



Photo: J. Verfaillie

## 06 Short-wave reflection and albedo

# Learning objectives

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- Describe how we can quantify and model the short-wave spectral properties of a surface.
- Explain how a surface's reflectivity is affected by surface geometry.
- Understand how the sun's position relative to an object affects reflectivity.

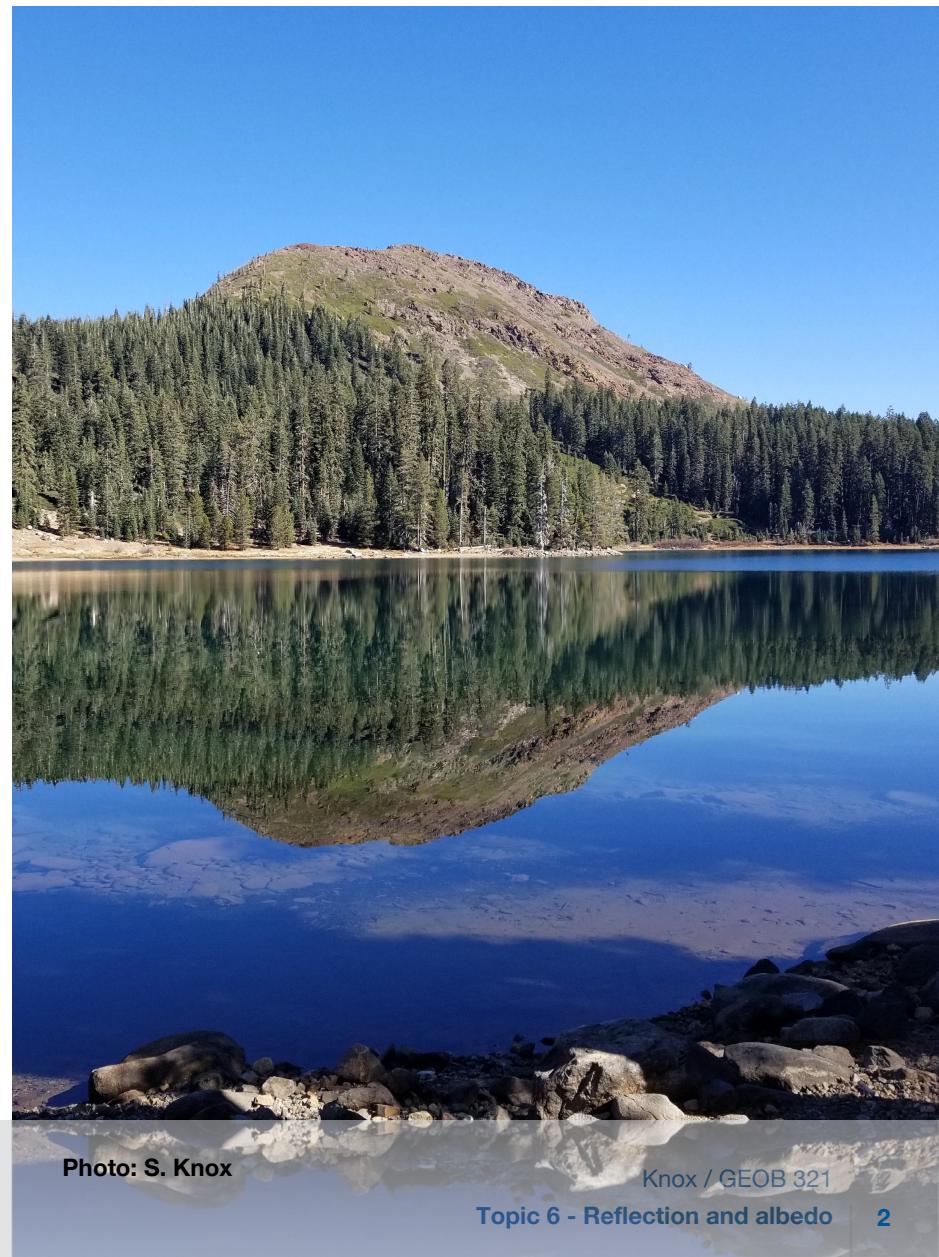


Photo: S. Knox

Knox / GEOB 321

Topic 6 - Reflection and albedo

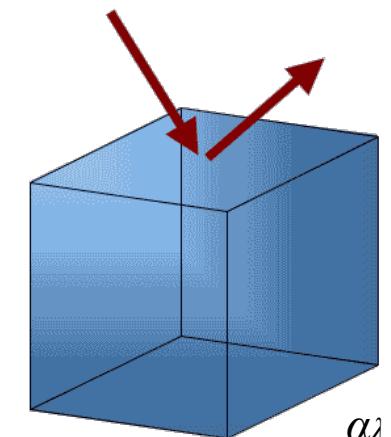
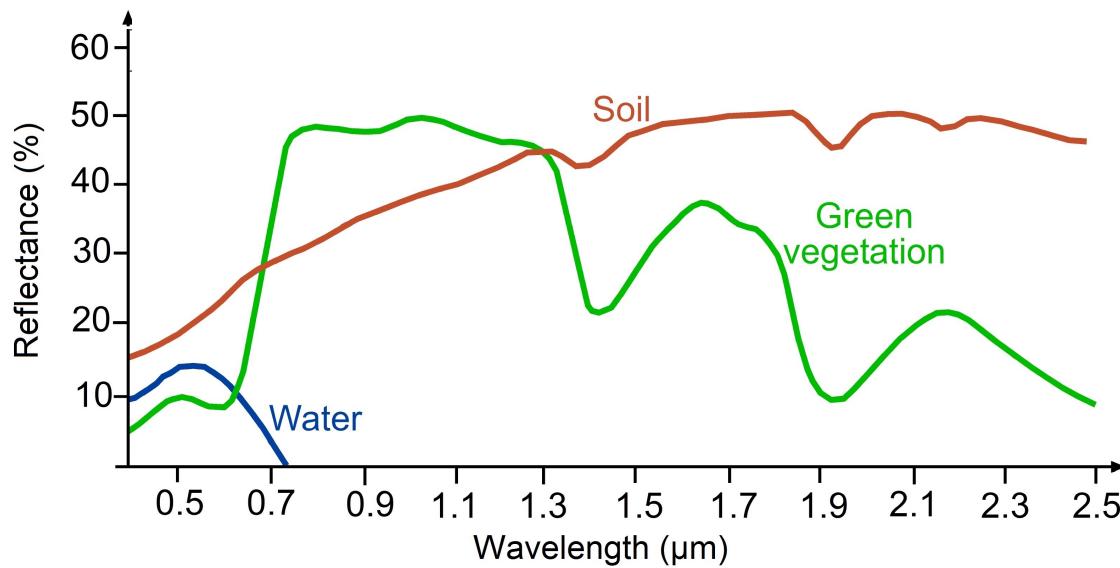
# Reflectivity and reflection coefficient

## Spectral reflectivity

$$\alpha_\lambda = \frac{\text{radiation reflected}}{\text{radiation incident}}$$



Spectral reflectivity  $\alpha_\lambda$  relates to a **single** wavelength.



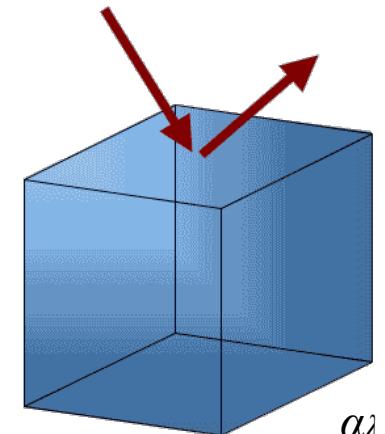
Source: <http://www.seos-project.eu/modules/classification/classification-c01-p05.html>

# Reflectivity and reflection coefficient

## Spectral reflectivity

$$\alpha_\lambda = \frac{\text{radiation reflected}}{\text{radiation incident}} \quad \star$$

