CGSN Site Characterization: Pioneer Array

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CGSN Site Characterization: Pioneer Array

Scope

This report describes conditions in the atmosphere, in the ocean, and on the sea floor in the vicinity of the OOI Pioneer Array. The Pioneer Array infrastructure components, and the layout of the components at the site, are then presented along with the motivation for refinements to the initial Pioneer Array design.

Overview

The Pioneer Array is a multi-scale array utilizing fixed and mobile assets to provide observations spanning the shelfbreak front on the northwest Atlantic continental shelf. A front is a region where horizontal property gradients show a local maximum. The shelfbreak front is quasi-continuous offshore of the US east coast, with the foot of the front found in the vicinity of the change or "break" in bottom slope where the continental shelf meets the continental slope (Linder and Gawarkiewicz, 1988). The heart of the Pioneer Array is a moored array aligned perpendicular to isobaths and spanning the shelf break (Fig.1). The central site is intended to be at the climatological center of the shelf break jet. The inshore and offshore sites will span the typical variability in frontal location (excluding near-surface and near-bottom extremes), and will also capture the typical meanders of the jet.

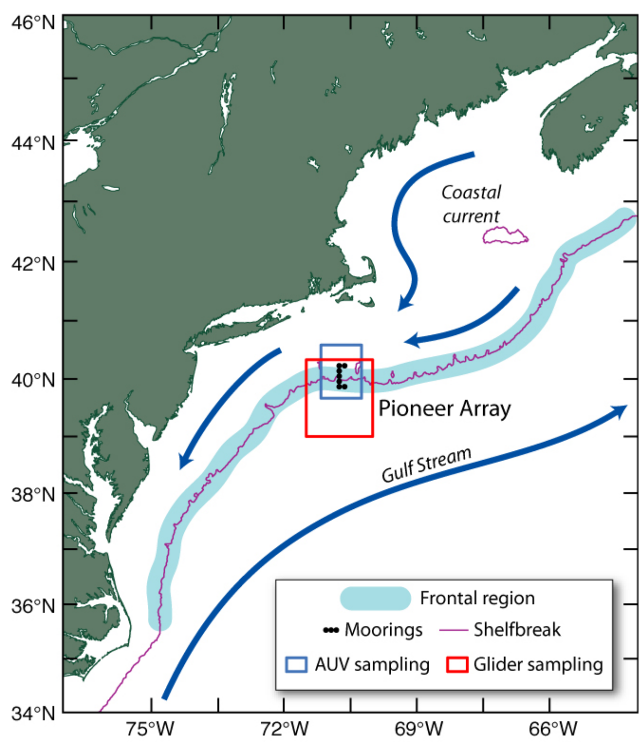


Figure 1. Location of the Pioneer Array relative to the shelfbreak frontal region.

The Pioneer moored array is shown schematically in Fig. 2. The inshore and central sites of the across-shelf mooring line utilize electrical-mechanical (EM) surface moorings paired with surface-piercing profilers, while the offshore site contains an EM surface mooring and wire-following profiler mooring. The two "intermediate" sites, inshore and offshore of the central site, utilize wire-following profiler moorings and ensure that the moored array samples the frontal system coherently. The two upstream moorings are also wire-following profiler moorings, and provide along-shelf gradients to aid in determination of advective fluxes.

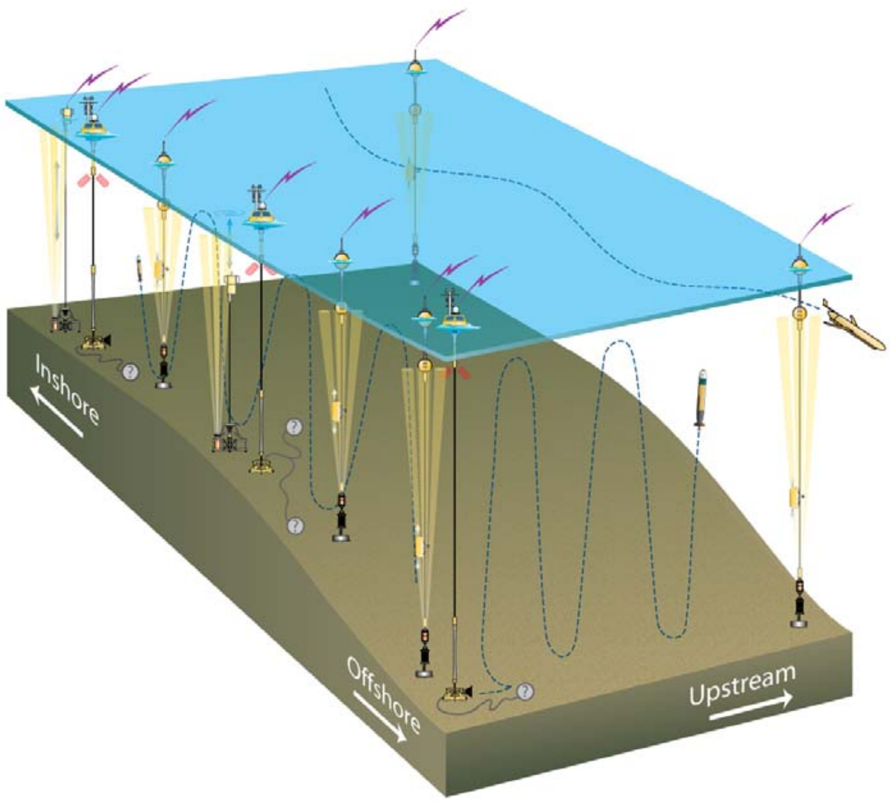


Figure 2. Schematic diagram of the Pioneer Array, showing surface moorings, AUV docks (base of inshore and offshore surface moorings), Multi-Function Nodes (base of surface moorings), surface-piercing profilers (inshore and central sites), wire-following profilers, and (schematic) AUV and glider transects in the vicinity of the moored array. Multi-Function Nodes will support expansion by addition of science-user instrumentation, depicted by (?). **NOTE:** Final mooring locations and array configuration are defined and controlled in Section 2.2.

In order to provide synoptic, multi-scale observations of the outer shelf, shelf break frontal region, and slope sea, the moored array is supplemented by nine mobile platforms – six gliders and three AUVs. Two AUVs will operate from docking stations at the base of the surface moorings, running synchronized, synoptic sampling missions over the continental shelf and slope in the vicinity of the moored array. The third AUV will be operated independently of the docks (e.g. from a ship during mooring service cruises or from a small coastal vessel during glider service cruises), will provide adaptive sampling and event-response capability without interrupting the baseline AUV missions, and will be a means of assessing moored sensor degradation (by comparison with freshly calibrated sensors on the vehicle). A fleet of six gliders will survey the outer shelf and the slope waters offshore of the moored array.

Conditions within the Pioneer Array region (Sec. 1) were assessed relative to the science goals, leading to refinements to the layout of the array elements (see Sec. 2) relative to that described in the OOI Final Network Design (1101-00000). Note that the mooring site locations and glider/AUV operation areas used in all figures in Sec. 1 are the initial proposed locations. The final array configuration is defined and controlled in Sec. 2.2.

1. Site Survey

1.1. Bathymetry

1.1.1 Bathymetry Data Evaluation

There are several sources for bathymetric data in the Pioneer Array area (Fig. 3). The first two are freely available global databases with approximately 1-minute resolution: ETOPO-1, and Smith and Sandwell (1997). The third is near-shore bathymetry, at resolutions as fine as 3 seconds, from the Coastal Relief Model at NOAA's National Geophysical Data Center (NGDC).

At the scale of Fig. 3, in depths of 1000m and shallower, data from all the sources match closely. Coastal Relief Model data do not extend to the deeper depths (note the missing blue contours near the bottom of Fig. 3), so for regional-scale bathymetry we have two choices among the sources listed above: ETOPO-1 and Smith and Sandwell (1997). In areas of the continental slope where there is a significant discrepancy between the two, Smith and Sandwell (1997) appears generally more believable (see Fig. 4; note also dubious features in the ETOPO-1 bathymetry (red) near 39.5°- 40° N, 68°- 70° W in Fig. 3). For regional-scale bathymetry in the Pioneer Array area, therefore, we recommend the Smith and Sandwell (1997) dataset.

Near the moored array, multi-beam sonar surveys made available by the USGS Woods Hole Science Center (Uri Ten Brink, personal communication) provide a fourth source of bathymetric data; these measurements are accurate and have very high resolution, but limited spatial coverage.

Near the moored array, the accuracy of the three datasets can be inferred from comparisons with the USGS multi-beam survey data; all three have similar error levels (Fig. 5). Interestingly, due to the reduced density of sounding data in deep water, the higher-resolution Coastal Relief Model data (bottom panel, Fig. 5) do not appear to capture small-scale bathymetric features in this region any better than the lower-resolution datasets. In the interest of simplicity and consistency, then, we favor the same data source for the immediate vicinity of the moored array that we chose for larger scales, i.e. Smith and Sandwell (1997). However, a merged bathymetry map incorporating both multi-beam and Smith and Sandwell (1997) data was also created (see Sec. 2.2.1).

The spatial density of the soundings used to create the NGDC Coastal Relief Model database increases dramatically near the coast. In these areas, the level of detail in the Coastal Relief Model dataset far surpasses that of the global datasets (Fig. 6). This resource will be useful in the planning of any near-shore operations.

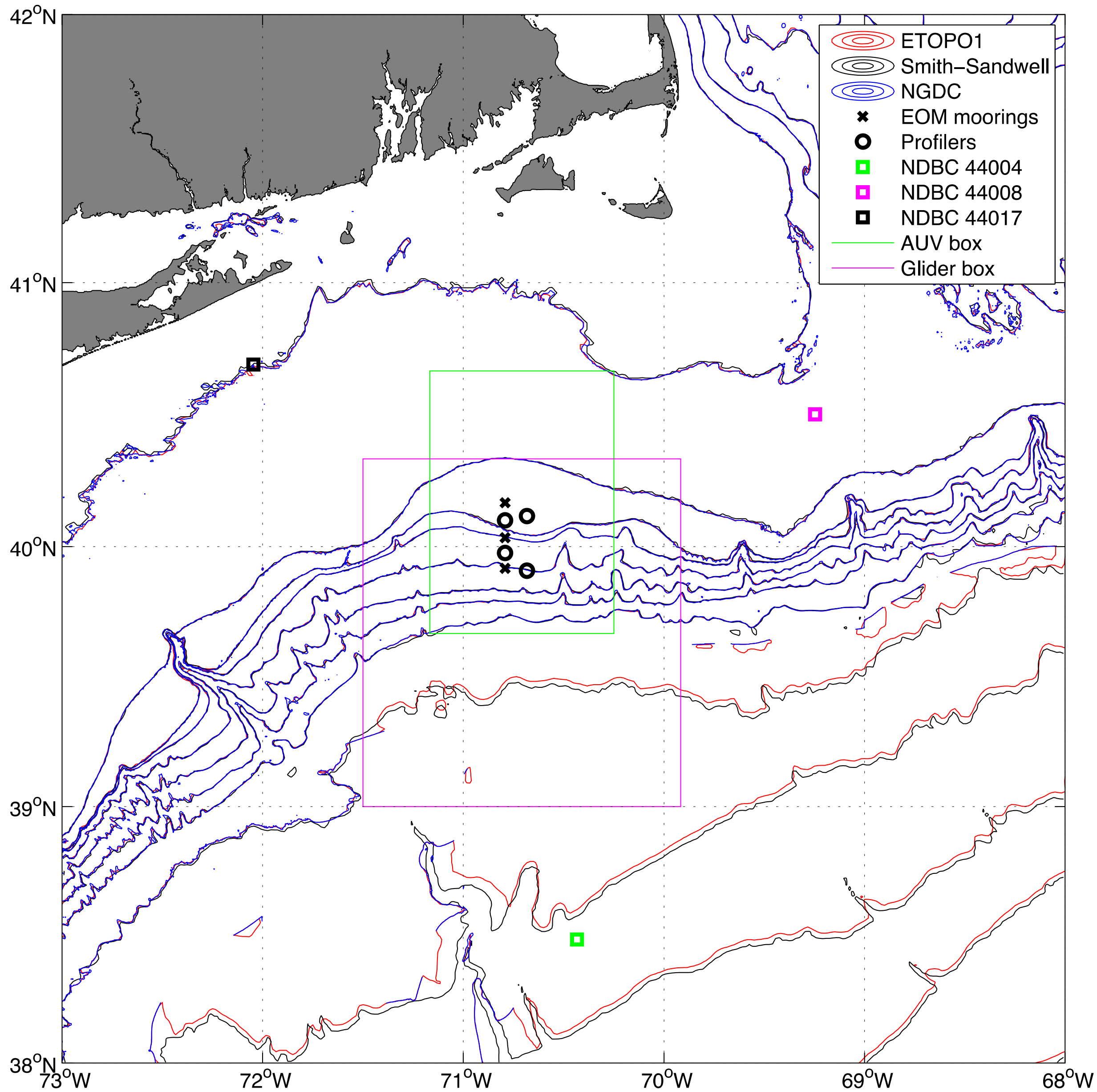


Figure 3. Bathymetry from ETOPO-1 (red), Smith and Sandwell (1997) (black), and NGDC Coastal Relief Model (blue). Contour intervals are 50m from 0-200m, and 500m from 500-4500m. Initial mooring locations, AUV and glider operational areas, and existing National Buoy Data Center (NDBC) stations are also shown. **NOTE:** Final mooring locations and array configuration are defined and controlled in Section 2.2.

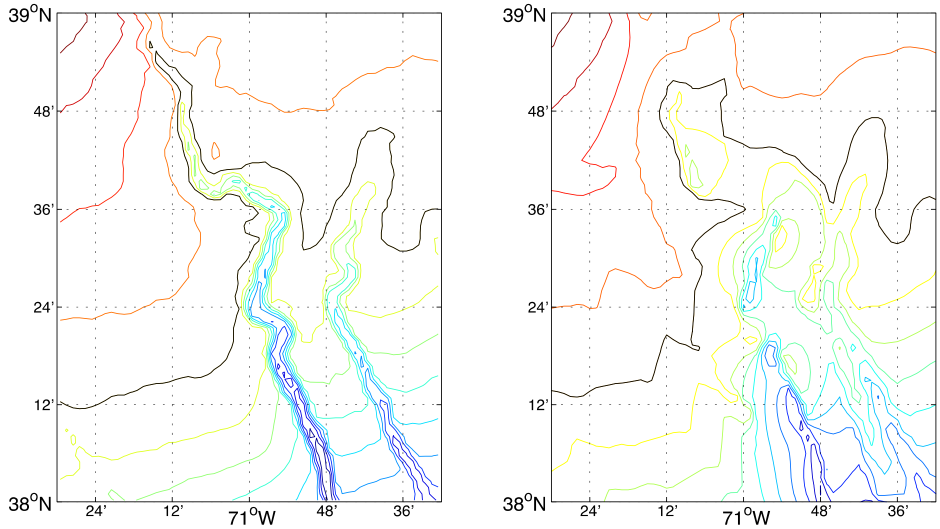


Figure 4. Bathymetry from Smith and Sandwell (1997) (*left*) and ETOPO-1 (*right*). Contour interval is 100m; the 3000m contour is black. The continuity of the canyons in the Smith and Sandwell (1997) dataset suggests that in this region its accuracy is superior to that of ETOPO-1.

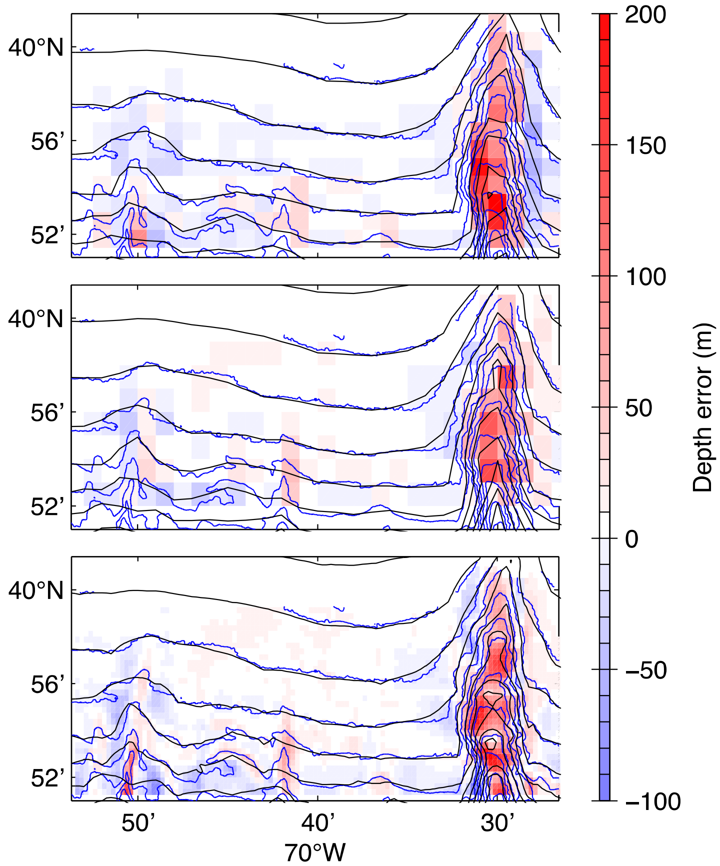


Figure 5. Comparison of USGS multi-beam survey data (blue contour lines) with bathymetry from (*top*) Smith and Sandwell, (1997) (*center*) ETOPO-1, and (*bottom*) NGDC Coastal Relief Model (black contour lines). The contour interval is 100m. Color indicates the depth discrepancy.

