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HURRICANES AND THE GULF STREAM

A Double Whammy Impact on Coastal Flooding

By Tal Ezer

Long-time residents of Norfolk and the Hampton Roads area remember the flooding caused by Hurricane Isabel (2003) which had the second highest storm surge on record.

Fewer people are alive to remember the largest storm surge ever recorded in Norfolk over 90 years of tide gauge measurement—this was the Chesapeake-Potomac Hurricane of 1933. Sea level rise (SLR) accelerates the frequency of minor tidal flooding (Ezer and Atkinson, 2014) and increases the number and intensity of storm surges (Fig. 1). Weaker storms that could be ignored in the past now cause major flooding with the additional SLR. If a hurricane with the same track and intensity as the hurricane of 1933 happened today, storm surge could reach ~2 m (~6 feet) over the highest tide level, with potential floods far exceeding any past storms.

In September 2018, ODU was spared the wrath of Hurricane Florence which was headed our way before making a left turn toward the Carolinas (nevertheless, as a cautious measure ODU closed and partly evacuated). But something unexpected did happen here—while Florence moved away from Virginia, the Hampton Roads area nevertheless experienced 2-3 weeks of minor tidal flooding (Fig. 2, page 2) even though the storm was nowhere in sight. New research at CCPO on the interaction between storms and the Gulf Stream (Ezer, 2018) may be able to shed light on this previously unexplained phenomenon.

Research at CCPO by Ezer, Atkinson and collaborators focused on the impact of ocean dynamics on coastal sea level and flooding. Ezer and Corlett (2012), Ezer et al. (2013) and Ezer (2013) were ODU's first publications on the subject after the establishment of the Climate Change and Sea Level Rise Initiative (initially led by L. Atkinson; now the new Institute for Coastal Adaptation and Resilience, ICAR). The early studies found a clear connection between long-term variability in the Gulf

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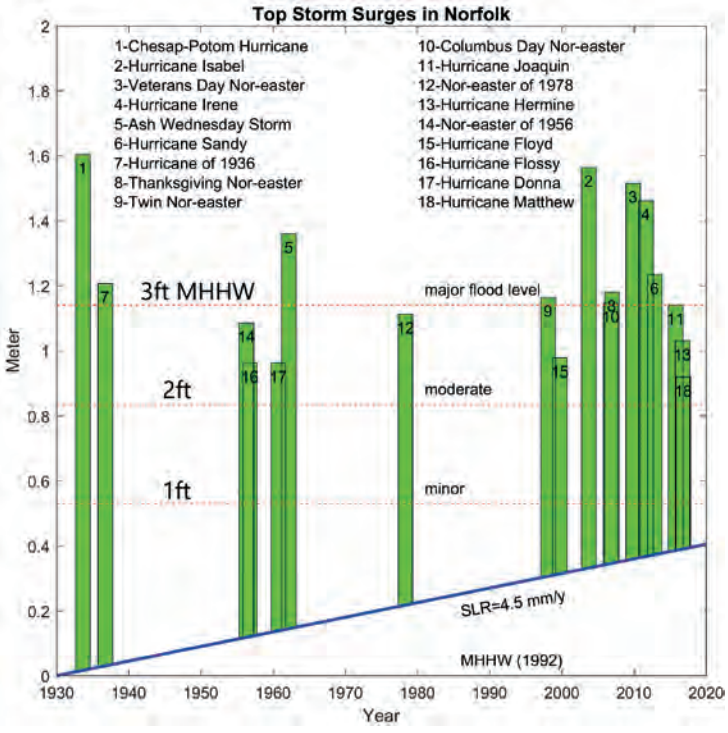

Fig. 1. The water level (relative to Mean Higher High Water [MHHW] in 1992) for the top storm surges as recorded by the Norfolk tide gauge (at Sewells Point). Note that over 60% of these storm surges occurred during the past 20 years while less than 40% occurred during the previous 70 years.

