NOPP

National Oceanographic Partnership Program

SUMMARY OF THE 2024 NOPP HURRICANE COASTAL IMPACTS (NHCI) PROJECT FORUM SERIES

Held virtually as part of the ongoing

NOAA Coastal Ocean Modeling Science Seminar Series

June - July 2024

THE NATIONAL OCEANOGRAPHIC PARTNERSHIP PROGRAM

The National Oceanographic Partnership Program (NOPP) was established by Congress in Fiscal Year 1997 to promote the goals of ensuring national security, advancing economic development, protecting quality of life, and strengthening science education and communication by improving knowledge of the ocean (Public Law 104-201, 10 U.S. Code §7901-7903 and more recently, Public Law 116–283, §1055(b)(2)(A)). These goals are accomplished through partnerships among Federal agencies, academia, industry, and non-governmental organizations. The program effectively advances national goals through the development of interagency initiatives and projects that span agency missions, research sectors, and scientific and technological disciplines.

PARTNERSHIP FORUMS

NOPP Partnership Forums, first established in 2022, are a component of NOPP focused on facilitating partnerships in ocean science, research, and education that address pressing ocean science topics and priorities. Partnership forums, convened individually or in conjunction with scientific conferences, are in-person or virtual meetings between Federal agencies, academia, and the private sector including industry, NGOs and philanthropic organizations.

Leveraging the preexisting NOAA Coastal Ocean Modeling Seminar Series, the NOPP Office hosted a series of 5 virtual sessions in June and July of 2024 for the public to learn about the contributions and activities of 9 teams on the NOPP Hurricane Coastal Impacts (NHCI) project. More information on NOPP Partnership Forums can be found here.

AN OVERVIEW OF THE NHCI PROJECT

As a federal Program Manager on the project, Reginald "Reggie" Beach was invited to give an overview of the project's history and intentions. The goal of the project is to enable better understanding and predictive ability of hurricane impacts in order to better prepare coastal communities for extreme weather events. Beach highlighted key achievements to date and described the makeup of each task's team. The five tasks detailed in the NHCI project funding call were as follows:

- Task 0: COAMPS-TC[1] Supplied Variables, at 4 km resolution, hourly, beginning 5 days from projected landfall
- Task 1: Digital Elevation Models (DEM), to include topography and bathymetry
- Task 2: Remote Sensing (collect imagery sufficient to image the entirety of the coastline each year, with localized imagery prior to, during and after any landfall for ground truth purposes)
- Task 3: In Situ Measurements (up to three teams to be funded, including equipment purchase, deployment, recovery and refurbishment)

[1] Coupled Ocean Atmosphere Model Prediction System-Tropical Cyclone

- Task 4: Wave, Surge, Sediment Transport (moveable bed), Structure Response Forecasting (WSSTSR Forecast); up to three teams to be funded. Only one team will be funded to utilize any one particular model

The team presentations given at the 2024 NHCI Forum Series are summarized below and organized by project task. Because the forum series took place at the beginning of 2024's hurricane season, the results discussed are primarily from Hurricanes Ian (2022), Idalia (2023), and Lee (2023) data. The series agenda can be found in Appendix I and recordings of the sessions can be viewed here.

TASK 0: WIND FORCING (COAMPS-TC)

James "Jim" Doyle and Jon Moskaitis (Naval Research Laboratory) presented on Real-time tropical cyclone prediction with Coupled Ocean Atmosphere Model Prediction System-Tropical Cyclone (COAMPS-TC) in support of NHCI. COAMPS-TC is a specialized version of the Navy's mesoscale numerical weather prediction (NWP) model and is designed to predict tropical cyclone (TC) track, intensity, and structure (wind radii). Doyle explained COAMPS-TC's real-time capabilities, development history, and Atlantic Basin performance to the session attendees. COAMPS-TC is run operationally at the Fleet Numerical Meteorology and Oceanography Center (FNMOC). There is also a deterministic version that utilizes a US Navy global model called NAVGEM (Navy Global Environmental Model) and this version is denoted as COTC. CTCX is another version which is almost identical to COTC except that it is being driven by the NOAA Global Forecast System (GFS) as the parent model. Doyle emphasized that the CTCX track and intensity performance is competitive with GFS (among one of best track models in the world), HWRF and HMON (NOAA high-res models). Finally, Doyle highlighted they provided real-time support for the NHCI project by running deterministic COAMPS-TC in which they ran it at 4 km resolution and supplied fields every hour up to 120 hours.

