

# Data, data everywhere

## Earth 530: Earth surface processes in the Critical Zone

Tim White (tsw113@psu.edu)

### Critical Zone:

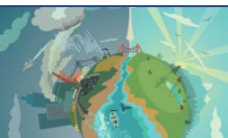
- Term published by the U.S. National Research Council in 2001 BROES report

= Thin veneer at Earth's surface spanning from the top of vegetation canopy through soil to deep in the subsurface where fresh groundwater circulates.



# Tropical rainforest:

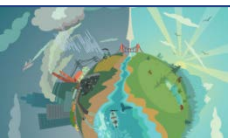
- Extensive forest canopy with complex understory
- Thick mature soils and deep weathered regolith
- Potentially deep aquifers



# Polar realm:

- Stunted vegetation
- Thin discontinuous soils
- Permafrost

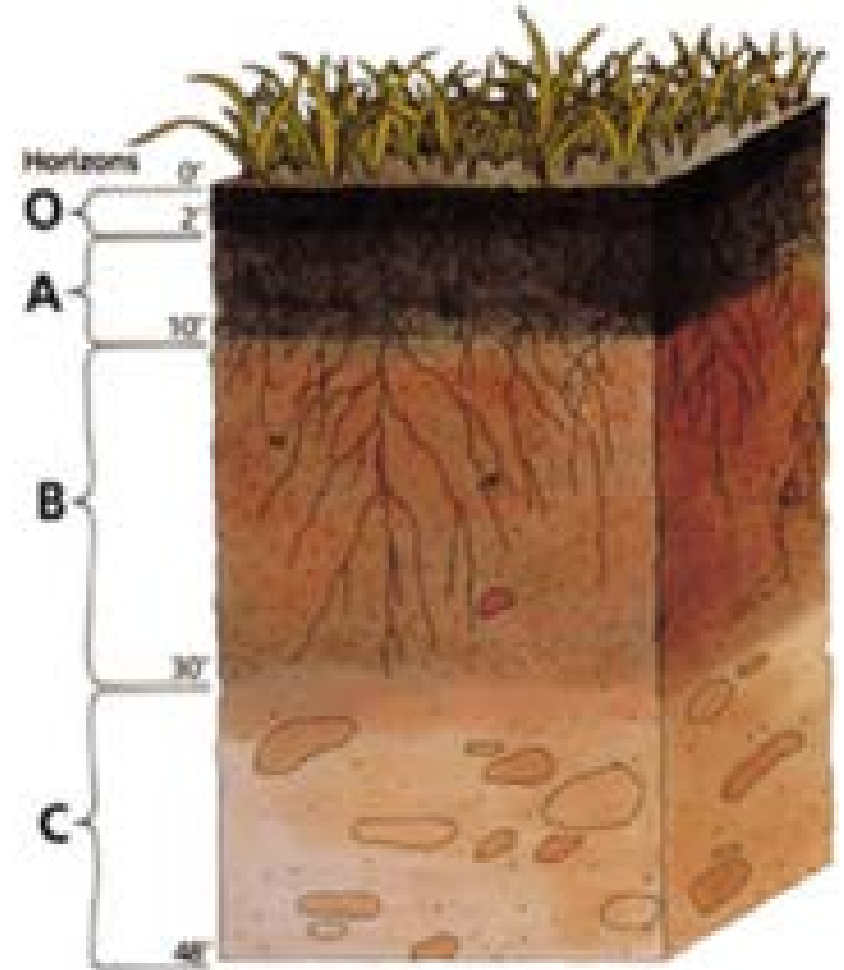
Longyearbyen Valley,  
Spitsbergen



# Soil is a central component of the Critical Zone

**Important for:**

- agriculture
- water filtration
- C sequestration
- biodiversity



**But the CZ is much more.....**



Soil exists at the “**Critical Zone**



**Soil Crit Zone**

**But the CZ is much more.....**



**PennState**  
College of Earth  
and Mineral Sciences

MASTER OF EDUCATION IN  
**Earth Sciences**

# Societal relevance:

The zone within which most terrestrial life exists and depends on.

Ongoing climate and land use changes to the zone may stress terrestrial life including humanity – thus a better understanding of CZ processes and function may aid adaptation to change.





## Changes in the global value of ecosystem services



Robert Costanza<sup>a,\*</sup>, Rudolf de Groot<sup>b</sup>, Paul Sutton<sup>c,d</sup>, Sander van der Ploeg<sup>b</sup>, Sharolyn J. Anderson<sup>d</sup>, Ida Kubiszewski<sup>a</sup>, Stephen Farber<sup>e</sup>, R. Kerry Turner<sup>f</sup>

<sup>a</sup> Crawford School of Public Policy, Australian National University, Canberra, Australia

<sup>b</sup> Environmental Systems Analysis Group, Wageningen University, Wageningen, The Netherlands

<sup>c</sup> Department of Geography, University of Denver, United States

<sup>d</sup> Barbara Hardy Institute and School of the Natural and Built Environments, University of South Australia, Australia

<sup>e</sup> University of Pittsburgh, United States

<sup>f</sup> University of East Anglia, Norwich, UK

## ARTICLE INFO

## Article history:

Received 12 October 2013

Received in revised form 18 February 2014

Accepted 1 April 2014

## Keywords:

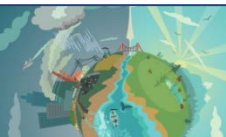
Ecosystem services

## ABSTRACT


In 1997, the global value of ecosystem services was estimated to average \$33 trillion/yr in 1995 \$US (\$46 trillion/yr in 2007 \$US). In this paper, we provide an updated estimate based on updated unit ecosystem service values and land use change estimates between 1997 and 2011. We also address some of the critiques of the 1997 paper. Using the same methods as in the 1997 paper but with updated data, the estimate for the total global ecosystem services in 2011 is \$125 trillion/yr (assuming updated unit values and changes to biome areas) and \$145 trillion/yr (assuming only unit values changed), both in 2007 \$US. From this we estimated the loss of eco-services from 1997 to 2011 due to land use change at

the estimate for the total global ecosystem services in 2011 is \$125 trillion/yr (assuming updated unit values and changes to biome areas) and \$145 trillion/yr (assuming only unit values changed), both in 2007 \$US. From this we estimated the loss of eco-services from 1997 to 2011 due to land use change at \$4.3–20.2 trillion/yr, depending on which unit values are used. Global estimates expressed in monetary

Total global gross domestic product (2013): US\$74.3–87.3 trillion  
(source: Wikipedia)

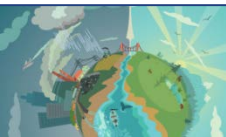


# Critical Zone Services

- 
- \* **Pollination**
  - \* **Fulfillment of cultural, spiritual/intellectual needs**
  - \* **Regulation of climate**
  - \* **Insect pest control**
  - \* **Maintenance and provision of genetic resources**
  - \* **Maintenance and regeneration of habitat**
  - \* **Provision of shade and shelter**
  - \* **Prevention of soil erosion**
  - \* **Maintenance of soil fertility**
  - \* **Maintenance of soil health**
  - \* **Maintenance of healthy waterways**
  - \* **Water filtration**
  - \* **Regulation of river flows and groundwater levels**
  - \* **Waste absorption and breakdown**