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Inside

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Figure 2: Car drives through flooded Botetourt Street in Norfolk, Virginia in September 2018 (hurricane Florence was over North Carolina at that time). Picture taken by T. Ezer.

HURRICANES | Continued

Stream (GS), the Atlantic Meridional Overturning Circulation, AMOC (Ezer, 2015) and coastal sea level. Coastal sea level is elevated during periods of weakening GS, associated with a decrease in the sea level slope across the GS or a shift in its position. These studies have implications for how future climatic changes in ocean circulation and potential slowdown of AMOC may impact our coasts.

However, the early studies did not explain short-term minor tidal flooding (often called "nuisance" or "clear day" floods) that are now commonplace in Norfolk. These floods are unpredictable and cause significant disturbances to transportation and damage to cars parked in or driven into salt waters (e.g., Fig. 2). Recent studies (Ezer, 2016; Ezer and Atkinson, 2017; Ezer et al., 2017; Ezer, 2018) tried to understand this phenomenon using numerical models, tide gauges, GS flow measurements and satellite altimeter data. The studies found that sudden weakening in the GS transport (measured by a cable across the Florida Strait) can predict minor flooding in Norfolk a few days in advance. The signal is propagated along the GS by fast-moving barotropic waves that trigger coastal trapped waves, so there is only a short lag between the detection of a change in the GS near Florida and elevated sea level on the U.S. East Coast downstream along the GS. These short-term variations can be due to natural oscillations associated with mesoscale activity or variations in the offshore wind, but also due to offshore tropical storms and hurricanes which disrupt the flow of the GS. The impact on the GS and flooding in Norfolk from hurricanes that did not make landfall in Virginia were seen during Hurricanes Sandy (2012), Joaquin (2015), Matthew (2016) and Florence (2018). Fig. 3, for example, shows the slowing down of the GS and elevated sea level in Norfolk during a period of three weeks after hurricane Florence hit the Carolinas' coasts.

The recent studies explained this "double whammy" impact of hurricanes: first comes the storm surge, and then the indirect impact of the hurricane on ocean dynamics, where a disruption of the flow of the GS by the hurricane can cause a period of minor flooding long after the hurricane disappeared. The studies show that it may take a few weeks for this mighty current to fully recover from the hurricane's impact. This research can help improve predictions of storm surge models and prepare for the impact of future sea level rise.

References

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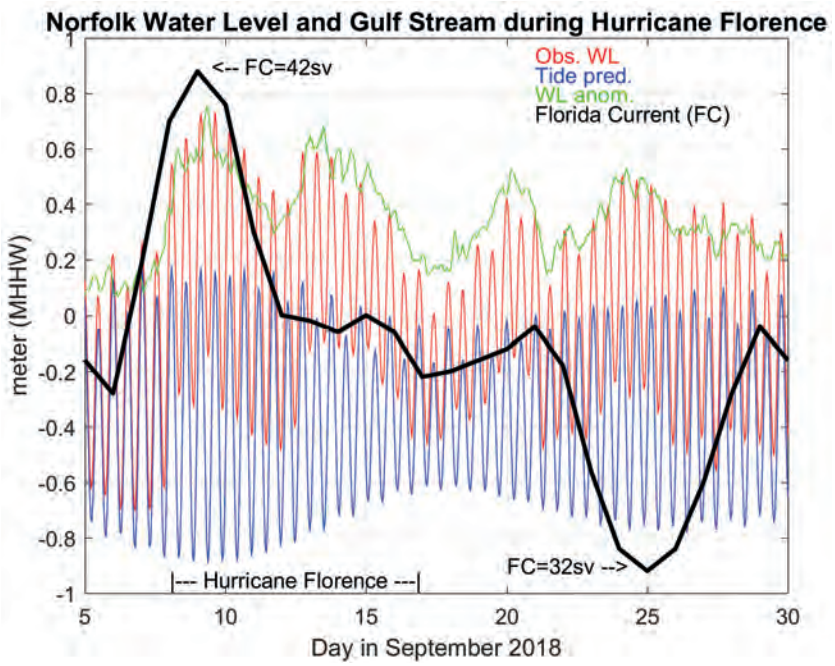


