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GPS Survey of the Western Tien Shan

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REPORT ON THE TIEN SHAN GLOBAL POSITIONING EXPERIMENT, 1994

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There were two major developments in 1994 in our collaborative GPS experiment in the Tien Shan of the Former Soviet Union (FSU). Both were motivated by our expectation that we will ultimately obtain better science at lower cost if we involve our colleagues in the FSU more deeply in 1) the collection and 2) the analysis of data. As an experimental test of the concept of having our local collaborators carry out the field work semi-autonomously, we sent 6 MIT receivers to the Tien Shan for a period of 3 months. To enable our collaborators to have the capability for data analysis, we provided computers for two data analysis centers and organized a two-week training session, run by Professor Thomas Herring of MIT.

This report emphasizes the rationale for deeper involvement of FSU scientists, describes the training sessions, discusses the data collection, and presents the results. We also discuss future plans. More detailed discussion of background, general scientific objectives, discussions with collaborators, and results for the campaigns in 1992 and 1993 have been given in previous reports. This project involves the amalgamation of two, separately funded projects, one by PIs Hamburger and Reilinger and the other by PIs Molnar and Hager. Each of these two projects is funded jointly by NASA and NSF. In addition, the work is being conducted under the auspices of the US-USSR Agreement on Cooperation in the Field of Environmental Protection, with support from the United States Geological Survey.

GENERAL SCIENTIFIC OBJECTIVES AND BACKGROUND

As the world's most prominent intracontinental mountain belt, the Tien Shan provides an outstanding natural laboratory to address two general problems in geodynamics: (1) the processes by which distributed intracontinental shortening occurs, and (2) the mechanisms that allow strain to be absorbed adjacent to an intracontinental strike-slip fault along which slip varies markedly. Moreover, with a high level of seismicity and with rapid deformation, the Tien Shan offer the potential for witnessing post-seismic deformation and the opportunity to study localized deformation within the regional framework of intracontinental tectonics.

Intracontinental mountain building. The present range owes its height and high level of seismic and tectonic activity to roughly north-south crustal shortening. Hence, it serves as a prominent consequence of India's collision with and subsequent penetration into the Eurasian Plate (Figure 1). Yet, this area lies 1000-2000 km from the northern edge of the Indian plate, and hence deformation should be largely unaffected by peculiarities of the ancient plate margin. Thus, the Tien Shan provides a laboratory to study intracontinental shortening without the influence of asymmetries of kinematics and structure established at the time of the collision, as are clear, for example, in the Himalayas and the Alps.

Approximately two thirds of our network spans a segment of the Tien Shan where the structure is relatively simple. Ranges and intervening basins trend nearly east-west. Blocks of crust, with east-west dimensions of approximately 100 km or more, constitute ranges that are thrust over other blocks to form basins. North-south dimensions of such blocks of only 20-30 km are comparable to the depths to the more ductile lower crust. We anticipate that a comprehensive study of the velocity field in this region will allow us to study the interconnections of the block movements and deformation at depth and to understand how the penetration of India into the rest of Eurasia is communicated to the areas farther north.

Strike-slip geodynamics. The Tien Shan offers a good example of a second feature peculiar to intracontinental deformation. A major strike-slip fault, the Talaso-Ferghana fault, truncates the western part of the region (Figure 1). The east-west trending blocks and the faults between them seem to be cut off by the Talaso-Ferghana fault. Moreover, the Talaso-Ferghana fault ends in the northwestern part of the Tien Shan. In oceanic regions, transform faults, along which slip is constant, abruptly truncate at spreading centers and subduction zones. In continental regions, however, strike-slip faults do not end abruptly, but seem to "die out" by distributed, permanent deformation on one or both sides of the fault. The Talaso-Ferghana fault is perhaps the world's premier example of such an intracontinental strike-slip fault. Slip seems to be rapid, possibly 10 mm/yr. Yet, the fault passes from being a major structure to being absent in a distance of only 100 km. Bounding the fault on both sides are high ranges suggestive of rapid crustal shortening, but also possibly reflecting rapid rotations about vertical axes. The geometry of deformation permits us to determine the kinematics of deformation using GPS. This kinematics should facilitate an understanding of the importance of the relative strengths of the brittle layer at the surface and the region below it that flows ductilely.

We began field work in July, 1992, with a small-scale pilot experiment in the northern Tien Shan, in the republics of Kazakhstan and Kyrgyzstan. In June - July, 1993, we carried out a 7-week field experiment which constituted a major expansion of this pilot network. The field program included reconnaissance and installation of benchmarks for regional GPS sites in Kazakhstan and Kyrgyzstan, a training program for collaborating scientists, and an 18-day observation campaign covering the newly installed 86-station geodetic network. The network is closely tied to a regional GPS network established by the German GeoForschungZentrum geodetic group (GFZ), under the direction of Christof Reigber, and Kazakh, Kyrgyz, Russian, and Uzbek scientists.

As reported previously (Souter et al, 1993), we determined apparent site displacements for 12 sites by comparing the 1992 and 1993 surveys. To summarize these results, we showed that we could determine relative positions between sites hundreds of kilometers apart quickly, efficiently, and precisely, with formal errors for daily solutions of approximately ± 5 mm. Observing for many sessions decreases the uncertainties. But this decrease is not as rapid as it would be if the error spectrum were white. In particular, the largest apparent displacement between the initial 1992 survey and the repeat survey in 1993 was between two sites located on relatively stable portions of the Kazakh platform: Kurdai (KURD) and Azok (AZOK). Taken at face value, the difference suggests that KURD moved east ~ 15 mm with respect to AZOK in the interval between the measurements. The difference between relative positions of 15 mm is large, but it is smaller than the total range observed for a shorter line between MEDE and AZOK that was observed many times in 1992. With only 3 (consecutive) days of observation at KURD (and most other sites) each year, we could not reject the hypothesis that the apparent displacement is an unfortunate artifact. In fact, this is our preferred explanation – we expect there to be at most very slow (< 1 mm/a) relative movement between these sites, for both sites seem to lie on the relatively stable Kazakh platform.

