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Performance analysis of IMD's GUAN standard - Compatible network

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सार – भारत मौसम विज्ञान विभाग (आईएमडी) ने हाल ही में जीपीएस आधारित रेडियोसाउंडिंग सिस्टम को रोजगार के माध्यम से ऊपरी वायु रेडियोसाउंडिंग नेटवर्क को उन्नत किया है। 43 रेडियोसॉन्डिंग सिस्टम में से 6 स्टेशन, प्रत्येक क्षेत्रीय हेड क्वार्टर में, अर्थात नई दिल्ली, मुंबई, कोलकाता, चेन्नई, नागपुर और गुवाहाटी को उच्च गुणवत्ता वाले रेडियोसौंउंडिंग सिस्टम से सुसज्जित किया गया है, मेसर्स ग्रे रेडिओसोन्ड, जर्मनी बनाओ। रेडियो सौंडे मापन की गुणवत्ता और विश्वसनीयता आवश्यक है क्योंकि प्रोफाइल में भी छोटी अशुद्धता भविष्य के विश्लेषक को महत्वपूर्ण विवरणों को देखकर और सही निष्कर्ष बनाने से रोका जा सकता है। इसलिए अक्टूबर, नवंबर और दिसंबर - 2016 के महीनों में इन स्टेशनों के प्रदर्शन की बारीकी से निगरानी की गई है।

यह पाया गया है कि इन स्टेशनों को डब्ल्यूएमओ सदस्य द्वारा किए गए प्रतिबद्धताओं के लिए पूरी तरह से अनुपालन किया गया है ताकि वे जीयूएन नेटवर्क में रेडियोसॉन्डिंग स्टेशन को शामिल कर सकें। सभी 6 स्टेशन न्यूनतम अवलोकन संबंधी आवश्यकताओं को प्राप्त करने में सक्षम हैं, जैसे कि महीने में लगने वाले नंबर, 100 एचपीए स्तर की न्यूनतम आवश्यकता से परे देखा गया वादन, और अधिकांश मामलों में 5 एचपीए स्तर की लक्ष्य आवश्यकता तक पहुंच। जीओ-संभावित ऊंचाई, और हवा वैक्टर के मामले में आरएमएस प्रस्थान, न्यूनतम आवश्यकताओं (एमआरक्यू) के भीतर और बहुत ही लक्ष्य आवश्यकताओं (टीआरक्यू) के निकट पाए गए हैं, जो मनाया गया डेटा की प्रकृति को स्थापित करता है। मासिक क्लायमेटोलॉजिकल एवरेज में मनाया गया पक्षपात MRQs के भीतर मनाया जाता है और टीआरक्यू के पास जाता है। टिप्पणियां पूरी तरह से टिप्पणियों के सभी मानकों के लिए एक GUAN मानक स्टेशन के लिए रेडियोसौंउंडिंग की आवश्यक न्यूनतम आवश्यकताओं को पूरा करती हैं, और GUAN मानक रेडियोसाउंडिंग वेधशालाओं की लक्ष्य आवश्यकताओं के बहुत करीब आ रही हैं। इसलिए, ये स्टेशन डब्लूएमओ ग्लोबल अपर एयर क्लाइमेटोलॉजिकल ऑवर्वेशन सिस्टम नेटवर्क (जीयूएएन) मानक रेडियोसौंउंडिंग ऑक्सेटरीज़ के अनुरूप हैं।

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 Radisounding 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, Thiruvanantha puram, 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

