INDIAN NATIONAL SCIENCE ACADEMY

INDIAN NATIONAL REPORT FOR IUGG 2011

XXV IUGG GENERAL ASSEMBLY
28 JUNE - 7 JULY 2011
MELBOURNE, AUSTRALIA

INDIAN NATIONAL SCIENCE ACADEMY

INDIAN NATIONAL REPORT FOR IUGG 2011

XXV IUGG GENERAL ASSEMBLY
28 JUNE - 7 JULY 2011
MELBOURNE, AUSTRALIA

NATIONAL COMMITTEE FOR INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS (IUGG) AND INTERNATIONAL GEOGRAPHICAL UNION (IGU)
(www.iugg.org and www.igu-net.org)

1. *Professor Harsh Gupta, FNA, NGRI, Hyderabad – Chairman*
2. *Dr. J.R.Kayal, Emeritus Scientist, JU, Kolkata - Member*
3. *Dr. B.Nagarajan, IISM, Survey of India, Hyderabad - Member*
4. *Professor D.K.Nayak, NEHU, Shillong - Member*
5. *Professor R.B.Singh, University of Delhi, Delhi - Member*
6. *Dr. V.M.Tiwari, NGRI, Hyderabad - Member Secretary*

PREFACE

This report has been prepared on the behalf of the Indian National Science Academy (INSA), New Delhi. I have a great pleasure in presenting this report to the International Union of Geodesy and Geophysics (IUGG) at its General Assembly in Melbourne, Australia during 28th June, to 7th July, 2011. The report summarizes Indian activities in the geophysics and geodesy for the period of January 2007 to December 2010 and is structured to reflect eight associations of IUGG.

The quadrennium 2007-2010 has been very exciting for the earth system sciences internationally and India is no exception to it. Four International Science Years namely, International Year of Planet Earth (IYPE, 2007-2009), International Polar Year (IPY, 2007-2008), Electronic Geophysical Year (EGY, 2007-2008) and International Heliophysical Year (IHY, 2007) were successively complemented during this period. These years have brought a lot of visibility and importance to the earth science research. India was a lead associate of these initiatives.

Indian researchers have been actively involved in the Antarctic and Arctic studies and assessments of Himalayan glaciers, which have been summarized by Rasik Ravindra in the chapter on Cryospheric Sciences. B. Nagarajan and V.M. Tiwari report on the activities related to Gravimetry and Geodesy and underlined the Indian efforts of redefining geodetic datum, electronic tide gauges installation and applications of space geodetic techniques. Archana Bhattacharyya compiled a report on the contributions in the Geomagnetism and Aeronomy. S.N. Rai and S.K. Jain reviewed studies on the Hydrological Sciences. Work related to climatic changes particularly monsoon and extreme rainfall is discussed by N.N Singh and A. Ranade. S.S.C. Shenoi has addressed Indian efforts in understanding ocean around India. The extensive contributions of India in seismological and Earth's interior are presented by J.R. Kayal and R.K. Chadha. K.S. Krishna, T. Pal, and J.S. Ray have documented the volcanological studies during the report period.

I am thankful to all colleagues who contributed and who helped to compile this report. I would also like to thank the IUGG National Committee members and officers of the Indian National Science Academy, especially Drs. A. K. Moitra and Brotati Chattopadhyay, for their help in bringing out this Report.

Harsh K. Gupta, FNA
Chairman, National Committee for IUGG-IGU,
Indian National Science Academy, New Delhi

CONTENTS

INDIAN ACTIVITIES ON INTERNATIONAL SCIENCE YEARS (2007-2009)

Harsh K. Gupta

Chairman, National Committee for International Years

National Geophysical Research Institute (CSIR), Hyderabad India

Email : harshg123@gmail.com

The triennium year 2007, 2008 and 2009 had been celebrated as International Year of Planet Earth (IYPE), International Polar Year (IPY), Electronic Geophysical Year (eGY) and International Heliophysical Year (IHY). The aim of these International Science Years was to highlight the significance and relevance of Earth System Sciences to the public through the outreach programme and enhancing scientific research through Science Programme. The basic existence of mankind is because of unique property of the Planet Earth and Space around it. However we do not realise its importance and know very little about it. Global climate change, sea level rise, deglaciation, geological hazards and demand of earth resources for higher standard of living and increasing population has resulted in degradation of the health of Planet Earth. Realising the importance, the year 2008 was proclaimed as Year of the Planet Earth by United Nation. India was amongst the first few countries to take initiative to emphasise the importance of sustainable Earth System (Figure 1).

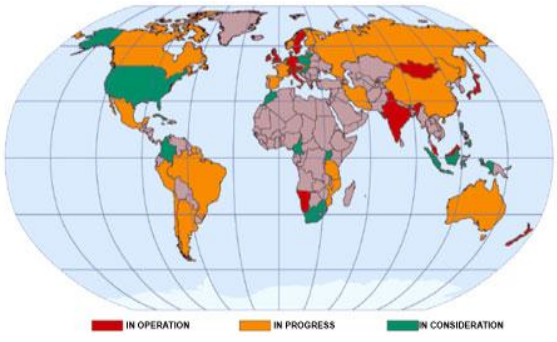

Figure1: Map displaying progress in developing national committees for IYPE. India was amongst few countries that has national imitative in the early phase (EPISODE, 2006)

A national committee was constituted by the Indian National Science Academy (INSA) on the International Years in 2006. This committee was entrusted to identify and document the planned scientific initiatives and strengthen the activities of bringing Earth System Sciences to society. The committee formulated the following plans in the very beginning

- *Counseling to strengthen the outreach programme of the various government departments and non-government organizations*
- *Organization of a workshop on the activities of International Years at INSA*
- *Organization of all Indian Student contest as a part of the International student contest for the official launch of IYPE during Feb 12 & 13, 2008 at Paris.*
- *Encouraging India's participation in the International Events*
- *Committee also recommended Coordinators of individual Years.*

Indian scientific community had responded very well to the International Science Years. Numerous activities and events have marked the International Science Years in India. They are documented and posted on the website particularly developed for it (http://iypeinsa.org).