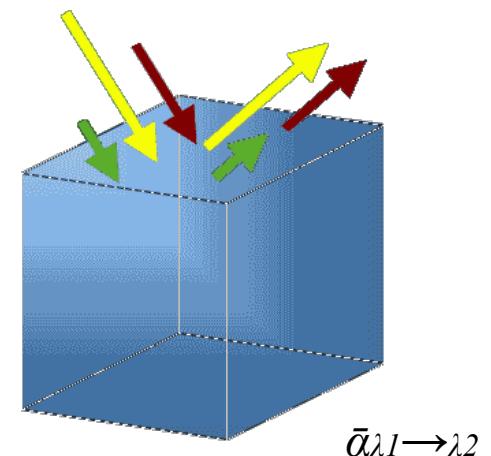
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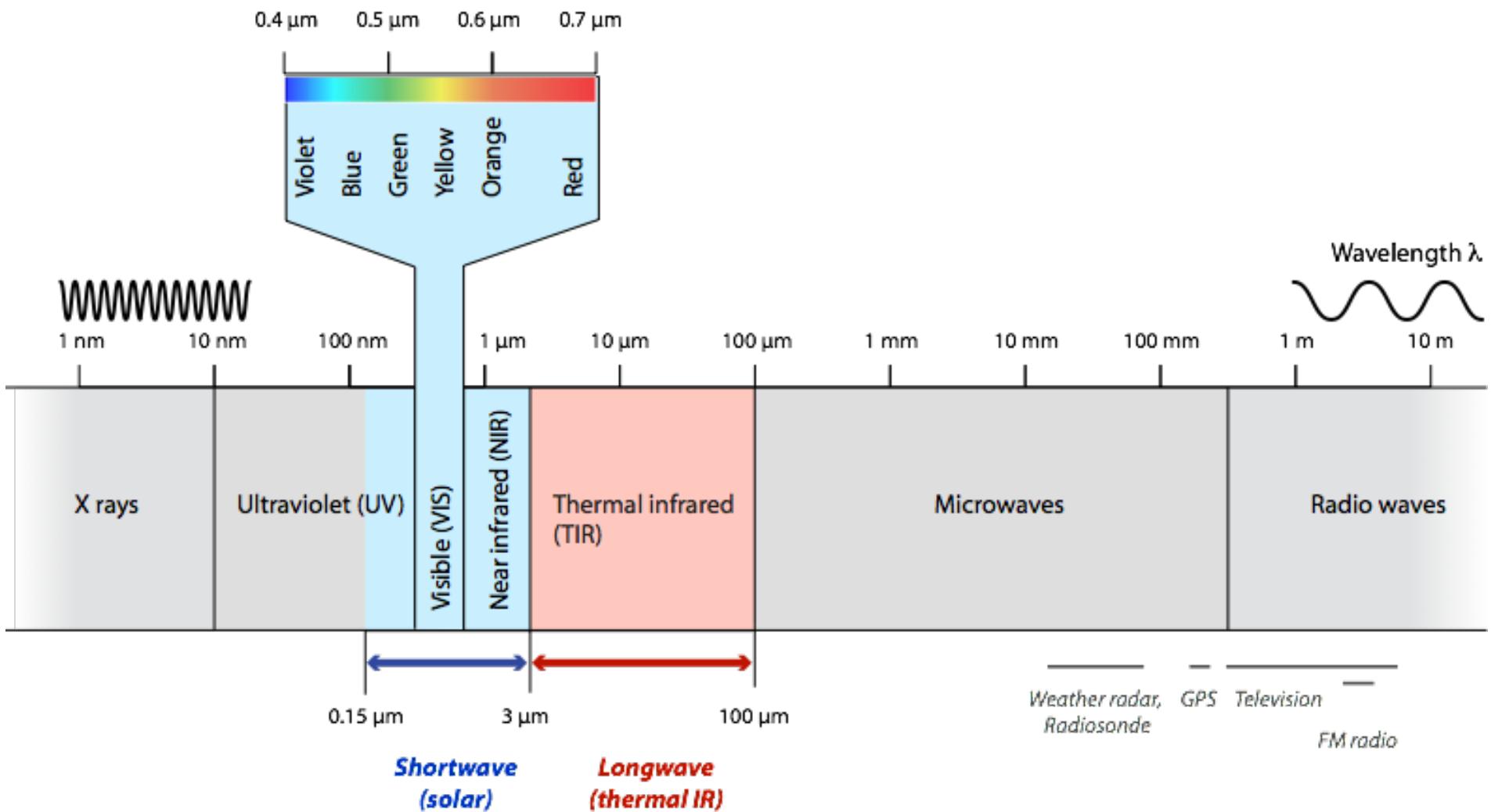
**Reflection coefficient** – Average reflectivity from  $\lambda_1 \rightarrow \lambda_2$  weighted by distribution of incoming radiation in the same waveband:

$$\bar{\alpha}_{\lambda_1 \rightarrow \lambda_2} = \frac{\int_{\lambda_1}^{\lambda_2} \alpha_\lambda I_\lambda d\lambda}{\int_{\lambda_1}^{\lambda_2} I_\lambda d\lambda}$$

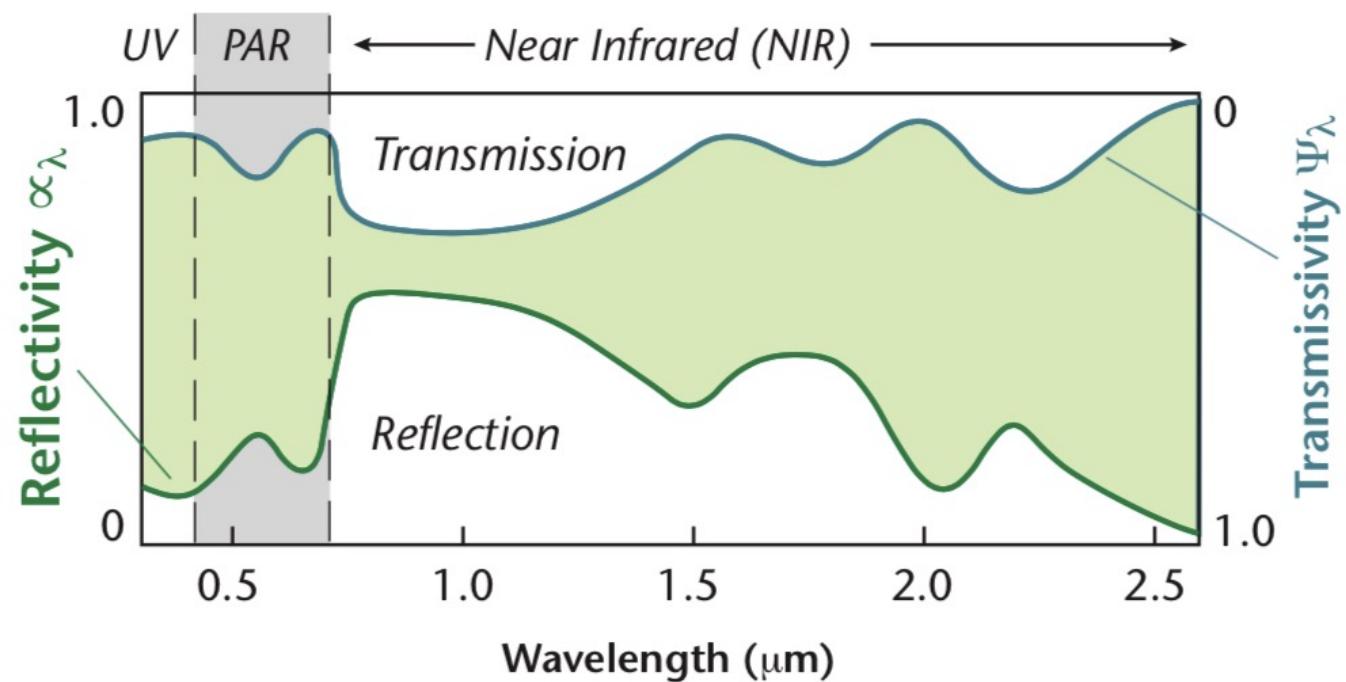
when  $\lambda_1 \rightarrow \lambda_2$  refers to the whole solar band (0.15 to 3  $\mu\text{m}$ )  
 $\bar{\alpha}_{\lambda_1 \rightarrow \lambda_2} = \bar{\alpha}_\lambda$  is called **surface albedo**  $\alpha$ .



# The electromagnetic spectrum



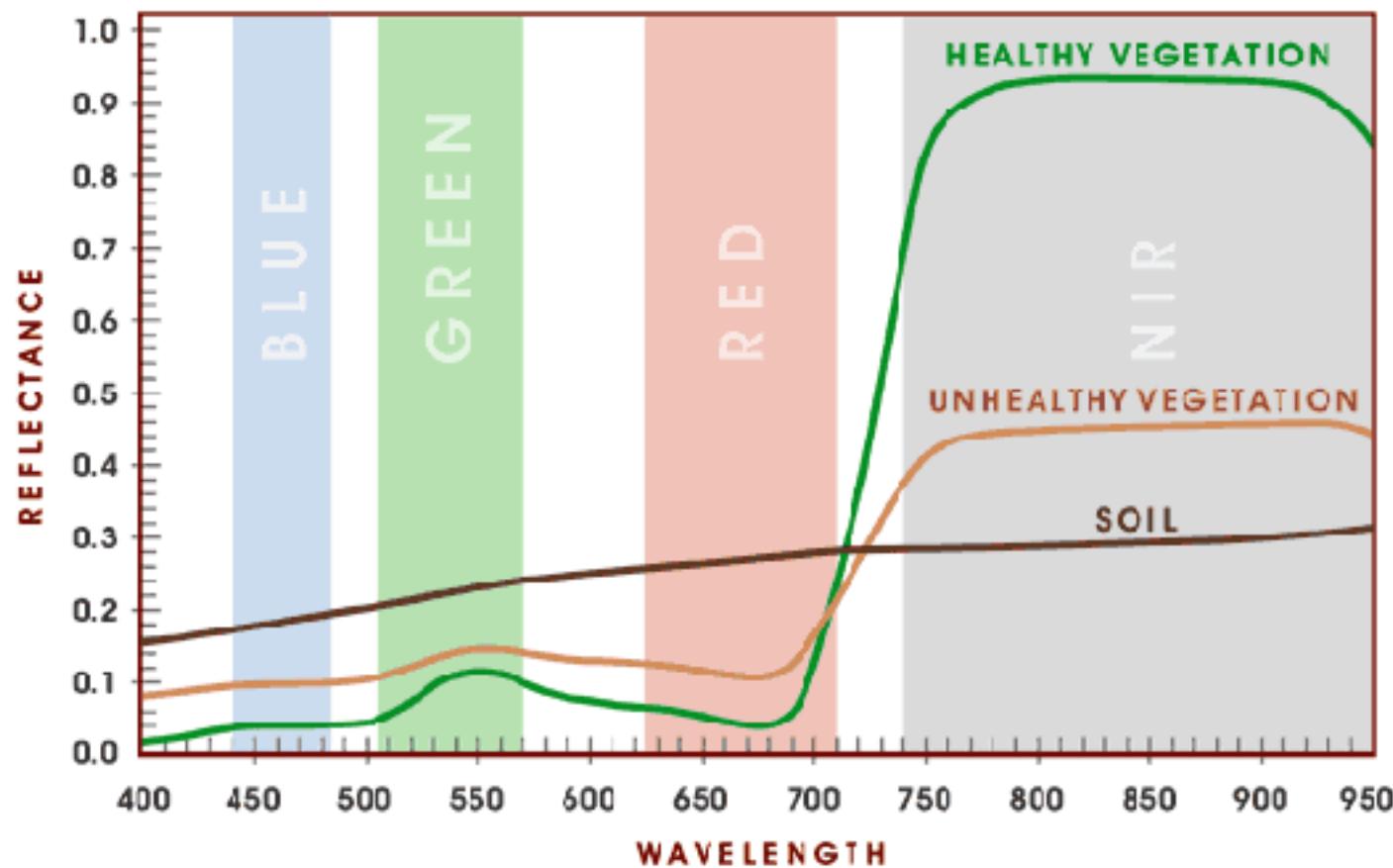
# Spectral reflectivity of a leaf



What does the green area represent?

