Arabian Plate Motion Using KACST's GNSS Network; A first results

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King Abdulaziz City for Science and Technology (KACST) has established, in 2016, a recent network of Continuous Operating Receivers (CORS) distributed all over Saudi Arabia, except the southern Empty Quarter. This network was designed to serve many scientific applications; Geodetic Reference Frame, plate motion, ionospheric studies, deformations, etc... It consists of 16 CORS stations connected to a common data center in Riyadh, via dedicated Access Point Name APN. In this paper we show the first KACST results of the Arabian plate motion estimated from this CORS network.
Global Navigation Satellite Observations (GNSS) data from 12 stations spanning about three years (from 2016 to 2018) has been collected and processed with Bernese Software V5.2 using The Center for Orbit Determination in Europe (CODE) products. Data from 24 IGS stations has also been included in the processing for frame definition. The data processing was done in the form of daily sessions and free normal equation systems were generated for all days. Daily datum-free normal equation systems were transformed to the geodetic datum determined by IGS stations in ITRF2014 reference frame and the coordinate time series (north, east and up) for the stations were obtained. The coordinate time series of each point were analyzed separately and the effects on coordinate changes with time were modeled. The functional model includes outliers detection, discontinuities, one or more linear velocities, and a set of periodic components. Proper modelling of these effects is of great importance for the reliability of the estimated velocity components. Hence, all parameters of the model (discontinuities, velocity changes, periodic functions and outliers) are statistically tested for their significance. The initial results of the network show that stations velocities are changing between 26-30 mm/year for the north component and 26-35 mm/year for the east components. Finally, the estimated station velocities and Arabian plate motion is compared with the previous studies.

Key words: KACST; GNSS, ITRF2014, Bernese

Introduction:

Arabian plate is located in Arabian plate motion has seen becoming an issue for scientists due to its important and its relation to global tectonic motion. it is known that Arabian plate motion is countering a northeastern counter clock wise motion. The Arabian plate is moves in northeast with the rate of about 49 mm/yr in absolute sense. There is a need to observe and model precisely the Arabian plate motion. The Arabian plate is bounded by the Red sea in the west to the Arabian Gulf

and Taurus mountains (Turkey) in the north, Gulf of Aiden in the south, and Zagros (Iran) in the east. In the west of the Arabian plate, there is a fault within the Red Sea where earthquakes and volcano activities are occurred. These activities are of small magnitude and continuously happening during the last thousands of years. Geologists describe the Arabian plate as non-stable having the faults and volcanic formation in the west, see Figure 1. Some researches indicate that the rotation rate of the Arabian plate relative to the adjacent plates (Eurasia and Africa) could reach the range of 20-30 mm/yr counterclockwise (Reilinger R., et al., 2006), see Figure 2. Furthermore, intra-plate deformation may occur in some places of the plate due to these activities and need to be modeled.

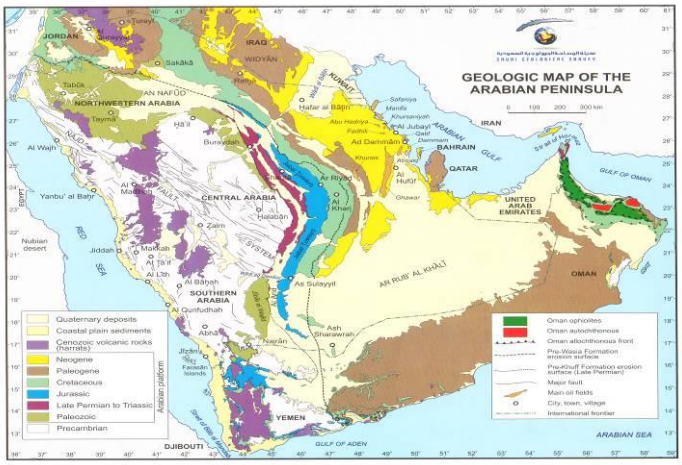
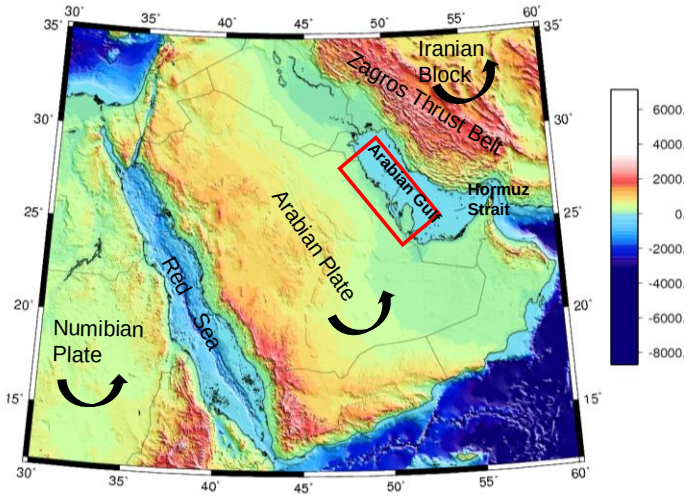