The website was updated periodically to communicate the latest information about International Years and Indian activities during these years. The central secretariat located at the National Geophysical Research Institute, Hyderabad served as a nodal agency for interlinking the information and activities of different organisations in and outside India.

International Year of Planet Earth- IYPE

The International Year of Planet Earth (IYPE) started with a well planned mega event under the auspices of Indian Science Congress which is held every year in the first week of January and is the largest scientific meeting in India, covering all disciplines of natural sciences. More than 5000 participants, from India and abroad, took part in the annual mega event, Indian Science Congress-2007 . "Planet Earth" was chosen as the focal theme for the 2007 Science Congress. Hon'ble Prime Minister of India, Dr. Manmohan Singh, inaugurated the Science Congress on 3rd January 2007 at Annamalai University and stressed on the importance of earth sciences and the need of the hour as to how to stop degradation of planet earth. Hon'ble Minister for Science and Technology and Ministry of Earth Sciences, in his address underlined the Government of India's commitment of integrating all earth science related activities, and the Governments creation of a separate Ministry of Earth Sciences. India is currently the only country in the world, which has a dedicated ministry for Earth Sciences. It was emphasised that Earth Sciences touched the basic aspects of life on earth and it was of prime importance to realize its worth. Hon'ble President of India, Dr. A. P. J. Abdul Kalam, addressed the scientists and had a separate session with the students from all over the India. He formally launched Planet Earth related activities in India by releasing symbolic balloons.

Figure 2: Then Hon. President of India, Dr. A.P.J. Abdul Kalam released the balloons to commemorate the INTERNATIONAL YEAR of PLANET EARTH

A dedicated session on International Science Years was organised during the Indian Science Congress, which was very well attended. Details of the workshop are posted on the webpage (http://iypeinsa.org).

International Polar Year Activities

The Indian chapter of the International Polar Year (IPY) 2007-2008 was launched at National Centre for Antarctic & Ocean Research (NCAOR), MoES on 1st March 2007 by Prof. U. R. Rao, former Chairman, Indian Space Research Organization with subsequent lectures by Dr. Rasik Ravindra, Director, NCAOR & Dr. S. R. Shetye, Director, National Institute of Oceanography, Goa. A "calendar of events" was released by Prof. U.R. Rao that listed outreach activities to be undertaken. NCAOR had sponsored the visit of two students to Antarctica during the 25th Indian Antarctic Expedition (IAE) under the "Students Participation Programme". A series of lectures were delivered by one of them at more than twenty schools & colleges in the rural & suburban areas of Maharashtra, India. Students from several schools and colleges and scientists/visitors from various Indian institutes/foreign countries have visited NCAOR & its laboratories, especially ice core laboratory, to get a firsthand experience of polar research. NCAOR, in collaboration with WWF-India, has carried out competitions such as poster & model making, stamp designing, petition writing etc. for school children during 2007-2009. The first competition, poster making & slogan writing, was held at New Delhi on April 10, 2007 and prizes were distributed by the H'ble Minister of Science & Technology and Earth Sciences on the Earth Day, 2007. The winners of these competitions were invited for launching of the XXVII Indian Antarctic Expedition at Goa and were felicitated by the Secretary, Ministry of Earth Sciences on 5th December 2007. The award winning posters were published in the form of a calendar for the year 2008-09 that was freely distributed. Moreover, under the "Popular Book Series" initiative of the Ministry of Earth Sciences, a book entitled "Story of Antarctica" was published by NCAOR for free distribution among school children. Similar books on "Story of the Oceans" and "Glaciers - The Rivers of Ice" have already been published & distributed to students in different states of India. NCAOR also celebrated the International Polar day on 4th December 2008 that involved lectures, short movies, competitions & activities focusing on research above the Polar Regions for school

children and the launch of a "virtual weather balloon" by them.

International Heliophysical Year (IHY)

- *A one-day meeting held at Indian Institute of Astrophysics (IIA), Bangalore, on January 13, 2007, to discuss various public outreach (PO) activities, was attended by many scientists from various national centres. Scientists at IIA came up with a concept design of simple experiments to study the Sun in the visible and radio wavelengths. Prototypes of these instruments were on display during the IIA Open House Days on August 9-10, 2007. IIA has also taken the initiative of arranging an adequate number of these instruments to be produced for distribution in schools and colleges throughout the country.*
- *Posters on Sun, Space Weather, and Solar-terrestrial relations were on display as the main theme at an exhibition celebrating IHY 2007. The exhibition also included a demonstration by Navnirmiti of Mumbai, on details of using low-cost tools to understand the Sun.*
- *At the Inter University Centre for Astronomy and Astrophysics (IUCAA), Pune, PO activities include producing small telescopes, such as refractor telescopes with 40mm lens, and demonstrating to children how to observe the Sun by projecting the solar image.*

An important part of PO activities was public lectures on IHY themes, particularly for school and college students by scientists from Indian Institute of Geomagnetism (IIG) and other institutes. IHY related public debates and training programmes have also been conducted by the Radio Astronomy Centre (TIFR, Ooty) from mid-2006 to mid-2008 in several schools and colleges, at which students were provided with training on how to use the radio telescope and how to carry out data analysis.

