# Determination of Current Velocity Field (Rate) of North Anatolian Fault in Izmit-Sapanca Segment

**Cetin MEKIK, Bulent TURGUT, Haluk OZENER, Turkey**

**Key words**: North Anatolian Fault, GPS observations, Geodetic observations, Velocity

## SUMMARY

This study focuses on the GPS observations and their analyses conducted in the Izmit-Sapanca Fault Segment which highly seismic activities take place on and is situated on the western part of North Anatolian Fault (NAF). In order to monitor displacements occurring in this fault segment, the Sapanca micro-geodetic network was established in 1990 by Kandilli Observatory and Earthquake Research Institute of Bogazici University. The two points in this network, namely SISL and SMAS, provided a clear means to monitor the displacements caused by the Izmit Earthquake, M=7.5, in August 17$^{th}$, 1999.

In this study, GPS observations carried out in the Sapanca micro-geodetic in the periods from 2005 to 2010 were analyzed using GAMIT/GLOBK scientific processing software so as to determine current velocity field of the region. The analyses indicate, taking Eurasian reference frame fixed, that SISL point on the northern section of the fault has sustained a displacement with an average velocity of 6.5 mm/year while SMAS point on the southern section of the fault 19.6 mm/year. It has been found that the results obtained from this study are in coherence with the general velocities of Anatolian Plate.

## ÖZET

### Kuzey Anadolu Fay Zonu’nun İzmit-Sapanca Segmentindeki Güncel Hız Alanının (Miktarının) Belirlenmesi

Bu çalışma Kuzey Anadolu Fay Zonu (KAFZ) batı kesiminde yer alan ve oldukça yüksek bir sismik aktiviteye sahip olan İzmit-Sapanca fay segmentinde gerçekleştirilmiştir. Bu segmentte meydana gelecek yer değiştirmeleri izlemek amacıyla 1990 yılında Bogaziçi Üniversitesi, Kandilli Rasathanesi ve Deprem Araştırma Enstitüsü Jeodezi Anabilim Dalı’nca kurulan Sapanca mikro-jeodezik ağında 17 Ağustos 1999, M = 7.5, Izmit, Depremi sırasında meydan gelen yer değiştirme SISL ve SMAS noktalarında net bir şekilde izlenmiştir.

Bu çalışmada, bölgedeki güncel hız alanının belirlenebilmesi için, Sapanca mikro-jeodezik ağında 2005-2010 yılları arasında GPS tekniğiyle yapılan gözlemler GAMIT/GLOBK bilimsel yazılımı ile değerlendirilmiştir. Avrasya sabit referans çerçevesine göre, fayın kuzeyinde bulunan SISL noktasında 6.5mm, güneyde yer alan SMAS noktasının yıllık ortalama hızı 19.6mm olarak hesaplanmıştır. Sonuçların Anadolu Plakasının genel hızlarıyla uyumlu olduğu görülmektedir.

# Determination of Current Velocity Field (Rate) of North Anatolian Fault in Izmit-Sapanca Segment

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## 1. INTRODUCTION

Turkey is geologically the part of the Alpine-Himalayan orogenic belt. Tectonics of Turkey is the consequence of the Anatolian plate's movement due to the squeeze between the Arabian and the Eurasian plates (McKenzie 1972, Dewey et al. 1973, Mercier et al. 1989, Jackson et al. 1982, Barka 1992, Armijo et al. 1996). The crustal thickening in the collisional zone has been accompanied by the west-southwest escape of the Anatolian block towards the Hellenic arc system by the right-lateral North Anatolian Fault Zone (NAFZ) and the left-lateral East Anatolian Fault Zone (EAFZ) (Arpat and Şaroğlu 1972, Şengör 1979; Şengör and Yılmaz 1981, Şengör et al. 1985, Dewey et al. 1986, Şaroğlu et al. 1992b, Tatar et al. 1996, Hubert-Ferrari et al. 2003, Allen et al. 2004, Barazangi et al. 2006) at a slip rate of 24±1 and 9±1 mm/yr, respectively (McClusky et al. 2000, Reilinger et al. 2006). The North Anatolian Fault (NAF) runs along the northern part of Turkey about 1200 km from Karlıova to the north Aegean (Ketin 1967, Canıtez 1973, Şaroğlu et al. 1987, Barka and Kandinsy-Cade 1988, Taymaz et al. 1991, Şaroğlu et al. 1992a, Koçyiğit et al. 2001, Şengör et al. 2005).

