City-Scale Weather Monitoring with Campus Networks for Disaster Management: Case Study in Hyderabad

Hideya Ochiai
The University of Tokyo
jo2lxq@hongo.wide.ad.jp

Masato Yamanouchi
Keio University
masato-y@kmd.keio.ac.jp

Y K Reddy
Indian Meteorological Department
yeredla@yahoo.com

Hiroshi Esaki
The University of Tokyo
hiroshi@wide.ad.jp

***Abstract*—A weather station with communication capability allows remote weather monitoring, which observations help us to estimate flooding and to make an alarm for evacuation from potential weather-related disasters. Rainfall often comes with a very local weather phenomenon, and to capture them, we have to deploy many weather stations geographically densely. This paper provides our study on a city-scale weather monitoring system for disaster management applications. We have identified a compact observation scheme for city-scale weather monitoring with campus networks, and developed our weather stations. In this work, we have deployed our weather stations at 18 locations over the city of Hyderabad India, and evaluated the performance of our city-scale weather monitoring system. With our preliminary analysis on the observations of 15th June 2014, we confirmed that our system had detected very heavy, local and short-term rainfall, sudden temperature changes, sudden wind changes, and rapid and very local air pressure changes. These results indicate that we can use this type of city-scale weather monitoring system for capturing the local weather phenomenon and for disaster management applications.**

Keywords*—*Weather Monitoring System, Disaster Management, Time-Series Data Collection

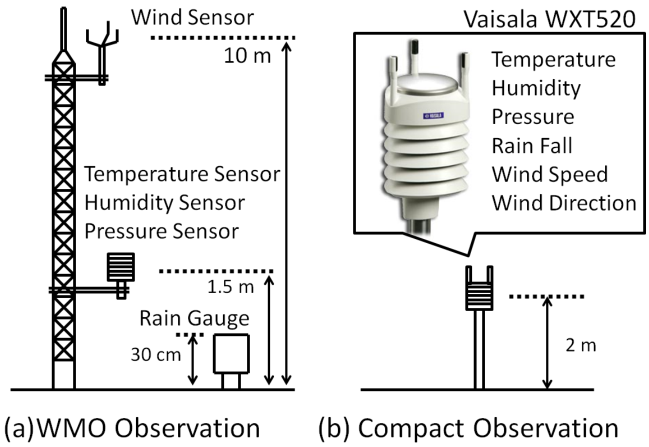

Fig. 1. Weather observation should be ideally made on (a) WMO scheme, but for disaster management purposes, we have chosen (b) compact method for city-scale weather monitoring.

I. Introduction

Protecting a city from weather-related disasters has entered a new age with the spread of Internet as the communication infrastructure. Almost all the universities, colleges and schools have Internet in their campuses these days. Weather stations with Internet connectivity allow remote weather monitoring, which observations help us to estimate flooding and to make an alarm for evacuation from potential disasters.

In many countries, weather stations are already deployed all over the country. However, those weather stations are usually geographically not dense enough to observe meso-gamma scale (i.e., 2km - 20km scale, or we call city-scale in this paper) weather phenomenon. They sometimes fail to detect very heavy rainfall occurred next to a weather station. In order to observe such rainfall, it is necessary to explore a weather monitoring system that we can deploy geographically densely over the city.

This paper provides our study on a practical city-scale weather monitoring system that uses campus networks for collecting data. In this work, we have based on Live E! weather monitoring platform [2], improved the deployment styles and communication features, implemented and tested on the city of Hyderabad, India.

The ideal weather monitoring system should be based on the observation standard of world meteorological organization (WMO). However, in this work, we explore a system of simpler but geographically denser weather monitoring that can be used for weather-related disaster management applications: i.e., to detect local heavy rainfall and to make an alarm.

The weather stations in our work are based on Vaisala WXT520 (see Figure 1). This is a compact weather sensor that observes temperature, humidity, air pressure, rainfall, wind speed and direction. In this work, we have deployed it about 2 meters high from the ground with about every 10 km: totally at 18 locations over Hyderabad. We recognize that, according to WMO, to precisely observe the weather, we have to deploy (1) a wind sensor at 10 meters high, (2) temperature, humidity and air pressure sensors at 1.5 meters high, and (3) rain gauge at 0.3 meters high. However, the cost of installing such a weather station is so high, and we cannot generally deploy them geographically so dense.