# Spectral reflectivity of healthy vs. unhealthy vegetation

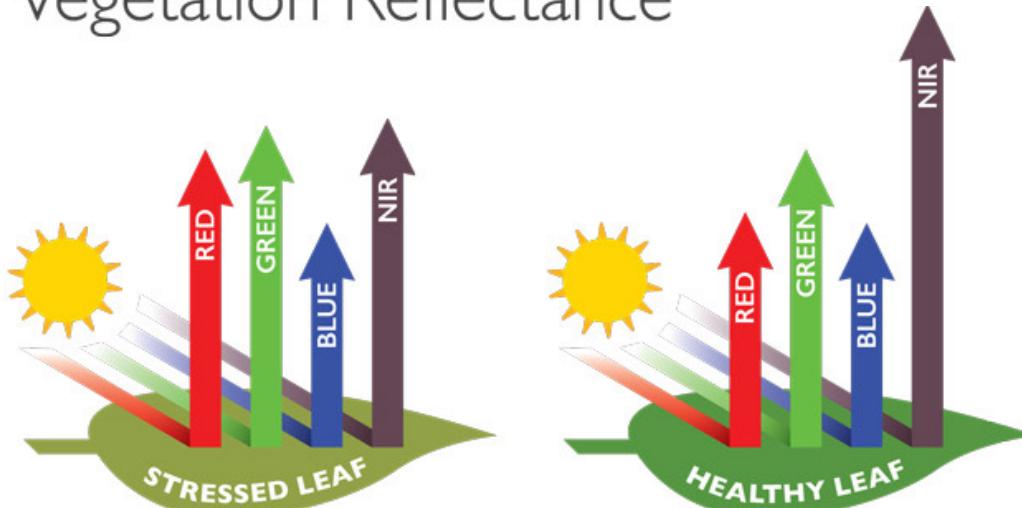
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Source: <http://physicsopenlab.org/2017/01/30/ndvi-index/>

# Measuring vegetation health - normalized difference vegetation index

Vegetation Reflectance



**HEALTHY**  
VEGETATION REFLECTANCE

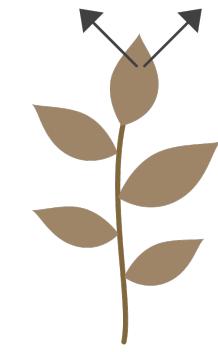
50% NIR    8% RED



**NDVI =**

**STRESSED**  
VEGETATION REFLECTANCE

40% NIR    30% RED



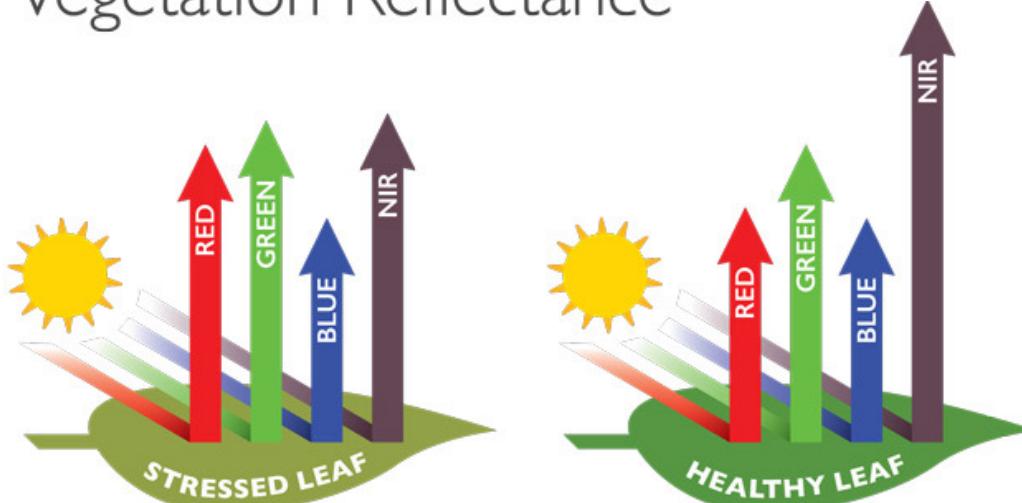
**NDVI =**

$$\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}}$$

Source: <https://www.agricolus.com/en/indici-vegetazione-ndvi-ndmi-istruzioni-luso/>

# Measuring vegetation health - normalized difference vegetation index

Vegetation Reflectance



**HEALTHY**  
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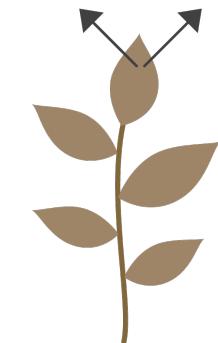
50% NIR    8% RED



$$\text{NDVI} = 0.72$$

**STRESSED**  
VEGETATION REFLECTANCE

40% NIR    30% RED



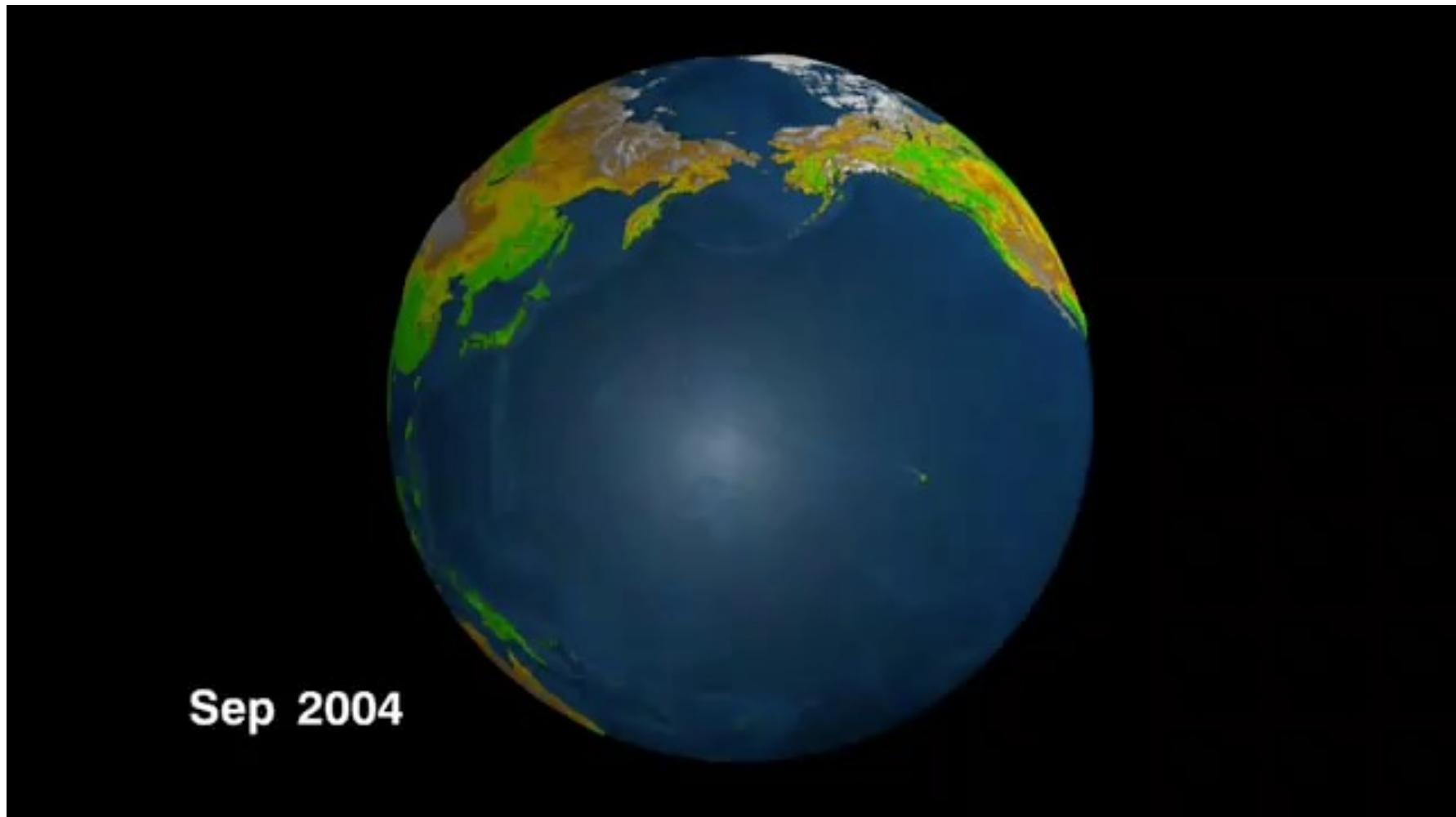
$$\text{NDVI} = 0.14$$

$$\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}}$$

Source: <https://www.agricolus.com/en/indici-vegetazione-ndvi-ndmi-istruzioni-luso/>