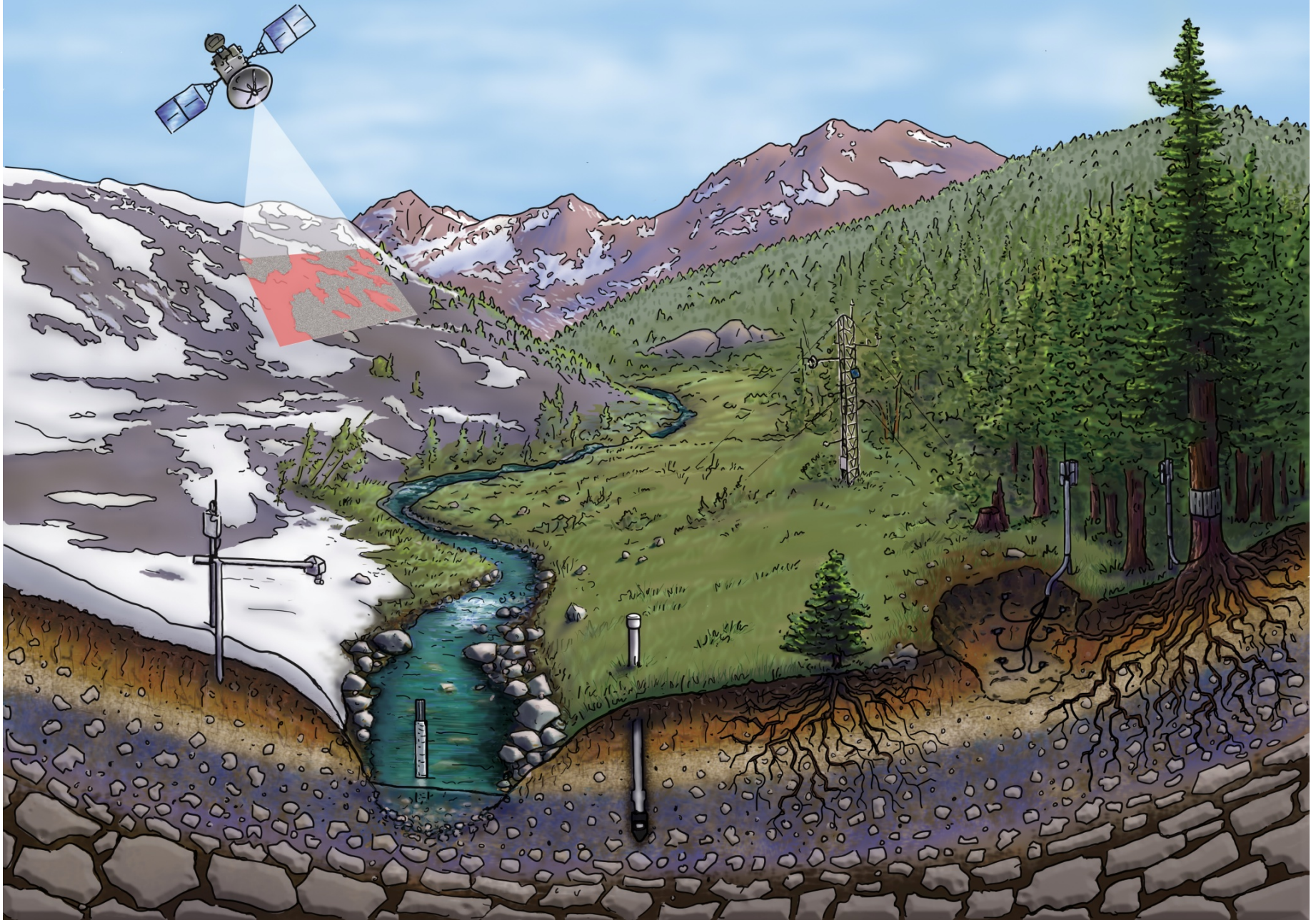
**If we allow natural assets to decline, so do the benefits.  
But if we care for and maintain natural assets, we will reap  
greater returns.**





**PennState**  
College of Earth  
and Mineral Sciences

MASTER OF EDUCATION IN  
**Earth Sciences**



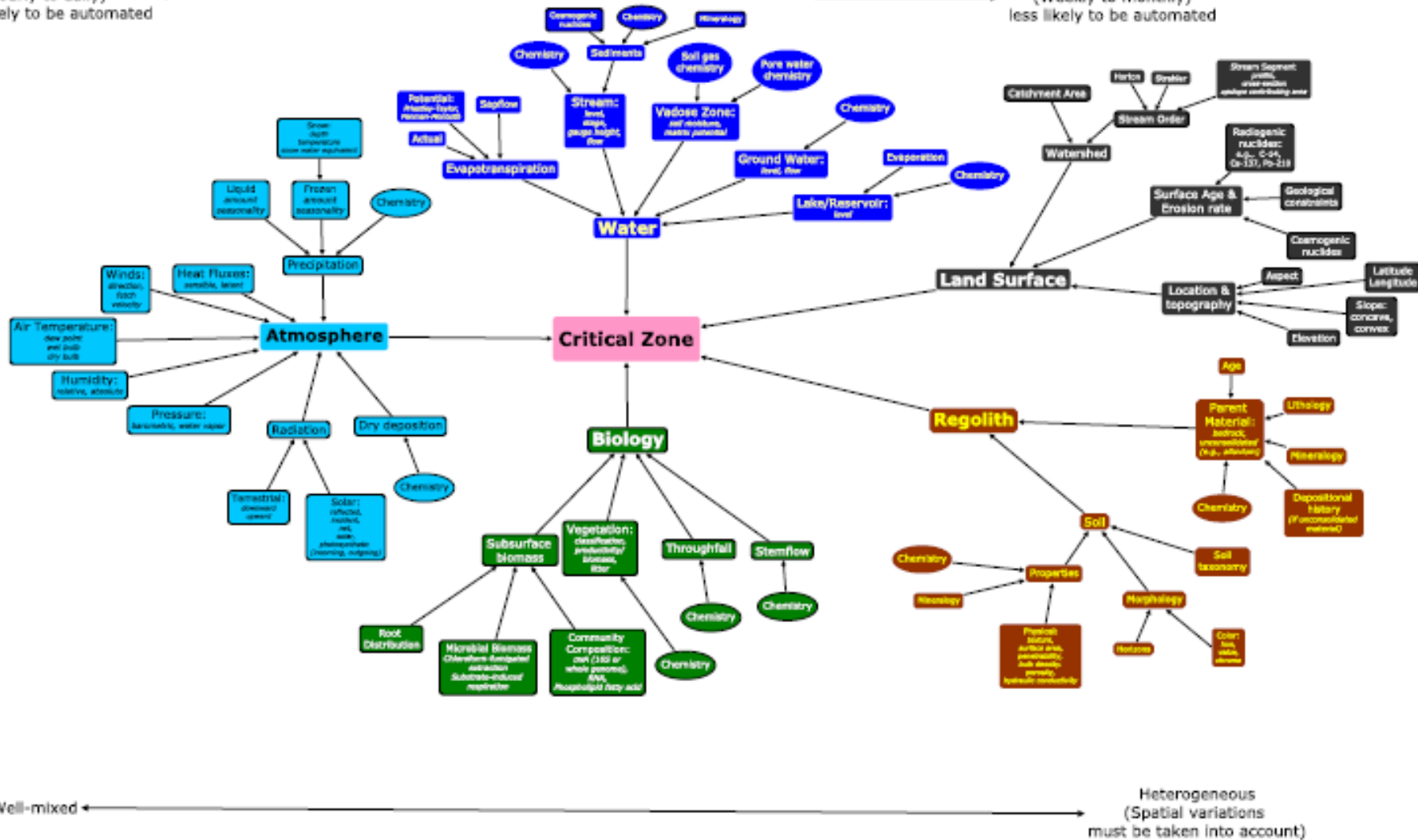
**PennState**  
College of Earth  
and Mineral Sciences

MASTER OF EDUCATION IN  
**Earth Sciences**

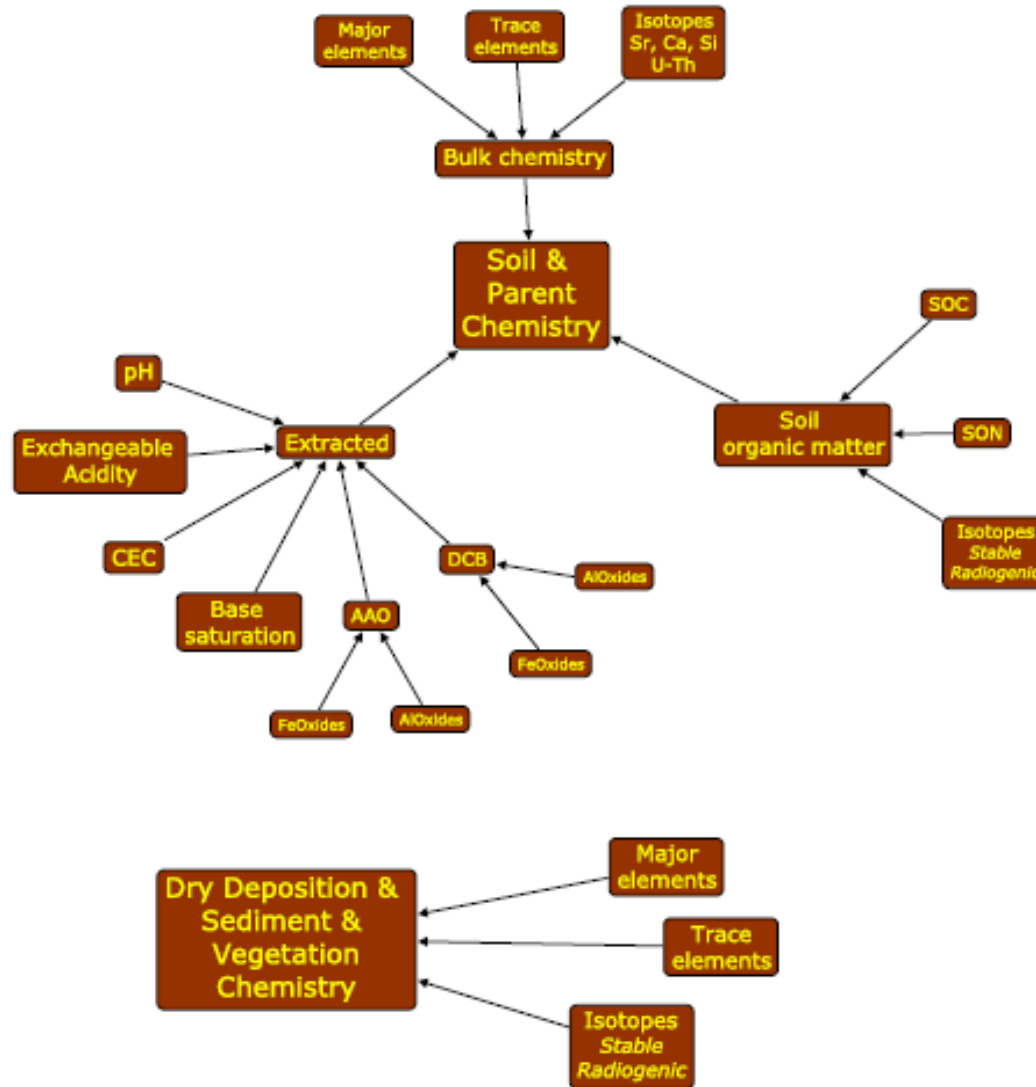
# CZOs have drafted an ontology that describes the structure of the data