Figure 1: Geologic Map of the Arabian Peninsula



Reilinger et al (2006)

Figure 2: Motion of the Arabian plate w.r.t. adjacent plates.

Nowadays, Global Navigation satellite System GNSS is becoming a precise tool for evaluation and modelling the plate motions. This is due to the increase number of long time span observations from GNSS stations located over the continents. In 2015, King Abdulaziz City for Science and Technology KACST, has established a Continuous Operating Receivers CORS network consisting of 16 stations. These stations are distributed along Saudi Arabia and located in the main cities, see Figure 3. The aim of this network is to support the scientific research in the country in the geodesy, tectonics, geophysics, … etc. This is to keep the continuity of KACST's contribution to the scientific communities regionally and globally, especially the cooperation with the International GNSS Services IGS, which has been started since 2002 by establishing the 8 IGS sites in Saudi Arabia; NAM, HALY, SOLA, RASH, TAYS, FRSN, JIZN, and ALWJ. Although these eight stations were disconnected in the past few years, there is a plane to have them back this year.

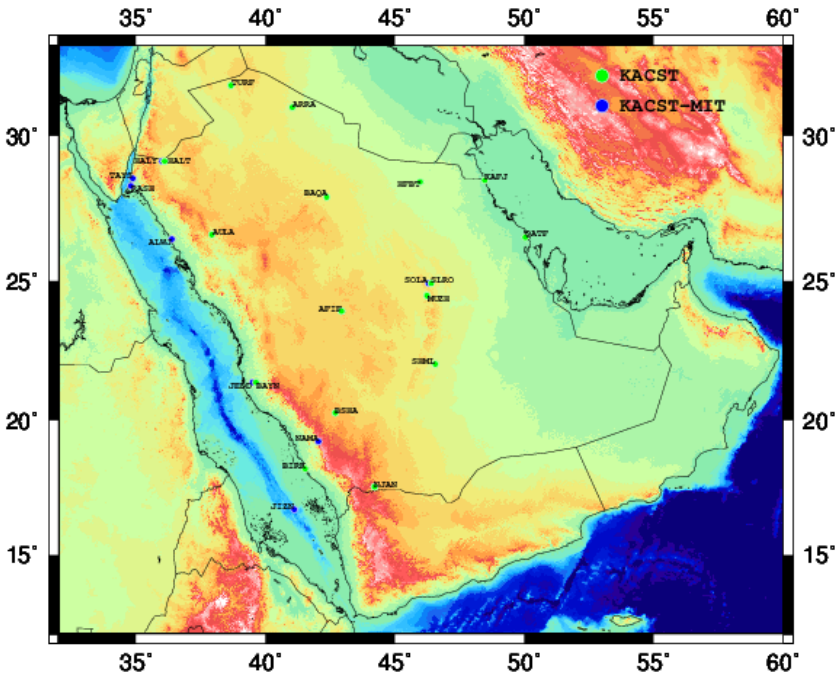


Figure 3: Location of the 16 CORS established recently by KACST.

