Development of Innovative Technology to Provide Low-Cost Surface Atmospheric Observations in Developing Countries

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Introduction

- **Initial weather station development supported by USAID and NWS**
- **Build capacity to reduce hydrometeorology-related risk in developing countries**
- **Observe and communicate weather and climate information to rural communities**
- **Develop observation networks and applications to reduce weather related risk**

Surface Observation Network Challenge

- **Commercial automatic weather stations are limited in developing countries**
  - High cost limits the number of available sites
  - Maintenance and security issues
- **Low-cost commercial weather stations not viable**
  - Performance marginal
  - Components become obsolete
- **Vision**
  - Use 3D printers – inexpensive technology
  - Use low-cost, reliable micro-sensors
  - Design a system that that can be assembled locally at MET Offices or other local agencies
  - “Print and replace” components when systems fail
  - Enable local agencies to take ownership in building and maintaining observation networks

3D-Printed Automated Weather Station (PAWS)

Weather Station Sensor Platform

Data acquisition and processing: Raspberry Pi Single Board Computer (SBC)

Cost: $300-600

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

3D-Printed Automated Weather Station (PAWS)

Data acquisition, communication, and power system

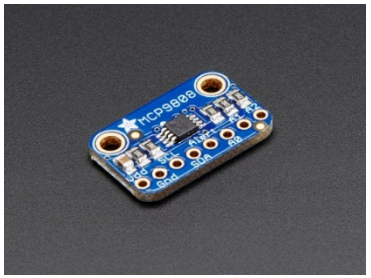
Precipitation Rate

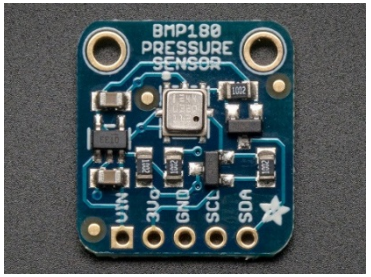
Wind Speed

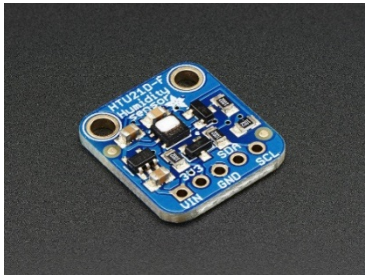
Wind Direction

3D-Printed Automated Weather Station (PAWS)

Radiation Shield and State Variables:
Pressure, Temperature & Humidity







Power and Communications

Commercial and solar power solutions

Direct network, wireless link, cell modem, and satellite modem communication solutions (GOES, METEOSAT)

3D-Printed Automated Weather Station (PAWS)

Component	Estimated Cost (USD)
Initial cost to build 3D Printed Weather stations (3D printer, tools, supplies)	3D Printer: 1500*3 ($4500)+ Tools (screw drivers, wire cutters, soldering iron): $200 Supplies (wires, connectors, solder): $100
Mounting Components (pipes, brackets, guy wires)	$100/site
Raspberry Pi and power cable	$60/site
Micro-sensors for temperature, pressure, humidity, wind, and precipitation	$75/site
3D Printed Plastic filament for instrument housing	$60/site
Power	Commercial Power: minimal cost Solar power/battery system: $200/site
Communications	Direction Connection: minimal cost Wireless USB: $15/site Cell Modem: $30/site* Satellite Modem: $100/site*

+We recommend purchasing three 3D printers at each MET Office to provide additional printing capability and backup resources

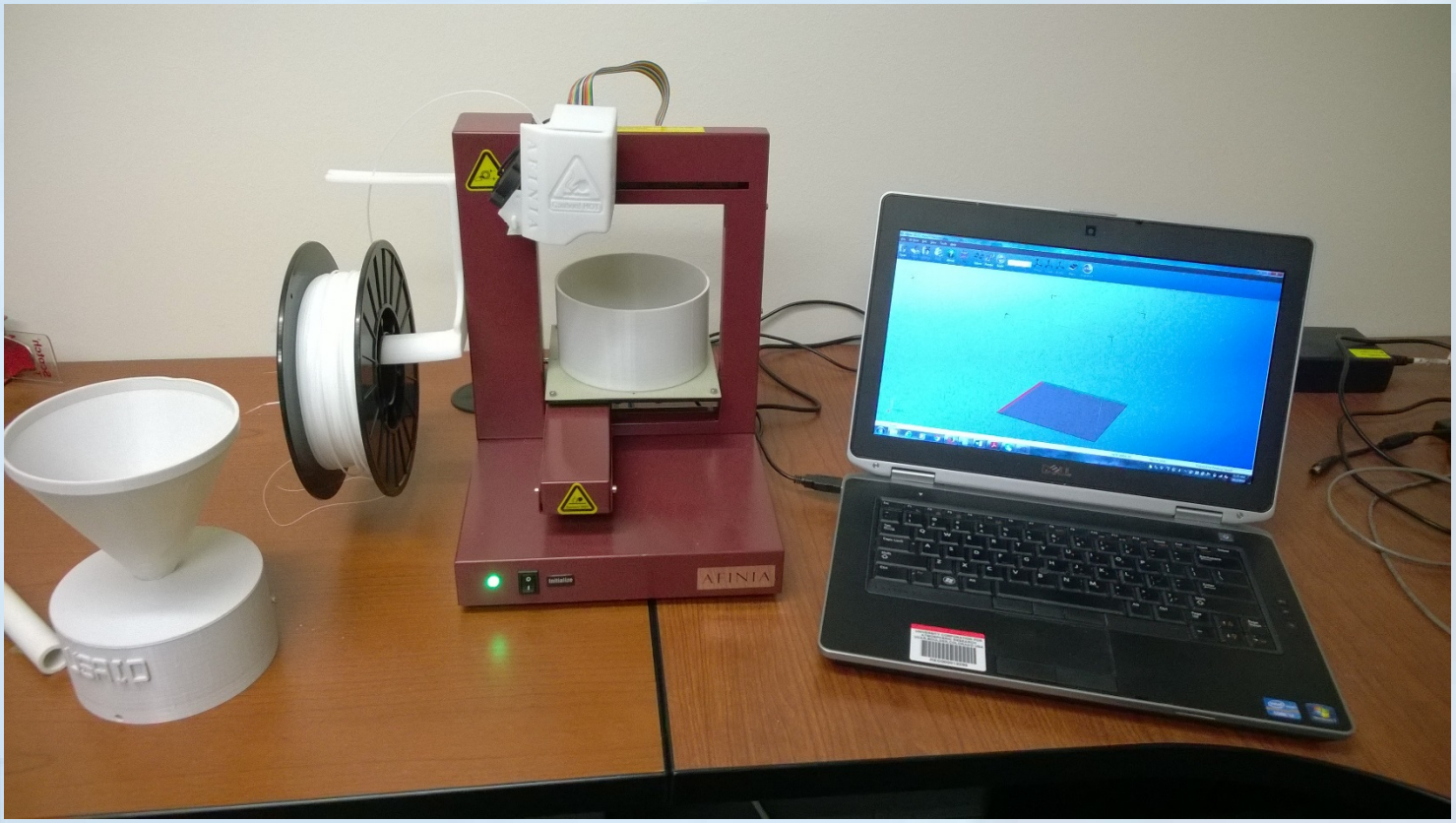
*The cost doesn't include the monthly or yearly service costs. The cost will be dependent on local service providers

3D-Printed Automated Weather Station (PAWS)

Summary	Estimated Cost (USD)
Initial Setup Cost for each local network	~$5000
Setup cost per station	$300 – 600 (dependent on power and communication options
Monthly communication costs per station	$0 - ~$30 (dependent on local service provider or satellite service)

Other costs and optional components
Desktop Computers/Data Storage for observation analysis and climate services archiving
Training of local personnel
Maintenance costs
Additional sensors in development: solar radiation, cloud cover, lightning detection, soil moisture and temperature, streamflow/stage, air quality

How to Make a 3D-Printed Weather Station?



