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Abstract

One arc-minute resolution grid bathymetry of the East China Sea has been developed by compiling a large number of sounding data derived from various sources. The dataset was found to retain advantages of two existing grid bathymetries: representing basic bottom features found in navigational charts as in skkutopo1m dataset, while it resolves detailed bottom features observed in gebco2014 gridded bathymetry. Through comparisons between new and nine existing datasets, spurious bottom features in previous datasets were identified in near-coast regions and in areas where the source data were sparsely distributed. The verification also has clarified the regions where additional sounding records are required to improve the data quality.

Keywords：*Bathymetry, East China Sea, Digital Terrain Model, continental shelf*

1. Introduction

Even though bathymetry is one of the most important properties which regulate the dynamics of coastal seas, uncertainty still exists in our knowledge on the depth of shallow marginal seas. It is partly because typical spatial scales of bottom features in shallow seas are so small that the features may often slip through the networks of satellite and in-situ survey lines. The amount and quality of available sounding data have been much less than those required to map the whole sea area.

The situation, however, has greatly improved in the last decade. Many countries in East and Southeast Asia have initiated intensive sounding surveys for mapping purpose, and increasing number of detailed navigational charts have newly published especially in the last several years. Furthermore, recent scientific surveys using multi-beam soundings also have provided detailed bathymetric information.

This study compiles a gridded bathymetry of the East China Sea (ECS) including the Bohai and Yellow seas by utilizing a large number of sounding data, many of which have been published recently. The aim of this study is to produce a bathymetric map of the ECS which can resolve features having a spatial scale of 5-10 km, and to evaluate the reliability of bathymetric data of the ECS. Similar grid bathymetry of the South China Sea is presented in another article[1)].

2. Materials and methods

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2.1 Existing bathymetric datasets

Table 1 is a list of gridded bathymetric datasets covering the East China Sea (ECS) which provide depths at data points defined on a longitude-latitude grid. The existing datasets fall into three streams.

Etopo series are global grid data distributed by U.S. National Centers for Environmental Information (NCEI). The first etopo product published in 1988, etopo5[2)], has a spatial resolution of 5 minutes (1/12 degrees) and was superseded by etopo2[3)] (2 min resolution) in 2001 and further by etopo1[4)] (1 min resolution) in 2009. While etopo5 referred to in-situ sounding records, etopo2 and etopo1 rely mostly on satellite altimetry techniques[5)] which have greatly improved the quality of water depths in deep oceans. In this study, the revised edition of etopo5 issued in 1990[6)], the first[3)] and second[7)]

Table 1 List of bathymetric datasets covering ECS

Name	Res	Released	Coverage
etopo5	5min	1988[2)] (1990[6)])	global
etopo2	2min	2001[3)] (2006[7)])	global
etopo1	1min	2009[4)]	global
gebco00	1min	2003[8)]	global
gebco81	1min	2008[9)]	global
gebco08	0.5min	2009[10)]	global
gebco2014	0.5min	2014[11)]	global
skkutopo1m	1min	2002[12)]	East Asia
tecs	1min	2016	ECS

(issued in 2006) edition of etopo2 and the grid-registered version of etopo1[4] were examined.

Gebco (General Bathymetric Chart of the Oceans) gridded bathymetries have been distributed by British Oceanographic Data Centre (BODC). In this study, we verified gebco centenary edition issued in 2003[8] (1 min res; referred to as gebco00 hereafter), gebco one minute grid last updated in Nov. 2008[9] (1 min res; gebco81), gebco_08 version 20100927[10] (0.5 min res, first release appeared in Jan. 2009; gebco08) and gebco_2014 version 20150325[11] (0.5 min res, initial version published in Nov. 2014; gebco2014).

A dataset that belongs to the third stream is SKKUtopo1m[12] (1 min res, published in 2002) compiled from in-situ sounding data. Unlike etopo and gebco global datasets, its geographical coverage is limited to East Asia (117°E-143°E and 24°N-52°N).

We did not use two Japanese gridded datasets, i.e., JEGG500[13] issued by Japan Oceanographic Data Center (JODC) covering the southern and southwestern ECS (122°E-132°E and 24°N-30°N; 128°E-144°E and 30°N-38°N) in a resolution of 500 m and JTOPO30v2[14] published by Marine Information Research Center (MIRC), Japan Hydrographic Association (JHA) which covers 120°E-150°E and 18°N-48°N in 0.5-minute interval. It was because the former was supplied in spatially-smoothed form and did not conform with some raw sounding data, while the latter was focused mainly on deep oceans adjacent to Japanese waters so that only a limited number of sounding records were used to map the main shallow portion of the ECS.