Moskaitis discussed COAMPS-TC performance on Hurricane Ian (2022) and Idalia (2023) as well as gave an overview of the COAMPS-TC ensemble. All CTCX track forecasts issued within five days of the South Carolina landfall correctly indicated that Hurricane Ian would emerge off the Florida east coast and make a second U.S. landfall in SC. CTCX forecast positions at the time of observed landfall were not perfect, but typically had errors that were superior to the National Hurricane Center (NHC) long-term average. For Hurricane Idalia, COAMPS-TC performed very well for its track, with only a slight bias to the west of the observed landfall location. Also, COAMPS-TC consistently predicted a scenario of rapid intensification up to landfall, which is what was observed for Hurricane Idalia (see Figure 1). Moskasitis finally gave a brief overview of the COAMPS-TC ensemble which consists of 21 forecast model runs at a given forecast initial time. He highlighted the NHCI Applications for COAMPS-TC ensemble including to use COAMPS-TC ensemble forecast to force an ensemble of coastal impact model runs (real-time or retrospective).

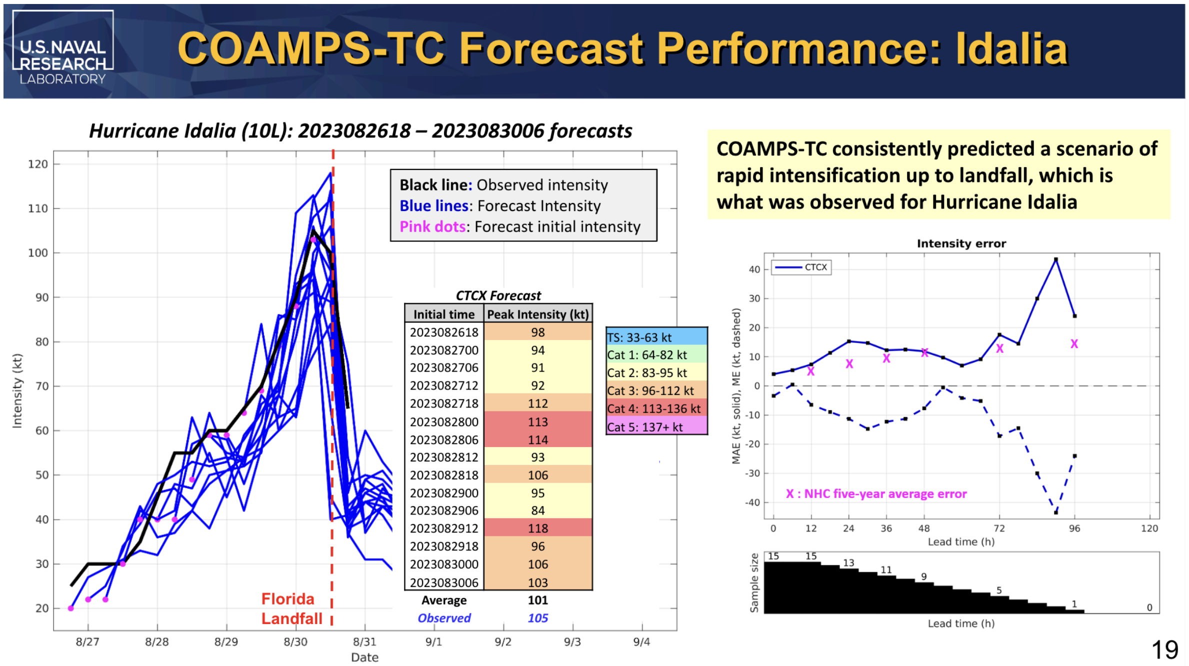

Figure 1. The COAMPS-TC forecast performance on Hurricane Idalia, as presented by Jim Doyle and Jon Moskaitis (Naval Research Laboratory) at the NHCI Forum Series on 06/18/2024.