# NDVI at the global scale

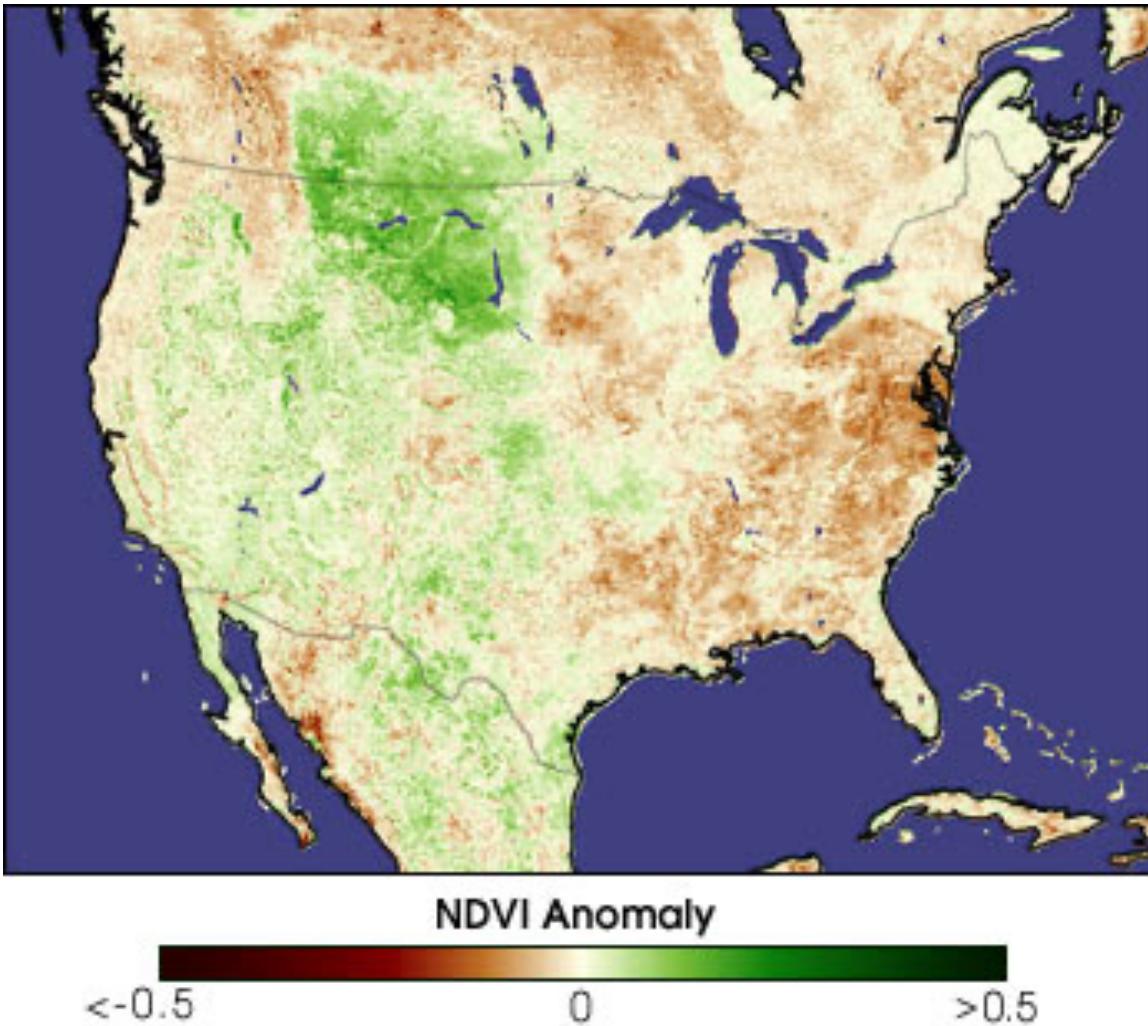
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Source: <https://svs.gsfc.nasa.gov/3584>

# NDVI as an indicator of drought

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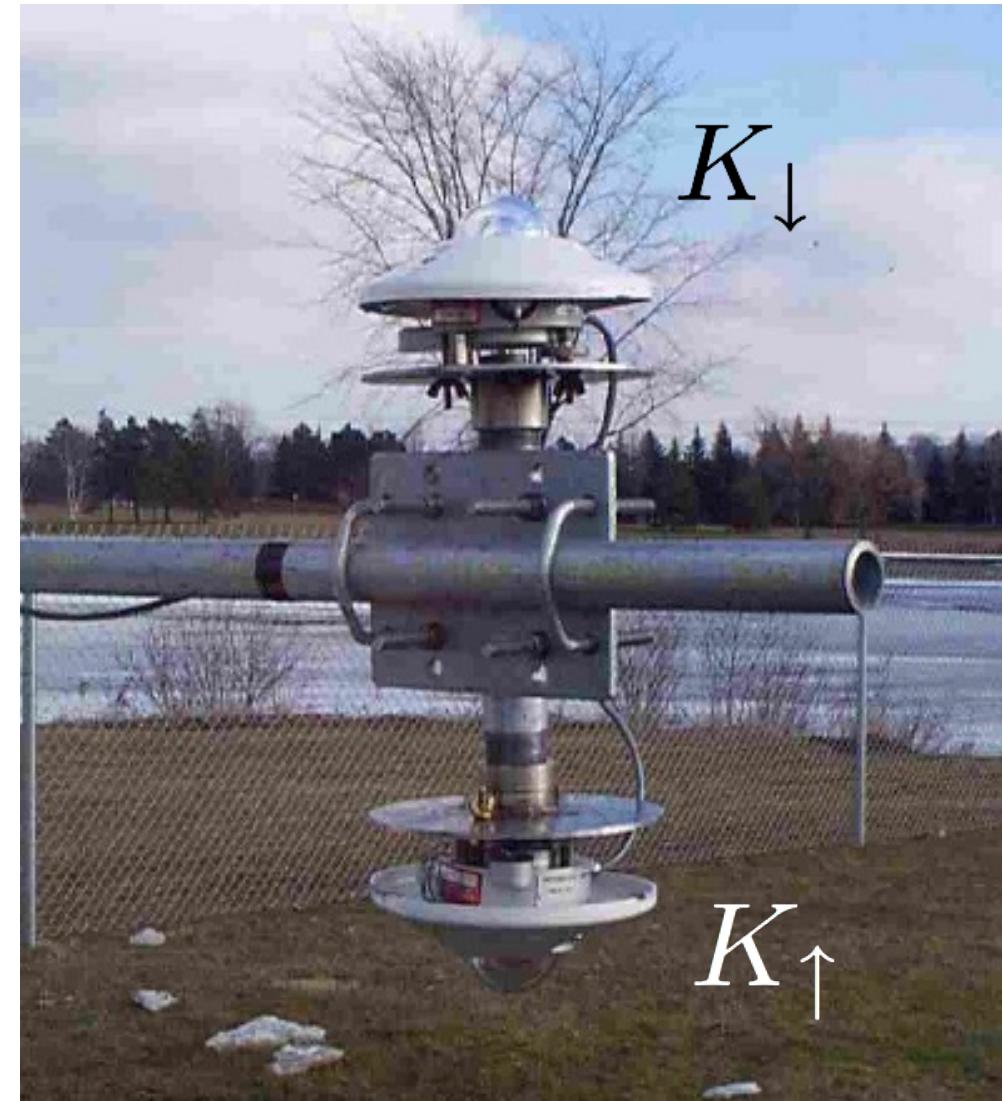
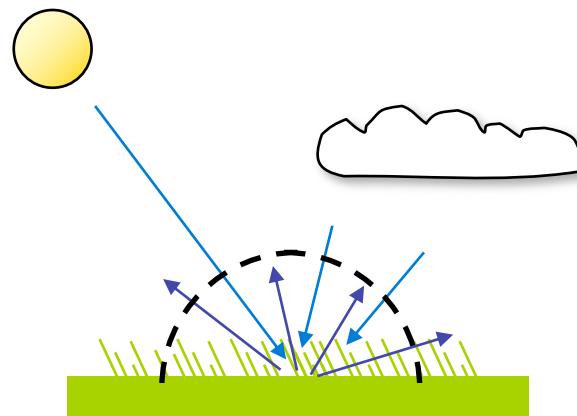


Source:  
[https://earthobservatory.nasa.gov/features/MeasuringVegetation/measuring\\_vegetation\\_3.php](https://earthobservatory.nasa.gov/features/MeasuringVegetation/measuring_vegetation_3.php)

# Review: Albedo

The albedo  $\alpha$  can be simply measured as the fraction of incident solar radiation reflected by a surface.

$$\alpha = \frac{K_{\uparrow}}{K_{\downarrow}} \quad \star$$



# Albedo

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Albedo is a very significant surface variable to microclimate because it controls the absorption of the main source of energy by day.

Albedo has a strong influence on the climate system. Adjacent surfaces receive the same amount of  $K_{\downarrow}$  but the impact is determined by  $\alpha$ .

Surface	$\alpha$
Fresh snow	
Old snow	
Short grass	
Crops	
Deciduous Forests	
Coniferous Forests	
Water *	

Shown are typical values. Individual values vary widely.  
\* for small zenith angles  $Z$  only.

