NCST Technical Investigation of Hurricane Maria (Puerto Rico)

Hazard Characterization Project

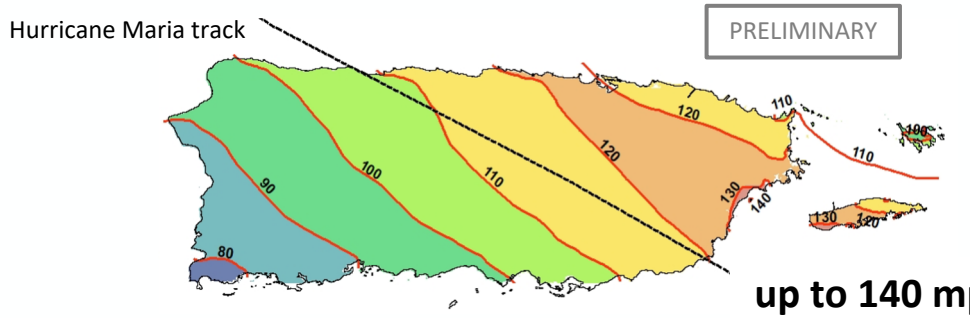
Project Leaders: DongHun Yeo and Scott Weaver

Objective: To characterize the wind environment associated with Hurricane Maria's impact on Puerto Rico, using measurements and modeling of the time-dependent hurricane wind-field in conjunction with wind tunnel studies of topographic effects, and to document other hazards associated with the hurricane, including storm surge, rainfall, flooding, and landslides.

Background: Hazards from Hurricane Maria (HM)

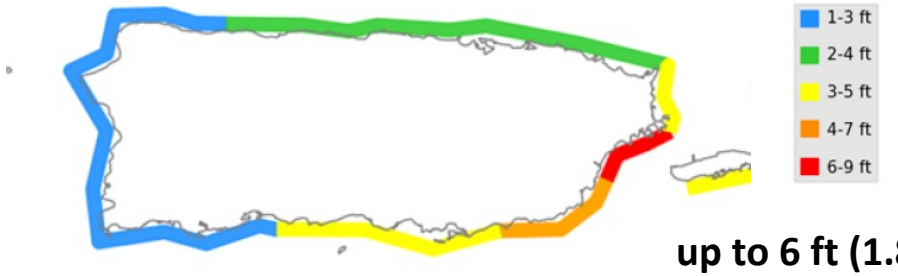
- Puerto Rico was subjected to multiple hazards due to HM: extreme winds, coastal inundation, and heavy rainfall, causing inland flooding and landslides
- Accurate characterization of multiple hazards is of fundamental importance for projects across the HM program
- HM caused extensive damage to instrumentation, introducing significant challenges in hazard quantification
- A combination of measurements and modeling can be required to characterize spatial and temporal variation of hazards

Peak gust wind speed (flat terrain)



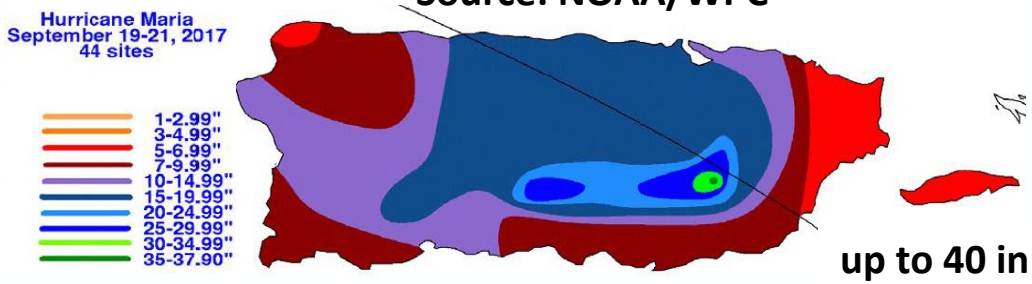
up to 140 mph (63 m/s)

Coastal inundation above ground level
Source: NOAA/NHC



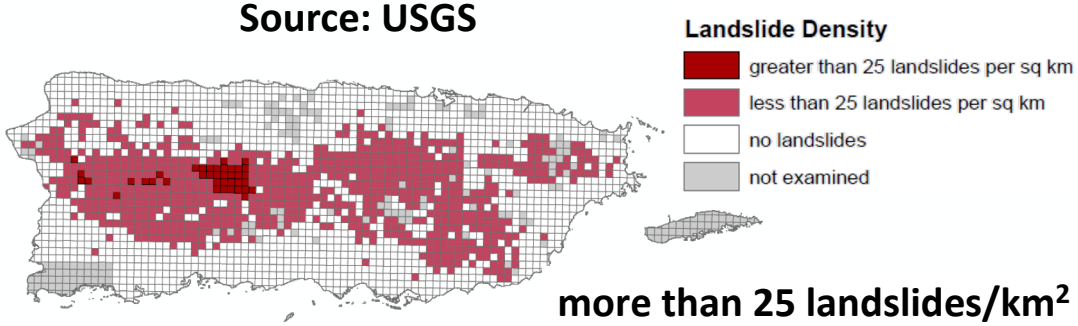
up to 6 ft (1.8 m)

Total rainfall accumulation
Source: NOAA/WPC



up to 40 in (100 cm)

Concentration of landslides
Source: USGS

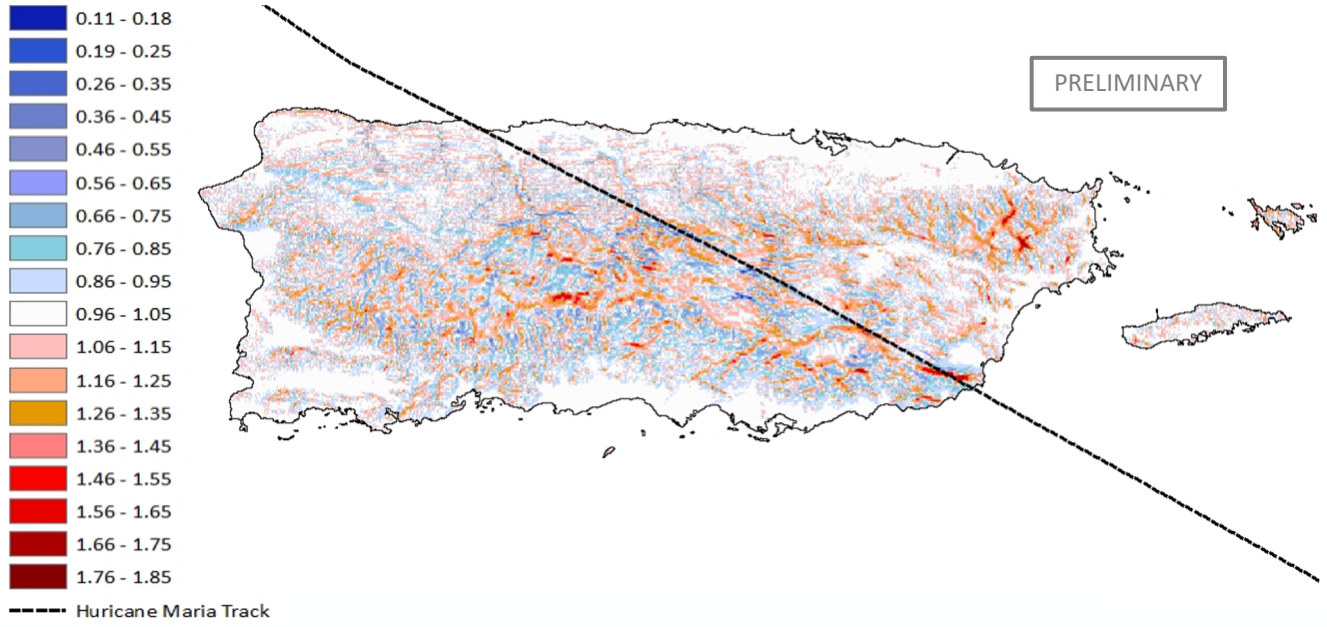


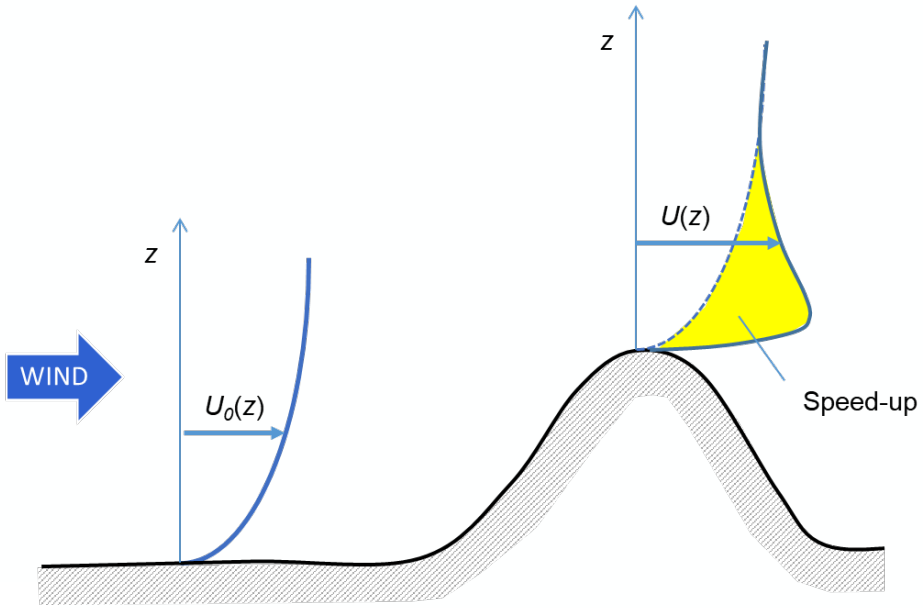
more than 25 landslides/km^2

Motivation: Characterizing Topographic Speed-Up

- Preliminary analysis showed that Puerto Rico's mountainous topography could increase peak gust wind speeds by as much as 80 % when compared to the same weather pattern over flat terrain
- Quantifying this "**topographic speed-up**" is important in order to have an accurate understanding of wind loads experienced by buildings and infrastructure

Topographic Speedup Factor (TSF) at 10 m elevation

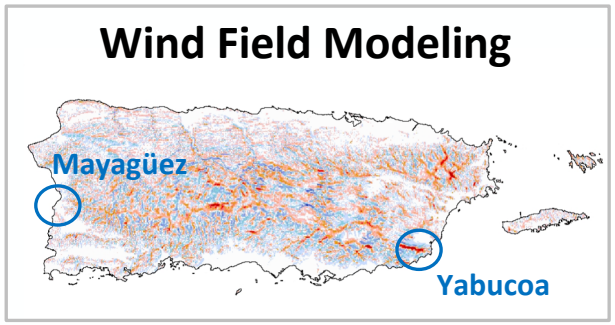


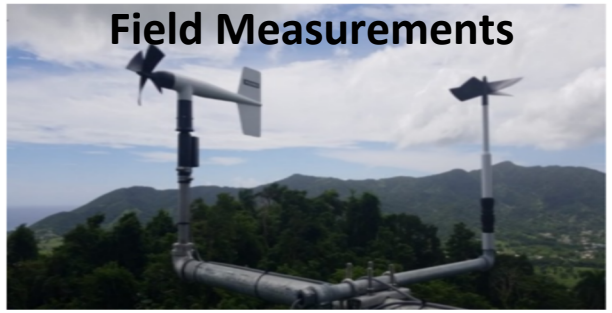


$$\text{TSF}(z) = \frac{\text{Peak gust speed with topo. corrections, } U(z)}{\text{Peak gust speed without topo. corrections, } U_0(z)}$$