Figure 3: Hourly observed water level in Norfolk (red line) was well above the predicted tide level (blue line) following hurricane Florence. Measurement of the Florida Current shows a decline of ~30% (~10sv, 1sv=million cubic meter per second) in the transport that lasts for at least 2 weeks after the passage of the hurricane.

Student Spotlight

BRETT BUZZANGA

I have followed a somewhat nonstandard path through academia thus far, and so will write a few words about the choices that have brought me (back) to CCPO. As with many such stories, it begins with a brilliant and inspiring professor: Stephen Eric Bronner, a political theorist at Rutgers. Through him I became engrossed with Critical Theory, a method of inquiry that attempts to diagnose and remedy the ills of society. At the heart of this method is dialectical materialism, which essentially tries to understand society and culture through the environmental and historical circumstances that shape them. My undergraduate degree culminated in a short thesis, my first real foray into research, in which I traced how such forces influenced the Fabian Society and its role in British politics.

Upon graduation, I began working for a friend's green energy startup, where I was struck by how much I did not know about our environment. This did not sit well with me, especially considering its fundamental importance in driving economy and society. So a year after finishing my Bachelor's degree, I enrolled full time in my local community college, where I spent the next 18 months studying basic sciences and math, earning an Associate's Degree.

While there was no doubt some influence from my passion was for *in situ* wave observations (read: surfing), I doubt I have to rationalize the pull towards oceanography to this readership; simply put, water is life. Eight months and a trip around the world later, I arrived at ODU to pursue a Master's degree with Dr. Hans-Peter Plag. This went remarkably well; Hans-Peter was a great fit as I transitioned from a social to an earth scientist. I was given the flexibility to explore topics such as regenerative agriculture and complexity science, and time to learn the scientific and geospatial skills I needed to succeed.

Along the way, I had the opportunity to apply some of these skills to measure subsidence throughout Hampton Roads using a remote sensing technique called InSAR (Interferometry from Synthetic Aperture Radar observations). This is part of the larger research effort being conducted by Dr. Ben Hamlington and the NASA Sea Level Rise Change team to understand how sea level rise will impact coastlines in the coming years and decades. When Ben presented the opportunity to continue the work on subsidence and contribute to the research on sea level rise in pursuit of a Ph.D., it was an easy decision to come back to CCPO.

For the next few years, I will be fully focused on honing my technical expertise and understanding of physical oceanography. Beyond that, I suspect my interests will shift towards finding ways to apply scientific knowledge and solutions to the systemic problem of unsustainability at the center of our civilization. CCPO, as demonstrated through the CCSLRI, MARI, and the partnership with the ODU Resilience Collaborative, is a leader in both of these complementary endeavors, and I am truly grateful to have been welcomed back onboard.

LETTER FROM THE DIRECTOR

The 2018 Fall Semester has seen several transitions at CCPO. Larry celebrated his retirement and new position as Emeritus Professor. Grace joined CCPO to help Michelle Covi with outreach efforts. Brett returned, although he never really left, to pursue a Ph.D. degree. Ali Burgos graduated with a M.S. in ocean science and has moved to Washington, D.C. to begin a prestigious Knauss Fellowship advising US government agencies. Mia departed CCPO to pursue a career in real estate. She helped CCPO become more modern in our approach to social media and publicized our various activities.

Gabriel (Gabe) Csanady passed away on December 21, 2018 in Cambridge, Ontario, Canada after a long illness. Gabe joined the Oceanography Department at ODU in the late 1980s and was one of the major contributors in the establishment of CCPO. I invite you to read Gabe's obituary (https://memorials.henrywalser.com/gabriel-csanady/2462531/obituary.php) and learn about his fascinating history and career. Gabe was a commanding presence at ODU and throughout the global physical oceanography community. His contributions and insights will be missed.

