Turkish National Fundamental GPS Network (TNFGN)

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Abstract

The realization of Turkish National Fundamental GPS Network (TNFGN) has been achieved after three years of data collection and analysis effort. The network points having inter-station spacings of about 15 – 65 km were also collocated at some points of Turkish National Horizontal Control Network and Vertical Control Network. Among those points, some of the existing GPS stations previously measured within the content of geodynamic activities was also surveyed. Those stations having adequate number of repeated occupations were utilized in order to determine the velocity field of Turkey. All GPS data were processed by Bernese Software Version 4.0 using IGS products. Combination of TNFGN data together with specific number of IGS global sites common in each year solution has been managed by GLOBK Software Version 5.06 with all previously measured data in Turkey. The station coordinates and velocities were computed in ITRF96. Processing of data yielded daily repeatabilities of about 1 – 4 mm for North and East components and about 5 – 7 mm for Up component. Overall evaluation has showed of about cm or better station coordinate accuracy in 3D.

1. Introduction

Geodetic activities for the establishment of fundamental horizontal, vertical, gravimetric and magnetic control networks of Turkey have been performed in a period of spanning about 70 years. Most of those control networks have been completed and put into the service of geodetic community within the last 30 years of 20th century.

The advents in modern geodetic data collection instrumentation had made it possible and easy to maintain the improvement and optimization activities of those networks within last phase or right after their establishments. During the same period, the requirements for making connections and referencing reliable and accurate fundamental networks have been increased in the field of geographic and land information system materials servicing in the production of large scale mapping. However, basic and the most important motivation for the improvement and the control of the geodetic networks in Turkey have been the deformation phenomena from the respect of its highly active tectonic nature in its origin.

Turkey is situated in eastern Mediterranean within Alpine-Himalayan tectonic belt, where continental collision of major plates Africa, Arabia and Eurasia take place. In order to monitor the activity and to make geodetic inferrements for the area, many space based geodetic projects have been initiated. When the aims were thought out at the planning phase of those projects, we quantified two types of work. One was to investigate the plate kinematics and the dynamics of the region at selected areas according to the tectonic settings without paying particular attention to the geometric distribution of the points; other was to establish geodetic control and maintain the process for the solutions of geodetic and geophysical problems. Even though such a quantification exists in the nature of the performed works, it is possible to cogitate no noticeable discrepancies when the quality of the data is considered at the expense of almost the same data analysis strategies (global sites, IGS products, models at sophisticated processing software etc) are applied. In this respect, in the foundation of Turkish National Fundamental GPS Network, we made use of all periodically observed GPS data available in Turkey since 1992 in order to determine time dependent coordinates in a well-defined reference frame and to make inferrements for the deformation of the area.

Turkish National Fundamental GPS Network (TNFGN) was planned under these considerations in 1996. About 600 points, of which some are coincident with the previously measured existing GPS points and Horizontal and Vertical Control Network stations, were established to determine three dimensional coordinates (X,Y,Z) and their velocities (V_x,V_y,V_z) and orthometric heights (H) and geoid heights (N) of the stations.

In the second and third section, the measurements and their analysis of TNFGN will be explained; and, in the third section, the determination of velocity field pertaining all data will be given. Orthometric heights and geoid heights are out of the scope of this report.

2. GPS Measurements

In order to meet the above stated purposes, General Command of Mapping (GCM) has initiated the project activities by defining the technical criteria and the requirements for planning, field recognizance, observation and data analyses phases of Turkish National Fundamental GPS Network under a document called "Technical Specifications of Turkish National Fundamental GPS Network" in 1997 /1/. According to this document, stations of the TNFGN were mainly composed of two types of geodetic points;

a) Old stations from existing networks established so far in Turkey. These essentially comprise the stations from
   - First and Second Order Horizontal Control Network
   - First and Second Order Vertical Control Network

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- Satellite Laser Ranging (SLR) stations from WEGENER/MEDLAS project (Yigilca, Melengiçlik, Yozgat and Ankara)
- Collaborated Geodynamic Project Networks of Turkish Union of Geodesy and Geophysics with Massachusetts Institute of Technology (MIT), Federal Institute of Geodesy and Cartography (BKG formerly IfAG), Technical Institute of Zurich, Switzerland (ETHZ),
- Turkish National Permanent GPS Network (TNPGN). At the time of establishment of TNFGN, only three stations (Ankara, Diyarbakir and Gebze-TUBI) were contributed from TNPGN.

b) According to the definition of the TNFGN, the new sites were so selected in order to meet the requirements stated in Technical Specification Document. These were planned as to be evenly distributed all country within the inter-station distances 15 to 65 km considering the Turkish Geoid surface trend in Anatolian and Thrace peninsula and geographical aspects. The outlines for the new site selection can be summarized within the following considerations /1/;
   - Station accessibility for almost all seasons; so they are selected as to be around urban areas, not too close to be destroyed in the urbanization phase but, away from them as to allow easy travel in between the roads connecting the provinces.
   - Ground status allowing the pillar construction at stable and hard bedrock for the durability of the stations.
   - Satellite observational constraints for an electro-magnetic and multipath free environment in the vicinity of the stations.

