The International Hydrographic Review

Vol. 9, No. 2

September 2008

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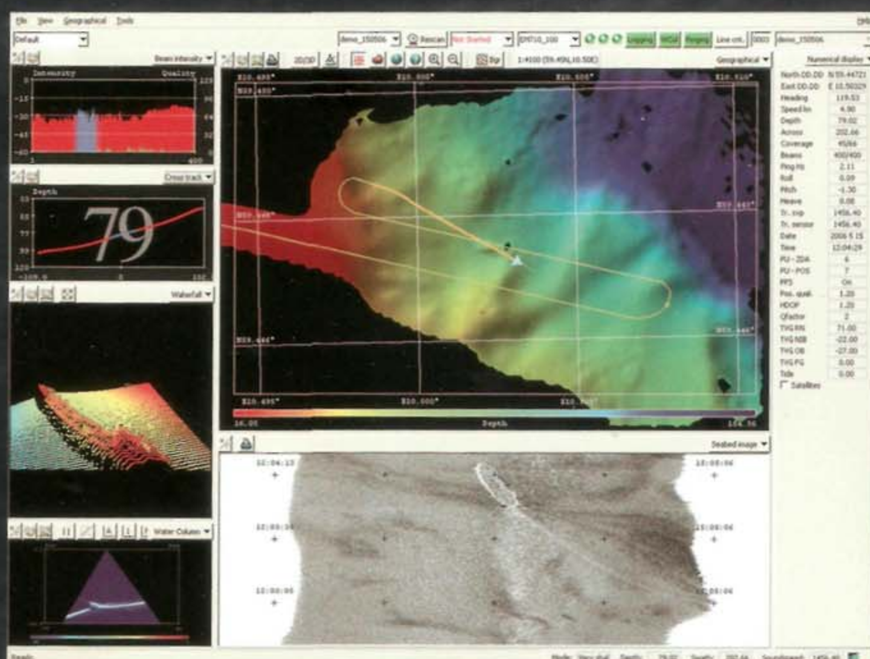

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Information to contributors

1. The International Hydrographic Bureau (IHB) would like to inform the world hydrographic community that the IHR will continue from now on as a digital publication. This digital collection of relevant technical articles as it is today, will be made available free of charge from the International Hydrographic Review section in the IHO website, with up to two peer-reviewed editions a year (April and October), depending on the number of papers and articles submitted and accepted. A printed annual compendium of articles will be made available, free of charge, to IHO Member States only.

The above mentioned provisions will begin in 2009.

2. To facilitate the transition to the new IHR format, the IHB Directing Committee, with the help of the IHR Editor, will review and update the existing Technical Instructions for Contributors in order to comply with the new requirements proper to the digital publications. These instructions and procedures will be posted in the IHO web site under the IHR section in the IHO website by 01 December 2008 at the latest.

3. The International Hydrographic Review as always remains heavily dependent upon the IHO Member States and other hydrographic organizations and bodies providing suitable articles. During this transitional period the IHB Directing Committee kindly invites all contributors to keep in touch with the IHB and to provide their contributions in digital form (text: WORD document. Illustrations: in one of the following formats TIFF,, GIF, JPEG or EPS) directly to :

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Editorial

This issue will be the final hard copy version of the International Hydrographic Review. In common with many scientific journals, the increasing costs of publishing as herd copy and at the same time the ready access of material published on the Web have dictated this change. The IHR (New Series) has been published under a contractual arrangement with the International Hydrographic Bureau IHB) since 2000 with GITC bv and latterly with Reed Business bv. It has now been decided to cease this arrangement and publication will revert to the IHB. The Review will continue as a digital publication available free of charge from the IHO website with up to two peer-reviewed editions a year (April and October) depending on the number of papers and articles submitted and accepted. A printed annual compendium of articles will be made available, free of charge, to IHO Member States only. The above mentioned provisions will begin in 2009. It is important to note that only material that has been peer-reviewed and edited will appear on the website. It is therefore hoped to inform the hydrographic community of the latest developments in the profession and at the same time to continue this important record of progress.
The editor would like to take this opportunity to thank the publishers, all those who have contributed material, the editorial board and reviewers, for maintaining the New Series. It must be noted and stressed that it is quality of contributions that establishes the reputation of a journal and it is essential that the community continues to support the Review by providing interesting articles. Instructions to authors for the digital articles will be much the same as at present and will be published on the website and also available for the author. Dealing with a multi-lingual community authors should not be inhibited from contributing over concerns over a linguistic ability in English. It is hoped that the community will continue to contribute strongly to this publication.

This final hard copy issue includes the usual mix of articles. Starting with an interesting historical article from Australia, it covers various technical matters.

Although the historical article does not have a strong focus on hydrography it touches on the problems of early navigators and the evidence that the first white people to reach Australia were from ships en route to the East Indies. The paper on data management combines two developing interests that have been previously discussed in this journal - LIDAR as a measurement tool and CUBE as a data management device. The Law of the Sea papers discuss on the one hand the immediate and practical geographic problems of defining maritime boundaries and on the other hand, the large scale economic problems of dividing up the oceans. A paper on depth contouring deals with the classic matter that cartographers have faced over many years on the best ways to present hydrographic information. Finally a paper describes the interest of a developing country in developing tidal products.

Adam J. Kerr, Editor

Article

The Mystery of the Deadwater Wreck

By Rupert Gerritsen (Australia)

Abstract

Historical research indicates there may be the remains of a 17th century Dutch shipwreck in part of an estuarine system in the south west of Western Australia. A variety of highly credible informants described the wreck in the 19th century, yet is seems to have 'disappeared'. This paper endeavours to explain what happened to the wreck, why it 'disappeared' and where it is now.

Résumé

Les *recherches historiques indiquent que les débris d'une épave hollandaise datant du 17e siècle pourraient se trouver dans une partie du système estuahen du sud-ouest de I'Australie occidentale. Une varieté d'informateurs très fiables a décrit I'épave au 19e siècle ; toutefois, celle-ci semble avoir « disparu ». Cet article vise à expliquer ce qu'il est advenu de I'épave, les raisons de sa disparition et I'endroit où elle se trouve actuellement.*

Resumen

La investigación histórica indica que podrían existir restos de un naufragio Holandés del siglo XVII en la parte del sistema estuarino en el sur oeste de Oeste Australiano. Una variedad altamente creíble de informantes describen el naufragio en el siglo XIX sin embargo pareciera que ha "desaparecido". Este escrito se aventura a explicar que le paso al naufragio, el porque este "desapareció"y donde se encuentra ahora.

In 1611, as the Dutch were building their trading empire in the East Indies, one of the captains of the Vereenigde Oost-Indische Compagnie (VOC), Hendrik Brouwer, tested out the idea that the Indies could be reached more quickly and easily by sailing due east from the Cape of Good Hope, following the Roaring Forties across the southern Indian Ocean, and then turning north to make for Java. The experiment was a great success, it halved the time such voyages took, and in 1616 the VOC officially adopted the 'Brouwer Route' and instructed their captains to follow it. Unbeknownst to them, the Brouwer Route took them very close to the west coast of Australia. At that time all that was known of Australia was 250 kilometres of the west side of Cape York in northern Australia, charted by Willem Janszoon in the *Duyfken* in 1606. Following the Brouwer Route, Dutch ships soon began encountering the west coast of Australia, the first being Dirk Hartog in the *Eendracht* in 1616. Hartog landed at Point Inscription on 25 October 1616 and left behind an inscribed pewter plate, now held by the Rijksmuseum in the Netherlands, signifying his historic 'discovery'.

Hartog's encounter with Australia's west coast highlighted a problem with the Brouwer Route. Sailors at that time were unable to determine longitude and so couldn't accurately determine their position. The Dutch simply instructed their captains to 'keep in Easterly course for at least a thousand mijlen [7,300km],' (Sigmond and Zuiderban 1995:33) before turning north for Java. But the captains could onlyjudge this distance by dead reckoning, and so if they miscalculated they would then come up against the Western Australian coast. These were dangerous waters, with many inshore reefs and coral islands such as the Abrolhos Islands. This did not present too much of a problem if the encounter occurred in daylight hours, but it was a different story if the approach took place at night. It was in such circumstances that four Dutch ships came to grief between 1629 and 1727, the *Batavia* (1629), the *Vergulde Draeck* (1656), the *Zuytdorp* (1712) and the *Zeewijk* (1727), all with considerable loss of life (Henderson 2007:20-40, 46-53, 63-71).

As a result of these disasters at least 73 and perhaps as many as 280 passengers and crew from those ships ended up permanently marooned on the coast of Western Australia. The first of these were soldier Wouter Loos and cabin boy Jan Pelgrom de Bye, the first European residents of Australia. They were deliberately abandoned, probably at Hutt River (450 kilometres north of state capital, Perth), on 16 November 1629 (Gerritsen 2007), for their part in the infamous Batavia Mutiny, following the sinking of the *Batavia,* in which 125 people were murdered by the mutineers (Drake-Brockman 1963; Dash 2002).

What became of all those unfortunate folk is one of the enduring mysteries of Australian history. Isolated finds of coins and artefacts, as well as some archaeological evidence, pointed to their initial survival, but gave no indication of their ultimate fate. In an attempt to ascertain this, I pioneered an alternative approach, involving an examination of traditional Australian Aboriginal cultures along the west coast of Australia at the commencement of British colonisation of Western Australia in 1829. This research, first published as And Their Ghosts May Be Heard in 1994 (Gerritsen 1994), tried to identify unusual features in those cultures which may have been the result of the impacts and influence of the castaways. Evidence emerged of genetic influences, myths and legends that appeared to have a connection with the presence of foreigners, unusual forms of social organisation, strong indications that a yam plant was introduced, along with technological innovations that appeared to have originated with the Dutch interlopers. One of the more controversial lines of evidence involved linguistics. It was argued that 16% of one particular language, Nhanda, was of Dutch derivation.

To ascertain where the different groups of mariners may have ended up an innovative linguistic methodology, Anomalous Sound Mapping, was employed. This involved searching for and mapping 'alien' phonemes in Aboriginal languages, sounds such as 'kn-' at the beginning of words, and the occurrence of 'f', 's', 'z', and 'sh', sounds that are not a normal part of the phonology of Aboriginal languages in the western part of Australia (Gerritsen 1994:211-20). Unexpectedly this pointed to an anomaly in the south west of Western Australia, in the region around Busselton and Bunbury, far from any known pre-colonial shipwreck. However, when limited historical research was carried out it became evident that there were a number of credible 19th century accounts of a wreck to the north of Busselton, in an area known as the Deadwater (Gerritsen 1994:260-62).

Following publication of And Their Ghosts May Be

Heard, further historical research into this wreck was carried out, and continues as new evidence comes to light. This research has revealed a body of information about the wreck, but as yet the actual wreck-site has not been located. This may seem surprising as all the other known Dutch wrecks in Western Australian water have been found, despite being in highly inaccessible locations in most instances. The *Batavia,* for example, was found on Morning Reef in the Wallabi Group of the Abrolhos Islands on 4 June 1963. The *Vergulde Draeck* was found 5.6 kilometres off the coast, 90 kilometres north of Perth on 14 April 1963. Wreckage from the *Zuytdorp* was first noted in 1927 on cliffs 570 kilometres north of Perth, although the vessel was not identified until 1959. Captain Stokes of the famous *Beagle* first reported wreckage from the *Zeewijk* in the Pelsaert Group of the Abrolhos Islands in 1840, although the wreck-site itself was not located until 1968. Even the remnants of Australia's first shipwreck, the Tryall, were found 100 kilometres off the north west coast in 1969 (Henderson 2007:13-15,25,36-37,47-48,65-68). So why hasn't the Deadwater Wreck been found? A number of unusual circumstances have contributed to the inability to locate the Deadwater Wreck. To understand why, it is necessary to consider the history of the wreck, some related events and the coastal geomorphology of the area.

Map: The Vasse and Wonnerup Estuaries and the Deadwater (adapted from Busselton 1930 - 1NE 1:25,000).

The Deadwater is a long shallow channel three kilometres long but only about 100 metres wide at its widest, which branches off the combined outlet of the Vasse and Wonnerup Estuaries (Wonnerup Inlet), about 10 kilometres east north east of the resort town of Busselton, in a locality known as Wonnerup. It runs for almost its entire length behind a low coastal barrier dune fringing Geographe Bay and is very shallow, normally only a metre or so deep at its deepest point.

Perhaps this is not the location where one might expect to find a shipwreck. Yet rumours of a wreck in the Deadwater began to circulate not long after Busselton was founded in 1834. The first public reference to the wreck appeared in a Perth newspaper, the Inquirer and Commercial News, in 1856:

'For years past it has been reported that the remains of a Dutch vessel were to be seen in a portion of the Wonnerup Inlet termed the Dead Water, and some persons stated they saw the wreck' (Anon. 1856:3)

Apparently a search for the wreck triggered the newspaper report, which added that 'the party returned unsuccessful'. Five years later, a paper, 'On the geology of a part of Western Australia.' published in London by the Geological Society of London, revealed further information about the wreck:

'remains of a vessel of considerable tonnage have been discovered in a shallow estuary near the Vasse Inlet, now quite shut out from the sea, which, from its appearance I should judge to have been wrecked more than two hundred years ago, during which time the land appears to have risen two or three feet [60-90 cm]' (Gregory 1861:482)

Apart from its apparent age, the situation of the wreck, 'shut out from the sea' where the land had 'risen two or three feet', was indeed a rather curious aspect to the account. The informant Frank Gregory's credentials are well-accepted however, he was a surveyor who became an explorer of some renown, receiving the Royal Geographical Society's Founder's Medal in 1863, later becoming a member of the Legislative Council in Queensland (Erickson 1987:2:1271).

Further incidental information was recorded in 1869 in the diary of local settler, Henry Prinsep, who wrote, 'saw Reynolds who told me he had found the old ship in the dead water at Wonnerup' (Prinsep: 1 May 1869). Then in 1876 the local timber company foreman, Thomas Bindloss, applied to the Colonial Secretary's Office for the salvage rights to the Deadwater Wreck (Bindloss 1876). This triggered further revelations about the wreck. It would appear a party had visited the wreck around 1846. This included Worsley Clifton who was in fact now the Receiver of Wrecks. As a 16 year-old it seems he had visited the wreck in the company of his brother-in-law George Eliot, the Resident Magistrate of Bunbury at that time (Clifton 1876). While there is no definite link, that visit may have been promoted by Gregory, who was surveying in the area early in 1847 (WAS 32a), and mentions in his paper of 1861 that he had seen the wreck about 15 years previously.

In his reports to the Colonial Secretary, Clifton stated that the wreck was, 'situated in ... the Dead Water ... to the North of its present mouth about 40 yards [36m] from the beach and 2¼ miles [3.6km] from the Jetty of the West Australian Timber Company,' and that there was a 'sand hill of low height between her and the Sea.' He went on to say that it was 'covered in Water, Sand and Seaweed to a depth of about fourteen feet [4.2m],' and that it 'is evidently ancient'.

In describing the remains of the vessel *Clifton* observed that, 'from the crutch of her Boom, rings of the mast, and large grappling Iron found many years ago, near the wreck which I have seen, it must have been a very large ship.' He also noted that 'Two ancient coins, I was informed by the late J. G. Bussell JP were found on the sand beach a few years ago ... - also about 70lbs [32kg] of quicksilver was found in the sand, loose ...'

It would appear Bindloss's salvage claim also led to further investigations of the wreck being carried out. Captain W. E. Archdeacon, leader of an Admiralty hydrographic survey being conducted in that part of Western Australia (Anon. 1876:3), and Alfred Burt, one of the surveyors, reportedly visited the wreck-site around this time. Burt, who became the Registrar of Titles and Deeds, recalled years later that one of the early settlers in the district, John McGibbon, had informed him that 'some old timbers still standing in the middle of deep water about half a mile [800m] from shore had, when the settlers first arrived in the Vasse, formed part of the hulk of an old ship' (DCC 1910). McGibbon led Captain Archdeacon and Burt to the 'mysterious old ship', and informed them that 'according to rumour, it was the remains of an old Dutch man o'war' (Cowan 1929). According to Burt it 'was embedded in sand and water of a land-locked pool not far from the sea', it 'stood two or three feet [60-90cm] above the water', had 'a high stern', and was 'built in the olden style' (Cowan 1929).

Bindloss's salvage claim was immediately contested by farmer Joseph Reynolds, the same individual Prinsep had mentioned in his diary. It appears Reynold's case rested on the fact that he had leasehold on that portion of the Deadwater where the wreck was located (Clifton 1876). Reynolds had purchased the land in 1860 from the estate of John Hurford who had been murdered by his wife Bridget and her lover in 1855. But Reynolds' appeal was rejected and Bindloss was awarded the salvage rights.

There the matter rested for 26 years, apart from some commentary provided by Augustus Gregory. Augustus Gregory, also a surveyor in Western Australia at the same time as his brother Frank, had carried out surveying work in the area in 1854 (WAS 32b). He was to become even more renowned as an explorer than Frank and went on to become the Surveyor-General in Queensland, and a member of the Queensland Legislative Council as well (Erickson 1987:2:1271). In the 'Inaugural Address' he gave to the first meeting of the Queensland Branch of the Geographical Society of Australasia in 1885 he referred to the Deadwater Wreck, noting that it was a vessel, 'the construction of which indicated a very early date in naval architecture' (Gregory 1886:24). Some years later he added to this, indicating:

'This wreck is wholly covered by the tide, and was found by a bather, who, resting on what he took for the stump of a tree, found that it was the mast of a vessel. Several articles were recovered from the wreck, and their patterns are similar to Dutch ships of that period [late 17th century]' (Gregory 1902-3:131)

Figure 1: Probable Location of the Deadwater Wreck.

By 1902 Bindloss had either died or disappeared because Reynolds applied for, and was granted, the salvage rights to the Deadwater Wreck in that year. He stated that his intention was 'to get up the wreck that is on my land' as he put it (Reynolds 1902). Reynolds may have actually already removed material from the wreck in the 1860s. As mentioned, he had told Prinsep in 1869 that he had found the wreck, and in his letter to the Colonial Secretary's Office in 1902 he admitted that, 'In 1860 I sent up all the ironwork belonging to the wreck' (Reynolds 1902). Julius Brockman, a teenager working in the area at the time, also claimed that, 'When I was a boy, I remember Mr Reynolds got relics from the wreck, knives, forks and other things' (Halls 1981:18, Brockman 1987:23,26).

After Reynolds was granted the salvage rights the wreck seemingly disappeared, despite E. L. Grant Watson's (Watson 1968:74-5) claim to have visited the wreck-site in 1910. Watson came to Western Australia in that year with A. R. Brown (later Professor Radcliffe Brown) as part of a Cambridge University anthropological expedition to Western Australia. Before departing Western Australia, Watson asserts he travelled to the Busselton area and saw the wreck. Watson's account appears to be a case of plagiarism and fabrication however. There are gross factual errors and inconsistencies contained in the narrative of his visit to the area and some of its tourist attractions. His description and discussion of the wreck, furthermore, mirrors the content of an article published in a Perth newspaper, the Western Mail, at the time (DCC 1910), including misconceptions contained in that article (Gerritsen 1995:11-12). In 1914 journalist Dirksey Cowan, the author of the newspaper article, specifically searched for the wreck, without success.

Based on the various scanty reports of the wreck it is estimated to have been about 30 metres long and dating from the period 1650 - 1750 (Gerritsen 1995:14-16). Regarding the location of the wreck, informants appear to consistently indicate that it was in the Deadwater, and that there was a low dunal ridge between it and the sea. Clifton's account provides a fairly specific location, '2¼ miles [3.6km] from the Jetty of the Western Australian Timber Company at Wonnerup' [where 'ramp' is located on the beach in south west corner of Map 1], and '40 yards from the beach [36.6m].' Reynolds claim that it was on his land, Sussex Location 11, which encompassed all of the Deadwater, is consistent with this.

While a considerable body of evidence, from credible sources, point to an historic wreck of some size having been found in the Deadwater in the 19th century, unfortunately there are also significant inconsistencies, contradictions and complications. McGibbon, who led Burt to the wreck, is reputed to have claimed it was in 'deep water about half a mile [800m] from shore,' whereas Burt later indicated that it was in 'a land-locked pool not far from the sea.' When measured in 1994, the middle of the Deadwater lay only 185 metres from the shore of the adjacent Geographe Bay (Gerritsen 1995:18). Geographe Bay has a dynamic shoreline that advances and then retreats, as a result of storm surges, by up to 200 metres in a cycle that has a period of about 60 years (Gerritsen 1995:18-19). But even allowing for this there is a clear inconsistency. Furthermore, the son of one of the earliest British settlers in the district, George Layman II, recalled that 'as a boy he used to fish from the wreck and when he jumped about on it, it moved up and down' (Halls 1981:20). Not what one would expect of a large deeply-embedded vessel. A Mrs H. M. Maguire, in her reminiscences recorded in 1936, referred to a wreck she had seen in the 1871, in which 'only the deal planking' was visible at that time (Halls 1981:17). She thought the wreck had a 'length of about fifteen feet' (Halls 1981:19). Both these sources are seemingly at odds with accounts of a vessel with a 'high stern', of 'considerable tonnage' and buried to a 'depth of fourteen feet' and 'two or three feet above the water'.

Another area of inconsistency relates to the location of the wreck. An account by another local, Frank Ryall, refers to a vessel also '15 feet long' with decking, from which he had fished as a boy in 1928. This wreck was located at the entrance of the Deadwater, just over one kilometre from the site where the Timber Company's jetty had been (Ryall 1994; Personal Communication - F. Ryall, 21 February 1995). Another elderly resident, John Bax, when interviewed in the 1990s, indicated that he had known 'for years' about the 'ribs of a long-boat' in the same location as identified by Ryall (Cullity 1992).

Perhaps the simplest explanation for these contradictions is that there is more than one wreck in the area. There is certainly historical evidence that there was another vessel wrecked in the area prior to colonisation. In late May 1801 the French Baudin Expedition commenced its scientific exploration of Australia, with high hopes that they could emulate the success of Captain Cook's voyages along Australia's east coast and in Pacific. On 30 May, the Geographe and Naturaliste entered Geographe Bay and in the following days the scientists enthusiastically reconnoitred the countryside. By 4 June the expedition had moved to the eastern side of the bay and continued their investigations, even managing to make contact with some of the local Indigenous population, the Wardandi. In the early hours of 5 June Baudin sent the Geographe's 'chaloupe', its longboat, under the command of his 'flag-captain' Citizen Le Bas to explore the Wonnerup-Vasse Estuary (Baudin 1974:176). Early in the evening, with an 'on-shore gale', the 'chaloupe' became trapped on the lee shore and was carried 'on to the beach' by large waves, which then swamped it. By the next morning it had already become partially filled with sand (Peron 2006:76-77). This appears to have been in the vicinity of the mouth of the Estuary.

Because of the stormy weather it was a day before Baudin could be informed. The following day, 7 June, equipment was sent ashore, 'cables, casks, pulley-blocks, purchase-tackle' (Peron 2006:81), and for a day and half they tried to refloat the longboat. But, with a deep low pressure system approaching it was decided to abandon it, the salvage equipment and the scientific specimens, and retrieve all the crew and scientists still on shore. By the early evening, with an intense cold front almost upon them, the last of the crew were retrieved. In the darkness, with wind approaching gale force and two metres waves crashing over the boat, they dragged the last six men from the shore to the boat with ropes. Alas one of the crew, Timothee Vasse from the Naturaliste, was lost in the darkness, swept away on his third attempt to clamber on to the boat. The ships then immediately sailed out of the bay and made for deeper water.

