Performance analysis of IMD’s GUAN standard - Compatible network

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ABSTRACT. India Meteorological Department (IMD) recently up-graded the upper air radiosounding network by employing GPS based radiosounding systems. Out of 43 radiosounding systems 6 stations, each at its regional head quarters i.e., New Delhi, Mumbai, Kolkata, Chennai, Nagpur and Guwahati have been equipped with high quality radiosounding system, make M/s GRAW Radiosonde, Germany. The quality and reliability of the radiosonde measurements are essential because even small inaccuracies in the profiles can prevent the forecaster from observing critical details and making the correct conclusions. Hence, the performance of these stations has been closely monitored during the months of October, November and December-2016.

It is found that these stations are fully compliant for the commitments to be made by the WMO Member for inclusion of a radiosounding station into the GUAN network. All the 6 stations are capable to achieve minimum observational requirements like Nos. of sounding in a month, soundings observed beyond minimum requirement of 100 hPa level and in most of the cases approach up to the target requirement of 5 hPa level. The RMS departures in case of geo-potential height and wind vectors have been found well within the minimum requirements (MRQs) and very near to the target requirements (TRQs) which establishes the accuracies of observed data. The biases observed in monthly climatological averages are observed within the MRQs and approaching to the TRQs. Observations perfectly fulfill the essential minimum requirements of radiosounding for a GUAN standard station for all the parameters of observations and very closely approaching the target requirements of GUAN standard radiosounding observatories. Hence, these stations are compatible to be WMO Global Upper Air Climatological Observations System network (GUAN) standard radiosounding observatories.

Key words – GUAN network, Radiosonde, Geopotential height, Temperature, Humidity, Zonal wind, Meridional wind, Minimum requirement (MRQ), Target requirement (TRQ), Bias, Standard deviation (SD), Root mean square error (RMSE).
1. Introduction

Global observing system (GOS) network for upper air observations (Radiosounding) consisting of about 1,300 upper-air stations, radiosondes, attached to free-rising balloons, make measurements of pressure, wind velocity, temperature and humidity from just above ground to heights of up to 30 km (Fig. 1). Over two thirds of the stations make observations at 0000 UTC and 1200 UTC. Between 100 and 200 stations make observations once per day. In ocean areas, radiosonde observations are taken by about 15 ships, which mainly ply the North Atlantic, fitted with automated shipboard upper-air sounding facilities (ASAP).

As a part of global observing system (GOS) network, India Meteorological Department (IMD) has 43 operational Radiosonde radiowind stations in their upper air network (Fig. 2).

In 2007, the modernization of IMD was undertaken for improvement in observational and analytical capability to raise it to at par with leading world Meteorological centers. For Improvement in data quality of upper air observations 10 stations were upgraded with GPS based systems during the year 2009. At these stations data quality has improved substantially which has been validated by National Centre for Medium Range Weather Forecast (NCMRWF) and European Centre for Medium Range Weather Forecast (ECMWF). The improvement in quality of data ultimately resulted in removal of black list tag from ECMWF for these up-graded radiosonde stations (Kumar et al., 2011). The Radiosounding observatory, New Delhi, was upgraded by using one of the best GPS based sounding system MW-31 (make VAISALA, Finland) during 2010. 5 No’s. GPS based systems were started during 2012. These stations could not continue due to technical reasons. After a gap of one year of non-functioning, earlier upgraded 10 stations were again re-started during 2013. Under the Atmospheric Observation System Network (AOSN) scheme, IMD started further up-gradation of remaining non GPS stations and all the 43 stations in radiosounding network of IMD have been up-graded by state-of-the art GPS based radiosounding systems by July 2016.

In first phase of modernization of India Meteorological Department, 10 stations were upgraded by employing Modem make GPS based radiosondes during 2009 namely, Portblair, Goa, Minicoy, Thiruvananthapuram, Hyderabad, Vishakhapatnam, Mohanbari, Patna, Srinagar and Chennai. Performance of these stations was examined by Kumar et al. (2011) using ECMWF global data monitoring report. Quality of GPS based...
### TABLE 1

