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Title: Satellite Image Analysis for Surveillance, Vegetation and Climate Change

Author(s): Michael Cai (ISR-3)

Intended for: Global Biosurveillance: Enabling Science and Technology
2nd Biothreat Nonproliferation Conference

January 19 ~ 21, 2011, Santa Fe, NM

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Satellite Image Analysis for Surveillance, Vegetation and Climate Change

Michael Cai (Space Data Systems Group, ISR Division, LANL)

Abstract

Recently, many studies have provided abundant evidence to show the trend of tree mortality is increasing in many regions, and the cause of tree mortality is associated with drought, insect outbreak, or fire. Unfortunately, there is no current capability available to monitor vegetation changes, and correlate and predict tree mortality with CO_2 change, and climate change on the global scale.

Different survey platforms (methods) have been used for forest management. Typical ground-based forest surveys measure tree stem diameter, species, and alive or dead. The measurements are low-tech and time consuming, but the sample sizes are large, running into millions of trees, covering large areas, and spanning many years. These field surveys provide powerful ground validation for other survey methods such as photo survey, helicopter GPS survey, and aerial overview survey.

The satellite imagery has much larger coverage. It is easier to tile the different images together, and more important, the spatial resolution has been improved such that close to or even higher than aerial survey platforms. Today, the remote sensing satellite data have reached sub-meter spatial resolution for panchromatic channels (IKONOS 2: 1 m; Quickbird-2: 0.61 m; Worldview-2: 0.5 m) and meter spatial resolution for multi-spectral channels (IKONOS 2: 4 meter; Quickbird-2: 2.44 m; Worldview-2: 2 m). Therefore, high resolution satellite imagery can allow foresters to discern individual trees. This vital information should allow us to quantify physiological states of trees, e.g. healthy or dead, shape and size of tree crowns, as well as species and functional compositions of trees. This is a powerful data resource, however, due to the vast amount of the data collected daily, it is impossible for human analysts to review the imagery in detail to identify the vital biodiversity information. Thus, in this talk, we will discuss the opportunities and challenges to use high resolution satellite imagery and machine learning theory to monitor tree mortality at the level of individual trees.

Satellite Image Analysis for Surveillance, Vegetation and Climate Change

Michael Cai (dmc@lanl.gov)

Space Data Systems Group
Los Alamos National Laboratory

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Outline

- **Tree Mortality, CO_2, and Climate Change**
- **Remote Sensing and Vegetation Monitoring**
  - o Airborne Instrument
  - o Satellite-borne Instrument
  - o Image Classification
- **Studies at LANL**
  - o Image Classification
  - o Vegetation Modeling
  - o Climate Modeling
- **Outlook**

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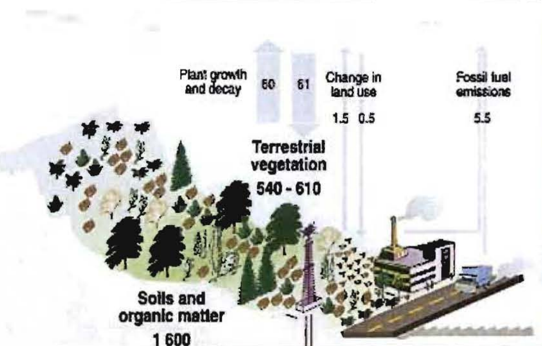
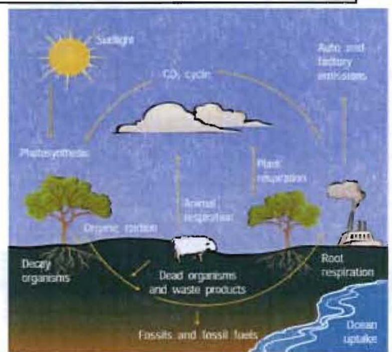
Forests dominate the terrestrial carbon cycle

Forests store 86% of the planet's above-ground carbon and 73% of the planet's soil carbon (Sedjo & Roger, 1993).





Forests, as primary carbon stores (sinks), are threatened by increasing global tree mortality, land-use changes (deforestation), and eco-system migration!