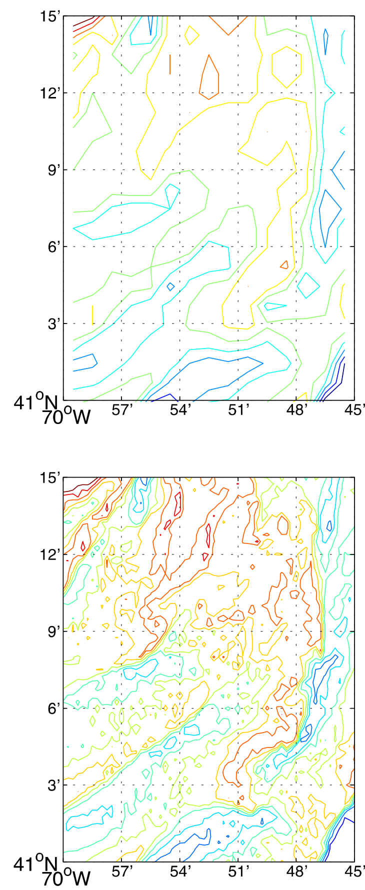


Figure 6. Smith and Sandwell (1997) bathymetry (*top*) and NGDC Coastal Relief Model bathymetry (*bottom*) from an area near the Cape Cod coastline.

1.1.2 Bathymetry Data Presentation

Elements of the Pioneer Array are plotted in Fig. 7 over a map of Smith and Sandwell (1997) bathymetry. Also shown are shipping lanes (see Sec. 1.4.1), obtained from NOAA nautical chart 12300. The across-shelf moored array is centered at the shelf break (about 150 m depth) and spans depths from 130 – 500 m. The AUV operations area extends from the outer shelf to the upper continental slope, over depths from about 60 – 2200 m. The glider operations region extends from shelf break to the slope sea, over depths from about 80 – 2800 m.

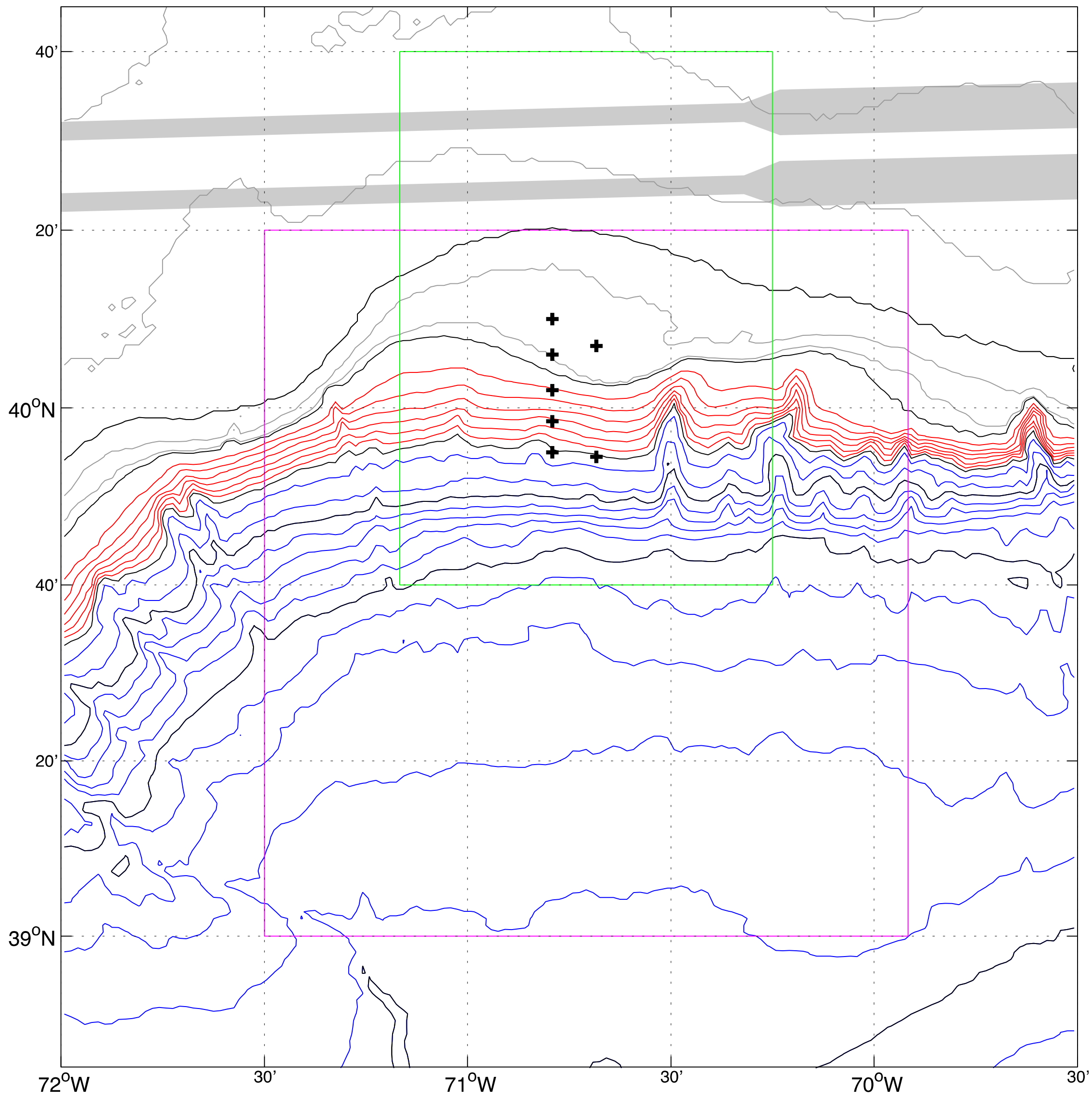


Figure 7. Bathymetry in the Pioneer Array area. Gray contours are at 20m intervals up to 140m, red contours are every 50m from 200 to 450m, and blue contours are spaced at 200m starting at 600m. Contours at 100, 150, 500, 1000, 2000, and 3000m are black. Initial mooring sites are marked with black crosses. As in Figure 3, the magenta box delineates the initial glider operational area, and the green box the AUV operational area. Shaded areas are shipping lanes.

NOTE: Final mooring locations and array configuration are defined and controlled in Section 2.2.

1.1.3 Bottom Type

The USGS Continental Margin Mapping (CONMAP) data catalog provides a source for bottom type data in the vicinity of the Pioneer Array. These data are in the form of shapefiles specifying closed contours surrounding areas with a homogenous bottom type. The data from the relevant region are displayed in Fig. 8. Gravel is defined to have a grain size greater than 2 mm, sand between 1/16 and 2mm, silt between 1/256 and 1/16mm, and clay smaller than 1/256 mm. If one of these classes is dominant, but others are present in significant percentages, the dominant class is listed last, after a slash; "clay-silt/sand," for example, refers to regions where sand dominates, but is mixed with smaller fractions of clay and silt. Considering the dominant class only, we find that the northern portion of the moored array is in a region dominated by silt, while the central and southern portions are in a region dominated by sand.

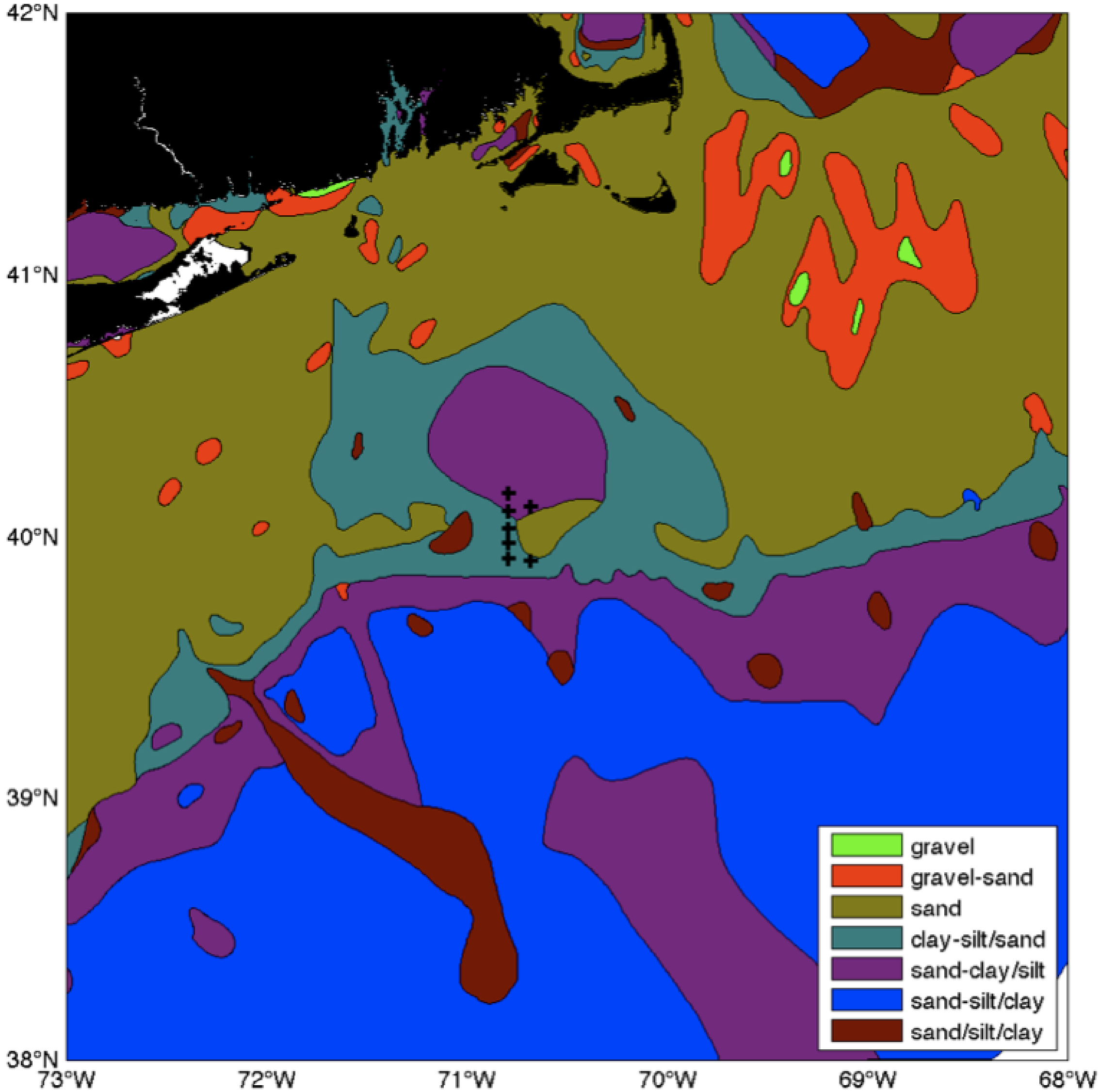


Figure 8. Distribution of sediment types in the region surrounding the Pioneer Array. Areas in which data are unavailable are left white. Initial mooring sites are marked with crosses.

NOTE: Final mooring locations and array configuration are defined and controlled in Section 2.2.

The online viewer usSEABED 2005, created by USGS, provides access to data from individual sediment samples off the US Atlantic coast. Relevant information from a few sites near the Pioneer moored array are presented in Table 1, ordered by water depth at the sample site. All sediment samples in the vicinity of the moored array site were described as at least 95% terrigenous, with the remainder comprising shell and foraminifera. The sample locations and percentage of sand at each site in the table are indicated graphically in Fig. 9. Note that since sand and mud make up nearly 100% of the samples at all sites, the non-sand fraction can be considered mud. Consistent with the CONMAP data, the SEABED data in Fig. 9 show that the northern portion of the moored array is dominated by mud (silt and clay) while the central and southern portions are in dominated by sand.

Table 1. Sediment sample data

Latitude	Longitude	Depth (m)	Gravel %	Sand %	Mud %
40.2230	-70.6270	115	0	5	94
40.2692	-70.7192	116	0	26	74
40.1750	-70.6167	117	0	29	71
40.2537	-70.8188	119	12	0	88
40.1833	-70.8000	122	0	12	88
40.1220	-70.6330	124	5	54	42
40.0830	-70.6420	125	3	68	29
40.1167	-70.8000	128	0	86	14
40.1525	-70.7267	129	0	42	59
40.0850	-70.7297	130	1	40	60
40.1025	-70.7286	135	1	41	58
40.0100	-70.7350	135	3	66	31
40.0642	-70.7308	136	6	52	43
40.1167	-70.7500	138	0	33	67
40.1358	-70.7275	138	0	31	69
39.9917	-70.7358	147	1	91	8
40.0400	-70.7325	153	4	55	42
40.0480	-70.6480	155	2	94	5
40.0200	-70.6530	182	0	97	3
40.0480	-70.8120	183	0	89	11
40.0333	-70.7000	200	0	86	14
40.0333	-70.8000	265	0	92	9
39.9666	-70.6666	300	0	76	24
40.0020	-70.8080	305	0	60	40
39.9083	-70.5833	487	0	66	34
39.9133	-70.8000	545	0	62	38
39.9500	-70.8000	680	0	87	13
39.8417	-70.5833	824	0	48	52
39.8383	-70.7600	896	0	25	75

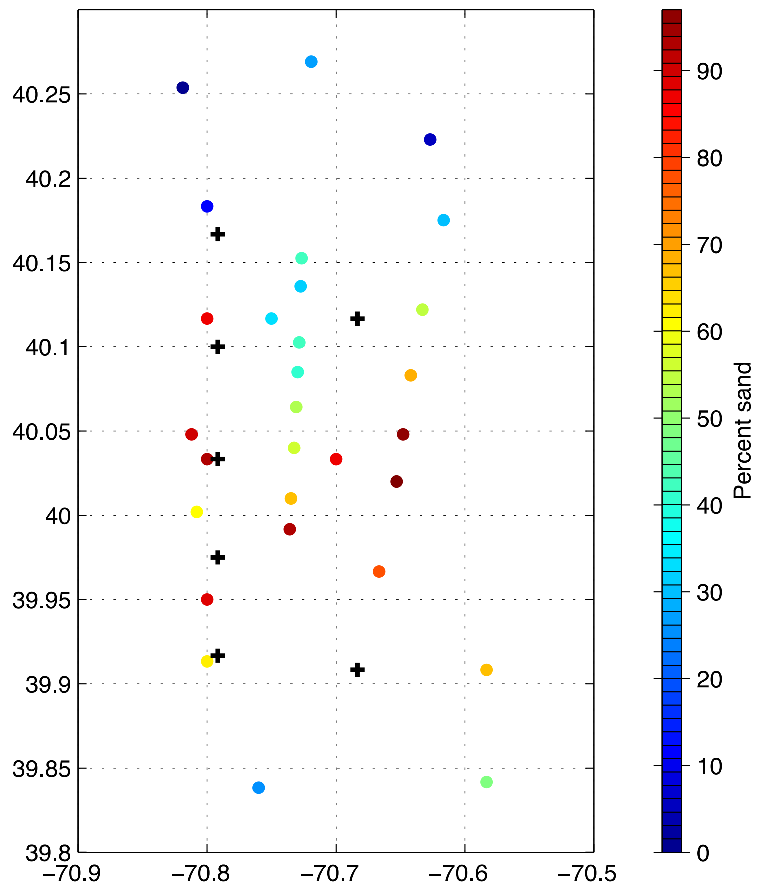


Figure 9. Initial Pioneer mooring locations (black crosses) and sediment sample sites (colored dots) listed in Table 1. Color indicates percentage of sand found at the site.
NOTE: Final mooring locations and array configuration are defined and controlled in Section 2.2.

