# Mold Growth, Allergy and Asthma Risk in The Residential Buildings in The Aftermath of Hurricanes


Ebrahim Ahmadisharaf, PhD



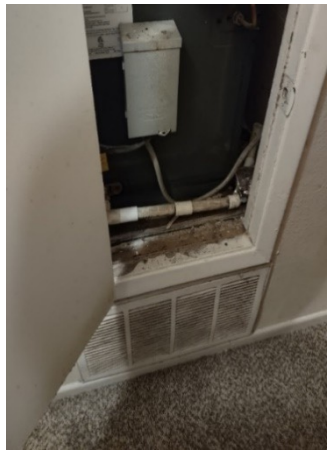
**FAMU-FSU**

**College of Engineering**

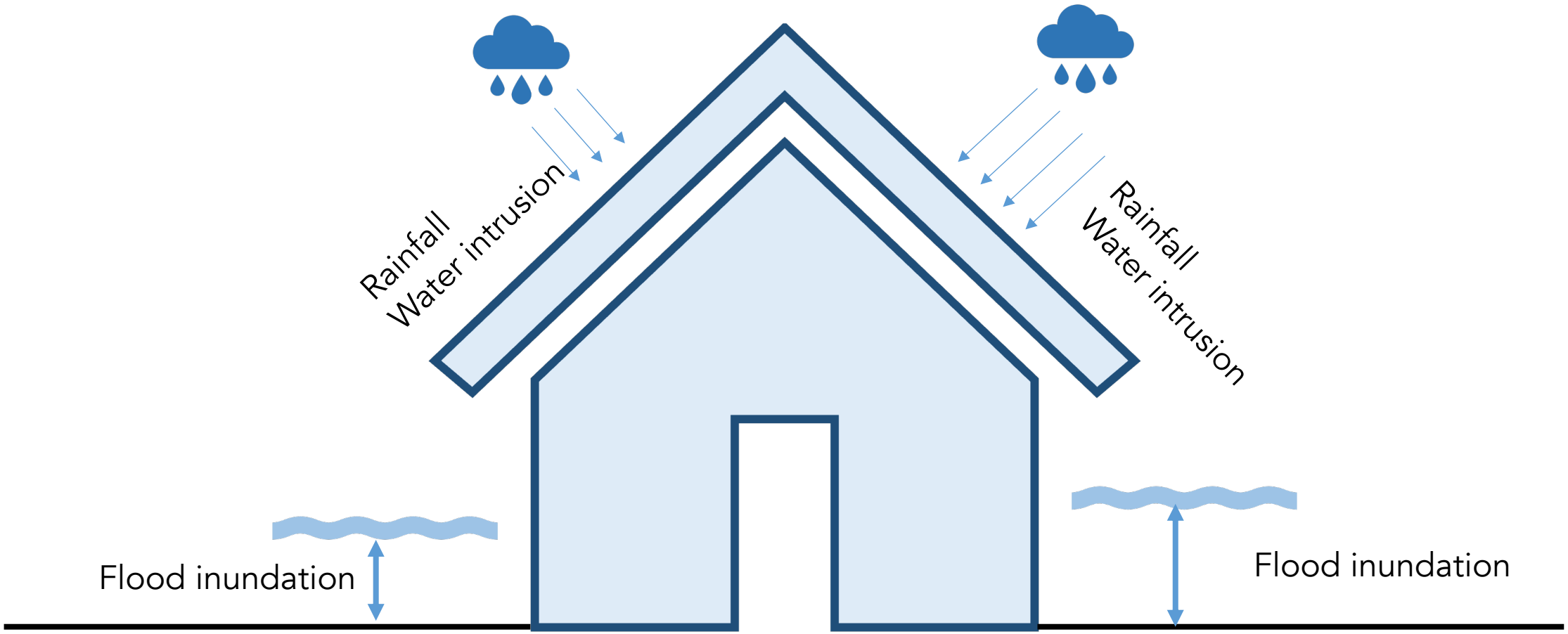

# Overview & Significance

*Direct impacts*

*Indirect impacts*



# Problem


Rainfall
Water intrusion
Rainfall
Water intrusion
Flood inundation
Flood inundation

# Knowledge Gaps & Objectives

Floods & water intrusion

Flood, Human behavior & Building properties

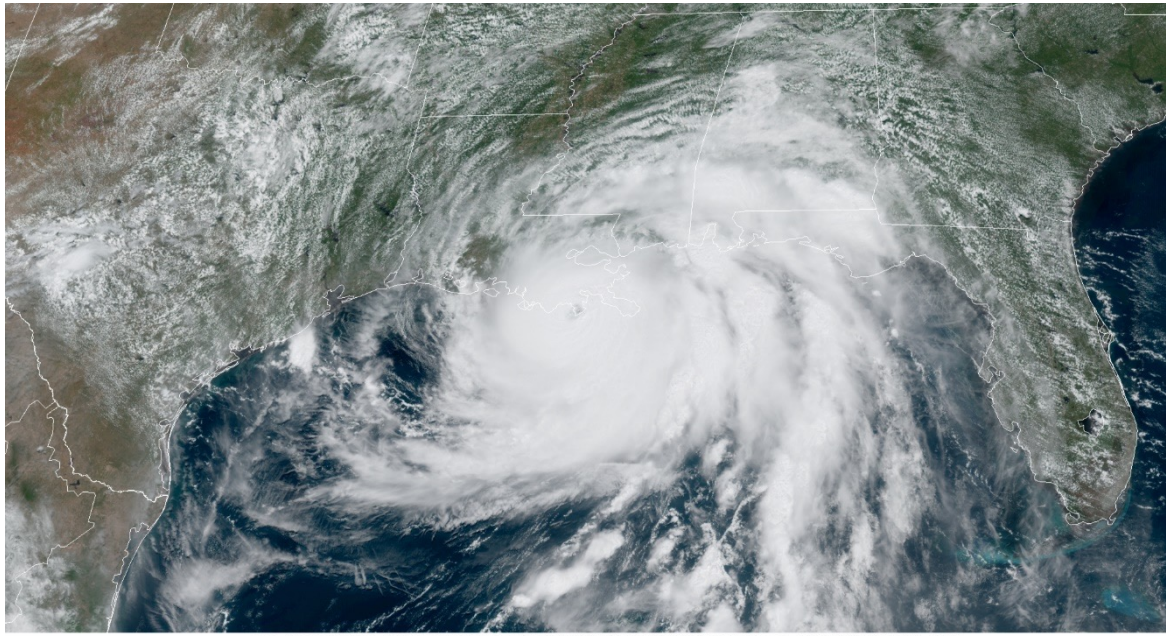
Short-, Mid- and long-term Impacts of Floods

