U.S. Globec Georges Bank Phase III

Real-time Modeling on Cruises EN323 and EN324

May – June 1999

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1. Executive Summary

R/V Endeavor cruises EN323 and EN324 were part of the U.S. Globec Georges Bank Phase III study focused on cross-frontal exchange. The principal objective was simultaneous assessment of the transport of water and plankton in the vicinity of the tidal mixing front. The approach was to inject Rhodamine dye into specific density strata and then measure the movement of the dye patch and the associated planktonic community with respect to the neighboring front. This was accomplished through incorporation of the fluorometric dye detector into the Video Plankton Recorder (VPR) system, facilitating real-time assessment of both tracer and plankton distributions (down to the species level). The adjacent waters were also seeded with radio- and satellite-tracked drifters. Real-time data assimilative modeling of the flow field (and associated transports of tracer and plankton) was carried out in concert with the observational activities, in order to (1) provide an additional interpretive framework for the measurements, and (2) provide nowcast/forecast products which could be used in planning sampling strategy.

This general experimental design was implemented in three different tracer injections:

(1) South Flank - surface
(2) South Flank - pycnocline
(3) North Flank - pycnocline

Observational and modeling activities for the first two were coordinated with the R/V *Edwin Link*, which also had a real-time modeling effort aboard. There was observational coordination with R/V *Oceanus* in the latter two experiments.

Each of the three experiments was associated with distinct biological circumstances. During the surface dye experiment, *Calanus* was abundant in the stratified waters and nearly absent in the well-mixed area where hydroid predators were present in large numbers. Intensive survey operations revealed striking covariance in the fine scale distribution of these two animals. The South Flank pycnocline release was purposefully located in a patch of *Calanus*. As the dye patch was tracked over the following four days, *Calanus* all but disappeared from the tagged water mass. The decrease in *Calanus* abundance was accompanied by the appearance of large schools of herring, mackeral and whales, which were observed feeding at the surface. Finally, the North Flank pycnocline experiment was carried out in the presence of very high concentrations of the colonial diatom *Chaetoceros socialis*. These phytoplankton were most abundant in a thin (~5m) layer at the base of the pycnocline in the stratified area, but their distribution clearly extended into the well-mixed region.

The real-time modeling effort was focused on diagnosis and prediction of water movement and associated transports of tracer and plankton. A data assimilative regional circulation model was used to produce hindcasts, nowcasts, and forecasts from which the relevant transports could be gleaned. Skill of the model predictions was evaluated against observed drifter trajectories. On the basis of those assessments, the best forecast-runs were selected for use in operational products supplied to the chief scientist. These products took several forms: (1) "stick plots" of the modeled velocity at a particular site (for planning tracer injections with the phase of the tide), (2) time-annotated trajectories of both fixed-depth and fluid following particles (representing drifters and dye, respectively), (3) animations of clouds of fluid-following particles (representing dye), and (4) synoptic maps of the dye observations generated by advecting the station locations with the model flow field. In addition to these operational products, model solutions were also used as a basis for data-assimilative coupled physical/biological simulations. Observed distributions of *Calanus* and hydroids were assimilated into the modeled flow fields in order to assess their relative transports and interactions.

In all, 170 model simulations were carried out during the two cruises, consisting of hindcasts, forecasts, sensitivity analyses and coupled physical/biological runs. This archive of model calculations and observations provides a basis for evaluating the performance of the forecast system, and determining under what conditions it performs best. Generally speaking, model forecasts were improved most by (1) using the most recent hydrographic observations for prescribing the mass fields used in the initial condition; (2) forcing the model with observed winds for that portion of the simulation which precedes bell time; (3) assimilating the "right" amount of ADCP data. This final point requires explanation. During some periods of the experimental work, forecast skill was consistently improved by adding more observations. However, such was not always the case, particularly on the North Flank. Apparently there was significant time-dependence in the flow, for which the best treatment in the current forecast system was careful, temporal windowing of the ADCP data which were assimilated. Explicit representation of this time dependence is a recommended avenue for further research.

In aggregate, the error growth characteristics of the model forecasts were surprisingly uniform. For the four-day time horizon over which forecast skill was evaluated in the various experiments, forecast error was a linear function of the duration of the prediction (Figure S.1). On average, separation between simulated and observed trajectories of drifters and dye grew at a rate of 3 km/day. This is a remarkable statistic given that the RMS error of the model fit to the ADCP data rarely fell below 7 cm/sec, and was commonly in excess of 10 cm/sec. Furthermore, the relative uniformity of the growth rate over such a wide range of conditions is worthy of note.

There are several opportunities for further improvement of the simulations in a hindcast mode. For example, additional observations can be assimilated, such as the drifter data themselves (these data were used for forecast evaluation and therefore not assimilated) and mooring records (not available in real time). Synthesis of all available observations in the context of hindcast simulations will provide realistic representation of the three-dimensional physical and biological fields as they evolve in time. These space-time continuous fields will be used to diagnose the underlying physical and biological processes involved in cross-frontal exchange on Georges Bank.

2. Pre-cruise Climatological Forecasting

Prior to the cruise, a set of simulations was carried out to examine the surface layer transport characteristics of the operational area for the first tracer release. A schematic timeline is shown below:

EN323_clim.XX series

```
            --------------DCR------------------------------------ Q4.1
        *
     CS

Date 05/08  05/09  05/10  05/11  05/12  05/13  05/14  05/15  05/16
YD   127    128    129    130    131    132    133    134    135
```

Legend	
CS:	Cold Start
DCR:	Drifter Cloud Release

In the baseline run, mass fields and elevation boundary conditions were set to the May-June climatology. There was no flux of heat or momentum through the surface. A set of five sensitivity experiments around this baseline run were conducted (Table 1). In runs 2 and 3, climatological wind stress and heat flux were added sequentially. In run 4, the mass fields were initialized using hydrography from the most recent broadscale cruise (*Oceanus*). Run 5 is the same as run 4, except that it is forced with a 25 knot NE wind rather than the climatological wind (4 knots out of the SW). Finally, run 6 is the same as run 4 except the drifters are allowed to move vertically rather than being fixed at the surface.

Table 1: Run table for the pre-cruise climatological forecasting experiments.

Run ID	**Description**
EN323_clim.01	Climatological forecast for May 11 dye release
EN323_clim.02	(01) + clim wind stress
EN323_clim.03	(02) + clim heat flux
EN323_clim.04	(03) using mass fields from *Oceanus* broadscale cruise 17-26 April 1999
EN323_clim.05	(04) + Wind NE 25knt.
EN323_clim.06	(04) + drifters moving vertically

Movement of the drifters is generally toward the southwest (Figure PRE.1). In most runs, the array columns tend to rotate counter clockwise in the east, and clockwise toward the west. As the drifters make their way southwest, the array columns also tend to compress. Addition of climatological wind stress and heat flux had little impact; the four-knot breeze from the southwest slows the progress of the particles slightly. Use of the *Oceanus* broadscale hydrography generally reduces the westward flow. In comparison with the previous runs based on the climatological mass fields, particles in the east are displaced to the north, while those in the west wind up further south. A

25-knot northeast wind has the most dramatic impact of all the experiments: the particle cloud is displaced much further to the west, yet the integrity of the original array configuration is maintained. Finally, comparison of runs 4 and 6 demonstrates that allowing these near- surface particles to move vertically with the flow has a negligible impact on their final positions in this case.

3. EN323 Narrative

MAY 4

Operational forecasting began with a "best prior estimate" (BPE) simulation forced by climatological tides and mean elevation [run EN323_FC.01]. Mass fields are initialized with objectively analyzed hydrography from recent *Oceanus* broadscale cruise [provided by Jim Manning]. Wind forcing based on Leuttich winds. Time dependent boundary conditions (TDBCs) provided by Leuttich far-field model. Climatological heat fluxes. Calculation begins on May 1 (day 120) with a 1-day ramp-up of forcing (both elevation BCs and surface fluxes). A 5x5 array of fluid-following drifters is released at the surface in the operational area on May 4 (day 123). The forecast is run through May 7 (day 126). A schematic timeline is displayed below.

Forecast run: EN323_FC.01

```
                          *      DR-------------------------
                   *
            CS

Date        05/01  05/02  05/03  05/04  05/05  05/06  05/07
YD           120    121    122    123    124    125    126
```

Legend

CS: cold start
*: ramp-up of clim BCs
DR: numerical drifter release

Generally speaking, the drifters move westward (Figure 0504.1a). Drifters in the southern portion of the array are displaced slightly more than those in the northern portion.

In order to assess the impact of the time-dependent boundary forcing provided by Leuttich's far field forecast, an identical twin experiment was conducted with that forcing removed [EN323_FC.02].

Without the TDBC forcing, the westward displacement is reduced by approximately half of that in the prior experiment (Figure 0504.1b). Slight northward movement (toward the crest of the bank) is also evident.

MAY 5

Shipboard preparations prevented forecasting activities until after departure. Set sail at 1920. Conducted another BPE forecast based on the latest meteorological products [EN323_FC.03]. Did not receive any new information from Leuttich, so TDBCs were not used. Surface forcing record created from an amalgamation of NMFS (Manning) and UNC (Leuttich) forecast products. Wind stress: UNC(120.00-126.45) + NMFS(124.12-127.50). Heat flux: Climatology(120.00-122.12) + NMFS(122.12-125.50) + NMFS(124.12-127.50). The records are merged under the assumption that later products are more accurate because more observations have been assimilated into the system; thus, newer records replace older ones in cases of temporal overlap. See the forcing log for more details regarding the incoming atmospheric forcing.

Run EN323_FC.03 essentially extends run EN323_FC.02 by one day. Due to the fact that there has been little change in the weather, results are similar to the prior run (Figure 0505.1). The drifters are simply displaced further in the same direction. Curvature in the columns of the array is slightly different, perhaps due to the phasing of the tide one day later.

MAY 6

ADCP data acquisition began just after midnight. Examination of the first two pingdata files in the morning revealed a problem which was traced to the ship's gyro being significantly different from the ADCP compass. The Captain reported that the ship's gyro was set for the Southern Hemisphere. He switched it back to Northern Hemisphere at approximately 1030 and the problem appears to be solved. Watching the ADCP computer readout (which displays the difference between the two compass readings), it was clear that it was taking time for the adjustment to settle in. It was not until about noon local time before the two compasses were once again in synch. Thus good data start at about 1600GMT, about year day 125.7 (Figure 0506.1).

New meteorological information from both UNC and NMFS was received on board via email during mid-morning. UNC products included hindcast data, but no forecast. Therefore the EN323_FC.02-03 series (no TDBC forcing) was continued in run EN323_FC.04.

Testing of the VPR began at approximately 1200. By 1500, those operations were completed. At that point, the ship began a four hour steam to the starting location of first survey grid.

In advance of a drifter deployment scheduled for the early morning hours of May 7, a trial assimilation experiment [EN323_FC.05] was launched using the ADCP data collected between 1100 and 1800 (only about 40km worth of track line). Consistent with earlier experiments, the prior was fairly close and the inversion procedure brought the error right down into the noise level:

```
Prior:      24.3 cm/sec
2nd Q4 run:  7.8 cm/sec
3rd Q4 run:  6.9 cm/sec
```

[In retrospect, reduction of the residual velocity error to the noise level was only possible because such a small data set was being used; see May 8 narrative for information on calibration of the ADCP data.]

MAY 7

VPR survey continued and five drifters (surface and 20m) were released between 0830 and 1030. Launched forecast EN323_FC.06 with drifters at the five release locations. ADCP data up until 1030 assimilated. Forcing identical to EN323_FC.04. In the 2.5 day BPE forecast (iteration 1), the drifters move westward (Figure 0507.1a). The westward drift is more pronounced in the surface drifters, and separation develops between the surface/20m pairs. The inversion procedure reduces the velocity error significantly, but not down to the levels that have been achieved in some of the other limited-area experiments conducted in pre-cruise workshops.

Prior: 22.3 cm/sec
2nd Q4 run: 17.3 cm/sec
3rd Q4 run: 17.0 cm/sec

Assimilation of the ADCP data caused the drifters to be displaced further, in a more southwesterly direction (Figure 0507.1b). More separation develops between the surface/20m pairs than in the BPE simulation.

A forecast sensitivity experiment was conducted (EN323_FC.07) in which the surface forcing was turned off (both wind stress and heat flux). As expected, the lack of surface forcing had little impact on the deeper drifters (Figure 0507.2). However, the southwestward movement of the surface drifters was reduced significantly. In this case very little separation develops between the surface/20m pairs.

At this point it was recognized that fluid-following numerical drifters had been used in the forecast experiments thus far, focusing on preparation for the tracer release experiments. However, this is not the right choice for simulating drifters, which are drogued at particular depths. Run EN323_FC.06 was thus repeated with fixed-depth numerical drifters (run EN323_FC.08). Happily, there was very little difference in the horizontal trajectories of the fluid-following and fixed-depth drifters (not shown).

Our 1530/1930 email downloads contained updated UNC and NMFS meteorological products. Run EN323_FC.09 was launched, which includes up-to-date heat flux and winds, and active TDBC forcing. The results of the new BPE simulation show all drifters moving predominantly northwest (Figure 0507.3a). Assimilation of the ADCP data eliminates that tendency (Figure 0507.3b), and the drifters once again move to the southwest, much like run EN323_FC.09. Thus, assimilation dramatically alters outcome with respect to the BPE in this case. It is of interest to determine what aspect of the new BPE simulation caused the drifters to move northwest. Given that both surface and 20m drifters appear to be equally affected, it seems likely that the TDBC forcing from the far-field model may be the cause. A sensitivity experiment with the TDBC forcing turned off is needed to verify this [see May 8].

Nearing the end of the first survey, it became clear that the frontal structure portrayed by the observations was very heterogeneous. Viewing the "curtain plot" of temperature as if it were synoptic would indicate the front had a great deal of spatial structure. However, looking at the simulated drifter trajectories, it appears that this structure can be explained in large measure by tidal flows (i.e., the front moves onshore(offshore) during flood(ebb) tide.) The amplitude of the tidal excursion in this area is quite large (nearly 10km) and therefore the front fluctuates over a range which is nearly half of the across-isobath extent of the survey track. A decision was therefore made to extend the survey tracks longer in the across-isobath direction. This had to come at the expense of along-isobath resolution, so that the ship could cover roughly the same east-west distance in the allotted time.