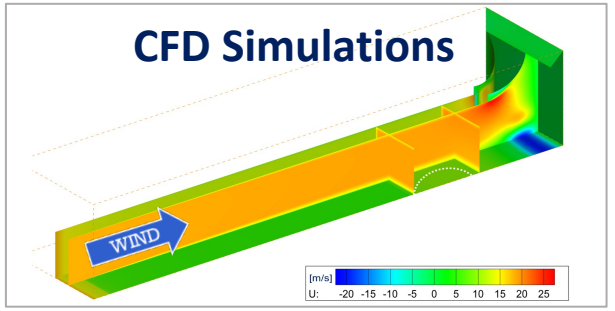
Wind Hazard

Project Plans (1/3): Planning Stage



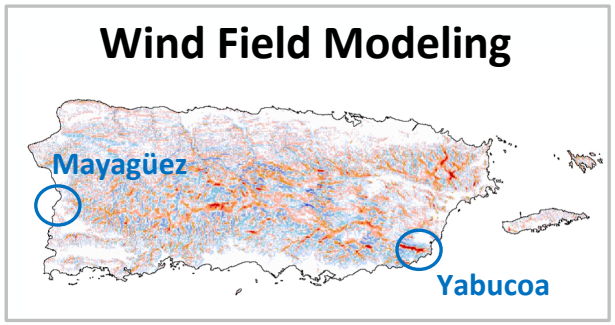


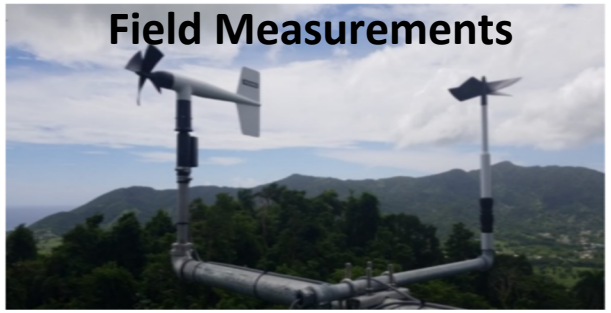
Arrows represent flow of information



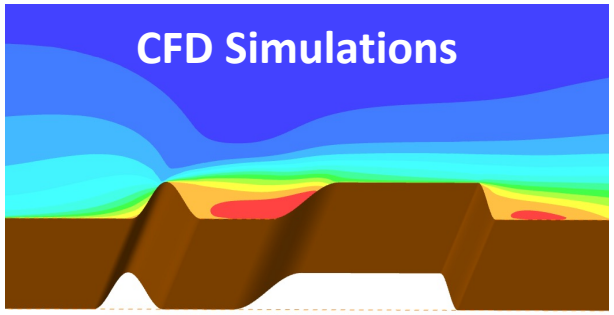
- Initial wind field model provided preliminary wind field data for Hurricane Maria to assist in development of project plans
- Computational Fluid Dynamics (CFD) simulations of flow field in University of Florida wind tunnel enabled evaluation of alternative configurations to block laser light while minimizing flow distortion

Project Plans (2/3): Measurement and Modeling Stage



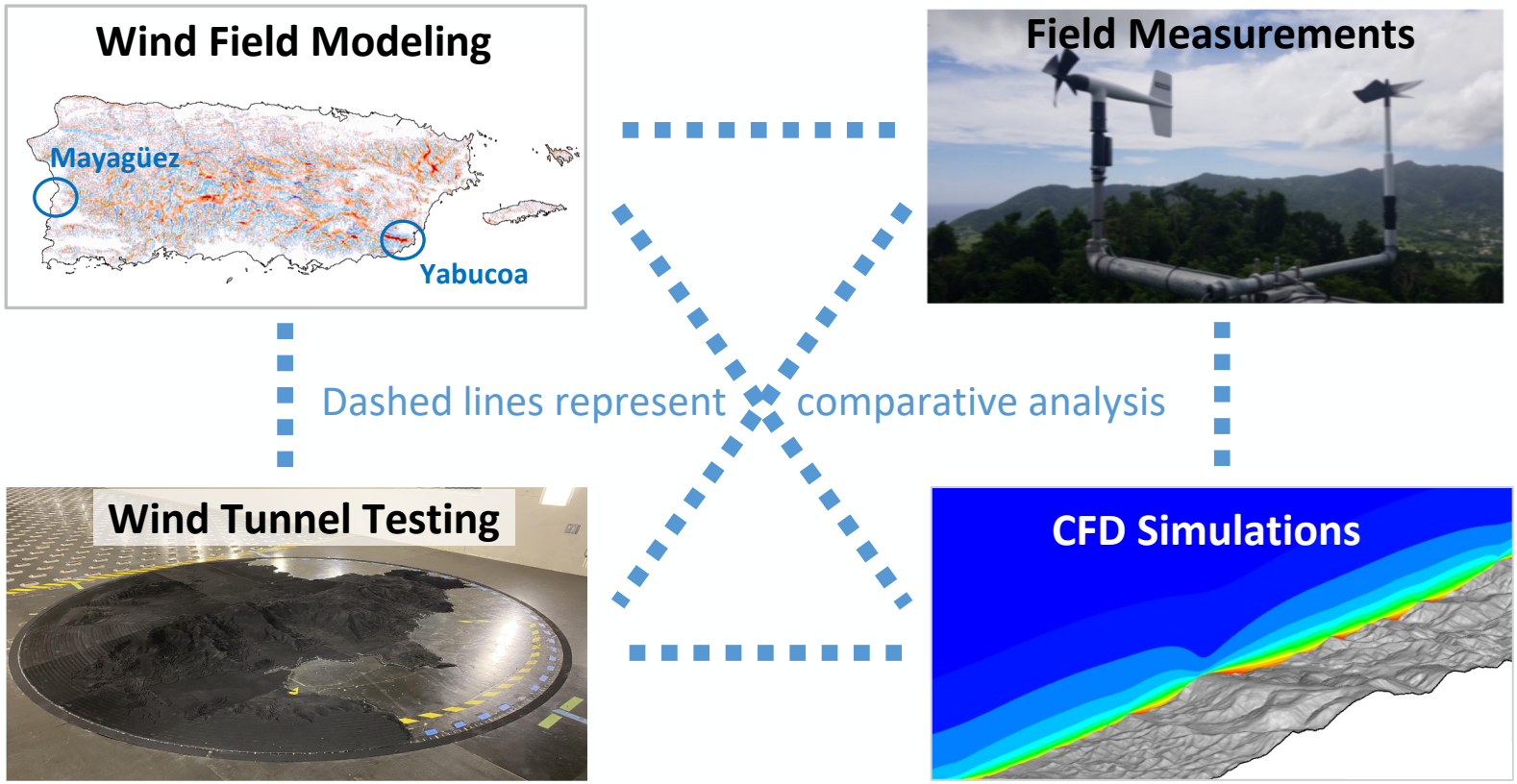


Arrows represent model validation/refinement



- Collect and analyze datasets on topographic speedup from wind tunnel testing and field measurements
- Develop CFD models and perform simulations of topographic speedup effects
- Employ wind tunnel and field measured data for validation/refinement of CFD topographic models
- Improve hurricane wind field model to optimize fit, better capture asymmetry, and quantify uncertainty
- Develop final wind field model, including topographic speedup effects informed by wind tunnel data, to provide time-varying wind velocities throughout Puerto Rico for duration of Hurricane Maria

Project Plans (3/3): Integration Stage



- Sources of information from all methods are integrated for evaluation of topographic speed-up effects in Puerto Rico during Hurricane Maria
- Evaluation of current provisions for topographic effects informs the development of findings and recommendations for improvements to codes and standards

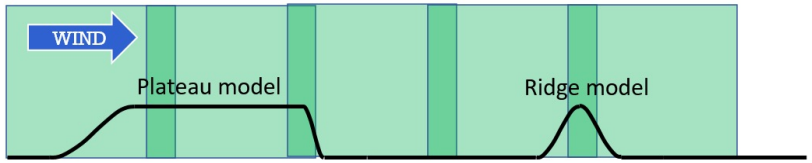
Wind Tunnel Testing

Purpose: Obtain flow-field measurements from wind tunnel testing of topographic features to provide experimental data with quantified uncertainties for characterization of topographic speedup effects and for validation of numerical models

Contract with University of Florida to support wind tunnel testing tasks: model fabrication and testing

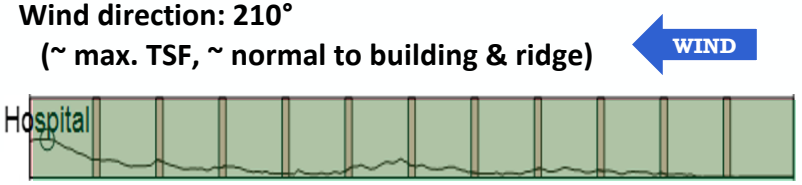
Previous work:

- Developed testing plans for generic and Mayagüez and Yabucoa topographic models (1:3100 scale)
- Fabricated generic models (smooth, rough, and terraced surfaces; three configurations: A, B, C) and Yabucoa topographic model

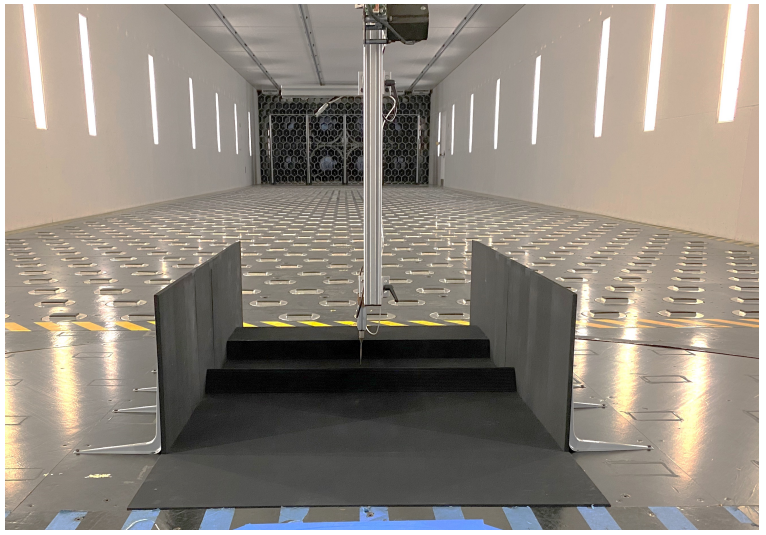


Test plan for generic topographic model

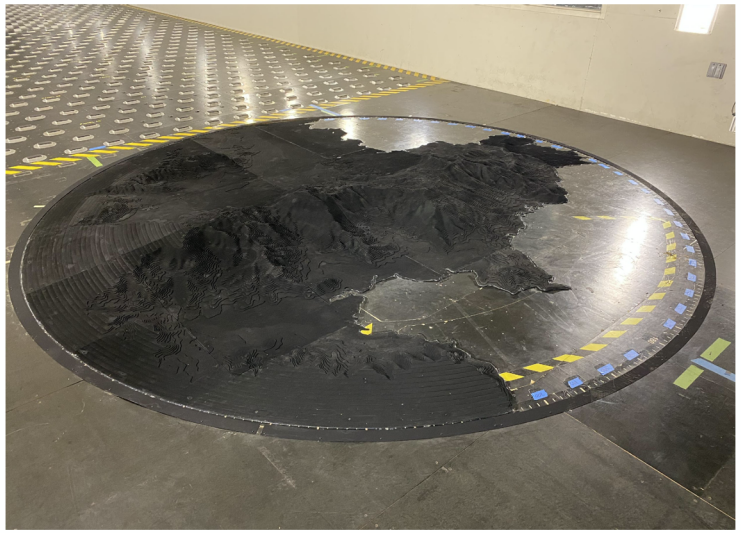
Wind direction: 210°
(~ max. TSF, ~ normal to building & ridge)