Best Wishes,
Dr. John Klinck
Director, CCPO & Professor of Oceanography

CCPO Staff Spotlight

GRACE WALKER

As a new resident of the Hampton Roads area, I am very excited to be working in ODU's Department of Ocean, Earth & Atmospheric Sciences! In October 2018, I filled a new position as Program Specialist and Outreach Coordinator. This job is an amazing opportunity to do work for both the Virginia Sea Grant and Mid-Atlantic Regional Association Coastal Ocean Observing System (MARACOOS). Both organizations collaborate and cross-over with CCPO, who has warmly welcomed me onboard their team.

Prior to moving to this area, I used to live nearby. I am a Maryland native and received my B.S. in General Biology at the University of Maryland, College Park. Afterwards, I lived and worked in Venezuela for one year and explored South America before moving to Hawaii to get my M.S. in Marine Science at Hawaii Pacific University. I was fortunate to land a job right out of graduate school in NOAA's Marine Debris Program as the Pacific Islands Assistant Regional Coordinator. In this position, I realized I truly enjoyed interacting with diverse groups of people – from government officials at the city, state, and federal level, as well as academics, non-profit community members and the general public. I have a strong biology background, but recognized my interests aligned more with the outreach aspect of communicating science effectively with various audiences and engaging in partnerships with different stakeholders. Doing work with locals, native Hawaiian groups, and American Samoan government exposed me to new cultures and perspectives, which is something I genuinely appreciate.

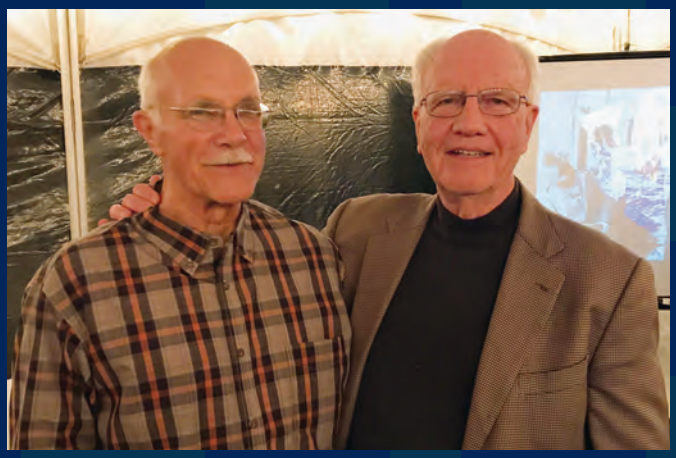
As someone who loves to learn, I feel right at home at a university, especially one filled with endless research events, opportunities, and connections. In my new position with ODU, I continue to use and improve my outreach and engagement skills and build partnerships for the Virginia Sea Grant Climate Adaptation and Resilience Program and MARACOOS. I am fortunate to work for Dr. Michelle Covi, outreach extraordinaire, and represent both organizations as I create new relationships and work with the community to address coastal hazards and sea level rise impacts here in Hampton Roads. I am currently working with the National Academy of Sciences and Sea Grant on a Mid-Atlantic Oil Spill Preparedness Workshop that delves into the regional health, social, and economic impacts from spills. Additionally, I am able to connect with several Eastern Shore communities through my work with The RAFT (Resilience Adaptation Feasibility Tool) and assist these communities to become more resilient to flooding and other coastal storm hazards. I look forward to exploring this area, finding more opportunities this new job offers, and working with a passionate group of people.

Larry's Retirement Party

Larry Atkinson celebrated his retirement and promotion to Professor Emeritus with a party on October 20, 2018 that was attended by colleagues, friends, and family.

