Effect of non-wooden radiation shield on measurements of air temperature and humidity in Automatic Weather Stations at climatologically different Indian stations Pune and Mumbai

Amudha B[1]., Anjan A., Ranalkar M., Vashistha R.D., and Rudra Pratap

India Meteorological Department, Pune, India.
Tel:91-20-25535411/25882353 Fax: 91-20-25521529
Email: anjit_anjan@yahoo.com, mranalkar@yahoo.com,
ramdhanvashistha@yahoo.co.in, rpmishra_2006@yahoo.co.in

1. *Present address: Regional Meteorological Centre, India Meteorological Department, Chennai,India*
Tel:91-44-28230091 Fax: 91-44-28276752
Email: amudha_aug@yahoo.com, amudha_aug@hotmail.com

ABSTRACT

India Meteorological Department(IMD) has upgraded during 2006-07 its network of Automatic Weather Stations with 100 Sutron-make, USA and 25 of indigenous Astra-make AWS. The earlier network had 15 AWS of Sutron-make with measurements of temperature and humidity sensors done with sensors housed in conventional wooden Stevenson screens. For the first time in the upgraded network of 100 AWS a UV stabilized white thermoplastic radiation shield is used inside which the temperature and humidity sensor is mounted. The measurement of air temperature is made with a thermistor. The humidity measurement is made with Rotronic Hygromer C94 sensor. Both the sensing elements are set inside a single probeand mounted inside a radiation shield to protect the sensor from direct radiation, dust, rain etc.

Existing conventional manned surface observatories in IMD are the backbone of the Indian weather forecasting network. Air temperature is measured with mercury thermometer housed in a wooden Stevenson screen. The relative humidity is computed from the values of dry bulb and wet bulb thermometers placed inside the wooden Stevenson screen. It has been observed from the initial comparative study of data of automatic weather stations that marked deviations in measurement of temperature are observed at 03 UTC (0830 hrs IST-morning hours) and less in case of other synoptic hours. An attempt has been made to analyse the variations in one year's data in the case of two climatologically different locations like Pune and Mumbai covering the four seasons in India. Comparison has been made with the co-located conventional surface observatory data. The results have been discussed and the effect of wind on the air temperature measurements has also been analysed for both the stations. Preliminary analysis indicates that in remote unmanned field AWS there is no control over the microclimatological effects and short-term fluctuations in the ambient air of the temperature and humidity sensor which result in measurement errors.

Key words: Temperature, humidity, radiation shield, monsoon season, Automatic Weather Stations

1. Introduction

India Meteorological Department(IMD) upgraded its obsolete network of Data Collection Platforms with 15 state-of-art microprocessor based Automatic Weather Stations in 1997. Comparative studies were undertaken for the AWS colocated with conventional observatories and the results were within WMO specified accuracy limits(Vashistha et al, 2005). IMD further upgraded its network of Automatic Weather Stations with 100 systems of Sutron-make, USA and 25 of indigenous Astra-make AWS during 2006-07. AWS utilize the geostationary Indian satellite Kalpana-I for telemetry with Pseudo-random burst sequence(PRBS) type of transmission. Hourly data from these stations is received at the Earth Station Pune (Ranalkar, 2007). Data is coded in WMO synop format and sent over Global Telecommunication System(GTS) through the Regional Telecommunication Hub(RTH) at New Delhi.

During the initial stages of validation of the data while commissioning the upgraded AWS it was observed in few sites that marked differences in temperature were observed generally during 03 UTC(0830 hrs IST, morning hours) and less in other synoptic hours. Thermoplastic radiation shields for housing the temperature and humidity sensor is used in IMD for the first time as only wooden Stevenson screens were used in the earlier AWS for housing the temperature sensors. Since a fully functional and expanded AWS network is envisaged in the next few years under the modernization and automation of IMD, this attempt has been made to analyse and document the factors which lead to the deviations in temperature measurements due to the effect of radiation shield under continuous field operations.

The effects of radiant exchange on thermometer readings of air temperature were recognized over 150 years ago, and eventually led to the design of the Stevenson screen in 1864. Early studies indicated that an alternate radiation shield other than the conventional wooden Stevenson screen is necessary and that it should be made of materials which have small thermal conductivity and heat capacity. The structure of the shield should be so as to provide minimum obstacle to the flow of air through it, especially in the absence of aspiration. (Hadlock, 1972).

Numerous studies by MacHattie 1965, Fuchs and Tanner 1965, Hadlock 1972, McKay and McTaggart-Cowan 1977, Tanner 1996, Barnett 1998, Lin 2001, Hatton 2002, Van der Muelen 1998,2000,2007, Zahumensky 2003 have investigated both the shield performance and errors in air temperature caused by shields. The main finding is that air temperature errors caused by a radiation shield could range from -0.5°C to +2.5°C(Lin, 2001). Though the wooden screen gives a close approximation to the true air temperature, undisturbed by the effects of direct solar or terrestrial radiation, it is unsuitable for many applications. It is too bulky to be portable and it does not give full protection from radiant exchange(Erell, 2003).

Sensors and conventional thermometers can be calibrated with respect to internationally approved standard procedures. Shields however are not subject to any kind of WMO approved standardization(Van der Meulen, 1998). Guide to Instruments and Methods of Observation, WMO No.8 has instructions on the construction of shields but no typical shield is recommended.

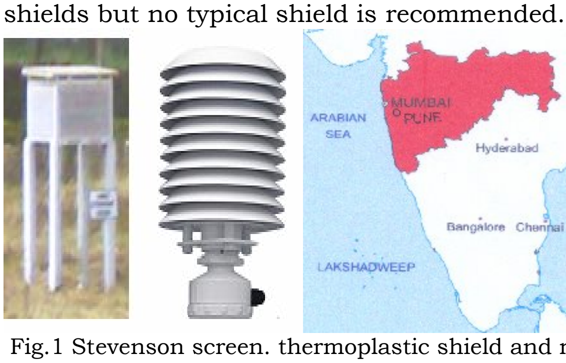

Fig.1 Stevenson screen. thermoplastic shield and map showing Mumbai, Pune.

2. Background

In this paper, two AWS installed during July 2006 at Pune and Mumbai(Santa Cruz) in Maharashtra State are considered for a whole year 2007. Both the sites have co-located conventional surface observatories facilitating the comparison of data. Mumbai (19°7'N /72°51'E is in the windward side of the Western Ghats and is a coastal city at elevation of 15m, strongly influenced by strong onset of sea breeze and maritime air. Pune (18°31'38"N/73°51'12"E) with an elevation of 559 m is in the leeward side of the same Ghats called Sahaydri hill ranges.

AWS are generally unmanned and few of them are located in remote areas of the country with no human intervention. AWS are powered by a 12V, 65AH battery supported by solar panel. Periodic maintenance visits at least twice a year is ensured. Hourly data are recorded as programmed in the data logger and transmitted through the satellite to the earth station at Pune. Fig.1 shows the Stevenson screen, radiation shield and location map of Mumbai and Pune.

