Remote sensing of active fire, fire effects, and fuels

RNR 355 Introduction to Wildland Fire

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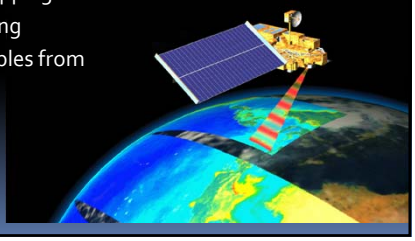
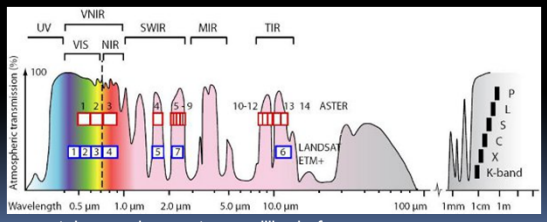
Outline

- Remote sensing basics
- Active fire mapping
- Post-fire mapping
- Fuels mapping
- Some examples from my research



Remote sensing basics

- Human eye: .39-.75
- Active fire mapping: SWIR/MIR/TIR
- Post-fire: VIS/NIR/SWIR
- Fuels: VIS/NIR/SWIR



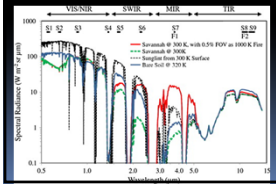
1 µm (micron or micrometer) = one-millionth of a meter

Fire/Remote sensing terminology

- Burn severity: the degree to which an ecosystem has changed due to fire (post-fire)
  - Relative magnitudes of severity, discrete classes, contextual (severity can be objective- or ecosystem-specific)

Fire/Remote sensing terminology

- Most fires exhibit radiometric temperatures of between 750 and 1200 K
- Peak thermal emission occurs in SWIR (1.6-2.5) and MIR (3-5) windows (see Robinson 1991)
- Strong solar reflective signal in SWIR means most fires are detected in MIR

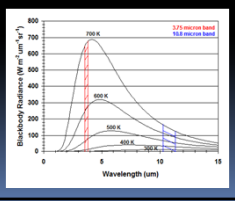


Robinson, J. M. 1991. Fire from space: global fire evaluation using infrared remote sensing. *International Journal of Remote Sensing* 12 (1):3–24.

Fire/Remote sensing terminology

- Fire Radiative Power (FRP): measure of the rate of energy released from fire
  - Measured using the thermal and middle infrared region of the electromagentic spectrum ($\Delta T_{MIR\text{-}TIR}$)

Active fire detection technique was originally developed by Matson and Dozier (1981) for data from NOAA's Advanced Very High Resolution Radiometer (AVHRR).



Satellites

- Satellite resolutions: spatial, temporal, spectral
- Orbit

Main fire mapping satellites

- Geostationary Satellite system (GOES)
- AVHRR (Advanced Very High Resolution Radiometer)
- MODIS (Moderate Resolution Imaging Spectroradiometer)
- Landsat
- ESA Sentinel-3 Sea and Land Surface Temperature Radiometer (SLSTR) (2013)

Forest Service MODIS Active Fire Mapping Program

Sensor	Platform Type	Spatial Resolution (Reflectance/TIR Bands)	Temporal Resolution (per instrument)	Fire Algorithm	Data Source
MODIS	Polar orbiting	250m, 500m, 1km/1km	2 times daily	MOD14/MYD14	Direct Readout; NASA Rapid Response System
AVHRR	Polar orbiting	1km/1km	2 times daily	FIMMA	NOAA NESDIS
GOES	Geostationary	1km/4km	4 times hourly	WF-ABBA	NOAA NESDIS
VIIRS*	Polar orbiting	375m/750m	2 times daily	TBD	Direct Readout; Rapid Response
GOES-R#	Geostationary	500m, 1km/2km	4 times hourly	TBD	Direct Readout; NOAA NESDIS

