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Sustenance of Global Climate Observation System Upper Air Network (GUAN) of India Meteorological Department

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सार – अगस्त 2015 के दौरान भारत मौसम विज्ञान विभाग (आईएमडी), राष्ट्रीय मौसम विज्ञान / जल विज्ञान प्रणाली (एनएमएचएस) ने उच्च गुणवत्ता वाली रेडियोसाउंडिंग प्रणालीका उपयोग करके अपने 6 प्रादेशिक मौसम केंद्र के मुख्यालयों नामतः नई दिल्ली, मुंबई, कोलकाता, चेन्नई, नागपुर और गुवाहाटी में एकमानक रेडियोसाउंडिंग सिस्टम गुआन (GUAN) स्थापित किया है। इन स्टेशनों को जर्मनी निर्मित एम/एस ग्रॉ रेडियोसॉन्डे, डीएफएम-09 रेडियोसॉन्डे के साथ उच्च गुणवत्ता वाले जीपीएस आधारित रेडियोसाउंडिंग सिस्टम मॉडल नंबर जीएस-ई से लैस किया गया है। एक वर्ष के उनके निष्पादन के आधार पर, आईएमडी ने इन स्टेशनों को गुआन नेटवर्क में शामिल करने के लिए महासचिव, डब्ल्यूएमओ के माध्यम से जीसीओएस सचिवालय से अनुरोध किया। जलवायु परवायुमंडलीय प्रेक्षण पैनल (एओपीसी-22), एक्सेटर, यूके द्वारा 27-31 मार्च, 2017 को आईएमडी के दावे पर चर्चा की गई और उसे अनुमोदित किया गया। तब से, निष्पादन की बारीकी से निगरानी की गई और पाया गया कि ये स्टेशन गुआन नेटवर्क में रेडियोसाउंडिंग स्टेशन को शामिल करने के लिए डब्ल्यूएमओ सदस्य द्वारा की जाने वाली प्रतिबद्धताओं के लिए पूरी तरह से अनुपालन करते हैं। सभी 6 स्टेशनों ने न्यूनतम प्रेक्षण आवश्यकताओं को प्राप्त कर लिया है जैसे एक महीने में परिज्ञापी की संख्या, 100 एचपीए स्तर की न्यूनतम आवश्यकता से अधिक प्रेक्षित परिज्ञसिरयाँ, और अधिकांश स्थितियों में 5 एचपीए स्तर की लक्ष्य अपेक्षा। भूविभव ऊंचाई, प्रेक्षित तापमान और पवन वैक्टर के मामले में आरएमएस विचलन न्यूनतम अपेक्षाओं (एमआरक्यू) के भीतर और लक्ष्य अपेक्षाओं (टीआरक्यू) के बहुत करीब पाया गया है, जो प्रेक्षित किए गए डेटा की परिशुद्धता को प्रमाणित करता है। मासिक जलवायु औसत में प्रेक्षित अभिनतियों को एमआरक्यू में प्रेक्षित किया जाता है और टीआरक्यू तक पहुँच रहती है। इन स्टेशनों ने वास्तव में प्रेक्षण के सभी मानकों के संबंध में एक गुआन मानक रेडियोसाउंडिंग स्टेशन के लिए रेडियोसाउंडिंग प्रेक्षणों की आवश्यक न्यूनतम आवश्यकताओं को पूरा किया है, और लगातार गुआन मानक रेडियोसाउंडिंग वेधशालाओं की लक्ष्य आवश्यकताओं के करीब पहुंच रहे हैं। स्थापना के बाद से नेटवर्क बिना किसी रुकावट के कार्य कर रहा है और सभी मानकों को पूरा करते हुए अच्छा प्रदर्शन कर रहा है तथा निरंतरता के लिए प्रतिबद्ध है।

ABSTRACT. India Meteorological Department (IMD), the National Meteorological / Hydrological system (NMHS) of India, has established GUAN standard radiosounding systems at 6 stations at its regional head quarters namely New Delhi, Mumbai, Kolkata, Chennai, Nagpur and Guwahati using high quality radiosounding system during August 2015. These stations have been equipped with M/s GRAW radiosondes, Germany make, high quality GPS based radiosounding system model No GS-E along with DFM-09 radiosondes. Based on their performance of one year, IMD requested GCOS secretariat through Secretary General, WMO for inclusion of these stations into GUAN network. IMD's claim was discussed and approved by Atmospheric Observation Panel on Climate (AOPC-22), Exeter, UK, 27-31 March, 2017. Since then, the performance has been closely monitored and 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 have achieved 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, observed temperatures 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. These stations actually fulfilled 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 continuously. The network has sustained without a break since the establishment, performing well meeting all the standards and committed for continuation.

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

1. Introduction

For measuring the profiles of upper air parameters like, Temperature, relative humidity, wind direction, wind speed along with geo-potential heights (pressure) free-rising balloons are used and radiosondes are attached to make these measurements, under Global observing system (GOS) network for upper air observations (Radiosounding) which consist of about 1,300 upper-air stations around the globe (Fig. 1). These profiles are measured from just above ground to heights of up to 30 km. 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 GOS network, India Meteorological Department (IMD) has 56 operational Radiosonde radiowind stations in their upper air network (Fig. 2).