All stations were numbered on the basis of Turkish 1 : 100 000 scaled topographic map index and they were quantified according to the above stated point types and plotted onto those maps. Following to the reconnaissance, all new stations were built as concrete pillars and the existing markers were checked for the observations. The duration of main phases of the project for three years was summarized in Tab. 1.

As it was stated in the introduction, among the motivations for the foundation of such a network are to determine the datum transformation parameters between the local datum (ED-50) and ITRF as well as determination of GPS levelling geoid of the country. So, the connections were ensured by occupying the existing Horizontal Control (Triangulation) Network and the precise leveling observations were conducted in order to make links between the TNFGN stations and the Vertical Control (Leveling) Network. Even the envisaged number of common points were adequately selected in planning phase, we unexpectedly come up with small numbers of common triangulation station especially in Black Sea region because of destruction of horizontal points. In this respect, the station characteristics and the number of points observed for each year of the project was given in Tab. 2.

Tab. 1: Main phases of TNFGN and the established/observed stations.

years	recognisance & construction	observation / dates	total stations
1997	02 JUN-14 JUL / 42 days	12 AUG(224)-10 NOV(314) / 46 days	296
1998	15 MAY-13 JUN, 24 JUN-02 AUG / 60 days	16 JUN(167)-22 JUN(173), 04 AUG(216)-03 NOV(307) / 55 days	207
1999	Done 3 days before observations at a station	28 JUN(179)-20 AUG(232) / 21 days	91

Tab. 2: Station characteristics in TNFGN.

YEARS	New Stations	Existing Stations			Leveling Connections		
		Hor. Cont.	Ver. Cont.	Geodynamic	New Station	Hor. Cont.	Geodyn.
1997	105	54	-	41	72	5	19
1998	109	27	1	16	46	1	7
1999	58	7	-	6	19	-	1
TOTAL	272	88	1	63	137	6	27

The observations in 1997 have been taken place in Western, Central and Black Sea regions of Turkey within seven sub-areas starting from east to west and then south directions. Within each group (sub-area), two stations were held continuously operated while at least two regional (mainly SLR and Permanent Sites) stations were operated in common between successive groups. By adopting such an observation strategy, we have intended to make enough data redundancy in between sub-area observations allowing control and redundancy checks in the analyses. Almost similar strategies were followed in 1998, where the observations were mainly performed Mediterranean, Central and western part of Eastern Turkey. In the last phase of the project, that's in 1999, we divided the observation region, Eastern Anatolia, into three sub-areas and hold one quasi-permanent site during all observation days in addition to the TNPGN stations /2/. The distribution of the network stations was shown in Fig.1.

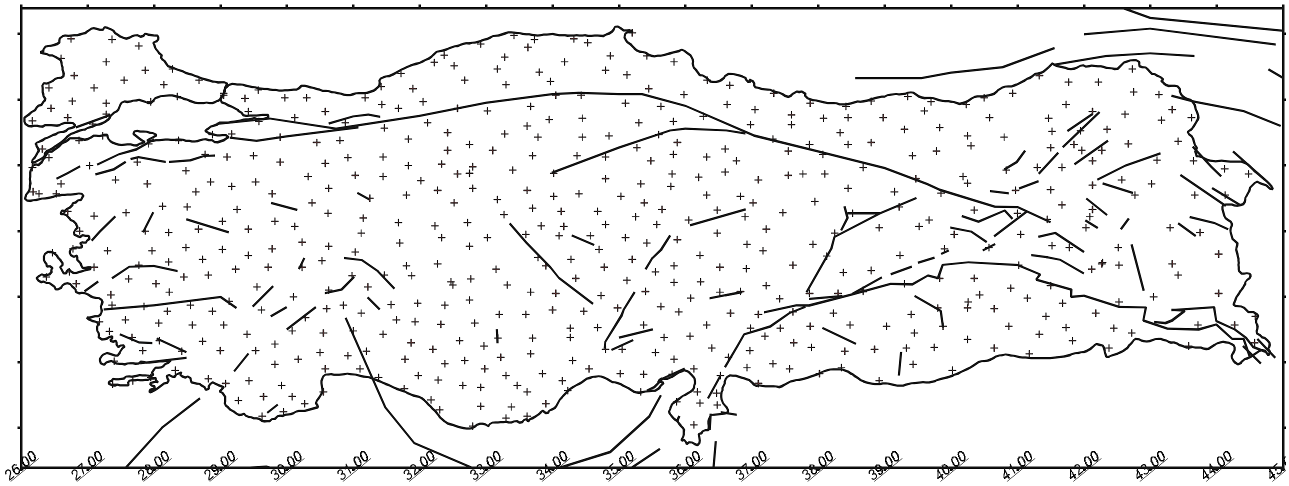

Fig. 1: The distribution of TNFGN stations.

The network stations were observed in relative static observation mode collecting phase and code data by utilizing dual frequency geodetic receivers given in Tab. 3 /2/. It has been adopted almost the same the observation parameters pertaining for three years of campaigns. These were summarized in Tab. 4.

Tab. 3: Receiver types and their quantities used in the local observations of Turkish Fundamental GPS Network.

