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A New Digital Map of Limits of Oceans and Seas Consistent with High-Resolution Global Shorelines

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ABSTRACT

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We present a vector map of the limits of oceans and seas intended to be integrated into a geographic information system (GIS). This map is based on the document S-23 titled "Limits of Oceans and Seas" and published by the International Hydrographic Organization (IHO). The third edition of this document, published in 1953, still serves as an official reference. The realization of this map from a text containing numerous ambiguities, disused place-names, or imprecise coordinates required important documentary investigations. This was made possible through the use of online resources such as map libraries, satellite imageries, geographic names databases, and institutional geoportals. The main innovations of our map are its accuracy, its precision of about 10 s of meridian arc, and its consistency with the Global, Self-consistent, Hierarchical, High-resolution Shoreline database and with satellite images such as Land Satellite and moderate-resolution imaging spectroradiometer. All remaining uncertainties for the drawing of limits are presented in the results. Although based on an IHO document, our map does not possess any official status. Nevertheless, we hope that our map will facilitate and encourage more detailed spatial analyses related to oceans and seas. This map is freely available for noncommercial use.

ADDITIONAL INDEX WORDS: *Limits of oceans and seas, IHO S-23, Global Self-consistent, Hierarchical, High-resolution Shoreline (GSHHS), geographic information system (GIS), vector map.*

INTRODUCTION

Having a digital map of limits of oceans and seas of the Earth is necessary for some studies in different fields, such as oceanography, geography, meteorology, and halieutics. Within the context of our scientific studies, *i.e.,* vertebrate invasions and extinctions on islands, we developed a geographic information system (GIS) based on the Global Self-consistent, Hierarchical, High-resolution Shoreline (GSHHS) data set (National Geophysical Data Center, 2010; Wessel and Smith, 1996) describing the roughly 180,000 islands of the world. To perform spatial analysis at various scales and in different regions, we needed a vector layer of limits of oceans and seas consistent with other data sets such as global bathymetry and satellite imagery.

The International Hydrographic Organization (IHO) is an intergovernmental consultative and technical organization. Its authority to name and define oceans and seas of the world is recognized by its 80 signatory countries. These limits have no economic or political character and are intended strictly for hydrographic uses. The IHO special publication S-23, "Limits of Oceans and Seas," whose third edition was published in 1953, specifies and names 101 entities. A fourth edition of this document, revised and enlarged, was finished in 1986 and updated in 2002. The two draft versions of the fourth edition were distributed to IHO members, but their official publications have been suspended pending an agreement between South Korea and Japan regarding the international standard name of the sea called "Japan Sea" in the document of 1953 (IHO, 2000). Consequently, the edition of 1953 is still officially in force to date (IHO, 2000).

To our knowledge, the only georeferenced digital map based on special publication S-23 of the IHO and freely available was, until today, one constructed by the Vlaams Instituut voor de Zee (VLIZ, 2005). However, we could not use this map because its resolution is not compatible with a high-resolution global shoreline database, such as the GSHHS integrated into our GIS relating to the world's islands. In addition, this map

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reveals important differences in comparison with the IHO text. For example, according to the IHO (1953), the northern limit of the South Pacific Ocean circumvents the Gilbert Islands (00°00′ N, 174°00′ E), which extend from both sides of the equator, in such a way as to include them all in the South Pacific Ocean. In the VLIZ map, this circumvention has been drawn around Kiritimati Atoll (01°52′ N, 157°23′ W), located more than 3200 km east of the Gilbert Islands.

Our objective was therefore to construct a georeferenced vector map of the limits of oceans and seas as defined by "Limits of Oceans and Seas" (IHO, 1953) and with an accuracy and a precision compatible with the GSHHS coastline (National Geophysical Data Center, 2010) and a global data set such as Land Satellite (LANDSAT) and moderate-resolution imaging spectroradiometer (MODIS) images (Global Land Cover Facility, 2011).

MATERIAL AND METHODS

The limits of oceans and seas that we mapped are those specified in the third edition of special publication S-23 of the IHO, published in 1953. We were unable to use the three images found within this document because their resolution was too low for our purposes. We therefore made every attempt to respect the information contained within the text. Our approach also retained the nomenclature of oceans and seas of this text. To construct our vector map, we used Esri ArcInfo 10 and the GSHHS 2.1.0 shoreline data set (National Geophysical Data Center, 2010), which we chose because of its very high spatial resolution.