Electronic Geophysical Year (eGY)

Electronic Geophysical Year (eGY) activities in India were limited. Nevertheless, several government organisations, particularly institutes of Indian Space Organisation had developed a large data base, their inventories and availability for common man. Details of the same can be found in the presentations posted on http://iypeinsa.org.

Acknowledgements: *This article is based on the reports submitted by Indian National Committee on International Science Years. Many colleagues have contributed in preparing this report. I have had generous support from INSA and all the members of national committee. I thank them for their thoughtful efforts during these years.*

GEODETIC AND GRAVITY STUDIES IN INDIA (2007-2010)

B. Nagarajan[1] & V.M. Tiwari[2]

[1]*Indian Institute of Surveying & Mapping, Survey of India (DST), Hyderabad*
Email: ngeoid@yahoo.com
[2] *National Geophysical Research Institute (CSIR) Uppal Raod, Hyderabad*

1. Introduction

This article summarizes most of the activities of Indian researchers related to the themes of International Association of Geodesy (IAG) during the quadrennium 2007-2010. A number of scientific organizations and research institutions in India are involved in gravity and geodetic measurements and their analyses. Numerous efforts by these institutions contributed greatly to improve our knowledge of crustal deformation phenomena, lithospheric structure, resource exploration, tidal model and so on. In the following pages, brief description of the work is presented, which is primarily based on institution's report.

2. Geodetic networks: Reference Frame and Datum

Survey of India has taken new initiatives in the field of Geodesy and Geodynamics by Setting up of Ground Control Points(GCP) library for Realization of Horizontal Reference system, Redefinition of Indian Vertical Datum, Augmentation and expansion of Indian Tide Gauge Network and Real Time GPS Network. Expansion of GPS permanent Station network and setting up new CORS GPS Permanent station at IISM campus are some of the few initiatives which has been taken by the department .

Under the Modernization of Indian Tide Gauge/ GPS Network, Survey of India has already installed a network of Tide Gauge stations collocated with GPS receivers and real time data transmission facilities through VSAT which has been a major input for Indian Tsunami Warning System.

The GCP Project for redefinition of Horizontal Datum consists of Primary control points at spacing of approximately 250 to 300 km. In all, 292 such precise control points have been established, observed and computations completed during the period under report. These first order control points have been monumented and protected with fencing.

In the Redefinition of Indian Vertical Datum project, High Precision Levelling forming a framework covering 45,775 linear km in fore and Back direction has already been completed along with Gravity observations on the established bench marks along levelling lines by SOI. In all eleven Levelling circuits comprising of twenty nine Levelling lines with nineteen junction points have been adjusted using the least square techniques.
A Permanent GPS station with Real Time Data Transmission facilities has been established in Indian Institute of Surveying and Mapping, Survey of India Uppal Hyderabad. Continuous GPS observations at National Geophysical Research Institute (NGRI), Hyderabad, Indian Institute of Sciences (IISc) Bangalore and Maitri, Indian Antarctic Station serve important data sets to IGS and IERS for realising ITRF reference frame. The GPS PS at IISM being on high quality Sheet Rock can also provide major inputs towards the realization of reference frame.

3. Modernisation of Indian Tide Gauge Network

A great deal of effort has been made for the extension and modernisation of Tide Gauge Network. Aftermath great earthquake of Sumatra and subsequent tsunami on 26th December, 2004, SOI has initiated the project

entitled "Modernization and expansion of Tide Gauge Network along Indian coast and its Islands". Presently 26 state-of-the-art digital tide gauges co-located with the dual frequency GPS receivers at strategic locations all along the Indian Coastline and its Islands are established. Tidal and GPS data recorded at remote locations is being transmitted in real time to the centrally located hub station at National Tidal Data Centre / National GPS Data Centre, Geodetic & Research Branch, SOI, Dehradun through a dedicated VSAT network.

In SOI Real Time GPS Network at present, fourteen stations have been configured and a ***GPS Geodetic Network*** *has been successfully established to monitor base line variations for crustal deformation and other associated studies. The present network consists of three stations in Andaman & Nicobar Islands, two station in Lakshadweep Islands and other ten well distributed stations along the east and west coast of India. Apart from this, data from a network of 42 permanent GPS stations across the country is also being received and archived. The Real Time GPS Data Centre at Faculty of Geodesy, IISM, Hyderabad is well equipped with Real Time Data Processing Software such Trimble Integrity Manager and GPS Net and Post processing software such as Bernese 5.0 & GAMIT.*

Survey of India has taken up the first step towards disaster management and mitigation by planning to link 21 Geospatial Data Centers (GDC's) through dedicated VSAT intranet network. Under this network, it has been envisaged to exchange high volume of digital topographical data between GDC's to the central station located at the National Geospatial Data Centre (NGDC) located at Dehradun.

4. Precision Project Surveys for some select sites

SOI has carried out the precision geodetic surveys for ascertaining dam deformation, verticality of the minarets of historical monuments, tunnel alignment surveys and in the various parts of country as mentioned below.

