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Episodic GPS Campaigns at Lakshadweep Islands along the Chagos-Laccadive ridge to investigate the inferred continental flexure in the west of India and the non-rigidity of the oceanic part of the Indian Plate

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ABSTRACT

The Episodic GPS campaigns were initiated at Lakshadweep islands for the first time in India by National Geophysical Research Institute (NGRI) with the objectives of refining the already estimated strain accumulation in the south of Indian peninsula, reaffirming the inferred continental flexure in the south-west of India, and investigating the rigidity of larger oceanic part of the Indian plate. To start with two sites Kavaratti and the northern most island Chetlat were chosen. With the new state-of-the-art GNSS receivers, which could track 30 GPS and 11 GLONASS Satellites with 5^{o}elevation mask, GPS measurements were carried out simultaneously at both Kavaratti and Chetlat for two weeks during March 2007 and repeat measurements were carried out recently in these islands. Very recently the southern most island Minicoy also was included in the experiment design and simultaneous GPS measurements were carried out in both Minicoy and Kavaratti. The acquired data was processed in the latest ITRF 2005 reference Frame. The site coordinates of Kavaratti, Chetlat and Minicoy and also the baseline lengths between Hyderabad and these three sites were estimated in the Global Network Solution. These GNSS receivers, the methodology involved, the results of estimated site coordinates and the baseline lengths between Hyderabad and these islands are discussed in this paper. The estimated baseline length between Hyderabad and Kavaratti is 991, 303.3067 ± 0.0082m. The estimated baseline length between Hyderabad and Chetlat is 892, 216.5594 ± 0.0040m. The estimated baseline length between Hyderabad and Minicoy is 1171, 071.8777 ± 0.0065m. The estimated accuracy of the baseline length is in the range of 4 to 8 mm, which shows the quality of data processing.

These studies across a 1,200-km-long "strain gauge" that is optimally oriented almost parallel to the compression seen on the land would enable the understanding whether this is due to the Himalayan collision, or the extension of the Capricorn-India diffuse boundary that could have extended this far north.

INTRODUCTION

GPS geodesy studies were initiated to improve the understanding of the complex plate motions, diffuse and poorly located plate boundaries, and striking intraplate deformation that characterize the Indian Ocean basin. Although much has been learned using marine geophysical and seismological data and described by geologic plate motion models based on magnetic anomalies, transform azimuths, and earthquake slip vectors, the kinematics are poorly characterized compared to simpler regions, which inhibits understanding of the regional dynamics. The geographic distribution of the rigid Indian plate comprises the 2000 km long chain of islands atop the Chagos-Lakshadweep ridge. These include Lakshadweep islands, part of India, Maldives islands, and the islands that are located on the Indian plate proper (the southernmost part of the chain includes Diego Garcia, which may lie on the Capricorn Plate). This unique geographic feature lies on the Oceanic Lithosphere, in the stable interior of the Indian Plate. In effect it constitutes a 1200 km long "strain gauge", optimally oriented in the N-S direction, which is capable of measuring possible deformation of this oceanic part of the Indian plate, for comparison with deformation of its continental part.

It is anticipated that significant advances in knowledge of the kinematics of thecomplex plate interactions and intraplate deformation in the Indian Ocean basin, which is the type example showing that oceanic, as well as continental, plates can deviate dramatically from the ideal rigid behavior assumed in classic plate tectonics. The Indian Ocean basin, roughly speaking the area surrounding the triple junction where the Central Indian (CIR), Southwest Indian (SWIR), and Southeast Indian (SEIR) ridges meet (Fig.1), strikingly illustrates the complexities of applying ideal rigid plate tectonics to oceanic plates.

The Central Indian basin thus plays a major role in evolving ideas about when to regard a region as a plate and how to characterize its boundaries. Plate tectonic ideas have evolved from viewing plates as rigid and divided by narrow boundaries to accepting that plates can deform internally and be separated by broad boundary zones [e.g., Gordon and Stein, 1992; Gordon, 1998; Stein and Sella, 2002]. Such zones are common on land, but rarer in the oceans, making the Indian Ocean of special interest. Because the concepts of plates and plate boundaries are kinematic, kinematic data provide rigorous means of examining them. Hence India, Australia, and Capricorn are viewed as distinct plates and the earthquakes between them as plate boundary earthquakes, rather than as intraplate deformation within a single Indo-Australian plate, because three rigid plates fit the rates and directions of motion recorded by magnetic anomalies and transform fault azimuths better than would be expected purely by chance due to the additional free parameters [Stein and Gordon, 1984].

