Environmental Monitoring and Hazard Mitigation using UAV-IoT technologies

Project FIREfly, and what it could mean for the Asia Pacific Region

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What I work on

- **Sustainable aviation**
- **UAV-IoT systems**
  including FIREfly
- **AI-assisted CFD**
  computational fluid dynamics
- **Biomimetic aerodynamics**

Research supported by

EU Horizon | Boeing China | ISIF Asia

Ningbo Science and Technology Bureau

45 minutes of talk, then an open discussion



1 FIREfly 1.0
The original concept and first field tests

2 FIREfly 2.0
Real deployments, dashboard and precision seed dropping

3 The Pacific
What transfers, what needs work, who is involved

Then, 10 to 15 min: open discussion. Which hazards matter most in Asia-Pacific, and what do you need from monitoring?

1

FIREfly 1.0

The original concept: detect smoke early, anywhere, on a small budget

Late detection turns a local hazard into a crisis





Seasonal haze

Every dry season, wildfires in the mountains blanket the Chiang Mai region in smoke.

Health and social cost

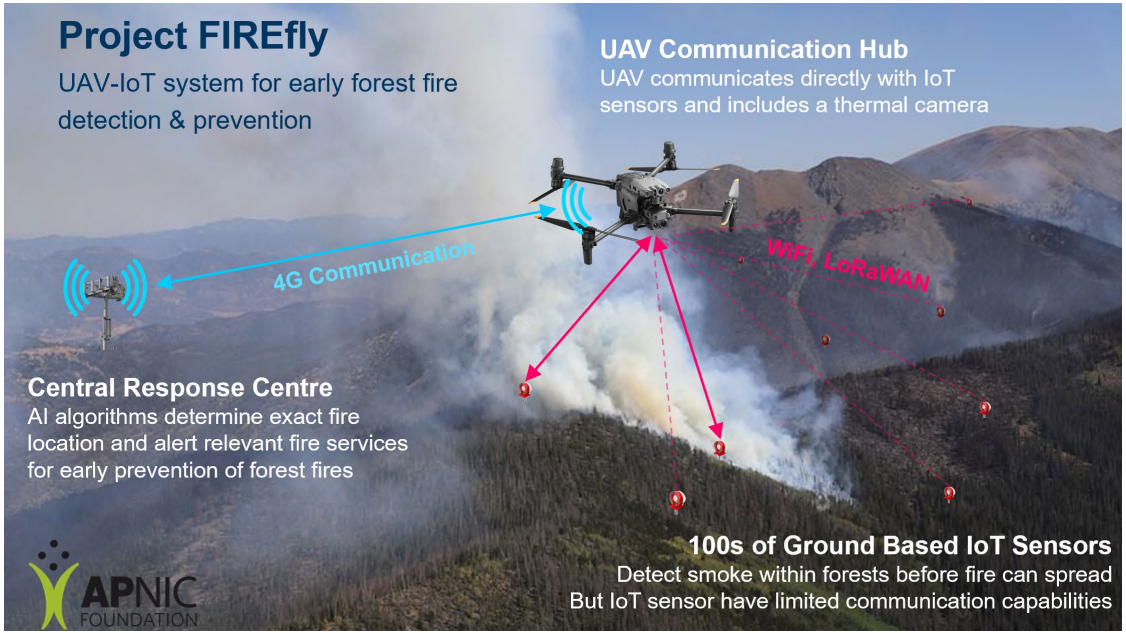
Whole communities breathe the smoke and live with the disruption.

Early detection is the lever

Catching fires early helps prevent extreme wildfire events.

Image sources: Thai PBS World, Bangkok Post, CNN

The concept: sensors on the ground, a drone above



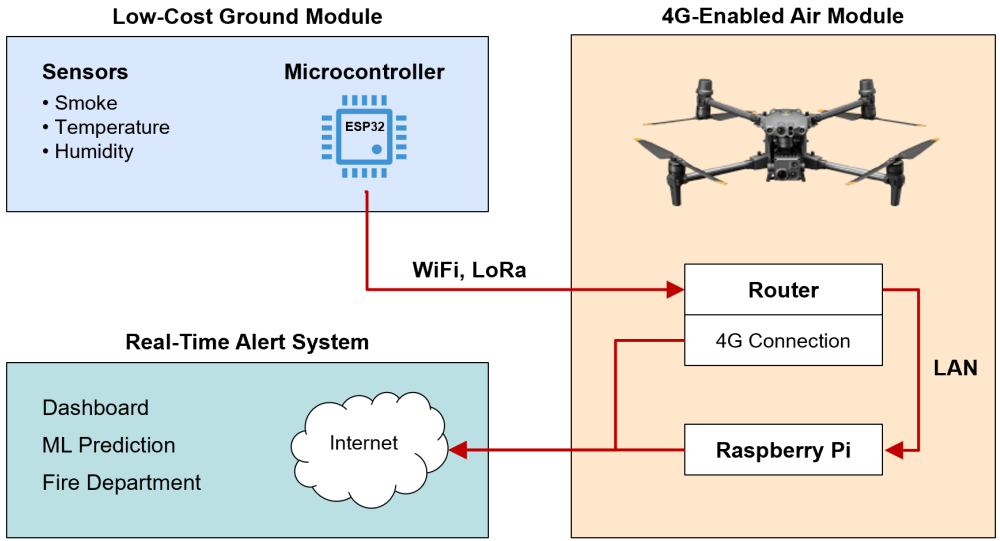
Concept illustration

100s of ground sensors detect smoke inside the forest, but have limited communication range

A UAV communication hub talks directly to the sensors and carries a thermal camera

A central response centre uses AI to locate the fire and alert the fire services

How it connects: ground, air and alert



1 Sense
An ESP32 ground module reads smoke, temperature and humidity.

2 Relay
WiFi or LoRa to the drone's router, then 4G to the internet.

3 Alert
Dashboard and ML prediction notify the fire department.

The ground module: a low-cost smoke sensor





Goal: perpetual operation of the smoke sensors, so early detection does not depend on site visits for power.

Senses smoke (air quality), temperature and humidity

Thinks on an ESP32 microcontroller with a low-power sleep mode

Powers itself with a battery and integrated solar panel

Copes with gaps using a protocol for intermittent connectivity, with many modules in parallel

The air module: a drone that bridges the gap







40+ min
flight time target

1280x1024
thermal camera

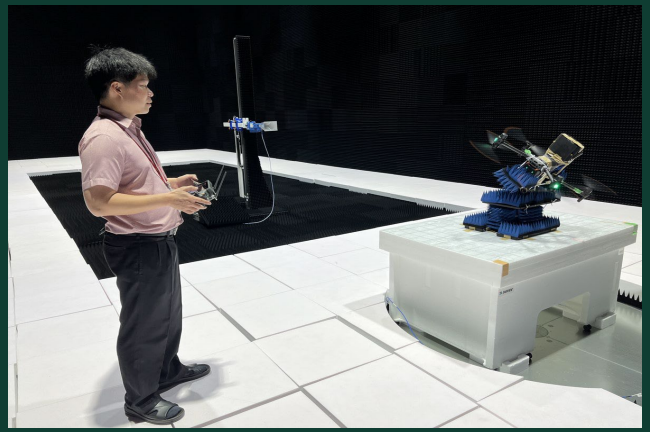
Lightweight air module: a 4G router and a Raspberry Pi 5 for real-time onboard processing.

Goal: a fully automated UAV that communicates with IoT sensors beneath the trees.

