Design and Development of WSN, IoT, and TinyML Devices: from Edge to Data Centers

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Outline

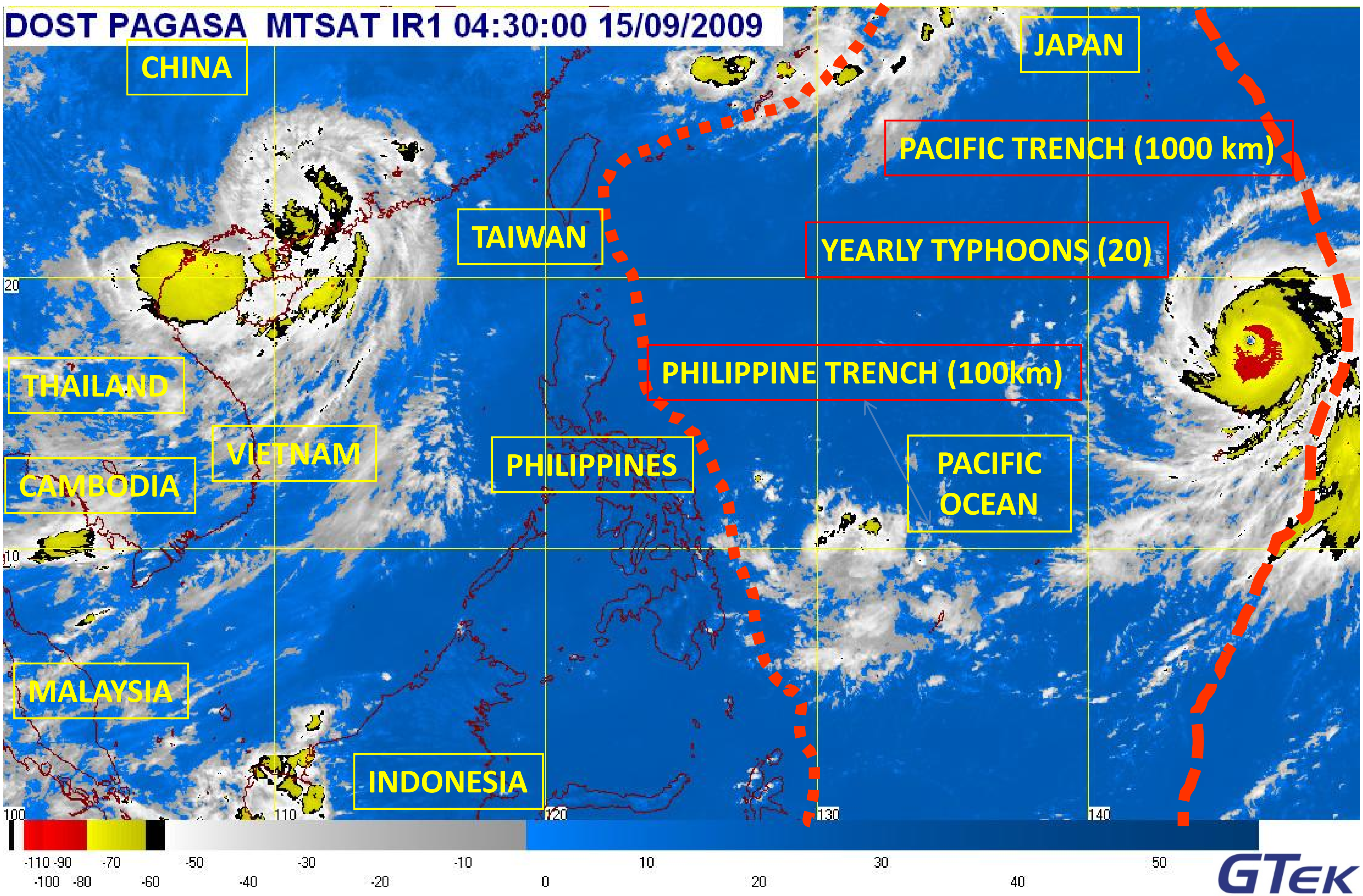
1. WSN, IoT, and TinyML Motivations: Societal Applications in the Philippines

2. Community-Based Disaster Early Warning System

3. Environmental Monitoring System

4. Structural Integrity Monitoring and Early Warning System

Motivations: Real-world Applications



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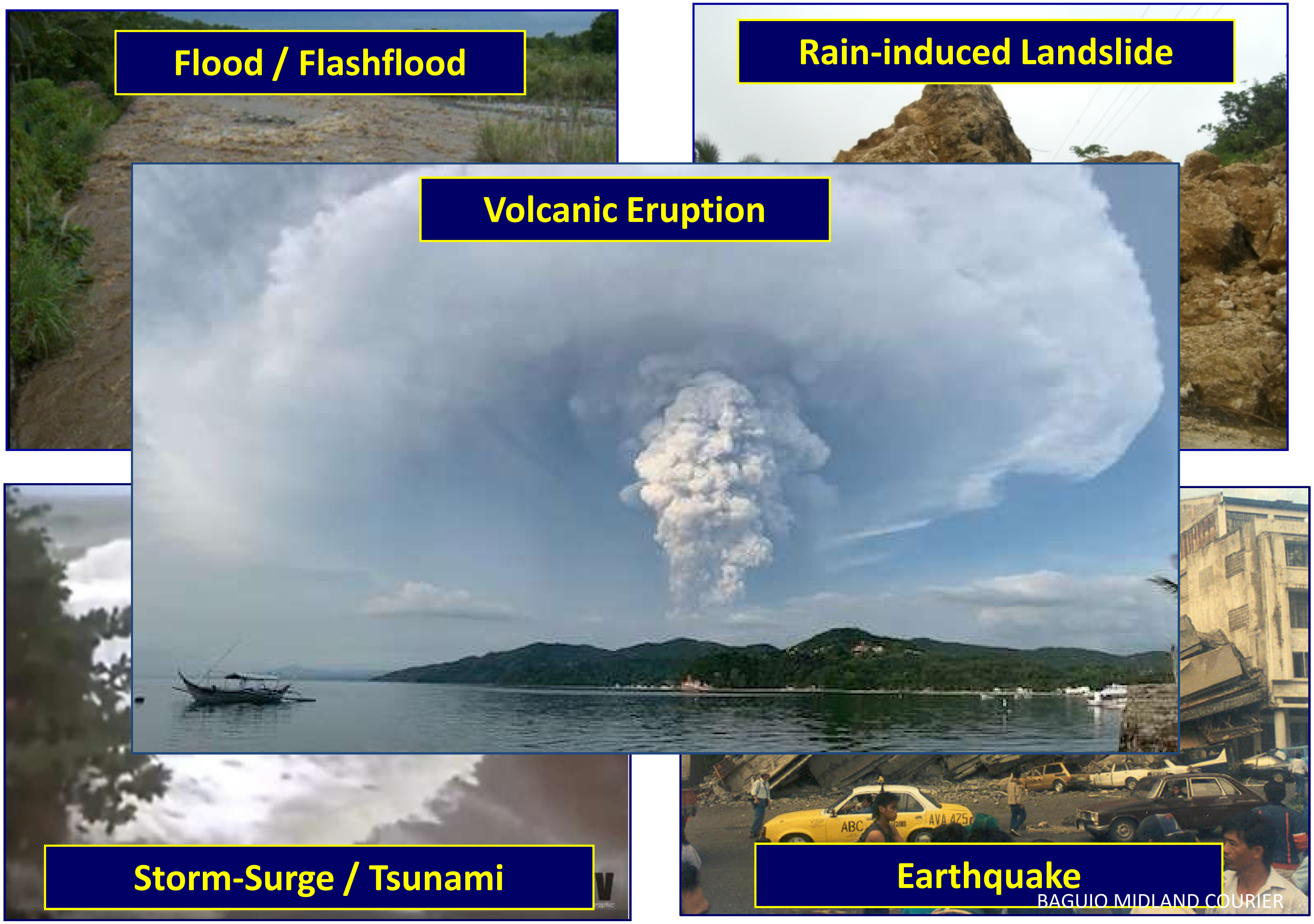
NATURAL DISASTERS… WAITING TO HAPPEN.



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The grim devastation wrought by the catastrophic flashflood in Ormoc, Leyte, Philippines. In November 1991, more than 5000 people perished in this single tragedy. Unusually heavy, continuous rains (580.5 millimeters in 24 hours) brought by tropical storm Uring caused landslides at the steep slope of a river system leading to the city of Ormoc.

A massive mudslide occurred in Saint Bernard on February 17, 2006 in the Philippine province of Southern Leyte that caused widespread damage and loss of life. The deadly landslide followed a ten-day period of heavy rains and a minor earthquake of magnitude 2.6 on the Richter scale. The official death toll stands at 1,126.

Anyone could be a victim of a disaster!

= Unaware + Unprepared

Feb 2007: Eastern Samar Landslide, during installation

To Protect Yourself =

(Right Information + Right Plan) x (Enough Lead-time)

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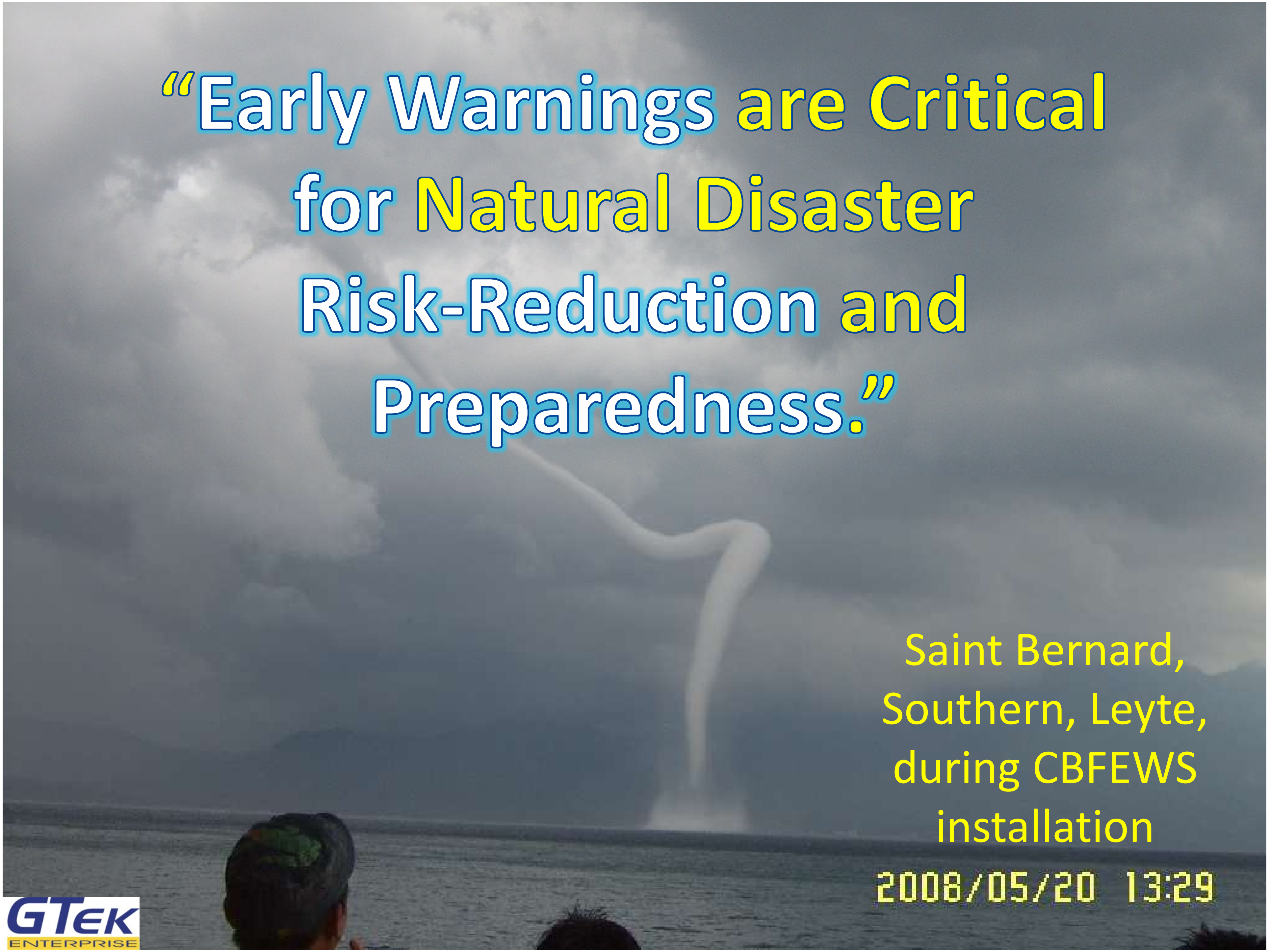
"Early Warnings are Critical for Natural Disaster Risk-Reduction and Preparedness."
Saint Bernard, Southern, Leyte, during CBFEWS installation
2008/05/20 13:29
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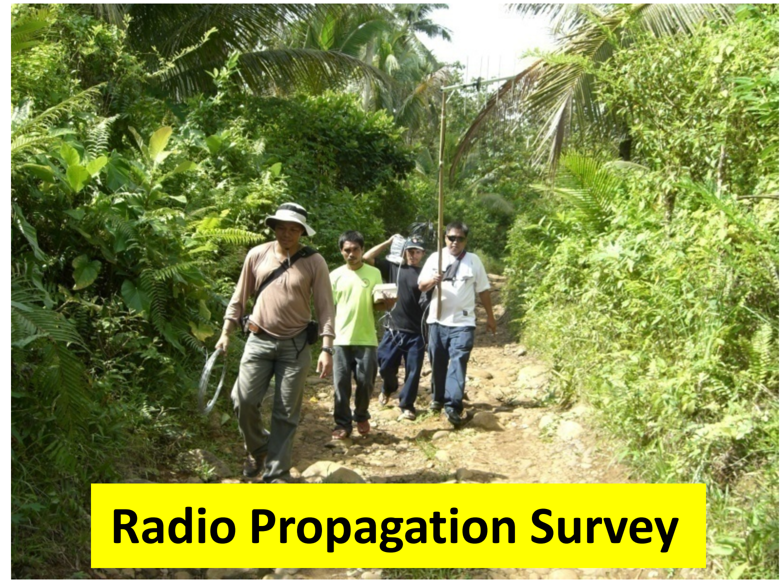
Community Interviews


