Benefits and Challenges of using Low-Cost Weather Stations

Paul Kucera, Ph.D. and Martin Steinson

UCAR/COMET

Boulder, CO USA

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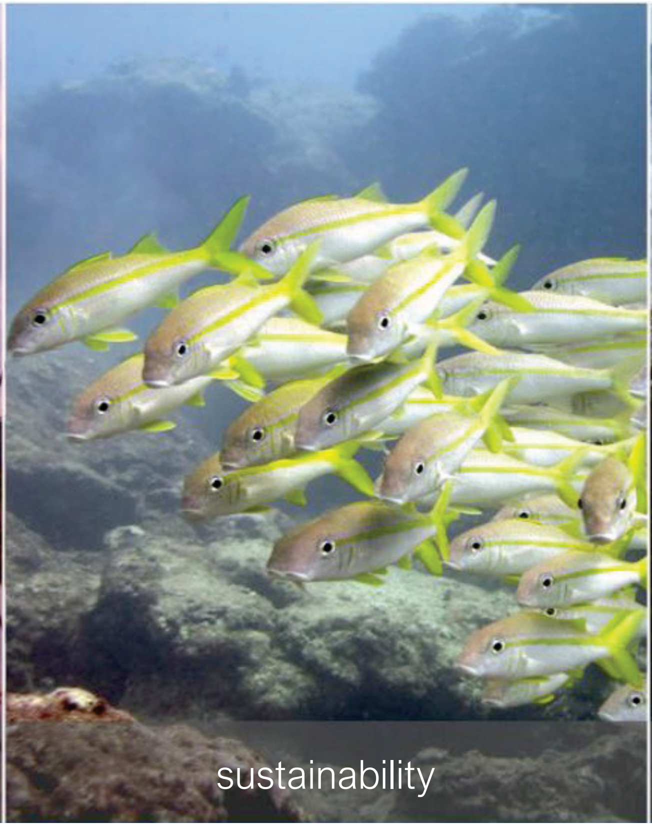

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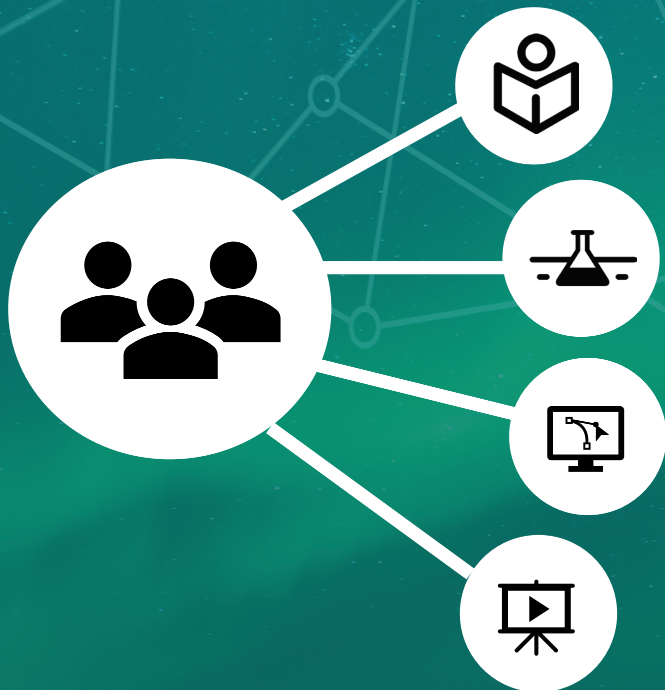

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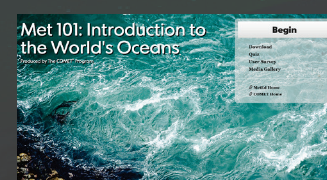
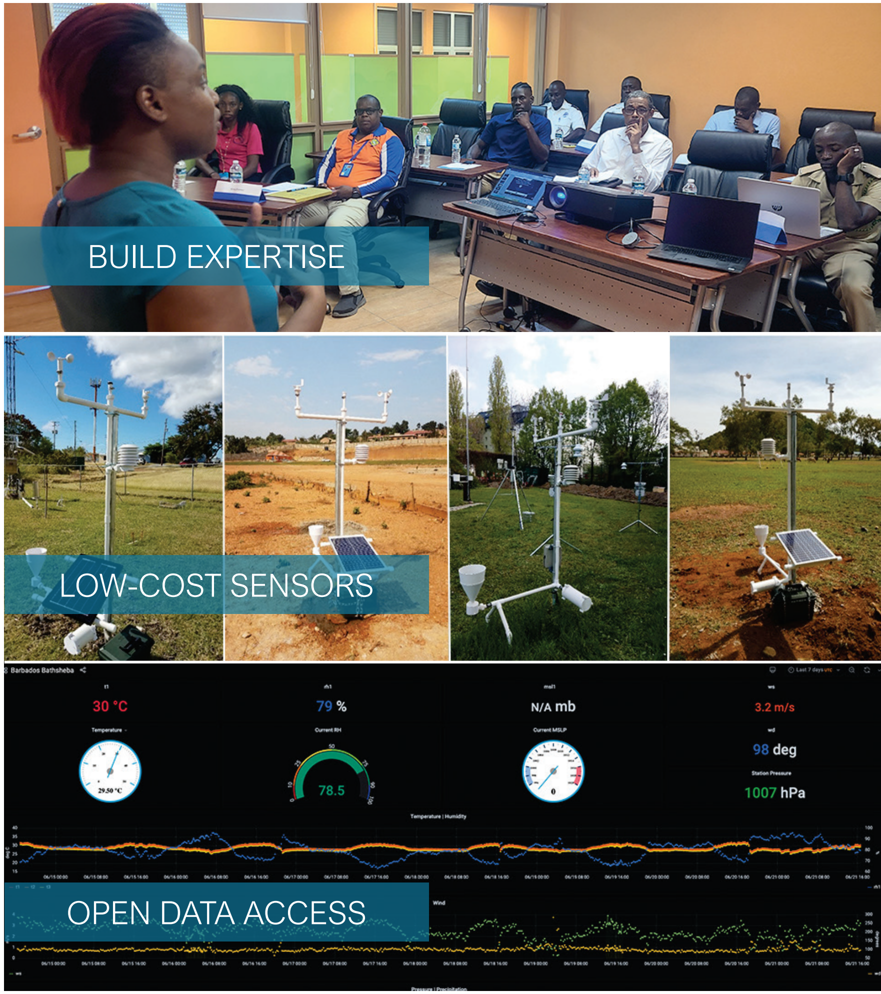


