1. PROJECT INFORMATION

GOA IERP Project Number:	G84
Title:	Exploring temporal and spatial variability in Gulf of Alaska groundfish dynamics with integrated biophysical models
Overall project duration	May, 2010 - February, 2015
Overall project funding	**$999,995**
Report period	October 2010 to 30 April 2011
Report submission date	April 29th 2011
Lead Author of Report	Georgina Gibson and Sarah Hinckley (co-Lead PIs)

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2. PROJECT OVERVIEW

a. Briefly (4-5 sentences) describe the core purpose of your project, and the underlying need for this research.

Groundfish recruitment in the Gulf of Alaska is thought to be controlled by physical processes (i.e. climate and transport) and biological processes (i.e. growth and predation) experienced between offshore spawning sites and the end of the young of year (YOY) stage. We will use the Regional Ocean Modeling System (ROMS), a Nutrient-Phytoplankton-Zooplankton (GOANPZ) model, and Individual-Based Models (IBMs) to examine recruitment mechanisms and derive indices related to recruitment for five ground fish species; arrowtooth flounder, walleye pollock, Pacific cod, Pacific Ocean perch, and sablefish. We will also incorporate the indices in a multispecies model (MSM) to explore the consequences of recruitment variability on the GOA ecosystem and fisheries. Indices produced, and conclusions about the effects of physical and biological processes on the GOA ecosystem under different physical regimes will aid in the management of these important fish stocks.

b. State the specific GOAIERP hypothesis or hypotheses that your project is addressing.

Our project will address two of the overarching GOAIERP hypothesis:

1) **The gauntlet**: The primary determinant of year-class strength for marine groundfishes in the GOA is early life survival. This is regulated in space and time by climate-driven variability in a

biophysical gauntlet comprising offshore and nearshore habitat quality, larval and juvenile transport, and settlement into suitable demersal habitat.

2) **Regional comparison:** The physical and biological mechanisms that determine annual survival of juvenile groundfishes and forage fishes differ in the eastern and western GOA regions.

To achieve the objectives of our project we will address the following testable hypotheses with our suite of models:

1. *Historical environmental variability in the GOA can be characterized in terms of a few (≤ 6) distinct physical regimes and we can identify these regimes from ROMS simulations.*
2. *Recruitment variability of the five focal species is primarily influenced by variability in the proportion of young fish transported from offshore spawning areas to nearshore nursery areas (connectivity) due to interannual differences in the strengths of the physical regimes that characterize the GOA environment.*
3. *Recruitment variability is secondarily influenced by the survival of young fish successfully transported to nursery areas, which varies due to differences in physical factors (wind speed and direction, water temperature, runoff, mixing) and biological processes (prey abundance, competition, predation) encountered along the transport pathways.*

c. List the specific objective(s) of your research project.

The objective of this project is to identify how recruitment of five target groundfish species in the GOA is affected by environmental variability in the region. We will project the effects of different environmental regimes, and the resulting recruitment variability, on upper trophic level ecosystem dynamics for the GOA under current fishing regimes.

- **NEP5 Regime Analysis:** Use Empirical Orthogonal Function (EOF) and other analysis tools to identify a small number (≤ 6) of distinct physical regimes that comprise the major components of environmental variability in the GOA. Categorize each year as representative of a particular regime.
- **IBM Connectivity:** Calculate the proportions of individuals that arrive at juvenile nursery areas from specific source areas (spawning regions or early larval distributions).
- **Trajectory analysis:** Examine the differences between survivors and non-survivors (or those who do not reach nursery areas) by examining correlations between physical and LTL variables and individual characteristics along individual trajectories from the IBMs through the YOY stage
- **Indices: C**alculate indices related to recruitment success from the IBM results for each of the five focal groundfish species. Transform indices into anomalies from mean recruitment biomasses.
- **MSM simulations:** Incorporate recruitment indices from the IBMs into the MSM model to test how the effects of the different environmental regimes on recruitment interact with population dynamics processes and fisheries.

3. PROGRESS SUMMARY

a. Provide a table showing the timeline and milestones for the current reporting period only.

