GNSS application trends in Central Asia

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SUMMARY

Advanced Global Navigation Satellite Systems (GNSS) have being used intensively in the Central Asian region in the last years. The former Soviet Union countries: Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan, have used the common ellipsoids and coordinate systems in the last century. They have different policies and activities on reforms in the geodesy and cartography fields in the last decades. Implementation of the global satellite positioning by replacing traditional survey technologies has created challenging issues related to the establishment of GNSS reference networks, implementation of the local geodetic datums, new coordinate systems and international collaboration. The present situation with different applications, such as land management, Geoinformation systems, engineering, transportation, geodynamic and environmental studies, and trends of GNSS technology in the four countries of the region are considered and analysed in this work.

Key words: GPS, GNSS, Geodetic Networks, Reference Stations, Central Asia

1. INTRODUCTION

The Global Navigation Satellite Systems (GNSS) have been used for solving the wide range of positioning tasks in land cadastre and urban mapping, engineering survey, construction and transportation, geodynamic studies, military and other applications. The different methods of global satellite positioning and navigation allow achieving position accuracy down to the millimeter level. Applied use of these systems gives significant economic efficiency on geodetic works worldwide by reducing the required resources and time. The geodesy science and technologies have experiencing dramatic changes created by real time and long term precise measurements by using GNSS technologies (Seeber, 1993). The combination of satellite navigation, internet, wireless communication and geoinformation technology is perfect mix on contemporary technologies. Integration of these advanced technologies launched many new applications, which could not be imagined before.

The five former Soviet Union Republics in Central Asia: Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan, became sovereign countries in the early 1990s (Fig.1). The economic and social levels of these countries have been similar at the beginning of the new century having many common parameters and conditions in the socio-economic and technological development. But, the different levels of natural resources, demographic, political and social development factors have influenced the diverse levels of their socio-economic development.

Fig.1. Central Asia

The present situation related to the use for contemporary satellite geodesy needs analyzing of the problem statement and emerging tasks in order to implement the contemporary technologies and international reference frames. The study area includes Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan, such as available research data on the current situation in Turkmenistan is very limited. These countries have a very close economic and political cooperation, joint energy, irrigation, transport and communication systems. They have started developing national policies on wider use of GPS/GNSS technologies and this study is dedicated to investigation and analysis the present trends in the region in order to contribute to the development, transborder cooperation and unification of the reference systems and local datums.

2. TRADITIONAL REFERENCE ELLIPSOID AND COORDINATE SYSTEMS IN THE STUDY AREA

Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan as well as other republics of the former Union of the Soviet Socialist Republics (USSR) recently have used the common ellipsoid and coordinate systems. The latest local reference ellipsoid developed in 1940 as a result of the large scale geodetic measurements by soviet geodesists and astronomers leaded by Prof. Feodosi Nikolaevich Krasovsky and was named after him as Krasovsky 1940. All paper based topographic maps, which are still in use in the former soviet territory and some of other neighboring countries, are based on Krasovsky Reference Ellipsoid. Its main parameters are:

- Larger semi-axel a=6 378 245 m,
- Flattening f=1/298.3.

The main cartographic projection used in the Central Asian region was the Gauss-Kruger projection with 6^o and 3^o zones. The main Datum, Geodetic and Cartesian coordinates were Pulkovo 1942 (SK-42), based on the ellipsoid Krasovsky 1940. There are other coordinate systems used in the Soviet Union as Pulkovo 63, SK-90 etc., but Pulkovo 42 has been used as a base for all other following reference systems. The altitude system of the region has been based on the Baltic Sea with a zero-level Kronshtadt tide gauge (Yakovlev, 1989).

The State Geodetic Networks (GGS) of the Central Asian countries were parts of the former USSR's net. Its regional part was based on the first Central Asian geodetic net realized in 1885-1946 based on the ellipsoid Bessel 1841. The next GGS in the region was developed in 1946-1988 within the State program developed by Prof. F. Krasovsky following the

"Fundamentals of Construction of the State Geodetic Network of USSR" issued in 1954 and 1961 on the ellipsoid Krasovsky 1940. Its class 1 network has chains of approximately equilateral triangles with sides of 20-25 km located roughly in the direction of the Earth's meridians and parallels at intervals of 200-250 km with 800-1000 km perimeter. The area that bordered by the class 1 triangulation chain is covered with solid nets of class 2 triangles with sides of about 10-20 km. The network of geodetic points can be made more dense by construction of class 3 and class 4 triangles.

