GEO 409: Global Climate Change and Variability

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., ... C Robertson, G. P. (2024). Overlooked cooling effects of albedo in terrestrial ecosystems. *Environmental Research Letters*, *1S*(9), 093001.

GEO 409:
Global Climate Change and Variability

Albedo Effects on Earth’s Climate: Warming and Cooling

Cheyenne Lei, Ph.D.
(she/her)

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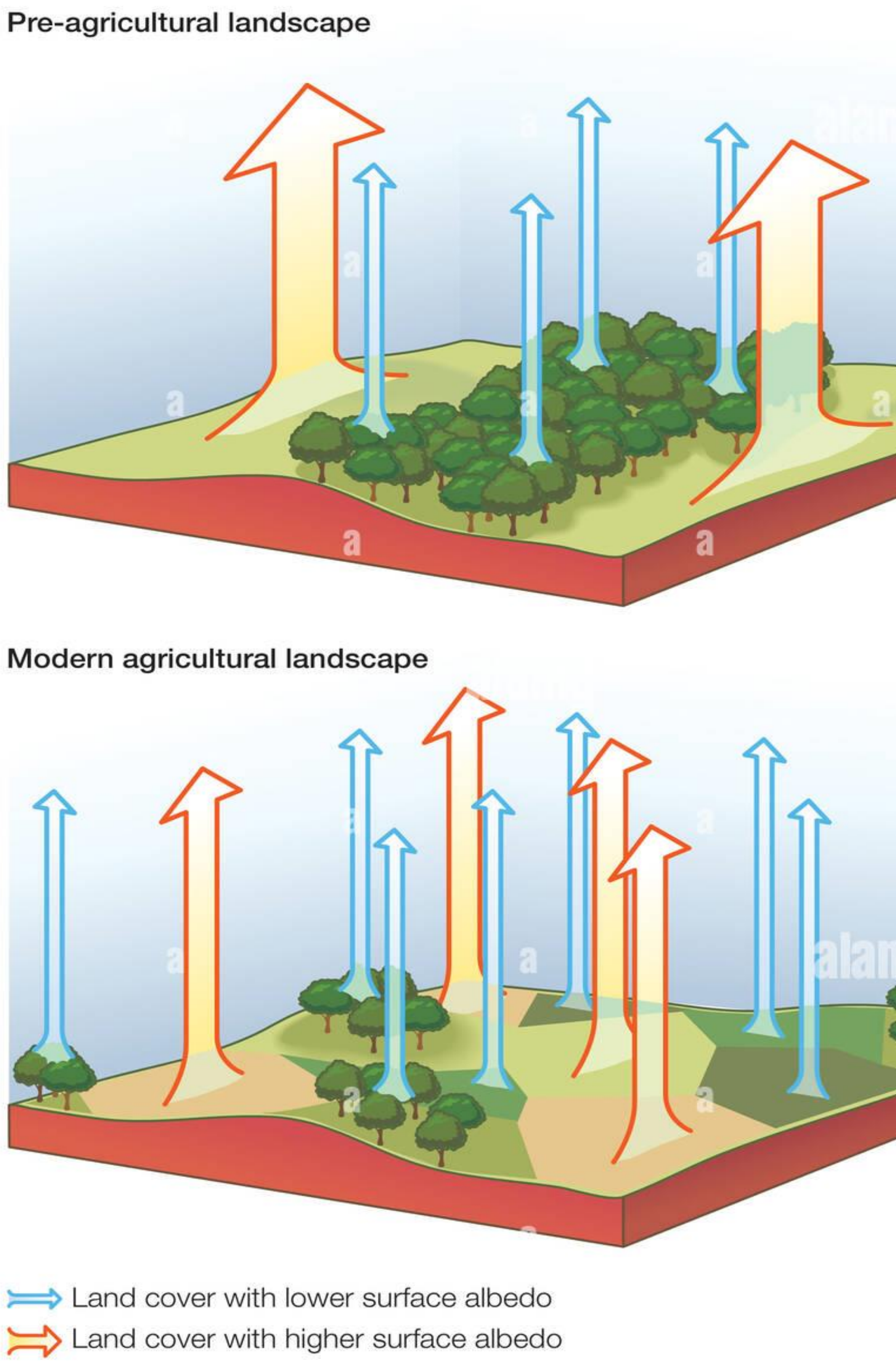
Earth Observations

MICHIGAN STATE
UNIVERSITY



Today's Agenda

What is albedo?

Albedo of terrestrial ecosystems

How do we measure albedo

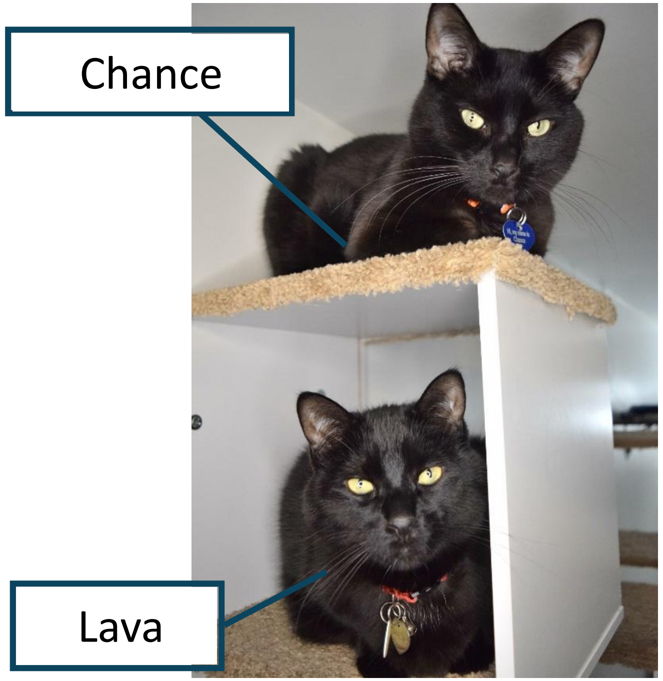
Albedo and Global Warming Potential

Land use and albedo

INTRODUCTION

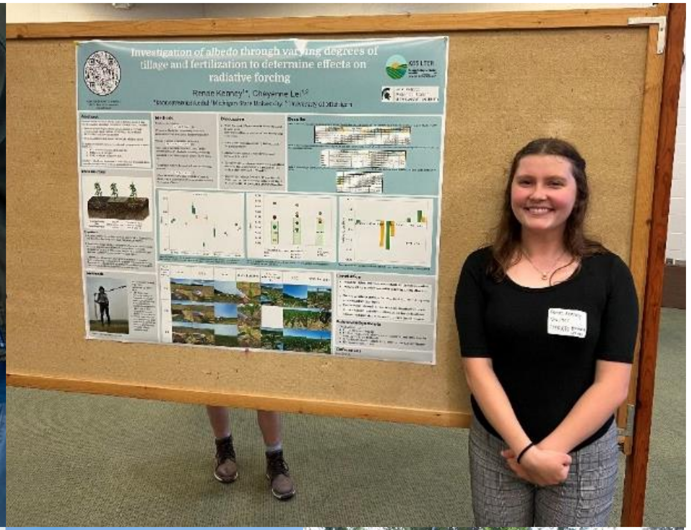
About Me (雷善言)

- Call me Dr. Lei
- I am a cat and motorcycle enthusiast
- I play League of Legends (Platinum) & Apex Legends (Apex Predator)
- On a 1250-day Duolingo streak



Teaching & Mentorship

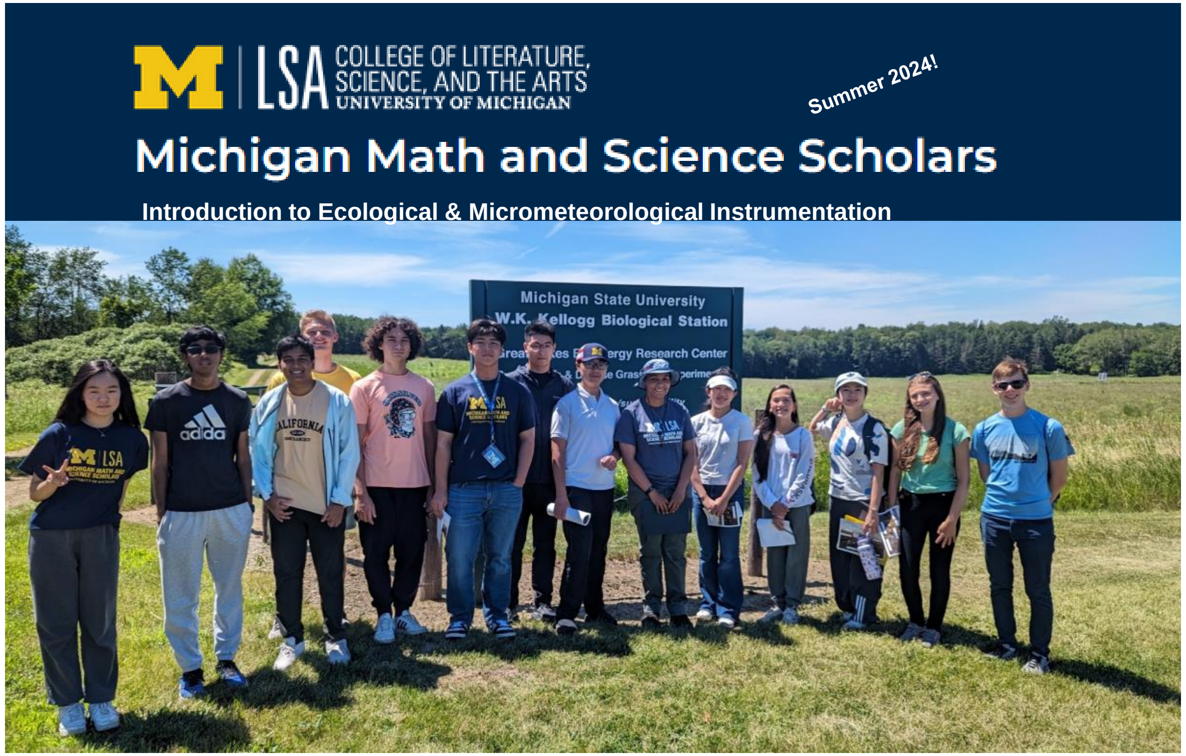
Middle and high school students performing hands-on science activities at community outreach events.



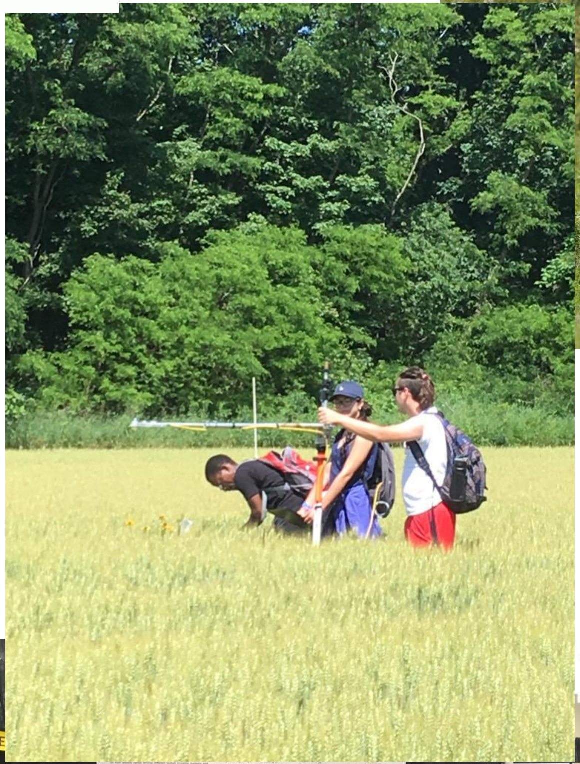
Student undergraduate interns performing research in the field, and presenting at research symposiums.

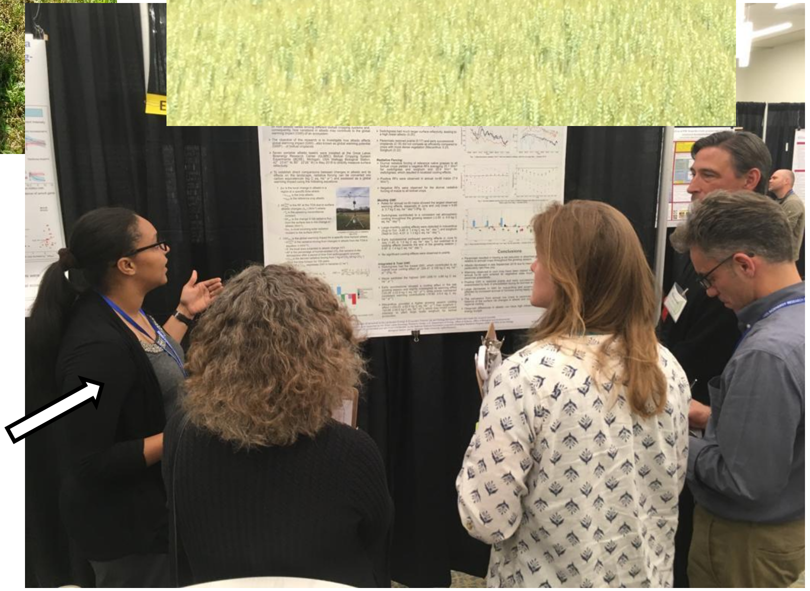
Field Science: Application of Meteorology in Field Ecology

Meteorology, the study of the earth's weather, is important in ecology as it helps us understand how climate affects living ecosystems. This course will explore measurements including temperature, rainfall, wind and soil moisture and how they influence the world around us. Students passionate about the environment and the impact of our changing climate will enjoy using different sensors and instruments to observe changes on the landscape in real time!

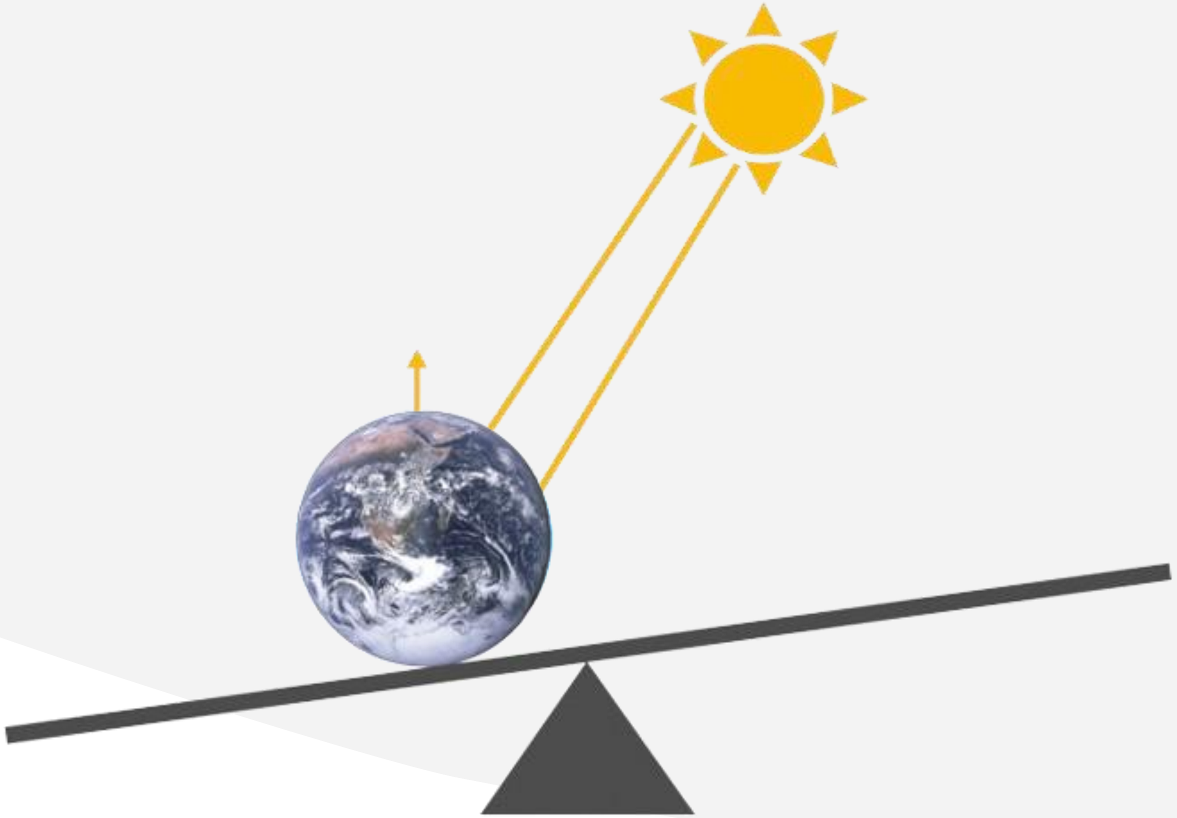


Building relationships!





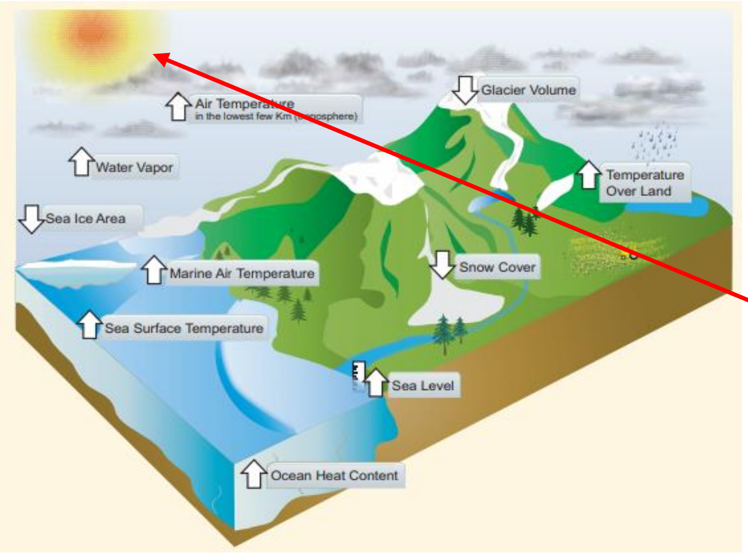
WHAT IS ALBEDO?

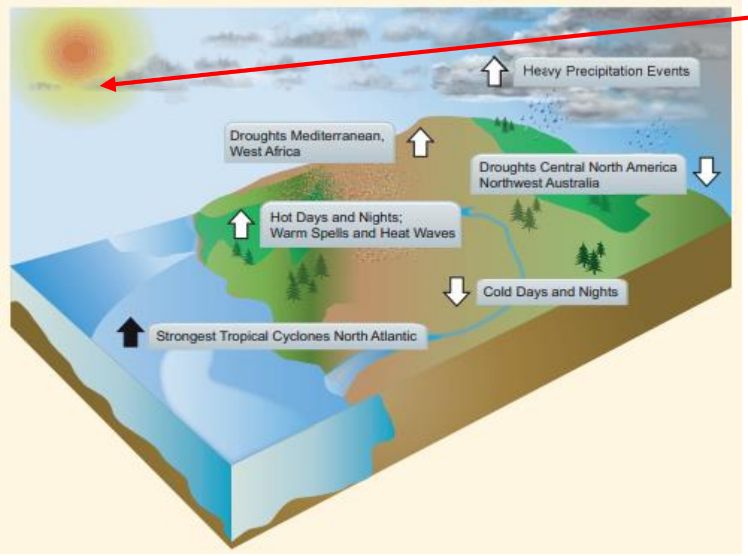


Back to the Basics - Opening Activity

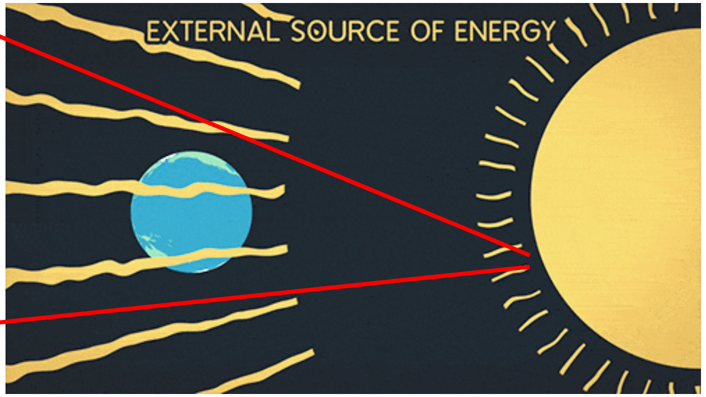
Which one will be hotter?

