Monitoring Plate Tectonics and Subsidence in Turkey by CORS-TR and InSAR

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Key words: deformation, subsidence, GNSS, CORS, InSAR

SUMMARY

A recent Continuously Operating Reference Station network, called CORS-TR (or TUSAGA-AKTIF) network has been established in Turkey and north of Cyprus. CORS-TR network was established by Istanbul Kultur University in corporation with General Directorate of Land Registry and Cadastre (GDLRC) and General Command of Mapping (GCM) as one of the major research and scientific projects funded by Scientific and Technological Research Council of Turkey (TUBITAK) between May 2006 and May 2009. CORS-TR network was designed to fulfill several important tasks ranging from geodetic measurements in crustal deformation studies to the modeling the atmosphere (troposphere and ionosphere) over Turkey. The network consists of 147 reference stations with three more to be located and three control centers those are supposed to collect the GNSS data and to process them for the Real Time Kinematic applications, such as cadastral works or vehicle navigation tasks.

This paper deals with the monitoring capability of the CORS-TR network in tectonic plate and subsidence in Turkey and Cyprus. Due to the fact that Anatolian plate has been squeezed by Arabian plate towards the Eurasian plate, earthquakes have been great natural hazard that threat the country socially and economically. Hence, it is crucial gain the knowledge in the characteristic and dynamics of the tectonic fault lines to mitigate the earthquake hazard. That mission seems to be partly accomplished by the outcomes of CORS-TR network. That could be demonstrated by looking the results of GNSS data process obtained from a short period measurement data. On the other hand, to improve the monitoring capabilities, it is needed to extent the current studies to additional data acquisition and process techniques of that have been mature enough to be benefitted in the tectonic plate and subsidence phenomenon. This paper also implies that a new monitoring system that is based on interefometric process of the radar images recorded by satellites has been part of an on-going study by the authors.

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1. INTRODUCTION

Earthquake prone countries like Turkey are prone to take precaution measurements in advance to mitigate the results of the natural hazards. There are many different study areas those focus on the analysis of the characteristics of the strong ground motions, development of the structural design guidelines and also learning the plate mechanisms cause the earthquakes. During the recent decades, the studies aimed learning the plate mechanisms gained an acceleration after the introduction of the space-based application tools such as GNSS and radar image acquisition systems. This paper exhibits the versatility of the space-based monitoring systems and their immediate use in Turkey where the active fault lines and surface deformations (subsidence) exist.

Turkey is located on Anatolian plate where the Arabian, Eurasian and the African plates conjunct, Figure 1. The recent studies showed that the Anatolian plate has been squeezed by Eurasian and Arabian plates due to the global plate tectonics (McClusky et al, 2000). As a result, all around the Anatolian plate, the high slip rates as much as 24mm/year have been observed (Meade et al, 2002).