1.2. Oceanographic Conditions

1.2.1 Current Profiles

During the Nantucket Shoals Flux Experiment (NSFE), a field program carried out between March 1979 and May 1980, current profiles were measured at six stations near the proposed Pioneer Array. NSFE Station N5 was located at 40°2.2’ N, 70°22.1’ W, approximately 30 km east of the center of the moored array site. Current measurements were made at depths of 10, 28, 88, 118, and 183m. Maximum mean velocities were 2-4 cm/s to the northeast at 118 m, but variability was large compared with mean flow (Fig 10). The distribution of current speeds at 10 m depth from all sites shows a mean and maximum speeds of 25 and 89 cm/s, respectively, with 75% of the speeds below 32 cm/s and 95% of speeds below 48 cm/s. Both velocity variability (Fig. 10) and speed decrease with depth. The distribution of speeds at 88 m and 183 m at the NSFE N5 site show means near 12 cm/s with 95% of speeds below 25 cm/s.

Much of the current variability at the site was associated with semidiurnal and diurnal tides, and with energetic inertial motions (the inertial period at the site is 18.7 hours). Throughout this range of frequencies, the clockwise component of the rotary spectra of NSFE current velocities dominates the counterclockwise component (Fig. 11).

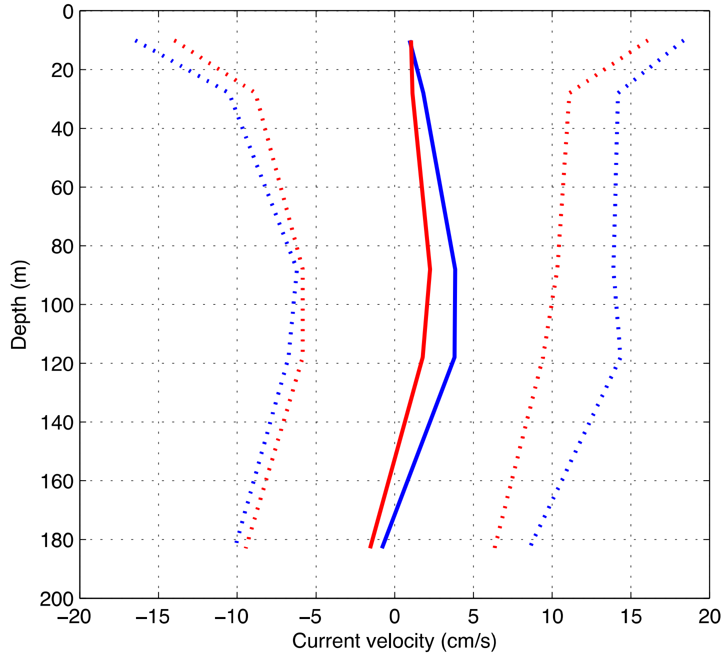


Figure 10. Mean flow (solid lines) plus and minus one standard deviation (dotted lines) at NSFE Station N5 in the eastward (blue) and northward (red) directions.

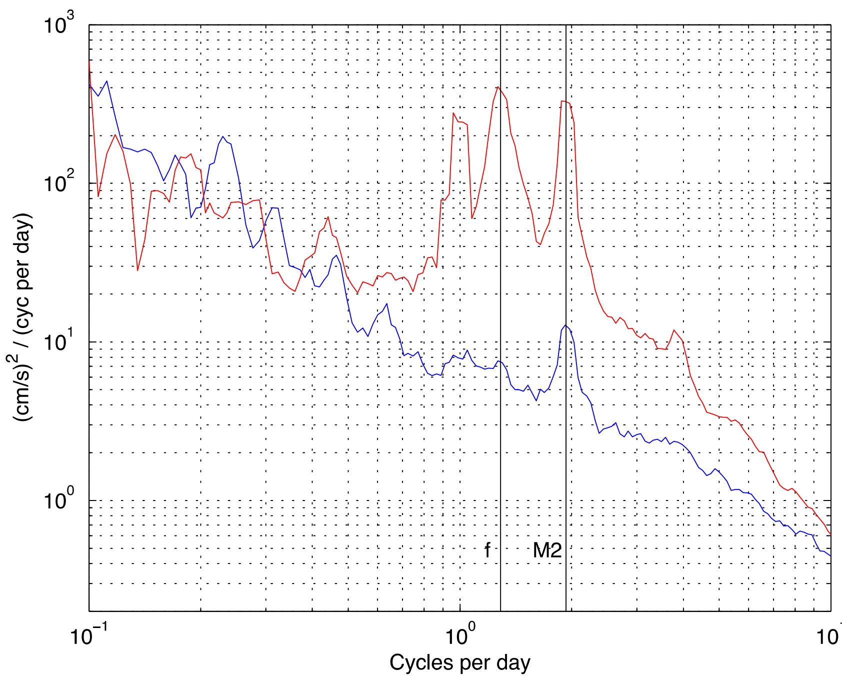


Figure 11. Rotary spectra of current velocities at NSFE Station N5. The clockwise component (red) dominates the counterclockwise component (blue) over a broad range of frequencies. The inertial frequency *f* is marked, as is the lunar semidiurnal tidal constituent *M2*. There is also a significant peak in clockwise energy in the diurnal tidal band.

Time-series measurements of current were made during the Coastal Mixing and Optics (CMO) experiment from August 1996 to June 1997 (Lentz et al., 2003). Velocity profiles were obtained from multiple discrete current meters deployed on a surface mooring in 70 m of water near the inshore moorings of the Pioneer Array site (near 40.5°N, 70.5°W). There were 10 current meters deployed from just under the surface buoy at a depth of 4.55 m down to 65 m (i.e. 5 m above the bottom). These data are shown in Figure 12 for all current profiles with a surface current greater than 0.5 m/s.

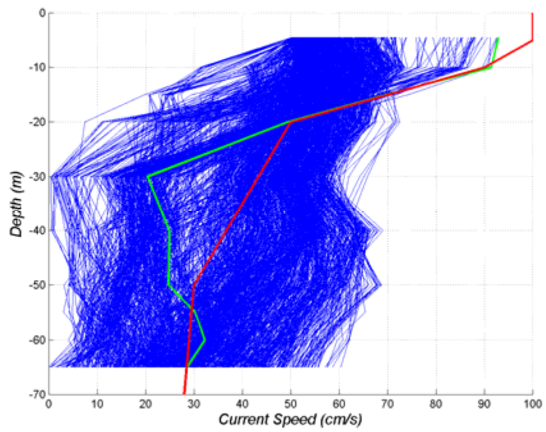


Figure 12. The **blue lines** are current profiles that were measured from July 1996 to June 1997. Current profiles were measured with averaging every 7.5 minutes. Only current profiles for which the surface current (actually at depth of 4.55 m) was greater than 0.5 m/s are plotted. The **green line** corresponds to the current profile with the largest current speed (93 cm/s at 4.55 m depth). The red line is the estimated current profile used for the Coastal test mooring design.

A representative maximum current speed profile for the inshore portion of the Pioneer site (presented in Table 2) is based roughly on the maximum current profile measured during the CMO deployment in 1996-1997 as shown in Figure 12.

Table 2. Maximum current speed profile for the inshore portion of the Pioneer moored array.

Depth (m)	0	5	10	20	50	150
Speed (cm/s)	100	100	90	45	30	20

1.2.2 Tidal Variability

National Data Buoy Center (NDBC) Station 44402, equipped with a DART II payload measuring bottom pressure, is located at 39°29'14" N, 70°35'38" W, near the center of the glider operational area (Fig. 3 and 7). The maximum tidal range at the station is approximately 1.5 m, with RMS variability of 0.32m (Fig. 13).

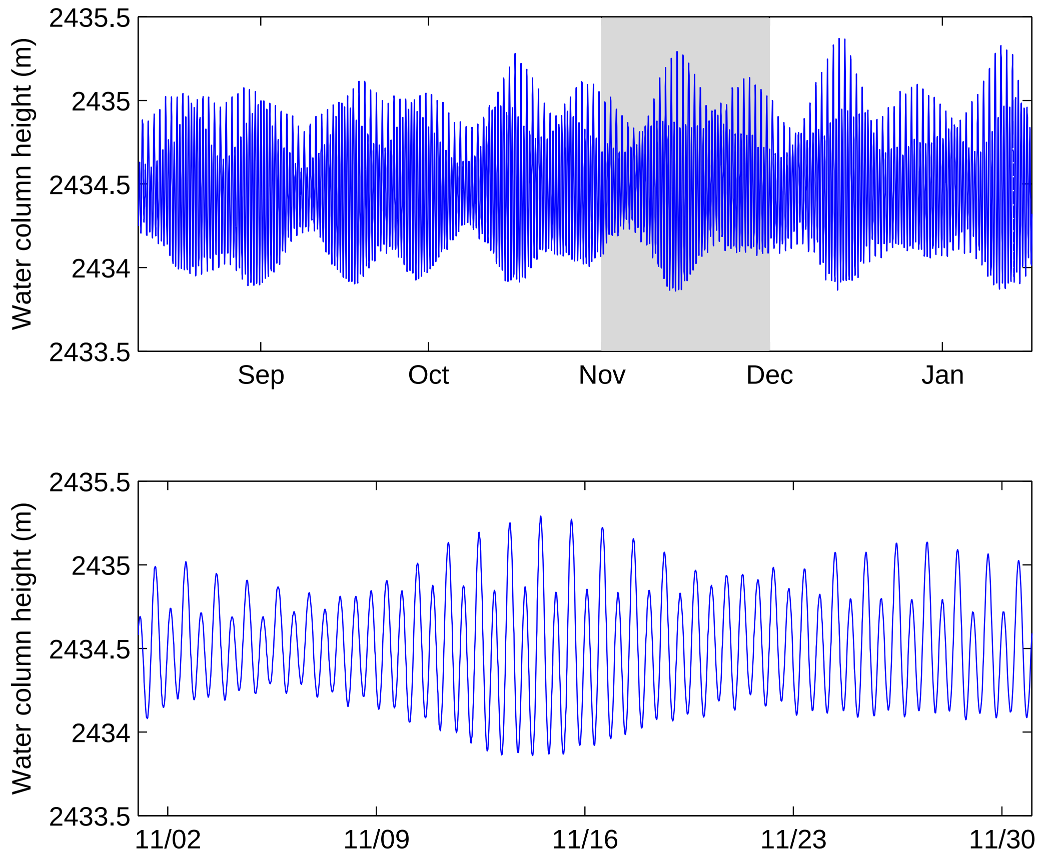


Figure 13. Water column height measured at NDBC Station 44402. *Top:* 5 months of data from August 2008 to January 2009; *bottom:* data from November 2009 (shaded in top panel) expanded for clarity.

Shearman and Lentz (2004) provide review of tidal variability in the Pioneer Array region based on observations from the Coastal Mixing and Optics experiment and other mooring observations. Their study area extends from about 1000 m depth to the coast between 69°30'W and 71°30'W. They find that the M2 (semidiurnal) barotropic tide constitutes the majority of the total current and sea level variance. All the major tidal constituent vectors rotate clockwise, and depth-averaged tidal ellipses are roughly circular (ellipticities 0.7 to 1.0). M2 tidal elevations decrease toward the northeast to a minimum over Nantucket shoals. M2 barotropic tidal current amplitudes increase strongly toward the northeast from about 5 cm/s near 71°W at the shelfbreak to a maximum of about 35 cm/s over the shoals. Low-mode baroclinic tides are weak (maximum amplitudes ~ 4 cm/s) with vertical structure consistent with a first baroclinic mode. Baroclinic M2 tidal ellipses are oriented across-isobath. High-frequency (approaching the buoyancy frequency) internal solitons, generated on semidiurnal intervals, are found following the pycnocline. During the winter, the stratification is strongest at depth and high-frequency internal solitons are seen as waves of elevation as opposed to waves of depression that are typical for fall or spring. In general, the baroclinic tidal and high-frequency internal current variance is strongly related to stratification, and decreases across the shelf.

1.2.3 Spatial and Temporal Scales in the Frontal Region

A number of observational and modeling studies have resulted in estimates of length scales characteristic of dynamical features in the shelfbreak region of the Mid-Atlantic Bight. Linder and Gawarkiewicz (1988) describe a climatological shelfbreak front based on monthly averages of historical hydrographic profiles within a region spanning the Pioneer Array (their Nantucket Shoals region). The mean bathymetry shows a distinct shelfbreak at about 100 m depth. The shelfbreak front at mid-water column (50 m depth), as defined by the 34.5 psu isohaline, is 10-20 km offshore of the shelfbreak. The foot of the front intersects the bottom at depths varying from ~80-110 m, representing relatively small (+/- 5 km) onshore/offshore displacements. The shelfbreak jet, a surface-intensified equatorward flow associated with the front, was found to have width and depth (defined as the point where velocity was 50% of the maximum) of 15-20 km and 60 m, respectively. The mean location of the core of the jet was above the 125 m isobath, about 5 km offshore of the shelfbreak. The variability of the core location by month was from 3 to 12 km offshore of the shelfbreak.

A recent modeling study of the Mid-Atlantic Bight shelfbreak front (Chen and He, submitted) reproduced many features of the climatology reported by Linder and Gawarkiewicz. They report a persistent salinity front (a gradient of 1-2 psu over 10-20 km) near the shelfbreak. The foot of the front intersects the bottom at depths varying from ~100-150 m, representing onshore/offshore displacements of about 15 km along the model bathymetry. They also report a surface-trapped jet just shoreward of the front, with center roughly coincident with the shelfbreak. The characteristic width and depth of the modeled jet are 20-30 km and 100 m, respectively.

Gawarkiewicz et al. (2004) computed temporal correlation scales and along- and across-shelf spatial correlation scales for temperature (T), salinity (S), density (ρ), and along- and across-shelf velocity (*u* and *v*). The estimates were based on observations from an undulating towed body which executed multiple surveys in a region roughly encompassing the NW quadrant of the Pioneer glider operating region and overlapping the Pioneer moored array region. Correlation scales for all variables were estimated at 18 and 54 (or 57) m depth. Velocity correlation scales were also estimated at 41 m depth.

The spatial scale estimates reported by Gawarkiewicz et al. (2004) are reproduced in Table 3. The mean horizontal scales in x (along-shelf) and y (across-shelf) directions are 9.9 km and 10.5 km, respectively. The means are strongly influenced by large scales estimated for ρ and u at 54 m (Table 3); the majority of x and y scales fall between 7 and 9 km. The baroclinic Rossby radius at the front was estimated at 7.4 km. There was little evidence for anisotropy in length scales in the frontal region, although observations at mid shelf (away from the front) have shown along-shelf coherence over scales of 10-15 km (Lentz et al., 2003).

In contrast to the variability observed for spatial scale estimates, the temporal scales for all variables at all depths were quite consistent, with a mean decorrelation time of 1.1 day and standard deviation of 0.3 day.

He et al. (submitted) calculated decorrelation scales for sea surface temperature (SST) and ocean color, a proxy for surface chlorophyll concentration, from satellite measurements. The domain swath was centered over the shelf break, extending from south of Cape Cod to offshore of Delaware, with a across-shelf extent of about 100 km. Thus, the domain was significantly larger than that of the Gawarkiewicz et al. study and not focused as tightly on the frontal region. The along- and across-shelf correlation scales obtained for SST were 45 km and 19 km, respectively. The corresponding scales for ocean color were 40 km and 25 km. Thus, the characteristic scales at the surface, within a regional domain are larger than at depth at the shelfbreak front. In addition, the surface scale estimates show notable anisotropy (along-shelf scales > across-shelf scales).

Table 3. Correlation scales for along- (x) and across-shelf (y) directions

Variable	Depth, m	a_x, km	a_y, km
T	18	7	9
T	54	7	7
S	18	4	12
S	54	7	8
ρ	18	8	7
ρ	54	20	20
u	18	17	12
u	41	11	12
u	57	9	9
v	18	8	9
v	41	9	9
v	57	12	12

1.2.4 Stratification

Climatological profiles

Monthly climatalogical profiles of physical oceanographic variables were downloaded from the World Ocean Atlas (WOA). Gridpoints at which profile data are available are spaced at 1 degree in both latitude and longitude. WOA profiles used for this evaluation are centered at 39.5°N, 70.5°W, representative of the continental slope water to the south of the Pioneer moored array. The water column is most stratified, on average, in August, and least stratified in February. Comparing WOA hydrographic profiles from these two months (Fig. 14) shows that most of the annual variability occurs in the upper 100-150 m. At the surface, the temperature change is about +15 degrees C and the salinity change is about -1 psu from February to August.

