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# Studies on Seismotectonics and Geodynamical Processes between Antarctica and India

L. Prem Kishore, T. Chaitanya, A. **Akilan,** G.S. Srinivas,
G.B. Navin Chander, S.V.R.R Rao, E.C. Malaimani and N. Ravikumar

National Geophysical Research Institute
Uppal Road, Hyderabad - 500 007

**Abstract**

The on-going research activities at Antarctica were successfully carried out during XX IAE for the scientific objectives of studying the crustal deformation processes, the plate driving mechanisms and the response of the Indian Ocean Hthosphere, to monitor the space and time distribution of Earthquake occurrences and obtain hypocental parameters, magnitudes of earthquakes, release of energy, strain accumulation and stress drop, velocity inversion for underground structure and physical properties, earthquake source mechanism, receiver function analysis, attenuation of seismic waves and anisotropy studies by operating the GPS station and the Seismological Observatory continuously. The GPS Station continues to contribute to Scientific Committee on Antarctic Research (SCAR) and International Earth Rotation Service (IERS), the Seismological Observatory continues to contribute to NEIC (USGS) and ISC (UK) and plays a pivotal role in the Global Seismographic Network in Antarctica. By participating and contributing data, both GPS and Seismic Observatory at Antarctica have gone global. Both the stations working in tandem aid mutually the studies on tectonic processes, analyzing the seismic activities in and around Antarctica, yield a comprehensive picture on Indian Plate Kinematics. These scientific objectives would provide the challenges and future opportunities to further the scientific investigations to unravel the unknown behavioral patterns of the earth systems, especially in the Indian Ocean. The paper discusses the importance of collocating GPS and Seismological Observatory at the same site.

**Keywords:** GPS, Digital Broad Band Seismometer, NEIC, SCAR, IERS, ISC

## Introduction

Space geodesy, GPS-Geodesy and Seismic Studies being pursued by NGRI are very relevant as it can test many predictions related to plate boundary conditions which remain otherwise unconfirmed. Besides, studies of this kind have rarely been conducted on the larger oceanic part of the Indian plate. The need to focus the study on the Indian Ocean Margin becomes mandatory in the present scenario of intraplate and interplate earthquakes that do occur frequently in India forcing to reevaluate the

rigidity of the Indian plate as well as Indian Ocean Margin. To broad base the studies to understand the tectonic activity and crastal deformation in the south of Indian peninsula, the driving mechanisms and the response of the Indian Ocean Lithosphere, the data from the IGS stations in the islands surrounding Indian plate is included in the global network solution. During XX IAE the Permanent GPS station at Maitri, was operated continuously and the data accrued and archived were processed and analyzed to estimate the Time Series Site coordinates of Maitri in ITRF 97 Reference Frame at Epoch 1998.1

Similarly the Seismic Observatory was also operated continuously and the earthquake events were recorded. The collocation of both GPS and Seismic Stations at Maitri, Antarctica have necessarily to co-exist and work in tandem for several years in order to collect Time Series capable of providing reliable information on crustal deformation processes and the seismic activities that are taking place in and around Antarctica. The India -Eurasia collision zone has been the focus of intense studies by the Space Geodetic community for Indian Plate Motion. So far space geodetic studies by GPS have been made in southern and central India that bears on the rigidity of the Indian plate (Malaimani et al., 2000; Paul et al., 2001), whose velocity data for 2 sites fit the rigid plate model within uncertainties, estimated at about 3.7 cm/yr. for Hyderabad and 3.9 cm/yr. for Bangalore.