* VIIRS launch on NPOESS Preparatory Project (NPP) mission in June 2010 and subsequent NPOESS missions
# GOES-R launch in 2015 and subsequent missions

MODIS Active Fire Mapping

- Moderate Resolution Imaging Spectroradiometer (MODIS) on Terra and Aqua Satellites
- 2000- and 2002-present
- Brightness temperatures from T4 (mid-wave) and T11 μm (long-wave) channels
- T4>360 K, ΔT>10 K,
  - where ΔT = T4T11
- Information about actively burning fires, including their location and timing, instantaneous radiative power, and smoldering ratio

MODIS Active Fire Mapping

- http://activefiremaps.fs.fed.us/
- False alarms?
  - Red and NIR used to reject false alarms
  - 2.1 band used to reject water-based misclass
- Fire activity smaller than 1km can be detected
  - 100m² flaming fire (50% probability)
  - 50m² flaming fire in ideal viewing conditions (~100% probability)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An Enhanced Contextual Fire Detection Algorithm for MODIS

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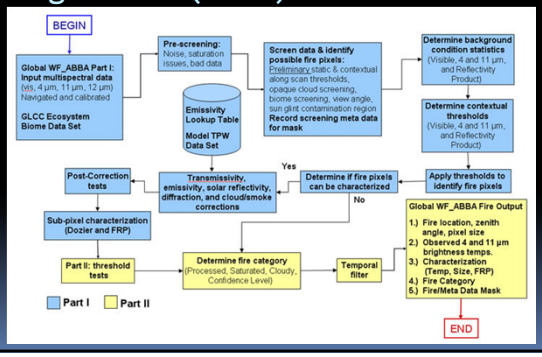
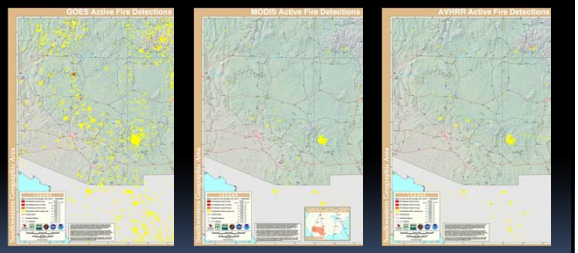
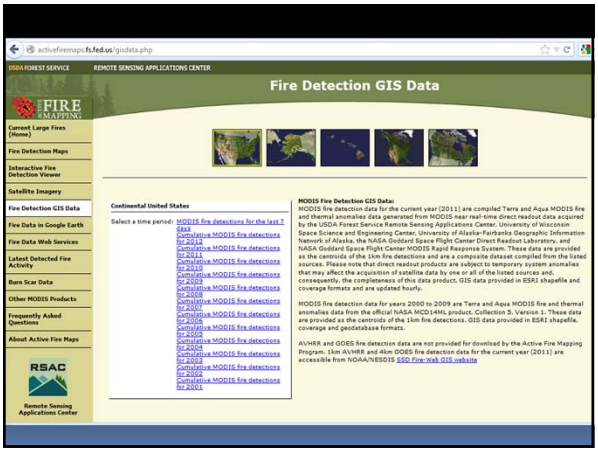
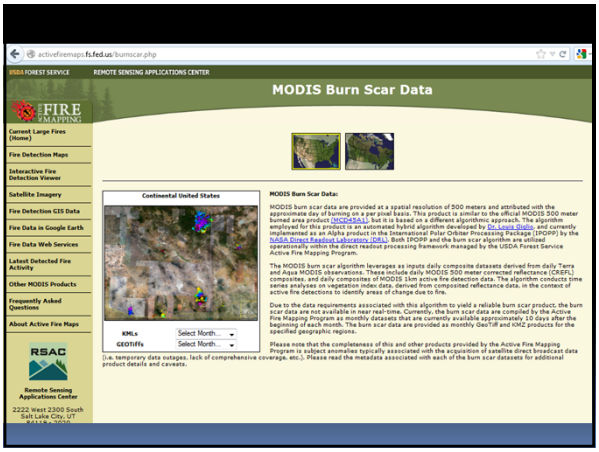
Automated Biomass Burning Algorithm (ABBA)



