6. Site Parameters for the U.S. DART® Array

In this section, the details of each of the 39 sites comprising the current U.S DART® array are provided. As noted earlier, some sites predated the decision to expand the array in the wake of the 2004 tragedy and were retained. In particular, the primary role of the Hawaiian DART® 51407 is the detection of a locally generated tsunami. As such its siting is outside the scope of this study, as are the sites of the "Equatorial" DART® 51406, and the non-U.S. Chilean tsunameter 32401. Although the two Australian sites 55012 and 55015, in the Coral Sea and Tasman Sea, respectively, were chosen by the Australian Bureau of Meteorology (Greenslade, personal communication) and those in the Indian Ocean are the responsibility of Thailand (23401) and Indonesia (53401), similar graphical products for these sites are included for completeness.

With the exception of the mid-ocean DART® sites, 51406 and 51407, each graphic has a common format. To the left a broad region in the vicinity of the finally chosen site is shown with EEZ boundaries in red (based on the freely available dataset from VLIZ at `www.vliz.be/vmdcdata/marbound`), and land in black. Water depths exceeding the engineering limit of 6000 m are crosshatched in blue. Following the analysis of Mofjeld *et al.* (2001) the locations of scattering features in the bathymetry are indicated by color contours in shades of red of the scattering index S:

$$S = 1 - 2\varepsilon/(1 + \varepsilon^2) \tag{2}$$

where

$$\varepsilon = \sqrt{H_1/H_0} \tag{3}$$

represents the extent to which the actual depth of a feature H_1 deviates from the average depth H_0 in the vicinity. For this study the Smith-Sandwell bathymetry is used to represent H_1 while ETOPO60, regridded linearly from one degree to $2'$ resolution, is employed as H_0. Substantial scattering of tsunami waves is to be expected where S exceeds a value of 0.2 ($H_1 < 1{,}500$ m in regional depths of 4,000–6,000 m) while major scattering results when S is greater than 0.5 ($H_1 < 400$ m). Ideally, to avoid excessive complexity in the detected tsunami signal that may not be fully represented in the comparison model series of the propagation database, a DART® should not be placed where there are significant scattering features between it and the sources it is intended to monitor. In these graphics sources are represented with the green rectangles of the propagation database unit sources.

The propagation database allows the computation of first wave arrival time, for a given unit source, at each point in the basin. Combining this information it is possible to determine the earliest arrival from any of the sources in the database and contour that field. The contour lines are referred to as “minimum travel time envelopes” and, in the accompanying graphics, the 15-, 30-, 45-, and 60-min envelopes are drawn. Although there have been to date too few sizable seismic events near DART® sites to fully explore the relationship between seismic noise amplitude and duration, the conventional wisdom is that at least 30 min of tsunami travel time is needed for the faster propagating (2–4 km/s) seismic waves to sufficiently outrun the true tsunami signal. The travel time envelopes thus aid in site selection, and most sites have been chosen at or beyond the 30-min envelope. Because the travel times between Alaskan and Aleutian sources and the Hawaiian Islands are in many cases close to the 3-hour warning period desired by emergency managers, sites closer to the 15-min envelope have been selected. Local bathymetric considerations have in some instances supported such recommendations. Near-source placement will result in earlier detection, though possibly at the expense of forecast quality. As noted earlier, to compensate for this possible degradation, the spacing of the Alaskan and Aleutian DART® sites has been reduced in order to provide cleaner though somewhat later additional signals to possibly refine the early forecast based on the first-reporting DART®.

Travel time envelopes are based on all unit sources within a basin. Generally the propagation database holds two rows of sources: the B-row adjacent to the plate boundary, and an A-row representing earthquakes deeper on the descending slab. In places, additional source rows are necessary to represent submerged areas of shelf inshore of the A-row. To avoid excessive complexity in the graphics and tables that follow, attention is generally focused on B-row statistics. Because this row is typically closer to the DART® sites, and because the other rows are generally beneath shallower water depths with slower speeds of propagation, the B-row detection times reported are less than those of neighboring inshore unit sources,

Details of the siting environment for each DART® location are provided in a set of graphics in the following sections. Common features of these images are as follows: EEZ boundaries are drawn in red, land mass in black (Japan’s Honshu in Fig. 7, for example), and waters exceeding the maximum deployment depth of 6,000 m shaded in blue. The primary instrument location is the black square within a $5^\circ \times 3^\circ$ rectangle whose topography and speed characteristics are shown in the panels to the right; neighboring sites are marked with smaller blue squares. Color-contoured in shades of red is the scattering index, described at the beginning of this section. Strong scattering of a wave between origination and detection can increase the uncertainty in the source identification (“inversion”) process. Minimum travel time envelopes (in black), are drawn at 15-min intervals. Unit sources from the propagation database are drawn in green with some B-row detection times (in minutes) shown *for the prime site*. The detection time of concern in the forecast setting is the earliest one available when instruments of the array act in concert. Graphics and a table providing such overall statistics are available in Section 7. Note that the figures in the PDF version of this report www.pmel.noaa.gov/pubs/PDF/spil3192/spil3192.pdf are better suited to close examination.

Bathymetry is based on Smith-Sandwell and is color-contoured in the uppermost panel to the right. Line contours at 50-m intervals are drawn within a 400-m band near the DART® depth. This aspect of the graphic, intended to reflect depth variability near the site, is not fully satisfactory. A larger scale image would be better and can, in many cases, be found in the graphics of the Site Recommendation Reports of Appendices B through I. In practice, an on-site survey during deployment is needed to adequately determine the bathymetry.

Surface current speed statistics, based on a 600-day sample of NLOM hindcast results near and at the site are shown in the remaining panels. The 5% exceedance statistic (or 95th percentile) of the NLOM surface current speed distribution is color-contoured. Based on daily speed estimates between 1 January 2006 and 23 August 2007 from this numerical hindcast model (which assimilates satellite altimetry), the value contoured is exceeded on 30 (5%) of the 600 readily available days. The extent to which such conditions might persist at the chosen DART® site is displayed in the final two panels as a time series and a histogram of the speed distribution. Note that for the speed histograms, the same speed scale (0–2 m/s) is employed for all sites to facilitate identification of the moorings most at risk of damage by excessive speeds. The NLOM model has been applied for multiple years and provides hindcasts over the whole water column. The 600-day subset of surface speeds employed here was acquired via anonymous FTP access. The process was somewhat time consuming and, as noted earlier, occurred after the site selection in response to the difficulties experienced with 42408 and 44402. Access to a more complete set of NLOM results would permit a more thorough exploration of mooring design and deployment issues, but is beyond the scope of this memo.

6.1 The Western Pacific

Six sites forming the West Pacific Group were the subject of the Site Recommendation Report reproduced in Appendix B. They are intended to provide warning to the island nations of the western Pacific and, more remotely, to Hawaii, of events in the complex of sources extending from Japan southward via the Marianas Arc to Yap, and from the Nankai Trough to New Guinea via the Ryukyus and Philippines. Site details and data return details are provided in Table 2. The Data Return statistic provided in this and later tables is intended to reflect intermittency in the data stream; periods of extended outage are excluded. As such the statistic provided in these tables relates to the performance criteria for tsunameter reliability (see www.ndbc.noaa.gov/dart/dart2_pc_1.shtml) where a return rate in excess of 80% is mandated. As will be seen, this standard is significantly exceeded for all but one of the DART® sites (77.6% at 21418 in the Northwest Pacific. A graphical representation of intermittency and major gaps

Table 2: Location and performance of the Western Pacific DART® Group (to 30 October 2008).

WMO Identifier	Location	Data Begins	Major Disruptions	Data Return (%)
21413	30.55°N, 152.11°E, 5827 m	27 Nov 2006	One	97.0
52401	19.26°N, 155.76°E, 5569 m	12 Dec 2006	One	98.3
52402	11.56°N, 154.58°E, 5799 m	15 Dec 2006	None	99.6
52403	4.02°N, 145.58°E, 4436 m	19 Dec 2006	One	95.4
52404	20.95°N, 132.31°E, 5926 m	1 Dec 2006	None	98.6
53405	12.88°N, 132.32°E, 5957 m	4 Dec 2006	None	99.2

in the data stream is presented in Section 7.3, where an overall data return statistic is provided.

The northernmost site, **21413** lies near the 60-min envelope, essentially midway between sites 21418 and 52401, to the east of an area of excessive depths. As seen in Fig. 7 it provides detection times between 77 and 87 min for the unit source segment shown but has successfully detected the minor Kuril Island event of January 2007 further to the north. For sources directly to the west the path is open; in other directions, especially the SW, are numerous scatterers. DART® 21413 is located on a stretch of flat seafloor but is rather close to the path of the Kuroshio with sustained surface currents in excess of 0.6 m/s not uncommon.

Some 1,300 km to the SSE, and on the 60-min envelope for sources in the Marianas, lies **52401** whose characteristics are displayed in Fig. 8. Numerous scattering centers are present in this region; the dominant ones along the southern edge are the Caroline Islands, which act to limit the penetration of tsunamis generated off New Guinea into the wider Pacific. Current speeds are somewhat weaker, though steadier, than at 23413, with a median of 0.3 m/s.

Further south, just outside the EEZ boundary of the Federated States of Micronesia, is DART® **52402**. The site (see Fig. 9) provides good detection possibilities for events on the southern portion of the Marianas Arc. Sources of the Manus oceanic convergent boundary, north of New Guinea, are about 2 hours to the south. The site should normally be beyond the influence of the North Equatorial Current and has a median speed of about 0.3 m/s and only rare current spikes exceeding 0.5 m/s.

DART® **52403** is the southernmost of the West Pacific group and is located in International waters just south of the Federated States of Micronesia EEZ. The location (see Fig. 10) is well placed to intercept waves from Manus, northern New Guinea, the Marianas, and the East Philippines. The current speed regime may be somewhat severe and, based on NLOM statistics, a move to the southwest may be indicated. Notice two sites (marked with flag icons) in the southwest that Indonesia plans to instrument in November 2008 (one with a DART®-ETD) which will supplement the U.S. array.

Coverage of Ryukyu-Nankai and the northern portion of the East Philippines source region is provided by DART® **52404**, which was placed in In-

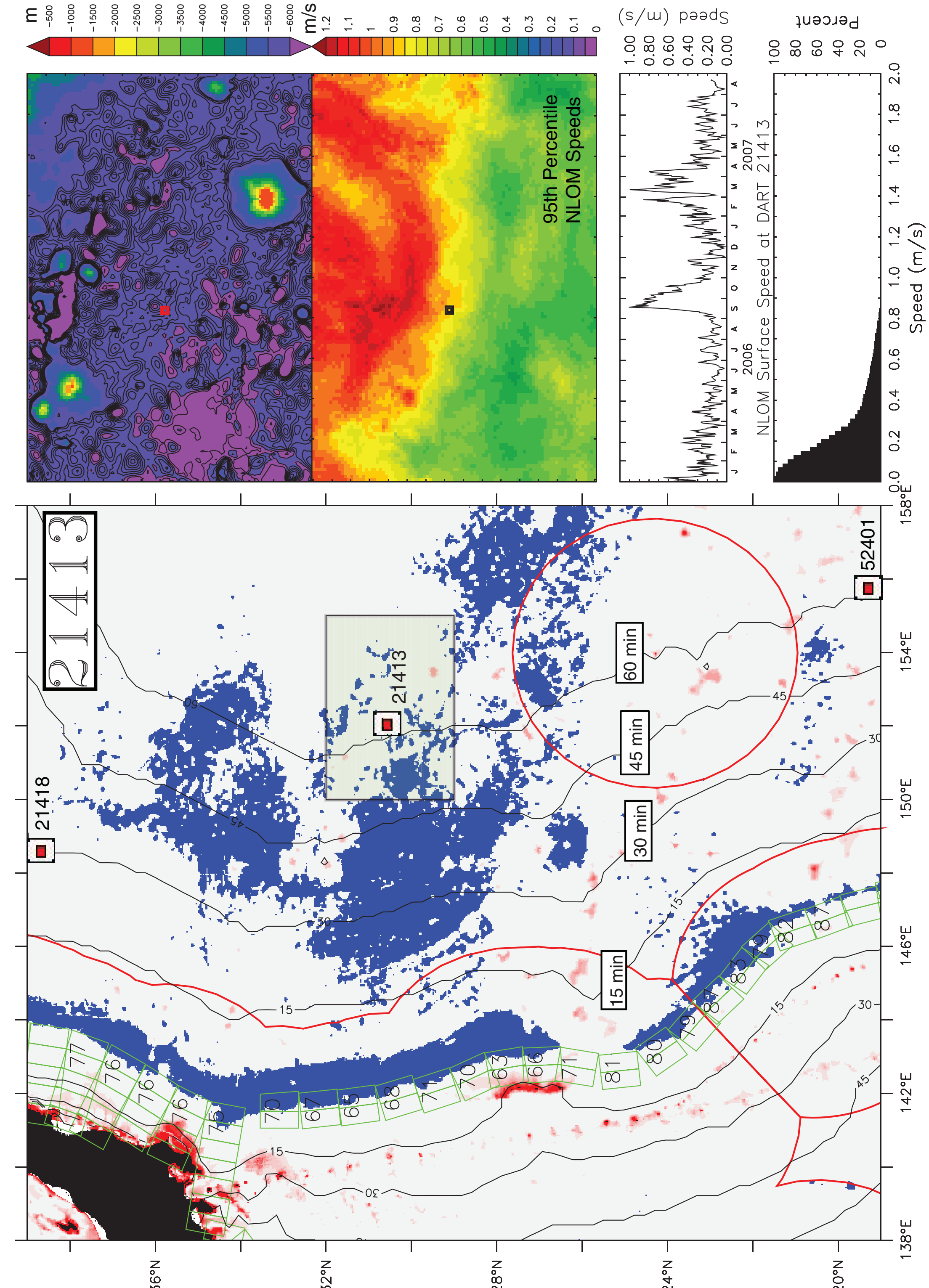

Figure 7: Siting environment for DART® **21413** in the Western Pacific.

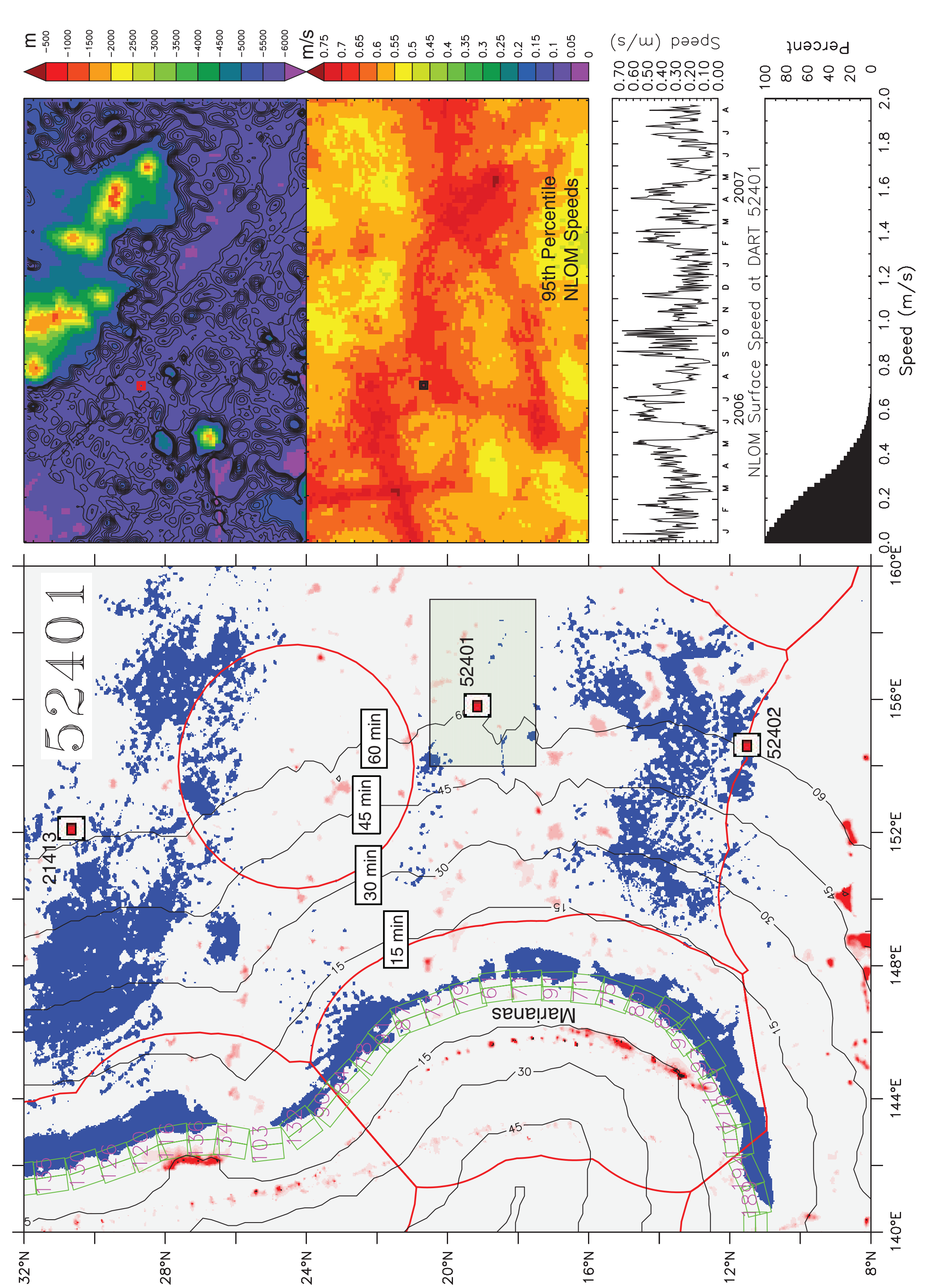

Figure 8: Siting environment for DART® **52401** in the Western Pacific.

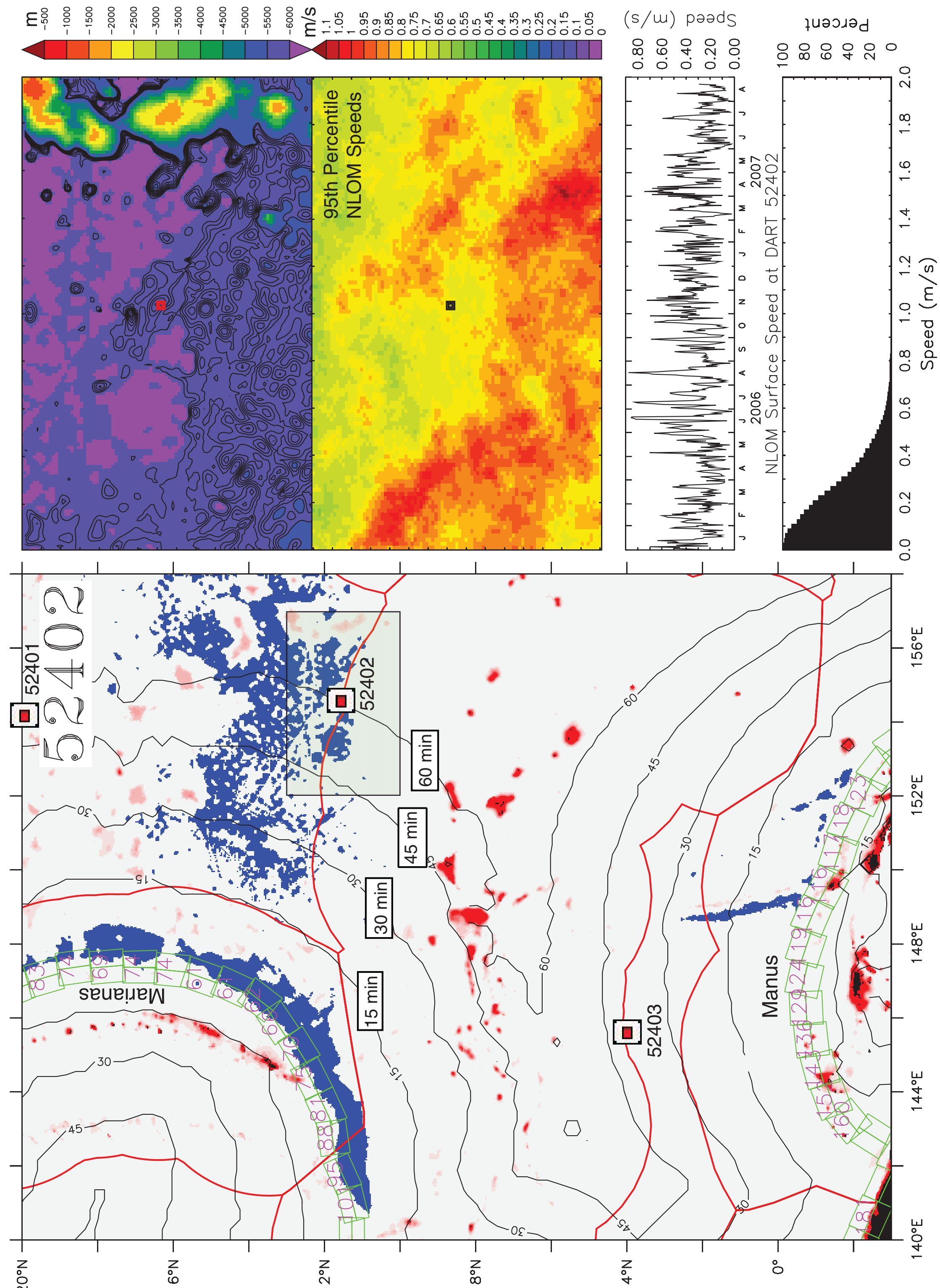

Figure 9: Siting environment for DART® **52402** in the Western Pacific.

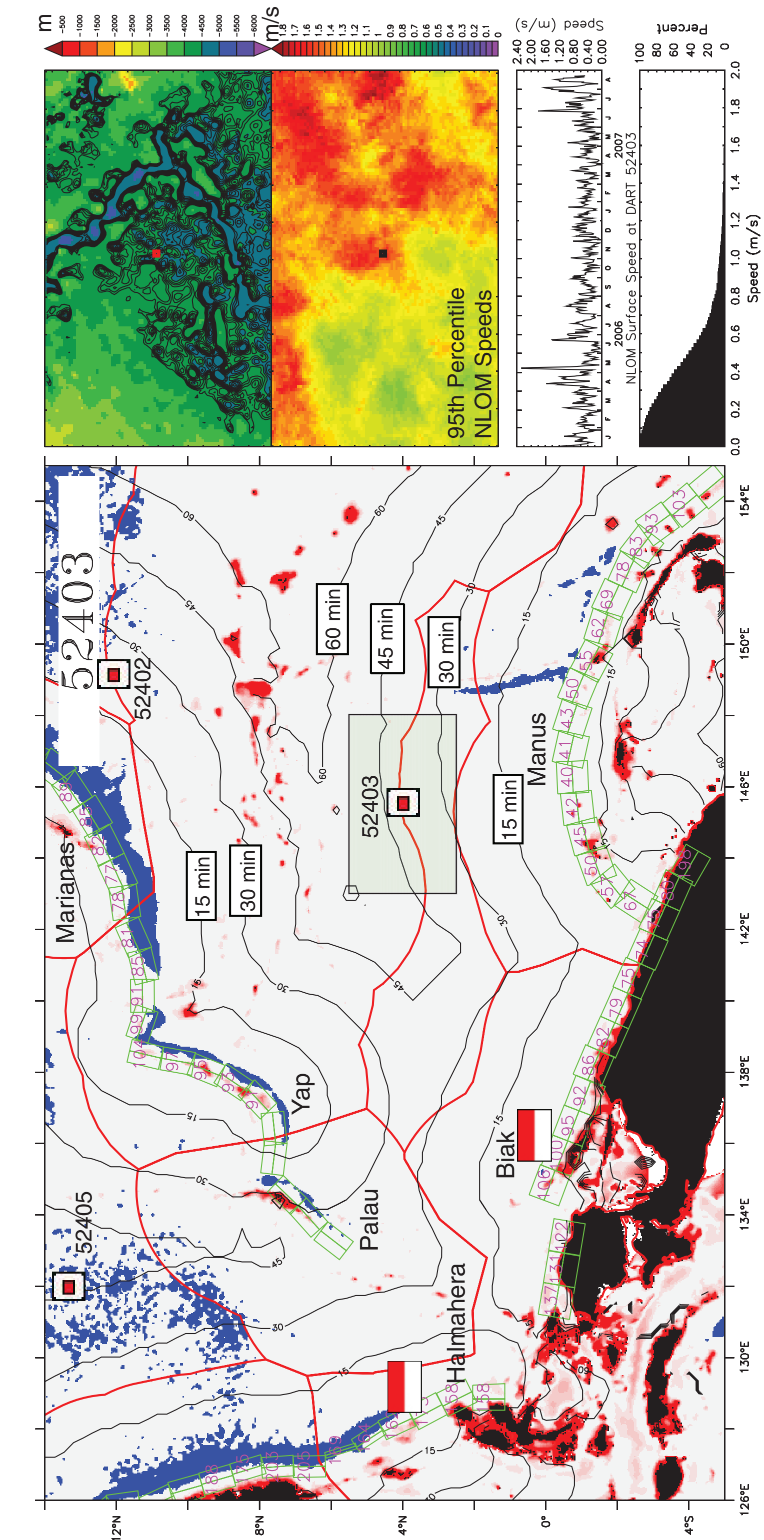

Figure 10: Siting environment for DART® **52403** in the Western Pacific.