The Arabian plate extends from the Red sea in the west to the Zagrous Mountains in the east, and from the Gulf of Aden in the south to the Taurus Mountains in the north. Its formation includes later volcanic in the west and marine and continental sediments in the east (Reches and Schubert, 1987). The geological setting of Riyadh region is sedimentary section belongs to the Arabian continental shelf deposits (Vaslet et al., 1991). Riyadh SLR site is generally stable since the internal deformation of the Arabian plate is small (i.e. ~1mm/year) and below the capabilities of geodetic observations (ArRajhi, A., et al., 2010), since it is located in the interior of the Arabian

plate where traces of late deformation are unexpected (Alkadhi and Hancock, 1980). The Arabian plate is located in a region of complex tectonics including the effects of adjacent four major tectonic plates, Arabia, Nubia, Somalia, and Eurasia. The associated velocity due to the interaction of these plates reveals that the Arabian Peninsula is experiencing a rapid motion of about 20 to 30 mm/yr counterclockwise (Reilinger, et al., 2006; McClusky et al. 2000). Based on geodetic measurements, the current motion of the Arabian plate is described, by some researchers as slow motion (McClusky et al. 2000; Vigny et al. 2006). Recent estimates using Satellite Laser Ranging SLR data (Alothman and Schillak 2013) has shown that the motion is in a good agreement with ITRF2008 velocity, geological model NNR NUVEL1A and with recent GPS estimates. This study has shown that the velocities were 29.1±0.2 mm/yr, 31.6±0.2 mm/yr, and 1.9±0.3 mm/yr in the North, East and vertical directions, respectively, with a horizontal and 3D velocity 42.9±0.2 mm/yr and azimuth 47.4±0.8 arc degrees. Also, Alothman et al., 2016 has shown that angular velocity of the Arabian plate motion was about 0.5188°/Myr, and is consistent with other models, in particular the GEODVEL geodetic model and the MORVEL geophysical model using a multi-year analysis of GNSS.

GNSS Data and Processing

Global Navigation Satellite Observations (GNSS) data have been collected from 12 Continuous Operating Receivers CORS, distributed all over the Kingdom, with spanning time about three years (from 2016 to 2018). The data has been processed with Bernese Software V5.2 (Beutler et al., 2007) using the Center for Orbit Determination in Europe (CODE) products, available at http://www.aiub.unibe.ch/download/CODE.

Data from 24 IGS stations distributed around the study area, has also been included in the processing for frame definition. These stations are : ANKR, ARTU, DRAG, IISC, KIT3, MAL2, MAS1, MATE, MBAR, NICONKLG, NORT1, POL2, POLV,POTS, REUN, SUTM, TEHN, YAR2, YIBL, ZECK, ZIM2, ZIMM. Processing strategy has been adopted to fulfill the requirements of modelling plate motion. The data processing was performed in daily sessions and free normal equations have been generated for all days of observations. Then, the daily datum-free normal equation systems were transformed to the geodetic datum determined by IGS stations in ITRF2014 reference frame and the coordinate time series (north, east and up) for the stations were calculated. The time series of the coordinates station were analyzed separately to model the effects on coordinate changes with time. The functional model includes outliers detection, discontinuities, one or more linear velocities, and a set of periodic components. Proper modelling of these effects is of great importance for the reliability of the estimated velocity components. Hence, all parameters of the model (discontinuities, velocity changes, periodic functions and outliers) are statistically tested for their significance. The resultant velocities are shown in Figure 4.

The initial results of the network show that stations velocities, in the north and east directions, are ranging between 26-30 mm/year for the north component and 26-35 mm/year for the east components. The computed time series for the coordinates in North, East, and Up directions are shown in Figure 5. Finally, the estimated station velocities and Arabian plate motion is compared with the previous studies. Comparison with previous estimates, e.g. (Alothman et al., 2016) reveals

that estimates are consistent and the Arabian plate motion is continuing within it's previous velocity in the past decade. The maximum annual velocity in the east direction is shown at BIRK and BSHA which might be an evident of the opening of the Red sea as these stations located south in the Arabian Peninsula. The maximum velocity in the north direction is at QATF.
Comparison between the velocity of SALRO and previous estimates was investigated and shown in Table 2. The annual vertical estimates of BAQA station, in the north, is the largest deformation among other sites, which is suggesting that this site is experiencing a large regional uplift motion. This can be investigated later by comparing more nearby stations and including longer time span.
Another comparison ha been made to evaluate the estimated velocity of SOLA/SLRO site computed in this study and some previous estimates; Alothman et al., 2016 (using GNSS observations) , Alothman and Schillak 2014 (using Satellite LASER Ranging Observations SLR), and estimates from the Scripps Orbit and Permanent Array Center SOPAC, University of California, San Diego, which is available at: http://sopac.ucsd.edu/map.shtml