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Surface	$\alpha$
Fresh snow	0.95
Old snow	0.4
Short grass	0.25
Crops	0.2
Deciduous Forests	0.2
Coniferous Forests	0.1
Water *	0.05

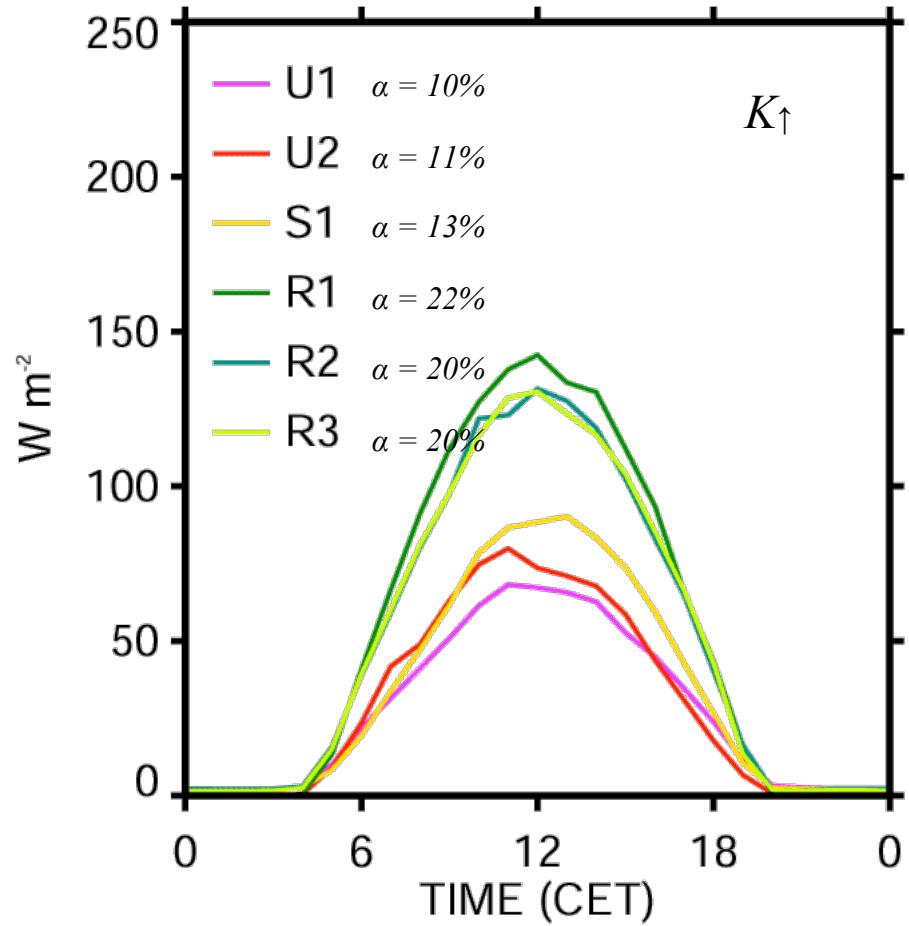
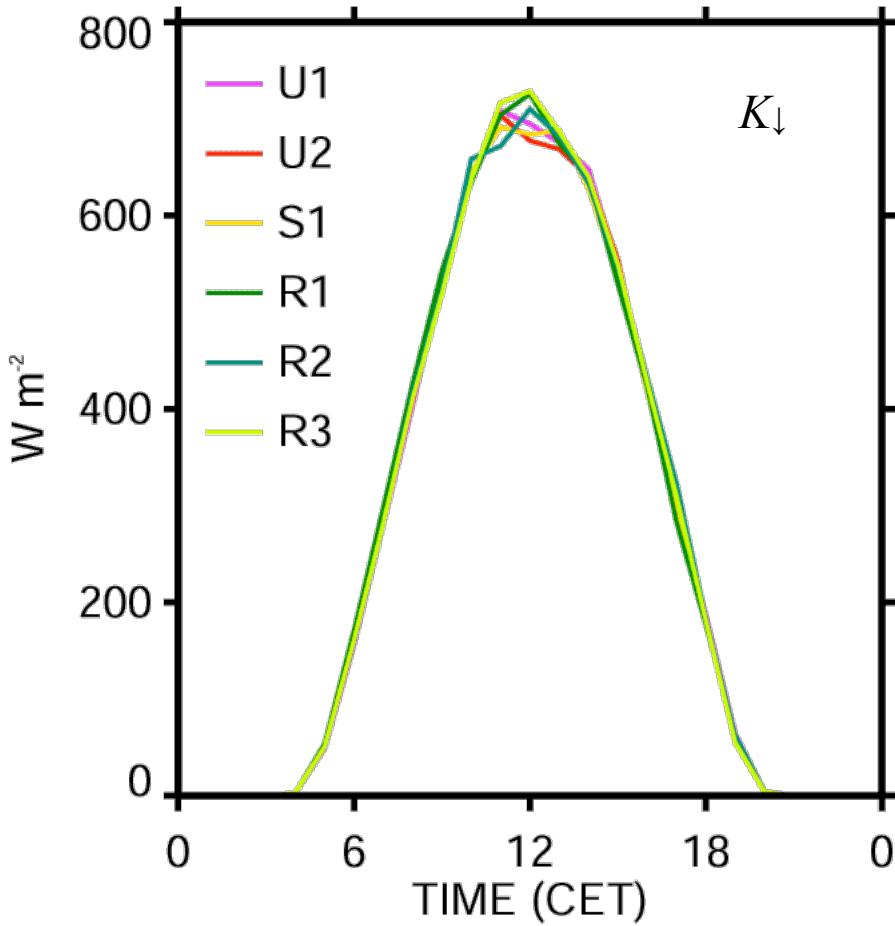
Shown are typical values. Individual values vary widely.  
\* for small zenith angles  $Z$  only.

# Albedo - globally



Source: <https://www.youtube.com/watch?v=O0B8Yi7AZvQ>

# Shortwave reflection creates energetic differences



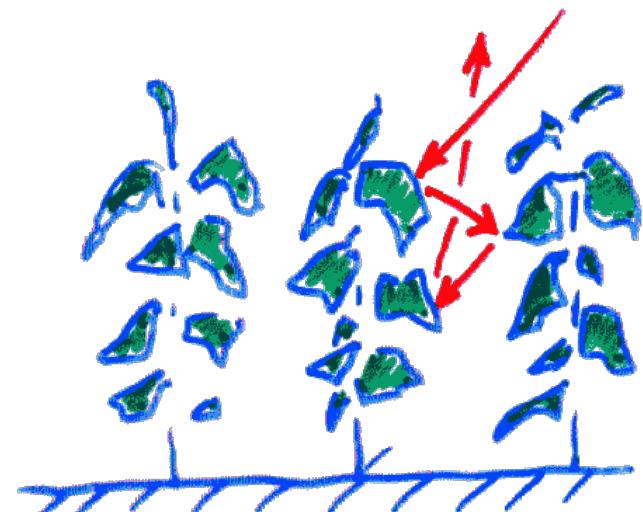
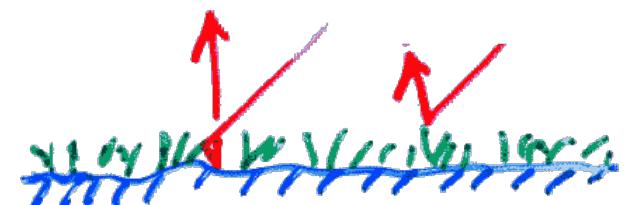
U = urban, S = suburban, R = rural (grass, crops)

# Albedo and stand height

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Albedo depends on stand height:

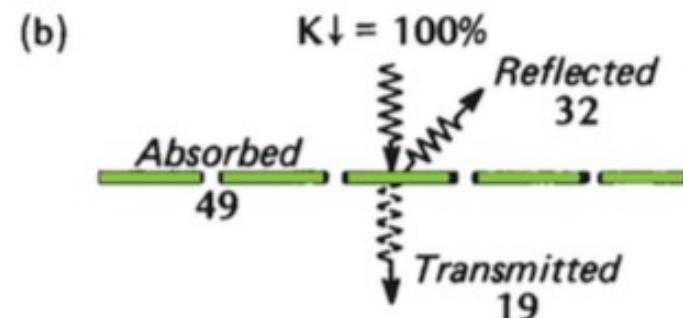
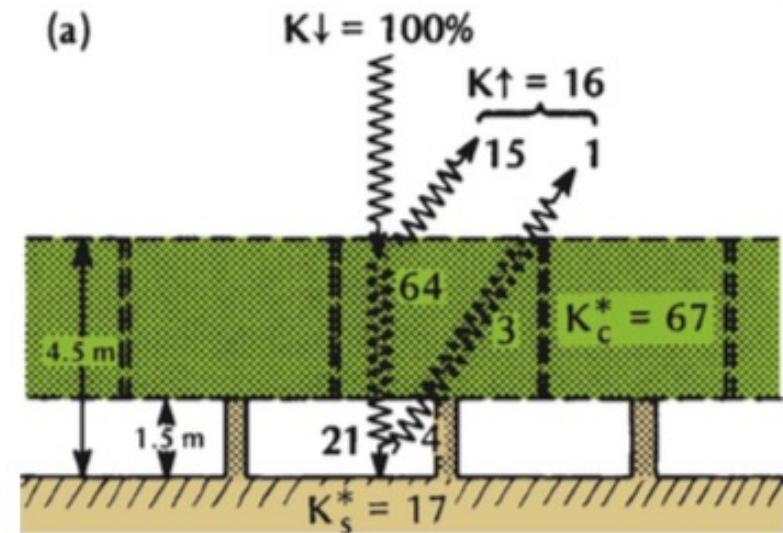
- Increased “trapping” of solar radiation with increased height (multiple reflections)
- Individual leaves generally have higher reflectivity than a canopy of the same leaves.