GPS DATA ACQUISITION AND ANALYSIS

The Lakshadweep island map and the chosen sites were shown Figure 2. Only Kavaratti and Chetlat islands were chosen initially for logistic purposes and very recently the southernmost island Minicoy also was included and the repeat measurements at Kavaratti and Chetlat islands were carried out. Continuous GPS+GLONASS measurements were carried out in both Kavaratti and Chetlat islands for two weeks initially and two weeks of simultaneous data were also obtained at Kavaratti and Minicoy recently. The data was processed in a global network solution using Bernese software version 4.2.These state-of-the-art GNSS receivers could track 30 GPS and 11 GLONASS Satellites with 5º elevation mask. First Episodic GPS Campaign has begun at Lakshadweep Islands.

RESULTS AND DISCUSSION

The acquired data was processed in ITRF 2005 Reference Frame. The site coordinates of both Kavaratti, Chetlet and Minicoy were estimated .The estimated baseline lengths between Hyderabad and both these islands are shown below.

Estimated site coordinates of Kavaratti
Latitude 10º 33′ 22.2200″ ±0.0199
Longitude 72º 37′ 54.1650″ ±0.0174
Height (ellip) = -82.0332 ±0.0199m
Orthometric Height =11.567m (Height above MSL)

Estimated site coordinates of Chetlat
Latitude 11º 41′ 23.6471″± 0.0207
Longitude 72º 42′ 38.3379″± 0.0228
Height (ellip)= -83.3895± 0.0654m
Orthometric Height= 8.8880m (Height above MSL)

Estimated coordinates of Minicoy
Lat= 08° 17′ 02.536284″ ± 0.0115
Lon= 73° 03′ 23.986176″ ± 0.0117
Height (ellip) = -83.6667 ± 0.0151
Orthometric height = 13.155 m (Height above MSL)

Estimated Baseline length in ITRF 2005 in the Global Network Solution between
Hyderabad and Kavaratti is: 991,303.3067± 0.0081m
Hyderabad and Chetlat is: 892,216.5594± 0.0040m
Hyderabad and Minicoy is: 1171, 071.8777 ± 0.0065m′

Once the proposed sites for Episodic GPS (EGPS) are reoccupied and velocity vectors are determined it would yield very significant results.

We therefore propose to extend our studies using Continuous GPS (CGPS) data, including new sites that have become available since 2000, and episodic (survey, campaign, or EGPS) measurements that we will make. We have already established some of the EGPS sites, and others will be established. As shown in Fig. 1, CGPS sites resolve the horizontal velocities used for plate motions to about 1 mm/yr in five years. EGPS data are less precise due to errors in setting up equipment and because they are occupied only for a few days every few years. We have found that the former can be reduced using fixed antenna heights, making the resulting velocities only about two times less precise, because the uncertainty is dominated by the time series length. Because EGPS is cheaper, it is a cost-effective way of addressing tectonic problems. These results will be combined with those from marine geophysical and seismological studies, which have the complementary advantages of not being restricted to island sites. In addition, geologic data have the ability to sample over time. We will assess how well earlier models fit the GPS data, explore possible temporal changes in plate motion, and compare differing estimates of plate rigidity and intraplate deformation. Once again referring to Fig.1, which shows the sites in the study