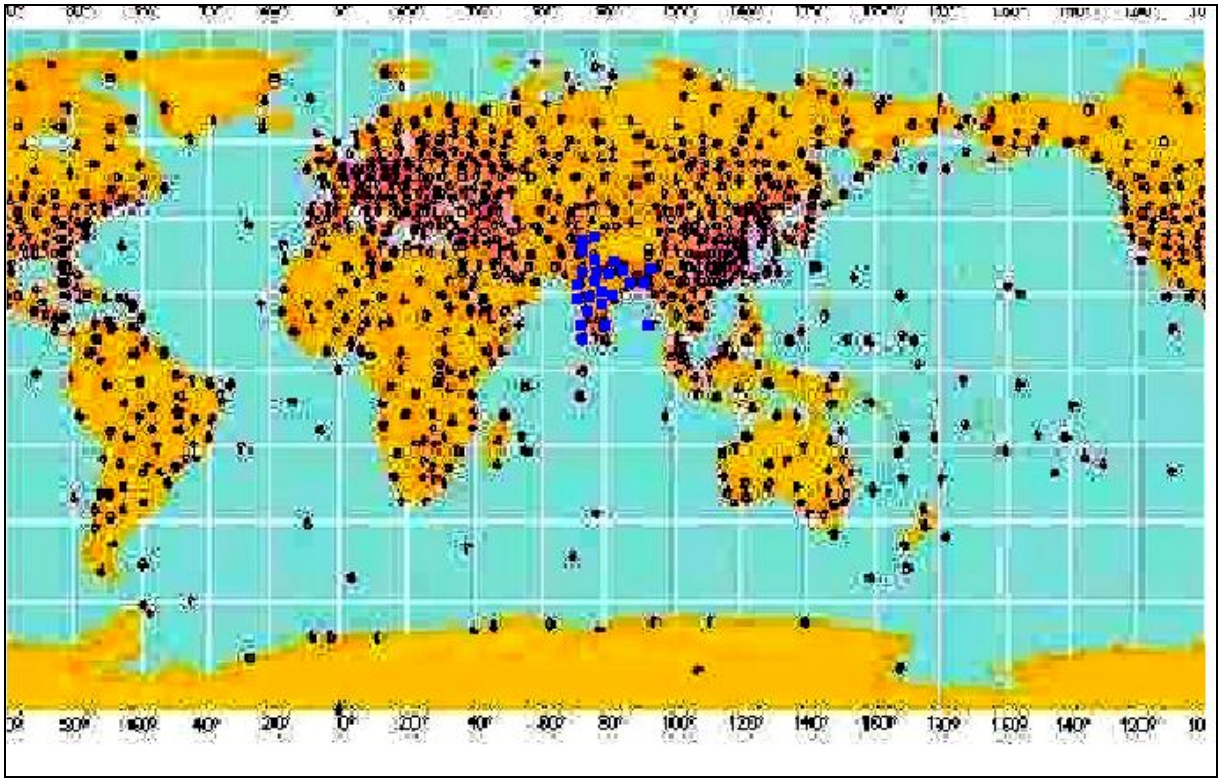


Fig. 1. Global observing system network for upper air observations

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		1 / 0000 UTC	
2.	Jammu	42055	29 Oct, 10.2015	1 / 0000 UTC	
3.	Patiala	42101	27 Jul, 2015	1 / 0000UTC	
4.	Jodhpur	42339	24 Oct, 2015	1 / 0000 UTC	
5.	Jaipur	42348	14 Aug, 2015	1 / 0000 UTC	
6.	Sundernagar	42065	8 Oct, 2015	1 / 0000 UTC	
7.	Dehradun	42667	3 Dec,.2015	1 / 0000 UTC	
8.	New Delhi	42182	1 Aug, 2015	2 / 0000 & 1200 UTC	GUAN standard station
9.	Gwalior	42361	1 Aug, 2015	1 / 0000 UTC	
10.	Lucknow	42369	18 Oct, 2015	1 / 0000 UTC	
11.	Gorakhpur	42379	18 Oct, 2015	1 / 0000 UTC	
12.	Patna	42492		1 / 0000 UTC	
13.	Siliguri	42379	12 Oct, 2015	1 / 0000 UTC	
14.	Guwahati	42410	18 Aug, 2015	2 / 0000 & 1200 UTC	GUAN standard station
15.	Mohanbari	42314		1 / 0000 UTC	
16.	Agartala	42724	6 Oct, 2015	1 / 0000 UTC	
17.	Kolkata	42809	12 Aug, 2015	2 / 0000 & 1200 UTC	GUAN standard station
18.	Ranchi	42701	14 Oct, 2015	1 / 0000 UTC	
19.	Bhubaneshwar	42971		1 / 0000 UTC	
20.	Raipur	42875	24 Aug, 2015	1 / 0000 UTC	
21.	Jharsuguda	42886	8 Jul, 2016	1 / 0000 UTC	
22.	Gangtok	42299	8 May, 2016	1 / 0000 UTC	
23.	Jagdalpur	43041	27 Aug, 2015	1 / 0000 UTC	
24.	Ahmedabad	42647		1 / 0000 UTC	
25.	Mumbai	43003	21 Aug, 2015	2 / 0000 & 1200 UTC	GUAN standard station
26.	Aurangabad	43014	6 Sep, 2015	1 / 0000 UTC	
27.	Goa	43192		1 / 0000 UTC	
28.	Bhopal	42667		1 / 0000 UTC	
29.	Nagpur	42867	5 Aug, 2015	2 / 0000 & 1200 UTC	GUAN standard station
30.	Hyderabad	43128		1 / 0000 UTC	
31.	Vishkhapatnam	43150		1 / 0000 UTC	
32.	Machilipatnam	43185	24 Oct, 2015	1 / 0000 UTC	
33.	Chennai	43279	8 Aug, 2015	2 / 0000 & 1200 UTC	GUAN standard station
34.	Karaikal	43346	9 Oct, 2015	1 / 0000 UTC	
35.	Bangalore	43295	19 Aug, 2015	1 / 0000 UTC	
36.	Mangalore	43285	14 Oct, 2015	1 / 0000 UTC	
37.	Kochi	43353	19 Oct, 2015	1 / 0000 UTC	
38.	Trivandrum	43371		1 / 0000 UTC	
39.	Portblair	43333		1 / 0000 UTC	
40.	Amini	43311		1 / 0000 UTC	
41.	Minicoy	43369		1 / 0000 UTC	
42.	Pune	43063	15 Jun, 2016	1 / 0000 UTC	
43.	Ratnagiri	43110	18 Jun, 2016	1 / 0000 UTC	

