GPS / GSM Based Embedded System for Atmospheric Boundary Layer Profiling and Weather Monitoring

Femy Paulose[1], Aby Mathew[1]*, Gibies George[2]

[1]Sree Narayana Gurukulam College Engineering
[2]Indian Institute of Tropical Meteorology

*Corresponding Author
abysngce@gmail.com
Assistant Professor
Dept. Electronics and Communication Engineering
Sree Narayana Gurukulam College Engineering, Kadayiruppu, Ernakulam, India

Abstract: ***Mesoscale weather conditions in the Atmospheric Boundary Layer (ABL) are directly related to the daily life of human society. But the understanding about mesoscale weather is very limited compared to large scale weather phenomena such as tropical cyclones, monsoon, heat wave, cold wave etc. Operational meteorological agencies are unable to properly monitor and predict mesoscale weather phenomena, due to the difficulties involved in continuous atmospheric measurements. However, local self governing bodies (panchayats, municipalities, corporations etc.), can monitor mesoscale weather, if provided with required infrastructure and instruments to monitor local weather. The present study is to design and implement a system for monitoring the local weather by using the advantages of state-of-art technologies like Global Positioning System (GPS), Global System for Mobile Communication (GSM) and embedded system. The monitoring system is developed using the best available meteorological sensors. The temperature measurements are found comparable with mercury thermometer. The temperature sensors have very good accuracy especially for a warm atmospheric condition. This study presents the daytime variations of temperature, pressure and humidity during four consecutive days in the middle of July 2014 at Pattimattom (10.02 degN, 76.45 degE), a village station near Kochi. One among the four days is a clear sky day and another one is a rainy day. Hence the study is able to reveal the contrast between a dry day and a wet day.***

Keywords: Global Positioning System (GPS), Global System for Mobile Communication (GSM), Atmospheric Boundary Layer (ABL)

1. Introduction

Temperature, pressure and humidity are most important weather parameters in the atmosphere. We can get the surface values of these parameters using surfaces Automatic Weather Stations (AWS) consisting of sensors and datalogger (Haralambos et al. 2007). But these parameters vary with height and vertical profiling of the atmosphere (Sanker and Norman 2009) is required for proper understanding of weather phenomena. Routine upper air sounding system (Wang et al. 2001; Jaakko et al. 2010; Harrison et al. 2012) usually does vertical profiling of atmosphere twice a day. But the upper air sounding stations are located hundreds of kilometres apart and it is well known that the atmosphere has a horizontal variability of much smaller scale, especially in the Atmospheric Boundary Layer (ABL; close to the Earth surface). Hence the upper air sounding will not represent the small scale horizontal variability in the ABL. Therefore, we have to develop instruments which are less costly and efficient to get boundary layer profiles at locations of interest to study its horizontal variability. The instrument is based on embedded system, Global Positioning System(GPS) and Global System for Mobile Communication(GSM) communication. This system is portable so that, it can be used at any location (city/town/village) provided there is sufficient coverage for the GSM network.

Section 2 provides the details of system design, which involve the identification of the relevant sensors and component modules. The design and implementation of GPS/GSM based embedded system with atmospheric sensors for monitoring the local weather are described. Section 3 describes the calibration and comparison of the temperature sensor with mercury thermometer. Section 4 provides the preliminary analysis of data and its meteorological aspects.

2. System Design

The GPS-GSM embedded sounding system consists of an observing platform and a ground station. Observing platform is the embedded systems including a microcontroller, GPS (GTPA010), GSM (SIM900) and the atmospheric sensors. Ground station is a laptop personal computer connected to a GSM modem to receive the data transmitted from the observing platform. The atmospheric pressure, temperature and humidity data measured by the appropriate sensors are processed by the microcontroller and sent through GSM module (SIM900) along with the GPS position and time information. These transmitted signals are received by the ground station system. Data which has been received from the observing platform can be viewed either on a personal computer or a mobile phone or a tablet.

