Developing Digital Soil Maps of Africa

An update on recent activities

Presented to the International Forum at the

National Cooperative Soil Survey Conference (NCSS)

Annapolis, MD

June 20, 2013

- 4 year, $18M grant from the Gates Foundation; Phase 1 Project period from Nov 2008-Mar 2013
- Develop continent-wide baseline digital soil maps, and accompanying soil information systems, for Africa South of the Sahara
- Main grantee: CIAT Nairobi (formerly TSBF) with subgrants to:
  - Earth Institute: Center for Agriculture and Food Security (formerly TropAg) and Center for International Earth Science Information Network
  - World Agroforestry Centre (ICRAF), Nairobi
  - International Soil Reference and Information Center (ISRIC), Netherlands
- Partnership with Ethiopia Ministry of Agriculture

Vision -- Emerging information system for soil and ecosystem monitoring and mapping, based on **open source platforms and applications**, including:

- the use of sensor and **mobile technologies** for **field data collection** and information dissemination
- the maintenance **of continuously updated spatial databases** according to international standards for exchanging soil information
- the design and implementation of **networked scientific computing platforms** to support data analysis and product development
- the use of **R+geospatial workflows** to document and replicate the processes used to construct output maps, predictions and recommendations
- 3-D **data visualization, analysis, decision support and mapping services** providing **dynamically produced** and **updatable information**.

Connection between AfSIS and the GlobalSoilMap.net

•1 of the project's 5 objectives included funds to help develop the Global Soil Consortium

•Consortium was to coordinate the development of a Global [Digital] Soil Map (this AfSIS objective was led by Alfred Hartemink, formerly of ISRIC)

•2009 paper was an output of the Global Soil Consortium, AfSIS activities also organized around these main steps

Digital Soil Mapping: 5 steps

(as outlined in Sanchez et al 2009 Science Policy Forum paper)

- Step 1: Data Input
  - Ground observations
  - Base maps: Spatially contiguous covariates assembled and calibrated from available data
- Step 2: Estimation of soil properties
  - Minimum Global Soil Map data set: clay content, organic
  - carbon, pH, CEC, EC and bulk density
- Step 3: Pedotransfer functions
  - Prediction of soil functions, such as available soil water storage, carbon density, and phosphorus fixation

POLICYFORUM

ENVIRONMENTAL SCIENCE

Digital Soil Map of the World

Maps can provide soil inputs (e.g., texture, organic carbon, and soil-depth parameters) to models predicting land-cover changes in response to global climatic and human disturbances.

Digital Soil Mapping

Steps 4 and 5: Soil Management Recommendations

- Step 4: Field trial legacy data and 'social covariates'
  - Crop yields, agroecological zones, road density, input supply networks
- Step 5: Develop evidence based soil management recommendations

POLICYFORUM

ENVIRONMENTAL SCIENCE

Digital Soil Map of the World

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Increased demand and advanced techniques could lead to more refined mapping and management of soils.

Soils are increasingly recognized as major contributors to ecosystem services such as food production and climate regulation (1, 2), and demand for up-to-date and relevant soil information is soaring. But communicating such information among diverse audiences remains challenging because of inconsistent use of technical jargon, and outdated, imprecise methods. Also, spatial resolutions of soil maps for most parts of the world are too low to help with practical land management. While other earth sciences (e.g., climatology, geology) have become more quantitative and have taken advantage of the digital revolution, conventional soil mapping delineates space mostly according to qualitative criteria and renders maps using a series of polygons, which limits resolution. These maps do not adequately express the complexity of soils across a landscape in an easily understandable way.

The Food and Agriculture Organization (FAO) of the United Nations (UN) and the UN Educational, Scientific and Cultural Organization (UNESCO) published the first world soil map in 1981, using a single soil classification terminology (3). The map has been utilized in many global studies on climate change, food production, and land degradation. But its low resolution (1:5 million scale) is not suitable for land-management decisions at field or catchment scales. One of the most-cited soil degradation studies, the *Global Assessment of Human-Induced Soil Degradation*, is based on expert judgment by a few individuals, has very low resolution (1:30 million scale), and lacks quantitative information on soil properties that indicate the degree of soil degradation (4). At present, 109 countries have conventional soil maps at a scale of 1:1 million or finer, but they cover only 31% of the Earth's ice-free land surface, leaving the remaining countries reliant on the FAO-UNESCO map (5). [See supporting online material (SOM) for more history.]

To address these many shortcomings, soil scientists should produce a fine-resolution, three-dimensional grid of the functional properties of soils relevant to users. We call for development of a freely accessible, Web-based digital soil map of the world that will make georeferenced soil information readily available for land-users, scientists, and policy-makers. A foundation for such an effort is being laid by the GlobalSoilMap.net (GSM) project. This effort originated in 2006 (6) in response to policy-makers' frustrations at being unable to get quantitative answers to questions such as: How much carbon is sequestered or emitted by soils in a particular region? What is its impact on biomass production and human health? How do such estimates change over time?

The GSM consortium's overall approach consists of three main components: digital soil mapping, soil management recommendations, and serving the end users—all of them backed by a robust cyberinfrastructure. [See Fig. S1, expanded from (7).] Specific countries may add their own modifications.

Maps can provide soil inputs (e.g., texture, organic carbon, and soil-depth parameters) to models predicting land-cover changes in response to global climatic and human disturbances.

Digital Soil Mapping

Digital soil mapping began in the 1970s (8) and accelerated significantly in the 1980s because of advances in informatics and remote-sensing technologies, computing, statistics and modeling, spatial information and global positioning systems, measurement systems (such as infrared spectroscopy), and in more recent times, online access to information. Experimentation with these technologies is leading toward consensus (7, 9–12), and operational systems are being implemented.

A digital soil map is essentially a spatial database of soil properties, based on a statistical sample of landscapes. Field sampling is used to determine spatial distribution of soil properties, which are mostly measured in the laboratory. These data are then used to predict soil properties in areas not sampled. Digital soil maps describe the uncertainties associated with such predictions and, when based on time-series data, provide information on dynamic soil properties. They also differ from conventional, polygon-based maps, in that they are pixel-based and can be more easily displayed at higher resolutions currently used by other earth and social sciences.