More frequent measurements  
(Hourly to daily)  
more likely to be automated

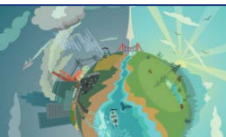
Less frequent measurements  
(Weekly to monthly)  
less likely to be automated



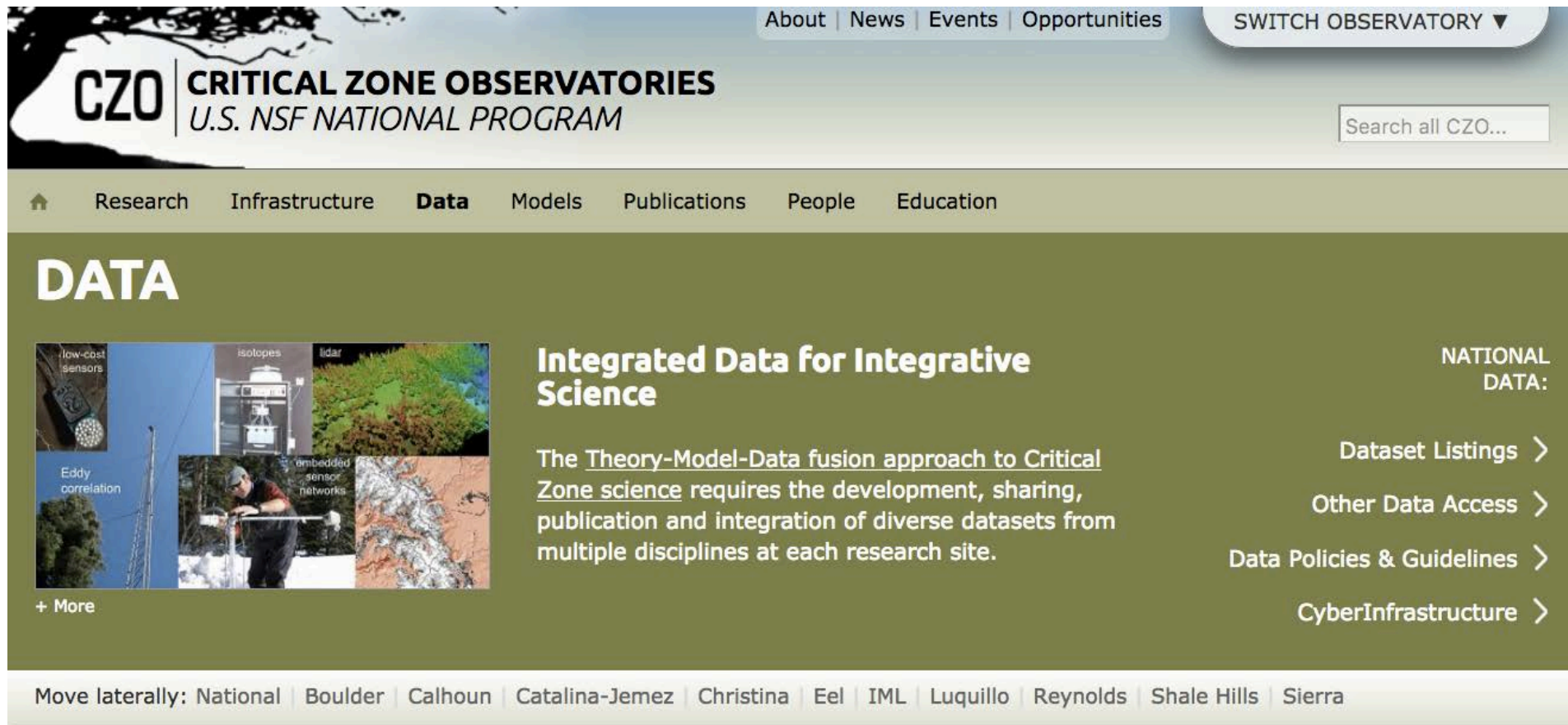
# Solid chemistry



CZO →	Boulder Creek	Calhoun	Catalina-Jemez	Christina River	Eel River	IML	Luquillo	Reynolds Creek	Shale Hills	Southern Sierra
<b>Land-Atmosphere</b>										
LiDAR	X	Z	X	X	X	X	X	Y, Z	X	X
Eddy flux	Y	Z	X			X, Y, Z		Y	X	X, Z
Wind speed and direction	X	Z	X	X	X	X, Y	Y	Y	X	X
Precipitation and throughfall	X	X, Z	X	X	X	X, Y	Y	Y	X	X, Y, Z
Wet and dry deposition	Y	X, Z	X	X		Y	Y	Y	X	X
Snowpack distribution and duration	X		X					Y	X	X
<b>Vegetation and Microbiota</b>										
Structure and function above and below biomass	X	X	X	X	X, Z	X	Y	Y, Z	X	X, Y, Z
Microbial composition above and below ground	X	X, Z	X	X	X	X	Y	Z		X, Z
ET - species composition and structure relationships	Y	Z	X		X	y		Y, Z	X	X
<b>Soil (Vadose Zone)</b>										
Solid - elemental composition and mineralogy	X	X, Z	X	X	X	X	X	Y, Z	X	X, Y
Solid - texture and physical characterization	X	X, Z	X	X	X	X	X	Y, Z	X	X, Y, Z
Solid - organic matter content	X	X, Z	X	X	X	X	X	Y, Z	X	X, Z
Solid - radiogenic isotope composition	X		X	X		X	X		X	X, Z
Fluid - soil moisture (sensors)	X	X, Z	X	X	X	X	X	Y, Z	X	X, Z
Fluid - soil temperature (sensors)	X	Z	X	X	X	X	X	Y, Z	X	X, Z
Fluid - soil solution chemistry (samplers)	X	X, Z	X	X	X	X	X		X	X, Y, Z
Fluid - soil gas chemistry (samplers/sensors)		X, Z	X	X	X		X, Y	Z	X	Z
<b>Saprolite and Bedrock (Saturated Zone)</b>										
Solid - petrology and mineralogy	X	X, Z	X	X	X	Y	X	Z	X	X, Z
Solid - elemental composition and OM content	X	X, Z	X	X	X	X	X	Z	X	X, Z
Solid - texture, physical/architectural constraints	X	X, Z	X	X	X	X	X	Z	X	X, Z
Fluid - potentiometric head, temperature (sensors)	X	Z	X	X	X	X	X	Y	X	X
Fluid - groundwater chemistry (samplers/sensors)	X	X, Z	X	X	X	X	X	Z	X	X, Z
Fluid - saprolite/weathered bedrock gas chemistry		X, Z			X					X
Geophysical surveys - depth to bedrock	X		X	X	X		X	Y	X	X
<b>Surface Water</b>										
Instantaneous discharge	X	X, Z	X	X	X	X, Y	X, Y	Y	X	X, Y, Z
Stable isotopes of water	X	Z	X		X		X		X	X
Stream water chemistry (samplers/sensors)	X	X, Z	X	X	X	X	X, Y, Z	Z	X	X, Y
Sediments (samplers/sensors)	X	Z	X	X	X	X	X	Y, Z	X	Y, X
Extent of wetted channel		Z			X					Y, X
Aquatic biota (invertebrates, fish, etc.)					X		Y			Y



