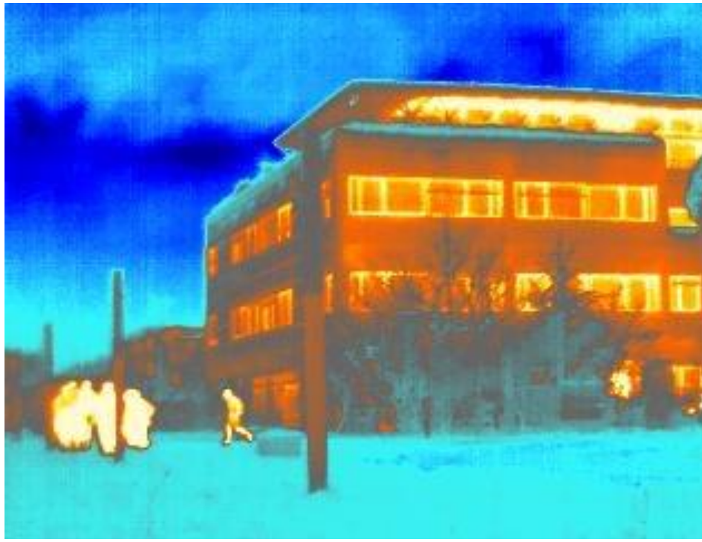
Photo: A. Black, UBC

07 Long-wave radiation.

Learning objectives

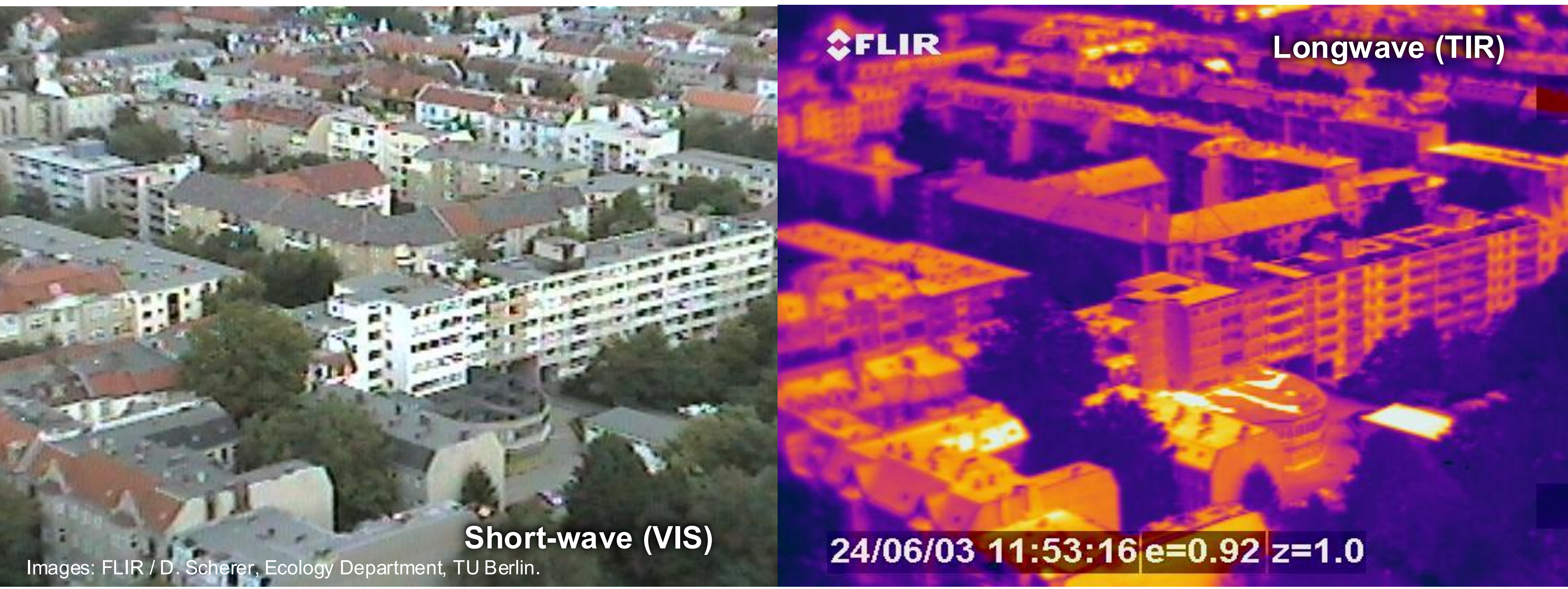
- Explain how radiation laws apply to long-wave radiative exchange as well.
- Describe how long-wave radiation can interact with surfaces.
- Explain how we can calculate longwave outgoing radiation, and how it relates to surface emissivity.



People in front of a heated building in winter as seen in the thermal infrared by a thermal camera (Source: A. Christen)

What is ‘Longwave’ radiation?

- Wavelength range: 3 μm to 100 μm
- Longwave = far-infrared = thermal infrared radiation (TIR)



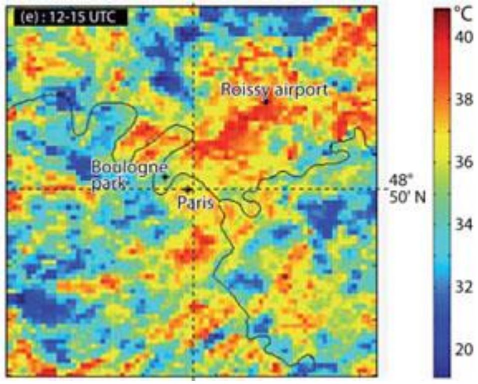
Images: FLIR / D. Scherer, Ecology Department, TU Berlin.

Measuring long-wave radiation

There is a range of instruments available that measure long-wave radiation received in a particular **field of view** (FOV), within a particular **band**, and/or with a particular spatial **resolution**.

Pyrgeometer

Thermal camera



Thermal satellite channel

Review: Stefan-Boltzmann law: grey body

Natural objects are not full radiators. The **emittance** from these objects (called grey bodies) is given by

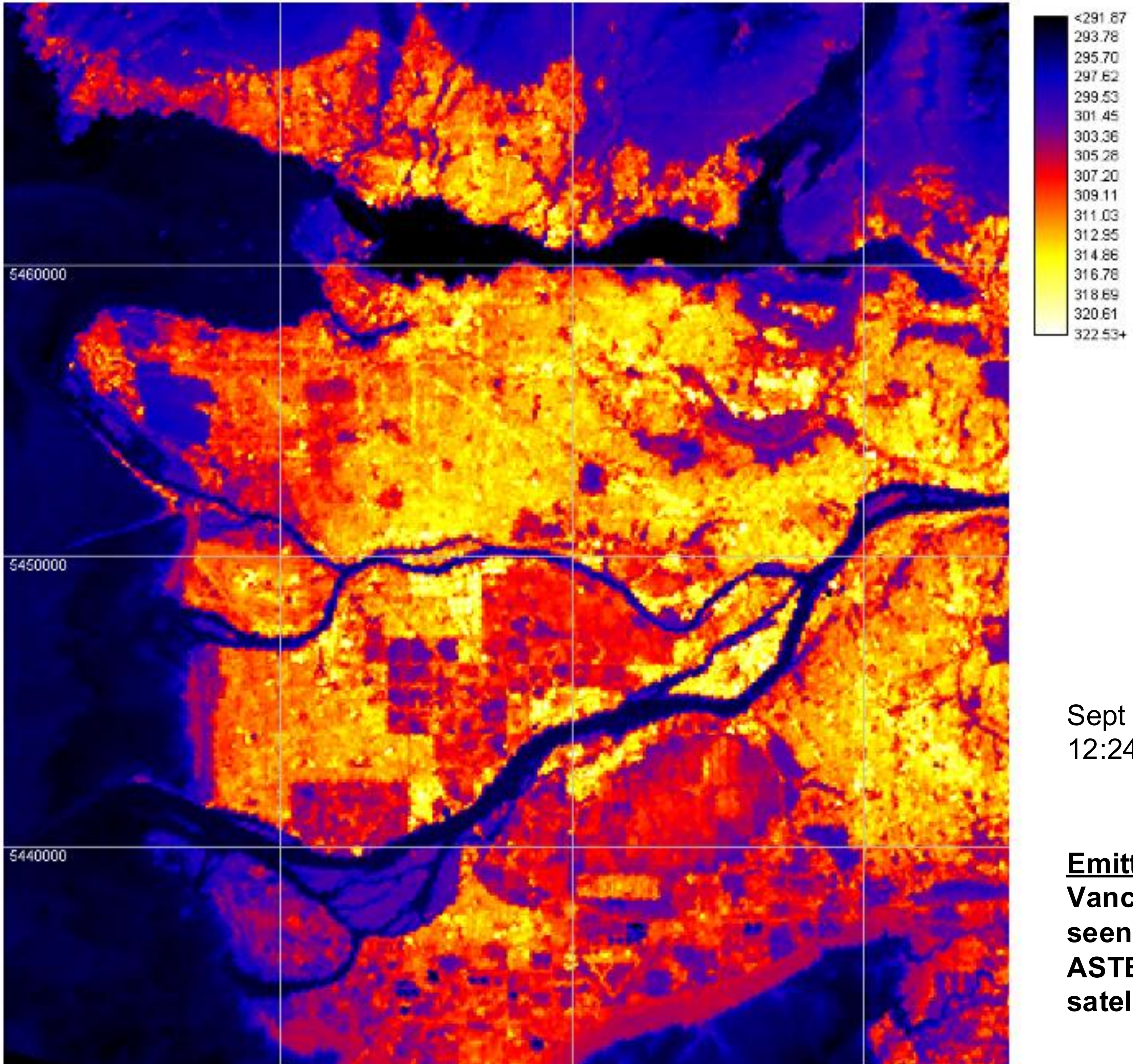
$$E_g = \varepsilon \sigma T^4 \quad \star$$

where ε is their **surface emissivity**. Emissivity is the ratio of the actual emission to that of a blackbody (i.e. ε = 1.0).