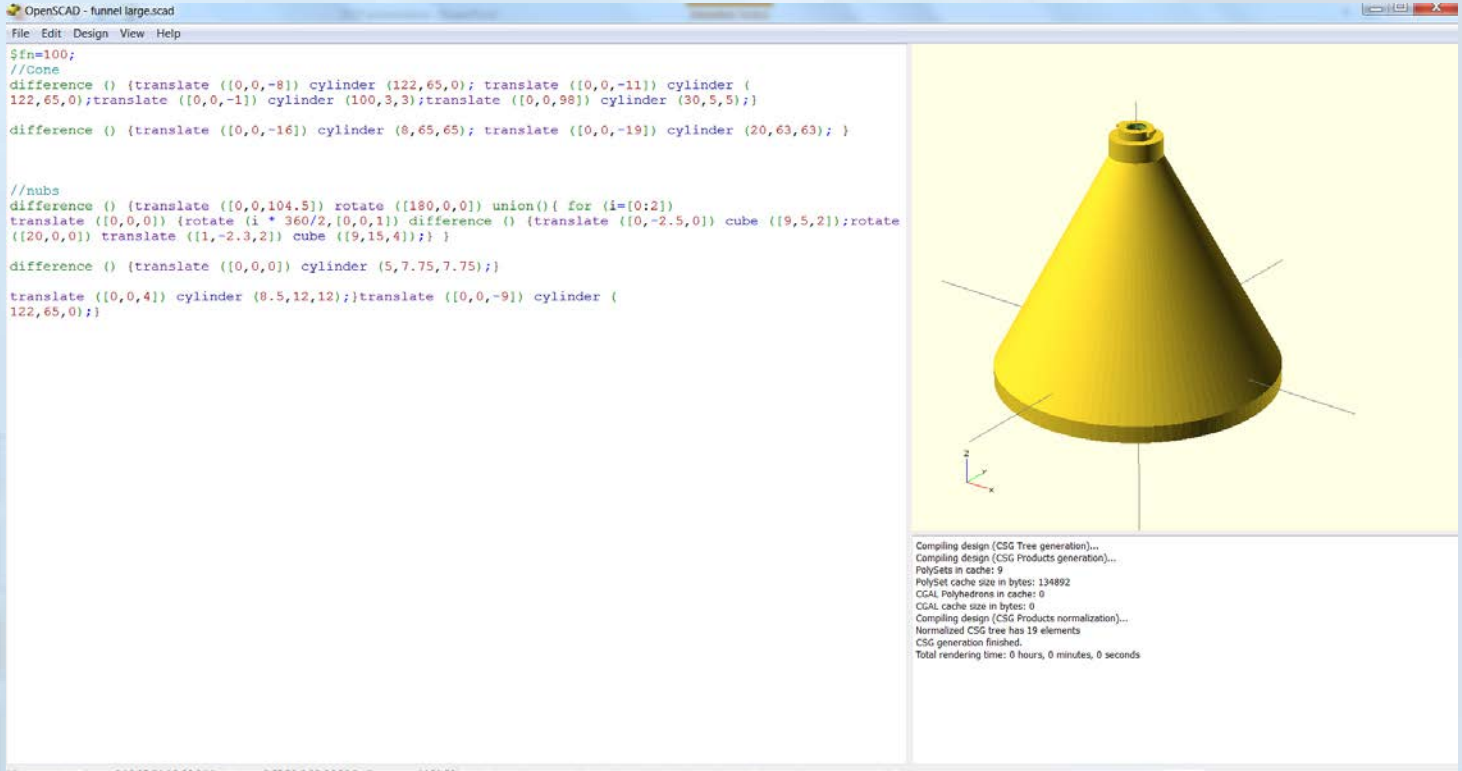
3D Printer, Plastic Filament and Computer Aided Drawing (CAD) Software

Filament Materials Tested

- **Acrylonitrile butadiene styrene (ABS)**
  - Better Detail
  - Easier to clean up
  - Example: Legos
- **Polylactic acid (PLA)**
  - Less detail
  - Tougher material
  - Biodegradable thermoplastic aliphatic polyester derived from renewable resources, such as corn starch
- **Conductive**
  - Early versions not very conductive
- **Soluble**
  - Early version not good

Computer Aided Drawing Engineering

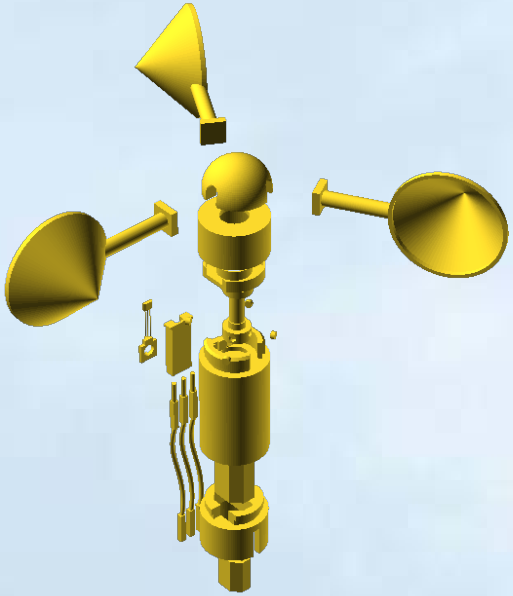
- **Open SCAD**
  - Free software, open source CAD software tools: **http://www.openscad.org**
  - Like a 3D compiler that reads in a script file



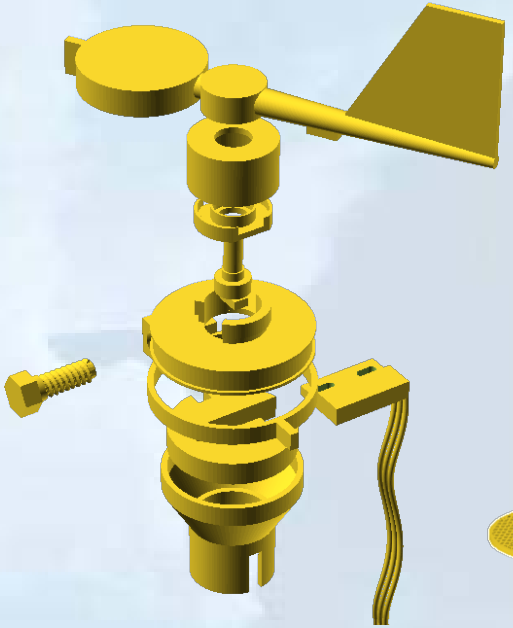
3D Printed Weather Station Component Designs