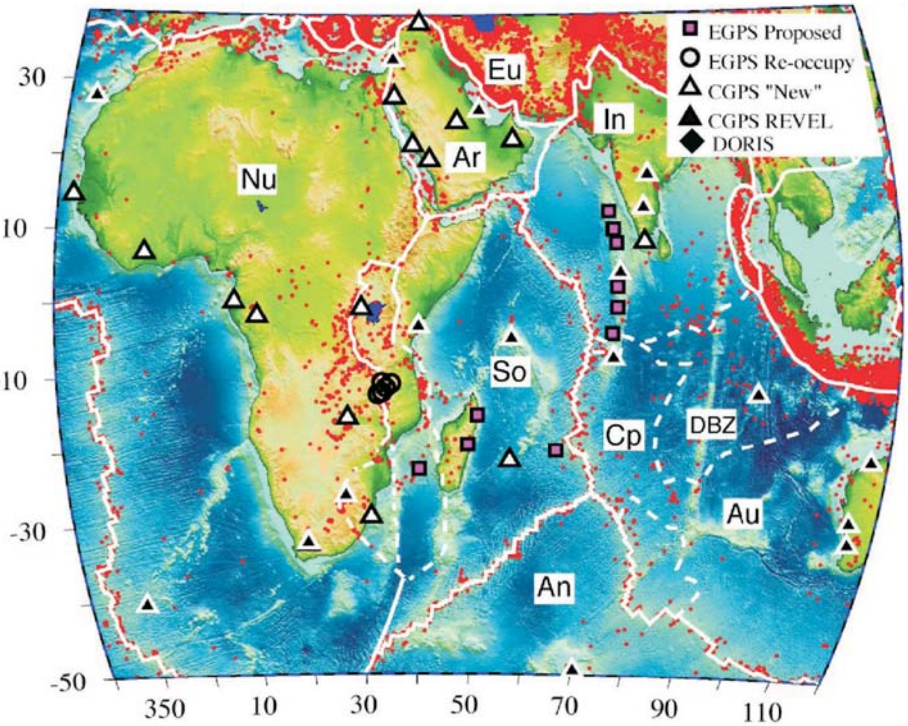

Figure 1: Proposed and existing geodetic site locations for the Indian Ocean basin, plate boundaries. White lines are plate boundaries, dashed where diffuse or uncertain. EGPS sites (circles) shown across the rift and on Madagascar will be reoccupied. Squares denote new island EGPS sites. Triangles are existing CGPS sites; solid were used in REVEL model and open have become available since 2000. Plate abbreviations An-Antarctica, Ar-Arabia, Au-Australia, Cp- Capricorn, Eu-Eurasia, In-India, Nu-Nubia, So-Somalia.

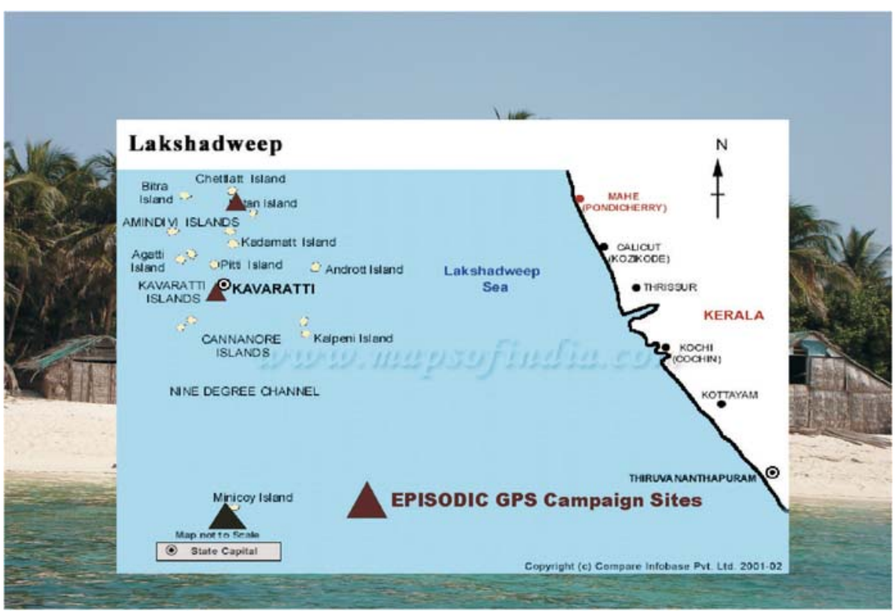

Figure 2. The map showing Lakshadweep islands and the sites chosen for episodic GPS campaigns. The brown triangle indicates the sites Kavaratti, Chetlat and Minicoy chosen for GPS campaigns.

area, will be augmented by others such as the ones in Australia and Antarctica. The sites are divided into several groups:

1) Existing CGPS sites of the International GPS Service (IGS) network, which provide publicly available\ data. Such data were used in Sella et al.'s [2002] REVEL model and comparable studies by others. Site velocities from that study will be better constrained, owing to the longer time series (REVEL used data from 1993-2000, and precision increases roughly as 1/length of data). Moreover, additional sites now available will give better estimates of plate motion.

2) Three CGPS sites operated by National Geophysical Research Institute (NGRI) at Hyderabad and Mahendragiri, India and Maitri, Antarctica.

3) Eleven new island EGPS sites: Europa and Grande Comore in the Mozambique Channel, Mauritius and Rodriguez in the Central Indian Ocean, Socotra in the Gulf of Aden, and six in the Laccadive-Maldives islands. These will give significantly better coverage of the Somali and Indian plates, which will improve Euler vector estimates. In addition, the Laccadive-Maldives sites span about 11°of latitude and provide unique sampling of the Indian plate, permitting "strain gauge" measurements of possible deformation.

