the Navy Operational Global Atmospheric Prediction System (NOGAPS) at a resolution of 0.5º to 1.0º as in the global HYCOM simulation. At such resolution, the characteristic wind patterns resulting from the interactions of the northeast trade winds and the high mountains of Hawaiian Islands are not well represented. Plans are in place to replace the NOGAPS winds with observations (e.g. QuikSCAT) and high-resolution regional atmospheric model output (e.g. MM5). These local wind anomalies affect mostly the eddy field in the lee of the islands.

2.2 Implementation of particle tracking routines in the HYCOM model

Particle tracking capability has been recently implemented by the HYCOM

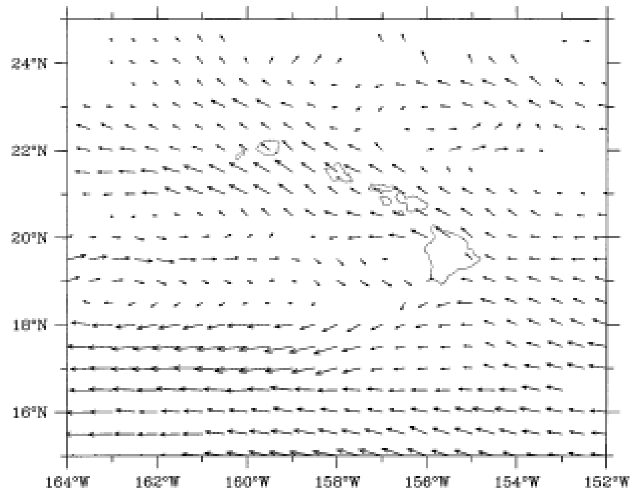
Consortium group into HYCOM version 2.2 for parallel computer systems. It supports 3-d Lagrangian floats which are advected by horizontal and vertical velocity components, isopycnic floats which are advected by along-isopycnal velocity components on specified density layers in the ocean interior, isobaric floats which are advected by horizontal velocity components at a fixed pressure depth, and stationary floats which act as instruments or moorings. Isobaric floats, if placed near the ocean surface, may be considered as simulated surface drifters, which in turn may represent passive fish larvae.

Implementation of surface drifters consists of two main steps, first, spatial interpolation of the velocity components to drifter locations, and second, interpolation in time for drifter advection. For spatial interpolation, a cluster of 16 model grid points surrounding the drifter position is determined. Land points and points that sit at the ocean bottom are masked from the interpolation. If 10 or more points remain, a two-dimensional polynomial surface is fit to the data to perform the interpolation. A bilinear scheme is used if there are fewer than 10 points. A drifter is considered to have gone aground if there are two or less active ocean points. For temporal interpolation, the 4^{th} order Runga-Kutta algorithm is used, which requires model velocity at the current time step and two earlier time steps. To facilitate this requirement, drifter advection is performed as frequently as every 4 model time steps or less during the model integration.

2.3 Preliminary analysis of flow and transport

In the region encompassing the MHI, the main current system of the mean circulation includes the westward North Equatorial Current (NEC) to the southe of the MHI, the Northern Hawaiian Ridge Current (NHRC) flowing towards the northwest along the northern side of the ridge, the Hawaiian Lee Current (HLC) also flowing towards the northwest along the southern side of the ridge, and the eastward Hawaiian Lee Countercurrent (HLCC) at about 19°N (Fig. 3, upper panel) as estimated from real ocean drifters (Firing et at al. 1999; Qiu et al. 1997). Fig. 3, lower panel, shows the mean flow field for years 2003 and 2004 from the HYCOM simulation. The main current system is well represented. In addition, it shows that the mean channel flows between the islands are northward. The channel flows require validation against observations if available.

North of the MHI, there is a definite signature of a northwestward flow along the ridge until about 25° N where a branch of the eastward North pacific Current (NPC) exists, with a stronger branch further north at about 30° N (Fig. 4). The strength of these current branches is variable in time.



