

A Common Vision for Earth Surface Science

Changes manifested in the soils, waters, landforms, and ecosystems that comprise the surface earth—the “environment” for most life and human activity—are now accelerating, largely due to human activities. As described below, our ability to understand such change is not keeping pace: we cannot yet predict transformations of the earth surface that impact our lives. It is imperative that we address the following question:

How can we quantitatively predict the response of the earth surface to natural and human perturbation?

In particular, we need to predict the effect of climate and environmental change on the properties and fluxes that affect waters, soils, sediments, landforms, ecosystems, and human populations. Such predictions for the evolution of the surface earth — *earthcasts* — would allow us to explore the fundamental controls on the surface earth for the good of future humans, and to provide the science input needed by policy makers for strategic decision-making.

The problem. Given our growing ability to forecast weather and climate, how is it that we lack the ability to earthcast the associated changes in the “Critical Zone”? A number of factors are involved. For example, strong nonlinear feedbacks plus slow mixing rates of the surface earth allow extreme heterogeneities to develop and persist in physical, chemical, and biological variables over space and time. We do not yet understand quantitatively how this heterogeneity in the rock + regolith + sediment + water + air + biota system arises, as would be necessary for earthcasts. Nonetheless, successes in modeling and predicting the more homogeneous fluids of the atmosphere or ocean, suggest that earthcasts should be similarly possible.

The complexity of the Critical Zone has resulted in the current lack of comprehensive, long-term, and systematic observations of the key variables needed to develop predictive models. Specific research challenges that must be overcome to predict the response of the surface earth to change include new techniques to measure the controlling variables at the relevant time and space scales, development of the conceptual models as well as thermodynamic and kinetic data necessary to predict the fluxes of matter and energy occurring at interfaces between reservoirs with very different dynamics, development of a complete set of flux equations for surface processes, and improvements in modeling of dynamical complexities and emergent phenomena. With such advances in data and theory, earthcasting can advance through the development of a comprehensive, open, community-based modeling framework.

Because of the extreme heterogeneity of the surface earth, advances in understanding have typically been made on a region-by-region or case-by-case basis. Although we do not want to understate the importance of local controls and effects, we nonetheless must relentlessly search to generalize our results beyond characterization toward prediction, with the goal of transcending place. Are we currently training a generation of such global earthcasters? The simple answer is no -- instead we generally train scientists to think within discipline-specific boundaries despite the abundance of

important problems that entail coupling between physics, chemistry, and biology. We therefore have a human resources issue: the inherent complexity of the earth surface has required a reductionist approach to generate understandable data such that we lack synthesis of environmental data. These boundaries are enforced by existing discipline-based funding structures.

The solution. What will allow us to advance, given these limitations? One way to transcend place and bridge disciplinary boundaries is to seek to understand common “geopatterns”. Geopatterns – recurring patterns of environmental variables in space and time – represent phenomena that emerge despite the great heterogeneities manifested in the surface earth. Geopatterns that we should be able to predict include, soil horizonation; spatial structure of river networks and channels; linkages among large scale atmospheric circulation patterns and patterns of flood and drought; patterns manifest in the built environment; patterns in water chemistry over space and time; structures of populations of subsurface and above ground biota; and even the topography of mineral surfaces. The way forward will incorporate conceptual approaches exploiting understanding of self-similarity and other mathematical advances, as well as new datasets provided by LIDAR, genomic analysis, field-deployable instrumentation, remote sensing of environmental variables, nanoscale imaging and analysis, theoretical chemical simulations, and other new analytical, computational, or theoretical innovations. The way forward might best be described as a structured empirical approach combining field and experimental observation with laboratory analysis and modeling at a scale never before attempted for surface earth processes.