During the Q&A portion, a question was asked about the use of data assimilation to determine the initial conditions. Doyle said that they rely on the information NHC provides such as the intensity, position, etc. He emphasized that it's not a traditional data assimilation system but that they do rely on GFS's initial state which uses data assimilation in conjunction with the synthetic vortex approach that accounts for the characteristics of the vortex as analyzed by NHC. Another attendee asked where the COAMPS-TC takes the ocean boundary conditions from. Doyle stated that COAMPS-TC is coupled to the NRL coastal ocean model, NCOM, and it takes its boundary ocean conditions from the global HYCOM model. Another question was asked about if/how they initialize the NCOM model in order to make sure it's on track. Doyle stated that NCOM utilizes a data assimilation system called the Naval Coastal Ocean Data Assimilation (NCODA) and can assimilate all the available ocean observations that are there in real-time. Finally, Doyle and Moskaistis were asked if they can describe a little more in how they generate the ensemble and what they perturb to generate it along with the variables used. Moskaitis went into more detail, explaining a number of perturbations for the ensemble including at the synoptic scale, the vortex, forecast, and on the model itself.

TASK 1: DIGITAL ELEVATION MODELS (DEM)

Dean Gesch (U.S. Geological Survey (USGS)) presented on Coastal Elevation Models and Land Surface Variables for Forecasting Hurricane Impacts. Gesch emphasized that the greatest uncertainties are on the land, so his task addresses those land factors that affect forecasting impacts, with a strong focus on remote sensing to inform topobathymetric digital elevation models (TBDEMs) with vegetation characteristics, sediment type and grade, and structures and infrastructure types. TBDEMs are a merged rendering of both topography and bathymetry to provide an integrated seamless elevation product. Gesch said that elevation data sources include light detection and ranging (Lidar), Structure-from-Motion (SfM), and bathymetric sonar (acoustic). He described the Coastal National Elevation Database (CoNED) Applications Project by USGS (see Figure 2) and the Continuously Updated DEMs (CUDEMs) by NOAA NCEI, both of which are used to inform models used to help predict how land factors might be impacted by hurricane landfall.