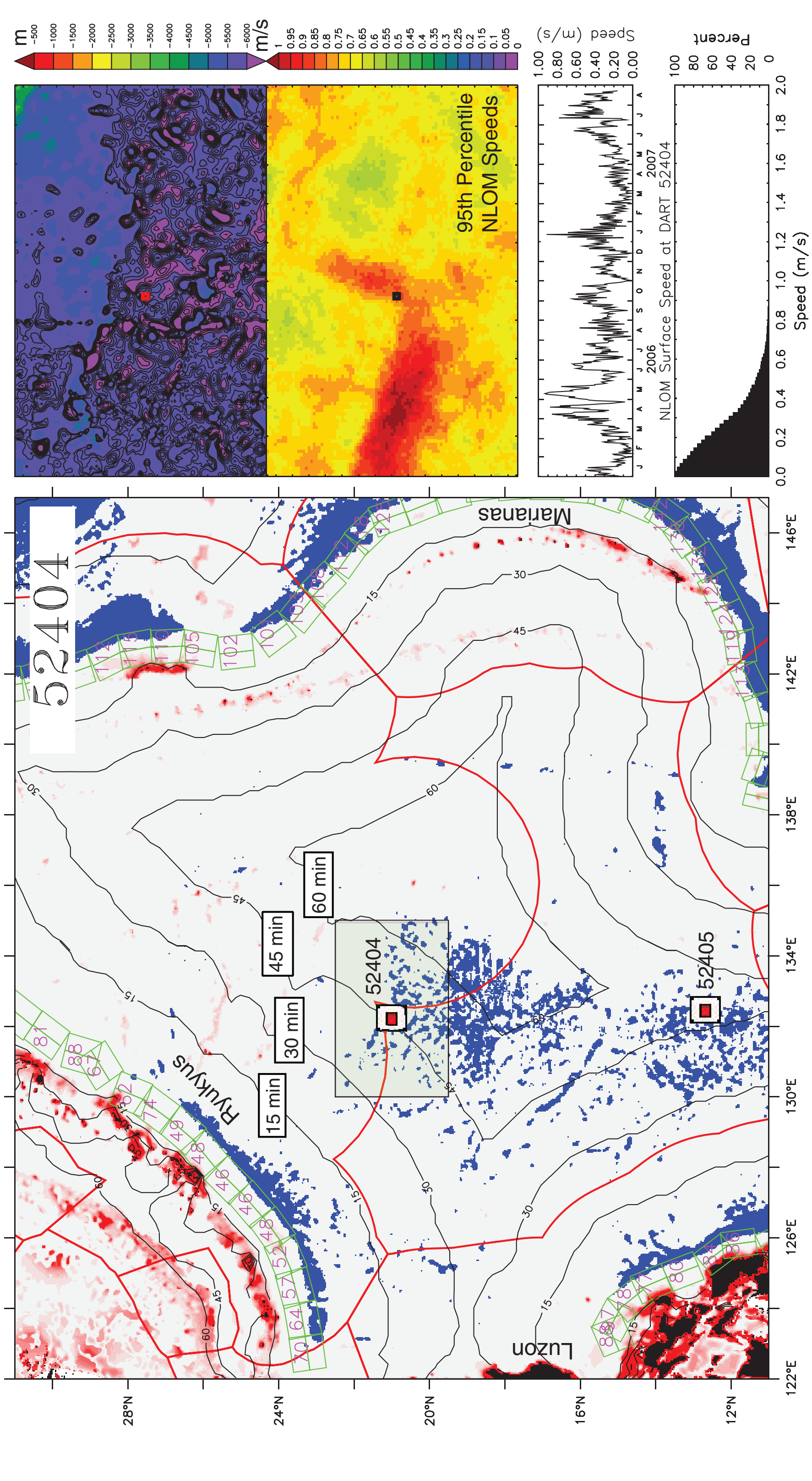

Figure 11: Siting environment for DART® **52404** in the Western Pacific.

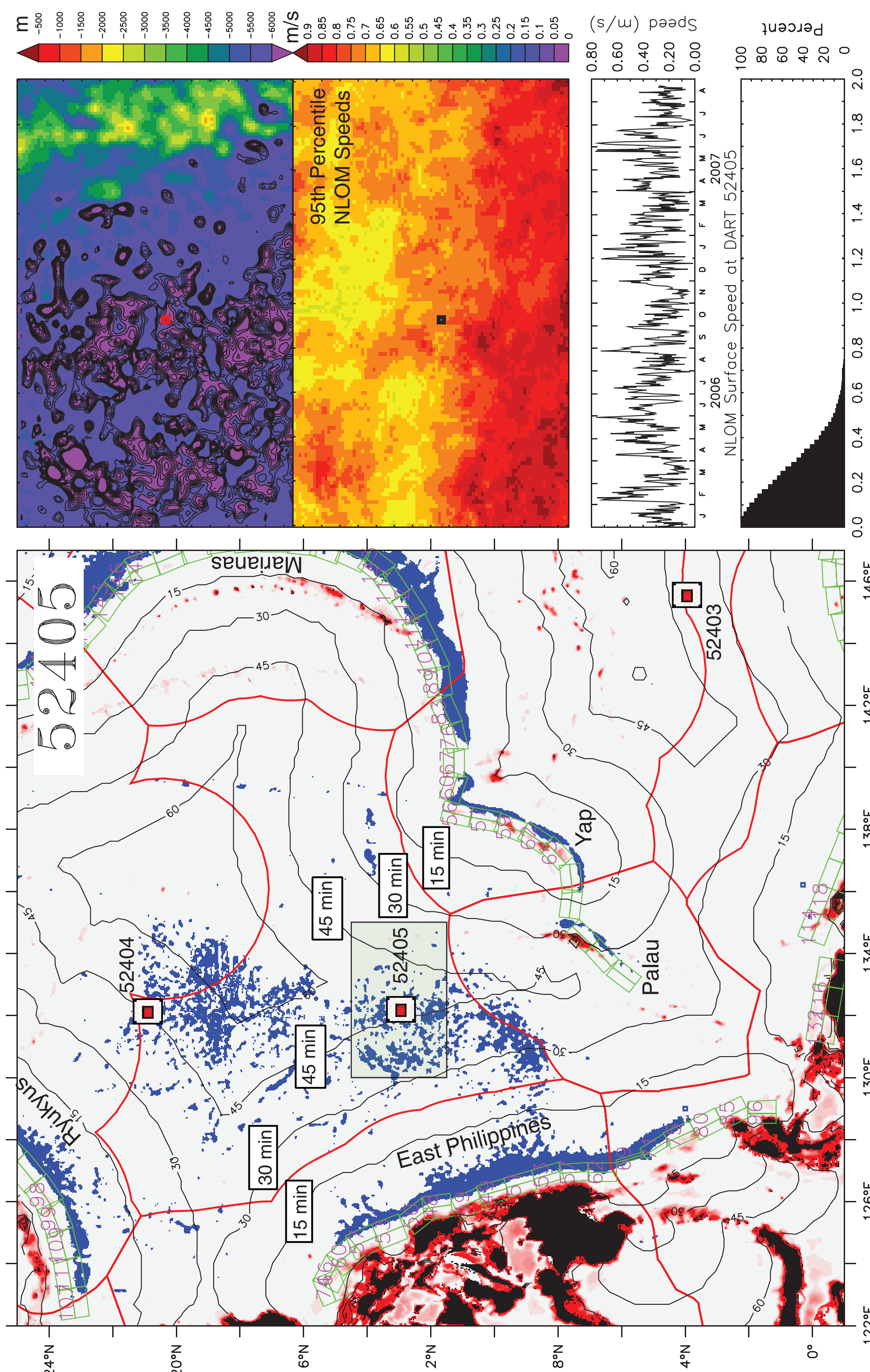

Figure 12: Siting environment for DART® **52405** in the Western Pacific.

Table 3: Location and performance of the Northwest Pacific DART® Group (to 30 October 2008).

WMO Identifier	Location	Data Begins	Major Disruptions	Data Return (%)
21414	48.94°N, 178.27°E, 5420 m	11 Aug 2006	One	96.0
21415	50.17°N, 171.84°E, 4709 m	28 Jul 2006	One	92.6
21416	48.05°N, 163.49°E, 5782 m	26 Jul 2007	None	99.5
21417	43.19°N, 157.17°E, 5482 m	24 Jul 2007	Two	87.0
21418	38.71°N, 148.69°E, 5665 m	23 Jul 2007	Several Minor	77.6

ternational waters just outside the Japanese EEZ (Fig. 11). It may detect waves propagating westward from the Marianas, perhaps with reversed polarity (time order of leading peak/trough) to that seen at 52401 and 52402, but the wave trains may be attenuated by passage through the island arc. Site selection was constrained by the EEZ boundary and areas of deep water to the south and west. While surface speeds are generally acceptable, Kuroshio meanders may occasionally impinge on the site.

Site **52405** (Fig. 12) provides coverage of the entire East Philippines source region and the southern portion of the Marianas arc near Yap. For the latter a reversed polarity signal to that seen by 52403 may be expected. As for 52404, the water depth at 52405 is close to the instrument limit of 6,000 m. The site is on the northern edge of a zone of high current speed extremes.

6.2 The Northwest Pacific

Five sites form the Northwest Pacific Group and were the subject of the initial Site Recommendation Report reproduced in Appendix G. The objective of this group is to extend westward the coverage of the Aleutian Trench sources provided by the legacy sites 46401 (now relocated to 46413), 46402, and 46403 that predated array expansion. Site details and data return details are provided in Table 3.

The group begins with **21414** near the dateline, south of Amchitka, and extends to 21418 east of Honshu, providing earlier and superior detection for sources in the western Aleutians, and the Kamchatka and Kuril trenches. DART® 21414 is located on the 15-min envelope (see Fig. 13) in order to provide adequate (3 hour) warning to Hawaii of events associated with the Aleutian Trench. Its scope is much wider and produced useful information, though at delayed times, of the Kuril Island events of 2006 and 2007. These wave trains traversed the Emperor Seamount Chain, which appears as a series of scattering features along 170°E in Fig. 13. Local bathymetry is quite benign but high NLOM current speeds, not far to the east, are possibly associated with eddies shed by the Alaskan Stream and might have caused data loss had 21414 been deployed at the time.

Moving westward, site **21415** is located south of Attu within the U.S. EEZ. The location, as seen in Fig. 14, provides a clear view of sources near

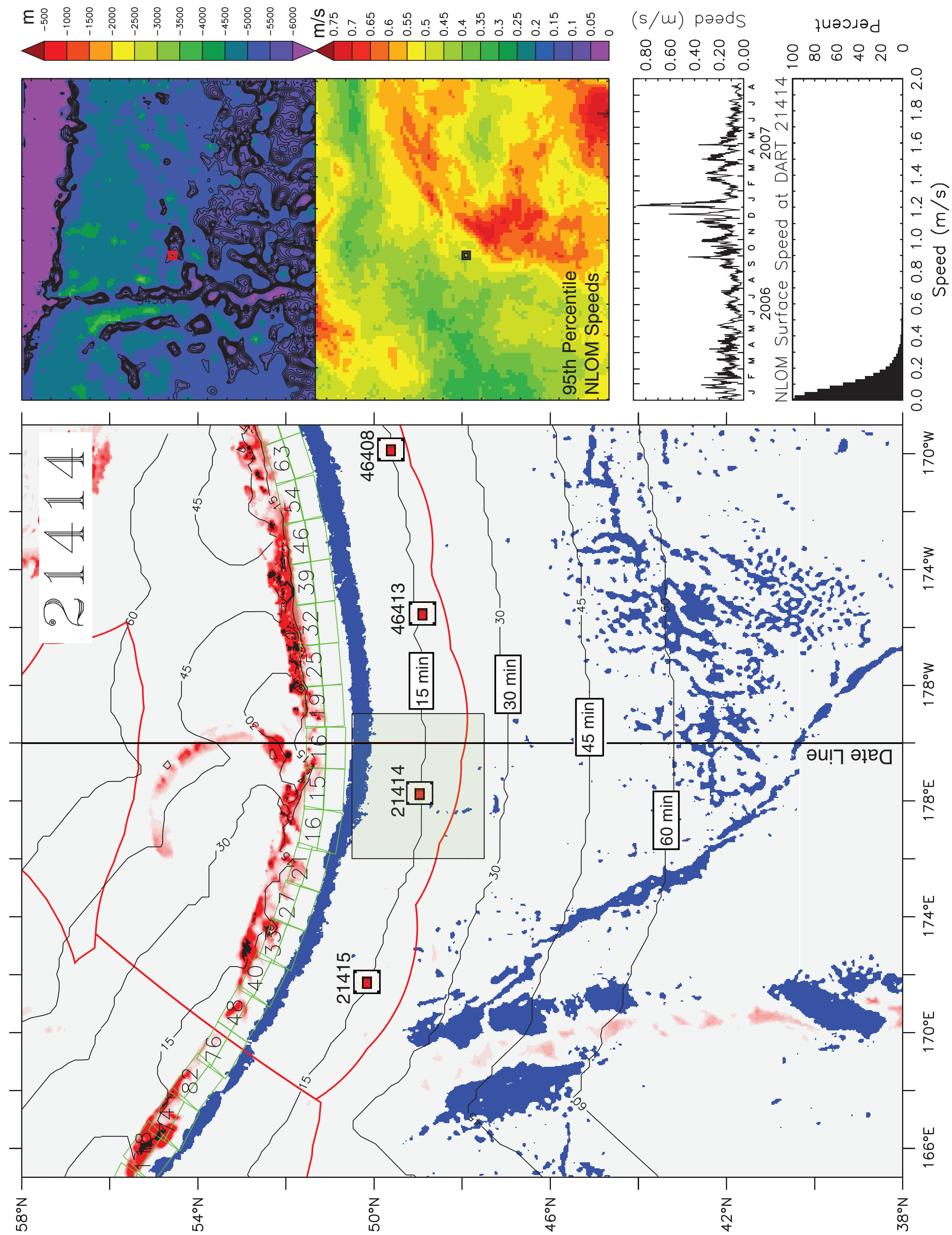

Figure 13: Siting environment for DART® **21414** in the Northwest Pacific.

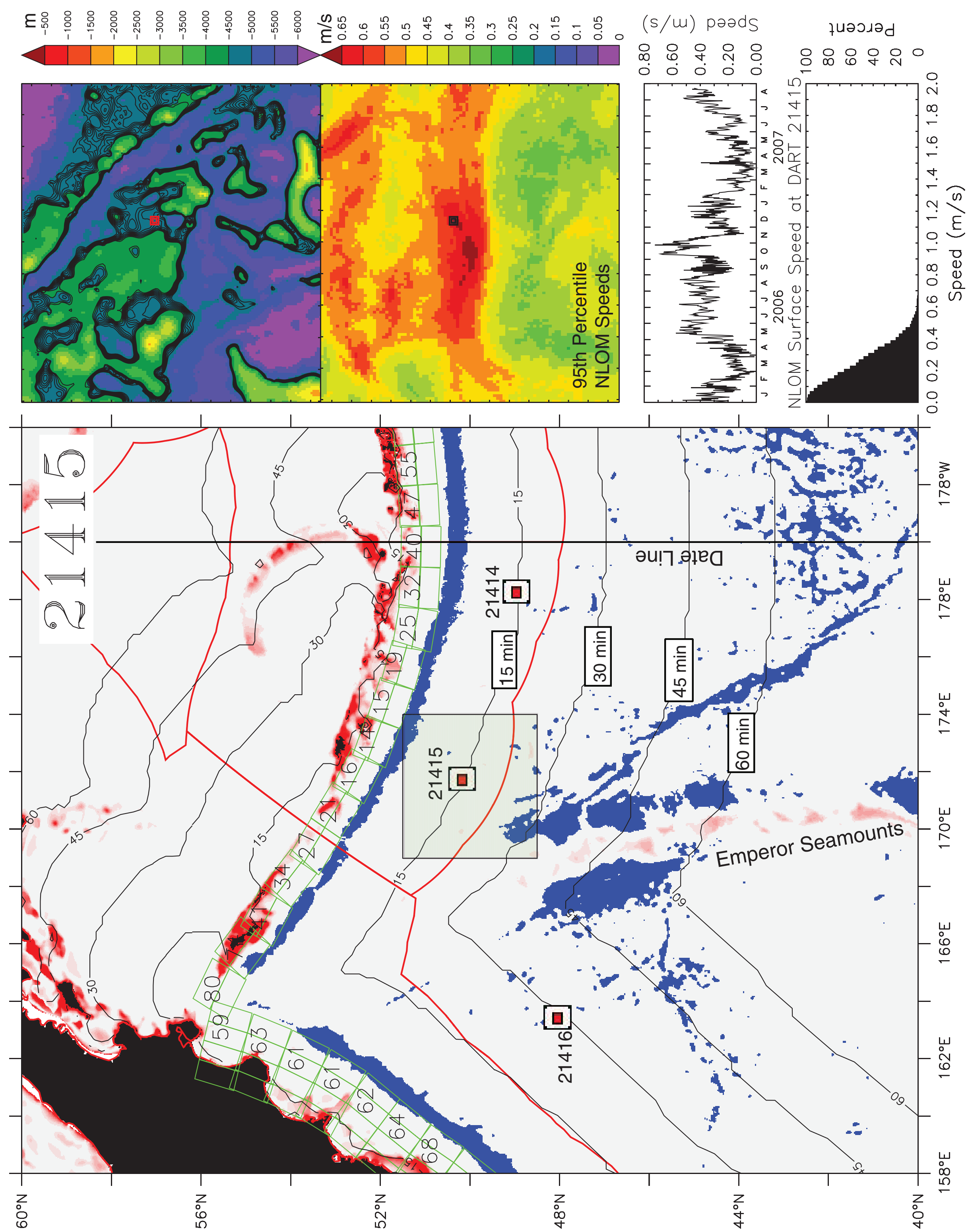

Figure 14: Siting environment for DART® **21415** in the Northwest Pacific.

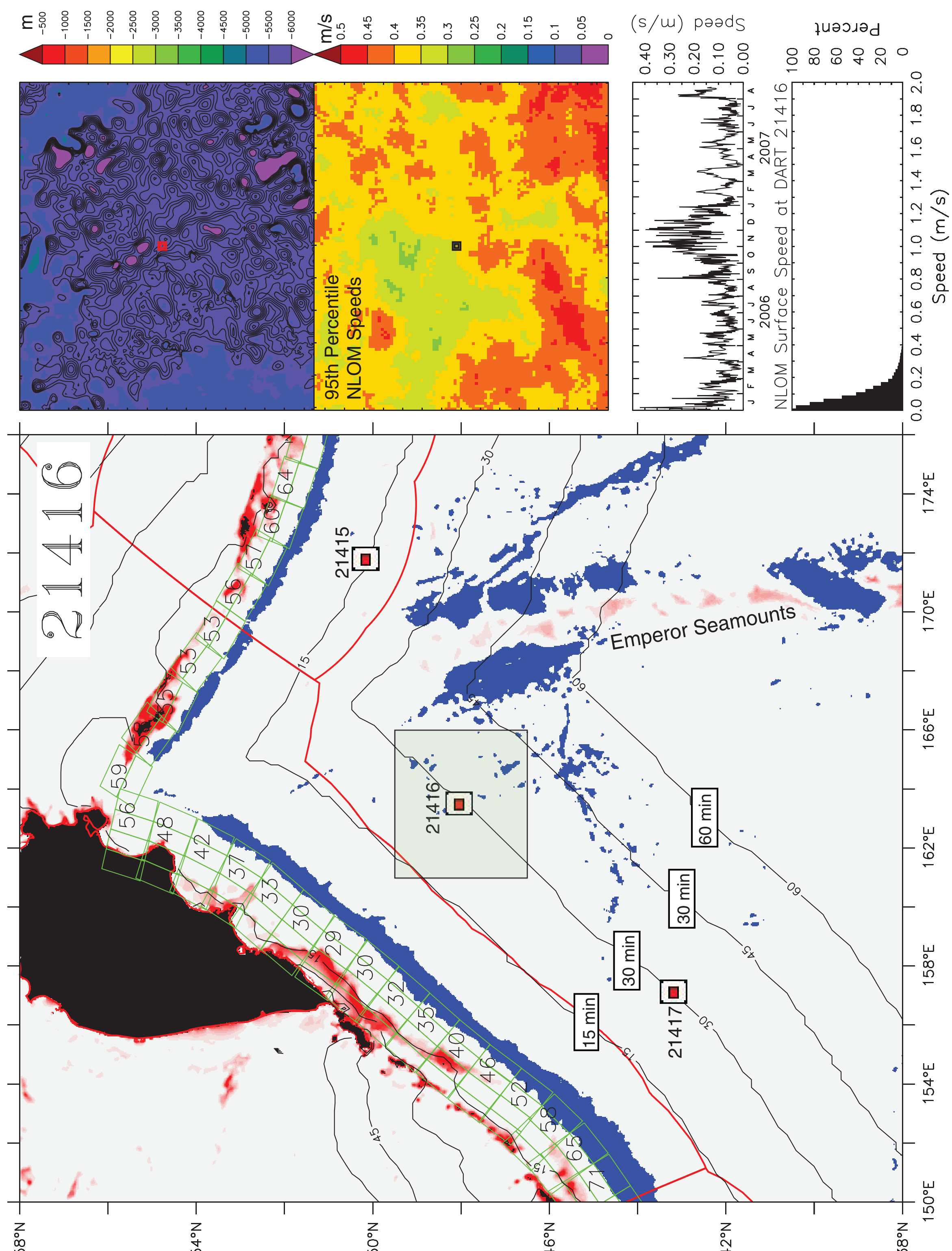

Figure 15: Siting environment for DART® **21416** in the Northwest Pacific.

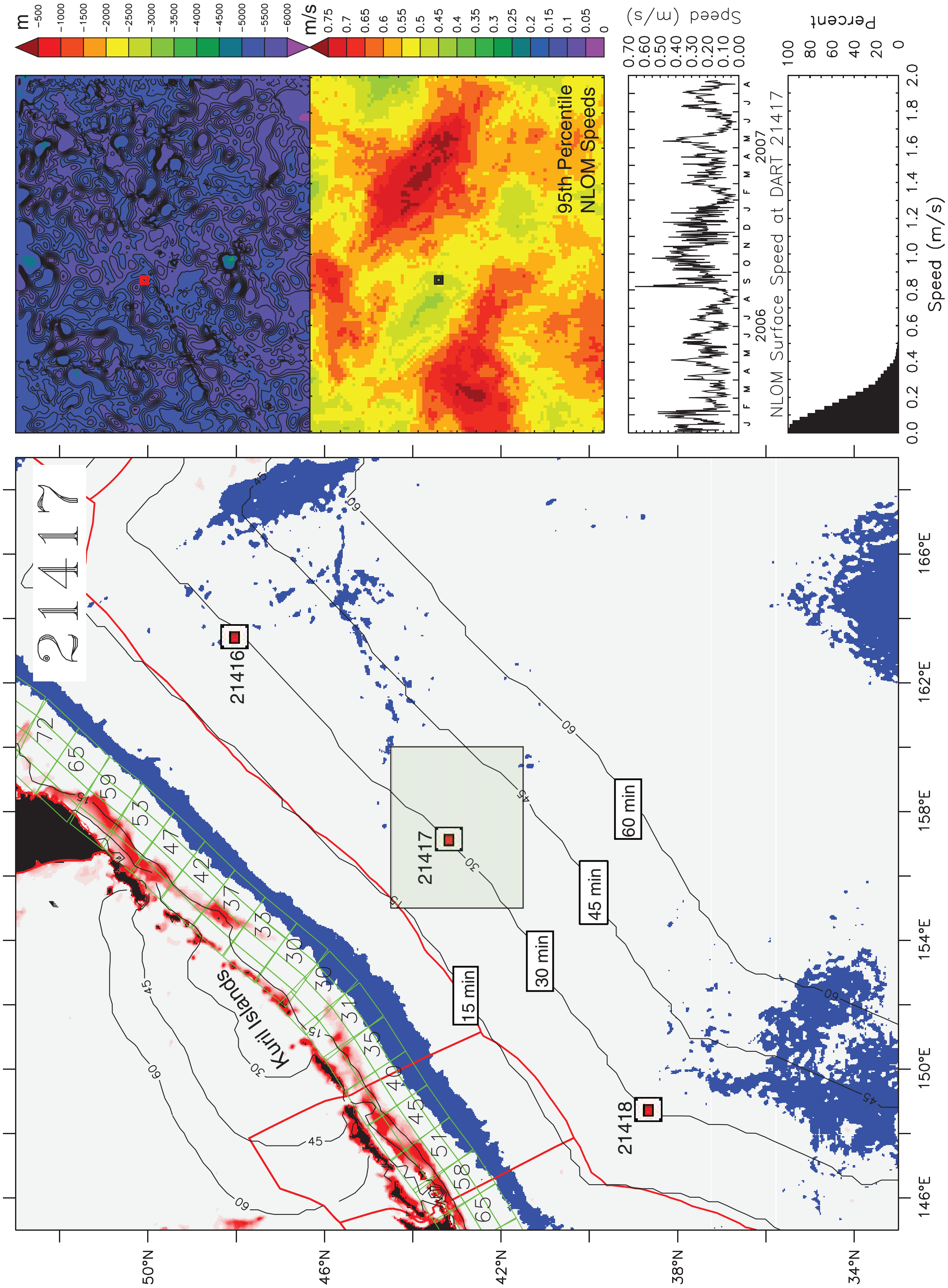

Figure 16: Siting environment for DART® **21417** in the Northwest Pacific.

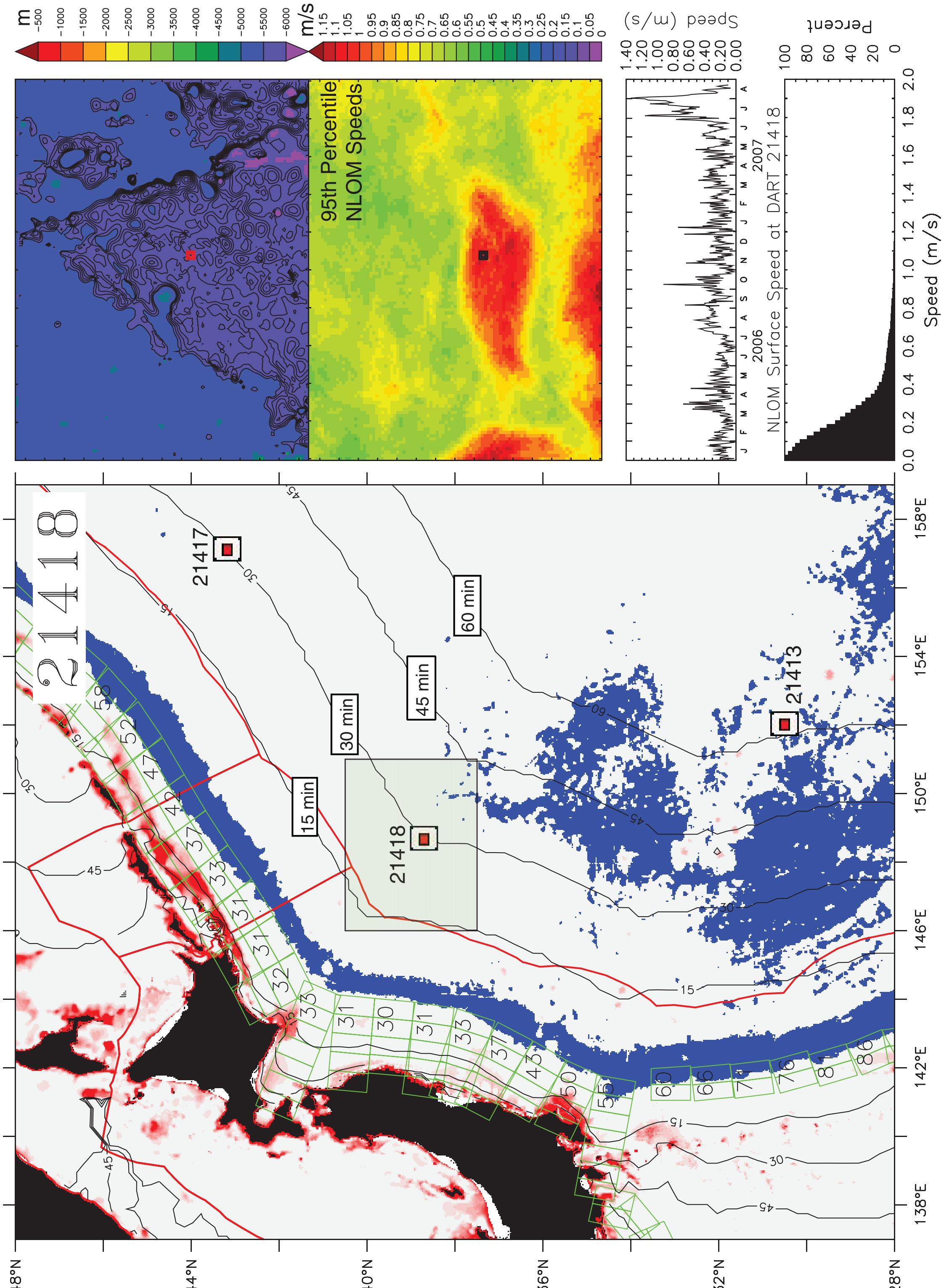

Figure 17: Siting environment for DART® **21418** in the Northwest Pacific.

the junction of the Aleutian and Kamchatka trenches, and those further south, with a reduced influence of the Emperor Seamount Chain compared to 21414. Surface current speeds are higher than desirable, perhaps accounting for the increased intermittency in the data return (90%). To the extent to which this issue persists, and NLOM adequately represents the speed regime, a move to the southwest of its current location may be indicated.

