C-SAW: Time domain controls on carbon storage, release, and transformation in coastal and estuarine waters following extreme events. An OCB Scoping Workshop Proposal.

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Summary. The land-air-water continuum plays a key role in the global carbon (C) cycle and provides major feedbacks to climate and biogeochemistry of the Earth system, with implications for coastal and estuarine ecosystems, their habitats, and the communities and economies that depend on them. One of the major research priorities of OCB is "Carbon cycling and associated biogeochemical fluxes and exchanges along the aquatic continuum, from rivers to the coastal ocean," which encompasses these spatial domains. Within these domains, the spatiotemporal imprint of extreme events are important contributors to projected future emissions of greenhouse gases. Further, Earth System Models (ESMs) critical to the prediction of weather and future change in Earth's climate, and supplies of water and energy, require parameterizations of C stocks and vertical and lateral fluxes between these three spatial domains. While the spatial dimensions have been examined to some extent, we currently lack a holistic understanding of the temporal dimensions that modulate C and nutrient storage in coastal landscapes, occurrence and linkage among disturbances (extreme weather, floods, fires) that release carbon and nutrients into receiving waters, and that control the fate of carbon and nutrients in receiving waters. Moreover, we lack coherent linkages among past occurrences of these events and the now- and forecasting ability desirable to improve ESMs. We propose to OCB a Scoping Workshop that will bring together a diverse group of scientists to build a community of monitors/observers, experimentalists, and modelers to address these challenging knowledge gaps across these spatial and temporal domains.

Background and Rationale. Climate change is fundamentally altering coastal carbon cycles, by altering linkages among the land-air-water spatial domains. These alterations have been documented for the past 20-30 years due to increases in extreme weather events (fires, drought, tropical cyclones). Conceptually, these events are episodic and represent *pulses* experienced by the affected ecosystems, as opposed to the gradual *presses* (sea level rise, land use change), often under which the pulses occur. Responses to these events can reorganize coastal carbon cycles by translocating enormous amounts of carbon and nutrients (e.g., N and P) stored in coastal landscapes to the coastal ocean via biogeochemically active terrestrial-aquatic interfaces (TAIs): river corridors, riparian and tidal wetlands, etc. In addition, these pulses can also transport microorganisms capable of driving biogeochemistry (Kominoski et al. 2020). However, these responses exist within time domains that are poorly understood and not constrained in coupled biogeochemical or Earth system models (Ward et al. 2020).

The aim of this proposal is to push forward our knowledge of extreme weather and fire effects on coastal carbon cycling by hosting a Scoping Workshop at North Carolina State University in October 2022. This workshop will bring together researchers from across the connected land-air-water domains as represented by the Aquatic Continuum Science Focus Group. That OCB-NACP group led a breakout session at NACP 2021 and hosted Extreme Event webinars in 2021. The breakout session identified a critical lack of knowledge about how timing of events generally does not consider the antecedent conditions preceding the event. While pulses to receiving waters have received attention (i.e., the Pulse-Shunt Concept; Raymond et al. 2016), recovery (or replenishment) of C, nutrients, and microbial communities in the landscape, as well as post-event recovery in receiving waters, requires more attention.

Finding temporal connections and paradigms for extreme events is a leading edge. We have begun to answer the question "if tropical cyclones are increasing in frequency" with the understanding that tropical cyclones are indeed increasing in their intensity. Perhaps most important is the realization of the increase in extreme precipitation associated with tropical and extratropical cyclones (Paerl et al. 2019; Kunkel et al. 2020). This work has very recently been confirmed in paleo records using tree rings (Maxwell et al. 2021). For coastal biogeochemistry, recent efforts have examined the resultant carbon and nutrient loading questions (e.g. Paerl et al. 2018).

