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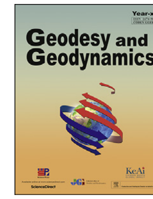

Application of time series modeling to a national reference frame realization

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This paper presents an option for modern dynamic terrestrial reference system realization in Uzbekistan for user needs. An additive model is explored to predict patterns of time series and investigate means of constructing forecast time series models in the future. The main components (trend, periodical, and irregular) of the KIUB (DORIS) and KIT3, TASH, MADK, and MTAL (GNSS) international station coordinate time series were investigated. It was shown that seasonal nonlinear trends occurred both in the height (U) component of all stations and the east (N) component of high mountainous stations such as MTAL and MADK. The seasonal periodical portion of the time series determined from the additive model has a complicated pattern for all sites and can be explained as both hydrological signals in the region and improvement of observational quality. Amplitudes of the best-fitting sinusoids in the North component ranged between 1.73 and 8.76 mm; the East component ranged between 0.82 and 11.92 mm; and the Up component ranged between 3.11 and 40.81 mm. Regression analysis of the irregular portion of the height component of the two techniques at the Kitab station using tropospheric parameters (pressure and temperature) was confirmed as only 57% of the stochastic portion of the time series.

1. Introduction

Uzbekistan is on the Asian continent in the basin of the great Amudarya and Syrdarya rivers. It is in a desert subtropical zone, surrounded by the Turan Lowland to the west and mountainous highlands to the east. The natural environment of the Republic of Uzbekistan is characterized by high seismic conditions. The country's territory, lying atop the Eurasian/Indian plate boundary, is subject to ground movements throughout the country of 3–5 cm/year, disregarding the effects of large earthquakes [1]. This amounts to up to 2 m in the years since the static non-geocentric datum Coordinate System of 1942 (CS-42) was established. The adjustment of the State geodetic network confirmed regional deformations of 10 m or more [2]. With significant improvements in positioning technology now enabling centimeter-level positioning capability via space geodesy methods such as the Global Navigation Satellite System (GNSS), the need to modernize the geodetic datum is inevitable. Terrestrial Reference Frame (TRF) realizations represented by precise coordinates of the Continuously Operation Reference Station (CORS) network are derived from space geodesy techniques at both a global and regional scale [3]. The improvement in International TRF (ITRF) accuracy and stability not only benefits scientific studies at a global scale, but also provides a stronger framework for precise (centimeter-level) GNSS-enabled positioning for national or regional datums. With the purpose of improving the national geodetic reference frame, the new State Geodetic network (SGN), based mainly on using the GNSS measurements, is now established in Uzbekistan [4]. This project plans to establish and maintain a CORS network of 50 reference stations throughout the country. The network station positions will be regularly calculated and updated and data will be made available to the international community [5]. At present, CORS includes both permanently working points and passive points. A modern national reference frame will be a realization of ITRF on a fixed epoch using the methods of optimal data fusing and defining a regional deformational model.

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GNSS measurements provide possibilities to establish a dynamic TRF, represented by a stations motion model, which allows calculation of future and past values of coordinates [6]. For constructing a forecast model of station coordinate time series the behavior (linear, periodical) of the station coordinates should be explained via time series analysis. Permanent station time series include various types of signals, such as miss-modeled errors, effects of observational environments, random noise, or any other effects produced by analysis software and settings of prior stochastic models. Different data analysis to the station time series sought to extract useful signals, such as crustal deformation and seasonal variations in station dynamics [7]. The latest version of the ITRF (ITRF2014) is generated with an enhanced modeling of nonlinear station motions, including seasonal (annual and semi-annual) signals of station positions and post-seismic deformation (PSD) [8]. The autoregressive (AR) and autoregressive moving average (ARMA) techniques of GNSS time series analysis has been applied for crustal deformation studies in Japan [9]. Noise analysis of coordinate times series is considered in [10]. The annual signals have been estimated using the least squares estimation (LSE) with an assumption of the stationarity of amplitude and phase, and uncertainties were calculated with the colored noise using the First Order Gauss Markov model for the Polish network [11].

In this study, we present an additive model for the Uzbekistan CORS GNSS network station (Kitab, Tashkent, Maidanakm and Maidantal) time series construction. Regular, seasonal, and irregular components were estimated based on the model. A comparison of GPS and DORIS results for the Kitab station was performed for the periodical and irregular portion of the time series.

