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Technical and operational characteristics of GPS radiosounding system in the upper air network of IMD

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सार – हाल ही के वर्षों में विश्व खगोलीय प्रणाली (जी. पी. एस.) पर आधारित उपरितन वायु रेडियो परिज्ञापी प्रणाली का अत्यधिक प्रभावी प्रणाली के रूप में उपयोग किया गया है। रेडियो सौंदे में जी.पी.एस. अभिग्राही यंत्र के लगाए जाने से प्रेक्षण संबंधी शुद्धता में सुधार आया है और धरातल पर लगे उपकरणों पर कार्य करना सरल हो गया है। उपरितन वायु आँकड़ों की उन्नत गुणवत्ता प्राप्त करने के लिए 10 स्टेशनों पर जी. पी. एस आधारित नई उपरितन वायु प्रणालियाँ लगाई गई हैं। इस शोध पत्र में जी. पी. एस. लगे उपरितन वायु रेडियो परिज्ञापी प्रणाली के विषय में विवेचन किया गया है। इस संजाल के 10 स्टेशनों पर जी. पी. एस. रेडियो सौंदे स्थापित किए जाने से इन स्टेशनों के आँकड़ों की गुणवत्ता में काफी सुधार हुआ है जिसे राष्ट्रीय मध्य अवधि मौसम पूर्वानुमान केन्द्र (एन. सी. एम. आर. डब्ल्यू. एफ.) और यूरोपीय मध्य अवधि मौसम पूर्वानुमान केन्द्र (ई. सी. एम. डब्ल्यू. एफ.) द्वारा वैधीकृत किया गया है। सभी स्थितियों में आँकडों की गुणवत्ता में विलक्षण परिवर्तन हुआ है और इसके परिणामस्वरूप यूरोपीय मध्य अवधि मौसम पूर्वानुमान केन्द्र ने भारतीय जी. पी. एस. स्टेशनों पर लगा काली सूची का तगमा हटा दिया है।

ABSTRACT. In recent years, the upper air radiosounding system based on Global Positioning System (GPS) is used as an effective method. GPS receiving device in a Radiosonde improves observation accuracy, allowing simplification of ground equipment. To get improved quality of upper air data, ten stations have been upgraded with new upper air systems based on GPS. This paper describes the upper air radiosounding system that adopts the GPS. After the introduction of GPS Radiosonde in the network at 10 places, data quality has improved substantially at these stations, which has been validated by National Centre for Medium Range Weather Forecasting (NCMRWF) and European Centre for Medium-Range Weather Forecasts (ECMWF). In all cases the quality change has been remarkable and as a result black list tag is removed by ECMWF for the Indian GPS stations.

Key words – GPS, Radiosonde, Radiowind, M2K2-DC, SR2K2, IR2K2, ICAR, IGOR.

1. Introduction

India Meteorological Department (IMD) has been operating a network of 39 Radiosonde/radiowind stations including 3 stations under mountain meteorology project and 2 stations for Radiosonde data only, twice a day on operational basis. The network comprised of 10 imported radiotheodolites installed in 2002, 14 radiotheodolites of indigenous make installed in 1992-93 & at remaining stations Ground Systems were installed in 1990-93 with wind finding radars.

In 2007, the modernization of IMD was undertaken with a view to bring out major improvement in the services provided by IMD. Various aspects of modernization including up gradation of observing system and availability of data at Central data centre in real time were planned. According to Das Gupta *et al.* (2005), Upper air data of IMD network was doubted for many years by leading Numerical Weather Prediction (NWP) centers of the world and observations were rejected by data assimilation systems. To get improved quality of upper air data, ten stations have been upgraded with new upper air systems based on Global Positioning System (GPS). Ground System and Radiosonde used with the system has been tested in World Meteorological Organization (WMO) intercomparison and was judged to merit of high quality Radiosonde and is also WMO approved on code 57. Details about commissioning of systems are mentioned in Table 1.

2. Brief of system

Radiosonde (M2K2-DC)

M2K2-DC is the model number of GPS Radiosonde. Fig. 1 shows a GPS Radiosonde and its block diagram. Total weight of the Radiosonde is 210 gram including batteries. Each Radiosonde consists of unwinder (30 m), which also prevents the Radiosonde to drag on ground in windy conditions. Factory calibration data of each Radiosonde is stored on EEPROM (Electrically

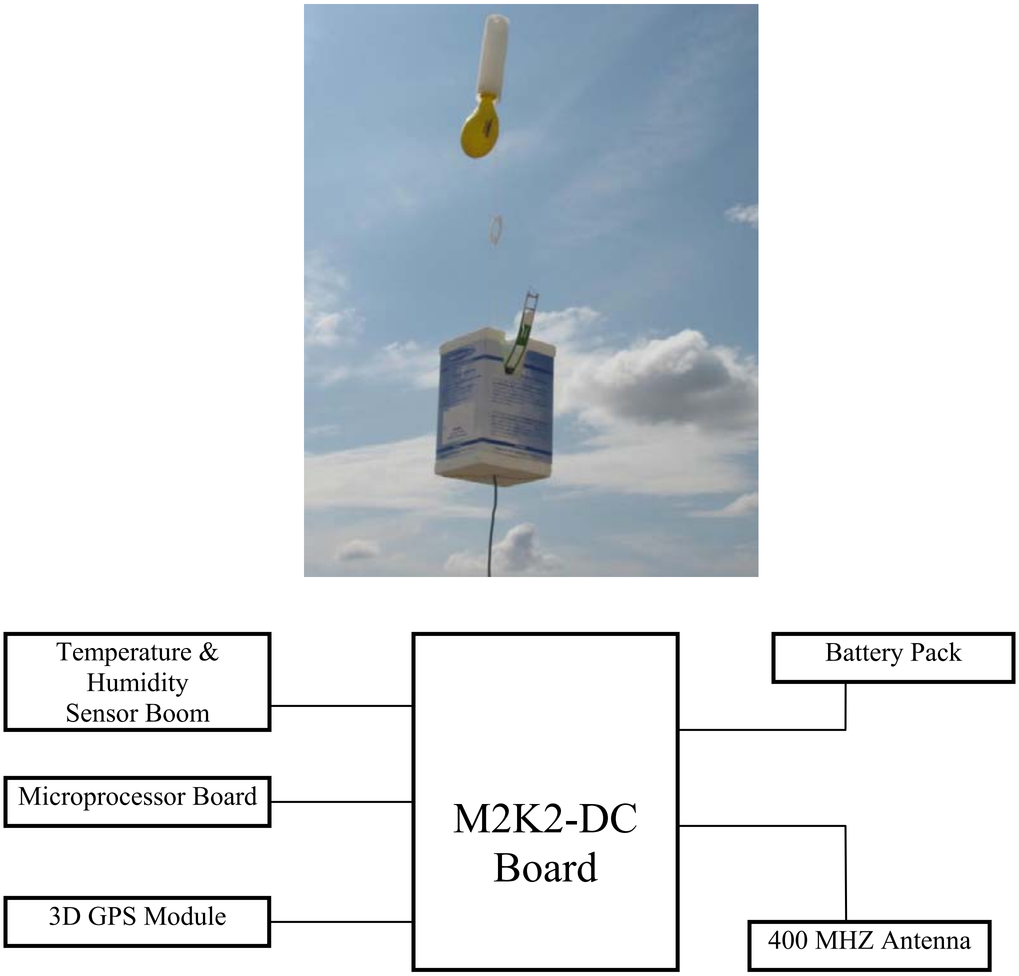


Fig. 1. M2K2-DC Radiosonde & its block diagram

TABLE 1

Commissioning details of systems

S. No.	Name of station	Station Index	Latitude	Longitude	Date of commissioning
1.	Thiruvananthpuram	43371	8.79° N	76.57° E	9^{th} March 2009
2.	Mohanbari	42314	27.79° N	95.01° E	9^{th} April 2009
3.	Chennai	43279	12.59° N	80.11° E	13^{th} April 2009
4	Port Blair	43333	11.39° N	92.44° E	16^{th} April 2009
5.	Minicoy	43369	8.16° N	73.03° E	23^{rd} April 2009
6.	Goa	43192	15.79° N	73.49° E	11^{th} May 2009
7.	Hyderabad	43128	17.77° N	78.28° E	14^{th} May 2009
8.	Visakhapatnam	43150	17.92° N	83.18° E	18^{th} May 2009
9.	Patna	42492	25.86° N	85.06° E	21^{st} May 2009
10.	Srinagar	42027	34.55° N	74.50° E	25^{th} May 2009