To the southwest lies the next site, **21416**, of the Northwest Pacific group. The terrain in the region (see Fig. 15) and the greater travel times to U.S. interests permit considerable flexibility in siting. The chosen site is on the 30-min envelope, outside the Russian EEZ, and provides coverage of sources from the Western Aleutians to Hokkaido. In an area of weak surface currents, data return has been good (99.49%) in the 15 months of deployment analyzed, compensating for the early loss of 21417 off the active Kuril Island region to the south.

Site **21417** lies directly offshore from the epicenters of the November 2006 and January 2007 Kuril Island events (Fig. 16). As for 21416, the terrain made this an easy site to select. Fortuitously, the site lies in a local minimum of the NLOM speed field. Whether the structure is persistent or an artifact of the 600-day 2006–2007 sample of hindcasts available is not known. The circumstances of the early loss of 21417: the dragging of the surface unit eastward, out of range of acoustic communication with the seafloor unit, following 5 weeks of 100% data return, suggests contact with a vessel. The instrument was redeployed in May 2008 and the data return exceeded 99% from then until another loss occurred. Later in this report, data on shipping lanes and fishing activity are considered as a possible explanation of these losses. Such data will be incorporated in future siting studies.

The southernmost element of the Northwest Pacific group of DART®s is **21418**. The site, seen in Fig. 17, was chosen based on terrain, EEZ, and tsunami travel time considerations, but without due regard for the ambient current regime. Based on the NLOM statistics it would appear that the mooring is exposed to the northern edge of the Kuroshio, perhaps explaining the severe intermittency of the data return in the present deployment, which has reduced the data return rate to 77.6%. During the first deployment (July 2007–May 2008), the return rate of 84.7% was lower than that at any other site, though exceeding the 80% standard. Should the intermittency persist, and an association with speed distribution can be confirmed, a move to a site to the northeast along the 30-min envelope may be indicated.

6.3 The Aleutians and Alaska

Six sites comprise the Aleutian/Alaska Group and were the subject of the Site Recommendation Report reproduced in Appendix E. The sites, ordered from the west near Adak to the Gulf of Alaska southeast of Anchorage, and their data return details, are provided in Table 4. The region has a long history of the use of BPR technology to detect tsunamis (Eble and González, 1991). In particular, 46413 represents a re-siting of a previous instrument (46401) from a location 46.64°N, 170.79°W further offshore to the southeast;

Table 4: Location and performance of the Aleutian and Alaska DART® Group (to 30 October 2008).

WMO Identifier	Location	Data Begins	Major Disruptions	Data Return (%)
46413	48.87°N, 175.59°W, 5568 m	10 Aug 2006	Two	95.7
46408	49.63°N, 169.86°W, 5387 m	14 Aug 2006	None	98.0
46402	51.06°N, 164.00°W, 4712 m	1 Jan 2003	Two	98.7
46403	52.64°N, 156.93°W, 4508 m	1 Jan 2003	Three	97.5
46409	55.30°N, 148.50°W, 4184 m	29 Sep 2005	None	98.4
46410	57.50°N, 143.99°W, 3740 m	28 Jul 2006	One	89.6

46402 is a slightly adjusted continuation of the site previously occupied since 2003 near 50.44°N, 165.03°W. Taken together with sites 21415 and 21414 of the Northwest Pacific group, a picket line with nominal zonal spacing of 6°, close to the 15-min envelope results that should provide adequate warning to the Hawaiian Islands for Aleutian and Alaskan events.

Site **46413** is the westernmost of the Aleutian/Alaska group and is described by Fig. 18. There are no scattering centers of note between 46413 and the source line inshore of the Aleutian Trench. The bathymetry and current speed regime (based on NLOM) are also benign and result in little intermittency in the data stream. The site registered the Kuril Island tsunami events of November 2006 and January 2007 which, before the Northwest group were fully deployed, provided input to a useful assessment of these mild events, and an unplanned test for SIFT system components under development.

Further to the east along the 15-min minimum travel time envelope is site **46408**, whose characteristics are displayed in Fig. 19. As was the case for 46413, scattering features are confined to the island chain of the Aleutians, and the Bering Sea basin and shelf to their north, and should not affect tsunami signal reception. In the vicinity of 46408 the currents are weak, though there is evidence of the Alaskan Stream to the north. With a 97.91% data return rate since its establishment in August 2006, 46408 appears to be a reliable element for the detection of tsunami signals in the North Pacific.

Proceeding eastward, the next site of the Aleutian/Alaska group is **46402**. As noted earlier, though slightly moved from its original location, this site has a long history of tsunami monitoring in the region. Its current location appears to be well removed from the Alaskan Stream, though there is an episode in the time series and a noticeable tail to the speed distribution (lower right panel in Fig. 20) that suggests that the site may not be immune to eddies shed by the Stream. Note however that, as yet, no direct link has been established between high-speed episodes in the NLOM record and intermittency in the DART® data stream.

The next site in the group is **46403**, offshore from the Shumagin Islands as portrayed in Fig. 21. Although there are no scattering features of concern, for the sources between Unimak and Kodiak that are detected early by 46403, the beginnings of such features are evident near 150°W. These may influence

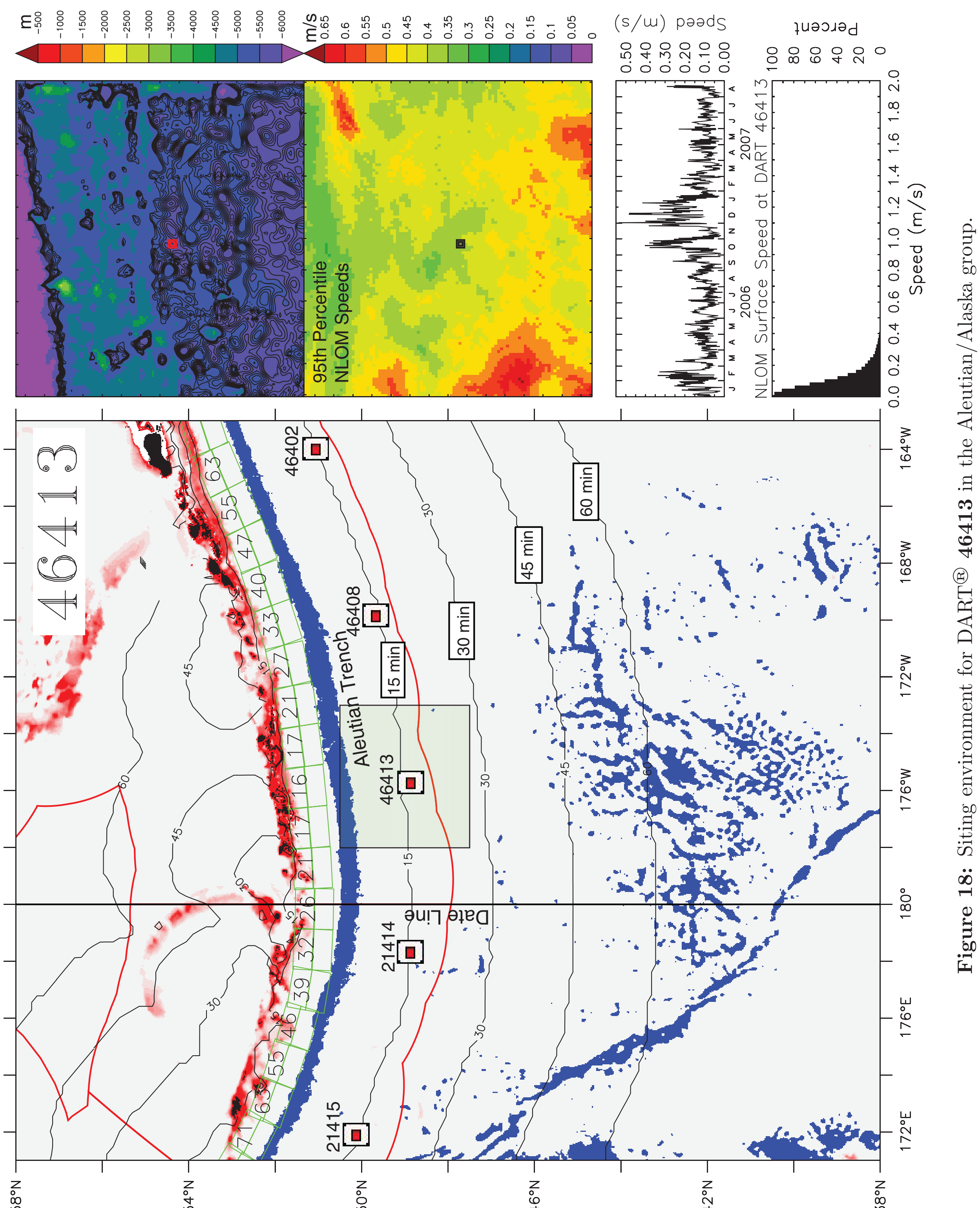

Figure 18: Siting environment for DART® **46413** in the Aleutian/Alaska group.

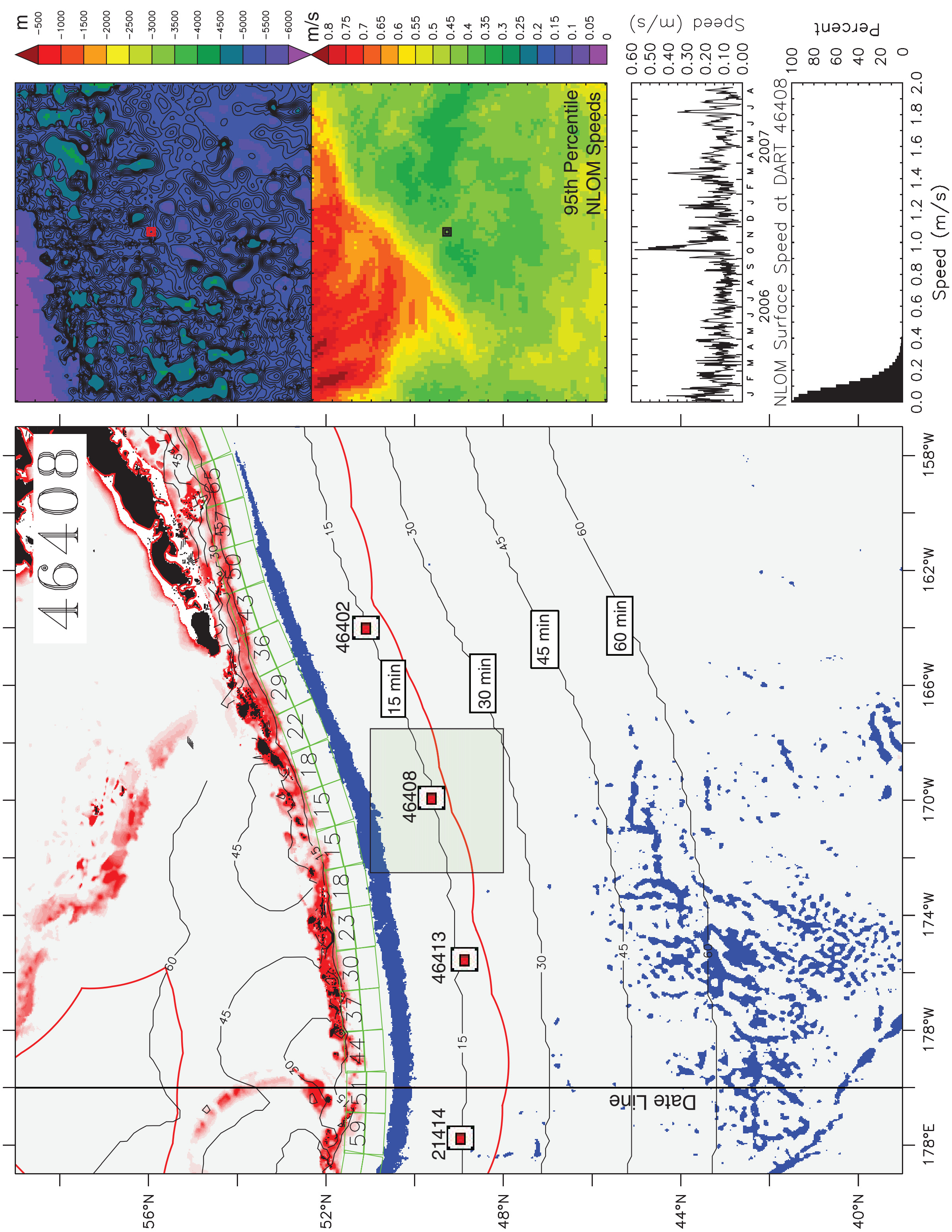

Figure 19: Siting environment for DART® **46408** in the Aleutian/Alaska group.

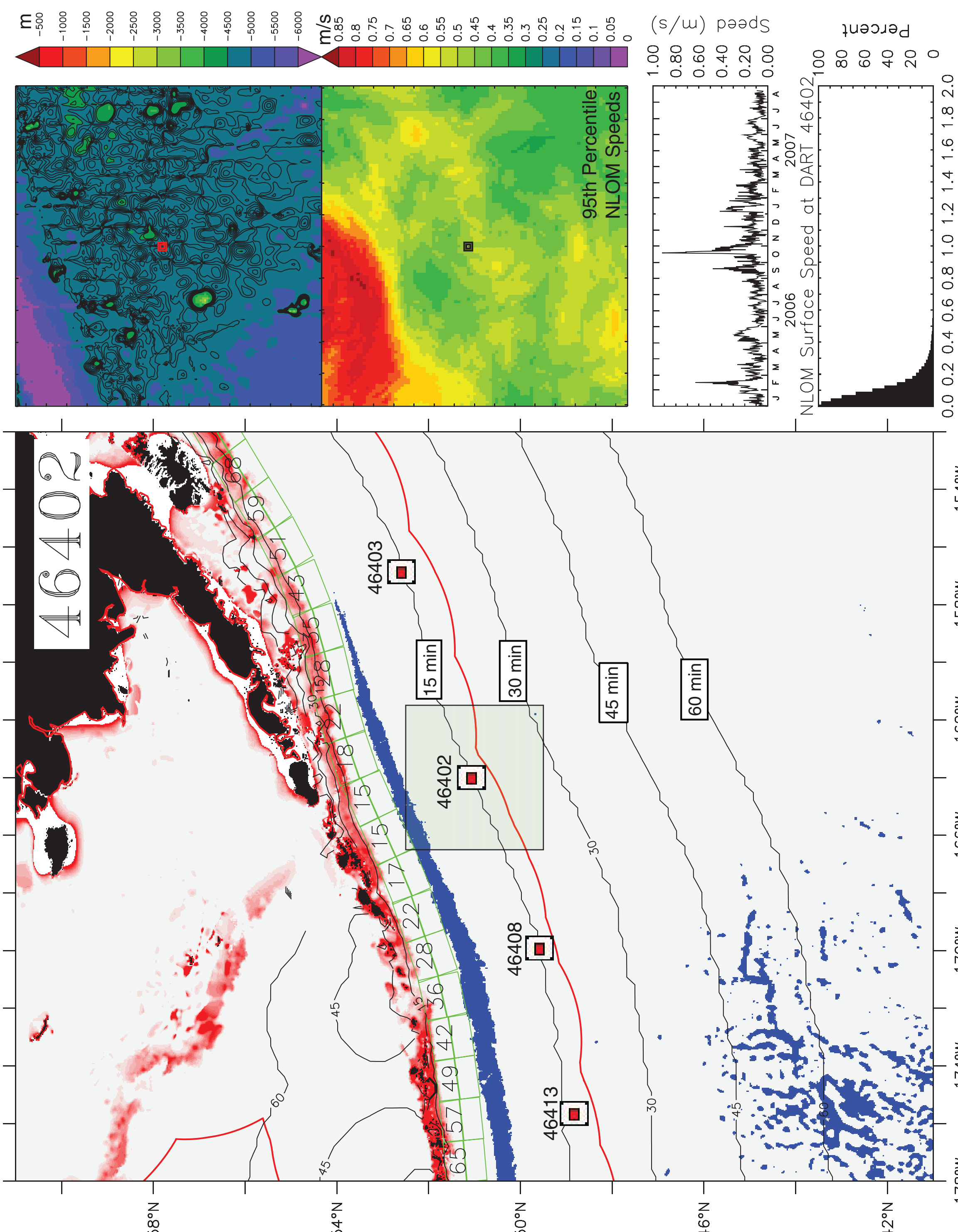

Figure 20: Siting environment for DART® **46402** in the Aleutian/Alaska group.

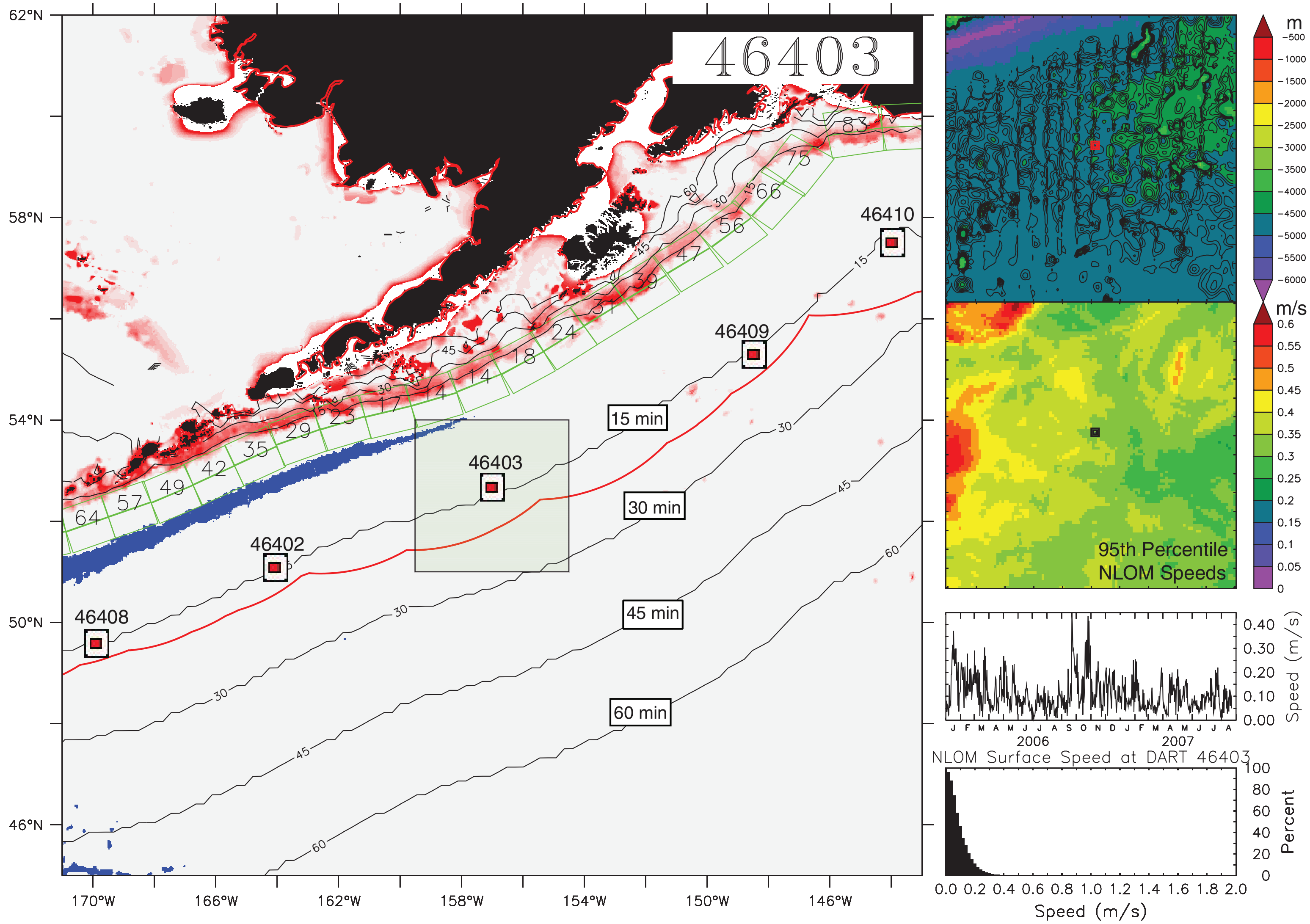

Figure 21: Siting environment for DART® **46403** in the Aleutian/Alaska group.

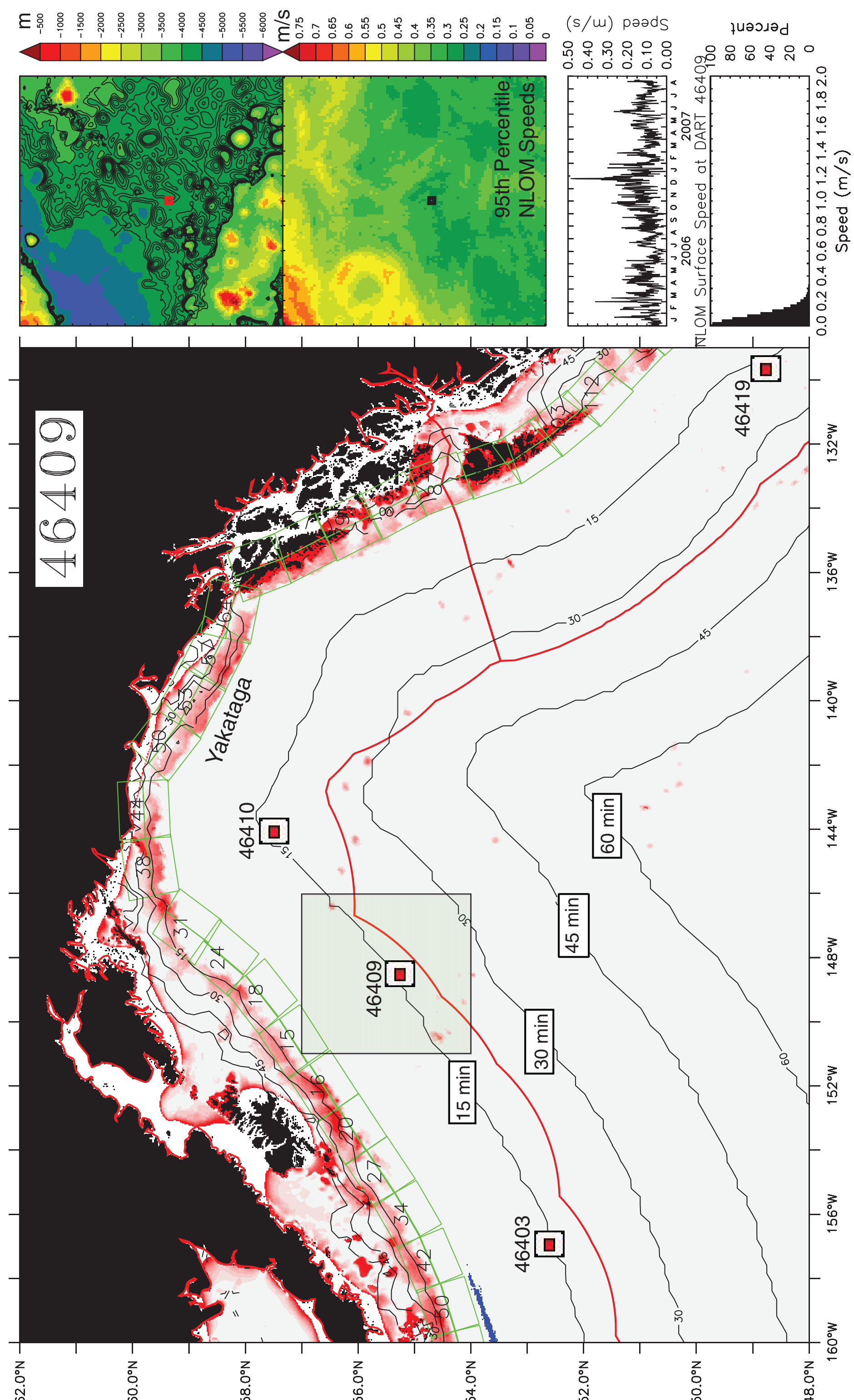

Figure 22: Siting environment for DART® **46409** in the Aleutian/Alaska group.

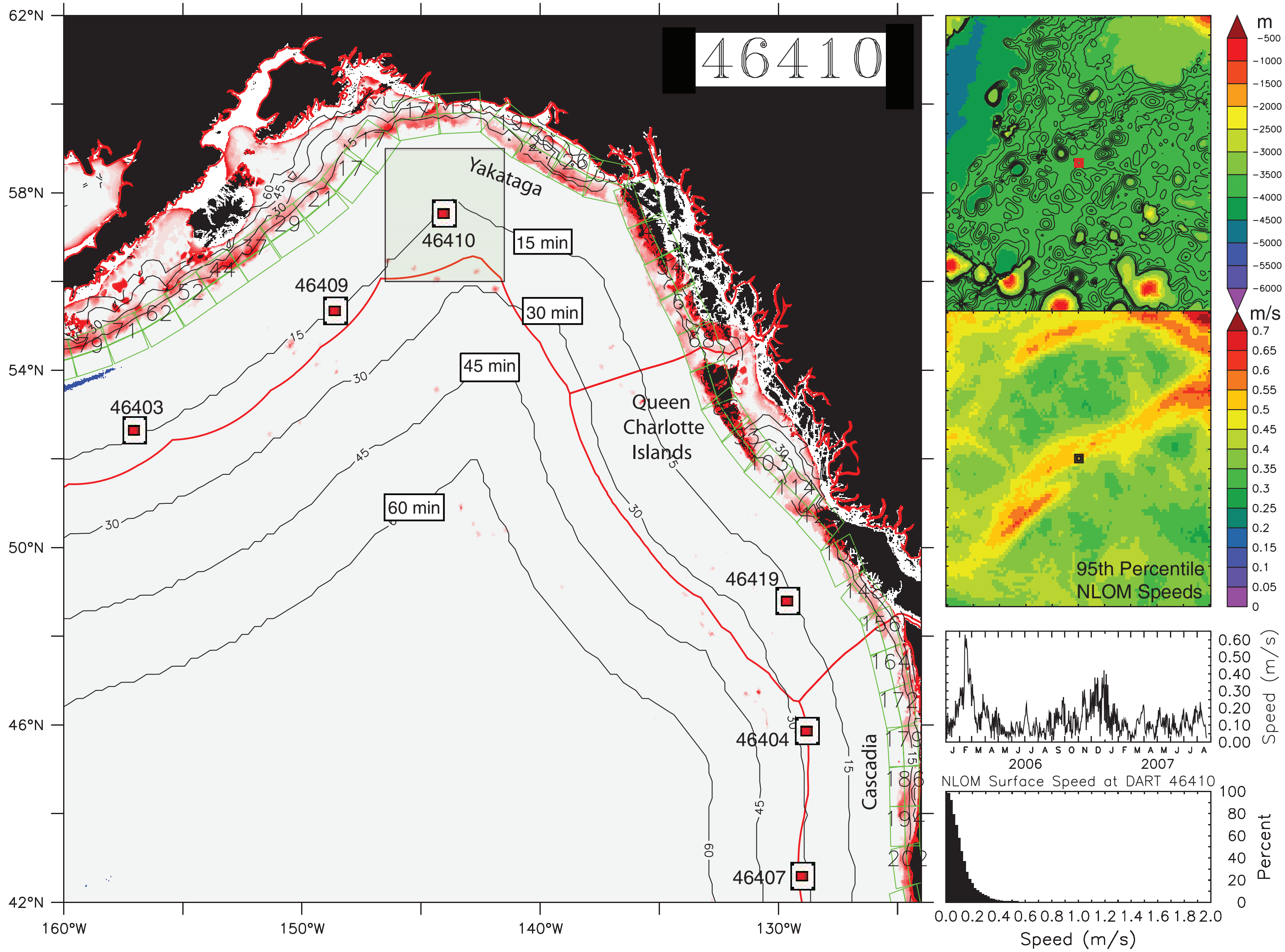

Figure 23: Siting environment for DART® **46410** in the Aleutian/Alaska group.

the reception of signals originating further east for which the Gulf of Alaska sites, 46409 and 46410, are the primary detectors. Surface current speed would appear to be of little concern at 46403, with no values exceeding 0.45 m/s in the 600-day record of NLOM hindcasts studied.