It has been cogently argued that rather than there being two wrecks, the chaloupe is in fact the Deadwater Wreck. The main proponent of this view, Henderson, is a highly respected maritime historian and maritime archaeologist, and former Director of the Western Australian Maritime Museum. In his view longshore drift caused 'a build-up of sand on the seaward side of the chaloupe', thus bringing it into the estuary (Henderson 1980:57-63; 2007:85-87). He ascribes all the reports about the Deadwater Wreck, of the distances involved, descriptions of the vessel, the salvage claims, and the materials recovered, to the French longboat.

Certainly there appears to have been changes to estuarine outlet. The first British explorers in the area, Collie and Preston in 1829, and later Lt. Bunbury in 1836, indicate that the Vasse and Wonnerup Estuaries had a dual outlet (Collie and Preston 1829:102-3; Bunbury 1930:99-100). The first survey by H. M. Ommanney in 1838 (WAS 32c), as well as the earliest maps of the area (e.g. Landgate:1850), also show separate outlets, about 1.5 kilometres apart. But the separate outlets appear to have disappeared by 1870, and the original Wonnerup Estuary outlet is now the approximate location for the current joint outlet (Wonnerup Inlet), with the more southerly outlet blocked. And, as would be expected, sediment accumulation at the current joint outlet seems to have led to a progradation of the coast there.

The argument that the chaloupe and the Deadwater wreck are the same vessel may not be sustainable however. The confluence of the Vasse-Wonnerup outlet and the mouth of the Deadwater is only about 1.2 kilometres from the site where the Timber Company's jetty had been, whereas the early reports of the Deadwater Wreck describe it as 'quite shut out from the sea' and being 3.6 kilometres from the jetty. Nineteenth century observers also describe it as being a 'ship', 'ancient', or of an 'early date in naval architecture,' descriptions that do not appear to be consistent with the longboat. Materiel, such as mast rings, the 32 kilograms of 'quicksilver' *[mercury]* and the two 'ancient coins' would not appear to be consistent either with the remnants of the longboat, equipment brought ashore in the salvage attempt on 7-8 June 1801 or the abandoned possessions of the French scientists. Furthermore, it has been reported that on Sunday, 15 February, 1959, 'in a quiet backwater of the Vasse Estuary at Wonnerup,' sand miners 'found a 14-feet [4.3m] section of what appears to have been a ship's boat,' which they removed, placing on the back of a utility vehicle and taking it away (JR 1959). Alas this action probably resulted in its rapid disintegration. Consequently, it can be inferred from these lines of evidence that there were two distinct wrecks, the Deadwater Wreck at the northern end of the Deadwater, and the chaloupe at the mouth of the Deadwater, with the latter having been destroyed in recent times.

There have been a number of proposed attempts to search for the Deadwater Wreck in the last century or so. Many have come to nothing. Nevertheless, several attempts have been undertaken, stimulated in most instances by particular finds. An array of items have turned up which initially were claimed to have a possible association with the Deadwater Wreck. These include a cannon, at least one pistol, at least two anchors, a large rudder and a ship's 'knee' or 'stanchion'.

The cannon appears to have been retrieved from a foundry in the early 1960s, before it could be smelted. But when its provenance was investigated it was ascertained that it probably came from the Grace Darling, a ship that ran aground in Geographe Bay near the estuary outlet in 1874 (Henderson and Henderson 1988:134; Gerritsen 1995:34; McRae n.d.:1-2,13-15). The pistol, donated to the Western Australian Museum by J. G. Reynolds early in the 20th century, was found upon examination to be an American 'Bootleg' pistol, manufactured in the period from 1830 - 1860. As American whalers called in and operated around Geographe Bay in the 1840s, it is thought to have come from one of these vessels. Two distinct finds of anchors have also been reported. One was found somewhere near the Deadwater during sand (ilmenite) mining operations but 'disintegrated after being left out' (Wells n.d.). The rusty fluke of another anchor was found by Gary Dillon 'years ago' in the middle portion of the Deadwater (O'Brien n.d.). A magnetometer search in 1990 at the location where it had been found yielded nothing

Figure 2: Location where the longboat had been.

further (Coroneos et al. 1990). In the 1960s a large rudder was located at the southern end of Rabbit Island in the lower Vasse Estuary. Ilmenite miner Len Brennan and school headmaster Ted Sommerville attempted to extricate the rudder, which was buried in a bank, using a bulldozer. Unfortunately the rudder, reportedly '8-10 feet high [2.4-3.0m]' fell to pieces and the remnants were left in situ (Reynolds 1992; Personal Communication -A. J. Reynolds, 11 May 1995). Early in 1995 some 'planks and ironwork' from the rudder were salvaged and sent to the Western Australian Maritime Museum (WAMM) for testing. Analysis showed the rudder to be made of some variety of local eucalypt, indicating it derived from the Colonial Period or later. It too may have come from the Grace Darling. (O'Brien 1995:24 April 1995; Personal Communication - D. Garratt, 26 April 1995). Lastly, the ship's knee, with some iron straps attached, was discovered in the upper portion of the Deadwater by Brian McRae in 1989. The knee was made out of a mahogany, Swietenia macrophylla, found in the Honduras and Central and South America (McRae n.d.:6-7,16-17). An investigation on behalf of WAMM concluded, however, that it dated from the mid-19th century or later because the straps were 'cast, rather than wrought iron' (Coroneos et al. 1990:22). A magnetometer search at the site revealed nothing further (Coroneos et al. 1990).

Searches for Deadwater Wreck have faced a number of confounding factors. Clearly the wreck has been significantly degraded by pilfering and salvage. Consequently it is conjectured that all that is likely to remain is the bottom, some cannons and an amount of non-structural debris. The wreck may have been further disturbed by small-scale ilmenite mining operations in the 1960s. The extent of this is uncertain, with some informants saying the Deadwater was dredged for its entire length, others that only 1% was mined, or that it was mostly just the lower portion of the Deadwater. There is still disagreement about this, but in my view the last option is probably correct (Gerritsen 1995:77-80; Henderson 2007:88).

The third confounding factor is the presence of ilmenite in the area. Ilmenite, a crystalline form of iron titanium oxide ($FeTiO_3$), is weakly magnetic. Consequently it gives rise to false magnetometer readings, so that searchers trying to relocate the chaloupe using this technology, for example, excavated several small areas where an anomaly was detected, only to find it was just a patch of ilmenite. (O'Brien n.d.; O'Brien, Harewood and Rooney 1994). This problem could of course be overcome by employing other remote sensing technologies.

Two questions remain regarding the Deadwater Wreck. What ship was it and how did it get there? McRae has suggested it may have been a Portuguese caravel, based on the wood from the knee he found (McRae n.d.). This raises the spectre of the notorious 'Mahogany Wreck', supposed by some to exist on the western coast of Victoria in south eastern Australia (Potter 1987; Powling 2001). It also would give some support to highly contentious claims that the Portuguese preceded the Dutch to Australia. However, the assertion by A. C. Gregory that Dutch artefacts had been retrieved, rumours from an early stage that it was a Dutch vessel, and the frequency of Dutch ships being wrecked in Western Australian waters, strongly suggest that it was a Dutch vessel. There are four Dutch ships from the 17th and 18th centuries of which we are aware that are unaccounted for, that is, they sailed from Cape Town into the Indian Ocean and were never heard from again. These are the *Zeelt* (1672), the *Ridderschap van Holland* (1694), *Fortuyn* (1724) and *Aagtekerke* (1726). The *Fortuyn* may have been destroyed by a cyclone south of Java, while the *Ridderschap van Holland* is suspected to have been taken by pirates off Madagascar and ultimately wrecked (Henderson 2007:41-45,53-57). Of the remaining two, the *Zeelt* is favoured. Although nothing is known of their fate, the size of *Zeelt,* a 90-ton hooker, seems more consistent with the hypothetical size of the Deadwater Wreck than the 850-ton, 43.5 metre, *Aagtekerke* (Henderson 2007:57-58,69). The earlier date for the Zeelt may also be in its favour as some of the terminology used in reference to the Deadwater Wreck seems to suggest a vessel from the earlier part of the putative date range, 1650 - 1750.

The second question, as to how it found its way into the part of the Deadwater where it finally came to rest, is an interesting one. I contend it came through a now defunct northern outlet, formerly the main outlet for the estuarine system. This feature can be seen in the Google Earth image below.

There are several grounds for this contention. A bank, about two metres high, forming the Deadwater's inland side, curves round to the beach at its north-

Figure 3: Northern Outlet of Deadwater (Google Earth™ mapping services).

ern end. This curve can be seen in Map 1 and the Google Earth image if one follows the line of Forrest Beach Road. At the northern outlet the dunal ridge on the seaward side of the Deadwater is much lower than further south. Historical, geomorphological and cartographic evidence also indicates the water in the Deadwater was much deeper and extended further north in the past. Surveyor Ommanney reported in 1838 that the Deadwater had 'very deep water' (WAS 32c Letters:75) and the 1850 map (Landgate 1850) shows the water extending almost as far as the northern end of the Deadwater. The inland ridge, made of an admixture of limestone, sand and loam shows undercutting at levels a metre or two above the present water level. The resultant scenario suggests the northern outlet formed the main outlet for at least the Wonnerup Estuary in the past, that the ship sailed into the Deadwater through this outlet, and then grounded in the area the wreck has been reported, where it was abandoned.

With the blocking of the northern outlet, the Deadwater slowly began to silt up. But the water level was still high, as attested by Ommanney. This is probably what made the wreck difficult to find in earlier days, as indicated by A. C. Gregory's account of how it was first found. It may have only been visible when water levels were low, and this only occurred when a lengthy dry spell and low tides combined. A series of drainage and flood control measures undertaken since the 1920s appear to have also significantly affected the Deadwater, and this is what has primarily led to water levels falling and retreating to their present configuration, leading to increased siltation (Gerritsen 1995:40).

The 'northern outlet' scenario and the photo of the probable wreck site may also resolve a couple of the apparent contradictions noted earlier. McGibbon's reputed comments, that the wreck was in 'deep water half a mile from the shore' takes on new meaning when it is realised that he lived north of the northern outlet, with his house almost the only private residence shown on the 1876 Admiralty survey chart in which Burt was involved in preparing (WASA: CONS 3847). Thus McGibbon may have been using the northern outlet as his reference point, as a measurement of 800 metres from the northern outlet comes to the same location identified as the wreck-site based on the distance provided by Clifton. Finally, it will be noted in Figure 1 there is a narrow sandy strip running around the northern side of the water. This sandy strip, usually wider when the tide is lower (Personal Observation), is the type of feature I believe was being referred to regarding the coins found on the 'sand beach' and the wreck being '40 yards from the beach'. Given the changes in water and silt levels, the beach in Figure 1 is not the same beach as the one originally referred to, but most likely a similar beach formed at the northern edge of where the water extended to formerly.

So what is the future of the Deadwater Wreck? The Australia on the Map Division of the Australasian Hydrographic Society last year adopted the search for the Deadwater Wreck as one of its projects. They are endeavouring to arrange for a systematic professional archaeological search for the wreck. Hopefully this will take place in the not too distant future and the mystery of the Deadwater Wreck will finally be laid to rest.

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(WAS[A] refers to Western Australian State Archives)

Biography of the Author

Rupert Gerritsen is an independent scholar based at the National Library of Australia. His best known work is And Their Ghosts May Be Heard, a detailed exploration of the fate of the Dutch mariners marooned on the Western Australian coast in the 1600s and early 1700s. He has published extensively in historical ethnography, archaeology, maritime archaeology and historical linguistics. He was co-founder of "Australia on the Map: 1606 - 2006", and is currently Chair of the "Australia on the Map Division of the Australasian Hydrographic Society."
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Article



Total Propagated Uncertainty (TPU)

for Hydrographic LiDAR to Aid Objective Comparison to Acoustic Datasets

By Carol Lockhart, Doug Lockhart and José Martinez, Fugro Pelagos (USA)

Abstracts

Previously, when comparing LiDAR datasets to other LiDAR or acoustic datasets, comparisons have always presumed that one control dataset is ultimately correct, with no errors. All error is attributed to the second dataset. Surface and target analysis methods have therefore been somewhat subjective. The use of TPU takes into account the fact that each depth point is an estimate with an associated uncertainty. This paper discusses a method to derive TPU for LiDAR sensors, so that CUBE may be used to perform an objective comparison of LiDAR bathymetry and acoustic datasets.

Résumé

Auparavant, lorsque Ton comparait des ensembles de données LiDAR à d'autres ensembles de données LiDAR ou accoustiques, on présumait qu'un ensemble de données de controle était finalement correct, sans aucune erreur. Toute erreur était attribuée au deuxième ensemble de données. Les méthodes d'analyse de surface et d'objectif étaient toutefois quelque peu subjectives. L'utilisation du TPU prend en compte le fait que chaque point de profondeur représente une estimation à laquelle est associée une incertitude. Cet article traite d'une methode en vue de dériver le TPU pour les capteurs LiDAR, de facon à ce que CUBE puisse être utilisé en vue d'établir une comparaison objective de la bathymétrie LiDAR et des ensembles de données acoustiques.

Resumen

Previamente, cuando se compara la base de datos LIDAR con otras bases de datos LIDAR o acústicos, las comparaciones siempre presumen que una base de datos de control es finalmente correcta, sin errores. Todo error es atribuido a la segunda base de datos. Los métodos de análisis de blancos y superficie ban sido por lo tanto en cierta medida subjetivos. El empleo de TPU toma en consideratión el hecho que cada puto de profundidad es una estimación con una incertidumbre asociada. Este articulo discute un método para derivar TPU del sensor LIDAR, de forma tal que CUBE pueda ser empleado para hacer una comparación objetiva delas bases de datos de batimetría LIDAR y acústica .

In August 2007, Fugro Pelagos collected data with the SHOALS-1000T bathymetric LiDAR system in Shilshole Bay, Seattle, for NOAA Office of Coast Survey (OCS). Data were collected at various spot spacings, altitudes, and times of day, over an area previously surveyed with an 8101 multi-beam echo sounder. In addition, the area contained targets of known size, built and placed on the seafloor by Fugro Pelagos in 2005. Data were collected to study the Total Propagated Uncertainty (TPU) of the SHOALS-1000T LiDAR measurements and the system's target detection capabilities.

Target detection tests have been conducted previously over the Shilshole area, for the LADS, SHOALS-400 and SHOALS-1000T sensors (McKenzie et al., 2001; Lockhart et al., 2005). However previous comparisons, have always presumed that the multibeam control dataset is ultimately correct, with no errors. Therefore, all error is attributed to the LiDAR dataset. Surface and target analysis methods have consequently been somewhat subjective. In addition in areas with many targets, they can become very labour intensive. Target detection for hydrographic surveys is currently specified by the International Hydrographic Organization (IHO) Special Publication No. 44 (IHO, 1998).

The use of Total Propagated Uncertainty (TPU) takes into account the fact that each depth or elevation point is an estimate with an associated measurement uncertainty. These uncertainties can then be used by the Combined Uncertainty and Bathymetry Estimator (CUBE) algorithm developed at the University of New Hampshire (Calder and Mayer, 2001) to build an attributed bathymetry surface: now a required standard deliverable for NOAA OCS.

If surfaces can be built, with knowledge of the uncertainty, then there is the potential to use the CUBE algorithm to compare these different density multibeam and LiDAR datasets more objectively, including for target detection. In theory this would allow the analysis of the final surfaces to see if they represent the same seafloor, and targets, once the uncertainty of the measurements is taken into account.

Before the CUBE analysis can be conducted however, TPU models must exist for each dataset. Although TPU is now commonly used for multibeam data processing, a TPU model did not exist for the SHOALS-1000T data. Therefore the first step was to develop this uncertainty model.

Data Acquisition

Shilshole Bay in Puget Sound, Washington has been used extensively in the past by NOAA OCS and Fugro Pelagos to conduct multibeam sonar and LiDAR verification surveys. For this study, multibeam data was acquired with a Reson 8101 multibeam echosounder (MBES) in 2005, shortly after manufactured targets were placed on the seafloor. Figure 1 shows a colour-coded DEM of the MBES coverage, the location of the targets and the planned extents of the LiDAR acquisition.

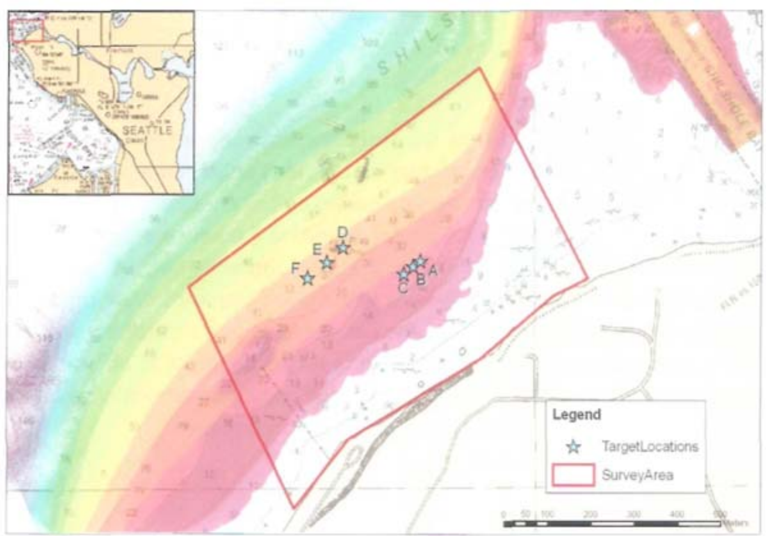

Figure 1: Survey Location, Shilshole Bay, Puget Sound (WA, USA).

The targets themselves are boxes constructed from steel, as shown in Figure 2. Three sizes were constructed: 2x2x2m, 2x2x1m and 1x1x1m. One target of each size was placed in 7m water depth (reduced), and another set of targets was placed at approximately 12.5m water depth, as indicated in Table 1. Although initially reflective, over time these targets reflectivity has become very similar to that of the surrounding seafloor (Figure 2).

Target ID	Target Description	Latitude	Longitude	Approximate Depth (m)
A	2x2x1m	47-40-16.42N	122-25-12.67W	7
B	2x2x2m	47-40-16.06N	122-25-13.47W	7
C	1x1x1m	47-40-15.53N	122-25-14.46W	7
D	2x2xlm	47-40-17.45N	122-25-21.19W	12.5
E	2x2x2m	47-40-16.38N	122-25-23.01W	12.5
F	1x1x1m	47-40-15.25N	122-25-25.10W	12.5

Table 1: Shilshole Target Descriptions.

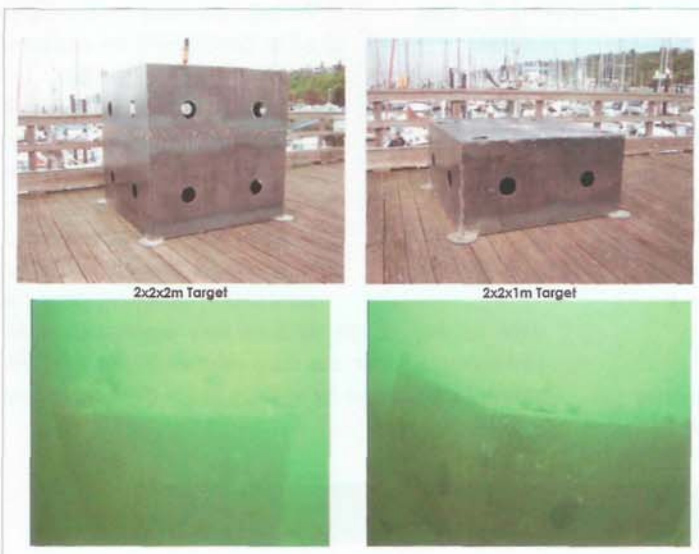

Figure 2: Targets: Constructed and on the Seafloor in December 2007.

mean high water (MHW) line out to the 20m depth contour. The survey limits included the area where targets were set on the seabed in 2005.

Survey flight missions were conducted at various spot spacing, flight altitudes, flight line directions and time of the day as shown in Table 2. In all instances lines were planned with 20% overlap. These multiple datasets were collected so that percentage of data coverage (i.e. 100%, 200%, 300%, etc.), flight altitude, flight direction and time of day could be assessed to see how each factor may or may not affect bathymetric LiDAR target detection.

The SHOALS-1000T survey took place on 27 to 29 August 2007 during which the following data were collected:

- Bathymetric LiDAR data from the SHOALS-1000T
- Digital Aerial Photography from the SHOALS-1000T
- GPS Ground Control

A complete description of the SHOALS-1000T can be found in Guenther et. al. *Meeting the Accuracy Challenge in Airborne Lidar Bathymetry.* This document is generally available on line.

The hydrographic LiDAR flight lines were planned to collect data from the approximate location of the

Figure 3: SHOALS-1000T as installed. The operator console is to the left, power and cooling are in the center stack, and the laser, IMU and camera are to the left.

Mission	Spot Spacing (m^2)	Altitude	Direction	Time of Day
1	3x3	400m	E→W	Day
2	3x3	400m	W→E	Day
3	3x3	400m	E→W	Day
4	3x3	400m	E→W	Night
5	3x3	400m	W→E	Night
6	3x3	300m	E→W	Night
7	3x3	300m	W→E	Night
8	2x2	400m	E→W	Day
9	2x2	400m	W→E	Day
10	4x4	400m	E→W	Day
11	4x4	400m	W→E	Day

Table 2: Bathymetric LiDAR Acquisition Missions

LiDAR Data Processing

Raw SHOALS-1000T data from the airborne system were downloaded into the Optech SHOALS Ground Control System (GCS) on Windows XP workstations. GCS includes links to Applanix POSPac software for GPS/inertial processing and to IVS Fledermaus software for data visualization and 3D editing. GCS was used to apply the KGPS/inertial solutions, apply tide data, auto-process the LiDAR waveforms, edit data and export point cloud files to ASCII XYZ format files. The ASCII XYZ files were used for TPU calculations.

Edited data were also imported to CARIS HIPS for analysis with the CUBE algorithm.
In order to assess σthe affect of data coverage percentage, flight altitude, flight direction and time of day, on target detection, flight missions were organized into processing datasets (Table 3) prior to data editing,. Each dataset was processed independently, so that the data editor did not gain additional knowledge by looking at all flight missions at once.

Dataset	Missions Included
A	400 m @ 3x3 200% coverage with flight in **opposite** directions
B	400 m @ 3x3 200% coverage with flight in **same** directions
C	400 m @ 3x3 200% coverage with flight in opposite directions at night
D	400 m @ 3x3 **300%** coverage
E	400 m @ 3x3 **400%** coverage
F	400 m @ 3x3 **500%** coverage
G	**300 m** @ 3x3 200% coverage with flight in opposite directions
H	400 m @ **2x2** 200% coverage with flight in opposite directions
I	400 m @ **4x4** 200% coverage with flight in opposite directions

Table 3: Processing Datasets.

Derivation of SHOALS-1000T TPU Model

The TPU can be understood as the sum of all random and systematic uncertainties in the measurement process, including the uncertainty contribution of all sensors embedded in the SHOALS-1000T system. Determining each sensor's uncertainty independently to develop a TPU is a work in progress. Due to the complexity of the physical interaction of the laser pulse with the sea surface, sea water and sea floor an analytical TPU may not be possible. Therefore, at this time, an alternate method must be used to derive a TPU estimate for the SHOALS 1000T system.

This study uses depth variance as a proxy for an analytical TPU. Because the bathymetric LiDAR footprint spreads with depth, as the light scatters and absorbs in the water column, the SHOALS data were separated into ASCII XYZ files with discrete depth ranges, starting at 2m water depth down to 16m, at 2m step increments. For each depth interval, variance is estimated as a function of horizontal radius. This variance function is then calculated for a radius of zero giving vertical variance for that depth interval.

