A way forward towards stable and upgraded horizontal datum for India

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Abstract

A precise datum is very significant as starting or reference point for multitude of activities like, floodplain maps, property boundaries, civil surveys, precise agriculture, crustal deformation and climate studies or other works requiring coordinates that are consistent. A big nation like India, with almost its own tectonic plate, must have a well-defined network of horizontal datum for determining accurate and reliable 3-D positioning for every user, anywhere and anytime. This paper discusses the significance, methodology of realization and transformation, applications, static or dynamic coordinates, for paving the future way of National horizontal datum of India.

Keywords: 3-D positioning, realization, transformation, type of geodetic reference system, National horizontal datum.

Introduction

A set of geometrical or numerical quantities, or constants which serve as a reference for other quantities, forms a datum[1]. Generally, in geodetic surveying, two types of datums are considered: horizontal datum which approximates the shape of the Earth for determination of accurate positions, and a vertical datum to which elevations are referenced[1,2]. The specific interest of this paper, Horizontal Datum, forms the basis to provide precise geometric positions, i.e. latitude, longitude and ellipsoidal elevation, of any point on the Earth's surface. For this, at least eight constants are needed to form a complete horizontal datum: three to specify the origin of the coordinate system, three to specify the orientation of the coordinate system, and two to specify the dimensions of the reference ellipsoid[3]. Such theoretical and mathematical definition is known as reference system and realization of such system to make it accessible to users is known as a reference frame[3]. Datum is synonymous with reference frame.

To simulate the Earth's surface mathematically, ellipsoids were defined[3]. There are different ellipsoids[1] based on whether they justify the surface of the whole Earth or just a country, specifically. These were realized by tedious triangulation surveys, using traditional equipment like theodolites, set up mostly on hill-tops or large towers, as they were dependent on line-of-sight restrictions. The advent of satellite technology, especially Global Positioning Satellite (GPS) service, made the traditional techniques and old datums outmoded. Unlike the traditional approach of physical survey, this modern technology had considerably eased the human effort and provided wide coverage, and highly precise observations for the geodetic survey networks. On the other hand, there is a strong global requirement for accurate positioning, navigation and timing as well as machine guidance and control[4]. These all can be fulfilled by GNSS (Global Navigation Satellite Systems) receivers, continuously operated on the survey control points to realize a strong horizontal datum for the region[4]. This forms a CORS (Continuously Operating Reference Stations) network[4]. They have the perfect capability to provide well-referenced, accurate and reliable spatial data, and support satellite and other related applications, even in real-time. Such coordinates can also be connected to regional, e.g. APREF[5] (Asia-Pacific Reference Frame), and global, e.g. ITRF[6] (International Terrestrial Reference Frame), reference frames for a range of highly accurate global applications.

The National CORS system has rapidly become the most preferred method for accurate 3D positioning, world-wide. Many influential nations have well-maintained, highly accurate, accessible and consistent[7] national horizontal datum. They all have a common mission to provide precise coordinates at any time and anywhere[8]. The United States of America (USA) has National Spatial Reference frame (NSRF) with CORS as foundational component[7]. They have approximately 2000 CORS with 20+ years of data, which are run by various government, academic and private organizations[7,9]. This defines the robust National horizontal datum of USA, that enables the user to determine geodetic latitude, longitude and elevation at any point within the nation and its territories[9]. In Australia, for closely aligning the national datum to ITRF2014, refinements were made in its old datum to come up with GDA2020 (Geocentric Datum of Australia 2020)[10]. The coordinates were computed using a rigorous, 3D network adjustment of all available GNSS (> 6hr) and terrestrial data, and the transformation parameters were derived from CORS[10]. The German Reference Network (DREF91) has been carried out in April 1991 by GPS campaign for the first time to replace the Bessel ellipsoid (1841) as reference surface[11]. The network comprised of 109 sites with maximum standard deviation of 1 to 2 cm horizontal[11] and since then, it has been regularly updated. In 2016, Germany established the integrated geodetic spatial reference as holistic approach for spatial reference[12]. The DREF91 (2016) consists of 250 control stations and 350 reference stations of SAPOS (Satellite Positioning Service of the German State Survey)[12], which is the GNSS CORS network of federal states[13]. The realization includes three hierarchically adjusted networks to provide sub-centimeter accuracy[13]. These brief insights will help in assessing the situation in India.

The status of India's horizontal datum has not been considered holistically before now. This review paper will discuss major boosting steps for a stable and upgraded national horizontal datum for India. Stability, here, refers to the ability of the reference frame to maintain its consistency over time[3]. However, this geodetic infrastructure is a shared national asset that is required to maintain international leadership in economic and scientific committees, support national security[3] and to satisfy all other crucial national needs.