2.2 Tecs bathymetry

The regional bathymetry compiled in this study, tecs, provides heights over an area ranging 116°E-131°E and 24°N-42°N in a resolution of 1 minute. Tecs covers the whole ECS and the westernmost part of the Japan Sea. For an area west of 125°E and south of 27°N, the dataset is compatible with the South China Sea bathymetry, tscs[1].

The dataset focuses mainly on the continental shelf shallower than 200m, which comprises more than 70% of the ECS area and an effort was made to resolve bottom features having a spatial scale of 5-10 km, a typical width of submarine linear sand ridges found at various locations in the ECS.

Compilation of the dataset was made under two concepts. In contrast to other global datasets keeping a universal quality standard over a wide area by applying a spatial filter, tecs was compiled on a best-effort basis, i.e., pursuing the best quality at each locality by utilizing as many source data as possible.

Furthermore, a care was taken to avoid generating spurious depth values, which was accomplished by adopting a conservative interpolation scheme and by excluding extreme sounding values, e.g., depth at the top of a small and isolated seamounts which does not represent the water depth of the region.

2.3 Data source

In this study, only in-situ sounding data were used to compile the sea portion of tecs. The primary source of the sounding data was electronic and paper charts issued by local countries (China, South Korea, Japan and Russia), electronic charts by U.K. and paper charts by U.S. As for Chinese and Korean waters, we used substantially all the electronic charts categorized as Harbour, Approach and Coastal scales (1:10k to 1:300k) available at Dec. 2015 and adopted the version issued at around Feb. 2012 when available to retain the consistency among the charts. Paper charts were scanned and converted into WGS84 coordinates if necessary.

In addition, a large number of single-beam sounding records in Japanese waters collected by Japan Coast Guard, as well as multi-beam sounding data at regions east of Taiwan and in the Japan Sea south of 38°N were used to generate the dataset. The multi-beam data were converted into grid-point data having a spacing of 0.2 minutes because the original resolution was too high for the current purpose.

For the land portion, we used GLOBE dataset[15], a global gridded topography dataset provided in 0.5-minute interval.

Fig.1 illustrates the number of source data that fall into 5 minute bins. Aside from nearshore regions, the sounding data were densely distributed in areas west and southwest of Korean Peninsula, west of Taiwan and in the southern part of the Japan Sea. It is to be noted that many of the data found in these area have been originated from electronic charts and multi-beam products published in the last five years.

2.4 Data processing

All the paper and electronic charts were displayed on a computer screen and the depth points were digitized into xyz (longitude, latitude and depth) format. The obtained data were compared with other sounding records supplied in digital form.

It is to be noted that not all the depths indicated in the charts were adopted for the data compilation. Incorporating all the depths indicated in electronic charts, which was conducted in a pilot study, resulted in a generation of a grid bathymetry having depths shallower than those observed. It was because navigational charts tend to indicate the shallowest

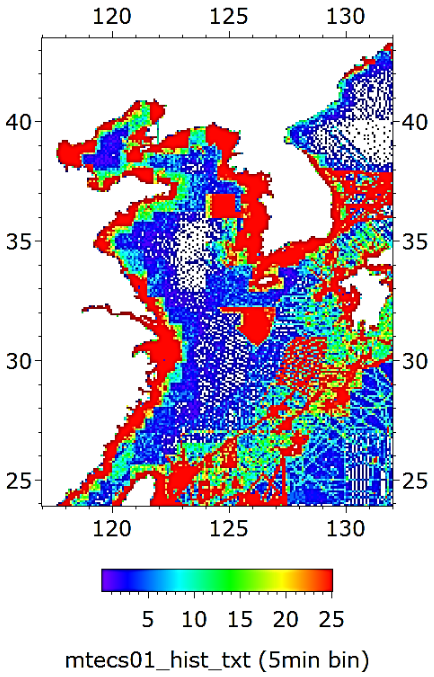


Fig. 1 Histogram showing the number of sounding data used for compilation included in 5 min bins. Bins without any sounding data are indicated in white colors. Note the number of data in a bin is not limited to 25 and may exceed 1000.