Given our desire to measure and interpret tectonic displacements, not long-term errors, it became clear that it would be preferable to survey our network more frequently than once every two years, as originally proposed. But large yearly field campaigns with many US participants would be prohibitively expensive. From the large experiment that we ran in 1993, it was clear that there were many local scientists who could carry out field measurements as competently as we PIs. Perhaps a better use of resources would be to provide GPS receivers for our collaborators to use for longer periods of less intense campaigns. In addition, our FSU associates desired to become able to independently analyze GPS data collected in collaboration with us and with others. We therefore planned a pilot experiment in 1994, with no additional funding, to determine if this approach would work.

Field Measurements

In May, 1994, UNAVCO shipped 6 Trimble 4000 SSEs (P/X code) belonging to MIT to the Institute of High-Temperature Physics (Russian Academy of Sciences, "IVTRAN," under the direction of Yuri Trapeznikov) base near Bishkek, Kyrgyzstan. PI Michael Hamburger traveled to IVTRAN to provide training and oversee the planning of the campaign schedule. After this initial training, the experiment was turned over to Trapeznikov's supervision for its duration. (The presence of U.S. scientists during three different stages of the field campaign permitted us to provide technical support during the experiment and to ensure close communication with American PIs.)

Data were recorded round-the-clock in 10 60-hour and one 40-hour sessions, carried out during a six-week long campaign. Receivers operated at the IVTRAN test site near Bishkek throughout the recording period and at Cholponata (CHOL) for all but one of the sessions. In addition, several other sites were observed during several consecutive 60-hour sessions to provide better assessment of repeatabilities. Over the six-week period, we were able to observe at 38 of our 86 sites (Table 1). The GPS receivers operated nearly flawlessly for the duration of the experiment.

The equipment was returned by co-I Bradford Hager at the end of July. It was in excellent condition – the only "casualty" being a crashed hard disk in one of the PC's. (Hager brought these receivers back to the US as accompanying luggage at a cost of only $100/container.)

Data Analysis

The original data recorded in the field were transferred onto floppy disks. Three copies of all field data were made and verified before leaving Bishkek. We left one copy with IVTRAN and brought two copies to the US. One copy has been archived at UNAVCO. We will also archive a copy with CDDIS.

Our data analysis procedure has two main steps. In the first step, we break the rather long (60-hour) sessions into a series of 24-hour (or 12-hour) sessions, organized by GPS day. We analyze each day of data from all our receivers, along with data from three stations in the global tracking network, using the GAMIT software developed at MIT and Scripps. We use daily orbits provided by the Scripps orbit facility as the starting model. The data are cleaned and cycle slips patched, where possible, automatically. Integer ambiguities are resolved, where appropriate, using well-known techniques. The output of this stage of the analysis is an estimate of station coordinates and other parameters (e.g., orbit perturbations and atmospheric parameters), along with their covariance matrices, for each day on which observations were made.

In the second step of the analysis, we combine the individual daily solutions into a solution for coordinates and (where appropriate) velocities using the GLOBK software package developed at Smithsonian Astrophysical Observatory and MIT. GLOBK rigorously combines the adjustments of the site coordinates and orbital parameters and their covariance matrices from the individual-day solutions using a Kalman filter to provide what we call the "global" solution; we simultaneously estimate local station coordinates, global station coordinates, and satellite orbits.

Our current solution for velocities is shown in Figure 2, where the error ellipses represent 95% confidence intervals. The 12 sites in the northern part of the network generally have smaller uncertainties because they have been observed 3 times over a two-year period, in contrast with the other sites, which have only been observed twice, with one year between campaigns.

For the broad, north-south profile extending across the Tien Shan, the apparent deformation rates are sufficiently high (given the presently attainable precision of GPS measurements) that they show resolvable displacements within one year of repeat measurements. Although a second round of repeat measurements is essential to obtain sufficiently accurate estimates of station position for robust tectonic interpretation (see discussion below), the comparison of 1993-94 site positions for the Tien Shan network is providing tantalizing initial results that we cannot resist commenting upon:

(1) The long, north-south baselines extending across the central Tien Shan suggest consistent north-south shortening, taking place at rates of 15-22 mm/yr. This high rate is somewhat surprising, as it accounts for some 30-40% of the total India-Eurasia plate convergence rate, in spite of the fact that the network does not span across the

boundary between the Tarim Basin and the Tien Shan, where much of the present-day seismicity is concentrated.

(2) Most of convergence appears to be accommodated by intramontane shortening within the Tien Shan, rather than across the northern foreland of the mountain belt. In particular, the largest gradient in the deformation field takes place across the Issyk-Kul basin, which separates the Terskei Alatau and the Kungei Alatau ranges in the central Tien Shan.

(3) A systematic divergence of displacement vectors is observed in the southwestern portion of the study area, suggesting local block rotations in the southern Tien Shan.

But these results are preliminary the main focus of this report is on the impact that the third year of data has on our estimates of relative site velocities. In Figure 3, we show the evolution of our most frequently observed line, between Cholponata (CHOL) and Azok (AZOK), where we have had at least 7 days of observations in each of 3 years. The daily solutions all cluster about the linear trend. Note, however, the outlier in the north component in 1994 – if this line had only been observed on that day, or even on three days including that day, the estimate for the northward site velocity would have been substantially lower. Also note that the error bars and scatter in the daily solutions in 1994 are better than for 1992 (primarily due to better orbital control by the global network) and only slightly worse than for 1993. Thus, we conclude that we are not paying much of a penalty in short-term scatter by observing with a network of 6, rather than 18 instruments, a conclusion that has guided our future observing strategy for the Tien Shan network.

