Transient Events: A Rapid-Response, Multi-Platform Observing Strategy for Detecting and Understanding Abrupt Change in Aquatic Ecosystems

A response to the Request for Information for the Decadal Survey for Earth Science and Applications from Space 2028–2037 (ESAS 2028)

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It is one of a series of five ocean biology and biogeochemistry white papers led by this author team.

The authors welcome feedback and comment; please contact the corresponding author.

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Transient Events: A Rapid-Response, Multi-Platform Observing Strategy for Detecting and Understanding Abrupt Change in Aquatic Ecosystems

An Adaptive Observing and Modeling Approach for the 2028-2037 Decadal Survey

A response to the Request for Information for the Decadal Survey for Earth Science and Applications from Space 2028-2037 (ESAS 2028)

NASA Earth System Science Research Sphere: Biosphere (Aquatic Ecosystems), with direct relevance to the Atmosphere, Cryosphere, Geosphere, and Hydrosphere spheres

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Executive Summary

Extremes, not average conditions, increasingly govern the state of aquatic ecosystems and the risks they carry for people. Events far outside normal variability can reshape ecosystem structure and function within hours to weeks, and both the observational record and climate projections indicate such extremes are growing more frequent, more intense, and longer lasting. Whether an extreme becomes a disaster is largely a question of anticipation: whether it is detected early, whether its trajectory can be predicted, and whether that prediction becomes a warning in time to act. These Transient Events take many forms, including harmful algal and bacterial bloom outbreaks, marine heatwaves, oil and industrial chemical spills, volcanic ash deposition, wildfires, hurricanes, storms, river discharge and combined sewer outflows, rapid coastal flooding, erosion, coral bleaching, or intense acidification pulses. Despite their diversity, these events share a common observational challenge: their episodic and often unpredictable timing, location and duration are poorly matched to the fixed sampling intervals and revisit frequencies of most operational observing systems. This white paper presents the science case for an integrated observing and modeling strategy capable of detecting, quantifying, and predicting marine responses to Transient Events, and for translating those predictions into timely warnings. No single platform can meet the combined demands of fine spatial detail, rapid revisit frequency, adequate spectral discrimination, and all-weather capability that these events require. Addressing this challenge within NASA's Hydrosphere and Biosphere will require an integrated observing and prediction framework that combines: sustained and expanded satellite ocean color observations, including geostationary continuity; appropriately calibrated low-cost CubeSat constellations capable of increasing spatial and temporal sampling; a coordinated, rapidly deployable suite of suborbital airborne (crewed and uncrewed), underwater autonomous and in-situ assets; edge-computing AI to automatically detect anomalies and trigger downstream tasking; targeted disturbance-ecology field campaigns paired with standby rapid response capability; and integrated modeling and data assimilation to predict event evolution. We recommend priority investments in each of these elements, together with the data infrastructure, algorithm development, and interagency coordination needed to convert observations into timely and actionable intelligence for coastal communities, resource managers, and emergency responders.

1. Introduction: The Science Question and Societal Challenge

Change in aquatic ecosystems is not always gradual; it is often extreme events, rather than shifts in the mean state, that drive the most consequential ecological responses and societal impacts. Marine heatwaves, for instance, have grown longer and more frequent over the past century [1,2], are projected to intensify further as the ocean warms [3], and have already contributed to biodiversity loss, the decline of habitat-forming species and the fisheries they support [4]. An extreme event delivers within hours to weeks a magnitude of forcing that routine variability would spread across years [5,6]; the problem it poses is therefore one of anticipation: whether the event can be recognized as it begins, its trajectory forecast, and the forecast delivered to decision makers while still actionable. Heavy rainfall can swell rivers within hours, delivering large pulses of sediment, nutrients, and other materials to coastal waters and triggering hazards such as harmful algal blooms (HABs) [7,8]. In a matter of days, volcanic eruptions and coastal wildfires can deposit more ash-borne nutrients onto surface waters than a phytoplankton community would otherwise receive over an entire year [9,10–14]. Storms and convective events can deepen mixing to hundreds of meters, diluting phytoplankton and their grazers together, disrupting predator-prey coupling, injecting nutrients, and triggering blooms [15,16]; and an oil or industrial chemical spill can convert a pristine ecosystem into a toxic one within days, inflicting damage that lasts for decades. Such Transient Events - abrupt, often short-lived perturbations to the physical, chemical, or biological state of an aquatic system - can exert effects that are disproportionate to their duration, reshaping marine ecosystem structure, biodiversity, and biogeochemical cycling. Mild events may produce only transient changes, whereas moderate disturbances can favor opportunistic species, alter species interactions, and trigger successional shifts in community composition. Extreme disturbances can cause widespread mortality, open habitat to pioneer species, reorganize food webs, and in some cases push ecosystems into fundamentally different states [17,18].