3. Observational set-up

Meteorological data from conventional surface observational network is received at eight synoptic hours viz., 00,03,06,09,12,15,18 and 21 UTC. Indian Standard Time(IST) is 5½ hours ahead of UTC time. Observatories record air temperature with a mercury thermometer housed in a wooden Stevenson screen. The relative humidity is computed from the values of dry bulb and wet bulb temperatures.

In the existing AWS network, IMD has switched over to electronic sensors. The measurement of air temperature is made with a precision 10K thermistor. The humidity measurement is made with Rotronic Hygromer C94 sensor. The temperature range of -40°C to +60°C corresponds to 0 to 1V and 0 to 100% humidity to 0 to 1V. Both the sensing elements are set inside a single probe mounted inside a RM Young radiation shield to protect the sensor from direct radiation, dust, rain etc. The round-shaped multi-plate radiation shields have become the default screen in automatic weather stations in industrialized countries.

RM Young non-aspirated radiation shield is used in all 100 AWS of IMD network. It is made of UV stabilized white thermoplastic plates and white powder coated. The technical literature states that the shield error @1080 W/M^2 of solar radiation intensity is dependent on wind speed inside the shield, passing through the sensor. The errors are 0.4°C RMS @ 3 mps (5.8 knots), 0.7°C RMS @2 mps (2.8 knots), 1.5°C RMS @1 mps (1.94 knots). It should be remembered that the sensor time constant is different from the radiation shield time constant and thus the shield temperature changes are not synchronous with temperature sensor changes. Wind direction and speed are measured with a Gill Ultrasonic sensor. Rainfall is measured with the help of a tipping bucket raingauge. Fig. 2 shows the AWS sites in Pune and Mumbai Santa Cruz respectively.

Fig.2 AWS located at Pune and Mumbai

4. Climate of Mumbai and Pune

Mumbai and Pune cities are located in Maharashtra State which is north of 14°N and south of 22°N of India. The State is bounded by Arabian Sea on its western side. The Western Ghats (Sahyadri) run north to south with average height of the range being about 1 km. West to east the region stretches across a distance of 800 kms. The western slopes and the coastal districts get very heavy monsoon rains, while to the east of the Ghats rainfall drops to less than a tenth within a short distance from the Ghats. Mumbai and Pune get rainfall mainly during South West Monsoon season (June-Sep).

Mumbai Santa Cruz is a coastal city with the Arabian Sea to its west. The climate of Mumbai district is characterized by an oppressive summer, dampness in the atmosphere nearly throughout the year and heavy southwest monsoon rainfall.

The surrounding area of CAgMO Pune observatory is a gently undulating plain with hills at a distance and high range of mountains far to the west. The climate of Pune is generally dry. Rainfall occurs mainly during the South West Monsoon Season (June-Sep). The rainfall is very heavy in the narrow strip of Pune district in the immediate neighborhood of the Western Ghats and decrease rapidly eastwards.

Climatologically, wind is calm in Pune during mornings of Nov-March and predominantly westerlies during Apr-Oct. In Mumbai SCZ the wind direction is calm and varies from easterly to northeasterly during Nov-Mar and from northwesterlies to westerlies during Apr-Oct. During evenings wind is calm or easterlies during Nov-Dec and westerlies in the remaining months for Pune and in Mumbai SCZ it is mostly northwesterly. Variation in wind speed for Pune is less than 3 knots during Oct-Mar and having the highest mean wind speed of 6.4 knots in June, the wind speed markable only during SW(June-Sep) Monsoon season. The mean wind speed is maximum in July at Mumbai SCZ during SW monsoon season.

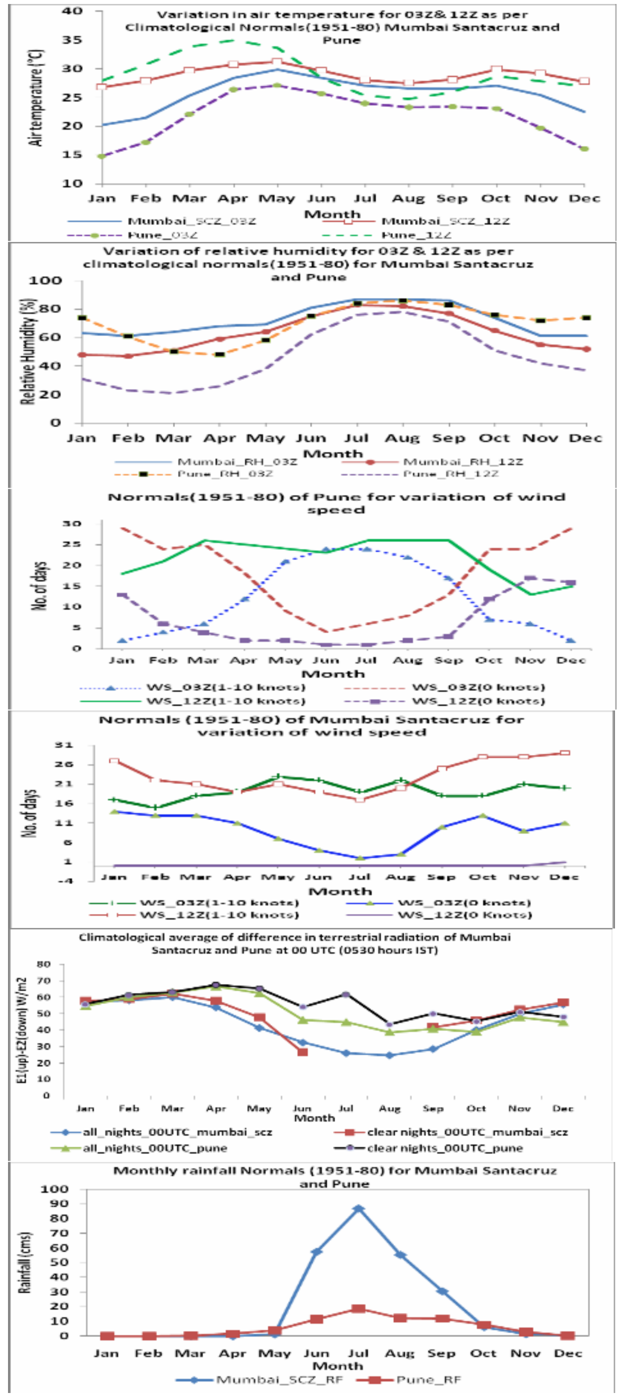

Fig. 3 Climatological normals of Mumbai SCZ & Pune

The climatological normals for Pune and Mumbai Santa Cruz are shown in Fig.3 to understand the variations in local climatology. Normals of terrestrial radiation over both stations is also presented.

5. Effects on meteorological measurements

a) Effect of wind

Wind speed is a major factor in determining inter-screen temperature differences (Van der Meulen, J.P, 2007). In AWS the temperature and humidity sensors are mounted at 2 m height above ground level. The conventional dry and wet bulb thermometers are kept at around 1.5 m above ground level in the Stevenson screen. The wind field for the conventional sensors and the AWS temperature, humidity sensor will be the same as both are almost at the same level (1.5 m and 2 m respectively) and the observatory is co-located.