Test plan for Mayagüez topographic model



Generic topographic model



Yabucoa topographic model

Wind Tunnel Testing: Recent Progress

Generic topographic models:

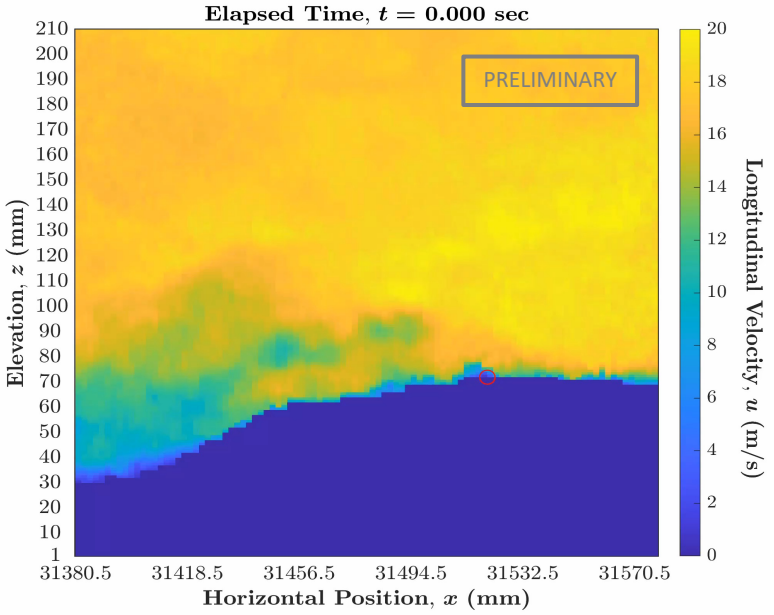
- Completed testing of generic topographic models with terraced surfaces

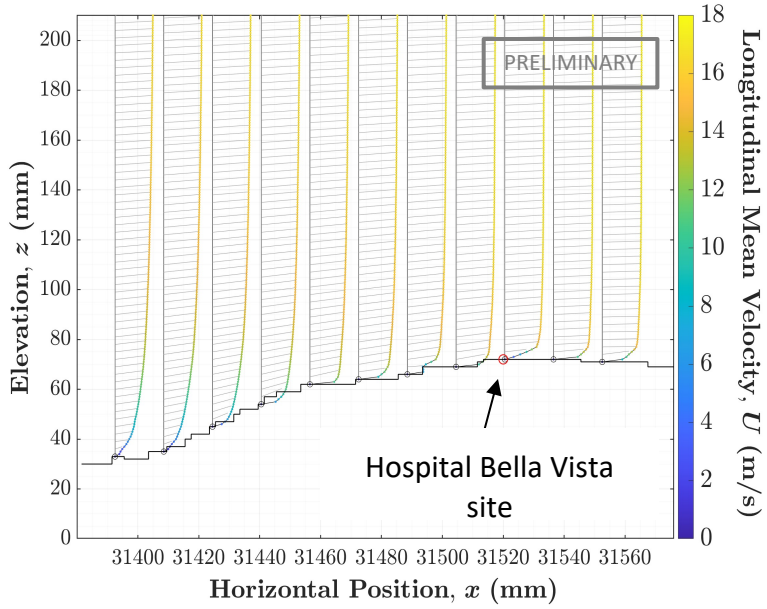
Puerto Rico regional topographic models:

- Fabricated the Mayagüez topographic model
- Completed wind tunnel tests of Mayagüez and Yabucoa topographic models (1:3100 scale) using Particle Image Velocimetry (PIV) measurement system

Improvement of PIV system allowed measurement much closer to the surface (within 10 m above ground at full scale)

Mayagüez topographic model





Mayagüez longitudinal wind velocity data from PIV for wind direction of 230°: video (left), time-averaged plot (right)

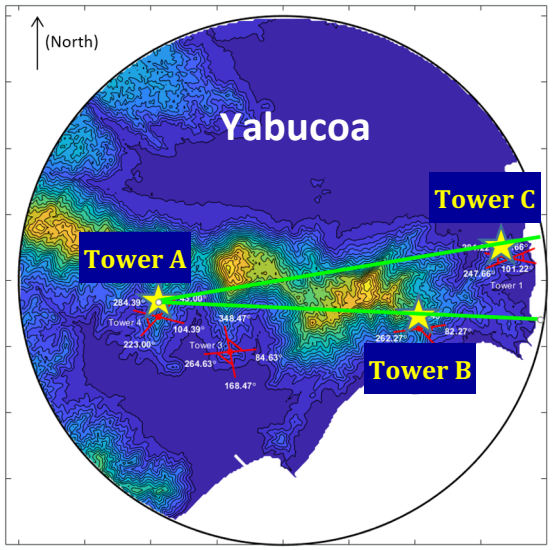
Field Measurements

Purpose: Obtain full-scale measurements of winds in regions of topographic interest in Puerto Rico, to provide information for validation of wind tunnel test results and numerical models

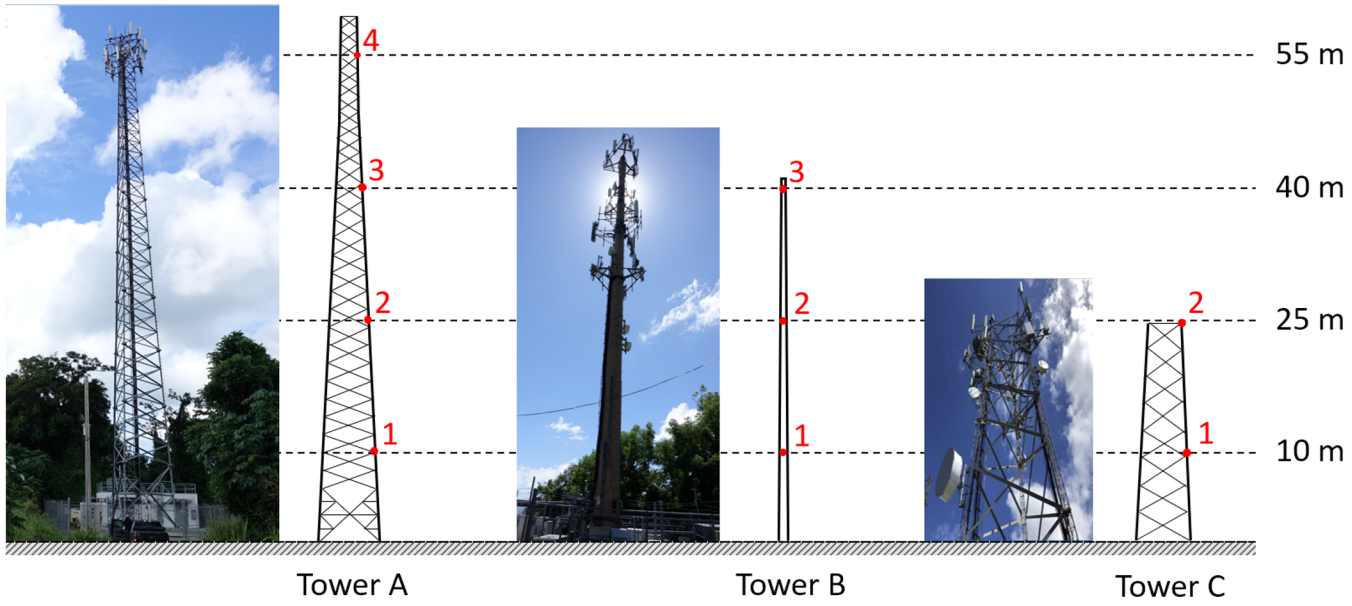
Contract awarded to University of Florida (subcontractor: WeatherFlow)

Previous work:

- Selected three communication towers in Yabucoa region for measurement of topographic effects on winds, along with installation heights for deployment of anemometers



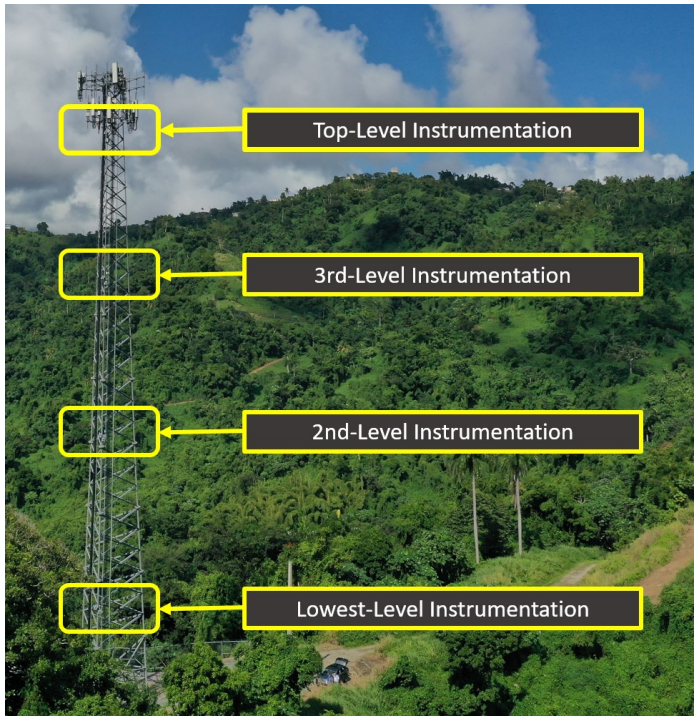
Locations of towers in Yabucoa



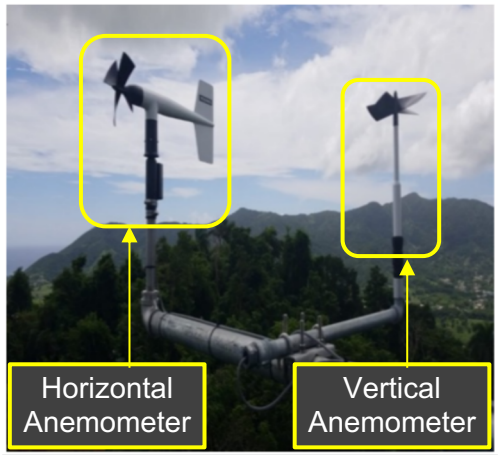
Installation heights for anemometers on towers

Field Measurements: Recent Progress

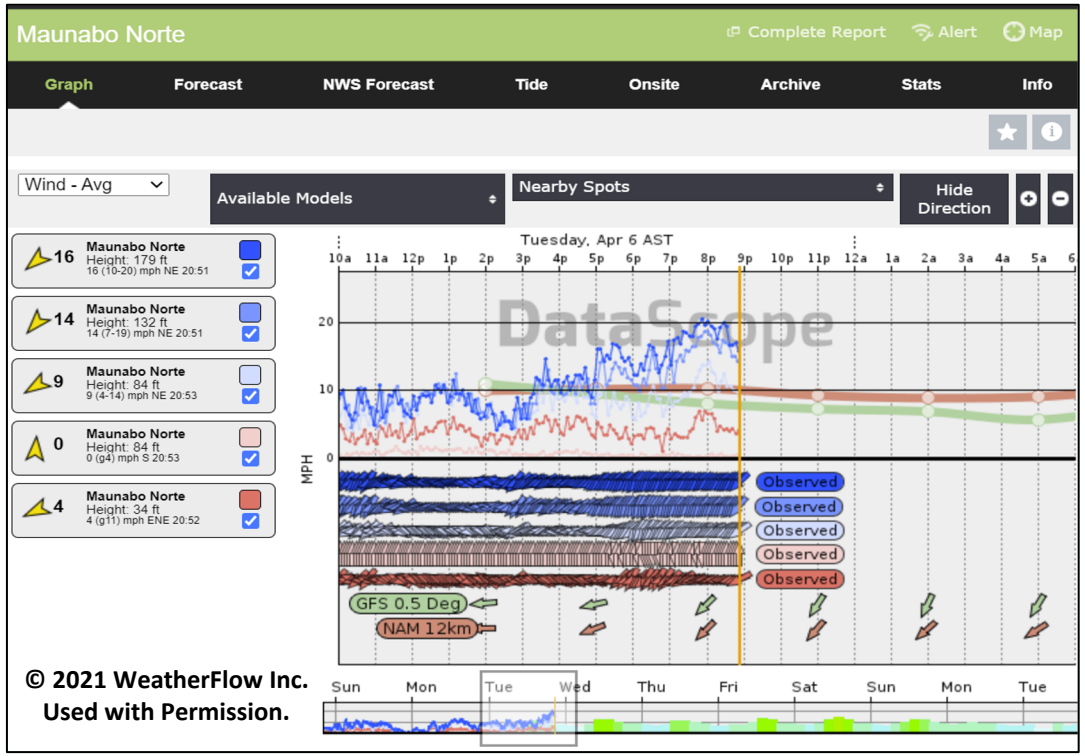
- Installed meteorological measurement stations on 3 towers in Yabucoa region for measurement of topographic effects on winds
- Upgraded data acquisition systems to enable recording of continuous 3-s wind velocity histories from vertical and horizontal anemometers at all 3 towers starting in late February 2021
- Real-time feed of measured data is available to NIST and partnering agencies, including National Weather Service in San Juan



