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Estimates of plate velocity and crustal deformation in the Indian subcontinent using GPS geodesy

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GPS studies have been carried out by CSIR Centre for Mathematical Modelling and Computer Simulation (C-MMACS), Bangalore in the Indian subcontinent since 1994 to determine displacement and strain accumulation in the region over the past few years. This communication integrates the results obtained over the years in different regions of the Indian subcontinent using GPS geodesy to get an overall picture of deformation and related interpretations and discussions. The regions broadly covered by C-MMACS are the southern Indian peninsula, Ladakh, Garhwal, Kumaun, Darjeeling, Sikkim, Gujarat, Andamans and Shillong. GPS-derived velocity vectors of about 50 sites are given in the ITRF 97 (International Terrestrial Reference Frame), Indian reference frame and relative to IISc IGS station. Notable conclusions from the above study are as follows: Southern peninsular India moves as a rigid plate with the velocity of Indian plate. Convergence of 10–20 mm/yr occurs in the 2500 km stretch of the Himalayan arc from Kashmir to Arunachal and the convergence rates vary from west to east. Extension between the Himalayan GPS sites and Lhasa (southern Tibet) site is consistent with the east-west extension of the Tibetan Plateau.

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THE Indian subcontinent is one of the most earthquake-prone areas of the world. Several major earthquakes[1] have occurred at the plate interiors and boundaries in this subcontinent during the last three decades, causing massive losses (Koyna, 1967; Badhrachalam, 1969; Broach, 1970; Udaypur, 1988; Uttarkashi, 1991; Latur, 1993; Jabalpur, 1997; Chamoli, 1999; Bhuj, 2001). Earthquakes in India are mainly caused due to release of elastic strain energy created and replenished by persistent collision of the Indian plate with the Eurasian plate. Though the tectonics of the Indian subcontinent is dynamic and complex, evolution of precise GPS geodesy since 1990 makes it possible to understand the dynamics involved and also the measurement of strain accumulation in the Indian plate. One of the primary objectives of the CSIR Centre for Mathematical Modelling and Computer Simulation (C-MMACS), Bangalore is to generate an insightful understanding of the deformation mechanism in the Indian subcontinent, which is the major cause of earthquakes. This can be achieved using GPS to measure and understand deformation mechanism related to stresses at all scales. This would result in better understanding of physical processes of earthquake phenomena. The geo-tectonics of the Himalayas, Kachchh and south Indian shield, which were covered by a dense network of GPS stations, is discussed briefly.

The Himalayas, Karakoram and Tibetan plateau, which together span a wide deformation zone of 2500 km, are a result of Indo-Eurasian collision. The southern limit of this zone[2] of compressive intercontinental deformation is marked by a smooth circular arc of the Himalayan fold and thrust belt that rises abruptly over the under thrusting. Both the geological structure and active tectonics[3] along the 2500 km stretch of the Himalayan arc from Kashmir to Arunachal, are of significant importance due to continuous seismic activities in this region. The Kachchh region of western India[4] is an excellent example of a tectonically controlled landscape comprising an assemblage of various geomorphic features. This region has a unique history of continued tectonism (Kachchh, 1819; Anjar, 1956; Bhuj, 2001), which is a reflection of movements along major faults; Kathiawar fault, Nagar Parkar fault, Allah Bund fault and Kachchh mainland fault. Earthquakes in the Indian peninsular shield fall in the category of Stable Continental Region Events. Monitoring of these events is of paramount importance, as many siesmogenic faults may be responding to the present crustal deformation process. Continental crust of southern India[5] exhibits unique characteristics whose geophysical signatures differ markedly from those of its counterparts in other parts of the world. It consists of large zones of complex folding, major and minor faults and granulite exposures, and this region cannot be classified as an area of low seismic activity.