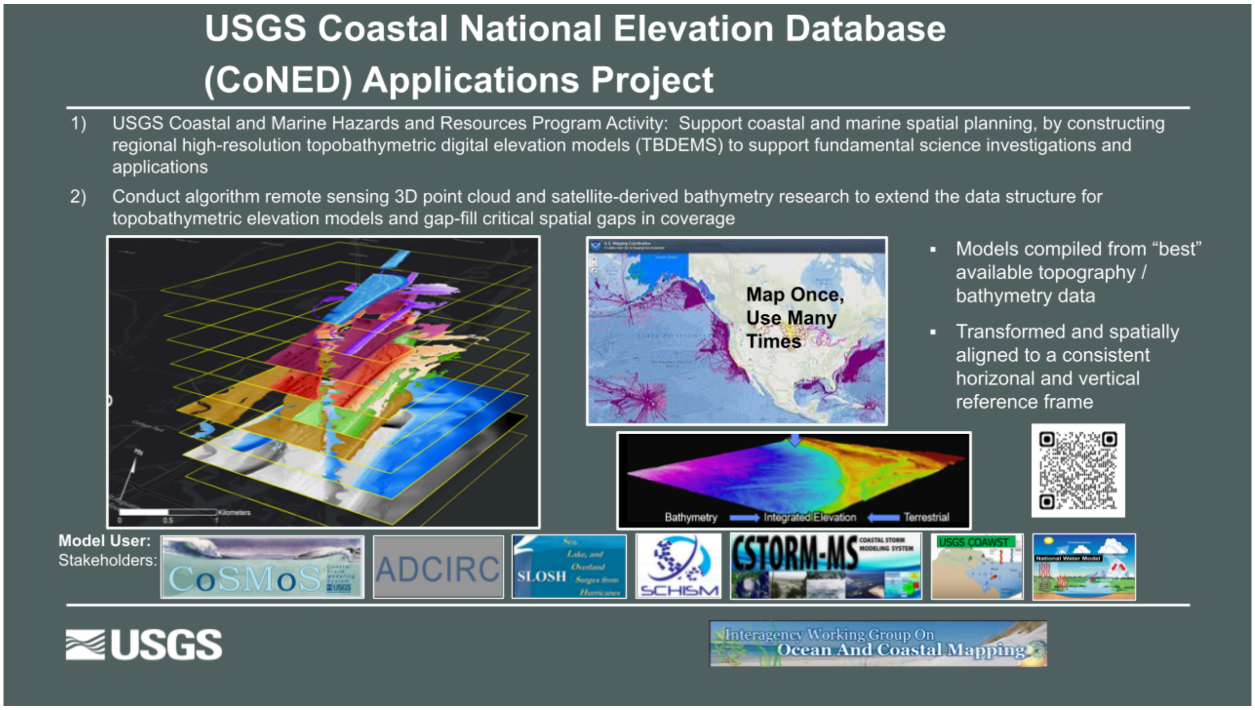

Figure 2. The Coastal National Elevation Database (CoNED) Applications Project by U.S. Geological Survey (USGS), as presented by Dean Gesch (USGS) at the NHCI Forum Series on 06/25/2024.

Gesch highlighted the importance of being able to trace back to the source data contributing to these models and the variable accuracy of those data. He also mentioned the importance of keeping models up to date with new data and discussed gaps in data, such as with river bathymetry variables further inland upstream. Gesch presented different model methods and outputs. Key takeaways included that coastal elevation error can be problematic for inundation estimation especially in coastal wetlands and that morphological variables such as beach width, slope, and shoreline variability tend to be more important than wave variables for estimating sediment type.

During the Q&A portion, a question was asked if there is a product that extends the CUDEM into the deep ocean, such as off the shelf break, with a consistent vertical datum for ocean modeling. Gesch confirmed that NOAA does have other products and nesting of models, such as the Coastal Relief Model, which do go further out, but they might have less resolution and the vertical datum might be incomplete.

TASK 2: REMOTE SENSING

Roland Romeiser (University of Miami) and Steven Beninati (University of Massachusetts at Amherst) presented on Remote Sensing of Hurricane Impacts from Space. Using synthetic aperture radar (SAR) imagery from various satellites, their team develops and evaluates techniques for a rapid assessment of changes and damages on land during and after hurricane landfalls. Beninati first gave an overview of coastal monitoring using a commercial SAR constellation which focused on waterline detection and topographic reconstruction. He noted that waterlines can be detected by finding pixels with a high gradient. He then discussed how waterline detection during Hurricane Ian (2022) was used using SAR and how it compared to USGS tide gauge observations. Beninati highlighted that SAR waterline estimations followed the trend of the tide gauge at some of their test sites. Next, he discussed using SAR Stereogrammetry for topographic reconstruction. Beninati noted that topographic height estimation is based on disparity (distance between corresponding pixels). The team applied this method at two sites: Monterey, CA and Panama Beach, FL. Overall, SAR is an effective tool for monitoring coastlines and further work includes improving detection of shoreline in cluttered areas.

Romeiser discussed utilizing TerraSAR-X Radargrammetry for rapid mapping of topographic changes. He presented results from Hurricane Ian (2022) in the Tampa Bay area and initial TerraSAR-X Radargrammetry Results for St. Petersburg, FL. Romeiser compared the Radargrammetry height with the Continuously Updated Digital Elevation Model (CUDEM) height before and after tuning. Next, he explained a waterline extraction example for Hurricane Idalia (2023) and wind retrieval examples for Hurricane Lee (2023). Key takeaways included that Radargrammetry products provided by Airbus are in good agreement with lidar-based reference topography (NOAA-CUDEM) after simple tuning and effective spatial resolutions and small-scale accuracy still needs to be determined.

During the Q&A portion, a question was asked if the wind fields are real-time. Romeiser stated that the RCM array image in his presentation was acquired from a Canadian satellite and the wind field represents the wind field at the time of the image acquisition. Regarding real-time, he noted they don’t receive these images instantaneously because they have to receive the image and process the image. This process can take about a few hours after they have the image acquisition. Romeiser also confirmed that the winds are 10m winds.

TASK 3: IN SITU MEASUREMENTS

Jim Thomson and Jacob Davis (Applied Physics Laboratory (APL), University of Washington) as well as Isabel Houghton (Sofar Ocean) gave a presentation on Buoy observations of wave spectra in hurricanes. Thomson explained that his team studies waves because they modify the air-sea exchanges of heat and moisture which fuel hurricanes, hurricane waves endanger ships and damage infrastructure, contribute to coastal storm surge and flooding, and historically have been difficult to measure. He described how they deploy Sofar Ocean Spotter and microSWIFT buoys, the second of which can be deployed from dropsonde tubes out of the US Navy airplanes when open door deployments aren’t feasible. They made critical observations of Hurricane Idalia (2023)’s extreme waves, sea surface temperature, and barometric pressure with high spatial coverage as it approached Florida’s Big Bend coast.