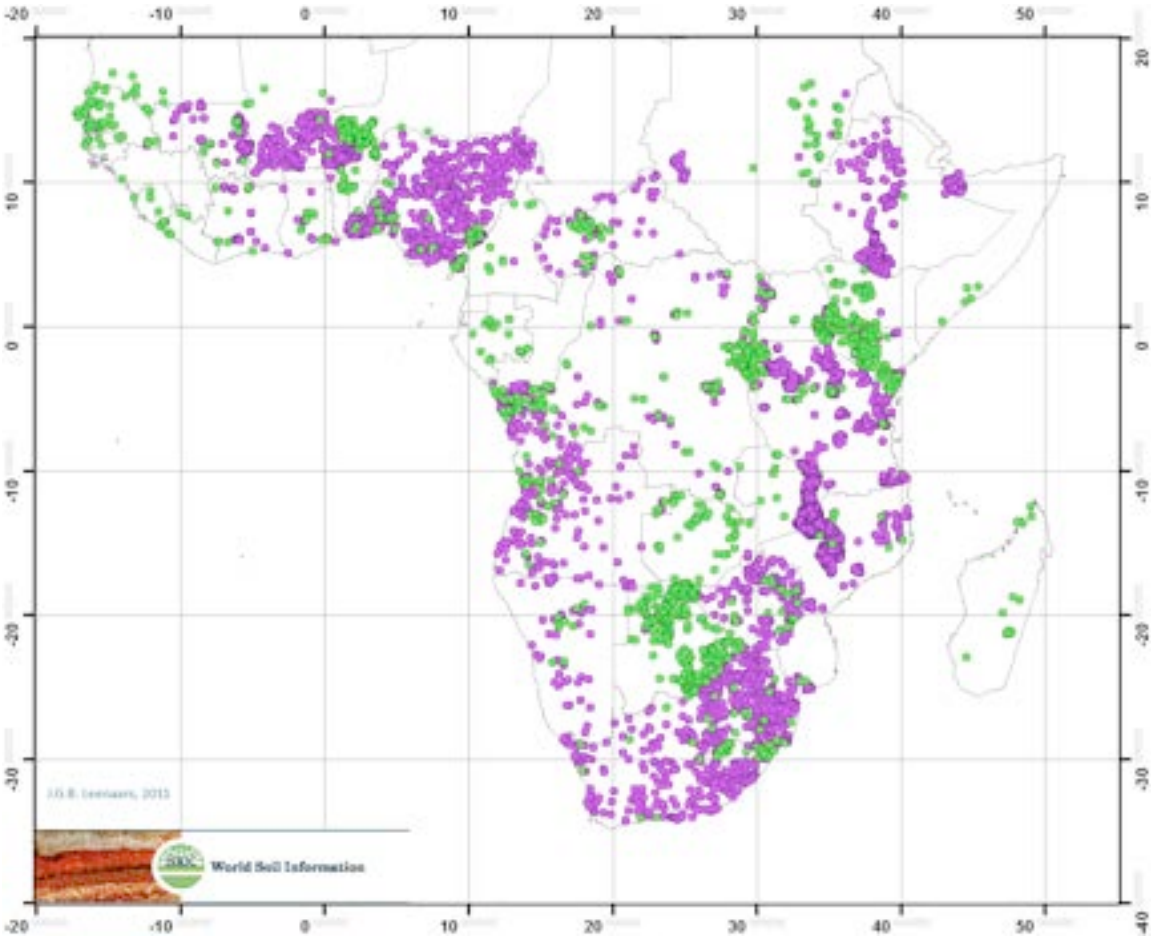
There are three main steps in digital soil mapping. Step 1, data input, starts with the production of base maps, assembling and collating spatially contiguous covariates from available data (e.g., the 90 × 90-m-resolution digital terrain models from Shuttle Radar Topography Mission (SRTM v.3)). Covariates, reflecting state factors of soil forma-

Downloaded from www.sciencemag.org on June 17, 2013

Step 1a. Data Input (Ground Obervations) Legacy Data

12000+ georeferenced soil profiles for 37 countries collected from over 300 data sources

Used as inputs for baseline continent-wide soil property maps

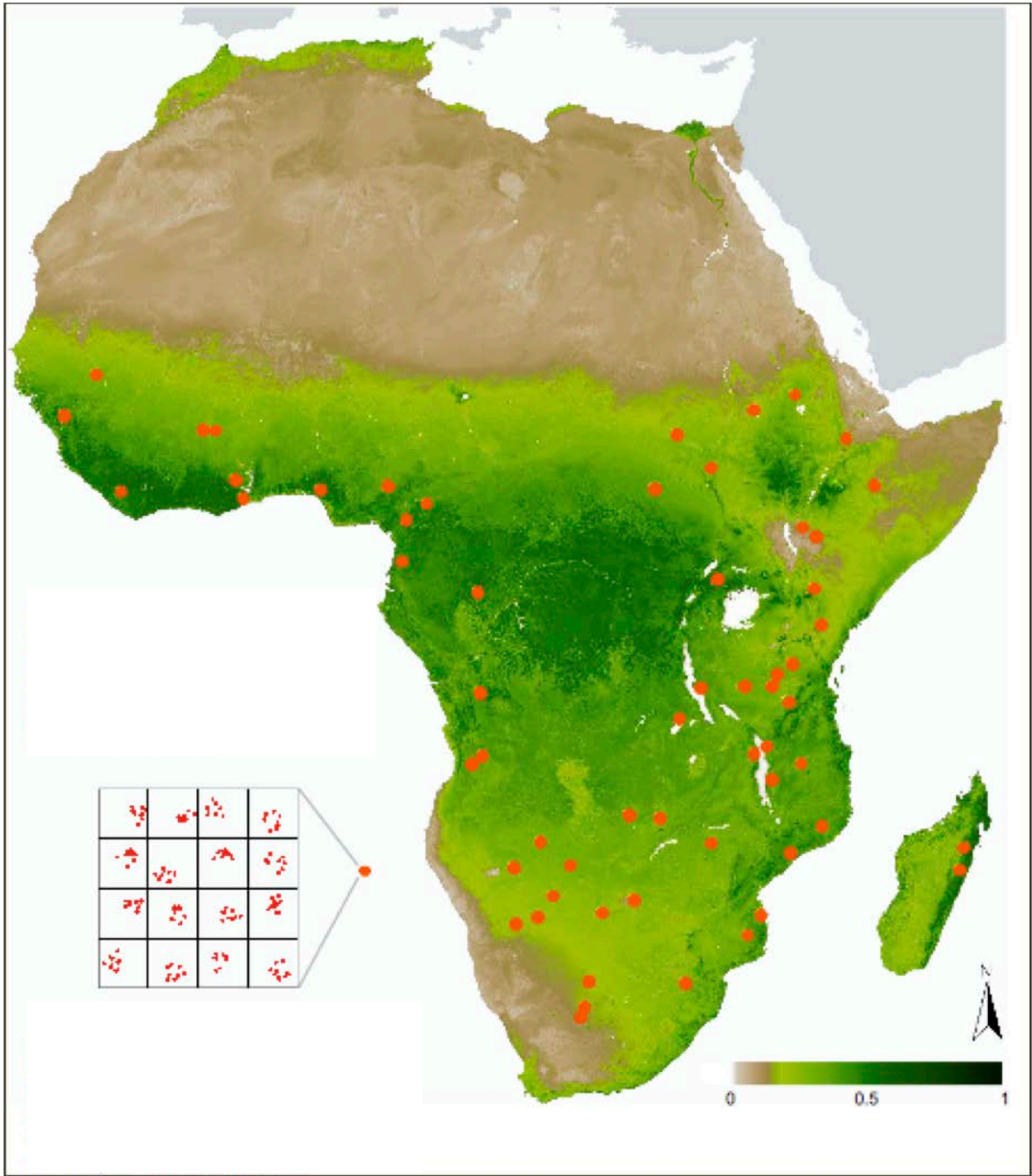


1b. Data Input: New Data Collection and Analysis

19,200 new soil samples from 60 sentinel sites across the continent (red dots)

Each site contains 160 plots (16 clusters each containing 10 plots)

