Aiding Communication Resilience during Severe Weather-Induced Natural Disasters

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Introduction and Motivation

1. The Hazard Problem — "When Weather Becomes an Emergency"
Lightning, severe thunderstorms/tornadoes, and flash flooding share a nasty characteristic: once conditions deteriorate, the useful decision window can become very short.

The Texas Hill Country flood events are especially strong examples because flooding, power/road/communications impacts, and rapidly evolving convection can occur together. The message is: *the meteorological hazard and communications problem can compound each other.*

2. The Information Problem — "We Are Always Looking Into the Past"
Radar, satellite, lightning data, gauges, and even automated observations have latency. Meanwhile, internet/cellular/cloud access may become degraded.

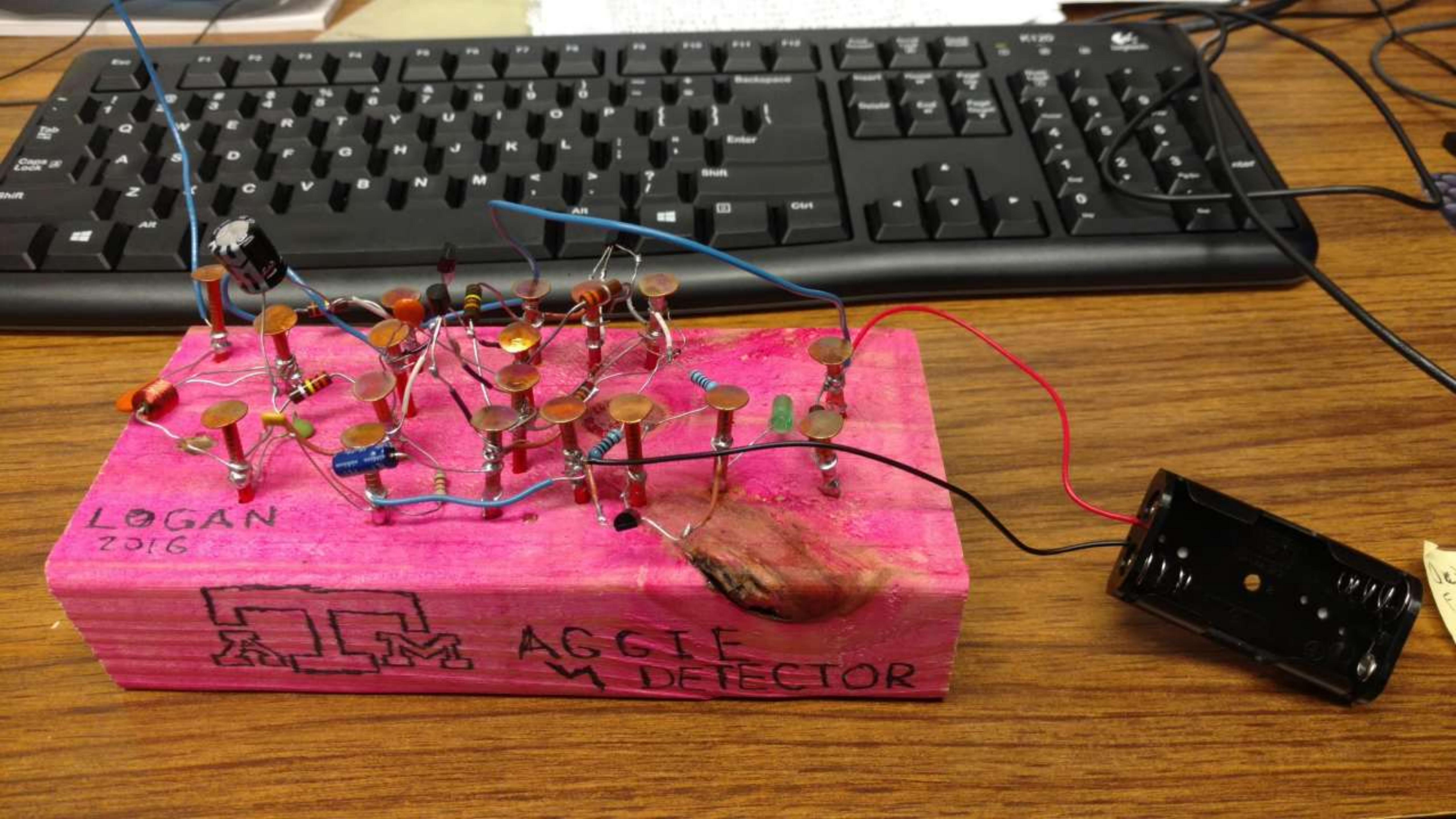
If you are looking at your cell phone and waiting for the lightning symbol to appear over your location before acting, you are already reacting to history.

The goal therefore is not to obtain perfect real-time knowledge; it is to **maintain adequately timely situational awareness to make useful decisions**.

3. Meteorology / research products and methods: Lightning observations and diagnostics; storm identification/tracking; radar; rainfall and flood diagnostics; automated processing; compact storm-status generation; case verification. (**All of which take time!)

