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Review Article

Gravity, GPS and Geomagnetic Data in India

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Gravity, Global Positioning System (GPS) and Geomagnetic data sets in India are acquired by different research, academic and government institutions, under various projects. These data sets have extensively been utilized for natural resources and lithopsheric explorations, earthquake studies, atmospheric and ionospheric studies, control surveys, aircraft navigation, etc. The data are archived at individual institutions and have different modes of procurement considering some of the data, e.g., gravity data are classified in nature. Some of these data sets are contributed to the international observational network for example IGS and INTERMAGNET and are available as open source for the scientific communities. Present article provides information about different types of available Gravity, GPS and Geomagnetic data, their archival and mode of availability to the user community.

Key Words: Gravity; GPS; Geomagnetism; India

Introduction

The Earth's gravity field varies with time and space due to numerous reasons. The gravity variation with time are both periodic and non periodical. The non periodic gravity variations are often utilized to map mass transport in the Earth system (Tiwari and Hinderer, 2012). However, spatial variation of gravity field corrected for topography and latitudinal variations, known as gravity anomalies are more commonly used by geophysicists and geologists to infer subsurface density distributions caused by differences in the nature of the rocks. Therefore, knowledge of causative sources of gravity anomalies offers several objectives e.g. exploration of natural resources, lithospheric density structure and deep density anomalies involved in the geodynamic processes (Mishra *et al.*, 2008; Tiwari *et al.*, 2013). Measurements of gravity field are made in combination of absolute and relative measurements. Recorded data are processed to derive gravity anomalies following known procedures. Gravity and geodetic measurements in India date back to last century. Earlier measurements were made using pendulum and these were very crude. In seventies, International Association of Geodesy initiated International Gravity Standardization Network (IGSN, 1971). India has been a part of that initiative and several absolute values of gravity field were recorded by relative gravity meter connected to Potsdam reference gravity station. These gravity stations tied to IGSN reference station have been serving as primary reference stations in the country.

Global positioning System (GPS) is a navigation system, which receives signals from a number of satellites orbiting the Earth and provides information about position, velocity, and UTC time. GPS satellites were initially launched and maintained by United States. Now, due to the development of technology, several satellites are being launched by different countries like Russia and India, which provide similar information and complement to GPS. In recent era, recording of precise GPS data, their processing and

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numerous applications to the Earth, atmospheric and ionosphere are noteworthy. Considering its importance, a large number of observations are being recorded and data are archived and made available to users.

At any point on the surface of the Earth, the magnetic field is a vector quantity. The magnitude of the field is represented by the Total field F. The three components of the magnetic field are Horizontal Intensity ‘H’, Vertical Intensity ‘Z’ and the Declination component ‘D’ of the location defining the angle between the true north and the magnetic north. Observations of these recordings are done on a continuous basis at magnetic observatories with the help of magnetometers specially designed to monitor the sensitive variations in the earth’s magnetic field.

Like gravity anomalies, magnetic anomalies also play an important role in investigating subsurface information of rock properties. They are derived from Earth’s magnetic field measurements with necessary processing including International Geomagnetic Reference Field (IGRF) corrections. Magnetic measurements intended for obtaining magnetic anomalies are carried out on ground and also by aeroplane/helicopter in air. Since airborne data collection is expensive, only selected regions of primary interest for exploration are covered for magnetic measurements in various parts of India (Rajaram *et al*., 2006).