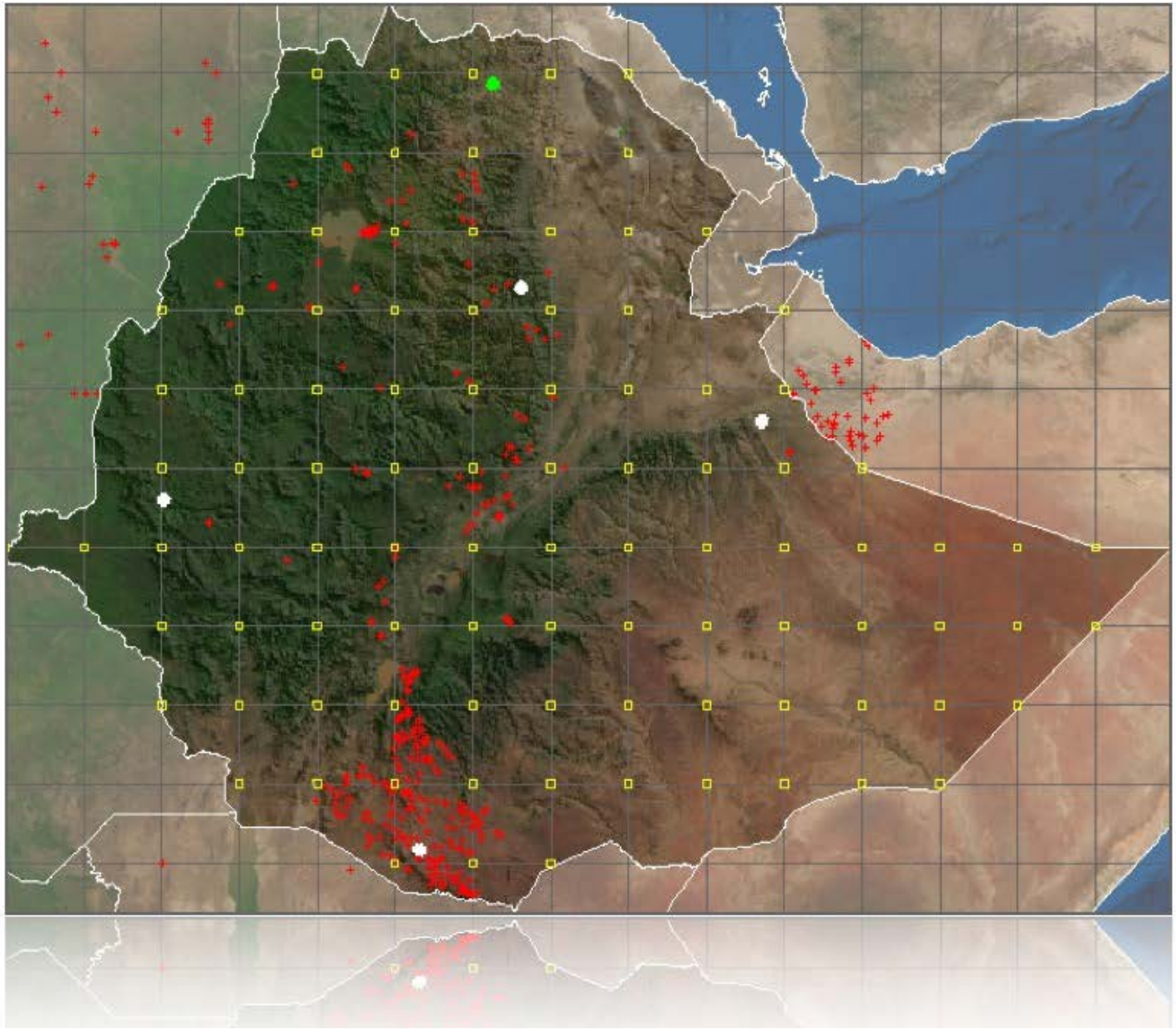
Field data collected at plot and subplot level (4 subplots in each plot): # of trees and diameter, bushes, land cover, land use, slope



Partnering with Ethiopia Soil Information Service (EthioSIS)

- Onsite technical assistance in mapping and remote sensing (July-Sept 2012)
- Development of computing infrastructure needed for soil sample data management digital soil mapping and information dissemination
- Hardware, software, and network setup, security assessment at the Ministry of Agriculture and National Soil Testing Center
- Geospatial metadata training for representatives from 10 national agencies

Ethiopia sampling plan at Lat/Lon degree confluences (yellow squares). Red crosses are existing legacy profiles. White & green crosses, represent existing sentinel sites.



Step 1b. Data Input
Mobile Tools for Data Collection

Building on the success of Child Count, AfSIS partnered with the Modi Lab at Columbia University

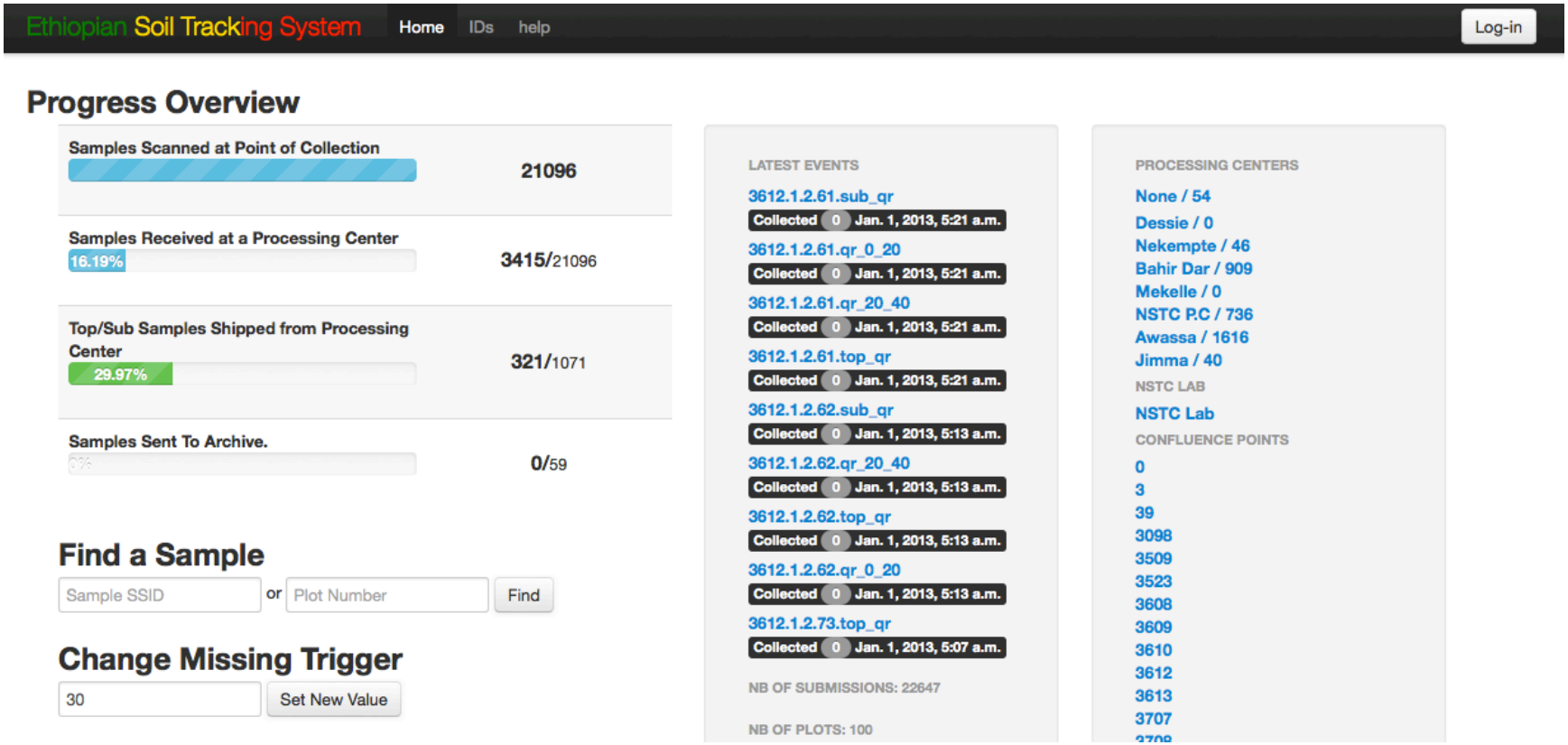
- Pilot studies: scientists and extension agents used mobile tools to collect yield data and measure the area extent of fields
- LDSF data collected using Android tablets at 40+ sentinel landscapes in Ethiopia
- Soil samples QR codes scanned using mobile tools at field sites and processing centers across Ethiopia

