Report on efforts to model and replicate the paths of the Carbon Explorers deployed April 2001.
NOAA GC04-304 (James Bishop, PI)

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January, 2006

I. Introduction

This report is intended to document the efforts I made to model the North Pacific in order to understand the path of the Carbon Explorers, deployed April 10, 2001. Interestingly, these floats moved westward and northward in the first two months after deployment at Ocean Station PAPA (hereafter, OSP), rather than eastward as expected. My intent was to force the model with the observed winds and temperatures in order to replicate the path of the floats during this time period. I then wanted to compare these paths with the conditions in 2003, when the floats took a more accelerated path and saw different biomass signatures. Unfortunately, I was never able to replicate the path of the 2001 floats: the model floats always went eastward. So, this report is a documentation of what I tried, some thoughts about why I was not successful, and a final section explaining where the files are located at NERSC, in case someone else wants to expand on the current work.

II. General Model Information

I ran the POP model at NERSC on the Seaborg computer. The CCSM version of POP comes with two supported grids: the gx3v5, or approximately 3 degrees by 3 degrees (low resolution hereafter) and the gx1v3, or approximately 1 degree by 1 degree (high resolution hereafter). The low resolution grid only has about 6 grid points in the Gulf of Alaska and the sign of the flow at OSP cannot be determined adequately from a linear interpolation of these points, so it is necessary to use the high resolution grid for this study.

My intention was to run at low resolution for a long spin-up time (~ 100 years), and then run at high resolution for the actual April 2001 simulations. Unfortunately, I had a lot of trouble with the low resolution spin-up. Although I tried varying the viscosity and time steps repeatedly, I kept getting noisy oscillations at the grid scale in the deep ocean. I finally found a viscosity scheme that gave a seemingly stable solution. I then built a MATLAB script that interpolated the low resolution temperature and salinity onto the high resolution grid. However, there remained some instabilities in this high resolution data and I could not get the model to initialize.

So, in the end I ran the model at high resolution starting from mean Levitus climatological conditions and forced using mean April forcing conditions for four months, and then I began the two month analysis simulation. To run the model, forcing fields must be provided for the heat flux, fresh water flux, and momentum flux (windstress). The two cases I ran both used the same temperature and freshwater forcing, but I tried both monthly averaged NCEP wind forcing and daily Quikscat wind forcing, as detailed below.

III. Temperature and Salinity Forcing

In order to simulate April 2001 conditions, I used the NOAA NCDC ERSST version2 SST data, which is reported to be "improved extended reconstructed global sea surface temperature based on COADS data". I accessed this data from the portal at Columbia, http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCDC/.ERSST/ . This is monthly averaged data, so I used the April 2001 month as a constant forcing for the model. This forcing was achieved using a restoring scheme, so that the surface model temperature was relaxed back to the NOAA values with a timescale of 0.5 days. This constitutes strong restoring, so the model surface temperature is effectively set at the NOAA values.

I was not able to find a similar 2001-specific dataset for freshwater input. POP has the option of being forced using either explicit freshwater fluxes or calculating a "virtual flux" based on surface salinity information. So, I used the April climatological salinity data from the Levitus dataset, http://iridl.ldeo.columbia.edu/SOURCES/.LEVITUS94/ . Again, this forcing used a restoring scheme with a timescale of 0.5 days.

For both sets of data, the input files had to be processed and put on the correct POP grid. POP uses a grid with the north pole centered over Greenland, so the model grid has a complicated geometry. I built MATLAB scripts (prep_forcing_files.m and prep_forcing_files_core.m in /data/66/henning/MATLAB_DIAG/OCEAN_BGC) that use the griddata function to convert from the data grid to the model grid. I also had to convert the salinity data from psu to the model units of g/g by dividing by 1000.