Today, natural Transient Events are increasingly compounded by human disturbances, amplifying risks to ecosystems and public health, and threats to life, coastal infrastructure, commerce, and livelihoods. Harmful algal and bacterial bloom outbreaks linked to nutrient loading, warming, and altered hydrology; oil spills and industrial chemical releases; and accelerating coastal erosion all require timely detection and reliable forecasts to enable rapid, informed action. Harmful blooms of certain phytoplankton and bacteria can generate potent neurotoxins that threaten zooplankton, shellfish, birds, fish, marine mammals, and humans [19,20]. The causes of these blooms remain complex and poorly understood, making routine monitoring capable of detecting their early phases essential. However, monitoring and forecast systems are imperfect, and the conservative thresholds needed to protect public health can produce false positives, while the closures they trigger impose substantial and unevenly distributed costs on fishing communities [21–23]. Oil and other hydrocarbon products, meanwhile, are transferred multiple times between extraction and final use, mostly by ship or seabed pipeline, and a spill at any of these points can disperse over large distances within hours, damaging organisms from phytoplankton to marine mammals and compromising coastal livelihoods for years [24,25].

Understanding and responding to Transient Events requires a consistent framework for identifying an observable property, quickly distinguishing an anomaly from background conditions, characterizing its spatial extent and movement, quantifying its severity, and establishing its duration. The hierarchical definition developed for marine heatwaves, classifying an event by intensity, duration, and spatial extent relative to a climatological baseline, remains the standard framework and a useful template for consistency across event types [2,26]. Because these events are so poorly matched to the cadence of routine observing systems, meeting this challenge requires that we:

> *Develop the scientific knowledge and observing infrastructure to detect, quantify, predict, and understand marine responses to Transient Events enabling resource managers to better prepare for, mitigate, and recover from the impacts.*

This challenge is inherently cross-cutting. Transient Events are frequently coupled to atmospheric forcing (storms, extreme precipitation), cryospheric change (seasonal ice melt and drift), and hydrologic extremes (flooding, riverine discharge). Their consequences - ranging from beach and fishery closures to contamination of drinking-water supplies - extend directly into the societal dimension of NASA's Earth science portfolio. As the climate warms, the frequency and character of Transient Events will very likely change, yet their short- and moderate-term implications have not been a significant focus of NASA research to date; investment in the coming decade is needed so that observing and prediction capabilities keep pace. This paper is the detection and prediction counterpart to the companion Global Biosphere white paper [27], which addresses resilience and the thresholds beyond which ecosystems persistently reorganize. Here we focus on the observing, modeling, and analysis capabilities needed to recognize an extreme event as it unfolds, forecast its trajectory, and translate those forecasts into timely early warnings.