Step 1b. Data Input
Tracking Samples Using QR Codes

- Using built-in scanners in phones and tablets
- Building a soil sample registry using unique identifiers
- Allowing 10000+ samples to be tracked in real time

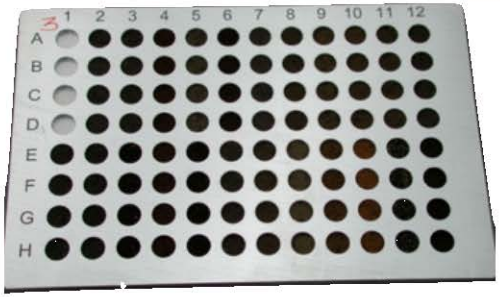
Ethiopia Soil Tracking System

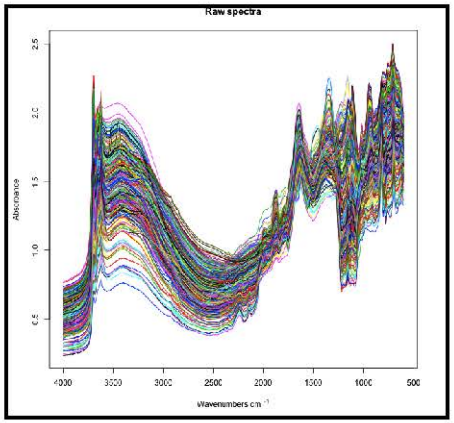
Preview at http://ests.modilabs.org/



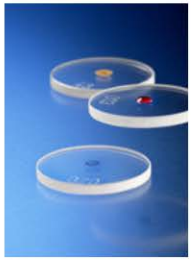
Step 1c Data Input: Analysis Soil and Plant Diagnostics

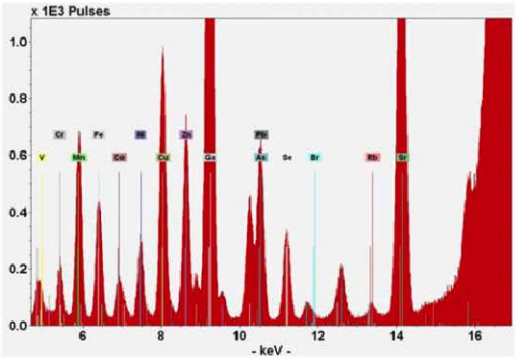
Infrared spectroscopy



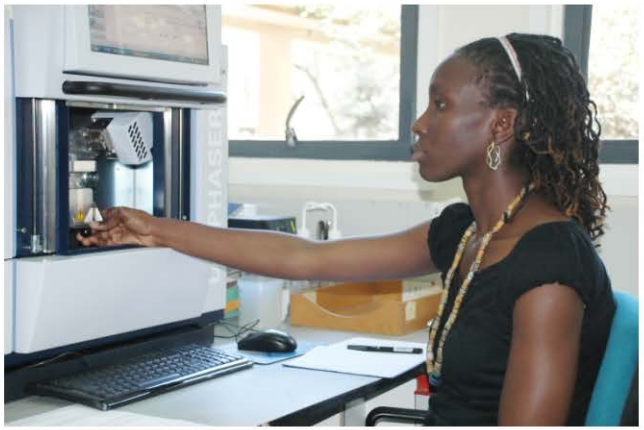


Total X-Ray Fluorescence





X-Ray Diffraction



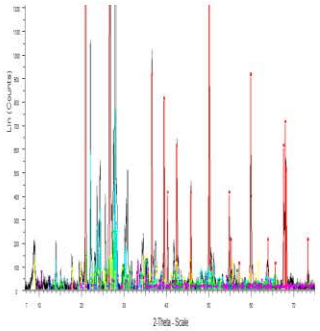


Table 1. Results of Quantitative Phase Analysis

Phase	wt.%
Calcite	8.7 (0.2)
Siderite	2.5 (0.2)
Ankerite	6.2 (0.2)
Quartz	57.1 (0.4)
Muscovite	2.4 (0.3)
Pyrite	0.4 (0.1)
Kaolinite	20.3 (0.4)
Hematite	2.0 (0.2)
Barite	0.4 (0.1)
Total	100.0

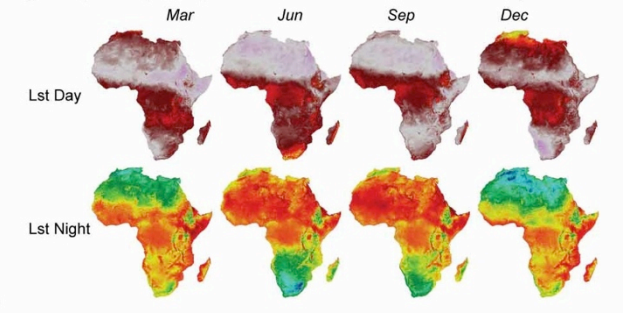
- **Soil reference analyses**
  - Organic matter
    - Total C & N, Org C (combustion)
    - Fractions
    - Isotopes, delta13C, 15N
  - Basic chemical fertility
    - Mehlich 3
      - Al, Ca, Mg, Na, P, K, S, Fe, Mn, Cu, B, Zn, Mo
    - Exch acidity (KCl extraction, unbuffered)
    - pH, Electrical conductivity
    - P sorption characteristics
  - Basic soil physical
    - Laser diffraction particle size analysis
      - Dispersed
      - Non-dispersed
    - Moisture release curve
      - Soil fines
      - Intact cores
  - Element profiling (Na to U)
    - TXRF soil
    - TXRF water extract
  - Mineral profiling
    - Quantitaitve powder XRD
  - Engineering properties
    - Atterberg limits
    - Linear shrinkage
    - Hygroscopic water content
  - Radionucleides
    - 137Cs, 210Pb
    - Profiling
  - Soil biological properties
    - Microbial DNA profiling
    - Soil faunal DNA profiling
    - Soil carbon saturation deficit
  - Plant growth bioassay
    - Pot studies
  - Soil classification
    - Additional properties