The limits specified by the IHO (1953) go through points, which are specified by their geographic coordinates, a toponym, or simply an indication in text, *e.g.,* "the Northwest point of Meighen Island." We termed as "reference points" all these specified points and all points created at intersections with coastline during construction of our map.

Reference Points Specified by Geographic Coordinates

Geographic coordinates specified by the IHO (1953) are approximate, and their precision is about 1 min. Therefore, we used georeferenced LANDSAT images from the Global Land Cover Facility (2011) and the virtual globe Google Earth (Google, 2011) as standards to correct the mismatching between IHO coordinates and their related topographical object, such as a cape. All coordinates have been redefined in the World Geodetic System 1984 (NIMA, 1997).

Reference Points Specified by a Toponym

To find and locate reference points specified by a toponym only, we used several data sources; in most cases, we intersected sources of information to validate location. For regions in which toponyms used by the IHO (1953) are close to current names, we utilized an atlas (Times Books, 2007), institutional geoportals of several nations (Atlas of Canada, 2011; Denshi Kokudo/Digital Japan, 2010; GeoNorge, 2010; Géoportail, 2010; Malaysia geoportal, 2011; NunaGis, 2010; OS OpenData, 2010), printed nautical charts of the French Service Hydrographique et Océanographique de la Marine, digital nautical charts (C-Map Norway, 1999), or scanned topographic maps (University of Texas Libraries, 2011). However, for many reference points, the toponym used by the IHO (1953) differed from the toponym currently in use. This was particularly the case in the region running from north of Japan to south of Indonesia and occasionally in Europe, *i.e.,* Baltic Sea and Svalbard. To find these points, we used two main sources: old maps of the U.S. Army Map Service (Topographic Map Series, 1936–1968) available online (University of Texas Libraries, 2011) and the GEOnet Names Server (GNS) of the National Geospatial Intelligence Agency (2011). This latter source provided access to a world database of geographic names for about 5 million features in 2011. It gives different known toponyms, past or current, for the same place and spelling variants. In addition, these toponyms are geographically referenced. However, the 1-min resolution of coordinates frequently proved to be inadequate. For example, Horsburgh Reef, currently also named Batu Puteh Pulau or Pedra Branca, is a reference point of the eastern limit of the Singapore Strait. However, coordinates given by GNS locate this place inland. We were able to refine these coordinates using the search engine for places included in Google Earth, and then we established them precisely with a digital nautical chart (C-Map Norway, 1999).

Other References

For limits corresponding to bathymetric features, such as isobaths, we used the General Bathymetric Chart of the Oceans (GEBCO) database (2010).

Positioning of the Reference Points

All reference points were positioned consistently with the GSHHS and, when it was possible, with LANDSAT and MODIS images. According to the different regions of the world, discrepancies can be important between the GSHHS and these satellite images. In these cases, we gave priority to the GSHHS for consistency. Positioning precision of reference points was evaluated on 12 points located in different world regions by comparing several standard documents (nautical charts, nautical directions, dry land topographical maps, and orthorectified satellite imagery).

Uncertainties

Despite our efforts, toponyms of the IHO (1953) occasionally could not be located or proved aberrant. Moreover, for a few seas, information from the IHO (1953) was insufficient to draw limits. To solve these uncertainties, we propose solutions based on geographic logic and the closest adherence possible to the IHO text. Proposed solutions remain consistent with LANDSAT, MODIS, GEBCO, and GSHHS data. For example, drawing of limits beside groups of islands is sometimes specified in the IHO (1953) only by the phrase "in such a way that all the narrow waters between [these islands] are included in the Sea." In some cases, such a brief specification did not