Mold Growth

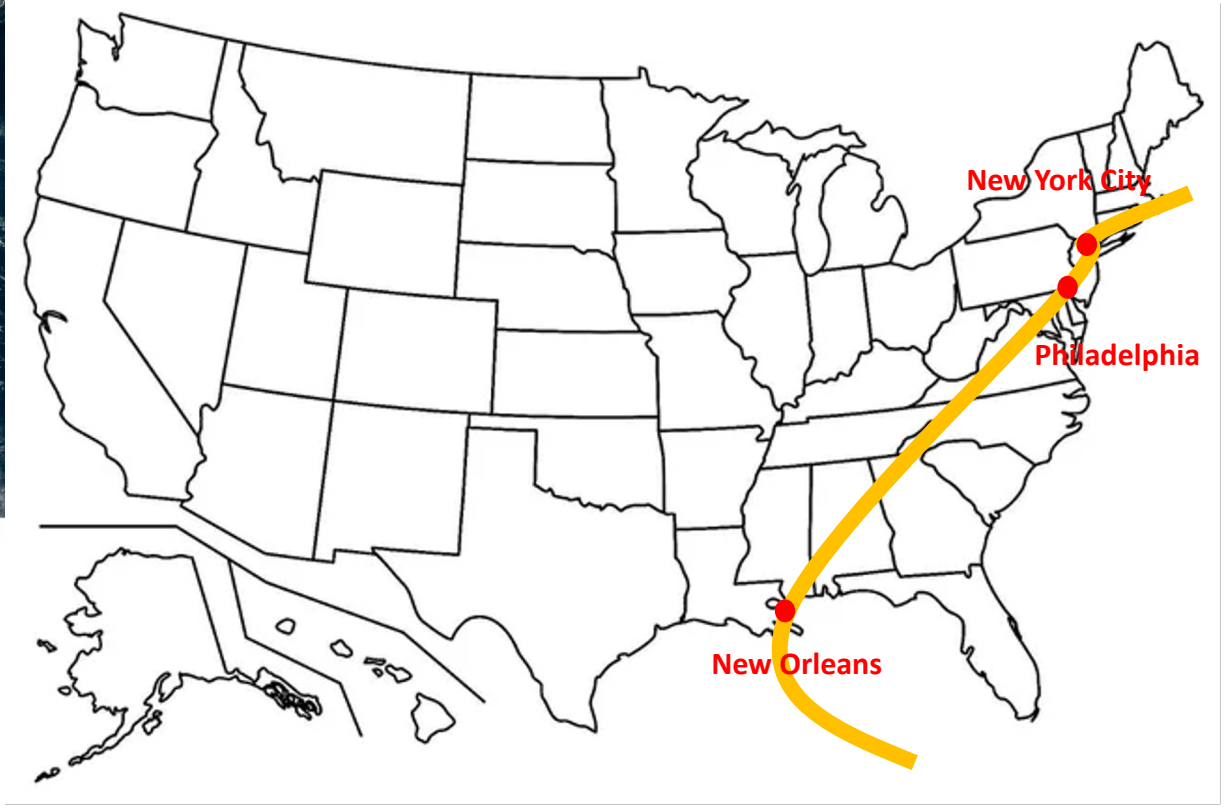
Allergy

Asthma

# Case Study: Hurricane Ida



29 Aug 2021 17:01Z NOAA/NESDIS/STAR GOES-East ABI GEOCOLOR



# Outline

- Recruiting Volunteers
- Home Inspections
- Laboratory Experiments
- Flood Modeling
- Relationship Analyses

# Recruiting Volunteers

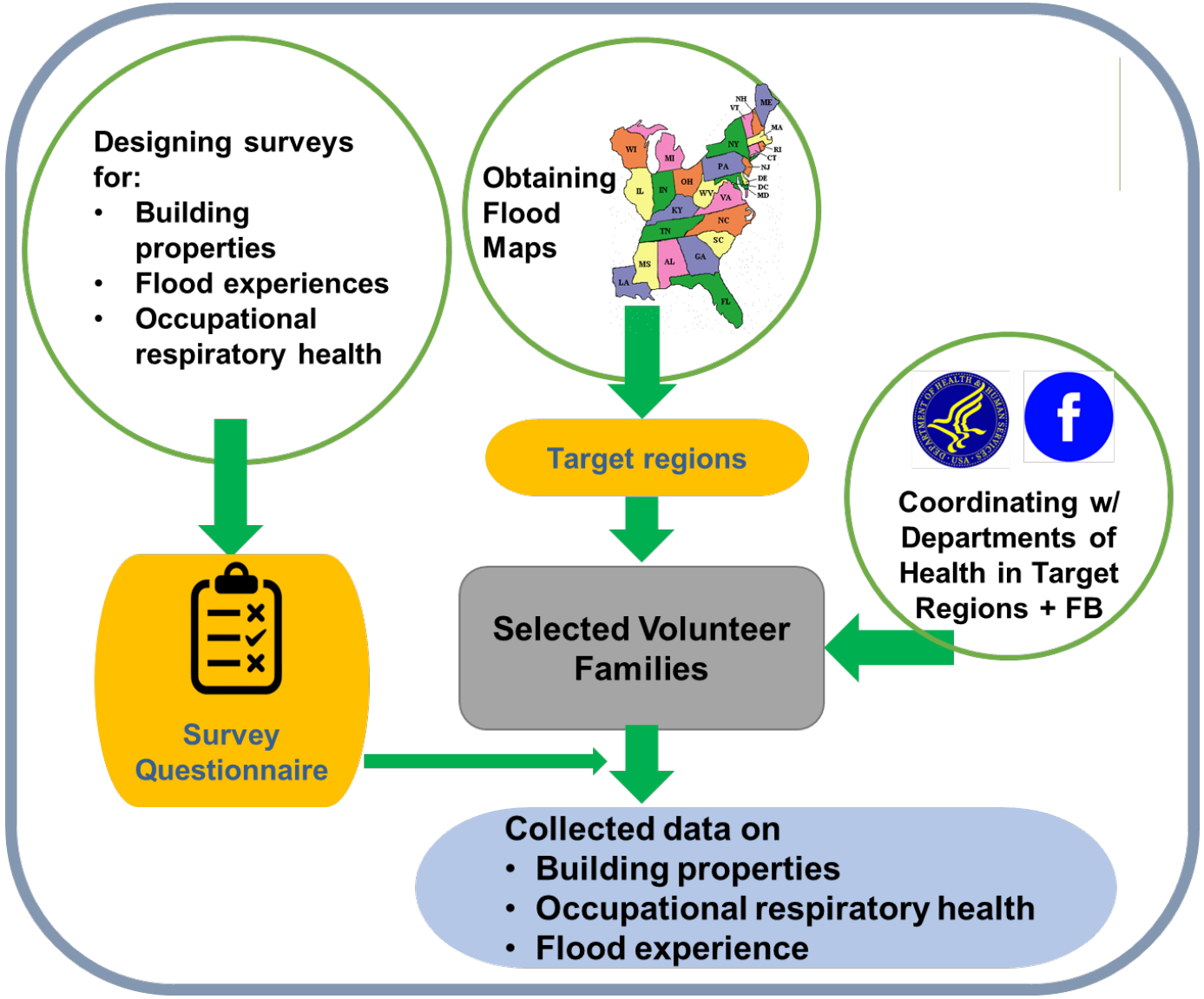
# Data Collection

**Recruiting volunteers and preliminary survey:**

- Social media
- Working with LSU's cooperative extension, NGOs, clinics, hospitals and faith-based organizations
- Collaboration with State government

**Collected data:**

- Survey questionnaire from volunteers included:
  - respiratory health of family members
  - building and HVAC characteristic
  - experience of rainfall and flooding



# Recruiting Approach & Criteria

- Affected by Hurricane Ida
- Not necessarily major impacts
- Control samples
- Homeowners
- Presence of smoking members
- Intervention after the hurricane
- Variety of volunteers

- Preliminary survey


OFFICE FOR HUMAN SUBJECTS PROTECTION

# Home Inspections

# Home Inspections

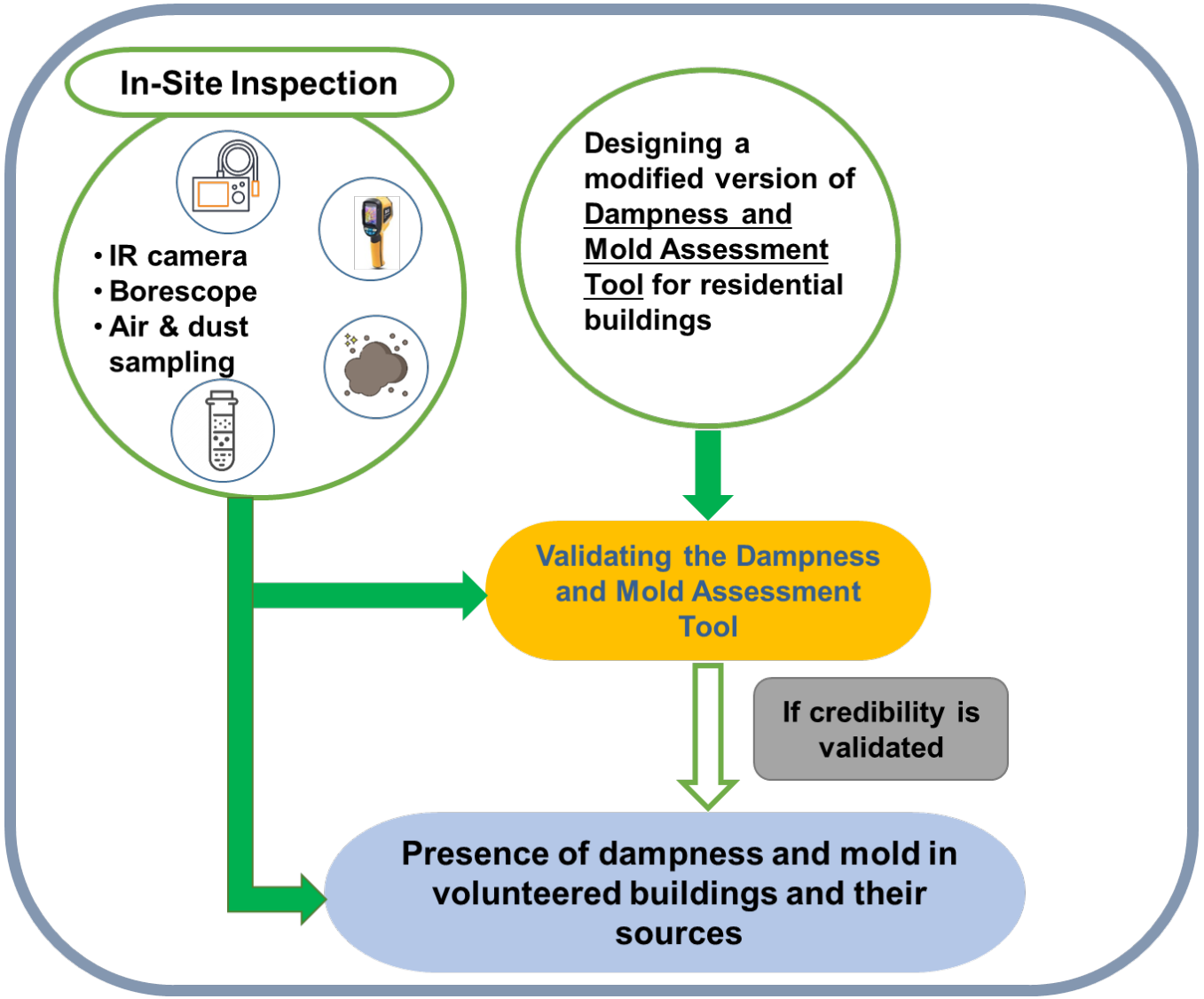
**For evaluating the presence of mold and dampness in buildings we performed:**

