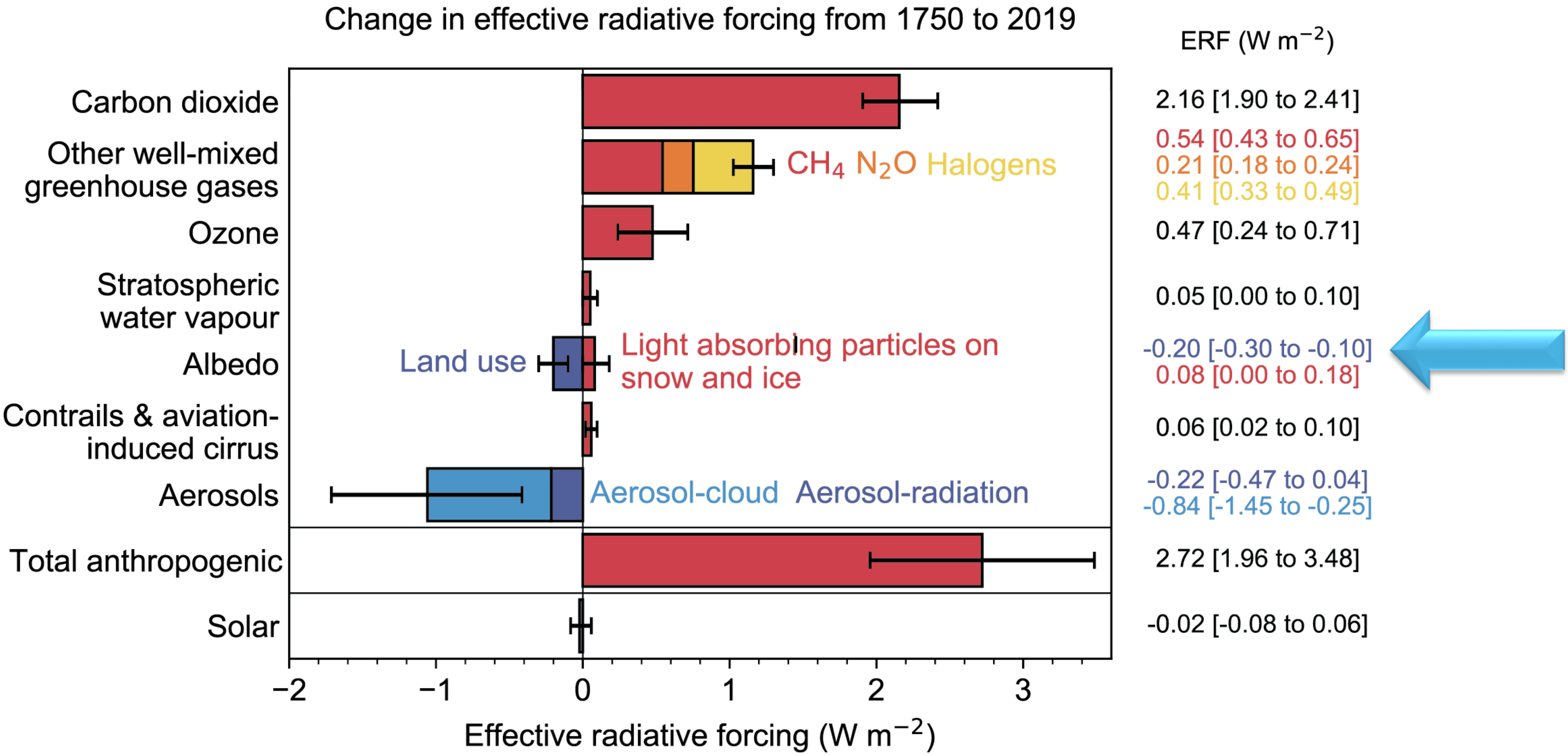
Sep 15: Albedo Effects on Earth's Climate: Warming and Cooling

- Albedo of terrestrial ecosystems
- Land use and albedo
- Albedo measurements
- Albedo and GWP

