Overview and discussion of Decadal Survey Missions relevant to the Terrestrial Ecology Program

- ASCENDS – Randy Kawa
- DESDynI – Ralph Dubayah
- HyspIRI – Simon Hook
- ICESat-2 – Amy Neuenschwander
- OCO-2 – Chip Miller
- SMAP – Kyle McDonald

ASCENDS

Active Sensing of CO_2 Emissions Over Nights, Days, and Seasons

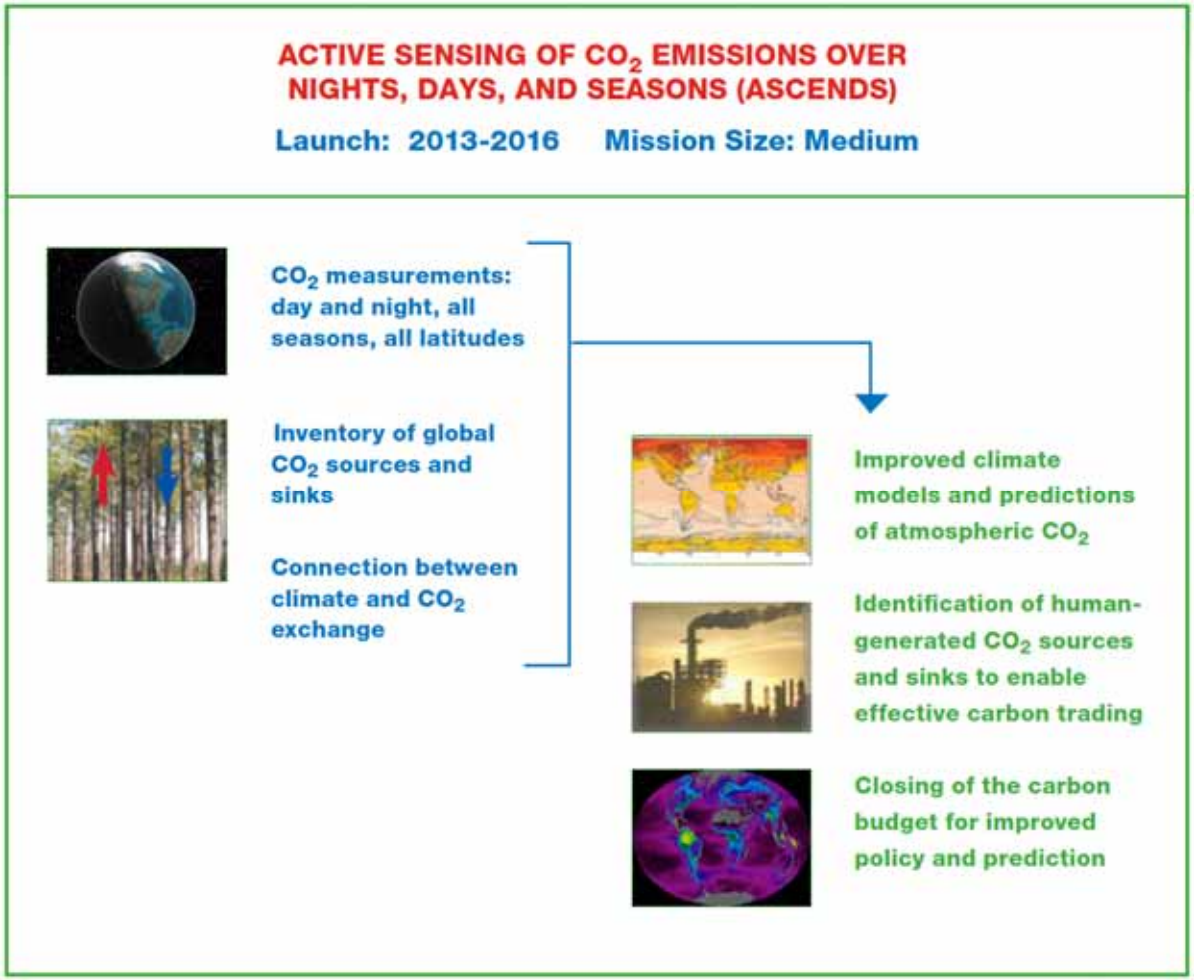
Randy Kawa
NASA Goddard Space Flight Center
March 16, 2010

Outline:

- Science Objectives
- Instrument Suite
- Status
- Examples
- Future Activities, Events

Science Objectives

Goal: to enhance understanding of the role of CO_2 in the global carbon cycle.



Science Objectives:

(1) quantify global spatial distribution of atmospheric CO_2 on scales of weather models in the 2010-2020 era

(2) quantify current global spatial distribution of terrestrial and oceanic sources and sinks of CO_2 on 1-degree grids at weekly resolution

(3) provide a scientific basis for future projections of CO_2 sources and sinks through data-driven enhancements of Earth-system process modeling.

Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond
http://www.nap.edu/catalog/11820.html

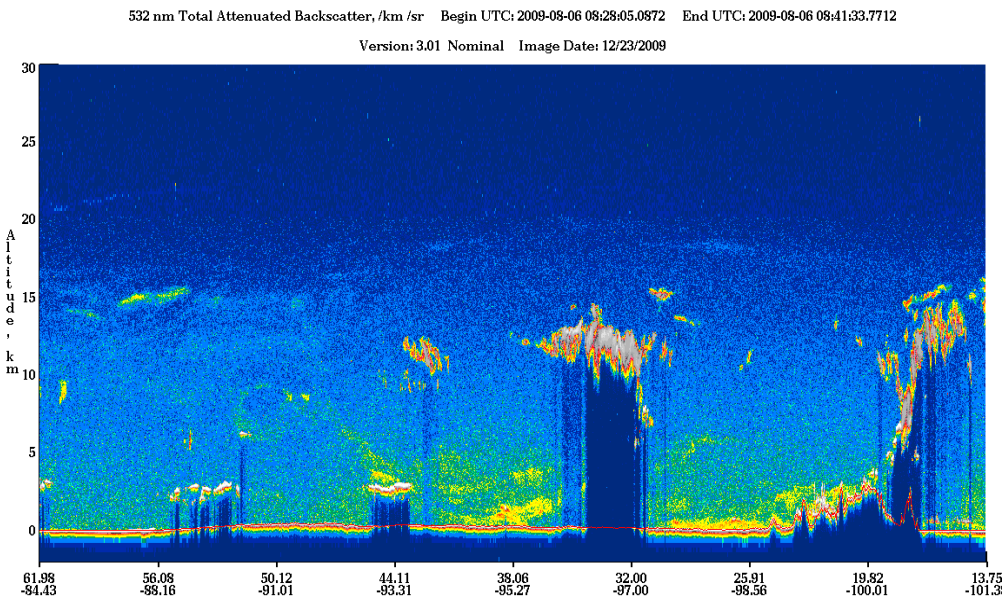
Instrument Suite

1) Laser remote sensing of CO_2 and O_2
2) Ideally complemented by a CO sensor

Why lasers ?

- Measures at night & at all times of day
- Continuous "glint" measurements over oceans
- Measures at high latitudes
- Illumination path = observation path
- Small measurement footprint, see between clouds
- Minimize effect of atmospheric scattering
- Possible to resolve vertical profile information

"Mixing ratio (CO_2) needs to be measured to a precision of 0.5 percent of background (slightly less than 2 ppm) at 100-km horizontal length scale over land and at 200-km scale over open oceans."



Development Status

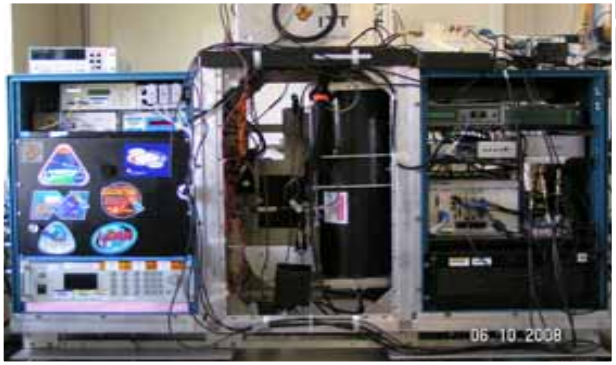
- Multiple groups have been developing technologies and methods for CO_2 space lidar for more than 10 years.
- Several airborne prototypes are currently in development and testing under NASA Instrument Incubator Program, Airborne Technology Transition, and ASCENDS flight project support.
- ASCENDS community workshop held in July 2008 to refine science goals, objectives, and requirements (http://cce.nasa.gov/ascends/index.htm).

Coordinated Airborne Experiments

LaRC/ITT Acclaim lidar instrument in NASA UC-12, Ed Browell, Team Leader

GSFC Airborne CO_2 lidar instrument in NASA Lear-25, Jim Abshire, Team Leader

JPL Airborne CO_2 lidar instrument in Twin Otter, Gary Spiers, Team Leader

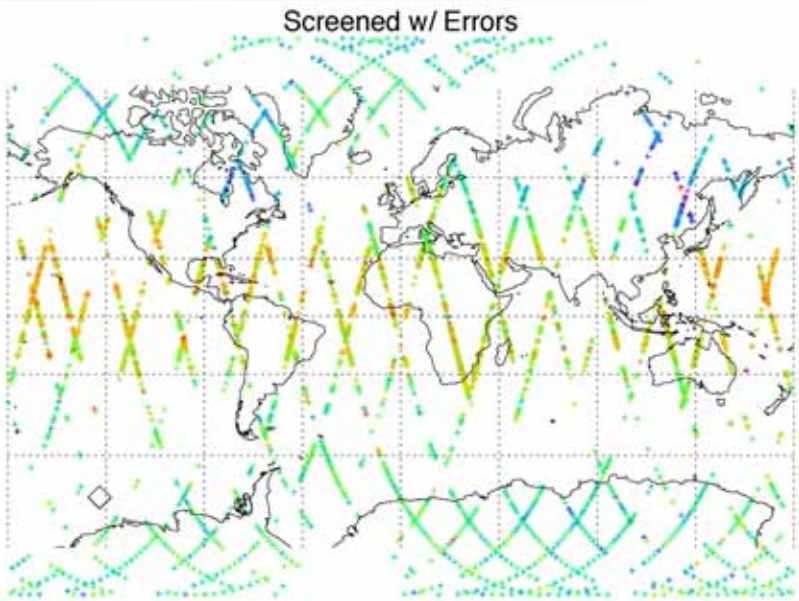


Ponca City OK, Airport
July 2009

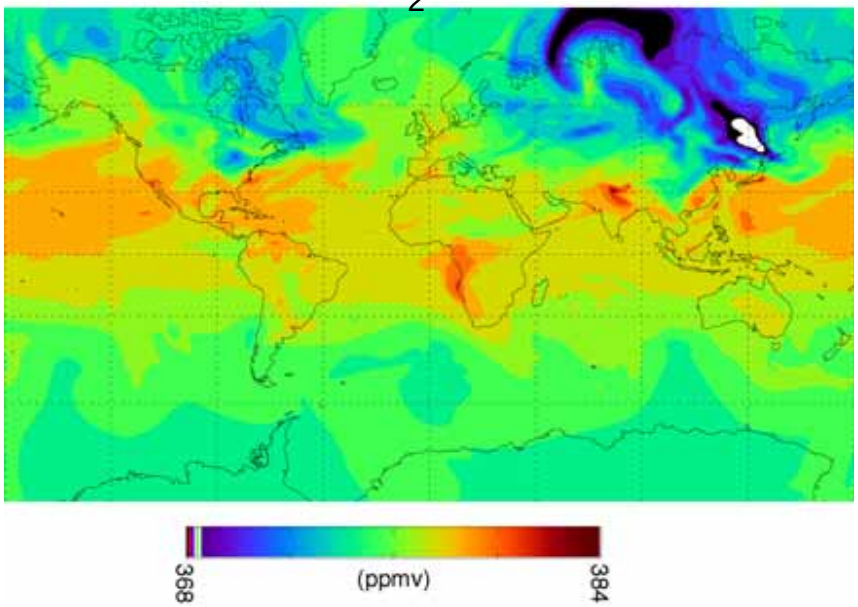
Future Activities, Events

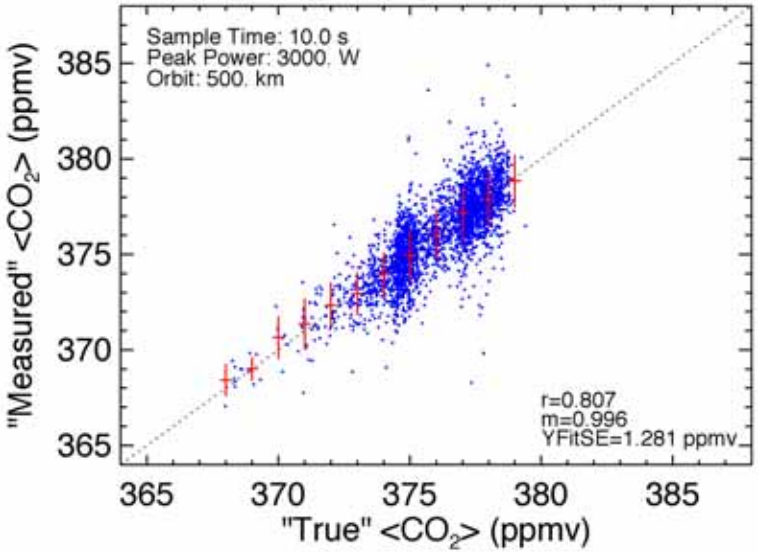
- Flight instrument tests this summer with 3 CO_2 lidars on DC-8.
  - First test of O_2 lidar
- ASCENDS modeling activity ongoing, CO_2 observing system simulations in 2010.
- Next workshop being considered for late 2010/early 2011.
- Space mission design study pending.
- EU A-SCOPE (Advanced Space Carbon and Climate Observation of Planet Earth) mission definition study complete, mission development under consideration (http://www.esa.int/esaLP/LPfuturemis.html).

Mission Simulation



Model <CO_2> 2006-07-26

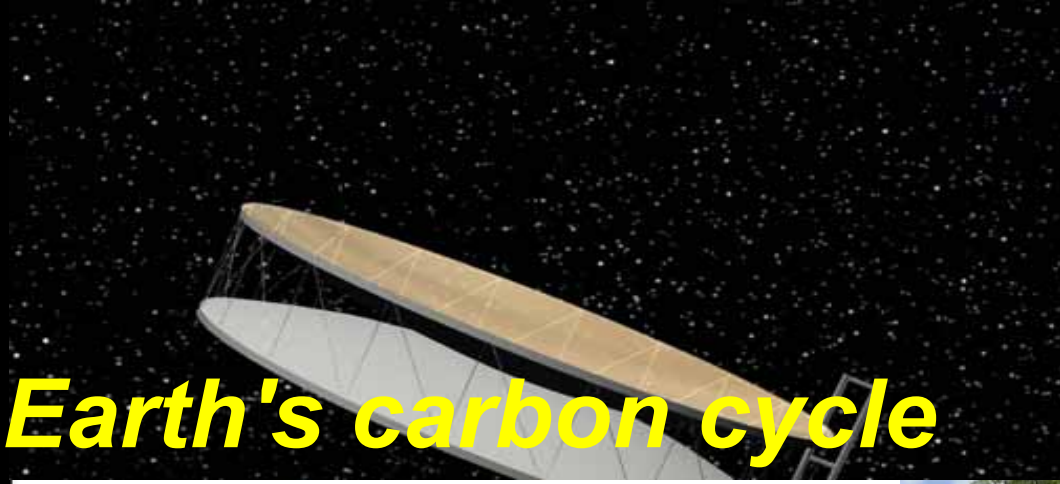




- Single-sample errors average 1.28 ppmv for this instrument configuration.
- Consistent with ASCENDS measurement requirements.

Kawa et al., Tellus-B, submitted, 2010

Global Vegetation Structure Dynamics from NASA's DESDynI Mission



How are the Earth's carbon cycle

Ralph Dubayah

University of Maryland

DESDynI

DESDynI

- **D**eformation**, E**cosystem **St**ructure**, and Dyn**amics of **I**ce
  - **Recommended by National Research Council Decadal Survey to measure changes in land, ice and vegetation structure**
- **Outline**
  - **Mission Science Goals and Objectives**
  - **Instrument Suite**
  - **Measurement Approach**
  - **Current Status**

DESDynI Scientific Focus Areas

DESDynI addresses a broad-based range of the science questions

Deformation	Ecosystems	Ice Masses	Subsurface Reservoirs
Earthquakes Probability, aftershocks, stress transfer	**Aboveground biomass** Carbon storage in vegetation	**Ice Sheet Flow** Response of ice sheets and shelves to ocean and atmosphere	**Aquifers** Withdrawal and Recharge Subsidence
Volcanoes Volume, depth, and migration of magma chamber	**Changes in carbon stocks** Carbon sources and sinks	**Mtn glaciers & ice caps** Response to climate trends	**CO_2 Sequestration** Subsurface migration
Landslides Detect preslip	**Habitat Structure** Biodiversity assess-ment, ecosystem processes	**Sea Ice** Interaction between ocean and atmosphere	**Oil Reservoirs** Subsidence, pipe breakage

Key Challenges

Additional Science Benefits

Science Objectives

CHARACTERIZE THE EFFECTS OF CHANGING CLIMATE AND LAND USE ON TERRESTRIAL CARBON CYCLE, ATMOSPHERIC CO_2, AND SPECIES HABITATS

- Characterize global distribution of aboveground vegetation biomass
- Quantify changes in terrestrial biomass resulting from disturbance and recovery
- Characterize habitat structure for biodiversity assessments

Science Objective 1: Biomass

Characterize global distribution of aboveground vegetation biomass

Desired Final Data Products	**Global biomass** at **250 m** with accuracy of **10 MgC/ha** (or **20%**, not to exceed 50 Mg/ha) at **5 years**. Resolution increased to **100 m** for **low biomass** areas (<100 Mg/ha)
Measurement Objectives	Forest canopy height and profiles, spatial and vertical structure, biomass from SAR
Instruments	Multi-beam lidar, polarimetric L-band SAR

Science Objective 3: Habitat Structure

Characterize habitat structure for biodiversity assessments

Desired Final Data Products	Various forest structure products, including vegetation vertical canopy profiles at **25 m** spatial resolution, **30 m along-transect posting**, with a maximum of **250 m across-transect** posting globally, and **1 m vertical resolutio**n (99% canopy cover).
Measurement Objectives	Forest canopy structure including **height, canopy profile, canopy cover, canopy roughness, biomass, vertical diversity**
Instruments	Multi-beam lidar, polarimetric L-band SAR

