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Editorial: Application of Satellite Altimetry in Marine Geodesy and Geophysics

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Editorial on the Research Topic

Application of Satellite Altimetry in Marine Geodesy and Geophysics

The satellite altimetry concept was first proposed in 1969. Since then, many satellite altimetry missions have been implemented. With the development of the satellite altimetry technique, altimetry modes have been created for ocean and land observations, such as the traditional pulse-limited radar, the synthetic aperture radar (SAR), the laser mode, the three-dimensional imaging mode, and the global navigation satellite system refection (GNSS-R) mode. **Figure 1** gives an overview of all satellite altimetry missions. China also developed the ocean dynamic environment satellite missions, HY-2A/2B/2C/2D. These three missions (HY-2B/2C/2D) are currently simultaneously collecting global marine information and monitoring changes in ocean states.

Altimeter data quality may be affected by an error in instruments, atmospheric delay, sea state bias, geophysical environment correction (e.g., solid earth tide correction, ocean tide correction, inverse barometric effect, etc.), and precise orbit determination, The coastal waveforms may be seriously contaminated by the land and seabed. Therefore, these systematic errors should be corrected and presented in geophysical data records (GDRs). Researchers can then apply alternative correction models and new waveform retracking algorithms to further improve the quality of satellite altimetry data.

Radar altimetry missions include the exact repeat mission (ERM) and the geodetic mission (GM). The oceanic environment can be continuously monitored with ERM data. The GM data are mainly used to study marine geodesy and geophysics. Laser altimeter, SAR altimeter, and three-dimensional imaging altimeter collect massive ocean data. Once fused, multi-source altimeter data can provide high-resolution and precise ocean information. In marine geodesy, geophysics, and oceanography, altimeter data have been used in several studies including marine gravity, geoid, mean sea surface, mean dynamic topography, sea levels rising, ocean currents, geostrophic, sea wind, and wave, bathymetry, and seabed tectonics.

This Research Topic includes 17 papers in the field of satellite altimeter data processing, exploring applications to marine geodesy and geophysics. A summary of these papers is given below.

CALIBRATION OF SATELLITE ALTIMETER DATA

HY-2A mission was successfully implemented in 2011, which is the first altimetry satellite of the marine dynamic environment satellite series of China. HY-2B (the follow up to HY-2A) was

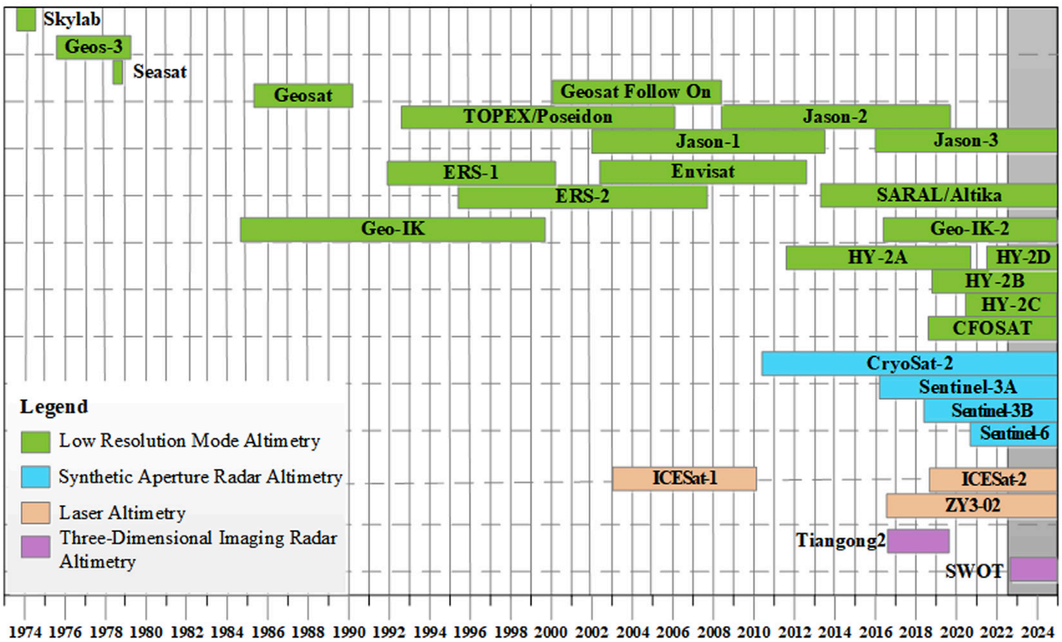

FIGURE 1 | Overview of satellite altimetry missions.

launched in 2018, and HY-2C and HY-2D were implemented in 2020, and 2021, respectively. Now, HY-2B, HY-2C, and HY-2D are simultaneously running global ocean observation. Wang J. et al. 2021 compared HY-2B GDR data and Jason-3 GDR data based on sea level anomalies, backscatter coefficient, sea state bias, wet tropospheric delay, and ionospheric delay. The cross-calibration performed in this study enables an evaluation of the performance of HY-2B for marine geodesy, geophysics, and oceanography.