Active fire detections from GOES, MODIS and AVHRR

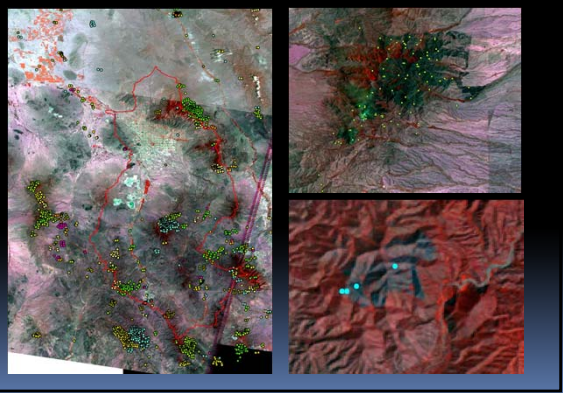






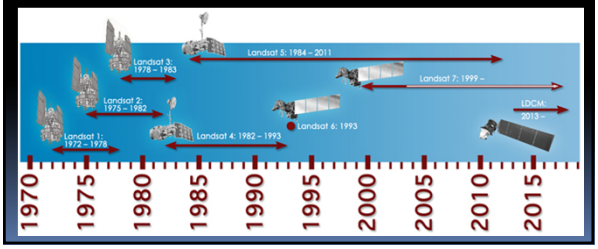
Global Data

MODIS thermal anomalies 2001-present



Post-fire mapping with Landsat

- Multispectral Scanner (MSS)
- Thematic Mapper (TM)
- Enhanced Thematic Mapper (ETM+)
- Landsat Data Continuity Mission (LDCM)



Landsat MSS, TM and ETM+

Multispectral Scanner (MSS)	Landsat 1-3	Landsat 4-5	Wavelength (micrometers)	Resolution (meters)
	Band 4	Band 1	0.5-0.6	60
	Band 5	Band 2	0.6-0.7	60
	Band 6	Band 3	0.7-0.8	60
	Band 7	Band 4	0.8-1.1	60

Thematic Mapper (TM)	Landsat 4-5	Wavelength (micrometers)	Resolution (meters)
	Band 1	0.45-0.52	30
	Band 2	0.52-0.60	30
	Band 3	0.63-0.69	30
	Band 4	0.76-0.90	30
	Band 5	1.55-1.75	30
	Band 6	10.40-12.50	120* (30)
	Band 7	2.08-2.35	30

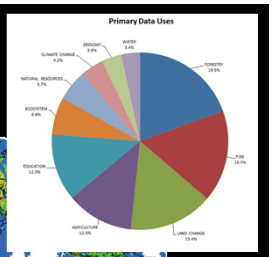
Enhanced Thematic Mapper Plus (ETM+)	Landsat 7	Wavelength (micrometers)	Resolution (meters)
	Band 1	0.45-0.52	30
	Band 2	0.52-0.60	30
	Band 3	0.63-0.69	30
	Band 4	0.77-0.90	30
	Band 5	1.55-1.75	30
	Band 6	10.40-12.50	60 * (30)
	Band 7	2.09-2.35	30
	Band 8	.52-.90	15