Site **46409** lies the northern Gulf of Alaska, south of the Kenai Peninsula. Only the B and A rows of unit sources are displayed in Fig. 22, but the propagation database includes source rows further inshore. Though not identified as subducting plate boundaries in the Bird (2003) database, the Yakataga Zone and the plate boundary that extends southward past the Queen Charlotte Islands are a potential source of tsunami waves and have been incorporated into the propagation database. Surface speeds near 46409, based on NLOM, would not appear to be of concern but the presence of numerous scattering features were a major constraint in site selection. The chosen site lies midway between two major groups of such features.

Site **46410** has the distinction of being the most northerly site in the U.S. array. Given the distance to site 46419, the closest of the West Coast group, it might have been preferable to place 46410 somewhat to the south near the 30-min envelope. However, the multiple scattering features in that direction might increase the complexity of the tsunami signals, whereas the selected site should provide clean detection of the source regions that have historically posed a greater threat. The surface speed pattern exhibits a lobe of higher values in the vicinity of the chosen site and another further north. The frequency of such events, beyond the 2006–2007 NLOM period analyzed, is not known and, while the intermittency of the data return (91.9%) from 46410 is the poorest in the group, other possible causes, such as sea state, have not been ruled out.

6.4 The U.S. West Coast

Five sites (one within the Canadian EEZ) form the West Coast Group, and were the subject of the initial Site Recommendation Report reproduced in Appendix E. Site details and data return details are provided in Table 5. As was true for the Aleutian/Alaska group, the West Coast has a long history of DART® data collection predating the Indian Ocean disaster of 2004 which led to the expansion in tsunami detection capability in the Pacific and Atlantic Oceans. For the West Coast itself the threat is multi-faceted, including the severe local threat associated with Cascadia, the potential for local landslide-associated wave generation off southern California, and the exposure of the entire coast to tele-tsunamis. Cascadia, of course, poses a severe threat to the entire basin; West Coast elements of the U.S. DART® array must serve the need of forecasts to remote areas. As discussed earlier, in the event of a major event in Cascadia, ground motion, recognized by an informed public, may be the only advance warning to coastal communities in the region. High-quality DART® data, processed through the SIFT system, can provide estimates of inundation and the expected duration of significant wave activity to guide the emergency response. The reality that "warning" and "forecast" may differ in meaning from their usual interpretation in the

Table 5: Location and performance of the U.S. West Coast DART® Group (to 30 October 2008).

WMO Identifier	Location	Data Begins	Major Disruptions	Data Return (%)
46419	48.74°N, 129.61°W, 2775 m	25 Jul 2006	One	89.1
46404	45.86°N, 128.78°W, 2740 m	11 Jan 2003	Three	90.8
46407	42.60°N, 128.89°W, 3266 m	10 Dec 2007	None	97.7
46411	39.33°N, 127.01°W, 4266 m	27 Sep 2005	One	95.2
46412	32.25°N, 120.70°W, 3777 m	29 Sep 2005	None	98.8

context of a locally generated tsunami is not unique to Cascadia, but can complicate siting decisions in such circumstances.

Site **46419**, plotted in Fig. 24, lies off Vancouver Island, slightly outside the 15-min envelope and within the Canadian EEZ. The main rationale for its choice is that, in combination with its three regularly spaced neighbors (46404, 46407, and 46411) to the south, it provides early detection of tsunami waves generated in the vicinity. The detection times 46419 provides are about an hour for sources near the Queen Charlotte Islands and 90 min for those at the southern end of Cascadia. Further detail on its siting, together with a more useful chart of the bathymetry, can be found in Appendix E. In hindsight, the choice from the point of view of current speeds is reasonable. There may be episodes of speeds in excess of 0.5 m/s but the median is about 0.2 m/s in the NLOM analysis. Between its deployment in July 2006 and its malfunction in January 2008, the instrument provided a data return in excess of 98%.

Among U.S. West Coast DART®s, **46419** plays another role: to provide a "second look" at waves generated and detected off Alaska, but propagating toward the Pacific Northwest. Though not computed with that in mind, the proximity of the Cascadia source line to the open coastlines of Vancouver Island and the U.S. between Neah Bay and Cape Mendocino permit another interpretation for 46419's "detection times" of Fig. 24. Detection by 46419 can provide "warning times" of at least 30–90 min for waves arriving from the north. Warning times have not been emphasized in this document since the coarse spatial resolution of the propagation database, and possible non-linear behavior close to shore, limits the ability to determine coastal arrival times without better representation of inshore bathymetry.

Sites **46404** and **46407**, portrayed in Figs. 25 and 26, respectively, provide the primary coverage for Cascadia subduction zone events. Like 46419 they have the potential to provide an assessment of impacts to the Northwest Pacific Coast for remote events, though quantifying their utility in this regard is beyond the scope of this memo. In particular 46407 is well placed to detect waves directed toward Crescent City, California, whose harbor, perhaps due to resonance and the action of the Mendocino escarpment in directing energy toward it, is often impacted by remote events. Site 46407, as described in Appendix E, is a relocation of the long-term site 46405 that lay beyond the 60-min envelope; both 46404 and 46407 now lie close to the

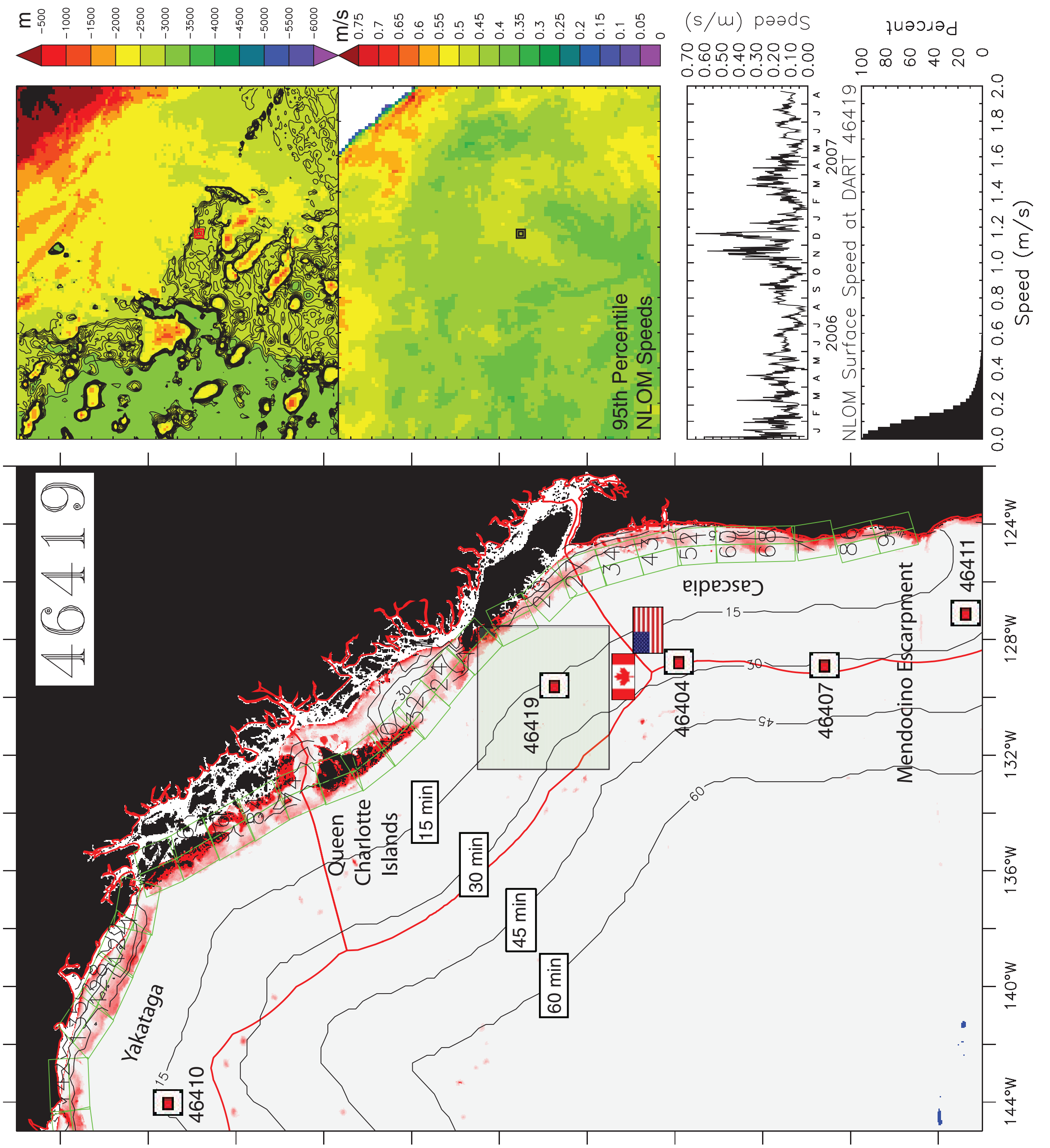

Figure 24: Siting environment for DART® **46419** in the U.S. West Coast group.

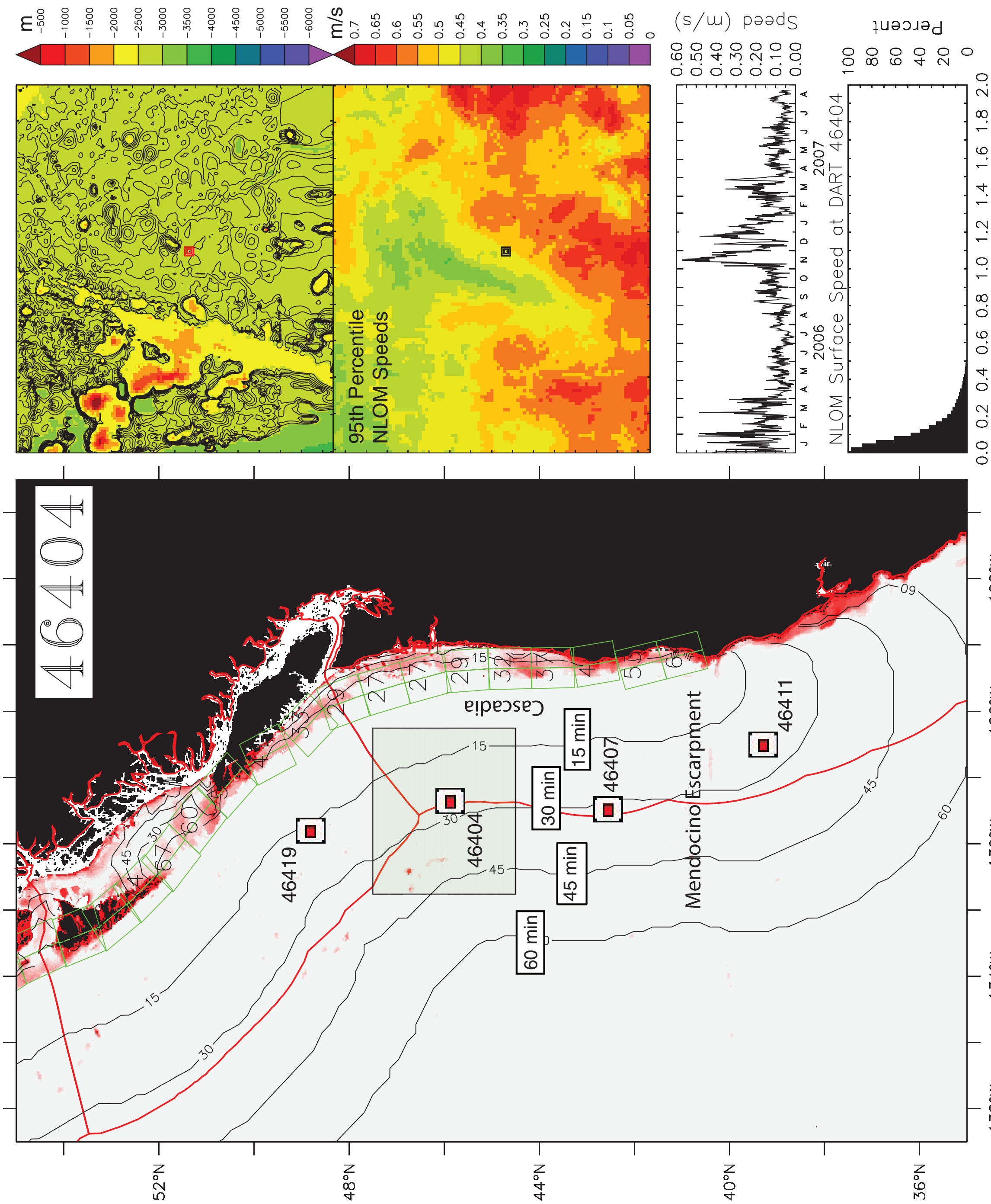

Figure 25: Siting environment for DART® **46404** in the U.S. West Coast group.

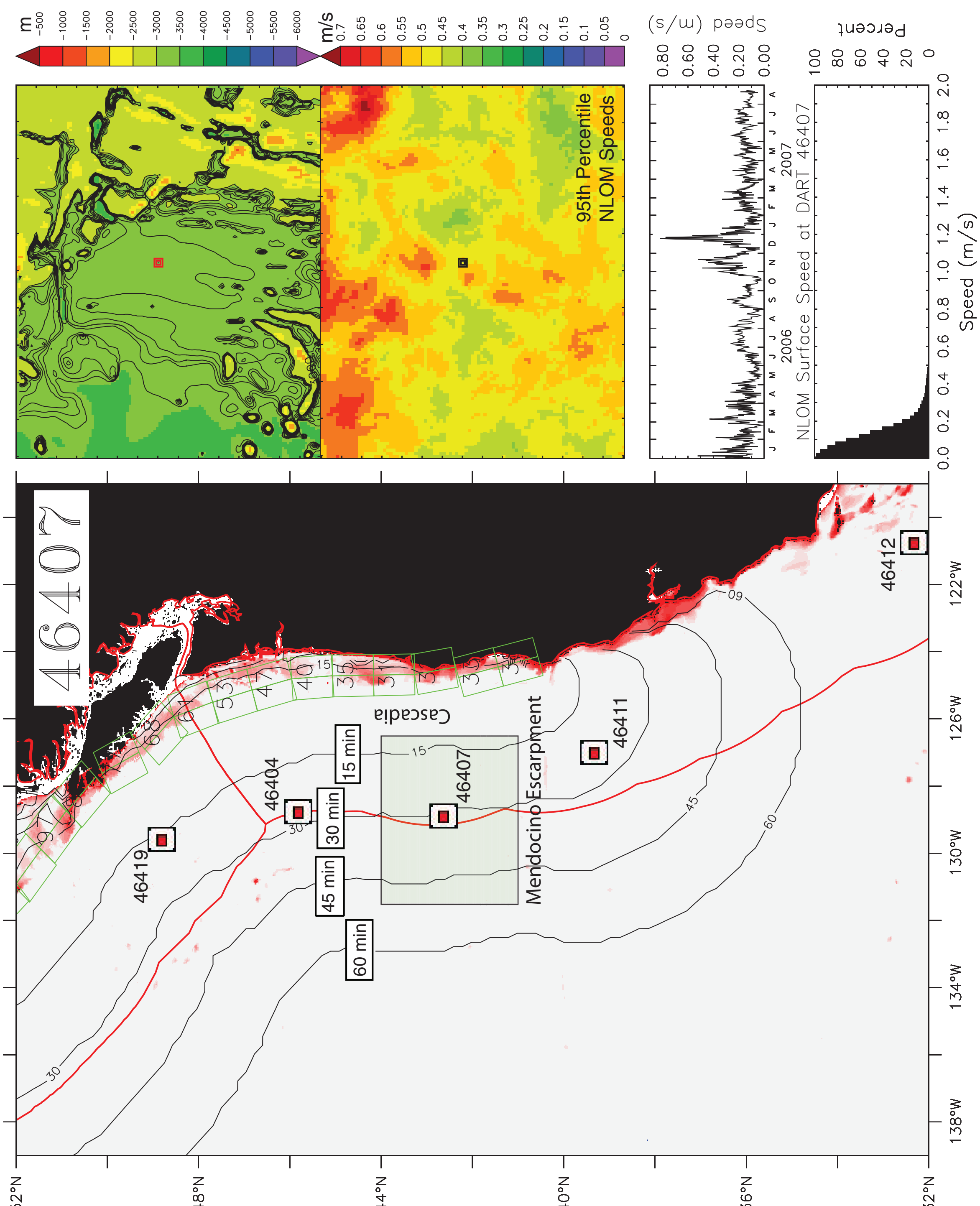

Figure 26: Siting environment for DART® **46407** in the U.S. West Coast group.

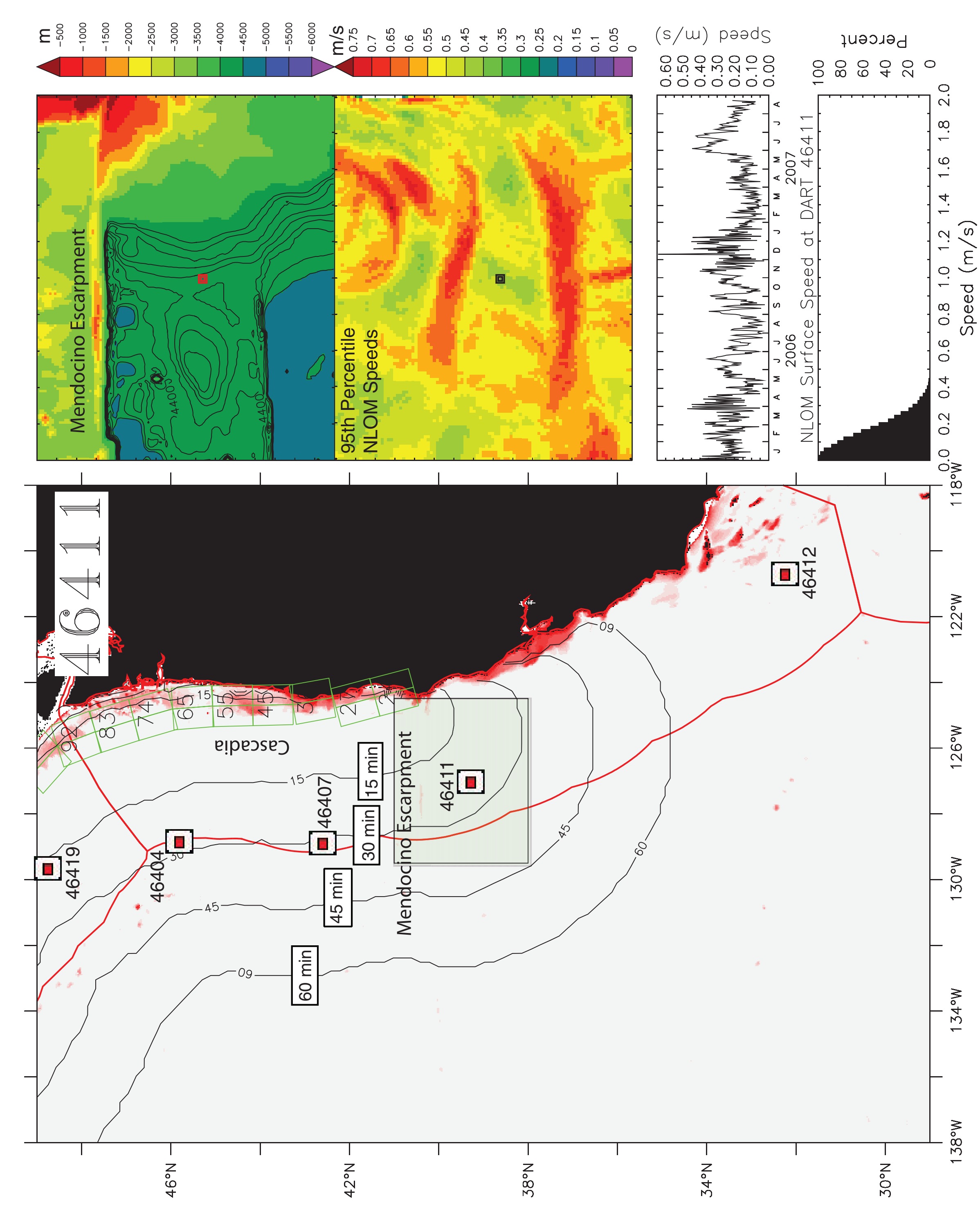

Figure 27: Siting environment for DART® **46411** in the U.S. West Coast group.

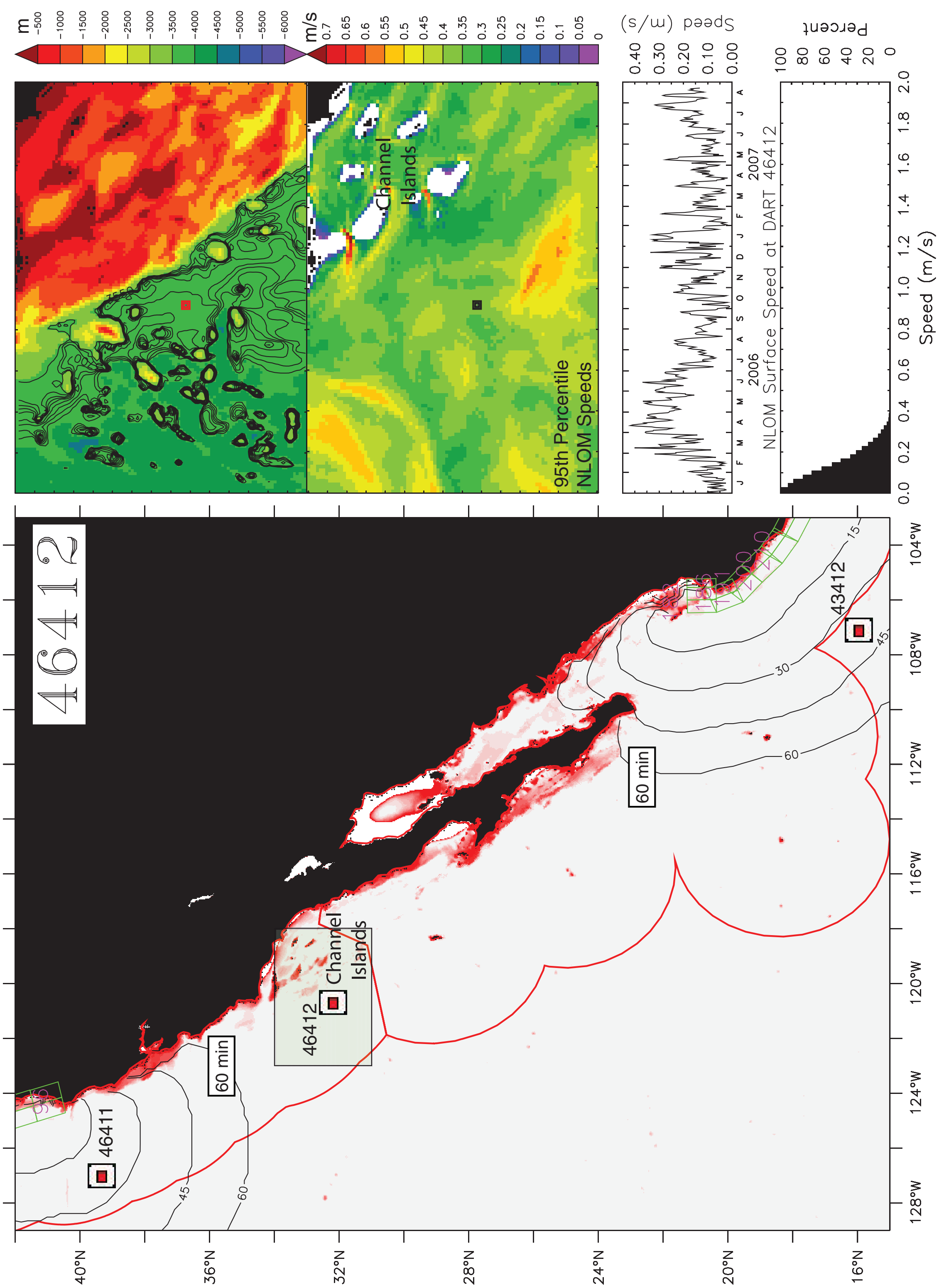

Figure 28: Siting environment for DART® **46412** in the U.S. West Coast group.

Table 6: Location and performance of the Central/South American DART® Group (to 30 October 2008).

WMO Identifier	Location	Data Begins	Major Disruptions	Data Return (%)
43412	16.03°N, 107.00°W, 3239 m	21 Mar 2007	None	87.3
43413	10.84°N, 100.08°W, 3468 m	24 Mar 2007	None	97.5
32411	4.92°N, 90.69°W, 3247 m	27 Mar 2007	None	98.2
32412	17.97°S, 86.39°W, 4326 m	2 Nov 2007	None	99.9
32401 (Chile)	19.58°S, 74.81°W, 4881 m	23 Mar 2005	None	98.2

30-min envelope. There are some minor scattering centers to the northwest of 46404 but, while rugged, the bathymetry is quite amenable to DART® operations as is the current regime as portrayed in NLOM hindcasts.