MAY 8

The fact that the residual velocity error was so high in assimilation run EN323_FC.06 was troubling. Closer examination of the residuals revealed that they were consistently ninety degrees to the right of the ship's along-track direction (Figure 0508.1). This suggested that there might be a problem with the rotation angle used to correct the alignment of the ADCP (parameter PHI in Charlie Flagg's processing software). A calibration experiment was conducted in which PHI was systematically varied to minimize the RMS velocity observed in a sample data set (en323_dr1) consisting of the first portion of the first VPR survey. It was found that the optimal rotation angle was 9.01 degrees (Table below and Figure 0508.2).

Angle	RMS Velocity	
5.00	0.5072	
6.63	0.4547	* Old PHI
7.00	0.4459	
8.00	0.4289	
8.50	0.4245	
8.75	0.4233	
8.88	0.4230	
8.94	0.4229	
8.97	0.4229	
9.00	0.4228	
9.01	0.4228	* Optimal PHI
9.03	0.4228	
9.13	0.4229	
9.25	0.4231	
9.50	0.4240	
10.00	0.4280	

A clear difference between the old and new calibrations is evident in the processed data (Figure 0508.3). With the old calibration, there is clear vertical striping in the along-track velocity (now obvious in retrospect). This striping is not present when the new calibration is used.

Run EN323_FC.06 was then re-run (as EN323_FC.06b) with the calibrated ADCP data. The residuals dropped down to levels consistent with prior experiments:

	Prior Calibration EN323_FC.06	New Calibration EN323_FC.06b
BPE:	22.3 cm/sec	14.9 cm/sec
2nd Q4 run:	17.3 cm/sec	7.9 cm/sec
3rd Q4 run:	17.0 cm/sec	6.9 cm/sec

It is interesting to note that while this calibration significantly reduced the residual velocity error, it did not have a particularly adverse impact on the forecast drifter trajectories; they were very similar to those in the run using the uncalibrated data (Figure 0508.4). This demonstrates how effective the inversion in frequency space is at ignoring noise not associated with the signal of interest.

After it was determined that this new calibration of the ADCP data was needed, the ship's tech Bill Fanning was consulted as to why there would have been any change in its configuration. He said that the transducer had been out for service last year and it was re-installed in January. Eureka!

Regular forecasting operations were continued using the new ADCP calibration. The May 8 central forecast EN323_FC.11 included updated atmospheric forcing as well as TDBCs received in the 1530 email download. ADCP data from the first survey is assimilated. Duration of the run is now extended to day 129.5. Results show that the drifters continue their westward movement. This appears to be consistent with a preliminary look at the drifter observations; the data will be available in digital form on May 9 for quantitative comparisons.

MAY 9

Ship operations:

The first VPR survey was completed. The dye injection sled was tested. Late in the afternoon the third VPR survey was begun.

Forecasting activities:

Several numerical experiments were conducted to test the sensitivity of the results to (1) TDBC forcing and (2) which portions of the ADCP were used in the inversion procedure. The RMS residual velocity errors before and after assimilation are shown in the first two columns of the table below.

Evaluation of these simulations requires a quantitative measure of forecast skill. The third column of the table displays the mean distance between the simulated and observed drifter trajectories at the time of the last available drifter fix (day 127.8). This is referred to as the forecast error (FE) in kilometers.

		BPE cm/s	**Q4.3 cm/s**	**FE km**
EN323_FC.11	Central [May 8]	13.8	8.3	3.6
EN323_FC.12	(11) - TDBCS	13.4	8.0	3.6
EN323_FC.13	(12) with ADCP Svy 2	12.1	7.2	5.9
EN323_FC.14	(12) with ADCP Svy 1+2	12.9	8.2	4.2
EN323_FC.15	Central, TDBCS, ADCP Svys 1+2	13.6	8.1	4.2
EN323_FC.16	(15) - TDBCS	13.0	7.9	4.2

Simulated and observed drifter trajectories are plotted together for each experiment in Figures (0509.1a-f). Close correspondence of the looping tidal excursions once again demonstrates the accuracy of Quoddy's tidal predictions.

Run 13, which assimilates only the second survey, has the largest forecast error. It is interesting to note that this run fits the ADCP velocities the best. However, the second survey contains far fewer velocity measurements than the first. What appears to be happening is that the inversion procedure is producing larger amplitude boundary perturbations to fit this smaller data set; this degrades the forecast skill.

Runs 11 and 12 are the best. Close examination of the results reveals that run 11 has a slight edge; however, using the above measure of forecast skill they are indistinguishable.

Runs 14-16 are not very much different from each other in terms of forecast skill; they are significantly worse than runs 11 and 12.

Thus, it appears that assimilation of the second survey degrades the forecast skill of the drifter trajectories for the time period in which the drifter data are available. This may be because the drifter record more closely overlaps the first survey in time. These results could indicate there has been some temporal evolution in the velocity field within the survey area. It will be interesting to make similar comparisons with additional drifter data as it comes in.

A drop in sea surface temperature observed on drifter 5 (surface, south of the front) suggested its northward movement had carried it across the front. In order to see how much of this cross-frontal movement was due to the southerly wind, an experiment EN323_FC12nw was carried out with the wind forcing turned off. [Experiment 12 was chosen as the control run for this experiment because it is equally as "good" as run 11, and it does not include TDBCS which could conceivable conflict with the absence of wind forcing.] The trajectory of this surface drifter is dramatically different in the wind (EN323_FC12, Figure 0509.2a) and no-wind (EN323_FC12nw, Figure 0509.2b) cases. Without wind, the drifter moves swiftly to the southwest. In contrast, the drifter moves north-northwest when wind forcing is applied (see Figure 0509.3 for the wind record used to force the simulation). Note that this northward movement is maximal early in the deployment when the wind is southerly; later in the simulation the wind turns northwest and the drifter's cross frontal movement is reversed.

This has substantial implications for the surface tracer experiment. The plan is to release the dye south of the front (approximately where the southernmost drifters were deployed) and survey it as it moves across the front. The model results suggest that cross-frontal exchange at the surface is dominated by the Ekman flow. Under the strong northwest wind that is forecast to blow during the tracer release on Tuesday, the patch could conceivably move away from the front.

May 10

Ship operations:

Third VPR survey continued. Drifters picked up along the way.

The lab experienced a temporary power outage at approximately 1045. Although all computers and electronics plugged into clean power did not appear to be affected, the ADCP data file being written at the time (pingdata.006) was corrupted just after 1999/05/10-14:53:00 GMT. The corrupted segment ends at 22:31, when the end of pingdata.006 is reached.

In preparation for the tracer release experiment the following day, the chief scientist requested two products from the modeling team: (1) a detailed prediction of the time series of currents at the planned tracer release site (for the purpose of phasing the release with the tide), and (2) a prediction of where the dye would go once released. Although we had experience releasing clouds of numerical drifters which would be suitable for the latter purpose, we had not yet produced an operational product of the type needed for the former. This required activation of the numerical mooring capability within the forecast system. Simulation EN323_FC.13 was then re-launched as EN323_FC.13tr with the appropriate moorings in place. This trial run gave us time during the day to examine the output and develop the necessary visualization tools.

Our central operational forecast (run EN323_FC.19) for the day was launched using updated meteorological information and far-field forcing received in the 0930 download. The ADCP data from VPR survey 2 was used, as in run EN323_FC.13. At the time (the second of three evaluations; see below) it was believed that run 13 was the best prior forecast based on the measure of forecast skill described above. [As it turns out, that determination was based on a flawed version of assessment 2; an error occurred in transcribing the results into tabular form]. Three different forecast sensitivity experiments were carried out: EN323_FC.20 was run without TDBC forcing; EN323_FC.21 was the same as 20, except that more ADCP data was used (starting with the second survey and ending at the time of the forecast launch) [ADCP file svy2plus]; EN323_FC.21 used both survey 1 and survey 2 [ADCP file svy1p2].

The forecast skill assessment available by the end of the day (assessment #2, based on drifter data up through day 128.8) suggested that run EN323_FC.15 was the best, with a mean difference of 6.8km between the simulated and observed drifter positions. Numerical moorings and a cloud of drifters were incorporated into that simulation, and it was re-run as EN323_FC.15dr. The forecast currents for the tracer release site provided to the chief scientist are shown in Figure 0510.1.

Evaluation of forecast skill:

Three different assessments of forecast skill were made as updates of the ADCP data came in on May 8, 9 and 10.

Forecast Error (km)

		1	2	3
	Assessment #	**1**	**2**	**3**
	Day of update	**05/08**	**05/09**	**05/10**
	End of drifter record	**127.8**	**128.8**	**129.9**
EN323_FC.11	May 8 Central, ADCP Svy	13.6	7.4	8.0*
EN323_FC.12	(11) - TDBCS	3.6	7.6	8.4*
EN323_FC.13	(12) ADCP Svy 2	5.9	7.6	10.2*
EN323_FC.14	(12) ADCP Svy 1+2	4.2	7.2	8.2*
EN323_FC.15	May 9 Central, ADCP Svys 1+2	4.2	6.8	6.9
EN323_FC.16	(15) - TDBCS	4.2	7.0	7.4
EN323_FC.19	May 10 Central, ADCP Svy 2	8.5	10.5	
EN323_FC.20	(19) - TDBCS	8.3	10.2	
EN323_FC.21	(20) ADCP Svy2 Plus	9.9	12.1	
EN323_FC.22	(20) ADCP Svys 1+2	9.1		
EN323_FC.23	(15) Observed buoy winds	7.1#		

* Simulation ended approximately 0.4 days before the data record.
\# Hindcast simulation.

Results:

In the first two evaluations, the central forecast proved to be as skillful or more so than all other runs. The central forecast on May 10 was less so. Note that not all available ADCP data was used in the May 10 Central forecast. At bell time there was a suspicion that the subtidal flow had changed. It was therefore decided to include only the data from the second survey in the central forecast; the rationale was that the second survey would be more representative of the present conditions. This turned out not to be the case: sensitivity run EN323_FC.22, which included ADCP surveys 1 and 2, was more skillful.

Examination of the wind records used to force the model revealed the presence of several moderate wind events which did not materialize in our location (Figure 0509.3). A repeat of the most skillful forecast in comparison 3 (EN323_FC.15, May 9 Central) was run in hindcast mode using the observed buoy winds to see if it would result in any improvement. In fact, it did not improve the skill.

Figures 0510.2a-k show comparisons of simulated and observed drifter trajectories for each of the runs in comparison 3. See the animation for presentation of the most skillful forecast (EN323_FC.15, May 9 Central).

For reference, a timeline for the May 10 Central Forecast is displayed below:

```
                         -------------------------------------------- Q4.2,3
                      *
                   HS
              ------------------------------------------------------- Q4.1
            *                              [Drifters------]
         CS                           [ADCP---------]

Year Day 120  121  122  123  124  125  126  127  128  129  130  131  132
     May  1    2    3    4    5    6    7    8    9    10   11   12   13

ADCP    start: 125.7
          end: 128.3

Drifter start: 126.6                                          Legend
          end: 129.9                                  HS: Hot Start
```

Calanus simulations:

Real-time processing of the VPR data makes it possible to provide a stream of time, latitude, longitude, and depth coordinates at which individual animals are observed and identified. *Calanus* data from VPR Survey 2 was provided to the modeling team shortly after completion of the survey. It contained approximately 2000 observations of the animal. These were decimated by extracting every 20th animal from the data stream, so that approximately 100 remained. This decimation procedure was intended to preserve the "concentration" aspect of the animal distribution. These 100 space-time coordinates of animal location were fed into Quoddy as numerical drifters in run EN323_FC.17 (which was based on forecast EN323_FC.14). Run 17 simulated fixed-depth particles; EN323_FC.18 advected them with the full fluid velocity (including w). Animation of the results clearly demonstrates the impact of the sheared flow on organism transport. Patches of organisms in the high velocity regions can be seen passing by those in adjacent areas of lower velocity. The animations also raised an interesting sampling issue. In some cases it appears that as the ship cornered the endpoints on the sawtooth track, the tide swung the very same patch of water right into the path of the ship.

MAY 11

At approximately 0100 a mishap occurred in which the VPR ran into the bottom, damaging the instrument and the winch. It was brought back through manual operation of the winch onboard by approximately 0430. An ADCP box survey was begun at approximately 0500 while the repairs of the VPR and winch were attempted. It was decided late that afternoon to return to Woods Hole for repairs.

4. EN324 Narrative

MAY 14

Departed Woods Hole 1530. Satellite imagery from May 10 shows complex SST structure (Figure 0514.1). A warm filament and small eddy are present in the study area, possibly under the influence of a ring / streamer / intrusion offshore. *Edwin Link* reports that their deep drifter south of the front is moving east; assimilation of their ADCP data is reported to capture this behavior to some extent. All these points argue the need for velocity measurements in the stratified region south of the survey track we are to occupy. A course was laid out so that we would enter the model domain at 40° 40'N, 69° 00'W and proceed east until reaching the 80m isobath, then proceed ENE along the mean position of the 8m isobath up to 40° 57' 67° 04', a point just SE of the beginning of the survey track (Figure 0514.2).

Forecasting Activities:

May 14 central forecast includes ADCP data from the *Edwin Link*, file el9905a2.m3d. Drifters from EN323 and EL9905 were launched in the simulation [EN323pEL9905.ind]. Subsequently an error was discovered in the parameter used to ramp up the atmospheric forcing; this effectively started the simulation with the forcing at full strength. This was corrected in EN324_FC.02, in which the atmospheric forcing was ramped up over a 1-day perid. A sensitivity experiment EN324_FC.03 was conducted with TDBC forcing turned off.

We had yet to receive any of the observed drifter trajectories by the close of business on this day, so it was not possible to undertake any quantitative evaluation of the forecasts. However, it was noticed that the RMS residual velocity in these simulations was slightly higher than usual:

	FC.01	FC.02	FC.03
Q4.1	20.0	20.0	17.4
Q4.2	11.7	11.7	11.2
Q4.3	10.4	10.4	10.4

In communications with the *Edwin Link*, Cisco and Jim indicate they had similar results. They attribute the higher residuals to noise in the ADCP data associated with frequent stops for CTD casts. Close examination of the alongtrack residuals does not reveal any systematic error (Figure 0514.3)

It is interesting to note that the inclusion of TDBCS in runs 1 and 2 introduces an additional RMS velocity residual of approximately 2.5 cm/sec to the prior (comparing with run 3 with TDBCS turned off). The assimilation procedure appears to clean this up, with the final results of all three runs indistinguishable in terms of this statistic.