Objectives

- **Sharpen methods pertaining to amateur radio to build a resilient communication transport mechanism:** VARA/Winlink/APRS and potentially other modes; investigate practical bandwidth/message-size limits; determine field hardware and antennas; think about ways to back up power; investigate repeater/simplex/HF options; design training exercises
- Understand what actually survives a communications failure and, importantly, **facilitate human ground truth coming back the other direction**.
- The objective is not to recreate the internet over amateur radio. It is to preserve essential **situational awareness** when the internet is no longer dependable.


LOGAN
2016
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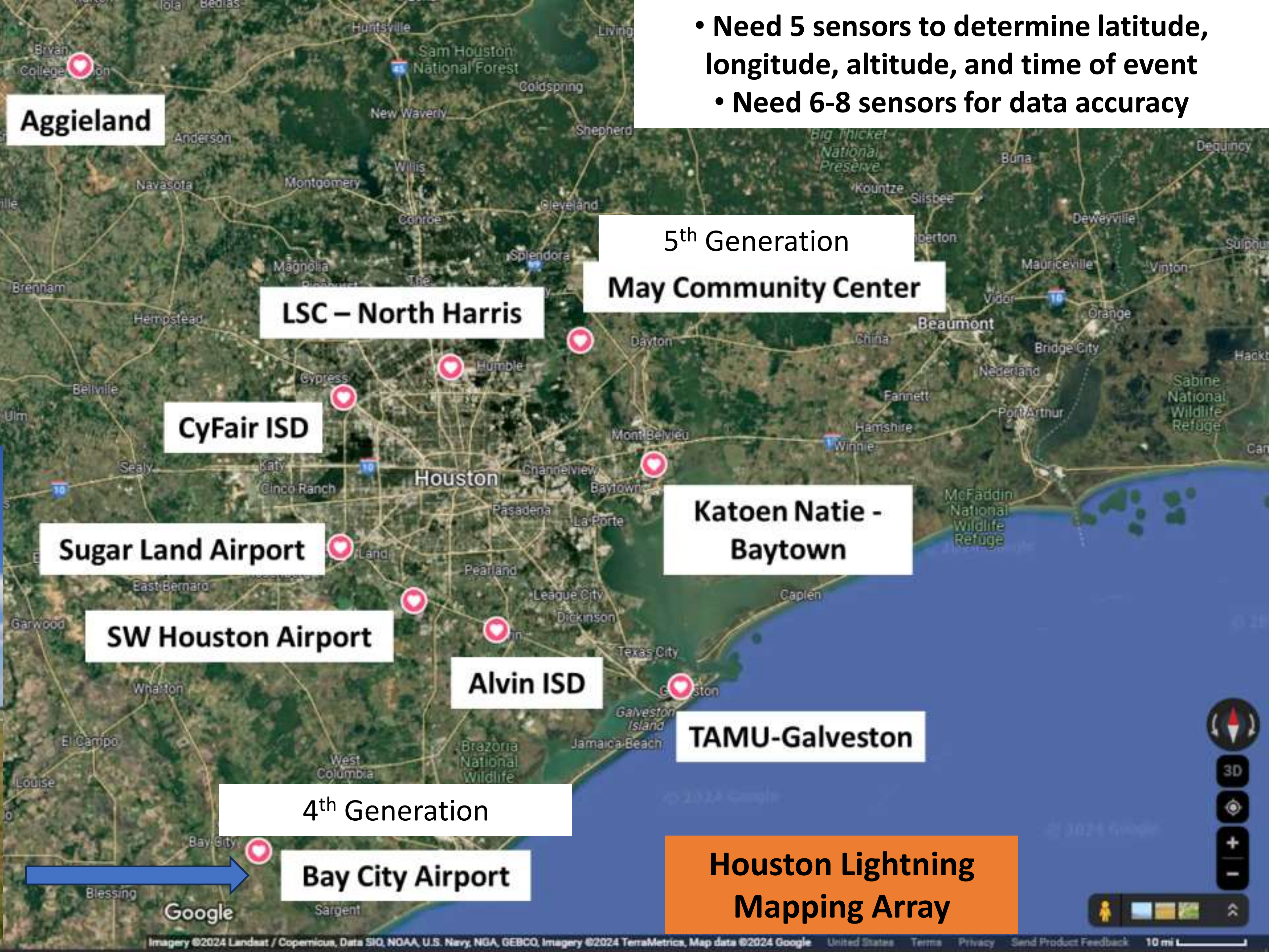
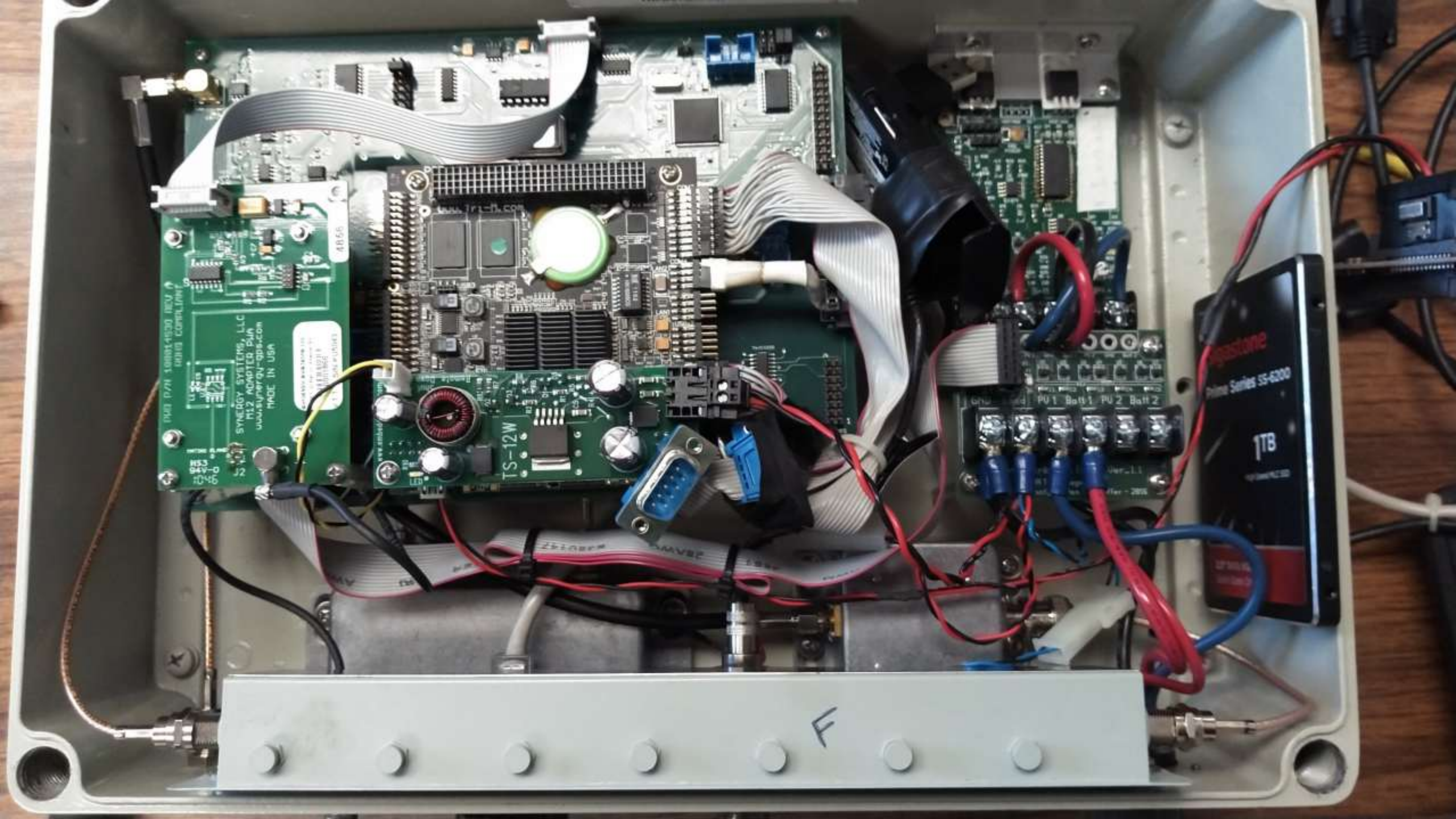
AGGIE
DETECTOR