GPS studies were carried out by different scientific groups in India with foreign collaboration[6–16], in different regions of the subcontinent. This communication presents the results of GPS measurements in the southern peninsula, Ladakh, Garhwal, Kumaun, Darjeeling, Sikkim, Gujarat, Andamans and Shillong regions from 1994 to 2002, to give significant insights into the overall crustal deformation mechanism in the Indian subcontinent. The style of regional deformation using GPS has been studied in detail in specific regions of the southern peninsula, Ladakh, Garhwal, Kumaun and Gujarat[6,9,11,12,14–16] using campaign-style GPS measurements. The results presented here lay emphasis on the absolute and relative motion of all GPS sites, both campaign-style (short-period observations) and permanent (long-period observations) mode.

GPS measurements were carried out at various sites (Table 1) in the Indian subcontinent from 1994 to 2002. Figure 1 shows the campaign-style, reference and permanent GPS sites operated by C-MMACS along with the IGS stations. Leh, Hanle, Almora, Bangalore and Kodaikanal are permanent stations, which run continuously throughout the year. Delhi, Jamnagar, Bhopal and Shillong (Figure 1) are reference stations, where more than 10 days of GPS measurements were available every year. The rest of the sites were campaign-style sites, with three days of measurement every year. Trimble geodetic receivers (either SSE or SSI) and Trimble choke ring antennae were used for all the measurements. Antennae at permanent stations were mounted on concrete pillars grouted to the bedrock. All the campaign-style and reference stations were marked by 2 to 3 mm diameter holes drilled onto the bedrock exposures to allow subsequent identification. Antennae were mounted on bipods above the bedrock. Bernese 4.2 GPS post-processing software was used for processing GPS data. All GPS data have been used along with the IGS stations in the network to estimate the coordinates and velocities. Absolute free solution has been used to estimate the station coordinates and velocities. The resulting solution thus will have the estimates of coordinates and velocities of all the stations in the network (including the IGS stations) in the ITRF 97 reference frame. For the campaign sites both absolute free and relative fixed strategies were used to arrive at the absolute and relative motions of these stations. In this communication, emphasis is made on the motion of all the sites in the ITRF 97 reference frame, Indian reference frame and relative motion of the sites with reference to IISc. The regional motion and deformation of sites is not part of this communication as the objective is to look at the velocities of different regions in the Indian subcontinent and how they vary from region to region. Table 2 and Figure 1 give the GPS-derived horizontal velocities and azimuths in the ITRF 97 reference frame, Indian reference frame and relative to IISc at sites in the Indian subcontinent. Errors (Table 2) range from ± 1 to 6 mm in the estimation of coordinates and velocities of the GPS sites. Error ellipses are not plotted in Figure 1 for the sake of clarity.

Figure 1 shows the site velocities in ITRF 97, Indian reference frame and with IISc station fixed. The velocities are summarized in Table 3 for different regions of the Indian subcontinent. ITRF 97 velocities of South India (Table 3; Figure 1) are not significantly different from the Indian plate velocity of 58 ± 4 mm/yr at N44°E[7] and also the IGS site (IISc) velocity of 54 ± 3 mm/yr N51°E in ITRF2000 reference frame. Similar velocities[10] are reported for the Deccan trap region, western India using GPS measurements. Motion of GPS sites in south India in the Indian reference frame as well as relative to IISc station (Figure 1; Table 2) are not significant, considering the error bars. This implies that south India moves as a rigid plate with velocity approximately equal to the Indian plate velocity. The regional results[6] indicate negligible regional dilatational and shear strain changes in the southernmost 530 km of India.

In contrast to the southern Indian peninsula, GPS measurements indicate significant convergence across the Himalayan arc. Motion of sites in Ladakh (Tables 2 and 3; Figure 1) shows that the ITRF velocities of Ladakh are 10 mm less than the motion of Garhwal sites and the direction of motion is more towards the east. Motion of the