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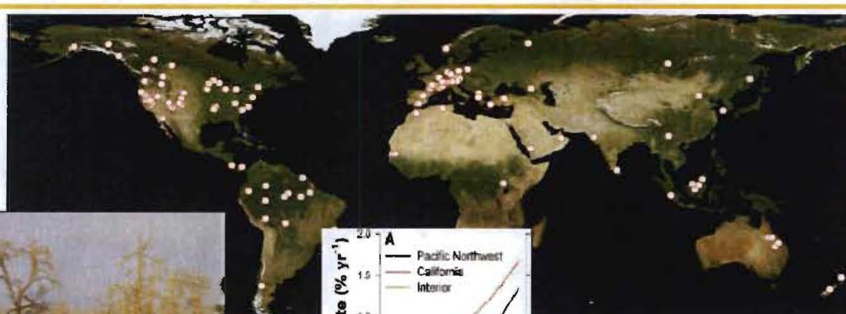
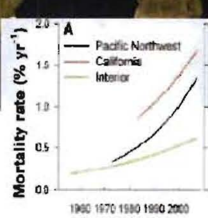
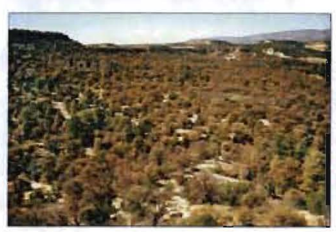
Problem: vegetation mortality is growing globally



Craig Allen et al, 2010
Forest Ecology and Management **259**:660



Van Mantgem et al. 2009.
Science 323: 521-524



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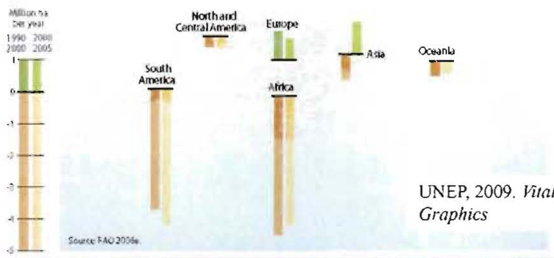
Problem: the rate of deforestation around the globe has increased dramatically.

In the period 1990-2000 the world is estimated to have suffered a net loss of 8.9 million hectares of forest each year, but in the period 2000-2005 this was reduced to an estimated 7.3 million hectares per year.

Annual net change in forest area, 1990-2005



UNEP, 2009. *Vital forest Graphics*

Jungle burned for agriculture

Urbanization

Wildfire

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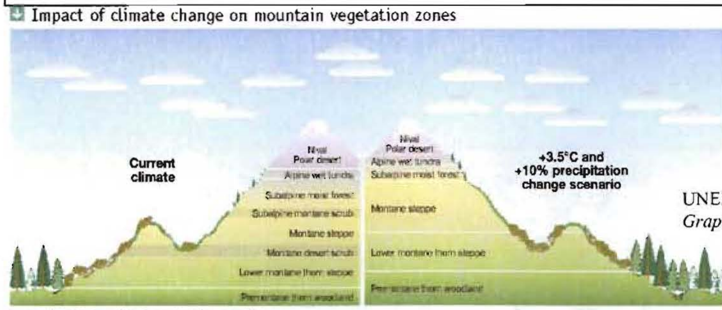
Problem: rising temperature may force forest communities to migrate to cooler areas and toward higher elevations.

The climate may change faster than species' natural capacity to migrate. As a result, forest community composition will likely change, and opportunistic "weedy" species will readily replace native species that are displaced by climate change. Hansen et al, 2001; Sherry, et al, 2007; Oregon Wild Repost, 2007

Impact of climate change on mountain vegetation zones



UNEP, 2009. *Vital forest Graphics*

According to the latest projections, changes in climate will mean that by 2050 the world's ecosystems, including its all important forests, will be releasing more carbon than they are capable of absorbing!

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Questions related to Remote Sensing, Tree Mortality, CO_2 Cycle and Climate Changes

Is tree mortality associated with changing climate?

- need to understand of mechanisms of tree mortality both experimentally and theoretically

Can tree mortality be detected globally from space?

- Need to monitor regional and global vegetation pattern changes due to tree mortality
- Need to detect early warning signs and signatures of tree stress due to environmental changes

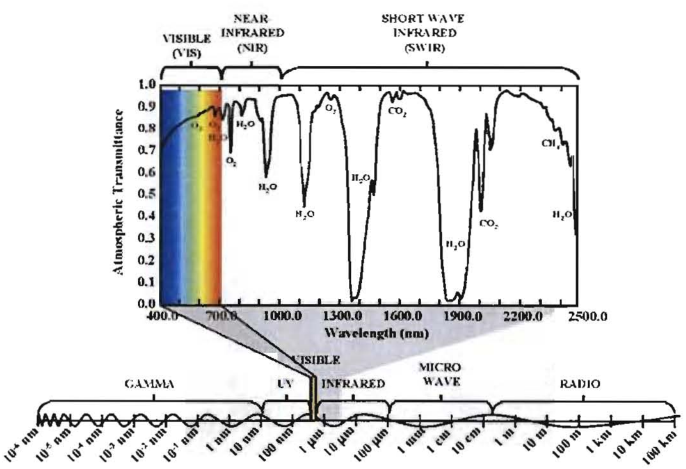
How much does vegetation migration drive changes in C storage?