2. Data and method

Stations at Kitab, Tashkent, Maidanak, and Maidantal were installed in Uzbekistan in a framework of different successful international geodynamic projects such as International GNSS Service for Geodynamics(IGS), International DORIS Service (IDS) and Central Asia Water (CAWa) during the period 1991–2016 (Table 1) [12–14].

The analysis of time series components was based on the following data:

- The series of weekly geocentric coordinates of the KIT3 and TASH station time series were processed at the German Research Centre for Geosciences (GFZ) using the EPOS.P8 software and the IGS second Data Reprocessing Campaign (IGS REPRO2) solution. Some improvements were implemented in the latest software version: the reference frame IGb08 based on ITRF2008, antenna calibration igs08.atx, geopotential model (GPT2), and the Vienna Mapping Function (VMF) [15,16].
- The KIUB DORIS time series of station positions used in the present study were the grgwd40 solution in STation Coordinate Difference (STCD) format, which was provided by the CNES/CLS Analysis Center [13] using the GINS/DYNAMO software package [17] and available on the IDS web site at [18];
- Processing of the MADK and MTAL station data [19] was performed using GIPSY/OASIS II software package developed by the Jet Propulsion Laboratory. The strategy of the precise point positioning (PPP) [20] had been applied for analyses of GPS measurements, with the use of utility gd2p.pl (GNSS data to position) of the software. The models and standards used for the processing correspond to the International Earth Rotation and Reference Systems Service (IERS) standards 2010 [21]: the ocean tidal models, solid Earth tides, troposphere model GPT2 [22], an ocean load pole tide model for station position, using second order ionosphere correction (IRI2021 model), troposphere horizontal gradients stochastically estimated with the use of the "random walk" strategy, elevational angle for ground site 7°, receiver's phase center variations accounted for using the IGS "ahtex" file [23], transmitter clock parameters and GPS orbit fixed to the precise ephemeris and clock corrections, produced at the JPL with the use of IGS/FLINN.

Table 1
Stations in Uzbekistan.

Station	Location	North (N) East (E) Up (U, m)	Period of work	Project
KIT3	Kitab	39° 08′ 05″0.16 66° 53′ 07″0.61 622.49	Since 1994	IGS
KIUB	Kitab	39° 8′ 5″0.0 66° 53′ 7″0.4 624.4	1991–2016[a]	IDS
MADK	Maidanak	38 °40′ 25″0.57 66° 53′ 48″0.71 2551.33	Since 2012	CAWa
TASH	Tashkent	41° 19′ 40″0.98 69 °17′ 44″0.05 439.70	Since 2001	IGS
MTAL	Maidantal	41° 59′ 47″0.65 70 °38′ 18″0.03 1445.68	Since 2014	CAWa

[a] Since 2016, because of technical reasons, DORIS was removed in place of Kitab (the new acronym is KIVC). Additionally, the station was equipped with a new GNSS receiver of REGINA (REseau Gnss pour l'Igs et la Navigation).

All data were expressed in the local geodetic reference frame (N: North component, E: East component and U: Vertical component). Because the time series had different time intervals of measurements and data availability (Table 1), the change in the observed series $S(t_i)$ was acquired assuming that $S(t_1) = 0$ for the time initiation of t_i $(i = 1)$.

We considered in this research an additive model, in which each time series component $S(ti)$ obtained in the observational times ti $(i = 1, 2, 3, \ldots, N)$ had three components: trend $T(t_i)$ - long term movements in the mean; periodical $C(t_i)$ – cyclical fluctuations related to seasonal changes; and stochastic $E(t_i)$ – other random or systematic fluctuations [24], as follows:

$$S(t_i) = T(t_i) + C(t_i) + E(t_i) \tag{1}$$

The trend and seasonal component are described using a decomposition procedure that can be conducted over several steps. Long-term changes (the trend) are used to determine the station movement (or velocity) and can be modeled by the m-order polynomial function as follows:

$$T(t_i) = \sum_{k=0}^{m} a_k t_i \tag{2}$$

where a_k $(k = 1 \ldots. m)$ are the parameters depending on the order of the polynomial function and estimated using the Least Squares Method (LSM).

Detrended time series analysis was followed by seasonal component analysis. Annual seasonal variations and their harmonics are usually described as follows:

$$C(t_i) = \sum_{s=1}^{p} [A_i \sin(\omega_i t + \varphi_i)] \tag{3}$$

where $\omega = 2\pi$ rad/year is the angular velocity of one year and A and φ are the amplitude and phase shift, respectively. A major component

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