Fire Applications in Relation to Anthropogenic Modification of the Land (H-4), Changes in Carbon Sinks (E-5), and Atmospheric Pollutants (C-8)

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The role of fire in the Earth System

2017 Decadal Survey
Response for Information #2

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Significance of Fire on the Earth System

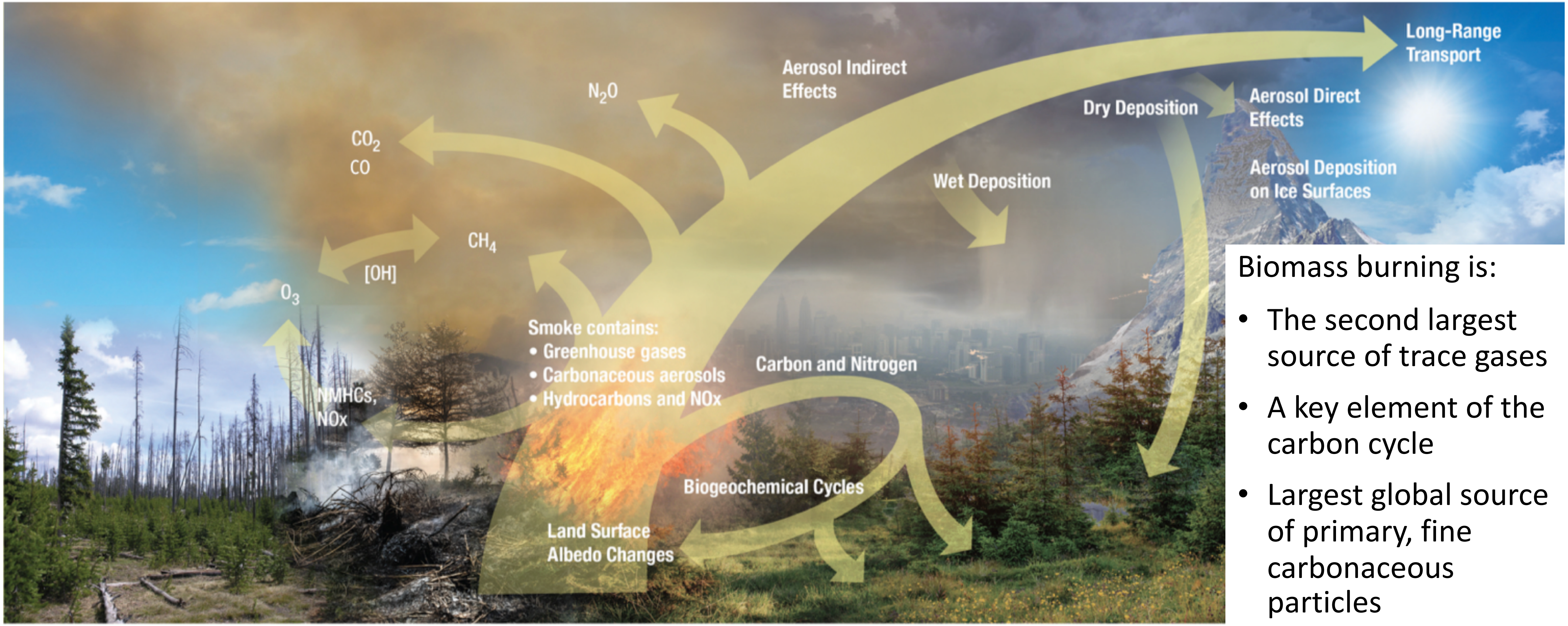


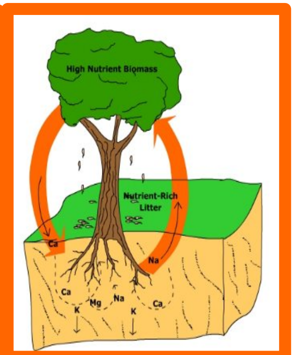
Figure 1. *A schematic of the role of fire in the earth system. Figure modified from Ward et al. (2012)*[33].

Biomass burning is:

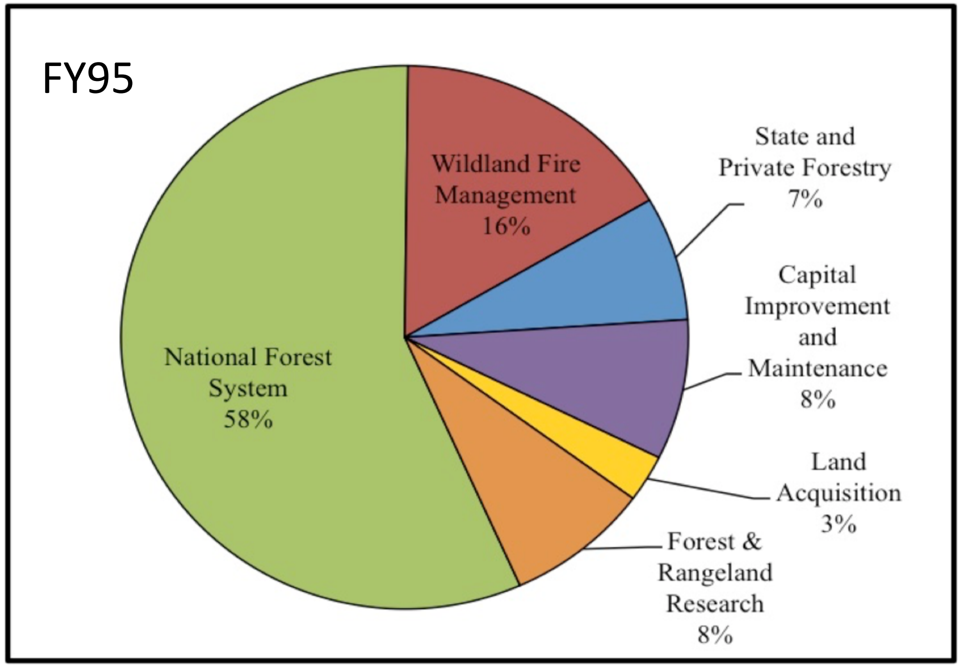
- The second largest source of trace gases
- A key element of the carbon cycle
- Largest global source of primary, fine carbonaceous particles
- A catalyst for ecosystem transition (affecting albedo)