Erasable Programmable Read-Only Memory) and transmitted with each data frame. Temperature and humidity sensors are fitted on a thin sensor boom to assure appropriate exposure condition of the measurement. Each Radiosonde includes the following components:

(*i*) Temperature and humidity sensors boom

(*ii*) 3 dimensional GPS module

(*iii*) Transmitter

(*iv*) Microprocessor board

(*v*) Battery-pack

(*vi*) External on/off switch

(*vii*) Unwinder

Temperature

Temperature sensor consists of a thermistor chip wrapped into a glass ball. Its tiny size (0.9 × 2 mm) allows excellent response time around 1sec. Temperature sensor is led on a layer processed against humidity and solar radiations. Boom end undergoes a special vacuum metallization process reducing both solar and infrared radiation effects. Solar radiation correction is less than 1.5 °C at 23 hPa.

Humidity

Humidity sensor consists of a capacitor of which value is directly proportional to relative humidity. It is composed of 3 primary components:

(*i*) Basic layer as an electrode

(*ii*) A dielectric of characteristics vary along relative humidity

(*iii*) A short response porous electrode as the second electrode of the capacitor

A cap protects the sensor from rain and mechanical damage while allowing adequate ventilation. A second thermistor is located under the cap in order to take into account the actual temperature (under the cap) and doing so better integrate influence of this parameter on the measurement of relative humidity.

Pressure

In general, a Radiosonde is equipped with a pressure sensor for obtaining the altitude. Since this Radiosonde without GPS does not have sufficient resolution of pressure sensor in the stratosphere that exceeds 30,000 m and due to that accuracy of measurement at a high altitude is poor. Therefore, a GPS receiving device in a Radiosonde allows accurate observation in a wide range of altitude from near the ground to the stratosphere, resulting in improvement of the defect of the pressure sensor and also elimination of the pressure sensor from the Radiosonde. Pressure is calculated from GPS altitude, temperature and humidity according to barometric equation (Laplace law).

GPS windfinding

3D GPS module provides the position of the sonde (latitude, longitude and altitude) as well speed components (North-South, East-West and Z). These data are correlated to time. Position is calculated every second by triangulation method between 4 or more satellites. Velocity is not calculated from the difference between 2 positions but directly issued from Doppler. On short time scales, velocity is more accurate than position when it becomes less accurate on large time scales. System takes into account both measurement methods in order to provide the most accurate data. These data are compared to GPS reference station (Differential GPS) in order to clear satellites disturbances and eventual interferences.

Ground system (SR2K2)

SR2K2 is the model number of Ground system. Fig. 2 shows a ground system and its block diagram. The signals sent by the Radiosonde are received by the 400 MHz receiver, demodulated and decoded. This information including PTU parameters as well as sonde calibration and positioning data are then transmitted to the computer. The GPS receiver of the station is also connected to the computer. This is used to obtain a differential correction on the position in order to increase the accuracy of wind speed and direction measurements. The data are processed by the IR2K2 program (Data acquisition software) and the whole information is available for use by the operator. All the functions of the receiver (frequency control, scanning, signal strength measurement, volume control) are accessible *via* the computer. The panels of the boards are fitted with pilot lights. All the electronic boards are plugged in a backplane board for easy maintenance.

Main function

SR2K2 Upper Air Ground System's primary function is to acquire Pressure, Temperature and Humidity (PTU) & wind data measured and sent by a Radiosonde during its ascent to the upper atmosphere.

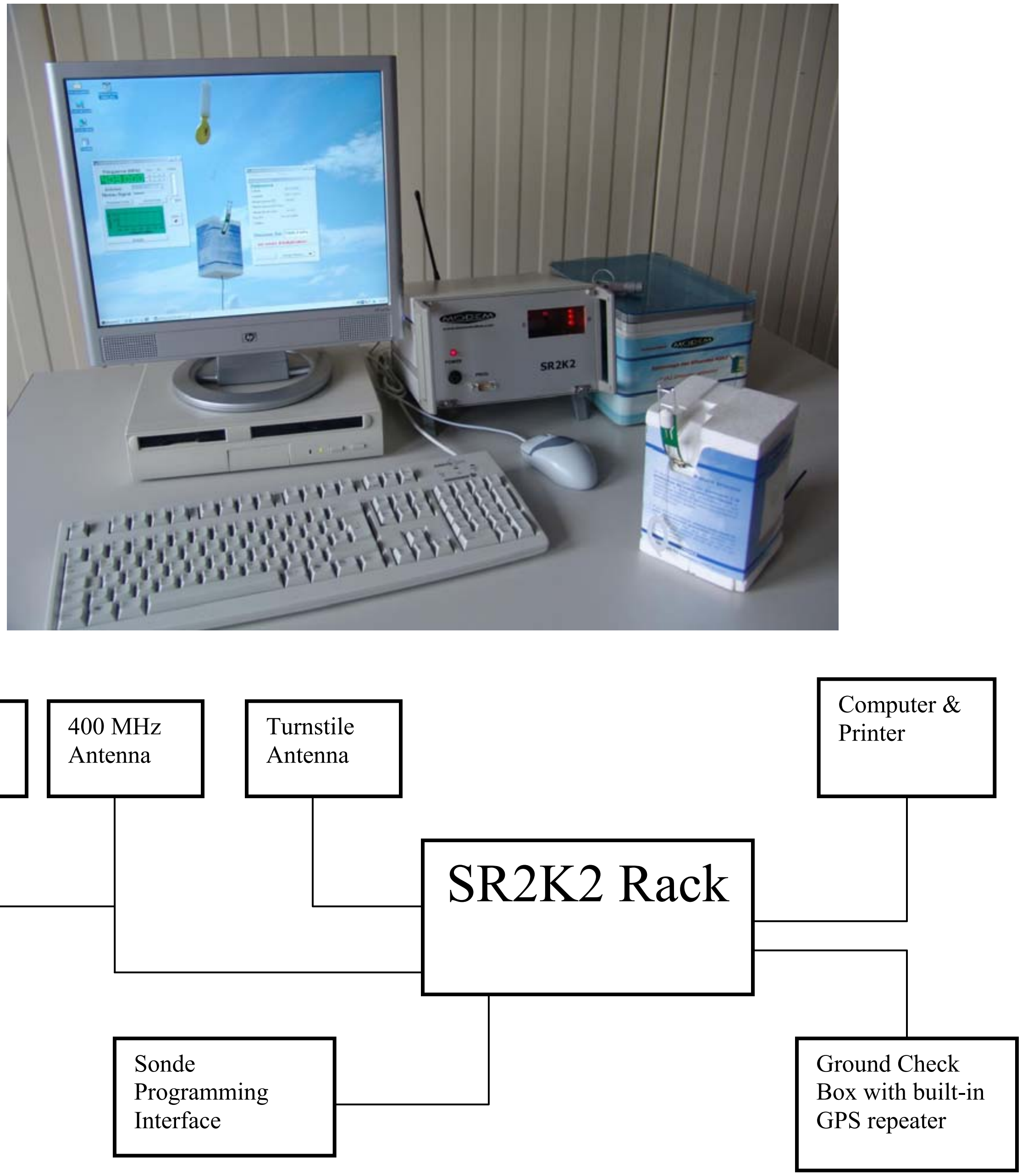


Fig. 2. SR2K2 upper air ground system & its block diagram

Secondary functions

Associated to different accessories, the complete ground station allows:

(*i*) Raw data processing

(*ii*) Data archiving on hard disk or other digital storage unit

(*iii*) Reference GPS station for differential calculation (DGPS)

(*iv*) Real time data displaying (tables and/or graphics)

(*v*) Sonde programming interface

(*vi*) Real time data processing

(*vii*) Editing of WMO messages (TEMP, PILOT, BUFR etc.)

(*viii*) Data transmission *via* Ethernet network

General design

SR2K2 rack is the primary component of the system to which all accessories are connected. To be fully operational, SR2K2 rack is connected to the following accessories:

(*i*) GPS antenna with cable (30 m)

(*ii*) 400 MHz radio antenna with cable (30 m)

(*iii*) Turnstile antenna with cable (30 m)

(*iv*) Window based PC workstation.

(*v*) IR2K2: Data acquisition software

(*vi*) IGOR Graphic module: Scientific graphing, data analysis & image processing software tool.

(*vii*) ICAR Module (Edition of WMO messages): ICAR software (Interface of calculation and analysis of radiosounding) module allows real time graphical display of data and automatic generation of aerological report and TEMP or PILOT message.

(*viii*) Sonde programming interface

(*ix*) GPS repeater

(*x*) Ground check system

SR2K2 Rack

This unit has fold-down front panel and the upper and lower removable covers which facilitate access to the internal components.

(*i*) The unit contains a backplane board in which the following are plugged:

(a) SR2K2 Decoder board.
(b) SR2K2 Receiver board.
(c) SR2K2 GPS board.

(*ii*) Power supply board.

(*iii*) Built-in Barometer board.

SR2K2 decoder board

This board comprises the logic part used as an interface between the signals from the 400 MHz radio receiver board and the computer. Its purpose is also to decode the radio frames and to convert the level of the Radiosonde programming signals.

SR2K2 receiver board

It consists of 400 MHz receiver and Phase Shift Keying (PSK) demodulator. Its function is the amplification and the filtering of the signals received by active receiving antenna system to demodulate the digital signal sent by the transmitter of the Radiosonde. The signals received between 400 and 406 MHz are translated into narrow band by the receiver programmable frequency synthesizer, which is composed of several parts: the voltage controlled variable oscillator, its output amplifier, a programmable divider, a phase comparator, and the reference frequency oscillator which determines the frequency stability.

SR2K2 GPS board

This board comprises the GPS receiver of the base station, its GPS signal retransmission device used to reinitialize the Radiosondes without placing them outside a building. The GPS receiver board is a 14 channel receiver.

Power supply board

Input : 110 or 220 VCA

Output : 12V CC ± 5% for electronic boards

An additional input for 12 V supply if main is not available.

Built-in barometer board

IR2K2 software automatically takes in account the ground pressure which is essential for correct sounding process. However, pressure information can be entered manually also by the operator.

400 MHz antenna

It's an Omni-directional active antenna with built-in low noise amplifier. Its small size makes installation easy on either horizontal or vertical support.

Turnstile antenna

This antenna is used to receive the signal when the Radiosonde is overhead.

GPS antenna

TRIMBLE BULLET GPS antenna is providing GPS signals to the ground system which are used as a reference GPS ground station for differential processing (DGPS).

TABLE 2

Technical specifications

General features	
Dimensions	: Width : 92 mm, Length : 107 mm, Height: 160 mm
Weight	: 210 gram (including batteries)
Pressure	
Method	: Calculated from GPS altitude
Range	: 1100 to 3 hPa
Accuracy	: ±1 hPa at Surface, ±0.1 hPa at 60 hPa
Temperature	
Sensor	: Thermistor
Range	: +60° to –90°
Resolution	: 0.1°C
Accuracy	: +/- 0.5°C
Response time	: <2s
Measurement arte	: 1Hz
Calibration	: Yes
Factory calibration	: Stored on EPROM
Humidity	
Sensor	: Capacitor
Range	: 0% to 100%
Resolution	: 1%
accuracy	: +/-5%
Response time	: <2s
Measurement rate	: 1 Hz
Calibration	: Yes
Factory Calibration	: Stored on EPROM
Wind	
3D GPS	: Differential calculation
Altitude range	: Unlimited
Position accuracy	: 10 m
Accuracy.	: 0.15 m/s
Direction accuracy	: 2 °
Position resolution	: 0.01 m
Horizontal speed resolution	: 0.01 m/s
Direction resolution	: 0.1 °
Measurement rate	: 1 Hz
Transmitter	
Compliant with ETSI EN 02054 standard	
Frequency range	: 400 to 406 MHz
Frequency step	: 200 KHz
Frequency setting	: By Software
Max drift	: +/- 2 KHz
Power	: 200 mW
Modulation	: PSK 4800 bauds
Power supply	
Batteries	: 1.5V alkaline
Autonomy	: >3 h
Battery pack	: 4 dry cells
Calibration	
Factory calibration	: Stored on EPROM and transmitted with each data frame
Calibration	: Calibration of Temperature and Humidity sensors prior launch
Limitations	
Temperature	: -90 °C to +60 °C Above +60 °C, the Radiosonde is still working but measurement quality is no longer guaranteed

PC workstation

System is delivered with a latest generation window based PC workstation.

Sonde programming interface

The interface consists a specific cable connecting the sonde to the SR2K2 ground station and allowing the operator to change the frequency of the sonde transmitter.

Ground check system

Ground check system allows calibration of temperature and humidity sensors prior to launch. This includes:

(*i*) Reference Temperature and Humidity sensors
(*ii*) USB port
(*iii*) GPS repeater antenna

Built-in GPS repeater allows indoor initialization of Radiosondes while sonde calibration is in progress. It is no longer necessary to place the sonde outdoor. SR2K2 is receiving data from the Radiosonde through radio link and in the other hand data from reference sensors through a USB link connected to the ground check. Therefore, the software will automatically store the new calibration after operator's validation. The goal of the GPS repeater system is to re-transmit GPS signals indoors. This allows very easy Radiosonde GPS initialization without having to go outside. This is very useful specially during bad weather conditions. Reference sensors need to be standardized yearly through the utility software provided.

Dual antenna option

This device allows connection of two 400 MHz radio antennas (omni-directional and turnstile). Switch box includes a reverser allowing the operator to select reception mode:

Position 1 : Reception from omni-directional antenna

Position 2 : Reception from turnstile antenna

Position 3 : Automatic mode. The system will shift automatically to the antenna receiving the best signal.

3. Technical specifications

General features and technical specifications are mentioned in Table 2.