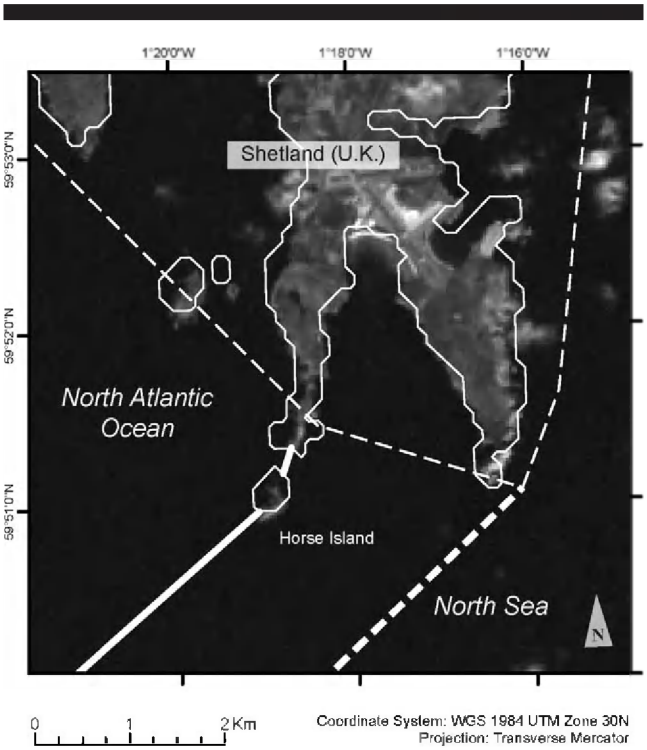

Figure 1. Illustration of the precision of our map by overlay on orthorectified LANDSAT imagery, and comparison with the precision of the VLIZ (2005) map: NW limit of the North Sea (continuous line denotes GSHHS; thick continuous line denotes the limit in our map; dotted line denotes the shoreline in VLIZ; thick dotted line denotes the limit in VLIZ).

allow us to draw clear limits, because the meaning of "narrow waters" is scale dependent. In these complex cases, we chose to border the concerned groups of islands according to the boundaries of convex hulls constructed around groups of islands or around several subgroups, which we chose (see Results and Discussion). We used the ArcInfo Minimum Bounding Geometry function to construct these convex hulls, with a 300-m buffer beyond the coast to take into account precision of the GSHHS.

Construction of the Map

To minimize distortions of the map caused by its representation in projected coordinates systems, we constructed two types of lines, between reference points, using the ArcInfo tool Construct Geodetic. First, to draw limits following a parallel, we created loxodromes. A loxodrome is a complex curve on the earth's surface that crosses every meridian at the same oblique angle. Second, to draw all other limits, we constructed geodesic lines. A geodesic line is the shortest line between two points on the surface of a spheroid.

In the final data set that we propose, limits are merged with the GSHHS shoreline 2.1.0 (National Geophysical Data Center, 2010) and attribute data include the spherical area and the spheroidal perimeter length of each polygon (*i.e.,* sea)