Larry Atkinson with the plaque recognizing him as the founding director of the Center for Coastal Physical Oceanography.

Chuck McClain and Larry Atkinson recalling their first meeting on a cruise off of west Africa as a part of the GATE project.



Chuck McClain, Larry Atkinson and Gail Dodge discussing Larry's plans for the future.

Ann Atkinson, Cynthia Jones and John Klinck celebrating Larry's retirement.

Lou Codispoti (graduate school friend) and Larry Atkinson thinking about the muffle furnace that mysteriously disappeared.

JUST THE FACTS

Presentations

Aguiar-Gonzalez, B., C.F. Moffat, **M.S. Dinniman, J.M. Klinck**, D.A. Sutherland, D.P. Costa, E.W. Domack, C. Gordo-Rojas, A. Marrero-Diaz, and A. Rodriguez-Santana. Variability and Pathways of Along-Shelf Exchange in the West Antarctic Peninsula. 2018 Fall AGU Meeting, Washington, D.C., December 2018.

Allen, T. and **T. Ezer**. Climate and oceanic processes impacting communities in the Southern Rivers Watershed. Sea Level Rise Summer Symposium Series, City of Virginia Beach, September 19, 2018.

Barthel, A., C. Veneziani, N.M. Urban, **M.S. Dinniman**, and C.M. Little. Towards Quantifying Multi-model Uncertainty in Antarctic Basal Melt Rate using High-resolution Regional Ocean Modeling. 2018 Fall AGU Meeting, Washington, D.C., December 2018.

Barthel A., N. Urban, M. Veneziani, **M. Dinniman**, and C. Little. Towards quantifying multi-model uncertainty in Antarctic basal melt rate. FRISP workshop 2018, Aussois, France, September 2018.

Davis, L.B., E.E. Hofmann, J.M. Klinck, M. Mulholland, and A. Meza. Understanding Environmental Controls on *Cochlodinium polykrikoides* Blooms in the Lower Chesapeake Bay, poster presentation, 2018 Fall AGU Meeting, Washington, D.C., December 2018.

Dinniman, M.S., P. St-Laurent, K.R. Arrigo, **E.E. Hofmann**, and G. van Dijken. Direct and Indirect Contributions to Micronutrient Supply to the Open Surface Waters around Antarctica. 2018 Fall AGU Meeting, Washington, D.C., December 2018.

Dinniman, M., Ocean Melting of Antarctic Ice Shelves: Why do we care (besides sea level rise)? Invited seminar, Division of Oceanography, Instituto Nazionale di Oceanografia e Geofisica Sperimentale, Trieste, Italy, November 2018.

Ezer, T., On two types of impacts of hurricanes on coastal sea level and flooding: Direct storm surges versus remote influence through disruption of the Gulf Stream flow, 2018 Fall AGU Meeting, Washington, D.C., December 2018.

Ezer, T., The science of sea level rise and why flooding increases in Virginia, 2018 Annual Summit of Virginia Academy of Science, Engineering and Medicine: Securing Prosperity in the Coastal Zone, Richmond, VA, November 7, 2018.

Ezer, T., Computer modeling of the ocean: how to be an oceanographer without getting wet, Science on Friday Series, College of Science, ODU, Norfolk, VA, November 2, 2018.

Ezer, T., Climate change, sea level rise, hurricanes and the Gulf Stream: Are they all related?, OEAS Seminar, ODU, Norfolk, VA, October 11, 2018.

Ezer, T., Numerical modeling of the interactions between hurricanes, the Gulf Stream and sea level, The 10th International Workshop on Modeling the Ocean (IWMO-2018), Santos, Brazil, June 25, 2018.

Ezer, T., Sea level rise and flooding in the Hampton Roads, Seminar to REU students, Old Dominion University, June 21, 2018.

Ezer, T., Sea level rise and variability in the Chesapeake Bay: numerical modeling of the impact of climate change, hurricanes and the Gulf Stream, Chesapeake Research & Modeling Symposium, Annapolis, MD, June 12, 2018.