Maunabo Norte (Tower A)



2nd Level Instrumentation at Maunabo Norte



Website with real-time feed of measured data from towers

CFD Simulations

Purpose: Develop computational fluid dynamics (CFD) models for topographic effects on winds, verify CFD simulations, validate CFD results against wind tunnel and field measurement data, and use the validated CFD models to evaluate and characterize topographic speedup effects in Puerto Rico

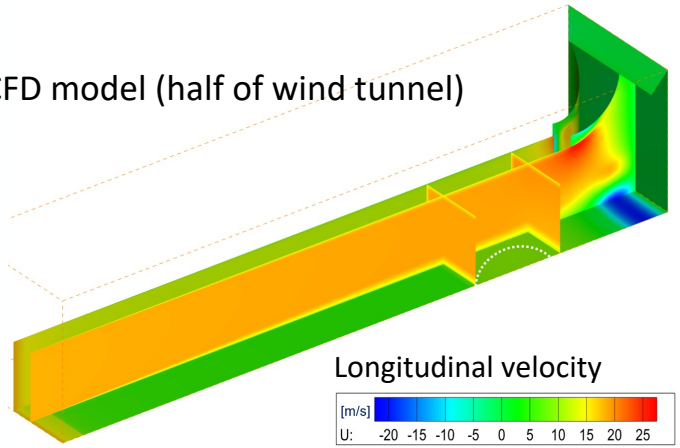
Previous work:

- Evaluated alternative configurations of wind tunnel to block laser light while minimizing flow distortion
- Implemented canopy model for simulating approach flows over roughness blocks
- Simulated approach flows using canopy model and roughness blocks, respectively

Evaluation of flow field in wind tunnel

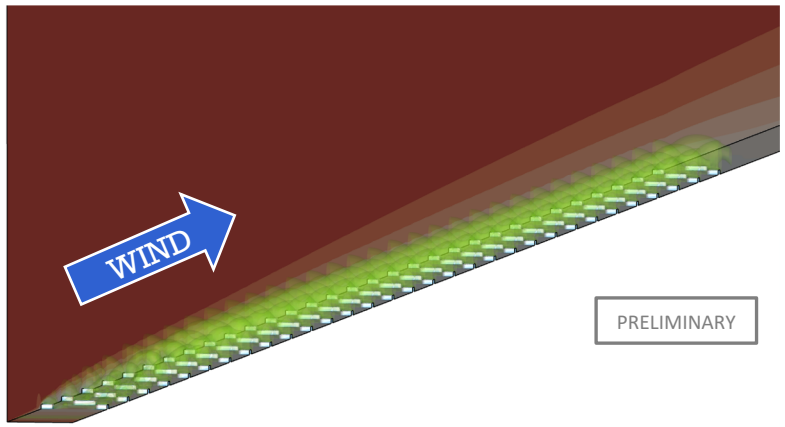
Wind tunnel facility

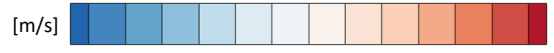
CFD model (half of wind tunnel)



Longitudinal velocity

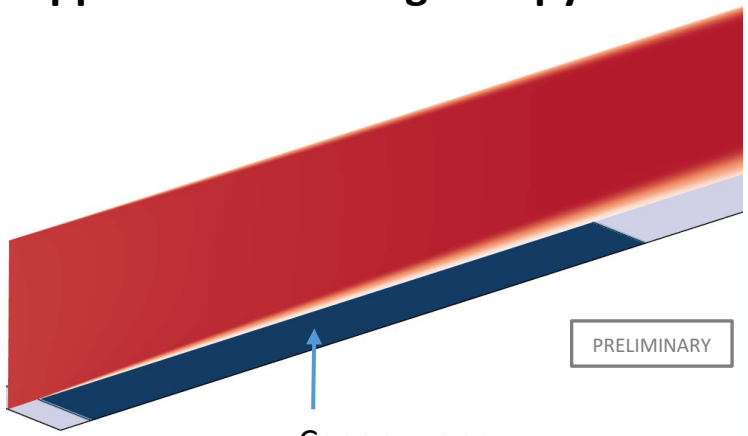
Approach flow using roughness blocks



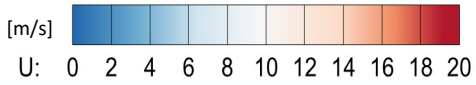


Iso-surfaces of Q criterion (30 s^{-2})

Approach flow using canopy model

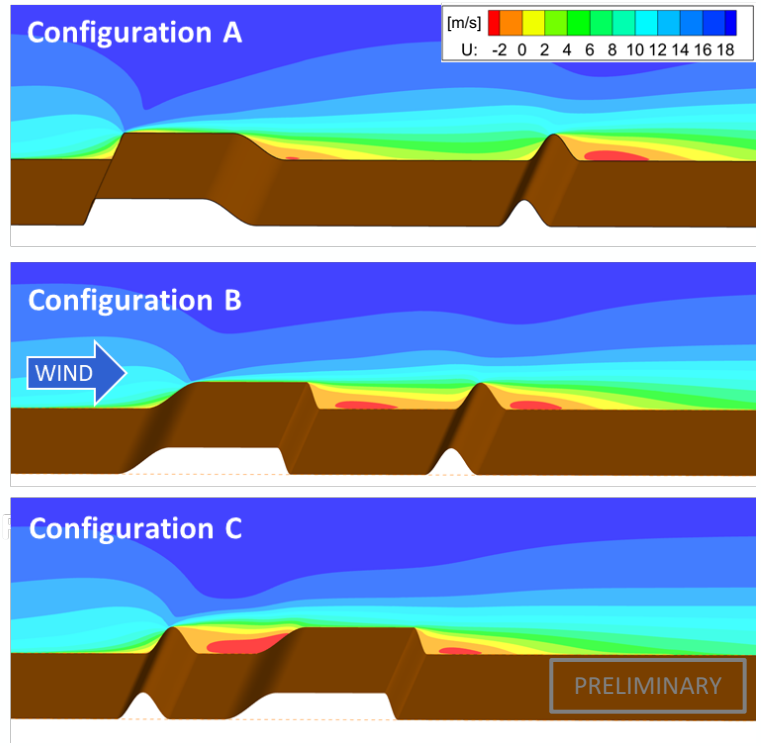


Canopy zone

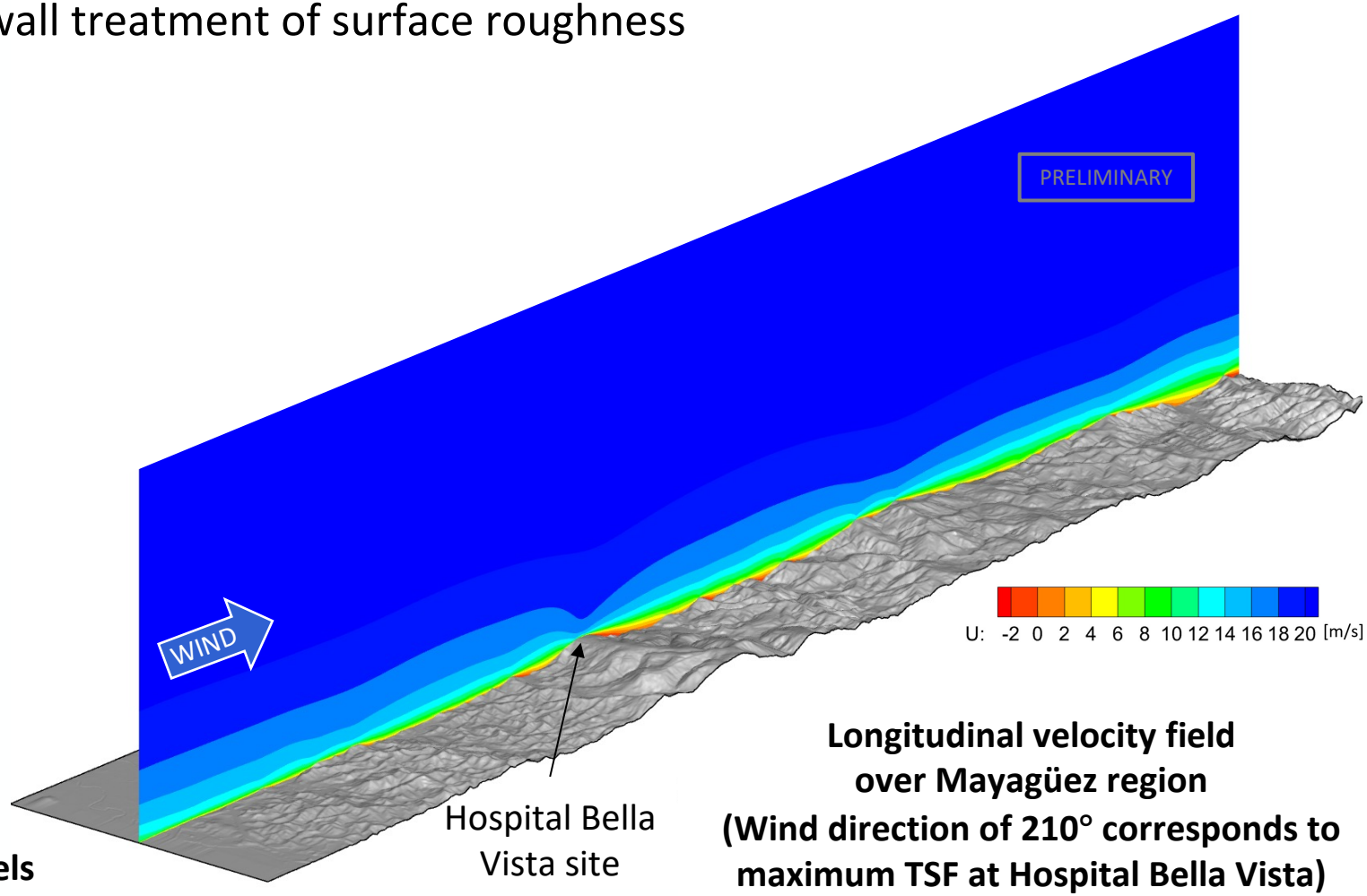


CFD Simulations: Recent Progress

- Developed Verification and Validation (V&V) procedure for estimating uncertainties in simulation results
- Developed a procedure for mesh generation using Digital Elevation Model (DEM) files for Puerto Rico
- Performed simulations of flows over generic and Mayagüez topographic models, with ongoing refinement of approach flow and wall treatment of surface roughness