- Need to remotely sense eco-system transitions or migrations, and predict the C storage (positive or negative) using vegetation models.

Do vegetation changes such as tree mortality influence climate?

- Need to predict global vegetation dynamics and their consequences to carbon cycle and climate change

Visible, Near Infrared (NIR), Short Wave Infrared (SWIR) Are Primary Spectral Bands for Vegetation Monitoring

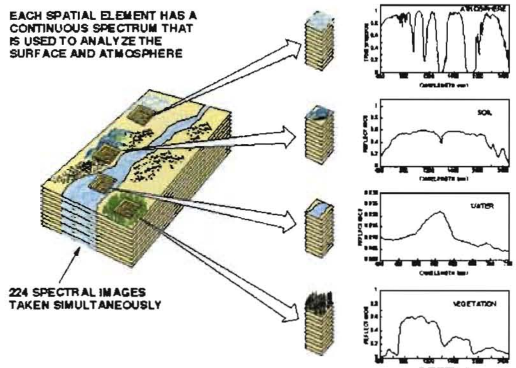


Airborne Instruments: AVIRIS (the Airborne Visible Infrared Imaging Spectrometer) JPL/NASA

AVIRIS:
400 ~2500 nm
~10 nm sampling interval
224 channels
20 m resolution at 20 km altitude

JPL

AVIRIS CONCEPT



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Satellite-based Earth Observations: MODIS, Landsat, EO-1, Quickbird-2, Worldview-2

				Spectral Resolution		Spatial Resolution		Temporal Resolution (Days)
	Satellite(s)	Launched on (mm-dd-yyyy)	Sensor(s)	No of Bands	Spectral Distribution	Pixel size (m)	Swath (km)	
Moderate Spatial Resolution	**MODIS**	12-18-1999 05-04-2002	Terra Aqua	36	VIS/NIR/SWIR/MWIR,LWIR	250/500/1000	2330	1
Medium Spatial Resolution	**Landsat-7** (ASTER)	15-04-1999	Panchromatic Multispectral Thermal	1 6 1	P/B,G,R,3 NIR/TIR	15/30/60, 120	185	16
Medium Spatial Resolution	**EO-1**	21-11-2000	ALI Hyperion	10 220	1P/2B, 1G, 1R, 3NIR, 2SWIR/220Hyperspectral	10/30/30	37/7.7	16
High Spatial Resolution	**QuickBird-2** (IKONOS)	18-10-2001	Panchromatic Multispectral	1 4	P/B, G, R, NIR	0.6/2.4	16.5	5
Very High Spatial Resolution	**WorldView-2** (Geoeye)	8/10/2009	Panchromatic Multispectral	1 8	P/2B, 1G, 1Y, 1R, 1RE, 2NIR	0.5/1.84	16.4	1.1

Sample Pictures from MODIS and Landsat

Dust mixed with smoke across central Africa in early January 2011 (**MODIS**)

This striking engineering test image is a natural-looking color composite of 3 different visible wavelength bands. It nicely shows details of urban areas around San Francisco, California, USA (**Landsat**)

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Sample Pictures from EO-1: ALI/Hyperion

Paris was pictured at 30-m (left) and 10-m (right) spatial resolution from the Ali land imager.

The hundreds of bands in hyperspectral imagery enable researchers to differentiate minerals and rocks that appear similar in visible light. Outcrops near Khirbat en-Nahas, Jordan that are uniformly dark in natural color (NASA images by Robert Simmon, using Hyperion data

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Sample Pictures from Quickbird

This QuickBird satellite image depicts flooding in Nashville, Tennessee. Flooding from the Cumberland River, damaged or destroyed many historic landmarks throughout the famous city's downtown area.