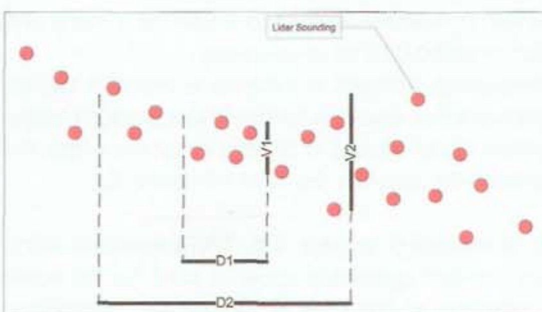

Figure 4: Variance as a function of distance.

Figure 3 shows the increase in variance with increased radius of investigation. The red dots show sounding depths and there is an apparent slope from left to right. In this study, the variance is initially assumed to be isotropic; and assumption that is clearly in error. Slopes and other features such as sand waves will result in anisotropic variances. An effort is made at a later step to identify and account for geographically associated anisotropy. There is no effort in this study to identify instrument based anisotropy.

For all depth intervals, total variance is expected to grow with each incremental search radius; however, variance growth as a function of distance, defines a function that allows the estimation of variance at zero radius, which cannot be resolved directly. A variogram is used to determine the node variance when the constant of a polynomial fit is found, as shown in Figure 5. Variance functions for each depth interval are shown in Figure 6.

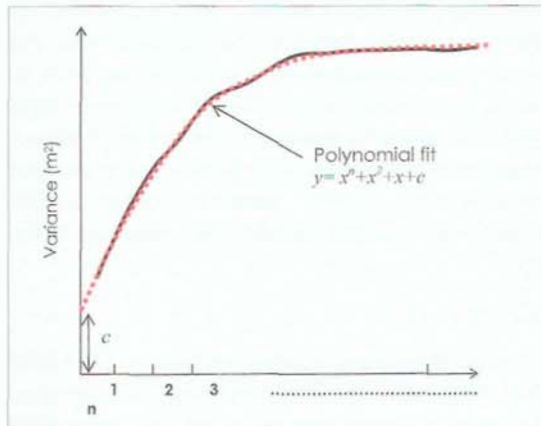

Figure 5: Variogram for Determining Node Variance.

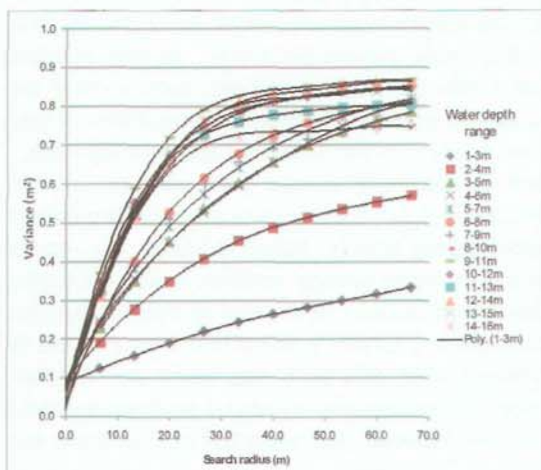

Figure 6: Variance Function for each Depth Interval (including Zero Radius).

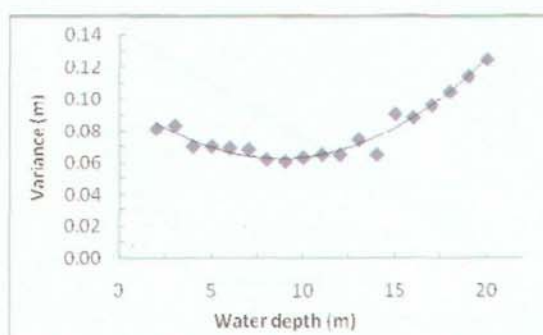

Figure 7: Variance as a Function of Water Depth.

Calculated node variances for each depth interval are shown in Figure 7. From this, one can see that variance fluctuated between 0.07-0.09m to 15m water depth and then grew to about 0.125 m at 20m water depth.

This total variance estimate (σ^2_T) calculated as described above, includes the variance from the sensor measurements as well as the variance inherent in the seafloor (σ^2_s) due to slope and roughness. Therefore to produce an estimate of sensor measurement variance (σ^2_m), an estimate of seafloor variance needs to be calculated or modeled and removed from the total variance, as presented in the form:

$$\sigma^2_m = \sigma^2_T - \sigma^2_S$$

To model the natural seafloor variance in the LiDAR data, introduced by slope and bottom roughness, a morphology trend was observed and determined from the gridded multibeam DEM surface. The slope gradient, and the amplitude and frequency of the general bottom roughness, were used in the creation of a synthetic surface grid model. Variance analysis was conducted on the synthetic surface using the variogram approach to provide an estimate of variance solely from the slope and bottom roughness.
Different synthetic surface point densities (0.5m, 1m, 2m and 3m) were used to account for potential sub-sampling effects. Figure 8 shows the results of the synthetic surface variance analysis showing clearly that variance as function of distance remains constant and follows a linear trend not affected by different point density. It was found that the variance for the modeled synthetic seafloor averaged 0.015m. However, due to the use of a synthetic surface, it is likely that this is a low estimation of actual seafloor variance. Estimated seafloor variance was then removed from the total variance to provide an estimate of the sensor variance. The square-root of final sensor variance (standard deviation) was then used as the TPU estimate, with the value varying dependent on water depth.

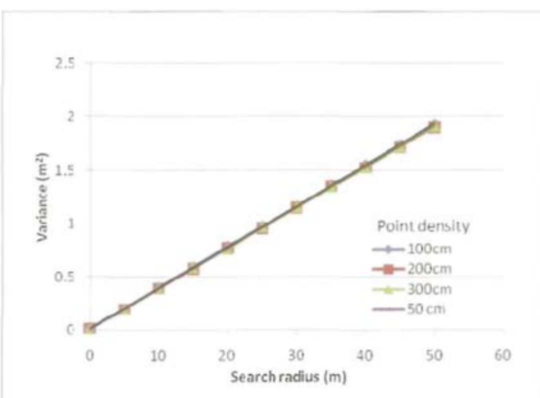

Figure 8: Variance of the Synthetic Seafloor at Varying Point Density.

Table 4 shows the calculated TPU for the Shilshole Bay survey, where maximum bottom depth detection was at about 16 meters. TPU was attributed to each LiDAR depth in CARIS HIPS and used to create attributed uncertainty DEM products.
It should be noted that uncertainty calculated still includes any uncertainty present from the tide application. It would be beneficial to repeat this exercise using PPK GPS LiDAR data on the ellipsoid, to provide a result which more closely represented the sensor uncertainty alone.

Table 4 also shows for comparison the depth accuracy specification for IHO Order 1 given, in the form:

$$D_a = \sqrt{a^2 + (bxd)^2}$$

where D_a is water depth, and values for a and b are 0.5 m and 0.013 m, respectively.
Comparing numbers in columns 5 and 6, it can be deduced that accuracy for the SHOALS-1000T bathymetric LiDAR depths in Shilshole Bay are within the acceptable accuracy limits of IHO Order 1.

It is important to note that TPU estimation using the method presented above is valid for the water conditions at the time of the survey. Bathymetric LiDAR measurement uncertainty will vary depending on local water column conditions and seafloor reflectance. In this study, what we are calculating can be better described as a local estimate of TPU. We do not have enough data from one survey to sample the entire bandwidth of the uncertainty. If water conditions and depth of bottom detection are very similar in other locations sharing common environments, this model can be applied. To use in a different environment, TPU would need to be recalculated using this same method.
This method can also be refined by the use of Kriging, which will allow uncertainty relationships in the along-track and across-track direction to be modeled. This is currently being examined by Fugro Pelagos.

1	2	3	4	5	6	7	8	9
Depth (m)	Total Sea-floor Variance (σ^2_T) m²	Synthetic Seafloor Variance (σ^2_s) m²	Sensor Variance (σ^2_m) m²	Sensor Variance of a Mean (σ^2_m)/√2 m²	Sensor StDev (σ_m) TPU m	Sensor 2-StDev m	IHO Order 1 (2-StDev) m	Status
1	0.094	0.015	0.079	0.056	0.236	0.472	0.500	Passed
2	0.083	0.015	0.068	0.048	0.219	0.439	0.501	Passed
3	0.085	0.015	0.070	0.049	0.222	0.445	0.502	Passed
4	0.072	0.015	0.057	0.040	0.201	0.402	0.503	Passed
5	0.072	0.015	0.057	0.040	0.201	0.402	0.504	Passed
6	0.071	0.015	0.056	0.040	0.199	0.398	0.506	Passed
7	0.070	0.015	0.055	0.039	0.197	0.394	0.508	Passed
8	0.064	0.015	0.049	0.035	0.186	0.372	0.511	Passed
9	0.063	0.015	0.048	0.034	0.184	0.368	0.514	Passed
10	0.065	0.015	0.050	0.036	0.189	0.377	0.517	Passed
11	0.067	0.015	0.052	0.037	0.192	0.383	0.520	Passed
12	0.067	0.015	0.052	0.037	0.192	0.384	0.524	Passed
13	0.076	0.015	0.061	0.043	0.208	0.415	0.528	Passed
14	0.067	0.015	0.052	0.037	0.192	0.384	0.532	Passed
15	0.092	0.015	0.077	0.054	0.233	0.467	0.537	Passed
16	0.090	0.015	0.075	0.053	0.230	0.460	0.542	Passed

Table 4: Final Sensor Variance and TPU Values Compared to IHO Order 1.

Using CUBE to Identify Targets in LiDAR Data

CUBE transforms measured points at relatively random locations into regularly spaced depth estimates in a grid. On each grid node, four values are produced: depth, uncertainty (from depth TPU), number of hypothesis and hypothesis strength. Depending on how close or sparse vertically contributing depths are to resulting node value, the algorithm develops more than one potential depth candidate but selects one as the most likely one.

CUBE was designed to aid in the processing of dense multibeam echosounder datasets. However it is not commonly used on sparser bathymetric LiDAR datasets. Some experiments were run to identify suitable CUBE parameters to be used with the LiDAR data points. In the example below (Figure 9), which shows 400% LiDAR coverage, there are 5 LiDAR hits on the target. CUBE successfully generates a likely primary hypothesis (green cubes) from these 5 data points which represent the target. However the primary hypothesis representing the target is relatively weak. The cubes in the image indicate the uncertainty of the measurement in the vertical, with the strength of the hypothesis indicated by the width of the cubes. The CUBE algorithm also generates an alternate hypothesis, shown by the red cubes.

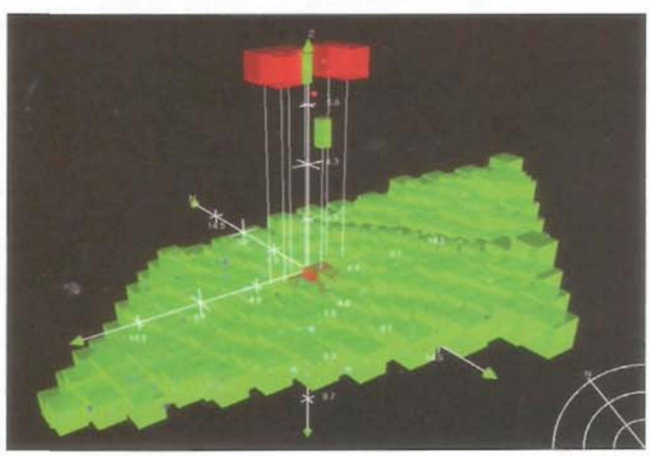

Figure 9 - CUBE Hypotheses for Target B (2x2x2m) in 7m Water Depth with 400% Coverage

In almost all cases, when LiDAR acquired a data point on a target, CUBE correctly created a primary hypothesis, which in some way represented that target. This is likely due to the sparseness of the data, which in many cases with 200% LiDAR coverage or less, prevents the possibility of multiple hypotheses. However the primary hypothesis over the targets was usually weak. In a typical product flow, the primary CUBE hypothesis is then used to create a surface. But if the hypothesis is weak, the surface will not be 'pulled' to the top of the target and will not therefore accurately represent the shallow data points. Further work is still required in order to identify a set of CUBE parameters that will provide a strong primary hypothesis on the targets when they are observed in the LiDAR data.

Conclusions

TPU can be estimated for LiDAR depth intervals through variance node analysis. The analysis can be performed over a small control area in water conditions very similar to the actual main survey area, and therefore could be calculated on a project-by-project, or area-by-area basis.

The calculated TPU presented here for Shilshole Bay still includes any uncertainty present from the tide application to the LiDAR data. It would be beneficial to repeat this exercise using PPK GPS LiDAR data on the ellipsoid, to provide a result which would more closely represent the sensor uncertainty alone.

This methodology for calculating TPU should be further refined and automated with the use of Kriging. At the time of writing, CUBE has not been successfully used to compare the LiDAR and multibeam datasets. However the authors feel that with further effort, particularly in choosing suitable CUBE parameters for LiDAR and multibeam hypothesis selection, this can be accomplished.

Acknowledgements

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Article

The Geography of a Maritime Boundary Delimitation

By Adam J. Kerr (UK)

Abstracts

A Judgment of the International Court of Justice, dated 8 October 2007, resolved the Case Concerning Territorial and Maritime Dispute between Nicaragua and Honduras in the Caribbean Sea. Essentially the case involved the delimitation of the maritime boundary between the two countries on their eastern sides. This paper describes the geographic matters involved in the Judgment and the influence of the availability of modern technology.

Résumé

Un Jugement de la Cour Internationale de Justice, en date du 8 octobre 2008, a conclu l'affaire concernant le différend territorial et maritime entre le Nicaragua et le Honduras dans la Mer des Caraïbes. L'affaire concernait essentiellement la délimitation d'une frontière maritime entre les deux pays sur leurs côtés orientaux. Cet article décrit les questions géographiques soulevées dans le Jugement ainsi que l'influence de la disponibilité de la technologie moderne.

Resumen

Un Juicio de la Corte Internacional de Justicia, de fecha 8 de Octubre, 2008, resolvió el Caso Concerniente a la Disputa Territorial y Marítima entre Nicaragua y Honduras en el Mar Caribe. Esencialmente el caso envuelve la delimitación de la frontera marítima entre dos países en sus lados del este. Este escrito describe los temas geográficos involucrados en el Juicio y la influencia de la tecnología moderna disponibilidad.

Introduction

The written judgment goes at length into the geographic situation in which a solution had to be made (Judgment, Case Concerning Territorial and Maritime Dispute between Nicaragua and Honduras in the Caribbean Sea. 8 October 2007 - hereinafter referred to as the "Judgment"). The two countries both span the isthmus of Central America and have both a Pacific and Atlantic (Caribbean) coast. The Judgment concerned solely the latter. Much of the land boundary between the two countries follows the River Coco. This river, stated to be the longest river of the Central American isthmus, had a significant effect on the Judgment. The actual coastline, particularly that of Nicaragua, is extremely mobile with significant lateral transport of sediments, resulting in the formation of numerous deltas, sandbars lagoons and other features of an unstable coastline (Judgment, paragraph 31). Offshore there are numerous reefs and cays of disputed sovereignty, position and dimensions. To complicate the situation further the available mapping and charting is of uncertain quality. No national charts of the two countries involved are available and the most relevant charts describing the offshore cays are those of the British Admiralty but comprised of surveys dating back to 1830-43 (e.g. UK Chart 2425). Fortunately the availability of modern satellite imagery, in particular that provided by Google Earth, allows a reasonably up-to-date high resolution description of both mainland and island coastlines and features.

Although the Judgment refers to the various underwater physiographic features of the Caribbean Sea and in particular, the description of the undersea feature called the Nicaraguan Rise (Judgment, paragraphs 22 and 27), the decision does not seem to have involved any particular consideration of the offshore submarine geomorphology (Judgment, paragraph 138). This is fortunate because the amount of offshore data available and in the public domain is very sparse. An examination of the GEBCO (General Bathymetric Chart of the Oceans) digital atlas shows very little systematically measured bathymetric data.

Figure 1: Source: Judgement Nicaragua v. Honduras 8 October 2007.

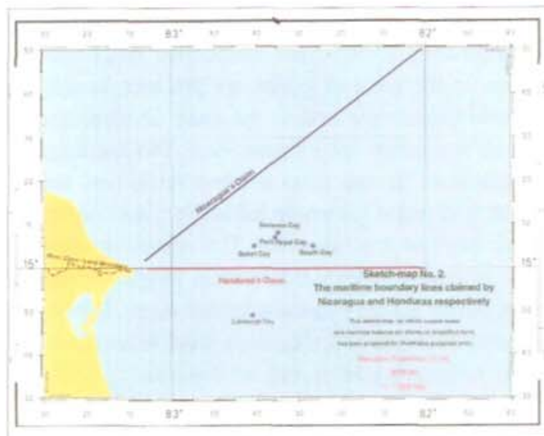

Figure 2: Source: Judgement Nicaragua v. Honduras 8 October 2007.

The General Direction of the Line

In their written and verbal pleadings the two countries took two rather different approaches in defining the boundary. Honduras claimed that a parallel of latitude (14 degrees 59.8 minutes north), projected eastwards from the mouth of the River Coco, should be used. Nicaragua examined the possibility of a median or equidistant line but contended that the present case was not one in which the equidistance/special circumstances approach would be appropriate for the delimitation to be effected. Instead it proposed constructing a maritime boundary from "the bisector of two lines representing the entire coastal front of both states." (Judgment, paragraph 273). Nicaragua asserted that the instability of the mouth of the River Coco was one of the reasons not to use the equidistance method but other factors, such as the convex shape of the coast, makes the method difficult. The Court supported these views and reached the conclusion that the construction of an equidistance line from the mainland is not feasible (Judgment, paragraph 283.)

The idea of a general line of the coast has been used in other cases, notably that of US and Canada in the Gulf of Maine (Delimitation of the Maritime Boundary in the Gulf of Maine Area, Judgment, ICJ Reports 1984), While the Court showed preference for the method proposed by Nicaragua, as opposed to a parallel of latitude proposed by Honduras, it was concerned with the manner in which the general direction of the coasts was proposed. The Nicaraguan pleadings proposed that the lines should be defined from a point at the entrance of the River Coco, which had been the eastern terminus of the land boundary, to the points were the coast of the two countries joined their respective neighbouring states. In the case of Honduras this was its boundary with Guatemala and in the case of Nicaragua it was its boundary with Costa Rica. The Nicaraguan coastal front so defined is approximately 480 km. in length and while generally following the coastline it skirts most of it to seaward. The Honduran coastal front is approximately 640 km in length. It leaves most of the actual coastline to the north. When the bisector of these two proposed lines is computed it tends to have a bias to the northwards.

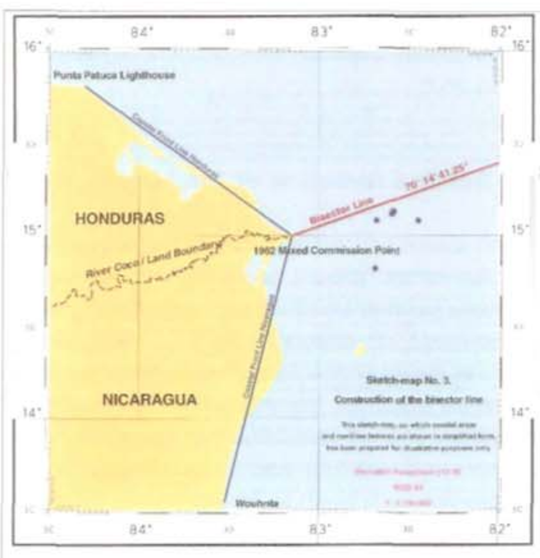

Figure 3: Source: Judgment Nicaragua v. Honduras 8 October 2007.

Before going on to describe the various options for the Court in selecting general directions of coastal fronts it may be useful to digress onto the possible use of a median or equidistance line and its subsequent rejection. The Court had been asked to determine a single maritime boundary between the area of territorial sea, continental shelf and economic zone, in accordance with equitable principles and relevant circumstances recognised by general international law as applicable to such a maritime boundary (Judgment, paragraph 17). Although Nicaragua was not a party to the 1982 Convention on the Law of the Sea (UNCLOS) at the time it filed its application in this case, the parties were in agreement that UNCLOS was now in force between them and its relevant articles were applicable between them in the dispute (Judgment, paragraph 261). UNCLOS differs in its articles 15 describing the delimitation of the territorial sea between states with opposite or adjacent coasts with articles 74 and 83 on the delimitation of the economic one and continental shelf. Article 15 is more prescriptive in terms of the possible use of the median line, although it is not mandatory. In the Judgment, the possible use of the median line was explored but the geography of the coastline in the vicinity of the mouth of the River Coco does not result in a satisfactory solution. As stated by Nicaragua, there are only two points that could control the direction of the line (Judgment, paragraphs 84 & 102). These are a point in Nicaragua and a point in Honduras that face each other across the mouth of the river. From these points the coastlines of both countries trend away to leave the coastline with a convex shape. The approach to drawing a median line between two adjacent states works well enough on a concave coast as the line is well controlled by measuring equal distances from points on the two adjacent coasts. However in the case of a convex coast, such as that at the mouth of the River Coco, the line is very poorly controlled. As historical data presented showed the deltaic mouth to be very unstable and the two points would be liable to frequent change. This would result in a boundary that would be subject to continual change in direction. The problems of using a median or equidistance line were recognised by the Court and some other approach was sought.

In considering the possible use of coastal fronts and a bisector the Court considered three different points along each country's coastline and using a common central point, computed three different bisectors. The points chosen (Judgment, paragraph 293) were:

- For Nicaragua: Punta Gorda, Wounta, Rio Grande.
- For Honduras: Cabo Falso, Punta Patuca, Cabo Cameron.

For the central point, where the coastal fronts met, the Court considered it most convenient to use the point fixed in 1962 by the Mixed Commission, as the terminus of the land boundary. From the above the following coastal fronts could be calculated:

- Cabo Falso (distance 137km) with Punta Gorda (distance 74km)
- Punta Patuca (distance 154km) with Wounta (distance 166km)
- Cabo Cameron (distance 230km) with Rio Grande (distance 235km).

In making these comparisons some matters of geography and geodesy have to be considered. It is necessary to identify prominent points along the respective coastlines and to obtain their geographic coordinates. Due to the rather poor resolution of the map and chart data some assistance can be provided by modern satellite imagery to obtain precise coordinates. As can be seen from the sketch maps attached to the Judgment, these coordinates were referenced to the World Geodetic System 1984 (WGS 84), including the coordinates of the Mixed Commission point of 1962, which can be assumed to have originally been in the North American 1927 datum and had to be converted to WGS 84. In actually computing the azimuths and lengths of the coastal front lines and the bisectors it was important that this be done along the geodesies.

The Court examined each possibility and decided (Judgment, paragraph 298) that the front that extends from Punta Patuca to Wounta, would avoid the problem of cutting off Honduran territory (as proposed in the original Nicaraguan proposal) and at the same time would provide a coastal façade of sufficient length to account properly for the coastal configuration of the disputed area. Thus a Honduran coastal front running to Punta Patuca and a Nicaraguan coastal front running to Wounta were, in the Court's view, the relevant coasts for drawing the bisector. The resulting bisector has an azimuth of 70 degrees 14 minutes and 41.25 seconds.

The Effect of the Cays

It was noted earlier that a number of reefs and cays are located off the relevant coast. It was stated that the cays are small, low islands, comprised largely of sand derived from the physical breakdown of the coral reefs. The reefs are very extensive but the cays are small (see UK Chart 2425). Depending upon the sovereignty and location of these features the Court had to decide in what way they may influence the boundary line. This not only brought into question matters of a social nature but of physical geography and its interpretation. The mapping and charting of these offshore features is probably even less precise than that of the mainland. Most of the reefs and cays that had a possible bearing on the case were located approximately 20 miles off the mainland and as such, outside the territorial sea. Although the charts and maps lack precision, detailed information is available on the positions of some of these features from US-Honduran surveys, dated in the early nineteen seventies. Although these surveys made no attempt to precisely delineate the features they did measure the precise horizontal position of survey markers embedded on the islands. These surveys used a Doppler satellite system for the measurements. Accompanying the measurement data were some diagrams and photographs which provided some information on the visual appearance of the cays. Photographs of the actual survey markers appear to show that they were embedded in the coral rather than the less permanent sand. This permanency of the markers becomes important in view of the hurricanes in the area.