Radio Propagation Survey

Solution: Designed and Developed a Community-Based Disaster Early Warning System


Rainfall Gauge

Water-level Gauge

2002: Urgent need to Implement Hydro-Meteorological Data Monitoring and Early Warning System

Objectives:

1. To warn the authorities and vulnerable population ahead of time of any threat of flood/flashflood and landslide.

2. To provide enough lead-time between a critical warning and completion of evacuation of lives and properties to safer grounds.

3. To collect data about river system characteristics (rainfall intensity and water-level) for research and creating mathematical models of the river system.

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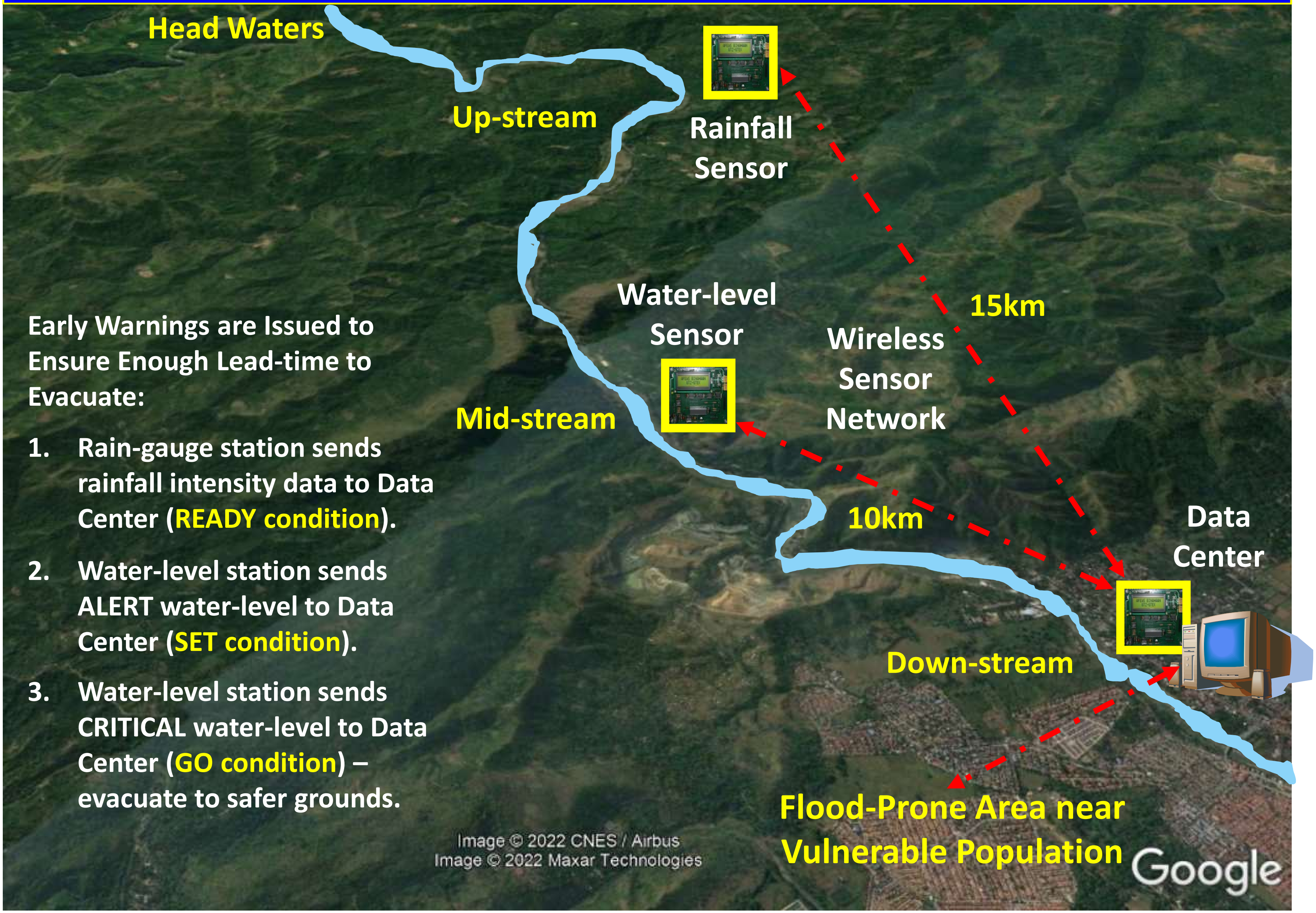
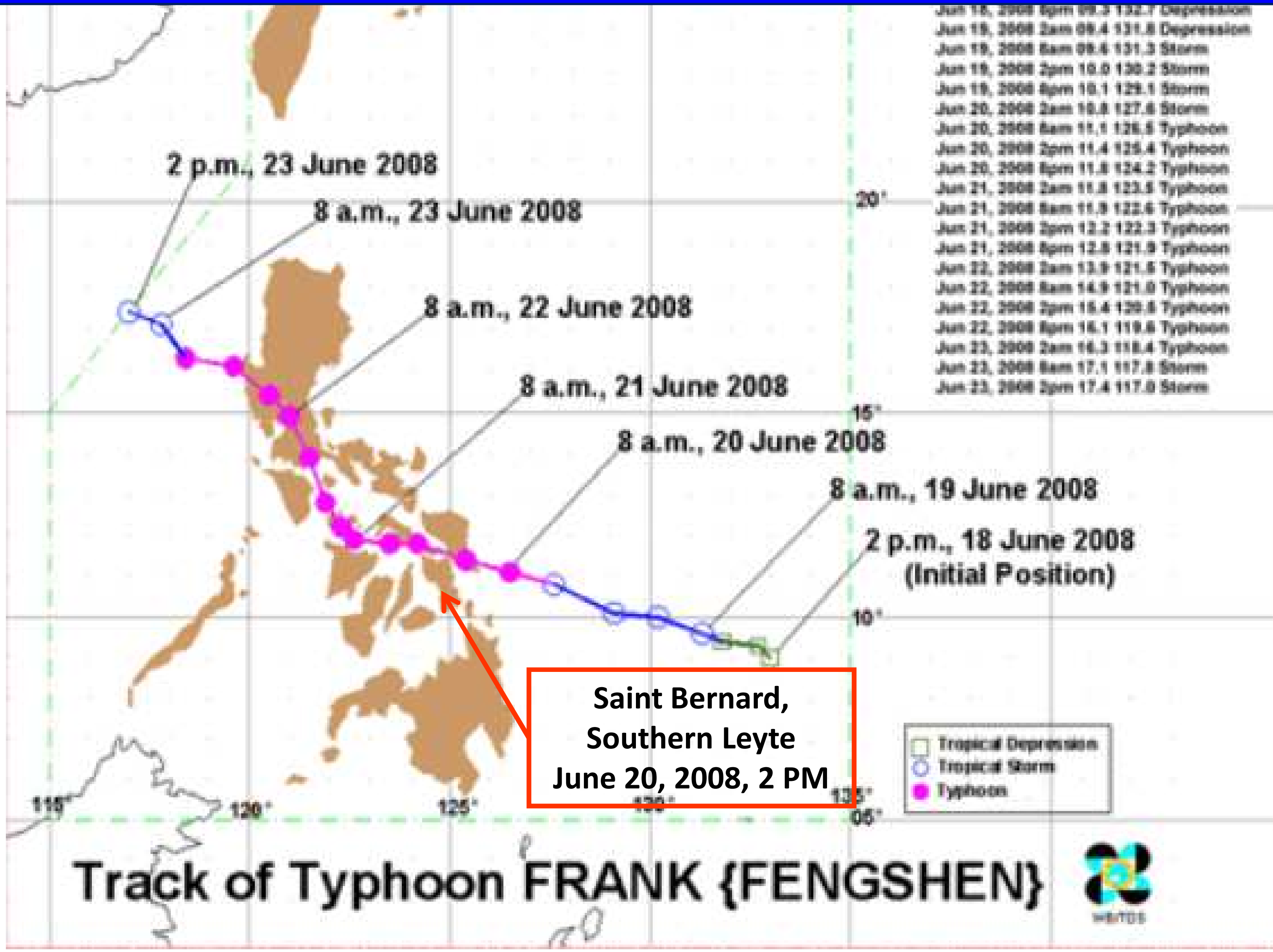
Community Based Flood Early Warning System (CBFEWS) Model



Early Warnings are Issued to Ensure Enough Lead-time to Evacuate:

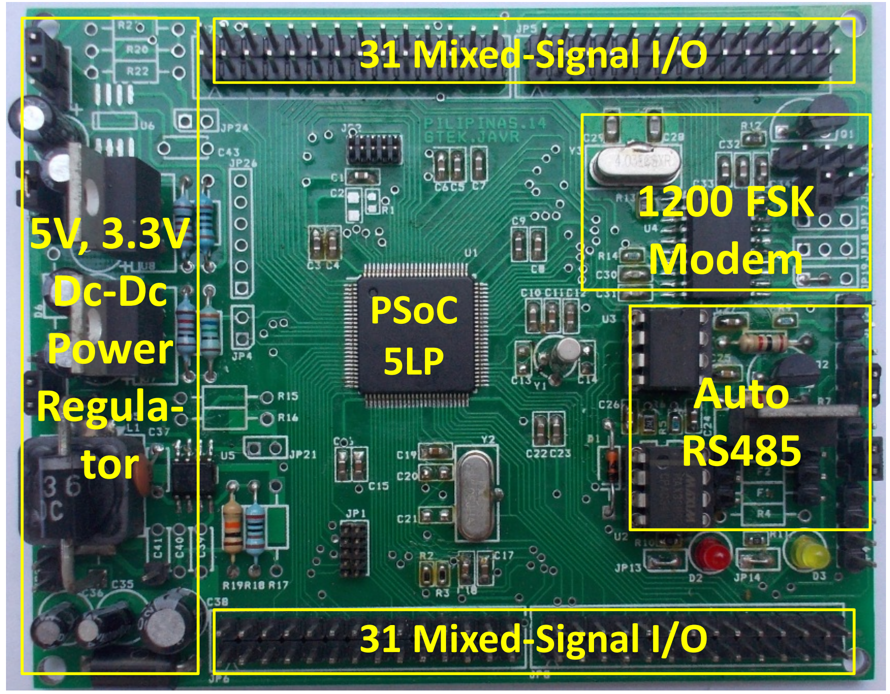
1. Rain-gauge station sends rainfall intensity data to Data Center (READY condition).
2. Water-level station sends ALERT water-level to Data Center (SET condition).
3. Water-level station sends CRITICAL water-level to Data Center (GO condition) – evacuate to safer grounds.

The Real Test: June 20, 2008 at Saint Bernard, Southern Leyte



The **CBFEWS detected a critical flood level**, autonomously informed the authorities via wireless, rescuers forced evacuated and **saved 474 people** one hour before the devastating flashflood surged down from the mountains.