	2010		2011			
Research Activity Milestone	3	4	1	2	3	4
Run 3km ROMS/GOANPZ for prior years PI's: Coyle						
NEP5 Regime Analysis PI's: Ladd & Hermann.						
Comparison between Float Tracking Tools PI's: Parada, Stockhausen, Gibson						
Construction of IBMs for the 5 target species Dependency: LTL, MTL and UTL information PI's: Parada, Stockhausen, Gibson, Hinckley						

b. Describe report period progress.

NEP5 Regime Analysis: During this reporting period we have begun the regime analysis which consists of validation of the NEP5 ROMS run and the pattern analysis. Progress and results are described in the Results section, below.

IBM Connectivity, Trajectory Analysis, and Indices:

In order to accomplish these three objectives, several preliminary steps need to be taken. First, a comparison of the different Float Tracking tools (DisMELS, Ichthyops, and the offline ROMS float tracking) need to be compared to the online ROMS float tracking), to make sure that they are producing similar results. Second, conceptual models for all IBMS need to be developed, parameters and algorithms for each IBM collected, and the IBMs themselves developed. Only by accomplishing these tasks, can the IBM Connectivity, Trajectory Analyses and Development of Indices be carried out. Below is a brief description of what we have accomplished towards the main objectives; initial results are presented in the Results section.

- **Comparison between Float Tracking Tools**

During this reporting period we developed the protocol that will be used to compare the skill of our IBM tools to track 'floats' relative to the ROMS float tracking, online and offline. This step is necessary in order to assess offline skill of two different IBMs in capturing 'truth' in float tracking. Preliminary float tracking experiments have been performed using the DisMELS IBM tool.

- **Construction of IBMs for the 5 target species**

Conceptual models for each of the five target species have been developed. The level of model complexity varies with species; some species are better understood than others. The conceptual models include information on depth and location of spawning, length of stage duration, process rates and behaviors where available. The pollock, Pacific cod and sablefish IBMs will be constructed in Ichthyop, an IBM package developed by Lett et al. and adapted by Parada for our species and region. A flow chart of the Ichthyop-based IBM code was not available so time was spent developing one. This will be a useful tool during model development and will facilitate discussion of IBM functionality with GOAIERP field PIs. The arrowtooth and POP IBMs will be developed in DisMELS software, an IBM package developed by Stockhausen.

MSM simulations:

To date no progress has been made on this objective. Within our timeline this work is not scheduled to begin until 2014.

c. Describe preliminary results.

Run 3km ROMS/GOANPZ for prior years

The 3km ROMS-NPZ model has been run for 2001-2003 and movies of model output for 2001 were presented to GOAIERP field scientists at the meeting in early December 2010 (that focused on field work). The purpose of this presentation was to stimulate discussion of how features seen in the movie output (such as eddies, on or offshore flow, etc.) might affect the distribution and timing of production, therefore affecting field sampling.

To facilitate discussion of NPZ model results with the field PIs, a series of movies for iron, nitrate and mesozooplankton were produced for 2001. Iron concentration was computed to 30 m depth, nitrate concentration to 25 m depth, and mesozooplankton to 100m depth for each location and day. The station locations for field sampling, as determined by December 2010, were overlain on the movies so the time evolution of variables could be followed relative to station locations.

Also, hydrographic fields were extracted from the daily average files for 2001, downloaded to hard drives and delivered to the IBM modelers so they could begin formulating their code and testing the performance of their float tracking algorithms for the IBMs.