INTERNATIONAL CAPACITY DEVELOPMENT PROGRAM

OUR MISSION

Empower people across the globe to identify, predict ,and communicate and prepare for weather, water, and climate impacts to reduce risk to their communities

- Training solutions
- Customized observation technology
- Application driven decision support solutions
- Impact-based forecasting and weather services
- Cloud-based weather forecast technology



Low-Cost Observation Systems

Low-Cost Observation Networks - Introduction

- In 2014, the 3D-Printed Automatic Weather Station (3D-PAWS) initiative was launched to support disaster risk reduction programs
- The goal is to design and implement sustainable observation capacity in the least-developed, data-sparse regions
- Provide early warning observation capability to reduce risk for vulnerable communities
- Provide a low-cost innovative, sustainable solution to support hydrometeorology-related applications

3D-PAWS Platform

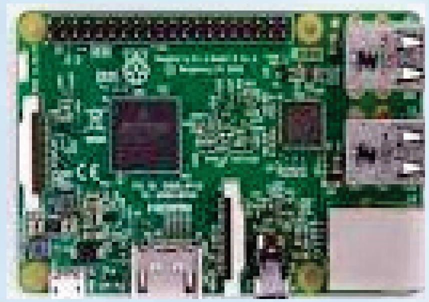
Low-Cost Observation Networks – Capacity Development

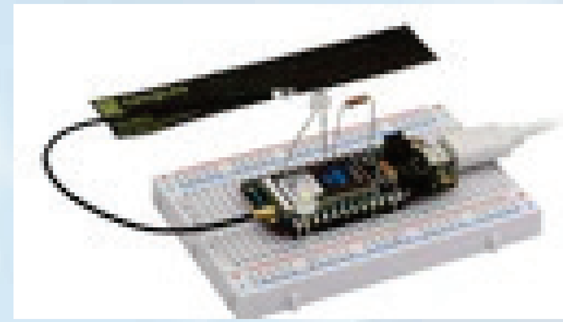
- Use 3D printers – inexpensive technology
- Use off-the-shelf low-cost micro-sensors
- Design a system that that can be assembled locally
- “Print and replace” components when systems fail
- Enable local partners to take ownership in building and maintaining observation networks

Original 3D-PAWS Platform

3D-Printed Automated Weather Station (3D-PAWS)

Data acquisition and communication using Single Board Computers (SBC) and micro-processors





Wind Speed

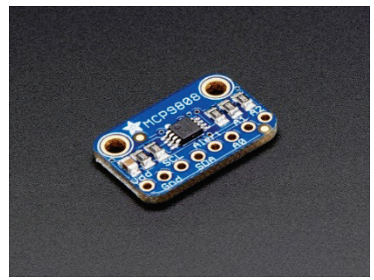
Wind Direction

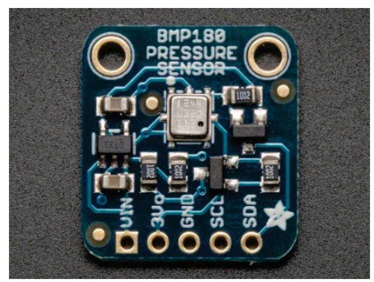
Light Sensor

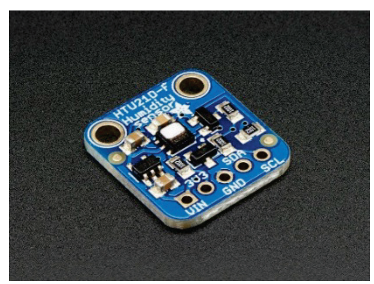
Precipitation Rate

3D-Printed Automated Weather Station (3D-PAWS)

Radiation Shield and State Variables:
Pressure, Temperature & Humidity







Power and Communications

Commercial and solar power solutions

Direct network, wireless, cell modem, satellite communication (Iridium, GOES, METEOSAT), LoRa* networks

*In development

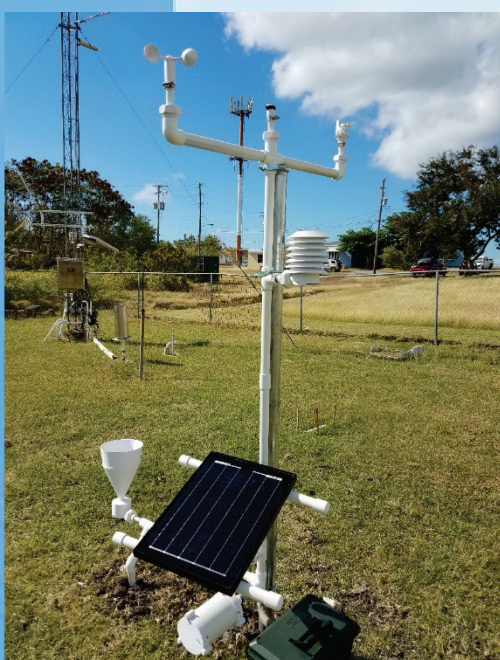
3D-PAWS: Expanding the global weather observation data collection “footprint"

3D-PAWS Design and Configuration

- Parameters
  - Temperature
  - Pressure
  - Humidity
  - Wind speed and direction
  - Rainfall
  - Solar light

- Data and Networking
  - Real-time data access and local data archive
  - Temporal resolution: 1 min or longer
  - Communication: Wireless, mobile, satellite, LoRa*

Barbados



Uganda

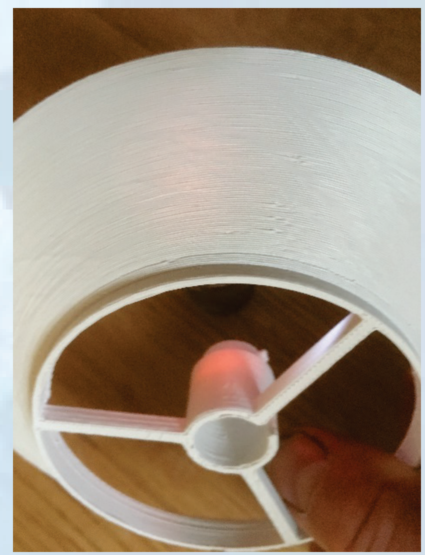
Vienna

Kenya

3D-Printed Automated Weather Station (3D-PAWS)