In the case of AWS, wind speed and direction measurements are done with the Gill ultrasonic wind sensor mounted a height of 10m as per WMO guidelines. Three minute vector averaging of samples taken every second (180 samples) prior to the top of the hour gives the wind speed and direction at full hour UTC. Wind direction and speed measured by the conventional observatory is a scalar quantity depending on visual reading of the cup counter anemometer. The three minute average of the readings of cup counter anemometer gives the wind speed.

The wind at 10 m is perhaps not representative of the ambient wind field near the temperature sensors. The micro-climatological effects creating the errors in temperature go unnoticed. Height at which wind instruments are located in the observatory is 8 mt above ground level in the case of Mumbai and 2 mt in the case of Pune. Both observatories are generally grass covered throughout the year.

b) Effect of radiation

The sunrise is between 0545 hrs to 0630 hrs IST(0015 UTC 0100 UTC) for both Pune and Mumbai but intensity of solar radiation starts increasing after 730 hours IST. India being a tropical country most parts of the country have intense solar radiation throughout the year. The difference in temperature measurements noticed mostly during 03 UTC(0830 am IST) is mainly due to rapid warming in morning hours. Terrestrial radiation too is significant as climatological averages indicate a clear distinction in the balance of terrestrial radiation during clear and cloudy nights at Pune and Mumbai.

Readings of temperature are taken within 10 minutes preceding the specified UTC in the case of conventional observatories. AWS temperature measurements are instantaneous values taken exactly at the top of the hour(UTC). It is important that readings of temperature be taken within the 10 minutes preceding the specified time, because of the rapid warming at that time of the day. For instance, an error of about 0.2°C would be caused by a reading 10 minutes late, assuming typical heating of 12°C between 6 am and 2 pm in tropical countries. The timing is not critical for observations in the afternoon, when temperatures change less rapidly (Linacre E). Due to inherent lag, the variation in temperature sensed by thermoplastic radiation shield is not sensed by the wooden Stevenson screen, during the rapid warming time in the mornings.

c) Effect due to rainfall

The humid atmosphere during monsoon season plays a positive effect and minimizes the errors in temperature which was evident from the analysis of monsoon data of Pune and Mumbai.

6. Methodology

The objective is to study the variations in temperature and humidity measurements and analyse errors induced due to the type of radiation shield used for housing the sensors in field operational conditions. Data of all eight synoptic observations from conventional observatories co-located with AWS at Pune and Mumbai has been taken for the period Jan-Dec 2007 along with AWS data of the same period. Since the AWS are unmanned and unattended, no special precautions were taken except for routine maintenance visits which were ensured at least once in six months.

The entire data set of the year 2007 was analyzed. Bias and standard deviation in temperature has been tabulated and graphically presented. Jan, April, June and Nov 2007 have been considered as sample months to cover the four seasons viz., Winter(Jan-Feb),Pre-monsoon/Summer(Mar-May), Monsoon(June-Sep), Post-monsoon/North-East monsoon(Oct-Dec) of India. Variation in temperature and humidity at 03 UTC, wind speed of AWS, Observatory for 03 UTC and other synoptic hours and the deviations in temperature during 03 UTC and other synoptic hours have been plotted. Significant variations are clearly evident from the graphical figures provided in Figs.4 to 12.