Gravity Data

Over the last few decades, a large number of gravity data are recorded in the different parts of India by several institutions for their specific projects. These data were compiled in seventies and a map of 10 mGal (1mGal=10^{-3} cm/sec^2) interval on 1:5 million scale was prepared. However, such a map is not adequate enough for present day exploration requirements and was mostly utilized only for regional lithospheric and geodynamic studies (e.g. Tiwari *et al*., 2013). To improve upon the gravity anomaly maps prepared in seventies and eighties, an effort was made in bringing five major research/government organizations namely CSIR-National Geophysical Research Institute (CSIR-NGRI), Survey of India (SOI), Geological Survey India (GSI), Oil and Natural Gas Corporation (ONGC), Oil India Ltd. (OIL) to collaborate with the primary goal of updating and publishing gravity anomaly map of India from the basic gravity data collected under various projects by these five collaborative organisations. A virtual data bank combining data from all the organizations for entire India totalling 143,786 are archived and grid was prepared at GSI, Hyderabad. For uniform coverage over entire country, an optimal spatial interval of 3 minutes arc interval is chosen thereby only 51,356 gravity observations are considered to prepare the revised gravity anomaly map of India 2006 (Fig. 1). Since data were heterogeneous in quality, type of corrections and their absolute value determinations were always not based on International Gravity Standardization Network (IGSN, 1971); all the data were reprocessed additionally incorporating detailed terrain corrections. The corrected data were supplied to the GSI printing division for printing of maps on the 1:2milion scale (Sundaram *et al*., 2007). The Bouguer maps were superimposed on geological map published by GSI on the same scale, which reveal one to one correlation between a number of anomalies and geological structure/mineralized zone. Though the sharing of digital gravity data are restricted as per the Ministry of Defence (MoD) guidelines, the availability of 5 sets of gravity anomaly maps provide vital information for the planning and studies ranging from mineral/hydrocarbon exploration to tectonic studies (Mishra *et al*., 2008). These maps can be procured from GSI, details of which are stated at web-pages (http://ngri.org.in/pdffiles/aboutngri/gravitymap.pdf; http://www.gsi.gov). One of these maps (GMSI, 2006), Bouguer Anomaly Map of India (Image) is presented in the Fig. 2.

Global Positioning System (GPS) Data

In India, crustal deformation studies using GNSS (mostly GPS) started with the establishment of a permanent International GNSS Service (IGS) station at IISC Bangalore in early 1990’s. This was followed by the development of a National Programme on crustal deformation studies in 1997-98. Several campaign mode observations of plate motion and crustal deformation using GPS were initiated. In

