EXPLORING THE ENDS OF THE EARTH

BY PAUL WESSEL

With low-tech equipment, variable levels of planning, and plenty of courage, late nineteenth and early twentieth century explorers mesmerized the world with daring attempts to reach Earth's geographic poles.

The one hundredth anniversary of Robert Peary's controversial North Pole claim was in April 2009, and the centennial of Roald Amundsen's undisputed dash to the South Pole is coming up in December 2011. Much less known are the "poles of inaccessibility" (PIA), which are distinguished by their great distances from any coast (Stefansson, 1920). As 50% of humanity lives within 200 km of the coast, such remote points are particularly difficult to reach. In addition to numerous local maxima, there are two global maxima of particular interest: the Eurasian PIA, representing the land-locked point farthest from the ocean, and the South Pacific PIA, being the most remote oceanic point. The Eurasian PIA has been called the "Center of the Earth" (CE), and it was "conquered" in 1985 by Richard and Nicholas Crane during a bike journey across the Himalayas (Crane and Crane, 1987). However, recent calculations have placed the CE considerably further south (Garcia-Castellanos and Lombardo, 2007). The oceanic PIA is more elusive and was only recently named "Point Nemo" (Lukatela, 2005) after the globe-trotting captain in Jules Verne's classic *20,000 Leagues Under the Sea*.

To better determine PIAs and to investigate whether any explorers have reached these extreme locations, in particular, the most remote oceanic point, I created a grid of coastal distances using the full-resolution Global Self-consistent Hierarchical High-resolution Shorelines (GSHHS) coastline database (Wessel and Smith, 1996) as my coastline representation; it is distributed with GMT, the Generic Mapping Tools (Wessel and Smith, 1998). However, the Antarctic coastline is considerably better represented in the Antarctic Digital Database (ADD) (ADD Consortium, 2000); in fact, GSHHS has discrepancies relative to ADD that in some areas exceed 50 km (Figure 1). Thus, I only used the GSHHS coastline north of 60°S and relied on the ADD version 4.1 coastline exclusively south of 60°S. I then operated on this combined data with the GMT tool *grdmath* whose operator LDIST calculated the shortest distance from all points on a specified 1 x 1 arc minute equidistant grid to the actual coastlines. The LDIST algorithm uses spherical trigonometry to determine the point on a great circle shoreline segment that is closest to a specified grid node, which is usually a location intermediate to the given data points defining the line segment. Because the coastline file contains more than 10 million individual points, I broke the calculations into numerous smaller overlapping regions and ran sets of eight simultaneous tasks on an eight-processor workstation. This approach constituted a brute-force and not very elegant solution; there are better ways to optimize the distribution of coastlines prior to making this type of calculation, such as partitioning the coastline using spherical Voronoi polygons (e.g., Renka, 1997). However, I chose this simple approach because GMT already had the

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necessary algorithms implemented, and using them required little preparation by me other than developing a few shell scripts. I decided to perform the calculations with the highest possible accuracy, selecting exact geodesic distance calculations on the WGS-84 ellipsoid. No lakes or islands in lakes were included in the calculations; hence, the part of GSHHS that was used derives entirely from the World Vector Shorelines (WVS) data set (Soluri and Woodson, 1990). After about a week of continuous computations, I spliced the results from individual regions together and assembled the final 21,600 x 10,800 global grid, with geodesic distances stored to the nearest centimeter in 4-byte integer format. For ease of distribution, this ~ 900 Mb GMT grid was compressed using the lossless *grdzip* algorithm (Wessel, 2003), resulting in a 170 Mb file that is available from the author on request. The grid of shoreline distances was color-coded and is presented in Figure 2. Blue colors represent distances from oceanic nodes to the nearest shore, whereas red colors represent distances from land-locked nodes to the same shoreline.