DESDynI Instruments

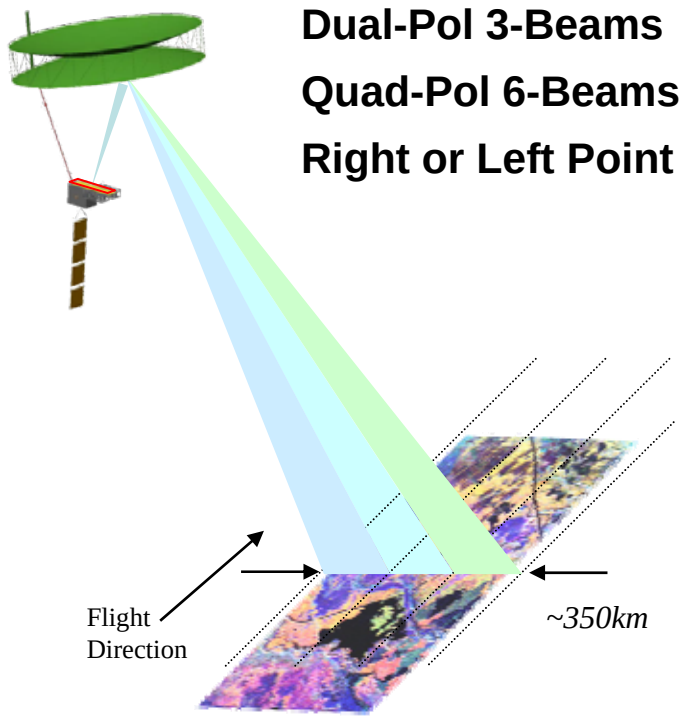
L-Band Synthetic Aperture Radar

Interferometric SAR

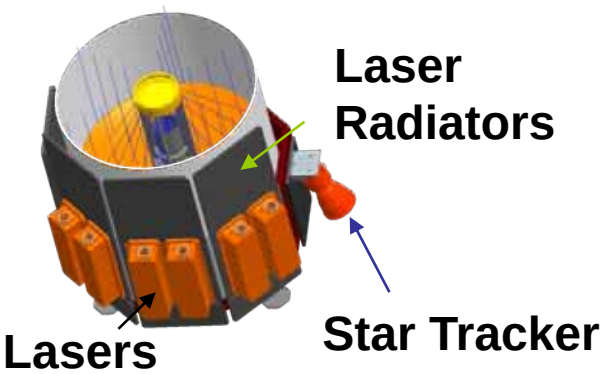
Dual-Pol 3-Beams

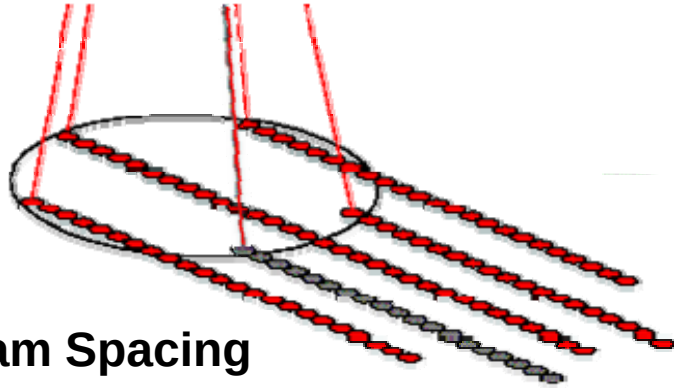
Quad-Pol 6-Beams

Right or Left Point



Multi-beam Lidar





Beam Spacing
1 km

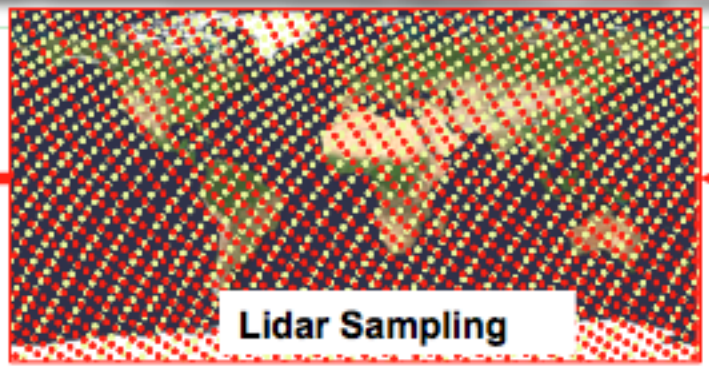
Measurement Approach

Lidar

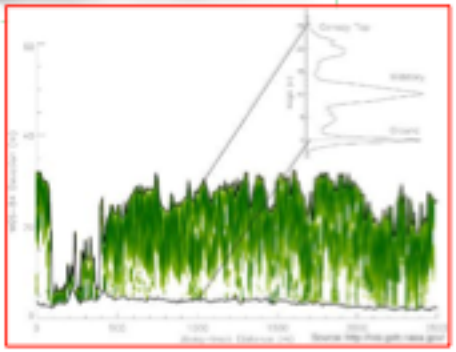
Backscatter

Vertical Structure

Full-range of biomass

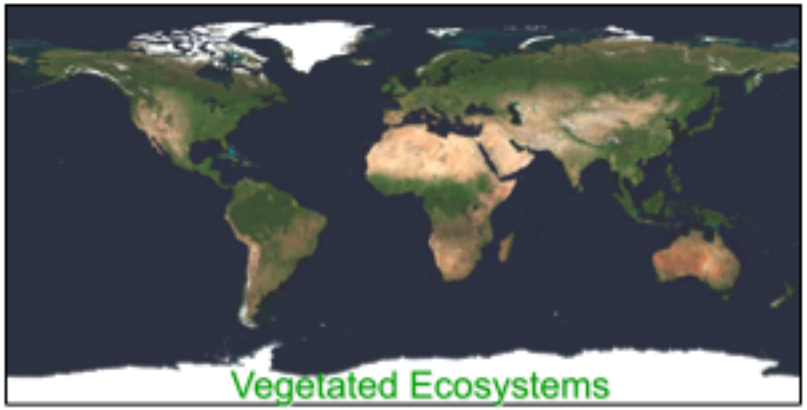


Lidar Measurement



GLOBAL BIOMASS, FLUXES & SPECIES HABITAT

- **MODELS**
- **FUSION**
- **GROUND OBS.**



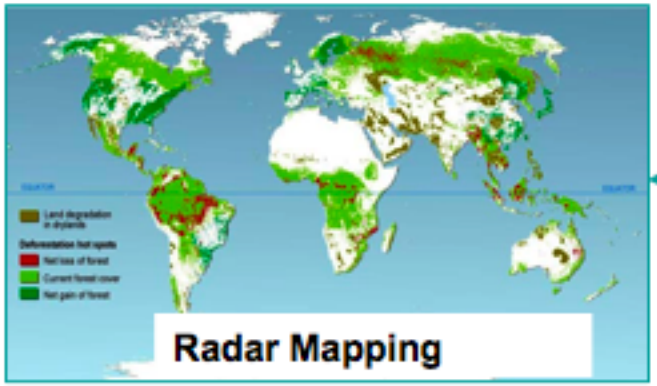
Radar

Backscatter

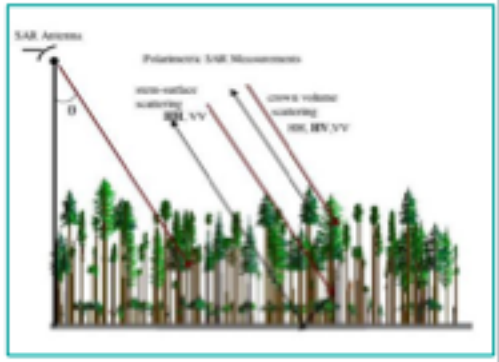
Volume Structure

Disturbance

Low to medium biomass (< 100 Mg/ha)



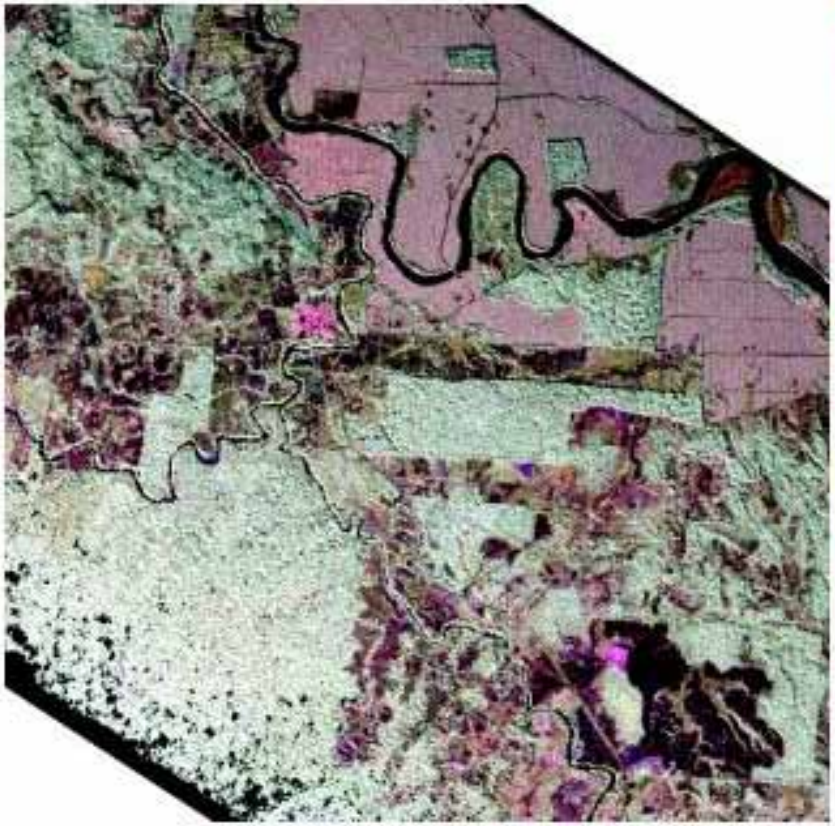
Radar Measurement



DESDynI

L-band Measurement of Structure

Polarimetric Image of La Selva



LHH, LHV, LVV

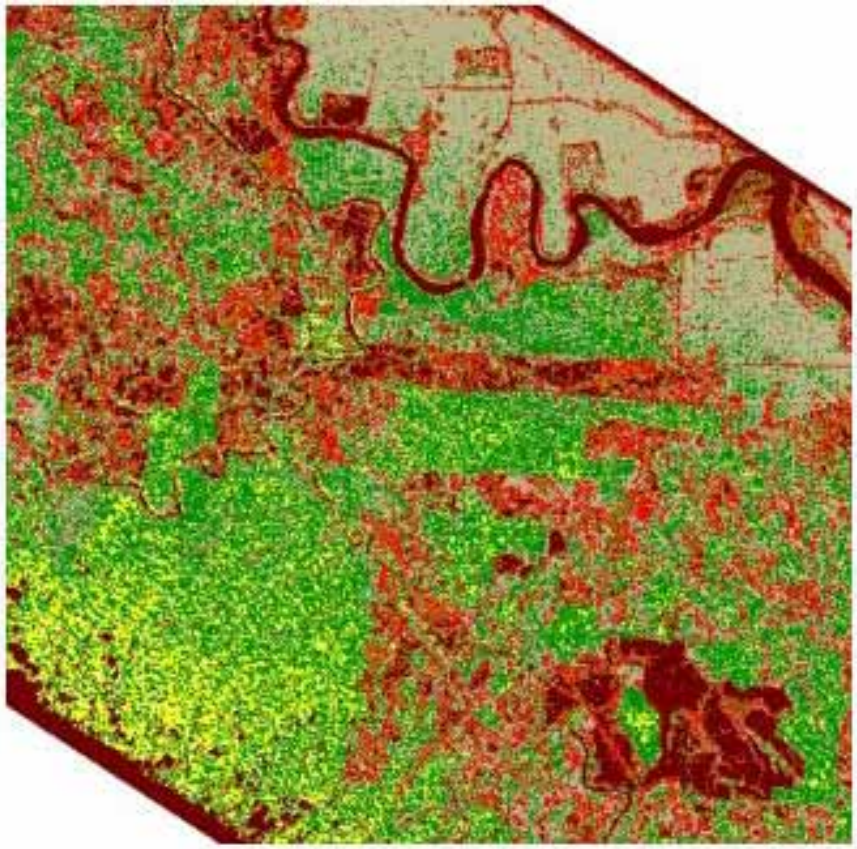
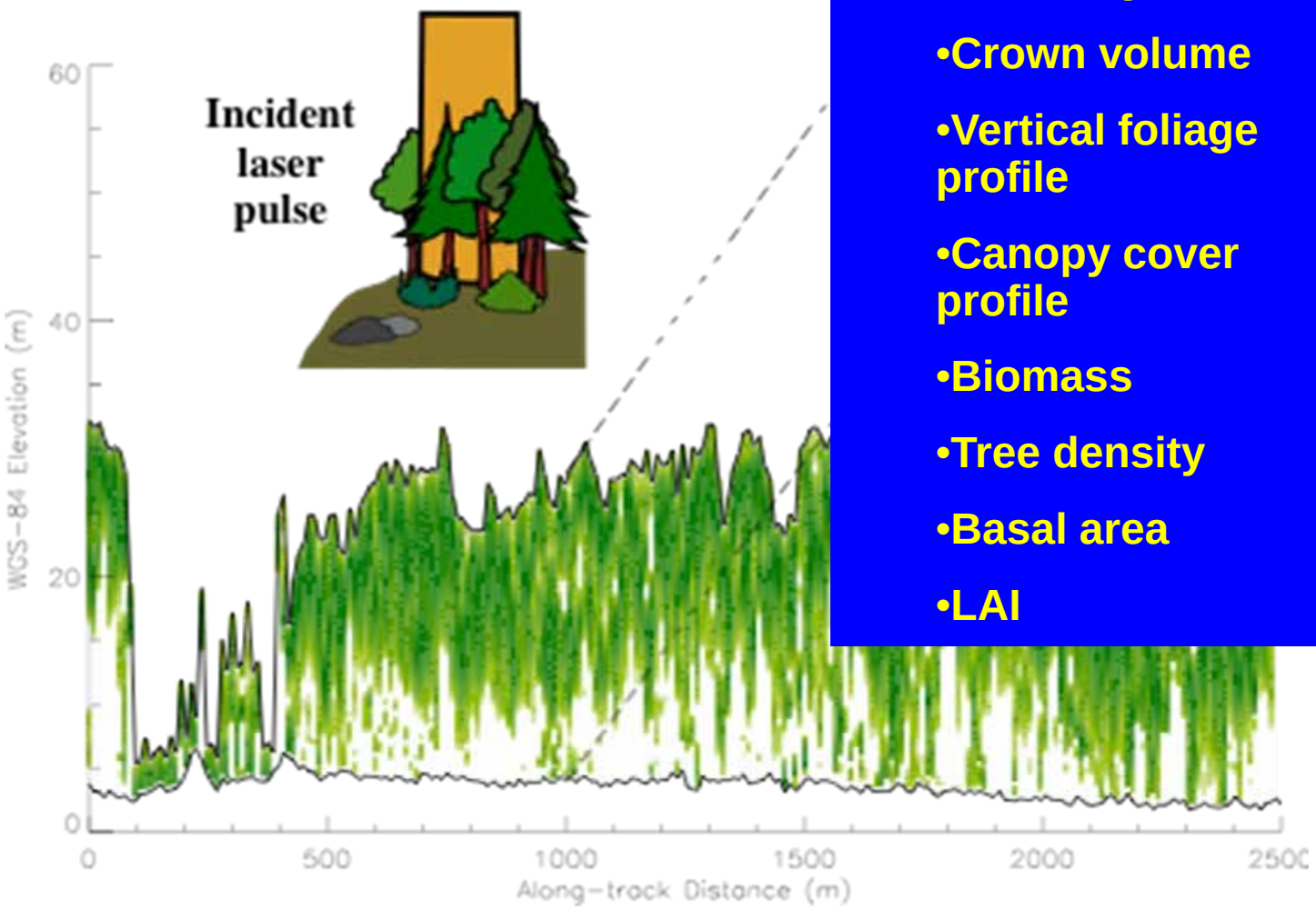


Image Segmentation

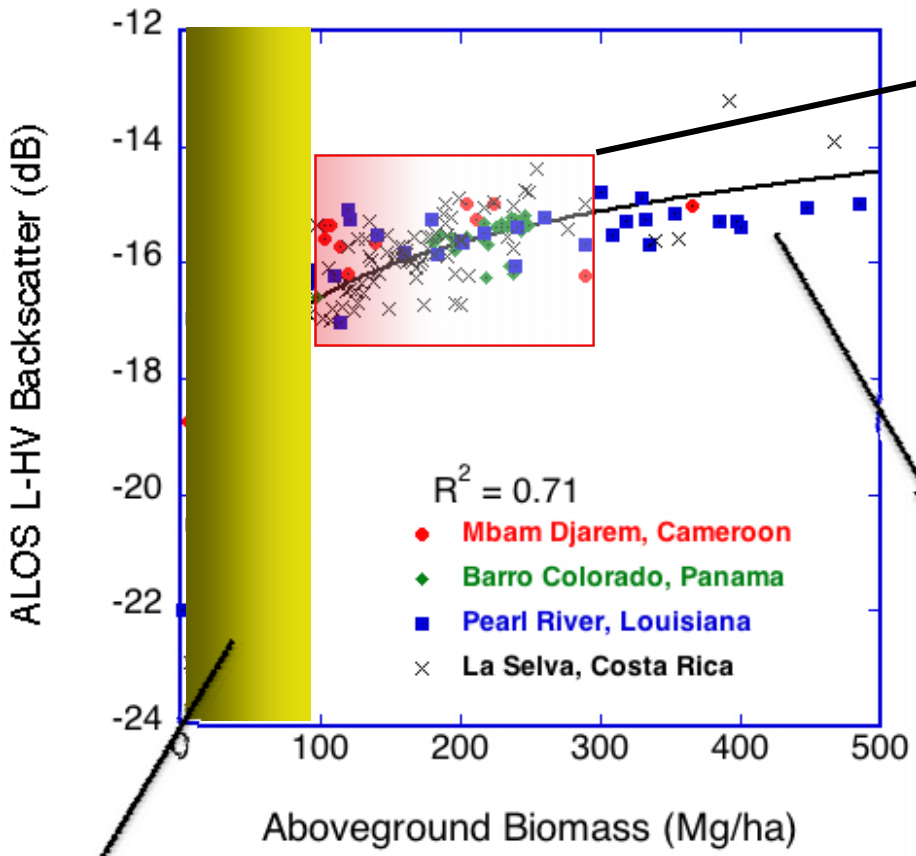
Forest Structure from Lidar



- Tree height
- Crown volume
- Vertical foliage profile
- Canopy cover profile
- Biomass
- Tree density
- Basal area
- LAI

DESDynI

Biomass Estimation Using Radar and Lidar



Low or no sensitivity above 100 Mg/ha Fusion with lidar samples may extend this range

Highest biomass areas estimated using dense grid of lidar samples alone at coarser resolutions

Many different studies achieved 10-20% accuracy for biomass below < 100 Mg/ha

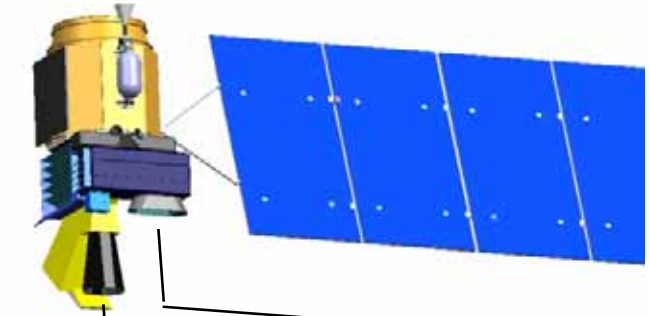
DESDynI

Current Status and Science Activities

- **Science Definition Activities**
  - **Measurement requirements and science traceability**
- **Algorithm Development**
  - **LIDAR/SAR Fusion**
  - **Sampling Strategies**
  - **3D radiative transfer**
- **Field Studies**
  - **Ongoing data collection and analysis at legacy West Coast, East Coast, Boreal, Tropical sites**
- **Ecosystem Modeling Studies**
  - **Modeling requirements for biomass, flux & habitat**
- **Mission Concept Review (soon…)**
- **Science Definition Team (soon…)**
- ***Posters at this meeting cover many of these***

NRC Decadal Survey HyspIRI

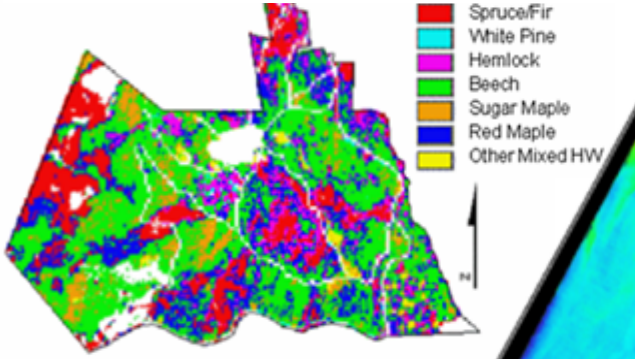
Visible ShortWave InfraRed (VSWIR) Imaging Spectrometer
+
Multispectral Thermal InfraRed (TIR) Scanner

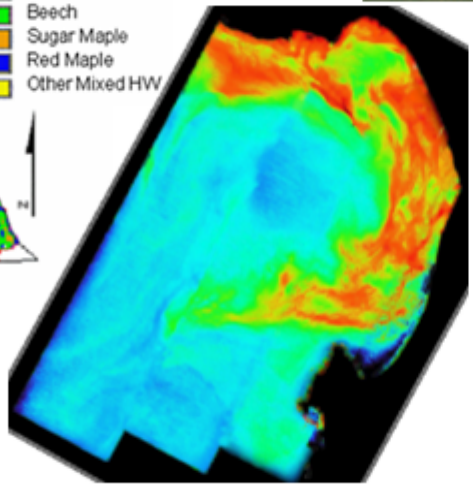


VSWIR: Plant Physiology and Function Types (PPFT)