RECEIVER TYPES	1997	1998	1999
Trimble 4000 SSE	8	7	6
Trimble 4000 SSI	-	-	6
Ashtech Z-Surveyor	-	5	3
Leica System 300	9	-	-
Turbo Rogue 8000SNR	1	1	2

Tab. 4: Observational Parameters used in the TNFGN measurements.

PARAMETERS	CRITERIA
Observation Time	7 hours (local sites) 12 hours (Common sites between sub-areas) 24 hours (Permanent stations)
Number of sessions	2 days/station
	3-7 days /common stations between sub-areas
Satellite cut-off angle	15 degrees
Data sampling rate	30 seconds
Min number of satellites observed	1
Meteorological observations	At the beginning and the end of one session
Leveling tie measurements	Two-way control measurements meeting $\pm 6\sqrt{K_{km}}$ K: levelling distance

3. Data Analysis

For the processing of the TNFGN stations, two software suites were used. The data reductions including pre- and post-analysis of the data were performed by using Bernese Software Ver 4.0 /3/, whereas for the combination and the estimation of station coordinates and site velocities, GLOBK software /4/ was used.

The Bernese Software primarily uses double differences as basic observable while four different linear combinations (ionosphere free LC, geometry free LC, wide lane and Melbourne-Wübbena) of the original phase and code data on L1 and L2 frequencies in parameter estimation algorithms. In the pre-processing stage, all local data were converted into the Receiver Independent Exchange Format (RINEX) by paying proper attention to the reduction of antenna heights to the Antenna Reference Point (ARP) following the standard values for different antenna types posted at International GPS Service (IGS) web site (http://igscb.jpl.nasa.gov). The antenna phase center offsets for all receivers and available satellites were obtained from the analysis Center for Orbit Determination in Europe (CODE) under IGS.

For all the analyses of three-year data, RINEX data of almost the same subset of global stations operating under IGS Global Network were downloaded from IGS global data centers. Additionally, earth rotation parameters (ERP), the combined precise IGS orbit information in SP3 format and ITRF coordinate and velocity solution files were obtained from IGS Central

Bureau. In 1997, we have adopted the ITRF94 coordinate solution of IERS, while it was ITRF96 for 1998 and 1999 in the post-processing stage of the data /5/. The global site coordinates were translated to the observation epoch by well-known equation

$$X(t_c) = X(t_o) + V_x (t_c - t_o)$$

Where t_c and t_o are the observation and reference epochs respectively and V_x is the station velocities in related ITRFyy solution set/6/. The global sites and their published and translated coordinates used in the analyses were tabulated in Tab. 5. We have benefited much from IGS precise ephemerides having an accuracy of about better than 10 cm by holding them fixed within one-day arcs. The same is also true for IGS-computed satellite clocks and earth rotation values which were regularly organized for all years. Utilizing all these information and the original code data, receiver clock offsets and the approximate station coordinates were estimated and in-between station (single) differences were formed according to the survey plan in the area. Also an ionosphere model was created for each day using phase data of representative stations in that session. And all raw phase data were passed through editing algorithm in baseline mode, later the ambiguities were resolved by Quasi Ionosphere Free (QIF) method. For each station and its relevant observation time, tropospheric zenith delays were estimated. Following, the sessions were estimated with very loose constraints and the internal precession checks-repeatabilities were performed. A summary of measurement model used in the processing by Bernese Software was given in Tab. 6.

Tab. 6. Summary of models used in the processing stage.

Orbit	IGS final combined orbits
Earth orientation parameters	IGS final ERPs
Satellite clocks	IGS final satellite clocks
Troposphere	Saastomoinen model Zenith delays estimated per 2 hours A priori weights: 5.00 m (Absolute); 1.00 m (Relative)
Ionosphere	Single layer model created by local phase data
Receiver clocks	Corrections estimated by code data in epoch-wise
Antenna phase centers	IGS phase center definitions
Phase ambiguity resolution	Quasi ionosphere free (QIF) algorithm
Weighting strategy	Double difference observable :1-2 cm 15 degrees cut-off angle without elevation dependent weighting

In the parameter estimation phase of individual year (1997, 1998 and 1999) solutions, we performed three-step computation scheme; each day in a year has first combined by loose constraints of about ±1 m and their normal equations have been obtained. Consequently, a similar loose combination has been performed for groups and then we did a final loose solution in order to get the campaign (year) using normal equations obtained in previous steps. Utilizing loose solutions, we intended to check the short-term repeatabilities as an indication of internal precision of each year data. Those repeatabilities for each year have been depicted in Fig. 2, 3 and 4 for years 1997, 1998 and 1999 respectively.