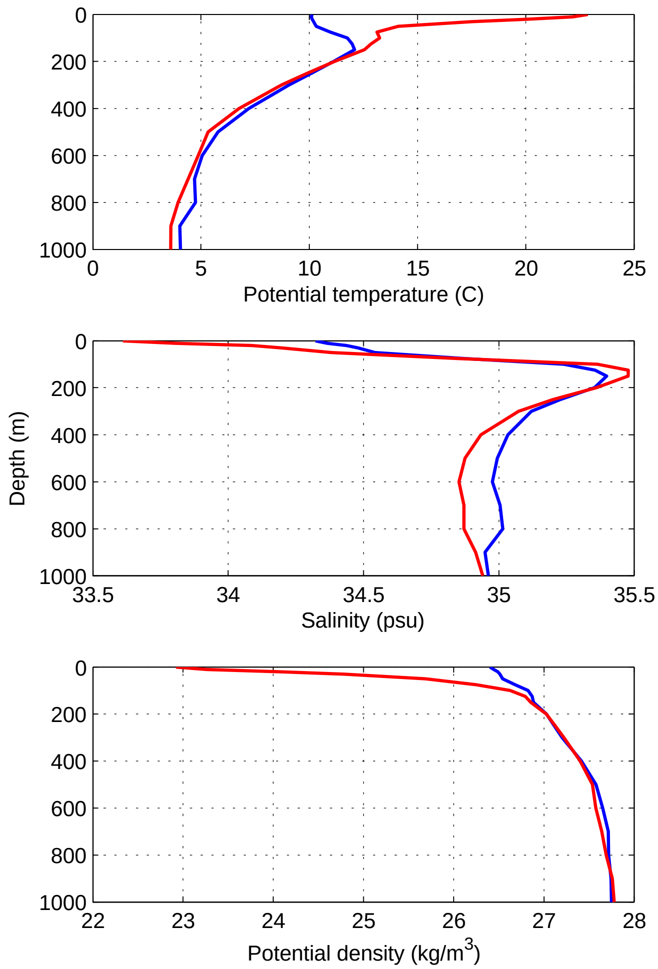


Figure 14. Climatological hydrographic profiles for February (blue) and August (red) from the World Ocean Atlas at 39.5°N, 70.5°W.

Monthly profiles of potential temperature, salinity, and potential density at 39.5°N, 70.5°W are plotted in Fig. 15. The profiles are truncated, showing only the upper 500m, in order to highlight the near-surface structure and because the seasonal changes deeper in the water column are slight. The climatology suggests that a salinity maximum persists throughout the year near a depth of 150m and that temperature inversions are common in the upper 200 m.

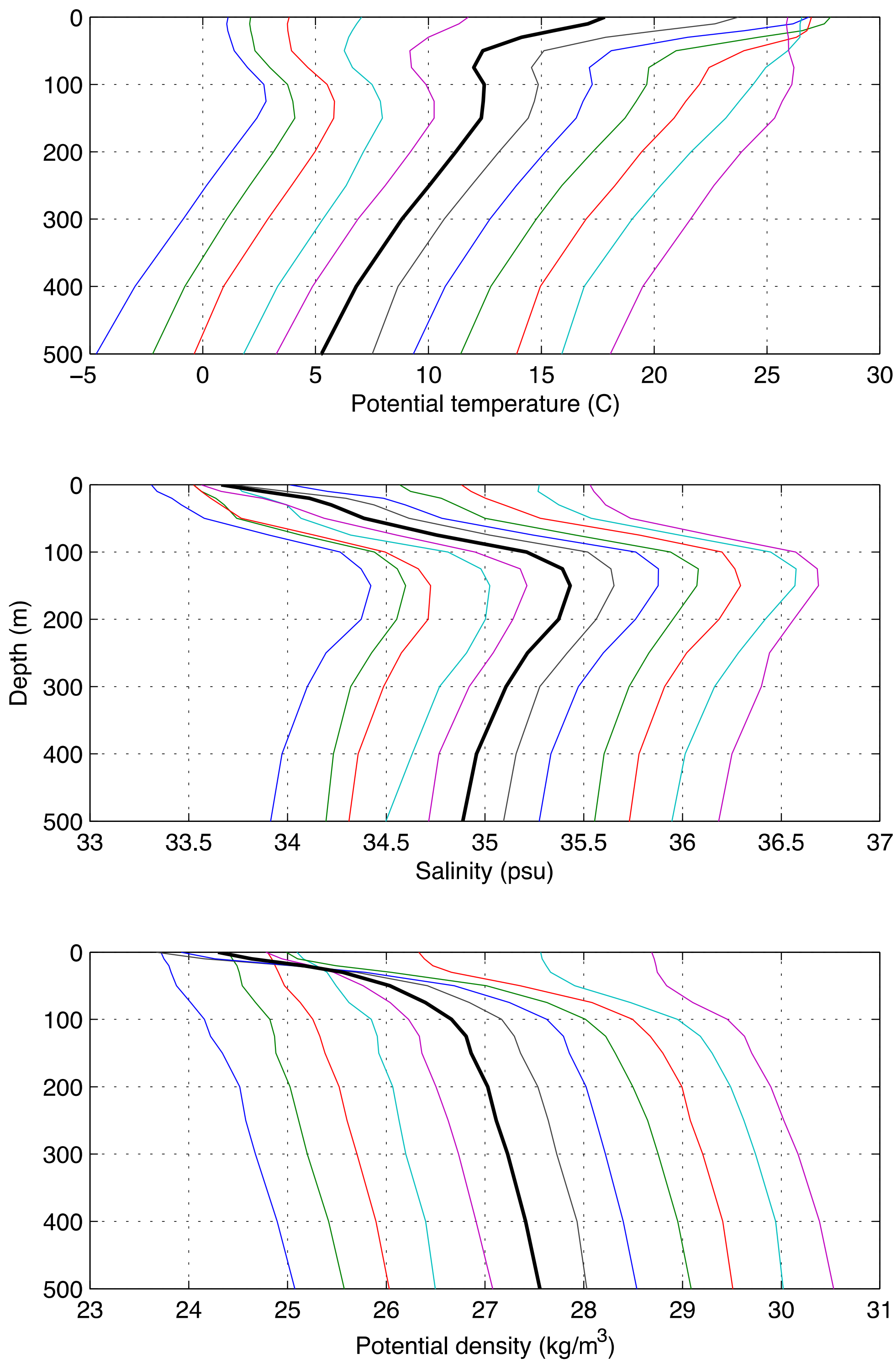


Figure 15. Climatological profiles of (*top*) potential temperature, (*center*) salinity, and (*bottom*) potential density for 39.5°N, 70.5°W. One profile is plotted for each month, with January on the left. The x-axis labels correspond to the June profiles (bold, black lines), with each successive month offset by 2°C (*top*), 0.2 psu (*center*), and 0.5 kg/m^3 (*bottom*).

Short-term variability

The central mooring of the 1996-1997 Coastal Mixing and Optics Experiment was located at 40.49°N, 70.50°W, approximately 40 km NNW of the Pioneer Array inshore mooring sites, representative of continental shelf water. Ten-month time series of temperature and salinity were collected at three depths at this location. These records provide an indication of the hydrographic variability in the Pioneer Array area on sub-week to monthly timescales, and are reproduced here (Fig. 16) from Lentz et al., 2003 (their Fig. 3).

Seasonal changes (February to August) in surface temperature and salinity are +15 degrees C and -2.5 psu, although Lentz et al. note that the high salinities at the bottom in winter are anomalous. Maximum surface to bottom temperature differences occur in summer, with magnitude of about 10 degrees C. Surface to bottom salinity differences may be large at any time of year, with magnitudes of 1-2 psu. Surface to bottom density differences range from nearly isopycnal to magnitudes of about 1.5 kg/m^3 in summer.

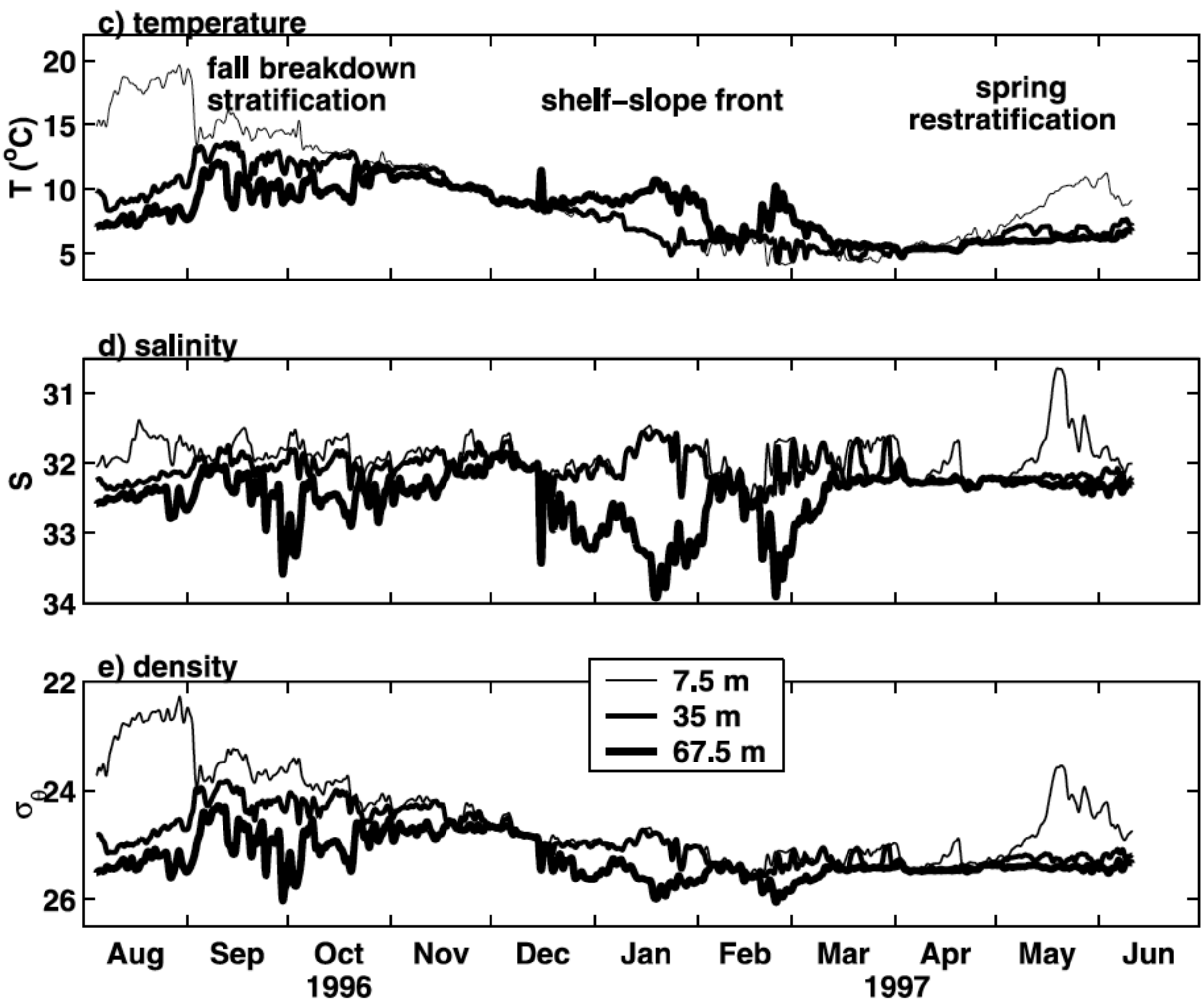


Figure 16. Temperature (*top*), salinity (*center*), and density (*bottom*) at depths of 7.5, 35, and 67.5 m, measured at the central Coastal Mixing and Optics Experiment site (40.49°N, 70.50°W) during a 10-month period in 1996-1997. *[Reproduced from Lentz et al., 2003 (lower 3 panels of their Figure 3)]*.

1.3. Environmental Conditions

1.3.1 Historical Wind Data

NDBC stations 44004, 44008, and 44017 (see Fig. 3 for locations) provide a source for average wind speed and direction measurements at a temporal resolution of 10 minutes in the vicinity of the Pioneer Array. Maximum gust speed and direction are also recorded. At the time of this writing, data are available, with occasional gaps, during the periods: Jan 1978 – Mar 2008 (44004); Aug 1982 – Dec 2008 (44008); Sep 2002 – present (44017).

Scatterometer measurements made from satellites are a second source for information on wind speed and direction near the site. The *Climatology of Global Ocean Winds (COGOW)* provides a convenient interface for accessing historical wind data derived from NASA's QuikSCAT scatterometer. Data are available at a spatial resolution of 0.5°of latitude/longitude, and daily temporal resolution. The data used here correspond to a 0.5° x 0.5° patch centered at 40°15'N, 71°45'W. Each daily value represents an average of measurements made in the bracketing 3-day interval. Data are currently available for the period Aug 1999 – Nov 2009.

Wind speed records from all three buoys and the satellite observations are strongly correlated (Fig. 17), suggesting that, at temporal scales longer than a day, statistics from any of the sources would accurately characterize climatological wind conditions at the Pioneer site. Using NDBC 44004 and 44008 to characterize the site (Fig. 18) shows that average wind speed has a distinct seasonal cycle, increasing from about 10 knots in July to 18 knots in January. Wind speed extremes are more variable. Extremes of 30 to 60 kt are found in all months, and extremes of 40 to 60 kt in all months except May, July and August.

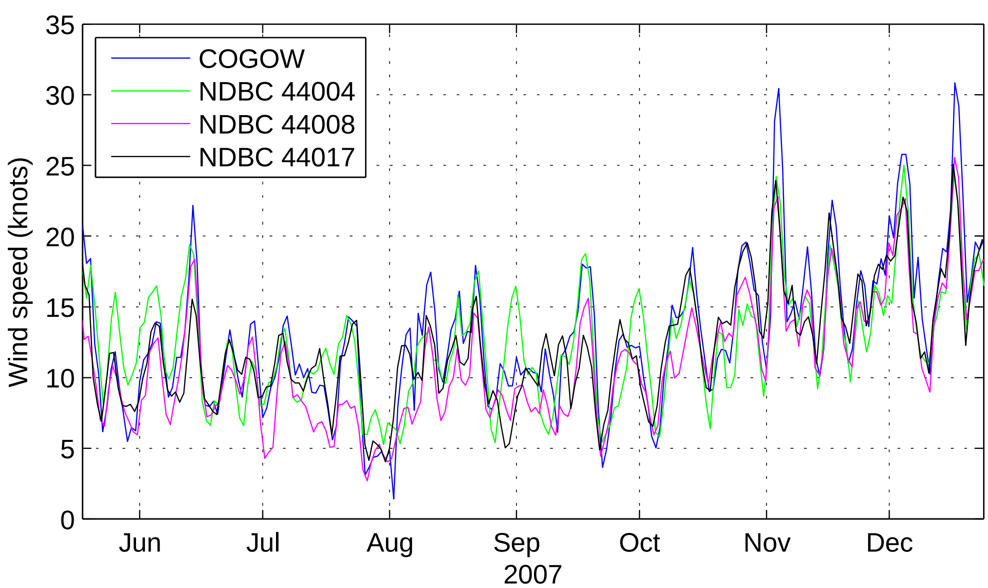
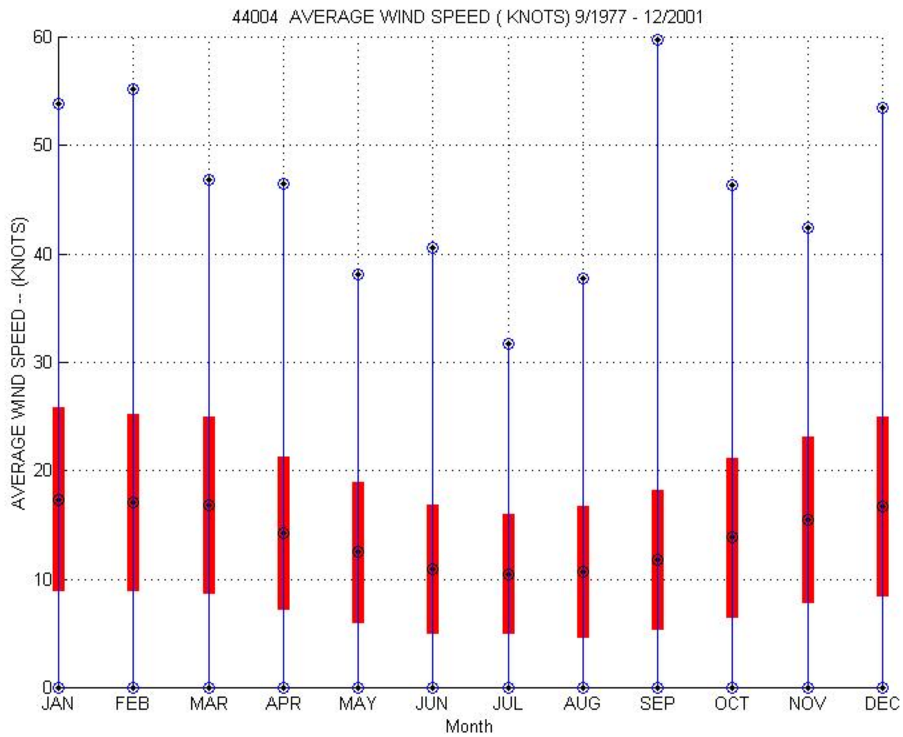


Figure 17. Wind speed measurements from three NDBC buoys and a COGOW product based on NASA's QuikSCAT scatterometer during a 7-month period in 2007 when data from all four sources are gap-free. The buoy data were filtered with a 3-day running mean for consistency with the satellite data product.