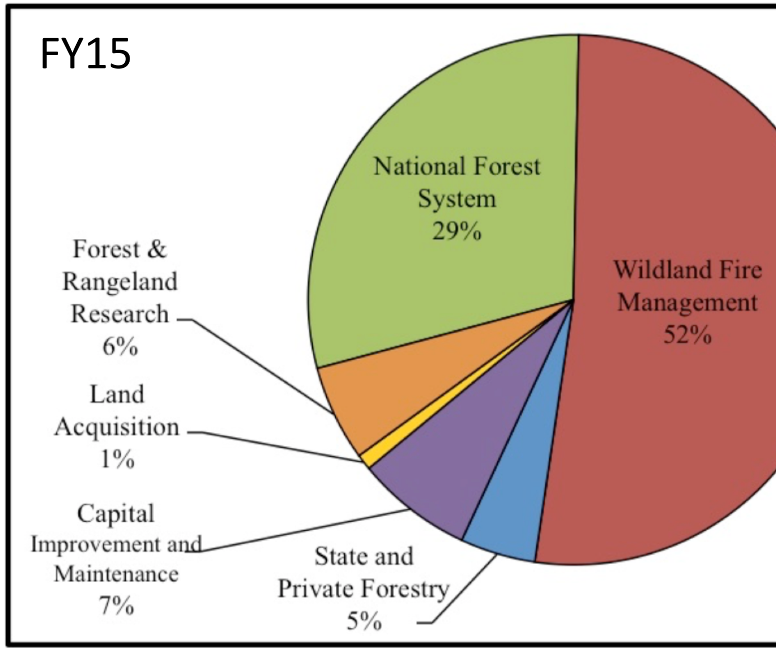
Significance of fire to people

- Increasing fire danger
- Longer burning seasons
- Growing wildland urban interface



Appropriations by Fund at USFS





USFS Report, 2015

Decadal Survey call to understand three components of wildfire

CARBON AND BIODIVERSITY

- ***QUESTION E-5.*** Are carbon sinks stable, are they changing, and why?
  - (Important) **E-5c.** **Understand ecosystem response to fire events**

APPLICATIONS: DISASTER RESPONSE AND RECOVERY

- ***QUESTION H-4.*** How does the water cycle interact with other Earth System processes to change the predictability and impacts of hazardous events and hazard-chains… and how do we improve preparedness and mitigation of water- related extreme events?
  - (Important) **H-4d.** **Understand linkages** between anthropogenic modification of the land, including fire suppression, land use, and urbanization **on frequency of and response to hazards**

POLLUTANTS

- ***QUESTION C-8.*** What will be the consequences of amplified climate change [in polar regions] on global trends of sea level rise, atmospheric circulation, extreme weather events, global ocean circulation, and carbon fluxes?
  - (Important) **C-8g.** **Determine the amount of pollutants** (e.g., black carbon, soot from fires, and other aerosols and dust)…

Fire-specific science and applications questions

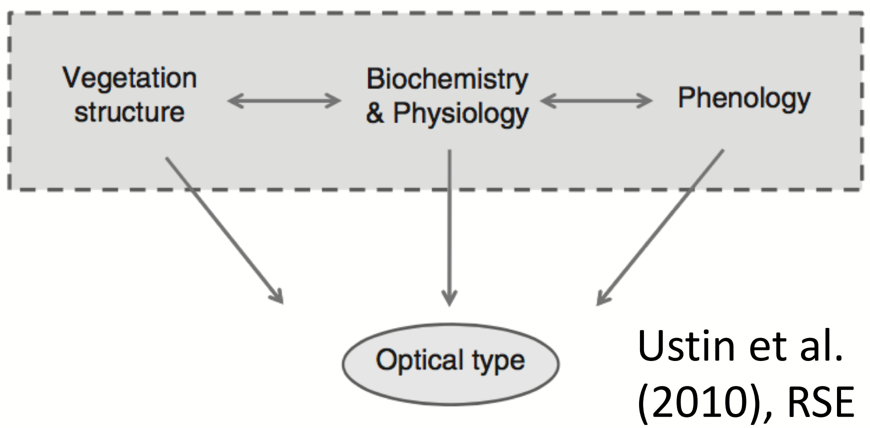
Decadal Survey Fire Priorities	**Science and Applications Questions from RFI #2**
Carbon and Biodiversity	How does fire affect ecosystem services (e.g., clean air and water, habitat, and biodiversity) and which ecosystems are the most vulnerable to changes?
Applications: Disaster Mitigation, Response, Recovery	How do fuel type, structure, amount, and condition influence fire?
Pollutants	How do these smoke emissions influence climate and health and air quality as they are globally transported?