As for the Izmit-Sapanca segment of the fault, NAFZ branches from 30.6º E westward into three active segments, the northern branch, the İzmit-Sapanca Fault, is not defined as a narrow shear zone, but is a complex deformation zone as wide as 5-8 kilometers. GPS derived velocities suggest that the Izmit-Sapanca fault is active and defines the northern boundary of the Anatolian block at the eastern end of the Marmara Sea. Studies monitoring horizontal crustal movements on this segment of NAFZ were started by the Geodesy Department of Kandilli Observatory and the Earthquake Research Institute of Bogazici University in 1990 (Figure 1). After 4-year terrestrial geodetic measurements, the department has continually collected GPS data since 1994 (Gurkan et al., 1999; Ozener; 2000, Gurkan et al., 2001). A number of research have been conducted along the faults for investigating seismic potential by other researchers (Ambraseys and Finkel 1991, Stein et al. 1997, Barka and Reilinger 1997, Reilinger et al. 2000, Ayhan et al. 2002, Ergintav et al. 2002, Meade et al. 2002, Reilinger et al. 2006, Ergintav et al. 2007, Reilinger et al. 2009).

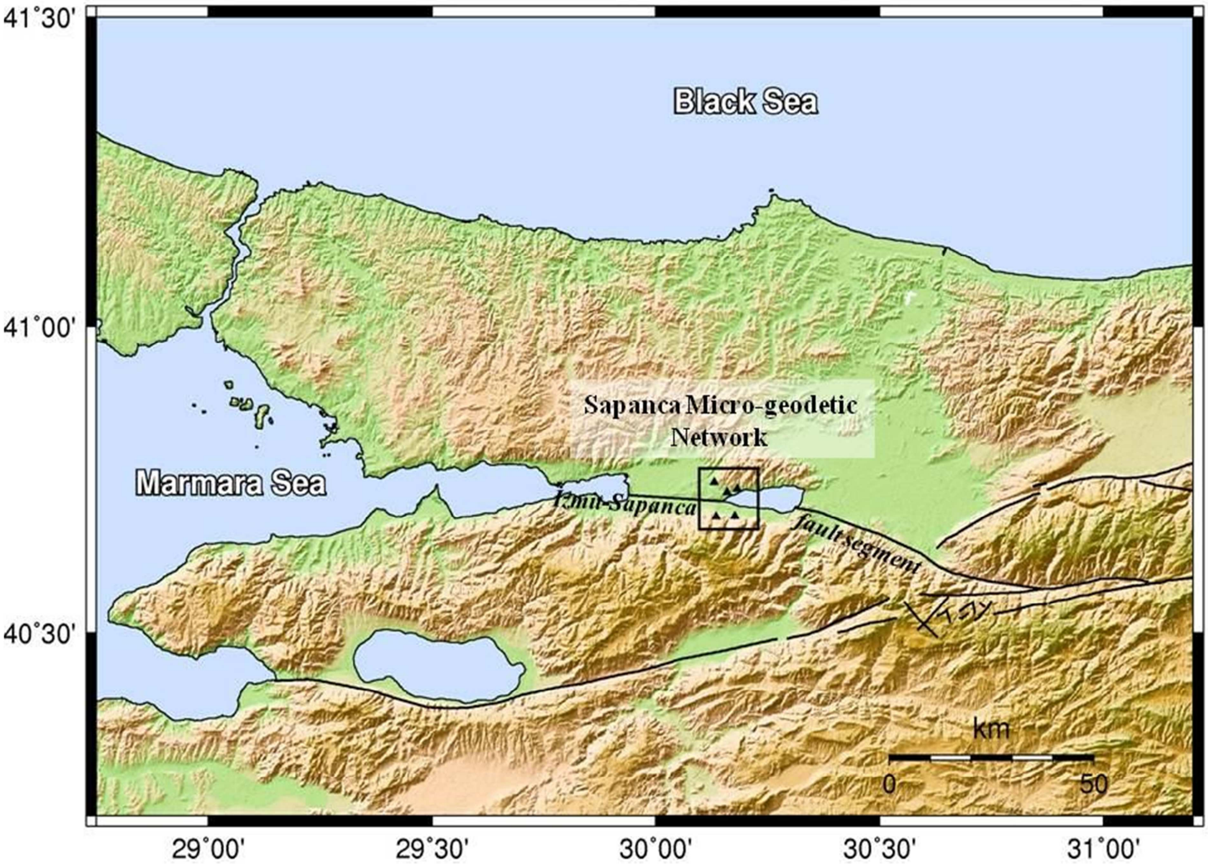


**Figure 1**. Sapanca Mikro-geodetik Network and Izmit Sapanca fault segment of NAFZ.

The displacements in the Sapanca micro-geodetic network during the Izmit earthquake (Mw=7.5) on 17 August, 1999 were clearly monitored on SISL and SMAS points of the micro-geodetic work whose details are given in the following section. It was determined that SISL and SMAS points were moved away from each other approximately 3 m as a result of the earthquake which can easily be seen from the curvilinear coordinate components, their mean errors and the correlation coefficient between East and North uncertainties given in Table 1 (Reilinger et al. ,2000).

