II. Project Details

1. Project Title (maximum 15 words):*

The title should clearly represent the project and help articulate the importance and goals of the project to a non-technical reader. Titles are a primary referent for projects. The titles of awarded projects will be announced publicly and should not sacrifice clarity for novelty.

Enhancing Gulf of Mexico Loop Current and hurricane forecasts through studying hurricane--Loop Current eddy interactions

2. Project Acronym (if applicable):

(No response)

3. Project Key Words (maximum 5 words):*

Loop Current, hurricanes, eddies, forecasting

4. The Problem (maximum 100 words):*

Please describe the research question, issue, and/or gap being addressed.

There are many views on the consequences of warm core and cold core eddies associated with the Loop Current (LC) in the Gulf of Mexico on hurricanes. But the impacts of hurricanes on the evolution of the LC and its eddies, the ensuing biogeochemical and ecosystem consequences, and the resulting societal consequences remain poorly understood. The improvement of hurricane forecasts depends upon proper representation of the LC and its eddies so we focus on understanding and representing their interactions with hurricanes.

5. Goal and Objectives (maximum 150 words):*

Please describe the overall project goal and its SMART (Specific, Measurable, Achievable, Relevant, Time-oriented) objectives.

We aim to understand the physical and biogeochemical impacts of hurricanes on the LC and its eddies through hindcast (years 1-2) and downscaled future climate simulations (years 3-5) with energy and tracer budget analyses. In situ (AUVs, gliders, ship-based hydrography, floats, PIES, and moorings) and satellite (sea-level from altimetry, bottom pressures from gravimetry, sea surface temperatures from GOES-16 and surface salinities from microwave) observations will reveal model deficiencies and will be prepared for assimilation (years 1-5). An ocean heat content product will be developed (years 1-2), as will the ocean data assimilation system, built on JEDI with HYCOM as the ocean model (years 3-5). The expanded and newly optimized hybrid ensemble-variational data assimilation system will assimilate all-sky satellite radiances and near-surface observations to improve hurricane forecasts (years 1-2). Observing system simulation experiments will reveal observational gaps and impacts (years 3-4) with the goal of coupled the ocean-atmosphere systems (year 5).

6. Approach (maximum 500 words):*

Please describe how the goal and objectives will be achieved.

While it is well known that warm core eddies impact hurricane intensity in the Gulf of Mexico (GoM), an outstanding problem is the question of how hurricanes impact evolution of the Loop Current (LC) and its eddies, and how these impacts may in turn affect marine safety and ecosystem processes. The consortium plans to study this two-way impact between LC and hurricanes, improve our understanding and prediction of LC and LC eddy dynamics in the GoM, and advance data assimilation (DA) capabilities in this region. This effort brings together LSU, experts in ocean observing systems and physical and biogeochemical ocean modeling, and OU, experts in hurricane data assimilation and modeling. With this combined expertise, the consortium will develop key insights into the interaction of hurricanes and the Loop Current system in the past and in the future, including the biogeochemical ocean impacts, while working with stakeholders to understand the broader impacts of these interactions. They plan to perform research and development, leveraging the state of the art NOAA HYbrid Coordinate Ocean Model (HYCOM) and Hurricane Analysis and Forecast System (HAFS), their associated data assimilation system,

and a suite of observations.

The consortium proposes to:

- Perform hindcast simulations to understand the impacts of hurricanes on the physics and biology of the LC and its associated eddies. This includes adding an ocean biogeochemistry module to the HYCOM ocean model component.
- Analyze in situ (AUVs, gliders, ship-based hydrography, floats, PIES, and moorings) and satellite (sea-level from altimetry, bottom pressures from gravimetry, sea surface temperatures from GOES-16 and surface salinities from microwave) observations to better understand the transport associated with warm core eddies (WCEs) and Loop current frontal eddies (LCFEs) and how well the model captures the atmosphere-ocean coupled physics associated with eddy modification
- Assess the impact of hurricanes on WCEs' and LCFEs' trajectories and intensity, and how this my impact marine infrastructure in the GoM
- Develop an ocean heat content product based on a machine learning algorithm and estimated with a combination of floats and satellite altimetry and gravimetry data in the GoM
- Import and further develop the JEDI HYCOM DA code to include assimilation of observations such as ocean heat content
- Downscale global climate model projections statistically based on historical examples of tropical cyclone-eddy interactions and CMIP6 model output
- Expand the hybrid ensemble-variational (EnVar) DA system for NOAA's HAFS to assimilate all sky satellite radiances (e.g. GOES-16) and to optimize the assimilation of existing and future near sea surface observations
- Conduct Observing System Simulation Experiments (OSSEs) and real data experiments to investigate impacts of novel observations on hurricane intensity, track, precipitation, near surface meteorological field prediction
- Study impact of improved ocean state estimate on hurricane prediction and develop toward coupled DA by using selected ocean observations
- Participate in collaborations to study the societal impacts of hurricanes and reveal how predictions of hurricanes and their associated ocean impacts can be used more equitably in the future
- Perform outreach and provide educational opportunities to underrepresented communities affected by hurricanes in the GoM region

7. Application (maximum 200 words):*

Please describe how the results from this project will be used and by whom.

