Albedo Trends Related to Land Cover Change and Disturbance: A Multisensor Approach

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Replacing forest w/ short stature vegetation
=> increased albedo
=> net radiative cooling
Global RF from Land Use Change (IPCC AR4)

Radiative forcing of climate between 1750 and 2005

- Long-lived greenhouse gases
  - CO₂
  - N₂O
  - CH₄
  - Halocarbons
- Ozone
- Stratospheric water vapour
- Surface albedo
- Land use
- Black carbon on snow
- Linear contrails
- Total Aerosol
- Cloud albedo effect
- Total net human activities

Radiative Forcing Terms

Human activities

Natural processes

- Solar irradiance
- Total net human activities

Radiative Forcing (watts per square metre)

-2 -1 0 1 2

~0.6 W/m² land use
Up to -0.5 W/m² land use … but could be zero!

From IPCC AR4, Ch. 2
Improved Albedo via Multi-Sensor Fusion

Objective: improved estimates of albedo impacts of land use change and forest disturbance by fusing information from Landsat (spatial resolution) and MODIS (angular information)

- **Global Scale**: Improved Albedo vs. Land Cover LUT
  - “pure”, geographically specific land cover samples
  - recalculation of global land use RF since 1500

- **Landscape Scale**: How do disturbance & LC change affect regional albedo?
  - 30m albedo by combining Landsat reflectance and MODIS BRDF
  - application to long-term Landsat LC change maps
Improved Albedo-Land Cover LUT \((Gao)\)

Retrieve “pure” examples of MODIS albedo (MCD43A) for IGBP types (MCD12) by looking for 500m cells with low \(\text{VAR}(\rho_{\text{Landsat}})\).

Hierarchical approach: Inherit nearest example to provide example of every IGBP type at every location of globe.

Separate albedo LUT for:
- albedo type \{wsa, bsa\} & spectral band \{vis, nir, sw\}
- climatologic date \{1-46 8-day periods\}
- snow covered & snow-free
Grassland, Snow-free, Shortwave, WSA, 0.05° (Albedo)

Global WSA = 0.178
Grassland, Snow-free, Shortwave, Stdev of WSA, 0.05° (uncertainty)

Global Standard Deviation of WSA = 0.041
Modeled MODIS white-sky albedo from LUMs in shortwave on August (2001-2010) at 0.05 degree
Climatology Albedo

Modeled Albedo

Snow-free WSA
Shortwave
August
0.05 degree
Modeled snow-covered shortwave white-sky albedo in January from LUMs
Global Albedo and Radiative Forcing
(Ghimire, Williams)

Compute blue-sky albedo for each month \((m)\), year \((y)\) and pixel \((p)\) as:

\[
\alpha_{m,y,p} = \sum_{l=0}^{17} \sum_{s=0}^{1} \sum_{r=0}^{1} f_{l,y} f_s f_r \alpha_{l,s,r,m,p}
\]

\(f_{l,y}\) is fraction \((f)\) of a given land-cover class \((l)\) at year \((y)\),

\(f_s\) is fraction of snow-covered \((s=0)\) and snow free \((s=1)\) (NCEP/NCAR reanalysis)

\(f_r\) is fraction of diffuse \((r=0)\) and direct \((r=1)\) radiation (NCEP/NCAR reanalysis)

Albedo maps from 1500 to 2005 are then converted into surface radiative forcing \((F_s)\) using incoming solar radiation \((I)\) from NOAA-CIRES Reanalysis as:

\[
F_s = \alpha_{m,y,p} I
\]
Global Land Cover History 1500-2005
Hurtt et al (2006) LU Harmonization cross-walked to IGBP land cover types
Global Albedo Change 1500-2005

(2005 – 1500) Global Δ surface SW albedo = 0.0012
Spatial Patterns of Surface Albedo Change

Δ SW albedo (2005 – 1500)
Global ALCC Radiative Forcing Change 1500-2005

(2005 – 1500) Global $\Delta$ RF surface = -0.13 W m$^{-2}$

Pongratz, 2009, GRL
Recent Assessments of Global ALCC Forcing Since ~1700

<table>
<thead>
<tr>
<th>This study:</th>
<th>-0.12 W/m² (-0.13 since 1500)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pongratz (2009):</td>
<td>-0.18 W/m²</td>
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<tr>
<td>Betts et al (2007):</td>
<td>-0.18 W/m²</td>
</tr>
<tr>
<td>Brovkin et al (2006):</td>
<td>-0.14 W/m²</td>
</tr>
<tr>
<td>IPCC AR4 (2007):</td>
<td>-0.50 to -0.08 W/m² (various data sets)</td>
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</tbody>
</table>
Regional Patterns: Africa

Dominant Classes in Year 1500

Open Shrubland Woody Savanna

Dominant Classes in Year 2000

Grassland Cropland
Frac:onal Gain for Dominant Gained Biome

Frac:onal Loss for Dominant Lost Biome

Change in Annual Average Outgoing Shortwave from the Surface [W m\(^{-2}\)]