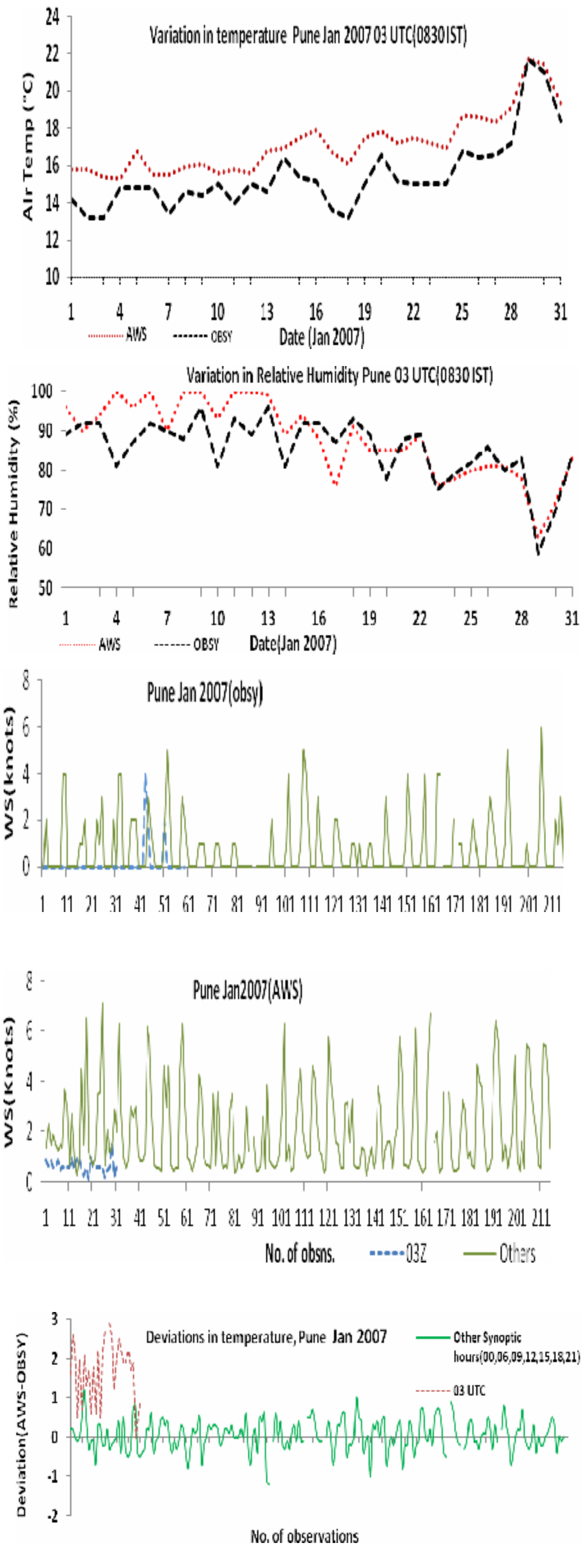

Fig. 4 Variation in meteorological parameters for Pune Jan 2007

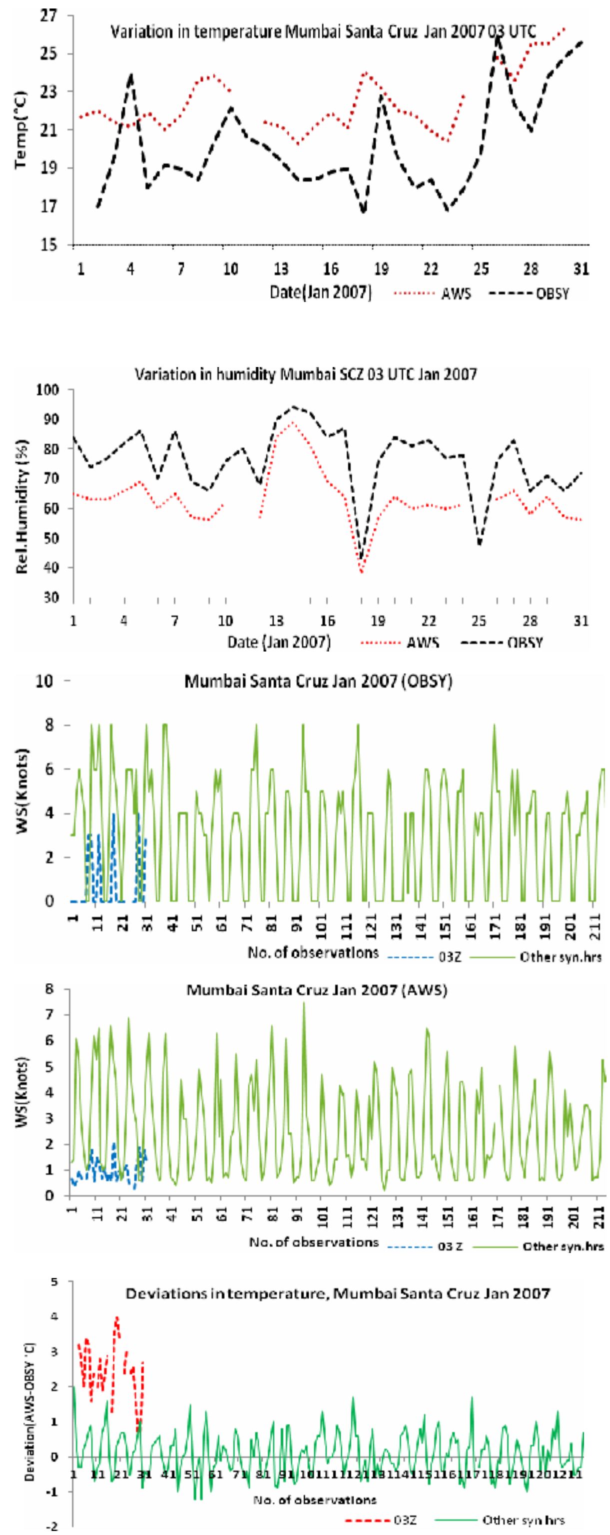

Fig. 5 Variation in meteorological parameters for Mumbai SCZ Jan 2007

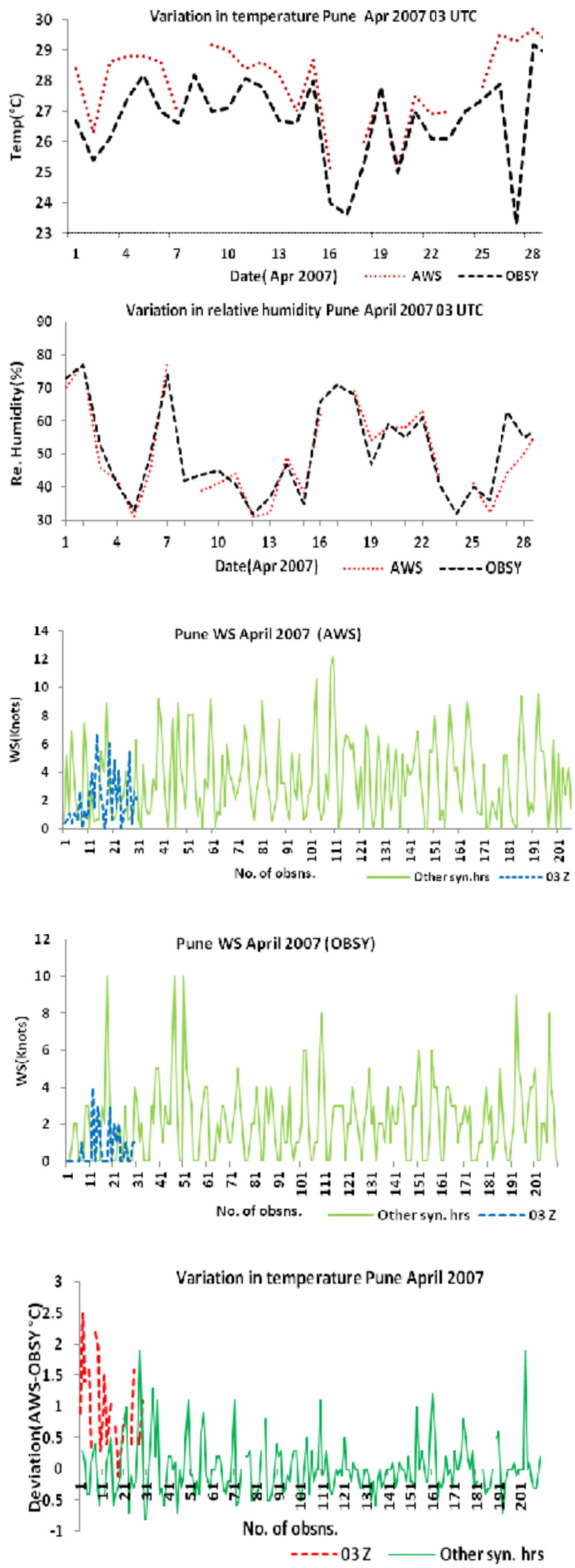

Fig. 6 Variation in meteorological parameters for Pune Apr 2007

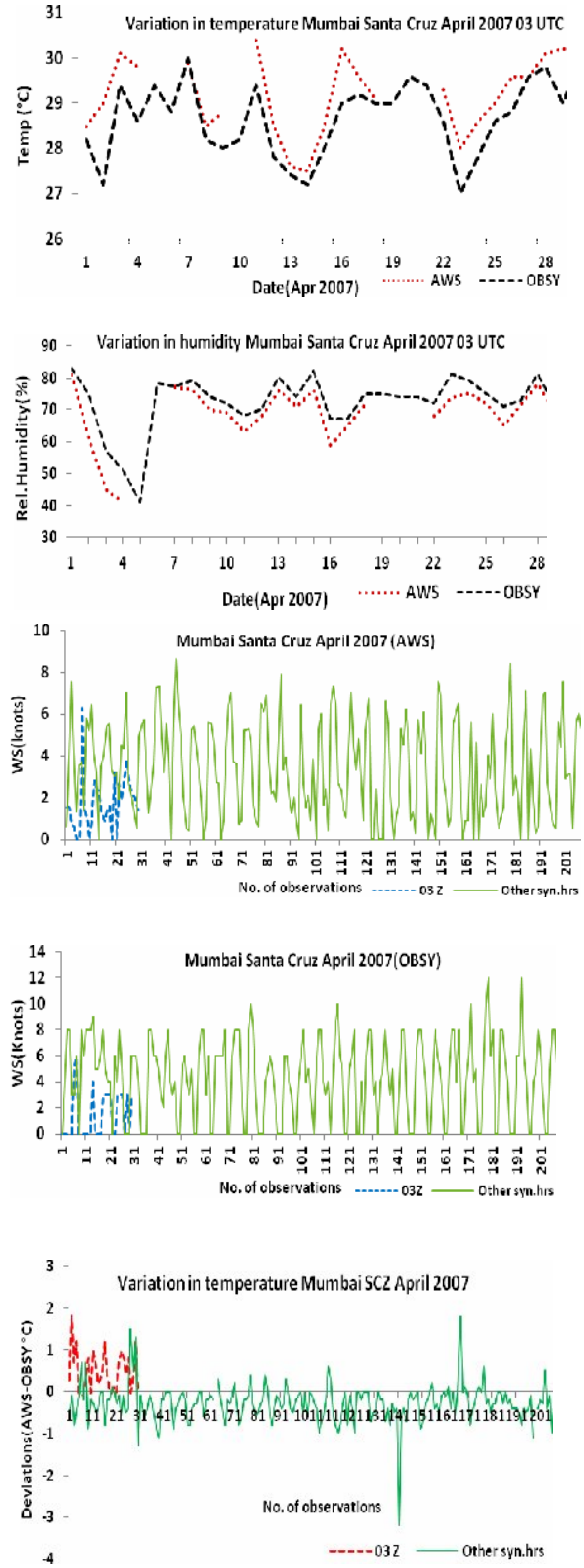

Fig. 7 Variation in meteorological parameters for Mumbai SCZ Apr 2007

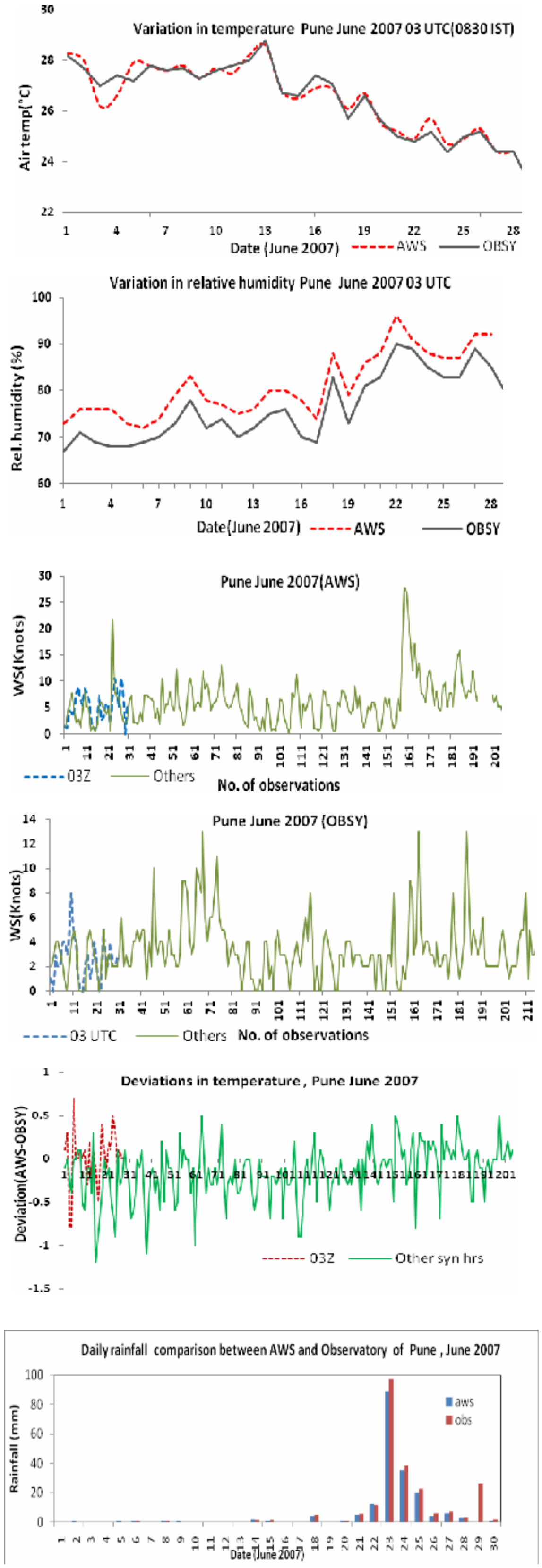

Fig.8 Variation in meteorological parameters for Pune June 2007

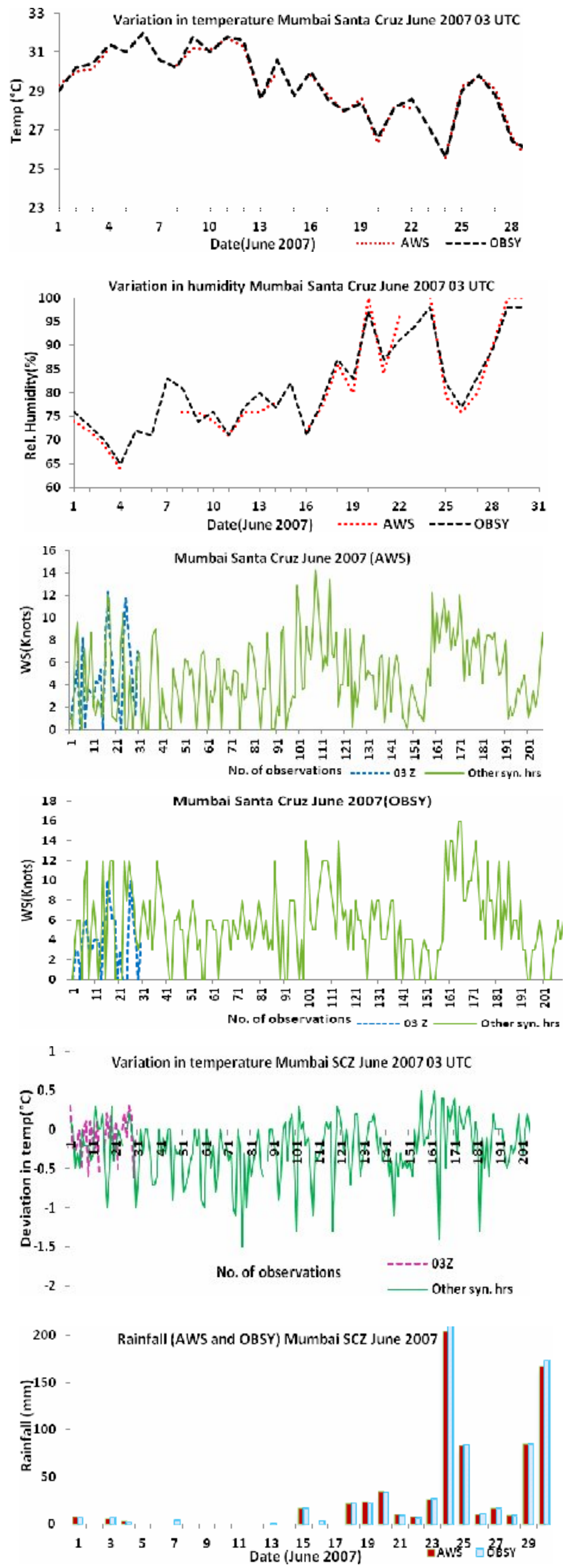

Fig.9 Variation in meteorological parameters for Mumbai SCZ June 2007

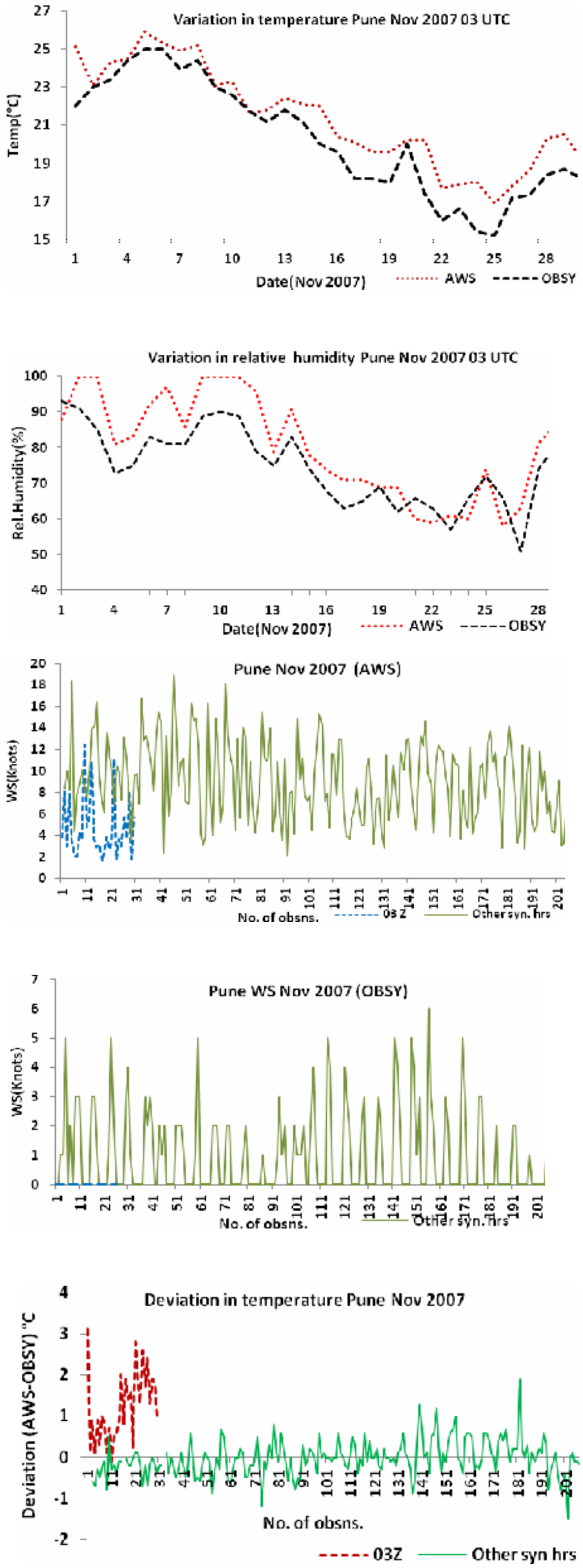