IV. NCEP Mean Wind Forcing

The only remaining forcing fields to specify are the longitudinal and latitudinal direction windstress values. First I used monthly averaged values from the NOAA/NCEP reanalysis data, http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP-NCAR/.CDAS-1/ . This case was intended to provide the mean model conditions in April 2001 based on this model/data hybrid windstress dataset. Again, this dataset had to be interpolated to the model grid, and the values had to be multiplied by –10 to change from Pascals to dynes/cm^2 and to change the sign of the reanalysis data: in the reanalysis data, positive windstress implies the ocean adds momentum to the atmosphere, but the model needs positive to imply the atmosphere adds momentum to the ocean.

I ran this case for six months of spinup time and then ran for two months, saving the model variables averaged over each day for analysis. Figure 1 below shows the sea surface height in centimeters from this analysis time in the North Pacific. The sea surface height determines the barotropic mode of circulation, and thus serves as a proxy for the depth-averaged velocity streamfunction. In general, the flow is clockwise around the Gulf of Alaska (clockwise around negative values), with eastward flow occurring in the southward portion of the figure (counter-clockwise around positive values). The location of ocean station PAPA is shown with the X and occurs near the boundary between the Gulf of Alaska return flow and the eastward moving current.

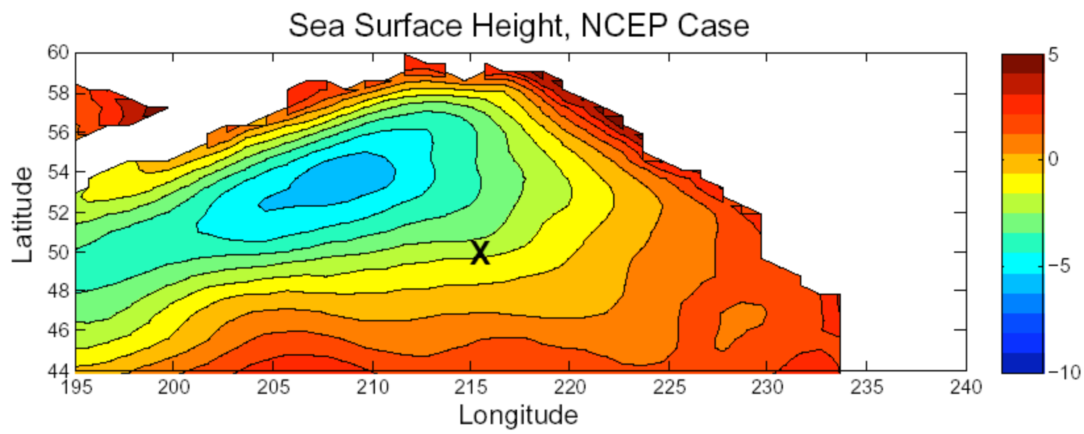

Figure 1: The sea surface height averaged over two months of data in centimeters for the NCEP reanalysis case. This is a proxy for the streamfunction of the depth-averaged flow. Flow is clockwise around negative values and counterclockwise around positive values. The X denotes the position of OSP.

Using the daily-averaged output current velocities, I wrote an offline script to calculate the trajectory of a float deployed at the same location as the actual Carbon Explorers on day 1 of the simulation. The script locates the four closest gridpoints to the current float location, linearly interpolates the zonal and meridional velocities at the current time to get a velocity vector, and then calculates the new location if the float moves according to that vector for one day. Because the Carbon Explorers surfaced and then plunged to depth multiple times per day on a two day repeat cycle, the velocities used were the average velocities between the surface and 1000 meters depth. The direction of the current does not vary dramatically with depth, although the magnitude does, with lower currents occurring away from the surface.

Figure 2 shows the original figure from Bishop et al., 2002 with the actual float trajectories along with the calculated model trajectory in green. This can be interpreted as the mean trajectory a float would take in April 2001. In accordance with the mean current in the model, this trajectory is eastward and away from the actual float trajectories.