# All that CZO data is publicly available.....



The screenshot shows the top navigation bar with links for 'About', 'News', 'Events', and 'Opportunities'. A 'SWITCH OBSERVATORY' dropdown menu is on the right. The main header features the CZO logo and the text 'CRITICAL ZONE OBSERVATORIES U.S. NSF NATIONAL PROGRAM'. A search bar is located on the right side of the header. Below the header is a navigation menu with links for 'Research', 'Infrastructure', 'Data', 'Models', 'Publications', 'People', and 'Education'. The 'Data' link is highlighted. The main content area has a large 'DATA' heading. Below it is a grid of images with labels: 'low-cost sensors', 'isotopes', 'lidar', 'Eddy correlation', and 'embedded sensor networks'. To the right of this grid is the section title 'Integrated Data for Integrative Science' and a paragraph describing the Theory-Model-Data fusion approach. On the far right, under 'NATIONAL DATA:', there are four links: 'Dataset Listings', 'Other Data Access', 'Data Policies & Guidelines', and 'CyberInfrastructure'. At the bottom of the main content area is a horizontal menu with links for various observatories: 'National', 'Boulder', 'Calhoun', 'Catalina-Jemez', 'Christina', 'Eel', 'IML', 'Luquillo', 'Reynolds', 'Shale Hills', and 'Sierra'.

About | News | Events | Opportunities

SWITCH OBSERVATORY ▼

**CZO** | CRITICAL ZONE OBSERVATORIES  
U.S. NSF NATIONAL PROGRAM

Search all CZO...

Research | Infrastructure | **Data** | Models | Publications | People | Education

## DATA

low-cost sensors | isotopes | lidar | Eddy correlation | embedded sensor networks

### Integrated Data for Integrative Science

The Theory-Model-Data fusion approach to Critical Zone science requires the development, sharing, publication and integration of diverse datasets from multiple disciplines at each research site.

NATIONAL DATA:

- Dataset Listings >
- Other Data Access >
- Data Policies & Guidelines >
- CyberInfrastructure >

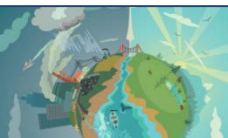
+ More

Move laterally: National | Boulder | Calhoun | Catalina-Jemez | Christina | Eel | IML | Luquillo | Reynolds | Shale Hills | Sierra

**Search for Datasets**

**Browse Datasets**

**Integrated Data System**



**PennState**  
College of Earth  
and Mineral Sciences

MASTER OF EDUCATION IN  
**Earth Sciences**

# Outreach: [criticalzone.org](http://criticalzone.org)

SWITCH OBSERVATORY ▼

**CZO** | **CRITICAL ZONE OBSERVATORIES**  
U.S. NSF NATIONAL PROGRAM

About | News | Events | Opportunities | Contact

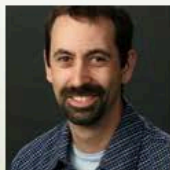
Research Infrastructure Data Models Publications People Education/Outreach

What is the "Critical Zone"?  
It's Earth's skin, a porous near-surface layer that extends from the tops of the vegetation down into the groundwater.  
**EXPLORE WHERE ROCK MEETS LIFE >>**

- Air
- Life
- Soil
- Water
- Rock



## Spotlight



### Alain Plante

INVESTIGATOR, COLLABORATOR  
Christina CZO, Luquillo CZO

Biogeochemistry

## Opportunities

**Announcement of opportunity: CZO SAVI Summer Interns Program 2015**

**Announcement of opportunity: CZO SAVI International Scholars Program**

[View Opportunities >](#)

## Quick Links

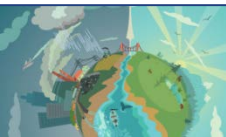
[What is the "Critical Zone"?](#)

[Our Ten Observatories](#)

[Future Directions for CZO Science](#)

[Common CZO Infrastructure and Measurements](#)

[Special issues on the CZ](#)

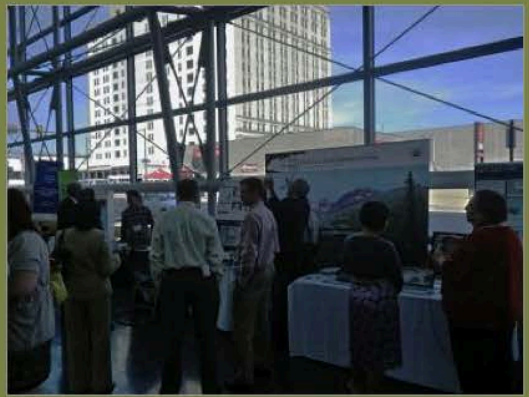


**PennState**  
College of Earth  
and Mineral Sciences

MASTER OF EDUCATION IN  
**Earth Sciences**

# Outreach to secondary education community:

## K-12 Education



+ More

**A national-scale CZO education and outreach effort has begun.**

The CZOs participate in a variety of organizational forums to develop a focused and effective education and outreach presence.

NATIONAL  
EDUCATION-OUTREACH:

- General Public >
- K-12 Education ▶**
- Higher Education >
- Research Community >

Move laterally: [National](#) | [Boulder](#) | [Catalina-Jemez](#) | [Christina](#) | [IML](#) | [Luquillo](#) | [Reynolds](#) | [Shale Hills](#) | [Sierra](#)

### Example activities

The below activities engaged K-12 teachers or administrators overseeing K-12 funding programs.

<http://criticalzone.org/national/education-outreach/k-12-education-1national/>





# Outreach to secondary education community:



## AGI Earth Science Week

CZO researchers cooperated with the American Geosciences Institute's Earth Science Week in 2013, 2014, and 2015, providing "hands on" learning exercises that were sent to more than 16,000 teachers nationwide. The CZO National Office intends for this cooperation to continue on an annual basis. More information is available in a [2014 News story](#) and a [2015 News story \(African Dust feeds the Puerto Rico ecosystem\)](#).

### AGI hands-on learning exercises:

[LiDAR exercise for high school classrooms \(4 MB pdf\)](#)

[Water resources management simulation \(1 MB pdf\)](#)

[Paleoclimate influence on landscape evolution \(1 MB pdf\)](#)

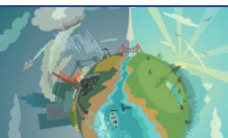
[The Influence of Dry Deserts on Tropical Rain Forests \(1 MB pdf\)](#) | [Online Version](#)

- [African Dust Supplementary \(2 MB pdf\)](#)
- [Rain chemistry data AGI \(0.5 MB xlsx\)](#)

### Example activities

The below activities engaged K-12 teachers or administrators overseeing K-12 funding programs.

<http://criticalzone.org/national/education-outreach/k-12-education-1national/>



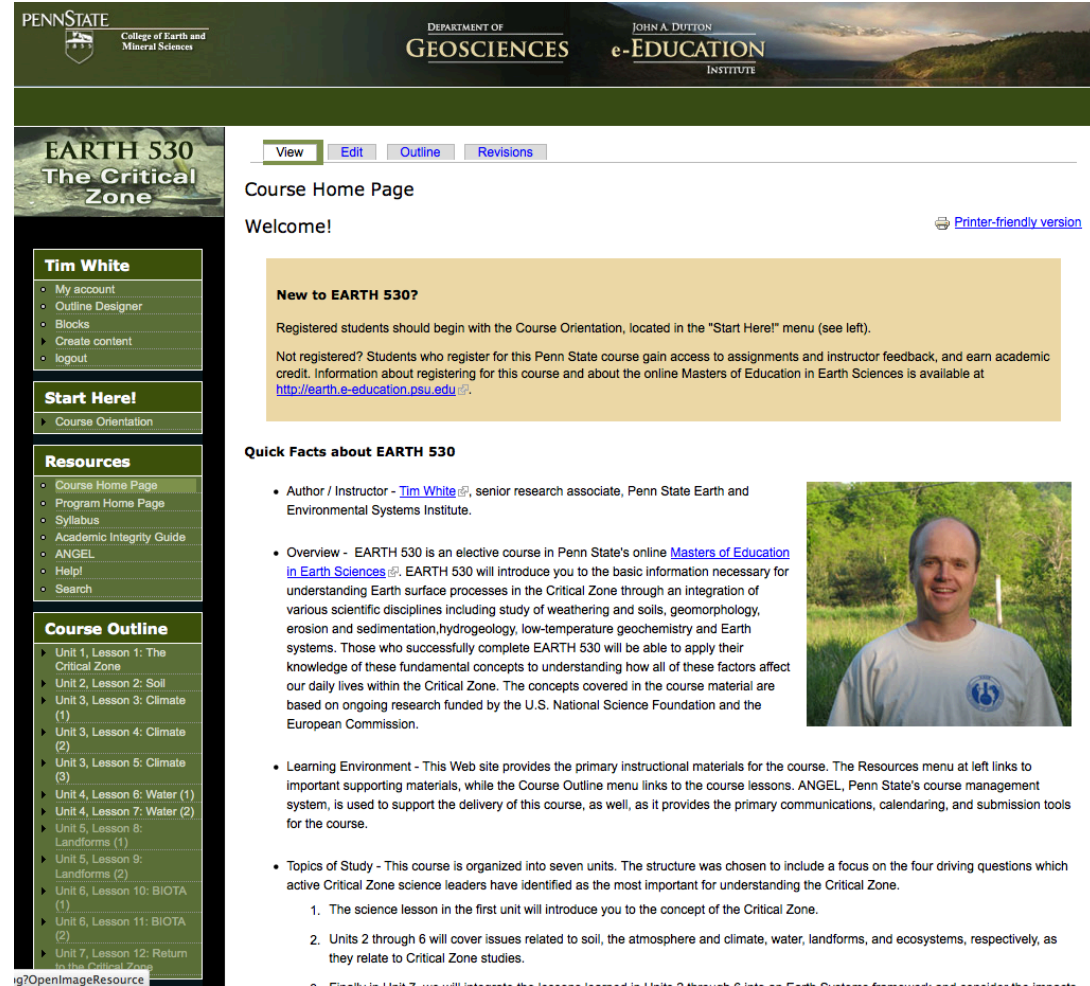
# Outreach to secondary education community:

Earth 530 integrates various scientific disciplines that include the study of:

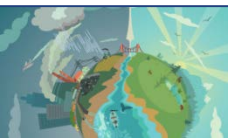
- weathering and soils
- landforms and landscapes
- erosion and sedimentation
- hydrogeology
- low-temperature geochemistry
- biology and ecology
- Earth systems

Upon completion students can apply knowledge of fundamental concepts to understanding how they affect our daily lives in the Critical Zone.

The concepts covered in the course are based on ongoing research funded by the U.S. National Science Foundation and the European Commission.



The screenshot shows the course website for Earth 530, 'The Critical Zone'. At the top, it features logos for Penn State College of Earth and Mineral Sciences, the Department of Geosciences, and the John A. Dutton e-Education Institute. The main header includes the course title 'EARTH 530 The Critical Zone' and navigation tabs for 'View', 'Edit', 'Outline', and 'Revisions'. Below the header, there is a 'Course Home Page' section with a 'Welcome!' message and a 'Printer-friendly version' link. A yellow box highlights 'New to EARTH 530?' with instructions for registered and non-registered students. A 'Quick Facts about EARTH 530' section follows, listing the author/instructor (Tim White), an overview of the course, and details about the learning environment and topics of study. A portrait of Tim White is shown to the right of the overview text. On the left side of the page, there is a sidebar menu with sections for 'Tim White' (My account, Outline Designer, Blocks, Create content, logout), 'Start Here!' (Course Orientation), 'Resources' (Course Home Page, Program Home Page, Syllabus, Academic Integrity Guide, ANGEL, Help, Search), and 'Course Outline' (Units 1 through 7 with lesson counts).



# Critical zone science is transdisciplinary

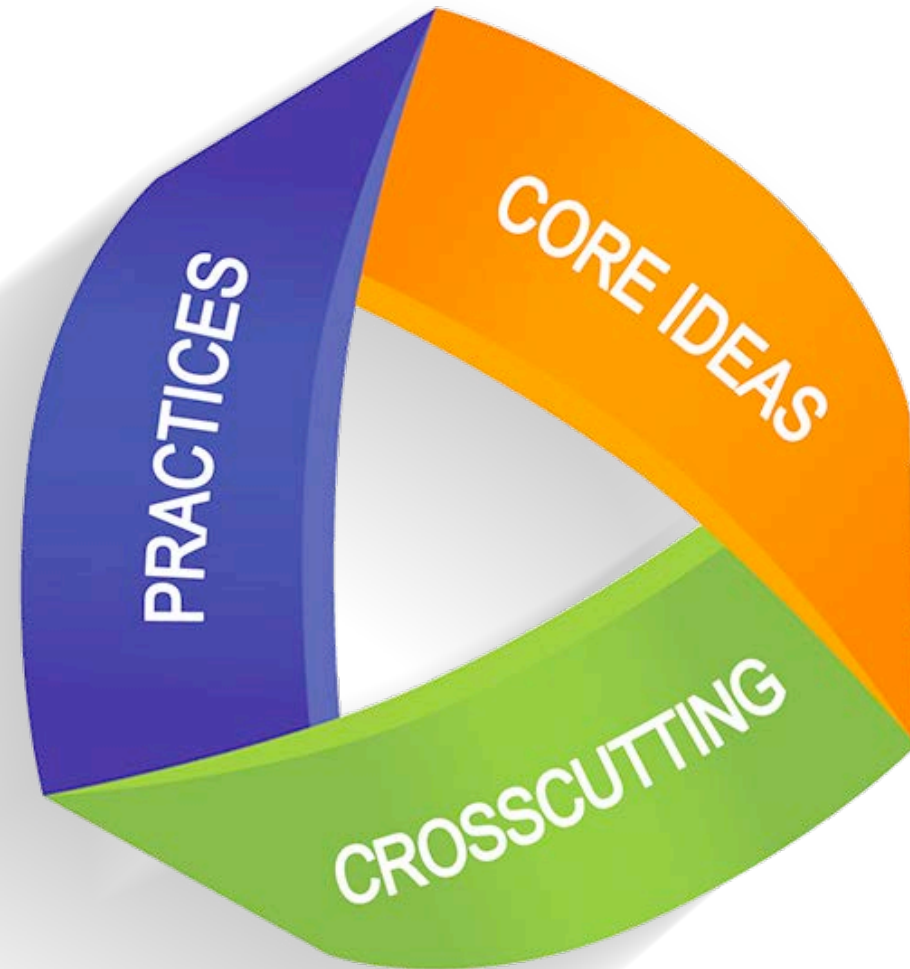
- different disciplines working jointly

Thus Earth 530 aligns well with the three dimensions of science learning of the Next Generation Science Standards:

- Crosscutting concepts
- Science and Engineering practices
- Disciplinary core ideas

Science is both a body of knowledge and an evidence-based model and theory building enterprise that continually extends, refines, and revises knowledge.

The three dimensions are combined to form Standards.



## High School

### Life Science

### Earth & Space Science

### Physical Science

High School Life Science Introduction	High School Earth & Space Science Introduction	High School Physical Science Introduction
HS. Structure and Function	HS. Space Systems	HS. Structure and Properties of Matter
HS. Inheritance and Variation of Traits	HS. History of Earth	HS. Chemical Reactions
HS. Matter and Energy in Organisms and Ecosystems	HS. Earth's Systems	HS. Forces and Interactions
HS. Interdependent Relationships in Ecosystems	HS. Weather and Climate	HS. Energy
HS. Natural Selection and Evolution	HS. Human Sustainability	HS. Waves and Electromagnetic Radiation
High School Engineering Design Introduction		
HS. Engineering Design		



## Students who demonstrate understanding can:

### Performance Expectations



Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems. [HS-ESS2-2](#)

[▶ Clarification Statement and Assessment Boundary](#)



Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection. [HS-ESS2-3](#)

[▶ Clarification Statement and Assessment Boundary](#)



Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes. [HS-ESS2-5](#)

[▶ Clarification Statement and Assessment Boundary](#)



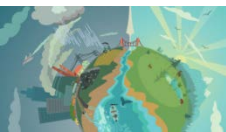
Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere. [HS-ESS2-6](#)

[▶ Clarification Statement and Assessment Boundary](#)



Construct an argument based on evidence about the simultaneous coevolution of Earth's systems and life on Earth. [HS-ESS2-7](#)

[▶ Clarification Statement and Assessment Boundary](#)



A unique facet of critical zone science is that it considers depth in time and space, that is a geological perspective, that might otherwise be disregarded in the classical Earth surface and environmental sciences.



