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Compilation and validation of bathymetric data for the South China Sea with an emphasis on shallow region

Katsuto UEHARA*1,†
†E-mail of corresponding author: uehara@riam.kyushu-u.ac.jp

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Bathymetric data with a resolution of 5 min called gbscs5 have been compiled for a shelf region shallower than 200 m in the South China Sea by referring to paper charts, electronic charts, and trackline sounding data. Through a comparison between the new dataset and existing datasets (etopo5, etopo1, gebco08), characteristics of each dataset, including the existence of artificial features derived from erroneous sounding data or a conversion error of depth units, were documented for each dataset. It was found that small-scale bathymetric features observed along the shelf edge in gebco08 bathymetry are bounded by survey lines and were likely to be a spurious figure generated when applying a high-order interpolation scheme. Tidal simulations conducted with changing bathymetries have shown that the newly compiled dataset will produce smaller deviation from observed values than the existing bathymetries. While all four datasets analyzed in this study were found to be suitable for estimating overall tidal features of the South China Sea, a care must be taken when applying the tidal model results to a particular coastal region.

Key words: *South China Sea, continental shelf, bathymetry, tidal model, internal tide generation*

1. Introduction

Ocean bathymetry is one of the major factors which control dynamical processes such as oceanic currents, coastal upwelling, tides, tsunamis, and internal waves. Accurate water depth is therefore essential when studying ocean dynamics.

During the last 25 years, a number of digital terrain models (DTMs) covering global lands and oceans have been developed. While the quality and resolution of such datasets have improved greatly for open oceans as satellite-altimetry data become available in the late 1990s[1], large uncertainties still remain for bathymetries in shallow waters where the spatial scale of bottom features are small. Further refinement of bathymetric dataset for shallow regions is necessary to improve the overall performance of ocean models.

In this study, bathymetry data of the South China Sea are compiled for depths shallower than 200 m and compared with existing bathymetry data.

*1 Center for East Asian Ocean-Atmosphere Research, Research Institute for Applied Mechanics

2. Materials and methods

2.1 Existing bathymetry datasets

Three existing DTMs, etopo5, etopo1, and gebco08, which contain land altitudes and ocean depths on a global longitude-latitude grid were used for analyses. The study area ranges from 99°E to 125°E and from 0° to 23°N (Fig. 1).

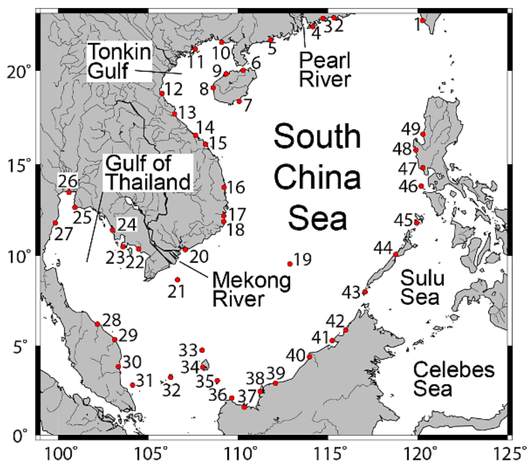

Fig.1 Map of the study region. Circles denote locations of tide-gauge stations used for analyses.

Etopo5 (Fig.2a) is a 5 min resolution dataset developed in 1988 which is distributed by U.S. National Geophysical Data Center (NGDC) in National Oceanic and Atmospheric Administration (NOAA). Water depths of etopo5 are based on ship sounding data. This dataset was superseded by a 1 min resolution etopo1 in 2009 (Fig.2b)[2]. Ocean depths in etopo1 are derived mostly by satellite altimetry technique.

Gebco08 dataset was released in 2010 by British Oceanographic Data Centre (BODC) and has a spatial resolution of 0.5 min (Fig.2c). It was generated by combining ship depth sounding data with interpolation of sounding points guided by satellite derived gravity data.