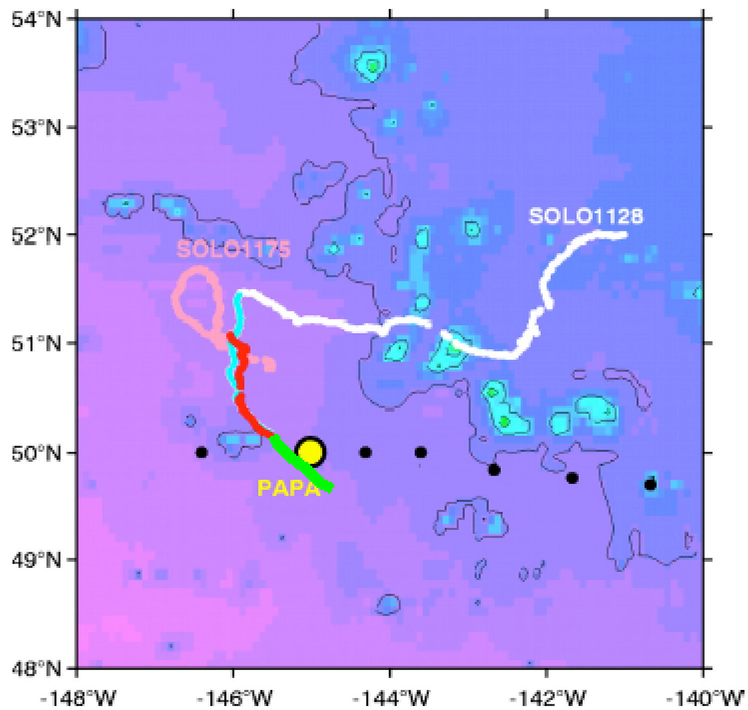

Figure 2: This is the original plot from Bishop et al., 2002, with the NCEP monthly-averaged model float trajectory superimposed in green.

V. Quikscat Forcing

Because the monthly-averaged April 2001 winds do not reproduce the correct float trajectories, it is necessary to look at the daily variations in these winds near the float deployment site. To do that, I downloaded the Quikscat windstresses for April and May 2001. Quikscat winds are collected via a satellite with a two day repeat cycle, with coverage spanning about 90% of the globe. Thus, wind values should be seen as instantaneous snapshots of the winds in a given location. Then, windstress values are calculated based on two different parameterizations.

I downloaded the Quikscat windstress files from podaac.jpl.nasa.gov as described on http://podaac.jpl.nasa.gov/products/product183.html and converted the file format from hdf to netcdf. Then I averaged together the two windstress values from the two different parameterizations (in general these values differ by 10% or less) and I merged together the data from both the ascending and descending pass of the satellite. Then I mapped the data from the Quikscat grid to the model grid. The result was data on a "checker board", with spaces left in places the satellite did not pass at all on the given day. So, I then merged and averaged together the passes from two adjoining days to get coverage over as much of the globe as possible. Finally, I had to apply a smoother to the resulting data to fill in the last bits of missing data, since the overall satellite coverage is only 90% of the globe. The resulting field was then a best guess of smooth and continuous windstress values on the model grid.

I then ran the model for two months, starting from the final state of the mean NCEP runs. The mean April sea surface height for this run is shown in Figure 3. It is somewhat, although not significantly, different from the mean NCEP case, and the mean current is again eastward in the vicinity of OSP.

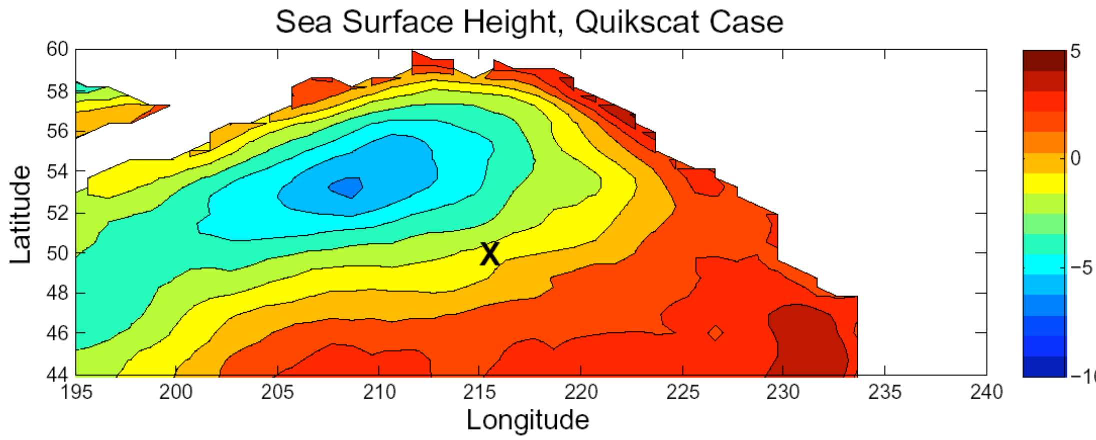

Figure 3: As in Figure 1, but for the Quikscat winds case.

