Global Experimental Design using Critical Zone Observatories

The Update from Beijing

TERENO International Conference 2014

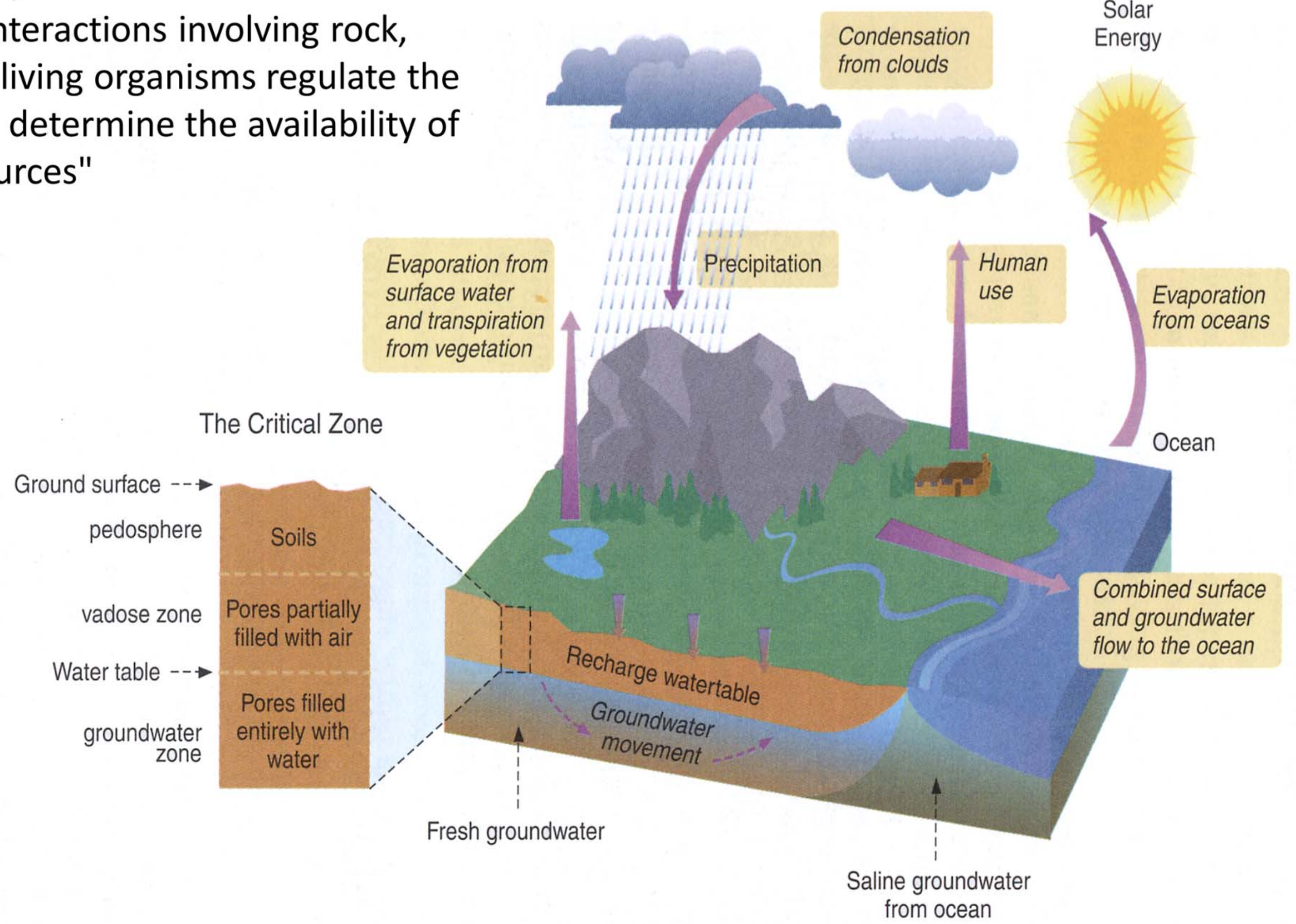
Steve Banwart, U. Sheffield, UK
SoilTrEC: Soil Transformations in European Catchments
European Commission Large Integrating Project

Summary of the Talk

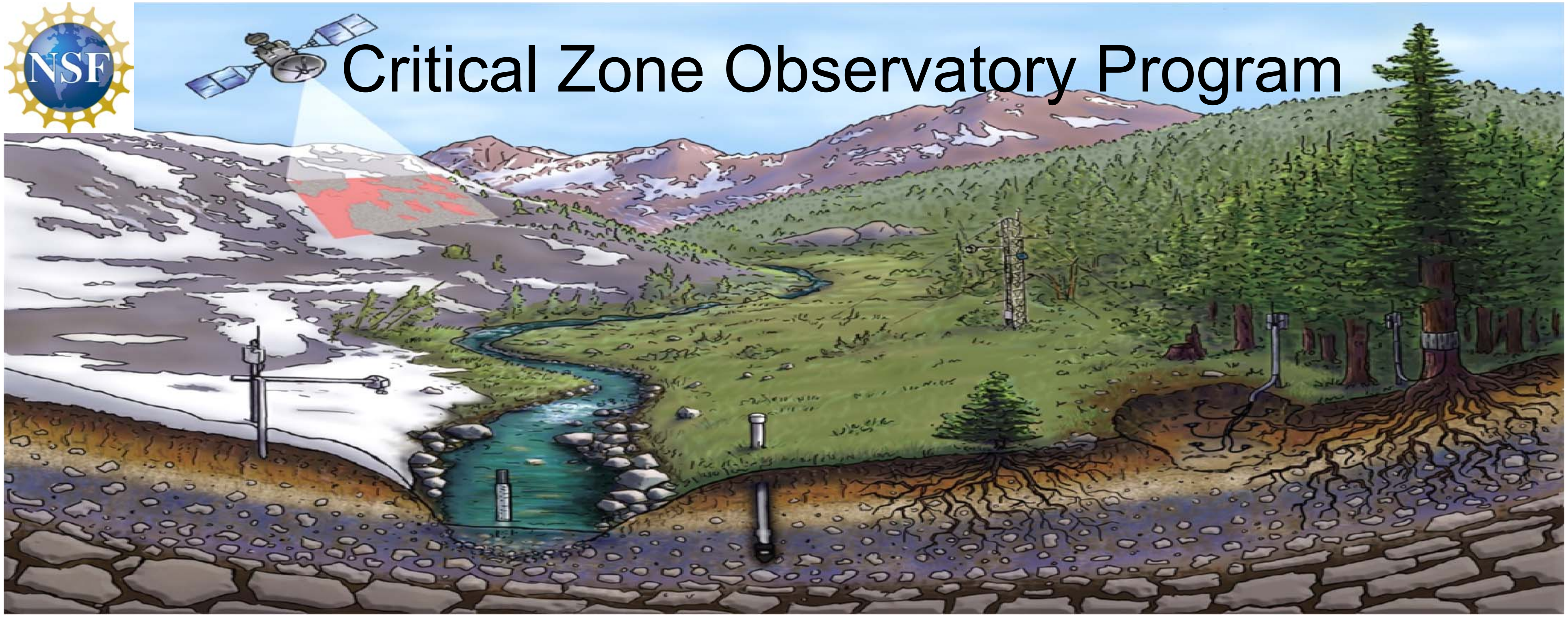
- Critical Zone science and global challenges
- Tackling European soil threats: the SoilTrEC project
- Planetary scale experimental design
- The update from Beijing

Earth’s Critical Zone

"the heterogeneous, near surface environment in which complex interactions involving rock, soil, water, air, and living organisms regulate the natural habitat and determine the availability of life-sustaining resources"
(NRC Report, 2001)



Critical Zone Observatory Program



"Real progress will required problem focused, multidisciplinary field work in natural observatories where detailed, long-term observations can be made using a variety of disciplinary tools." (US National Academy of Science Report, BROES, 2001)

The approach to observation is motivated by:

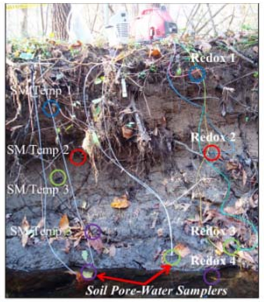
- hypothesis testing,
- process understanding across temporal and spatial scales
- mathematical model development,
- Utilising multiple sensor and sampling methods,
- Often high-density instrument arrays,
- Time series/real time measurements of coupled process dynamics,
- Combining large data sets with numerical simulation

Coupled Process Dynamics Across Spatial and Temporal Scales

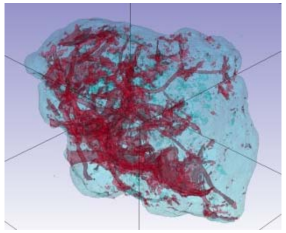
Basin

Watershed

Soil profile

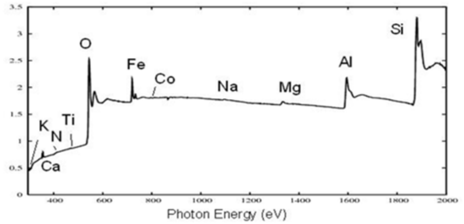


Grain



Molecular

Near-edge X-ray Absorption Fine Structure (NEXAFS)



Millennium Development Goals

Within the Critical Zone, soil ecosystem services are central to meeting United Nations Millennium Development Goals

- To end poverty and hunger
- To ensure environmental sustainability
  - Integrate sustainability into country policy and programmes
  - Significantly reduce the rate of biodiversity loss
  - Increase access to basic drinking water and sanitation

The Perfect Storm

In March 2010 the UK Government Chief Scientist stated that projected pressures from growth in population and wealth would by 2050 create a "perfect storm" of converging challenges:

- Increase in population to over 9.3 billion
- Quadrupling in the global economy
- Doubling in demand for food and for fuel
- More than 50% increase in demand for clean water
- … all while mitigating and adapting to the impacts of global climate change.

