Empirical models of albedo transitions in managed boreal forests: Overview, validation, and transportability

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In addition to the C-cycle, forest disturbances perturb a suite of radiative, aerodynamic, and physiological processes regulating fluxes of water and energy between the surface and atmosphere thus impacting local and global climate.
Boreal Forests & Albedo

Failure to account for albedo forcing [in boreal regions] may have consequences that are potentially at odds with the aims of climate change mitigation

- Betts et al., *Ag. & Forest Met.* (2007)

Albedo dominates biogeophysical forcings
Research Motives

- Large Gap:
  1. Albedo dynamics in *managed forest* contexts
     - Impacts of management intervention on canopy structure and albedo trajectories under both current and future climates
  2. Simple, stand-alone models
     - Albedo schemes in Land Surface Models (LSMs) like JSBACH and CLM4 are highly parametrized
       - $f(\text{LAI}, \text{SAI}, \text{Height}, \text{CC\%}, \text{Temp.}, \text{Precip}, \text{Snow Cover} \ldots)$
     - Need easy linkage with NFI and readily available meteorological variables
       - Especially if the goal is to predict albedo across the landscape
Empirical models of monthly and annual albedo in managed boreal forests of interior Norway

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Hedmark, Norway:

- 11-year MODIS dataset (MCD43A3)
- 131 managed forest sites
  - 35 Spruce dominant (Picea Abies)
  - 50 Pine dominant (Pinus sylvestris)
  - 46 Birch dominant (Betula spp.)
- Altitude range: 235–1000 m
- Monthly mean Temp (°C) range: −11.4 – 15.2
- Albedo observations per site: \( n = 495 \)
- Site Index (H\(_{40}\)) range: 8 (birch only) – 17
Potential Albedo

- The albedo of a site absent forest cover: $f(\text{climate})$
  - Based on 1440 observations at open area/young harvest sites
  - Climate variable: Monthly mean near surface air temperature ($\bar{T}$)

**Potential Albedo**: Best fit with a logistic function

Canopy Modifier

- A modifying component: \( f(\text{structure}) \)
  - **Age**: Previous studies indicate that age might be a suitable proxy for a suite of canopy structural attributes dictating albedo transitions in boreal forests
  - Provides a direct link to the time dimension
    - Albedo decreases exponentially with age \((A)\).
      \[
      \phi = k_1 e^{-(k_2 A)}
      \]
  - A variation including Site Index \((H_{40})\) was also tested, but its inclusion was NOT found to enhance model performance
    \[
    \phi = k_1 e^{-(k_2 A + k_3 H_{40})}
    \]

Surface fits: \[ \alpha = k_1 + \left[ 1 - \frac{1}{(1 + e^{-k_2T})^{k_3}} \right] (k_4 + k_5 e^{-k_6A}) \]

\[ R^2 = 0.90 \]

\[ R^2 = 0.85 \]

\[ R^2 = 0.82 \]

\[ R^2 = 0.66 \]
Transportability

- Test sites
- Original study area

Do the models perform well outside the region in which they were developed?

Short answer: NO
The Conifer-generic model was re-trained by expanding the geographic scope of the sample

- Temp and Age data taken from 12 Fluxnet sites across boreal Canada & N. Eurasia
Saskatchewan BERMS – Old Sites

- Published model (Bright et al. 2013) performed poorly (red)
- Updated model (green) better reproduces seasonal amplitudes
- Both over-predict summer albedo relative to MODIS (black)
Saskatchewan BERMS – Young Sites

- Updated model appears more robust at capturing albedo temporal transitions of younger-aged stands
- Seasonal transitions are well-reproduced, both models
Validation Only Sites

- Fyodorovskoe (RU): Updated model better captures longer-term inter-annual mean (black dashed, left) trend in winter
- Sodankylä (FI): Both models underpredict winter albedo
Alternatives?

- Seasonal evolution of correlation coefficients of albedo and forest structure attributes in a 5 km² patch of conifer-dominant forests in eastern Norway:

![Graph showing correlation coefficients]

Clear evidence that forest structure in winter is strongly inversely correlated with albedo.
Alternatives

- An alternative incorporating LAI and CC% instead of Age:

\[ \alpha = k_1 + \left( 1 - \frac{1}{\left( 1 + e^{-k_2 t} \right)^{k_3}} \right) \left( (1 - e^{-\frac{LAI}{2}}) \right) k_4 \left( 1 - CC\% \right) \]

- Performance metrics:

<table>
<thead>
<tr>
<th>Canopy Modifier</th>
<th>f(LAI, CC%)</th>
<th>f(Age)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMSE</td>
<td>0.0458</td>
<td>0.0460</td>
</tr>
<tr>
<td>R^2</td>
<td>0.767</td>
<td>0.762</td>
</tr>
<tr>
<td>Akaike Info. Criterion</td>
<td>-5.089 E3</td>
<td>-5.076 E3</td>
</tr>
</tbody>
</table>
General Summary of Model Fidelity

The BAD

- Models are insensitive to summertime vegetation dynamics (phenology, “greening“)
- Models may not accurately capture spring temporal transitions in years/regions with high late-winter/early-spring snow pack

The GOOD

- Seasonal amplitude in the updated Conifer-generic model well-captured (particularly for older stands)
- Broadly applicable for a range of boreal conifer species
- Long-term inter-annual winter means well captured for most test regions
Conclusions

- Mitigation-oriented forest management policies without albedo considerations are sub-optimal in boreal regions.

- Due to their simplicity, statistical models can offer an attractive alternative to forest reflectance and process-based models typically found in LSMs.
  - As few as 1 climate & 1 structural predictor are needed.

- Preliminary results suggest that incorporating additional structural predictors can slightly improve accuracy without increasing complexity.
  - **Downside I:** If the objective is to predict albedo developments in time, additional models are needed linking structural predictors with time or stand age.
  - **Downside II:** Requires additional resources and data.
Thanks.

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Source: Anderson et al., (2010)