- *Dam Deformation Studies were carried for Rihand Dam, for Jamrani Dam and SriSailam Dam Projects.*
- *Precision survey for ascertaining the Verticality of the minarets of Qutub Minar and Taj Mahal.*
- *Tunnel alignment surveys and checking of alignment was carried out for developmental projects, namely, Kol Dam, Loharinag Pala HE Project and Tapovan Vishnugad HE Project.*

5. Geodetic Observations for Earthquake Studies

Several national research institutes (e.g. IIG, NGRI, SOI, WIHG, IIG) have established GPS stations for monitoring crustal deformation in plate boundary regions like Himalaya and Andaman. These measurements enrich our knowledge of earthquakes processes. For example, post Sumatra earthquake monitoring shows deformation of 10-40 cm that allowed to provide recurrence time of M>9 earthquake in the Sumatra –Andaman region. GPS measurements in Andaman also indicated that the transient stresses generated by viscoelastic relaxation process in the lower crust through upper mantle are capable of rupturing major faults. Based on far and near field GPS offsets, this work reveals that substantial segmentation of slip occurred along the Andaman Islands with the southern quarter slipping ~ 15 m in unison with the adjacent Nicobar and Northern Sumatra segments of length ~ 700 km. Following the 2005 Kashmir earthquake, the GPS velocity at GUMR (southeast of the rupture zone) is 8.6 cm/year, which is significantly higher than the Indian plate velocity indicating near-field shallow postseismic crustal deformation

In peninsular India, GPS and gravity measurements are being made in Koyna region, known of triggered seismicity in campaign mode. Significant seasonal gravity changes are observed, that are also corroborated with GPS data. These seasonal

changes observed in gravity and GPS data have important implication on effect of loading of reservoir and in turn earthquake processes in the region. The relatively rapid decay of GPS-measured deformation rates in the 2001 Mw 7.6 Bhuj intraplate earthquake region of NW India indicates increasing effective viscosities from 3 x 10^{18} Pa s in the first 6 months to 2 x 10^{19} Pa s of the mantle during the 6-year observation period, consistent with a time and stress-dependent rheology, such as power-law flow by dislocation creep.

6. SG and AG Gravity Observations

Two Superconducting Gravimeters (SG) are set up as a part of multi parametric geophysical observatories. One is being operated at Guttu, in Himalayan region by Wadia Institute of Himalyan Geology (WIHG), Dehradun and other is set up in Kutchch by Institute of Seismological Research Gandhinagar. These SGs are recording Earth's gravity field with 0.1 µGal accuracy continuously. A series of absolute gravity measurements using FG5 Absolute Gravity meter (AG) have been made at NGRI, Hyderabad to monitor long-term gravity changes and a network of absolute gravity stations cutting across India is established and monitored periodically.

7. Gravity Survey for Resource exploration

National intuitions, Geological Survey of India (GSI), ONGC, OIL, NGRI and other exploration companies are mainly engaged in gravity surveys for exploration of natural resources. Some of the target areas are Ganga basin, Brahmaputra valley, NW India and central India. A few of them are mentioned below.
Gravity survey is carried out in the Sandur schist belt, south India for iron ore exploration. Gravity studies are undertaken in the Narayanpet kimberlite field. More than 5000 of gravity measurements are made in the eastern part of the Deccan syneclise covered with a grid spacing of ~4 Sq. kms. Modelling of gravity anomalies provided a 3D basement configuration of the eastern part of Ganga Basin, Three dimensional modeling of the gravity anomalies was carried out to delineate the basement undulations Sadiya Block, Upper Assam. Delineation of old underground coal mines and study of migration front before and after sand stowing was suggested from gravity studies.

8. Gravity Studies for Geodynamics

The wavelet analysis of bathymetry of western offshore covering western Basin, Laxmi ridge, Laxmi Basin, Panikkar Ridge, continental slope and continental shelf, indicates the nature of crust of Laxmi Basin as continental. Gravity data across NW Himalaya have been modelled and interpreted to delineate the major tectonic boundaries using wavelet transform and other spectral methods. Gravity and geoid measurements across the arc in the NW – Himalaya show a long wavelength flexure in the crustal level. This also shows a mid-crustal lateral in-homogeneity along the arc as confirmed by the GPS measurements. Computation of gravity-gradiometry tensors have been completed from a regional density model across the Western Continental Margin of India along with parts of the Alps and the Andes. To delineate lithospheric structure, about 4500 gravity measurements were carried at an interval of 3 to 5 km in a corridor on either side of the geotransect from Palani to Kayanakumari. Analysis of gravity anomalies supports the idea that the Achankovil Shear Zone is an intra-cratonic litho-tectonic feature and the two provinces across it are related by a continual progression in single metamorphic terrain rather than an ancient geo-suture. The gravity gradient image is derived from the bouguer anomaly map prepared from newly collected observations combined with earlier gravity data. The horizontal gravity gradient map of the area south of 14^0N reveals a continental mosaic of gravity trends akin to structural domains such as the Eastern Dharwar Craton, the Eastern Ghats Mobile Belt, the extended Eastern Ghats Mobile Belt, the Southern Granulite Terrain, and the Western Dharwar Craton

9. Tools and Application Development

A method for optimal designing of 2-D gravity survey network is proposed and used in the gravity studies over Jabera-Damoh region of

the Vindhyan Basin, which is considered as a potential hydrocarbon bearing area. A scheme using L_p norm modified Voronoi tessellation is developed that circumvent the need of several polygons to construct the causative bodies in modeling of gravity anomalies. Inversion techniques and computer programs are developed for the calculation of listric fault structure with variable density. A computer program is developed to compute regional and residual anomalies from gravity data by implementing the finite elements method. MATLAB codes are written to compute Gravity Gradient Tensors (GGT) due to arbitrary shaped bodies and also to derive GGT from gravity data.

