

Low-cost weather stations

What they measure, what they cost, where they break — and three networks built in Ghana, Kyrgyzstan and Timor-Leste.

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02 The instrument

03 Cost and choice

04 The hard places

05 Data and upkeep

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01

Why we measure

What the data is for

Initialising and verifying forecast models, which need surface truth

Agricultural advisories — sowing dates, irrigation, pest and frost warnings

Hydrology and early warning: rainfall thresholds for floods and landslides

Siting solar and wind generation, and sizing the grid that carries it

A climate record that only exists if someone kept measuring



Rainfall



Wind



Temperature



Crop advisories

Where the gaps are

Sparse to begin with

Networks were built around capitals, airports and colonial-era stations. Whole provinces have never had an instrument in them.

Reporting, not existing

A station on the map is not a station on the wire. Many exist but do not transmit — no power, no line, no budget for the SIM.

Not shared

Where data does exist it is often sold, or locked in a ledger. The gap on the global map is partly a policy gap.



The least-observed terrain

Weather changes over hundreds of metres,
not hundreds of kilometres

Valley-floor stations are the ones with roads —
and the ones that mislead

The hazards that kill — flash floods, outburst
floods, landslides — start upstream

02

**The
instrument**

What an automatic weather station is

Sensors and housing

A handful of transducers, a radiation shield, a mast and a fence. The mechanical parts fail long before the electronics do.

Logger and power

A microcontroller that samples on a schedule, a panel, a battery and a charge controller. Storage on board for when the link is down.

Telemetry and back end

A radio, a gateway, a server that decodes and stores, and a dashboard someone actually opens. The last part is the one most often missing.

The measured variables

VARIABLE	TYPICAL SENSOR	HEIGHT	REPORTED AS
Air temperature	Thermistor in a shield	1.25–2 m	1 min mean
Relative humidity	Capacitive polymer	1.25–2 m	Dew point derived
Wind speed / direction	Cup or ultrasonic, vane	10 m	10 min mean plus 3 s gust
Precipitation	Tipping bucket, 0.2 mm	0.5–1 m	Per interval
Pressure	MEMS barometer	Any, altitude logged	Reduced to sea level
Solar irradiance	Silicon pyranometer	Above obstacles	W/m ² and daily total

Temperature and humidity

The sensor is cheap and good; the shield is what you are really buying. An unventilated shield in still air at high solar loading reads warm by a degree or more — the dominant error in most low-cost deployments, and worse at altitude where irradiance is higher.



Wind

Ten metres is the standard height, and almost nobody in a low-cost network reaches it. Report the mast height with the data. Cups have a starting threshold — below roughly 0.2 m/s they simply do not turn — and bearings are the first thing to seize in dusty or icing conditions.

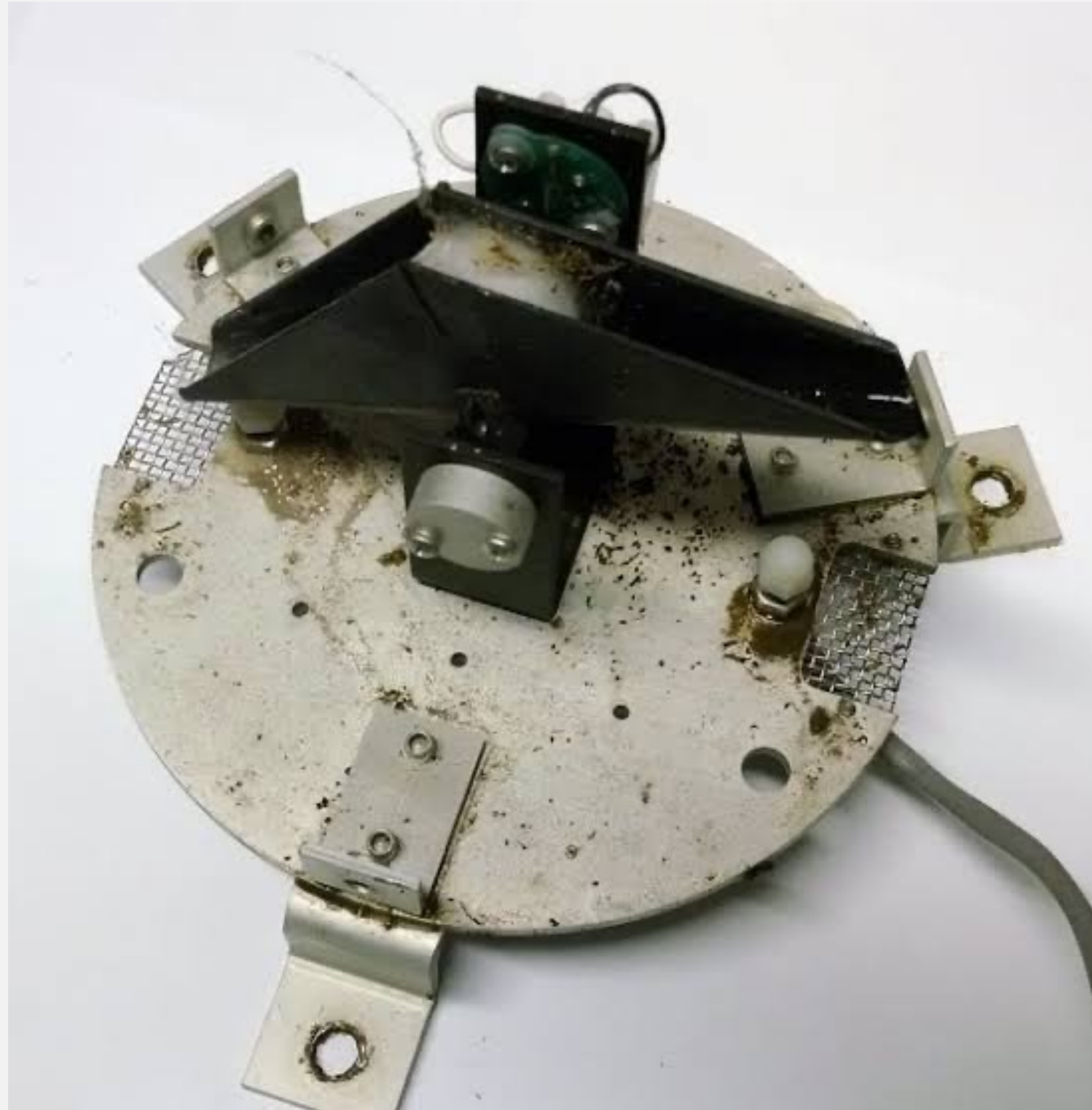


Precipitation

A tipping bucket counts 0.2 mm at a time, so it under-reads drizzle and saturates in extreme rain. It measures nothing frozen unless it is heated. It is also the one instrument with a hole in it: leaves, dust and insects block the funnel, and a blocked gauge reports a drought.