Present Status of National Horizontal Datum in India

With the limited resources available to the user community, the following is the known status of National Horizontal Datum (NHD) in India. Early in the 19th century, the Great Trigonometrical Survey[14] was commenced, as a basis for mapping the general topography of India[15]. Almost the whole country was covered by traingulation[14]. Albeit, due to the limitation of instrumentation techniques at that time, the accuracy achieved was within few hundred metres[15]. In past, the Indian Geodetic Datum was based on Everest ellipsoid[16,17]. The Everest ellipsoid[17] was a locally fit ellipsoid and developed from the combination of several triangulation networks[16]. It came in 1830s[17]. But, this was least satisfactory of all the major datums[17] as it cannot be extended too far from the origin[1]. Also, with the upcoming satellite era, the past geodetic control of India became inadequate[15] for most of the geodetic, geodynamic, geophysical and defense applications, as they required global datum. At that time, WGS-84[18] was widely used by many countries as the datum for mapping[15]. Therefore, in 2005, a transformation campaign was conducted to determine the transformation from Everest to WGS-84[16]. This method was a quick solution to the insufficient Indian datum problem and for acquiring improvised coordinates without much hassles. In this transformation campaign, 300 GT stations[16] (established for Great Trigonometrical survey) were selected and 72 hours of static GPS observation were taken on them to compute the WGS-84 coordinates of these stations. Then with the coordinates available in both systems, WGS-84 and Everest, transformation parameters were calculated and distributed to the user community[16]. These transformation coordinates were accurate up to ~3 meters[16] and therefore, it was decided that the accuracy was good enough for 1:50,000 scale maps[16]. As emphasized earlier, this method was not the best solution to get an improved Indian datum, but a quick fix for carrying out geocentric applications. As the chosen control points were the existing bygone GT stations and hence, their distribution was not uniform for the whole country. Moreover, ITRF had started being more recognized and widely used than WGS-84[6,19]. So, to come up with the re-defined version of the Indian Geodetic Datum, a new realization campaign was brought in by the Survey of India (SoI) in 2005, simultaneously. It started with phase I, around 300 new GPS (1st order) control sites were established all around India with 200-300 km distance between them. Unlike the GT stations of previous campaign, these new chosen benchmarks were uniformly distributed and selected by extensive reconnaissance survey. The establishment of the permanent survey monuments on these sites were made using forced centering device to mark the exact point of reference. Static GNSS observation for 72 hours were made on these 1st order control points and fixed precise coordinates were determined. Three IGS stations (DGAR, KIT3, LHAZ) were considered to fix the independent coordinates of each stations in ITRF05. Then, phase-II was planned to densify the geodetic control network with around 2,400 stations (2nd order control) with 30-40 kms distance between them. But, the development of the second phase didn't go as planned and even the already established control network was not updated and maintained over long to serve the purpose of proper horizontal datum for India. As per ground reports, many of these survey control monuments were destroyed during the various developmental activities and vandalism, due to the lack of awareness. The adjusted network was not re-adjusted to take in account of the destroyed and damaged control stations, and their data. Due to which, the purpose of Indian Geodetic Datum failed and precise coordinates were not available for any applications requiring sub-cm accuracy. This adversely affected the user community of India and many scientific developments of the Nation[15]. Although, SoI is trying to combat this situation with infrastructural plans, this paper will certainly assist in the endeavour by highlighting significant steps and providing some beneficial recommendations in the upcoming sections.

Modern-Day Realization of National Horizontal Datum

As modern-day realization of NHD, the CORS should fulfil three significant goals – **Accessibility** (equipment should be fast, inexpensive, reliable and improving), **Accuracy** (resistance to distance dependent errors and benchmark instability), and **Consistency** (eliminates systematic errors, aligned with latest global reference frames)[19]. In this section, we will be discussing the sequential steps that are required to realize NHD through GNSS CORS Network in India.

1. Network Procedure

The National Geodetic Network will comprise three hierarchical levels or tiers[4,20], such as the 1st, 2nd and 3rd order control points. The 1st order network will be ultra-high accuracy CORS network equipped with geodetic quality receivers that can track all broadcasted global/regional navigation satellites, stable antenna monument, and with IGS site compliant features[4,20]. These points should be well distributed[2] across the country and it's coordinates will support definition of global reference frame[4,20]. The 2nd order nationwide network will densify the latter and will be adjusted under the condition that the three-dimensional coordinates of all the 1st order control points are fixed[2]. They will be equipped with similar features as the 1st order CORS, but will be normally operated and maintained by national or state government agencies[4,20]. The 3rd order CORS points will be equipped with basic interoperable receivers[4], for further densification of the 2nd order network, within 15 – 20 kms[13] or even less point density. The above three level networks are hierarchically adjusted[13]. The final outcome will provide precise geographical coordinates (latitudes and longitudes) and ellipsoidal heights at any point in the country, with sub-centimetre accuracy.

