



Frontiers in International Critical Zone Science
 21st-23rd May 2014, Beijing, China

Workshop Report

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Summary

Science funding agencies in China, France, Germany, UK, and USA convened 40 leading Earth systems scientists with the aim of drafting the science content and schedule of actions to initiate a multilateral international research programme in Critical Zone science. Science questions focussed on past evolution of CZ architecture, how that evolution shapes current CZ functions, and how these functions respond to human impact and intervention; participants also considered methods of investigation to quantify the 3-D spatial-temporal structure and function of Earth's CZ. Conferees identified initial steps to establish methods for common observations, governance and data sharing and management. Discussions among funders confirm broad multi-national support for the science agenda and aspirations of the CZ science community. A series of actions were proposed to help develop international collaboration and funding for multilateral CZ research. This schedule of actions includes an initial rapid dissemination of workshop outputs via blogs, news releases, popular and technical science articles submitted by the end of 2014, and establishment of an international scientific committee by the funders. It is the aim of the scientific community to have a framework for a multilateral CZ programme and a roadmap to deliver this, in place by the end of 2014.

Critical Zone Observatory Science

Earth's Critical Zone (CZ), the thin surface layer from the top of vegetation to the top of unaltered bedrock that sustains human activity, is under intensive pressure from climate change and growth in human population and wealth.

Critical Zone Observatories (CZO) have been established globally during the past seven years to intensively investigate the complex interactions of rock, soil, water, air and organisms that regulate CZ properties and determine the availability of life-sustaining resources. CZOs address a key component of emerging Earth Systems science.

Workshop Aims

Five national funders The Natural Sciences Research Council of China (NSFC), The Natural Environment Research Council (NERC) of the UK, The National Science Foundation (NSF) of the USA, The German Research Foundation (DFG) and the National Centre for Scientific Research (CNRS) of France jointly convened and sponsored this international workshop. The aim was to bring together these funders with high-level international science leaders in order to advance the implementation of a coordinated, jointly funded, global programme of research that matches the urgency of major societal challenges and achieves international leadership in Critical Zone science advances and impact.

The workshop objectives were to define:

- The global societal challenges that can be addressed by Critical Zone Observatory science,
- The major knowledge advances, current achievements, and the frontiers of Critical Zone science,
- Specific science advances and contributions to solving global challenges in the coming 10 years,
- The international research challenges that will drive the expected advances,
- The governance and partnerships to enable integration of research between international CZOs, and
- A schedule of steps to develop a coordinated international programme of CZO research.

Workshop Activities

Plenary talks by invited international science leaders defined the major societal challenges, presented the state-of-knowledge and current international CZO advances, and helped shape a vision for the frontiers of CZO science and the solutions to which it will contribute. This was the first time that Critical Zone science was shared among the research programmes of these 5 countries.

Plenary Speaker	Title
Martin Goldhaber, USA	Critical Zone Science and Global Societal Challenges
Gordon Grant, USA	Advances in Critical Zone Science – the transformative research results
Whendee Silver, USA	Frontiers in Critical Zone Science – research advances for the next 10 years
William Dietrich, USA	USA Critical Zone Observatory Research and Opportunities
Congqiang Liu, China	China Critical Zone Observatory History and Infrastructures for Research
Yongguan Zhu, China	China Opportunities in Critical Zone Observatory Science
Bojie Fu, China	The Chinese Ecological Research Network – infrastructure and opportunity
Xi Chen, China	Chinese Hydrological Research Network
Jerome Gaillardet, France	European Critical Zone Observatory Research and Opportunities

Science questions to drive forward international CZO research were solicited from the scientific committee in advance of the workshop. The science questions were structured into 4 themes before the meeting. Participants were assigned to 4 working groups which each tackled a theme outside of the plenary sessions and advanced planning for each theme to contribute to an international CZO programme. A fifth cross-cutting working group tackled the challenge of international CZO governance and operational requirements for common observations and data management and sharing. Plenary discussion for feedback between groups was held between working sessions. The working sessions were structured for sequential development of a science programme with following steps.