Step 1d. Data Input: Africagrids.net

Africa - Wide 'Soil Covariates'

- Digital Elevation Model – SRTM and Aster
- **Remote Sensing Derived Map Layers of Key Ecosystem Variables using MODIS data products**
- Sept 2012, with quarterly updates: Publicly available long term and monthly averages of reflectance, vegetation and leaf area indices, land cover, net primary productivity, land surface temperature:

ftp://africagrids.net

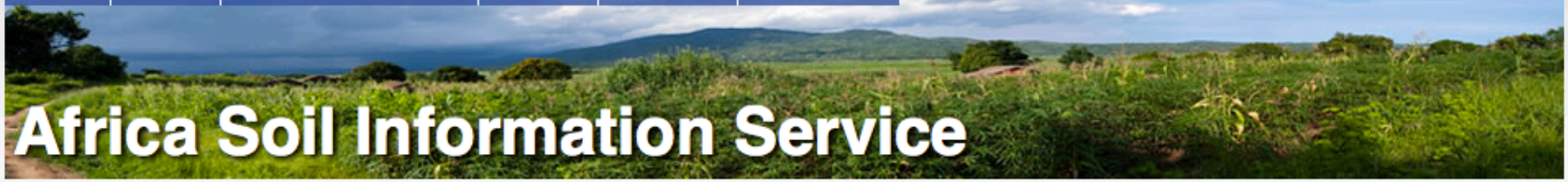


Base Maps, cont
MODIS Time Series Grid Development

- For 250m resolution for the entire continent, using the full time series from 2000-2012 to calculate averages, variances
- Importance of repeat measurements over time -- real power of MODIS
- **Input grids** -- hundreds of dates per dataset – have been assembled and are available **for spatio-temporal modeling**

To do this we needed…

Short videos explaining each dataset also in development (sample here):
http://www.youtube.com/watch?v=9Zt7BxQ3Zyw&feature=youtu.be



Return to » Data and Map Portal

Data and Map Portal

- Overview
- Digital Soil Mapping
- Interactive Map Tool
- Remote Sensing Datasets
  - Remote Sensing
- Soil Databases
- Field Data Collection
- Spectral Diagnostics
- Management Recommendations

INTERNAL AFSIS DATA HOLDINGS

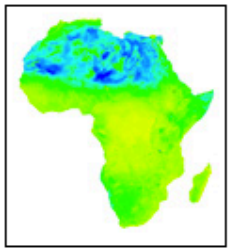
- LEGACY SOIL PROFILE AND FIELD TRIAL DATA

NAVIGATION

- ADD CONTENT
- COMPOSE TIPS
- FORUMS
- SEARCH

AfSIS Datasets

NASA's Moderate Resolution Imaging Spectrometer (MODIS) satellite imagery provides the raw data for numerous global datasets, including land ecosystem variables (vegetation indices, leaf area index, vegetation net primary production), as well as atmospheric and ocean variables. Many of these land ecosystem variables are strongly correlated with soil properties and conditions and can therefore be used as powerful predictors of those properties, particularly when ground observations and physical soil samples for a given location are not available, as is the case with much of the African continent. The datasets below are being used to generate baseline soil property maps.

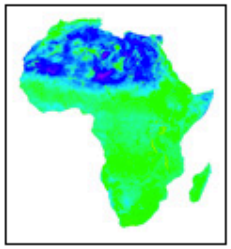


Reflectance Red Band 1

Download Directory: ftp://africagrids.net/250m/MOD13Q1/Reflectance_red

This directory contains the MOD13Q1 Reflectance Band 1 (Red) dataset at 250m resolution for the continent of Africa averaged fully and monthly since 2000. The grids were created by the Africa Soil Information Service (AfSIS) using the Moderate Resolution Imaging Spectroradiometer (MODIS) imagery from the National Aeronautics and Space Administration (NASA) hosted by the International Research Institute for Climate and Society (IRI) Data Library.

Read-me file: Red_readme.txt



Reflectance Near-infrared (NIR) Band 2

Download Directory: ftp://africagrids.net/250m/MOD13Q1/Reflectance_nir/

This directory contains the MOD13Q1 Reflectance Band 2 Near-infrared (NIR) dataset at 250m resolution for the continent of Africa averaged fully and monthly since 2000. The grids were created by the Africa Soil Information Service (AfSIS) using the Moderate Resolution Imaging Spectroradiometer (MODIS) imagery from the National Aeronautics and Space Administration (NASA) hosted by the International Research Institute for Climate and Society (IRI) Data Library.