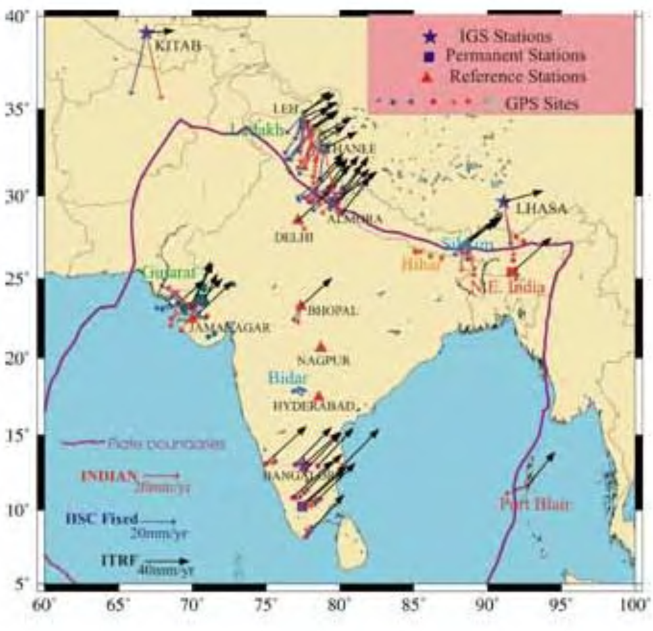

Figure 1. C-MMACS GPS sites and their velocities (1994–2002) in ITRF 97, Indian reference frame and relative to IISc IGS site.

Table 1. Sites occupied by C-MMACS (1994–2002)

Site	Code	Latitude	Longitude	Mode	Remarks
Sukhi	SUKI	31.00	78.68	Campaign site	Garhwal Himalaya
Auli	AULI	30.53	79.56	Campaign site	Garhwal Himalaya
Tunganath	TUNG	30.49	79.21	Campaign site	Garhwal Himalaya
Chamba	CHAM	30.40	78.37	Campaign site	Garhwal Himalaya
Burfu	BURF	30.36	80.19	Campaign site	Kumaun Himalaya
Munshairi	MUNS	30.06	80.20	Campaign site	Kumaun Himalaya
Lansdowne	LANS	29.85	78.68	Campaign site	Kumaun Himalaya
Chaukadi	CHAU	29.84	80.04	Campaign site	Garhwal Himalaya
Lhasa	LHAS	29.66	91.10	IGS site	China
Pol2	POL2	42.68	74.69	IGS site	Kyrghystan
Almora	KTML	29.64	79.62	Reference site	Kumaun Himalaya
Mahe	MAHE	28.96	80.15	Campaign site	Nepal Himalaya
Delo	DELO	27.09	88.50	Campaign site	Sikkim Himalaya
Bangalore	IISC	13.02	77.57	IGS site	Bangalore, India
Shillong	SHIL	25.53	91.85	Campaign site	Northeast
Bhopal	BHOP	23.28	77.36	Campaign site	Central India
Delhi	JNUC	28.54	77.17	Reference site	Delhi
Kitab	KIT3	39.13	66.89	IGS site	Uzbekistan
Mijar	MIJA	13.06	74.94	Campaign site	South India
Rangaswamy betta	RANG	13.03	76.97	Campaign site	South India
Krishnamakonda	KRIS	12.95	78.52	Campaign site	South India
Nanmangalam	NANM	12.93	80.18	Campaign site	South India
Devarabetta	DEVA	12.63	77.63	Campaign site	South India
Port Blair	CARI	11.61	92.72	Campaign site	Andamans
Chenimalai	CHEN	11.16	77.59	Campaign site	South India
Palghat	PLGT	10.83	76.82	Campaign site	South India
Manaparai	MANA	10.66	78.46	Campaign site	South India
Palani	PLNI	10.43	77.56	Campaign site	South India
Kodaikanal	KODI	10.23	77.47	Permanent site	South India
Ponnarkulam	PONN	8.18	77.68	Campaign site	South India
Jamnagar	JAMN	22.47	70.01	Reference site	Gujarat
Delo	DELO1	27.09	88.50	Campaign site	Sikkim Himalaya
Kyonoksala	KYON	27.37	88.71	Campaign site	Sikkim Himalaya
Mungpo	MUNG	26.98	88.4	Campaign site	Sikkim Himalaya
Namchi	NAMC	27.16	88.32	Campaign site	Sikkim Himalaya
Leh	LEH	34.13	77.60	Permanent site	Ladakh Himalaya
Hanle	HNLE	32.78	78.96	Permanent site	Ladakh Himalaya
Chusul	CHUS	33.58	78.65	Campaign site	Ladakh Himalaya
Panamik	PNMK	34.73	77.57	Campaign site	Ladakh Himalaya
Tirth	TRTH	34.57	77.62	Campaign site	Ladakh Himalaya
Staksha	TKSH	34.82	77.52	Campaign site	Ladakh Himalaya
Tangse	TANG	34.03	78.18	Campaign site	Ladakh Himalaya
Lukung	LKNG	34.0	78.41	Campaign site	Ladakh Himalaya
Moglub	MGLB	34.01	78.30	Campaign site	Ladakh Himalaya
Muth	MUTH	33.19	78.70	Campaign site	Ladakh Himalaya
Dipai	DIPA	26.75	85.09	Campaign site	Bihar
Bheria-Bishanpe	BERI	26.38	86.14	Campaign site	Bihar
Diwanganj	DEWA	26.28	86.90	Campaign site	Bihar
Masaha	MASA	26.62	85.13	Campaign site	Bihar
Bulakipur	BULA	26.68	85.44	Campaign site	Bihar
Bidar Baseline	BBL1	17.96	77.52	Campaign site	Bidar
Bidar Baseline	BBL2	17.89	77.61	Campaign site	Bidar
Gaur	GAUR	17.91	77.93	Campaign site	Bidar
Jala	JALA	17.81	77.17	Campaign site	Bidar
Bhim	BHIM	17.65	77.4	Campaign site	Bidar
Villa	VILLA	17.99	77.39	Campaign site	Bidar
Rtir	RTIR	17.88	76.83	Campaign site	Bidar
Rane	RANE	18.08	77.23	Campaign site	Bidar
Cita	CITA	17.81	76.81	Campaign site	Bidar
Boladi	BOLA	23.37	69.81	Campaign site	Bidar
Charkda	CHAR	23.15	69.99	Campaign site	Gujarat
Khatrod	KHAT	23.18	69.80	Campaign site	Gujarat