The weather stations we have deployed transmit observations to an Internet server with an HTTP-based protocol. To connect such Internet weather stations, we have used campus

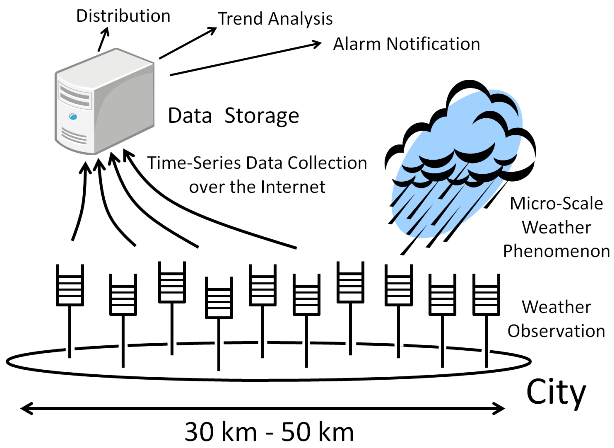

Fig. 2. System architecture for city-scale weather monitoring. Weather stations deployed in a city periodically submit their observations to the data storage server on the Internet. Applications such as data distribution, trend analysis and alarm notification use the data gathered at the server.

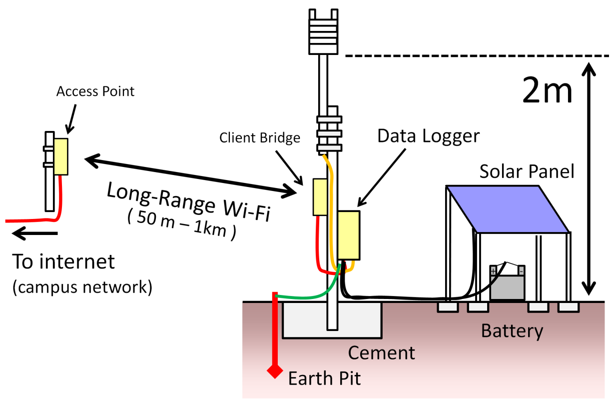

Fig. 3. The design of a weather station (Wi-Fi + Self-Power model). This system is autonomous and can be easily deployed into an open space. We don't have to deploy long power and Ethernet cables (e.g., 100 meters) from the power point and network switch of the site organization.

networks of universities, colleges and research organizations.

In Live E! weather monitoring[2], we have deployed weather stations in varieties of manner just considering the use of campus networks. We sometimes deployed on top of a building and sometimes near buildings or trees, which degraded the performance of the weather station. The deployment was mainly made in Japan, where the power-supply and Internet connectivity is very reliable. Thus, we did not consider the tolerance to the loss of them, which happens frequently now in India. In this work, to maximize the performance, we have defined our uniform observation scheme first, and then re-designed weather station systems to fit to these requirements.

We recognize that 3G and GPRS communication is also available these days all over the world. However, in this work, we try not to rely on such communication services, which we have to pay the communication fee every month. This deployment and weather monitoring is made on a five year research project called DISANET. If we have taken such communication scheme, we will have a risk of stopping the system right after the project.

This paper is organized as follows. Section 2 describes the design of our city-scale weather monitoring system. Section 3 provides the deployment details. In section 4, we describe the result of our preliminary analysis. Section 5 provides the discussion and related work. We conclude this paper in section 6.

II. City-Scale Weather Monitoring

This section describes the system architecture for city-scale weather monitoring. We also describe the identified weather observation scheme for this project, and the design of weather station and communication scheme.

A. System Architecture

The architecture that we have adopted for this work (i.e., city-scale weather monitoring) itself is quite common. As figure 2, we setup a data collection server on the Internet with global and static IP address. We install weather stations on the sites with, in many cases, private IP addresses under network address translators (NAT). Each weather station submits its observations to the server. The server provides data to multiple applications: e.g., alert notification for disaster management, trend analysis for weather-related research, and distribution to agricultural organizations and water-management organizations.

The weather stations should be deployed geographically uniformly as much as possible in order to observe wide-area weather phenomenon with sufficient density.

B. Weather Observation in this Project

Though Vaisala WXT520, a compact weather sensor we chose for city-scale weather monitoring, is much more lightweight than WMO-based weather stations, there are some requirements, especially in selecting the location, to maximize the performance of its observation.