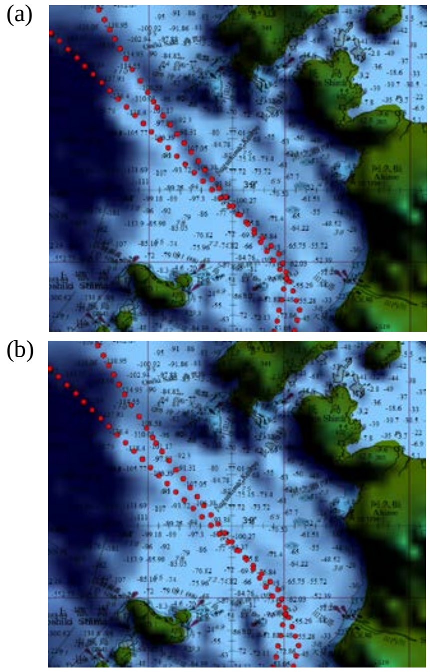


Fig. 2 Bathymetric relief off the west coast of Kyushu Island created (a) with and (b) without using single-beam sounding depths along survey lines indicated in red dots. Depth values and a navigational chart (Japanese chart W180) are overlain for reference.

depth in a specific area than depths representing a certain region. A care was taken to adopt depth values representing the area especially at places where sounding data were sparsely distributed.

Depth contours were not digitized unless contours (1) mark the location of a steep slope where the depth changes greatly or (2) represent the extent of elongated shoals or trenches where depths vary in anisotropic manner, because the contours generally differ among charts.

Single-beam sounding records were verified by comparing with other depth data. Some of the records obtained from several particular cruises were not adopted in this study because they show depths systematically different from those observed at surrounding locations and inclusion of such dataset may often produce artificial features (Fig. 2).

Some of the multi-beam records also indicate erroneous values especially at shallow regions and along the edge of a swath band. It was therefore necessary to verify the data carefully before being used as a part of the source data.

The gridded land data were introduced to fill hollow areas devoid of input data, which helped generating realistic bathymetries around land features such as promontories and islands where coastlines were intricate or were closed.

All the sounding records and the topographic grids were combined together and converted into a grid data having a spacing of 1 minutes which was made by applying Natural Neighbor interpolation scheme of Surfer 13 application (Golden Software). This scheme does not generate values beyond the range of the actual dataset. In this study, we have chosen this conservative interpolation method to avoid generating spurious features, with the cost of losing some information contained in the original sounding data.

3. Results

Fig. 3 shows the bathymetry of the ECS derived from the existing and newly developed datasets. Here we focus on shallow regions and depths between 0 m and 150 m are drawn with a separate color scale.

It was found that all datasets show depth pattern slightly different among each other in the shallow portion of the ECS. An exception is the bathymetry of gebco08 and gebco2014 (Figs. 3g and 3h) which differ only in a deep area south of Ryukyu Islands. Another exception is etopo2 (v1) bathymetry (Fig. 3b): depths in some regions deviates largely from those found in other datasets, e.g., depth exceeding 200 m in the central Bohai Sea, the northern Yellow Sea and Haizhou Bay,