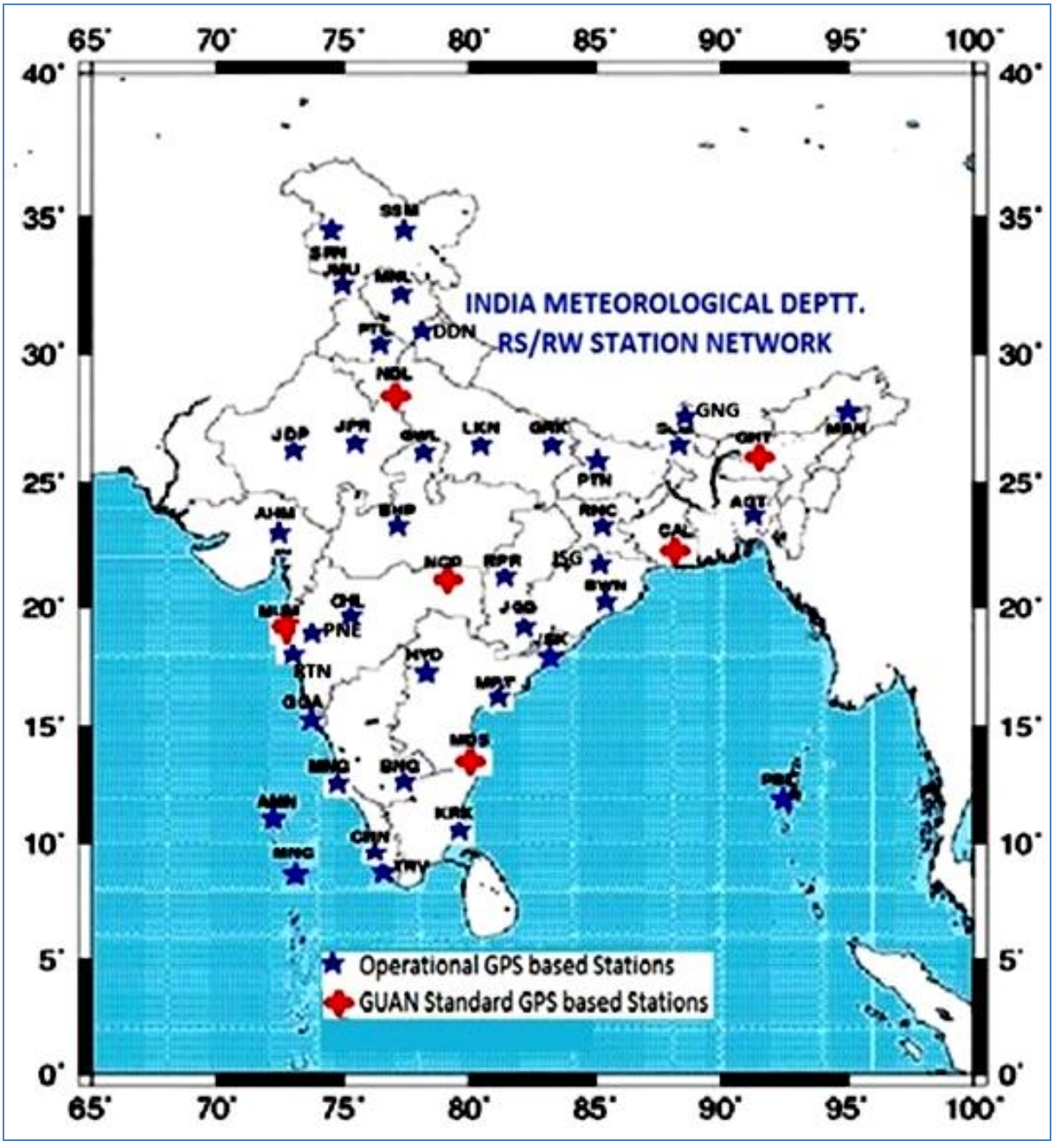


Fig. 2. India Meteorological Department radiosounding network

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).

