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METEOROLOGY

Temporal-spatial distribution of oceanic vertical deflections determined by TOPEX/Poseidon and Jason-1/2 missions

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ABSTRACT

Deflections of the Vertical(DOV) are essential data in the geodetic observation reduce, the earth gravity field and geoid model refinement, and the mass earth change. The meridional and prime vertical components of global oceanic DOVs are estimated from altimetry data of TOPEX/Poseidon, Jason-1, and Jason-2, through 1992 to 2013 with the crossover method, to analyze the temporal-spatial distribution of marine DOVs. Comparing with the EGM2008-modelled DOVs, precisions of meridional and prime vertical components can be up to 0.98” and 1.02”, respectively. The time series of annual mean DOVs from 1992 to 2013 are studied to get the annual variation law. Annual changes of meridional and prime vertical components are small over most oceans. But the annual changes are significantover oceans with large submarine topography undulations.The spatial distribution of oceanic DOVs is also analyzed. The absolute DOVs over oceans around lands, islands, and large oceanic trenches are greater than those over the other oceans. The meridional and prime vertical components are consistent withthe longitude and latitude directions, respectively.

Keywords: Deflection of the Vertical (DOV), satellite altimetry, temporal-spatial distribution, crossover point, marine gravity field.

RESUMEN

Las Desviaciones de la Vertical (DOV, del inglés Deflections of the Vertical) son información esencial en la simplificación de la observación geodésica, el campo gravitatorio terrestre y el perfeccionamiento del modelo geoide, y el cambio de la masa terrestre. Se estimaron los componentes meridional y principal vertical de las desviaciones de la vertical oceánica global con la información altimétrica de TOPEX/Poseidón, Jason 1 y Jason 2, de 1992 a 2013, con un método de cruce para analizar la distribución espacio-temporal de las desviaciones de la vertical marinas. Comparadas con las desviaciones de la vertical obtenidas con el modelo EGM2008 (Modelo de Gravitación de la Tierra), la precisión de los componentes meridional y principal vertical puede aumentarse 0.98" y 1.02", respectivamente. Se estudiaron las series temporales de la media anual de las desviaciones de la vertical desde 1992 a 2013 para obtener la ley anual de variación. Los cambios anuales de los componentes meridional y principal vertical son muy pequeñas en la mayoría de los océanos. Sin embargo, los cambios anuales son mayores en aquellos océanos con una topografía submarina de grandes ondulaciones. También se analizó la distribución espacial de las desviaciones de la vertical oceánicas. Las desviaciones de la vertical absolutas alrededor de los continentes, islas y fosas oceánicas mayores son superiores que aquellas sobre los otros océanos. Los componentes meridional y vertical principal son consistentes con las direcciones de la longitud y la latitud, respectivamente.

Palabras clave: Desviación de la vertical (DOV), altimetría satelital, distribución espacio-temporal, punto de cruce, campo de gravitación marino.

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1. Introduction

The Deflection of the Vertical (DOV)as one basic research topic in geodesy and geophysics can characterize thedirection of gravity vector and provide one tight local tie among space geodetic techniques (Shen et al., 2015). The traditional methods to measure DOV includethe astronomical geodetic surveying, gravimetry, combination of astronomical geodesy and gravimetry, and global navigation satellite system (GNSS). Based on the astronomical geodetic principle, the automatic measurement system integrating GNSS and CCD zenith telescope can precisely measure DOVs (Guo, Song, Chang, &Liu,2011; Hirt&Seeber, 2008; Tian et al., 2014, Peng&Xia,2015).These measurement methods of the vertical deflectionare applicable to lands (Ning,Guo, B. Wang,& H. M. Wang, 2006), but are unable to measure practically the oceanic vertical deflection due to limitations of these techniques under effects of ocean dynamic environment over open oceans (Guo,Chen,Liu, Zhong,&Mai, 2013;Guo, Liu, Chen, Wang, &Li,2014). DOVs over open oceans are commonly calculated from the Earth gravity field model at present (Jekeli, 1999; Pavlis, Holmes, Kenyon, & Factor,2012). Ship-borne gravity data can also be used to estimate the oceanic vertical deflections. But the ship-borne gravimetry can mostly be carried out over coastal seas, and most of theoceans are short of gravity field data. With the rapid development of satellite altimetry, altimeter data can widely be used to estimate the oceanic vertical deflection (Fu and Cazenave, 2000; Guo, Hu, Wang, Chang,&Li, 2015).

