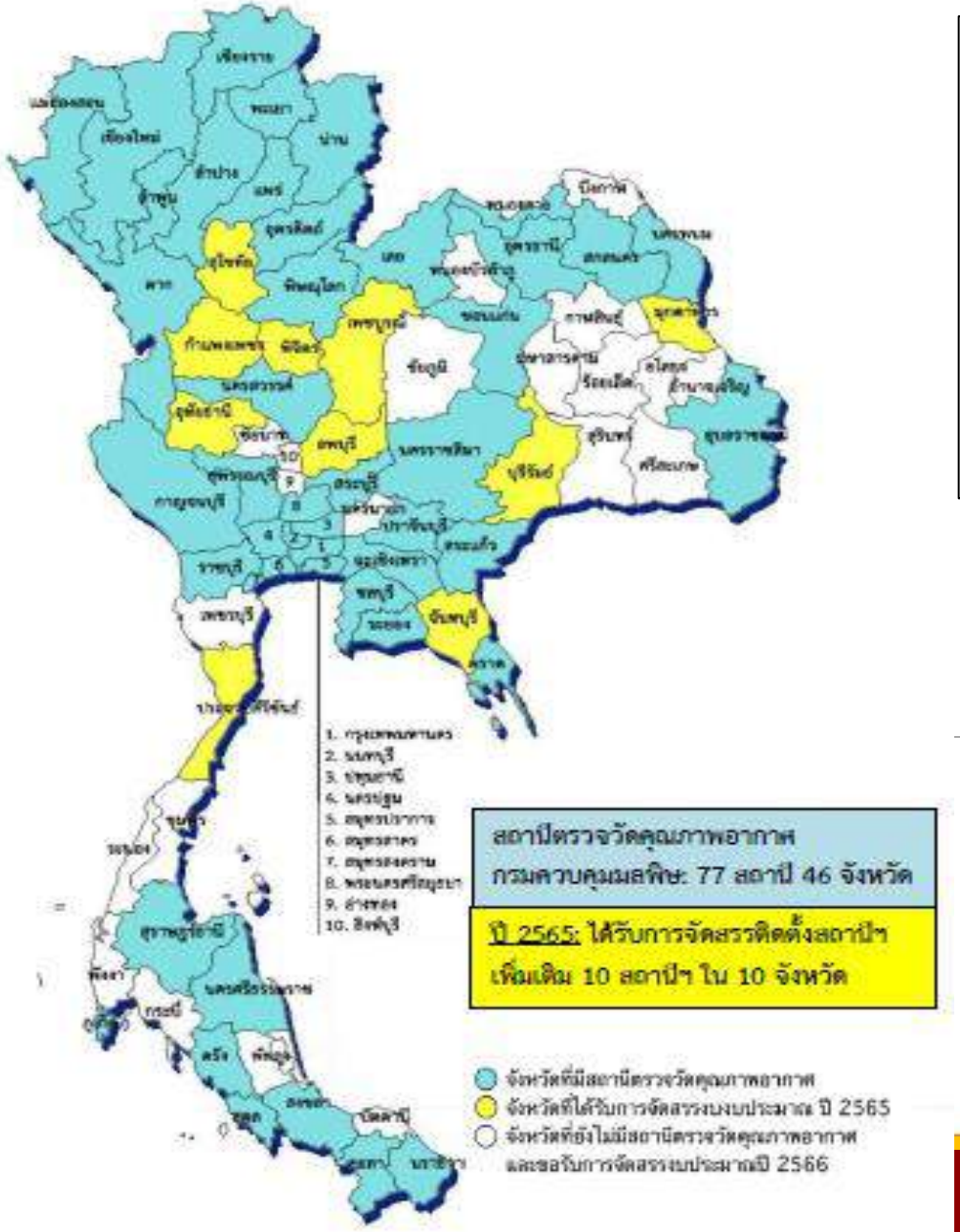
EANET Seminar on Expanding Monitoring System using Low-Cost Sensor (LCS)

21 July 2022 (13:00-15:15 BKK Time)

Issues of LCS and Efforts Against the Issues:

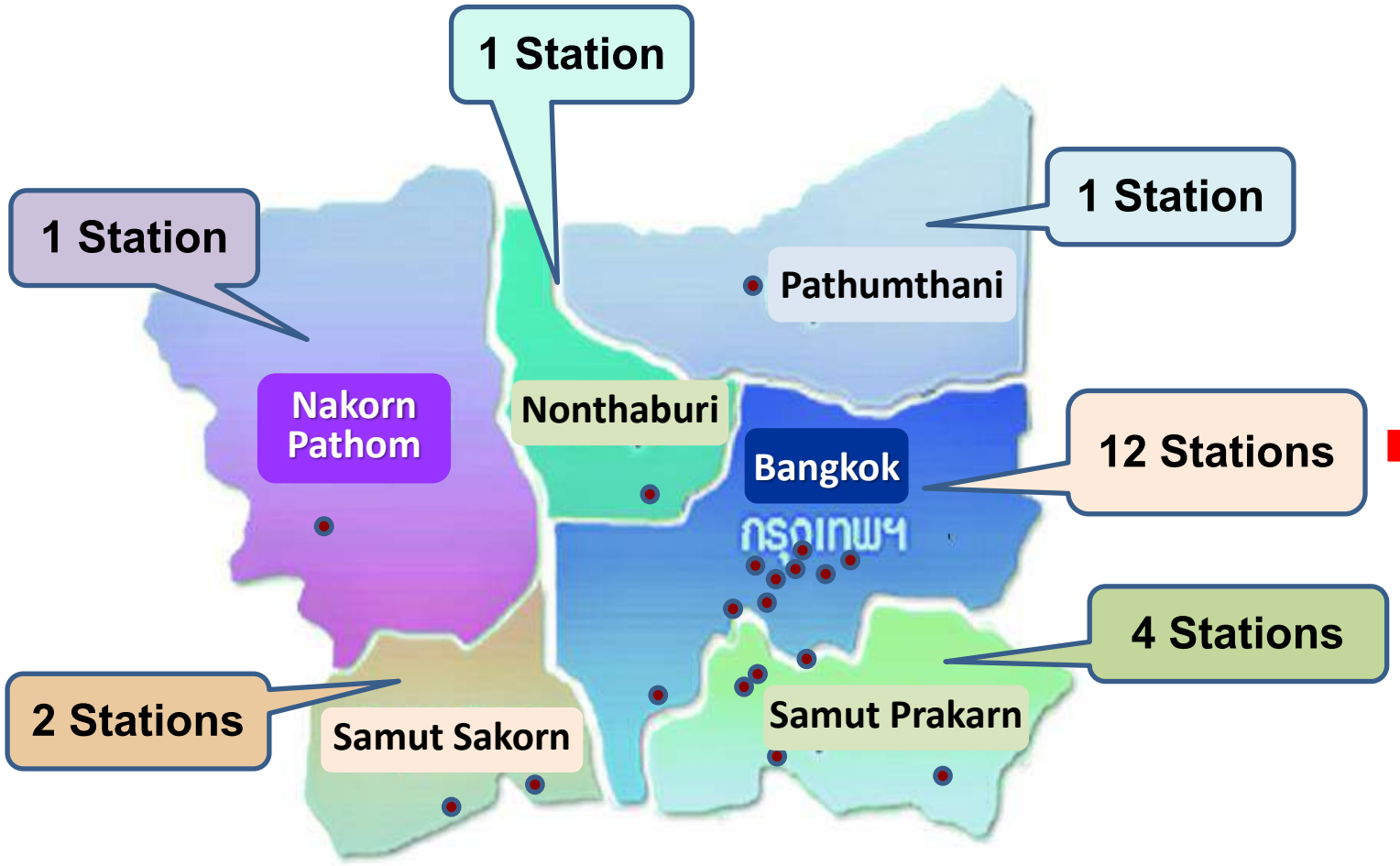
Thailand's Experiences

Thailand Air Quality Monitoring Network (PCD) in 2021



- **Automated air quality monitoring stations**
  - **77 stations in 46 provinces**
  - **Monitored parameters: $PM_{2.5}$, PM_{10}, O_3, CO, NO_2, SO_2 and meteorological parameters such as wind speed, wind direction, temperature, humidity, solar radiation, and precipitation.**
- **Air quality monitoring mobile units: 9 units**
- **Outdoor standalone $PM_{2.5}$ monitors**

Official $PM_{2.5}$ Monitoring Network in Bangkok Metropolitan Region
Pollution Control Department



Years	$PM_{2.5}$ Monitoring Stations
2011	1
2012	1
2013	1
2014	2
2015	3
2016	5
2017	6
2018	19 (Bangkok and Vicinity)
2020	21 (Bangkok and Vicinity)
	68 (Nationwide)
2021	21 (Bangkok and Vicinity)
	77 (Nationwide)

$PM_{2.5}$ Monitoring Network - BMA

Phyathai District

BMA has installed 1 station in each district for a total of 50 stations + a few mobile units

Sathorn District

Bangkok Air Quality Monitoring Network (BMA) in 2021- 76 Stations

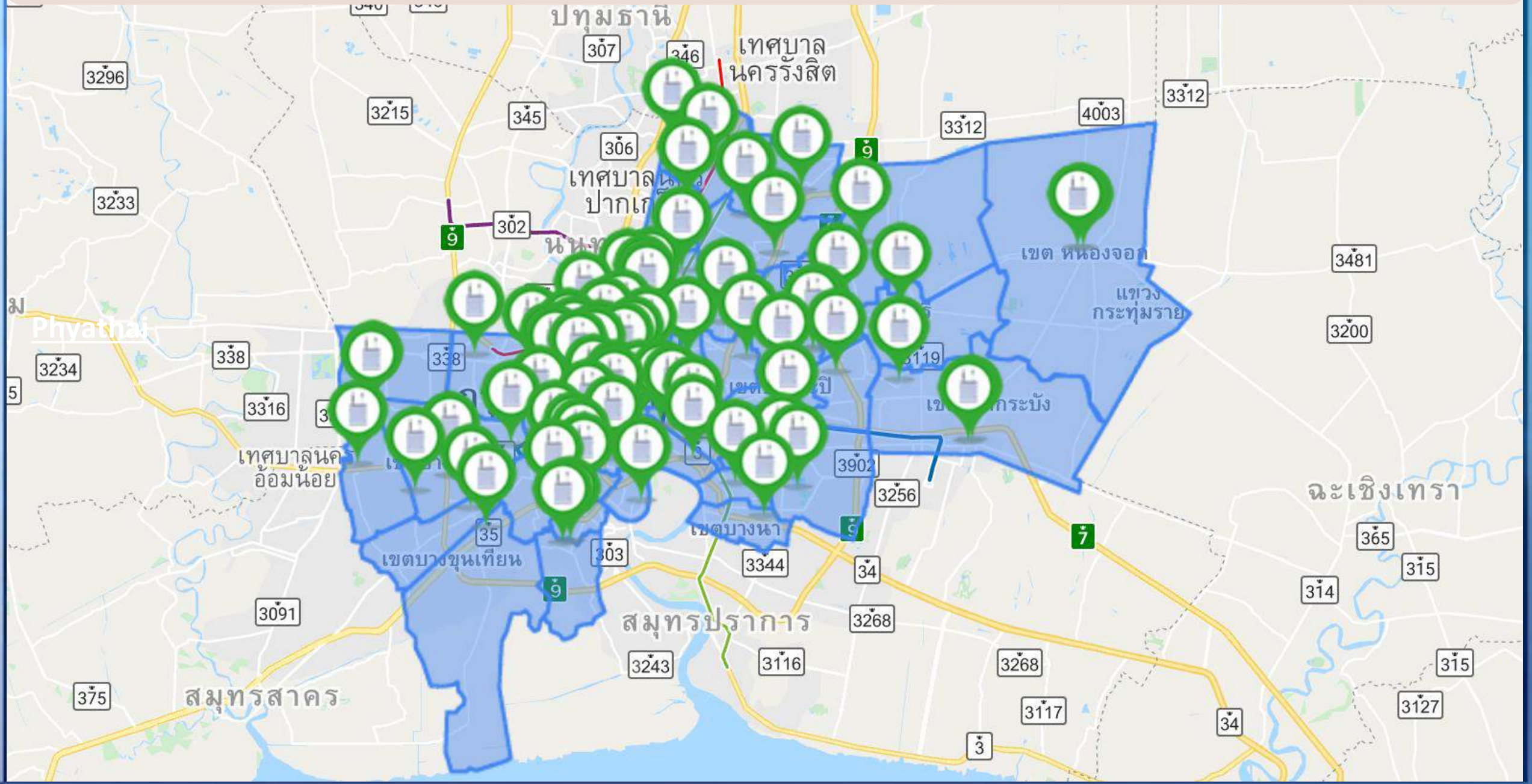
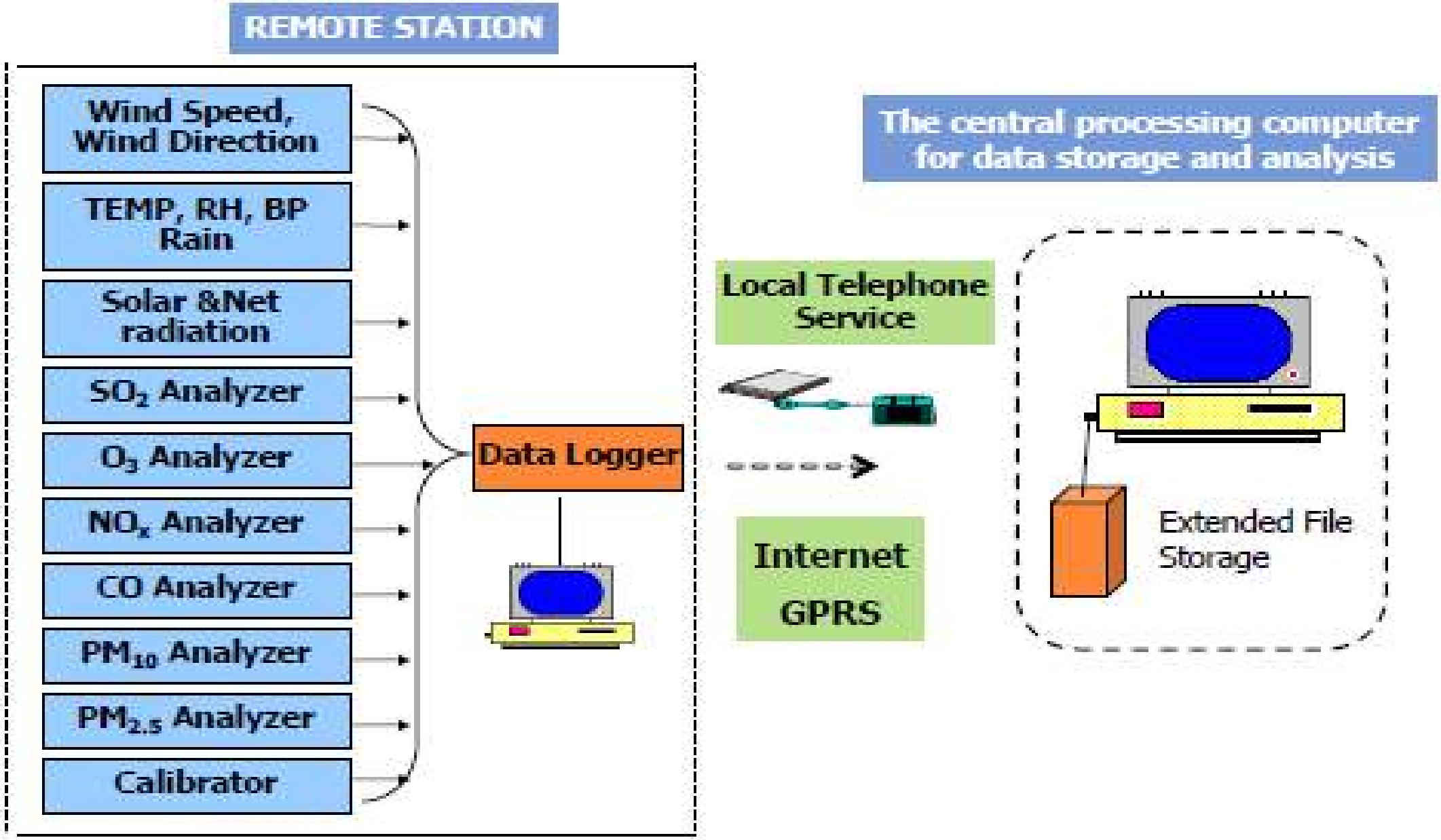