2. Setup of CORS Infrastructure

This step discusses some key aspects of establishing CORS infrastructure. The primary instrument will be a continuously observing dual frequency GNSS receiver, including IRNSS (Indian Regional Navigation Satellite System) signal receiving capability. The infrastructural guidelines should be compliant with the IGS standards[21], that are adapted to suit the Indian conditions. The site conditions should have minimal impact on the measurement[3]. The receivers should operate to guarantee the efficiency of the network, and long-term quality of its products[20,21]. Antenna should be stable and comply with the best multipath reducing measures[21]. Tough security and safety measures should be placed to increase the longevity of the antennas. Lastly, these CORS receivers should cover the whole Indian subcontinent evenly and be densely distributed to serve any user with the best possible accuracy.

3. GNSS Data Processing and Analysis Facilities

Data Centres (DCs) are very important and should be established with state-of-the-art facilities to receive observation data from the permanent CORS network of the country. Good quality checking routines like Unix/Hatanaka compression/decompression, TEQC quality, should be incorporated to avoid storing of poor data[22]. All the stored quality observations should agree to the common guidelines of data format. The NHD stations will upload Receiver Independent Exchange (RINEX) data in DCs[23], and they will be analysed in Analysis Centres (ACs). The ACs acquire quality data to generate precise station positions and velocities of datum points[23]. Also, the ACs should provide weekly/daily output for qualitative analysis. Graphical visualization tools, e.g. residual plots, correlation coefficients plots, etc., should be used for quality control of the recorded data[22]. A few local ACs should be setup to introduce redundancy in the results for eliminating any systematic errors from single solution. To fulfil this mission, a good combination tool and proper weighing of individual solutions are imperative.

4. Network Adjustment

The quality of a geodetic network is concerned with the precision[3] and reliability of the coordinates[24]. If it would have been an ideal world with no errors, then this step wouldn't be necessary. But, no measurement is free of errors and hence, adjustment is necessary to distribute these errors in the best possible way. The least squares technique provides a dependable means for determining the best possible coordinates of survey control points and their uncertainties from a redundant set of measurements[25].

According to Lee et al. 2006[2], there are essentially two classes of network adjustment for geodetic surveying:

a) Minimally Constrained Adjustment

To assess internal observations independent of external control, minimally constrained adjustment is used. In a geodetic network, this adjustment makes the coordinates of only one station fixed, i.e. not allowed to be adjusted in position and orientation. In this way, no errors except those due to current observations will be accounted for in the network. Thus, this will provide internal precision of the derived coordinates in survey and allow to check for outlier existence and remove them. It is also used to validate measurements and readjust a-priori weights.

b) Overly Constrained Adjustment

After removal of the outliers in the previous adjustment, fully or overly constrained adjustment is performed. This is carried out by fixing at least three stations in order to define the datum, orientation, and scale of the network. Therefore, all GNSS-CORS of the network are held fixed, likewise, for adjusting the 2nd order network for precise coordinates, an over constrained adjustment is carried out with the 1st order control points held fixed. This adjustment should be tested to verify that the imposed constraints do not result in measurement failure[25].

After the network is adjusted, a statistical measure of how well the adjustment results matched the expected outcome of the observations is carried out. This is given by a-posteriori variance factor. Once the adjusted results pass the a-posteriori test, the reference network of NHD is suitable for use.

5. Maintenance and Upgradation of Network

The rigorous realization of datum based on CORS networks requires constant monitoring of the coordinates and velocities of the stations defining the datum. These defining stations must be maintained over the years. Each station on the ground is important for the realization of the datum and even a smallest change in any of the stations will cause a change in the adjusted network of the datum and will have subsequent effects in providing precise[3] coordinates to the user.

Upgradation of the Network is important from time-to-time to bring in and adapt improved methodologies for better functioning and improved quality of products. The periodic upgrades are necessary to take care of the following.

1. Expanding to every nook and corner of the country by installing new stations in the area gaps of the previous network[7].
2. Modernizing with technological advancements.
3. Ensuring higher accuracy of the datum.
4. Maintaining to be in sync with the improved and modified global standards, e.g. latest ITRFyy realization.
5. Incorporating all the dynamic changes of the Indian Plate in the periodic updates.