Testing the air module in flight and in the lab

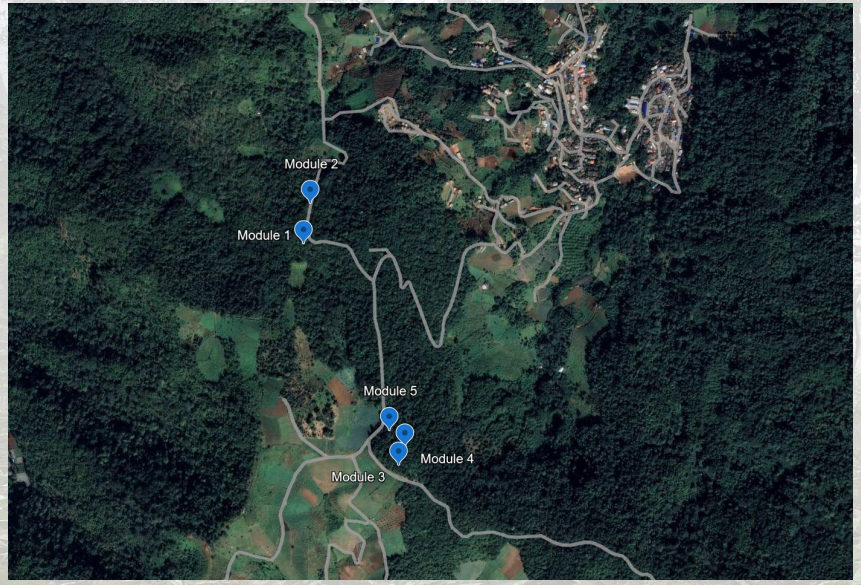


Air module in flight (video, 12 s)



Challenge: propellers and reflective surfaces can interfere with the signal. We tested the setup in an anechoic chamber at NICT.

Field experiments in Chiang Mai, with FORRU

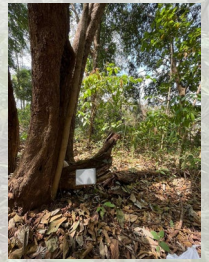


Module locations, Chiang Mai

Forest Restoration Research Unit (FORRU), Chiang Mai University. We evaluated:

- ✔ Battery life
- ✔ Communication links
- ✔ Weather resistance
- ✔ Sensor data analysis
- ✔ Data relay by the UAV air module

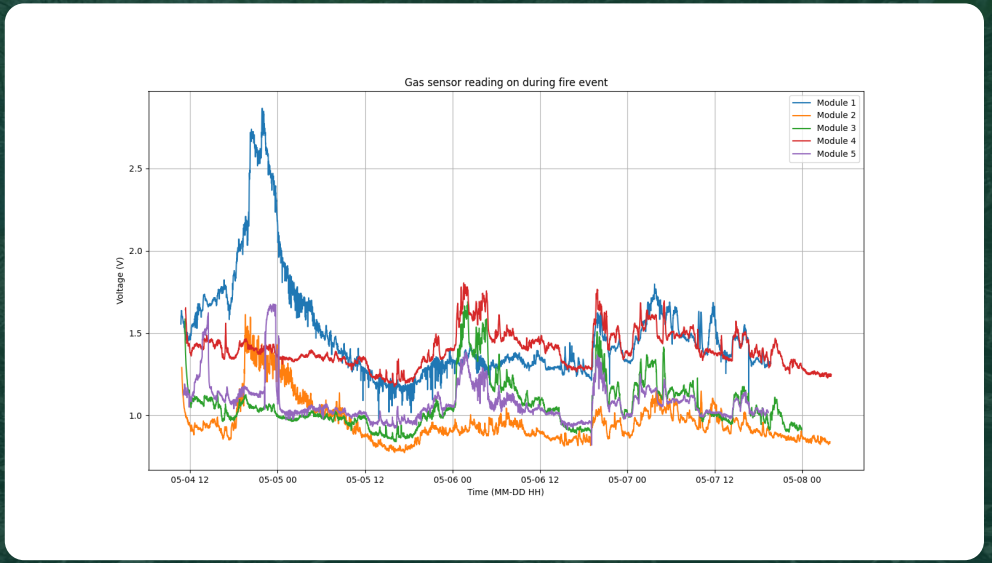





The first sensors captured a real fire



NASA FIRMS fire hotspots (red) near the sensor location



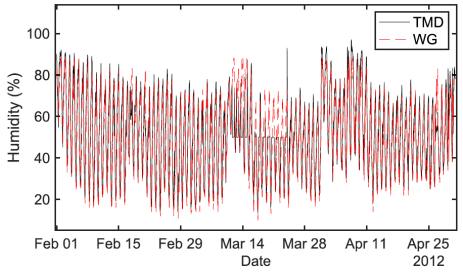
Gas-sensor readings from the deployed modules during the fire near Ban Mae Sai village, 3-5 May 2024, captured by Module 1