1) A weather station should be deployed into an open space, because buildings, mountains and trees become fatal obstacles for weather observation:

- It cannot correctly observe temperature and humidity if obstacles block the sunlight.
- It cannot correctly observe rainfall if obstacles are nearby, because they sometimes block the rain coming from that direction.
- It cannot correctly observe wind if obstacles are nearby, because they change the wind speed and direction around the obstacles.

2) Weather monitoring should be made in the same style as much as possible, because the observation value changes, for example, depending on the height from the ground:

- The temperature at the terrace of a building at the daytime is usually lower than the temperature of 2.0 meters high from the ground.
- The wind speed at the terrace of building is usually larger than the wind speed near the ground.

- If we have deployed them without considering these effects, we cannot easily compare the observations among different sites because they have different features.

In this work, we try to deploy weather stations in open spaces as much as possible. We have also chosen 2 meters as a standard height of the sensor from the ground.

As for observation interval, to detect sudden weather changes expected to happen in city-scale weather phenomenon, we consider one minute as our observation interval; i.e., a weather station submits observations every minute.

C. Weather Station System Design

Open spaces usually do not have network and power supply around 50 or 1000 meters range. To provide network and power to a weather station deployed in an open space, we propose to use (1) long range Wi-Fi to provide network connectivity, and (2) self-power system to reduce civil works.

Figure 3 shows the design of a weather station we have identified in this work. This weather station has a self-power system with solar panel and battery, is connected over long range Wi-Fi to the campus network of the site organization. The sensor is attached on top of a pole concreted by cement on the ground. The standard height is 2 meters. The data logger and Wi-Fi module is also attached to the pole.

Typically, a weather sensor itself (e.g., Vaisala WXT520) provides observations over serial communication lines. So, in this design, we use an embedded computer to read observations from the sensor on its serial cable and to send it to the data storage server over TCP/IP/Ethernet. The Ethernet interface is connected to a Wi-Fi client bridge, which associates to a Wi-Fi access point. The Wi-Fi access point should be deployed so as to provide radio connectivity to the weather observation site. In many cases, the terrace of a building works. With the pair of Wi-Fi access point and client bridge, this system connects the embedded computer of the data logger to the campus network.

To provide power to the embedded computer and the other equipment, this system has charge controller and DC-DC converter(s). The charge controller manages the solar power and battery charging, and supplies the power to the DC-DC converter(s). The DC-DC converters appropriately change the voltage and provide electricity for the embedded computer, weather sensor and Wi-Fi client bridge.

There are some options for the design of a weather station. For example, if the power is available near the weather station, we can use it with uninterruptible power supply (UPS). If the network and power is available at the same location and it is not difficult to deploy cable, we can use PoE injector and splitter to provide network and power over a single Ethernet cable. If we use weather resistant cable with proper civil works, those approaches may also work.

D. Communication for Weather Data Collection

In this work, we have used facility information access protocol (FIAP)[5] to collect weather observations from the stations. FIAP defines time-series data model and data storage

