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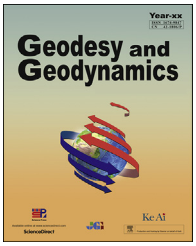

Uncertainty analysis of atmospheric friction torque on the solid Earth

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ABSTRACT

The wind stress acquired from European Centre for Medium-Range Weather Forecasts (ECMWF), National Centers for Environmental Prediction (NCEP) climate models and QSCAT satellite observations are analyzed by using frequency-wavenumber spectrum method. The spectrum of two climate models, i.e., ECMWF and NCEP, is similar for both 10 m wind data and model output wind stress data, which indicates that both the climate models capture the key feature of wind stress. While the QSCAT wind stress data shows the similar characteristics with the two climate models in both spectrum domain and the spatial distribution, but with a factor of approximately 1.25 times larger than that of climate models in energy. These differences show the uncertainty in the different wind stress products, which inevitably cause the atmospheric friction torque uncertainties on solid Earth with a 60% departure in annual amplitude, and furtherly affect the precise estimation of the Earth's rotation.

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1. Introduction

To better understanding of the angular momentum transform between solid Earth and atmosphere, ocean, or land hydrology, the torque method are usually involved in the references [1–5]. Nowadays, the best studied geophysical fluid torque is the atmospheric torque on the solid Earth, while the oceanic torque is only touched by a few researchers (e.g., Fujita et al. [3]), and the land hydrology torque is still not systematically researched at present. For the atmospheric torque on the solid Earth, the studies focus mainly on the

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balance of global angular momentum in the atmospheric data set and Earth rotation, and the relations between meteorological oscillations such as El Nino-Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO) etc. and the regional atmospheric torques, and on the diurnal angular momentum budget changes, etc. [2,6–10]. The atmospheric torques can be dividing generally into mountain torque, friction torque, and gravity wave drag torque.

Mountain torque is a function of pressure and orography, which exerted the solid Earth through a difference in pressure across any raised Earth surface. The most significant mountain torque is locating in the mountains or mountain massifs regions. For example, if the pressure over the west slope of the mountain is stronger than that over the east side, it acts to push the Earth to rotate faster and slows the atmosphere rotation down, which imparting angular momentum from the atmosphere to the solid Earth [5,10]. The friction torque is the wind or oceanic current frictional force on the solid Earth surface, which will directly speed or slow down the rotation of solid Earth. If there is a net global eastward surface wind, the atmosphere wind friction force will speed the solid Earth's rotation up, transfer the atmospheric angular momentum to the solid Earth, and thus the atmosphere loses angular momentum. The gravity wave drag torque is part of the mountain and friction torque that is too small to be resolved by present Global Circulation Models (GCMs), due to the nature of coarse resolution of climate models will not resolve the regional/local mountains and mountain-induced waves, and their contribution to the mountain torque (e.g., Palmer et al. [11]; Egger et al. [4]). For example, mountains usually have very jagged terrain, there can be turbulence and pressure (small spatial physical process of far below GCMs grid size) applied to the mountain that will not be picked up by the GCMs, thus the gravity wave drag torque was introduced as a way to remedy this [5].

For all three torques mentioned above, the most accurate one is the mountain torque, due to the accurate observation of the surface atmospheric pressure can be acquired from surface meteorological stations and GCMs. The last two torques encountered obvious problems. The wind friction stress can not be observed directly in practice, which must be converted from observed wind speed data by using experimental equations with a parameter named as drag coefficient (e.g., Trenberth et al. [12]; Rao et al. [13]). In general, the wind drag coefficient is the function of wind speed and roughness of the Earth's surface. The roughness definition is very difficult in both land and ocean regions. For example, in the land region, the very jagged terrain, unreachable regions with no observations, and time-variable of the true Earth surface due to rain, snow, runoff etc., will inevitably change the roughness of the friction surface, and make the wind drag coefficient change accordingly. In the ocean region, the status does not get better too. The sea surface state is the function of oceanic wave height and duration, atmospheric friction thickness, air-sea temperature difference, relative humidity at the air-sea interface, ocean surface current, oceanic turbulence, and atmospheric stability, etc. (e.g., Kara et al. [14,15]). All these factors will affect the value of wind drag coefficients to be determined accurately in space and time domain, and inevitably make the wind stress conversion prone to be contaminated. For the gravity wave drag torque, due to gravity wave drag stress is the compensation of subgrid-scale orography effects of atmospheric gravity wave, it only can be estimated by parameterization scheme in the GCMs under some hypothesis theories (e.g., Lott and Miller [16]; Zhong and Chen [17]). Though the researches on the gravity wave drag have some progress and used in a lot of GCMs such as European Centre for Medium-Range Weather Forecasts (ECMWF), and National Centers for Environmental Prediction (NCEP) atmospheric models, it suffers unquestionable errors due to limited knowledge about the sub-scale atmospheric dynamics and limited comparison between the realistic investigation and the theory simulations. Furthermore, the non-orography gravity wave drag induced by atmospheric convention etc, is still mysterious for us at some degree and need to be clarified to improve the estimation accuracy of gravity wave drag stress.

In this paper, we will compare wind stress of GCMs and QSCAT satellite observations, and estimate the uncertainty of the wind stress field and draw a picture of these uncertainty effects on the calculation of friction torque on the solid Earth in global ocean region.

2. Method and data

To estimate the uncertainty of atmospheric friction torque, five data sets are used. Three types of 10 m wind speed data acquired from: (1) ECMWF ERA-interim data with 1.5° grid in both latitude and longitude, respectively (http://apps.ecmwf.int/datasets/data/interim_full_moda/); (2) NCEP reanalysis data with 1.875° grid in both longitude and latitude, respectively (http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html); (3) QSCAT satellite observed wind speed with original 0.25° spatial grid (http://www.remss.com/missions/qscat). Due to the friction torque calculation needs wind stress but not wind speed, we transfer the surface 10 m wind data $\mathbf{V}$ to surface wind stress $\boldsymbol{\tau}$ by using experimental equation presented by Trenberth et al. [12], as follow

$$\boldsymbol{\tau} = (\tau_e, \tau_n) = \rho C_d |\mathbf{V}| (u, v) \tag{1}$$

$$10^3 C_d = \begin{cases} 0.49 + 0.065|\mathbf{V}| & \mathit{for} \quad |\mathbf{V}| > 10\ \mathrm{m/s} \\ 1.14 & \mathit{for} \quad 3 \le |\mathbf{V}| \le 10\ \mathrm{m/s} \\ 0.62 + 1.56|\mathbf{V}|^{-1} & \mathit{for} \quad |\mathbf{V}| < 3\ \mathrm{m/s} \end{cases} \tag{2}$$

where $\mathbf{V}$ is the wind vector with west-east component u (positive east) and north-south component v (positive north), $\rho = 1.3\ \mathrm{kg/m^3}$ is the density of dry air, C_d is the drag coefficients which can be calculated from equation (2), and τ_e and τ_n are the average east-west and north-south wind stress, respectively.

Two types of direct model output wind stress data are also acquired from ECMWF interim data and NCEP reanalysis models with the same spatial resolution as the 10 m wind data. All these five wind stress data are then averaged to monthly interval from Jan. 2000 to Nov. 2009. The QSCAT data are available only in the most part of the ocean, thus we mask the NCEP and ECMWF climate model data to the same spatial