Some observed changes to climate





Components of the climate system that would be expected to change in a warming world. (IPCC, 2021)



Sometimes we forget that the sun is always **shining**!

When sunlight reaches the earth, it heats the land, ocean, and atmosphere.

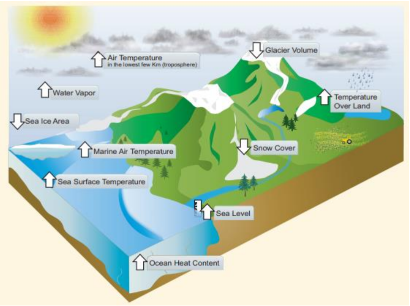
This source of energy is constant!

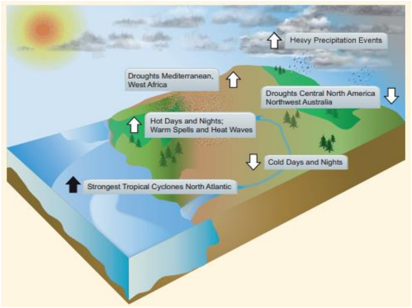
How does the Earth respond to changes in climate?

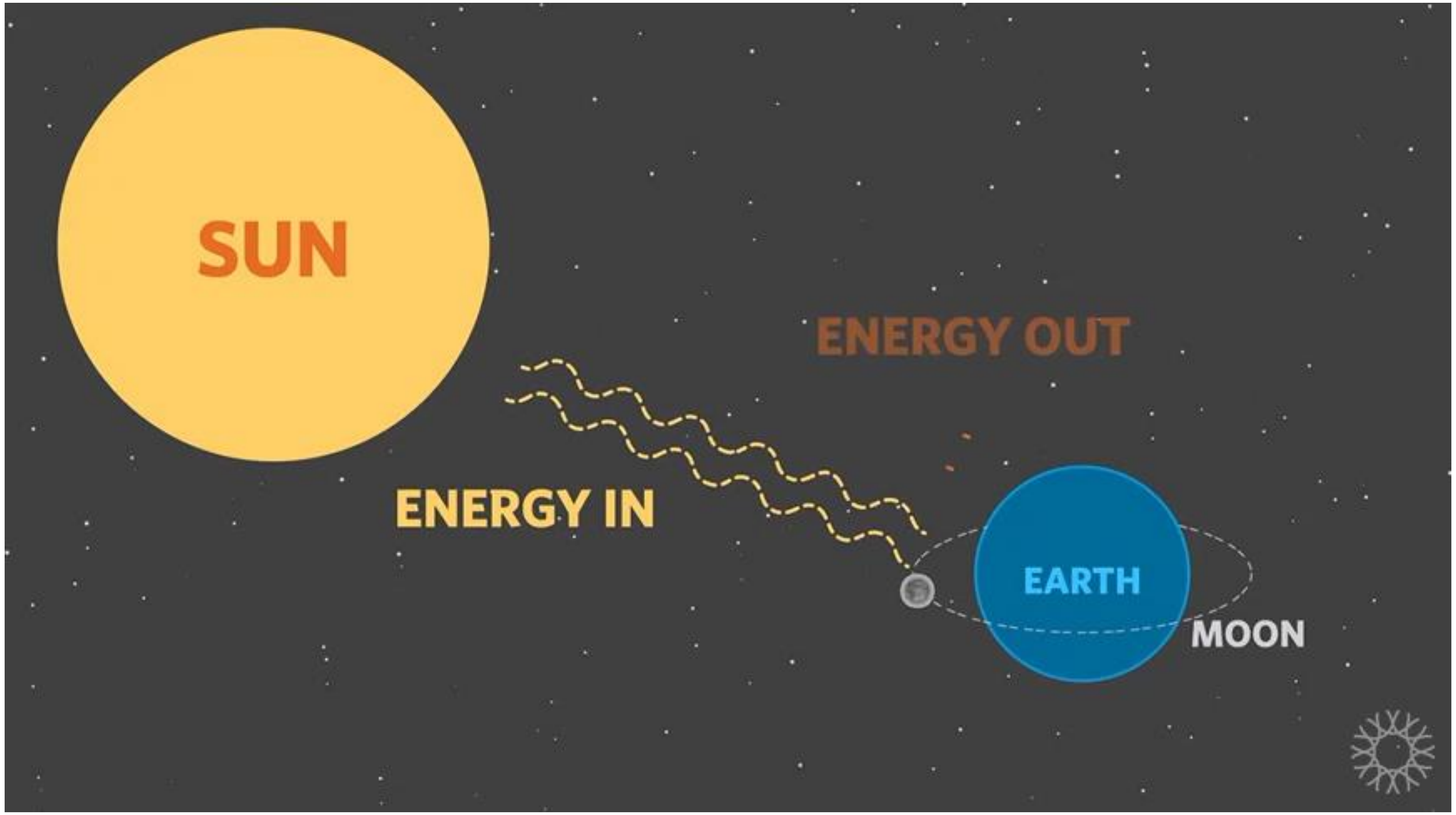
The Earth-Atmosphere systems works in equilibrium

- Energy that reaches Earth from the sun
- Energy that flows from Earth back to space

Variations can occur, but eventually returns to balance!







Climate change is happening all around us!

CLIMATE

White House releases report on reflecting sunlight to cool the earth, no formal study planned now

PUBLISHED FRI, JUN 30 2023•3:06 PM EDT | UPDATED MON, JUL 3 2023•10:37 AM EDT

Catherine Clifford
@IN/CATCLIFFORD/
@CATCLIFFORD

SHARE

KEY POINTS

- On Friday, the White House released a federally mandated report on solar geoengineering, which is an umbrella term that describes methods of reflecting sunlight away from the earth to cool the atmosphere.
- The Biden-Harris Administration has no plans underway to launch a comprehensive research program into solar radiation modification. But the report lays out the case for what such a research program would look like and why it could be beneficial.

We know the Arctic is melting – but it's also on fire. And these wildfires could transform the pace, and scope, of global warming in ways that could affect us all.

The Arctic is transforming before our eyes: the ice caps are melting, **the tree-line is shifting northwards**, **starving polar bears wander into cities**. **The region is warming twice as fast** as the rest of the planet due to climate change, largely due to changes in albedo – the loss of sunlight-reflecting ice and snow, replaced by sunlight-absorbing ocean and soil. This is driving a dangerous positive feedback cycle where heating spirals into more heating.

And, now, the Arctic isn't only losing its ice. It is being set ablaze.

Gargantuan forest fires in Siberia, **which burned for more than three months,** created a cloud of soot and ash as large as the countries that make up the entire European Union. More than four million hectares of Siberi[...] Russian military were deployed, people across t[...] and the cloud spread to Alaska and beyond. Fire[...] of Greenland, Alaska and Canada.

Munching Moose Cool Forest Floors

By making clear-cut forests patchier, moose create a reflective surface that bounces back sunlight and keeps temperatures down.

By Rebecca Dzombak 7 March 2023

Moose prefer munching the thin branches and nutritious leaves of deciduous trees, but acidic pine will do in a pinch. Credit: Bryan Rodriguez, Unsplash

A translation of this article was made by Wiley. 本文由Wiley提供翻译稿。

Source: *Journal of Geophysical Research: Biogeosciences*

Moose can cool boreal forests, according to a new study. Salisbury et al. show that these large grazers expose gaps between trees, revealing a snowy forest floor that reflects light and keeps temperatures down.

Vertical bifacial solar seeking greenhouse albedo, deployment space

A Colorado farmer has installed vertical bifacial solar, leveraging greenhouse albedo to increase output. The installation demonstrates promising generation during winter months, while maximizing limited land space.

JULY 31, 2023 JOHN FITZGERALD WEAVER

COMMERCIAL & INDUSTRIAL PV | MODULES & UPSTREAM MANUFACTURING | TECHNOLOGY AND R&D | UNITED STATES

Image: Sandbox Solar

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JULY 28, 2023 Editors' notes

Study reveals how delayed Antarctic melt season reduces albedo feedback

by Li Yuan, Chinese Academy of Sciences

Credit: Unsplash/CC0 Public Domain

The ice-covered continent of Antarctica is not free from climate change. On the contrary, a rise in temperatures at high latitudes is much stronger than that in global mean temperatures, a phenomenon known as the polar amplification effect.

Sacramento's urban heat island effect, explained

A new study found nearly two-thirds of Sacramento's population lives in an area where the urban heat island effect makes it around 8 degrees warmer

Credit: Gabriel Porras

Author: Brenden Mincheff
Published: 4:48 PM PDT July 27, 2023
Updated: 4:48 PM PDT July 27, 2023

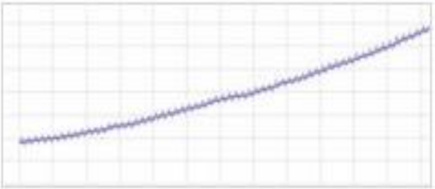
SACRAMENTO, Calif. — A new study from Climate Central finds downtown Sacramento and Capitol areas are more than 8°F warmer because of city design. It's due to something called the 'urban heat island effect.'

But how exactly can we see these changes to climate?

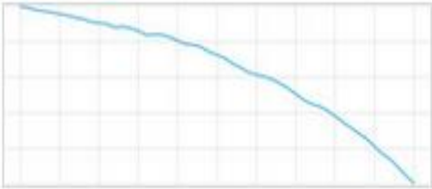
Greenhouse Gases

Arctic Sea Ice

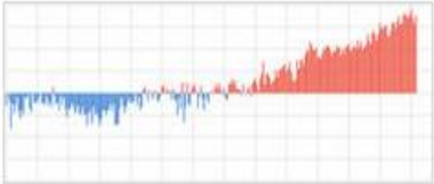
Carbon Dioxide



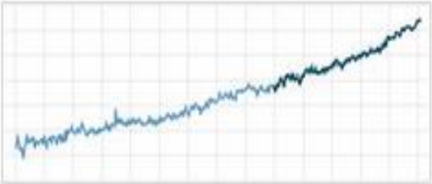
Mountain Glaciers



Ocean Heat

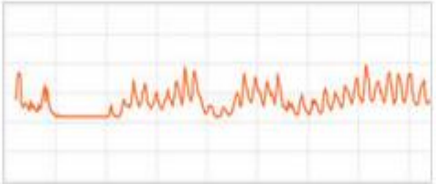


Sea Level

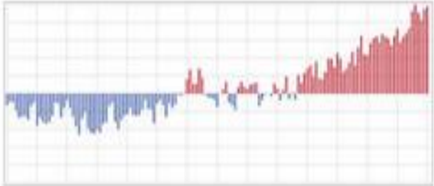


Spring Snow

Incoming Sunlight

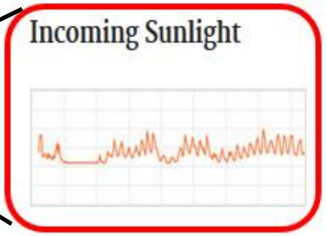


Surface Temperature



Focus for today:
Incoming sunlight!

What IS albedo?

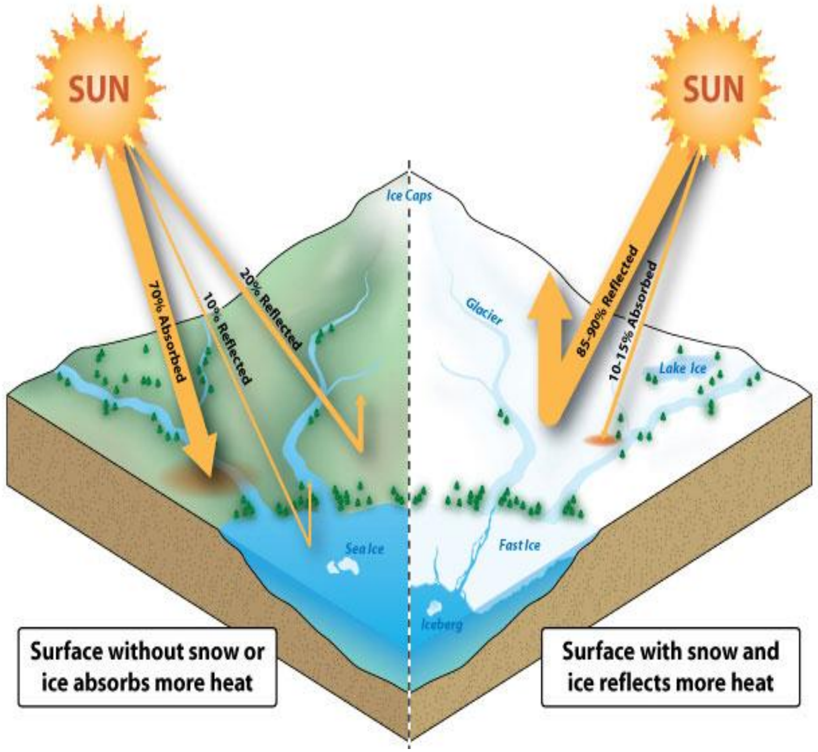


$$albedo\ (\alpha) = \frac{S_{w\uparrow}}{S_{w\downarrow}}$$

The higher the albedo, the more light it reflects.
The lower the albedo, the more light it absorbs.

OSIRIS-Rex Mission: What is albedo?

Albedo

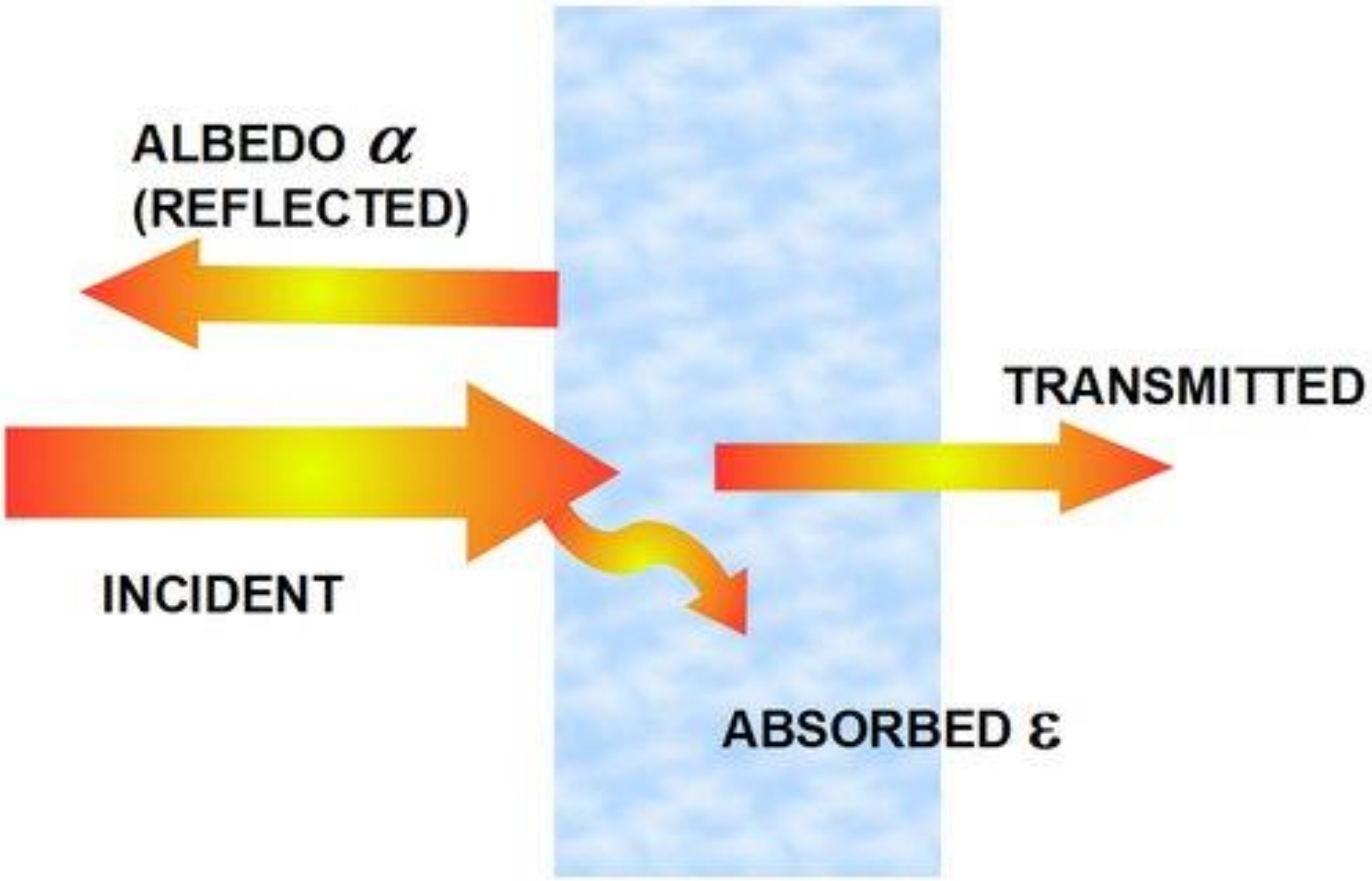


Changes of albedo with on different landscapes.

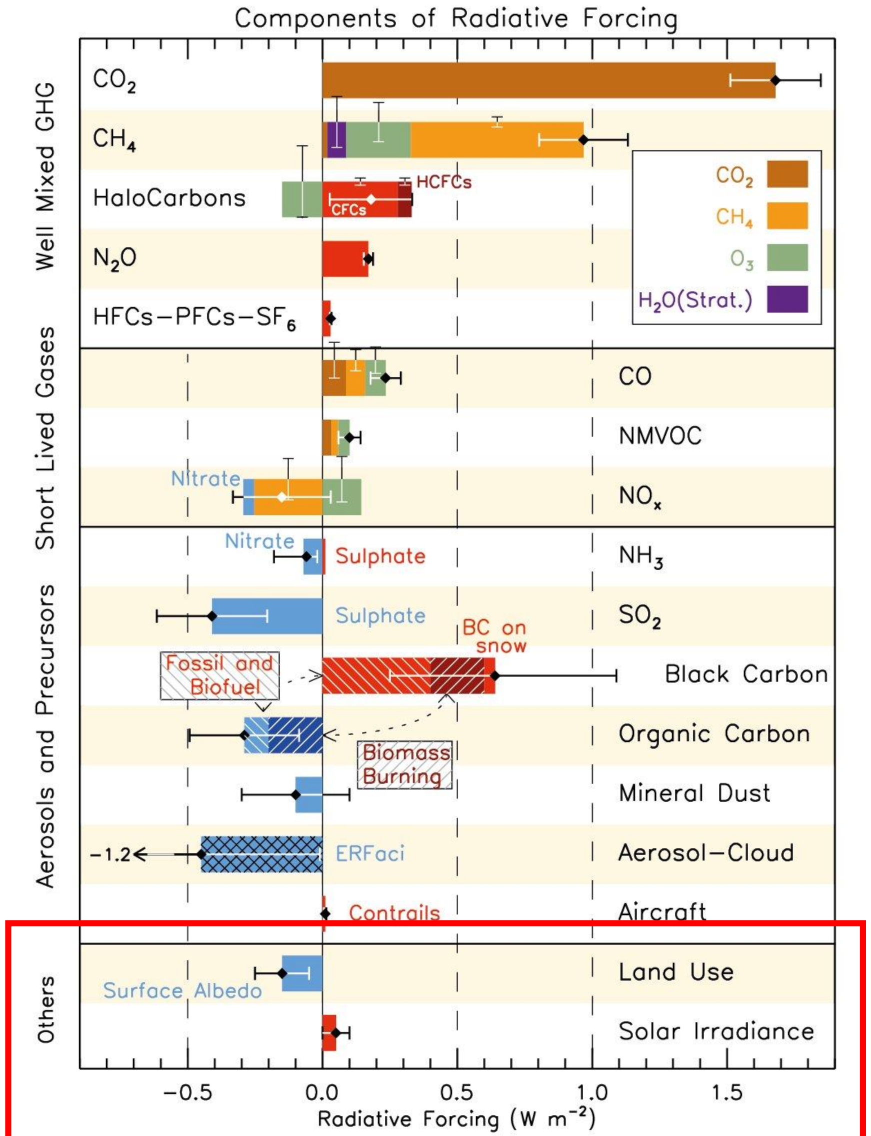
What IS albedo?