ML deployment: predicting forest-fire risk

Input data

Time series weather data

$$T(t), p(t), h(t), r(t), V_W(t), \theta_W(t)$$



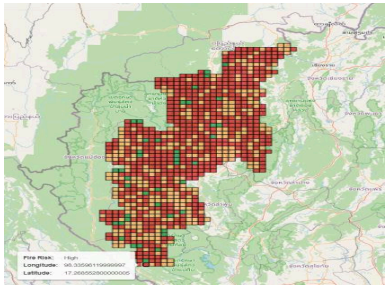
ML models

- Random Forest
- Support Vector Machines
- Transformers
- Model ensemble

Model output

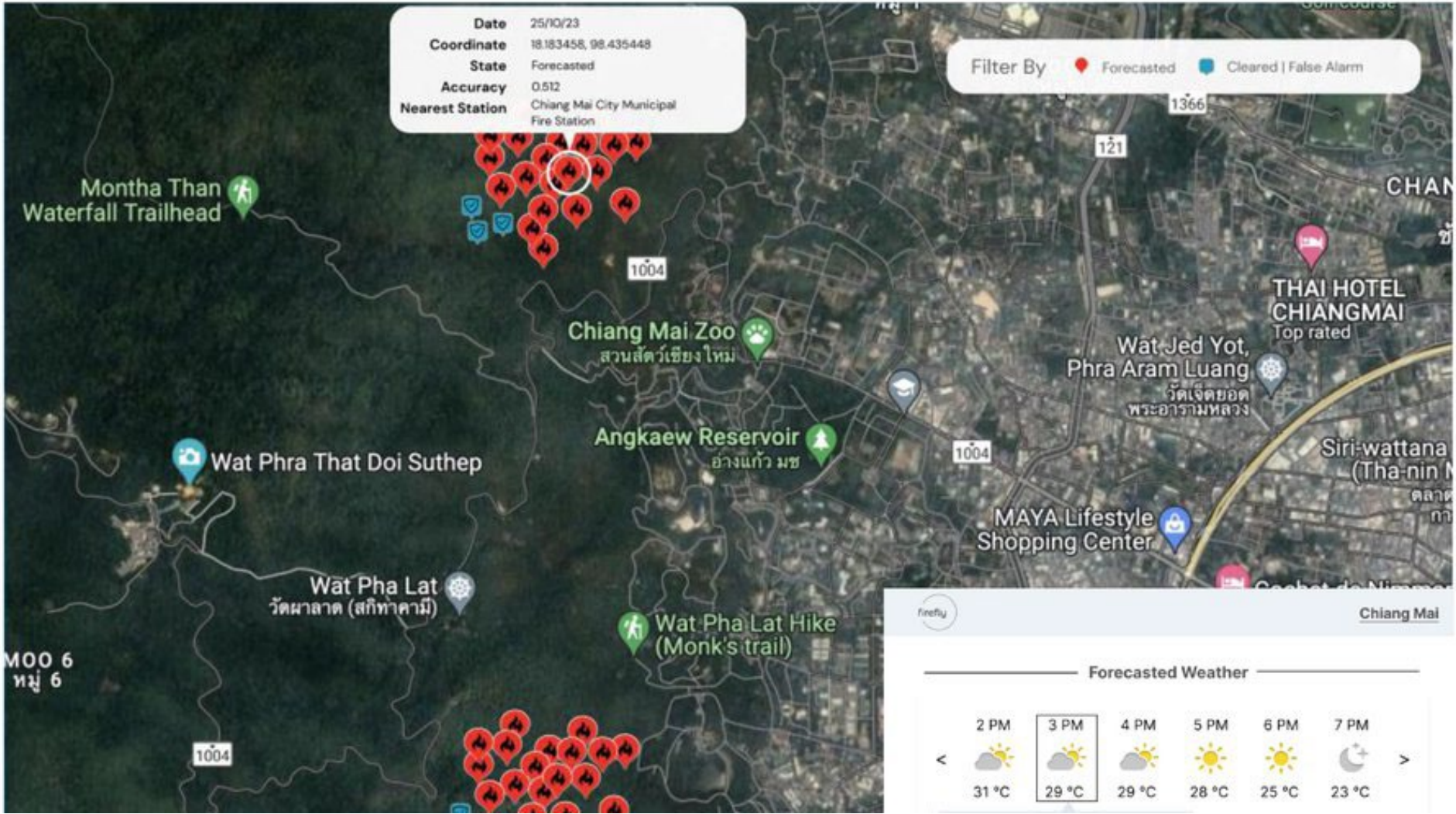
Risk levels of fire

$$P_r(T, p, h, r, V_W, \theta_W, x, y)$$

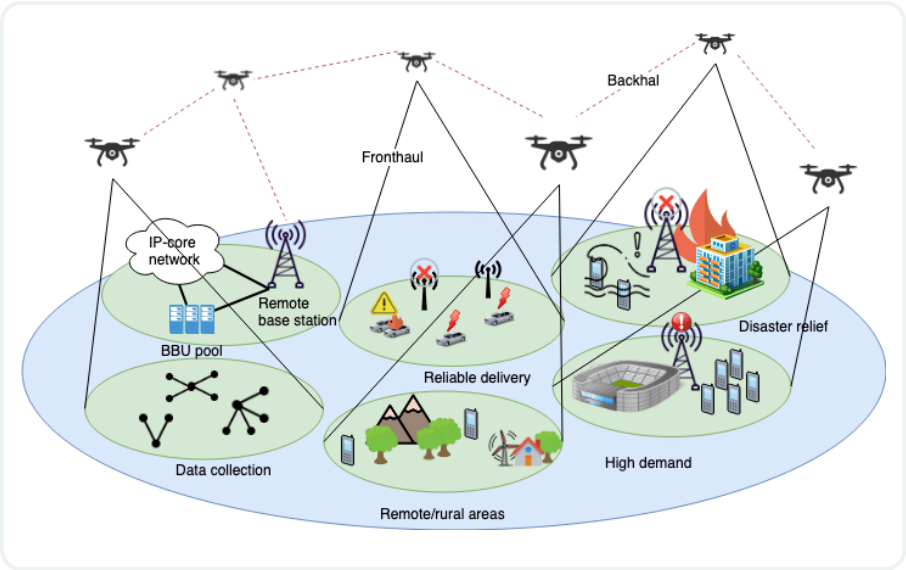


A fire-risk level for each map cell feeds the dashboard, which alerts the fire department.

Puttapirat et al., Forest Fire Monitoring and Prediction Using Machine Learning, IEEE AI/ML conference, 2024


Date 25/10/23
Coordinate 18.183458, 98.435448
State Forecasted
Accuracy 0.512
Nearest Station Chiang Mai City Municipal Fire Station
Filter By
Forecasted
Cleared | False Alarm
1366
121
1004
Montha Than Waterfall Trailhead
Chiang Mai Zoo
สวนสัตว์เชียงใหม่
THAI HOTEL CHIANGMAI
Top rated
Wat Jed Yot, Phra Aram Luang
วัดเจ็ดยอด พระอารามหลวง
Angkaew Reservoir
อ่างแก้ว มช
Wat Phra That Doi Suthep
Siri-wattana
MAYA Lifestyle Shopping Center
Wat Pha Lat
วัดผาลาด (สกิทาคามี)
Wat Pha Lat Hike (Monk's trail)
MOO 6
หมู่ 6
firefly
Chiang Mai
Forecasted Weather
2 PM 3 PM 4 PM 5 PM 6 PM 7 PM
31 °C 29 °C 29 °C 28 °C 25 °C 23 °C

What FIREfly 1.0 showed: an Internet of Drones+Prediction Capabilities



Internet of Drones*: A hybrid UAV-IoT link extends what IoT sensors can do where networks do not reach.

Real events captured: Nodes in the field recorded an actual fire, not only lab data.

Prediction and alerts: A prediction model and dashboard alert the fire department in real time.

A small step towards early detection of wildfires, and hopefully prevention.

*Hesse et al., Workshop: Digital Solutions for Natural Event Management, IEEE WF-IoT, 2023



2

FIREfly 2.0

Bigger networks, real deployments, wildlife and restoration, and a live dashboard

What FIREfly 2.0 adds



Better fire prediction

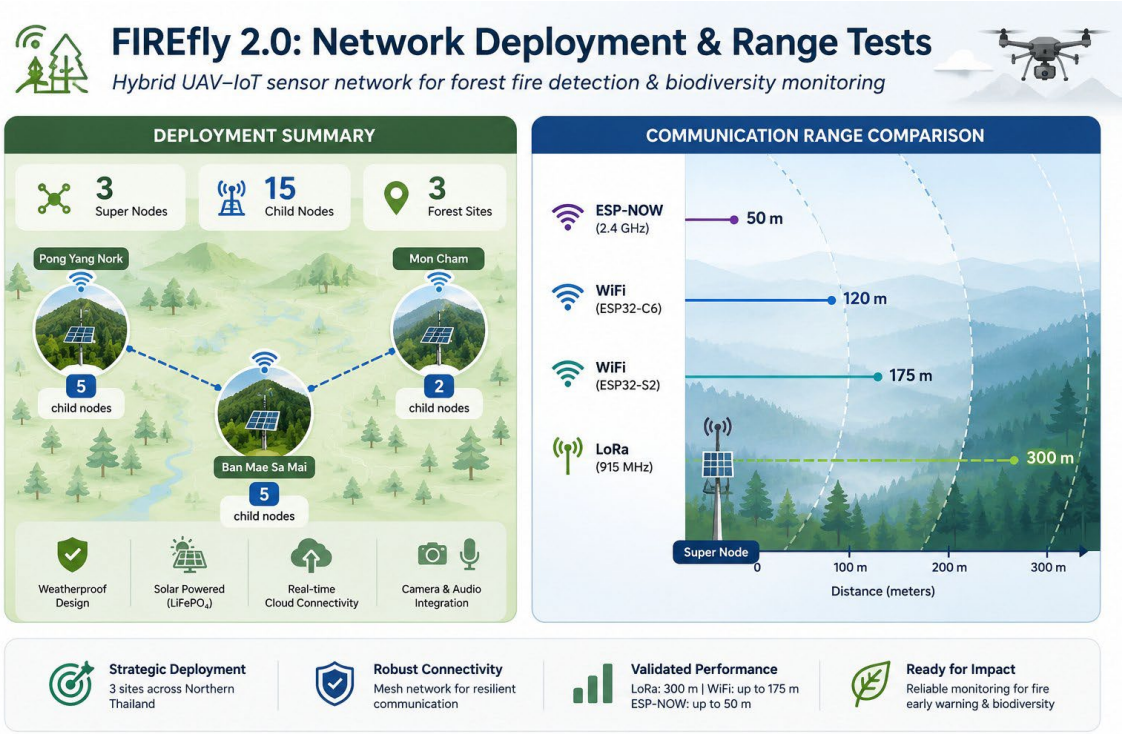
- A larger network of ground sensors
- Enhanced communication protocols
- Weather-station data for fire-risk assessment
- Dashboard for real-time alerts



Biodiversity and reforestation

- Ground sensors for wildlife activity, tree health and regeneration
- Estimation of carbon potential
- Automated seed dropping