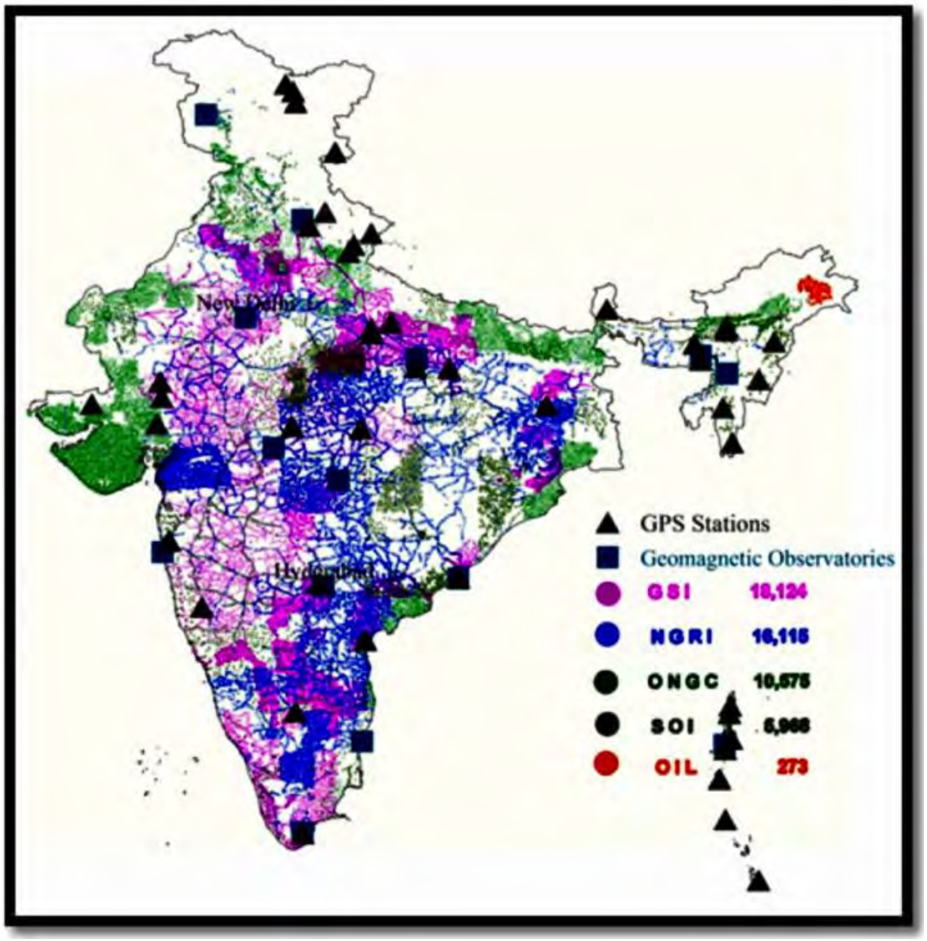

Fig. 1: Filled circle in different colours are locations of gravity observations recorded by different organizations mentioned in the index. Numbers mentioned against each organization are number of gravity observations contributed while preparing Gravity Map Series of India-2006. Triangles are GPS stations and Rectangles are geomagnetic observatories. Source: Gravity Map Series of India-2006

1997, another IGS GPS station was installed at NGRI Hyderabad. By the beginning of this century, the programme expanded extensively. Presently, there are about 100 permanent or semi permanent GPS stations in India maintained by different organizations such as NGRI, SOI and CMMACS etc. Several campaign mode studies in the seismically active regions have been taken up through periodical GPS observations for a few days. All permanent stations are installed on elevated ground, away from trees and buildings to avoid obstructions in tracking the GPS satellites. Generally hard rock site is preferred so that actual ground motion can be recorded. A RCC pillar of height 6-8 feet, reinforced with steel rods is erected (Fig. 3a) on the hard rock. In case, the hard rock is not exposed, the pillar is erected right from the foundation which either reaches the firm ground or at least 6 feet below the ground surface. The semi-permanent stations are also made on the firm base (Fig. 3b). Locations of the VSAT connected permanent stations operated by different organizations are plotted in Fig. 1. All the permanent stations acquire GPS data at 30 second sampling interval and a daily file (called as the RINEX observation file) is generated. This file is used to compute the coordinates of the site which could be accurate at ~3 mm level. The time series showing the daily variation of these coordinates provides an estimate of site motion, which when compared with the plate motion, provides estimate for the crustal deformation in that region. Many of these stations are now connected through VSAT and all the data are

