Determining Favorable Locations for VGOS Establishment in India

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Abstract To support the ambitious goals of the Global Geodetic Observing System (GGOS), more antennas are required to achieve the uniform global distribution of the VLBI network. Many countries are joining the VLBI Global Observing System (VGOS) network with their proposed stations. India is one such country that is planning to establish this state-of-the-art technology for national and global needs. Thus, extensive simulation studies were performed on 42 potential locations to assess the performance of different regions of India. Optimized scheduling, Monte-Carlo simulations and analysis were carried out to examine the impact on the estimated geodetic parameters from the addition of an Indian VGOS antenna to the reference network. As the performance from the simulation study depends on the considered reference network, four different reference networks are considered for this assessment. The simulation assumes ideal situations, but in reality the VGOS observations depend on the practical conditions on site. Thus, environmental variables, such as extreme weather events, that might affect the performance of VGOS are also incorporated with a weighted scoring model for investigating the performance of different regions in India. This comprehensive study will help to indicate the favorable locations in India with high performance potential for VGOS.

Keywords VGOS, India, scheduling, simulations, environmental variables, favorable locations

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1 Introduction

Very Long Baseline Interferometry (VLBI) actively contributes to deriving the International Terrestrial Reference Frame (ITRF), and the International Celestial Reference Frame (ICRF) is solely derived from it. Apart from that, it's the only technique to determine the complete set of Earth Orientation Parameters (EOP) that are used for the transformation between the terrestrial and celestial reference frames. VLBI with its indispensable accuracy will support most demanding commercial, military, and scientific applications of a country. Thus, India will benefit enormously by establishing VLBI, specially the space applications sector. VLBI will help to serve the national scientific community well by creating opportunities for global collaboration and by developing strong economic and scientific spheres. Co-location of VLBI with the other existing space geodetic techniques in India, especially the CORS network, will strengthen the link between the national frame and the ITRF.

Thus, investigating the optimal performance of VGOS in different parts of India was significant for a comprehensive understanding of the region. The effect of an added antenna on the precision of geodetic parameters was examined from the simulation study. Different locations experience different environmental conditions that may impact the ideal operation of VLBI assumed in the simulation study. Also, maintaining the long history of VLBI data provided by these locations is essential for reference frame stability, and hence, the vulnerability of the considered locations from different regions of India was also incorporated along with the latter. This practical and thorough analysis of VGOS performance was used to determine favorable locations for the establishment of an antenna in the Indian subcontinent.

2 Methodology

In this study, the reference network for the simulation is a global network of VGOS stations which are either currently operative or are working on the installation of a VGOS signal chain, as depicted in the status of the projected VGOS network of IVS. To this, an antenna was added one-by-one from the prospective VGOS locations in India, called the study locations. 42 study locations were chosen to cover the whole Indian subcontinent. The setup of the reference network and study locations is shown in Figure 1. Because the expected precision of the derived geodetic parameters from the addition of an antenna depends on the reference network geometry to which it was added, four cases of different reference network geometries were considered in the study.

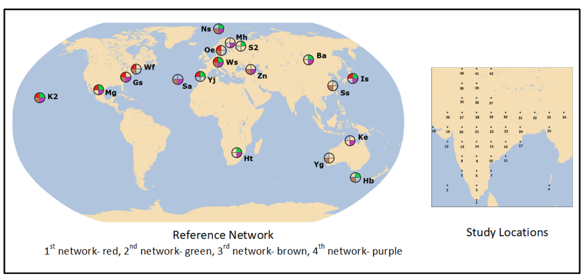

Fig. 1 Reference network stations and study locations. All VGOS stations are shown by their IVS code names, except VGOS at Seshan (Ss), Badary (Ba), Zelenchukskaya (Zn), and Svetloe (S2).