Proceeding southward, DART® **46411** lies offshore between Cape Mendocino and Point Arena. Prominent in the bathymetry panel of Fig. 27 is the Mendocino Escarpment. The surface current speed distribution represented by NLOM has features oriented east-west that are aligned with strong topographic gradients, but the site of 46411 lies in a local minimum with few spikes in speed exceeding 0.4 m/s in the time period examined.

Completing the U.S. West Coast group is DART® **46412**, west-southwest of San Diego, California. While there is not a direct threat to this region from seismically generated tsunamis (the earthquake mechanisms being more strike-slip than normal or reverse-thrust in nature and, in consequence, involving less vertical motion of the sea floor), there is the risk that the frequent earthquakes may trigger a submarine landslide. The site chosen for 46412, as shown in Fig. 28, reflects that hazard, being located at the closest point to the Channel Islands at which the water depth is adequate. With a detection time in excess of 3 hours, 46412 is the first DART®, other than 43412 and 43413 off Central America, to detect waves generated south of Baja California that may impact the U.S. mainland. The paths for such waves are likely to be quite oblique to the main beam and would likely only be detectable for larger source magnitudes (above $M_w = 7.8$ using the methods discussed in the Section 7.2).

6.5 Central and South America

Four U.S. sites form the Central and South American Group and were the subject of the initial Site Recommendation Reports reproduced in Appendix F. Site details and data return details are provided in Table 6. Note that details of the Chilean tsunameter (32401) have been added to Table 6, and the discussion that follows, for completeness.

Sites **43412** and **43413** have primary detection responsibilities for sources associated with the Central American Trench, of which they have a clear view, unobstructed by significant scattering features. As seen in Fig. 29, the northern element of the pair is placed close to the 30-min envelope to intercept waves en route to the U.S. West Coast as well as providing some warning and relevant information to local emergency managers of the popular beach resorts from Cabo San Lucas to Acapulco. While episodes of higher current speed are not uncommon, the median is less than 0.2 m/s. Site 43413 (Fig. 30) is somewhat further offshore in order to monitor sources from southern Mexico to Costa Rico. It lies midway between 43412 and the site of the northernmost of the South American DART®s, 43413. While to the south of some strong current features, the extended tail of the NLOM speed histogram suggests that currents may on occasion be an issue.

The South American subduction zone, offshore from Columbia and Peru, is oriented so as to pose a greater threat to U.S. interests than sources off Central America. The presence of multiple scattering features, including the Galapagos, Cocos Ridge, some small island groups, and their associated EEZs, make the choice of a location for **32411** difficult. The selected site, fortunately, is near a minimum of the 5% exceedance current speed distribution, but the possibility of short bursts of excessive speeds is greater than at most recommended sites. As seen in Fig. 31, there is a strip of international water between the Galapagos and mainland Colombia that is closer to the South American sources, but the recommended 32411 location in a notch of the EEZ boundary will, it is hoped, provide superior wide coverage. There is the possibility that a DART® might be deployed by Ecuador, most likely within their EEZ limits because of the local threat. This would be a valuable addition to the overall array, which is rather sparse off South America.

Continuing southward, that sparseness is evident in Fig. 32, which shows the site chosen for the U.S. DART® **32412**. Initially a site further to the north was considered but reports of a greater likelihood of vandalism, south of the Galapagos, were provided by NDBC. The selected site is well offshore (at about the 80-min envelope) in order to capture events from a wider range of sources, including those further south than the long-standing Chilean tsunameter 32401. Numerous scattering features, and the lengthy travel times, may diminish the utility of 32412 to detect sources far to its south. The current speed environment near 32412 is quite benign, with a median less than 0.2 m/s and few daily NLOM hindcasts exceeding 0.35 m/s. The poor coverage of southern Chilean sources, in the absence of tsunameters south of 32401, has been recognized as a deficiency in the array. After much discussion, it is planned to move the instrument currently named 51406 to a site south of the Juan Fernandez Islands as indicated in Fig. 32

Though the siting of the Chilean tsunameter predated and was not part of the array expansion effort, Fig. 33 summarizes its characteristics in the same format employed for the others. The Peruvian earthquake of August 2007, in addition to causing casualties and damage inland, generated a minor tsunami, which was detected by 32401. This provided an unscheduled test for SIFT components under development (Wei *et al.*, 2008a). The near shore location of the source demonstrated the need to add extra rows to the propagation database; this has since been done.

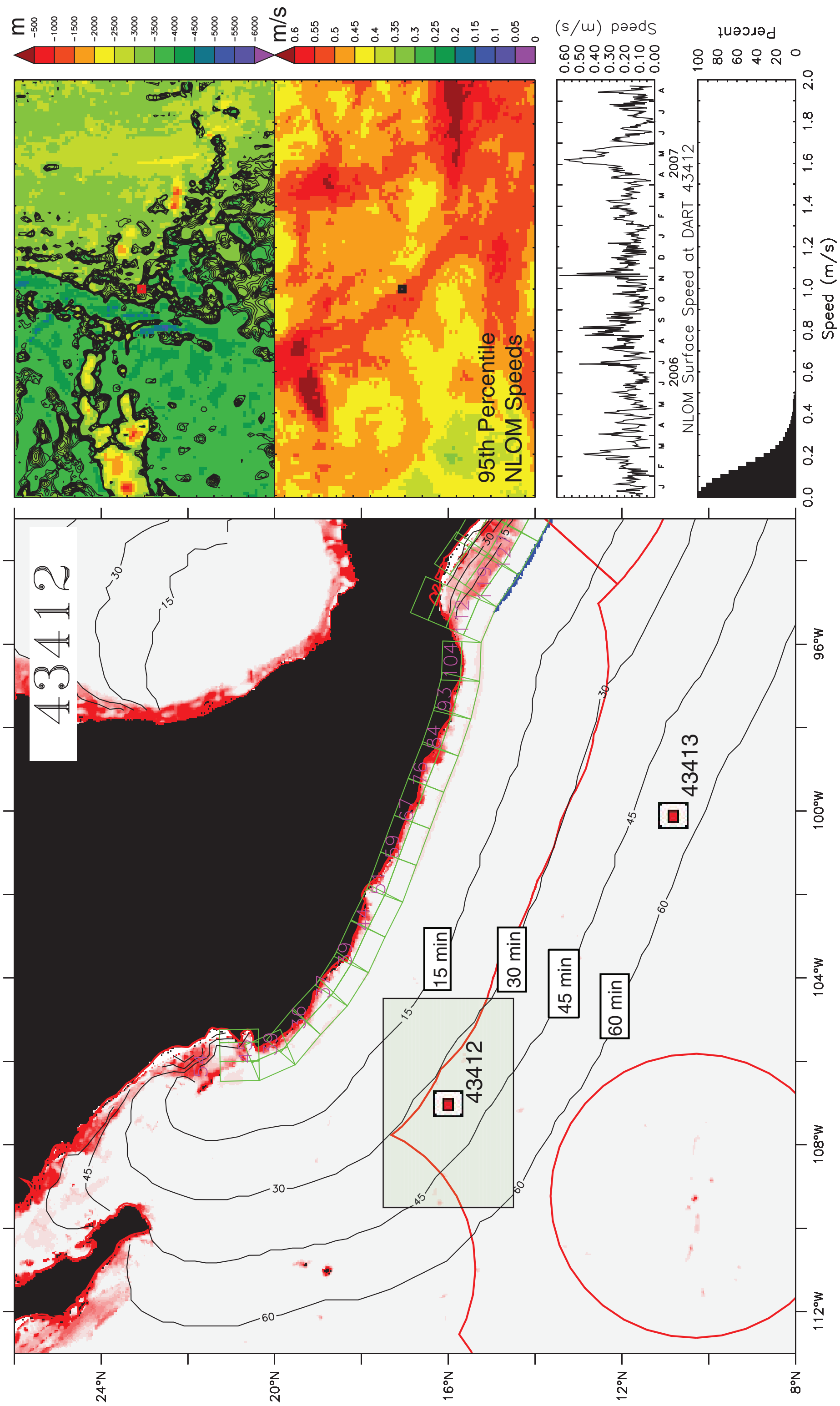

Figure 29: Siting environment for DART® **43412** in the Central and South American group.

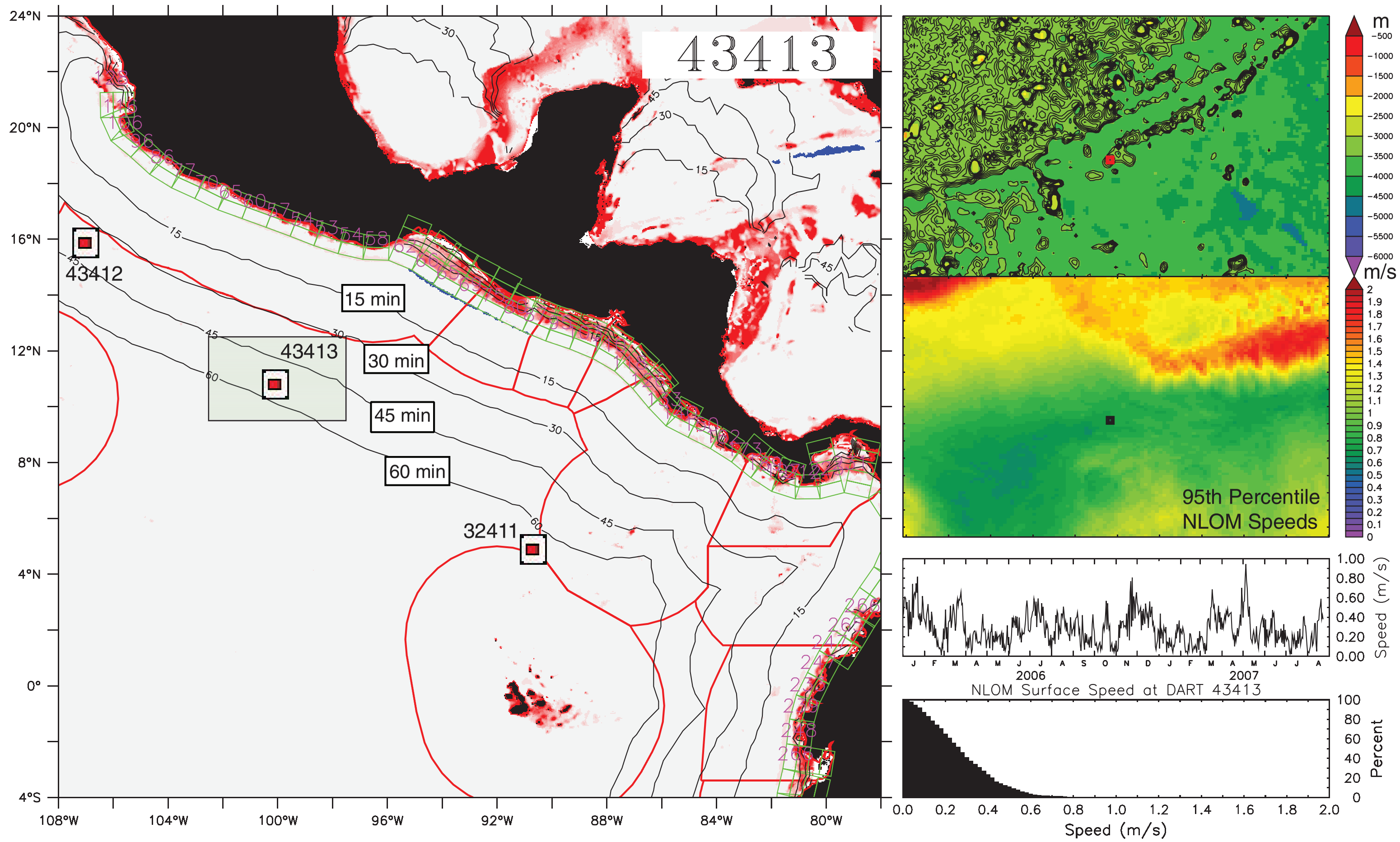

Figure 30: Siting environment for DART® **43413** in the Central and South American group.

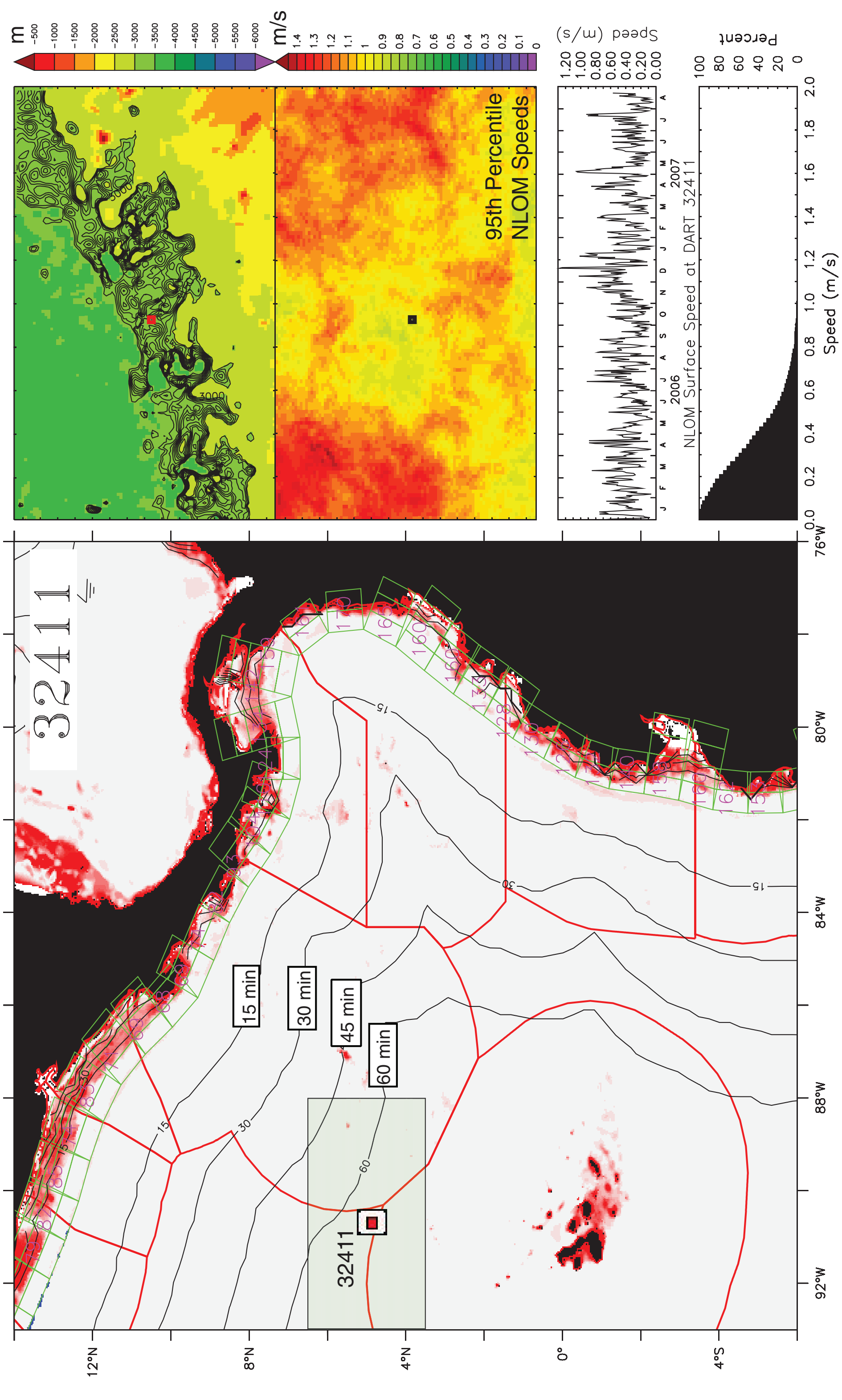

Figure 31: Siting environment for DART® **32411** in the Central and South American group.

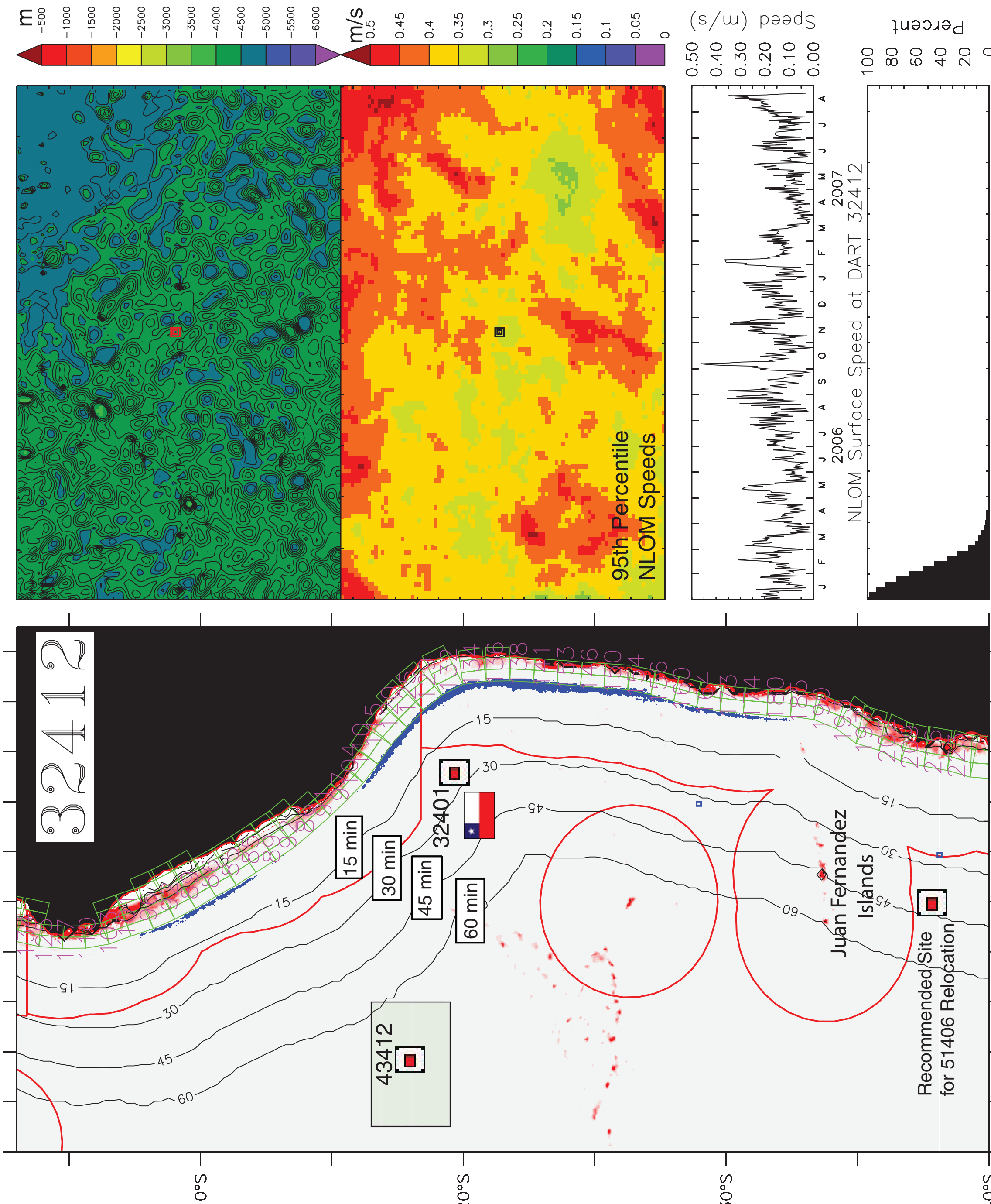

Figure 32: Siting environment for DART® **32412** in the Central and South American group.

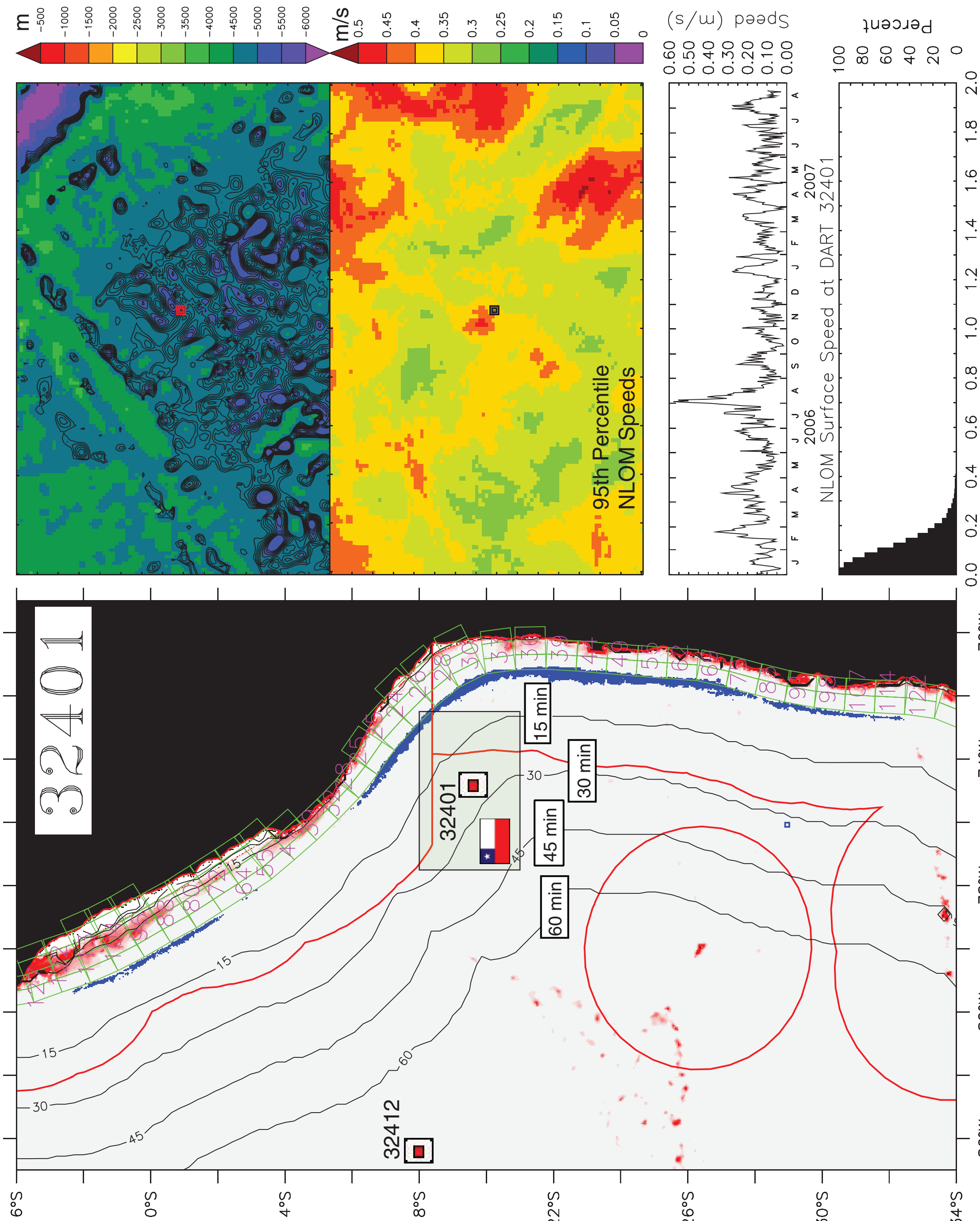

Figure 33: Siting environment for the Chilean Tsunameter **32401**.

Table 7: Location and performance of the Southwest Pacific DART® Group (to 30 October 2008).

WMO Identifier	Location	Data Begins	Major Disruptions	Data Return (%)
52406	5.34°S, 165.08°E, 1849 m	4 Mar 2008	One	97.4
51425	9.50°S, 176.25°W, 4962 m	28 Feb 2008	None	98.7
51426	23.01°S, 168.11°W, 5675 m	11 Feb 2008	One	96.5
54401	33.00°S, 172.99°W, 5837 m	17 Feb 2008	None	96.2
55012 (Aust.)	15.80°S, 158.50°E, 3284 m	27 Mar 2008	None	99.1
55015 (Aust.)	46.93°S, 160.47°E, 4944 m	16 Apr 2007	Two	96.5

6.6 The Southwest Pacific

Four U.S. sites form the Southwestern Pacific Group and were the subject of the initial Site Recommendation Reports reproduced in Appendices H and I. Site details and data return details are provided in Table 7. Note that details of two Australian DART®s (55012 in the Coral Sea and 55015 in the Tasman Sea) are included in Table 8 and the discussion that follows. The latter sites were selected by the Australian Bureau of Meteorology to provide warning to their East and South coasts, but extend the capability and source coverage of the Pacific array.

This portion of the array extends the coverage provided by the Western Pacific group, discussed in subsection 6.1, for source segments in the vicinity of New Guinea and extending eastward via the Solomon Islands to Vanuatu, then from Tonga via the Kermadec Islands to New Zealand. One Australian tsunameter, 55012 in the Coral Sea, supplements the coverage provided by the four U.S. DART®s. Another Australian instrument, 55015 in the Tasman Sea, has primary responsibility to monitor sources near the Puysegur Trench, which extends southward from New Zealand's southern island and poses a significant hazard for Australia's southeastern seaboard in addition to the local threat. Occasional earthquakes occur along the plate boundary south of Puysegur which 55015 is better placed to detect than is 54401, the southernmost of the U.S. Southwest Pacific group. Some graphics are provided for these Australian sites since, together with the Chilean tsunameter, their capabilities need to be considered in assessing the performance of the array as a whole.

DART® **52406**, as its WMO designation suggests (the first two digits representing the sea area), is closest (2,300 km) to 52403 of the West Pacific group. As shown in Fig. 34, the extensive EEZ ownership resulting from the numerous island groups, which act as scattering features, makes site selection quite difficult in this region. The New Guinea-Vanuatu source line is to a large extent screened from the open Pacific by the island chains, though the Solomon Islands tsunami of April 2007 was detectable, though mild, off Hawaii. The gap between San Cristobal and the Santa Cruz Islands is one of the wider openings and 52406 was sited to monitor the source line in this area (between the Solomons and Vanuatu) with detection times of about

1 hour. It could also detect tsunami waves that might propagate eastward from Manus and northern New Guinea. The topographic (upper right) panel of Fig. 34 shows that the BPR lies on the south-facing slope of a bank. This increases the signal somewhat since the low amplitude of the waves from most unit sources in the region is an issue. Normally the caveat that imperfect representation of the bathymetry in the propagation runs reduces the fidelity of the model results might preclude the site. However, the combination of weak signal, complex bathymetry, and EEZ boundaries limited the selection. In hindsight the NLOM speed statistics is another count against the site. While it would appear to avoid the strongest NLOM speed features, the frequency and strength of high-speed events, if valid, would be of concern. The data return statistics (discussed in Section 7.3 using Fig. 57b) do not show much intermittency. NLOM statistics are not available for the period of 52406's deployment to shed light on this inconsistency.

Siting of DART® **51425** was also difficult, as a result of the almost complete EEZ ownership in the target area, the numerous scattering features, and the sharp turn the source line takes between Tonga and the Samoa Islands. The selected site is in a narrow strip of international water where it monitors the east-west portion of the source line (with detection times of about 50 min), and is in the energy beam of waves originating in the Vanuatu region but directed toward Hawaii. Though the latter have detection times of about 3 hours, the warning time for Hawaii is still adequate. Another area available for siting is American Samoa, but the selected site, in combination with the two other elements of the group, provided a more comprehensive coverage. Of concern are the somewhat elevated statistics of the NLOM speeds, though, as for 52406, the data returns to date have been highly reliable.