A large scale modernization of IMD observational system network was started during 2007 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 state of the art GPS based radiosounding systems during the year 2009. As a result data quality has improved substantially at these stations, which has been validated by NCMRWF and ECMWF, ultimately resulted in removal of black list tag from ECMWF for these up-graded radiosonde stations (Kumar *et al*., 2011). Further, under the Atmospheric Observation System Network (AOSN) scheme, IMD started up-gradation of the remaining non GPS stations and further densification of the upper air network of IMD. Hence, the radiosounding network of IMD had been improved from 39 stations in 2007 to 56 stations at present and all the 56 stations are operating with the most advanced GPS based radiosounding systems. Performance of these stations are continuously monitored using the monthly monitoring reports of NCMRWF and ECMWF. None of these 56 stations figure in the black listed stations and the observed data has been continuously accepted by their forecasting models.

The 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), as an outcome of 2nd World Climate Conference established Global Climate Observing system (GCOS) network in 1992 under the GOS network. The Global Climate Observing System (GCOS) is co-sponsored by the World Meteorological

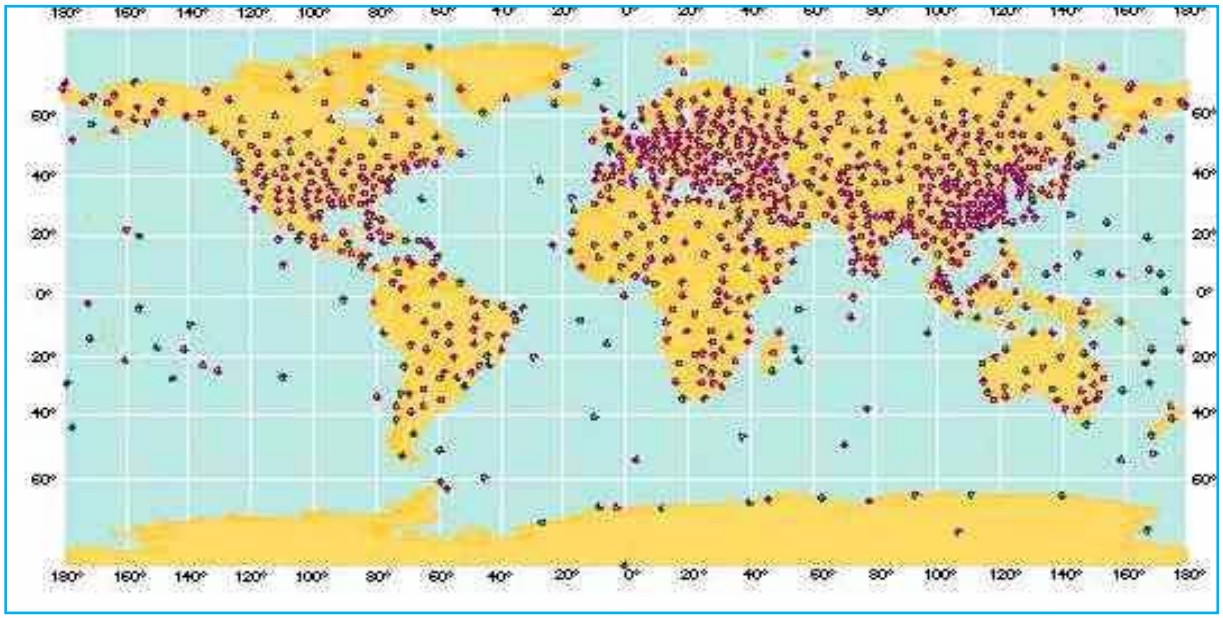

Fig. 1. Global Upper Air Observing System Network

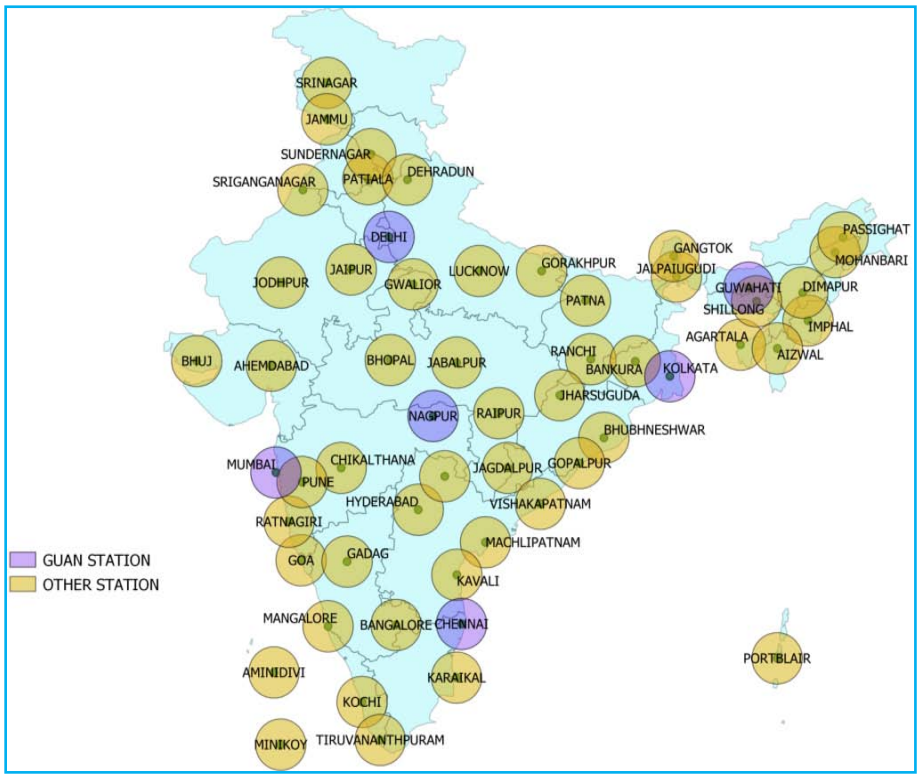

Fig. 2. IMD Upper Air Observational Network

Organization (WMO), the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (IOC-UNESCO), the United Nations Environment Program (UN Environment) and the International Science Council (ISC). It regularly assesses the status of global climate observations of the atmosphere, land and ocean and produces guidance for its improvement. GCOS expert panels maintain definitions of Essential Climate Variables (ECVs) which are required to systematically observe Earth`s changing climate. The observations supported by GCOS contribute to solving challenges in climate research and also underpin climate services and adaptation measures.

The GCOS Upper-Air Network (GUAN) is a program of the Global Climate Observing System (GCOS). The GUAN consists of stations selected from the Global Observing System of the World Weather Watch.In the upper air domain of GCOS, IMD, aiming on further improvement of upper air data quality and to contribute towards global climatological observations in upper atmosphere, initiated the establishment of GUAN standard radiosounding observations at its 6 Regional Meteorological Centres (RMCs). The details of stations are given in Table 1;