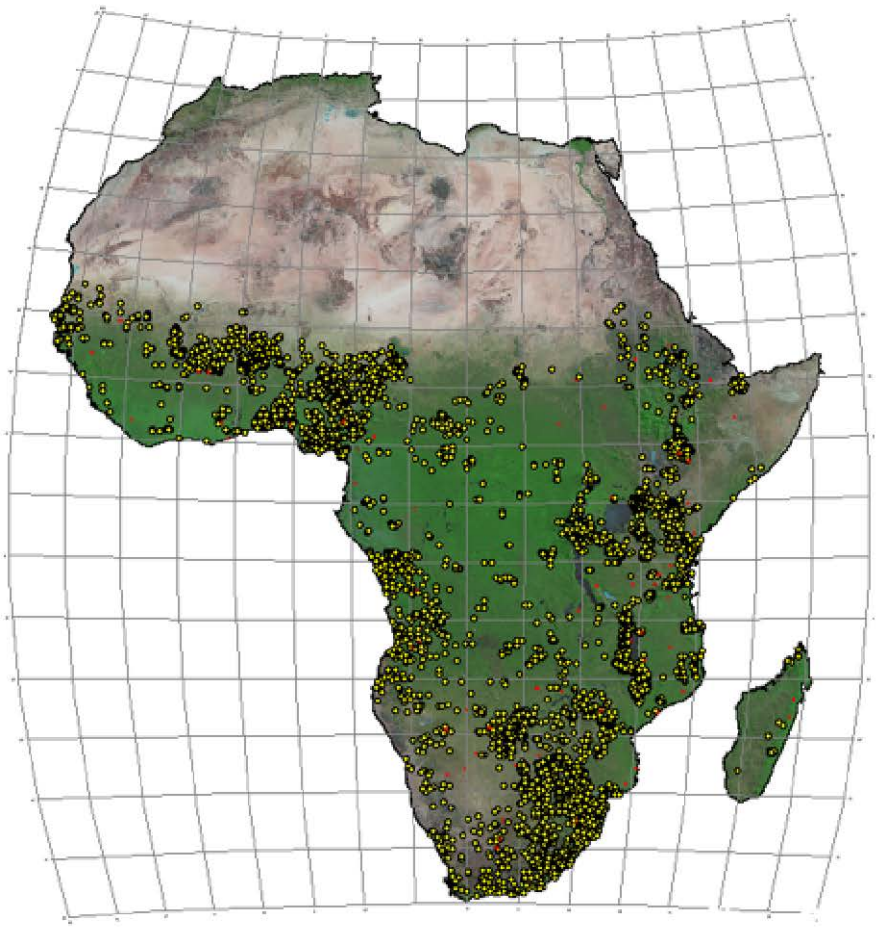
Read-me file: Nir_readme.txt

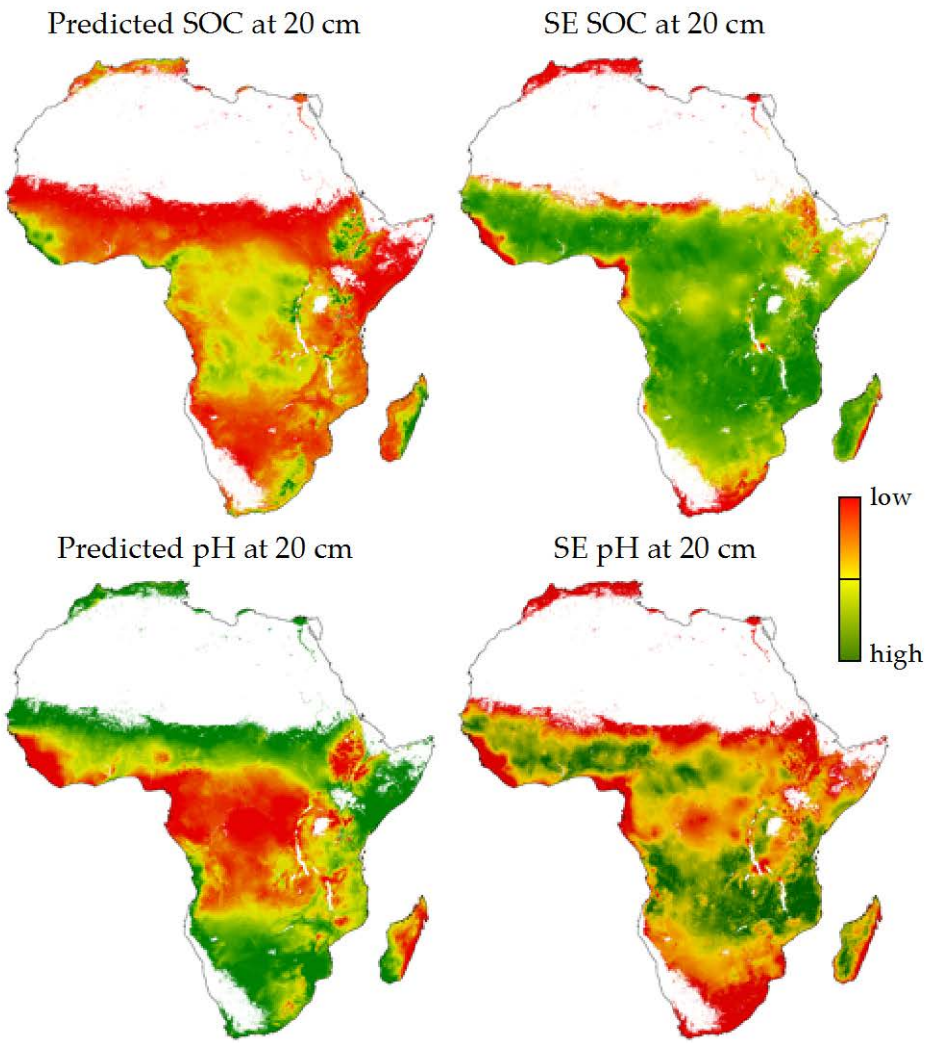
Scientific computing platforms

- Grid-based calculations for time series averages, variances, and principal components
- Set up of a dedicated Linux server for multiple users on 3 continents: *ssh user@Afsisdata.ciesin.columbia.edu*
- **Automating processing of steps**: Raw image download, GIS processing, and statistical analysis
- Multi-user scripts for **Unix shell, MODIS Reprojection Tool, Geographic Resources Analysis Support Software (GRASS) and R**
- System is virtualized so it can be moved into and out of cloud-based systems for faster computing as needed

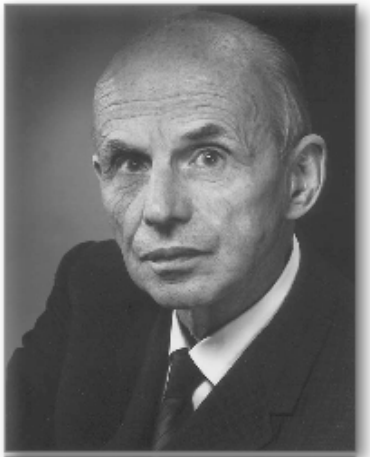
Step 2. Estimation of Soil Properties

Data: Legacy profiles + various remote sensing grids





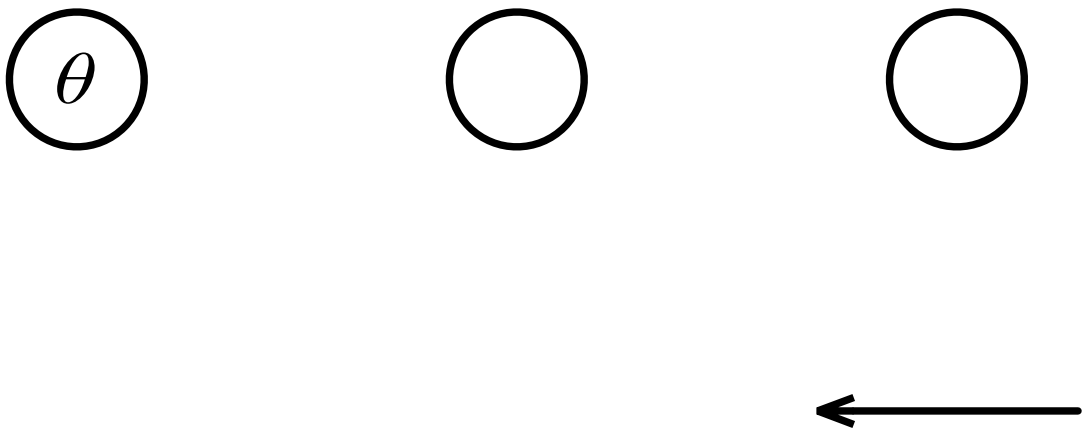
Hans Jenny (1899 -1992)



Soil & ecosystem prediction?