Houston Lightning Mapping Array

- Need 5 sensors to determine latitude, longitude, altitude, and time of event
- Need 6-8 sensors for data accuracy

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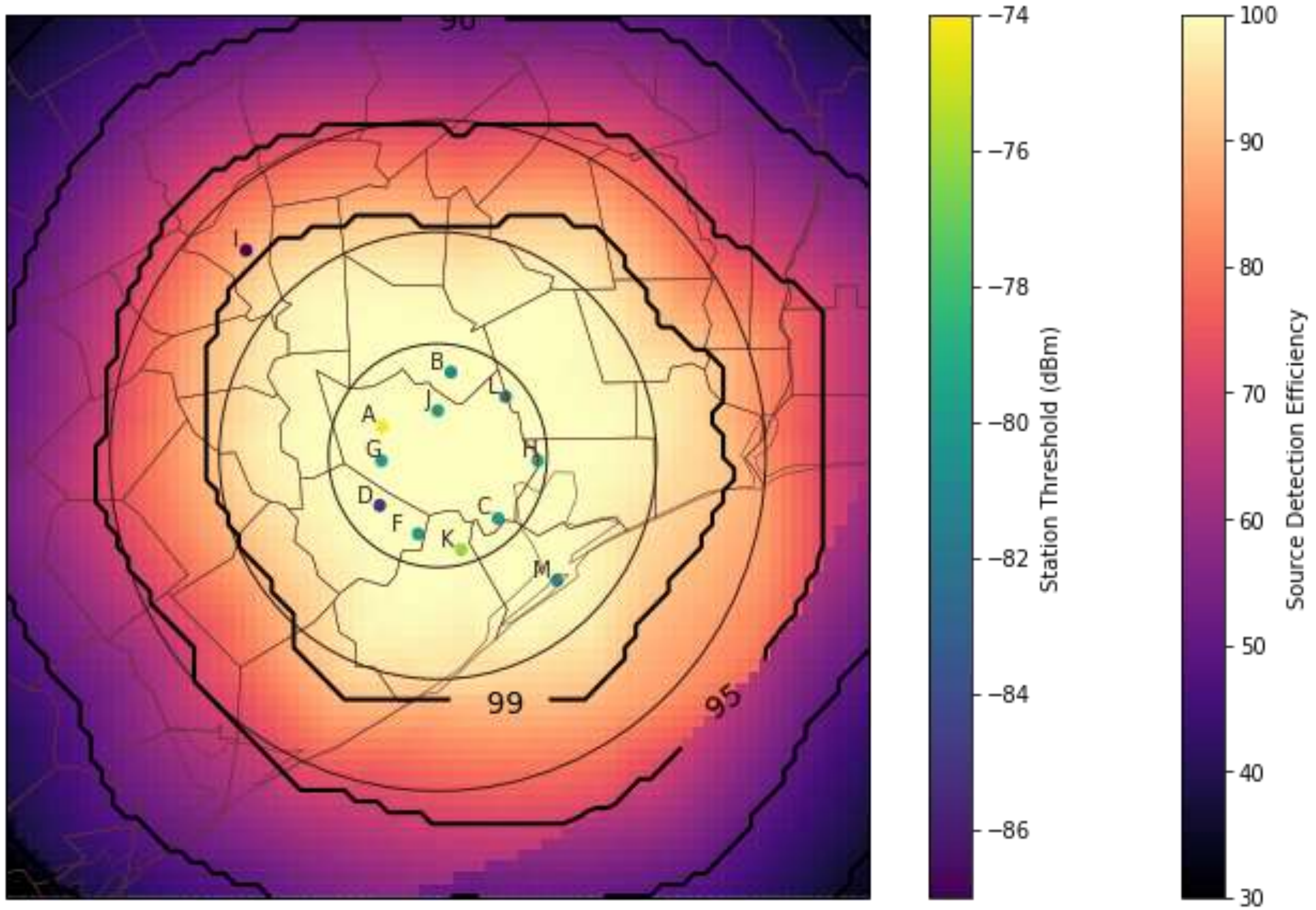
Houston Lightning Mapping Array