When light hits an object, three things can happen:

- Reflected (bounces off)
- Transmitted (goes through)
- Absorbed (stays in)



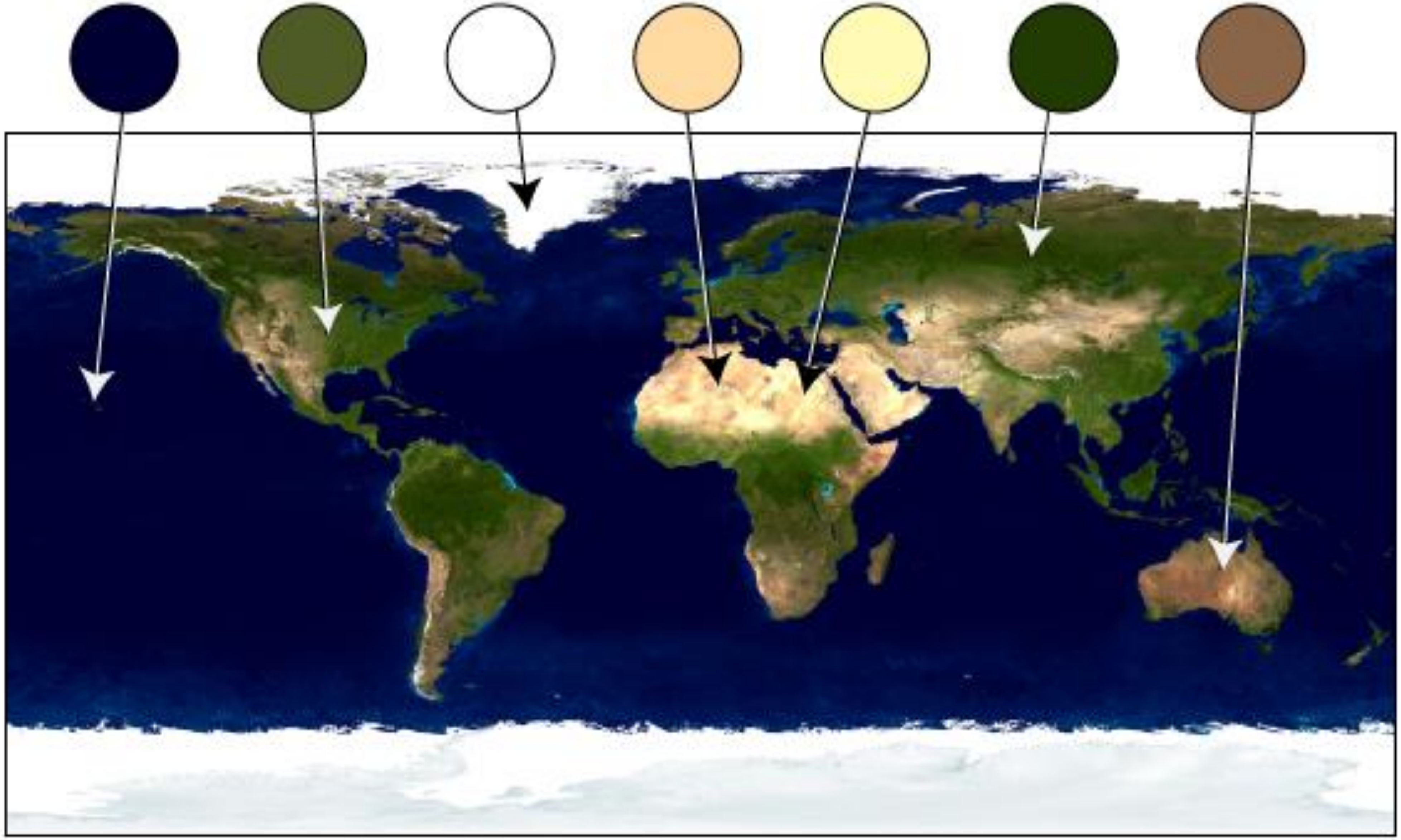
Importance of albedo



Any questions?

ALBEDO OF TERRESTRIAL SYSTEMS

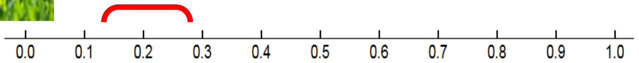
The surface of the Earth is a patchwork of colors



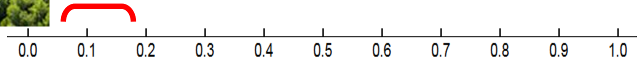
https://scied.ucar.edu/learning-zone/how-climate-works/albedo-and-climate

Albedo in real-life

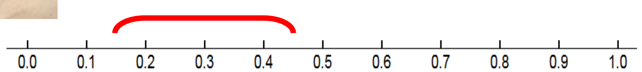
Grass



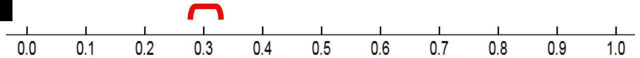
Forest



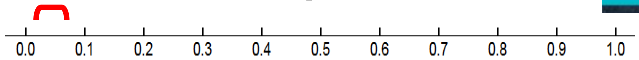
Sand



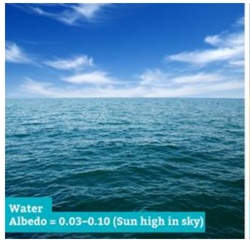
Earth



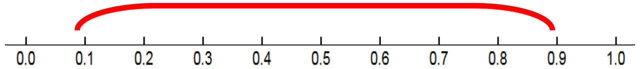
Asphalt

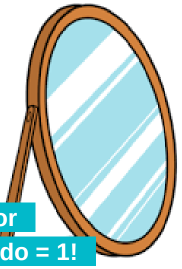


Snow



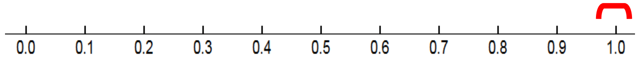
Water





Mirror
Albedo = 1!

A Mirror!



Albedo in real-life

Stages of growth development of agricultural crops during the early growing period to peak growing season at KBS LTER. Lei et al., 2024

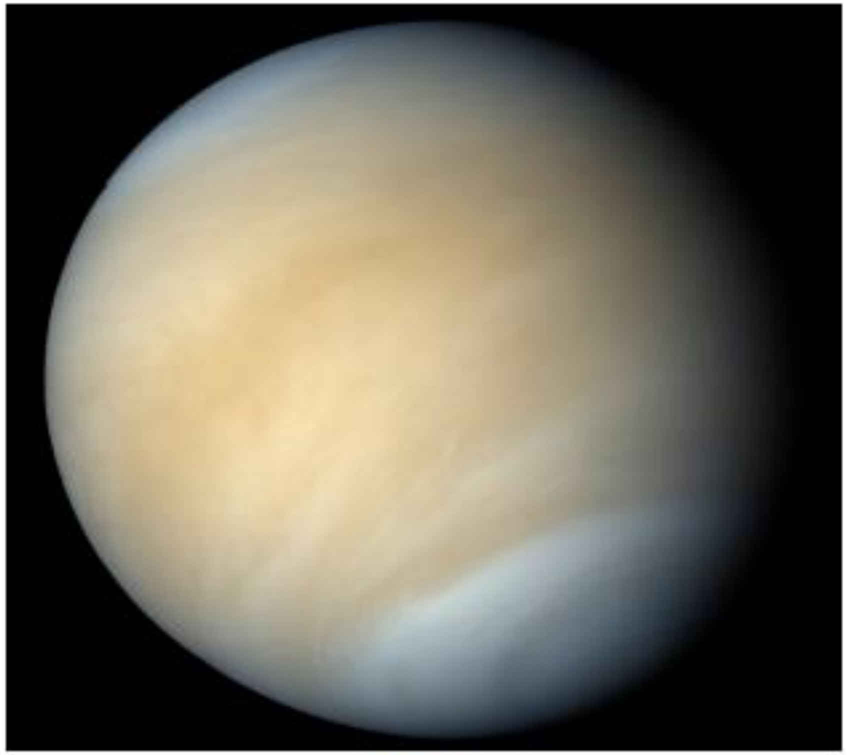
Fresh asphalt	0.04
Open ocean	0.06
Worn asphalt	0.12
Coniferous forest	0.08-0.15
Deciduous Forest	0.15-0.18
Bare Soil	0.17
Green grass	0.25
Desert sand	0.4
New concrete	0.55
Ocean ice	0.5-0.7
Fresh snow	0.8
Aluminum	0.85

Albedo in real-life

Albedo applies even to a planetary scale!

Which planet has a higher albedo? Why would this be important?

Earth



Venus

Albedo in real-life

Albedo at our poles!

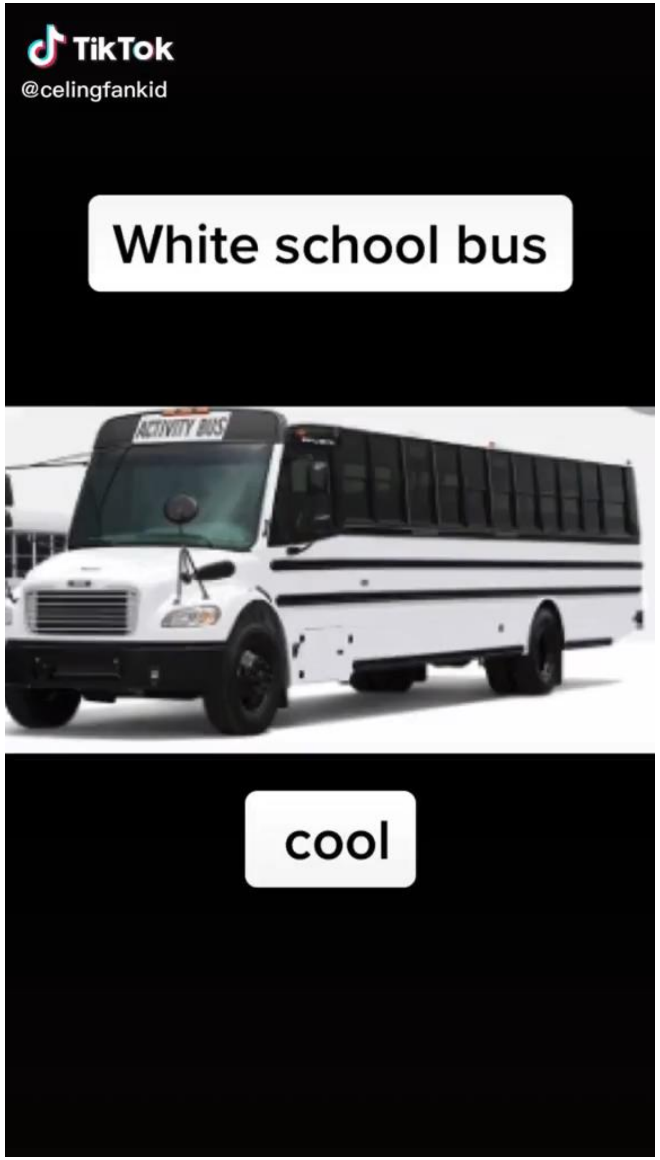
Would fresh snow or dirt snow have a higher albedo?
Which would absorb more sunlight?

Fresh snow

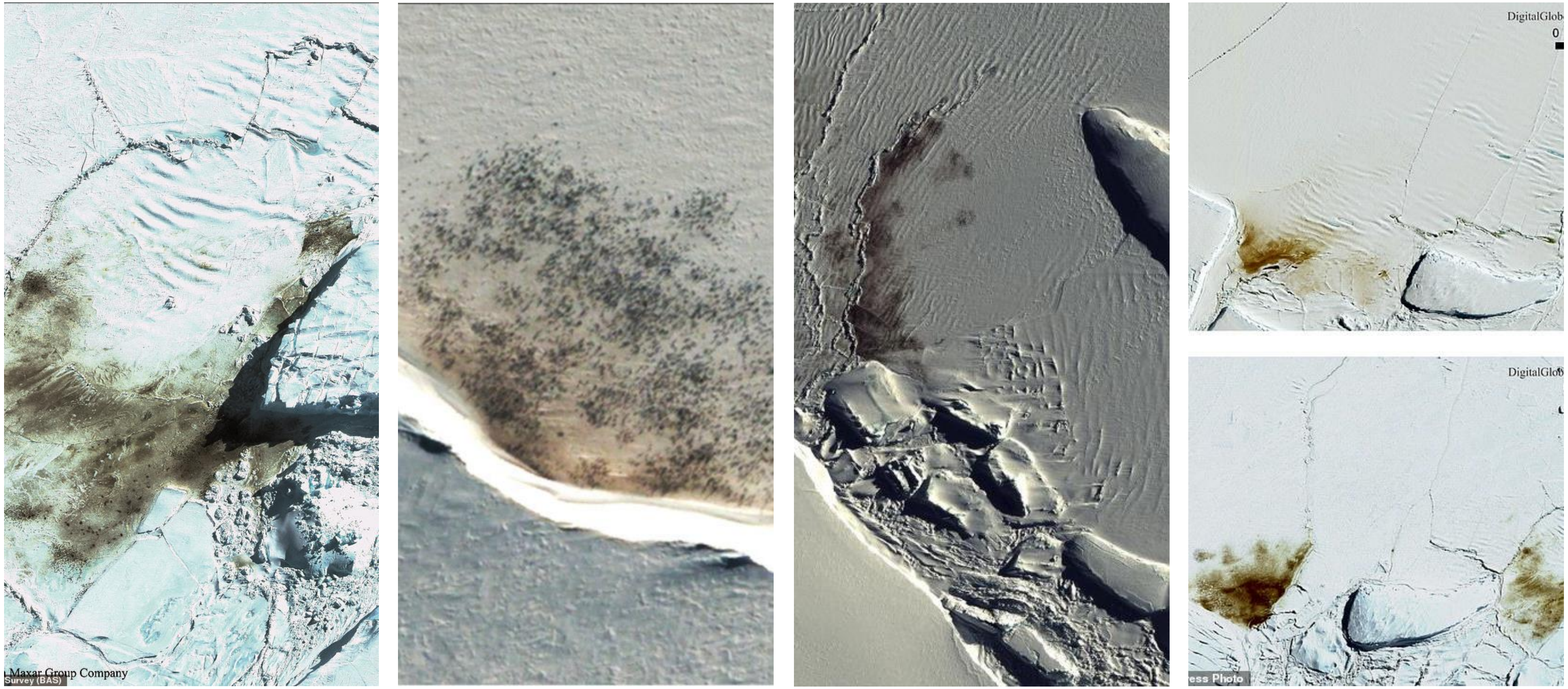
Dirty snow

Albedo in real-life

Why do school buses often have white-painted roofs?



Albedo in real-life



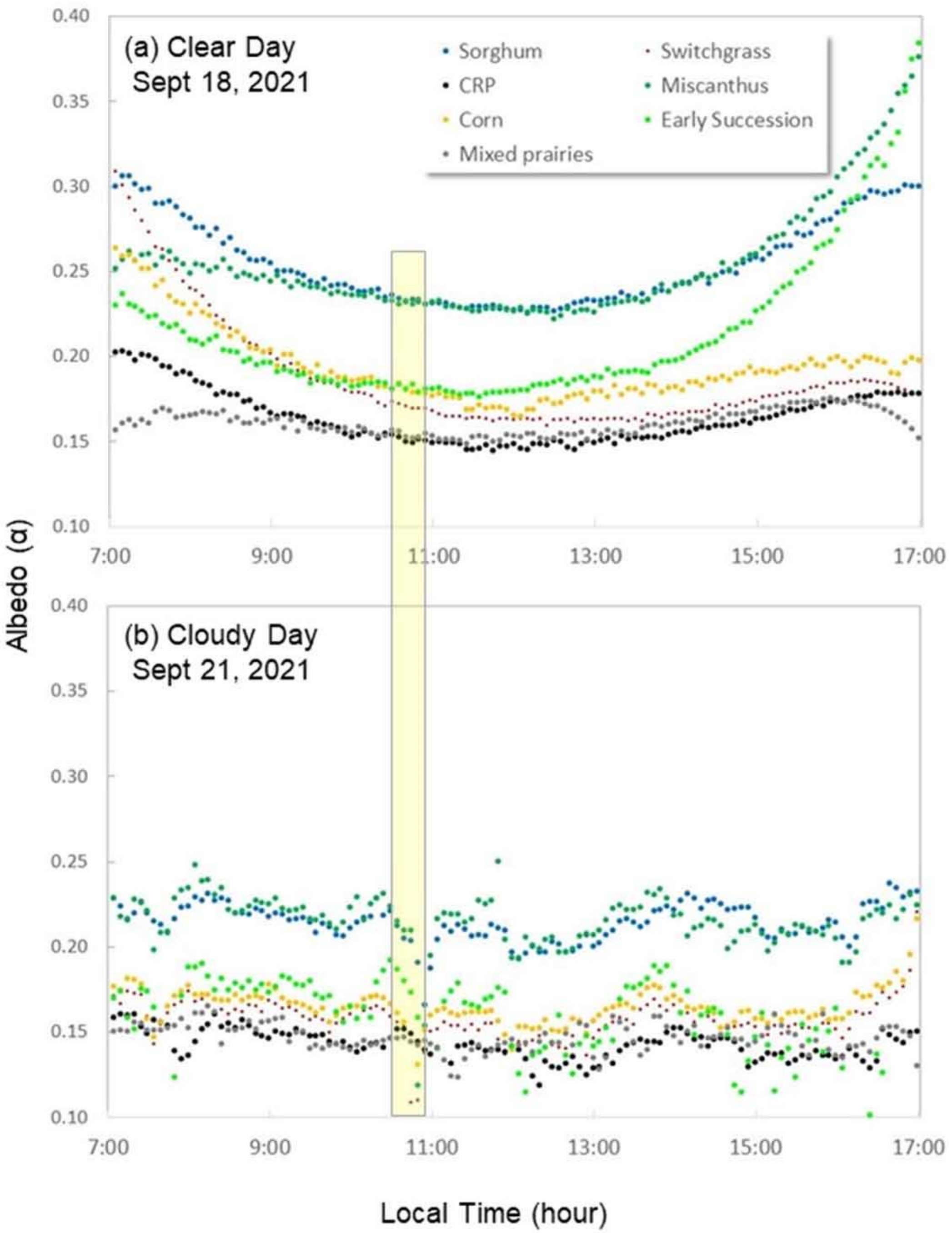
Satellite photos of emperor penguin colonies

The bigger the stain, the more penguins there are!

Albedo in real-life

What about diurnal changes in terrestrial systems?

What does the yellow bar on the figure represent?