(*Continued*)

Table 1. (*Continued*)

Site	Code	Latitude	Longitude	Mode	Remarks
Hatria	HATR	23.45	69.05	Campaign site	Gujarat
Bela	BELA	23.9	70.82	Campaign site	Gujarat
Dajka	DAJK	23.69	70.83	Campaign site	Gujarat
Dajka	DAJE	23.67	70.81	Campaign site	Gujarat
Faradi	FARA	22.93	69.51	Campaign site	Gujarat
Gangta	GANG	23.74	70.50	Campaign site	Gujarat
Kakarwa	KAKA	23.49	70.39	Campaign site	Gujarat
Kanduka	KAND	23.56	70.69	Campaign site	Gujarat
Kanmer	KANM	23.39	70.87	Campaign site	Gujarat
Kharsar	TURT	24.57	70.79	Campaign site	Gujarat
Khalunjar	KHAR	24.34	70.76	Campaign site	Gujarat
Chitrod	CHIT	23.39	70.68	Campaign site	Gujarat
Khoj	KHOJ	23.01	69.41	Campaign site	Gujarat
Manava	MANA	21.36	71.09	Campaign site	Gujarat
Nagar Ghantiarno	NAGR	24.32	70.79	Campaign site	Gujarat
Pata-i-Shah	PATA	23.56	70.94	Campaign site	Gujarat
Roha hill	ROHA	23.20	69.27	Campaign site	Gujarat
Sackpur	SACK	21.56	71.51	Campaign site	Gujarat
Samatra	SAMA	23.19	69.47	Campaign site	Gujarat
Sukhpur	SUKH	23.28	70.16	Campaign site	Gujarat
Vankaner	VANK	22.60	70.93	Campaign site	Gujarat
Seimological observatory, Shillong	CSOS	25.53	91.85	Permanent site	Northeast
Bomdilla	BOMD	27.27	92.44	Campaign site	Northeast
Tawang	TAWA	27.58	91.94	Campaign site	Northeast
Munn	MUNN	25.41	91.84	Campaign site	Northeast
Laidera	LAID	25.50	91.66	Campaign site	Northeast
Moutherishan	MOUT	25.54	91.45	Campaign site	Northeast
Moitsngi	MSNG	25.34	91.59	Campaign site	Northeast
Mopen	MOPE	25.23	91.44	Campaign site	Northeast
Guwahati	GHTY	26.135	91.74	Campaign site	Northeast