List of radiosounding stations in the upper air network of IMD

| S. No. | Station     | Index No. | Date of up-gradation | No. of launches per day / time | Remarks                          |
|--------|-------------|-----------|----------------------|--------------------------------|----------------------------------|
| 1.     | Srinagar    | 42027     | 29 Oct, 2015         | 1 / 0000 UTC                   |                                  |
| 2.     | Jammu       | 42055     | 27 Jul, 2015         | 1 / 0000 UTC                   |                                  |
| 3.     | Patiala     | 42101     | 24 Oct, 2015         | 1 / 0000 UTC                   |                                  |
| 4.     | Jaipur      | 42348     | 14 Aug, 2015         | 1 / 0000 UTC                   |                                  |
| 5.     | Sundernagar | 42065     | 8 Oct, 2015          | 1 / 0000 UTC                   |                                  |
| 6.     | Dehradun    | 42667     | 3 Dec, 2015          | 1 / 0000 UTC                   |                                  |
| 7.     | New Delhi   | 42182     | 1 Aug, 2015          | 2 / 0000 & 1200 UTC            | GUAN standard station            |
| 8.     | Gwalior     | 42361     | 1 Aug, 2015          | 1 / 0000 UTC                   |                                  |
| 9.     | Lucknow     | 42369     | 18 Oct, 2015         | 1 / 0000 UTC                   |                                  |
| 10.    | Gorakhpur   | 42379     | 18 Oct, 2015         | 1 / 0000 UTC                   |                                  |
| 11.    | Patna       | 42492     | 1 / 0000 UTC          |                                  |                                  |
| 12.    | Siliguri    | 42379     | 12 Oct, 2015         | 1 / 0000 UTC                   |                                  |
| 13.    | Guwahati    | 42410     | 18 Aug, 2015         | 2 / 0000 & 1200 UTC            | GUAN standard station            |
| 14.    | Mohanbani   | 42314     | 1 / 0000 UTC          |                                  |                                  |
| 15.    | Agartala    | 42724     | 6 Oct, 2015          | 1 / 0000 UTC                   |                                  |
| 16.    | Kolkata     | 42809     | 12 Oct, 2015         | 2 / 0000 & 1200 UTC            | GUAN standard station            |
| 17.    | Ranchi      | 42701     | 14 Oct, 2015         | 1 / 0000 UTC                   |                                  |
| 18.    | Bhubaneswar | 42971     | 1 / 0000 UTC          |                                  |                                  |
| 19.    | Raipur      | 42875     | 24 Aug, 2015         | 1 / 0000 UTC                   |                                  |
| 20.    | Jharsuguda  | 42886     | 8 Jul, 2016          | 1 / 0000 UTC                   |                                  |
| 21.    | Gangtok     | 42299     | 8 May, 2016          | 1 / 0000 UTC                   |                                  |
| 22.    | Jagdalpur   | 43041     | 27 Aug, 2015         | 1 / 0000 UTC                   |                                  |
| 23.    | Ahmedabad   | 42647     | 1 / 0000 UTC          |                                  |                                  |
| 24.    | Mumbai      | 43003     | 21 Aug, 2015         | 2 / 0000 & 1200 UTC            | GUAN standard station            |
| 25.    | Aurangabad  | 43014     | 6 Sep, 2015          | 1 / 0000 UTC                   |                                  |
| 26.    | Goa         | 43192     | 1 / 0000 UTC          |                                  |                                  |
| 27.    | Bhopal      | 42667     | 1 / 0000 UTC          |                                  |                                  |
| 28.    | Nagpur      | 42867     | 5 Aug, 2015          | 2 / 0000 & 1200 UTC            | GUAN standard station            |
| 29.    | Hyderabad   | 43128     | 1 / 0000 UTC          |                                  |                                  |
| 30.    | Vishakhapatnam | 43150 | 1 / 0000 UTC            |                                  |                                  |
| 31.    | Machilipatnam | 43185 | 24 Oct, 2015          | 1 / 0000 UTC                   |                                  |
| 32.    | Chennai     | 43279     | 8 Aug, 2015          | 2 / 0000 & 1200 UTC            | GUAN standard station            |
| 33.    | Karaikal    | 43346     | 9 Oct, 2015          | 1 / 0000 UTC                   |                                  |
| 34.    | Bangalore   | 43295     | 19 Aug, 2015         | 1 / 0000 UTC                   |                                  |
| 35.    | Mangalore   | 43285     | 14 Oct, 2015         | 1 / 0000 UTC                   |                                  |
| 36.    | Kochi       | 43353     | 19 Oct, 2015         | 1 / 0000 UTC                   |                                  |
| 37.    | Trivandrum  | 43371     | 1 / 0000 UTC          |                                  |                                  |
| 38.    | Portblair   | 43333     | 1 / 0000 UTC          |                                  |                                  |
| 39.    | Amini       | 43311     | 1 / 0000 UTC          |                                  |                                  |
| 40.    | Minicoy     | 43369     | 1 / 0000 UTC          |                                  |                                  |
| 41.    | Pune        | 43063     | 15 Jun, 2016         | 1 / 0000 UTC                   |                                  |
| 42.    | Ratnagiri   | 43110     | 18 Jun, 2016         | 1 / 0000 UTC                   |                                  |
radiosounding network of 16 stations has also been verified by Ansari et al. (2015) using NCMRWF data monitoring report for the month of December 2013. Further, performance of these stations during November-2015 to January 2016 was analyzed by Ansari et al. (2016) and presented at WMO TECO-2016 conference during 27 to 30 September, 2016 at Madrid, Spain. The details of IMDs upper air network are given in Table 1.