Transformation to global/regional reference frames

The necessity to determine transformation parameters from the local reference frames to that of global and regional frames is for the ability to study global and regional phenomena, respectively[26,27]. Then, the observations from the same geodetic stations can be used for local, regional as well as global applications, as required. The most commonly used methodology is to convert coordinates from one system to the other deploying a least squares principle and known fundamental points, whose coordinates are known on both systems[16,28]. Therefore, more common control points in NHD with that of regional and global systems are required for good transformation[27]. India has 5 IGS registered stations (IISC, HYDE, LCKI, HUTB, PBR2)[29] which are a part of ITRF realization and one APREF registered station (IITK00IND). A country like Japan, which is relatively 10 times smaller, has 14 IGS stations[29] and 10 APREF stations[5]. This reflects that India should consider investing in modern geodetic infrastructure at the same pace as its counterparts. Figure 1 depicts the levels of transformations with respect to NHD.

ITRS (International Terrestrial Reference System) is a global spatial reference system co-rotating with the Earth in its diurnal motion in the space[4,6]. It is geocentric and time dependent[6,27] i.e. its coordinates change with linear function of time due to tectonic motion[28]. It is realized by four space geodetic techniques[6] – Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) and GNSS[3,4]. Therefore, having other techniques in India along with CORS will help to align the NHD more closely with the ITRF. The regional frame, APREF, is realized from the integration of the well-sampled velocity fields of Asia and Pacific regions, from regional and national permanent GNSS networks[5]. Let's consider INREF (Indian Reference Frame) as the name of our nation's NHD, for this section only. We will see the transformation approach between ITRF and INREF. In similar lines, the transformation of INREF to APREF or any other terrestrial reference frame will be handled.

The 3-D similarity transformation[6,11] connects two frames with different geodetic datum consisting of different origin, orientation around three axes and scale. This leads to the basic equation of the 7-parameter (one scale, three translation and three rotation) Helmert transformation as[6,28]:

$$X_2 = X_1 + T + D \bullet R \bullet X_1 \tag{1}$$

where,

D is the scale factor.

The cartesian coordinates are in X matrix.

The subscripts 2 and 1, denote the two different frames with 2 being the desired output and 1 being the input or the start frame.

$$X_1 = \begin{bmatrix} X_1 \\ Y_1 \\ Z_1 \end{bmatrix}, X_2 = \begin{bmatrix} X_2 \\ Y_2 \\ Z_2 \end{bmatrix} \tag{2}$$

T is the translation vector of the origin along the X, Y, Z axes.

$$T = \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix} \tag{3}$$

R is the rotation matrix around the X, Y, Z axes with angles α, β, ϒ (counter-clockwise in RHS), respectively. So,

$$R = R_z(\gamma) \bullet R_y(\beta) \bullet R_x(\alpha) \tag{4}$$

$$R_x(\alpha) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & \sin\alpha \\ 0 & -\sin\alpha & \cos\alpha \end{bmatrix}$$

$$R_y(\beta) = \begin{bmatrix} \cos\beta & 0 & -\sin\beta \\ 0 & 1 & 0 \\ \sin\beta & 0 & \cos\beta \end{bmatrix} \qquad (5)$$

$$R_Z(\gamma) = \begin{bmatrix} \cos\gamma & \sin\gamma & 0 \\ -\sin\gamma & \cos\gamma & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Therefore, the general model of transformation from one reference frame to another will be[27,30]:

$$\begin{bmatrix} X_2 \\ Y_2 \\ Z_2 \end{bmatrix} = \begin{bmatrix} X_1 \\ Y_1 \\ Z_1 \end{bmatrix} + \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix}_{1,2} + \begin{bmatrix} D_{1,2} & -R_{z(1,2)} & R_{y(1,2)} \\ R_{z(1,2)} & D_{1,2} & -R_{x(1,2)} \\ -R_{y(1,2)} & R_{x(1,2)} & D_{1,2} \end{bmatrix} \begin{bmatrix} X_1 \\ Y_1 \\ Z_1 \end{bmatrix}$$

(6)

Now, specifically discussing the transformation approach[27] from ITRFkk (e.g. ITRF14) to INREFnn (e.g. INREF21), both of them are in different epochs kk and nn. Input data will be the ITRFkk and INREFnn station coordinates and its velocities of common GNSS control stations at the reference epoch, t_r. But, the transformations will be computed at campaign epoch, t_c. For ease of writing the equations, X^I and X^{IN} denote the cartesian coordinate matrix in ITRF and INREF, respectively. The dot above the X denotes their velocities.

