MAUSAM, **66**, 3 (July 2015), 367-374

551.509.5 : 551.501.7

Verification of quality of GPS based radiosonde data

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सार – अधिकांशतः सत्यापन तकनीकों और परिणामों से यह पता चला है कि समय पर सटीक प्रेक्षणों के माध्यम से प्राप्त डेटा की गुणवत्ताओं का सटीक और विश्वंसनीय मौसम पूर्वानुमान देने में महत्वपूर्ण योगदान होता है। भारत मौसम विज्ञान विभाग में जी पी एस आधारित रेडियो साउन्डिंग के लगाए जाने से डेटा की गुणवत्ता में बहुत हद तक सुधार हुआ है और आई एम डी के उपरितन वायु आँकड़े के विषय में ई सी एम डब्ल्यू एफ द्वारा लगाए गए ब्लैक टैग की अवधारणा समाप्त हुई है और इससे मौसम पूर्वानुमान देने में काफी अधिक सुधार हुआ है।

इस शोध पत्र में जी पी एस आधारित रेडियो सौंदे डेटा की गुणवत्ता की तुलना आई एम डी के गैर जी पी एस आधारित रेडियो सौंदे डेटा से करने का प्रयास किया गया है। एन सी एम आर डब्ल्यू एफ के दिसम्बर 2013 के उपरितन वायु डेटा की गुणवत्ता रिपोर्ट से पता चलता है कि प्रथम अनुमान में 16 जी पी एस आधारित स्टेशनों से इस मॉडल में डेटा प्राप्त हुए हैं जबकि गैर जी पी एस रेडियो सौंदे से प्राप्त डेटा में 16 प्रतिशत से 85 प्रतिशत डेटा अस्वीकार कर दिए गए हैं। गुणात्मक डेटा के मानक विचलन 9.4 भू-विभव मीटर (GPM) से 28.6 GPM की सीमा में है। 100 हे.पा. स्तर में जी पी एस आधारित तापमान डेटा में पूर्वाग्रह की सीमा 0.1° सेल्सियस से -1.0° सेल्सियस है जबकि गैर जी पी एस के लिए ये मान 2.6° सेल्सियस से 5.0° सेल्सियस है। जी पी एस आधारित 100 हे.पा. भू-विभव उच्चता के आर एम एस ई मान 14.0 जी पी एम से 81.8 जी पी एम की सीमा में है जबकि गैर जी पी एस में आर एम एस ई के मान 31.8 जी पी एम से 209.5 जी पी एम के क्रम में है। इस प्रकार यह अनुमानित है कि जी पी एस आधारित रेडियो सौंदे गुणात्मक डेटा उपलब्ध कराने के योग्य है जो अच्छी व गुणवत्ता के मौसम पूर्वानुमान प्रणाली का मेरूदण्ड है।

ABSTRACT. Most of the verification techniques and results reveal that timely and accurate observations and the data quality thereof is the most important factor for an accurate and reliable weather forecast. With the augmentation of GPS based radiosounding in IMD, the data quality has been improved to a great extent leading to removal of black tag by ECMWF on upper air data of IMD, and putting large impact on improvement in weather forecast.

An attempt has been made to verify the quality of GPS based radiosonde data in comparison to non-GPS IMD radiosonde data. December 2013 upper air data quality report of NCMRWF indicates that model has accepted all the data received from 16 GPS based stations being within the tolerance limits of the first guess, whereas the data received from non GPS radiosondes has a rejection rate of 16% to 85%. The standard deviation of quality data are within a range of 9.4 Geopotential Meter (gpm) to 28.6 gpm, whereas for non GPS standard deviation is of the order of 7.3 gpm to 115.9 gpm. The bias in GPS based temperature data at 100 hPa level are within a range of 0.1 °C to -1.0 °C, whereas for non GPS the values are of the order of 2.6 °C to 5.0 °C. The RMSE values of GPS based 100 hPa Geopotential heights are within a range of 14.0 gpm to 81.8 gpm, whereas for non GPS RMSE values are of the order of 31.8 gpm to 209.5 gpm. Thus, it is inferred that GPS based radiosondes are able to provide quality data which is the backbone for a good quality weather forecast system.

Key words – GPS, Radiosonde, Geopotential height, Temperature, Standard deviation, Root mean square error (RMSE), Verification, Numerical weather prediction (NWP).