| Site | Long.(°) | Lat.(°) | E Disp.(mm) | N Disp.(mm) | E+/-(mm) | N +/-(mm) | RHO |
|---|---|---|---|---|---|---|---|
| SMAS | 30.13 | 40.68 | -1409.90 | 107.60 | 9.60 | 8.70 | 0.026 |
| SISL | 30.13 | 40.74 | 1635.30 | -27.90 | 9.40 | 8.90 | 0.007 |

**Table 1**. GPS coseismic displacements and 1-sigma uncertainties. RHO is the correlation coefficient between the E (east) and N (north) uncertainties (Reilinger et al. ,2000).

## 2. GEODETIC OBSERVATIONS

The GPS observations in the Sapanca micro-geodetic network have been carried out since 1994. However, this study includes only the results obtained from 5 GPS campaigns between the years 2005-2010. Reinforced concrete pillars were constructed on all network points in order to reduce, if not to eliminate, the centering errors to minimum (Figure 2a and b). All the GPS observations were conducted on each network point for approximately 8 hours using Trimble™ 4000 SSE/SSi receivers and geodetic antennas for which extra attention is paid to employ the same type and model as much as possible (see Table 2), and directed to north for the elimination of phase eccentricity errors.

**Figure 2a.** Pillar at SASK point

**Figure 2b.** Pillar used at SISL point

| | 2005 | 2006 | 2007 | 2009 | 2010 |
|---|---|---|---|---|---|
| **Receiver** | 4000SSi | 4000SSE/SSi | 4000SSi | 4000SSE/SSi | 4000SSE/SSi |
| **Antenna** | Perm. L1/L2 | Perm. L1/L2 | Perm. L1/L2<br>CompL1/L2wGP | Perm. L1/L2 | Perm. L1/L2<br>CompL1/L2wGP |