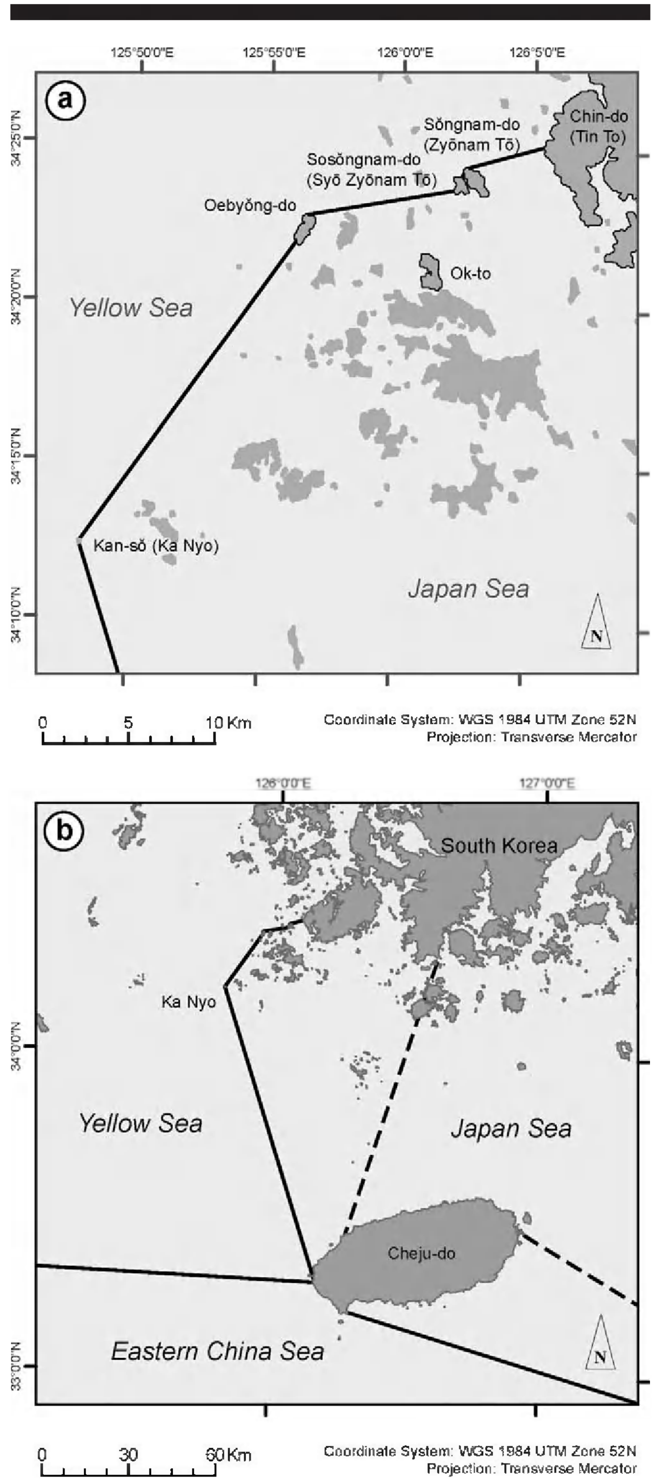

Figure 2. (a) Illustration of the positioning accuracy of toponyms in our map, and (b) comparison with the accuracy of the VLIZ (2005) map: SE limit of the Yellow Sea and N limit of the Eastern China Sea (names in brackets denote toponyms of the IHO, 1953; names without brackets denote current toponyms; continuous line denotes the limit in our map; dotted line denotes the limit in VLIZ; shoreline denotes GSHHS).

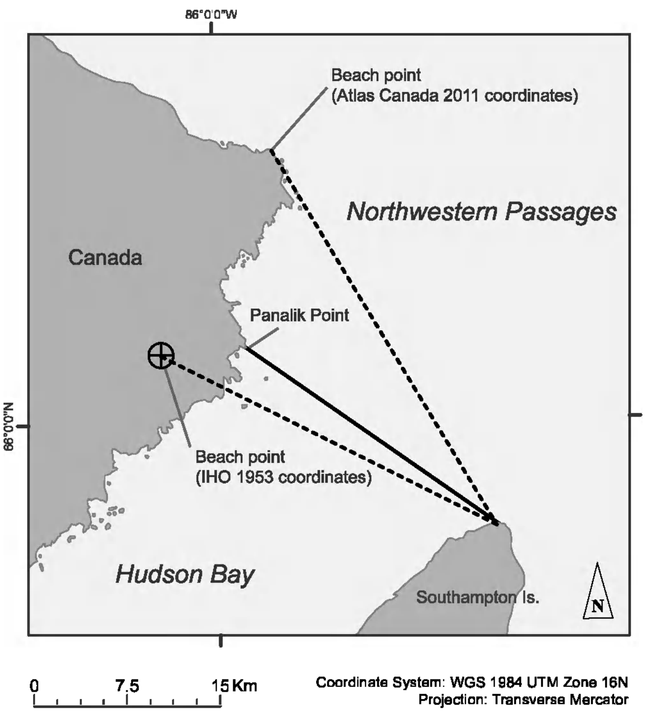

Figure 3. Uncertainty relating to the northern limit of the Hudson Bay (continuous line denotes the limit in our map; dotted line denotes the limit in accordance with IHO, 1953; shoreline denotes GSHHS).