In contrast, the line between Azok and Medeo (MEDE) was observed many times in 1992, but only 3 times in each of 1993 and 1994 (Figure 4). Based on analysis of the first two years of data, we had inferred N-S extension between these two sites – a perhaps surprising result for an environment dominated by compressional deformation. But the 1911 M=8.6 Chon Kemin earthquake occurred just to the south of Medeo, and we had provisionally interpreted this extension as the result of postseismic viscoelastic relaxation in the lower crust. The addition of additional data strongly suggests that the inference of extension was incorrect.

As a final example, we show the line between Azok and Kurdai (KURD), both sites on the Kazakh platform (Figure 5). The surprisingly large apparent displacement in the east component of this line between 1992 and 1993 was one of the most important factors motivating us to obtain additional measurements in 1994. Indeed, there is no resolvable displacement between 1993 and 1994, supporting the inference that the 1992 survey was anomalous. The data displayed in this figure provide testimony to the benefit of making multiple occupations of sites, spaced at intervals of weeks or more early in the course of an experiment, in order to detect anomalies resulting form long-term systematic errors or blunders. And once again, the scatter of the "small" 1994 experiment is better than the 1992 experiment, and comparable to that in 1993.

These results were presented at the Fall 1994 DOSE meeting in Boulder. The abstract of the presentation is included as an appendix.

Training in Data Analysis

Through a special NSF initiative to help provide infrastructure support for scientific organizations in the former Soviet Union, PI Michael Hamburger obtained funding to establish two data processing facilities in Bishkek – one based at Kyrgyzgeodeziya, and a second facility established in collaboration with the IRIS data processing center at the IVTRAN laboratory. Funds were used to provide Sun Sparcstations with Gbyte disk drives, Exabyte tape drives, compact disk readers, laser printers and other peripherals--all the required hardware to support independent analysis of locally collected GPS data at either of these data analysis centers.

In June, 1994 Professor Thomas Herring of MIT, assisted by MIT graduate students Barbara Souter and Svetlana Panasyuk, conducted a formal training program on GPS data processing for our Russian, Kyrgyz, and Kazakh counterparts. The two-week training session was hosted at the IVTRAN facility, with computers provided by IVTRAN and Kyrgyzgeodeziya. Scientists from IVTRAN, Kyrgyzgeodeziya, Kazgeodeziya, and IPE Moscow participated. The training was particularly successful for the IVTRAN scientists, who were able to carry out a complete analysis of the data collected during the 1994 field season.

FUTURE WORK

(1) Based on the success of last summers' field experiment, we are currently planning to make repeat measurements of the 86-station Tien Shan GPS network in 1995 using the same approach. Our counterparts in Kyrgyzstan and Kazakhstan are pursuing the necessary formalities and seeking funds to support this effort. The present plan is to send 3 TurboRogue receivers and 6 Trimble SSE's to Central Asia for a period of a year, where our colleagues will make all of the measurements. In an expansion of the observing scenario conducted last year, we will deploy the 3 TurboRogue receivers as permanent receivers – one at the IVTRAN polygon in the north-central Tien Shan, a second near the

Talgar seismic station east of Almaty (Kazakhstan), and a third near the Toktogul Reservoir, in the central Tien Shan. We are working on plans to make data from the IVTRAN receiver available via Internet. The 6 SSE's will be used to make 2 occupations of the network, with at least 36 hours of continuous data available from each mobile receiver for each site occupation. In addition, we plan to send an 2 additional SSE's for a few months to be used to tie in reference marks at the sites. We are exploring the use of an innovative new mark, developed by our colleagues at IVTRAN, which permits precise positioning of an antenna over a mark using a vertically positioned screw-in steel rod, and obviating the need for error-prone antennas and optical plummets currently in use for temporary field sites.

We are also exploring possibilities of joint observations, with Chinese colleagues, that would permit us to tie the Tien Shan network to the Tarim Basin to the south. Because of the lengthy duration of our field season, we expect to be able to tie our network to other regional networks operating in Nepal, India, and China. These will make possible large-scale measurements of the India-Eurasia tectonic deformation.

(2) As should be clear from the brief summary above, further analysis of the existing data and development of improved software is ongoing. We are fortunate to have acquired as a collaborator Tom Herring, who has used this unique data set to demonstrate the capability of obtaining high-precision GPS geodetic measurements even in the absence of local fiducial control. This very useful collaboration has developed as a result of the close cooperation between those who undertake the massive logistics needed to collect the data and those who develop the sophisticated software and expertise needed to process it.

(3) At the same time, several of us are independently pursuing related projects on structural geology, neotectonics, seismicity, and lithospheric structure of the Tien Shan. These include: (a) a regional project to examine active geologic structures and seismicity associated with the deformed sedimentary basins in the Tien Shan (M. W. Hamburger and S. Ghose, Indiana University); (b) a detailed study of the surface faulting and aftershocks associated with the 1992 Suusamyr earthquake (R. Mellors, S. Ghose, M. W. Hamburger, Indiana University); (c) ongoing seismotectonic studies using the IRIS broadband seismic network extending across the northern Tien Shan mountain front in Kyrgyzstan and Kazakhstan (R. Mellors, M. W. Hamburger, G. Pavlis, Indiana University; through support from IRIS); (d) ongoing seismotectonic and earthquake prediction studies in the Pamir-Tien Shan region (M. W. Hamburger, G. Pavlis, Indiana University); (e) an interpretation of the ~ 8-mm/a, east-southeast velocity of the VLBI receiver near Shanghai with respect to the Eurasian plate (P. Molnar, MIT), (f) a bound on the Late Quaternary slip rate along the right-lateral Talaso-Ferghana fault, which is

based on field work carried out in 1991 with support from elsewhere (P. Molnar, MIT), and (g) as a synthesis of large earthquakes and geological constraints on rates of active deformation in the Tien Shan, a study begun with support from a previous NASA grant (P. Molnar, MIT). In addition, we are preparing a proposal for a multidisciplinary project that will include geological, geomorphic, geodetic, seismological, and magnetotelluric investigations in order to examine the deep structure and lithospheric dynamics of the Tien Shan. This project began with a workshop and field trip in the Kyrgyz Tien Shan during the summer of 1994. Support will be sought from the Continental Dynamics Program of NSF.