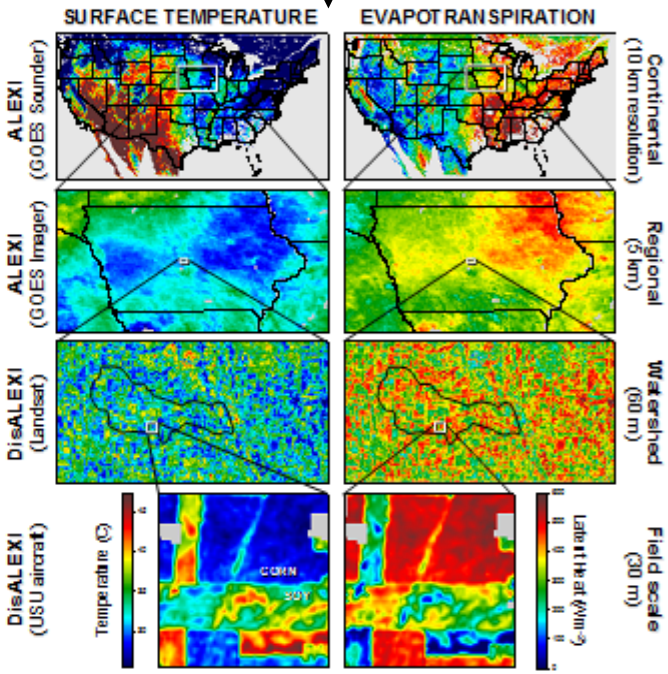
Multispectral TIR Scanner

Map of dominant tree species, Bartlett Forest, NH

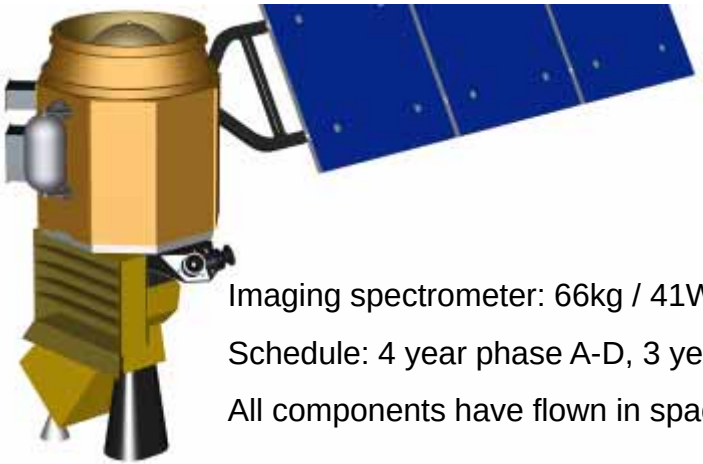


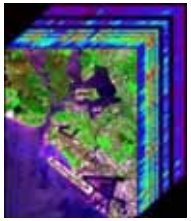


Red tide algal bloom in Monterey Bay, CA



HyspIRI Imaging Spectroscopy Science Measurements





Imaging spectrometer: 66kg / 41W

Schedule: 4 year phase A-D, 3 years operations

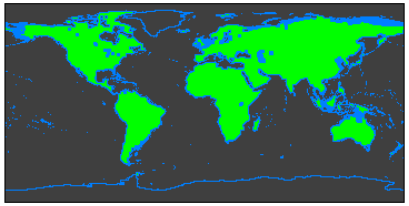
All components have flown in space

Science Questions:

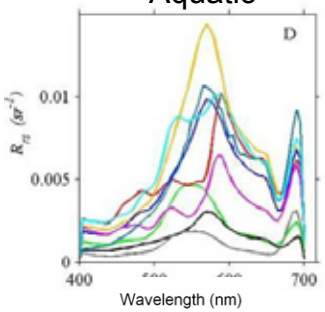
- *What is the composition, function, and health of land and water ecosystems?*
- *How are these ecosystems being altered by human activities and natural causes?*
- *How do these changes affect fundamental ecosystem processes upon which life on Earth depends?*

Measurement:

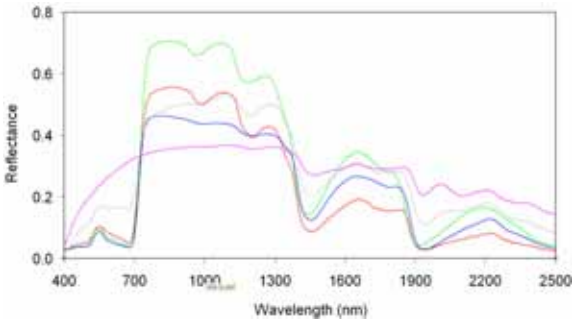
- 380 to 2500 nm in 10nm channels
- Accurate 60 m sampling
- 19 days revisit mapping mission
- Global land and shallow water



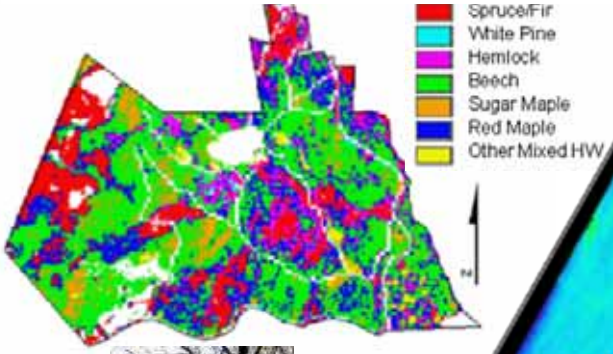
Aquatic

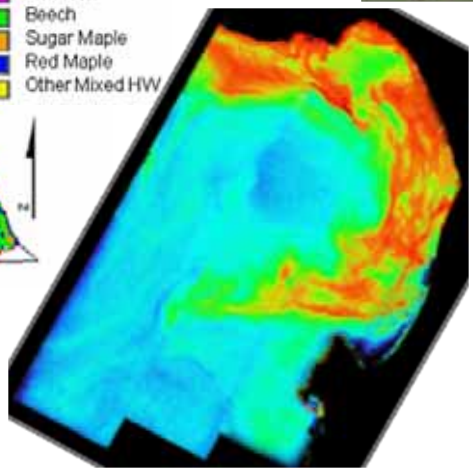


Terrestrial



Map of dominant tree species, Bartlett Forest, NH





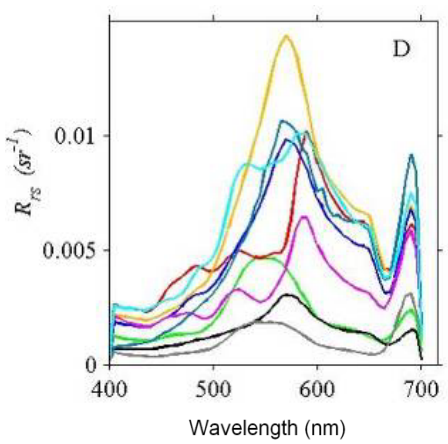
Red tide algal bloom in Monterey Bay, CA

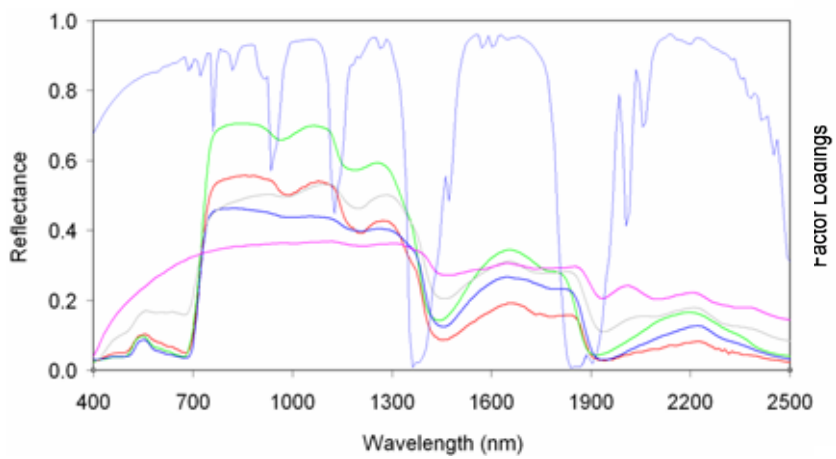
VSWIR Overarching Science Questions

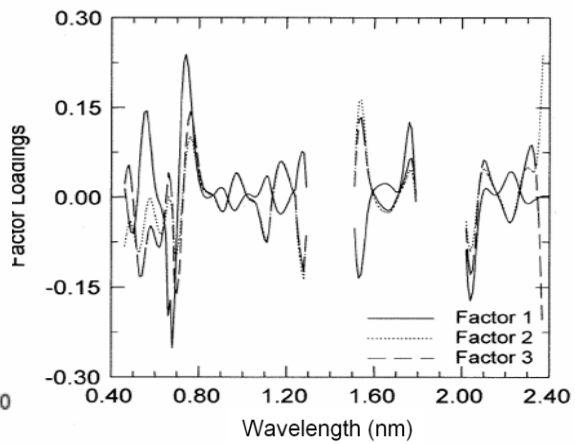
- **VQ1. Pattern and Spatial Distribution of Ecosystems and their Components, (EM,JG)**
  - What is the pattern of ecosystem distribution and how do ecosystems differ in their composition or biodiversity? [DS 195]
- **VQ2. Ecosystem Function, Physiology and Seasonal Activity, (EM,JG)**
  - What are the seasonal expressions and cycles for terrestrial and aquatic ecosystems, functional groups and diagnostic species? How are these being altered by changes in climate, land use, and disturbances? [DS 191, 195, 203]
- **VQ3. Biogeochemical Cycles (SO, SU)**
  - How are biogeochemical cycles for carbon, water and nutrients being altered by natural and human-induced environmental changes?
- **VQ4. Changes in Disturbance Activity (RK,GA)**
  - How are disturbance regimes changing and how do these changes affect the ecosystem processes that support life on Earth?
- **VQ5. Ecosystem and Human Health, (PT,GG)**
  - How do changes in ecosystem composition and function affect human health, resource use, and resource management?
- **VQ6. Land Surface and Shallow Water Substrate Composition (RG, HD)**
  - What is the land surface soil/rock and shallow water substrate composition?

Basis for Continuous Spectral Measurement

- Plant and phytoplankton functional types and species have biochemical and biophysical properties that are expressed as reflectance and absorption features spanning the spectral region from 380 to 2500 nm.
- Individual bands do not capture the diversity of biochemical and biophysical signatures of plant functional types or species.
- Changes in the chemical and physical configuration of ecosystems are often expressed as changes in the contiguous spectral signatures that relate directly to plant functional types, vegetation health, and species distribution.
- Other constituents of the Earth system (Minerals, Soils, Snow, etc) have spectral characteristics allow use of this spectroscopic measurement approach for corresponding science questions.
- Important atmospheric correction information and calibration feedback is contained within the spectral measurement.

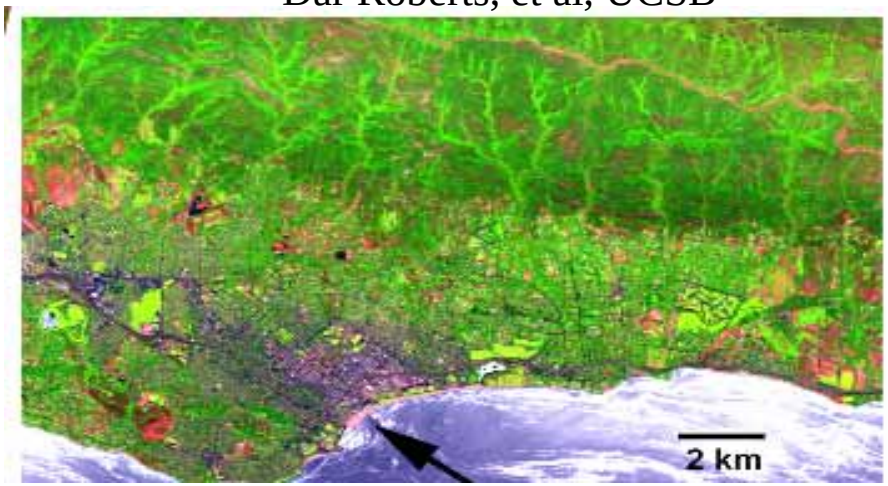




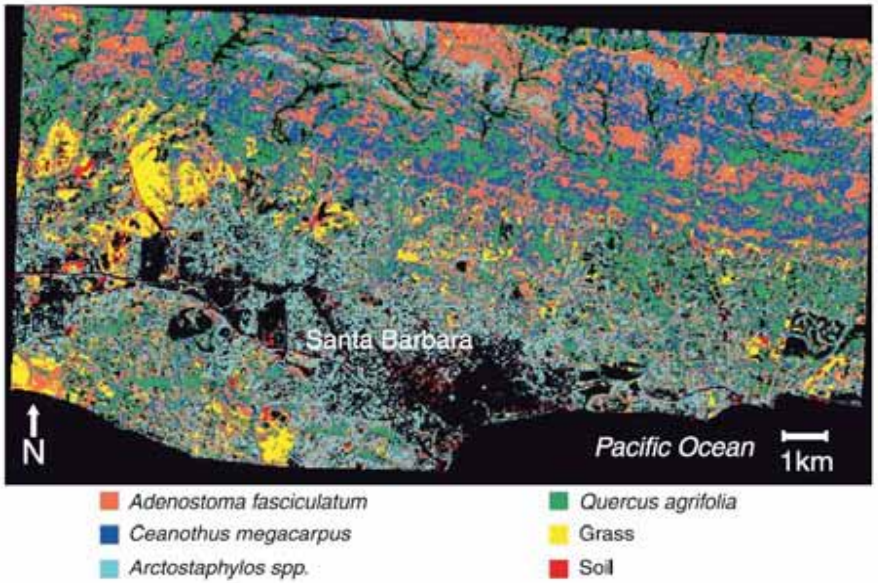


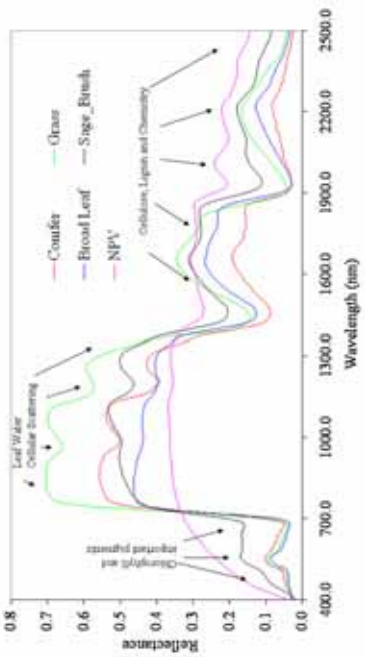
Vegetation Functional Type Analysis, Santa Barbara, CA

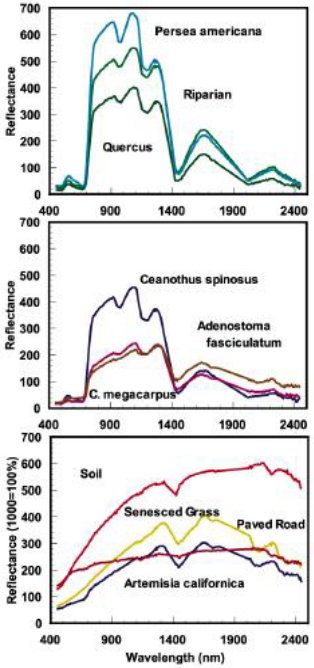
Dar Roberts, et al, UCSB



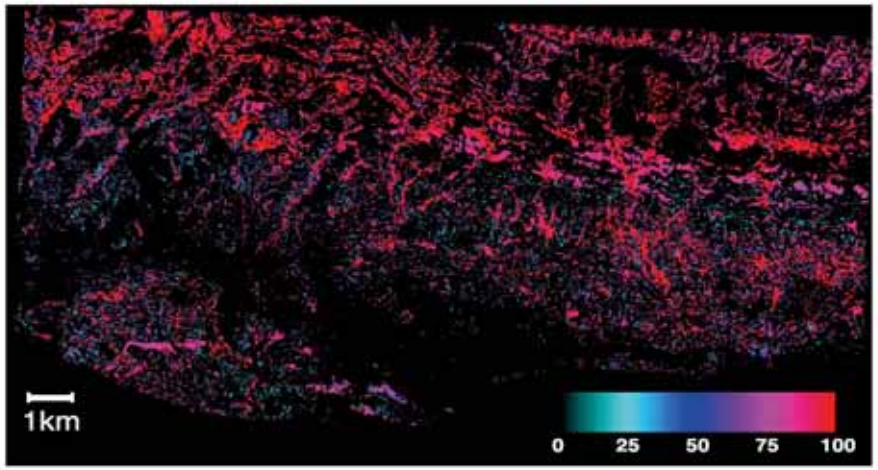
MESMA Species Type 90% accurate







Species Fractional Cover

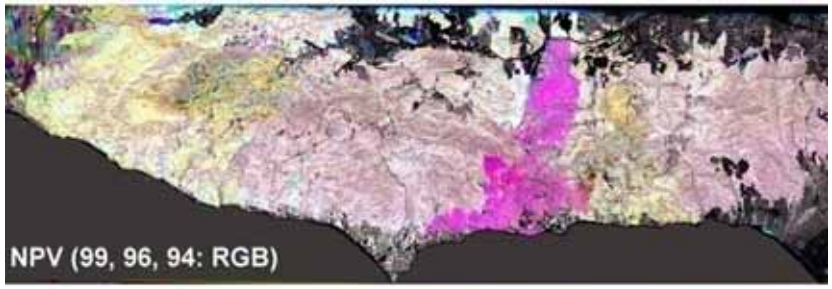


Dennison, P.E., and Roberts, D.A.,2003 Endmember Selection for Multiple Endmember Spectral Mixture Analysis using Endmember Average RSME, *Remote Sens. Environ*., 87(2-3), 123-135.

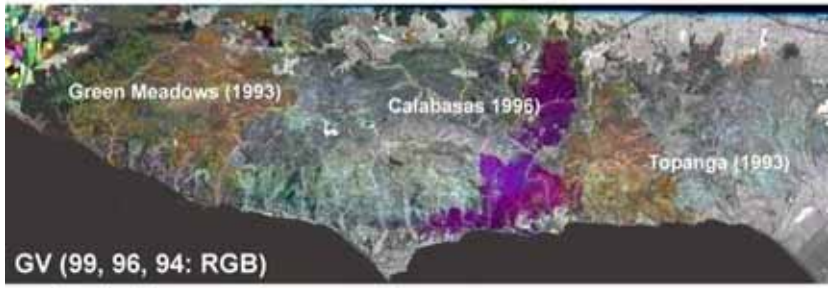
Roberts, D.A., Dennison, P., Ustin, S.L., Reith, E., and Morais, M., 1999, Development of a Regionally Specific Library for the Santa Monica Mountains using High Resolution AVIRIS Data, Proc. 8th AVIRIS Earth Science Workshop, JPL, Pasadena, CA 349-354., Feb 8-11, 1999.

Response to Disturbance

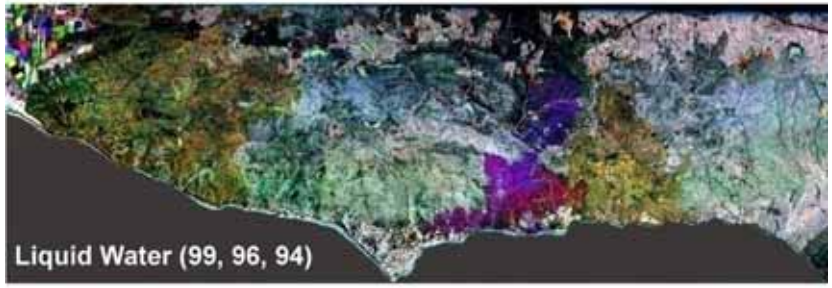
Non photosynthetic Vegetation



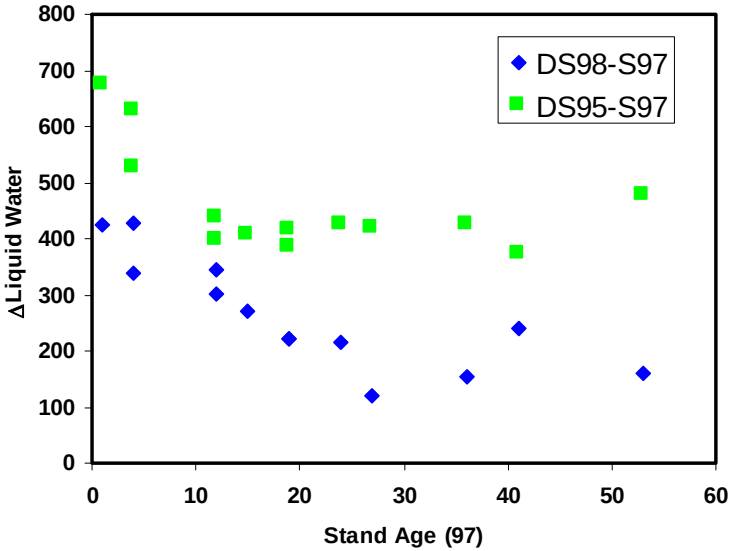
Green vegetation



Canopy Liquid Water



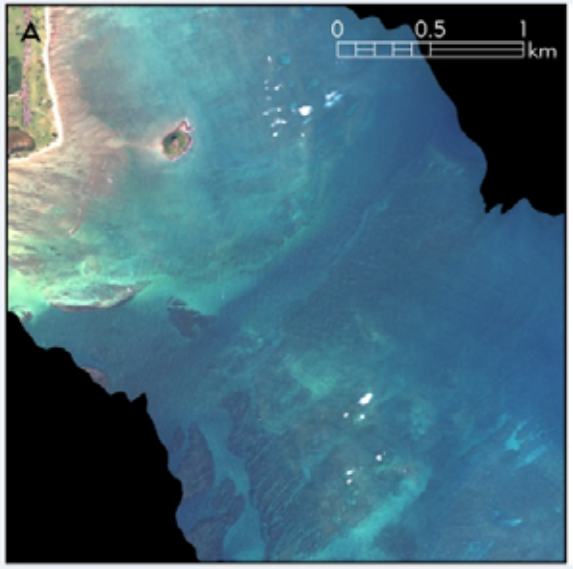
Post-fire response to three different fires, two in 1993 and one in 1996. Canopy moisture is the most sensitive measure of change, as shown by overlap between the 1996 and 1993 Calabasas and Topanga fires. High fire return intervals in Southern California are impacting ecosystems, eliminating some shrub species.