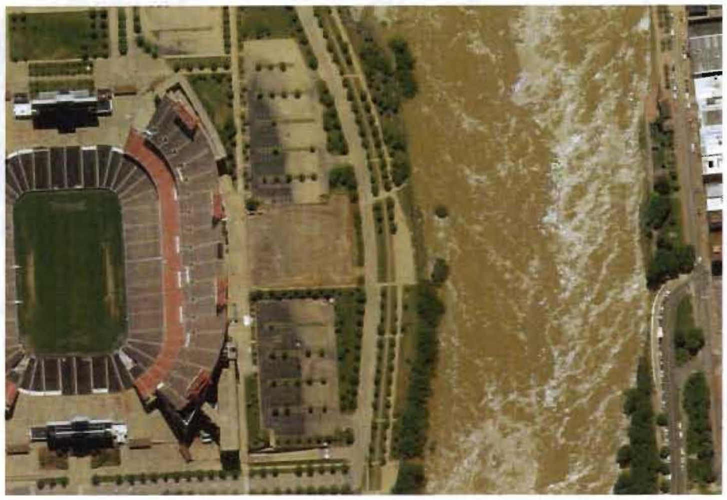

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Image Classification: Place landscape into categories (classes), trees, crops, water, etc

Supervised learning: Learning based on known cases using training data.

Training data: A sample data with assigned classification/ regression categories/classes (e.g. tree vs. soil)

Two Steps:

1. Training step: Learn classifier/regressor from training data.
2. Prediction step: Assign class labels/functional values to test data.

Common Methods

SVMs, Neural network, Minimum distance to mean, and Maximum likelihood

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Image Classification: Place landscape into categories (classes), trees, crops, water, etc (continued)

Unsupervised learning: Learning without training data.

Rather than defining training sets and carving out pieces of n-dimensional space, classes are defined beforehand and instead we use statistical approaches to divide the n-dimensional space into clusters with the best separation.

Common Methods
Clustering (K-means, IsoData), Dimension reduction techniques (PCA, ICA)

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Needed Capabilities: *monitor* and *predict* global vegetation dynamics and their consequences to carbon storage and climate change

20110014DR: **Terrestrial Vegetation, CO_2 Emissions, and Climate Dynamics**. PIs: McDowell (EES), Cai (ISR), Ringler (T)

20100582ER: **DOVE: Discovery Of Vegetation over the Earth Using High Resolution Remote Sensing Data.** PIs: Cai (ISR), McDowell (EES)

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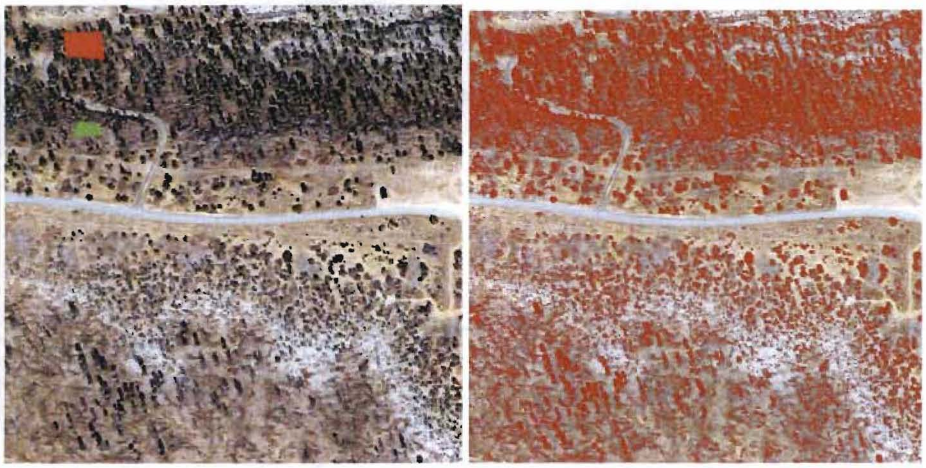
Research: novel remote sensing of <u>stress and mortality</u> at high spatial/temporal resolution (1m, 2 days, global)



Supervised learning separates vegetation/background
Cai, McDowell, Brumby, LANL LDRD, 2010

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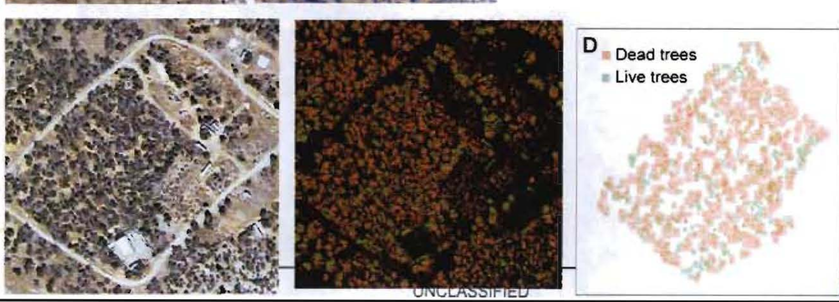
Research: novel remote sensing of <u>stress and mortality</u> at high spatial/temporal resolution (1m, 2 days, global)