## Introduction to Lidar

Lidar = Light Detection and Ranging

**Range.** The measurement of the speed which a pulse of light returns to a sensor is converted to elevation above sea level.

$$R = \frac{1}{2}(tc)$$

- R = range
- $t$  = time
- $c$  = speed of light

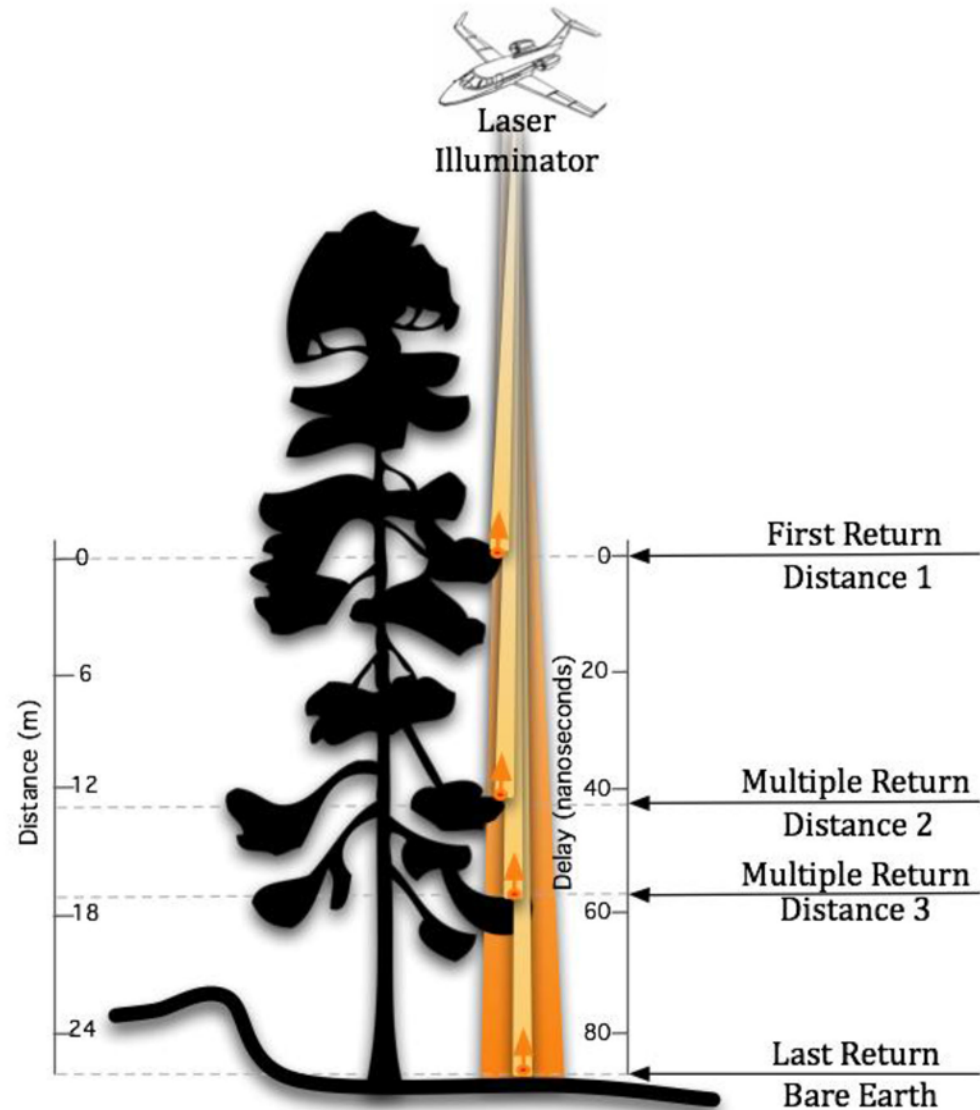
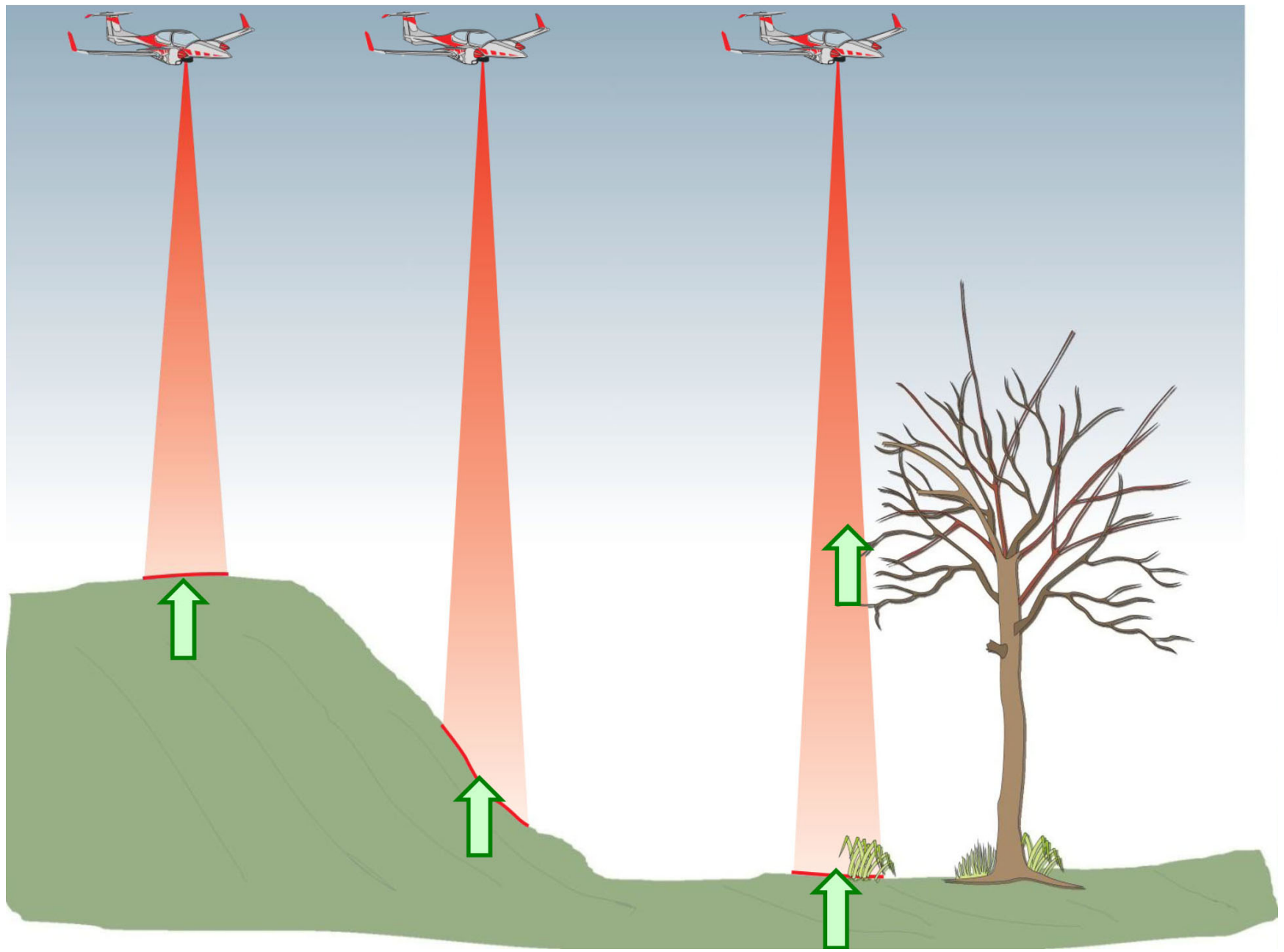


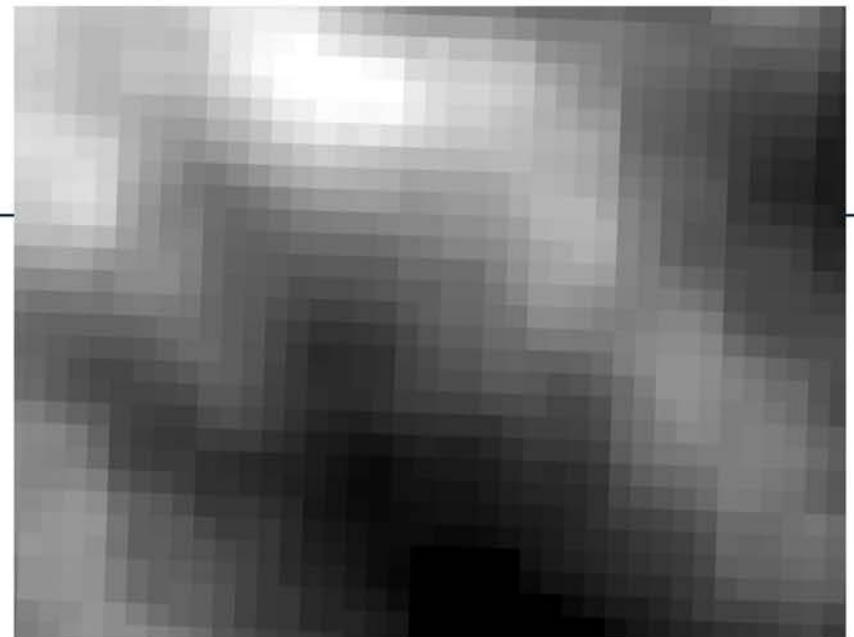
Image modified from Lefsky et al. 2004 with tree graphic from globalforestsience.org.