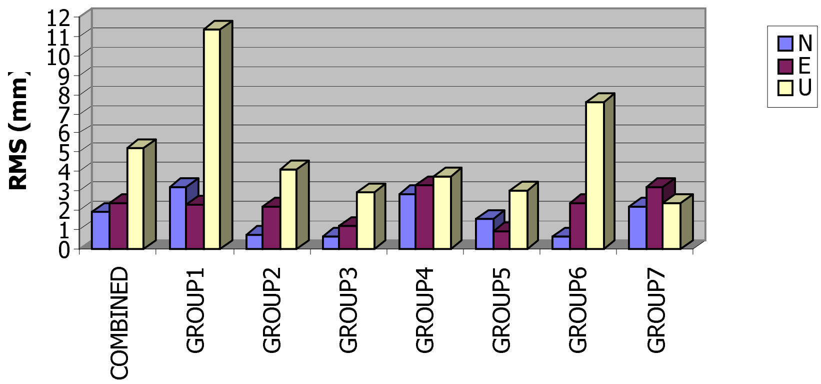

Fig. 2. The repeatabilities of the groups with respect to the combined 1997 solution.

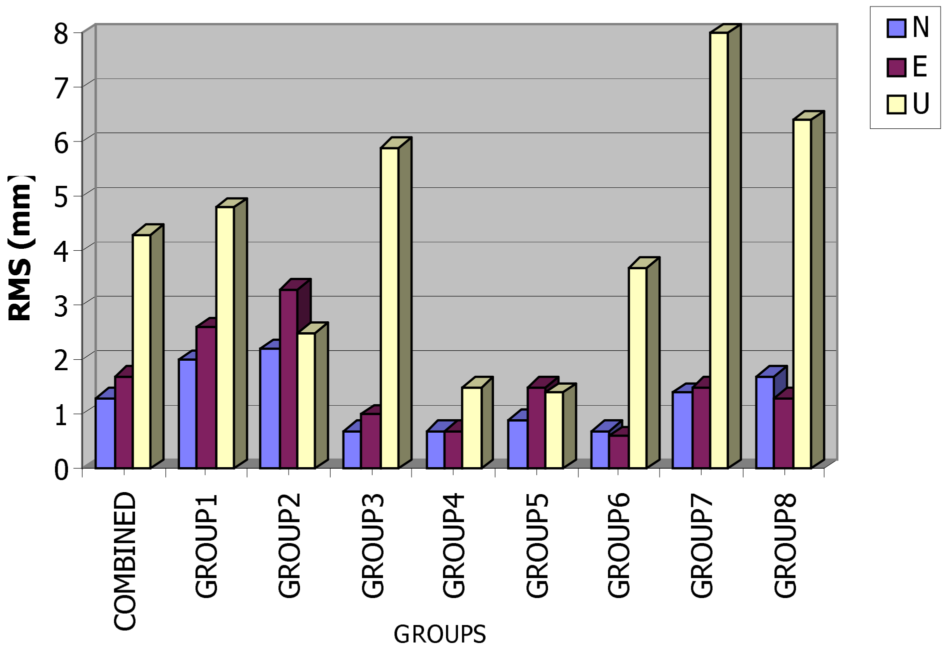

Fig. 3.The repeatabilities of the groups with respect to combined solution in 1998

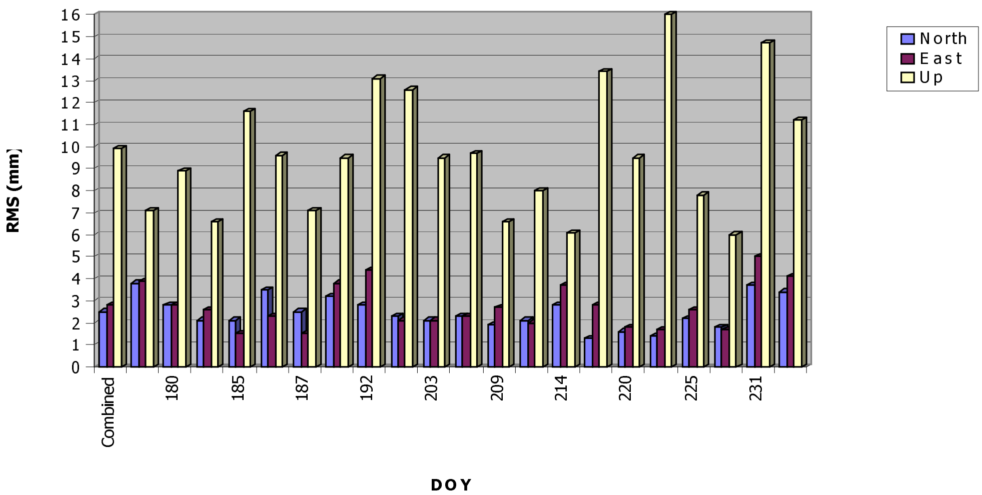

Fig. 4. The daily repeatabilities for the year 1999.

The first column in the Fig. 2, 3 and 4 is the weighted average rms of all the relevant data in that year. As it can be seen from Fig. 2, repeatabilities for north and east components are about 3 mm, whereas it is 11 mm for up component in 1997. The values for the repeatabilities in 1998 are better as they are about 1.5, 2 mm and 7 mm for north, east and up component respectively. In 1999, the values that we obtained are about 2.5 mm, 2.8 mm and 9.9 mm for north, east and up components /5/, /7/.