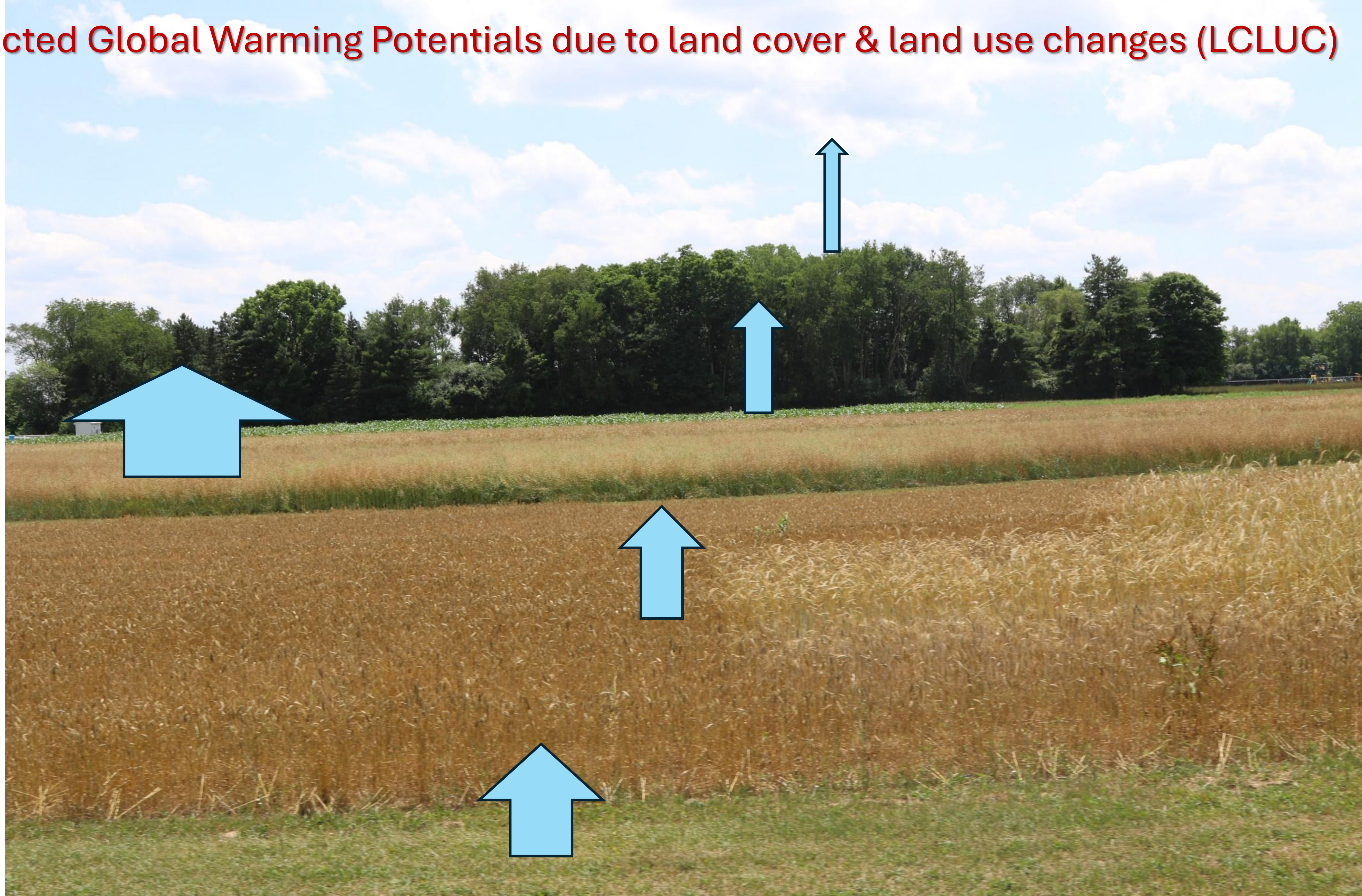
Reading

Chen, J., Lei, C., Chu, H., Li, X., Torn, M., Wang, Y. P., ... & Robertson, G. P. (2024). Overlooked cooling effects of albedo in terrestrial ecosystems. *Environmental Research Letters*, *19*(9), 093001.

AR6_WGI (p204)


Change in effective radiative forcing from 1750 to 2019
ERF (W m^{-2})
Carbon dioxide
2.16 [1.90 to 2.41]
Other well-mixed greenhouse gases
CH_4 N_2O Halogens
0.54 [0.43 to 0.65]
0.21 [0.18 to 0.24]
0.41 [0.33 to 0.49]
Ozone
0.47 [0.24 to 0.71]
Stratospheric water vapour
0.05 [0.00 to 0.10]
Albedo
Land use
Light absorbing particles on snow and ice
-0.20 [-0.30 to -0.10]
0.08 [0.00 to 0.18]
Contrails & aviation-induced cirrus
0.06 [0.02 to 0.10]
Aerosols
Aerosol-cloud
Aerosol-radiation
-0.22 [-0.47 to 0.04]
-0.84 [-1.45 to -0.25]
Total anthropogenic
2.72 [1.96 to 3.48]
Solar
-0.02 [-0.08 to 0.06]
−2
−1
0
1
2
3
Effective radiative forcing (W m^{-2})

Albedo-inducted Global Warming Potentials due to land cover & land use changes (LCLUC)



Radiation Balance

Albedo (a) is a measure of how much light or radiation a surface reflects compared to how much it receives. It is expressed as a fraction (0-1) or percentage (%).

Examples

- Fresh snow: 0.8–0.9
- Grass: 0.2–0.3
- Asphalt: 0.05–0.1
- Ocean water: 0.06
- Coniferous forests: 0.08–0.15
- Deciduous forests: <0.18
- Corn fields: ~0.18–0.25
- Desert: 0.35–0.45
- Urban: 0.10–0.25

CNR net radiometer

Solar radiation pathways and estimation of radiative forcing (RF) resulted from changes in land surface albedo (Δα).

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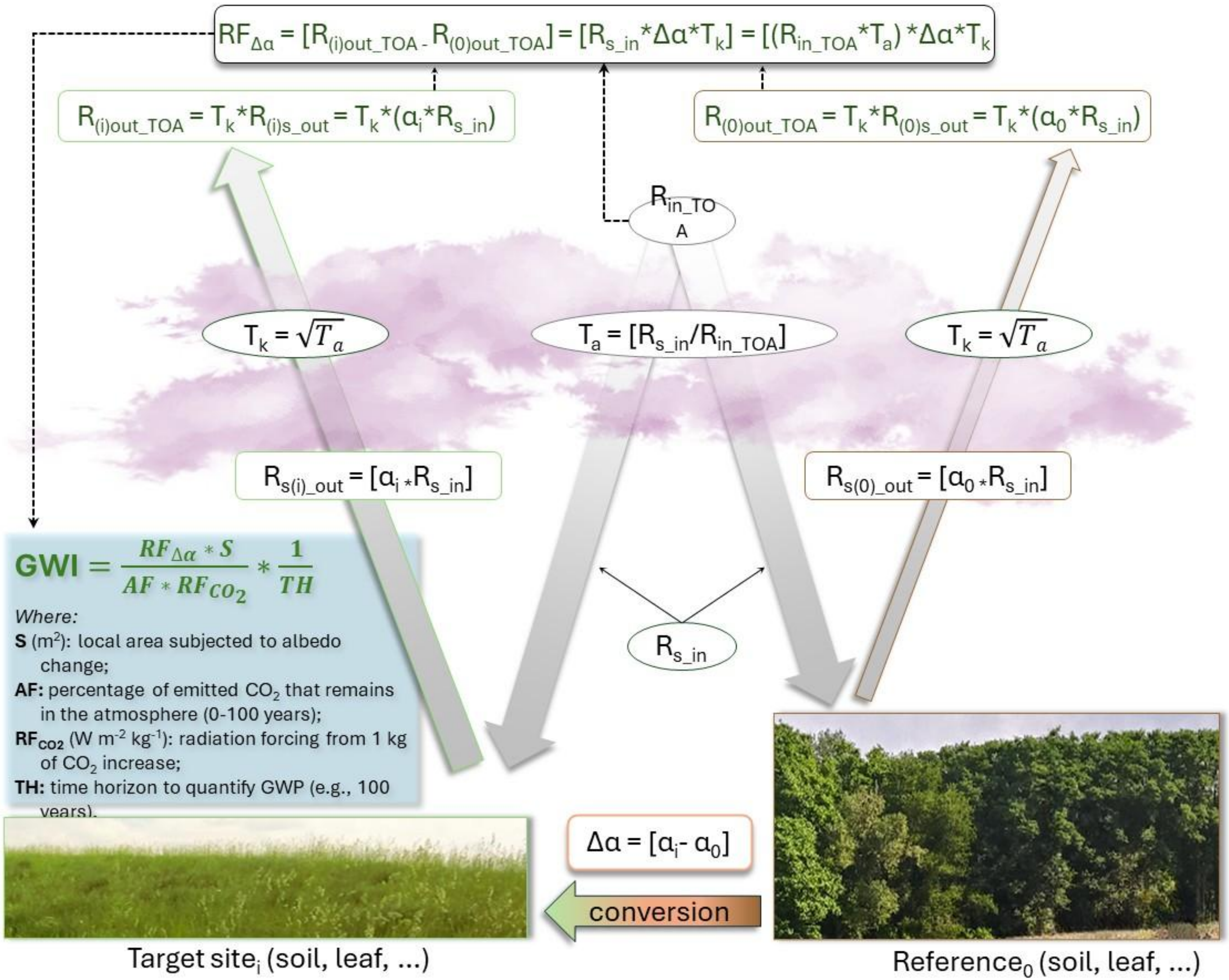
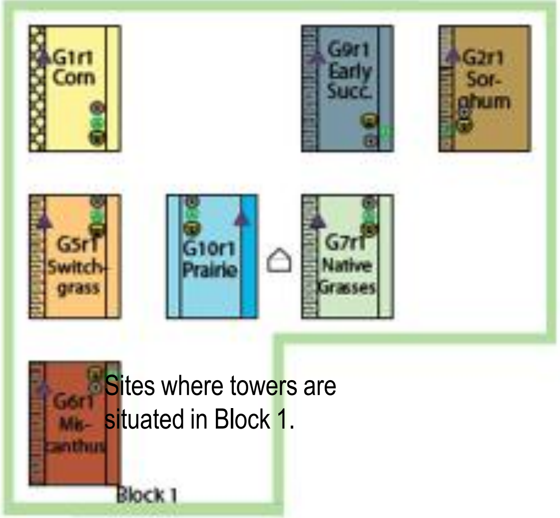