To provide models to predict these geopatterns within the next ten years, the disciplinary communities within the surface earth sciences need to organize both individually and collectively *and the funding agencies must facilitate this process*. For example, low-temperature biogeochemists must cooperate both among themselves and across disciplinary boundaries, and the same statement can be made for geomorphologists, ecologists, and hydrologists. These communities must work with federal agencies to develop steady, consistent funding streams to promote both the individual disciplines and advances with respect to the cross-disciplinary questions.

Recognition of this fact has driven the growth over the last five years of the three organizations that developed this vision: the Consortium of Universities for the Advancement of Hydrologic Sciences Inc. (CUAHSI), a formal consortium with NSF funding representing hydrologic science; the Critical Zone Exploration Network (CZEN), an NSF-funded group of scientists interested in the “critical zone” ; and the National Center for Earth Surface Dynamics (NCED), an NSF Science and Technology Center with primary emphasis on integrated earth-surface dynamics combining earth sciences, engineering, and ecology. Other initiatives include SAHRA (hydrologic science), CLEANER (environmental engineering), NCEAS and NEON (ecological sciences), CEKA (environmental chemistry), and LTER (biological sciences).

Through these efforts, many of the main communities (hydrology, low-temperature geochemistry, ecology, water quality engineering) that must work together have achieved at least some level of organization, and have laid the foundation to make ‘earthcasting’ possible. CUAHSI represents 116 universities, colleges, and research

institutions and has begun programs in informatics and instrumentation as well as developing observatory design. NCED provides an organizational structure for multidisciplinary research, a network of application contacts in agencies and industry, cross-disciplinary research successes, and a working surface observatory. CZEN, on very modest funding, has established a worldwide network of people working on the Critical Zone from more than 50 universities, has begun a cyberinfrastructure initiative, and has developed a compelling design concept for an observatory network. Cyberinfrastructure development through CUAHSI's Hydrologic Information System, through the proposed Community Surface Dynamics Modeling System, through CZEN's cyberinfrastructure efforts, as well as through other developments led by other entities (e.g. SAHRA, CLEANER, CEKA) will make earthcasting feasible at scales and with a sophistication that was previously impossible.

The time is ripe for an initiative on earthcasting. The scientists in disparate communities are already self-organizing—sometimes without funding—across disciplinary boundaries. Nonetheless, the current patchwork of organizations is not sufficient to reach this goal. Some groups (e.g. geomorphology, sedimentary geology) do not have a dedicated organization working to create community-level initiatives. For the majority of surface-process scientists, success rates for funding are in the single digits and funding comes and goes in short-term programmatic initiatives that do not establish community nor support long-term investigations. Research representation within the two Science and Technology Centers (SAHRA, NCED within earth sciences, which are developing long-term collaborative structures, is uneven, with a primary emphasis on hydrology, morphodynamics, and ecology. And, as indicated in the list above, many of the key organizations are unfunded or partially funded.

Observatory Network. Given the large number of environmental variables that affect surface earth processes and the coupled nature of how these variables impact phenomena, a research strategy must be developed to test appropriate governing equations across a wide variety of temporal and spatial scales. A network of sites must be created using a coordinated, adaptive, and scalable strategy to gather the data and test the models needed for earthcasting across environmental variables.

Such an observatory network will employ sites that are instrumented hierarchically for the long term to explore questions of spatial and temporal scale, and sites that are investigated for shorter periods as natural laboratories established across gradients in environmental variables (green and blue sites respectively in Figure 1). Given that the long-term sites are extremely expensive, the number of such sites must be kept small. These sites should be considered as reference sites or benchmarks to which

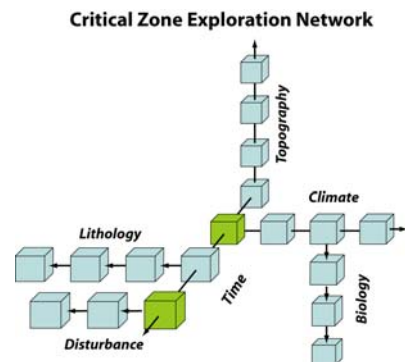


Figure 1. A conceptual diagram outlining a proposed network of observatories to investigate earth surface processes. The environmental gradients shown are only examples. Other gradients that could be explored include pH or other characteristics of water chemistry, uplift rate, or deformation rate.