To get an idea of the variability in the windstress in the Quikscat case, Figure 4 shows the Quikscat data for April (black), the mean Quikscat data in April (grey),and the mean NCEP windstress for April (red) at the latitude of OSP for both the zonal windstress (left) and meridional windsterss (right). In general, the mean NCEP and mean Quikscat values are nearly equal across the basin. However, the individual Quikscat values do indeed vary strongly around these mean values. Also shown are the time mean values and standard deviations of the windstress at OSP, and in both cases, the standard deviation is at least as large as the mean. In particular, the meridional value is six times the value of the mean, suggesting a high degree of variability.

However, just because the windstress values are highly variable, this does not necessarily imply that the current values are equally variable. The currents are affected by both the actual value of the windstress (geostrophic currents) and by the curl of the windstress (Ekman currents). The actual currents will also be affected by the viscosity of the model. Thus, Figure 5 shows the coefficient of variation (standard deviation divided by mean) for both the current and the windstress along the latitude of OSP. In the zonal direction, the current values are highly variable in the western part of the basin near the Aleutians and the strong Alaskan Coastal Current. However, the windstress and current are equally variable at OSP, with both having a coefficient of variation of about 1. In the meridional direction, the current is less variable than the windstress, with a coefficient of variation at OSP of 1 compared to 6 for the windstress. Thus, although the windstress is highly variable in the latitudinal direction, the current is much less so.

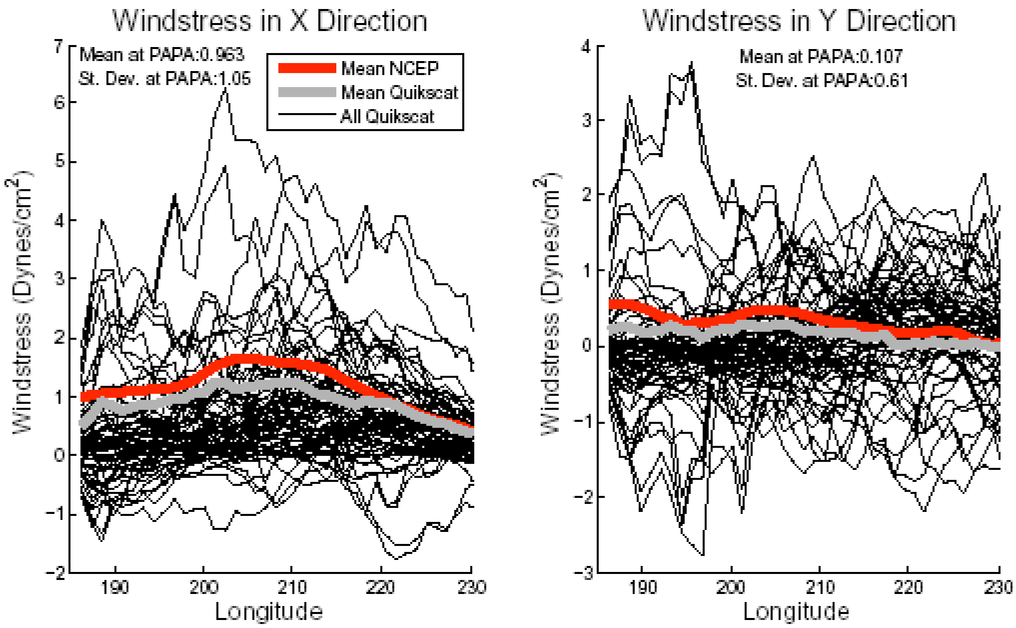

Figure 4: A comparison of the windstress values for the month of April 2001 for the zonal (left) and meridional (right) directions along the latitude of OSP. The mean NCEP (red) and Quikscat (grey) lines are shown, along with all 30 of the individual Quikscat snapshots. The mean and standard deviation of the Quikscat values at OSP are also listed.