The observation platform based on LPC2148 microcontroller, BMP085 and SY-HS-220 sensor modules. The LPC2148 is a 32-bit microcontroller with

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ARM7TDMI-S CPU.LPC2148, receives the data from the sensors and transmit it to the ground station using the GSM module along with the GPS information (Fig. 1). The sensor module BMP085 is used to measure the pressure and temperature in the atmosphere. It is a Bosch company product based on piezo-resistive technology for EMC robustness, high accuracy and linearity as well as long term stability. This is a new generation high precision digital pressure sensor for the consumer applications. The SY-HS-220 module has a humidity sensor which gives an analog output with pre-processing. The GPS module provides the information about the time, latitude, longitude and altitude of observation platform to the microcontroller. The whole data is transmitted to the ground station through the GSM transmitter in the observation platform. Ground station is simple personal computer connects to the GSM modem or a mobile phone.

The instrument has a temperature sensor with resolution 0.1 degC, pressure sensor with resolution 0.01 hPa and humidity sensor with resolution 1% connected to the microcontroller. The range of humidity measurement is between 30% and 90% relative humidity. The range of pressure measurement is between 300 hPa and 1100 hPa. The valid range of temperature measurement is between negative 40 degC and positive 85 degC Accuracy of pressure sensor is 0.01 hPa and that of humidity sensor is about +_5%RH. The time required for BMP085 module to calculate temperature and pressure are 4.5 ms and 7.5 ms respectively.

3. Comparison with Mercury Thermometer

The calibration of the temperature sensor in the instrument is done using a mercury thermometer of 0.1 degC resolution. The resolution of the instrument temperature sensor (BMP085) is 0.1 degC and the valid range is from -40 degC to +85 degC. The root mean square error of the temperature sensor is obtained to be 0.44 degC. But most of the error is occured in an atmospheric condition cooler than 26 degC (Fig. 2).

4. Analysis of Meteorological Aspects of the Data

The profile of mesoscale weather conditions in atmospheric boundary layer is closely related to the topography of the region such as water body, urbanisation, housing colonies, factories, vegetation etc. Mostly all parameters in nature have a diurnal or daily pattern because they respond to the radiative forcing related to the day night contrast. In meteorology, the term "diurnal" most often refers to the change of temperature from the daytime high to the night time low. A diurnal cycle is any pattern that recurs every 24 hours as a result of one full rotation of the Earth. In climatology, the diurnal cycle is one of the most basic forms of climate patterns. A semi-diurnal cycle refers to a pattern that occurs about every twelve hours or about twice a day. Often these can be related to lunar tides with a periodicity of about 12 hours and 25 minutes, which arises due to the combination of gravitational and centrifugal forces in Earth-Moon system. There is also tidal forcing from the Sun, but it is less in magnitude compared to the radiative forcing. Here we are presenting the intradiurnal variations of day time weather conditions on four consecutive days in the middle of July 2014 at Pattimattom (10.02 degN, 76.45 degE), a village station near Kochi. The diurnal cycle observations are helpful to the detailed study of the relationship between meteorological parameters. Cloud cover reduces the incoming solar radiation to the Earth surface and cause cooling of ABL. But a sunny forenoon and cloudy afternoon prevent the longwave terrestrial radiation and cause greenhouse warming effect. The temperature and relative humidity are closely related, because warm atmosphere have higher saturation mixing ratio and hence lower relative humidity with same amount of moisture in it. The warming of atmosphere lead to convection and reduction of atmospheric pressure.