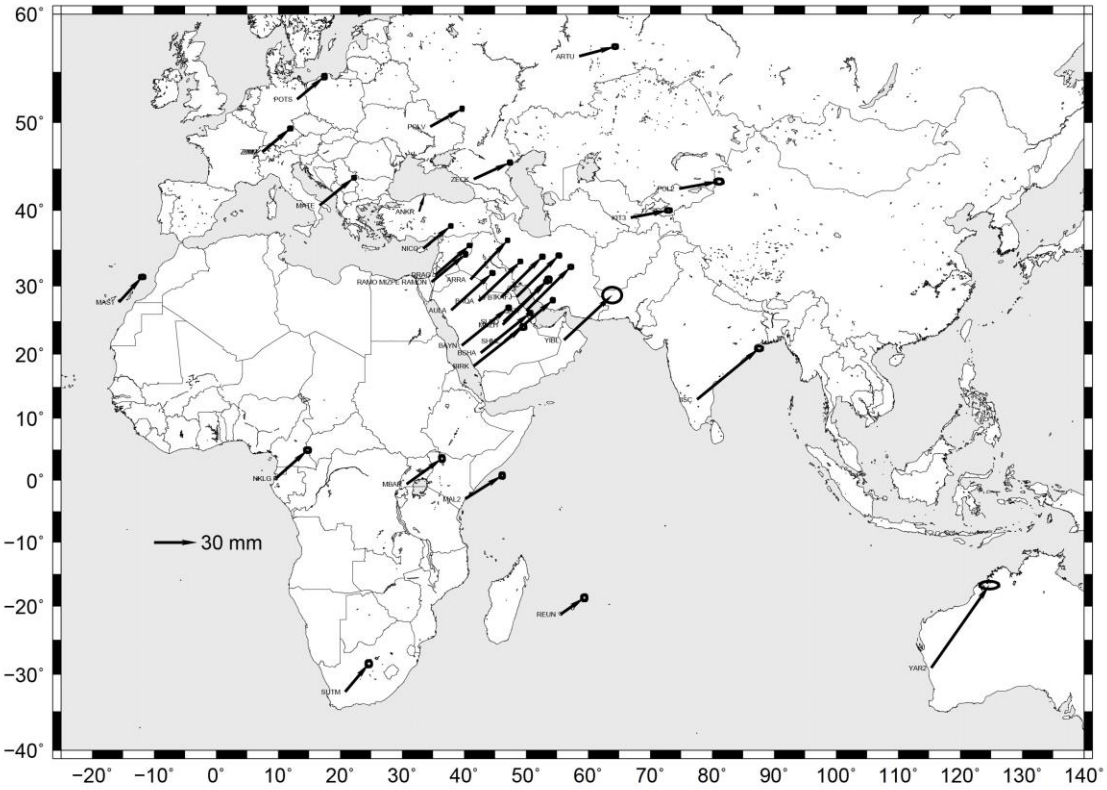
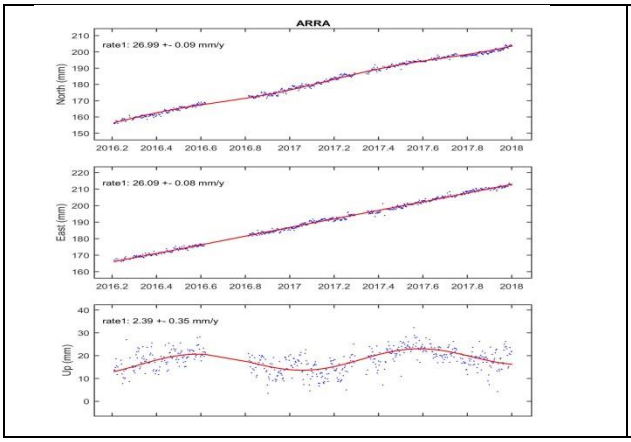
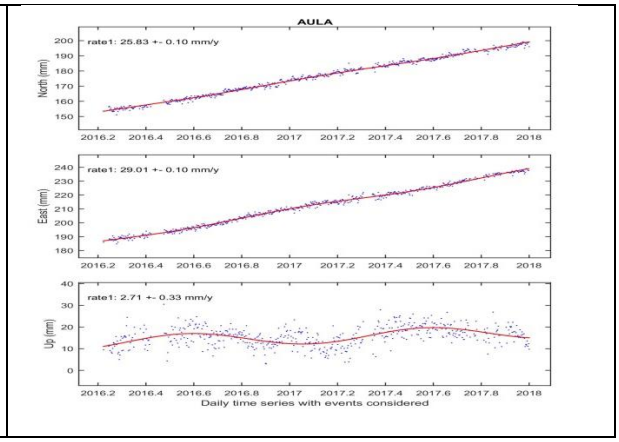