## The Indian Ocean

The classic Triple junction as shown in Fig. 1 in the Indian Ocean named as Rodrigues Triple junction (RTJ) where the three plates Somalia-

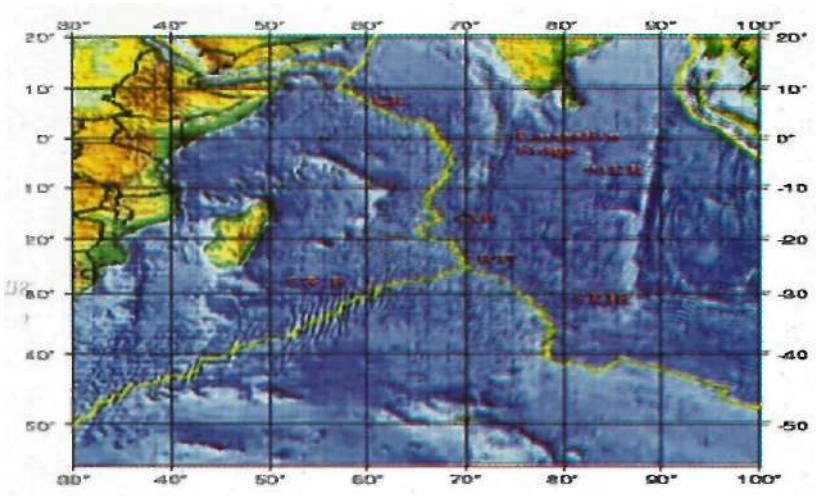



*Fig. 1: Indian Ocean depicting the classic Indian Triple Junction.*

Antarctica-Indo-Australia diffuse plate boundary meet makes an interesting study of Indian Plate Kinematics. The three mid-ocean ridge (MOR) systems that form the triple junction are (i) Southwest Indian Ridge (SWIR), (ii) Southeast Indian Ridge (SEIR), and (iii) Central Indian Ridge (CIR) and its northwestern continuation Carlsberg Ridge (CR). Many earthquakes of magnitude 6 or 7 have occurred in this century near the Ninety East Ridge (90ER) and give a rate of seismic moment release comparable to that along the San Andreas fault in California (Royer and RG Gordon, 1997).

Except for a 1-2 mm/yr. difference in spreading rates along the Southwest Indian Ridge (due to the circuit closure constrains about the South America-Africa-Antarctica plate circuit), NUVEL-1 differs significantly from and is nearly identical to three and five-plate models for the motion of the Antarctic, Australian, African, Indian and Arabian plates, which, bind the India Ocean Basin (DeMets et al. 1988; Gordon & DeMets, 1989; Gordon et al., 1989). Latest studies have clearly disproved the earlier estimation that India-Australia plate is shortening. Many researchers now concur with the tectonic theory that India-Australia plate is lengthening and Australia is drifting away from India. Also a new platelet Capricorn has been proposed in the central-western Indian Ocean with a broad, diffuse boundary (Royer and Gordon, 1997; Gordon et al., 1998).

## Methodology

The continuous data was acquired by the AshTech, 12 channel geodetic, dual frequency GPS receiver. This GPS data from Maitri is included in the Global Network Solution. Having become a permanent geodetic marker, Maitri continues to contribute to the Scientific Committee on Antarctic Research (SCAR) Epoch GPS Campaigns and the data from Maitri is available in the International Data Archive of SCAR. As one of the SCAR GPS Stations, Maitri Station data is used in the realization of ITRF 2000 Reference Frame that is released in 2001.Maitri station position and velocity vector are also estimated in this process.

The Permanent Seismic Observatory which houses a GURALP CMG-3ESP Broadband Seismometer, Data Acquisition System with a processor of Reftek make was operated continuously all the 24 hrs and the data acquisition was at the sampling rate of 50 samples per second. The acquired data is archived in CDs at Antarctica and brought back later on to NGRI for further processing. Since installation, the seismic observatory continues to contribute and is a part of NEIC (USGS) and remains in Global Seismographic Network in Antarctica.

## Data Processing and Analysis

The GPS receiver acquires 24 hrs. data continuously. This Raw data is down loaded and converted everyday using RINEX format and archived as 1 day RINEX Observation and Navigation Files. This accrued data till date has been processed and analysed using versatile software Bernese Version 4.2 and the site coordinates of Maitri have been estimated in ITRF 1997 Reference Frame.