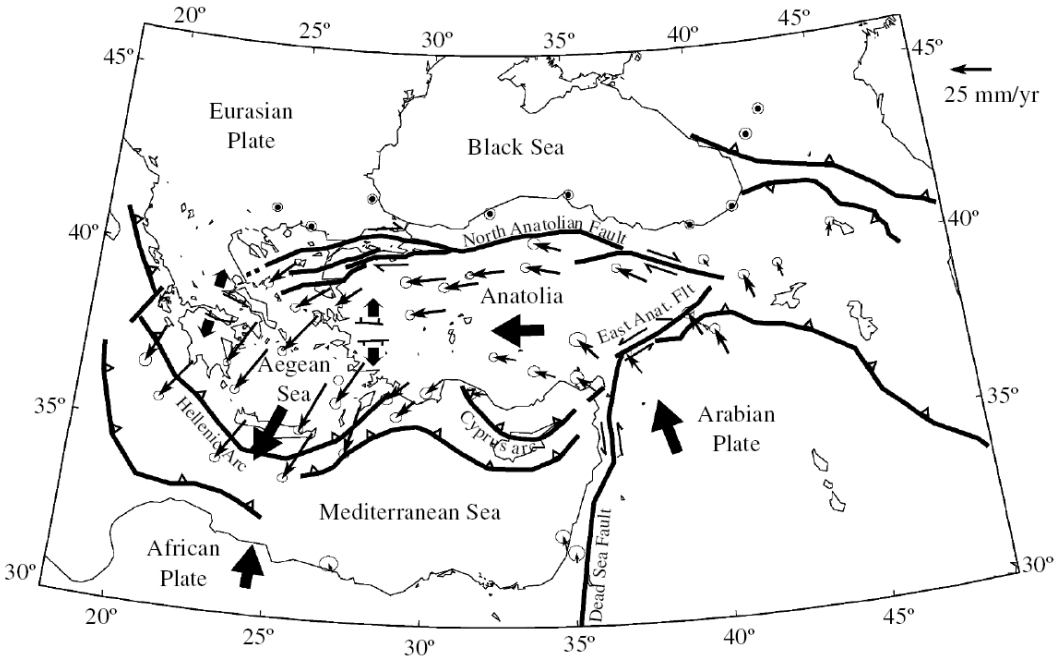

Figure 1. Tectonic setting of Turkey McClusky et al (2000)

Due to the high seismicity, earthquakes have been a fact of daily life in Turkey. For example, Izmit Earthquake struck on August 17th, 1999 and claimed more than 18,000 people and $6 billion economical loss, has still fresh psychological effects on people's mind. Izmit and Duzce earthquakes in 1999 were the latest of the sequential seismic events observed on the North Anaolian Fault (NAF) line that is one of the most active strike-slip type fault, Figure 2.

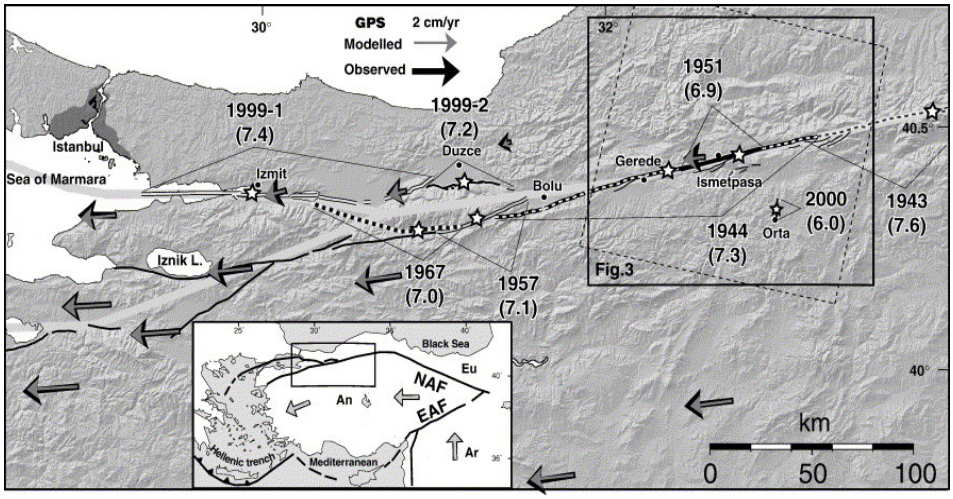

Figure 2. Seismic events on the North Anatolian Fault line (Cakir et al, 2005)

In addition to two main and numerous minor fault lines, whole country covers abundance of different geological formation from igneous to metamorphic. Such a wide spectrum of geological formation also creates hazardous events apart from tectonic plate movements in various parts of Turkey. Among them, the potential risk that threats the inhabitants should be encountered in Konya region where there are hundreds of sinkholes occurred due to the dominantly calcareous soil underlying entire region, Figure 3.