2. State of the Science: Achievements and Limitations

Satellite and suborbital remote sensing have demonstrated substantial value for observing Transient Events. Medium spatial resolution polar orbiting ocean color sensors, with repeat coverage of 2-3 days, have contributed significantly to harmful algal bloom monitoring [28–30] (Figure 1), and high spatial resolution polar orbiters have proven useful despite a roughly 16-day repeat cycle [31]. Detection of cyanobacterial outbreaks, for example, exploits the diagnostic phycocyanin absorption feature near 620 nm together with measurement wavelengths near 665, 680, and 710 nm [29,30], though this spectral complement is not available on all high spatial resolution sensors. Geostationary ocean color sensors, such as NASA's upcoming GLIMR (Geostationary Littoral Imaging and Monitoring Radiometer) Earth Venture Instrument, provide hourly views of a fixed location that can track dispersing plumes, monitor active algal blooms, and map changing flood extents in real time. Continuity of GLIMR-equivalent regional coverage is critical for long-term coastal monitoring, and large CubeSat constellations could eventually supply comparable temporal coverage given adequate spectral resolution and calibration.

Suborbital platforms are well matched to Transient Events because they operate under cloud cover and resolve features at meter scales or finer. Hyperspectral imaging spectrometers flown on piloted aircraft, including the NASA Portable Remote Imaging SpectroMeter (PRISM), the GEO-CAPE Airborne Simulator, and the Airborne Visible-Infrared Imaging Spectrometer-Next Generation (AVIRIS-NG), have been used to monitor coastal habitat change [32,33] and to delineate coastlines, water depth, and benthic composition in shallow and flooded areas [34]. Fluid lensing, a passive technique that exploits time-dependent optical aberrations at the water surface to magnify seafloor features, has enabled decimeter-scale benthic imaging from uncrewed aerial vehicles and could, with a baseline record, evaluate habitat change following a Transient Event [35,36]. The same technology has since attracted continued federal investment for automated airborne detection of submerged targets [37]. Airborne lidar, a technology dating to the first laser fluorosensors flown to map oil slicks in the early 1970s [38,39], can assess phytoplankton standing stocks, with fluorescence channels offering a potential route to physiological information [40,41]; estimate oil film thickness at the water surface [42,43]; and map shallow water bathymetry to an elevation accuracy of 10-30 cm [44]. In the water column, autonomous underwater vehicles and profiling floats, including BGC-Argo, already contribute physical, chemical, and bio-optical observations relevant to disturbance monitoring [45–47].

Collectively, these capabilities are already used to assess bloom responses, track turbidity plumes, marine heatwaves, oil spills and marine debris, characterize coastal flooding, and monitor shoreline change. Nevertheless, the science and technology of Transient Event remote sensing remain in their infancy [48], and three fundamental limitations constrain the community's ability to detect, characterize, predict, and warn of these events.

First, the unpredictable timing and location of Transient Events are poorly matched to the sampling cadence of most operational observing systems. No single satellite sensor provides the combination of spatial resolution, temporal revisit, spectral information, and all-weather capability needed to characterize the full range of these events. Passive ocean-color observations are particularly vulnerable to cloud cover and atmospheric contamination. This limitation is especially acute during storms, wildfires, and volcanic events, when persistent clouds, smoke, or ash can obscure the surface or complicate atmospheric correction; the same conditions can constrain airborne observations through poor visibility, hazardous flight conditions, or restricted access. As a result, obtaining critical measurements immediately before, during, and after an event has often depended more on favorable circumstance than on deliberate observing design.

Second, no coordinated asset pool, deployment plan, or data handling and response infrastructure yet links the diverse observing technologies capable of characterizing Transient Events. Aircraft, uncrewed aerial systems, autonomous surface and underwater vehicles, ships, moorings, and other in situ platforms have each proven valuable during individual events, but their rapid deployment remains constrained by costs, logistics, weather, payload capacity, endurance, and access, constraints that bind most tightly during the very events of greatest interest. Equally important, near-real-time processing, integration, and transmission of observations are not yet routine across platforms, limiting the ability to retask assets, assimilate observations, or deliver timely warnings.