The levelling network of the USSR had 4 classes: I, II, III and IV. I class levelling is done by specially marked lines that form closed polygons with a perimeter of about 1 600 km done with the greatest precision. Thus, for class I lines the random error of levelling is not greater than 0.5 mm, and the systematic error is only 0.08 mm per kilometre of the levelling line. The class II levelling network is constructed of lines laid along railroads, highways, unpaved roads, and large rivers in the form of closed polygons with perimeters of about 600 km. Differences in elevation for class II levelling lines are determined with a mean random error of not more than 1 mm and a systematic error of not more than 0.2 mm per kilometre of the levelling line. Class I and class II levelling networks are made more dense by class III and class IV levelling lines (Instruction, 1961).

The State Gravimetric Network of USSR (Fundamental and I, II, III classes) was designed for determination of the highly precise weight at the selected control points in order to provide: vertical gradient correction, determination of the altitude system, determination of the geoid and quasigeoid and applied use, mainly in the geophysical studies. (Program of investigation at SFGN Points, 1980). With GNSS technology, geoid determination gains great importance in vertical positioning. GNSS provides altitudes in an altimetry system different from the system that includes altitudes obtained by the levelling classical methods. There is an emerging need in more accurate geoidal mapping, since the coordinate transformation accuracy is a function of the geoid determination accuracy.

These geodetic networks of the Central Asian countries have been used in all types of cartographic works and traditional geodetic surveying. Further application of these networks is complicated because of lack of the net adjustments in the last decades and existing limitations for the civil use of the Pulkovo 1942 (SK-42) coordinate system.

3. GNSS TECHNOLOGY IN CENTRAL ASIA

The Global Navigation Satellite System (GNSS) became as a main component in high accuracy geodetic surveys today. GNSS employ the main space-based satellite navigation systems for navigation and positioning, such as GPS (USA), GLONASS (RF), GALILEO (EU), COMPASS/BeiDou (PRC), for the high global positioning quality and service reliability for the civil users.

Main components of the global positioning systems are satellite, control and user segments. GNNS uses satellite-based augmentation systems (SBAS) for the regional augmentation using additional satellite-broadcast messages. Such systems are commonly composed of multiple ground stations, located at accurately-surveyed points. The ground stations take measurements of one or more of the GNSS satellites, the satellite signals, or other environmental factors which may impact the signal received by the users. The ground-based augmentation system (GBAS) supports augmentation using terrestrial radio messages. The ground based augmentation systems are commonly composed of one or more accurately surveyed ground stations, which take measurements concerning the GNSS, and one or more radio transmitters, which transmit the information directly to the end user (Hofmann-Wellenhof, 2008).

The surveying and mapping companies in the Central Asian countries are taking advantage of GNSS because of its dramatically increased productivity and results with more accurate and reliable data. Today it is a vital part of surveying and mapping activities in the region providing data much faster than conventional surveying and mapping techniques, reducing the amount of equipment and labor required (Chymyrov, 2009).

The first regional large scale initiative on scientific application of GPS technology was the Central Asian tectonic study by the German Research Centre for Geosciences (GFZ) in 1994-1998. Measurements at ~400 campaign-style GPS points and another 14 continuously recording stations in Central Asia define variations in their velocities in the Tien-Shan mountain range (Fig.2). They show that at the longitude of Kyrgyzstan the Tarim Basin converges with Eurasia at 20 ± 2 mm/yr, nearly two thirds of the total convergence rate between India and Eurasia at this longitude (Zubovich et al., 2010). Such tectonic studies are very important because of very high seismic activity in the region.