MAY 15

At 0246 local time the ship reached the first waypoint at the western edge of the model domain and slowed to 10knt. Examination of the ADCP data revealed a lot of noise, with only about 25% good returns. At 0530 the ship was slowed to 9knt. The return rate rose to 75%; data collection starts here.

VPR trimming began in the late morning, and was completed by 1300. Rendez-vous with the *Edwin Link* occurred shortly thereafter. Scientific briefings took place, and supplies and data were exchanged. The term "Zodiac-net" was coined to describe the medium over which drifter trajectory data was transmitted between modeling groups on the two ships.

VPR survey operations began immediately after rendez-vous.

Late in the day, the extremely light winds made for a spectacular sight as we approached the tidal mixing front in the first leg of the survey. Capillary waves were clearly present in the stratified side of the front, while they were almost imperceptible in the well- mixed area. The well-mixed region took on a glassy appearance. This change was undeniably associated with water properties (as opposed to the atmosphere); there was no perceptible change in the ship's anemometer as she passed through the frontal region. The frontal boundary was razor sharp; the transition occured over a distance of meters. Perhaps the change in roughness was due to a surfactant which is present at the sea surface in the well-mixed area, but not in the stratified region. Upon closer examination, the patterns in surface roughness appeared to reveal interleaving of the two water masses. In one instance, the front was interupted by a narrow strip oriented roughly perpendicular to the front, aligned with the NE wind. Small eddies appeared to be associated with this structure, with horizontal scales of 10-20m. There was much excitement and speculation about the mechanisms, which may have been responsible for this fantastic display.

Forecasting activities:

The May 15 central forecast (EN324_FC.04) used ADCP data from the *Edwin Link*, in addition to that collected aboard *Endeavor* prior to bell time. Due to the fact that the NMFS model weather product did not arrive, we had to proceed with an incomplete heat flux record. The flux file was edited by hand so that zero heat flux was persisted after the end of the data record.

Experience from the last leg had shown there were sometimes large differences between the AVN model wind product and the observed winds. The current period was no exception (Figure 0515.1). Sensitivity forecast EN324_FC.05 was forced with a hybrid wind record, composed of the buoy winds available at bell time and AVN model winds thereafter.

Processing of the new drifter data was not yet completed by the close of business on the 15th. Quantitative evaluation of the forecasts was therefore postponed until the following day.

May 16

VPR survey continued until approximately 1100. A surface drifter was deployed at the front. *Endeavor* steamed 6km south of the front and released tracer from 1300-1435. Three drifters were deployed in the tracer as the patch was being laid out. An initial survey of the tracer patch was then carried out. Subsequently, *Endeavor* steamed back to the front to re-assess the distance between the patch and the front. On the way back south toward the tracer, another surface drifter was deployed in between the front and the patch; *Endeavor* continued through the patch and deployed another drifter seaward of the patch. Survey of the dye patch then recommenced.

Forecasting activities:

The May 16 central forecast (EN324_FC.06) included *Endeavor*'s ADCP data up through bell time. The heat flux forcing record was incomplete because the necessary data file was not received. Two sensitivity experiments were carried out; the first (EN324_FC.07) eliminated TDBC forcing, and the second (EN324_FC.08) included ADCP data from the *Edwin Link* (several days old at bell time).

Evaluation of forecast skill:

The first forecast evaluation was undertaken with runs from May 14 and May 15 (simulations 01 though 05). This comparison was carried out using simulated drifters which were released at the reported locations. Due to delays inbetween drifter deployment and the beginning of data acquisition, the drifter observations do not begin until a finite time after deployment. In one case (drifter 234) data did not begin until a full tidal cycle after the reported release. It therefore seemed appropriate to carry out a second comparison in which simulated drifters were released at the space/time points of the first entry in each data record. Runs EN324_FC.01 through EN324_FC.05 were re-run as EN324_FC.01_dr through EN324_FC.05_dr with the new release positions. This removed all ambiguity with respect to consistency in the space/time starting points of the simulated and observed drifter trajectories. Fortunately, the results of the second comparison were similar to the first; as expected, the forecast error decreased in the second comparison because of its shorter duration (see below). This suggests that there were no problems with the release points used in the first comparison.

As before, forecast error is defined as the mean distance between simulated and observed drifters at the end of the drifter record. Using this metric, forecast 08 has the highest skill; it is the one with the most up-to-date forcing and most complete ADCP data set used in the assimilation. Comparison of forecast 07 with the May 16 central (forecast 06) suggests that the TDBC forcing slightly degrades the skill. Therefore it is possible that a slight improvement in forecast 8 could result by removing the TDBC forcing from that simulation.

Forecast Error (km)

	Assessment #	1	2
EN324_FC.01	May 14 Central; EL ADCP	10.9	9.7
EN324_FC.02	(01) ramping up atmos	10.8	9.6
EN324_FC.03	(02) - TDBCS	10.9	9.8
EN324_FC.04	May 15 Central; EL+EN ADCP	10.8	9.8
EN324_FC.05	(04) + buoy winds	10.0	10.1
EN324_FC.06	May 16 Central; EN ADCP		10.2
EN324_FC.07	(06) - TDBCS		10.1
EN324_FC.08	(06) + EL ADCP		9.4

The data used in these evaluations consists of four drifters from the *Edwin Link*: two deployed in the well-mixed area at the 50m isobath (drogued at 13 and 33m), and two in the stratified region at the 63m isobath (drogued at 8m and 33m). Simulated and observed trajectories are shown for each forecast experiment in the second comparison are shown in Figures 0516.1(a-h). The results demonstrate very little sensitivity to the inputs, which were varied in this set of simulations.

The westward motion of the 33m drifter in the well-mixed region is fairly well represented in the model. In the best forecast (8), the distance between the simulated and observed drifter position at the end of the 2.3-day record is 6.3km. This is slightly below the mean 2-day error of 6.8km from the best forecast of the set conducted on the previous leg of the cruise (see EN323 report).

The early portion of the 13m drifter record in the well-mixed area closely resembles that of the deeper drifter. About half way through the record, the 13m drifter took a turn to the southwest and accelerated. Neither the turn toward the southwest nor the speedup of the drifter motion was captured in any of the simulations. The simulated trajectory in forecast 8 does have a slightly more southerly component to its movement, but not nearly enough to make it match the observations. Moreover, the southerly component in the model is fairly monotonic; it does not contain the abrupt change in direction present in the observations.

In the stratified region, both drifters move in a mostly southerly direction. Early in the record, there is an eastward component to the motion, which is more pronounced in the shallower drifter than it is in the deeper. Although the southward component of the observed drifter motion is captured in the simulations, the east-west aspect is not. Both shallow and deep simulated drifters move to the southwest. The reason for this discrepancy is not known. However, it is interesting to note that the southwestward movement of the simulated drifters was even more pronounced in the BPE run (Figure 0516.2). Assimilation of ADCP data partially arrested this southwestward motion; the simulated drifters do not go nearly as far to the southwest after assimilation. This result is consistent with that reported by Werner and Manning on the *Edwin Link*.

Operational Products:

Operational products generated on May 16 were based on forecast EN324_FC.08. This forecast had the highest skill, not only in terms of the mean forecast error (see table above), but also the error metric for the drifter phenomenologically closest to the tracer release point (the shallow drifter in the stratified region). Surface current predictions were produced for the tracer release site via a numerical mooring (Figure 0516.3). In addition, a cloud of particles was launched around the release site in the model solutions. The results are best visualized with an animation (see web page); plots of the initial and final particle locations are provided in Figure 0516.4. A time-annotated plot of the drifter trajectory at the center of the cloud (which represents the center of mass of the tracer) is shown in Figure 0516.5.

Note that the original cloud release at 0.5m depth (run EN324_FC.09, based on Q4.3 of EN324_FC.08) ran into some problems with particles breaching the surface, even though these were fixed-depth drifters. The simulation was re-run as EN324_FC.10 with particles released at 2.5m depth, and the problem was avoided.

MAY 17

Dye survey operations continued until 1610. The ROV was tested later that afternoon. A larger scale dye survey was embarked upon at 1900 to define the extent of the tracer patch.

Forecasting:

The May 17 Central forecast (EN324_FC.13) showed a slight improvement in forecast skill (9.3km mean distance) over the best forecast from the prior day (EN324_FC.08, 9.4km mean distance). Qualitatively, however, there was very little difference in the simulated drifter trajectories.

One particularly striking aspect of the observations is the shallowness of the pycnocline in the stratified region. Surface stratification is very strong, and confined to a thin layer only 6m depth in some cases. The possibility that this vertical structure is important to the fate of the dye patch cannot be ruled out. It is therefore relevant to assess the extent to which this structure is present in the model. Examination of vertical sections of temperature extracted from the simulations reveals a comparatively diffuse thermocline (Figure 0517.1a). It was speculated that the diffuse thermocline could be a result of surface mixing that was too vigorous. Experiment EN324_FC.08h was conducted to see if a sharp pycnocline could be formed by increasing the surface heat flux to five times the climatological mean for this season. Clearly, this is an unrealistically large heat flux, but the intent of the experiment was to qualitatively assess the phenomenological impact on the solution. In fact, a much sharper pycnocline forms (Figure 0517.1b). However, this increase in surface heat flux is incompatible with the present boundary conditions on temperature, which are clamped to the observed values. This results in the spinup of an anomalous baroclinic jet around the bank, making the simulated circulation very unrealistic. It is clear that realistic treatment of this strongly stratified upper layer will require some effort involving several aspects, including the turbulence model, surface fluxes, and horizontal boundary conditions.

As it turns out, the observed surface stratification described above may have strong lateral gradients which are not associated with the tidal mixing front. The satellite image from May 15 (which arrived just after the numerical stratification experiment was analyzed) shows a discrete patch of warm water straddling the Schlitz mooring line, oriented northeast-southwest adjacent to the 60m isobath (Figure 0517.2). Analysis of the alongtrack hydrography from the VPR surveys suggests this feature is associated with a salinity anomaly that is approximately 0.5 psu fresher than the surrounding water. There was much speculation about the origin of this feature.

Operational Products:

Surface current predictions from the numerical mooring at the tracer release site were updated (Figure 0517.3) and provided to the chief scientist.

MAY 18

Survey of the tracer patch continued. A weak dye signal remained at the apparent center of mass. Several things appear to have happened: (1) dye in the very thin upper layer was driven by the easterly wind toward the front and into the well-mixed region where it was fairly uniformly distributed in the vertical; (2) dye which penetrated below the thin surface layer in the stratified area was mixed rapidly toward the bottom; (3) dye in both the well-mixed and stratified areas was dispersed in the along-isobath direction so that the patch expanded to about 10km in size; (4) the patch translated with the subtidal flow at a rate of approximately 10km per day.

Forecasting Activities:

Given that the dye had been mixed vertically both offshore and onshore of the front, the question arose as to how that might impact advection of the tracer by the subtidal flow. The chief scientist asked that we compare our forecast trajectory for the cloud of particles released at the surface with a cloud released at depth. Figure 0518.1 compares the trajectories of a surface particle at the center of the cloud (solid line) with one at 30m depth (dashed line). Westward translation of the deeper particle is not as rapid as that of the surface particle. A separation of 5-10km develops over the 1.76 days of forecast simulation time presented here.

The decrease in forecast error that was noted in the May 17 central forecast was interesting. This improvement could have resulted from any of the following: (1) better atmospheric forcing (i.e. hindcast wind/heat fluxes), (2) more velocity observations, or (3) more recent velocity observations. In an attempt to distinguish between (2) and (3), a sensitivity experiment to the previous day's central forecast (EN324_FC.13) was conducted in which the older velocity data from the *Edwin Link* survey was not assimilated. The forecast error of run EN324_FC.14 increased from 9.3 to 10.1km, although the qualitative characteristics of the drifter trajectories remained the same (Figure 0517.2). Thus, it appears that more velocity data is better in this case.

Given that, we chose to assimilate as much data as possible into the May 18 central forecast. Updated ADCP data from the *Edwin Link* received via email was merged and sorted with all available EN324 data. The mean forecast error was reduced to 9.1km from the 9.3km result of the May 17 central forecast. Once again, there was little change in the character of the drifter trajectories (Figure 0517.3).

A note on the atmospheric forcing used in the May 18 central forecast: there was a period of several days in which the model forecast heat fluxes were not received from NMFS due to an email problem. That problem was corrected and transmissions were resumed in time to be incorporated in this day's central forecast. However, there was a gap in the heat flux record between the end of the May 14 transmission (day 136.50) and the beginning of the May 18 transmission (day 137.12). This gap was filled manually by copying the heat fluxes from day 137 into those needed to complete the record for day 136.

May 19

The final survey of the tracer patch was concluded in the wee hours of the morning. A VPR section out to the 200m isobath and back was then occupied. We appeared to have reached a warm core ring at the most offshore extent of the track. Upon return to the study site, the six drifters which had been deployed prior to, during, and just after the tracer release were recovered. ROV operations were then undertaken, lasting until approximately 2300. A VPR survey of the study site was then begun in preparation for the second tracer release experiment, to take place in the pycnocline.

Forecasting Activities:

A disk failure on the shore-based mail server prevented any email from reaching the ship. Therefore, we did not have the atmospheric weather or far-field ocean model forecasts needed to produce our operational products. We could have proceeded without the far-field ocean model and forced the forecast system with wind predictions based on NOAA weather radio reports. However, it was not necessary to do so because shipboard operations planned for the following day (continuation of the VPR survey of the study area) did not require any input from the modeling team.

The arrival of new drifter data from both *Endeavor* and *Edwin Link* sources provided additional opportunity for forecast evaluation. Observed drifter trajectories were compared with model results from the most up-to-date forecast, run EN324_FC.16. This simulation was re-run as EN324_FC.20 with the new drifter release points, shown in Figure 0519.1. The discussion below is split between surface drifters and those with subsurface drogues because there is a dramatic difference in our ability to forecast the motion of these two groups.

Deep Drifters:

In the well-mixed region, both the 16m and 26m drifters move southwest (Figure 0519.2). The shallower drogue moves slightly slower (approximately 10 km/day) than the deeper (approximately 5 km/day), indicating the presence of vertical shear even though water mass properties appear well-mixed. Simulated trajectories are quite similar to the observations, with separations at the end of the two-day record of only 1.6 and 3.7km for the shallow and deep drifters, respectively.

The flow in the stratified area is more sluggish. Both the 12m and 36m drifters move west at speeds of 3 km/day or less. The simulated drifter trajectory at 36m agrees quite well with the observed trajectory, with only 3.9km separation developing by the end of the record. A larger separation (6.8km) develops in the shallower case because the model drifter moves in a more southerly direction than is observed.