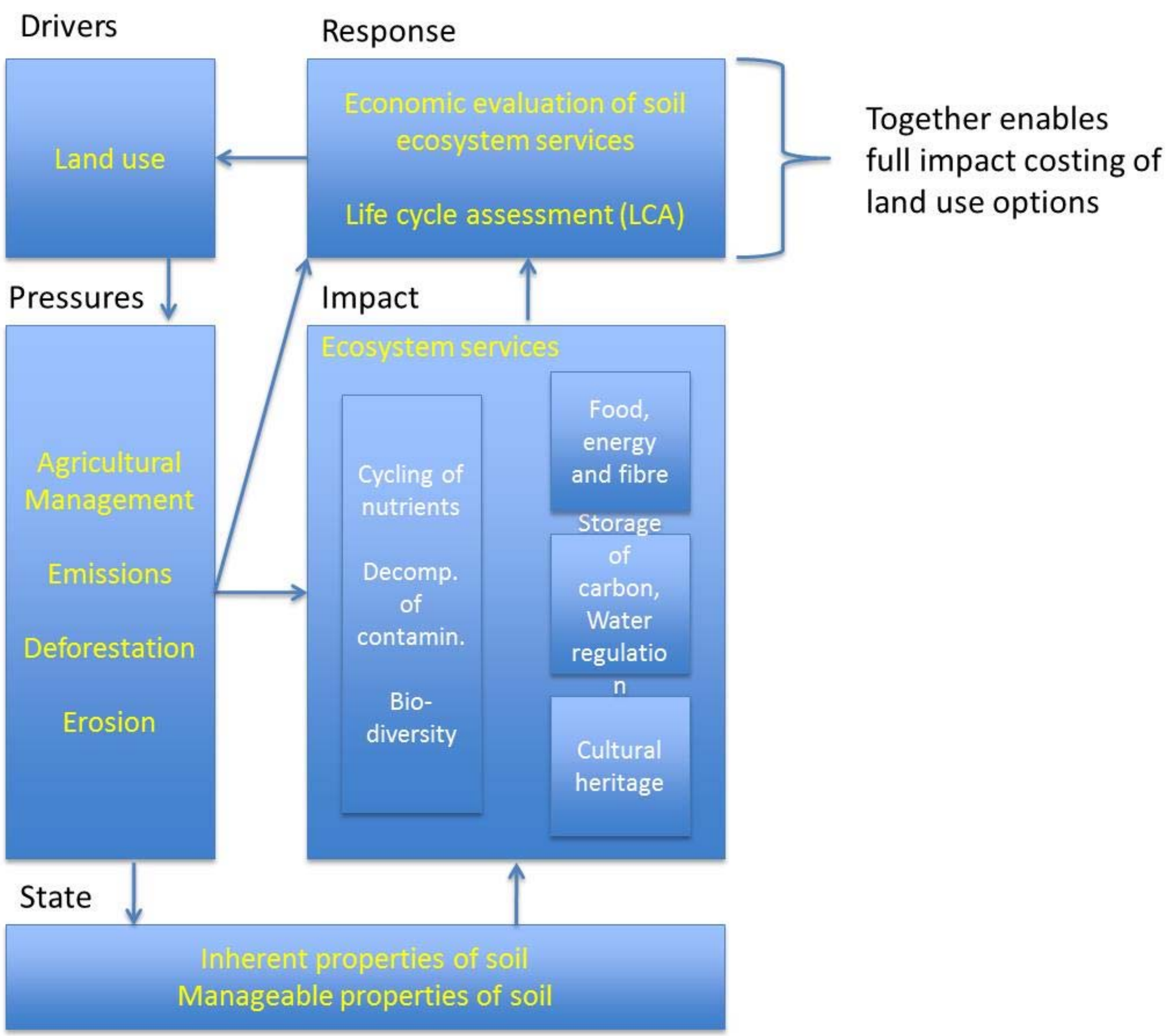
Updated Projections

During the past year several of these projections have been updated.

- Human population is expected to reach 9.7 billion by 2050
- GHG levels for N_2O and CH_4 have just exceeded previous records
- CO_2 levels are increasing faster than in previous years
- Agricultural yields are projected to decrease overall due to insufficient water
- US Climate Assessment concludes impacts are already occurring
- Projected productive land by 2050 outstrips environmental capacity by 10-45%

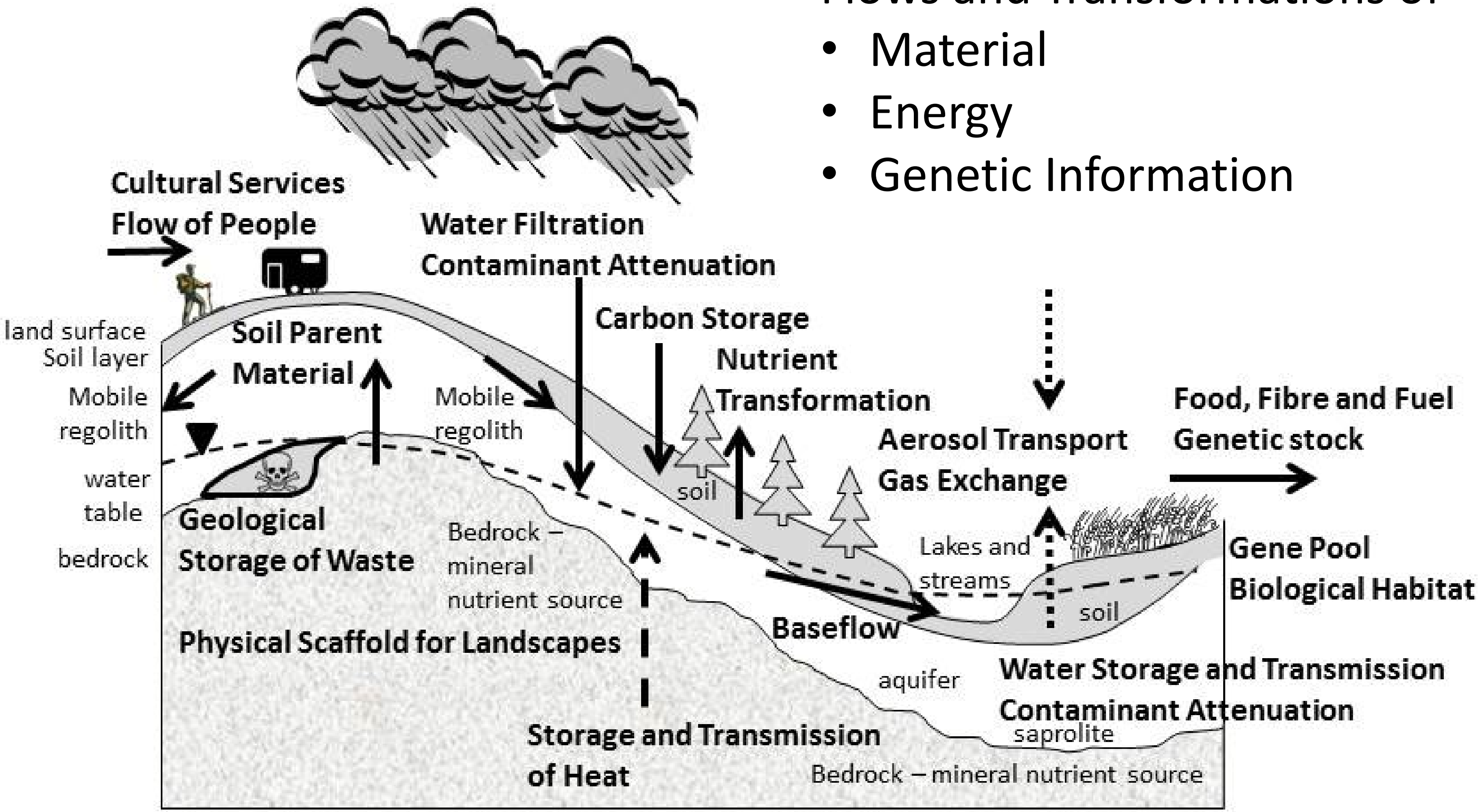
…. The Storm is growing in intensity

The Chain of Impact



Critical Zone Services

Flows and Transformations of
- Material
- Energy
- Genetic Information



Soil Erosion

Satellite image, ERDF Deltanet Project: www.deltanet-project.ec

Desertification: Loss of Carbon

Changing Biodiversity




Loss of Fertility

- Compaction

- Salinisation

- Sealing

- Contamination

Earth's Critical Zone: the architecture Treetop to Bedrock

Soil Ecosystem Services - the heart of Earth's Critical Zone

- Food and fibre production
- Filtering water
- Transforming nutrients
- Carbon storage
- Biological habitat
- Gene pool

EU Thematic Strategy for Soil Protection, EC (2006)