NEP5 Regime Analysis

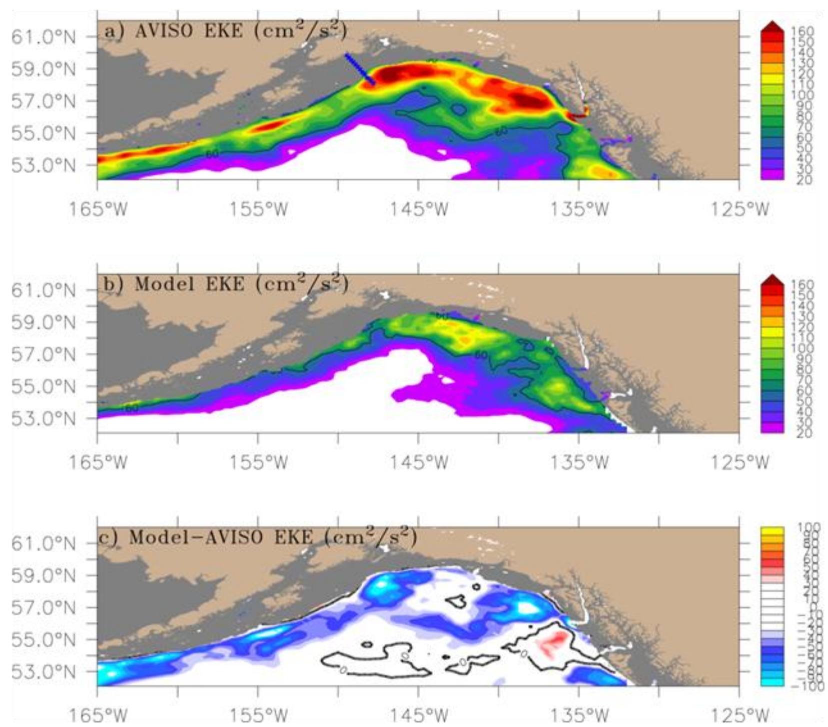

Figure 1. a) Time mean (1993-2005) EKE from AVISO data in the Gulf of Alaska. The Seward CTD stations are marked by the blue line. b) Time mean (1993-2005) EKE from NEP5 simulations. c) Difference in modeled and observed EKE.

General performance of ROMS Northeast Pacific (NEP) and Gulf of Alaska (GOA) models has been described in previous studies [i.e. Hermann et al., 2009; *Dobbins et al.*, 2009]. Here we provide a brief description of model validation for the particular ROMS NEP5 run used in this study. We used Seward line 1997-2004 CTD data and AVISO satellite sea surface height (SSH) observations for model-data comparisons. The variables we examined along the Seward Line include: temperature (T), salinity (S), and mixed layer depth (MLD). We seek to answer the following questions: 1) Is the model able to reproduce the observed seasonal cycle of MLD and its interannual variability? 2) What is the magnitude of model T and S errors in mean seasonal cycle (i.e., the monthly climatology), and in interannual variability (varying month by month and year by year)? 3) Are model errors larger in the warm (spring and summer) or cold (fall and winter) seasons? We differentiate cold and warm seasons because of implications for biological processes. Additionally, we computed eddy kinetic energy (EKE) from observed and modeled SSH and compared time-mean EKE spatial patterns as well as temporal variability of EKE.

Both CTD data and NEP5 simulations show a summer minimum MLD of 15-20 meters along the Seward stations. The model also does a faithful job in capturing the timing of seasonal MLD evolution. However, simulated multi-year mean monthly ocean temperature is 0.5-1.0°C too warm, and the warm bias is concentrated near the top 20 meters in the summer months (June-July-August).

Because of its 10km resolution, NEP5 multi-year mean EKE averaged over the GOA domain is 20% weaker than observed, (comparing Fig. 1 a and b). Although weaker, the simulated spatial pattern (Fig.1, panel b) has the same character as observed (Fig.1, panel a): the high EKE band extends into ocean interior in the eastern GOA but is confined near the shelf-break in the western GOA. EKE patterns were analyzed using EOF and Extended EOF (EEOF) analyses of the EKE time series at all locations. Our goal here is to identify the years and locations where eddies predominate, in both models and data. Once a proper correspondence between models and data is established for spatial eddy statistics, the model may be used as a proxy to identify which large-scale atmospheric/oceanic drivers result in eddy-rich and eddy-poor years. Representative years will then be examined at fine spatial resolution via the CGOA model. A preliminary EOF analysis of weekly NEP5 output (Fig. 2) demonstrates how the major El Nino event of 1997-1998 resulted in higher EKE in the eastern Gulf, in both model and data. EOF analyses of perturbation SSH (Hermann et al., 2009) also demonstrated this strong El Nino signature in an earlier version of the NEP model (and altimeter data).