Science and Applications Questions	***Some Working* Hypotheses**
How does fire affect ecosystem services (e.g., clean air and water, habitat, and biodiversity) and which ecosystems are the most vulnerable to changes?	Fire acts as a catalyst for ecosystem type conversion in transition zones between ecotones.
How do fuel type, structure, amount, and condition influence fire?	The current state of "megafires" as the new normal is primarily driven by climate change, not a century of fire exclusion.
How do these smoke emissions influence climate and health and air quality as they are globally transported?	Primary and secondary pollutants from fire emissions have significant radiative forcing.

To address the science and application questions, we must

Hypotheses	**Objectives**
Fire acts as a catalyst for ecosystem type conversion in transition zones between ecotones.	Monitor post-fire recovery of ecosystem composition and 3-D structure, annually at 30 m resolution
	Map vegetation carbon and nitrogen, seasonally at 30 m resolution
	Map burned area and severity, annually at 30 m pixel resolution
The current state of “megafires” as the new normal is primarily driven by climate change, not a century of fire exclusion.	Map ecosystem condition: soil moisture and vegetation productivity, moisture, stress and mortality, weekly at 30 m resolution
	Map burned area and severity, weekly at 30 m pixel resolution
Primary and secondary pollutants from fire emissions have significant radiative forcing.	Map fire emissions and smoke transport, sub-daily at ≤375 m pixel resolution

Objectives	**Imaging Spectroscopy Physical Parameters**
Monitor post-fire recovery of ecosystem composition and 3-D structure	Vegetation canopy composition - continuous characterization of *optical types* that capture vegetation functional diversity linked to biodiversity, annually at 30 m resolution
	Burned area and severity – burn fraction, annually at 30 m pixel resolution
Map vegetation carbon and nitrogen	*Canopy chemical composition*, annually at 30 m resolution
	Fuel accumulation – *gross primary productivity* derived from *fraction of photosynthetic active radiation, leaf area index,* or *vegetation greenness,* seasonally at 30 m resolution
Map ecosystem condition: soil moisture and vegetation productivity, moisture, stress and mortality	*Ecosystem Flammability - Proxies of vegetation stress* such as equivalent water thickness, weekly at 30 m resolution
	Ecosystem Health – discrimination of *live and senescent vegetation, annually at 30 m resolution*
	Fuel accumulation – *same as above*
Map burn area and severity	Burned area and severity – burn fraction , weekly at 30 m pixel resolution
Map fire emissions and smoke transport	Everything above
	Combustion Efficiency - Fire Temperature, sub-daily at ≤375 m pixel resolution
	Aerosol Optical Depth, sub-daily at ≤375 m pixel resolution
	Secondary Pollutant - Ammonia, sub-daily at ≤375 m pixel resolution