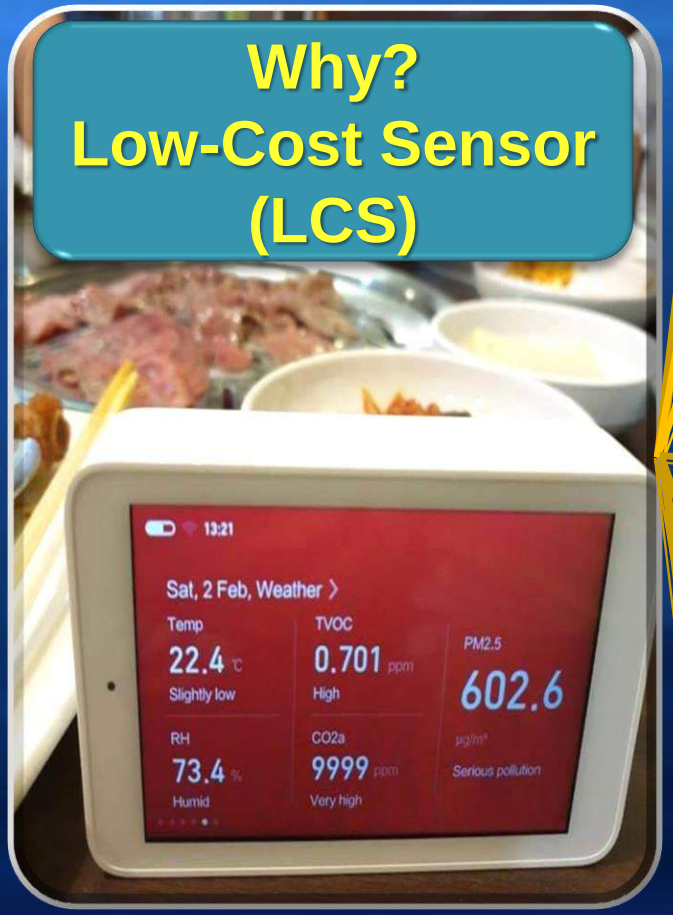
Diagram of Ambient Air Quality Monitoring Station and Data Transmission System



Official $PM_{2.5}$ Monitoring Methods by PCD

- **Standard Method : USEPA Federal Reference Method (FRM)**
- **Equivalent Methods : USEPA Federal Equivalent Method (FEM)**
  - **Beta-Ray Attenuation Method (BAM)**
  - **Tapered Element Oscillating Microbalance (TEOM)**
  - **Light Scattering**
  - **Dichotomous Air Sampler**

Why? Low-Cost Sensor (LCS)



- Standard air quality ($PM_{2.5}$) monitors are relatively high cost
- Limited spatial and temporal coverage of standard air quality monitoring network – $PM_{2.5}$
- Citizen are much more aware of air pollution problem – $PM_{2.5}$
- Citizen are more alert and concerns of health impacts of air pollution – $PM_{2.5}$
- Citizen want to know real-time air quality near them and where they will be to prepare themselves to deal with the situation – Citizen monitoring
- Citizen do not trust and believe in government's air quality (PM_{25}) data
- Sensors are relatively low cost, affordable, easy to operate, portable, and can provide real-time direct reading and used by citizen scientists

Varieties of $PM_{2.5}$ Low-Cost Sensor (LCS)

What?
Low-Cost Sensor (LCS) for $PM_{2.5}$

Optical instruments based on the detection of light scattering from particles and the $PM_{2.5}$ mass concentration was calculated from the distribution of light scattering intensity by considering the relationship between scattering intensity and particle size.

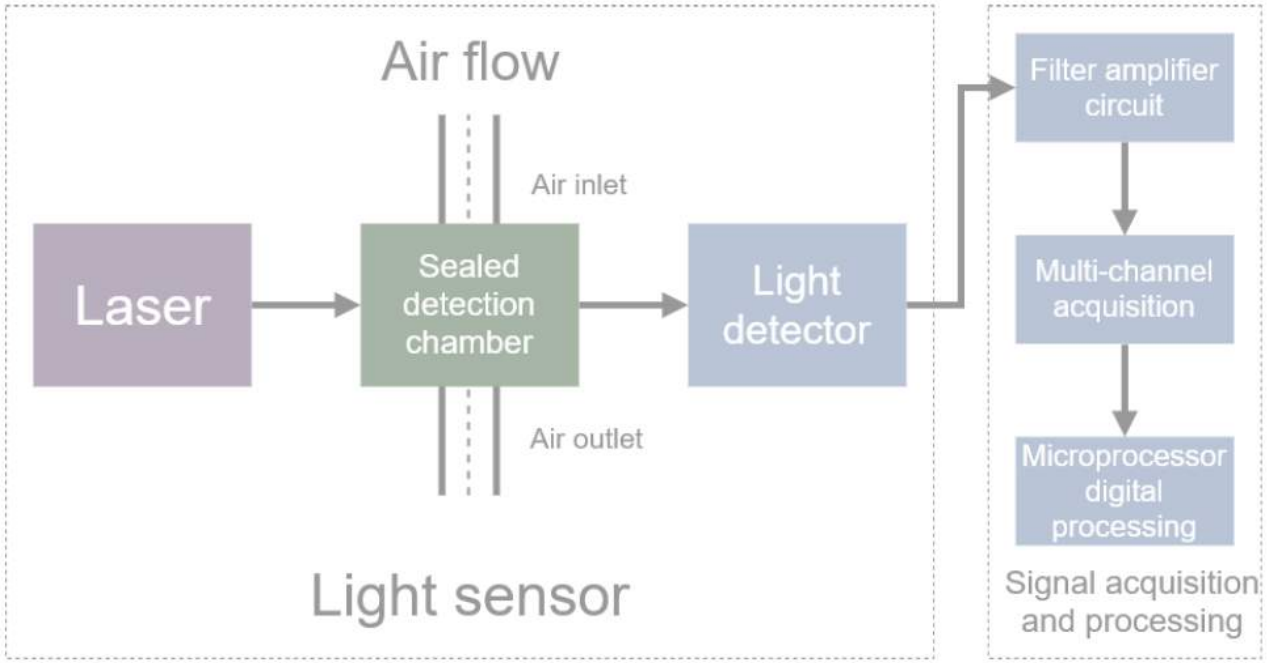


Figure 3. Graphical representation of how the *HM-3301* PM sensor works.

Sergio Trilles , Ana Belen Vicente, Pablo Juan, Francisco Ramos, Sergi Meseguer and Laura Serra (20190. Reliability Validation of a Low-Cost Particulate Matter IoT Sensor in Indoor and Outdoor Environments Using a Reference Sampler. Sustainability

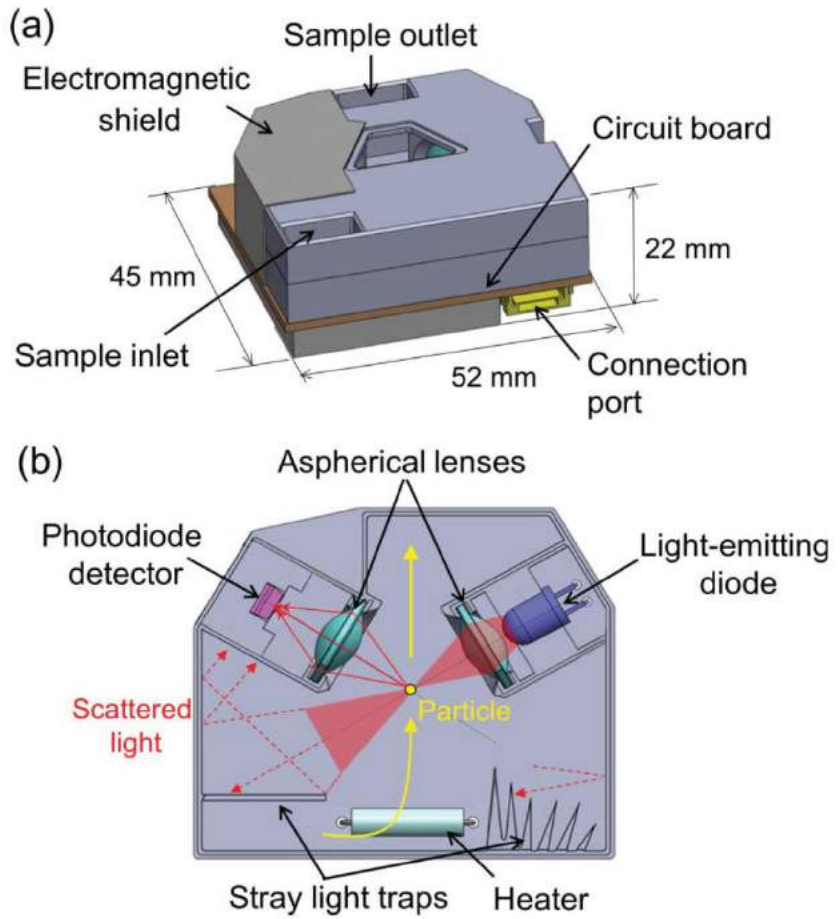
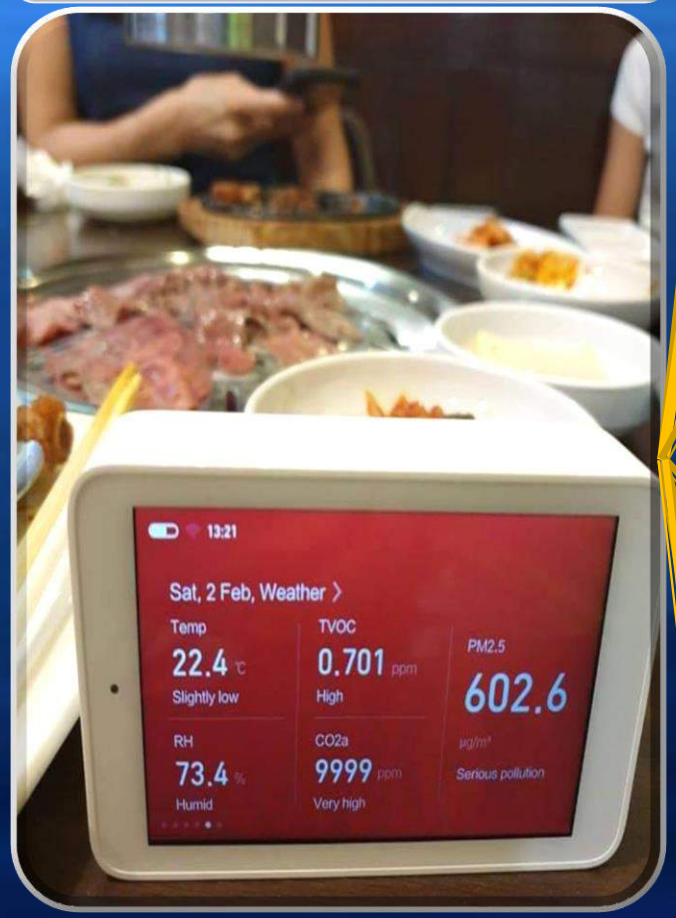


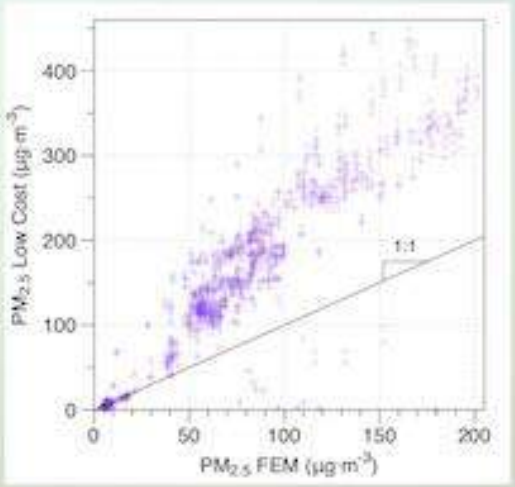
Figure 1. Schematic diagrams of the newly developed $PM_{2.5}$ sensor: (a) outside and (b) inside.