Additionally, for each year, we have checked the external accuracy of the solutions by holding fixed a global site coordinate (Wettzell) and then estimate the coordinates of the rest of global sites. When they were compared with their observation epoch translated coordinates, we came up the tolerable differences ranging from 0.1 cm to 2.2 cm except Kitap and Bahrain sites in 1998 and 1999. So, they were accordingly considered in the combination stage while reference frame was going to be defined in GLOBK software.

Velocity Field Determination

Turkey is situated in an active deformation region in eastern Mediterranean within Alpine-Himalayan organic belt, where continental collision of major tectonic plates Africa, Arabia and Eurasia take place. The simplified tectonic elements of Turkey and its surrounding has been depicted in Fig. 5.

In the figure, it is possible to see the right-lateral transform, normal and thrust fault zones in the plate boundary and intra-plate boundary deformation zones. The most significant tectonic process causing active deformation in the area is closely related to the northerly motion of the Afro-Arabian plate relative to the Eurasia /8/. The tectonic activity in the region is basically described as the collision along Bitlis and Zagros thrust and fault belt in east Anatolia caused by north and northwest motion of Arabian plate with respect to Eurasia plate with a velocity of 20 mm/yr, yielding a compression in the east and, consequently, westward motion and counter-clock wise rotation of Anatolian plate with a rate of 20-25 mm/yr. In the west, as a result of Africa plate motion in the north direction with a velocity of about 5-10 mm/yr towards Eurasia, and its subduction at Hellenic arc causes an extension of Aegean block with a velocity of about 30-35 mm/yr /8/, /9/.

When such an active deformation in the region is taken into consideration, the determination coordinate variations with respect to time plays an utmost importance for the continuous maintenance and the improvement of TNFGN stations. It is unavoidable that the initial accuracy of the network may be deformed in a very short time unless velocities of network stations have not been properly determined. Time dependent coordinate changes at the points are generally quantified by inter-seismic effects caused by the motion of tectonic plates before the earthquake and the co-seismic effect at the time earthquake epoch and the post-seismic effects after earthquakes.

Since, only the 15 % of the TNFGN stations (Tab. 2) have been repeatedly observed, secular velocities are only known for these stations. It has been planned to re-measure TNFGN within five years in order to determine the velocities for the rest of the stations. However, in order to meet the present day requirements, additional repeated data set which have been previously observed in Turkey have been included to the TNFGN data. Utilizing this data, it has been aimed to determine the secular velocity field of the region at single epoch observation stations by some prediction methods which shall be explained below.

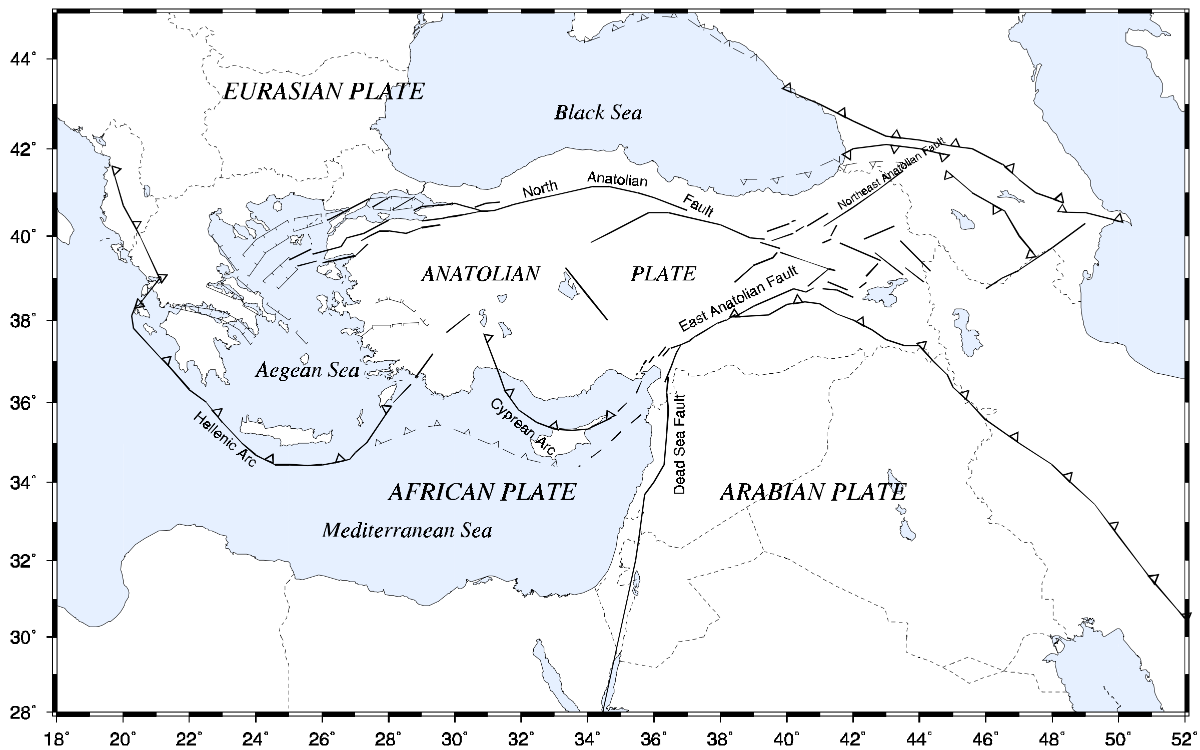

Fig. 5: The simplified tectonic features of the area. Solid lines are strike-slip faults, line with thick marks normal faults and the lines with triangles are thrust faults with triangles on the overriding block (After McClusky S. et al.).