<u>In-site inspection</u>

- Dampness (IR camera)
- Air and dust sampling (mold presence)
- Ventilation rate (blower door test + exhaust fan air flow meter)

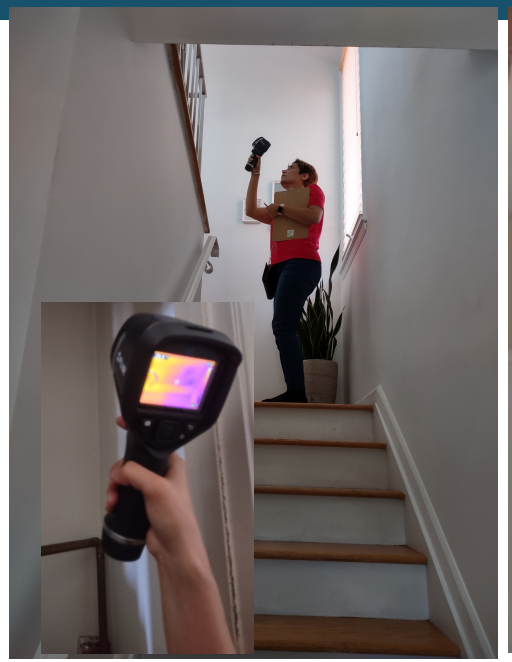
**Dampness and mold assessment tool**

- Damage (chipping paint/wallpaper - cracks – deformation)
- Stains (yellow/orange spots/area)
- Visible mold (gray-brown-black spots/area)
- Wet/dampness (condensation, water leaks – flooding)



# Home Inspections

1. Visual mold and dampness assessment (w/o any device)
2. Professional mold and dampness assessment (w/ IR Camera)
3. Air sampling for mold (sent to a certified lab)
4. Surface sampling for mold (sent to lab)
5. Blower door test for measuring the ventilation
6. Exhaust fan airflow measurement



# Comprehensive Survey

- General information (name, address, gender and race)
- Respiratory health and medication use (before and after)
  - Respiratory complications (e.g., asthma and Bronchitis)
  - Frequency of visiting doctors
- Occupational behavior and building characteristics
  - Time spent at home and smoking habits
  - Building and HVAC system characteristics
    - Roof, insulation and foundation types
    - Number of rooms receiving direct sun light
    - HVAC system type/control
    - Use of humidifier/dehumidifier
- Water damage control and experience
    - Location and extend of water damage/intrusion
    - Control measures before/during/after hurricane

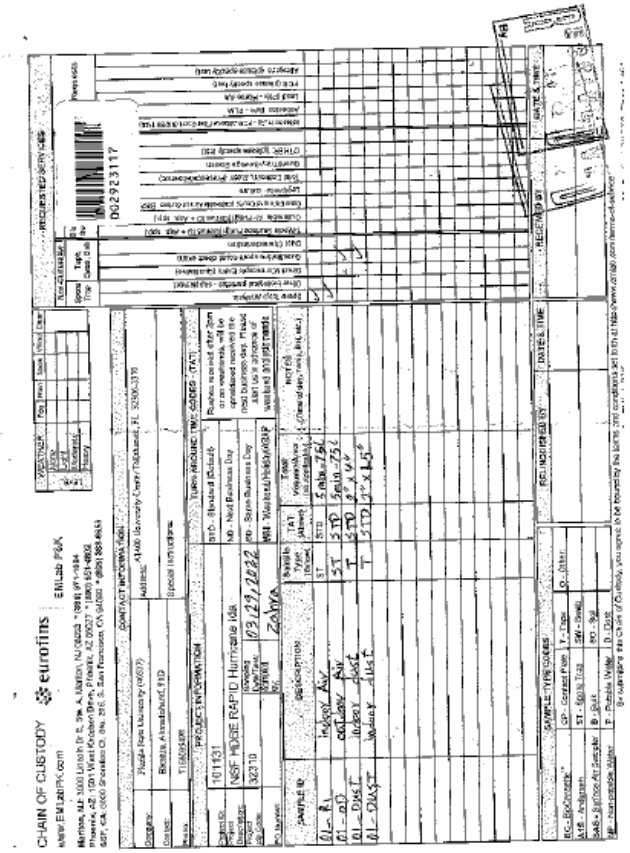

OFFICE FOR HUMAN SUBJECTS PROTECTION

qualtrics XM

# Laboratory Analyses

# Laboratory Analyses

eurofins | EMLab P&K



**Eurofins EMLab P&K**
1815 West Diehl Road, Suite 800, Naperville, IL 60563
(866) 871-1984 Fax (856) 334-1040 www.emlab.com

Client: Florida State University
C/O: Ebrahim Ahmadisharaf, PhD
Re: 101131; NSF HDBE RAPID Hurricane Ida

Date of Sampling: 03-29-2022
Date of Receipt: 05-10-2022
Date of Report: 05-12-2022

**SPORE TRAP REPORT: NON-VIABLE METHODOLOGY**

| Location: | 01-R1: indoor air | | | 01-OD: outdoor air | | |
|---|---|---|---|---|---|---|
| Comments (see below) | A | | | None | | |
| Lab ID-Version‡: | 14033192-1 | | | 14033193-1 | | |
| Analysis Date: | 05/12/2022 | | | 05/12/2022 | | |
| | raw ct. | % read | spores/m3 | raw ct. | % read | spores/m3 |
| Ascospores | | | | 1 | 25 | 53 |
| Basidiospores | 1 | 25 | 53 | 3 | 25 | 160 |
| Chaetomium | | | | | | |
| Cladosporium | 5/43 | 25/100 | 840 | 35 | 25 | 1,900 |
| Curvularia | 1 | 100 | 13 | | | |
| Epicoccum | | | | 2 | 100 | 27 |
| Myrothecium | | | | | | |
| Nigrospora | | | | | | |
| Other brown | 1 | 100 | 13 | | | |
| Other colorless | | | | | | |
| Penicillium/Aspergillus types† | 6 | 25 | 320 | | | |
| Pithomyces | | | | | | |
| Rusts | | | | | | |
| Smuts, Periconia, Myxomycetes | | | | 4 | 100 | 53 |
| Stachybotrys | | | | | | |
| Stemphylium | | | | | | |
| Torula | | | | | | |
| Ulocladium | | | | | | |
| Zygomycetes | | | | | | |
| Background debris (1-4+)†† | > 4+ | | | 2+ | | |
| Hyphal fragments/m3 | 27 | | | < 13 | | |
| Pollen/m3 | 13 | | | 610 | | |
| Skin cells (1-4+) | 1+ | | | < 1+ | | |
| Sample volume (liters) | 75 | | | 75 | | |
| § TOTAL SPORES/m3 | | | 1,200 | | | 2,200 |

**Comments:** A) 43 of the raw count *Cladosporium* spores were present as a single clump. Trace overloaded with debris. The counts provided should be considered as minimal.