Tomoki Nakayama, Yutaka Matsumi, Keiko Kawahito & Yoshifumi Watabe (2018). Development and evaluation of a palm-sized optical $PM_{2.5}$ sensor, Aerosol Science and Technology, 52:1, 2-12

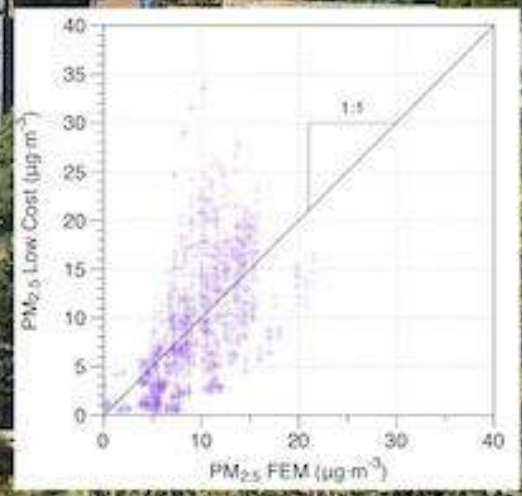
Issues of $PM_{2.5}$ LCS



- Varieties of $PM_{2.5}$ LCS with variable quality and performance
- No calibration, no QA/QC, no standardization and tend to give much higher reading than standard monitor at high concentration.
- Intensity of scattered light depends on only on particle size but also particle shape and composition.
- Affected by humidity – Growth of particles (increasing size) with increasing humidity
- Air sample volume and density of particles required for converting particle numbers to particle mass are required for calculating particle mass concentration
- Reading depends very much on where it is placed
- Instantaneous and short-term (less than 24 hours) readings presently do have any meaning with regard to health effects
- Issues related to data interpretation and presentation



$PM_{2.5}$ LCSs tend to give much higher reading than standard monitors at high concentrations



Lawrence Berkeley National Laboratory
https://newscenter.lbl.gov/2020/08/18/low-cost-home-air-quality-monitors-prove-useful-for-wildfire-smoke/

EPA 600/R-14/159 | June 2014 | www.epa.gov/ord

EPA
United States
Environmental Protection
Agency

Air Sensor Guidebook

Office of Research and Development
National Exposure Research Laboratory

USEPA Air Sensor Guidebook (2014)

- Some citizen scientists may become concerned if they measure levels of a pollutant higher than the health benchmarks (Standards).
- However, it is very important for the user to consider the time period over which the pollutant level was measured.
- For example, the US daily $PM_{2.5}$ standard is 35 $\mu g/m^3$. Because the standard is based on the average of hourly monitoring measurements over a 24-hour period, it does not mean that a single $PM_{2.5}$ measurement taken over a few minutes, or even hours, above 35 $\mu g/m^3$ is cause for immediate concern.
- Again, for the AQI, it is very important to remember that the concentration that you enter into the AQI calculator is meant to be an average value over a longer time period, (for example, over 24 hours) not just a single reading taken over the span of a few minutes or hours.

USEPA Air Sensor Guidebook (2014)

- The increasing use of sensors is expected to provide more data on air pollution than has previously been available, and in shorter time increments. For example, it will be much easier to track minute-by-minute changes in pollution levels. As a result, we will become more aware of short-term, peak levels of some pollutants.
- However, the actual health effects of very short term elevated levels of most pollutants are not well understood and EPA has not established health information defining such short-term pollutant exposures and the health-based interpretation of sensor measurements.
- Much research has to be performed before it is understood how health messaging for short periods of data collections should be communicated.

Issues Related to Data Interpretation and Presentation

- LCSs provide real-time reading, 1-hr average and 24-hr average concentrations of $PM_{2.5}$.
- Presently, real-time reading and 1-hr average concentrations of $PM_{2.5}$ do not have any meaning related to health effects since their health effects has not been well understood (no health effect criteria for them).
- Different countries have different 24-hr average ambient air quality standard for $PM_{2.5}$ and different criteria for AQI, therefore AQI based on one country's standard and criteria cannot be compared with AQI of other countries.
- Since there are no ambient air quality standards for real-time reading and 1-hr average concentrations of $PM_{2.5}$, therefore there is no AQI criteria for them and it is not possible to present them in term of AQI.
- Confusion to the public and citizen if data interpretation and presentation are not technically correct.

Thailand AQI Criteria

AQI	Air Quality	Color	Warning Messages and Recommendations
0 - 25	Very Good	Blue	Good for out door activities and mobility
26 - 50	Good	Green	Can do out door activities and mobility
51 - 100	Moderate	Yellow	General Public : can do outdoor activities as normal Vulnerable Group : If coughing, shortness of breath, eyes irritation, should limit time for outdoor activities
101 - 200	Begin to have health effects	Orange	General Public : Should watch over health; If coughing, difficult breathing, eye irritation, should reduce outdoor activities or use personal protective devices if necessary Vulnerable Group : Should reduce time for outdoor activities or use protective devices if necessary; If coughing, shortness of breath, eyes inflammation, tight chest, headache, abnormal heart beat, nausea, or tired, should seek medical advises
> 200	Have health effects	Red	Everyone: Avoid every outdoor activities, avoid areas with severe air pollution or use personal protective device if necessary; if having health sypmtomps, should seek medical advises

AQI versus Concentrations

AQI	$PM_{2.5}$ ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	O_3 (ppb)	CO (ppm)	NO_2 (ppb)	SO_2 (ppb)
	24-hr average Concentration		8-hr average Concentration		1-hr average Concentration	
0 - 25	0 - 25	0 - 50	0 - 35	0 - 4.4	0 - 60	0 - 100
26 - 50	26 - 37	51 - 80	36 - 50	4.5 - 6.4	61 - 106	101 - 200
51 - 100	38 - 50	81 - 120	51 - 70	6.5 - 9.0	107 - 170	201 - 300
101 - 200	51 - 90	121 - 180	71 - 120	9.1 - 30.0	171 - 340	301 - 400
> 200	> 91	> 181	> 121	> 30.1	> 341	> 401

Calculation of AQI from Measured $PM_{2.5}$ Concentrations

The Air Quality Index is a piecewise linear function of the pollutant concentration. At the boundary between AQI categories, there is a discontinuous jump of one AQI unit. To convert from concentration to AQI this equation is used:

$$AQI = \frac{I_{high} - I_{low}}{C_{high} - C_{low}} (C - C_{low}) + I_{low}$$

Where:
- I = the (Air Quality) index,
- C = the pollutant concentration,
- C_{low} = concentration breakpoint that is ≤ C,
- C_{high} = the concentration breakpoint that is ≥ C,
- I_{low} = the index breakpoint corresponding to C_{low},
- I_{high} = the index breakpoint corresponding to C_{high}.

Thai AQI Criteria for $PM_{2.5}$ (Thai's table of breakpoints for $PM_{2.5}$)

AQI	$PM_{2.5}$ ($\mu g/m^3$)
	24-hr avg. conc.
0 - 25	0 - 25
26 - 50	26 - 37
51 - 100	38 - 50
101 - 200	51 - 90
> 200	> 90

For 24-hr average concentration of $PM_{2.5}$ of 36 $\mu g/m^3$

$$AQI = \frac{50 - 26}{37 - 26} (36 - 26) + 26 = 47.8$$

For 24-hr average concentration of $PM_{2.5}$ of 50 $\mu g/m^3$

$$AQI = \frac{100 - 51}{50 - 38} (50 - 38) + 51 = 100$$

Thai AQI

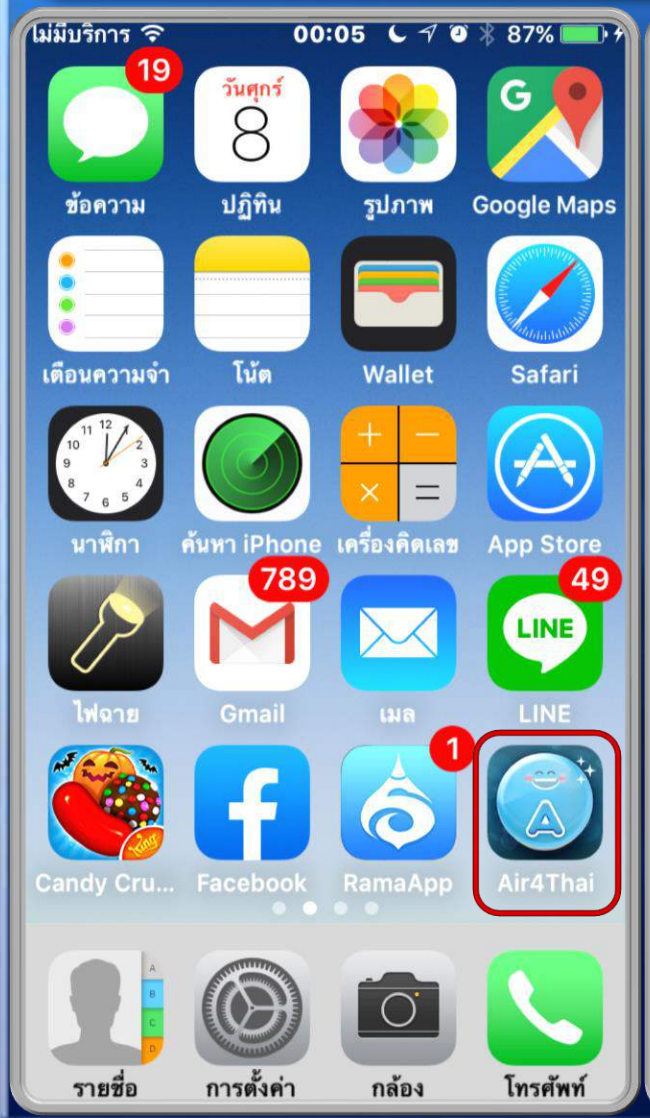
AQI	$PM_{2.5}$ ($\mu g/m^3$)
	24-hr avg. conc.
0 - 25	0 - 25
26 - 50	26 - 37
51 - 100	38 - 50
101 - 200	51 - 90
> 200	> 90