TABLE 1

List of GUAN standard sounding stations

S. No.	Station	Index No.	Date of commencement
1.	New Delhi	42182	1st August, 2015
2.	Mumbai	43003	21st August, 2015
3.	Kolkata	42809	12th August, 2015
4.	Chennai	43279	8th August, 2015
5.	Guwahati	42410	18th August, 2015
6.	Nagpur	42867	5th August, 2015

After establishment of these stations during 2015 their performance was monitored, analyzed and presented at WMO TECO-2016 conference. Consequently, the candidature of these stations was claimed by IMD at the GUAN Secretariat through WMO.

2. Data and methodology

2.1. During 2009, IMD upgraded 10 Nos. of upper air stations in the first phase of modernization by employing Modem, France, make GPS based radiosondes at 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 radiosounding network of 10 stations has also been verified by Ansari *et al*. (2015) using NCMRWF data monitoring report. Further, performance of these 6 GUAN standard 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.

2.2. 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).

(*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 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.

2.3. The basic requirement for the GUAN as defined in WMO Guide to GCOS Surface and Upper - Air Networks : GSN and 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.

2.4. *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 metres in geopotential height and and 4 m/s in wind vector.

2.5. *Homogeneity of observations*

The GUAN biases, including those due to changes in the local environment, should be limited if at all possible

TABLE 2

Checklist of commitments *vis-a-vis* performance of IMD GUAN stations

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

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

2.6. *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. Analysis

These stations have been equipped with M/s GRAW radiosondes, Germany make, high quality GPS based radiosounding 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 radiosounding. The system and radiosonde have taken part in last WMO radiosonde inter comparison held at Yanjiang China during 2010 and scored 4.0 and above in each parameter of radio-sounding profile.

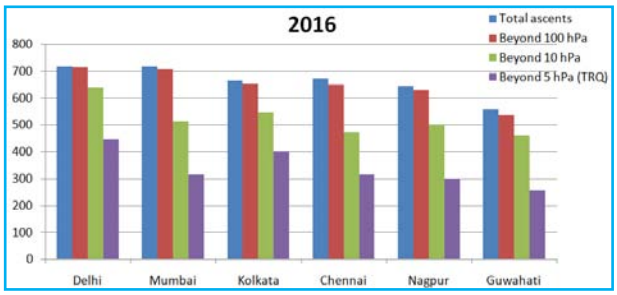

Fig. 3. Analysis of observation for 2016

3.1. Checklist of commitments *vis-a-vis* performance of IMD GUAN stations is given in Table 2.

3.2. *Observation's Minimum Requirements (MRQs) and Target Requirements (TRQs)*

The basic 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 2.3. The performance of all the 6 stations has been analyzed and plotted for the years 2016-2020.