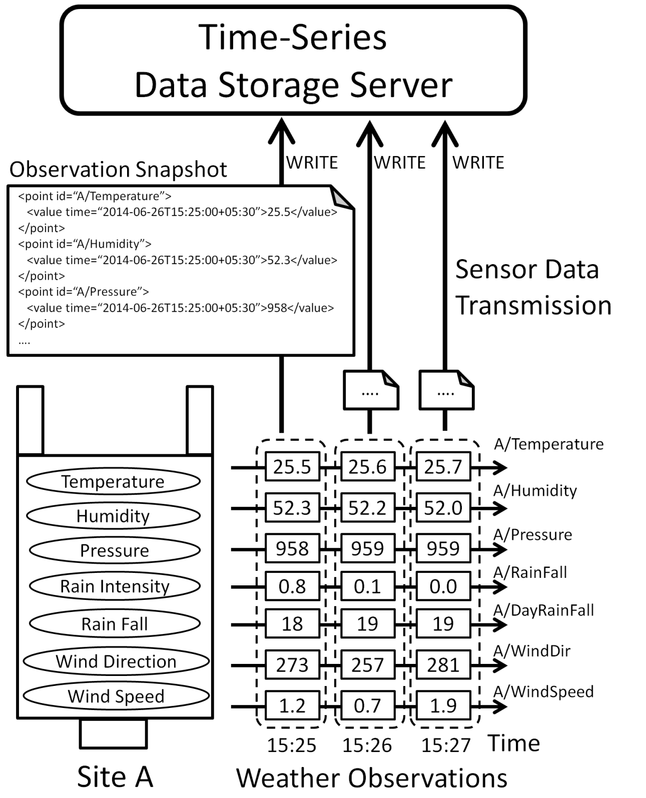

Fig. 4. Transmission of weather observations into time-series data storage. We presented weather observations onto FIAP's time-series data model. The embedded computer transmits the observation snapshot to the data storage every minute.

for such time-series data, which we can also apply to weather monitoring applications.

As figure 4, we consider that a weather station has multiple elemental sensors. Those sensors individually and periodically generate observations as time-series data. In order to manage the observations, data logger assigns a text-based unique identifier for time-series data. Here, in weather monitoring applications, each identifier may contain the name of the site and the type of the sensor. For example, we can design the identifier for temperature sensor of site A as "A/Temperature" in the text.

Data logger submits the observations by FIAP's WRITE procedure. If the network is working, it submits data every minute after getting the observations from the sensors. However, the network sometimes becomes unavailable because of power failure or Wi-Fi link disruption. To get the tolerance for temporal communication failure, the failure should be detected and observations should be re-submitted after the recovery of the network.

The data logger should have an adjusted clock to put correct timestamps to the observations. We can use network time protocol (NTP) to synchronize its clock to a network time server.

III. DEPLOYMENT IN HYDERABAD, INDIA

As figure 5 shows, we deployed weather stations at 18 locations in Hyderabad, India. We made the deployment so as