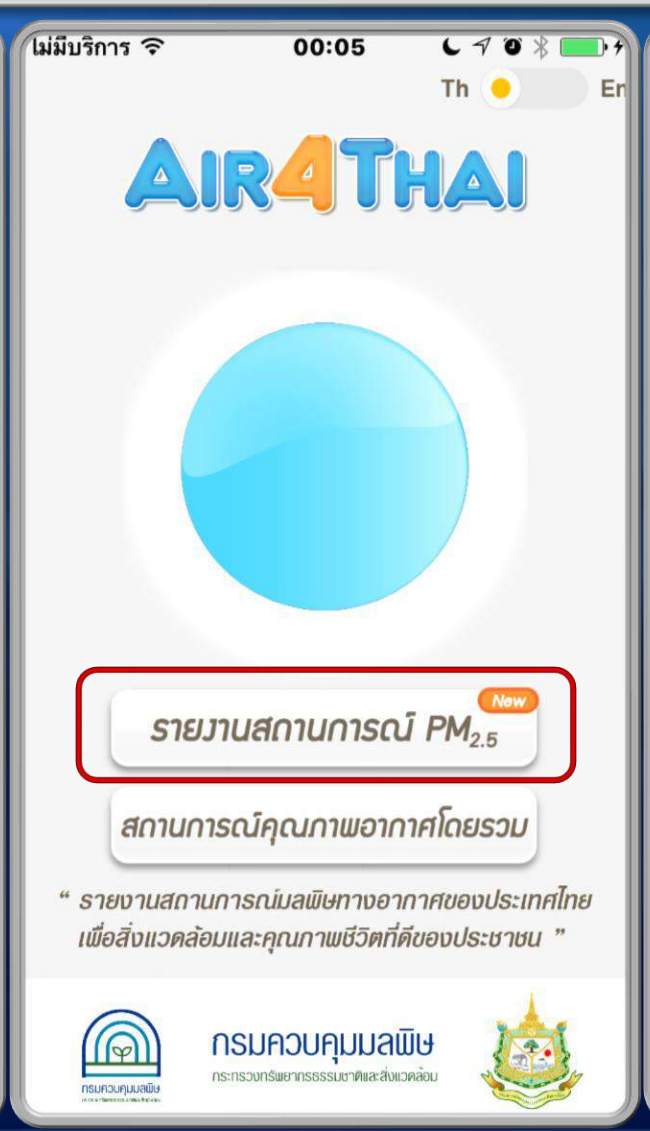
US AQI

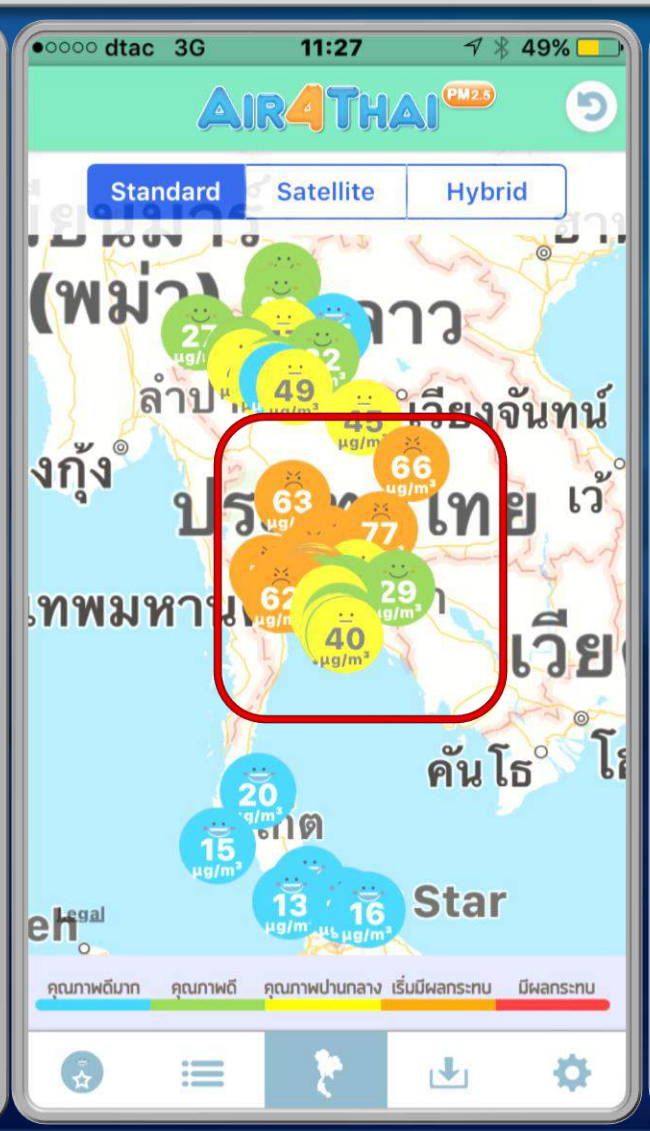
AQI Category	Index Values	Revised Breakpoints ($\mu g/m^3$, 24-hour average)
Good	0 - 50	0.0 – 12.0
Moderate	51 - 100	12.1 – 35.4
Unhealthy for Sensitive Groups	101 – 150	35.5 – 55.4
Unhealthy	151 – 200	55.5 – 150.4
Very Unhealthy	201 – 300	150.5 – 250.4
Hazardous	301 – 400	250.5 – 350.4
	401 – 500	350.5 – 500

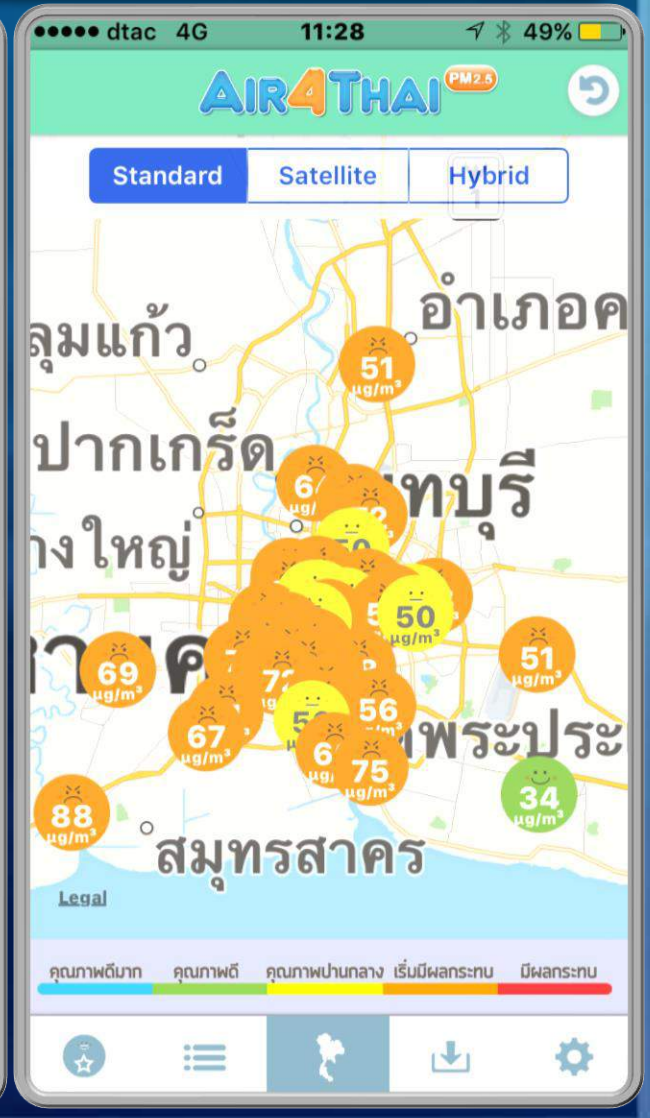
24hr-PM2.5 ($\mu g/m^3$)	Thai AQI	US AQI	China AQI	Singapore PSI
36	47 Good	103 Unhealthy for Sensitive Group	51 Good	78 Moderate
75	162 Unhealthy	161 Unhealthy	100 Good	121 Unhealthy

Web and Mobile Application AIR4THAI for Air Quality Report









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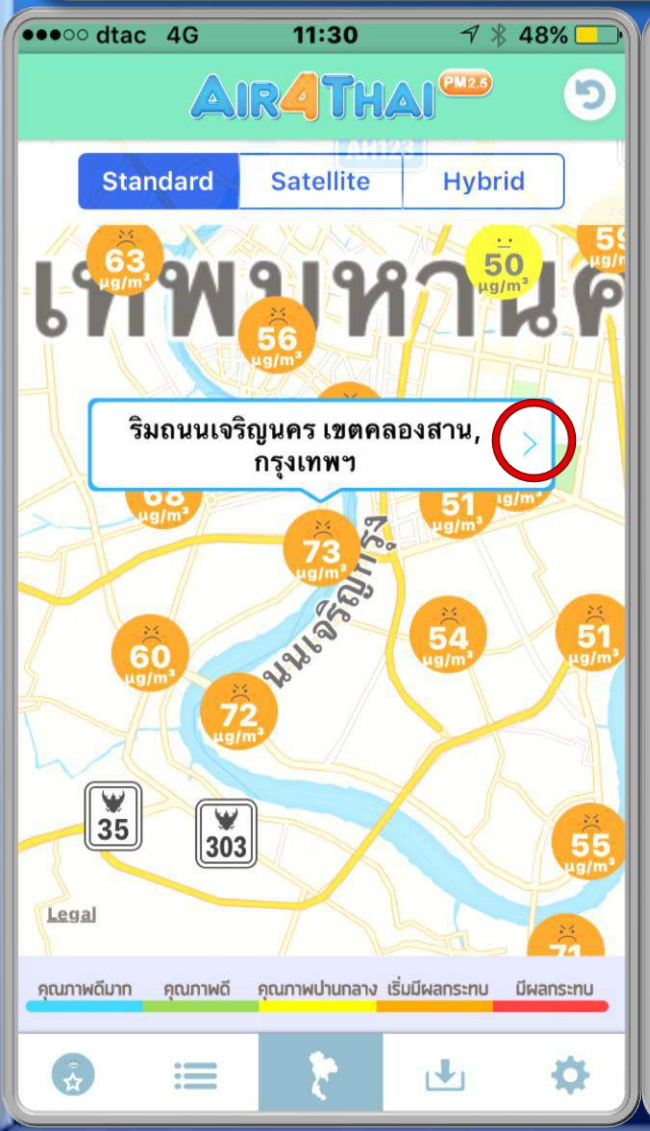
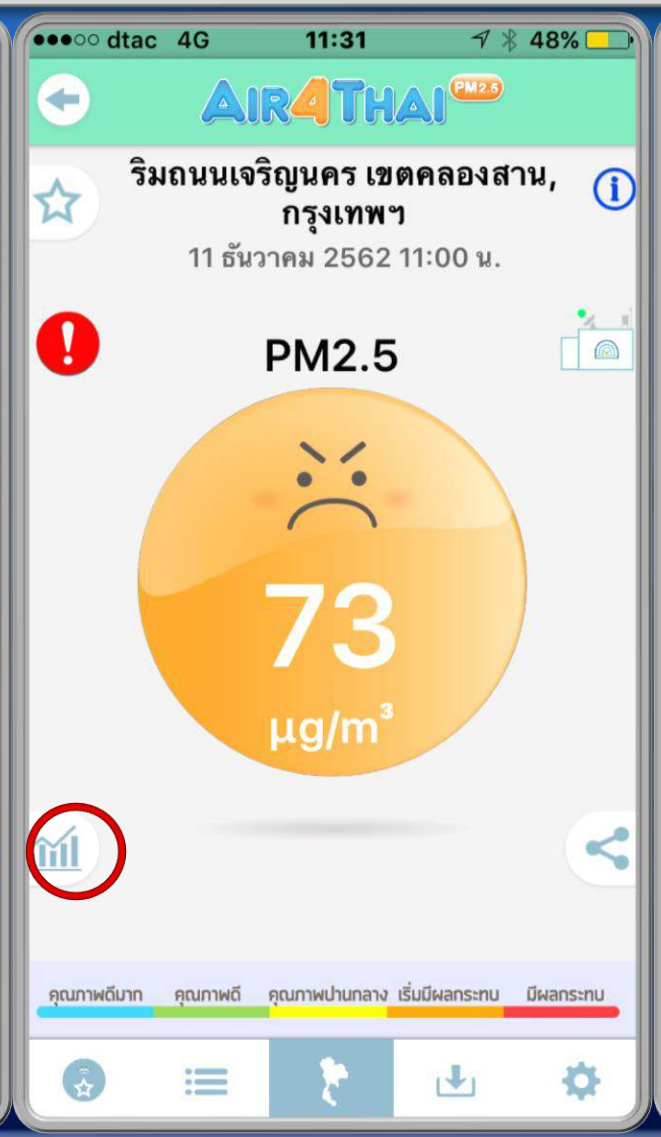
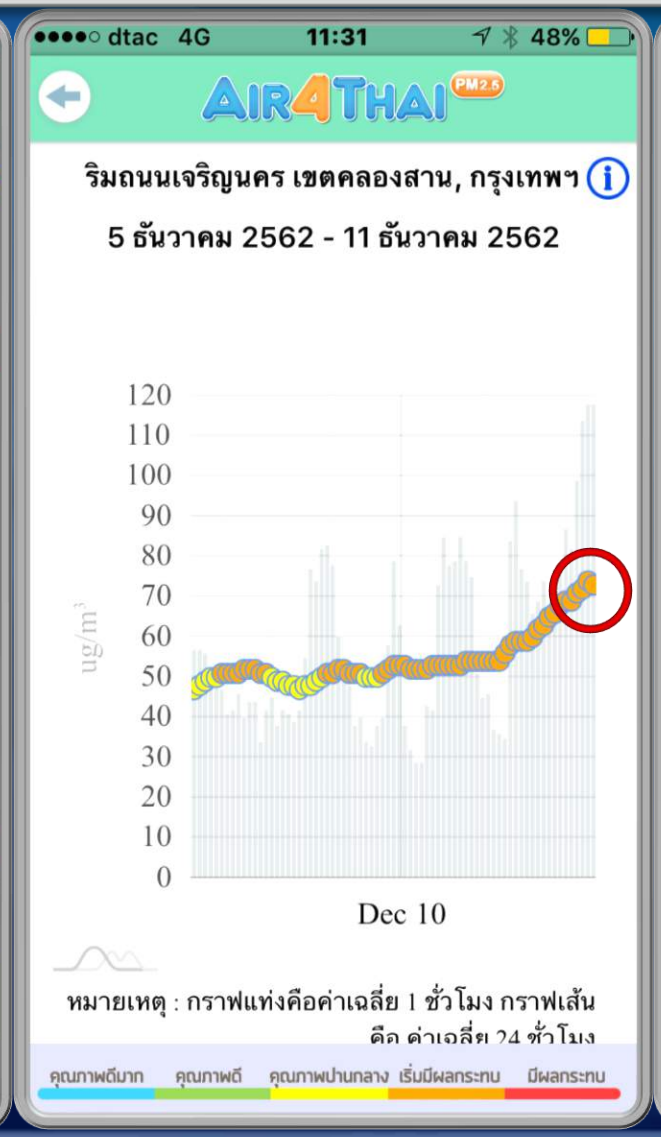
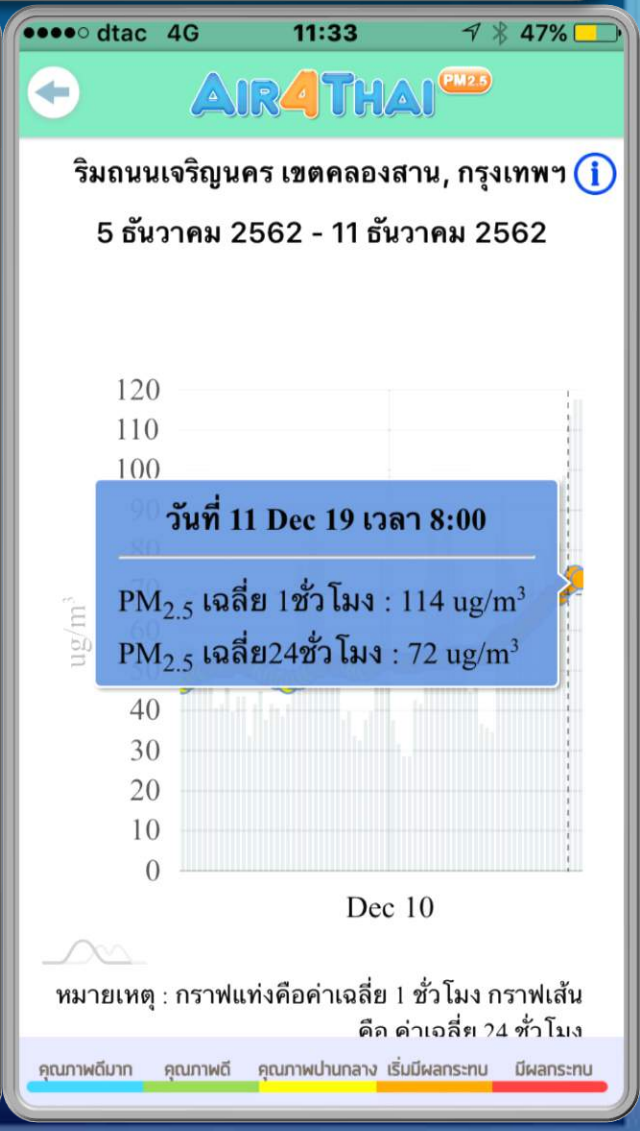
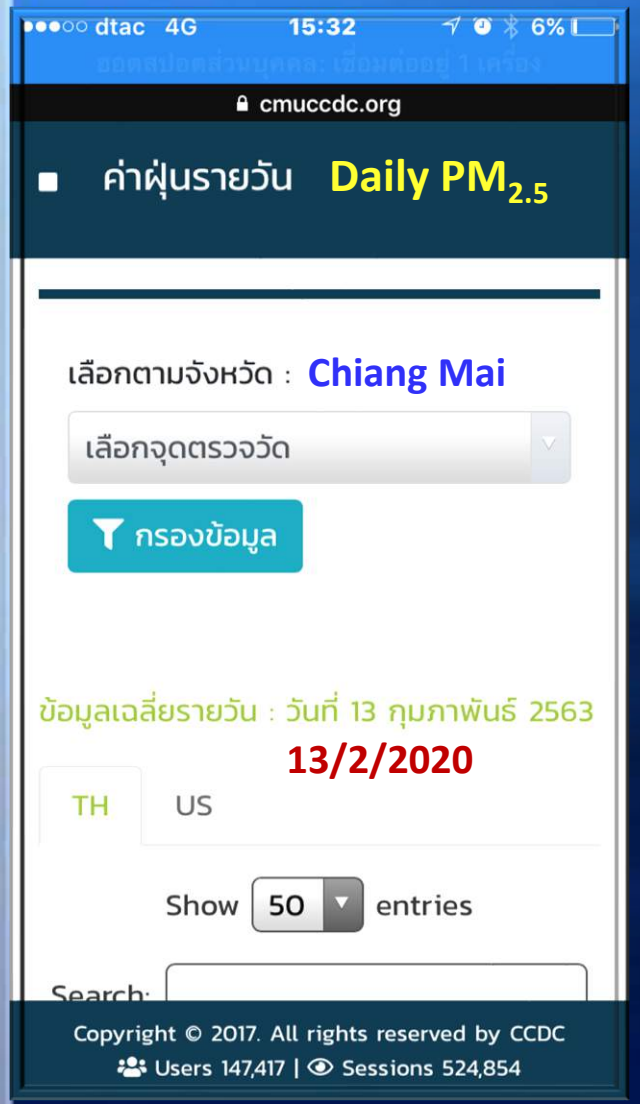