In this respect, previously measured data set, which have been collaboratively collected by some institutions abroad during years between 1992 and 1999, have been first analyzed by Bernese Software as it is explained in sections 2 and 3, later they have been input to the GLOBK software, consequently, they have combined and velocity field has been determined /10/, /11/. Even though, we have surveyed GPS data before 1992, we haven't included them because of lack of availability precise ephemerides and earth rotation parameters at that time. All data used in this combination have been summarized in Tab. 7.

Tab. 7: The existing data in between 1992 and 1999 used in the combination together with the TNFGN. The values in the parenthesis indicate the number of local and global IGS stations

Camp.\Yr	1992	1993	1994	1995	1996	1997	1998	1999	Remarks
MIT	X (29)		X (65)		X (79)		X (64)		MIT
NAFZ	X (34)	X (35)		X (38)		X (39)			North Anatolian Fault Zone-BKG
MARM	X (51)		X (57)		X (17)				ETHZ (Marmara Region)
WETR	X (42)	X (41)	X (26)			X (44)			Western Anatolia-BKG
MARE				X (10)					GCM Campaign on tide-gauges
EUVN						X (15)			GCM-EUVN Campaign
KTGA							X (30)		GCM Campaign on the Turkish Republic of Northern Cyprus
MARS							X (50)	X (38)	Marmara Project (TÜBITAK, GCM, Ist. Tech. Uni. and Bogaziçi Uni.)
TNFGN						X (302)	X (225)	X (106)	TNFGN

In the combination phase of the data by GLOBK software, two different approaches were adopted. In the first one, each observation campaign were independently evaluated, and, in the second one, a coherent year solution has been obtained by combining the individual campaigns having negligible time period (3 months or less) in between each of them in a year. In case that time period is greater than 3 months, then, they were included into the combination as single campaign. In both approach, similar results have been obtained. These computations have been performed by both ADDNEQ (Bernese Software) and GLOBK. However, because of memory limitations in ADDNEQ, all campaigns except the TNFGN were combined by two software at the same time in order to check the results. It has been observed ignorable amount of differences. Later, by including TNFGN data, all campaigns were combined by GLOBK applying 1 mm constraints on the ITRF96 coordinates and the velocities of six IGS station (ONSA, MATE, WTZ1, WTZR, GRAZ, ANKR) and the coordinates and the velocities of all stations in ITRF96 have been obtained (Fig. 6).

Additionally, the relative velocity field of Turkey and its surroundings have been determined. For this reason, the Eurasia-fixed reference frame have been defined using the same six IGS sites. The published coordinates in ITRF96 (Epoch 1997.0) of these stations have been directly adopted as a-priori coordinates. On the other hand, the plate velocities of the same sites have been computed by using Cartesian rotation elements (Ω_x, Ω_y, Ω_z) given in NNT-NUVEL-1A /3/ global plate model; later, residual velocities have been computed by subtracting these velocities from the same stations' ITRF96 values. Lastly, by constraining 1 mm the coordinates and the residual velocities, the velocity field of Turkey in Eurasia-fixed frame has been obtained (Fig.7).

In order the estimate the inter-seismic velocities of TNFGN sites having no repeated observations (cr. ref Tab. 2) by using the velocities already estimated at repeated sites, some prediction methods were applied /12/. These were Weighted Average (WA), Surface Polynomial (SA) and Least Squares Collocation (LSC). Following the method explained above, at about 179 repeatedly observed stations, the velocity components in Geocentric Cartesian System (V_x, V_y, V_z) and in Local Geodetic System (V_n, V_e, V_u) have been determined. For the prediction of the velocities, any of the mentioned coordinate system can be taken as the observation group, and then, the conversions can be easily done by using the equations given in /13/. In the study, the velocity components in Local Geodetic System (V_n, V_e, V_u) have been adopted as observation group, and the velocities at the other sites have been predicted using three prediction techniques stated above. Even the results from WA and LSC were considerably agree with each other, it has been seen that SA method has been differed from both techniques. It has been considered that SA wasn't a convenient method for the determination of local behaviour of velocity field due to smoothing in itself.