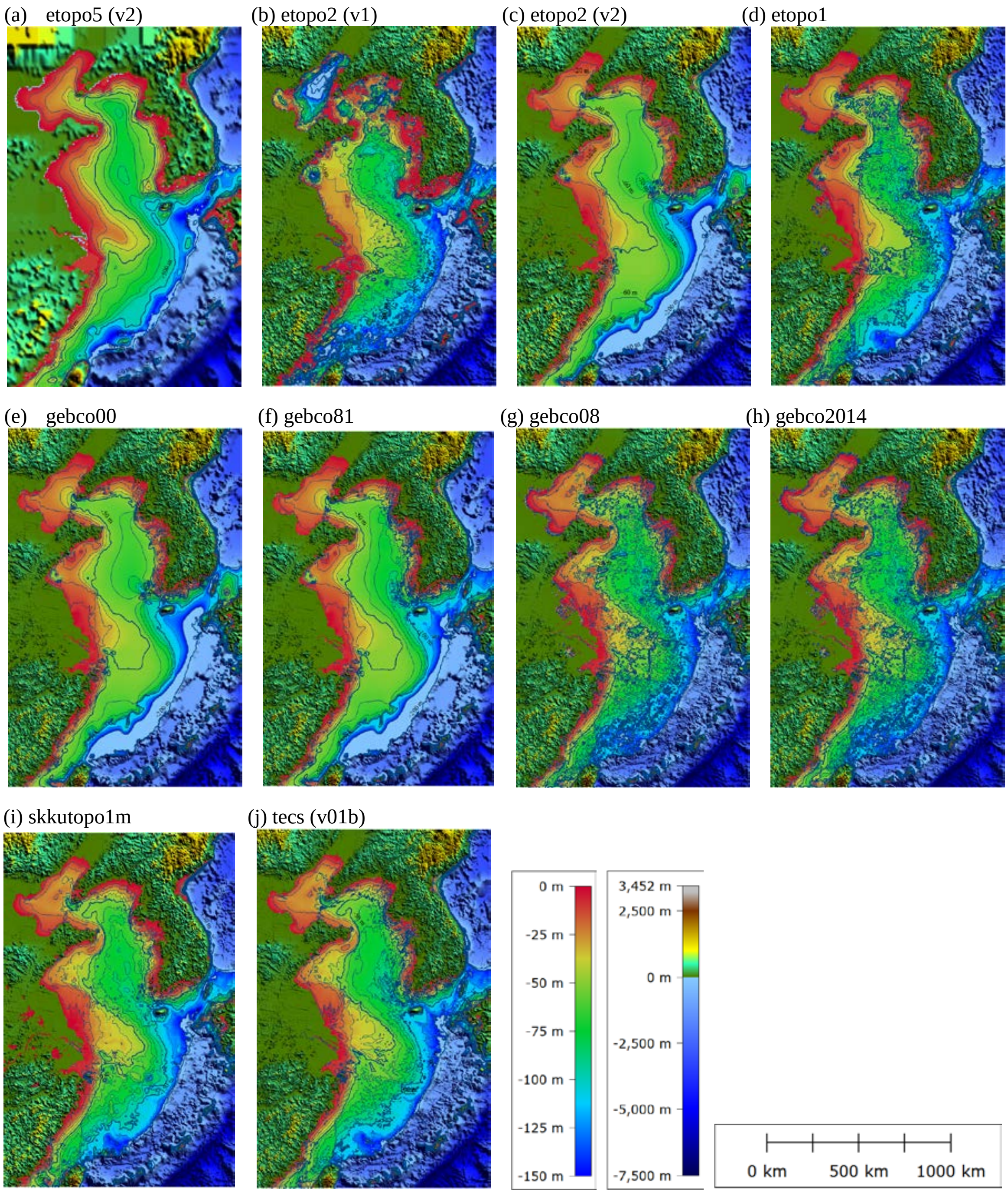


Fig. 3 Depth distribution around the ECS derived from ten different bathymetric datasets (the list of the datasets is found in Table 1). Depth contours were drawn for every 10 m from 10 to 100 m, 120 m, 150 m and 200 m depth. The color scale in the left hand side applies to depth range 0-150 m, whereas the scale in the right is used in other heights/depths.

while depths being too shallow along the western and southern coasts of Korea. These apparent errors found in etopo2 (v1) were modified in the second version (Fig. 3c).

Etopo5 (v2) bathymetry (Fig. 3a) based on in-situ sounding data showed depth pattern somewhat similar to those found in navigational charts, except in area off Jiangsu coasts where an extensive inner shelf was not existent and in the Yangtze Shoal where the depth seems to be shallower than observed. These discrepancies may have caused because detailed depth information around two areas were not available at the time the dataset was published.

In etopo2 (v2) and etopo1 (Figs. 3c and 3d), the extent of nearshore region shallower than 20 m and the representation of water depths in the Yangtze Shoal seems to have improved