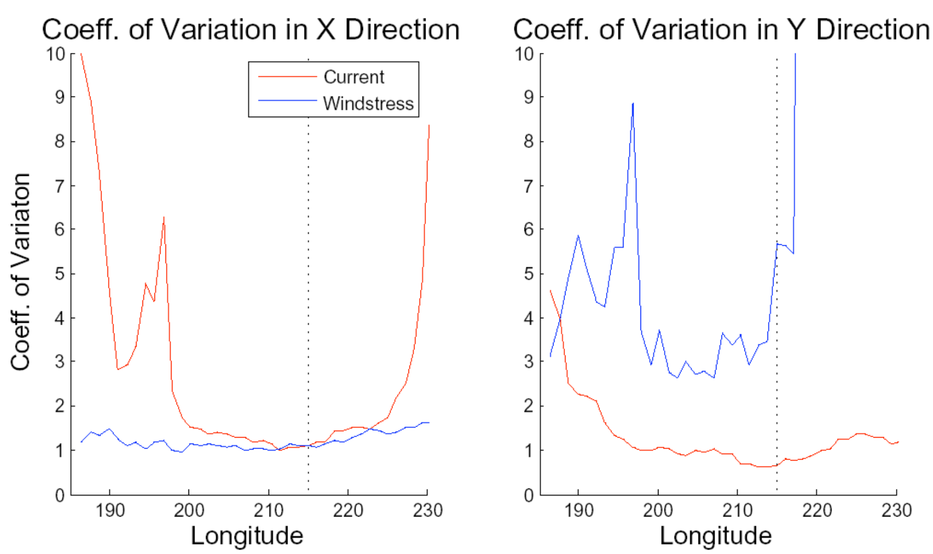

Figure 5: The coefficient of variation (standard deviation divided by the mean, where both are calculated with respect to time) for the model current (red) and the Quikscat windstress (blue) along the latitude of OSP for the zonal (left) and meridional (right) directions for the 60 days of the simulation. The dotted line shows the location of OSP.

Based on this analysis of the variability of the current and following the suggestion of Inez Fung, Figure 6 shows an investigation of the actual float track in the Quikscat run (red line) along with possible float tracks based on stochastic forcing (blue lines). The red line was generated in the same way as the green line of Figure 2, only for the Quikscat run. This should be interpreted as including both the mean April conditions and the specific variability associated with each day as measured by the instantaneous Quikscat measurements. To look at other possible tracks, I generated a stochastic zonal and meridional current each day. These stochastic currents were found using a Gaussian random number generator, with the mean currents specified from the NCEP run and the standard deviation set equal to the mean, as Figure 5 suggests is the case near OSP. The blue lines are then the resulting float tracks based on 50 separate deployments subject to the different stochastic currents. The floats do not go northward in any of these cases; in fact, the standard deviation for the meridional current must be set closer to 6 times the mean for the variability to be sufficient to lead to northward tracks.