10. Local Gravimetric Geoid

Precise information of geoid undulation is vital for determining orthometric height using GPS and understanding the subsurface mass distribution of the earth. There are global gravity models that allow determining geoidal undulations; however, the global models are constrained by spatial resolutions. Thus determination of geoid heights over local area is obtained through the GPS- leveling observations or calculated from terrestrial gravity values. Gravimetric geoid using spherical FFT is computed in two regions of India; one over South India region, where a large geoidal depression exists and other in northern Indian region. Computed gravimetric geoid is compare with global model and with geoid determined from GPS-leveling data.

11. **Satellite Gravimetry and Its Application**

Satellite altimeter-derived geoid/gravity maps of adjoining ocean of India are prepared. Satellite altimetry derived gravity data are extensively used for exploration studies and lithospheric models over aseismic ridges in the Indian Ocean. These studies include: geoidal decay vs. crustal age analysis over the $85^{o}E$ and Ninetyeast ridge, isostatic mechanism over Chagos Laccdive Ridge, studies of rifted margins and so on. A composite high resolution satellite gravity image has been generated covering part of Antarctica to the western Indian offshore to analyze its tectonic implications. Study of the morphological characteristics patterns and their correlation to different spreading rates over the Carlsberg ridge has been carried out. A 3D lithospheric density model of the southern part of the Andaman-Sumatra subduction zone is build from joint modeling of satellite derived gravity and geoid data. The extent of subduction and depth increases from the north to the south with reference to the trench. Southward from $10^{0}N$ the presence of Ninety East Ridge is reflected in the flattening of the anomaly curve on the subducting plate.

The Gravity Recovery and Climate Experiment (GRACE) satellite data are analyzed for hydrological changes. Using eight years of GRACE data total water storage variability over India is computed. Temporal changes in the earth's gravity field as recorded by GRACE Satellite Mission reveals large scale mass loss that is attributed to excessive extraction of groundwater. Besides, hydrological applications, GRACE data are also used to understand co-seimic deformation due to large mega-thrust earthquakes in the subduction zones.

12. Mapping of Sea Bottom Topography

Detailed bathymetry modelling has been carried out over a part of the western offshore including Bombay High with high resolution gravity data. Comparison of satellite-derived predicted and available in-situ bathymetry for three profiles over Bombay High region shows satisfactory results.

Related Publications

Agarwal, BNP; Srivastava, S (2010), A FORTRAN program to implement the method of finite elements to compute regional and residual anomalies from gravity data, Computers & Geosciences, 36, 848-Times Cited: 0

Ambikapathy A., J.K. Catherine, V.K. Gahalaut, M. Narsaiah, A. Bansal, P.Mahesh (2010) 2007 Bengukulu earthquake, its rupture model and implications for

seismic hazard, Journal of Earth System Science, 119, 553-560.

Anand, S. P., Rajaram, M., Majumdar, T. J., and Bhattacharyya, R., (2008), Structure and Tectonics of 85oE Ridge from analysis of Geopotential Data. Tectonophysics (2008), doi:10.1016/j.tecto.2008.09.036 (Online Publication), 11 p.

Arora B. R., Kamal, Kumar A., Rawat G., Kumar N. and Choubey V. M., 2008. First observations of free oscillations of the earth from Indian superconducting gravimeter in Himalaya, Curr. Sci., 95, 1611-1617.

Arora K., Rajasekhar R.P. and Mishra D.C.; (2007). ,Density Models of the Crust under the Dharwar Granite-Greenstone Terrain and the Satpura Mobile Belt: Archaean-Proerozoic Analogue of Plate Tectonics'; IAGR Memoir no. 10, 217-225

Banerjee, P; Burgmann, R; Nagarajan, B, et al., (2008), Intraplate deformation of the Indian subcontinent, Geophysical Research Letters, 35, L18301,

Bansal A.R. (2007) Power law relation of bathymetry and gravity roughness with age of oceanic crust below ninety east Ridge, Indian Journal of Marine Sciences, 36(2), 105-109.

Bhattacharyya, R, and Majumdar, T J, (2009), Bathymetry prediction over a part of the Bombay High in the western offshore using very high resolution satellite gravity data. Current Science, 97 (8), 1152-1161.

Bhattacharyya, R, Verma, P K, and Majumdar, T J, (2009), High resolution satellite geoids/gravity over the western Indian offshore for tectonics and hydrocarbon exploration. Indian Journal of Marine Sciences, 38(1), 116-125.

Bhattacharyya, R., Majumdar, T. J., and Chatterjee, S., (2007), Satellite geoid/gravity for offshore exploration over a part of the western Indian offshore. Paper presented in PETROTECH-2007, New Delhi, Jan. 15-19, 2007.

Catherine J.K., V.K. Gahalaut, A. Ambikapathy, Bhaskar Kundu, C. Subrahmanyam, S. Jade, Amit Bansal, R.K. Chadha, M. Narsaiah, L. Premkishore, D.C.Gupta (2009), 2008 Little Andaman aftershock: genetic linkages with the subducting 90ºE ridge and 2004 Sumatra-Andaman earthquake, Tectonophysics, 479, 271-276.