As a subset of GOS network, World Meteorological Organization (WMO) in collaboration with the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU) established Global Climate Observing system (GCOS) network
TABLE 2

Checklist of commitments to be made by the WMO Member

| S. No. | Parameters                                                                                                                                  | Compliance |
|-------|----------------------------------------------------------------------------------------------------------------------------------------------|------------|
| 1     | The NMHS shall make its best efforts to continue the operation of the station at the required performance level for the foreseeable future. | Yes        |
| 2     | The NMHS shall provide for the dissemination of monthly CLIMAT and/or CLIMAT TEMP reports in accordance with WMO WWW Regulations.       | Yes        |
| 3     | The NMHS shall provide for the transfer of historical data to the World Data Centre for Meteorology - Asheville (NCDC, Asheville, USA) in the required formats. | Yes        |
| 4     | The NMHS shall provide for the transfer of metadata (station location and altitude, description of environment, exposure, observation practices and instrumentation, past changes) to the World Data Centre - Asheville in the required formats. | Yes        |
| 5     | The NMHS shall ensure that the information on the station as recorded in WMO Publication No. 9, Volume A, is correct.                  | Yes        |
| 6     | The NMHS shall endorse the classification of all data provided under this commitment as "Essential" in the context of Resolution 40 of the twelfth World Meteorological Congress (Geneva, 1995). | Yes        |
| 7     | The NMHS shall nominate a focal point within the Service for direct contact at the working level with the GCOS Secretariat, the Monitoring and Analysis Centres and the GCOS/AOPC Advisory Group on the GUAN. | Yes        |
| 8     | Adherence to the rules for dissemination of CLIMAT and CLIMAT TEMP reports includes the assignment of a WMO block and index number to the station. According to the World Weather Watch (WWW) Regulations, CLIMAT and CLIMAT TEMP reports should be provided by the 5th day of the month following the month to which the data refer and not later than the 8th day. | Yes        |

in 1992, as an outcome of 2nd World Climate Conference. In the upper air domain of GCOS, IMD, aiming on further improvement of upper air data quality, initiated the establishment of GUAN standard radiosounding observations at its 6 Regional Meteorological Centres (RMCs).

2. Requirement of GUAN Observatory

2.1. For establishment of GUAN observatory, there are some standards required to be strictly followed. Inclusion of a station in the networks requires that certain commitments be made by the WMO Member concerned which are normally represented by the responsible National Meteorological / Hydrological System (NMHS). These commitments are:

(i) The NMHS shall make its best efforts to continue the operation of the station at the required performance level for the foreseeable future.

(ii) The NMHS shall provide for the dissemination of monthly CLIMAT and/or CLIMAT TEMP reports in accordance with WMO WWW Regulations.

(iii) The NMHS shall provide for the transfer of historical data to the World Data Centre for Meteorology - Asheville (NCDC, Asheville, USA) in the required formats.

(iv) The NMHS shall provide for the transfer of metadata (station location and altitude, description of environment, exposure, observation practices and instrumentation, past changes) to the World Data Centre - Asheville in the required formats.

(v) The NMHS shall ensure that the information on the station as recorded in WMO Publication No. 9, Volume A, is correct.

(vi) The NMHS shall endorse the classification of all data provided under this commitment as "Essential" in the context of Resolution 40 of the twelfth World Meteorological Congress (Geneva, 1995).
TABLE 3
Performance analysis with respect to accuracy & homogeneity

