FROM CORES TO CODE: ENHANCING DATA-MODEL INTEGRATION TO IMPROVE FORECASTS OF COASTAL CHANGE – AN INTRODUCTION TO IGCP PROJECT 725

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Abstract: Here, we detail the scientific motivation underpinning IGCP Project 725 (2021–2026), followed by an overview of Project goals, structure, leadership, recent activities, and plans for the 2023–2026 timeframe. IGCP Project 725 seeks to address the gap of how coastal geologists and numerical modelers often approach the issue the issue of coastal change in different and not always complementary ways. This was done by promoting and supporting integration of stratigraphic data and/or direct observations of coastal change with numerical models to fore- and hind-cast coastal behavior in response to drivers that operate over a range of spatial and temporal scales. Accurate forecasts of coastal change are best achieved by combining geological field and laboratory data—generally collected with the goal of reconstructing past coastal change—with predictive numerical models. Doing so would allow both to progress simultaneously in an integrated way that pushes forward our understanding of coastal processes across timescales and our ability to forecast both the drivers of, and human/ecological/physical responses to, coastal change. Failure to bridge these two communities will lead us to miss a significant opportunity to address fundamental questions that will help to safeguard, enhance resilience, and support proper mitigation efforts in coastal communities throughout the world.

Introduction

Coastal environments and ecosystems offer significant economic opportunities and environmental and cultural benefits to the 2.4 billion people (~40% of the world's population) that live within 100 km of the coast (United Nations, 2017). However, coastal systems, and the human and ecological communities they support, are presented with challenges that operate over a range of spatial and temporal scales (Martinich et al., 2013). These include risks from both long-term, climate-change-driven changes to the factors responsible for coastal change (sea-level rise, coastal storms, tectonic activity), as well as to the frequency and intensity of more immediate perturbations from severe weather events and recurrent flooding. Combined, these drivers can result in significant coastal changes, including, for example, gradual to rapid inundation of coastal land and resultant geomorphic changes to patterns of erosion and sediment deposition. In turn, these coastal responses cause significant damage to infrastructure, loss of life, economic hardship, and degradation of coastal ecosystems (Gopalakrishnan et al., 2016; Anarde et al., 2018; Van Holle et al., 2019). As such, coastal populations face increased costs, including those associated with life, health, and wellbeing; these costs are often borne disproportionately by the most vulnerable and traditionally underserved communities.

A critical scientific need for facilitating effective decision making about how best to manage the coastal zone is the ability to accurately forecast coastal response to climate and anthropogenic changes; and one which relies on robust understanding of the drivers, processes, and scale of coastal change. Central to achieving this goal is the successful integration of geological expertise, robust data collection and analysis, and the application of numerical models to provide quantitative forecasts of the drivers and physical-system responses to coastal change, both spatially and temporally. Bridging these divides is the primary goal of the *International Geoscience Programme (IGCP) Project 725: Forecasting Coastal Change*. Here, we detail the scientific motivation underpinning IGCP Project 725 (2021–2026), followed by an overview of Project goals, structure, leadership, recent activities, and plans for the 2023–2026 timeframe.

IGCP Project 725: Coastal Science 'From Cores to Code'

Context: Coastal Science within the International Geoscience Programme

Since the initiation of IGCP Project 61 in 1974, there has been an unbroken sequence of coastal-change-oriented IGCP projects (200, 274, 367, 437, 495, 588, and 639) that have brought together international scientists from related disciplines (including historians, archaeologists, modelers, and geodesists) to share and discuss the latest findings and advancements in sea-level, sedimentological, and coastal-process research. These previous projects have largely focused on geological records of coastal dynamics and related geohazards, and have been instrumental in advancing the methodology, interpretation, and standardization of approaches to understand these hazards and their impact on the world's coastlines (*e.g.*, Scott et al., 1989; Green et al., 2015; Rubin et al., 2017). Interrogation of the coastal geological/stratigraphic record has, for example, allowed us to supplement and extend instrumental and documentary records of sea-level change, coastal dynamics, and coastal seismic hazards (Atwater, 1987; Donnelly et al., 2004). This has improved our understanding of ‘baseline’ conditions against which contemporary observations can be compared and contextualized (Kopp et al., 2016), and has provided a holistic view of the magnitude and frequency of occurrence of hazardous events, such as storms, earthquakes, and tsunami (Dura et al., 2015; Bregy et al., 2018; Pizer et al., 2021). Standardized and integrated geological records from around the world have also refined our understanding of the mechanisms and drivers of sea-level and coastal change (Horton et al., 2009; Garrett et al., 2022).