2.2 Gbscs5 bathymetry

The newly compiled 5 min resolution dataset (gbscs5; Fig.2d) was based on gebco08. Firstly, the 0.5 min resolution gebco08 was remapped onto a 5 min resolution grid compatible to that of etopo5 (cell-registered configuration, i.e., cell edges are along lines of latitude and longitude) by taking average of the second and third quadrants of 100 depth values allocated within the enlarged grid cell (Fig. 2e).

Grid cell values were modified over an area shown in Fig.2f, which includes a wide shelf west of 110°E and an area along southern Chinese coasts. The water depth of the revised region was mostly shallower than 200 m, as our aim was to improve the data quality in shallow waters.

The revision was made by overlaying (a) scanned paper charts issued by U.S., Russia, U.K., Vietnam, and Thailand, (b) electronic charts (ENCs) supplied as a part of U.K. Hydrographic Office (UKHO) Admiralty Vector Chart System (AVCS) and South China Sea Electronic Navigational Charts (SCS ENC) by East Asia Hydrographic Commission (EAHC), and (c) trackline bathymetry data distributed at NGDC website which contain serial sounding records along survey sections, and (d) depth contours generated from gebco08 bathymetry for every 10 m from 0 m to 200 m and for 500 m depth (displayed for reference purpose only and not used for depth estimation) on a single screen of a GIS software. A representative depth at a certain grid cell was estimated by referring to depth sounding values appear inside the cell, normally by taking an average of maximum and minimum depths found in the cell.

Comparison between the depth sounding values derived from charts and trackline data with depth contours of gebco08 indicated that the number of depth points used to compile gbscs5 was larger than that for gebco08, which was probably because we employed large scale charts containing detailed bathymetry especially at nearshore regions.

Horizontal datum of scanned paper charts were converted from local datum to WGS84 coordinates if necessary. Tidal correction was not applied here because we could not obtain appropriate offset values to make a correction at the current stage.

We did not employ an automated method such as an interpolation scheme to obtain a gridded dataset mainly for two reasons. Firstly, it was found that navigational charts, especially small-scale ones, tend to indicate depth values at shallow shoals more frequently than those in deep troughs or those at a moderate depth, so that a simple interpolation of depth values without considering such bias often result in an underestimation of a representative depth.

Another reason was that the distribution of available sounding points in the South China Sea are generally not dense enough for automated interpolation scheme to resolve subgrid scale anisotropic features such as narrow troughs and elongated ridges.

The low spatial resolution of the new dataset (5 min) compared to the existing ones (up to 0.5 min) was also due to the overall sparseness of the depth sounding data, which is evident in regions south of Vietnam (especially in offshore area between 4°N and 8°N), central Gulf of Thailand, Gulf of Tonkin west of 108°E or south of 18°N, and southern Taiwan Strait 118°E-119.5°E and 22°N-23°N (Fig. 3).

2.3 Tidal experiment

A two dimensional finite difference model was introduced to verify the performance of the new bathymetry data. The model was forced by specifying harmonic constants (M_2, S_2, N_2, K_2, K_1, O_1, P_1, and Q_1 constituents) of a global tidal model TPXO7.2[3] along open boundaries and also by applying astronomical forcing (M_2, S_2, K_1, and O_1). A series of numerical experiments were conducted with different bathymetries (etopo5, etopo1, gebco08, and gbscs05; all datasets were converted into 5 min resolution) but other conditions were kept unchanged. Model results were compared against tide-gauge data for M_2 and K_1 constituents at all stations listed in Zu et al.[4-5] (except for 5 stations situated north of 23°N) (see Fig. 1 for locations). Each numerical run was conducted for 222.625 days with a time step of 12 sec and