| Name of the station | 100 hPa level | 500 hPa level |
|---------------------|---------------|---------------|
|                     | 0000 UTC | 1200 UTC | No. | Rej | SD | Bias | RMS | No. | Rej | SD | Bias | RMS | No. | Rej | SD | Bias | RMS |
| Parameter - Geopotential height |
| Delhi 31 | 0 | 13 | -7.1 | 14.5 | 31 | 0 | 9.1 | 5.6 | 10.7 | 31 | 0 | 17 | -8.8 | 18.7 | 31 | 0 | 5.9 | -2.4 | 6.4 |
| Mumbai 31 | 0 | 7 | -6.9 | 9.6 | 31 | 0 | 11 | 6.2 | 12.2 | 31 | 0 | 6.2 | 0.8 | 6.3 | 31 | 0 | 5.5 | -3.4 | 6.5 |
| Kolkata 31 | 0 | 7 | -0.8 | 7.2 | 31 | 0 | 6.7 | 3.9 | 7.8 | 31 | 0 | 5.9 | 1.2 | 6.0 | 31 | 0 | 6.3 | -1.2 | 6.4 |
| Chennai 31 | 0 | 8 | -1.7 | 8.1 | 31 | 0 | 10 | 12 | 15.4 | 31 | 0 | 6.1 | -4.3 | 7.5 | 31 | 0 | 6.8 | 4.6 | 8.2 |
| Guwahati 31 | 0 | 7 | -6.9 | 9.6 | 31 | 0 | 8.5 | 1.8 | 8.7 | 31 | 0 | 7.6 | 6.9 | 10.3 | 31 | 0 | 6.9 | -2.3 | 7.3 |
| Nagpur 31 | 0 | 9 | 1.5 | 8.7 | 31 | 0 | 9.9 | 1.2 | 10.0 | 31 | 0 | 11 | 2.1 | 11.2 | 31 | 0 | 9.2 | -1.3 | 9.3 |
| Parameter - Temperature |
| Delhi 31 | 0 | 1 | -0.3 | 0.7 | 31 | 0 | 1.2 | 0.5 | 1.3 | 30 | 0 | 0.8 | -0.2 | 0.8 | 30 | 0 | 0.6 | 0.1 | 0.6 |
| Mumbai 31 | 0 | 1 | 0.5 | 1.2 | 31 | 0 | 1.1 | -0.2 | 1.1 | 31 | 0 | 0.9 | -0.3 | 0.9 | 31 | 0 | 0.8 | -0.3 | 0.9 |
| Kolkata 31 | 0 | 1 | -0.2 | 0.9 | 31 | 0 | 0.8 | 0.3 | 0.9 | 30 | 0 | 1.2 | -0.4 | 1.3 | 30 | 0 | 0.9 | 0.0 | 0.9 |
| Chennai 31 | 0 | 1 | -0.3 | 1.2 | 31 | 0 | 1.3 | -0.3 | 1.3 | 31 | 0 | 0.8 | -0.4 | 0.9 | 31 | 0 | 0.8 | -0.2 | 0.8 |
| Guwahati 31 | 0 | 2 | 0.9 | 2.1 | 31 | 0 | 1.5 | 0.2 | 1.5 | 31 | 0 | 1 | 0.3 | 1.0 | 31 | 0 | 0.9 | 0.6 | 1.1 |
| Nagpur 31 | 0 | 1 | -0.2 | 1.0 | 31 | 0 | 0.8 | 0 | 0.8 | 31 | 0 | 1.2 | -0.6 | 1.3 | 31 | 0 | 1.1 | -0.4 | 1.2 |
| Parameter - Zonal wind component |
| Delhi 31 | 0 | 3 | 1.4 | 3.1 | 30 | 0 | 2.9 | 0.3 | 2.9 | 31 | 0 | 2.7 | 0.3 | 2.7 | 31 | 0 | 2.5 | -0.6 | 2.6 |
| Mumbai 31 | 0 | 3 | 0.2 | 3.1 | 31 | 0 | 3.3 | 0.5 | 3.3 | 31 | 0 | 2.2 | -0.5 | 2.3 | 31 | 0 | 2.4 | -0.8 | 2.5 |
| Kolkata 31 | 0 | 3 | 0.9 | 2.8 | 30 | 0 | 2.7 | 0.4 | 2.7 | 31 | 0 | 2.7 | -0.3 | 2.7 | 31 | 0 | 2.5 | 0.3 | 2.5 |
| Chennai 31 | 0 | 3 | -0.4 | 2.7 | 30 | 0 | 2.9 | -0.9 | 3.0 | 31 | 0 | 1.9 | -0.7 | 2.0 | 31 | 0 | 2 | 0.6 | 2.1 |
| Guwahati 31 | 0 | 3 | -0.6 | 3.3 | 31 | 0 | 2.7 | -0.5 | 2.7 | 31 | 0 | 3.2 | 0.3 | 3.2 | 31 | 0 | 2.9 | 0 | 2.9 |
| Nagpur 31 | 0 | 2 | 0.4 | 2.2 | 31 | 0 | 2.4 | 0.6 | 2.5 | 31 | 0 | 2.6 | -0.6 | 2.7 | 31 | 0 | 2.4 | -0.9 | 2.6 |
| Parameter - Meridional wind components |
| Delhi 31 | 0 | 3 | -0.4 | 3.2 | 31 | 0 | 3.4 | -0.2 | 3.4 | 31 | 0 | 2.4 | 0.5 | 2.5 | 31 | 0 | 1.9 | -0.4 | 1.9 |
| Mumbai 31 | 0 | 3 | 0.5 | 3.1 | 31 | 0 | 3.8 | 0.5 | 3.8 | 31 | 0 | 2.2 | -0.9 | 2.4 | 31 | 0 | 2.2 | -1.1 | 2.5 |
| Kolkata 31 | 0 | 4 | 0.8 | 3.6 | 31 | 0 | 3.6 | -0.3 | 3.6 | 31 | 0 | 2.6 | -0.5 | 2.6 | 31 | 0 | 2.1 | 0.2 | 2.1 |
| Chennai 31 | 0 | 3 | -0.6 | 3.5 | 31 | 0 | 3.7 | 0.1 | 3.7 | 31 | 0 | 1.9 | 0.5 | 2.0 | 31 | 0 | 2.6 | 0.4 | 2.6 |
| Guwahati 31 | 0 | 3 | 0.7 | 3.4 | 31 | 0 | 3.4 | -0.6 | 3.5 | 31 | 0 | 2.1 | -0.6 | 2.2 | 31 | 0 | 2.3 | 0.6 | 2.4 |
| Nagpur 31 | 0 | 3 | -0.5 | 3.1 | 31 | 0 | 3.5 | 0.5 | 3.5 | 31 | 0 | 2.8 | 0.1 | 2.8 | 31 | 0 | 2.5 | 0.5 | 2.5 |