**Table 2.** Receiver and antenna models used in GPS campaigns conducted in the Sapanca micro-geodetic network.

The processing of the GPS data is performed with the GAMIT / GLOBK (Herring et al., 2010) software package using the International Terrestrial Reference Frame ITRF2005. 14 IGS stations, namely ANKR, BUCU, GRAZ, ISTA, KIT3, MATE, NICO, NSSP, ONSA, SOFI, TRAB, TUBI, WTZR, ZECK, are included in the process to calculate Earth Rotation Parameters more precisely and to associate the local network with the global network. Precise final orbits by the International GNSS Service (IGS) are obtained in SP3 (Standard Product 3) format from SOPAC (Scripps Orbit and Permanent Array Center). Earth Rotation Parameters (ERP) comes from USNO-Bulletin-B (United States Naval Observatory_Bulletin_B). The 9-parameter Berne model is used for the effects of radiation and the pressure. The IERS 2003 model (McCarthy and Petit, 2004) and FES2004 (Letellier, 2004 ) are used for the solid earth tide and the ocean tide loading effects. The Zenith Delay unknowns are computed based on the Saastamoinen a priori standard troposphere model with 2-h intervals. Iono-free LC (L3) linear combination of L1 and L2 carrier phases is used. Loosely constrained daily solutions obtained from GAMIT are included in the ITRF2005 reference frame by a 7 parameters (3 offset–3 rotation–1 scale) transformation with 34 global IGS stations. Station velocities are obtained from trend analysis by time series which formed by daily precise coordinates combined with Kalman analysis.

The Sapanca micro-geodetic network was established to monitor the crustal deformations in the Izmit-Sapanca segment of the North Anatolian Fault, consisting of points with intervisibilty due to fact that all the observations on the points were carried out using conventional terrestrial method until 1994. The network points SISL, SESM and SASK were chosen to be on the northen part of the fault while the points SMAS and SYNK to be on the southern part of the fault. Since 1994 the points in the network have been annually observed applying GPS technique. Figure 3 is given to depict the locations of the network points on a bird's eye map. Employing GPS observation techniques has led us to concentrate on two network points, one on each side of the fault, chosen for their best descriptive characteristics of the fault, namely SISL and SMAS. Besides, SESM and SYNK points have attained narrow signal clearance sight to GPS satellites over the years because of overgroving vegetation and trees. Moreover, SESM point has produced a velocity vector which may be contributed to local movements of the point. SASK point, on the other hand, is closer to the fault line than the rest of the points, which might be affected by the fault's local movements. Table 3 lists the Eurasia-fixed velocity field of the points in the network for the period of years 2005-2010 and Figure 4 their horizontal velocities.