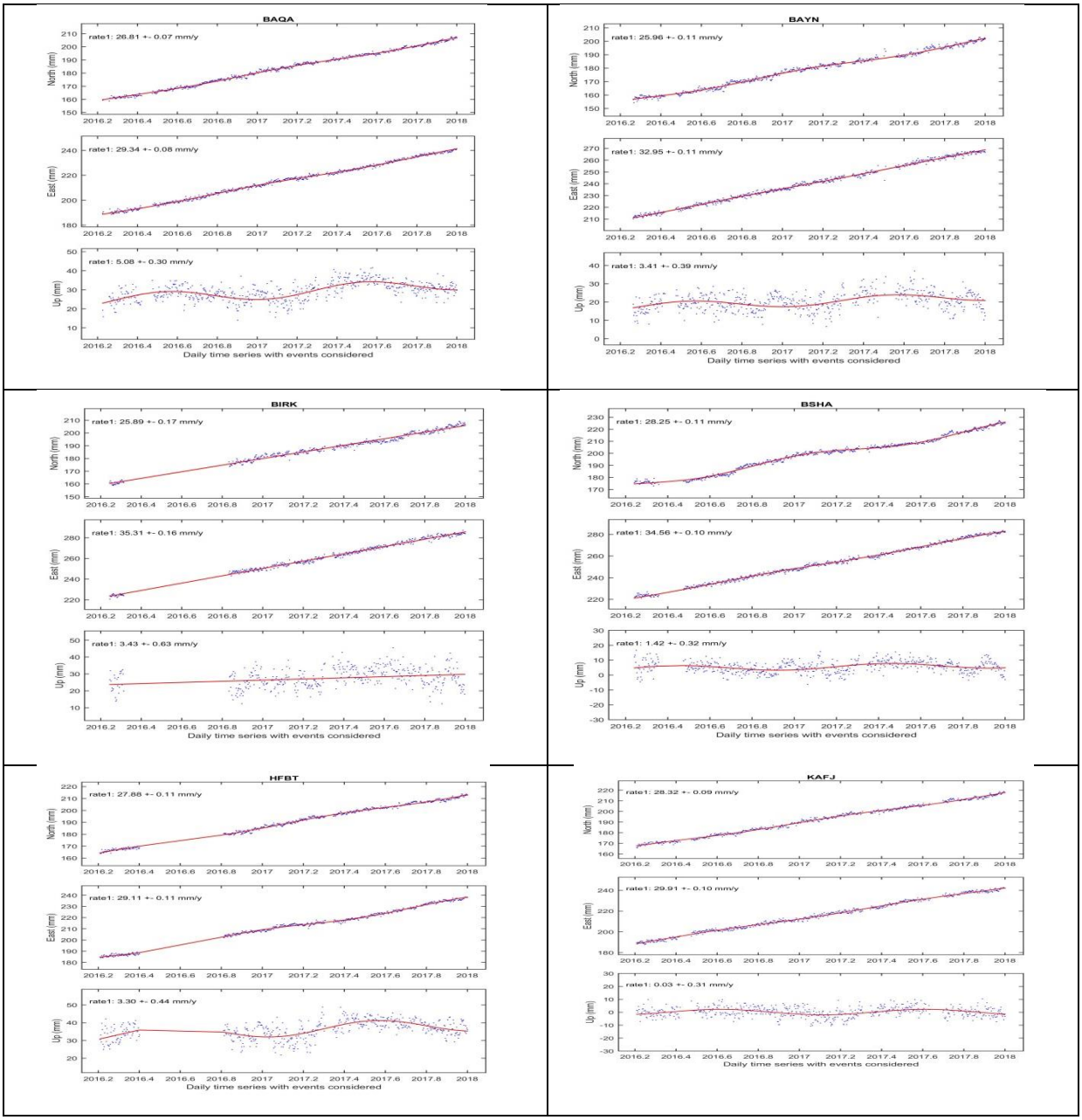
Figure 4: The estimated velocities of all stations used in the study.