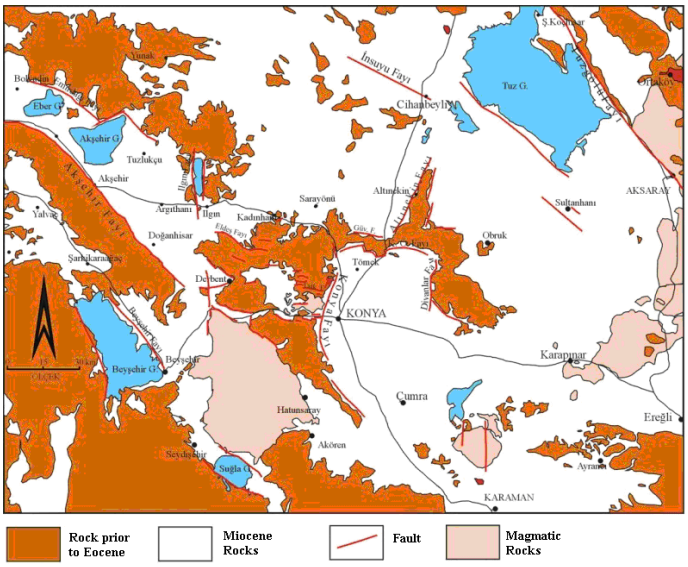

Figure 3. The geology of Konya Region

Turkey, as a highly seismic country, has very good earthquake-resistant design provisions and codes. However, it is also worthwhile to have systems that run continuously to observer the tectonic plate movements as a great tool for valuable ground motion predictions. This paper explains one of the major nation-wide CORS system aimed to give a better understanding in the monitoring of the tectonic plate movements in Anatolia, and briefs about a new study uses InSAR techniques in the determination of the deformation of the ground due to the non-seismic natural hazards.

2. MONITORING TECHNIQUES and SYSTEMS

2.1 GNSS and CORS-TR System

Istanbul Kultur University (IKU) in association with General Directorate of Land Registry and Cadastre (GDLRC) and General Command of Mapping (GCM) proposed the establishment of national continuously operating reference station (CORS) system that aimed

- to establish network-based CORS-TR stations functioning 24 hours/day with RTK capabilities,
- to model the atmosphere (troposphere and ionosphere) over Turkey contributing to atmospheric studies and weather predictions and signal and communication studies,
- to provide mm-level accuracy for tracking plate tectonics, measuring deformations and contributing to earthquake prediction and early warning systems,
- to determine datum transformation parameters between the old system (ED50) and ITRF97.

The proposal was sponsored by Scientific and Technological Research Council of Turkey (TUBITAK) on May 2006 and named as CORS-TR (or TUSAGA-AKTIF in Turkish). During the first months of the project, a comprehensive benchmark test was organized to gain experience on CORS network and its components (Eren et al, 2009). Based on the experiences and the results of the company performances, the final design of the CORS system (150 reference stations, three control centers, data communication systems etc.) was prepared, Figure 4. 147 of 150 reference stations and 3 Control Centers (CC) were successfully established in Turkey and in Cyprus before the end of April 2009. The remaining three CORS stations will be installed to the locations where it may be needed for special purposes such as tectonic studies. The three control centers of the CORS-TR system were placed in GDLRC, GCM and IKU for governmental, military and scientific studies, respectively. The reference stations and the control centers have been in use since September 2009. Currently, there are more than 1100 RTK users of the network.

The reference stations are installed on the ground and on the roof of large but low-story governmental buildings (cadastre offices, meteorological observation stations, universities etc.) from where the technical support can be supplied. The distances between the stations range from 80-100km. Even if it may sound too much, the benchmark test results displayed that such a range of station distances could be acceptable.