Continuous measurements

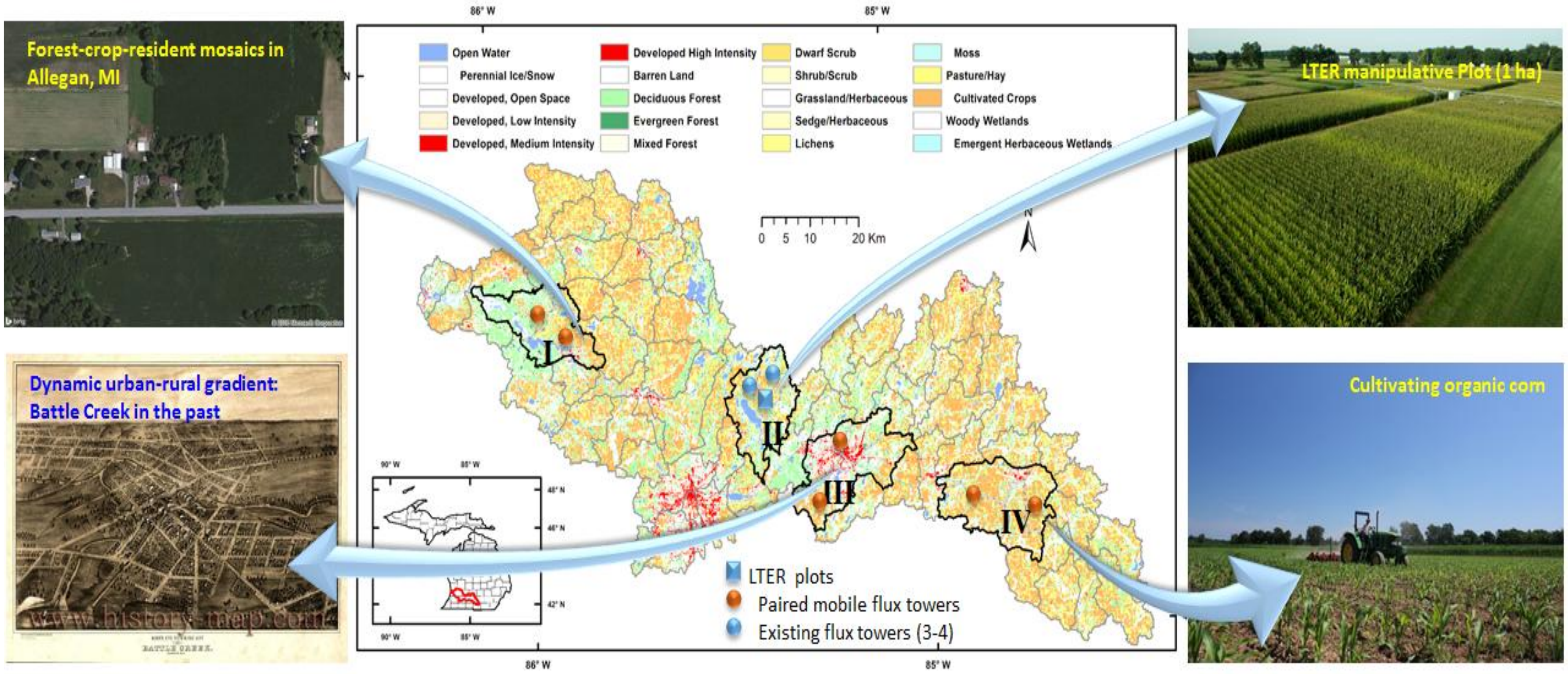
Methodology

- Portable albedo tower: (n = 7)
- Reference albedo tower: (n = 1) (total n = 44)
- May 20th, 2018 – December 31st, 2020
- Data retrieved weekly
- Towers raised to maintained consistent field of view