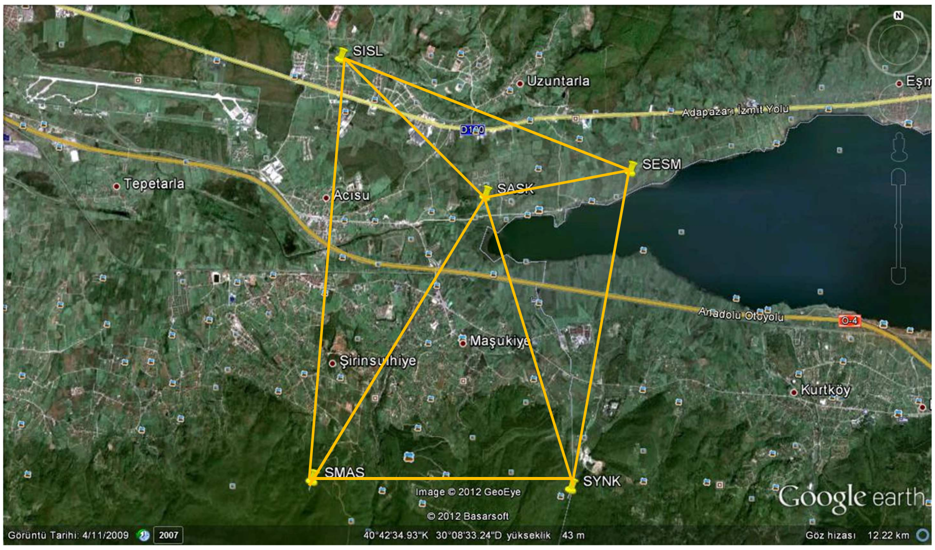


**Figure 3.** Locations of the Sapanca micro-geodetic points (courtesy of Google Earth™)

| Site | Lon. (deg) | Lat. (deg) | $E_{vel}$ (mm/yr) | $N_{vel}$ (mm/yr) | $E_{sig}$ (mm/yr) | $N_{sig}$ (mm/yr) |
|---|---|---|---|---|---|---|
| SASK | 30.159 | 40.730 | -12.17 | -0.71 | 0.65 | 0.76 |
| SESM | 30.181 | 40.735 | -7.50 | -8.01 | 1.28 | 1.55 |
| SISL | 30.130 | 40.745 | -6.35 | -1.20 | 0.75 | 0.89 |
| SMAS | 30.134 | 40.690 | -19.58 | -0.02 | 0.86 | 1.00 |
| SYNK | 30.176 | 40.691 | -16.82 | -0.88 | 3.45 | 4.05 |

**Table 3.** Eurasia-fixed velocity field of the points in Sapanca micro-geodetic between the years 2005and 2010.

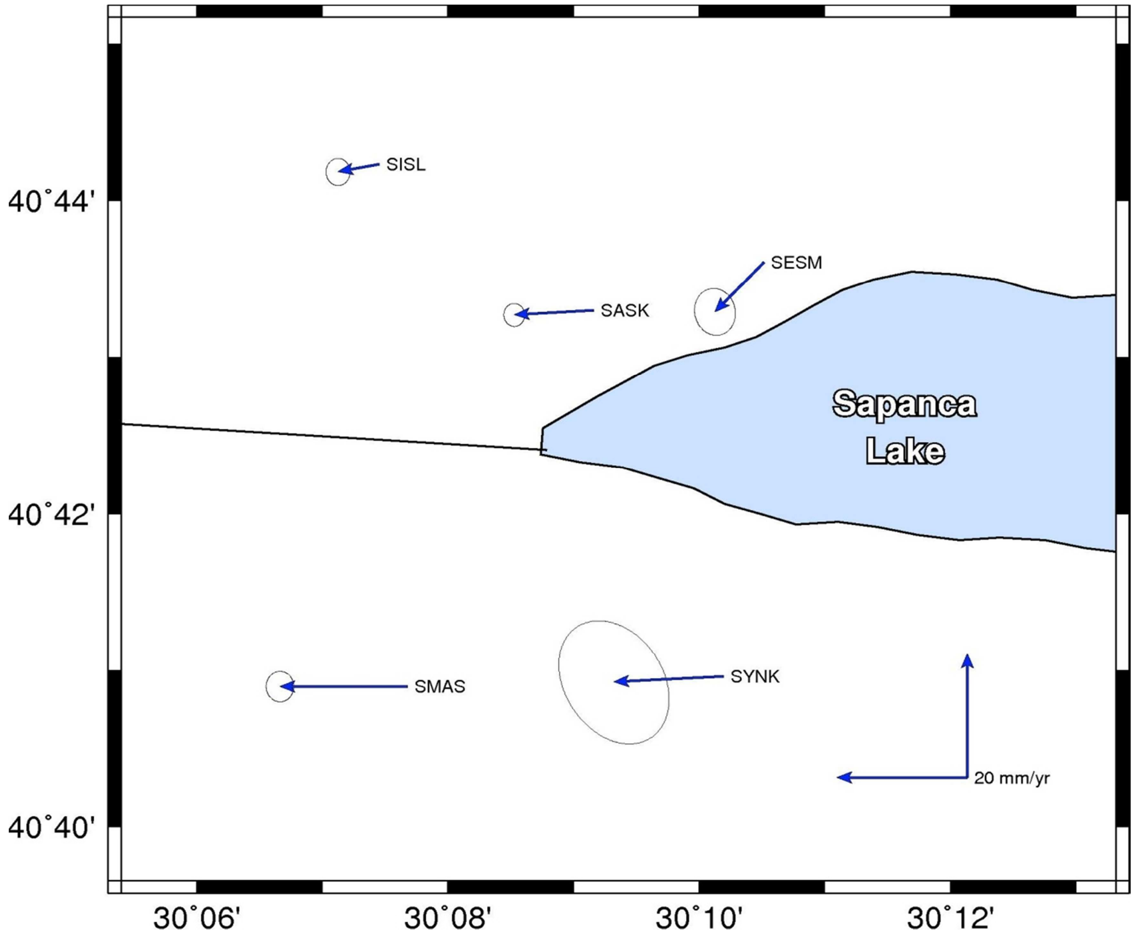


**Figure 4.** GPS horizontal velocities and their %95 confidence ellipses in a Eurasia-fixed reference frame for the period of 2005-2010