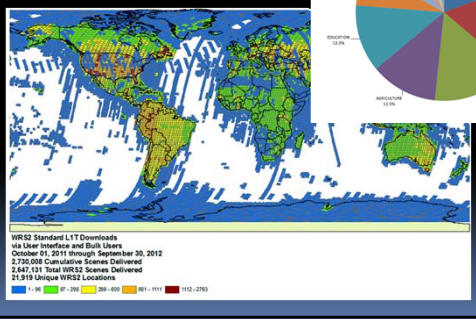
Landsat Data Continuity Mission

Landsat Data Continuity Mission (LDCM) Projected Launch February 11, 2013	Bands	Wavelength (micrometers)	Resolution (meters)
	Band 1 - Coastal aerosol	0.433 - 0.453	30
	Band 2 - Blue	0.450 - 0.515	30
	Band 3 - Green	0.525 - 0.600	30
	Band 4 - Red	0.630 - 0.680	30
	Band 5 - Near Infrared (NIR)	0.845 - 0.885	30
	Band 6 - SWIR 1	1.560 - 1.660	30
	Band 7 - SWIR 2	2.100 - 2.300	30
	Band 8 - Panchromatic	0.500 - 0.680	15
	Band 9 - Cirrus	1.360 - 1.390	30
	Band 10 - Thermal Infrared (TIR) 1	10.3 - 11.3	100
	Band 11 - Thermal Infrared (TIR) 2	11.5 - 12.5	100

Landsat

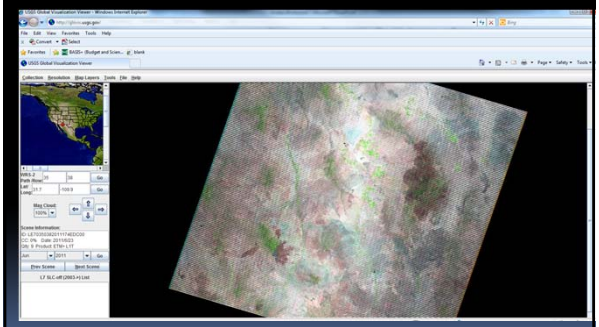
How Users Put Landsat Data to Work
October 1, 2011 to September 30, 2012





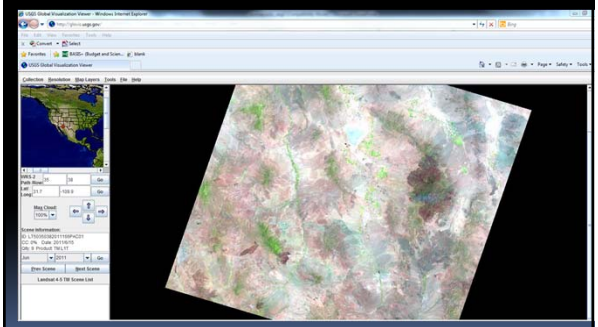
Acquiring Landsat

Acquiring Landsat



Landsat 7 (ETM+) scene 35/38, June 23, 2011. Horseshoe II fire scar visible.

Acquiring Landsat



Landsat 5 (TM) scene 35/38, June 15, 2011. Horseshoe II fire scar visible.

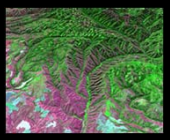
Burned Area Emergency Response (BAER)

- Objective is to prescribe and implement emergency stabilization measures in order to prevent further damage to life, property and natural resources
- **BAER teams are deployed to fires where special efforts are required to mitigate potential hazards resulting from fire effects**
- **Post-fire damage assessment**
  - **Focus on soil and water quality effects**
  - **Calculate potential erosion and debris flows**
  - **Determine values at risk downstream**
  - **Identifies priority areas to be treated**
  - **Determine appropriate treatments that help to mitigate some of the risk**
- **Response plan is required within 7 days of fire containment**
- **RSAC remote sensing support is critical in generating the BAER response plan**

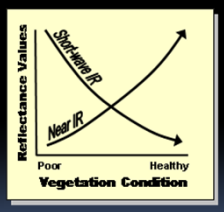
Burned Area Emergency Response Imagery Support

Objective is to provide rapid delivery of remote sensing products to Forest Service BAER teams
- Pre-/Post-fire satellite imagery
- Burned Area Reflectance Classifications (BARC)
- Other relevant geospatial data and products

- RSAC remote sensing support provided at or immediately after fire containment
- RSAC provides imagery and data products within 24 hours of image acquisition
- Multiple BAER teams/wildland fire incidents are supported simultaneously by RSAC
- Critical technical factors:
  - Spatial resolution – 20 to 30m
  - Spectral resolution – SWIR band
  - Acquisition timing – at or near fire containment
  - Delivery from provider – FTP; same day of acquisition