Mean forecast error for the deep drifters is 4.0 km.

Surface Drifters:

Whereas the trend in the deeper drifters was movement toward the west and southwest, the surface drifters have a pronounced northwest component to their motion (Figure 0519.3). This aspect of the observed drifter motion is not captured by the simulations, resulting in a mean forecast error (11.9 km) that is much higher than that for the deeper drogues. It is possible that this discrepancy may be associated with windage on the surface structure of the instruments; the directionality of the additional displacement is not inconsistent with what would be expected under the easterly wind conditions present during the deployment.

May 20

VPR survey continued; expected completion at 0400 May 21. Rain and fog during the day, and 20-30 knot NW wind blows up during the night. Email system operational again.

Forecasting Activities:

UNC forecast products were not received, so the central forecast EN324_FC.28 had to proceed without TDBC forcing, using winds extracted from NMFS source.

The May 20 central forecast, its two predecessors, and associated sensitivity experiments were evaluated against the available drifter data set described in the May 19 narrative. The results for deep and shallow drifters are presented in tabular form below:

Mean Forecast Error (km)

		Surface	Deep
EN324_FC.23	May 17 central [FC.13 re-run]	13.5	3.4
EN324_FC.20	May 18 central [FC.16 re-run]	11.9	4.0
EN324_FC.24	(20) + EL9905 Mass Fields	12.3	3.0
EN324_FC.28	May 20 central	12.7	4.0

It appears that we have finally hit the point of diminishing returns with respect to "more data (and commensurately longer runs) are better." The May 17 central forecast has a lower forecast error than both the May 18 and May 20 central runs. This is a welcome result, as the longer simulations (up to 18 days from cold start to finish) were taking several hours to run. Also, it is interesting to note the improvement in forecast skill when the mass fields were updated with the EL9905 bongo data (run 24). This is consistent with the results reported by the *Edwin Link* team.

Operational Products:

During the VPR survey, a remnant from the tracer release was found in a small patch in the pycnocline of one of the survey legs. When this came to light, the chief scientist requested a forecast of where that patch would be the following day so it could be resampled. At that time, the central forecast had yet to be run due to delays in the delivery of emailed forecast inputs. Instead, the central forecast from May 18 was re-run as EN324_FC26 with a numerical drifter inserted at the observed and place. A time-annotated plot of the forecast drifter trajectory was provided to the chief scientist. That forecast simulation ended at 0800 the following morning, approximately one hour after the search for the patch was to begin. The same run was extended one day under the assumption of constant forcing (Figure 0520.1). Knowing that there had been a dramatic change in the weather, the May 20 central forecast was launched with the products that were available at the time; this included NMFS wind stress and heat flux. The strong northwest wind caused the simulated drifter to move much farther southwest, as to be expected with a strong northwest wind (Figure 0520.2).

MAY 21

VPR grid survey completed. It was decided to continue survey work for one more day before proceeding with the second tracer release. During those operations, the predicted location of the remnant patch of the previous tracer release (see May 20 "Operational Products" section) was sampled, and only background levels of dye were found. In retrospect this is not too surprising. The signal of the remnant patch at 6m was only just above background before the wind event began. During the wind event, the mixed layer deepened to approximately 15m. Given the dilution associated with both vertical and horizontal mixing, the remnant patch most likely became undetectable. It was therefore decided to render a "No Decision" in evaluation of the forecast skill in this case.

Forecasting Activities:

Launch of the May 21 central forecast was delayed until after the 1930 email download in the hope that the UNC atmospheric and far-field model forecasts would arrive. Although those products were not received, we were fortunate that the NMFS extraction of the atmospheric forecast did. The central forecast was thus launched using NMFS winds and heat fluxes, but without TDBC forcing.

During the day, additional experiments were carried out to follow up on other issues relating to the drifter comparisons conducted on May 20. Results from the *Edwin Link* suggested that forecast skill could be improved by decreasing the vertical mixing coefficient EKMIN and using shipboard winds when available. Run EN324_FC.24m was an identical twin to EN324_FC.24 except that the vertical mixing coefficient EKMIN was decreased from 2.0E-3 to 2.0E-5. Run EN324_FC.24mw was an identical twin to EN324_FC.24 except that ship observations were used to construct the wind stress and heat flux forcing files for the portion of the simulation time in which they were available. The results of these two experiments are shown below, together with the those from the control run:

Mean Forecast Error (km)

			Surface	Deep
EN324_FC.24	(20)	+ EL9905 Mass Fields	12.3	3.0
EN324_FC.24m	(24)	EKMIN = 2.0E-5	13.4	4.0
EN324_FC.24mw	(24)	EL Atmospheric forcing	9.5	2.0

Contrary to the results reported by the *Edwin Link* team, decreasing the vertical mixing coefficient did not improve the forecast skill; in fact, the mean forecast error increased for both surface and deep drifters. However, it is important to note that the *Endeavor* experiment was not identical to that performed on the *Edwin Link*. For example, the *Endeavor* control run used model-derived winds, while the *Edwin Link* control run was based on surface fluxes derived from shipboard observations. It is quite likely there were other important differences, such as forecast timing parameters as well as the ADCP data used in the assimilation procedure. Furthermore, the drifter data sets used in the forecast evaluation are slightly different. The *Edwin Link* used their four drifters, while we used their four plus our six, separated out into surface and deep categories.

In my opinion, the only conclusion that can be drawn from the combined experience thus far is that the smaller value of EKMIN does not necessarily improve forecast skill; the results are sensitive to which control run was used.

This does not appear to be the case with respect to the atmospheric forcing sensitivity. Mean forecast error in run EN324_FC.24mw was 66 percent less than in the control run. This reduction in error is comparable to the results reported by the *Edwin Link* team, who experienced a 54 percent decrease. Thus it seems reasonable to conclude that shipboard wind and heat fluxes should be used whenever possible.

We also experimented with the use of the weighted least-squares inversion procedure rather than the Fourier method that has been used up to now. Three different experiments have been performed, with the following values used for the condition number and error term weights:

	Rcond	**W0**	**W1**
EN324_FC.21	0.0001	0.25	250.0
EN324_FC.22	0.1	0.25	250.0
EN324_FC.25	0.0001	0.1	1000.0

The weights (0.25, 250.0) were chosen for this particular case using the recipe derived in the December meeting at NCSC. The set of parameters used in EN324_FC.25 were the same as in the EN302 practice case from our December meeting. In each of these three experiments, the perturbation boundary conditions computed in the inversion procedure were so small (order 10^-12 in one case) that they did not make a perceptible impact on the BPE run. I am inclined to believe that either (1) I am making an error, or (2) there is a scaling problem in the output of the WLS inversion procedure.

Operational Products:

Early in the day, the chief scientist requested forecast products for the next day's tracer release in the pycnocline. As the central forecast had yet to be run, the planned position and time of the release was incorporated into the previous day's central forecast and re-run as EN324_FC.29. Current predictions and forecast trajectory are shown in Figures 0521.1a,b. When the central forecast EN324_FC.30 became available later that day, forecast products were re-issued (Figures 0521.2a,b). That forecast simulation only ran through approximately 2000h local time the following day; it was extended an additional day in run EN324_FC.31 assuming persistence in forcing (Figures 0521.3a,b). The updated forecast suggested stronger advection toward the southwest, as to be expected with strong winds from the northwest.

May 22

During the night a patch of *Calanus* was tracked along an isopycnal surface far to the west, leaving *Endeavor* approximately 18 miles away from the operational area where *Oceanus* and *Edwin Link* were located. The VPR was brought on deck, and *Endeavor* steamed back to the operational area. VPR survey operations were begun to identify a location suitable for the tracer release. However, two aspects of the observed conditions were not favorable. First, the pycnocline was extremely sharp, 2 meters or less in vertical extent. This made it nearly impossible to inject without contaminating waters both above and below the pycnocline with dye. Second, *Calanus* was less abundant overall, and there was no patch of organisms coincident with the proposed location for release of the dye. For both of these reasons, the chief scientist decided to postpone the tracer release until the following day. In the meantime, survey operations continued. Later that night, it became clear that the fluorometer on the VPR was picking up a signal from Houghton's dye released in the bottom boundary layer earlier in the day. Given the potential for interference between the two dye experiments, the chief scientist decided to relocate further west.

Forecasting Activity:

The May 22 Central forecast EN324_FC.32 was computed with all of the latest ADCP data and forcing products. As expected, the forecast skill based on the drifter deployment during days 135-137 continued to degrade slightly (see below).

The duration of the forecast runs (14.5 days) is approaching the outer bounds of our experience thus far. A parallel forecast was initiated with a starting date oriented around the next set of drifter deployments and dye experiments, to begin on day 142. A new starting date on day 132 was chosen via the following rationale, working backwards in time: (1) We would like to have about 3 days of ADCP data to assimilate prior to the beginning of drifter/dye operations; (2) approximately 3 days of adjustment to the perturbation boundary conditions is needed prior to assimilation of the ADCP record; and (3) approximately 3 days of spin-up from cold start is needed to adjust the BPE run.

This suggests the following timeline:

```
                             ---------------------------------------- Q4.2,3
                           *
                        HS                                 [Dye--->
              ------------------------------------------------------- Q4.1
            *              [Drifters--]                    [Drifters
         CS                               [ADCP-----------]

Year Day 132  133  134  135  136  137  138  139  140  141  142  143  144
     May  13   14   15   16   17   18   19   20   21   22   23   24   25
                                                  [Wind]
```

Unfortunately, there is a wind event right in the middle of the ADCP record used in this run. It is clear that the wind event had a significant impact on the hydrographic structure and currents on the bank. The thin layer of stratification was mixed downward, and there appeared to be significant wind-driven flow toward the southwest. How to best accommodate these changes in our upcoming forecasting activities remains an open question. Would it be best to re-initialize after the wind event, or run right through it? How much data should be incorporated before and after? There is a myriad of choices to be made. Any suggestions would be most appreciated!

We have little new information with which to evaluate the new forecast; it will be a day or two before new drifter data start to come in. Although the run does span the earlier drifter deployment, those records begin in the model's adjustment period, just after the hot start on day 135. Therefore, comparison with those data is a poor measure of forecast skill. As to be expected, the skill is quite poor relative to prior runs (see below).

The final run completed on May 22 was an attempt to improve on the central forecast based on the experience of the preceding days. It was initialized with the mass fields from the *Edwin Link* and forced with their wind observations when available. Consistent with prior experience, forecast skill improved significantly.

Mean Forecast Error (km)

		Surface	Deep
EN324_FC.32	May 22 Central	11.6	4.4
EN324_FC.33	(32) started later	14.7	9.0
EN324_FC.34	(32) EL Mass fields, Wind	11.4	2.0

Operational Products:

Forecast products were issued for the tracer release based on the day's central forecast (Figures 0522.1a,b). When the improved forecast EN324_FC.34 became available, operational products were re-issued (Figures 0522.2a,b).

MAY 23

The morning of May 23 found *Endeavor* further to the west, engaged in survey operations to find a location suitable for the tracer release. Generally the conditions were more favorable than what had been observed further to the east the day before: the pycnocline was thicker, and patches of *Calanus* were more abundant. Tracer release operations began at approximately 1345 and were completed by 1430. Drifters were deployed both inside and outside the tracer patch. A survey of the initial tracer distribution ensued, followed by ROV operations. A larger scale survey to delimit the outer bounds of the patch was then begun.

Forecasting Operations:

The May 24 Central forecast (EN324_FC.36) was computed using all the latest forcing products and ADCP data sets. In a continuing effort to study forecast timing issues, a parallel forecast (EN324_FC.37) was computed with a later starting date. This forecast pair is analogous to runs 32/33 conducted on the May 22.

Operational Products:

At 0900 the chief scientist provided the forecasting team with an approximate time and location for the tracer release. As the May 23 central forecast had yet to be run, pycnocline current predictions and forecast trajectories for the release were based on the prior day's best forecast (EN324_FC.34), re-run as EN324_FC.35. The results were analyzed and provided to the chief scientist (Figures 0523.1a,b).

When the pair of May 23 forecasts (runs 36 and 37) were completed, clouds of particles were launched at both tracer release locations (Houghton and Ledwell). See animations for best presentation of these results.

Forecast trajectories for the center of mass of the Ledwell tracer are shown in Figures 0523.2a,b. Little net motion is forecast in run 36 until the strong southerly winds predicted to arrive the night of May 24 accelerate the patch toward the east. Qualitatively, forecast 37 is similar, except that the tendency for eastward motion is more pronounced earlier in the deployment. As yet, there is no discernable motion in the tracer patch, which would tend to favor the central forecast (run 36) as having more skill. However, this evaluation is highly qualitative. As more information becomes available on the movement of the tracer patch and drifters, more quantitative evaluation will be possible.

Forecast trajectories for the Houghton release are shown in Figures 0532.3a,b. Movement of this deeper patch is more sluggish than that predicted for the pycnocline. Again, eastward motion is more pronounced in run 37 than run 36. In this case, there are some qualitative observations of tracer movement with which to compare the model forecasts. In the radio communications amongst *Endeavor*, *Oceanus,* and *Edwin Link* on the morning of May 23, it was reported that the tracer patch was bounded to the south by 41° 05'N, to the east by 67° 22'W, and to the west by 67° 30'W; the northern extent was yet to be determined. These delineations are shown as a dashed line on Figure 0532.3a. In radio communications on the morning of the May 24, it was reported that the patch was bounded to the north by 41° 08'N, to the east by 67° 25.5', to the south by 41° 04'N, and to the west by 67° 31'W. These delineations are shown as a solid line in Figure 0532.3a. Thus, there appears to be a slight westward drift in the observed tracer patch. Again, the central forecast (EN324_FC.36) appears to be qualitatively more consistent with the observations.

MAY 24

Survey operations continued. Once the large-scale survey of the dye distribution was completed, an extensive set of lines was occupied to map the *Calanus* patches in the area. At approximately 2000h, survey of the dye patch recommenced. Throughout these survey operations, periodic lines to the front were occupied to measure the distance between the front and the dye/*Calanus* patches of interest.

Forecasting Operations:

The May 24 Central forecast EN324_FC.38 was computed with all the latest forcing products and data records. Once again a twin experiment was conducted with a delayed starting time (EN324_FC.39).