We intend to use the NEP5 model (time coverage 1969 – 2005; spatial resolution 10 km) to examine temporal variability in physical mechanisms that may affect recruitment (Pattern Analysis). These processes include wind forcing, cross-shelf transport, eddies, and stratification on the shelf. In addition to EKE, we have examined velocities along the 200m and 1000m isobaths from the model (Fig. 3). While the majority of transport is along the shelf-break (Alaska Current/Alaskan Stream) a small component of flow results in onshore or offshore transport. West of 150°W, current speeds along the 1000 m isobath (in the Alaskan Stream) average ~25 cm s^{-1} in the surface 50 m while currents speeds normal to the isobath average ~ 1 cm s^{-1} in the off-shelf direction. On the eastern side of the basin (146°W – 136°W),

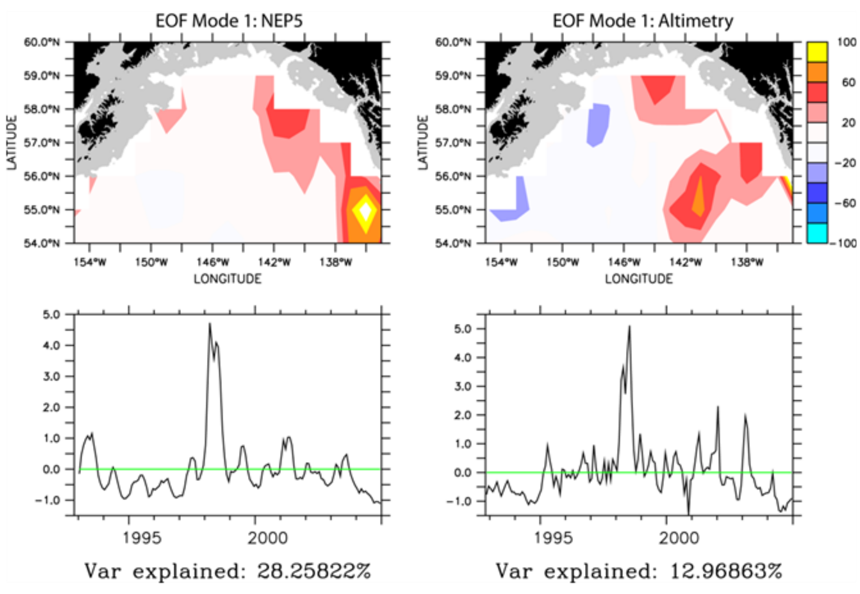

Figure 2. EOF mode 1 of NEP5 model runs (left) and Altimetry data (right).

the along isobath flow averages ~13 cm s^{-1} while the flow normal to the isobath averages ~2 cm s^{-1} in the on-shelf direction. Speeds (both along and across isobath) are fastest in the winter months and weaker during the summer. The cross-shelf transport is related to multiple mechanisms, including wind forcing, bathymetric steering, and eddies.

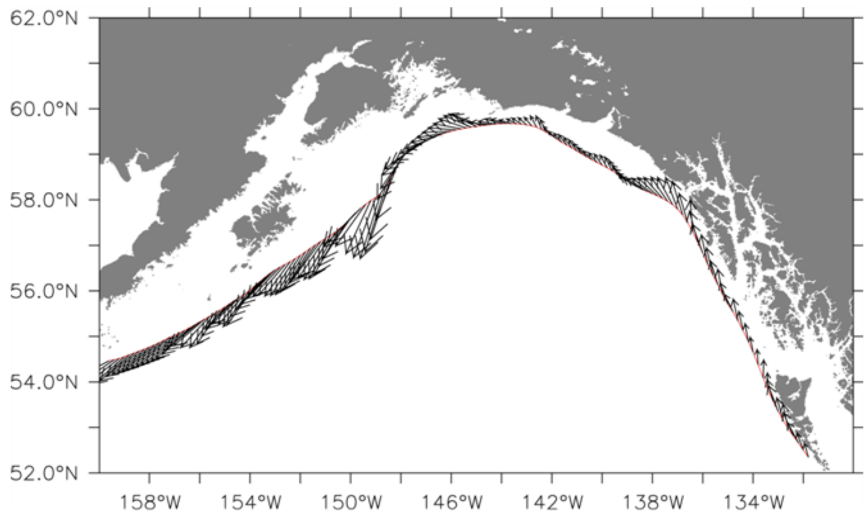

Figure 3. Velocity along the 1000m isobath averaged over top 50m and 1969 -- 2005.