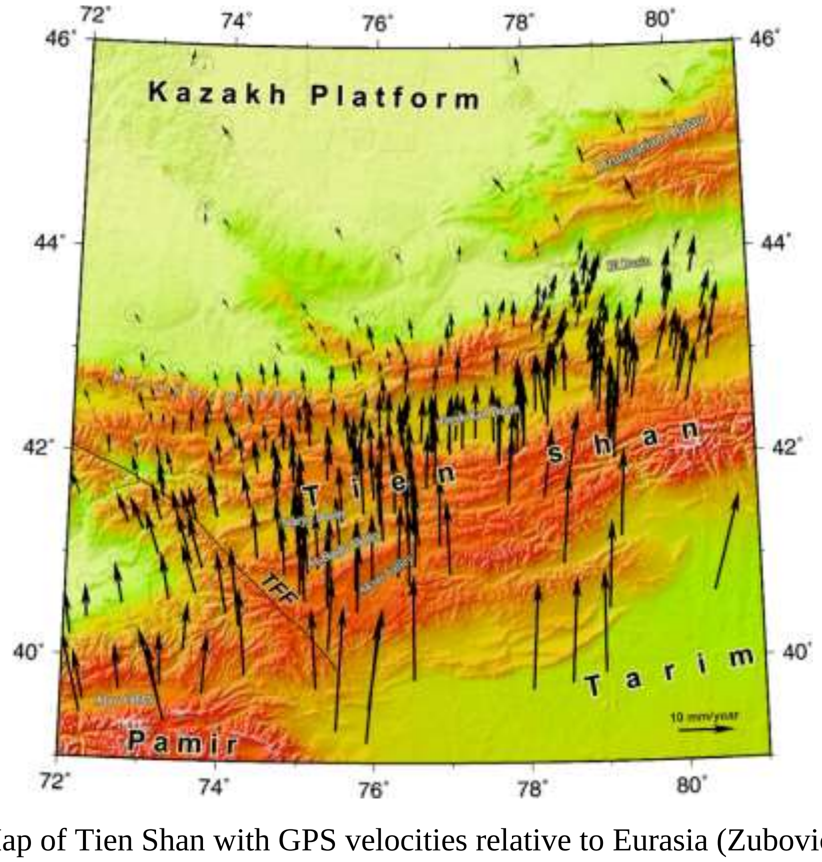

Fig.2. Map of Tien Shan with GPS velocities relative to Eurasia (Zubovich et al., 2010)

The first applied large scale use of GNSS survey for developing a Geoinformation system (GIS) in Kyrgyzstan was realized in 2010-2011. The Issyk-Kul Sustainable Development Project (ADB, 2009) has been realized in order to easy the negative impact of urban development to the antropogenic pollution of Issyk-Kul lake. One of the most important component of the project was the development of GIS for each city with infrastructure assets mapped for improving the management capacity of water supply (Vodokanal) and other utility enterprises. Different data acquisition techniques have been considered for GIS development and RS was the most competitive option in this work used in combination with other traditional and new mapping technologies.

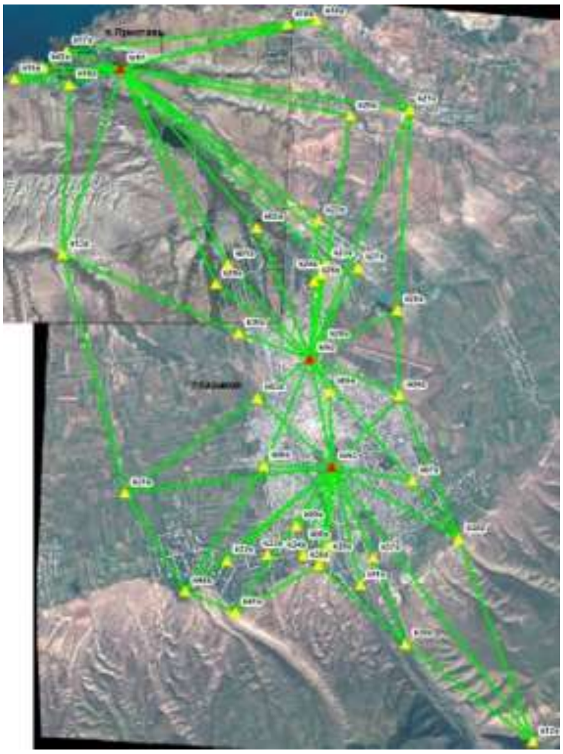

Fig. 3. Local GNSS Survey network in Karakol city with 55 GCP

Design, construction and GNSS survey of ground control points for georeferencing of satellite imagery and raster maps were realized. The original Ortho-Ready Standard format of satellite imagery products are corrected by using the ground control points (GCP) in the selected reference system ITRF-2005. Number and location of GCP were designed by considering the urban area and terrain types. Traditional total station survey has used GCP for common georeferencing of all satellite imagery, topographic and urban cadaster products. The total number of GNSS control points are 90 – 22 GCP for Balykchy, 13 GCP for Cholpon-Ata and 55 GCP for Karakol (Fig.3). Georeferencing of raster maps and vectorization of elevation marks were carried out by using the established and located GNSS network for each city as well as land survey points applicable for identification on images (Zhantaev et al, 2011).

Many other good practices of GNSS applications are available to analyze in the Central Asia. Most of geodetic investigations and engineering survey, GIS development and digital mapping, transport and other civil and military activities have been using the global satellite positioning (Roessner, 2013; Zheentaev et al. 2012). The present study shows the growing demand on implementation of the active GNSS and Location based services (LBS), which need purposeful development of the national and regional geodetic networks and unified reference frames.