3.2.1. The analysis of the observations for the year 2016 is given in Fig. 3;

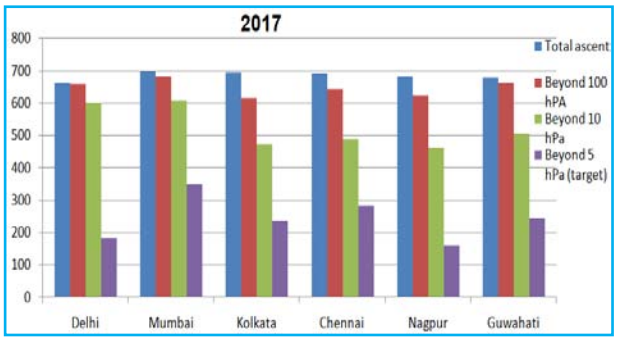

Fig. 4. Analysis of observation for 2017

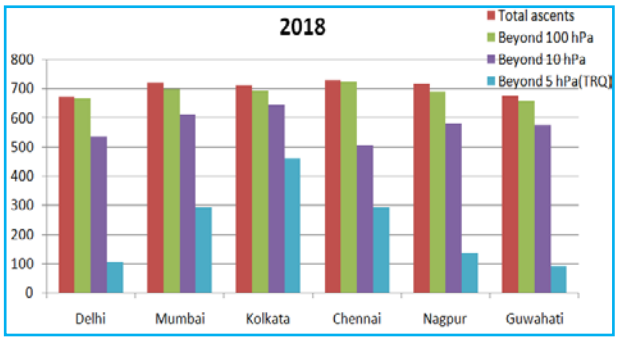

Fig. 5. Analysis of observation for 2018

From the analysis for the year 2016, it is observed that;

(*i*) At Delhi, almost all the ascents have crossed troposphere, 89% reached 10 hPa approaching TRQ and 62% have achieved TRQ.

(*ii*) At Mumbai, 99% ascents recorded up to above troposphere, 72% reached beyond 10 hPa approaching TRQ and 44% have actually achieved TRQ.

(*iii*) In case of Kolkata, during the year almost all the ascents crossed troposphere, 82% reached 10 hPa approaching TRQ and 60% have achieved TRQ.

(*iv*) Almost all the ascent sat Chennai recorded up to above troposphere, 71% reached beyond 10 hPa approaching TRQ and 47% have actually achieved.

(*v*) In case of Nagpur, 98% of the ascents were recorded above troposphere, 78% reached beyond 10 hPa approaching TRQ and 47% have achieved TRQ.

(*vi*) At Guwahati stations 96% of the ascents recorded up to above troposphere, 83% reached beyond 10 hPa approaching TRQ and 46% have achieved TRQ.

3.2.2. The analysis of the observed data for the year 2017, are given in Fig. 4;

From the analysis for the year 2017, it is observed that;

(*i*) At Delhi station all the ascents have crossed troposphere, 91% reached 10 hPa approaching TRQ and 28% have achieved TRQ.

(*ii*) Radiosounding station at Mumbai almost all the ascents recorded up to above troposphere, 87% reached beyond 10 hPa approaching TRQ and 50% have actually achieved TRQ.

(*iii*) In case of Kolkata 89% of the ascents crossed troposphere during the year, 68% reached 10 hPa approaching TRQ and 34% have achieved TRQ.

(*iv*) 93% of the ascents at Chennai recorded up to above troposphere, 71% reached beyond 10 hPa approaching TRQ and 41% have actually achieved.

(*v*) At Nagpur station, 92% of the ascents were recorded above troposphere, 68% reached beyond 10 hPa approaching TRQ and 23% have achieved TRQ.

(*vi*) At Guwahati stations 97% of the ascents recorded up to above troposphere, 74% reached beyond 10 hPa approaching TRQ and 36% have achieved TRQ.

3.2.3. The analysis for the year 2018, are given in Fig. 5;

From the analysis for the year 2018, it is observed that;

(*i*) Almost all the ascents at Delhi station have crossed troposphere, 80% passed 10 hPa approaching TRQ and 16% have achieved TRQ.

(*ii*) At Mumbai, 97% ascents observed up to above troposphere, 85% reached beyond 10 hPa approaching TRQ and 41% have actually achieved TRQ.

(*iii*) In case of Kolkata, 97% ascents observed up to above troposphere, 91% reached beyond 10 hPa approaching TRQ and 65% have actually achieved TRQ.

(*iv*) All the ascents at Chennai recorded up to above troposphere, 69% reached beyond 10 hPa approaching TRQ and 40% have actually achieved the TRQ.

(*v*) At Nagpur, 96% of the ascents were recorded observations above troposphere, 81% reached beyond 10 hPa approaching TRQ and 19% have achieved TRQ.