Newly published work has revealed connections between fires on land and deposition of nutrients that promote plankton production and carbon sequestration in coastal waters, creating yet another linkage between these domains (Kramer et al. 2020; Tang et al. 2021, Wang et al. 2021). Aside from extreme

precipitation and fires, temperatures themselves are rising, with evidence emerging of marine heat waves that are clearly linked to atmospheric heat waves. In coastal areas, these events cause changes to key “blue carbon” habitats such as seagrasses, which diminishes their ability to store carbon, both aquatic and which can exacerbate low pH and dissolved oxygen levels (Tassone et al. 2021). Temporal linkages between air and water temperatures are an added unknown; hence, as for the land environment and changes to coastal ecosystem processes caused by increasing air and water temperature. Temporal linkages that can facilitate C and nutrient transport thus need deeper investigation. Khorshidi et al. (2020) identify meteorological as well as climatic drivers priming the landscape for megafires. Hence, like changes to land use and land cover, we can see the connectivity of these events that modify the landscape with facilitating the hydrologic transport mechanisms, even as atmospheric transport has also emerged as relevant. We posit that our task now as a community is to document these linkages to effects on coastal carbon cycles while also detailing how the time domain on C replenishment in the landscape of coastal watersheds drives C transport and cycling in the coastal ocean. These effects harm water quality as well as carbon mitigation, emphasizing the need for a holistic temporal approach to understanding these climate related effects that have clear societal implications.

The NACP 2021 breakout group summarized the knowledge gap as a “see-saw” whereby a build up of carbon (C) and nutrients in the landscape occurs, only to be lost and replenished in cyclical fashion. “C-SAW” can thus be represented schematically in the following manner:

Storage. Organic matter and nutrients **storage** in landscapes occurs over varying periods of time

Disturbances such as extreme precipitation events (tropical and extratropical storms) and fires are the pulses that **release** carbon into receiving waters (e.g., estuaries, large river plumes).

Transformation of carbon and nutrients in receiving waters occurs via multiple degradation pathways leading to the return of organic carbon to the atmosphere as CO2 or sequestration in coastal soils and sediments.

We further posit that C storage, release, and transformation occurs over a range of *temporal* scales. The most clear effects are acute: episodic - and discrete - periods of time perhaps lasting several days to several weeks. However, chronic changes over decades have manifested in long-term monitoring programs where temporal (and spatial) resolution is sufficient to observe and model these patterns. The aforementioned acute and chronic scales are what is happening now and over recent times. Much longer timescales reaching into paleo records can reveal patterns, as evidenced by tree rings.

Advancing OCB Priorities. This scoping workshop directly addresses the OCB aquatic continuum science focus on “rivers to the coastal ocean” but builds out that focus to a community that integrates terrestrial and aquatic (freshwater and marine) scientists under a common theme of extreme events. OCB is striving to grow its connections to NACP and this is a key way of doing so because C-SAW will require “collisions" between researchers from multiple disciplines to create the way forward in observing and understanding global change’s clear influence on the land-ocean continuum through extreme events. We will reach out to existing and related networks such as COMPASS (https://compass.pnnl.gov/), which is focused on terrestrial-aquatic interfaces, and HERS (https://bit.ly/3BI68DV), which is building a hurricane-focused network. Members of this extreme events working group participated in the HERS kickoff meeting and have established initial outreach by including John Kominoski, a Co-PI for HERS. A further connection is with the SWISLR RCN, which focuses on rural coastal environments: https://www.swislr.org. Connections to the Ocean Observatories Initiative (OOI)’s Coastal Pioneer Array (https://bit.ly/3pmmChl) will be made, further linking C-SAW in time and space to ocean observing activities. This workshop will also facilitate international collaboration, particularly with Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) and federal funding agencies. Specifically, CSIRO researchers have participated in recent NACP activities, are co-chairing a session on extreme events at the 2022 Ocean Sciences Meetings with OCB members and will propose a delegation of researchers and government representatives that will participate in the OCB workshop.

Workshop Goals. A key finding of the State of the Carbon Cycle Report (SOCCR-2)’s Future of the North American Carbon Cycle projects that extreme events will increase greenhouse gas emissions in the future (Huntzinger and Chatterjee et al, 2018). Therefore, the goal of the workshop is to clarify the

spatiotemporal imprint of storms and fires within the context of the C-SAW paradigm. We propose to reach this goal by bringing together the land-air-water communities to focus on the spatiotemporal effects of fires and storms across the aquatic continuum. The following conceptual questions serve as a framework to achieve the workshop's goal.