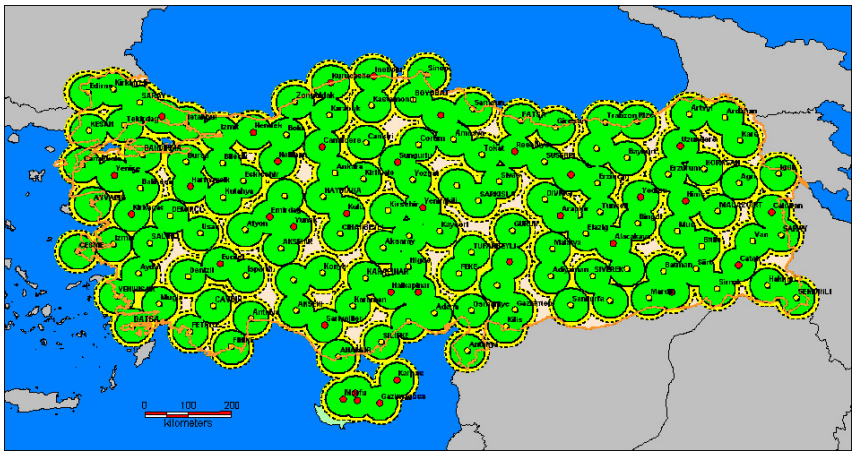

Figure 4. CORS-TR reference stations in Turkey and Cyprus

2.2 InSAR process and Supersites

For the last 2 decades, the satellite based earth observation systems have gained importance due to their numerous advantages. Therefore, the techniques for the evaluation of the satellite observations have improved enormously. Among them, Synthetic Aperture Radar (SAR) images and their interferometric applications have been complementary to very specific scientific studies like tectonic, volcanic, subsidence etc. Even if the GNSS data at points where the ground deformation exist provide information, it is not possible to estimate the ground deformation surface of the area. That is due to the spatial scattering of the observation points; hence, additional data acquisition techniques are needed. At this point, the use of InSAR would yield the surface deformation results with respect to the available satellite images obtained between two distinctive time instances, Figure 5.

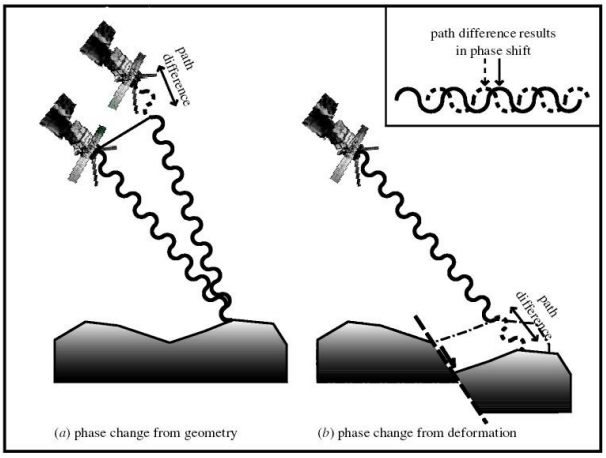

Figure 5. Schematic of radar interferometry (Wright, 2002)

The results of the InSAR process provide the relative deformation values those are due to either seismic excitation or subsidence, Figure 6. In order to establish more rational monitoring system, the marking points of the InSAR processes must be selected among the points where the absolute coordinates are well know at the time instances of the radar scenes.

Therefore, it is preferable to have points where the coordinates are estimated at anytime. CORS-TR stations in all over Turkey and Cyprus yields the points to be used in remote sensing studies, particularly InSAR processes. The use of the InSAR results calibrated with the GNSS observations would solve many problematic cases in Turkey as aforementioned, i.e. Konya case.

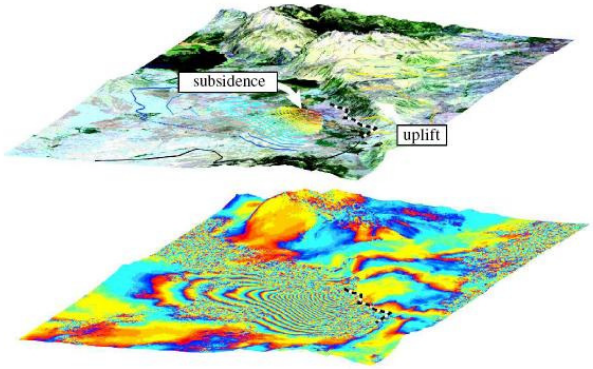

Figure 6. The 1995 Dinar (Turkey) earthquake caused the left of the fault line (marked by black and white strip) subsided while the north uplifted, each fringe represent 28mm unit deformation (Wright, 2002)