02 · THE INSTRUMENT



Barani accuracy example

TYPE	ACCURACY	STABILITY	RANGE	MEETS WMO
Temperature	±0.2 °C typical	<0.02 °C / year	−40 to 105 °C	yes
Relative humidity	±1.5 %RH at 25 °C	<0.3 %RH / year	0 to 100 %RH	yes
Solar irradiance	5 % of daily total	−0.6 % / year	0 to 2000 W/m²	no
Pressure	±1.5 hPa at 25 °C	−1 hPa / year	300 to 1100 hPa	no
Rain	1 % with a compact gauge	Gauge dependent	Up to 500 mm/h	yes

03

Cost and choice

Three classes of station

CLASS	ORDER OF COST	TRACEABILITY	UPKEEP	FIT FOR
Reference	Tens of thousands	Certificates	Specialist	Climate records
Conventional AWS	Several thousand	Vendor calibration	Service contract	National networks
Low-cost	Hundreds	Cross-comparison	Local and frequent	Density and gradients

Accuracy versus density

The single reference site

Excellent numbers from one point. Says nothing about the next valley.

The anchored network

Many low-cost nodes cross-checked against one reference. The useful case.

The abandoned station

Good hardware, no maintenance budget, no data after year two.

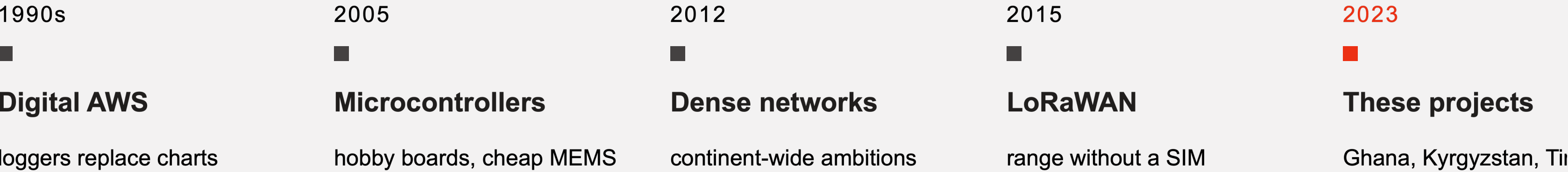
Crowdsourced sensors

Dense and free, but unknown siting and no way to correct the bias.

← fewer stations

more stations →

How the field got here

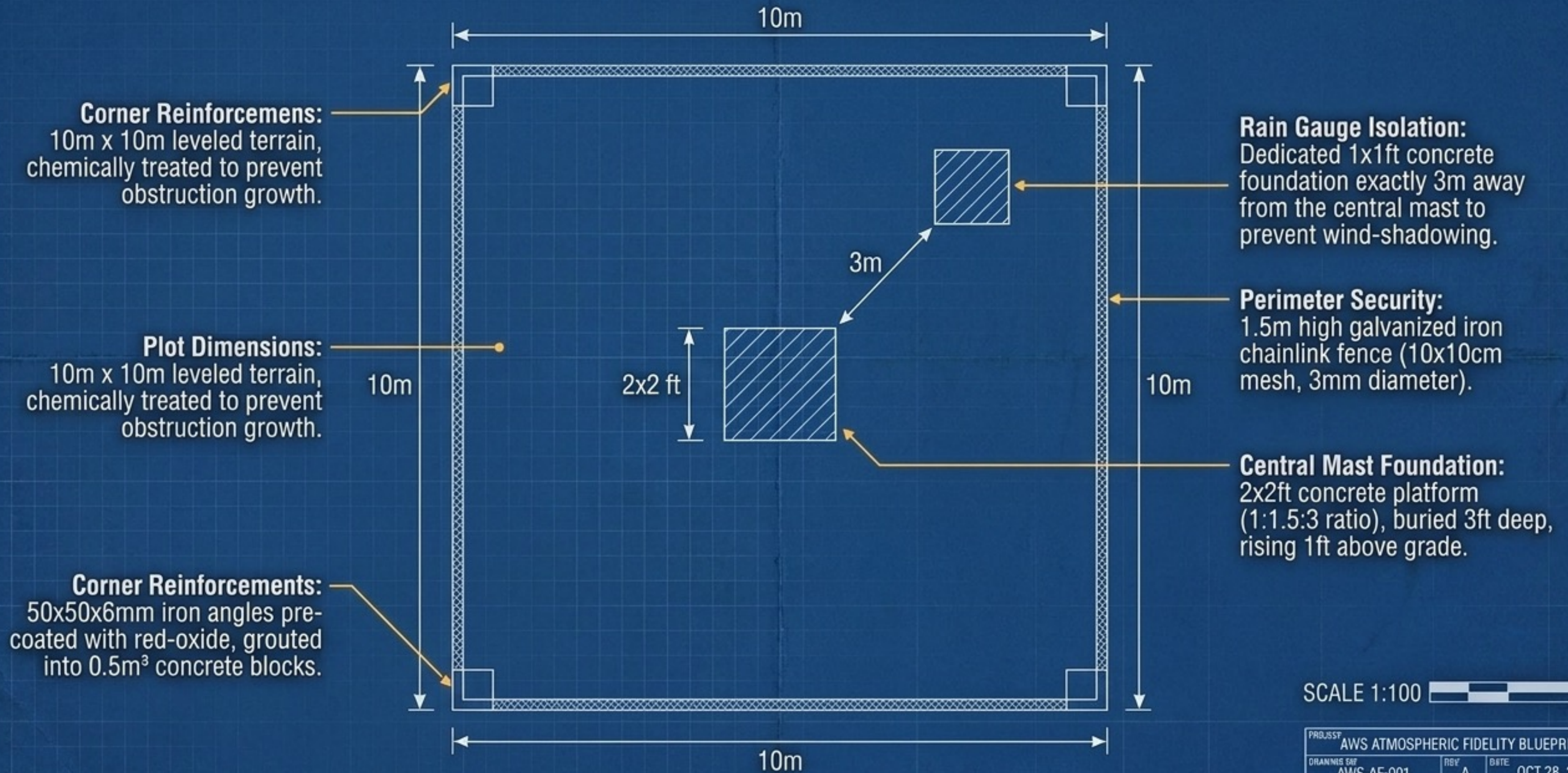


Each step removed a recurring cost. The remaining one — a person who climbs the mast — is the one technology has not removed.