Several of the cays were located within 12 miles of the previously determined bisector line. As the Court decided by virtue of UNCLOS Article 3, that

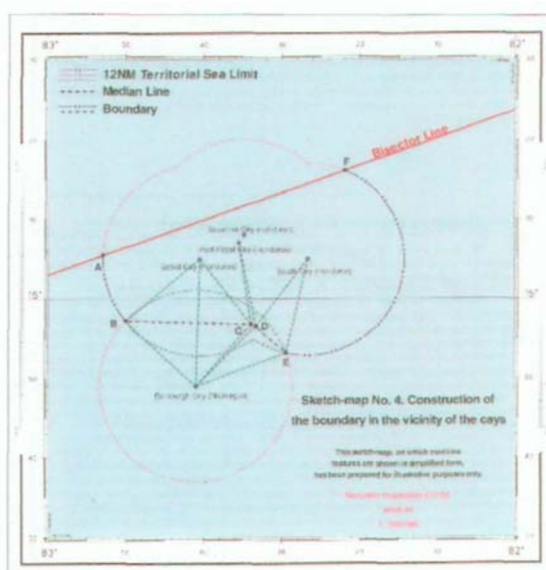

Figure 4: Source: Judgment Nicaragua v. Honduras 8 October 2007.

such islands could be allowed a territorial sea of 12 miles of their own (Judgment, paragraph 302) there was a possibility that their existence would influence the direction of the line as it passed in their vicinity. A first task for the Court was to decide on the disputed sovereignty. The Court decided that Honduras had sovereignty over Bobel Cay, Savanna Cay, Port Royal Cay and South Cay (Judgment, paragraph 227). Sovereignty having been established it becomes a matter of precisely determining the sea areas that would be included and how these areas would affect the division made by the bisector line described previously. The most precise geographic position of the four cays under Honduran sovereignty can be obtained from observations of a Honduran/USA survey in the 1970s. These observations had been taken using a Doppler satellite system and are recorded by the US Board of Geographical Names. A number of photographs taken during these surveys were made available to the Court by the Parties in their pleadings and show that the cays were covered with vegetation and there were some buildings. Apparently owing to the lack of precise information on the size and shape of the cays no attempt was made to draw the 12 mile limits from the actual low water line as is prescribed for the Normal Baseline in Article 5 of UNCLOS. Furthermore, there are very large areas of reef surrounding some of the cays (see UK Chart 2425) but once again they are poorly mapped and no attempt was made to use the seaward low water line as prescribed for reefs in Article 6.

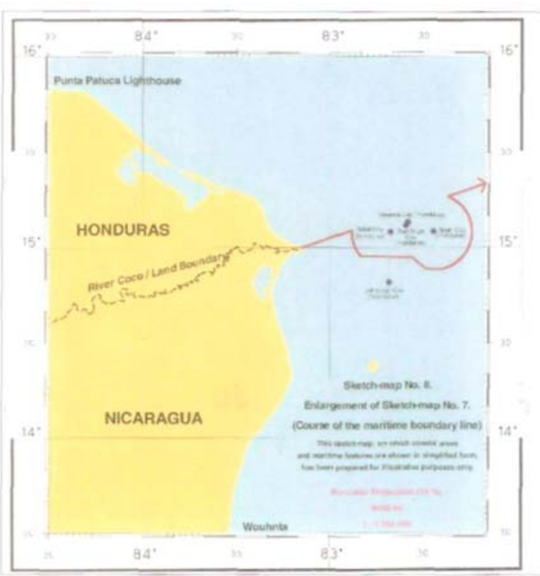

Figure 5: Source: Judgment Nicaragua v. Honduras 8 October 2007.

The circles of 12 mile radius defining the territorial sea are entirely centred on the single point of each cay. In the Judgment, the Court discussed the possible use of low-tide elevations and the lack of general customary law which unequivocally permits or excludes appropriation of low-tide elevations, as noted in the Qatar and Bahrain judgment (Judgment, paragraph 141), which supported the decision not to use low-tide elevations in this case. The Court decided that it was only able to consider the effect of the territorial sea of the four Honduran cays (Bobel, Savanna, Port Royal and South) that overlapped with the Nicaraguan area to the south of the bisector. It also considered the territorial sea of one Nicaraguan cay (Edinburgh) that overlapped with the territorial sea claimed by the Honduran cays. The overall effect of these overlaps (Judgment, paragraph 302) was to break the bisector line and to draw the boundary along a series of arcs to the southwards of the bisector line.

Geographic Uncertainty and Assistance of Technology

It is only when one is faced with the actual task of delimiting a maritime boundary that the theory must give way to the practical and the unique geographic conditions of any area must be examined. This is particularly evident in the lack of precise geographic data in some parts of the world and is in places evident in the nautical charts which are often the only source that portray such data. UNCLOS, for instance, refers to information that is provided on large-scale charts officially recognised by the coastal State. However if the charts themselves are lacking in detail or precision it may bring into question the boundaries that are to be delimited. Priorities for nautical charts are usually driven by concern for the safety of shipping and if there is little shipping the existing charts may be found quite lacking in both density and precision of the data needed for precise boundary delimitation. Adding to this problem is the fact that some developing countries have yet to develop any hydrographic capabilities and there may be no charts published by the country itself of its own territory. In the case of the Nicaragua/Honduras boundary it may be noted in this regard that a significant source of information, particularly concerning the offshore cays, was a chart published by the British Admiralty drawn mainly from surveys carried out in the nineteenth century (UK Chart 2425). Both Parties used this chart extensively in their pleadings. This chart also covered critical areas of the mouth of the River Coco which according to satellite imagery presented to the Court by the Parties had undergone significant changes in topography.

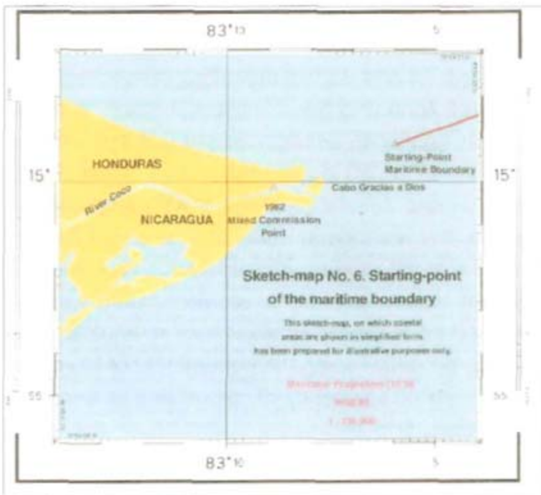

Figure 6: Source: Judgment Nicaragua v. Honduras 8 October 2007.

Particularly important to the definition of the coastal front lines is the precise positioning of the coastline of the two countries. Although some national topographic maps are available to supplement information shown on the nautical charts there is some doubt about the precise position of the coastline. Much of this, particularly along the Nicaraguan coast, is of a mobile nature, as evidenced by the numerous spits, lagoons and other features, which tend to evidence mobile geography. The changing topography of the mouth of the River Coco was presented by the Parties as satellite imagery, taken over a period of time and in the pleadings, showed just how changeable was both the course of the river and the islands within its deltaic mouth. Evidence was presented showing how the mouth of the river was being gradually extended seawards and the entrance channels were changing their positions and probably their depth. A key feature was the point determined by the Mixed Commission in 1962 as the eastern end of the land boundary, which at that time was positioned on the thalweg but today may not be located in this deepest part of the channel. The value of modern satellite imagery to complement the information shown on published charts and maps may be realised.

The limitations of the nautical charts used in defining the offshore cays, reefs and other features also has to be considered in cases such as this. Apart from the precise positioning of the cays, that has been discussed earlier, there is the need to examine the use of features which are not permanently above water. According to the nautical charts there are extensive reefs in the vicinity of the cays, some parts of which may be above water at certain stages of the tide. The Court noted that there was no dispute on the fact that Bobel Cay, Savanna Cay, Port Royal Cay and South Cay remain above water at high tide and thus fall within the regime of islands under article 121 of UNCLOS (Judgment, paragraph 137). However it also took note of the fact that there were a number of smaller, islets, cays and reefs in the same area of which their physical status (such as whether they are completely submerged above sea level, either permanently or at high tide) and consequently their legal status is not clear (Judgment, paragraph 136). While the Court did discuss in the Judgment the situation in which features are not permanently above water and which lie outside a State's territorial waters. In this they made reference to the case of Qatar v. Bahrain but it does not appear to have examined the entire situation of Article 13 of UNCLOS in which it is possible to extend the breadth of the territorial sea when a low-tide elevation is situated wholly or partly at a distance not exceeding the breadth of the territorial sea. Although it did recall "the rule that a low-tide elevation which is situated beyond the limits of the territorial sea does not have a territorial sea of its own." (Judgment, paragraph 141). The intent of this discussion is not to discuss that legalities of the situation of islands, reefs and low-tide elevations but to note the difficulty of decision making when the geographic details of such features are not well defined on existing charts. It is possible to supplement information provided on the charts with some recent satellite positioning surveys discussed earlier and by imagery from satellite sources and available on Google Earth.

Conclusions

The Nicaragua/Honduras maritime boundary case has demonstrated clearly how difficult it is to define boundaries in areas of the world that are lacking both up-to-date topographic and hydrographic data. Mapping and charting agencies are today driven by economic factors and if there is limited demand for the products their work is often given low priority.

Fortunately, countering this difficulty, the ready availability of satellite and other aerial imagery has done much to provide precise geographic information. Although several articles of the UNCLOS 1982, such as the critical Article 5 on Normal Baselines, state that only features as " marked on large scale charts officially recognised by the coastal State," this is not always realistic. Not only because the best charts are often not those of the coastal state but also because the charts officially recognised by the coastal state are sometimes out of date or inaccurate when compared with the latest satellite or other aerial imagery, which has yet to be incorporated in the charts.

The particular situation of defining precisely the seaward low-water line of a reef (Article 6, UNCLOS 1982) and indeed low-water elevations in general (Article 13), needs examination in the light of modern technology. Charts compiled from surveys dating before the availability of airborne imagery will have been carried out from boats and the difficulty and danger of approaching a coast, often involving a heavy surf, did not permit precise surveys of the features. Airborne surveys will do much to improve this situation and eventually lead to more precise charts.

The commonly accepted practice of using rivers to define boundaries can lead to difficulties when the rivers carry large amounts of silt and consequently may continuously change their topography. The Court discussed the situation of the River Coco, noting that it was the longest river of the Central American isthmus and bears one of the largest volumes of water. It went on to discuss its dynamic nature and in particular its network of diverging and shifting river channels. Due to the unique geographic situation of every river it is difficult to have rules that can suit all situations. Although the legal situation in deltas and rivers is discussed in UNCLOS it deals more with the situation of drawing baselines across the mouths of rivers than of actually how to determine a boundary along the line of the river. Rules for accretion and deposition of rivers is more likely to be found in laws concerning terrestrial rather than maritime boundaries.

Finally, some comments may be made on the drawing of median or equidistance lines, titles that are often used interchangeably. The construction of equistance lines has been discussed in numerous texts and some of the earliest discussions can be found in Shalowitz (Sea and Shore Boundaries Vol. 1). Its importance seems to have diminished over the years and while it now exists in Article 15 of UNCLOS for a means to delimiting the territorial sea with opposite or adjacent coasts, it does not exist in Articles 74 and 83, for delimiting respectively the Economic Zone and the Continental Shelf. In these case an equitable solution is stressed. While the construction of an equidistance line between opposite states seems to present no geometric difficulties, the Nicaragua/Honduras case has demonstrated that the construction of such a line between adjacent states can be a problem. Unfortunately most text book examples show how an equidistance line may be drawn when the general line of the coast in the area of adjacency of two states is concave. This allows firm geometric control over the direction of the boundary line. However when the coast has a convex shape, as has the area of adjacency of Nicaragua and Honduras at the mouth of the River Coco, it is not possibly to geometrically construct the equidistance line with any surety as the coastline on both sides trends away and no points can be used to control the line. In this case only two points can be used to control the boundary and these are situated on each side of the mouth of the River Coco and relatively close together. If the line is to be propagated offshore the progressive equal distance controlling its direction cross at an increasingly acute angle, leading to a weaker and weaker position. The case is further weakened by the fact that two points are liable to changing geographic position and these changes will affect the direction of the line which could make significant differences to the division of territory as the lines goes further offshore. These comments do not entirely condemn the equidistance method used for adjacent states, as it has been successfully used in a number of delimitations, but that the method fails to provide a well controlled boundary when the coastline has a convex shape.

In summary it may be noted that the Nicaragua/Honduras boundary provided a fine laboratory for studying many of the difficulties caused by geography and the difficulties that must be faced by the maritime boundary maker.

Obituary

Mortimer Rogoff

Scientist and engineer

Mort Rogoff, aged 87, died at Nantucket, USA, August 2008.

Mort Rogoff came into the hydrographers' world through his developments of the electronic chart in which he played a major part. He contributed to many of the ideas and standards which today provide the basis for much of the work of Hydrograpic Offices engaged in the work of producing ENCs and stimulating their use in navigation. The obituary below was provided by his close friend and colleague, Giuseppe Carnevali.

Mort loved to be a several decades ahead of the world.

During the war he developed a radio communication system that was totally undetectable by the enemy because its power was below the background noise and the frequency variable in a random way.

This was the birth of the spread spectrum, the technology on which modern GPS and cellphones are based. Unfortunately he was not allowed to get public credit or to patent the technology because it was top military secret.

Half a century ago he developed a computer network system and a text exchange protocol that could be viewed as the harbingers of the Internet and of email.

More than a quarter century ago he developed a revolutionary electronic chart system.

Although GPS did not exist, and small computers were rudimental, he managed to survey Loran coordinates in New York and Tampa to create differential Loran with sub-metre accuracy, and then he found a computer in Japan with half a megabyte of memory and 4MHz clock (which means 1,000 times slower than today's home computers) and through clever software he was able to perform all the functions of today's advanced electronic chart systems, including a digital vector database of the highest detail, and radar overlay.

The ISO standard for electronic charts, which he tenaciously squeaked through the system, caught everybody off guard: nobody could argue against the need for a standard, but nobody was ready to endorse one, yet nobody had the guts to oppose it. So the standard is there, an excellent standard, which for sure will become commonplace - a few decades later, as always, when the world manages to catch up with Mort's creations.

Mort took off for the ultimate climb from his lab/home in Nantucket, after watching the last beautiful sunset on the harbor with his witty and beloved wife of 65 years, children and grandchildren.

He forgot to take with him his computers, his radios, the equipment with which he had managed to start a new career as an accomplished photographer, but he will continue to churn out innovations for many decades, as we continue to discover more things that he had discovered for us earlier on.

Article

UNCLOS Article 76 - Implementation by Smaller Developing States

Entitlement, Evidence, Expertise and Expense

By Ian Russell, Sole Principal Seaconsult UK and Ron Macnab,
Geological Survey of Canada (Retired) (Canada)

Abstract

The stringent requirements for scientific evidence to substantiate Extended Continental Shelf (ECS) entitlement place developing states at a severe disadvantage. Most lack means and expertise to collect, interpret and present the necessary data sets unaided. The Convention's legal jargon lends itself to ambiguous constructs which may require recourse to expensive legal consultancy. States Parties to UNCLOS have recognised the continuing difficulties faced by the smaller developing States in complying with the ECS submissions deadline. Relaxation of submission timing will mitigate but not resolve these difficulties. The wider international community needs to be apprised of the issues and seek their resolution.

Résumé

Les prescriptions strides en matière de preuves scientifiques aux fins de démontrer la pertinence de l'extension du plateau continental (ECS) désavantagent sévèrement les pays en développement. Un grand nombre de ces pays manquent de moyens et de savoir-faire pour recueillir, interpréter et présenter sans assistance les ensembles de donnees nécessaires. Le jargon juridique de la Convention prete lui-même a des constructions ambiguës pouvant exiger le recours à des conseils juridiques onereux.

Resumen

Los exigentes requerimientos de evidencia científica para sostener la pertinencia de la Plataforma Continental Extendida (ECS) dejan a los países en desarrollo ante una severa desventaja. La mayoría carece de medios y experiencia para colectar, interpretar y presentar sin ayuda, los juegos de datos necesarios. La dificultad legal de la Convención lleva en si misma a ambigüedades que pueden requerir recurrir a una onerosa consultoría legal. Los Estados parte de CONVEMAR han reconocido las continuas dificultades enfrentadas por los pequeños Estados en desarrollo en el cumplimiento de la fecha limite para las sumisiones a la ECS. El relajar el tiempo de sumisión mitigara pero no resolverá estas dificultades. La amplia comunidad internacional necesita tomar conciencia de estos asuntos y buscar sus soluciones.

... the complexity of the issues to be investigated and costs involved in compiling a credible submission are enormous. Implementation of article 76 of the Convention requires collection, assembly, and analysis of a body of relevant hydrographic, geological and geophysical data in accordance with the provisions outlined in the Scientific and Technical Guidelines. The complexity, scale and the cost involved in such programme, though varying from state to state according to the different geographical and geophysical circumstances require enormous amounts of resources.

Statement to 18th Meeting SPLOS June 2008
by Kenyan Delegation

Despite the fact that SIDS have large ocean areas rich in resources (fisheries, oil and gas, minerals, renewable energy), many island States are unable to benefit from the existence of these resources within their EEZ as a result of inadequate technical and management capacity.

Reports from the Third Global Conference on
Oceans, Coasts and Islands
January 23-28, 2006, UNESCO, Paris[1]

... furthermore, sea level is rising almost by a factor of two, faster than it did during the half century prior to 1990. Low lying areas, coastal mega-cities, and several small islands, are subject to increased erosion and loss of coastal protection ...

In certain island States people are already evacuating due to the rising sea and increases in storm frequency and intensity. ... Other island nations such as Tuvalu and Kiribati are currently preparing plans for eventual resettlement of their populations in other countries.

Conference Overview and Outcomes
from the 4th Global Conference on Oceans, Coasts, and Islands
April 7-11, 2008, Hanoi, Vietnam[2]

The above excerpts illustrate the dilemma of the governments of Small Island Developing States (SIDS) and Least Developed Countries (LDC), some with low lying coasts, wanting to extend jurisdiction over their continental shelves beyond 200M. Delineation of the outer limit of the continental shelf, where this requires ship-borne investigations to complement pre-existing archive data, can be prohibitively expensive. In a complex case the subsequent data processing and the preparation, presentation and defence of a submission could be comparable with that of data acquisition.

The difficulties faced by smaller and more disadvantaged coastal states in acquiring and analyzing the data sets for ECS delineation are presented. We question whether this distorts priorities for other more pressing societal concerns or relevant marine scientific endeavours. Costs involved in mobilizing hydrographic and seismic operations will be appraised in the context of prevailing economic conditions.

We review legal, scientific and technical capabilities and the national research facilities needed to undertake the delineation task. The extent and adequacy of external affordable advice and assistance that smaller states could call upon is assessed. Actions for consideration by States Parties and others to resolve the issues raised are proposed.

A matrix has been prepared summarising the potential ECS extent and resources of developing coastal States, the status of their submissions to the Commission on the Limits of the Continental Shelf (CLCS) and relevant training. This data, compiled for West and East Africa, the Western Indian Ocean, South Pacific and Caribbean, is provided at **Appendix 1.**

Entitlement

Small island developing states (SIDS) are characterised as large ocean States due to establishment of the 200 mile Exclusive Economic Zones (EEZ), resulting in these small islands being custodians of much of the world's ocean space.

(Global Oceans and Islands Forum, 2006)

A report from a recent South Pacific Applied Geoscience Commission (SOPAC) UNCLOS art.76 training event (Islands Business, 2008), stated that the potential ECS entitlement of the eight participating

[1] Small Island Developing States and the Mauritius Strategy - Summary prepared by La Verne Walker, St. Lucia at http://www.globaloceans.org/globalconferences/2006/pdf/WSSD-MDGAssessmentSIDS.pdfaccessedJune2008
[2] Advancing Ecosystem Management and Integrated Coastal and Ocean Management in the Context of Climate Change at http://www.globaloceans.org/globalconferences/2008/pdf/Conference-Overview-and-Outcomes.pdf accessed June 2008

SIDS *"would extend their jurisdiction over a combined area of 1.5 million square kilometres of seabed and subsoil".* This represents a 10% increase in the area of their combined EEZ which is consistent with the SOPAC Oceans and Islands programme manager's assessment that "some *of the nations with potential could realise in the region of a 10 - 15% increase in seabed territorial jurisdiction".*

Assessment

There are in existence various detailed assessments of the number of coastal states that could be entitled to claim an ECS under the provisions of UNCLOS art.76; but these are held on proprietary data bases and consequently were not readily accessible to the authors. The information on entitlement provided here is therefore probably incomplete. It derives principally from (Murton et al, 2001) and (Monahan et al, 2005) augmented from SOPAC and Caribbean Community (CARICOM) sources and from submission intentions advised to CLCS (SPLOS, 2008a).

Of some 81 States identified as having a potential entitlement to an ECS, 4 have yet to ratify UNCLOS and one has advised its present intention not to make a submission, while reserving its right to do so. To date (end June 2008) CLCS has received 12 submissions, including a joint one from France, Ireland, Spain and UK. Only three, those from Australia, Brazil and Barbados, are full and final. The remainder are partial submissions or reserve a position on a further submission. Australia has lodged a dormant submission for its Antarctic Territories. Barbados and Indonesia are the only developing dates to have made submissions so far and both were in 2008.

There are 49 developing countries yet to complete their submissions, 26 of which are categorised by the UN as Least Developed (United Nations, 2008). Some of these countries are also listed as SIDS. The figure for outstanding entitlements includes 12 other SIDS. Thus at the time of the meeting of States Parties to the Law of the Sea (SPLOS) in June 2008 there were some 40 nation states with specifically identified economic and environmental disadvantages and vulnerabilities having a potential entitlement to an ECS, as shown in Table 1.

EEZ Delimitation constraint

At the 2008 Global Forum on Oceans, Coasts and Islands it was noted that although the majority of SIDS had ratified UNCLOS, by 2006 not one of them had successfully delimited their EEZ or deposited the appropriate instruments with the UN Division of Ocean Affairs and Law of the Sea (DOALOS). This is an essential prerequisite for boundary negotiations with neighbours and for identifying any extension to the continental shelf beyond 200M.

There is understandable hesitancy in concluding boundary agreements especially in areas well endowed with natural resources. The need to provide legal certainty for exploration and exploitation licensees should provide an incentive to seeking a settlement. The impending CLCS submission deadline was another. However, *"several Pacific nations either have or/ are entertaining signing exploration licences for deep* sea *mineral exploration yet none of these have ratified EEZ nor have they submitted ECS claims"* (Webb, 2008).

Historically boundary negotiations have been protracted, costly and occasionally acrimonious. The stand off between Barbados and Trinidad and Tobago over fishing rights was fractious and ill-natured. The long running dispute between Guyana and Suriname nearly led to war. Both boundaries had implications

Submission status/Intention Category	Full	Partial	By May 2009	By May 2110	Intention advised or indicated	Intention not yet advised	Not ratified
Developed	1	7	7		1	1	1
Transition	1	1	1		0	3	2
DCS		1	9	1	0	4	
SIDS	1		6		5	1	
LDC/SIDS			6		8	11	1
TOTAL	3	9	29	1	14	20	4

Table 1: Summary status of CLCS Submissions (June 2008)

for the delineation of the continental shelf beyond 200M. Their resolution, by awards of arbitral tribunals, in April 2006 and September 2007 respectively, enabled the parties to notify their intentions to proceed with submissions to the CLCS, although a boundary dispute between Guyana and Venezuela remains to be resolved.