sites in the Indian reference frame and relative to IISc (Table 2 and 3, Figure 1) gives the convergence[9,16] between the Indian subcontinent and Ladakh at 14 to 20 mm/yr. Convergence rates in Garhwal–Kumaun Himalayas are 10–18 mm/yr. This is not significantly different from the rates reported earlier[11,13]. ITRF velocities in the Garhwal–Kumaun Himalayas are slightly higher when compared to those of Ladakh and the motion is more towards the north. Motion of Sikkim sites (Table 3, Figure 1) is significantly different from that of Ladakh, Garhwal Himalayas. Convergence rate in the Sikkim region is 10–12 mm/yr. These results indicate that about 10 to 20 mm/yr of India and Eurasian convergence is accommodated across the Himalayas from Sikkim to Ladakh and the deformation rates are not same, which suggests different deformation mechanisms in these regions. Inversion of the GPS-derived deformation will give more insight into the deformation mechanism in these regions. Velocities in the Himalayan region when compared with those at Lhasa (in southeastern Tibet) indicate an east-west extension of ~ 20 mm/yr ± 5 mm, which is consistent with the east-west extension[16] of southern Tibet.

No significant inferences about the plate motion and long-term deformation can be made from the motion of GPS sites in Gujarat (Tables 2 and 3, Figure 1), as the two epochs of measurements were made soon after the Bhuj 2001 earthquake and so the velocity vectors are more indicative of post-seismic deformation[12,14,15] due to the Bhuj earthquake. Only one site at Jamnagar has one epoch of measurement before the earthquake, which gives the velocity of 60 ± 8 mm/yr at N46°E that also includes the co-seismic deformation of the Bhuj 2001 earthquake. Velocity vectors in Gujarat (Tables 2 and 3, Figure 1) do indicate a post-seismic deformation of rates averaging 1 to 2 mm/month[15], which is consistent with continued slip on the Bhuj rupture zone. One more epoch of measurement is necessary to infer the long-term plate motion and inter-seismic deformation in the Gujarat region. In the Indian reference frame, the motion of Delhi and Shillong is negligible, whereas Port Blair has a velocity of 13 ± 3 mm/yr at N250°E.

Notable conclusions that arise from the above study are as follows. Southern peninsular India moves as a rigid plate with the velocity approximately equal to the Indian plate velocity, and regional deformation in the southern peninsula is negligible. Convergence rates in Himalaya indicate that significant amount of India and Eurasia convergence is accommodated here. GPS-derived velocity and defor-

Table 2. GPS-derived horizontal velocities and azimuths in ITRF reference frame, Indian reference frame and relative to IISc IGS station