The latest studies since 1997 reveal that there may be a new plate named Capricorn emerging in the Indian Ocean due to the boundary reorganizations. Again for the same scientific objectives, the IGS stations COCO, Coco island on the southern edge of India-Australia boundary and one IGS station SEY1, Seychelles in Mahe island in Somalia plate are selected for the estimation of baselines between Hyderabad and these sites. The sanctity of selection of these stations is that they are closer to India and they lie in the Indian Ocean. To delve more in detail to comprehend the dynamics of the driving forces in the Indian Ocean, Kerguelen in Antarctican Plate is chosen as a reference station as it is relatively a stable station, very long base lines from Kerguelen to Maitri, Casey Davis in Antarctican Plate, Yaragadee and Tidbinbilla in Australian Plate, Seychelles in Mahe island in Somalia plate and COCO, Coco island on the southern edge of India-Australia boundary have been estimated.

The state-of-the-art Broadband Digital Seismometer records the global earthquake events and also the earthquakes in and around Antarctica. The seismic data is analysed using SEISAN software and Preliminary Detection of Epicenters (PDE) Program also had been implemented to detect the expected arrival times of events at Maitri and estimate Hypocentral Parameters. EPI Map of the events from 1998 to 2001 had also been prepared. A bulletin of the Seismograms recorded thus far had also been prepared that would form a valuable source of catalogue of Seismicity in and around Antarctica as a significant contribution of NGRI.

## Results and Discussion

### *Maitri has gone Global*

Fig. 2 shows Maitri in the Global scenario. Since Maitri is one of the SCAR GPS stations contributing to the SCAR database, Maitri data till 2001 is included in the International Data Base of the SCAR Epoch GPS campaigns. With the continuing Indo-German mutual scientific

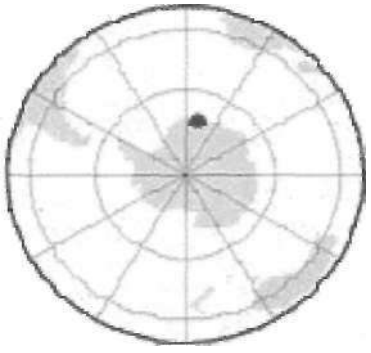


*Fig.2: Maitri Goes Global*

collaboration with Institute of Planetary Geodesy, Technical University of Dresden, Germany, and with the participation of two of the German Scientists even in the latest expedition with our NGRI scientists, SCAR 2000 and 2001 Epoch GPS campaigns and the other details including the online station description of Maitri are made available in the data archive for the global access for any user for geodynamics. The data and all the other details of the expedition can be accessed at the following websites:

http://www.tu-dresden.de/ipg/SCARGPS/MAIT.html
http://www.tu-dresden.de/ipg/SCARGPS/db_2000.html
http://www.tu-dresden.de/ipg/SCARGPS/db_2001 .html

Being a permanent geodetic marker at Schirmacher Oasis in Eastern Antarctica, MAITRI contributes to International Earth Rotation Service (IERS) and its densification of the International Terrestrial Reference Frame (ITRF 2000) formulation, by conforming to the stringent requirements of IERS.

Maitri is included in the realization of ITRF 2000 Reference frame, which is released in 2001. The Primary ITRF 2000 sites and collocated Techniques where in Maitri also figures as shown in Fig. 3 and its estimated station positions and velocity at Epoch 1997.0 as shown in Fig. 4 are included in the list of SCAR GPS stations which can be accessed at the following web sites:

http://lareg.ensg.ign.fr/ITRF/ITRF2000/map.html
http://lareg.ensg.ign.fr/ITRF/ITRF2000/results/ITRF2000_SCAR.SSC

By contributing and processing a high quality geodetic data from Maitri, NGRI plays a globally major role in maintenance and improvement of a Global Reference Frame.