Fig.10 Variation in meteorological parameters for Pune Nov 2007

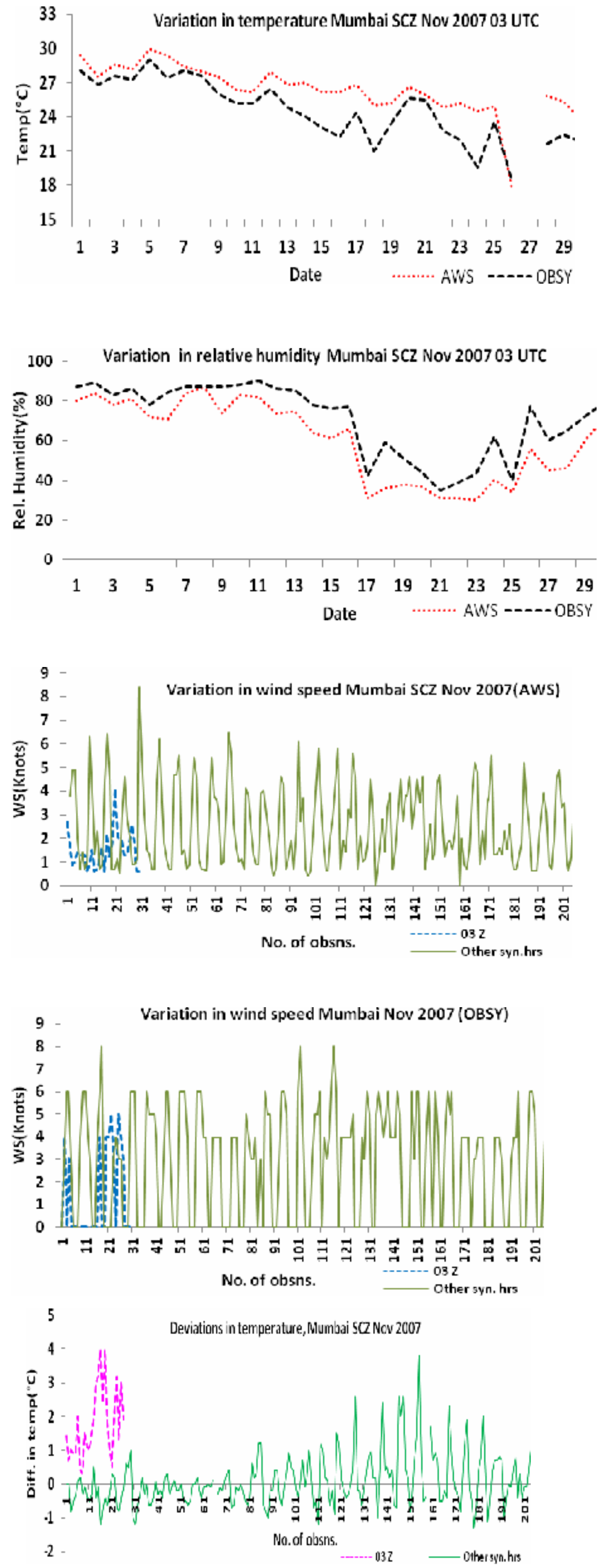

Fig.11 Variation in meteorological parameters for Mumbai SCZ Nov 2007

Month / Year 2007	Mumbai Santa Cruz				Pune			
	03 UTC	***Other syn. hrs***	***03 UTC***	***Other syn.hrs***	***03 UTC***	***Other syn hrs***	***03 UTC***	***Other syn.hrs***
	BIAS (°C)		**STD.DEV(°C)**		**BIAS(°C)**		**STD.DEV(°C)**	
Jan	2.46	0.08	0.84	0.6	1.64	0.04	0.78	0.38
Feb	1.81	-0.06	1.09	0.51	1.45	0.076	0.74	0.52
Mar	1.2	-0.19	1.05	0.49	1.56	0.075	0.88	0.54
Apr	0.59	-0.29	0.46	0.46	1.14	-0.015	1.2	0.54
May	-0.07	-0.42	0.31	0.34	0.26	-0.19	0.3	0.27
Jun	-0.11	-0.25	0.28	0.38	0.006	-0.15	0.32	0.3
July	-0.05	-0.05	0.33	0.42	0.21	-0.1	0.27	0.25
Aug	0.33	-0.05	0.65	0.42	0.74	-0.24	1	0.7
Sep	-0.003	-0.24	0.37	0.62	0.3	-0.13	0.3	0.33
Oct	1.72	-0.15	1.52	0.41	0.92	-0.11	0.64	0.37
Nov	1.77	-0.03	1.07	0.56	1.21	-0.03	0.85	0.43
Dec	1.49	0.09	1.18	0.77	1.63	-0.006	1.64	0.44

Table 1 : Bias and Standard deviation in temperature measurement-Mumbai and Pune 2007

7. Results and discussions

The general observation is that AWS measured value is higher than that of conventional observatory data in the case of temperature and humidity measurements at Pune. In the case of Mumbai relative humidity values recorded by AWS were less than observatory values for all the four months taken for analysis. AWS measured temperature values were more than that of observatory in the case of Mumbai SCZ.