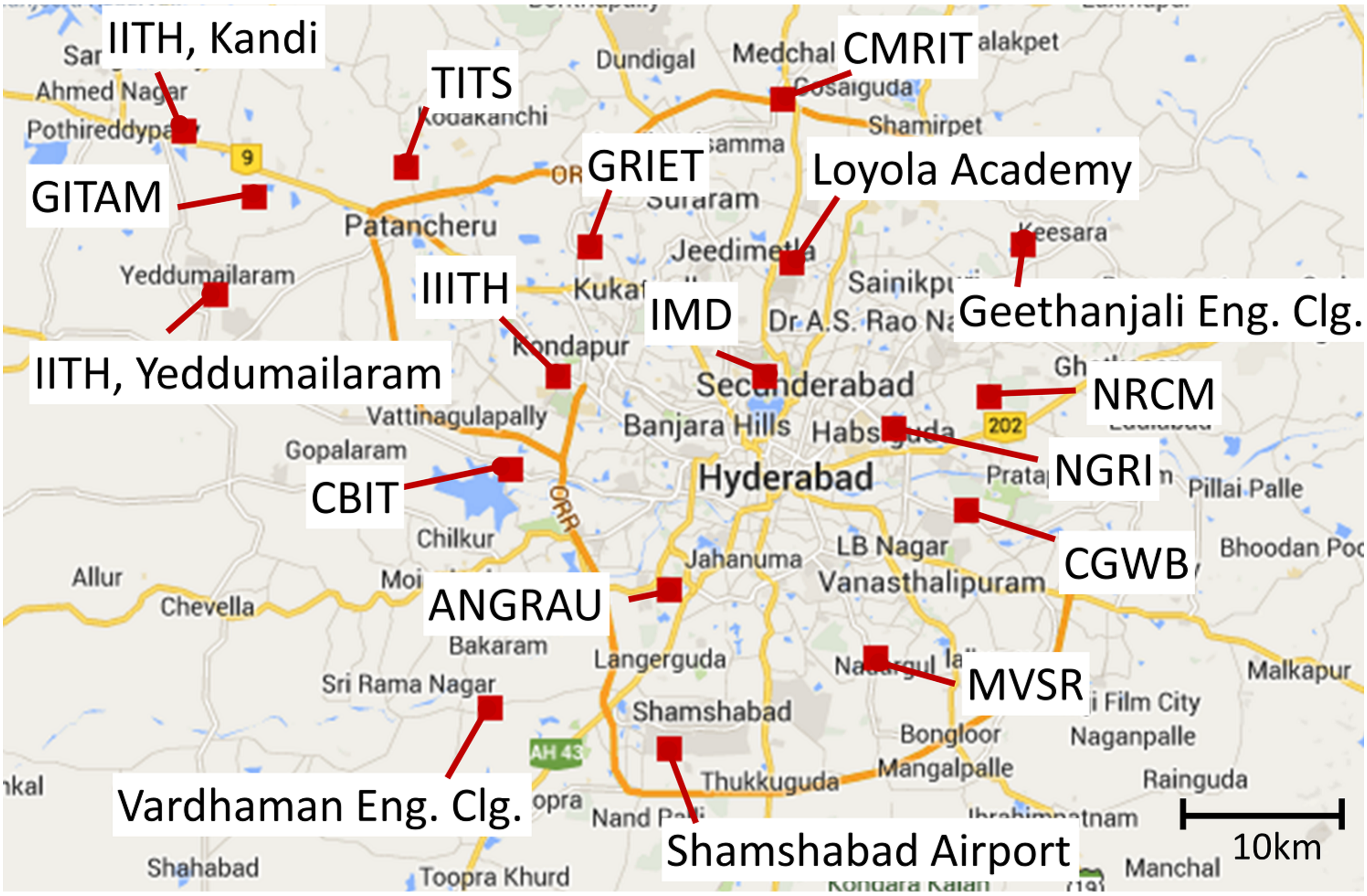

Fig. 5. Weather station deployment map in Hyderabad, India. We have deployed at 18 locations. They cover most of the area of Hyderabad.

TABLE I. WEATHER STATION DEPLOYMENT DETAILS

Location Name	Model	Date
IMD Hyderabad, Begumpet	Wi-Fi + Site Power	Sep 2010
Loyola Academy, Alwal	Power over Ethernet	Nov 2012
GITAM University, Rudraram	Power over Ethernet	Jun 2013
Shamshabad Airport	Wi-Fi + Site Power	Sep 2013
IIT Hyderabad, Yeddumailaram	Wi-Fi + Site Power	Sep 2013
IIT Hyderabad, Kandi	GPRS + Self Power	Sep 2013
NGRI, Uppal	Wi-Fi + Site Power	Oct 2013
IIIT Hyderabad, Gachibowli	Wi-Fi + Site Power	Nov 2013
NRCM, Chengicherla	Wi-Fi + Self-Power	Nov 2013
GRIET, Nijampet	Wi-Fi + Site Power	May 2014
CBIT, Gandipet	Wi-Fi + Self-Power	May 2014
CMRIT, Kandlakoya	Wi-Fi + Site Power	May 2014
CGWB, Tattiannaram	Wi-Fi + Self-Power	May 2014
Geethanjali Eng.Clg., Cheeryal	Wi-Fi + Site-Power	Jun 2014
MVSR, Nadargul	Wi-Fi + Self-Power	Jun 2014
ANGRAU, Rajendranagar	Wi-Fi + Self-Power	Jun 2014
TITS, Indresham	Wi-Fi + Self-Power	Jun 2014
Vardhaman Eng.Clg., Shamshabad	Wi-Fi + Self-Power	Jun 2014

to cover most of the city area.

Table I shows the model and the deployment date of each weather station. At an early stage, we started with (1) Wi-Fi + Site-Power or (2) Power over Ethernet models. However, these schemes required heavy civil works – we had to ditch for more than 50 meters with 30 cm depth and bury cable carefully under the ground sometimes across a road. So, in the latter part of the deployment, we have adopted (3) Wi-Fi + Self-Power model (as described in Section II.C). This model allowed the reduction of civil works and made deployment feasible for all the sites. All the deployment has been finished on the 10th of June 2014.

For the deployment based on Wi-Fi + Self Power model, we have used a pair of EnGenius ENH500 for long range Wi-Fi communication. As this Wi-Fi unit requires DC24V 700mA, we used 180W solar panel (18V, 10A) and 12V 100Ah Pb battery. And, we used a 24V-output DC-DC converter for this Wi-Fi module, and a 5V-output DC-DC converter for the embedded computer and Vaisala WXT520.

We have also used GPRS solution for IIT Hyderabad, Kandi, where no Internet was provided in the campus at the time of deployment. GPRS model was also helpful for installation, but we now pay the communication fee (about the equivalent of 5 USD) every month.