Catherine Joshi and Gahalaut, V.K., (2007) Glimpse of earthquake cycle in Sumatra-Andaman region, Current Science, 92, 114-118.

Chakravarthi, V., (2010), Gravity anomalies of 2D fault structures with fault planes described by polynomial functions of arbitrary degree, Current Science, 99, 654-656.

Chakravarthi, V., (2010), Gravity anomalies of strike limited listric fault sources with analytically defined fault planes and arbitrary density contrast variations with depth, Near Surface Geophysics, 8, 279-286.

Chakravarthi, V., (2010), LSTRKFALTG - A forward modeling code to compute theoretical gravity anomalies of strike limited listric faults with prescribed vertical variation in density, Computers & Geosciences, 36, 675-679.

Chakravarthi, V., Sundararajan, N., (2007), 3D gravity inversion of basement relief – A depth dependent density approach, Geophysics, 72, I 23- I 32.

Chakravarthi, V., Sundararajan, N., (2007), INV2P5DSB - A code for gravity inversion of 2.5-d sedimentary basins using depth dependent density, Computers & Geosciences, 33, 449-456.

Chakravarthi, V., Sundararajan, N., (2007), Marquardt optimization of gravity anomalies of anticlinal and synclinal structures with prescribed depth-dependent density, Geophysical prospecting, 55, 571–587.

Chakravarthi. V., (2008), Gravity inversion of 2.5D faulted beds using depth dependent density, Current Science, 95, 1618-1622.

Chakravarthi. V., (2009), Automatic gravity inversion for simultaneous estimation of model parameters and regional gravity background: An application to 2D pull-apart basins, Current Science, 96, 1349-1360.

Chakravarthi. V., (2009), Gravity anomalies of pull-apart basins having finite strike length with depth dependent density: A ridge regression inversion, Near Surface Geophysics, 7, 217-226.

Chakravarthi. V., Sundararajan, N., (2008), TODGINV - A code for gravity optimization of anticlinal and synclinal structures with parabolic density contrast, Computers & Geosciences, 34, 955-966.

Chamoli A and Dimri VP (2007), Evidence of continental crust over Laxmi basin (Arabian Sea) using wavelet analysis, Indian Journal of Marine Sciences, 36(2), 117-121.

Chamoli A, Bansal AR and Dimri VP (2007), Wavelet and rescaled range approach for the Hurst coefficient for short and long time series, Computer & Geosciences, 33, 83-93.

Chamoli, A., (2009), Wavelet Analysis of Geophysical Time Series, e-Journal Earth Science India, 2(IV), 258-275, http://www.earthscienceindia.info/; ISSN: 0974-8350.

Chandrasekhar, D.V, Roland Bürgmann, Reddy, C. D., Sunil, P. S., David A Schmidt, (2009), Weak mantle in NW India probed by geodetic measurements following the 2001 Bhuj earthquake, Earth and Planetary Science Letters, 280, 229–235.

Chatterjee, S, Bhattacharyya, R, and Majumdar, T J, 2007b, Utilization of high resolution satellite gravity over the Carlsberg Ridge. Marine Geophysical Res., DOI 10.1007/s11001-007-9033-6, October 2007, 9 p. (Journal Volume: Dec. 2007, V. 28, No. 4, pp. 309-317).

Chatterjee, S, Bhattacharyya, R, and Majumdar, T J, 2007c, Validation of ERS-1 and high resolution satellite gravity with in-situ ship-borne gravity over the Indian offshore regions – accuracies and implication to subsurface modeling. Marine Geodesy, 30, 197-216.

Chatterjee, S., Bhattacharyya, R., and Majumdar, T. J., 2007a, Generation and study of high resolution satellite gravity over the Sumatran earthquake region. International Journal of Remote Sensing (Tsunami Edition), V. 28, Nos. 13 & 14, July 2007, pp. 2915 – 2925.

Gahalaut, V.K., C. Subrahmanyam, B.Kundu, J.K.Catherine, A.Ambikapathy, (2010) Slow rupture in Andaman during 2004 Sumatra-Andaman earthquake: consequence of subduction of 90ºE ridge, Geophysical Journal International, 180, 1181-1186.

Gahalaut, V.K., J.K.Catherine, Sridevi Jade, R. Gireesh, D.C.Gupta, M Narsaiah, A Ambikapathy, A. Bansal, R.K.Chadha, (2008) No evidence of unusually large postseismic deformation in Andaman region immediately after 2004 Sumatra-Andaman earthquake, Geophys. Res. Letters, 35, L10307, doi:10.1029/2008GL033704.

Gahalaut, V.K., Kalpna (2007), Burma Plate motion, Journal of Geophysical Research (Solid Earth). 112, B10402, doi:10.1029/2007JB004928.

Gahalaut, V.K., S.Jade, J.K.Catherine, R.Gireesh, M.B. Ananda, P. Dileep Kumar, M.Narsaiah, S.S.H.Jafri, A.Ambikapathy, A.Bansal, R.K.Chadha, D.C.Gupta, B.Nagarajan, S.Kumar, (2008), GPS measurements of postseismic deformation in the Andaman-Nicobar region following the giant 2004 Sumatra-Andaman earthquake, J.Geophysical Research (Solid Earth), 113, B08401, doi:10.1029/2007JB005511.