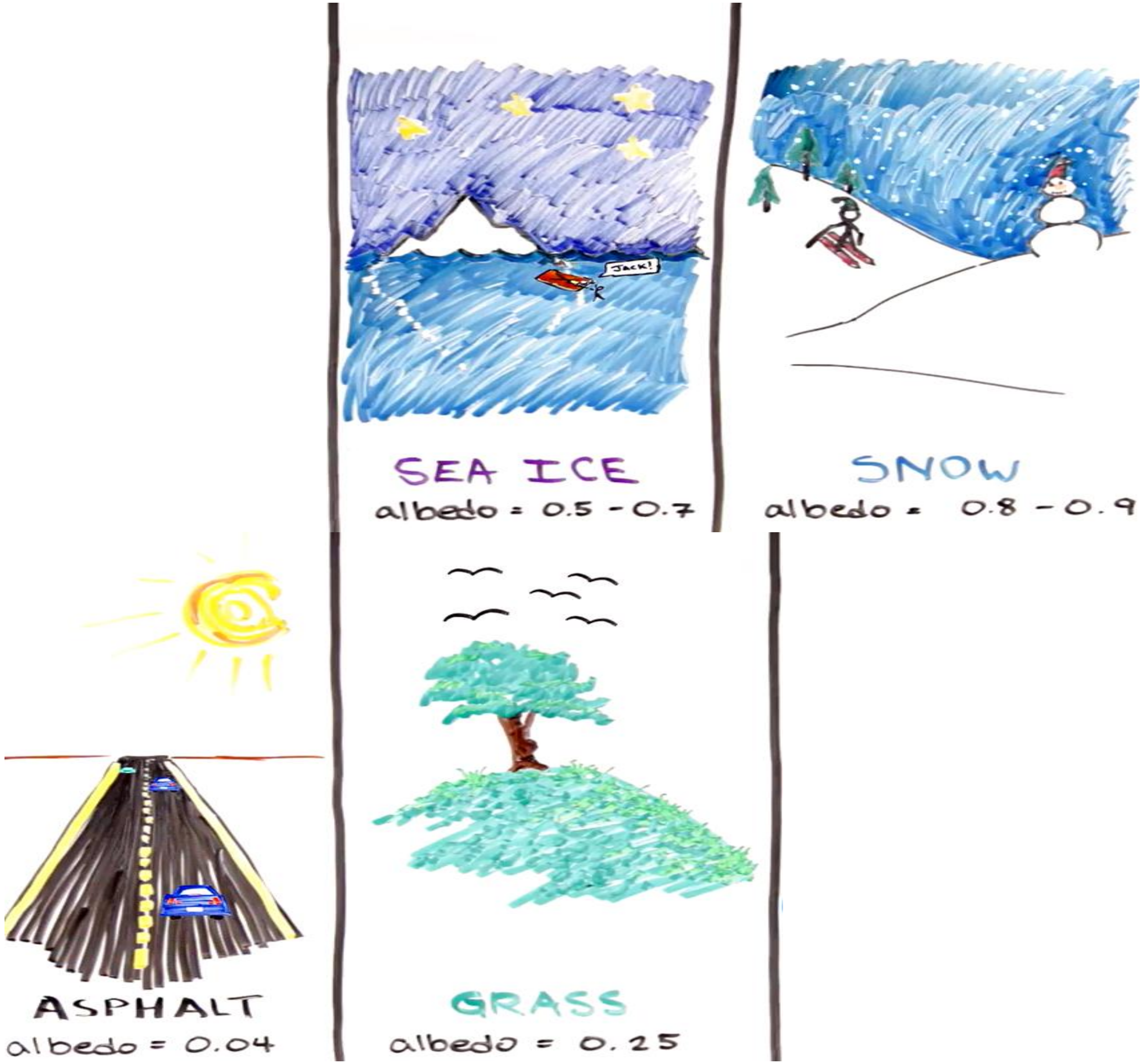
Chen et al. 2024

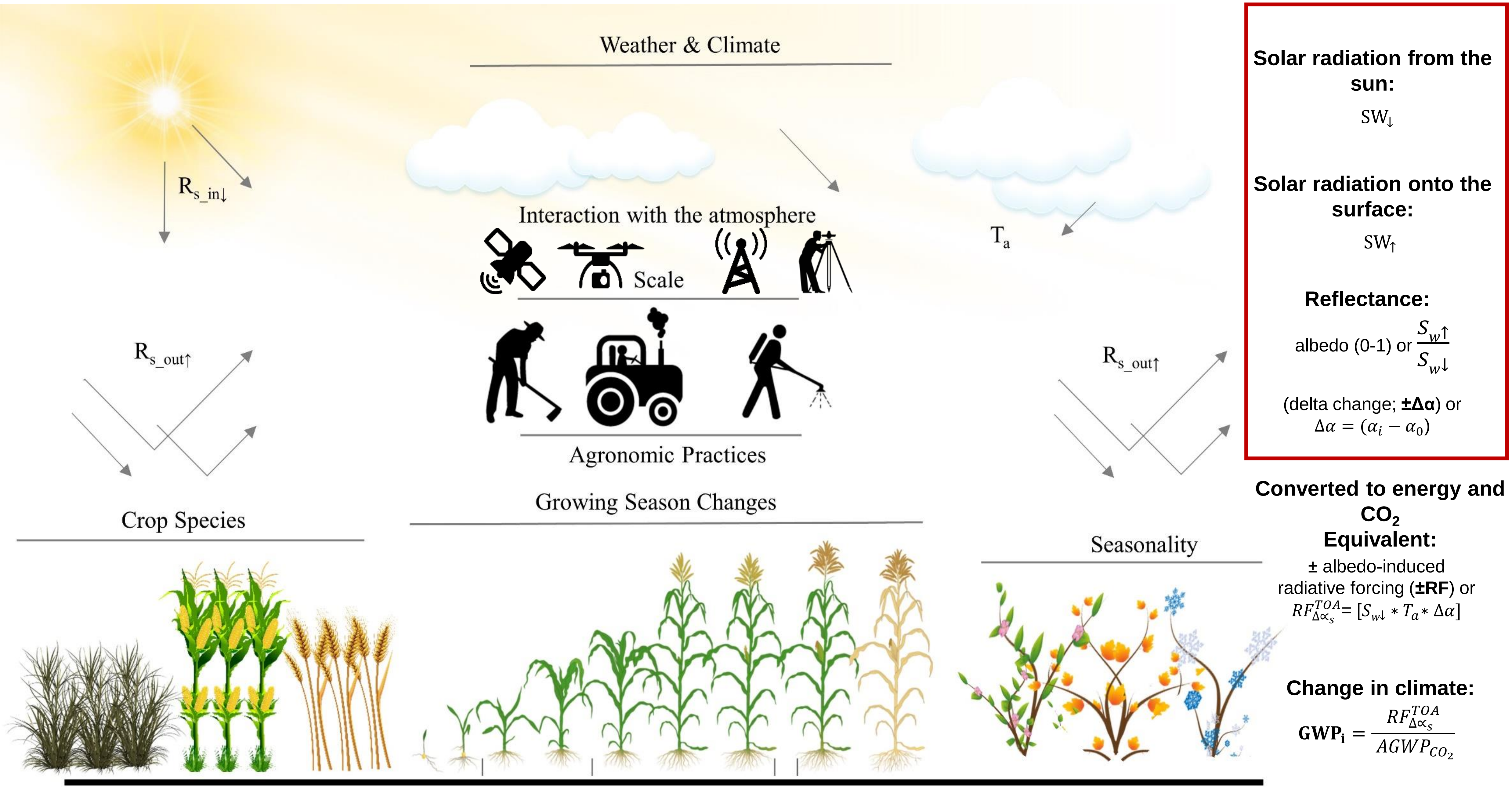
Factors affecting albedo

Main Foci

- Changes in ice/snow cover
- Clouds
- GHGs
- Surface composition and color
- Urban heat island effects
- Urbanization
- Pollution

- Land use land cover change (LULCC)
- Vegetation crops & species
- Moisture (soil, air, vegetation)
- Temperature (soil, air)
- Surface & plant texture
- Atmospheric conditions





Weather & Climate
$R_{s\_in\downarrow}$
Interaction with the atmosphere
Scale
T_a
$R_{s\_out\uparrow}$
$R_{s\_out\uparrow}$
Agronomic Practices
Growing Season Changes
Crop Species
Seasonality
Solar radiation from the sun:
$SW_{\downarrow}$
Solar radiation onto the surface:
$SW_{\uparrow}$
Reflectance:
albedo (0-1) or $\frac{S_{w\uparrow}}{S_{w\downarrow}}$
(delta change; ±Δα) or
$\Delta\alpha = (\alpha_i - \alpha_0)$
Converted to energy and CO_2 Equivalent:
± albedo-induced radiative forcing (±RF) or
$RF^{TOA}_{\Delta\propto_s} = [S_{w\downarrow} * T_a * \Delta\alpha]$
Change in climate:
$\mathbf{GWP_i} = \frac{RF^{TOA}_{\Delta\propto_s}}{AGWP_{CO_2}}$

Let’s calculate albedo of multiple systems

$$albedo\ (\alpha) = \frac{S_{w\uparrow}}{S_{w\downarrow}}$$

Ex 1: If at 10:30am on September 16th, 2026, the incoming solar radiation ($S_{w\downarrow}$) for a Miscanthus site in Michigan is 1120 Wm^{-2}, and the outgoing solar radiation ($S_{w\uparrow}$) is 250 Wm^{-2}, what is the average albedo for this site?

$$\Delta\alpha = (\boldsymbol{\alpha_{iNEW}} - \boldsymbol{\alpha_{0REF}})$$

Ex 2: I now know the albedo of my miscanthus site and now am interested in analyzing the change in surface reflectivity ($\Delta\boldsymbol{\alpha}$) to a reference forest site on the same day with the same $S_{w\downarrow}$, and a $S_{w\uparrow}$ of 150 Wm^{-2}. What is the mean albedo change?

Any questions?

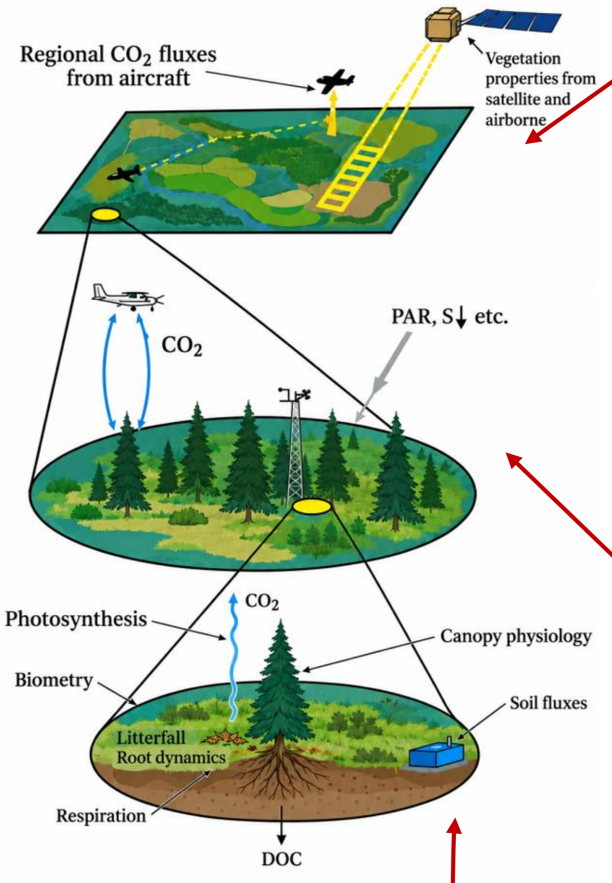
HOW DO WE MEASURE ALBEDO?

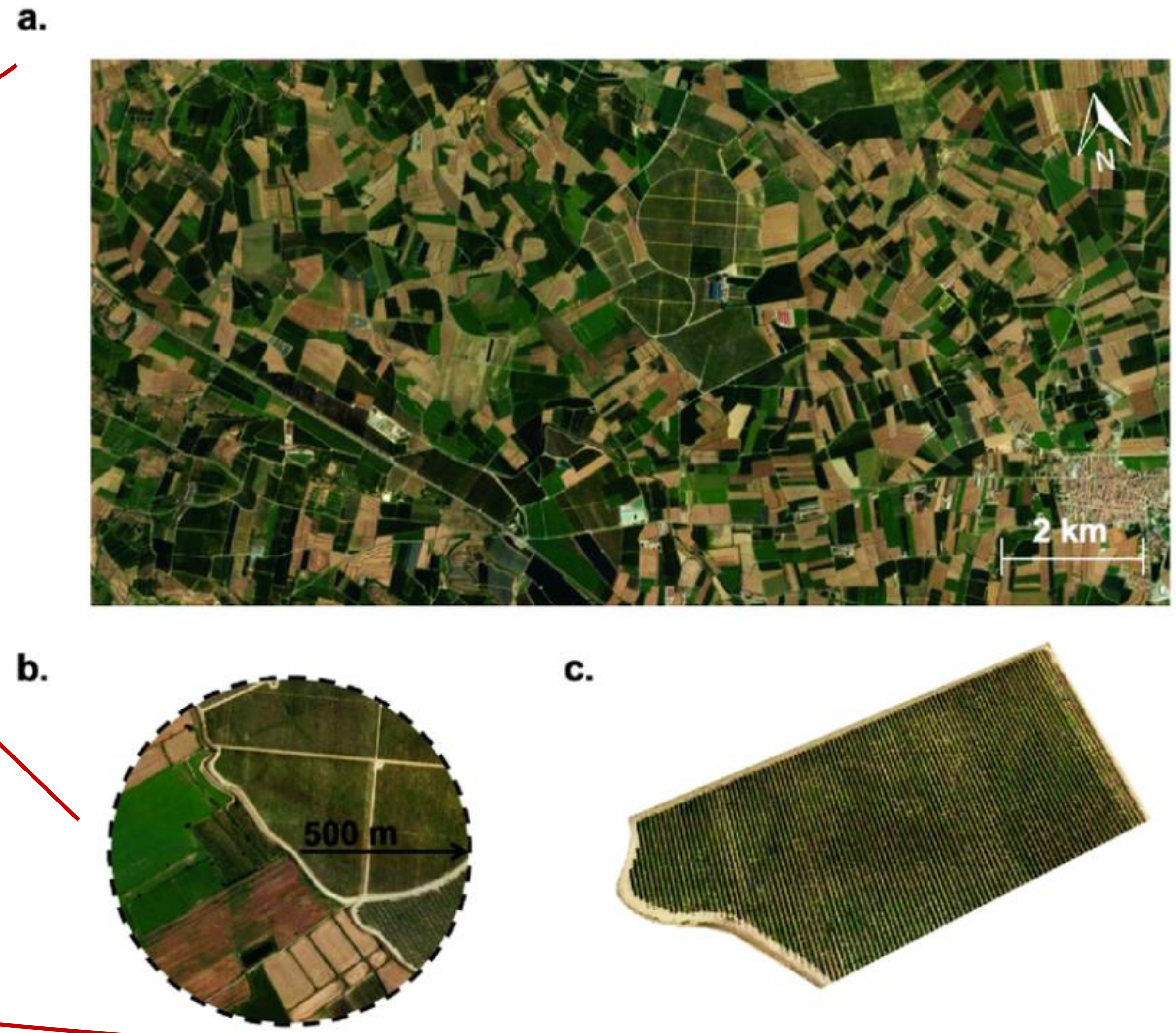
Different ways to measure albedo!

Regional Scale

Local Scale

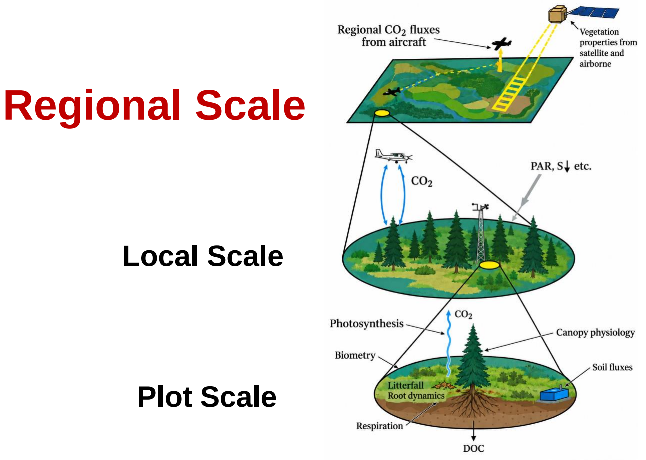
Plot Scale





Clemente-Orta, G., & Álvarez, H. A. (2019).

Satellite (remote sensing) measurement of albedo



Satellites measure albedo by **detecting the amount of sunlight reflected from Earth's surface and atmosphere across various wavelengths.**

https://www.youtube.com/watch?v=uWZEvZ118DM

Satellite (remote sensing) measurement of albedo

Advantages of measuring with satellites

- Measure extremely large areas
- Less manpower
- Can have longer historical measurements
- Model albedo for the future

Disadvantages of measuring with satellites

- Remote sensing instruments only indirectly measure albedo
- Calibration
- Sensors can break
- One pixel can cover multiple land surfaces
- Cost to launch a satellite in space

Disappearing Aral Sea

Lake expansion in the Tibetan Plateau

New dam (Sudan)

Disappearing lake (Lake Milh-Iraq)

$$\Delta a = a - a_{ref}$$

$$RF_{\Delta a} = SW_{in}\, T\, \Delta a$$

USGS: January 2003. Credit: Grant Falvo (KBS)

$$\Delta a = a - a_{ref}$$

$$RF_{\Delta a} = SW_{in}\, T\, \Delta a$$

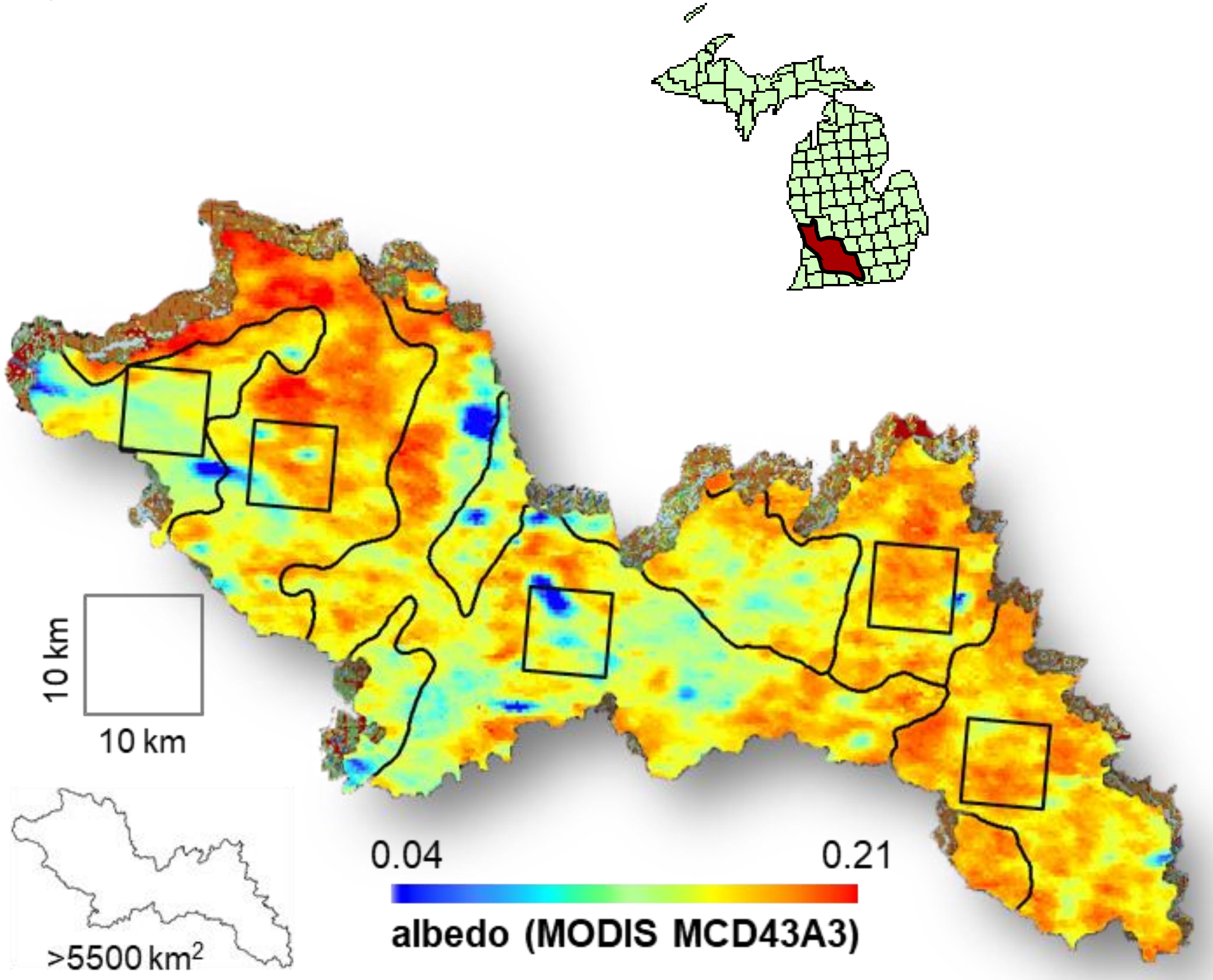
USGS: April 2010.Credit: Grant Falvo (KBS)

$$\Delta a = a - a_{ref}$$

$$RF_{\Delta a} = SW_{in}\, T\, \Delta a$$

USGS: July 2015. Credit: Grant Falvo (KBS)