Hofmann, E.E., J.M. Klinck, E.N. Powell, M.A.M. Friedrichs, **P. St-Laurent**, and H. Tian. Increased Dermo Disease in Chesapeake Bay Oysters Caused by Continued Warming and Nutrient Loading, oral presentation, 2018 Fall AGU Meeting, Washington, D.C., December 2018.

Klinck, J.M., D.P. Costa, and L. Hückstädt. Distribution of CDW intrusion sites in eastern Amundsen Sea and west Antarctic Peninsula continental shelves revealed by Antarctic seals. 2018 Fall AGU Meeting, Washington, D.C. December 2018

Oliver, H., **P. St-Laurent**, R.M. Sherrell, and P.L. Yager. Controls on marine primary productivity in a coastal polynya receiving large iron inputs from melting West Antarctic ice shelves, 2018 WAIS workshop, Stony Point, NY, September 16-20, 2018.

Oliver, H., **P. St-Laurent**, R.M. Sherrell, and P.L. Yager. Controls on summer phytoplankton blooms in a highly productive Antarctic coastal polynya, 2018 Fall AGU Meeting, Washington, D.C., December 2018.

Riverman, K.L., D.A. Sutherland, R. Obermeyer, B. Aguiar-Gonzalez, C.F. Moffat, **M.S. Dinniman**, and **J.M. Klinck**. Grounding zone depth modulates oceanic control on glacier terminus retreat along the west Antarctic Peninsula. 2018 Fall AGU Meeting, Washington, D.C., December 2018.

Schwans, E., B.R. Parizek, R.B. Alley, D. Pollard, M. Morlighem, H. Seroussi, and **P. St-Laurent**. Bed character of Thwaites Glacier: Implications for stability, 2018 WAIS workshop, Stony Point, NY, September 16-19, 2018.

Schwans, E., B.R. Parizek, R.B. Alley, D. Pollard, M. Morlighem, R.T. Walker, T. LaBirt, H. Seroussi, and **P. St-Laurent**. Ice Sheet System Model (ISSM) studies of controls on stability of Thwaites and Pine Island Glaciers, West Antarctica, 2018 Fall AGU Meeting, Washington, D.C., December 2018.

Signorini, S., A. Mannino, M.A.M. Friedrichs, **P. St-Laurent**, J. Wilkin, A. Tabatabai, R. Najjar, **E.E. Hofmann**, F. Da, H. Tian, and Y. Yao. Estuarine Dissolved Organic Carbon Flux from Space: with Application to Chesapeake and Delaware Bays, 2018 Fall AGU Meeting, Washington, D.C., December 2018.

St-Laurent, P., M.A.M. Friedrichs, Y. Xiao, **E.E. Hofmann**, A. Mannino, R. Najjar, D. Narvaez, S.R. Signorini, H. Tian, J. Wilkin, Y. Yao, and J. Xue. Ocean Circulation Causes Strong Variability in Mid-Atlantic Bight Net Community Production, oral presentation, 2018 Fall AGU Meeting, Washington, D.C., December 2018.

Wiggert, J.D., C. Pan, **M.S. Dinniman**, Y. Lau, P.J. Fitzpatrick, S.J. O'Brien, C. Bouchard, M.K. Cambazoglu, and **E.E. Hofmann**. Impact of Diurnal Sea Breeze on Planktonic Dynamics and Hypoxia Onset in the Mississippi Bight. 2018 Fall AGU Meeting, Washington, D.C., December 2018.

Yager, P.L., **P. St-Laurent**, H. Oliver, R.M. Sherrell, S.E. Stammerjohn, and **M.S. Dinniman**, Hi-res model illustrates how melting ice impacts coastal carbon cycle, 2018 WAIS workshop, Stony Point, NY, September 16-20, 2018.