Post-fire mapping: Burned Area Reflectance Classification (BARC)



Normalized Burn Ratio (NBR)
Differenced Normalized Burn Ratio (dNBR)

NBR = (NIR – SWIR) / (NIR + SWIR)

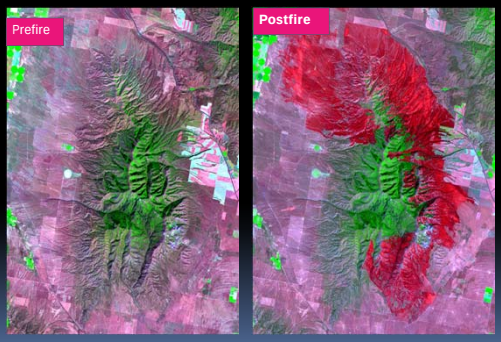
dNBR = Pre NBR – Post NBR

Normalized Difference Vegetation Index (NDVI)
Differenced NDVI (dNDVI)

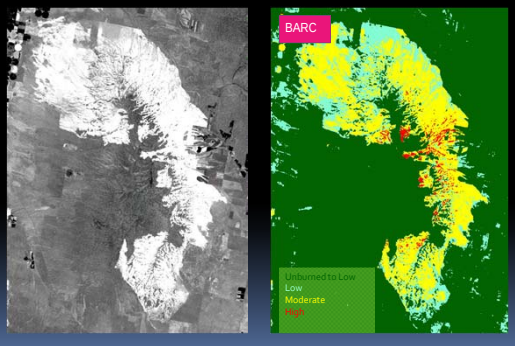
NDVI = (NIR – Red) / (NIR + Red)

dNDVI = Pre NDVI – Post NDVI

Post-fire mapping



Post-fire mapping



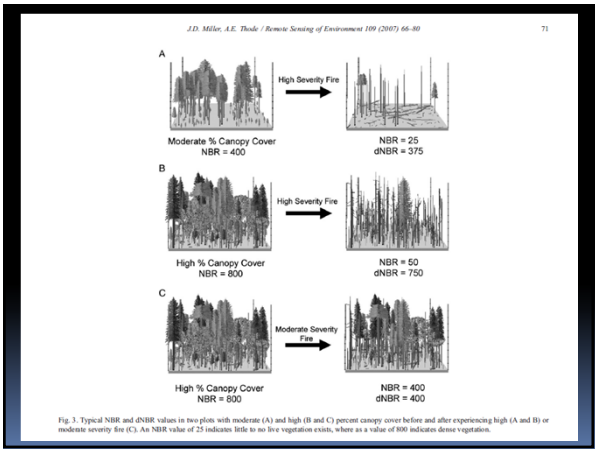
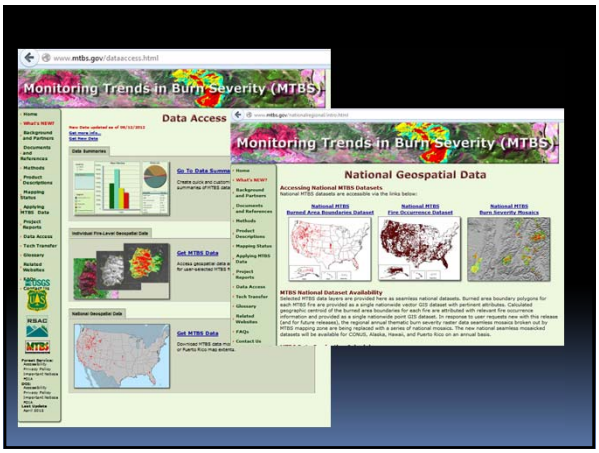
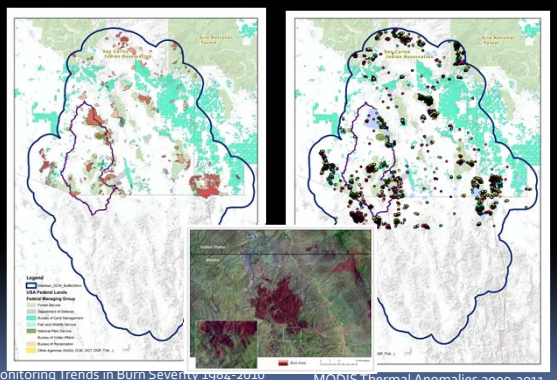