The directions of horizontal velocities from the Sapanca micro-geodetic network are in coherence with the results obtained for the horizontal velocities of the same area found by [Aktug et al, 2009] as given in Figure 5.

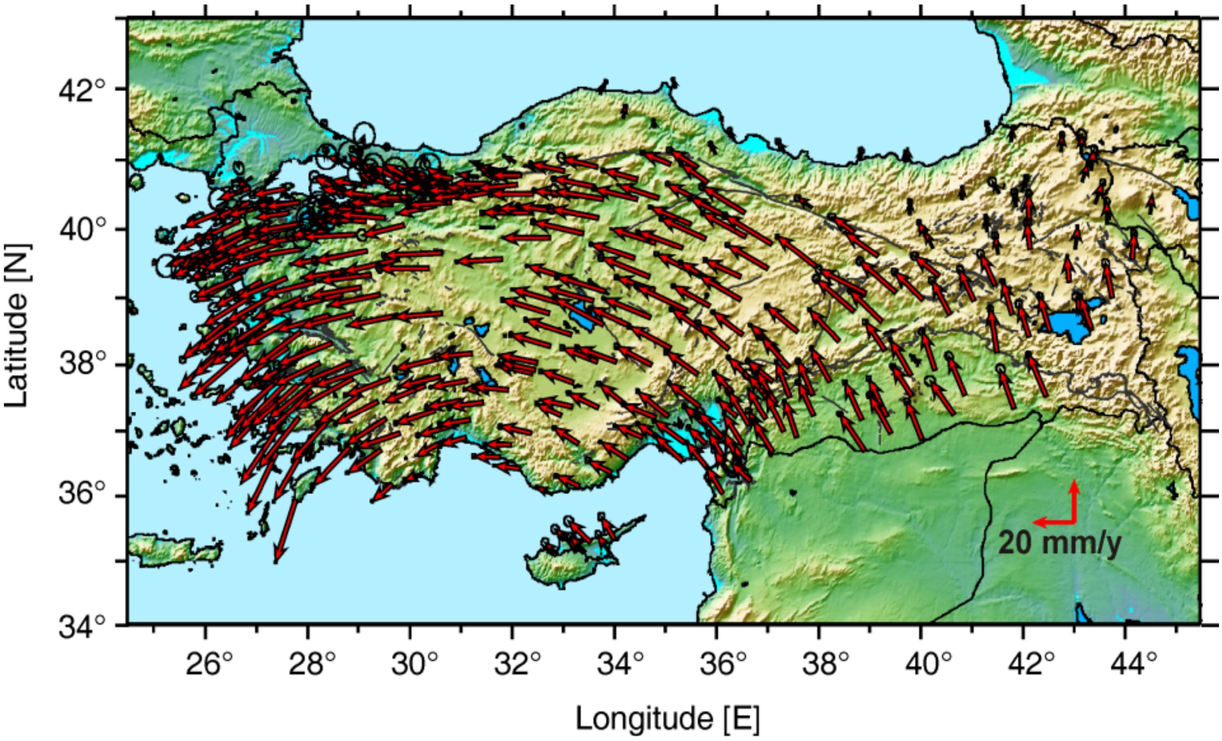


**Figure 5.** Horizontal Velocity field in a Eurasia-Fixed Frame using residual velocities of 17 IGS sites in Eurasia (ellipses are at 95% confidence level).(Aktug et al., 2009)

## 3. CONCLUSIONS

After the analyses of the GPS observation periods it has been found that the point SISL on the northern part of the fault moved 6.5mm per year while the point SMAS on the southern part of the fault 19.6mm per year in a Eurasia-fixed frame. This finding appears to be in conformity with the known behavior of the North Anatolian Fault Zone.