With the development of satellite altimetry technique, oceanic DOVs are mainly utilized to determineoceanic gravity field model with high precision. DOVs on crossover points can be calculated from altimeter data by the crossover method (Sandwell, 1984). Altimeter data of ERS-1 and Geosat were processed to estimate DOVs of crossover points from which gravity field over Antarctic oceans was estimated by the Laplace equation (Sandwell, 1992). Sandwelland Smith (1997) used ERS-1 and Geosat altimetry data to compute DOVs of crossover points which are interpolated to get DOVs of grids and then estimated the gravity anomalies over oceans with the Fast Fourier transformation (FFT).Single differences of sea surface height along thetrack and corresponding track azimuths are used to calculate oceanic DOVs along thetrack (Olgiati, Balmino, Sarrailh,& Green, 1995). Altimetry data from multi-satellite altimetry missions can be integrally processed to get DOVs along tracks which are interpolated to calculate DOVs of grids used to estimate marine gravity anomalies. Gravity anomalies along tracks with the along-track DOVs are more accurate than those determined by FFT with the inverse Stokes formula. The inverse Vening Meinesz formula is derived to calculate DOVs with the grid method (Hwang, 1998). The geoid and gravity anomalies over China seashas been calculated from oceanic DOVs with the crossover method (Li,Ning, Chen,& Chao, 2003). DOVs from the crossover method are more accurate than those from the grid method and the along track method, and the grid method is optimal to determine the high-resolution precise marine gravity field using altimeter data (Peng and Xia, 2004). DOVs over China coastal seas are calculated from Geophysical Data Records (GDR) of EnviSat with the grid method (Xing, Li &Liu, 2006). Comparing with EGM96 (Lemoine et al., 1998), precisions of the prime vertical and meridional components are 6″ and 3″, respectively. Multi-altimeter data are processed to calculate global DOVs with the grid method. Comparing with EGM96, precisions of the prime vertical and meridional components over global oceans are 1.97” and 1.12”, respectively.

TOPEX/Poseidon (T/P) launched in 1992, Jason-1 initiated in 2002 and Jason-2 initiatedin 2008 can together measure oceans. Jason-2 as Jason-1 follow on runs the same track of T/P and continuously surveys oceans. Theprecision of single observation is estimated to be near to 3 cm (Beckley et al., 2010; Fu and Cazenave, 2000; Tunini et al., 2010).T/P and Jason-1/2 providealtimetry data with high precision which are processed by the crossover method. Global oceanic DOVs are estimated and then the temporal-spatial distribution of global oceanic DOVs is studied in the paper.

2. Satellite altimetry data

GDRs version C of T/P, Jason-1, and Jason-2 released by the Physical Oceanography Distributed Active Archive Center(PO.DAAC) are processed in the paper. Time spans of T/P, Jason-1, and Jason-2 data are from October 1992 to August 2002 with cycles 2 to 364, from August 2002 to January 2009 with cycles 22 to 259, and from January 2009 to May 2013 with cycles 21 to 177, respectively. T/P starts the precise satellite altimetry era, and Jason-1 and Jason-2 follow T/P. These three altimetry satellites are in the same exact repeated orbit. Figure 1 shows global tracks and crossover points of T/P cycle 17.

The radial precision of T/P orbit determination is better than 3 cm, and the radial precisions of Jason-1 and Jason-2 orbit determination can be up to 1 cm based on the on-board satellite tracking systems. Sea surface height accuracyfrom these three altimeter data can be lower than 3 cm. To get more precise sea surface heights, altimetry data should be edited based on the criterions provided by AVISO (AVISO/Altimetry, 1996; Dumont et al., 2011; Picot, Case, Desai, Vincent, &Bronner, 2012; Shah, Sajeev, & Gopika, 2015).