04

The hard places

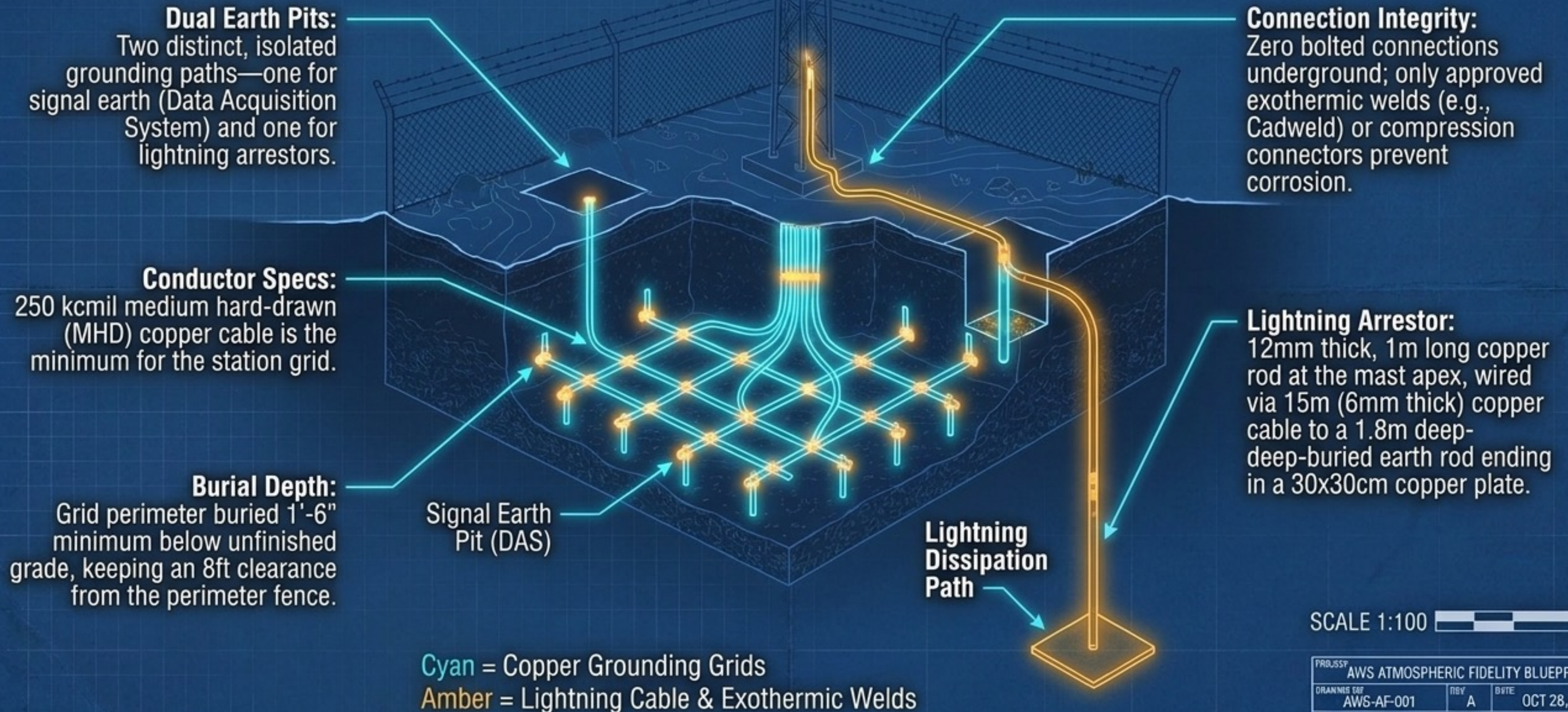
ESTABLISHING THE AWS PHYSICAL FOOTPRINT



SCALE 1:100 

PROJECT AWS ATMOSPHERIC FIDELITY BLUEPRINT		
DRAWING SET AWS-AF-001	REV A	DATE OCT 28, 2023
ENGINEER: A. METEOROLOGIST		

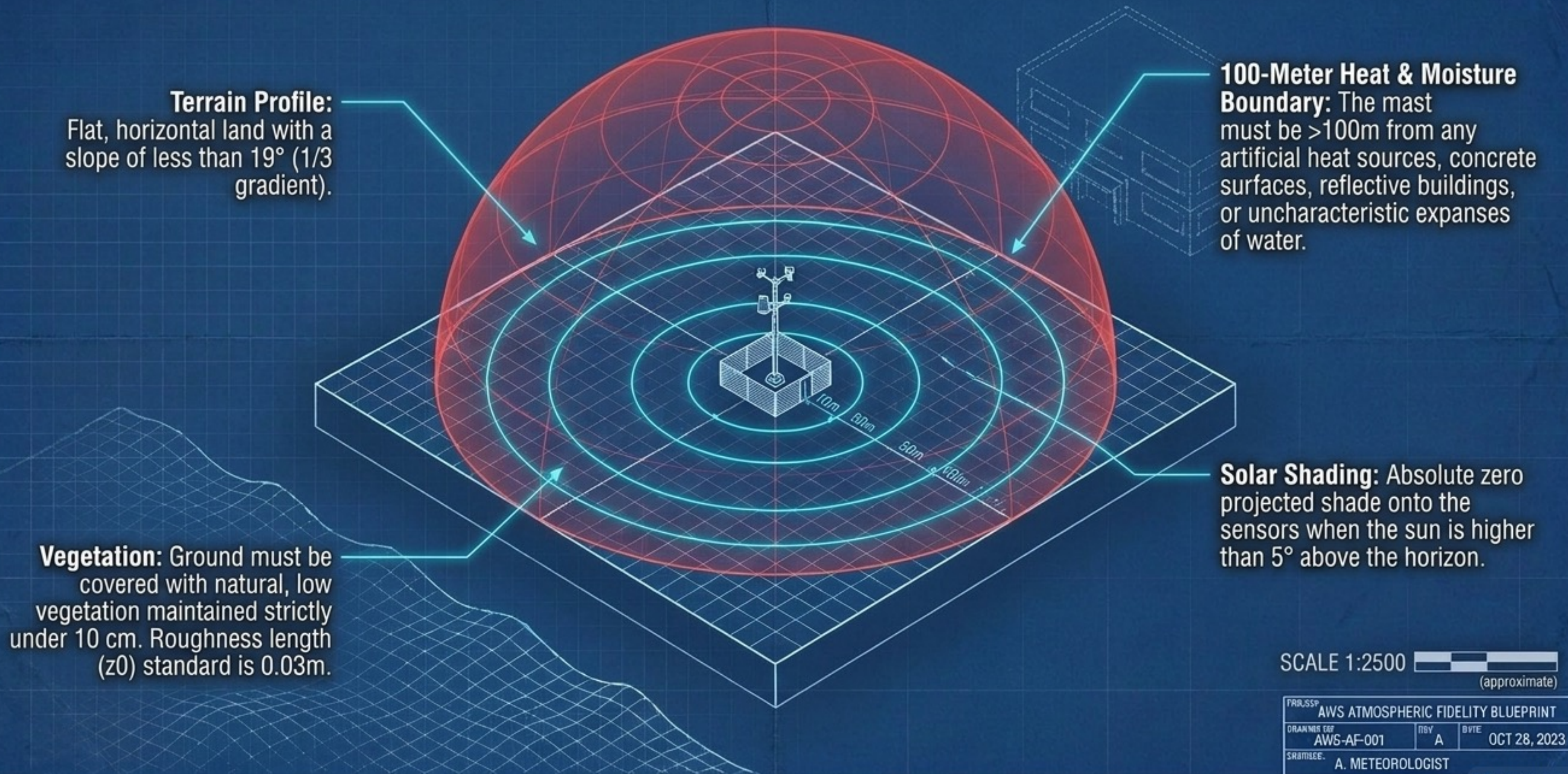
Subsurface Grounding and Lightning Dissipation