4. NATIONAL GNSS NETWORKS IN CENTRAL ASIAN COUNTRIES

Governments, companies and scientific organizations of any country implement GNSS technology to facilitate efficient use of resources that requires accurate location information about its assets, which can benefit from the efficiency and productivity provided by global satellite positioning and navigation. Use of full power of GNSS technology can be achieved in case of employing the network of permanent GNSS stations, which consist of continuous, permanent GNSS stations such that a user anywhere in the country would have free access to the databases of reference stations (Hofmann-Wellenhof et al. 2008).

A survey-quality GNSS receiver will be permanently installed in the convenient location with known position as a Continuously Operating Reference Station (CORS), to be used as a starting point for any GNSS measurements in the adjacent area. One or several survey quality GPS/GNSS receivers can then be used to simultaneously collect survey data at any required points and the data in real time or later combined with the GNSS data obtained from CORS to calculate the positions. If there are more than one CORS available, the unknown position can be calculated with respect to these multiple known positions, giving more confidence in the results.

The current situation with GNSS Networking in Central Asia is different from one to other country. The national policies in these countries vary depending not only from economic situations, but mainly from state-administrative decisions.

Kazakhstan is the largest country in the region with its territory of 2 727 300 square kilometers and 17 125 million population (Statistical handbook, 2013). It is one of the fast developing and oil rich countries in the world with complex terrain of flatlands, steppe, taiga, deltas, mountains and deserts. The National GNSS network has been under development within the project "Creation of the Ground based Infrastructure of High-accuracy Satellite Navigation System", realized by the Joint-Stock Company "National Company "Kazakhstan Gharysh Sapary". This network has operational 10 CORS mainly covering the two of the most densely populated and economic active regions and about 50 stations are under development (Fig.4). ITRF, WGS 84 and Pulkovo 42 and SK-95 reference systems have been used for the geodetic and mapping activities in the country (Nurgalieva and Tuleuova, 2014).

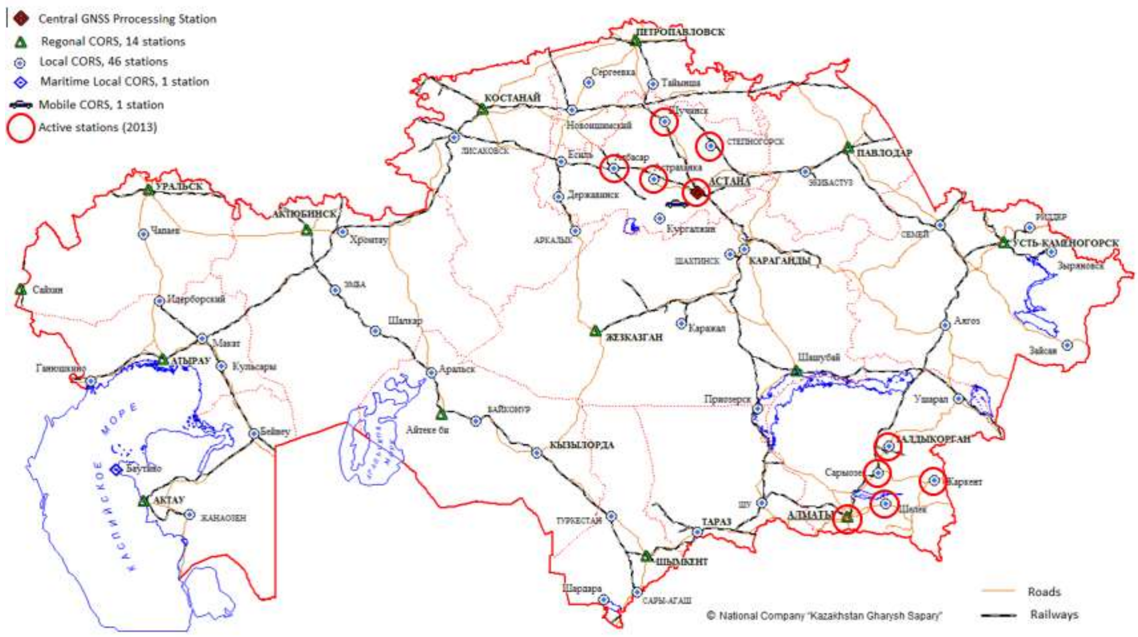

Fig. 4. The National GNSS Network of Kazakhstan

The Kyrgyz State Geodetic Network (GGS) has being transformed based on ITRF by using GPS and other methods of the satellite geodesy. It is designed to have three different order geodetic control points of the network structure on principles of positioning from general to the local positioning for Kyrgyzstan's territory of 199 951 square kilometers.