Third, and most fundamentally, our mechanistic understanding of marine ecosystem responses to disturbance remains rudimentary [49,50]. Much of the conceptual foundation of disturbance ecology has emerged from terrestrial and benthic systems [17,51]; although many of its principles are likely relevant to pelagic ecosystems, their applicability across the open ocean and coastal waters remains insufficiently tested [49]. This knowledge gap has direct consequences for satellite remote sensing: two phytoplankton communities with similar hyperspectral signatures, such as those now resolved operationally by PACE [52], may have different underlying compositions if their disturbance histories differed, yet current operational data products carry no information on that history. The same limitation extends to prediction. Seasonal forecasting of ocean biogeochemistry and marine ecosystems has demonstrated real skill for some variables and regions [53–55], but much of that predictability derives from the underlying physical environment; forecasting rapid biological responses to discrete disturbances at sub-seasonal timescales remains comparatively underdeveloped [56].

3. Proposed Observing and Modeling Strategy

Addressing the Transient Events Grand Challenge requires an integrated, multi-platform observing and modeling strategy that spans satellite, suborbital, and in situ assets, coupled to a coordinated rapid response infrastructure and an improved mechanistic understanding of disturbance ecology. Several of the priority elements outlined below build directly on the capabilities described in the companion Global Biosphere [27], Interface Habitats [57], and Leveraging Ocean Data and Models [58] white papers, forming a system-of-systems approach while extending them to the distinct demands of detecting, tracking, and predicting rapidly evolving events.

3.1 Foundation: Sustained and Continued Satellite Ocean Color Observations

Sustained medium- and high-spatial resolution polar orbiting ocean color observations, together with continuity of GLIMR-equivalent geostationary regional coverage, is foundational to Transient Event detection. Geostationary observations provide the high-frequency sampling needed for tracking blooms, river and sediment plumes, oil spills, and other rapidly evolving features over the course of a single day, while polar orbiting sensors provide the broader spatial and spectral context, provided they retain the spectral complement needed to discriminate harmful algal blooms. GLIMR's flexible pointing can further concentrate observations on regions experiencing rapidly evolving events. This combination of frequent regional observations and broader polar-orbiting coverage provides the essential observational foundation for detecting events, tracking their evolution, and directing the complementary airborne and in situ assets of the strategy described below.

3.2 New Capability: Low-Cost CubeSat Constellations for Sub-Daily Coverage

Development of a low-cost constellation of CubeSat-type sensors, with adequate calibration and spectral resolution for Transient Event applications, would extend sub-daily observing coverage beyond the geostationary footprint to coastal and large inland waters globally. The SeaHawk-HawkEye CubeSat, which returned research-grade ocean color imagery at 120 m resolution from a 3U platform before being decommissioned in October 2023, established the basic feasibility of this approach [59]. Properly assigned wavelengths, informed by the spectral requirements established for Global Biosphere and Interface Habitats applications, would allow such a constellation to contribute meaningfully to bloom, plume, and flood detection at a fraction of the cost of a single large mission, while cross calibration with medium spatial resolution missions would ensure data continuity and comparability.

3.3 Suborbital Rapid-Response Platforms: Aircraft, Uncrewed Vehicles, and Advanced Sensors

Piloted aircraft carrying hyperspectral imaging spectrometers, fluid-lensing instruments, and fluorescence and bathymetric lidar remain the most capable means of resolving Transient Events at meter-scale resolution and under cloud cover, and continued development and deployment of these passive and active sensors is essential. Small uncrewed aerial vehicles offer a lower cost, more rapidly deployable complement, particularly as gimbaled imaging payloads and, prospectively, autonomous water sampling capabilities mature. Post processing of drone imagery into time sensitive products will require parallel investment in automation and modeling. Continued studies are also needed to evaluate how underwater vehicle technologies can most effectively characterize the time evolution and ecosystem consequences of events already in progress.

3.4 In Situ and Autonomous Underwater Observation, Including a Standby Asset Pool

Autonomous observing platforms - including underwater vehicles, gliders, and profiling floats such as an expanded BGC-Argo array [60] - are essential for extending Transient Event characterization below the ocean surface, where satellite measurements provide little direct information on physical, chemical, and bio-optical conditions. Nearshore and inland waters remain particularly undersampled and will require complementary autonomous systems designed for shallow, dynamic, and spatially constrained environments. Realizing the full potential of these platforms will require continued advances in vehicle navigation and control, machine learning–guided adaptive sampling and mission planning, and algorithms for automatically discriminating and quantifying targets of interest. Because many disturbances are as ephemeral underwater as from orbit, we recommend a coordinated 'standby' pool of autonomous and suborbital assets mobilized rapidly to events as they are detected.