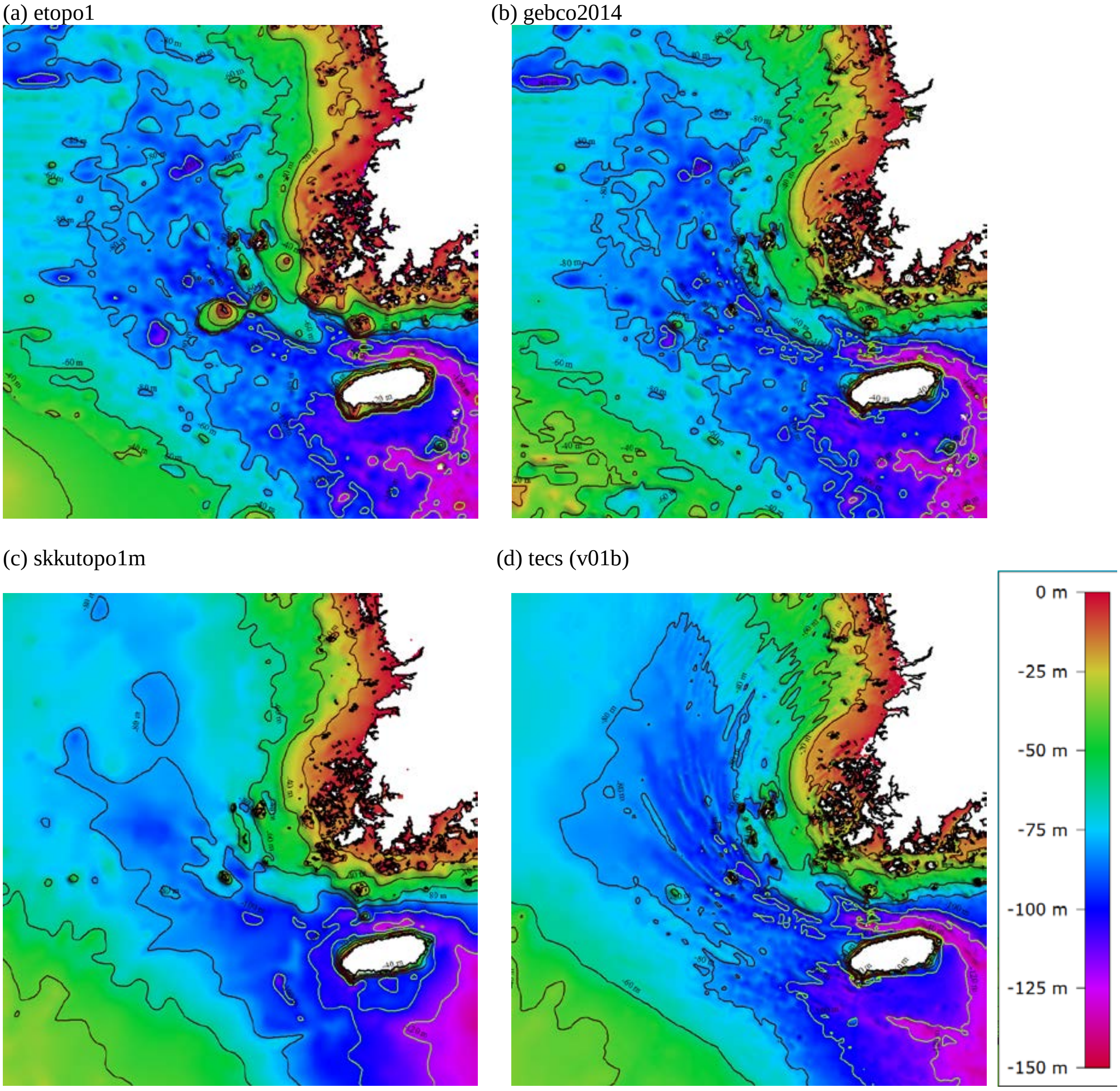


Fig. 4 Depth distribution off southwest Korea for (a) etopo1, (b) gebco2014, (c) skkutopo1m and (d) tecs bathymetries. Contour lines are drawn for every 20 m and lines indicated in a light green color denote depths greater than 100 m. Note that a color scale is different from the one used in Fig. 3.

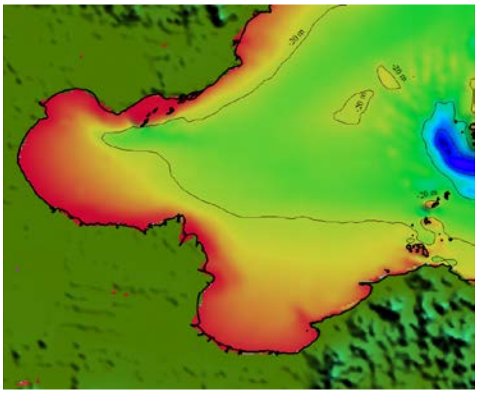
when compared to etopo5 (Fig. 3a). On the other hand, these new datasets do not seem to represent areas deeper than 40 m properly. In addition, a spurious shoal has emerged in an area south of Jiaozhou Bay in etopo2 (v2) and etopo1.

Though etopo1 implies many small-scale structures compare to etopo2, it was not clear whether these features are realistic ones. An apparent jump of 50 m contour across latitude 30°N off Hangzhou Bay found in etopo1 is probably related to the northern limit of a Japanese gridded bathymetry used in etopo1 which did not have enough accuracy outside Japanese waters.

While the depth patterns of gebco00 (Fig. 3e) were virtually the same with that of etopo2 (v2) (Fig. 3c), those in the Korean side of the Yellow Sea were modified in its revised edition, gebco81 (Fig. 3f). The contour pattern of gebco81 in the modified area resembles more to that of etopo5 than to etopo2 (v2).