First of all, scheduling was carried out by optimized weighting of the scheduling parameters in each of the four cases. These weights were decided from the best schedule obtained from the multi-scheduling. Then, a Monte-Carlo simulation strategy was adopted with input parameters of 4 ps of white noise per baseline observation, $1 \text{x} 10^{-14}$s @ 50 min of Allen Standard Deviation (ASD) for modelling clock drifts, and tropospheric delay with a structure constant (Cn) value of $1.80 \text{x} 10^{-7}$ $m^{-1/3}$. Then, analysis of the estimated geodetic parameters was performed by comparing the precision of the estimates determined from just the reference network and that from the reference network with an added VGOS antenna at the study location. VieSched++ was used to perform scheduling, simulations, and analysis. In this study, the mean formal error was used as the measure of precision for the simulation study carried out to examine the impact on geodetic parameters from the addition of an Indian VGOS antenna. The estimated geodetic parameters studied in this study are station coordinates and EOP, i.e. X and Y coordinates of Polar Motion (PM), the difference between universal time and coordinated universal time (dUT1), and X and Y coordinates of Celestial Pole Offsets (CPO).

Now, the investigation of the impact of possible problematic environmental events on the study locations was divided into two criteria—"operationality" and vulnerability. The operationality examined those probable environmental events that decrease the quantity of observations by frequent halts in the antenna operation and degrade the observation quality by increasing the noise in some cases, while the vulnerability dealt with the probability of any natural calamity causing destruction to the VLBI establishment at the study location. To incorporate these environmental effects of the study locations, a weighted scoring model was used. These models are the summation of weighted scores of the multiple criteria that are to be taken into account, and they are a great aid for decision making. In this, the weights are assigned based on the importance of the considered criteria, and scores are based on the impact. The following weighted scoring model was considered to determine the final scores of the study locations.

$$score_{final} = (0.4 \times score_{opr}) + (0.6 \times score_{vul})$$

0.4 and 0.6 are the respective weights of operationality and vulnerability. The weight of vulnerability is set a bit more as the considered environmental variables in this criterion can potentially cause irreversible damage to VLBI. The $score_{opr}$ was determined by calculating the annual occurrence of extreme weather events such as thunderstorms, dust/sand storms, snowfall, rainfall ($>$ 10 mm), and hail storms on the study locations using data provided by the Indian Meteorological Department (IMD). For incorporating the effect of strong winds on study locations, the wind hazard map of the IMD was assessed. The weightage of meteorological weather events and strong winds were

Table 1 Interpretation of scores used in the weighted scoring model for incorporating environmental variables.

Scores	Operationality	Vulnerability
3	Susceptible to frequent periods of inoperation and more chances of getting noisy data	High risk of complete destruction
2	Lesser halts in operation and some chances of getting noisy data	Moderate risk of destruction
1	Very-low or no halts and no chance of getting noisy data	Low chances or no risk of destruction