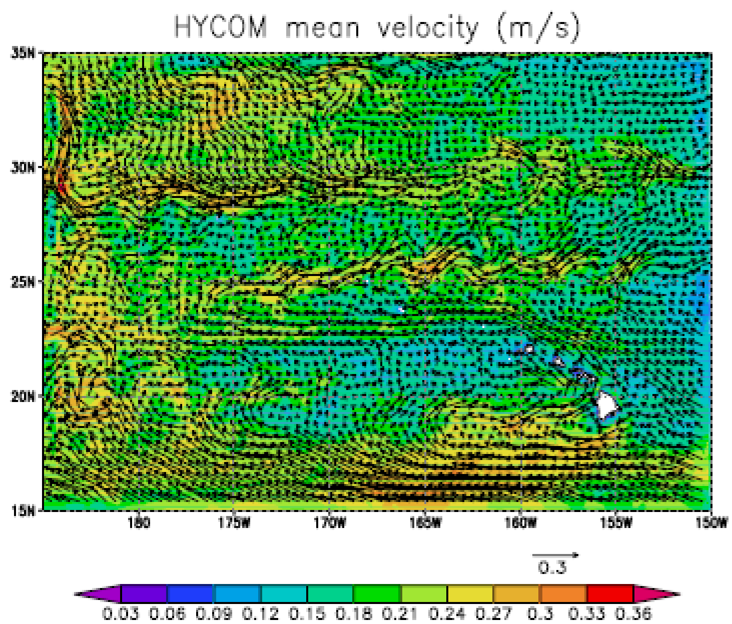


Fig. 3. Mean flow field for the MHI region, estimated from real ocean drifters (upper) by Fring et al. (1999) and Qiu et al. (1997), and from the HYCOM model (lower).

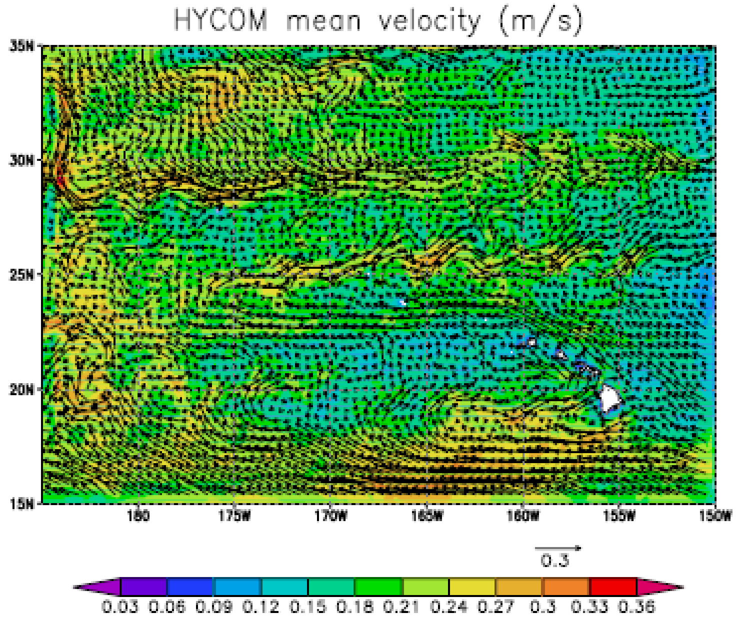


Fig. 4. Mean flow field for the whole of the Hawaiian Archipelago from the HYCOM model.

2.4 Preliminary passive larval dispersion modeling

As a test of the particle tracking routines in HYCOM, surface drifters representing fish larvae were released around Oahu at two proposed Marine Protected Areas, namely EMPA (157.64ºW, 21.4ºN) and WMPA (158.36ºW, 21.61ºN), and Penguin Bank (157.38ºW, 20.98ºN) during spring of 2003 at monthly intervals (April, May and June). The particles were tracked for 6 months or more. Fig. 5 shows tracks of representative drifters, two from each release site. The different characteristics of the drifter tracks for each of the three months highlight the highly variable flow. For drifters released in April 2003 (Fig. 5a), all traveled northwestward from the MHI to the NWHI. Drifters released in May 2003 followed the ridge initially then diverted to the northeast upon encountering the NPC (Fig. 5b). The drifters released in June 2003 exhibited a slightly more varied pattern (Fig. 5c). The ones released at Penguin Bank became grounded near the shores of Kauai. Others traveled northwestward along the ridge with some diversions on the way, one of which looped around and began traveling eastward with the NPC. With exceptions, the designated MPAs do appear to be good spawning grounds for dispersing passive fish larvae to the NWHI by ocean currents.