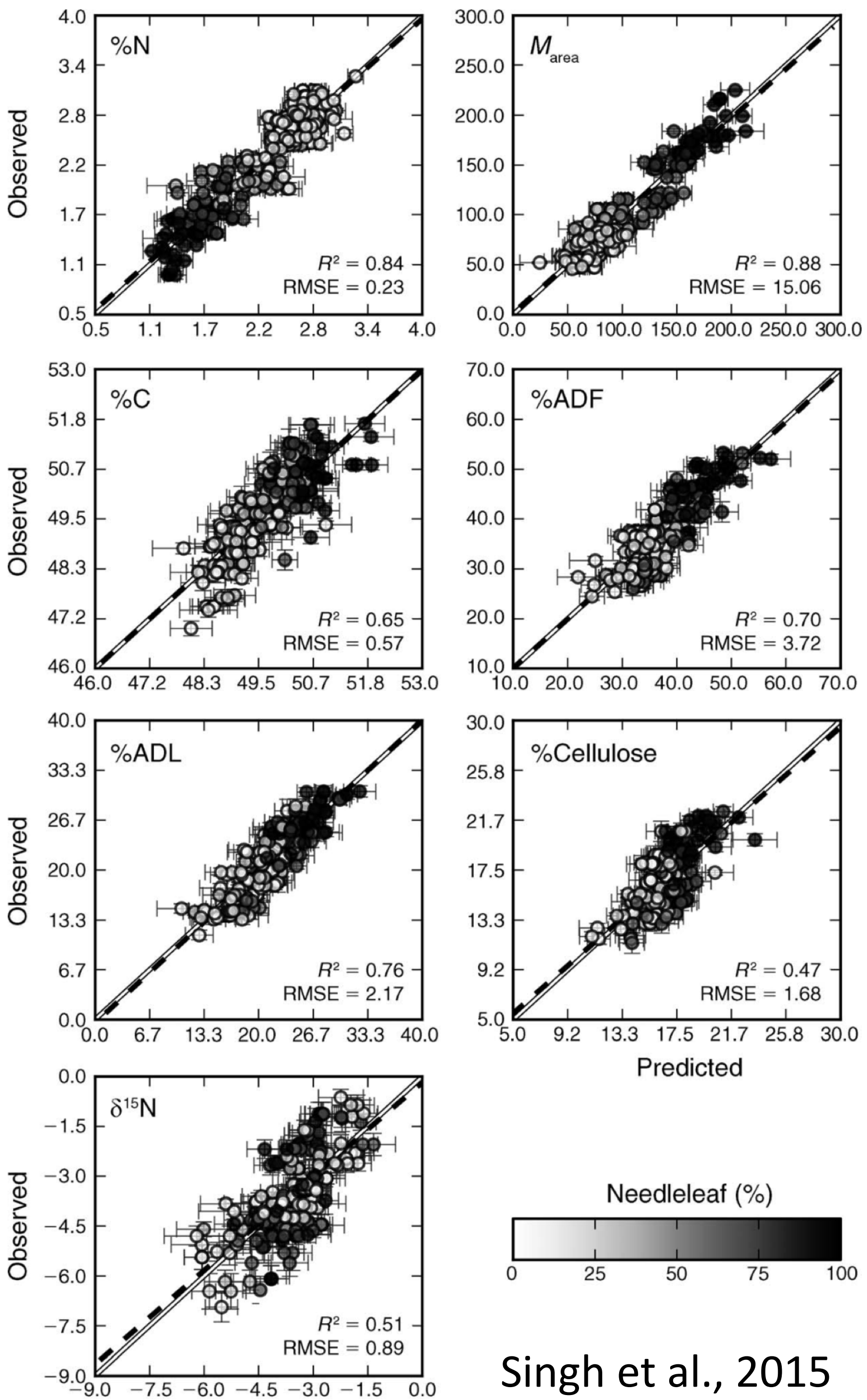


Ustin et al. (2010), RSE

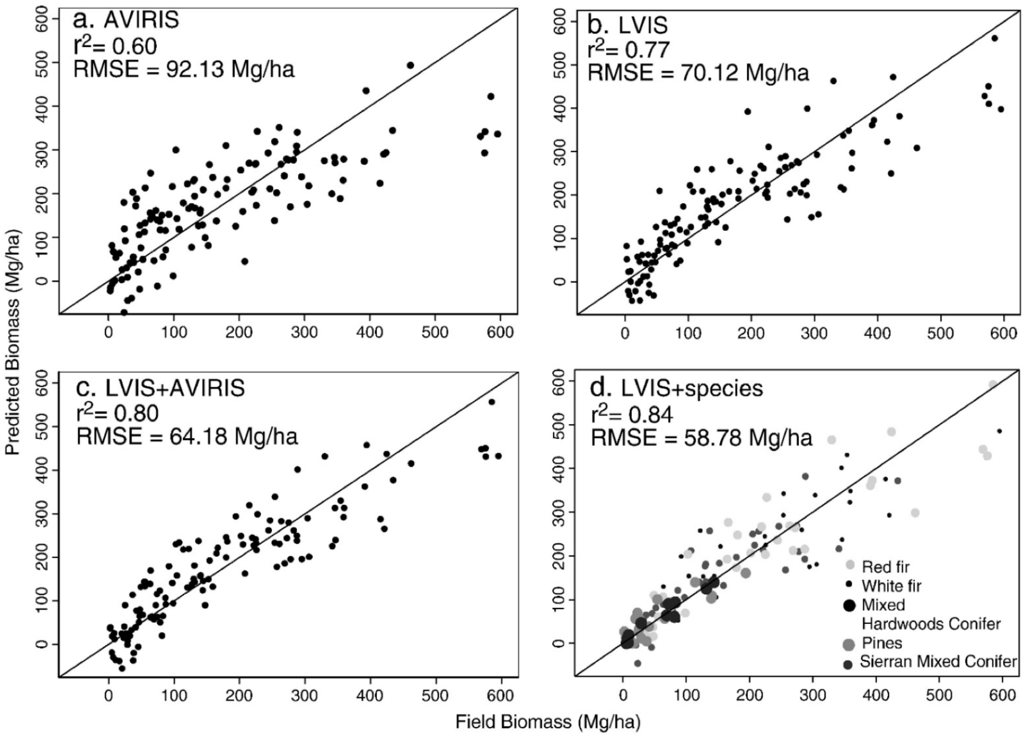
Canopy Chemical Composition
- Uncertainty 20%(?)
- 30 m spatial resolution
- Annual temporal resolution
- Over ≳5 years with uncertainty(?)

Optical Types
- Uncertainty 20%(?)
- 30 m spatial resolution
- Annual temporal resolution
- Over ≳5 years with uncertainty(?)

Imaging Spectroscopy Observations
Vegetation optical types
Canopy chemical composition
Fuel accumulation
Ecosystem flammability
Ecosystem health
Burn fraction
Combustion efficiency
Aerosol Optical Depth
Secondary pollutants - Ammonia



Singh et al., 2015



Swatantran et al., 2011

Imaging Spectroscopy Observations
Vegetation optical types
Canopy chemical composition
Fuel accumulation
Ecosystem flammability
Ecosystem health
Burn fraction
Combustion efficiency
Aerosol Optical Depth
Secondary pollutant - Ammonia