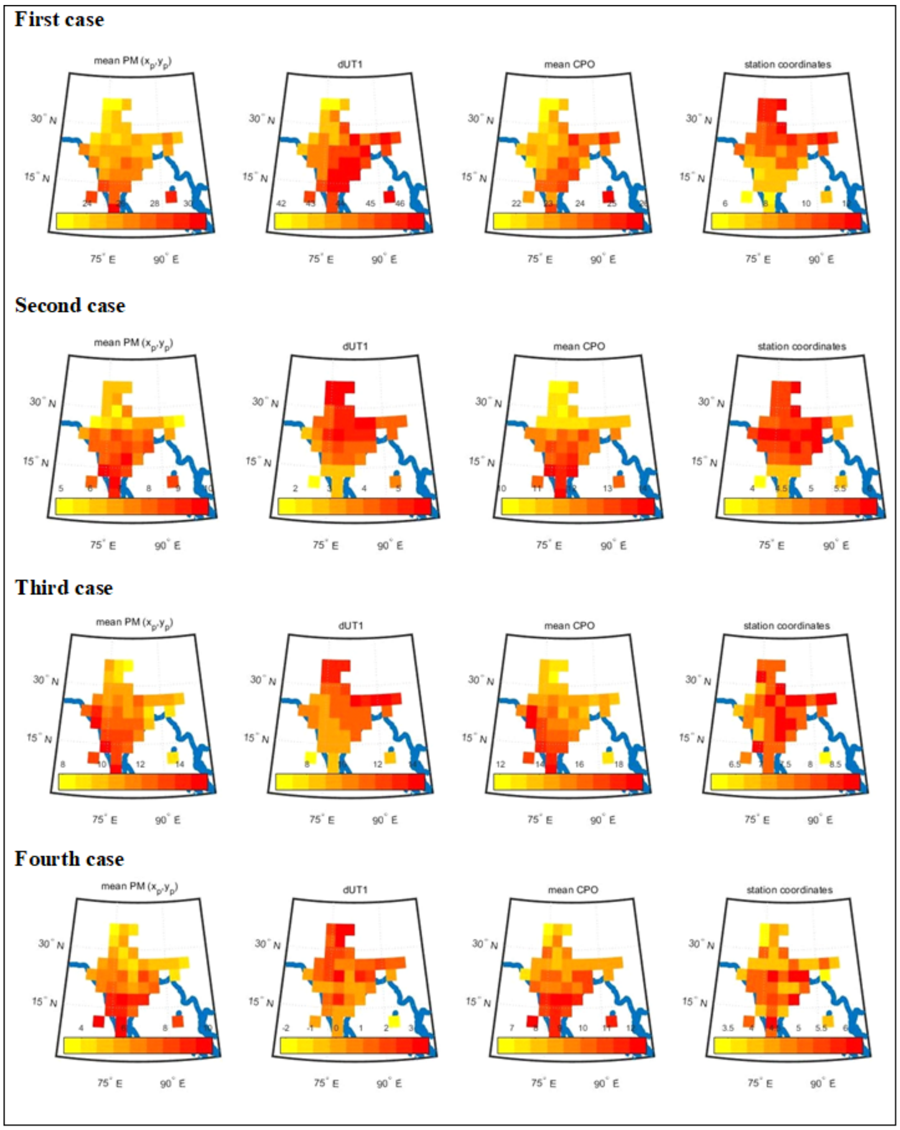

Fig. 2 The expected improvement percentage in the precision of the estimated geodetic parameters from the simulation study.

kept the same for calculating the $score_{opr}$. For calculating the $score_{vul}$, common natural calamities such as earthquakes, floods, cyclones, and landslides, were considered, and their weights were based on their occurrence probability in India, i.e. 0.05, 0.52, 0.31, and 0.11 respectively. The occurrence frequency and impact of stated extreme events on different regions were taken from the Vulnerability Atlas of India (published by the IMD). Then, the study locations were categorized into one of the three categories of Excellent, Good, and Poor, based on the normal distribution of their $score_{final}$ values.

3 Results

The results from the simulation study are shown in Figure 2. The improvement percentage in the expected precision of a geodetic parameter is depicted by individual color blocks plotted over the study location. The geodetic parameters that are shown are the mean of PM coordinates (mean PM), dUT1, mean of CPO coordinates (mean CPO), and station coordinates. The mean PM and mean CPO were plotted, as the values of their X and Y coordinates were similar. Further, it wouldn't ever happen that just a single study location from a region would show optimal performance, but the group of study locations from a region will display homogeneous performance. Thus, the performance of different regions in India are discussed in the results of the study.

In the first case of a network with eight reference stations, the expected improvement obtained is the maximum of all the considered cases in this study. The reason for this is the relatively smaller number of reference stations in this case and, too, that they are clustered in America and Europe. This is also the reason for the southern study locations performing better than other regions in India, for the polar motion and CPO estimates of this case. For dUT1, the eastern study locations show smaller precision. This is due to the long east-west baseline extensions that can be formed with the reference stations for better sensitivity to dUT1. The expected improvement in the station coordinates is larger for the north and northeastern regions by a factor of $\sim$2.8.