Fig. 3. Typical NBR and dNBR values in two plots with moderate (A) and high (B and C) percent canopy cover before and after experiencing high (A and B) or moderate severity fire (C). An NBR value of 25 indicates little to no live vegetation exists, where as a value of 800 indicates dense vegetation.

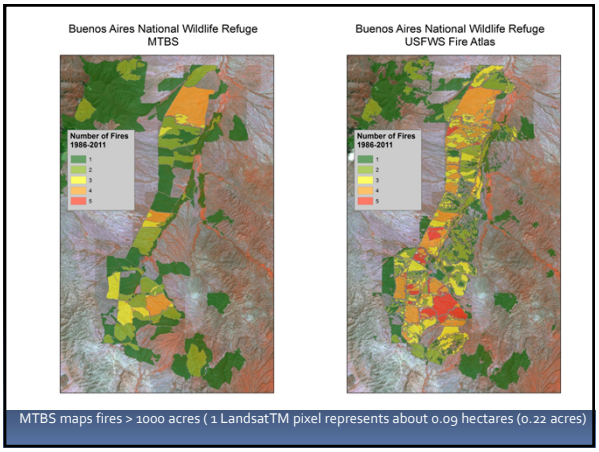


Sky Islands



Monitoring Trends in Burn Severity 1984-2010

MODIS Thermal Anomalies 2000-2011

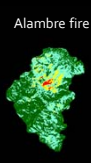


MTBS maps fires > 1000 acres (1 LandsatTM pixel represents about 0.09 hectares (0.22 acres)

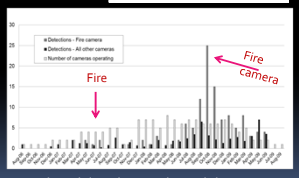
Example of data use:

Javelina (*Pecari tajacu*)

Alambre fire



dNBR map



Mixed model analyses indicated that time-since-fire was significant for javelina sightings ($p = 0.02$).

Mapping fuels

- Use the Normalized Difference Vegetation Index (NDVI) timeseries to produce a live fuel moisture stress index (FMSI)
- Use FMSI to model fuel phenologies and fire hazards
- Yool, S.R. (2011). Remote Sensing of Live Fuel Moisture; in Q. Weng (ed.) Advances in Environmental Remote Sensing: Sensors, Algorithms and Applications; Ch. 13

Fuel moisture stress index (FMSI)

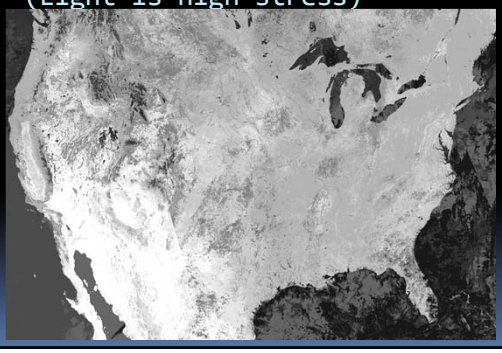
- By converting the NDVI timestep value for each pixel into multi-temporal Z-score, we produce for each pixel a Fuel Moisture Stress Index (FMSI)—expressing the pixel's *distinctive timestep fuel moisture stress* within the complete time series
- The Z score represents the distance in standard deviations of a sample from its population mean