3.5 Disturbance Ecology Field Campaigns and Rapid Response Study Design

Closing the mechanistic gap identified in Section 2 requires targeted field investigation of disturbance responses in natural pelagic and benthic systems. Two approaches might be considered. The first is purposeful manipulation experiments creating a measurable disturbance over multiple square kilometers, analogous to prior iron enrichment experiments [61–63] and emerging field trials of ocean carbon dioxide removal [64]. Such experiments are scientifically valuable but remain ethically and environmentally complex and face substantial regulatory hurdles, particularly because current Earth system models cannot yet resolve many of the downstream consequences of deliberate perturbations with confidence. For Fe fertilization, substantial uncertainty remains around iron-cycle representation, remineralization depth, trace-gas production, and export permanence [65,66]; any manipulation experiment must be designed to reduce these predictive uncertainties rather than presume them resolved. The second approach is a coordinated 'standby' rapid response along the lines of NOAA's 'storm chaser' framework in which teams and assets are pre-positioned in regions with frequent natural disturbance. Observing System Simulation Experiments (OSSEs) could help optimize the design, placement, and timing of both approaches while maximizing the value of existing and planned satellite assets, particularly the high-frequency observations of geostationary sensors such as GLIMR.

3.6 Integrated Modeling, Data Assimilation, and Early Warning

Predicting where a Transient Event originated, how it will evolve, and where its impacts will propagate requires integrated modeling and data assimilation combining satellite and in situ observations with sea-surface temperature, circulation, vector winds, bathymetry, and, for coastal events, shoreline and watershed characteristics. Expanded model performance testing across regimes and event types is needed, and sub-seasonal to seasonal forecasting of ocean biology and biogeochemistry would directly support this by anticipating conditions favorable to disturbance onset. Forecasting of marine heatwaves has advanced rapidly and is increasingly well understood mechanistically [67], with seasonal prediction of biological and biogeochemical variables demonstrating skill in some regions [53,54,68]. By contrast, sub-seasonal prediction of biological and biogeochemical responses remains an important capability gap [56], yet it is precisely at these timescales that many Transient Events emerge and evolve. Closing this gap is essential for effective early warning. Forecasts have operational value only when their lead time, spatial specificity, and reliability can support costly decisions such as closing a fishery, beach, or drinking-water intake. Quantifying forecast skill, uncertainty, and false-alarm rates must therefore be integral to prediction system development from the outset. Statistical indicators of declining ecosystem resilience, developed under the Global Biosphere challenge [27], provide a complementary measure of where disturbances are most likely to have long-lasting consequences, and coupling those slow indicators of vulnerability to fast forecasts of an event in progress is a promising near-term research opportunity.

3.7 Data Infrastructure and Interagency Coordination for Rapid Response

None of these capabilities will realize their full value without infrastructure for rapid, ideally real-time processing of large volumes of co-located data from disparate observing technologies, so that response measures can be engaged quickly [58]. New or improved in-water retrieval and atmospheric correction algorithms are also needed, including spectral libraries of algal types, dissolved constituents, and floating and benthic materials, and algorithms tolerant of the extreme water vapor, dust, and aerosol conditions of Transient Events. Development of these capabilities can be accelerated by close collaboration between domain specialists and data scientists and should be coordinated with NOAA and other response and recovery programs so that NASA observations translate efficiently into operational decision support.

4. Key Measurement Requirements

The strategy above requires the following capabilities, in approximate order of observing system readiness.

Ocean color continuity requires uninterrupted, PACE- and GLIMR-equivalent hyperspectral observations, including the 620, 665, 680, and 710 nm bands needed to discriminate cyanobacterial blooms from background, together with hourly geostationary revisit to track event evolution within a single day.