IV. DETECTION OF CITY-SCALE WEATHER PHENOMENON

Weather conditions are not uniform over a city. Rainfall usually happens locally, temperature sometimes changes quite rapidly and wind direction also changes suddenly. The local phenomenon may even change air pressure. As a preliminary evaluation of our city-scale weather monitoring system, we have analyzed the pattern of rainfall, temperature, wind direction and air pressure.

We have made this analysis on the observations of the evening of 15th June 2014. We have detected very heavy and

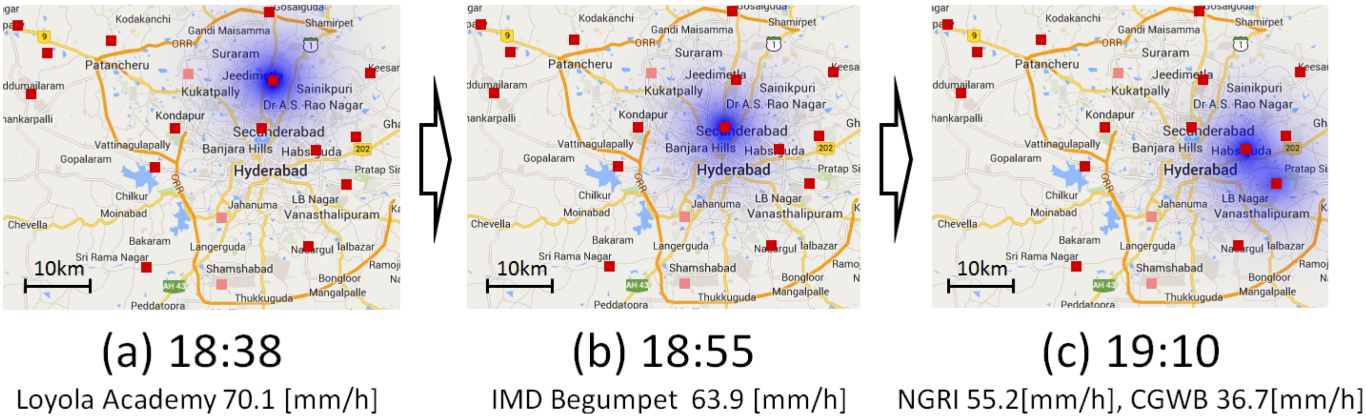

Fig. 6. Heavy rainfall detected by our city-scale weather monitoring system on 15th of June 2014. It was suddenly detected at (a) Loyola Academy, and then it moved to (b) IMD Begumpet. Finally, it moved to (c) NGRI and CGWB. Other sites did not detect rainfall. This result indicates that our weather monitoring system have successfully detected very local short-term heavy rainfall.

short-term rainfall in a part of the city, which is one of the local weather phenomenons that we target with this system.

A. Local Short-Term Heavy Rain

Figure 6 shows how the rainfall was observed on 15th June 2014 by our weather monitoring system.

On the day, Loyola Academy begun to detect rainfall at 18:35 and finished at 18:45. The duration was only 10 minutes. The maximum intensity of the rain was 70.1[mm/h] at 18:38. Next, IMD Begumpet detected rainfall from 18:52, recording the intensity of 63.9[mm/h] at 18:55. The rain has continued for 11 minutes at IMD. Then, it moved to NGRI and CGWB. NGRI started to detect at 19:03, and CGWB at 19:04. The maximum intensity was 73.7[mm/h] at 19:06 at NGRI, and 36.7[mm/h] at 19:10 at CGWB. The rain finished at 19:13 and 19:20 respectively. Other sites did not have rain.

Here, the distance between Loyola Academy and IMD is about 7 km, IMD and NGRI is 8 km, NGRI and CGWB is 6 km.

This result indicates that our city-scale weather monitoring system has certainly detected such very local, short-term and heavy rainfall. It has recorded how the rainfall begun, moved and ended over the city.

B. Sudden Temperature Drop

Figure 7 shows how the temperature of Loyola Academy, IMD, NGRI, CGWB and CBIT have changed from 18:00 to 20:00. CBIT is located at east side of Hyderabad (about 20 km east from IMD). CBIT did not have rainfall on the day.

As the graph shows, the temperature of Loyola Academy started to decrease first, and then the temperature of IMD, NGRI, and CGWB decreased in this order. This corresponds to the order of the rainfall.