Damma Glacier CZO
Switzerland

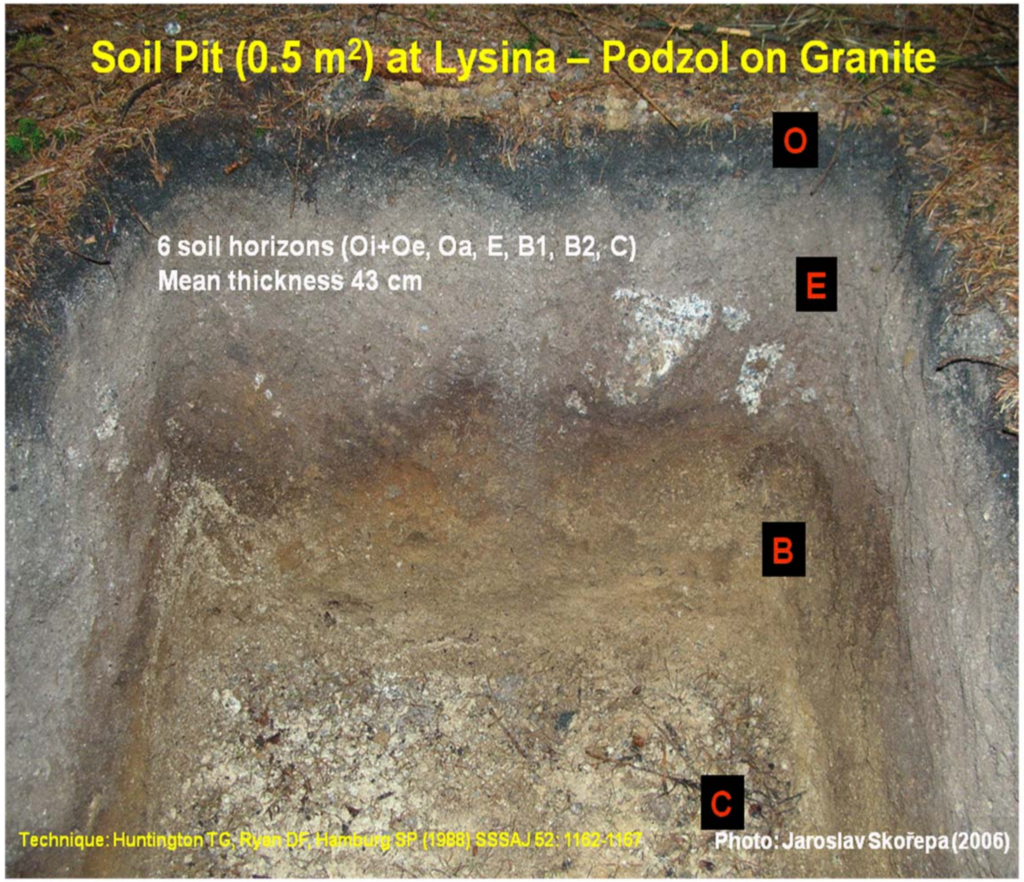
Fuchsenbigl CZO, Austria

PIs: Winfried Blum, Georg Lair, BOKU

Lysina CZO, Czech Republic

Even-Aged Norway Spruce
Plantation at Lysina

PIs: Martin Novak, Pavel Kram
Czech Geological Survey



Koiliaris CZO, Crete

PI: Nik Nikolaidis, TUC

The Golden Aggregate

Empirical evidence of an “agronomically favourable” soil structure

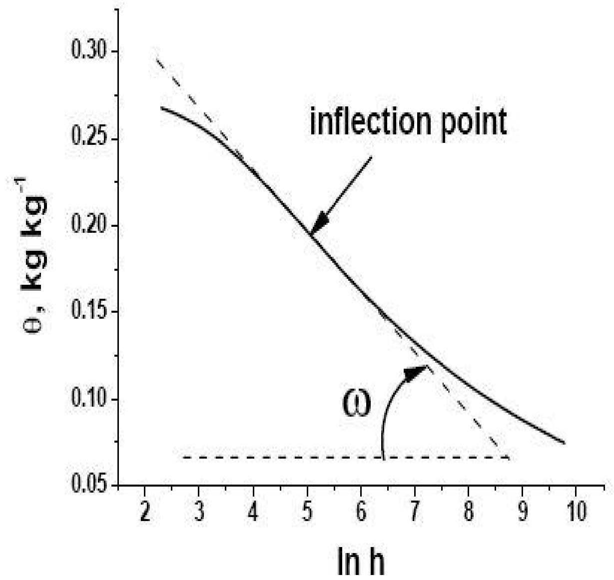
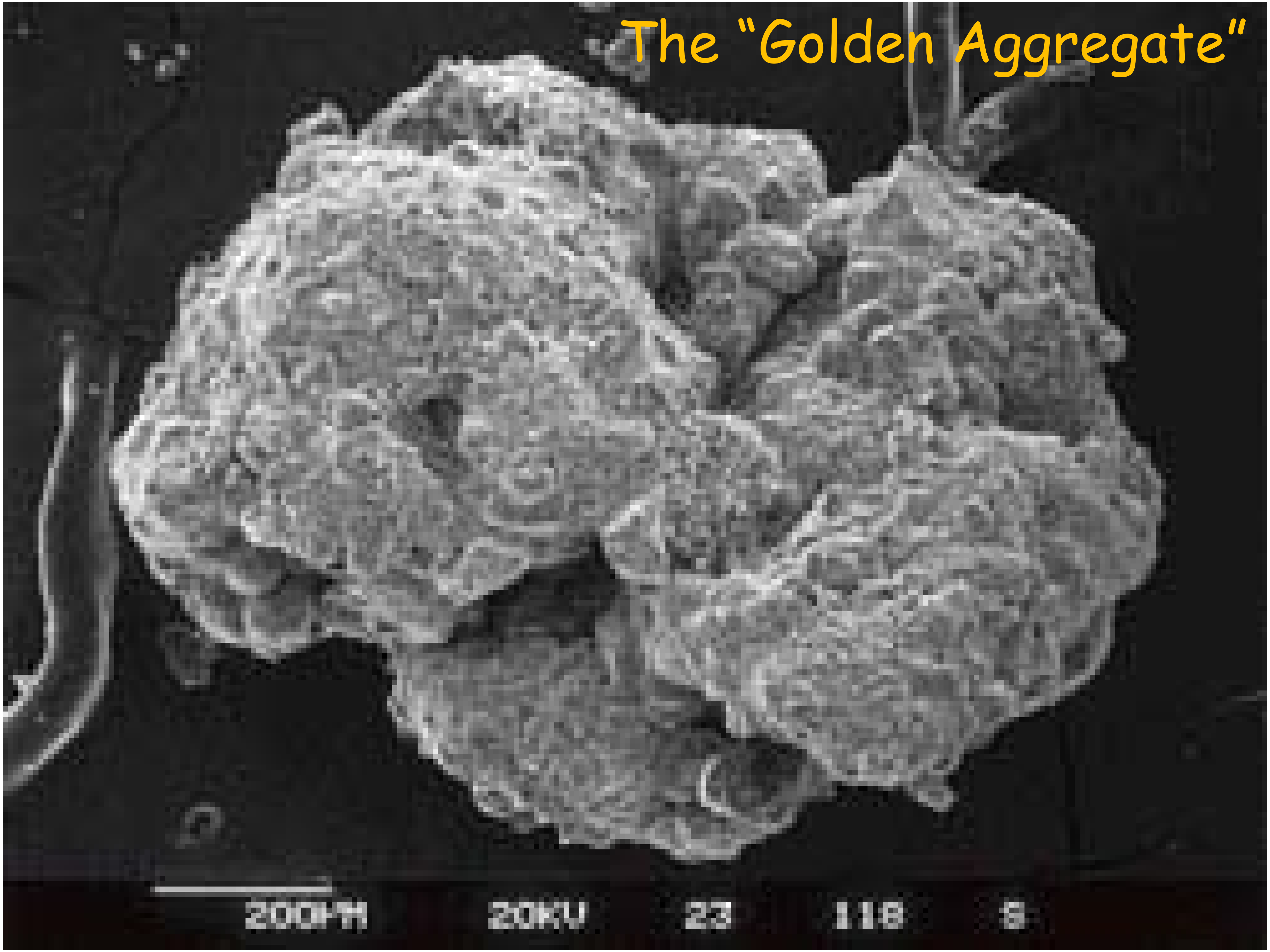
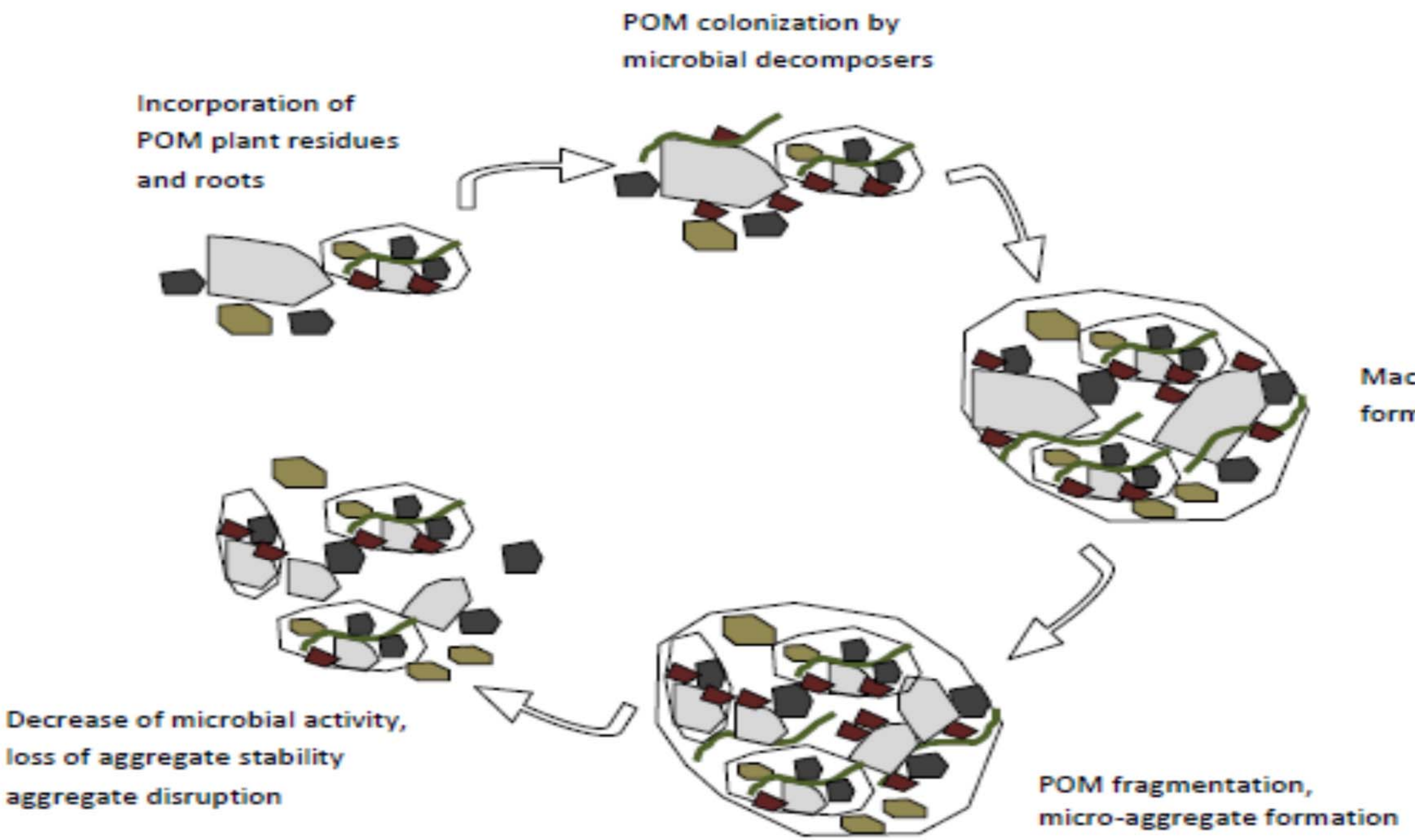


Fig. 3. Soil water retention curve showing water content θ vs. pressure head h (cm). The inflection point is where the slope (S=tanω) changes from positive to negative.