The first set of drifter observations from the latest deployment arrived (3 tracks from Manning), permitting some quantitative evaluation of forecast skill. Figure 0524.1 compares the observed drifter trajectories with simulated tracks from the central forecast. In general, forecast skill is not as good as we have become accustomed to in earlier deployments. The 8m drifter released at the 65m isobath is the only case in which there is appreciable skill; a 2.8km separation develops between the simulated and observed trajectories as they move to the southwest during the two tidal cycles of observations. Comparisons with the 13m and 33m drogues are poor, with separations in excess of 9km developing during this relatively short data record. The 33m simulated drifter moves south-southeast in contrast with the observed movement to the southwest. The west-southwest direction of the simulated 13m drogue is approximately correct, but the movement is far too slow. Furthermore, there is a large error in the tidal phasing by the end of the record. We have not seen this type of error in any of our forecast experiments thus far. Perhaps a mistake may have been made either in data processing or in incorporation of the simulated drifter into the model solution. We will look into this further.

Even if there is a problem with the 13m drogue, there is no denying this forecast is of inferior skill. In radio communications the morning of May 25, the modeling team on board the *Edwin Link* reported similar results. The discussion led to some speculation that decrease in forecast skill may have something to do with the lack of spatial overlap between the drifter data and the current ADCP velocity measurements being assimilated. For reasons described in earlier transmissions, *Edwin Link* and *Endeavor* have separated by about 30km in terms of their operational area. Given the recent outage of the ADCP on the *Edwin Link*, it is primarily *Endeavor*'s ADCP data which are being assimilated. Thus, in the forecast evaluation described above, we are essentially trying to predict the path of *Edwin Link*'s drifters some 30km east of the area in which recent velocity measurements are available. This could explain the lack of forecast skill. Shortly we will have the opportunity to compare the model results with *Endeavor*'s drifter tracks, which are closer to the area of velocity observations; such a comparison should help shed light on these issues.

Operational Products:

An updated forecast trajectory for the dye patch based on the May 24 central run was provided to the chief scientist (Figure 0524.2) The results suggest a brief period of eastward movement associated with the southerly wind event, then motion back toward the west. Given the issues brought to light by the most recent evaluation, the operational products for this day were provided with the caveat that forecast skill was "uncertain relative to prior results obtained thus far on the cruise."

MAY 25

VPR survey operations continued.

Forecasting Activities:

Much of the day was spent investigating the potential causes of the decrease in forecast skill we have experienced in the last drifter deployment. Five sensitivity experiments were conducted around the May 24 central forecast EN324_FC.38. The first (run 40) represented an attempt to "restart" the forecast system based on the canonical forecast timing parameters used at the December meeting at NCSC. This differs from the timing scenario described in the May 22 narrative in that ADCP data during the drifter deployment is assimilated. Thus, such a run test our ability to hindcast the drifter trajectories rather than to forecast them. The timing diagram is as follows:

EN323_FC.40

```
                             ----------------------------------------
Q4.2,3
                           *
                        HS                        [Dye--->
              -------------------------------------------------------   Q4.1
            *                                     [Drifters
         CS                                [ADCP-----------]

Year Day 134  135  136  137  138  139  140  141  142  143  144  145  146
     May  15   16   17   18   19   20   21   22   23   24   25   26   27
                                                  [Wind]
```

Analysis of the results from EN323_FC.40 revealed some large spikes in the ADCP data record. The bad values were edited out, and simulation EN323_FC.41 was run with the new data record. Run EN323_FC.42 reverted back to the mass fields created from the last broadscale survey conducted on *Oceanus*; TDBCS were turned off in run EN323_FC.43, and atmospheric forcing was turned off altogether in run EN323_FC.44.

The table below shows the mean forecast error for each run, in addition to the separations for each drifter. As these runs were being carried out, it appeared to us that there might be an error in the launch point location of the 13m drifter provided in the .ind file. This was corrected in run EN324_FC.41cdr, and resulted in significant improvement in the forecast skill. Beyond that, the results of the sensitivity experiments were qualitatively consistent with our experience up to this point (i.e. runs 42-44). Still, the forecast error remains higher than it was preceding the series of wind events we have had recently. Moreover, there are qualitative differences between the simulated and observed drifter trajectories (Figures 0525.1a-f). The causes are still under investigation.

		13m	8m	33m	Mean
EN324_FC.40	(38) new timing	(10.2)	2.9	8.2	(7.1)
EN324_FC.41	edited ADCP file	(10.2)	5.7	5.5	(7.1)
EN324_FC.41cdr	edited ADCP file	5.4	5.5	2.1	4.4 ##
EN324_FC.42	OC Mass fields	5.0	4.9	4.8	4.9
EN324_FC.43	TDBCS off	5.1	4.8	5.2	5.0
EN324_FC.44	Tau, Q off	5.0	6.2	4.3	5.1

** () indicates statistics which are affected by the suspected problem in the release location of the 13m drifter.
these numbers were subsequently found to be in error; see below.

Operational Products:

No new operational products were issued on May 25.

MAY 26

VPR and dye surveys continued.

Forecasting Activities:

A second battery of sensitivity tests was conducted using an updated set of drifter data, including seven drifters deployed from *Endeavor*. We take EN324_FC.45 to be the central case for the comparison; it is a re-run of EN324_FC41cdr in which the numerical drifters maintain a fixed depth. Note that the set of runs described in the May 25th narrative mistakenly used fluid-following drifters. Comparison of runs 41cdr and 45 shows that it actually makes little difference in this particular case:

		13m	8m	33m	Mean
EN324_FC.41cdr	Drifter w~=0	6.2	6.1	6.1	6.1
EN324_FC.45	Drifter w==0	6.3	6.0	5.9	6.1

We now compare runs EN324_FC.45 through EN324_FC.48 for all ten drifters, separated into shallow and deep categories. Run EN324_FC.46 uses wind observations from *Endeavor*; TDBC forcing is turned off in run EN324_FC.47. Finally, TDBC forcing was turned back on after correcting an error in the code being used onboard *Endeavor* to generate the .cbc file from the UNC products. Note that this problem was particular to the version of detide_adcirc being used on *Endeavor*, and should not affect other users. Its effect was that input data from only the first file (01-02 May) actually made it into the .cbc file. The corrected TDBC forcing was turned back on in run EN324_FC.48.

Deep drifters:

	ID Z	087 13m	234 8m	200 33m	037 19m	022 19m	010 19m	003 16m	006 34m	Mean
45 Control		6.3	6.0	5.9	5.5	6.3	2.3	10.6	2.1	5.6
46 EN Winds		6.4	6.3	7.0	4.1	4.0	2.0	7.8	4.3	5.2
47 TDBCS off		6.2	7.8	6.1	4.0	4.1	2.1	8.0	3.7	5.3
48 TDBCS2		6.5	9.9	6.4	8.0	7.7	3.1	9.2	6.0	7.1

Shallow drifters:

	ID Z	009 2.5m	011 2.5m	Mean
45 Control		16.1	6.5	11.3
46 EN Winds		12.3	6.6	9.5
47 TDBCS off		12.4	6.9	9.7
48 TDBCS2		11.5	8.8	10.2

See Figures 0526.1a-l for comparisons of the simulated and observed trajectories.

Once again, the forecast error for the surface drifters is much higher than that of the deeper drogues. The use of shipboard observations for hindcast winds improved the forecast skill for both deep and shallow groups. Turning the original TDBC forcing off caused a slight increase in forecast error. Turning this forcing back on after the *Endeavor* pre-processing procedure was corrected significantly degraded forecast skill. This led to a closer examination of the space-time structure of the elevations contained in the .cbc file. Comparison with files generated on the *Edwin Link* is currently underway; those findings will be reported at a later date.

The May 26 Central forecast EN324_FC.49 was computed with all the latest forcing products and ADCP data. Just after its completion, new drifter data arrived. Its evaluation will be conducted using the new data, and will be reported in the May 27 narrative.

MAY 27

Late in the day on May 26 the chief scientist decided to carry out an additional tracer release in the pycnocline prior to our departure for the North Flank. This opportunity was facilitated by (1) *Endeavor*'s scientific work proceeding slightly ahead of schedule, and (2) the availability of extra dye left over from previous experiments. Mid-morning on May 27, a small quantity of dye was injected to the north of the original patch, somewhat closer to the front. After an initial survey of the new injection, the final survey of the first pycnocline patch was begun. During that survey, a warm salty intrusion was noted in the pycnocline in the southeastern part of the track. This feature may be related to warm core ring activity south of the bank.

Forecasting Activities:

The May 27 central forecast EN324_FC.51 was run with all the latest forcing products, ADCP data and mass fields from the *Albatross* broad scale survey currently underway.

Another set of sensitivity experiments was conducted, of which six are reported here. The table below documents the forecast error statistics; simulated and observed trajectories are shown in Figures 0527.1a-f. Run EN324_FC.47 from the previous day's experiments is taken to be the control. That simulation was run out longer as EN324_FC.54dr so that it could potentially be used as a basis for operational products; as expected, increasing the simulation time did not significantly affect the forecast skill. Assimilation of an additional day's worth ADCP data in the May 26 "central" forecast EN324_FC.49b led to a decrease in forecast skill [the quotation marks refer to the fact that some adjustments were made to the true central forecast for May 26; see run table for details]. This suggests we have once again reached diminishing returns with respect to the assimilation of additional data. Use of the more recent mass fields from the *Albatross* broad scale survey does not improve this situation; in fact it makes it worse (contrary to prior experience). The results of the May 27 "central" forecast continue the trend of decreasing forecast skill with longer simulation time and more ADCP data assimilated. Starting the simulation later and assimilating ADCP data which is on average more recent improves the skill (run EN324_FC.55). These results highlight sensitivity of the predictions to forecast timing parameters. A thorough study of these issues is clearly needed; this sensitivity is likely interwoven with the nature of the time dependence in the subtidal flow.

Run ID	Description	Forecast Error (km)
EN324_FC.47	control	5.2
EN324_FC.54dr	(47) run longer	5.2
EN324_FC.49b	May 26 "central"	7.8
EN324_FC.50b	(49b) Alb. Mass	10.3
EN324_FC.52b	May 27 "central"	9.1
EN324_FC.55	(52b) shorter	8.1

Operational Products:

As we prepared to undertake our final dye surveys on the North Flank, the chief scientist requested predictions of where the two patches would be during the following 36 hours. Based on the sensitivity experiments conducted earlier in the day, run EN324_FC.54 was chosen as the basis for those predictions. Numerical drifters were launched at the release site of the second dye patch, as well as at the last observed position of the center of mass of the first. Forecast trajectories are shown in Figures 0527.2a,b. The particle representing the first dye patch was forecast to move toward the west, while the one representing the second dye patch, released closer to the front, was projected to move southwest.

May 28

The final survey of the first pycnocline release was conducted in the midst of a spectacular display of the oceanic food chain in action. For most of the day, huge schools of herring were present at the surface, for as far as the eye could see. The herring were being fed upon by an incredible abundance of whales. White water caused by the feeding activity was everpresent. In the early afternoon a great white shark was spotted.

Interestingly, the high concentration of *Calanus* present in this water mass just a few days before seems to have been drastically reduced. During one of the drifter recoveries, a member of the modeling team took the liberty of jigging up several mackeral and herring from the vast schools that surrounded the boat. Investigation of their gut contents revealed that they were stuffed full of copepods. Interesting "anecdotal evidence" of grazing activity by these higher predators.

Operational Products:

By May 28, the drifter data set used in the forecast evaluation described in the preceding narrative was 5-6 days old. Given the apparent temporal variability observed during that period (e.g., the wind events and water mass intrusion), it is not clear that those data constitute a reliable measure of forecast skill for the current conditions. Therefore, we decided to issue two sets of operational products: (1) those based on forecasts with the best skill according to the prior evaluation with drifter data, and (2) those which assimilate the most up-to-date data sets.

For the purposes of the survey of the older patch, operational products of the first category were issued on May 27. Two forecasts of the second type were issued on May 28, based on runs EN324_FC.52b and EN324_FC55 (Figures 0528.1a,b). Both show the patch moving more toward the southwest than west as in the prior product. The forecast trajectory based on EN324_FC.52b shows the particle moving much faster; that based on EN324_FC.55 moves only about 2/3 as far during the same time interval.

By 1300h on May 28, the apparent center of mass of the dye patch had been determined. The location was most consistent with simulation EN324_FC.55 ——the one in which the forecast timing parameters were adjusted to best match current conditions.

May 29

The final survey of the first pycnocline release was completed by approximately 2300h on May 28. A section to the front was then occupied. From there, *Endeavor* proceeded to the drifter that had been deployed in the tracer patch. That location constituted the center point of an expanding box survey used to define the extent of the tracer patch. By early afternoon the survey was complete. The drifter was recovered, and *Endeavor* departed for the North Flank.

Operational Products:

On May 28, the chief scientist requested a forecast of the patch location for May 29. The previous day's dye tracking operations had shown the forecasts based on the most recent data to be the most skillful; therefore an ensemble of simulations in that category were selected to bracket the most likely range of possible trajectories: EN324_FC.52b, 54 and 55. Particles were launched at the tracer release site in each of these simulations; their trajectories are shown in Figures 0529.1a-c. Late in the day May 28th, an updated fix on the drifter deployed in the dye patch was received. Based on that observation, forecast EN324_FC.55 was the most skillful. During the two tidal cycles that had passed since deployment, a 3km separation had developed between the simulated and observed trajectories, with the predicted location to the west- southwest of the observed location (Figure 0529.1c). This observation and evaluation presented the opportunity for an updated prediction of the location of the dye/drifter for use in the search which followed the frontal survey. A new particle was launched in simulation EN324_FC.55 at the last observed position, and its forecast trajectory was provided to the chief scientist (Figure 0529.2). The flow contained a relatively strong subtidal component toward the southwest. At 0300h on May 29, the frontal survey was completed; the ship then headed for the forecast position. At 0430h, *Endeavor* passed the drifter to port, less than 1km from its predicted location. Thus endeth our forecasting activities on the North Flank.

MAY 30

Our transit to the North Flank yielded some interesting results. The VPR was towed during the first part of the journey, up until the point where large amplitude sand waves made towyo operations unsafe (just west of Cultivator Shoal). Interestingly, the water on the crest of the bank never appeared to be completely mixed. A thin stratified layer persisted at the surface throughout the entirety of the observations. While this layer did get thinner as we proceeded shoalward, it never completely disappeared. Although we had seen a very thin layer of stratification atop the well mixed zone earlier in the cruise, it was our assumption that further up onto the shoal more vigorous tidal mixing would wipe this out. Such did not appear to be the case. These observations may be useful to put an upper bound on the mixing rates within the so-called "well-mixed" area.

