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# Introduction to the special issue on gravity and geoid in the Asia Pacific

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**ABSTRACT**

This special issue (SI) includes papers related to some recent efforts on geoid modeling in the Asia-Pacific region. In total, twelve papers were submitted to this SI, covering geoid models in Australia, mainland China, India, Indonesia, South Korea, Malaysia, Nepal, the Philippines, Taiwan, and Thailand. The methods for geoid modeling are rather diversified, with different considerations in gravity data processing and terrain effects. It is suggested that a mechanism for gravity data sharing should be developed and software packages can be freely distributed to geoid modelers. Observed GNSS/leveling along a route over varying terrains across Taiwan are released for testing geoid modeling methods and for accuracy assessments.

## 1. INTRODUCTION

This special issue (SI) publishes papers that show recent gravity data processing and geoid modeling works in the Asia-Pacific region. This SI is an activity of the International Association of Geodesy sub-commission 2.4e (IAG-SC2.4e), entitled "Gravity and Geoid in the Asia-Pacific". IAG-SC2.4e is to promote gravity data collection and sharing, geoid modeling and evaluating techniques, and geoid applications in the Asia-Pacific region. Some accepted papers have been presented in the first Asia Pacific geoid workshop (29 October 2020; http://space.cv.nctu.edu.tw/The-First-Asia-Pacific-geoid-workshop-4e), as oral papers.

Specifically, this SI accepts papers that show the latest geoid models in Australia (McCubbine et al. 2021), mainland China (Xie et al. 2021), India (Goyal et al. 2021), Indonesia (Bramanto et al. 2021), South Korea (under review), Malaysia (Tugi et al. 2021), Nepal (Timilsina et al. 2021), the Philippines (Gatchalian et al. 2021), Taiwan (Huang et al. 2021), and Thailand (Dumrongchai et al. 2021). Some of the papers are not directly involved with national geoid models. For example, Bramanto et al. (2021) show a software package that can efficiently process airborne gravity data in Java, Indonesia. Xue et al. (2021) used the land gravity values from the global gravity grid of Scripps Institution of Oceanography (version V28.1) to examine Bouguer anomalies and geological boundaries in mainland China. Yazid et al. (2021) optimized marine gravity determination from satellite altimetry around Malaysia. Tugi et al. (2021) used the gravity-geologic method to predict oceanic depths around Malaysia.

This SI does not cover some of the papers (in oral forms) presented in the Asia Pacific geoid workshop of 29 October 2020. Thus, this SI does not reflect the complete picture of geoid modeling in the Asia-Pacific region. For example, the geoid modeling efforts in Japan, Vietnam and New Zealand are not shown in this SI. In addition, geoid modelers in the following four nations presented oral papers in the workshop of 29 October 2020, but did not submit papers to this SI. Relevant geoid information for the four nations is given in the following citations and web pages

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(private communications with Koji Matsuo, Dinh Toan Vu, and Brian Bramanto in November to December 2021 and a google search): Japan geoid (Matsuo and Kuroishi 2020), Vietnam geoid (Vu et al. 2019), Indonesia geoid (https://srgi.big.go.id/page/model-geoid), and New Zealand NZGeoid2016 (https://www.linz.govt.nz/data/geodetic-system/datums-projections-and-heights/vertical-datums/new-zealand-quasigeoid-2016-nzgeoid2016). A paper from the International Service for the Geoid (ISG; under review) shows some of inventory geoid models in the ISG in the Asia-Pacific region. Readers who are interested in the geoid models of the Asia-Pacific nations not mentioned here can use a search engine and country names to find the models.

The cover image of this SI shows the free-air gravity anomalies and geoidal heights from the global gravitational model EGM 2008 (Pavlis et al. 2012), based on the geopotential coefficients in this model complete to harmonic degree 2160 with the incomplete higher coefficients beyond degree 2160. A geoid model from EGM2008 is most likely very useful for any given country, but the model may lack high wavenumber geoidal components in mountainous areas.

To model a geoid in a given country, most likely trans-national gravity data around the country are needed. An important activity of IAG-SC2.4e is to encourage gravity data sharing between the members of this commission. A suggested method for sharing is that individual countries contribute gravity data to an IAG service such as the International Bureau of Gravity (BGI) and then retreat the needed trans-national gravity measurements from this service. Figure 1 shows the distribution of land gravity measurements from BGI in the Asia-Pacific region. Except Australia, New Zealand, South Korea, and Japan, most countries are covered with sparse gravity data.