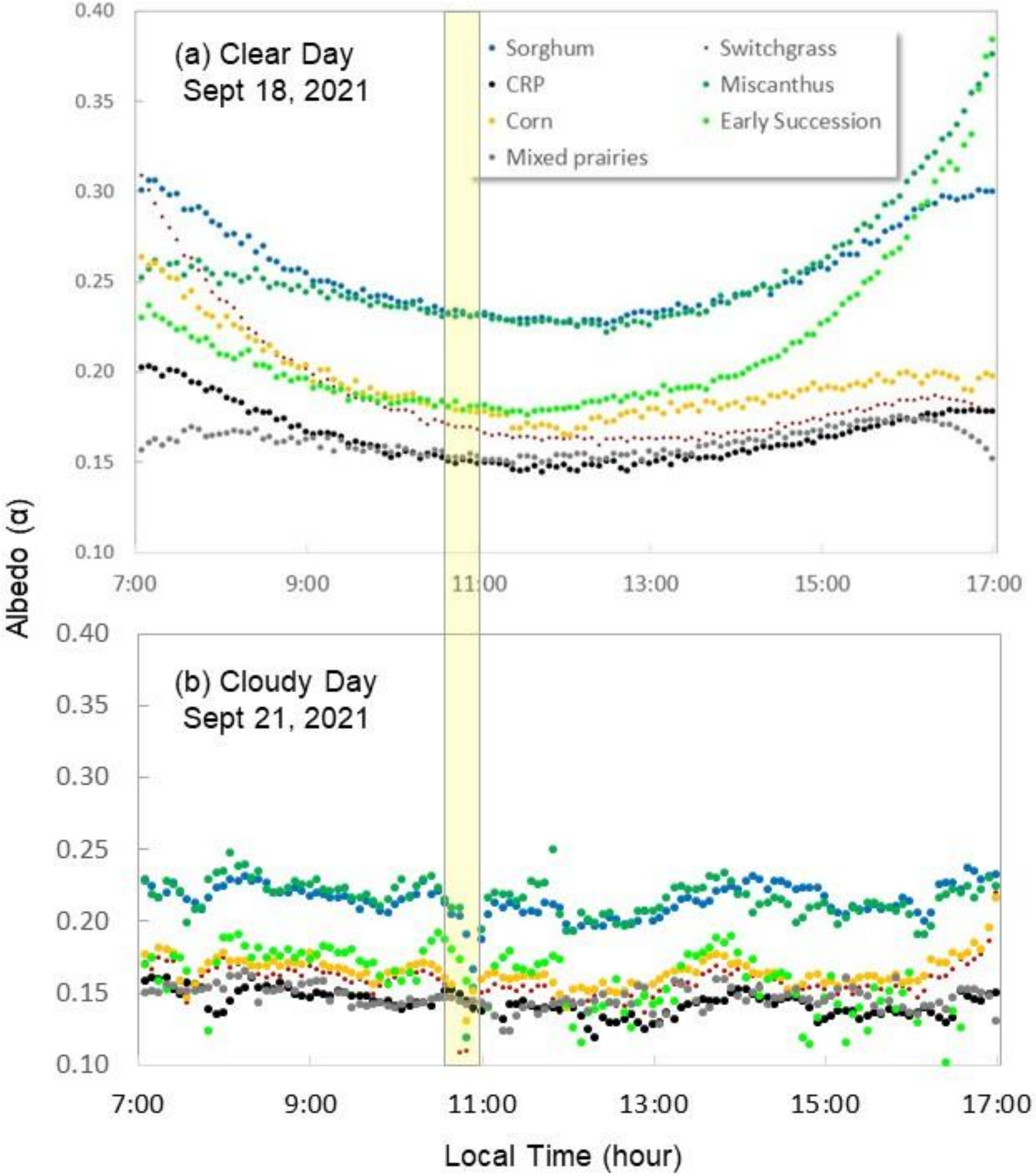


LULCC as a global phenomenon

Current land cover of the Kalamazoo Watershed, which includes 127 sub-watersheds. The watershed was examined for the changes of CO_2^{eq} during a 40-year period (1978–2018) using Landsat/Sentinel with the climate and human activities.



Diurnal changes and variations in land surface albedo under clear (a) and cloudy (b) sky conditions for seven bioenergy crops at the Kellogg Biological Station (KBS) in Southwest Michigan. The yellow shaded area on the bar graph represents the local time (~10:30 h) when the Landsat/Terra satellites pass over the study sites.



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(a) The average radiation force (RF) due to altered land surface albedo (Δα) during the growing season (GS) and non-growing season (NGS) was measured for eight major ecosystem types in southwestern Michigan in 2021. (b) The global warming potential due to albedo differences (GWPΔα) was assessed for the native temperate forest ecosystem in the same region.