4. Performance analysis

The ECMWF global data monitoring report is a monthly publication intended to give an overview of the availability and quality of observations from the Global Observing System within the World Weather Watch of the World Meteorological Organisation. The information presented on data quality is based on differences between observations and the values of the most recent ECMWF forecast ("first guess") of the same parameter. In ECMWF's Global Data Report for the month of June 2009 under list of suspect Radiosonde in terms of geopotential height (meters)/wind speed (m/s)/wind direction (degrees), data of GPS stations of India are not reported as suspect stations under any category.

One of the known problem of Indian RS/RW temperature observation was its random large fluctuation on daily scale, Das Gupta *et al*. (2005). According to report on "Quality of observations from Indian Stations", by Das Gupta, (2009), have evaluated the performance of upper air observations from these stations by comparing with their T254L64 Global Data Assimilation System (GDAS) first guess (6hr- forecast from T254L64 model). It has been observed that after the introduction of GPS Radiosonde, these types of large fluctuation were not seen for guess temperature field.

Data provided from Radiosonde sounding systems are the most critical to the NWP and forecasting services. Thus, the performance of Radiosonde and the relative accuracy of Radiosonde winds are subject to great deal of scrutiny. Errors and uncertainties encountered in Radiosonde measurements, particularly errors in temperature and moisture, can occur at higher altitudes (*e.g*., beginning in the upper-troposphere) and are caused by factors such as exposure to solar radiation, sensor heating, and time lag. Data collected at lower altitudes (*e.g*., below about 10 km) do not tend to display such errors.

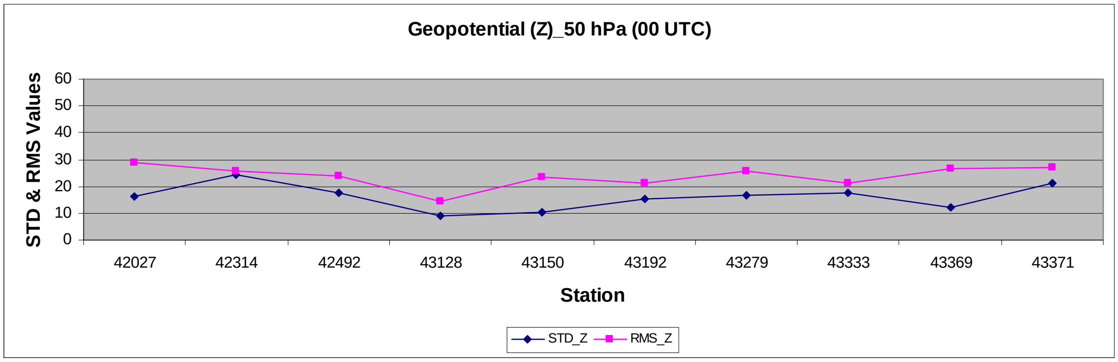
Determining the absolute accuracy of an upper-air instrument is difficult because there is no "reference" instrument that can provide a known or true value of the atmospheric conditions. This is due to uncertainties caused by meteorological variability, spatial and temporal separation of the measurements, external and internal interference and random noise. A true precision or the standard deviation of a series of measured values about a mean measured reference value can be calculated.

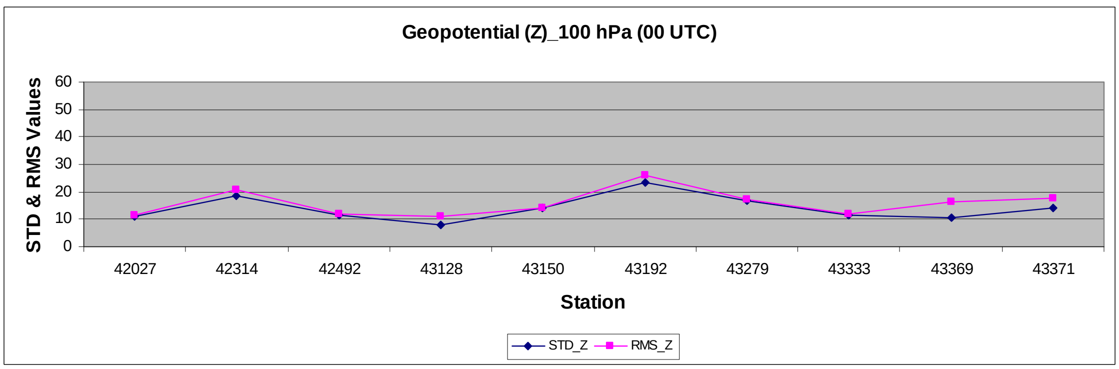
Further to quantify the reasonableness of the data, one compares observations from the upper-air system being evaluated to data provided by another sensor that is known to be operating properly. Calculating a measure of