As per Boucher and Altamimi (2011), the following transformation approach will be applied[30]:

1. ITRF coordinates of the common control stations in recent ITRFkk will be transformed from reference epoch t_r to campaign epoch t_c, by this equation.

$$X^I_{kk}(t_c) = X^I_{kk}(t_r) + \dot{X}^I_{kk} \cdot (t_c - t_r) \qquad (7)$$

2. Now, ITRFkk at t_c will be transformed to ITRFnn using the latest IERS published values of seven transformation parameters, using equation (6).
3. Then, equation (8) will be used to transform from ITRFnn to INREFnn.

$$X^{IN}(t_C) = X^I_{nn}(t_C) + T_{nn} + \dot{R}_{nn} \bullet X^I_{nn}(t_C) \bullet (t_C - nn)$$

(8)

The above three-step procedure can be performed in one-step using 14-parameter transformation[27,31] between ITRFkk and INREFnn. The transformation has to be flawless for high precision applications. Therefore, assessing the accuracy and reliability of the resultant transformation parameters is important. This can be done on some chosen checkpoints as an independent check by comparing actual and transformed positions[28]. The transformation parameters have to be standard, readily available, and easily accessible to avoid any confusion among the user community.

Static and Dynamic Coordinates

Static and dynamic coordinates have their own significance with respect to different applications. Traditionally, static reference system was common with fixed benchmarks on the ground as control[32]. The coordinates of such control points are fixed at reference epoch and are time-independent[32,33,34]. Albeit, such unaltered coordinates are useful for administrative purposes like mapping, cadastre, and practical applications[34] that can ignore the tectonic motion. But in reality, the Earth's surface is continuously moving[26] due to the plate tectonics and local deformation events[33] like earthquakes, landslides, etc.[32]. This deteriorates the static coordinates over time. A major disparity occurs due to the fact that the GNSS satellite orbits are calculated with respect to ITRF[6]. Thus, the GNSS conferred positions will deviate drastically from that of static coordinates. Over time, when the degraded accuracy of static coordinates drops below the GNSS accuracy and user expectations, it's time for its renewal[32,33]. Upgrading the static reference frame are laborious and expensive[32], and hence cannot be done frequently. To fulfil the sub-cm accuracy needs of real-time applications and studying the Earth system, time-dependent coordinates are must. This is provided by dynamic reference system[27], which is based on the global ITRS-based coordinates[32,34]. This system is complex and confusing for many users[33] as the coordinates are continuously changing with no proper epoch[34]. This renders it unsuitable for many practical applications[32,33]. For embracing the advantages of these two geodetic reference systems, the approach of semi-dynamic (semi-kinematic) reference system is widely followed[32,35]. This is based on CORS control network which gives time-dependent coordinates and determines the national deformation model incorporating local movements[33,34]. The semi-dynamic system uses this deformation model[35] to transform dynamic coordinates consistently to a fixed reference epoch[32,33]. This gives quasi-static coordinates referring to a specific epoch which do not vary until they exceed a certain critical level[34], so that non-geodetic users don't deal with complexities of the dynamics. Figure 2 gives a pictorial representation of the concept discussed here. Countries like New-Zealand[35] and Australia[8], where horizontal plate motions are up to 5-7 cm/year follow semi-dynamic reference system[10,35]. Therefore, the latter approach is highly recommended for a tectonically active country like

India, which is subjected to plate movements up to 5-6 cm/year[36] and other intra-plate activities[34]. This will avoid the expenses for updating the static datum regularly, without compromising the accuracy of coordinates[32,33].

Benefits

The burning question nowadays is "Where on Earth am I?" From a pilot to a geodesist, this question is of utmost importance and requires different precision in positions accordingly[3]. Therefore, the range of accuracy of the required coordinates varies from metres to millimetres.

The multifarious activities of huge economic, social and environmental impacts, now depend directly or indirectly on the precise positioning data[19,37,38]. The following are some highlights from the wide range of NHD applications.

(a) Societal Applications

1. It will provide precise reference for surveying that are significant for many engineering works like construction of roads, rails, canals, pipelines, powerlines, communication infrastructures, etc[4,40].

2. The global reference coordinates are not modified to accommodate changes from local deformations. At that time, NHD is updated for the changed positions and give actual coordinates in the affected nation. For e.g. "Japan and Chile could not use the ITRF after the 2010 earthquakes"[40].

3. It will assist in providing disaster relief efforts[4,19] in emergency healthcare, delivery of basic needs like food, water or clothes to exact locations of disaster hit areas in the country. Such inaccessible locations can be reached by air ambulance, drones or helicopters.

4. It will help to manage the land resources by improving the cadastral mapping[40] and providing "definitive" national and various administrative boundaries[41].

5. With the growing purchasing power, smartphones account for almost 80% of the global installed base[38] of satellite positioning devices and majority of the applications (apps) use the location data for its services[7]. The NHD will improve localized positioning data to impart better niche services.