This law is the basis of remote sensing in the TIR incl. satellite sensors.

Surface	Emissivity ε*
Soil	0.90 – 0.98
Grass	0.90 – 0.95
Crops	0.90 – 0.99
Forests	0.97 – 0.99
Water	0.92 – 0.97
Iron	0.13 – 0.28

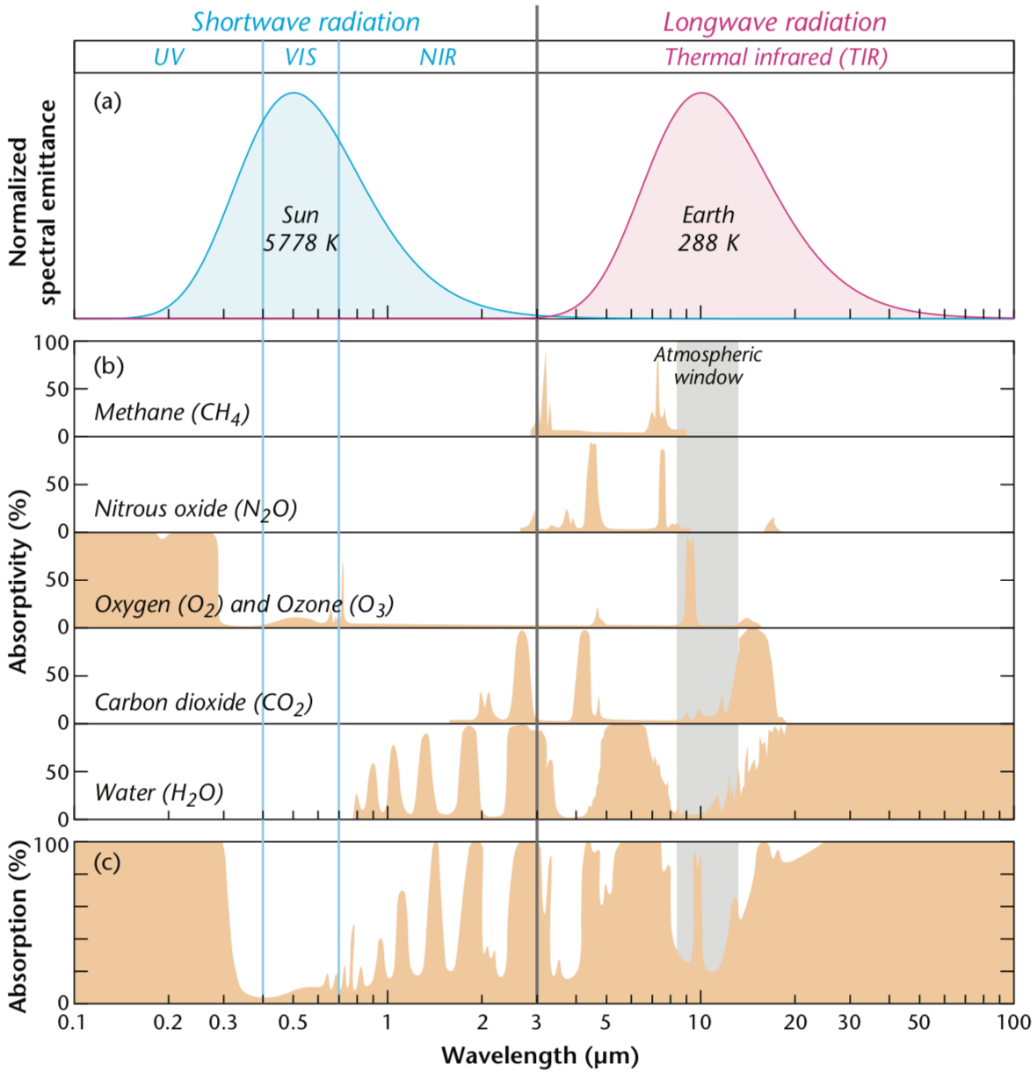
* in the long-wave range of the spectrum (relevant for microclimates)



Sept 3 2010
12:24 PDT

<u>Emittance</u> of Vancouver seen from ASTER satellite

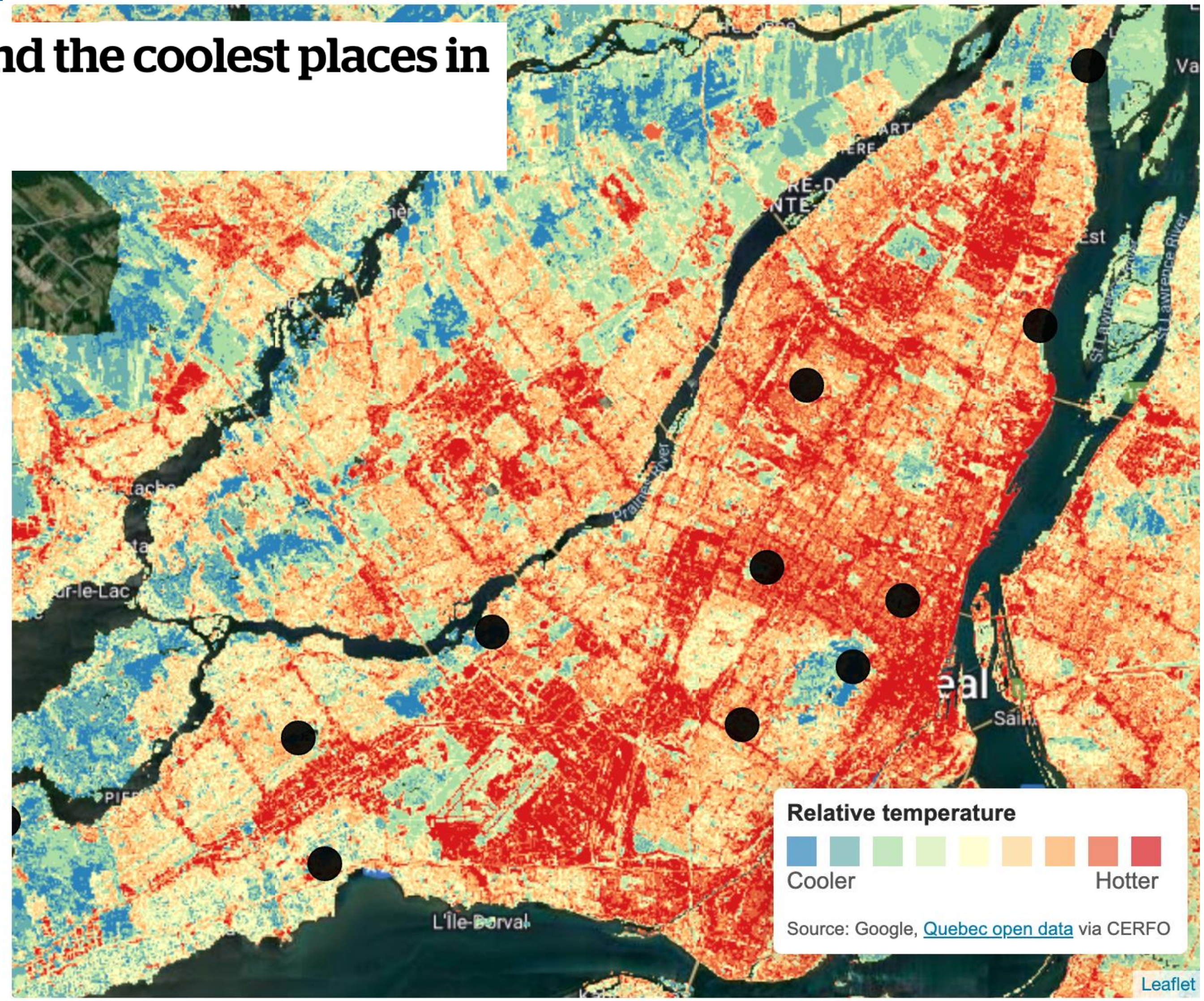
Atmospheric window & remote sensing in the TIR



From emittance we can estimate surface temperature

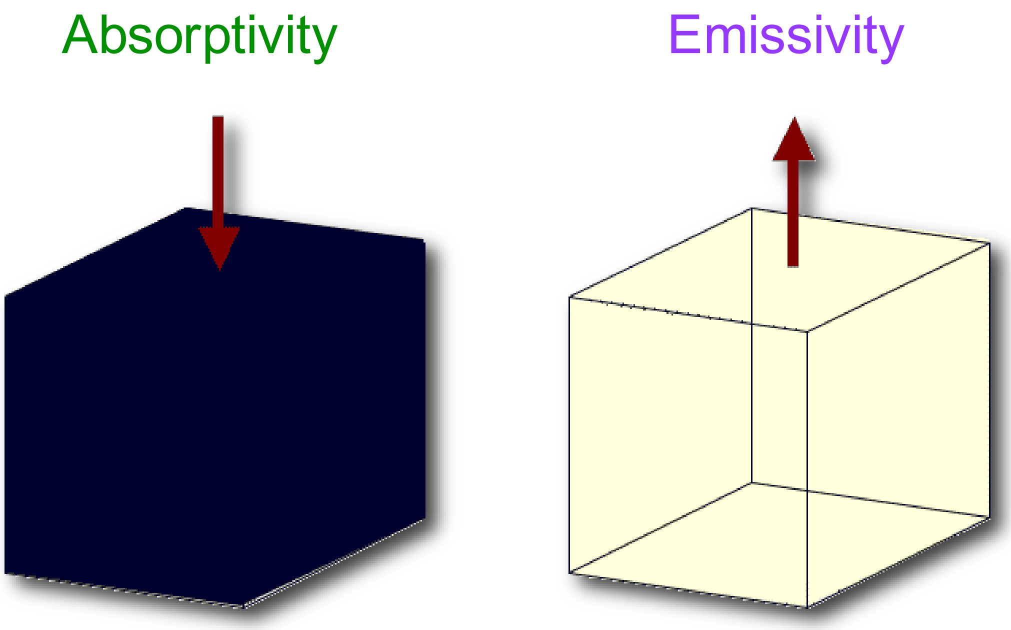
Where are the warmest and the coolest places in Montreal?