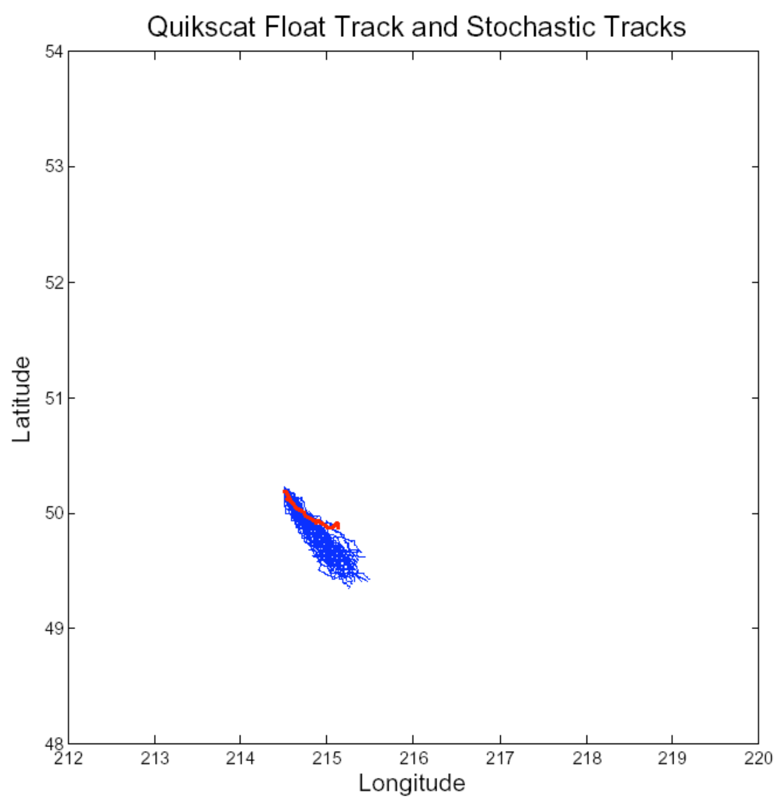

Figure 6: The track for the Quikscat case (red) along with stochastic tracks from 50 theoretical deployments (blue). The stochastic tracks are based on currents that result from Gaussian random number generators, where the mean is equal to the NCEP mean current at the given location, and the standard deviation is set to be equal to the mean. The axes in this figure are set to be the same as those in Figure 2.

VI. Concluding Thoughts

Why didn't the model produce currents that send floats in the correct direction? Judging from the schematic below (Figure 7), OSP is located near the boundary between the northward return flow of the Alaska Current (white) and the eastward North Pacific Current (green). In Figure 1, both these currents are represented, but the branch that goes northward is located approximated two degrees northward of OSP. It seems the model does not adequately model the transition between these two currents, so that OSP is modeled to be within the North Pacific Current rather than the Gulf of Alaska return flow. This could still be a problem of resolution; a model run at higher resolution might better model this transition. However, Figure 8 shows another schematic from a different source, and this schematic shows OSP well within the North Pacific Current. Thus, it remains somewhat of a mystery as to why the actual floats behaved so differently from the model.

It is entirely possible that a mesoscale eddy was passing at that time, and I looked at images from the TOPEX/POSEIDON satellite for April 8, 2001 to try to see if there were small scale anomalies; however, the resolution of the data was not sufficient for conclusions to be drawn.

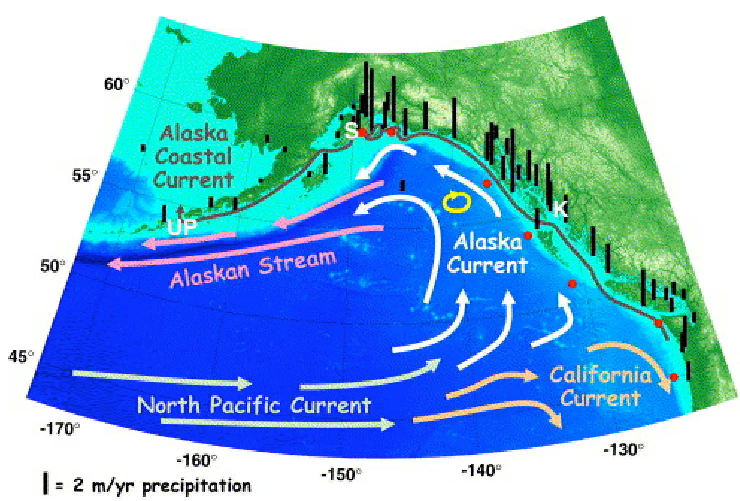

Figure 7: Schematic of Gulf of Alaska currents, taken from Weingartner and Royer, 2005.