Motivation: Need for Improved Coastal Data-Model Coupling

Although it is widely understood that future sea-level rise will exacerbate erosion and flooding frequency (*e.g.*, Nicholls and Cazenave, 2010), decoupling the historical effects of slow sea-level rise from the impacts of extreme events (*e.g.*, hurricanes, tsunamis) and/or the natural evolution of coastal systems (beaches, barrier islands, dunes, etc.) has proven challenging. This has made future coastal-change predictions—particularly those yielded from observations alone—unreliable. Tighter connection of modeling efforts to field and laboratory data is a prerequisite for the development of more robust, process-consistent models, conclusions, understanding, and predictive capabilities surrounding coastal change. Despite shared scientific goals, field/process geologists and numerical modelers often approach the same research question in different, and not always complementary, ways. Similarly, coastal geologists and geomorphologists have often been at odds with coastal engineers as solutions have been sought to combat coastal erosion and ameliorate coastal hazards such as storm surges or tsunamis (*e.g.*, Pilkey and Cooper, 2014; Neal et al., 2014).

Numerical models, while imperfect (Thieler et al., 2000; Cooper and Pilkey, 2004; Cooper et al., 2018), can help to decouple past signals and to explore future changes in landscapes (*e.g.*, beach erosion, barrier-island migration, recurrent flooding of population centers), the forces driving those changes (*e.g.*, sea-level rise, storms, tsunamis), and the location-specific factors mitigating or exacerbating them (*e.g.*, antecedent geology, human alteration of coastal sediment fluxes). Process-based numerical models have been relatively successful in capturing the effects of short-term (one year or less) coastal-change hazards (*e.g.*, McCall et al., 2010; Harter and Figlus, 2017), and geometric or compartment-based models are widely used to explore bulk behavior on century and longer timescales (*e.g.*, Dillenburg et al., 2000; Stolper et al., 2005). However, these tools generally lack the ability to capture change on intermediate, ‘mesoscale’ (years to multiple decades) timescales relevant to addressing coastal hazards from a management perspective. Ecological processes are often overlooked as well, leaving the resulting models lacking the needed resolution of biophysical feedbacks important on such timescales. As a result, the emphasis on coastal management remains largely short-term in perspective with the focus on buffering the impacts from individual storms or calculating future flooding probabilities assuming static morphology (Sweet and Park, 2014; Serafin and Ruggiero, 2014; Vitousek et al., 2017). Further, although advances in modeling and field-based stratigraphy and process-observations are progressing, this is, at best, in parallel with one another, rather than in an integrated fashion. In some cases, the models are ahead of geological data; for example, modeling of probabilistic scenarios that are not ground-truthed or constrained by physical evidence.

On the other side, geologic studies provide valuable information, but tend towards site-specific case studies. The resulting insights could be better applied to key societal issues if they were better idealized from case studies through modeling. In the context of coastal change, by combining even basic relationships between sediment transport and environmental driving forces, morphodynamic feedbacks can interact in numerical simulations, allowing them to be understood without personal bias, and leading to an understanding of coastal records and 'emergent' behavior (Lazarus et al., 2011) grounded in underlying processes (Grilli et al., 2017). This can involve modelling short-term drivers, such as wave and hydrodynamics processes (Mortlock and Goodwin, 2016), or models developed to understand long-term shoreline behavior (Nienhuis et al., 2017; Ciarletta et al., 2019; Swirad et al., 2020).