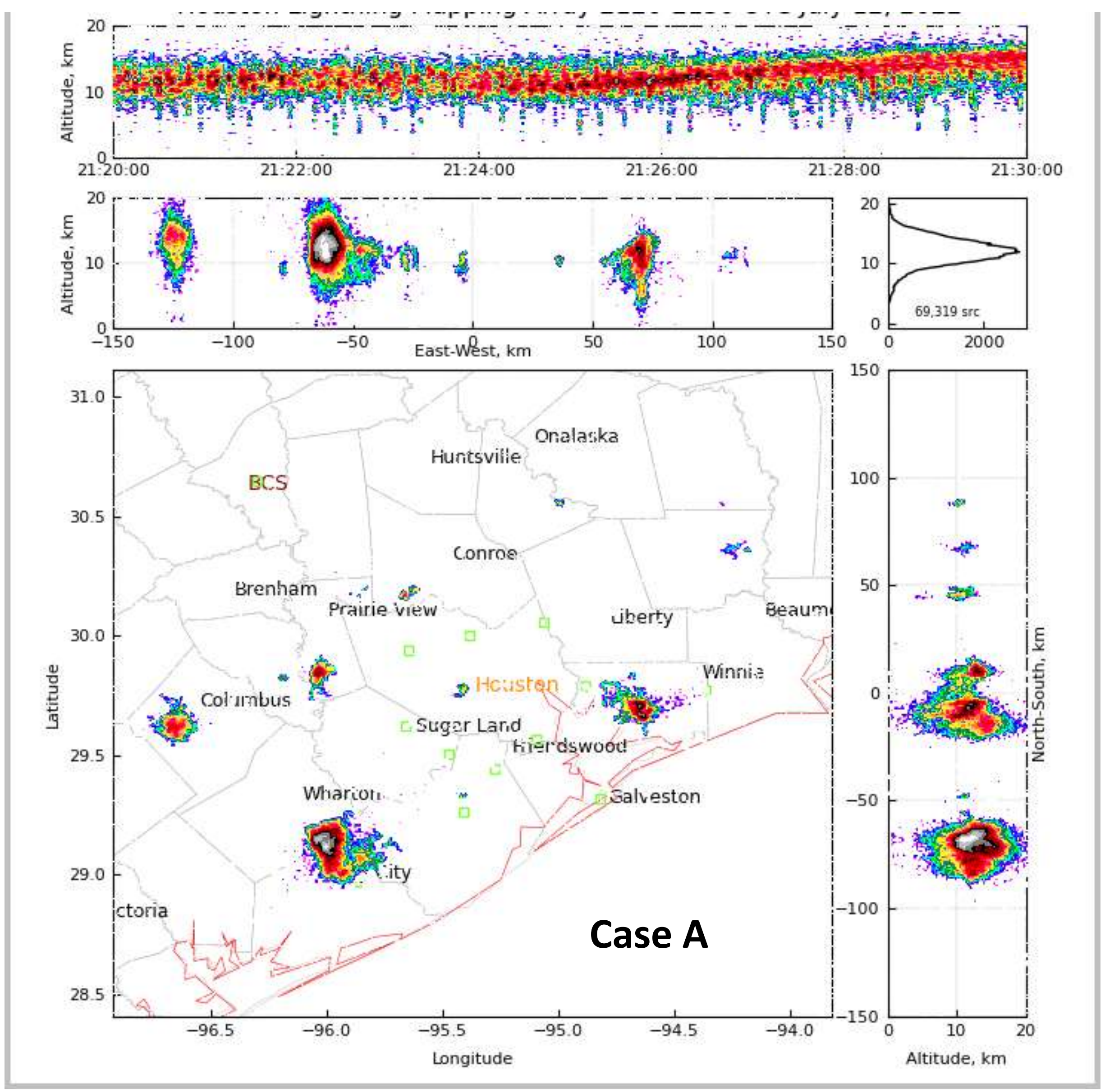


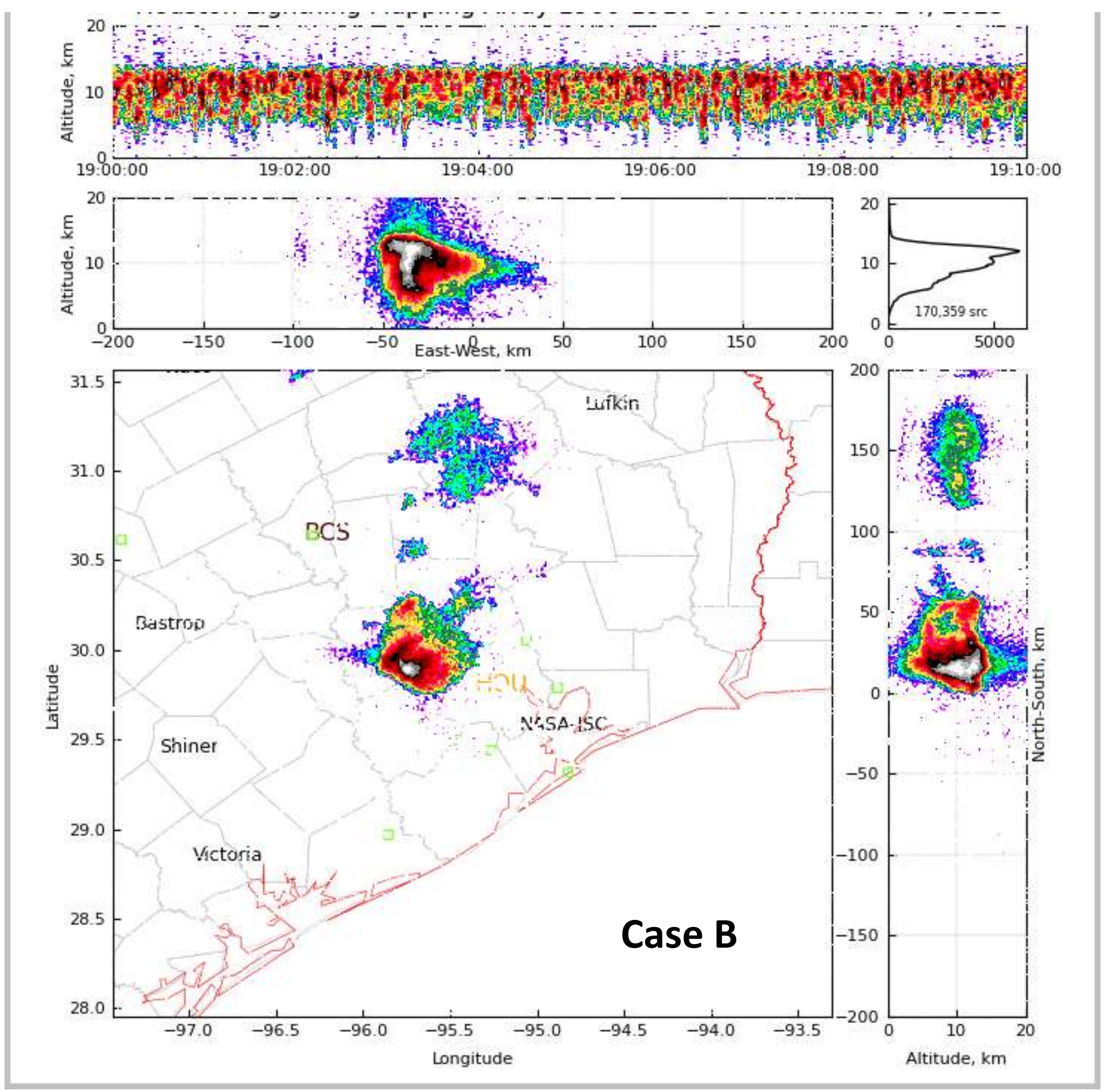
Courtesy of Dr. Eric Bruning, Texas Tech