- Described by water retention curve
- 0.25mm < d_p < 10mm
- >60% of particle mass in this range
- Aggregates of
  - Parent rock
  - clay minerals
  - Nanometric oxides
  - organic matter
- Ionic composition of soil water

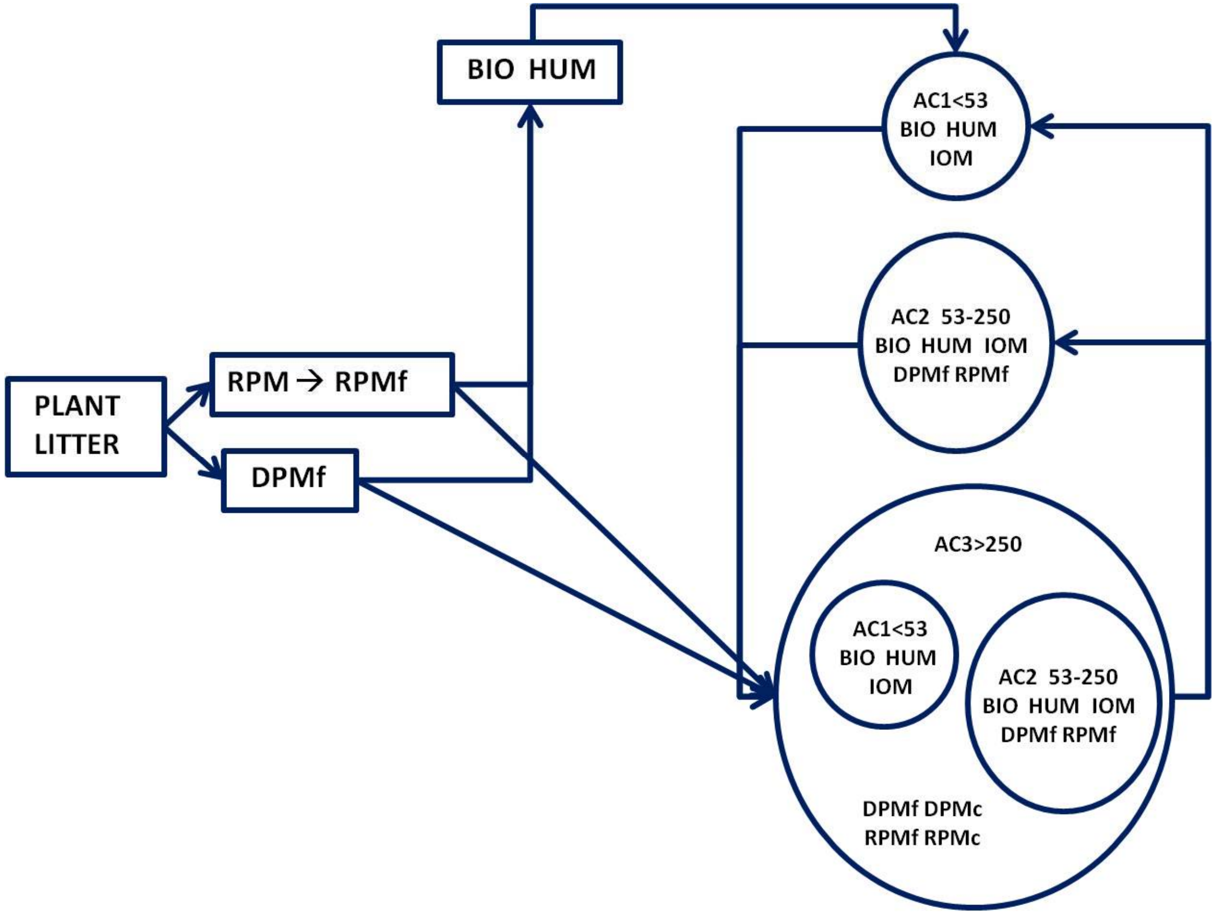

The "Golden Aggregate"
200µm 20KV 23 118 S

CAST Conceptual Model

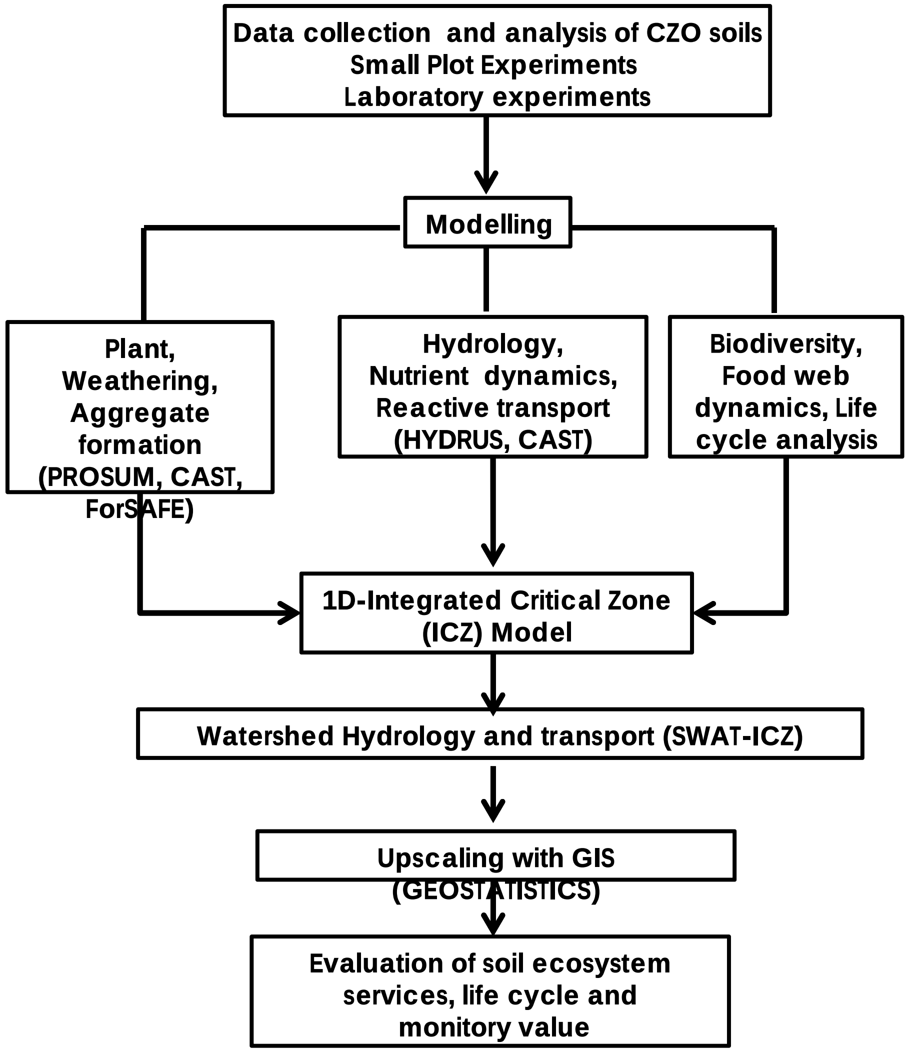


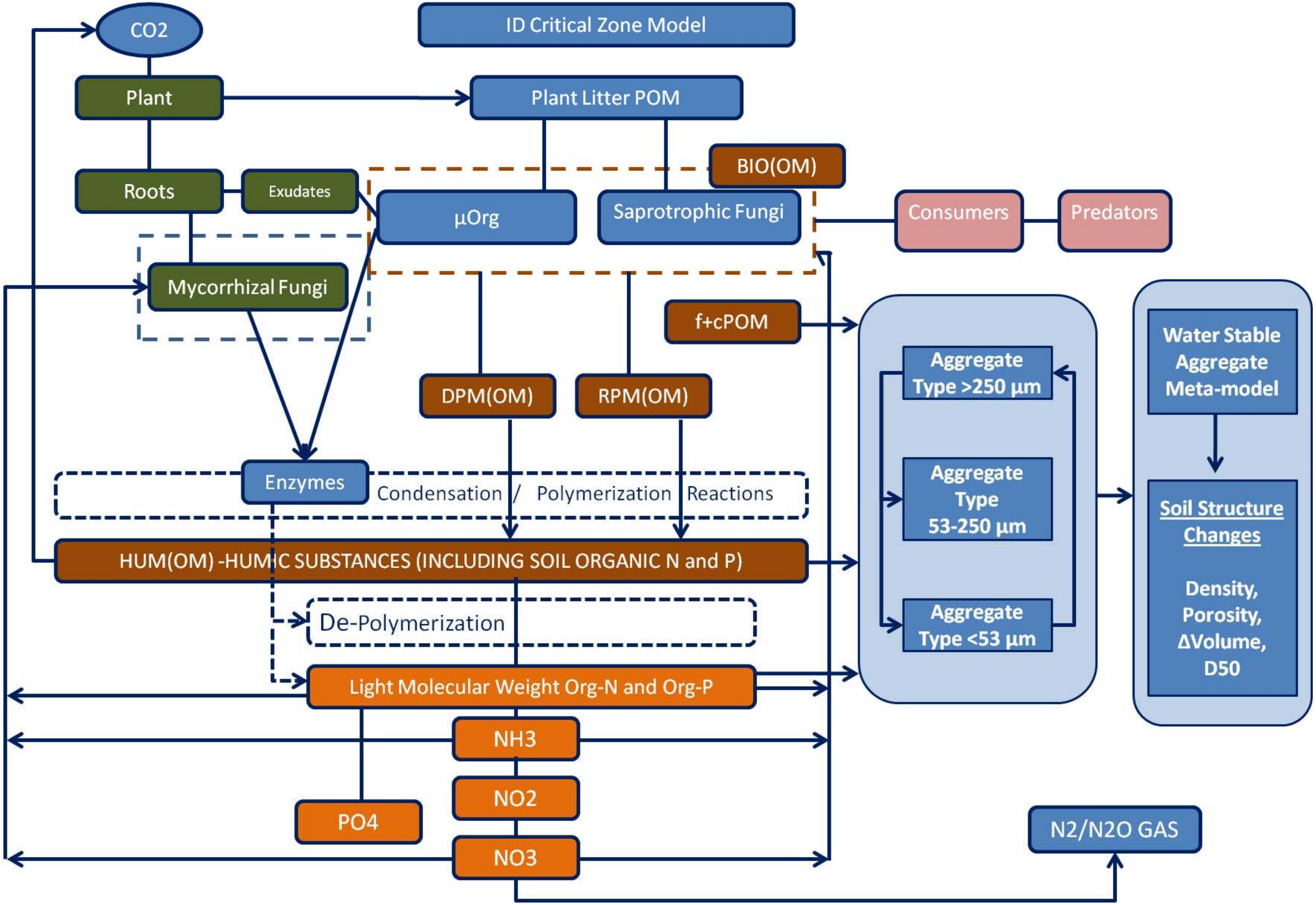
Combined ROTH-C and STRUC-C Models

Nikolaidis et al., Technical U. Crete



Modelling Structure in SoilTrEC





Nikolaidis N. and Bidoglio G. (2012) Sustainable Agriculture Reviews.