$$s, l = f(L_0, X, t) + \epsilon$$

- Can't measure all soil & ecosystem properties and processes everywhere, at all times ... necessary. Predictions for unmeasured or partially measured locations and points in time are needed for land management.
- Spatial prediction - for mapping.
- Temporal prediction - for monitoring changes.
- Space-time prediction - for monitoring soil & ecosystem changes in landscapes ... (next frontier).
- Experiments - for evaluation of new sensors, measurement systems and land management practices.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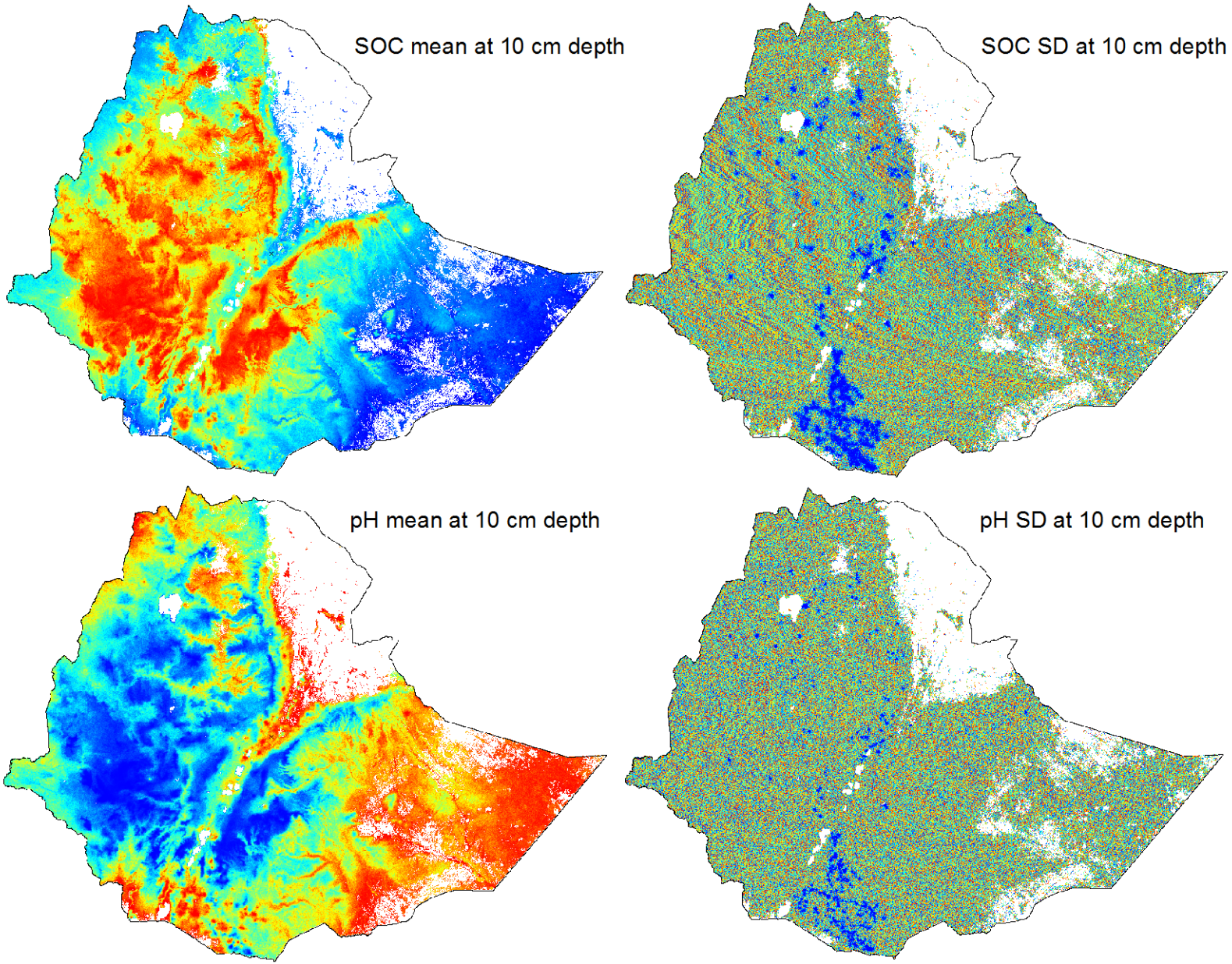
Ethiopia soil predictions based on legacy data

Africa-wide predictions available at: http://www.africasoils.net (on request, updates in progress)