- **HLMA detection efficiency**
- **Greater than 95% lightning detection for the Houston Metropolitan Area**
- **Detection efficiency and data quality decrease at a proportion to the inverse square of the range ($1/r^2$)**
  - **Only the most powerful sources can be detected at the edge of the range of detection**
- **At least six CWAs are included in the greater HLMA region of detection: HGX, FWD, EWX, CRP, LCH, and SHV**
- **Coverage extends out over the Gulf**

Storm Dynamics and Electrodynamics

- Certain regions favor intense lightning activity due to dynamics and electrodynamics.
- Develop a metric to take advantage of high-resolution VHF source data from the Houston Lightning Mapping Array.
  - Exceptionally high spatial and temporal granularity
- The metric is intended to diagnose the electrical organization of the thunderstorm updraft (or mesocyclone).
  - When used scientifically the metric can diagnose storm updraft coherence across all storm modes using lightning only ← as the first degree of freedom
  - When used operationally, can serve as an additional “warn-on” tool
  - Forensics capability



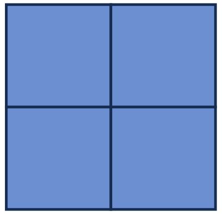


Can you tell which case is the most concerning?

Lightning-based Updraft Organizational (LBUG) Metric

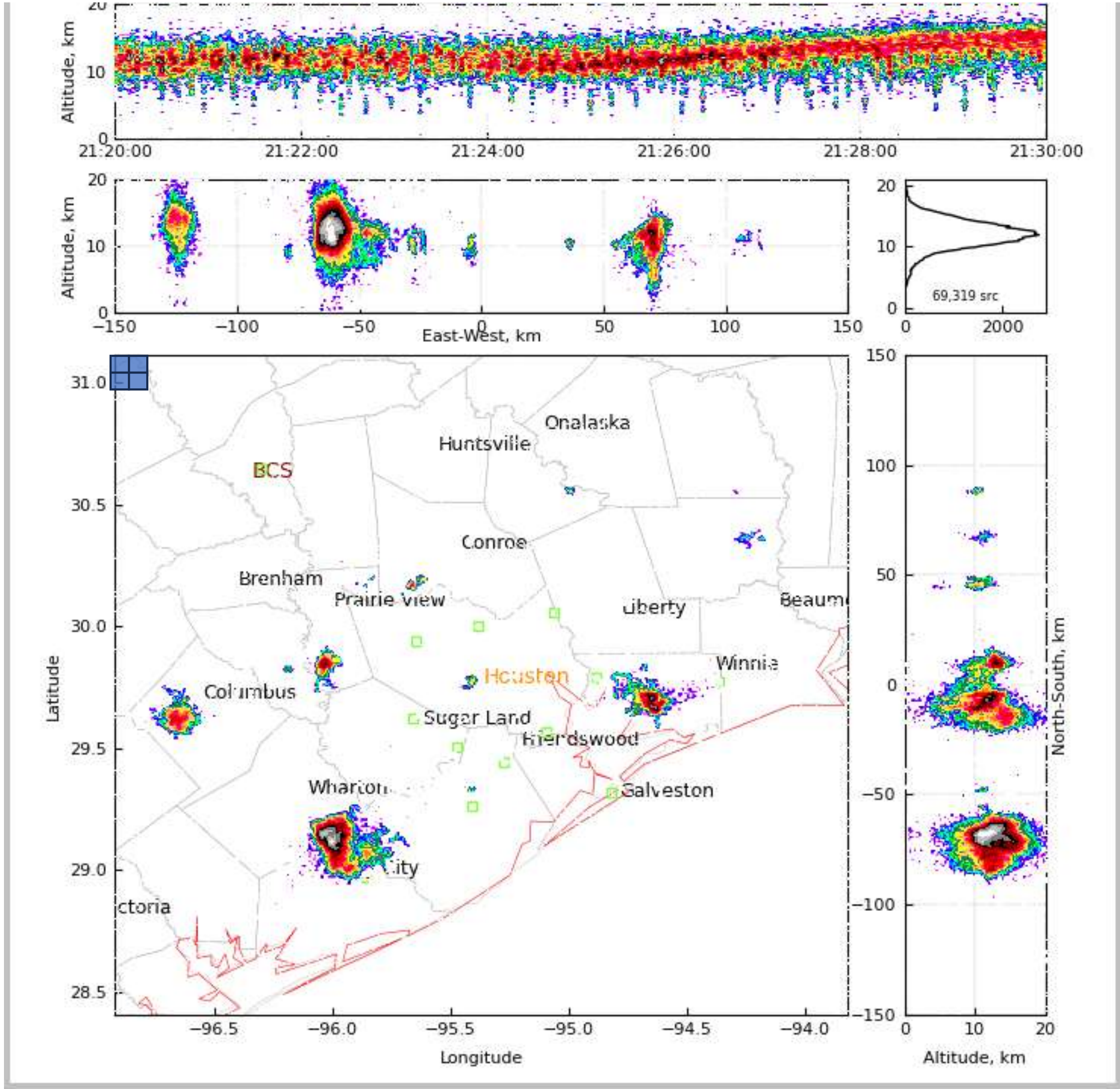
- Track all storms within a specified domain in near real-time
  - "Burst logic" method to identify significant lightning burst regions
  - Use edge detection gradient analysis to diagnose electrical organization of the updraft
    - Pulse thunderstorms tend to have short-lived, transient updrafts
    - Multi-cell thunderstorms have more organized stable updrafts
    - Supercell thunderstorms tend to have long-duration rotating updrafts called mesocyclones
  - Use a "pixel logic" threshold to constrain the LBUG to identify electrically dominant centroids
    - LBUG will only "light up" on the most electrically coherent storm (**primary**) with the **secondary** and **tertiary** storms continuing to be "storms of interest"
  - Output the magnitude and track of the LBUG center of mass (COM) and compare with the burst metric timing and location as well as radar reflectivity/velocity signatures, SPC reports, flood reports, and lightning reports