TABLE

Table 1: Site numbers, names, 4-character ID's, the GPS days observed, and coordinates of sites in our network that were reobserved in 1994.

FIGURES

Figure 1. Map of central and eastern Asia showing the topographic and structural setting of the Tien Shan (from J.-C. Thomas, Ph.D. thesis, Univ. of Rennes, 1993).

Figure 2. Estimates of the velocities for sites observed in our test experiment in 1994. The 12 sites in the northern part of the network with smaller error ellipses were observed in 1992, 1993, and 1994, whereas the remaining sites were observed only in 1993 and 1994.

Figure 3. Temporal evolution of the baseline estimates for AZOK-CHOL. Relative coordinates are given for 7 days in 1992, 13 days in 1993, and 9 days in 1994. The straight lines represent the velocity estimates from the global analysis.

Figure 4. Temporal evolution of the baseline estimates for AZOK-MEDE. Relative coordinates are given for 12 days in 1992, 3 days in 1993, and 2 days in 1994. The straight lines represent the velocity estimates from the global analysis.

Figure 5. Temporal evolution of the baseline estimates for AZOK-KURD. Relative coordinates are given for 3 days in each of 1992, 1993, and 1994. The straight lines represent the velocity estimates from the global analysis.

1994 GPS Sites

#	ID	name	159	160	161	163	164	165	166	167	168	169	170	171	175	176	177	178	179	180	181	182	183	184	185	186	189	190	191	192	193	194	195	196	longitude (degree)	latitude (degree)	height (m)
30	POLY	POLIGON	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	74.69	42.679	1690
32	KURD	KURDAI	■	■	■																														75.086	43.379	580
33	ADAR	AIDARLY	■	■	■																														75.524	44.13	620
36	KULJ	KULDJABASH													■	■	■	■	■	■	■	■	■	■	■	■									76.298	40.816	3240
37	MAYA	MAIA	■	■	■																														76.477	43.155	1070
65	KYZA	KYZART																■	■	■															42.092	75.135	2520
68	KULA	KULANAK																			■	■	■												41.358	75.568	2190
69	KKOY	KARAKOYUN																						■	■	■									41.018	75.55	2400
70	JUAN	JUANARYK																■	■	■															42.105	75.647	1950
72	TOKO	ORTO-TOKOI													■	■	■																		42.355	75.837	2130
75	KEKE	KECHI-KEMIN													■	■	■																		42.762	76.065	1680
76	RYBA	RYBACHE													■	■	■																		42.523	76.103	2160
77	NARY	NARYN																						■	■	■									41.445	76.253	2280
78	KKDJ	KARAKUDJUR																■	■	■															41.9	76.205	2730
79	TEGE	TEGEREK																									■	■	■						42.137	76.593	2130
82	KARG	KARAGOMAN																			■	■	■												41.732	76.776	2760
84	MEDE	MEDEO				■	■	■																											43.18	77.02	1343
85	CHOL	CHOLPONATA				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	42.72	77.072	2750
86	AZOK	AZOK	■	■	■	■	■	■	■	■	■	■	■	■																					43.897	77.115	440
87	ISYK	ISSYK				■	■	■																											43.26	77.49	1737
88	ANAN	ANAN'EVO										■	■	■																					42.792	77.603	1840
90	ARAB	ARABELSU																									■	■	■						41.86	77.75	4020
91	ALTY	ALTYN EMEL				■	■	■																											43.91	77.763	564
92	CHLZ	CHUL-ZHOTA							■	■	■																								43.27	77.854	2720
95	JETY	JETTY OGUZ																												■	■	■			42.297	78.275	2100
96	ISHT	ISHTYK																									■	■	■	■	■	■			41.6	78.21	3570
99	TYUP	TYUP										■	■	■																					42.635	78.557	1800
100	KOKP	KOKPEK							■	■	■																								43.45	78.65	1170
102	AKSH	AKSHYRAK																									■	■	■						41.795	78.542	3690
103	KNSU	KENSU										■	■	■																					43.023	78.825	1740
104	TUAK	TURGEN AKSU																												■	■	■			42.415	78.95	2880
105	CHRN	CHARYN							■	■	■																								43.27	78.975	1030
108	KOYL	KOYLYU																												■	■	■			42.167	79.093	2700
109	KRLT	KARALATASH																						■	■	■									41.123	76.433	3210
170	RSON	REKA SONGKEL																			■	■	■												41.76	75.37	3005
	BOZO	BOZOLA																															■	■	42.532	77.139	2501
	BOZT	BOZTERI																															■	■	42.476	77.154	2081
	DZHA	DZHAAKTACH																															■	■	42.532	77.172	2427