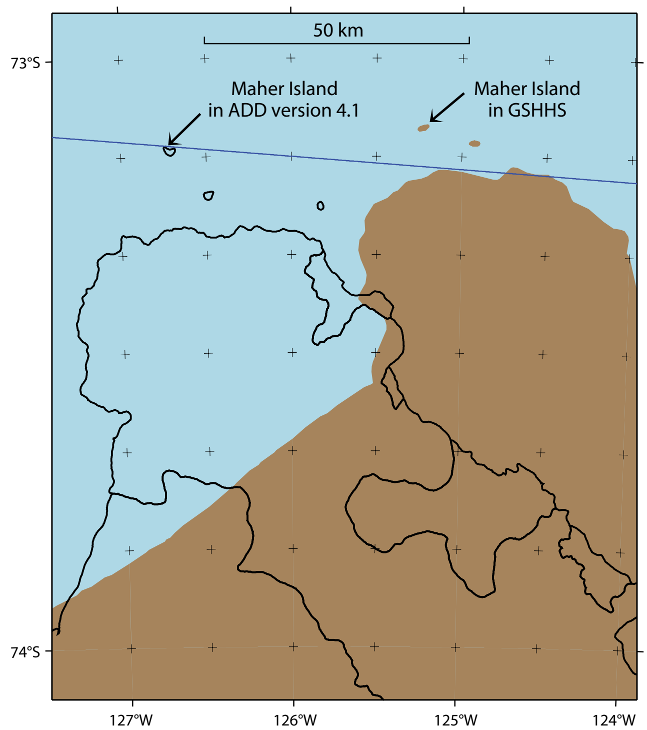

Figure 1. Antarctic coast from Global Self-consistent Hierarchical High-resolution Shore-lines (GSHHS) coastal database (or Digital Chart of the World [DCW]) shown as a brown landmass. Arrows indicate locations of Maher Island in GSHHS and ADD version 4.1. The more accurate ADD version 4.1 coastlines (solid lines) indicate a substantial east-west (~ 50 km) and minor north-south (~ 3–4 km) shift. The blue line is the great circle radius (r = ~2,698,736.33 m) from Pt. Nemo to the closest point on the new and more accurate Maher Island location.

Curious to determine if anyone had accidentally mapped the remote oceanic point during a seagoing expedition, I examined the marine track lines in the area available from the US National Geophysical Data Center (NGDC) in Boulder, Colorado. I was unable to find a cruise that crossed directly (or nearly so) over Pt. Nemo, which my calculations now placed at (48°58'19.3996"S, 123°24'51.1468"W), ~ 2,698,736.33 m from the three nearest points on Easter, Ducie, and Maher islands and ~ 11 km from the previous determination based on cruder data with an inaccurate Antarctica shoreline (Lukatela, 2005). The cruise in the NGDC marine underway geophysical database that came closest to Pt. Nemo was cruise ID 15040042, which is the Scripps Institution of Oceanography cruise South Tow Leg 2 from 1972, carried out on R/V *Thomas Washington* with John D. Mudie as chief scientist (see red track in Figure 2). This cruise came within ~ 90 km of Pt. Nemo (at a maximum distance of 2611 km from nearest land) and registered a depth of 3661 m on Friday, February 25, 1972 at 23:10 UTC (3:10 p.m. local time). The geologic feature closest to Pt. Nemo is the Menard Fracture Zone, about 50 km to the north, extending off the Pacific-Antarctic Ridge ~ 5° north of the Eltanin fracture zone system. The seafloor at Pt. Nemo formed approximately 12.8 million years ago (Müller et al., 2008) and seems fairly unremarkable at an estimated depth of 3651 m. Interestingly, it seems that the scientist having been farthest from land is Dennis Hayes, who was chief scientist on cruise ID 01020045 (Lamont-Doherty *Eltanin* Leg 43) two years earlier when R/V *Eltanin* reached a point 2683 km from land; this distance is over 200 km from Pt. Nemo but nevertheless is ~ 72 km more distant from the coast than the most remote location reached by the aforementioned Scripps cruise. The elongated shapes of the distance contours surrounding Pt. Nemo explain this apparent contradiction.

Going inland, and using my distance calculations, the corresponding land-based, most remote point, or CE, is located at 45°20'26.50"N, 88°14'52.19"E, which is a distance of 2,513,871.82 m away from sea, specifically the Bay of Bengal, the Yellow Sea, and Ob Bay of the Kara Sea. This result largely agrees with the findings of Garcia-Castellanos and Lombardo (2007). The Cranes, however, had calculated the CE to be at 46°16'48"N, 86°40'12"E, with a maximum distance to the coast of 2648 km. I note that their position differs considerably from the GSHHS estimates (by almost 160 km). The discrepancy is most likely attributable to the lower accuracy of coastline data available in the mid-1980s, a cruder method of calculation, and subjective selection of points to represent coastlines with "an unobstructed view of the open sea" (Crane and Crane, 1987). Although the distance calculations are relatively routine, and my dense, global grid calculation results are, to first order, similar to cruder GSHHS-based estimates (e.g., Garcia-Castellanos and Lombardo, 2007), the differences I find are due to my use of accurate geodesic rather than great-circle distances, the consideration that an intermediate location between the data points that define the coastline might be closest to a node, and the inclusion of the full 10 million points of the GSHHS and ADD coastlines. However, as Garcia-Castellanos and Lombardo (2007) noted, the accuracy of the CE location is still subject to the large uncertainties associated with the coastline locations for the deltas in the Gulf of Bengal and the Arabian Sea. Thus, for the CE region, these uncertainties exceed any improvements in precision by my calculations. I note that river deltas do not play a part in determining Pt. Nemo, whose location is calculated using the location of the three