Maitri GPS data from 1997 to 2001 was processed in Global Network Solution including the GPS stations in and around Antarctica and in Indian

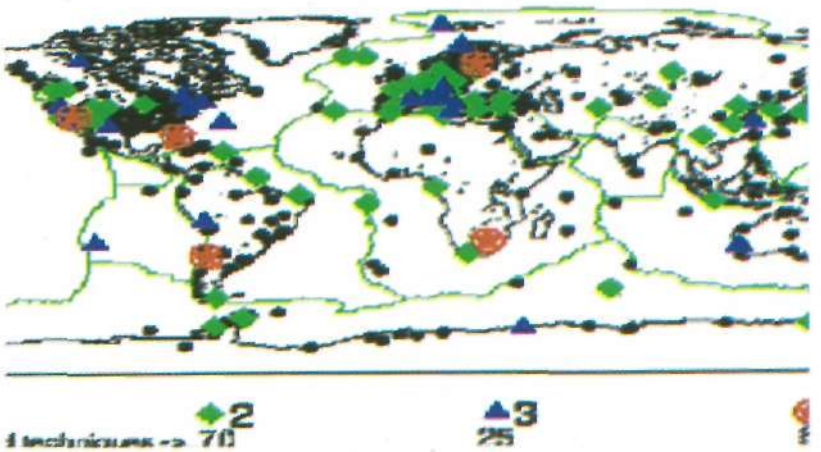



*Fig. 3: The Primary ITRF 2000 sites and collocated Techniques where in Maitri also figures.*

ITRF2000 STATION POSITIONS AT EPOCH 1997.0 AND VELOCITIES
SCAR STATIONS

| DOMES NB. SITE NAME | TECH. ID. | X/Vx | Y/Vy | Z/Vz | Sigmas | SOLN |
|---|---|---|---|---|---|---|
| | | m/m/y | | | | |
| 30607M001 SIGNY ISLAND | GPS SIG1 | 2189251.377 | -2235016.413 | -5539523.643 | .004 .004 .008 | |
| 30607M001 | | .0141 | -.0026 | .0008 .0021 .0022 .0049 | | |
| 30608M001 GOUGH ISLAND | GPS GOUG | 4795578.541 | -835299.537 | -4107634.065 | .009 .004 .008 | |
| 30608M001 | | .0140 | .0181 | .0152 .0039 .0018 .0034 | | |
| **66028M001 MAITRI** | **GPS MAIT** | **2063437.646** | **428659.438** | **-5999849.117** | **.006 .003 .017** | |
| **66028M001** | | **.0081** | **.0008** | **-.0056 .0024 .0012 .0068** | | |
| 66023M001 FORSTER / Schirm | GPS FOR1 | 2061522.357 | 431615.717 | -6000314.499 | .004 .002 .010 | |
| 66023M001 | | .0081 | .0008 | -.0056 .0024 .0012 .0068 | | |
| 66023M002 FORSTER / Schirm | GPS FOR2 | 2061809.139 | 432116.115 | -6000155.357 | .005 .003 .014 | |
| 41507M003 | | .0079 | -.0102 | .0028 .0007 .0009 .0011 | | |
| 41510M001 LA PLATA | GPS LPGS | 2780102.969 | -4437418.863 | -3629404.583 | .002 .002 .002 | |
| 41510M001 | | .0025 | -.0072 | .0087 .0006 .0009 .0008 | | |
| 41602M001 FORTALEZA | GPS FORT | 4985386.627 | -3954998.587 | -428426.482 | .002 .002 .001 | |
| 41602M001 | | -.0013 | -.0044 | .0121 .0004 .0004 .0003 | | |
| 41606M001 BRASILIA | GPS BRAZ | 4115014.087 | -4550641.532 | -1741444.061 | .003 .003 .002 | |
| 41606M001 | | .0005 | -.0063 | .0115 .0016 .0017 .0008 | | |
| 41610M001 CURITIBA/PARANA | GPS PARA | 3763751.637 | -4365113.774 | -2724404.732 | .006 .007 .005 | |
| 41610M001 | | .0049 | -.0085 | .0090 .0033 .0038 .0026 | | |
| 41703M003 EASTER ISLAND | GPS EISL | -1884951.760 | -5357595.877 | -2892890.504 | .001 .002 .002 | |