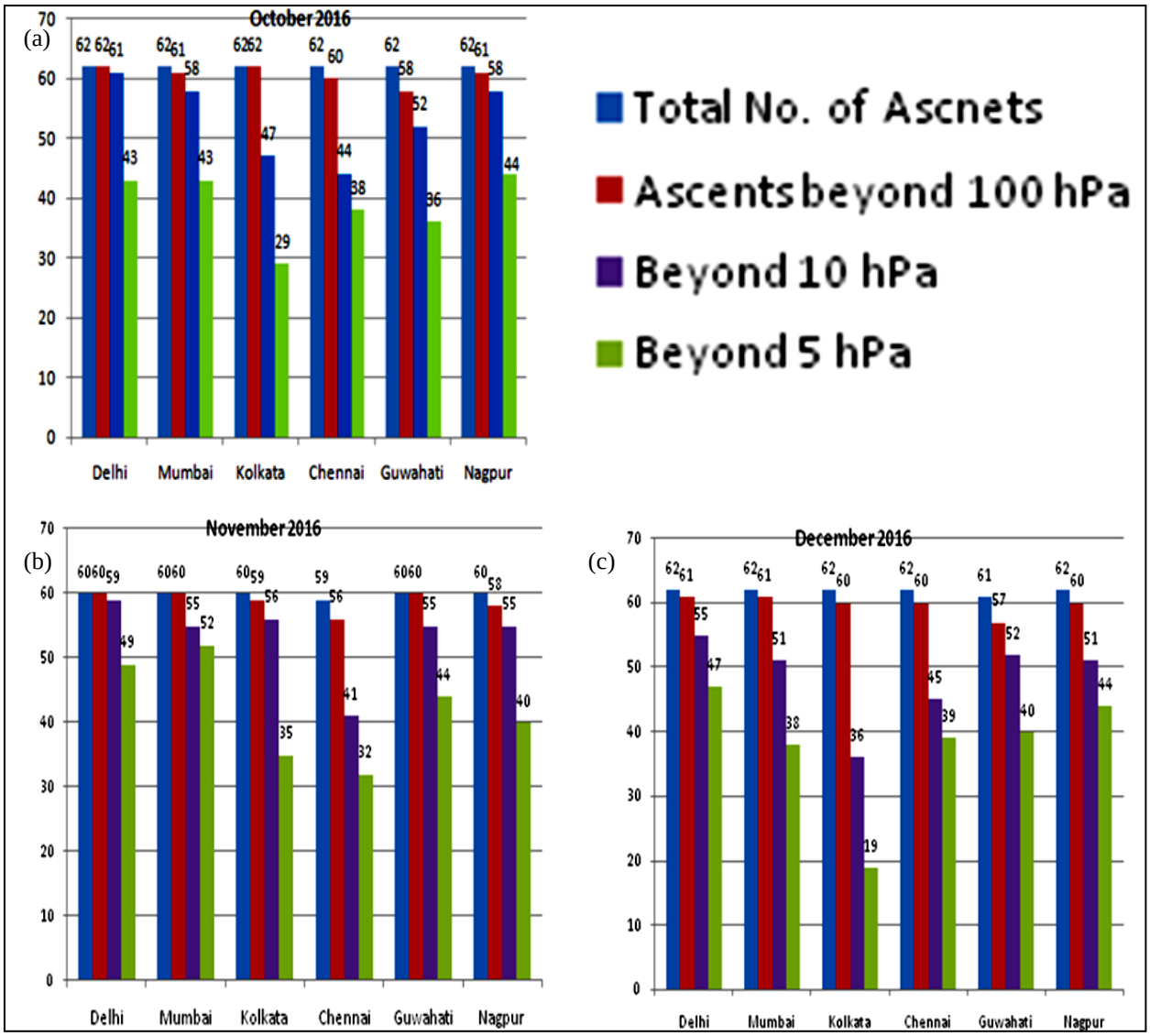
TABLE 3

Performance analysis with respect to accuracy & homogeneity

Name of the station	Performance analysis for the month of October 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	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	0.9
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	30	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	30	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



Figs. 3(a-c). Performance analysis with respect to MRQs & TRQs

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 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 climatological average	2% of present climatological average	1% of present
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 radiosoundinf 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	Performance analysis for the month of November 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	No.	Rej	SD	Bias	RMS	No.	Rej	SD	Bias	RMS
Parameter - Geopotential height																				
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 - Temperature																				
Delhi	30	0	1.7	-0.5	1.8	30	0	1.2	0.8	1.4	30	0	0.9	0.4	1.0	30	0	1.1	-0.1	1.1
Mumbai	30	0	1.2	0.3	1.2	30	0	1.1	0.6	1.3	30	0	0.7	0.4	0.8	30	0	0.6	-0.2	0.6
Kolkata	30	0	1.1	0.4	1.2	30	0	1	-0.2	1.0	30	0	0.8	-0.6	1.0	30	0	0.7	-0.2	0.7