Comparison between Float Tracking Tools

Considerable time was devoted to a discussion of how best to evaluate the ability of the float tracking algorithms in our alternative IBM tools to accurately reproduce actual float tracking as delivered by ROMS online float tracking. The protocol for the comparison experiments was solidified and is presented below:

PROTOCOL FOR COMPARISON OF FLOAT TRACKING TOOLS:

1) Experiments:

ROMS online =truth (George/Ken)

- ROMS offline (George/Ken)
- ICHTHYOP (Carolina)
- DisMELS (Buck)

2) Float Behavior:

Particles will be passive, Lagrangian drifters with no biology and no diffusivity

3) Initial particle locations:

Particles will be seeded uniformly throughout the model domain shoreward of 1500m with a 0.5deg horizontal spacing. Locations have been determined and distributed to the PIs conducting the experiments.

4) Release times:

Particles will be released Feb 1st, April 1st, June 1st 2001.

5) Release depths:

At each location, particles will be released at set depths: 5, 10, 20 40, 60, 100, 200, and 400 meters. Floats will be treated as neutral density 3D Lagrangian particles.

6) Tracking Duration:

Floats will be tracked for 180 days.

7) Time Step (External from ROMS):

For the offline tools, daily average, tidally filtered files of hydrographic forcing from ROMS will be used to drive the floats.

8) Time Step (Internal to IBM):

This will be sub-daily and can vary by offline tool. This is a tunable parameter that can be adjusted to improve the ability of the offline tools to track floats.

9) Analysis:

For each float track we will calculate the sum of squared distance deviation ratio (ssddrs) time series to assess deviation from "truth". This will tell us how well the different IBM tools are doing and what the rate of divergence is. Horizontal and vertical tolerance parameters needed to determine ssddrs will be selected following discussions with field PIs.

Stockhausen has identified initial locations for the release of simulated floats based on criteria PIs in the Modeling Project had previously decided upon: that floats would be released at 0.5° x 0.5° horizontal spacing across the model domain inside the 1500 m isobath (Fig. 4). As a preliminary trial, Stockhausen also compared the results from two float tracking simulations using DisMELS and daily ROMS CGOA model output. One simulation was performed using a Lagrangian integration time step of 20 (model) minutes while the other was performed using an integration time step of 1 day. While the results of this comparison (Fig. 5) do not directly address the issue of DisMELS integration accuracy compared with "online" ROMS, they do indicate the tradeoffs associated with increasing the integration time step used in DisMELS itself (i.e., internal accuracy vs. computational resources). A 1-day integration time step yields substantially different results from the 20 minute time step for many of the sample floats shown and, as a consequence, may not be acceptable.

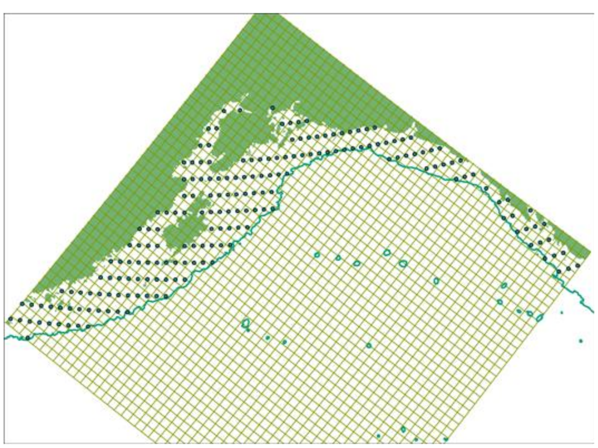

Figure 4. Initial horizontal locations (circles) for simulated floats in the float tracking experiment. Also shown are the ROM CGOA grid (squares are 5 x 5 grid cells), the 1500 m bathymetric contour (thick green lines), and the ROMS land mask (solid green).