Gopal, R, (2007), Three-dimensional mapping of Hanseran evaporite bed from Bouguer anomaly over Ganganagar basin, Rajasthan, Journal Of The Geological Society Of India, 70, 1003-1014.

Jade, S; Mukul, M; Bhattacharyya, AK, et al. (2007), Estimates of interseismic

deformation in Northeast India from GPS measurements, Earth And Planetary Science Letters, 263, 221-234.

Jade, S; Vijayan, MSM; Gupta, SS, et al. (2007), Effect of the M 9.3 Sumatra-Andaman islands earthquake of 26 December 2004 at several permanent and campaign GPS stations in the Indian continent, International Journal Of Remote Sensing, 28 3045-3054.

Jade, S; Vijayan, MSM; Gupta, SS, et al. (2007), Effect of the M 9.3 Sumatra-Andaman islands earthquake of 26 December 2004 at several permanent and campaign GPS stations in the Indian continent, International Journal Of Remote Sensing, 28, 3045-3054.

Khan, PK; Chakraborty, PP, (2007), The seismic b-value and its correlation with Bouguer gravity anomaly over the Shillong Plateau area: Tectonic implications, Journal Of Asian Earth Sciences, 29, 136-147.

Krishna, K S, Laju, M, Bhattacharyya, R, and Majumdar, T J, (2009), Study of geoid and gravity anomaly data of conjugate regions of Bay of Bengal and Enderby Basin – new constraints on breakup and spreading history between India and Antarctica. . Journal of Geophysical Research, Vol. 114, B03102, doi:10.1029/2008JB005808.

Kumar N., Singh AP, and Singh B (2009) Structural fabric of the southern Indian shield as defined by gravity trends. J Asian Earth Sciences, 34: 577-585.

Kumar N., Singh AP, Prabhakar Rao MRK, Chandrasekhar DV and Singh B (2009), Gravity signature, derived crustal structure and tectonics of Achankovil Shear Zone, South India. Gondwana Research, 16: 45-55.

Kumar, K; Dumka, RK; Miral, MS, et al., (2008), Estimation of retreat rate of Gangotri glacier using rapid static and kinematic GPS survey Author(s):
Source: Current Science, 94, 258-262.

Likhar, S; Kulkarni, MN; Sakr, K, (2007),Crustal deformation studies in the area of the 26(th) January 2001 earthquake in Bhuj region of Gujarat , Journal Of The Geological Society Of India, 70 912-916.

Mahesh, P., Amit Bansal, B. Kundu, V.K.Gahalaut (2011) Mechanism of M7.5 (2009), Coco earthquake, north Andaman region, Journal of Geological Society of India, 77, 243-251.

Mahesh, P., Bhaskar Kundu, J.K.Catherine, V.K.Gahalaut, (2011) Anatomy of the (2009), Fiordland earthquake (Mw 7.8), South Island, New Zealand Geoscience Frontires, 2, 17-22.

Majumdar, T. J., and Bhattacharyya, R., (2010), Generation and study of satellite gravity over Gujarat, India and their possible correlation with earthquake occurrences. Geocarto International, 25 (4), July 2010, 269–280.

Majumdar, T. J., and Chander, S., (2010), Simulation of SARAL (Satellite with ArRgos and ALtika) resolution gravity over the western Indian offshore for geological/structural interpretation. Geocarto International, 1–14, DOI: 10.1080/10106049.2010.535617.

Mishra DC and Rajasekhar RP (2008), Gravity and Magnetic Signatures of Proterozo RiftedMargins: Bundelkhand Craton and Bijawar and Mahakoshal Group of Rocks and Vindhyan Basin and their Extension under Ganga Basin , J. Geol. Soc. India, 71, 3, 377-387.

Mishra, D.C. Mishra , V.M. Tiwari and B. Singh, (2008), Geological Significance of Gravity Studies in India, Golden Jubilee Memoir Geol. Soc. Ind., 329-372.

Mishra, DC; Rajasekhar, RP, (2008), Gravity and magnetic signatures of proterozoic rifted margins: Bundelkhand Craton and Bijawar and Mahakoshal group of rocks and Vindhyan basin and their extension under Ganga basin, Journal Of The Geological Society Of India, 71, 377-387

Mukul, M; Jade, S; Bhattacharyya, AK, et al., (2010) Crustal Shortening in Convergent Orogens: Insights from Global Positioning System (GPS) Measurements in Northeast India,

Journal Of The Geological Society Of India, 75, 302-312.

Mullick, M; Riguzzi, F; Mukhopadhyay, D, (2009), Estimates of motion and strain rates across active faults in the frontal part of eastern Himalayas in North Bengal from GPS measurements Terra Nova, 21, 410-415.

Patel, PR; Kulkarni, MN, (2008), Preliminary results of gps studies for monitoring land subsidence over the shallow gas reservoir in India Survey Review, 40, 356-365.

Pollitz, F; Banerjee, P; Grijalva, K, et al., (2008), Effect of 3-D viscoelastic structure on post-seismic relaxation from the 2004 M=9.2 Sumatra earthquake Geophysical Journal International, 173, 189-204.

Radhakrishna, M; Lasitha, S; Mukhopadhyay, M, (2008), Seismicity, gravity anomalies and lithospheric structure of the Andaman arc, NE Indian Ocean, Tectonophysics, 248-262

Radhakrishna, M; Subrahmanyam, C; Damodharan, T, (2010), Thin oceanic crust below Bay of Bengal inferred from 3-D gravity interpretation, Tectonophysics, 493, 93.