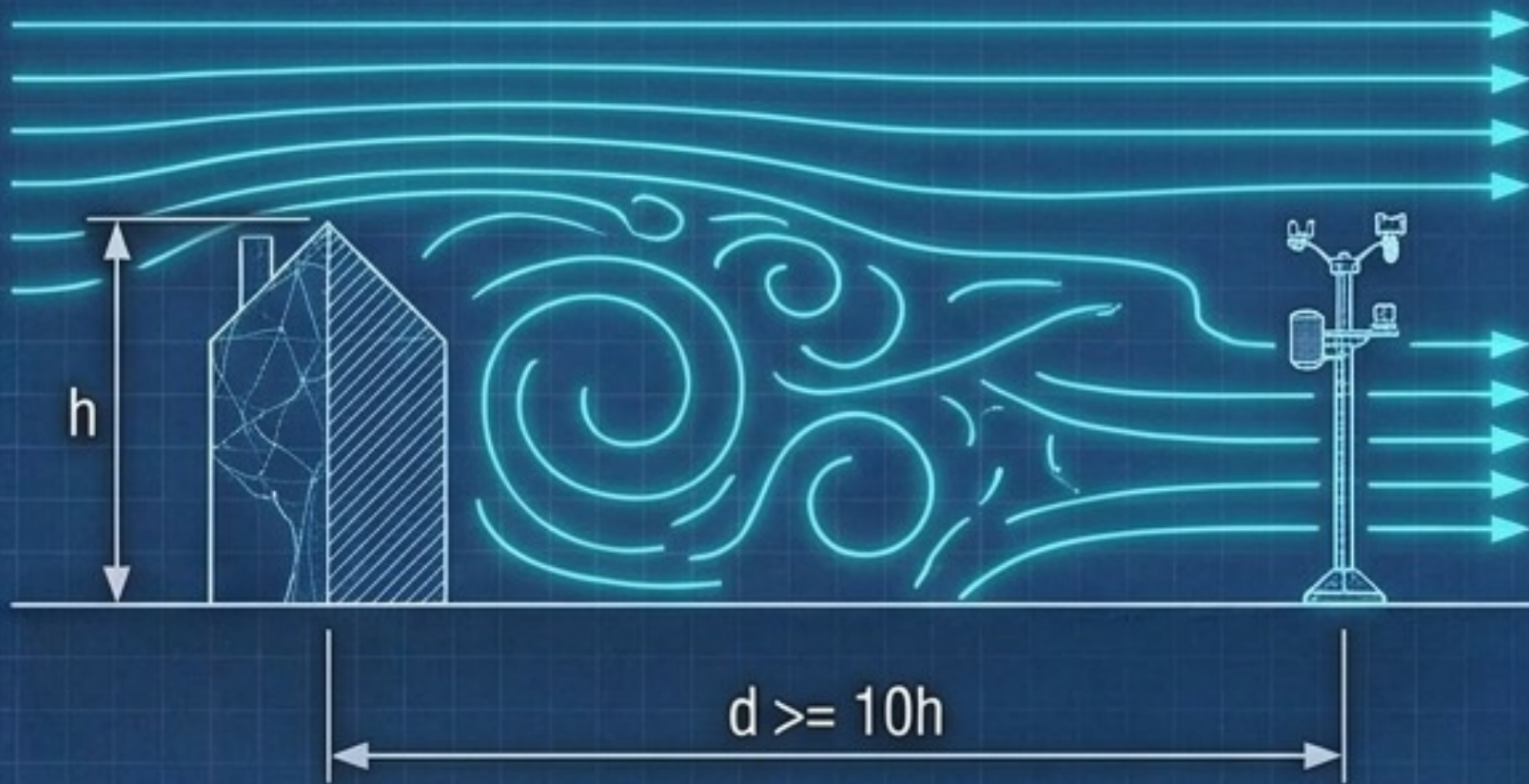
SCALE 1:100

PROJECT	AWS ATMOSPHERIC FIDELITY BLUEPRINT		
DRAWING EGT	AWS-AF-001	REV	A
DATE	OCT 28, 2023		
SUBMITTER	A. METEOROLOGIST		

MACRO-SITING FOR WMO CLASS 1 COMPLIANCE



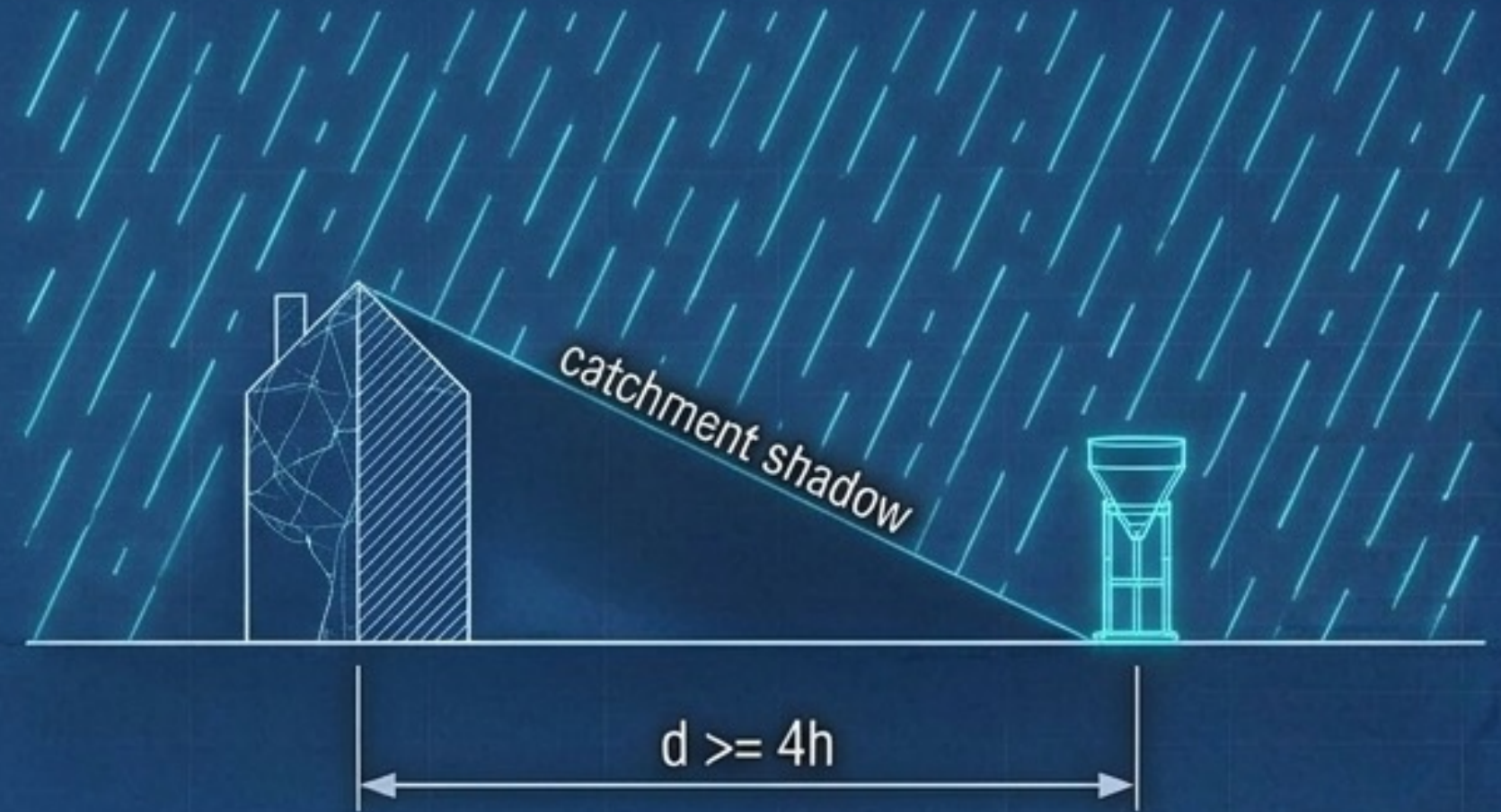
Calculating Obstacle Shadows and Aerodynamic Clearance



Wind Obstacles (The 10x Rule)

Formula: $d \geq 10h$. The mast must be at a distance of at least 10 times the height of surrounding obstacles.