### Biome of Dominant Gain

### Biome of Dominant Loss

**warming effect**

**cooling effect**
Fractional Gain for Dominant Gained Biome

Fractional Loss for Dominant Lost Biome

Change in Annual Average Outgoing Shortwave from the Surface [W m\(^{-2}\)]

**OSH to GRA**

**GRA to OSH**

**OSH to GRA**

**WSA to SAV or GRA**

- Warming effect
- Cooling effect
Regional Patterns: North America
Fractional Gain for Dominant Gained Biome

Fractional Loss for Dominant Lost Biome

Change in Annual Average Outgoing Shortwave from the Surface [W m⁻²]

warming effect

cooling effect
Fractional Gain for Dominant Gained Biome

Fractional Loss for Dominant Lost Biome

Biome of Dominant Gain

Biome of Dominant Loss

Change in Annual Average Outgoing Shortwave from the Surface [W m⁻²]

GRA, ENF to CRO

MF, DBF to CRO

GRA, MF to CRO

ENF To CRO

Color Bar:

warming

cooling

0.9

0.8

0.7

0.6

0.5

0.4

0.3

0.2

0.1

0

-28.60

-25.03

-21.45

-17.88

-14.30

-10.73

-7.15

-3.58

0.00

3.58

7.15

10.73

14.30

17.88

21.45

25.03

28.60
3. Landscape-Scale Albedo Evolution (*Shuai*)

*How does disturbance and land cover change affect regional albedo?*

Derive 30-meter albedo by combining:
- 30m *Landsat nadir reflectance*
- 500m *MOD43 BRDF* (*Shuai et al.*, 2011)

Generate per-pixel time series albedo using *Landsat* archive, and relate to forest disturbance type, severity
Temporal albedo over ARM EF15 site (Grassland)
Black Sky Albedo

Clear Cut Harvest Example (Mid-Summer)

IndSR composite
R(b4):0.03-0.40
G(b3):0.00-0.06
B(b2):0.01-0.08

Year

Averaged 30-m Landsat shortwave band albedo over 5 by 5 pixels

Clear Cut Harvest Example (Mid-Summer)

Black Sky Albedo

Averaged 30-m Landsat shortwave band albedo over 5 by 5 pixels

Year


P1_BSA P2_BSA Ctrl_BSA P1_WSA P2_WSA Ctrl_WSA
Temporal White Sky Albedo (WSA) in the upper panel, with IndSR band5,4,3 composite in the upper-right panel and plots for individual forest disturbance in the lower graphic, show the evolution of WSA and surface reflectance (vegetation water content).
Significant summer albedo (WSA) trends, 1985-2011 based on temporal regression & T-test

- No significant trend
- Negative trend
- Positive trend
Next Steps

• Provide uncertainties for global albedo & RF trajectories

• Extend to 2100 using IPCC RCP scenarios

• Incorporate snow-covered albedo into landscape analyses & provide annualized RF

• Integrate albedo into USFS Forest Vegetation Simulator (FVS)
Thank You
Backup
Comparison Between “Concurrent” and “BRDF LUT” Methods
(Montana, 5/10/2006)
• Direct and diffuse incoming solar radiation for surface radiative forcing
  
  – Determine albedo induced surface radiative forcing by overlaying (multiplying) direct and diffuse solar radiation maps with corresponding albedo change maps.

  \[ \Delta F_{\text{surface,month}} = -I^\downarrow_{\text{surface,month,year}} (\alpha_{\text{surface,month,2000}} - \alpha_{\text{surface,month,YYYY}}) \]

  – NCEP/NCAR reanalysis 1 product for direct and diffuse solar radiation

  – Same data source for forecast

  – Also source for snow cover climatology
Comparison of Landsat and MODIS Albedo with In-Situ SURFAD

![Graph showing comparison of Landsat and MODIS Albedo with In-Situ SURFAD](image_url)
Spatial Patterns of Surface Radiative Forcing Change

Global $\Delta$ RF surface = -0.13 W m$^{-2}$
Uncertainty of the modeled snow-covered shortwave white-sky albedo in January from LUMs
Hierarchical Albedo LUT for IGBP Land Cover Types

1. Use Landsat global GLS2000 to identify homogenous land cover examples at MODIS 500m resolution

2. Extract MODIS albedo climatology for these homogenous examples

3. Propagate values to coarser scales to support modeling scenarios (i.e., future landcover ≠ current landcover)

The albedo LUT is presented as:
\[ \rho(i, j, L) \]
where:
- \( i \) = land cover type
- \( j \) = geographic location (pixel)
- \( L \) = resolution level
Uncertainty of the Modeled WSA from albedo LUMs in shortwave on August (2001-2010) at 0.05 degree
Significant albedo (WSA) trends, 1985-2011 based on temporal regression & T-test

- **No significant trend**
- **Negative trend**
- **Positive trend**

Averaged landscape shortwave BSA for each undisturbed NLCD class