Earth and Planetary Surface Processes Perspectives on Integrated, Coordinated, Open, Networked (ICON) Science

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Key Points:

- The study of Earth and Planetary Surface Processes would benefit from the further advancement and application of ICON principles.
- An important aspect of ICON is that science effectively serves both the scientific communities and broader society.
- This commentary highlights current and future application of ICON principles within the Earth and Planetary Surface Processes community.

ABSTRACT

This article is composed of two commentaries about the state of ICON principles (Goldman et al. 2021) in Earth and Planetary Science Processes and discussion on the opportunities and challenges of adopting them. These commentaries focus on how "Field, experimental, remote sensing and real-time data research" and "Inclusive, equitable, and accessible science" both currently benefit from and would be able to grow as a discipline with more directed implementation of, ICON principles.

1 Introduction

Integrated, Coordinated, Open, Networked (ICON) science aims to enhance synthesis, increase resource efficiency, and create transferable knowledge. This article belongs to a collection of commentaries (Goldman et al., 2021) spanning geoscience on the state and future of ICON science.

2 Field, experimental, remote sensing and real-time data research

2.1. Current State of ICON in EPSP Earth and Planetary Surface Processes (EPSP) is a multidisciplinary field encompassing the full range of processes that generate and erode landscapes, create stratigraphy, and that couple the internal dynamics of the surface to climatic, tectonic, and anthropogenic forcings. As such, it is deeply "in touch" with our community members on a day-to-day basis as scientists and civilians. Certain aspects of this science are accessible to a wide range of our communities, and unintentional inputs from our communities influence some of the very subjects of the fields we study. Thus, EPSP is a science that benefits from the ICON framework, meaning science which integrates processes and aims to co-ordinate data and protocols across different sub-disciplines, adheres to the FAIR (Findable, Accessible, Interoperable, Reusable) data-sharing principles, and promotes wide ranges of community participation. Members of the EPSP scientific community bring field and remote monitoring, and laboratory, computational and theoretical skills to the table, as we discuss in the first part of this paper. EPSP science also benefits from the networking and inclusion of a wide range of our human communities, some of whom have traditionally operated outside the range of what we consider "western" or "modern" science which we address in the subsequent section.

2.1.1 Field Monitoring The current diversity of EPSP field monitoring programs span a wide range of spatio-temporal and organizational scales, but integrating these efforts remains a challenge that will require further coordination and networking to overcome. Long term (interannual to interdecadal) field monitoring projects covering large spatial domains (state to international scale) tend to be managed by large organizations such as state and federal agencies, with long-term funding sources. Short term (event to interannual) monitoring projects and/or those focused on small spatial scales (local to state) tend to be managed by small organizations and individuals such as academic researchers and local stakeholders, with short-term funding. However, larger-scale consortia of small organizations and individual researchers are beginning to integrate and coordinate small-scale projects with increased utility for large-scale synthesis. Some examples from academia include citizen science-centered projects such as the CGS Landslide Inventory and the CoastSnap coastal monitoring program. Many others exist that have strong inter-disciplinary value and are well networked through strong ties to the EPSP community, such as the Community Collaborative Rain, Hail and Snow Network (CoCAHRAS). Coordination challenges for citizen science-based projects include the provision of dedicated staff for data quality assurance including issues surrounding the creation and provision of training material for citizen scientists to collect high-quality data.

2.1.2 Real-Time Data Monitoring Programs Open FAIR (Findable, Accessible, Interoperable, Reusable) data is revolutionizing the fields of EPSP. Online platforms offering access to real-time data from international to local monitoring programs have proliferated over recent decades. Examples relevant to EPSP include the USGS National Water Information System (NWIS), NOAA National Center for Environmental Information (NCEI), CUAHSI Hydrologic Information System (HIS)/Hydroshare, USEPA Streamcat, and the crowd-sourced FireMappers dataset. The telemetry and cyberinfrastructure associated with these enable researchers to coordinate research methods (e.g., relying on common base data sets) and share data from individual monitoring sites (e.g., CUAHSI HIS). However, in many areas monitoring is limited to watershed outlets with few spatially distributed real-time watershed monitoring networks available. While the former have great utility to the EPSP community, the latter are highly valuable to development and testing of models (both data-driven and process-based) and highlight the need for increased integration, coordination and networking in EPSP research.