Precipitation

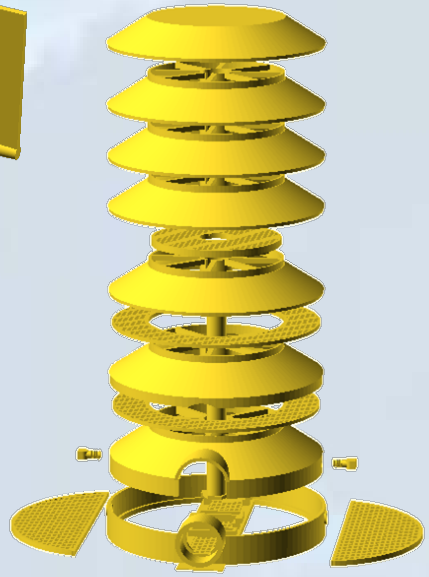
Wind Speed



Wind Direction

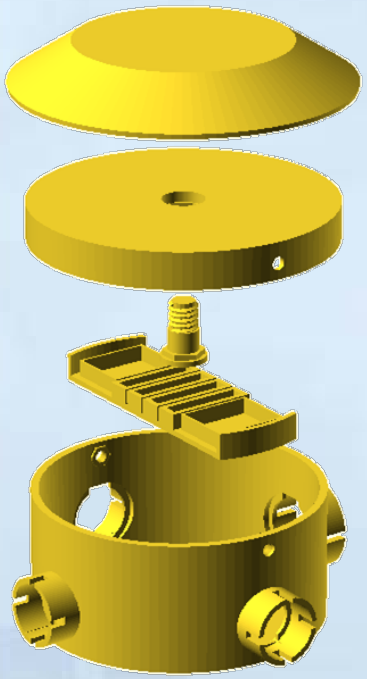


Radiation Shield

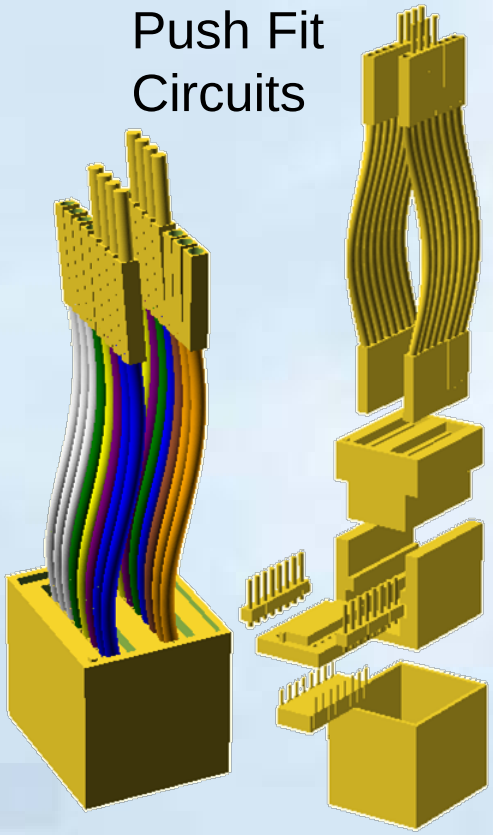


3D Printed Weather Station Component Designs

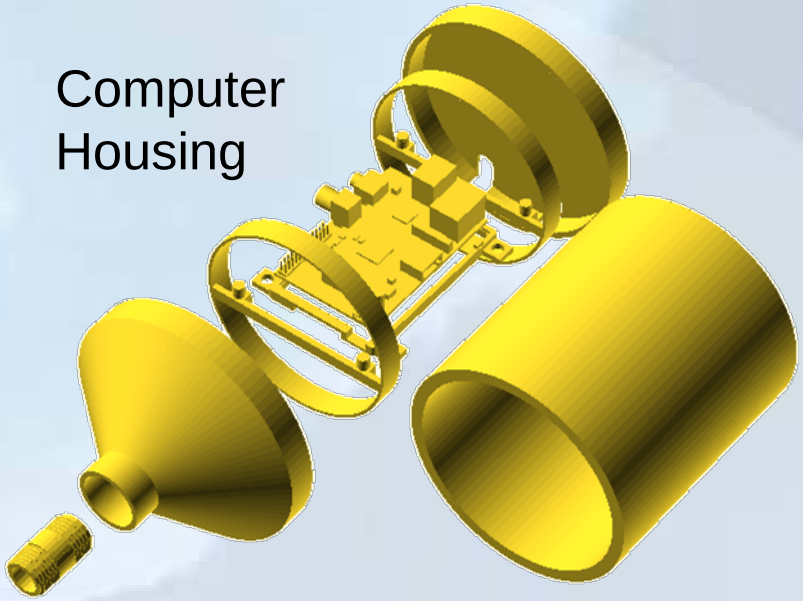
Junction Box



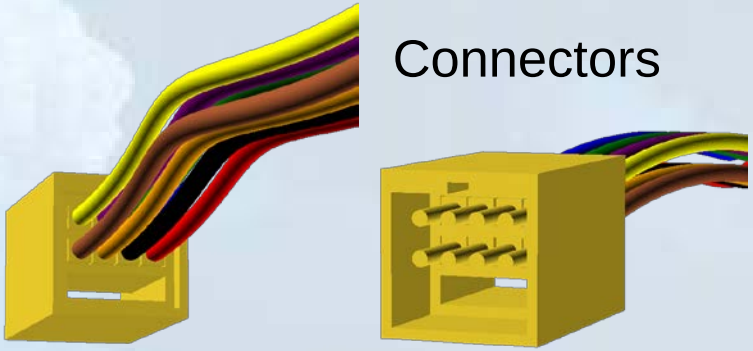
Push Fit Circuits



Computer Housing



Connectors

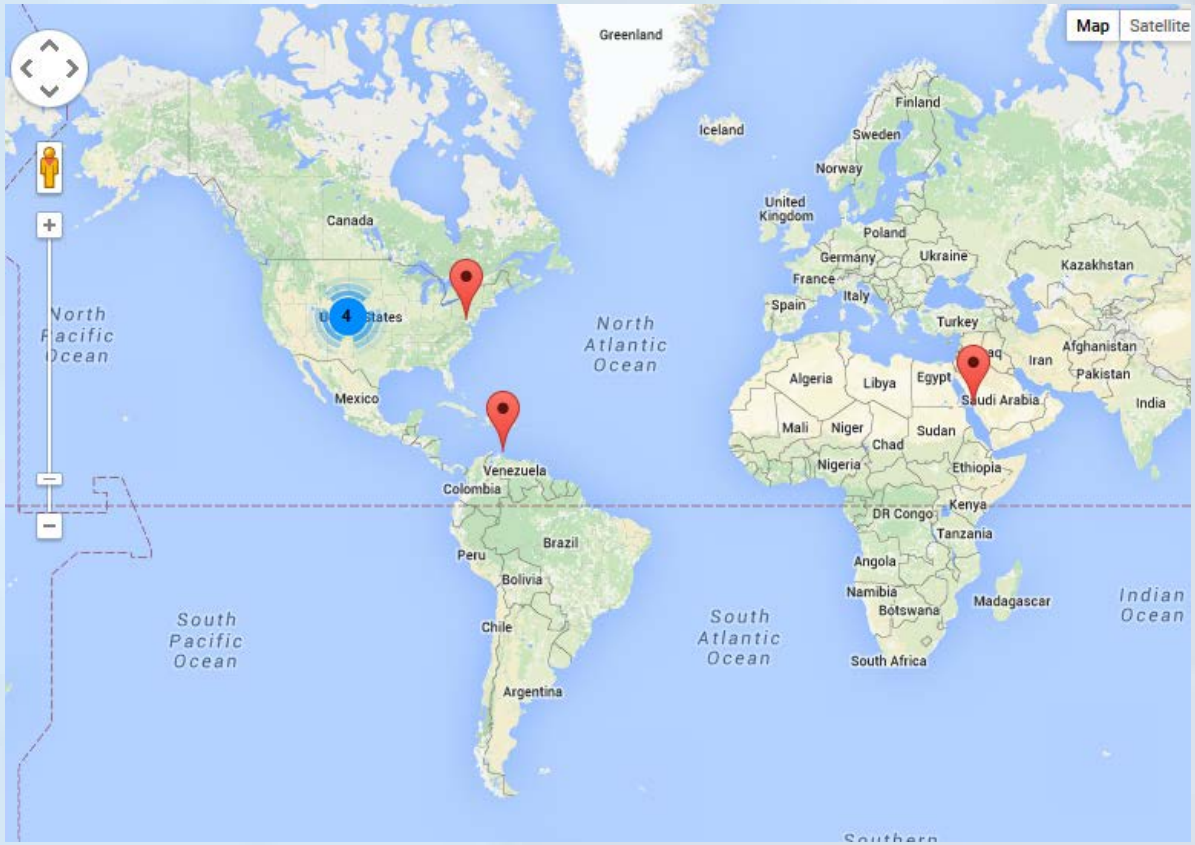


~100 components of the weather station are 3D printed

Testbed locations

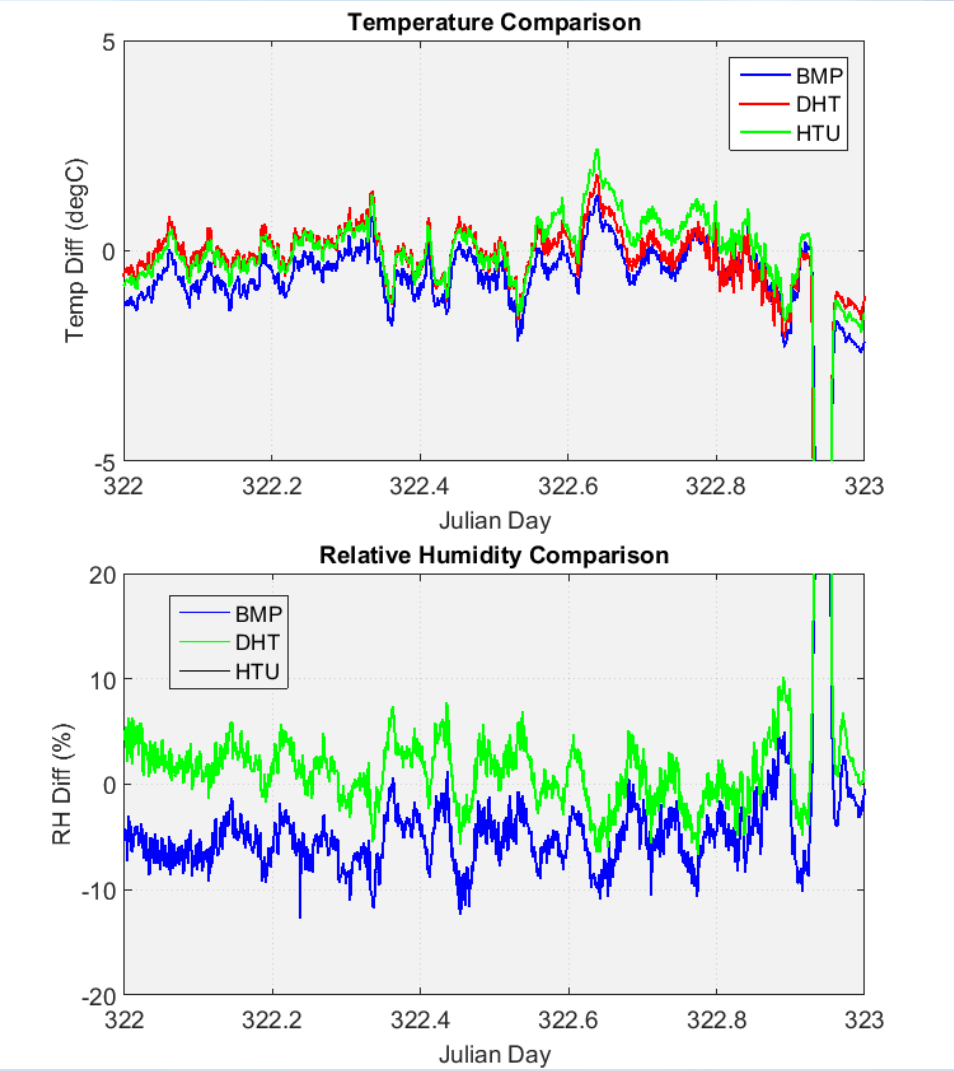