Longitudinal velocity field over generic models



Longitudinal velocity field over Mayagüez region (Wind direction of 210° corresponds to maximum TSF at Hospital Bella Vista)

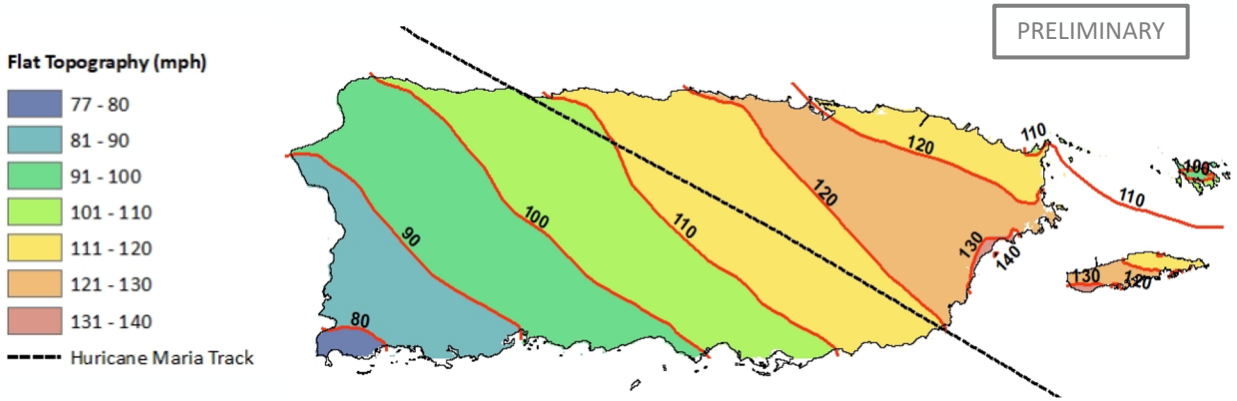
Wind Field Modeling

Purpose: Develop a time-dependent wind-field model of Hurricane Maria's impact on Puerto Rico that optimally matches available measured data

Contract with Applied Research Associates to support wind field modeling tasks

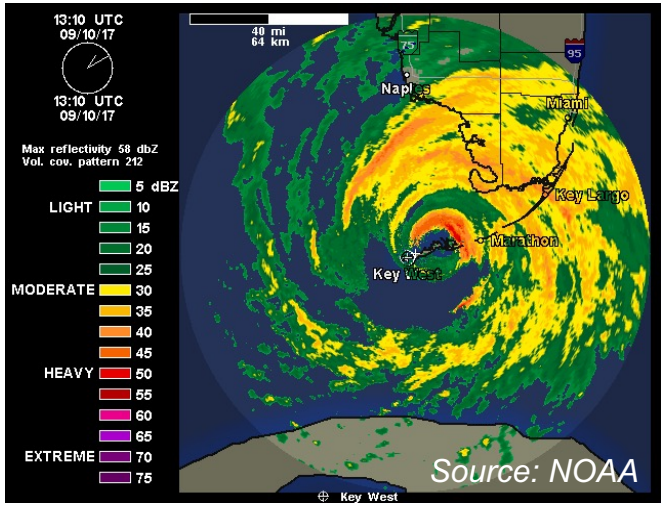
Previous work:

- Completed initial wind field model by fitting the model to available surface-level meteorological observations
- Developed methodology for adaptation of model to handle better strongly asymmetric wind fields and incomplete data
- Developed methodology for optimization of model fitting to observed data, including assessment of goodness of fit and quantification of uncertainty



Peak gust wind speed in flat terrain during Hurricane Maria (Initial wind field model)

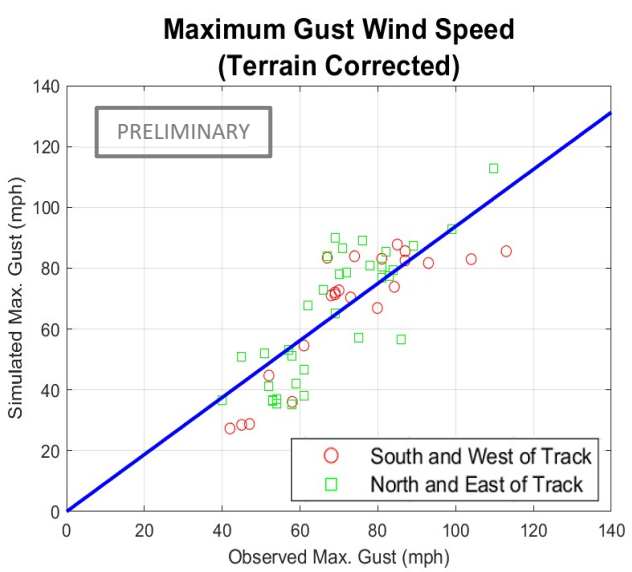
Asymmetric hurricane flow field



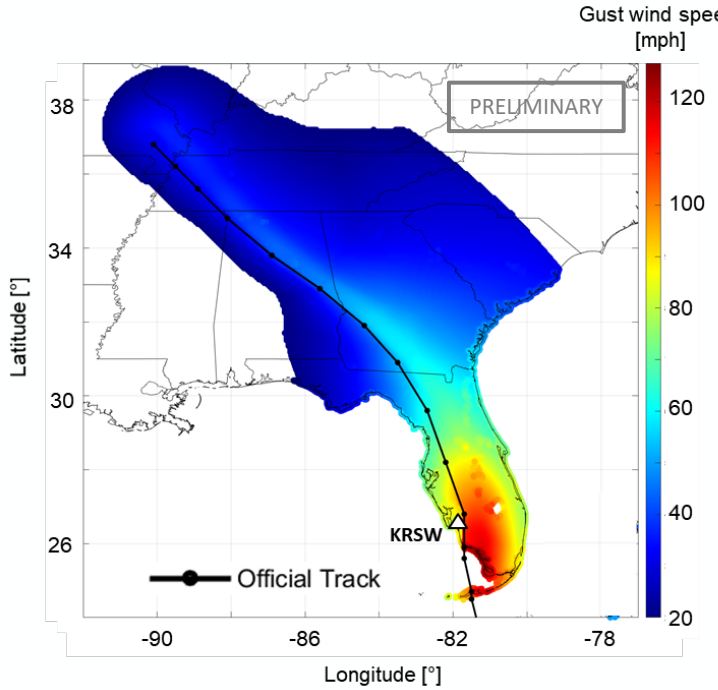
A new Peak Factor was developed to improve the hurricane model fit to account for asymmetries in the wind field

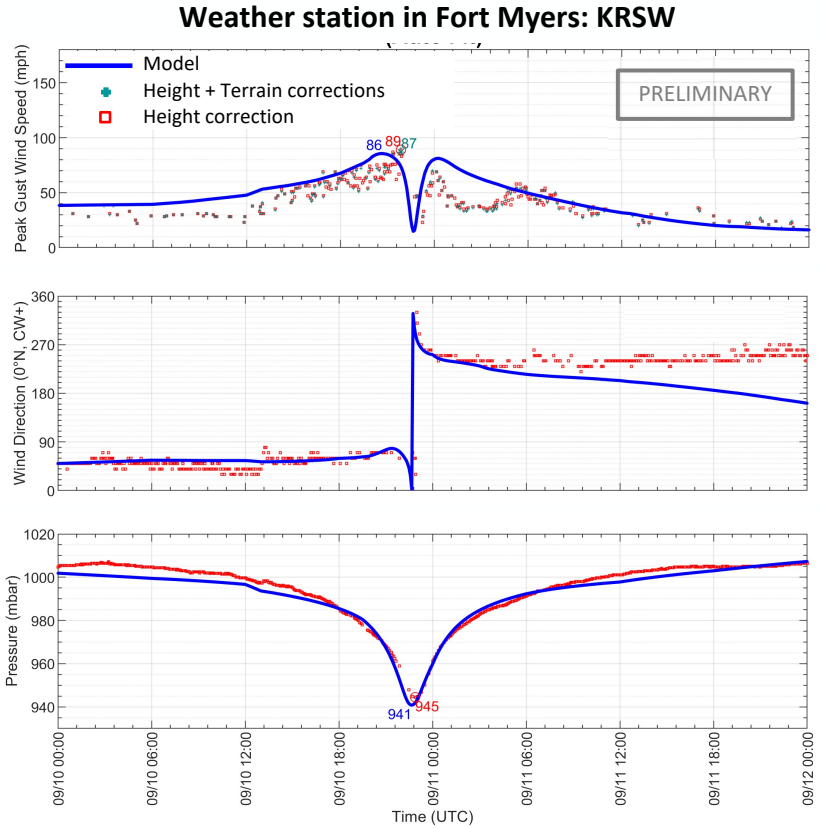
Wind Field Modeling: Recent Progress

- Completed adaptation of hurricane model application to handle better strongly asymmetric wind fields and incomplete data
- Tested the procedures for automation and optimization of model fitting to observed data on several historical hurricanes (Irma, Michael, Dorian)