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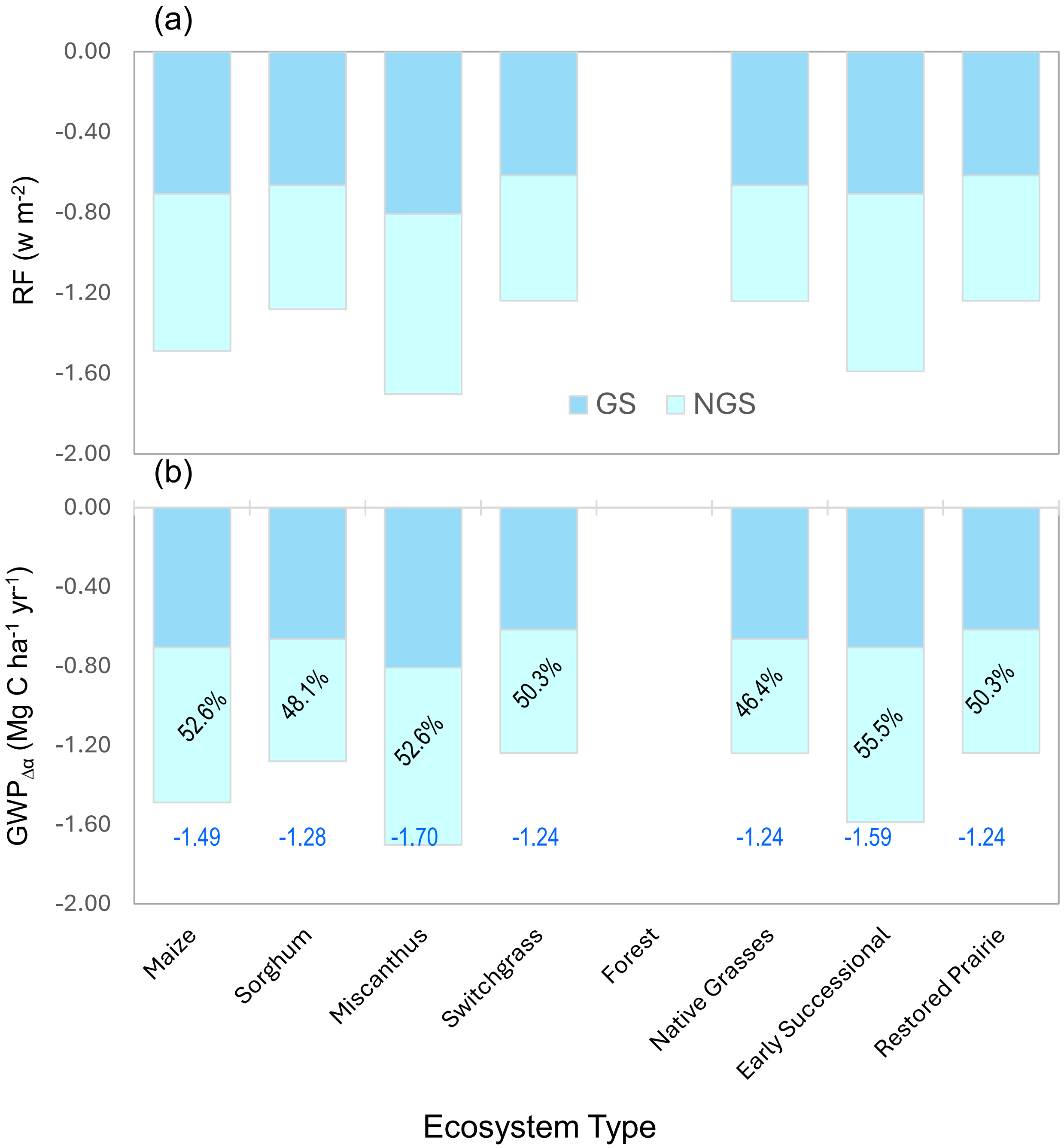
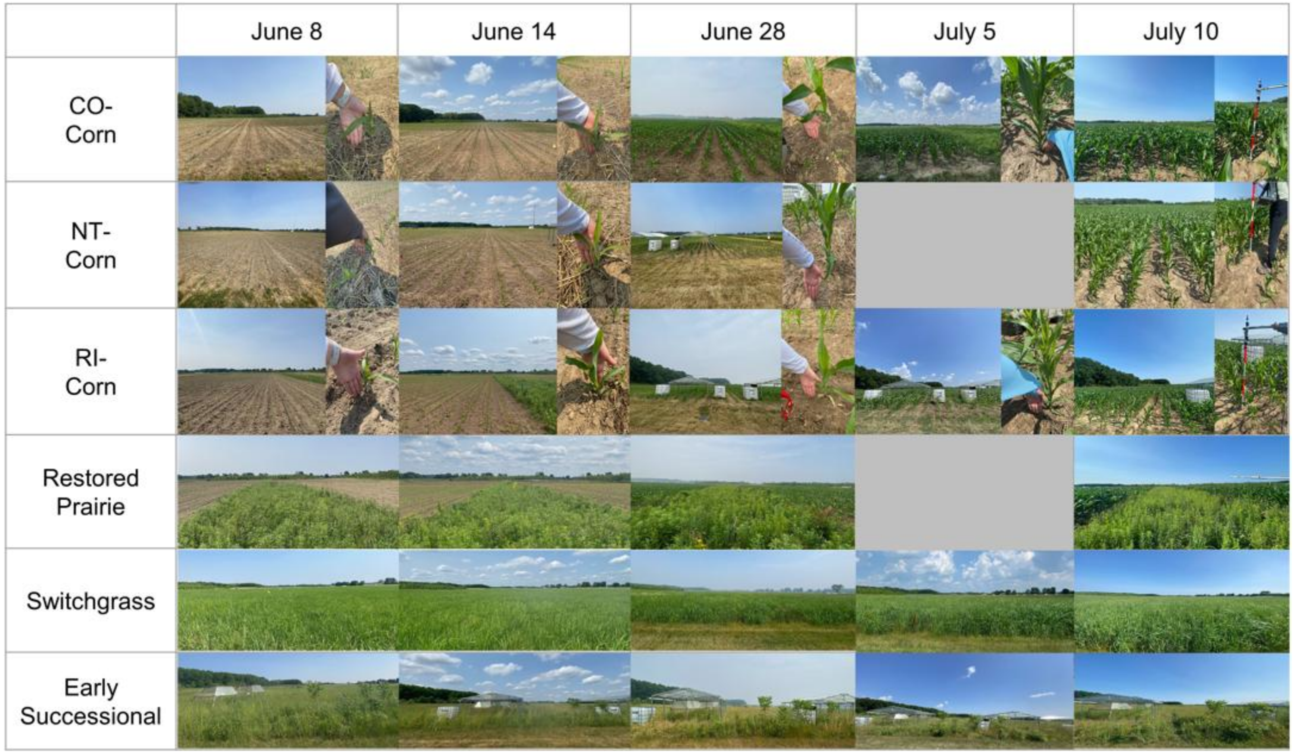
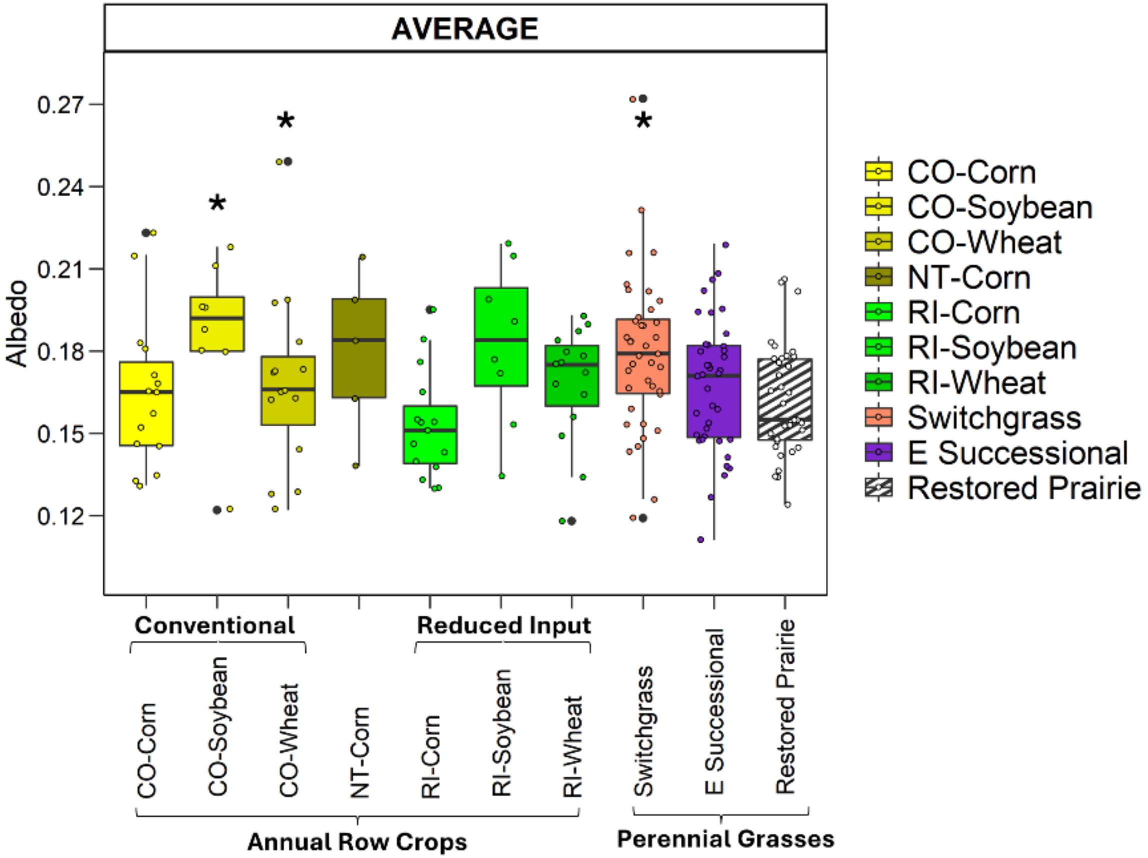