Gebco08 and gebco2014 bathymetries (Figs. 3g and 3h) generally show more realistic contour patterns, in terms of the similarity with those presented in navigational charts, compared to etopo and previous gebco bathymetries. A significant improvement was observed for the bathymetry in the Bohai Sea and the overall shape of the Yangtze Shoal. These 1/2-minute resolution datasets were also capable of resolving some detailed features such as radial sand ridges off the Jiangsu coast. As in the case of etopo1, however, we could not confirm whether a large number of small-scale features indicated in gebco08 and gebco2014 are real features. For the

(a) skkutopo1m



(b) gebco2014

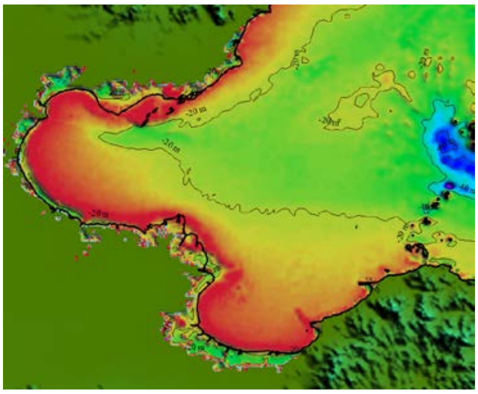


Fig. 5 Bathymetry of the western Bohai Sea created by using (a) skkutopo1m and (b) gebco2014 datasets. Thin line denotes 20 m isobath contour whereas thick line indicates coastline derived from GSHHS shoreline database[18].

land portion, the northern Jiangsu coast was not presented correctly, due to the error inherent in SRTM30 topographic data[15] used in the datasets.

Skkutopo1m and tecs bathymetries (Figs. 3i and 3j), regional products based solely on in-situ sounding data, were found to show similar contour patterns which basically follow features presented in navigational charts. In addition, both datasets do not indicate unrealistic depths indicated in etopo and gebco datasets, e.g., a deep hole exceeding 100 m in the Yangtze Shoal in gebco2014 (Fig.3h). These two datasets therefore seem to represent consistent regional bathymetry in the sense showing generic features properly without having unrealistic extreme values.

Difference between skkutopo1m and tecs was found in the representation of small scale features, e.g., radial sand ridges off the Jiangsu coast was not well resolved in the former dataset. Such discrepancy may be ascribed to difference in the number of sounding data available at the time of data compilation, and also to the difference in the computer power to process large data.

4. Discussion

4.1 Data validation

To examine the characteristics of the bathymetric datasets more in detail, enlarged bathymetry maps of four major datasets, etopo1, gebco2014, skkutopo1m and tecs, are shown in Fig. 4 for region off the southwest Korea. It is found that all four dataset show common basic feature that a trench deeper than 60 m transverse the area from southeast to northwest.

It was found that generic contour pattern observed in etopo1 (Fig. 4a) were quite similar to those in gebco2014 (Fig. 4b), e.g., distribution of 60 m contour including those bounding deep trenches in the northernmost area which were not observed in skkutopo1m or tecs (Figs. 4c and 4d). Pattern of 40 m contour in the southwestern portion also resembles with each other.

On the other hand, gebco2014 seems to represent small-scale features found in the Korean side of the Yellow Sea more in detail. For example, linear sand ridges in the northeastern area were discernible only in gebco2014 and tecs. An isolated island northwest of Cheju Island (Soheuksando), eastern and western sides of which are bounded by trenches deeper than 100 m, seems to have represented in proper size in gebco2014 and tecs.

Small-scale features in the southwestern part of Fig. 4 were observed only in gebco2014 (Fig. 4b). Though the feature might be reflecting actual deep and shallow depths sampled from a sequence of submerged valleys observed in this region, it probably requires more sounding data to resolve the feature in more realistic manner.

A lattice-like feature ca. 70 m deep found in the northwestern area of etopo1 and gebco2014 (Figs. 4a and 4b) were originated from an inclusion of single-beam sounding data not adopted in tecs (Fig. 4d). Depth contour of tecs, in contrast, does not show detailed structure compared to etopo1 and gebco2014 in this area because there was not enough sounding data available in the mid-Yellow Sea.

In etopo1, gebco2014 and tecs, a series of circular ridge-and-hollow features were found at a region west of Cheju Island, which seems to have caused by insufficient sampling interval of the source sounding data compared to the spatial scale of bottom features. This result suggests that the number of sounding data is still insufficient to resolve bottom features at some regions.

In summary, it was suggested that tecs dataset provides consistent bathymetry patterns as in skkutopo1m, while the dataset also resolves detailed small-scale features at area where sounding data are densely distributed.