	ITRF 97		Indian reference frame		Relative to IISc	
Station	Azimuth (°)	Velocity (mm)	Azimuth (°)	Velocity (mm)	Azimuth (°)	Velocity (mm)
SUKI	40.9	38.74 ± 1.9	210.9	14.34 ± 1.7	230.9	17.07 ± 2.3
AULI	39.2	44.45 ± 3.2	215.6	8.93 ± 3.1	242.0	11.91 ± 4.0
TUNG	33.0	39.21 ± 2.6	233.4	14.74 ± 3.0	247.5	18.69 ± 3.3
CHAM	41.7	46.30 ± 1.9	196.7	7.30 ± 1.6	234.8	9.53 ± 2.4
BURF	37.5	35.47 ± 6.0	221.3	18.19 ± 6.0	235.0	20.76 ± 6.0
MUNS	33.4	51.18 ± 1.9	279.3	5.64 ± 2.5	284.4	10.76 ± 2.7
LANS	41.3	49.58 ± 2.5	187.3	4.42 ± 2.1	244.2	6.49 ± 2.9
CHAU	43.9	46.06 ± 2.2	192.2	8.80 ± 1.7	224.2	9.56 ± 2.4
MAHE	37.5	51.50 ± 1.6	251.7	3.05 ± 1.9	276.3	7.28 ± 2.2
SHIL	48.2	54.24 ± 6.0	172.1	6.37 ± 3.9	154.8	4.29 ± 4.8
BHOP	47.4	46.38 ± 4.2	190.8	10.17 ± 3.6	207.4	9.73 ± 3.9
MIJA	47.3	62.10 ± 4.4	78.9	6.10 ± 5.4	73.4	7.32 ± 5.4
RANG	43.9	57.41 ± 2.1	265.6	0.13 ± 2.8	43.9	1.79 ± 2.4
KRIS	43.1	57.38 ± 2.0	285.0	1.05 ± 2.5	19.1	1.92 ± 1.8
NANM	44.4	57.70 ± 2.3	197.2	0.61 ± 1.8	55.2	2.12 ± 2.7
DEVA	43.6	57.90 ± 3.3	329.4	0.57 ± 2.7	34.6	2.31 ± 3.1
CARI	38.5	48.51 ± 2.6	250.1	13.31 ± 3.2	255.9	8.63 ± 3.4
CHEN	44.3	59.49 ± 2.1	38.5	1.43 ± 2.0	49.4	3.89 ± 2.4
PLGT	47.3	59.91 ± 5.2	101.5	3.42 ± 6.0	83.7	5.44 ± 6.0
MANA	45.9	58.49 ± 4.8	129.4	1.39 ± 5.0	79.0	3.46 ± 6.0
PLNI	48.0	63.67 ± 6.0	79.5	6.53 ± 6.0	73.4	9.07 ± 6.0
KODI	48.3	62.93 ± 6.0	85.8	6.07 ± 6.0	77.7	8.57 ± 6.0
PONN	42.1	62.91 ± 2.0	7.4	5.23 ± 1.6	28.5	7.52 ± 2.1
JAMN	46.3	60.79 ± 3.0	77.2	9.79 ± 2.6	70.0	5.69 ± 2.8
DELO	51.9	52.17 ± 3.5	163.1	10.73 ± 2.7	113.4	7.95 ± 3.9
KYON	62.1	46.49 ± 1.2	171.2	20.77 ± 1.0	183.6	12.05 ± 1.4
MUNG	56.8	52.96 ± 2.0	154.7	14.88 ± 2.8	152.8	5.37 ± 2.9
NAMC	54.3	45.61 ± 1.6	182.8	15.89 ± 1.9	213.7	8.64 ± 2.0
CHAR	21.3	56.02 ± 4.1	312.1	18.49 ± 4.0	307.4	22.25 ± 4.1
KHAT	27.9	55.80 ± 3.4	320.5	12.35 ± 3.4	303.1	12.68 ± 3.6
HATR	48.0	39.02 ± 4.3	198.9	14.24 ± 4.2	257.8	13.46 ± 4.5
BELA	45.0	28.72 ± 4.2	214.5	23.94 ± 3.9	200.7	10.59 ± 3.7
DAJK	26.6	32.43 ± 3.6	240.5	22.38 ± 4.2	256.9	24.86 ± 4.5
IISC	47.5	53.88 ± 1.0	184.0	5.06 ± 1.0	341.0	0.00
KIT3	85.6	31.35 ± 4.8	167.2	37.44 ± 5.6	194.0	35.01 ± 5.6
POL2	79.6	32.34 ± 4.6	167.6	35.88 ± 6.0	194.5	31.58 ± 6.0
LHAS	73.9	45.25 ± 4.6	169.5	30.45 ± 5.0	171.1	24.15 ± 5.1
KTML	54.3	58.20 ± 4.2	119.9	15.63 ± 4.2	108.1	7.96 ± 4.3
JNUC	46.6	51.99 ± 4.5	142.4	7.14 ± 4.5	250.0	2.05 ± 4.6
LEH	54.8	34.74 ± 4.0	185.9	21.53 ± 4.0	214.6	19.93 ± 4.1
HNLE	63.3	40.90 ± 2.7	168.7	23.72 ± 3.3	190.0	18.31 ± 3.4
CHUS	57.8	31.91 ± 2.7	190.0	24.97 ± 2.0	213.3	23.20 ± 2.5
PNMK	49.7	39.11 ± 3.4	181.6	16.10 ± 4.5	221.8	14.87 ± 3.8
TRTH	66.2	39.77 ± 2.5	166.7	26.04 ± 4.0	189.3	20.59 ± 4.2
TKSH	59.3	40.74 ± 3.5	166.8	21.16 ± 5.3	196.7	16.29 ± 5.3
TANG	57.3	31.43 ± 3.2	190.3	24.92 ± 4.9	214.4	23.51 ± 4.4
LKNG	54.6	30.34 ± 3.9	194.7	24.80 ± 4.6	218.5	24.07 ± 4.4
MGLB	53.3	29.51 ± 1.0	197.0	24.99 ± 1.0	220.5	24.69 ± 1.4
MUTH	57.3	32.65 ± 2.6	189.7	24.30 ± 2.9	213.1	22.40 ± 2.9