Air temperature measurements on four days in July and the average are presented in Figure 3. The four day mean temperature (Fig. 3) at 06:00 IST is about 25.5 degC. Afterwards the Earth start radiating the heat as it receives the energy from sunlight. This results in the gradual increase of atmospheric temperature until 12:00 IST to about 29.2 degC. The mean temperature cools to about 24 degC during 22:00 IST. The daily maximum temperature and its time of occurrence depends on the meteorological conditions of the day. Usually daily maximum temperature occur between 12:00 IST and 14:00 IST. On 16th July 2014 the daily maximum temperature of the station is 29.9 degC occurred at 12:00 IST. On 17th July 2014 a daily maximum temperature of 30.5 degC is occurred at 14:00 IST. This is an indication of the clear sky condition of the day. The daily maximum temperature of 18th July 2014 is 29.1 degC occurred at 13:00 IST. On the cloudy day with strong rainfall (19th July 2014) the daily maximum temperature could not go beyond 28.1 degC occurred at 12:00 IST. The temperature drops in the early afternoon on 19th July 2014 is due to monsoon conditions like cloudiness, strong wind and heavy rainfall received on the day. The amplitude of the temperature diurnal cycle is largest on 17th July 2014, while it is smallest on 19th July 2014. This day to day variation can be attributed to the change in cloudiness. The the day time mean temperature was 27 degC for dry days, while mean temperature on 19th July 2014 was 25.33 degC due to rainy condition. The daily peak of temperature on 17th July 2014 is observed at 14:00 IST while that of 19th July 2014 is at 12:00 IST.

Atmospheric pressure (Fig. 4) exhibit a semi diurnal cycle with two maxima (one at early morning and another at late evening). The day time minimum pressure is observer at about 15:00 IST. During early morning the four day mean atmospheric pressure is 1006.7 hPa at 06:00 IST and increase gradually until it is peaking at about 09:00 IST with a mean value of 1006.8 hPa and then decreased gradually. The day time minimum is at 16:00 IST with a mean value of 1004.0 hPa which is followed by further increase and reaches a value of 1006.25 hPa during 22:00 IST. The high pressure (daily mean of 1006.88 hPa) condition on 19th July 2014 compared to other days (daily mean of 1005 hPa) is consistent with low temperature and high humidity associated with a strong precipitation.

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The four day mean values of relative humidity (Fig. 5) range from 60% to 80% RH. The maximum relative humidity is observed at early morning, which is decreased further due to increase in temperature. Humidity observation reveal that 17th July 2014 is dry (daily mean humidity is 65%) and 19th July 2014 is wet (daily mean humidity is 80.64%) compared to other days (daily mean humidity is 74%). The low temperature (25.33 degC) and high pressure (1006.88 hPa) are consistent with the wet condition on 19th July 2014. Similarly high temperature (30.1 degC) and low pressure (1003.32 hPa) on 17th July 2014 is consistent with the dry weather.

5. Conclusion

The design, installation and operation of an effective embedded system for atmospheric boundary layer profiling and mesoscale weather monitoring are described in this paper. This system is easy to be installed and capable of operating throughout the year, while maintenance of all the components used in this system is quite simple. Moreover, the uses of GSM communication system simplify the complexity of the ground station. The ground station can be as simple as a laptop personal computer connected to a GSM modem. We can also receive the data directly to a mobile phone or a tablet module in the condition of unavailability of PC. One of the major advantages of using GSM communication is the large horizontal coverage with low cost. The system can be carried out and operate at any remote location which have a GSM network coverage. The modularity of the system allows us to replace any of the sensors while a better one is available. The GPS module, provide location and time information. The portability and simplicity of the ground station reduce the establishment cost considerably. The new system can be implemented in 10 rural stations with the same cost of a single upper air radiosonde station.

We have compared the temperature values with a mercury thermometer and found that the Root mean square error of the temperature sensor is 0.44 degC. During warm condition (Temp>26 degC) the instrument exhibit very high accuracy of temperature measurement. Accuracy of pressure sensor is 0.01 hPa, which is very good compared to other available sondes. We have done a diurnal cycle analysis at a rural station, and found that the day to day variations in the weather condition are strongly coupled to the diurnal patterns of the weather parameters in the local boundary layer.