- What soil and hydrologic schematics (e.g., "Pulse Shunt Concept", Raymond et al. 2016) do we adapt that span the aquatic continuum and how do they interact with sea-level rise?
- How do we build OC degradation and replacement rates across the continuum, along with C-nutrient-microbe interactions fueling autochthonous production and sequestration?
- How can we incorporate foodweb dynamics and community compositional changes across the continuum?
- How do we acknowledge and incorporate the importance of comparative analysis across the continuum in response to extreme events?
- What models are best suited to capture and link residence times of C and nutrients in wetlands/soils and estuaries (receiving waters)?
- How can we increase our capacity for "biogeochemical storm chasing" (building on meteorological model) through regional networks of observations?
- What international collaborations are needed to constrain the diversity of coastal environments and be coordinated to resolve larger scale feedbacks by which extreme events are coupled to ocean-climate phenomena like ENSO, which can exacerbate fires on one continent and cyclones on another?
- How do we ensure that we have the relevant seconds/minute/hour-scale measurements to capture these events with in situ and remote sensing observation platforms?
- How do we integrate Eulerian and Lagrangian observations?

These questions will be framed in the plenary talks, invite workshop participation through lightning talks and/or posters, and be answered via breakout sessions to facilitate discussion.

Deliverables. This workshop will leverage existing research collaborations as outlined above and establish new opportunities for collaboration. In doing so, we will identify the observational needs, including coordinated observations, required to understand the temporal and spatial linkages, yet clarify distinct regional and event-specific observations. Building such a community of researchers will require coordination between observations, experiments, and models.

Communicating the results of the workshop is standard practice, but important. Making the presentations publicly accessible via OCB and NACP will be important, as well as writing a workshop report for dissemination. We envision writing short articles to Eos, the ASLO Bulletin, etc. that communicate the opportunities for research. A white paper capturing our knowledge gaps and posing solutions to filling those gaps, while motivating cross-disciplinary research to move the science and our overall understanding of underlying processes forward. Building on the energy from this workshop will be important and we will seek to propose science sessions at future conferences and meetings, while synergizing with HERS and COMPASS as well as other initiatives such as NSF Coastal and People (CoPe) research coordination network, "Building a Collaboratory for Coastal Adaptation over Space and Time (C-CoAST)". Collaborative proposals are an anticipated natural outcome of this activity as well. However, agency buy-in to this initiative is important, to incentivize continued work on this important topic. Hence, we will work to brief program officers at relevant sponsoring agencies (e.g., DOE, NASA, NSF).

A key activity associated with this workshop will be outreach to, and coordination with, larger networks such as the OOI, which is repositioning the Coastal Pioneer array to the southern Middle Atlantic Bight. This repositioning provides an unparalleled opportunity for accumulating baseline information as well as proposing discrete experiments and process-oriented studies.

Workshop Details. We propose October 2022 as the time for this workshop to take place, providing enough lead time for planning and advertising for the meeting, and to include a meeting of the scientific organizing committee (SOC) during the 2022 OCB workshop. Members of the OCB-NACP Aquatic Continuum Science Focus group will join members will join the following list from the Extreme Events working group that formed after the 2021 NACP breakout session:

Name	Affiliation	Research focus	Diversity measures
Chris Osburn, Chair (he/him)	NC State University	Organic matter cycling; Rivers and estuaries	University
Tom Bianchi	University of Florida	Biogeochemistry, evolution	University
Joey Crosswell	CSIRO, Australia	Coastal carbon, nutrients and sediment; International development for climate action	Gov't; Early career
Karl Kaiser	TAMU-Galveston	Organic geochemistry in coastal waters	University;
John Kominoski	Florida International U.	Organic matter cycling, rivers, wetlands, estuaries	University; OCB Focus group; HERS; Florida Coastal Everglades LTER program
Sasha Kramer (she/her)	UC Santa Barbara	Phytoplankton ecology and community composition, ocean optics, wildfire impacts on coastal ocean	University; student
Hans Paerl	UNC-Institute of Marine Sciences	Nutrient-OM interactions & microbial processes in estuarine and coastal waters	University
Alan Roebuck	PNNL	Organic matter cycling in rivers	Gov't; Early career
Elliott White Jr.	Stanford University	Southeast US and Gulf Coast forests and C loss with sea-level rise	Early career, Black, SWISLR RCN

Acknowledging the low diversity of this committee at present, we will reach out through various networks (e.g., Black in Marine Science; Black in Geoscience) to attract participants in the workshop from underserved communities and universities. Seeking guidance from OCB and NACP, we will add a committee member who can aid in this effort and engage diverse participants. In particular, we will reach out to faculty at institutions representing underserved populations to encourage their and their students' participation. The workshop will adhere to OCB guidelines on Justice, Equity, Diversity, and Inclusion (JEDI). Crucial to developing a research community is creating an environment and space wherein all are welcome and secure to express themselves freely. Workshop attendance will require agreement to and adherence to the OCB Code of Conduct which aligns with the JEDI goals of the proposed host institution. We will seek guidance from OCB and NACP to ensure we develop an inclusive and welcoming program.