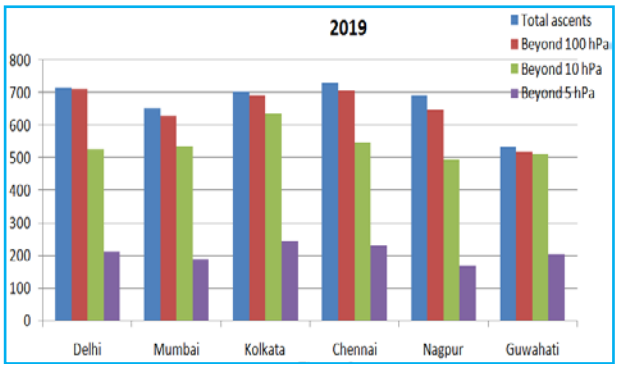

Fig. 6. Analysis of observation for 2019

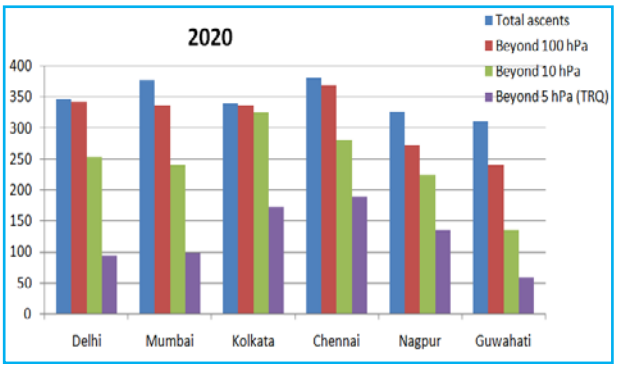

Fig. 7. Analysis of observation for 2020

(*vi*) At Guwahati stations 98% of the ascents recorded up to above troposphere, 86% reached beyond 10 hPa approaching TRQ and 14% have achieved TRQ.

3.2.4. The analysis for the year 2019, are given in Fig. 6;

From the analysis for the year 2019, it is observed that;

(*i*) At Delhi station all the ascents have crossed troposphere, 74% reached 10 hPa approaching TRQ and 30% have achieved TRQ.

(*ii*) Radio sounding station at Mumbai 96% of the ascents recorded up to above troposphere, 82% reached beyond 10 hPa approaching TRQ and 29% have actually achieved TRQ.

(*iii*) Kolkata station recorded 98 % of the ascents crossing troposphere during the year, 90% reached 10 hPa approaching TRQ and 35% have achieved TRQ.

(*iv*) At Chennai 97 % of the ascents recorded up to above troposphere, 75% reached beyond 10 hPa approaching TRQ and 32% have actually achieved.

(*v*) At Nagpur station, 94% of the ascents were recorded above troposphere, 71% reached beyond 10 hPa approaching TRQ and 25% have achieved TRQ.

(*vi*) At Guwahati stations 97% of the ascents recorded up to above troposphere, 96% reached beyond 10 hPa approaching TRQ and 38% have achieved TRQ.

3.2.5. The analysis for the year 2020, are given in Fig. 7;

From the analysis for the year 2020, it is observed that;

(*i*) At Delhi, almost all the ascents have crossed troposphere, 73% reached 10 hPa approaching TRQ and 27% have achieved TRQ.

(*ii*) At Mumbai, 89% ascents recorded up to above troposphere, 64% reached beyond 10 hPa approaching TRQ and 26% have actually achieved TRQ.

(*iii*) In case of Kolkata, during the year almost all the ascents crossed troposphere, 96% reached 10 hPa approaching TRQ and 51% have achieved TRQ.

(*iv*) Almost all the ascents at Chennai recorded up to above troposphere, 74% reached beyond 10 hPa approaching TRQ and 49% have actually achieved.

(*v*) In case of Nagpur, 83% of the ascents were recorded above troposphere, 69% reached beyond 10 hPa approaching TRQ and 41% have achieved TRQ.

(*vi*) At Guwahati stations 77% of the ascents recorded up to above troposphere, 43% reached beyond 10 hPa approaching TRQ and 19% 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 in order to achieve root mean square (RMS) departure at 300 hPa in geo-potential height up to 80 m and that 300 hPa wind vector 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 a period of 5 years from January 2016 to December 2020, by using the monthly global data reports of ECMWF and NCMRWF. It has been observed from both the reports of the period;