6. Future Scope

In the present study we have presented the system implementation and the analysis of fixed station observation for four consecutive days. Since the system is portable and mobile, it can be used for horizontal as well as vertical profiling of the ABL. It can be mounted on an automobile or a balloon platform for horizontal and vertical profile respectively. The GPS positioning information during ascent on balloon can be utilized for calculating wind speed and direction. But the major challenge of vertical profiling is the difficulty of recollecting the instrument. In future, the instrument can be modified slightly with a GPS based auto control miniature glider aircraft system to make it returnable and reusable. The GPS position during descending motion represents the position and direction of glider system. The GSM-SMS based communication can be replaced by GSM-GPRS based communication or further upgraded to the higher (3G or 4G) versions. Atmospheric chemistry sensors can also be included to get the chemistry profile of atmospheric boundary layer.

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Appendix

BMP085 digital pressure sensor, http://www.adafruit.com/datasheets/BST-BMP085-DS000-06.pdf
SY-HS-220 humidity sensor, http://www.rhydolabz.com/documents/sensors/sy-hs-220.pdf
SIM900 GSM/GPRS module, http://www.propox.com/download/docs/SIM900.pdf
GTPA010 GPS module, http://www.rhydolabz.com/wiki/?p=420
LPC2148 microcontroller, http://www.alldatasheet.com/datasheet-pdf/pdf/432847/NXP/LPC2148.html

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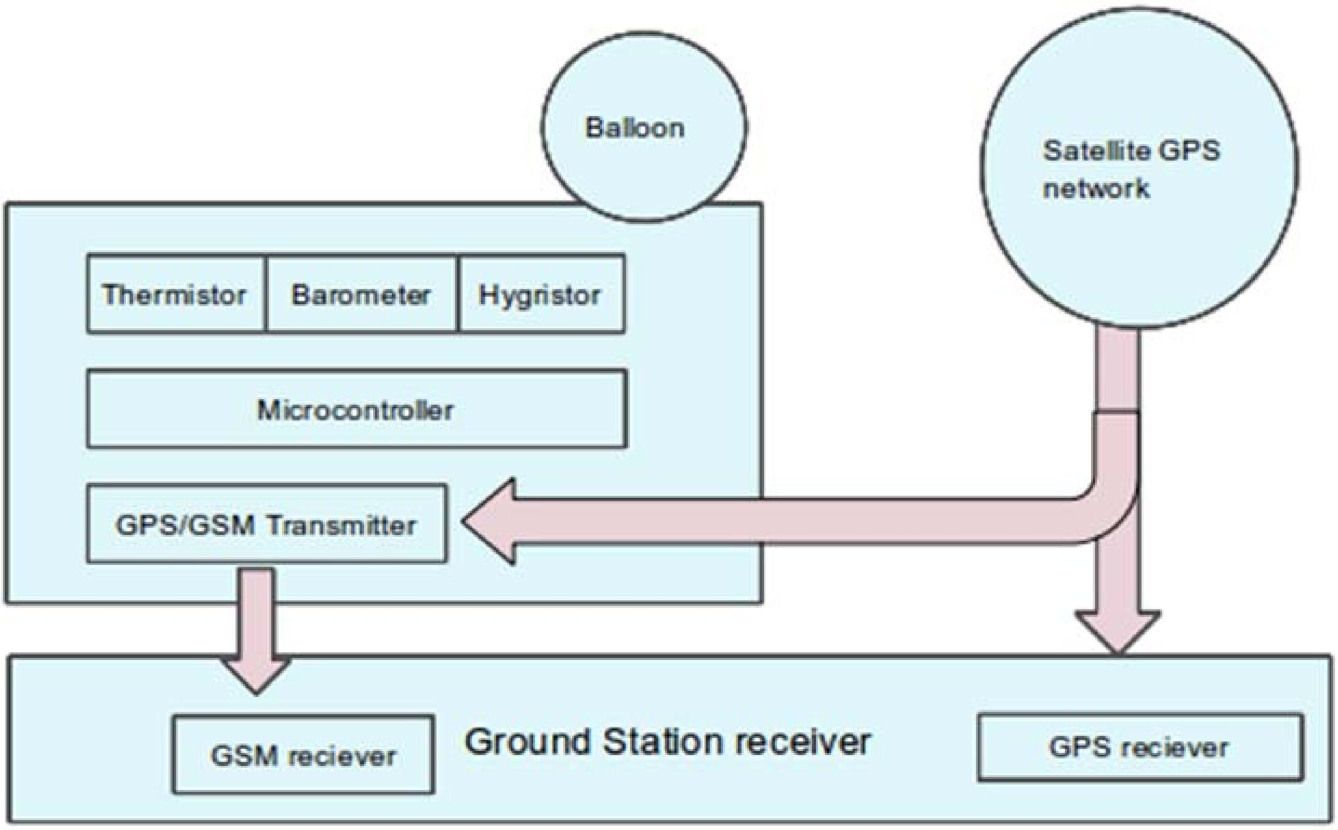