Thin Obstacle Exception: For thin obstacles (masts/trees) over 8m tall, clearance is 15 times the obstacle's width.



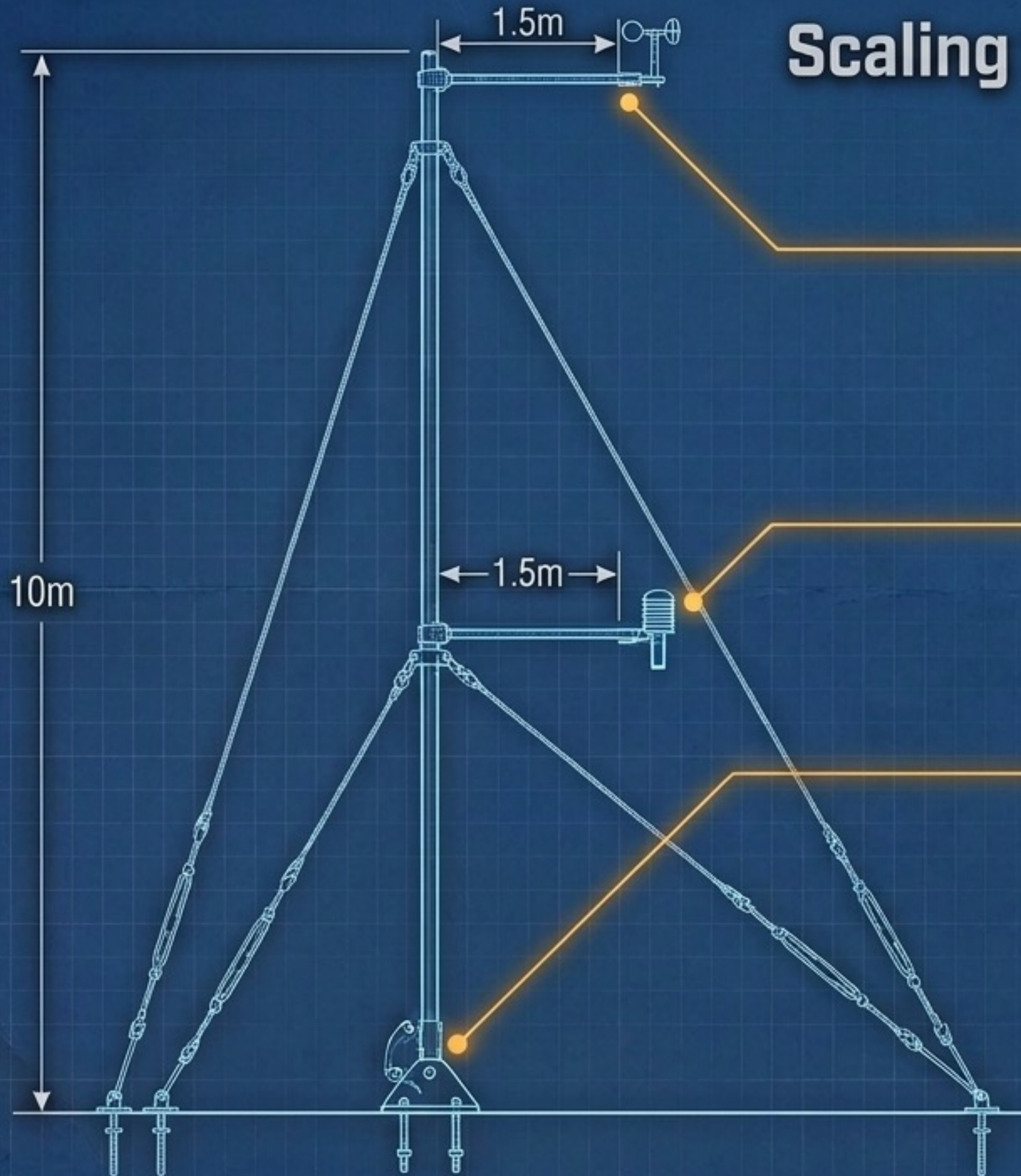
Precipitation (The 4x Rule)

Formula: $d \geq 4h$. Obstacles must be at least 4 times their height away from the rain gauge catchment to prevent turbulence that artificially lowers catch rates.

Uniformity: Ideal conditions place the gauge in a clearing surrounded by low obstacles of uniform height (ratio of highest to lowest < 2) subtending elevation angles between 14° and 26° .

TITLE: AWS ATMOSPHERIC FIDELITY BLUEPRINT		
DRAWN BY: AWS-AF-001	REV: A	DATE: OCT 28, 2023
SUBMITTED BY: A. METEOROLOGIST		

Scaling the Mast: Precise Sensor Geometry



10.0 meters - Ultrasonic Wind: Mounted on a 1.5m horizontal boom to escape mast turbulence. Ultrasonic measurement eliminates moving parts for $< 2^\circ$ direction accuracy.

2.0 meters - Temperature & Humidity: Mounted on a 1.5m horizontal boom. (WMO allows 1.25m - 2.0m, but standardizing at 2.0m minimizes extreme micro-surface ground heating).

Ground Level + 1.0 meter - Rain Gauge: Physically separated by 3m from the mast to avoid structural wind-shadowing.

Mast Support: Three rust-proof stainless steel guy wires stabilize the mast against severe sheer winds.

SCALE 1:500

TITLE: AWS ATMOSPHERIC FIDELITY BLUEPRINT		
DRAWN BY: AWS-AF-003	REV: A	DATE: OCT 28, 2023
DRAWN BY: A. METEOROLOGIST		

Siting in mountainous terrain

No site satisfies the rules; choose which rule you are breaking, and say so

Ridge, slope and valley floor are three climates within a kilometre

Record elevation, aspect and slope angle — they explain most of the scatter

The site you can reach in winter beats the meteorologically ideal one



Ice, snow and extreme wind

Rime ice stops cups and freezes vanes; the data looks calm, not missing

Snow buries low sensors and loads panels — mount steep, mount high

Batteries lose usable capacity below freezing; choose the chemistry for the site

Buy the mast for gusts you have never measured there, because nobody has

Design every joint for a person wearing gloves at altitude



Rime ice



Snow load



Cold batteries



Extreme gusts

Power off-grid

Size for the worst week

Not the annual average. Monsoon overcast or a snow-covered panel sets the battery size, and autonomy of several days is the usual target.

Sleep is the design

A station that wakes, samples, transmits and sleeps runs on milliwatts. The radio and any heater dominate the budget; everything else is noise.

Report your own health

Send battery voltage and panel current with every packet. Most field trips are diagnosed from that channel before anyone leaves the office.

