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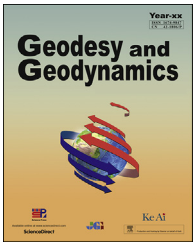

Influence of ocean tidal loading on InSAR offshore areas deformation monitoring

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ABSTRACT

The ocean tide can cause the redistribution of the seawater mass, resulting in earth's surface deformation, namely ocean tidal loading (OTL). OTL vertical displacement may reach several centimeters, especially in coastal areas, so its effect in the field of high precision geodesy must be considered. This study concentrates on the influences of OTL on InSAR deformation measurements. We improve the osu.chinasea.2010 regional model and then compare the improved regional model with other regional models. It turns out that the improved regional model can achieve higher precision. Then we use it to replace the offshore part of the global model to generate the present model. We find that the displacement observed by the present model is 2–3 mm larger than that of other models on some sites. Finally, the present model is used to correct the deformation observed by InSAR of Shanghai and Los Angeles. A comparison between the displacements of IGS station with the corrected data shows that the OTL correction can improve the accuracy of InSAR deformation results by about 20%.

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1. Introduction

Ocean Tidal Loading (OTL) is the elastic response of the earth to the redistribution of water mass from the ocean tides [1]. It causes periodic displacements to ground stations, which vary with the station locations. In coastal areas, OTL displacements can be several centimeters [2], seriously affecting the accuracy of geodetic surveying. Therefore, OTL displacements should be considered in high-precision geodetic surveying.

As OTL effects become increasingly prominent, many global ocean tidal models and regional models have been put forward, laying a solid foundation for more precise studies.

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Using hydro-dynamical interpolation methods, Schwiderski established the first relatively accurate global ocean tide model, the SCHW80, in 1980 with the data of more than 2000 gauge stations [3]. After that, series FES94.1 to FES2004, series GOT00 to GOT4.8, series TPXO.2 to TPXO7.2, NAO99JB, and osu.chinasea.2010 [4] were proposed gradually. These global ocean tide models are precise and similar in calculating OTL displacements of the seafloor. However, they can't provide accurate observation in offshore areas, where the seafloor relieves are complicated. Penna et al. found that for International GNSS Service (IGS) sites, the root mean square (RMS) error is about 3 mm in the vertical direction when using different tidal models, but for some coastal areas (such as the Weddell sea and Antarctic Ross ice shelf) the RMS can be up to 8 mm [5]. Therefore, it is important to improve the accuracy of ocean tide models in coastal areas.

Interferometric Synthetic Aperture Radar (InSAR) is a new technology for earth observation from the space and has been widely used in monitoring, seismic displacement, volcanic eruption, glacial drift, land subsidence and landslide [6–11]. However, OTL's impact was often ignored in processing the InSAR data. Some studies have shown that the OTL displacement in coastal areas can be several centimeters, especially in the vertical direction [12]. And the temporal InSAR can achieve millimeter-level precision, when the long time series InSAR data are available. Hence, the effect of OTL should be considered, especially in coastal areas. And the wide use of ScanSAR also requires the consideration of the deformation caused by OTL in InSAR deformation monitoring. At present, the OTL correction has been used in GPS, Very Long Baseline Interferometry (VLBI) and other high precision space geodesy technology. DiCaprio Christopher J. and Simons Mark have proven that OTL can cause deformation up to millimeters or even centimeters near coastal regions [13]. Rignot considered OTL correction in the research of glacial drifts using InSAR, and gained a good result finally [14]. However, there is very few researches about OTL displacement correction in coastal areas deformation monitoring by InSAR.

In this study, we firstly improve the osu.chinasea.2010 regional model by assimilating data from 60 offshore gauge stations in China, and then compare the results obtained by the improved regional model with those of the tpxo7.2-atlas ocean tide model. Afterwards, we calculate the OTL displacements of some stations in China using the improved regional model. Finally, we correct the deformation obtained by InSAR in Shanghai and Los Angeles, and then compare the results with the displacements of IGS station.