Davis discussed studying hurricane wave slopes for his doctoral dissertation because they are essential in the parameterization of deep-water breaking processes and can be used as a proxy for roughness and form drag. By analyzing Hurricane Ian (2022) deployment data, he found that wave slopes saturate at high winds and correlate with wind-wave alignment. He concluded that capturing these physics helps move the forecasting community towards a sea-state dependent drag parameterization.

Houghton shared a Sofar Ocean schematic which maps out how buoy surface observations can be assimilated and analyzed to improve forecasting. She noted that their buoys are uniquely directional, allowing wave period and direction information resolved by buoys to inform spectral wave model skill.

As part of the Q&A period, Davis clarified that his wave slope is an integral quantity of mean square slope computing from a frequency spectrum, rather than a representative height over a representative length computation. Houghton then answered a question, saying that the buoys can measure observations into the nearshore environment, but that their assimilation model is not optimized for coastal data; Sofar is currently focusing on open ocean observations, and would need to augment their system to have nested grids. She also explained that their data assimilation schematic at a high level uses optimal interpolation but not on the bulk significant wave height, but rather every frequency bin of the five moments from the directional wave buoys. She added that the observations are hourly, and this higher frequency of data assimilation leads to higher fidelity. Thomson clarified that the drifters that Martha Schönau mentions in her talk gather directional information like the Spotter buoys.

Martha Schönau (Scripps Institution of Oceanography) presented on Offshore Wave Observations using Air-Deployable Directional Wave Spectra Drifters (DWSBDs & A-DWSDs). The team's work complements and adds onto the work of Thomson, Davis, and Houghton. Schönau emphasized that drifters are a great instrument to study hurricanes because they are easy to deploy, cost effective and dynamic. She discussed the types of air-deployable directional wave spectra drifters they use which include Directional Wave Spectra Barometer Drifters (DWSBDs) and A-size Directional Wave Spectra Drifters (A-DWSDs). She noted that at the beginning of hurricane season they put out a sustained array, have adaptive sampling to increase the observation rate, and can target extreme events with air deployments. Schönau discussed observations across Hurricanes Ian (2022) and Idalia (2023) and showed that the storm generated wave fields in the Gulf of Mexico differ based on the storm's strength and transit. A key takeaway was that storms can have significantly different alignment of swell and wind-waves compared to slower moving, open-ocean basin storms. Therefore, these observations are important.

During the Q&A portion, clarification was wanted on what WAVEWATCH III model output was used for Schönau's comparisons with drifter observations and she confirmed that NOAA's Atlantic gridded WAVEWATCH III model output was used for those comparisons. It was noted Schönau was comparing wind speed at 10m height and was curious how they convert from this surface to 10m winds. Schönau stated that the MiniMet drifters actually measure the wind at 3m and then they extrapolate to 10m and discussed in more detail where this has been compared.

Jenna Brown (U.S. Geological Survey (USGS)) and Isabel Houghton (Sofar Ocean) presented on Real-time and Observed Measurements of Hurricane-Induced Hydrodynamics and Flooding. Their task within the NHCI project is to collect in-situ, both real-time and recorded, measurements of hurricane-induced hydrodynamics and flooding which includes waves and water levels in the near shore. Brown emphasized that these observations are critical for providing ground truth observations and model validation. Brown explained that their team is trying to expand on the spatially dense sensor deployments by the USGS along the coast and provide detailed measurements or water levels and waves in shore-perpendicular transects. She then showed a graphic which displayed regions they are interested in covering (i.e., nearshore, surf zone, beach & dunes, and inland). Her team is particularly focused on collecting more observations seaward of the dune and extending out to the 20m depth contour which will allow them to relate the offshore forcing conditions in deepwater to the dynamic surf zone and shoreline conditions and the subsequent impacts on coastal barriers and communities. The approach her team took to meet the objectives included utilizing existing piers and other infrastructure for shore-based deployments. Brown touched on some of the challenges their team has had as well as highlighted ways her team has been able to overcome some challenges. One accomplishment has been the successful, rapid deployment of sensors ahead of Hurricanes Ian (2022), Idalia (2023), and Lee (2023).