CBC



https://www.cbc.ca/news/canada/montreal/montreal-warm-cool-places-interactive-1.3669639

Review: Kirchhoff's law



Assuming no transmission the absorptivity of a body (ζ_λ) equals its emissivity (ε_λ) at a given wavelength.

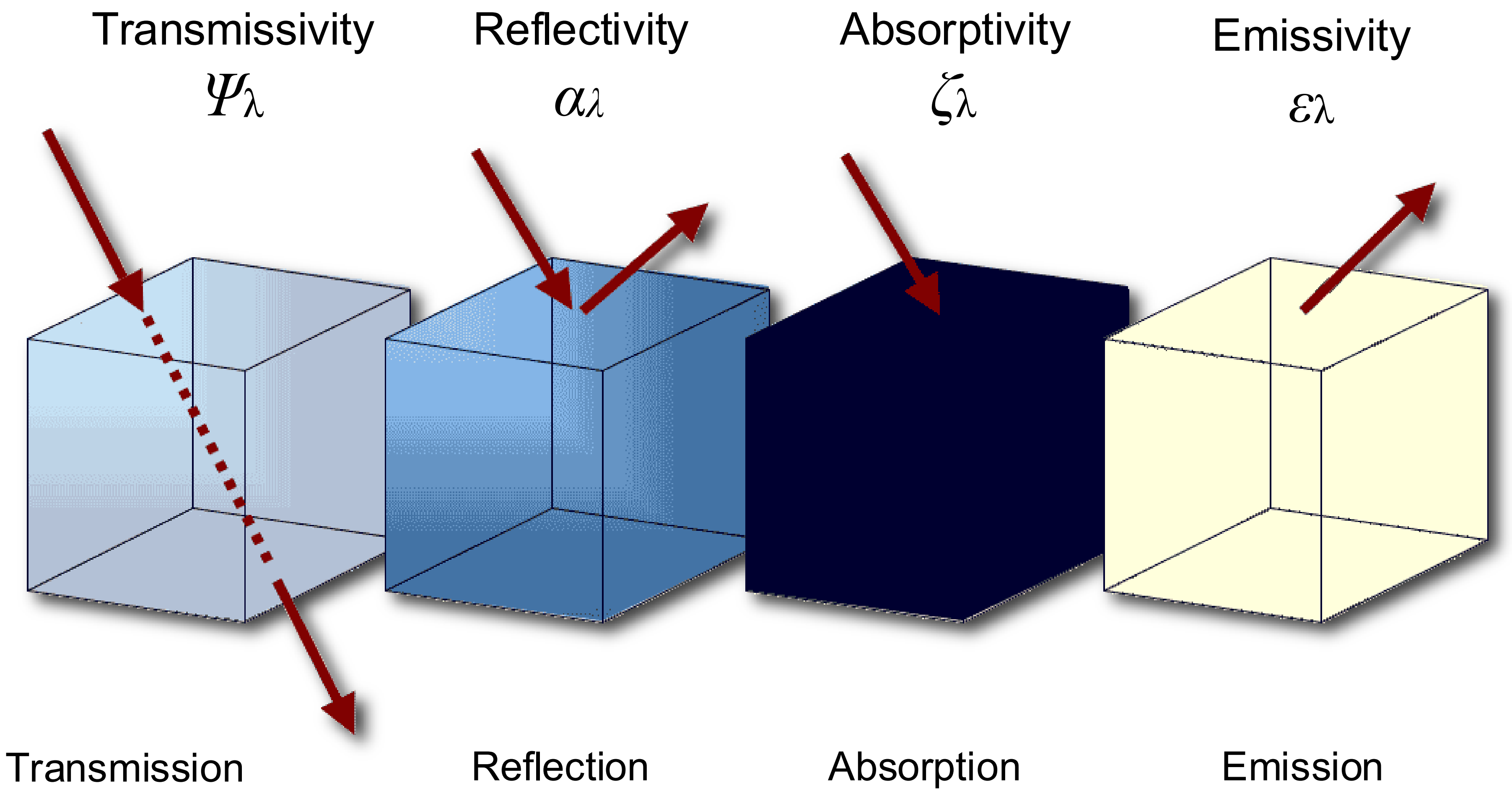
A good absorber is a good emitter

$$\zeta_\lambda = \varepsilon_\lambda \quad \star$$

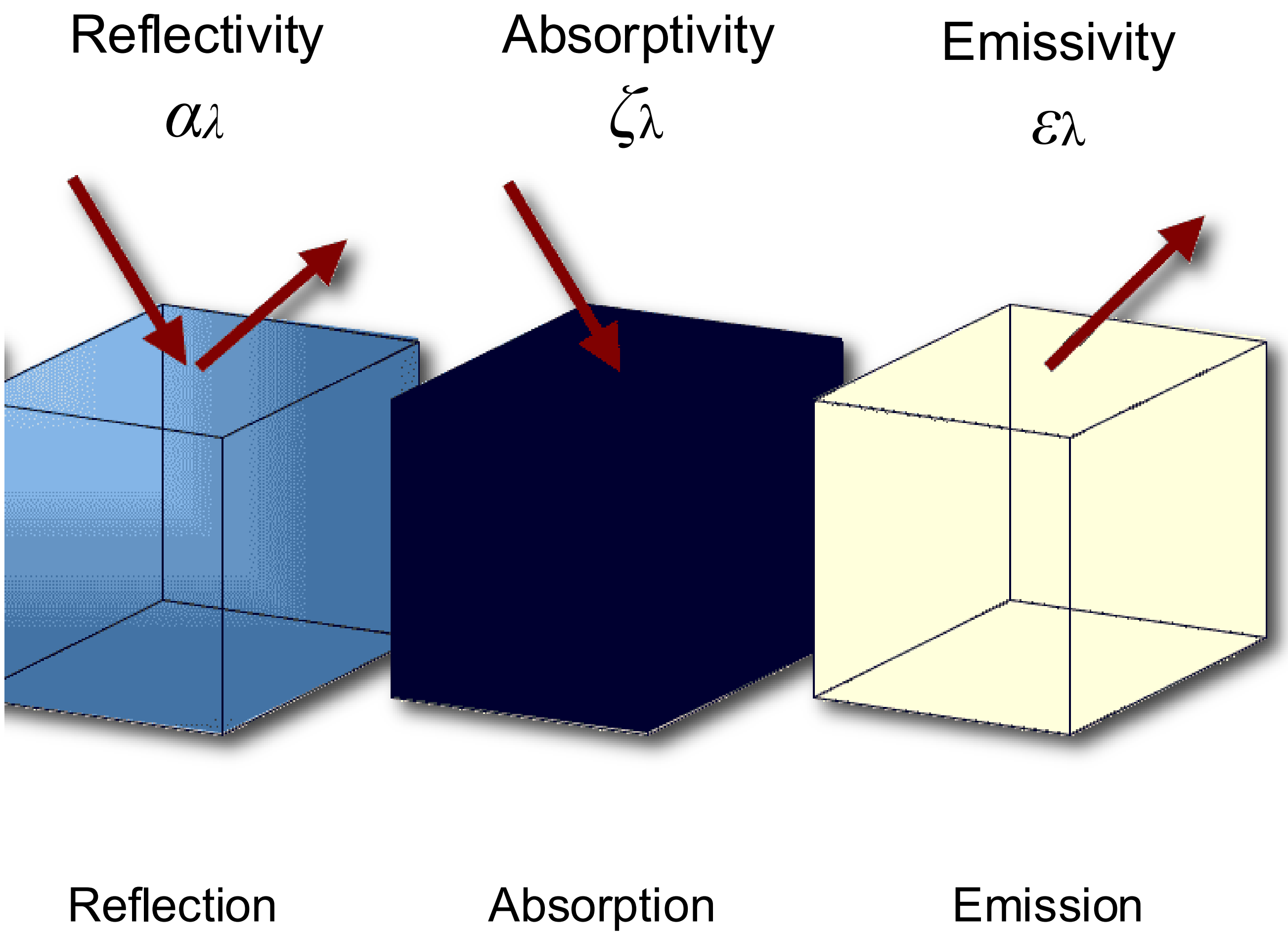
Kirchhoff’s law of thermal radiation

- Kirchhoff’s law only applies if the wavelength considered is the same – do not mix them together.
- Kirchhoff’s law only has relevance to **long-wave exchange** in climatology.
- The law does not apply to fluorescent objects, which can absorb energy at a given a wavelength and release it at another one.