Original 12 IGS-stations were selected for the connection of the new Kyrgyz State Geodetic Network to ITRF and the five closest IGS stations (GUAO, KIT3, CHUM, POL2 and SELE) are used for the final network adjustment. Five stations in the Zero order network and the reference station in Bishkek are connected to surrounding IGS-stations in a GPS-campaign accomplished in September 2006. 67 geodetic control points are established in the First order network measured with GPS technique in the field season 2006 (Fig.5). The GPS survey campaign in season 2007 is realized to get a better connection between the Zero and First order networks. Survey data from the Zero and First order networks is processed by the Swedish National Land Survey (Lantmäteriet) in the Bernese software. Densification of the First order network is carried out by developing the Second order network with more than 100 geodetic control points to extend the new reference system to the all territory of country (Abdiev, 2008).

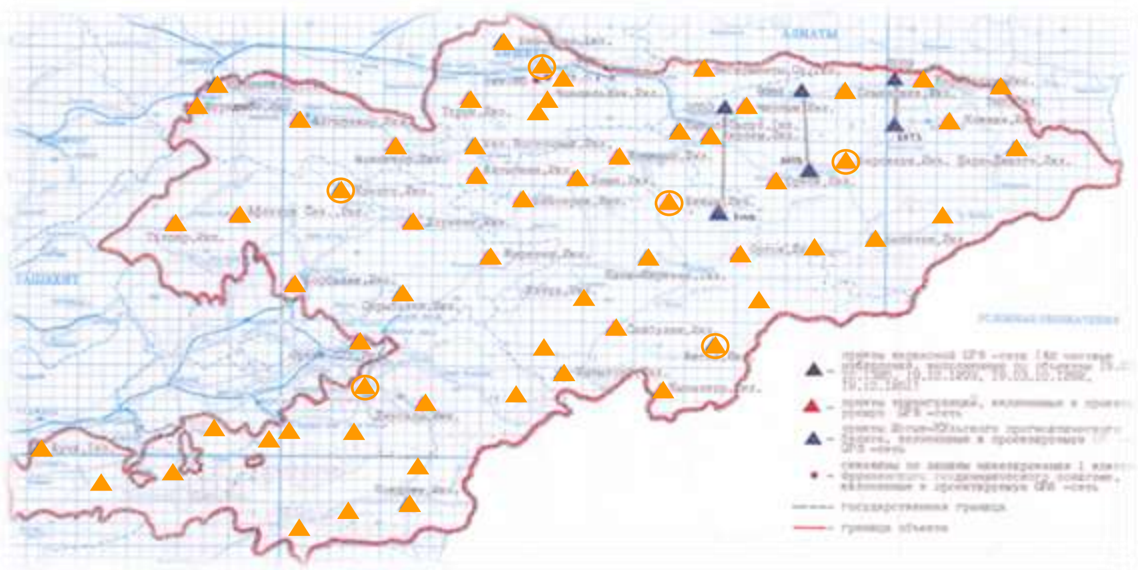

Fig. 5. The ITRF based Kyrgyz State Geodetic Network (SGCS KR)

The Kyrgyz Government has announced the National Reference System "Kyrg06" in 2010 (Decree No.235 from October 7, 2010). The National Reference System is ordered to use for geodetic and topographic activities, engineering survey, construction and exploitation of buildings and structures, land surveying and maintaining the state cadaster. Kyrg-06 is based on the International Terrestrial Reference Frame ITRF-2005, UTM projection with five 3^{o} zones (Abdiev and Chymyrov, 2013).

Traditionally the State Geodetic Network is maintained by the State Geodetic and Cartography Service of Kyrgyzstan (SGCS KR) mainly for the national level geodetic, mapping and state security purposes. Application of GGS for the land cadaster and registry of rights on immovable property has became very important after the land privatization and market economy in Kyrgyzstan from the beginning of 2000s. The Department of Cadaster and Registration of Rights on Immovable Property (DCR) under the State Registry Service of the Kyrgyz Republic (SRS KR) has been actively using and updating the new State Geodetic Network and the National Reference System "Kyrg-06".

The GNSS Reference Network Control Center – KyrPOS, established and administered by DCR SRS KR, started providing public service in 2010 (DCR, 2014). The Centre is operating and managing the network of GNSS reference stations by providing satellite differential corrections for users of GPS/GNSS field receivers on base of Leica GNSS Spider software. At present time, KyrPOS controls the work of 13 permanent reference stations, 6 of which cover Chui region, 5 cover Fergana valley and 2 are installed in Issyk-Kul region and has more than 90 temporary base stations observed (Fig.6). All CORS have internet connection with central server and serve all types of cadastral and geodetic GPS/GNNS surveys in the most populated regions of the country where all active property markets are concentrated.