In the case of wind speed, the mechanical cup anemometer (scalar wind speed) is used in the observatory and ultrasonic wind sensor(vector averaging of wind speed and direction) is used in AWS and hence the trends can be compared and not individual values as such. The bias and standard deviation in temperature measurement for the whole year for Mumbai and Pune is shown in Table 1. Graphs for Jan-Dec 2007 are presented in Figs.12 & 13. Seasonwise analysis of the sample months Jan, Apr, June and Nov are provided.

i) Winter(Jan-Feb)

Pune : The month of Jan 2007 was taken as a sample month for the study of seasonal change in winter. Fig. 4 presents the variations in meteorological parameters at Pune. In the case of 03 UTC it is observed that wind is calm on most occasions both as per climatology and observed values. The wind speed is lesser at 03 UTC than at other synoptic hours. When the ambient wind speed is less than 4 knots(2 mps) errors are prone to occur and ± 0.2°C radiation error could be induced by the effect of solar and infra-red loading on the surface of the air temperature sensor in non-aspirated shields(Lin etal, 2001). When insolation was greater than 700 Wm^{-2} and air speed less than 2 mps(4 knots) temperature errors were quite large, greater than 2°C (Brock et al, 1995).

Deviations in temperature measurement were less during other synoptic hours varying within ±0.5°C on most occasions barring few instances of error exceeding 0.5°C. Bias is positive at 1.64°C (No. of values: 30) at 03 UTC and 0.04°C for other synoptic hours(No. of observations: 220), during the entire month. The standard deviation was 0.78°C and 0.38°C for 03 UTC and other syn. hours respectively.

Calm winds in winter season(Jan-Feb), significant drop in minimum temperature during night time, clear nights, , diurnal change in temperature up to 13°C during January, morning temperatures hovering around 13-16°C, humid atmosphere, sudden increase of insolation, inherent lag in the wooden thermometer screen in picking up variations, notable changes in temperature occurring within 10 minutes of observation especially during morning time all contribute to errors up to 3°C at 03 UTC during January.

Mumbai: Fig.5 provides the variations for Mumbai during Jan 2007. It is observed that wind speed is less than 4 knots for the entire month of Jan at 03 UTC as per AWS and Observatory values and deviation in temperature was higher reaching up to 4°C on few days. Errors in humidity were also more during Jan 2007 at 03 UTC. For other UTCs, the deviation was within ±1°C on most occasions except few sporadic instances when it was between 1.5°C to 2°C.

In contrast to Pune's diurnal range of temperature and humidity being 13°C and 40% respectively during Jan, Mumbai has a diurnal range of 6°C for temperature and 20% for humidity which may also be a significant factor contributing to the variations.

ii) Summer / Pre-monsoon(Mar-May)

Pune: April was taken as a sample mon th for summer season. Graphical presentation of the variations is provided in Fig.6. Errors in temperature measurements at 03 UTC reduced considerably. Wind speed at 03 Z was less than that of other synoptic hours and was less than 7 knots measured both by AWS and observatory. The error in temperature was 2-2.5°C on two occasions and less than 1.5°C on remaining days at 03 UTC. For other synoptic hours, mixed variation with positive bias reaching up to 1.8°C and negative bias ranging around -0.5°C on rest of the hours is observed.

The climatological normals of 03 UTC and 12 UTC indicate a temperature change of up to 9°C in April and very less change in humidity of the order of 10%. In the present case, the humidity varied from 30-75% with little error between humidity measured by AWS and Observatory and almost matching each other at 03 UTC.

Mumbai: Fig. 7 provides the variations in meteorological parameters for Mumbai Santa Cruz during April 2007. The deviation in temperature was less than 1.5°C at 03 UTC on most of the days except for one occasion when it reached 2°C.As the day progresses, the deviation becomes less and hence during other synoptic hours the bias is not so pronounced and is within limits less than 1°C during most occasions. Humidity values at 03 UTC agreed well on most days except one or two days.

iii) Monsoon season(June-Sep)

Pune: Fig.8 gives a clear picture of the significant variations of all meteorological parameters including rainfall during June 2007. During monsoon season (June-Sep) wind speed is predominantly westerlies reaching up to 15 knots which contributes towards minimizing the errors and the deviation is within ±0.8°C at 03 UTC. The diurnal change in temperature is less during rainy season in contrast to the winter season of Pune. Bias is near zero during June for temperature.

Mumbai: Fig.9 includes the variation in rainfall along with other parameters as during June 2007, very heavy rainfall of the order of 210 mm occurred at Mumbai Santa Cruz. This factor along with the onset of southwest monsoon during June over Pune and Mumbai has incursion of moisture and strong westerlies up to 18 knots.

The temperature and humidity measured by both AWS and observatory agreed very well. The deviations in temperature were within ±0.5°C at 03 UTC and reached a maximum of 1.5°C on few occasions at other synoptic hours. The bias in temperature measurement is negative during June. The ambient westerly wind speed during the entire month reaching up to 12 knots coupled with humid atmosphere has resulted in a significant drop in the errors of temperature measurements.

iv) Post-monsoon season(Oct-Dec)

Pune: Fig.10 shows the variation of meteorological parameters during Nov 2007 as temperature starts dropping gradually from around 25°C in the beginning of the month to around 15-18°C towards the end of Nov. The data analysis showed that the deviation in temperature reached 3°C on two occasions during other synoptic hours (No. of observations 212) whereas at 03 UTC the deviation was more reaching upto 3.1°C on one occasion and above 1°C on most occasions.

Wind speed at 03 UTC was between 6-10 knots at 03 UTC as measured by AWS but Observatory had reported calm winds on most days of Nov at 03 UTC. Decreasing trend in humidity values is noticed over the entire month with significant error in the days 1-15 Nov and less error subsequently up to 30 Nov.

Mumbai: Fig.11 depicts the variations during Nov. Mumbai data shows that 03 UTC deviations range from 0.3°C to 4°C and for other synoptic hours it was within ±1°C on most occasions. Bias was positive at 03 UTC and negative for other UTCs. Errors in temperature were more during 16-30 Nov than the beginning of the month. Errors in humidity were less during 1-15 Nov and gradually started started increasing after the humidity had a decreasing trend from near 70-80% in the beginning of the month to 40% during the third week of November.

v) Bias at 03 UTC

Inverse parabola type of variation in bias is observed for both Pune and Mumbai for 03 UTC observations in temperature. Bias in Jan and Feb were near 1.5°C for Pune. From March-June, the bias gradually decreased becoming near 0°C in June and started increasing from July onwards for Pune.

Bias in temperature of Mumbai SCZ recorded at 03 UTC was higher than Pune during Jan-Feb and subsequently was less than Pune from Mar-Sep. The positive bias(AWS>OBSY) observed from Jan-Apr at Mumbai SCZ started decreasing when it reached a negative trend (OBSY>AWS) during May-July. The trend reversed and started increasing towards positive bias from July to Dec.