6. More and more automated vehicles, UAVs, drones, and augmented reality platforms[38], are coming up as the futuristic goals of the society and these all will depend solely on reliable and precise positioning services.

7. It can be used for the implementation of railway network[41] across India with sub-cm positional accuracy and also, offer enhanced safety for lower costs (i.e. railway signalling)[38].

(b) Economic Applications

1. Though India's new geospatial policy has democratised mapping[42], but accurate maps can only be formed from good metrological reference, provided by stable static coordinates of NHD.
2. It will help to map the waterbodies around India and become the primary source of PNT (Position, Navigation, Timing) information at them[38,37]. This will certainly be useful for fishermen, recreational boats, freight ships and addressing any distress call.
3. This service will enable precise agriculture[38] by providing good positional accuracy to drones or pesticide spraying UAVs. This will be vital to the economy as "agriculture and related industries account for 17% of India's GDP and feeds almost 50% of its workforce"[39].
4. The dynamic coordinates of the NHD can be used for Indian satellite orbit determination[8], by tracking localized changes in the control and monitoring stations.
5. The aviation market will rely completely on such precise positioning services[38] for operation and safety of increasing number of domestic aircrafts.
6. This service will improve remote sensing by accurate positioning of aerial mapping aircrafts[9,19]. This improves the reliability of photogrammetric restitution of large areas, specifically remote and inaccessible terrain[9].
7. The above concept can also be used to assist technologies like LIDAR, InSAR, sonar, etc., in mapping terrains with digital cameras[9].

(c) Environmental Applications

1. The variations of vertical crustal velocities at the NHD CORS sites near tide gauge stations will be used to relate local sea level changes to global ITRF[9]. This will be beneficial for observing ~7,500 kms of Indian coastline.
2. It will assist in geodynamical studies by monitoring local deformations, and intra/inter Indian plate movements, which are mostly precursors of seismic activity, volcanic eruptions, and local subsidence[40].
3. With the analysis of data from ground-based CORS receivers, tropospheric parameters can be obtained as a part of estimation[9,41], which will support the meteorological research of the country, and improve weather forecasts[3].

4. Local ionospheric models can be developed to model and mitigate local ionospheric effects[9] by well-suited correction models in space based geodetic observations.
5. Specifically, this will help to improve predictions of natural disasters[7] like tsunami, cyclones, earthquakes, flooding, etc. Moreover, this will assist to examine their size and intensity, impact area, and development of early warning systems[3,4], and GIS based evacuation routes for minimising crowding and panic.

Conclusion

The NHD forms the pillar of georeferencing in India and its needs has been emphasized much in the last section and in figure 3. Reiterating that the concept of NHD is not new to India, and there have been past realizations of the Indian datum. Albeit, the science in this respect has taken a big leap globally, but India's progress in this sector is substandard. We have been more dependent on the global reference frame, than our local frame for indigenous applications. Establishing well-defined network for better NHD is not enough, and the defining network station coordinates have to be adjusted and maintained diligently, transformation parameters have to be determined, and repetitive epochal campaigns should be conducted for exceptional updates. Shortcoming in any one of these integrated processes will affect the precise positioning services, vital defence and scientific studies of India. Moreover, the accuracy of ~2 cm[4,10] in the GNSS derived heights of the CORS network will assist in developing better vertical control for the whole country[1,19].

From the geodynamic point of view, India is in unique position with its own tectonic plate. So, it becomes much more important to have its own spatial reference frame to monitor the changes in coordinates locally. Moreover, it can be geographically and temporally interpolated or extrapolated, whenever and wherever required within the Indian subcontinent, as per local needs. Though most of the key points were discussed in the previous sections, the following are some crucial points from the user's perspective for a better NHD.

- It should be consistent[7] in all parts of the Indian subcontinent.
- The static coordinates must not change frequently[32].
- The dynamic coordinates should be closely aligned with the global system, so that we can have better coordinates for many global

applications like airport obstacles, freight ships, etc.

- Provide accessible transformation tools[7,19] with contemporary programming and consistent transformation parameters.
- Increase in the number of common points in global, regional and national reference frames, i.e. IGS/ITRF, APREF and NHD, respectively around the country to get good transformation[28].
- Co-location with other existing space geodetic infrastructure[7,19], i.e. VLBI, SLR and DORIS, of India is essential to strengthen the link between the national frame and the ITRF.
- Publish a formal publication of the NHD, that can be accessed by the users and the scientific community.
- Awareness among the people about the significance of these geodetic monuments of NHD and implementation of stricter laws to protect them. This initiative will preserve these structures from destruction and vandalism.
- A competent body with large workforce should be chosen to establish and monitor the status of the control monuments and replace/repair its instrumentation, in case of failure.
- Another proficient body should take the duty of coordination of the NHD network and act as coordinator between station operators, data, and analysis centres, and maintains the Product and Information system[23].
- India should develop its own software for quality check, processing of CORS data and monitoring exclusively the geodynamical activities of the Indian Plate.
- Perform necessary periodic campaigns for NHD upgradation and incorporation of changes.
- Provide regular training and tutorials to the user community.