**PennState**  
College of Earth  
and Mineral Sciences

MASTER OF EDUCATION IN  
**Earth Sciences**



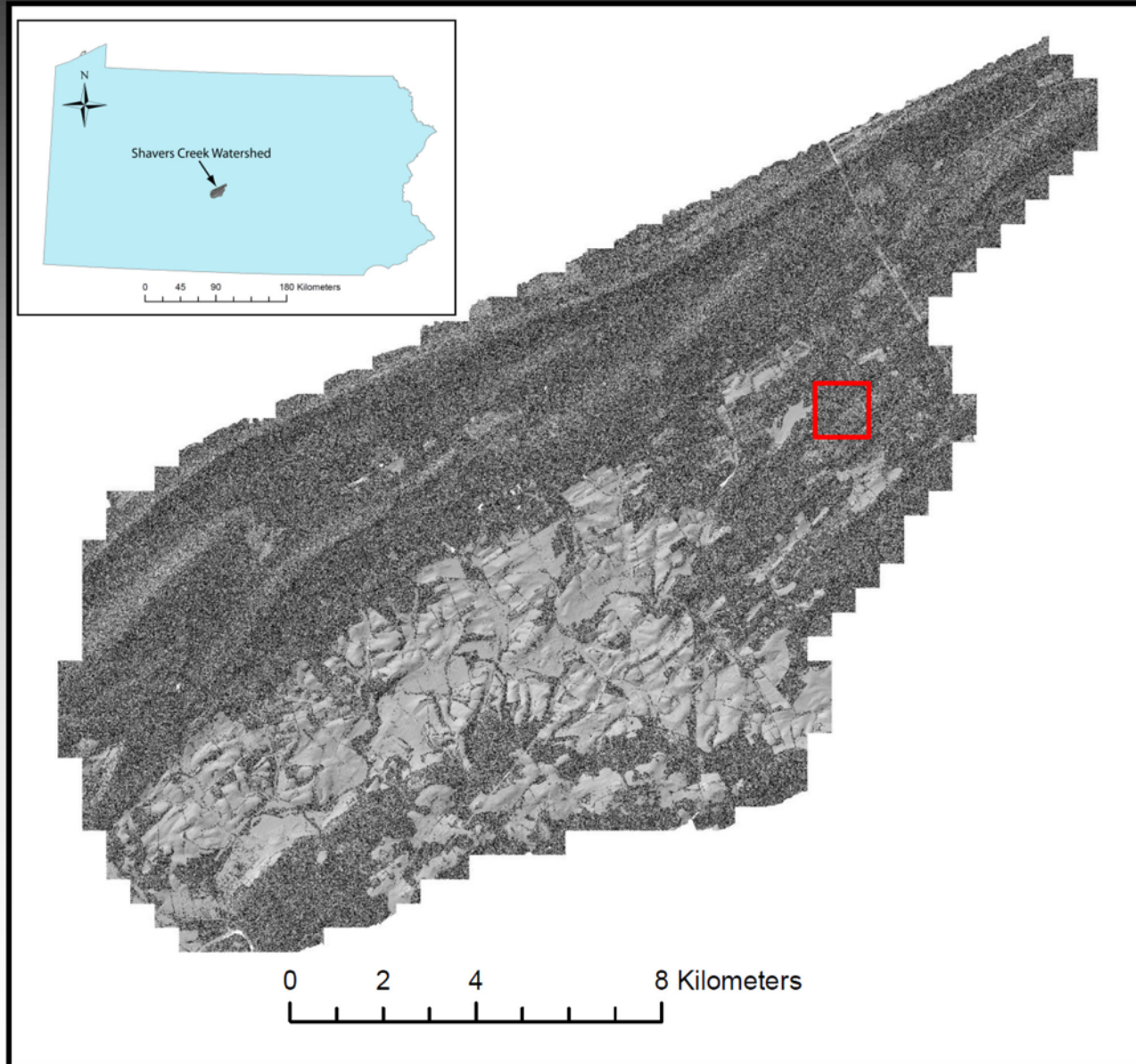


Lidar technology can penetrate the vegetation, and extract the bare earth for ecosystem and earth science studies.

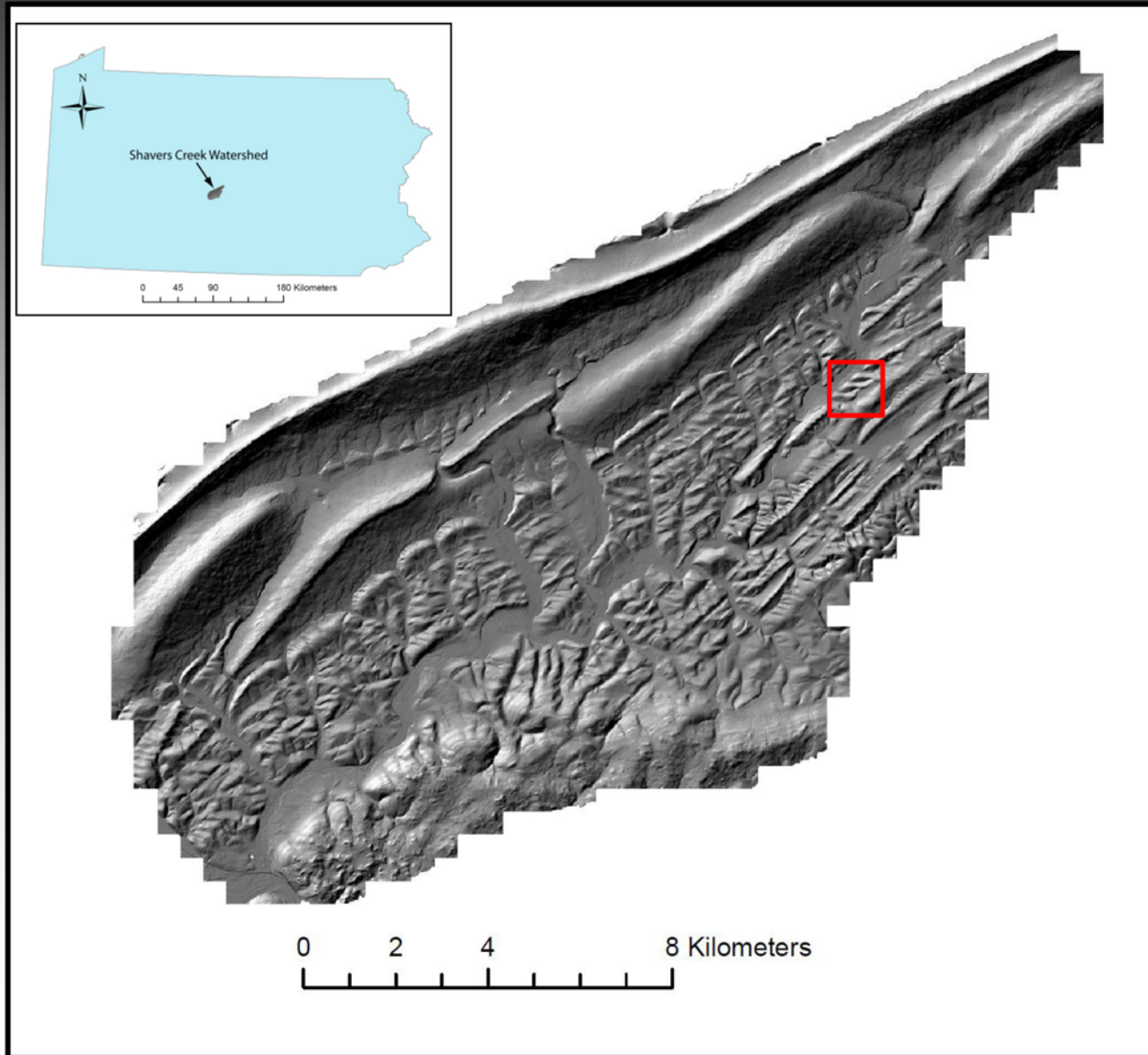
- Upper Left: 1 m resolution aerial photography
- Upper Right: 30 m resolution DEM from USGS
- Lower Right: 1 m resolution DEM from Lidar