1. Introduction

India Meteorological Department (IMD) has 39 operational Radiosonde radiowind stations in their upper air network. 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 centres. Performance evaluation of the RS/RW observation has been performed by Kats *et al*. (2008) for Roshydromet, Russian Federation National upper air Network, covering the aspects of the operation quality, accuracy, achieved heights, completeness, timeliness, archiving etc. Hollingsworth *et al*. (1986) used First Guess field as the primary reference for performance analysis of upper air data. According to Das Gupta *et al*. (2005) upper air data of IMD was doubted for many years by leading numerical weather prediction centres of the world and observations were rejected by data assimilation systems. 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 NCMRWF and ECMWF, 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 and earlier upgraded 10 stations are again re-started during 2013 after a gap of around a year of non-functioning of these stations. At present 16 stations in the upper air network of IMD are equipped with GPS based radiosounding systems. The details are given in Table 1. Ten (10) stations are equipped with non-GPS, conventional radiotheodolite based systems using IMD-mark-IV modified radiosondes. The details are given in Table 2.

TABLE 1

List of GPS based sounding stations

Station	Index No.	Station	Index No.
Srinagar	42027	Bhubaneshwar	42971
New Delhi	42182	Hyderabad	43128
Mohanbari	42314	Vishkhapatnam	43150
Patna	42492	Goa	43192
Ahmedabad	42647	Chennai	43279
Bhopal	42667	Portblair	43333
Kolkata	42809	Minicoy	43369
Nagpur	42867	Trivandrum	43371

TABLE 2

List of non-GPS (IMD- MK-IV) sounding stations

Station	Index No.	Station	Index No.
Gwalior	42361	Raipur	42875
Lucknow	42369	Mumbai	43003
Gorakhpur	42379	Jadgalpur	43041
Guwahati	42410	Machilipatnam	43185
Ranchi	42701	Mangalore	43285

2. Data and methodology

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. Presently IMD is operating 16 GPS based radiosounding stations whose performance has been examined using NCMRWF data monitoring report for the month of December 2013.The NCMRWF monthly data report is intended to give an overview of the availability and quality of observations from the global observing system. The information/ analysis on data quality is based on differences between observations and the values of most recent forecast (first guess) of each of the parameters in the data set. Performance evaluation of the RS/RW observation is a multi dimensional concept covering various aspects of the operation quality, accuracy of observations, achieved heights, completeness, timeliness, proper reporting, archiving, etc. (Kats *et al*., 2008). First Guess field can be used as the primary reference for performance analysis (Hollingsworth *et al*., 1986). Thus, it is necessary to compare monitoring results with Numerical Weather Prediction (NWP) centers' analyses. Determining the absolute accuracy of data is very difficult because of non availability of a reference data source / instrument, which can provide a known true value of the atmospheric conditions. This is due to the uncertainties caused by Meteorological variability, spatial and temporal separation of measurements, external and internal interferences and random noise. Biases in the meteorological parameters have been calculated as the difference between the observed value and the value of the parameters from the most recent forecast (first guess) of the GDAS model used by NCMRWF.

$$\text{Bias} = \text{Observed value} - \text{First guess} = O_i - B_i$$

A true precision or the standard deviation of a series of measured value about a mean measured reference can be calculated and used as a tool for quality measurements. For reasonableness of the data comparison of observations of upper air data can be done with another sensor known to be operating properly and in a better manner. The standard deviation can be calculated as:

$$\text{Standard deviation (SD)} = \sqrt{[\,1/N\sum(O_i - \mu)^2]}$$

where, $\mu = 1/N(\sum O_i)$ is the mean of observed values O_i

Calculating a measure of the uncertainty between the observations is referred to as comparability and here the

TABLE 3

Variations in temperatures at 500 hPa level for GPS based stations and non-GPS Stations