Terraces of MILIA Traditional Village

<u>Compost Amendments the last 10 years</u>

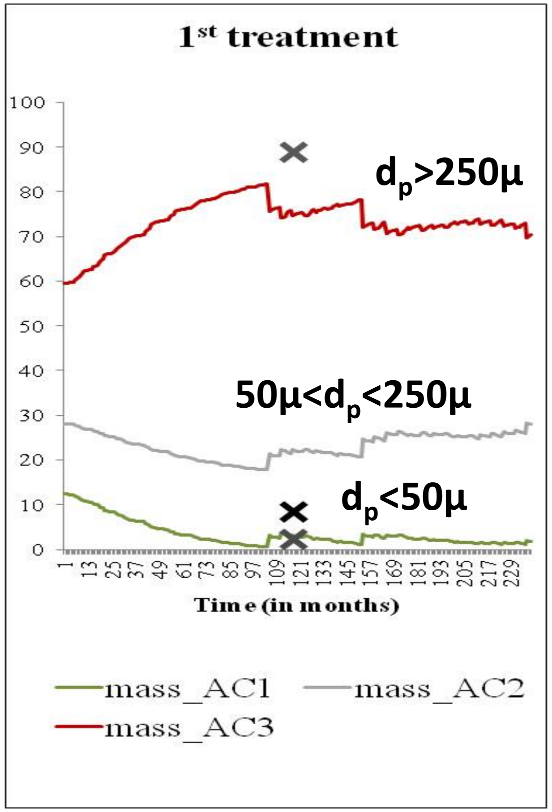
For 10 yrs, every year
1

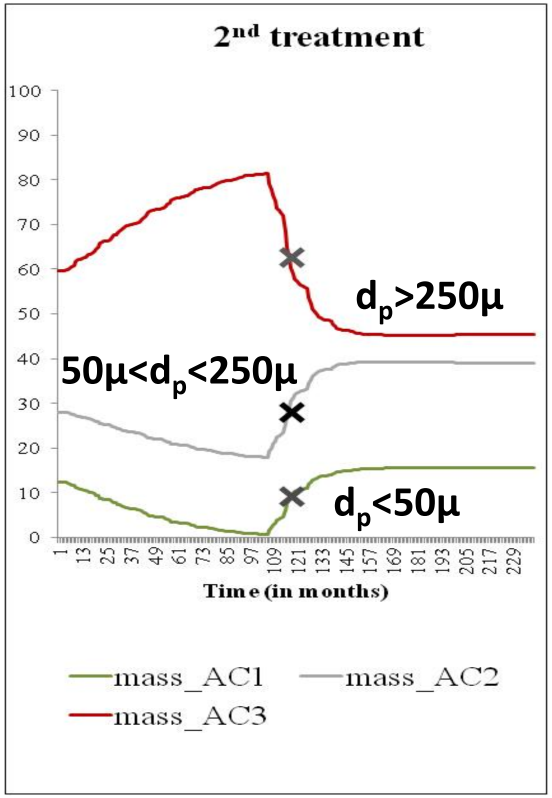
For 8 yrs and 2 yrs fallow
2

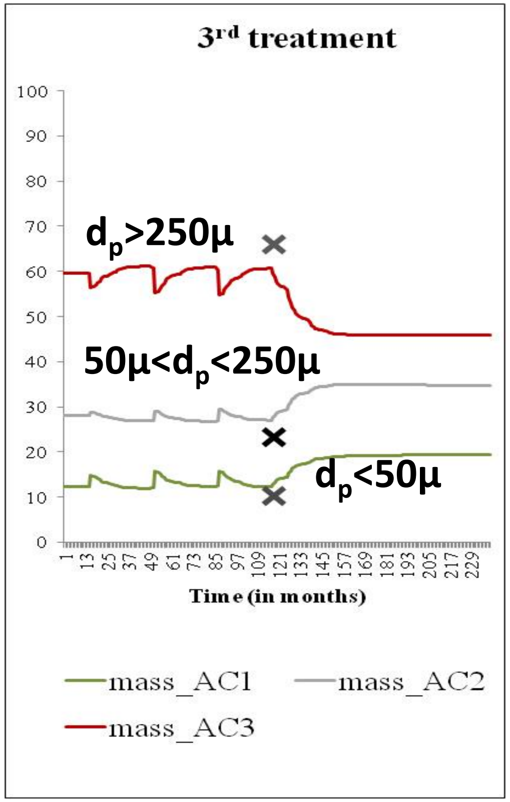
Every 3 years
3

Slides and results: Nikolaidis and co-workers, Technical University of Crete

Soil Water Stable Aggregate (WSA) Distribution, %

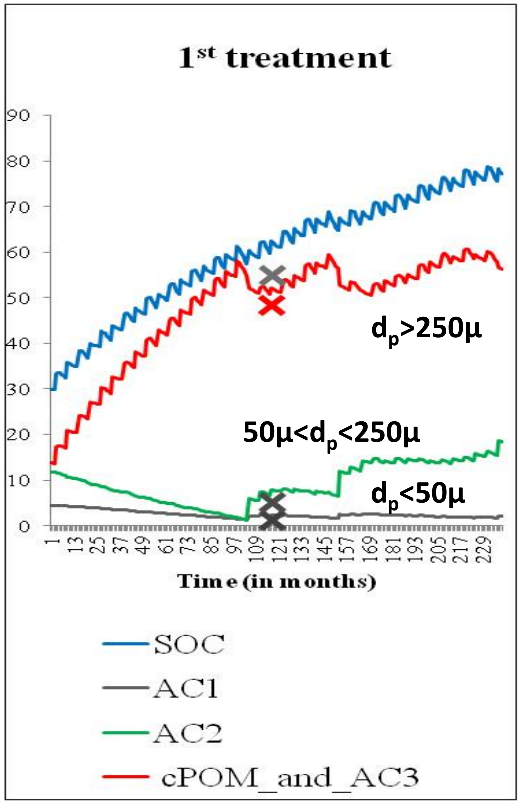


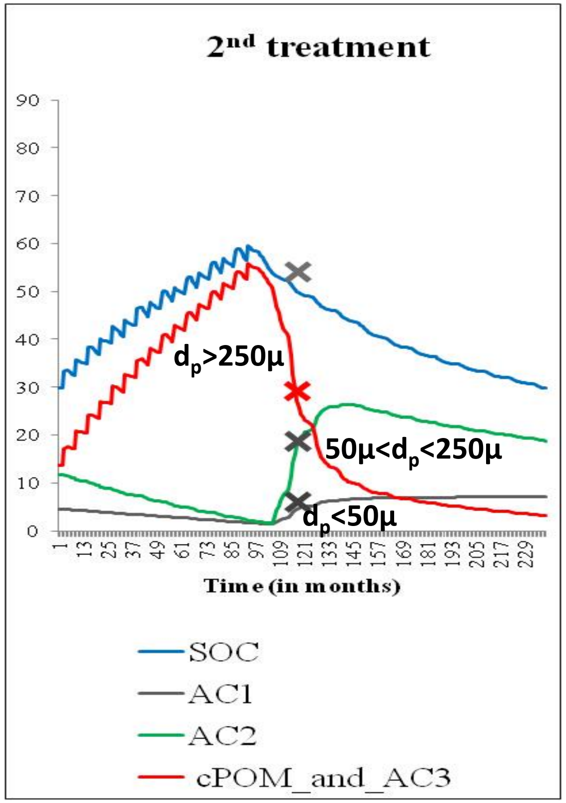


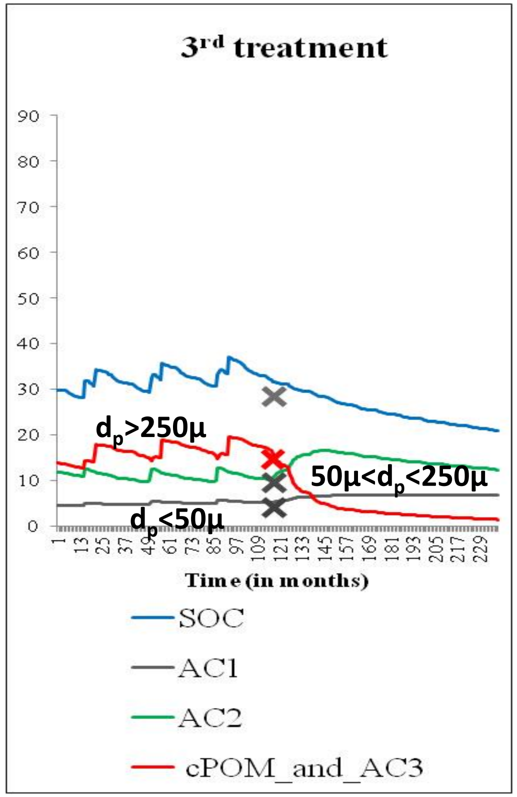


Slides and results: Nikolaidis and co-workers, Technical University of Crete

Soil Organic Carbon Stock Distribution tn C/ha

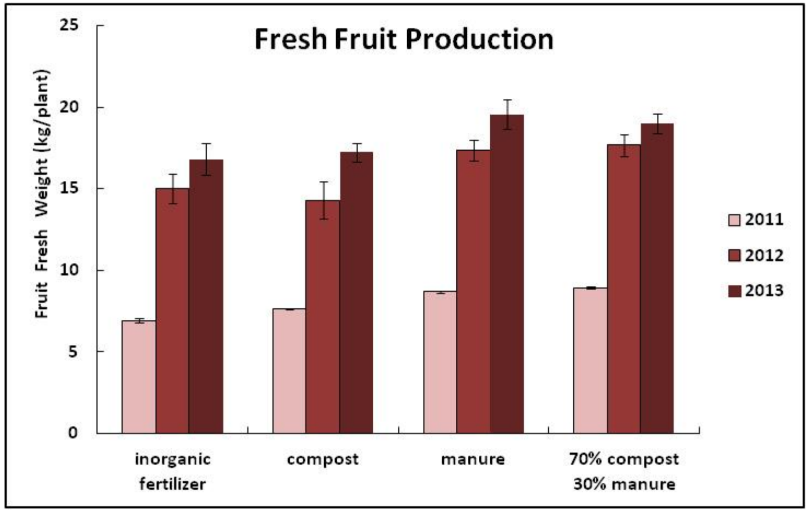






Slides and results: Nikolaidis and co-workers, Technical University of Crete

Agricultural Intensification

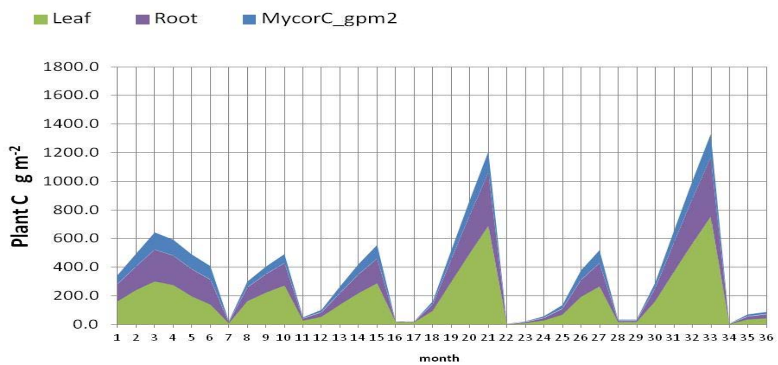


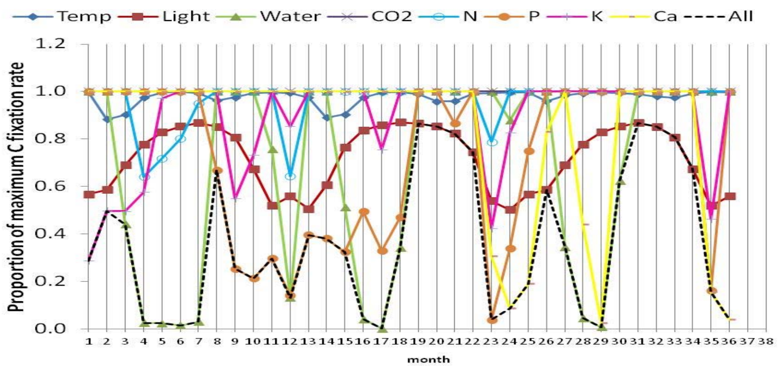
3 years of tomato growth at the same plot
Exceptional yields – 16-18 t/ha