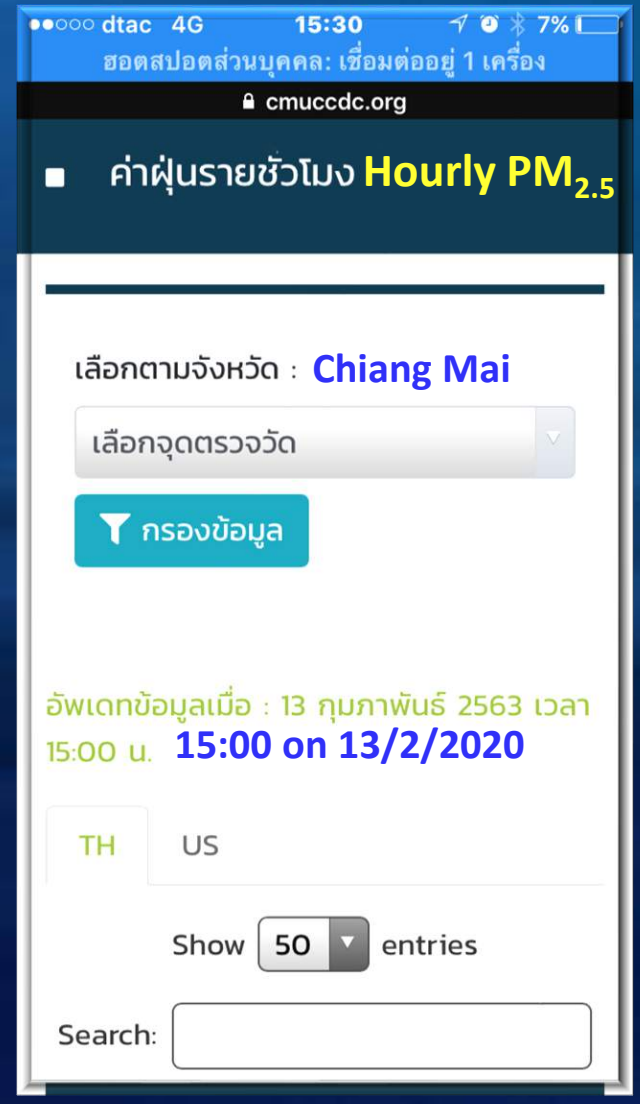


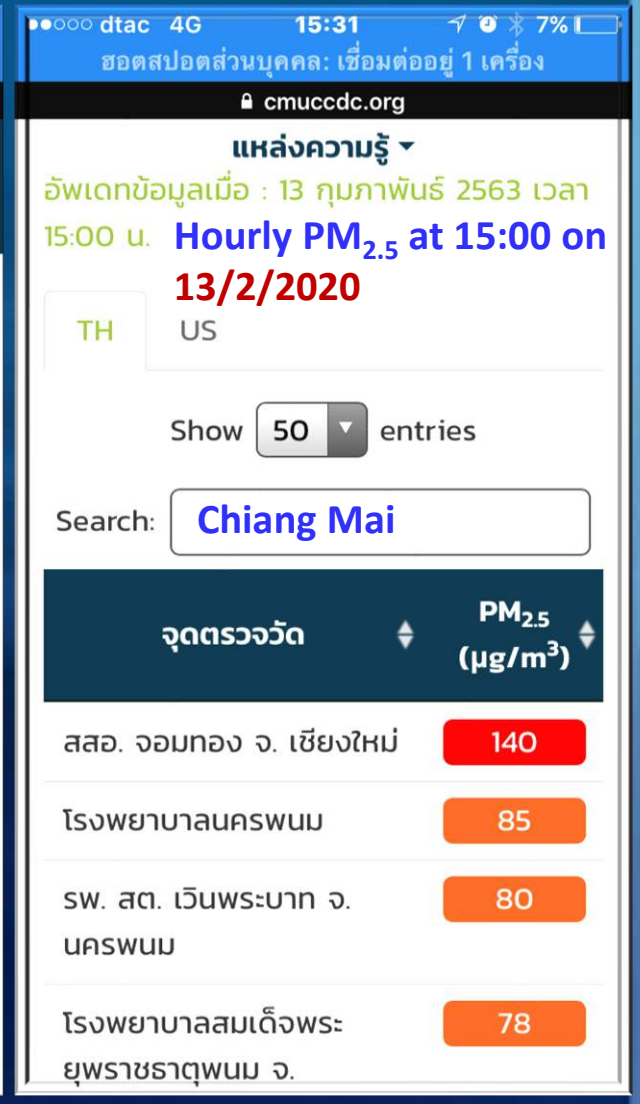




Interpretation and Presentation of Air Quality ($PM_{2.5}$) by LCS (DUSTBOY)

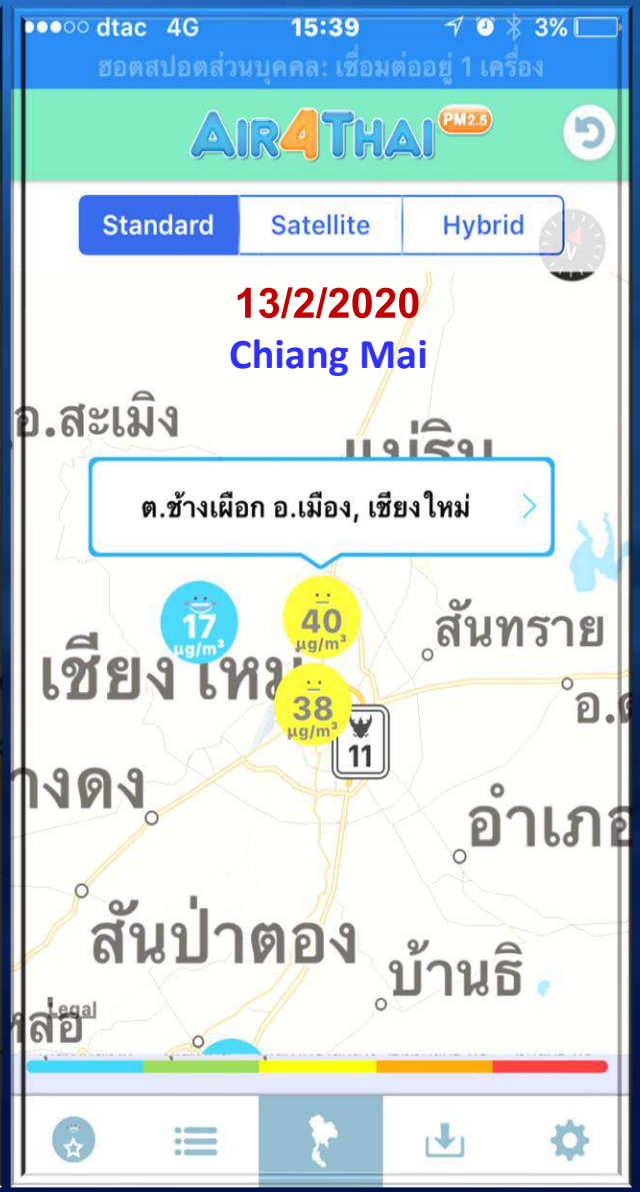






PCD $PM_{2.5}$ Report

Chiang Mai University $PM_{2.5}$ Report (DUSTBOY $PM_{2.5}$ LCS)



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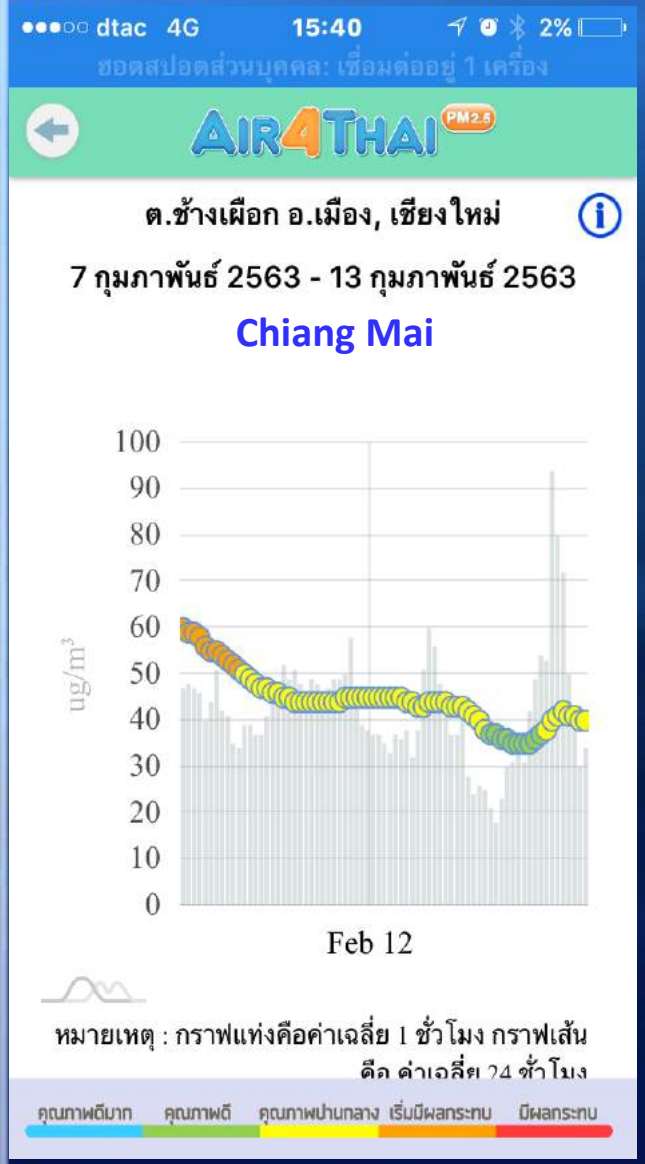