2. Theory of OTL and OTL displacement correction

The tidal loading is computed by the Green's function of ocean loading [15]. The OTL displacements $L(\varphi,\lambda,t)$ is given by

$$L(\varphi,\lambda,t) = \iint_S \rho R^2 H(\varphi',\lambda',t) G(\theta) \sin\varphi' d\varphi' d\lambda' \tag{1}$$

where ρ is the ocean water density, φ is the observation of the calculation point, λ is the longitude of the observation point, φ' is the colatitude of the load point, λ' is the longitude of the load point, $H(\varphi',\lambda',t)$ is the tidal height at (φ',λ'), $G(\theta)$ is the Green's function of mass loading, θ is the angular distance between the observation point and the load point, R is the earth radius [16].

We mainly discuss the displacement in the vertical (UP), north-south (NS) and east-west (EW) directions. The OTL displacement can be written as

$$\begin{aligned} L(\varphi,\lambda) &= [L_{UP}(\varphi,\lambda)\ \ L_{NS}(\varphi,\lambda)\ \ L_{EW}(\varphi,\lambda)]^T \\ G(\theta,A) &= [U(\theta)\ \ V(\theta)\cos A\ \ V(\theta)\sin A]^T \end{aligned} \tag{2}$$

where $V(\theta)$ and $U(\theta)$ are the mass loading Green's functions in the horizontal and vertical directions, which can be written as [17]:

$$\begin{aligned} U(\theta) &= \frac{Rh'_\infty}{2M\sin\frac{\theta}{2}} + \frac{R}{M}\sum_{n=0}^{N}(h'_n - h'_\infty)P(\cos\theta) \\ V(\theta) &= \frac{Rl'_\infty \cos\frac{\theta}{2}\left(1+2\sin\frac{\theta}{2}\right)}{2M\sin\frac{\theta}{2}\left(1+\sin\frac{\theta}{2}\right)} + \frac{R}{M}\sum_{n=0}^{N}(nl'_n - l'_\infty)\frac{1}{n}\frac{\partial P_n(\cos\theta)}{\partial\theta} \end{aligned} \tag{3}$$

Due to the complex submarine topography in offshore areas, observations obtained by global ocean models (such as TPXO7.2-ATLAS model) are low in precision, especially in the Western Pacific regions. Therefore, we employ regional model in this study, which can be expressed as:

$$\begin{aligned} L(\varphi,\lambda,t) = &\iint_{S-\Omega} \rho R^2 H(\varphi',\lambda',t) G(\theta) \sin\varphi' d\varphi' d\lambda' \\ &+ \iint_{\Omega} \rho R^2 H_\Omega(\varphi',\lambda',t) G_\Omega(\theta) \sin\varphi' d\varphi' d\lambda \end{aligned} \tag{4}$$

where Ω is the area, $H_\Omega(\varphi',\lambda',t)$ the tidal height and $G_\Omega(\theta)$ the mass loading Green's function of the interest offshore areas.

There are many non-tectonic deformations in InSAR researches, such as, solid earth tides, pole tide, seasonal and non-seasonal non-tidal loading. Blewitt found that the wavelengths of solid earth tides and pole tide have an order of magnitude greater than ocean tide loading [18]. What's more, we can eliminate solid earth tides and pole tide loading by introducing an additional phase. However, atmospheric loading is similar to ocean loading effects, and atmospheric loading displacements can be centimeter-level [19]. Therefore, we also consider the atmospheric loading effects in this study. As the deformation obtained by InSAR is in line of sight (LOS), but the atmospheric loading and the OTL displacement is positive in the vertical upward direction. The InSAR OTL correction can be expressed in the following formula.

$$LOS_{IOT} = LOS_{INSAR} - (V_{AT} + V_{OTL})/\cos\alpha \tag{5}$$

where LOS_{IOT} is the deformation with OTL correction in the LOS direction, LOS_{INSAR} is the deformation without OTL correction, V_{OTL} is the OTL displacement, V_{AT} is the atmospheric loading, α is the squint angle of SAR satellite. V_{AT} can be expressed by the following formula.

$$V_{AT}(\varphi',\lambda',t) = \iint_s G(\delta) P(\varphi,\lambda,t) ds \tag{6}$$

where $G(\delta)$ is the atmospheric loading Green's function, $P(\varphi,\lambda,t)$ is the average atmospheric pressure of integral area

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