Range tests shaped our deployment strategy



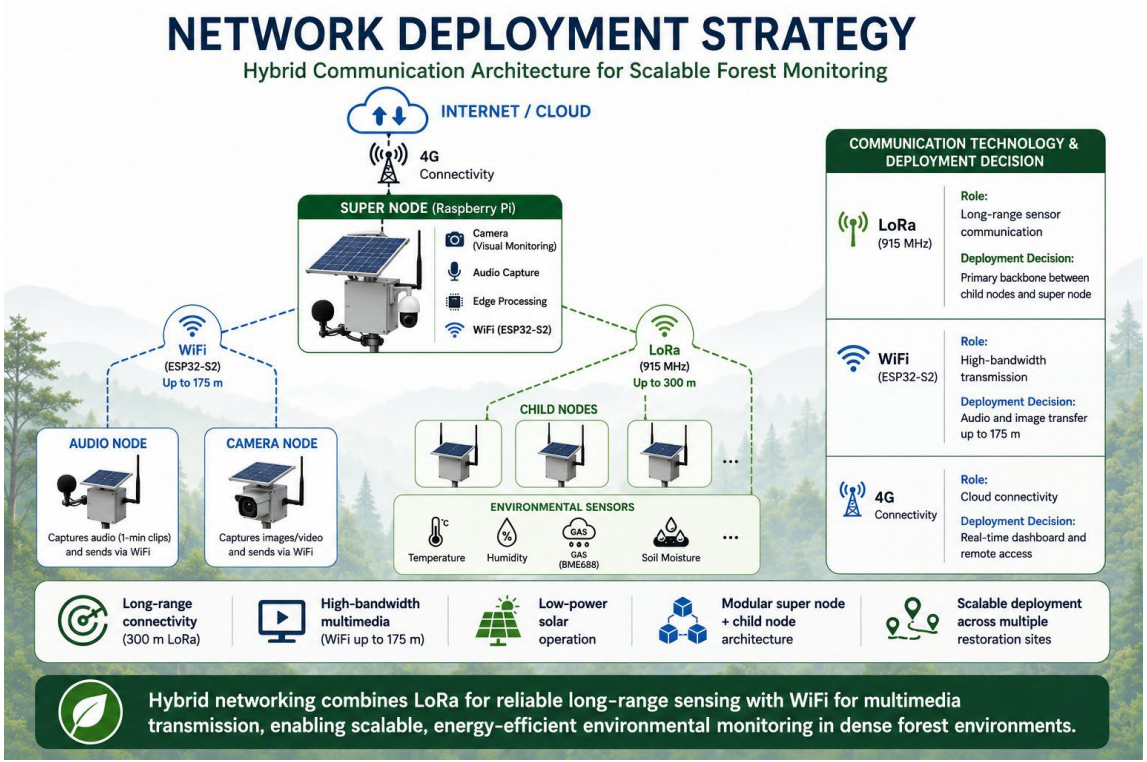
LoRa reaches farthest: 300 m between child and super nodes

WiFi: 120 to 175 m, depending on the chip; ESP-NOW 50 m

Three sites: 3 super nodes and 15 child nodes in northern Thailand

These tests helped us formalise a deployment strategy.

The deployment strategy: a hybrid network



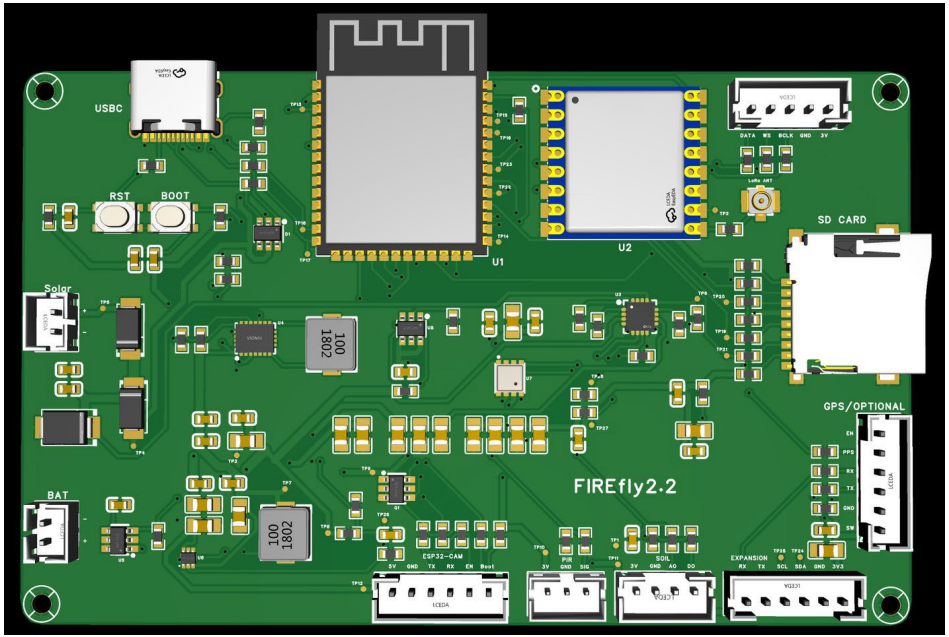
LoRa: backbone between child nodes and the super node

WiFi: audio and image transfer up to 175 m

4G: real-time dashboard and remote access

Modular, solar powered and scalable across sites.

Sensor development: one modular board





Assembled prototype

Why it matters: putting components on a single modular board makes nodes easier to build, repair and extend with new sensors.

Real deployment: three forest sites in Thailand



Team beside a deployed super node

3
forest sites

3
super nodes

15
child nodes

Weatherproof enclosures

Solar powered (LiFePO4 batteries)

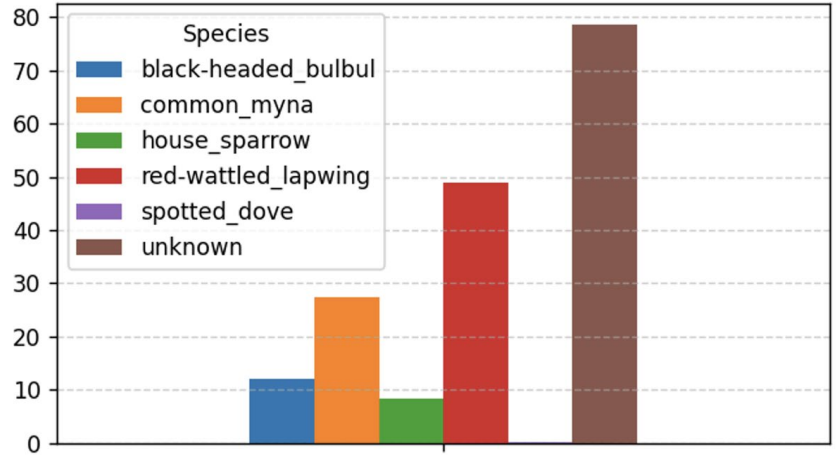
Real-time cloud connectivity

Camera and audio integration

Deployment results: the nodes also hear birds



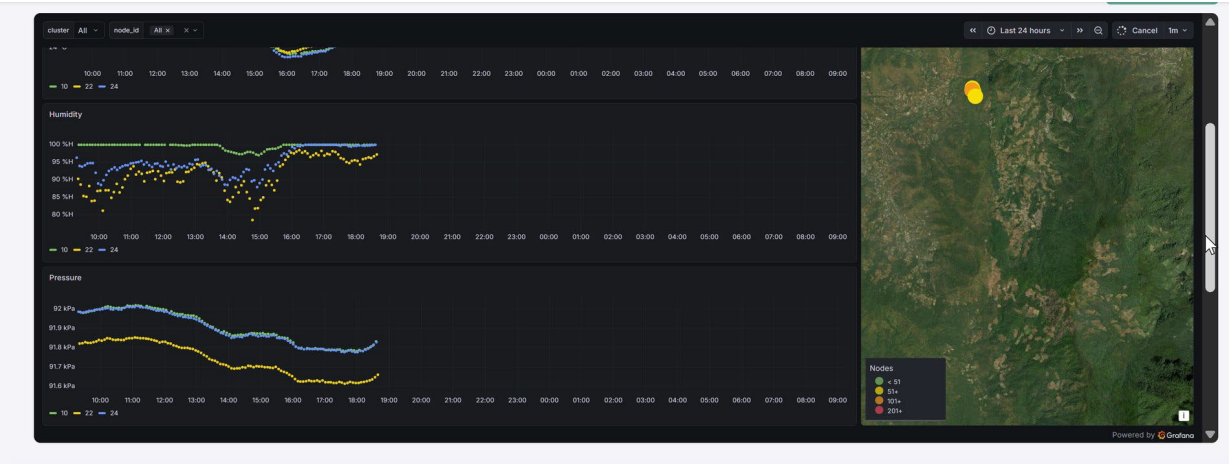
Super node and child node in the field



Bird species detected from node audio

Microphones were added to super and child nodes. About 100 minutes of audio was analysed to identify bird species.