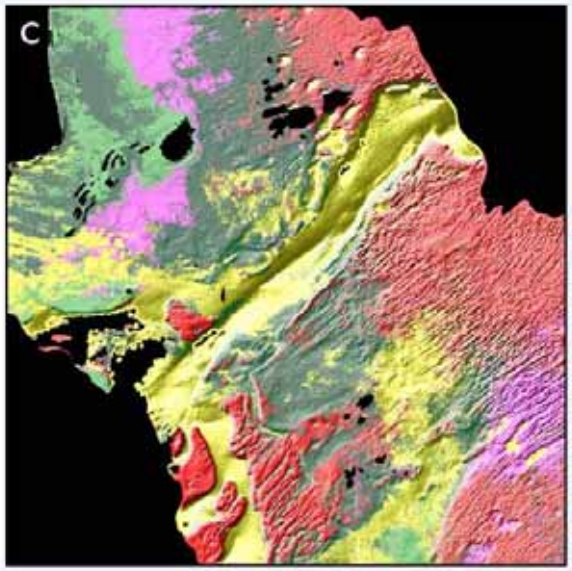
Interannual changes in canopy moisture show significant stand age differences up to 30 years (shown as the difference in canopy moisture between spring98 and spring 97 –blue, and spring97 and spring 95 - green). These results indicate that seasonal drought response is age dependent in shrublands, with older stands less impacted by drought. These results require seasonal imaging spectroscopy observations.

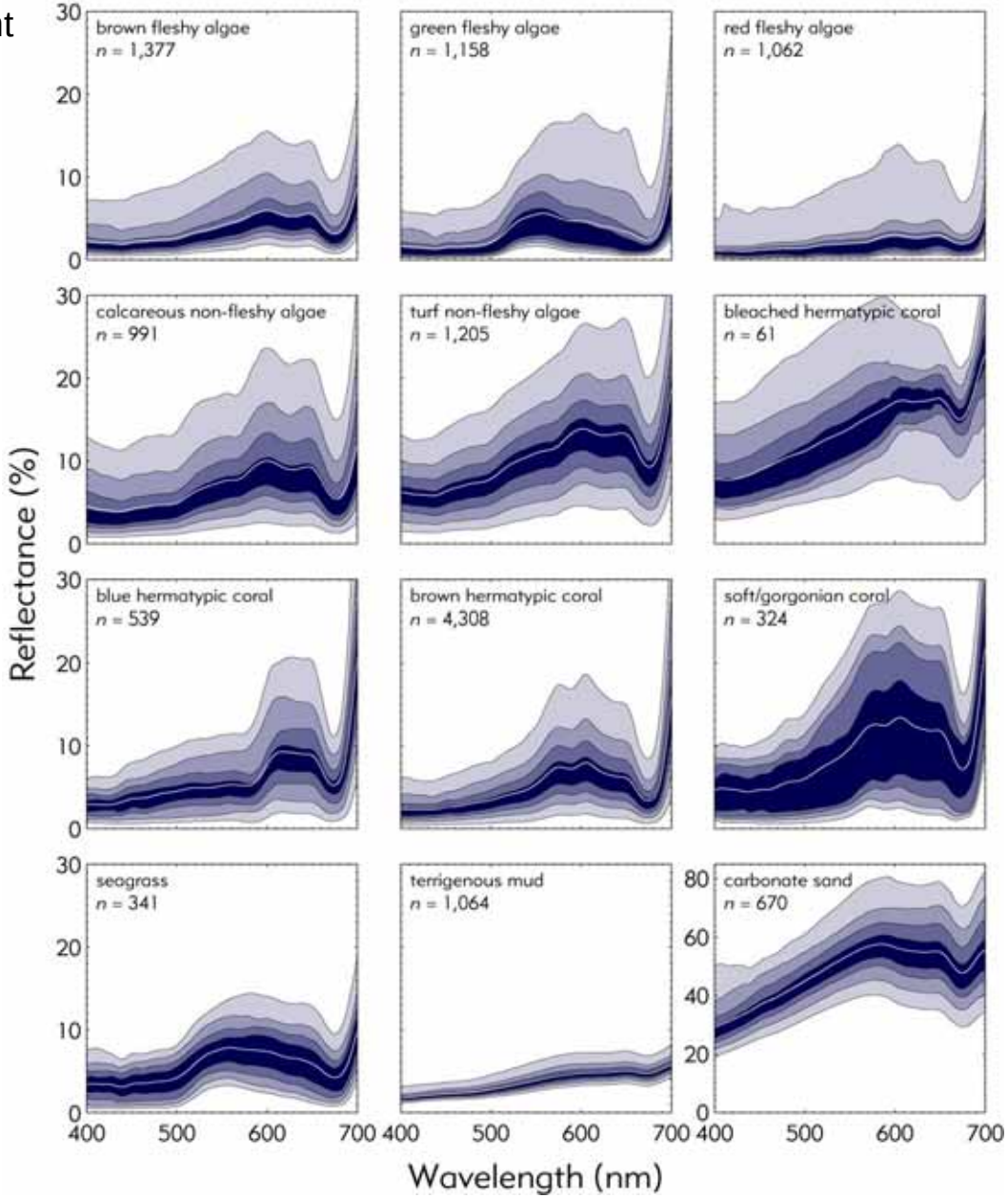
Roberts D.A., 2000, Remotely Sensed Analysis of Successional Patterns following Wildfire in the Santa Monica Mountains, presented at the First Center for Environmental Analysis (CEA-CREST) symposium, Pasadena, CA, May 19, 2000.

Imaging Spectrometer Measurement



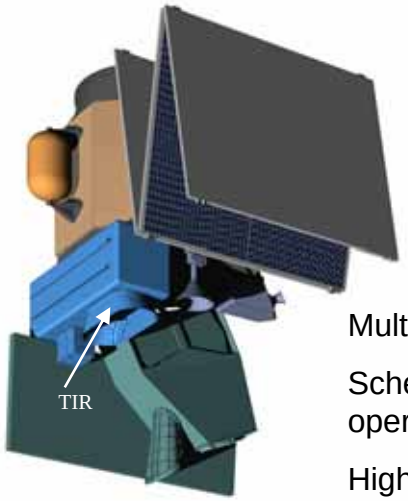
Benthic Compositional Mapping

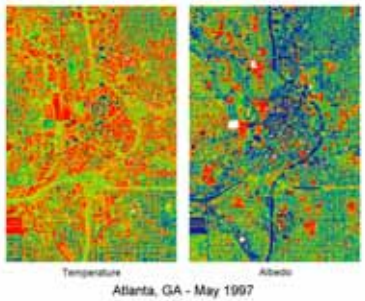




Spectral Measurements of Shallow Water Benthic Composition (E. Hochberg, Nova Southeastern University, FL)

HyspIRI Thermal Infrared Multispectral (TIR) Science Measurements





Multispectral Scanner

Schedule: 4 year phase A-D, 3 years operations

High Heritage

Science Questions:

TQ1. Volcanoes/Earthquakes (MA,FF)

– How can we help predict and mitigate earthquake and volcanic hazards through detection of transient thermal phenomena?

• TQ2. Wildfires (LG,DR)

– What is the impact of global biomass burning on the terrestrial biosphere and atmosphere, and how is this impact changing over time?

• TQ3. Water Use and Availability, (MA,RA)

– How is consumptive use of global freshwater supplies responding to changes in climate and demand, and what are the implications for sustainable management of water resources?

• TQ4. Urbanization/Human Health, (DQ,GG)

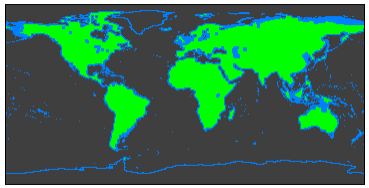
– How does urbanization affect the local, regional and global environment? Can we characterize this effect to help mitigate its impact on human health and welfare?

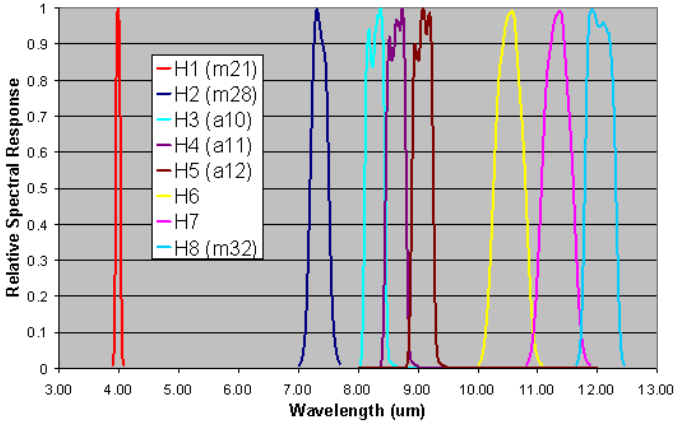
• TQ5. Earth surface composition and change, (AP,JC)

– What is the composition and temperature of the exposed surface of the Earth? How do these factors change over time and affect land use and habitability?

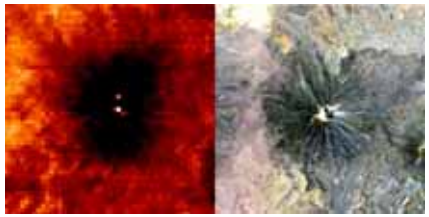
Measurement:

- 7 bands between 7.5-12 µm and 1 band at 4 µm
- 60 m resolution, 5 days revisit
- Global land and shallow water

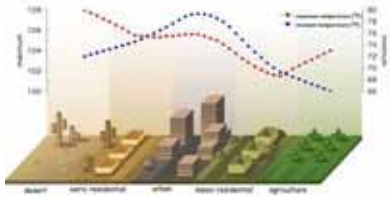




Andean volcano heats up

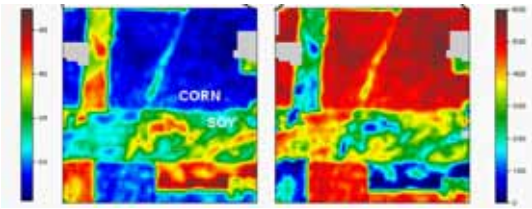


Urbanization



Volcanoes

Water Use and Availability



Surface Temperature

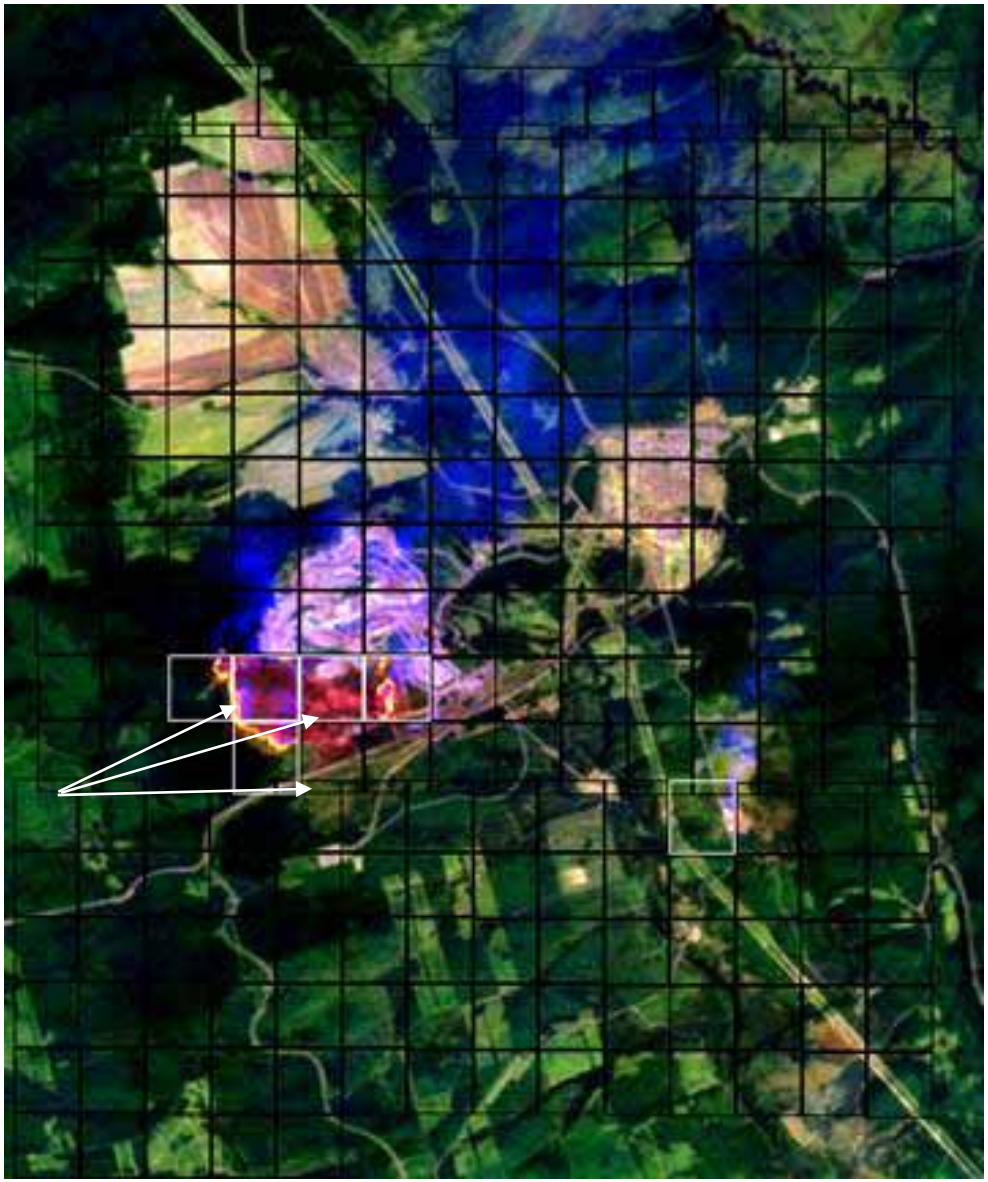
Evapotranspiration

Wildfires:
How are global fire regimes changing?

High resolution thermal instrument can distinguish between the forest and non-forest parts of the flaming front allowing the fire type, intensity, etc., to be determined which indicates fire regime.

White squares show fire pixels detected by MODIS. Insufficient information to detect fire type

MIR band provides radiant flux to estimate rate at which biomass combusted and instantaneous emission estimate



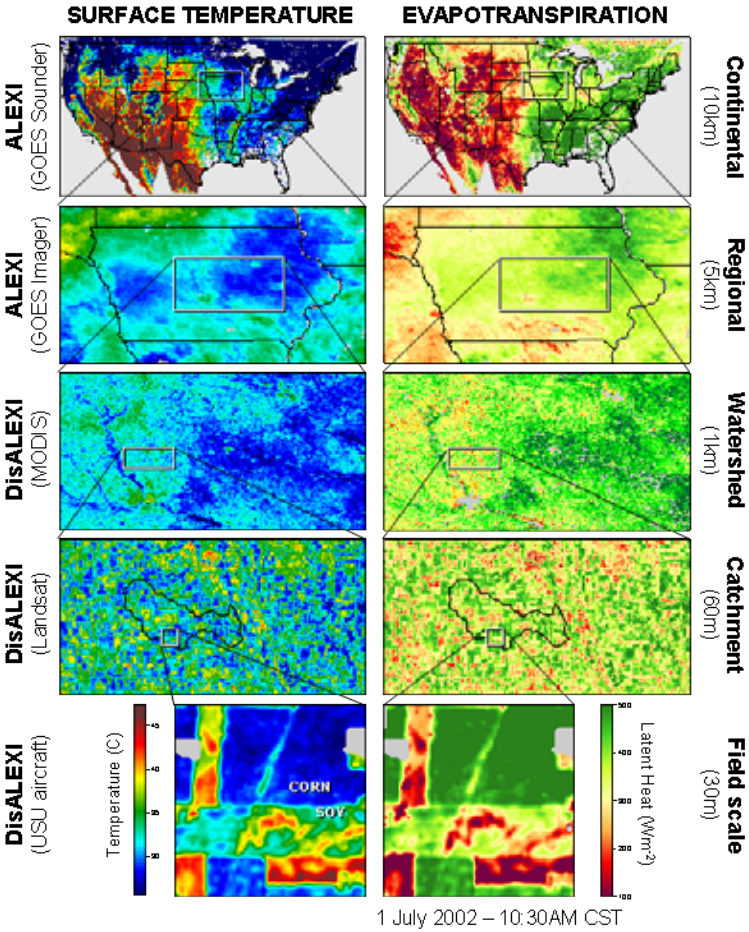
30 m ASTER scene with MODIS pixels superimposed (black squares)

Central Siberia

30 May 2001

HyspIRI will provide high spatial resolution mid to thermal infrared data for determining the fire regime and allowing flux estimation on a weekly basis

TQ3a: How is climate variability impacting the evaporative component of the global water cycle over natural and managed landscapes?
(DS 166, 196, 203, 257, 368; WGA)



Multi-scale ET maps for 1 July 2002 produced using surface temperature data from aircraft (30-m resolution), Landsat-7 ETM+ (60-m), Terra MODIS (1-km), and GOES Imager (5-km) instruments (Anderson and Kustas (2008), Eos, 89, 233-234)

Science Issue:

- Based on principles of surface energy balance, the land-surface temperature signal conveys valuable information about the evaporative component of the hydrologic cycle and its response to varying climatic drivers. If we can accurately monitor this response in relationship to land-use and land-cover conditions, we will improve our ability to forecast water consumption and demand and to develop effective climate adaptation strategies for our water systems.

Tools:

- HyspIRI TIR observations of surface brightness temperature at <100m resolution to resolve field-scale land use, preferably with 3+ bands in the 8-12µm region for atmospheric and emissivity corrections. The weekly revisit of HyspIRI will improve accuracy of seasonally integrated ET estimates.
- Collocated/contemporaneous maps of vegetation index and landuse.
- Insolation data to estimate net radiation.
- Regional scale ET maps using coarser resolution TIR imagery from geostationary satellites and MODIS/VIIRS provide spatial context for local assessments.

Approach:

- Periodic maps of instantaneous clear-sky ET from a TIR-based surface energy balance algorithm can be interpolated to produce daily ET maps using time-continuous observations of reference ET or available energy from met stations or geostationary satellites.
- Record of daily ET at scales resolving major land use patterns can be analyzed in conjunction with gridded climate data.

Summary

We have developed a sets of science questions that are well aligned with the HyspIRI Mission called for in the NASA Earth Science and Applications Decadal Survey.

We have reviewed and refined these questions that relate to both science and applications objectives and developed traceability to a set of science measurements.

We have established a high heritage and low risk approach for acquiring the HyspIRI VSWIR and TIR science measurements

<u>Upcoming Events</u>
HyspIRI Symposium
May 4-5, Goddard Space Flight Center, Md

HyspIRI Workshop
Aug 24-26, Pasadena, CA

Decadal Survey call for ICESat-2

"Given the rapidity of the change in polar sea ice and ice sheets and the limited remaining lifetime of ICESat, a critical gap would arise if new measurements were not made prior to …2015."