1. Define 4 specific science questions (1 for each group) to advance international CZ research
2. Refine and agree on the 4 science questions
3. Identify key hypotheses, science objectives, outline methods and expected transformative results
4. Specify features of CZO networks and infrastructure that are necessary to achieve these results

Group 1. Mechanistic linkages in flows and transformations of energy, material and genetic information across the vertical and geospatial extent of catchments and aquifers as ecological-geophysical units
Group 2. Model Hindcasting of CZ Evolution, Interpreting the Present, Forecasting Future Change and Global Impacts
Group 3. The Response, Resilience, and Recovery of the CZ to Perturbations of Environmental Change
Group 4. Integration of Observation and Sensing Technology, e-Infrastructure, and Modelling
Group 5. Common Observations, Governance and Data Coordination of International CZO Networks

Representatives from the funding agencies met for planning discussions during the breakout sessions.

Outputs

The working groups identified key science questions intended to drive forward the 4 focus areas and the cross-cutting topic for an international CZO science programme.

Working Group 1: Mechanistic linkages in flows and transformations of energy, material and genetic information across the vertical and geospatial extent of catchments and aquifers as ecological-geophysical units

Discussion Leaders: Whendee Silver and Chantal Gascuel, Rapporteur: Harry Vereecken

Key Science Questions

1. Where are the regions located globally where the CZ is most sensitive with respect to global change feedbacks, provisioning and regulatory ecosystem services or has unique research characteristics?
2. What are the factors and drivers that determine CZ sensitivity in terms of the R3 space (Response, Resilience, Recovery) across scales and how can we predict trajectories of its evolution?
3. What are plausible strategies for adapting, mitigating and accommodating change in Earth's CZ?

Hypotheses

Hypothesis 1. Semi-arid pastoral lands are highly susceptible to global change through desertification and grassland degradation.

Hypothesis 2. Permafrost in Northern latitudes melting leads to dramatic increase in rate of key CZ processes, including decomposition, CO₂ release to atmosphere, and setting up strong positive feedbacks.

Hypothesis 3. A unifying CZ characteristic is that the thickness of the CZ as defined by the proportion of the biologically active zone relative to the total CZ thickness, is indicative of sensitivity to change.

Objectives

1. Determine factors that determine susceptibility to change of semi-arid pastoral lands:
 - Quantify the impact of stressors including overgrazing and conversion to cropland that are reshaping the CZ due to loss of vegetation, leading to loss of sediment, carbon, and nutrients,
 - Elucidate mechanisms that drive sensitivity including thin soil layer and CZ depth with low buffering capacity, loss of soil structure and organic matter, and erosion by wind and water.
2. Determine the factors controlling sensitivity of CZ response to the phase change induced by land surface warming and permafrost melting:
 - Determine the rate and extent to which the high concentration of organic matter in the CZ can be mineralized leading to dramatic structural rearrangement and subsidence,
 - Quantify the effect of this structural rearrangement on the balance and overall hydrological cycle and impacts on sediment and nutrient release and O₂ ingress,
 - Elucidate the mechanisms and strength of impact on CZ process caused by changes in microbiological process which are shifting from anaerobic to aerobic metabolism.

Outline of Research Methods

1. Afforestation/revegetation experiments in semi-arid pastoral lands to examine effects on hydrology and erosion and to determine the effect of soil carbon on degradation and restoration.
2. Permafrost systems will be studied with pilot scale hydraulic engineering such as rearranging water courses and use of low head dams to reverse or slow structural alteration and microbial impacts by restoring anaerobic conditions, and thereby test the feasibility of large scale hydraulic manipulation.

Expected Transformative Advances

1. Identifying impacts of rapid environmental change and solutions to mitigation and adaptation of change impacts with CZOs as research and demonstration/test facilities at those places where the greatest changes and disturbances are to be expected with respect to water, carbon and organisms.
2. Methods of backcasting and not only forecasting to study the evolution of carbon from the past into the future and to address both human legacy and adaptation when studying CZ processes.

Required CZO Network Design and Infrastructure Development

Extension of global CZO network to include field sites within the large global area of semi-arid grassland and savannah, and to the peri-Arctic; candidate sites were noted but no site selection has been done.

Working Group 2: Model hindcasting of CZ evolution, interpreting the present, and forecasting the future change and global impacts

Discussion Leaders: Dan Richter, Zhengtang Guo, Rapporteur: Michael Ellis

Key Science Questions

Overarching question: How does the evolution of the CZ architecture and function (process) inform future land-use options and ecosystem services?

Hypothesis

At human intergenerational time scale, the future state of the CZ is a coupled function of external drivers (e.g., climate, land-uses and management [particularly human habitation at intensities from semi-rural up to megacities], invasive biota, etc.) and internal dynamics of the catchment-based CZ system.