Embedded PSoC-Based Controller (2014)



SENSORS:

- WATER LEVEL
- RAINFALL INTENSITY
- TEMPERATURE & HUMIDITY
- PRESSURE / ALTITUDE
- PROXIMITY / MAGNETIC
- AUTOMATIC WEATHER STATION (AWS)
- VOLTAGE, CURRENT, & POWER
- LIGHT INTENSITY
- ACCELERATION / EARTHQUAKE
- INCLINATION / TILT
- TOXIC GAS / CHEMICAL
- LIGHTNING INTENSITY & RANGE

DATA TRANSCEIVERS:

- VHF / UHF
- LoRa
- Cellular IoT
- ISM (Sub 1-GHz Bands)

DESIGNED FOR MULTI-HAZARD EWS APPLICATIONS:

- FLOOD EWS (FEWS)
- LANDSLIDE EWS (LEWS)
- TSUNAMI & STORM SURGE EWS (TSSEWS)

INTERFACES:

- COMPUTER
- ETHERNET , WIFI
- GPS, BLUETOOTH
- ZIGBEE

POWER SOURCES:

- SOLAR
- WIND
- BATTERY / DC
- AC

NON-VOLATILE MEMORIES:

- SD CARD
- FLASH / EEPROM
- DATA LOGGER

WARNING INDICATORS:

- SIREN / BUZZER
- BEACON LIGHT
- LCD / LED

Single HW design for many applications

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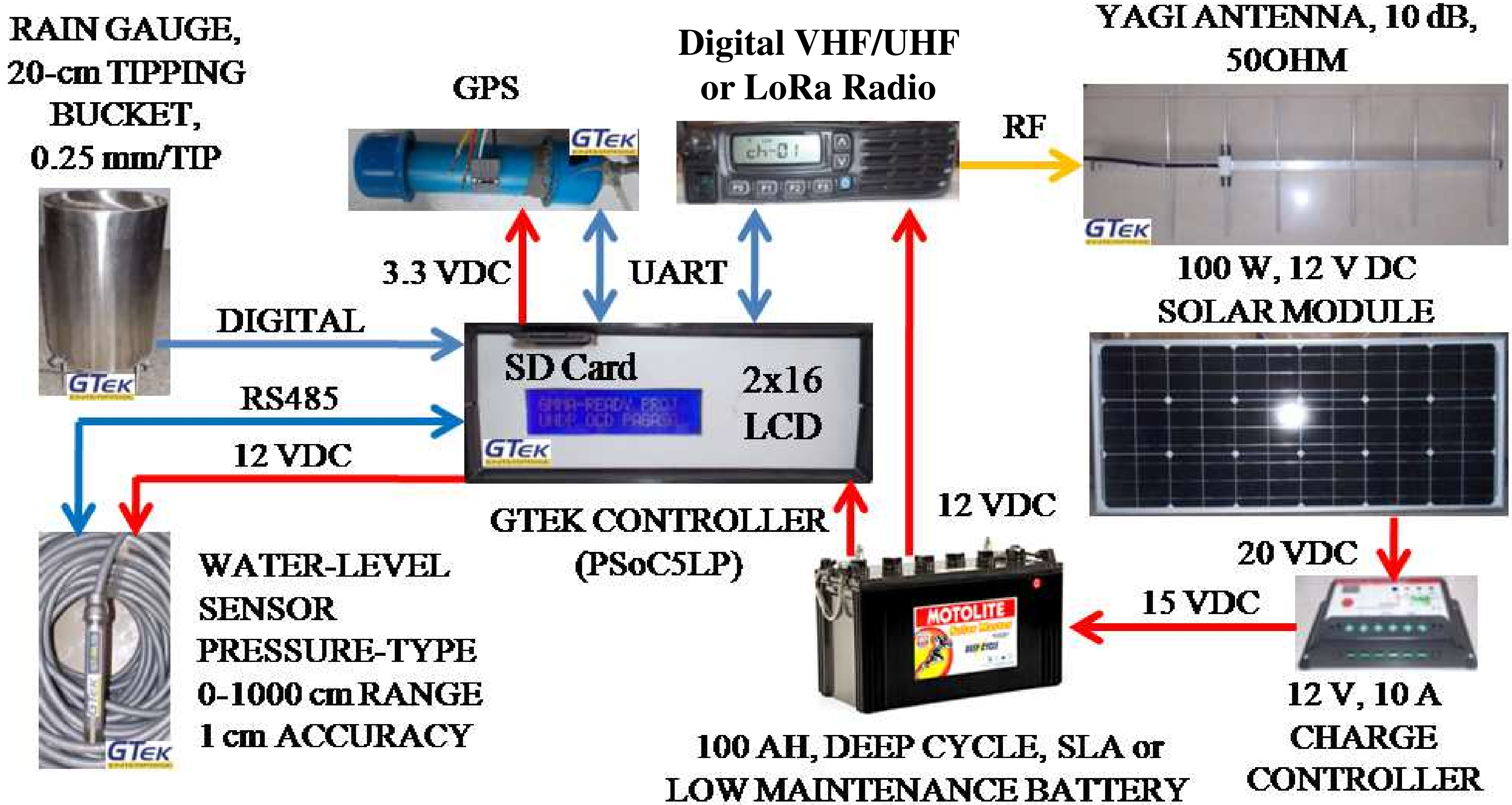
Community-Based Flood Early Warning System Station



CBFEWS Station Equipment Design.

Deployment of Community-Based Flood EW System

Fig. 4. Rain-gauge Installation (a) on frame and (b) on building rooftop.

Rain Gauge Station

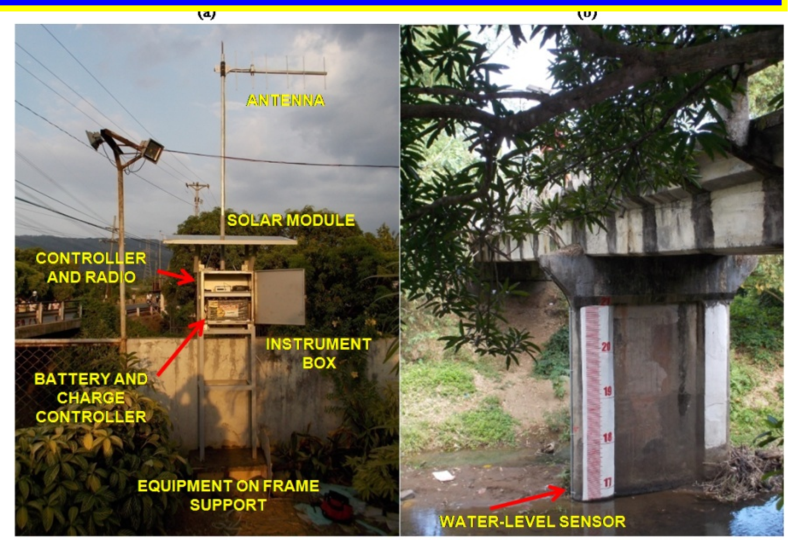


Fig. 5. Water-level Station Installation (a) on frame and (b) sensor inside a protection metal pipe bolted on bridge column.

Water-level Station

Data Center Station

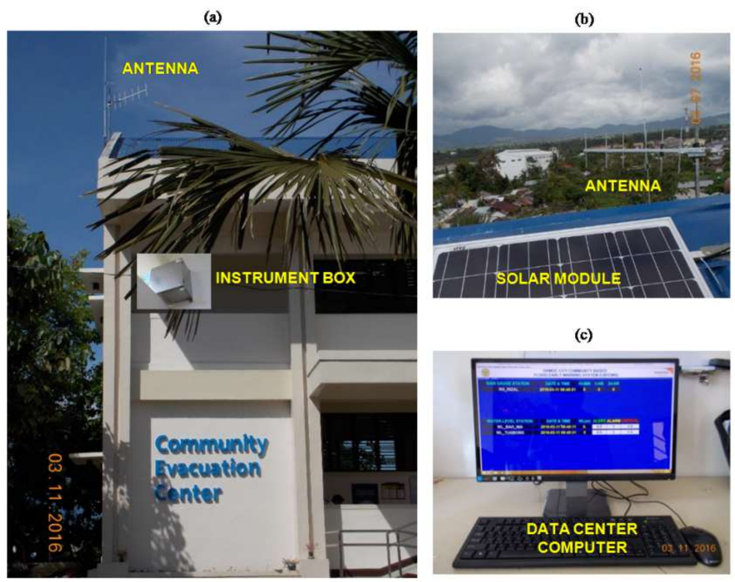


Fig. 6. Data Center integrates an (a) instrument box, a (b) solar module, and a (c) data collection computer.

Greater Metro Manila Ready Project (GMMA READY) Sponsored by the UNDP (2015)

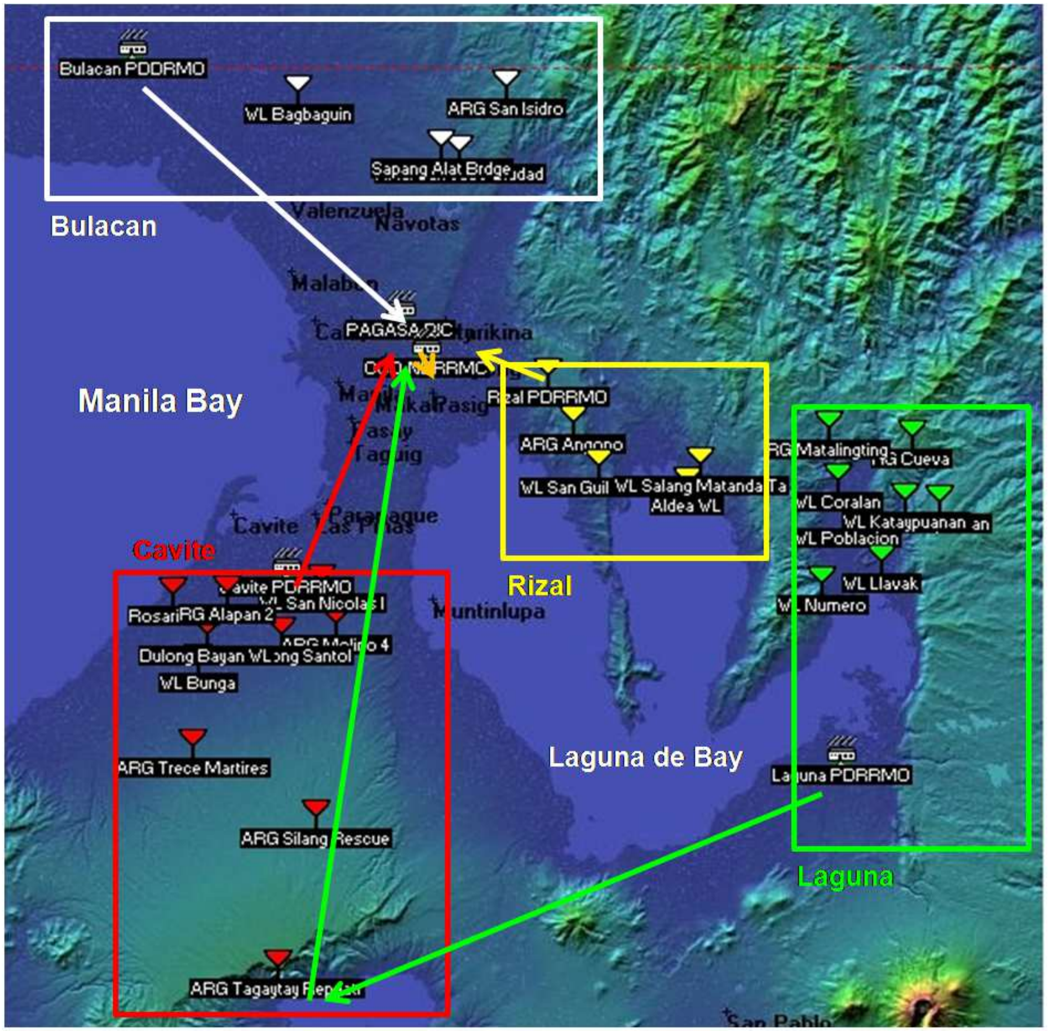
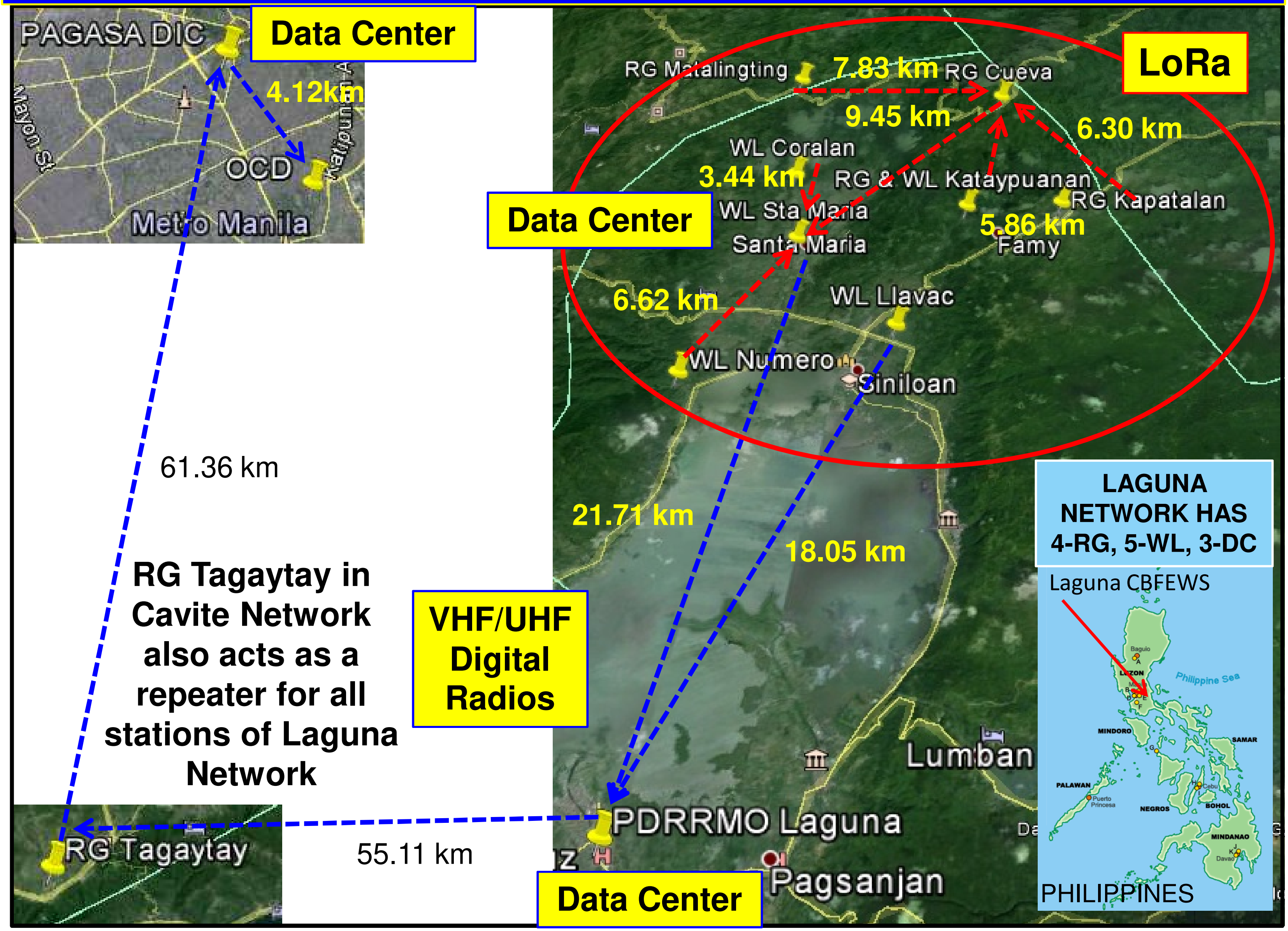