(ICESat fired its last laser pulse on October 11, 2009)

ICESat-2 Scientific Objectives from Decadal Survey

1) Determine mass balance of ice sheets and their contribution to sea level
   - How and why is it changing, how will it change in the future
2) Repeat measurements of sea ice freeboard, enabling estimates of sea ice thickness change
   - What controls ice growth and shrinkage? What are implications for global climate of changing sea ice cover
3) **Measuring canopy depth to support estimating changes in terrestrial biomass**
   - How much carbon is stored in above-ground biomass (complement to DESDynI)

ICESat-2 Level-1 Science Requirements

- ICESAT-2 shall measure ice-sheet elevation changes to 0.2 cm/yr accuracy on an annual basis.
- ICESAT-2 shall measure ice-sheet annual surface elevation change rates on outlet glaciers to an accuracy of better than 0.25 m/yr over areas of 100 km2 for year-to-year averages, and along linear distances of 1 km along-track.
- ICESAT-2 shall resolve winter (accumulation) and summer (ablation) ice-sheet elevation change to 2.5 cm at 25 km x25 km spatial scales.
- ICESAT-2 shall provide monthly near-repeat coverage of sea-ice freeboard to an uncertainty of 3 cm at 25 km x25 km spatial scales for the Arctic Ocean and Southern Oceans.
- ICESAT-2 shall make measurements for a minimum five-year duration.
- **ICESAT-2 shall produce a global vegetation height surface with 3-m accuracy at 1-km resolution[1].**

1- ICESat-2 will not achieve the vegetation science objectives specified by DESDynI Science Study Group (SSG), but rather will support them to the extent possible with complementary data without compromising ice science objectives.

ICESat-2 Mission Concept

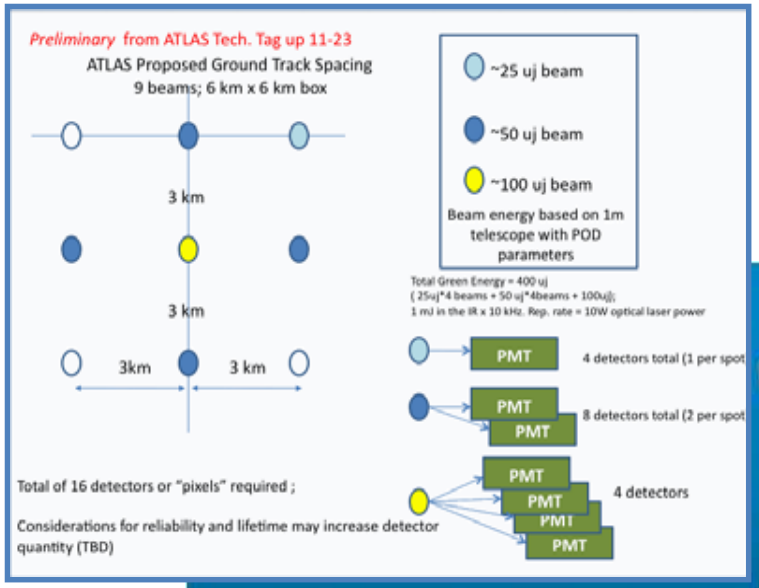
In contrast to ICESat design, ICESat-2 will use micro-pulse multi-beam photon counting approach

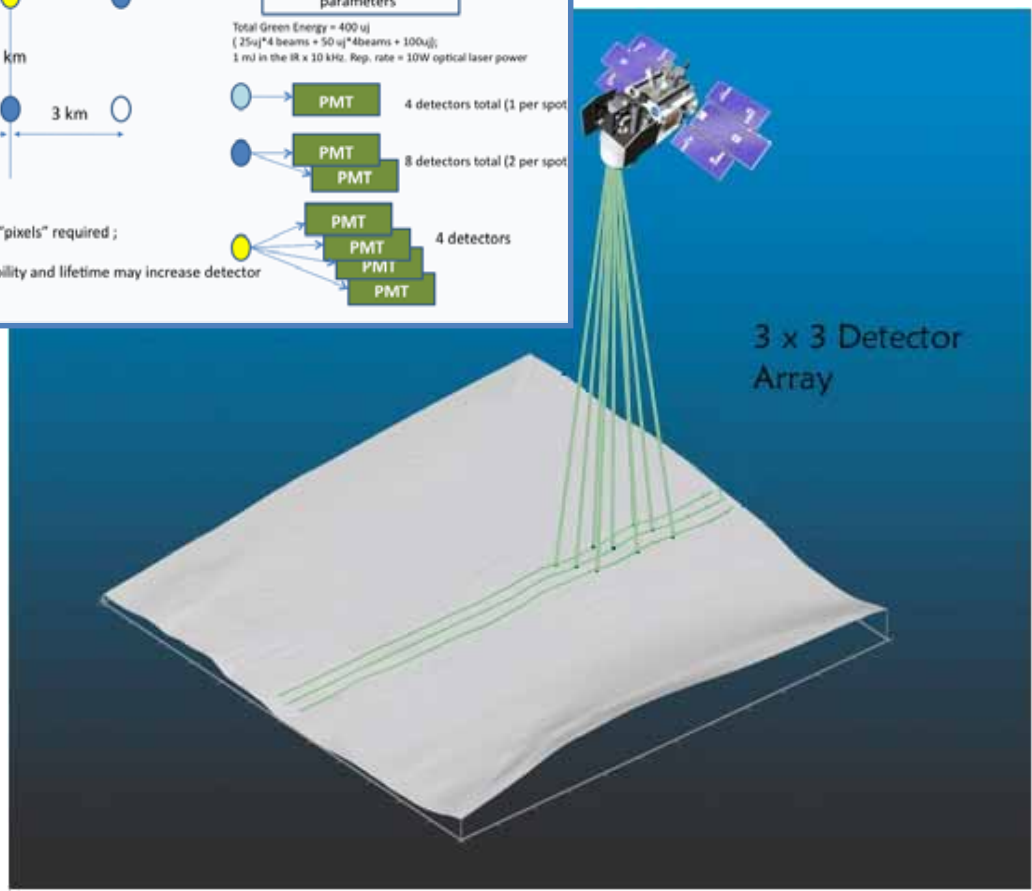
Motivation:
Dense cross-track sampling to resolve surface slope on an orbit basis.

High repetition rate (10 kHz) generates dense along-track sampling (~70 cm).

Detector readiness requires use of green laser instead of NIR.

Estimated Launch Date of 2016.

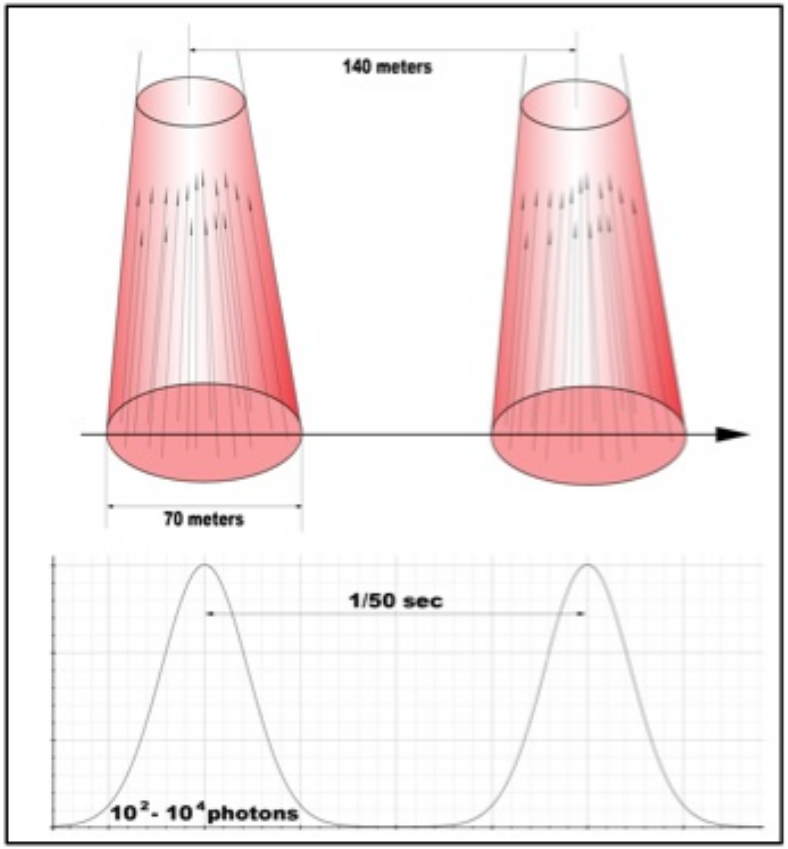


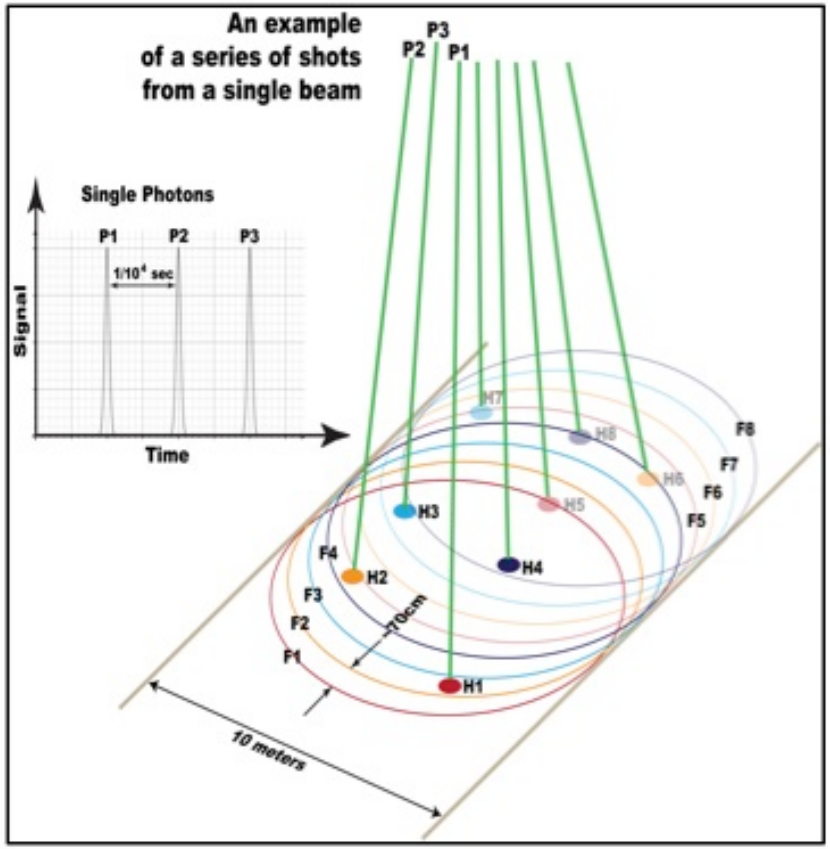


What's New with ICESat-2

Original Concept "Analog" Pulsed Laser
50 Hz laser repetition rate
70 m footprint
140 m between footprints

Now → MicroPulsed Laser
10 KHz laser repetition rate
1+ photon from 10 m footprint
70 cm between adjacent footprints





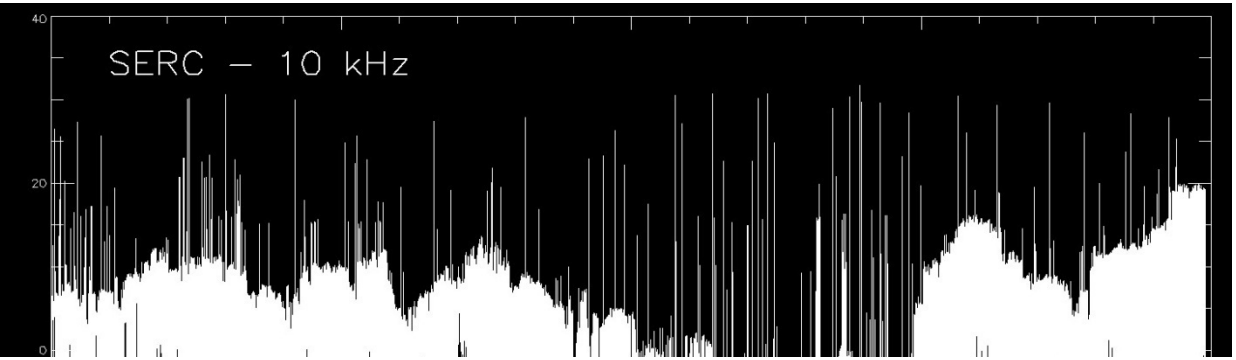
Is ICESat-2 capable of generating a usable Vegetation Product for the Science Community?

SDT members working on vegetation structure have expressed concerns about whether the approach will enable a vegetation height product to be produced for multi-layered or moderate- to full-volume canopies where it may be possible that insufficient photons will be detected to distinguish a ground return from one within the canopy, sub-canopy, or shrub layers.

SDT is conducting tests and simulations to assess whether ICESat-2 will meet the ecosystem requirements.

1) Conducted low altitude airborne Photon Counting flights over Pine Barrens and SERC in October 2009
   A. Sigma Space system flown at 2000 ft AGL at 20 kHz laser repetition rate
   B. 14 deg conical scanning system, 532 nm laser wavelength
   C. Data flown at dusk to reduce solar background noise
2) Photon Counting Simulator is being developed at GSFC
3) High altitude flights (MABEL) are planned for Spring/Summer 2011

Initial Ground Detection Assessment



Reference ground surface was generated based on full resolution Photon Counting Data.

Estimates of ground surface were computed from down-sampled data*.

* Down-sampled only at ICESat-2 rep rate and along-track spacing (10 kHz with 70 cm spacing)

- Reference
- Amy
- Ross
- Guoqing

Limitations – these are aircraft data; <u>not</u> a space simulation

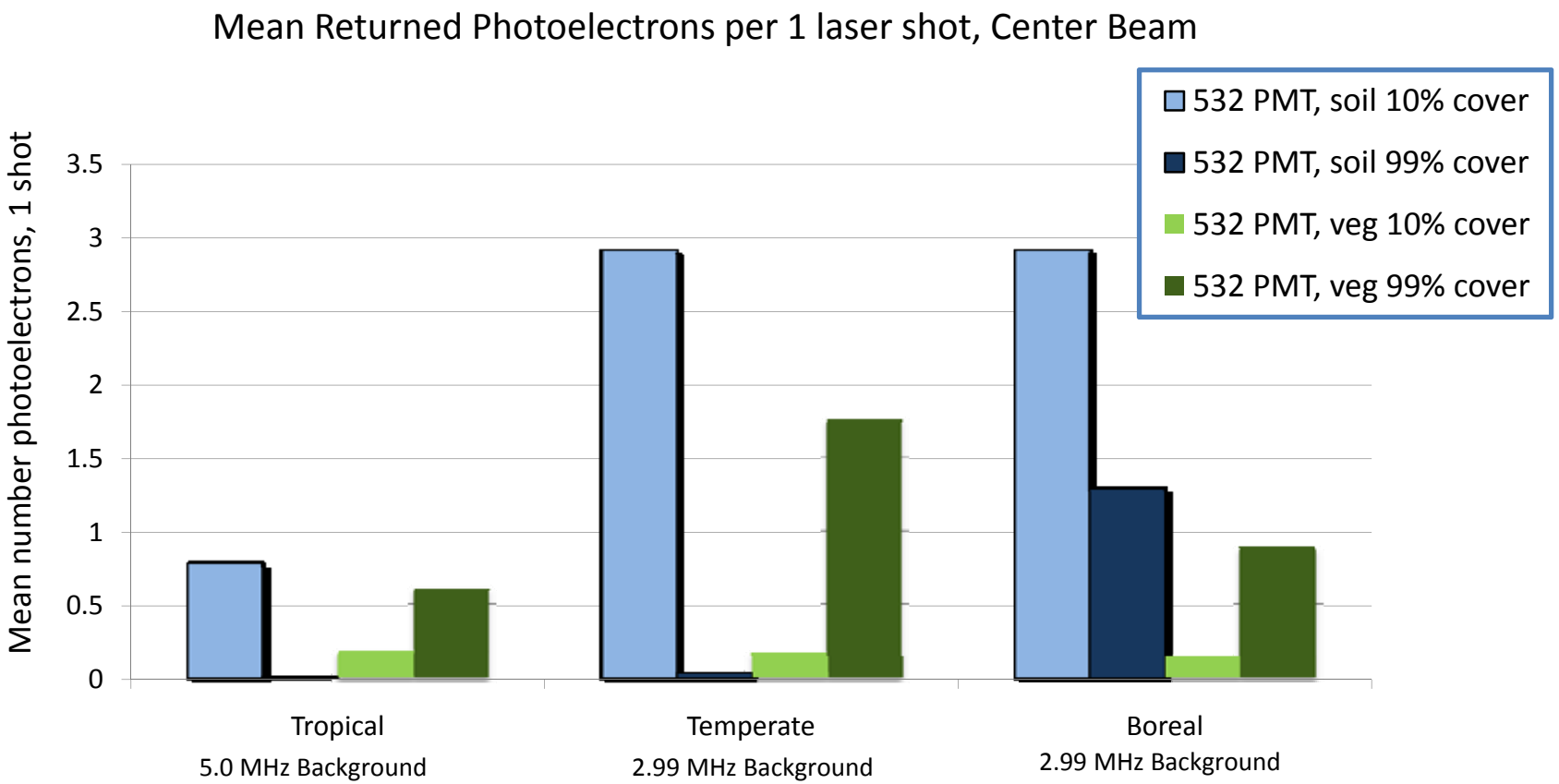
- Data range-gated above and below forest, no atmospheric contamination.
- Probability of detection/shot = 0.3 (controversial, 0.1-0.2 may be more realistic).

<u>10 kHz results - 70 cm along-track, n = 115</u>:

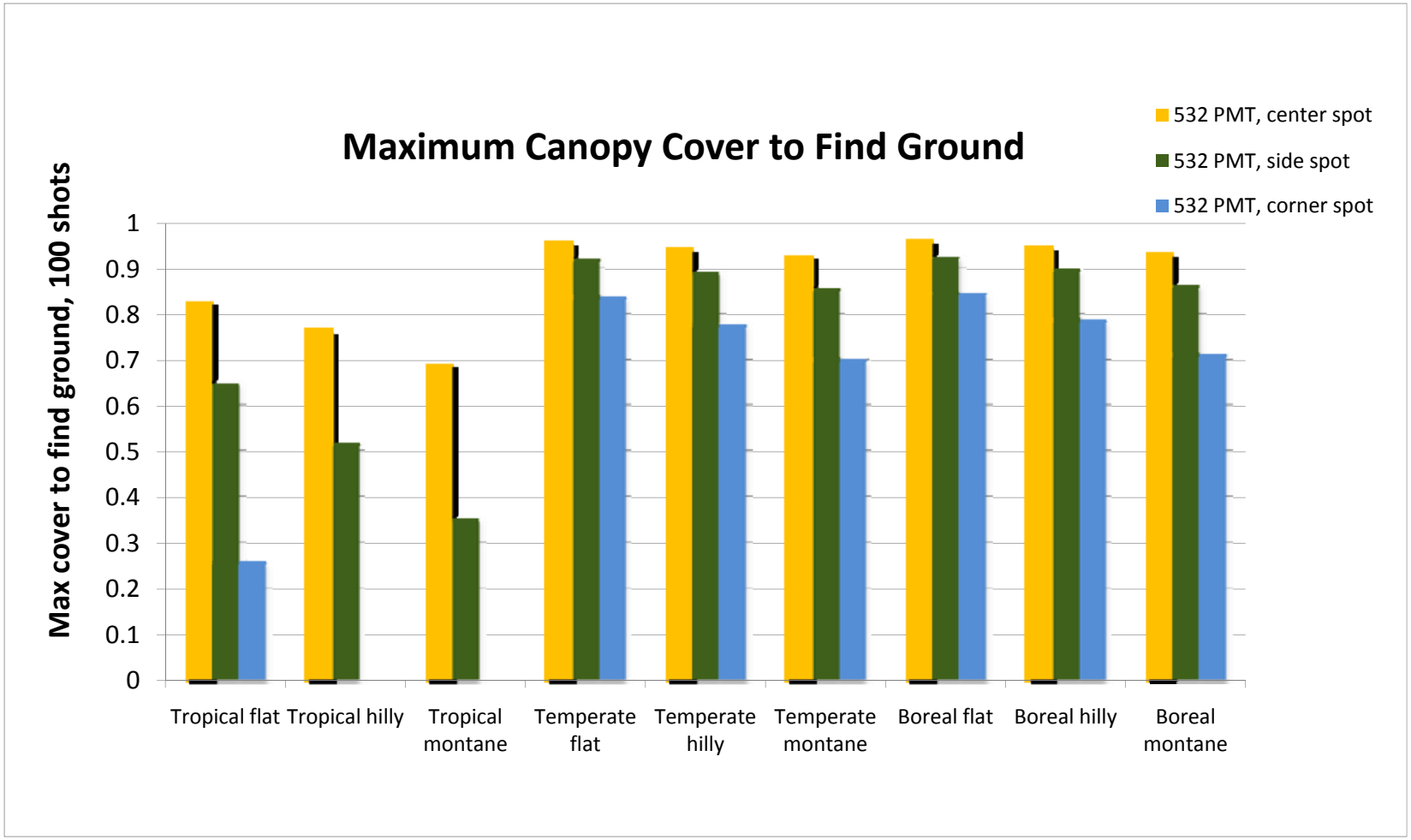
	Mean Difference (m)	Std Dev (m)
Amy	-2.05	4.12
Ross	-1.59	4.43
Guoqing	1.71	5.29

Photon Counting Design Case Results

ICESat-2 Instrument engineering team modeled estimates on the number of returned photons per laser shot as a function of laser energy, surface reflectance, canopy cover, surface roughness, surface topography, and solar background noise. SDT provided parameters for design cases of Tropical, Temperate, and Boreal forests.