Objectives

Principal aim: to develop a theory of critical zone evolution (or theories of its components that can be dynamically coupled) in order to build conceptual and predictive models of CZ evolution, behaviour and vulnerability to future changes. By necessity therefore, the following objectives arise:

1. A need to understand the most important natural and human processes that control the behavior of a life-sustaining architecture and function of the CZ from local to global scale, and
2. A need to quantify the trajectory (antecedent conditions over historical and geological time-scales) and current state of the CZ system in order to initialize and train predictive models.

Outline of Research Methods

1. Establish a high-resolution record of antecedent behaviour of the catchment-based CZ system (e.g., records of past precipitation, temperature, fires, sedimentation, aeolian deposition, erosion, change of fluvial morphologies, mass movement, hillslope creep, etc.). This would include isotopic analyses, clay mineral analyses of floodplain sediments, biomolecular analyses, geomorphic analysis to establish the landscape trajectory, soil analyses to establish residence time and temporal evolution.
2. Quantify the active nature of the catchment-based CZ system (e.g., measuring soil biogeochemical process rates, fluxes of sediment, particulate and dissolved C, CO₂ and other gases, denitrification, phosphate transport, etc.).
3. Controlled field experiments to address the role of specific human and natural processes (e.g., response of the CZ system to land degradation and reclamation; dam removal; changes in above and below ground biodiversity such as removal or addition of invasive biotic species).
4. Parallel field and lab experiments to develop theoretical CZ-process rules and indicators of vulnerability to future environmental change (e.g. soil erosion as a function of hillslope, aspect, change in hydrologic cycle, etc).

Expected Transformative Advances

1. The ability to provide useful probabilistic predictions of the response of specific CZ environments to scenarios of future change (e.g., to provide to decision makers: how the environment will likely respond given a scenario of changes in climate and proposed improvements in land management).
2. To understand the role of antecedent conditions (the systems' momentum) in the response of that system to a future change in either/both external and internal conditions.

Required CZO Network Design and Infrastructure Development

One of the most significant and understudied CZ environments is the coastal urban environment (e.g. Shanghai, Shenzhen), particularly those that are coupled to economically important delta regions (e.g., Zhengzhou). A CZO should be as comprehensively measured via (as far as possible) autonomous sensors that telemeter data to the broad and open community. Sensors should tackle both surface and shallow-subsurface mass, chemical and biotic flux, and should be underpinned by shallow geophysical investigations of subsurface (i.e. groundwater depths) architecture and by a geomorphic analysis that quantifies antecedent conditions.

Working Group 3: The Response, Resilience, and Recovery of the CZ to Perturbations of Environmental Change

Discussion Leaders: Yongguan Zhu and Steve Banwart, Rapporteur: Anne Verhoef

Key Science Questions

Overarching question: How to optimise the multiple CZ functions by understanding, defining and managing the 3Rs (Response, Resilience, Recovery)

Hypotheses

Hypothesis 1: The functioning of the CZ is defined by the spatial distributions of stocks, fluxes and transformation rates through the vertical zone

Hypothesis 2: The CZ behaves like an organism; the mechanistic interactions between CZ components define the chain of impacts of a perturbation

Hypothesis 3: The impact of perturbation is scale and location dependent

Objectives

The overall aim is to optimise the multiple CZ functions by understanding perturbation, defining and managing the 3Rs (Response, Resilience, Recovery) with a focus on intra-generational time scales of perturbation. The objective are:

1. To define the 3R framework by liaison with relevant communities of theory for proper definitions
2. To choose, define and measure functions (biomass productivity, greenhouse gas regulation, land surface water and energy balance, water storage, pollution attenuation, functional biodiversity)
3. To determine what type of perturbation and gradient gives us a unique understanding of 3Rs.