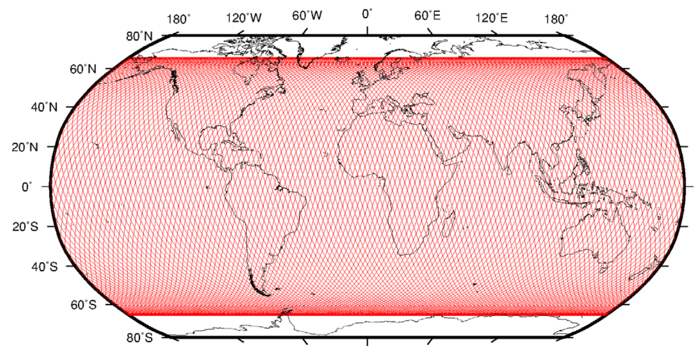

Figure 1. T/P tracks and crossover pointsfor cycle 17

3. Determination of oceanic DOVs

The crossover method is one of thebest waysto determine precise oceanic DOVs from satellite altimetry data. Altimetry profiles of ascending and descending arcs can be determined by the geoid gradient or the single difference of DOV along thetrack, and then the prime vertical and meridional components of DOV can be solved by combining thetrack gradients.

The meridional componentand ξ the prime vertical component η of DOV are calculated from the two directions of geoid gradients (Heiskanen&Moritz,1967), that is

$$\xi = -\frac{1}{R}\frac{\partial N}{\partial \varphi} \qquad (1)$$

$$\eta = -\frac{1}{R\cos\varphi}\frac{\partial N}{\partial \lambda} \qquad (2)$$

where *R* is the average radius of the Earth. ∂N / ∂φ =1/ 2|φ̇ | (N ̇a-N ̇d)and ∂N / ∂ λ=1/ 2|λ ̇ | (N ̇a+N ̇d) and, in which φ andare the directions of prime vertical and meridional speedsof nadir pointrespectively, is the derivative of geoid heightwith respect to time on thealtimetry data point relative,and subscripts and denotethe ascending and descending arcs respectively. ,, and can be obtained by the time and location information in the altimetric data (Hwang& Parsons,1995; Sandwell& Smith,1997).The detailed data processing procedure is following.

1) Altimetry data preprocessing. These three-altimeter data are read with the corresponding program based on data formats. These data are edited according to the relatedcriteria published by the data providers. All geophysical corrections are applied to altimetry data. These data including latitude, longitude, sea surface height and time are saved based on the ascending and descending arcs.

2) Determination of crossover point. The quadratic polynomials are used to fit the ascending and descending arcs on geodetic latitude and longitude based on the positioning information in altimetry data, respectively. The quadratic equations of ascending and descending arcs are combined to solve coordinates of thecrossover point.

3) Unification of time and space datum. There exist systematic biases between different altimeter data under effects of a different ellipsoid, time-varying sea surface height, satellite orbit determination error, altimeter error and geophysical correction error. Corrections of coordinate frame biases for different altimetry data are calculated to unify the time and space datum for T/P, Jason-1, and Jason-2.

4) Sea surface height of crossover point. Sea surface height of crossover point is interpolated from the ascending and descending arcs' data based on coordinates with the distance weight method.

5) DOV determination of crossover point. 8-10 altimetry points around crossover point are selected based on the position of thecrossover point. The quadratic polynomial on latitude and longitude, and the quadratic curves of latitude and longitude with respect to time are fitted based on information about sea surface height, latitude, longitude and time of altimetry point, respectively. Then derivatives of these quadratic polynomials are made to get , andwhich are substituted for equations (1) and (2) to calculate the prime vertical and meridional components of DOV on crossover point.

6) Repeat step 5) to calculate all DOVs of all crossover points. The same pass may be different for all cycles and the farthest distance of crossover points for the same ascending and descending arcs may be up to 1 km for T/P, Jason-1 and Jason-2 (Fu and Cazenave, 2000; Luz Clara, Simionato, D'Onofrio, & Moreira, 2015). So the mean position of crossover point for the same ascending and descending arcs should be determined.

7) Reduce DOVs of crossover points to the mean position with the inverse distance weighted interpolation method within the studied time span. We can get oceanic DOVs of crossover pointsfrom altimetry data from 1992 to 2013. So the temporal-spatial distribution of oceanic DOVs can be obtained.