3D Printing Materials

- ABS and PLA are the most used plastics
- ABS is not UV resistant and will degrade in sunlight – only use on "internal parts"
- ASA plastic is used for 3D-PAWS: very UV resistant
- Opacity of plastic is important



3D-PAWS: Expanding the global weather observation data collection "footprint"

3D-Printed Automated Weather Station (3D-PAWS)

Component Design

- **OpenSCAD (http://www.openscad.org)**
  - 3D CAD file
  - Output as .stl file to 3D printer
  - 3D printer “slices” into machine code

3D-Printed Automated Weather Station (3D-PAWS)

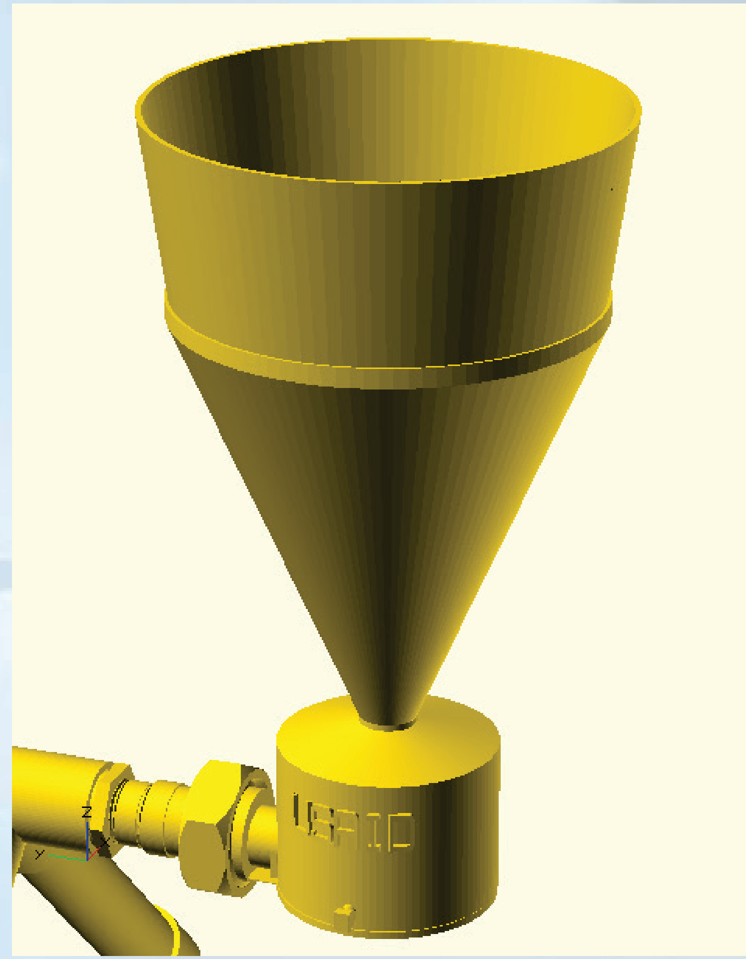
Anemometer

- **3 cup design**
- **Tested in NOAA wind tunnel up to Cat 5 hurricane speed (70 m/s)**

3D-Printed Automated Weather Station (3D-PAWS)

Rain Gauge

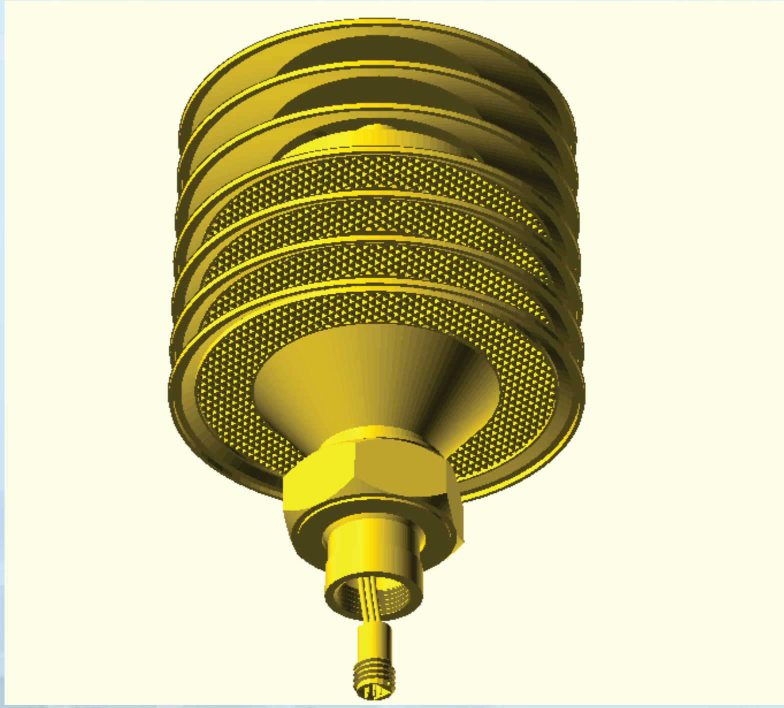
- Tipping bucket design
- 0.2 mm resolution
- Same sensor as anemometer