Mass-radiation interactions

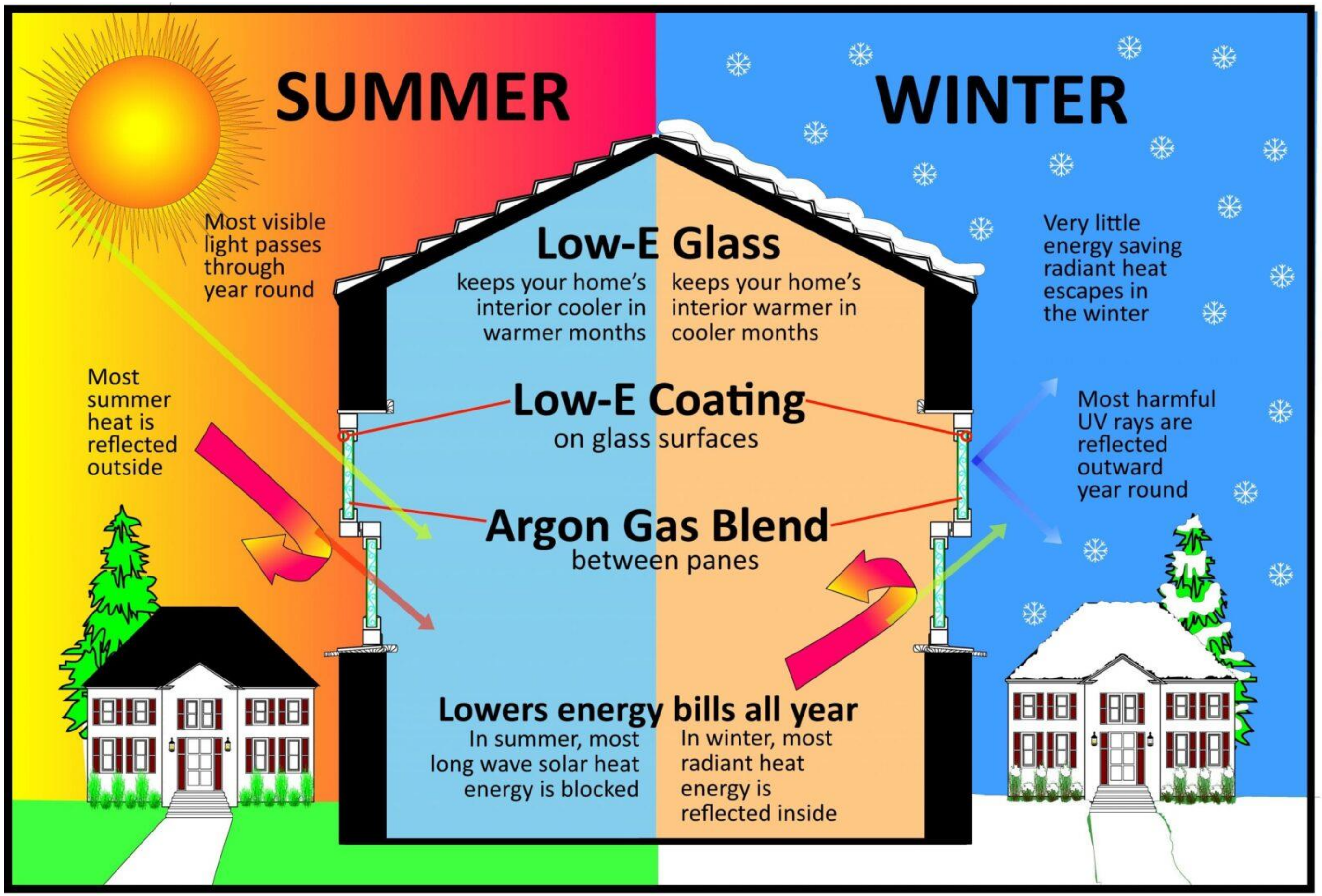


most surfaces are opaque to long-wave radiation therefore absorptivity typically = emissivity



Low emissivity = reflects much of the radiant thermal energy

Low-e glass as one practical example of a low emissivity surface



Is long-wave reflection important?

Energy conservation	Transmissivity		Absorptivity		Reflectivity		★
	$\psi_{o,LW}$	+	$\zeta_{o,LW}$	+	$\alpha_{o,LW}$	$= 1.0$	

However, most surfaces are opaque to long-wave (i.e., $\psi_{o,LW} \sim 0$) so

$$\zeta_{o\,LW} + \alpha_{o,LW} = 1.0$$

and since $\zeta_{o\,LW} = \varepsilon_{o,LW}$ (according to Kirchhoff's Law)