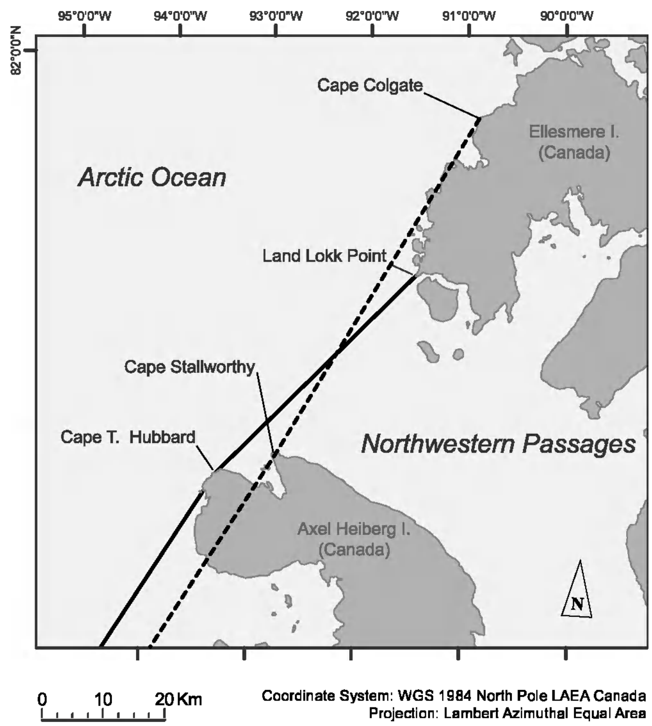

Figure 4. Uncertainty relating to the limit of the Arctic Ocean between Axel Heiberg Island and Ellesmere Island (continuous line denotes the limit in our map; dotted line denotes the limit in accordance with IHO, 1953; shoreline denotes GSHHS).

calculated with the ArcInfo extension Tools for Graphics and Shapes (Jenness, 2008).

RESULTS AND DISCUSSION

The vector map of the limits of oceans and seas that we constructed is freely available in Esri Shapefile format for a noncommercial use, from: http://w3.rennes.inra.fr/ecologie_sante_ecosystemes/HRMLOS/.

In this data set, attribute data include the name, the spherical area, and the spheroidal perimeter length of each feature.

We positioned 709 reference points that define the limits of 101 entities, oceans and seas, specified by the IHO (1953). We added the Southern Ocean, later accepted by the IHO, whose northern limit is the 60° S parallel (IHO, 2000). This addition modifies the limits of the South Atlantic Ocean, the Indian Ocean, and the South Pacific Ocean. However, we have not added new entities revealed by the overlay of the IHO limits and the GSHHS, such as the Straits of Johor, various deltas of large rivers, the Suez Canal, and the Panama Canal.

Positioning Precision of the Reference Points

The main innovation of our map is its precision (Figure 1). This precision and the correctness of reference points were achieved as a result of research efforts, which have allowed us to find and determine the position of all toponyms of the IHO (1953), with the exception of four (described later). Positioning precision of reference points is approximately 10 s of meridian arc (about 300 m). Positioning accuracy of reference points is mainly related to the accuracy of the GSHHS and is sometimes reduced in regions where there are significant discrepancies between the GSHHS and the other sources of standard data. This is the case, for example, for the limit between the Coral Sea and the South Pacific Ocean in the region of Maewo Island, in Vanuatu. In this region, the shift between the GSHHS and the LANDSAT imagery reaches 6.7 km.

We found many differences between the map of VLIZ (2005) and ours. Most of them are probably attributable to difference between shoreline data and working scale used to construct the map (Figure 1). However some of these differences seem to correspond to errors in VLIZ mapping (Figure 2).

Limits for Which Uncertainties Remain

In 13 cases we could not draw limits with certainty due to (1) a toponym that we could not find, (2) a toponym or a reference point that seem aberrant, (3) an ambiguity of the reference text, or (4) a shoreline change. These 13 cases are explained in detail here. Quotations are all taken from the text of the IHO (1953).

Uncertainties related to toponyms that we did not find:

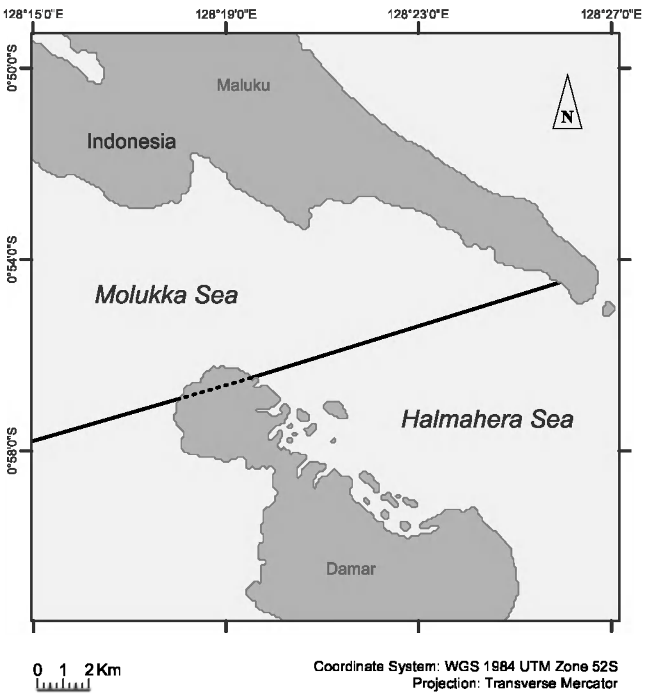

Figure 5. Uncertainty relating to the southern limit of the Molukka Sea (continuous line denotes the limit in our map; dotted line denotes the limit in accordance with IHO, 1953; shoreline denotes GSHHS).

