Common questions of the US NSF–supported Critical Zone Observatories

Version 2014

Introduction

The Critical Zone Observatories (CZO's) now funded by NSF represent a wide range of geological, climatic, and land use settings that can provide an opportunity to develop a broad and general understanding of the evolution and function of the critical zone. By identifying shared or "common" research questions across these CZO's there is also now the opportunity to advance rapidly new understanding in key issues. The work of many CZO's can accomplish what no one observatory can provide. This is not just because of diversity of sites, but also the diversity of the researchers- who collectively bring the essential observational and theoretical skills and knowledge to these common problems.

To identify common questions, we elected to work from the submitted proposals for each of the funded CZOs. Our hypothesis was that although each proposal was written to explore questions specific to the individual CZO, there would be core questions common to many of the proposals. By building upon what has been proposed and funded, we can more readily advance upon these questions. Some questions received more attention than others, but our impression is that no obvious common question is absent from the list developed from the proposals.

We did not create the list of questions by simply reporting verbatim statements from individual proposals. Instead, we identified a shared conceptual framework and three general common questions, and then broke these three questions into component and more narrowly focused – but still common- questions. Most proposals had dozens of sub-questions motivating, by necessity, particular research plans, which we do not attempt, record here.

A. Shared conceptual framework that motivates questions

1. The critical zone evolves a structure that influences the storage and flux of water, solutes, sediments, gases, biota and energy.

2. By mediating these stores and fluxes, the critical zone provides ecosystem services, and is thus critical to people.

Here "structure" generally refers to material properties of the critical zone, including vertical and lateral variation in porosity, permeability, fracture characteristics, water retention, density, composition, and texture (size distribution). The critical zone also includes the vegetation mantle. The flux through and out of the critical zone connects it to the atmosphere and to the river ecosystems which receives its drainage.

"Ecosystem services" as considered in these proposals include carbon storage, water supply, nutrients, vegetation growth, and functional forest and river ecosystems.

B. Three general shared questions:

1. What controls critical zone properties and processes?

2. What will be the response of the critical zone structure, and its stores and fluxes, to climate and land use change?

3. How can improved understanding of the critical zone be used to enhance ecosystem resilience and sustainability, and restore ecosystem function?

Intensive field measurements at the observatories will provide the data to guide process understanding to develop models that explain critical zone evolution, to forecast possible future states, and to guide land use decisions. All of the CZO's have modeling components, though a wide range of approaches is used.

C. Specific shared questions:

The three general questions are too broad for any one critical zone observatory to address fully. The NSF-supported critical zone observatories in the 2013-2018 period have identified, however, many more focused questions within this framework. We have identified 21 common questions that three or more CZO's have specifically defined in their proposals. All CZO's share at least 6 common questions, and some as many as 15. For a given CZO proposal, however, these common questions are typically further narrowed, typically towards specific key mechanisms to be explored. Such specificity is necessary to guide particular field or modeling campaigns.

Here we list the 21 common questions of the CZO's and describe briefly, as needed the topic. Table 1 is provided as a simple summary table. The topics are organized by the three general shared questions and are labeled by a numbering scheme that corresponds to the table. One goal was to identify the most specific but still widely shared questions, and those are noted as subcategories within the general question, e.g. 1.1.a.1 and 1.1.a.2 in the first question.

1.1. What controls critical zone properties?

This question focuses on what controls the evolution of the critical zone properties, including the structure (as defined above) and the vegetation they support.

a. How does critical zone development depend on lithology?

a.1. How do the properties of granitic rocks influence critical zone development?

a.2. How do the properties of shale influence critical zone development?

b. How does geologic history and landscape evolution influence critical zone structure?

The influence of tectonics would also be considered here.

c. *How does critical zone development vary with climate?*

Some critical zone observatories include significant gradients in climate. At three observatories, strong gradients of climate occur along elevation rise. At the hillslope scale, aspect can lead to strong local differences in critical zone structure- reflecting the influence of differing microclimate conditions. CZO's vary greatly on the specificity of what "climate" means as a driver of critical zone development.

c.1. How does hillslope aspect, as it influences local climate, affect critical zone evolution and structure?

d. *How does critical zone development depend on topography (e.g. slope, relief, hillslope shape, drainage density)?*

e. *How does biota influence CZ development?*

For Boulder, Shale and Southern Sierra, the biota of greatest research interest is trees.