Brown discussed the team's 2024 storm response plans which include shore-based and offshore deployments, using air-deployed Sofar Submersible Spotters, spanning both sides of projected hurricane landfall on the U.S. Atlantic or Gulf of Mexico coast 2-3 days prior to landfall. Houghton then explained the new instrument, Sofar Submersible Spotters, developed to allow the team to get new wave and water level observations from the nearshore. She emphasized that this new instrument is a fully subsurface bottom pressure sensor allowing us to observe waves and water levels that can be deployed from the air and doesn't have a surface signature really limiting the survivability of these extreme conditions at 20m. A key feature of this design is the rapid response deployability and capacity to have high spatial coverage. Houghton then showed the session attendees a mock-up of the general rapid response design for this project and discussed some of the ways they validate the observations from this instrument. She ended her presentation highlighting plans for 2024 and tests they already completed for preparation.

During the Q&A portion, a question was asked about having any monitoring of water levels, inland, up our rivers and into estuaries. Brown confirmed that USGS does operate and maintain some permanent gauges and stream gauges that are in the coastal area that also deploy rapid sensors in the inland waterways ahead of these major hurricanes and that data can be found on the USGS website or Flood Event Viewer (FEV). Another question asked about issues with the bottom pressure sensors drifting and how that issue is dealt with. Isabel stated that the time scale that they are interested in is not a concern and from their testing and validation of the RBR pressure sensor, they are extremely precise and calibrated. Since they are trying to measure storm surge over the course of 1-3 days, the drift should not really be impacting that in any way.

TASK 4: FORECASTING (WSSTSR)

Ap van Dongeren (Deltares) gave a presentation on Forecasting Hurricane Impacts on US Coasts, Including Uncertainties. van Dongeren discussed a modeling approach in which hurricane hazards and impacts can be forecasted using the Delft Super Fast Inundation of CoastS (SFINCS) (for storm surge and flooding), Hurrywave (for waves), XBeach (for morphological change), and FIAT (for structural damages). He showed results from Hurricanes Ian (2022), Idalia (2023), and Beryl (2024); for Ian results, he noted it's essential to include rain for accurate flood predictions, and for Idalia results, he mentioned there was some difference between the model and observations for smaller wave periods before the storm entered the Gulf of Mexico. He concluded that his team now has a forecasting system for the entire Gulf of Mexico and Eastern Seaboard that they can run deterministically for best track and probabilistically with ensemble members; it accurately predicts peak water levels within 10 cm of observations and accounts for uncertainty in land levels to create realistic flood extent and impact predictions, and these forecasts can be made within an hour using cloud computing.

During the Q&A section, a question was asked if van Dongeren's model could be used to estimate surface currents to aid in search and rescue, but he said that their SFINCS open-source compound flood model is primarily for water level and structure damage datasets. The lower resolution for this purpose allows the forecast to be updated quickly, but he said for surface currents they would likely need a model with much higher resolution. He also clarified that the Hurrywave model will be made available publicly online soon.

Rick Luettich (The University of North Carolina at Chapel Hill) presented on Predicting Coastal Impacts from Tropical Cyclones using the ADCIRC Prediction System. He explained how the modular system utilizes the MetGet multi-model meteorological API, XBeach for morphology change, and either ADCIRC+SWAN or ADCIRC+WWIII for waves and storm surge. Luettich mentioned that recent additions include coupling to either HEC-RAS or SFINCS to represent compound flooding. He shared data from Hurricanes Ian (2022) and Idalia (2023) to show how the US Navy's COAMPS-TC tropical cyclone meteorological model can be used to demonstrate capabilities and discuss ongoing directions of development.

For Hurricane Ian data analysis, ADCIRC+WWIII had more scattered significant wave height, whereas the ADCIRC+SWAN model over predicted. He noted that models predicting Hurricane Idalia wind speed showed more energy in the directional frequency spectrum than Spotter buoy observations revealed. When discussing Idalia data for maximum wind speed, maximum water level, and maximum significant wave height (Hs), Luettich said that while 60 min intervals are probably sufficient for forecasts, his team will be asking their US Navy partners for 15 min interval data to analyze after the hurricanes have passed.