Across disciplines, we will build on the OCB-NACP interactions from NACP 2021 to include earth, atmospheric, freshwater, and marine scientists. Using these connections, we will encourage open attendance, and utilize an application process to ensure balance across several dimensions:

- Biogeochemists, climate scientists, terrestrial and aquatic ecosystem scientists, regional modelers
- Expertise in observations, processes, modeling, data science at local and regional scales
- Modern and paleo perspectives
- Career stage (including graduate students)
- Geographical representation

We envision about 80 attendees, which could be expanded with remote participation, if necessary. Depending on the response to a call for applications and final meeting logistics, this group should be large enough to represent the dimensions listed above, as well as equitably represent the diversity of the geosciences. Selection of participants will be done by the SOC, with oversight from OCB. We anticipate that student participants from local NC universities will assist with logistical support.

Workshop Format. The scoping workshop will take place over 2.5 days, allowing for several plenary sessions to provide a comprehensive overview of topics and breakout sessions facilitate ideation activities and fortuitous and fruitful interactions among attendees. Broadly, we will create environments where exchange of ideas can flow freely but are facilitated by our key objectives as outlined above. SOC will be responsible for facilitating the workshop and early career researchers to serve as scribes with the SOC facilitating group discussion. Preparatory work for the meeting by the SOC will be conducted via virtual meetings, facilitated with freely accessible collaborative technologies. The preparatory work will include a 1-day virtual meeting for all attendees so that all are informed of our goals and approach prior to arriving in Raleigh for the workshop.

Overview of a potential meeting agenda:
Sunday: Evening reception to welcome participants; Briefly introduce the workshop goals and expectations; Social mixer.
Monday:
Morning: Meeting welcome and synthesis of prep activity prior to meeting; Plenaries.
Afternoon: Lunch; Breakout groups (by event) ideate on overcoming gaps and meeting challenges; Reporting back to plenary.
Evening: Networking reception & dinner
Evening SOC meeting: Develop event & time-based issues for Day 2 discussion.
Tuesday:
Morning: Plenary; Lightning talks & posters.
Afternoon: Collisional "round-robin" breakout groups mix disciplines of researchers, the events they study, and the time-frames the work in, to consider gaps and challenges identified on Day 1. Reporting back to plenary.
Evening: Dinner on own with opportunity to sign up to join a dinner group.
Evening SOC meeting: Develop key challenges for focus of Day 3 wrap-up discussion.
Wednesday:
Morning: Breakout groups based on events identify future steps; Plenary to discuss ways to broaden community & agency support and build on existing networks, based on prior days' discussions.
Afternoon: SOC planning of report writing.
Adjourn.

Budget and Budget Justification. We would like to support all attendees, but we will emphasize participation of junior scientists and provide travel support as practical. The SOC (8 members) and invited keynote speakers (~8) will also be fully covered. Participants who are not invited speakers will be expected to pay their own travel to and from the workshop. However, we wish to cover airfare and per diem for 10 early career scientists and/or scientists from underserved institutions. We anticipate 20 attendees (totalling 100) who will be local and not require lodging or travel costs, but will have meals covered. Anticipating an in-person workshop, we nevertheless request support for webcasting should a virtual format be necessary.

Travel: 8 invited speakers, 8 organizers, 10 early career/BIPOC stipends at $750 each.	$19,500
Lodging: Est. ~$150/night for 3 nights/participant (70 total, assume 10 local)	$31,500
Catering: Breakfast ($10/person), Lunch ($15/person), Breaks ($8/person/day = AM + PM break), $50/person for one dinner, $40/person for mixer on Sunday (apps)	$15,120
Onsite Meeting Costs: Meeting space, A/V, transportation, meeting room wifi, supplies, etc.)	$5,000
Total:	**$71,120**

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