The dashboard: one place to see what the sensors see



Live time series from every node

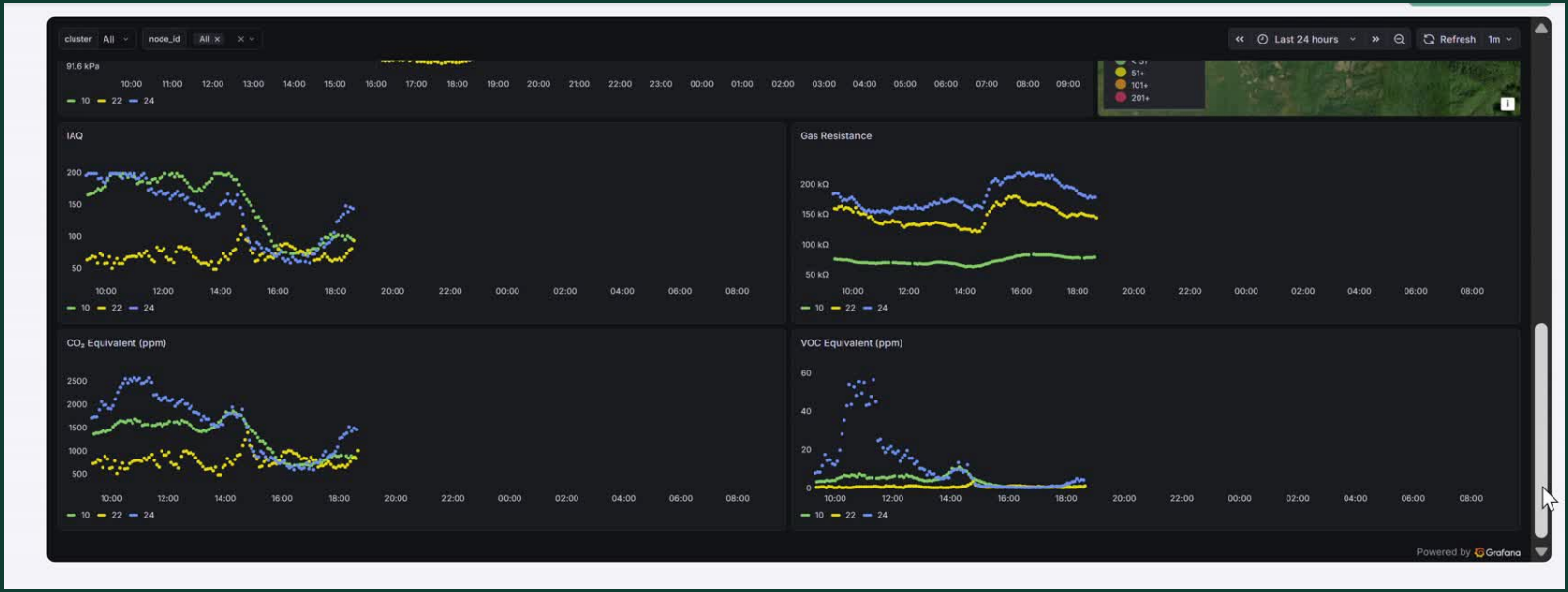
Map view of node locations

Web based: open it from any browser

Try it: project-firefly.org/dashboard

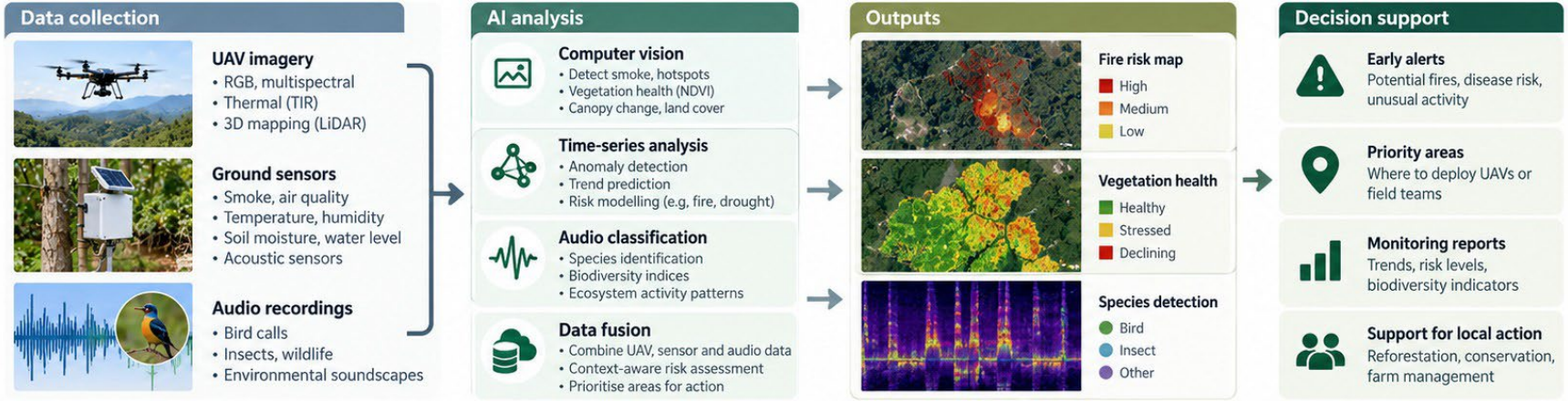
For decision-makers, the value is one shared view and a clear alert, rather than raw data.

Dashboard in action



Screen recording, 20 s. Live version: project-firefly.org/dashboard

Behind the dashboard: how AI turns data into decisions



Many sources, one pipeline

UAV imagery, ground sensors and audio recordings feed the same system.