Istanbul Kultur University in corporation with Istanbul Technical and Bogazici Universities has been take place in Supersites initiative that started by European Space Agency (ESA), NASA and National Science Foundation (NSF), (Supersites web site). The initiative promotes the Earth science data from its participants to be used in InSAR, GNSS crustal deformation measurements studies. Therefore, besides the processing of the GNSS data from CORS-TR network, there is an on-going study in parallel to establish an additional monitoring mechanism that uses InSAR technique in Turkey. The new study concentrates not only in earthquake prone Istanbul area but also Konya region where there are distinctive subsidence spots (sinkholes) that threat the daily life of the people. The results of this new InSAR-based monitoring system calibrated with CORS-TR network will be released within 2010.

3. CORS-TR OBSERVATIONS

As of April 2008, the first CORS-TR station, ISTN, in IKU Campus started receiving the GNSS signals. By the end of the year 2008, the most of the remaining CORS stations installed and joined network. During the installation period, there had been many issues between the communication of the CORS stations and the control centers, but, up to now, there has not been any circumstance to replace the antenna place due to the environmental effects, such as multipath or atmospheric conditions.

At the end November 2009, the entire CORS-TR data obtained from the stations were processed in GAMIT/GLOBK program. The results of the process displayed that one can differ the seasonal effects on the long period repeatability, the robustness of the data from the stations are satisfactory as seen on Figures 7 and 8.