During the Q&A period, Luettich elaborated that the tradeoff between 60 min and 15 min data output intervals is an optimization problem, as they become quite large data files that need to be transferred to users in a timely manner and forecasts themselves have inherent uncertainty regarding tropical cyclone intensity and track. Ideally there would be more frequent output as different sources of error can be reduced. Luettich also mentioned that each model has its own parameters, including the morphology model; his team tried running them with standard recommended parameters, and they need to prioritize because there's limited access to a lot of the data.

Maitane Olabarrieta and Arthriya Subgranon (University of Florida) presented on Forecasting Hurricane Impacts in the US East Coast and Gulf of Mexico. The main goal of their project is to build a forecasting system to ultimately predict the water levels, currents and ocean waves, but they also want to forecast the morphological changes and impacts on infrastructure. Olabarrieta discussed the forecasting system they use for the project which is based on the Coupled Ocean-Atmosphere-Wave-Sediment Transport

(COAWST) Modeling System. She then showed some results of their forecasting system for Hurricanes Michael (2018) and Ian (2022). The results of the predictions for Hurricane Michael were reasonable, although it was observed that the directional wave spectra were not that well captured. Olabarrieta noted that single daily forecasts need to be provided 5 days prior to hurricane landfall which can be a challenge and Hurricane Ian was used as an example to highlight these challenges. A key takeaway from their study was that forecasted waves and water levels are highly sensitive to small changes (~100 km) in TC track at landfall which can cause significant changes in their model results.

Subgranon next presented on forecasting damage to infrastructure. The motivation for this project is to be able to predict the potential damage hurricanes will have on residential buildings using Machine Learning (ML) techniques. She explained to the session attendees how her team defines damage as well as the ML approach used to make the forecasts on damage to infrastructure. Subgranon highlighted their novel framework: Building Level Damage Forecasting Coastal Events (BuiLD-FORCE) they use for damage forecasting and explained the information they need to collect (i.e., building and hazard features). She then showed an example of their forecasting framework being used on Hurricane Ian (2022). They found that the damage forecasting model made a good prediction in the Coastal Urban Areas but not the Barrier Islands which can be caused by uncertainty in the model and not taking into account the vegetation landscape.

During the Q&A portion, a question was asked about "building construction year" or the like as being one of the features because evolving building codes and practices would seem to make that valuable to consider. Subgranon confirmed that it is included as one of their features and explained the details of exactly how it is included.

ACKNOWLEDGEMENTS

The NOPP Office[2] thanks all of the speakers and attendees for their participation and engagement in the 2024 NHCI Forum Series. Special appreciation is given to Alexander Kurapov (NOAA) for assistance with coordinating logistics and allowing the forum series to take place as part of the preexisting NOAA Coastal Ocean Modeling Science Seminar series.

[2] Funding for the NOPP Office is provided via National Atmospheric Administration (NOAA) contract to Integrated Systems Solutions, Inc. (Contract/Task Order#1305M419DNCNA0016/1305M322FNRMA0216) and the U.S. Navy's Office of Naval Research.

Appendix I. 2024 NHCI Forum Series Agenda

Date	Time	Speakers
June 18, 2024	1:00 - 2:00 PM EDT	● Reginald "Reggie" Beach (Office of Naval Research) ● James "Jim" Doyle & Jon Moskaitis (Naval Research Laboratory)
June 25, 2024	1:00 - 2:00 PM EDT	● Dean Gesch (U.S. Geological Survey (USGS)) ● Jenna Brown (USGS) & Isabel Houghton (Sofar Ocean)
July 9, 2024	1:00 - 2:00 PM EDT	● Jim Thomson, Jacob Davis (Applied Physics Laboratory (APL)/University of Washington), & Isabel Houghton (Sofar Ocean) ● Martha Schönau (Scripps Institution of Oceanography)
July 16, 2024	1:00 - 2:00 PM EDT	● Ap van Dongeren (Deltares) ● Roland Romeiser (University of Miami) & Steven Beninati (University of Massachusetts at Amherst)
July 23, 2024	1:00 - 2:00 PM EDT	● Rick Luettich (The University of North Carolina at Chapel Hill) ● Maitane Olabarrieta & Arthriya Subgranon (University of Florida)