There are about 48 countries in the Asia-Pacific region. Many countries in the region have invested considerable resources on improved geoid models. Recent progress in satellite altimetry greatly increases coastal marine gravity accuracy. Satellite remote sensing data have been used to generate digital elevation models that are needed for geoid modeling. Many countries now also increase their GNSS/leveling observation campaigns to collect data to assess and to control the qualities of national geoid models. All such datasets may be used to improve the accuracies of geoid models in the Asia-Pacific region.

Since the publication of the lecture notes "Geodetic Boundary Value Problems in View of the One Centimeter Geoid" (Sansò and Rummel 1997), cm-level accuracy has been the ultimate goal pursued by geoid modelers around the world. As an example of promoting this cm geoid goal, the National Geodetic Survey of the USA released its gravity and elevation data in Colorado, where 14 international teams constructed their individual Colorado geoid models. According to Wang et al. (2021), the accuracy of the 14 Colorado geoid models may reach 2 cm, based on the assessments with the observed geoidal heights from GNSS/leveling along a profile (highway) in Colorado (GSVS17).

Following the Colorado experiment described by Wang et al. (2021), this SI announces that gravity data and elevation data for geoid modeling in Taiwan (Huang et al. 2021) can be freely used for experiments by sending your request to the executive author of SI (C. Hwang). Figure 2a shows a LiDAR-derived digital elevation model (DEM) in Taiwan, which features varying terrains from low-lying coastal areas to high mountains up to 3952 m. Figure 2b shows the elevation differences between the LiDar-derived DEM and the 15" SRTM DEM. Elevation data are essential for removing or condensing the terrain mass external from or to the geoid, and the DEM accuracy has an immediate impact on the geoid model accuracy. Figure 2b suggests that the two DEMs differ by up to several hundred meters in the mountainous areas of Taiwan. Figure 2a shows the locations of the benchmarks with observed geoidal heights along a leveling route across Taiwan, with the highest elevation being 3275 m. The observed geoidal heights in Fig. 2a, like those along GSVS17 in Wang et al. (2021), can be used to assess geoid model accuracies.

Several excellent lecture notes and textbooks have explained the theories and numerical methods for geoid modeling, e.g., the 2006 version of the classic book "Physical Geodesy" (Hofmann-Wellenhof and Moritz 2006). There are two basic categories of geoid modeling approaches as follows:

(1) Deterministic approach: based on Stokes integral or Hotine integral, which transforms gravity anomalies (usually residual gravity anomalies) to (residual) geoid heights. The kernel functions can be modified to suit the data and the integration capsize.
(2) Stochastic approach: based on least-squares collocation (LSC) for transforming gravity anomalies (usually residual gravity anomalies) to (residual) geoid heights. One feature of LSC is that it considers the heights of gravity data points using covariance functions.

In both approaches, the terrain effect and its indirect effect on the geoid must be considered. In some cases, height anomalies are computed first and geoidal heights are obtained by corrections using heights or Bouguer anomalies. All numerical methods for geoid modeling use the remove-restore-compute procedure because it is not possible to carry out a global integration when computing a geoidal height or height anomaly at a given location. It is not uncommon that gravimetric-only geoidal heights can vary with the integration cap size, the reference field and other factors. Thus, only relative geoidal heights are often assessed against observed relative geoidal heights. When a gravimetric-only geoid model is "adjusted" by a shift to a local mean sea level, or by blending with observed geoidal heights, the resulting geoid is a "hybrid" geoid that may be directly used in orthometric heighting. But observed geoidal heights are