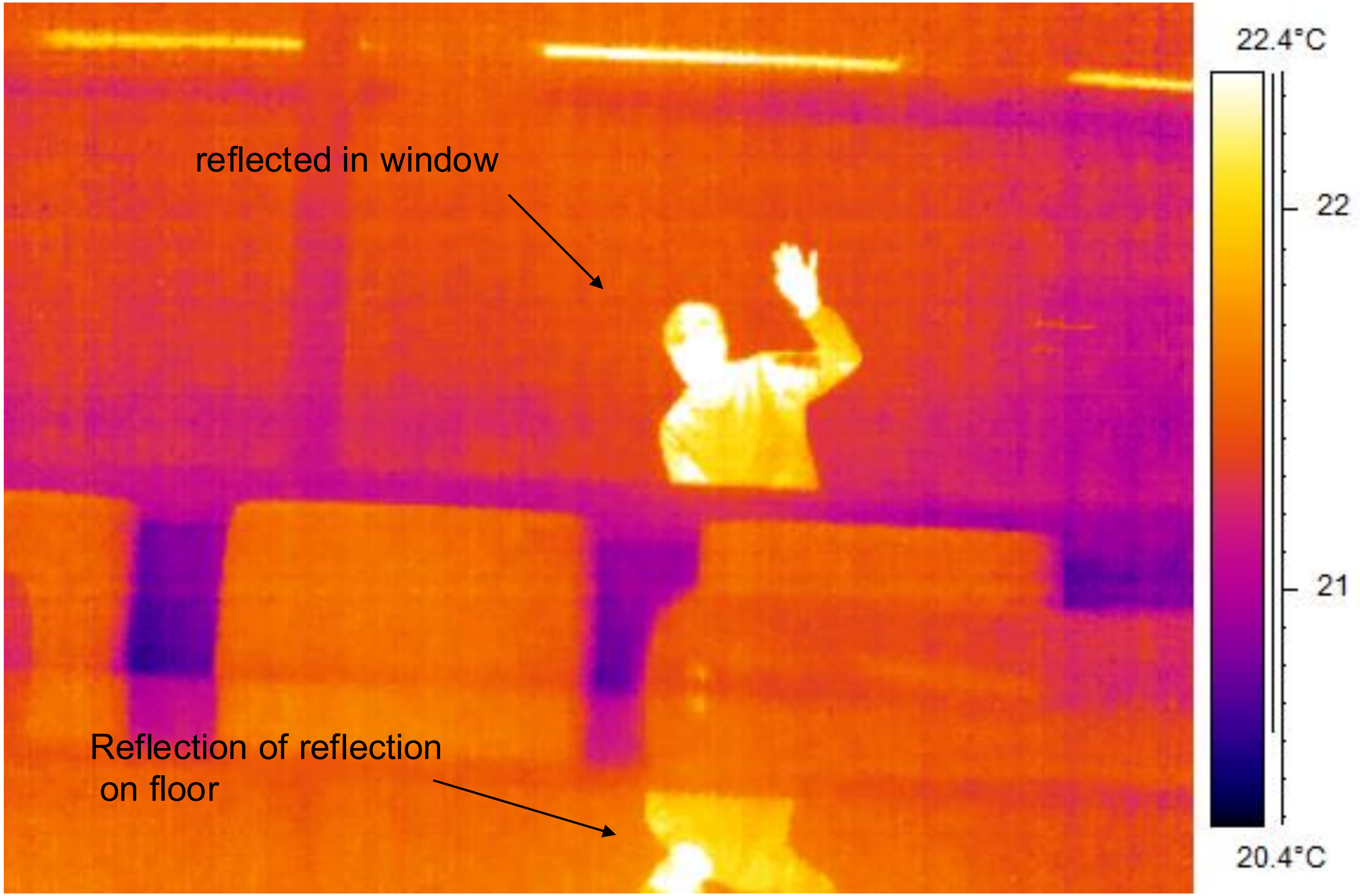
$$\alpha_{o,LW} \;=$$

Join at:
vevox.app

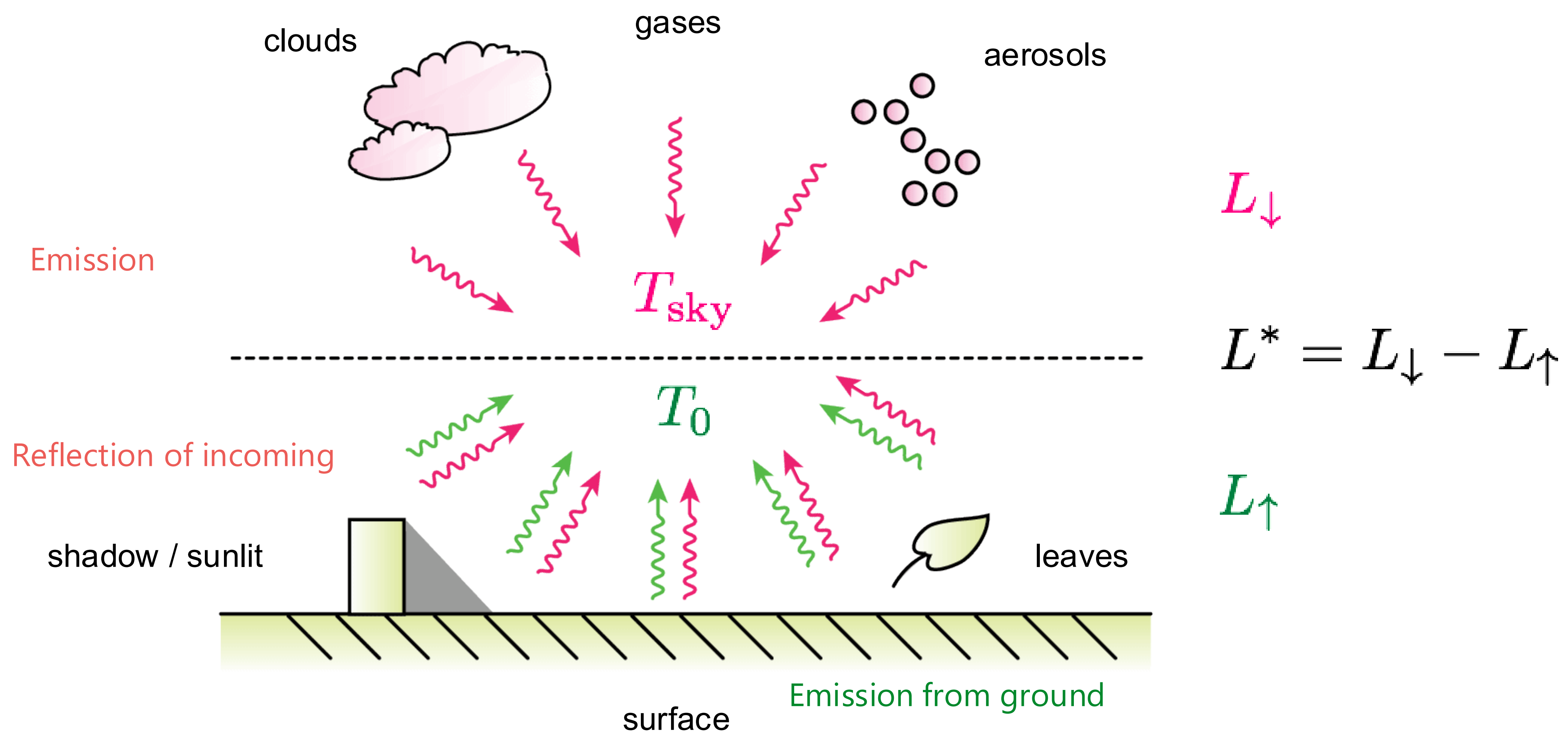
ID:
433-971-976

The subscript '0' refers to values of the land surface (in contrast to atmosphere with subscript a). In the upcoming slides we will implicitly assume values are in the long-wave band, and omit the subscript 'LW'

Long-wave reflection



Long-wave radiation exchange of a surface



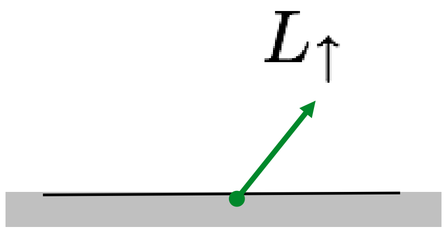
Calculating $L_{\uparrow}$

$$\varepsilon = \frac{\text{radiative flux density emitted by a body}}{\text{radiative flux density emitted by a blackbody}}$$

defines blackbody as ε = 1.0, and grey bodies as $\varepsilon < 1.0$.

emission

$$L_{\uparrow} = \varepsilon_o \sigma T_o^4$$



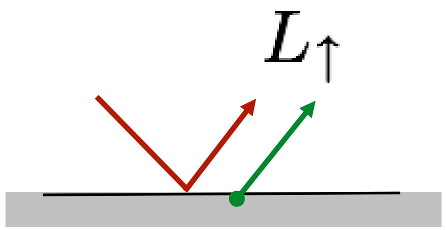
Calculating $L_\uparrow$

$$\varepsilon = \frac{\text{radiative flux density emitted by a body}}{\text{radiative flux density emitted by a blackbody}}$$

defines blackbody as ε = 1.0, and grey bodies as ε < 1.0.

emission | reflection in the long-wave

$$L_\uparrow = \varepsilon_o \sigma T_o^4 + \underbrace{(1 - \zeta_o)}_{\alpha_o} L_\downarrow$$

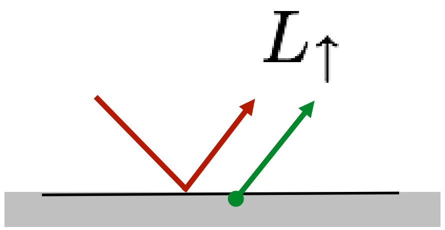


Calculating $L_\uparrow$

$$\varepsilon = \frac{\text{radiative flux density emitted by a body}}{\text{radiative flux density emitted by a blackbody}}$$

defines blackbody as $\varepsilon = 1.0$, and grey bodies as $\varepsilon < 1.0$.

$$L_\uparrow = \overbrace{\varepsilon_o \sigma T_o^4}^{\text{emission}} + \overbrace{\underbrace{(1 - \zeta_o)}_{\alpha_o} L_\downarrow}^{\text{reflection in the long-wave}}$$



where ζ_o - absorptivity of surface in the long-wave, α_0 reflectivity of surface in the long-wave and from Kirchhoff's law ($\zeta_\lambda = \varepsilon_\lambda$):

where subscript '0' indicates surface value.

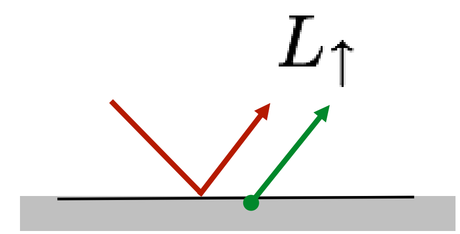
Calculating $L_{\uparrow}$

$$\varepsilon = \frac{\text{radiative flux density emitted by a body}}{\text{radiative flux density emitted by a blackbody}}$$

defines blackbody as ε = 1.0, and grey bodies as ε < 1.0.

emission — reflection in the long-wave

$$L_{\uparrow} = \varepsilon_o \sigma T_o^4 + \underbrace{(1 - \zeta_o)}_{\alpha_o} L_{\downarrow}$$



where ζ_o - absorptivity of surface in the long-wave, α_o reflectivity of surface in the long-wave and from Kirchhoff's law ($\zeta_\lambda = \varepsilon_\lambda$):

$$L_{\uparrow} = \varepsilon_o \sigma T_o^4 + (1 - \varepsilon_o) L_{\downarrow} \quad \star$$

where subscript '0' indicates surface value.

Net long-wave radiation flux density *L**

The long-wave net radiation L^* at the surface is the difference between the input from above $L_\downarrow$ and the output from emission and reflected $L_\downarrow$:

$$L^* = L_\downarrow - L_\uparrow$$

Net long-wave radiation flux density *L**

The long-wave net radiation L^* at the surface is the difference between the input from above $L_\downarrow$ and the output from emission and reflected $L_\downarrow$:

$$L^* = L_\downarrow - L_\uparrow$$

$$L^* = L_\downarrow - (\varepsilon_o \sigma T_o^4 + \overbrace{(1 - \zeta_o)}^{\alpha_o} L_\downarrow)$$

Net long-wave radiation flux density *L**

The long-wave net radiation L^* at the surface is the difference between the input from above $L_\downarrow$ and the output from emission and reflected $L_\downarrow$:

$$L^* = L_\downarrow - L_\uparrow$$

$$L^* = L_\downarrow - (\varepsilon_o \sigma T_o^4 + \overbrace{(1 - \zeta_o)}^{\alpha_o} L_\downarrow)$$

$$L^* = L_\downarrow - (\varepsilon_o \sigma T_o^4 + (1 - \varepsilon_o) L_\downarrow)$$