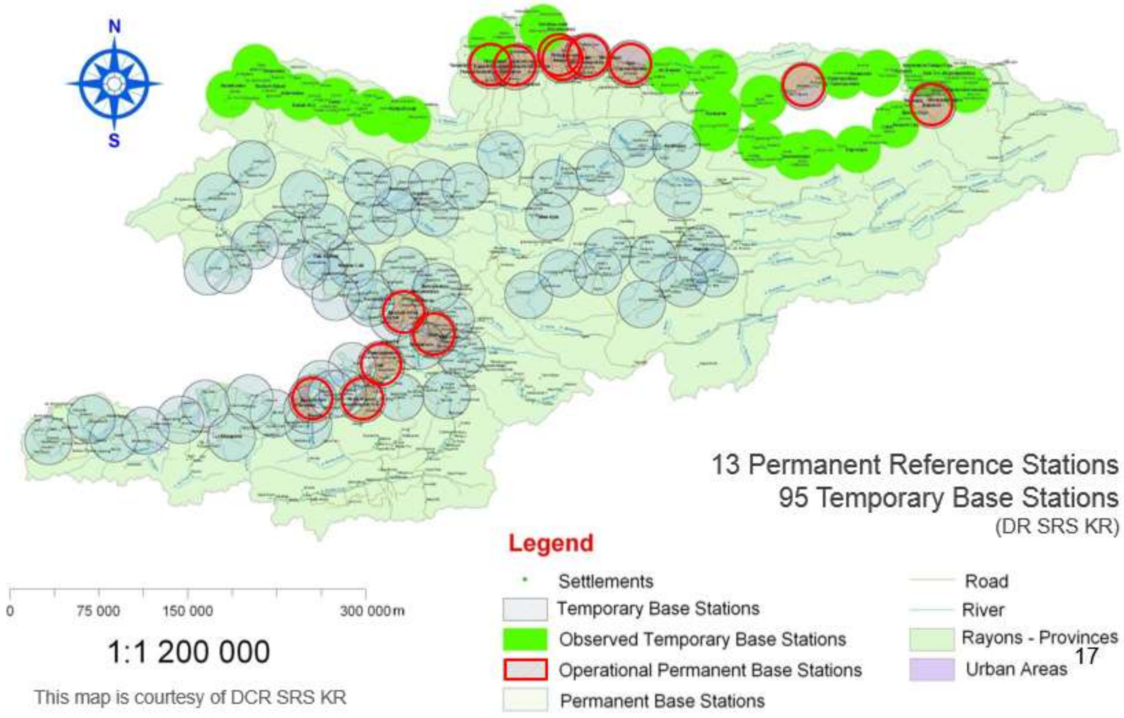

Fig. 6. The Kyrgyz Network of CORS and Temporary Base Stations

Tajikistan is located between Kyrgyzstan and Uzbekistan to the north and west, China to the east, and Afghanistan to the south with an area of 143 100 square kilometers and about 8 million population (Agency on Statistics under the President of Tajikistan, 2014). Mountains cover more than 90% of the country. After independence, Tajikistan suffered from a devastating civil war, which lasted from 1992 to 1997. Since the end of the war, newly established political stability and foreign aid have allowed the country's economy to grow. The current economic situation remains fragile and it has influenced the present situation in the national economy including geodetic and mapping policies.

Tajikistan has been planning to develop the new National Reference system based on ITRF in order to support the implementation and wider use of GNSS technology. At this time, there is an active GNSS reference station in the capital - Dushanbe city, which is providing satellite differential corrections for users of GPS/GNSS receivers on the irregular base.

Uzbekistan has been the regional center for astronomic and geodetic activities in Central Asia for centuries. The first Astronomic Observatory was built in Samarkand by the Timurid astronomer Ulugbek in 1428. The Samarkand observatory became famous for the edition of the "Ulugbeg Zidj", containing a theoretical introduction and charts describing 1 018 stars. The observatory was destroyed in 1449 and rediscovered in 1908 (Zhitomirskiy, 1995).

The Tashkent Astronomical Observatory (Ulugbek Astronomical Institute of the Uzbek Academy of Sciences since 1966) was involved to the International Latitude Service (ILS) in 1899-1919 and a new latitude station was established in Kitab in 1930 (Ehgamberdiev, 2000). Since the 1990s Kitab station hosted the GPS/GNSS Reference Station (KIT3, included in IGS) and ground based beacon of DORIS satellite tracking systems, providing IERS data center with precise coordinates at subdaily frequency. In 1998 Kitab Latitude Station was renamed on Department of Geodinamics of the Ulugbek Astronomical Institute, Uzbek Academy of Sciences. There is CORS in Tashkent and these two stations are providing limited satellite data corrections to GNSS users in the country (Fig.7).