TABLE 3

Performance analysis with respect to accuracy & homogeneity for the year 2016

Name of the station	0000 UTC					1200 UTC				
	Parameter-Geopotential height									
	No.	Rej	SD	Bias	RMS	No.	Rej	SD	Bias	RMS
Delhi	359	0	8.3	-4.1	9.3	359	0	9.1	5.1	10.4
Mumbai	359	0	7	-5.6	8.9	359	0	8	6.2	10.1
Kolkata	333	0	6.7	-1.1	6.8	332	0	6.7	3.9	7.7
Chennai	337	0	7.6	-1.7	7.8	336	0	8.1	9.2	12.2
Guwahati	324	0	6.3	-4.1	7.5	321	0	8.5	1.8	8.7
Nagpur	330	0	8.2	1.5	8.3	328	0	7.9	1.2	8.0
	Parameter-Temperature									
Delhi	No.	Rej	SD	Bias	RMS	No.	Rej	SD	Bias	RMS
Delhi	359	0	1.1	-0.2	1.1	359	0	1.2	0.2	1.2
Mumbai	359	0	1	0.1	1.0	359	0	1.1	-0.2	1.1
Kolkata	333	0	0.8	-0.2	0.8	332	0	0.8	0.3	0.8
Chennai	337	0	0.9	-0.1	0.9	336	0	1.3	-0.1	1.3
Guwahati	324	0	1.2	0.2	1.2	321	0	1.5	0.2	1.5
Nagpur	330	0	1	-0.1	1.0	328	0	0.8	0	0.8
	Parameter-Zonal Wind Component									
Delhi	359	0	2.9	1.4	3.2	359	0	2.6	0.3	2.6
Mumbai	359	0	3	0.2	3.0	359	0	3.1	0.5	3.1
Kolkata	333	0	3	0.9	3.1	332	0	2.7	0.4	2.7
Chennai	337	0	3.1	-0.4	3.1	336	0	2.5	-0.9	2.7
Guwahati	324	0	2.6	-0.6	2.7	321	0	1.7	-0.5	1.8
Nagpur	330	0	2	0.4	2.0	328	0	1.9	0.6	2.0
	Parameter-Meridional Wind Components									
Delhi	359	0	3	-0.4	3.0	359	0	3.4	-0.2	3.4
Mumbai	359	0	3	0.5	3.0	359	0	3.8	0.5	3.8
Kolkata	333	0	4	0.8	4.1	332	0	3.6	-0.3	3.6
Chennai	337	0	3	-0.6	3.1	336	0	3.7	0.1	3.7
Guwahati	324	0	3	0.7	3.1	321	0	3.4	-0.6	3.5
Nagpur	330	0	3	-0.5	3.0	328	0	3.5	0.5	3.5

TABLE 4

Performance Analysis with respect to Accuracy & Homogeneity for the year 2017

Name of the station	Parameter-Geopotential Height									
	0000 UTC					1200 UTC				
	No.	Rej	SD	Bias	RMS	No.	Rej	SD	Bias	RMS
Delhi	334	0	7.9	3.2	8.5	330	0	9.3	-1.9	9.5
Mumbai	352	0	7.1	-4.6	8.5	348	0	7.8	3.2	8.4
Kolkata	350	0	7.4	-1.3	7.5	348	0	8.2	-1.3	8.3
Chennai	348	0	6.8	-1.6	7.0	348	0	7.1	-2.1	7.4
Guwahati	340	0	6.3	-4.2	7.6	343	0	6.4	-3.6	7.3
Nagpur	342	0	5.9	2.4	6.4	342	0	4.8	-2.5	5.4
	Parameter-Temperature									
Delhi	No.	Rej	SD	Bias	RMS	No.	Rej	SD	Bias	RMS
Delhi	334	0	0.9	-0.2	0.9	330	0	0.9	0.2	0.9
Mumbai	352	0	1	0.1	1.0	348	0	0.8	0.1	0.8
Kolkata	350	0	0.8	-0.2	0.8	348	0	0.9	-0.2	0.9
Chennai	348	0	1	-0.3	1.0	348	0	1.1	-0.1	1.1
Guwahati	340	0	1.5	0.1	1.5	343	0	1.3	0.1	1.3
Nagpur	342	0	0.9	-0.2	0.9	342	0	1.2	0.2	1.2
	Parameter-Zonal Wind Component									
Delhi	334	0	3.1	1.4	3.4	330	0	2.8	0.8	2.9
Mumbai	352	0	3	0.2	3.0	348	0	2.9	0.3	2.9
Kolkata	350	0	3	0.9	3.1	348	0	2.6	0.7	2.7
Chennai	348	0	3.3	-0.4	3.3	348	0	2.7	-0.5	2.7
Guwahati	340	0	3.4	-0.6	3.5	343	0	2.9	0.6	3.0
Nagpur	342	0	1.9	0.4	1.9	342	0	2.1	-0.7	2.2
	Parameter-Meridional Wind Components									
Delhi	334	0	2.7	0.8	2.8	330	0	2.8	1	3.0
Mumbai	352	0	3.1	0.3	3.1	348	0	2.3	0.4	2.3
Kolkata	350	0	2.5	0.7	2.6	348	0	2.5	0.6	2.6
Chennai	348	0	2.8	-0.5	2.8	348	0	2.6	0.5	2.6
Guwahati	340	0	2.3	0.6	2.4	343	0	2.4	-0.7	2.5
Nagpur	342	0	1.8	-0.7	1.9	342	0	1.7	0.6	1.8