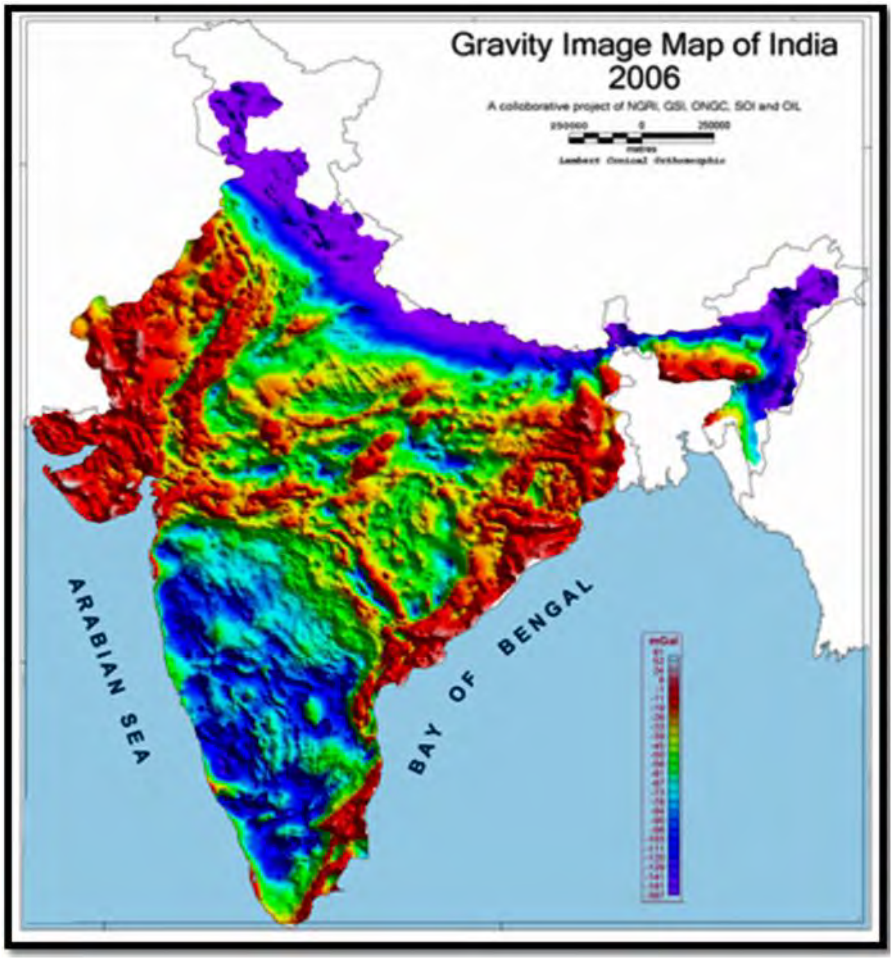

Fig. 2: Bouguer Gravity Anomaly Map of India depicting nature of anomalies in the different parts of India. High (red) and low (blue) values of gravity anomalies indicate high and low subsurface density distributions respectively. Source: Gravity Map Series of India-2006

archived at Indian National Centre for Ocean Information Services (INCOIS), Hyderabad and Indian Meteorological Department (IMD), New Delhi data centres. There is a data sharing policy and these data can be made available to any researcher/officials on request from INCOIS (http://www.isgn.gov.in). These data are now extensively used in earthquake studies besides the atmospheric studies, ionospheric studies, control surveys, aircraft navigation, etc. (e.g. Banerjee *et al*., 2008; Mahesh *et al*., 2012; Gahalaut *et al*., 2013).

Geomagnetic Data

Chapman and Bartels (1940) and Vestine (1960) represented the source of the regular magnetic variation in terms of a current sheet at an altitude of ~100 km above the earth's surface with two vertices, at around 350^{o} latitude. Regular and systematic variations of the magnetic components at many observatories around the globe have subsequently brought out an important finding by way of the Equatorial Electrojet, a phenomenon representing the enhanced flow of east-west current over the magnetic equator. The geographical location of India in the global scenario is ideal for monitoring the developments in the Equatorial Electrojet activities and its associated effects in the Global current system. The existing extensive network of magnetic observatories through Russia from magnetic pole to peninsular India centered along 145^{o} geomagnetic meridian provides unique data sets of magnetic variations from pole to dip equator. Data from magnetic observatories are utilized to study time varying phenomenon and its spatial variability.

Geomagnetic Observatories in India

The Indian Institute of Geomagnetism (IIG) (www.iigm.res.in) is currently operating twelve strategically located Magnetic Observatories covering the length and breadth of India. Each magnetic observatory is set up with a specific scientific interest of investigation and various scientific results are being published by IIG. Geomagnetic signals generated or propagated through the ionospheric region get modified at the dip equator i.e. geomagnetic field variations undergo equatorial enhancement during daytime. The Tirunelveli (TIR) Magnetic Observatory (M.O.) located in this equatorial region started operation in 1996. Pondicherry M.O. (PND) (1993) is located in the fringe region of the equatorial electrojet belt. The prime M.O. Alibag (ABG) (1904), successor to the Colaba Observatory (1826-1904), is located on the West Coast of India away from the influence of the equatorial electrojet. IIG, India is holding the legacy of long geomagnetic data series. ABG (Fig. 3c) is a calibration centre for magnetic compasses of Indian Navy, Airforce and serves as a base station for marine magnetic surveys carried out off Arabian Sea coast. The details of currently operating magnetic observatories are provided in Table 1. In addition to all of the above magnetic observatories (Table 1) operated by IIG, two more magnetic observatories in India; namely, Hyderabad (HYB) and Sabarwala (SAB) are operated by CSIR-National Geophysical Research Institute, Hyderabad and Survey of India, Dehra Dun respectively and both started functioning in1964. HYB M. O. initiated variaometer measurements using LaCourVariometer (HZD) instrument and later upgraded to modern magnetic observatory and became an INTERMAGNET Observatory since 2009. A new magnetic observatory is being set up by CSIR-NGRI at Choutupal (CPL) with digital measurements and it will be a successor to HYB (Fig. 1). The locations of observatories are plotted in Fig. 1.