emitted

reflected

Kirchhoff's Law

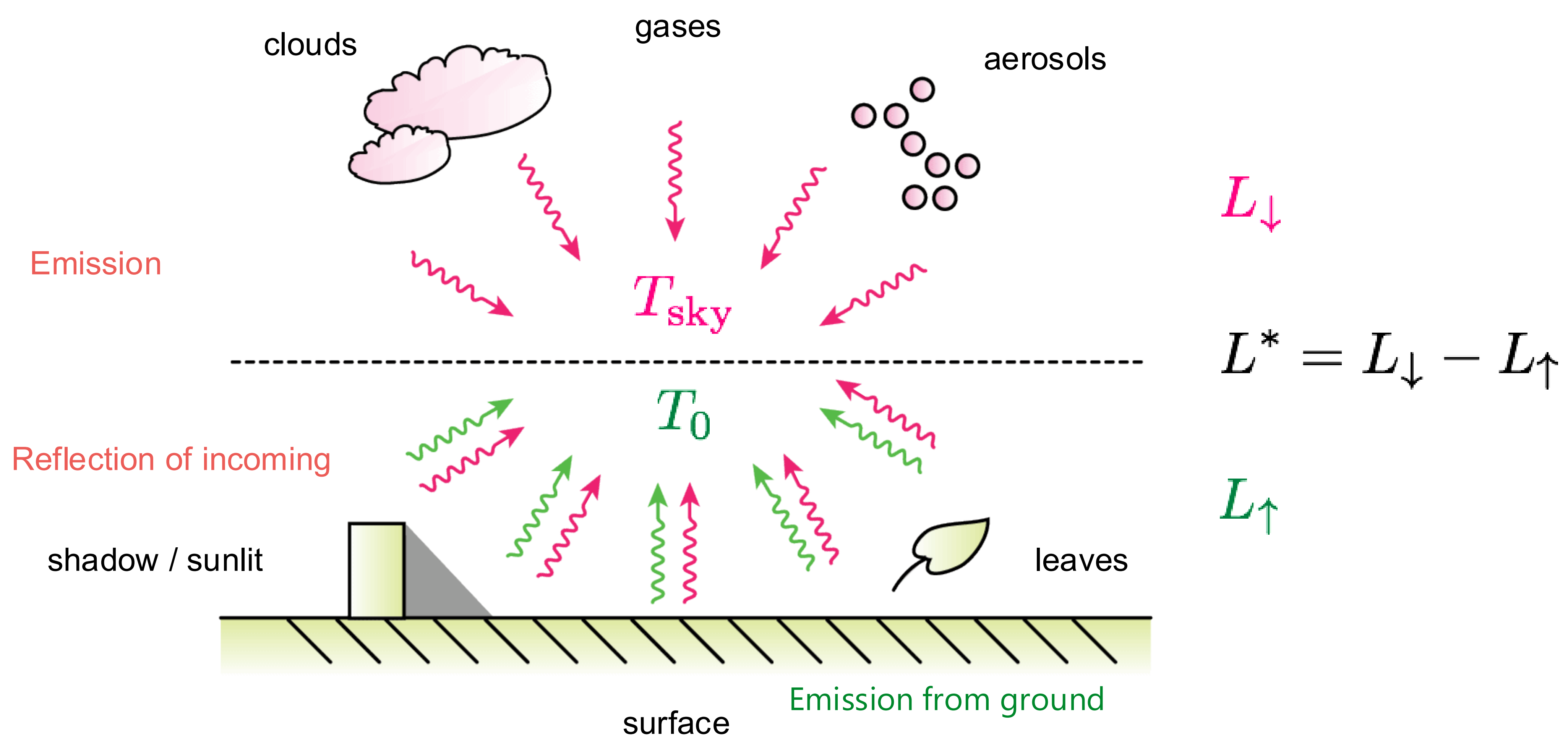
Question for discussion

What influences $L_{\downarrow}$?

Join at:
vevox.app

ID:
433-971-976

Long-wave radiation exchange of a surface



Long-wave radiation - example of measurements

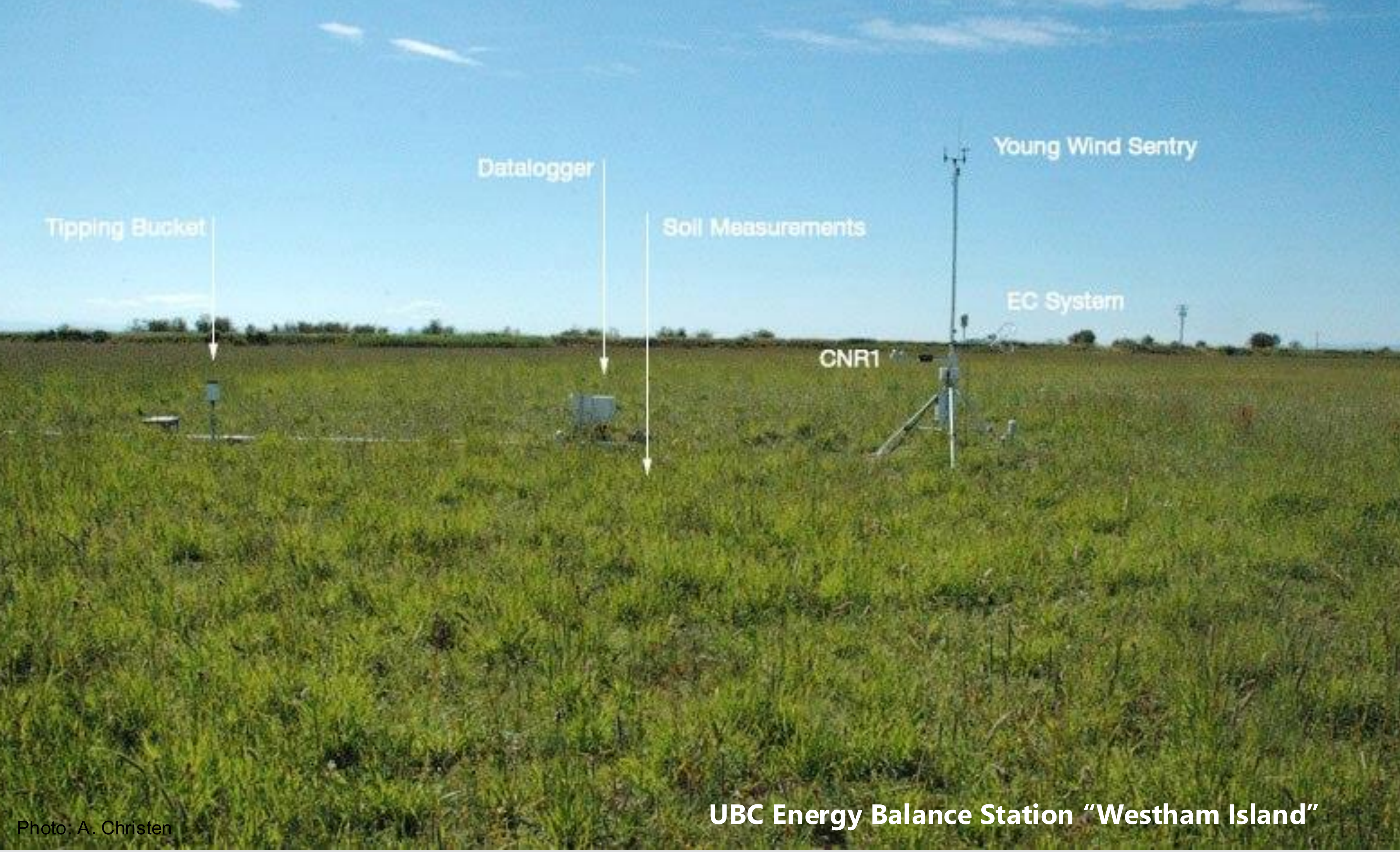
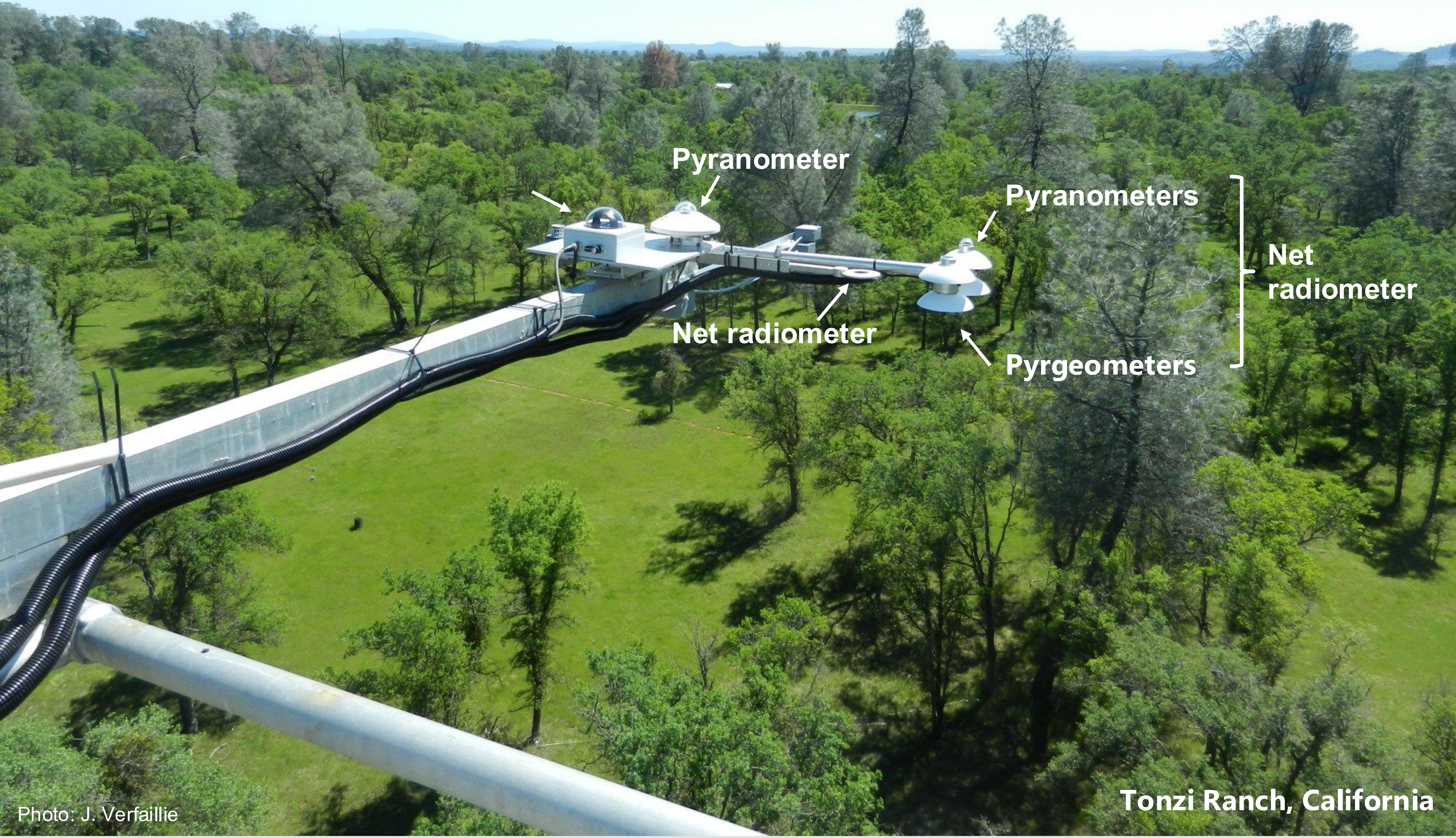