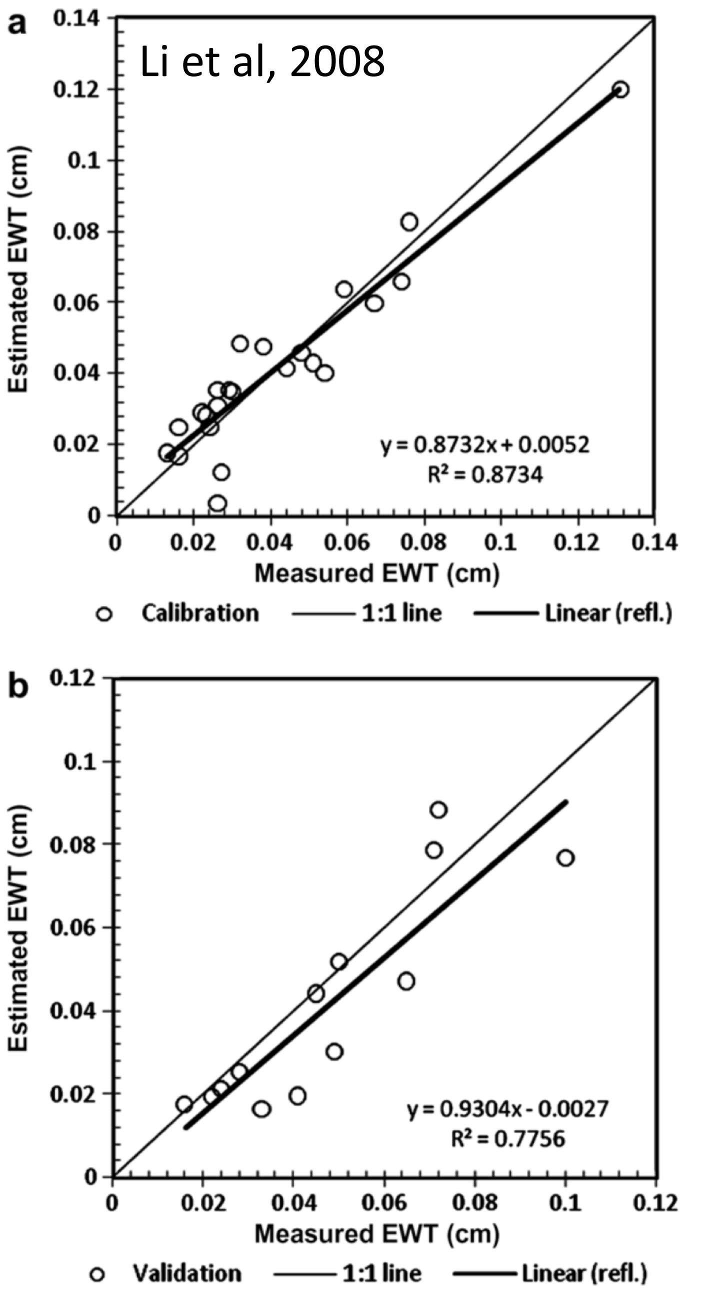


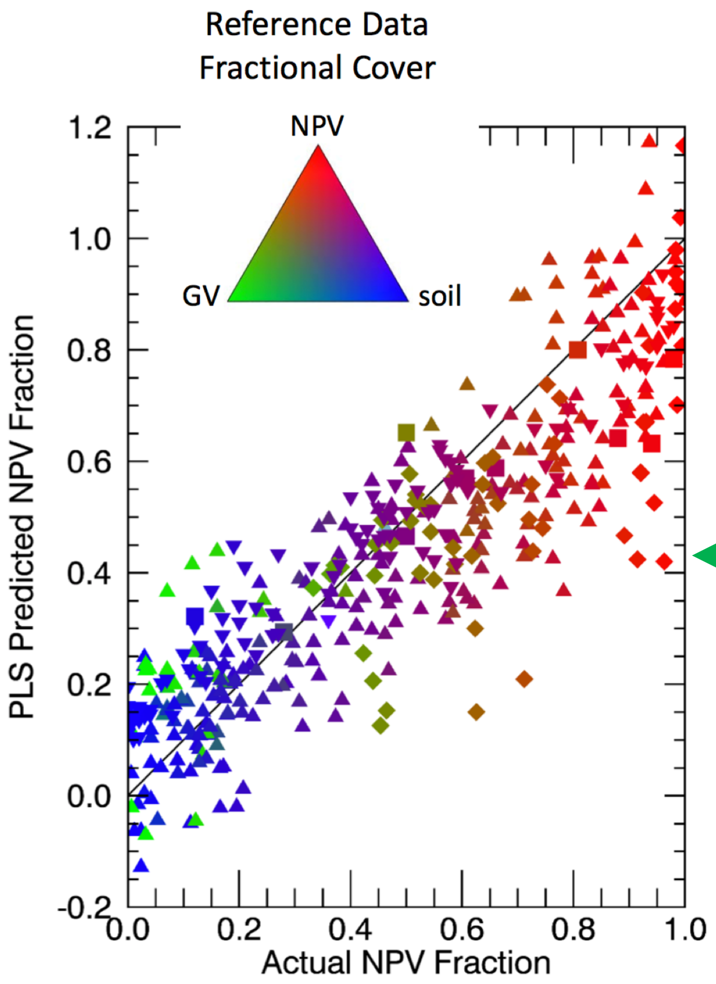
Fig. 3. Comparison of field measured canopy EWT with GA-PL retrieved EWT from AVIRIS image reflectance in the calibration (a, up and validation (b, bottom).

Fuel Accumulation

- Uncertainty 20% (?)
- 30 m spatial resolution
- Annual temporal resolution
- Over ≳5 years with uncertainty(?)

Ecosystem Flammability

- Uncertainty 20% (?)
- 30 m spatial resolution
- Weekly temporal resolution
- Over ≳5 years with uncertainty(?)



Dennison et al., in prep.