Data from all the magnetic observatories are processed with suitable software, and the digital data are compared between stations and checked for spikes, artificial disturbances, noise, jumps, time shifts etc. The raw data are then de-spiked, artificial jumps if any are adjusted and three minute running averages are carried out on noisy data to reduce the scatter. Also any loss of data in one system is replaced by the data from the alternate magnetometer system by adding appropriate constants to the variation data such that the data for consecutive days have continuity.

INTERMAGNET Network

The International Association of Geomagnetism and Aeronomy (IAGA) initiated the INTERMAGNET network to exchange the online data from important magnetic observatories under one umbrella during 1987. INTERMAGNET (www.intermagnet.org) is the global network of geomagnetic observatories, monitoring the Earth's magnetic field and helps in adopting modern standard specifications for measuring and recording equipment in order to facilitate data exchanges in close to real time. Observatories send one-minute data in near real time using standard INTERMAGNET formats via satellite, computer and telephone networks to Geomagnetic Information Nodes (GINs). It is an accreditation to magnetic observatory and maintenance of high standards of data quality. ALIBAG since 1997, HYB from 2009 and recently Jaipur magnetic observatory (2013) are the members of INTERMAGNET network in India.

Magnetic Anomaly Maps

Magnetic measurements made over specific regions by different organization are sources of magnetic anomaly map in India. These data do not cover entire country and had been acquired on the ground and by the aircraft at different altitude. An attempt is made to compile all the available data and prepare a map at constant altitude i.e. 5000 ft. The digital data as well as old processed maps can be procured from GSI (http://www.gsi.gov) on nominal charges.

Table 1: Magnetic observatories in India. IAGA code and operating institute names are also mentioned in the column 3. Indian Institute of Geomagnetism (IIG), National Geophysical Research Institute (NGRI) Survey of India (SOI)

S.No.	Magnetic Observatory	IAGA code (operating institute)	Instrument type	Start	Geographic		Geomagnetic	
					Latitude	Longitude	Latitude	Longitude
1.	Tirunelveli	**TIR (IIG)**	Izmiran DFM	1996 2000	8° 42' N	77° 48' E	0.15° N	150.71°
2.	Port Blair	**PBR (IIG)**	DFM	2011	11° 48'	92° 43'	2.28°	165.56°
3.	Pondichery	**PND (IIG)**	Izmiran DFM	1993 2000	11° 55'	79° 55'	3.16°	153.05°
4.	Visakhapatnam	**VSK (IIG)**	Izmiran DFM	1994 2001	17° 41'	83° 19'	8.64°	156.77°
5.	Alibag	**ABG (IIG)**	Izmiran DFM	1975 1993	18° 37'	72° 52'	10.40°	146.81°
6.	Nagpur	**NGP (IIG)**	Izmiran DFM	1991 2003	21° 09'	79° 05'	12.38°	152.99°
7.	Rajkot	**RKT (IIG)**	DFM	2007	22° 18'	76° 47'	13.70°	150.90°
8.	Silchar	**SIL (IIG)**	Izmiran DFM	1999 2011	24° 56'	92° 49'	15.33°	166.23°
9.	Allahabad	**ALH (IIG)**	DFM	2005	25° 27'	81° 51'	16.44°	155.96°
10.	Shillong	**SHL (IIG)**	Izmiran DFM	1975 2012	25° 34'	91° 53'	16.00°	165.39°
11.	Jaipur	**JAI (IIG)**	Izmiran DFM	1975 2002	26° 55'	75° 48'	18.36°	150.41°
12.	Gulmarg	**GUL (IIG)**	Izmiran DFM	1977 2005	34° 05'	74° 24'	25.59°	149.87°
13.	Hyderabad	**HYB (NGRI)**	Izmiran DFM	1964 2008	17° 25'	78° 33'	8.66°	151.88°
14.	Sabhawala	**SAB (SOI)**	Askania	1964	30° 22'	77° 48'	21.62°	152.37°