Although the reference stations are distributed better in the second network than in the previous one, most of them are in the northern hemisphere above 22 degrees. Thus, the southern and central study locations show maximum improvement in PM and CPO in the second case. The northern study locations show maximum improvement in estimated dUT1 by $\sim$4 relative to other Indian regions. The estimated station coordinates don't show substantial variation in precision among the study locations, but still the northern regions perform better in the second case.

The number of reference stations in the third network is just one more than that in the second network. But, the expected improvement shown is much more than in the latter network. The reference network is almost similar in both cases, except that one of the southern hemisphere reference stations (HART15M) does not participate. This might be the reason for the increased improvement in the precision shown by the addition of an Indian antenna in this case over the previous case. The southern antennas in India show smaller precision in the polar motion and CPO estimates. The northeastern, and then northern study locations show maximum improvement in dUT1. There is no visible trend observed in the study locations for the expected precision of station coordinates, but the northern and northeastern regions perform well.

In the fourth network more reference stations, mostly situated around India, are considered in the reference network. Thus, the expected improvement is the minimum of all the cases. But the trend of southern and some central study locations portraying maximum improvement in polar motion and CPO is persistent in this case too. The VGOS antennas from the northern study locations show maximum improvement in derived dUT1. The precision of station coordinates is improved by the addition of Indian VGOS stations, but no clear regions of maxima can be observed in India for this case.

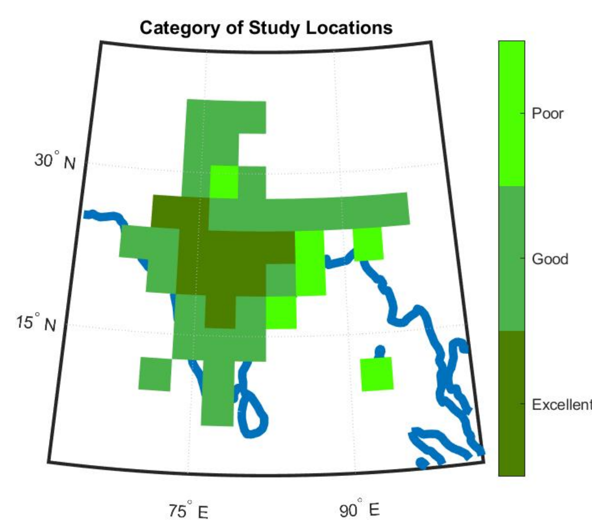

Fig. 3 The different categories assigned to study locations based on the impact of environmental variables on VGOS.

The impact of the disturbing environmental variables in the Indian locations can be visualized from Figure 3. It shows that the eastern coastal regions and some northern locations at the foothills of the Himalayas are the poor choice for VGOS, although most of the Indian locations provide suitable environmental conditions for VGOS.

4 Conclusions

The selection of favorable locations for optimal performance of VGOS is a complex problem which involves many variables. Apart from the precision of estimated geodetic paramaters, the decision for a proposed VGOS location will depend on other factors such as staff availability, vicinity to supporting supplies, geological conditions, RFI, power availability, broadband internet accessibility, funding, and other requirements. But, these factors are highly variable and difficult to quantify, and hence they were not investigated in this study. To make the expected performance of the potential locations more practical, the impact of environmental variables was investigated in this study along with the precision of geodetic parameters, such as EOP and station coordinates. The scheduling of the considered sessions was optimized to make it realistic. The examination of the four cases considered in this study interprets that the southern and central regions of India improve the polar motion and CPO estimates by a factor of 1.4 to 3.3 and 1.2 to 2 respectively, depending on the reference network geometry, while the VGOS antennas from the northern and northeastern regions show the best precision of dUT1 estimates by a factor of 1.1 to 4. The station coordinates are improved by a factor of 1.5 to 2.4, without any specific region showing the best precision in all of the cases. This makes it clear that the optimal location for a new VGOS establishment in India will depend on the geodetic parameter of interest. The study also indicates that a VGOS antenna established at any Indian location will improve most of the geodetic parameter estimates, and the difference in the precision does not vary substantially among the study locations. Further, the impact of the examined environmental factors depicts that the Indian plateau regions are excellent choices for optimal VGOS performance.

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