Especially, the temperature of CGWB has dropped rapidly – from 32.6 to 26.9 degrees Celsius in 15 minutes (19:00 – 19:15). On the other hand, the temperature of CBIT has just gradually decreased as usual.

This result indicates that our weather monitoring system has detected sudden temperature drop happened locally.

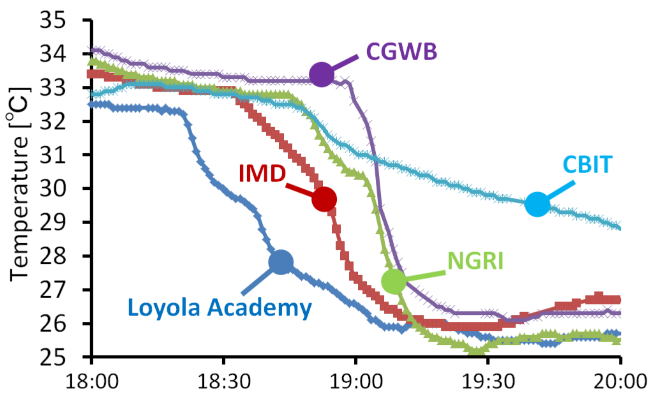

Fig. 7. Temperature patterns observed with our city-scale weather monitoring system on 15th June 2014. Temperature suddenly dropped at the sites of rain. Especially, the temperature of CGWB dropped about 2.8 degrees Celsius from 19:02 to 19:06, while the temperature of CBIT did not decrease so fast.

C. Sudden Change of Wind Direction

Figure 8 shows how the wind directions of Loyola Academy, IMD, NGRI, CGWB and CBIT have changed from 18:00 to 20:00.

As the graph shows, before 18:45, the wind directions at all the sites were from west. However, wind of Loyola Academy and IMD changed after that. At Loyola Academy, the wind direction has rotated and finally it came from south east after 19:15. At IMD, it has changed to come from north. The wind of NGRI started to change at 19:04, and it did not settle before 20:00. The wind of CGWB suddenly changed to come from north at 19:15 but finally it came from south east. The wind of CBIT was almost settled: though it has small differences, it came from west all the time.

This result indicates that our weather monitoring system could take the geographical snapshots of wind directions, which represent very local and rapidly changing weather phenomenon.

D. Local Air Pressure Changes

Air pressure is usually considered to be almost uniform over the city. However, we have also detected sudden air

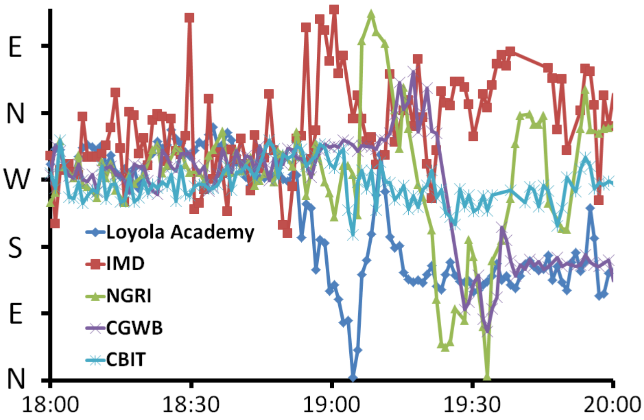

Fig. 8. Wind directions observed with our city-scale weather monitoring system on 15th June 2014. Before 18:45, the wind came from west at all the sites. After 18:45, wind direction started to change from Loyola Academy, IMD, NGRI and CGWB in this order. Finally, they settled to different directions. The system has observed local wind flows generated by such city-scale weather phenomenon.

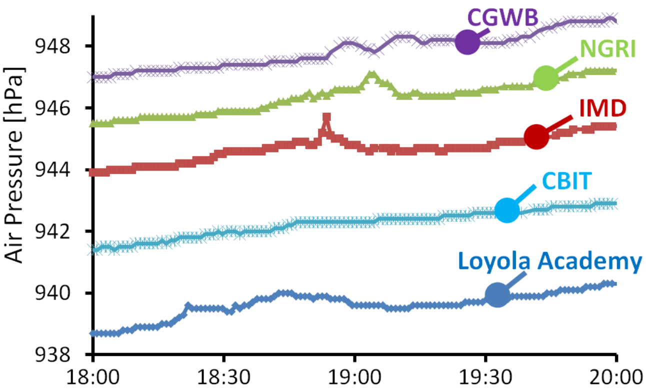

Fig. 9. Air pressure observed with our city-scale weather monitoring system on 15th June 2014. The absolute values of air pressure are different by location because of the altitude from the sea level is not the same. Sudden peak appeared in IMD and NGRI's observations at the time when they had heavy rainfall.