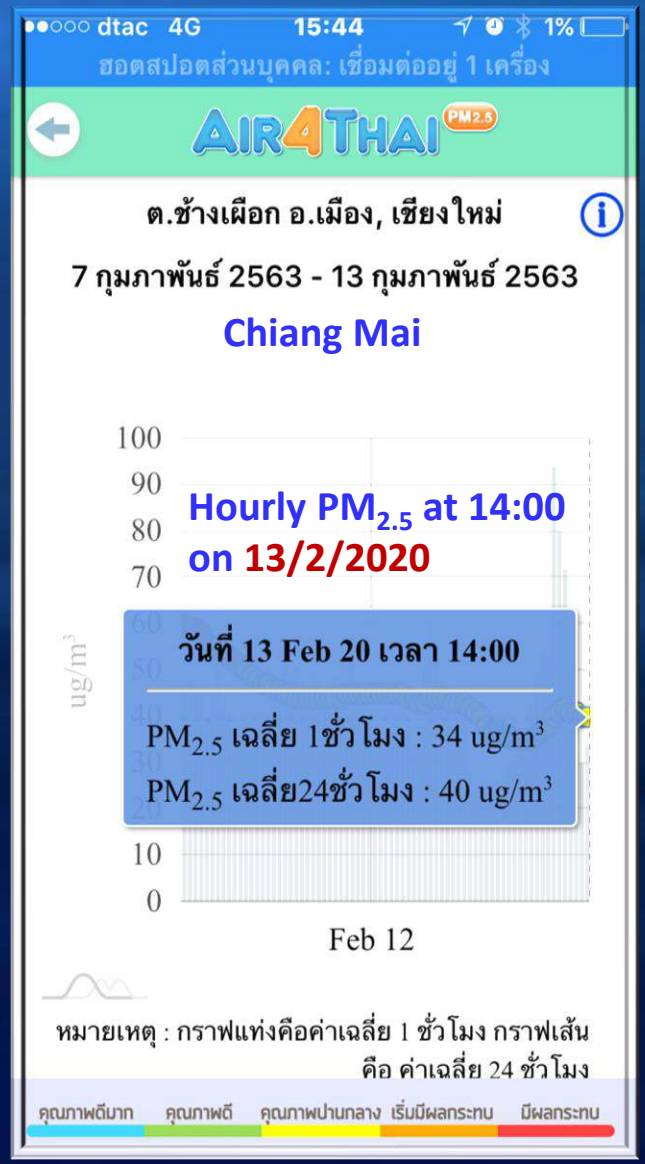

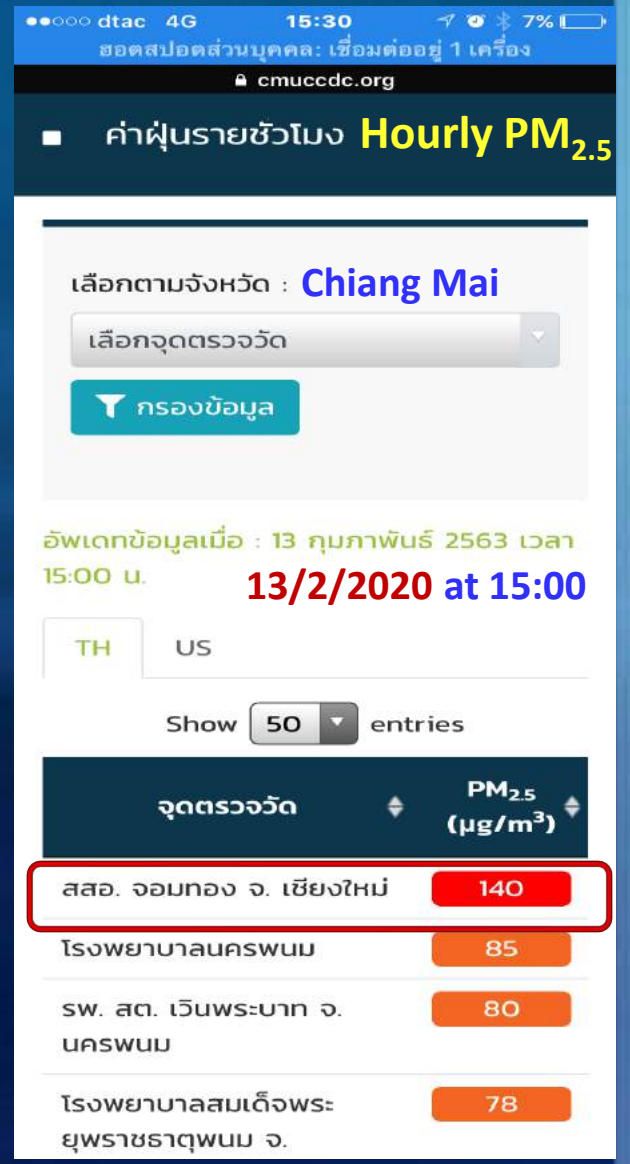

Interpretation and Presentation of Air Quality ($PM_{2.5}$) by LCS (DUSTBOY)

dtac 4G 15:34 5%
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cmuccdc.org

แหล่งความรู้

ข้อมูลเฉลี่ยรายวัน : วันที่ 13 กุมภาพันธ์ 2563

TH US **Daily $PM_{2.5}$ TH AQI**

Show 50 entries

Search:

จุดตรวจวัด	$PM_{2.5}$ ($\mu g/m^3$)	TH AQI
โรงพยาบาลสมเด็จพระยุพราชเด่นชัย จ. แพร่	161	271
สำนักงานสาธารณสุข	151	261

dtac 4G 15:35 4%
ฮอตสปอตส่วนบุคคล: เชื่อมต่ออยู่ 1 เครื่อง
cmuccdc.org

แหล่งความรู้

โรงพยาบาลศรีสังวาลย์ จ. แม่ฮ่องสอน	151	261
สสอ. จอมทอง จ. เชียงใหม่	124	234
โรงพยาบาลลอง จ. แพร่	121	231
รพ.สต. เมืองน้อย จ. แม่ฮ่องสอน	120	230
โรงพยาบาลบ้านผือ จ. อุดรธานี	115	225
โรงพยาบาล	113	223

dtac 4G 15:34 5%
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ข้อมูลเฉลี่ยรายวัน : วันที่ 13 กุมภาพันธ์ 2563

TH US **Daily $PM_{2.5}$ US AQI**

Show 50 entries

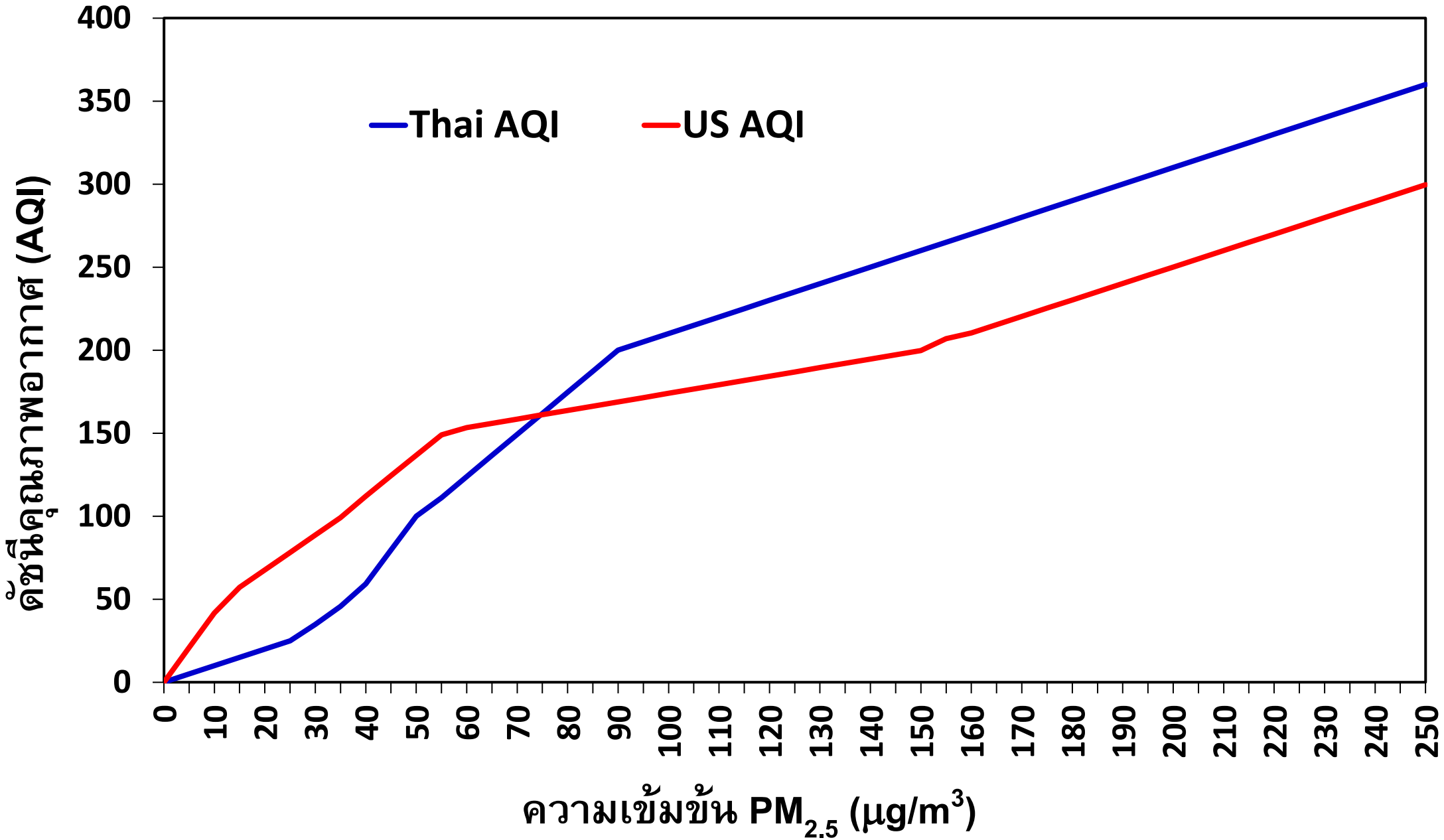
Search:

จุดตรวจวัด	$PM_{2.5}$ ($\mu g/m^3$)	US AQI
โรงพยาบาลสมเด็จพระยุพราชเด่นชัย จ. แพร่	161	211
สำนักงานสาธารณสุขจังหวัด	151	201

dtac 4G 15:35 5%
cmuccdc.org

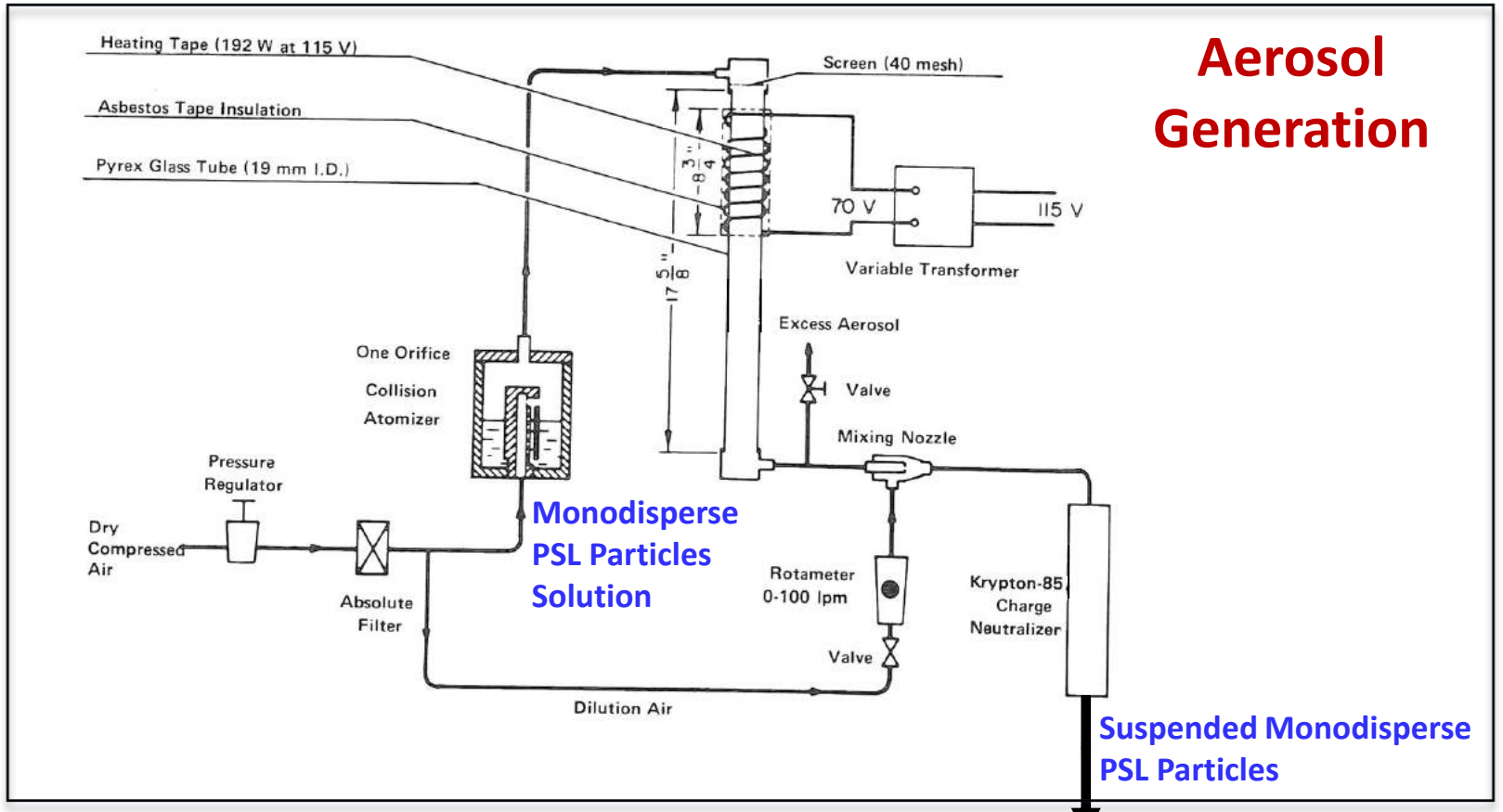
แม่ฮ่องสอน แหล่งความรู้

โรงพยาบาลศรีสังวาลย์ จ. แม่ฮ่องสอน	151	201
สสอ. จอมทอง จ. เชียงใหม่	124	186
โรงพยาบาลลอง จ. แพร่	121	185
รพ.สต. เมืองน้อย จ. แม่ฮ่องสอน	120	184
โรงพยาบาลบ้านผือ จ. อุดรธานี	115	181
โรงพยาบาลธัญญารักษ์ แม่ฮ่องสอน	113	180