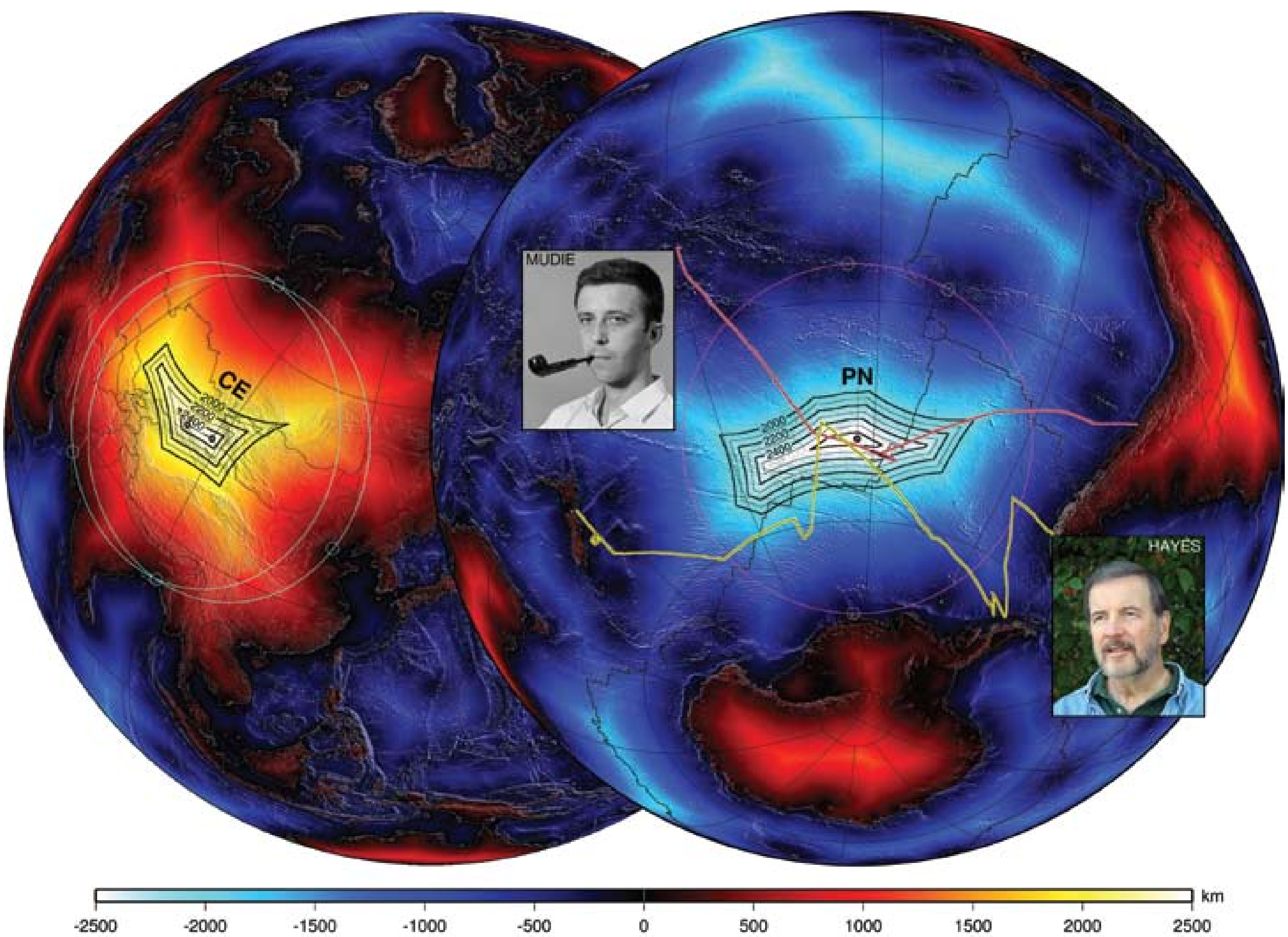

Figure 2. Distance to the nearest coastline from land or sea. Pt. Nemo (PN) is the most remote oceanic point, while the most remote continental point (CE) lies in China. Two points are candidates for CE; the easternmost point is ~ 4 km more remote. Lines show the final 100 km contours for each point. Red (Scripps South Tow cruise, Leg 2; John Mudie, chief scientist) and yellow (Lamont-Doherty *Eltanin* Leg 42; Dennis Hayes, chief scientist) tracks show expeditions from the early 1970s that came closest to Pt. Nemo. Large cyan (CE) and magenta (PN) circles indicate distances to the three nearest coastline points (small white circles).

aforementioned rocky islands.