AI finds the pattern

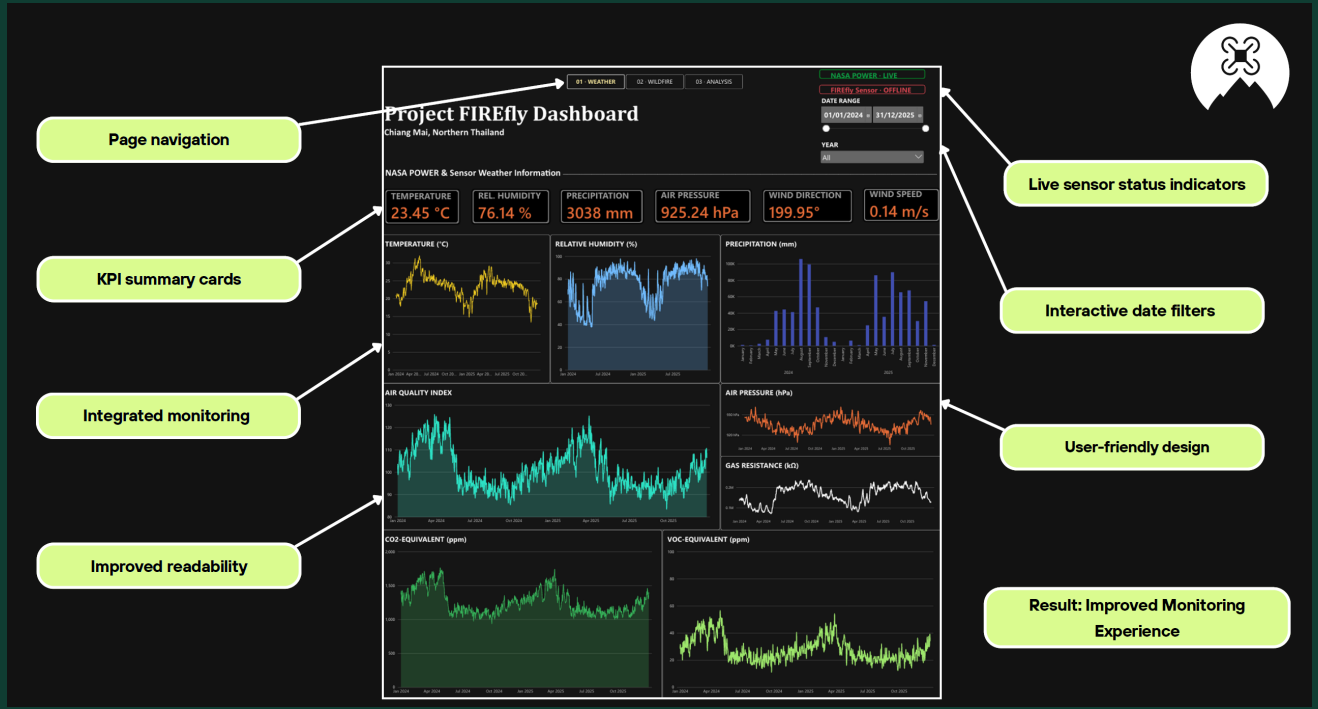
Computer vision, time-series, audio classification and data fusion.

The output is a decision

Alerts, risk maps and priority areas for local teams.

AI-generated illustration, conceptual.

Future Dashboard-All in One data



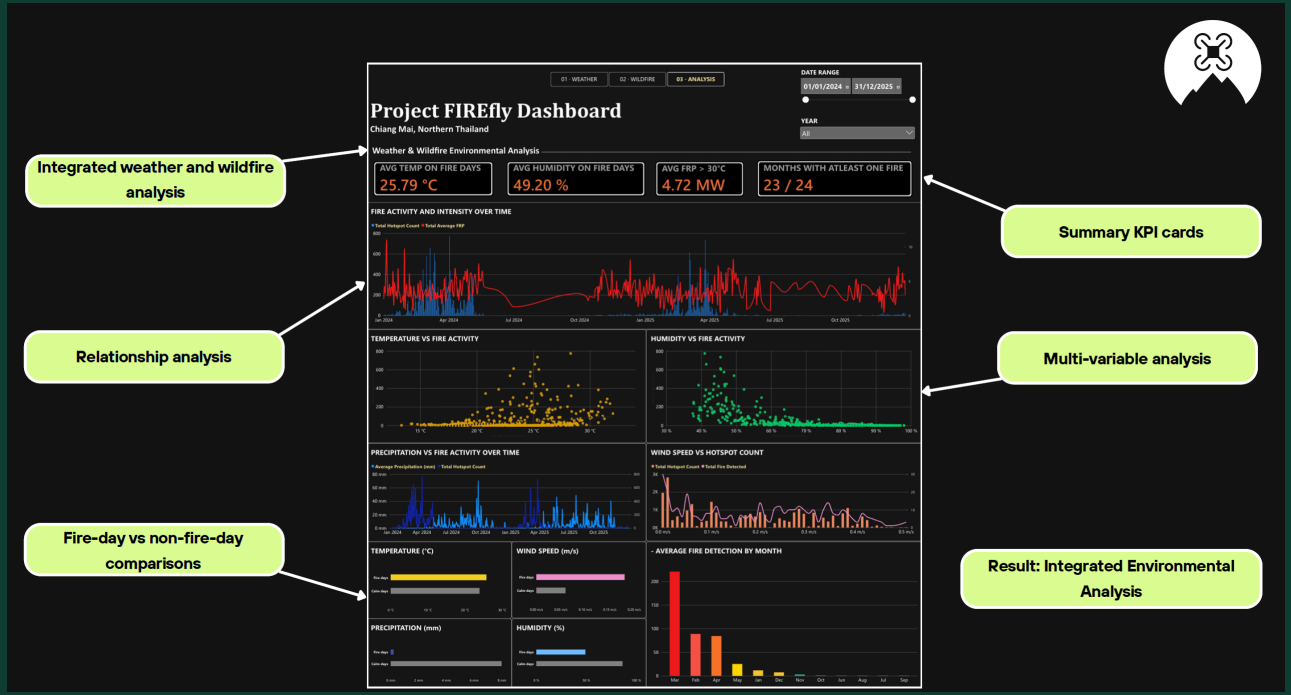
Sensor Data presented in one simple screen

Future Dashboard-All in One data



Fire hotspots in an easy to monitor dashboard

Future Dashboard-All in One data



In-depth Trend Analysis

What FIREfly 2.0 adds



Better fire prediction

- A larger network of ground sensors
- Enhanced communication protocols
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- Dashboard for real-time alerts



Biodiversity and reforestation

- Ground sensors for wildlife activity, tree health and regeneration
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- Automated seed dropping

Reforestation from the air, one seed ball at a time





Biochar seed balls: 30 mm, 17.5 g



Open-source multirotor UAV (Holybro X500, Pixhawk and ArduPilot)

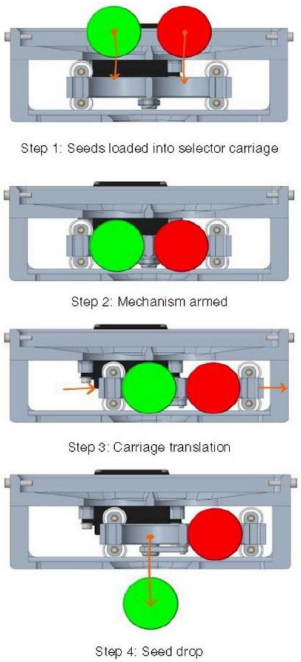
The problem: nursery planting is slow and labour-intensive in remote sites, and blanket seeding wastes seeds and spaces them unevenly.

The idea: place individual seed balls at set spacing, about 2 m for framework species.

The tool: a lightweight, gravity-fed dropper on a standard multirotor.

The team: built with FORRU-CMU and funded by APNIC Foundation (ISIF Asia).

How the precision dropper works



One seed per command. A servo slides a carriage so exactly one seed ball meets the outlet.

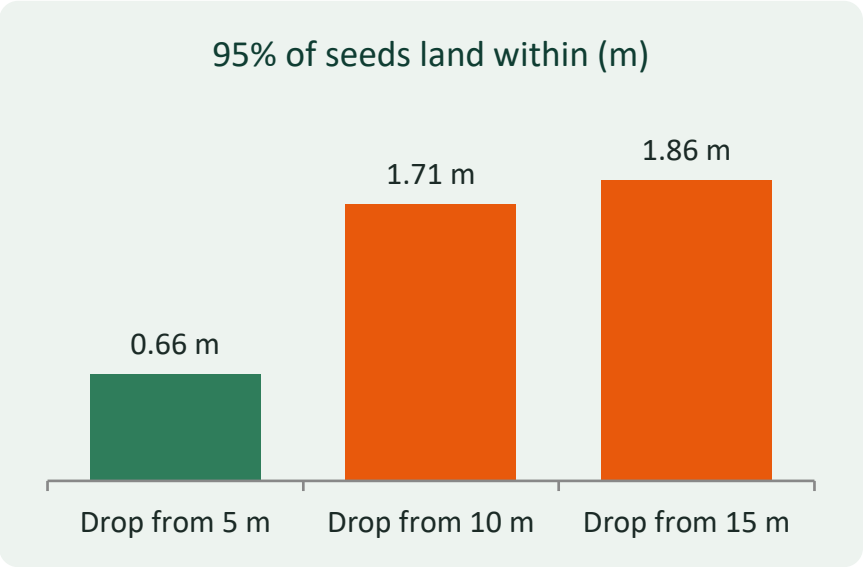
Every drop confirmed. An outlet limit switch logs each release with its GPS position, so drops can be audited.