Some bilateral negotiations entered into prior to 1982, when UNCLOS was opened for signature, were suspended during the ratification process and only latterly resumed. Negotiations between Nigeria and Benin started in 1968 and a Protocol based on the 1958 Geneva Convention was agreed, but never ratified. In 2000 Nigeria indicated the need to take account of UNCLOS 1982, the latest technology for maritime boundary delimitation and the economic interests of the two countries. Discussions resumed in 2003 and were amicably concluded in 2006. This was a considerable achievement given the disparity in size and financial muscle between the parties and the fact that the median line runs through one of the most hydrocarbon-rich areas in the Gulf of Guinea (Akohou 2008). As with the earlier examples both parties have been able to state their intention to prepare CLCS submissions. In Benin's case this will be in the form of a joint submission with neighbouring coastal States in the Gulf of Guinea (SPLOS, 2008b).

It becomes apparent from the foregoing that in areas of overlapping maritime zones the progress towards ECS delineation will be painfully slow as the outstanding number of submissions for West Africa, Western Indian Ocean and Pacific testify. Figure 1 well illustrates the point for the latter region, where in 2006 there were some forty-five (45) shared maritime boundaries between Forum Island states with only sixteen (16) formally negotiated and three (3) ratified. Twenty-six (26) are yet to be negotiated (SOPAC Annual Report, 2006).

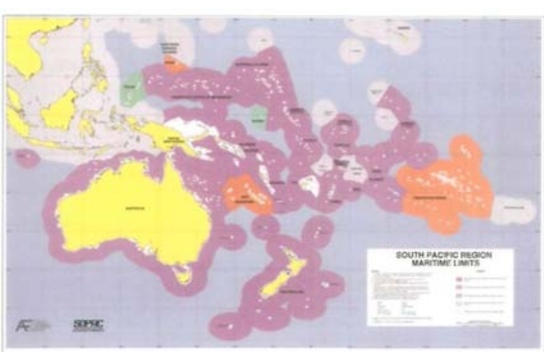

Figure 1:EEZ map, showing the impact of the 200M zone for the smaller island states in the Pacific area.

The situation in the Eastern Caribbean is also a complex one; given the mixed colonial inheritance and the continuing interests of maritime metropolitan powers with dependent territories in the region. The small independent Island States feel disadvantaged in negotiations with experienced, well resourced and technically proficient delegations from these countries. A total of approximately 39 potential maritime boundaries remain to be delimited (CARICOM, c.2004/5).

Evidence

Use Availability and Acceptance of public data

Given the high market demand for survey vessels, compounded by escalating fuel costs, developing States and particularly SIDS and LDC will be seriously disadvantaged if the full development of their CLCS submission requires the acquisition of new data to augment that in the public domain. Mobilisation to locations remote from areas of current commercial or scientific interest and where as little as 5-7 days data acquisition is required (ComSec, 2004), may not be commercially viable. It is questionable whether the expenditure on dedicated new delineation surveys can be justified when results may perhaps only marginally strengthen a case developed from public data.

It will therefore be important for disadvantaged states to be allowed to maximise their use of public data. In future this might be supplemented by generalised sea floor depictions derived from remote sensing and sediment thickness models; extrapolated from those regional settings, where ground truthing exists. The latest decision of SPLOS relaxing the criteria for satisfying the CLCS submission deadline (SPLOS, 2008c) will allow time for data to be collected and validated from improved instrumentation in the next generation of satellites with dedicated geophysical sensor pay loads. This may then become admissible as evidence for e.g. Foot of Slope (FOS) and the 2,500m contour.

Improvements in accessibility of publicly available scientific and technical data relevant to the preparation of CLCS submissions may now be anticipated following the SPLOS request to CLCS to research this area and publicise its findings (SPLOS, 2008d). The "OneGeology" initiative[3], officially launched at the 33rd International Geological Congress in Oslo in August 2008, is seeking to expand its coverage into the marine domain. For states not now under pressure to complete their full submissions by a prescriptive deadline, this may become an important and readily accessible data archive. However, it is proving difficult for the project to establish contact with those who might hold or know the whereabouts of data in the non-territorial offshore domain (Jackson, 2008). Presumably CLCS will face the same problem.

There is a possibility that military ocean survey data, particularly bathymetry, might eventually become accessible. In 1995 the report of the MEDEA Special Task Force (comprising senior academics and government administrators, among others) concluded that the US Navy's bathymetric holdings warranted declassification (Hawker, 1995); but no action resulted. The UKHO and the Russian Navy are known to have significant classified survey data archives.

There is a precedent from Papua New Guinea (Nidung, 2008a) that a submission can be developed using public data alone. The GRID-Arendal UNEP Shelf Programme (Fabres, 2008a) has identified other states that may be able to do the same. However, such claims have yet to be tested by exposure to detailed scrutiny by a CLCS sub-commission.

ECS delineation and EEZ exploration conflicting priorities

The earlier cited excerpts on the subject of the impact of sea level rise encapsulate the dilemma confronting many developing countries looking to delimit their marine estate and to subsequently explore and exploit its resources. Pressures on the land can perhaps be relieved by the realisation of offshore potential; but in what time scale and at what cost? In extreme cases in the Pacific and Indian Oceans will some SIDS still exist at this point? On the other hand accelerating the process of mapping and evaluating marine resources may yield some means of mitigation.

It could be argued that SIDS with extensive EEZ, rather than commissioning surveys to meet specific Art.76 criteria, should devote their limited financial and marine science resources to Ocean Management, fisheries research and CZM issues. These are recurrent themes demanding action by international fora convened to implement the principles of the 1992 Rio Declaration incorporated in Agenda 21 (United Nations, 1992). The full implementation of Agenda 21, the Programme for Further Implementation of Agenda 21 and the Commitments to the Rio principles were strongly reaffirmed at the World Summit on Sustainable Development (WSSD) held in Johannesburg, South Africa in 2002.

The Mauritius International Meeting, convened to review the progress of implementation, identified the need for EEZ mapping (Mauritius Strategy, 2005) in support of integrated use of the marine estate.

States contemplating ECS delineation surveys might be advised to expand the scope of work to include an element of reconnaissance level resource exploration; on the principle of "measure once use twice". Cost Benefit analysis is an essential prerequisite for any decision on developing an ECS submission. It is debateable whether undue emphasis on complying with demands of the Technical and Scientific Guidelines (CLCS/11) is skewing what should be an holistic approach to seabed exploration and subsequent sustainable exploitation.

UNCLOS art.76 survey methodology would only provide evidence for non-living resources; although the presence of genetic resources might be inferred from the geological setting. Water column measurements, essential for bathymetry, also aid marine biological research as would the bathymetry itself.

Data collection Issues

Developing States do not always appear to be fully aware of their rights and obligations under the UNCLOS provisions on the conduct of Marine Scientific Research (MSR). The failure by developed nations to routinely share the results of research has been highlighted by ABLOS (2005) and elsewhere. There is a need, particularly for SIDS and LDC to be alert to the activities of research vessels and commercial

[3] OneGeology is an international initiative of the geological surveys of the world and a flagship project of the 'International Year of Planet Earth'. Its aim is to create dynamic geological map data of the world available via the web. www.onegeology.org last accessed 30 June 2008

survey ships which may be in transit through their EEZ and/or over their putative ECS in order to make opportunistic use of their capabilities where possible. In the case of EEZ, survey transit rights could be conditional on data sharing and track line configuration; but as a correspondent (Nidung, 2008b) has pointed out,

For some countries, asking researchers to deviate and run some lines as part of MSR consent to access national waters was not a viable choice because of costs involved and time. Sharing of data ... is important under UNCLOS and whilst cooperation is possible in reality this does not happen too often between developed and developing countries ...

The gathering and processing of the necessary data for ECS entitlement and other Marine Scientific research cannot be entirely contracted out. Survey and data compilation activities must be seen and used as capacity building exercises. In this connection the following excerpts, from personal communications are pertinent;

If Benin does have specialists in the fields of geology, geophysics, petroleum and mining engineering, and oceanography, they should be re-deployed or otherwise charged with the implementation of this undertaking, which requires substantial human and technological resources.

Dossou Rodrigue AKOHOU
Jurist to the Legal Affairs Directorate of the Ministry of Foreign Affairs of Benin
(Literal translation from original French)

... important that Kiribati for instance is fully involved in the process, to have its own officials learn from every step undertaken towards the submission to the CLCS as these skills will be valuable in future, especially if it stays with the country.

(Renaate, 2008)

Expertise - Requisite Skill Sets and Infrastructures

Lack of capacity and technical know how have immensely contributed to the inability of developing countries to utilize marine resources found within their national jurisdictions.

(Kenyan Delegation, 2008)

Benin as one of the world's Least Developed Countries is tremendously handicapped by a lack of qualified personnel, of technical means, and of the technology needed to collect the necessary data. Given such limitations, there is a high risk that developing states will not be able to participate fully in this process...

(Akohou, 2008)

Many of the small island countries do not have geologists/geoscience personnel or mining departments in their countries. It's the fisheries officials for example who are driving the Article 76 work in FSM. From the beginning Article 76 is not understood because the legal aspects and technical aspects of a continental shelf are different and many cannot visualize what is being proposed by the Article.

Masio Nidung
Coordinator, PNG maritime Boundary Project

The Generic Case

In most cases, the delimitation of an ECS is a complex process that requires a range of abilities and resources that cannot be provided by individuals and singular institutions. Typically, this need is met by the establishment of several working groups that specialize in different tasks according to discipline. Such groups may be constituted formally or informally and their compositions will vary from country to country, but for the most part they consist of teams that assume various - and distinct - responsibilities: legal and diplomatic oversight; bathymetric mapping and interpretation; geo-scientific mapping and interpretation; documentation and data management; administrative and support functions; etc.

Table 2 lists the primary skill sets that must be called into play during the implementation of almost any Article 76 program. Many of these skill sets are complementary and as a rule, some individuals can be identified who are capable of serving in more than one of the listed capacities. Other skills may be the province of specialists who alone can provide expertise in their specialized fields. From a human resource perspective, a significant aspect of managing an ECS project is the orchestration of a variety of team members who can bring their respective skills and energies to bear on tasks as and when required. To complicate matters, the mix of skill sets and designated operatives will in all likelihood evolve through the life of the project as it advances through its successive stages, and as staff turnover

Skill sets for Art. 76 implementation	**Coastal State**	**ITA/Contract**	**Remarks**
Project planners and managers			ITA project definition
Financial controllers and managers			
Contract managers (tendering, awarding, and monitoring)			Joint activity
Team leaders and managers			
Database experts (construction and management)			Technology transfer through counterparts
GIS (Geographical Information Systems) experts			Technology transfer through counterparts
Cartographers			
Data interpreters (bathymetry, geology, and geophysics)			Technology transfer through counterparts
Survey managers (planning, design, and execution)			Survey contractor
Documentation experts (legal and technical)			
Presentation	Political	Technical	Joint activity
Negotiation	Political	Technical	Joint activity
UNCLOS legal expertise			May need ITA

Table 2: Human resource requirements

or altered circumstances require adjustments in team sizes and compositions.

Some of the skill sets listed in Table 2 are acquired through formal education, while others may be developed through on-the-job experience that has been accumulated during previous task assignments. Regardless of their provenance, the list implies the existence of a cadre of experts who are qualified, available, and prepared to devote themselves to a project that could be expected to last several years.

Table 3 identifies in general terms the administrative and organisational arrangements that need to be implemented for the orderly and efficient development of an ECS limit. These include but are not limited to: policy and planning decisions; funding arrangements; institutional commitments; infrastructure development; qualified agencies and organisations; and advanced technical facilities.

SIDS and LDC

...we face same challenges as the other Pacific neighbours ... many of our senior officials initially ... did not understand the significance of the whole ECS issue and the fact that we had to plan and budget to progress this issue in our respective countries.
(Nidung, 2008c)

... little awareness (at this high level) of what actual resources are to be utilised, what activities had to be undertaken and thus as a result, little commitment has been made for the approval or immediate release of local funds to this exercise.
(Renaate, 2008)

Numerous communications from individuals operating within SIDS and LDC in widely-separated parts of the world, and who are familiar with their national Article 76 programmes, indicate a persistent pattern of administrative unreadiness, indeterminate policies, conflicting national priorities, inadequate funding, insufficient manpower, and scarce technical resources. In short, they paint an unsettling picture of conditions which are not conducive to the timely and effective implementations of their national Article 76 programs. Most articulate the requirement for externally funded provision of International Technical Assistance. Few if any can contemplate meeting the full cost of procuring survey services should their need be identified by a DTS.

SIDS and LDC can usually identify individuals who possess a collective accumulation of the skill sets listed in Table 2; but most of these tend to be stretched to the limits of their capacity and are in demand in other key economic sectors. Compiling

Administrative and organizational arrangements	**Requirement for success**	**Remarks**
National commitment to the initiative	Cabinet level ownership	
Designated leadership for the overall undertaking	Ministerial if not Vice President level	
Clear management and communication framework	Authority to command resources and co-operation across government	
Cost-benefit analysis to assess the prospective economic return of a CSE		Desk top Study (DTS) with ITA
Multiyear budget plan for the duration of the project	Early identification of external funding sources and application criteria	Provision for local funding component
Appropriate legal and diplomatic infra-structures (national government and/or academia)	Motivation of requisite skilled person-nel to give time to project	
Agencies appropriately staffed and equipped to collect, manage, and analyze data	Project dedicated staff at working levels	Not a part time activity
Adequate facilities for data management, processing, and visualization	Licences for proprietary software & purchase of work station	Budget issues
Access to high-speed communications for information and data exchange, etc.	Hardware and capacity upgrades	
Training and succession plans for develop-ing staff skills and maintaining staff levels		Motivation and incentive issues

Table 3: Infrastructure and institutional requirements

a CLCS submission and possible downstream over-sight of offshore development may not be seen as a career move by some. It is unrealistic to expect the majority of SIDS and LDC to attain the full range of skills listed in Table 2. Nor are they likely to put in place in their entirety the necessary dedicated infra-structure and institutional arrangements outlined in Table 4 in the foreseeable future.

Training

With the support of key UN agencies such as United Nations Environmental Programme (UNEP) Shelf Pro-gramme and others, many developing countries are now in the process of finalizing the delimitation of their EEZ. The Commonwealth Secretariat (ComSec), which has many SIDS and LDC as well as other de-veloping countries in its membership, has provided assistance in UNCLOS matters and co-sponsored training courses in the implementation of UNCLOS art.76 with the UN Division for Ocean Affairs and the Law of the Sea (DOALOS). International academic and scientific institutions have also played their part as have independent consultants. A UNEP/DOALOS workshop is planned for West Africa later in 2008 to complement and earlier DOALOS/ComSec train-ing session.

In the Pacific region SOPAC, in collaboration with Ge-oscience Australia and the UNEP Shelf Programme, has been delivering an extensive and sustained schedule of workshops to help member states de-velop their CLCS submissions. The most recent took place in Fiji in May 2008. SOPAC has designed and developed a working database "Pacific Islands Regional Maritime Boundaries Information System (PIRMBIS)" which fulfils the requirements of UNCLOS and provided training to member countries to com-plete their maritime limits (Webb, 2008). This is the end product from an AusAID funded project (Artak and Lai, 2004) to design, develop and implement a Regional, Maritime Boundaries initiative. This project commenced in 2002 and was a successor to an ear-lier Maritime Boundaries Delimitation Project (1991-2001).

Limitations

Despite all the above efforts progress overall is un-even. In parts of Latin America, East African states and Angola, where the UNEP programme has been in dialogue with the decision makers, submission preparations are well advanced. There has been no direct access to decision makers in the Pacific and in "... some cases the progress of work is hindered by the lack of human resources and the instability of the teams. Cases of technical committees being formed to disaggregate or be disaggregated some months later have occurred recently" (Fabres, 2008b).

Expense

Finally, technical assistance should consist not only of advice rendered by CLCS experts, but should include financial support for the collection and use of bathymetric, geological, and geophysical observations. These factors are particularly problematic because under present circumstances, Benin possesses only limited data sets, and to all intents and purposes it is incapable of meeting the very high cost of chartering a seismic vessel with its associated techhnology. (Akohou, 2008)

Capacity Issues

The proceedings of high level international conferences and meetings, the authors' personal experience and responses to enquiries of those engaged in the development of their national CLCS submissions reveal that there is a need for an integrated approach to ocean use and management. The research has also identified that many developing states, especially the smaller ones, face chronic difficulties in addressing their maritime problems. The need for capacity-building to offset the lack of financial, technical, and human resources to deal with these problems is recognised and it is evident that efforts are being directed to this end.

As usual it is a question of priorities and conflicting demands on limited financial resources. Specific challenges to SIDS include, inter alia, environmental degradation, natural disasters, food security, water scarcity, HIV/ AIDS, narco-trafficking, small arms trafficking and the impact of terrorism on the economic sectors and tourism in particular. Difficulties in dealing with these problems are exacerbated by a 50% reduction in Official Development Aid (ODA) to SIDS in the period 1994-2004 (Chowdhury, 2004). A situation that is unlikely to improve in the current global financial climate.

Survey Costs

Estimating the cost of operating a commercial survey vessel is subject to many uncertainties that are linked to global market conditions, the circumstances of specific operations and the nature of the data to be acquired. The latter will dictate the type of vessel and instruments to be provided. In some circumstances it is not unusual for bathymetry and seismic data acquisition to be carried out by separate contractors. Although for short duration surveys in remote locations this is clearly impractical. The costs outlined here are general estimates only, and should not to be taken as exact figures. They are however, indicative of the order of magnitude of the expense that could be incurred in delineating the outer limit of the continental margin in accordance with CLCS Guidelines.

Current high demand and supply for the Oil & Gas sector has led to some very high 2D and 3D seismic acquisition rates. Similarly, the current rapid resurgence of growth in telecommunication market sector has led to huge increase in demand for deep water multi-beam vessels. Such vessels are in short supply; resulting in higher market rates. Costs for data acquisition and submission development have effectively doubled since 2004. Indicative day rates (vessel, personnel and survey systems only) provided in 2006 were; Bathymetry/Geophysical survey capability USD15-25k and for deep seismic survey USD35-50k.

Activity	Minimum	Maximum	Poss. Example	Remarks
Mobilization	Zero if vessel in transit through location	$2-3 M	$850,000	Lump Sum
Survey execution	$50,000	$400,000	$150,000	Day rate
Post-processing	$2,500	$5,000	$4,000	Per acquisition day
QC			$1,500	Day rate with costs
Standby	65%	90%	75%	% of daily rate
Administration			15%	% of daily rate per day

Table 4: Indicative costs (USD) of data acquisition for ECS delineation obtained from industry contacts with experience of ECS delineation survey and the full CLCS submission process.

There are four primary categories of costs associated with vessel operation: mobilisation, survey execution, standby, and administrative. Of these the biggest variable is that of the mobilisation of the survey vessel to location. This cannot be quantified until the specifics of each case are considered by the contractor. The daily rate for survey execution will depend on the modus operandi of data acquisition. This could vary from simply Multi-Beam Echo sounder (MBES) or even Single Beam Echo sounder (SBES) to define a few critical FOS points, to the execution of a full seismic survey, including the full suite of geophysical sensors and bathymetric systems. The range of survey costs, with the addition of seismic data post-processing is shown in Table 4.

From the example in the table, acquisition costs for a 7 day deployment with port call and one down weather day would be in the order of USD2.0M. It will be seen that in other circumstances this amount might not even get a vessel to location. The indicative cost of a similar exercise in 2004 was USD0.85M (ComSec, 2004). Data acquisition, be it from public data sources or newly acquired, usually a combination of the two, is only a portion of the total foreign exchange cost associated with the delineation and submission process.

Submission Costs

For a developing state, with limited scientific, administrative and legal resources a significant input of International Technical Assistance (TA) should be provided for. This could be as much as 30% of the cost of acquisition. Matching costs for the local component of the project might be 15% of the foreign component. There would be an additional foreign exchange element, even for nationals, when required to attend CLCS sessions in New York or preparatory and continuation training overseas. Thus in the example the total cost of a submission with a contingency of 5% would be approximately USD3.OM. It must be appreciated that for comparative purposes with the only historical data obtainable, the survey duration has been assessed at an absolute minimum.

Cost sharing

Joint commissioning of survey work on a regional basis is an option. This would be particularly relevant for SIDS in the Pacific and the Caribbean and some African coastal States. There is anecdotal evidence[4] that for a variety of reasons this option has not been exploited to date by some larger coastal states despite the potential cost savings on offer; but there are examples of co-operative surveys which include Australia-New Zealand, Canada-Denmark (Greenland) and Canada-USA. Should any States be in a position to make a joint submission then the sharing of survey costs, human resources and data becomes feasible. This possibility exists for the Ontong Java Plateau, the Gulf of Guinea and perhaps in the Caribbean.

Use of Consultants and National Experts

As indicated earlier the use of consultants is likely to be a significant cost item. If international consultants are to be engaged this should be for the total project duration. Examples have been cited of international TA being restricted to the development of a case for submission; but without adequate transfer of the skills and knowledge to prosecute a successful claim.

In addition there should be a maximum involvement of national experts throughout the project as success will depend on continuity between the principal phases of the project namely, DTS, Data acquisition and processing, the preparation of the submission, its presentation to the CLCS and its defence in the face of any CLCS objections. It is possible and perhaps practicable that different consultants will be engaged for each phase. Consistency in the national team is therefore all the more important and appointments to the team should take this into account.

Career civil servants and political appointees may only serve for a limited period; but the core technical and legal personnel should be permanent appointees and dedicated to the project. The benefit of this approach would extend beyond a successful submission. The technical and analytical capabilities developed and international contacts fostered would be readily adaptable to other initiatives. This could include the management of the newly acquired marine estate and the effective commissioning and oversight of exploration and exploitation activities.

Concluding Discussion

CLCS Submission in perspective

The process of ECS delimitation and proving entitlement is a minor component of the total development cycle. Consequently it merits a proportionate investment of national resources. This is particularly pertinent when the required skill sets and/or human resources are more urgently needed elsewhere and over a much longer term. Administrations therefore need to adopt a strategy which will deliver a positive CLCS recommendation without distorting long term development goals. Joint submissions or mutually agreed boundaries with neighbours and regional co-operation with survey programmes should all be considered.

The submission process should be used to develop a cadre of experts, with transferable skills, able to negotiate and manage future offshore exploration and exploitation contracts. Meeting CLCS guidelines for delineation of an ECS is only a first step in a protracted sequence to realise the potential benefits from an ECS. The subsequent developmental phases are unlikely to warrant investment in an independent offshore infrastructure given the finite nature of the resource and the unpredictability of global demand.

Commercial service providers

The DTS is a vital stage in which investment in international TA can be very cost effective. Ideally it could yield access to sufficient public data for submission development without recourse to acquisition of new data. It would optimally identify the minimum data requirement and present the cost benefit case for delineation options.

Should surveys need to be commissioned then the first choice would be to identify government research vessels programmed to transit or work in the region. Depending on the scope of work, it is more likely that commercial survey services will need to be contracted. In either case funding will need to be procured.

Profit sharing option

Economically viable exploitation of deep seabed resources is not an immediate prospect. Consequently there is a requirement to establish a win-win risk sharing and reward modus operandi among interested parties, to meet immediate, medium and long-term goals of the coastal State. In financial terms this will inevitably mean that the coastal State will need to mortgage some of the future revenues from its seabed assets. This will require skilful negotiation with the exploration and exploitation contractors and the probable involvement of the International Seabed Authority (ISA).