Improved data-model integration has benefits for both interpretations of long-term coastal sedimentological records and forecasts of coastal-system responses to future climate and anthropogenic change. For example, data-informed modeling studies have revealed the timescales over which changes within river basins (*e.g.*, human-caused deforestation or damming) are communicated to the coast in the form of altered sediment fluxes (Nittrouer and Viparelli, 2014; Nienhuis et al., 2017) and revealed the primacy of upland erosion rates (over, for example, wave climate) in controlling shoreline orientations (Ashton et al., 2016). Even relatively simple models of coastal evolution, informed by real-world data, reveal how cyclic or episodic coastal morphological behavior can arise autogenically, rather than from allogenic climatic or sea-level forcing, as may be presumed from field mapping alone (Hein and Ashton, 2020). However, inappropriate application and limited integration of field data and modelling can result in significant debate and potentially erroneous conclusions being reached. A recent controversial example arose from an attempt to model global sandy beach response to sea-level rise (Vousdakis et al., 2020), leading to incorrect forecasts of widespread coastal erosion. This work caused alarm in many coastal communities—especially in Australia—and generated significant criticism of its methods and conceptual underpinning (Cooper et al., 2020) due to poor recognition of the specific local-scale conditions of the beaches modeled, geologically inappropriate application of the now-controversial Bruun rule, and the upscaling thereof. In addition, the accuracy of model forecasts can be heavily influenced by assumed yet inaccurate and/or poorly constrained field data and behavior (*e.g.*, Brain et al., 2011).

Goals of IGCP Project 725

Recent studies demonstrate the immense promise of improving the predictive capacity of numerical models to fore- and hind-cast coastal change through combining expertise from field (stratigraphic, mapping, process), laboratory, modeling, and machine-learning approaches (*e.g.*, Cohn et al., 2019; Esposito et al., 2020; Montaño et al., 2020; Keogh et al., 2021; Pilarczyk et al., 2021; Shawler et al., 2021; Castelle et al., 2022; Mariotti and Hein, 2022). IGCP 725 aims to further bridge this gap, and provide a community platform for tackling the challenge of predicting coastal change, particularly at meso- and shorter timescales.

Specifically, this project aims to improve the knowledge transfer between modelers and geologists/geomorphologists in a manner that allows both communities to mutually benefit from better understandings of each other's disciplines. It is the team's intent that this will lead to more grounded model goals and outcomes, and more generalizable and actionable knowledge derived from field-based case studies. In turn, this will better improve the accuracy of, and confidence (both scientific and stakeholder) in, coastal management decision making and policy. Specific problems being addressed are: (1) how can field and process geologists focus their work to provide modelers with the most useful data to ensure that model simulations are grounded in observational reality?; (2) what could numerical modelers provide to field and process geologists to allow them to define their field sampling strategies?; (3) what are the key uncertainties in model outputs, and how can field and process geologists help to constrain these?; (4) how do specific field sampling and data-collection strategies influence the accuracy and precision of model outputs and results?; (5) what data resolution is needed with respect to the dynamics of natural systems to provide accurate simulations of coastal change and how does this change across short-term, mesoscale, and geologic time periods?; (6) over what spatial and temporal scale can the geological record provide appropriate validation of model outputs?; and (7) how can numerical models improve our understanding of the genesis, dynamics, and preservation of stratigraphy and landforms?

Additionally, although there is considerable literature on how best to model coastal behavior for particular applications, there is limited consensus on how this can be done holistically and consistently across multiple spatiotemporal scales. Making these coupled field-model outcomes—and the insights into complex coastal systems and the interplay with coastal hazards that arise from these processes—accessible to the coastal management and engineering communities is of primary importance for coastal risk assessment, forecasting, and mitigation. As such, IGCP Project 725 also considers: (1) What type of data and model outputs are needed by coastal stakeholders who have varying, and ultimately finite, time and financial resources?; and (2) How can model forecasts and scenarios best be communicated to end users and applied in coastal management?

The project focuses on these questions in the context of the following research themes and applications: (eco-)geomorphology, coastal process (wave, tide, currents, aeolian processes) dynamics; geochronology; stratigraphy and associated preservation potential; coastal hazards; and human-natural couplings. We will also lead the broader community in identifying cross-cutting issues and resolutions to move beyond modelling approaches constrained by location or temporal scale to ensure that linkages between scales, drivers, and setting are appropriately considered. This approach allows our project to provide a platform for groups of modelers and field and laboratory geologists to discuss methods, data, and best practice across a range of spatial and temporal scales to identity and bridge misunderstandings and conflicts, and to note best approaches that can be exchanged between coastal research groups.