Slides and results: Nikolaidis and co-workers, Technical University of Crete

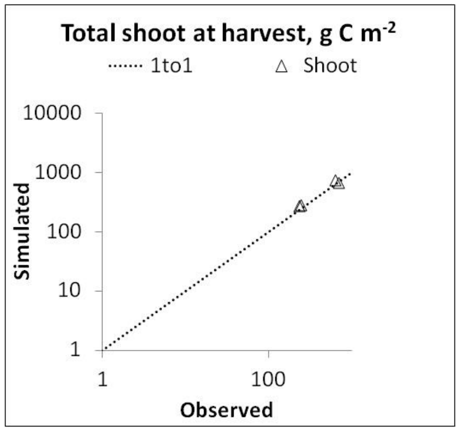
1D-ICZ Model – Plant Module Results

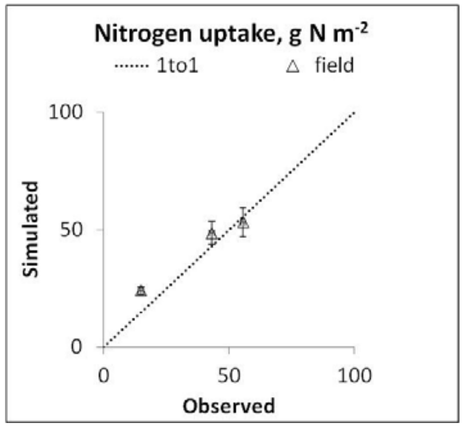
Compost Treatment





Biomass Production

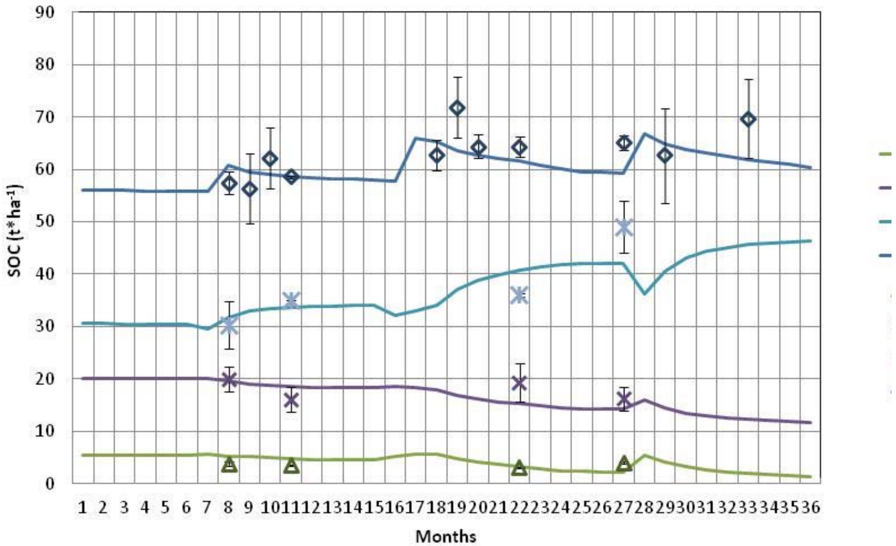


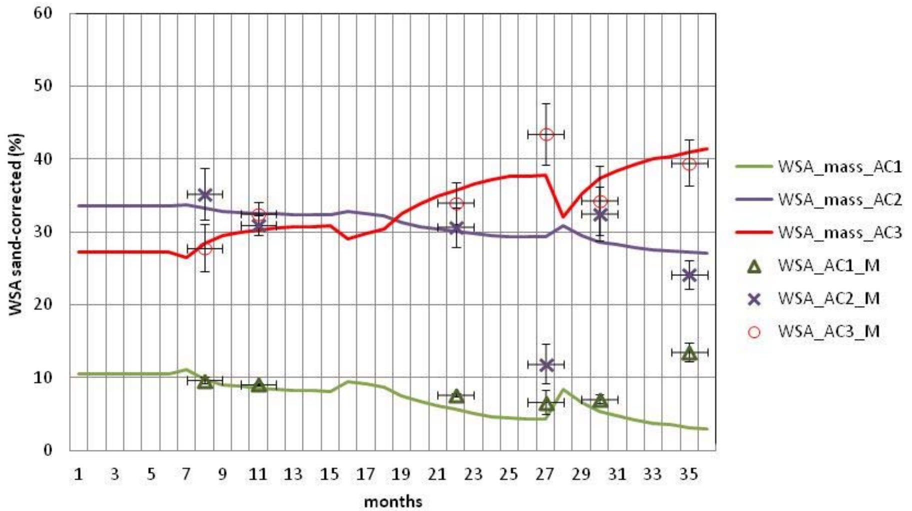


Slides and results: Nikolaidis and co-workers, Technical University of Crete

1D-ICZ Model – C/N/P and Soil Structure Module

Compost Treatment

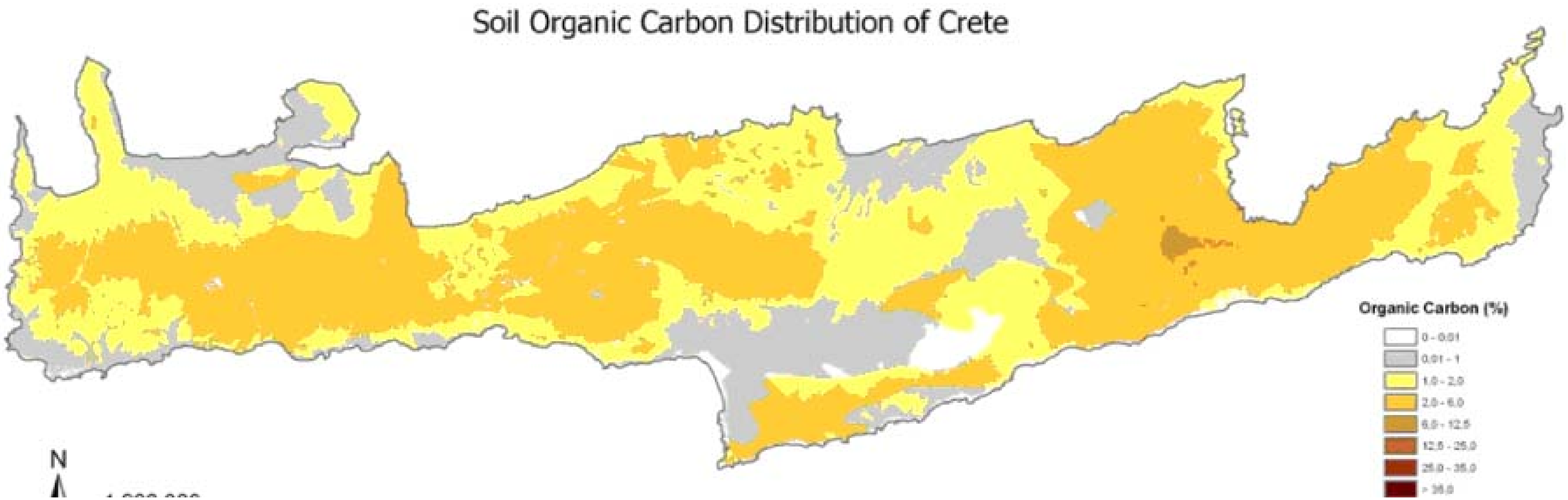




Carbon sequestration **Water Stable Aggregates – soil fertility**

Slides and results: Nikolaidis and co-workers, Technical University of Crete

Scaling up Soil Properties to Regional Scale



Soil Sustainability – by design

- Design of land use and soil restoration through computational simulation
- Model of soil processes embedded within Critical Zone process model
- Parameterisation via web-accessible GIS
- Scenario analysis for mitigation of/adaptation to environmental change
- Valuation of full range of critical zone services

Going Global

SCIENCE VOL 326 20 NOVEMBER 2009

ENVIRONMENT

Monitoring Earth's Critical Zone

Earth's rapidly changing near-surface environment needs systematic observation to better manage future crop production, climates, and water quality.

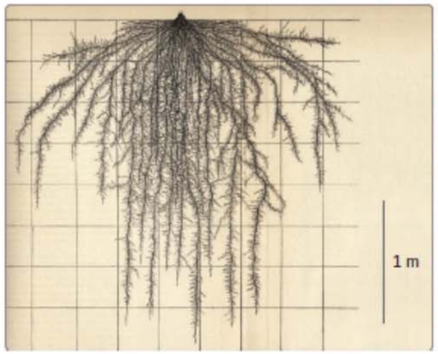
Daniel deB. Richter Jr. and Megan L. Mobley

Geologists tell us that we live in the Anthropocene, the period marked by humanity's global transformation of the environment (*1*). More than half of Earth's terrestrial surface is now plowed, pastured, fertilized, irrigated, drained, fumigated, bulldozed, compacted, eroded, reconstructed, manured, mined, logged, or converted to new uses. These activities have long-lasting effects on life-sustaining processes of the near-surface environment, recently termed Earth's "critical zone" (*2*). The full range of Anthropocene changes in Earth's critical zone is not well quantified, especially belowground (see the figure) (*3*–*6*), where observed changes justify a major expansion in monitoring to are the objects of studies aimed to enhance crop management, manage rising greenhouse gas emissions, and improve water quality.

To meet humanity's growing needs for food, fiber, and bioenergy, plant and soil productivity will be vastly expanded in the next few decades, with substantial effects on the belowground critical zone. Monitoring of critical zones is ongoing worldwide, but with uneven organization and scientific quality (*3*, *4*, *6*, *7*). Outstanding exceptions are found in developing nations of southern and southeast Asia (*8*), where dozens of long-term rice and wheat experiments test the sustainability of the intensively managed critical zones on which food supplies for several billion people depend. The results dem- substantial fractions of greenhouse emissions from agriculture and forestry can be mitigated by land-management strategies (*9*, *10*). This landmark study, along with monitoring networks such as U.S. Department of Agriculture's GRACEnet (*11*), will likely be instrumental in controlling agricultural greenhouse-gas emissions.