Ecosystem Health
- Uncertainty 15%(?)
- 30 m spatial resolution
- Annual temporal resolution
- Over ≳5 years with uncertainty(?)

Imaging Spectroscopy Observations
Vegetation optical types
Canopy chemical composition
Fuel accumulation
Ecosystem flammability
Ecosystem health
Burn fraction
Combustion efficiency
Aerosol Optical Depth
Secondary pollutant - Ammonia

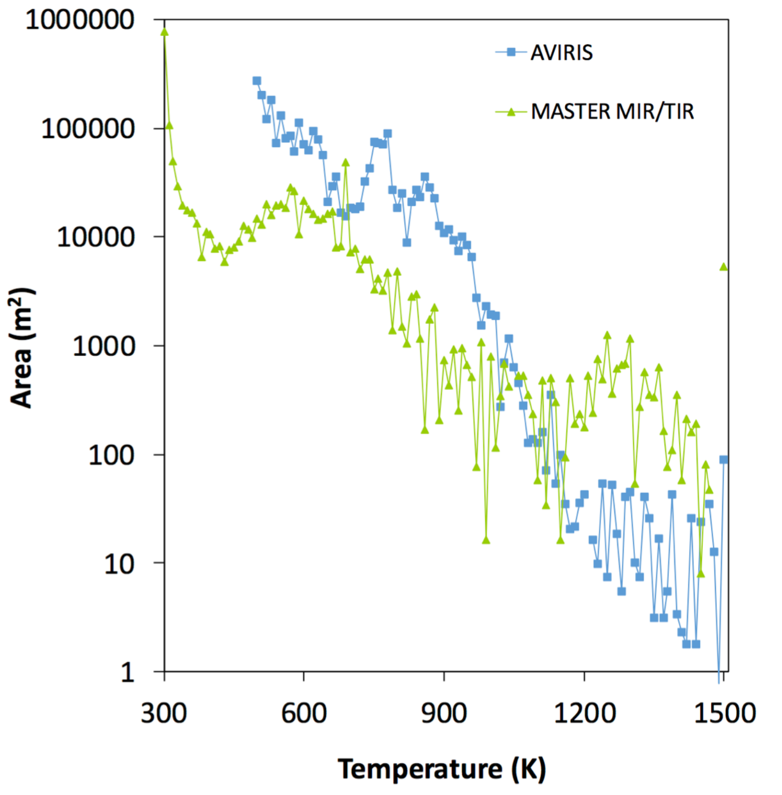
Burn Fraction
- Uncertainty 25%(?)
- spatial ABC resolution
- DEF temporal resolution
- Over ≳5 years with uncertainty(?)

Field measure	GeoCBI				% black trees/shrubs				Burned fraction			
Scenario	a	b	R^2	RMSE	a	b	R^2	RMSE	a	b	R^2	RMSE
AVIRIS (all)	3.05	−0.05	0.86	0.12	1.06	−0.06	0.65	0.18	0.92	0.05	0.78	0.15
OLI	4.74	−2.07	0.65	0.11	1.50	−1.31	0.44	0.14	0.71	0.12	0.51	0.24
AVIRIS (multispectral)	3.59	−0.93	0.65	0.14	1.15	−0.62	0.44	0.18	0.66	0.15	0.47	0.25

Veraverbeke et al, 2014

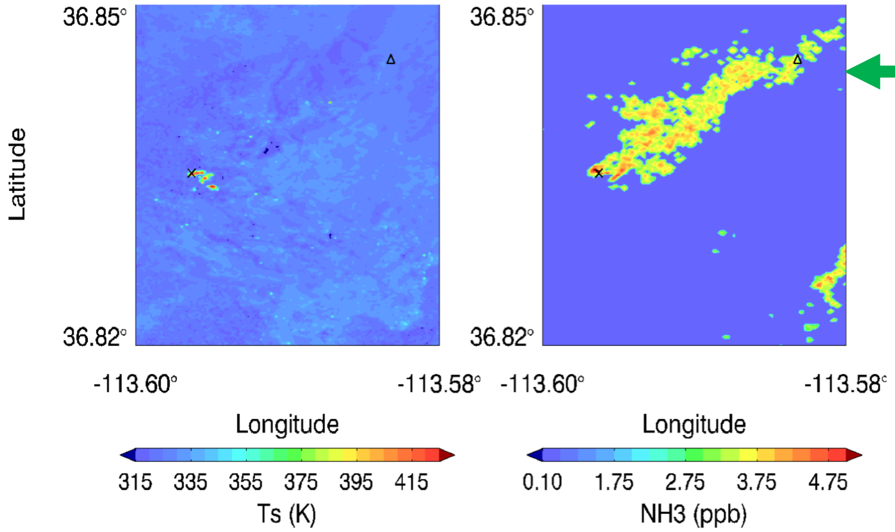
Aerosol Optical Depth
- Uncertainty 20% (?)
- ≦ 200 m spatial resolution
- Sub-daily temporal resolution
- ≦ 3 years with uncertainty

Imaging Spectroscopy Observations
Vegetation optical types
Canopy chemical composition
Fuel accumulation
Ecosystem flammability
Ecosystem health
Burn fraction
Combustion efficiency
Aerosol Optical Depth
Secondary pollutant Ammonia



Dennison & Matheson, 2011

Combustion Efficiency
- Uncertainty 20%(?)
- ≦ 200 m spatial resolution
- Sub-daily temporal resolution
- ≦ 3 years with uncertainty