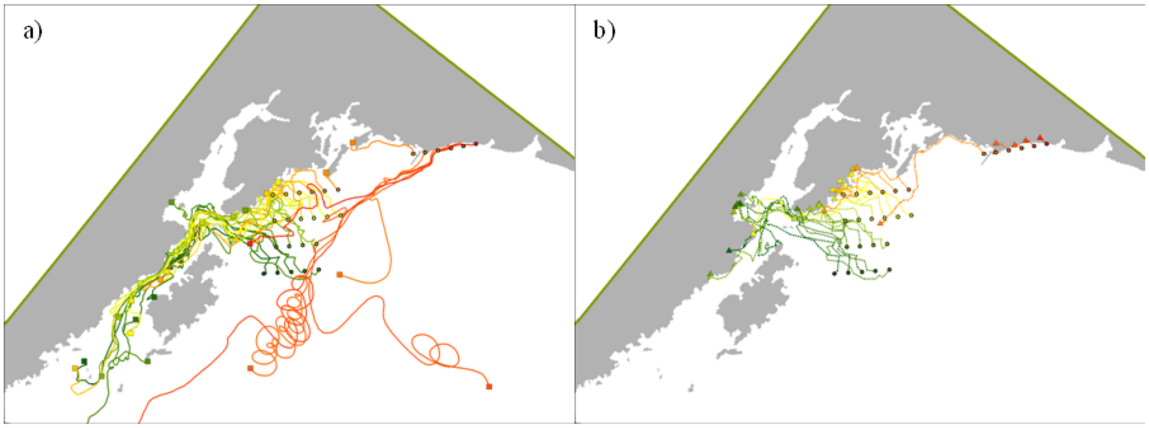

Figure 5. Comparison of simulated tracks for selected floats using a 20-minute lagrangian integration time step (a) and a 1-day time step (b). Circles represent starting locations, squares (a) and triangles (b) represent final locations of simulated floats after 85 model days. Individual float tracks use the same color coding in both maps.

Construction of IBMs for the 5 target species

1. **Conceptual Models:** Figure 6 shows an example of the conceptual models that have been developed for each of the target fish species.

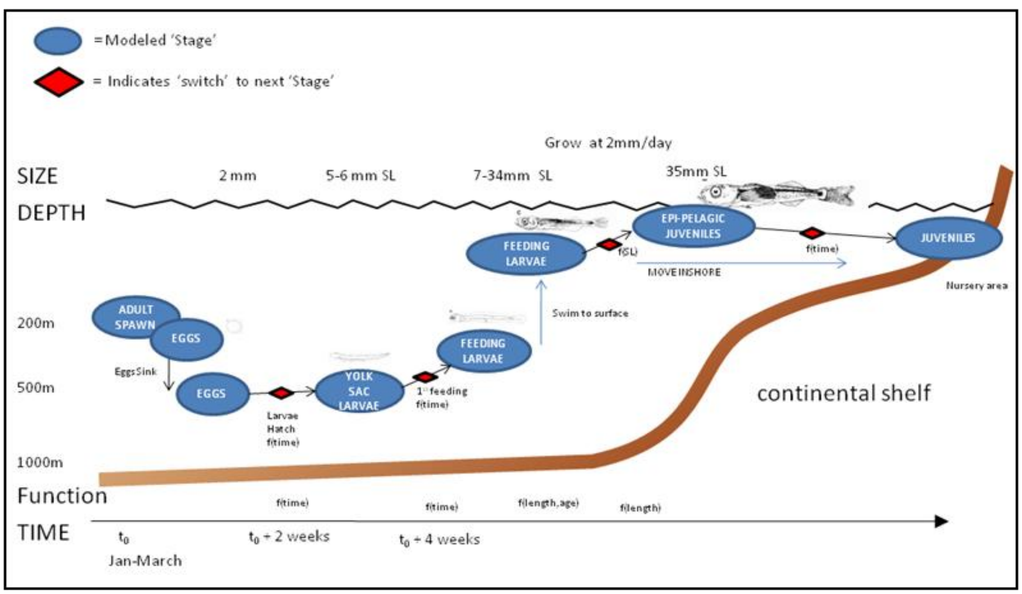

Figure 6. Conceptual model of sablefish life history. Similar models have been developed for each of the target fish species.