Fig. 7. GMMA-READY CBFEWS Network covers four provinces surrounding Manila, has 34 stations: 15 WL, 13 RG, and 6 DC.

Laguna CBFEWS IoT Network



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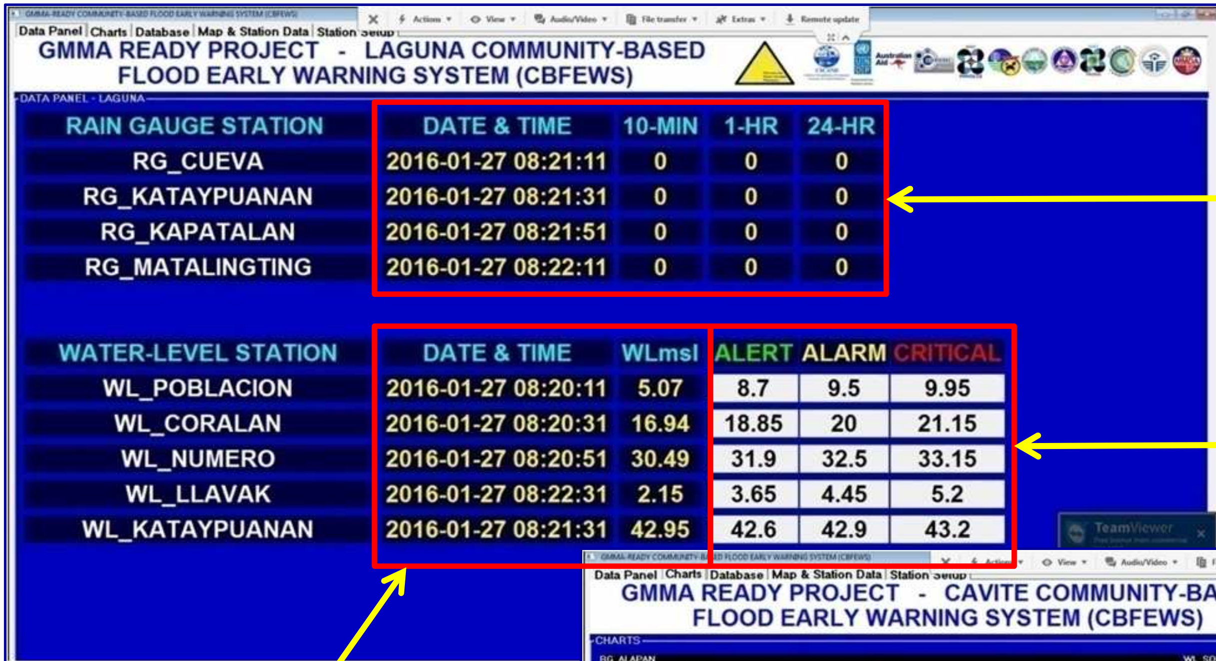
Data Thresholds and Charts for Early Warning



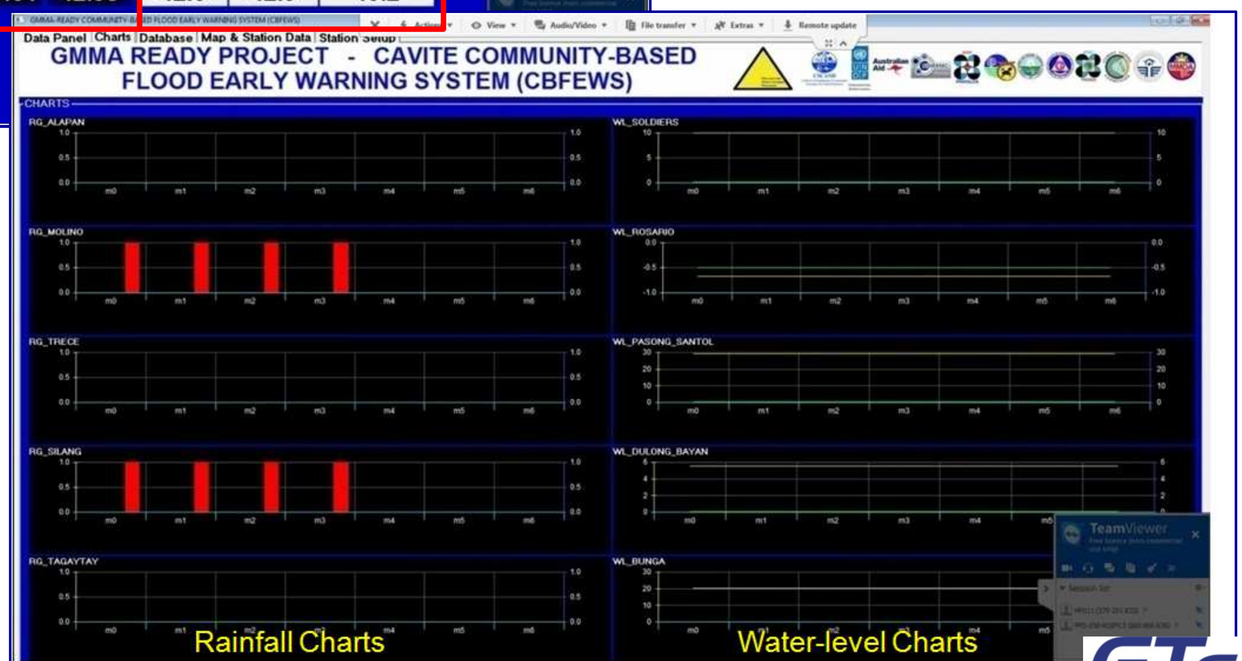
RAIN GAUGE STATION	DATE & TIME	10-MIN	1-HR	24-HR
RG_CUEVA	2016-01-27 08:21:11	0	0	0
RG_KATAYPUANAN	2016-01-27 08:21:31	0	0	0
RG_KAPATALAN	2016-01-27 08:21:51	0	0	0
RG_MATALINGTING	2016-01-27 08:22:11	0	0	0

WATER-LEVEL STATION	DATE & TIME	WLmsl	ALERT	ALARM	CRITICAL
WL_POBLACION	2016-01-27 08:20:11	5.07	8.7	9.5	9.95
WL_CORALAN	2016-01-27 08:20:31	16.94	18.85	20	21.15
WL_NUMERO	2016-01-27 08:20:51	30.49	31.9	32.5	33.15
WL_LLAVAK	2016-01-27 08:22:31	2.15	3.65	4.45	5.2
WL_KATAYPUANAN	2016-01-27 08:21:31	42.95	42.6	42.9	43.2

No Rain

Early Warning Thresholds

Actual water-level measurements taken every 10 minutes

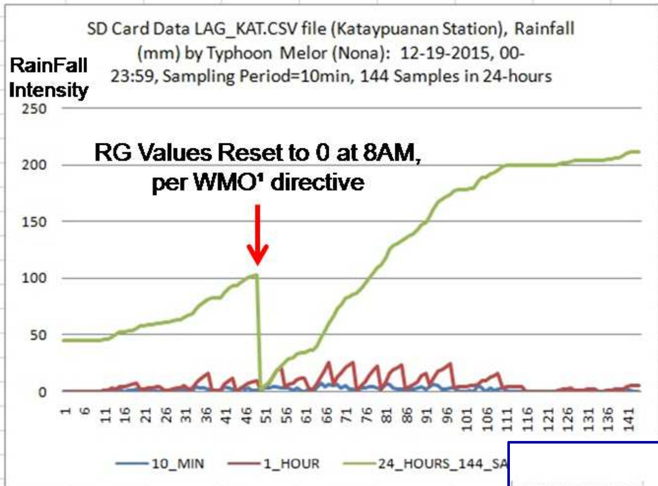


Laguna CBFEWS Telemetry Network: Data Collection

	10-MIN	1HR	24HR
151219065000	4	10	91
151219070000	2	12	93
151219071000	0	0	93
151219072000	3	3	96
151219073000	2	5	98
151219074000	3	8	101
151219075000	1	9	102
151219080000	1	10	103
151219081000	1	1	1
151219082000	3	4	4
151219083000	4	8	8
151219084000	5	13	13
151219085000	5	18	18
151219090000	4	22	22
151219091000	4	4	26
151219092000	3	7	29
151219093000	1	8	30
151219094000	3	11	33
151219095000	1	12	34
151219100000	0	12	34
151219101000	2	2	36
151219102000	0	2	36

Date_Time (YYMMDDhhmmss)

RAINFALL INTENSITY OVER 24 HOUR PERIOD



1- WMO (World Meteorologica

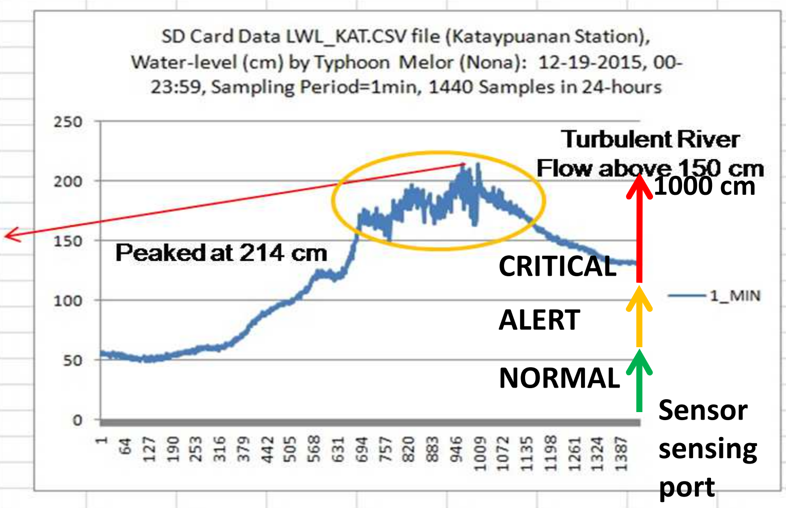
Rainfall Intensity (mm)

- 10-MIN
- 1HR
- 24HR

	1-MIN
151219155406	204
151219155506	193
151219155606	198
151219155706	189
151219155806	198
151219155906	205
151219160006	200
151219160106	193
151219160206	186
151219160306	196
151219160406	214
151219160506	189
151219160606	185
151219160706	207
151219160806	184
151219160906	204
151219161006	200
151219161106	176
151219161206	207
151219161306	193
151219161406	202

Date_Time (YYMMDDhhmmss)

WATER-LEVEL OVER 24 HOUR PERIOD



Flood Early Warning Definitions: Warns the people to get READY, SET, and GO to evacuate to safer grounds.