Satellite (remote sensing) measurement of albedo

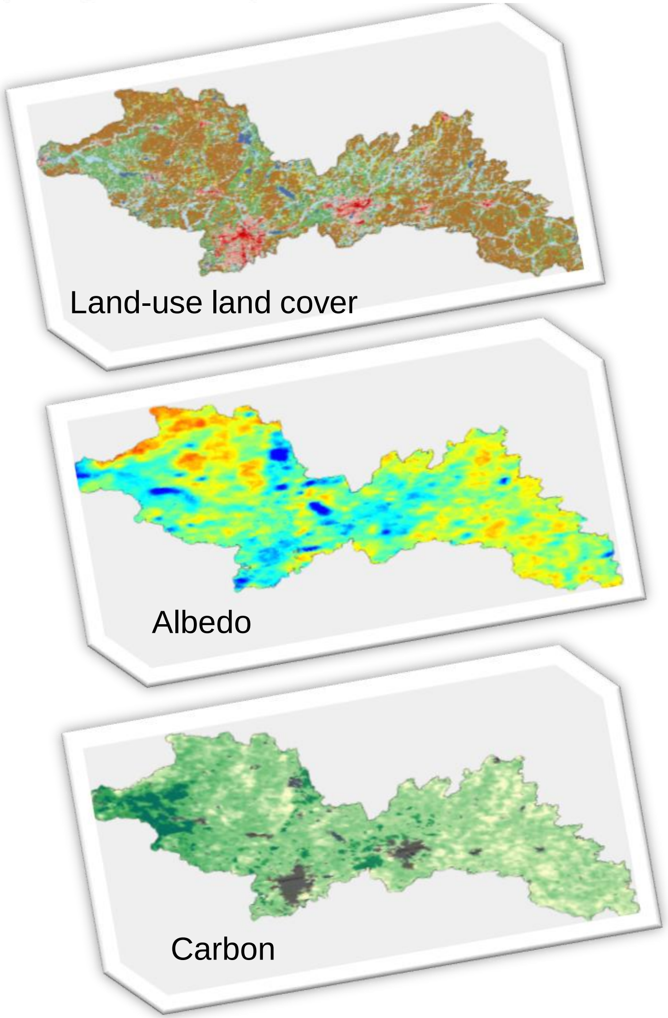


land MDPI

Article

Albedo-Induced Global Warming Impact at Multiple Temporal Scales within an Upper Midwest USA Watershed

Pietro Sciusco [1,2,*], Jiquan Chen [1,2,3], Vincenzo Giannico [4], Michael Abraha [2,3], Cheyenne Lei [1,2,3], Gabriela Shirkey [1,2], Jing Yuan [2] and G. Philip Robertson [3,5,6]



Sciusco, P., Chen, J., Giannico, V., Robertson, G.P., Abraha, M., ***Lei, C.****, Shirkey, G., Yuan, J. (Land, 2022).*
Sciusco, P., Chen, J., Abraha, M., ***Lei, C.****, Robertson, G.P., Lafortezza, R., Shirkey, G., Ouyang, Z., Zhang, R., & John, R. (Landscape Ecology, 2020).*

Unmanned Aerial Vehicles & Towers

b.

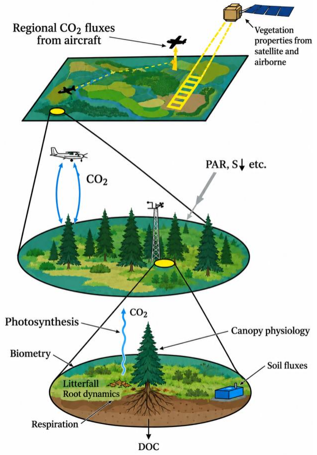
c.

https://www.kbs.msu.edu/2020/01/brandon-dsouza-reu/

Regional Scale

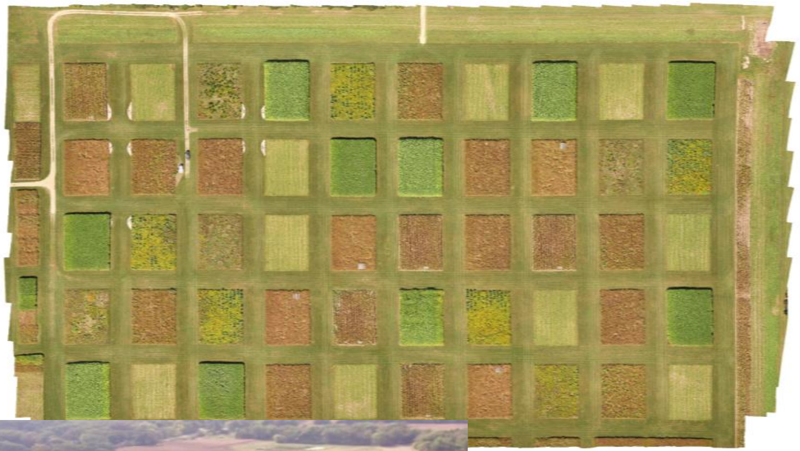
Local Scale

Plot Scale



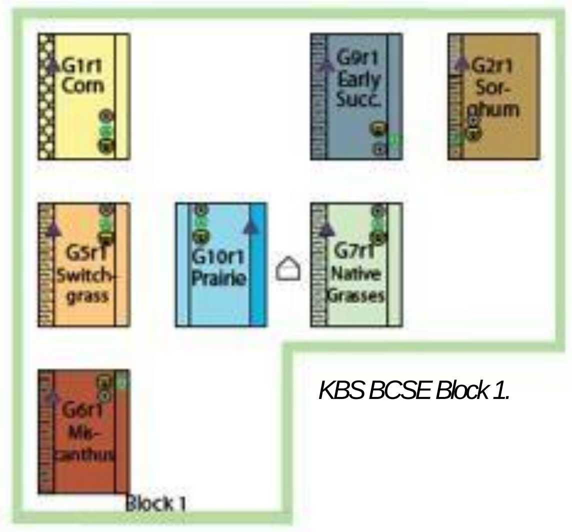
Measuring albedo using drones and towers **combines mobile high-resolution aerial data with continuous stationary baseline measurements to bridge the gap between ground plots and coarse satellite observations.**

Local Scale: Unmanned Aerial Vehicles



Local Scale: Towers

Portable albedo tower: (n = 7)
Reference albedo tower: (n = 1) (total n = 44)
2018 – 2022, data retrieved weekly
Towers raised to maintained consistent field of view



KBS BCSE Block 1.

Unmanned Aerial Vehicles & Towers

Red = Warming
(Low reflectivity)

Green = Cooling!
(High reflectivity)

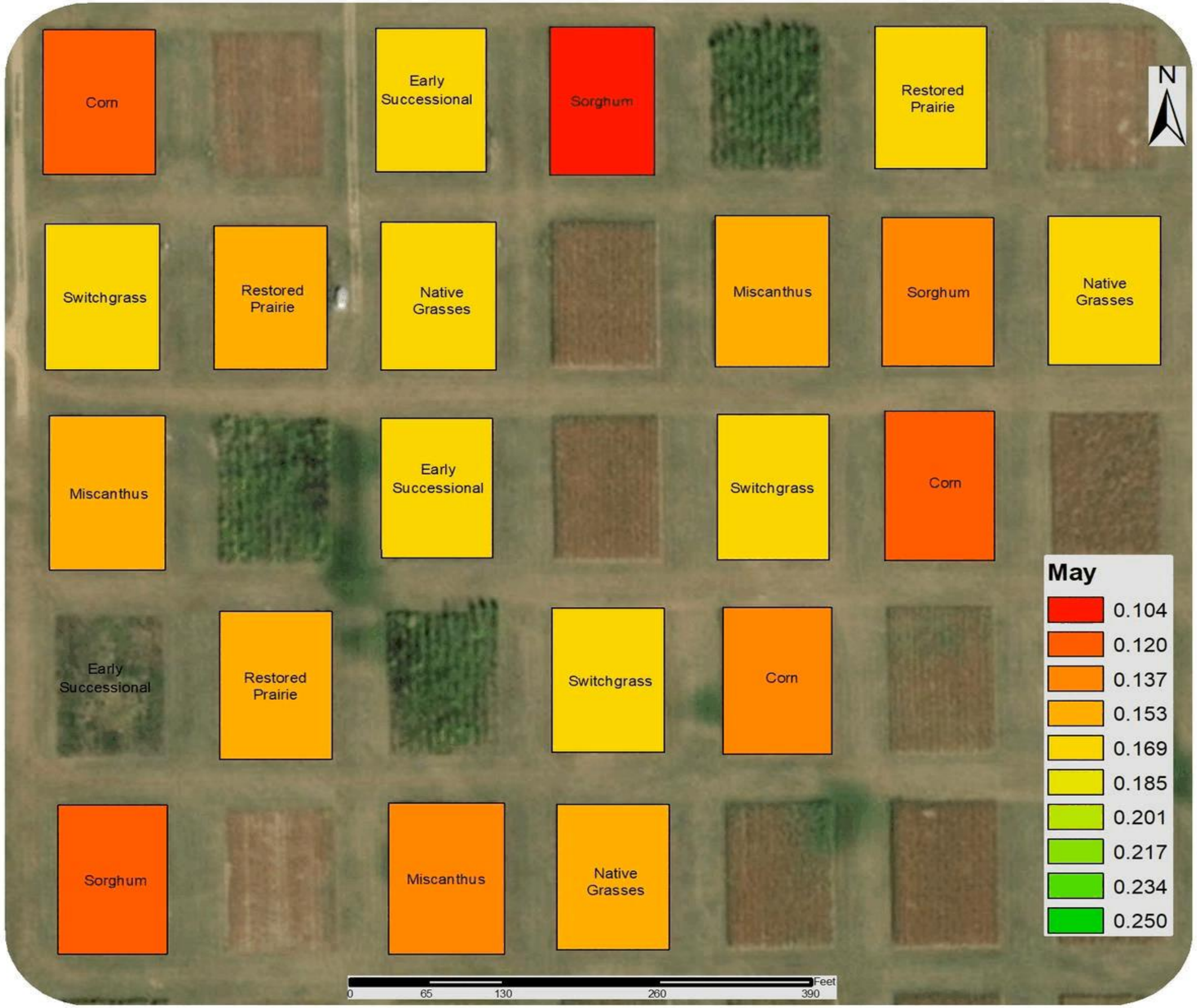
Advantages of measuring with drones/towers:

- Measure large areas
- Less manpower
- Model albedo for the future
- No clouds in imagery

Disadvantages of measuring with drones/towers:

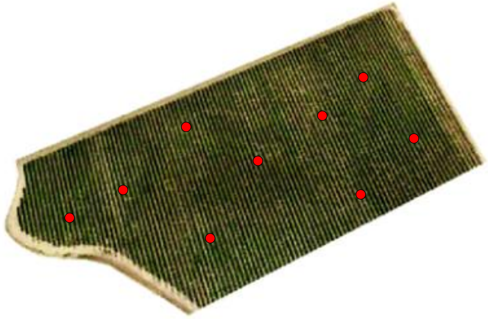
- Lots of calibration
- Sensors can break
- Can be expensive
- Must have an person flying the drone / maintaining towers

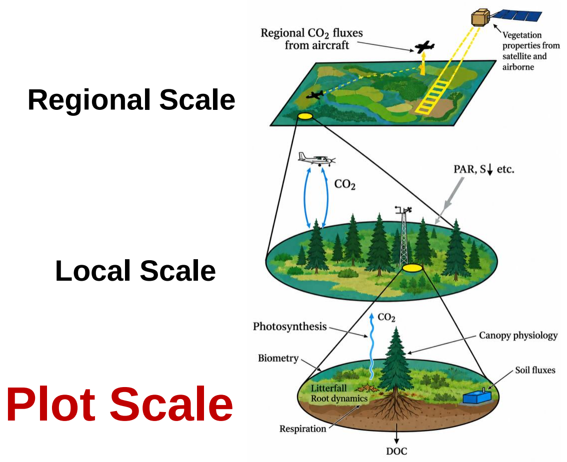
(at least for now!)



Average monthly albedo from May to October for all replicates (R1, R2 and R4) over three consecutive seasons from 2018 to 2020.

Instantaneous (Survey) measurements





Measuring albedo using survey points involves **recording incoming and reflected solar radiation at specific field locations using net radiometers or pyranometers.**

Instantaneous (Survey) measurements

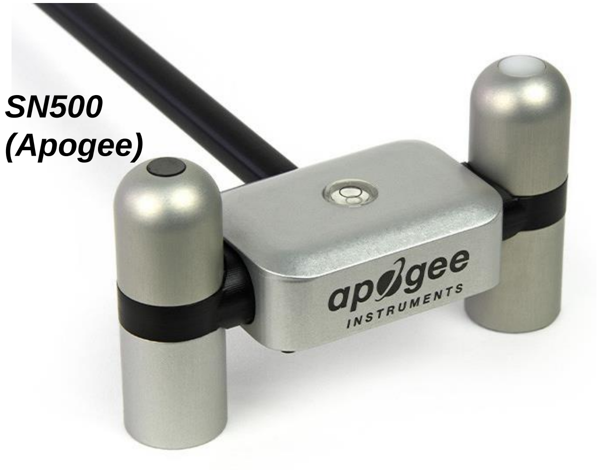
NR01
(Campbell Scientific)

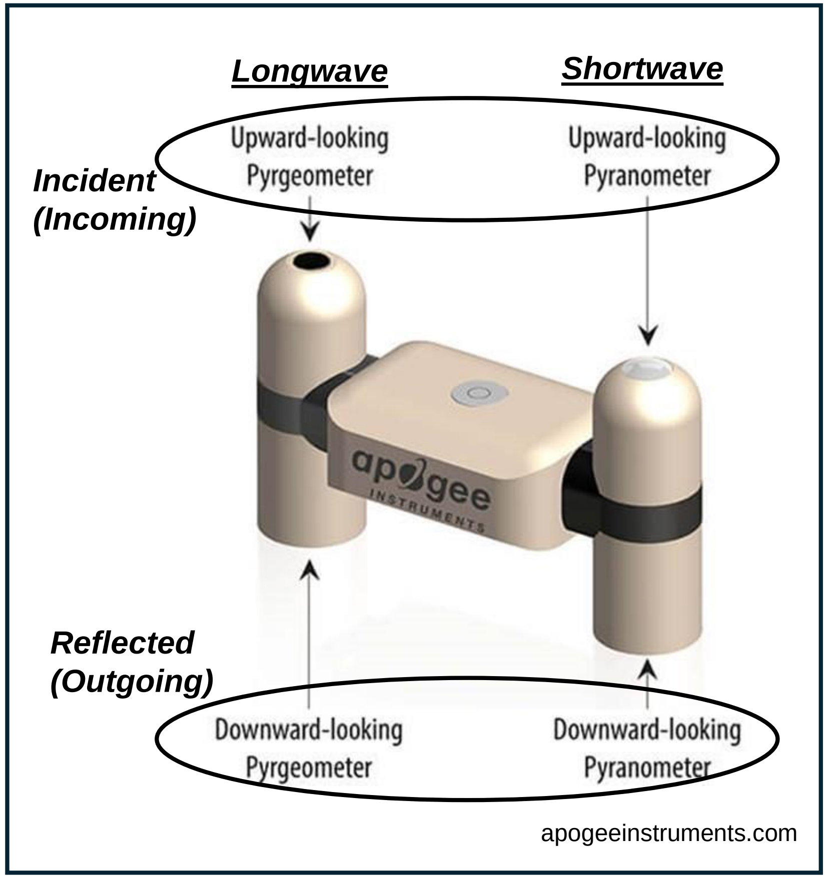
SRA01
(Hukseflux)

CNR1
(Kipp & Zonen)

CNR4
(Kipp & Zonen)

SN500
(Apogee)





Instantaneous (Survey) measurements

Advantages of measuring with field sensors:

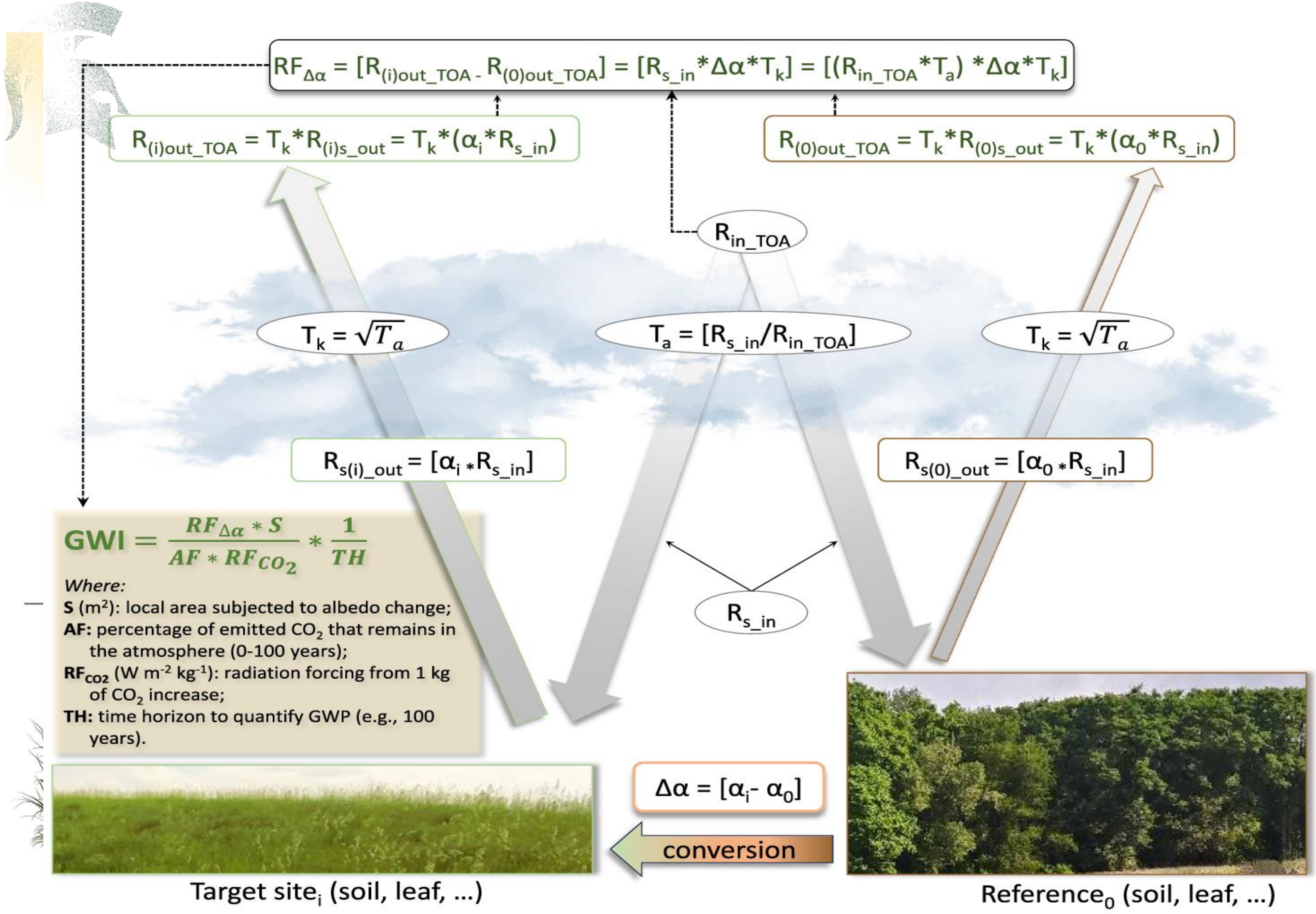
- Measure smaller areas
- Better temporal resolution
- No missing data from clouds

Disadvantages of measuring with field sensors:

- Intensive manpower
- Cost of instrumentation
- Smaller areas may not fully represent larger region

Any questions?