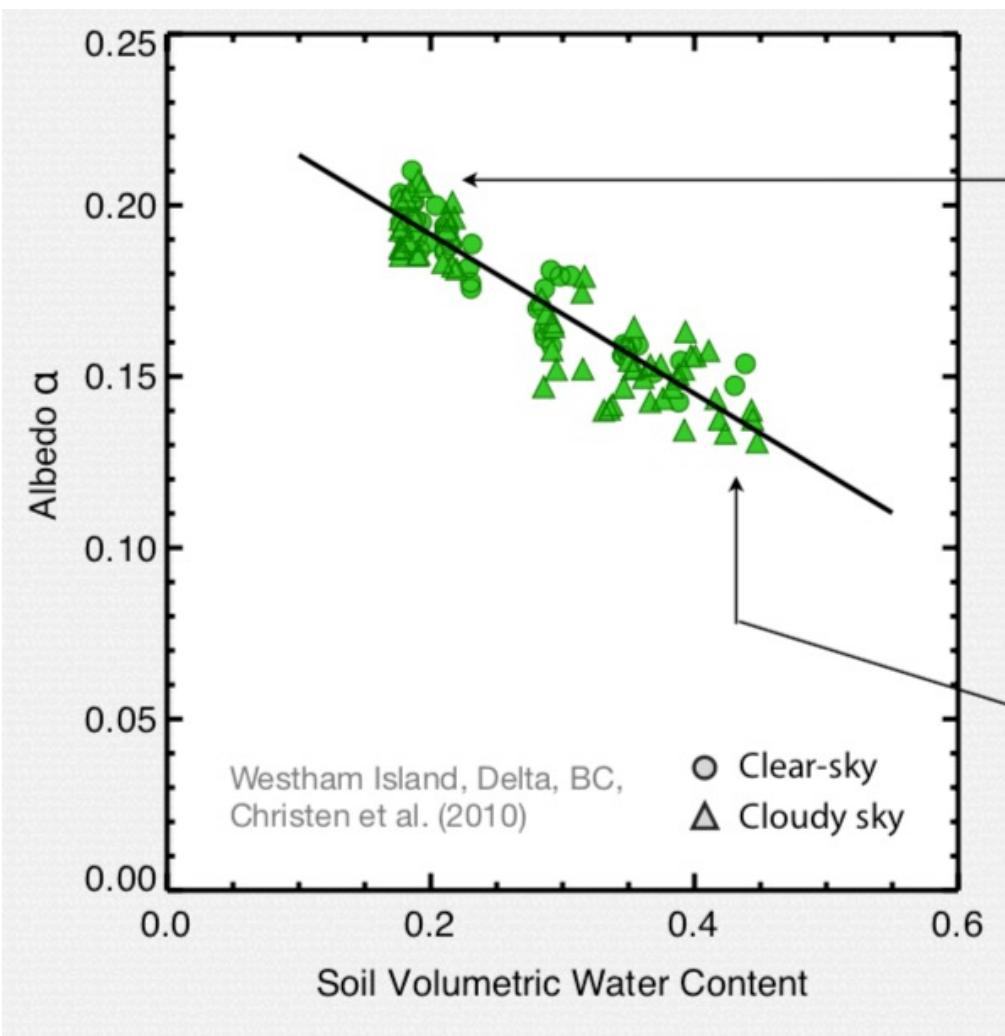
# Albedo and stand height

Albedo depends on stand height:

- Increased “trapping” of solar radiation with increased height (multiple reflections)
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# Albedo depends on leaf state and canopy height



# Monthly average albedo

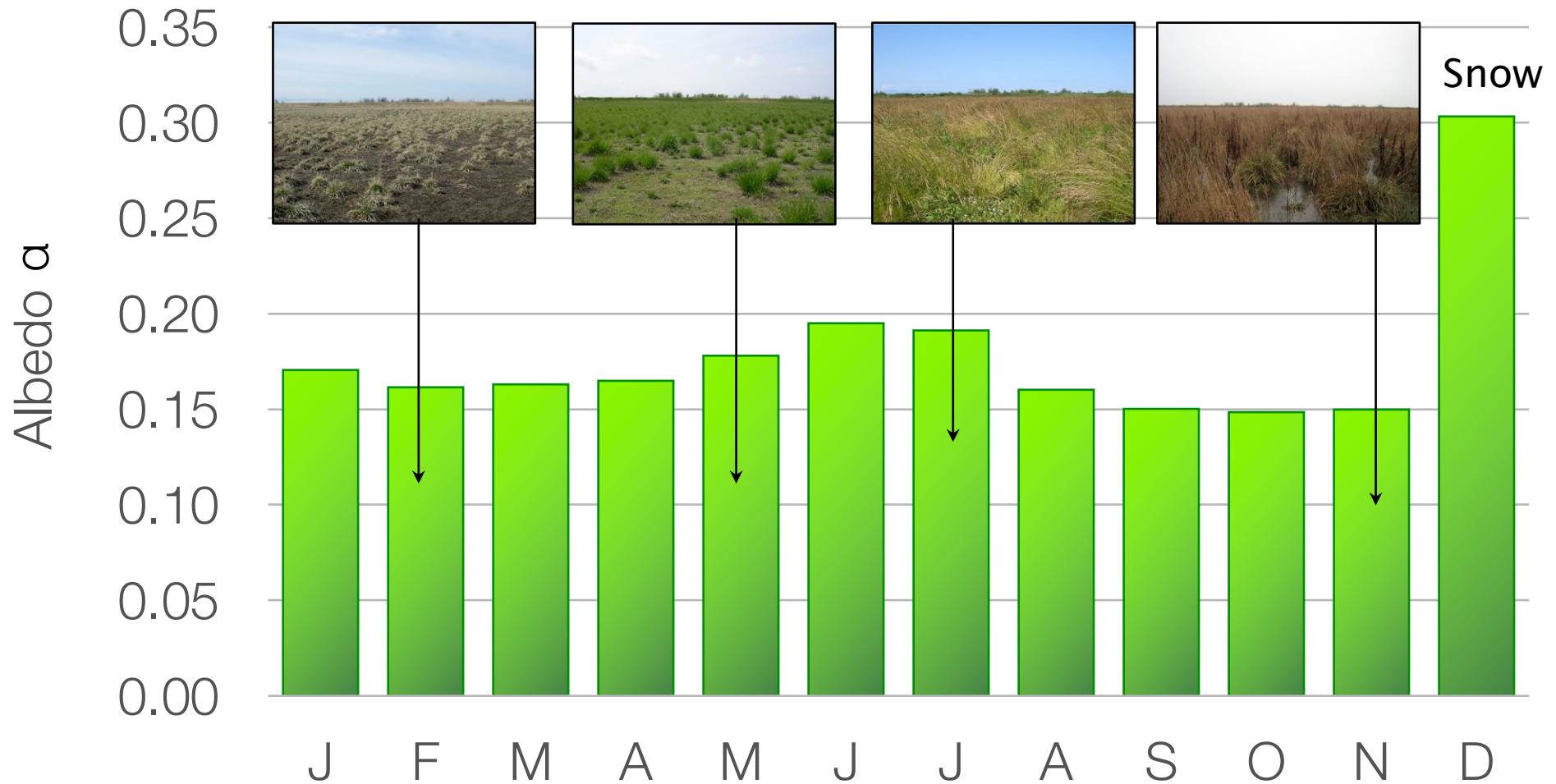




Photo: A. Christen



Photo: A. Christen

# Ice-albedo feedback

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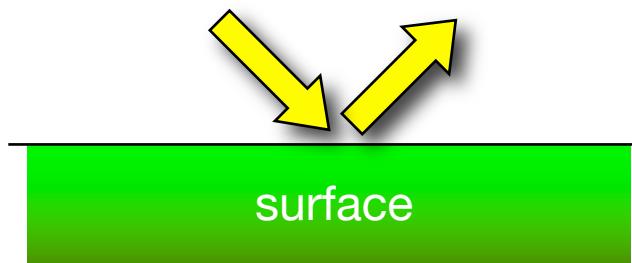


Source: <https://svs.gsfc.nasa.gov/20021>

# Specular and diffuse reflection

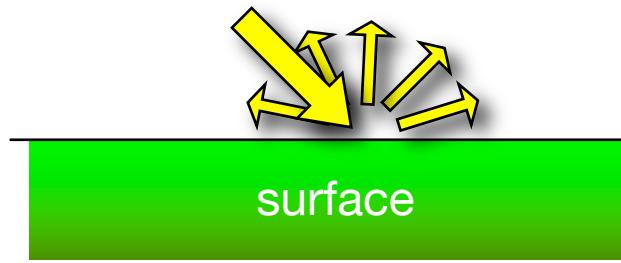
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**specular**



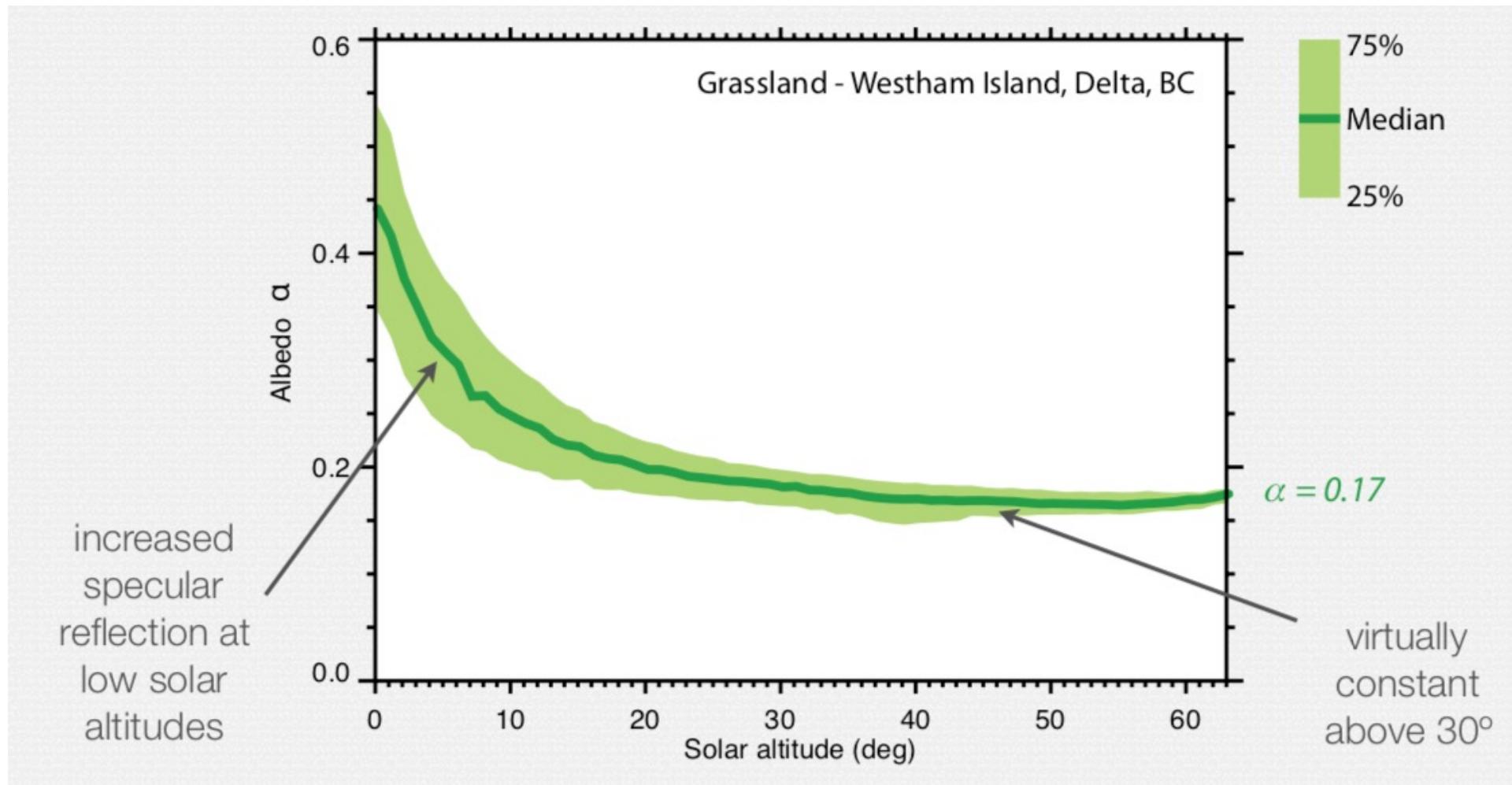
Beam reflected at same angle (like mirror).