Kuai et al. (in prep)

Secondary pollutants
- Uncertainty 20% (?)
- ≦ 200 m spatial resolution
- Sub-daily temporal resolution
- ≦ 3 years with uncertainty

Imaging Spectroscopy Observations	Imaging Spectroscopy Observables
Optical Types Canopy chemical composition Ecosystem Flammability Ecosystem Health Fuel accumulation	• Continuous spectral range 0.4-2.5 µm • Unknown spectral sampling • High signal-to-noise • Global mapping (not sampled)
Combustion Efficiency	~4 µm band with ≥400 K saturation and sufficient thermal range for fire detections (may require 2-bands for sufficient sensitivity at the lower temperatures); NEdT of 0.2K AND • Continuous spectral range 8-12 µm (OR 0.4-2.5 µm) • Unknown spectral sampling • High signal-to-noise • Global mapping (not sampled)
Aerosol Optical Depth	• Continuous spectral range 0.4-2.5 µm • Unknown spectral sampling • High signal-to-noise • Global mapping (not sampled)
Secondary Pollutants	• Continuous spectral range 8-12 µm • Unknown spectral sampling • High signal-to-noise • Global mapping (not sampled)

Need Contemporaneous (not simultaneous) Measurements with Program of Record

- Contribute to current thermal (MODIS, VIIRS, and ECOSTRESS) and VSWIR (Landsat and ESA's Sentinel 2/3) information product to provide frequent observations useful **<u>for immediate response to fire</u>**
  - Need to bridge the datasets to provide information products available through one record
- **<u>Longer-term science and applications questions (e.g., vegetation requirements) require new information products</u>** to advance the current state of fire science anc applications

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Imaging spectrometer emulates Landsat: A case study with Airborne Visible Infrared Imaging Spectrometer (AVIRIS) and Operational Land Imager (OLI) data

Check for updates

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ABSTRACT

Remote sensing data are most useful if they are available with sufficient precision, accuracy, spatiotemporal and spectral sampling, as well as continuity across decades. The Landsat and Sentinel series, as well other satellites are currently covering significant parts of this observational trade space. It can be expected that growing demands and budget constraints will require new capabilities in orbit that can address as many observables as possible with a single instrument. Recent optical performance improvements of imaging spectrometers make them true alternatives to traditional multispectral imagers. However, they are much more adaptable to a wide range of Earth observation needs due to the combination of continuous high spectral sampling with spatial sampling consistent with previous sensors (e.g., Landsat). Unfortunately, there is a knowledge gap in demonstrating that imaging spectroscopy data can substitute for multi-spectral data while sustaining the long-term record. Thus, the objective of this analysis is to test the hypothesis that imaging spectroscopy data compare radiometrically with multi-spectral data to within 5%. Using a coincident Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) flight with over-passing Operational Land Imager (OLI) data on Landsat 8, we document a procedure for simulating OLI multi-spectral bands from AVIRIS data, evaluate influencing factors on the observed radiance, and assess the difference in top-of-atmosphere radiance as compared to OLI. The procedure for simulating OLI data include spectral convolution, accounting for the minimal atmospheric effects between the two sensors, and spatial resampling. The remaining differences between the simulated and the real OLI data result mainly from differences in sensor calibration, surface bi-directional reflectance, and spatial sampling. The median relative radiometric difference for each band ranges from −8.3% to 0.6%. After bias-correction to minimize potential calibration discrepancies, we find no more than a 1.2% relative difference. This analysis therefore successfully demonstrates that imaging spectrometer data can contribute to Landsat-type or other multi-spectral data records. It also shows that cross-calibration from a spectrometer to a radiometer can be easily performed as a result of the imaging spectrometer high spectral sampling and its ability to recreate multi-spectral response functions.

Synergies with other ESAS 2017 Observing Systems

Fire Science Hypotheses	Objectives
The role of secondary pollutants from fire emissions has significant radiative forcing as compared to primary pollutants and green house gases.	Map in loss of biomass
Fire acts as a catalyst for ecosystem type conversion in transition zones between ecotones.	Monitor post-fire recovery of ecosystem **3-D structure**, annually at 30 m resolution

Targeted Observable	Science/Applications Summary	Candidate Measurement Approach	Designated	Explorer	Incubation
Aerosols	**Aerosol properties, aerosol vertical profiles, and cloud properties** to understand their effects on climate and air quality	Backscatter lidar and multi-channel/multi-angle/polarization imaging radiometer flown together on the same platform	X		
Terrestrial Ecosystem Structure	**3D structure of terrestrial ecosystem** including forest canopy and above ground biomass and changes in above ground carbon stock from processes such as deforestation and forest degradation	Lidar**		X	
Surface Topography and Vegetation	**High-resolution global topography** including bare surface land topography ice topography, vegetation structure, and shallow water bathymetry	Radar; or lidar**			X

Needed Trade Studies for Fire Science and Applications

- Observation requirements need OSSE of wildfire behavior and smoke transport to constrain uncertainties and observation record length
- VSWIR requirements
  - Spectral range and sampling requirements are really unknown
  - Retrievals have merely been demonstrated with the sensor data available
    - We need a simulation study to test what spectral range and sampling are required to make retrievals (IS information AND analogous Landsat bands)
  - Observable algorithm scaling and consistency using time series data
  - For uncertainty requirements, we need to test algorithm robustness across variable landscapes (e.g., topography)