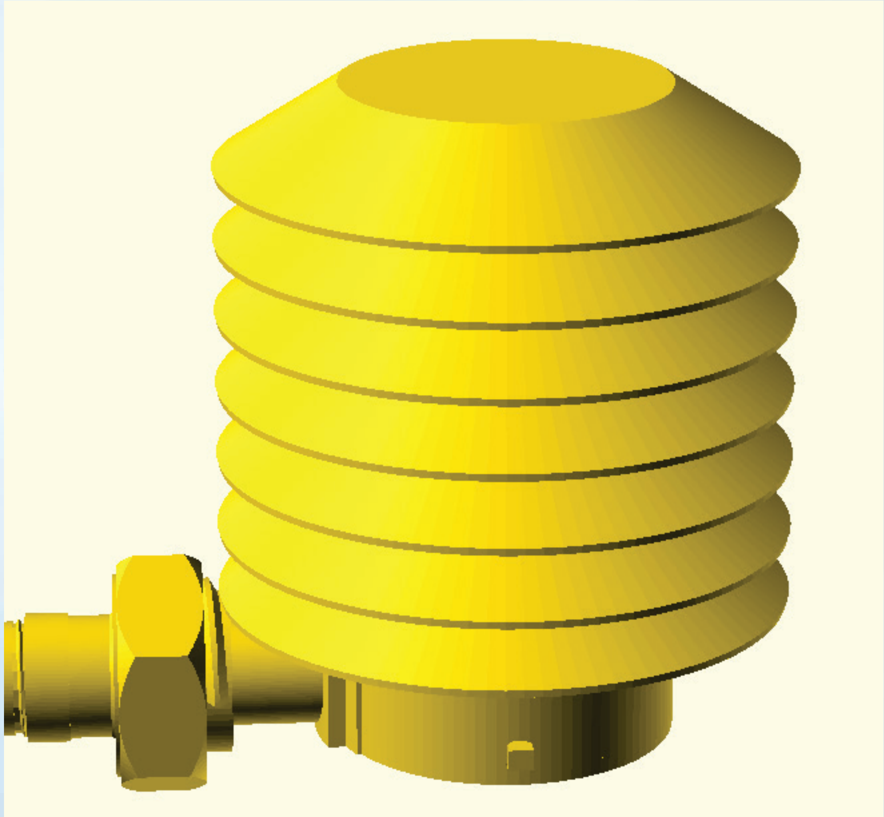


3D-Printed Automated Weather Station (3D-PAWS)

Radiation Shield

- **Temperature**
- **Relative humidity; temperature**
- **Barometric pressure; temperature**

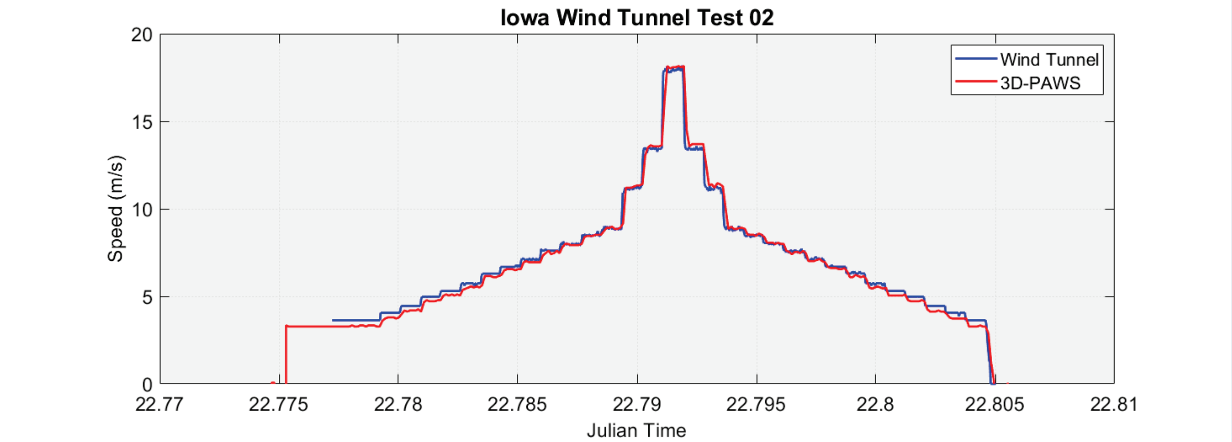




3D-PAWS: Expanding the global weather observation data collection “footprint"

Wind Tunnel Testing

- **The 3-cup anemometer and wind vane sensor were tested in the NOAA wind tunnel (high speed) and University of Iowa and NCAR wind tunnel (low speed)**
- **3-cup anemometer**
  - Durability at high wind speeds
  - Calibration consistency at low and high wind speeds
- **Wind vane sensor**
  - Wind direction calibration at low and high wind speeds
  - Stability of the sensor at various speeds



NOAA Testbed – Calibration and Testing

- **Sensors calibrated and evaluated testing at the NOAA Testbed in Sterling, VA**
  - Calibration
  - Failure conditions

Sensor Evaluation

- Overall, the sensors compared well with calibrated reference sensors in field comparisons
- A laboratory reference evaluation is currently ongoing at WMO Regional Instrumentation Center (RIC) located at the Turkish State Meteorological Services (TSMS)
- The table below provides a summary of sensor measurement characteristics and performance during the evaluation:

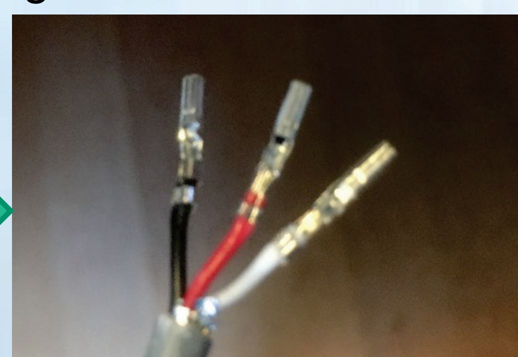
Parameter	Resolution	Uncertainty
Temperature (°C)	0.1 °C	±0.4 °C
Pressure (hPa)	0.1 hPa	±0.4 hPa
Relative Humidity (%)	1 %	±5.7 %
Wind Speed (m/s)	0.1 m/s	±0.8 m/s
Wind Direction (deg)	1 deg	±5 deg
Rainfall (mm)	0.2 mm	10%

Advancing the Technology

3D-PAWS

- COVID was a “silver lining”
- New designs to building to make the build more user-friendly and reliable
- Incorporate new technologies to simplify construction
- Reduce power consumption and increase sustainability