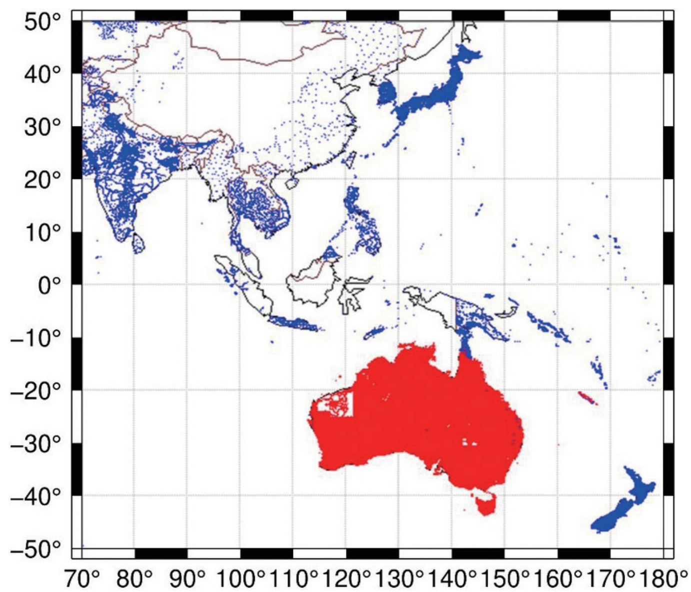


Fig. 1. The distribution of land gravity measurements from the International Gravimetric Bureau (BGI; https://bgi.obs-mip.fr) in the western Asia-Pacific region.

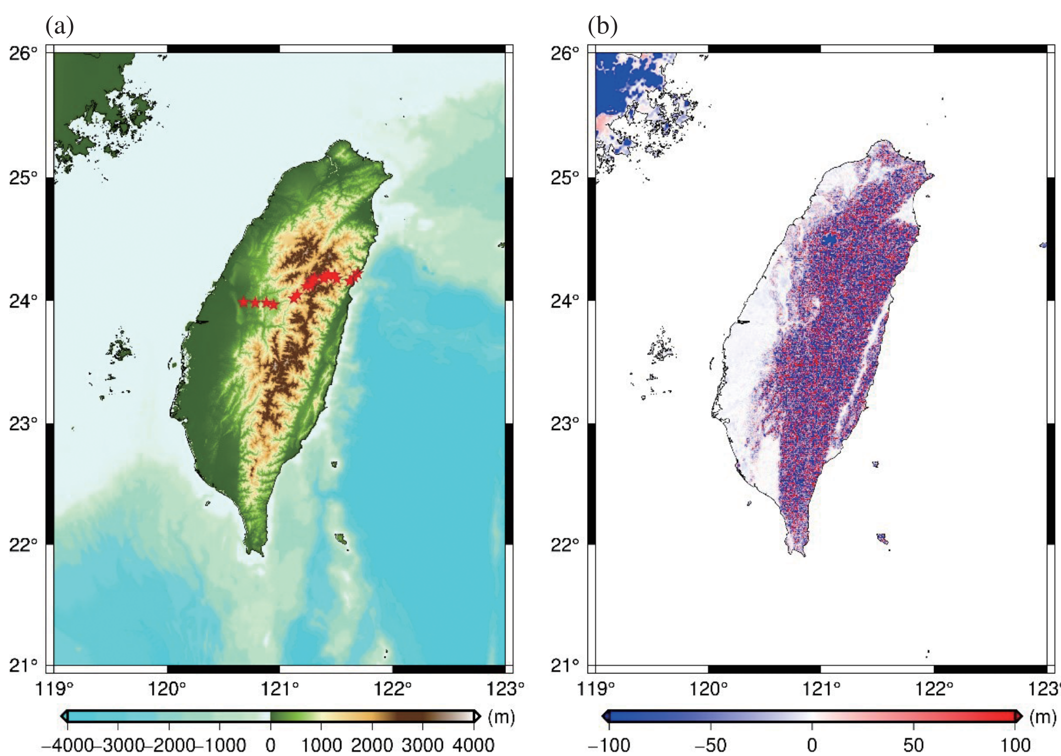


Fig. 2. (a) The latest digital terrain model around Taiwan from LiDAR (land) and multibeam measurements (oceans), and the distribution of GNSS/leveling points across a west-east provincial route in central Taiwan (red stars). (b) The differences between the elevations from LiDAR and from the SRTM DEM (15" resolution) in Taiwan.

not necessarily correct because of the uncertainties in the heights from GNSS and from leveling. For example, vertical tectonic motions in Taiwan can introduce errors in the observed geoidal height at a benchmark if the times of the GNSS observation and the leveling observation s at the benchmark are not the same.

In summary, modeling a 1 cm-geoid is an unfinished task in the geodetic community. The papers presented in this SI highlight this continual effort only in the countries related to these papers.

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