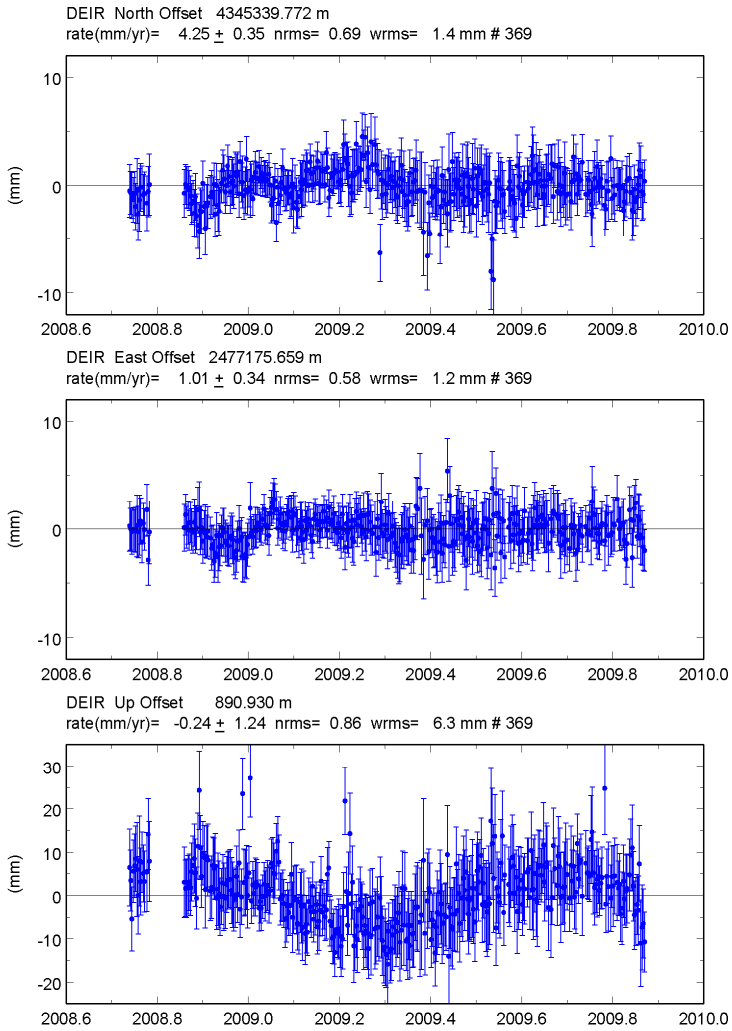

Figure 7. The ground station (DEIR) and its long-period repeatability result

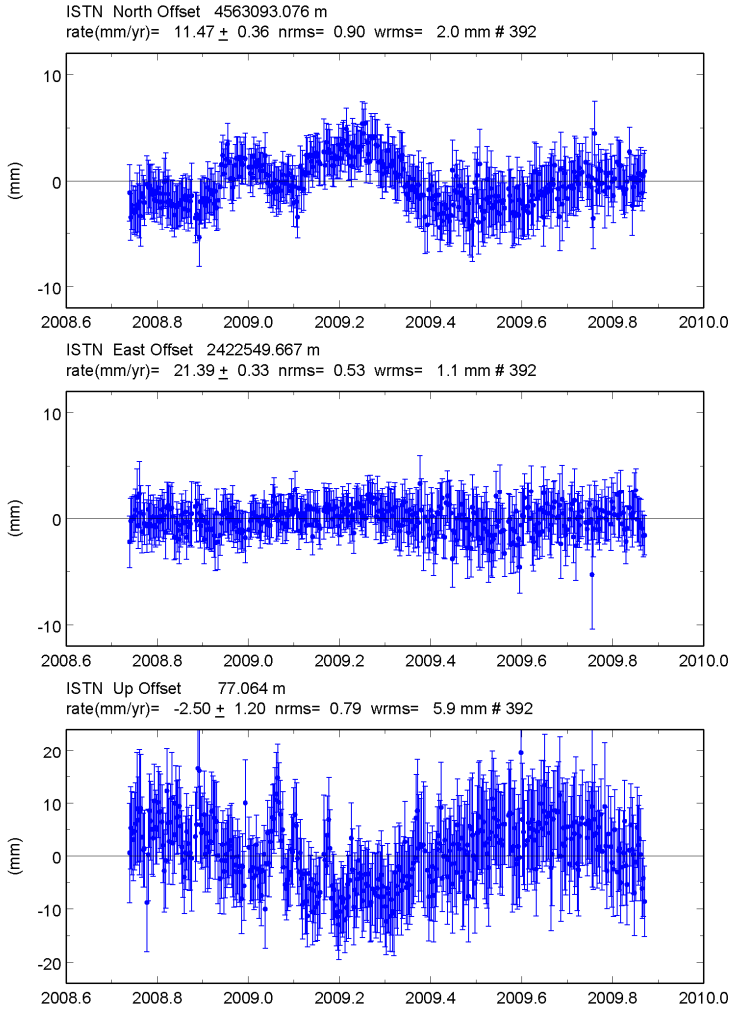

Figure 8. The roof-top station (ISTN) and its long-period repeatability result

The short history of the CORS-TR network has the great potential of displaying the tectonic movement of the Anatolian plate as seen in Figure 9. The GAMIT/GLOBK process of 141 CORS stations with the data between 1st and 333rd days of 2009 has already represented the motion of the Anatolian plate with respect to the Eurasian plate.