- ↑ Level 3: 101 cm < Critical, GO
- ↑ Level 2: 51 cm < Alert <= 100 cm, SET
- ↑ Level 1: 0 cm < Normal <= 50 cm, READY

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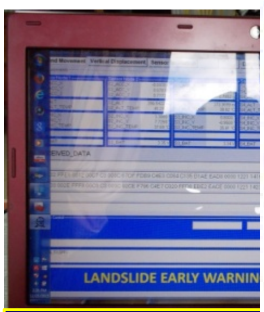
2014: Community-Based Landslide Early Warning System (event driven), Maasin City, Southern Leyte, Philippines Sponsored by the German International Cooperation

Sensor Node1

ground crack/m



CBLEWS C
Applic

Fig. 22. CBLEWS Landslide Sensor Pole/Node.

Sensor Node5

CBLEWS
Gateway

2015: Saving Lives and Properties Through an IoT Network Sponsored by the German International Cooperation

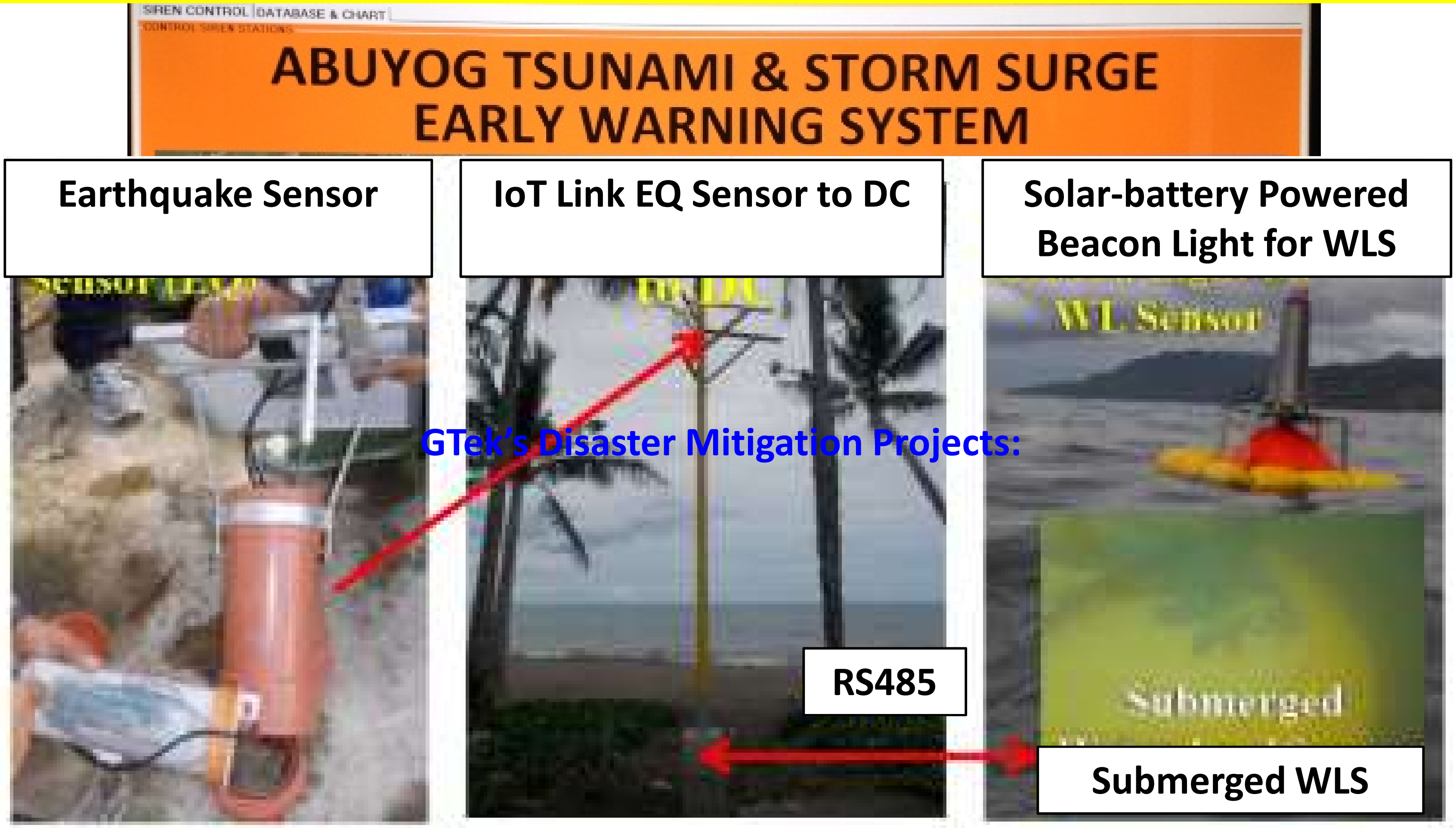


Fig. 26. Integrated Storm-Surge, Earthquake, and Tsunami Sensor

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The San Sebastian Basilica,

Plaza Del Carmen, Quiapo, Manila, Philippines

An all steel Gothic church completed in 1891, the metals are the same with the ones used with the Eiffel Tower, Paris, which was completed two years earlier in 1889.

The San Sebastian Basilica,

Plaza Del Carmen, Quiapo, Manila, Philippines

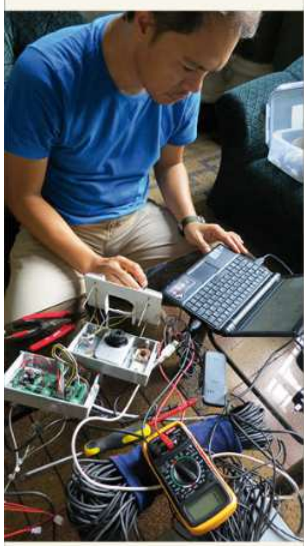
https://sketchfab.com/3d-models/san-sebastian-basilica-philippines-d7e29a61d8f842e682aed2e6e9fce5dd

2012 Projects with San Sebastian Basilica:

Remote-controlled drop-down (30-meters) 8MPixel Point-and Shoot Camera System. Using PSoC, RS485 network, and a laptop.

The column base showing water, and large holes caused by rust

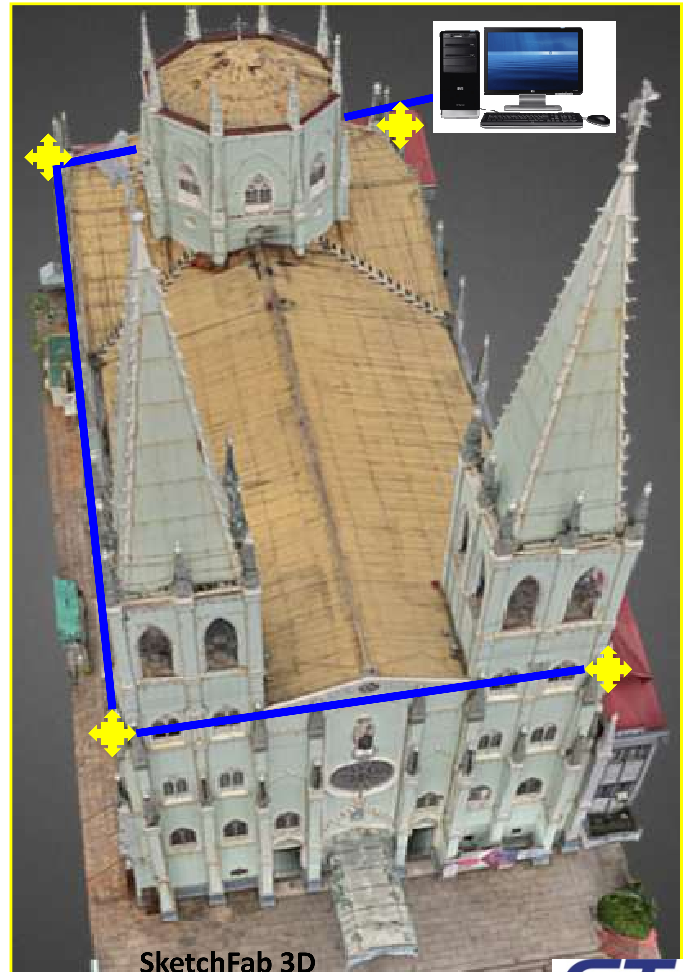
The inside of a column looking down 20 meters. Sequential photographs were taken every quarter meter



Reggie Mercado rigging a system of wires, cables, laptop and camera to look 20 meters down the hollow columns

Dry run: the technical team is glued to the monitor as the camera is lowered to the column base, which has never been seen since construction in 1891. From left: Engineer Reggie Mercado, executive director Tina Paterno, and architect Jonathan Dangue

Walls inclination remote-monitoring using PSoC, precision dual-axis inclination sensors, RS485 network, and a computer