Getting the data off the mountain

LINK	RANGE	POWER	RECURRING COST	CATCH
GSM / GPRS	Cell coverage only	High in transmit	SIM per station	Stops where you need it
LoRaWAN	Several km	Very low	None	You must own a gateway
Wi-Fi	Building scale	High	None	Only for campus sites
Satellite	Everywhere	High	Per message	Cost scales with size
Manual collection	A field trip	None	Travel	No early warning, ever

LoRaWAN in brief

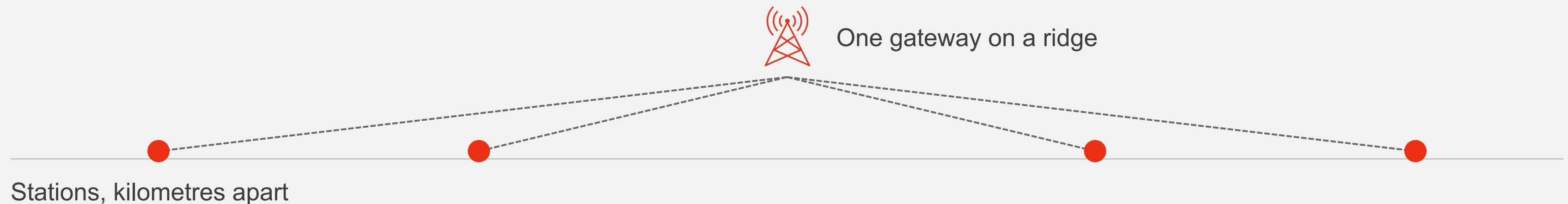
Long-distance communications — kilometres from a few milliwatts

Low-power by design: years on a battery for a station-sized payload

Low cost, and no recurring cost once the gateway is yours

Unlicensed spectrum in most countries — check the national regulator anyway

Gateways are access points: one on a ridge serves a whole catchment



Line of sight in terrain

Range in the mountains is a terrain problem, not a radio problem. Profile the path before you climb: the terrain in green, the optical line in blue and 60 % of the first Fresnel zone in magenta. If the terrain crosses the magenta, move the gateway, not the antenna.

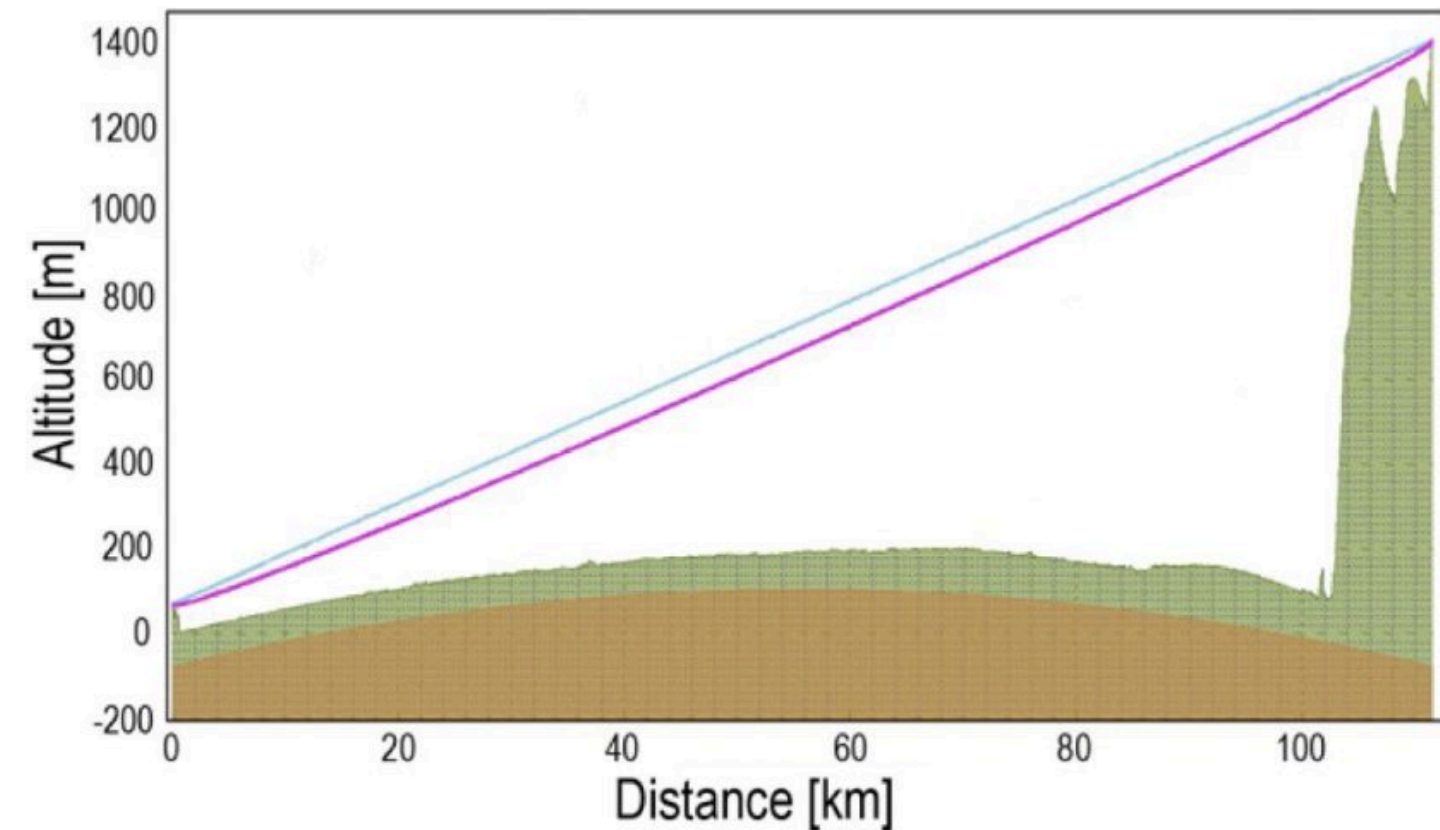


Figure 3. LOS over land Terrain Profile: Brown area indicates the curvature of the earth, modified by the refraction index; Green area is the terrain profile as seen by the radio wave; Magenta line is the 60% of the first Fresnel zone; and the blue line is the optical line of sight.