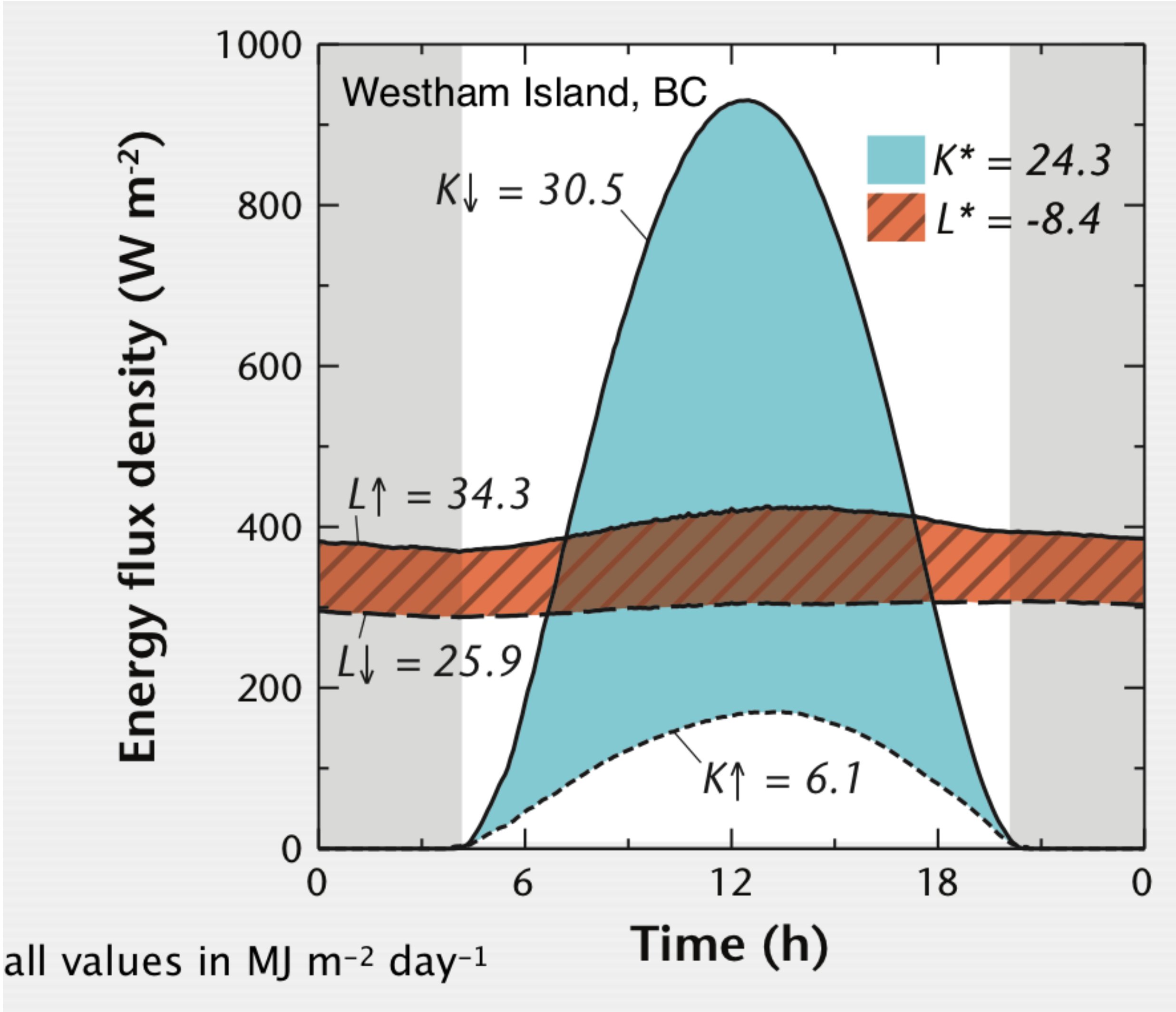
Photo: A. Christen

UBC Energy Balance Station “Westham Island”

Long-wave radiation - example of measurements

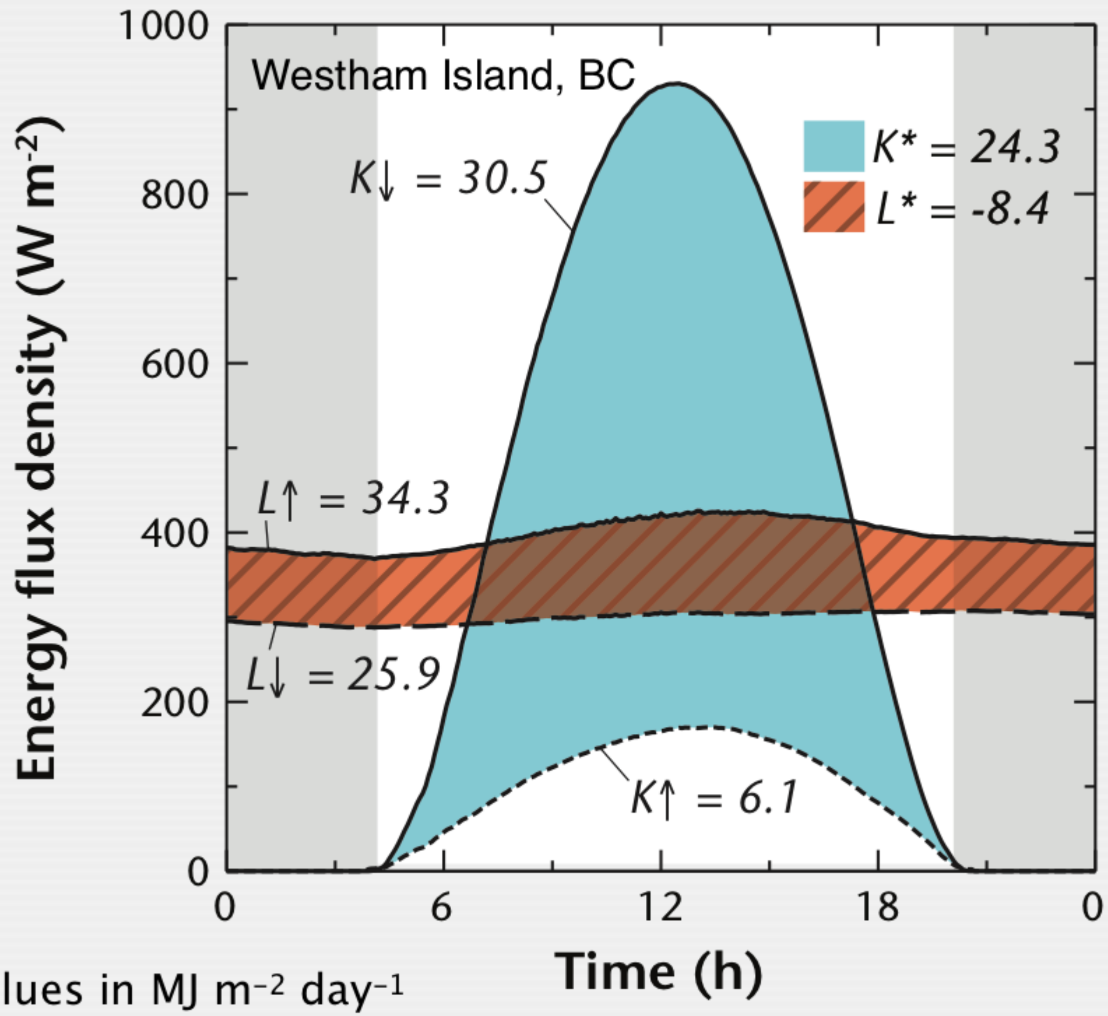


Diurnal course of radiation - clear sky day



Images from Katkam in Vancouver

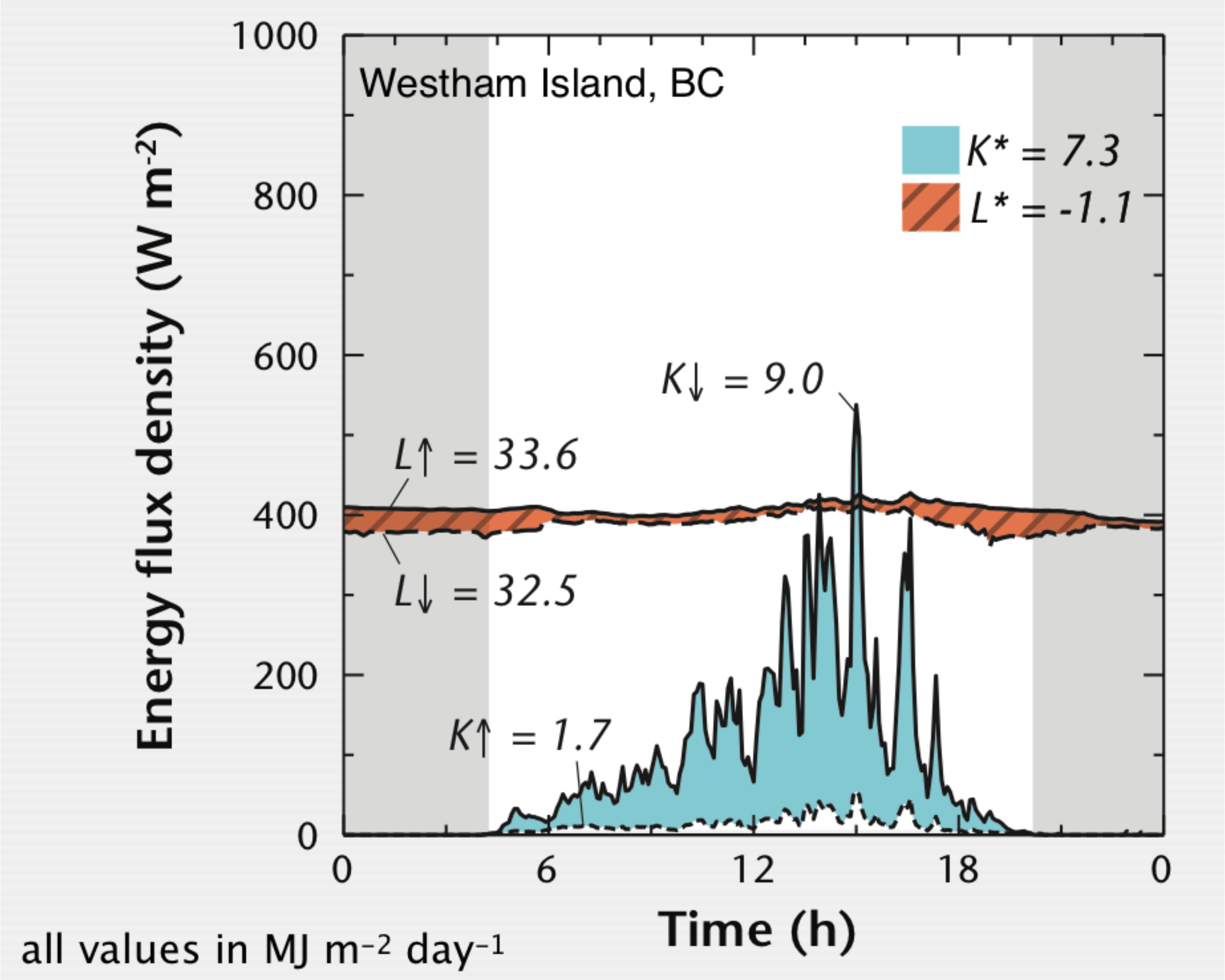
Class activity - Why is $L_{up} > L_{down}$?