Follows the terrain. A downward LiDAR keeps a constant height above hilly ground.

Two species at once. Two hoppers carry up to 40 seed balls; the mechanism weighs 660 g.

Chosen from three concepts: the carriage scored +9, against +3 for a drum and +2 for an iris.

Field results: low and precise works best



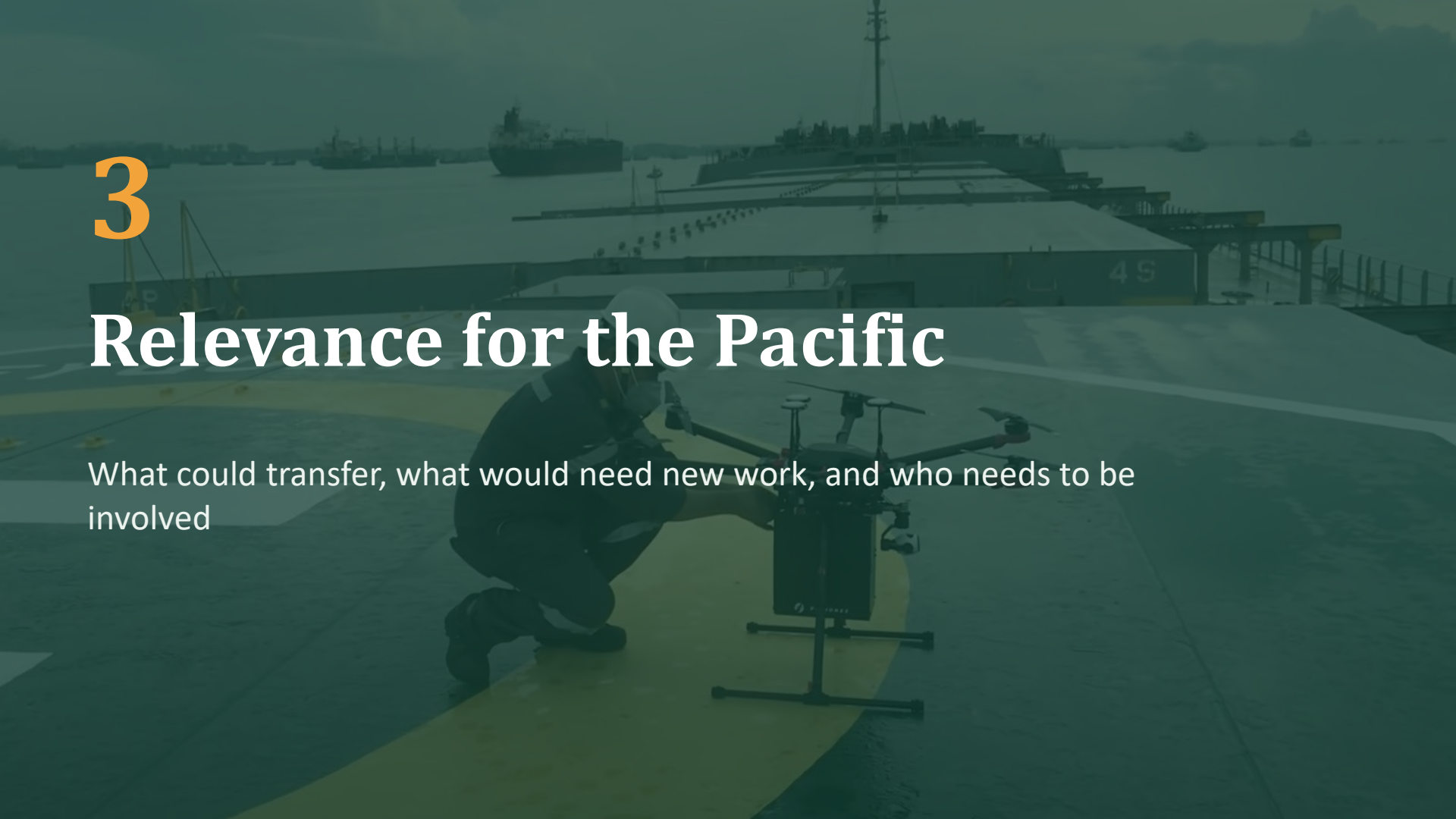
27
planned drops

24
confirmed by switch

90%
success rate



Prototype limits: 30 balls and about 10 min of flight; jamming at high fill levels. A larger UAV with a 20 L hopper could carry about 900 balls.



3

Relevance for the Pacific

What could transfer, what would need new work, and who needs to be involved

Many Pacific settings share the same constraints



Remote sites

Sites spread across islands and rugged terrain are costly to visit and hard to watch continuously.



Patchy connectivity

Coverage can be intermittent or absent, so systems must work offline and sync when a link appears.



Multiple hazards

Governments handle fire, flood, landslide, storm and drought, so shared sensing infrastructure pays off.

FIREfly was designed around exactly these constraints: low cost, low power, intermittent links.

What transfers, and what would need new work

Transfers directly

- Low-cost, solar-powered, modular nodes
- LoRa backbone with WiFi and 4G where available
- Drone relay for sites out of reach
- Web dashboard and alerting

Needs new work

- Sensors tuned to each hazard, with validation
- Testing in salt, humidity and storm conditions
- Range re-measured on islands and over water
- Local ownership: who maintains it, who acts on alerts

Possible use cases to explore

Bushfire and grassland fire	Temperature, humidity and gas sensing is already built and field-tested.
Landslide and slope monitoring	Child nodes already measure soil moisture; rainfall and slope sensors would be added.
Local weather gaps	FIREfly 2.0 integrates weather-station data; useful where stations are sparse.
Biodiversity and restoration	Acoustic monitoring, drone surveys and seed dropping have been trialled.

Who in this room has a role in a pilot?

Disaster management	Owns the alert and the response: who is told, how fast, and what they do.
Meteorological services	Weather and rainfall data that make hazard prediction more accurate.
Environment and climate	Biodiversity, restoration and climate monitoring needs.
Communications and digital	Connectivity, data platforms and integration with national systems.
Universities	Local testing, student projects and long-term technical capacity.

A sensible path: start small, learn, then scale

1

Define

Agree one hazard, one site and one alert owner.

2

Pilot

Deploy a handful of nodes plus a dashboard.

3

Measure

Test range, power and weather resistance on site.

4

Scale

Add sites and sensors and link to national systems.

Our lesson from Thailand: test in real conditions and build with local partners who act on the alerts.