Figure 1: A block diagram describing the major component of the embedded system and communication.

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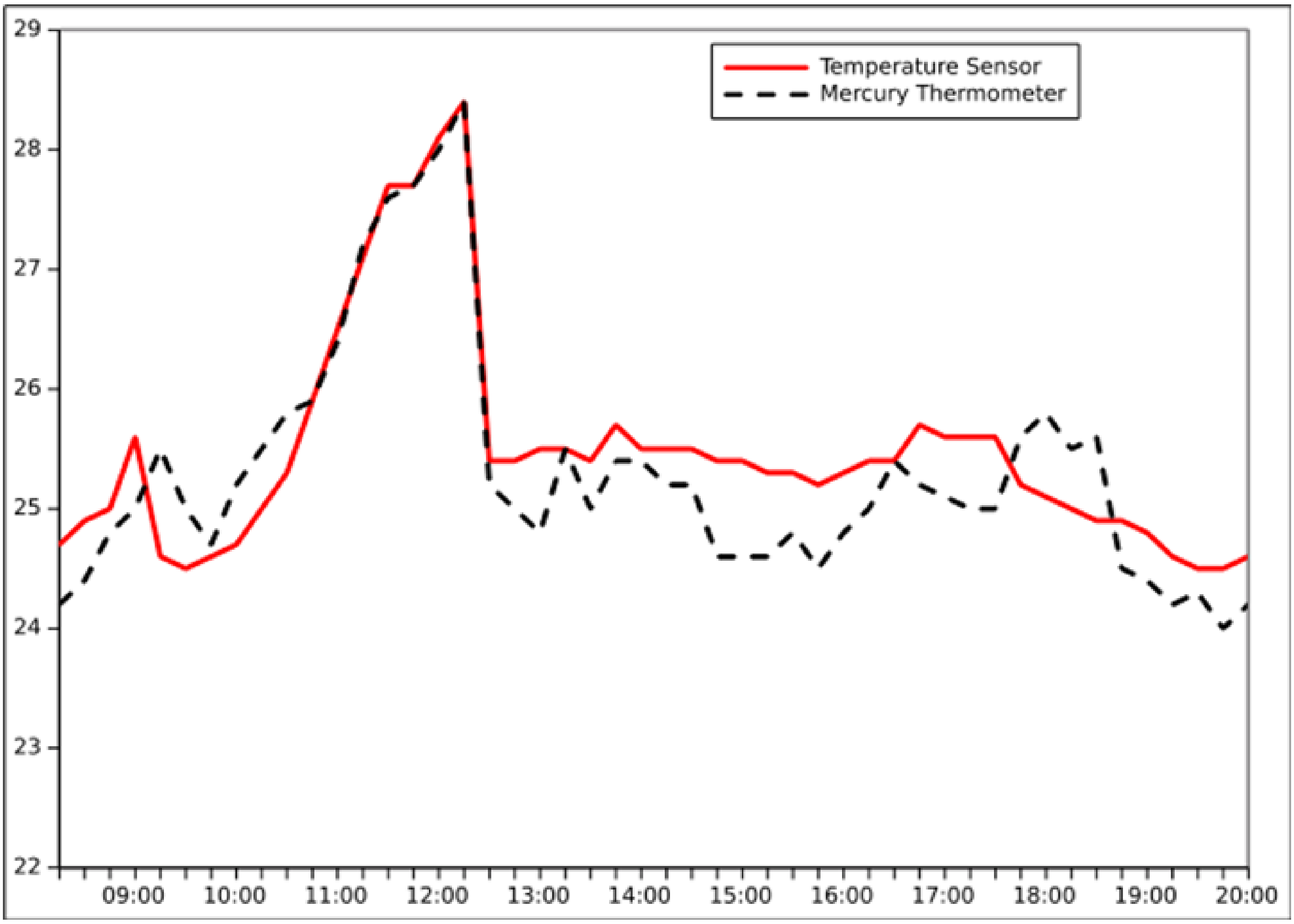