The above points exhibit that an integrated approach from various competent organizations is predominant for proper functioning of the NHD service. With this, we aspire for a better future of the horizontal datum in India.

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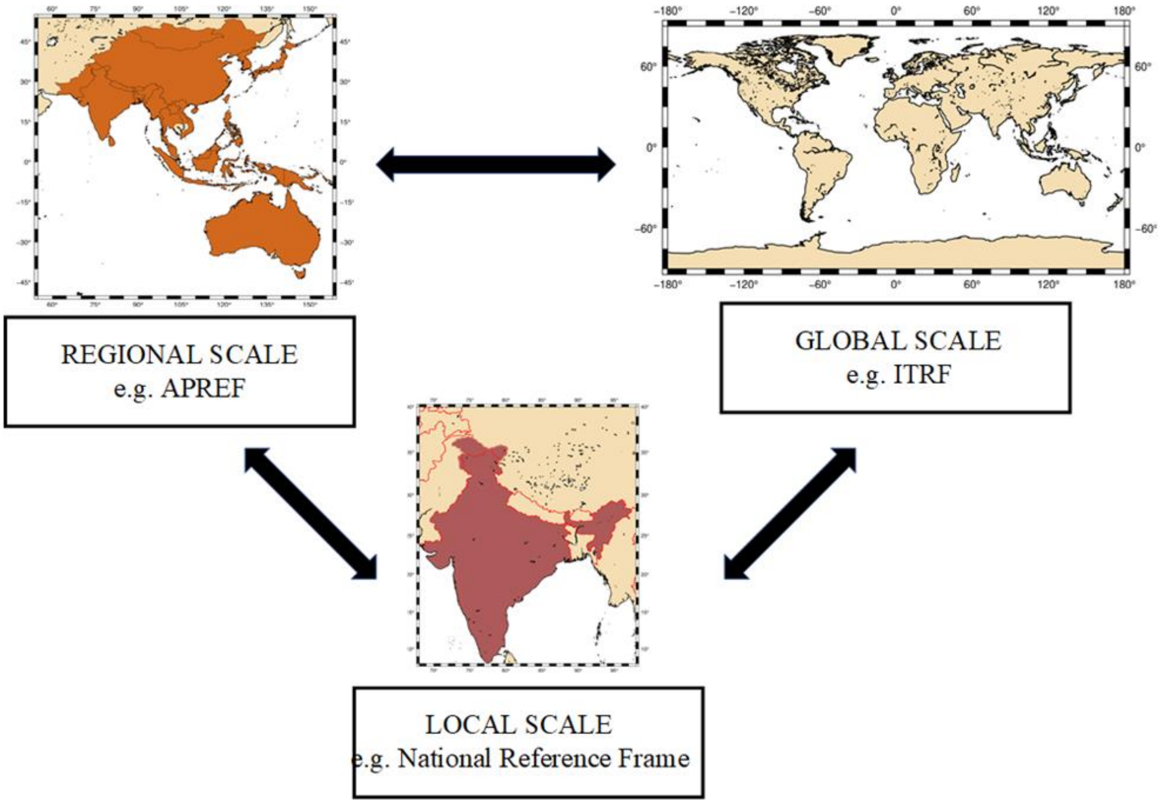
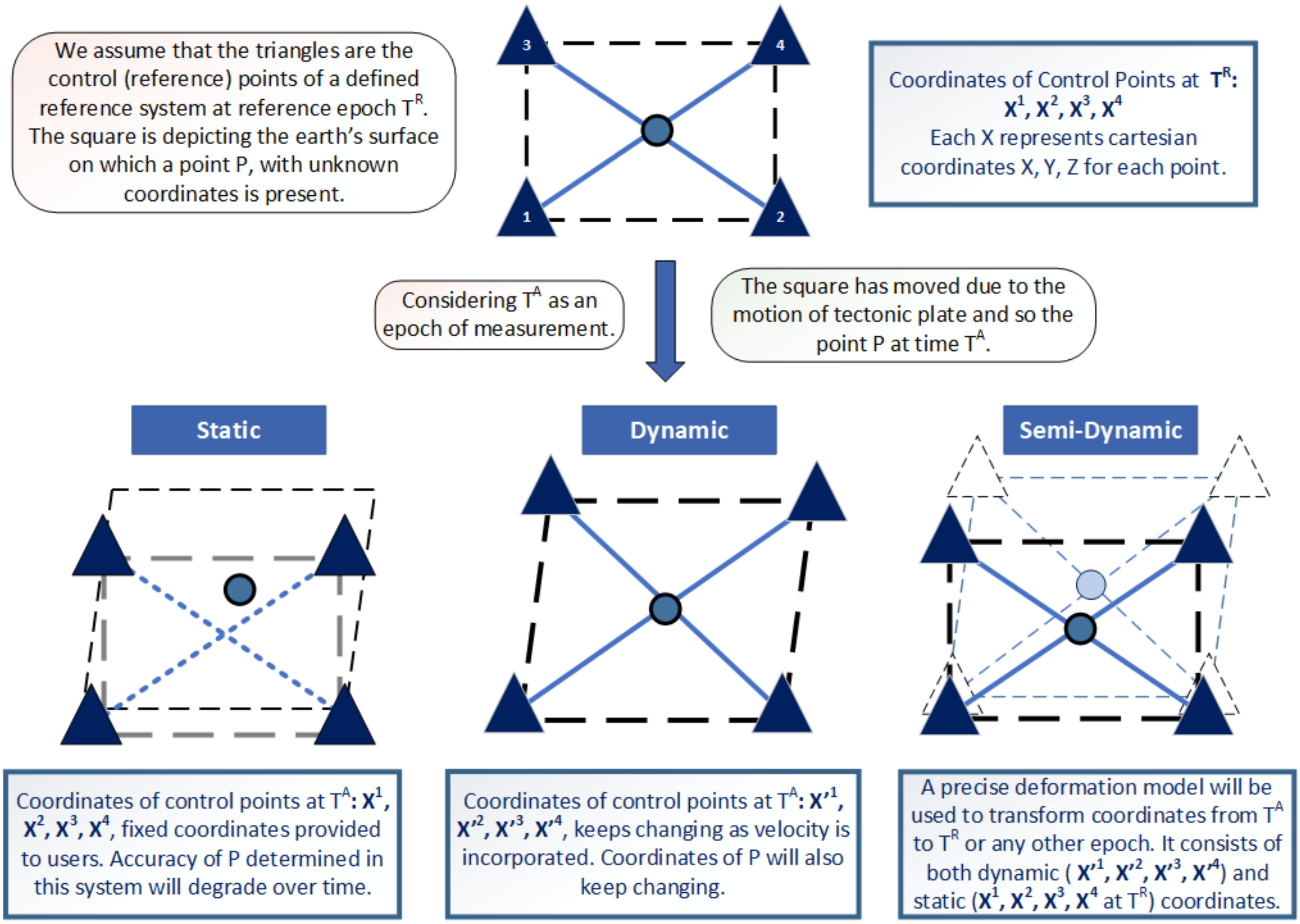
Figure Legends