**Eurofins EMLab P&K**
1815 West Diehl Road, Suite 800, Naperville, IL 60563
(866) 871-1984 Fax (856) 334-1040 www.emlab.com

Client: Florida State University
C/O: Ebrahim Ahmadisharaf, PhD
Re: 101131; NSF HDBE RAPID Hurricane Ida

Date of Sampling: 03-29-2022
Date of Receipt: 05-10-2022
Date of Report: 05-12-2022

**QUANTITATIVE SPORE COUNT REPORT**

| Location: | 01-DUST: indoor dust | | 01-DUST: indoor dust | |
|---|---|---|---|---|
| Comments (see below) | None | | None | |
| Sample type | Tape sample | | Tape sample | |
| Lab ID-Version‡: | 14033190-1 | | 14033191-1 | |
| Analysis Date: | 05/12/2022 | | 05/12/2022 | |
| Dilution | 1:1 | | 1:1 | |
| | raw ct. | spores/unit | raw ct. | spores/unit |
| Alternaria | | | | |
| Arthrinium | | | | |
| Ascospores | | | | |
| Aureobasidium | | | | |
| Basidiospores | | | | |
| Bipolaris/Drechslera group | | | | |
| Botrytis | | | | |
| Chaetomium | | | | |
| Cladosporium | | | | |
| Curvularia | | | | |
| Epicoccum | | | | |
| Fusarium | | | | |
| Myrothecium | | | | |
| Nigrospora | | | | |
| Other colorless | | | | |
| Penicillium/Aspergillus types† | 1,538 | 1,500,000 | 346 | 350,000 |
| Pithomyces | | | | |
| Rusts | | | | |
| Smuts, Periconia, Myxomycetes | | | 1 | 1,000 |
| Stachybotrys | | | | |
| Stemphylium | | | | |
| Torula | | | | |
| Ulocladium | | | | |
| Zygomycetes | | | | |
| Background debris (1-4+)†† | > 4+ | | > 4+ | |
| Sample size | 1 | | 1 | |
| Unit | 1 in2 | | 1 in2 | |
| § TOTAL SPORES/UNIT | | 1,500,000 | | 350,000 |

**Comments:**

Samples → Eurofins, analyze → Mold Species → Reports → Share → Volunteer

ISES International Society of Exposure Science

International Society of Exposure Science · Lisbon, Portugal 2022

# Assessment Reports

## Mold and Ventilation Assessment Report

**Inspection Date:** [redacted]
**Volunteer Name:** [redacted]
**Home Address:** [redacted]

**Harvard Inspection and Assessment Team Members:**
[redacted]

**Collaborator Laboratory:**
Eurofins EMLab P&K
1815 West Diehl Road, Suite 800, Naperville, IL 60563
(866) 871-1984 Fax (856) 334-1040 www.emlab.com

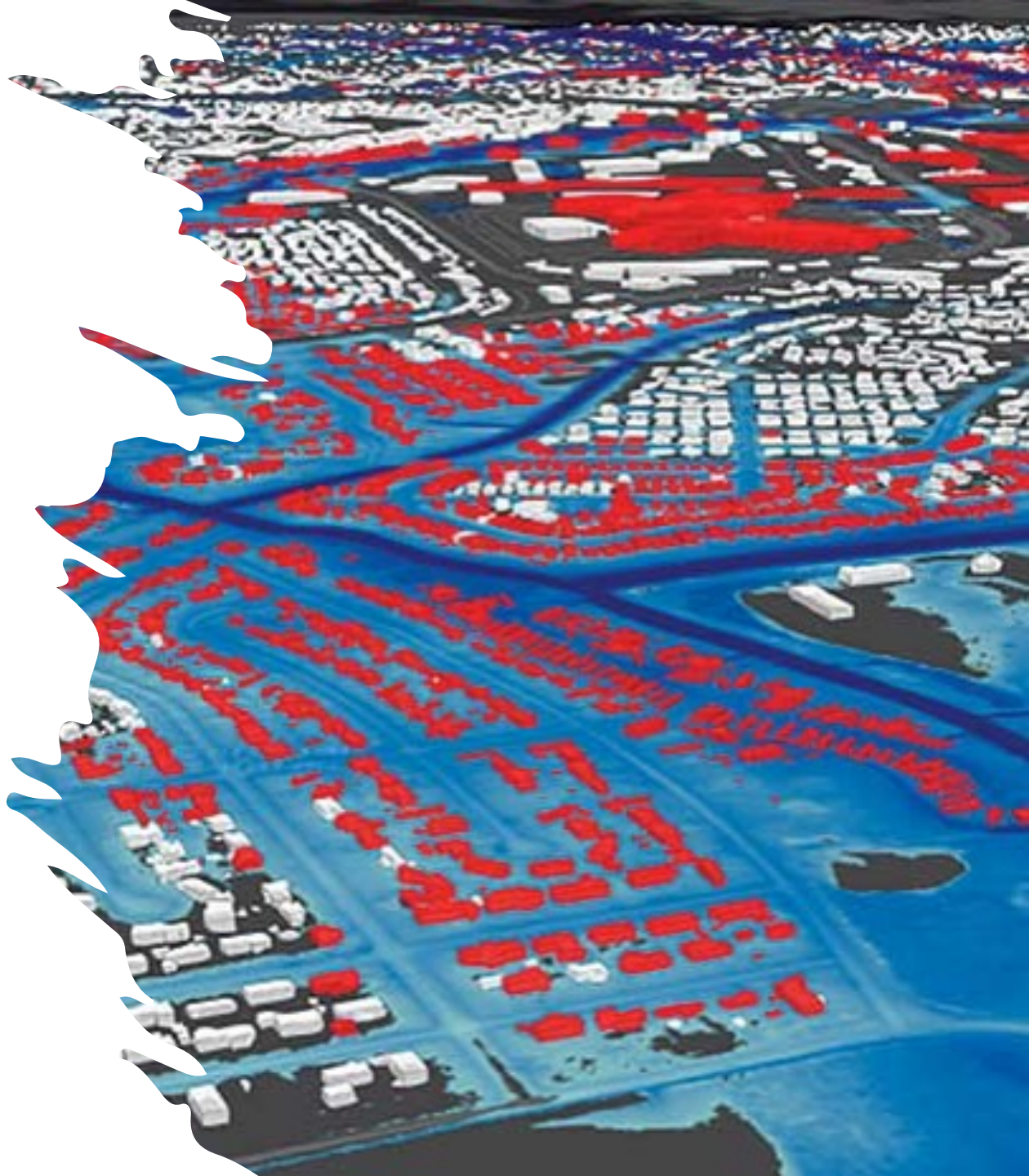
### Inspection Summary

The subject property was inspected in-person for mold and dampness as well as air tightness. The mold and dampness assessment was performed using infrared camera and air and surface sampling. The air tightness of the building was measured using a blower door test. The following observations were made throughout the inspection.

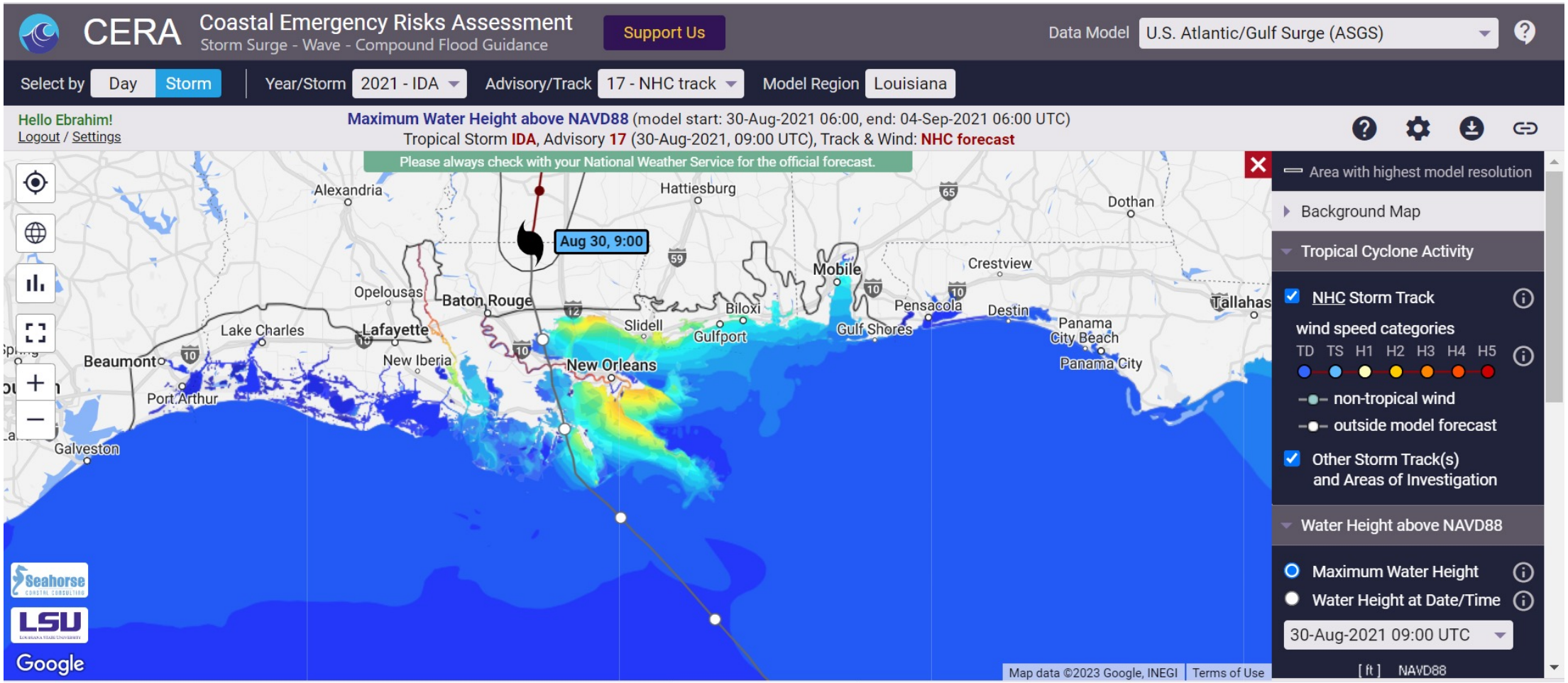
- *Air Sampling* – The collected samples from indoor air show a **moderate** likelihood of indoor amplification
- *Surface Sampling* – The collected samples from home surfaces indicate a **low** spore population count in the bathroom
- *Mold Odor* – Mold odor was classified as **5**
- *Damage Assessment* – On average the observed damages in the property were classified as **Moderate**.
- *Natural Ventilation* – The ventilation rate of the inspected home was **higher** than ASHRAE 62.2-2019 minimum ventilation requirement for residential building.