Current Testbed Sites:
- NCAR Marshall Test Facility on Boulder, CO
- NOAA Testbed Facility, Sterling, VA

Planned Deployments
- University of Iowa, Iowa City, Iowa (Spring 2016)
- Curaçao Met Department (Summer 2016)
- King Abdullah University of Science and Technology (KAUST), Saudi Arabia (Summer 2016)



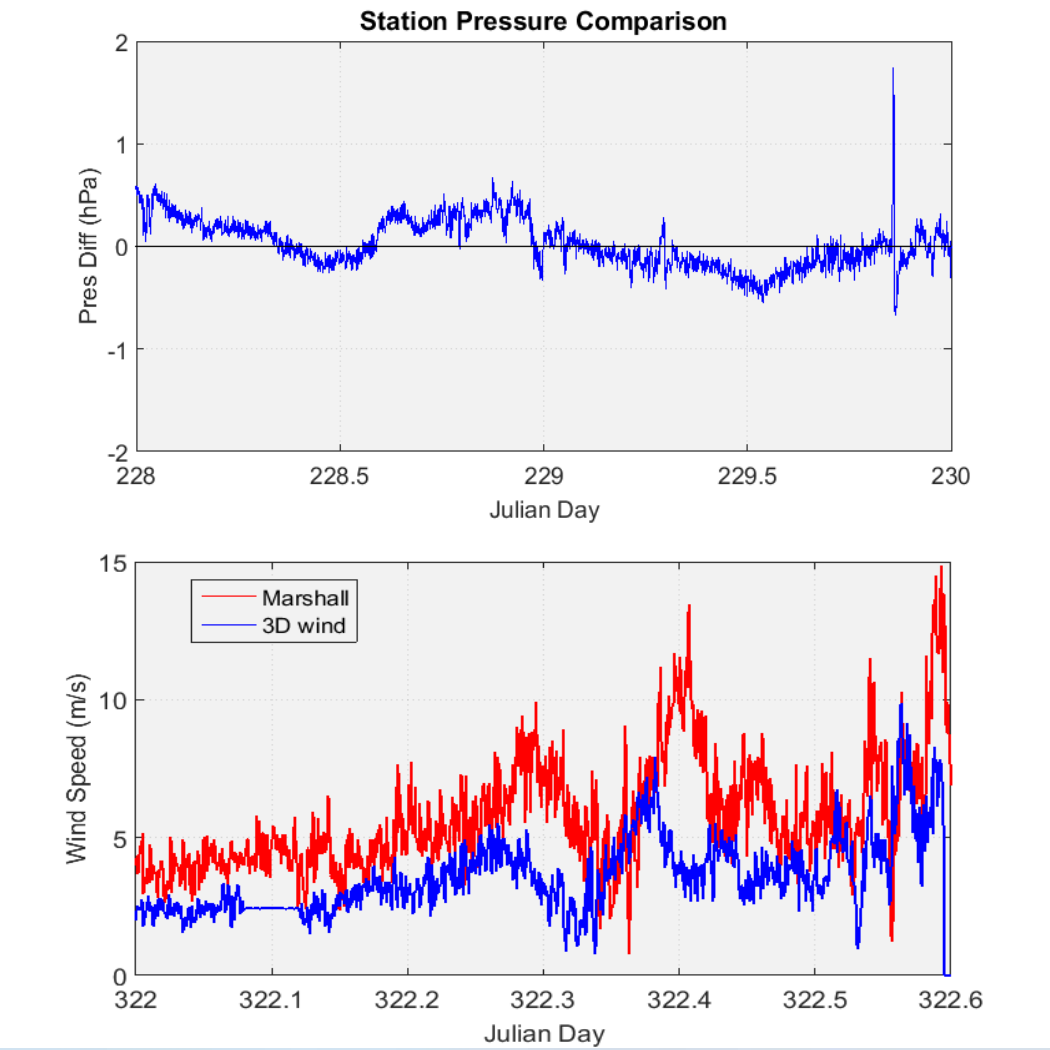
Prototype Evaluation – Initial Results

- Testing and evaluation is being conducted at NCAR and NOAA Testbed facilities
- Comparison of sensors with observation standards show reasonable results