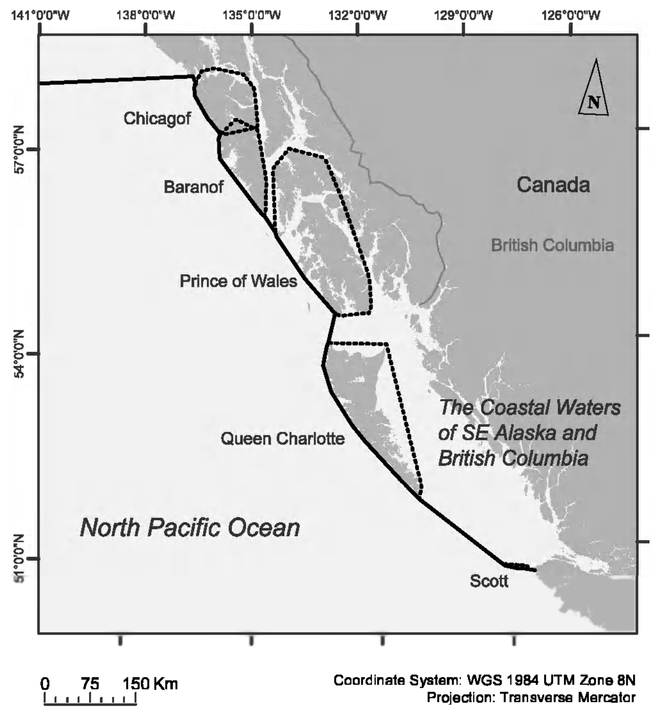

Figure 6. Uncertainty relating to the western limit of the coastal waters of Southeast Alaska and British Columbia (continuous line denotes the limit in our map; dotted line denotes convex hulls constructed to define drawing of our limit; shoreline denotes GSHHS).

(1) "(h) Aegean Sea (The Archipelago). On the South . . . Cape Aspro (28°16′ E) in Asia Minor" (p. 18). According to a crossing of GNS data, we concluded, without certainty, that this place is Hayirsiz Burun (36°43′21″ N, 28°17′25″ E).

(2) "51. Yellow Sea (Hwang Hai). On the Southeast . . . to Ka-Nyo . . . , thence to the North point of Oku To (34°22 N)" (pp. 31–32). The closest toponym of Oku-to that we found is Ok-to (34°21′10″ N), but we were unable to confirm that it is the same reference point. Moreover, the choice of this point would split in two the archipelago that extended off the SW of island Chin-do. Instead of Ok-to, we therefore used island Oebyŏng-do, whose latitude (34°22′19″ N) better corresponds to the IHO text (Figure 2a).

(3) "59. The Coastal Waters of Southeast Alaska and British Columbia. On the West . . . Black Rock Point (50°44′5″ N) in Vancouver Island" (p. 34). The reference point that we used is Cape Scott (50°46′59″ N, 128°25′59″ W), which seems the best place in respect of this specification.

(4) "60. Gulf of California. On the South . . . Piastla Point (23°38′ N) in Mexico" (p. 35). According to a comparison of data from GNS (National Geospatial Intelligence Agency, 2011), Google Earth (Google, 2011), C-Map Norway (1999), and Bash (2011), we concluded that this place is Punta Piaxtla, which we located, without certainty, at 23°40′04″ N and 106°48′14″ W.

Uncertainties related to toponyms or reference points that seem aberrant:

(1) "16. Hudson Bay. On the North . . . Beach Point (66°03′ N, 86°06′ W) on the Mainland" (p. 11). Coordinates quoted are absurd because they are located about 5 km inland (Figure 3). According to the geoportal Atlas of Canada (2011), the nearest point with this name is located about 18.6 km to the north (66°11′49″ N, 85°53′53″ W). This point is not facing Southampton Island, and a straight line from this point to the north of the island would cross the mainland shoreline at several other points. We chose to use as a reference point a place with a name in the Atlas of Canada. Among them, Panalik Point (66°3′19″ N, 85°57′1″ W) is the most coherent and the closest to quoted coordinates.