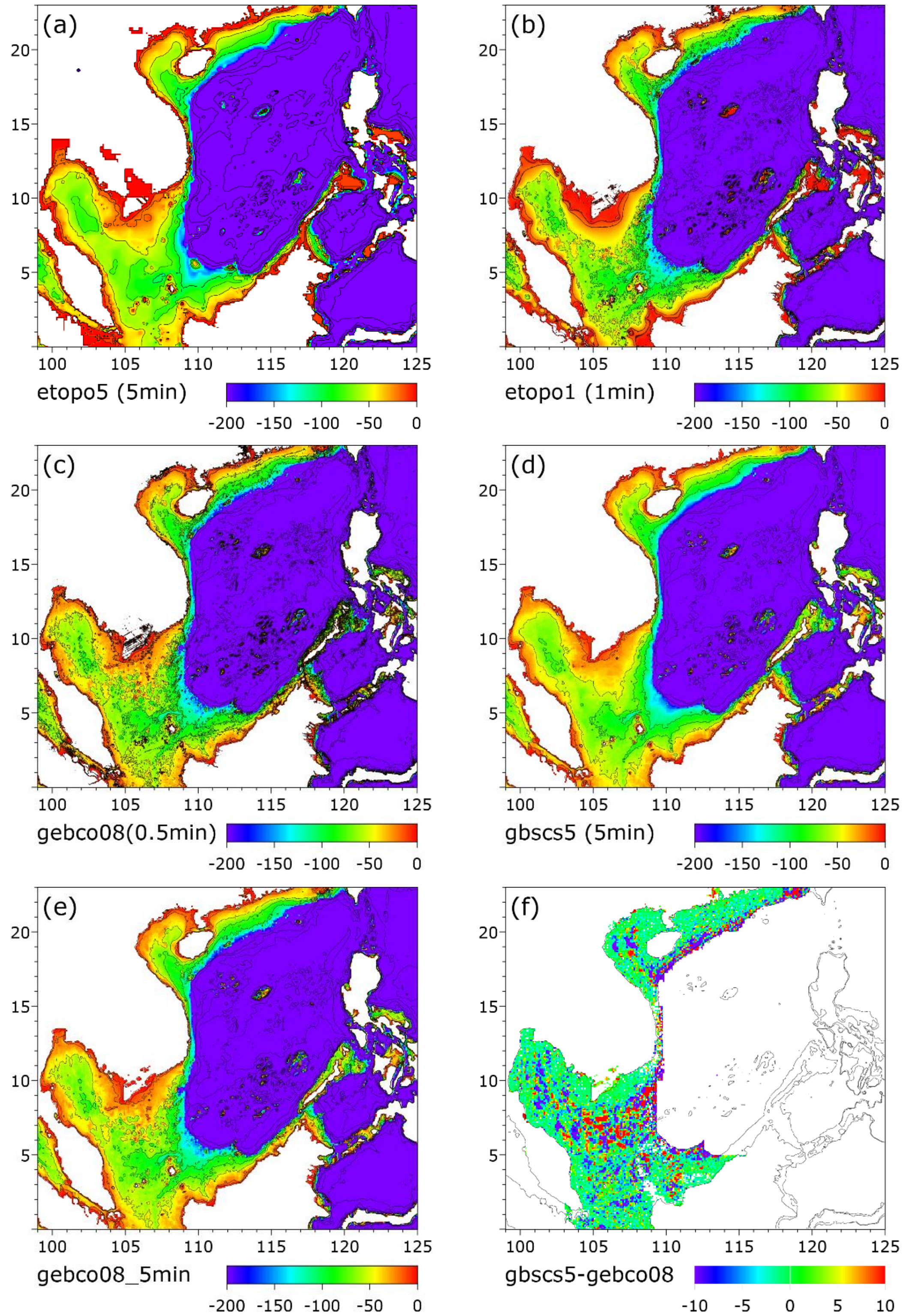

Fig.2 Depth contour of bathymetric datasets used in this study: (a) etopo5, (b) etopo1, (c) gebco08, (d) gbscs5, (e) gebco08 (converted to 5min resolution), and (f) difference between Figs. 2d and 2e. Contour lines are drawn for (a-e) depth 0, 20, 50, 75, 100, 500, 1000, 2000 and 4000m or (f) 0 and 200m.

the last 182.625 days were used for analyses. Quadratic bottom friction coefficient was set as 0.0025 and horizontal eddy viscosity coefficient was $100 m/s^2$. Details of the model formulation are found in other article[6].