Prototype Evaluation – Initial Results

- Good results from the pressure sensor
- Wind speed underestimation
- Good lab comparison of precipitation gauge

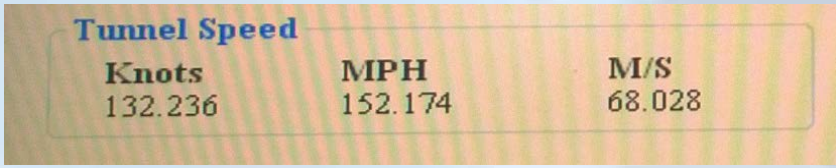


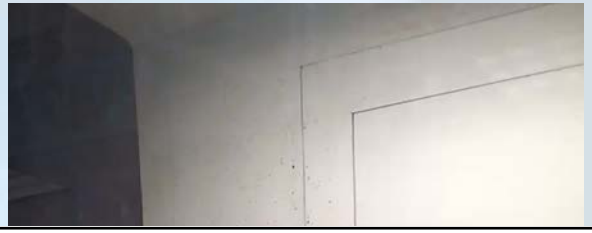
NOAA Testbed – Calibration and Evaluation Testing

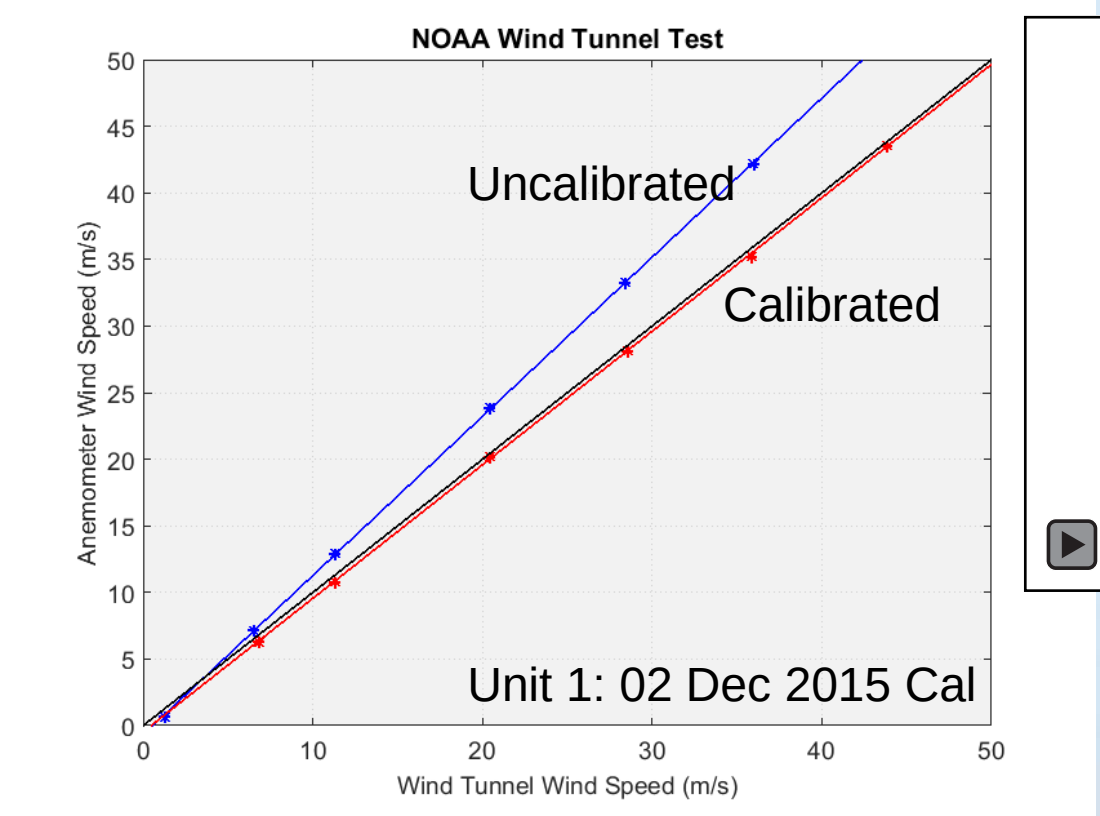
- **Sensors calibrated and evaluated testing at the NOAA Testbed in Sterling, VA**
  - Calibration
  - Failure conditions

NOAA Testbed – Calibration and Stress Testing

- **3-Cup anemometer was calibrated and stress tested in "hurricane force" winds**
- **Wind vane tested for stability**