ALBEDO AND GLOBAL WARMING POTENTIAL



Solar radiation from the sun:

$SW_{\downarrow}$

Solar radiation onto the surface:

$SW_{\uparrow}$

Reflectance:

albedo (0-1) or $\frac{S_{w\uparrow}}{S_{w\downarrow}}$

(delta change; **±Δα**) or $\Delta\alpha = (\alpha_i - \alpha_0)$

Converted to energy and CO_2 Equivalent:

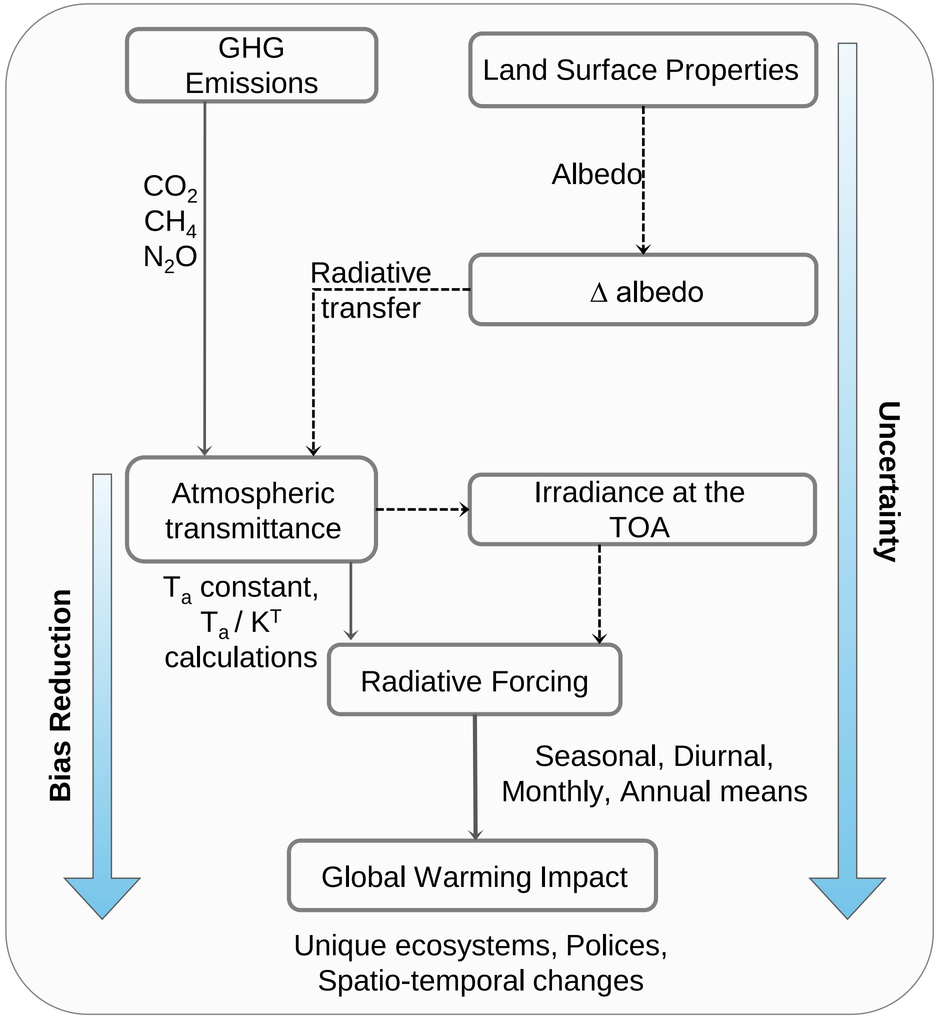
± albedo-induced radiative forcing (**±RF**) or $RF_{\Delta\alpha_s}^{TOA} = [S_{w\downarrow} * T_a * \Delta\alpha]$

Change in climate:

$$\mathbf{GWP_i} = \frac{RF_{\Delta\alpha_s}^{TOA}}{AGWP_{CO_2}}$$

Global Warming Potential

$$GWP_{\Delta\propto_s} = \frac{S * RF^{TOA}_{\Delta\propto_s}}{AF * \ RF_{CO_2}} \frac{1}{TH}$$



Framework for using albedo and GHGs to determine global warming impact (GWP/GWI).

Parameters of GWP

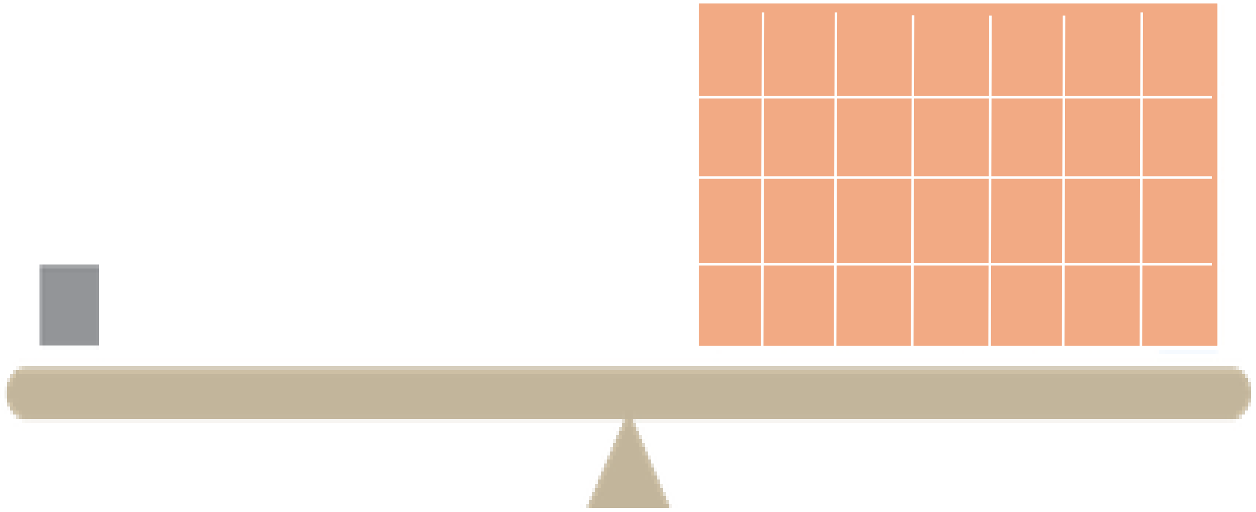
For your viewing pleasure.

Symbol	Name	Description
CO_2	carbon dioxide	A colorless gas that occurs naturally in Earth's atmosphere.
pCO_{2ref}	reference of partial CO_2 pressure	Reference of partial CO_2 pressure in the atmosphere, approximately at 389 ppmv or 0.383 g kg^{-1}.
T_a	upwelling transmittance constant	Upwelling transmittance can be used as a constant based on a clear day (0.854), sunny day (0.73) or cloudy day (0.48), or it can be calculated based on zenith angle from time of day (Chapter 1).
TH	time horizon	The time horizon used when calculating GWP. The IPCC usually refers to TH 20 years, 100 years, and 500 years.
α	albedo	The proportion of incident light to total solar radiation that is reflected by a surface. It is usually unitless but can be expressed as a percentage (*i.e.* 0.2 = 20%).
TOA	top of the atmosphere	The place where solar energy enters the Earth system, and where reflected light and thermal radiation from the sun-warmed Earth exit.
S_w	shortwave	Shortwave radiation (UV/visible light) from solar energy within the atmosphere.
rf_{CO2}	radiative forcing of CO_2	Marginal RF of CO_2 emissions at the current atmospheric concentration. It is the derived radiative forcing from 1 kg of CO_2 at a constant of 0.908 (W kg CO_2^{-1}).
AF	airborne fraction	Proportion of human-emitted GHG that remains in the atmosphere after a certain period of time. AF is 0.69, 0.48, and 0.32 for time horizons of 20, 100, and 500 years, respectively.
S	local area	The area affected by the change in surface albedo (m^{-2}).
$\Delta\alpha_s$	delta albedo	The local change in albedo in a region at a specific time. Calculated by subtracting a reference albedo.
$RF_{\Delta\alpha}$	albedo-induced radiative forcing	The change in net radiative flux from the surface driven by surface albedo changes ($\Delta\alpha$).
ΔRF_{TOA}	delta radiative forcing at the top of the atmosphere	The RF at the TOA due to surface albedo changes. It is usually a function of latitude and it is related to changes in α.
$GWP_{\Delta\alpha}$	global warming potential	Also called global warming impact (GWI), it is a quantified measure of the relative radiative forcing impact of a variable, specific to CO_2.
M_{CO2}	molecular weight of CO_2	The atomic weight of carbon is 12, while oxygen is 16. Therefore, the molecular weight of CO_2 is 44 g mol^{-1} (Table 5-4).
m_{air}	atmospheric mass	The total mean mass of the atmosphere, which is 5.1480×10^{18} kg.
S_{Earth}	area of Earth	The surface area of the Earth, which is ~510 million km^2 (5.1×10^8 km^2).
Δ_{F2x}	forcing of CO_2 concentration	Radiative forcing resulting from a doubling of current CO_2 concentration in the atmosphere, at a current rate of +3.7 $W.m^{-2}$.
M_{air}	molecular weight of dry air	The weight of dry air (28.95 g mol^{-1}). It is composed of Nitrogen (78%), Oxygen (20.85%), Argon (0.93%) and other gases (0.04%).

What is global warming potential (GWP)?

Global warming potential is **a measure of how much heat a greenhouse gas traps in the atmosphere over a specific time period, relative to the same mass of carbon dioxide.**

1 kg $\boldsymbol{RF^{TOA}_{\Delta\propto_s}}$ = **??** kg of CO_2



Advantages of using GWP:

- Highly efficient method
- Can be done for many GHGs
- Allows landscape effects to be converted into CO_2 equivalences (CO_2-eq)
- Emissions of CO_2 required to have the same climatic effect as the change being investigated.
- Use in policy

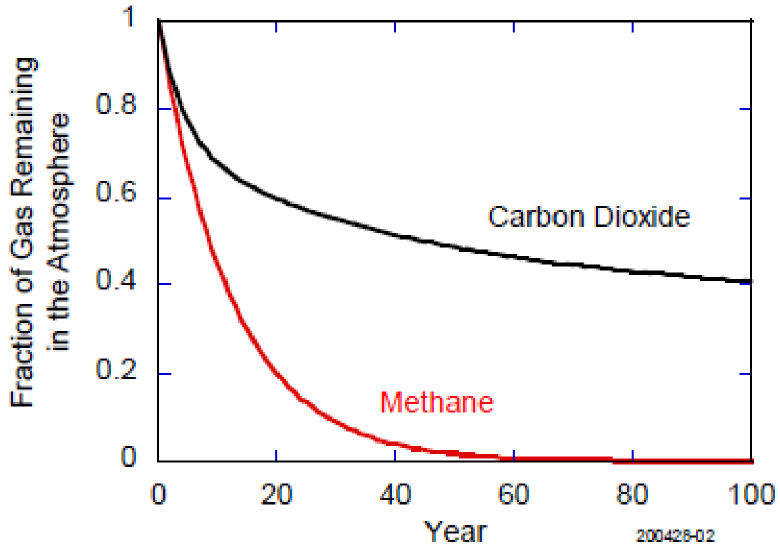
Disadvantages of using GWP:

- Very sensitive to short-lived GHGs
- Calculated in different ways
- Many constants/formulas
- Does not represent actual temperature change from gases
- Difficulty in monitoring sources/sinks of most gases

What is global warming potential (GWP)?

The United States primarily uses the 100-year GWP as a measure of the relative impact of different GHGs.

Other metrics may differ based on timeframe, the climate endpoint measured, or the method of calculation.



Typical atmospheric decay of CO_2 and CH_4 over time.

Chemical	Global Warming Potential (GWP)		Global Temperature Potential (GTP)		Perturbation Lifetime
	GWP_{20}	GWP_{100}	GTP_{20}	GTP_{100}	
Methane (CH_4)	84	28	67	4	12.4 years
Carbon Dioxide (CO_2)	1	1	1	1	Up to thousands of years
Nitrous Oxide (N_2O)	264	265	277	234	121 years
Chlorofluorocarbon-13 (CFC-13)	10,900	13,900	11,700	15,900	640 years

TABLE 1 Intergovernmental Panel on Climate Change Assessment Report 5 (Table 8.A.1)
Note – values presented above do not include any secondary carbon emission consideration (e.g., the degradation of CH4 to CO2). Methane's GWP100 officially could range from 28-34 times more potent than CO2 if such affects are considered.

Different gases have vastly different heat-trapping abilities.

Understanding each component

$$GWP_{\Delta\alpha_s} = \frac{S * RF^{TOA}_{\Delta\alpha_s}}{AF * RF_{CO_2}} \frac{1}{TH}$$

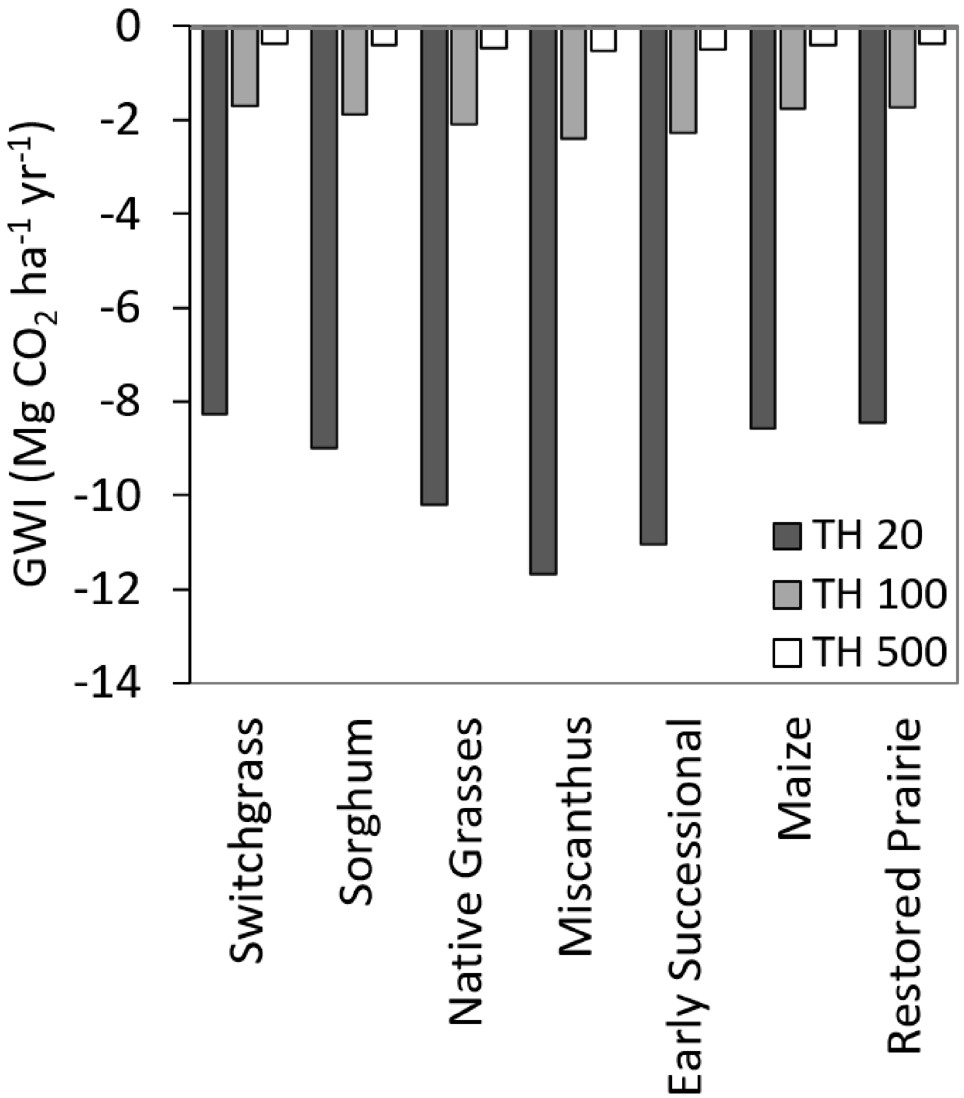
Take a look at direct contributions to GWP from conversion of forest to biofuel crops from surface albedo and three most common THs (20, 100 and 500 years) at the Kellogg Biological Station.

20 years

***TH**: Time Horizon*

100 years

500 years



Understanding each component

$$GWP_{\Delta\propto_s} = \frac{S * RF^{TOA}_{\Delta\propto_s}}{AF * RF_{CO_2}} \frac{1}{TH}$$

$RF^{TOA}_{\Delta\propto_s}$ ($W\text{m}^{-2}$): Direct radiative forcing at the top-of-atmosphere (TOA) level due to the change in the surface albedo

$$RF^{TOA}_{\Delta\propto_s} = -\frac{1}{N} T_a * SW_{\downarrow} * \Delta\alpha_s$$

where:

T_a: the upwelling transmittance derived from estimating thermal radiant fluxes within the environment
$SW_{\downarrow}$: is local incoming solar radiation incident to the surface (W m^{-2})
N: the number of temporal period (i.e. hours/days/years)
$\Delta\alpha_s$: the local change in albedo between two specific surfaces:

$$\Delta\alpha_s = \alpha_{iNEW} - \alpha_{oREF}$$

Understanding each component

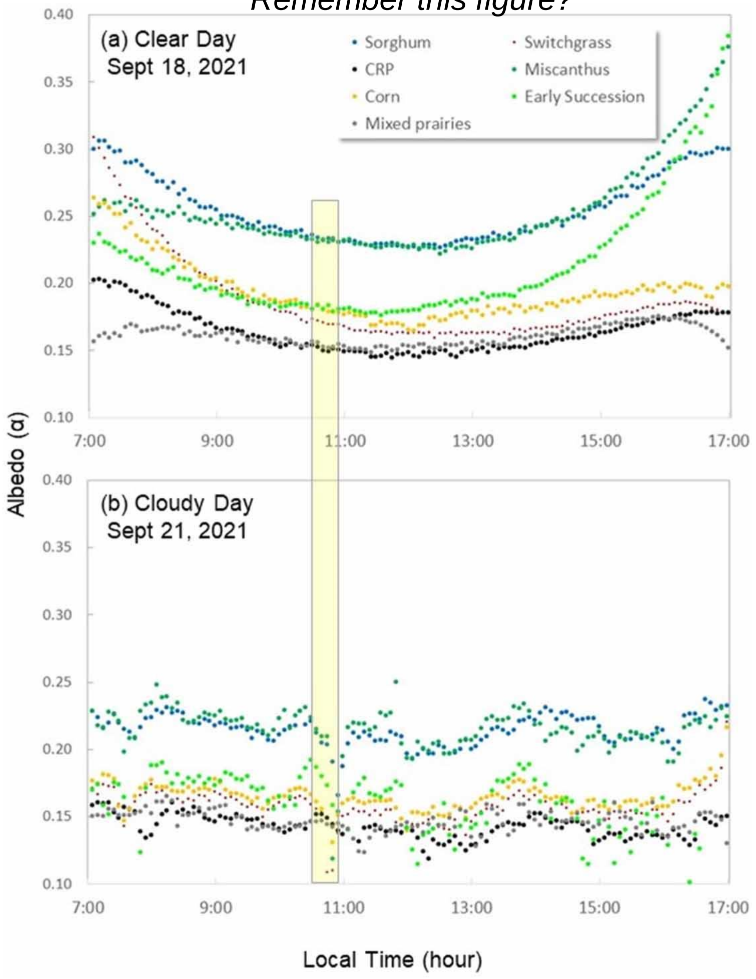
$\boldsymbol{T_a}$: The Upwelling Transmittance

Accepted constant of a clear-day: 0.854 (Lenton and Vaughn, 2009)

- T_a depends on multiple factors:
  - Cloudiness
  - Time of day
  - Solar and zenith angle
  - Latitude

- Manually calculating T_a can reduce error and bias up to 30% of $RF^{TOA}_{\Delta\propto_s}$
  - Manual T_a ranges: 0.475 < T_a > 0.854

Remember this figure?