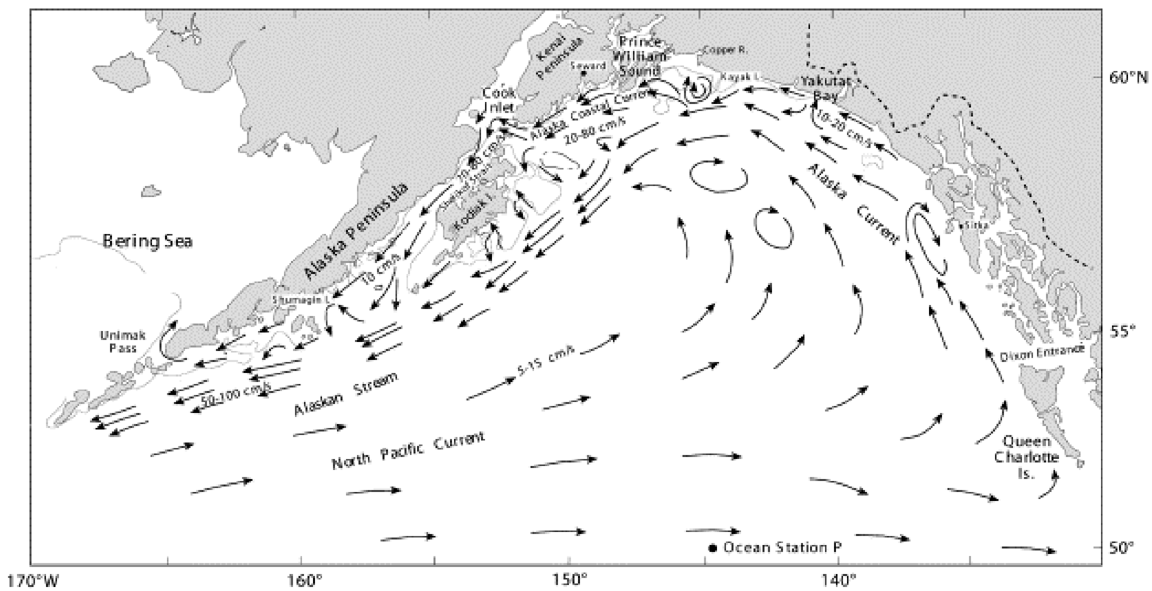

Figure 8: An overview/sketch of the circulation in the Gulf of Alaska as reported in Hermann et al., 2002. In this case, OSP is clearly in the eastward moving branch, as modeled by POP.

VI: Location of Files at Seaborg

All the runs done for this report were done at NERSC on the Seaborg computer. In my account, in the pop directory, are various directories that come with pop (input_templates, mpi, serial, source, tools, and doc) along with other directories for the experiments. Spinup_gx1v3_april_2001 is the high resolution spinup using NCEP mean conditions. Then gx1v3_april_2001_annual is the continuation of that run for 2 months for the analysis portion. Finally, gx1v3_april_2001_quikscat is the Quikscat run. The restart files are stored in each of these directories, along with the scripts and executables used to run them.

All the forcing data for these runs are stored in the input_files directory according to resolution, and then in each experiment directory there is a pointer that points to the forcing, grid, and initial condition files. The only exception are the windstress values for the quikscat run, which are stored in the tau_values.tar file in that directory.

The full time-averaged (tavg) files are all gzipped and stored on the mass storage system at NERSC. This is accessed from my directory by typing hsi, and then the files can be seen by typing “ls”. From these time averaged files, I extracted the North Pacific sector and lumped the results into one long netcdf file. These are located in on the UCBerkeley Henning “atmos” account and on a CDROM provided.

References:

Bishop, J.K.B., R.E. Davis, and J. T. Sherman, 2002: Robotic observations of dust storm enhancement of carbon biomass in the North Pacific. Science 298, 817-821.

Hermann, A.J., D. B. Haidvogel, E.L. Dobbins and P.J. Stabeno, 2002: Coupling global and regional circulation models in the coastal Gulf of Alaska. Progress in Oceanography 53, 335-367.

Weingartner, T. J. and T. C. Royer, 2005: Freshwater variability and predictability in the Alaska Coastal Current. Deep-Sea Research Part II-Topical Studies in Oceanography, 52 (1-2): 169-191.