pressure changes. Figure 9 shows the trend of air pressure at Loyola Academy, IMD, NGRI, CGWB and CBIT. The absolute values are different because the altitude of the sensor from the sea level is not the same. The air pressure of all the sites gradually increased from 18:00 to 20:00, this is a global trend always observed in Hyderabad. However, the system has detected sudden increase of air pressure at IMD (about 0.9[hPa] at 18:54) and NGRI (about 0.5[hPa] at 19:04). This is about one or two minutes before the maximum rain intensity recorded. After the rainfall, the pressure has decreased more than before the rainfall.

V. Discussion and Related Work

The data observed with our city-scale weather monitoring system is not compatible to the data of WMO-standard weather stations, especially regarding to wind and rainfall. However, if we consider using this system for disaster management applications, it may have enough performance to estimate flooding and to make an alarm for some areas of the city. In our preliminary evaluation, we have confirmed that it can detect very local weather phenomenon, which is necessary for estimating the local situations in disaster management.

With the advent of sensor networking technologies, many researchers have so far developed weather and environment monitoring systems. However, those works did not address the observation method for city-scale weather monitoring that we targeted in this paper. The work of IrisNet[3] focused on the integration of heterogeneous sensors provided by multiple operational domains. Semantic sensor web[6], [1] developed a framework which allows to describe varieties of observation features and to integrate heterogeneous sensors on a web-centric information infrastructure. The development and deployment studies of Sensor Asia[4] discussed the issues of easy installation of field servers (a kind of weather station) and designed the sensor system for such requirements. Our previous work[2] also focused on the development of information infrastructure for weather stations, however, without making a standard observation scheme. In this paper, assuming disaster management applications, we have identified an observation method for city-scale weather monitoring as the requirement for the system. Then, we developed, implemented and tested on the real field.

VI. Conclusion

We have studied a city-scale weather monitoring system for disaster management applications. For weather-related disaster management, it is necessary to capture very local weather phenomenon, especially rainfall to estimate flooding and to make an alarm. To maximize the performance of the monitoring system, we have identified the requirements for weather observation within the limits of compact scheme, and developed weather stations considering the communication features. We have deployed weather stations at 18 locations over the city of Hyderabad, India. According to our preliminary analysis on the observations of 15th June 2014, our system had detected very heavy, local and short-term rainfall, sudden temperature changes, sudden wind changes, and rapid and very local air pressure changes. These results indicate that we can use this type of city-scale weather monitoring system for capturing the local weather phenomenon and for disaster management applications.

References

[1] M. Botts, G. Percivall, C. Reed, and J. Davidson. Ogc® sensor web enablement: Overview and high level architecture. In *GeoSensor networks*, pages 175–190. Springer, 2008.

[2] H. Esaki and H. Sunahara. Live E! project; sensing the earth with internet weather stations. In *Applications and the Internet, 2007. SAINT 2007. International Symposium on*, pages 1–1. IEEE, 2007.

[3] P. B. Gibbons, B. Karp, Y. Ke, S. Nath, and S. Seshan. Irisnet: An architecture for a worldwide sensor web. *Pervasive Computing, IEEE*, 2(4):22–33, 2003.

[4] K. Honda, A. Shrestha, A. Witayangkurn, R. Chinnachodteeranun, and H. Shimamura. Fieldservers and sensor service grid as real-time monitoring infrastructure for ubiquitous sensor networks. *Sensors*, 9(4):2363–2370, 2009.

[5] H. Ochiai, M. Ishiyama, T. Momose, N. Fujiwara, K. Ito, H. Inagaki, A. Nakagawa, and H. Esaki. FIAP: facility information access protocol for data-centric building automation systems. In *IEEE INFOCOM M2MCN workshop*, 2011.

[6] A. Sheth, C. Henson, and S. S. Sahoo. Semantic sensor web. *Internet Computing, IEEE*, 12(4):78–83, 2008.