Altimetry data should be edited and corrected before DOV calculation because of contamination of many kinds of errors. The same editing criteria are used to modifyand correct altimetry data to get precise results. To check the precision of oceanic DOVs from altimetry data, itwasselected T/P data of cycle 17 to compute oceanic DOVs of crossover points in the global area (-60°S~60°N, 0°~360°), which are compared with the modeled DOVs from EGM2008 (Pavlis, Holmes, Kenyon,& Factor,2012). Table 1 lists the statistical results. From Table 1, it can be seen that theprecisions of prime vertical and meridional components are 1.02″ and 0.98″ comparing with EGM2008-modelled components, respectively, which indicates that oceanic DOVs of crossover points from altimetry data are reliable.

Table 1. Statistical results of oceanic DOVs from T/P, Jason-1, and Jason-2

Component	Max (″)	Min (″)	Mean (″)	STD(″)	RMS(″)
Meridional	4.89	-4.86	0.07	0.98	0.98
prime vertical	4.98	-4.99	0.00	1.02	1.02

4.Temporal variations of oceanic DOVs

The earth gravity field not only changes in space but also changes in time. The temporal-spatial variation of the earth gravity field is one important part of geodynamics (Ding, Li, &Ding, 2006). The gravity field change containing the abundant geophysical information of interior earth can be studied throughthe DOV variations.

Oceanic DOVs of crossover points for each cycle are calculated from altimetry data of T/P, Jason-1, and Jason-2 with the crossover method. The mean position of crossover point is determined by averaging positions of crossover points from the same ascending and descending arcs in one year. DOVs from the altimetry data of about 37 cycles in one year are used to get the mean DOV of the averageposition with the inverse distance weighted interpolation method. So itispossibletoget a group of DOVs of annual mean crossover pointson a global scale, which can make up a time series of annual mean DOVs from 1992 to 2013. The time series can be analyzed to study the interannual variations of oceanic DOVs. Figures 2 and 3 show annual variations of meridional and prime vertical components of oceanic DOVs determined by the crossover method, respectively.

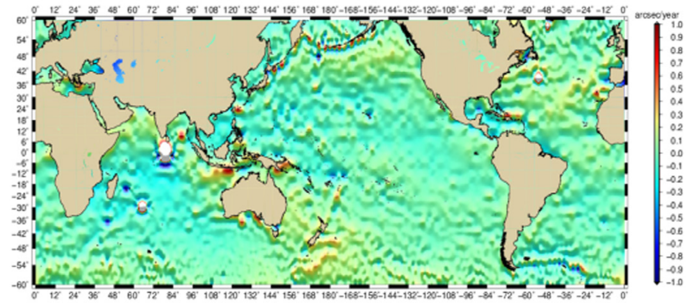

Figure 2. Annual change rate ofmeridional componentof DOV

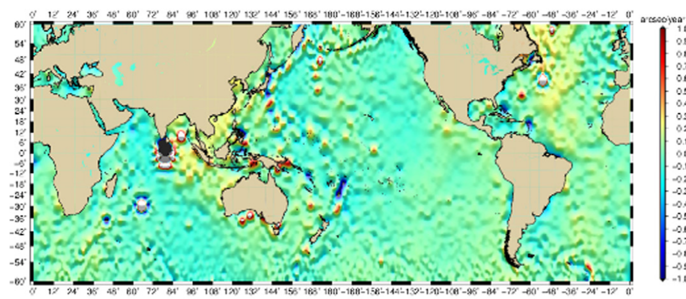

Figure 3. Annual change rate ofprime verticalcomponent of DOV

From figure 2, it can be found that the annual change of meridional component over most oceans is slight in 1992-2013, and the annual change in most oceans in the north hemisphere is greater than that in the south region. The annual change over open oceans far away from islands and lands is small and apt to convergence, such as the middle Pacific Ocean and the Middle Indian Ocean. The annual variation over coastal seas is great, such as the Bering Sea, the Indonesian Sea, the New Zealand Sea, and the Caribbean Sea. On the one hand, the mass over these coastal seas changes greatly. On the contrary, the variation can reflect the lower altimetry data quality over coastal seas than that over open oceans.

Figure 3 shows the annualchangesin prime vertical components. Annual variations are small and apt to convergence over most oceans except for the eastern oceans of the North American, the Bengal Bay, and the China coastal seas. Also, the annual variation is significantover some oceans around islands in the Pacific Ocean.