1 mph = 0.447 m/s

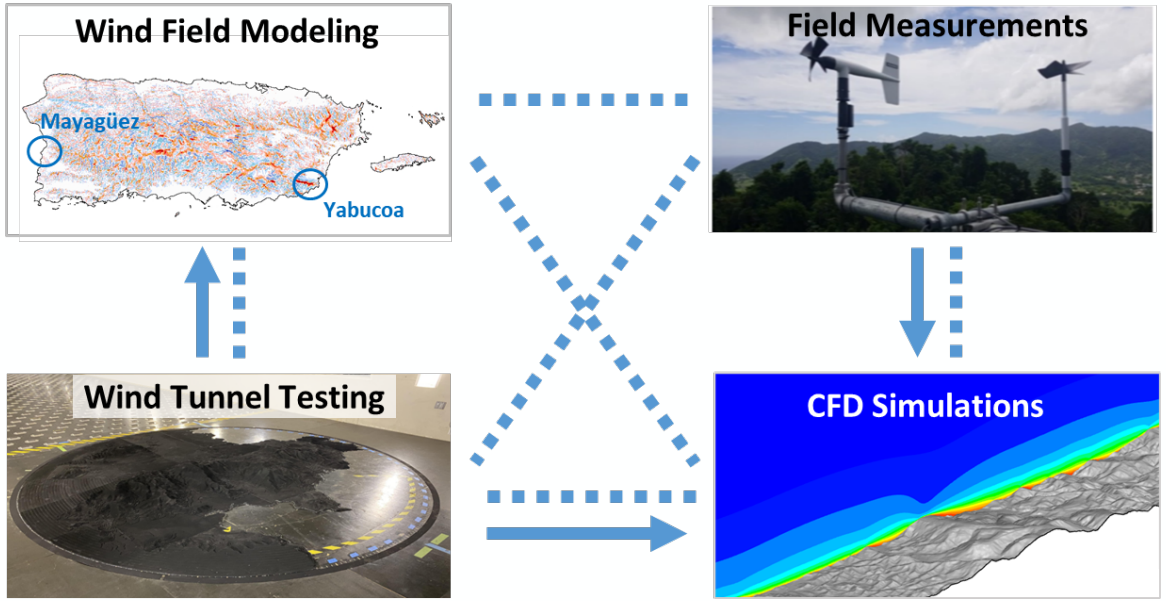




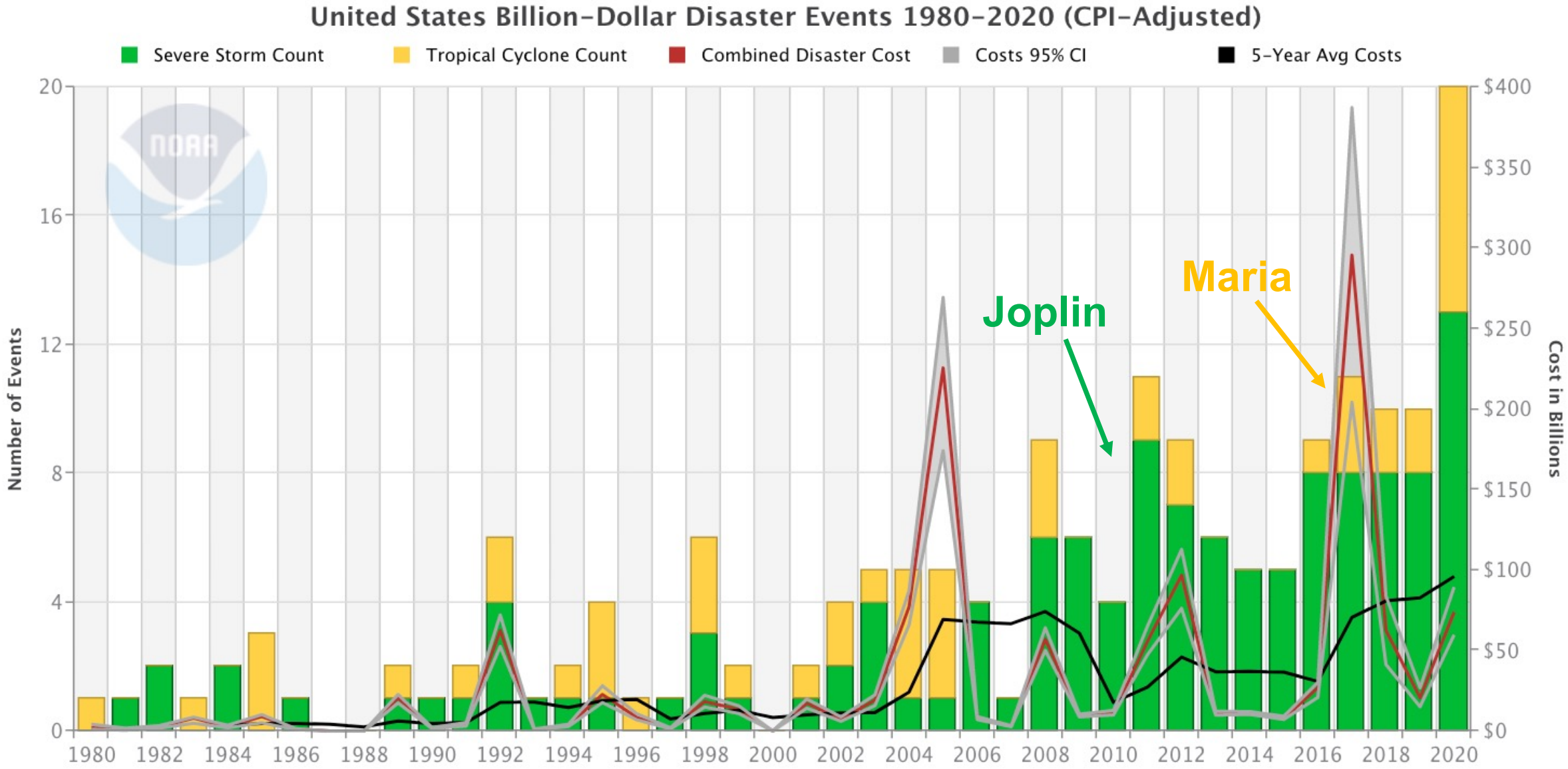
Hurricane Irma: Automatic fitting test (9 iterations to convergence)

Wind Hazard: Next Steps

- Complete wind tunnel testing and CFD simulations of generic topographic and Mayagüez models and perform comparisons for validation and refinement of CFD models
- Analyze measured data from wind tunnel testing and field measurements for the Yabucoa region and compare the measured data with CFD simulations for validation of CFD models and evaluation of topographic effects on wind speed profiles
- Complete the final wind field model of Hurricane Maria based on modeling improvement and updated consideration of topographic speedup effects, once the experimental topographic speedup data has been obtained and analyzed



Motivation: Characterizing Wind and Water Impacts

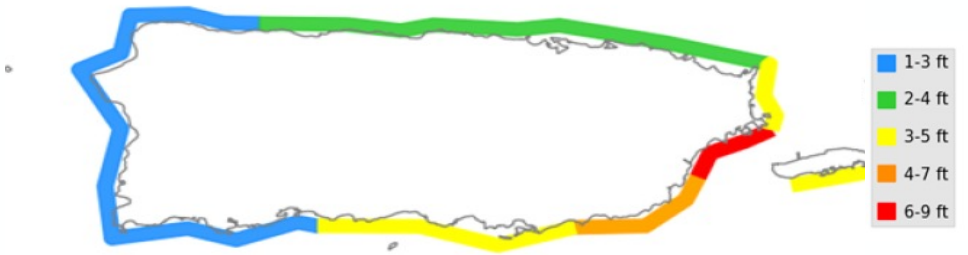


Other Hazards

Project Plans

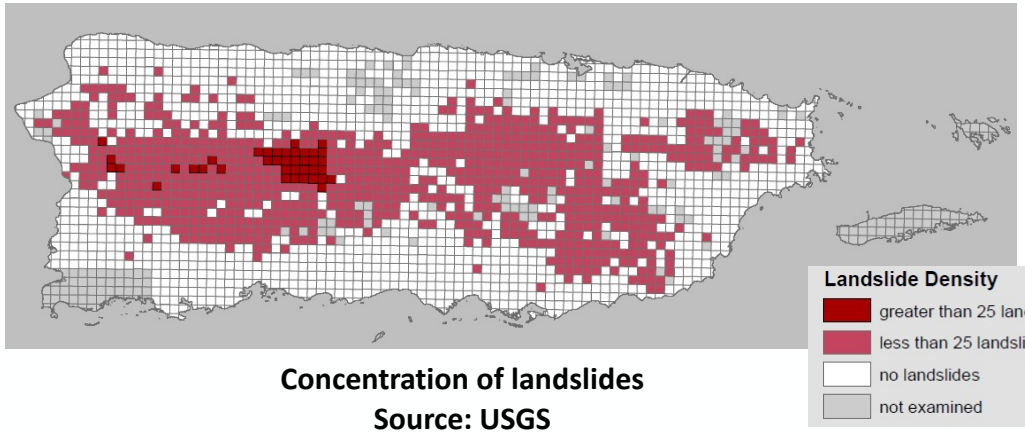
Other Hazards

Evaluate additional data and models to identify the best available characterization of the other hazards associated with Hurricane Maria including rainfall, landslides, flooding, and storm surge.

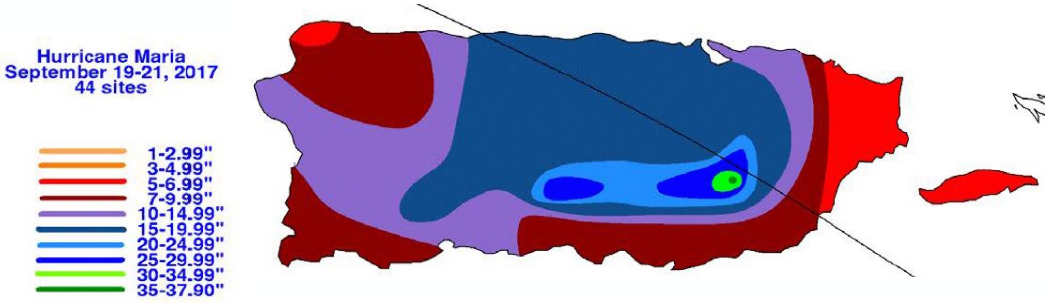


1ft = 0.3048m

Inundation above ground level
Source: NOAA/NHC



Concentration of landslides
Source: USGS



1in. = 25.4 mm

Precipitation in inches
Source: NOAA/WPC

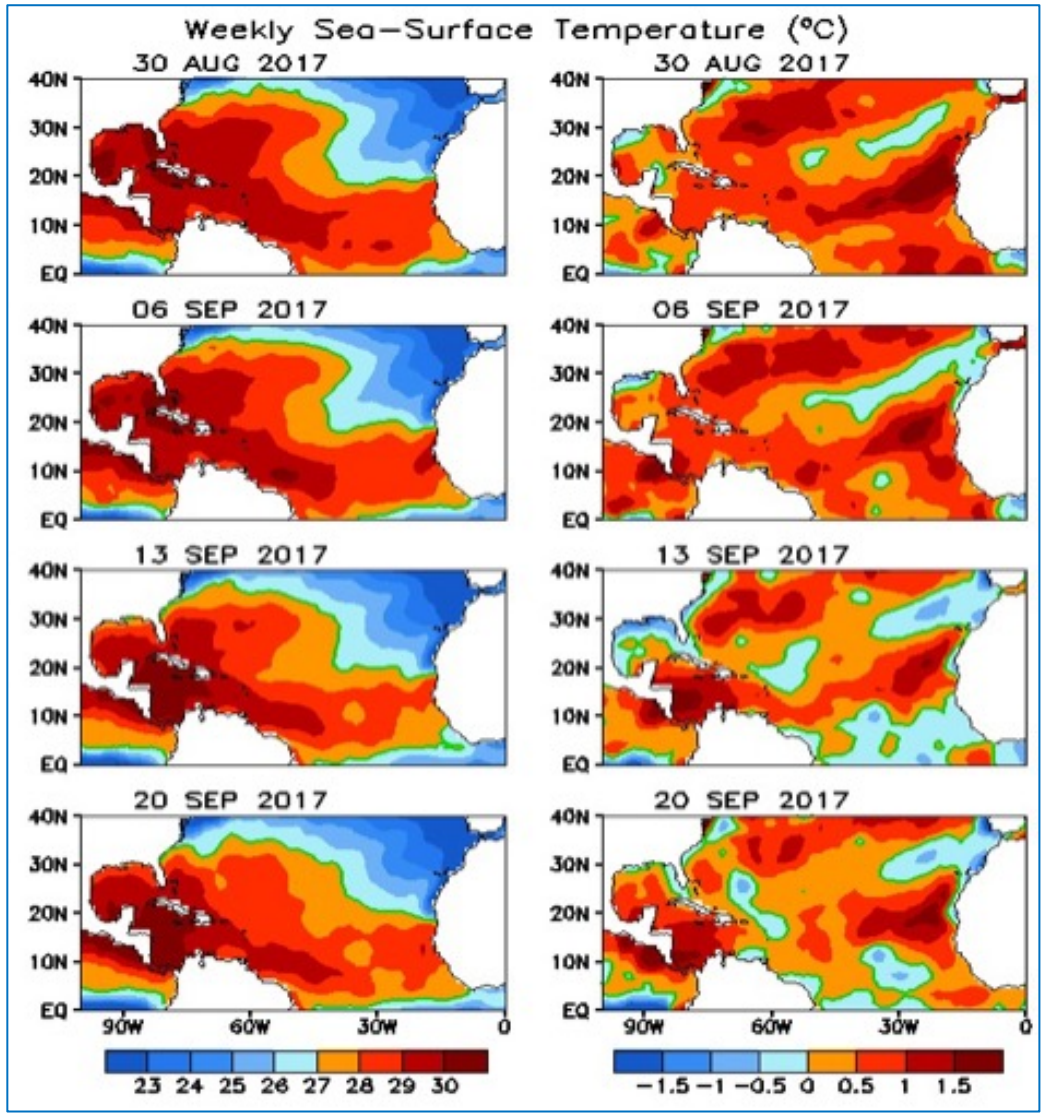
Recent Progress: Other Hazards

- Expanded the description of the meteorological history of Hurricane Maria to include the short-term climate factors underpinning the 2017 hurricane season
- Compiled and evaluated official National Weather Service forecast products issued weeks to days prior to Hurricane Maria's landfall
- Conducted sub-daily comparisons of space-based and ground-based precipitation data in Hurricanes Irma and Maria
- Initial draft completed of report sections on multi-hazard assessment of Hurricane Maria in collaboration with NWIRP postdoctoral research scientist and technical consultation with NASA lead project scientist for the Global Precipitation Measurement Mission (GPM)