LBUG Operation



4-pixel operator
(~0.02 deg or ~2 km pixel size
depending on size of domain)

- Burst metric first identifies VHF source pixels that represent at least 2% of all lightning activity within the domain
- LBUG metric "turns on" when the pixel operator encounters a region of strongly positive VHF source edge gradients at the 92nd percentile.
  - LBUG will not turn on when the gradient is near or approaches zero.
- Weighted percentile analysis lines up LBUG with region of **strong** electrical organization and ignores weaker electrically active regions.
- LBUG is usually a sign of an intensifying updraft due to related electrical, microphysical, and dynamic processes beneficial to lightning activity.



Keep weather awareness alive when communications fail

A resilient complement to NWS, commercial platforms, and normal internet/cellular delivery

The problem

Severe weather can damage the infrastructure that delivers critical information.

Smaller jurisdictions may also face cost or subscription barriers.

The design goal

Local-first. Low-bandwidth. Modular. Keep essential observations moving through alternate communications paths when normal pathways are compromised.

What this is NOT

Not a replacement for forecasters.

Not a claim to beat commercial systems. Not AI making life-safety decisions.

It is another **layer of resilience**.

Forecasts help us prepare. Operations help us respond.

The target is the period when conditions are already deteriorating - the "OMG space."

Turn many datasets into a compact operational picture

The science layer interprets storm evolution; it does not assert that the observations are instantaneous.

Reality check: every observation is history

Lightning, radar, satellite, and gauges all have latency.

If the "red dot" is over you, that event already happened.

Value comes from trends, organization, persistence, and context.

Operational objective

Reduce a complex storm to a few defensible indicators:

Where is the organized region? Is it strengthening or shifting?

Which cell deserves attention now?

• THE COMMUNICATIONS BRIDGE

Sensor first. Local processing second. Multiple paths out.

Amateur radio provides resilient delivery options.

LOCAL INPUTS

- Boltek Electric Field Mill Sensor
- NOAA Weather Radio
- Houston Lightning Mapping Array / Tracking Algorithm for Mesoscale Convective Systems (TAMS) metrics
- Radar / gauges

→

LOCAL ENGINE

- Parse + threshold individual datasets
- Combine datasets
- Create compact status
- No cloud computing required

→

DELIVERY

- APRS
- Winlink
- VHF/UHF/HF
- Mesh / local dashboard

If one path fails, the information does not have to disappear.

Amateur Radio Emergency Service (ARES) / Community Emergency Response Team (CERT) Use Case

A weather "escape net" for emergency management

The amateur radio role is not to forecast the storm - it is to keep trusted information moving.

Severe storm / flood -> cellular or internet-compromised -> EOC still needs situational awareness

1. Observe

Local sensors continue collecting.

Research metrics flag organization.

NWS products remain authoritative when available.

2. Distill

Send only what matters:
time, location, trend, confidence, threshold/event, and source.

Keep packets small and interpretable.

3. Relay

ARES moves the message through whatever path survives.

Human operators retain judgment and provide ground truth on the “all clear” and “compromised” ends.

What Actually Goes Over the Radio?

Heavy weather data stays upstream. A compact storm-status packet crosses the constrained link.