Original: Intensive Fabrication



New: Easy Quick Connect Cables

Advancing the Technology

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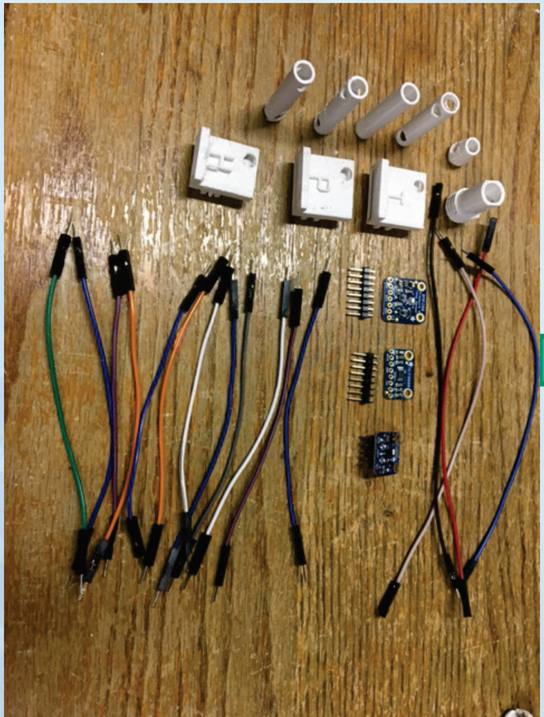
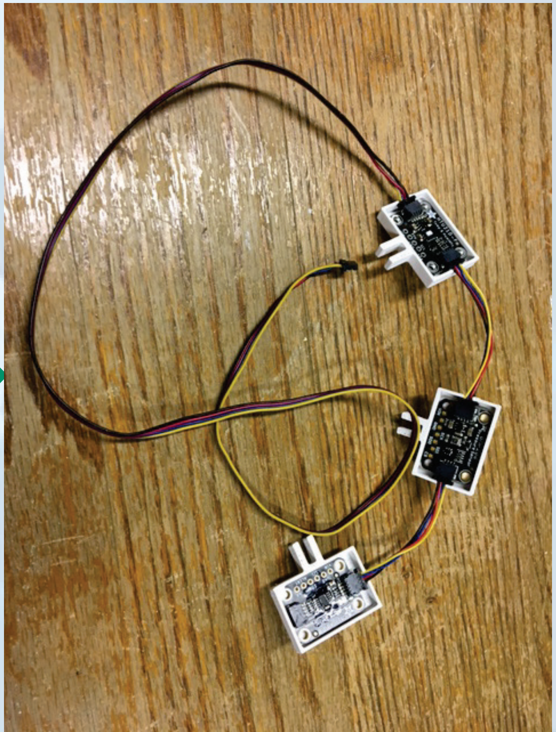


New



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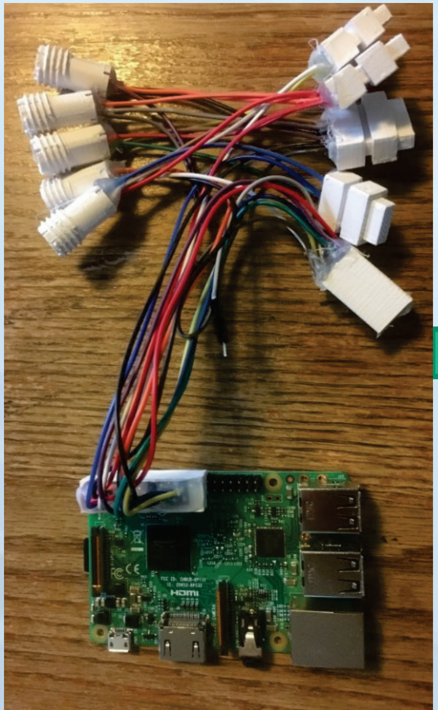

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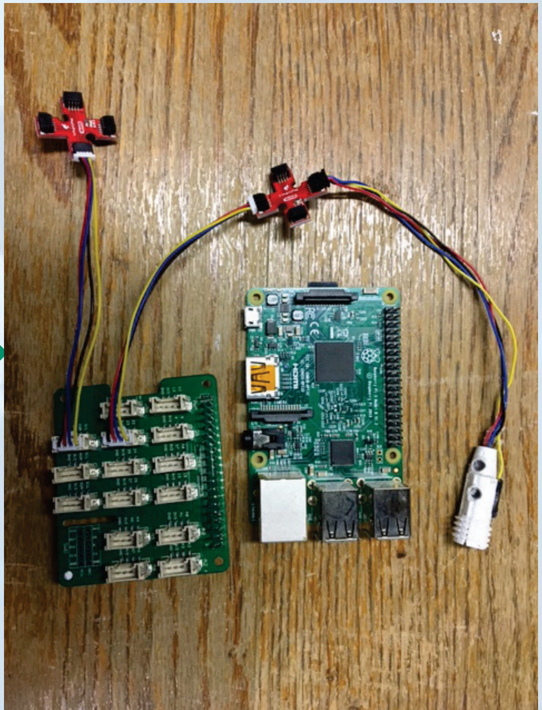


Advancing the Technology

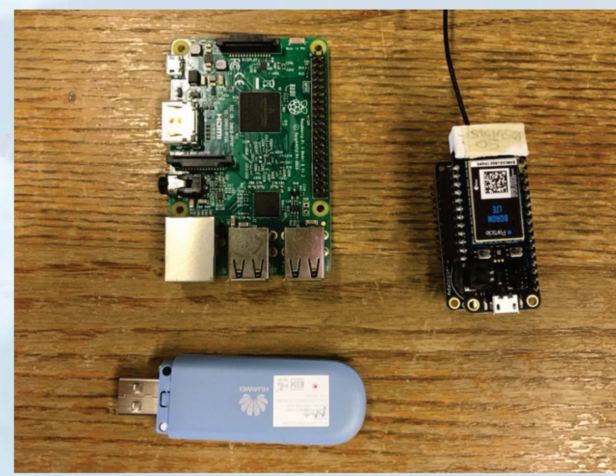
3D-PAWS

- **COVID was a “silver lining”**
- **New designs to building to make the build more user-friendly and reliable**
- **Incorporate new technologies to simplify construction**
- **<u>Reduce power consumption and increase sustainability</u>**

Solar Panel

Battery

Data Logger/Communication



Advancing the Technology

3D-PAWS

- COVID was a "silver lining"
- **New designs to building to make the build more user-friendly and reliable**
- **Incorporate new technologies to simplify construction**
- **Reduce power consumption and increase sustainability**