4) Nine reoccupied EGPS sites: seven in Tanzania/ Malawi spanning the East African rift, which we would occupy, and two on Madagascar, established by NGRI. The new EGPS sites have been chosen both in terms of scientific objectives and operational considerations including ease and cost of access. Access and logistics will be utilized by NGRI's existing projects in Madagascar, Mauritius, and Yemen. Despite the extensive studies to date, major issues remain unresolved. As illustrated in Fig. 3, motions across some of the plate boundaries seem well constrained, as implied by good agreement between space geodetic and geologic models. In others, apparent discrepancies exist.

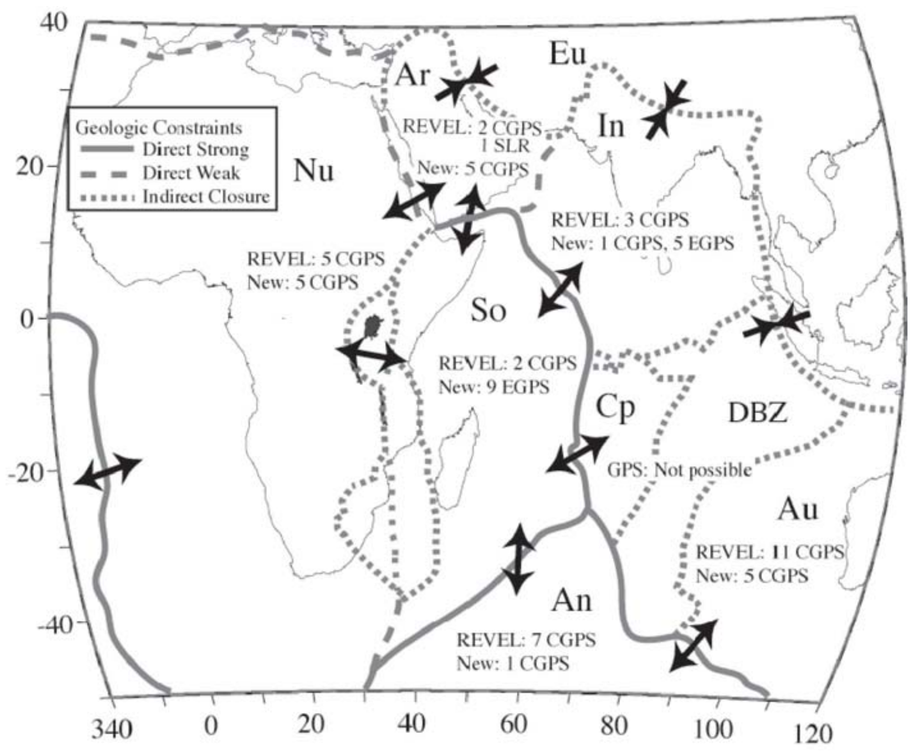

Figure 3. Boundaries in study area showing relative knowledge of plate motion from geologic models. Our study, using GPS data beyond those used in REVEL model as shown, together with longer time series at REVEL sites, will improve Euler vector estimates for all plates listed except Capricorn, which does not have islands. See Figure1 for abbreviations.

3.2 INDIAN PLATE MOTION

3.2.1 We anticipate improved estimates for Indian plate motion, due to both longer time series at sites used by Sella et al. [2002], the new NGRI site, and the EGPS sites. Improving the velocity estimate is important, because previous GPS studies yield estimates of Indian-Eurasian motion 14-25% slower than predicted by NUVEL-1A [Shen et al., 2000; Holt et al., 2000; Paul et al., 2001; Sella et al., 2002]. At this point it is not clear whether this reflects systematic errors in NUVEL-1A [Gordon et al., 1999], true deceleration, or a combination. The issue is important because plate motions have been evolving as a result of India-Eurasia convergence.

