Report of the Steering Committee
Critical Zone Observatory (CZO) All-Hands meeting, May 8-12, 2011
Tucson, AZ

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Overview: The CZO Steering Committee met in conjunction with the All-Hands meeting on May 8-12, 2011 in Tucson, AZ. The venue of the meeting – Biosphere 2 – was an inspired choice: the site of an audacious experiment in integrating complex natural systems. The Critical Zone Observatory network can be viewed as a similarly complex, interdisciplinary experiment, but one that promises to yield far more wide-ranging and vital scientific progress and insights.

Unlike previous national CZO meetings, which emphasized site-based science and largely featured site PIs in speaking roles, the All Hands meeting was organized to focus on cross-site themes, included a mix of invited outside speakers and CZO-based talks, and gave a prominent role to students and post-docs engaged in both intra- and inter-site research. The Committee members and other attendees gave high marks to this mix; without exception everyone felt that this format encouraged cross-site thinking and fostered a sense that exciting science was being done, with more to come. In particular the Committee felt that the All-Hands meeting provided a great opportunity for students and post-docs to see and experience the breadth of CZO science and enable them to place their research in the context of larger research questions. As noted in our Committee recommendations, we suggest that this type of All-Hands format be followed in the future, at least every other year.

We took the charge for our discussions and organized our comments from Jon Chorover's three goals for the meeting:

1. Advance cross-site science
2. Promote cross-site network integration
3. Improve linkage and involvement of broader scientific community with CZOs; enhance national prominence and profile

Our comments are intended to highlight progress in each of these areas, identify issues and concerns, and make recommendations where appropriate.

Advance cross-site science:

There is an intrinsic and acknowledged (by everyone) tension within the CZO network between the fundamental science organized around individual sites, and the exciting, but much less funded, mandate to engage in cross-site analyses, experiments, and collaborative activities. As NSF has repeatedly emphasized, the sites were competed and awarded based on their site-focused proposals, and this

remains the backbone of the CZO network. Yet some of the most exciting prospects for scientific advancement are likely to occur from cross-site work and synthesis. Hence, creative chaos. In fact, what distinguishes the CZO program from other ongoing and emerging national biophysical research efforts, including LTER and NEON, is that the CZOs are organized around a compelling, albeit fuzzy concept: the structure, dynamics, and evolution of the Critical Zone (CZ). Each site is allowed to develop its own vision of the CZ and organize its research effort around that vision. This is in contrast to other ecohydrologic research networks, which tend to be organized geographically by ecosystems (LTER) or environmental gradients (NEON). The result for the CZO network is a diverse and "bottom up" portfolio of scientific questions and approaches.

Yet it is clear that the sites are communicating, interacting and genuinely interested in developing a common language – a *lingua franca* – across sites, and this effort is beginning to pay off. As exhibited at the meeting, there is an emerging set of cross-site themes and concepts. These include:

1) **A range of alternative concepts and frameworks for organizing CZ thinking and research:** Examples of this include viewing CZ processes across a range of gradients (i.e., climatic, moisture, elevational); zones (i.e., elevational, ecotype, biomes, lithologic); geomorphic or topographic positions (i.e., hillslope orientation, valley/ridge); energetics (i.e., EEMT); spatial hierarchies, or in terms of landscape evolution and time. These are all exciting and potentially revealing ways of characterizing the Critical Zone, and examining how processes are expressed or suppressed across these sources of variation.

The primary question to be addressed by the CZO's is "How will the CZ evolve in response to changing climate and land use?" (http://criticalzone.org/Research.html). It is not yet clear how the current experimental design will address this question. Most of the study sites are in pristine area with little current or expected land disturbance activities. The past, present, and future human impact on the CZ does not seem to be under consideration, but this topic could be a topic of various cross-site studies. Besides the obvious effects of increasing temperature and CO_2, there are other impacts like fire, atmospheric deposition from proximity to roads and power plants, soil cultivation, etc. This topic could be called the effects of pervasive human activities, that overprint all the processes the CZOs are studying. While concepts and frameworks are still emerging, CZOs might begin to consider how they will address the question of CZ evolution in response to climate and land use change.