GPS based radiosonde stations						**Non-GPS based radiosonde stations**					
Station	Count	% Rejected	SD (°C)	BIAS (°C)	RMSE (°C)	Station	Count	% Rejected	SD (°C)	BIAS (°C)	RMSE (°C)
SRN	31	0	1.0	0.0	1.0	GWL	11	72	4.1	-0.9	4.2
NDL	31	0	0.7	0.2	0.7	LKO	7	85	1.3	-0.9	1.6
MNB	30	0	1.8	-0.2	1.8	GRK	10	60	1.4	-0.5	1.5
PTN	31	0	0.9	-0.4	1.0	GHT	8	87	2.0	-1.2	2.3
AHM	30	0	0.7	-0.6	0.9	RNC	26	30	2.8	0.7	2.8
BHP	26	0	0.6	0.0	0.6	RPR	7	42	2.6	0.8	2.7
KOL	31	0	1.0	-0.4	1.1	MUM	12	58	2.0	-0.3	2.0
NGP	19	0	0.8	-0.4	0.9	JGD	18	22	1.3	-0.8	1.5
BBS	31	0	0.8	-0.4	0.9	MPT	5	80	2.8	-4.3	5.2
HYD	31	0	0.6	0.0	0.6	MNG	6	50	2.9	-1.5	3.2
VSK	31	3	0.9	-0.6	1.1						
GOA	11	9	0.9	-0.7	1.1						
CHN	29	0	0.6	-0.5	0.8						
PBL	29	0	0.8	-0.3	0.8						
MCY	27	0	0.7	-0.6	0.9						
TRV	29	0	1.2	-0.7	1.4						

comparability is the Root Mean Square Error (RMSE) of a series of differences between the observations, which is given by:

$$\text{Root Mean Square Error (RMSE)} = \sqrt{[1/N\sum(O_i - B_i)^2]}$$

where,

O_i is observed value and B_i is the first guess value of the selected parameter.

Standard deviation and the root-mean square are the major criteria for assessment of data quality of upper air data. Standard Deviation (SD) & Root Mean Square Errors (RMSE) of the following parameters have been obtained and analyzed;

(a) Geopotential height (Z)

(b) Temperature (T)

(c) Zonal wind component

(d) Meridional wind component

3. Results and discussion

3.1. *Earlier studies*

One of the major problems of Indian Radiosonde temperature observation was its random large fluctuations on daily scale (Das Gupta *et* al., 2005). Another report on "Quality of observations from Indian stations" in 2009, Das Gupta (2009), has evaluated the performance of upper air observations of these stations by comparing with their Global Data Assimilation System (GDAS) first guess (6 hr forecast from the model). It has been observed that GPS radiosonde data does not show much large fluctuations, whereas for non GPS radiosondes, it persisted.

While analyzing the performance of 10 GPS based station upgraded under modernization of IMD phase-I scheme during 2009, Kumar *et al*. (2011), have shown that with introduction of GPS based radiosounding the last level achievement was beyond 100 hPa in > 90% of cases of sounding and > 70% of cases have achieved the level beyond 20 hPa. The performance of Chennai radiosounding station has been given in the Fig. 1.