2. **DisMELS**: Although DisMELS has been used successfully with other ROMS models, it was not initially compatible with the ROMS CGOA model--primarily due to differences between that model and others in the values used to indicate land cells ("land masking"). Modifying DisMELS to run with the ROMS CGOA model ouptut involved a non-trivial effort to accommodate the land

masking scheme used in the CGOA model. This task has been completed and DisMELS now runs with ROMS CGOA model output.

3. **Predator Stomach Sampling Protocol:** An in-depth analysis of the AFSC Food Habits database to identify potential fish predators of YOY of the 5 main species was conducted. An analysis was also done to aid in development of predator stomach sampling plans for GOAIERP, AFSC Groundfish, and AFSC Hydroacoustics cruises. In this analysis the likelihood of specific predator species eating each of the 5 GOAIERP species in each major GOAIERP region was identified. This analysis enabled us to determine the number of samples of each predator species to collect in each region.

4. **Code Flow Charts:** A flow chart (Fig. 7) was developed for the Ichthyops model, to aid in understanding and explanation of the IBMs which will use this tool.

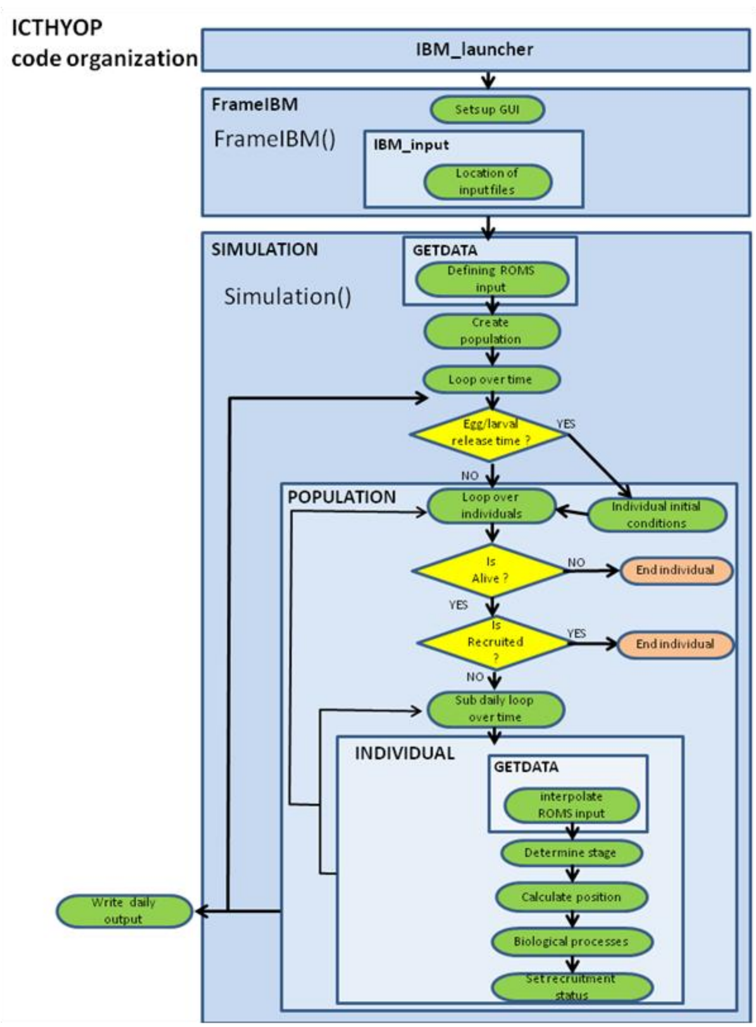

Figure 7. Flow chart to show the code organization of the Icthyop IBM tool

d. Describe integration activity.