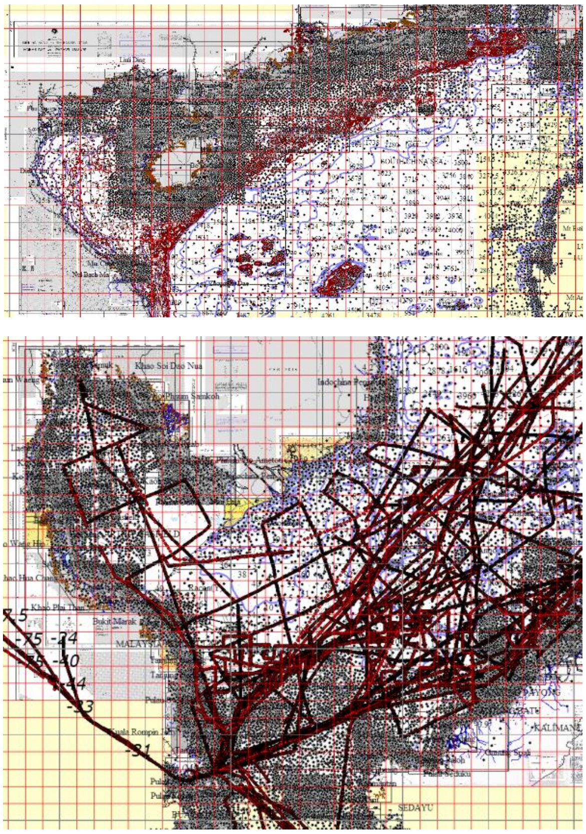

Fig.3 Screenshots of overlaid depth information derived from paper charts, encs (dots and blue lines), and trackline sounding data (thick brown lines) in northwestern (upper panel, 105°E-121°E and 15°N-23.5°N) and southwestern (lower panel, 98.5°E-115°E and 0°-14°N) South China Sea. Red lattices denote latitudes and longitudes in 0.5 degree interval, which are six times coarser than the resolution of gbscs5. Thin brown lines denote depth contour (every 10 m up to 200 m and 500 m) derived from gebco08 bathymetry.

3. Results

3.1 Comparison between depth datasets

Figure 2 shows the water depth of three existing datasets as well as that of gbscs5 developed in this study. Though the overall features were similar among the four datasets, discrepancies were also evident. Here, we confine our view to areas shallower than 200 m.

3.1.1 Etopo5

The depth contour of etopo5 show patterns similar to those of gbscs5 at depths between 20 m and 100 m (Figs. 2a and 2d) except that the contour of etopo5 was generally smoother. The resemblance is probably because both datasets are based on ship sounding data. The contour of etopo5 is smooth because a smoothing filter was applied when producing the grid data.

On the other hand, etopo5 seems to have problems with the coastline position and depth shallower than 20 m. At lowlands in several locations, such as those north of Gulf of Thailand, in southwestern Sumatra Island, in the Mekong River delta, and along the northwestern coast of Gulf of Tonkin, grid point values were padded with 0 m and coastlines were not represented correctly. Furthermore, depths at some coastal regions, such as those along the east coast of Laizhou Peninsula (110.3°E, 21°N), off the Pearl River mouth, northeast and southwest of Palawan Island (120.5°E, 11°N and 117°E, 7.5°N), were padded with an erroneous value of 10 m.

In offshore regions, there were three major differences between etopo5 and gbscs5: (1) depth of etopo5 in the central part of Gulf of Thailand was deeper than that of gbscs5, (2) an isolated shoal situated along the shelf edge in the southwestern South China Sea (109.8°E, 5.6°N) was existent only in etopo5, and (3) the depth of a shoal in the southeastern Taiwan Strait (118°E, 22.7°N) was much shallower in etopo5. We could not collect enough materials to make further discussion on this discrepancy because depth information was sparse in these three areas.