$T_a = 0.854$

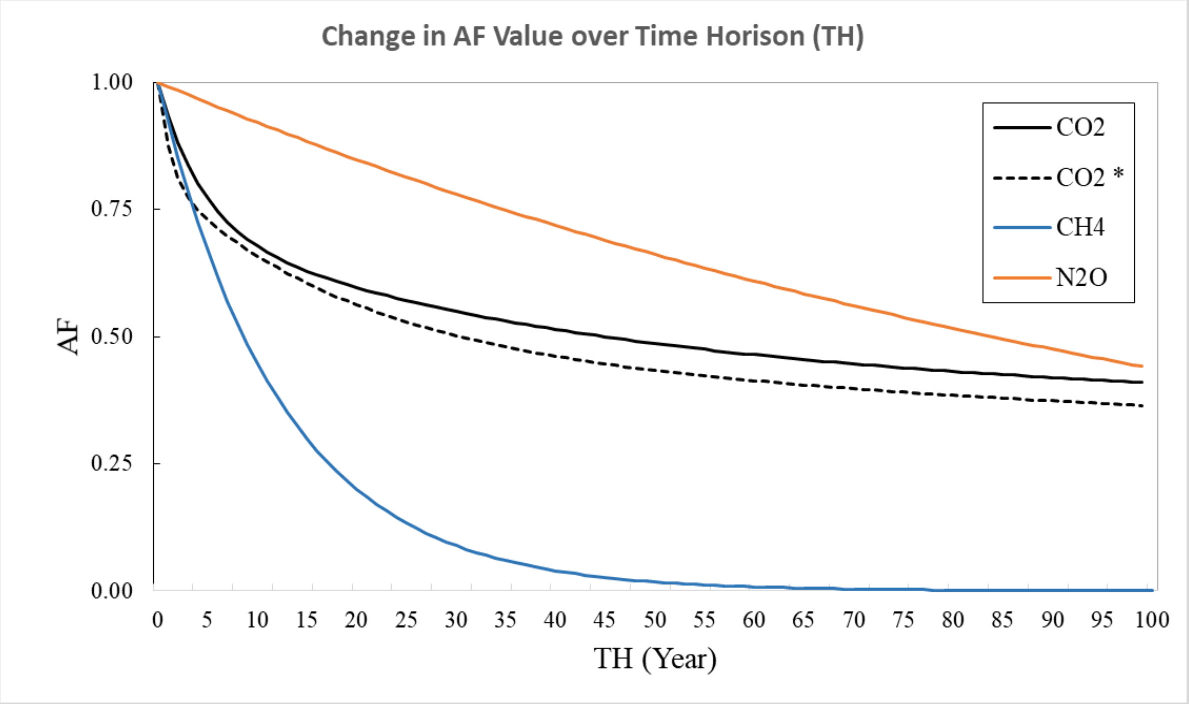
Understanding each component

$$GWP_{\Delta\propto_s} = \frac{S * RF^{TOA}_{\Delta\propto_s}}{AF * RF_{CO_2}} \frac{1}{TH}$$

S: the local *area* subjected to albedo change (m^{-2}).

AF: Airborne Fraction - percentage of emitted CO_2 that remains in the atmosphere after a period of time.

- Value has been disputed by many researchers:
  - 0.53 (Joos et al. 2013)
  - 0.55 (Akbari 2009)
  - 0.52 (Bright et al. 2015)
- *AF* differs for different emissions in the atmosphere:
  - CO_2: 0.52
  - CH_4: 0.13
  - N_2O: 0.68



S: 1 m^{-2}

AF: 0.52

Understanding each component

$$GWP_{\Delta\propto_s} = \frac{S * RF^{TOA}_{\Delta\propto_s}}{AF * RF_{CO_2}} \frac{1}{TH}$$

RF_{CO_2} ($WkgCO_2{}^{-1}$): *Derived radiative forcing from 1 kg of CO_2.*

$$\frac{\ln(2) * pCO_{2ref} * M_{CO_2} * m_{air}}{S_{Earth} * \Delta F_{2X} * M_{air}}$$

where:

pCO_{2ref}: a reference of partial CO_2 pressure in the atmosphere (389ppmv or 0.383 kgg^{-1})

S_{Earth}: the area of the Earth's surface ($5.1*10^{14}$ m^2)

M_{CO_2}: the molecular weight of CO_2 (44.01 $gmol^{-1}$)

m_{air}: the mass of the atmosphere ($5.148*10^{18}$ kg)

ΔF_{2X}: the radiative forcing resulting from a doubling of current CO_2 concentration in the atmosphere (+3.7 Wm^{-2})

M_{air}: the molecular weight of dry air

$RF_{CO_2} = 0.909$ $WkgCO_2{}^{-1}$

Let’s calculate the GWP of an ecosystem

$$GWP_{\Delta\propto_s} = \frac{S * RF^{TOA}_{\Delta\propto_s}}{AF * RF_{CO_2}} \frac{1}{TH}$$

Ex. 3. Find the GWP for CO_2 for a switchgrass (*Panicum virgatum*) site with the following known components: $SW_{\downarrow}$: 478 Wm^{-2} and $SW_{\uparrow}$: 134 Wm^{-2}, when the reference native grasses have a $SW_{\downarrow}$: 482 Wm^{-2} and a $SW_{\uparrow}$: 83 Wm^{-2}.
The T_a of the day is 0.854.

Too much to remember? Never fear!

Modeling global warming potential (GWP) of three major GHGs and albedo for an ecosystem

by assuming different levels of the fluxes for CO_2, CH_4, N_2O and albedo (a)

Jiquan Chen, Cheyenne Lei and Pietro Sciusco

Flux term	CO_2	CH_4	N_2O	Δα (0-1)	Total
μmol CO_2 m^{-2} s^{-1}	0.5500	0.0008	-0.00002	0.11	
g m^{-2} day^{-1}	2.0914	0.0011	-0.0001		
Mg ha^{-2} yr^{-1}	7.6334	0.0040	-0.0003	-9.42	
(replace CO_2 with the corresponding gas for a					
Carbon content (CO_2%)	50	50	50	50	
$Sw_{\downarrow}$ (W m^{-2})				478	
pCO_{2ref} (g kg^{-1})	0.38289	0.00178	0.00032		
M_{CO2} (g mol^{-1})	44.01	16.04	44.013		
Lifetime (yr)	12.1	12.4	121		
ΔF_{2x} (W m^{-2})	3.7	0.48	0.15		
Re_x (W m^{-2} ppb^{-1})	1.37E-05	3.63E-04	3.00E-03		
TH (20, 100, 500 years)	100	100	100	100	
m_{air} (kg)	5.15E+18	5.15E+18	5.15E+18	5.15E+18	
M_{air} (g mol^{-1})	28.95	28.95	28.95	28.95	
S_{earth} (m^2)	5.10E+14	5.10E+14	5.10E+14	5.10E+14	
S (m^2)	1.00	1.00	1.00	1.00	
N (days)	365	365	365	365	
AF_x (TH = 100)	0.52	0.13	0.68		
Ta (0-1)				0.854	
AGWP	9.35E-14	2.61E-12	2.43E-11		
ΔRFTOA	-8.805E-14	-8.805E-14	-8.8046E-14		
RF (W gCO_2^{-1})	1101			6180	
RF (W $kgCO_2^{-1}$)	0.909			0.1618	
GWP CO_2eq (kg m^{-2} yr^{-1})	-0.9417	-0.0337	-0.0036		
GWP ref CO_2eq (kg m^{-2} yr^{-1})	1.00	28.48	264.86		
CO_2eq (kg ha^{-1} d^{-1})	20.9136	0.3157	-0.2014	-25.7991	
CO_2eq (Mg ha^{-1} yr^{-1})	7.6334	0.1152	-0.0735	-9.4167	
Carbon-eq (Mg ha^{-1} yr^{-1})	2.0839	0.0315	-0.0201	-2.5707	
Biomass-eq (Mg ha^{-1} yr^{-1})	4.1679	0.0629	-0.0401	-5.1415	**9.3321**
Comoposition (%)	**-44.66**	**-0.67**	**0.43**	**55.09**	**100.0**

corresponding gas for a

2.0167

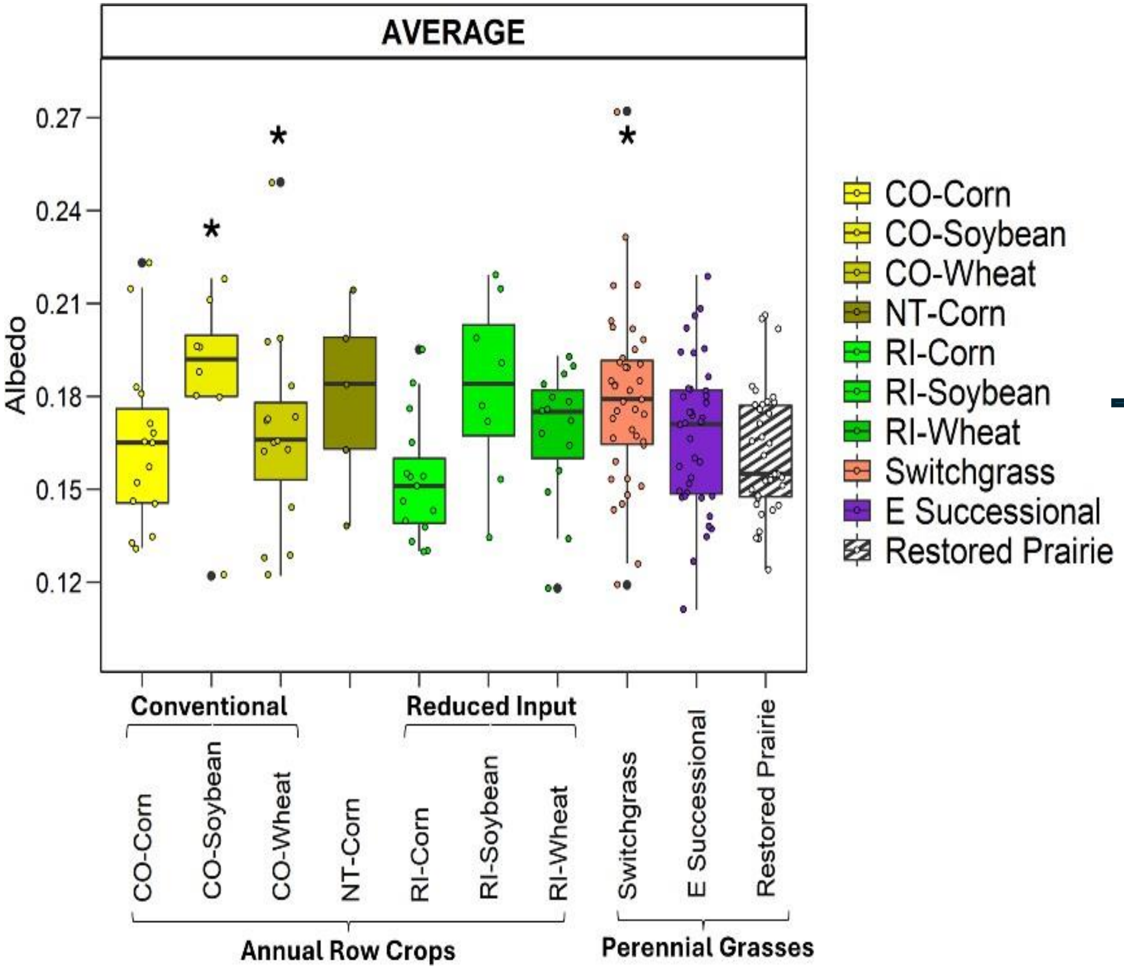
Application Notes: the variables highlighted in blue should be provided by the user

1) Flux level of each GWP species (colored in blue) in Line 6 should be provided by a user based on in situ data;
2) Incoming radiation (SW↓) varies by day of year (DOY), latitude and sky conditions. This value should also be provided based on actual measurements;
3) Values in Lines 11-26 are parameters for AGWP and GWP calculations. The values are based on IPCC report (AR5 2013), or the literature;
4) Values in Lines 29-27 are calculated from Eqs. 5.4 - 5.13;
5) Values for GWP_{CH4} and GWP_{N2O} at line 32 are obtained following the equations 8.SM.19 and 8.SM.20 of the WGI AR5 supplementary material (IPCC 2013)
6) Values in Lines 34-35 are conversions for different unit;
7) The negative sign in Linese 32-35 indicate GWP offset (i.e., a cooling effect), whearas a positive sign indicates a warming effect.

Any questions?

LAND USE AND ALBEDO

What does this mean for a changing landscape?

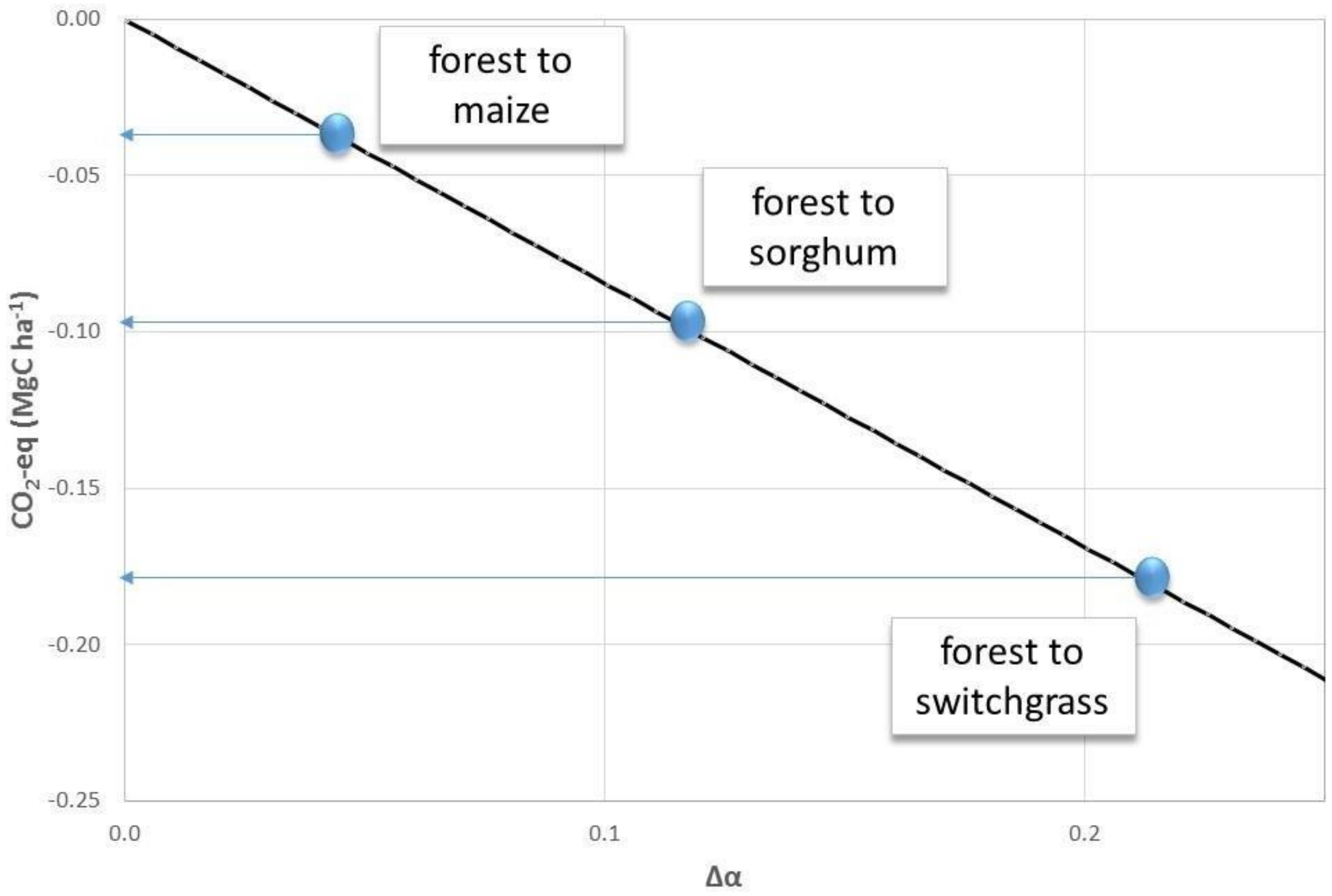


		Chlorophyll		ΔRFTOA	GWI CO_2e
Crop	Albedo	Content	Δα	10^{-14} Wm^{-2}	Kg CO_2 m^{-2}
CSW-Conventional Corn	0.168 (±0.06)	43.76 (±12.46)	0.016	−2.02	−0.220
CSW-Conventional Soybean	0.186 (±0.03)	39.45 (±6.20)	0.034	−4.38	−0.478
CSW-Conventional Wheat	0.165 (±0.04)	22.92 (±12.02)	0.012	−1.62	−0.176
CSW-No-Till Corn	0.179 (±0.03)	41.00 (±8.31)	0.027	−3.47	−0.379
CSW-Reduced Input Corn	0.154 (±0.02)	43.36 (±13.03)	0.001	−0.12	−0.013
CSW-Reduced Input Soybean	0.182 (±0.03)	40.84 (±6.37)	0.030	−3.86	−0.421
CSW-Reduced Input Wheat	0.169 (±0.03)	27.85 (±14.63)	0.016	−2.13	−0.232
Switchgrass	0.179 (±0.04)	33.40 (±5.84)	0.026	−3.37	−0.367
E Successional	0.170 (±0.04)	28.72 (±5.94)	0.018	−2.30	−0.251
Restored Prairie	0.162 (±0.03)	33.07 (±8.45)	0.010	−1.23	−0.135
Reference (Bareground)	0.153 (±0.03)	—	—	—	—
Average	**0.171 (±0.03)**	**35.44 (±9.33)**	**0.019**	**-2.43×10^{-14}**	**−0.265**

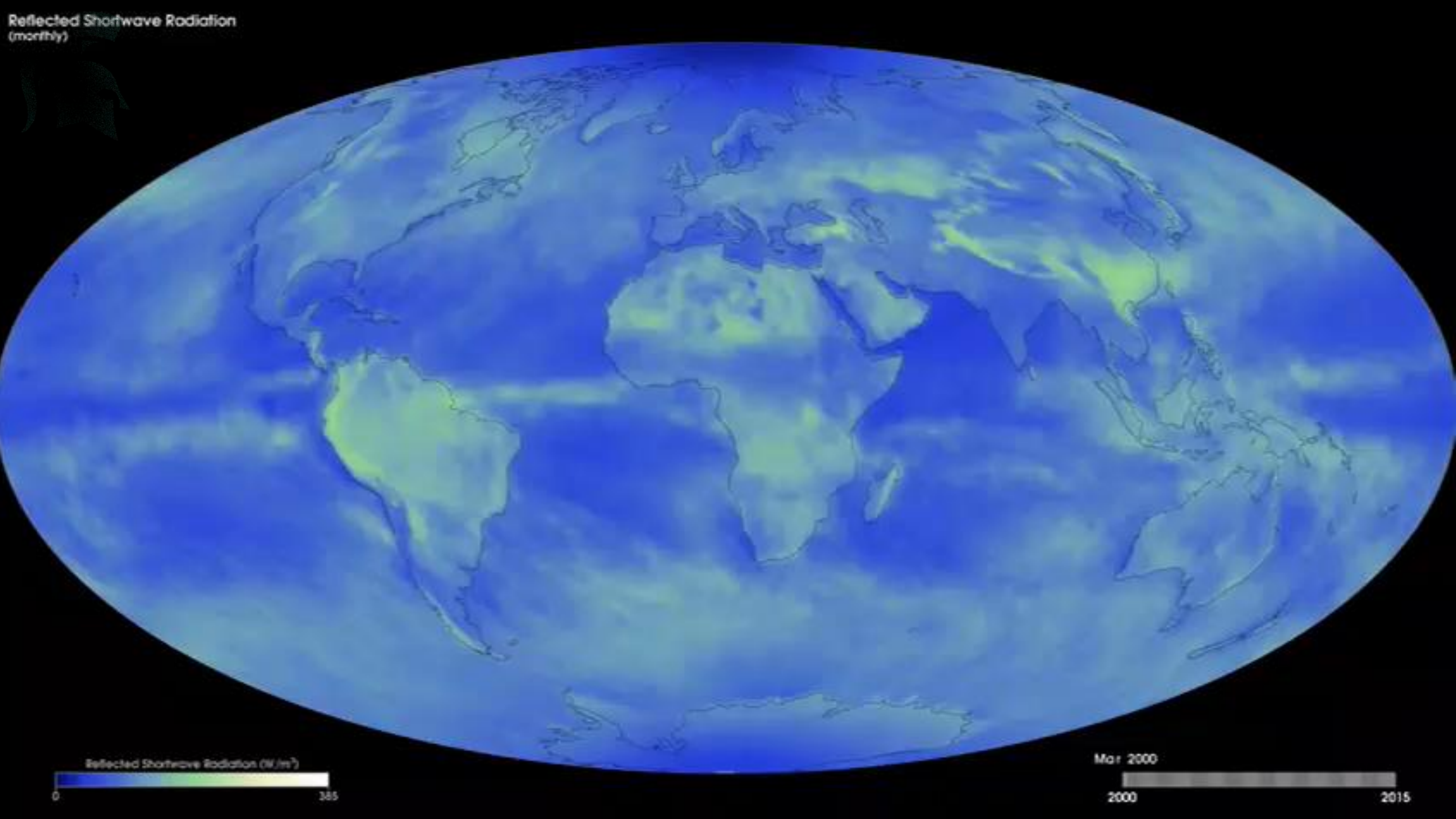
Annual average albedo suggesting potential cooling of the localized climate due to a conversion of bare ground landscape (reference) to another candidate crop.
Lei et al., 2024

What does this mean for a changing landscape?