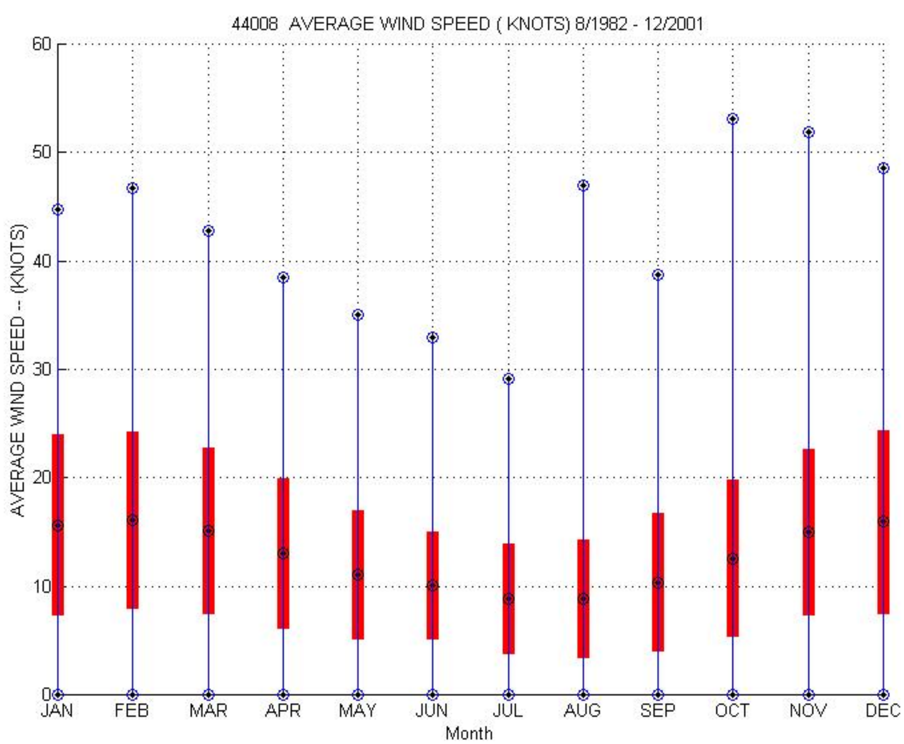


Figure 18. Monthly means, standard deviations, and extremes of hourly average wind speeds measured at NDBC Stations 44004 (*top*) and 44008 (*bottom*). *[Figures reproduced from <u>www.ndbc.noaa.gov</u>]*

The distributions of hourly average wind speeds and maximum gust speeds at NDBC Stations 44004 and 44008 are plotted in Fig. 19. The y-axes are scaled logarithmically to more accurately display the frequency of occurrence of rare high-wind-speed events.

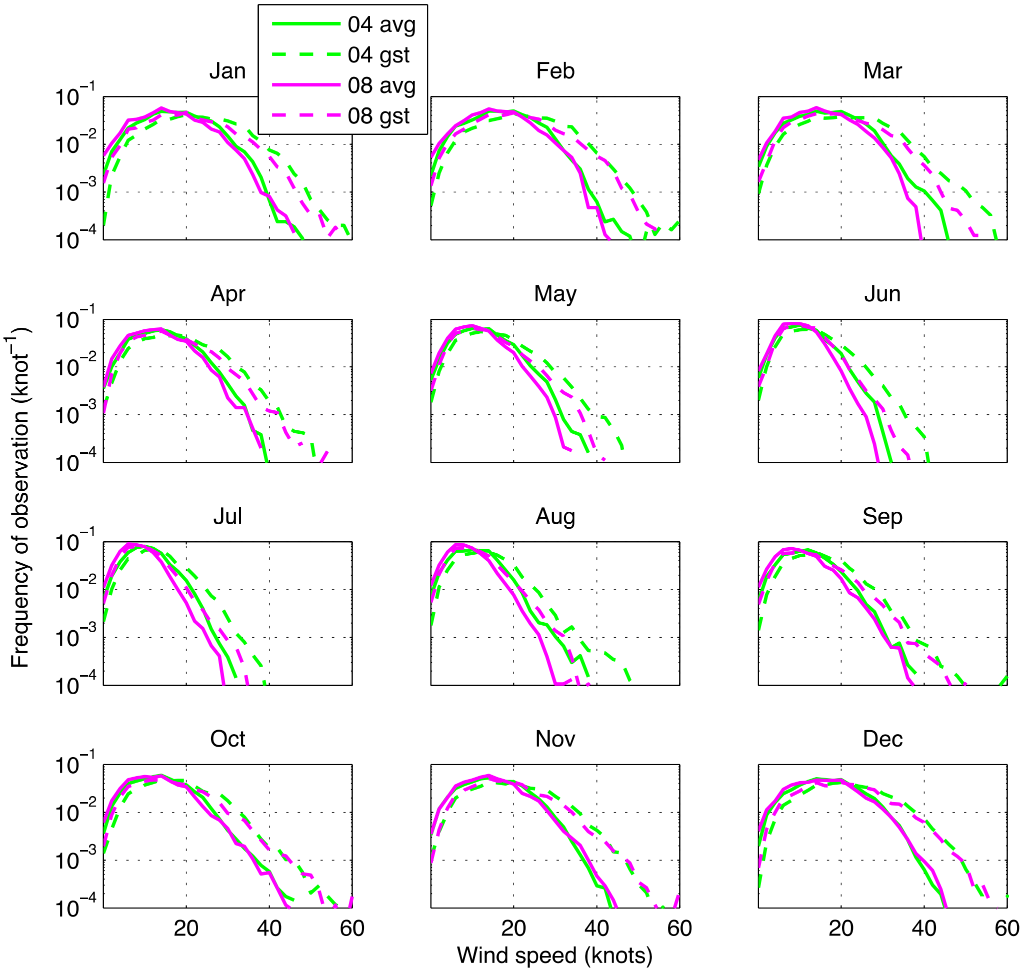
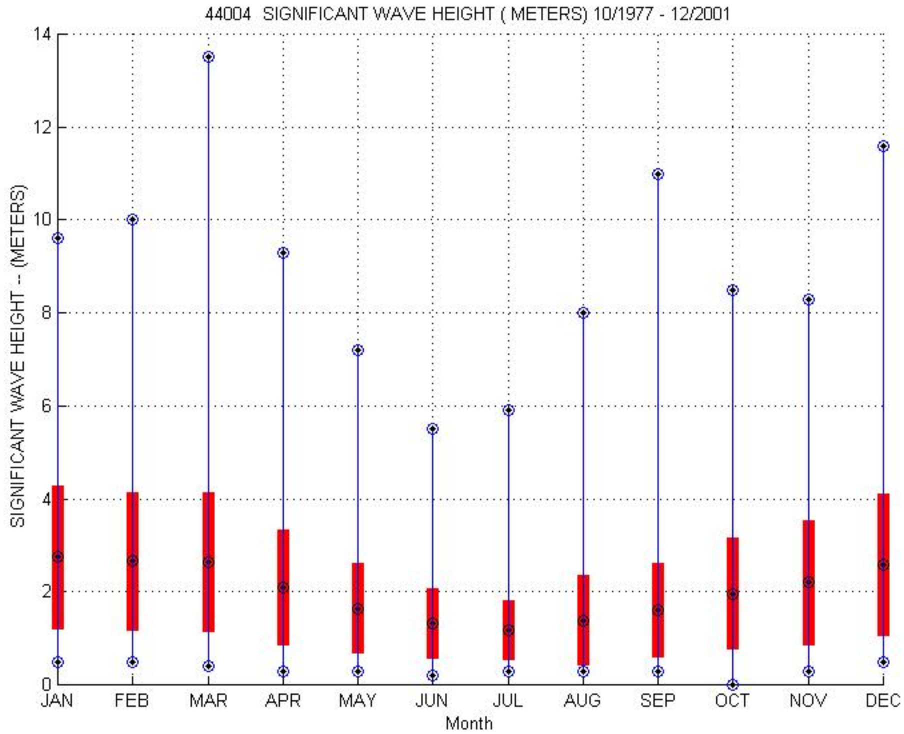


Figure 19. Monthly distributions of wind speed measurements made at NDBC Stations 44004 (green) and 44008 (magenta). The distributions of hourly averages are plotted as solid lines, and the distributions of hourly maximum 5-second gust speeds are plotted as dashed lines.

Diurnal wind variability is negligible at NDBC Stations 44004 and 44008. Station 44017, just 30 km from the eastern tip of Long Island (Fig. 3), is much closer to land. At this location, though barely discernable, there is a peak is the wind spectrum at a period of 1 day.

1.3.2 Historical Wave Data

Records of wave height, direction, dominant period, and average period are available at hourly resolution from NDBC Stations 44004, 44008, and 44017. Monthly means, standard deviations, and extremes of significant wave height (average height of the highest one-third of all waves) are shown in Fig. 20.



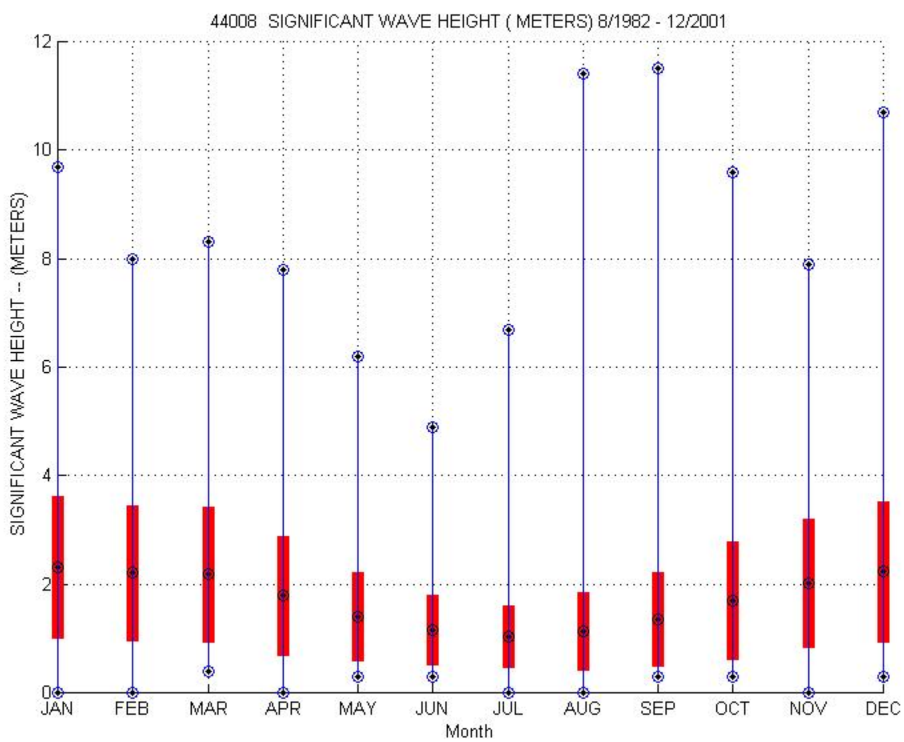


Figure 20. Monthly means, standard deviations, and extremes of significant wave height at NDBC Stations 44004 (*top*) and 44008 (*bottom*). *[Figures reproduced from www.ndbc.noaa.gov]*

Mean significant wave height shows a distinct seasonal cycle, increasing from about 1 m in July to near 3 m in January. Significant wave height extremes are more variable. Extremes of 8 to 12 m are found in all months except May, June and July.

1.3.3 Weather Extremes

The significant wave height and sustained wind for 10 year, 30 year, and 100 year events is estimated from wave and wind records from NDBC Buoy 44008, which is near the Pioneer site (see Appendix A for details of the analysis). The wave and wind records were compiled from summer 1988 – summer 2008, representing 20 years of data.

Table 4. Wind and wave extremes

	Significant Wave Height (m)	Peak Period (s)	Wind Speed (knots)
10 Year Return Period	11.0	14.6	49.8
30 Year Return Period	12.4	15.5	53.8
100 Year Return Period	14.0	16.6	58.5

1.3.4 Solar Radiation

NASA provides a large number of satellite-derived data products relating to “Surface meteorology and Solar Energy”. Daily average insolation on a horizontal surface is available at a horizontal resolution of 1° in latitude and longitude during the period Jul 1983 – Jun 2006. Histograms of average daily insolation reported for 40°N, 71°W are shown by month in Fig. 21. Winter months (Nov-Feb) show relatively compact distributions, with mean insolation near 100 W/m^2. Distributions are qualitatively different in spring and summer (Apr-Sep), when long tails are seen on the low end of the distribution. Peaks in the spring and summer distributions occur at values between about 300 W/m^2 and 350 W/m^2.

Radiometer measurements were collected at NDBC Station 44008 for a two-year period from April 2005 through March 2007. The LI-COR LI-200 pyranometer sensor measured shortwave radiation only, while the NASA product depicted in Fig. 21 describes total insolation across the entire spectrum; however during the 15-month period when the two datasets overlap, the agreement is reasonable (Fig. 22). The seasonal cycle of insolation, with maxima near 350 W/m^2 in summer and minima near 100 W/m^2 in winter, is clearly seen.

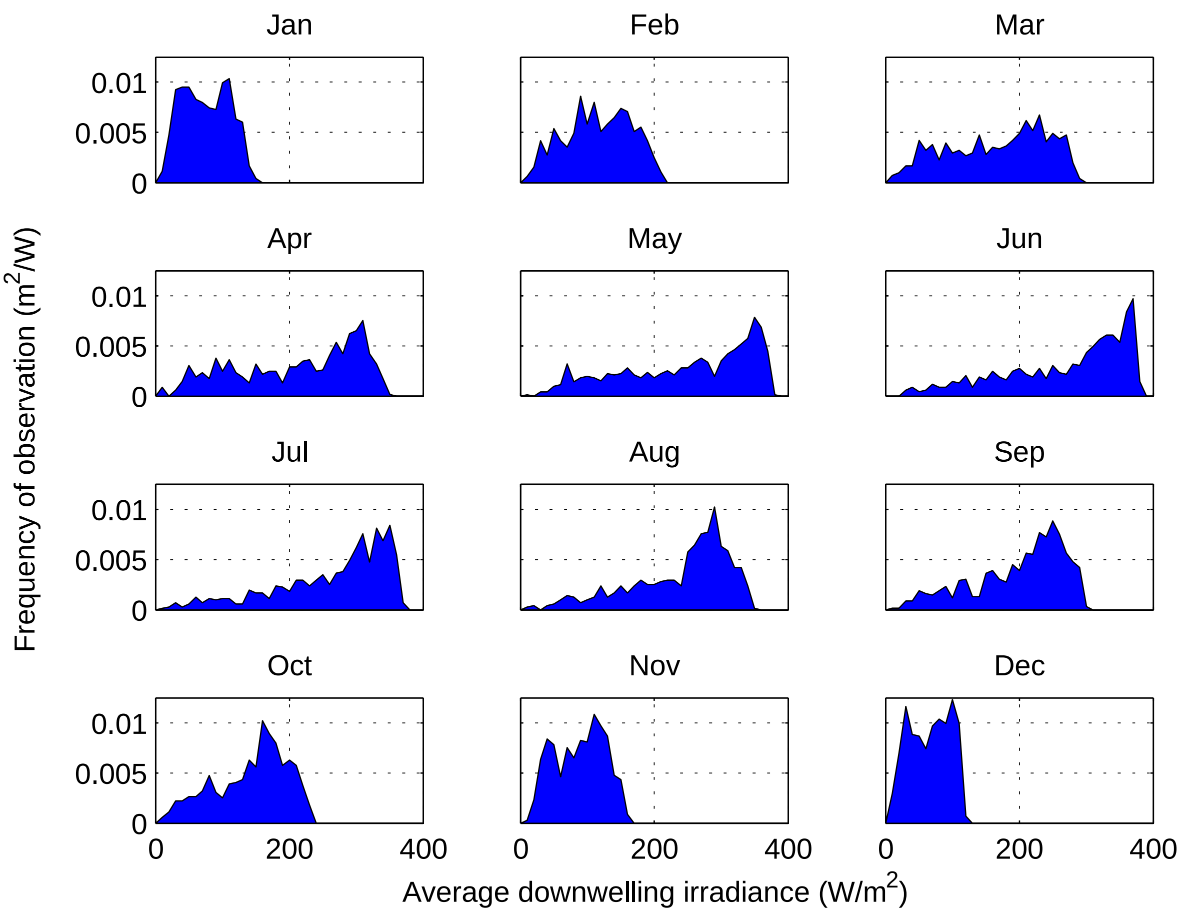


Figure 21. Monthly distributions of daily average insolation on a horizontal surface at 40°N, 71°W calculated from a NASA satellite-derived data product spanning 23 years.