Figure 1: Transformation levels between different terrestrial reference frames.

Figure 2: Representation of three types of geodetic terrestrial reference frames.

Figure 3: Applications of the Indian CORS infrastructure of the National Horizontal Datum.


REGIONAL SCALE
e.g. APREF
GLOBAL SCALE
e.g. ITRF
LOCAL SCALE
e.g. National Reference Frame


We assume that the triangles are the control (reference) points of a defined reference system at reference epoch T^R. The square is depicting the earth's surface on which a point P, with unknown coordinates is present.
3
4
1
2
Coordinates of Control Points at T^R: X^1, X^2, X^3, X^4 Each X represents cartesian coordinates X, Y, Z for each point.
Considering T^A as an epoch of measurement.
The square has moved due to the motion of tectonic plate and so the point P at time T^A.
Static
Dynamic
Semi-Dynamic
Coordinates of control points at T^A: X^1, X^2, X^3, X^4, fixed coordinates provided to users. Accuracy of P determined in this system will degrade over time.
Coordinates of control points at T^A: X'^1, X'^2, X'^3, X'^4, keeps changing as velocity is incorporated. Coordinates of P will also keep changing.
A precise deformation model will be used to transform coordinates from T^A to T^R or any other epoch. It consists of both dynamic (X'^1, X'^2, X'^3, X'^4) and static (X^1, X^2, X^3, X^4 at T^R) coordinates.


Global Geocentric Framework
Local Scale Applications
Indian CORS Infrastructure
(co-located with VLBI, SLR, DORIS)
SLR
DORIS
VLBI
GNSS
ISRO
Satellite Orbit
Water Level
Weather
Property
Glaciology
Infrastructure
Natural Hazard
Tunneling & Mining
Navigation
Agriculture