f. *How do hydrologic and geochemical processes drive critical zone development?*

g. *How important is dust accretion in critical zone development?*

h. *How has past land use influenced current CZ structure?*

<u>1.2. What controls critical zone processes?</u>

These questions can be explored in the shorter time frame, treating the critical zone as slowly changing, but a longer – evolutionary- time scale is also explored by some.

a. *What controls the chemical evolution of water through the critical zone?*

b. *What controls organic carbon storage in and flux from the critical zone?*

c. *How do biota influence solutes and gas fluxes from the CZ?*

c.1. What is the role of microbes deep in the critical zone in mediating solute evolution of runoff water and carbon processing?

c2. How does vegetation influence critical zone processes?

d. *How does CZ structure influence hydrologic processes?*

d.1. How do fractures in the critical zone influence hydrologic and solute evolution processes?

e. *How are CZ processes influenced by fire?*

2.1. What will be the response of critical zone structure, and its stores and fluxes, to climate change?

Every CZO raised the question of how the critical zone will respond to future climate change. These changes included earlier snow melt, changes in temperature and precipitation, and changes in corresponding fire regimes. These questions drive plans for direct process measurements that can serve to motivate and test models for future states.

a. How will critical zone processes mediate the effects of climate change on water resources?

2.2. What will be the response of critical zone structure, and its stores and fluxes, to land use change?

In these CZO's, the land use drivers included grazing, agriculture, controlled burning and forest thinning, and water diversion.

a. *What models best predict how CZO functions and outflows will respond to anticipated land use change?*

3. How can improved understanding of the critical zone be used to enhance ecosystem resilience and sustainability, and restore ecosystem function?

a. *How do critical zone processes influence river flow and ecosystems?*

b. *How can prediction of future CZO states and functions provide useful guidance in land use management decisions?*

	Boulder	Calhoun	Cristina	Eel	IML	Jemez	Luquillo	Reynolds	Sierra	Shale
1.1 What controls CZ properties?										
a. *How does the critical zone development depend on lithology?*	X	X	X	X		X	X	X	X	X
a1. *How do the properties of granitic rocks influence critical zone development?*	X	X				X		X	X	
a2. *How do the properties of shale influence critical zone development?*	X			X						X
b. *How does geologic history and landscape evolution influence critical zone structure?*	X				X		X		X	X
c. *How does critical zone development vary with climate?*	X	X				X	X		X	X
c1. *How does hillslope aspect, as it influences local climate, affect critical zone evolution and structure?*	X			X		X			X	X
d. *How does critical zone development depend on topography (e.g. slope, relief, hillslope shape, drainage density)?*			X	X		X	X			
e. *How does biota influence CZ development?*	X			X					X	X
f. *How do hydrologic and geochemical processes drive critical zone development?*	X	X		X		X	X			X
g. *How important is dust accretion in critical zone development?*						X	X		X	
h. *How has past land use influenced current CZ structure?*		X	X		X					
1.2 What controls CZ processes?										
a. *What controls the chemical evolution of water through the critical zone?*	X			X		X	X			X
b. *What controls organic carbon storage in and flux from the critical zone?*		X	X		X	X	X	X		
c. *How do biota influence solutes and gas fluxes from the critical zone?*										

	Boulder	Calhoun	Cristina	Eel	IML	Jemez	Luquillo	Reynolds	Sierra	Shale
***c1**. What is the role of microbes deep in the critical zone in mediating solute evolution of runoff water and carbon processing?*	X		X	X			X		X	X
***c2.** How does vegetation influence critical zone processes?*	X	X	X	X	X	X	X	X	X	X
***d.** How does CZ structure influence hydrologic processes?*										
***d1**. How do fractures in the critical zone influence hydrologic and solute evolution processes?*	X			X			X		X	X
***e.** How are CZ processes influenced by fire?*	X			X		X		X		
2.1 What will be the response of CZ structure, and its stores and fluxes, to climate change?										
***a.** How will critical zone processes mediate the effects of climate change on water resources?*	X	X		X		X			X	
2.2 What will be the response of CZ structure, and its stores and fluxes to land use change?										
***a.** What models best predict how CZO functions and outflows will respond to anticipated land use change?*		X		X	X			X	X	
3. How can improved understanding of the CZ be used to enhance ecosystem resilience and sustainability, and restore ecosystem functions?										
***a.** How do critical zone processes influence river flow and ecosystems?*	X			X	X	X	X			
***b.** How can prediction of future CZO states and functions provide useful guidance in land use management decisions?*		X		X	X			X		