To complete the analysis, I briefly discuss CE, which is located in the Dzoosotoyn Elisen Desert within northern Xinjiang Uygur Zizhiqu (Sin Kiang), China's most northwesterly province. From Google Earth imagery, I note the region near CE has numerous sand dunes, with vehicle tracks criss-crossing the landscape; some appear to cross the CE itself (Figure 3). I also see a hydrocarbon production facility ~ 3 km WSW of CE. The largest city most remote from the sea is Wulumuqi (formerly Urumqi), capital of the Xinjiang Uygur Autonomous Region of northwestern China, at a distance of about 2350 km from the nearest coastline. It is located ~175 km SSW of CE, with a population estimated at 1.5 million in 2005. This region has been in the news lately as the site of political unrest involving the Uygur population. Unlike Pt. Nemo, humans clearly have visited CE, albeit accidentally. I also note that due to the shape of the distance contours, a local maximum exists 493 km to the WSW with a distance of 2509 km, a mere 4 km less remote. Given the aforementioned uncertainties involved in characterizing the coastlines in delta areas, it is possible that improved coastline accuracy may further relocate the CE's true location (Garcia-Castellanos and Lombardo, 2007).

The fact that two pioneering cruises from the plate tectonics heydays of the early 1970s still compete for the honor of having surveyed the most remote seafloor symbolizes the fundamental change in oceanographic planning that has taken place since modern exploration commenced. Serendipitous crisscrossing of the oceans as practiced by Doc Ewing, Bill Menard, and others is no longer the norm, as cruises must be well focused on specific objectives planned way ahead of the expedition (e.g., Smith, 1993). Whether this change is entirely for the better is a matter open to debate. Given the renewed interest in ocean exploration (Hammond et al., 2008), perhaps Pt. Nemo will meet its undisputed conqueror during the next few years.

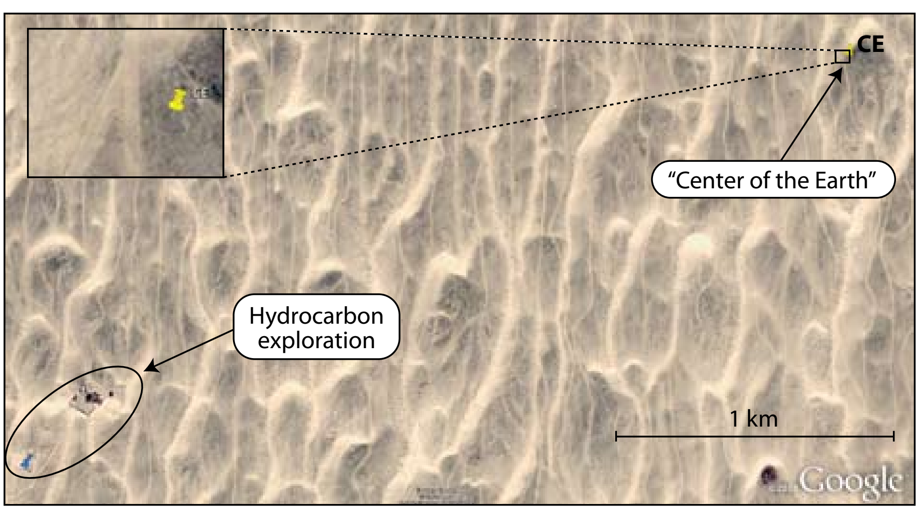

Figure 3. Google Earth imagery of the area near the "Center of the Earth" (CE), indicated by the yellow pushpin. Inset shows a fork in the dirt road just meters from CE. About 3 km to the WSW, the image shows a hydrocarbon exploration facility, most likely an oil rig, and temporary housing for workers.

ACKNOWLEDGMENTS

This work was supported by US National Science Foundation grant OCE-0241590. Comments by Daniel Garcia-Castellanos and several anonymous reviewers improved the paper. This is SOEST contribution no. 7959.

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