1.4. Other Constraints

1.4.1 Shipping Lanes

Figure 7 shows established commercial shipping lanes into and out of New York City, obtained from NOAA nautical chart 12300, along with Pioneer Array moorings, AUV operations region and glider operations region. The northern and southern lanes are for westbound and eastbound traffic, respectively. The shipping lanes cross through the northern portion of the AUV operational area, but do not intersect the moored array or the glider operational area. AUV operating depths well below the surface will be maintained as the shipping lanes are crossed. A “commercial shipping” dataset listing the number of large ships recorded in each 1-km^2 of the world ocean for a 12-month period starting in October 2004 is available from the National Center for Ecological Analysis and Statistics at UC Santa Barbara. The distribution of recorded ship tracks in the vicinity of the Pioneer Array suggests that large vessels generally use the designated lanes.

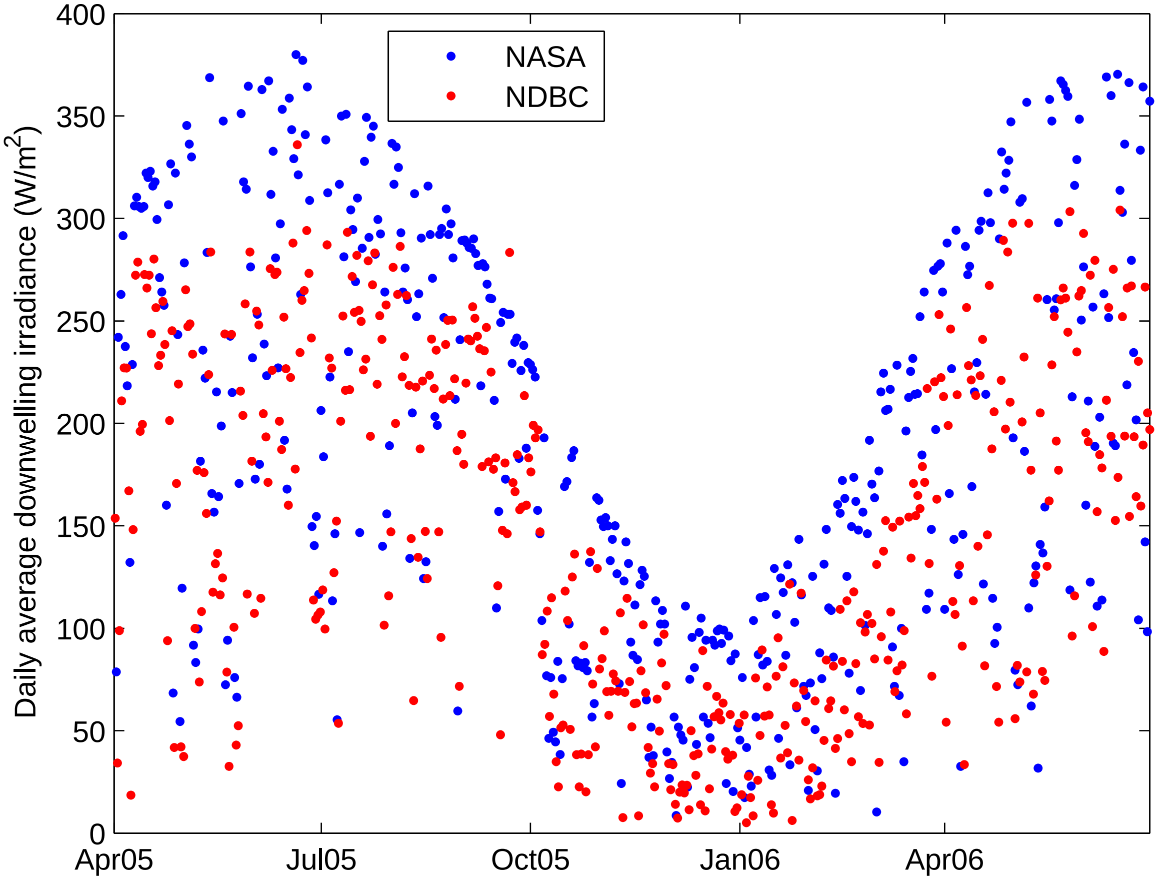


Figure 22. NASA daily average insolation and shortwave radiation measured at NDBC Station 44008. A daily average has been applied to the NDBC data.

1.4.2 Fishing Areas

NOAA's National Marine Fisheries Service Northeast Fisheries Science Center (NEFSC) maintains a database of the abundance of various marine species off the northeastern coast of the United States. Of the 47 species catalogued, 13 occur in the Pioneer Array area in concentrations as high or nearly as high as their concentrations elsewhere in the waters off the northeastern US coast. These species, and their highest observed concentrations in the array area, averaged over tows made between 1968 and 2005, are listed in Table 5. The single species that occurs in the array area in concentrations higher than anywhere else in the region covered by NEFSC is the Golden tilefish (Fig. 23).

Table 5. Concentrations of selected species

Common name	Scientific name	Max density in array area (km^{-2})
Alewife	*Alosa pseudoharengus*	> 0.36
American lobster	*Homarus americanus*	> 0.09
American shad	*Alosa sapidissima*	> 0.03
Atlantic mackerel	*Scomber scombrus*	> 0.89
Butterfish	*Peprilus triacanthus*	> 3.7
Goosefish	*Lophius americanus*	> 0.045
Northern longfin squid	*Loligo pealeii*	> 18
Northern shortfin squid	*Illex illecebrosus*	> 0.55
Red hake	*Urophycis chuss*	> 0.6
Silver hake	*Merluccius bilinearis*	> 1.24
Spiny dogfish	*Squalus acanthias*	> 2
Summer flounder	*Paralichthys dentatus*	> 0.08
Tilefish	*Lopholatilus chamaeleonticeps*	> 0.024

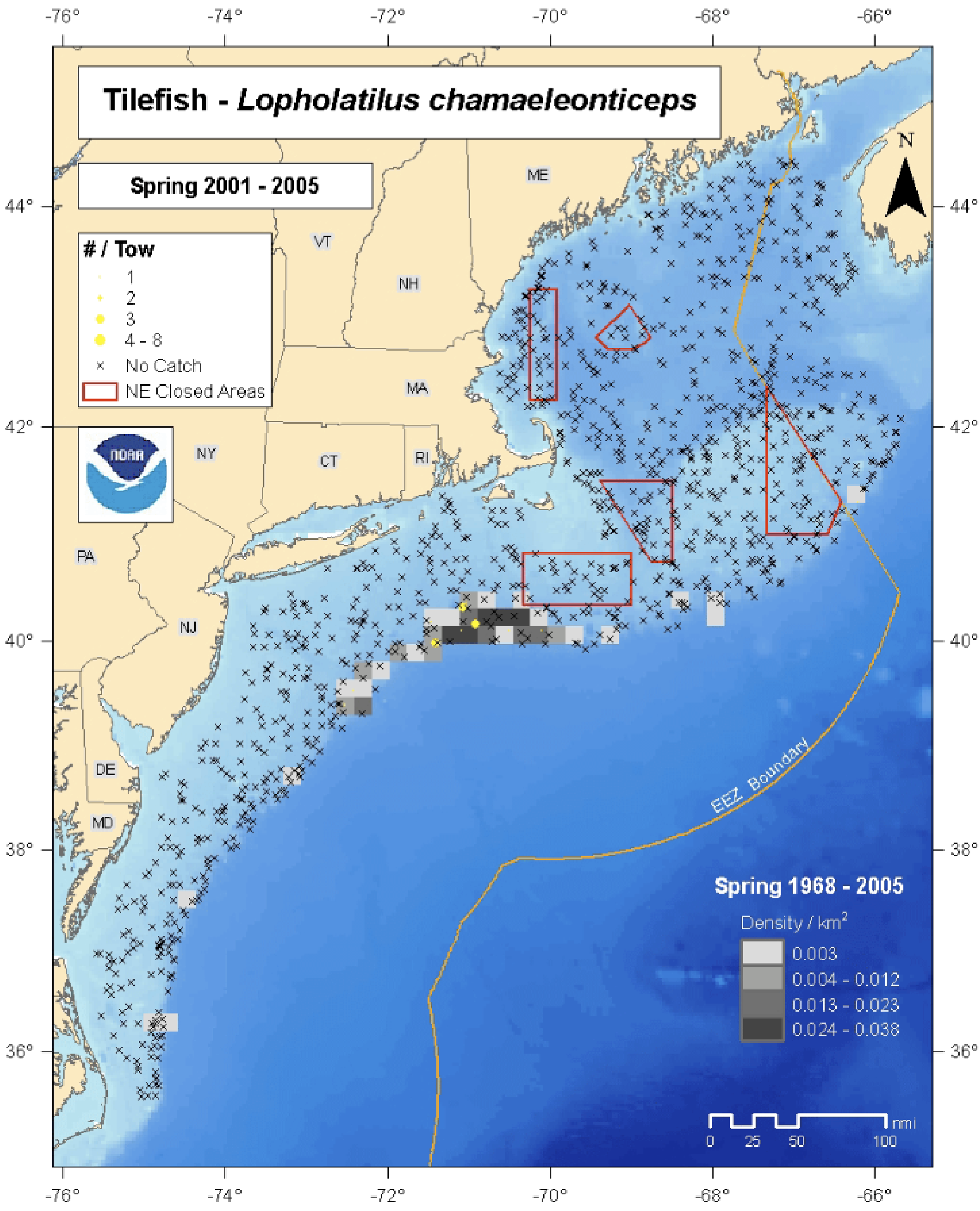


Figure 23. Springtime distribution of Golden tilefish off the northeastern US coast. Yellow dots and black crosses indicate the number of fish caught in each location during springtime tows from 2001-2005. The gray squares indicate the average number density of fish over springtime samples taken between 1968 and 2005. *[Reproduced from http://www.nefsc.noaa.gov/sos/]*

1.4.3 Protected/Dangerous Areas and Seafloor Cables

NOAA nautical chart 12300 shows an "explosives dumping area" to the southwest of the Pioneer moored array site, and unexploded torpedoes to the west (Fig. 24). Also shown on this chart are shipping traffic lanes and submarine cables.

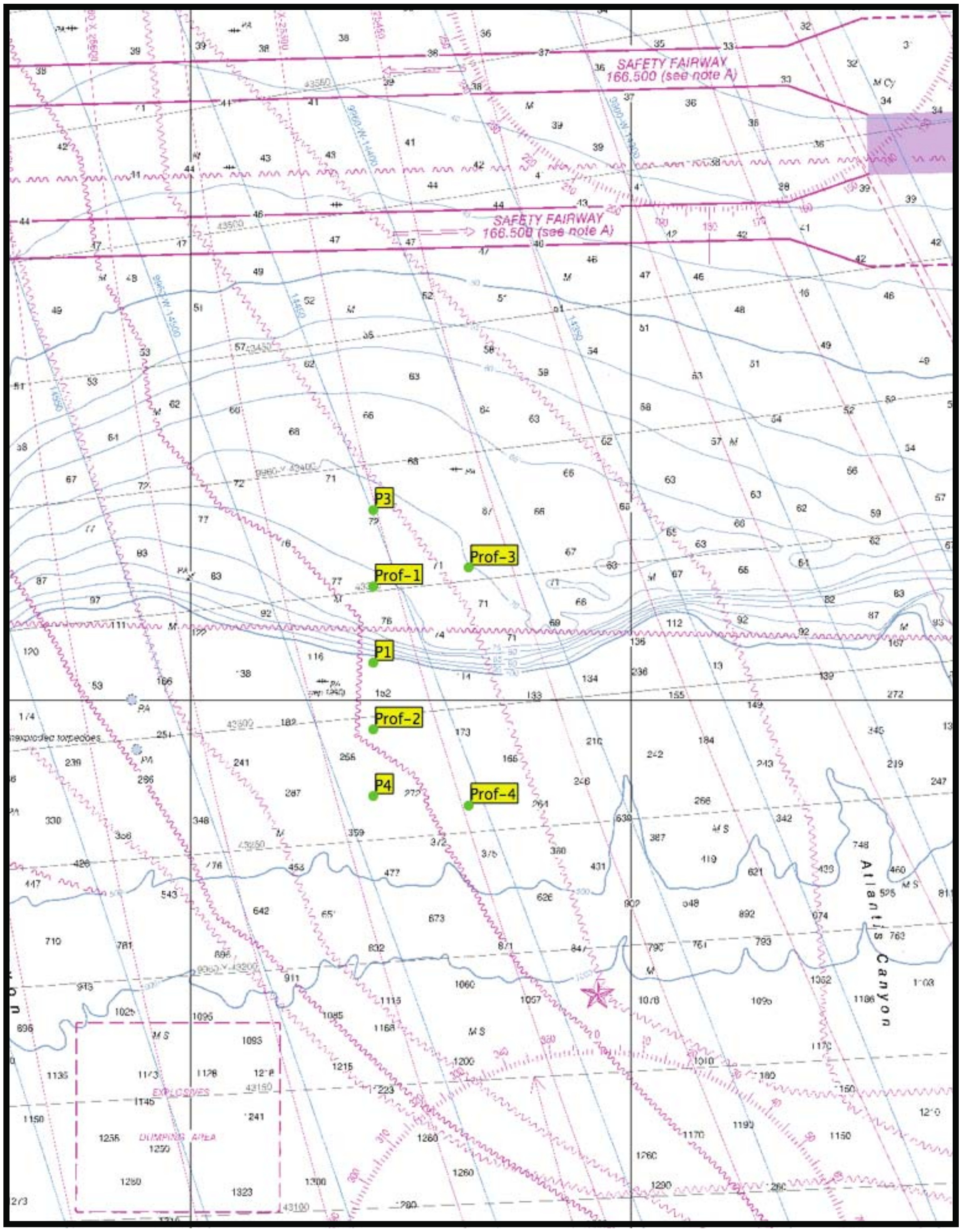


Figure 24. Pioneer moored array area from NOAA nautical chart 12300. Note the explosives dumping area in the lower left-hand corner. Squiggly lines mark submarine cables. Green dots are initial Pioneer mooring sites. Shipping lanes are indicated near the top of the figure.

NOTE: Final mooring locations and array configuration are defined and controlled in Section 2.2.

The NOAA Fisheries Service has designated a number of areas off the northeast US coast that are subject to increased regulation of allowable catch, fishing methods, fishing gear permitted aboard vessels, and fishing permits. The closest of these to the Pioneer Array area is the Nantucket Lightship Closed Area (NLCA), the southernmost of the closed areas outlined in red in Fig. 23. The NLCA, shown relative to the Pioneer Array as a blue-outlined box in Fig. 25, is a year-round closed area, closed to certain types of fishing at all times.

Also shown in Fig. 25 is an explosives dumping area from NOAA chart 12300.