A low-cost CubeSat constellation should provide sub-daily coverage of coastal and large inland waters at spatial resolutions of tens to hundreds of meters, with spectral resolution and calibration sufficient for cross-validation against medium-spatial-resolution heritage missions.

Suborbital sensors should provide meter-scale or finer spatial resolution with rapid tasking, including hyperspectral imaging spectrometers for advanced tracking of aquatic ecological conditions, Synthetic Aperture Radar (SAR) for all-weather flood mapping, fluid-lensing capability for shallow-water and benthic assessment, and dual wavelength (~532 and 1064 nm) bathymetric and fluorescence lidar with 10-30 cm elevation accuracy.

Uncrewed aerial vehicle payloads should support gimbaled imaging within existing flight duration (10-15 minute) and payload (3-5 kg) constraints, with a near-term goal of autonomous water sampling.

Autonomous underwater vehicles and profiling floats should provide physical, chemical, and bio-optical measurements at resolutions sufficient to characterize disturbance evolution, supported by adaptive sampling algorithms capable of retasking a vehicle once a target is identified.

Data systems must support real-time processing, transmission, and fusion of multi-platform data streams, together with the in-water retrieval and atmospheric correction algorithms needed under the extreme observing conditions Transient Events present.

Modeling and data assimilation systems require sea surface temperature, current, vector wind, bathymetry, and coastal morphology inputs at resolutions sufficient to predict the origin, direction, and speed of an evolving event's impacts, with expanded testing across event types to establish predictive skill.

These requirements are interdependent: the value of any single observing element is maximized when coupled to the infrastructure, deployment plan, and modeling capability of Section 3.

5. Feasibility and Implementation within the Decadal Time Frame

The technology required for most elements of this strategy is mature or nearing maturity. Hyperspectral airborne imaging spectrometers (PRISM, AVIRIS-NG), fluid-lensing instruments, and dual wavelength bathymetric lidar are already operational and require sustained funding and expanded deployment rather than new development. Continuity of polar orbiting ocean color observations builds directly on the Program of Record, with PACE operating since February 2024 [52]. Geostationary continuity rests on a less secure programmatic footing: GLIMR is a competed Earth Venture Instrument (EVI-5) rather than a Program of Record mission, and NASA is now procuring its spacecraft and launch commercially, so the schedule risk attached to this pillar is real and should be recognized explicitly. BGC-Argo float technology is similarly mature [60], and expansion into inland and nearshore waters is incremental rather than fundamentally new. However, US BGC-Argo funding winds down in October 2027; if this strategy is to be realized, sustained support for these vital in situ assets must be found.

A low-cost CubeSat constellation is achievable in the near term given the pace of commercial small-satellite development and the demonstrated performance of prior ocean color CubeSats [59], though cross calibration with heritage missions and assurance of adequate spectral resolution will require dedicated validation effort. Uncrewed aerial vehicle platforms are similarly mature for imaging and extending them to autonomous water sampling is a near-term rather than long-term goal given current trends in payload capacity.

The principal implementation challenges are therefore concentrated not in sensor readiness but in coordination, infrastructure, and workforce capacity. Establishing a standby pool of rapid response assets requires a deployment plan, funding mechanism, and interagency coordination that do not yet exist. Real-time processing and fusion across disparate platforms will require sustained investment in cloud-native cyberinfrastructure and Geo-AI algorithm development to automate anomaly detection and tasking [58]. Purposeful manipulation experiments (with the caveats noted in Section 3.5) or standby field campaigns will require OSSEs to optimize design before major field investment, and expanded modeling capability will require a trained workforce spanning physical oceanography, ecology, and data science. None of these challenges is a barrier to progress within the decadal time frame, but each requires deliberate planning and sustained investment beginning immediately.