Thai AQI
US AQI
ดัชนีคุณภาพอากาศ (AQI)
0
50
100
150
200
250
300
350
400
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
ความเข้มข้น PM2.5 (µg/m3)

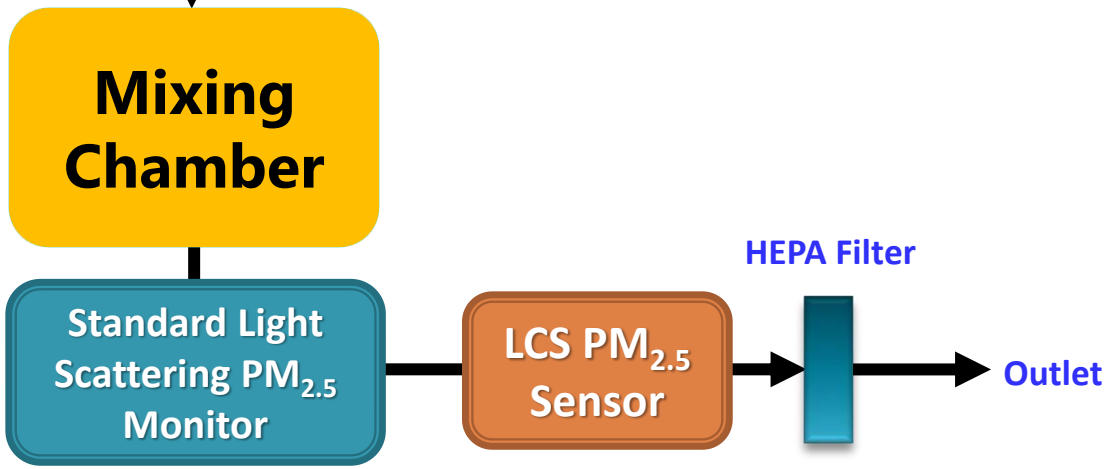
Efforts against the Issues

- Development of standardization and calibration system for $PM_{2.5}$ LCSs
- Development of AQI criteria for 1-hr average $PM_{2.5}$ concentration



Development of standardization and calibration system for $PM_{2.5}$ LCSs

Schematic Diagram of Low-Cost Sensor Calibration and Standardization System



Collocation of Various Thai LCSs for $PM_{2.5}$ with Standard $PM_{2.5}$ Monitor of PCD

AeroSURE
Song Khla University

BAM $PM_{2.5}$
Monitor

DUSTBOY
Chiang Mai University

NSTDA

Teledyne Standard
Light Scattering $PM_{2.5}$
Monitor

AirEnvir
Rajchamongkol Laan Na
University

Monitoring Stations at 3 Provinces

- Bangkok
- Chiang Mai
- Ubon Ratchthani

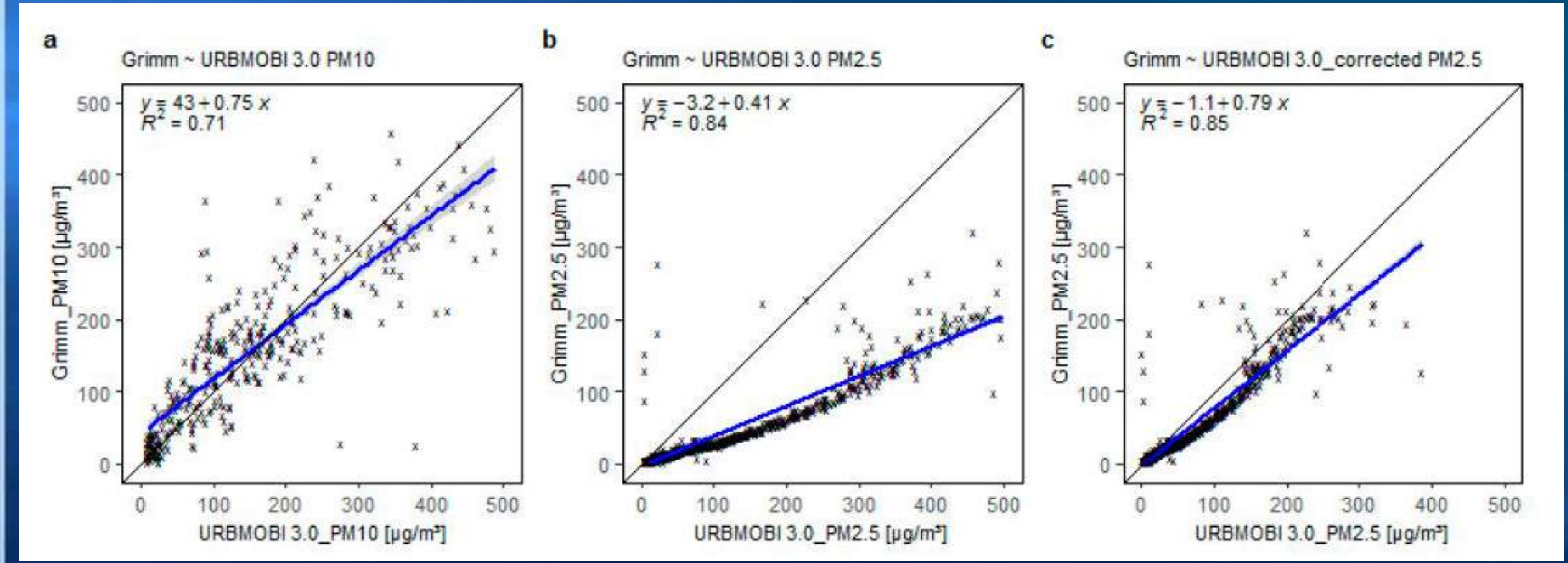


Figure 4. Results of the calibration tests recorded by the URBMOBI 3.0 (metal housing) and the reference instrument (Grimm 1.108) inside the particle generator with a time integral of 6 s; (a) PM10 scatter plot between Grimm 1.108 raw data and URBMOBI 3.0; (b) PM2.5 scatter plot between Grimm 1.108 and URBMOBI 3.0 raw data; (c) PM2.5 scatter plot between Grimm 1.108 raw data and URBMOBI 3.0 data corrected using the compensation function

Venkatraman Jagatha, J.; Klausnitzer, A.; Chacón-Mateos, M.; Laquai, B.; Nieuwkoop, E.; van der Mark, P.; Vogt, U.; Schneider, C. Calibration Method for Particulate Matter Low-Cost Sensors Used in Ambient Air Quality Monitoring and Research. Sensors 2021, 21, 3960.

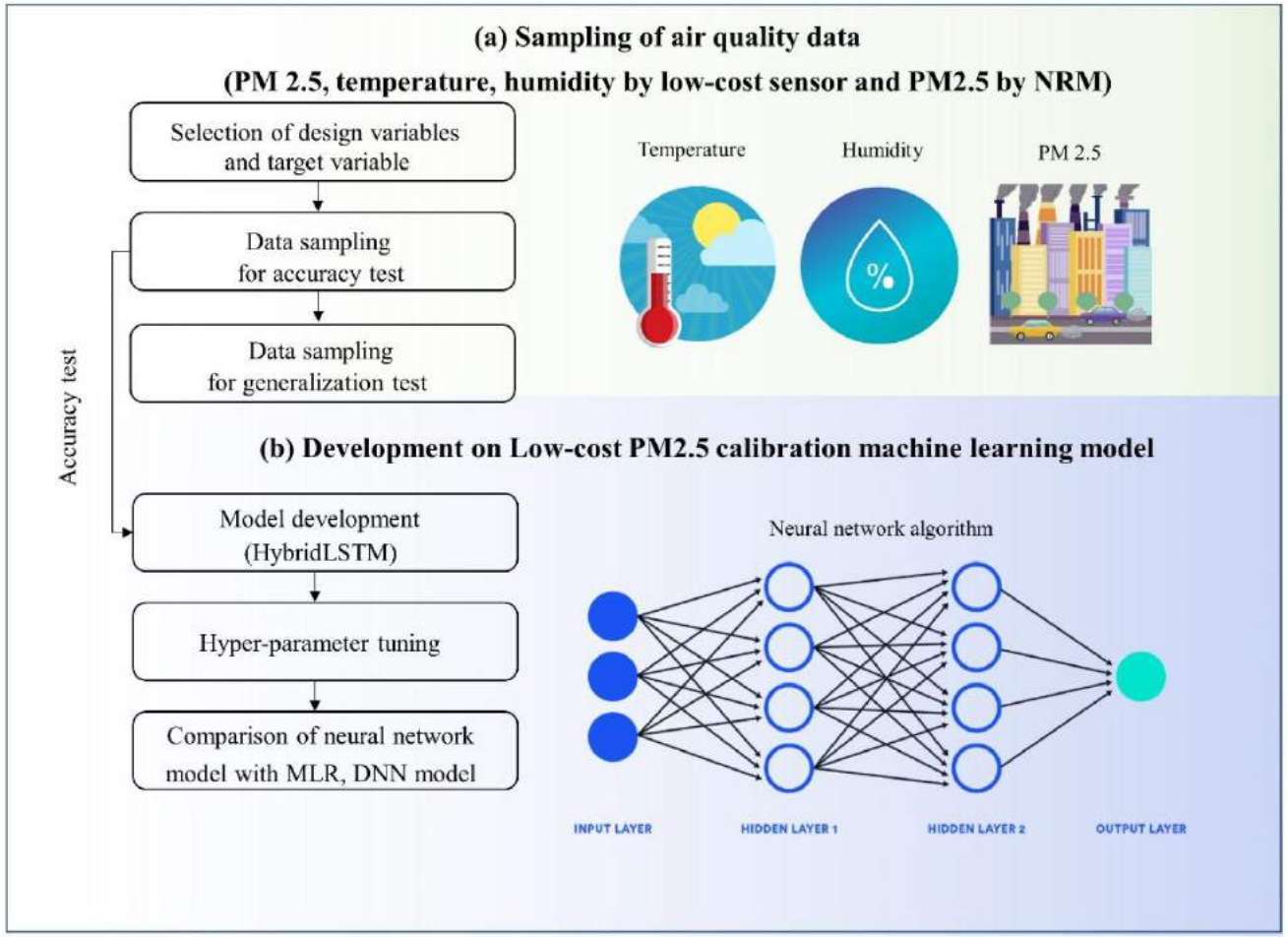


Figure 1. Research flow chart. This work is performed in two steps: (**a**) data collection for $PM_{2.5}$, temperature and humidity by low-cost sensor and $PM_{2.5}$ by gravimetric instrument with high accuracy. (**b**) Machine learning model development based on the collected dataset. Calibration performance from the developed model is compared with raw data by low-cost sensor and calibration results by benchmark method (multi-linear regression method, DNN).

Park, D.; Yoo, G.-W.; Park, S.-H.; Lee, J.-H. Assessment and Calibration of a Low-Cost $PM_{2.5}$ Sensor Using Machine Learning (HybridLSTM Neural Network): Feasibility Study to Build an Air Quality Monitoring System. Atmosphere 2021, 12, 1306. https://doi.org/10.3390/atmos12101306

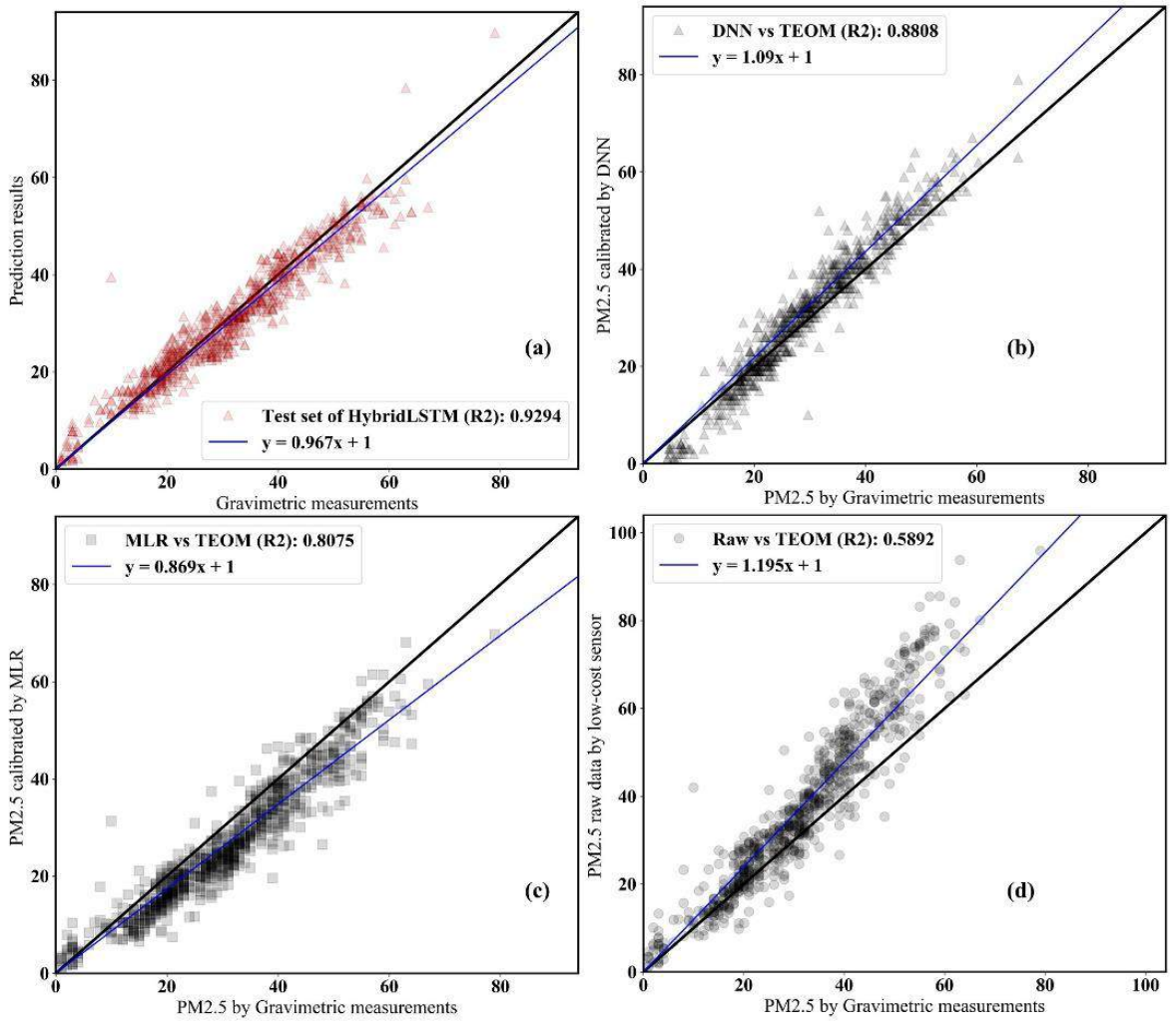


Figure 8. Results of scatter plot for the HybridLSTM (a), benchmark (b) and raw data (c) versus gravimetric measurements (d).