other sites will be compared. Using a chemical metaphor, these sites will establish the standard state, or “standard temperature and pressure (STP)” for a variety of surface earth processes. *To the largest extent possible, such sites must be instrumented hierarchically from the soil profile to the watershed scale, and where possible should be located within one lithology, one climate, and one biome. Importantly, these reference sites must be spearheaded by diverse teams of interdisciplinary scientists.* In contrast, the short term sites should be individually less expensive because they should entail less long-term monitoring. These sites should allow peer-reviewed investigation of key variables observed across gradients in order to target phenomena that can be predicted through modelling.

Importantly, establishment of such a network would be a first for any scientific community because choice of sites would be made *not strictly on the basis of individual site characteristics, but rather on the basis of the entire network.* In this respect, the communities have shown leadership in articulating this vision for a network, but they need assistance from funding agencies to establish the network because of the interdisciplinary needs in siting the observatories.

For example, the recent solicitation for Critical Zone Observatories by the NSF is a vital first step in realizing the vision for the long-term sites (Solicitation 06-588). Although the standard NSF review process will yield excellent sites, a worry remains as to how sites can be chosen to realize the long-term network vision. Will two sites be chosen that are excellent in themselves but are less desirable as baseline reference sites for the important driving questions? Establishment of an overarching umbrella organization of Earth Surface scientists to oversee and provide a vision for the network is doubtlessly needed. Such an umbrella group should be facilitated by the NSF. To be effective, such an “umbrella” should empower all the relevant disciplinary communities perhaps through organizational subentities while at the same time driving dialogue and coordination across boundaries.

Conclusions. The combination of field experience, analytical methods, pragmatic theory, and ability to integrate spatial complexity across time scales gives the geoscientist a unique ability to solve the problems manifested in the heterogeneity of the surface Earth. The Earth Surface Community has already begun the following activities, and we call upon this group to continue to

- 1) Promote community structures among the disciplinary groups within earth surface processes science to foster coordination and cooperation and advancement of science.*
- 2) Promote the development of a program and community structure for predictive, cross-disciplinary surface earth science with an observational network as its centerpiece that is defined and populated through peer review incorporating relevant disciplines.*

We call upon the Earth Surfaces funding agencies to respond to these community movements by spearheading the following:

- 1) Fund community structures among the disciplinary groups within earth surface processes.*

- 2) *Fund an umbrella organization to articulate vision and goals for Earth Surface Science.*
- 3) *Provide long-term funding within a core Earth Sciences program to train a cohort of earthcasters who will solve fundamental problems coupling physics, chemistry, and biology of the surface earth.*

Note concerning the history of this document. As constituted within Earth Sciences at NSF, Earth Surface Processes is currently separated into four programs: Geomorphology and Land-use Dynamics (GLD), Geobiology and Environmental Geochemistry (GEG), Sedimentary Geology and Paleontology (SGP), and Hydrologic Sciences (HS). Each of the communities that largely seek funding from these programs has evolved some form of organizing group or synthesis center that has attempted to organize the community for the purpose of furthering science within that discipline. The three entities are the National Center for Earth Surface Dynamics (NCED; GLD and SGP), the Consortium of Universities for the Advancement of Hydrologic Sciences, Inc. (CUAHSI; HS), and the Critical Zone Exploration Network (CZEN; GEG).

In March 2006, Chris Paola (NCED), Rick Hooper (CUAHSI), and Sue Brantley (CZEN) met to discuss a vision for Earth Surface Sciences and to discuss possible collaborative efforts for NCED, CUAHSI, and CZEN. All three participants agreed that the questions driving research among their communities were largely interdisciplinary and that further interaction among the groups would benefit all of them. This realization led to this document.

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