An Investigation of Impacts of Large Wildland Fires on Land Surface Properties in Alaska with Satellite Remote Sensing

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Land surface changes due to wildfires

➢ Large vegetation removal

➢ Post-fire surface albedo recovers quickly after initial drop, and may exceeds pre-fire values when char materials are removed and vegetation starts to regenerate

➢ Immediate post-fire day-time surface temperature increase
Fire and climate interactions

- Fire
  - Emission
    - Particle
    - CO₂
  - Vegetation
    - Heat
    - Water
  - CCN short and long
    - Cloud
    - Radiation
  - Temp
  - Wind
  - Humid

- Weather/climate
  - Lightning
  - Rad
  - Temp
  - Humid
  - Wind
  - Fuel T
  - Fuel M
  - Ignition
  - Risk
    - Occurrence
    - Spread

Flow diagram showing interactions between fire and climate factors.
Issues

➢ Complexity in land-surface property changes due to climate regimes, fire intensity, fuel type, seasonality, etc.
➢ Lack of tools in Earth System Models such as CESM for estimating these changes.
➢ Lack of understanding of the climate impacts of fires through land-surface property changes.
Wildfires and impacts in Alaska

➢ The Alaska boreal forests, peat-rich tundra, and permafrost hold about 53% of US carbon.
➢ 177 mega-fires in USA since 1997, nearly 30% occurred in Alaska.
➢ Surface albedo can increase significantly because of increased exposure of snow cover in burned areas in Alaska (Lyons et al. 2008, Huang et al. 2014, French et al. 2016).
➢ More systematic analyses are needed.
Objectives

➢ To detect changes in land surface properties due to wildland fires in Alaska

➢ To develop a systematic approach and software to characterize both short- and long-term post-fire land surface property changes through integrated spatio-temporal analysis

➢ To provide inputs of land surface property disturbances for parameterization development and climate-fire interaction modeling
Detection Procedure

- **Remote Sensing Data**
  - RS Data Processing
  - Time Series of Land Properties

- **MTBS Wildland Fire Data**
  - Rasterization
  - Wildland Fire Burned Area Map

- **GHCN Weather Data**
  - Extract Ground Weather Data
  - Time Series of Weather Data

- **Data analysis**
  - Spatio-Temporal Data Integration and Analysis

- **Surface change**
  - Surface Vegetative Changes
  - Surface Radiative Changes
  - Surface Hydrological Changes

- **Statistics**
  - Statistical Analysis and Inference

- **Impacts of Large Fires**

**MODIS:** Global, 500 m and 1000 m resolutions, 2000-present, 8-day products, Land cover type data (MCD12), Surface Albedo Data (MCD43A3), Surface Reflectance Data (MOD09A1), Leaf Area Index (LAI) data (MOD15A2), Land Surface Temperature Data (MOD11A2)

**Monitoring Trends in Burning Severity (MTBS) (USGS and USFS)**
- Burned area and severity map. CONUS, 30 m resolution, 1984-present
Spatial and temporal analyses

- **Comparison between burned and control pixels**
  - Select burned sample pixels and find corresponding control pixels which have the same prefire land cover type and very close surface albedo with burned pixels.
  - Fire-induced changes: difference between burned and corresponding control pixels.

- **Surface property before and after fires**
  - Build time series of land surface properties.
  - Assess surface property changes caused by fire.
45 large wildfires (burned area > 100k acres) in Alaska from 2002 to 2009, usually starting in June or July and ending from June to November.
Parameterization scheme design

Detected change

Fit with natural exponential function

Trend

Remove trend

Fluctuation

Fourier analysis

Max - Min within a year

Periodic variation

Amplitude of the year

Simulated change
8-day surface albedo statistics of the selected 45 fires show neglectable difference between burned and controlled pixels before fire events.

Albedo dropped immediately after burning because of ashes and dark scars. But, when winter came, albedo over burned areas increased significantly because of the increased exposure of snow.