Figure 2: Sensor temperature comparison with the mercury thermometer measurement

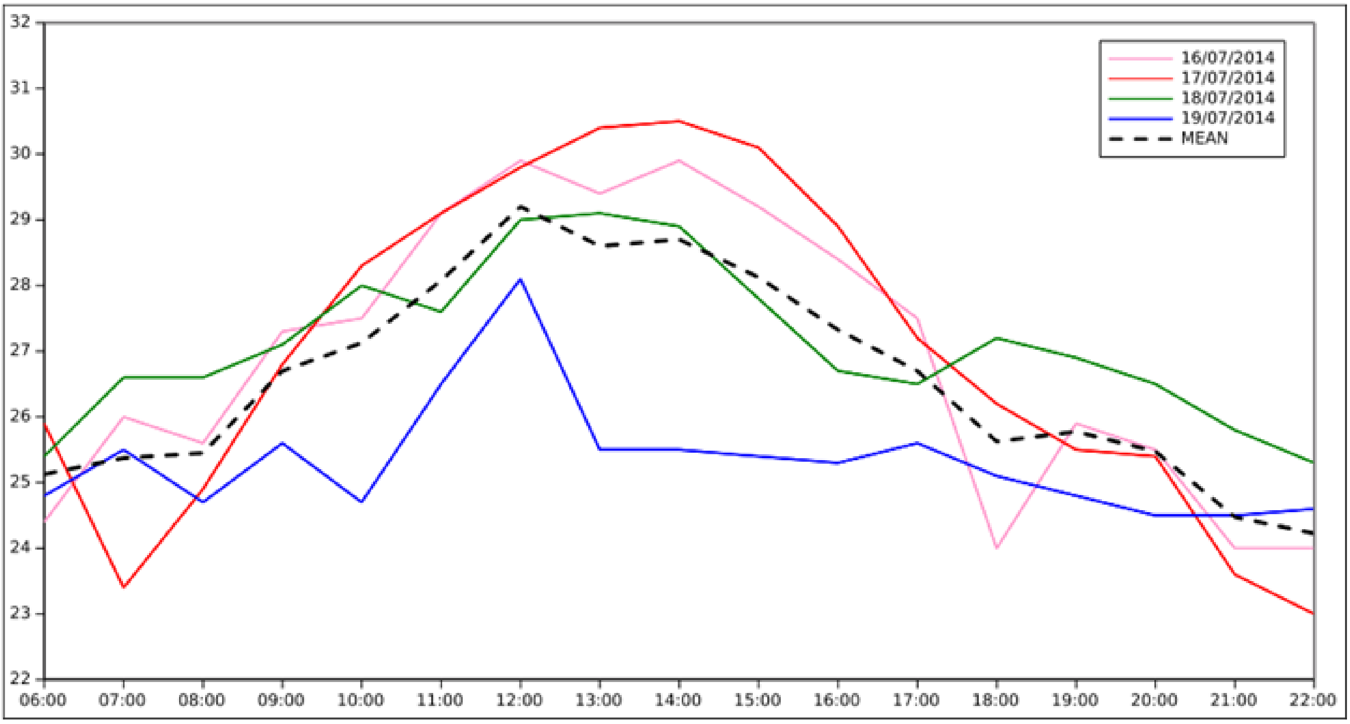

Figure 3: Day time variations of atmospheric temperature on four consecutive days along with the mean semi diurnal cycle.