Average albedo for all land use types (conventional, no-till and reduced input CSW annual row crop rotations, and perennials switchgrass, early successional and restored prairie) at MCSE (*Lei et al. 2024)*

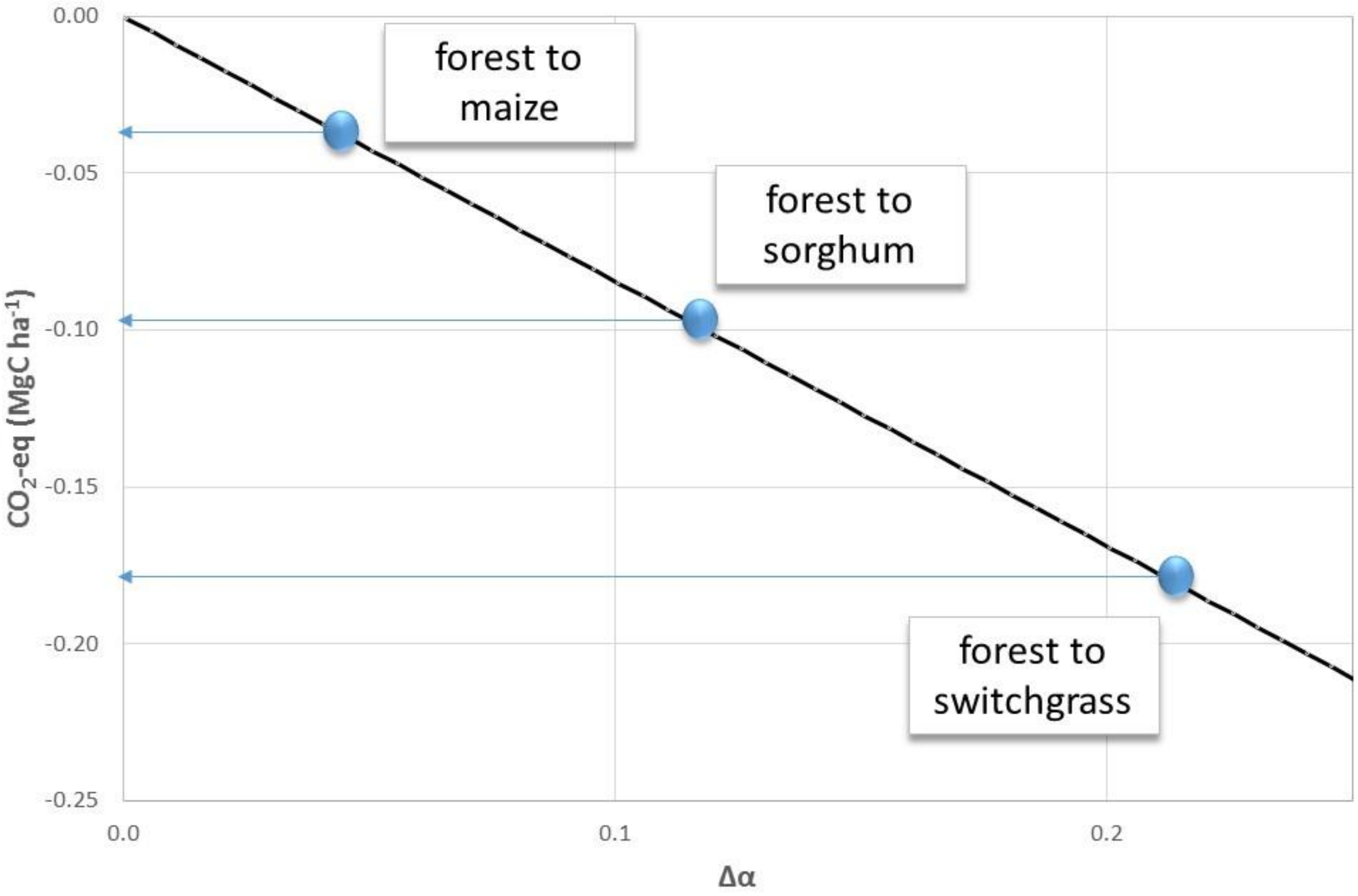
Stages of growth development of the study sites from early growing period to peak growing season at KBS LTER site





Changed albedo: What does it mean for climate?

Albedo-Induced Global Warming Potential (GWP)



Chen 2021. Applications of Biophysical Models in Ecosystem Studies.

Albedo-Induced Warming/Cooling Effects on Climate

nature communications

Article

https://doi.org/10.1038/s41467-024-46577-1

Accounting for albedo change to identify climate-positive tree cover restoration

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Check for updates

Natalia Hasler[1], Christopher A. Williams[2], Vanessa Carrasco Denney[3], Peter W. Ellis[4], Surendra Shrestha[2], Drew E. Terasaki Hart[3,5], Nicholas H. Wolff[6], Samantha Yeo[3], Thomas W. Crowther[7], Leland K. Werden[7] & Susan C. Cook-Patton[3]

Restoring tree cover changes albedo, which is the fraction of sunlight reflected from the Earth's surface. In most locations, these changes in albedo offset or even negate the carbon removal benefits with the latter leading to global warming. Previous efforts to quantify the global climate mitigation benefit of restoring tree cover have not accounted robustly for albedo given a lack of spatially explicit data. Here we produce maps that show that carbon-only estimates may be up to 81% too high. While dryland and boreal settings have especially severe albedo offsets, it is possible to find places that provide net-positive climate mitigation benefits in all biomes. We further find that on-the-ground projects are concentrated in these more climate-positive locations, but that the majority still face at least a 20% albedo offset. Thus, strategically deploying restoration of tree cover for maximum climate benefit requires accounting for albedo change and we provide the tools to do so.