Chennai	30	0	1.3	0.2	1.3	30	0	1.5	-0.6	1.6	30	0	0.9	-0.5	1.0	30	0	0.5	-0.4	0.6
Guwahati	30	0	2.9	1.3	3.2	30	0	0.9	-0.2	0.9	30	0	0.7	0.4	0.8	30	0	0.4	-0.9	1.0
Nagpur	30	0	1.5	-0.1	1.5	30	0	1.3	-0.2	1.3	30	0	0.8	-0.4	0.9	30	0	0.7	-0.3	0.8
Parameter - Zonal wind component																				
Delhi	30	0	3.1	1.6	3.5	30	0	4.1	1.2	4.3	30	0	3.3	1.2	3.5	30	0	3.1	0.8	3.2
Mumbai	30	0	3.3	-1	3.4	30	0	2.7	-0.4	2.7	30	0	1.8	-0.3	1.8	30	0	1.6	3.1	3.5
Kolkata	30	0	2.8	-0.7	2.9	30	0	2.5	-0.8	2.6	30	0	2.2	-0.7	2.3	30	0	2.7	1.2	3.0
Chennai	30	0	2.8	0.8	2.9	30	0	2.5	-0.6	2.6	30	0	1.2	-0.5	1.3	30	0	2	-0.8	2.2
Guwahati	30	0	3.1	-0.7	3.2	30	0	2.2	0.7	2.3	30	0	3.4	1.6	3.8	30	0	1.9	1.1	2.2
Nagpur	30	0	2.6	-1.1	2.8	30	0	2.5	-0.8	2.6	30	0	2.3	-0.8	2.4	30	0	2.1	-0.7	2.2
Parameter - Meridional wind components																				
Delhi	30	0	3.6	1.2	3.8	30	0	4	0.6	4.0	30	0	2.6	0.6	2.7	30	0	2.1	-0.6	2.2
Mumbai	30	0	3.2	-1.1	3.4	30	0	3.1	-0.8	3.2	30	0	2.1	-0.7	2.2	30	0	2.2	-0.5	2.3
Kolkata	30	0	3.4	-0.4	3.4	30	0	3	-1	3.2	30	0	3	-0.4	3.0	30	0	2.9	0.7	3.0
Chennai	30	0	3.1	-1.8	3.6	30	0	3.1	1.1	3.3	30	0	2.5	-0.4	2.5	30	0	3.3	0.8	3.4
Guwahati	30	0	4.1	-0.8	4.2	30	0	4.6	0.3	4.6	30	0	3.4	-1.5	3.7	30	0	2.6	0.5	2.6
Nagpur	30	0	3	0.7	3.1	30	0	2.6	-0.7	2.7	30	0	2.4	0.7	2.5	30	0	2.2	-0.8	2.3