2) **An emerging set of hypotheses and principles:** We heard examples of different hypotheses that could be used to explain variability in CZ structure and dynamics, including: a) optimality (i.e., in terms of soil development or vegetation water use); b) the importance of endogenous versus exogenous controls and inputs; c) energetics (EEMT) as a common currency for understanding CZ development; d) the importance of evolutionary pathways and time in CZ structure and processes; e)

the correspondence between atmospheric flows and fluxes and belowground CZ processes; and f) the concept that geology may be destiny, or at least an overarching control on the CZ. As noted above, we did not, however, hear much about human influence (e.g.,., atmospheric deposition, changing temperatures and rainfall regimes, fire).

We note that it appears that while the critical zone has been defined as lying "between the rock and the sky," groundwater flows back and forth between the critical zone and the bedrock, particularly in settings characterized by fractured bedrock. Moreover, the bedrock surface is poorly defined in many settings. The dissolution of elements from bedrock and subsequent transport of these materials down-gradient into the CZ can affect processes in the critical zone. There does not appear to be much attention given to this process, and, although drilling can be expensive, CZOs might consider whether the additional investment would provide important information.

Recommendations: It is too early to know how many of these frameworks and hypotheses will "have legs" over the long run. But this diversity of perspectives at such an early stage of the entire CZO enterprise bodes very well for the future, and may provide the foundation for the lasting contributions of the CZOs to scientific understanding. Clearly then, the best model for the network overall is a blend of both site-based and cross-site research. Unfortunately the natural tendency is for the cross site work to fall by the wayside. To ensure that this does not occur the sites should continue to be encouraged to develop a suite of common themes/questions, as well as a common set of data collected using common protocols, and devise novel methods and schemes to answer these overarching questions. Developing CZ theory should not dominate CZO science, but be a significant component of the work.

One idea that the Committee discussed for fostering cross-site work would be for NSF to establish and fund one or more post-doctoral research fellowships that would be specifically targeted at cross-site studies. CZO Fellows would be funded for up to 2-3 years to pursue research that used multi-site data to test hypotheses, build cross-site models, and develop approaches and methods that could be used across sites.

Program managers have indicated a willingness to consider proposals for cross-site studies and/or the integration of researchers from outside the core CZO teams. At the moment it may be difficult for some outside researchers to gain sufficient familiarity with the current activities and data from the active CZOs to generate competitive proposals. To date there are very few data from CZO activities available on the individual CZO web sites for example, although there is an increasing number of CZO-based publications. Making more and more specific information available to the scientific community should help promote the use of the CZO sites as a broader resource to the community. We understand this take time but wish to strongly encourage the PIs to enlarge the available data, both in kind and in quantity.

2) Promote cross-site network integration

An integral component of doing cross-site science is cross-site network integration. In fact, the 3rd of the three main CZO goals is to "develop and integrated data/measurement framework" (http://criticalzone.org/Research.html). We interpret this to mean the development of a common cross-site infrastructure of tools, databases, models, websites, and measurement programs. Mark Williams reported on the good, the bad, and the ugly with respect to this effort. To the good, database sharing and integration is proceeding much faster than had been anticipated. Each site now has a data manager, and datasets are routinely posted to the web. A shared vocabulary of data types and consistent format for metadata and ascii format is in progress, and methods for harvesting data and posting it to a central data portal have been prototyped. A protocol for uniquely identifying samples has been developed, and there is an emerging partnership with other databases such as EarthChemDB. These are all significant advances towards a fully functional integrated data network.

Recommendations: Mark outlined a number of short term recommendations with which the Committee concurs. These included continued development of data management tools and consistent data catalogs for each site, the suggestion to initiate a robust information management working group that consists of a scientist and data manager from each site, establishing policies and best practices for generating display files, detecting new information to harvest into CZO Central, and determining update frequency. Other valuable recommendations were contained within his slides. Mark's estimate to accomplish this work of approximately $400K/year (including overhead) needs to be seriously considered, as it represents a long-term investment in the health of the entire CZO network.

Further, CZO laboratories might consider participating in an inter-laboratory comparison to ensure consistency of data across all labs, as well as perhaps a standard reference sample program for quality assurance. Quality assurance results should be maintained along with field sample results.

The issue of shared or common techniques touches on several aspects of the CZO program. Many of the geochemical measurements are sufficiently comparable that no further work is needed to standardize or homogenize these. The same is true for many of the standard hydrological measurements. Good documentation of procedures on the individual CZO web sites and publications should be sufficient.

In other cases, individual groups have developed particular analytical tools or approaches that may be usefully applied elsewhere. In some cases it will likely make sense for researchers at one site to collaborate with those from another where the protocols have already been developed. For example, PIs associated with some sites have expertise in synchrotron or IR spectroscopy useful for characterizing mineral surface – organic interactions. These techniques are specialized, and it

would seem that use of the existing facilities and expertise by researchers from other sites is a sensible approach to a) disseminate the technical know-how, and b) to build additional cross-site comparisons.