(vii) The NMHS shall nominate a focal point within the Service for direct contact at the working level with the GCOS Secretariat, the Monitoring and Analysis Centres and the GCOS/AOPC Advisory Group on the GUAN.

(viii) Adherence to the rules for dissemination of CLIMAT and CLIMAT TEMP reports includes the assignment of a WMO block and index number to the station. According to the World Weather Watch (WWW) Regulations, CLIMAT & CLIMAT TEMP reports should
be provided by the 5th day of the month following the month to which the data refer & not later than the 8th day.

2.2. The basic requirement for the GUAN, should be interpreted such that every month at least one observation on each of at least 25 days should attain the Minimum Requirements (MRQs). The observing frequency (1 or 2 per day) in itself is not a criterion, although the Target Requirement (TRQs) for observation frequency is 2 per day, in accordance with WWW regulations for radiosonde observations.

Observational MRQs:

(i) Temperature up to 100 hPa.

(ii) Humidity up to the tropopause.

(iii) Wind direction and speed up to 100 hPa.

TRQs (in addition to the MRQs):

(i) Temperature and wind up to 5 hPa.

2.3. Accuracy in observations

For the GUAN, the criteria are defined as the RMS departures of observed values from 6-hour guess field values, in accordance with the practical verification schemes applied by the GUAN Monitoring Centre (ECMWF) for upper-air observations.
MRQs:

(i) Geopotential at 100 hPa: 80 metres.

(ii) Wind vector at 300 hPa: 8 m/s.

TRQs

From practical results, it appears that the minimum (best) values feasible for these parameters are about 10 m in geopotential height and 4 m/s in wind vector.

2.4. Homogeneity of observations

The GUAN biases, including those due to changes in the local environment, should be limited if at all possible to the values in the following table, to prevent misinterpretation of climatic changes:

| Network Parameter          | MRQ | TRQ |
|----------------------------|-----|-----|
| GUAN Temperature           | 0.2 °C | 0.1 °C |
| Specific humidity          | 2% of present climatological average | 1% of present climatological average |
| Wind                       | 2 m/s | 1 m/s |

2.5. CLIMAT and CLIMAT TEMP submission

For GUAN stations, the provision of CLIMAT TEMP reports is a Target Requirement. Also in this case a definition of Minimum Requirements is not obvious. Moreover, the provision of CLIMAT TEMPS depends on the availability of individual observations, which is often a weak spot in practice.

3. Data analysis and methodology

These stations have been equipped with M/s GRAW radiosondes, Germany make, high quality GPS based radio sounding system, GS-E along with DFM-09 radiosondes. The ground system GS-E and radiosondes DFM-09 are compatible to be used at a standard GUAN upper air observatory for radio sounding.

3.1. Checklist of commitments to be made by the WMO Member for inclusion of a radio sounding station into the GUAN network is given shown in Table 2.

3.2. Observation's Minimum Requirements (MRQs) and Target Requirements (TRQs): The minimum requirement of GUAN station is to take every month at least one observation on each of at least 25 days and meeting the criteria as mentioned in para 2.2. The performance of all the 6 stations has been analyzed and plotted for October, November and December 2016.

3.2.1. The performance analysis for is given in Figs. 3(a-c). From the analysis for the month of October 2016, Fig. 3(a), it is observed that

(i) At Delhi, all the ascents have crossed troposphere, 98% reached 10 hPa approaching TRQ and 69% have achieved TRQ.

(ii) At Mumbai, 98% ascents recorded up to above troposphere, 94% reached beyond 10 hPa approaching TRQ and 69% have achieved TRQ.

(iii) In case of Kolkata, during the month all the ascents crossed troposphere, 76% reached 10 hPa approaching TRQ and 47% have achieved TRQ.