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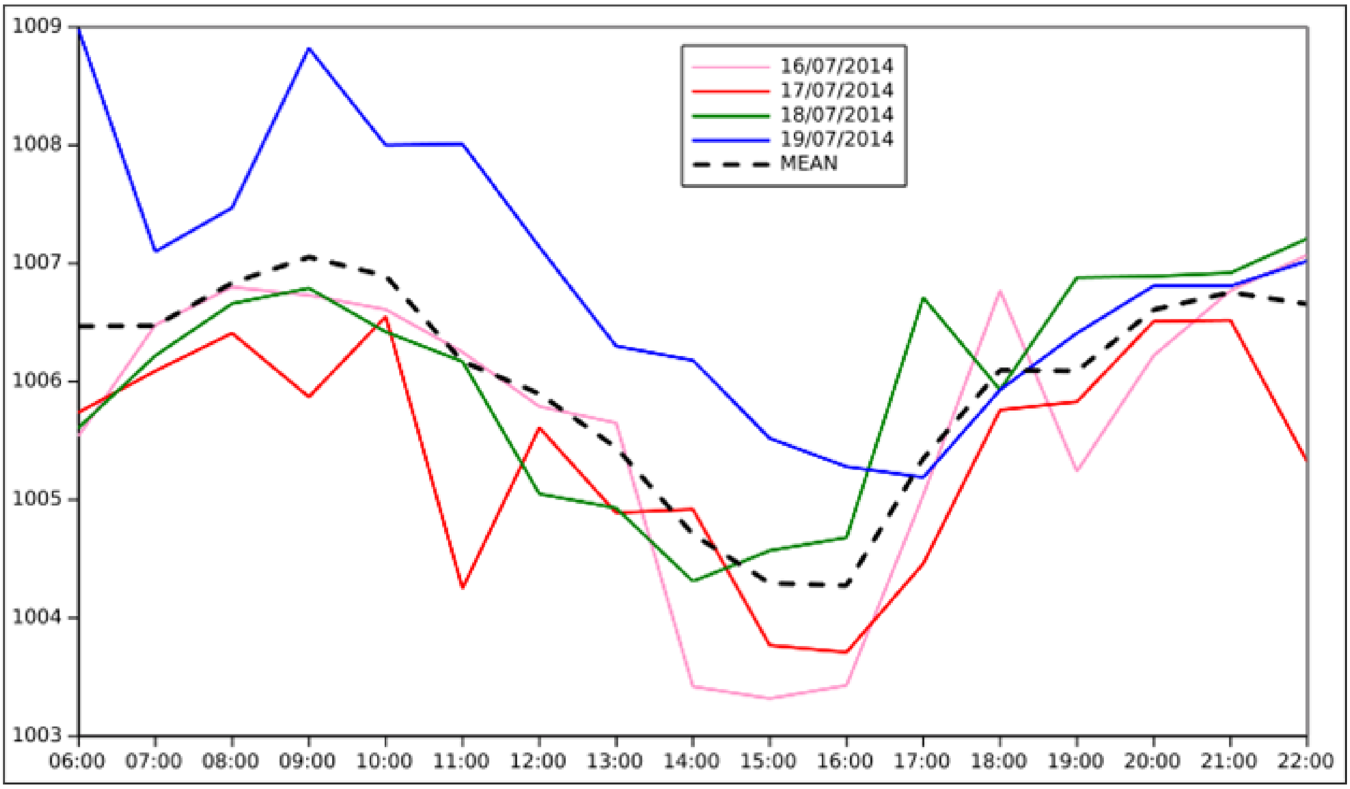

Figure 4: Day time variations of atmospheric pressure on four consecutive days along with the mean semi diurnal cycle.