One important area that has emerged is the construction of real-time sensor networks and data logging. All of the CZO sites employ at least some of this technology, and several have made a major investment in both time and money. There clearly have been many lessons learned at the site level, and better dissemination of the instrumentation used, costs, networking methods, and software could be a valuable resource for future sites in the CZO network or other site-based installations. There is limited value in reinventing the wheel, and other groups could certainly profit from the experience and knowledge gained by the CZOs. The effort by the Christina River Basin CZO to develop a low cost network of sensors based on Arduino open-source electronic components and programming language seems particularly valuable. Cost has been a significant barrier to installing sensor networks, so low-cost solutions are intrinsically attractive. Further, the nature of the Arduino system implies that users become familiar with basic sensor-logger-computer interfacing techniques, for example, and should provide valuable hands-on training for students. Implementation of this technology could help develop young scientists with useful skills for building and operating data acquisition devices and networks, something that students in the Earth Sciences may not otherwise have.

3) Improve linkage and involvement of broader scientific community with CZOs; enhance national prominence and profile

The Committee had extended conversations about how to expand involvement and "reach" of the CZO network. The CZOs are developing capability and experience as a network of observatories. In addition to advancing site science, the network should look for and develop opportunities for synthesis and outreach across and beyond the network. High impact outputs for both synthesis and outreach activities would demonstrate the advantages of network-level science and help justify the investment by NSF in the CZO initiative. Through working groups and workshops along and across CZO theme areas (geomorphology, hydrology, weathering, surficial processes), the network should develop synthesis articles and volumes. In addition, the NSF has a high interest in seeing science inform management and policy decisions as well as the public. This emphasis is evident through its broader impacts criteria. The CZO network in well positioned to contribute to local, regional and national discussion on a host of environmental issues, such as water use, quantity and quality, erosion, climate change effects, and carbon management. The CZO should consider network led outreach activities designed to address and inform the public and natural resource managers on relevant issues. If initiated this outreach effort should include a communication plan to ensure that the effort is successful in reaching target audiences and has high impact. Both synthesis and outreach initiatives could provide an opportunity for participation by non-CZO scientists. CZO-led integration between CZO and non-CZO science would help

broaden participation by the earth and environmental science communities, and demonstrate the value of NSF's investment in the CZO program.

One topic that was briefly discussed was the possibility for CZO "lite" sites. For example, there is a Chapman Conference scheduled this summer examining "The Galapagos as a Laboratory for the Earth Sciences". Does the CZO network provide a model for how such a laboratory linking deep earth, shallow mantle, and surficial processes could be organized? Is there room for satellite sites that may not have the full complement of site capabilities but still contribute to the network? We feel this should be further explored.

Summary: The CZO network is evolving rapidly and has the feel of a very exciting venue for integrated science. Fostering this excitement, developing cross-site themes, and broadening the exposure and reach of the network, and further clarifying methods for addressing the question of the effect of climate and land use on CZ evolution are the near-term challenges. We look forward to the day in the not-distant future when the Science section of the New York Times is devoted to the CZO.

Other comments and issues raised by individual committee members

Carol Kendall:

General comments on this meeting:
The AZ folks produced the best (most informative, most useful for understanding the various sites, most colorful) field guide I have ever had for a fieldtrip. Kudos!! The students and other site explainers were very well prepared to explain what they were doing at their sites, and were good at answering questions, They kept the entire group engaged for the full day. And there were no screwups.

I vastly preferred the format for this expensive all-hands meeting to the previous 3, largely because the focus was on SCIENCE (not what the different CZOs had been doing recently). I thought the different topics for different days were well-chosen, with an interesting mix of invited speakers and shorter talks by CZO scientists, often not the most senior folks but instead folks (students and post-docs) who were actively involved in different projects that fit the theme of the day. Maybe CZO can have this kind of meeting every other year.

To save money -- and to encourage the CZO scientists to interact with other watershed studies and programs (with an idea of extending the "effective" network size) – perhaps the CZO meeting could occur just before/after one of the biannual Gordon Watershed meetings some year. This meets July 10-15th this year in Maine. The short poster presentations worked well and generated enthusiasm for looking at the posters. The good venues for the posters also helped. At all (most?) of the previous CZOs, there was not enough time to see the posters, or they weren't presented at a convenient time or place.