Rajasekhar, R.P. and Mishra D.C, (2008), Crustal structure of Bengal Basin and Shillong Plateau: Extension of Eastern ghat and Satpura mobile belts to Himalayan fronts and seismotectonics, Gondwana Research, 14, 523-534.

Rajasekhar, R.P. and Mishra D.C, (2008), Crustal structure of Bengal Basin and Shillong Plateau: Extension of Eastern ghat and Satpura mobile belts to Himalayan fronts and seismotectonics, Gondwana Research, 14, 523-534.

Rajendran, CP; Rajendran, K; Anu, R, et al., (2007), Crustal deformation and seismic history associated with the 2004 Indian ocean earthquake: A perspective from the Andaman-Nicobar Islands, Bulletin Of The Seismological Society Of America, 97, S174-S191.

Rajesh, S, and Majumdar, T J, (2009), Geoid height versus topography of the Northern Ninetyeast Ridge: implications on crustal compensation. Marine Geophysical Research, DOI 10.1007/s11001-010-9088-7.

Reddy C.D. and Sunil, P.S, (2008), Post seismic crustal deformation and strain rate in Bhuj region, western India, after the 26th January 2001 earthquake, Geophys. J. Int. 172,593-606.

Reddy C. D., Sanjay K. Prajapati, Teruyuki Kato, (2009), A rheological model of post-seismic response due to 2004 Sumatra-Andaman earthquake: Contribution from low viscosity lithosphere, Journal of Earthquake and Tsunami, 3(1), 25-34.

Reddy, C.D and Sanjay K. Prajapati, (2009), GPS measurements of post-seismic deformation due to October 8, 2005 Kashmir earthquake, Journal of Seismology, 13, 415-420.

Reddy, C.D., Prajapati, S.K., Sunil, P.S., (2010), Co and post seismic characteristics of Indian subcontinent in response to the 2004 Sumatra earthquake, Journal of Asian Earth Sciences, doi: 10.1016/j.jseaes.2010.04.019.

Sarkar, RK; Saha, DK; Chowdhuri, SN (2008), Identification and Mapping of the Intra crustal Density Interfaces of a part of Kumaun-Garhwal Himalaya from Harmonic Inversion of Bouguer Anomaly,Himalayan Geology, 29, 81-85.

Singh S.K., Nagarajan. B and Garg P.K.,2007, Determination of local gravimetric geoid, Coordinates Vol. III, 14-19.

SOI, (2008), Annual Geomagnetic Bulletin containing the hourly values of geomagnetic parameters was published for the year 2006 and 2007.

SOI, (2010), Indian Tide Table and Hugli River Tide Table containing the High-Low water times and heights were published annually during the period under report.

Sreejith, K.M., Krishna, K.S., Bansal, A. R., (2008), "Structure and isostatic

compensation of the Comorin Ridge, north central Indian Ocean", Geophysical Journal International, 175, 729-741.

Srivastava, R.P.,Vedanti, Nimisha., Pandey, O.P., and Dimri,V.P., (2008),"Detailed gravity studies over Jabera-Damoh region of the Vindhyan basin, central India and crustal evolution." J. Geological Soc of India, 73,715-723.

Sunil, PS; Radhakrishna, M; Kurian, PJ, et al. (2010) Crustal structure of the western part of the Southern Granulite Terrain of Indian Peninsular Shield derived from gravity data, Journal Of Asian Earth Sciences, 551-564.

Sunil, PS; Reddy, CD; Ponraj, M, et al., (2007), GPS determination of the velocity and strain-rate fields on Schirmacher Glacier, central Dronning Maud Land, Antarctica Journal Of Glaciology, 53, 558-564.

Tiwari V. M., B. Singh, K. Arora, S. Kumar, (2010), The Potential of Satellite Gravity and Gravity Gradiometry in Deciphering Structural Setting of the Himalayan Collision Zone, Curr. Sci. 99, 1795- 1800.

Tiwari V. M., Wahr J.M. and Swenson S, (2009), Dwindling groundwater resources in northern Indian region, from satellite gravity observations, Geoph. Res. Lett., 36, L18401, doi:10.1029/2009GL039401.

Tiwari V. M., Wahr J.M., Feb, (2010), A short note on application of GRACE Satellite Gravity Mission for periodic assessment of groundwater storage, Proc. Ground Water Resource Estimation, IIT Delhi.

Tiwari V.M., and D.C. Mishra, (2008), Isostatic Compensation of Continental and Oceanic Topographies of Indian Lithosphere, Memoir 68 Geol. Soc. Ind., 173-190, 2008

Tiwari V.M., I. Grevemeyer, B. Singh and, J. P. Morgan, (2007), Variation of Effective Elastic thickness and melt production along the Deccan-Reunion hotspot track, Earth Planet. Sci. Lett, doi:10.1016/j.epsl.2007.08.023

Tiwari V.M., R.P. Rajasekhar and D.C. Mishra, (2009), Gravity Anomaly, Lithospheric Structure and Seismicity of Western Himalayan Syntaxis, J. Seismology , DOI 10.1007/s10950-008-9102-6.

Tiwari, V. M. (2010), On some recent applications of Gravimetry to Earth Sciences, J. Soc. Earth Sciences, Ind., 3(I), 43-53.

Wahr J., Tiwari V. M. and Swenson S., (2009), Monitoring groundwater variability from space: the GRACE satellite gravity mission, IAHS Publ. 330, 263-270.