05

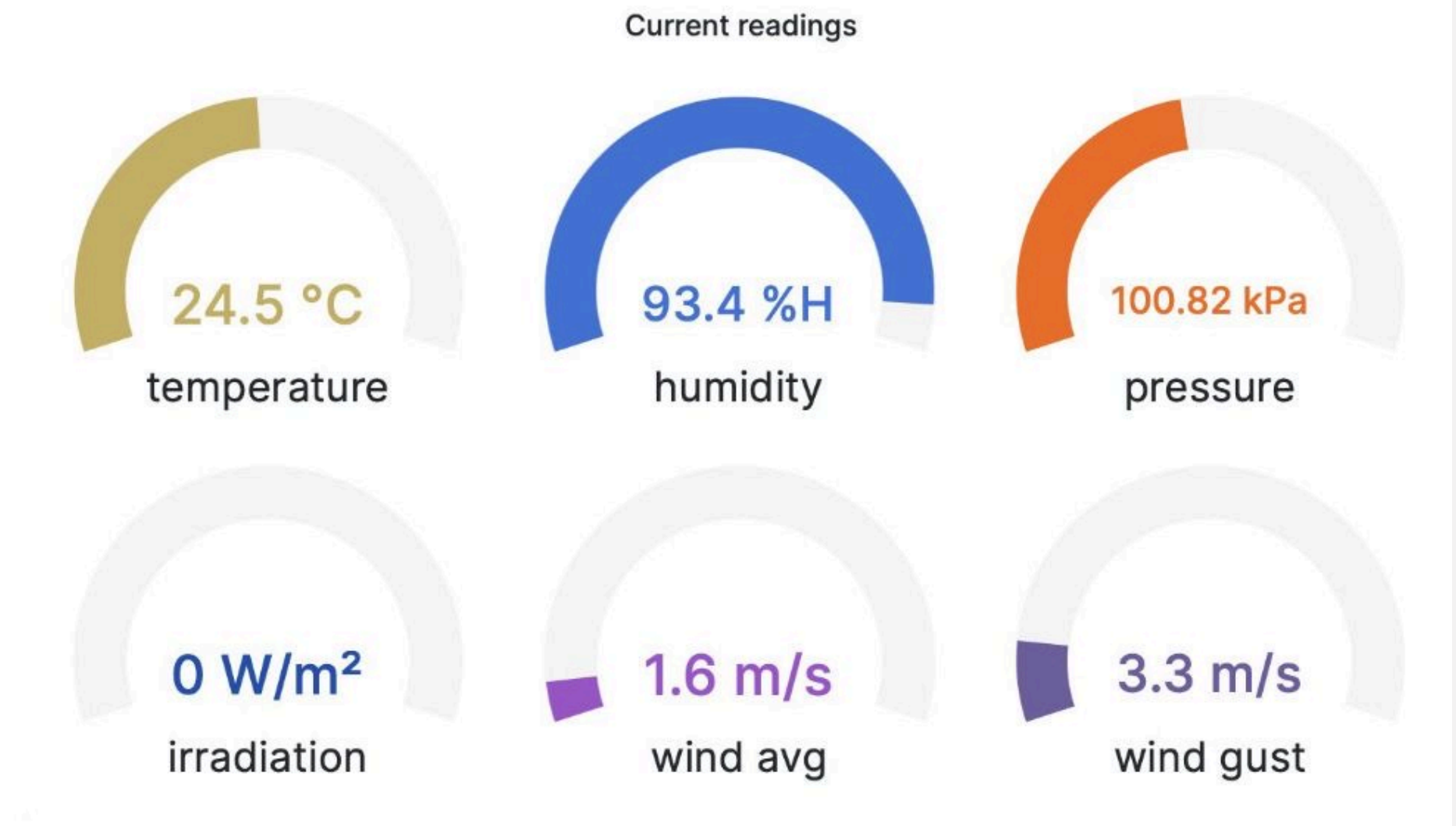
Data and upkeep

From sensor to dashboard

Sensor to logger, logger to radio, gateway to network server, network server to a database, database to a page a duty forecaster keeps open. Decide who owns each hop before the first station goes up — and make the raw archive someone's explicit responsibility.

Last readings pooled

Here is an example panel with “last readings” collected from all instruments.



How stations fail in the field

Blocked or occupied

Insects nest in rain funnels and shields. Spiders stop tipping buckets.

Silent drift

Plausible numbers, slowly wrong. Only a comparison catches it.

← obvious on the dashboard

Intro to weather stations · ICTP

Power

Dust on the panel, a corroded terminal, a battery at end of life.

People

Fences cut, masts felled, sites built over. Talk to the neighbours first.

invisible until you visit →

Maintenance, spares and local capacity

Budget maintenance as a line item from day one, or the network ends in year two

Ship spares with the stations; a customs delay is measured in months

Standardise on one design so any spare fits any site

Train two people per site, not one — and train them to teach the next two

Write the runbook in the language the technician actually works in



Building one: the bill of materials

PART	WHAT TO CHOOSE	SHARE OF COST
Sensor package	Integrated, or discrete on one bus	Largest single item
Radiation shield	Multi-plate, ventilated if you can	Small, high impact
Logger and radio	Low-power MCU with a LoRaWAN radio	Modest
Power	Panel, controller, days of battery	Modest
Mast, enclosure, fence	Galvanised, gasketed, boring	Often underestimated
Gateway	One per catchment	Shared across sites

06

Three projects

Three projects, one platform

COUNTRY	PARTNERS	THE DISTINGUISHING PROBLEM	DATA HOSTED
Ghana	NREN and the Met Office	Scaling from one station to hundreds	ICTP and in Ghana
Kyrgyzstan	ISOC Kyrgyz Chapter, CAIAG	High mountains, many stakeholders	In Kyrgyzstan
Timor-Leste	UNEP and local government	Spectrum regulation and first capacity	ICTP, first phase



Ghana: the NREN and the Met Office

The national research and education network hosts the gateways

Several devices installed, with the gateway serving both weather stations and water level sensors

The Met Office owns the meteorology; the NREN owns the infrastructure

Ghana: installation and training

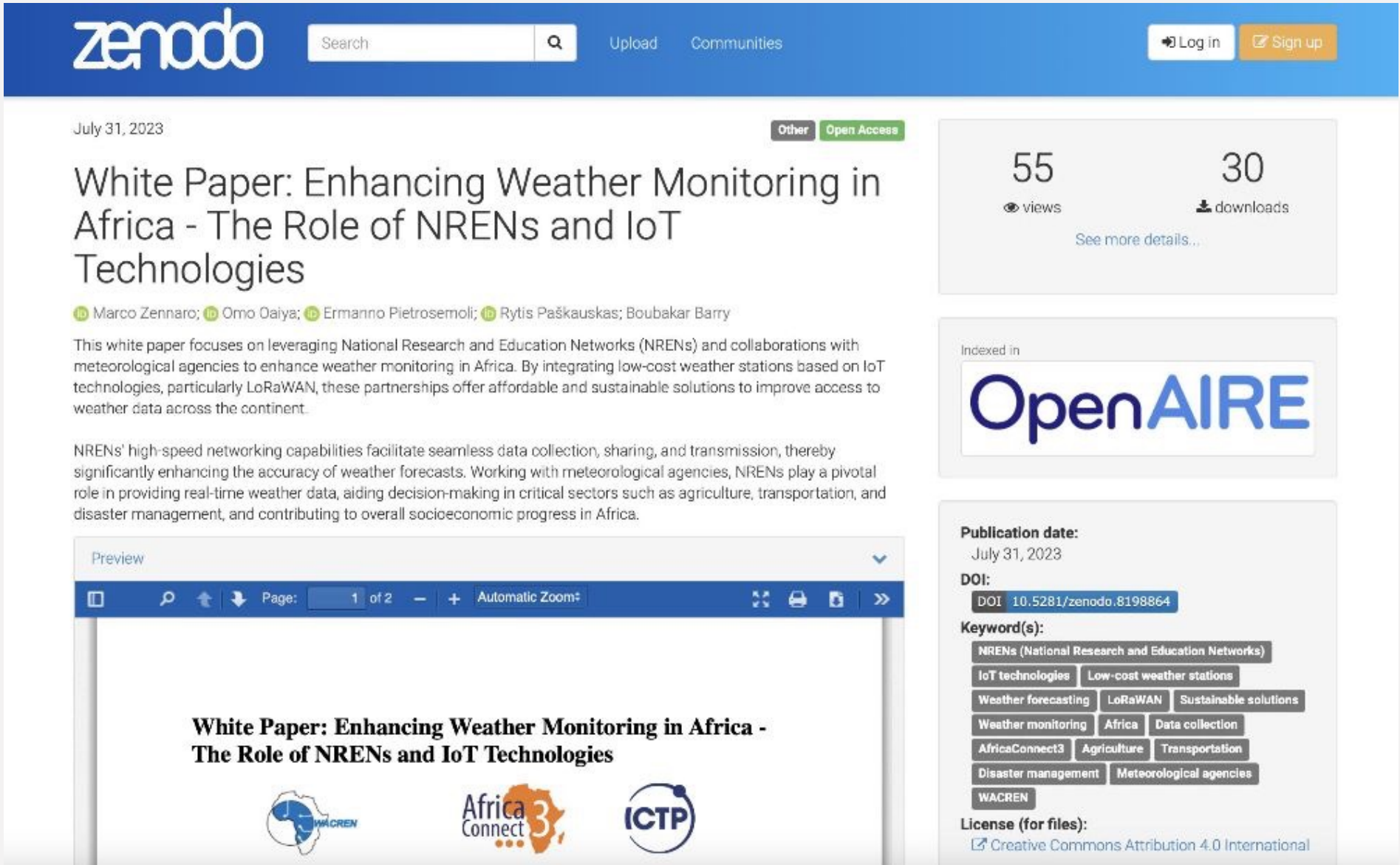
The workshop came before the hardware.