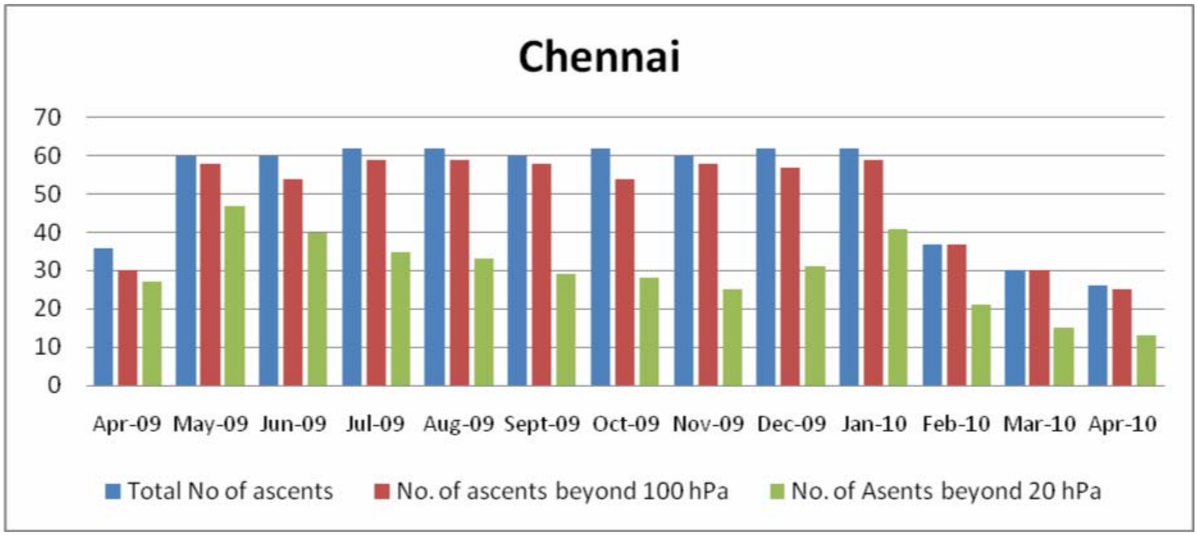

Fig. 1. Performance of Chennai radiosounding station

TABLE 4

Variations in geopotential heights at 500 hPa level

GPS based radiosonde stations						Non-GPS based radiosonde stations					
Station	Count	% Rejected	SD (gpm)	BIAS (gpm)	RMSE (gpm)	Station	Count	% Rejected	SD (gpm)	BIAS (gpm)	RMSE (gpm)
SRN	31	0	12.8	9.5	15.9	GWL	11	72	31.5	-58.6	66.6
NDL	31	0	10.5	2.8	10.9	LKO	7	85	19.4	-58.1	61.3
MNB	30	3	12.0	-19.0	22.4	GRK	10	60	37.9	-52.4	64.7
PTN	31	0	13.3	-0.2	13.3	GHT	8	75	40.8	-60.0	72.6
AHM	29	0	7.8	12.5	14.7	RNC	26	30	32.5	-7.4	33.4
BHP	26	0	7.8	4.0	8.7	RPR	7	42	33.5	-12.7	35.9
KOL	31	0	7.7	3.5	8.5	MUM	12	66	35.5	-63.0	72.3
NGP	19	0	4.7	7.6	9.0	JGD	18	27	25.9	-28.9	38.8
BBS	31	0	6.0	7.0	9.2	MPT	5	80	59.0	-98.8	115.1
HYD	31	0	6.5	11.4	13.1	MNG	6	50	45.5	-25.2	52.0
VSK	31	3	12.6	-3.4	13.1						
GOA	11	9	17.6	26.2	31.6						
CHN	29	0	9.0	21.4	23.3						
PBL	29	0	8.9	11.4	14.5						
MCY	26	0	9.6	20.5	22.6						
TRV	29	0	7.8	16.9	18.6						

For analyzing the quality of upper air data they used standrad deviation root mean square errors in Geopotential heights (*Z*), Temperature (*T*), Humidity (*H*), Wind speed and wind direction at 50 hPa level and 100 hPa level and found the random variations were largely reduced leading to significant improvement in data quality.

TABLE 5

Variations in zonal wind components at 500 hPa level

GPS based radiosonde stations						Non-GPS based radiosonde stations					
Station	Count	% Rejected	SD (m/s)	BIAS (m/s)	RMSE (m/s)	Station	Count	% Rejected	SD (m/s)	BIAS (m/s)	RMSE (m/s)
SRN	31	0	2.6	-1.7	3.1	GWL	5	0	1.3	1.1	1.7
NDL	31	0	3.2	1.7	3.6	GRK	5	20	2.5	-7.2	7.6
MNB	30	0	4.9	-1.6	5.2	GHT	6	0	8.6	-2.8	9.0
PTN	31	0	3.5	1.4	3.7	RNC	25	32	6.3	-13.0	14.4
AHM	30	0	1.4	1.0	1.8	RPR	4	0	3.4	-2.3	4.1
BHP	26	0	2.4	1.0	2.6	MUM	5	0	2.0	-3.8	4.3
KOL	31	0	2.7	1.0	2.9	JGD	11	18	4.5	1.2	4.7
NGP	19	0	2.2	-0.2	2.2	MPT	4	0	2.2	0.5	2.3
BBS	31	0	2.0	1.0	2.2	MNG	1	0	0.0	-1.2	1.2
VSK	31	0	2.8	0.6	2.9						
GOA	11	0	2.6	0.0	2.6						
CHN	29	0	2.2	-0.5	2.2						
PBL	29	0	2.1	-0.9	2.2						
MCY	27	0	2.6	-1.3	2.9						
TRV	29	0	2.6	-2.0	3.3						