5. Spatial distribution of oceanic DOVs

The Marine gravity field is mainly determined by the oceanic lithosphere and the deep mass distribution and geological structure. It shows the basic geographic information of oceanic lithosphere structure and the submarine topography (Chao, Yao, Li,&Xu, 2002). The uneven distribution of vast oceanic gravity affects the direction of themarine plumb line, which makes the spatial distribution of marine DOVs inconsistent. The marine gravity field can be analyzed by studying the spatial distribution of global oceanic DOVs. DOVs of crossover point for the same ascending and descending arcs in all cycles are interpolated to the mean position with the inverse distance weighted interpolation method. So the averageDOV of each crossover point in 1992-2013 can be obtained. Figures 4 and 5 show the global distribution of oceanic DOVs.

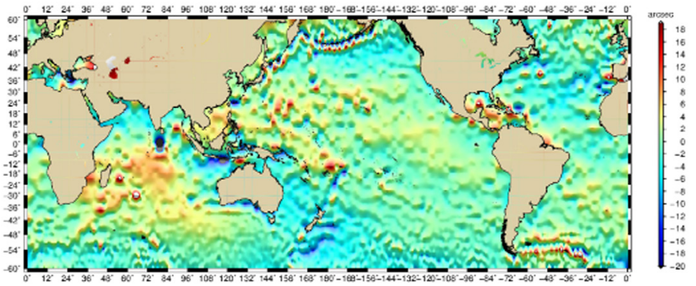

Figure 4. Spatial distribution of meridional component of DOV

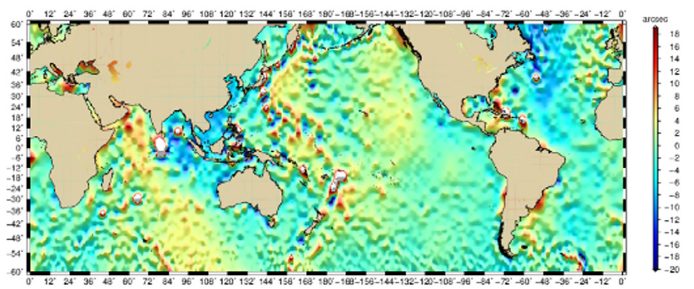

Figure 5. Spatial distribution of prime vertical component of DOV

From figure 4, it can be foundthat the absolute meridional components of DOV are comparatively large over the coastal oceans. The meridional components are large over the west Pacific Ocean and the Middle Indian Ocean. It is also large over the seas around islands and large oceanic trenches, such as the Bering Sea, the Japan seas, the Indonesian seas, and the Caribbean Sea. The significant meridional components over these oceans are mainly caused by the obvious marine mass changes. The meridional components are positive over the most Indian Ocean, the north-central Pacific Ocean, and the Caribbean Sea. Most meridional components over the other oceans are negative. The meridional components tend to be consistent along the longitude direction over most oceans.

From figure 5, it can be found that the spatial distribution of prime vertical components of oceanic DOVs is approximately consistent with the distribution of meridional components over most oceans. The absolute prime vertical components are large over the China seas, the west Pacific Ocean, the Indian Ocean, and the northwest Atlantic Ocean. It is also large over the oceans around islands and oceanic trenches, like the Bering Sea, the Japan seas, the Indonesian seas, the Caribbean Sea, and the ocean around the Mariana Trench. The large prime vertical components over these oceans may be mainly caused by the visiblechange of marine gravity field. The prime vertical components over the most Indian Ocean, the north-central Pacific Ocean and the Caribbean Sea are positive, and these are more negative over the other oceans. In contrast to the meridional component, the prime vertical components tend to be consistent along the latitudedirectionover most oceans.

6. Conclusions

Marine DOVs are determined from altimetry data of T/P, Jason-1, and Jason-2 in 1992-2013 with the crossover method. The temporal-spatial distribution of oceanic DOVs is studied. Comparing with the EGM2008-modelled DOVs, the precisions of prime vertical and meridional components determined from one-cycle altimetry data of T/P, Jason-1, and Jason-2 can be up 0.98″ and 1.02″, respectively, which indicates that DOVs of crossover pointsestimated from altimetry data are very reliable.