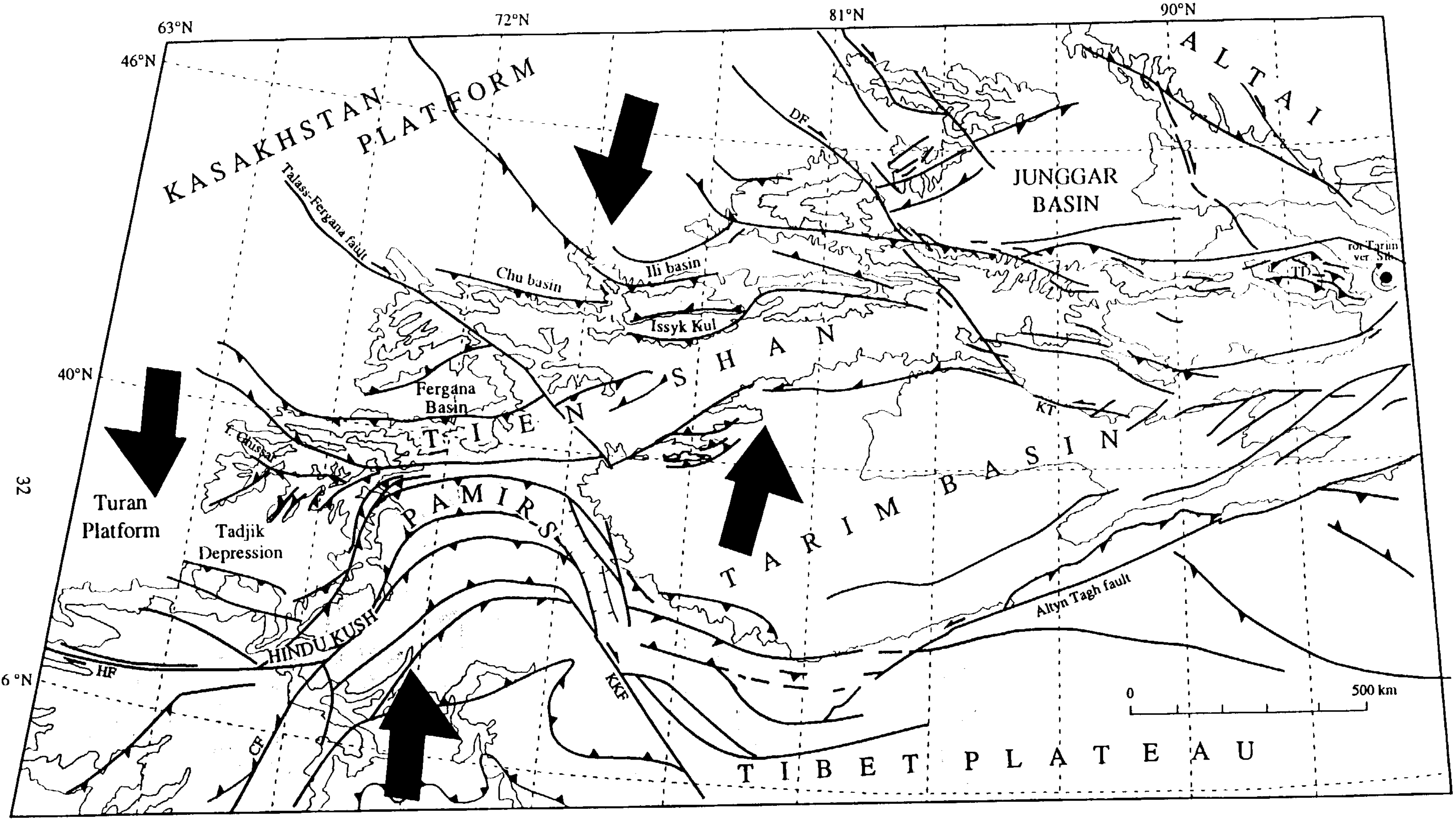
63°N
72°N
81°N
90°N
46°N
40°N
36 °N
KASAKHSTAN PLATFORM
ALTAI
JUNGGAR BASIN
Talass-Fergana fault
DF
Chu basin
Ili basin
Issyk Kul
Fergana Basin
TIEN SHAN
TARIM BASIN
KT
TD
rot Tarim
ver. Sh
Turan Platform
Tadjik Depression
F. Ghissar
PAMIRS
HINDU KUSH
HF
CF
KKF
Altyn Tagh fault
TIBET PLATEAU
0
500 km