TABLE 6

Variations in meridional wind components at 500 hPa level

GPS based radiosonde stations						Non-GPS based radiosonde stations					
Station	Count	% Rejected	SD (m/s)	BIAS (m/s)	RMSE (m/s)	Station	Count	% Rejected	SD (m/s)	BIAS (m/s)	RMSE (m/s)
SRN	31	0	4.8	-0.6	4.8	GWL	5	0	1.6	2.0	2.5
NDL	31	0	2.6	0.1	2.6	GRK	5	20	6.6	6.0	8.9
MNB	30	0	3.0	-0.1	3.0	GHT	6	0	4.0	3.3	5.2
PTN	31	0	2.7	-1.0	2.9	RNC	25	32	7.3	-1.5	7.4
AHM	30	0	3.4	-0.2	3.4	RPR	4	0	0.3	-0.5	0.6
BHP	26	0	3.1	0.2	3.1	MUM	5	0	1.9	-1.0	2.1
KOL	31	0	2.9	-0.2	2.9	JGD	11	18	10.5	-5.0	11.6
NGP	19	0	3.3	-0.1	3.3	MPT	4	0	4.2	2.5	4.8
BBS	31	0	2.9	0.3	2.9	MNG	1	0	0.0	-0.4	0.4
HYD	31	0	2.6	-0.1	2.6						
VSK	31	0	3.2	-0.5	3.2						
GOA	11	0	3.1	0.1	3.1						
CHN	29	0	2.4	0.2	2.4						
PBL	29	0	2.4	-0.2	2.4						
MCY	27	0	2.3	-0.7	2.5						
TRV	29	0	3.1	0.0	3.1						

TABLE 7

Variations in temperature at 100 hPa level in case of GPS stations

S. No.	Station	Count	% Rejected	SD (°C)	BIAS (°C)	RMSE (°C)
1	SRN	24	0	1.2	0.3	1.2
2	NDL	31	0	1.3	-0.4	1.4
3	MNB	28	0	1.5	1.3	2.0
4	PTN	31	0	1.1	0.0	1.1
5	AHM	29	0	0.9	0.1	0.9
6	BHP	26	0	1.2	0.1	1.3
7	KOL	30	0	1.4	0.7	1.5
8	NGP	19	0	1.1	0.6	1.3
9	BBS	30	0	1.5	0.6	1.6
10	HYD	27	0	1.2	0.6	1.3
11	VSK	17	0	0.9	-0.4	0.9
12	GOA	11	9	1.1	-1.0	1.5
13	CHN	22	9	1.9	0.1	1.9
14	PBL	28	0	1.5	0.5	1.5
15	MCY	25	0	1.7	-0.4	1.7
16	TRV	22	0	1.6	-0.1	1.6

TABLE 8

Variations in geopotential height at 100 hPa level in case of GPS stations

S. No.	Station	Count	% Rejected	SD (gpm)	BIAS (gpm)	RMSE (gpm)
1	SRN	24	0	21.6	66.3	69.7
2	NDL	31	0	30.8	8.9	32.1
3	MNB	28	0	14.1	61.7	63.3
4	PTN	31	0	17.8	-5.8	18.7
5	AHM	28	0	15.3	9.7	18.1
6	BHP	26	0	10.3	9.5	14.0
7	KOL	30	0	22.3	16.2	27.6
8	NGP	19	0	10.1	17.0	19.8
9	BBS	30	0	12.5	14.5	19.1
10	HYD	27	0	13.3	80.7	81.8
11	VSK	17	0	17.9	59.1	61.8
12	GOA	11	9	16.3	73.9	75.7
13	CHN	22	9	13.1	83.5	84.6
14	PBL	26	0	28.6	67.8	73.6
15	MCY	25	0	26.8	74.9	79.6
16	TRV	22	0	9.4	80.4	80.9

3.2. *Present study*

Based on the NCMRWF report on upper air data quality (December, 2013), the biases, standard deviations and root mean square errors (RMSE) in meteorological parameters like, geopotential heights (*Z*), temperature (*T*), zonal wind components and meridional wind components at 500 hPa level and 100 hPa level have been compared between GPS based radiosounding stations and non-GPS radiosounding stations.

3.2.1. The variations in temperature (*T*) at 500 hPa level have been tabulated in Table 3 for GPS based stations and non-GPS station.