Immediately upon our arrival on the North Flank, a VPR survey of our operational area was begun.

Forecasting Activities:

In preparation for our data assimilative work on the North Flank, a pair of simulations was carried out based on climatology. Identical experiments were run on the bank150 and gbk1 meshes: the model was initialized with the climatological mass field, and forced with climatological surface fluxes and elevation boundary conditions. A cloud of fluid-following particles, centered on the proposed tracer injection site, was released at 17m depth, the approximate position of the pycnocline. In the bank150 case (EN324NF_clim.01), the cloud translated approximately 13km/day eastward along the isobaths, such that its center of mass was displaced some 80km during the six day simulation (Figure 0530.1a). The eastward movement was about 30 percent slower in the gbk1 case (EN324NF_clim.02), in which the cluster's center of mass translates only 55km, with a mean speed of approximately 9km/day (Figure 0530.1b).

The particle clouds in both experiments converge into a relatively thin along-isobath strip, although the final distribution in gbk1 is somewhat more scattered. This pattern of convergence is accompanied by substantial vertical motion. The particles which lie shoalward in the initial condition move offshore, sliding underneath their offshore counterparts. This behavior is best visualized via animation (see web page). Our initial interpretation is as follows. The sheet of particles at 17m depth in the initial condition span a cross-bank density gradient. Whereas the particles offshore reside in the upper portion of the pycnocline, those in the well-mixed area occupy a denser isopycnal surface. As the tide moves off the bank, the shoaler particles slide along the isopycnal such that they lie below the offshore particles at the maximum off-bank tidal excursion. As the tide flows back onto the bank, they rise back up in the water column, but not to as shallow a depth as they began. Thus, there appears to be a secondary circulation at work which pumps water in the well-mixed region off the bank through the pycnocline. This has obvious implications for the upcoming tracer release experiment; we are actively continuing our diagnosis of these simulations.

Operational Products:

At this point we had yet to collect enough ADCP observations for a meaningful data assimilative run. However, the chief scientist felt that a climatological forecast of a particle trajectory from the tracer release site would be useful for planning purposes, particularly with respect to timing the release with the phase of the tide. We therefore provided Figure 0530.2, which shows a time-annotated trajectory of the center particle for the cloud released in simulation EN324NF_clim.01.

Addendum to the May 30 Forecasting Activities:

Subsequent to the analysis of the climatological simulations, there were enough ADCP data on the North Flank to begin data assimilative work. The May 30 central forecast was carried out on both bank150 and gbk1 meshes (runs EN324NF_FC.01 and 02, respectively). All of the latest forcing products were applied. ADCP data from the cross-bank transect and the first part of the North Flank survey were assimilated. The resulting residual velocity errors were higher than normal, on the order of 12 cm/sec (see table below). The magnitude of the error is slightly larger in the gbk1 case. The character of the residual velocity fields is quite similar in the two experiments (Figures 0530.3a,b). Although the fields are noisy, there does appear to be a bias in the vectors, which points in the on-bank direction.

The assimilation procedure exerts a relatively minor impact on the simulated trajectories of fluid-following particles released in the vicinity of the proposed injection site. Figures 0530.4a,b shows the trajectories of the central particle before (dashed line) and after (solid line) assimilation for both the bank150 (panel a) and gbk1 (panel b) experiments. Generally speaking, the assimilation tends to accelerate the along-isobath flow. Note, however, that the particle in the bank150 case runs into the boundary about two thirds of the way through the simulation.

The question arose as to what extent these aspects of the two simulations resulted from attempting to fit velocity observations from different regions of the bank simultaneously. Sensitivity experiments EN324NF_FC.03 and 04 are the same as EN324NF_FC.01 and 02, except that only velocity measurements from the North Flank were assimilated; the cross-bank transect was eliminated from the record. The magnitude of the residual velocity error is slightly reduced in the bank150 case, but nearly unchanged in the gbk1 run. The character of the residual velocity fields in these simulations is quite similar to the previous cases (Figures 0530.5a,b). The particle trajectories (Figures 0530.5a,b) show minor differences with respect to the prior runs. In the bank150 case, the center particle narrowly escapes its encounter with the boundary, so a trajectory for the full simulation is available. Increased along-bank movement effected by the assimilation procedure is still evident in the western portion of the track, but the particle slows down as it approaches the longitude at which the 50m isobath turns south. This deceleration is strong enough so that the total displacement is actually reduced by the assimilation procedure. This behavior is less evident in the gbk1 case. Although the particle does decelerate in the same area, the slowdown is less dramatic. Furthermore, the particle tends to move shoalward as it proceeds toward the east. In contrast, the cross-bank flow in the bank150 case is directed offshore. The causes of these differences are not yet known.

Run ID	**Grid**	**Description**	**RMS Vel Error (cm/sec)**
EN324NF_FC.01	b150	May 30 Central	11.4
EN324NF_FC.02	gbk1	May 30 Central	12.3
EN324NF_FC.03	b150	(01) NF ADCP only	10.3
EN324NF_FC.04	gbk1	(02) NF ADCP only	12.3

MAY 31 / JUNE 1

On May 31, the VPR survey of the North Flank continued. At 0400, ROV operations commenced in nearly ideal conditions. These were completed by 1200h, after which the drifters were recovered. A local survey in the vicinity of the proposed tracer release site was then begun in preparation for the injection scheduled for the following day.

In conjunction with the ROV operations, an assessment of groundfish abundance was carried out by a member of the modeling team. Despite the full moon and accompanying spring tides, which generally reduce the effectiveness of traditional hook-and-line sampling techniques, seven cod up to 11 pounds were collected during the two-hour course of the experiment. Thus, I am pleased to report that there are still cod on Georges Bank. However, their abundance was reduced by seven units as a result of the sampling procedure.

The local area survey was completed by the morning of June 1. Drifters were launched in a line across the isobaths, extending out beyond 200m. Injection of the dye began at 1330h, and was concluded by 1500. A single drifter was deployed in the dye patch. Immediately thereafter, dye survey operations began.

Forecasting Activities:

Both the May 31 and June 1 central forecasts were carried out on both bank150 and gbk1 meshes. Additional sensitivity experiments were conducted in which the mass fields were initialized with hydrography from the latest broadscale survey conducted by the *Albatross*. At the time, these fields were available for the gbk1 mesh only.

As in the May 30 forecasts, the residual velocity errors after assimilation were relatively high (see table below). Once again, the bank150 case had the lowest error.

Run ID	**Grid**	**Description**	**RMS Vel Error (cm/sec)**
EN324NF_FC.05f	b150	May 31 Central	9.7
EN324NF_FC.06f	gbk1	May 31 Central	14.4
EN324NF_FC.07f	gbk1	(06f) + Alb mass fields	15.9
EN324NF_FC.11	b150	June 1 Central	9.4
EN324NF_FC.12	gbk1	June 1 Central	15.6
EN324NF_FC.13	gbk1	(12) + Alb mass fields	17.3

The data we are attempting to fit on the North Flank are much noisier than what was encountered on the North Flank (Figure 0531.1). Examination of a typical section of ADCP data from the North Flank (Figure 0531.2) reveals much more vertical structure in the velocity field than we observed on the North Flank. Thus, some of the increased variance in our results is clearly attributable to the more dynamic flow in this area. However, there also appears to be significant environmental noise. Whereas the vertical profile of percentage good returns from the ADCP measurements was consistently 75% or above on the North Flank (except near the bottom), there is a pronounced subsurface minimum in good returns in our North Flank data records. In this thin layer located at 30-35m, the percentage of good returns drops below 50%. Interestingly, this anomalous behavior is collocated with an extremely dense layer of the colonial diatom *Chaetoceros socialis*. Flourometric chlorophyll measurements indicate concentrations in excess of 40 micrograms per liter, at or near the saturation of the instrument. We speculate that these planktonic colonies may impact the acoustic properties in this stratum, perhaps absorbing sound in their mucous matrix.

Data from the first drifter deployment on the North Flank provided a means for quantitative evaluation of our first set of forecasts in this region. Three drifters were launched in the deep waters off the bank: a surface and 19m drogue near the 150m isobath, and a 19m drogue at the 120m isobath (Figure 0531.3a). Both deep drogues moved rapidly (approximately 20 km/day) in the along-isobath direction. In addition, there is a clear on-bank component to their movement. The surface drifter trajectory is more difficult to interpret. Its movement in the first 12 hours is not dissimilar from the other two. Unfortunately, most of the position information for the second 12 hours is missing. During that time it appears to have looped back on itself. The reason for this behavior is not known.

These drifters were deployed in deep enough water that simulation of their trajectories is not possible on the bank150 mesh. Therefore we must rely solely on gbk1 for these comparisons. Results from the May 30 central forecast EN324NF_FC.02 (re-run as EN324NF_FC.10) are shown in Figure 0531.3a. The forecast error is lowest for the surface drifter, with the difference between the simulated and observed trajectories of 5km at the end of the one-day deployment. However, this agreement is clearly fortuitous: the rapid along-isobath motion of the observed drifter is not captured in the simulation. It is only when the real drifter stalls during the second 12 hours that the simulated drifter catches up.

Forecast errors for the deeper drogues in the May 30 simulation are approximately 10km. Most of this error consists of along-isobath velocities, which are too sluggish. However, the lack of on-bank movement in the simulated trajectories contributes to the error as well.

Assimilation of more data in the May 31 central forecast EN324NF_FC.06 slightly improves the skill for the deep drifters (Figure 0531.3b). There is a much more dramatic improvement when the mass fields derived from the most recent broadscale survey conducted by the *Albatross* are incorporated into simulation EN324NF_FC.07 (Figure 0531.3c). Forecast errors drop by approximately 50%, primarily as a result of more swift along-isobath velocity. The cross-bank flow is still not predicted by the model.

Two forecast runs conducted on June 1 parallel those from the prior day: the first used climatological mass fields, and the second used those from the *Albatross* survey. Once again, the skill of the forecast with more realistic mass fields is much better. However, forecast error in both of the June 1 runs is increased with respect to their counterparts from the preceding day. This decrease in skill is associated with a reduction in the along-isobath flow in the later runs (Figures 0531.3d,e). Thus, there appears to have been a very narrow temporal window during which assimilation of additional data actually improved model skill.

		Forecast Error (km)		
		Deep		**Shal**
Run ID	**Description**	**120m**	**150m**	**150m**
EN324NF_FC.02	May 30 Central	10.1	10.1	5.0
EN324NF_FC.06f	May 31 Central	9.7	9.7	5.0
EN324NF_FC.07f	(06f) + Alb mass fields	5.8	4.9	11.3
EN324NF_FC.12	June 1 Central	10.0	10.8	5.0
EN324NF_FC.13	(12) + Alb mass fields	7.5	8.3	7.4

JUNE 2

Dye survey operations continued.

Forecasting Activities:

The location of our operational activities necessitates use of the gbk1 mesh in our modeling work; the northern boundary of bank150 cuts right through the region of interest. Use of the larger mesh has made the problem more challenging from a computational point of view. Whereas typical forecast simulations (3 forward runs and 2 inversions) required 2.75 hours of CPU time on bank150, they require 6.3 hours on gbk1. The additional computational load has an impact on the throughput of the modeling work. Although four simulations can be run simultaneously, the results are not available until eight hours later (allowing time for post-processing and plotting). Thus, a typical working day accommodates only one "turnaround." More specifically: in the morning, results from the previous night are plotted and analyzed, and a new set of simulations is launched. Those results are available by late afternoon, and a second set of calculations based on those results is started that night; however, the new results are not available until the following day. With respect to forecasting operations, this dictates that each day's central run must be launched in the morning, regardless of whether or not updated forcing products arrive in the 0930 email download.

This is exactly the situation that arose on June 2. Because the updated atmospheric forecast was not received at 0930, the central forecast EN324NF_FC.14 was run using forcing products from the previous day. For the time period after which those products had expired, climatological surface fluxes were prescribed. A sensitivity experiment EN324NF_FC.15 was run in which ADCP data transmitted from *Oceanus* was assimilated. Both of these calculations were repeated later in the day when the updated atmospheric forcing products were received. The following table summarizes the results of these simulations with respect to their forecast skill in the first North Flank drifter deployment (now several days old). Note that the best forecasts from the previous three days are included for comparison. Simulated and observed drifter trajectories are plotted together in Figures 0602.1a-d.

		Forecast Error (km)		
		Deep		**Shal**
Run ID	**Description**	**120m**	**150m**	**150m**
EN324NF_FC.02	May 30 Central	10.1	10.1	5.0
EN324NF_FC.07f	May 31 Best	5.8	4.9	11.3
EN324NF_FC.13	June 1 Best	7.5	8.3	7.4
EN324NF_FC.14	June 2 Central	8.7	9.7	5.9
EN324NF_FC.15	(14) + *Oceanus* ADCP	8.7	9.7	5.9
EN324NF_FC.16	(14) + updated forcing	8.9	9.9	5.8
EN324NF_FC.17	(15) + updated forcing	8.9	9.9	5.8

These results demonstrate a continuing decrease in forecast skill associated with assimilating data too far beyond the time period of the drifter observations (as noted in the May 31 / June 1 narrative). Assimilation of ADCP data from the *Oceanus* has little impact on the forecast skill, due to the fact that she is conducting a local area survey some 70 miles away on the northeast peak. It is also worthy of note that the updated atmospheric forcing products did not significantly alter the results in this case. This is not surprising, given that this measure of skill is based on data from several days ago. More sensitivity can be expected in comparisons with the current drifter deployment, for which we expect to have data on June 3.

JUNE 3

The first full survey of the dye patch was completed. Preliminary analysis suggests the center of mass is moving at approximately 20km per day in the along-isobath direction. There also appears to be a significant off-bank component to its movement.

Forecasting Activities:

The June 3 central forecast EN324NF_FC.18 was run with all the latest forcing products and ADCP data. A sensitivity forecast EN324NF_FC.19 was conducted in which only "recent" ADCP data were assimilated (i.e. day 151 and later).

The first installment of data from the second North Flank drifter deployment arrived, permitting additional assessment of forecast skill. In all, seven drifters were deployed, consisting of (1) a cross-bank line of 19m drogues at the 120, 170, 200 and 210m isobaths, (2) a 19m drogue deployed in the dye patch itself, and (3) surface drifters at the 140m and 170m isobaths. Figures 1-3 compare the simulated and observed drifter trajectories for runs EN324NF_FC.16, 18 and 19, separated into the following groups: (a) the first drifter deployment; (b) second deployment, deep drifters; and (c) second deployment, surface drifters.