Outline of Research Methods

1. Establish what kind of disturbance or perturbation (gradient) we should focus on (sudden extremes, more gradual changes).
2. Aim for locations that are representative of pressing societal questions such as land use transitions from native ecosystems to farming and urban expansion into countryside.
3. Focus studies on the dynamics of land use transition, and extreme events (heatwave, flood, drought, fire) by combining new measurements campaigns with historical datasets and modelling.
4. Determine control points in CZ functions for planned human intervention to influence recovery and resilience.
5. Measure pools and rates of fluxes and transformations as indicators of functions to quantify 3R, during and after perturbation
6. Construct whole catchment CZ budgets for material and energy
7. Define key currencies and metrics for specific CZ functions
8. Identify catchments that summarize requirements set out in methodology

Expected Transformative Advances

1. Deepened understanding of mechanistic coupling of biological and geo-physico-chemical processes of CZ, and related modelling efforts
2. Increased understanding of 3Rs will enable sustainable management of CZ

Required CZO Network Design and Infrastructure Development

This remains to be discussed, but the following sites were proposed where existing CZOs may need to be supplemented by further sites to adequately capture the perturbation gradient.

Specific proposed sites

- Land use gradients in Heihe (black river) or Tibetan plateau catchment (wetland to desert)
- Land use gradients: Intensive agriculture to forest on red soils in Yingtan.

Working Group 4: Quantitative 3D characterisation of the critical zone including fluxes and reservoirs

Discussion Leaders: Chen Zhu and Laurent Longuevergne, Rapporteur: John Crawford

Key Science Questions

Overarching Goal: To motivate and guide theory development through provision of a platform for innovation in 3D spatio-temporal measurement technologies and wider application of existing techniques

Hypotheses

This is an enabling and capacity-building program and is not hypothesis driven.

Objectives

1. To advance methodologies for data processing and interpretation.
2. To establish and resource Centres committed to long-term advancement and innovation of measurement technologies.
3. Integrate chemical, physical and biological data across the range of scales relevant to the processes being studied.
4. Share new technologies, methodologies and research infrastructure to enable a step-change.

Outline of Research Methods

1. Create an international centre for measurement technologies and informatics
 - One-stop-shop for an international network of expertise on deployment, improvement and development of a suite of instruments for use at the Critical Zone observatories
 - Portal to a global lending resource for instrumentation
 - Ensuring and advising on data standards
 - Evaluation and validation of alternative measurement methodologies for the same variable
2. Establishment of trans-national programs to enhance data processing and analysis techniques
 - Training and sharing of best practice through international summer schools.
 - Inter-comparison between different methods
 - Better mechanistic models relating what we can measure to what we need to know
 - New statistical methodologies to describe 3D spatio-temporal systems
 - Improve methods for integrating multi-instrument data
3. Evaluation and development of methods for integrating data across scales
 - Establish an international programme of collaboration on new methods for combining geochemical, physical and biological measurements for process investigation
 - Create a web resource to connect CZO lab, field, and data managers and their expertise.
 - Development of new approaches for the integration of multi-resolution data

Expected Transformative Advances

International consensus on 3D measurement and quantification of the CZ and pathways to innovation

Required CZO Network design and Infrastructure Development

- This activity explicitly refers to infrastructure development and alludes to a proposed centre or centres that would be a hub for an international network of excellence.
- The activity must be integrated with activities on the development of an overarching theoretical framework and models. Effective governance structures must ensure effective coordination of all these activities in order to provide assurance of data quality and reliability for the CZO initiative.

Cross-Cutting Group: Common observations, supporting methods and international governance

Discussion Group members: Tim Filley, Jerome Gaillardet, Bojie Fu, Steve Banwart, Harry Vereecken
Rapporteur: Tim Filley

Key Science Questions

Overarching question: What immediate activities can support the development of a system of governance to define common baseline observations for essential terrestrial variables, index supporting methodologies, establish a culture and operational infrastructure for shared data and information management, and facilitate enhanced networking and virtual and physical scholar exchanges?

Hypotheses

As an essential enabling step towards a strategic long-term programme in CZ science, a multinational system of governance is required that establishes the necessary culture, operational infrastructure and quality management for shared data and information management.

Objectives

Overall Aim: define a set of steps that will develop the methodology for a common baseline of observations for essential terrestrial variables, to index supporting methodologies, and establish a culture and operational infrastructure for shared data and information management among participant sites in the international CZO network. This will build on existing efforts such as the Critical Zone Exploration Network (www.czen.org) catalogue of field sites, and will draw on the common measurements efforts and data for existing networks of CZOs and related field sites. These networks include the USA CZO programme, the TERENO network in Germany, the CRITEX network in France, the EC SoilTrEC network, and the Chinese Ecological and Hydrological Research Networks.

