Remote Sensing of Fuel Type, Load, and Condition

*Recent Research and Future Directions*

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Remote Sensing of Fuels

- Fuels are highly variable in space
- Remote sensing is well-suited to mapping this variability
- Surface fuels vs. canopy fuels
- Fuel properties that can be mapped using remote sensing:
  - Fuel type
  - Fuel load and structure
  - Fuel condition
Fuel Type

Important parameters for fuels assessment and fire behavior modeling:

– Vegetation type or species maps (often intermediate step)

– Fuel models
  • Anderson (1982) → 13 models
  • Scott and Burgan (2005) → 40 dynamic fuel models
Mapping Fuel Type

• Moderate resolution multispectral data are sufficient for mapping vegetation for use in simpler fuel model classifications
• Hyperspectral data permit discrimination of more detailed fuel types
• National fuels mapping project supported by US Forest Service, USGS, and Nature Conservancy

• Surface fuel models mapped using four variables:
  – existing vegetation type
  – canopy cover
  – canopy height
  – environmental site potential

• Existing vegetation type and canopy cover/height are derived from Landsat data

• Fuel model classification rulesets were developed using expert review and refined through calibration workshops
Multispectral vs. Hyperspectral

AVIRIS
TM
Santa Barbara Wildland-Urban Interface
Species-Level Fuel Type Map

Dennison and Roberts, 2003
Urban Fuels: Hyperspectral Mapping of Wood Shake Roofs

Fire Hazard Risk
California Department of Fire (CDF):
- Fire risk
- No risk
- Road network
- Wood shingle roofs mapped from AVIRIS data

Martin Herold
AVIRIS Image Acquired over 2003 Simi Fire
Important parameters for fuels assessment and fire behavior modeling:

- Fuel load (surface fuels)
- Canopy bulk density
- Canopy height
- Canopy base height
- Canopy cover
- Ladder fuels
Remote Sensing of Fuel Load and Structure

• Grass, shrub surface fuel loadings can be mapped using multispectral indices.
• LANDFIRE uses Landsat data as one input into a predictive model for canopy bulk density and canopy base height.
• Lidar can directly measure canopy height and canopy base height.
• Models can be used to estimate canopy bulk density from lidar returns.
Small Footprint Lidar Vertical Cross-sections

No Understory

Understory

Riaño et al., 2003
Canopy Bulk Density Mapping Using Clustering

Riaño et al., 2004
Fuel Load and Structure Estimation Using Canopy Complexity

- Small footprint lidar was used to create digital canopy model (DCM)
- Canopy complexity measures calculated from DCM
  - Rumple index (Parker et al., 2004) = ratio of DCM area to ground surface area
  - Standard deviation of DCM height

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Linear Model</th>
<th>Adjusted r²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available Canopy Fuel (Mg/ha)</td>
<td>8.071<em>MEAN -6.95</em>RUMPLE + 8.441</td>
<td>0.851</td>
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<tr>
<td>Canopy Bulk Density (kg/m³)</td>
<td>0.062<em>MEAN -0.063</em>RUMPLE + 0.099</td>
<td>0.745</td>
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</tbody>
</table>

Kerry Halligan and Dar Roberts
Available Canopy Fuel

- 10-20 Mg/ha
- 20-30 Mg/ha
- 30-40 Mg/ha
- 40-50 Mg/ha
- > 50 Mg/ha

Storm Creek Fire scar

Kerry Halligan and Dar Roberts
Large Footprint Lidar: LVIS

\[ r^2 = 0.71 \]
Large Footprint Lidar: LVIS

$r^2 = 0.48$
Shrub Canopy Height

- Lidar has limited abilities for retrieving fuel properties from shrubs and grasses
- Riaño et al. (2007) demonstrated small footprint lidar estimation of shrub height using aerial orthoimages to separate shrub returns from ground returns

Riaño et al., 2007
Fuel Condition

Important parameters for fuels monitoring and fire behavior modeling:

– Phenology and senescence
– Fuel moisture (live fuels)
– Fractions of live and dead fuels
Remote Sensing of Fuel Condition

• Fuel condition can be assessed using multispectral, hyperspectral and radar remote sensing
  – Phenology and senescence can be assessed using time series of vegetation indices
  – Live fuel moisture is correlated with direct and indirect measures of canopy water content
    • Water absorption indices
    • Chlorophyll absorption indices
  – Fractions of live and dead fuels can be measured using spectral mixture analysis (green vegetation fraction vs. non-photosynthetic vegetation fraction)
  – Soil moisture is correlated with radar backscatter
MODIS Index Correlations with LFM

Chamise Chaparral

MODIS VARI

MODIS EVI

Sagebrush

Kraivut Charoensiri and Phil Dennison

Dennison et al. 2007

MODIS Index Correlations with LFM

R² = 0.80

R² = 0.88

Live Fuel Moisture (%)
Satellite-derived Map of Chaparral Live Fuel Moisture
San Diego County - 8-15 October 2007

Stow and Niphadkar, 2007

Fuel Moisture Map

- Freeways
- Fire Perimeter from MODIS - 24 Oct 2007
- San Diego County Boundary
- Non-chaparral area
- Extremely low fuel moisture
- Low fuel Moisture
- Low - Moderate fuel moisture
- Moderate Fuel Moisture
- Moderate to high Fuel Moisture
- High Fuel Moisture

Kilometers
Eastern Forest Live Fuel Moisture

- MODIS band response to LFM simulated using PROSPECT leaf model
- An inversion model calibrated using ground data can be used to map live fuel moisture

Hao and Qu, 2007
Chaparral LFM Prediction

Dennison et al. 2008
SAR Monitoring of Soil Moisture

- Backscatter increases with increased soil moisture
- Scattering by vegetation canopies reduces the magnitude of the backscatter signal
- Works best in fire scars and low canopy cover
- Backscatter is well correlated with the “Drought Code” portion of the Canadian Forest Fire Danger Rating System

Laura Bourgeau-Chavez
SMA Fractions for Fuel Condition Monitoring

- Fractions of green vegetation and non-photosynthetic vegetation can be used to assess grass fuel condition.
- Elmore et al., 2005 used SMA fractions calculated from AVIRIS and MODIS data to monitor seasonal changes in grassland fuels.

Elmore et al., 2005
Fire Potential Index for MODIS

- MODIS indices more closely related to live fuel moisture can be used to improve the Fire Potential Index.
- A new FPI developed for Southern California uses VARI-based relative greenness, dead fuel moisture, moisture of extinction, and live-to-dead ratio.

Schneider et al., 2008
Fire Danger Monitoring Based on Energy of Pre-ignition

- Pre-ignition energy is the energy required to bring fuel from its ambient temperature to ignition temperature.
- Live fuel moisture and land surface temperature measured from MODIS data can be used to approximate pre-ignition energy.

Dasgupta et al., 2006

Fire Susceptibility Index values
Future Research Directions

1. Increased exploitation of lidar data, hyperspectral data, and data fusion
2. Movement towards mapping continuous fuel properties rather than discrete fuel models
3. More complex models of fire danger and fuel condition
   - Example: Non-photosynthetic vegetation fraction + soil water balance
4. Mapping disturbance and climate change impacts on fuels
   - Fire, bark beetle outbreaks, invasive species, drought
Issues Facing Future Research: Limited Data Availability

- Recent research using hyperspectral and lidar data can’t be applied to large areas
- Data availability is also an issue for applications using multispectral data
Issues Facing Future Research: Fuel Properties as Inputs for Fire Models

- Current operational fire spread models don’t make good use of most remote sensing products
- Can remote sensing products drive future fire models?
Issues Facing Future Research: Spatial Scale

• What scales are appropriate for research on remote measurement of fuel properties?
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