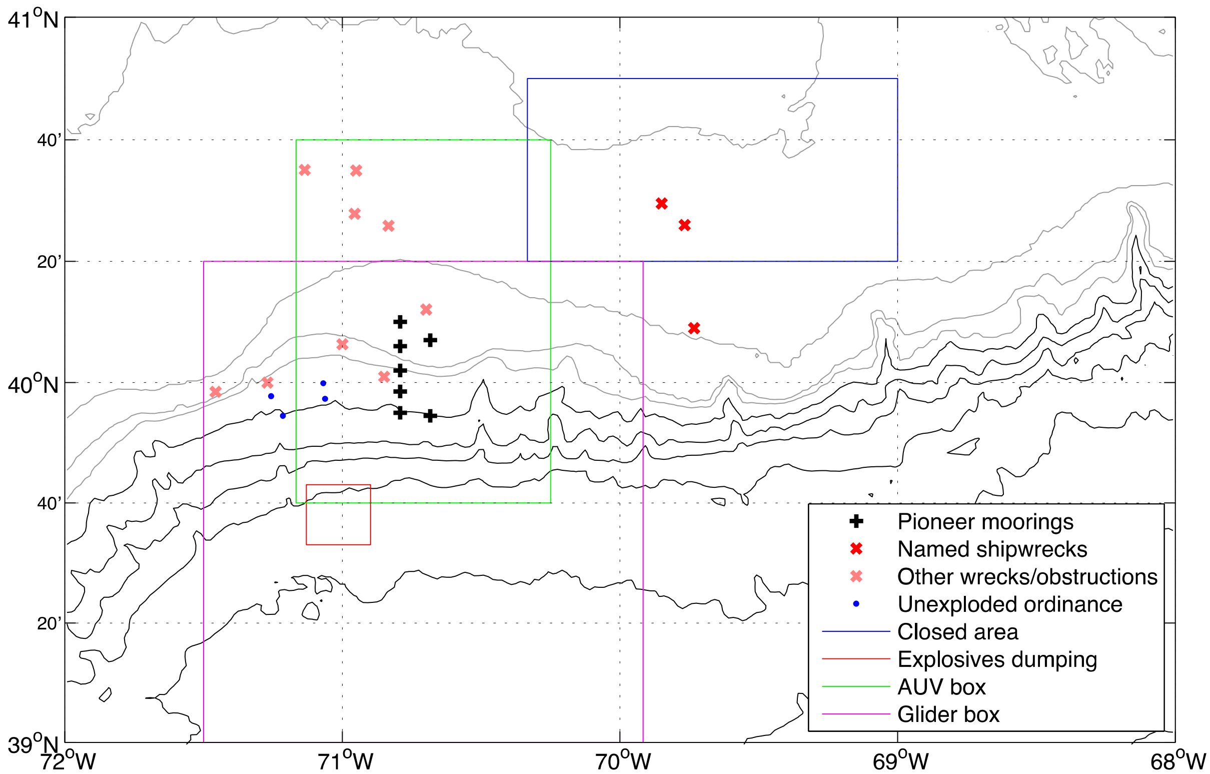


Figure 25. Map of the initial Pioneer Array mooring locations showing Smith and Sandwell (1997) bathymetry (gray contours at 50-m intervals up to 200 m, black contours at 500-m intervals), shipwreck sites, an explosives dumping area, and the Nantucket Lightship Closed Area.

NOTE: Final mooring locations and array configuration are defined and controlled in Section 2.2.

1.4.4 Marine Cultural Artifacts

A variety of marine cultural artifacts are found in the vicinity of the Pioneer Array. Their locations are marked with red crosses in Fig. 25, and they are described briefly below.

The most well known artifacts are three named shipwrecks roughly 70 km east-northeast of the Pioneer moored array, outside of the AUV and glider operating areas. The shallowest is the SS *Andrea Doria*, a 214-m ocean liner, which sank in July 1956 at 40°29.5'N, 69°51'W, in 70 m of water. Just to the southeast, in water depth of approximately 80 m, is the RMS *Republic*, a 174-m steam-powered ocean liner, which sank in January 1909 at 40°26' N, 69°46' W. The deepest wreck is the German U-boat *U-550*, which sank in April 1944 at 40°09' N, 69°44' W, in approximately 100 m of water.

Thirteen additional artifacts, are found on NOAA charts within the Pioneer Array region. Four unnamed wrecks or obstructions and four unexploded ordinance are found to the west of the moored array, within the AUV and glider operations areas. Four unnamed wrecks are found to the northwest of the moored array, within the AUV operations area. One unnamed wreck is found about 10 km north of the Upstream-Inshore site and 8 km northeast of the Inshore site.

1.4.5 Other Moorings

Four other moorings are known to be maintained within the Pioneer Array region. Two NDBC Stations, 44008 and 44017, are marked in Fig. 3 (44004, also marked, went adrift, was recovered, and has not been redeployed as of this writing). These are 3-meter discus buoys with published watch circle radii of 128 m and 87 m, respectively. Three other moorings in the area include NDBC Station 44402, a 2.6-meter discus buoy discussed in Section 1.2.2 *Tidal Variability*, and Station 44097, a Coastal Data Information Program 0.9-meter spherical buoy. The locations of these moorings are listed in Table 6. There may be additional moorings in the area of which we are unaware.

Table 6. Existing mooring locations

Mooring name	Latitude	Longitude
NDBC 44008	40°30’9” N	69°14’48” W
NDBC 44017	40°41’32” N	72°2’52” W
NDBC 44097	40°50’52” N	71°7’1” W
NDBC 44402	39°29’14” N	70°35’38” W

2. Site Design

2.1. Site Components

The Pioneer Array components are introduced in the Overview and shown schematically in Fig. 2. As noted, this is a multi-scale, multi-platform array consisting of three sampling areas, an across-shelf moored array, an AUV operations area and a glider operations area. The principal components making up the Pioneer Array are: Three surface mooring installations, two surface-piercing profiler installations, five wire-following profiler installations, three AUVs and six gliders.

The moored array consists of seven sites: five across-shelf locations designated Inshore, Central-Inshore, Central, Central-Offshore and Offshore, and two upstream locations designated Upstream-Inshore and Upstream-Offshore. Ten moorings of three distinct types (Fig. 26) are distributed among the seven sites. The mooring types are:

- Electrical-mechanical (EM) surface moorings, which incorporate buoys with power generation and include Multi-Function Nodes (MFNs) at their bases (Fig. 26 a-b). Instrumentation will be located on the surface buoys, at subsurface breakouts along the mooring line, and on the MFNs. Two of the MFNs will also include AUV docks.

- Surface-piercing profilers, with sensors mounted on a profiling body designed to sample the water column from a few meters above the bottom to the air-sea interface. Note that these installations will not have a surface expression except for the short time that the profiling body is at the air-sea interface (Fig. 26 c).

- Wire-following profilers, which sample the water column by means of an instrumented profiling body that moves up and down a mooring wire. Wire-following profiler in some locations installations include upward looking ADCPs at their bases. These installations will have a permanent surface expression in the form of a submersible surface buoy housing a telemetry subsystem (Fig 26 d).

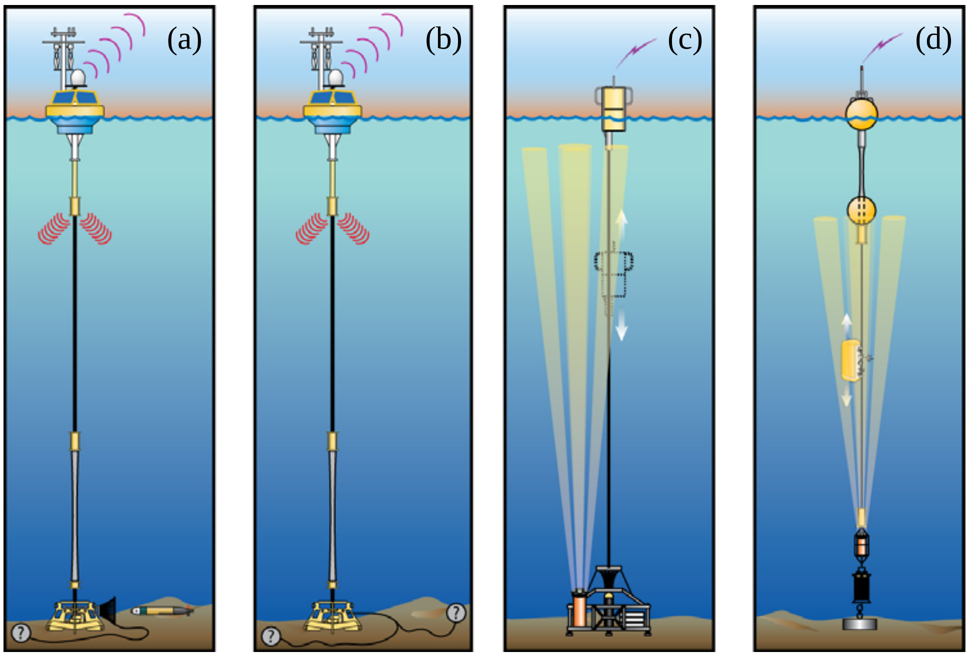


Figure 26. Schematic diagrams of the three Pioneer Array mooring types: (a)-(b) surface moorings with (a) or without (b) AUV docks at their base, (c) surface-piercing profiler, (d) wire-follower profiler with upward looking ADCP.

The distribution of mooring types within the array is as follows: The Inshore and Central sites contain surface moorings and surface-piercing profilers. The Offshore site contains a surface mooring and wire-following profiler. The Central-Inshore, Central-offshore, Upstream-Inshore and Upstream-Offshore sites contain wire-following profilers.

Three instrumented AUVs capable of sampling the water column to depths of 600 m will operate in the vicinity of the moored array. These vehicles will extend the footprint of the moored array both along-shore and across-shore. As described in the overview, two AUVs will operate from docking stations at the base of surface moorings while the third will be operated from ships during service cruises.

Six instrumented gliders capable of profiling the water column to depths of up to 1000 m will operate over the outer shelf and slope.

2.2. Site Configuration

The desired characteristics for the Pioneer Array location are a broad (~200 km) region of the continental slope with generally straight isobaths containing a local subregion of ~20 km in along-shelf extent with a well-defined shelf break, relatively straight isobaths, and no canyons. The broad region represents the glider operation area and the local subregion represents the moored array area. The desired conditions are found near 40° N, 71° W where isobaths at the continental slope run approximately east-west for ~100 km in either direction (Figs. 3, 7) and multi-beam bathymetry reveals a ~25 km extent of straight isobaths downstream of a canyon (Fig. 5).

Pioneer Array components were originally positioned using relatively low-resolution bathymetry and without the benefit of data comparison on a regional scale (Fig. 3) or multi-beam ground-truth within the moored array area (Fig. 5). The across-shelf array spacing was set at 10 km with the knowledge that this was the approximate magnitude of the decorrelation scale for dynamical features, but without careful review of published work or the benefit of additional observational and modeling papers that have recently become available. The site survey information in Sec. 1 of this report, and in particular the bathymetry discussed in Sec. 1.1, indicate that the original mooring positions reported in the OOI Final Network Design (1101-00000, Ver 1-06, 2008-10-31) must be adjusted to better accomplish the science goals. The initial review resulted in three principal changes: the across-shelf mooring line was shifted approximately 3.5 km to the west, the spacing between moorings was reduced, and the upstream locations were adjusted to be on the same isobaths as their companion moorings on the across-shelf line. In addition, the AUV operations area was extended approximately 10 km further inshore and the glider operations area is extended approximately 7 km further east.

The Pioneer Array configuration was further refined following meetings with the scientific community (Shelf/Slope Processes Workshop, 2010) and representatives of the commercial fishing industry (CFRF Workshop Report, 2012). This resulted in several changes to the initial moored array sites and a change to the glider operations area. The updated array configuration is documented here, while the detailed assessment steps leading to the configuration are described in the cited documents.

The final Pioneer Array configuration, consisting of a Moored Array, AUV Operations Area and Glider Operations Area is depicted in Fig. 27. Details are provided in Sec. 2.2.1-2.2.3.

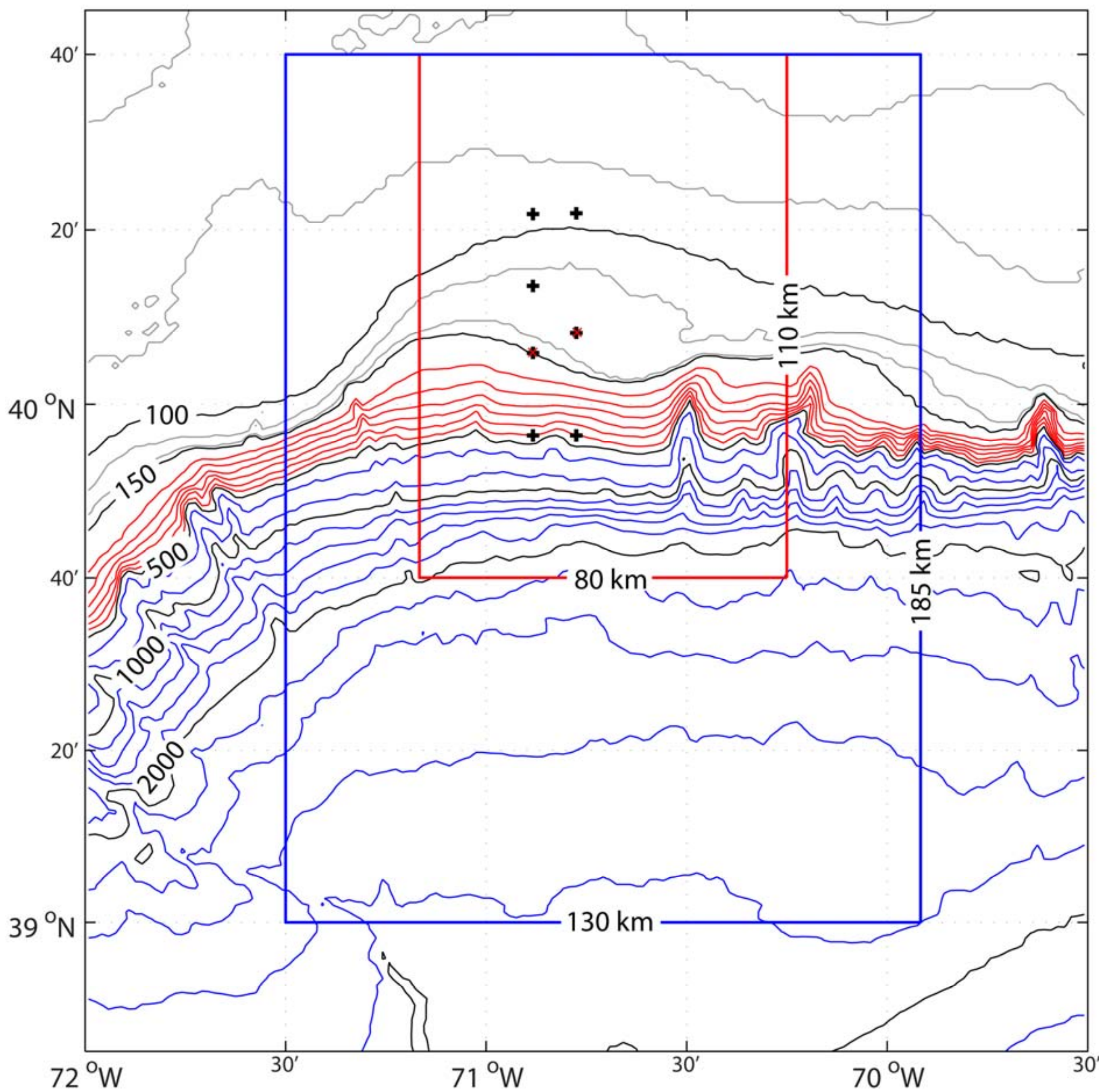


Figure 27. Final Pioneer Array configuration. Site centers (+) are shown along with red "x" symbols depicting locations of "hangs" avoided by mobile-gear fishermen. The AUV operations box is in red and the Glider operations box is in blue. Gray, red and blue contours are at 20 m, 50 m and 200 m intervals, respectively. Contours at 100, 150, 500, 1000 and 2000m are black. Selected contours are labeled in meters.

2.2.1 Moored Array

Changes to the initial moored array configuration are summarized below. Note that the Smith and Sandwell (1997) bathymetry data (Sec. 1.1.1) were used to make the maps. The final mooring sites are shown in Fig. 28. There are three main aspects to the rearrangement:

a) Shift the entire array to the west in order to locate the Central Offshore Site on an existing "hang" (a location already avoided by commercial fishermen due to the potential for snagging gear on a submerged object or formation). This is a shift of approximately 7 km, with the downstream line along 70° 53' W compared to the original location along 70° 48' W. A positive aspect of this shift is that the array is now further downstream from the canyon at 70° 30' W.

b) Shift the two Inshore moorings to the north to place them at the 50 fm (91.5 m) isobath. This isobath is an existing boundary between fixed and mobile fishing gear types (NMFS Northeast Region Information Sheet No. 7) rather than 52 fm. These are small depth (3.5 m) and location (~1.5 km) changes relative to the Inshore sites proposed by the Shelf/Slope Workshop and will still satisfy the goal stated therein of having the Inshore sites further shoreward to encompass the expected position of the foot of the shelfbreak front.

c) Shift the Central mooring site to the southeast in order to locate it on an existing hang. The eastward shift of about 9.3 km aligns the Central site with the longitude of the Upstream sites. The southward shift creates unequal separations of 13.6 km and 10.2 km from the Central site to Central Inshore and Central Offshore, respectively, compared to the equal separation of 8.4 km recommended by the Shelf/Slope Workshop. This disrupts the original linear (cross-shelf) arrangement of moorings along the downstream line – the tightly spaced linear subarray comprised of the Central Inshore, Central and Central Offshore mooring sites is eliminated. A potential negative impact is that, at their new locations, these three moorings may not provide coherent signals on short time scales, and the ability to "map" cross-shelf frontal structure will be compromised. On the positive side, the new arrangement establishes a triangular subarray which may serve the original scientific purpose of mapping cross-shelf structure on long time scales while at the same time providing a spatially-lagged array for assessment of propagating signals on short time scales.