The main section of the Tonga and Kermadec trench line, running from NNE to SSE between Samoa and the east coast of New Zealand, is monitored by two DART®s, **51426** and **54401** as shown in Figs. 36 and 37. International waters extend southward from the Niue EEZ. This island, together with the Louisville Ridge (see Fig. 37), are the most notable scattering features in the region. The Tonga Trench portion of the source line is well covered by 51426 near the 45-min envelope, though the instrument is in the lee of Niue for the most northerly sources. The site chosen for 54401 lies on the 30-min envelope with an uninterrupted view of Kermadec Trench sources. For both sites the NLOM speed statistics suggest that ambient currents should not be of concern, particularly at 54401.

As noted earlier, the Australian sites in the Coral and Tasman Sea are a valuable complement to the U.S. array. The sites were chosen by staff of the Australian BOM (Bureau of Meteorology) (Greenslade, personal communication) using methods, and a propagation database, similar to those described here. The calculations were shadowed at NCTR, providing a useful comparison of the underlying databases that were separately generated by the two programs. Because the source line between New Guinea and Vanuatu lies between the island arc and the Australian mainland, the Coral Sea DART® **55012** is better positioned than is 52406 to directly detect most unit sources in the line. The exception to this is the southern portion

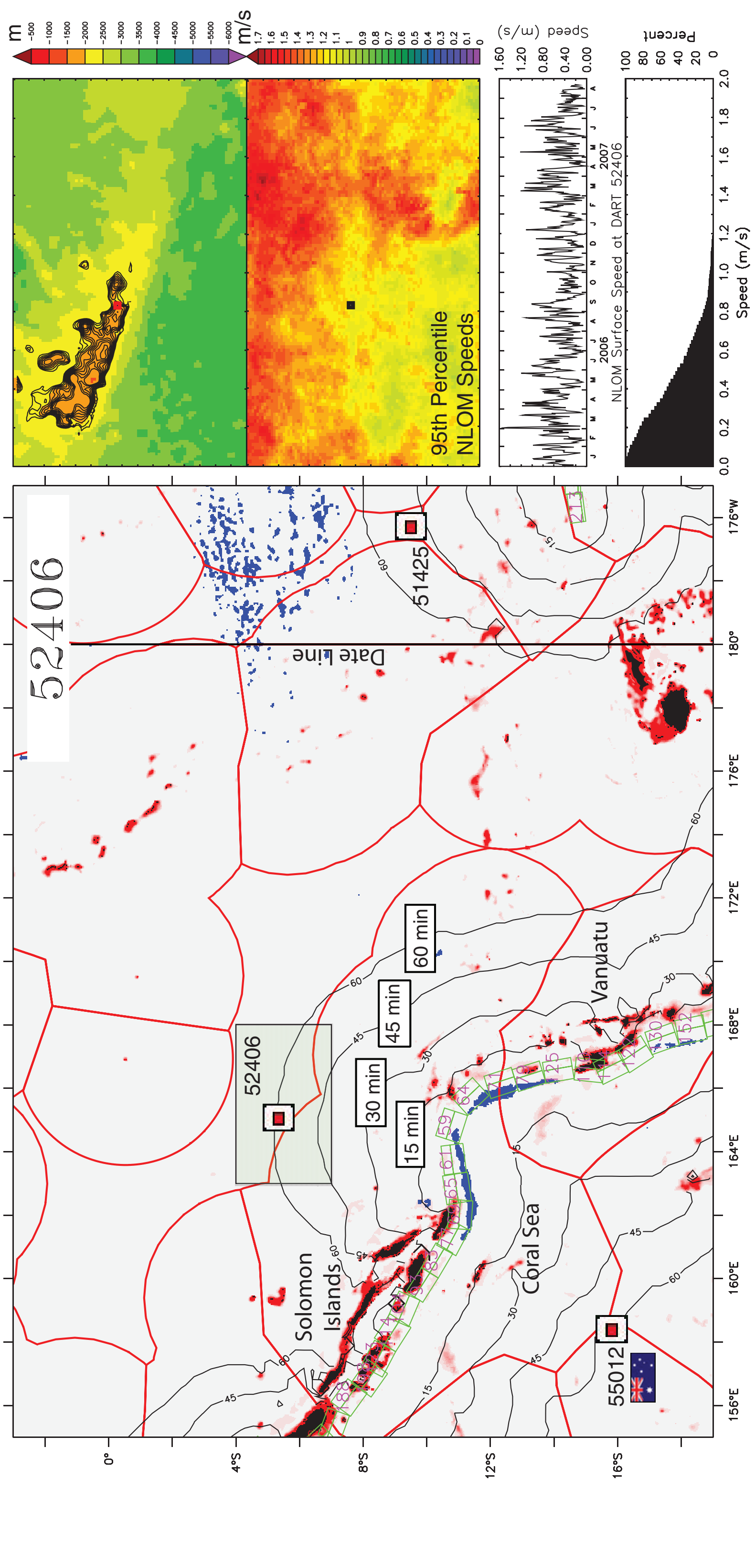

Figure 34: Siting environment for DART® **52406** in the Southwest Pacific group.

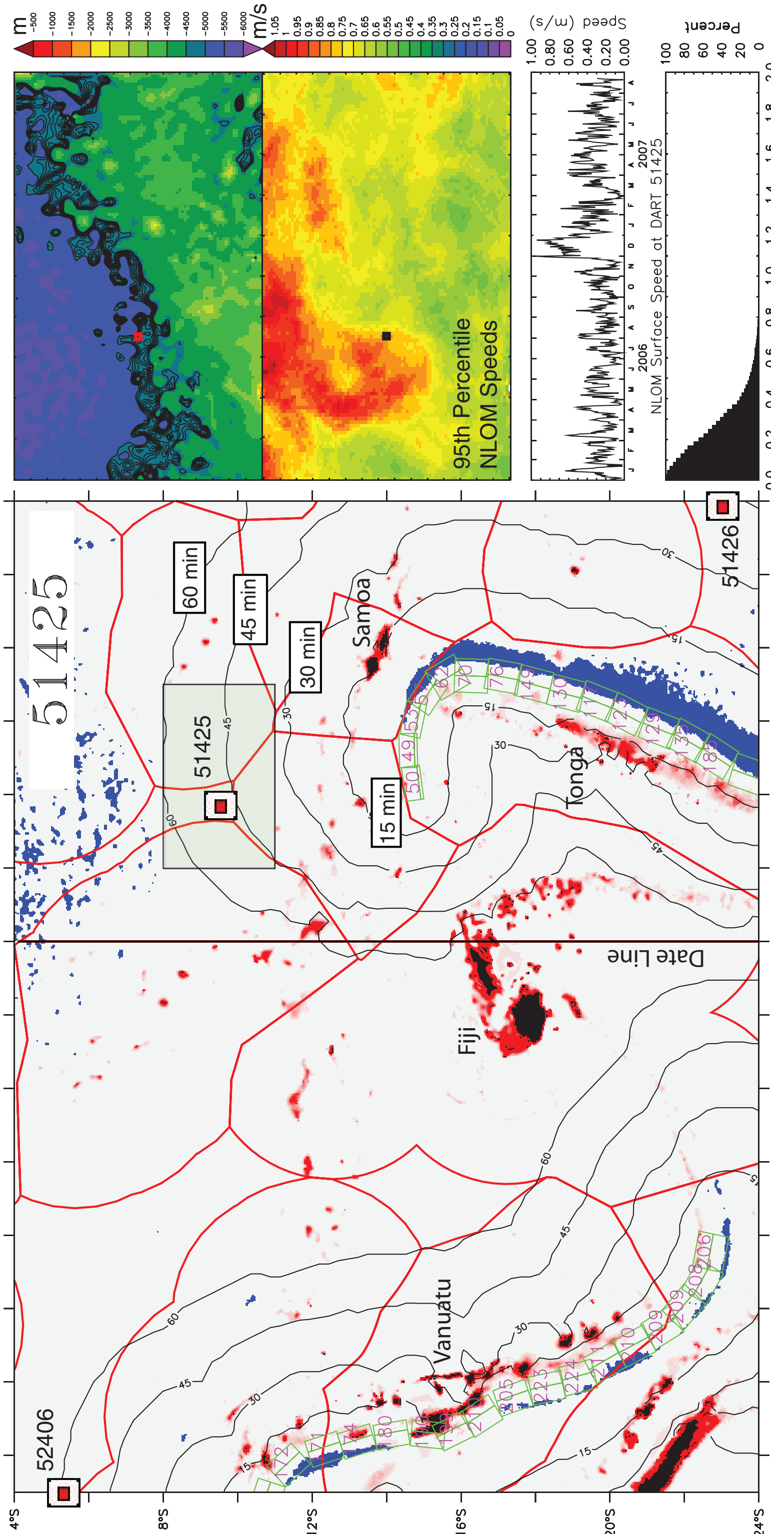

Figure 35: Siting environment for DART® **51425** in the Southwest Pacific group.

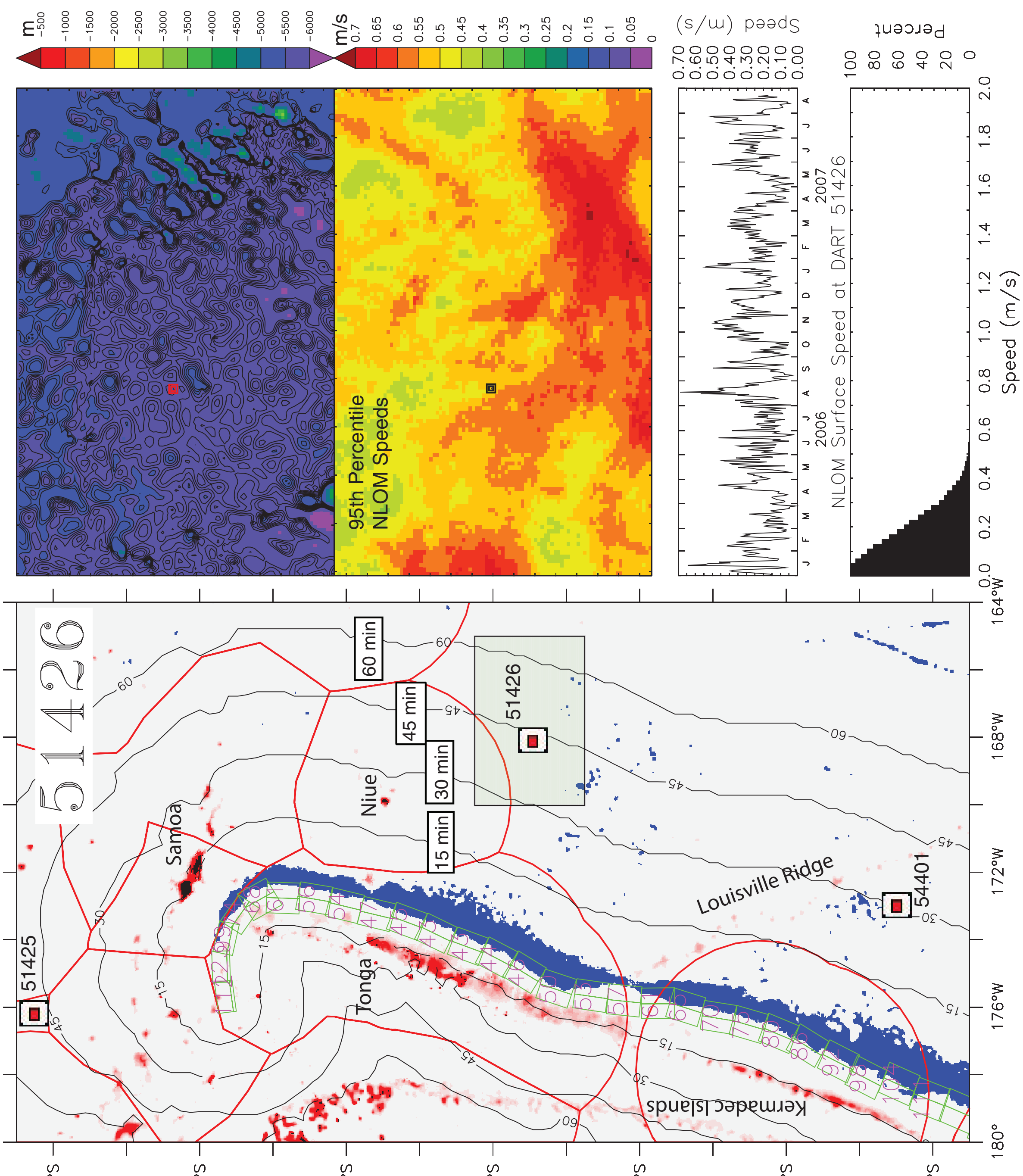

Figure 36: Siting environment for DART® **51426** in the Southwest Pacific group.

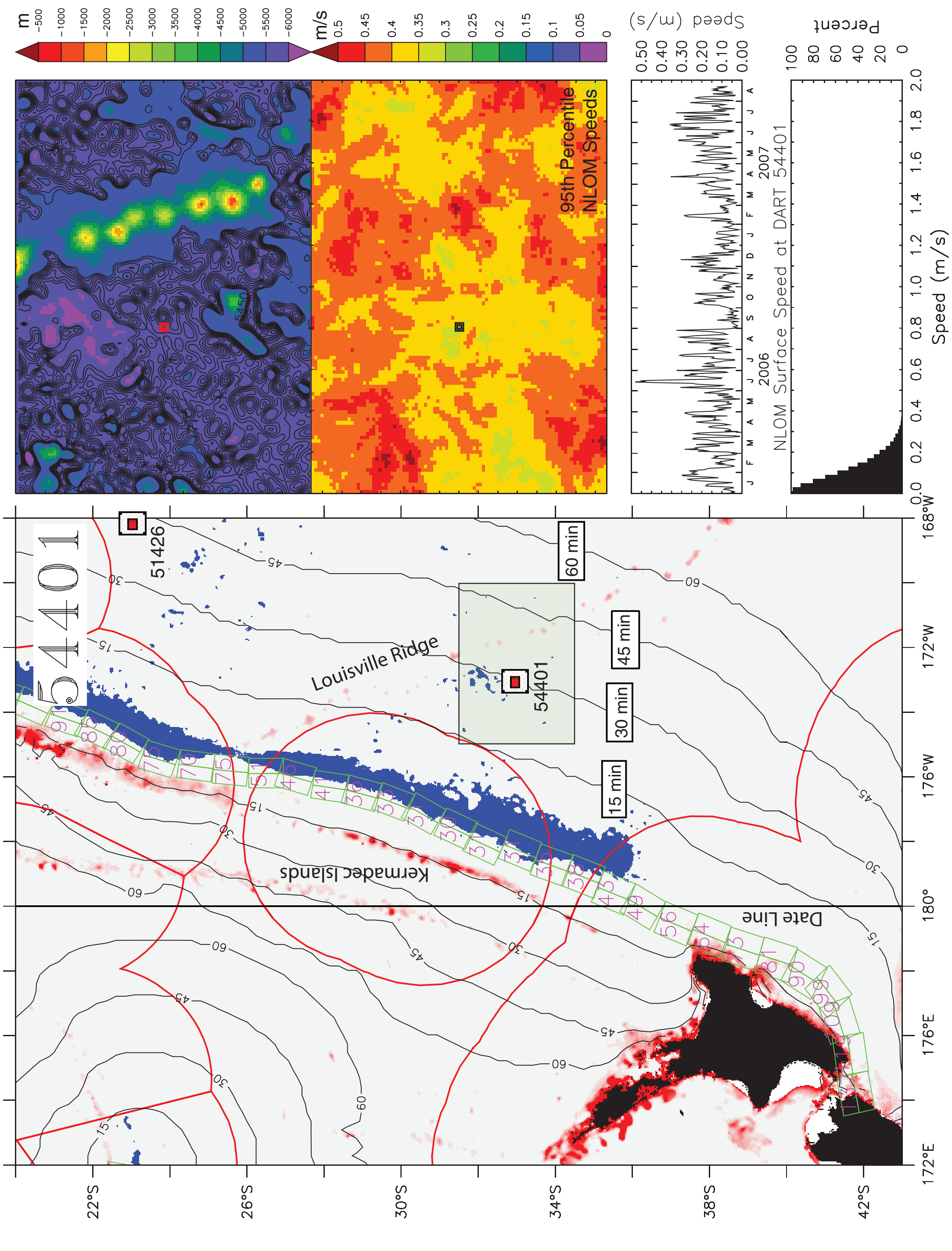

Figure 37: Siting environment for DART® **54401** in the Southwest Pacific group.

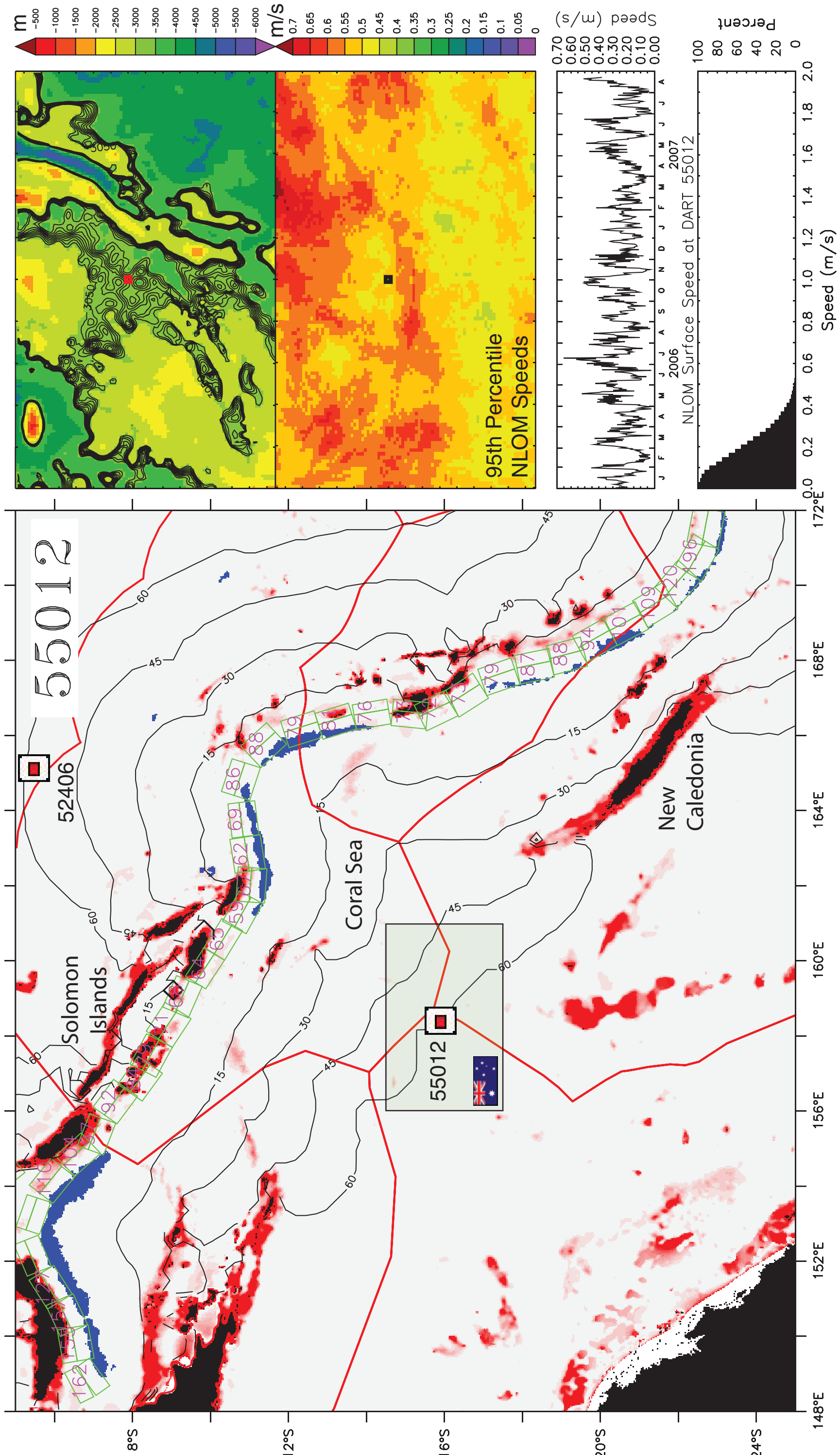

Figure 38: The Australian Coral Sea Site **55012**.

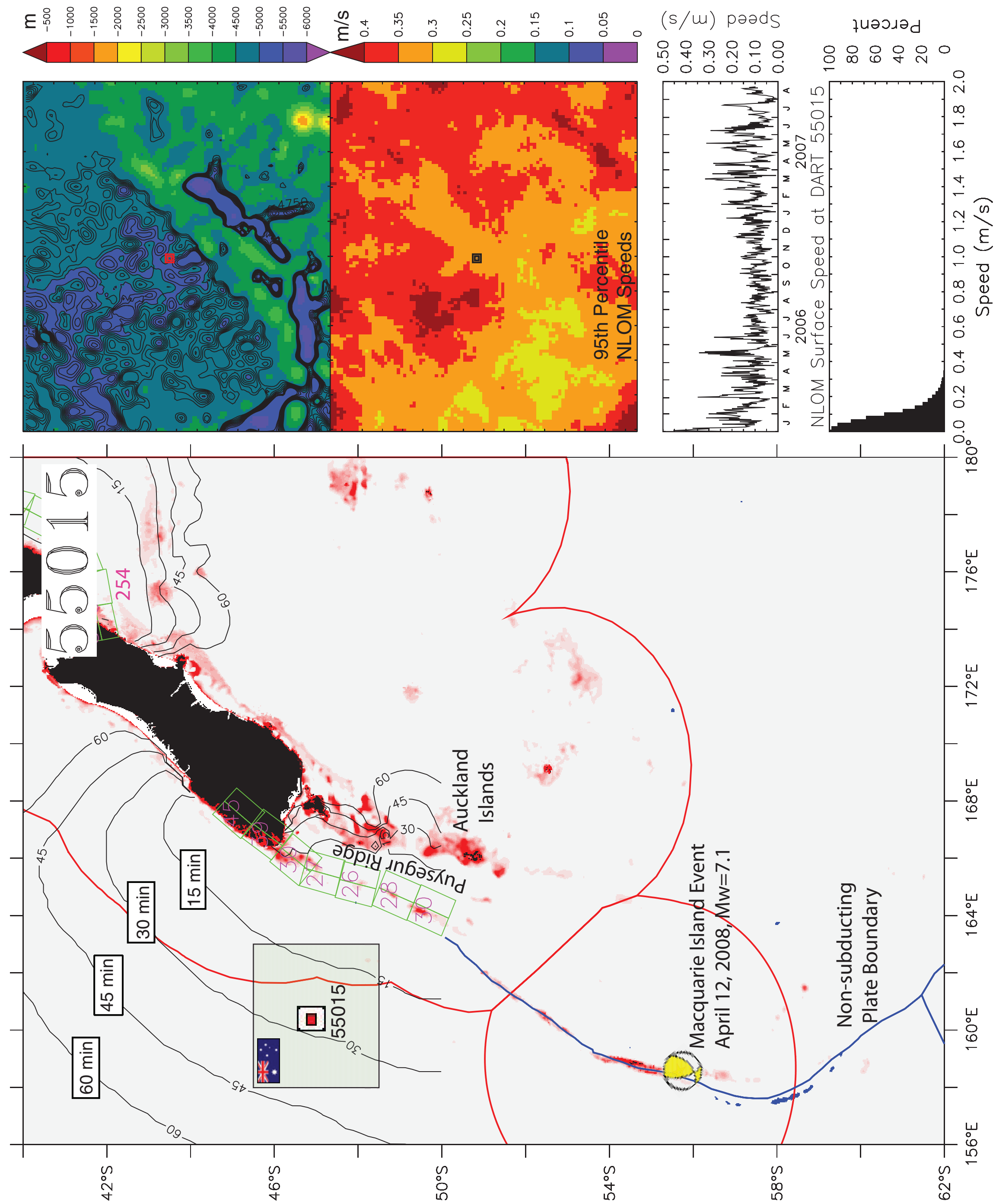

Figure 39: The Australian Tasman Sea Site **55015**.

of the source line where New Caledonia interrupts the direct path. DART® 52406 is slightly better positioned to detect waves originating south of New Britain. However, because of the numerous islands near the “tail” of New Guinea, as well as the Great Barrier Reef itself, these sources are unlikely to significantly impact Queensland.

Of greater concern to Australia is the Puysegur source line, which extends southward from New Zealand’s southwest coast. The DART® **55015** site in the Tasman Sea (originally named 55401), selected by BOM scientists (Greenslade, personal communication), endeavors to provide 90 min of warning to the threatened eastern coastlines of Tasmania and New South Wales. The unit sources and timing information in Fig. 39 are based on the NCTR propagation database. The “regular” Pacific grid, employed for most sources currently in the propagation database, cuts off at 50°S. Since this cannot adequately represent trans-basin propagation of southern sources such as Puysegur (and the southernmost South American sources described elsewhere in this memo), these were derived from MOST runs on an “extended” Pacific grid whose southern limit is Antarctica. Merging of “regular” and “extended” first wave results in the Pacific resulted in the apparent cut off at 50°S in Fig. 39. The current version of the database consistently employs the extended grid; future versions may use a global grid. Representations of the plate boundary and the occurrence of a “thrust”-type earthquake near Macquarie Island in April 2008, reveal the presence of some short segments of subduction further south than Puysegur Ridge. DART® 55015 is well placed to detect such sources, which are far removed from the next instrument 54401. For both of the Australian sites discussed here, current speeds (based on NLOM) should not be of concern for mooring integrity.

6.7 The Hawaiian and Equatorial Sites

Two long-standing U.S. sites (see Table 8), pre-date the expansion of the U.S. array in the Pacific and the rationale for their selection is not included in the Appendices. The Hawaiian site 51407, 140 nm southeast of Honolulu, was selected to provide warning of locally generated tsunami waves. The role of 51406 in the equatorial Pacific was originally to provide wide area coverage for the extended source regions of South America and the Southwest Pacific. Data from 51606 or 51407 can also serve to validate the SIFT forecast methodology when they register tsunami signals from remote events.

The DART® allocation decided at the Siting Workshop was to some extent predicated on the addition of further Chilean tsunameters south of 32401. In their absence, given the history of significant events off central and southern Chile, this stretch of subduction zone has the poorest coverage. There has been some discussion (some of it included in Appendices F and H) of how this issue might be resolved. Options include:

- The addition of one or more DART®s (beyond the initial 39)
- Redeployment of 51406 to a point south of 32401
- Reassignment of the westernmost instrument of the SW Pacific group

Table 8: Location and performance of the Equatorial and Hawaiian DART®s (to 30 October 2008).