For combined exploration and delineation surveys, the additional financial burden could be offset by survey contractors being awarded exploitation benefits from any resources located. Alternatively States Parties, through the ISA, might consider a long-term funding mechanism to enable developing states to delineate their ECS, with repayment from revenues derived from subsequent exploitation activity. The early removal of any ambiguity in jurisdiction, by the de facto landward delimitation of the Area, should be mutually beneficial.

SPLOS role

In addition to representing the interests of coastal States with the ISA, States Parties might also consider instructing the CLCS to issue discussion papers (or alternatively to expand its Guidelines) with a view to explaining the rationales behind key scientific and technical interpretations that have been taken so far in dealing with coastal state submissions. This would relieve States of the burden of retaining expensive legal and other advisory services.

Acknowledgements

Profound thanks are due to the many correspondents who have taken time from their very busy schedules to respond to repeated enquiries and requests for clarification. Most are cited as personal communications (pers com). Given the sensitivity of the subject some contributors wished to remain anonymous and are included in the following list of countries or regions from which responses were received. These were Benin*, Caribbean, Kenya, Kiribati*, Mozambique, Papua New Guinea*, the South Pacific*, Solomon Islands and a national delegation to the United Nations.

Significant contributions were received from those countries marked with an asterisk and additionally from the Manager of the UNEP Shelf programme at GRID-Arendal, Joan Fabres, who provided a global perspective. The regional overview of the South Pacific came from the Manager of the SOPAC Oceans and Islands Programme, Arthur Webb.

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Acronyms

- AGENDA 21: UN Programme for Sustainable Development - Earth Summit Rio de Janeiro 1992
- AU: African Union
- AUC: African Union Commission
- BPOA: Barbados Programme of Action for the Sustainable Development of SIDS
- CARICOM:Caribbean Community
- CLCS : UN Commission on the Limits of the Continental Shelf
- ComSec: Commonwealth Secretariat
- CSE: Continental Shelf Extension
- DOALOS: UN Division for Ocean Affairs and the Law of the Sea
- DTS: Desk Top Study
- ECLAC: Economic Commission for Latin America and the Caribbean
- ECS: Extended Continental Shelf
- EEZ: Exclusive Economic Zone
- FOS: Foot of Slope
- GGC: Gulf of Guinea Commission
- GRID: UNEP Global Resource Information Database
- HIPC: Highly Indebted Poor Countries
- ISA: International Seabed Authority
- ITA: International Technical Assistance
- LDC: Least Developed Countries
- LME: Large Marine Ecosystem
- M: International Nautical Mile (1852m)
- MEDEA: Measurement of Earth Data for Environmental Analysis
- MSR: Marine Scientific Research
- NOC: National Oceanography Centre Southampton (formerly SOC)
- OECS: Organisation of Eastern Caribbean States
- SIDS: Small Island Developing States
- SOC: Southampton Oceanography Centre
- SOPAC: Pacific Islands Applied Geoscience Commission
- SPLOS:States Parties to the UN Convention on the Law of the Sea
- UKHO: United Kingdom Hydrographic Office
- UN: United Nations
- UNCLOS: United Nation Convention on the Law of the Sea 1982
- UNCTAD: United Nations Conference on Trade and Development
- UNEP: United Nations Environment Programme
- UN-OHRLLS:UN Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States
- WSSD: World Summit on Sustainable Development (Johannesburg 2002)

Biographies

Ian Russell is a Chartered Hydrographic Surveyor. His interest in UNCLOS and the Continental Shelf dates from 1996. He co-authored a paper, given at the Second Conference on the Geodetic Aspects of the Law of the Sea (GALOS), on cost effective survey methods for the delineation of the Outer Limits of the Continental Shelf. He is a previous contributor to the original IH Review on search techniques for seabed obstructions. His first UNCLOS consultancy assignment was a review of Maritime Boundaries for a SIDS. He has subsequently advised clients on UNCLOS issues and been retained by coastal States evaluating their ECS entitlements and preparing submissions to CLCS.
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Ron Macnab is a retired marine geophysicist who wrote his first paper on UNCLOS and continental shelf extensions in 1987. Among other affiliations, he is a member of the American Geophysical Union (AGU) and of the International Law Association (ILA), where he participates in the deliberations of the Committee on the Legal Issues of the Continental Shelf (CLICS). He is past chairman of the IAG/IHO/IOC Advisory Board on the Legal and Technical Issues of the Law of the Sea (ABLOS).
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Appendices

	Coastal State *UN-OHRLLL List* *SIDS **LDC ***SIDS/LDC	EEZ *Million km²*	ECS *km²*	Test of Appurtenance[1] *A (passes)* *B (physically meets criteria)*[2]	Marine research and other submission preparations *Indicative only*
1	*Angola***	*0.606*	*251,304*	*A*	*Oil Exploration*
2	*Benin***	*0.003*	*2,759*	*B*	*Potential oil producer*
3	*Cape Verde****	*0.790*	*2,883*	*Does not meet Test (Monahan)*[1]	
4	*Congo*	*0.025*	*14,652*	*B*	*Significant oil producer*
5	*Dem. Rep. of ** the Congo*	*0.013*	*1,029*	*As 3*	
6	*Equatorial Guinea***	*0.283*	*15,566*	*As 3*	*Significant oil producer*
7	*Gabon*	*0.214*	*136,752*	*B*	*Major oil producer*
8	*The Gambia***	*0.020*	*10,662*	*B*	
9	*Ghana*	*0.218*	*25,943*	*B*	*DTS completed*
10	*Guinea***	*0.071*	*27,897*	*A*	
11	*Guinea-Bissau****	*0.038*	*16,807*	*A*	
12	*Mauritania***	*0.154*	*53,312*	*B*	*Exploration not*
13	*Morocco*	*0.278*	*824,562*	*B*	
14	*Namibia*	*0.524*	*1.1M (?)*	*A*	*ECS surveys completed*
15	*Nigeria*	*0.211*	*103,772*	*A*	*ECS surveys completed*
16	*Senegal***	*0.206*	*106,650*	*A*	
17	*Sierra Leone***	*0.156*	*51,030*	*B*	*ComSec assistance DTS*
19	*Togo***	*0.002*	*1,232*	*B*	*Potential oil producer*

Appendix 1 Table 1 - West African Coastal States with Potential for Continental Shelf Extension

Notes

1. The above States have attended Art.76 training and awareness events as follows
   (a) University of Durham UK, International Boundaries Research Unit 1999/2000 (Namibia, Nigeria, Senegal)
   (b) GRID-Arendal[6] 2003 (Angola, Guinea-Bissau, Senegal, Cape Verde)
   (c) Southampton Oceanography Centre 2001-05 (Senegal (2), Nigeria, Congo, Morocco, Angola, Ghana, Namibia)
   (d) DOALOS Accra 2005 (Angola, Benin, Cape Verde, Côte d'Ivoire,the Democratic Republic of the Congo, Gabon, the Gambia, Ghana, Guinea, Guinea-Bissau, Mauritania, Namibia, Nigeria, Senegal, Sierra Leone and Togo)
   (e)GRID[6]/BGR[7] Cape Town 2007 (Angola, Namibia).
2. A further Workshop is planned by the UNEP Shelf Programme for West African States in 2008
3. Only Angola and Namibia were represented at the 2003 University of Virginia School of Law, Annual Conference *Legal and Scientific Aspects of Continental Shelf Limits.*
4. For the following States the entry in the entry under *"Continental Shelf Outer Limit Claims"* in the DOALOS Table of claims to maritime jurisdiction 28 May 2008 reads N/A (*No information regarding current legislation is available),* Angola, Congo, Dem. Rep. Congo, Equatorial Guinea, Gabon, Gambia, Guinea, Guinea-Bissau, Togo

	Resources *Hydrocarbons (H); Minerals (M), Gas Hydrates (GH)*	**Neighbours** *Indicative only*	**Remarks** *and CLCS Submission information*
	M, M, GH	*Namibia, Congo*	*Tentative submission May 09*[3]
	H	*Togo, Nigeria & Ghana*	*Joint G. of Guinea submission*[4]
	No proven hydrocarbon reserves	*Senegal, Guinea-Bissau, Mauritania*	*Tentative submission Apr 09*[4]
	H,M	*Angola, Gabon, Dem. Rep. Congo*	*Not Ratified*
		Congo, Angola	*Coastline 37 km. AS* 6 *Possible claim (Murton)*
	H	*Gabon, Cameroon*	*Constrained by May 09 submission deadline. Possible claim (Murton)*
	H,M	*Equ.Guinea, Congo*	*As 6*
	H,M	*Senegal*	*As 6*
	H	*Togo, Cote d'Ivoire*	*Requested deferral to May 2010*[3]
	H,M	*Guinea-Bissau, Sierra Leone*	*As 6*
	H,M	*Guinea, Senegal*	*As 6*
	economically viable5	*Senegal, West Sahara*	*As 6*
	H,M	*W. Sahara, Algeria*	*Ratified 31 May 2007*
	H, M	*S Africa, Angola*	*Tentative submission Dec 07 not met*[3]
	H,M *Major oil producer*	*Benin, Equatorial Guinea, S. Tome et Principe, Benin & Cameroon*	*Tentative submission May 09*[3]
	H,M	*Gambia, Guinea-Bissau & Mauritania*	*As* 6
	H,M	*Guinea, Liberia*	*Tentative submission May 09*[3]
	H	*Benin and Ghana*	*Coastline 70 km. As 9*

1 MONAHAN D. *et al*, 2005. *Applying the Test of Appurtenance Globally*, International Hydrographic Review; Vol.6 No.l (New Series)
2 Unresolved maritime boundaries with neighbours may affect any ECS claim
3 SPLOS/INF/20 16 January 2008
4 SPLOS/INF/20/Add.l 7 May 2008 www.un.org/Depts/los/meeting_states_parties/eighteenthmeeting-statesparties.htm accessed 17 June 2008
5 ISA Technical Study: No.l (2000), Global Non-Living Resources on the Extended Continental Shelf: Prospects at the Year 2000, MURTON B.A. *et al*
6 UNEP Global Resource Information Database Centre based in Arendal Norway which hosts a facility (UNEP Shelf Programme) to serve UNCLOS Article 76, supporting the needs of developing countries and small island states; acting on their request regarding the delineation of their continental shelf.
7 Federal Institute for Geosciences and Natural Resources of Germany

	Coastal State UN-OHRLLL List ***SIDS** ****LDC** *****SIDS/LDC**	EEZ Million km^2	ECS km^2	Test of Appurtenance A(passes) B (physically meets criteria	Marine research and other submission preparations	
1	Comoros***	0.164		Does not meet Test according to Monahan et al or Murton	Nothing known	
2	Kenya	0.118	20,782	B	ECS surveys completed 2008 See notes 3 & 4	
3	Madagascar**	1.292	2.09M?	A	Yes See note 3	
4	Mauritius*	1.181	321,039	B	ComSec assistance maritime boundary negotiation. Seabed surveys (India & UK)	
5	Mozambique**	0.562	123,258	A	Oil exploration in progress. Proven reserves of natural gas onshore See note 4	
6	Seychelles*	1.349	321,039	B	DTS completed & other assistance from ComSec in UNCLOS matters & See note 3	
7	Somalia**	0.782	242,676	A	Nothing known	
8	South Africa	1.017	184,863	A	ECS surveys in hand 2008 and prior	
9	Tanzania**	0.223	55,681	B	See note 3	
10	Yemen**	0.5		B	DTS in progress	

Appendix 1 Table 2 - East African Coastal States with Potential for Continental Shelf Extension

Notes

1. The above States have attended Art.76 training and awareness events as follows
   (a) University of Durham UK, International Boundaries Research Unit 1999/2000 (Seychelles, Mauritius)
   (b) GRID-Arendal 2003 (Mozambique, Seychelles, Madagascar)
   (c) Southampton Oceanography Centre 2001-05 (Mauritius, Seychelles, Mozambique (2), Tanzania)
   (d) DOALOS Colombo 2005 (Kenya, Madagascar, Mauritius, Mozambique, Seychelles, S. Africa, Tanzania)
   (e) GRID-Arendal/BGR Cape Town 2007 (Comoros, Madagascar, Mauritius, Mozambique, Namibia, Seychelles, South Africa, United Republic of Tanzania)
   (f) National Oceanography Centre, Southampton, MSc. module 2008 (Yemen)
2. Mauritius, Seychelles, S. Africa and Tanzania were represented at the 2003 University of Virginia School of Law, Annual Conference *Legal and Scientific Aspects of Continental Shelf Limits*
3. The GRID-Arendal UNEP Shelf programme has been decisively involved in the delineation project in Kenya, Madagascar, Tanzania and Seychelles where national task forces where constituted during the dialogue with the programme or following capacity building workshops.
4. The Commonwealth Secretariat (ComSec) collaborated with DOALOS in the provision of Art.76 training and Desk Top Study (DTS) development for Kenya and Mozambique
5. States listed as LDC by UN-OHRLLS; Comoros, Madagascar, Mozambique, Somalia, United Republic of Tanzania and Yemen

	Resources Hydrocarbons (oil/gas) [H] Seabed minerals [M] Gas Hydrates [GH]	**Neighbours** Indicative only	**Remarks** and CLCS Submission information
		Madagascar, Tanzania, Mozambique, Seychelles, France	Intending to submit ECS claim before 13 May 2009[1]
	H,M,GH	Somalia, Tanzania	Intending to submit ECS claim before 13 May 2009[4]
	H, M,GH	Comoros, France, Seychelles, Mozambique	Submission by 21 Sep 2011 (ratified 22 Aug 2001)
	H, M and GH	Seychelles, France UK (Indian Ocean Territory)	Government intends to make an ECS submission[1]
	H,M,GH	S. Africa, Tanzania, France, Madagascar, Comoros	Constrained by 13 May 2009 submission deadline Maritime boundary concerns in Mozambique Channel
	H,M	Madagascar, France, Tanzania, Kenya, Comoros	Intending to submit ECS claim before 13 May 2009[1]
	H,M,GH	Kenya, Yemen	Constrained by 13 May 2009 submission deadline
	H, M and GH	Namibia, Mozambique	Intending to submit 2009
	H,M,GH	Kenya, Mozambique, Comoros	Intending to submit ECS claim before 13 May 2009[1]
	Onshore Oil and Natural gas	Somalia, Oman	Constrained by 13 May 2009 submission deadline

6. States listed as SIDS by UN-OHRLLS (Institutional List); Comoros, Mauritius, Seychelles
7. For the following States the entry in the entry under *"Continental Shelf Outer Limit Claims"* in the DOALOS Table of claims to maritime jurisdiction (as at 28 May 2008) reads N/A (*No information regarding current legislation is available),* Comoros, Kenya, Somalia, Tanzania

[1] SPLOS/INF/20 at www.un.org/Depts/los/meeting_states_parties/eighteenthmeetingstatesparties.htm last accessed 24 March 2008
[2] Statement by national representative on 17 June 2008 at 18th SPLOS Meeting

	Coastal State UN-OHRLLL List ***SIDS** ****LDC** *****SIDS/LDC**	**EEZ** Million km^2	**Test of Appurtenance** A (passes) B (physically meets criteria)	**Marine research and other submission preparations** Indicative only	
1	Cook Is*	1.8	Outer limit of continental shelf claimed to the outer edge of the continental margin	Deep-sea mineral prospecting late 70s, JAPAN/SOPAC deep-sea mineral resource programme. Tripartite Cruises [ANZ/USA/SOPAC], confirmed mineral potential of manganese nodules	
2	Fiji*	1.28	B	Tri-partite Cruise 1985-7 JAPAN/SOPAC Deep Sea Mineral Resources Programme (DSMRP) from 1985 with its final phase completed in 2002. ComSec assistance DTS	
3	F S Micronesia (FSM)*	2.98	B	EEZ explored in 1997 and 1998. JAPAN/ SOPAC DSMRP	
4	Palau*	0.63	Potential CSE (UNEP Shelf)[2]		
5	Papua New Guinea (PNG)*	3.12	B	Japan/SOPAC programme, cruise in EEZ in 1992. ComSec assistance DTS	
6	Solomon Is.***	1.34	B	CCOP-SOPAC Tripartite Programme (NZ/AUS/US) & EU/SOPAC Maps project 1993	
7	Tonga*	0.7	Potential CSE[4] (SOPAC)	ANZUS/CCOP/SOPAC Cruises 1982/84 Swath mapping RV 'Gloria' 1990-1, marine scientific survey 2003 assess potential deep-sea mineral resources	
8	Vanuatu**	0.71	Potential CSE (SOPAC)	EU/SOPAC Maps project 1993	
9	Kiribati**	3.7	Potential CSE (UNEP Shelf)	ComSec assistance DTS	
10	Tuvalu**	1.3	Potential CSE (UNEP Shelf)	EU/SOPAC Map project 1993 PIRMBS Maritime Boundary delimitation	

Appendix 1 Table 3 - South Pacific Applied Geoscience Commission (SOPAC) member States with Potential for Continental Shelf Extension (CSE)

Notes

1. All states have benefited from longstanding SOPAC programme of UNCLOS awareness raising and capacity building
2. SOPAC officers represented member states at the 2003 University of Virginia School of Law, Annual Conference Legal and Scientific Aspects of Continental Shelf Limits
3. Following states have attended international Art.76 training events, Fiji (3), PNG (3), Solomon Is (3)., FSM (3), Tonga (2), Vanuatu, Palau
4. In 2005 SOPAC commissioned the UK National Oceanographic Centre (NOC), to undertake desktop assessments (DTS) for Federated States of Micronesia (FSM), Kiribati, Palau, Solomon Is., Tuvalu and Vanuatu to establish their potential CSE .
5. Fiji, PNG and Tonga obtained independent advice on their CSE potential
6. Reliable figures for the potential area of CSE for individual SOPAC member states not available but understood from SOPAC that some states might be able to claim between 10 and 15% of the area of their EEZ
7. Fiji along with Cook Islands , Solomon Islands, Kiribati, Palau, the Federated States of Micronesia, Tonga and Papua New Guinea have a credible claim to more than 1.5 million km^2 of additional space beyond

	Resources	Neighbours Indicative only	Remarks and CLCS Submission information
	Major deposits cobalt rich manganese nodules	French Polynesia, Kiribati, American Samoa, Tonga	Not listed by SOPAC (2005) but linked with other eligible states as having a credible claim to "territory beyond current 200M EEZ"[1]
	Hydrocarbons Manganese crust Hydro thermal deposits	Tonga, NZ, New Caledonia, Vanuatu,& Solomon Is, Tuvalu, Wallis & Futuna Is.	Discussion with NZ and Tonga Constrained by May 2009 submission deadline
	Cobalt rich crust	Guam, PNG, Palau, Nauru, Solomon Is.	See 4
		FSM	Tentative submission May 09[5]
	Hydro thermal deposits	Solomon Is., Australia & FSM	Joint submission with FSM & Solomon Is. in progress to meet May 2009 deadline
	Hydro Thermal deposits Hydrocarbons	Vanuatu, PNG, Fiji, New Caledonia, FSM, Tuvalu	See 4
	Hydrocarbons Hydro thermal deposits	W. & American Samoa Fiji, NZ, Niue, Wallis & Futuna Is.	Intends to submit at future unspecified date[5]. Ongoing discussion with NZ & Fiji Licensed exploration in EEZ 2008
		New Caledonia, Fiji, Solomon Is.	Submit by 10 Sep 2009
	Cobalt rich crust	Tuvalu, Marshall Is, Cook Is., Nauru	Submit by 26 Mar 2013
	Cobalt rich crust	Kiribati, Fiji, Wallis & Futuna Is.	Submit by 08 Jan 2013

their current 200 M Exclusive Economic Zone

8. For the following States the entry under "Continental Shelf Outer Limit Claims" in the DOALOS Table of claims to maritime jurisdiction (as at 28 May 2008) reads N/A (No information regarding current legislation is available), Kiribati, Palau, Tonga, Tuvalu

1 Excerpt from SOPAC site http://www.sopac.org/tiki-read_article.php?articleId=l08 accessed 12 June 2008
2 UNEP Scanning Assessment Report (UNEP Shelf Programme 2005)
3 pers com A. Webb SOPAC Ocean and Islands Programme Manager 4 June 2008
4 SOPAC Annual Report 2005
5 SPLOS/INF/20 16 Jan 2008
6 SOPAC Annual Report 2005 http://www.sopac.org/data/virlib/AR/AR2005.pdf
7 SOPAC Annual Report 2006 http://www.sopac.org/data/virlib/AR/AR2006.pdf
8 pers com A Webb SOPAC Ocean and Islands Programme Manager 4 June 2008
9 Does not pass test of appurtenance according to Monahan (2005) and does not have potential CSE claim in SOPAC list (2005); but confirmed by A Webb as receiving SOPAC assistance to prepare a CLCS submission pers com 4 Jun
10 Excerpt from SOPAC site http://www.sopac.org/tiki-read_article.php?articleId=l08 accessed 12 June 2008

	Coastal State UN-OHRLLL List ***SIDS** ****LDC** *****SIDS/LDC**	EEZ Million km^2	ECS km^2	**Test of Appurtenance** A(passes) B (physically meets criteria)	Marine research and other submission preparations Indicative only	
1	Barbados*	0.187		A	EEZ boundary with 6 defined	
2	Bahamas*	0.655		CARICOM[2] Not by Monahan		
3	Cuba*	0.351		As 2		
4	Guyana*	0.13	61,003	A	Proven Oil reserves DTS completed Boundary with 5 defined	
5	Suriname*	0.101	89,1110	A	Proven Oil reserves Boundary with 4 defined	
6	Trinidad & Tobago* (T&T)			B	Proven Oil reserves EEZ boundary with 1 defined	
7	Venezuela	0.364	14,431	B	Proven Oil reserves	
8	Costa Rica	0.574		B		

Appendix 1 Table 4 - Caribbean Coastal States with Potential for Continental Shelf Extension

Notes

1. The above States have attended Art.76 training as follows;
   (a) Southampton Oceanography Centre 2001-05 (Barbados, Guyana, Suriname)
   (b) DOALOS Argentina 2006 (Bahamas, Barbados, Costa Rica, Cuba, Guyana, Suriname, Trinidad and Tobago)
   (c) GRID/BGR Port of Spain 2008 (Bahamas, Barbados, Costa Rica, Cuba, Guyana, Suriname and Trinidad and Tobago)
2. Guyana only state represented at 2003 University of Virginia School of Law, Annual Conference *Legal and Scientific Aspects of Continental Shelf Limits*
3. States 1-6 above are listed as SIDS by UN-OHRLLS (Institutional List); but 4 & 5 are omitted from the Economic List
4. For the following States the entry under *"Continental Shelf Outer Limit Claims"* in the DOALOS Table of claims to maritime jurisdiction (as at 28 May 2008) reads N/A *(No information regarding current legislation is available),* Bahamas, Barbados, Costa Rica and Suriname

	Resources Hydrocarbons (oil/gas) [H] Seabed minerals [M]	**Neighbours** Indicative only	**Remarks** and CLCS Submission information
	Not listed Murton Hydrocarbons[2]	T&T, Guyana, Suriname, France	Submitted May 08[1]
	Not listed Murton Hydrocarbons[2]	USA, Cuba	Ratified 29 Jul 83 Delineation dispute with USA
	Not listed Murton Hydrocarbons[2]	Jamaica, USA, Bahamas	Intending to submit by 13 May 09[3]
	H,M	Suriname, T&T Venezuela	Intending to submit by 13 May 09[3] Boundary dispute with Venezuela
	H,M	Guyana, Fr. Guiana & Barbados	Intending to submit by 13 May 09[3]
	Not listed Murton	Barbados, Grenada, Guyana, Venezuela	Intending to submit by 13 May 09[3]
	H. M	Guyana, T&T	Not ratified Boundary disputes with neighbours
	Not listed Murton	Panama, Nicaragua	Ratified 21 Sep 92

1 SPLOS/INF/20/Add.2, 6 June 2008
2 http://www.caricom-fisheriesxorri/website_content/publications/documents/Delimitation_of_Maritirne_Boundaries_within_CARICOM.pdf accessed 03 July 08
3 SPLOS/INF/20,16 January 2008

Article

A Solution to the Ambiguity Problem in Depth Contouring

By Lihua Zhang, Yanchun Liu, Qing Zhu, and Fuming Xiao (China)

Abstract

Depth contours on a chart are important for safe navigation. The ambiguity problem can appear when points of equal depth are joined in contouring. Unreasonable solutions may mistake a shallow area for a deep one, which could result in a potential danger for navigation. A solution is presented to solve the ambiguity problem using constrained lines formed by two shallow depths. The constrained lines are used to limit the joining of the points with equal depth. Experimental results demonstrate that the proposed solution can reduce the dangers of producing non-existent deep areas in bathymetric contouring.