Finally, improved water quality also depends on increased understanding of the physics, chemistry, and biology of the critical zone. Especially promising is the National Science Foundation's new Critical Zone Observatory (CZO) program, which studies natural and human-affected processes that control water chemistry, from upper soil layers of

TON, DC. (RIGHT) TERRY PRICE/GEORGIA FORESTRY COMMISSION/BUGWOOD.ORG



Weathering the Storm

Nature, 474, 151-152, 9 June, 2011

COMMENT

G. MCDOWELL/NATUREPL.COM

When water is scarce, dust storms strip away the scant soil in Mali.

Save our soils

Researchers must collaborate to manage one of the planet's most precious and threatened resources — for food production and much more, says **Steve Banwart**.

International CZO Networks

c$100M in new funding committed for CZO research worldwide since 2008

- NSF CZO programme
- EC SoilTrEC project
- French Network of River Basins
- German AquaDiva Project
- German Helmholtz Centres TERENO network of CZOs
- 2014 workshop in Perth, Australia on CZOs for the Southern Hemisphere
- Interest from China in a programme of Critical Zone research

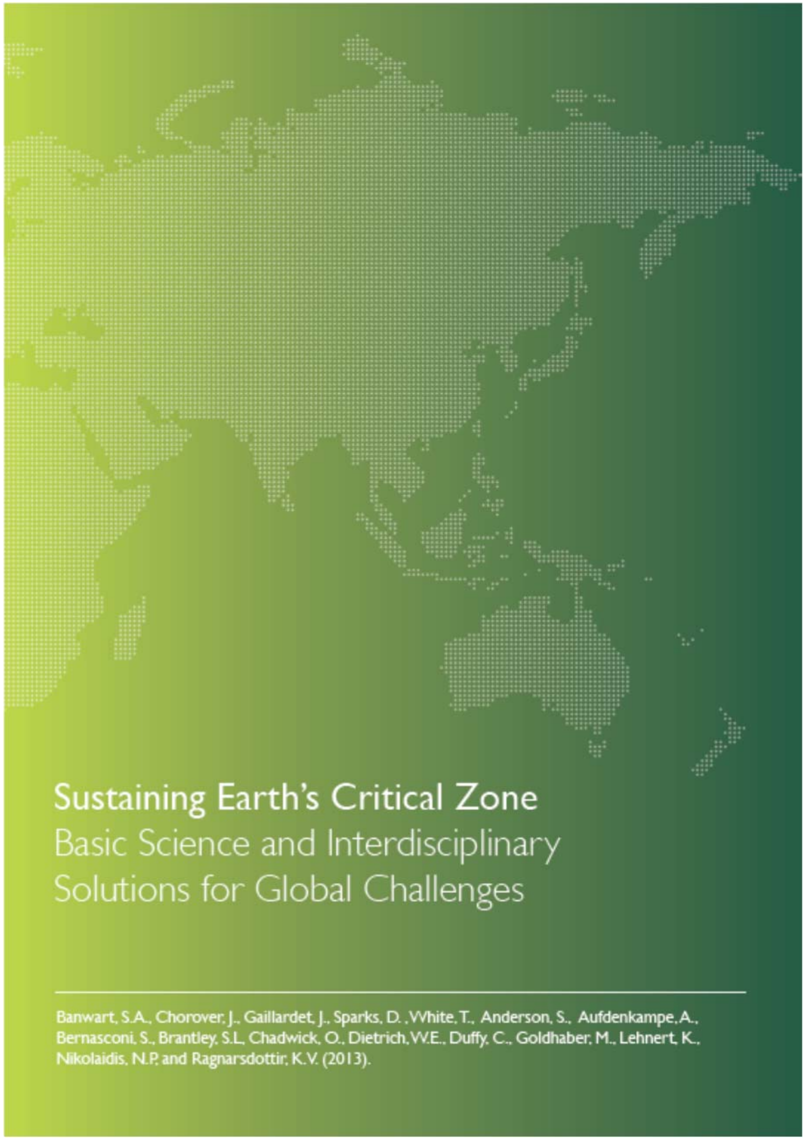
International Steering Committee

Steve Banwart, Jerome Gaillardet, Marty Goldhaber, Sue Trumbore, Don Sparks

Project and network collaboration on:

- Shared sites and data
- Numerical simulation approaches
- PhD and post-doc training

A 3-year Plan to establish an international CZO research programme



Available as download from

www.czen.org

CZOs to Focus International Science

H1 Climate gradient experiments today can shed light on Critical Zone response to future climate change.

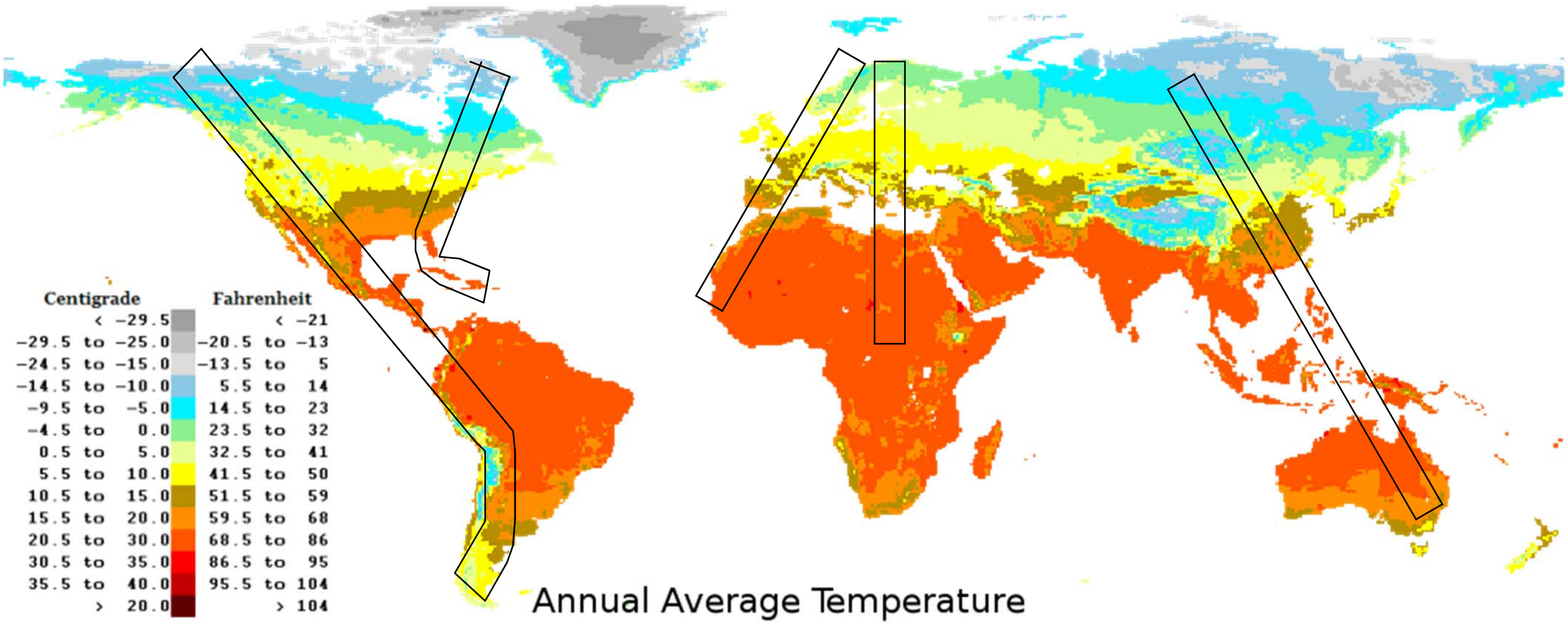
Study CZO processes on a gradient from the Artic to The Sahel (North-South Design)

H2 CZO processes will be increasingly vulnerable to greater intensity and frequency of extreme events; heat waves, deep freezes, droughts and floods.

Real-time monitoring of ecosystem services with forecasting simulations within selected CZOs