Adaptable Designs

New Sensor Development: Air Quality and Lightning Detection

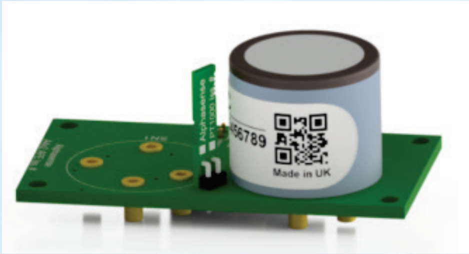
- Air quality
  - Particulate Matter, $PM_{2.5}$, PM_{10}
  - Ozone, O_3
  - Volatile Organic Compounds, VOC
  - Nitric Oxides, NO_x
  - Sulphur Oxides, SO_x
  - Methane, CH4
  - Carbon Dioxide, CO_2
- Lightning Detection

Applications:

- Air quality monitoring for health impacts
- Local severe weather detection

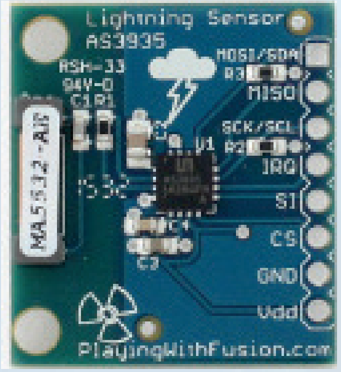
PM 2.5, 10

VOC



O3 and NOx

Lightning Detection



New Sensor Development: Water and Soil Sensing

New sensors:

- Soil Sensors
  - Temperature
  - Moisture
  - Multiple Depths
- Ultra Sonic Distance Sensing
  - Stream/canal gauging
  - Storm surge monitoring
  - Snow depth monitoring

3D-PAWS Soil Sensor

Ultra Sonic Distance Sensing

Flood and Water Resource Monitoring

- A water level/snow gauge has been developed for stream and canal applications:
  - Flood monitoring
  - Early warning
  - Water resource management (irrigation, dam operations)

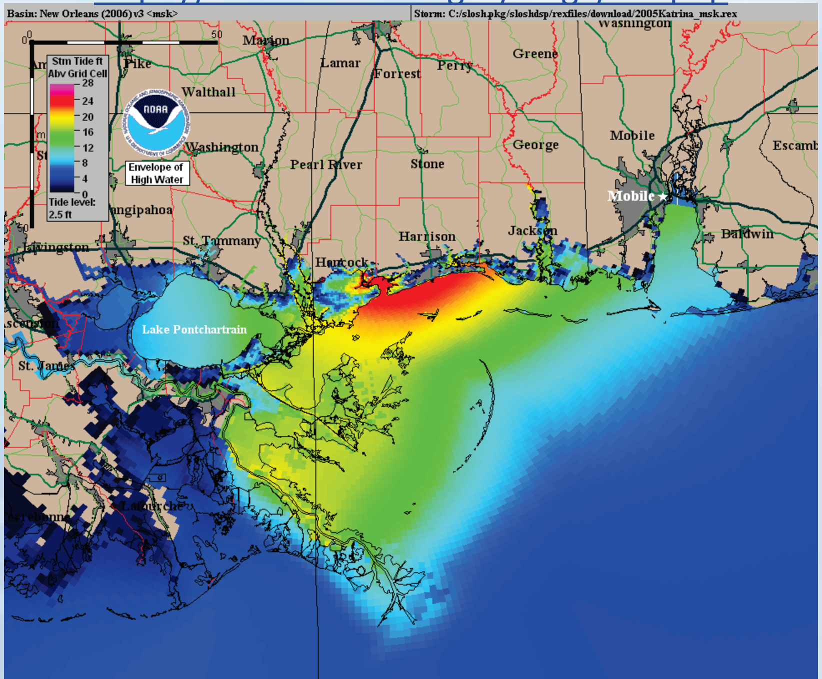
Snowpack Monitoring

- Snowpack monitoring:
  - Snowmelt water resource planning

Application: Storm Surge Monitoring

- The water level gauge has been adapted for storm surge and tidal monitoring applications:
  - Early warning and evaluation of storm surge prediction
  - Monitoring for port operations
- Two system configurations have been developed:
  - Sea-level monitoring only
  - Sea-level and wind monitoring

Image courtesy of the NHC Storm Surge Unit:
https://www.nhc.noaa.gov/surge/ssu.php