TABLE 5

Performance Analysis with respect to Accuracy & Homogeneity for the year 2018

Name of the station	0000 UTC					1200 UTC				
	Parameter-Geopotential Height									
	No.	Rej	SD	Bias	RMS	No.	Rej	SD	Bias	RMS
Delhi	340	0	7	3.1	7.7	332	0	7.3	-2.8	7.8
Mumbai	359	0	7.9	2.9	8.4	359	0	7.6	3.1	8.2
Kolkata	359	0	8.2	-1.2	8.3	350	0	8.1	1.6	8.3
Chennai	364	0	6.8	1.8	7.0	364	0	6.5	-1.5	6.7
Guwahati	337	0	6.7	3.9	7.8	336	0	7.2	-3.1	7.8
Nagpur	358	0	7.2	-1.6	7.4	357	0	6.8	1.9	7.1
	Parameter-Temperature									
Delhi	No.	Rej	SD	Bias	RMS	No.	Rej	SD	Bias	RMS
Delhi	340	0	1	0.2	1.0	332	0	0.9	0.1	0.9
Mumbai	359	0	0.8	-0.1	0.8	359	0	1	0.2	1.0
Kolkata	359	0	0.9	-0.2	0.9	350	0	0.8	0.1	0.8
Chennai	364	0	1.1	0.2	1.1	364	0	1	-0.2	1.0
Guwahati	337	0	1.3	-0.1	1.3	336	0	1	-0.1	1.0
Nagpur	358	0	1.2	0.2	1.2	357	0	0.8	0.2	0.8
	Parameter-Zonal Wind Component									
Delhi	340	0	2.9	0.6	3.0	332	0	2.9	0.3	2.9
Mumbai	359	0	3	0.4	3.0	359	0	3.3	0.5	3.3
Kolkata	359	0	2.6	-0.6	2.7	350	0	2.7	0.4	2.7
Chennai	364	0	2.9	0.7	3.0	364	0	2.9	-0.9	3.0
Guwahati	337	0	3	-0.6	3.1	336	0	2.7	-0.5	2.7
Nagpur	358	0	1.9	-0.5	2.0	357	0	2.4	0.6	2.5
	Parameter-Meridional Wind Components									
Delhi	340	0	3.1	-0.4	3.1	332	0	3.4	-0.2	3.4
Mumbai	359	0	3	0.5	3.0	359	0	3.8	0.5	3.8
Kolkata	359	0	3.6	0.8	3.7	350	0	3.6	-0.3	3.6
Chennai	364	0	2.8	-0.6	2.9	364	0	3.7	0.1	3.7
Guwahati	337	0	2.6	0.7	2.7	336	0	3.4	-0.6	3.5
Nagpur	358	0	3.2	-0.5	3.2	357	0	3.5	0.5	3.5

TABLE 6

Performance Analysis with respect to Accuracy & Homogeneity for the year 2019

Name of the station	0000 UTC					1200 UTC				
	No.	Rej	SD	Bias	RMS	No.	Rej	SD	Bias	RMS
	Parameter-Geopotential Height									
Delhi	359	0	7.8	3	8.4	356	0	8.1	-3	8.6
Mumbai	326	0	8	-2.7	8.4	327	0	7.8	2.6	8.2
Kolkata	352	0	8.1	-1.2	8.2	352	0	8.5	1.3	8.6
Chennai	365	0	6.9	1.6	7.1	365	0	7	-1.7	7.2
Guwahati	264	0	6.4	3.1	7.1	269	0	9	-2.1	9.2
Nagpur	345	0	6.3	-1.4	6.5	346	0	8.2	1.6	8.4
	Parameter-Temperature									
Delhi	No.	Rej	SD	Bias	RMS	No.	Rej	SD	Bias	RMS
Delhi	359	0	0.9	-0.3	0.9	356	0	0.9	0.4	1.0
Mumbai	326	0	0.8	0.5	0.9	327	0	1	0.3	1.0
Kolkata	352	0	0.7	-0.2	0.7	352	0	0.8	-0.2	0.8
Chennai	365	0	0.8	-0.3	0.9	365	0	0.8	-0.3	0.9
Guwahati	264	0	1.1	0.9	1.4	269	0	0.9	0.6	1.1
Nagpur	345	0	1	-0.2	1.0	346	0	0.7	-0.2	0.7
	Parameter-Zonal Wind Component									
Delhi	359	0	2.8	1.4	3.1	356	0	2.9	0.3	2.9
Mumbai	326	0	2	0.2	2.0	327	0	3.3	0.5	3.3
Kolkata	352	0	3.1	0.9	3.2	352	0	2.7	0.4	2.7
Chennai	365	0	3.3	-0.4	3.3	365	0	2.9	-0.9	3.0
Guwahati	264	0	2.9	-0.6	3.0	269	0	2.7	-0.5	2.7
Nagpur	345	0	3	0.4	3.0	346	0	2.4	0.6	2.5
	Parameter-Meridional Wind Components									
Delhi	359	0	3	0.3	3.0	356	0	3.1	0.3	3.1
Mumbai	359	0	3.6	0.5	3.6	327	0	3.4	0.5	3.4
Kolkata	333	0	3.1	0.4	3.1	352	0	3	0.4	3.0
Chennai	337	0	3.2	-0.9	3.3	365	0	3.5	-0.9	3.6
Guwahati	324	0	3.4	-0.5	3.4	269	0	3.6	-0.5	3.6
Nagpur	330	0	3	0.6	3.1	346	0	2.1	0.6	2.2