Résumé

Sur une carte, les isobathes sont importantes en ce qui concerne la sécurité de la navigation. Le problème de Tambiguïté peut apparaî tre lorsque des points de profondeur égale se rejoignent sur le tracé de l'isobathe. Certaines solutions non fondées rationnellement peuvent prendre par erreur une zone peu profonde pour une zone profonde, ce qui peut entrafner un danger potentiel pour la navigation. Une solution est présentée pour résoudre le problème de l'ambiguïté en utilisant des lignes contraintes formées par deux faibles profondeurs. Les lignes contraintes sont utilisées pour limiter la réunion de points d'une égale profondeur. Des résultats expérimentaux ont montré que la solution proposée peut réduire les dangers liés a la création de zones profondes non existantes dans le tracé bathymétrique.

Resumen

Las isobatas en una carta son importantes para la seguridad de la navegacion. El problema de ambigüedad puede aparecer cuando puntos de igual profundidad se unen en el trazado de la isobata. Soluciones no razonadas pueden confundir un área somera por una profunda, lo que podría resultar en un peligro potencial a la navegación. Una solución se presenta para resolver el problema de ambigüedad utilizando líneas forzadas formadas por dos profundidades someras. Las líneas forzadas se utilizan para limitar la unión de puntos con igual profundidad. Los resultados experimentales demuestran que la solución propuesta puede reducir los peligros de producir areas profundas no existentes en los contornos batimétricos.

A depth contour, a line connecting points of equal depth below the hydrographic datum, is used to represent submarine relief. With the advent of the electronic navigational chart, it gives the facility to mariners for setting up a safety depth contour, depending on the draft of the vessel. The safety depth contour will be highlighted on the display and an alarm will be provided when crossing this contour (Vatsa and Chauhan, 2002). With the evolution of the Electronic Chart Display and Information System (ECDIS) from a static display to provide real-time or forecast information, a "tide-aware" ship's safe contour needs to be acquired (Brennan et al., 2003, 2007). The depth contour has increasingly become a crucial feature for safe navigation. Nowadays there are two methods for contouring, i.e., triangulation and grid contouring (Kennie and Petrie, 1990). Contouring from triangulated data uses a triangulation technique and interpolates values based on the original data. Contouring from gridded data generates a set of gridded nodes using the neighboring original data points, and then interpolates positions of depth contours based on the regular gridded data. These methodologies for contouring have been continuously improved in recent years (Brennan et al., 2003; Li and Zhu, 2003).

However, the ambiguity problem still exists when joining points of equal depth whichever method is used to plot contours. In triangulation contouring, when four depths form a quadrangle and each edge has a point of equal depth as shown in Figure 1(a), various triangulations will lead to differences when joining points with equal depth. Similarly, if a grid cell has four points of equal value during grid contouring (as shown in Figure 2(a)), ambiguous results may appear when these are joined. Obviously, the different joinings will result in dissimilar submarine terrain representations and discrepancies in areas marked for safe navigation. Although the differences may be local and small, it is important to estimate submarine terrain and navigable areas without error. If the problem is not solved, it will result in potential dangers by indicating deep areas that in fact are shallow.

For navigation safety purposes, a conservative rule in contouring is to expand shallow areas and shrink deep areas (IHO, 1994; NSBQT, 1999; Russom and Halliwell, 1978). All depths less than and equal to the contour value should be compartmentalised into the shallow area in the plotting of the depth contour and deep areas cannot be extended to places without depths (Ye and Liu, 1991). When ambiguous joining of points with equal depth appears, the conservative rule should be utilized. Traditional solutions for the ambiguity problem can possibly mistake a shallow area for one that is deep, which is dangerous for navigation safety. The objective of this paper is to analyze the ambiguity problem during depth contouring, improve traditional solutions, avoid mistaking shallow areas for deep ones, and make contour plotting more reasonable.

Ambiguity in Plotting Depth Contours and its Influence on the Representation of Submarine Terrain

An important step during contouring is to interpolate positions of the contour values for each edge based on the values of the known nodes, and the use of linear interpolation is very popular (Kennie and Petrie, 1990). Then the interpolated points of all edges are connected up according to specified rules. Finally, the polylines from the connected points are further smoothed.

Ambiguity and Traditional Solutions in Triangulation Contouring

If each edge has a point of equal value in a depth quadrangle that consists of four soundings, different triangulation methods will result in the points being joined in different ways. It is known that the Delaunay method is used to form triangles in the majority of terrain modeling packages based on the triangulation method (Kennie and Petrie, 1990; Liu and Gong, 2001; Li and Zhu, 2003). When Delaunay triangulation is performed, the quadrangle, composed of four depths, is partitioned into two triangles. The method of joining points of equal depth is shown in Figure 1(b) (the shaded area, more than 10 metres, is the deep area). However, if the triangulation is shown as Figure 1(c), the deep areas obviously change. Thus, the area represented using diagonal lines in Figure 1(d) is regarded as the deep one.

If topographic characteristic lines are known during contouring on land, constrained Delaunay triangulation will be used for local optimization (Floriani, 1992; Liu and Gong, 2001). If a triangle threads a topographic characteristic line, the triangle will be deleted and the local network will be reconstructed (Liu and Gong, 2001). However, submarine terrain

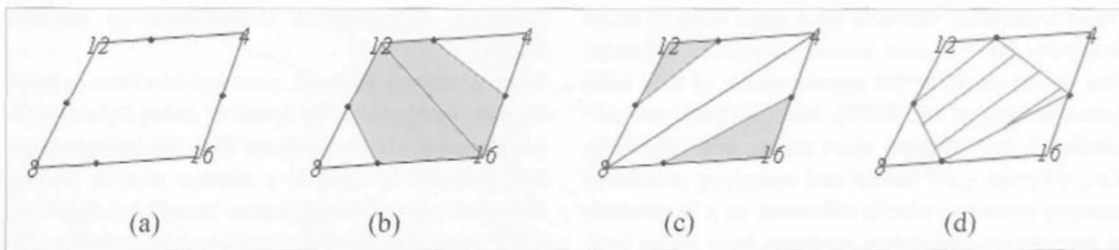

Figure 1: Ambiguity in triangulation contouring.

cannot be directly viewed due to the covering water, and the topographic characteristic lines can only be acquired accurately by well-positioned samples of sounding (Zhang et al., 2005), Unreasonable triangulation can possibly lead to the potential danger of producing non-existent deep areas.

Ambiguity and Traditional Solutions in Grid Contouring

Considering an individual grid cell (Figure 2), a simple linear interpolation is carried out along each edge of the grid in turn based on the values of the nodes and the positions of the contour values are obtained for each edge by interpolation. However, when each edge in a grid has a point of equivalent value, the ambiguity problem will occur, as indicated in Figure 2 (Kennie and Petrie, 1990; Liu and Fang, 1997; Li and Zhu, 2003; Zhang et al., 2005). If the points of equal value are joined as shown in Figure 2(b), but the actual seafloor is represented as shown in Figure 2(c), the possible shallow area represented using diagonal lines in Figure 2(d) is improperly classed as deep.

Several traditional solutions to solve the ambiguity are as follows:

1. A method of joining to the nearest point. As shown in Figure 3, if the points of equal a_1 depth and a_2 are found in a certain grid cell and a_1 locates in the edge *AD,* and there are other points of equal depth in other edges *AB, BC* and *CD,* the following point should be a, since it is the nearest one to a_2 of all points with equal depth in the grid cell *ABCD* (Hu et al., 1987).

2. A method based on direction changes. It is believed that contour lines seldom change direction abruptly. As shown in Figure 3, the points of equal depth a_1 and a_2 locate in a grid cell *ADEF* and a_2 in the edge *AD,* and there is a point of equivalent depth in each edge *AB, BC* and *CD.* According to minimum direction change, the following point should be a_3 not a_4 or a_5 (Wang et al., 1993).

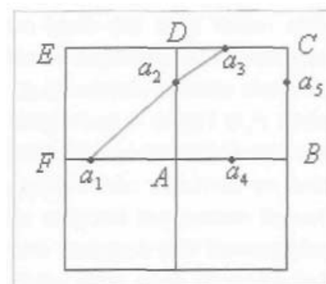

Figure3: Ambiguity in tracing

3. Subdivision once again (Kennie and Petrie, 1990; Li and Zhu, 2003). Another method is to split the grid cell into four grids or triangles, and assign the average value of the four grid nodes to the central points.

4. Interpolation based on fitting function. By considering neighboring nodes, a type of fitting function is employed to interpolate the contour (Kennie and Petrie, 1990; Liu and Gong, 1997).

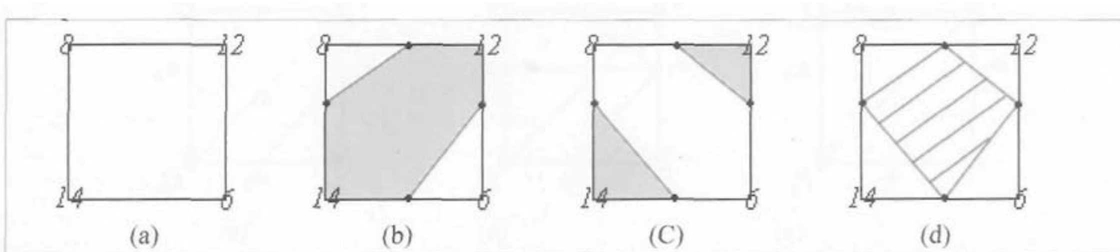

Figure 2: Ambiguity in grid contouring.

These traditional methods have been used to solve ambiguity for the past several decades. However, they do not consider the special needs of safe navigation (Zhang et al., 2005). Most of them are correlated to the different start points and directions (i.e., different start points and searching directions possibly make the results different), so it is possible to produce unreasonable contours from these traditional methods.

Rules and Control Methods of Shallow Depth Constraint

Rules of Shallow Depth Constraint

Due to the actual seafloor being covered by water and thus invisible, the rule of expanding shallow areas and shrinking deep areas is used to solve this problem when an ambiguity occurs (NSBQT, 1999; Zhang et al., 2005). Areas without detailed depth information would be considered on the shallow side rather than the deep one. So a constraining rule should be employed in contour plotting, namely that two shallow depths (e.g. the point P_1 and the point P_2 in Figure 4 and Figure 5) in the quadrangle are used to form a constrained line segment P_1P_2, and no contours can thread the constrained line. Joined means will become unique when using the constrained line segment and thus mistaking shallow areas for deep ones will be avoided.

Delaunay Triangulation Constrained by Shallow Depths

When ambiguity appears, a control condition is given for safe navigation. The result of using Delaunay triangulation is shown in Figure 4(b), which shows that it is possible to transfer a shallow area to a deep one, and so the triangulation should be improved during this process. For use on land, topographic characteristic lines are employed, and triangles intersecting them are located and deleted; then the local network is optimized (Floriani, 1992; Liu and Gong, 2001). However, the seabed is invisible and submarine topographic characteristic lines are difficult to obtain accurately by hydrographic sampling. The constrained segment $P_1 P_2$ is used as a virtual topographic characteristic line segment to optimize the local network. The final network is shown as Figure 4(c) after local optimization. Delaunay triangulation, constrained by shallow depths, can make the result unique and avoid mistaking shallow areas for deep ones.

Grid Contouring Constrained by Shallow Depths

As shown in Figure 5, in grid contouring, if a point of equal depth a_1 is found in one edge of a quadrangle, which point a_2, a_3 or a_4 will be chosen as the next point of equal depth? A basic rule for solving the ambiguity is that the two joined points should locate on the same side of the constrained line segment

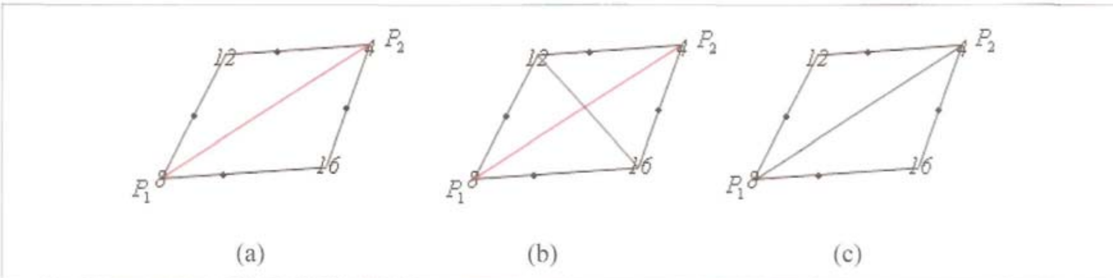

Figure 4: Local reconstructing of network.

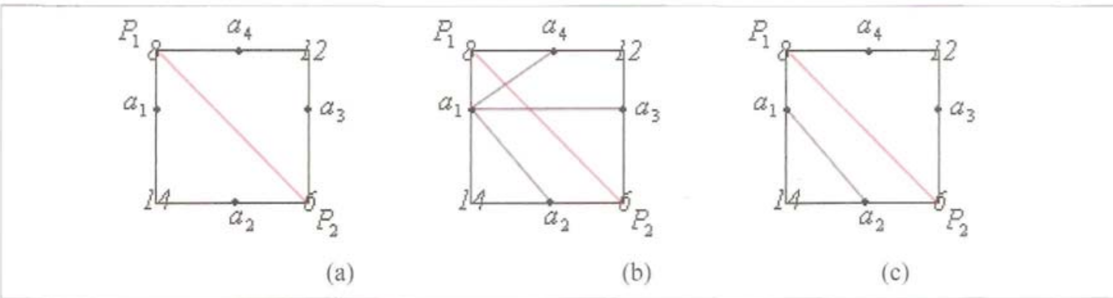

Figure 5: Different joining means in a grid.

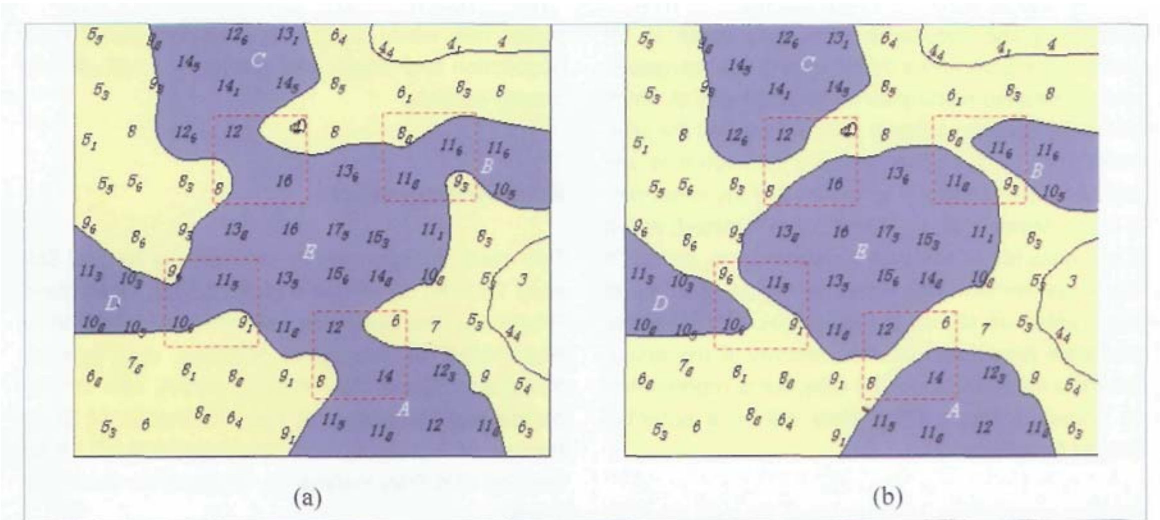

Figure 6: Contours obtained from different triangulations.

P_1P_2 formed by two shallow depths.

The given positions of P_1 and P_2 can be located by a pair of coordinates (x_{P_1}, y_{P_1}) and (x_{P_2}, y_{P_2}), respectively. Similarly, the positions of a_1, a_2, a_3 and a_4 are denoted using (x_{a_i}, y_{a_i}) = 1,2,3,4. The following equation is used to compute a value.

$$F(i) = [(y_{P_2} - y_{P_1})x_{a_1} - (x_{P_2} - x_{P_1})y_{a_1} - x_{P_1}y_{P_2} + x_{P_2}y_{P_1}]$$
$$[(y_{P_2} - y_{P_1})x_{a_i} - (x_{P_2} - x_{P_1})y_{a_i} - x_{P_1}y_{P_2} + x_{P_2}y_{P_1}]$$
$$i=2, 3, 4 \qquad (1)$$

If $F(i) > 0$, a_1 and a_1 locate on the same side of $P_1 P_2$, and a_1 is the next point of equal value adjacent to a_1 in the contour. In Figure 5, the following results are computed: $F(2) > 0$, $F(3) < 0$, $F(4) < 0$. So a_2 is the following point adjacent to a,, and the joining is shown in Figure 5(c). In the later search, a_3 and a_4 will be connected. The result from this solution is unique, and it is independent of the different start points and directions when searching for points of equal depth.

Experiment and Discussions

An example is used to test the proposed solution. The result shown in Figure 6(a) is derived from Delaunay triangulation contouring without a constraint. The result, after local optimization using the constraint by two shallow depths, is exhibited in Figure 6(b). In Figure 6, the safe areas have been changed

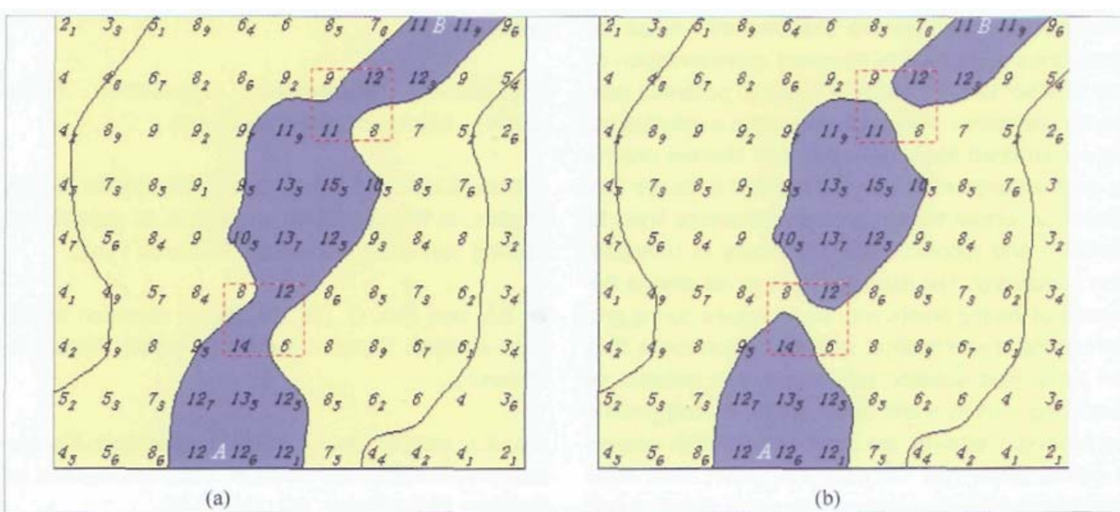

Figure 7: Contour difference from different solutions.

after using the constraint. (The safe depth is 10 metres, the blue areas in the charts are navigable, and red dashed rectangles highlight places at which ambiguity appears.) Figure 6(a) shows that the blue areas (e.g., *A, B, C, D* and *E)* are connected to one another if the constraint is not used. If the constraint is used, areas *A, B, C, D* and *E* are isolated, and it is not possible to navigate between them. In fact, if the actual terrain is as shown in Figure 6(a), but is represented as shown in Figure 6(b), it only wastes navigable resources. On the contrary, if the actual terrain is as shown in Figure 6(b), but is represented as shown in Figure 6(a), there will be a potential danger for navigation.

Another example is used to test for grid contouring. When each edge of a grid has an equal value point, and the traditional solutions (e.g., the method based on the nearest point or direction changes) are used, the result is as shown in Figure 7(a). If the constraint with shallow depths is used, the result is as shown in Figure 7(b). According to traditional solutions, there is a possible channel from area *A* to another one *B,* represented as navigable as shown in Figure 7(a). However, the channel is not navigable for vessels with the draft of 10 meters as shown in Figure 7(b). If the shallow depth constraint is not applied, an un-navigable channel is incorrectly considered as a navigable one.

Conclusions

The joining of points with equal depth during contouring may cause an ambiguity problem. The traditional solutions possibly mistake shallow water areas for deep ones and result in incorrect representation of the seafloor terrain, which will lead to potential danger for navigation. This paper presents a solution using constrained lines formed by two shallow depths to control contouring. The constrained lines are employed as virtual topographic characteristic lines to optimize and reconstruct a TIN locally in triangulation contouring. The lines are used to determine the means of joining points with equal values during grid contouring. Experimental results demonstrate that the presented solution can reduce the dangers of producing non-existent deep areas in bathymetric contouring. Certainly, the proposed solution applies a conservative rule for safe navigation, and more effective solutions would require more detailed and accurate information on the actual submarine topography; this would need very time-consuming data acquisition and might only provide a small gain in display efficacy.

Acknowledgements

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Article

Adopting a Reference Standard Port for Nigeria

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Abstract

Nigeria has a coastline of about 800km which is covered by only two Standard ports located at Bonny in Nigeria and Takoradi in Ghana. Tidal analyses were carried out to verify the rational in referencing some secondary port in Nigeria to the standard port in Ghana. Result showed that, for all locations in Nigeria, analysis made with reference to Bonny gives either better or similar accuracy when compared with analysis made with reference to Takoradi. It is therefore concluded that, depending on the availability of the needed tidal data, referred to Bonny, the use of Takoradi as the reference port for some locations in Nigeria may not be necessary.

Résumé

Le Nigéria possède une ligne de côte d'environ 800km qui est seulement couverte par deux ports principaux situés à Bonny au Nigéria et Takoradi au Ghana. Des analyses de marée ont ete menées pour justifier les relations référentielles de certains ports secondaires au Nigéria par rapport au port principal au Ghana. Les résultats ont montré que, pour l'ensemble des lieux situés au Nigéria, Tanalyse conduite en référence à Bonny donne une précision meilleure ou similaire comparée à l'analyse fait en référence à Takoradi. Il est en conséquence conclu que, selon la disponibilité des données de marée nécessaires, l'utilisation de Takoradi comme port de référence pour certains lieux au Nigéria pourrait ne pas être nécessaire.

Resumen

Nigeria tiene una línea de costa de cerca de 800km que esta cubierta por solo dos puertos principales ubicados en Bonny, Nigeria y Takoradi en Ghana. Se llevaron a cabo análisis de la marea para verificar la relación referencial de algunos puertos secundarios en Nigeria respecto del puerto principal en Ghana. Los resultados mostraron que, para todas las localidades en Nigeria, los análisis hecho con referenda a Bonny entregan ya sea una mejor o similar precisión cuando se comparan con los análisis hechos con referenda a Takoradi. Por lo tanto se concluye en que, dependiendo de la disponibilidad de los necesarios datos de marea, referidos a Bonny, el uso de Takoradi como puerto de referenda puede no ser necesario para ciertas localidades en Nigeria.