(iv) At Chennai, 96% of the ascents recorded up to above troposphere, 71% reached beyond 10 hPa approaching TRQ and 61% have actually achieved.

(v) Radiosounding station at Guwahati, 94% of the ascents recorded up to above troposphere, 84% reached beyond 10 hPa approaching TRQ and 58% have achieved TRQ.

(vi) In case of Nagpur, 98% of the ascents were recorded above troposphere, 94% reached beyond 10 hPa approaching TRQ and 71% have achieved TRQ.

3.2.2. The observations statistics for the month of November 2016 are shown in Fig. 3(b). It is found that

(i) All the ascents recorded at Delhi have crossed troposphere, 97% reached 10 hPa approaching TRQ and 82% have achieved TRQ.

(ii) At Mumbai, all the ascents recorded up to above troposphere, 91% reached beyond 10 hPa approaching TRQ and 87% have achieved TRQ.

(iii) In case of Kolkata, 97% crossed troposphere, 93% reached 10 hPa approaching TRQ and 58% have achieved TRQ.

(iv) At Chennai, 95% ascents recorded up to above troposphere, 69% reached beyond 10 hPa approaching TRQ and 54% have achieved TRQ.
TABLE 4

Performance Analysis with respect to Accuracy & Homogeneity

| Name of the station | 100 hPa level | 500 hPa level | 1200 UTC | 1200 UTC |
|---------------------|---------------|---------------|----------|----------|
|                     | 0000 UTC      | 1200 UTC      | 0000 UTC | 1200 UTC |
|                     | No. Rej SD Bias RMS | No. Rej SD Bias RMS | No. Rej SD Bias RMS | No. Rej SD Bias RMS |
| Delhi               | 30 0 10.6 -4.5 11.5 | 30 0 13.4 8.2 15.7 | 30 0 6.3 -4.1 7.5 | 30 0 6.4 -1.2 6.5 |
| Mumbai              | 30 0 8.2 -9 12.2 | 30 0 9.1 8.1 12.2 | 30 0 7.1 3.9 8.1 | 30 0 3.8 4.2 5.7 |
| Kolkata             | 30 0 9.2 0.6 9.2 | 30 0 10.1 0.7 10.1 | 30 0 6.3 2.9 6.9 | 30 0 6.6 3.3 7.4 |
| Chennai             | 30 0 5.9 -0.5 5.9 | 30 0 7.9 9.9 12.7 | 30 0 4 8.5 9.4 | 30 0 10.3 0.7 10.3 |
| Guwahati            | 30 0 10.3 3.2 10.8 | 30 0 10.9 -3.6 11.5 | 30 0 7.8 -6.9 10.4 | 30 0 6.5 -2.2 6.9 |
| Nagpur              | 30 0 7 1.2 7.1 | 30 0 8.1 2.1 8.4 | 30 0 4.4 9 10.0 | 30 0 5.6 6.5 8.6 |

Parameter - Geopotential height

| Name of the station | Temperature | Zonal wind component | Meridional wind components |
|---------------------|-------------|----------------------|---------------------------|
|                     | Parameter   | Parameter             | Parameter                  |
|                     | - Temperature|                      |                           |
|                     |             |                      |                           |
| Delhi               | 30 0 1.7 -0.5 1.8 | 30 0 1.2 0.3 1.2 | 30 0 3.1 1.6 3.5 |
| Mumbai              | 30 0 1.2 0.3 1.2 | 30 0 1.1 0.4 1.2 | 30 0 3.3 -1 3.4 |
| Kolkata             | 30 0 1.3 0.2 1.3 | 30 0 1.1 -0.2 1.0 | 30 0 2.8 0.8 2.9 |
| Guwahati            | 30 0 2.9 1.3 3.2 | 30 0 0.9 -0.2 0.9 | 30 0 3.1 -0.7 3.2 |
| Nagpur              | 30 0 1.5 -0.1 1.5 | 30 0 1.3 -0.2 1.3 | 30 0 2.6 -1.1 2.8 |

(v) Radiosounding station at Guwahati, all the ascents recorded up to above troposphere, 92% reached beyond 10 hPa approaching TRQ and 73% have achieved TRQ.