| Indoor Amplification Likelihood Guideline | |
|---|---|
| **Individual indoor fungal spore determination** | |
| Unlikely indoor fungal reservoir | IA ≤ OA |
| Low likelihood of indoor amplification | OA < IA ≤ OA + 200 Spores/$m^3$ |
| Moderate likelihood of indoor amplification | OA + 200 Spores/$m^3$ < IA ≤ OA + 400 Spores/$m^3$ |
| High likelihood of indoor amplification | IA > OA + 400 Spores/$m^3$ |
| **Total indoor fungal reservoir determination** | |
| Unlikely indoor fungal reservoir | IA ≤ OA |
| Low likelihood of indoor amplification | OA < IA ≤ OA + 400 Spores/$m^3$ |
| Moderate likelihood of indoor amplification | OA + 400 Spores/$m^3$ < IA ≤ OA + 800 Spores/$m^3$ |
| High likelihood of indoor amplification | IA > OA + 800 Spores/$m^3$ |

# Flood Modeling

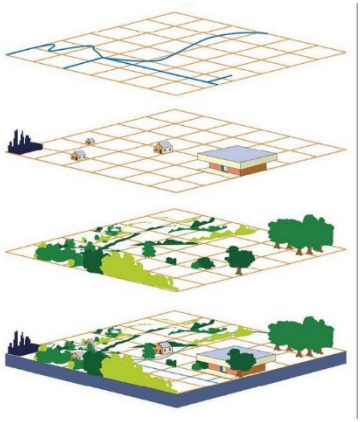


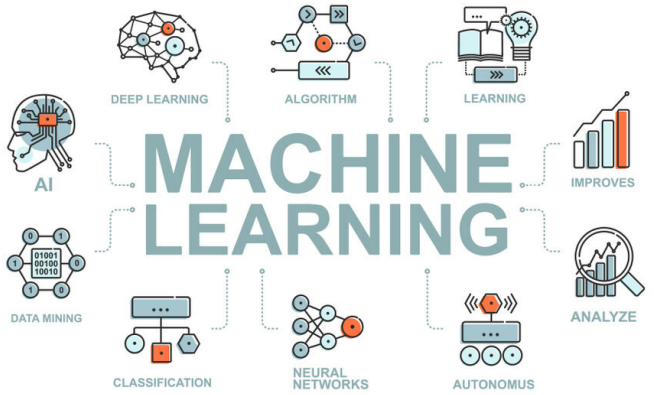
# Existing Flood Modeling Results



# Flood Modeling Framework

- Machine learning algorithms
- Geographic information system (GIS)
- Informed by physical processes





# Observed Flood Data

1. High water marks (HWMs)

2. Stream water levels

3. Satellite imagery

| Amount of vertical uncertainty | Uncertainty |
|---|---|
| Within ±0.05 foot. | Excellent (E) |
| Within ±0.10 foot. | Good (G) |
| Within ±0.20 foot. | Fair (F) |
| Within ±0.40 foot. | Poor (P) |
| More than ±0.40 foot. | Very poor (V) |

## Geographic Location

- Distance to the nearest stream
- Distance from storm track
- Distance from coastline

## Hydrologic Characteristics

- Height Above Nearest Drainage (HAND)
- Drainage Area
- Topographic Wetness Index (TWI)
- Flow Accumulation

## Meteorologic Factors

- Rainfall
- Wind

## Topographic Features

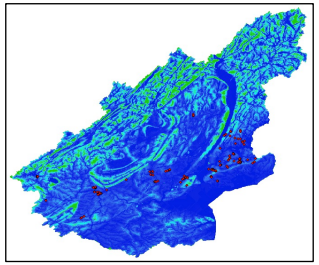
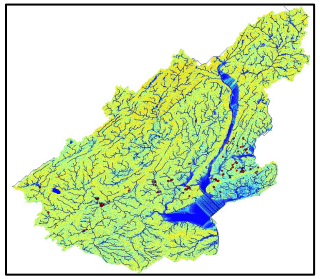
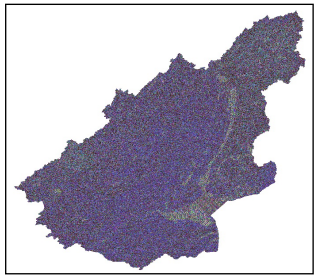
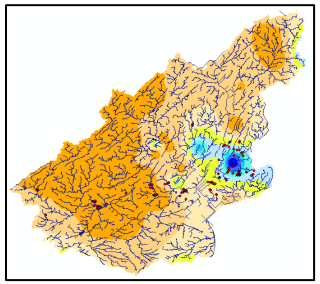
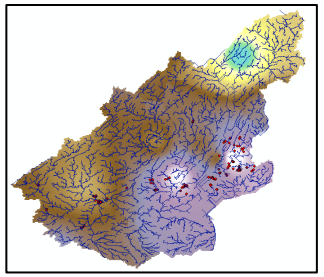
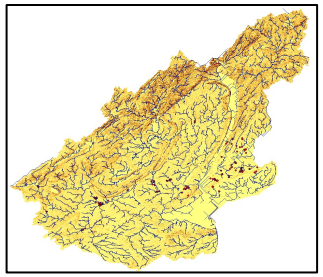
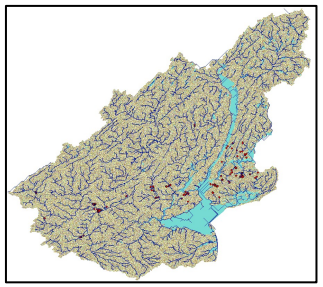
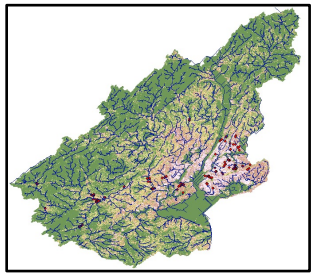
- Slope
- Slope Aspect
- Curvature