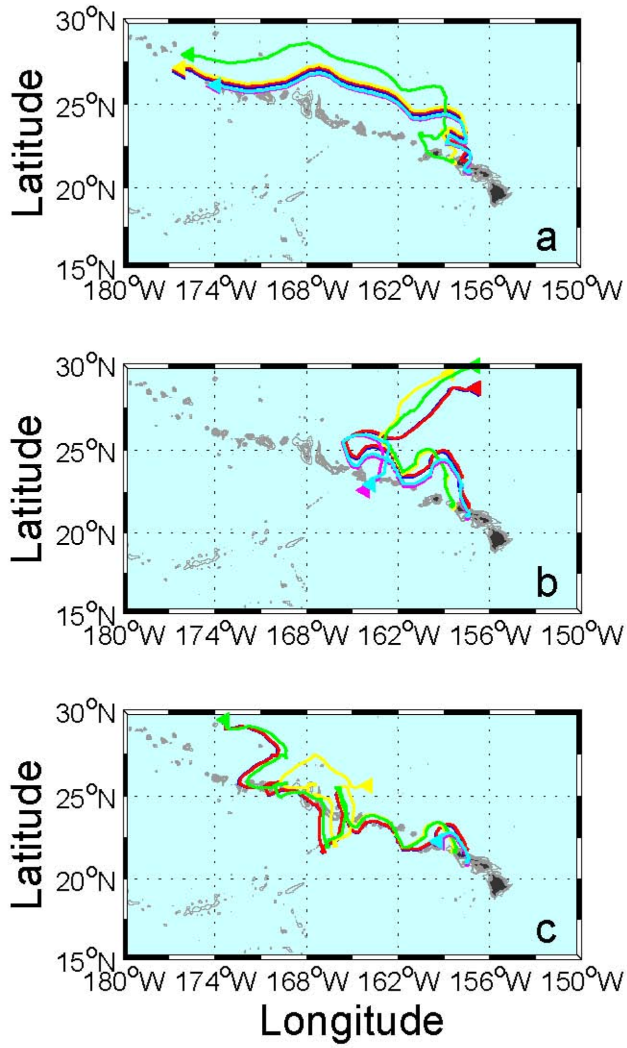


Fig. 5. Tracks of drifters released at the MPAs around Oahu in (a) April 2003, (b) May 2003, and (c) June 2003.

3. Conclusion.

The feasibility study undertaken under the contract has demonstrated the utility of the HYCOM model system for studying larval dispersion around the Hawaiian Islands and the connectivity of the archipelago. The preliminary results have highlighted the very variable nature of the flow and dispersion characteristics from month to month and for the need for the regional model to be embedded in a basin-scale model that captures correctly the eddying flow arriving from the east. The results also demonstrate the need for an ensemble of particle releases in order to obtain robust statistics of particle trajectories and dispersion characteristics. One deficiency in the model presented here is the representation of the local wind field around the islands which greatly influences the eddy field in the lee of the islands. A related study has demonstrated that using the output from a regional atmospheric model greatly improves the lee eddy field in the ocean model. The operational model system being developed by SOEST as part of the Hawaiian Ocean Observing System will use the HYCOM regional model and include local wind effects. This system will be a good tool for future studies of both near and far field larval dispersion.

4. Acknowledgements

We wish to thank Joe Metzger, NRL, for extracting model output from the global model for the Hawaiian Achipelago, Alan Wallcraft, NRL, for maintaining and updating the HYCOM model code, Jim Potemra, IPRC, for assisting with data transfer.

5. References

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