Data retrieval and Dissemination to Users

The World Data Centre for Geomagnetism, Mumbai is a part of ICSU World Data Centre System (WDCC2) and is operated by the Indian Institute of Geomagnetism, since 1971. It is the only International center for Geomagnetic Data depository in India and caters to the needs of space and earth scientists and researchers from other organizations, universities etc. The centre was started as WDCC2 (India and Japan) in the early seventies and later became WDC for geomagnetism, in 1991, in coordination with ICSU Panel on World Data centers. The data constitute the raw material for the scientific understanding. The World Data Centre system works to guarantee access to solar, geophysical and related environmental data. It serves the whole scientific community by assembling, scrutinizing, organizing and disseminating data and information. In the recent years the centre has prioritized its activities related to digital conservation to ensure digital archiving of magnetic data from the traditional media and also

(a)

(b)

(c)

Fig. 3: (a) A typical permanent GPS station at Port Blair, Andaman; (b) A typical semi-permanent GPS station at Yamunotri in the Himalayan region and (c) Prime magnetic observatory Alibag, which is in continuous operation since 1904 with DIM and DFM instruments which used for absolute and variation measurements

from very old hand written/printed data volumes and magnetograms. WDC, Mumbai has access to normal-run magnetograms, data volumes, microfilms and microfiches of world wide data. On-line data retrieving facilities for digital data including hourly, 1-minute and 1-second geomagnetic values are obtainable on payment. Copies of the data are available upon request. Data catalogues showing the status of data collection are available on WDC web site (URL: www.wdciig. res.in). Geomagnetic data from the network of observatories have been extensively used to study Solar quiet (Sq), electrojet currents, various periodicities observed in the geomagnetic variations, complexities of magnetic storms, transient magnetic variations like solar flares and solar eclipse, geomagnetic pulsation, etc. The Geomagnetic Observatory data are also being used at several institutes for studies on solar wind plasma and Interplanetary Magnetic Field (IMF) associations, space weather, solar flare effects, etc., leading to understanding the sun-earth interaction phenomena as inferred from the ground magnetic variations over the equatorial and low latitude.

Summary

We have presented the latest information on the availability, archival and procurement of the gravity, GPS and geomagnetic data in India, data are archived at different institutes and can be obtained by researchers based on the data sharing policy, which are different for different data sets. Gravity and magnetic anomaly records, only available in the form of maps due to data sharing restriction following Ministry of Defence guidelines, are restricted for open circulation and shared primarily to the government, academic and scientific organisations. Magnetic anomaly maps are available - only for some parts of the country on different recording platform. Therefore, it is essential to record new data uniformly. GPS data from IGS stations at Hyderabad and Bangalore have open accessibility and all other data (continuous and campaign mode) are made available to the Indian researcher after few years of moratorium. Obtaining magnetic records of geomagnetic observatories is straightforward and data can be acquired on request. For some stations, which are part of international network, data can simply be downloaded. Using hourly and 1 minute geomagnetic data from observatories of equatorial station Tirunelveli and low latitude station Alibag, Equatorial Electrojet Index (EEJ) are prepared periodically. Magnetic storm days are classified from magnetograms of Indian stations. In summary, above discussed data are available in three forms, open, registered and restricted access.

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