(*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	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	31	0	4.7	-1.7	5	31	0	5.5	-0.6	5.6
Mumbai	31	0	8.2	6	10.2	31	0	20.5	18.8	27.8	31	0	4.3	3.4	5.5	31	0	6.7	5.2	8.5
Kolkata	31	0	30	12.7	32.6	31	0	7.3	8.4	11.1	31	0	5.7	6.3	8.5	31	0	5.7	2.1	6
Chennai	31	0	28.1	-1.3	28.1	31	0	9.9	20.2	22.5	31	0	8.1	5.7	9.9	31	0	23.2	3.6	23.5
Guwahati	30	0	27	-10.7	29.0	31	0	7.6	-0.7	7.6	30	0	28.7	-22	35.9	31	0	10	-13.5	16.8
Nagpur	30	0	6.2	13.3	14.7	31	0	7.4	21	22.3	30	0	4.3	7.6	8.7	31	0	5	10.5	11.6
Parameter - Temperature																				
Delhi	31	0	1	-0.3	1.1	31	0	0.9	0.2	0.9	25	0	0.7	0	0.7	30	0	0.7	0	0.7
Mumbai	31	0	1.1	0.3	1.1	30	1	4	1.3	4.2	31	0	0.5	-0.2	0.6	30	0	0.5	0	0.5
Kolkata	31	0	1	0.3	1	29	0	0.9	-0.1	0.9	30	0	0.7	-0.1	0.7	29	0	0.5	0	0.5
Chennai	31	1	1.8	0.3	1.8	30	0	0.9	0.6	1.1	30	1	1.1	-0.2	1.1	31	0	0.7	-0.1	0.7
Guwahati	30	2	1.2	0.2	1.2	27	0	0.9	0	0.9	30	1	3	0	3	28	0	0.9	0.5	1
Nagpur	30	0	0.7	0.4	0.8	28	0	0.7	0.6	0.9	31	0	0.5	-0.3	0.6	30	0	0.5	-0.1	0.5
Parameter - Zonal Wind Component																				
Delhi	27	0	2	-0.4	2.1	29	0	2.8	0.5	2.8	25	0	2.9	-0.4	2.9	30	0	2.3	0.4	2.3
Mumbai	25	0	2.1	0.1	2.1	30	0	2.2	0.1	2.2	31	0	1.5	-1.1	1.8	30	0	1.3	-0.3	1.3
Kolkata	30	0	2.2	-0.6	2.3	29	0	1.7	0.3	1.7	30	0	2.4	0.2	2.4	29	0	1.8	0.5	1.8
Chennai	31	0	3.9	0.4	4	30	0	3	1.4	3.3	30	0	1.8	-0.2	1.8	31	0	2	-0.3	2
Guwahati	29	0	2.1	0.6	2.2	27	0	2.5	0.7	2.6	30	0	2.4	1.6	2.9	28	0	3.1	1.4	3.4
Nagpur	31	0	2.4	-0.8	2.5	28	0	2.4	0.2	2.4	31	0	1.8	0.3	1.8	30	0	1.8	-0.2	1.8
Parameter - Meridional Wind Components																				
Delhi	25	0	3.1	-1.2	3.4	29	0	3.3	0.4	3.3	25	0	3.1	0.3	3.1	30	0	2.2	-0.1	2.2
Mumbai	30	0	3.4	-0.5	3.5	30	0	2.5	-0.8	2.6	31	0	2.1	0.4	2.1	30	0	2.1	-0.1	2.1
Kolkata	28	0	3.4	-0.5	3.4	29	0	2.7	-0.2	2.8	30	0	2.1	0	2.1	29	0	2.2	0.3	2.2
Chennai	26	0	3.2	0.4	3.3	30	0	3.6	-0.2	3.6	30	0	2.8	-0.5	2.9	31	0	2.9	0	2.9
Guwahati	29	0	3.5	0.3	3.5	27	0	3.2	-0.5	3.2	30	0	2.3	0.7	2.4	28	0	2.4	-0.1	2.4
Nagpur	31	0	3.2	-0.3	3.2	28	0	2.8	-0.4	2.8	31	0	2.1	-0.2	2.1	30	0	2.6	-0.2	2.6

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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