  $Z = [(Xi - X\ mean) / X\ sd]$
- Then, $FMSI_{i,j,t} = - [(NDVI_{i,j,t} - NDVImean_{i,j,T}) / NDVIsd_{i,j,T}]$

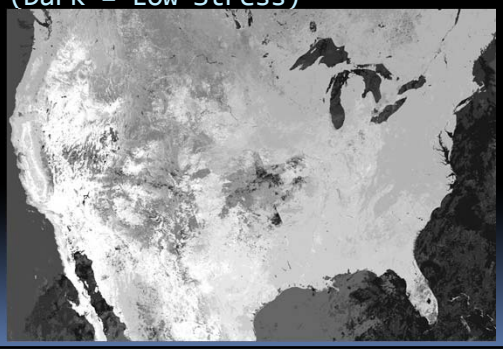
So the FMSI is a measure at a specific time of the distance in standard deviations of a pixel's fuel moisture stress from its mean (average) moisture stress across that pixel's complete time series

(The negative sign inverts the values, so pixels with low scores get mapped as bright, moisture-stressed pixels.)

FMSI (June)
(Light is high stress)

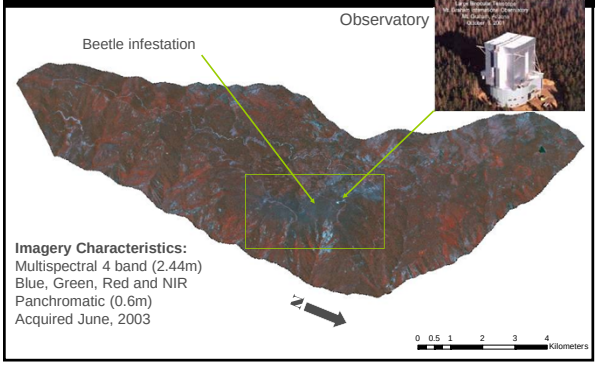


FMSI (September)
(Dark = Low Stress)



High resolution burn mapping of insect damaged forests

Pre-fire Quickbird Image



Post-fire Quickbird Image

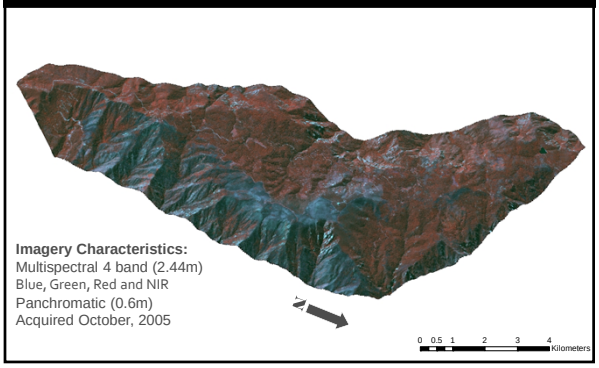
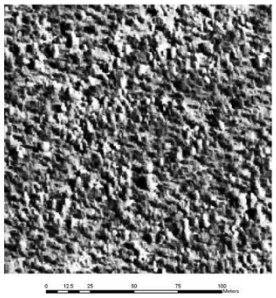
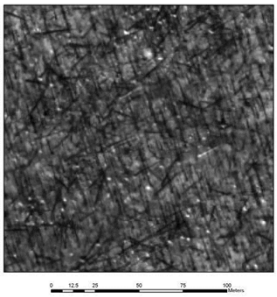


Image Variance

Pre-fire Spruce-fir Stand

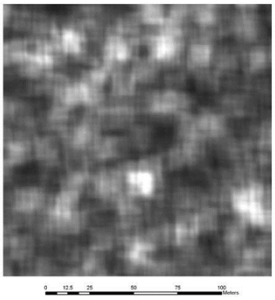


Post-fire (same area)