It has been observed that none of the data from 16 GPS stations has been rejected by the model whereas the rejection rate in case of non-GPS is very high. The biases between observed and first guess of the model are very less, within 0.7 °C in case of GPS stations, but variations are large, up to 4.3 °C for non GPS stations. Standard deviation for GPS stations is within 1.8 °C whereas it varies up to 4.1 °C for non GPS. RMSE values are very small and within 1.8 °C for GPS based and are very large up to 5.2 °C for non GPS radiosondes.

3.2.2. The variations in geopotential height (*Z*) at 500 hPa level have been tabulated in Table 4.

500 hPa geopotential height data has been accepted fully by the model for 13 stations out of 16 GPS stations, whereas the rejection rate in case of non-GPS radiosondes is very high. The biases between observed and first guess of the model are very less, within -19 gpm to 26.2 gpm in case of GPS stations, but it vary from -98.8 gpm to -7.4 gpm for non GPS stations. Standard deviation in values for GPS stations is within 17.6 gpm whereas it varies up to 59.0 gpm for non GPS. The RMSE values are within 31.6 gpm for GPS based and the same are 115.1 gpm for non GPS.

3.2.3. The variations in zonal wind at 500 hPa level have been tabulated in Table 5.

In case of 500 hPa Zonal wind, it has been observed that none of the data from 16 GPS stations has been rejected by the model whereas the rejection rate in case of non-GPS is very high. The biases between observed and first guess of the model are very less, from -2.0 meter per second (m/s) to 1.7 m/s in case of GPS based stations and the same vary from -13.0 m/s to 1.2m/s for non GPS

TABLE 9

Variations in zonal wind components at 100 hPa level in case of GPS stations

S. No.	Station	Count	% Rejected	SD (m/s)	BIAS (m/s)	RMSE (m/s)
1	SRN	24	0	2.4	-0.5	2.5
2	NDL	31	0	3.5	1.3	3.7
3	MNB	28	0	3.8	-0.6	3.8
4	PTN	31	0	4.0	0.9	4.1
5	AHM	29	0	2.9	-1.2	3.1
6	BHP	26	0	2.7	-1.0	2.9
7	KOL	30	0	3.1	-1.1	3.3
8	NGP	19	0	3.3	-2.3	4.0
9	BBS	30	0	2.7	-2.1	3.4
10	HYD	27	0	2.8	-1.8	3.3
11	VSK	17	0	3.3	-1.4	3.5
12	GOA	11	0	2.4	-0.8	2.5
13	CHN	22	0	3.7	-0.2	3.7
14	PBL	28	0	4.3	0.0	4.3
15	MCY	25	0	3.8	1.5	4.1
16	TRV	22	0	4.2	0.3	4.2

TABLE 10

Variations in meridional wind components at 100 hPa level in case of GPS stations

S. No.	Station	Count	% Rejected	SD (m/s)	BIAS (m/s)	RMSE (m/s)
1	SRN	24	0	3.1	-1.1	3.3
2	NDL	31	0	4.2	1.6	4.5
3	MNB	28	0	4.2	-0.6	4.2
4	PTN	31	0	4.0	-0.1	4.0
5	AHM	29	0	4.0	-0.1	4.0
6	BHP	26	0	3.6	0.4	3.6
7	KOL	30	0	4.4	0.1	4.4
8	NGP	19	0	3.9	-0.1	3.9
9	BBS	30	0	4.6	1.1	4.6
10	HYD	27	0	3.5	-0.6	3.6
11	VSK	17	0	3.2	-0.1	3.2
12	GOA	11	0	3.2	0.8	3.3
13	CHN	22	0	2.4	-1.5	2.8
14	PBL	28	0	4.5	1.0	4.6
15	MCY	25	0	3.6	-1.0	3.7
16	TRV	22	0	3.8	-1.3	4.0

stations. Standard deviation for GPS stations is within 4.9 m/s whereas it varies up to 8.6 m/s for non GPS radiosondes. The RMSE values are very less (within 5.2 m/s) for GPS based and the same are very high 14.4 m/s in case of non GPS based.

3.2.4. The variations in Meridional wind at 500 hPa level have been tabulated in Table 6.

None of the data from 16 GPS stations has been rejected by the model for 500 hPa meridional wind whereas the rejection rate in case of non-GPS is very high. The biases between observed and first guess of the model are very less, from -1.0 m/s to 0.3 m/s for GPS based stations and the same are from -5.0 m/s to 6.0 m/s for non GPS stations. Standard deviations for GPS stations are within 1.8 m/s whereas these vary up to 4.1 m/s for non GPS. The RMSE values are within 1.8 m/s for GPS based, and the same are very high, 5.2 m/s for non GPS.