The 19m drogue deployed at the 120m isobath moves at approximately 20km/day toward the northeast. Its motion is predominantly along the isobaths, but a definite cross-isobath component is directed offshore. Modeled trajectories exhibit comparable along-isobath velocity, but their cross-isobath movement is directed shoalward.

Drifter 022, initially drogued at 19m, was picked up by a fishing boat, transported a short distance, and then re-deployed as a surface drifter. Due to these complications, its trajectory will not be analyzed here.

The 19m drogue deployed at the 200m isobath exhibits some behavior which suggests it may have had a similar fate, but this was not confirmed. Its initial motions were erratic; the drifter then moved offshore and began looping trajectories toward the north. This behavior is not captured by the model. Because of the suspicious nature of this drifter's trajectory, it will be excluded from further discussion.

The 19m drogue 009 deployed in Franklin Basin moves predominantly westward. This behavior is captured to some extent in run EN324NF_FC.16; however, it is not represented in run EN324NF_FC.18, in which the simulated drifter moves little during the time period for which the drifter data area available.

The final 19m drogue 037 deployed in the dye patch shows behavior similar to drifter 006: it moves rapidly along isobaths, with a discernable cross-bank component directed offshore. As before, modeled trajectories capture the general characteristics of the along-isobath flow, but exhibit cross-isobath flow which is opposite to that observed.

Both surface drifters in deployment 2 move almost exclusively along the isobaths; only slight cross-bank tendencies are present. Simulated trajectories capture the magnitude of the along-isobath flow, but exhibit significant on-bank movement which is not observed (Figures 0603.1c, 2c, 3c).

Given the focus of the tracer release work on waters shoalward of 200m, we will use drifters 006 and 037 as our quantitative measures of forecast skill. A summary of recent results is displayed in tabular form below:

		Forecast error (km)		
	Run ID	**16**	**18**	**19**
		Jun 2	**Jun 3**	**Jun 3**
		Central	**Central**	**Later ADCP**
Deployment 1				
Deep	022	8.8	10.1	10.8
	037	9.8	10.6	10.9
Shal	007	5.8	5.5	5.2
Deployment 2				
Deep	006	10.7	9.8	9.5
	037	7.4	6.6	6.4
Shal	011	15.0	15.7	15.3
	007	10.6	3.8	2.8

Generally speaking, forecast skill in the first deployment decreases with time, while that for the second deployment improves. Visualization of the temporal overlap between the data which are assimilated, and the observations used in the assessment make the reason for these trends clear:

```
          Dep. #1     Dep. #2
         [Drifters] [Drifters---]

Year Day 149  150  151  152  153  154  155  156
     May  30   31    1    2    3    4    5    6

Run 16   [ADCP---------------]
Run 18   [ADCP--------------------]
Run 19             [ADCP----------]
```

Forecast skill improves with coincidence of the temporal windows which define the extent of the assimilated observations and data used for verification. This argues strongly for time-dependence in the flow.

Evaluation of forecast skill with respect to movement of the dye patch is more difficult than with drifters. The complication arises from the fact that it takes a day or more to complete a survey of the patch, during which tidal motions cause significant displacements of the water. A strategy for dealing with this issue was developed, consisting of the following: Simulated fluid-following drifters are deployed along the survey track in the model solutions, with dye measurements stored in a separate file. Each of the particles is released at the time of observation and advected forward until the end of the survey. At the final time, the collection of particles represents an estimate of the syoptic distribution of observations based on the modeled velocities, from which the tracer distribution can be mapped. The location of the tracer's center of mass at the final time can then be compared with the position of a fluid-following particle injected into the solution at the release site, providing an estimate of forecast skill.

An example of this procedure is shown in Figure 0603.4. Panel (a) shows the location of the North Flank tracer release (star) and the track line of the first dye survey in geographic coordinates (dotted line). Panel (b) shows the distribution of survey observations advected to the final time by the modeled velocities. Color indicates tracer concentration. Also shown is the simulated trajectory of a fluid-following particle injected into the solution at the point of tracer release. At the final time, forecast error for the center of mass is approximately 6km. The simulated tracer moved along the isobaths more rapidly than observed. Its cross-isobath component was directed onshore, in contrast with the observations which suggest an off-bank drift (note that the final time is high tide on the bank, whereas the release took place at low tide). One metric of forecast skill can be computed by dividing the distance between the simulated and observed center of mass by the total displacement of the patch, yielding a forecast error of approximately 20 percent.

Operational Products:

On the morning of June 3, the chief scientist requested an updated forecast of the dye trajectory. At that time, forecast runs had not yet been evaluated with data from the second drifter deployment. Based on the evaluations that had been completed, the May 31 Central forecast EN324NF_FC07 was the most skillful. A time-annotated plot of the simulated trajectory of the dye patch was provided (Figure 0603.5).

JUNE 4

Dye survey #2 completed; survey #3 begun.

Forecasting Activities:

Given the timing of the operational forecast simulations (launched each day at 1030, completed by 1630), mornings and afternoons provide the most logistically feasible opportunity for in-depth analysis of the previous day's runs. This activity on June 4 was focused on comparing model predictions with tracer observations. The June 3 forecast evaluation indicated time dependence in the flow, such that the most skillful predictions were those based on the most recent data. Forecast run EN324NF_FC.19 was identified as the best run to date (based on NF drifter deployment 2). With completion of the second dye survey early in the day, there was a new opportunity for model/data comparison. Figure 0604.1a shows the track lines of dye survey #2 in geographic coordinates; Figure 0604.1b displays the model-derived synoptic map of the tracer distribution using advected station locations. Note that the predicted center of mass of the dye patch is only 6km southeast of its <<observed>> position, at a time when the patch has moved approximately 50km from the point of injection. The punctuation surrounding the word <<observed>> is meant to emphasize the fact that the observations must be combined with an advective model of some type in order to make meaningful comparisons in geographic coordinates. In this case, the same model is being used for advection of the observation points and the simulated trajectory of the center of mass; thus the two are not completely independent. A perfectly independent comparison could be made by identifying the exact time and location of the observation which turned out to be the center of mass, and then comparing it to the simulated dye location at the time of observation.

Intoxicated with the apparent skill of this prediction, we then applied the same forecast run to the first dye survey to see whether or not the prior simulation of the tracer trajectory could be improved. Figure 0604.2 shows a synoptic map of tracer concentration based on run EN324NF_FC.19. The simulated center of mass of the dye patch is less than 1km from the <<observed>> position, at a time when the patch has moved approximately 28km from the release site. Surely this close agreement is to some degree fortuitous; however, it demonstrates the sensitivity of the forecast skill to the time interval during which data are assimilated.

The June 4 central forecast EN324NF_FC.22 was run with all the latest forcing products and ADCP data. Based on the forecast evaluation from the previous day, ADCP data prior to day 151 were ignored, as in run EN324NF_FC.19. Sensitivity run EN324NF_FC.23 used time-dependent boundary condition forcing generated from the UNC far-field model. Figure 0604.3 shows the temporal evolution of these elevations which are superimposed on those already present in the regional ocean model.

An updated data set for the second North Flank drifter deployment was used in the following evaluation. For comparison, the best run from the preceding day (EN324NF_FC.19) is re-evaluated below using the new data. Figures 0604.4-6 compare the simulated and observed drifter trajectories.

		Forecast error (km)		
	Run ID	**19 Jun 3 Later ADCP**	**22 Jun 4 Central**	**23 Jun 4 TDBCS**
Deployment 2 - Initial				
Deep	006	9.5		
	037	6.4		
Shal	011	15.3		
	007	2.8		
Deployment 2 - Extended				
Deep	006	16.3	19.0	17.5
	037	14.6	14.4	14.2
Shal	011	22.6	27.8	30.7
	007	9.7	35.0	34.3

Comparing the model results from the previous day (EN324NF_FC.19) to the longer set of observations, the discrepancies present in the prior evaluation tend to be accentuated (compare Figures 0604.4a,b with 0603.3b,c). The tendency for the deep drifters to move off-bank while the simulated drifters move on-bank produces high forecast errors, on the order of 15km. The surface drifters appear to have been driven shoalward by the moderate winds present on June 3. While this behavior appears to have been captured by simulated drifter ID #007, simulated drifter ID #011 proceeds much too far in that direction.

Interestingly enough, neither of the subsequent forecasts on June 4 results in significant improvement. In fact, forecast skill with respect to the surface drifters decreases appreciably. As for the deeper drifters, forecast skill for ID #006 drops, while it improves slightly for #037 (the drifter closest to the dye patch). Clearly this latter result may be related to the fact that ADCP data collection was most concentrated in the vicinity of that particular drifter.

Operational Products:

A time-annotated plot of the simulated trajectory of the dye patch based on forecast EN324NF_FC.19 (re-run as EN324NF_FC.21d) was provided to the chief scientist (Figure 0604.7).

JUNE 5

The fourth and final survey of the dye patch was begun. Unfortunately it was interrupted twice: first when the patch entered an area densely populated with lobster gear, and second when the main engine had to be shut down for maintenance.

Forecasting Activities:

The June 5 central forecast EN324NF_FC.24 was run with all the latest forcing products and ADCP data. Given the previous results, which indicated that ignoring "old" data could improve predictive skill, two sensitivity experiments EN324NF_FC.25 and 26 were run, each shortening the assimilated ADCP data record by approximately 24 hours. Later that day, the best forecast run EN324NF_FC.19 was re-run as EN324NF_FC.29 with updated TDBC forcing. The suite of runs conducted during June 3-5 was evaluated with yet another update of the second North Flank drifter deployment. Simulated and observed trajectories are shown in Figures 0605.1a-g; forecast errors are reported in tabular form below.

		Forecast error (km)						
Run ID		19 Jun 3 Later ADCP	22 Jun 5 Central	23 Jun 4 TDBCS	24 June 5 Central	25 June 5 ADCP-1	26 June 5 ADCP-2	28 June 5 TDBCS
Deployment 2 - Extended (days 151.6-154.5)								
Deep	006	16.3						
	037	14.6						
Deployment 2 - Extension 2 (days 151.6-155.4)								
Deep	006	9.0	9.5	10.7	9.7	9.5	12.0	9.2
	037	18.4	16.0	17.1	20.3	16.9	19.5	16.7

The results show that none of the June 5 forecasts resulted in improvement beyond what was achieved in run EN324NF_FC.19. Note that the forecast skill for drifter ID #006 actually improved when the longer data record was used. Comparison of Figure 0604.4a with Figure 0605.1a shows that the evaluation of simulated drifter #006 happened to occur during an anomalous on-bank loop of its tidal excursion. The same drifter was exhibiting more typical behavior in the subsequent comparison, resulting in reduced forecast error.

The conclusion of the third survey of the North Flank dye patch was used in yet another evaluation of forecast run EN324NF_FC.19. Figure 0605.2a shows the tracer release site and the survey tracks in geographic coordinates. The simulated trajectory and model-derived synoptic map of the dye are shown in Figure 0605.2b. After 80km displacement along the North Flank, the simulated center of mass is located 12km southwest of the <<observed>> position.

JUNE 6

The fourth and final dye survey was completed successfully. Drifters were recovered and *Endeavor* headed for home at approximately 1130 local time. During transit, the ship's speed was too high for collection of ADCP data.

Modeling Activities:

According to the evaluations based on deep drifter data, the best forecast during the North Flank tracer release experiment was run EN324NF_FC.19. The predicted trajectory of the center of mass of the dye based on that simulation is compared with the last survey. However, determination of the tracer's center of mass was made difficult by the presence of spikes in the raw data. This evaluation will have to await further processing of the dye observations.

5. Electronic Archive

All data and software used to produce the forecasts and analyses contained herein is archived electronically at

http://science.whoi.edu/users/mcgillic/globec/EN323-4/html/en323-4.html

The top-level directory of the archive is users/mcgillic/globec/EN323-4, at which the following subdirectories are found:

```
      Data              fcast_archives    pictures    software
      email_archive     html              report
```

Contents of each are briefly indicated below; descriptions are denoted by brackets.

```
./data:
      adcp              drifters          met_ship    met_shore
      satellite         vpr

./data/adcp:
      [pingdata files for each cruise]

./data/drifters:
      [.dft and .m3d files for drifter data sorted by date of availability]

./data/met_ship:
      [data files from Endeavor meteorological sensors]

./data/met_shore:
      NMFS              UNC

./data/met_shore/NMFS:
      [Data files generated from NMFS "New Model Weather" products]

./data/met_shore/UNC:
      [*_fort.61 and *_fort.72 files from UNC]

./data/satellite:
      [SST and SeaWiFS images]

./data/vpr:

./email_archive:

./fcast_archives:
      [output files from all model runs]

./html:
      [web-based archive products]

./pictures
      [photo album]

./report:
```

```
./software:
      FCAST_1.0             adcp                  pix
      FCAST_1.0_djm         atsee                 project_obs
      FCAST_1.1A            daily_ave             project_obs2
      FCAST_1.1A1           doc                   questions
      FCAST_1.1B            drifters              run_table
      FCAST_1.1B1           incoming_email        run_table.en323
      MESH                  ledwell_plots         run_table.en324_SF
      README                manifest              run_table_short.en323
      TDBCS                 misc                  truxton_standalone
      VIS_1.0               movies                vpr_data
      VIS_1.2               outgoing_email
```

6. Figure Captions

Executive Summary

Figure 1. Forecast error (measured as the distance between simulated and observed trajectories of dye/drifters at the end of the data record) plotted as a function of the duration of the prediction. Each point represents the best forecast for each skill evaluation conducted during cruises EN323 and EN324.

PRE-CRUISE

Figure 1. Initial and final positions (gray and black dots, repsectively) of particles release in the six climatological forecast experiments described in the pre-cruise narrative (see text).

0504

Figure 1. Initial and final positions (gray and black dots, repsectively) of particles release in forecast simulation (a) EN323_FC.01, and (b) EN323_FC.02.

0505

Figure 1. Initial and final positions (gray and black dots, repsectively) of particles release in forecast simulation EN323_FC.03.

0506

Figure 1. Cruise track (a) and ADCP observations (b) during *Endeavor*'s transit toward the operational area. The ship's gyrocompass was adjusted at approximately 1430GMT on day 125.

0507

Figure 1. Simulated drifter trajectories in forecast run EN323_FC.06: (a) iteration 1, and (b) iteration 3.