Annual changes of meridional and prime vertical components of DOVs over most open oceans are small. But the annual variations over most coastal seas are significant because mass changes over coastal ocean may be large and thealtimetry precision over coastal seas may be lower. Absolute DOVs over oceans around lands, islands and vastocean trenches are biggerthan those over the other oceans. This is mainly due to the obvious gravity change of interior earth and the severe submarine topography undulation. The meridional and prime vertical components of DOVs are consistent withthe longitude and latitude directions, respectively.

The spatial resolution of oceanic DOVs determined from altimetry data with the crossover method is limited by theexact repeating period of altimetry satellite. Thecombination of more satellite altimetry missions can improve the resolution of oceanic DOVs.

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References:

AVISO/Altimetry (1996). AVISO user handbook: merged TOPEX/Poseidon products (GDR-Ms). AVI-NT-02-101-CN, CLS & CNES

Beckley, B., Zelensky, N. P., Holmes, S. A., Lemoine, F. G., Ray, R., Mitchum, G. T., ... Brown, S. (2010). Assessment of the Jason-2 extension to the TOPEX/Poseidon, Jason-1 sea-surface height time series for global mean sea level monitoring. Marine Geodesy, 33(1), 447-471. DOI: 10.1080/01490419.2010.491029

Chao, D. B., Yao, Y. S., Li, J. C., & Xu, J. S. (2002). Interpretation on the tectonics and characteristics of altimeter-derived gravity anomalies in China South Sea (in Chinese). Editorial Board of Geomatics and Information Science of Wuhan University, 27(4), 343-347.

Ding, Y. F., Li, Y. F., & Ding, X. B. (2006). Deflection of vertical in modern geodesy (in Chinese). Journal of Geodesy and Geodynamics, 26(2), 115-119.

Dumont, J. P., Rosmorduc, V., Picot, N., Desai, S., Bonekamp, H., Figa J, ... Scharroo, R. (2011). OSTM/Jason-2 Products handbook. Edition 1.8. SALP-MU-M-OP-15815-CN, EUMETSAT/CNES/NOAA/NASA/JPL.

Fu, L. L., & Cazenave, A. (2000). Satellite altimetry and Earth Sciences: handbook of techniques and applications. San Diego, Academic Press.

Guo, J. Y., Chen, Y. N., Liu, X., Zhong, S. X., & Mai, Z. Q. (2013). Route height connection across the sea by using the vertical deflections and ellipsoidal height data. China Ocean Engineering, 27(1), 99-110.DOI: 10.1007/s13344-013-0009-9

Guo, J. Y., Hu, Z., Wang, J., Chang, X., &Li, G.(2015). Sea Level Changes of China Seas and Neighboring Ocean Based on Satellite Altimetry Missions from 1993 to 2012. Journal of Coastal Research: Special Issue, 73: 17-21. DOI: 10.2112/SI73-004.1

Guo, J. Y., Liu, X., Chen, Y., Wang, J., & Li, C. (2014). Local normal height connection across sea with ship-borne gravimetry and GNSS techniques. Marine Geophysical Research, 35(2):141-148.DOI: 10.1007/s11001-014-9216-x

Guo, J. Y., Song, L. Y., Chang, X. T., & Liu, X. (2011). Vertical deflection measure with digital zenith camera and accuracy analysis (in Chinese). Geomatics and Information Science of Wuhan University, 36(9), 1085-1088.

Heiskanen, W. K., & Moritz, H. (1967). Physical geodesy. San Francisco: Freeman.

Hirt, C., & Seeber, G. (2008). Accuracy analysis of vertical deflection data observed with the Hannover Digital Zenith Camera System TZK2-D. Journal of Geodesy, 82(6), 347-356. DOI: 10.1007/s00190-007-0184-7

Hwang, C. (1998). Inverse VeningMeinesz formula and deflection-geoid formula: applications to the predictions of gravity and geoid over the South China Sea. Journal of Geodesy, 72(5), 304-312. DOI: 10.1007/s001900050169

Hwang, C., & Parsons, B. (1995). Gravity anomalies derived from Seasat, Geosat, ERS-1 and TOPEX/POSEIDON altimetry and ship gravity: a case study over the Reykjanes Ridge. Geophysical Journal International, 122(2), 551–568. DOI: 10.1111/j.1365-246X.1995.tb07013.x