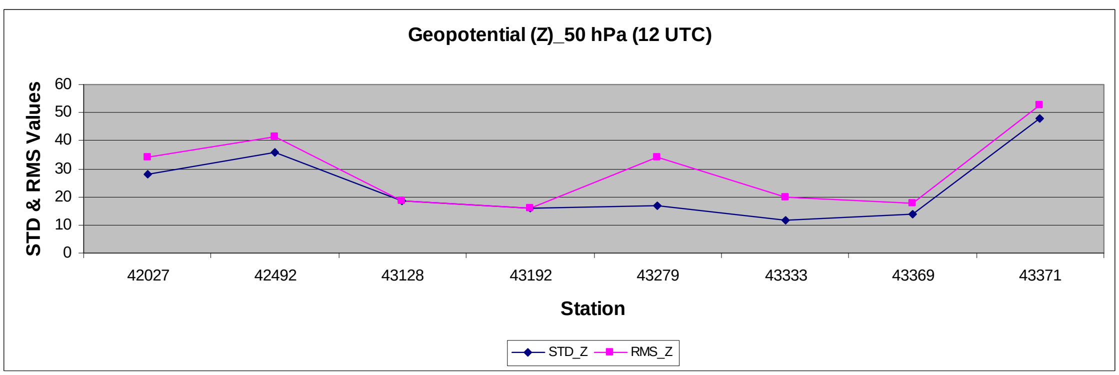
TABLE 3

Deviation, standard deviation & RMS errors at 50 & 100 hPa

Station	HH	Level	DEV_Z	STD_Z	RMS_Z	DEV_T	STD_T	RMS_T	DEV_H	STD_H	RMS_H	DEV_F	STD_F	RMS_F	DEV_D	STD_D	RMS_D
42027	00	50	23.96	16.44	29.06	1.01	1.98	2.22	1.6	7.11	7.28	1.91	3.49	3.98	-0.38	54.68	54.68
	00	100	2.64	11.22	11.53	-0.09	1.28	1.28	-8.35	15.99	18.04	0.12	3.59	3.59	-1.02	25.01	25.03
	12	50	19.27	28.27	34.22	0.79	1.97	2.12	-1.26	3.94	4.13	1.58	3.23	3.6	13.63	57.21	58.82
	12	100	-4.81	19	19.6	0.49	1.04	1.15	-18.78	12.77	22.71	-0.33	2.99	3.01	-4.87	23.21	23.72
42314	00	50	7.64	24.58	25.74	0.78	2.2	2.33	13.78	9.2	16.57	1.13	3.49	3.67	2.2	18.03	18.17
	00	100	-9.63	18.56	20.91	-0.48	1.11	1.21	-5.18	23.93	24.48	1.54	3.84	4.14	-0.83	36.13	36.14
42492	00	50	15.78	17.76	23.75	0.82	2.5	2.63	17.15	9.57	19.64	1.09	3.79	3.94	0.02	14.32	14.32
	00	100	-1.3	11.67	11.74	-0.42	1.78	1.83	-16.66	21.87	27.5	2.43	4.04	4.72	-2.6	20.87	21.03
	12	50	20.76	35.84	41.42	0.9	2.82	2.96	10.63	8.55	13.64	0.06	3.89	3.89	2.15	15.35	15.5
	12	100	-5.84	21.03	21.82	0.55	1.87	1.95	-39.75	25.5	47.23	3	4.02	5.02	-2.56	21.23	21.39
43128	00	50	10.89	9.16	14.23	0.81	2.17	2.32	23.26	7.81	24.54	-0.49	4.79	4.81	1.19	16.47	16.51
	00	100	-7.82	8.09	11.25	-0.05	1.84	1.84	-34.4	21.31	40.47	1.86	4.33	4.71	-2.4	8.79	9.11
	12	50	-1.85	18.6	18.69	1.13	2.38	2.63	7.21	5.31	8.95	-1.11	4.39	4.53	0.49	12.02	12.03
	12	100	-30.77	21.66	37.63	-0.22	1.14	1.17	-49.6	17.66	52.65	1.86	4.76	5.11	-3.52	7.8	8.56
43150	00	50	20.97	10.39	23.41	0.91	2.61	2.77	15.64	11.22	19.25	-0.57	5.15	5.18	-1.05	12.76	12.8
	00	100	0.03	14.15	14.15	-0.58	1.3	1.42	-33.99	23.09	41.09	1.6	4.31	4.6	2.98	10.29	10.71
43192	00	50	14.69	15.51	21.36	0.24	2.47	2.48	23.9	6.92	24.88	0.85	5.43	5.5	2.83	14.03	14.31
	00	100	-11.27	23.47	26.03	0.03	1.59	1.59	-26.52	22.55	34.81	2.82	5.45	6.13	-1.21	8.34	8.43
	12	50	1.52	15.92	15.99	-0.14	2.49	2.5	8.2	5.32	9.77	-1.29	5.43	5.58	1.91	13.27	13.4
	12	100	-11.48	17.42	20.87	-0.04	1.45	1.45	-38.8	18.55	43.01	0.39	3.98	4	0.02	7.95	7.95
43279	00	50	19.74	16.52	25.74	0.85	2.59	2.72	17.81	8.34	19.67	-0.91	5.91	5.98	3.13	17.62	17.9
	00	100	4.87	16.73	17.42	-0.53	1.67	1.75	-26.51	20.77	33.68	0.87	4.77	4.85	2.17	10.14	10.37
	12	50	29.78	16.79	34.19	1.07	2.28	2.52	4.92	3.68	6.14	-1.07	5.82	5.92	-2.16	16.47	16.62
	12	100	2.38	13.98	14.18	0.18	1.8	1.81	-40.52	18.87	44.7	0.74	4.88	4.93	-1.94	9.22	9.42
43333	00	50	11.31	17.67	20.98	0.64	2.64	2.72	15.84	5.6	16.8	-0.49	5.98	6	0.71	17.26	17.28
	00	100	-3.87	11.39	12.03	-0.41	2.37	2.4	-26.93	17	31.84	0.25	4.43	4.44	-1.65	10.07	10.21
	12	50	-16.18	11.63	19.93	0.33	2.29	2.31	33.25	18.03	37.83	1.46	5.2	5.4	0.8	19.13	19.15
	12	100	-16.38	10.12	19.26	0.28	1.88	1.9	-16.04	19.61	25.33	0.19	4.26	4.26	-3.46	14.5	14.9
43369	00	50	23.57	12.33	26.6	0.15	2.35	2.35	25.7	7.44	26.75	2	5.57	5.92	3.64	28.03	28.27
	00	100	12.53	10.68	16.47	0.19	1.94	1.95	-9.92	24.12	26.07	2.19	5.68	6.09	-1.71	14.94	15.04
	12	50	11.04	13.88	17.74	0.4	2.22	2.25	9.37	5.43	10.83	0.1	5.67	5.67	0.17	38.97	38.97
	12	100	1.93	9.81	10	0.26	1.92	1.93	-29.98	22.69	37.6	0.49	5.9	5.92	-2.95	8.99	9.46
43371	00	50	16.86	21.36	27.21	0.06	2.21	2.21	21.05	9.51	23.1	1.44	5.54	5.73	0.39	29.34	29.34
	00	100	10.68	14.01	17.61	0.12	1.96	1.96	-15.3	22.92	27.56	1.99	5.46	5.81	3.14	14.85	15.18
	12	50	22.22	47.97	52.87	0.75	2.32	2.44	13.48	14.61	19.88	0.54	5.21	5.24	-2.17	23.51	23.61
	12	100	1.44	37.79	37.82	0.49	1.61	1.68	-31.3	23.86	39.35	0.52	6.59	6.61	-1.31	23.77	23.81