(2) "117. Arctic Ocean. From Point Barrow to Cape Land's End on Prince Patrick Island— . . . to the Northwest point of Meighen Island to Cape Stallworthy (Axel Heiberg Island) to Cape Colgate the extreme West point of Ellesmere Island" (pp. 11–12). According to this specification, the limit of the Arctic Ocean, between Meighen Island, Axel Heiberg Island, and Ellesmere Island, goes through Cape Stallworthy, located in Axel Heiberg Island, and Cape Colgate, quoted as the western extremity of Ellesmere Island. The choice of these two points seems absurd because the limit crosses the northern part of Axel

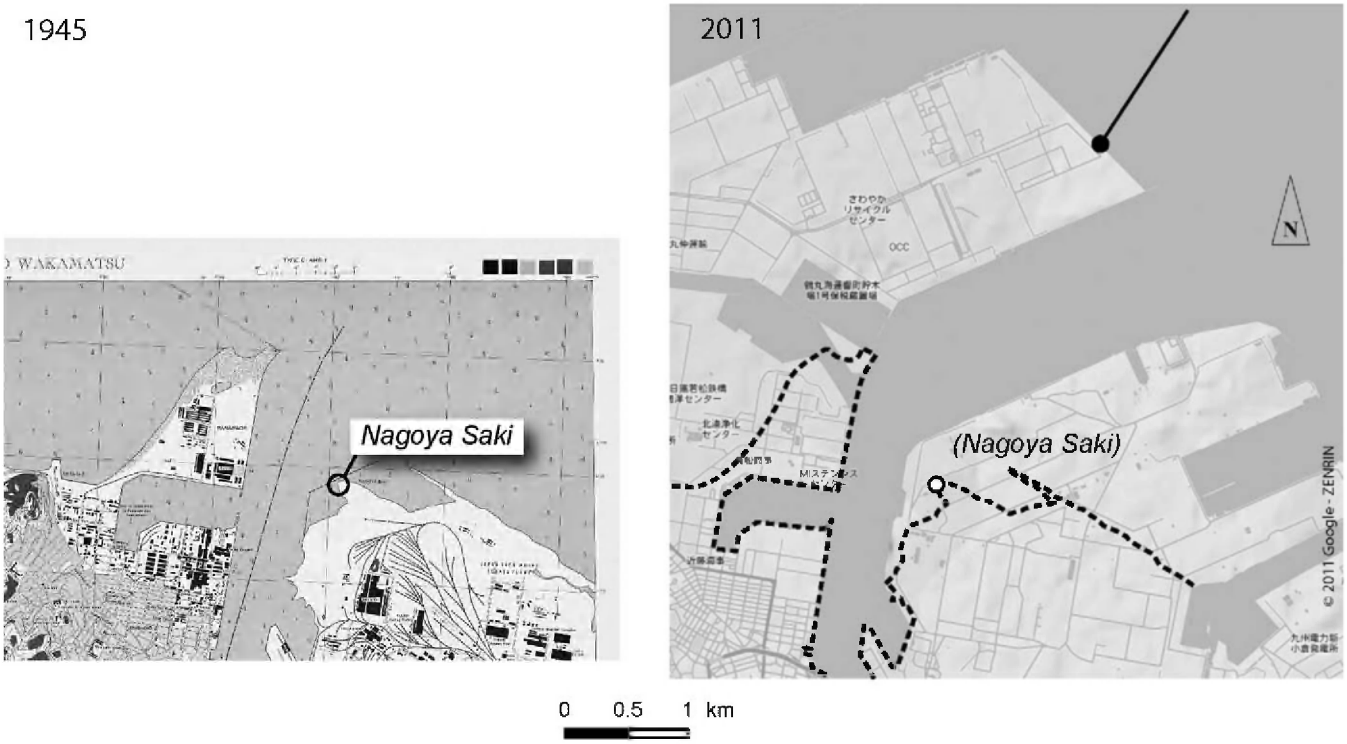

Figure 7. Uncertainty relating to the SE limit of the "Japan Sea" (nomenclature of the IHO, 1953): shoreline change related to an artificial extension of dry land to the north between 1945 (Army Map Service, 1945) and 2011 (Google, 2011), in the bay Dōkai-Wan on the island Kyûshû, Japan (circle denotes the former location of Cape Nagoya Saki; dotted line denotes the former shoreline; black point denotes the substitute reference point in accordance with our map; continuous line denotes the limit in accordance with our map).