ESAS 2017	Science / Applied Science Question	Objective(s)	Physical Parameters	Observables	Mission Functional Requirements	Partners and Data Baseline
E-5C	How does fire affect ecosystem services (e.g., clean air and water, habitat, and biodiversity) and which ecosystems are the most vulnerable to changes?	Fire acts as a catalyst for ecosystem type conversion in transition zones between ecotones.	Vegetation canopy composition - continuous characterization of optical types that capture vegetation functional diversity linked to biodiversity, annually at 30 m resolution; unknown uncertainty requirement, unknown duration - need OSSE	Continuous spectral range 0.4-2.5 µm Unknown spectral sampling High signal-to-noise Global mapping (not sampled)	Sun-Synchronous	WWF - develops and disseminates (via several platforms) information relevant to the WWF goals. WWF works with countries to validate and understand where changes happen on the ground and provide educational materials TNC-
			Canopy chemical composition, annually at 30 m resolution; unknown uncertainty requirement, unknown duration - need OSSE			
			Ecosystem 3-D structure, annually at 30 m resolution; unknown uncertainty requirement, unknown duration - need OSSE	LIDAR or SAR		CI – high remote sensing capability working with Landsat, MODIS, Sentinel 1 and 2, GPM, etc. They provide capacity building and open-source resources
			Fuel accumulation – gross primary productivity derived from fraction of photosynthetic active radiation, leaf area index, or vegetation greenness, seasonally at 30 m resolution; unknown uncertainty requirement, unknown duration - need OSSE	Continuous spectral range 0.4-2.5 µm Unknown spectral sampling High signal-to-noise Global mapping (not sampled)		WRI - WRI does not have a lot of direct remote sensing capability, however they partner with people that do and are a dissemination platform and provide capacity building.
			Burned area and severity – burn fraction , annually at 30 m pixel resolution; unknown uncertainty requirement, unknown duration - need OSSE	Continuous spectral range 0.4-2.5 µm Unknown spectral sampling, but must augment the multi-spectral if weekly is unavailable High signal-to-noise Global mapping (not sampled)		USGS EROS - a clearinghouse of remote sensing data for numerous forests and ecosystems applications and relies on optical imagery and LIDAR

ESAS 2017	Science / Applied Science Question	Science / Applied Science Objective(s)	Physical Parameters	Observables	Mission Functional Requirements	Partners and Data Baseline
H-4d	How do fuel type, structure, amount, and condition influence fire?	The current state of "megafires" as the new normal is primarily driven by climate change, not a century of fire exclusion.	Ecosystem Flammability - Proxies of vegetation stress such as equivalent water thickness, weekly at 30 m resolution; unknown uncertainty requirement, unknown duration - need OSSE	Continuous spectral range 0.4-2.5 μm Unknown spectral sampling High signal-to-noise Global mapping (not sampled)	Sun-Synchronous	USFS – GTAC: primarily relies on VSWIR and TIR and is sensor independent – i.e., Sentinel 2, Landsat, GOES, MODIS, VIIRS, NAIP, and commercial assets such as Worldview 2 and 3, and uses LIDAR
			Ecosystem Health – discrimination of live and senescent vegetation, annually at 30 m resolution; unknown uncertainty requirement, unknown duration - need OSSE			
			Fuel accumulation – same as above			World Bank – funds organizations with remote sensing capability to support REDD+ programs
			Burned area and severity – burn fraction , weekly at 30 m pixel resolution; unknown uncertainty requirement, unknown duration - need OSSE	Continuous spectral range 0.4-2.5 μm Unknown spectral sampling, but must augment the multi-spectral if weekly is unavailable High signal-to-noise Global mapping (not sampled)		

ESAS 2017	Science / Applied Science Question	Science / Applied Science Objective(s)	Physical Parameters	Observables	Mission Functional Requirements	Partners and Data Baseline
C-8g	How do these smoke emissions influence atmospheric dynamics and health and air quality as they are globally transported?	The role of secondary pollutants from fire emissions has significant radiative forcing as compared to primary pollutants and green house gases.	Everything above		peak observation time is 12-6 pm local time	EPA
			Combustion Efficiency - Fire Temperature, sub-daily at ≤200 m pixel resolution; unknown uncertainty requirement, unknown duration - need OSSE	NEdT of 0.2K with a ~4 µm with ≥400 K saturation and sufficient thermal range for fire detections (but may require 2-bands to have sufficient sensitivity at the lower temperatures) AND Continuous spectral range 8-12 µm (OR 0.4-2.5 µm) Unknown spectral sampling High signal-to-noise Global mapping (not sampled)		
			Aerosol Optical Depth, sub-daily at ≤200 m pixel resolution; unknown uncertainty requirement, unknown duration - need OSSE	Continuous spectral range 0.4-2.5 µm Unknown spectral sampling High signal-to-noise Global mapping (not sampled)		USFS AirFire – air quality monitoring and field data for validation
			Secondary Pollutant - Ammonia, sub-daily at ≤200 m pixel resolution; unknown uncertainty requirement, unknown duration - need OSSE	Continuous spectral range 8-12 µm Unknown spectral sampling High signal-to-noise Global mapping (not sampled)		
			change in biomass, annually at 30 m spatial resolution; unknown uncertainty requirement, unknown duration - need OSSE	LIDAR or SAR		


Questions?