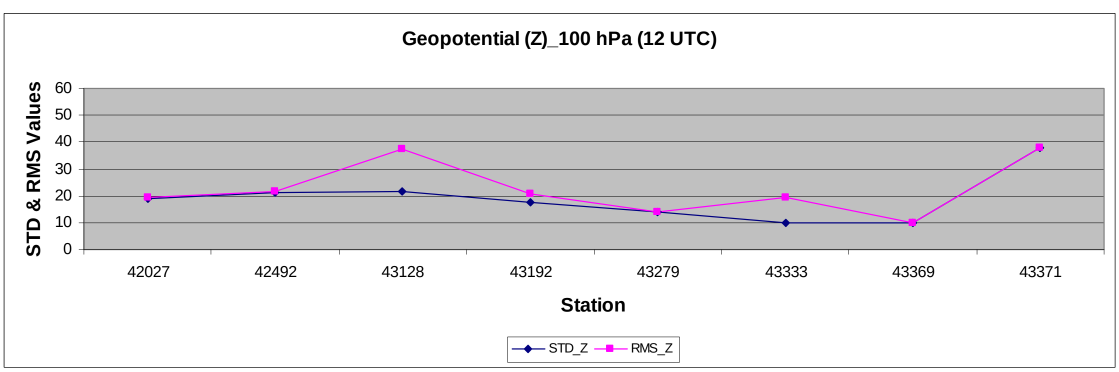


Fig. 3. Standard deviation & root mean square (RMS) errors for geopotential

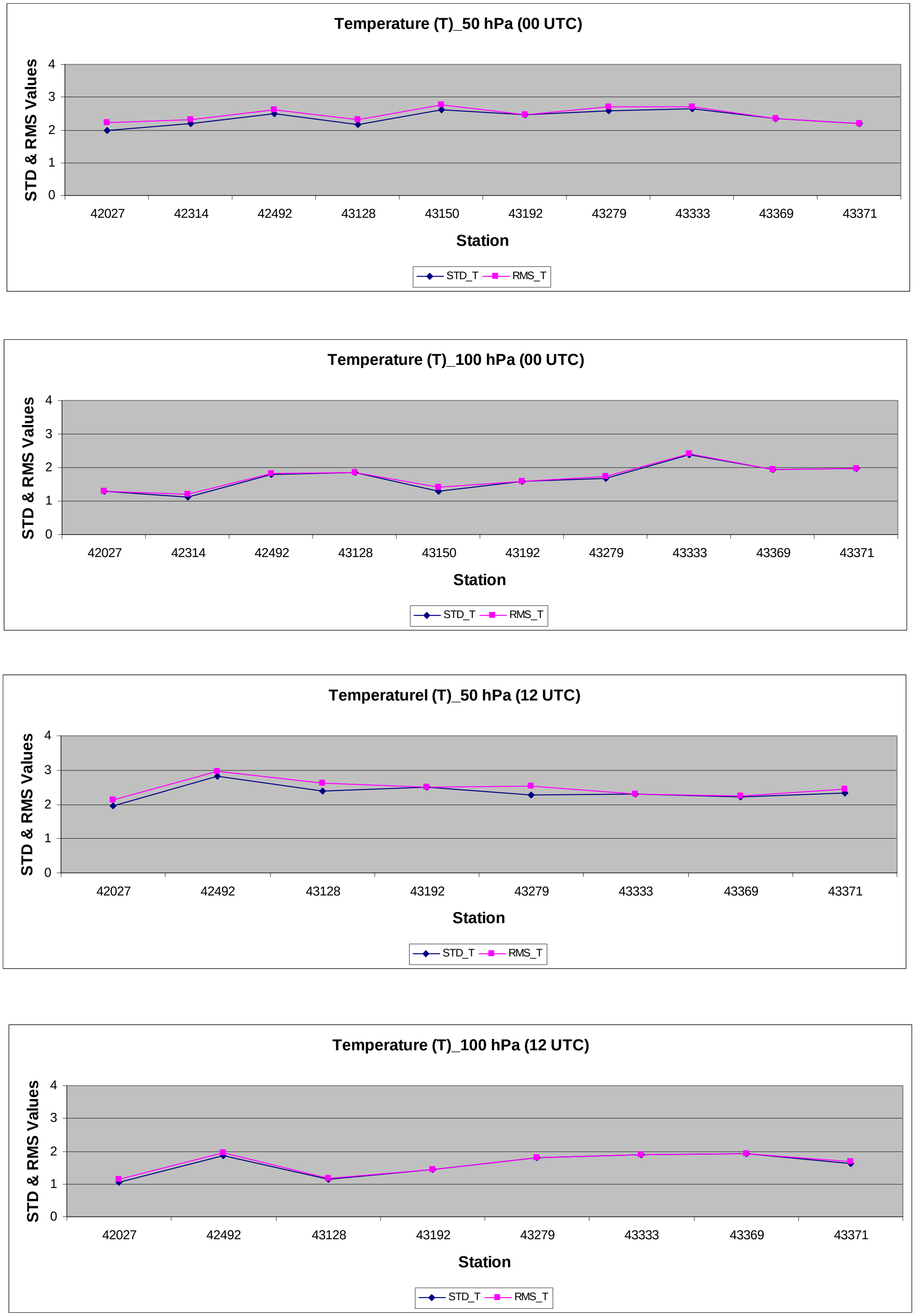
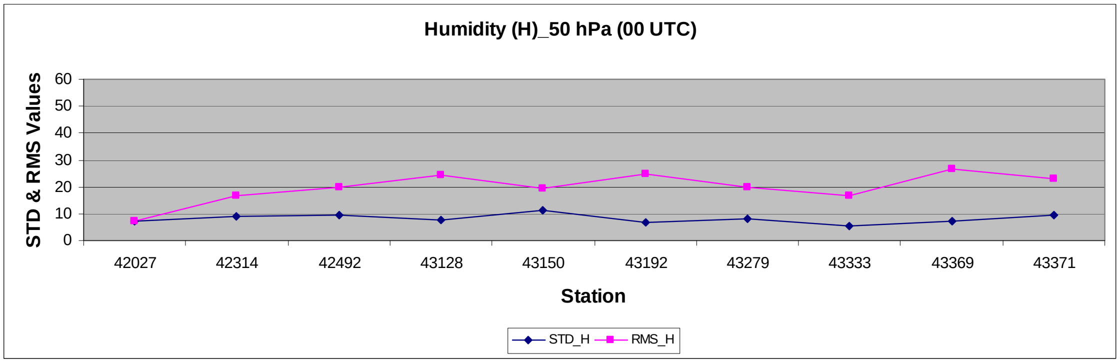
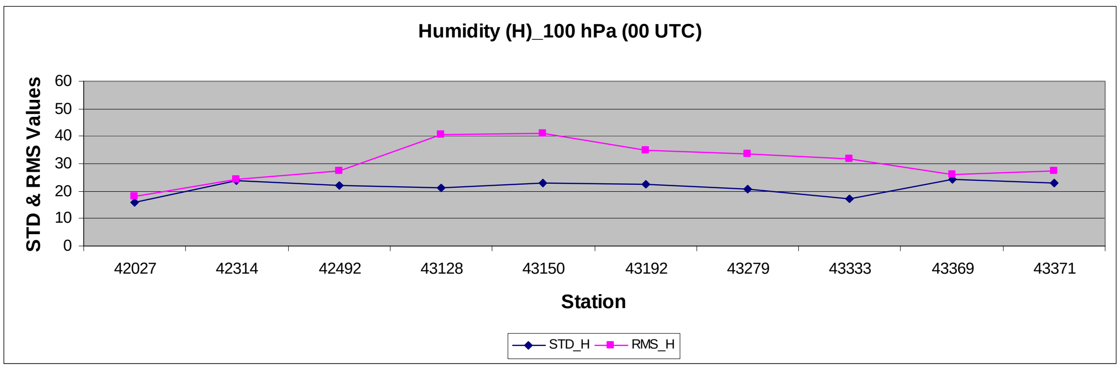
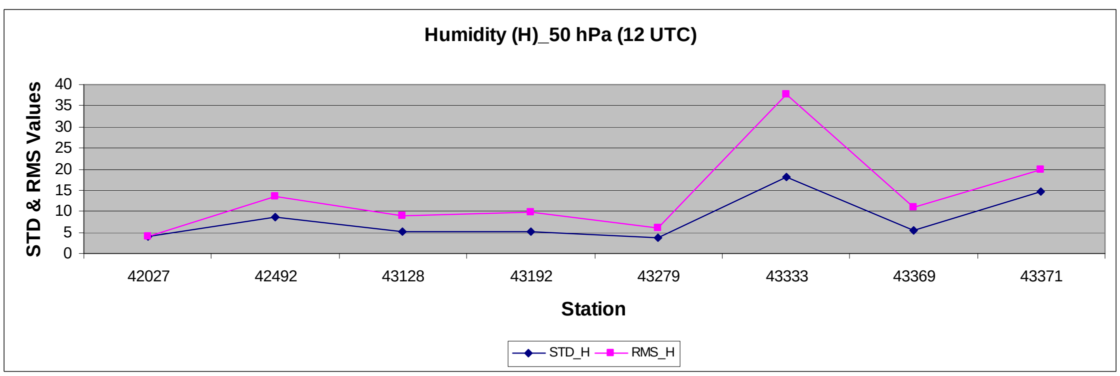