2.1.3 Remote Sensing Advances in remote sensing have contributed to the advancement of EPSP through the principles of ICON science. Remote sensing of Earth and Planetary surfaces provides integrated information on geologic processes at a variety of spatial and temporal scales. The development and coordination of remote sensing data collection techniques and user-friendly processing software and platforms has advanced Earth and Planetary sciences. Global open-access satellite data, such as Landsat and Sentinel, provide opportunities to study the global surface process. Google Earth Engine (GEE) is an emerging cloud-based and planetary-scale platform that provides public data archives and powerful cloud processors for the Earth's surface analyses. For example, Pickens et al. (2020) were able to quantify the extent and change of global surface water dynamics using 3.4 million Landsat scenes in GEE. Additionally, efforts to archive and analyze high-resolution (meter-scale or finer) topographic datasets such as OpenTopography provide an important and networked service to the earth surface process community.

Structure-from-Motion (SfM) photogrammetry is increasingly being used to provide low-cost high resolution approaches to mapping, and simultaneously combining process-based interpretations of landscape processes across physical, chemical and biological disciplines. Its application and development of interpretive approaches are used in many areas of earth surface processes and can be used as a tool to further apply ICON principles within the EPSP community.

2.1.4 Experimental Activity In EPSP, experimental modes of inquiry tend to be integrated because they are most often pursued with the goal of better understanding processes operating at much larger scales. Experimental activities play a growing role in various approaches to scientific inquiry in the EPSP community. This includes physical modeling in controlled experiments such as flumes and basins. These activities in controlled laboratory environments have played significant roles in building intuition, for example, of sedimentary processes where important dynamics can be hidden from the human eye and essentially inaccessible due to processes that erase previous records of these processes. Experimental activities also include the use of controlled laboratory settings for the development of experimental approaches to capture, monitor and quantify surface processes in the field. Advances in sensors and technological capabilities toward field activities often occur through experimental applications to surface processes.

Despite the integrated nature of EPSP experimental inquiry, our experimental community has traditionally been fairly fragmented with individual researchers and institutions performing physical experiments of geomorphic processes ranging in scales from individual grains to entire mountains or deltas. Although initially informal, there are now increasing community-wide efforts geared towards more effective, integrated and open methods of information sharing that includes both experimental methodologies and data. This has been facilitated by funding programs such as NSF EarthCube and Research Coordination Networks that support professional networks and their knowledge bases, for example, the Sediment Experimentalist Network (SEN, sedexp.net). Grassroots efforts such as Sustainable Environment, Actionable Data (SEAD, https://sead2.ncsa.illinois.edu/) also provide resources for this community to publish, archive, and receive recognition (through DOIs) promoting open data.

2.2 Challenges Fieldwork is an inherent part of surface research for ground-truthing, sample collection, observations of phenomena and integrating research across disciplines through time and space. Equity remains a key issue in the development of ICON/networks throughout EPSP. STEM disciplines are arguably founded on meritocracy where recognition is based on an objective value of output and data. A lack of equity in physical and social accessibility to the field hinder the current application of ICON in EPSP. There are many missed opportunities for scientific engagement with EPSP, including the development of field programs with gender balance, integration of the larger societal community or acknowledgement of traditional landholder aspirations.

A lack of data sharing is an obstacle to open science and a key challenge for the advancement of the EPSP community. Generated spatial data or physical samples are often poorly shared across the scientific community, even more so with physical samples and output from physical experiments or measurements. A lack of data accessibility is a challenge for the achievement of open science, particularly for real-time data. Non-continuity in real time data collection can be hindered due to lapses in funding needed to collect, store, and provide quality assessment/quality control on data output. Additionally, the coverage of detailed topographic maps (under 30m resolution) are not yet ubiquitous, meaning that many process-based modelling approaches are unable to be performed in settings where high resolution digital elevation models may be required.

Coordination, standardization, and harmonization of field, laboratory, and analytical methods would be one way to further advance data sharing, comparability, and synthesis in EPSP. However, there are barriers in standardization of sampling and surrogate sensing methods that post a challenge to fully embracing ICON principles. Approaches to field observations of land surface character, change, and flux are often developed by an individual research group or based loosely on inadequately documented and evaluated procedures, which can result in data of unknown quality and poor inter-comparability (e.g. Buffington, 2013). One particularly well-documented example of this includes suspended sediment. Despite studies documenting the differences and comparability of different laboratory measures of suspended sediment concentration (Gray, 2000; Williamson & Crawford, 2011), standard methodologies and sufficiently documented methods remain a significant challenge in the integration and interoperability of suspended sediment data. Similarly, the basis for accepting or rejecting EPSP analytical or modeling results remains contentious and poorly defined. Production and curation of truly Open data would alleviate these barriers, such as incentivizing the use of FAIR principles for individual data management plans and community databases.