B2 was a terrific venue for a meeting. Great accommodations, sufficiently large and comfortable meeting room (with a good large screen, great audio-visual support, good air conditioning, enough but not very comfy chairs, close-coffee, etc). In short, nothing detracted from the science (which I can't say about past CZO meeting rooms). The casitas were very close and comfortable. Lovely scenary, not too far from airport or field site. The tour of B2 was wonderful. Nice staff. Great food (esp Monday nite dinner). Well organized meeting plans. I enjoyed the Boulder meeting but the facilities were almost universally dismal compared to this meeting. Overly hot and too small meeting rooms, poor places for posters, not very well planned fieldtrip and field dinner site detracted from our ability to fully exchange ideas.
I was impressed by how clearly the AZ CZO presented their hypotheses, overarching questions, etc in their progress report. I only glanced thru the others and don't know if all of them made similar improvements.

I liked the creative chaos concept. I think this is where good cutting-edge science comes from. NEON's complete lack of this does not bode well for the future.
I was pleased to see CUAHSI and NEON here at this meeting (something I have suggested each meeting), with NEON posters and Hooper engaging in conversations.

In hindsight, we should have tried harder to get more WEBB and LTER presence too. Adding some of their watersheds to the CZO "family" is the most likely way CZO is ever going to get close to being a network. What we would like is for CZO folks to be viewing the WEBB and LTER as other potential sites for cross-site comparisons and tests of hypotheses – and vice versa. The CZOs are making a lot of technological advances that the older watershed programs could benefit from, and the other watersheds can share their successes as sites for community science, something that the CZO scientists need to work on. My understanding is that if other folks don't write proposals to NSF to work at these sites, or don't write ones that get funded, or don't make their collaborations a success, then the CZOs will have failed an important mission and will be likely phased out. I am amused that the CZOs are doing a much better job of doing multi-disciplinary watershed research than I thought that the CUAHSI program would ever manage, because of what appeared to me to be their very narrow definition of their hydrological focus (water budgets). There was not much of a place for ecology, biogeochemistry, soils, atmospheric processes, etc in their definition.

Other good cross-site topics might be:

(1) trying to explain the causes of spatial and temporal changes in MTT. Can we come up with a common metric for predicting this across different size watersheds, soil types, geology, ppt amount, etc.

(2) why some of the CZO and other watersheds show that aspect has a major effect on soils, biota, runoff, etc -- and others do not?

Most of the CZOs have rapidly taken advantage of the new possibilities of cheap laser specs (like those from LGR and Picarro) for water isotopes, but there are a lot of other isotopes that can provide useful info that are thus far being kinda ignored. There are also new laser specs that can let folks easily measure CO2 concentrations and d13C. These can be attached to all kinds of preparation devices such as EAs, GCs, DOC-analyzers, etc. Obviously relevant measurements are DOC-d13C, soil %C and d13C, soil gas CO2 and d13C, etc.

There are also all sorts of isotopes that they might want to use in the future -- which they could if they planned to archive samples. I think if NSF could provide some extra funds for each site to set up big freezers and cold rooms, folks could save isotope samples from almost everyplace they sample, for future analyses. I have been doing this for almost 10 years and I have been very happy that I did when I later had questions I could answer with the archived samples.

It wasn't clear to me that all the CZO folks were taking suitable precautions in their collection and storage of water isotope samples. None of the CZOs have experienced isotope geochemists on their staffs (except maybe Del which doesn't have a laser spec and isn't yet thinking about water isotopes). In short, they are novices who

don't appear to be talking to REAL long term experts. I worry about the data quality of samples being collected and stored, and would love to see their protocols.

Lou Derry:

Overall I was pleased by the way the program has evolved over the last year. There is clearly increased cross-talk between the CZO sites. The people who are most engaged in this appear to be the senior gradate students and postdocs, who recognize the opportunities and have the time to think about questions and possible paths toward answers. I have the impression that the PIs are so deeply engaged in the day-to-day work of running the sites and managing their programs that they don't have much time to devote to these sort of questions even as they recognize they are important. This is not a criticism, merely an observation.

The observation suggests a potential new approach. We discussed the idea of some postdoctoral funding targeted toward developing cross-site science and asking broader questions. Postdocs could spend a couple years working with data from two or more sites to develop integrative studies across the CZO site network. We propose that at least some CZO-related postdoc proposals should include an explicit plan to test hypotheses across sites.