Fig. 4. Standard deviation & root mean square (RMS) errors for temperature







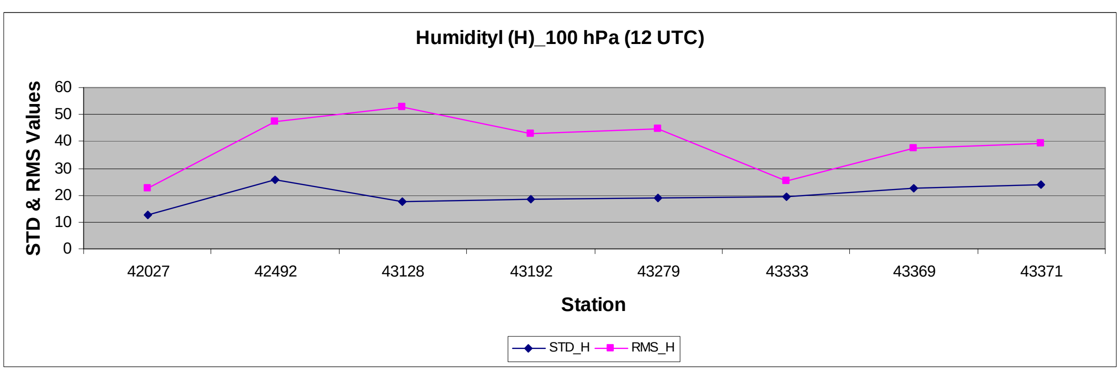
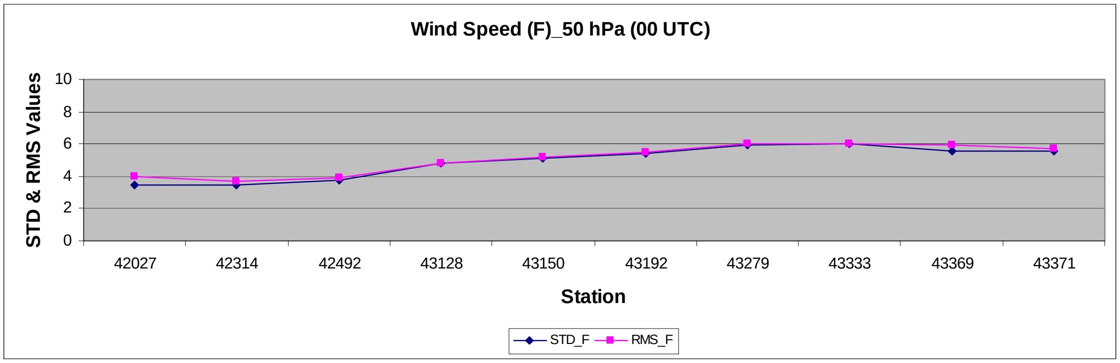
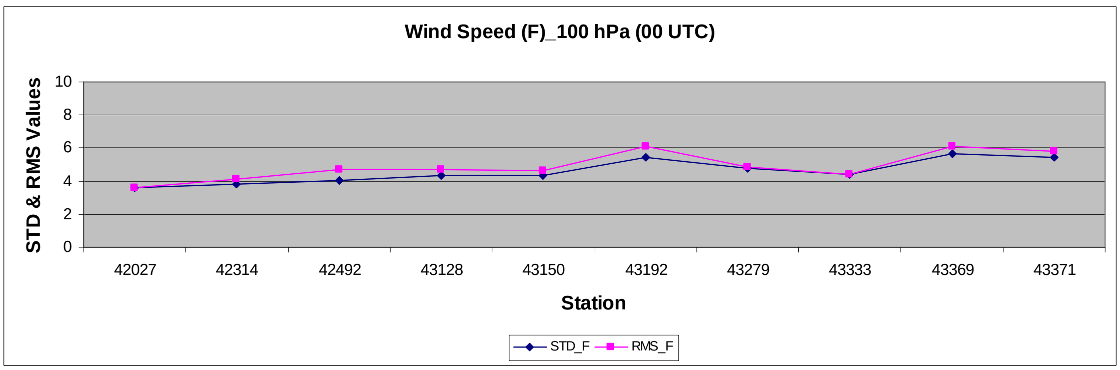
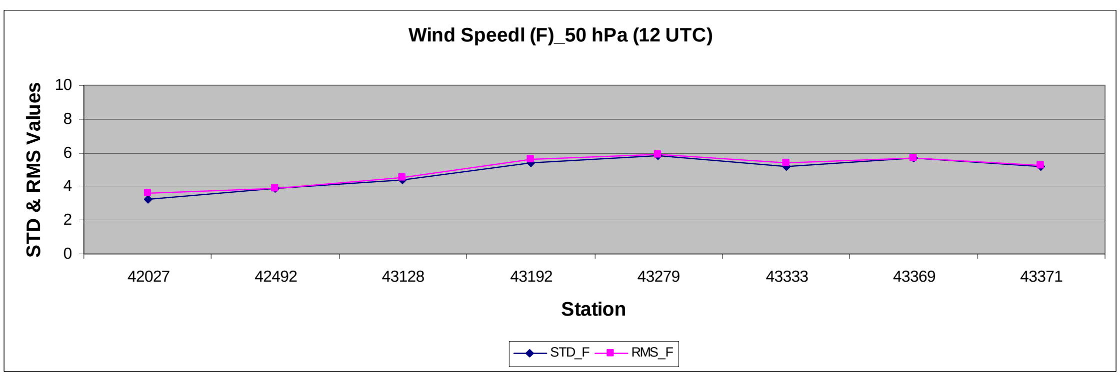