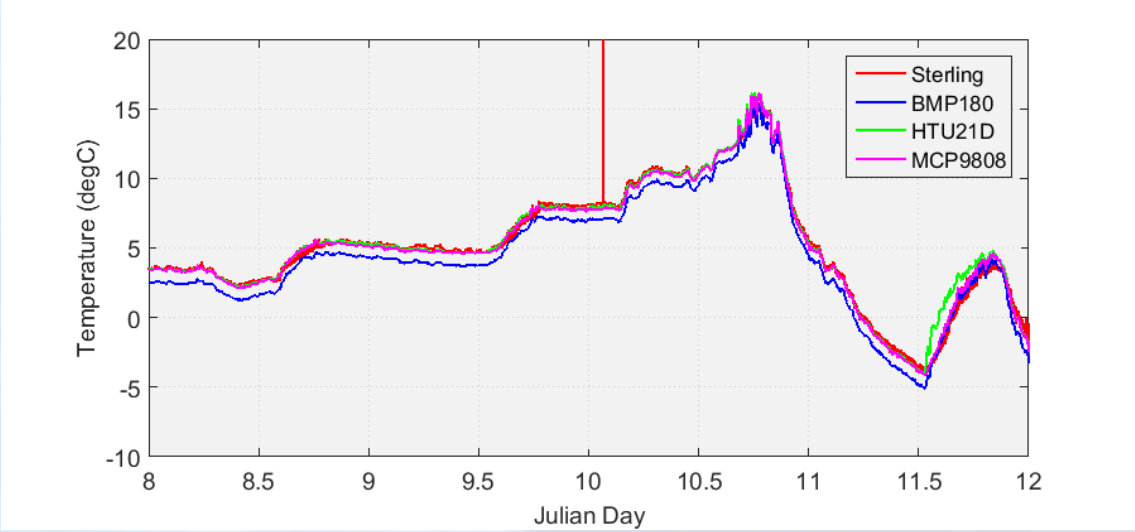


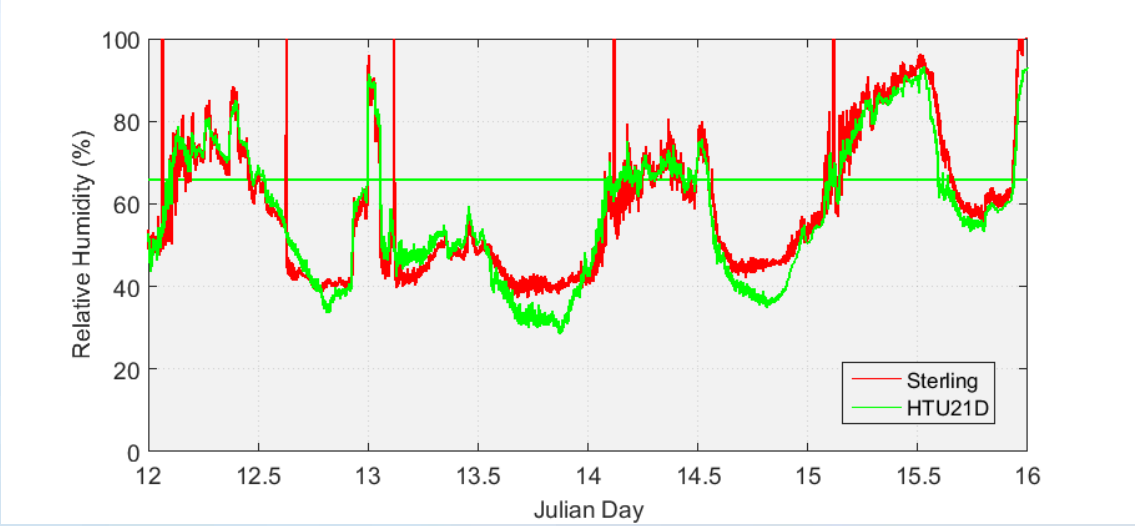




NOAA Testbed – Comparison Results

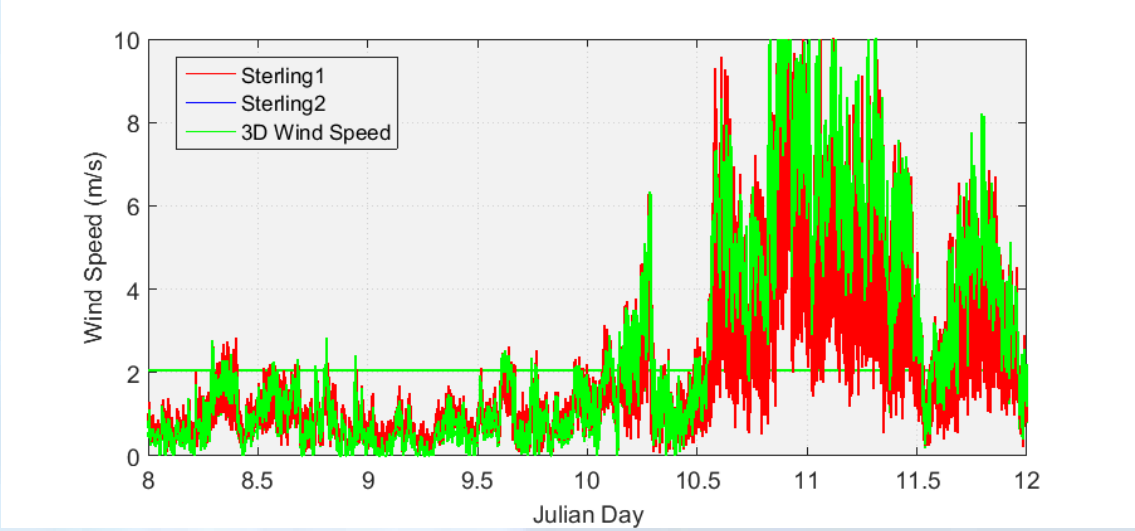
- Temperature well-matched with reference sensors
- Relative Humidity reasonable
  - Dry bias at lower humidity values

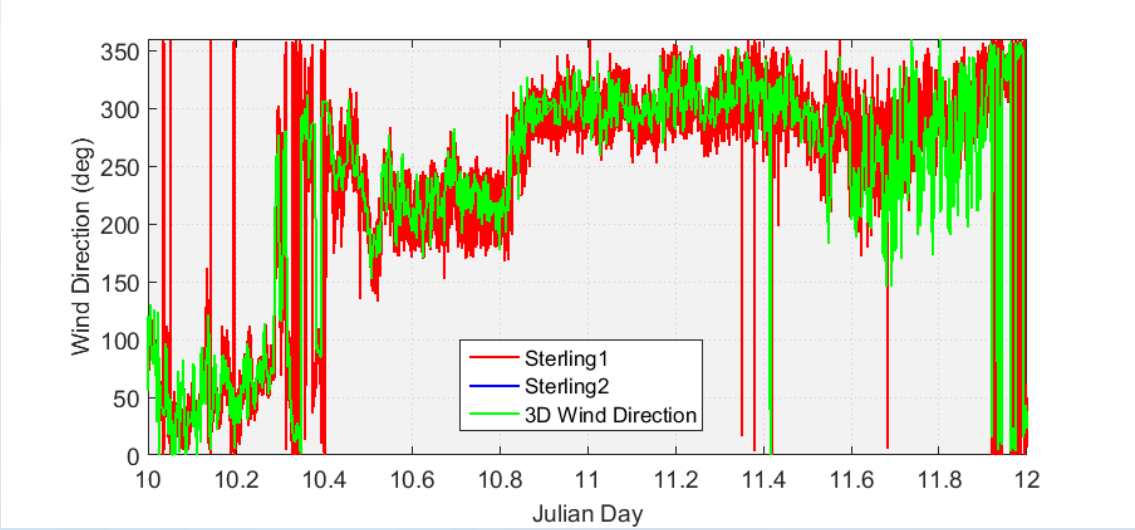




NOAA Testbed – Comparison Results

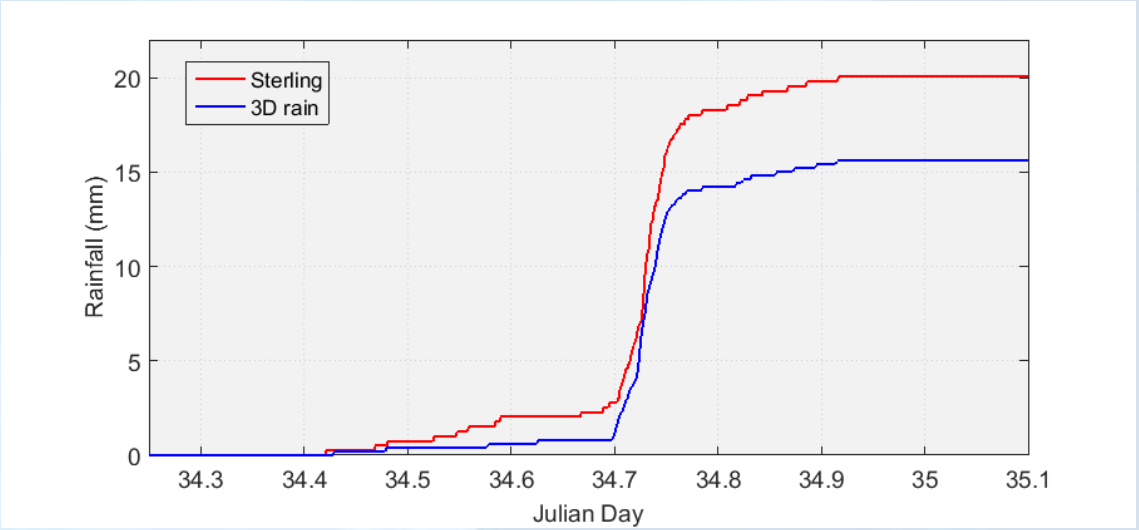
- Wind speed well-matched with reference sensors
  - Slower response at higher wind speeds
- Wind direction well-matched with reference sensor





NOAA Testbed – Comparison Results

- Underestimation in light precipitation conditions
  - Wind speed likely impacting measurements