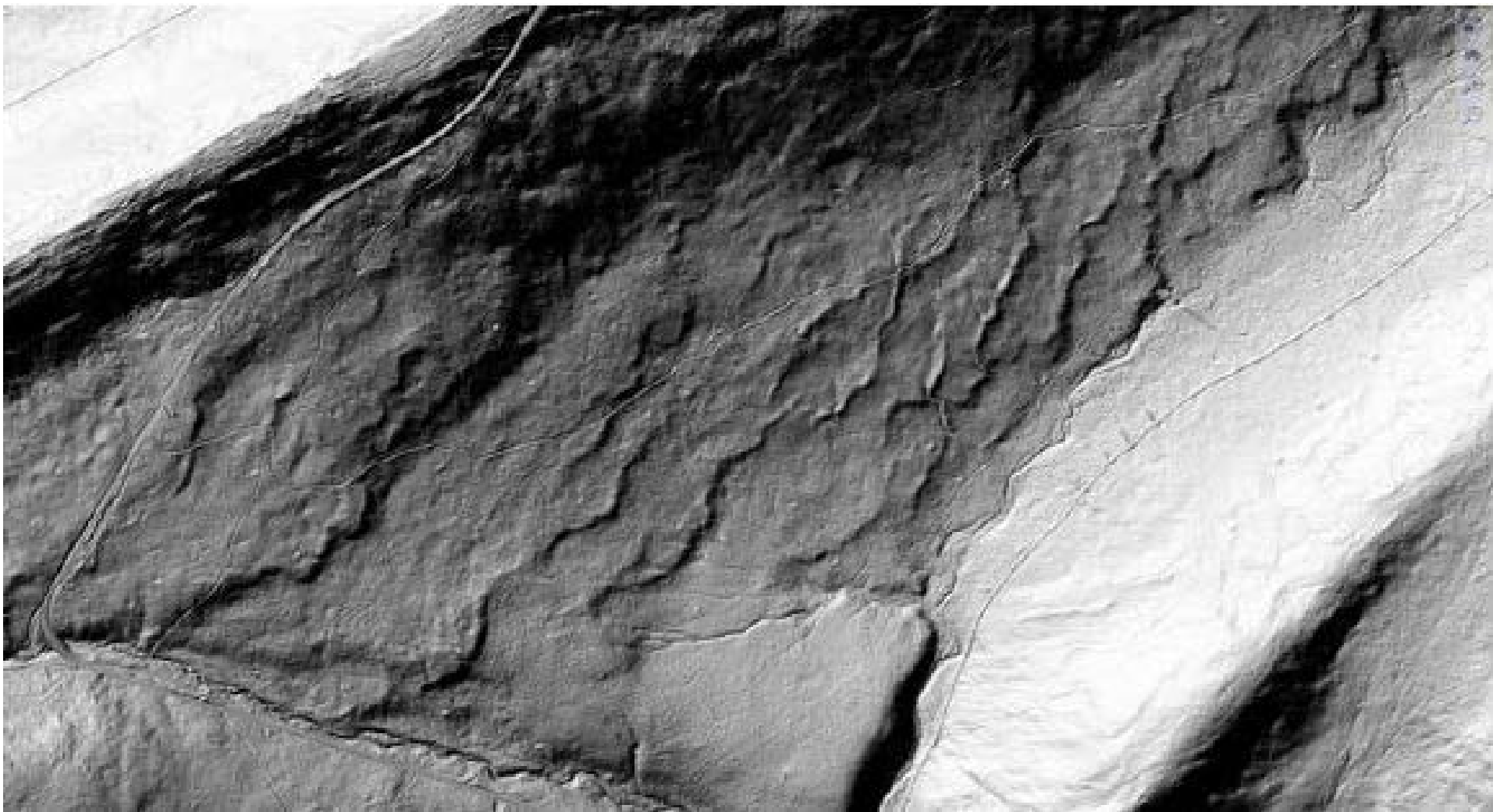
LiDAR acquisition at Shavers Creek was completed in two phases:  
Leaf-on survey completed 7/14/2010 – 7/16/2010



LiDAR acquisition at Shavers Creek was completed in two phases:  
Leaf-off (snow clear) survey completed 12/3/2010 – 12/9/2010



South facing slope, Tussey Mountain, near Pine Grove Mills, Centre/Huntingdon Cty, PA



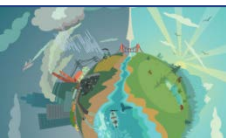
# Chugach Mountains, Alaska



**PennState**  
College of Earth  
and Mineral Sciences

MASTER OF EDUCATION IN  
**Earth Sciences**

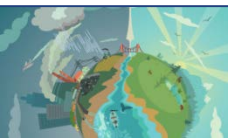
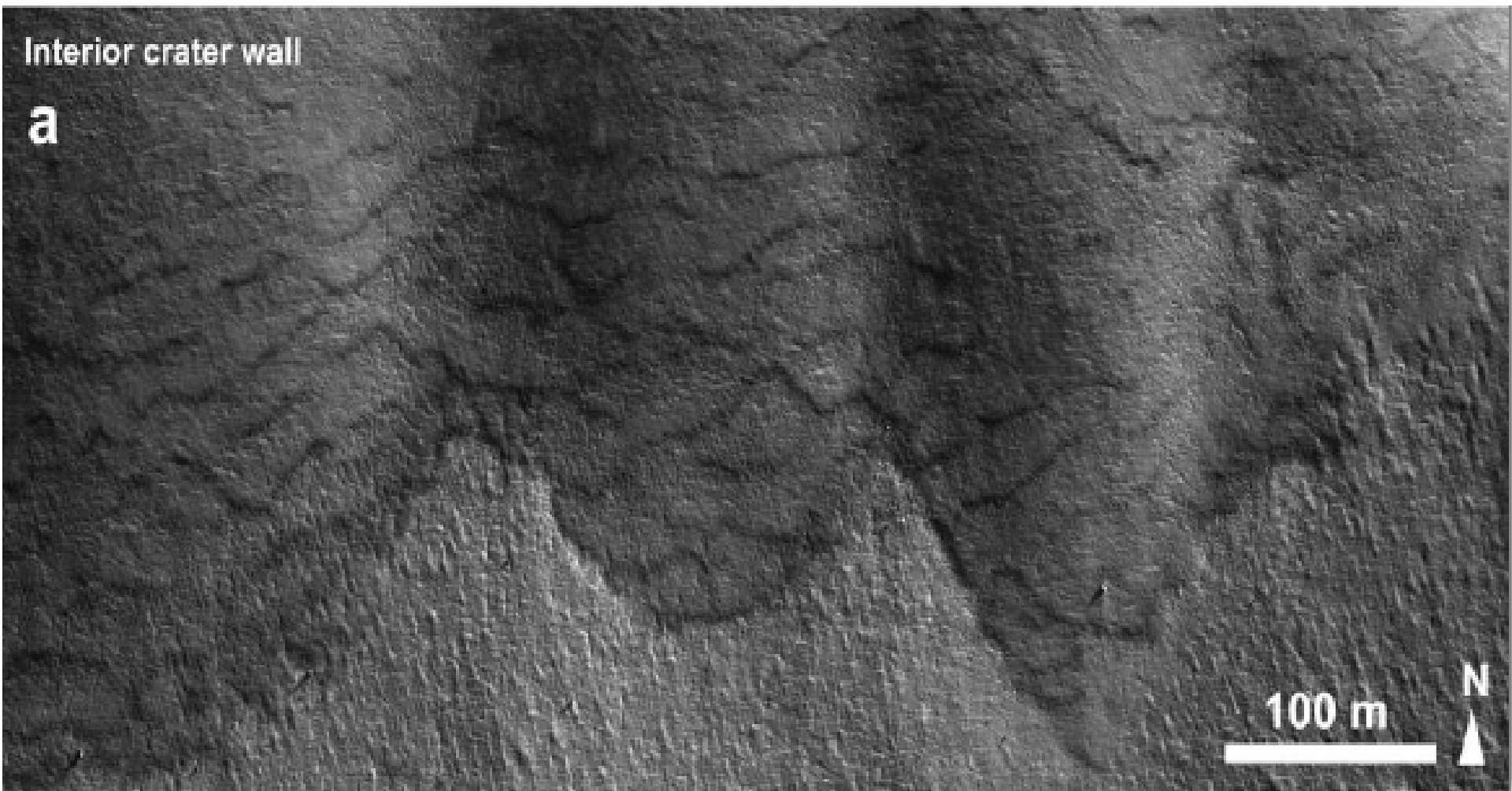
# Talkeetna Mountains, Alaska



**PennState**  
College of Earth  
and Mineral Sciences

MASTER OF EDUCATION IN  
**Earth Sciences**

# Mars



Water is life. CZ processes are mediated by freshwater. How many of you or your students can answer a simple question like:

“Where does a raindrop go when it hits Earth’s surface?”  
or

“Where does the stream behind our school ?”  
or

“Where does the water in our well at home come from?”  
or

“is the stream behind our school flowing less (or more) than it was last year, or ten years ago, or.....?”