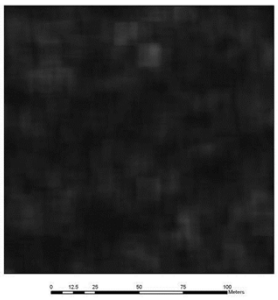


Texture Images

Pre-fire Spruce-fir Stand

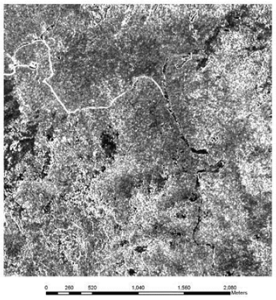


Post-fire (same area)

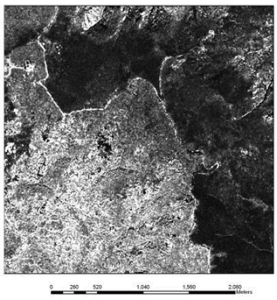


Texture Images – Burn Scar

Pre-fire



Post-fire

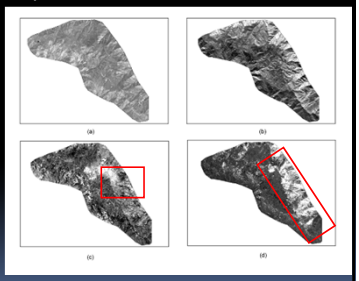


Principal Components

- 8 multispectral band input

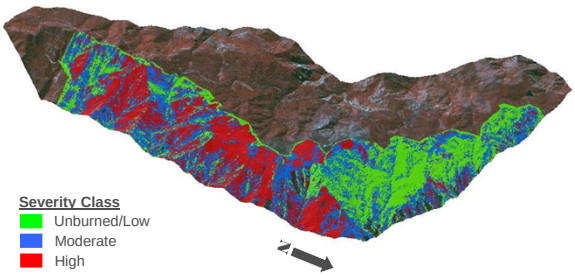
Eigenvector matrix:

- PC_3 strong negative values in pre and post NIR bands
- PC_4 loadings pre and post-fire Red/NIR

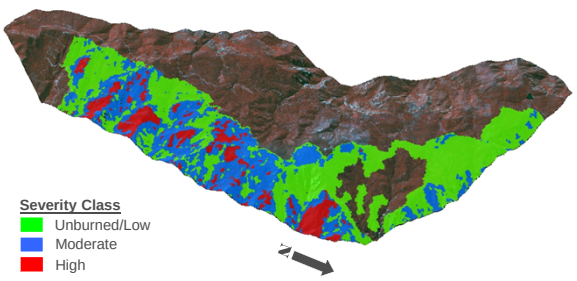


First four principal components: a) PC1 b) PC2 c) PC3 and d) PC4

High-resolution Map

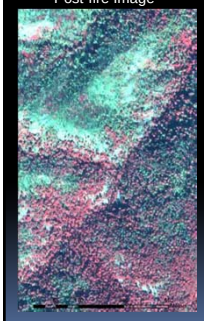


BARC map

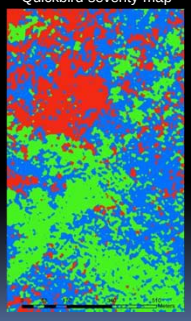


Map detail

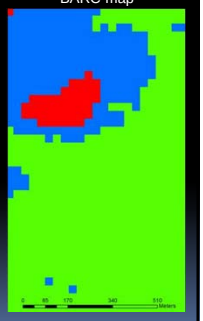
Post-fire Image



Quickbird severity map



BARC map



Accuracy Assessment

- 713 ground points collected at MGRS midden locations
- Fire damage measured at lower canopy (0-100%) and upper canopy (0-100%)
- 10m radius around midden locations
- Severity class assigned:
  - Combined upper and lower canopy damage
  - Low/unburned(< 40%)
  - Moderate (41-120%)
  - High (>120%)

Accuracy Results: Kappa

10m buffer	Quickbird	BARC
Overall:	.82	.27

20m buffer	Quickbird	BARC
Overall:	.93	.27

- 10m: Quickbird problems with moderate class
- 20m: Quickbird moderate class good, high class lower
- BARC problems with both moderate and high

Questions?

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