HLMA + TAMS + Radar > Burst / LBUG Analysis > STORM STATUS > VARA / Winlink / APRS > Emergency Management

EXAMPLE STATUS PACKET

```
WXTIME 1925 UTC  AGE:15 MIN STORM ID:236

LIGHTNING: ORGANIZED/PERSISTENT

BURST METRIC: PRIMARY    LOCATION: 29.96N, 95.62W
LBUG METRIC: STRONG/PERSISTENT
TREND: STRENGTHENING  CONFIDENCE:HIGH
STORM STATUS: SEVERE
CELL MOTION: NE 18KT TOWARDS KLEIN, TX
MONITORING SOURCES: HLMA/TAMS/NEXRAD/NWS
```

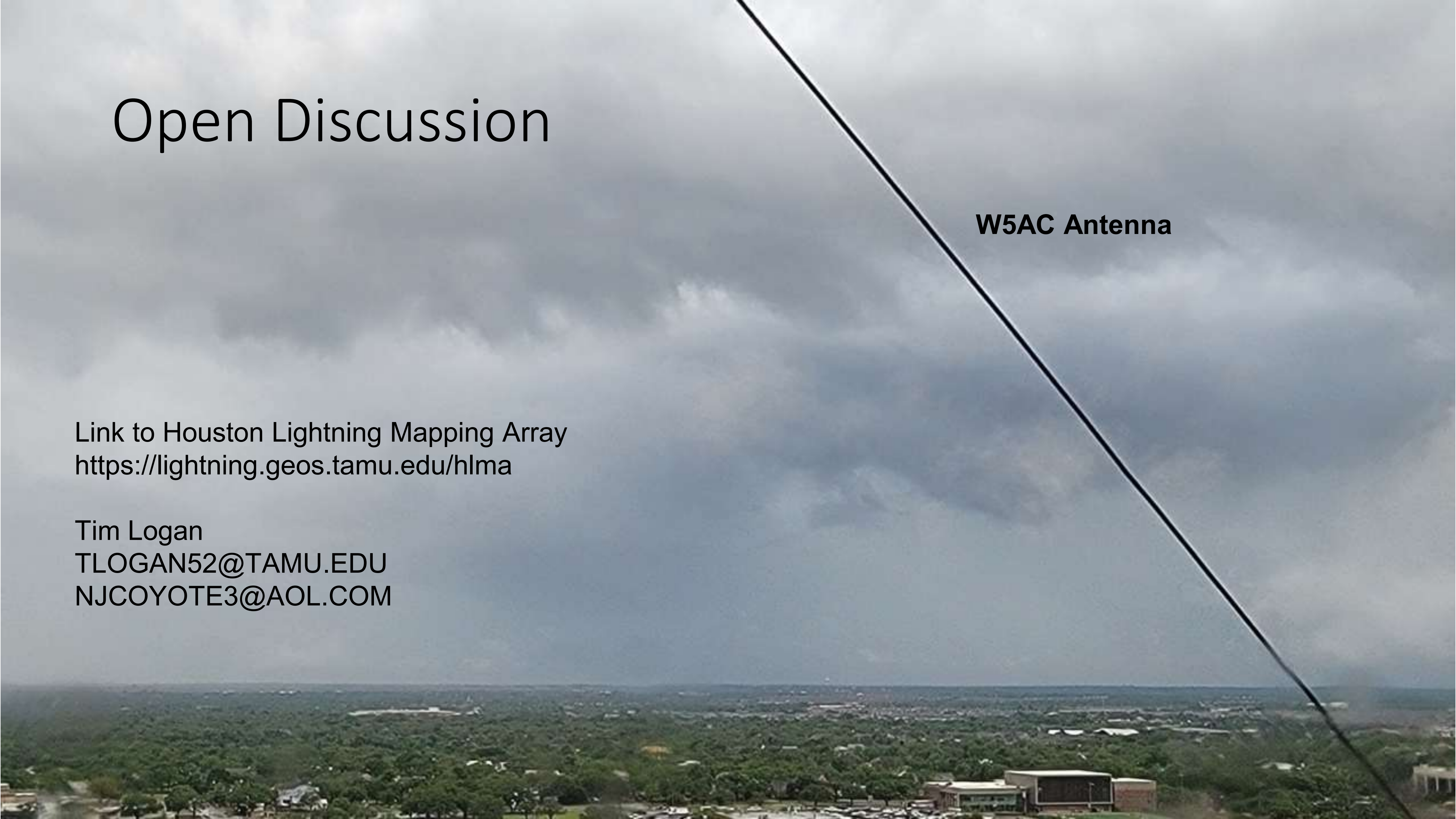
Work Design Goals

Small
A few hundred bytes can carry the essential storm state.

Meaningful
Transmit interpretation - not thousands of VHF sources or imagery.

Resilient
The packet can move over VARA, Winlink, APRS, or another surviving path.

Open Discussion



Link to Houston Lightning Mapping Array
https://lightning.geos.tamu.edu/hlma

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