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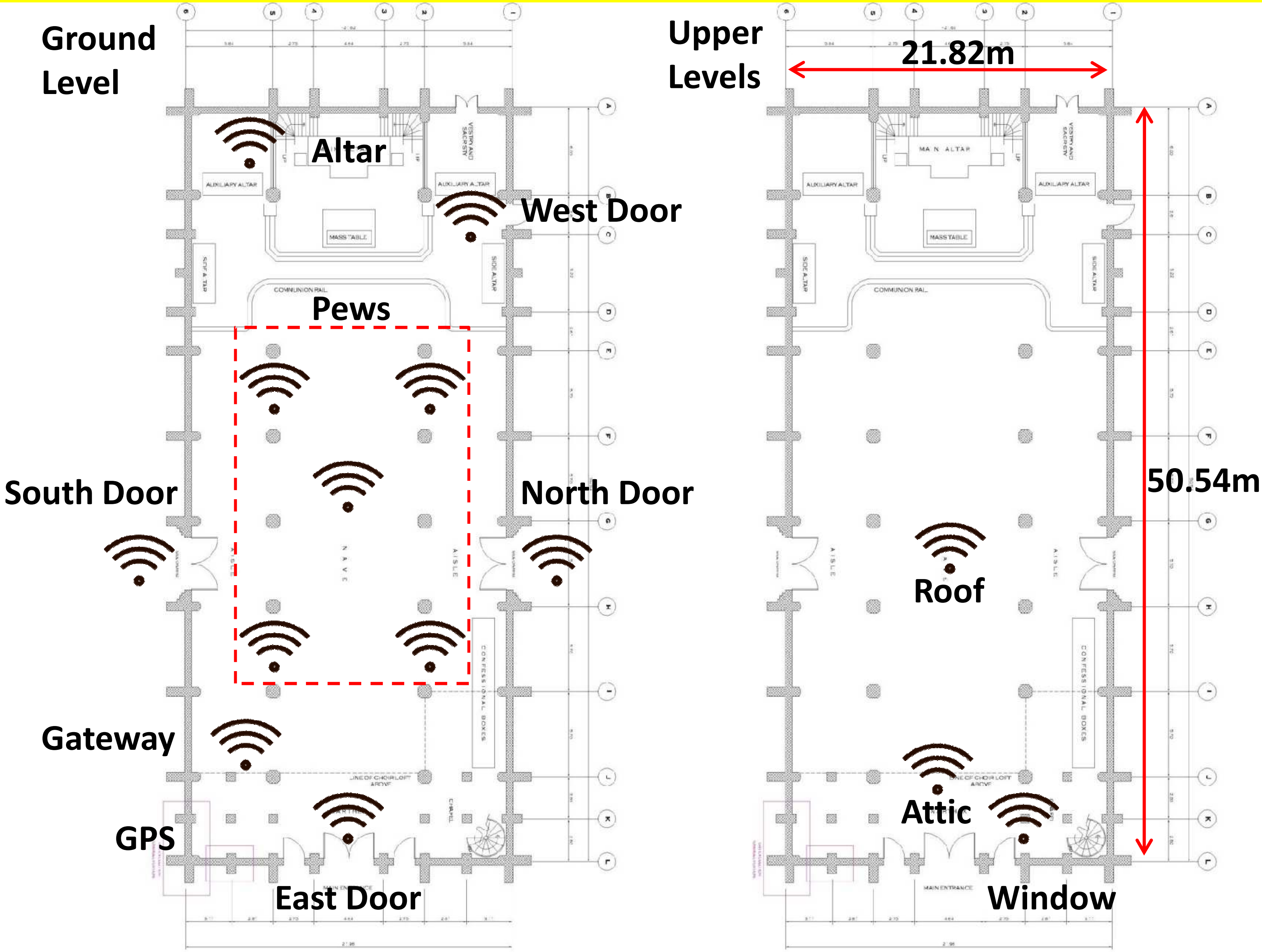
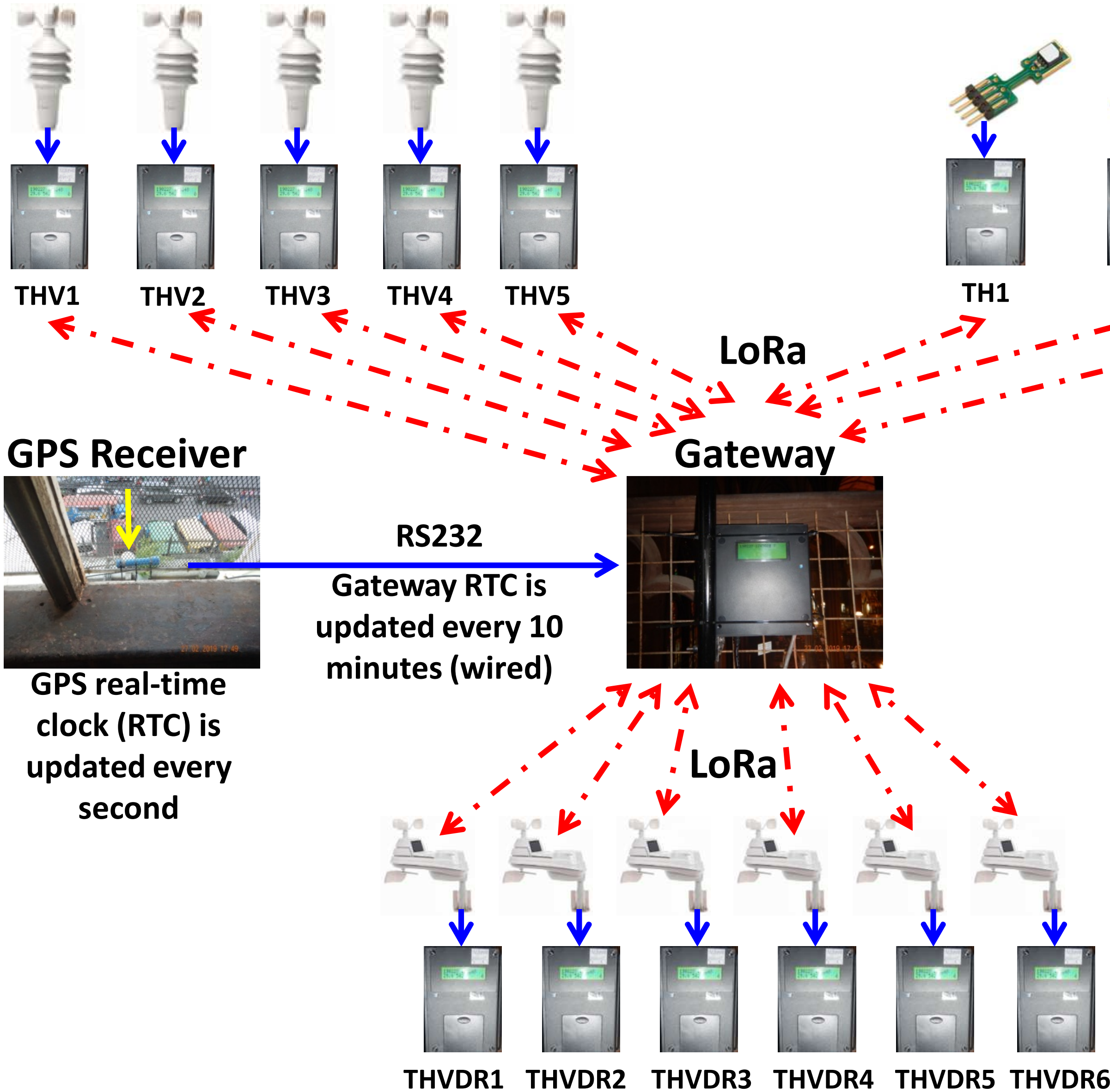
San Sebastian Basilica IoT Network Layout



SSB Environmental Monitoring System Operation

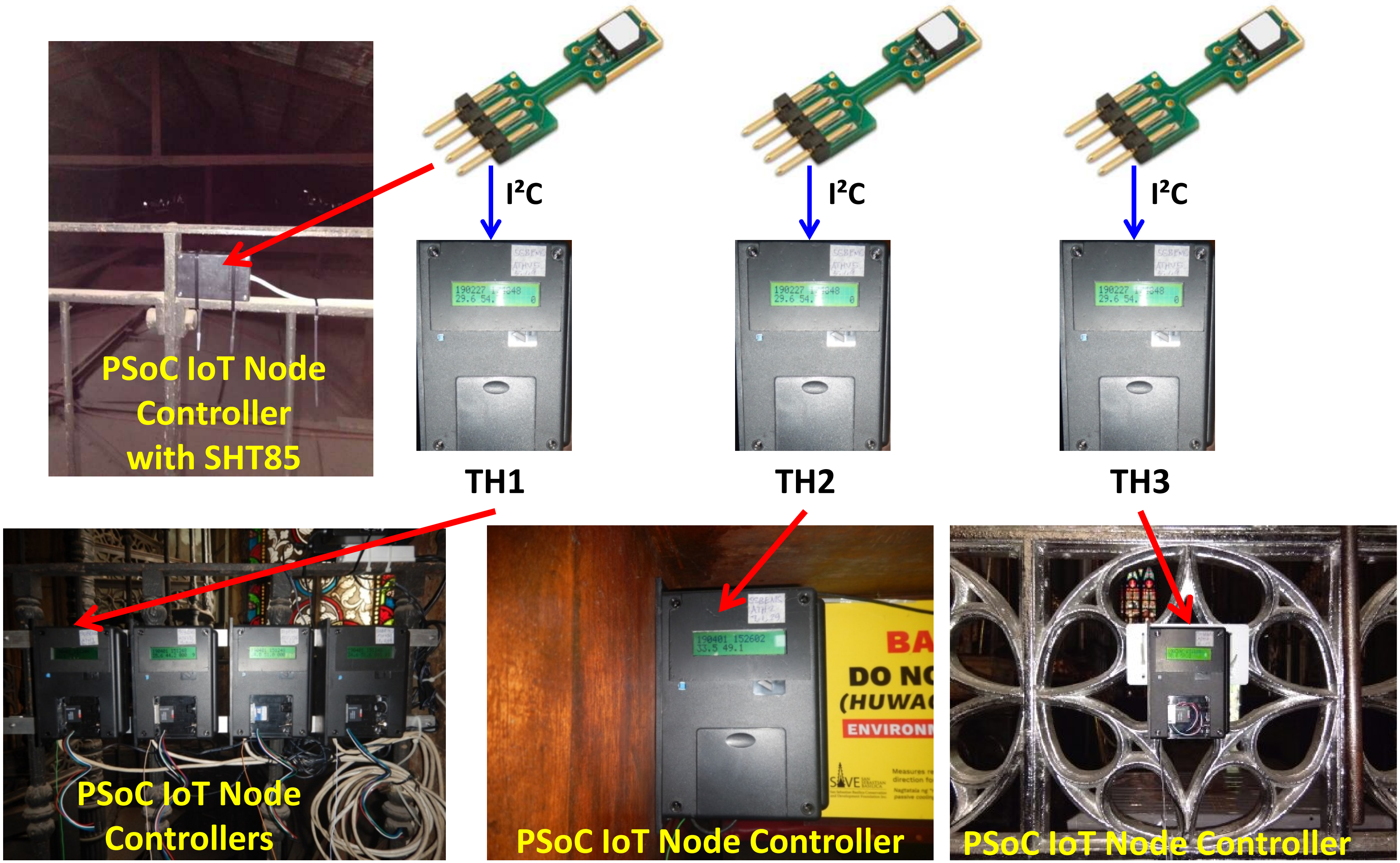


Synchronized Data Capture

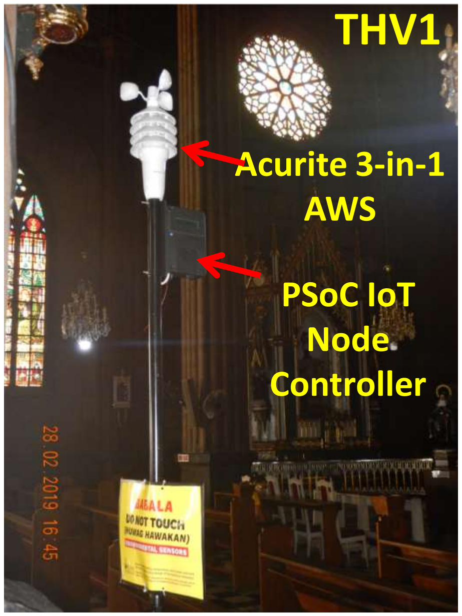
1. GPS RTC is updated every second.
2. Gateway's RTC is updated every 10 minutes.
3. All stations' RTC are synchronized to the Gateway's RTC every minute via LoRa.
4. Simultaneously, all sensors' data are acquired and saved (logged) in the SD memory card every minute.
5. Every 10 minutes, Each station data is sent via LoRa to the gateway and immediately logged in the gateway's SD memo

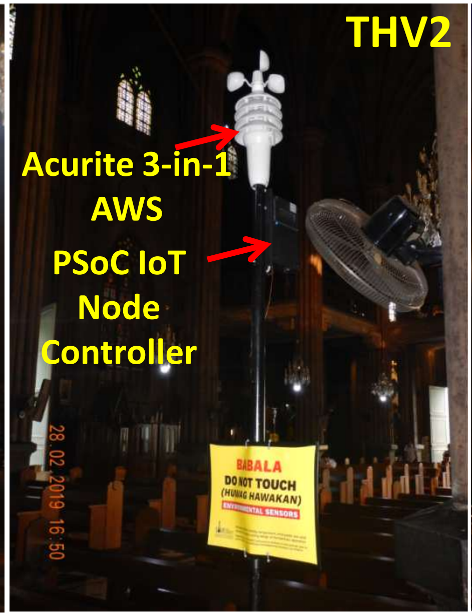
SSBEMS IoT Device Installation

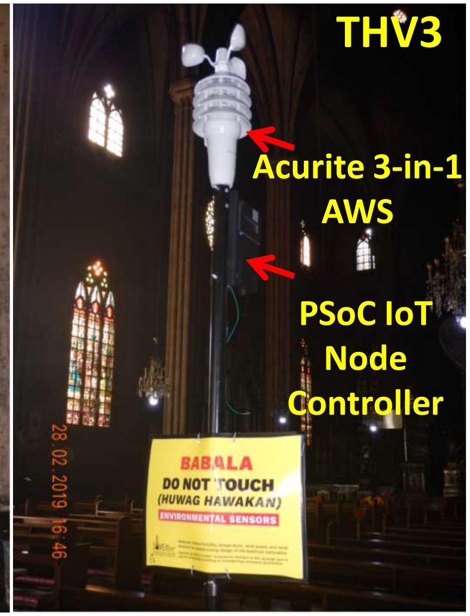
Temperature and Humidity , SHT85, (THx) WSN Setup