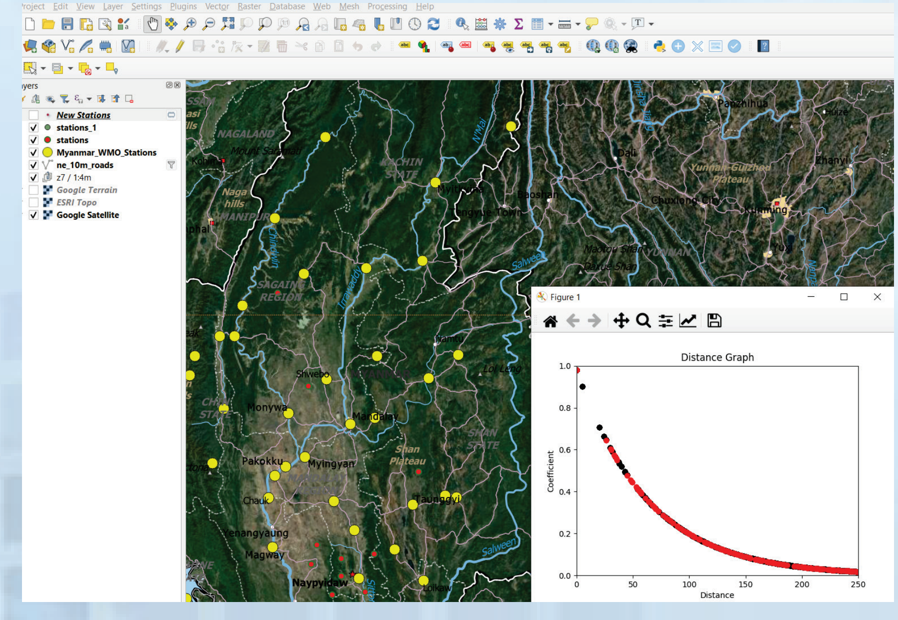


Rainfall Networks

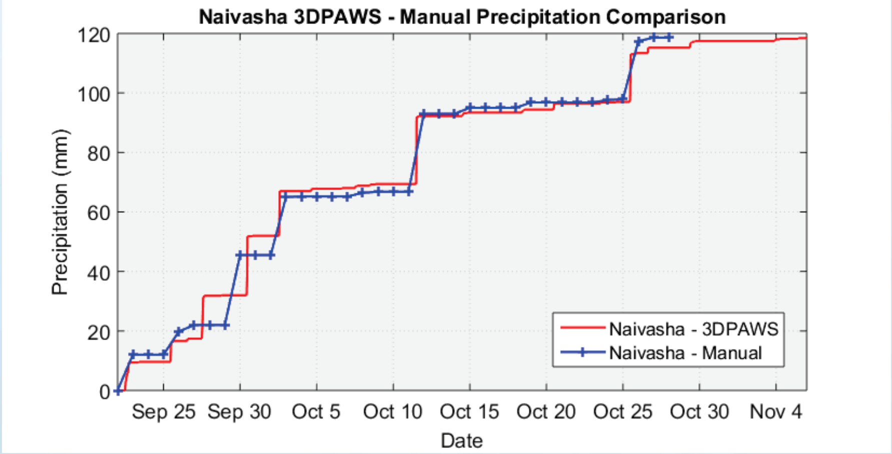
3D-PAWS and standalone rain gauges used to fill in the gaps of existing observations networks

- Watershed monitoring for flood risk
- Agriculture applications – drought risk and food insecurities
- Use GIS network design tool to support optimal site locations

GIS Network Design Tool



3D PAWS and Manual Precipitation Gauge Comparison

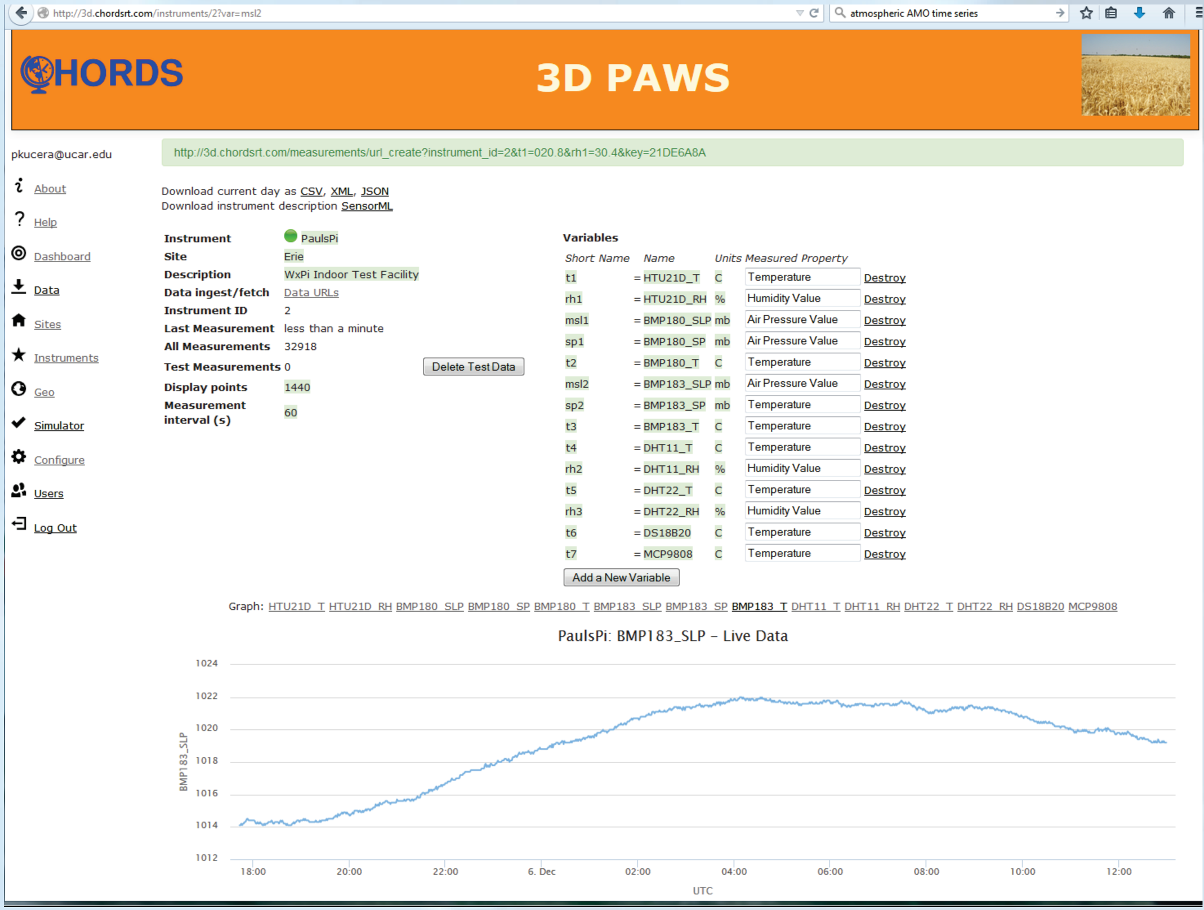


Open Data Access

Data are stored locally at each station
- 2+ years of data can be stored on local flash drive

Real-time Access:
- Web-data services (e.g., CHORDS)
- Local NMHS's
- GLOBE data services

Example: NSF EarthCube Initiative: CHORDS (**C**loud-**Ho**sted **R**eal-time **D**ata **S**ervices for Geosciences) data-portal



Example - PAWS Project Data Portal: http://3d.chordsrt.com

Hands-On Training

3D-PAWS Open-Source Project

https://sites.google.com/ucar.edu/3dpaws/home

3DPAWS

3D-PAWS

What is 3D-PAWS?

Many surface weather stations across the globe suffer from incorrect siting, poor maintenance and limited communications for real-time monitoring. To expand observation networks in sparsely observed regions, the 3D-PAWS (3D-Printed Automatic Weather Station) initiative has been launched by the University Corporation for Atmospheric Research (UCAR) and the US National Weather Service International Activities Office (NWS IAO), with support from the USAID Office of U.S. Foreign Disaster Assistance (OFDA).