Outline of Research Methods

1. The group proposes that a representative from each participating country join the USA NSF All Hands CZO program meeting in September to:
 - observe and interact with the USA national working group,
 - agree the actions for a 2-year program of specific steps to support common observations, indexing of supporting methodologies, and data sharing,
 - raise awareness of existing protocols, requirements, and benchmarks within national CZO programs and projects, and other observatory networks, and
 - discuss opportunities for establishing a visiting scholars network across CZO programs.
2. The group proposes to form a working group that will include representatives from each of the 5 countries participating in the Beijing workshop. The first step is to specifically review USA, TERENO (Germany) and CRITEX (France) CZO network practice and compare their common measurements and supporting methodologies, and data sharing protocols, between these programs and also with other observatory and data management programs in the UK and China.

Required CZO Network Design and Infrastructure Development

- Secure, web based platforms for information exchange across international CZO networks
- Web based platforms to house the global index of methodologies and access to support common baseline observations
- Web based platform to facilitate the exchange of ideas and persons engaged in international CZO related activities

Feedback of Funders to Workshop Participants

The funders reported to the workshop participants following the final plenary session that summarised the working group outputs. The key messages are:

1. The expectations and needs of CZ researchers will be considered in formulating funding policies and strategies,
2. Important steps include developing national funding programs and fostering connections, networking, and coordination among researchers within their own countries but also internationally,
3. Where possible, funders would like to jointly promote and support such activities as workshops and establishment of an international CZ science network,
4. In the medium - long term, the funders agree that a multilateral research funding program on CZ science is essential to push forward cross-disciplinary and international research in this area,
5. The Belmont forum, with a steering committee and a joint funding scheme of each funder paying for its own researchers, is a good example, but not the only option for multilateral joint funding,
6. Under this multilateral framework, bilateral activities are also included and encouraged,
7. An international Critical Zone science committee with leading scientists in this area from all over the world is needed,
8. The international CZ science committee would, e.g. mobilise scientists to outline the priority areas, research and goals, and to help facilitate interactions of the Critical Science community, and
9. Integration and coordination among the existing programs are recognized as necessary.

Schedule of Forward Plans

The participating scientists confirmed their commitment to working together and with their collaborating partners in the worldwide CZ science community to:

1. Advance as rapidly as possible a framework for an initial jointly funded international CZ research programme, and
2. Develop a strategy for the medium-long term implementation of a multilateral CZ programme of research funding.

The proposed schedule of actions is listed on the following page (Table 1).

Schedule of Actions, 2014-2015		
Completion Date	Action	Lead
1 st June 2014 15 th June 2014 31 st July 2014	Outline workshop report to funders and participants 300 word “letter” drafted as workshop news item to <u>Science</u> News release from workshop’s participating organisations Feedback incorporated, full draft complete Submission of final report to funders	Workshop Chairs
8 th June 2014	Workshop blog posted on <u>World Economic Forum</u> web site	John Crawford
21 st Sept 2014	China, UK, Germany, France scientists join USA CZO All-Hands meeting	Selected by funders
14 th Dec 2014	NSF USA – hosted follow-up meeting with funders Int’l Scientific Committee (ISC) membership and terms of reference (ToR) proposed Outline framework and funding mechanisms agreed Support and ToR for international working group on common measurements and data sharing confirmed	Funders
14 th Dec 2014	International working group on common measurements and data sharing membership proposed to funders	Workshop Cross-Cutting Group
16 th February 2015 2 nd March 2015	Draft contribution to <u>Nature</u> Comment Proposal/draft for Comment submitted to <u>Nature</u>	Workshop Chairs with Congqiang Liu, Dan Richter
2 nd March 2015	Outline of contribution to <u>Scientific American</u> popular science article on Earth’s CZ	Dan Richter, workshop chairs, authors tba
16 th Jan 2015 31 st Jan 2015 2 nd March 2015	Outline of EOS article on international CZ advances since BROES 1, frontiers and R&D agenda First draft completed Target date for submission	Workshop chairs, speakers, others tba
2 nd March 2015	Call text agreed for Spring/Summer 2015 – initial funding stage	Funders
31 st March 2015	Draft roadmap for 2 and 5 year international programme development stages submitted to funders for internal review and for public consultation	ISC members
30 June 2015	Announcement of Opportunity opened	Funders

Sponsors

NSF China – host organisation; CNRS, France; DFG, Germany; NERC, UK; NSF USA

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