**diffuse**



Beam diffused isotropically (Lambertian).

# Albedo as a function of solar altitude



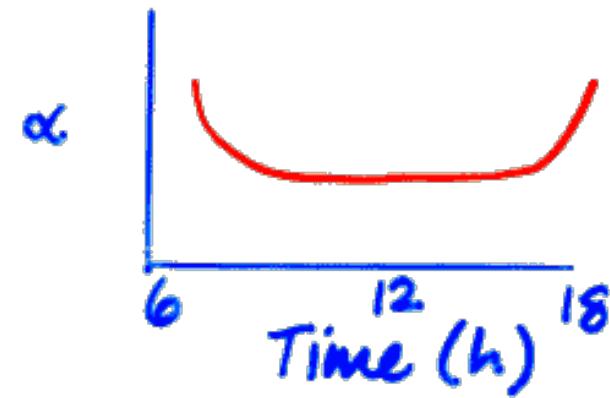
# Solar altitude and albedo

Natural surfaces seem to diffuse for  $Z < 60^\circ$ , and increasingly specular as  $Z \rightarrow 90^\circ$ . As a simple model we might use:

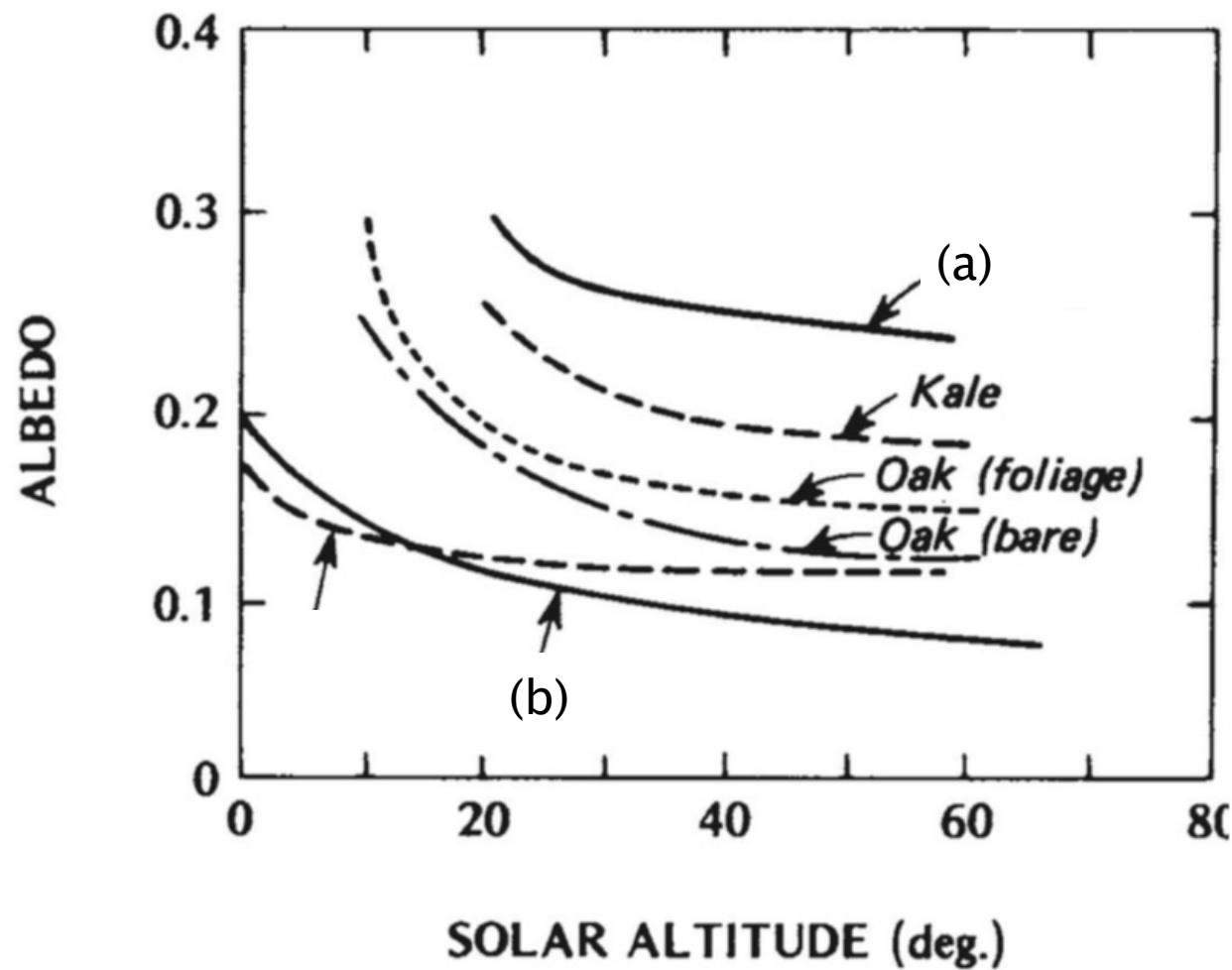
$$\alpha_Z = \alpha_0 + (1 - \alpha_0)e^{-kZ}$$

where  $k \approx 0.1$

The values in literature usually refer to the **middle part of the day or the albedo calculated from the daily totals of irradiance and reflectance.**