Global Experimental Design

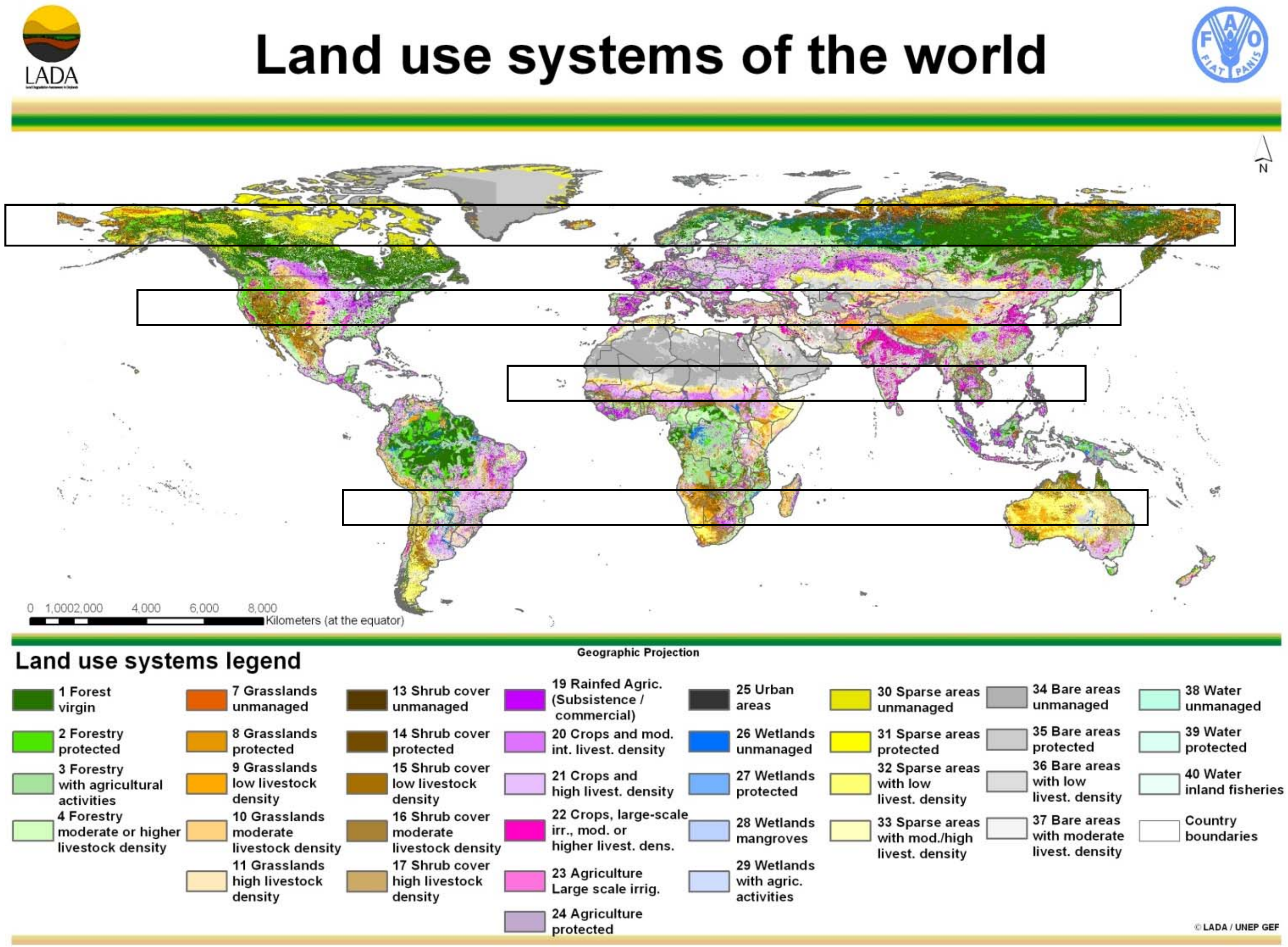
CZO Networks along gradients of climate



Map from World Climate. http://www.climate-charts.com/index.html

Global Experimental Design

CZO Networks along gradients of land use

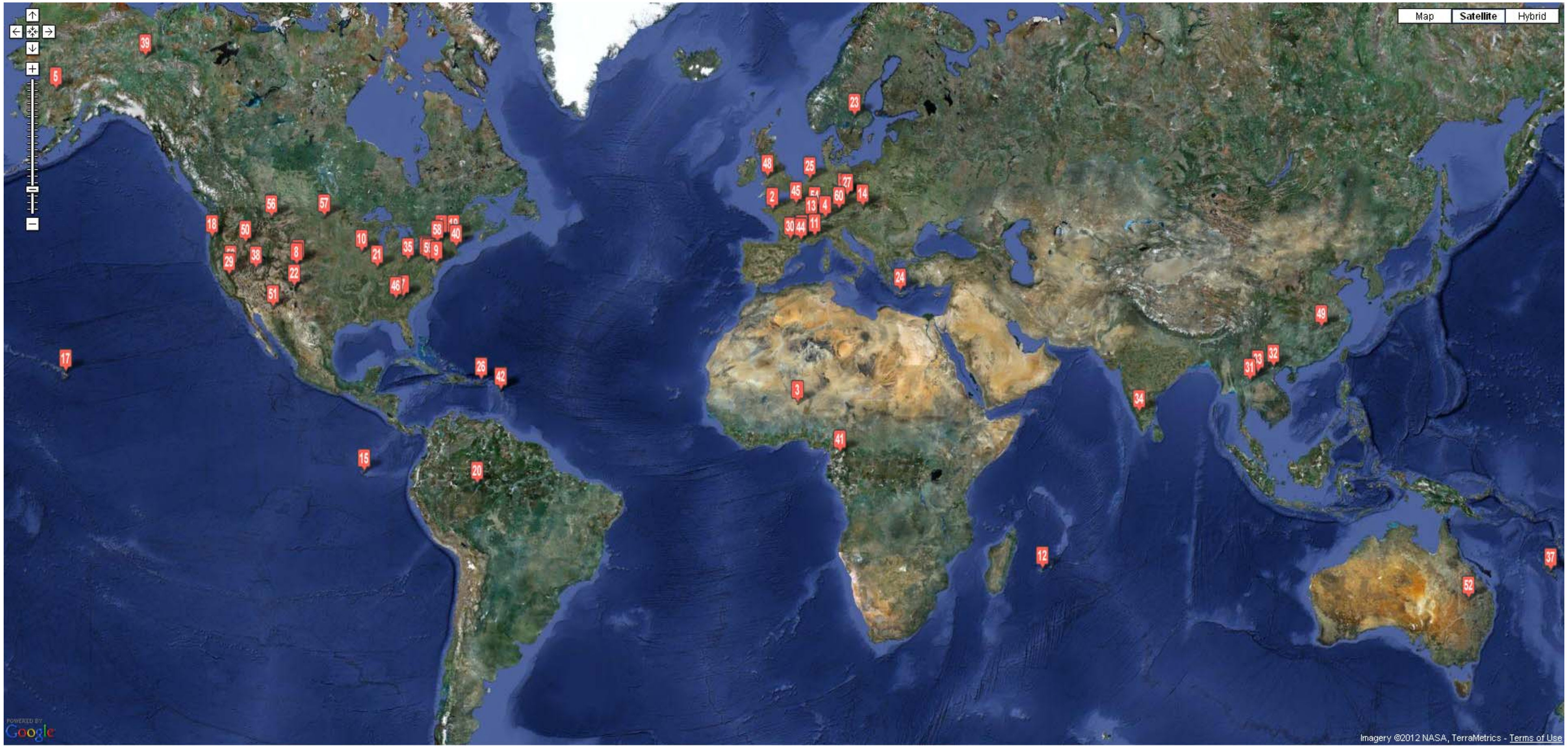


Map from: UN Food and Agriculture Organisation, Land Degradation Assessment in Drylands

SoilTrEC

The Global Laboratory

November 2011 U. Delaware Workshop



SOILTREC

National research platform for GES in China

CERN-A large platform for Critical Zone research

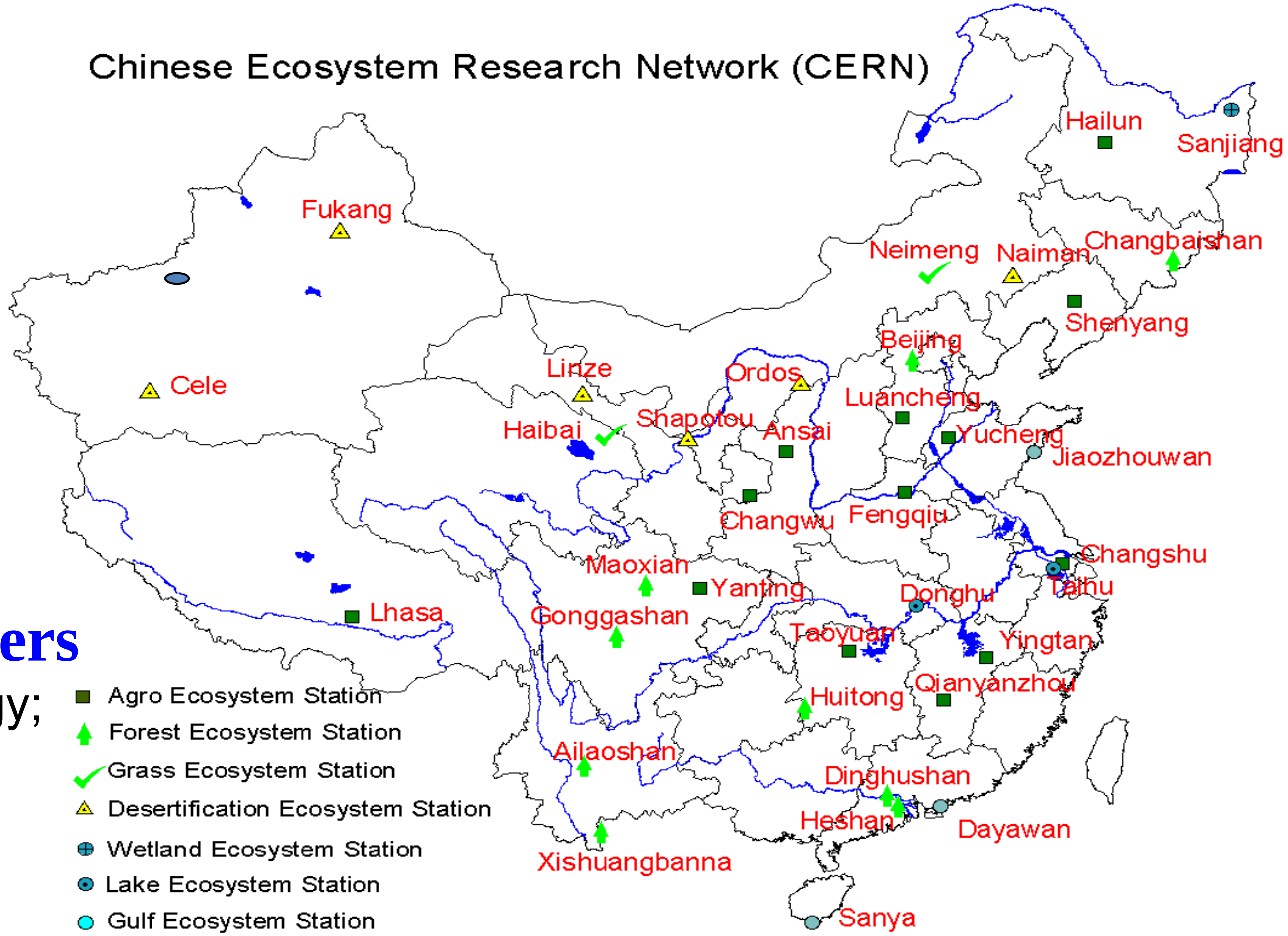
- **42 Stations**

Agro	15
Forest	10
Grassland	4
Desert	4
Lake	2
Gulf	3
Wetland	3
Urban	1

- **5 disciplinary centers**

  Water, soil, air, biology; aquatic-ecology

- **1 synthesis center**



2014年“国际关键带科学前沿”工作会议

Frontiers in International Critical Zone Science 2014

May 21-24, 2014，Beijing，China

Workshop Objectives

The global societal challenges
The major knowledge advances, current achievements, and frontiers of science
Specific science advances and contributions to solving global challenges
The international research challenges
The governance and partnerships to enable integration
A schedule of steps to develop an international programme of CZO research

Five Research Challenges

Defining Mechanistic linkages in flows and transformations of energy, material and genetic information in catchments and aquifers

Model Hindcasting of CZ Evolution, Interpreting the Present, Forecasting Future Change and Global Impacts

The Response, Resilience, and Recovery of the CZ to Perturbations of Environmental Change

Observation and Sensing Technology, e-Infrastructure, and Modelling to quantify the 3-D architecture of the Critical Zone

Common Observations, Governance and Data Coordination of International CZO Networks

Actions to Complete by end of 2014

- International Strategy Group established by funders
- Initial working group meeting on data standards and sharing
- Framework for a jointly-funded international CZO programme
- Road map for first joint calls in 2015
- Strategic platform for a long-term intergovernmental programme

ICSU
International Council for Science

CZOs

- Improve the usefulness of forecasts of future environmental conditions and their consequences for people
- Develop, enhance, and integrate observation systems to manage global and regional environmental change
- Determine how to anticipate, avoid and manage disruptive global change
- Encourage innovation (and mechanisms for evaluation) in technological, policy, and social responses to achieve global sustainability
- Determine institutional, economic, and behavioural changes to enable effective steps toward global sustainability

END