(vi) In case of Nagpur, 93% recorded above troposphere, 90% reached beyond 10 hPa approaching TRQ and 67% have achieved TRQ.
### TABLE 5
Performance Analysis with respect to Accuracy & Homogeneity

| Name of the station | Performance analysis for the month of December 2016 |
|--------------------|-----------------------------------------------|
|                    | 100 hPa level                      | 500 hPa level                      |
|                    | 0000 UTC  | 1200 UTC  | 0000 UTC  | 1200 UTC  |
|                    | No.  | Rej | SD  | Bias | RMS | No.  | Rej | SD  | Bias | RMS |
| Parameter - Geopotential Height |
| Delhi              | 31   | 0    | 6.7 | 1.2  | 6.8 | 31   | 0    | 7.1 | 13.9 | 15.6 |
| Mumbai             | 31   | 0    | 8.2 | 6    | 10.2 | 31   | 0    | 20.5 | 18.8 | 27.8 |
| Kolkata            | 31   | 0    | 12.7 | 32.6 |     | 31   | 0    | 7.3  | 8.4  | 11.1 |
| Chennai            | 31   | 0    | 28.1 | -1.3 | 28.1 | 31   | 0    | 9.9  | 20.2 | 22.5 |
| Guwahati           | 30   | 0    | 27  | -10.7 | 29.0 | 31   | 0    | 7.6  | -0.7 | 7.6  |
| Nagpur             | 30   | 0    | 6.2  | 13.3 | 14.7 | 31   | 0    | 7.4  | 21   | 22.3 |
|                    | **Bias** | **RMS** | **Bias** | **RMS** |
| Delhi              | 31   | 0    | 0.7  | 0.7  | 30   | 0    | 0.7  | 0    | 0.7  |
| Mumbai             | 31   | 0    | 0.5  | -0.2 | 0.6  | 30   | 0    | 0.5  | 0.5  |
| Kolkata            | 31   | 0    | 0.7  | -0.1 | 0.7  | 29   | 0    | 0.7  | 0.7  |
| Chennai            | 31   | 1    | 0.3  | 1.8  | 30   | 0    | 0.9  | 0.6  | 1.1  |
| Guwahati           | 30   | 2    | 1.2  | 2   | 1.2  | 27   | 0    | 0.9  | 0.9  | 3  |
| Nagpur             | 30   | 0    | 0.7  | 0.8  | 28   | 0    | 0.7  | 0.6  | 0.9  |

| Parameter - Temperature |
|------------------------|
| Delhi                  | 27   | 0    | 2    | -0.4 | 2.1  | 29   | 0    | 2.8  | 0.5  | 2.8  |
| Mumbai                 | 25   | 0    | 2    | 0.1  | 2.1  | 30   | 0    | 2.2  | 0.1  | 2.2  |
| Kolkata                | 30   | 0    | 2.2  | -0.6 | 2.3  | 30   | 0    | 1.7  | 0.3  | 1.7  |
| Chennai                | 31   | 0    | 3.9  | 0.4  | 4    | 30   | 0    | 3    | 1.4  | 3.3  |
| Guwahati               | 29   | 0    | 2.1  | 0.6  | 2.2  | 27   | 0    | 2.5  | 0.7  | 2.6  |
| Nagpur                 | 31   | 0    | 2.4  | -0.8 | 2.5  | 28   | 0    | 2.4  | 0.2  | 2.4  |

| Parameter - Meridional Wind Components |
|---------------------------------------|
| Delhi                                 | 25   | 0    | 3.1  | -1.2 | 3.4  | 29   | 0    | 3.3  | 0.4  | 3.3  |
| Mumbai                                | 30   | 0    | 3.4  | -0.5 | 3.5  | 30   | 0    | 2.5  | -0.8 | 2.6  |
| Kolkata                               | 28   | 0    | 3.4  | -0.5 | 3.4  | 29   | 0    | 2.7  | -0.2 | 2.8  |
| Chennai                               | 26   | 0    | 3.2  | 0.4  | 3.3  | 30   | 0    | 3.6  | -0.2 | 3.6  |
| Guwahati                              | 29   | 0    | 3.5  | 0.3  | 3.5  | 27   | 0    | 3.2  | -0.5 | 3.2  |
| Nagpur                                | 31   | 0    | 3.2  | -0.3 | 3.2  | 28   | 0    | 2.8  | -0.4 | 2.8  |

3.2.3. The analysis for the month of December 2016, are given in Fig. 3(c). From the analysis for the month of December, it is found that

(i) 98% of the ascents recorded at Delhi have crossed troposphere, 89% reached 10 hPa approaching TRQ and 76% have achieved TRQ.

(ii) At Mumbai, 98% ascents recorded up to above troposphere, 82% reached beyond 10 hPa approaching TRQ and 61% have achieved TRQ.

(iii) In case of Kolkata, 96% of ascents during the month crossed troposphere, 62% reached 10 hPa approaching TRQ and 31% have achieved TRQ.
(iv) At Chennai, 96% ascents recorded up to above troposphere, 73% reached beyond 10 hPa approaching TRQ and 63% have actually achieved.

(v) Radiosounding station at Guwahati, 93% ascents recorded up to above troposphere, 85% reached beyond 10 hPa approaching TRQ and 66% have achieved TRQ.

(vi) In case of Nagpur, 97% of the ascents were recorded above troposphere, 82% reached beyond 10 hPa approaching TRQ and 71% have achieved TRQ.