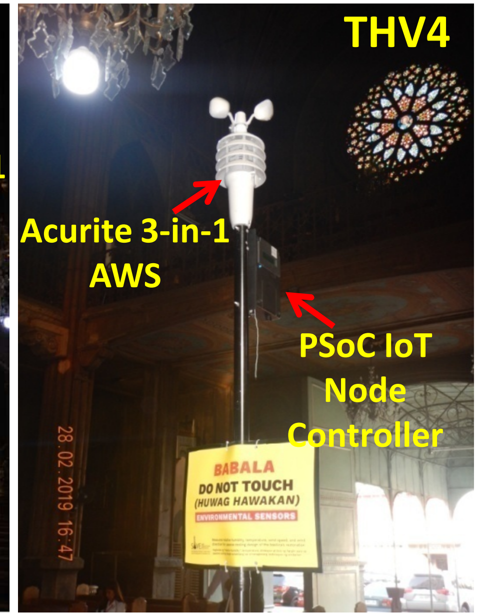


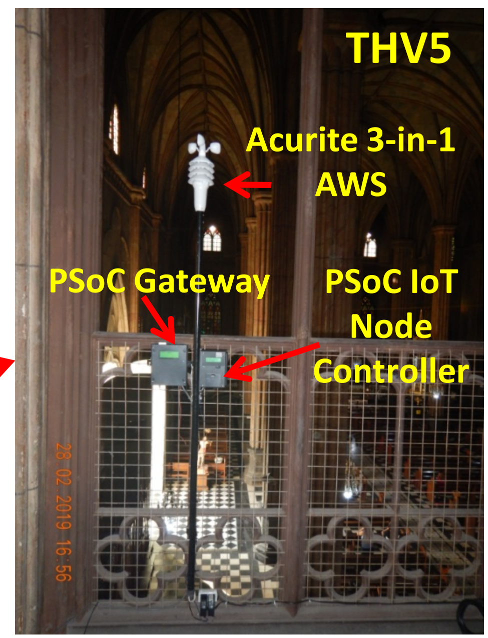
SSBEMS IoT Device Installation





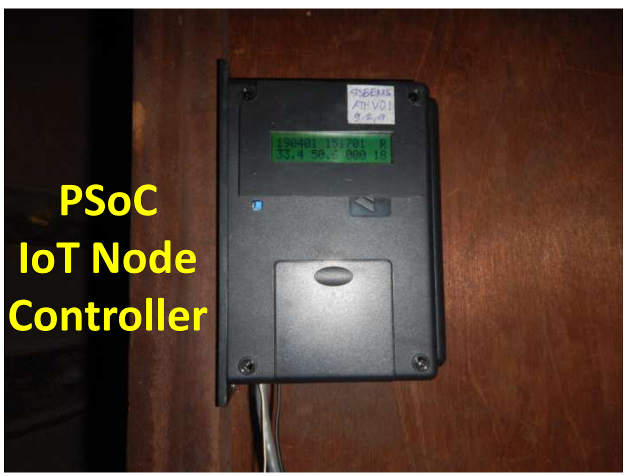






SSBEMS IoT Device Installation

THVDR1 – Basilica's East Side Door



THVDR2 – Basilica's West Side

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SSBEMS IoT Device Installation

THVDR5 – Basilica's Front Door

THVDR3 – Basilica's East Side Front Door

Controller

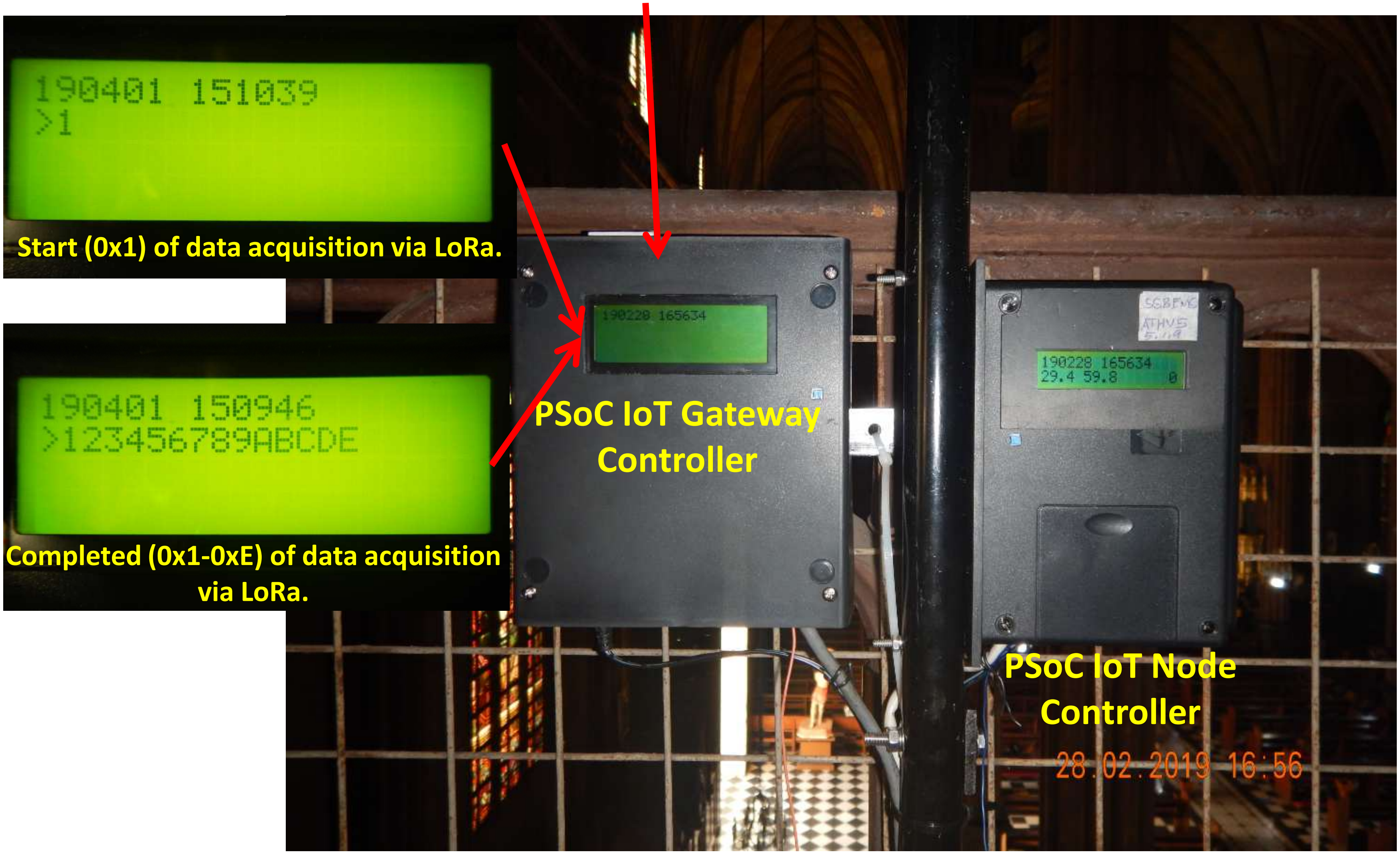
SSBEMS IoT Device Installation

THVDR4 – Basilica's Right Tower, 1 Level Below Bell Tower

THVDR6 – Basilica's Roof

IoT Gateway

PSoC Gateway – Choir Loft



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Node Controller: Power, Data Display, and Data Logger

Date Time WindDirection

Temp Hum Rainfall WindSpeed

LCD Backlight Switch

SD/uSD Card Data Logger (4GB/8GB/16GB)

How to manually copy the CSV file: Recommended copy time is between 5th min to 8th min of the 10-min cycle.

1. Turn-off 12VDC Power Switch.
2. Take-out SD card from port.
3. Copy CSV file using your computer.
4. Re-insert SD card.
5. Turn-on 12VDC Power Switch.
6. Station should operate normally.

2x16 LCD

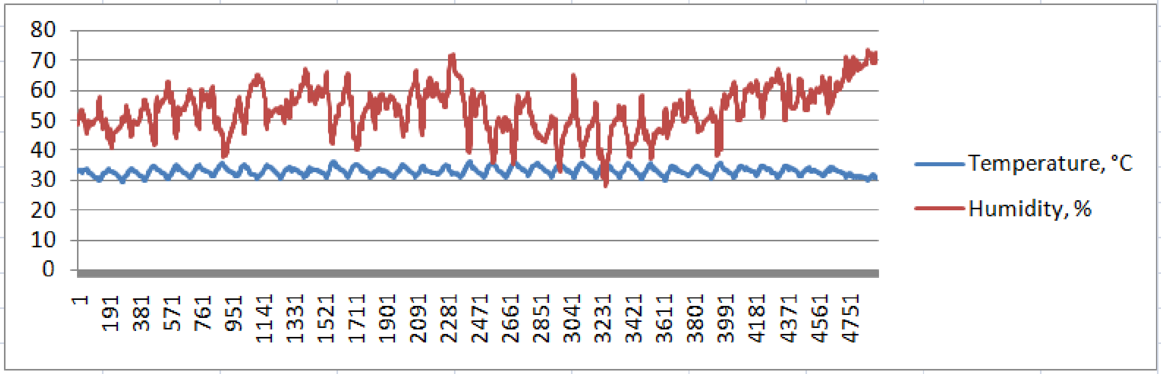
Fuse Holder-small

12Vdc Power Switch

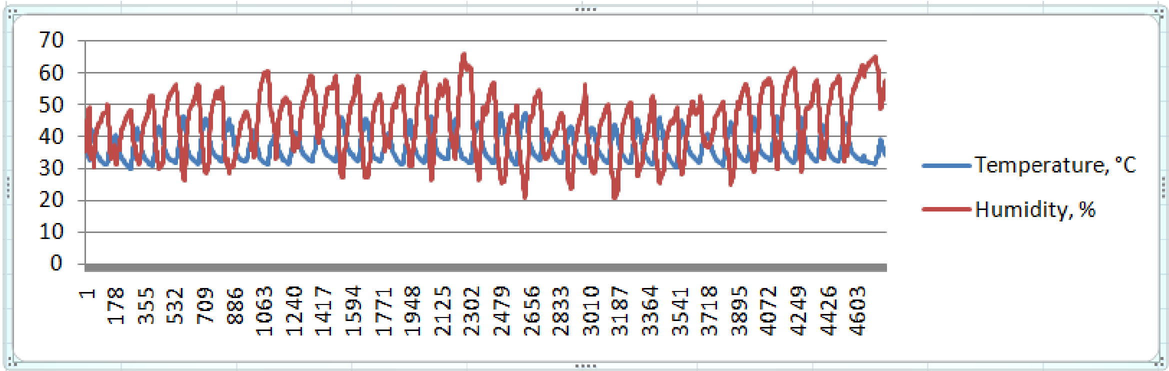
LoRa Antenna (433MHz)

Sensor Data Communication Cable

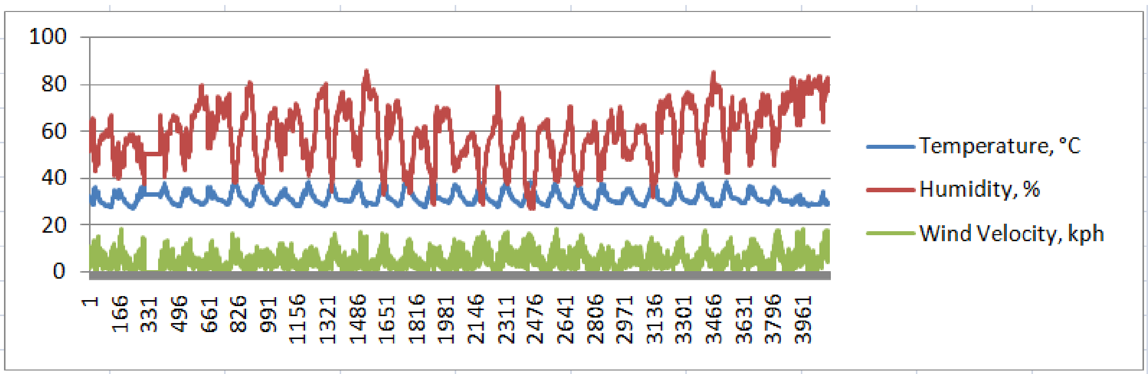
Actual Data Charts, March 29 to May 7, 2019