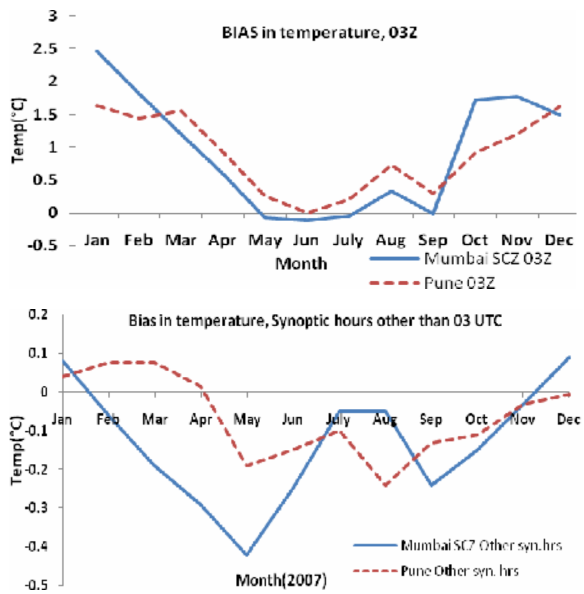

Fig.12 Bias during Jan-Dec 2007

vi) Bias at synoptic hours other than 03 UTC

The bias in temperature was positive from Jan-April for Pune subsequently becoming negative for the rest of the year. Except for Jan and Dec, bias was entirely negative for Mumbai Santa Cruz.

vii) Standard deviation

The standard deviation(SD) in temperature recorded at Pune was minimum in July for both 03 UTC and other synoptic hours with value of 0.27°C and 0.25°C respectively. For Mumbai Santa Cruz, the SD was minimum at 0.28°C in June for 03 UTC and 0.34°C in May for other synoptic hours.

Maximum SD was observed for Mumbai in Oct at 03 UTC with 1.52°C and 0.77°C for other synoptic hours. Similarly for Pune, the maximum SD occurred during Dec at 1.64°C at 03 UTC and 0.7°C for other synoptic hours.

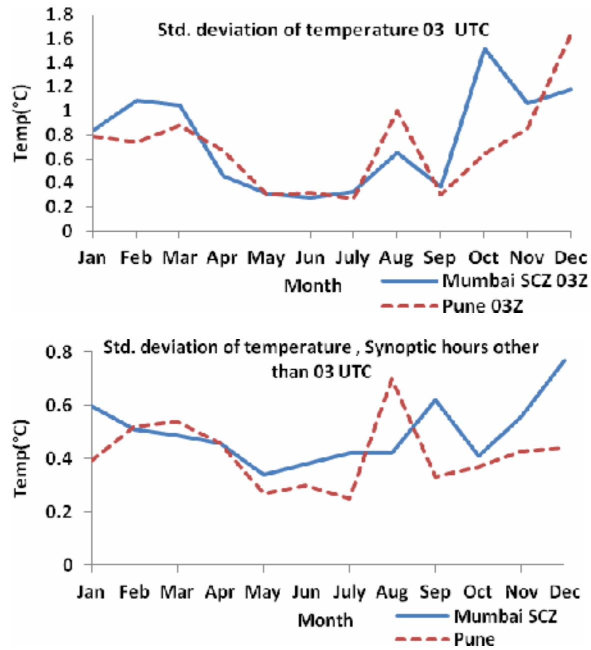

Fig.13 Standard deviation during Jan-Dec 2007

8. Conclusions

A strong influx of radiation during the morning hours (03 UTC), balance in terrestrial radiation, various effects associated with high levels of humidity during early mornings in winter, humid atmosphere during monsoon season, diurnal/seasonal variations of low and high wind speeds, short term fluctuations in the ambient air around the sensor, microclimatological effects not clearly known are the factors which lead to the errors in measurement of temperature. Climatology of the station also plays a significant role.

Design of radiation shields is not the only factor contributing to errors in such instances. Need for radiation shields specific to the local climatological conditions, mainly for the tropical weather conditions like India where temperatures range from as low as 2°C to 48°C in different seasons needs to be examined. It is felt that use of aspirated shields is also not a viable solution for AWS under all seasonal conditions considering the limitations in power consumption in a remote AWS.

Acknowledgement

The authors thank the Dy.Director General of Meteorology (Surface Instruments), India Meteorological Department, Pune for his constant motivation and guidance. First author thanks DDGM, RMC Chennai too for his support.

References

1. *Climate of Maharashtra, 2005, National Climate Centre, Publication of India Meteorological Department.*
2. *Climatological Normals, 1951-80, 1999, Publication of India Meteorological Department.*
3. *Climate data and resources – A reference and a guide, Edward Linacre,1992., Routledge, 11 New Fetter Lane, London EC4P 4EE.*
4. *Erell E., et al, 2003, "On the measurement of air temperature in the presence of strong solar radiation", Fifth International Conference on Urban Climate,1-5 September 2003, Lodz, Poland*
5. *Guide to Meteorological Instruments and Methods of Observation, WMO No.8,Sixth edition, 1996.*
6. *Hadlock R., Seguin W.R and Garstang M., March 1972, "A radiation shield for thermistor deployment in the atmospheric boundary layer", Journal of Appl. Meteorology, pp.393-399.*
7. *Handbook on Radiation(Mss), Radiation Lab of Instruments Division, Pune, India Meteorological Department, personal communication.*
8. *Hatton D.B., "Results of an intercomparison of wooden and plastic thermometer screens", Met Office, UK.*
9. *Lin X., Hubbard K.G., 2001, "Air flow characterisitics of commonly used temperature radiation shields", Journal of Atmos. Oceanic Technol., 18, pp.329-339.*
10. *Lin X., Hubbard K.G., et al, 2001, "Some perspectives on recent insitu air temperature observations: Modeling the microclimate inside the radiation shields", Journal of Atmos. Oceanic Technol., 18, 1470-1484.*
11. *Ranalkar M., Amudha B., et al. 2007, "Expansion and upgradation of Indian Automatic Weather Station network", Proceedings of Tropmet 2007, India.*
12. *Scott J. Richardson and Fred V. Brock, 1999, "Minimizing Errors Associated with Multiplate Radiation Shields"Journal of Atmos.Oceanic Technol., 16, pp. 1862–1872.*
13. *Van der Meulen, J.P., TECO 1998, "A Thermometer Screen Intercomparison"*
14. *Van der Meulen, J.P., TECO 2000, "Temperature measurements: some considerations for the inercomparison of radiation screens".*
15. *Van der Meulen, J.P., 2007, "Thermometer screen intercomparison in De Bilt (the Netherlands)"., Int.Journal of Climatology (accepted).*
16. *Vashistha R.D., Amudha B., Rudra Pratap, 2005, "Present status of surface meteorological observations in India", TECO 2005.*
17. *Zahumensky, I., "Procedures for intercomparison of thermometer screens/shields, in conjunction with humidity measurements in various climatic regions", 2003, CIMO/OPAG-SURFACE/ET-SBII&CM-1/IOC-1/Doc. 6.2.*