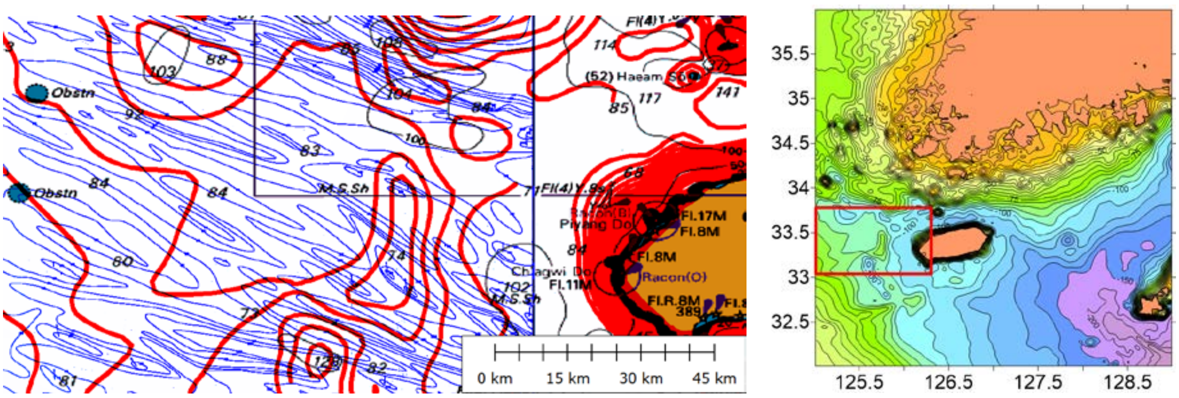


Fig. 6 Bathymetric contours (5 m interval) in region west of Cheju Island derived from skkutopo1m dataset (red lines) and from bathymetric chart based on acoustic sounding issued by Korean Institute of Geology, Mining and Materials in 1993 (blue lines), which were overlain by U.K. chart 3480. The location of the area is indicated in the map in the right hand side created from skkutopo1m bathymetry.

4.2 Spurious coastal features in gebco2014

Though previous analyses have shown that gebco2014 has high potential to represent bottom features in the ECS, its depth value seems to contain systematic error along some coastlines.

Fig. 5 compares the depth distribution of the western Bohai Sea derived from skkutopo1m with that from gebco2014. Unlike skkutopo1m (Fig. 5a), sea area presented in gebco2014 bathymetry has extended further landward from the actual position and depths along the inundated coastal zone exceeded 30 m (Fig. 5b), which is a spurious feature because many of the deep areas are supposed to be lowlands such as intertidal zones or shallow salt pans.

It is speculated that this spurious feature is related to the specification of gebco bathymetries not using 0 m height (or depth) to avoid problems when connecting land and sea data. Large area without having any height or depth might have produced the spurious values.

Fig. 5 shows another issue specific to the ECS where coastline has changed greatly in the past several decades. The coastline around the Yellow River Delta indicated in skkutopo1m (Fig. 5a) and gebco2014 (Fig. 5b) bathymetries resembles with actual coastlines observed in 1960s and 1950s, respectively. The coastline shown in Fig. 5 derived from GSHHS database[17)] also reflects the status of 1960s. As changes in the coastline have modified the tidal range in the Bohai Sea for more than 20 cm[18)], it might be necessary to incorporate latest coastlines to the bathymetric dataset when studying resent status of the ECS.

4.3 Impact of sounding data distribution

Red lines indicated in Fig. 6 denote the depth contour of skkutopo1m at the entrance of the Yellow Sea. Comparison with depth contours derived from more detailed bathymetric chart, shown in blue lines, suggests that a north-south shoal west of Cheju Island was a spurious feature generated by connecting depths on top of some ridges found in elongated ridge-and-swale features aligned in ESE-WNW direction.

This example shows that the usage of insufficient number of data compared to the spatial scale of bottom features may give rise to a spurious bathymetry.

The distribution of sounding data currently available (Fig. 1) shows that the in-situ data is lacking especially in the central Yellow Sea, the northern Japan Sea and the outer shelf area of the East China Sea. In addition, many depth data indicated in charts covering central Liaodong Gulf and North Korean waters are measured in more than half century ago and needs to be replaced. Additional sounding data are required to improve the quality of the bathymetric data in the ECS.

5. Summary and conclusion

New grid bathymetric data of the ECS has developed, which was found to possess the consistency of overall patterns as in skkutopo1m bathymetry and also was found to resolve some small-scale features as in gebco2014 dataset.

Differences in bottom features found in existing bathymetric datasets suggests the importance of choosing appropriate dataset. Aside from the new bathymetry compiled in this study, it might be safe to use skkutopo1m bathymetry or gebco2014 bathymetry (after revising spurious features) for the purpose of a regional study.