Albedo-Induced Warming/Cooling Effects on Climate

ARTICLE

https://doi.org/10.1038/s41467-022-31558-z

OPEN

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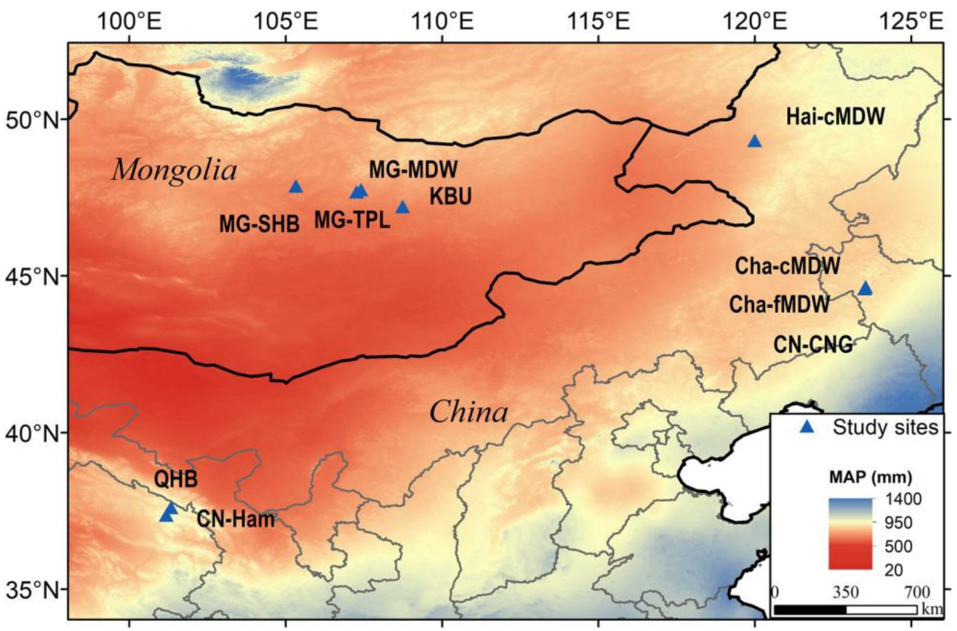
Albedo changes caused by future urbanization contribute to global warming

Zutao Ouyang[1,2✉], Pietro Sciusco[2], Tong Jiao[3], Sarah Feron[1,4,5], Cheyenne Lei[2], Fei Li[6], Ranjeet John[7], Peilei Fan[8], Xia Li[9], Christopher A. Williams[3], Guangzhao Chen[10,11], Chenghao Wang[1] & Jiquan Chen[2✉]

The replacement of natural lands with urban structures has multiple environmental consequences, yet little is known about the magnitude and extent of albedo-induced warming contributions from urbanization at the global scale in the past and future. Here, we apply an empirical approach to quantify the climate effects of past urbanization and future urbanization projected under different shared socioeconomic pathways (SSPs). We find an albedo-induced warming effect of urbanization for both the past and the projected futures under three illustrative scenarios. The albedo decease from urbanization in 2018 relative to 2001 has yielded a 100-year average annual global warming of 0.00014 [0.00008, 0.00021] °C. Without proper mitigation, future urbanization in 2050 relative to 2018 and that in 2100 relative to 2018 under the intermediate emission scenario (SSP2-4.5) would yield a 100-year average warming effect of 0.00107 [0.00057,0.00179] °C and 0.00152 [0.00078,0.00259] °C, respectively, through altering the Earth's albedo.

Albedo-Induced Warming/Cooling Effects on Climate



Zhu et al. Ecological Processes (2024) 13:17
https://doi.org/10.1186/s13717-024-00493-w

Ecological Processes

RESEARCH Open Access

Changes in albedo and its radiative forcing of grasslands in East Asia drylands

Qingsong Zhu[1], Jiquan Chen[2], Liangxu Wu[1], Yuting Huang[1], Changliang Shao[3], Gang Dong[4], Zhe Xu[1] and Xianglan Li[1*]

Abstract

Background Grasslands in drylands are increasingly influenced by human activities and climate change, leading to alterations in albedo and radiative energy balance among others. Surface biophysical properties and their interactions change greatly following disturbances. However, our understanding of these processes and their climatic impacts remains limited. In this study, we used multi-year observations from satellites and eddy-covariance towers to investigate the response of albedo to variables closely associated with human disturbances, including vegetation greenness (EVI) and surface soil volumetric water content (VWC), as well as snow cover and clearness index (T_a) for their potential relationships.

Results EVI and VWC during the growing season were the primary factors influencing albedo. EVI and VWC were negatively correlated with albedo, with VWC's total direct and indirect impacts being slightly smaller than those of EVI. During the non-growing season, snow cover was the most influential factor on albedo. VWC and Ta negatively affected albedo throughout the year. We estimated the impact of variations in EVI and VWC on climate to be in the range of 0.004 to 0.113 kg CO_2 m^{-2} yr^{-1} in CO_2 equivalent.

Conclusions This study indicates the significant impacts of climate change and human disturbances on vulnerable grassland ecosystems from the perspective of altered albedo. Changes in vegetation greenness and soil properties induced by climate change and human activities may have a substantial impact on albedo, which in turn feedback on climate change, indicating that future climate policies should take this factor into consideration.

Keywords Albedo, Global warming potential, Grassland, Disturbance

Albedo-Induced Warming/Cooling Effects on Climate

JGR Biogeosciences

RESEARCH ARTICLE

10.1029/2023JG007848

Albedo-Induced Global Warming Potential Following Disturbances in Global Temperate and Boreal Forests

Qingsong Zhu[1,2], Jiquan Chen[3], Bourque Charles P.-A.[4], Oliver Sonnentag[5], Leonardo Montagnani[6], Thomas L. O'Halloran[7,8], Russell L. Scott[9], Jeremy Forsythe[7,8], Bo Song[7,8], Huimin Zou[1,2], Meihui Duan[1,2], and Xianglan Li[1,2]

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Key Points:

- Age, forest type, and disturbance type significantly influence post-disturbance albedo dynamics, with age having the most substantial impact
- Elevated albedo in forests after disturbances exerts a dominant cooling effect within the first 20 years of succession
- Quantifying the climate impact of changing albedo post-disturbance should consider the successional trajectory, as its effects are highly time-sensitive

Supporting Information:

Supporting Information may be found in the online version of this article.