3.1.2 Etopo1

The position of coastline in etopo1 was improved significantly from that in etopo5 as the former incorporates Global Self-consistent, Hierarchical, High-resolution Shoreline data (GSHHS) published by NGDC in 2003 (Fig.2b). However, etopo1 still have small though systematic errors at around shorelines adjacent to lowlands such as Mekong and Pearl River deltas and the northern coast of Gulf of Tonkin, so that a care must be taken when the dataset is used with its original resolution.

It was also found that bottom features in coastal areas shallower than 50 m were smoothed excessively and 20 m contour was located much farther from the coast than etopo5 and gbscs5. Anomalous shallow depths were also found at Paracel (114.5°E, 16°N) and Spratly (116.5°E, 11.5°N) islands located in the central South China Sea and at a region northwest of Palawan Island (120°E, 11°N).

While undulating features observed in the Malacca Strait (102°E, 2°N) are obviously artificial, we could not acquire enough material to confirm the existence of two shoals observed in Gulf of Thailand (103.7°E, 6.5°N) and in Gulf of Tonkin (107.7°E, 19°), which were not found in etopo5 and gbscs5.

3.1.3 Gebco08

Depth contours shown in Fig.2c indicate that gebco08 bathymetry, which uses both sounding and altimetry information, has more realistic