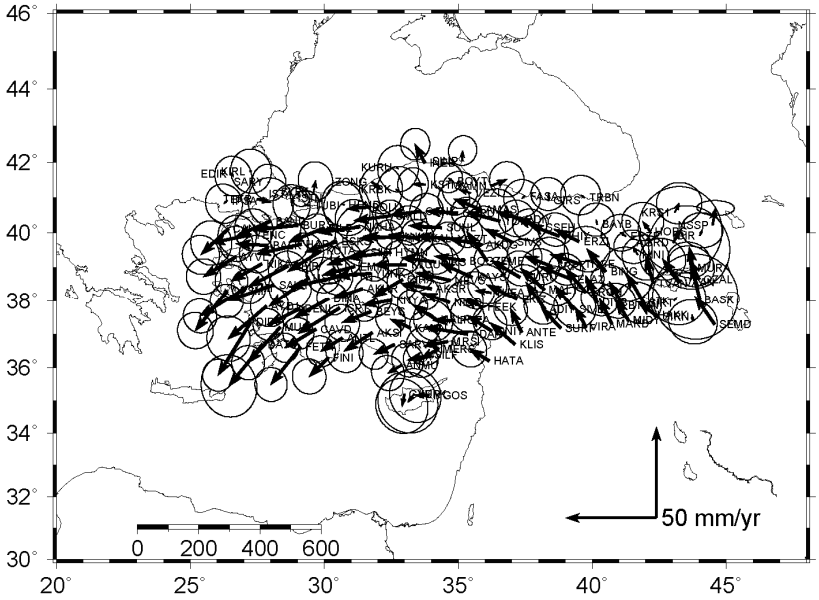

Figure 9. The velocity map of the CORS-TR network obtained between 2009.01 and 2009.333 epochs

The maximum displacement estimated from the 141 CORS stations are 19.91 mm/year (southwest direction) and 23.16mm/year (northwest direction) at FINI and UDER stations. Keeping in mind that the several researchers have commented that the Anatolian Plate has a slip rate of 24mm/year after the years long observations in their studies, the process result of 11 months long GNSS observations obtained from CORS-TR network encourages the reliability, stability and effectiveness of such a young network.

4. CONCLUSION

One of the recent CORS network established in a region where the seismic activity due the tectonic plates dynamics have been introduced in this paper. The network that consists of 147 reference stations covers the whole Anatolian Plate and north part of Cyprus. The monuments of the GNSS antennas were selected on the ground as well as on the top of large but low-story buildings after eliminating the factors that may cause multipath. Even if one criticizes this strategy, it may be said that such a placement is found acceptable because enlarging the base of the monument could provide more stable foundation condition. By this way, larger sky view and better protection was provided.

The GNSS observation campaigns provide valuable information on the tectonic plate movements within a particular region. However, they have some shortcomings that may limit

the extent of the studies. Among these shortcomings, it requires more human and financial resource to complete the observation series, it is concurrent observation capability is limited to the number of the GNSS receivers; it requires post-processing for the precise positioning task. A well planned CORS network can solve all these limitations and moreover important it is the main component of a monitoring system in tectonic plate and subsidence studies. As explained in the preceding chapter, the 11-month long GNSS data obtained from the nationwide network provided the similar result of the years-long studies. Therefore, it is not a great challenge to express that CORS-TR network with its RTK capability will provide a basis for a realistic monitoring system for the region. And even this network may be in cooperation with the neighboring CORS networks in order to give a better understanding in the characteristics of the Eurasian, African, Arabian plates and, also, wider monitored regions rather than Anatolia and part of Cyprus.

In order to extent the monitoring the plate tectonics and subsidence from scattered observation points to wide areas in Turkey, an additional technique based on InSAR process has been studied by the help of Supersites initiative. The new study has been organized by the participation of the other research groups in Turkey, and is expected to yield invaluable information for the deformation characteristics of the particular areas in Anatolia and Cyprus.

Even if only a small portion of the network ability has been summarized in this study, the CORS-TR system has brought a variety of opportunities to a number of applications from e-government to navigation in transportation.

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BIOGRAPHICAL NOTES

Prof. K. Eren, who is a graduate of Ohio State University, also has national and international academic and research experience as, Humboldt Fellow, United Nations expert and Professor in Middle East Technical University. He served as the Project Manager in the CORS-TR Project.

Prof. T. Uzel has very extensive academic and research experience. He carried out numerous research projects since 1965. He also served as the rector of Yildiz Technical University and the Director of IKU Graduate School. He served as the Coordinator in the CORS-TR Project.

Dr. Ahmet Anil Dindar recently completed his Ph.D. study after completing a successful research on “Energy-Based Seismic Analysis and Design of RC columns” in Bogazici University. He served as the Deputy Project Manager in the CORS-TR Project.

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