Uzebistan has planned the new State Satellite Geodetic Network with 5 CORS (including Kitab and Taskent stations) and 15 First order base stations observed (Fig.7). It is planned that this network will have ITRF based national reference system (Mirmakhmudov et al, 2013).

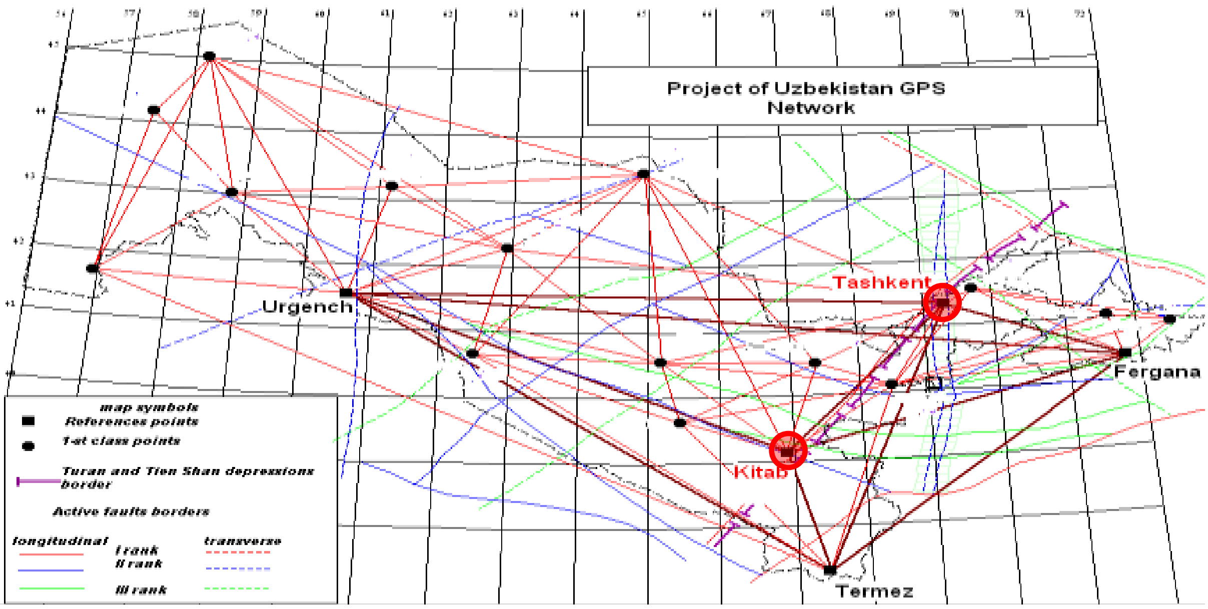

Fig.7. New State Satellite Geodetic Network of Uzbekistan (Mirmakhmudov et al, 2013)

5. ANALYSIS OF GNSS TRENDS IN THE REGION

Implementation and wider use of GPS/GNSS technology in Central Asia are going on and there are some regional peculiarities in such development. Identification and analysis of all trends will give clear picture on decision-making and further development of the satellite navigation and positioning in the region.

Land information systems and GIS. The most rapidly growing use of the large-scale GNSS technology in Central Asia is development of Land information systems (LIS) for the centralized and efficient land and urban cadaster data management. All these countries move toward market economy with land privatization and new land administration systems. Development of the national land information systems has been realized in all Central Asian countries on different level and structure. All these systems rely on GPS/GNSS technologies in geographic positioning as well as on international reference frames in developing cadastral maps and geodatabases. Number of Geoinformation Systems (GIS) is developed for environmental management, disaster risk reduction and pasture mapping in the region.

One of the most successful and interesting cases would be the implementation of GPS/GNSS technologies in designing LIS by the Department of Cadaster and Registration of Rights on Immovable Property (DCR) under the State Registry Service of the Kyrgyz Republic (SRS KR). DCR has established the active GNSS Reference Network and Control Center within projects “Registration of land and immovable property - I” and “Registration of land and immovable property - II”, 2000-2013. GNSS Reference Network with 13 CORS and the Network Control Center are operational and providing services to GNSS users on the national level. The economic efficiency of such GNSS services promotes further extension of satellite navigation and positioning in the country (Abdiev and Chymyrov, 2013).