WMO Identifier	Location	Data Begins	Major Disruptions	Data Return (%)
51406	8.49°S, 125.02°W, 4480 m	1 Jan 2003	One	97.4
51407	19.63°N, 156.53°W, 4718 m	28 Jun 2005	None	97.8

The latter option is based on the premise that the Australian Coral Sea DART® 55012, which was not envisaged during the Siting Workshop, is somewhat better placed to detect many of the sources between New Guinea and Vanuatu, than is 52406. This is because many of these sources lie to the south of the Solomon Islands, thus distorting and possibly limiting the penetration of tsunami energy into the Pacific. For sources east and south of New Caledonia, however, 55012 is less effective. Redeployment of 51406 can be argued against, based on its long history and the secondary coverage it provides for several source regions that potentially impact Hawaii. Ideally the addition of one or more instruments off Chile, either by the U.S. alone or in collaboration, would seem the most desirable choice.

The site occupied by DART® **51406** has a long history of occupation and has a near continuous record since 2003; prior to 2006 it was designated 46406. As discussed in Appendix F and in Section 7, 51406 is not the primary detector of any sections of the source line. It does, however, provide a later evaluation for waves from major events that might be in transit from South America to Hawaii, or from Tonga-Kermadec toward the West Coast. Despite this role and the history of the site, there is a valid argument that, if additional instruments are not forthcoming for the central and southern sections of the Chilean trench, the overall performance of the array would be better served by redeploying this DART® to one of the locations suggested in Appendix F. The bathymetry and current speed regime in the vicinity of the present site are portrayed in Fig. 40, where alternate sites that have been discussed are also indicated.

The major purpose for the Hawaiian DART® **51407**, is to monitor waves generated locally by landslides and subsidence triggered by earthquakes. The Halina fault along the south coast of Hawaii Island is associated with active slumping. In 1975 and 1868 earthquakes (M_w = 7.9 and 7.2, respectively) generated tsunamis that caused loss of life and damage near Hilo and in California. Detailed bathymetric and seafloor data accumulated during the JAMSTEC-Hawaii project (USGS, 2006) is summarized in a chart (`geopubs.wr.usgs.gov/i-map/i2809/bathy.pdf`) that identifies numerous past slumps and slides along the Halina and Kona coasts. DART® 51407 is located west of the North Kona Slump and is well placed to intercept slump-generated waves propagating toward Honolulu and the other islands. In October 2006 the instrument detected the disturbance associated with near-shore submarine earthquakes (M_w = 6.7 and 6.0) that caused a 10-cm wave in Kawaihae. The USGS-JAMSTEC chart illustrates, in greater detail

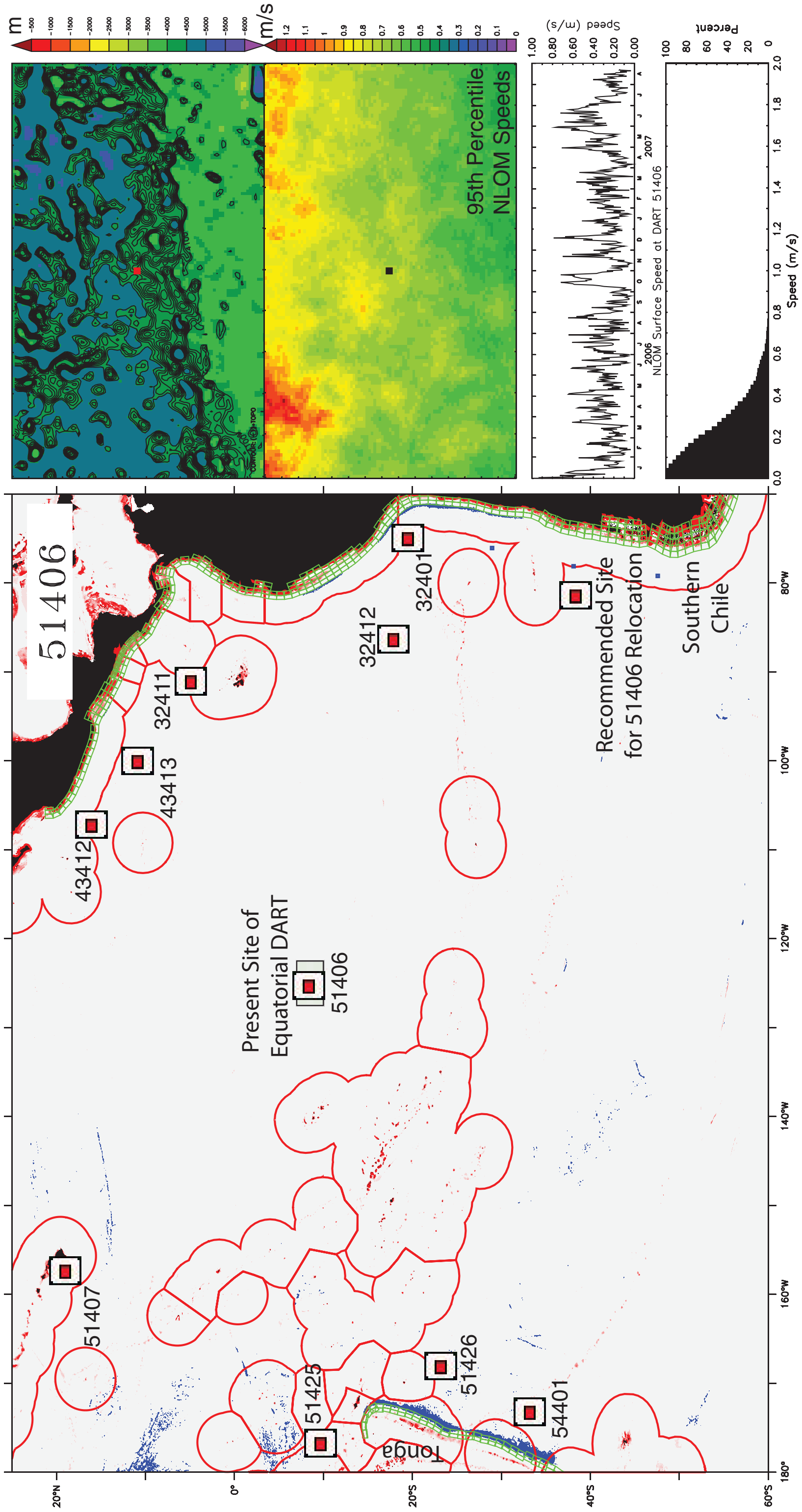

Figure 40: The Equatorial DART® **51406**.

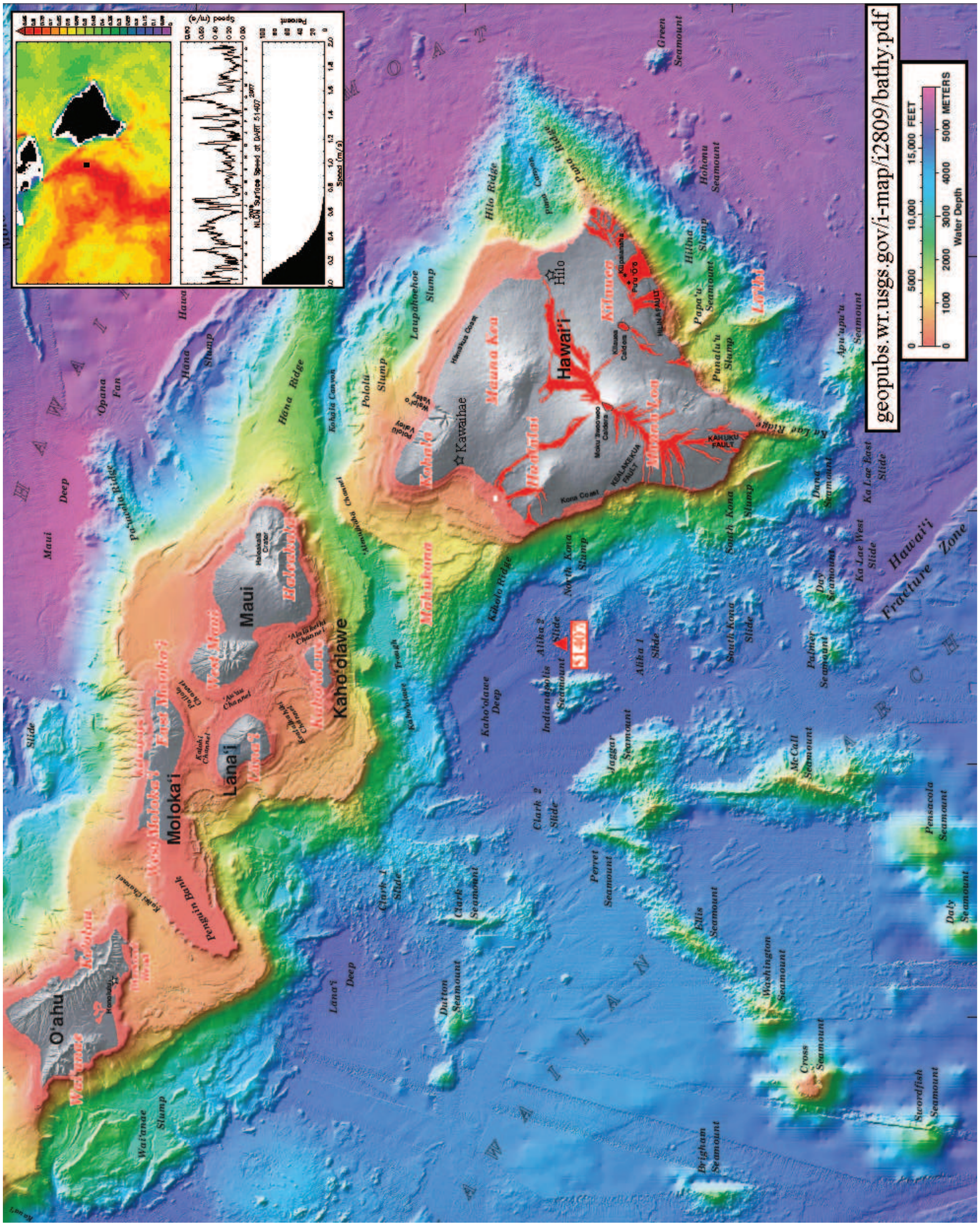

Figure 41: The Hawaiian DART® 51407.

Table 9: Location and performance of the Atlantic DART® Group (to 30 October 2008).

WMO Identifier	Location	Data Begins	Major Disruptions	Data Return (%)
41420	23.31°N, 67.65°W, 5667 m	7 Apr 2006	Two	98.0
41421	23.40°N, 63.90°W, 5800 m	11 Apr 2006	One	97.7
41424	32.93°N, 72.47°W, 5254 m	7 Apr 2006	Three	91.5
42407	15.26°N, 68.24°W, 4486 m	11 Apr 2006	Two	97.4
42408	25.21°N, 87.00°W, 3293 m	17 Apr 2006	Three	88.5
44402	39.49°N, 70.59°W, 2434 m	31 Aug 2007	None	96.0
44401	37.56°N, 50.00°W, 5391 m	28 Aug 2007	Two	90.6

than available for the other sites of this section, the presence of numerous seamounts southwest of the 51407 site that might scatter teletsunami waves from the Southwest Pacific. Nonetheless the April 2007 Solomon Islands tsunami was detected at DART® 51407 and used in the validation of the SIFT forecast scheme (Wei *et al.*, 2008b). In Fig. 41 the current speed statistics in the vicinity (derived from NLOM hindcasts) are inset to an extract from the USGS-JAMSTEC chart. While the instrument is sited where the speeds are on occasion among the strongest in the region, these have not in the past significantly impacted the data return.

6.8 The Atlantic, Caribbean, and Gulf of Mexico Sites

Though addressed and prioritized separately during the Siting Workshop, all seven sites of the Atlantic and its marginal seas are discussed together. They were the subject of a single Site Recommendation Report, reproduced in Appendix C, and some follow-up discussion when two sites were found to be exposed to excessive ocean currents. Site details and data return details are provided in Table 9.

The propagation database for the Atlantic is primarily based on potential seismic sources within the Caribbean and an arc outside the Caribbean extending from Trinidad to Hispaniola. Of these sources, the subset of greatest concern to the U.S. East Coast lie near Puerto Rico. They also threaten Puerto Rico itself and the Virgin Islands, though these are further threatened by sources along the Muertos Trough and offshore of South America. Other coastlines within the Caribbean are threatened by sources further west, including those off Panama. However, propagation database statistics reveal that the narrow passages of the Yucatan and south of Florida reduce the direct impact of seismically generated waves entering the Gulf of Mexico. For the Gulf, as well as the East Coast, landslide sources, perhaps triggered by seismic activity, are an additional threat.

The more remote seismic sources of the South Sandwich Island arc have recently been added to the propagation database and are of little concern. Various representations of the less well-known Eastern Atlantic source region that devastated Lisbon in 1755 have been explored. As noted earlier, the general layout of the Atlantic portion of the array, decided at the Siting Workshop, reflects the main threats with two DART®s north of Puerto Rico, one in the Caribbean, two close to the East Coast, and one in the Gulf of Mexico, to validate earlier detected waves of remote origin or potentially landslide-generated waves. The final site 44401 lies well to the east and should act to provide adequate warning for waves emanating from the eastern Atlantic.

The rationale for the specific sites chosen to the north of Puerto Rico is provide in Figs. 42 and 43, as well as in the original site recommendation report in Appendix C. Both lie in international waters along the 30-min envelope. Acting alone, DART® **41420** provides detection times of between 30 and 60 min for the sources of greatest concern along the Puerto Rico Trench and Hispaniola. DART® **41421** provides a similar coverage, though favoring the more eastern sources. Their combined capability, and similar results for the array as a whole, are provided in Section 7. Scattering features are confined mainly to the region north of the Dominican Republic and in the vicinity of the Turks and Caicos Islands. These, and the even greater impediment to tsunami passage posed by the Bahamas, provide protection to southern Florida. Survivability of the moorings would not appear to be a concern, based on the NLOM speed statistics. However, as seen in Fig. 57c of Section 7.3, both sites failed within a month of each other in March 2008. Other failures and intermittency were negligible and the reason for the failures may lie elsewhere.

Proceeding northward DART® **41424** lies near the U.S. EEZ boundary, east of Charleston, South Carolina. The site lies well to the east of the Gulf Stream path, which appears in the upper left corner of the 5% exceedence panel in Fig. 44. While occasional higher speed episodes are not unexpected, due to eddies associated with Gulf Stream recirculation, the extended loss of data at 41424 beginning in August 2006 does not seem related to the NLOM speed record. The record was interrupted again in November 2007 and in April 2008, resulting in a poor overall data return rate of 65%. In between breakages the site had a good record with few and brief interruptions. The NDBC Status Reports indicate a BPR failure though the mooring subsequently parted and the surface buoy drifted until it was recovered.

Serving as it does as the sole DART® in the Caribbean Sea with the role of providing warning to Puerto Rico, the Virgin Islands, and other island locations from widespread seismic and volcanic sources, **42407** had an excellent early record of data return (see Fig. 57c in Section 7.3). This has been marred of late by two interruptions, in December 2007 and April 2008. Both incidents were cited in NDBC Status Reports as possible BPR failures and may not be associated with environmental conditions. The passage nearby of Hurricane Dean in August 2007 (with winds in excess of 130 mph) caused a brief loss of data (4 hours) but otherwise registered the low atmospheric pressures associated with the storm. As seen in Fig. 45, the warning that can be provided for events on the Muertos Trough south and west of Puerto Rico, or off the Netherlands Antilles and western Venezuela, are likely to be short. Surprisingly, 42407 (as well as 41421 and 41424, though not 41420) were triggered seismically by the far distant Peru earthquake of

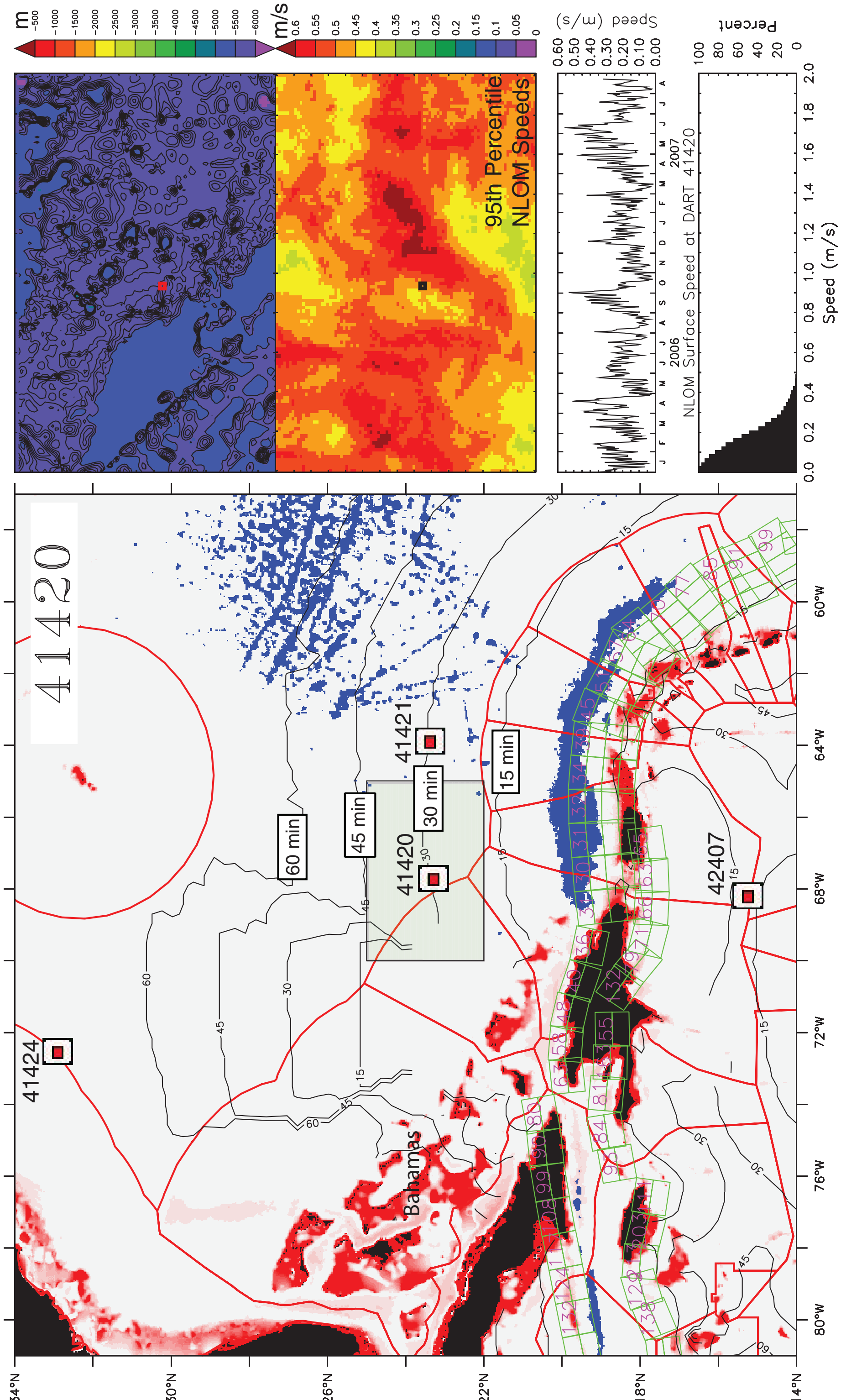

Figure 42: Siting environment for DART® **41420** in the Atlantic group.

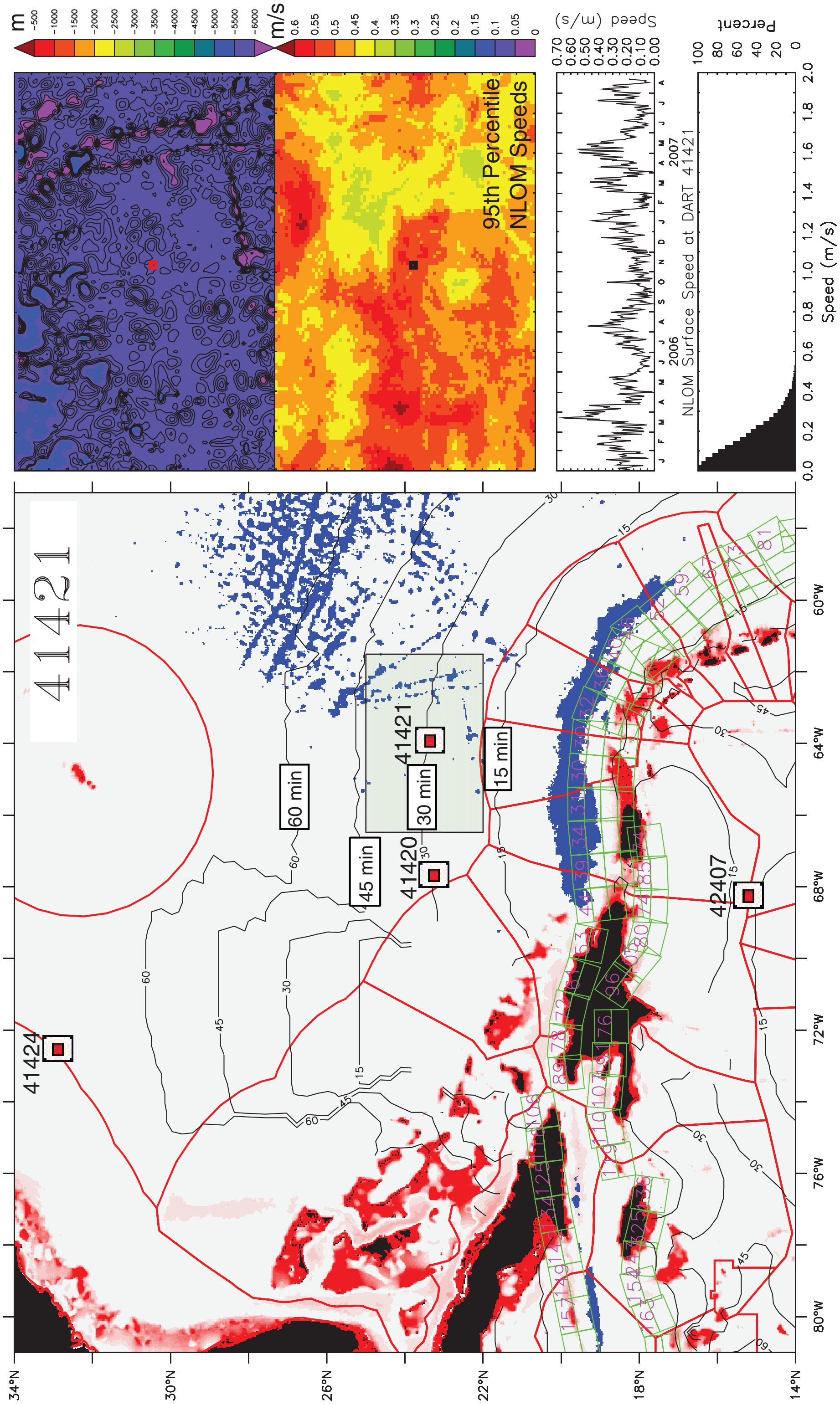

Figure 43: Siting environment for DART® **41421** in the Atlantic group.

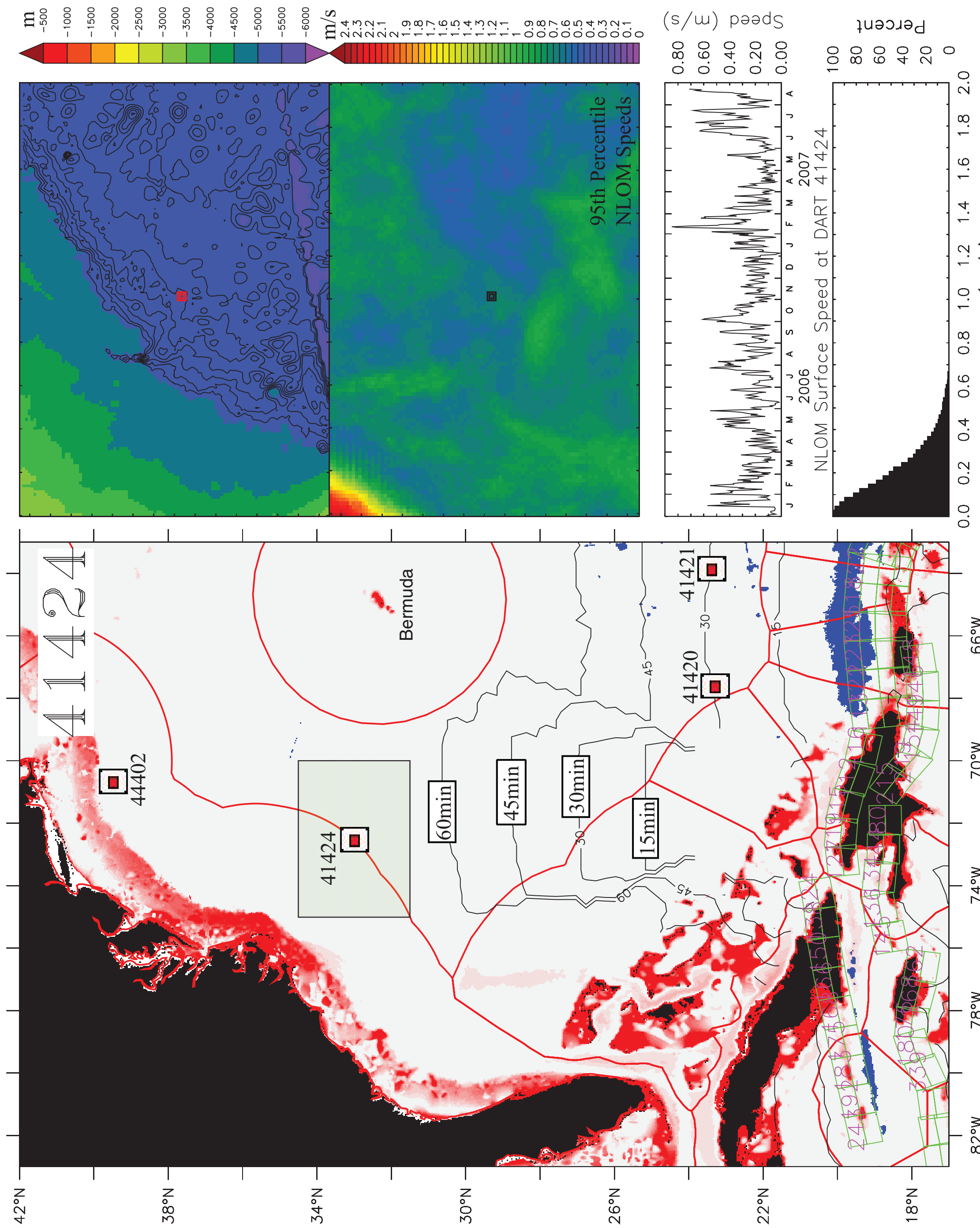

Figure 44: Siting environment for DART® **41424** in the Atlantic group.