Fig. 5. Standard deviation & root mean square (RMS) errors for humidity







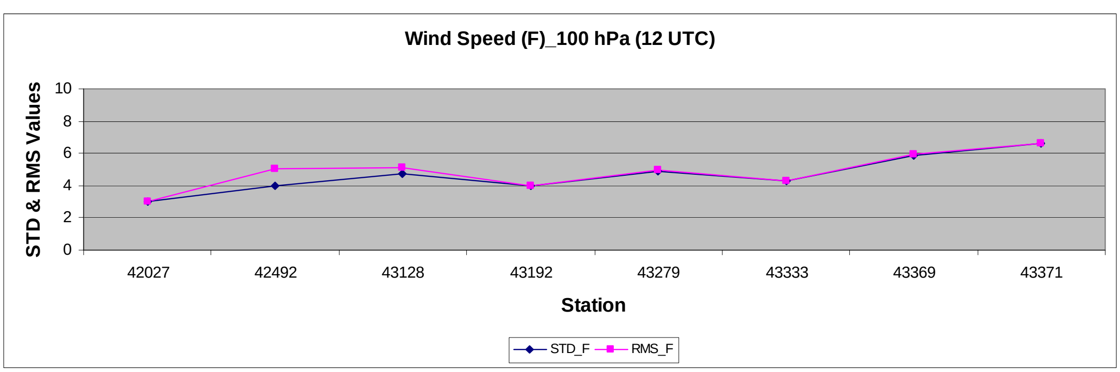
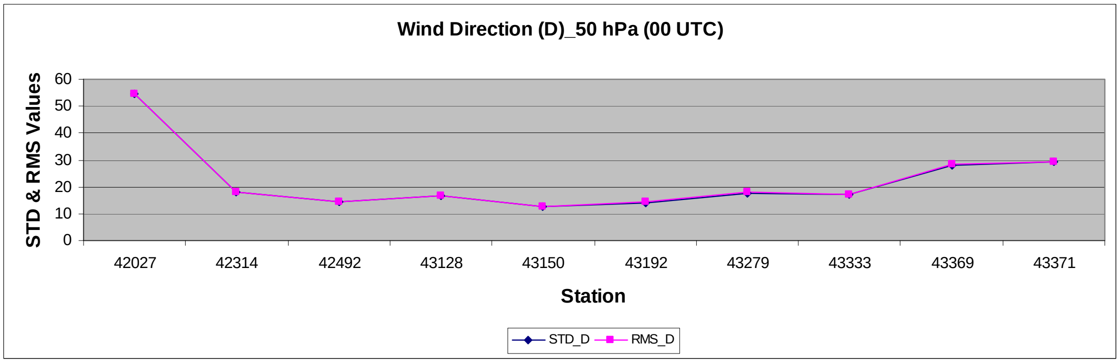
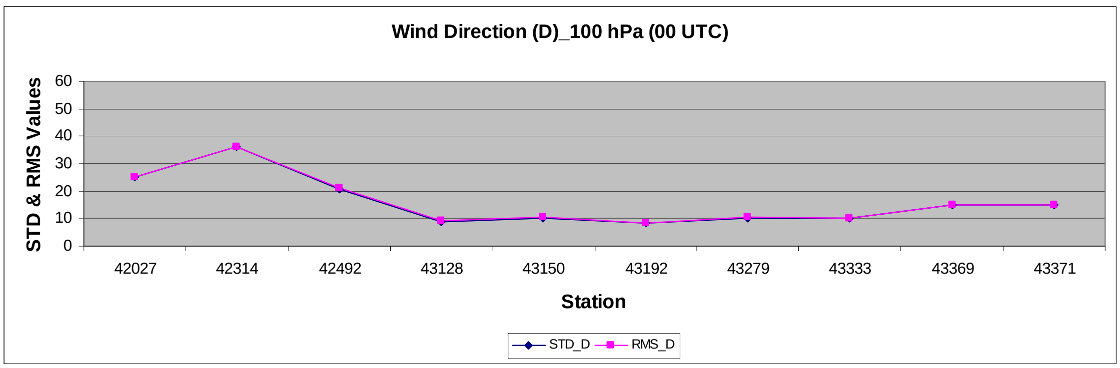
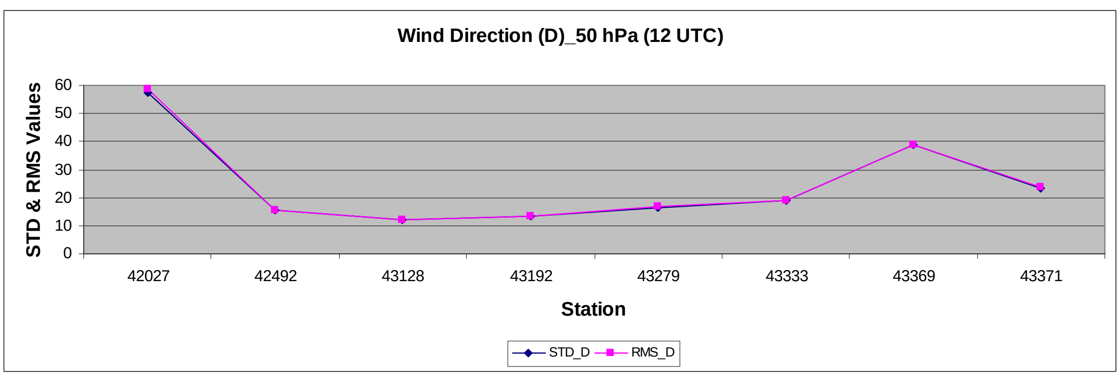


Fig. 6. Standard deviation & root mean square (RMS) errors for wind speed







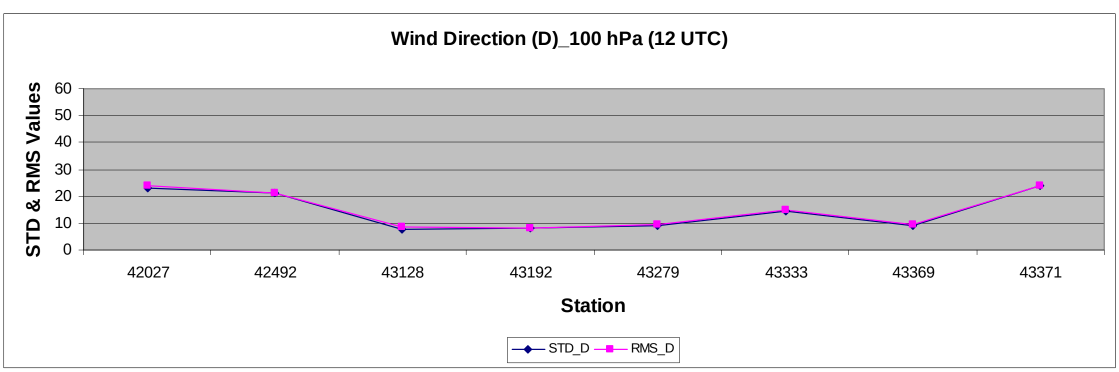


Fig. 7. Standard deviation & root mean square (RMS) errors for wind direction

TABLE 4

Month-to-month variations in maximum height observed at 10 stations in the network

S. No.	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
1.	Chennai	0	0	0	21	40	38	23	21	19	19
2.	Goa	0	0	0	0	11	9	18	21	18	34
3.	Hyderabad	0	0	0	1	27	41	22	14	25	24
4.	Minicoy	0	0	0	11	37	31	18	12	16	21
5.	Mohanbari	0	0	0	15	24	13	6	6	9	12
6.	Patna	0	0	0	0	4	22	18	28	24	28
7	Portblair	0	1	0	13	30	27	24	7	20	22
8.	Srinagar	0	0	0	0	12	45	24	20	20	15
9.	Thiruvananthapuram	0	0	12	17	34	36	24	27	31	29
10.	Visakhapatnam	0	0	0	0	12	22	11	13	17	20

the uncertainty between the measurements is referred to as the comparability. Comparability, for these purposes, is the root-mean-square (rms) of a series of differences between observations.

Standard Deviation & Root Mean Square Errors are the major criteria to identify the quality of upper air data. Deviation (DEV), Standard Deviation (STD) & Root Mean Square (RMS) errors of Geopotential (Z), Temperature (T), Humidity (H), Wind Speed (F) & Wind Direction (D) of one month data of the period August' 2009 at 50 hPa & 100 hPa are as mentioned in Table 3. Graphs of Standard Deviation (STD) and RMS errors at different levels are shown in Figs. (3-7) which indicates that random deviations largely reduced leading to significant improvement in data quality. The information presented on data quality is based on differences between observations and the values of the most recent forecast ("first guess") of the same parameter.

Maximum height reported by RS/RW observations increased significantly after introduction of GPS-Sonde. Ascents reaching above 10 hPa during January to October 2009 are mentioned in Table 4, which shows the improvement in attaining the maximum heights.

5. Conclusion

After the introduction of GPS Radiosonde in the network at 10 places, data quality has improved substantially at these stations, which has been validated by NCMRWF & ECMWF. In all cases the quality change has been remarkable and as a result black list tag is removed by ECMWF for the Indian GPS stations. Reports indicate an improvement in quality as mentioned below:

(*i*) Random large fluctuations have reduced on daily scale.

(*ii*) Root Mean Square Errors (RMSE) and bias of temperature observations from respective guess for different levels have reduced considerably.

(*iii*) Differences (O-B) between observations (O) and first guess (B) have reduced at all levels.

(*iv*) Observations are accepted by global/regional models.

(*v*) Rejections of specific humidity observations have reduced substantially.

(*vi*) Maximum height reported has increased significantly.

Reference

Das Gupta, M., Das, Someshwar, Prasanthi, K., Pradhan, P. K. and Mohanty, U. C., 2005, "Validation of upper-air observations taken during ARMEX-I and its impact on global analysis-forecast system", *Mausam*, **56**, 1, 139-146.

Das Gupta, M., 2009, "National Centre for Medium Range Weather Forecasting (NCMRWF)", "Report: Quality of observations from Indian Stations", 1-12.

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