## Land Surface & Subsurface Properties

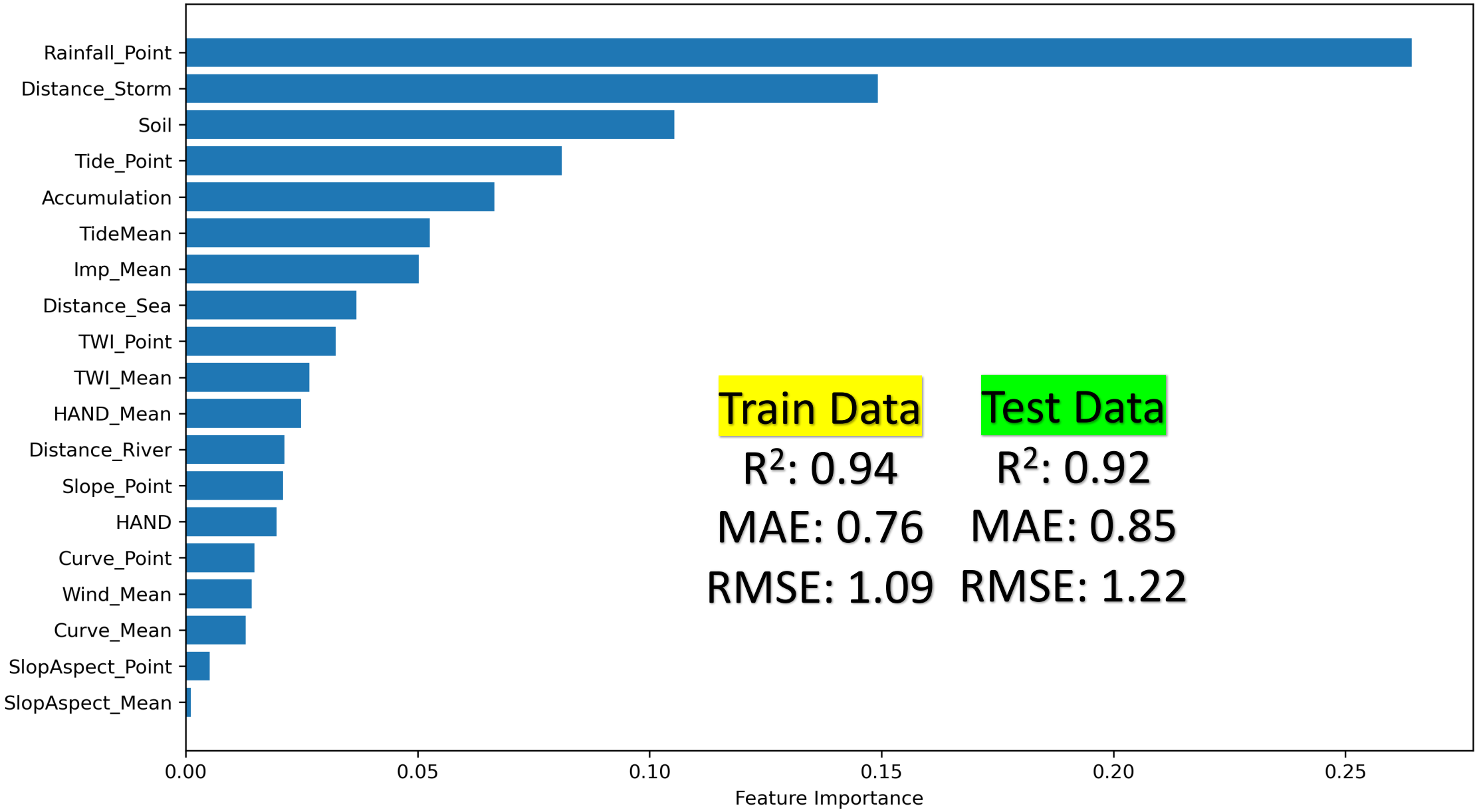
- Imperviousness
- Antecedent soil moisture