Introducing IGCP Project 725: Forecasting Coastal Change

IGCP Project 725 Activities

IGCP Project 725 (Fig. 1) was launched in mid-2021. With the official project title "Forecasting Coastal Change" and the nickname "From Cores to Code", it has hosted sessions at major national and international geoscience conferences (with several pending, including at Coastal Sediments '23); held the first in a series of annual virtual geochronology workshops; and highlighted dozens of papers, abstracts, and opportunities at the intersection between numerical modeling and field geologic and process data. Annual project meetings are planned for the coming years in Brazil, The Philippines, and Estonia, with a kick-off meeting occurring in 2022 at Durham University in the United Kingdom.

Annual Project Meetings

Following a one-year delay due to the COVID-19 pandemic, IGCP Project 725 held its first in-person conference in September 2022 at Durham University (UK). Officially dubbed the '*UK Coasts and Sea Level Meeting*', this meeting was

Fig. 1. Official logo of IGCP Project 725. Designed by Mahinaokalani Robbins (William & Mary Geology '21; current affiliation: Western Washington University).

attended by ~50 in-person and ~20 virtual participants from coastal geology and modeling backgrounds. It was co-hosted by the Sea level and Coastal Change QRA Research Group and the leadership of IGCP Project 639 ('*Sea Level Changes from minutes to millennia*'), and served as the unofficial hand-off of coastal IGCP projects from Project 639 to Project 725. Future meetings will be held annually, generally in boreal autumn/austral spring, with locations selected based on underrepresentation in the scientific literature. The next meeting is planned for November 2023 in southern Brazil (Fig. 2). Information on meeting registrations, calls for abstracts and travel supports for eligible scientists (e.g. ECR and scientists from developing countries) will be available will be available on our official project website (https://www.sfu.ca/igcp-725.html).

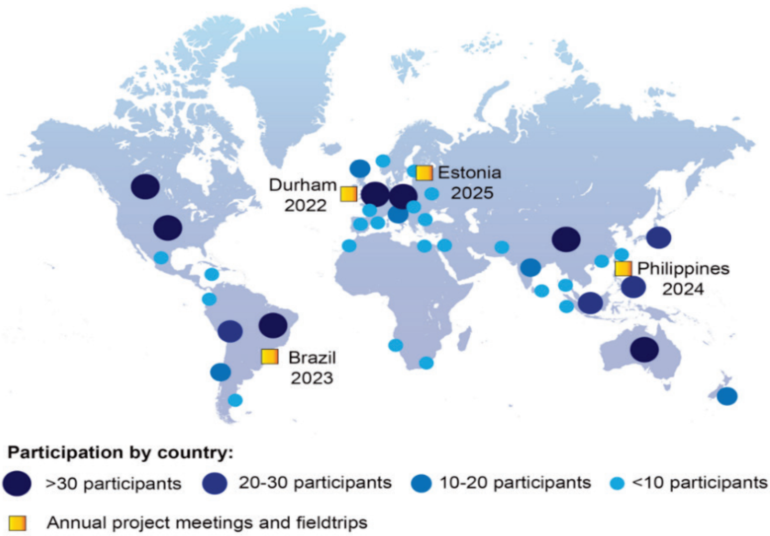

Fig. 2. Global map of participants in IGCP Project 725, as quantified through membership on the project listserv as of November 2022. Of the approximately 450 participants, 20% are DCRs, 40% are ECRs, and 48% are female scientists. Locations of planned future IGCP Project 725 meetings are shown as yellow squares. Base map obtained from freevectormaps.com.

Contributions to International Meetings

In addition to IGCP-specific meetings, IGCP Project 725 hosts special sessions focused on data-model integration in coastal geosciences at major international conferences, such as *Coastal Sediments '23*. Other IGCP 725 conference sessions have been held at, or are planned for, meetings of the American Geophysical Union and the European Geosciences Union, and at the 2023 International Union for Quaternary Research (INQUA) Congress.