TH3 – Altar, Left Side

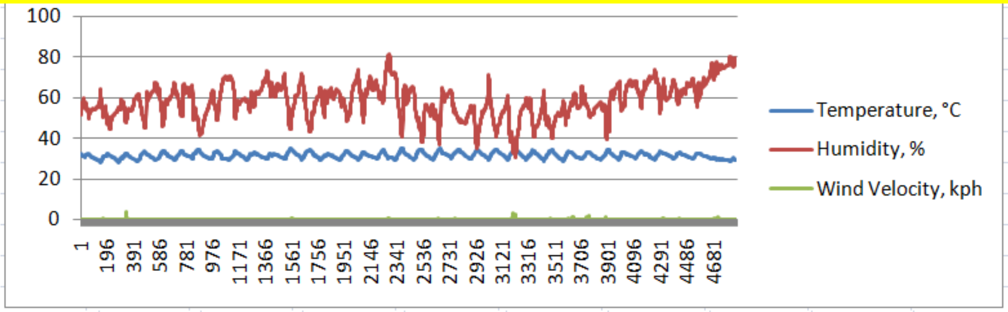


TH1 – Attic

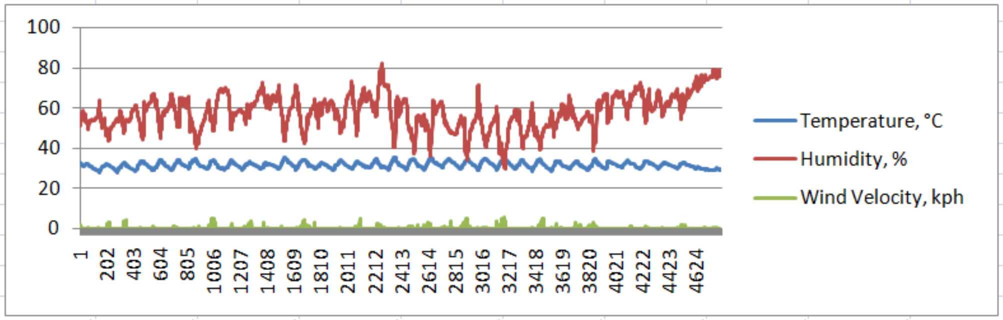


THVDR6 – Basilica's Roof

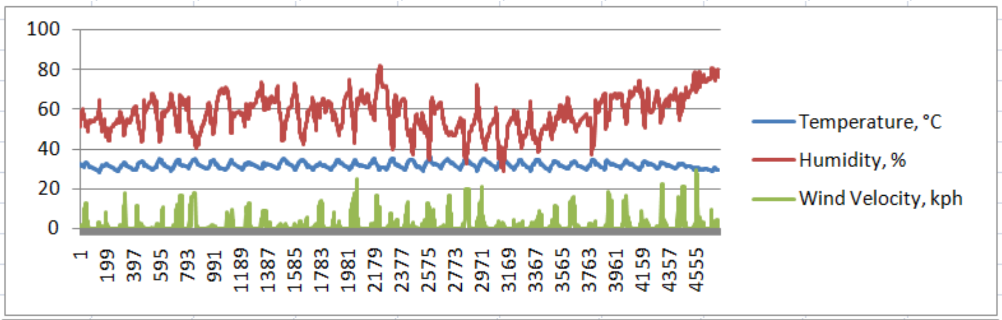
Actual Data Charts, March 29 to May 7, 2019



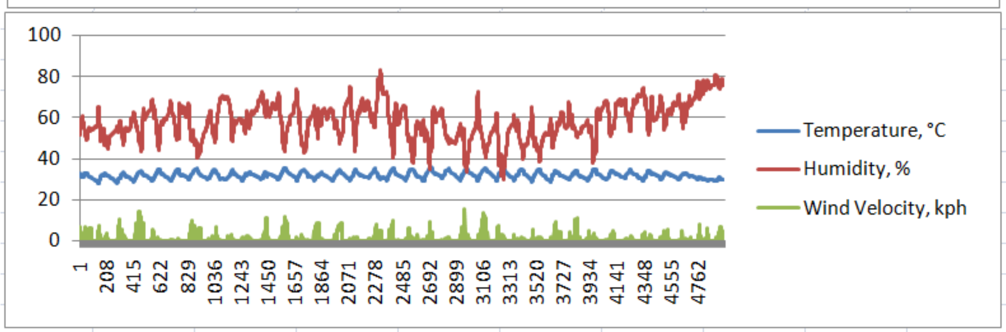
THV1 – Pew



THV2 – Pew



THV3 – Pew



THV4 – Pew

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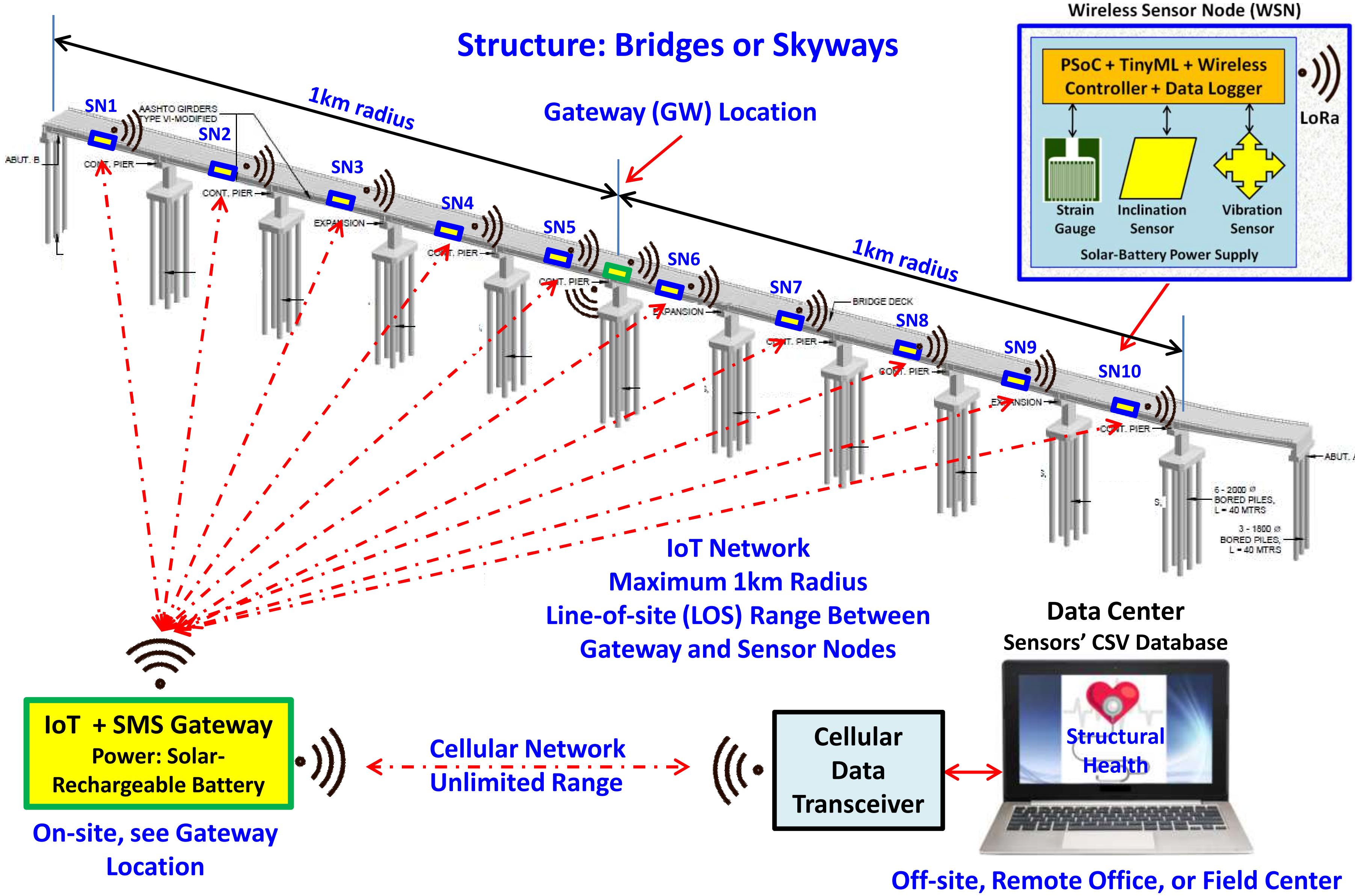
Structural Integrity Monitoring for Bridges, Anomaly Detection, and Early Warning System
Design, Development, and Fabrication: Mar – May 2024, Due in June 2024

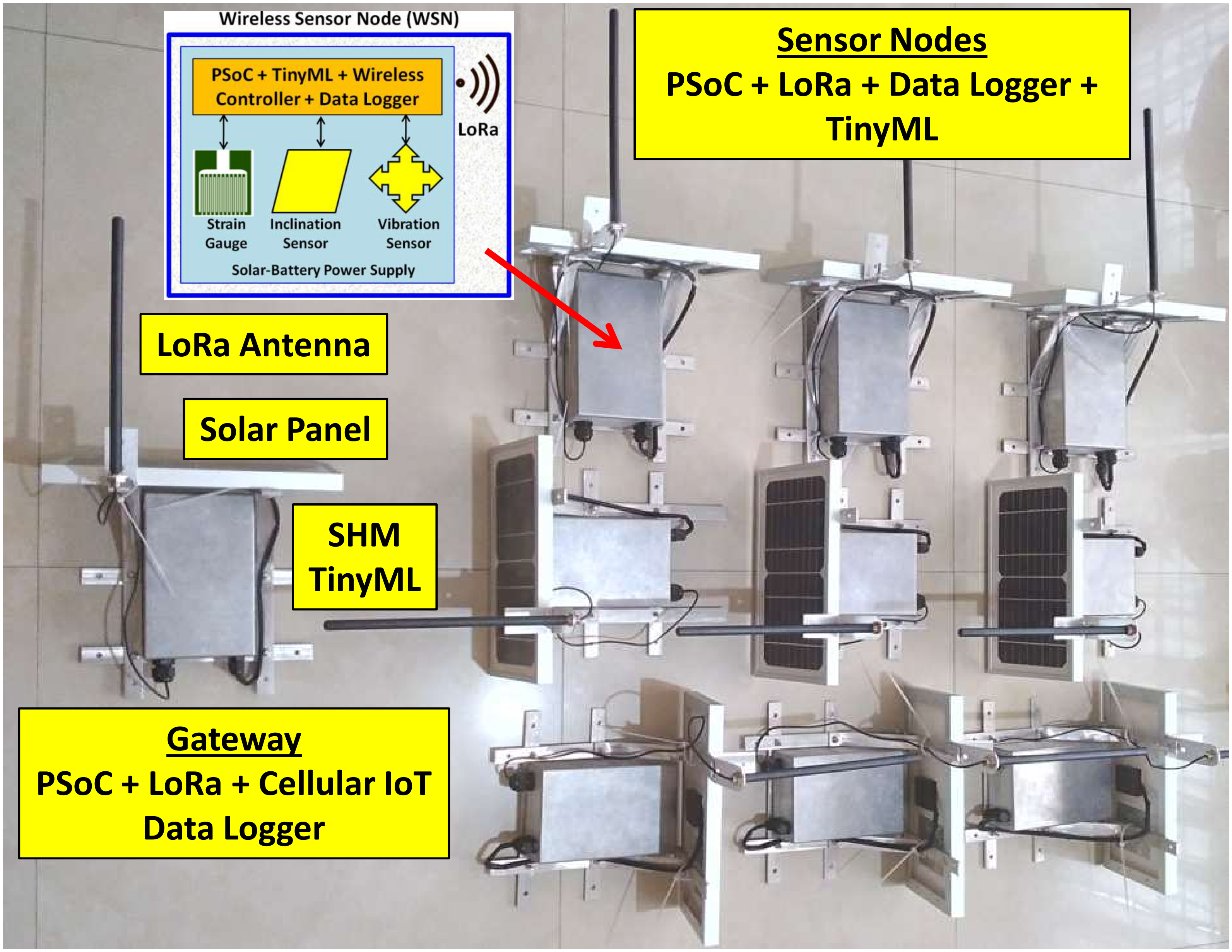
Project Specifications:

1. **To monitor cracks, vibrations, and inclinations on beams, walls, and columns of old bridges. Detect anomalies and generate condition flags.**
2. **To data log all collected measurements and anomaly flags in a CSV file stored in an SDCard of the devices (sensor nodes and gateway) on the bridge.**
3. **To transmit all data and early warning information from bridge's device to data center and save it in a CSV file, for structural engineers and authorities to inform the public of impending danger in using a bridge.**
4. **To use solar-battery power for remote bridge devices.**

Structural Integrity Monitoring (SIM) and Early Warning System Network Diagram



Bridge SIM: WSN + TinyML Equipments



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