2.3. Opportunities and recommendations The study of Earth and Planetary Surface Processes would benefit from the further advancement of ICON principles throughout each aspect of our work. Application of the ICON principles within EPSP will help us tackle common issues such as climate change and the increase in climate-related disasters such as wildfires and flooding that can disproportionately impact countries with a low human development index. Increasing the Open Fair access and exchange of data, software and models remains essential to increasing the pace and equity of advance in EPSP. Improving the distribution and access of high- resolution spatial data is a low risk/investment opportunity that can offer high benefits, driving the progress of research within EPSP particularly in areas that are hard to access or derive on ground quality assurance and control. Remote sensing imagery may aid field investigations for inaccessible or large sites with the improvement of spatial and spectral resolution (e.g., Ridgecrest, CA earthquake sequence of Ponti et al., 2020; Chamoli disaster of Shugar et al., 2021). The increasing availability and development of remote sensing data provide a network to integrate multiple disciplines and coordinate field investigations for open sciences. New and developing computational tools are providing increased potential for mining these large open data sets for combined outputs from wide ranging data sources. For example, machine learning has been used to derive actionable interpretations of multi-dimensional data. Notably, SHAP — (SHapley Additive exPlanations, Lundberg and Lee, 2017 -- provides the capability to "reverse-engineer" physical relationships toward predictive algorithms from multi-dimensional data.

Integrated, coordinated and networked activities will be required to tackle some of the greatest scientific challenges in EPSP. The pursuit of large-scale, high-resolution monitoring campaigns targeting regional scale phenomena at the event-scale have historically been limited to individual watersheds. Advances in high-frequency sensing enable this work, but successful application will require further commitment to ICON principles to study drivers of erosion and other geomorphological processes in an integrated fashion across scales. The key to achieving this will be coordinated, open sharing of methodology used for detecting and delineating event periods (e.g. rainfall-runoff, flood) from continuous monitoring records as methods currently vary across studies and event delineations are often not included in shared data sets. Significant advances in large sample research are being realized in the hydrological sciences with the benefit of deep learning and machine learning approaches (e.g., Tarasova et al., 2020; Gauch et al., 2021). Similar potential exists in geomorphology if data from concentration, flux, and event studies can be readily aggregated into unified datasets accessible to researchers throughout the EPSP community.

3 Inclusive, equitable, and accessible science

3.1 ICON and JEDI concepts

An important aspect of ICON is that science effectively serves both the scientific communities and broader society, thus a discussion of justice, equity, diversity, and inclusion (JEDI) is important to promoting ICON science. As discussed below, the history of EPSP science, that is, early geomorphology, has been problematic in many ways and certainly with respect to the ICON principles of being (1) Integrated across disciplines; (2) Coordinated using consistent methods; (3) Open by producing data that are Findable, Accessible, Interoperable, and Reusable (FAIR); and (4) Networked across institutions or collaborators. However, as we conclude in the closing paragraphs of this piece, steps are being taken with initiatives like the AGU "Bridge" program and programs like URGE, as well as the recommendations of Eicken et al. (2021) and Lane (2020), to create an EPSP community that adheres to the principles of ICON-FAIR.

3.2 Challenges to ICON and JEDI work

Geosciences as a whole is lagging behind many other STEM fields in regards to JEDI concepts among our ranks (Bernard and Cooperdock, 2018). Though what is included here is not a comprehensive list, many aspects of the history of modern geomorphology are problematic. For example, many land surveys conducted by early geomorphologists were used as a mechanism and justification for violent colonization of the "New World" (e.g., Powell Surveys in the Colorado River Basin, USA (Pico, 2019), and the Davisian Landscape Evolution view of Indigenous lands as 'untamed' (Pico, 2019)). By touting the history of these problematic figures (primarily of white European Ancestry) in our textbooks and leaving out narratives from Traditional Knowledge across many Indigenous cultures worldwide, we continue this exclusionary view of our science (Tooth and Viles, 2021), strongly undermining attempts to engender more Integrated and Networked EPSP science. This legacy also continues within geomorphology, notably through "parachute science" wherein (predominantly White) scientists from higher-income countries conduct research in lower-income countries with little to no input from native scientists in the creation of publications (Tooth and Viles, 2021; North et al., 2020). In regards to ICON, this issue highlights the need for more explicit inclusion of local groups as part of a Network during all phases of scientific work, particularly at the beginning as research questions and proposals are being formulated.