Heiberg Island and the western coast of Ellesmere Island. It seems more logical to choose Cape Thomas Hubbard (81°21′34″ N, 94°7′45″ W) for Axel Heiberg Island and Lands Lokk Point (81°36′46″ N, 91°53′17″ W) for Ellesmere Island (Figure 4). According to the geoportal Atlas of Canada (2011), the western extremity of Ellesmere Island is Lands Lokk Point located at 91°53′17″ W, vs. 91°1′11″ W for Cape Colgate.

(3) "52. Japan Sea. On the Northeast. In La Perouse Strait (Sôya Kaikyô). A line joining Sôni Misaki and Nishi Notoro Misaki (45°55′ N)" (p. 32). The toponym Sôni Misaki corresponds to a cape (46°02′43″ N, 141°55′02″ E) that we found in Sakhalin Island, not in Hokkaidō, as suggested by text. We used cape Soya Misaki (45°31′15″ N, 141°56′29″ E), located in Hokkaidō, which seems to be the correct place, as a reference point.

Uncertainties related to ambiguities of the reference text:

(1) "(c) Molukka Sea. On the South: A line from the Southern extreme of Halmahera to the North point of Bisa (Setile) Island" (p. 25). This limit surprisingly crosses the northern part of Damar Pulau, an island located between the two quoted points. Nevertheless, we adhered to the text (Figure 5).

(2) "54. Sea of Okhotsk. On the Southeast … in such a way that all the narrow waters between Hokusyû and Kamchatka are included in the Sea of Okhotsk" (p. 33). The text does not allow us to draw this limit with correctness (see Methods). To draw it, we constructed a convex hull around Kuril Islands, using the method specified. Then, we drew a limit along this convex hull in such a way that it included all of Kuril Islands.

(3) "55. Bering Sea. On the South … in such a way that all the narrow waters between Alaska and Kamchatka are included in the Bering Sea" (p. 33). The text does not allow us to draw this limit (see Methods). We constructed a convex hull and drew a limit in such a way that all of Aleutian Islands located to the west of Unimak Island are now included in the Bering Sea.

(4) "58. Gulf of Alaska. On the South … to Kabuch Point … in such a way that all the adjacent islands are included in the Gulf of Alaska" (p. 34). The text does not allow us to draw this limit (see Methods). We constructed a convex hull and drew a limit, which goes from Cape Spencer, located in the mainland, to encompass Sanak Islands in following the shape of the convex hull, which surrounds them, and then to join Cape Pankof, located on the Ikatan Peninsula, instead of Kabuch Point specified by the IHO (1953). The latter, located at the bottom of Ikatan Bay, seemed inappropriate to us.

(5) "59. The Coastal Waters of Southeast Alaska and British Columbia. On the West . . . so that all the narrow waters between them are included" (pp. 34–35). The text does not allow us to draw this limit (see Methods) in a region with numerous islands and indented shoreline. We constructed five convex hulls that encompass the groups of Scott, Queen Charlotte, Prince of Wales–Kulu, Baranof, and Chicagof. Past Scott Islands, we drew a limit that goes from Cape St. James (southern extremity of Queen Charlotte Island) to Point Cornwallis (Prince of Wales Group), Cape Bingham (Yakobi Island), and finally Cape Spencer in Alaska, in following shapes of the convex hulls surrounding the five island groups. But we excluded Hazy and Forrester Islands, which are farther into the open sea (Figure 6).

Uncertainty related to shoreline change:

(1) "52. Japan Sea. On the Southeast. In Simonoseki Kaikyo. A line running from Nagoya Saki (130°49′5″ E) in Kyûsyû" (p. 32). Cape Nagoya Saki, which we found on a map (Army Map Service, 1945), no longer exists because of an artificial extension of dry land where the sea used to be. As a substitute reference point, we used the NW extremity of the bay Dōkai-Wan (33°56′31″ N, 130°50′43″ E; Figure 7).

CONCLUSION

Although based on an IHO document, our georeferenced vector map of the limits of oceans and seas does not possess any official status. It will be obsolete as soon as the IHO publishes a new edition of its S-23 document "Limits of Oceans and Seas," and will retain only historical value. Nevertheless, our map has currently several relevancies, *i.e.,* it is based on a widely accepted document, it clarifies this document, it is freely available, and its precision and its accuracy are compatible with the GSHHS data set. We hope that our map, intended to be integrated into a GIS, will allow improvement of hydrographic works that use the limits of oceans and seas.

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