'Geochron January'

One of the primary goals of IGCP Project 725 is to educate the coastal community on tools and methods that can contribute to improved integration of field data and numerical modeling. In January 2022, the IGCP 725 team organized the first in a series of fully virtual 'Geochron January' workshops, focusing on one of the most critical components of paleo-reconstructions and future predictions: accurate geochronology. Through a series of recorded presentations and multi-room breakout sessions with global experts, this first event covered the basics of the applications, approaches, and pitfalls of radiocarbon dating. Specific topics covered included sampling strategies and dating of organic material (temperate and tropical coasts), carbonates, and archeological materials; a behind-the-scenes view of lab analyses; calibration of $\Delta^{14}C$ ages; and age-depth modeling. This first event reached nearly 200 scientists from 28 countries, of which 12 were developiong nations.

'Geochron January' workshops are envisioned to be annual events. As of this writing, a second iteration is planned for January 2023, emphasizing tools beyond radiocarbon, including short-lived radioisotopes, U/Th and luminescence dating, chrono horizons and cosmogenic-isotope dating. Information for this, and other, events hosted by IGCP 725 is also available on our project website.

The Scientists of IGCP Project 725

An initial listserv was compiled soon thereafter the launching of the project in mid-2021. This listserv includes ~450 coastal scientists from 40 countries (Fig. 2). This reflects the broad, international focus of IGCP Project 725, and its emphasis on promoting a diverse, equitable, inclusive, and anti-racist coastal geosciences community, largely through supporting (through training, opportunities, promotion, and funding) early career researchers and scientists from underrepresented groups and/or less developed countries.

ICGP Project 725 is led by Jessica Pilarczyk (Project Lead; Simon Fraser U.), Matt Brain (Durham U.), Chris Hein (Virginia Institute of Marine Science), Andy Green (U. KwaZulu-Natal), Annie Lau (U. Queensland), and Noelynna Ramos (U. the Philippines). Contact information is available on the project website, and all co-leads are authors of this manuscript; email addresses are listed accordingly.

Opportunities to Contribute to and Engage with IGCP 725

In addition to contributing to planned meetings, IGCP Project 725 offers a number of mechanisms through which scientists can become involved:

1. **Communication:** the IGCP 725 listserv is used to keep project members and interested scientists updated on upcoming events, special initiatives, and project notifications. Those wishing to join should email the project leaders (manuscript authors). Additionally, IGCP Project 725 has an official project website (https://www.sfu.ca/igcp-725.html) and is on Twitter at @igcp725.

2. **Publications:** To highlight the work of project participants, the IGCP 725 team is maintaining a list of publications with IGCP 725 acknowledgements. Add the following statement to the acknowledgement section: "*This work is a contribution to IGCP Project 725 'Forecasting Coastal Change'*." Doing so is a requirement for funding agencies that help subsidize annual IGCP 725 meetings and fieldtrips. Further, notification to the IGCP 725 leadership team upon publication will trigger advertisement for the work via our Twitter page and Publications database on the IGCP 725 website.

3. **Advertise with IGCP 725:** The IGCP 725 team can help advertise and disseminate information (*e.g.,* upcoming coastal-themed conference sessions, field trips, job or graduate school openings, etc.) to the global IGCP 725 community via annual meetings and workshops, the listserv, and through Twitter.

Conclusions

IGCP Project 725 is constructed around the principle that the time is upon the coastal geosciences community to merge the subdisciplines of field data collection/analysis and modeling. Doing so would allow both to progress simultaneously in an integrated way that pushes forward our understanding of coastal processes across timescales and our ability to forecast both the drivers of, and human/ecological/physical responses to, coastal change. Failure to bridge these two communities will lead us to miss a significant opportunity to address fundamental questions that will help to safeguard, enhance resilience, and support proper mitigation efforts in coastal communities throughout the world.

Acknowledgements

IGCP is funded by the United Nations Educational, Scientific and Cultural Organization (UNESCO) and International Geoscience Programme (IGCP). IGCP Project 725 receives additional support from the International Union for Quaternary Research (INQUA) Coastal and Marine Processes (CMP) Commission, Simon Fraser University, and the Canada Research Chair Program. This work is a contribution to IGCP Project 725 'Forecasting Coastal Change'.

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