Figure 1

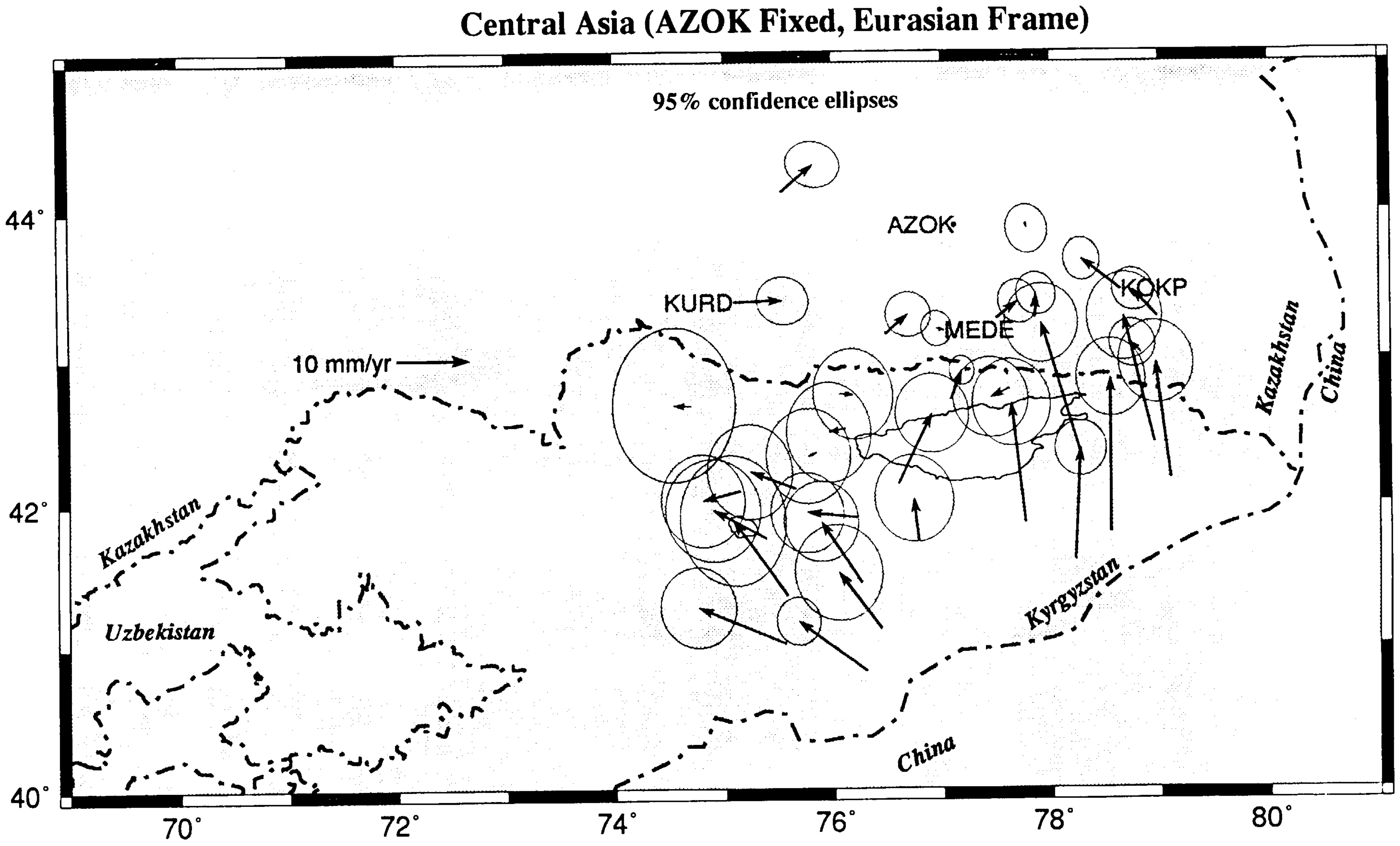
Central Asia (AZOK Fixed, Eurasian Frame)
95% confidence ellipses
AZOK
KURD
MEDE
KOKP
10 mm/yr
Kazakhstan
Uzbekistan
Kyrgyzstan
China
Kazakhstan
China
44°
42°
40°
70°
72°
74°
76°
78°
80°

Figure 2

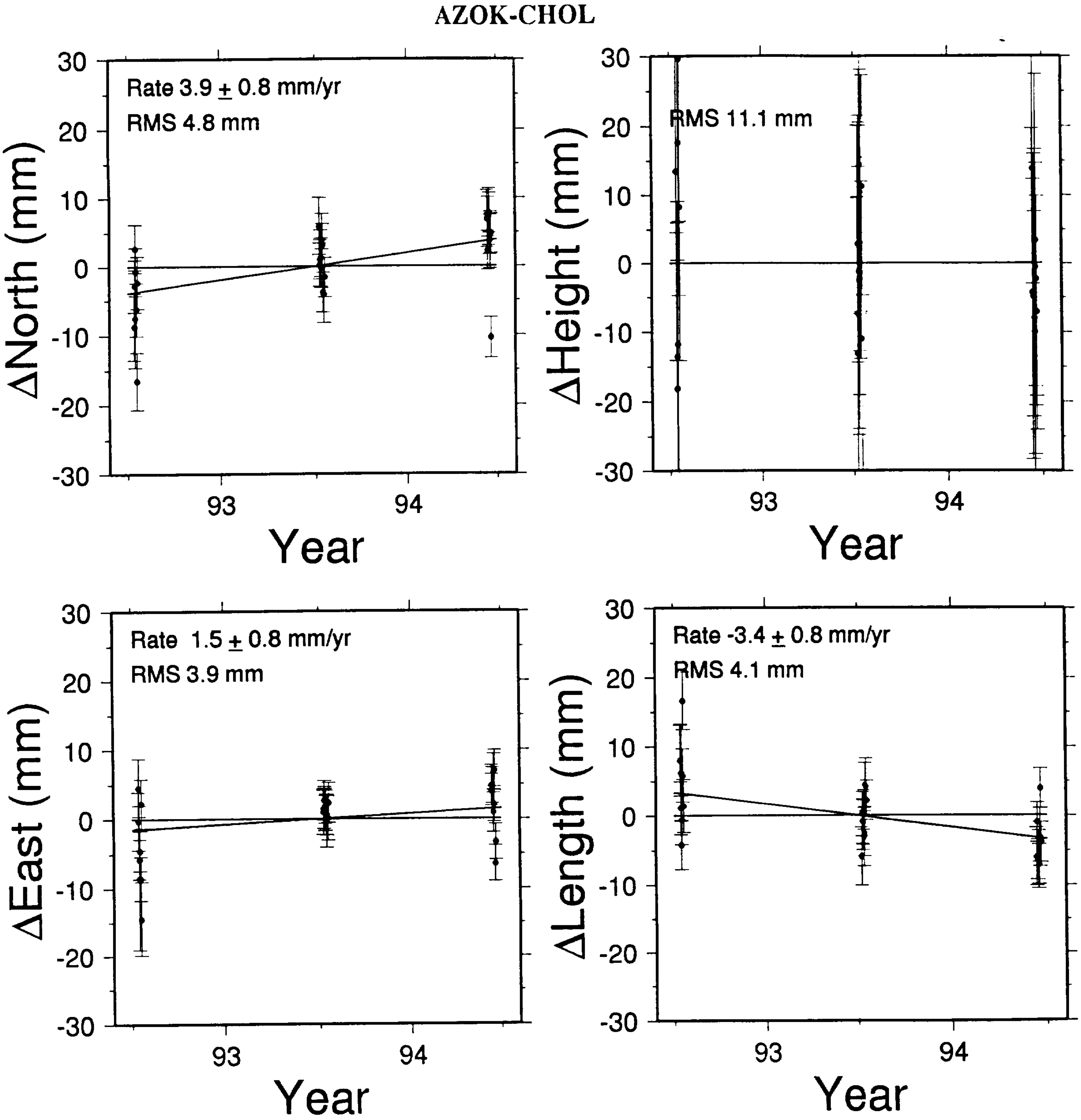
AZOK-CHOL
Rate 3.9 ± 0.8 mm/yr
RMS 4.8 mm
ΔNorth (mm)
30
20
10
0
-10
-20
-30
93
94
Year
RMS 11.1 mm
ΔHeight (mm)
Rate 1.5 ± 0.8 mm/yr
RMS 3.9 mm
ΔEast (mm)
Rate -3.4 ± 0.8 mm/yr
RMS 4.1 mm
ΔLength (mm)