The current study also has shown that a sufficient number of sounding data compared to the spatial scale of bottom features are necessary to avoid the emergence of spurious bathymetry. Though the situation has improved greatly in the last decade, additional sounding data covering the ECS is necessary to improve the data quality.

References

1) Uehara, K., Compilation of bathymetric data for the South China Sea 2: High resolution dataset based on multiple sources, Eng. Sci. Rep., Kyushu Univ., 37(2), 12-18, 2016
2) National Geophysical Data Center, NOAA, Digital relief of the Surface Earth, Data Announcement 88-MGG-02, 1988 (http://ngdc.noaa.gov/mgg/global/etopo5.HTML)
3) National Geophysical Data Center, NOAA, ETOPO2, Global 2 Arc-minute Ocean Depths and Land Elevations, 2001 (supplied in form of CD-ROM)
4) Amante, C., B.W. Eakins, ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis. NOAA Technical Memorandum NESDIS NGDC-24, 2009
(doi:10.7289/V5C8276M, accessed Nov.22, 2015)
(http://www.ngdc.noaa.gov/mgg/global/global.html)
5) Smith, W.H.F., D.T. Sandwell, Global Sea Floor Topography from Satellite Altimetry and Ship Depth Soundings, Science, 277(5334), 1956-1962, 1997
6) National Geophysical Data Center, NOAA, 5-Minute Gridded Global Relief Data Collection (ETOPO5), Data Announcement 93-MGG-01, 1993
(http://www.ngdc.noaa.gov/mgg/fliers/93mgg01.html)
7) National Geophysical Data Center, NOAA, 2-minute Gridded Global Relief Data (ETOPO2v2), 2006
(http://www.ngdc.noaa.gov/mgg/fliers/06mgg01.html)
8) IOC, IHO, and BODC, Centenary Edition of the GEBCO Digital Atlas, published on CD-ROM on behalf of the Intergovernmental Oceanographic Commission and the International Hydrographic Organization as part of the General Bathymetric Chart of the Oceans; British Oceanographic Data Centre, Liverpool, 2003
(http://www.gebco.net/data_and_products/gebco_digital_atlas/)
9) British Oceanographic Data Centre, User guide to the GEBCO One Minute Grid, BODC Document 301381, 2008 (https://bodc.ac.uk/data/documents/nodb/301381/)
10) British Oceanographic Data Centre, General Bathymetric Chart of the Oceans (GEBCO) The GEBCO_08 Grid (version 20100927), 19pp., 2010
11) British Oceanographic Data Centre, The GEBCO_2014 Grid, BODC Document 301801, 2014
(https://www.bodc.ac.uk/data/documents/nodb/301801/)
(http://www.gebco.net/data_and_products/gridded_bathymetry_data/gebco_30_second_grid/)
(https://www.bodc.ac.uk/data/online_delivery/gebco/gebco_30_second_grid/)
12) Choi, B.H., K.O. Kim, H.M. Eum, Digital Bathymetric and Topographic Data for Neighboring Seas of Korea, J. Korean Soc. Coast. Ocean Eng., 14(1), 41-50, 2002
13) Japan Oceanographic Data Center, J-EGG500, JODC-Expert Grid data for Geography -500m, 2002
(http://www.jodc.go.jp/data_set/jodc/jegg_intro.html)
14) Marine Information Research Center, Jana Hydrographic Association, JTOPO30v2--30 minutes grid bathymetric data around Japanese waters, 2nd edition, 2011
(http://www.mirc.jha.jp/products/JTOPO30v2/)
15) GLOBE Task Team, The Global Land One-kilometer Base Elevation (GLOBE) Digital Elevation Model, Version 1.0, 1999
(http://www.ngdc.noaa.gov/mgg/topo/globe.html)
16) Becker, J.J. et al., Global Bathymetry and Elevation Data at 30 Arc Seconds Resolution: SRTM30_PLUS, Mar. Geod. 32(4), 355-371, 2009
17) Wessel, P. and W.H.F. Smith, A Global Self-consistent, Hierarchical, High-resolution Shoreline Database, J. Geophys. Res., 101(B4), 8741-8743, 1996
(http://www.ngdc.noaa.gov/mgg/shorelines/gshhs.html)
18) Pelling, H.E., K. Uehara, J.A.M Green, The impact of rapid coastline changes and sea level rise on the tides in the Bohai Sea, China, J. Geophys. Res., 118, 11pp., 2013
(doi:10.1002/jgrc.20258)