6. Summary of Recommended Priorities

We recommend that the 2028-2037 decadal survey prioritize the following elements to address the Transient Events grand challenge:

1. Sustain and continue medium- and high-spatial-resolution polar orbiting ocean color observations, together with GLIMR-equivalent geostationary regional coverage, retaining the spectral bands necessary for detecting cyanobacterial blooms and other Transient Events (continued).
2. Develop a low-cost CubeSat constellation with adequate spectral resolution, radiometric performance and calibration to provide sub-daily Transient Event monitoring of coastal and inland waters (near-term/long-term).
3. Continue development and deployment of airborne passive and active sensors, including hyperspectral imaging spectrometers, fluid-lensing instruments, and dual wavelength lidar, to improve Transient Event characterization and response support (continued).
4. Expand uncrewed aerial vehicle capability, including gimbaled imaging payloads, autonomous water sampling systems, and other rapidly deployable, low-cost sensors, for flexible, low-cost Transient Event assessment (near-term).
5. Advance autonomous underwater observing capability and establish a coordinated standby asset pool that can be rapidly deployed when Transient Events are detected (immediate/near-term).
6. Expand the BGC-Argo and related float array to improve coverage of inland and nearshore waters relevant to Transient Event monitoring (near-term).
7. Design and execute disturbance-ecology field campaigns, including purposeful manipulation experiments and standby rapid-response deployments, informed by Observing System Simulation Experiments (near-term/long-term).
8. Develop cloud-native cyber infrastructure for real-time processing, fusion, and dissemination of large, multi-platform data volumes to support early warning and hazard response (continued).
9. Support development of new in water retrieval and atmospheric correction algorithms for the often extreme observing conditions associated with Transient Events (continued).
10. Advance sub-seasonal to seasonal forecasting of ocean biology and biogeochemistry and integrate modeling and data assimilation to improve prediction and adaptive sampling of Transient Events, establishing the skill and lead time required for early warning (near-term/long-term).

7. Conclusion

Transient Events are a ubiquitous, consequential, and historically under-prioritized feature of aquatic ecosystems. Their abrupt onset and unpredictable location defeat observing systems built for routine sampling, yet their consequences – from fishery and beach closures to contaminated water supplies and devastated habitats – will only grow as the climate warms. Meeting this challenge requires an observing system at once sustained and adaptive: sustained in its continuity of satellite ocean color and BGC-Argo-class in situ networks, and adaptive in its capacity to mobilize suborbital and underwater assets wherever an event occurs, with modeling skillful enough to convert detection into warning in time to act. By investing now in the infrastructure, algorithms, science, and partnerships described here, the decadal survey can make capturing key Transient Event measurements a matter of design rather than luck.

Figures

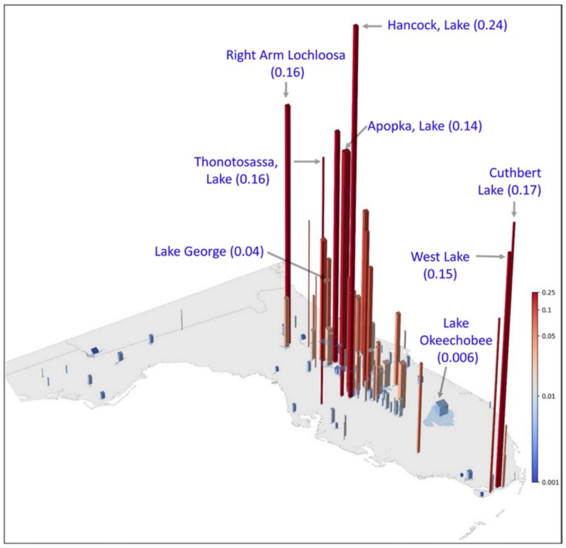

Figure 1. Algal bloom magnitude in Florida lakes in 2011 after normalization by lake surface area. Area-normalized magnitude (km^{-2}) of selected lakes provided as part of bar labels in parenthesis. Bar height and color are proportional to annual bloom magnitude (in A) and annual area-normalized magnitude (in B). The width of the bars is proportional to the lake surface area. Note that the colorbars are log-scaled. Reproduced from Mishra et al. (2019) [28], as presented in the NASA OBB Science Vision report [69].

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