Sensor operations and data collection will be performed with PAE collaborators, which will interface with the Gulf of Mexico Research Initiative Information and Data Cooperative (GRIIDC). The Earth Scan Laboratory (ESL) and the Wave-Current Information System (WAVCIS) at LSU collect real-time observations that are transmitted and relayed through the internet to the Gulf of Mexico Coastal Ocean Observing System every hour; these data will be used by the proposed project. Improved HAFS and HYCOM systems are expected to be delivered to US National Weather Service/NOAA for potential operational implementation. The improved forecasts will be used by our collaborators at Crowley and other shipping and energy companies to support safe operations of ships and FPSO units. Results will also be shared with researchers who study how to use forecast information in a more equitable manner across different communities. We will engage in outreach to communities that are underrepresented in the earth sciences to help build more trust in hurricane forecasts and encourage participation by members of these communities.

8. Consortium (maximum 500 words):*

Please describe how the project team is organized to ensure integration and the role and responsibilities of the different consortium members.

The consortium consists of four organizations with complimentary capabilities to achieve the specific GRP goals.

Louisiana State University's (LSU) Department of Oceanography and Coastal Sciences (DOCS) provides knowledge and research leadership in the GoM region for deepwater currents and meteorological understanding. Two LSU laboratories, the Earth Scan Laboratory (ESL) and the Wave-Current Information System (WAVCIS), provide a wealth of critical environmental measurements both above and below the GoM’s surface. ESL uses polar orbiting and geostationary satellites to quantify water surface temperature, circulation changes, water quality, sediment distribution and transport. ESL monitors deepwater currents, and high-velocity currents within Loop Current eddies that can disrupt oil collection on platforms in the Gulf. WAVCIS is a monitoring program that provides real-time data for meteorology

(wind, air pressure, humidity, etc.), water level (tide and storm surge), water velocity profiles, and waves or sea state which include wave height and period (or duration) off the Louisiana coast. WAVCIS investigates subsurface coastal currents using Acoustic Doppler Current Profilers (ADCPs) to take vertical profiles of fixed points in the water and measure water flow velocity. This information is transmitted back to the lab and relayed through the internet to the Gulf of Mexico Coastal Ocean Observing System every hour. LSU will be the overall leader for the team.

The University of Oklahoma (OU), through the National Weather Center (NWC), brings together OU's College of Atmospheric & Geographic Sciences (AGS), which includes the School of Meteorology (SoM) and the Department of Geography and Environmental Sciences (DGES), seven OU research centers, and five federal partners from NOAA, including the Storm Prediction Center and the National Severe Storms Laboratory. The AGS is known nationally and internationally as a center of excellence for severe weather research and prediction, including contributions to advanced NWP models and data assimilation, including NOAA's Finite Volume Cubed-Sphere dynamical core (FV3), HAFS, and HWRF. OU will support the investigation of the impact of hurricanes on LC prediction and perform Observation System Experiments (OSE) and OSSE experiments to improve hurricane forecasts.

PAE, LLC is a Technical Services and Operations and Maintenance (O&M) company that operates systems and sensors for a variety of high-tech Government customers including eight years as the NWS partner at NDBC for over 1000 at sea observing stations. PAE's team of engineers, scientists and technicians enhanced the NDBC mission with innovative approaches to sensor payloads and automated processing techniques and data quality assurance. PAE will lead the sensor operations and data collection and interface with the Gulf of Mexico Research Initiative Information and Data Cooperative (GRIIDC).

Crowley Maritime Corporation is the largest independent owner-operator of US-flag vessels in America providing transportation throughout the U.S. Gulf, East and West Coasts and Alaska. Crowley maintains a large and diverse fleet of 200 plus assets and also operates Floating Production Storage and Offloading (FPSO) vessels in the GoM. Impacted everyday by the weather, the company is a major user of the environmental data and forecasts for the safety and operation of their ships, FSPOs and wind generated energy.