Table 1; Estimated velocities, (North, East, and Up) and their standard deviations, for KACST'S GNSS stations.

Station	N m/y	s.d.	E m/y	s.d.	Up m/y	s.d.
ARRA	0.02699	±0.00009	0.02609	± 0.00008	0.00239	± 0.00035
AULA	0.02583	± 0.00010	.02901	± 0.00010	0.00271	± 0.00033
BAQA	0.02681	± 0.00007	0.02934	± 0.00008	0.00508	± 0.00030
BAYN	0.02596	± 0.00011	0.03295	± 0.00011	0.00341	± 0.00039
BIRK	0.02589	± 0.00017	0.03531	± 0.00016	0.00343	± 0.00063
BSHA	0.02825	± 0.00011	0.03456	± 0.00010	0.00142	± 0.00032
HFBT	0.02788	± 0.00011	0.02911	± 0.00011	0.00330	± 0.00044
KAFJ	0.02832	± 0.00009	0.02991	± 0.00010	0.00003	± 0.00031
MUZH	0.02916	± 0.00009	0.02932	± 0.00011	-0.00043	± 0.00029
QATF	0.02996	± 0.00011	0.03142	± 0.00012	0.00126	± 0.00040
SHML	0.02825	± 0.00011	0.03394	± 0.00010	0.00197	± 0.00031
SLRO	0.02624	± 0.00019	0.03219	± 0.00019	0.00028	± 0.00070






BAQA
rate1: 26.81 +- 0.07 mm/y
rate1: 29.34 +- 0.08 mm/y
rate1: 5.08 +- 0.30 mm/y
North (mm)
East (mm)
Up (mm)
Daily time series with events considered
BAYN
rate1: 25.96 +- 0.11 mm/y
rate1: 32.95 +- 0.11 mm/y
rate1: 3.41 +- 0.39 mm/y
Daily time series with events considered
BIRK
rate1: 25.89 +- 0.17 mm/y
rate1: 35.31 +- 0.16 mm/y
rate1: 3.43 +- 0.63 mm/y
Daily time series with events considered
BSHA
rate1: 28.25 +- 0.11 mm/y
rate1: 34.56 +- 0.10 mm/y
rate1: 1.42 +- 0.32 mm/y
Daily time series with events considered
HFBT
rate1: 27.88 +- 0.11 mm/y
rate1: 29.11 +- 0.11 mm/y
rate1: 3.30 +- 0.44 mm/y
Daily time series with events considered
KAFJ
rate1: 28.32 +- 0.09 mm/y
rate1: 29.91 +- 0.10 mm/y
rate1: 0.03 +- 0.31 mm/y
Daily time series with events considered