WAVEFORM RETRACKING FOR THE IMPROVEMENT OF SATELLITE ALTIMETER DATA

Satellite altimeter data in the coastal seas are seriously degraded because of waveform contamination. Coastal altimetry exploits seamless satellite altimetry datasets from open oceans to coasts, so that the altimeter data quality can satisfy the requirement of coastal geodesy, geophysics, and oceanography. Many waveform retracking methods have been developed to improve the coastal data quality to some extent, such as OCOG, threshold algorithm, β-parameter algorithm, function fitting method, multi-leading-edge method, X-track, and ALES. Wang and Huang, 2021b combined a novel realignment algorithm and a gate-wise outlier detector to make waveform decontamination over coastal seas and then used the threshold method and ICE1 to retrack the decontaminated waveforms. The case study of Jason-2 data indicated that the upgraded waveform decontamination strategy can provide a promising solution for coastal altimetry applications.

WAVE ANISOTROPIC FEATURE OF BACKSCATTER COEFFICIENT DETERMINED BY SATELLITE ALTIMETER

Satellite altimeters have collected large amounts of marine information, including sea surface heights, wind speeds, wave heights, and backscatter coefficients. Satellite altimetry modes mainly include the compressed radar pulse mode, low resolution mode, SAR, SARIn (synthetic aperture interferometric mode), wide swath mode, and laser pulse mode, which can affect the backscatter coefficients over the ocean surface. Xu et al. 2021 analyzed the sigma0 data from Sentinel-3A, Cryosat-2, and Jason-3 and found the anisotropic features for different ocean wave modes.

REGIONAL MSS AND MDT DETERMINED FROM SATELLITE ALTIMETER DATA

The mean sea surface (MSS) and the mean dynamic topography (MDT) are the basic geographical information of oceans. Hamden et al. 2021 processed 27 years of along-track altimeter data from multiple satellite altimetry missions and established the Universiti Technologi Malaysia 2020 Mean Sea Surface (UTM20 MSS) model with a grid of $1.5' \times 1.5'$ by considering the 19-years moving average technique (Yuan et al., 2021). The latest altimeter data are used (i.e., Sentinel-3A). The UTM20 MDT model is derived with a pointwise approach from the differences between UTM20 MSS and the local gravimetric geoid of Malaysia. The MDT yielded significant improvement compared to the precious regional models developed by the Universiti Technologi Malaysia.

Sun W. et al. 2021 constructed a mean sea surface model of the Antarctic Ocean by integrating the Technical University of Denmark 2018 MSS (DTU18 MSS) with 6-years ERM and GM data from HY-2A, the first ocean dynamic environment satellite from China. The power spectral density shows the model errors with different sea surface wave bands.

MARINE GRAVITY INVERSION FROM ALTIMETER DATA AND ITS ASSESSMENT

Ice, cloud, and land Elevation Satellite 2 (ICESat-2) uses a synchronized multi-beam photon-counting method to collect data from three pairs of synchronous ground tracks. ATLAS loaded on ICESat-2 uses a 523-nm laser to actively map surface elevations, including the ice sheet height, sea-ice thickness, and sea surface height. Che et al. 2021 processed ICESat-2 data to estimate the deflections of the vertical (DOV) and marine gravity anomalies over the South China Sea. They found that the combination of along-track and cross-track data can improve the precision of deflections of the vertical and gravity anomalies.

Since 1969, many altimetry missions have been implemented. The altimeter can collect ocean information with limited-wide depressed pulse mode, low resolution mode, SAR/SARIn, laser, or wide swath mode. Marine gravity field models can be derived with the inverse Stokes formula, inverse Vening-Meinesz (IVM) formula, least squares collocation method, and the Laplace equation. Many marine gravity models have been constructed using massive datasets from exact repeat missions and geodetic missions. The S&S series from the Scripps Institution of Oceanography, University of California San Diego, United States, and the DTU series from the Technical University of Denmark are typical representatives. Recently the space geodetic group of Shandong University of Science and Technology, China, has developed a global marine gravity field model ($1'\times1'$) with IVM from multi-source satellite altimeter data (Zhu et al., 2020). Li et al., 2021) use ship-borne gravity data to evaluate the S&S and DTU models over the offshore and coastal seas of China and discuss the contribution of Jason-2, SARAL, and Cryosat-2.

The precise global geopotential model (GGM) can supply abundant information about the Earth's gravity field. High-degree GGMs have been constructed using multi-source geodetic data, such as EGM 2008, GECO, SGG-UGM-1, EIGEN-6C4, GOCO05C, XGM 2016, and XGM 2019. Multi-satellite altimeter data have played an important role in constructing these high-degree GGMs, especially over oceans. These GGMs are widely applied in marine geodesy, geophysics, and oceanography. Wu Y. et al. 2021 assessed the updated high-degree GGMs over the South China Sea with heterogenous geodetic observations (e.g., airborne and ship-borne gravity data) and synthetic ocean reanalysis data (e.g., CNES-CLS13MDT, SODA3, ECMWF, and ORAS5). The choice of a precise GGM is crucial for oceanography, and these synthetic ocean data are very useful in regional oceans were good quality geodetic and geophysical data are lacking.