The inshore moorings remain south of the shipping lanes (Figs. 7) and within the same mix of bottom sediment types as for the initial configuration (Fig. 8). Examination of NOAA chart 12300 (Fig. 24) indicates that submarine cables do not intersect the 1 km Site Radius of the final sites. Available data sources do not list any known cultural resources at the final mooring sites and recent project-specific multibeam bathymetric surveys have not identified any significant objects or formations within the vicinity of the final Pioneer mooring sites (Pioneer Array SER, 2012).

The moored array is situated near the center of the broad region of generally straight isobaths, as described above. The longitude of the across-shelf mooring line was chosen as 70° 53' W so that the array would be several characteristic length scales away from the canyon near 70° 30' W (Fig. 27).

A bathymetric transect along the two across-shelf lines occupied by the array (Fig. 29) shows that the main shelfbreak occurs at about 150 m depth at 40° 04' N. Also evident is a secondary topographic "break" (near 100 m depth at 40° 20' N) which is a typical location of the foot of the shelfbreak front.

The across-shelf transect shows that the final configuration maintains the across-shelf spacing and water depths proposed by the Shelf/Slope Workshop (see Fig. 6 of that report). The depths of the Central Inshore and Central Offshore sites are identical to those from the Workshop. The Central site is 2 m shallower while the Inshore site is 3.5 m shallower.

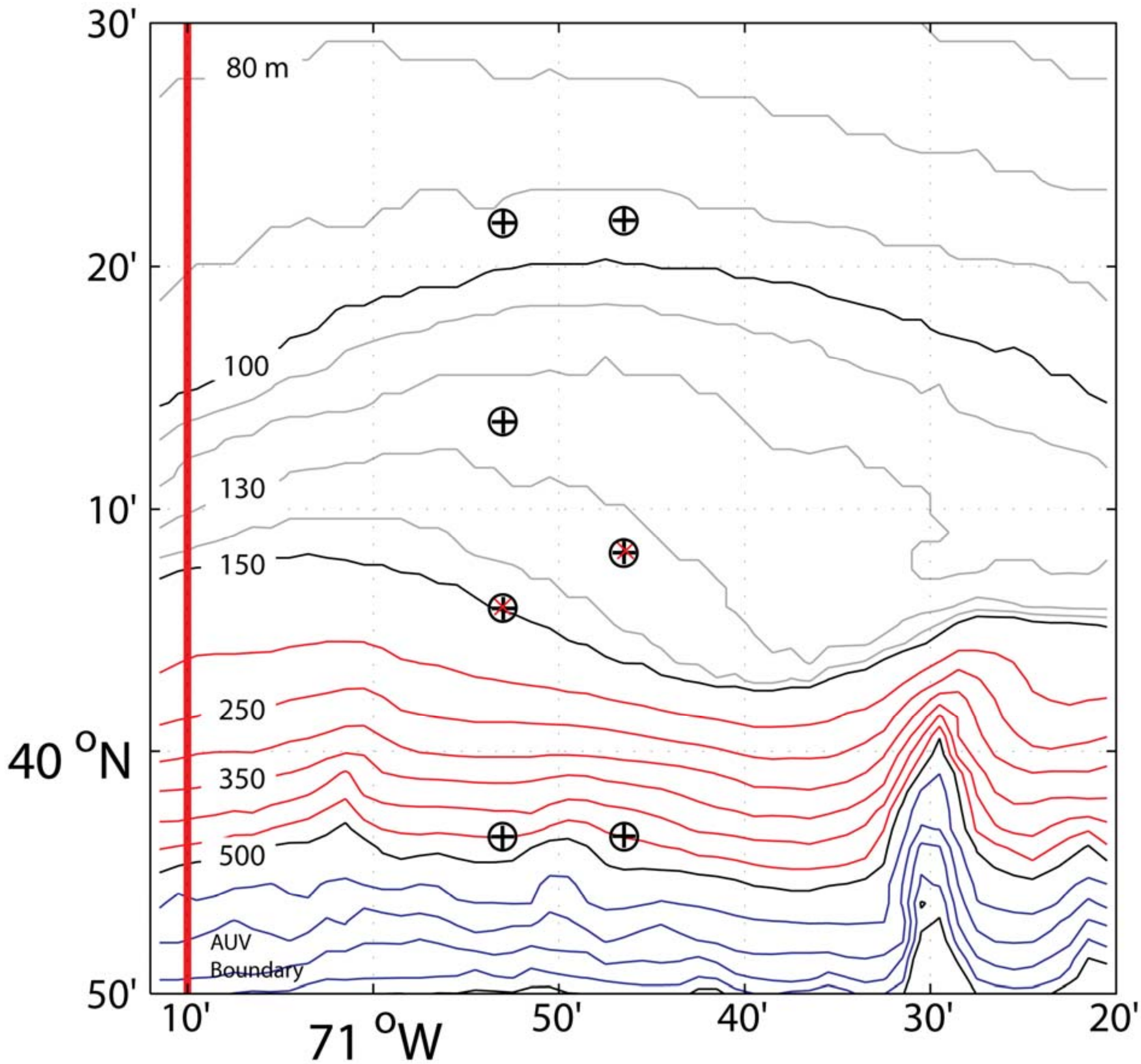


Figure 28. Pioneer Moored Array configuration. Site centers (+) and an approximate depiction of the 1 km (0.5 nm) Site Radius (circles) are shown. Red "X" symbols denote locations of "hangs" avoided by mobile-gear fishermen. Gray, red and blue contours are at 10 m, 50 m and 100 m intervals, respectively. Contours at 100, 150, 500, and 1000m are black. Selected contours are labeled in meters.

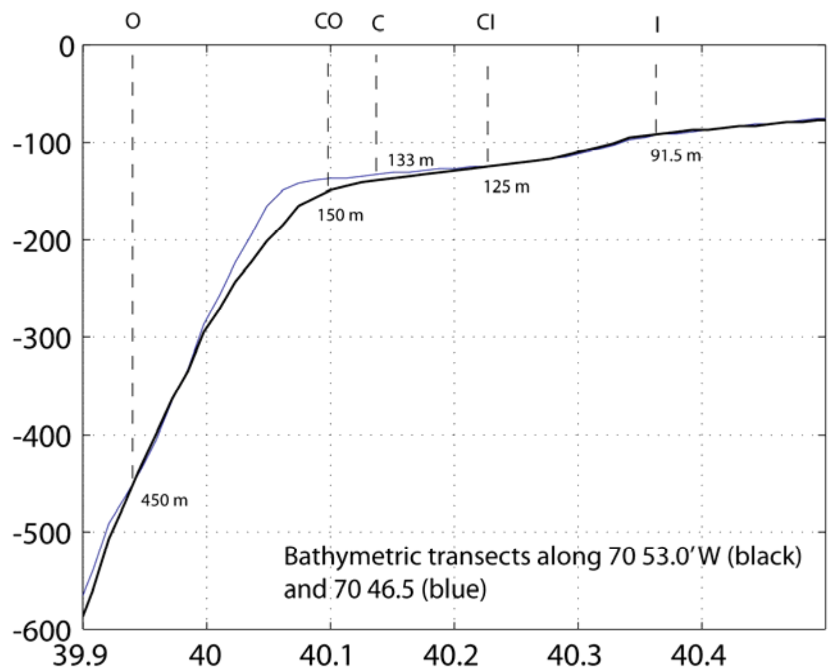


Figure 29. Pioneer Moored Array bathymetry transect. Bathymetry transect along the downstream mooring line at 70° 53.0' W (black line) and along the upstream mooring line at 70° 46.5' W (blue). The shelfbreak occurs at about 150 m depth. Locations of the mooring sites are indicated as vertical lines (see Table 7). Mooring site designations are O (Offshore), CO (Central Offshore), C (central), CI (central Inshore) and I (Inshore).

The scientific objective of having the Central site near the center of the "climatological" shelfbreak jet and the Inshore and Offshore sites spanning the typical range of the intersection of the temperature-salinity (T/S) front with the bottom and surface, respectively, is achieved (Shelf/Slope Workshop Report, 2010). Note that the expected 15-20 km width of the jet means that uncertainties of a few km will not be critical. As noted under item (c) above, the spacing between the Central site and adjacent sites may not be sufficiently close to maintain coherence on short time scales given the across-shelf decorrelation scales of 7-9 km. On the other hand, the objective of having Inshore and Offshore sites far enough from the front to be in shelf water and slope water, respectively, will be more effectively achieved. The Inshore and Offshore sites will span the climatological inshore and offshore variability of the intersection of the temperature-salinity (T/S) front with the bottom, and will also capture the typical meanders of the shelfbreak jet. The across-shelf mooring line extends approximately 47 km overall. A constraint set by the surface mooring design and the operating depth of the AUVs is that the Offshore sites must be in water depth < 600 m.

The upstream moorings provide along-shelf gradients to aid in determination of advective fluxes in shelf water and slope water. With the expectation that along-shelf correlation scales away from the front would be larger than those at the front, the upstream sites were to be 10-15 km from the across-shelf line. The spacing to the upstream sites is 9.2 - 9.3 km in the final configuration. Since the flow tends to follow isobaths, the upstream sites are at the same depth as the corresponding sites on the downstream line.

The moored array locations are summarized in Table 7.

Table 7. Moored array locations. Water depths are at Site Center.

Site	Site Center	Water Depth	Site Rad	Site Separation (between centers)	Site Separation (N/S)
Inshore	40°21.8'N 70°53.0'W	91.5 m	1 km	15.2 km from Central- Inshore	15.2 km from Central-Inshore
Central-Inshore	40°13.6'N 70°53.0'W	125 m	1 km	13.6 km from Central	10 km from Central
Central	40°08.2'N 70°46.5'W	133 m	1 km	–	–
Central-Offshore	40°05.9'N 70°53.0'W	150 m	1 km	10.2 km from Central	4.3 km from Central
Offshore	39°56.4'N 70°53.0'W	450 m	1 km	17.6 km from Central- Offshore	17.6 km from Central-Offshore
Upstream-Inshore	40°21.9'N 70°46.5'W	91.5 m	1 km	9.2 km from Inshore	–
Upstream-Offshore	39°56.4'N 70°46.5'W	450 m	1 km	9.3 km from Offshore	–

The characteristics of the moored array are described by four parameters:

- *Site Center.* This is the central location for a site, from which the Site Radius is measured. The Site Center is listed in array location tables and plotted on maps. However, the mooring or moorings at the site may not be located at the Site Center. They will be located within the Site Radius.

- *Site Radius.* This is the region within which the mooring or moorings at each site will be located. A region, rather than an exact location, is necessary to allow for local-scale bathymetric features unresolved on available maps, uncertainties in "anchor-over" position, anchor fall-back during deployment, and the possibility that a replacement mooring may be deployed before the deployed mooring is recovered. The Site Radius for the Pioneer Array is 1 km.

- *Site Separation.* This is the distance between Site Centers. Site separations for the final array configuration are listed in Table 7. Across-shelf (North/South) separations range from 4.3 to 17.6 km while the along-shelf separation is just over 9 km.

- *Mooring Separation.* This is the distance between mooring anchor positions for adjacent moorings at the same site, e.g., between the surface mooring and surface piercing profiler at the Inshore site. The Mooring Separation must allow for uncertainties in the anchor positions, the buoy watch circles (estimated to be <= 50% of the water depth), and ship maneuvering (to deploy a second mooring with the first already in place). The target Mooring Separation is about 500 m, or approximately twice the water depth at the site, whichever is larger. Actual separations will only be known after deployment.

2.2.2 AUV Operations Area

AUVs are employed within the Pioneer Array to provide several capabilities, including horizontal context for horizontally fixed platforms and adaptive sampling. Specifically, the AUVs will provide synoptic spatial transects within a shelfbreak frontal system that is expected to evolve on time scales of about one day, and will extend the “footprint” of the moored array towards mid-shelf (60 m depth) where extreme excursions of the front have been documented.

The AUV operations area is a box defined by the corners in Table 8, and is depicted graphically in Fig. 27. Within this box, the expectation is for baseline missions consisting of two AUVs running from surface mooring docking stations, running synchronized, synoptic sampling missions of up to 100 km along-shelf and 80 km across-shelf (total track length 200-250 km) within the AUV box. The nominal interval between missions will be seven days, determined by the rate of power generation by the surface buoys. The third AUV will be operated from a ship, and will have three purposes: 1) to provide adaptive sampling and event-response capability without interrupting the baseline AUV missions, 2) to provide regular comparisons of moored sensors with freshly calibrated sensors (on the vehicle) as a means of mitigating sensor degradation during long-term deployment, and 3) to serve as a replacement vehicle if the baseline missions cannot be accomplished due to malfunction. The water depths at the inshore and offshore extent of the AUV operations area will be approximately 60 m and 2200 m, respectively. AUVs will operate from the surface to within a few meters of the sea floor, or to a maximum depth of 600 m in deep water.

Table 8. AUV Operations Area

Description	Location	Depth
SE corner	39°40’N, 70°15’W	2200 m
SW corner	39°40’N, 71°10’W	2000 m
NW corner	40°40’N, 71°10’W	60 m
NE corner	40°40’N, 70°15’W	60 m

2.2.3 Glider Operations Area

Gliders within the OOI are employed for two general purposes: providing spatial context to horizontally fixed platforms and providing adaptive sampling capability. Gliders within the Pioneer Array originally focused on resolving mesoscale features on the outer shelf and over the continental slope that may indirectly affect, or directly impinge on the Pioneer moored array. At the Shelf/Slope Workshop this was refined to include three objectives: Establishing upstream conditions over the outer shelf and upper slope, providing coverage along the expected mean axis of the shelfbreak jet and adjacent slope waters, and resolution of important slope features such as eddies and streamers. To accomplish these objectives, the glider operations box was extended approximately 35 km further inshore, to 40°40’N. The final glider operations area is a box defined by the corners in Table 9 approximately 130 km along-shelf and 185 km across-shelf as depicted graphically in Fig. 27. Water depths at the inshore and offshore extent of the glider operations area will be approximately 60 m and 2800 m, respectively. Gliders will operate from the surface to within a few meters of the sea floor, or to a maximum depth of 1000 m in deep water.

Table 9. Glider Operations Area

Description	**Location**	**Depth**
SE corner	39°00'N, 69°55'W	2800 m
SW corner	39°00'N, 71°30'W	2600 m
NW corner	40°40'N, 71°30'W	60 m
NE corner	40°40'N, 69°55'W	60 m

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Appendix A

Methodology for determining extreme events

10, 30, and 100-Year Sea States

Historical records for significant wave heights comes mostly from reanalysis of wind data collected by satellites. The wind data is used as input into numerical models that calculate significant wave height. Since winds are averaged over a fairly course grid, the significant wave heights typically underestimate short-term events as measured by surface buoys. In one instance (***Station Papa***), we are able to compare 35-year results from GROW data reanalysis to overlapping 25-year measurements from an NDBC surface buoy (46001). The GROW data reanalysis underestimates 10,30, and 100-year sea states by about 10%.

Extreme events (10, 30, and 100-year sea states) are estimated using Peak-Over-Threshold method. We catalogue the peaks above a given threshold (typically 0.5 to 0.75 of the maximum significant wave height of the given time record). The peaks we choose must be separated by at least 48 hours (this is our subjective criteria to insure independent storm events). If there are two peaks within a ±48-hour window, then we only retain the largest peak within the window. We calculate the cumulative probability distribution for the peaks above our threshold such that $Pr(H_s \leq H_t) = 0$ where H_s is the significant wave height and H_t is the threshold and $Pr(H_s \leq H_m) = 1 - 1/(N+1)$ where H_m is the maximum peak and N is the total number of peaks above the threshold. Generalized Pareto Distributions are fitted to the measured distributions corresponding to different thresholds. Goodness of fit criteria is applied to the different threshold distributions, and this used to determine the parameters for the Generalized Pareto Distribution to use in estimating 10, 30, and 100-year sea states. The input cumulative probability for a N-year sea state is given by 1-1/(N*m) where m is the average number of peaks per year above the given threshold.

10, 30, and 100-Year Wind

Extreme wind events are determined in the same manner using Peak-Over-Threshold method. The wind data comes from satellite reanalysis studies and from surface buoy measurements.