Participants from the Met Office and the NREN assembled, joined and sited the nodes themselves,



Ghana: the white paper

Enhancing weather monitoring in Africa — the role of NRENs and IoT technologies. Published open access, so the next country does not start from a blank page: architecture, procurement and the regulatory steps are all written down.



Kyrgyzstan: the ISOC project

A strong local team — the best single predictor of a network that lasts

Many stakeholders: emergency services, the academy, universities, ISOC

An explicit argument about openness against security of the data

Everything hosted in country, from the gateway to the dashboard

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Kyrgyzstan: three mountain hazards

Glacier lakes

With the Institute of Water Problems of the Academy of Sciences, monitoring high-mountain glacier lakes — the source of outburst floods.

The Boom Gorge

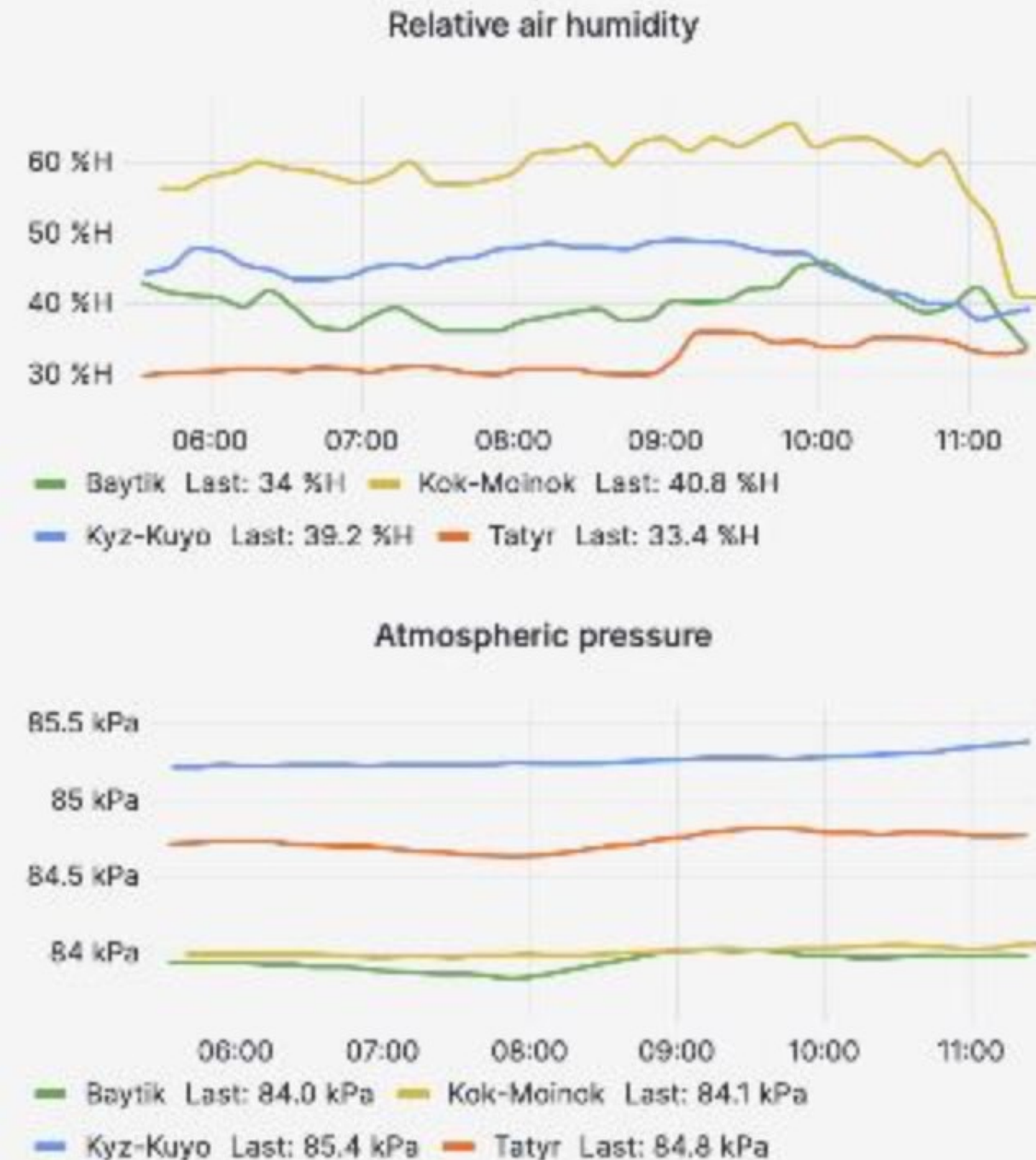
Automatic stations and sensors installed for local monitoring, at the request of the Ministry of Emergency Situations.

The Tatyr landslide

A LoRaWAN-enabled station and sensors on an active landslide, installed with CAIAG and the ISOC Kyrgyz Chapter.

Kyrgyzstan: data hosted in country

The server sits in Kyrgyzstan and the institutions that need the data can reach it without asking anyone abroad. That was a project requirement, not an implementation detail — and it is what turns a demonstration into an observing network.



Timor-Leste: UNEP and the government

Run with UNEP and the national directorate for meteorology and geophysics

A training course organised before any equipment was installed

Spectrum regulation for the band sorted out with the regulator



What the three projects share

A host institution that already runs infrastructure, not one invented for the project

Training first, hardware second — installations done by the people who maintain them

Unlicensed spectrum and no per-station subscription, so growth costs hardware only

A route to hosting the data in country, even where phase one hosts it elsewhere

If you want to start one

01 Name the decision your data will change

02 Find the institution that will still be there in five years

03 Check the radio regulations before you buy anything

04 Build two stations and run them side by side for a month

Questions for discussion

What accuracy does your decision actually require — and how do you know?

Who in your country owns the observing network, and who owns its data?

What breaks first at your sites: power, radio, sensors or people?

What would you measure if a station cost a hundredth of what it does?

THANK YOU

Questions