Goals of the 3D-PAWS initiative:

- Build capacity to reduce hydrometeorology-related risk in developing countries

3D-PAWS Networks – Current Status

- More than 220 3D-PAWS have been installed 15 countries
- Extensive in-country training and knowledge transfer

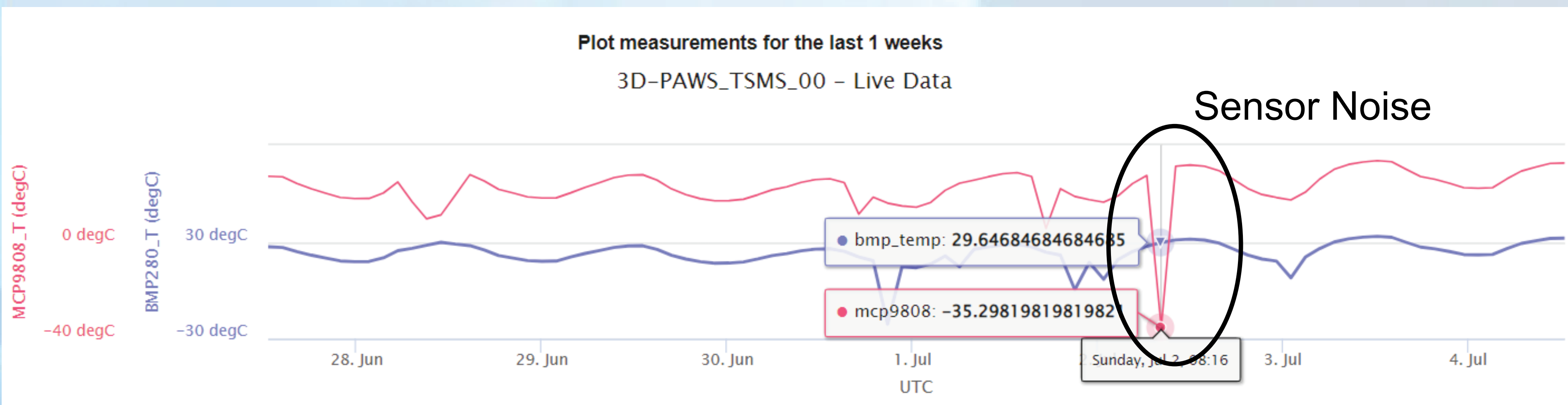
3D-PAWS Installations

- Bangladesh, Kenya, Uganda, Zambia, Senegal, US, Barbados, Curacao, Austria, Germany, Senegal, El Salvador, Turkey, France, Dominican Republic
- Planned: Zimbabwe

Challenges

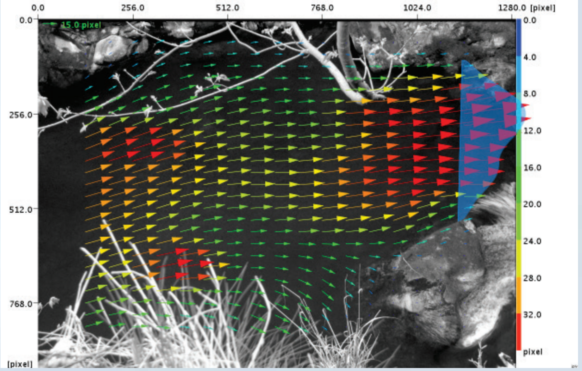
- Data quality/system reliability
- Communication
- Low power for long-term, remote deployments
- Lots of data!
    - 3D-PAWS in 15 countries
    - 220 stations deployed
    - 643 million observations recorded since 2021!

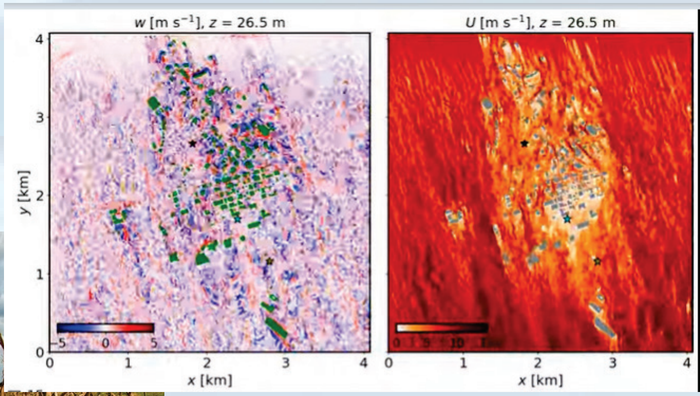
Measurements	Instruments	Sites	Storage	DB Expires	Uptime
642,897,934	95	73	unknown MB	2021-07-06	13 days



Opportunities

- Data reduction – only transmit useful information
- Prediction system maintenance – all environmental sensors need maintenance
- Image processing
- Early alert systems – provide community warnings
- Application driven local decision making
    - Agriculture
    - Smart City
    - Food Insecurity
    - Health monitoring (e.g., airborne diseases)





UN World Meteorological Organization: Early Warning for All

The "Early Warnings for All" initiative is an UN groundbreaking effort to ensure that everyone on Earth is protected from hazardous weather, water, or climate events through life-saving early warning systems by the end of 2027

Key Pillars:

- Disaster risk knowledge and management
- Detection, observation, monitoring, analysis, and forecasting
- Warning dissemination and communication
- Preparedness and response capabilities

- Only half of the countries worldwide report having adequate multi-hazard early warning systems
- Large gaps in the global observing system and warning capabilities necessary to hazards
- Early warning systems have proven to be a cost-effective and reliable way of protecting lives and livelihoods from natural hazards such as floods, heatwaves, storms, and tsunamis

UN World Meteorological Organization: Early Warning for All

Opportunities:

- Real-time decision support capabilities
  - Automated early-warning systems
- Reliable communication networks
- Quality control of observations (false alarms, missed events)
- Temporal and spatial integration of information to make smart decisions
- **Application of TinyML!?**

Early Warnings for All

Low-Cost Sensor Summary

- Low-cost observation networks provide innovative solutions to increase environmental monitoring capabilities
- Existing 3D-PAWS monitoring capabilities:
  - Atmospheric monitoring (T, P, RH, Wd, Ws, rain, solar)
  - Water level monitoring (stream, snow depth)
  - Air quality (Particulate Matter, gasses)
- Support environmental applications
  - Early Warning
    - Flash flooding
    - Storm surge inundation
  - Decision support
    - Water resource management
    - Agriculture

More Information:
Contact: Paul A. Kucera (pkucera@ucar.edu) or
Martin Steinson (steinson@ucar.edu)

3D-Printed Automated Weather Station (3D-PAWS)

Future Development

Thank You!

Contact: Paul A. Kucera (pkucera@ucar.edu)