## Coastal Factors:

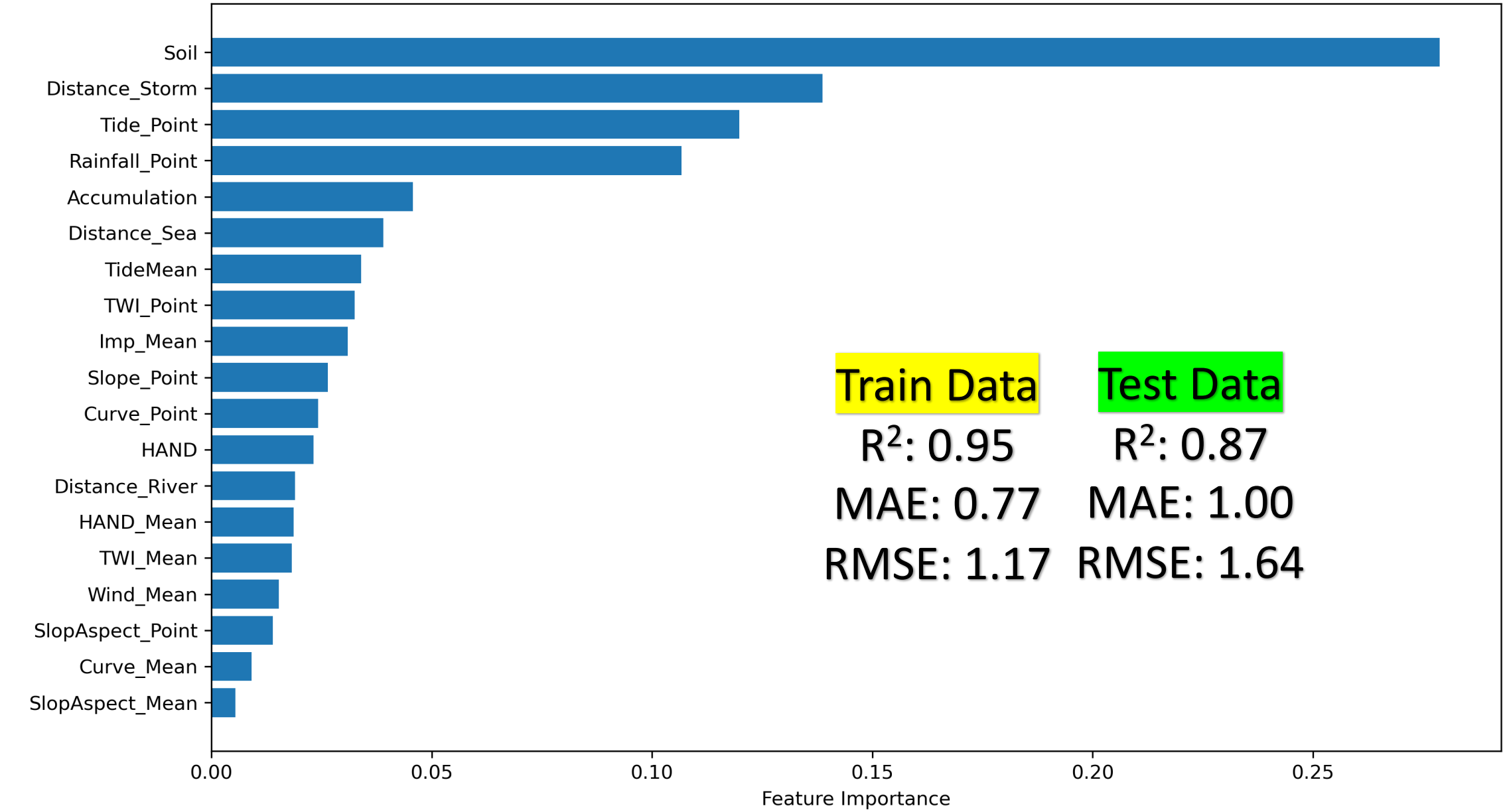
- Storm surge

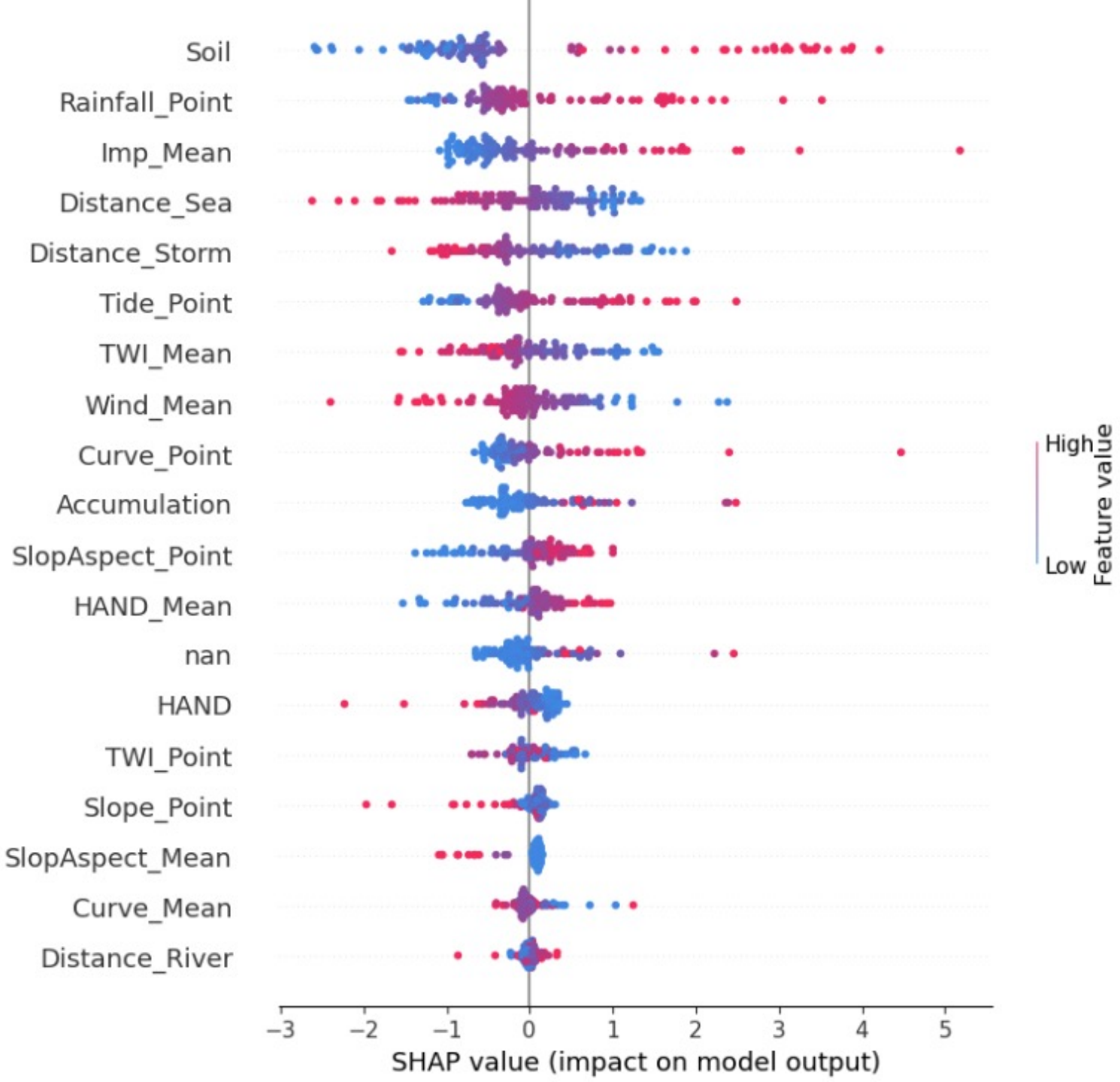
# RANDOM FOREST



# XGBOOST


Soil
Distance_Storm
Tide_Point
Rainfall_Point
Accumulation
Distance_Sea
TideMean
TWI_Point
Imp_Mean
Slope_Point
Curve_Point
HAND
Distance_River
HAND_Mean
TWI_Mean
Wind_Mean
SlopAspect_Point
Curve_Mean
SlopAspect_Mean
0.00
0.05
0.10
0.15
0.20
0.25
Feature Importance
Train Data
Test Data
R²: 0.95
R²: 0.87
MAE: 0.77
MAE: 1.00
RMSE: 1.17
RMSE: 1.64

# Neural Network




| Train Data | Test Data |
|---|---|
| $R^2$: 0.88 | $R^2$: 0.53 |
| MAE: 1.24 | MAE: 1.64 |
| RMSE: 1.91 | RMSE: 2.29 |

# Relationship Analyses

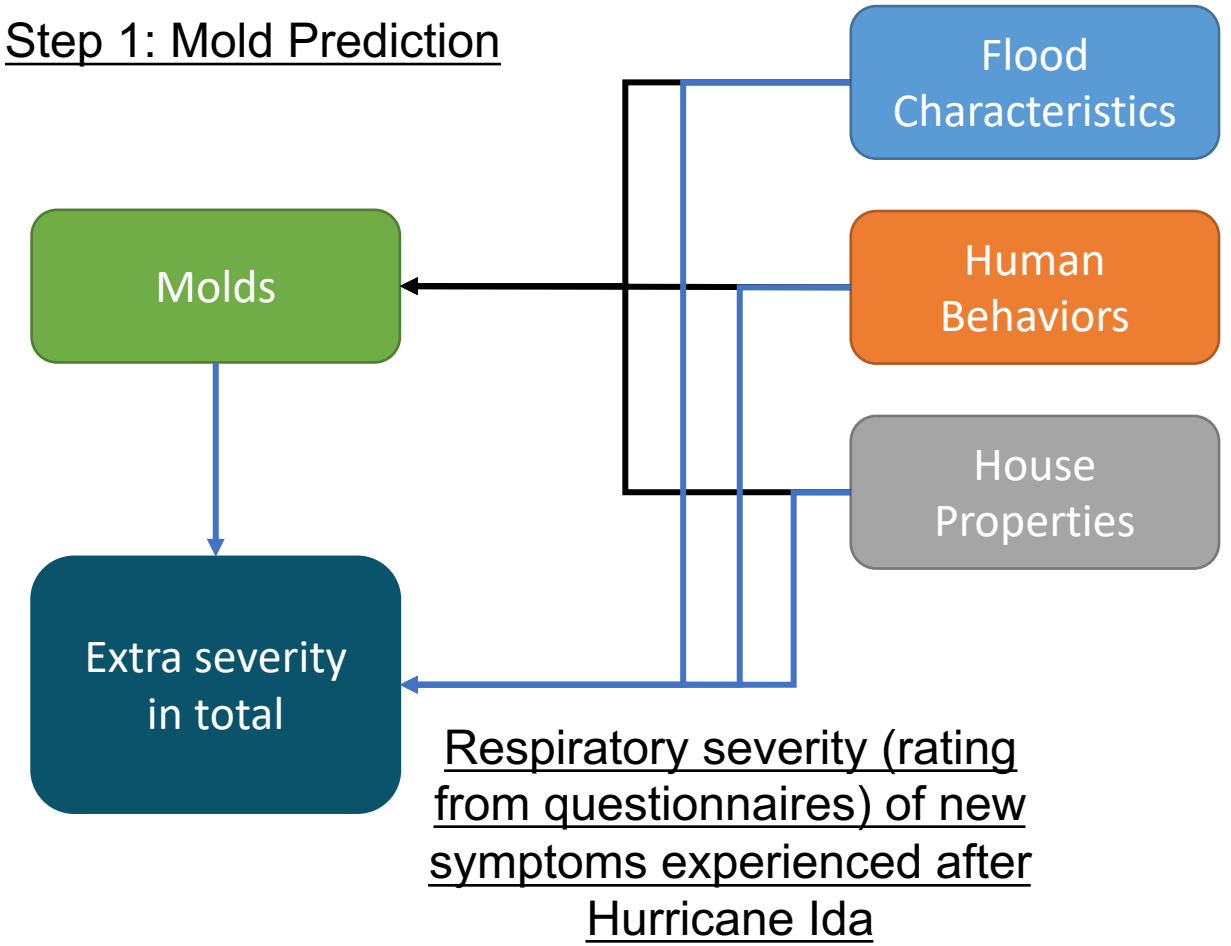
# Finding Relationships by Machine Learning

Developing databases and machine learning tools to:

- Find correlations among:
  - flood characteristics
  - Molds/spores
  - allergy and asthma risk

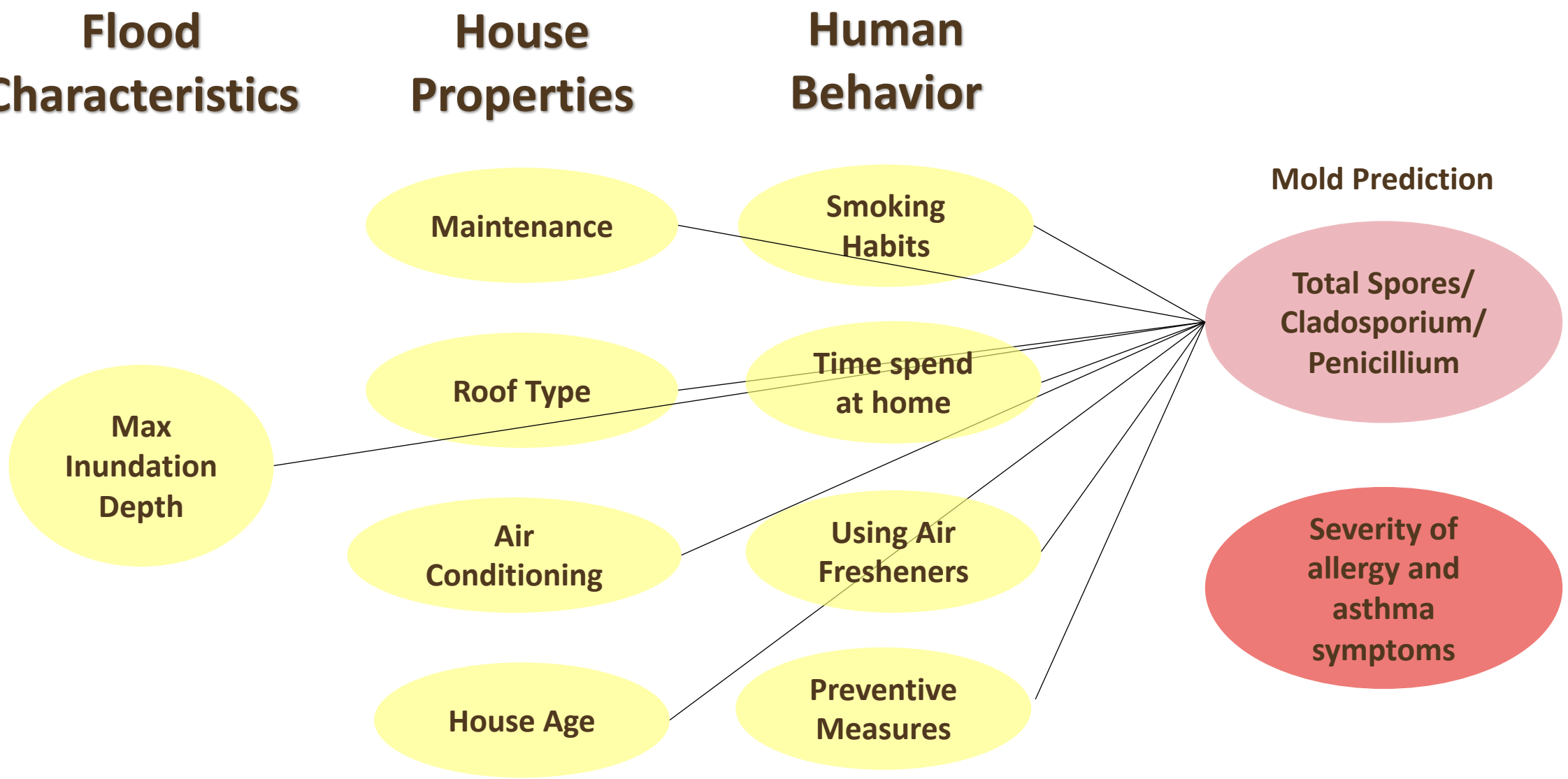
*Non-linear relationships among the features*