Global or regional marine gravity anomalies can be inversed from multi-source satellite altimeter data with the inverse Stokes formula, the inverse Vening Meinesz formula, and the least squares collocation method, respectively. The precision of marine gravity anomalies inversed from multi-satellite altimeter data are generally affected by the density of altimeter tracks, number of observations, precision of sea surface heights, and footprint position of satellite altimeters. Liu S. et al. 2021 used the altimetry data from Geosat, ERS-1/2, TOPEX/Poseidon, Envisat, Jason-1/2/3, Cryosat-2, HY-2A, SARAL, and Sentinel-3A to analyze the influence of altimeter data quality on the precision of marine gravity anomalies inversed from multi-source altimetry data. Their results show that an effective combination of multi-source satellite altimeter data can improve the precision and the spatial resolution of global/regional marine gravity derived from the satellite altimetry technique.

BATHYMETRY AND SEABED DENSITY CONTRAST

High-resolution marine gravity data can be determined from multi-source satellite altimeter data. Then the marine gravity data can be used to predict bathymetry based on the frequency relation between the depth of density interface and gravity anomalies in the frequency domain. Therefore, the mass density contrast is one important parameter for bathymetry. Wan et al. 2021 used the gravity geological method to study the density contrast over the Atlantic Ocean from the altimetry-derived gravity data and the ship-borne depth data.

Ocean depth plays a very important role in marine geodesy, geophysics, geology and oceanography, and studies of earth plate tectonics, ocean currents, tide, and marine navigation. Gravity-induced bathymetry is one of the main techniques to determine the seabed topography over large oceans. The gravity-geologic method, admittance function method, and least-squares collocation method are three main methods to estimate the seafloor depth from marine gravity data determined by satellite altimetry technique. Wei et al. 2021 constructed the marine gravity anomalies using HY-2A/GM data and predicted bathy bathymetry accordingly over the South China Sea. Their results suggest that the GGM can be widely applied to bathymetry prediction and HY-2A/GM-derived gravity data are feasible with good results for determining seabed topography.

APPLICATIONS TO LAND AND INLAND LAKE

Ice gaps over the Antarctic and Greenland and terrestrial glaciers are gradually melting due to global warming. The temporal gravity data of GRACE and GRACE-Follow On are generally used to study the global or regional mass changes and height variations. Chen et al., 2021) processed the SARIn data and low-resolution data of Cryosat-2, as well as the airborne topographic mapper data over the Greenland ice sheet. The elevation change rate is -11.83 ± 1.14 cm/year, corresponding to the volume change rate of -200.22 ± 18.26 km3/year.

The satellite altimetry technique can collect massive data reflecting from the sea surface and terrestrial surface, including inland lake surface. The lake level change can also be monitored with the radar altimeter, laser altimeter, and/or SAR/SARIn altimeter. The high-altitude lakes over the Tibetan Plateau are extremely sensitive to global climate change, and therefore the lake level evolution is very important for hydrological and climate change analysis. Sun M. et al. 2021 robustly processed the altimetry data from TOPEX/Poseidon and Jason-1/2/3 to construct the lake level series over lake Zhari Namco, and analyze the lake level variations, The results improve our understanding of inland water budget and the effects of climate change over the Tibetan Plateau.

GNSS-R ALTIMETRY

GNSS-R technique is an emerging remote sensing technology for sea surface altimetry to retrieve the sea surface height by measuring the time delay between direct GNSS signal and reflected signal. Several satellite missions (e.g., TechDemoSat-1, CYGNSS, and Bufeng-1) have been executed to step the GNSS-R technique into a new stage of collecting global sea surface information, like sea surface height, sea surface wind speed, sea ice, and so on. Wang Q. et al. 2021 integrated one machine learning fusion model and feature optimization to extract precise sea surface height.

Wu F. et al. 2021 studied the reflected sea surface model for GNSS-R signals. The mean dynamic topography (MDT) is different from the instantaneous sea surface and its normal is not along the vertical. The actual direct and reflected signals of ship-borne GNSS were processed and the MDT correction and the vertical correction can improve the precision of specular point positioning.

Liu Z. et al. 2021 analyzed the performance of airborne interferometric global navigation satellite system reflectometry (iGNSS-R) for sea surface altimetry and showed the relation between the altimetric data quality and the along-track spatial resolution. Yan et al. 2022 studied the atmospheric delay on sea surface altimetry with airborne and spaceborne GNSS-R techniques. Their results will provide a scientific reference for future spaceborne iGNSS-R altimetry missions.

AUTHOR CONTRIBUTIONS

JG, CH and XD make the contribution of topic management, manuscript review, writing and editing.

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