Preliminary Photon Canopy Penetration



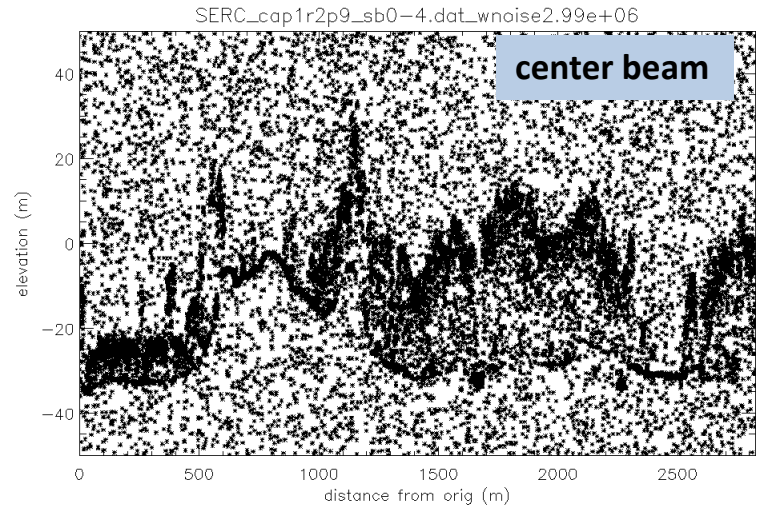
Simulation of ICESat-2 Data

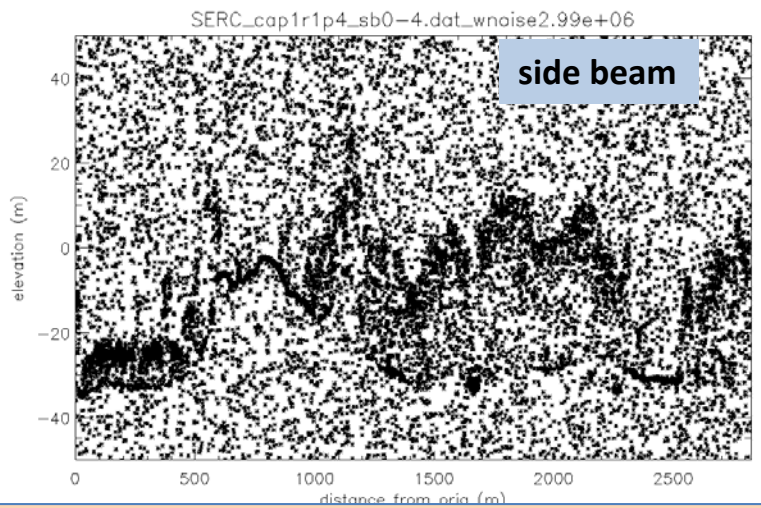
SERC – Smithsonian Environmental Research Center

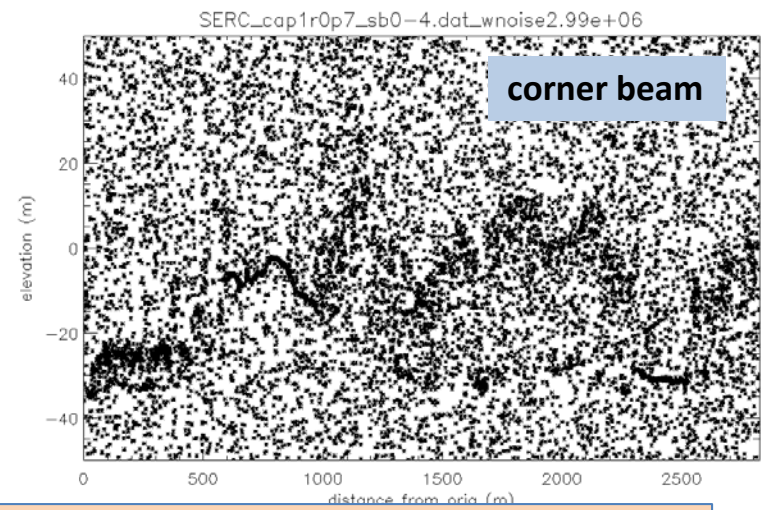
2.99 MHz atmosphere background noise applied

3 different values used for mean number of photons returned per shot

- 2.92001 – center beam
- 1.46001 – side beam
- 0.730003 – corner beam







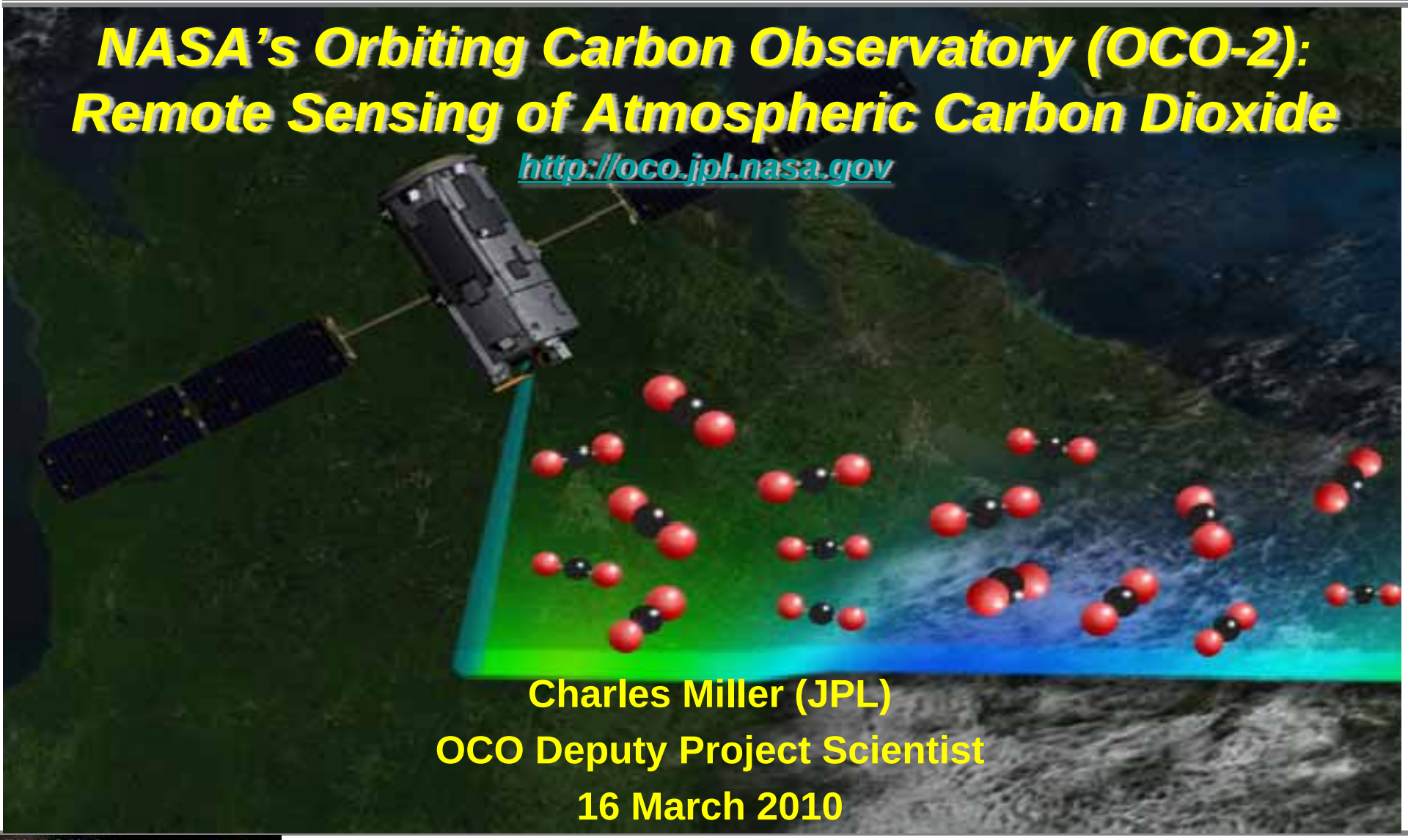
ICESat-2 Instrument engineering team modeled estimates on the number of returned photons per laser shot as a function of surface reflectance, canopy cover, surface roughness, surface topography, and solar background noise.

ICESat-2 Role for Terrestrial Vegetation

- Members of SDT is assessing the potential of ICESat-2 for providing complementary data for the ecosystem community.
- Looks promising for areas with light canopy cover, but could be limited in ecosystems with dense vegetation or poor atmospheric conditions
- Will perform better on night passes instead of daytime passes

NASA's Orbiting Carbon Observatory (OCO-2): Remote Sensing of Atmospheric Carbon Dioxide

http://oco.jpl.nasa.gov



Charles Miller (JPL)

OCO Deputy Project Scientist

16 March 2010

NASA Orbiting Carbon Observatory (OCO-2)

OCO was selected by NASA in 2002 as an Earth System Science Pathfinder designed to detect small changes in the spatial distribution of atmospheric CO_2

- The design was optimized to validate a technical approach for improving regional scale source/sink estimates over the globe

- The OCO spacecraft was lost on 24 February 2009 due to a launch vehicle malfunction

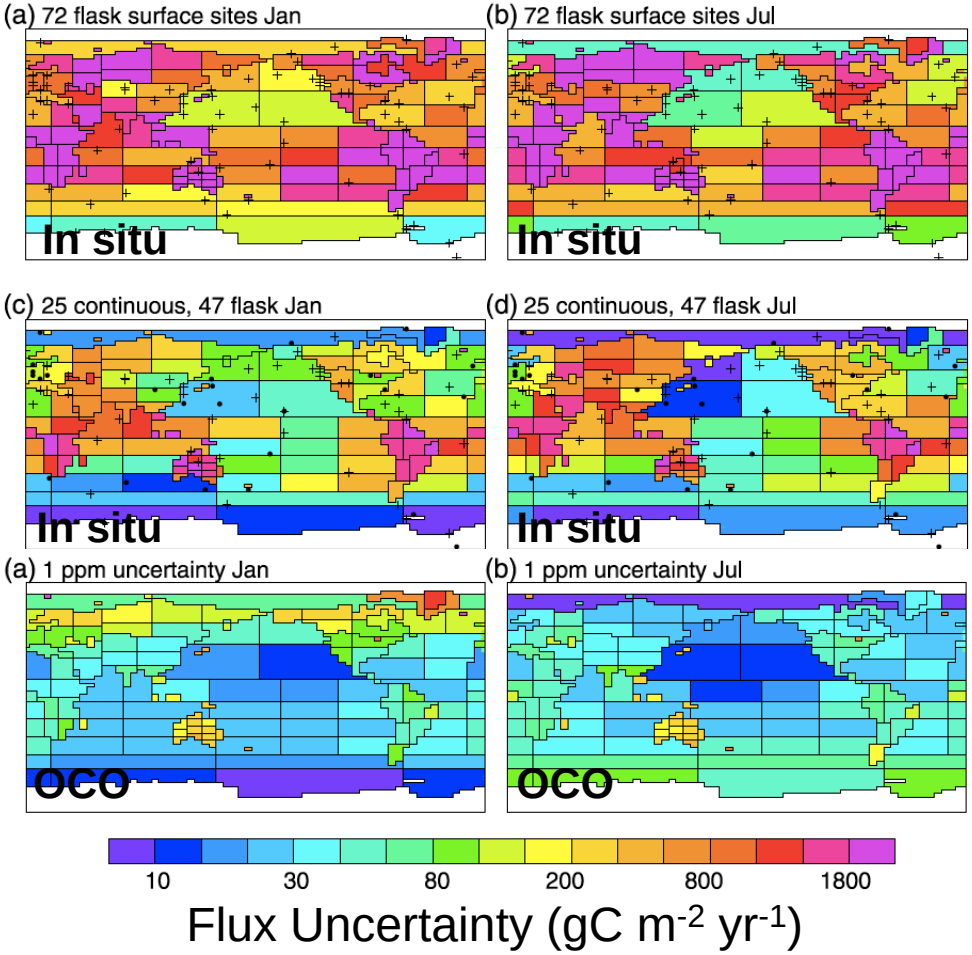
OCO-2 entered into a tailored formulation phase on 1 March 2010

- The Whitehouse highlighted funding for OCO-2 in its FY11 budget
- The President's funding profile supports OCO-2 launch readiness no later than Feb 2013 (assuming an October 1, 2010 authorization to proceed)
- OCO-2 will be a "carbon copy" with exceptions for parts obsolescence – **the basic instrument and sampling strategies remain unchanged**
- OCO-2 will provide unprecedented space-based CO_2 detection sensitivity
- OCO-2 capabilities are still state of the art

The Orbiting Carbon Observatory (OCO-2): Science Objectives

NASA's Orbiting Carbon Observatory (OCO) was designed to return space-based measurements of atmospheric carbon dioxide (CO_2) with the sensitivity, accuracy and sampling density needed to quantify regional scale carbon sources and sinks and characterize their variability.

- High precision is essential to resolve spatial variations in X_{CO2} of 1-2 ppm against a ~390 ppm background

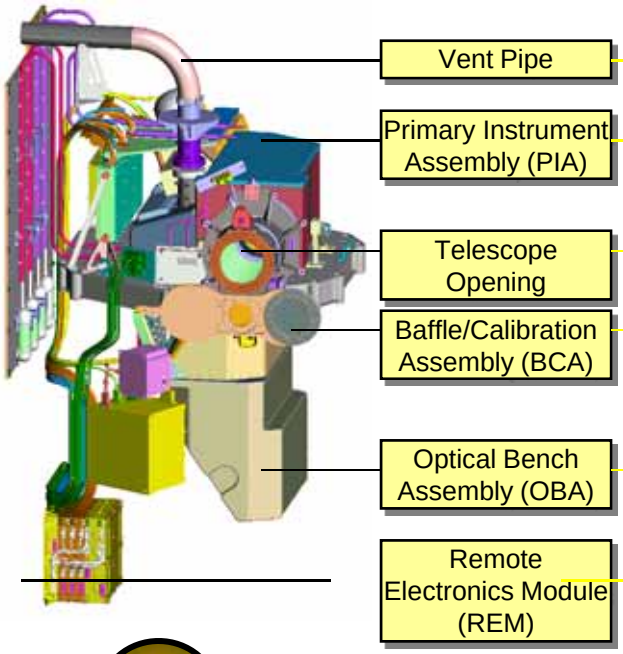


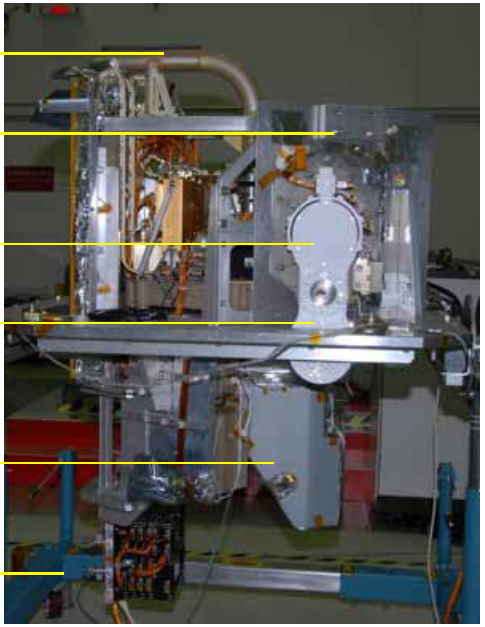
Olsen & Randerson (2004)

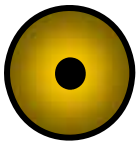
Miller et al. (2007)

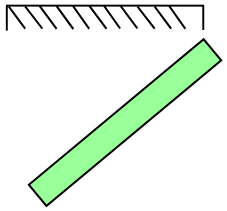
The OCO Instrument

- 3 co-boresighted, grating spectrometers record high resolution spectra of reflected sunlight in the 1.61 and 2.06 μm CO_2 bands and in the 0.765 μm O_2 band
- Each channel records spectra in 4 to 8 footprints @ 3 Hz, yielding 12 -24 soundings/sec





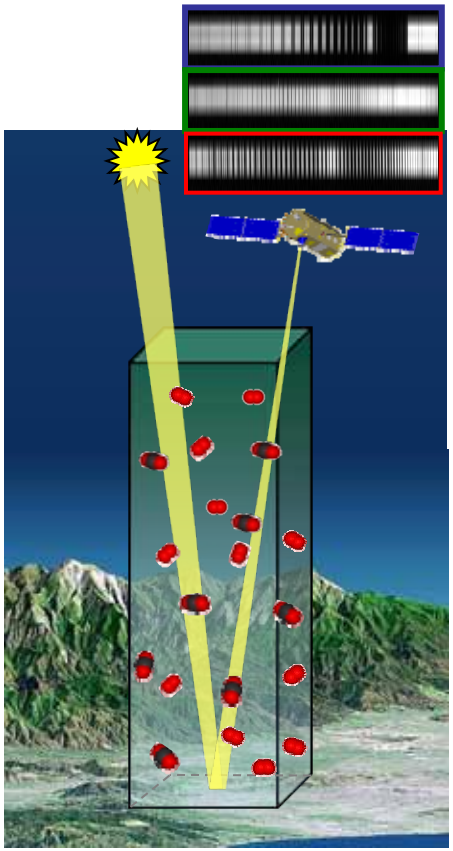




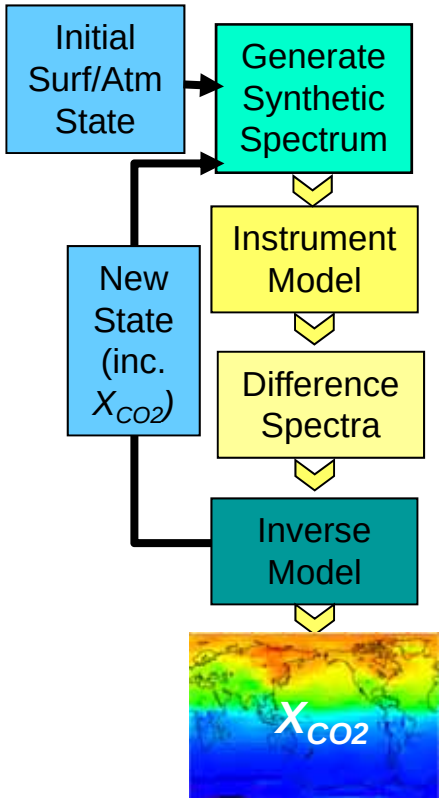
Slit

Measuring CO_2 from Space

- **Collect** NIR spectra of CO_2 and O_2 absorption in reflected sunlight



- **Retrieve** variations in the ***column averaged CO_2 dry air mole fraction, X_{CO2}*** over sunlit hemisphere

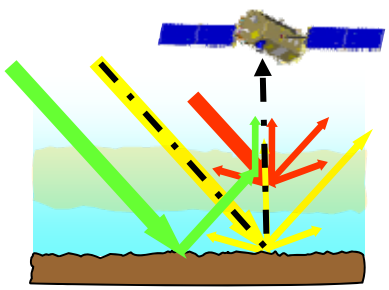


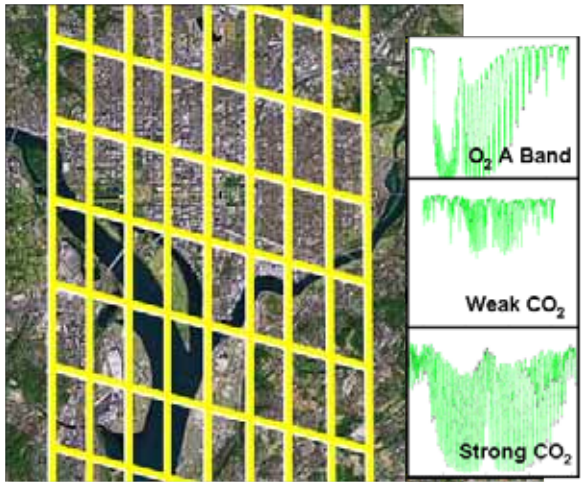
- **Validate** measurements to ensure X_{CO2} accuracy of 1 - 2 ppm (0.3 - 0.5%)

On-orbit Measurement Strategy: 3 Observation Modes

Nadir Observations:

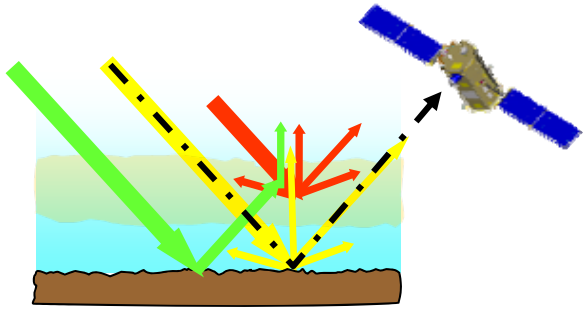
+ Small footprint (< 3 km^2)
– Low Signal/Noise over dark surfaces (ocean, ice)

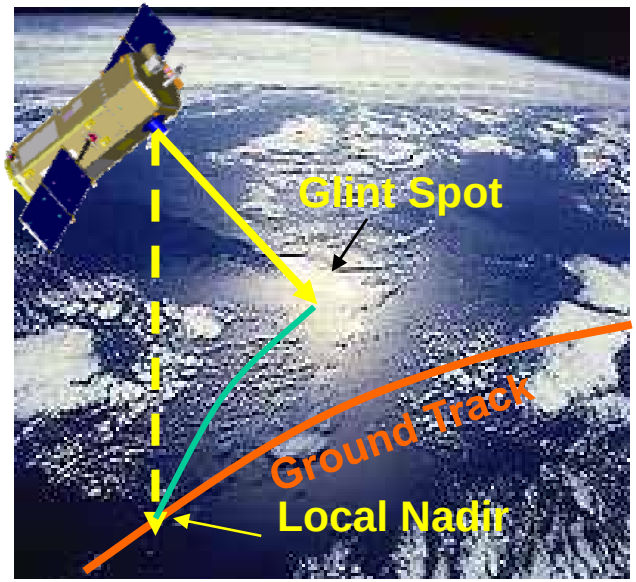




Glint Observations:

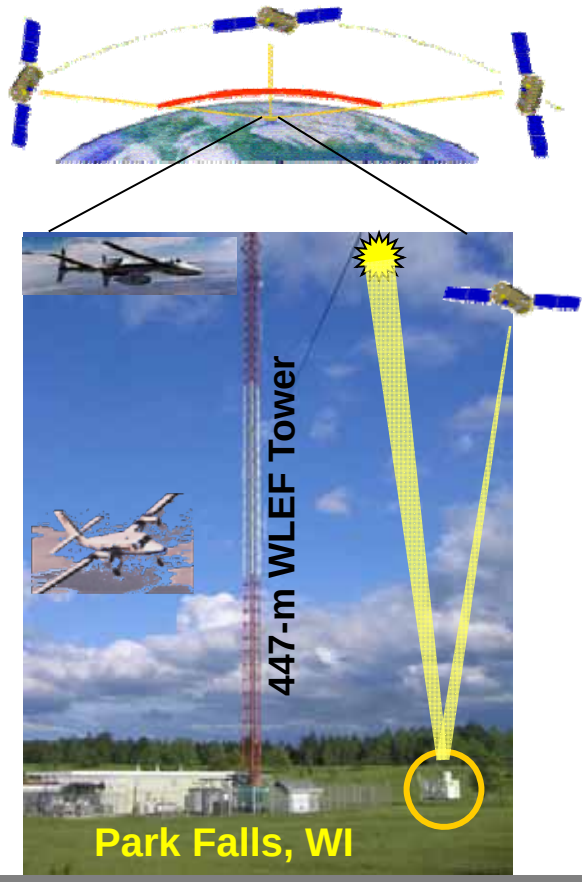
+ Improves Signal/Noise over oceans
– More cloud interference



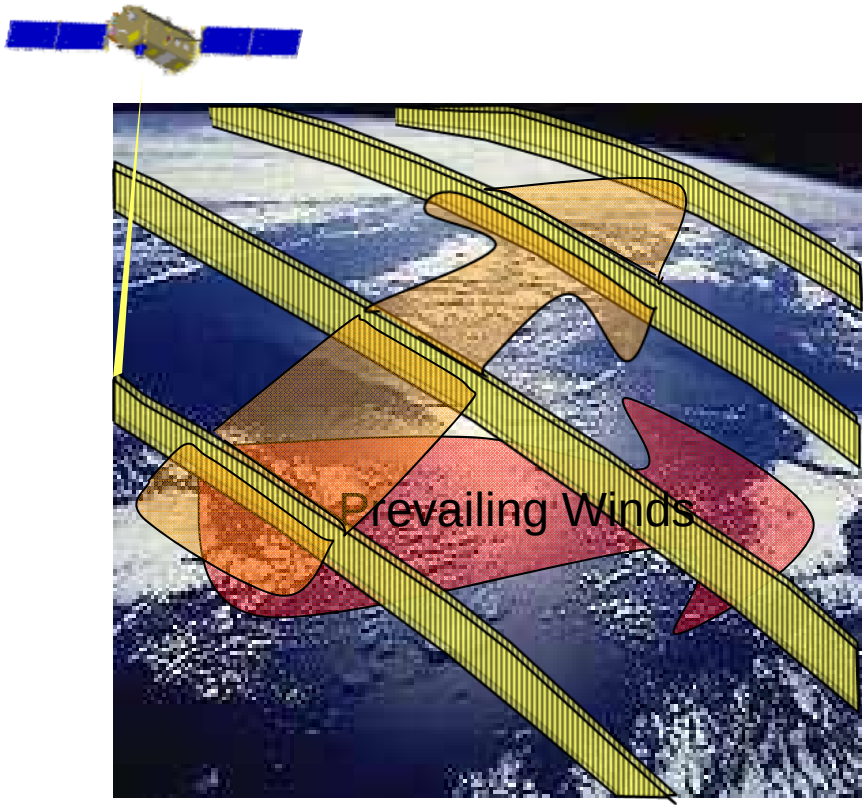


Target Observations:

- Validation over ground based FTS sites, field campaigns, other targets



Routine Global Sampling Strategy

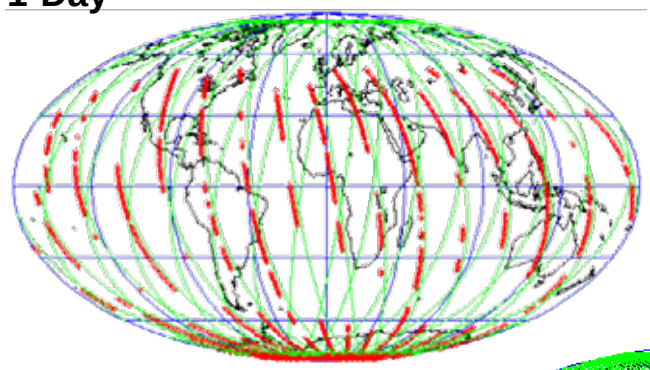


- The 14.6 orbit have tracks that are separated by ~24° longitude
- ~7% of the Earth covered on 16-day each repeat cycle

OCO Sampling Rate/Coverage

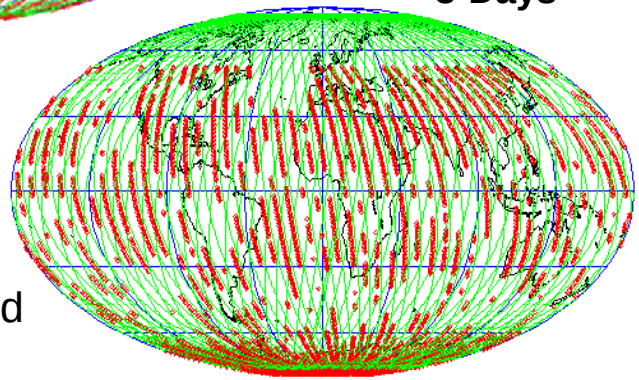
- 12 to 24 soundings/second
  - up to 10^6 Soundings/day

1-Day



~20% of all soundings expected to be cloud free (global average).

3-Days



Data are downlinked once or twice each day over a high latitude ground station

Chevallier et al. 2006

Future Activities and Upcoming Events

- **14-16 April 2010: ACOS/OCO-2 Science Meeting – Pasadena, CA**
- **2-7 May 2010: EGU Sessions on CO2 and CH4 remote sensing**
- **June 2010: OCO-GOSAT TIM and Railroad Valley, NV Vicarious Calibration campaign**
- **Dec 2010: OCO-GOSAT Joint Meeting (@ AGU)**
- **Launch Readiness: no later than February 2013**

Questions?

http://oco.jpl.nasa.gov

Science Justification for an OCO Reflight

- **Scientific rationale provided for the essential contributions that OCO observations could make to carbon cycle science even with multi-year records from AIRS, SCIAMACHY, TES, IASI and GOSAT**

- **Report submitted to NASA HQ in April 2009**

- **Reviewed by the National Academy of Sciences**

National Academy of Sciences Advocates OCO Reflight

Letter Report on the Orbiting Carbon Observatory
http://www.nap.edu/catalog/12723.html

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

Board on Atmospheric Sciences and Climate
http://dels.nas.edu/basc
500 Fifth Street, N.W., Keck WS603
Washington, D.C. 20001
Phone: 202-334-3512
Fax: 202-334-3825

July 28, 2009

Major General Charles F. Bolden, Jr.
Administrator
National Aeronautics and Space Administration
300 E Street, SW
Washington, DC 20546

Dear General Bolden:

A National Research Council committee is conducting a study on how well greenhouse gas emissions can be measured for treaty monitoring and verification. The committee's analysis suggests that NASA's Orbiting Carbon Observatory (OCO), which failed on launch in February 2009, would have provided proof of concept for spaceborne technologies to monitor greenhouse gas emissions, as well as baseline emissions data. This letter focuses on the capabilities of an OCO and currently deployed satellites that measure atmospheric carbon dioxide (CO_2) and their potential role in monitoring and verifying a greenhouse gas treaty.[1]

The committee's study is focused on emission estimates of the greenhouse gases resulting from human activities (e.g., fossil fuel burning, deforestation, agriculture) that have the greatest potential to warm the planet and in particular on CO_2 (see Attachment B for the committee charge). The committee is currently in the analysis and writing phase, with the expectation that its report will be delivered in December 2009. We are writing you now because a decision on replacing OCO will be made in the coming months,[2] before our final report is completed. Current proposals for an OCO reflight focus on the original scientific objectives of studying natural CO_2 sources and sinks.[3] In addition, it is important to consider the potential contribution of an OCO-like instrument for treaty monitoring and verification. Such capabilities may be an important consideration in treaty discussions at the December 2009 Copenhagen meeting of the United Nations Framework Convention on Climate Change.

EDITORIALS NATURE|Vol 460|23 July 2009

The carbon count

Scientists need better Earth-monitoring tools to see whether climate policies are working.

When the world's nations meet in Copenhagen this December to try to construct a successor to the 1997 Kyoto Protocol on climate change, one major point of discussion will be 'offsets'. These are deals that could help countries meet their targets for reducing emissions by paying for others to absorb greenhouse gases in natural carbon sinks such as rainforests, or by otherwise reducing the threat of global warming.

Any new agreement would presumably build on the existing Kyoto framework that allows certified credits from offsetting projects, such as planting trees, to be traded on the international emissions market. Voluntary carbon offsets are also becoming increasingly popular among businesses and air travellers who want to compensate for the carbon footprint of their activities.

As things stand, unfortunately, the success or failure of any such policy is largely a matter of guesswork: there has never been a global observation network capable of verifying whether the carbon dioxide emissions and offsets reported by individual countries make any sense. Carbon-cycle scientists estimate, for example, that around one-third of the CO_2 from fossil fuels burned globally is taken up by land vegetation. But they have no idea what the precise fraction is, or where the carbon actually goes: *in situ* measurements of biosphere-to-atmosphere carbon fluxes are scarce, and ecosystem inventory data are often unavailable. In addition, monitoring efforts suffered a dire setback on 24 February when NASA's US$278-million Orbiting Carbon Observatory (OCO) crashed into the ocean minutes after launch.

Any new international climate agreement, whether it emerges at Copenhagen or later, must therefore provide for a much-improved carbon-monitoring infrastructure for verifying its effectiveness. One key element will be satellite observations, which provide large-scale mapping of greenhouse-gas emissions and land-cover changes. NASA should get the support it needs to build a cheaper copy of OCO, which could be launched as early as 2011 (see *Nature* 458, 8; 2009).

But equally crucial will be high-precision, *in situ* measurement of carbon fluxes between soils, vegetation and the atmosphere. The many international agencies that make up the Integrated Global Observing Strategy partnership should implement, without further delay, their 5-year-old plan for an Integrated Global Carbon Observation programme. A good place to start would be to expand FLUXNET, an existing surface network of some 400 carbon-measurement towers that still has huge gaps, particularly in the tropics.

At the same time, the agencies that comprise the Intergovernmental Group on Earth Observations (GEO) could aim to produce globally harmonized data sets on global, national and local scales, using common algorithms, variables and units. GEO, which coordinates efforts to create the Global Earth Observation System of Systems, should also commission scientists to develop an integrated model that stitches all carbon observations together. It should then make these available for use at all levels by scientists and policy-makers alike.

A global carbon-measurement system along these lines should make international climate policies much more solid than they have been in the past. It might reveal that what we are doing is not enough, and that many offset projects fail to deliver. It might expose swindlers and profit-makers in the carbon business. Or it might prove that nature is a stronger ally than we have dared to hope. Whatever the outcome, a serious investment in carbon monitoring will be money well spent. ■

THE WALL STREET JOURNAL.
WSJ.com

JULY 31, 2009, 11:21 AM ET

Scientists to NASA: We Need A Reliable Way to Track Global Emissions

Forget all the haggling with China, India, and parts of the U.S. Congress—the real obstacle to a global climate-change treaty might be accurately measuring greenhouse-gas emissions in the first place.

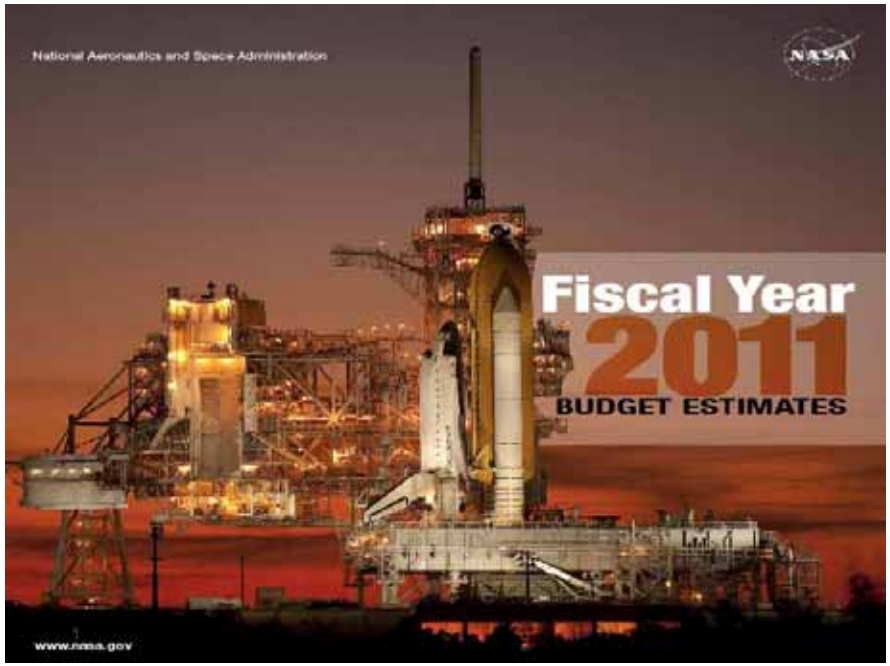
That's the warning from the National Academy of Science's National Research Council to the head of NASA. The upshot? Without a sophisticated satellite that can track global emissions, it will be hard to know what everybody is really up to: "[C]urrent methods for estimating greenhouse gas emissions have limitations for monitoring a climate treaty."

NASA had such a sophisticated satellite—the Orbiting Carbon Observatory—which failed to reach orbit in February. The space agency is considering trying again—thus the letter from the NAS pointing out just how useful such satellites can be.

OCO Reflight Highlighted in President's 2011 Budget Proposal

- **"Enhances the Nation's global climate change research and monitoring system, including reflight of a satellite that will help identify global carbon sources and sinks"**

- **"The Budget provides funds for NASA to develop and fly a replacement for the Orbiting Carbon Observatory, a mission designed to identify global carbon sources and sinks that was lost when its launch vehicle failed in 2009."**



http://www.nasa.gov/news/budget/fy11_oco.html

The President's funding profile supports the fastest possible OCO-2 launch:
LRD as soon as Feb 2013

The Soil Moisture Active/Passive Mission (SMAP)

Global measurement of surface soil moisture and freeze-thaw state

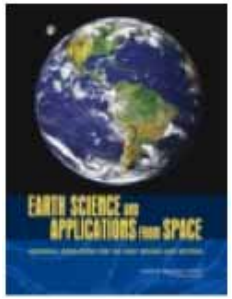
Kyle C. McDonald[1]
K. Kellogg[1] (Project Manager)
E. Njoku[1] (Project Scientist)
P. O'Neill[2] (Deputy Project Scientist)
D. Entekhabi[3] (Science Team Lead)

[1]Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA
[2]NASA Goddard Space Flight Center
Greenbelt, MD
[3]Massachusetts Institute of Technology
Cambridge, MA

NASA Terrestrial Ecology Science Team Meeting
March 15-17, 2010
La Jolla, California

SMAP Mission Context

SMAP is one of four Tier-1 missions recommended by the U.S. NRC Earth Science Decadal Survey



"Earth Science and Applications from Space: National Imperatives for the next Decade and Beyond"

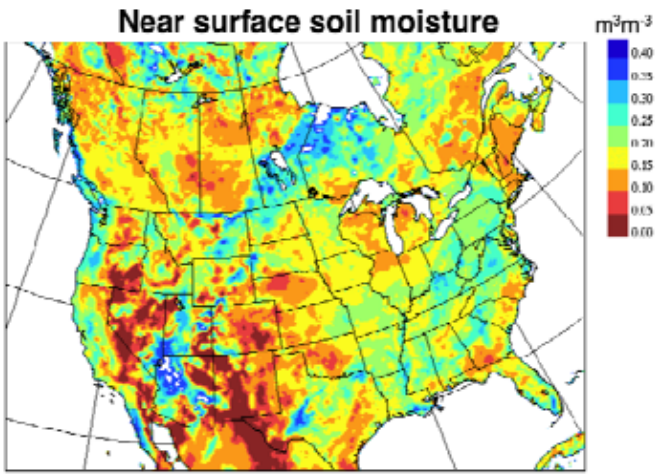
(National Research Council, 2007) http://www.nap.edu

Tier 1:	
	Soil Moisture Active Passive (SMAP)
	ICESAT II
	DESDynI
	CLARREO
Tier 2:	
	SWOT
	HYSPIRI
	ASCENDS
	GEO-CAFE
	ACE
Tier 3:	
	LIST
	PATH
	GRACE-II
	SCLP
	GACM
	3D-WINDS

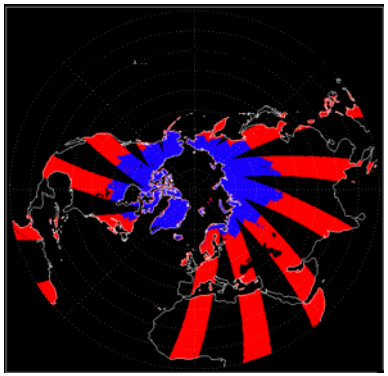
- SMAP was initiated by NASA as a new start mission in February 2008
- SMAP transitioned to Phase B in February 2010
- The target launch date for SMAP is May 2015 (could be accelerated to November 2014)

SMAP Science Objectives

- *Provide high-resolution, frequent-revisit global maps of soil moisture and freeze/thaw state to enable science and applications users to:*



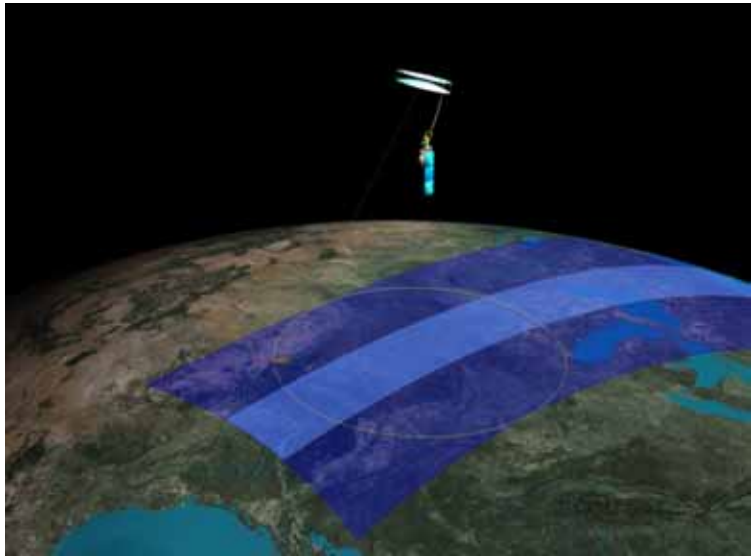
- Understand processes that link the terrestrial water, energy and carbon cycles
- Estimate global water and energy fluxes at the land surface
- Quantify net carbon flux in boreal landscapes
- Enhance weather and climate forecast skill
- Develop improved flood prediction and drought monitoring capability