- All PIs attended the All GOAIERP PI meeting in February 2010. Additionally we had an all-day, face-to-face GOAIERP modelers meeting on April 15th, and have conducted monthly PI telephone calls.
- Coyle is participating in the April-May 2011GOAIERP cruise to collect field samples around Kodiak.
- Gibson and Hinckley have had discussions with Mark Zimmerman about the habitat maps under development through the UTL project with regards their incorporation into the IBMs.
- Gibson has had discussion with Kalei from the UTL project with regards the state of knowledge on sablefish.
- Hinckley has collaborated with Olav and Jessica Tingg (AFSC) to set up the main (and a modeling) Sharepoint sites, that are now up and running and in active use by the group.
- Hinckley has had extensive discussions with Kerim Aydin, Sarah Gaichas, Troy Buckley and Ivonne Ortiz (all AFSC) about the design of a sampling plan for stomachs of potential predators of the young stages of the 5 main GOAIERP species.
- Hinckley has had discussions with Mike Canino (AFSC) about genetics sampling of the 5 primary species on GOAIERP cruises.
- Hinckley has had discussions with GOAIERP field PI's about sampling potential predators of the 5 main species on the GOAIERP cruises, and also about taking genetics samples.
- Hinckley has had discussions with Tom Hurst (NOAA) about conceptual models, and parameters and algorithms to be used in the Pacific cod model.
- Hinckley has participated in GABI and Retrospective Team activities.
- Stockhausen has discussed with D. Blood (AFSC) a possible re-analysis and incorporation in the arrowtooth flounder DisMELS model of the results from Blood et al. (2007) on temperature dependence of egg development in that species.
- Stockhausen has discussed with K. Bouwens (ADF&G) possible re-analysis and incorporation in the arrowtooth flounder DisMELS model of the results from Bouwens et al. (1999) on growth of larval arrowtooth flounder.
- Francis Weise has participated in the GOAIERP modelers monthly PI calls and the in person modelers PI meeting on April 15th. At this time it was decided that a full EMC structure did not make sense for this project, nor was a Modeling Manager necessary. The funds that were originally set aside for this will be reserved and can be used should the need arise at a later date for expertise outside the PIs knowledge or if feedback from impartial person was deemed appropriate.

e. Describe any concerns you may have about your project's progress.

ROMS currently includes simulation of tides in the circulation model. Tidal aliasing can result if tides are not filtered out before writing output to the average files. The test files which were generated as described above and are being used to test the float tracking algorithms do not have the tides filtered out. It was recently realized that this step had to be taken prior to using the ROMS output to force the offline IBMs, so this is being done. However, to date our project has progressed in accordance with our projected timeline and no problems have been encountered.

f. Poster and oral presentations at scientific conferences or seminars

The only presentations that have been made have been for GOAIERP internal meetings.

g. Education and outreach

To date no Education or Outreach activities have been performed under this project.

4. PROGRESS STATUS

We are pleased with the progress of our project to date. The only accomplishment that was due to be finalized within this reporting period was the NPZ model output handoff which has been accomplished. The other activities that we were working on during this reporting period are well under way but are not due to be finalized until subsequent reporting periods.

5. FUTURE WORKPLAN and DATA DELIVERY

Workplan

What	*Who*	*Start and end dates*	*Other key dates*
NEP5 regime analysis	Hermann, Ladd	Oct 2010-Dec 2011	
Comparison between Float Tracking Tools	Parada, Stockhausen, Gibson	Oct 2010-Sept 2011	
Construction of IBMs for the 5 target species	Parada, Stockhausen, Gibson, Hinckley	Oct 2010-Sept 2012	
Develop experimental design for model runs	Coyle Hermann, Ladd, Parada, Gaichas,Stockhausen, Gibson, Hinckley	May 2011-March 2012	
Run ROMS/GOANPZ model on NEP grid for boundary conditions for CGOA grid	Hermann, Hedstrom,Coyle, Gibson	Oct 2011-Dec 2012	

Data delivery.

GOAIERP Data Delivery Table		
Data type for delivery	Delivery Month & Year	Person sending data, with email address
NONE		

References

Dobbins, E. L., A. J. Hermann, P. Stabeno, N. A. Bond, and R. C. Steed (2009), Modeled transport of freshwater from a line-source in the coastal Gulf of Alaska *Deep Sea Res. II*, *56*(24), 2409-2426, doi:10.1016/j.dsr2.2009.02.004.

Hermann, A. J., E. N. Curchitser, D. B. Haidvogel and E. L. Dobbins. 2009. A comparison of remote versus local influence of El Nino on the coastal circulation of the Northeast Pacific. Deep Sea Research II, doi:10.1016/j.dsr2.2009.02.005.