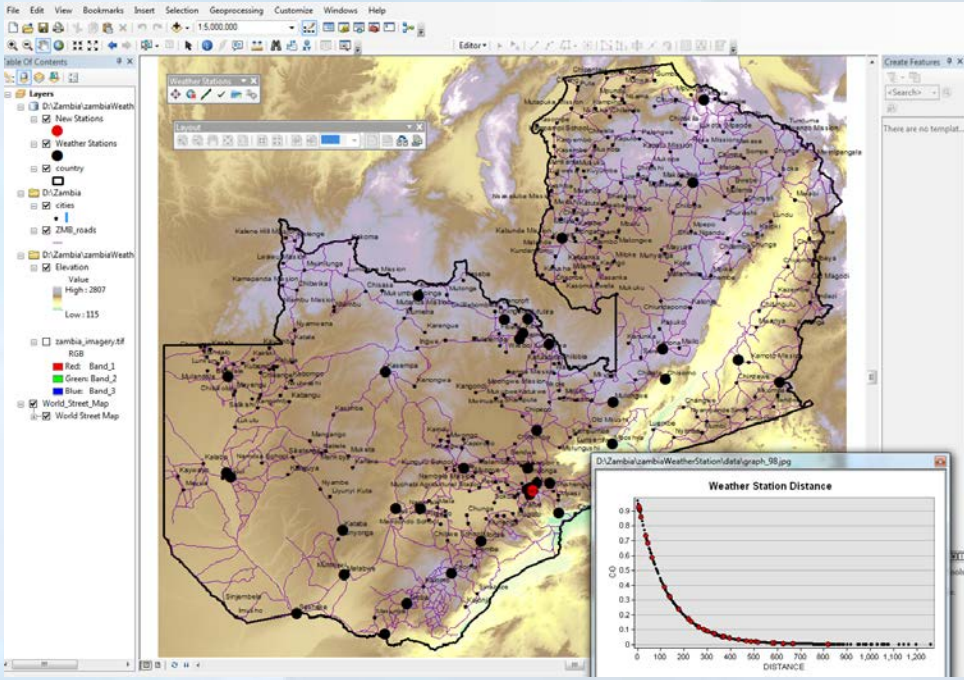


Surface Observation Network Design

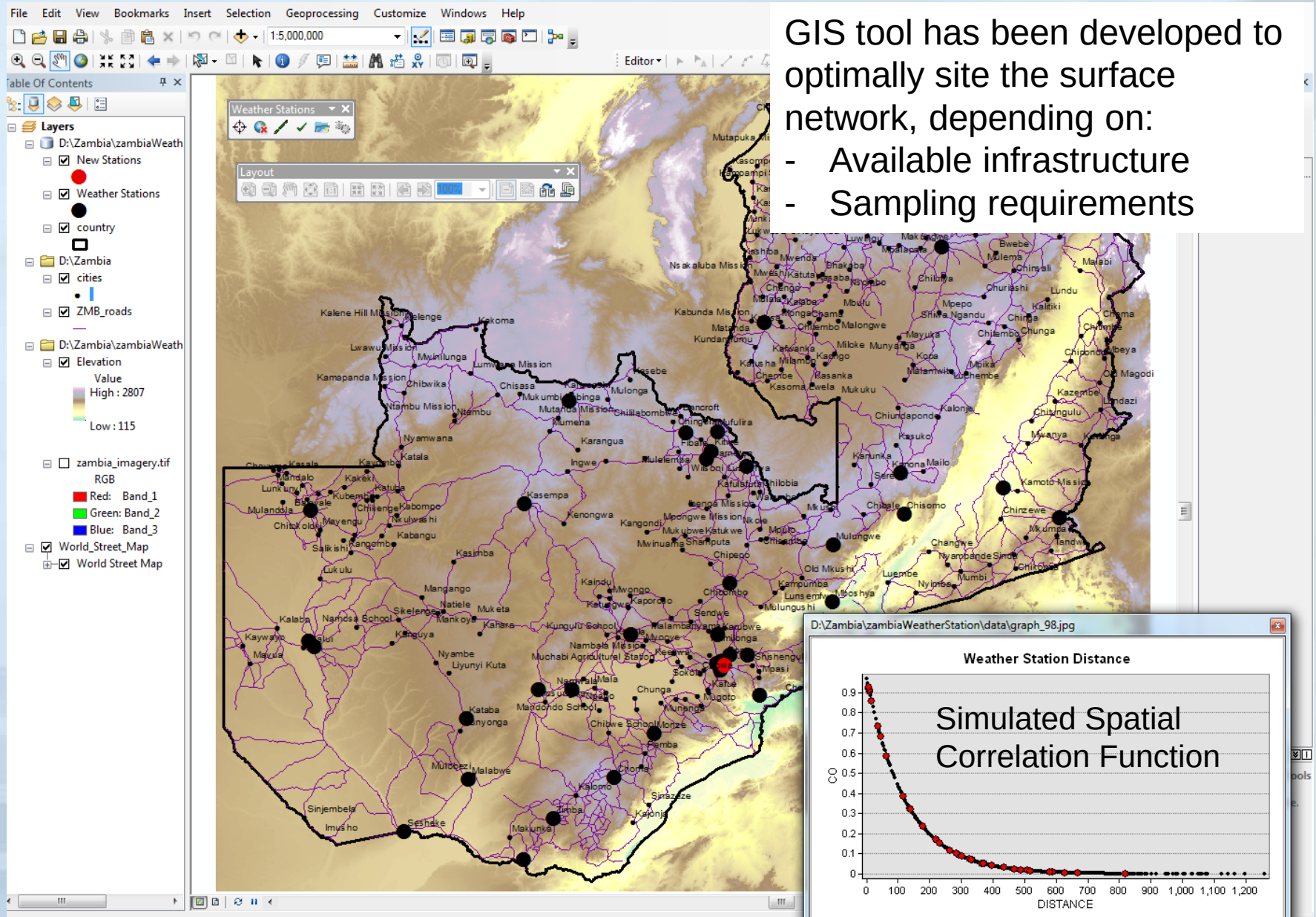
- **Evaluate the needs for hydrometeorological monitoring**
  - Short-term: early warning system (flash flooding, extreme heat)
  - Medium to long-term (health, water resources, agriculture)
- **Supplement existing networks**
- **Site selection factors:**
  - Land-surface/land-use conditions: complexity of the terrain, farmland, urban, park land
  - Accessibility: roads, secure locations, communication networks
  - Application requirements: monitoring near population centers, rivers, or other critical monitoring regions
- **Hydrometeorological considerations**
  - Daily to seasonal variability

Surface Observation Network Design

- **Network site selection criteria:**
  - Critical observation regions (input from local MET Offices)
  - Good sampling locations (away from trees, fences, building, etc.)
  - Secure locations
    - Schools
    - Fire stations
    - Radio stations
    - Private farms
    - Hotels
    - Government facilities
  - Accessibility
  - Communication and power
- **Network development using Geographical Information Systems (GIS)**



GIS Tool: Example Network in Zambia



GIS tool has been developed to optimally site the surface network, depending on:

- Available infrastructure
- Sampling requirements

Data Access

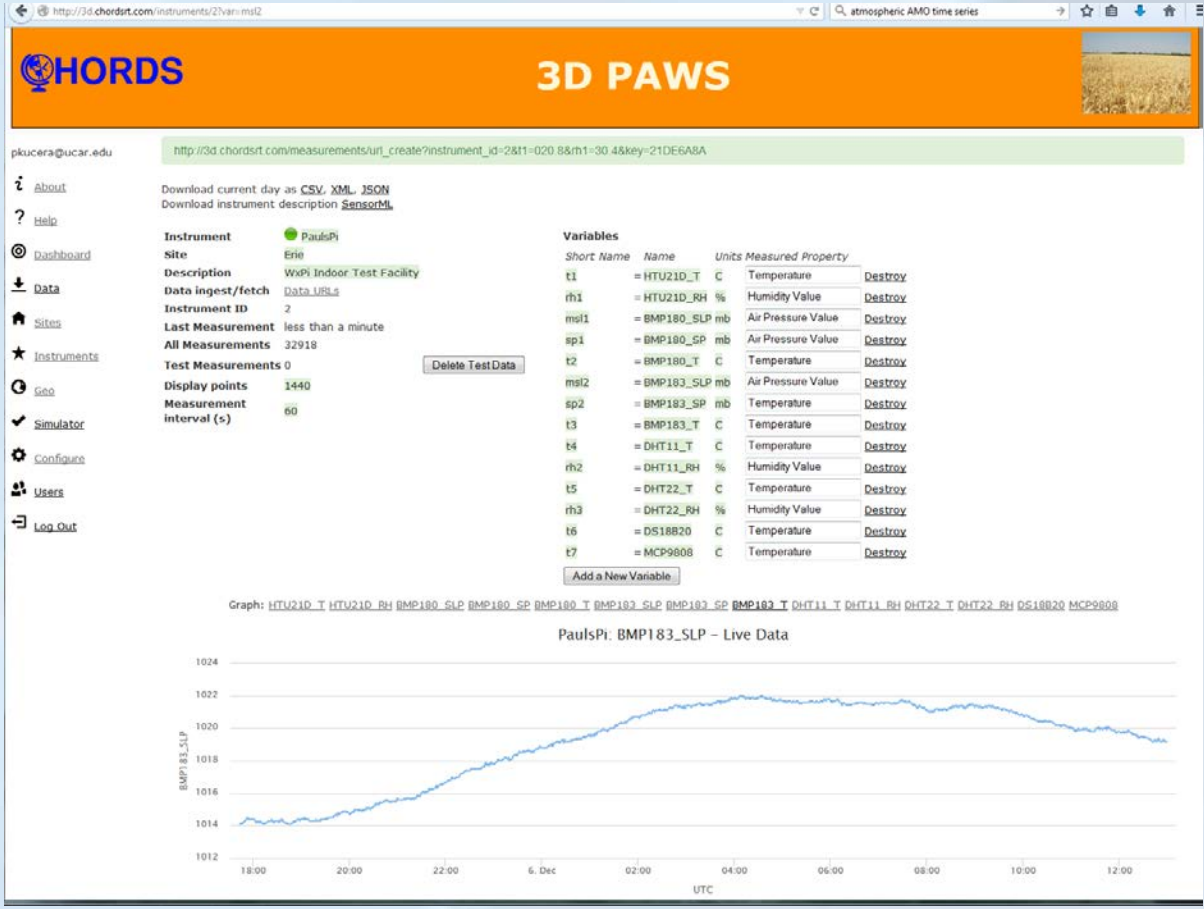
Data are stored locally at each station

- 1+ years of data can be stored on local flash drive

The goal is to make data accessible in real-time:

- Web-data services (e.g., CHORDS)
- Local HydroMet Office climate data services
- Internet of Things (IoT) data platforms (e.g., ThingSpeak)

Example: CHORDS (**C**loud-**Ho**sted **R**ealtime **D**ata **S**ervices for Geosciences) data-portal setup at NCAR

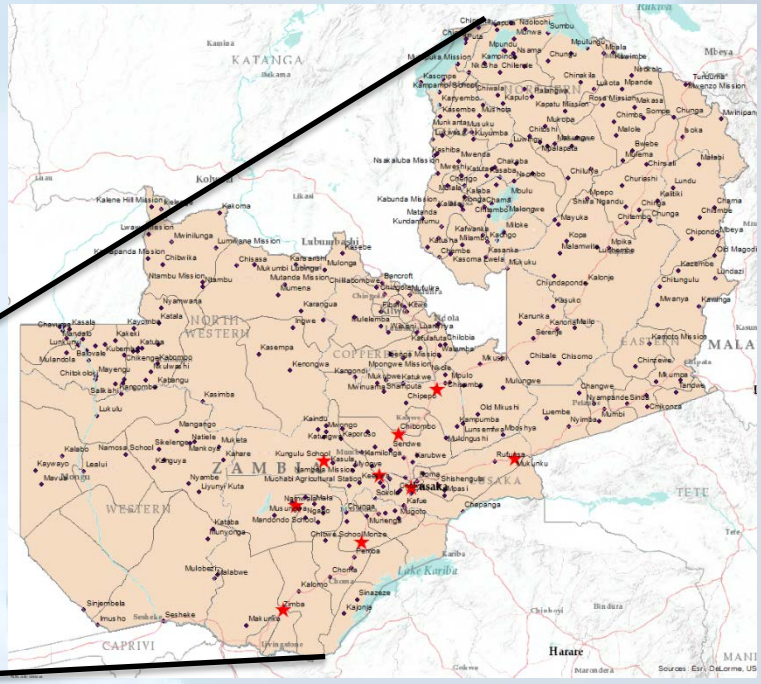


Example - PAWS Project Data Portal: http://3d.chordsrt.com

Network Deployment Strategy

- **Initial visit with in-country HydroMet Office or Agency**
- **Development of initial network using GIS and input from local experts**
- **Site Survey to identify locations**
- **Initial development and training on AWS setup**
- **Full development, transfer of technology, training to build instruments**
  - Provide 3D printers, sensors, communication equipment to deploy and maintain network for 3+ years
- **Database and application development, integration of network into operations**
- **Maintenance and systems upgrade**

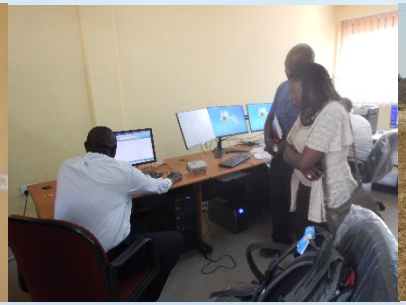
First International Deployment - Zambia



- **Build upon an ongoing early warning project**
- **Extend the observation network**
- **Develop new decision support applications**

First International Deployment - Zambia

- **Partnered with the Zambia Met Department**
- **Site survey – September 2015**
- **First site deployment – February-March 2016**
- **Expanded network – August-September 2016**
- **Integration into applications – Year 3**
- **Planned project duration – 5 years**
- **Expand to other data sparse regions: Caribbean, Pacific Islands, Asia, and other African regions**

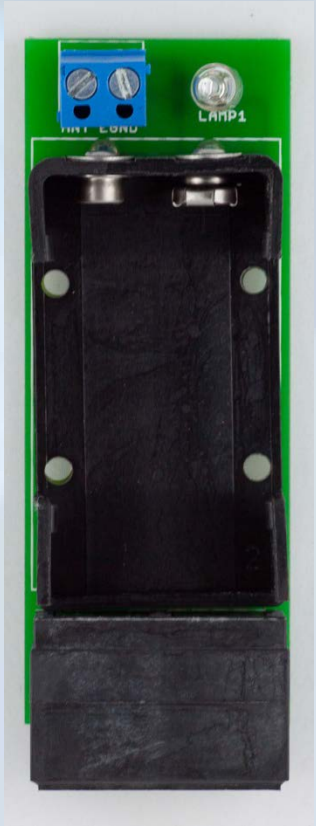


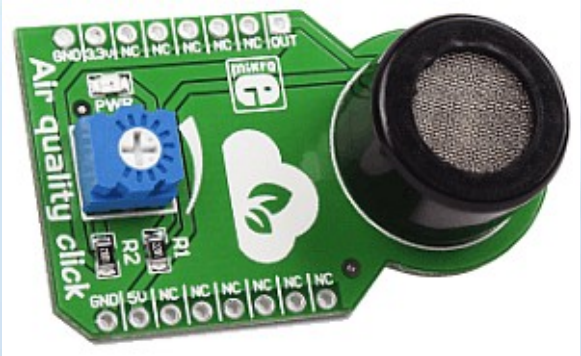
Application Development

- **Integrate data from observation network into regional applications**
  - **Regional Forecasting with the implementation of a WRF-data assimilation system**
  - **Early Alert Systems**
    - **Flash flooding**
    - **Severe weather**
  - **Regional decision support systems**
    - **Health**
    - **Agriculture**
    - **Water management**

New Sensor Development

- **Planned**
  - Soil moisture/temperature
  - Solar radiation
  - Streamflow/stage
- **Future**
  - Visibility
  - Lightning
  - Air quality (Ozone, NOX, SOX, VOC, etc.)





Expanding the Global Observation Network

- **Uganda - National Early Warning System for Crop Conditions and Disaster Risk Monitoring**
- **Caribbean Institute for Meteorology and Hydrology**
- **US – Education and Outreach, cooperative networks**
- **World Bank International Development Programs**

Thank you