The anomaly observed at the point SESM is considered to stem from the individual movement of the point which is not attributed to the seismic origin. Furthermore, the point SYNK has a diminishing signal clearance to visible satellites of its horizon owing to fast growing vegetation and trees around the site over the years, hence its elevated sigma values and large error ellipse (Figure 4). It is our assessment that the results ought to be improved by repeating GPS observations in this network.

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## BIOGRAPHICAL NOTES

Asc. Prof.Dr**. Cetin Mekik** was born in 1967. He graduated from Istanbul Technical University in 1988 as Geodesy and Photogrammetry Engineer. He obtained M.Phil. and Ph.D. degrees from Newcastle upon University, United Kingdom. He is currently working as a lecturer and researcher at Geodesy and Photogrammetry Engineering Department of Zonguldak Karaelmas University in Turkey. He has specialized in GPS and Network RTK (CORS networks) and recently completed the task of the technical supervising the CORS-TR (TUSAGA-Aktif Network) project for the Scientific and Technical Research Council of Turkey.

Mr. **Bulent Turgut** was born in 1966. He received the B.S. degree (1988) in Geodesy and Photogrammetry Engineering from Istanbul Technical University. He is currently working at

Geodesy Department of Kandilli Observatory and Earthquake Research Institute, University of Bogazici in Turkey and he is currently M.Sc. student in Geodesy and Photogrammetry Engineering of Zonguldak Karaelmas University in Turkey.

Prof. Dr**. Haluk Ozener** was born in 1967. He graduated from Istanbul Technical University in 1988 as Geodesy and Photogrammetry Engineer. He obtained M.Sc. and Ph.D. degrees. He is currently is the Vice Director of Kandilli Observatory and Earthquake Research Institute of Bogazici University and is also chairing the Geodesy Department. His primary field of research is Tectonic Geodesy.
He is member and director of over 20 research projects and the author/co-author of over 100 publications related to Active Tectonics of North Anatolian Fault Zone/East Anatolian Fault and Aegean Extensional Regime, geodetic monitoring of deformation, establishment of geodetic networks, GPS applications to Earth Science, earthquake hazards, bathymetric surveying, Geoinformation Systems/GIS applications.
He also serves as the chair of sub-commission 3.2 (Tectonics and Earthquake Geodesy) of IAG (International Association of Geodesy).

## CONTACTS

Asc.Prof.Dr. Cetin Mekik
Z. Karaelmas University
Engineering Faculty
Geodesy and Photogrammetry Eng. Department
67100 Zonguldak
TURKEY
Tel: +90532 4712203
E-mail: cmekik@hotmail.com
Web site: http://jeodezi.karaelmas.edu.tr/links/akademik/mekik/mekik.htm

Mr. Bulent Turgut
Bogazici University
Kandilli Observatory and Earthquake Research Institute
Geodesy Department
34680, Cengelkoy
Istanbul
TURKEY
Tel. + 90 216 5163352
Fax + 90 216 3320241
Email: turgut@boun.edu.tr
Web site: http://www.koeri.boun.edu.tr/jeodezi/turgut/en/index.htm

Prof. Dr. Haluk Ozener
Bogazici University
Kandilli Observatory and Earthquake Research Institute
Geodesy Department

34680, Cengelkoy
Istanbul
TURKEY
Tel. + 90 216 5163264
Fax + 90 216 3320241
Email: ozener@boun.edu.tr
Web site: http://www.koeri.boun.edu.tr/jeodezi/ozener/en/index.htm
**BIOGRAPHICAL NOTES**

**CONTACTS**

Title Given name and family name
Institution
Address
City
COUNTRY
Tel. +
Fax +
Email:
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