Yager, P.L., **P. St-Laurent**, H. Oliver, R.M. Sherrell, S.E. Stammerjohn, and **M.S. Dinniman**. High-resolution numerical ocean model illustrates how ice-sheet ocean interactions impact the biological pump of an Antarctic coastal polynya. 2018 Fall AGU Meeting, Washington, D.C., December 2018.

Publications

Atkinson, L. and **T. Ezer**, 2018. Norfolk, Virginia: A city dealing with increased flooding, Chapter 9, pp. 322-326, In: *Climate Change and Cities, Second Assessment Report of the Urban Climate Change Research Network*, Editors: Rosenzweig et al., Cambridge University Press.

Boesch, D.F., W.C. Boicourt, R.I. Cullather, **T. Ezer**, G.E. Galloway, Jr., Z.P. Johnson, K.H. Kilbourne, M.L. Kirwan, R.E. Kopp, S. Land, M. Li, W. Nardin, C.K. Sommerfield, and W.V. Sweet, 2018. Sea-level Rise Projections for Maryland 2018, University of Maryland Center for Environmental Science, Cambridge, MD, 28 pp.

Ezer, T., 2018. On the interaction between a hurricane, the Gulf Stream and coastal sea level, *Ocean Dynamics*, 68, 1259-1272, doi:10.1007/s10236-018-1193-1.

Friedrichs, M.A.M., **P. St-Laurent**, Y. Xiao, **E.E. Hofmann**, K. Hyde, A. Mannino, R.G. Najjar, D. Narváez, S.R. Signorini, H. Tian, J. Wilkin, Y. Yao, and J. Xue, 2018. Ocean circulation causes strong variability in Mid-Atlantic Bight net community production, *Journal Geophysical Research – Oceans*, https://doi.org/10.1029/2018JC014424.

Hofmann, E.E., E.N. Powell, **J.M. Klinck**, D.M. Munroe, R. Mann, D.B. Haidvogel, D.A. Narváez, X. Zhang, and K.M. Kuykendall, 2018. An overview of the factors affecting distribution of the Atlantic surfclam (*Spisula solidissima*), A continental shelf biomass dominant, during a period of climate change, *Journal Shellfish Research*, 37, 821-831, https://doi.org/10.2983/035.037.0412.

Powell, E.N., **E.E. Hofmann**, and **J.M. Klinck**, 2018. Oysters, sustainability, management models, and the world of reference points, *Journal Shellfish Research*, 37, 833-849, https://doi.org/10.2983/035.037.0413.

News/Awards

A collaboration between CCPO's Ezer and Atkinson and a Norfolk-based startup company, Green Stream Technologies, was one of the winning teams to receive a $10,000 prize in the MIT's Solve Challenge international competition. The project involves the development of low-cost flood detection and monitoring systems for flood-prone communities.

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CENTER FOR COASTAL PHYSICAL OCEANOGRAPHY (CCPO) and ODU RESILIENCE COLLABORATIVE (ODURC) SEMINAR SERIES

SPRING 2019 SEMINAR SCHEDULE

28 January	Cynthia Tomovic & Vukica Jovanović Old Dominion University
4 February	Philip Orton Stevens Institute of Technology
11 February	Kurt McCoy USGS, Virginia Water Science Center
18 February	Diego Narváez Universidad de Concepción
25 February	Dale Haidvogel Rutgers University
4 March	Kelly Brunt NASA Goddard Space Flight Center
18 March	Jacob Hochard East Carolina University
25 March	Richard Little Rensselaer Polytechnic Institute
1 April	Dylan McNamara University of North Carolina Wilmington
8 April	Joseph Zhang Virginia Institute of Marine Science

A General Electric wind turbine casts its shadow on ocean waves southeast of Block Island, Rhode Island. Photo credit: GE Reports and Jeff Milstein.

Mondays at 3:30 PM, reception at 3:00 PM
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