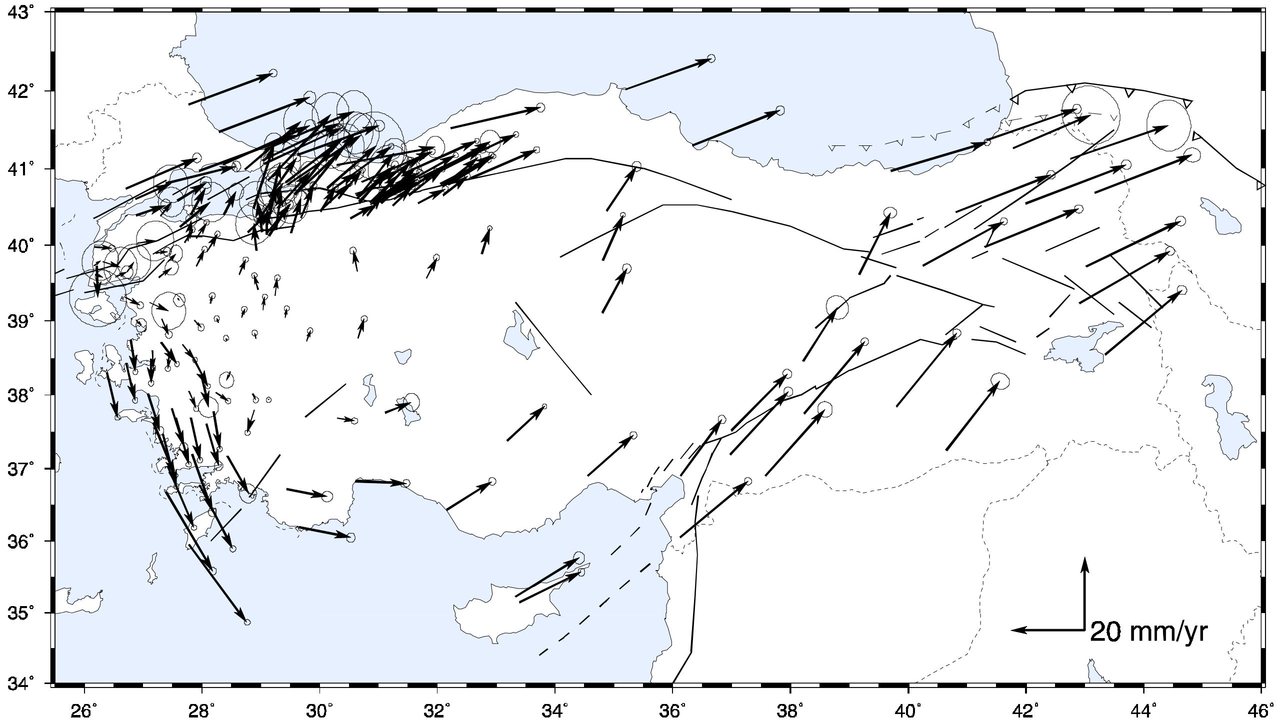

Fig. 6. ITRF96 velocity field of periodically observed stations including TNFGN sites.

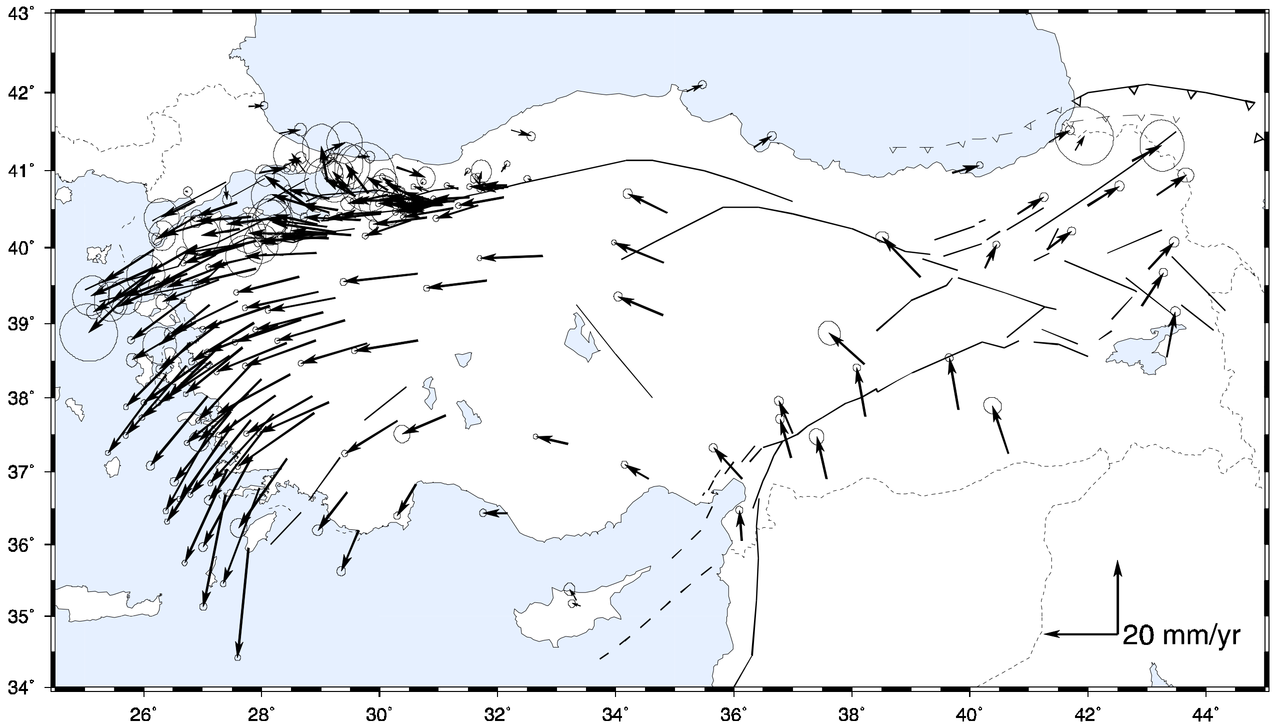

Fig. 7. The velocity field of Turkey in Eurasia-fixed frame.