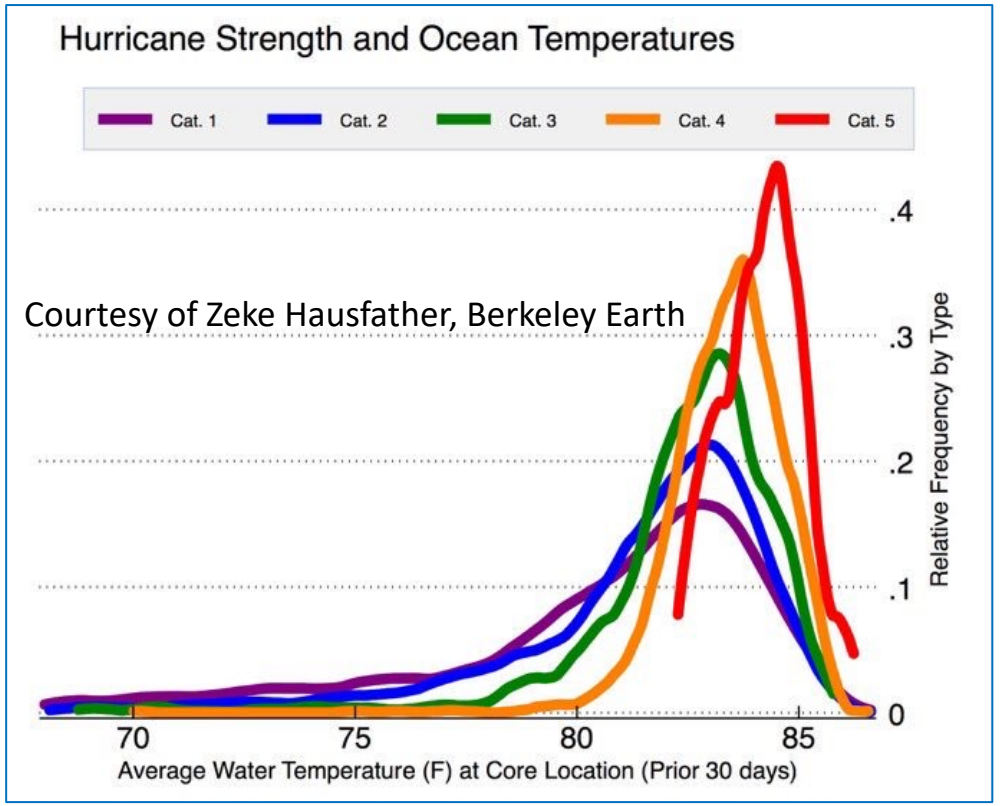
Recent Progress: Climate Factors

Expanded the description of the meteorological history of Hurricane Maria to include the short-term climate factors underpinning the 2017 hurricane season

Weekly Mean Weekly Anomaly



Data from NOAA Climate Prediction Center



The Rapid intensification of Hurricane Maria was explosive jumping from a category 1 to category 5 in 24 hours with an 80 mph wind increase

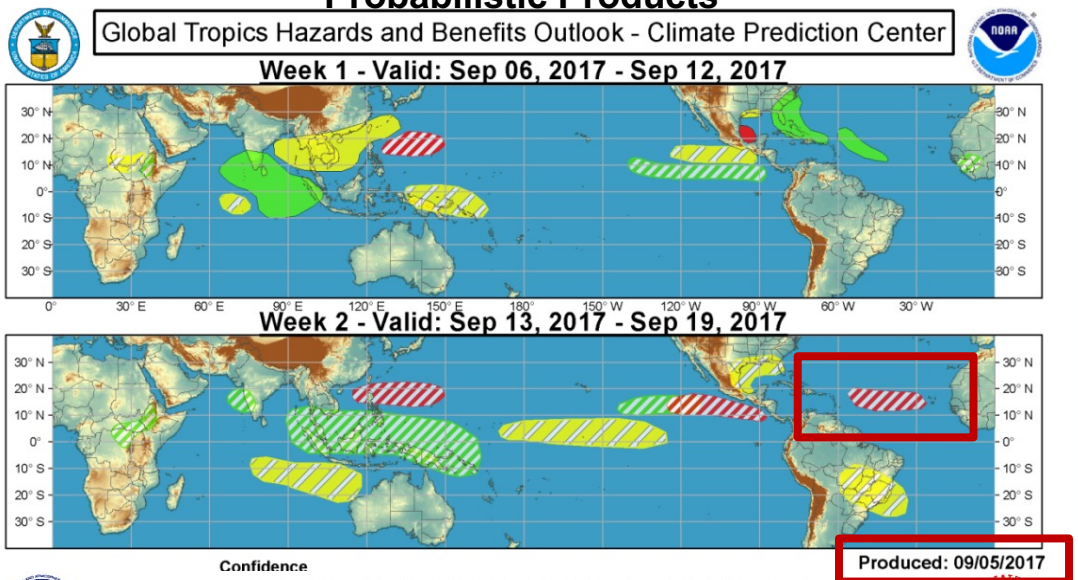
Other Hazards

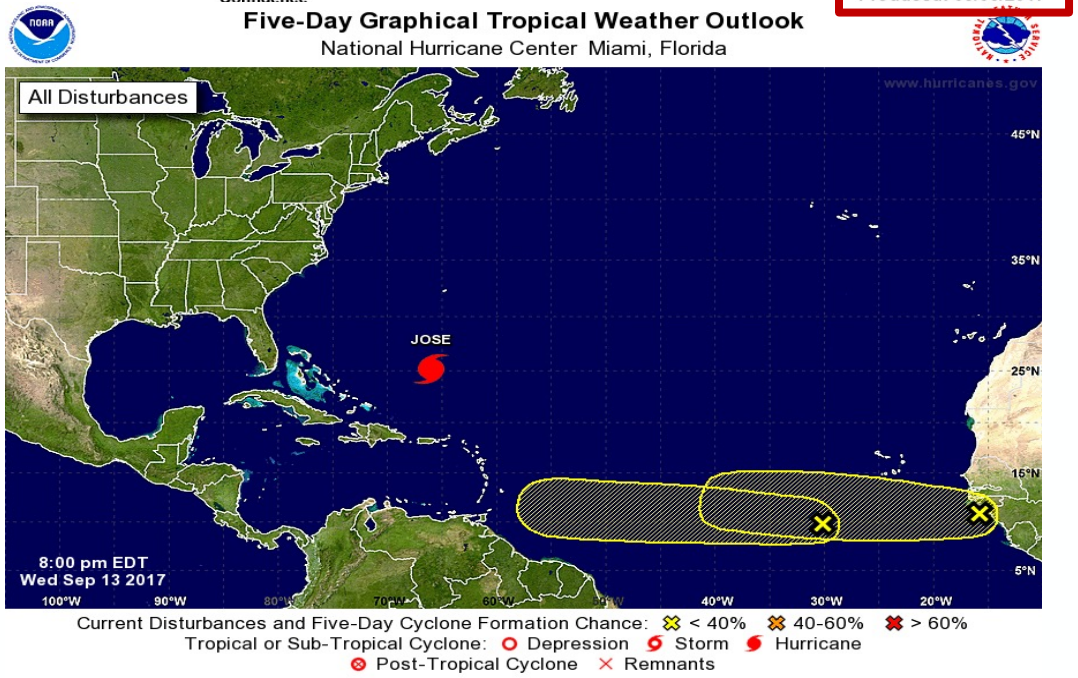
Recent Progress: Official Forecast Products

Compiled and evaluated official National Weather Service forecast products issued weeks to days prior to Hurricane Maria's landfall