BART prediction with new spectra

$$y(s) = \sum g_i X(s) + \epsilon(s)$$

ϵ

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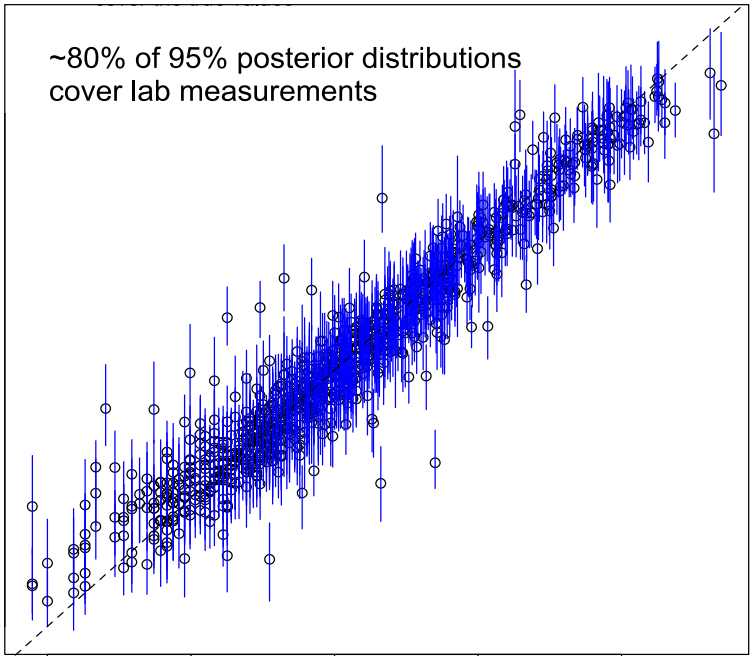
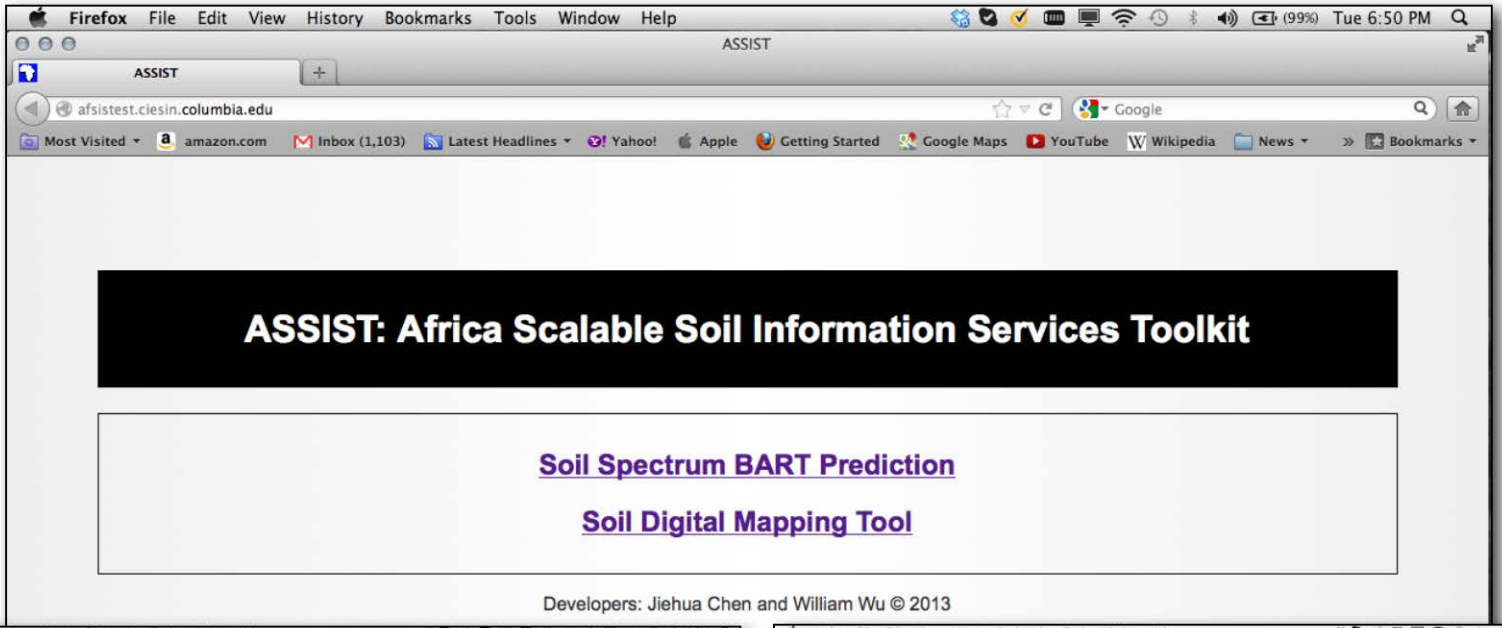
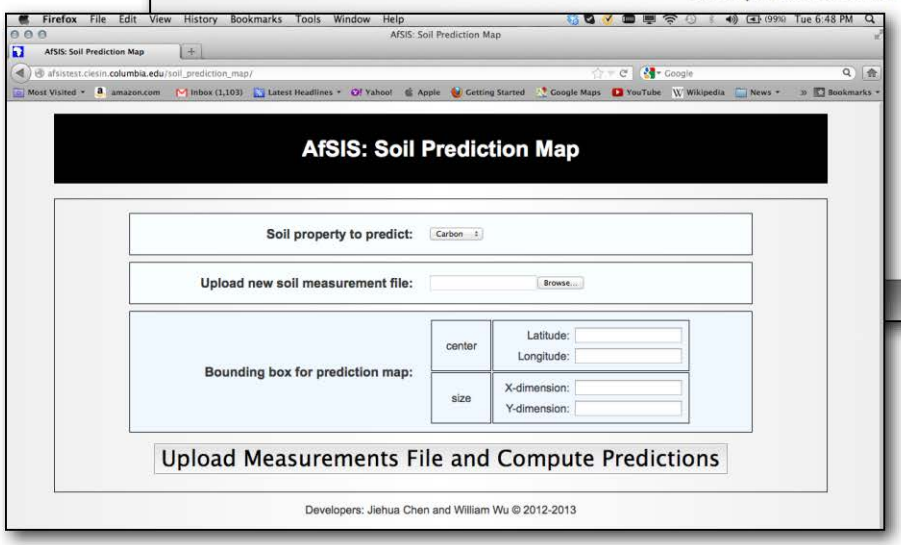
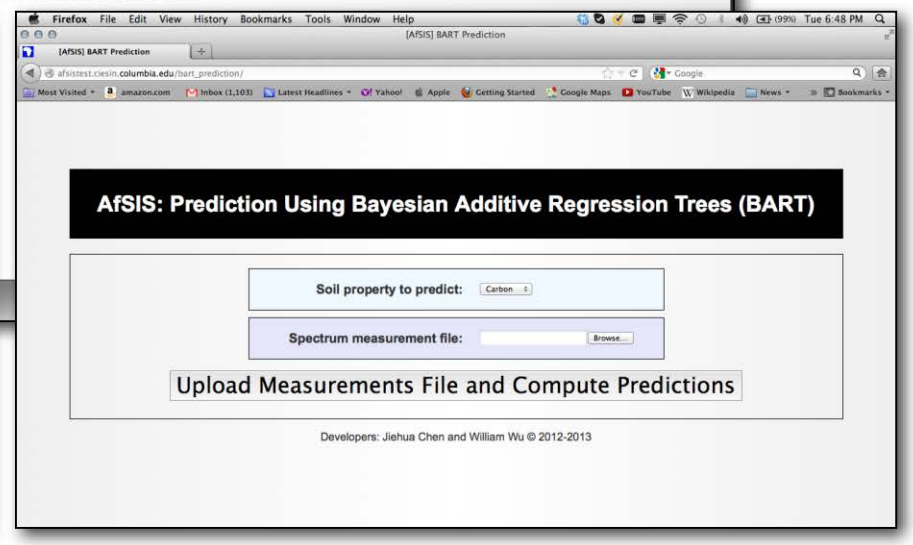

~80% of 95% posterior distributions
cover lab measurements

Web prediction service under development at:

http://afsistest.ciesin.columbia.edu







Step 4: Field Trial Data

- Co-located field trials with 5 sentinel sites
- Development of diagnostic Field Trial Database
- To determine the major nutrients and soil factors limiting crop production.
- To predict crop response to nutrient application in terms of crop growth, yield and nutrient uptake, from soil and foliar spectral and other AfSIS covariates (e.g. land degradation indices) under variable soil fertility conditions.
- To understand the reasons for non-responsive soils to (a) decide whether it is required to rehabilitate non-responsive soils, and (b) develop management practices required to restore productivity.

Step 5: Management Recommendations

- Kisongo agricultural extension pilot and socio-economic data collection within sentinel sites where diagnostic trials were conducted
- Ethiopia nutrient / fertility management recommendations in progress

Some takeaways

- Context: Rapidly emerging technologies, critical global environmental issues
- Need for common information standards to facilitate continental and global modeling
- How will more accurate soil information will be used in a development context?

AfSIS Phase 2

- 18 month grant from BMGF: June 2013 – Dec 2014
- Main grantee: Columbia Global Center, Nairobi

  with subgrants to:
  - Earth Institute: Center for Agriculture and Food Security (formerly TropAg) and Center for International Earth Science Information Network
  - World Agroforestry Centre (ICRAF)
  - International Soil Reference and Information Center (ISRIC)

- Focus for next 18 months…

AfSIS phase 2

- Continue to develop continental soil information products and soil prediction services
- Emphasize capacity building to apply national soil information systems in Tanzania, Ethiopia, Nigeria & Ghana
- Agronomic applications development and testing with national, regional and international partners

Collaborations with NRCS

- Collaborate in further extension of soil spectral libraries
- Training: Characterization of soils at sentinel sites using Soil Taxonomy
- ???

Thank you!

Questions:

Afsis.info@africasoils.net

Interactive Map Tool using Open Geospatial Consortium **Web Map and Web Processing Services**

- *Current*: **AfSIS Terrain derivatives** and soil and agriculture – related layers from external sources
- **MODIS Covariates** (also publicly available via ftp://africagrids.net) and baseline soil property maps
- Online Geoserver Database of all GIS Layers in the AfSIS collection available via WMS, including: maps from external sources, MODIS and other remote sensing covariates, and soil property maps