The differences in methods applied have been increased in plate boundaries, especially in the triple junctions of major plates Arabia, Anatolia and Eurasia. This was highly because of inadequate number of observations in these areas. Additional GPS observations have to be planned in such areas in order to model deformation efficiently. On the other hand, The agreement in the results of WA and LSC have been interpreted as they have had similar characteristics /12/. WA method can be reliably used for most of the practical purposes since the standard deviations in the predicted velocities in LSC method have appeared larger. The horizontal velocity field computed by WA method for those TNFGN stations having no repeated GPS observations has been depicted in Fig. 8.

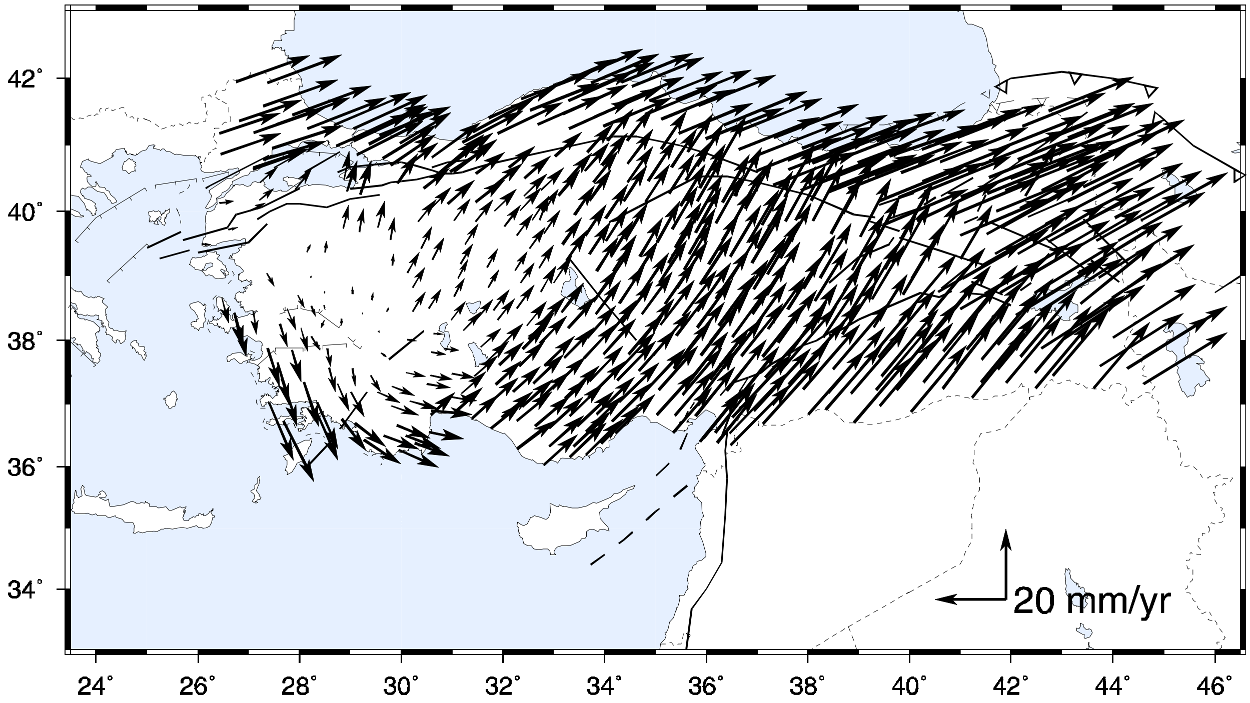

Fig. 8. Horizontal velocity field (V_n, V_e) predicted from the velocity estimates of repeated GPS stations in ITRF96.

5. Results

About 770 GPS stations have been observed in Turkey since 1988. The majority of those stations (about 531), which has single-epoch observations, were surveyed and analyzed within the establishment of Turkish Fundamental GPS Network by General Command of Mapping. The rest of the stations have been repeatedly resurveyed (at least two times) within the collaborated projects. The analyses of all stations surveyed after 1992 have been achieved by General Command of Mapping, and the coordinates and the velocity field have been determined in ITRF96. All data were archived in a data base and the continuous analyses were being carried out whenever a new campaign data was included to the all data group.

The computed velocity field reflects the inter-seismic variations at the stations in question. The current studies are still being carried out in order to model the co-seismic and post-seismic displacements caused by the earthquakes happened in Marmara and Central part of Turkey.

Since it is of great importance to control and monitor the on-going deformation in such a network, it has been planned to re-survey the TNFGN beginning from 2000. On the other hand, the stations from Horizontal Control Network have been included into the re-survey plan Also, the continuous data from Turkish Permanent GPS Network (TURPEGN) are still being utilized in the same sense.

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