Biographical Sketch

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A. Professional Preparation

University of California, Santa Cruz	Mathematics	BA 1996
University of California, Santa Cruz	Earth Science	PhD 2012
Oregon State University, Corvallis, OR	Oceanography	2012-2015
National Center for Atmospheric Research Boulder, CO	Ocean modeling	2015-2017

B. Appointments

09/21-	Assistant Professor, Louisiana State University, Baton Rouge, LA
09/18 – 08/21	Assistant Professor, University of Texas, Rio Grande Valley, Port Isabel, TX
09/17 – 08/18	Research Associate, University of Colorado, Boulder
06/15 – 08/17	Postdoctoral Researcher, National Center for Atmospheric Research, Ocean Section
10/12 – 06/15	Postdoctoral Researcher, Oregon State University

C. Products

(i) PRODUCTS MOST CLOSELY RELATED

1. Harrison, C.S., Glatzmaier, G.A., 2012. Lagrangian coherent structures in the California Current System – sensitivities and limitations. Geophysical & Astrophysical Fluid Dynamics 106, 22–44. https://doi.org/10.1080/03091929.2010.532793
2. Harrison, C.S., Long, M.C., Lovenduski, N.S., Moore, J.K., 2018. Mesoscale Effects on Carbon Export: A Global Perspective. Global Biogeochemical Cycles 32, 680–703. https://doi.org/10.1002/2017GB005751
3. Harrison, C.S., Siegel, D.A., Mitarai, S., 2013. Filamentation and eddy- eddy interactions in marine larval accumulation and transport. Mar Ecol Prog Ser 472, 27–44.
4. Rohr, T., Harrison, C., Long, M.C., Gaube, P., Doney, S.C., 2020a. Eddy-Modified Iron, Light, and Phytoplankton Cell Division Rates in the Simulated Southern Ocean. Global Biogeochemical Cycles 34, e2019GB006380. https://doi.org/10.1029/2019GB006380
5. Rohr, T., Harrison, C., Long, M.C., Gaube, P., Doney, S.C., 2020b. The Simulated Biological Response to Southern Ocean Eddies via Biological Rate Modification and Physical Transport. Global Biogeochemical Cycles 34, e2019GB006385. https://doi.org/10.1029/2019GB006385

(ii) OTHER SIGNIFICANT PRODUCTS

1. Brown, V., Gutknecht, J.L.M., Harden, L., Harrison, C.S., Hively, D.J., Jørgensen, C., Levi, T., Ugeisen, B.P., Rovengno, P., Wang, Y., Wiedenmann, J., Mangel, M., 2010. Understanding and engaging values in policy relevant science. Bulletin of the British Ecological Society 41, 48–56.
2. Harrison, C.S., Luo, J.Y., Putman, N.F., Li, Q., Sheevam, P., Krumhardt, K., Stevens, J., Long, M.C., 2021. Identifying global favourable habitat for early juvenile loggerhead sea turtles. Journal of the Royal Society Interface. https://doi.org/10.1098/rsif.2020.0799
3. Lovenduski, N.S., Harrison, C.S., Olivarez, H., Bardeen, C.G., Toon, O.B., Coupe, J., Robock, A., Rohr, T., Stevenson, S., 2020. The Potential Impact of Nuclear Conflict on Ocean Acidification. Geophysical Research Letters 47, e2019GL086246. https://doi.org/10.1029/2019GL086246

4. Sala, I., Harrison, C.S., Caldeira, R.M.A., 2016. The role of the Azores Archipelago in capturing and retaining incoming particles. Journal of Marine Systems 154, 146–156. https://doi.org/10.1016/j.jmarsys.2015.10.001
5. Scherrer, K.J.N., Harrison, C.S., Heneghan, R.F., Galbraith, E., Bardeen, C.G., Coupe, J., Jägermeyr, J., Lovenduski, N.S., Luna, A., Robock, A., Stevens, J., Stevenson, S., Toon, O.B., Xia, L., 2020. Marine wild-capture fisheries after nuclear war. PNAS. https://doi.org/10.1073/pnas.2008256117

D. Synergistic Activities

1. Earth System Model coordinator for FishMIP, an international fisheries model intercomparison project
2. Hispanic student outreach advisor for the 2021 CU Boulder Data Science REU
3. Lifetime member of SACNAS (Society for the Advancement of Chicanos and Native American Scientists)
4. Mentoring group leader for MPOWIR, (Mentoring Physical Oceanography Women to Increase Retention)
5. Currently funded to model the effects of extreme forcing on ocean biogeochemistry and fisheries using the CESM Earth system model, funded by the Open Philanthropy Project and NSF