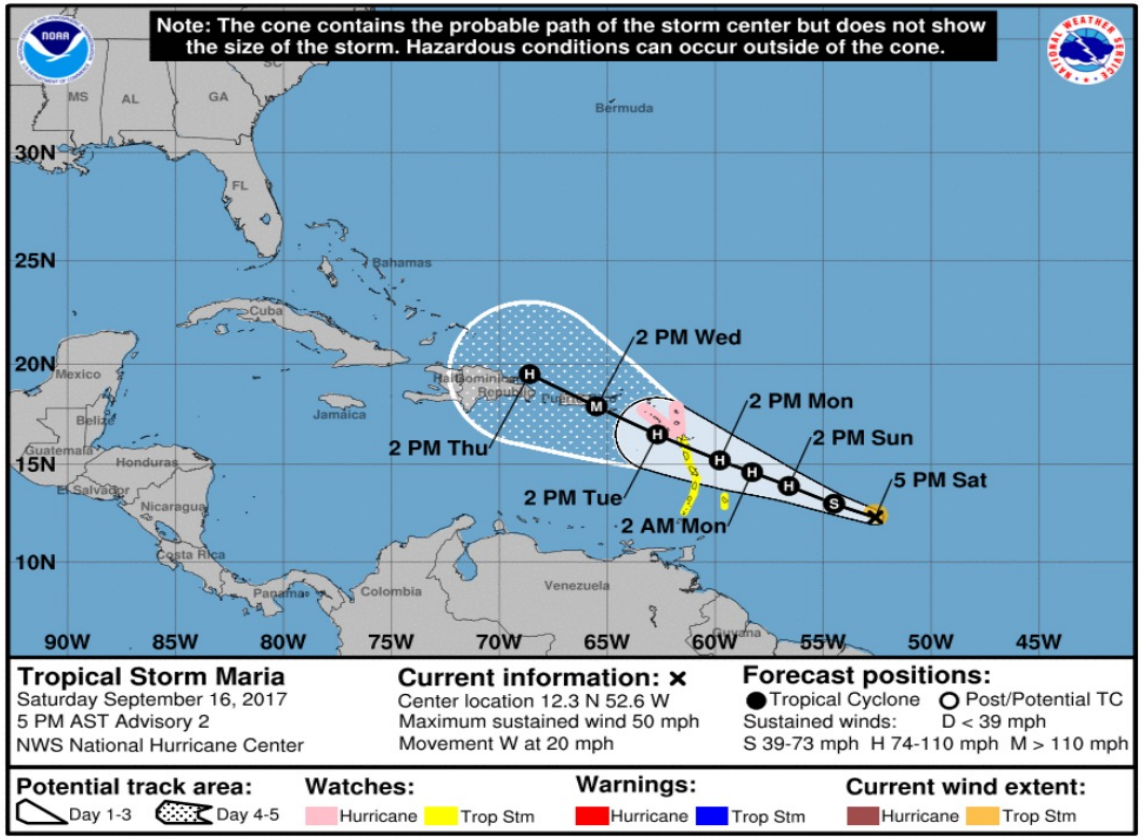
Other Hazards

Probabilistic Products

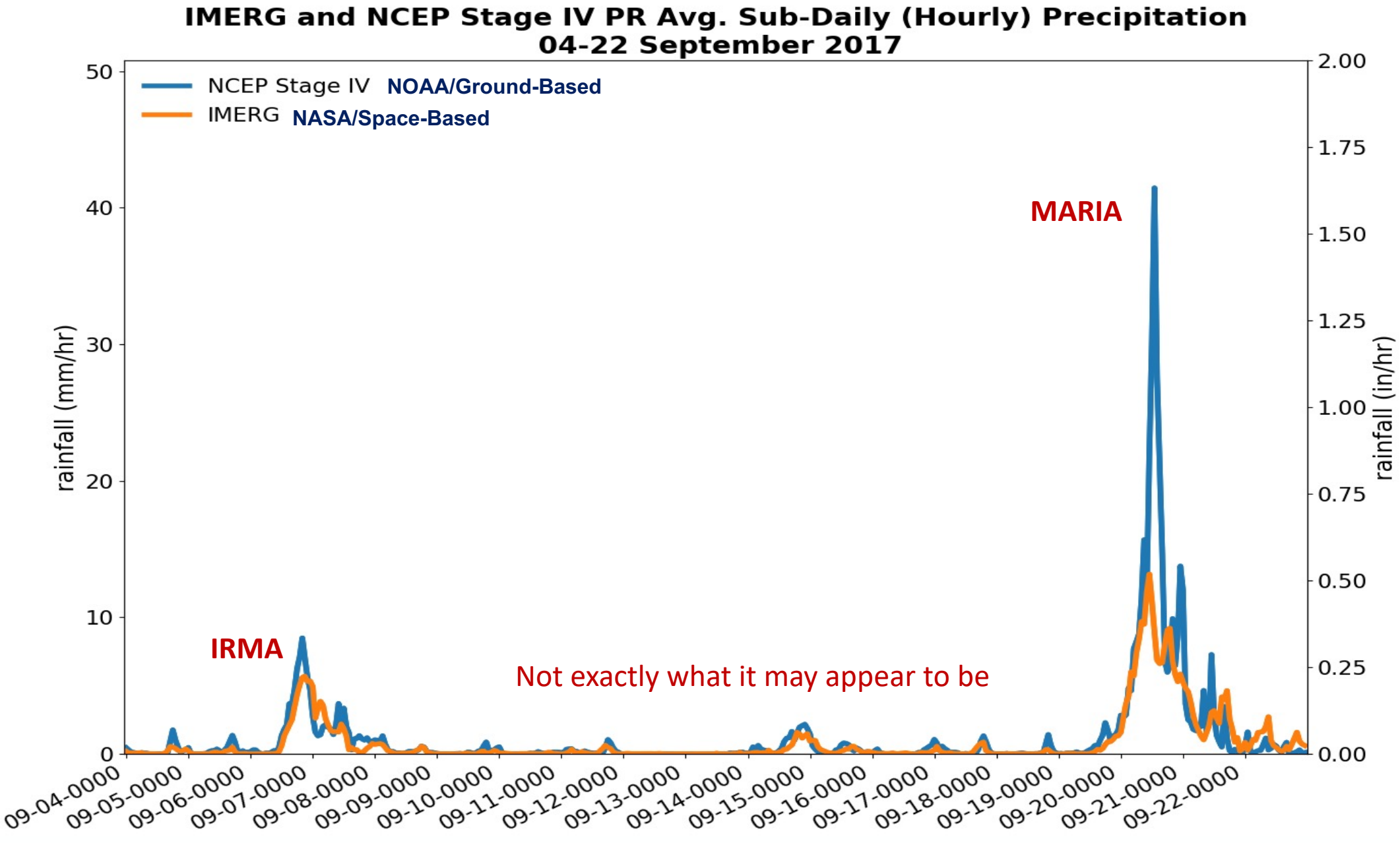




Deterministic Product

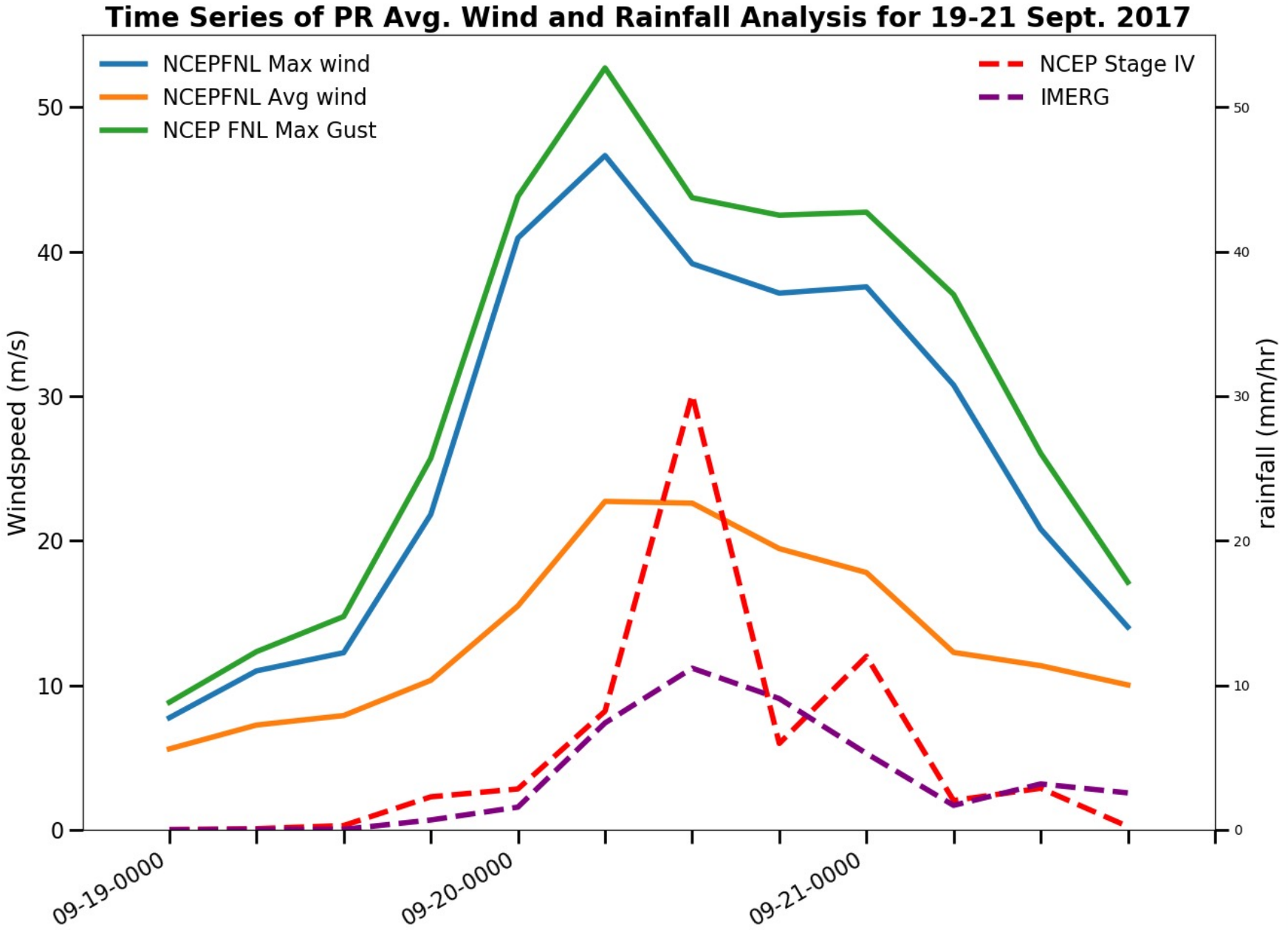


Recent Progress: Precipitation Data Analysis



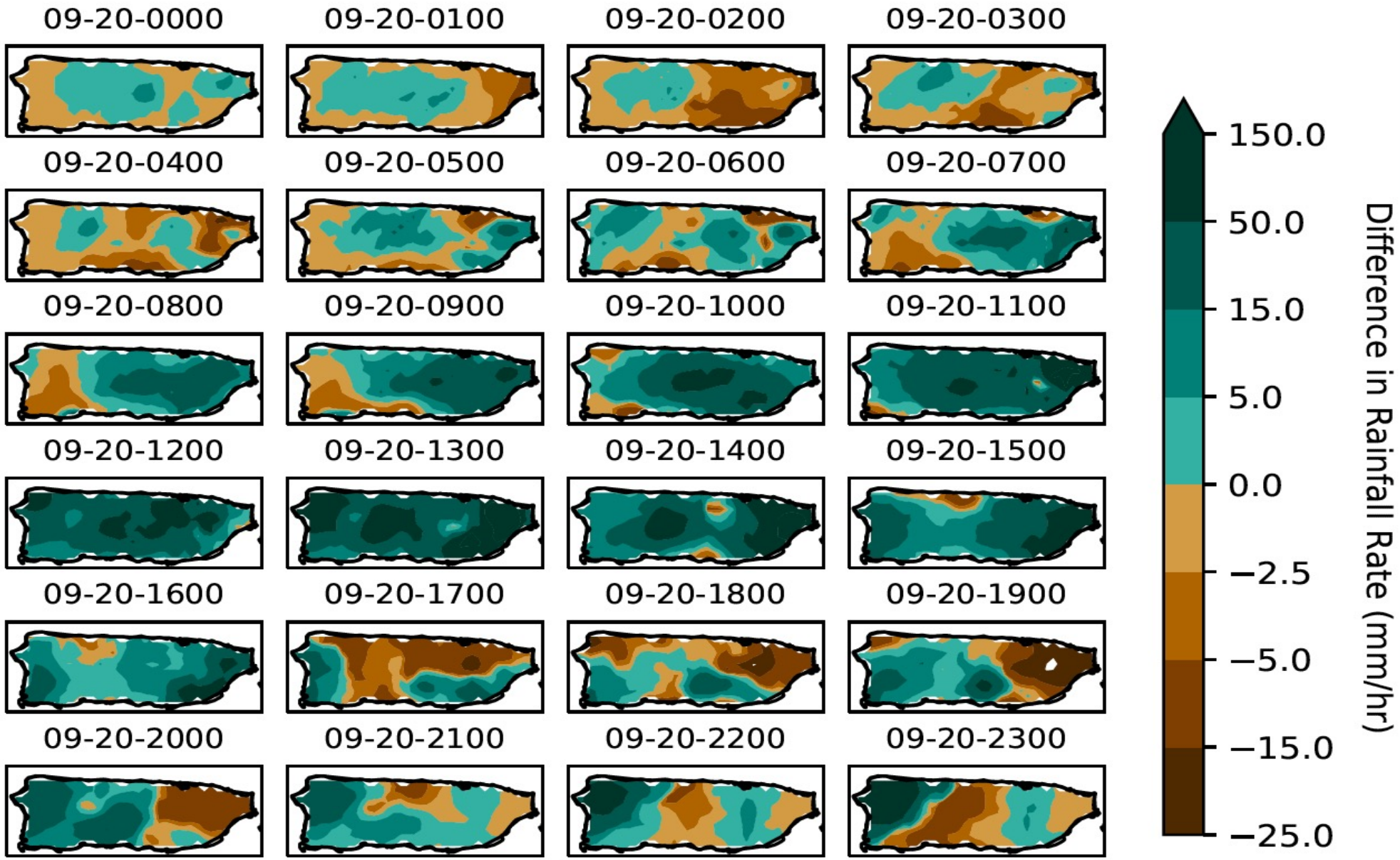
Other Hazards

Recent Progress: Precipitation Data Analysis



Other Hazards

Recent Progress: Precipitation Data Analysis



Other Hazards: Next Steps

Rainfall Measurement Science:

- Finalize comparative analysis of all ground-based and space-based rainfall measurement platforms for Hurricane Maria
- Conduct climatological analysis of rainfall data sets to contextualize the historical magnitude of Hurricane Maria's rainfall

Flood Hazard Data Collection:

- Analyze available sources of flood risk and event-based flood data
- Collaborate with academic scientists to assess the impact of variable rainfall measurements on flood modeling methodologies

Cross-Project Collaboration:

- Provide regular briefings to Hurricane Maria team on emerging results
- Revise other hazards report to reflect new research results and feedback for Hurricane Maria team

NCST Technical Investigation of Hurricane Maria's Impacts on Puerto Rico

Hazard Characterization Project

Project Leaders: DongHun Yeo and Scott Weaver
Project Team: Joe Main, Marc Levitan, Dereka Carroll-Smith, Rameche Somassoundirame

Questions?

Please 'raise your hand' using the Blue Jeans Participant window and unmute your audio and video