Mission Concept Overview

- **Orbit:**
  - *Sun-synchronous, 6 am/pm orbit*
  - *680 km altitude, 8-day exact repeat*
- **Instruments:**
  - *L-band (1.26 GHz) radar*
    - *High resolution, moderate accuracy soil moisture*
    - *Freeze/thaw state detection*
    - *SAR mode (non-imaging): 3 km resolution*
    - *Real-aperture mode: 30 x 6 km resolution*
  - *L-band (1.4 GHz) radiometer*
    - *Moderate resolution, high accuracy soil moisture*
    - *40 km resolution*
  - *Shared instrument antenna*
    - *6-m diameter deployable mesh antenna*
    - *Conical scan at 14.6 rpm*
    - *incidence angle: 40 degrees*
      - *Creates contiguous 1000 km swath*
      - *Swath and orbit enable 2-3 day revisit*

- **Planned Mission Development Schedule (subject to budget)**
  - *Phase A start: September 2008*
  - *Phase B start: February 2010*
  - *PDR: March 2011*
  - *CDR: June 2012*
  - *Instrument Delivery: September 2013*
  - *Target Launch Date: May 2015*
- **Mission operations duration: 3 years**



SMAP Data Products Table

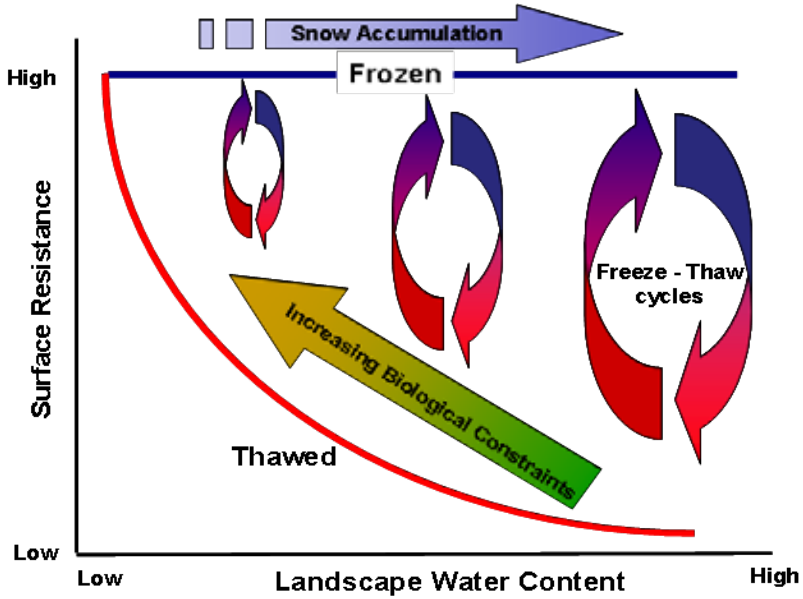
Data Product Short Name	Short Description	Spatial Resolution	Grid Spacing	Latency*
L1A_Radar	Radar raw data in time order	NA	NA	12 hours
L1A_Radiometer	Radiometer raw data in time order	NA	NA	12 hours
L1B_S0_LoRes	Low resolution radar σ_o in time order	5x30 km	NA	12 hours
L1B_TB	Radiometer T_B in time order	40 km	NA	12 hours
L1C_S0_HiRes	High resolution radar σ_o (half orbit, gridded)	1x1 km to 1x30 km	1 km	12 hours
L1C_TB	Radiometer T_B (half orbit, gridded)	40 km	36 km	12 hours
L2_SM_A**	Soil moisture (radar, half orbit)	3 km	3 km	24 hours
L2_SM_P	Soil moisture (radiometer, half orbit)	40 km	36 km	24 hours
L2_SM_A/P	Soil moisture (radar/radiometer, half orbit)	9 km	9 km	24 hours
L3_F/T_A	Freeze/thaw state (radar, daily composite)	3 km	3 km	36 hours
L3_SM_A**	Soil moisture (radar, daily composite)	3 km	3 km	36 hours
L3_SM_P	Soil moisture (radiometer, daily composite)	40 km	36 km	36 hours
L3_SM_A/P	Soil moisture (radar/radiometer, daily composite)	9 km	9 km	36 hours
L4_SM	Soil moisture (surface & root zone)	9 km	9 km	7 days
L4_C	Carbon net ecosystem exchange (NEE)	9 km	1 km	14 days

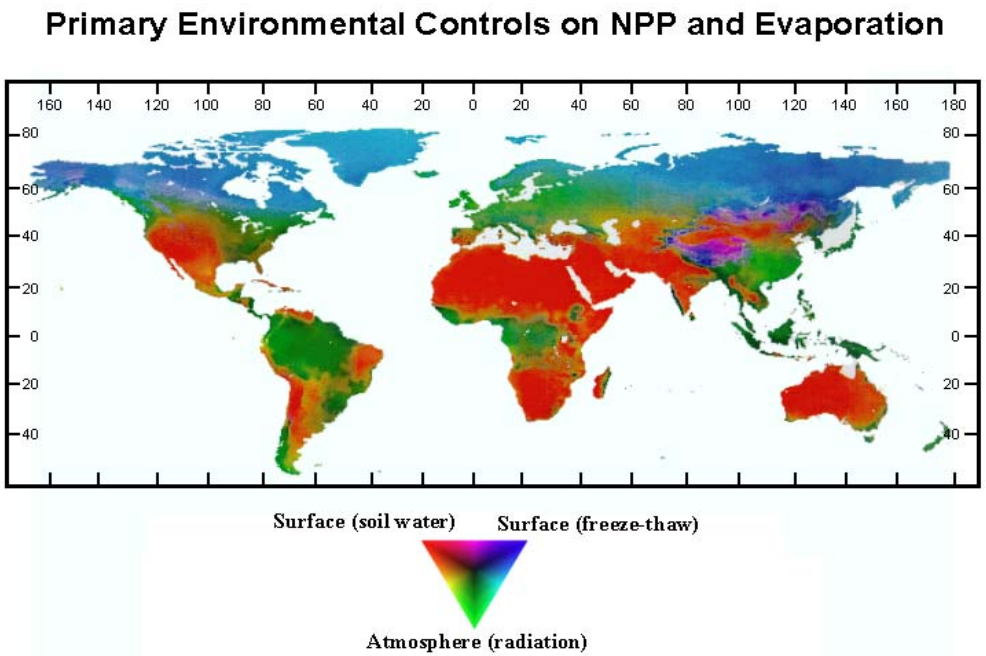
* SMAP L2 science requirements. Mean latency under normal operating conditions. The SMAP project will make a best effort to reduce these latencies

** Research products (archival at discretion of project)

SMAP Science Objectives

Soil moisture and freeze/thaw state are primary environmental controls on water mobility and associated constraints to evaporation and Net Primary Productivity

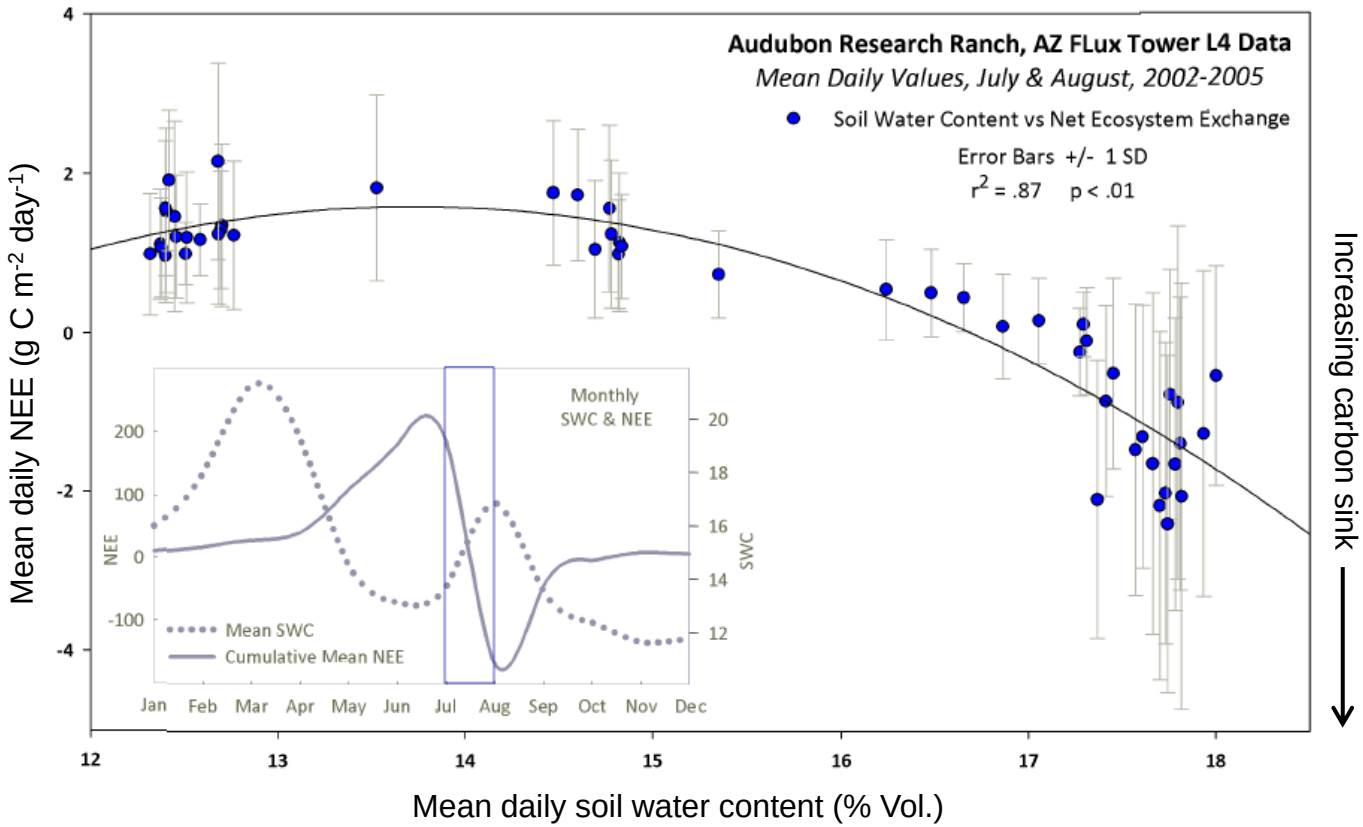




SMAP measurements of soil moisture and freeze-thaw cycles will provide an integrated measure of critical controls on surface water mobility and associated constraints to ecosystem processes. Decreasing water content imposes increasing constraints to CO_2 exchange, as do seasonal and episodic freezing. These temperature and moisture controls relate directly to land-atmosphere latent energy and water exchange, vegetation productivity, and sequestration of atmospheric CO_2

SMAP Science Objectives: Soil Moisture and NEE

Mid-Summer Tower Footprint



Source: http://public.ornl.gov/ameriflux/index.html

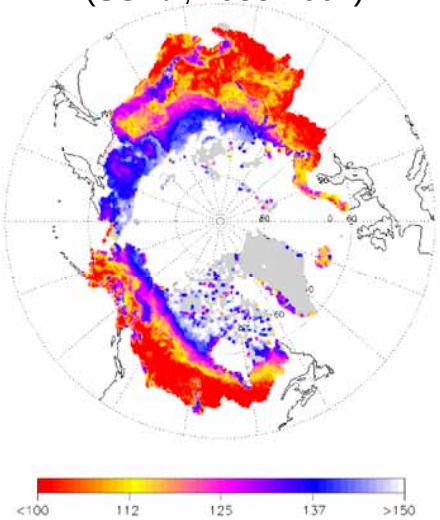
Soil moisture sustains vegetation net primary productivity and atmospheric carbon (CO_2) uptake in water limiting ecosystems.

SMAP Science Objectives: Freeze/Thaw and CO_2

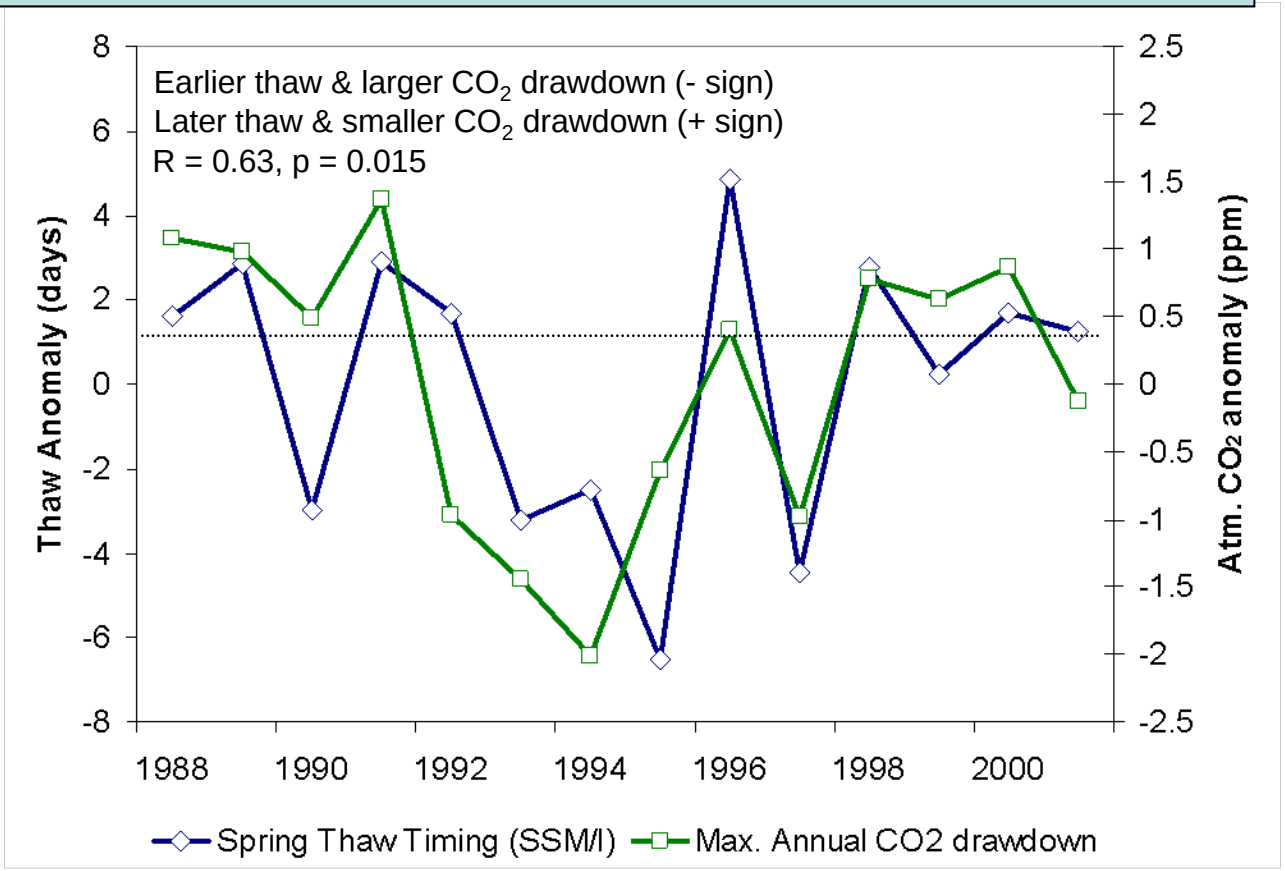
Spring Thaw Timing Regulates Annual Drawdown of Atmospheric CO_2 by Boreal Ecosystems

NOAA CMDL Observatory at Barrow

Mean Thaw Date
(SSM/I, 1988-2001)



Julian Day



Source: McDonald et al., *Earth Interactions* 8(20)

Freeze/thaw link to carbon source-sink activity: Early thaw years enhance growing season uptake (drawdown) of atmospheric CO_2 by NPP; Later thaw years reduce NPP and CO_2 drawdown.

SMAP Calibration and Validation activities

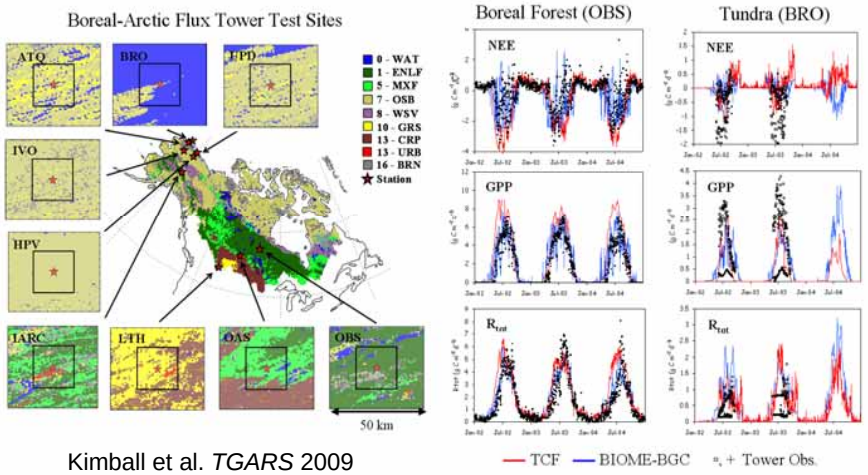
Pre-launch (2009-2015):

- Development, testing & selection of baseline algorithms;
- Development of algorithm software test-bed for algorithm testing & sensitivity studies;
- Verify algorithm sensitivity & accuracy requirements using available satellite, in situ and model based data & targeted field campaigns;
- Initialization/calibration/optimization of algorithm parameters

Post-launch (2015-2018):

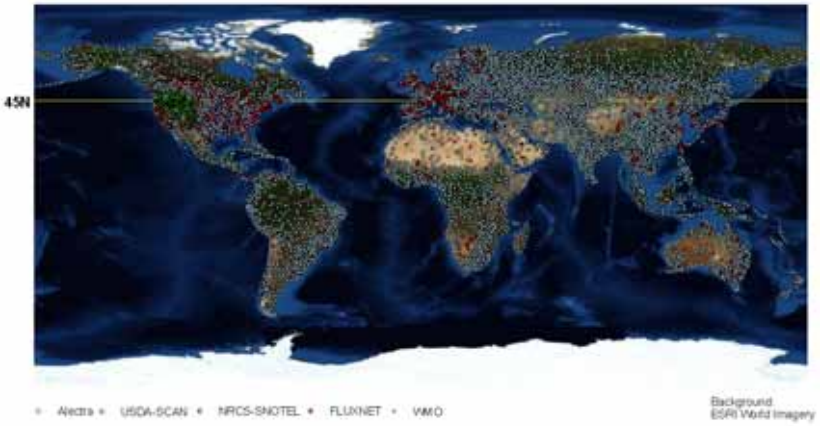
- Verify product accuracy through focused field campaigns and global observation networks;
- Model assimilation based value assessment (GMAO, TOPS, CarbonTracker);

Pre-launch L4_C Test using MODIS & AMSR-E Inputs

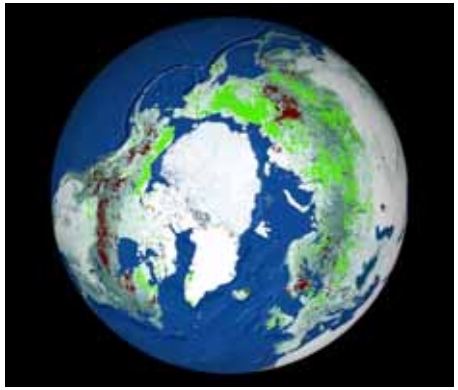


Kimball et al. *TGARS* 2009

Global Biophysical Station Networks



Potential Applications



Climate Change:

Monitoring of patterns, variations & anomalies in CO_2 source/sink activity; vegetation, moisture & temperature effects on carbon uptake and release.

Forestry and Agriculture:

Carbon sequestration assessment and monitoring; net productivity; drought impacts, disturbance & recovery; Spatial-temporal extrapolation of in situ observations.

Environmental Policy:

Regional carbon budgets; carbon accounting and vulnerability assessments.

End