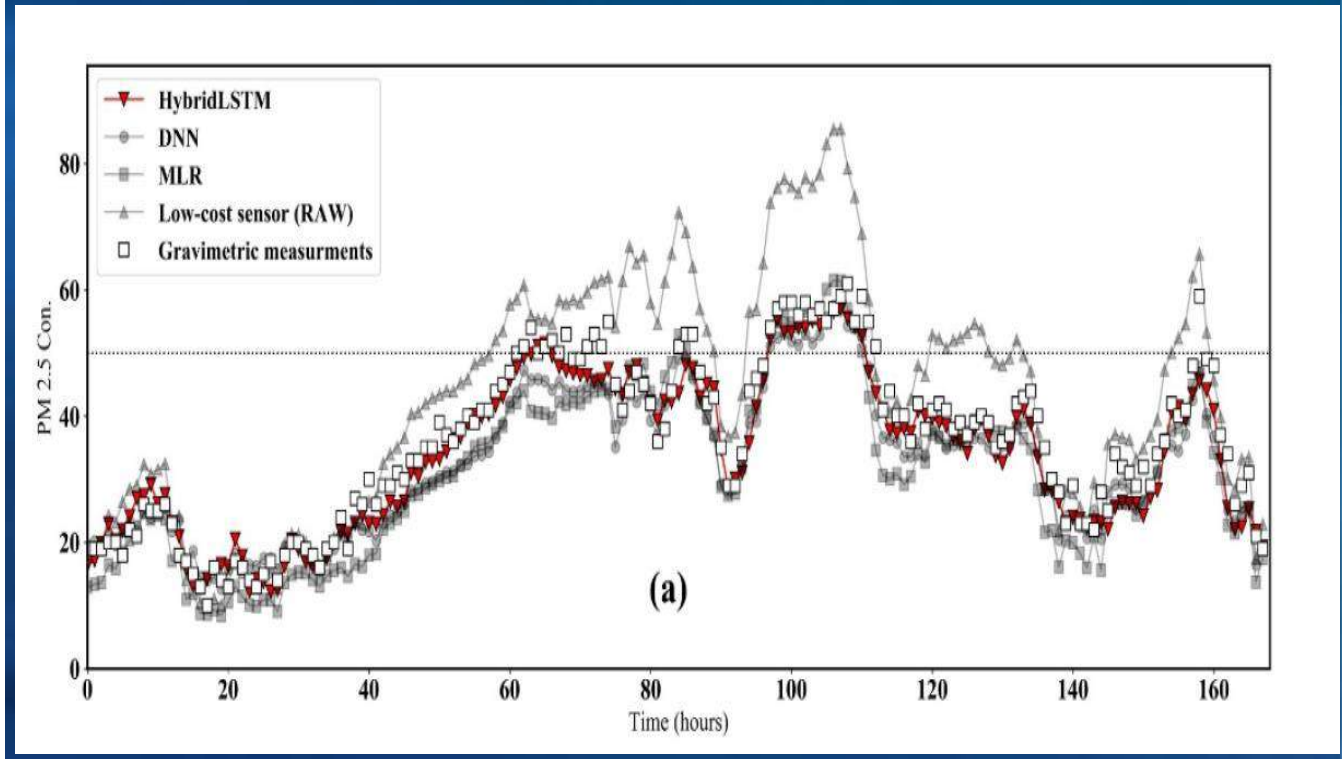
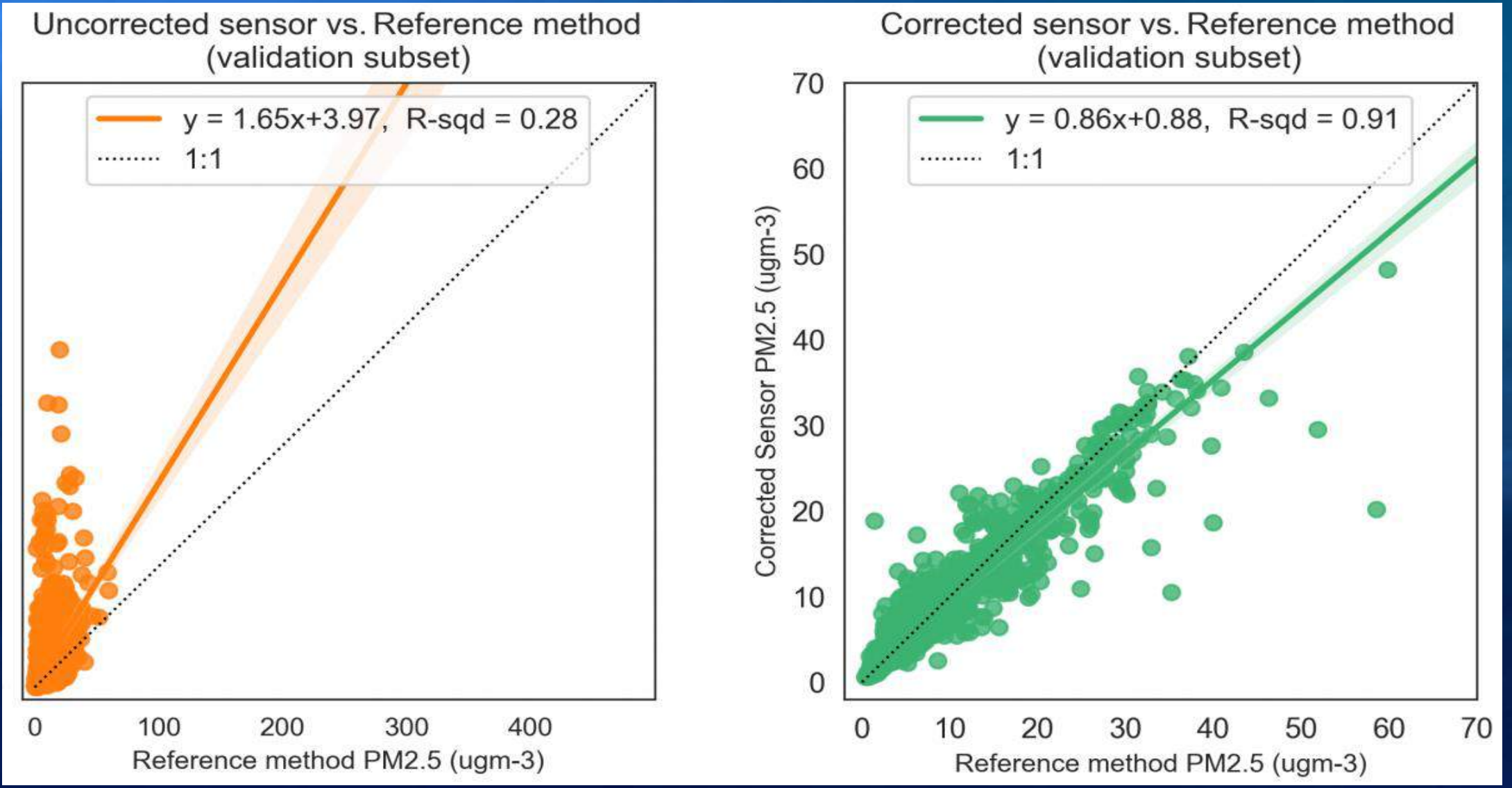


Figure 9. Results of time-series comparison results for the HybridLSTM, DNN, MLR and raw data versus gravimetric measurements at 1-week intervals

Park, D.; Yoo, G.-W.; Park, S.-H.; Lee, J.-H. Assessment and Calibration of a Low-Cost $PM_{2.5}$ Sensor Using Machine Learning (HybridLSTM Neural Network): Feasibility Study to Build an Air Quality Monitoring System. Atmosphere 2021, 12, 1306. https://doi.org/10.3390/atmos12101306

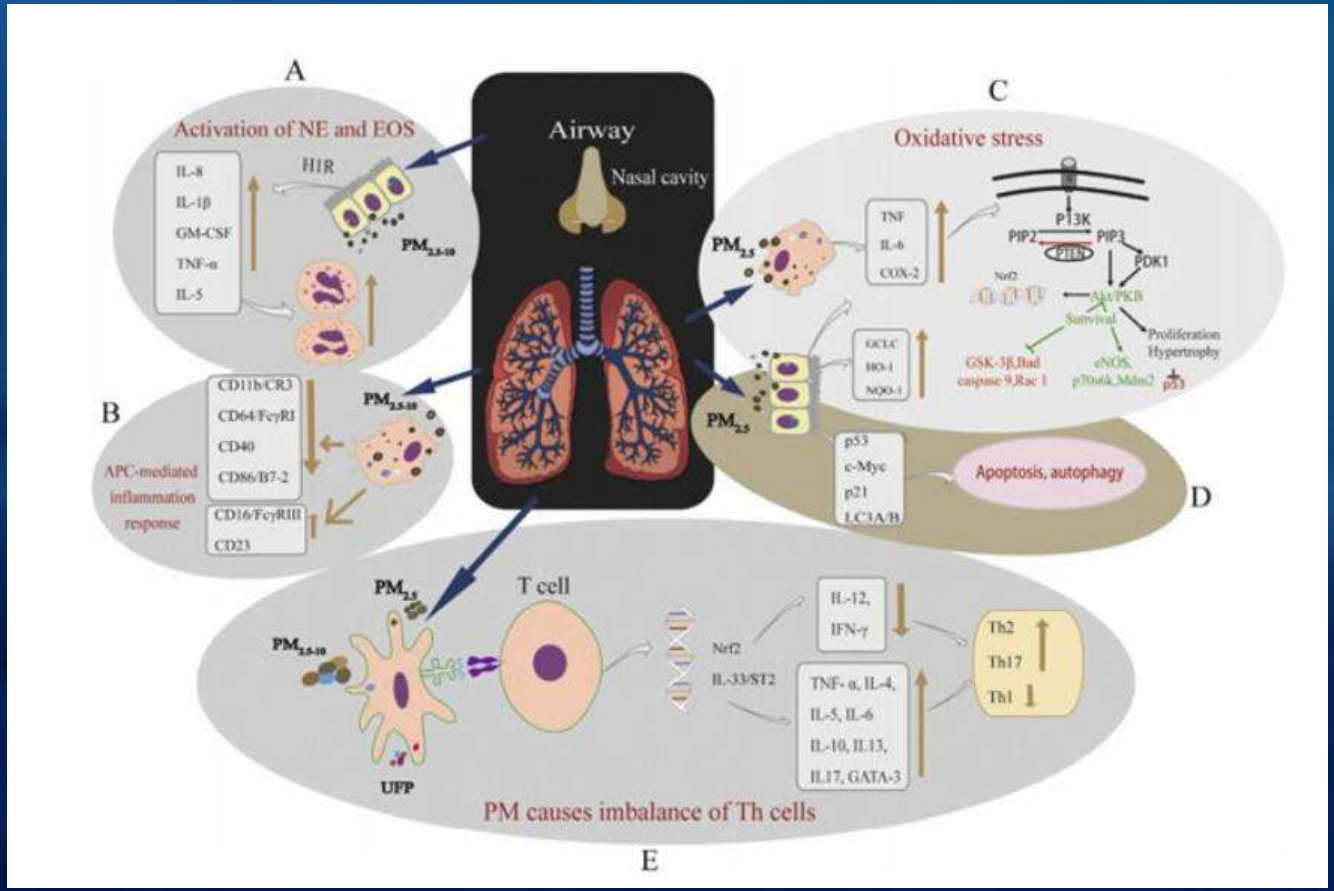
Machine Learning (ML) boosts performance of low-cost air quality sensors



https://www.southcoastscience.com/machine-learning-ml-boosts-performance-of-low-cost-air-quality-sensors/

Development of AQI criteria for 1-hr average $PM_{2.5}$ concentration

Conducting a research on “Impacts of $PM_{2.5}$ from Bangkok Streets in Allergic Rhinitis Patients; A Pilot Study for Standard $PM_{2.5}$ Level Adjustment Policy”



Thank you for your attention