The Admiralty Tide Tables (ATT) volume II on the Atlantic and Indian Oceans publishes information on tide and tidal stream for the coastal nations bounded by these oceans. Some of the information published includes the locations of the standard and secondary ports, high and low water times and heights at the standard ports, time and height differences of tides between the standard and secondary ports, etc. The records also contain the dates of establishment of the standard port, when data is available. An overview of the standard ports and extent of the secondary ports covered by each standard port is shown in figure 1 for the African Coastline.

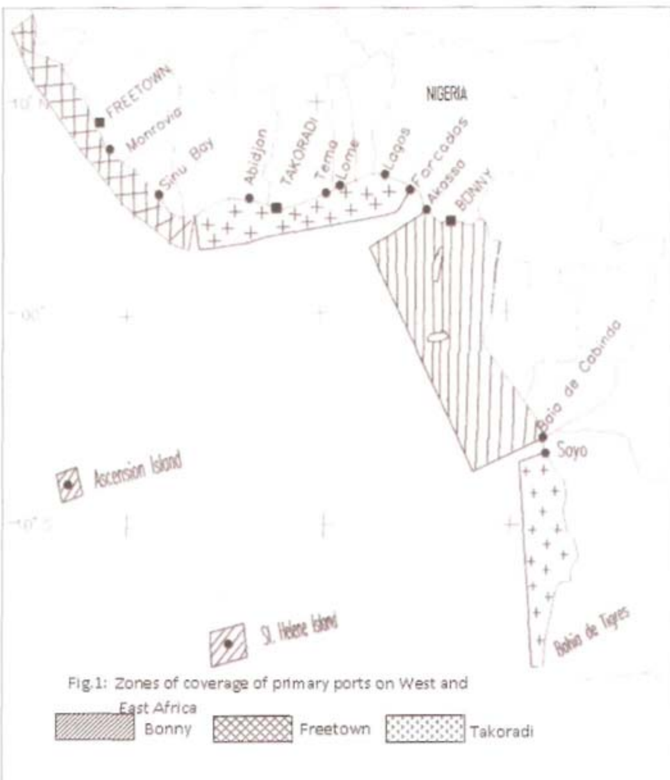

Figure 1: The Nigerian Coastline.

From figure 1, it can be observed that the Nigerian coastline is covered by two primary ports namely Takoradi and Bonny. The secondary ports covered by Takoradi extend from Lagos to Forcados while those covered by Bonny extend westwards to Akassa and eastwards to the Nigeria/Cameroun border. Since no information is given for the area between Akassa and Forcados, an uncertainty exists as to which of the two standard ports (Takoradi or Bonny) should be used as reference for reduction of hydrographic data obtained within this zone.

The use of standard ports as references for tidal operation in other locations is a frequent requirement in tides and tidal stream studies. Under the existing condition in Nigeria, it follows that for all operations between Lagos and Forcados, observations and data reduction should be referenced to the standard port in Takoradi. A situation where survey operation is executed in one country (Nigeria) and reference data is needed from another country (Ghana) may create some logistic problems especially in absence of full international cooperation.

Objective and Scope of Work

The paper tends to address the following problems:

1 To verify which of the reference standard ports, that is Bonny or Takoradi, that should be used for locations lying between Akassa and Forcados in Nigeria.

2. To verify whether it is possible to refer all the tidal studies in Nigeria to one Standard port which should preferably be located in Nigeria. If this is feasible, then the issue of using Takoradi as the reference standard port for any work in Nigeria may no longer be necessary.
3. On the interim, while the search for the location of the appropriate standard port is on, is it feasible to use Bonny as the reference for all stations in Nigeria without introducing serious errors in obtained results?

A positive result to the second objective will certainly obviate the need to address the first question. Similarly, a positive result to the third objective will be a welcome relief, for a fairly long period of time, to all those involved in hydrographic operations in Nigeria pending the establishment of more standard ports in the nation.

Standard Port for Nigeria

Standard ports are locations where tidal analysis have been made from tide observations lasting for at least one year, while secondary ports are locations where analysis have been made from observations lasting for a relatively short duration, usually between seven days and one month. Tidal analyses at standard ports are made by direct application of astronomic theory. In the ideal situation, tidal analysis should be carried out from observation made over a period of 18.61 years (approximately 19 years) which is the period of the moon's node. The number of tidal constituents which can be separated from tidal analysis depends on the duration of the observations. For observations lasting up to one year, 100 constituents can be separated while more than 300 constituents can be separated in observations lasting up to 19 years.

In the case of secondary ports, in which short-period analysis is made, the only constituents that can be reliably separated are the four principal constituents (usually M2 , S2, K1, 01). The constituent N2 is however sometimes included by some scholars. Observations made for short-period analysis do not actually provide enough data for complete separation of the above constituents, they are therefore separated by making reference to available standard ports. For this purpose, the theory of regional relationship is employed. The theory states that 'over a considerable stretch of any coastline, the ratios Ho1/Hk1 and Hs2/HM2 and the differences go1-gk1 and gs2-gM2 are approximately constant [6]. This does not however hold true near amphidromic points since at such points, each constituent has its own amphidromic distribution and the relationship between the various constituents will vary greatly near such locations [3].

Evaluation of Tidal Characteristics

The tidal constants for the above four major constituent (M2 , S2, K1, 01) are published for several locations in the ATT. The published values were used in this research to compute the mean spring range for the tidal stations on the West African coastline. Figure 2 shows the curve of mean spring range for the locations between Free Town and the ports lying the extreme east of Nigeria. Note that the plot is not according to any scale but is simply intended to depict the variation of tidal range from East to West of this coastline. From the plot, it can be observed that the tide range decreases from the east in Nigeria westwards to minimum at Lagos and increases from there westwards towards Takoradi and FreeTown. Consequently, Bonny and Takoradi apparently lie on opposite sides of an amphidromic point. It also shows that Bonny and all the other locations in Nigeria lie on the same side of this amphidromic point. The effect of this, if any, for the Nigerian tidal stations which are referred to Takoradi is yet to be determined.

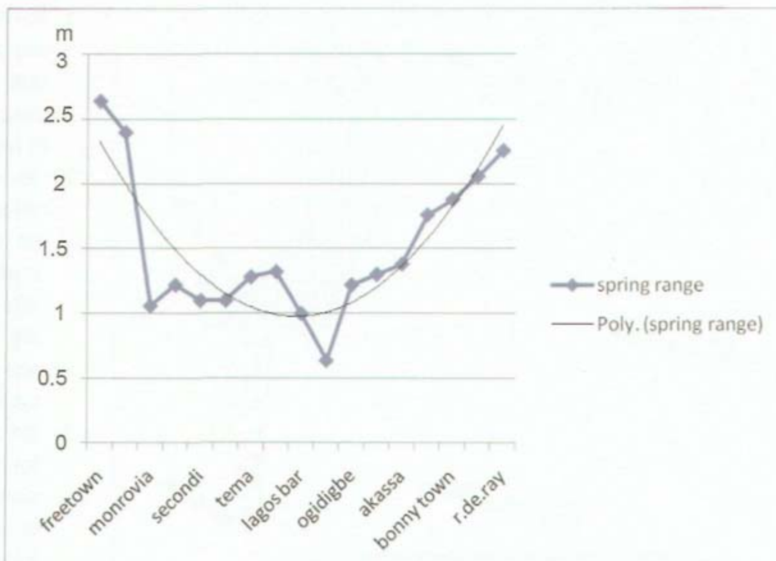

Figure 2: Spring range values on West-African coastline.

Historical Review of Standard Ports in West Africa

The colonial masters landed first on the shores of the then Gold Coast (Ghana) and, encouraged by the abundance of gold, settled and used it as base for further activities in West Africa. From here, they moved eastwards up to Forcados and continued their journey across the Bight of Biafra to East Africa where a more conducive climate encouraged them to settle. Therefore, as early as 1927, a tidal station has been established at Takoradi in Ghana. Water level observations were made at this location for a period of two years and subsequently used for analysis. Consequently, all the secondary ports located along the coast of West Africa and part of East Africa were referenced to Takoradi [8]. This extended to Forcados on the west part of the Niger Delta in Nigeria and Bahai-de-Tigres in Angola. It was in the wake of oil prospecting in the old Eastern Nigeria, and the discovery of oil at Oloibiri in 1957 that the town of Bonny gained importance. A tide station was established at Bonny by Shell/ B.P and tide analysis was subsequently made from one-year tidal observation at this station. Bonny town has since then served as the only internationally recognised standard port in Nigeria. All subsequent tide observations east of the Niger delta and up to Bahai-de-Cabinda in Angola were therefore referred to Bonny. Further tide observations and analysis at Bonny however continued for decades with few interruptions. In the absence of a concerted effort by Nigeria to establish more standard ports, it does appear that Bonny will continue to serve as the only available standard port in the nation.

It therefore apparently implies that the distribution of standard ports and their secondary ports on the African coastline is based more on operational convenience than on any scientific considerations. This further explains why there are no defined geographical boundaries between the secondary ports covered by Bonny and those covered by Takoradi.

Choice of Standard Port for Nigeria

The above discussions clearly show the need to adopt a reference standard port that can serve all the secondary ports in Nigeria, or, in the alternative, establish more standard ports in Nigeria for a more effective tidal study in the country. Since the later option is a policy issue and is likely to be a long-term programme, an immediate approach is to adopt the first option.

We therefore need to verify the following:

- Since Forcados and Akassa form the limits of the secondary ports referred to Takoradi and Bonny respectively, it is necessary to verify which of the standard ports should be used as reference for hydrographic operations between Forcados and Akassa.
- The suitability of adopting Bonny as the reference standard port for all locations in Nigeria. This will have an advantage by virtue of its location within the country.

To achieve this, the following investigations were carried out:

1. Short-period analysis for Lagos wharf, which is the tidal station in the extreme west of Nigeria, using Takoradi as a reference standard port and then Bonny as a reference standard port. The short-period analysis was chosen since this is the only condition for which reference is made to standard ports in the computation of tidal constants.
2. Repeat (i) above for Forcados, which is the extreme east location in Nigeria referenced to Takoradi. No analysis was made for Akassa due to unavailability of data. This does not however create any problem as Akassa is already referred to Bonny in Nigeria.
3. Each of the two sets of tidal constants (g and H) (i.e those with reference to Bonny and those with reference to Takoradi) is then used to predict tides for Lagos and Forcados.
4. The differences between the observed hourly water levels and the levels predicted with the two sets of constants were then computed separately.
5. The mean levels and root mean square were computed from iii and iv respectively. These values were employed to verify which set of the predictions gave a better representation of the observed data. The result from the above investigations will help to determine whether Bonny or Takoradi is more reliable as a reference standard port for the locations considered.

For the purpose of the above investigations, an in-house computer program was developed as none was locally available and available foreign software were relatively expensive. The least squares method was adopted in solving the equation for the harmonic analysis and the computer program was designed to incorporate the theory of Regional Relationship. The result from the program was first tested with real data and found reliable before being employed for further investigations.

Tidal Analysis and Predictions for Forcados Terminal and Lagos wharf

Among the Nigerian secondary ports referred to Takoradi, Lagos is located in the extreme west while Forcados is located in the extreme east. Fortunately, observed tidal data are available for these locations. Observations available for this study dates back to 1980 and 1990 for Lagos and Forcados respectively. This does not however create any problem since we are interested in a comparative study which simply requires that data should be used for the same epoch.

The tide analysis and prediction program was utilized for the following operations:

1. Short period analysis for Forcados terminal and Lagos-Apapa using Bonny as reference standard port.
2. Repeat the above analysis using Takoradi as reference standard port.

The results of the above operations are discussed below.

Tidal Analysis and Prediction for Forcados Terminal

Available tide observations for January 1st to 15th 1990 were used to carry out short period analysis for Forcados with reference to Bonny and Takoradi separately. Table 1 shows the results of the analyses while table 2 shows the

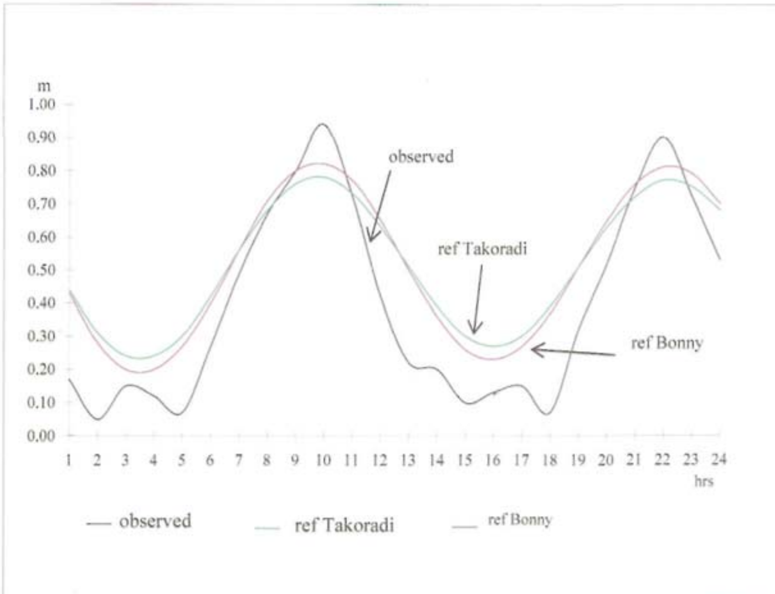

Figure 3: Observed and predicted tides for Forcados with ref. to Bonny.

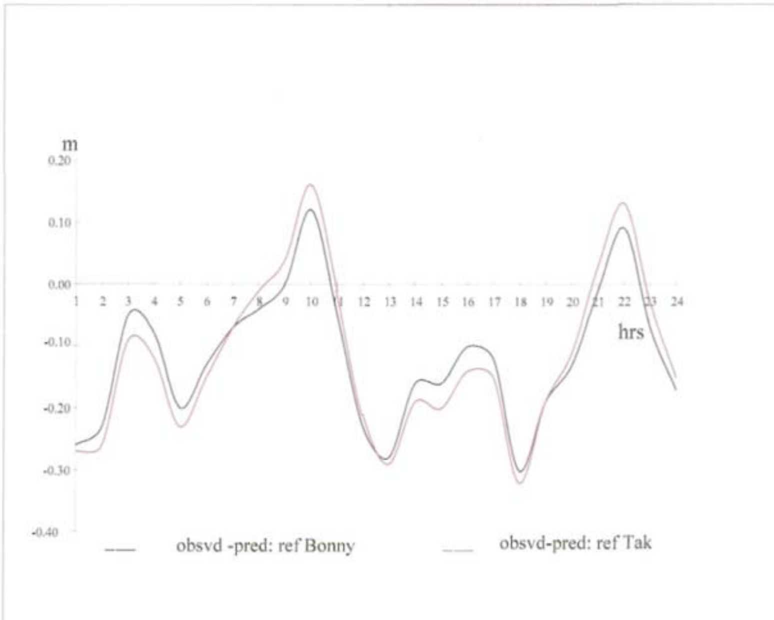

Figure 4: Observed -predicted values for Forcados ref. to Bonny.

Stn	ref	M_2 g°	M_2 H m	S_2 g°	S_2 H m	K_1 g°	K_1 H m	O_1 g°	O_1 H m	z m	Period
Forcados	Bon	142	0.37	179	0.12	290	0.01	253	0.00	0.45	15 days
	Tak	144	0.35	171	0.13	290	0.01	257	0.00	0.45	

Table 1: Computed Tidal Constants for Forcados Terminal.

Table 2

I_O =observed water levels
P_B= predicted with constants obtained by ref. to Bonny
P_T =predicted with constants obtained by reference to Takoradi
$D_{IB} = I_O - P_B$, D_T, $= I_O - P_T$, date =10/1/80

time	obsvd	predicted (m)		differences (m)	
hrs	I (m)	P_B	P_T	D_{IB}	D_{IT}
0	0.17	0.43	0.44	-0.26	-0.27
1	0.05	0.28	0.31	-0.23	-0.26
2	0.15	0.20	0.24	-0.05	-0.09
3	0.12	0.20	0.24	-0.08	-0.12
4	0.07	0.27	0.30	-0.20	-0.23
5	0.27	0.40	0.42	-0.13	-0.15
6	0.49	0.56	0.56	-0.07	-0.07
7	0.67	0.71	0.68	-0.04	-0.01
8	0.80	0.80	0.76	0.00	0.04
9	0.94	0.82	0.78	0.12	0.16
10	0.72	0.77	0.73	-0.05	-0.01
11	0.42	0.65	0.63	-0.23	-0.21
12	0.22	0.50	0.51	-0.28	-0.29
13	0.20	0.36	0.39	-0.16	-0.19
14	0.10	0.26	0.30	-0.16	-0.20
15	0.13	0.23	0.27	-0.10	-0.14
16	0.15	0.27	0.30	-0.12	-0.15
17	0.07	0.37	0.39	-0.30	-0.32
18	0.32	0.51	0.51	-0.19	-0.19
19	0.52	0.65	0.63	-0.13	-0.11
20	0.75	0.76	0.72	-0,01	0.03
21	0.90	0.81	0.77	0.09	0.13
22	0.72	0.79	0.75	-0.07	-0.03
23	0.53	0.70	0.68	-0.17	-0.15
mean	0.40	0.51	0.51	-0.12	-0.12
Std dev				0.11	0.13

Table 2: Observed and predicted tides for Forcados Terminal.

observed and predicted values for a chosen date.

Table 1 shows that the tidal constants obtained, for Forcados Terminal, by reference to Bonny and Takoradi are almost equal. In table 2, the mean value of differences (DIB) between observed and predicted water levels for Bonny is the same as the mean value of the differences (DIT) obtained for Takoradi. This apparently suggests that the same result is obtained by using either Bonny or Takoradi as reference port for Forcados. However the marginal lower value of standard deviation for Bonny shows that this station stands out as the logical choice when there is option to chose between the two.

Figures 3 and 4 show the plots of the observations and their differences respectively. Figure 4 gives a clearer picture of the errors from both locations. It is observed that the Bonny-related errors are almost always smaller than those of Takoradi. This apparently confirms that, under ideal situations, Bonny should be preferred to Takoradi

Stn	ref	M_2 g°	M_2 H m	S_2 g°	S_2 H m	K_1 g°	K_1 H m	O_1 g°	O_1 H m	z m	Period
Apapa-Lagos	Bon	134	0.34	171	0.11	15	0.06	338	0.01	0.95	15 days
	Tak	136	0.36	163	0.12	15	0.06	342	0.01	0.95	

Table 3. Computed Tidal Constants for Apapa-Lagos.

as the standard reference port for tidal work at Forcados.

Tidal Analysis and Prediction for Apapa-Lagos referred to Bonny and Takordi

Similar analysis and prediction carried out for Forcados were repeated for Apapa-Lagos. Observed water level was available for November 1st to 30th 1989. Table 3 shows the result of the analysis while table 4 shows the predictions for a chosen date. Figures 5 shows the plots of the observed and predicted tidal curves while figure 6 shows the differences between predicted and observed for the two sets of tidal constants. In table 4, the mean difference of 0.05m is equal for both sets of tidal constants. Figure 6 actually shows that the differences in the errors from the two sets of constants are random and appear equal. This is further confirmed by the equal values of standard deviation which is 0.08m for the two sets of tidal constants. This apparently suggests that Bonny can be used as the reference standard port for Apapa-Lagos, in place of Takoradi, without introducing any relative error.

From the above discussions, it follows that, pending the establishment of more standard ports in Nigeria, the Bonny standard port can be employed as the reference port for all tidal work in Nigeria.

Conclusion

The secondary ports on the Nigerian Coastline are referred to the standard ports at Bonny and Takoradi. Earlier publications of the Admiralty Tide Tables (ATT) show that the secondary ports between Lagos and Forcados are referred to Takoradi and untill that date there has been no published report to the contrary. It is also observed that the division of the Nigerian secondary ports between two standard ports is based more on operational convenience than on any mathematical consideration. Consequently, there are no defined geographic boundaries between the two groups of secondary ports. It has however been shown in this study that, pending the establishment of more standard ports in Nigeria, the standard port located at Bonny can be employed, for all practical purposes, as the reference port for all tidal work along the Nigerian coastline. It is therefore suggested that efforts should be made to determine the time and height differences between these secondary ports and the Bonny standard port, with the ulti-

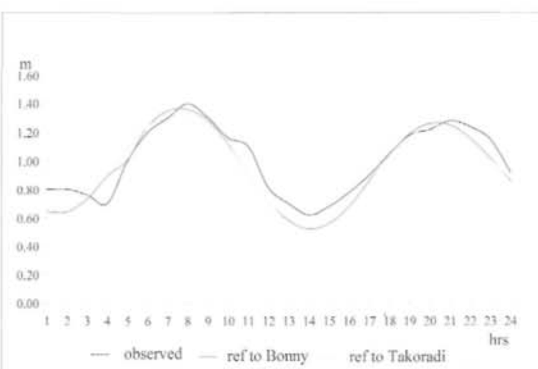

Figure 5: Observed and predicted tide for Lagos ref to Bonny and Takoradi.

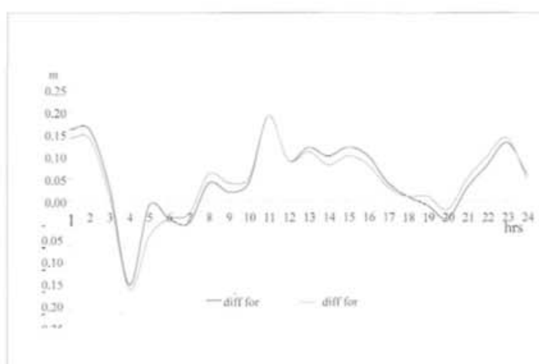

Figure 6: Observed -predicted for Lagos ref. to Bonny and Takoradi.

Table 4

I_O =observed water levels
P_B= predicted with constants obtained by ref. to Bonny
P_T =predicted with constants obtained by reference to Takoradi
D_{IB} = I_O- P_B, D_T, = I_O -P_T, date =10/1/80

time	obsvd	predicted (m)		differences (m)	
hrs	I_O(m)	P_B	P_T	D_{IB}	D_{IT}
0	0.80	0.64	0.66	0.16	0.14
1	0.80	0.64	0.66	0.16	0.14
2	0.76	0.73	0.75	0.03	0.01
3	0.70	0.89	0.90	-0.19	-0.20
4	1.00	1.01	1.08	-0.01	-0.08
5	1.20	1.24	1.24	-0.04	-0.04
6	1.30	1.35	1.33	-0.05	-0.03
7	1.40	1.36	1.34	0.04	0.06
8	1.30	1.28	1.26	0.02	0.04
9	1.16	1.12	1.11	0.04	0.05
10	1.10	0.91	0.91	0.19	0.10
11	0.81	0.72	0.72	0.09	0.09
12	0.70	0.58	0.59	0.12	0.11
13	0.62	0.52	0.54	0.10	0.08
14	0.68	0.56	0.58	0.12	0.10
15	0.78	0.68	0.70	0.10	0.08
16	0.90	0.86	0.87	0.04	0.03
17	1.05	1.04	1.04	0.01	0.01
18	1.18	1.19	1.17	-0.01	0.01
19	1.22	1.26	1.24	-0.04	-0.02
20	1.28	1.25	1.23	0.03	0.05
21	1.24	1.16	1.14	0.08	0.10
22	1.15	1.02	1.01	0.13	0.14
23	0.92	0.86	0.87	0.06	0.05
mean	1.00	0.95	0.96	0.05	0.05
Std dev				0.08	0.08

Table 4: Observed and predicted tides for Apapa-Lagos.

mate goal of finally adopting Bonny as the reference port for all tidal stations in Nigeria.

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