*Fig. 4: Estimated Position and Velocity of Maitri GPS Station in IERS.*

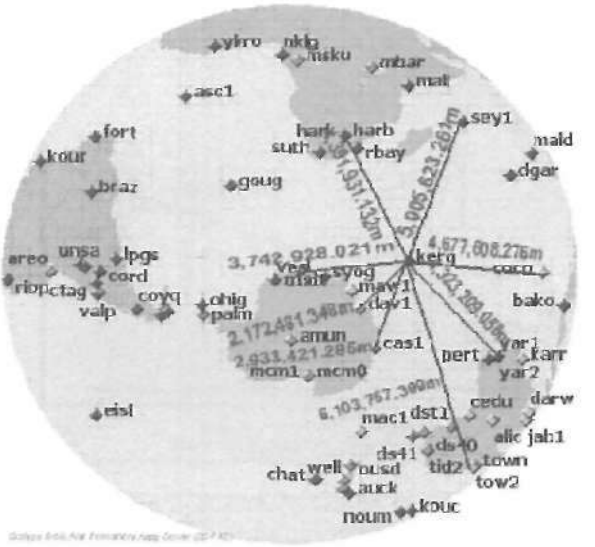
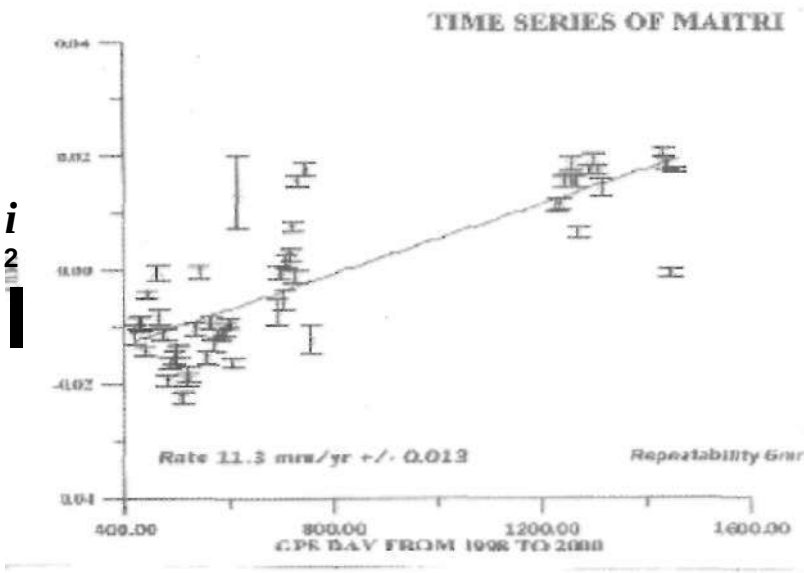



Fig. *5: GPS Global Network Diagram.*

**Table 1: Estimated baseline lengths from Kerguelen to other IGS Stations**

| Station | Baseline in mts. | WRMS |
|---|---|---|
| DAV 1 | 2,172,481.3483 | ± 0.007542 m |
| CAS 1 | 2,933,421.2856 | ± 0.009844 m |
| MAIT | 3,742,928.0214 | ± 0.009976 m |
| YAR 1 | 4,323,209.0566 | ± 0.012384 m |
| HRAO | 4,391,931.1326 | ± 0.015067 m |
| COCO | 4,677,608.2765 | ± 0.019246 m |
| SEY 1 | 5,005,623.2619 | ± 0.024019 m |
| TID 2 | 6,103,757.3093 | 0.029181 m |

Ocean. Baseline lengths were estimated from Kerguelen to all other stations. The network diagram is shown in Fig. 5. Table 1 shows the baseline lengths and WRMS. Site coordinates of all the stations have been estimated and the Time series of the site coordinates have been prepared. Time series of Maitri site coordinates are shown in Fig. 6a, 6b and 6c.This original estimation of the change in the baseline lengths conforms to the IGS Global Velocity Map. Table 2 shows the rate of change of the coordinates with the RMS values.