mation rates in the Himalayan arc vary from west to east, suggesting the deformation mechanisms in Ladakh, Garhwal, Kumaun and Sikkim Himalayas are different and are to be treated differently. GPS-derived extension vector between the Himalayan sites and Lhasa is consistent with the east-west extension of southern Tibet. Kachchh GPS results give post-seismic deformation consistent with Bhuj rupture zone, as GPS measurements were made after the 2001 earthquake and one more epoch of GPS measurements is needed to determine long-term plate deformation. GPS measurements in north-west and north-east India are insufficient; nevertheless velocities of Jamnagar and Shillong indicate significant deformation in these regions.

Table 3. Summary of GPS-derived motions in the Indian subcontinent

Region	ITRF 97 velocity	Velocity in Indian reference frame	Velocity relative to IISc station	Convergence rate
Southern India	57 to 64 mm/yr ± 2 to 6 mm at N42–48°E	0 to 6 mm/yr ± 1 to 6 mm ≈ 0	0 to 8 mm/yr ± 1 to 6 mm ≈ 0	Zero
Gujarat	28 to 56 mm/yr ± 3 to 4 mm at N22–48°E	12 to 24 mm/yr ± 3 to 4 mm at N 200–320°E	10 to 24 mm/yr ± 3.5 to 4.5 mm at N200–310°E	10 to 24 mm/yr
Ladakh	30 to 40 mm/yr ± 1 to 4 mm at N54–66°E	16 to 24 mm/yr ± 1 to 5 mm at N170–200°E	14 to 24 mm/yr ± 1 to 5 mm at N190–220°E	14 to 20 mm/yr
Garhwal and Kumaun	38 to 50 mm/yr ± 1 to 3 mm at N34–44°E	4 to 18 mm/yr ± 1 to 3 mm at N190–230°E	6 to 18 mm/yr ± 2 to 4 mm at N230–250°E	10 to 18 mm/yr
Sikkim	46 to 52 mm/yr ± 1 to 3 mm at N52–62°E	10 to 20 mm/yr ± 1 to 3 mm at N155–180°E	5 to 12 mm/yr ± 1 to 4 mm at N 160–200°E	10 to 12 mm/yr

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MEETINGS/SYMPOSIA/SEMINARS

Short-term Training Programmes on Industrial Training

Date: 7–26 June 2004
Place: Amravati

Topics include: Institute–industry linkage models; Strategic planning for institutional development; MoUs and letters of intents; Industrial visits and survey; Marketing skills; IPR issues, etc.

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International Conference on Agricultural Heritage of Asia

Date: 6–8 December 2004
Place: Hyderabad

Topics include: Women and food security; Animal management including fisheries; Agroforestry; Management of soil; Arbori-horticulture; Plant biodiversity; Rainfall prediction and water management, etc.

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