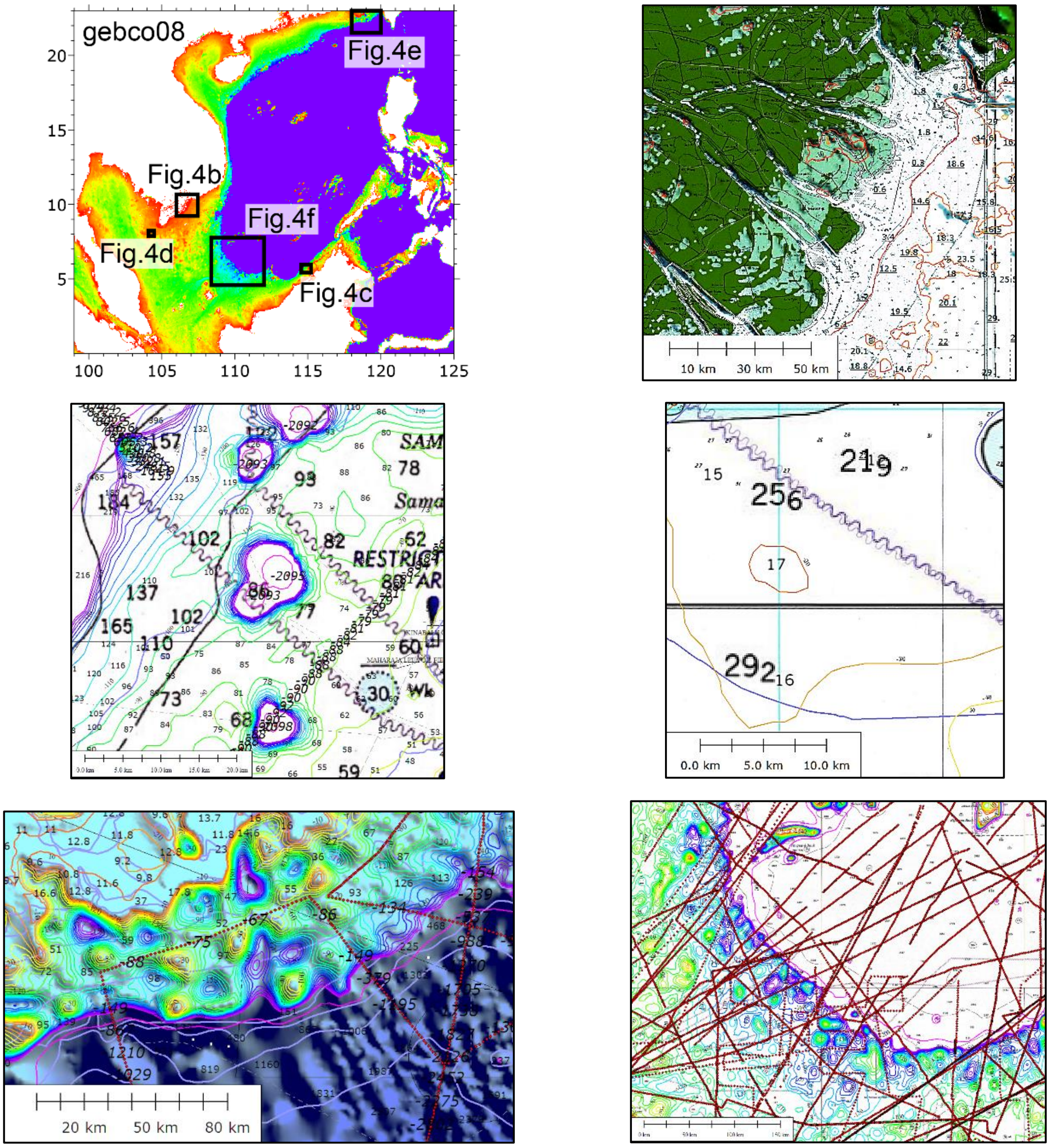

Fig.4 (a) Location of Figs.4(b-f). (b) Overlay of land area derived from gebco08 (dark green) and from a nautical chart (light green). (c) Anomalous depth (exceeding 2000m) observed in sounding data. Color contours indicating the depth of gebco08 in 10 m intserval from 0 m to 200 m as well as 500 m, and a series of anomalous sounding data exceeding 2000 m. (c) a circular 20 m contour of gebco08 crossing two points showing 17 fathom (31 m) and 25.6 m depths. Bold figures (e.g., 25.6 and 29.2) indicate depth in meters, obtained from different chart. (e) Depth contour of gebco08 (color contours) and sounding survey lines (thick brown lines) at a shelf edge south of Taiwan Strait (118°E-119.5°E, 22°N-23°N). (f) Same as (e) except for a shelf edge south of Vietnam in the southwestern South China Sea.

coastline and higher resolution than etopo5 (Fig.2a) and has more accurate bathymetry at shallow regions than etopo1 (Fig.2b). Depth difference between gebco08 and gbscs5 was found mainly in areas where the depth sounding information was sparse (Fig.2f).

Irrespective of overall improvements in the data quality, some erroneous values still remains in the depth data of gebco08 (Fig.4). For example, inaccurate coastline position were observed at several lowlands such as Mekong (Fig.4b) and Pearl River deltas, which seems to have inherited from etopo1. It was also found that gebco08 incorporates erroneous sounding data at a shallow shelf north of Brunei, which could be recognized by a series of isolated hollows deeper than 500 m (Fig.4c). Several small shoals appear in Gulf of Thailand in the gebco08 bathymetry seems to have made by a conversion error of depth units, i.e., depths indicated in fathoms (1.83 m) were regarded as meters and were underestimated (Fig.4d). It is to be noted that many sounding data obtained in 1930s-1960s are still in use in the South China Sea and several paper charts represent depths in fathoms. Similar depth conversion failure was also observed in SCS ENC.

In etopo1 and gebco08, spurious deep depths were often found in nearshore areas such as an inlet surrounded by high mountains and an intertidal zone where no depth information is specified. The erroneous values seem to have associated with an overshoot caused by the application of high-order interpolation scheme.

Small-scale bathymetric features observed at the shelf edge (Figs.4e and 4f) might also be spurious features caused by the overshooting effect, as ridges and troughs seem to be bounded by the survey lines and the depth sounding points, and the features were more apparent at areas where the overall depth changes abruptly from 2000 m to 200 m. In the southern Taiwan Strait, the magnitude of depth variation along the shelf edge was smaller at region west of 119°E, where the depth point is distributed more densely than at areas east of 119°E, which is consistent with the overshooting hypothesis. We cannot present clear conclusion on whether the features are artificial or not, because the area where such feature is evident generally coincides with an area where depth information is extremely sparse. More detailed survey on the bathymetry of shelf-edge region in the South China Sea is anticipated, as the shelf edge is considered as major generation site of internal waves.

