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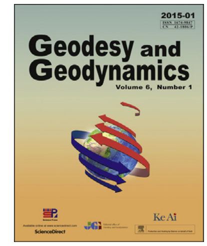

Mathematical model for computing precise local tie vectors for CMONOC co-located GNSS/VLBI/SLR stations☆

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A B S T R A C T

The seven co-located sites of the Crustal Movement Observation Network of China (CMONOC) in Shanghai, Wuhan, Kunming, Beijing, Xi'an, Changchun, and Urumqi are equipped with Global Navigation Satellite System (GNSS), very long baseline interferometry (VLBI), and satellite laser ranging (SLR) equipment. Co-location surveying of these sites was performed in 2012 and the accuracies of the solved tie vectors are approximately 5 mm. This paper proposes a mathematical model that handles the least squares adjustment of the 3D control network and calculates the tie vectors in one step, using all the available constraints in the adjustment. Using the new mathematical model, local tie vectors can be more precisely determined and their covariance more reasonably estimated.

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1. Introduction

Sites equipped with two or more space geodesy instruments such as the Global Navigation Satellite System (GNSS), very long baseline interferometer (VLBI), and satellite laser ranging (SLR), are called co-located sites, which are essential for connecting diverse space geodetic techniques via local tie vectors for computing the International Terrestrial Reference Frame (ITRF) [1]. A local tie vector is a 3D baseline vector between the reference points (RPs) of two telescopes [2,3]. An RP is the perpendicular intersection point of the primary fixed axis and secondary axis of a telescope [4], which can be approximately regarded as the geometric rotation center of an SLR or VLBI telescope, or the antenna reference point (ARP) of a GNSS antenna [5]. To determine the RP of an SLR or VLBI telescope, targets mounted on the telescope need to be measured during rotation sequences around the primary and secondary axes. Methods for computing RPs using a target's observed coordinates are found in references [2,3,5–7].

The 7 co-located sites of the Crustal Movement Observation Network of China (CMONOC) are shown in Fig. 1. All the sites are equipped with GNSS instruments; the sites in Shanghai, Kunming, Beijing, Xi'an, Changchun, and Wuhan are also equipped with SLR instruments, and the sites in Shanghai, Kunming, and Urumqi are equipped with VLBI instruments. The tie vectors at Shanghai, Wuhan, and Beijing were measured several years ago [8–12]. To measure the targets fixed on the SLR and VLBI telescopes, at least two and four control points, respectively, are required and these were determined by first establishing a 3D control network. A precise terrestrial survey of CMONOC co-located sites was performed from September to November 2011 using both GNSS and conventional terrestrial measurements, and details of the field work can be referred from Gong [5].

In their tie vector solutions, Gong [5] and Ma [13] implicitly assume that the primary axis of a VLBI or SLR telescope intersects with and is perpendicular to its secondary axis, the deflection of the vertical can be neglected when computing the rotation center, and the rotation centers around the primary axis of different targets fixed on a telescope have the same horizontal coordinates, while those around the secondary axis have the same vertical coordinates. Besides, the least squares adjustment of the 3D control network and the determination of the RP were performed separately, and some conditions such as the distance between two targets not being changed during rotation of the telescopes were neglected. Moreover, Gong [5] also assumed that the coordinates of the rotation centers of different rotation circles were independent. Since these assumptions cause approximately 3 mm of error on the solved tie vector [3], this paper introduces a new mathematical model for obtaining precise local tie vector solutions.

2. Mathematical models for solving CMONOC local tie vectors

The GNSS vectors of the 3D control points were computed using GAMIT v10.35 and Bernese v5.0 Software, which use the absolute phase center variation models. Then, the 3D GNSS vectors, the terrestrial observations of the control network, and the target points were solved together in Gong [5] and Ma [13] using the 3D least squares adjustment by fixing the IGS stations as the initial values. Therefore, the 3D coordinates of all the target points were derived in the 3D adjustment. Since each target rotating around an axis forms a plane circle, it gives rise to two constraining conditions [14–16]:

$$a\overline{x}_i + b\overline{y}_i + c\overline{z}_i + d = 0 \tag{1}$$

and

$$(\overline{x}_i - u)^2 + (\overline{y}_i - v)^2 + (\overline{z}_i - w)^2 = r^2 \tag{2}$$

where a, b, c, d denote the parameters forming a plane, u, v, w are the coordinates of the rotation center and r is its radius,

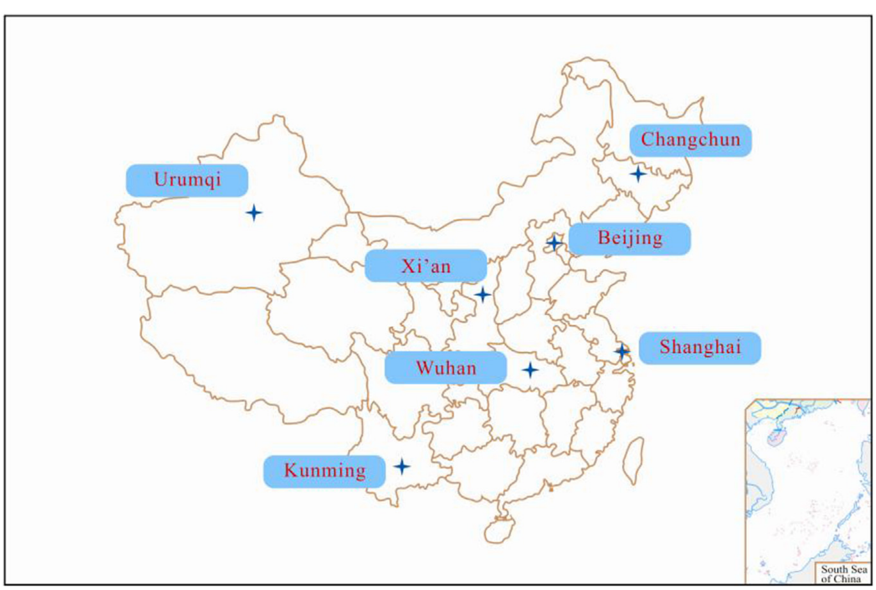

Fig. 1 – Locations of seven co-located sites in China.