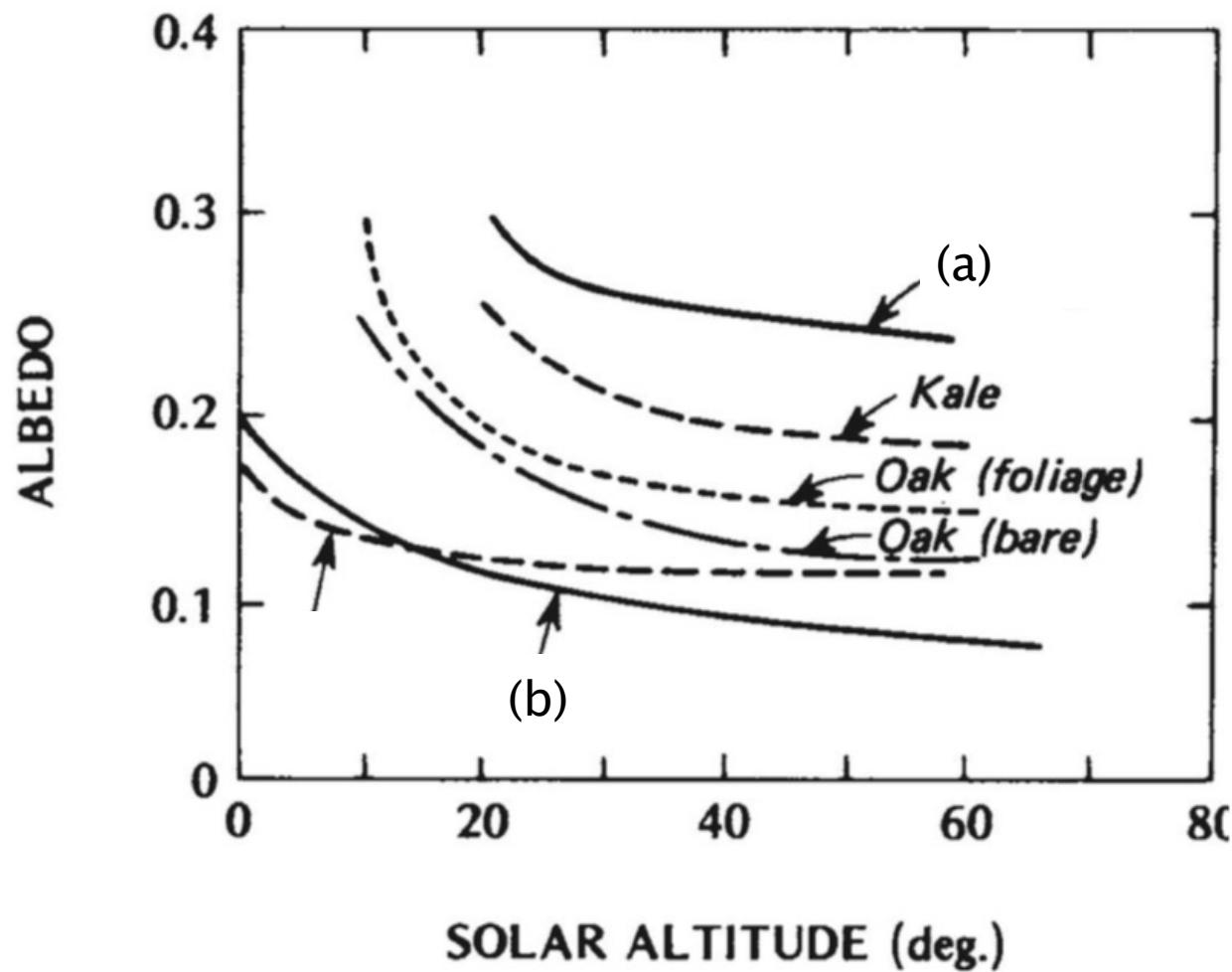


## Solar altitude, canopy height and albedo



# Which line (a or b) corresponds to a taller canopy? (Slido)

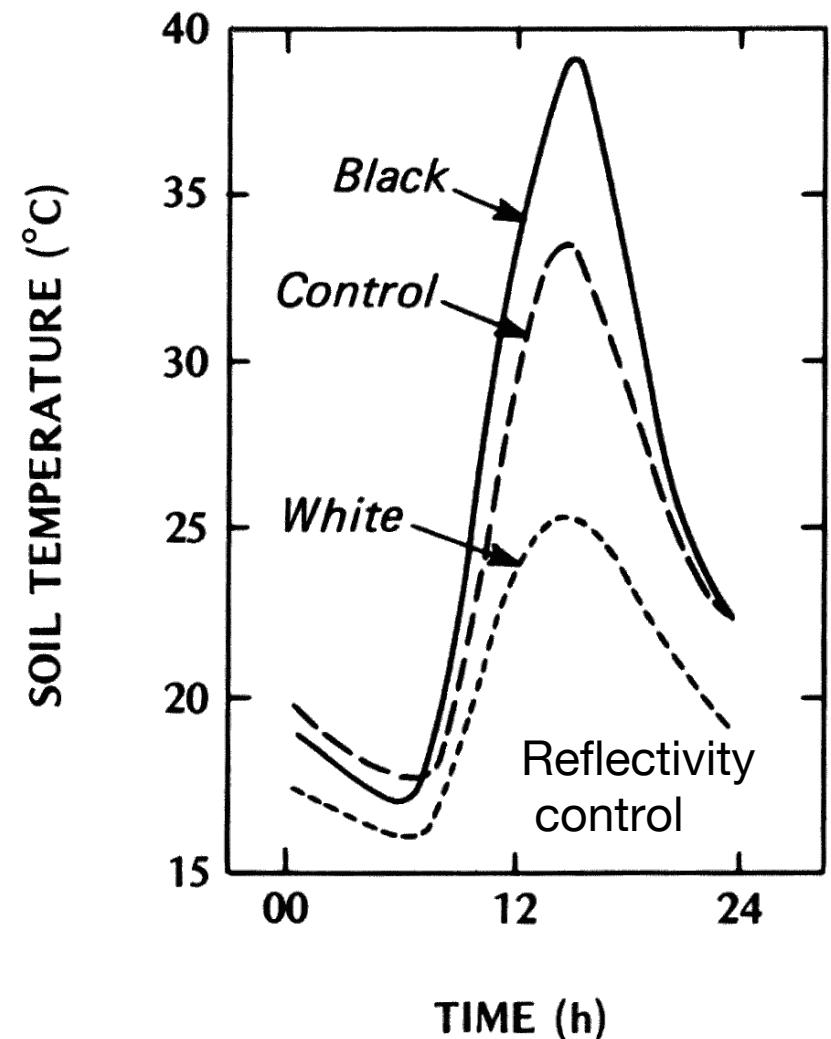
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# Control and modification.

There are mainly two ways to modify the short-wave radiative surface properties:

- (1) **Reflectivity control** - Changing the surface color in various wavelengths by painting the surface (e.g. roof-tops), or wrapping the surface in white or dark plastic (agriculture).
- (2) **Geometry control** - Changing the microtopographic feature of a setting to increase or reduce absorption.





# Albedo control



CBC news

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## White-roofs law would help cool Earth

**Mayor of Montreal borough proposes bylaw requiring white roofs**

Last Updated: Tuesday, August 31, 2010 | 10:53 AM ET    Comments  [186](#)    Recommend  [80](#)  
CBC News



All new roofs would be white under a Montreal borough's proposed bylaw aimed at taking advantage of a white roof's cooling effects.

Mayor François Croteau of Rosemont-La Petite-Patrie wants to make white roofs mandatory on new buildings. Roofs requiring repairs would have to be painted white as well.

From [The Times](#)

May 27, 2009

## Professor Steven Chu: paint the world white to fight global warming

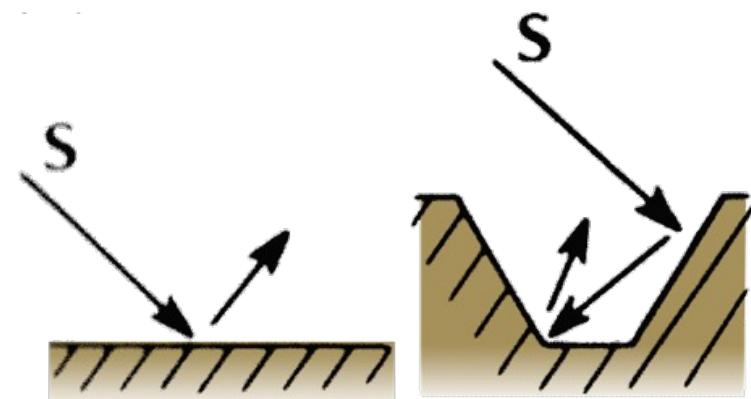
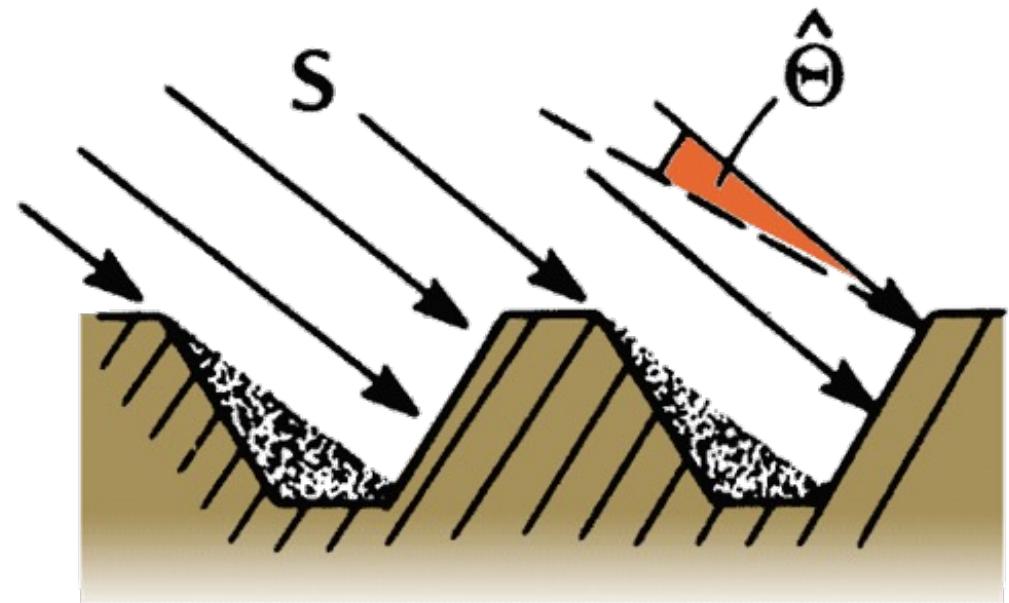
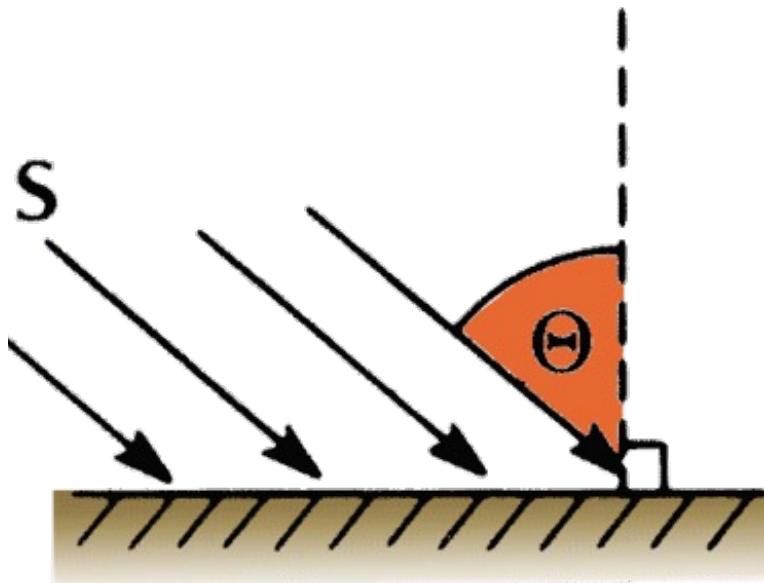




Photo: A. Christen

# Geometry control

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## Take home points

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- As short-wave radiation reaches a surface, part of it is reflected - can be quantified by **spectral reflectivity** and the **reflection coefficient** (called **albedo** for short-wave)
- Albedo is controlled by the material, 3D form, the leaf state and the presence of snow.
- Reflection can be **specular** and/or **diffuse** - and most natural surfaces become increasingly specular at low solar altitudes.
- Changing the albedo of a surface (material, geometry) is a powerful tool to microclimate **modification**.