Same platform, new applications: mangrove and coffee health



Mangrove health

- Water level and salinity at the root zone
- Air and soil temperature, humidity
- Canopy stress from drone imagery

Remote tidal forests that are costly to visit; a storm buffer for coastal communities



Coffee health

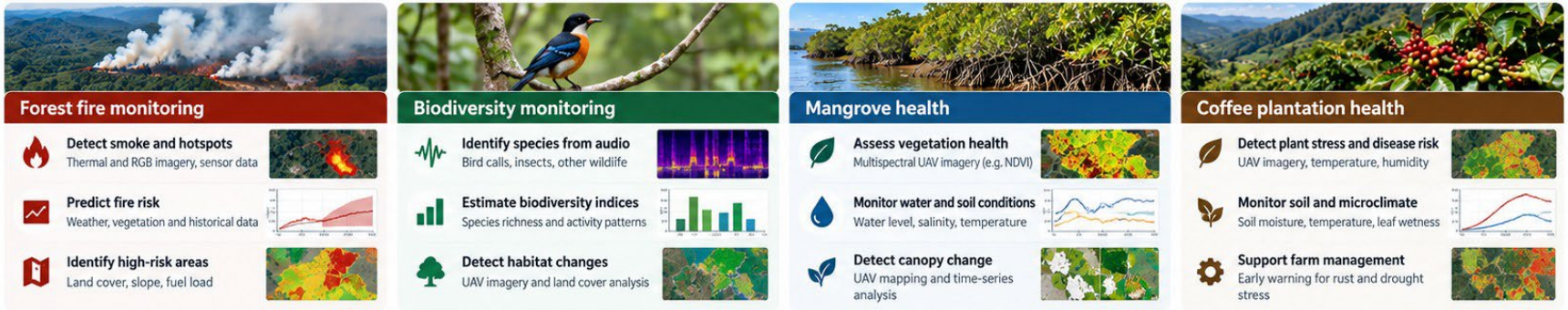
- Humidity, temperature and leaf wetness (disease risk)
- Soil moisture across slopes and shade levels
- Plant stress from drone imagery

Smallholder farms on steep terrain; earlier warning for rust and drought stress

What carries over: low-power LoRa nodes, UAV data collection and the dashboard. What changes: the sensors and the models.

AI-generated illustrations, conceptual. Sensor sets are proposed and not yet field-tested.

One toolkit, four monitoring problems



What carries over

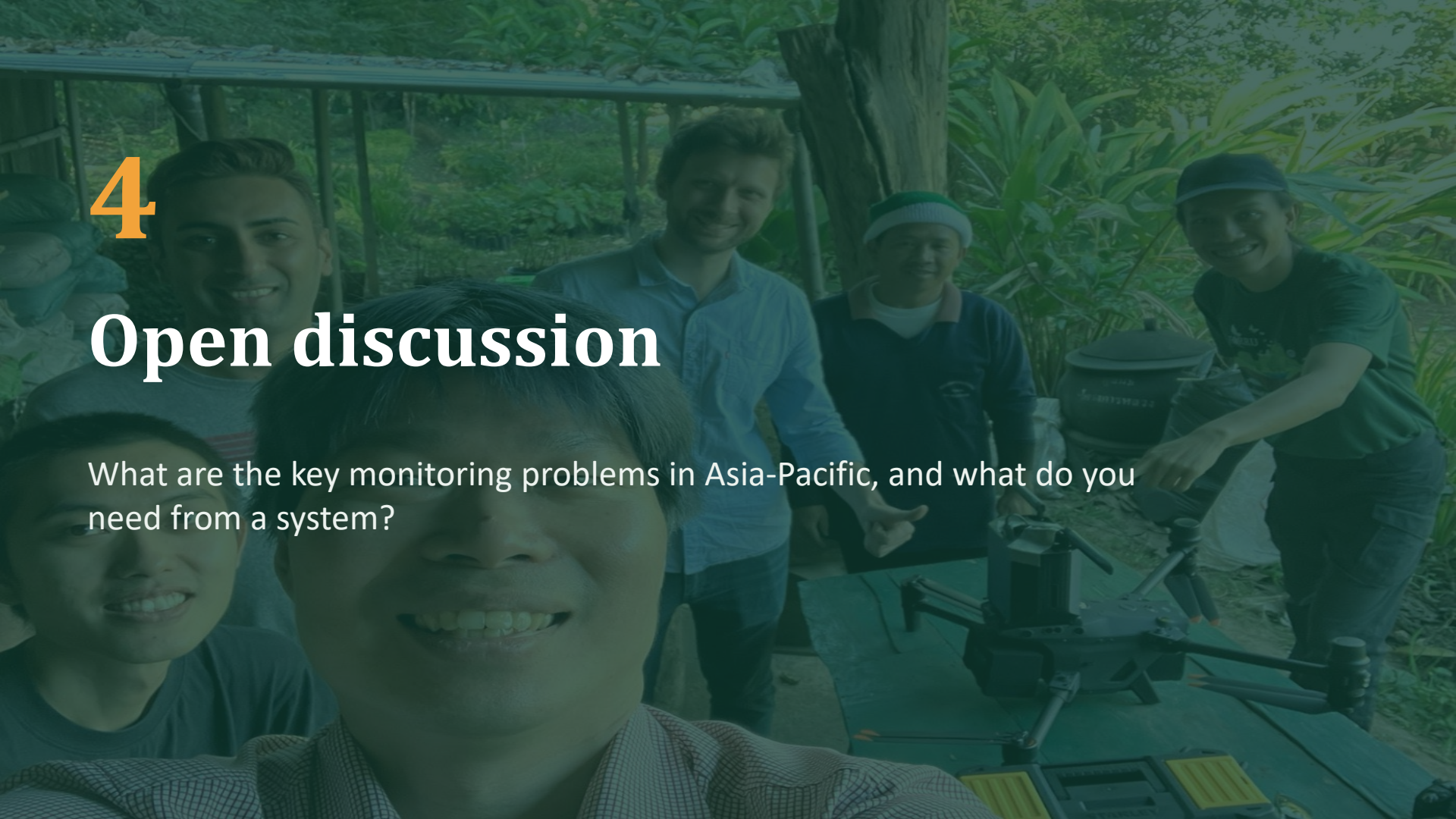
Low-power nodes, drone surveys, the dashboard and the way we turn data into alerts.

What each problem needs

The right sensors, local examples to train and check the models, and a partner who acts on the alerts.

Which of these looks closest to a problem in your country?

AI-generated illustration, conceptual. Uses beyond fire are proposed, not yet field-tested.



4

Open discussion

What are the key monitoring problems in Asia-Pacific, and what do you need from a system?

Key monitoring problems across Asia-Pacific

Tropical cyclones and surge

Storms can intensify fast over open ocean, where observations are sparse.

Floods and flash floods

Gauges and rain stations are thin in remote catchments.

Landslides

Rain-triggered slope failures; soil moisture is rarely measured.

Drought

Slow onset and the largest share of average annual loss in the region.

Wildfire and haze

Remote ignitions, and smoke that crosses borders.

Earthquakes, tsunamis, volcanoes

Sudden onset; non-seismic triggers can slip past warning systems.

Sources: UN ESCAP, Asia-Pacific Disaster Report 2019; World Bank, Pacific Catastrophe Risk Assessment and Financing Initiative

Why monitoring matters: the stakes

59%

of global disaster deaths since 1970 were in Asia-Pacific

UN ESCAP, Asia-Pacific Disaster Report 2019

60%

of the region's average annual loss comes from drought, once slow-onset events are counted

UN ESCAP, 2019

US$284 m

estimated average annual direct disaster losses in the South Pacific

World Bank, PCRAFI

The World Bank notes some Pacific countries could lose more in one event than their annual GDP.

What do decision-makers look for in monitoring?

Lead time

Warning early enough for people to act.

Reliability

Works in storms, salt and heat, with few false alarms.

Low cost and upkeep

Affordable to buy, power and repair locally.

Coverage without a network

Remote islands and intermittent links.

Clear alerts

The right person gets a clear message.

Trusted, shareable data

Validated, and usable across agencies.

A starting list for discussion: what would you add, remove or rank first?

Your turn: one monitoring problem each



2 min Think
Pick one monitoring problem from your own work.



9 min Share
Go round the room, about 1.5 minutes each.



3 min Rank
Vote for the three elements that matter most.

Three questions to answer

1. What hazard, and where?
2. What do you need to know, and how early?
3. What stops you monitoring it today?

Capture board: problems and needs

Hazard and place	What you need to know, and how early	Biggest barrier today

Thank you: let's keep talking

- Which hazard would you start with?
- Who would need to be in the room?
- What would you need to see to try a pilot?

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RMIT UNIVERSITY | University of Glasgow | APNIC FOUNDATION



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