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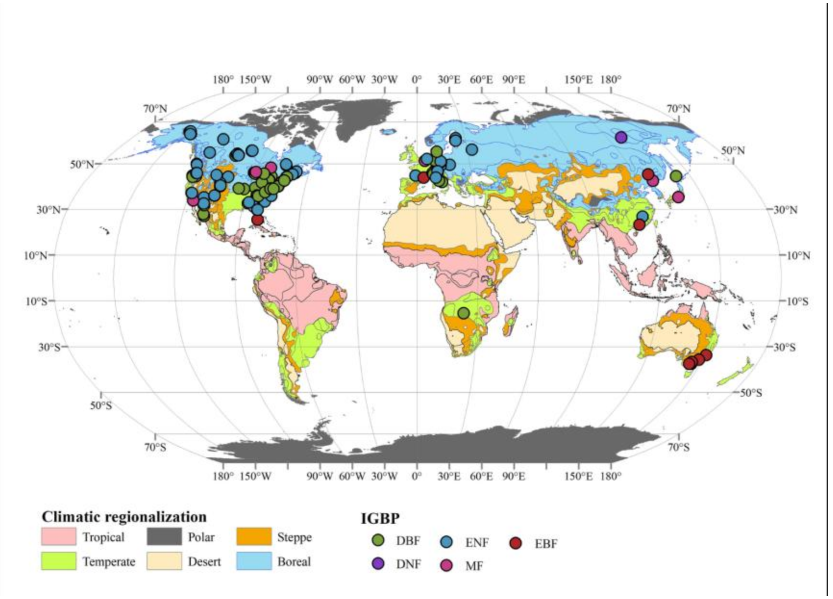
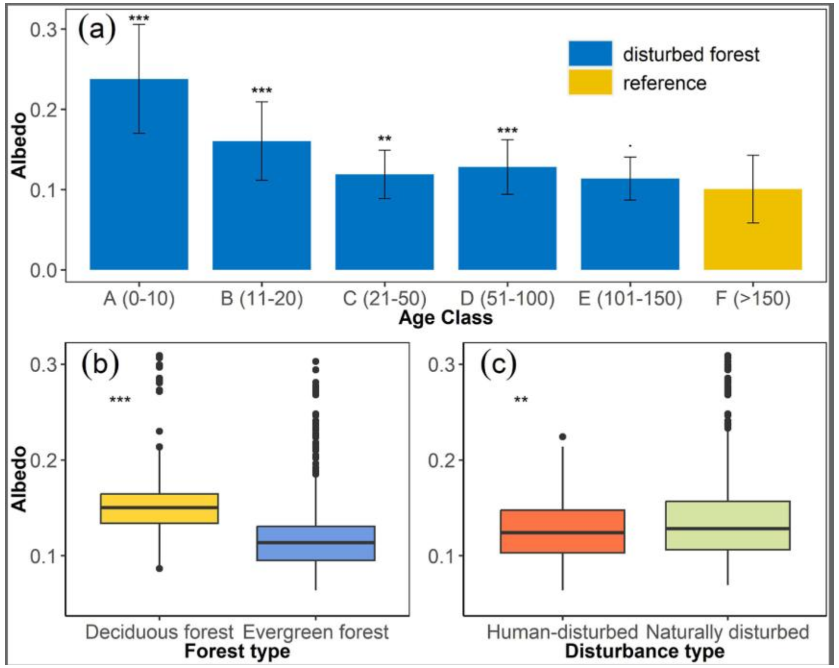
Citation:

Zhu, Q., Chen, J., Charles P.-A., B., Sonnentag, O., Montagnani, L., O'Halloran, T. L., et al. (2024). Albedo-induced global warming potential following disturbances in global temperate and boreal forests. *Journal of Geophysical Research: Biogeosciences*, *129*, e2023JG007848. https://doi.org/10.1029/2023JG007848

Abstract Forest disturbances can result in very different canopies that carry elevated albedo, thus causing substantial cooling effects on the climate. Unfortunately, the resulting dynamic global warming potential from altered albedo ($GWP_{\Delta\alpha}$) is poorly understood. We examined and modeled the changes in albedo over time after disturbances (i.e., forest age) by forest type, disturbance type and geographic location using direct measurements from 107 sites in temperate and boreal regions. Albedo in undisturbed forests was used as the reference to calculate albedo changes ($\Delta\alpha$) and $GWP_{\Delta\alpha}$ after a disturbance. We found that age is a significant factor for predicting albedo amid the obvious regulations from forest type and geographic locations. We found the strongest cooling $GWP_{\Delta\alpha}$ in the first 10 years after a disturbance, but it decreased rapidly with time. The changes in $GWP_{\Delta\alpha}$ were very different from the chronosequence of net ecosystem production (NEP). In the first decade after disturbances, $GWP_{\Delta\alpha}$ was negative (i.e., cooling) and surprisingly larger in magnitude, with an average of –0.609 kg CO_2 m^{-2} yr^{-1}, compared to NEP of –0.166 kg CO_2 m^{-2} yr^{-1}. Albedo continued to decrease and approached pre-disturbance levels until around 50 years, resulting in a nearly zero $GWP_{\Delta\alpha}$. This research illustrates that many forests in temperate and boreal regions can be considered significant cooling agents by taking into account the high albedo of young forests following disturbances.





In sum

1) Albedo-induced global warming potentials (GWP_{α}) has been overlooked?

2) GWP_{α} of intensively managed ecosystems/landscapes can be substantial and the credits had not been given to land owners like carbon

3) There remain serious technical challenges in collecting albedo data and calculate $GWP_{\alpha,}$ Especially T_k and $\Delta\alpha$

4) Integrating GWP_{α} to Earth System Models (ESMs) and/or remote sensing models appears imperative

Take-home-messages

1) What are the three major greenhouse gas (GHG) species other than water vapor?
2) Albedo-induced GWP is largely driven by land cover and land use changes.
3) Albedo values vary substantially across different ecosystem types (what are they?).
4) Albedo-induced GWP primarily relates to changes in shortwave radiation.
5) Albedo can change over time, from hourly to multi-year scales.

Next Lecture: Tips for Making an Effective Presentation

Quiz #2:

Feeback from Students for Improvement

Tips for Making an Effective Presentation

Reading

Naegle, K.M., 2021. Ten simple rules for effective presentation slides. *PLoS Computational Biology*, *17*(12), p.e1009554.

Next Lecture: Tips for Making an Effective Presentation

Quiz #2:

- Materials from Lectures on 9/3, 9/8/, 9/10, and 9/15
- How is global climate change quantified
- Physical Foundations for Global Climatic Changes
- GHG and albedo
- 5 questions, 2 points for each question