3.2 Tidal experiment

The rms deviation between observed and simulated results indicates that the model outputs derived by using gebco08 and gbscs5 bathymetries show better performance than those derived by using etopo5 and etopo1 datasets (Table 1). Larger rms deviation in etopo5 and etopo1 cases were caused mainly by large discrepancies observed at several specific stations, which indicate that all four datasets analyzed in this study would be suitable to obtain overall tidal features in the South China Sea while a care must be taken when focusing on a specific coastal location.

For example, etopo1 is not suitable to be used in a numerical model predicting tides in the upper Gulf of Thailand (station 26 in Fig.1) as the bathymetry is much shallower than observed and tides around the area are largely underestimated. Erroneous configuration of the Pearl River Estuary in etopo1 and gebco08 influenced tidal estimates along the coast of Guanxi Province in China (station 5).

Table 1 Root-mean-squared (rms) deviation of tidal harmonic constants (ampliutde and phase) between model run output using different bathymetry and observed values at 49 tide-gauge stations listed in Fig.1.

Dataset	M_2 amp (cm)	M_2 phase (deg)	K_1 amplitude (cm)	K_1 phase (deg)
etopo5	13.4	29.2	9.0	22.4
etopo1	11.0	40.2	10.6	37.9
gebco_08	9.0	24.1	7.0	15.4
gbscs5	8.9	19.1	6.4	6.0

Though tidal simulation using gbscs5 produces optimal results in overall sense, the model tends to overestimate tidal amplitudes along peninsula Malaysia (stations 28-31) and at southwest Borneo (station 38).

These large errors might be due partly to insufficient accuracy of model bathymetry in the central part of Gulf of Thailand and the area south of Vietnam, as the number of sounding data used for revision was small compared to other regions. In addition, usage of old sounding data may also have influenced the tidal output, because a recent study for the Bohai Sea in northern China indicates that a decadal shoreline change may alter M_2 amplitude for more than 10 cm[7].

4. Summary and Conclusion

New bathymetric dataset of the South China Sea shelf was compiled and compared with existing datasets. It was found that the new dataset, which refers to larger number of sounding data than in previous cases, seems to show better performance than the three existing datasets.

Additional sounding data are necessary to compile more accurate bathymetry dataset of the South China Sea shelf, especially at regions such as the central Gulf of Thailand, offshore area south of Vietnam from 4°N to 8°N, and shelf edge in the southwestern South China Sea, southern Gulf of Tonkin, and southern Taiwan Strait (118°E -119°E).

Acknowledgments

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References

1) W.H.F. Smith and D.T. Sandwell, Science 277 (1997) 1957-1962.
2) C. Amante and B.W. Eakins, NOAA Technical Memorandum NESDIS NGDC-24 (200) 19pp.
3) G.D. Egbert and S.Y. Erofeeva, J. Atmos Ocean. Tech. 19 (2002) 183-204.
4) T. Zu et al., Deep-Sea Res. I 55 (2008) 137-154.
5) G. Fang et al., Cont. Shelf Res. 19 (1999) 845-869.
6) K. Uehara, Rep. Res. Inst. Appl. Mech, Kyushu Univ. No.143 (2012) 69-73.
7) H.E. Pelling et al., J. Geophys. Res. 118 (2013) doi: 10.1002/jgrc.20258, 11pp.

Appendix

A1. URL of the data source

Etopo5
http://www.ngdc.noaa.gov/mgg/global/etopo5.HTML
Etopo1
http://www.ngdc.noaa.gov/mgg/global/global.html
Gebco08
http://www.bodc.ac.uk/data/online_delivery/gebco/
Trackline sounding data
http://maps.ngdc.noaa.gov/viewers/bathymetry/
SCS ENC
http://scsenc.eahc.asia/main.php