Parachute science remains a significant concern with respect to earth surface research in the Arctic. As the Arctic warms, its geomorphology is one of the most rapid and visible components of change. These changes are increasingly drawing scientific interest from geomorphologists (and in some instance planetary scientists in pursuit of analogs) from outside the region and with limited experience working with or knowledge of the people living in these regions. Across Alaska, many communities are advocating for a greater voice and role in the science conducted on and around their lands (Stone, 2020). Understanding and incorporating local communities and knowledge into nationally funded science programs will require skills not traditionally taught in earth science programs. Nationally funded "top-down" research commonly only engages local communities after a proposal has been written and funded. While "bottom-up" community-based projects may have limited connections to large-scale scientific studies being conducted in proximity to these communities. Eicken et al (2021), put forth recommendations for bridging the "top-down" and "bottom-up" divide that lie at the heart of the ICON science. These include coordinating the priorities and methodology in observing and data management programs at appropriate scales. Eicken et al. (2021) further emphasize the need for FAIR principles to be recognized in the context of scientific engagement with Indigenous communities to protect Indigenous intellectual property rights, and to ensure access to data that is unrestricted and in formats useful to, and usable by, local communities.

Historically excluded groups (Black, Indigenous, POC, differently abled, LGBTQIA+, women) are particularly at risk in disciplines where there is traditionally a strong element of fieldwork (e.g. Pickrell, 2020; St. John et al., 2012) and this is no exception for the Earth and Planetary Surface Processes community (Tooth and Viles, 2021). Fieldwork is often framed as needing a strong element of traditionally masculine prowess (e.g. King et al., 2018) which leaves many feeling unwelcome (Hill et al., 2021).

An additional challenge, not limited to EPSP, but still occurring here, is the prioritization of citation rate and impact factor as a measure of productivity, which leads to fewer incentives for mentorship particularly for historically excluded groups. This "publish or perish" mentality also compounds these inequities, as scientists from historically excluded groups commonly face greater barriers to first-author publication relative to their white male counterparts (North et al., 2020; Pico et al., 2020). Programs like URGE also point to the challenges of mentorship between, for example, a white mentor and a BIPOC mentee (Martinez-Cola, 2020), in truly understanding the complexities of the needs of the mentee.

3.3 Opportunities for ICON and JEDI work

Increasing diversity in the EPSP section is a moral imperative, and we firmly believe, after Tooth and Viles (2021) that the range of viewpoints and perspectives brings about much better science. Secondly, also after Tooth and Viles (2021) we recognize that many geomorphological projects require interaction with historically marginalized communities, indicating that the decolonization of geomorphology must be done by the enhancement of JEDI work in the EPSP community. Tooth and Viles (2021) and North et al., (2020) also discuss methods of fair collaboration with host country scientists as the way to combat the aforementioned "parachute science". Other ways of opening up the EPSP community to the historically excluded include studying more urbanized and less "pristine" landscapes, highlighting the alternatives to fieldwork, such as modeling and the use of Big Data (e.g. Koppes and King, 2020), and focusing on outreach to underrepresented (that is, the historically excluded) communities. King et al., (2018) suggest that conference climates can be "warmed" to historically excluded groups by a) greater emphasis on real-world justification for the science being done by all participants, not just women and students, b) territorial acknowledgements (a practice also promoted by the URGE program) and c) codes of conduct, which have been adopted by GSA and AGU. Lastly, a recent editorial for ESPL (Lane, 2021) notes changes happening at one of the larger community journals, including peer review changes.

A classic problem in many disciplines, including EPSP, is the so-called "leaky pipeline model" (e.g. Cronin & Roger, 1999) which has recently been reimagined with a beautiful geomorphic metaphor as a braided river model by Batchelor et al. (2021). This new model describes the movement of persons into STEM careers through varying entry points and through the career trajectory in a non-linear fashion, visually indicating the difference in pathways in contrast to the very linear pipeline model. As part of this, it is important to actively recruit and support scientists from historically excluded identities to EPSP and we advocate for the continued expansion of initiatives like the AGU Bridge Program which does just this. In addition, we must share the varied opportunities of a modern career within the EPSP community, work to protect our environment and recognize varied contributions in teaching, professional development and promotion.

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