Unsupervised learning separates live/dead vegetation
Cai, McDowell, Brumby, LANL LDRD, 2010

Independent test against ground truth data at TA-51

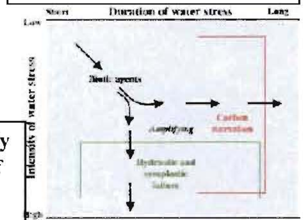


Research: understanding mechanisms of increasing tree mortality through controlled experiment, theory development and simulation

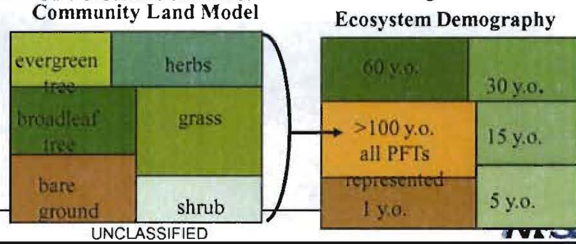
The first "next generation experiment" manipulating precipitation and temperature to understand mortality

McDowell et al. *New Phytologist* 2008
McDowell and Sevanto *New Phytologist* 2010
McDowell and Amthor *PNAS* in review

Carbon starvation and hydraulic failure as separate mechanisms (2008)



Ecosystem Demography-Community Land Model: revolutionary simulation of vegetation dynamics through improved spatial, vertical, and functional binning of age-classes

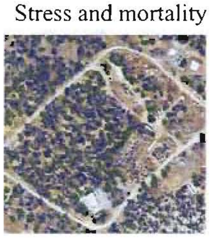


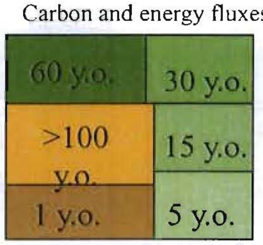
Research: conduct hypothesis-driven research regarding vegetation mortality, carbon cycle, and climate impacts and feed-backs

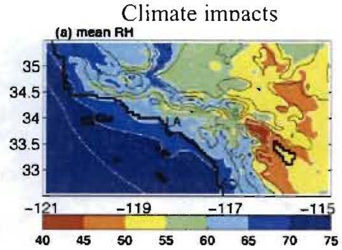
DOVE
Stress and mortality

DOVE-ED-CLM
Carbon and energy fluxes

DECM
Climate impacts



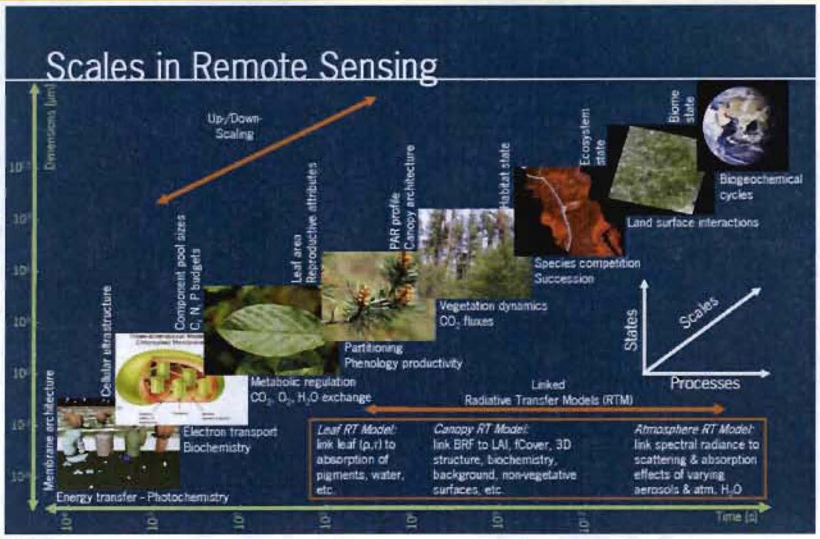




Future carbon impacts for DOVE

Future climate for ED-CLM

Outlook: Bridge Scaling Gaps, Assess Heterogeneity, and Develop Physical Models



Schaepman et al, 2009 *Remote Sensing of Environment, 113:S123*