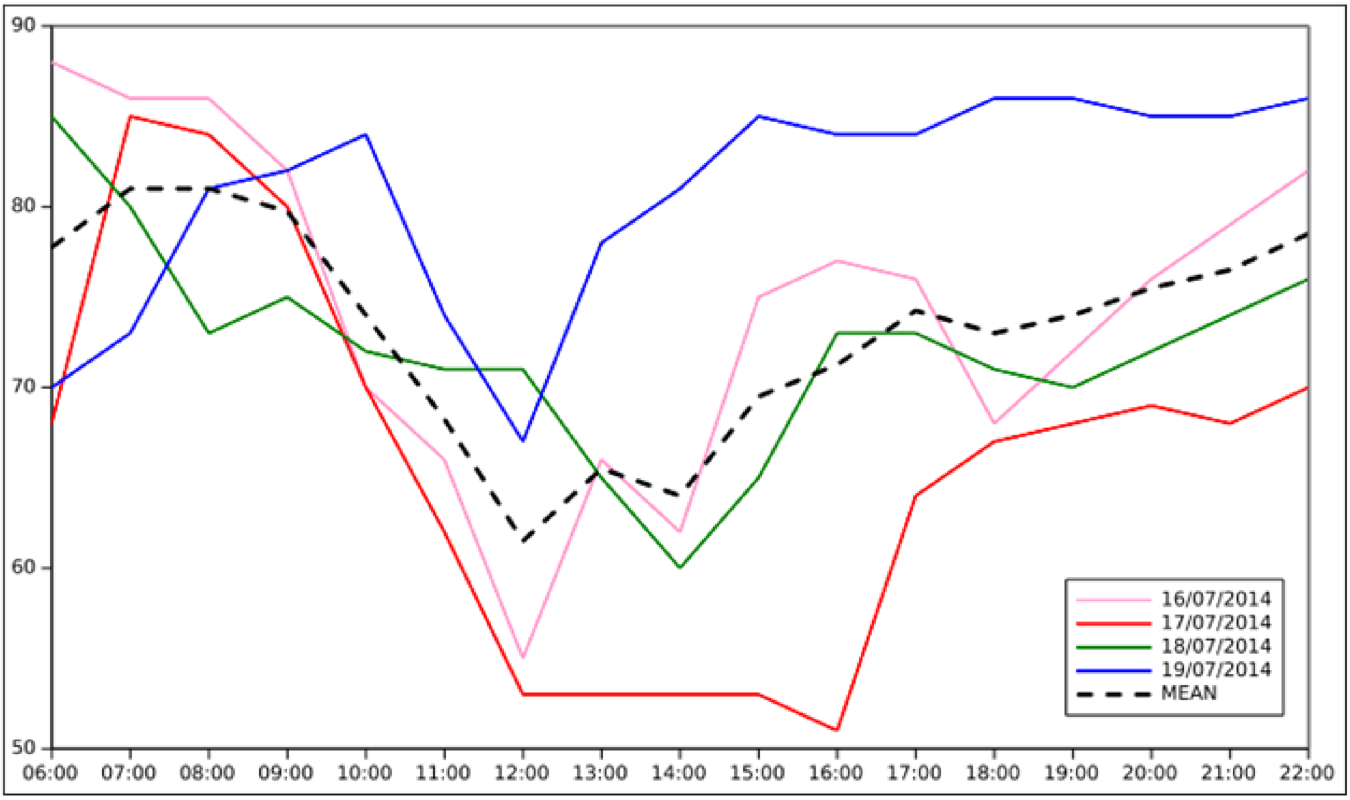

Figure 5: Day time variations of atmospheric humidity on four consecutive days along with the mean semi diurnal cycle

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