3.3. Accuracy & homogeneity in observations

To ascertain the accuracies in observations at the sounding stations, the criteria of GUAN standard observation is to be followed as to achieve root mean square (RMS) departure in geo-potential height up to 80 m and that in wind vector at 300 hPa up to 8 m/s under minimum requirements. These values are to be achieved up to 10 m and 4 m/s respectively as target requirement (TRQs).

The accuracies achieved at the 6 stations have been examined for the period October-December 2016, by using the monthly global data reports of ECMWF and NCMRWF. It has been observed from both the reports of the period;

(i) None of the stations figures in the list of suspect radiosondes in terms all the observed parameters viz; Geopotential height, Temperature, Humidity, Wind data [Tables (7-9) of global data monitoring report - ECMWF-Oct, Nov and Dec 2016]. It shows that all the data recorded has been found by the computing models within the acceptable limits of accuracies.

(ii) The standard deviation (SD), the biases and RMS departures have been calculated for temperature, geo-potential height, zonal and meridional wind components, at 100 hPa and 500 hPa levels, for the months of Oct-Dec-2016, using NCMRWF monthly data monitoring reports.

(iii) The performance analysis details indicating SD, bias and RMS, for the month of October-2016 is shown in Table 3.

For the month of October-2016, all the stations have obtained the RMS departures in geo-potential height and wind vectors under the required limits of 80 m and 8 m/s respectively. The RMS departures are very close to the target requirements of 10 m in geo-potential height and actually achieved that in case of wind vectors, that too for both 100 hPa as well as 500 hPa levels and both the times of observations at 0000 UTC and 1200 UTC.

(iv) The performance analysis for the month of November 2016, indicating SD, bias and RMS, is given below in Table 4.

For the month of November-2016 and for both the times of observations at 0000 UTC and 1200 UTC, all the stations have obtained the RMS departures in geo-potential height and wind vectors under the required limits, hence fully compliant to GUAN standard. The RMS departures are very close to the target requirements of 10 m in geo-potential height and actually achieved that in case of wind vectors for both 100 hPa as well as 500 hPa levels.

(iv) The performance analysis details indicating SD, bias and RMS, for the month of December-2016 is shown in Table 5.

3.4. CLIMAT and CLIMAT TEMP submission

The radio sounding systems are capable of generating monthly CLIMAT averages. All the stations are submitting CLIMAT TEMP on monthly basis regularly by next day of completing month.

4. Conclusions

Analyzing the performance of 6 radiosounding stations at New Delhi, Mumbai, Kolkata, Chennai, Nagpur and Guwahati during the months of October to December-2016, it is found that these stations are fully compliant for the commitments to be made by the WMO Member for inclusion of a radiosounding station into the GUAN network. All the 6 stations are capable to achieve minimum observational requirements like 25 or more nos of sounding in a month, all the sondings are taken beyond minimum requirement of 100 hPa level and in most of the cases reaching up to the target requirement of 5 hPa level. As to ascertain the accuracies of observations, the analyses of RMS departures in case of geo-potential height and wind vectors have been found well within the minimum requirements (MRQs) and very near to the target requirements (TRQs). The biases observed in monthly climatological averages are observed within the MRQs and approaching to the TRQs. These stations actually fulfill the essential minimum requirements of radiosounding observations for a GUAN standard radiosounding station, with respect to all the parameters of observation and very closely approaching the target requirements of GUAN standard radiosounding observatories. Hence, these stations are compatible to be GUAN standard radiosounding
observatories and may be included in WMO Global Upper Air Climatological Observations System Network.

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References

Ansari, M. I., Madan, Ranju and Bhatia, S., 2015, “Verification of quality of GPS based radiosonde data” Mausam, 66, 3, 367-374.

Ansari, M. I., Madan, Ranju and Pradhan, D., 2016, “Global Climate Observation System Upper air Network (GUAN) standard-compatible network of India Meteorological department (IMD)” WMO-TECO-2016 conference, Madrid, Spain, Sept. 27th to 30th, 2016.

European Centre for Medium Range Weather Forecasts (ECMWF), October, November and December - 2016, “Monthly Data Monitoring Report”, http://www.ecmwf.int/sites/default/files/Global_Data_Monitoring_Report_yyyymm.pdf

Kumar, Gajendra, Madan, Ranju, Sai Krishnan, K. C. and Jain, P. K., 2011, “Technical and operational characteristics of GPS radiosounding system in upper air network”, Mausam, 62, 3, 403-416.

Manual on the Global Observing System, WMO No. 544, 2.10.4.9

National Centre for Medium Range Weather Forecasts (NCMRWF), October, November and December-2016, Monthly Data Monitoring Report. (http://www.ncmrwf.gov.in/t574-model/obs_monitor/NCMRWF_MMR.pdf).