Notice any differences in magnitude if we change our reference landscape?



Chen 2021. Applications of Biophysical Models in Ecosystem Studies.


Reflected Shortwave Radiation
(monthly)
Reflected Shortwave Radiation (W/m²)
0
385
Mar 2000
2000
2015

Received: 13 February 2023 | Revised: 26 July 2023 | Accepted: 17 August 2023
DOI: 10.1111/gcbb.13098

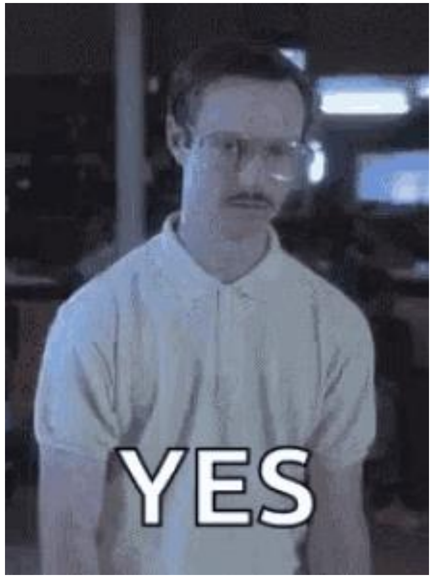
RESEARCH ARTICLE

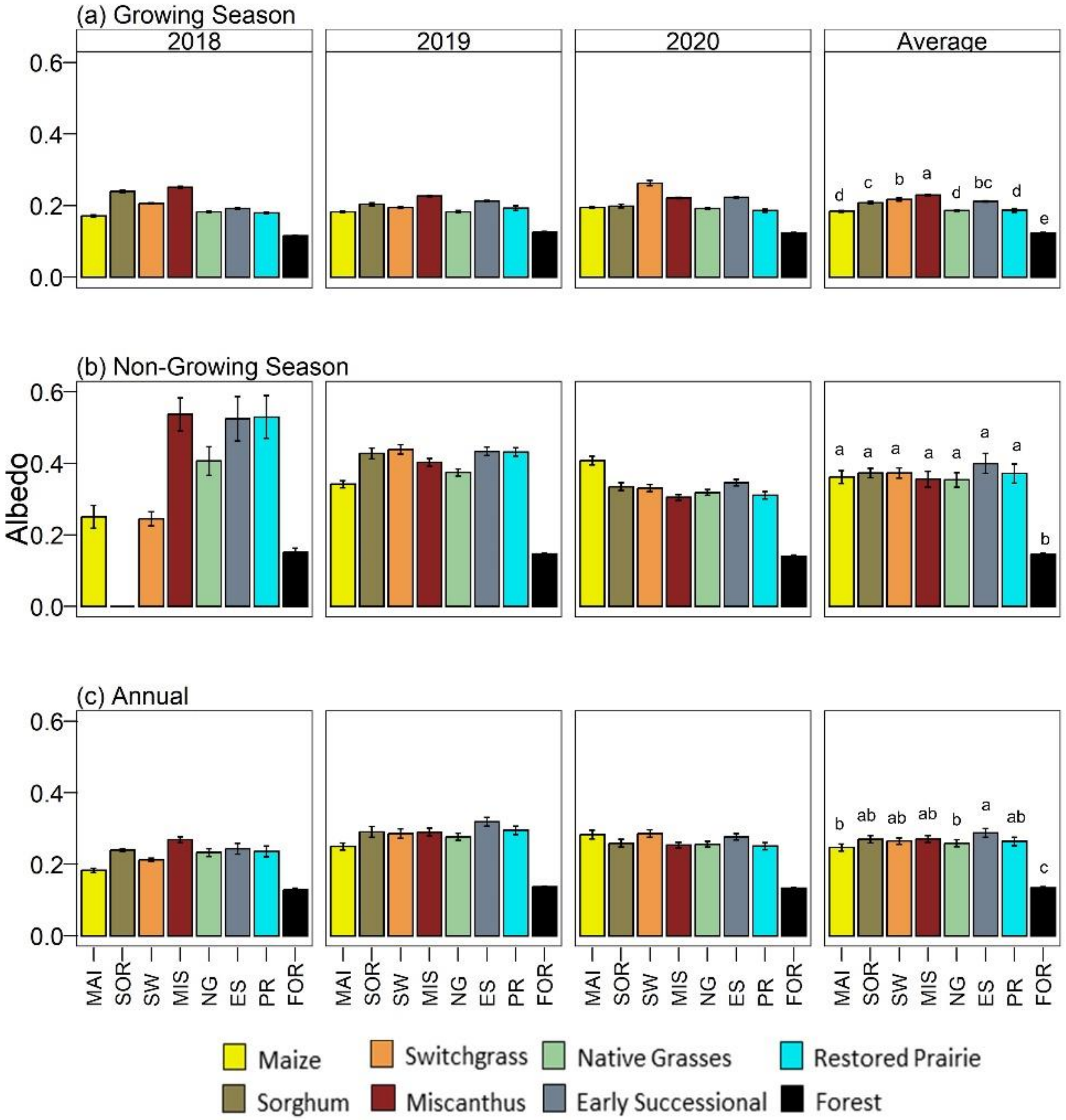
GCB-BIOENERGY WILEY

Climate cooling benefits of cellulosic bioenergy crops from elevated albedo

Cheyenne Lei[1,2,3] | Jiquan Chen[1,2,4] | G. Philip Robertson[1,4,5]

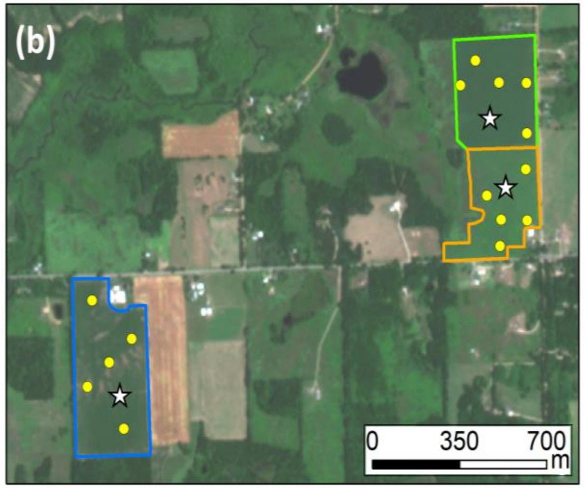
Differences between landscapes during the growing season and annually were statistically significant (p ≤ 0.05)

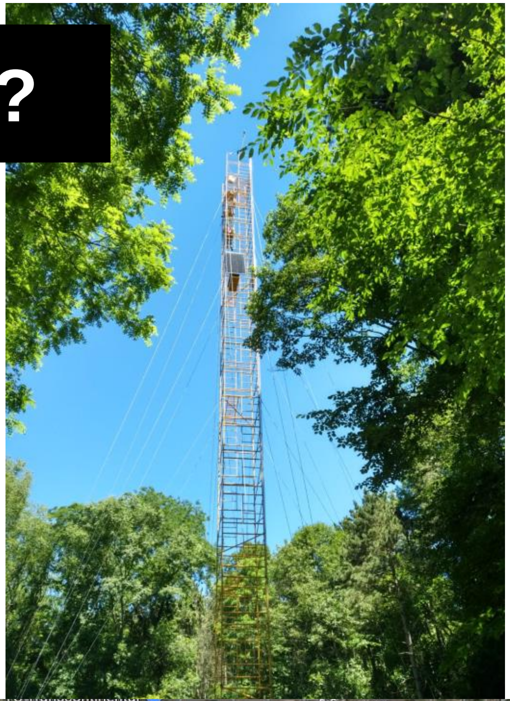


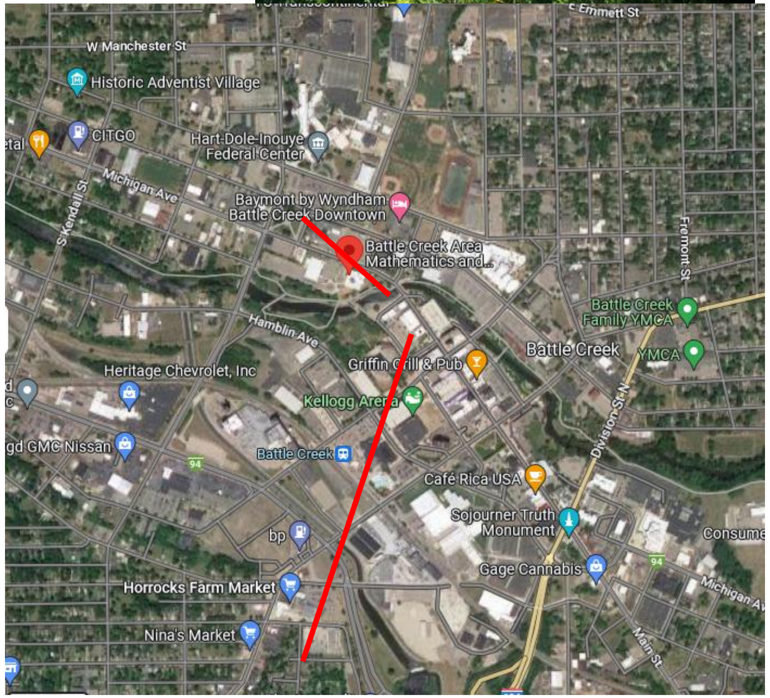


Mean albedo of the growing season (GS) (a), non-growing season (NGS) (b), and the entire year (c) for the seven crop types: including a reference forest at KEF.

What does this mean for a changing landscape?







What does this mean for a changing landscape?

Mapping out a 5-year agricultural cropping rotation:

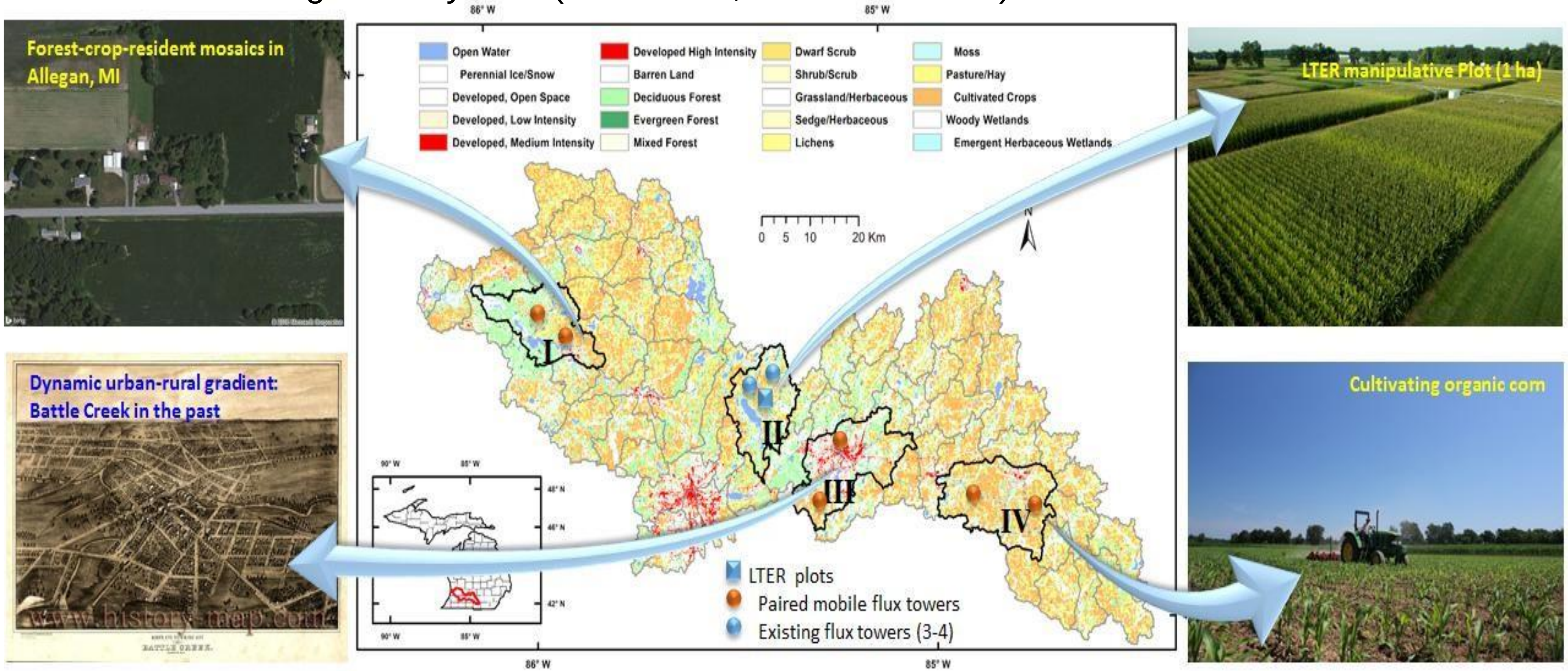
- Seven major cropping ecosystems:
  - Row crops, native grasses, genetically modified crops
- Annual vs Perennial:
  - Corn, Soybeans
  - Restored Prairie, Native Grasses, Miscanthus, Switchgrass
- Agronomic Management:
  - Fertilization vs non-fertilization
  - Stover reside vs non-stover residue

Biofuel Cropping System Experiment – Changes in farmer input and agronomic management on surface reflectivity

What does this mean for a changing landscape?

Current land cover of the Kalamazoo watershed, which includes 127 sub-watersheds. The watershed was examined

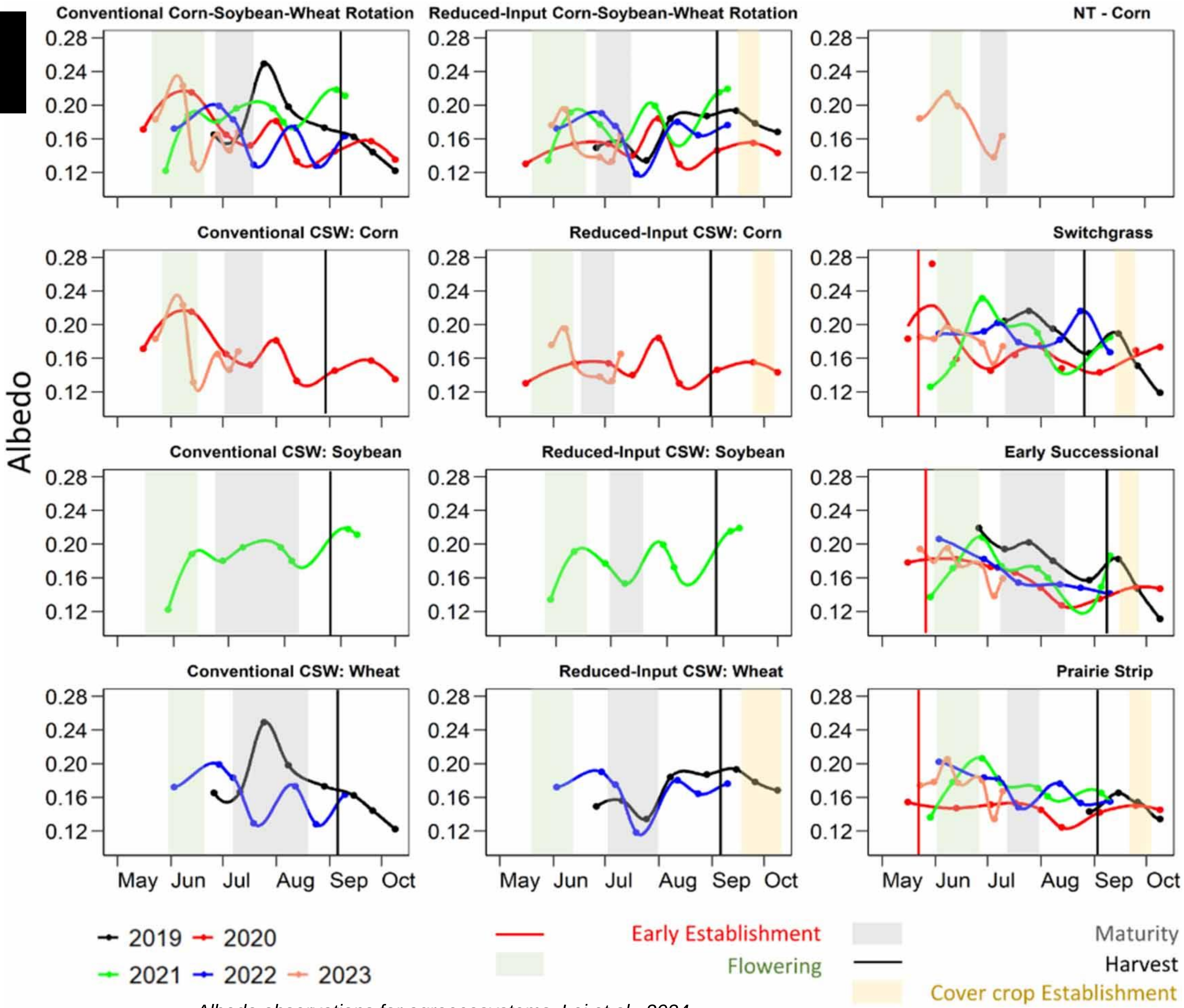
- Using Landsat/Sentinel data
- For changes of CO_2 during a 40-year period (1978–2018)
- Including ancillary data (i.e. climate, human activities)



One final example

Albedo observations with colored vertical lines and boxes indicating regions of:

- Early establishment differences between crops (red)
- Flowering stage between perennials and annual row crops (green)
- Maturity phase where crop canopies are homogenous (grey)
- Harvest (black)
- Cover crop establishment (yellow)



Albedo observations for agroecosystems. Lei et al., 2024

Wrapping up

Albedo is the ratio of change in solar radiation reflected to that which comes from the sun onto the earth surface.

Albedo in agriculture can be affected by multiple parameters including:

- Planting of different crop species
- Harvest and planting at different times during the year
- Cover cropping
- Fertilization and irrigation
- Sunlight, clouds and atmospheric conditions

This leads to varying cumulative effects of seasonality and agronomic management on albedo in terrestrial ecosystems.

These factors can feed into the magnitude of radiative forcing

- to determine how much energy from the sun is being absorbed or reflected from a landscape through climate modelling such as GWP.

Subsequently, these effects can influence the global warming potential of a system, and the warming/cooling of the atmosphere.

Any questions?

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