TABLE 7

Performance Analysis with respect to Accuracy & Homogeneity for the year 2020

Name of the station	Parameter-Geopotential Height									
	0000 UTC					1200 UTC				
	No.	Rej	SD	Bias	RMS	No.	Rej	SD	Bias	RMS
Delhi	280	0	7	-2.1	7.3	66	0	6.5	-2.1	6.8
Mumbai	270	0	7.1	-3.9	8.1	106	0	6.8	3.2	7.5
Kolkata	263	0	7.2	-2.1	7.5	75	0	7.8	3	8.4
Chennai	277	0	7.6	-2.7	8.1	103	0	7.4	-3.1	8.0
Guwahati	214	0	6.4	-3.9	7.5	96	0	7.1	3.4	7.9
Nagpur	230	0	6.5	2.5	7.0	94	0	7.5	-2.9	8.0
	Parameter-Temperature									
Delhi	No.	Rej	SD	Bias	RMS	No.	Rej	SD	Bias	RMS
Delhi	280	0	1	-0.2	1.0	66	0	0.9	0.2	0.9
Mumbai	270	0	0.8	0.1	0.8	106	0	0.8	-0.1	0.8
Kolkata	263	0	0.9	0.2	0.9	75	0	1	0.2	1.0
Chennai	277	0	0.8	-0.3	0.9	103	0	0.8	-0.1	0.8
Guwahati	214	0	0.7	-0.1	0.7	96	0	0.8	0.1	0.8
Nagpur	230	0	0.9	-0.2	0.9	94	0	0.9	0.2	0.9
	Parameter-Zonal Wind Component									
Delhi	280	0	3.1	-0.3	3.1	66	0	3.1	0.3	3.1
Mumbai	270	0	3.6	0.5	3.6	106	0	3.3	0.2	3.3
Kolkata	263	0	3.3	0.4	3.3	75	0	3.5	0.7	3.6
Chennai	277	0	3.2	-0.6	3.3	103	0	3.2	-0.6	3.3
Guwahati	214	0	3	-0.5	3.0	96	0	3	0.6	3.1
Nagpur	230	0	3	0.7	3.1	94	0	3.7	-0.5	3.7
	Parameter-Meridional Wind Components									
Delhi	280	0	3.3	-0.2	3.3	66	0	4	-0.4	4.0
Mumbai	270	0	3.9	0.4	3.9	106	0	3.9	0.3	3.9
Kolkata	263	0	3.7	-0.3	3.7	75	0	3.6	-0.5	3.6
Chennai	277	0	3.2	0.8	3.3	103	0	3.3	0.7	3.4
Guwahati	214	0	3.8	0.6	3.8	96	0	3	0.2	3.0
Nagpur	230	0	4	-0.7	4.1	94	0	4.1	-0.9	4.2

3.3.1. 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 reports every month - ECMWF). It shows that all the data recorded has been found by the computing models within the acceptable limits of accuracies.

3.3.2. The standard deviation (SD), the biases and RMS departures have been calculated for temperature, geo-potential height, zonal and meridional wind components, at 300 hPa levels, for the years 2016 to 2020.

3.3.3. The performance analysis details indicating SD, bias and RMS, for the year 2016 are given in Table 3;

For the year 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 the observations at 0000 UTC and 1200 UTC. The biases observed in temperature have also achieved the minimum requirements of 0.2 °C and approaching the target requirements of 0.1 °C. The biases observed in wind speed have actually achieved the target requirement of 1 m/s.

3.3.4. The performance analysis for the year 2017, indicating SD, bias and RMS, are given in Table 4;

For the year 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 and achieved the RMS departures as per target requirements of 10 m in geo-potential height. The biases observed in temperature have also achieved the minimum requirements and approaching the target requirements. The biases observed in wind speed have actually achieved the target requirements.

3.3.5. The performance analysis details indicating SD, bias and RMS, for the year 2018 are given in Table 5;

During the year 2018, at 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 and achieved the RMS departures as per target requirements of 10 m in geo-potential height. The biases observed in temperature have also achieved the minimum requirements and approaching the target requirements. The biases observed in wind speed have actually achieved the target requirements.

3.3.6. The performance analysis details indicating SD, bias and RMS, for the year 2019 are given in Table 6;

In 2019 all the stations have obtained the RMS departures in geo-potential height and wind vectors under the required limits and achieved the RMS departures as per target requirements of 10 m in geo-potential height for both the times of observations at 0000 UTC and 1200 UTC. The biases observed in temperature have also achieved the minimum requirements and approaching the target requirements. The biases observed in wind speed have actually achieved the target requirements.

3.3.7. The performance analysis details indicating SD, bias and RMS, for the year 2020 are given in Table 7;

For both the times of observations at 0000 UTC and 1200 UTC at all the stations, during the year 2020 the RMS departures in geo-potential height and wind vectors were found under the required limits and achieved the RMS departures as per target requirements. The biases observed in temperature have also achieved the minimum requirements and approaching the target requirements. The biases observed in wind speed have actually achieved the target requirements.

3.4. *CLIMAT and CLIMAT TEMP submission*

The radiosounding 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 years 2016 to 2020, it is found that these stations are fully complied for the commitments made by the IMD for existence in the GUAN network. All the 6 stations have achieved minimum observational requirements un-interrupted and in most of the cases reaching up to the target requirement of 5 hPa level. In order to ascertain the accuracies of observations, the analysis 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. Hence, network has achieved the required accuracies and homogeneity in the observations at all the six stations. 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 sustained without a break in WMO Global Upper Air Climatological Observations System Network.

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