F/g. *6 a, b, c: Time Series of Site Coordinates ofMaitri.*

Table 2: Estimated baseline lengths with Rate of Change

| Station | Baseline in mts. | Rate |
|---|---|---|
| DAV | 2,172,481.3483 | - 2.4 mm/yr |
| CAS 1 | 2,933,421.2856 | - 5.7 mm/yr |
| MAIT | 3,742,928.0214 | - 6.4 mm/yr |
| YAR 1 | 4,323,209.0566 | + 5.5 cm/yr |
| HRAO | 4,391,931.1326 | - 1.4 mm/yr |
| COCO | 4,677,608.2765 | + 5.5 cm/yr |
| SEY 1 | 5,005,623.2619 | + 5.6 mm/yr |
| TID2 | 6,103,757.3093 | + 2.8 cm/yr |

From our estimation, it could be construed that the islands Seyshells and Coco are moving away from Kerguelen towards Indian Plate at the rates of 5.6 mm/y and 5.5 cm/y respectively. The higher rate of movement of Coco Island may be due to the emergence of the platelet Capricorn. All these could be the result of the high spreading rates of the triple junction ridges and high to very high magnitudes of earthquakes in the Indian Ocean, significantly from 1997.

The tectonic theory is proved with our estimation that the Western Australian Site Yaragadee is moving away from Kerguelen at the rate of 5.5 cm/y complying with the other studies that the India -Australia are

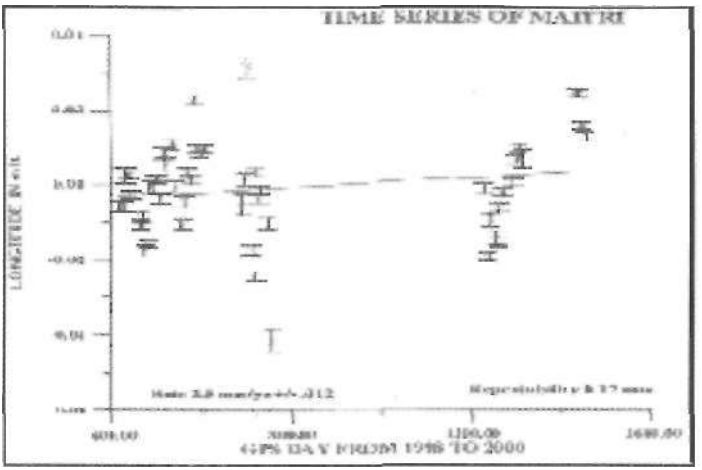



*Fig. 7: SCAR GPS Velocity Map*

drifting apart with only the diffused plate boundary between these two continents emerging. The other site in the Australia Plate Tidbinbilla in the east Australia is also estimated to be drifting away from Kergulen at the rate of 2.8 cm/y, which is in confirmation with the SCAR GPS Velocity Map (Fig. 7).

Interestingly the site in the South African Plate Hartebeesthoek shows a trend of moving towards Indian Plate. The stations within Antarctican Plate such as Maitri, Casey, and Davis show a consistent movement within the Antarctican Plate itself. Thereby it may be assessed, as there is no internal deformation within Antarctica and all these stations move together as a plate.

The collocation of Seismic Station with the GPS Station at the same site becomes relevant in the context of all the results estimated by GPS -Geodesy are corroborated by the Seismic data recorded and analysed.

A bulletin of the seismic events recorded from 1997 to 2001 that has been prepared is shown in Fig. 8. The EPI Map prepared which show the Epicenters of all the earthquakes occurred in and around Antarctica and recorded at Maitri (Fig. 9) corroborates the high seismotectonic activities in the Indian Ocean. Along with this the near-event earthquakes recorded (Fig. 10) at Maitri also corroborates the geodynamical processes that take place continuously in the Indian Ocean which result in the interplate movements. All these dynamic processes may constitute the driving mechanisms in between India and Antarctica. These forces also contribute to the non-rigid behavior of Indian Plate and the Indian Ocean Basin.