Step 1: Mold Prediction

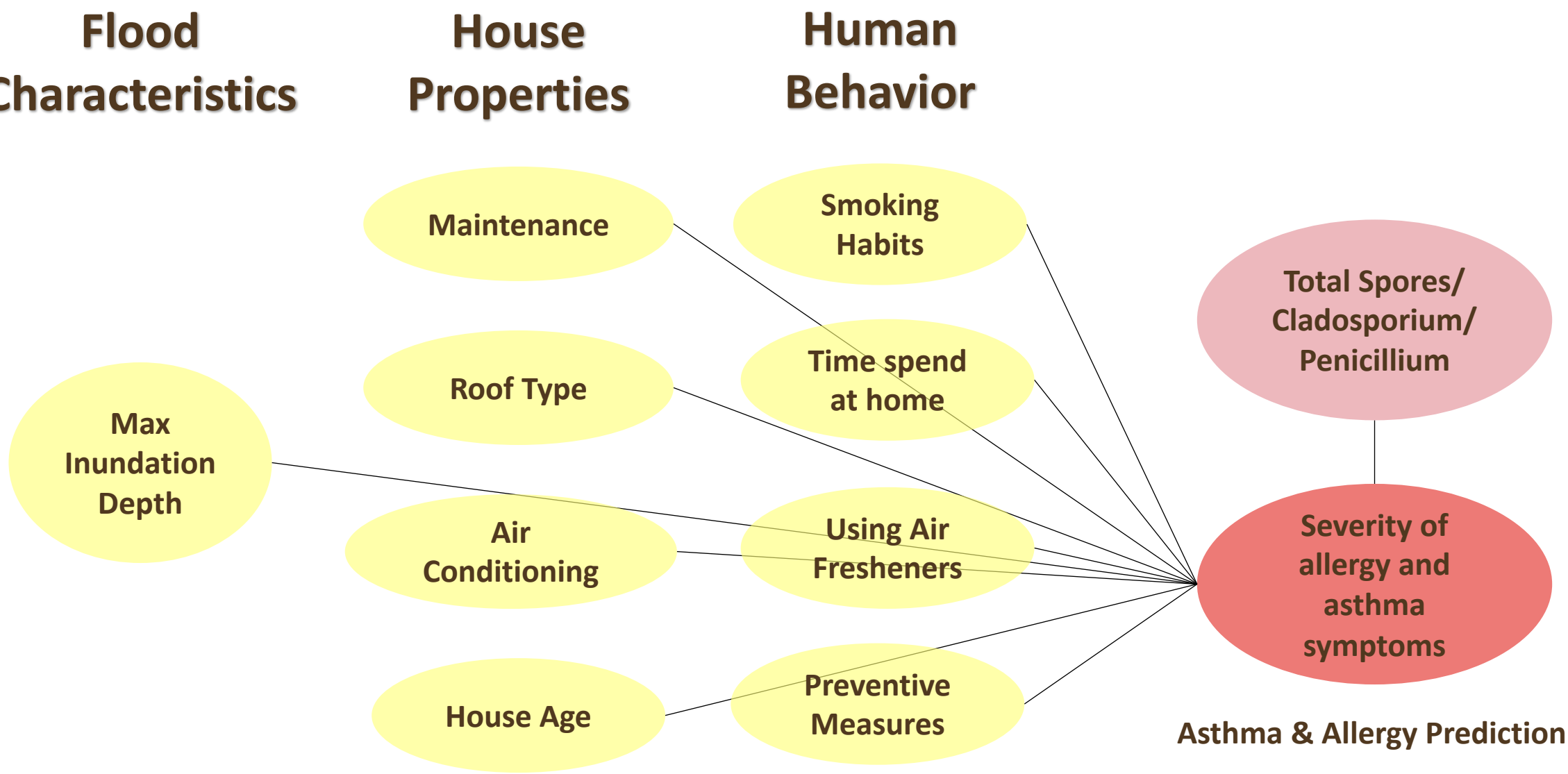



Step 2: Asthma & Allergy Predictions

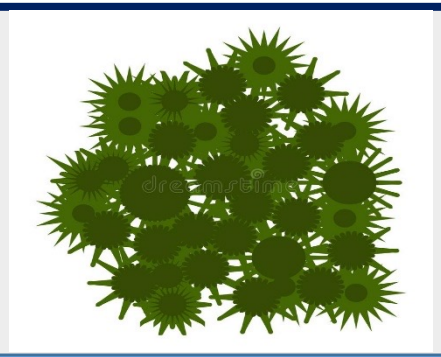
# Machine Learning Mold Prediction



# Machine Learning Asthma Prediction



# Machine Learning Important Features



- Using Air Fresheners (-)
- Home Repair Time/Year (-)
- Max Inundation Depth (Non-Linear)
- Preventive Measures (+)
- Home Built Time (-)

- Max Inundation Depth (+)
- Smoking Habits (+)
- Days Spent at Home (+)
- Home Repair Time/Year (Non-Linear)
- Preventive Measures (+)
- Molds (Non-Linear)

Feature relative importance results and impacts on output by Random Forest models

# Applications

1. Guide building designers and occupational health scientists: **Flood resilient indoor environments**
2. A foundation to develop **quantitative models** of flood-induced mold growth and allergy and asthma risk
3. Assist **public health officials, emergency managers** and **insurance companies**
4. Inform communities about the respiratory health risks associated with flood events
5. **Educate families** on the impact of flooding and water intrusion, building and HVAC system properties and their behaviors on health

# Limitation & Future Steps

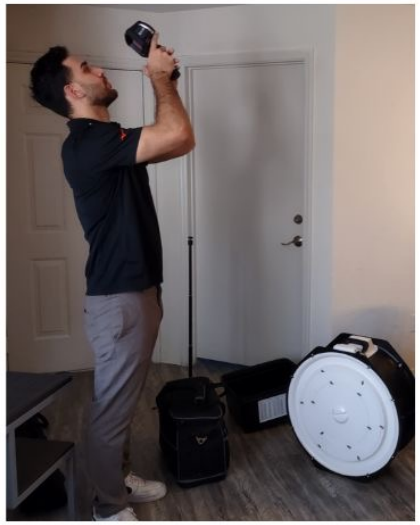
## Limitations

- Sample size
- Gradual impacts on human health
- Uncertainties in flood estimates

## Future Steps

- Conduct additional in-site inspections on houses
  - Validate the developed models with additional data
  - Conduct similar experiments for other hurricanes and a range of floods
- Community engagement
- A range of flood events: Non-extremes
- Develop generic models to predict the indirect impacts of floods on mold presence in homes and occupants' respiratory health
- Develop guidelines for homeowners and building designers to reduce the mold growth after flood events
- Collaboration

# Ongoing Work: Hurricane Ian



# Summary

1- Relationships among floods, mold growth, allergy and asthma risk in affected buildings post-hurricanes

2- Data collection, volunteer recruiting, surveys, home inspections, lab tests and modeling

3- Relationship analyses

4- Flood characteristics (e.g., greatest depth), human behavior (e.g., smoking and use of air fresheners) and building properties (e.g., roof age) affect mold growth and asthma risk

# Acknowledgements




- All volunteer participants

- **Team members:** Zhengxiao Yan, Maryam Pakdehi, Christian Caballero, Zahra Keshavarz, Joseph Allen and Parham Azimi



**FAMU-FSU**

**College of Engineering**

# Thank You!

eahmadisharaf@eng.famu.fsu.edu