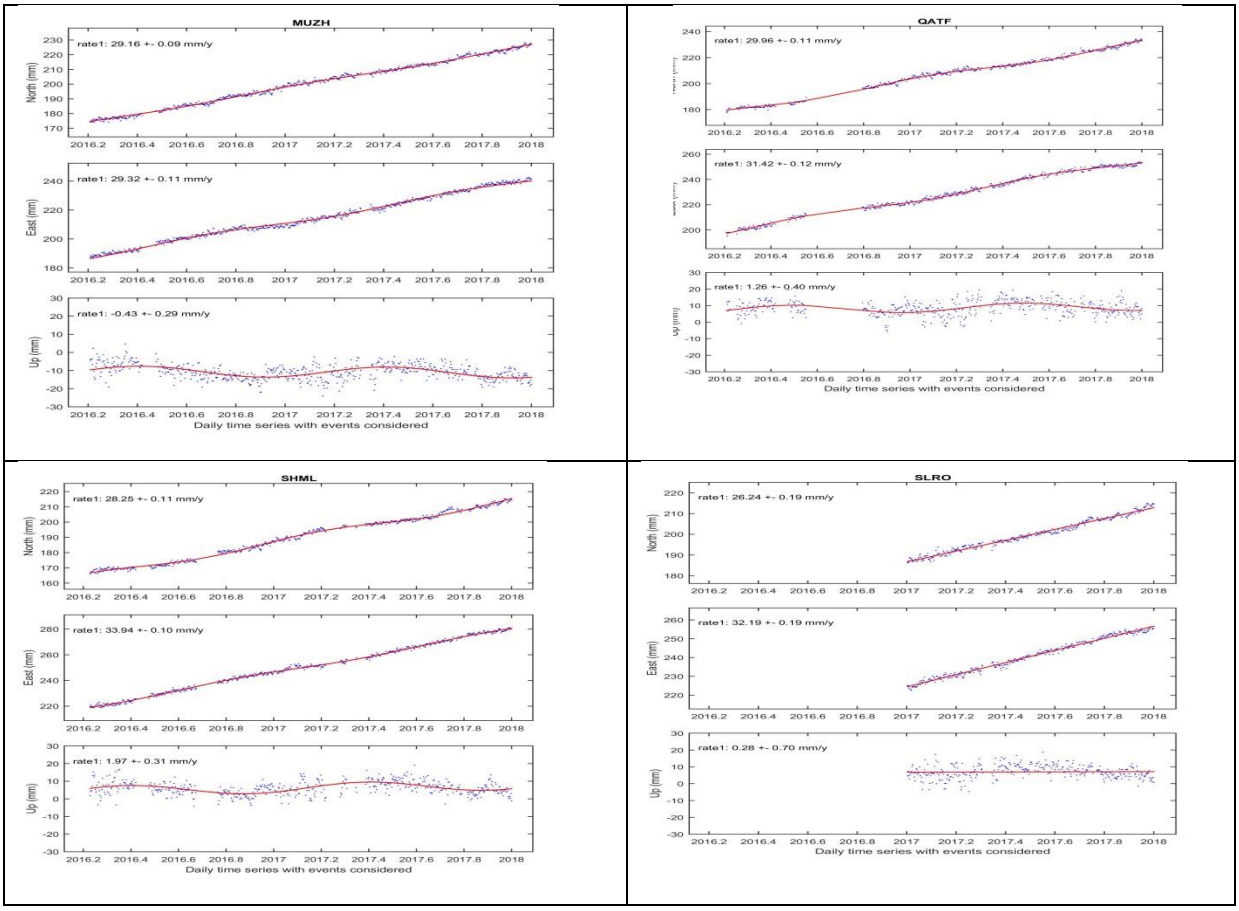


Figure 5: Time series of the North, East and Up components of the 12 CORS stations used for modelling the Arabian plate motion.

Table 2 – Comparison of GNSS stations velocities of SOLA/SLRO site computed in this study and previous estimates; Alothman et al., 2016, Alothman and Schillak 2014, and SOPAC.

	This study	**Alothman et al., 2016**	**Alothman and Schillak 2014**	**SOPAC**
VNorth (mm/yr)	26.2 ± 0.2	28.6±0.6	29.1±0.231.6±0.2	28.8±0.5
VEast (mm/yr)	32.2 ± 0.2	31.2±0.7	31.6±0.2	31.9±0.4

Conclusion

Arabian plate motion has been estimated using KACST's CORS GNSS stations. The computed horizontal velocities were found to be between 26-30 mm/year for the north component and 26-35 mm/year for the east components. Although the rime span of observations was not so long, but the results have shown that the Arabian Plate is still moving within it's previous estimates (in one decade). Comparison of the velocity of SOLA IGS site which is located in the center of the Arabian Plate has shown a general agreement between different estimates using GPS and SLR observations. Investigation of the vertical motion reveals that BAQA site in the north of Arabia is experiencing a regional large uplift.

Further investigation of the motion could be made after having longer time span of GNSSS observations of KACS's CORS network. Also, more stations from the new established CORS in KSA will strengthen the study.

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