3.2.5. The variations in temperature (*T*) at 100 hPa level have been tabulated in Table 7 for GPS based stations and for non-GPS station sufficient data was not available, hence not tabulated because only 2 stations crossed 100 hPa level and rejection rate was also high.

At 100 hPa level, none of the data from 16 GPS stations has been rejected by the model, except two stations for which rejection is only 9%, whereas most of the non-GPS could not reach up to 100 hPa level. Only two stations passed 100 hPa level for which rejection rate is very high. The biases between observed and first guess of the model are very less for GPS based radiosounding stations, from -1.0 °C to 1.4 °C in case of GPS stations, standard deviations for GPS stations is within 1.9 °C and RMSE values are within 2.0 °C.

3.2.6. The variations in geopotential height (Z) at 100 hPa level have been tabulated in Table 8 for GPS based stations and for non-GPS station sufficient data was not available, hence not tabulated.

None of the data from 16 GPS stations has been rejected by the model for 100 hPa Geopotential height except 2 stations for which 9% data has been rejected whereas most of the non-GPS could not reach up to 100 hPa level. Only two stations passed 100 hPa level for which rejection rate is very high. The biases between observed and first guess of the model are very less, from -5.8 gpm to 83.5 gpm, standard deviations is within 30.8 gpm and RMSE values are within 84.6 gpm for GPS based stations.

3.2.7. The variations in zonal wind components at 100 hPa level have been tabulated in Table 9 for GPS based stations and for non-GPS station sufficient data was not available, hence not tabulated.

None of the data from 16 GPS stations has been rejected by the model for 100 hPa zonal wind whereas most of the non-GPS could not reach up to 100 hPa level. Only two stations passed 100 hPa level for which rejection rate is very high. In case of GPS stations, biases between observed and first guess of the model are very less, from -2.3 m/s to 1.5 m/s, standard deviations for GPS stations is within 4.3 m/s and RMSE values are within 4.3 m/s.

3.2.8. The variations in meridional wind components at 100 hPa level have been tabulated in Table 10 for GPS based stations but for non-GPS stations sufficient data was not available, hence not tabulated.

None of the data from 16 GPS stations has been rejected by the model for 100 hPa meridional wind whereas most of the non-GPS could not reach up to 100 hPa level. Only two stations passed 100 hPa level for which rejection rate is very high. The biases between observed and first guess of the model are very less, from -1.5 m/s to 1.6 m/s, standard deviations is within 4.6 m/s and RMSE values are within 4.6 m/s in case of GPS based stations.

4. Conclusion

The study reveals that random large fluctuations in the observed data using GPS based radiosondes have reduced significantly. Difference (O-B) between observations (O) and first guess (B) have reduced at all levels. Hence, the NCMRWF GDAS model has accepted all the data received from 16 GPS based stations being within the tolerance limits of the first guess. Whereas the data received from non GPS radiosondes has a rejection rate of 16% to 85%. The Maximum height reported by GPS based radiosounding has increased significantly leading to most of the ascents terminating beyond 100 hPa level, whereas most of non-GPS radiosoundings are terminated before reaching 100 hPa level. Root Mean Square Errors (RMSE) and bias of temperature observations from respective guess for different levels have reduced considerably in case of GPS based soundings. The standard deviation of quality data (GPS based) are within a range of 9.4 gpm to 28.6 gpm, whereas for non-GPS based soundings the standard deviation in 100 hPa Geopotential height is of the order of 7.3 gpm to 115.9 gpm. The biases in GPS based temperature data at 100 hPa level are within a range of 0.1 °C to -1.0 °C, whereas for non-GPS the values are of the order of 2.6 °C to 5.0 °C. The RMSE values of GPS based 100 hPa geopotential heights are within a range of 14.0 gpm to 81.8 gpm, whereas for non-GPS, the same have a large range of variations from 31.8 gpm to 209.5 gpm.

Thus, it is inferred that GPS based radiosondes are able to provide quality data which is the backbone for a good quality weather forecast system.

Acknowledgement

The authors are thankful to Dr. L. S. Rathore, Director General of Meteorology, IMD, New Delhi, for constant encouragement, invaluable suggestions and expert guidance.

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