3.3 INDIAN PLATE RIGIDITY

3.3.1 The Indian plate deviates significantly from an ideal rigid plate, even given that much of the oceanic seismicity and deformation near the equator is now recognized to be part of the plate's diffuse southern boundary. Its continental boundaries to the north and west are also broad deformation zones. In addition, earthquakes occur within peninsular India south of 15ºN [Bilham and Gaur, 2000] and the adjacent oceanic lithosphere north of the diffuse boundary zone, and continental crust along the west coast appears to be flexed [Subrahmanya, 1996; Bendick and Bilham, 1999]. The earthquakes, such as the 1967 Koyna (Ms 6.3) and 1993 Latur (Ms 6.4) events, can be very destructive (the latter caused over 11,000 fatalities). Although the area seems geodetically relatively rigid, the deformation may be significant [Malaimani et al., 2000]. Paul et al.'s [2001] estimate of rigidity at the level of 7 x 10-9 1/yr permits 4 mm/yr over a 500 km baseline, enough for large earthquakes every few hundred years. We view these earthquakes as internal deformation of the Indian plate, since they are well south of the seismic zone where the 2001 Bhuj (Mw 7.7) earthquake occurred, that may be part of the diffuse India-Eurasia boundary [Stein et al., 2002; Li et al., 2002].

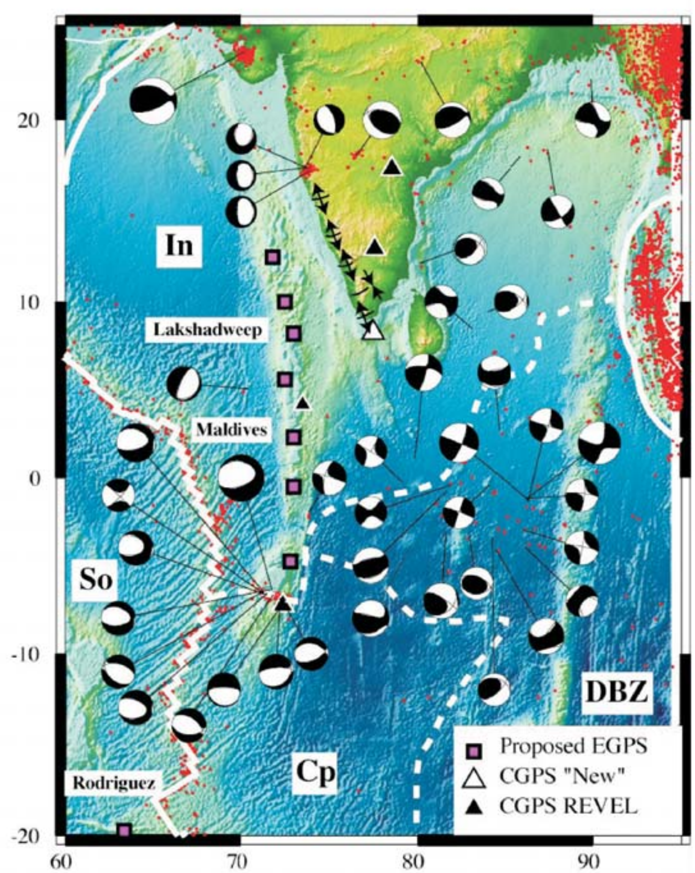

Figure 4. Site locations for GPS study of deformation in oceanic part of Indian plate illustrated by seismicity (red dots) and focal mechanism data. Anticlines and synclines show N-S compression on land [Bilham and Bendick, 1999]. Squares denote new island EGPS sites that form a "strain gauge". Triangles are existing CGPS sites; solid were used in REVEL model and open have become available since 2000. White lines are plate boundaries, dashed where uncertain. Cp-Capricorn, DBZ-Diffuse Boundary Zone, In-India, So-Somalia.

CONCLUSION

The episodic GPS measurements at Lakshadweep islands and future reoccupation of these sites would lead to understand the inferred continental flexure in the west and south of India. These studies would also help investigate the non-rigidity of this oceanic portion of the plate. The west of southern India constitute a 1,200-km-long "strain gauge" optimally oriented almost parallel to compression seen on land, perhaps due to from the Himalayan collision, or extension if the Capricorn-India diffuse boundary extend this far north [Henstock and Minshull, 2004]. We will combine these data with data from sites in continental India to compare the rigidity of the continental and oceanic regions. Thus the use of GNSS geodesy would improve the understanding of the complex plate motions, diffuse and poorly located plate boundaries, and striking intraplate deformation that characterize the Indian Ocean basin. Although much has been learned using marine geophysical and seismological data and described by geologic plate motion models based on magnetic anomalies, transform azimuths, and earthquake slip vectors, the kinematics are poorly characterized compared to simpler regions, which inhibits understanding of the regional dynamics. This study would resolve many of the above issues.

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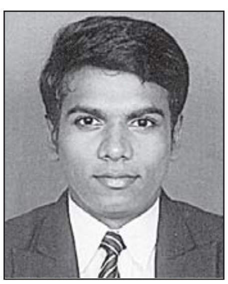

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