For the next year after fire, albedo of burned area increased over 0.05 in average during JAN-APR, slightly decreased 0.01-0.02 during MAY-SEP, and increased again during OCT-DEC.
Statistics of surface albedo of the selected 45 large fires over 6 year period (from the year before fires to 4 years after fires) show that the seasonal pattern of albedo change matches snow cover very well. During October-April of years after fires, albedo increased significantly.

During May to September, the attenuating difference with year between burned pixels and control pixels shows the albedo recovered gradually in 3-4 years in average.
Long-term albedo

The significant increase of albedo in spring and winter can last for many years.
- Reindeer fire in 2002. The changes in Spring and Winter last over decade.
Seasonal LAI

- Statistics of LAI difference between burned and control pixels over 6 year period (from the year before fires to 4 year after fires) show that LAI significant decreased shortly after fire because of vegetation removal and LAI recovered gradually during the following years.
- The LAI recovery may vary for individual events because of variations of land cover type, burned severity, etc.
- Second extremes in mid-October.

![Graph showing LAI differences over time](image1)

![Graph showing average LAI change](image2)
Long-term LAI

- Reindeer fire in 2002.
Similar to LAI, NDVI also decreased significantly shortly after fire.

NDVI recovery looked quick during the first and second years after fires, but became slower from the 3rd year.
Long-term NDVI

- NDVI Recovery
  - Example: Reindeer fire in 2002.
Seasonal surface Temperature (day-time)

- Statistics of MODIS day-time surface temperature difference between burned and control pixels over a 6 year period demonstrated significant increase of day-time surface temperature during May to September after fire events.

- Slight decrease of day-time surface temperature was found during October to April.

- The impacts of fires on day-time surface temperature may keep for years. The magnitude varied with seasons and slightly attenuated with year.
Small changes of night-time surface temperature during May to September.
Slight decrease of night-time surface temperature during October to April.
Before and after fire termination

\[ P(t) = \begin{cases} F_0(t), & t < t_0 \\ F(t), & t \geq t_0 \end{cases} \]
Separate into trend and fluctuation

\[ F(t) = F_t(t) + F_f(t) \]

\[ F_t(t) = -e^{a_0 + a_1 t + a_2 t^2} \]

\[ a_0 = -0.597 \]
\[ a_1 = -0.0073 \]
\[ a_2 = 0.00039 \]
Express fluctuation as multiple of periodic variation and amplitude for fluctuation

\[ F_f(t) = A(t) \cos \left( \frac{2\pi}{T} (t - t_0 - t_p) \right) \]

\[ A(t) = e^{b_0 + b_1 t + b_2 t^2} \]

- \( b_0 = -1.851 \)
- \( b_1 = -0.444 \)
- \( b_2 = 0.0403 \)
Simulation scheme

\[ F(t) = -e^{a_0 + a_1 t + a_2 t^2} + e^{b_0 + b_1 t + b_2 t^2} \cos \left( \frac{2\pi}{T} (t - t_0 - t_p) \right) \]
Conclusions

➢ Snow dependence is a major feature of the fire-induced albedo changes in Alaska. The changes may last for more than a decade, suggesting long-term climate impacts. But MODIS measurements are not long enough for some fires.

➢ Larger climate effect is expected in summer due to vegetation change and active air-land interactions despite larger albedo increase. In winter. The roles of albedo changes in surface energy balance have yet to be understood.

➢ fire-induced changes are featured by long-term deceasing trend and fluctuations with periodic variations and decaying amplitude. The data based scheme would provide a tool for simulating the regional climate effects of wildfires with earth system models such as CESM.
Future Research

➢ Detect more properties (moisture, cloud etc.)
➢ Connect surface changes among properties.
➢ Compare large wildland fires over various regions.
➢ Combine satellite and in-situ measurements.
➢ Develop parameterization scheme for Alaska and other regions and conduct climate impact modeling.
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