Engineering survey. The globalization and active involvement of the transnational companies in the economic activities in Central Asia give significant impact to the applied use of GNSS technology in the region. International and local construction and mining companies, transportation and logistics operators are using GNSS receivers for engineering survey, navigation and digital mapping. These companies are using a high accuracy positioning via satellites, mainly the classical DGNSS (or DGPS) and the Real Time Kinematics (RTK) techniques. These techniques are based on the use of carrier measurements, and the transmission of corrections from their own base stations, whose location is well known, to the rover, so that the main errors that drive the stand-alone positioning cancel out. Such users have to use an additional fixed GNSS receiver, which will add more cost to surveying. Implementation of the network of permanent reference stations can reduce the cost of surveying and improve the quality of survey data (Chymyrov, 2009).

Transportation and logistics. Use of GPS navigators and receivers in transportation and logistics is one of the most efficient applications of satellite positioning, timing and velocity measurements. All international airports in the Central Asia satisfy the International Civil Aviation Organization (ICAO) GNSS requirements, large cities are implementing GPS navigation in city transport, transport and logistics companies have trucks with GPS trackers, emergency services use GNSS services, etc.

Geodynamic, environmental studies and disaster risk management. Number of international research institutions and projects has established and operational on GPS/GNSS networks in Central Asia. Such significant scientific interest can be explained by the global initiatives on geodynamic studies focused at the high tectonic and seismic activities in the region. But the local governments do not have economic interests and initiatives on the national investments, which make possible the GNSS based researches only within international project and initiatives.

The German Research Centre for Geosciences (GFZ) has realized a number of regional scientific activities within their framework, such as the Global Change Observatory Central Asia (GCO-CA) initiative, in active continental geodynamics research, georisk and human habitat, water resources management, interaction between climate and geodynamics. It has established and long-term functioning monitoring network with 23 stations with GNSS sensors: Remotely Operated Multi-Parameter Stations (ROMPS), CORS, Smart-stations and Seismic stations of the Central-Asian Real-Time Earthquake Monitoring Network (CAREMON). The Central Asian Institute of Applied Geosciences (CAIAG) in Bishkek, Kyrgyzstan, a multidisciplinary local institute comprising most of the geoscientific disciplines like geology, glaciology, hydrology, geodesy, remote sensing, climatology and geophysics, jointly operates these dedicated monitoring networks with GFZ (CAIAG, 2014).

The Joint Institute for High Temperatures (IVTAN) of the Russian Academy of Sciences (RAS) has an operational array of more than 10 GNSS stations in the Central Asia. Some of these stations are included in the IGS and UNAVCO Networks (IVTAN, 2014).

Development of the National Geodetic Networks and Reference Systems. All of Central Asian countries are developing own National Geodetic Networks and Reference Systems. It is doubtless that these countries are going to accept ITRF based reference systems and develop own national datums and satellite geodetic networks. Only Kyrgyzstan has officially accepted the National Reference System “Kyrg06” and it is expected that other countries will have own reference frames in the next years. High accuracy GNSS observations and processing will be main tools in construction of new state geodetic networks.

CONCLUSIONS

GNSS technology has good perspectives in the Central Asian countries as in other parts of the world. Its full development is limited by the weak socio-economic situation in the regions and by underestimation of GNSS capabilities and advantages.

The national reference systems of these countries could be developed with a common regional datum and by taking into account the existing common research networks and international cooperation. There are two main regional networks, operated by GFZ and IVTAN with continuously operating GNSS observation stations, designed and established according to the high international standards within different international programmes. These GNSS networks can be combined with national satellite geodetic networks in order to design an integrated regional net with national chains. GNSS data collection and processing can be realized on the national level with close trans-bounder cooperation. Such a regional GNSS based geodetic net can improve the data integrity and reliability of the regional satellite positioning and navigation services.

The positive experience and emerging deficiencies of developing and official implementing of the new GGS in Kyrgyzstan can be interesting for other countries. The active Kyrgyz GNSS network is experiencing several problems because of the insufficient state funding for its maintenance and operation, free satellite differential correction service providing, unstable internet communication, etc. Active Kyrgyz GNSS Reference Network Control Center “KyrPOS” needs research study to identify the demand and develop the business plan on setting the GNSS differential correction service fee to maintain the network properly.

All Central Asian countries are developing own National Spatial Data Infrastructures (NSDI) and GNSS data collection and processing networks should be closely integrated into NSDI. Only in this case the spatial data quality, integrity, access and reliability could be achieved.

Capacity building in the Central Asian region is one of the weakest components in the development and application of GNSS technology. Such a gap between professional education and industrial application of the advanced technology can be reduced in the next years by implementing the new teaching curricula and training trainers.

The regional cooperation would give valuable results in solving many of the emerging tasks by using the existing GNSS networks, international cooperation and good practices. Developing of the common Central Asian geodetic datum and interoperable reference networks, NSDI and open data sharing would benefit the society from the GNSS technology.

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