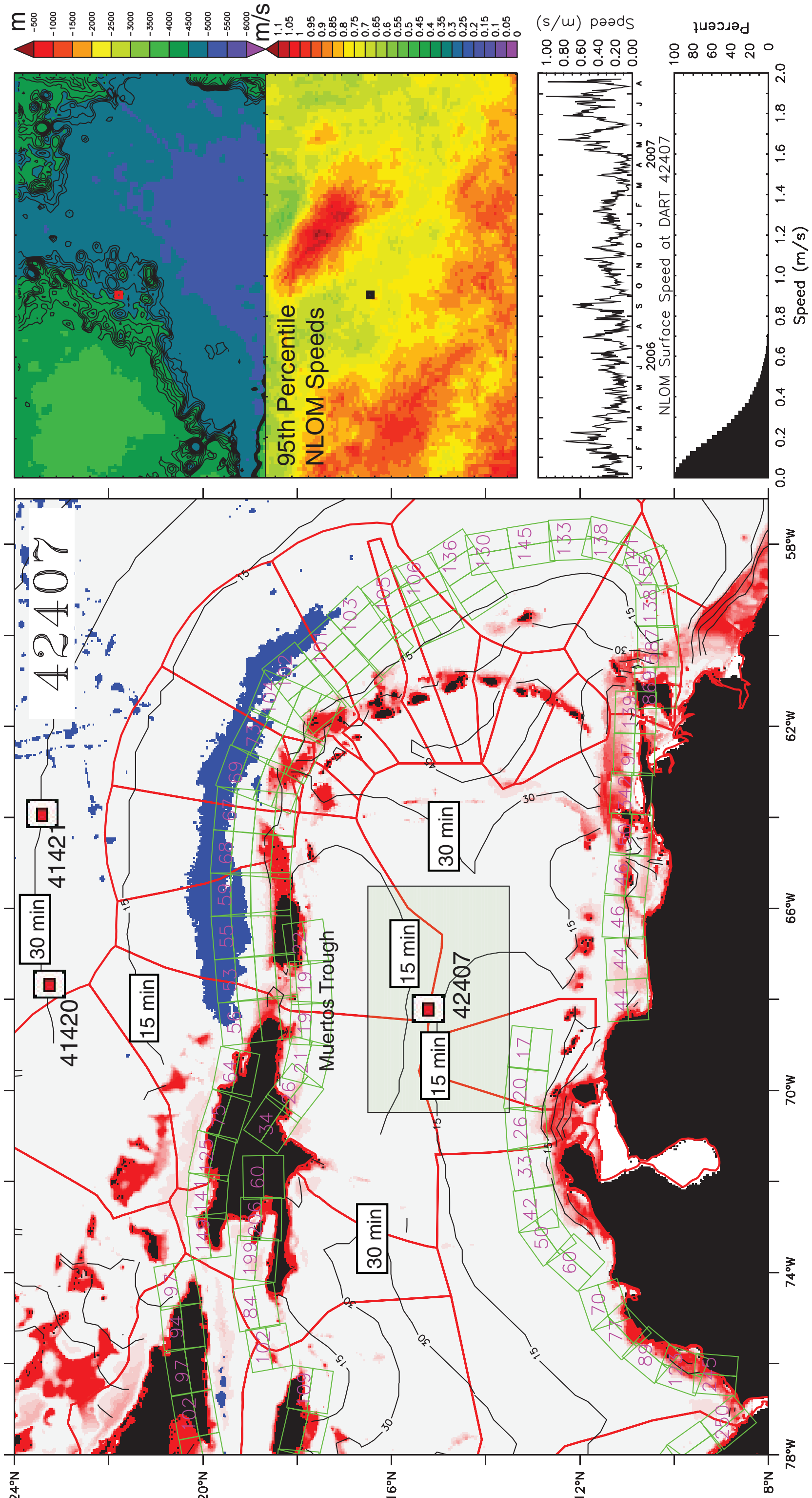

Figure 45: Siting environment for DART® **42407** in the Caribbean Sea.

15 August 2007. The nearby event near Martinique (29 November 2007) also caused triggering, though the tsunami wave, if any, was very weak.

The Gulf of Mexico DART® **42408** has had poor overall data return statistics with the surface buoy breaking free on a number of occasions and an episode of high intermittency (see Fig. 57c, Section 7.3) that may be associated with excessive Loop Current activity. A slightly revised site, based on the NLOM speed statistics, was occupied when the instrument was redeployed in August 2008 but another failure followed soon afterward. In December 2008, the site was abandoned in favor of a more protected site designated **42409** at 26.655°N, 85.797°W, some 200 km NE of 42408. Since the decision and redeployment came when this report was near completion, details of 42408 are retained and the new site is not discussed further. It is likely that as experience with 42409 accumulates, and the threats associated with submarine landslides are characterized, the issue of Gulf of Mexico DART® placement will require further study.

The role of DART® **44402**, in addition to perhaps monitoring local landslide-associated tsunami activity, is in the assessment of seismically generated waves, propagating toward the northeastern U.S. states and Canada, but which were likely detected earlier, close to their source. The initially recommended and occupied site for this instrument did not properly account for the variability of the Gulf Stream axis (whose climatological axis was drawn in Fig. C1 of Appendix C), or its strength. The survivability of the mooring has hopefully been improved by a move inshore in March 2008, as detailed in Appendix D and the NLOM speed statistics in Fig. 47.

Sources north of Puerto Rico are those of most concern and arrive at 44402 some 3 hours after the time of the earthquake. From Figs. 42 and 43, such waves would have first been detected by DART® 41420 or 41421 within 30–45 min of generation and perhaps been further assessed in transit using data from 41424. The closest inshore cells of the propagation database for the New England region suggest that coastal impact will occur some 90-180 min after the waves transit the 44402 site (the lesser lead times between Atlantic City to Nantucket, the longer for Boston to Portland, ME).

Waves directed toward the U.S. coast from the eastern Atlantic should, it is hoped, be first seen at DART® **44401**. As seen in Fig. 48, and also in Fig. C1 of Appendix C, the location is southeast of Newfoundland with a view to the east that is largely uninterrupted by scattering features. The current speed regime near 44401, based on NLOM hindcasts, would not seem too extreme and apart from some periods of intermittency (see Fig. 57c, Section 7.3) the record is complete since deployment in December 2007. The site recommendation took into consideration some sample beam paths and travel times of potential sources in the vicinity of Lisbon and La Palma. Research is ongoing to characterize the eastern Atlantic source distribution, which is not, as yet, incorporated in the propagation database.

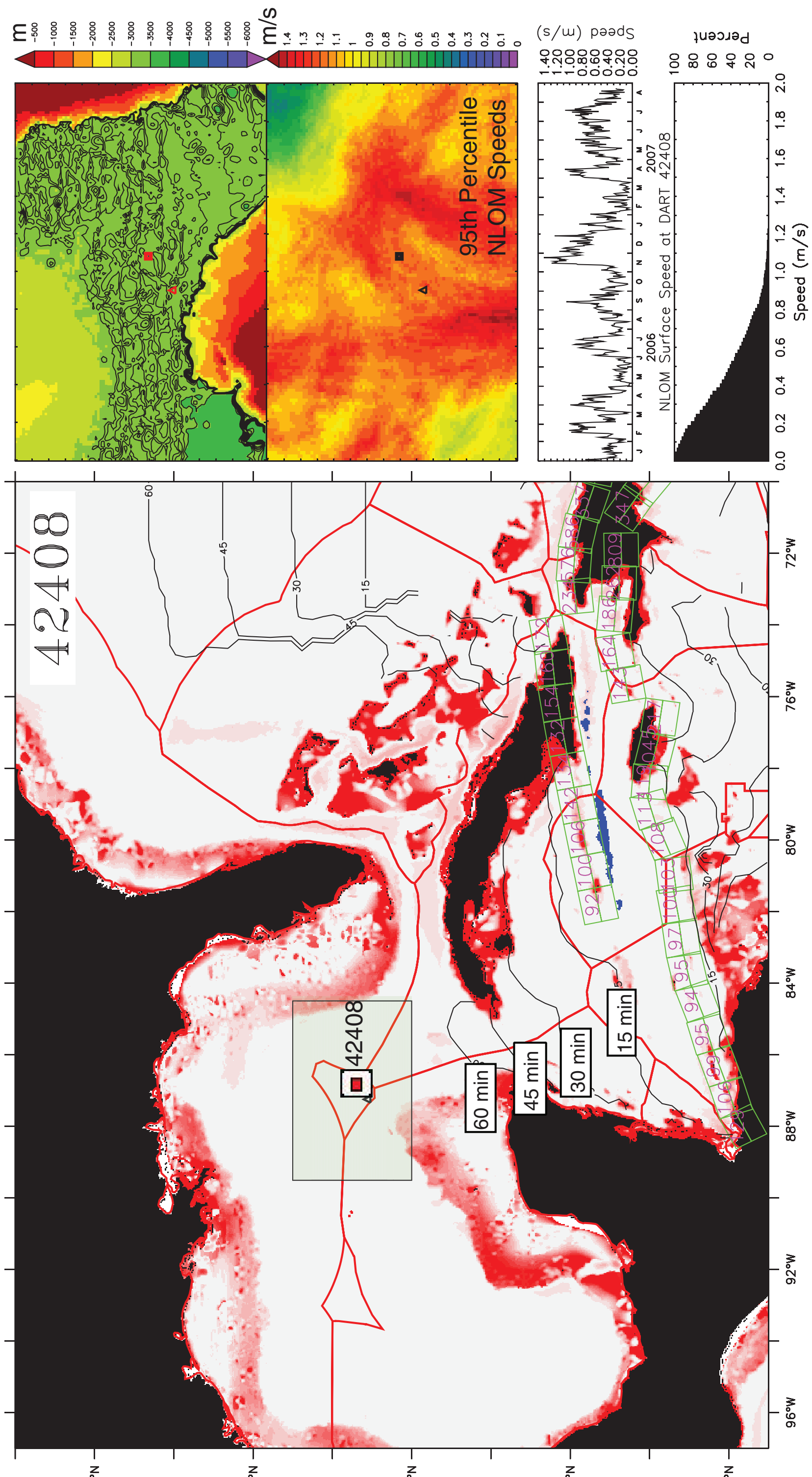

Figure 46: Siting environment for DART® **42408** in the Gulf of Mexico.

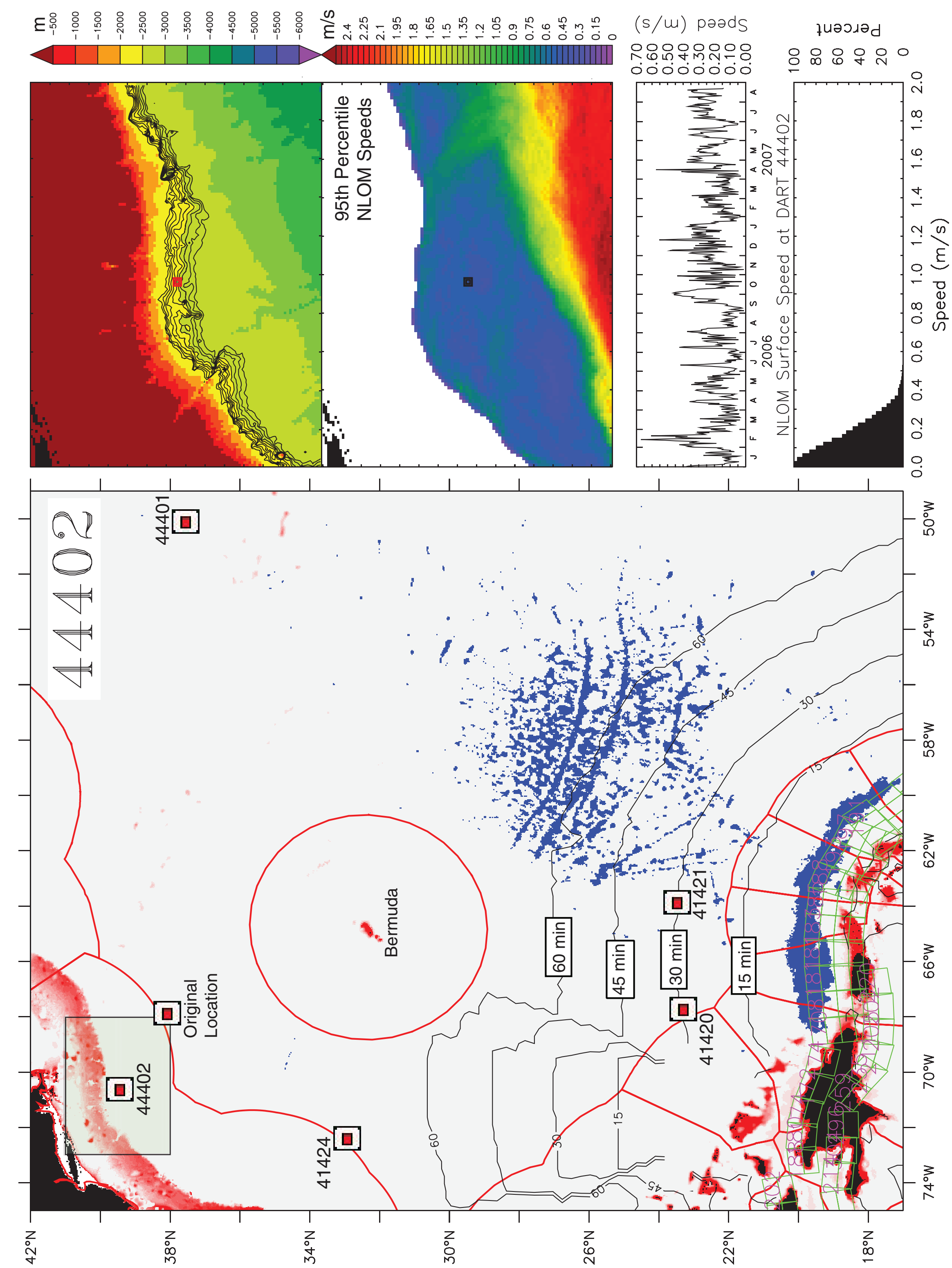

Figure 47: Siting environment for DART® **44402** in the Atlantic group.

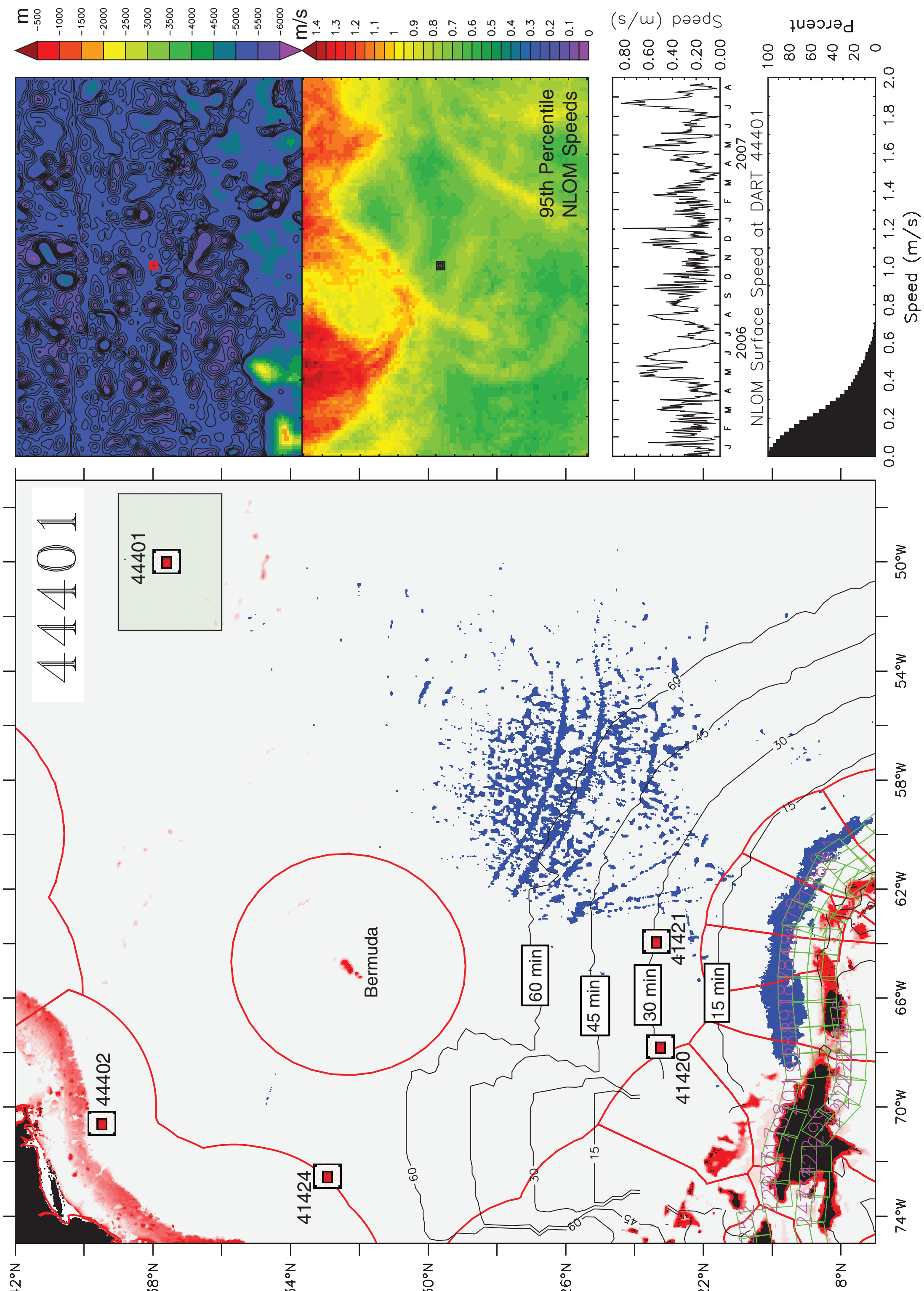

Figure 48: Siting environment for DART® **44401** in the Atlantic group.

Table 10: Location and performance of the Indian Ocean DART® instruments (to 30 October 2008).

WMO Identifier	Location	Data Begins	Major Disruptions	Data Return (%)
23401	8.91°N, 88.54°E, 3546 m	4 Dec 2006	None	93.7
53401	0.05°N, 91.90°E, 4481 m	27 Sep 2007	None	97.9 (before loss)

6.9 DART® Sites in the Indian Ocean

Though perhaps beyond the scope of a report on the U.S. DART® Array, it nonetheless seems appropriate to include a brief discussion and graphics relating to the siting choices for the two DART® instruments deployed in the Indian Ocean. These were established, by the governments of Thailand and Indonesia in cooperation with USAID, as part of an evolving international effort to provide detection and warning capabilities there. NCTR staff were involved in site selection and DART® data are available to the international community via the same NDBC websites that serve the U.S. arrays in the Pacific and Atlantic Oceans. Two further sites have been established by Australia using DART® technology (Greenslade, personal communication) and numerous other sites are in various stages of operation or planning.

During 2005, before a propagation database had been computed, some preliminary steps were taken to envision an Indian Ocean array. The tentative number and layout of array nodes were based on detection and warning time estimates drawn from travel-time computations. The TTT software (from Geoware) was employed for this purpose with point sources spaced at 100 km intervals along the plate boundaries off Indonesia, the Andaman-Nicobar region, and the Makran region of the northern Arabian Sea. The intent of this initial USAID effort was to select two sites whose joint coverage would optimize a warning capability for those nations most impacted by the 2004 disaster. The pair of sites that best satisfied that mandate among the set of locations identified in the preliminary array design are described in Table 10. Other relevant site parameters, including those derived from the now-available Indian Ocean propagation database, are provided in Figs. 49 and 50.

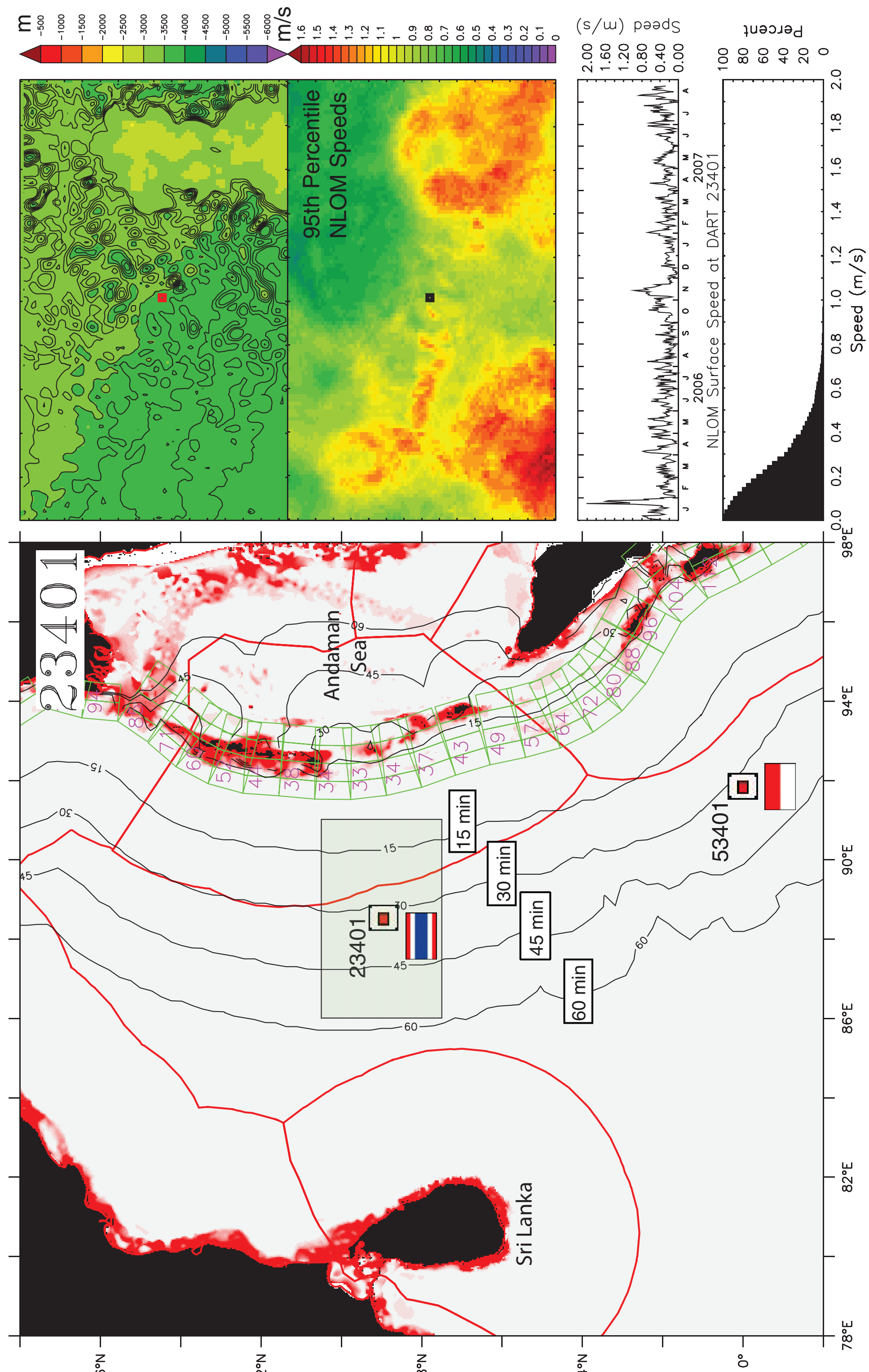

Figure 49: Siting environment for the Thailand DART® **23401** in the Indian Ocean.

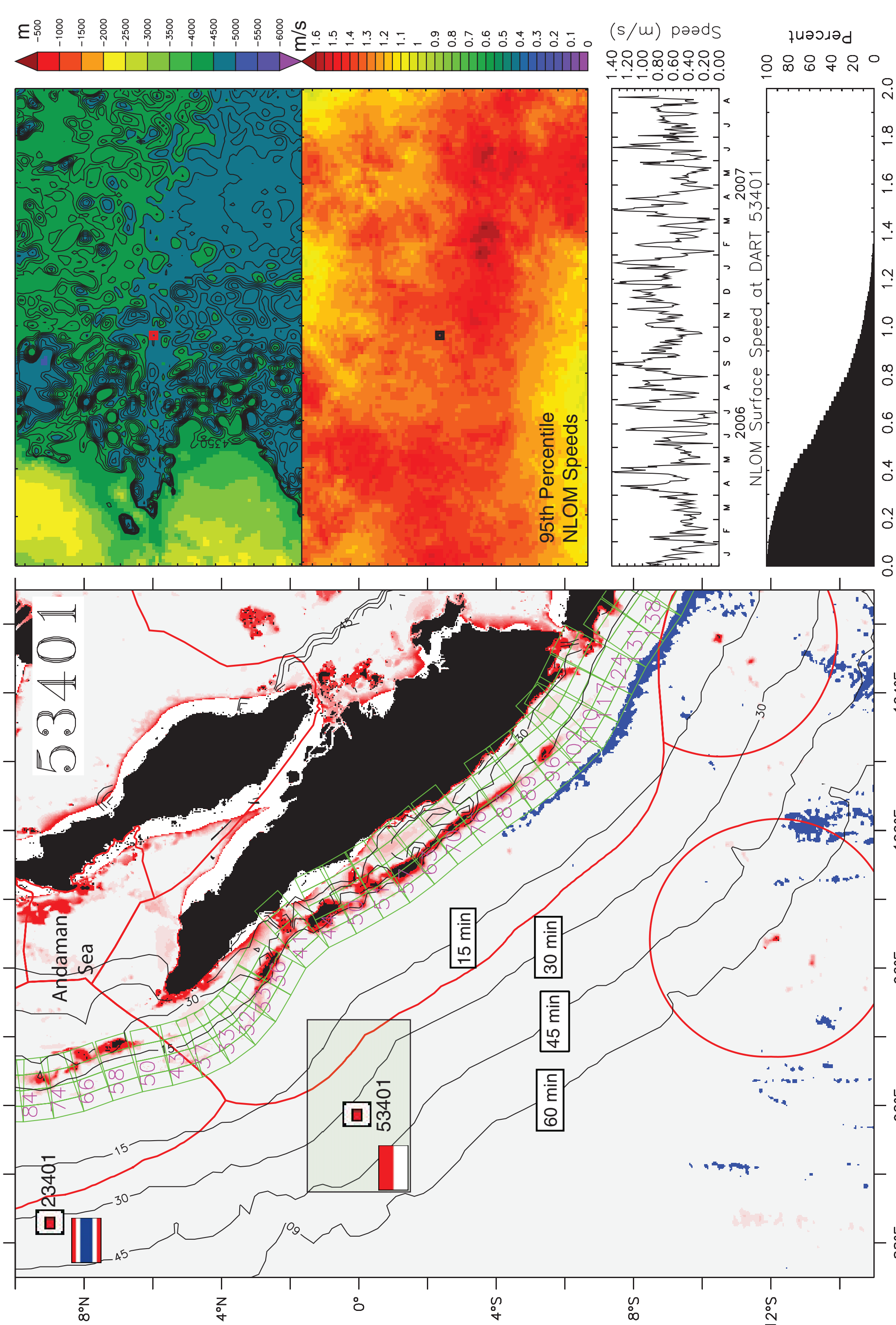

Figure 50: Siting environment for the Indonesia DART® **53401** in the Indian Ocean.