Jekeli, C. (1999). An analysis of vertical deflections derived from high-degree spherical harmonic models. Journal of Geodesy, 73(1), 10-22. DOI: 10.1007/s001900050213

Lemoine, F. G., Kenyon S. C., Factor, J. K., Trimmer, R. G., Pavlis, N. K., Chinn, D. S., & Olson, T. R. (1998). The Development of the Joint NASA GSFC and the National Imagery and Mapping Agency (NIMA) Geopotential Model EGM96. NASA/TP-1998-206861

Li, J. C., Ning, J. S., Chen, J. Y., & Chao, D. B. (2003). Geoid determination in China Sea Areas (in Chinese). Acta Geodaetica et Cartographic Sinica, 32(2),114-119.

Luz Clara, M., Simionato, C. G., D'Onofrio, E., & Moreira, D. (2015). Future sea level rise and changes on tides in the Patagonian Continental Shelf. Journal of Coastal Research, 31(3): 519-535. DOI: 10.2112/JCOASTRES-D-13-00127.1

Ning, J. S., Guo, C. X., Wang, B., & Wang, H. M. (2006). Refined determination of vertical deflection in China mainland area (in Chinese). Geomatics and Information Science of Wuhan University, 31(12), 1035-1038.

Olgiati, A., Balmino, G., Sarrailh, M., & Green, C. M. (1995). Gravity anomalies from satellite altimetry: comparison between computation via geoid heights and via deflections of the vertical. Bulletin Géodésique, 69(4),252-260.DOI: 10.1007/BF00806737

Pavlis, N. K., Holmes, S. A., Kenyon, S. C., & Factor, J. K. (2012). The development and evaluation of the earth gravitational model 2008 (EGM2008). Journal of Geophysical Research, 117, B04406. DOI: 10.1029/2011JB008916

Peng, F. Q., & Xia, Z. R. (2004). Vertical deflection theorem of satellite altimetry (in Chinese). Hydrographic Surveying and Charting, 24(2), 5-9.

Picot, N., Case, K., Desai, S., Vincent, P., & Bronner, E. (2012). AVISO and PODAAC User Handbook-IGDR and GDR Jason-1 Products. Edition 4.2. SALP-MU-M5-OP-13184-CN, CNES & NASA.

Sandwell, D. T. (1984). A Detailed View of the South Pacific Geoid From Satellite Altimetry. Journal of Geophysical Research, 89(B2), 1089-1104.

Sandwell, D. T. (1992). Antarctic marine gravity field from high-density satellite altimetry. Geophysical Journal International, 109(2), 437-448.DOI: 10.1111/j.1365-246X.1992.tb00106.x

Sandwell, D. T., & Smith, W. H. F. (1997). Marine gravity anomaly from Geosat and ERS1 satellite altimetry. Journal of Geophysical Research, 102(B5), 10039-10054. DOI: 10.1029/96JB03223

Shah, P., Sajeev, R., & Gopika, N. (2015). Study of Upwelling along the West Coast of India - A Climatological Approach. Journal of Coastal Research, 31(5): 1151 - 1158. DOI: 10.2112/JCOASTRES-D-13-00094.1

Shen, Y., You, X., Wang, J., Wu, B., Chen, J., Ma, X., & Gong, X. (2015). Mathematical model for computing precise local tie vectors for CMONOC co-located GNSS/VLBI/SLR stations. Geodesy and Geodynamics, 6(1), 1-6. DOI: 10.106/j.geog.2014.12.001

Tian, L. L., Guo, J. Y., Han, Y. B., Lu, X. S., Liu, W. D., Wang, Z., ... Wang, H. Q. (2014). Digital zenith telescope prototype of China. Chinese Science Bulletin, 59(17), 1978-1983. DOI: 10.1007/s11434-014-0256-z

Tunini, L., Braitenberg, C., Ricker, R., Mariani, P., Grillo, B., & Fenoglio-Marc, L. (2010) Vertical land movement for the Italian coasts by altimetric and tide gauge measurements. Procedures ESA Living Planet Symposium, Bergen, Norway.

Xing, L. L., Li, J. C.,& Liu X. L. (2006). Study on ocean vertical deflection of ENVISAT satellite altimetry along-track geoid gradient(in Chinese). Science of Surveying and Mapping, 31(5), 48-49.