Figure 3

AZOK-MEDE

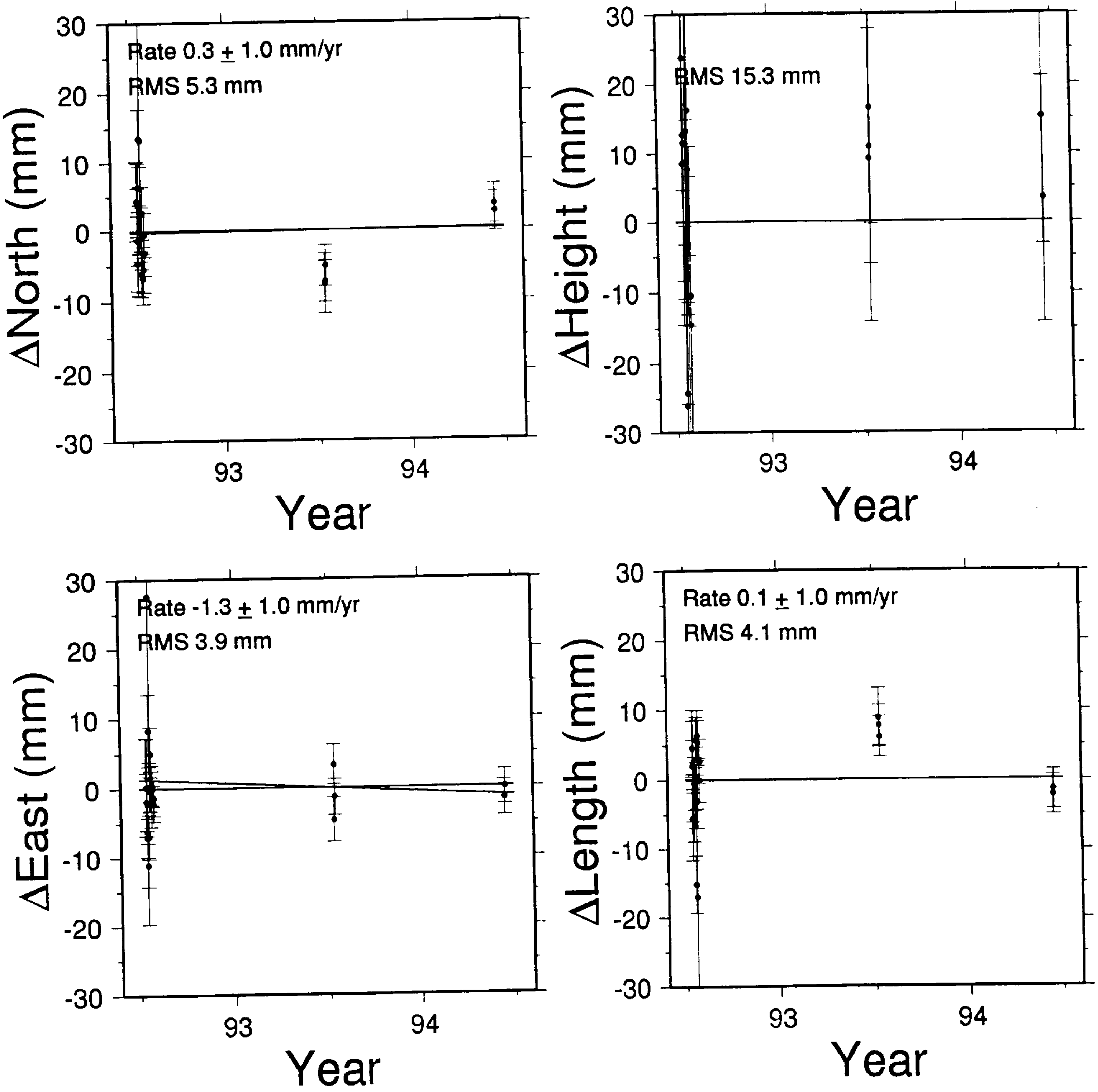

Figure 4

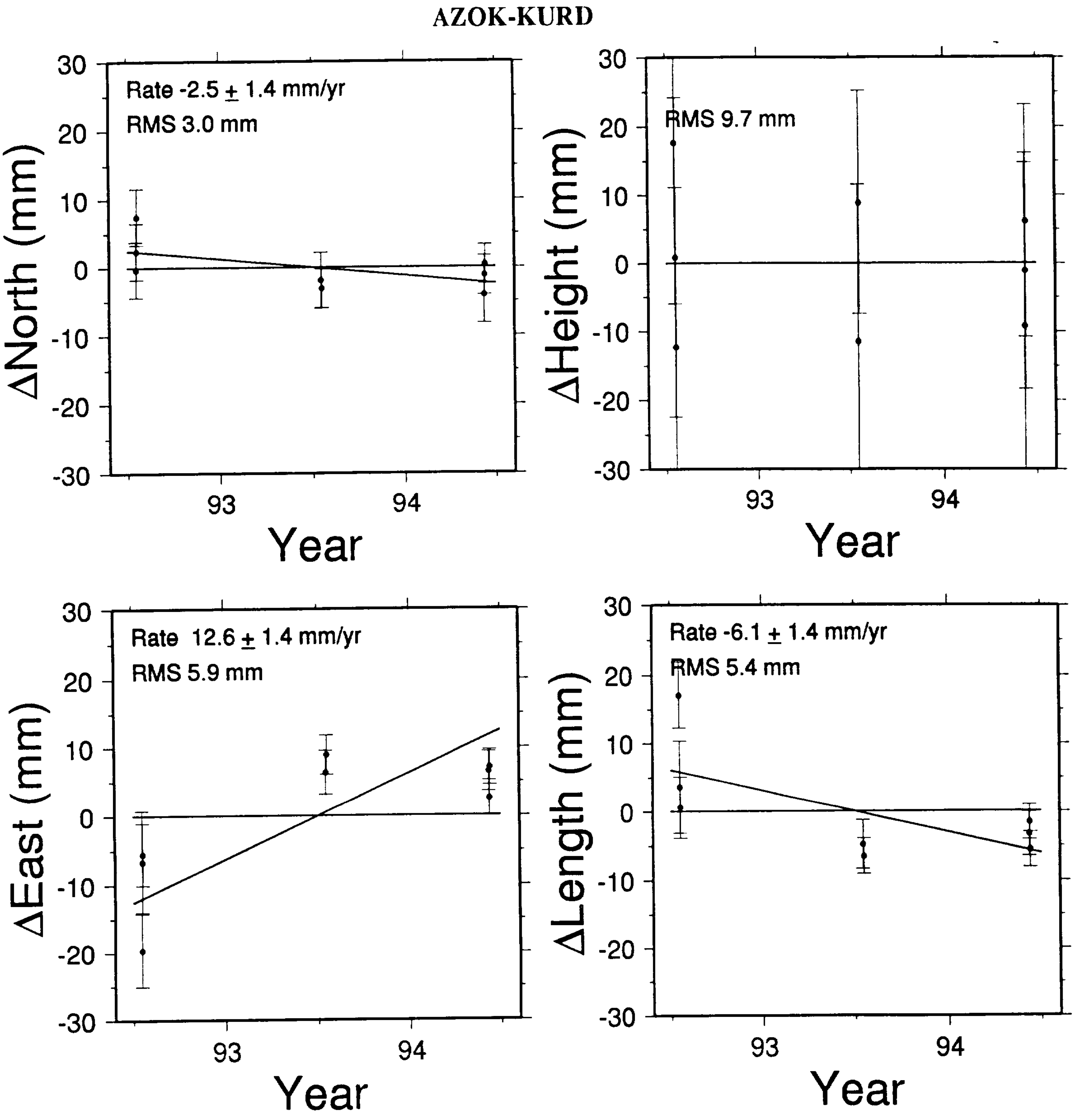
AZOK-KURD
Rate -2.5 ± 1.4 mm/yr
RMS 3.0 mm
ΔNorth (mm)
30
20
10
0
-10
-20
-30
93
94
Year
RMS 9.7 mm
ΔHeight (mm)
30
20
10
0
-10
-20
-30
93
94
Year
Rate 12.6 ± 1.4 mm/yr
RMS 5.9 mm
ΔEast (mm)
30
20
10
0
-10
-20
-30
93
94
Year
Rate -6.1 ± 1.4 mm/yr
RMS 5.4 mm
ΔLength (mm)
30
20
10
0
-10
-20
-30
93
94
Year

Figure 5

Apparant Displacements From Three GPS Surveys of the Tien Shan of Kyrgyzstan and Kazakhstan: Tectonic Displacements or Systematic Errors?

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The Tien Shan (literally "Heavenly Mountains") of Central Asia comprise the world's outstanding laboratory for the study of intracontinental mountain building. Under joint DOSE/NSF support, we are to carry out two major GPS experiments, in 1993 and in 1995, to measure the crustal velocity field in Kyrgyzstan and Kazakhstan. In 1992, in preparation for our first major campaign, we established a 13-site network spanning the Kungey-Alatau range on the northern margin of the Tien Shan. We remeasured this network in 1993 as part of a larger 85-site network covering an area approximately 300 km by 700 km and including much of the central and western Tien Shan. (This network shares benchmarks established by a German-Kazakh-Kyrgyz-Russian-Uzbek team in 1992.) The results are intriguing: Our most frequently observed baseline, extending across the Kungey-Alatau, from north of Issyk Kul to the Ili basin, apparently shortened by 7 ± 1 mm, consistent with indications of horizontal shortening from geological and seismological studies. But there are apparent displacements of sites on the Kazakh platform, where expected deformation rates are low, that are up to twice as large.

In 1994, we carried out a low-budget experiment that included about half the sites observed in 1993. We wanted to determine if the velocities estimated from the first two campaigns were correct and whether a less intense experiment, with fewer receivers operated over a longer time (with PI's participating in training and planning, but not in the field work itself), reduces cost without degrading the geodetic results. The data quality is excellent and the experiment was a great success. Our current analysis shows apparent N-S convergence of > 20 mm/yr on baselines spanning the mountain belt, consistent with geologic estimates. However, we find that these results are quite dependent on the data analysis scheme used (e.g. elevation cutoff, parameterization of the troposphere). In order to provide tectonically meaningful results, we need both a better understanding of systematic errors in GPS and more observations. Additional observations could be provided economically by providing receivers for use over extended periods of time by our local collaborators.