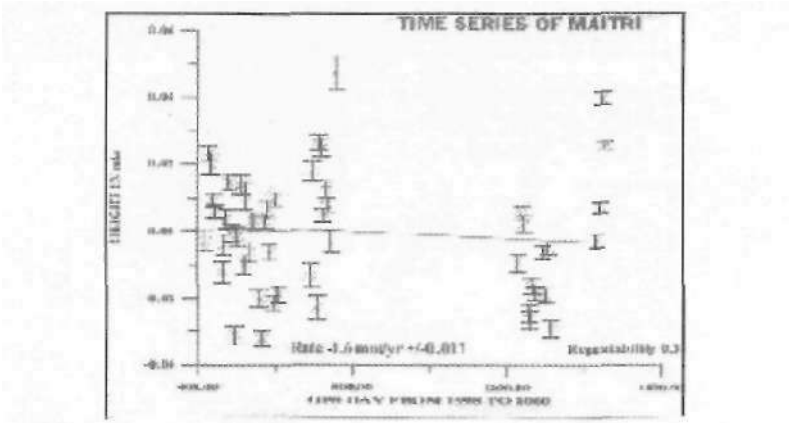



*Fig. 8: Sample of the bulletin of seismic events recorded at Maitri from 1997 to 2001.*

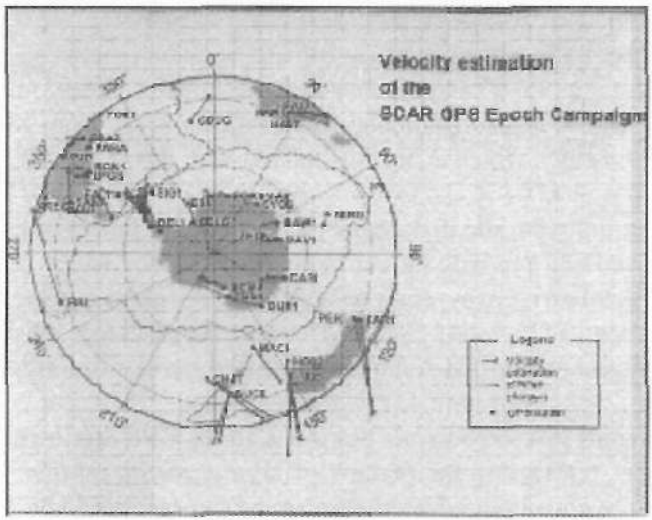



*Fig. 9: Global Seismic Events recorded at Maitri Seismic Observatory.*

## Conclusion

The time Series capable of providing reliable information on crustal deformation processes and the seismic activities that are taking place in and around Antarctica that have been estimated between 1997 and 2001 were possible only because of the collocation of both GPS and Seismic Stations at Maitri, Antarctica. This study has enabled us to achieve the objectives of getting a deeper insight into the driving mechanisms that are the causative factors for Indian Plate Kinematics, the seismoteconic and

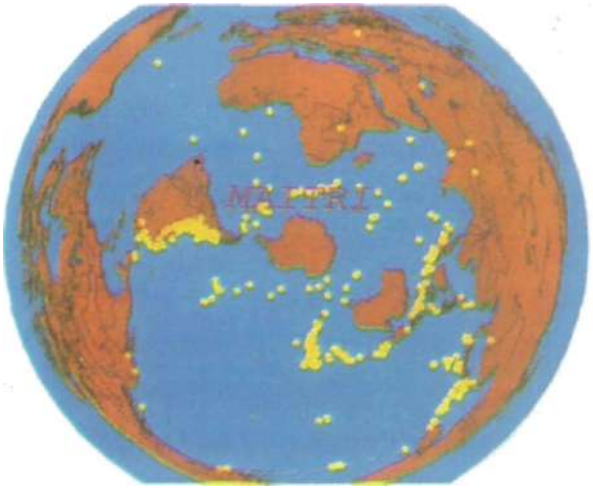



*Fig. 10: Near event of earthquake recorded at Maitri.*

geodynamical processes in the Southern Indian Peninsula. The GPS and the Seismic results show the strain accumulation and deformation processes towards the Indian Plate. Therefore these studies would continue for a longer span of time to precisely estimate the seismicity and tectonic activity in and around Antarctica and in the Indian Ocean.

The collocation of a Permanent GPS Station and Seismic Observatory will also result in monitoring the space and time distribution of Earthquake occurrences and obtain hypo central parameters, magnitudes of earthquakes, release of energy, strain accumulation and stress drop, velocity inversion for underground structure and physical properties, earthquake source mechanism, receiver function analysis, attenuation of seismic wavers and anisotropy studies.

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