Figure 2. Simulated drifter trajectories in iteration 3 of forecast run EN323_FC.07.

Figure 3. Simulated drifter trajectories in iteration 3 of forecast run EN323_FC.09.

0508

Figure 1. Residual velocity error remaining in the final iteration of simulation EN323_FC.06. Cruise track is penciled in as a solid line.

Figure 2. RMS of the observed ADCP velocity plotted as a function of offset angle PHI.

Figure 3. Calibration of the ADCP transducer rotation angle PHI: (a) location of the observations used in the calibration, (b) uncalibrated data, and (c) calibrated data.

Figure 4. Simulated drifter trajectories in iteration 3 of forecast run EN323_FC.06b.

0509

Figure 1. Simulated (solid line) and observed (solid line with dots) drifter trajectories for forecast experiments:

(a) EN323_FC.11
(b) EN323_FC.12
(c) EN323_FC.13
(d) EN323_FC.14
(e) EN323_FC.15
(f) EN323_FC.16

Figure 2. Simulated trajectory of drifter number 5 in iteration 3 of forecast experiments (a) EN323_FC.12, and (b) EN323_FC.12nw.

Figure 3. Top four panels: time series of wind stress in the May 7-10 forecast products provided by UNC. Bottom panel: wind stress derived from buoy observations.

0510

Figure 1. Predicted surface currents at the site of the first tracer release experiment.

Figure 2. Simulated (solid line) and observed (solid line with dots) drifter trajectories for forecast experiments:

(a) EN323_FC.11
(b) EN323_FC.12
(c) EN323_FC.13
(d) EN323_FC.14
(e) EN323_FC.15
(f) EN323_FC.16
(g) EN323_FC.19
(h) EN323_FC.20
(i) EN323_FC.21
(j) EN323_FC.22
(k) EN323_FC.23

0514

Figure 1: SST image for 10 May 1900 UTC [image.0510.1900.gif]

Electronic: image.0510.1900.gif
image.0510.1900.ps

Figure 2: Map of planned cruise track for 15 May. Also shown are ADCP track lines from *Edwin Link* and EN323 VPR surveys, and Schiltz mooring line.

Electronic:

Figure 3: Alongtrack residuals from EL9905 ADCP survey.

Electronic: el9905_resid.ps [plotting/en324_fc.m]

0515

Figure 1: Winds from the AVN model (a), buoy observations (b), and a hybrid record used in forecast run EN324_FC.05. Time is in year days GMT; stress in Pascals.

Electronic: may15_wind.ps

0516

Figure 1: Simulated and observed drifter trajectories for forecasts EN324_FC.01 (a), EN324_FC.02 (b), EN324_FC.03 (c), EN324_FC.04(d), EN324_FC.05(e), EN324_FC.06 (f), EN324_FC.07(g), EN324_FC.08(h).

Electronic: en324_fc.XX_dr.ps

Figure 2: Simulated drifter trajectories in the BPE (dotted) and after assimilation (solid).

Electronic: release1_el_comp.ps [plotting/release1_el_comp.m]

Figure 3: Surface current predictions based on a numerical mooring at the tracer release site.

Electronic: mooring_tr1_en324.ps

Figure 4: Initial and final locations of a cloud of particles launched around the tracer release site.

Electronic: en324_fc.10.ps

Figure 5: Trajectory of the central particle in the cloud shown in (4).

Electronic:

0517

Figure 1: Temperature cross section from along standard transect 1 taken from (a) the May 16 central forecast (EN324_FC.08), and (b) an experiment in which the surface heat flux was increased to five times its climatological value (run EN324_FC.08h).

Electronic: temp_sec.jpg
temp_sec2.jpg

Figure 2: Satellite SST image from 15 May.

Electronic: image.0515.1900.gif

Figure 3: Surface current predictions based on a numerical mooring at the tracer release site.

Electronic: mooring_tr1a_en324.ps

0518

Figure 1. Simulated particle trajectories at the surface (solid line) and 30m. Both particles originate at the center of a cloud at the tracer release site.

Electronic: en324_fc.10-14.ps

Figure 2. Simulated and observed drifter trajectories for forecasts EN324_FC.15.

Electronic: en324_fc.15_dr.ps

Figure 3. Simulated and observed drifter trajectories for forecasts EN324_FC.16.

Electronic: en324_fc.16_dr.ps

0519

Figure 1. Drifter release locations.

Electronic: drif_posit_0519.ps

Figure 2. Simulated and observed drifter trajectories: deep drogues.

Figure 3. Simulated and observed surface drifter trajectories.

0520

Figure 1: Forecast trajectory of the observed remnant of the tracer release.

Electronic: dye_patch_time_27.ps

Figure 2: Revised forecast trajectory of the observed remnant of the tracer release based on updated atmospheric forcing.

Electronic: dye_patch_28.ps

0521

Figure 1: (a) Simulated currents at the proposed tracer release site based on forecast EN324_FC.29; (b) Simulated trajectory of a particle launched at the tracer release site.

Electronic: mooring_tr2.ps

Figure 2: (a) Simulated currents at the proposed tracer release site based on forecast EN324_FC.30; (b) Simulated trajectory of a particle launched at the tracer release site.

Electronic: mooring_tr2a.ps
drifter_tr2a.ps

Figure 3: (a) Simulated currents at the proposed tracer release site based on forecast EN324_FC.31; (b) Simulated trajectory of a particle launched at the tracer release site.

Electronic: mooring_tr2b.ps
drifter_tr2b.ps

0522

Figure 1: (a) Simulated currents at the proposed tracer release site based on forecast EN324_FC.32; (b) Simulated trajectory of a particle launched at the tracer release site.

Electronic: mooring_tr2c.ps
drifter_tr2c.ps

Figure 2: (a) Simulated currents at the proposed tracer release site based on forecast EN324_FC.34; (b) Simulated trajectory of a particle launched at the tracer release site.

Electronic: mooring_tr2d.ps
drifter_tr2d.ps

0523

Figure 1: (a) Simulated currents at the proposed tracer release site based on forecast EN324_FC.35; (b) Simulated trajectory of a particle launched at the tracer release site.

Electronic: mooring_tr2e.ps
drifter_tr2e.ps

Figure 2: Simulated trajectories of a particle launched at the Ledwell release site, (a) based on forecast EN324_FC.36, and (b) EN324_FC.37.

Electronic: drifter_led_36.ps
drifter_led_37.ps

Figure 3: Simulated trajectories of a particle launched at the Houghton release site, (a) based on forecast EN324_FC.36, and (b) EN324_FC.37.

Electronic: drifter_houghton_36.ps
drifter_houghton_37.ps

0524

Figure 1: Comparison of observed drifter trajectories with those simulated in run EN324_FC.38dr.

Electronic: [missing]

Figure 2: Simulated trajectories of a particle launched at the Ledwell release site based on forecast EN324_FC.38.

Electronic: drifter_led_38.ps

0525

Figure 1: Comparison of observed drifter trajectories with those simulated in runs:

(a) EN324_FC.40
(b) EN324_FC.41
(c) EN324_FC.41cdr
(d) EN324_FC.42
(e) EN324_FC.43
(f) EN324_FC.44

Electronic: En324_fc.XX_dr.ps XX=40,41,41cdr,42,43,44

0526

Figure 1: (a–l) Comparison of observed drifter trajectories with those simulated in runs EN324_FC.45–48.

Electronic: en324_fc.XX_drYY.ps, XX=45,46,47,48 ; YY=1,2,3

0527

Figure 1: (a–f) Comparison of observed drifter trajectories with those simulated in runs EN324_FC.54dr,49b,50b,52b,55. See figure 0526.1 for run EN324_FC.47.

Electronic: en324_fc.XX_drYY.ps, XX=47,54dr,49b,50b,52b,55; YY=1,2

Figure 2: Simulated trajectories based on forecast EN324_FC.54 for (a) the first pycnocline tracer release since the last observation of its center of mass, and (b) the second pycnocline tracer release from its point of injection.

Electronic: drifter_led_54.ps
drifter_led_54a.ps

0529

Figure 1: Simulated drifter trajectories for the ensemble of forecasts (a) EN324_FC.52b, (b) EN324_FC.54, and (c) EN324_FC.55.

Electronic: drifter_led_52b_a.ps
drifter_led_54a.ps
drifter_led_55a.ps

Figure 2: Updated forecast of the drifter trajectory based on simulation EN324_FC.55.

Electronic: drifter_led_56a.ps

0530

Figure 1: Initial and final positions of a cloud of fluid-following particles released at a depth of 17m in (a) simulation EN324NF_clim.01, and (b) simulation EN324NF_clim.02. Simulation time is six days.

Electronic: en324nf_clim_pos.ps

Figure 2: Simulated trajectory of a fluid-following particle released at the proposed tracer release site on the North Flank.

Electronic: drifter_tr3.ps

Figure 3: Residual velocity error in the third Quoddy simulation of experiment (a) EN324NF_FC.01 and (b) EN324NF_FC.02.

Electronic: EN324NF_FC.01_vel.ps
EN324NF_FC.02_vel.ps

Figure 4: Simulated particle trajectories before (dashed line) and after (solid line) assimilation in experiment (a) EN324NF_FC.01 and (b) EN324NF_FC.02.

Electronic: en324NF_FC.01-02_pos.ps

Figure 5: Residual velocity error in the third Quoddy simulation of experiment (a) EN324NF_FC.03 and (b) EN324NF_FC.04.

Electronic: EN324NF_FC.03_vel.ps
EN324NF_FC.04_vel.ps

Figure 6: Simulated particle trajectories before (dashed line) and after (solid line) assimilation in experiment (a) EN324NF_FC.03 and (b) EN324NF_FC.04.

Electronic: en324NF_FC.03-04_pos.ps

0531-0601

Figure 1: Simulated and observed velocities in the three Quoddy runs of forecast run EN324NF_06.

Electronic: en324nf_fc.06f_adcp

Figure 2: A sample alongtrack ADCP velocity record from the North flank. Note that bottom tracking is lost at approximately the 180m isobath. Tick marks on top of each plot indicate data points which are ignored due to this dropout.

Electronic: nf_adcp.ps

Figure 3: Simulated and observed drifter trajectories in forecast runs
(a) EN324NF_02 (re-run as EN324NF_10)
(b) EN324NF_06
(c) EN324NF_07
(d) EN324NF_12
(e) EN324NF_13

Electronic: en324nf_fc10_dr1.ps
en324nf_fc06f_dr1.ps
en324nf_fc07f_dr1.ps
en324nf_fc.12f_dr1.ps
en324nf_fc.13f_dr1.ps

0602

Figure 1: Simulated and observed drifter trajectories in forecast runs
(a) EN324NF_14
(b) EN324NF_15
(c) EN324NF_16
(d) EN324NF_17

Electronic: en324nf_fc.14_dr1.ps
en324nf_fc.15_dr1.ps
en324nf_fc.16_dr1.ps
en324nf_fc.17_dr1.ps

0603

Figure 1: Simulated and observed drifter trajectories in forecast run EN324NF_16: (a) drifter deployment 1; (b) deployment 2 deep drifters; and (c) deployment 2 shallow drifters.

Figure 2: Simulated and observed drifter trajectories in forecast run EN324NF_18: (a) drifter deployment 1; (b) deployment 2 deep drifters; and (c) deployment 2 shallow drifters.

Figure 3: Simulated and observed drifter trajectories in forecast run EN324NF_19: (a) drifter deployment 1; (b) deployment 2 deep drifters; and (c) deployment 2 shallow drifters.

Figure 4: Forecast skill evaluation based on the movement of the North Flank dye patch: (a) tracer release location (star) and track lines for the first dye survey; (b) simulated trajectory of the dye and a synoptic map of the observations advected to the final time using modeled velocities (see text).

Electronic: release3_0603_frame1.ps
release3_0603_frame2.ps

Figure 5: Simulated trajectory of a fluid-following particle released at the tracer release site on the North Flank.

Electronic: drifter_tr3_07.ps

0604

Figure 1: Forecast skill evaluation based on the movement of the North Flank dye patch: (a) tracer release location (star) and track lines for the second dye survey; (b) simulated trajectory of the dye and a synoptic map of the observations advected to the final time using modeled velocities (see text).

Electronic: release3_06041_frame1.ps
release3_06041_frame2.ps

Figure 2: Simulated trajectory of the dye and a synoptic map of the observations in the first dye survey advected to the final time using modeled velocities.

Electronic: release3_0603h1_frame2.ps

Figure 3: Time series of elevation boundary conditions derived from the UNC far-field model used to drive forecast run EN324NF_FC.23.

Electronic: jun04_gbk1.cbc.ps

Figure 4: Simulated and observed drifter trajectories in forecast run EN324NF_19: (a) deployment 2 deep drifters; (c) deployment 2 shallow drifters.

Electronic: en324nf_fc.19_dr2d.ps
en324nf_fc.19_dr3d.ps

Figure 5: Simulated and observed drifter trajectories in forecast run EN324NF_22: (a) deployment 2 deep drifters; (c) deployment 2 shallow drifters.

Electronic: en324nf_fc.22_dr2.ps
en324nf_fc.22_dr3.ps

Figure 6: Simulated and observed drifter trajectories in forecast run EN324NF_23: (a) deployment 2 deep drifters; (c) deployment 2 shallow drifters.

Electronic: en324nf_fc.23_dr2.ps
en324nf_fc.23_dr3.ps

Figure 7: Simulated trajectory of a fluid-following particle released at the tracer release site on the North Flank.

Electronic: drifter_tr3_21d.ps

0605

Figure 1: Simulated and observed drifter trajectories (deep drifters only) in forecast runs

(a) EN324NF_19
(b) EN324NF_22
(c) EN324NF_23
(d) EN324NF_24
(e) EN324NF_25
(f) EN324NF_26
(g) EN324NF_28.

Electronic: en324nf_fc.19_dr1n.ps
en324nf_fc.22_dr1n.ps
en324nf_fc.23_dr1n.ps
en324nf_fc.24_dr1n.ps
en324nf_fc.25_dr1n.ps
en324nf_fc.26_dr1n.ps
en324nf_fc.28_dr1n.ps

Figure 2: Forecast skill evaluation based on the movement of the North Flank dye patch: (a) tracer release location (star) and track lines for the third dye survey; (b) simulated trajectory of the dye and a synoptic map of the observations advected to the final time using modeled velocities (see text).

Electronic: release3_0605_frame1.ps
release3_0605_frame2.ps