all values in MJ m^{-2} day^{-1}

Images from Katkam in Vancouver

Diurnal course of radiation - overcast / broken sky day

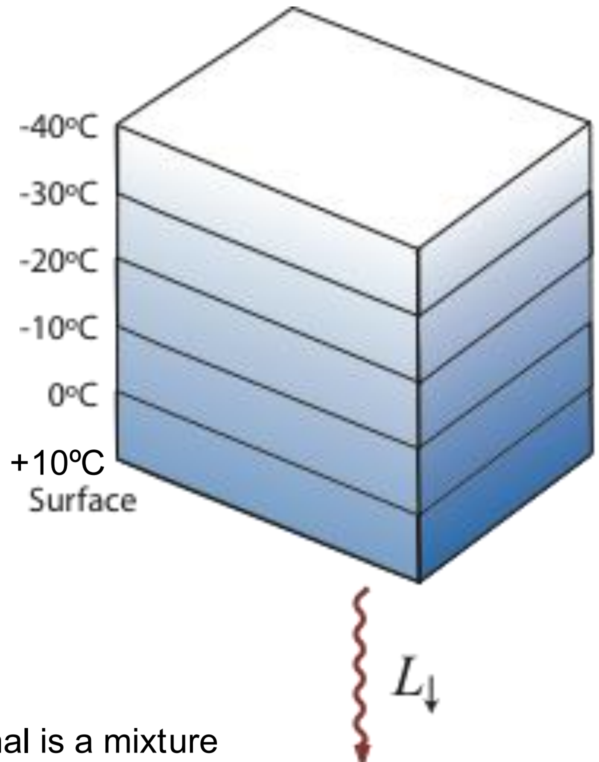


Images from Katkam in Vancouver

Effect of clouds on longwave irradiance

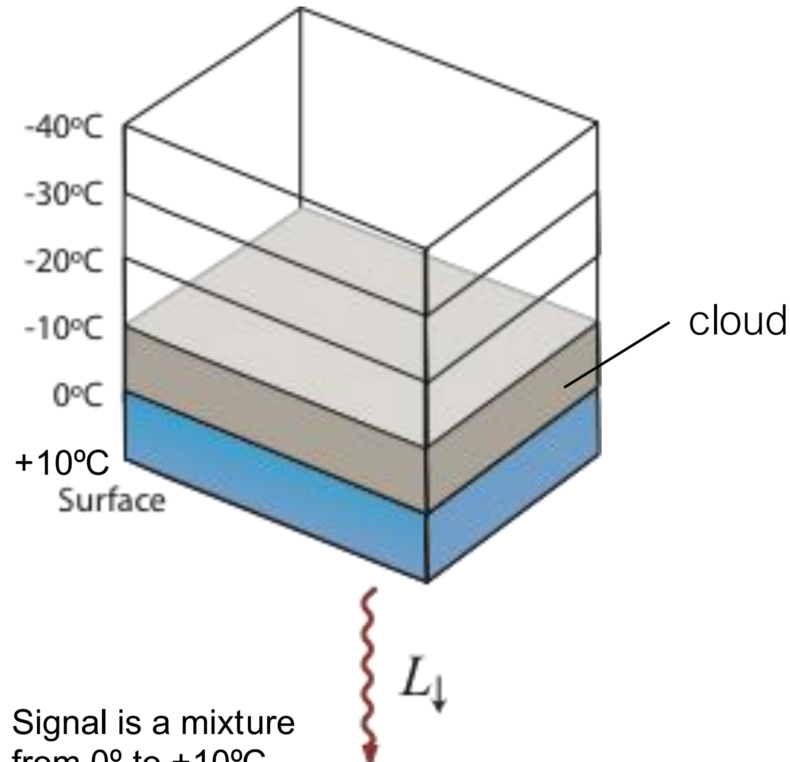
With a clear-sky, L↓ originates from **all layers** of the atmosphere, because the atmosphere is **partly transparent** ('atmospheric window' open)

With clouds L↓ originates from **the cloud base** and the atmosphere below the cloud, because the cloud is **opaque to long wave** ('atmospheric window' closed)



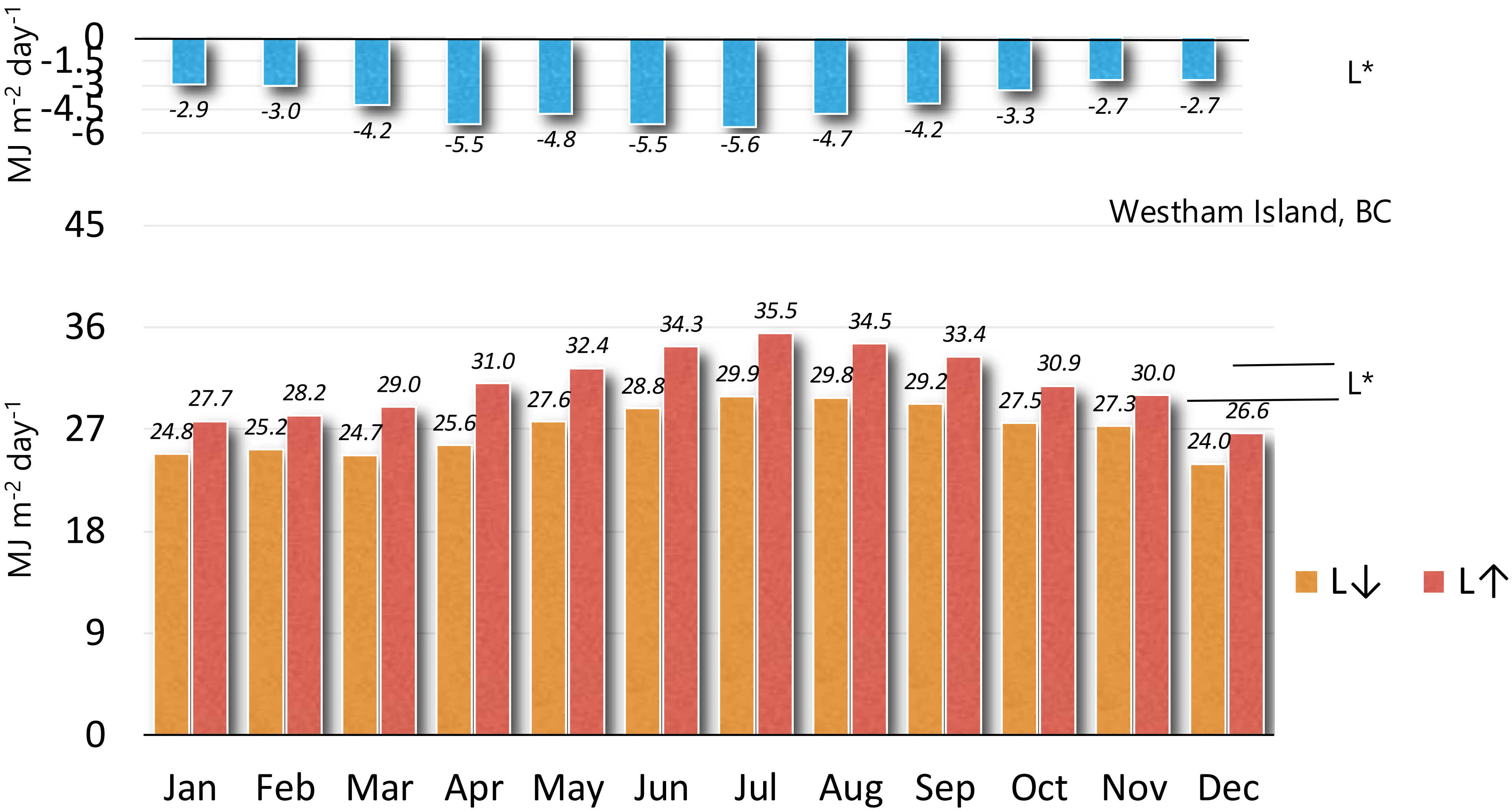
Signal is a mixture from -40ºC to +10ºC

<

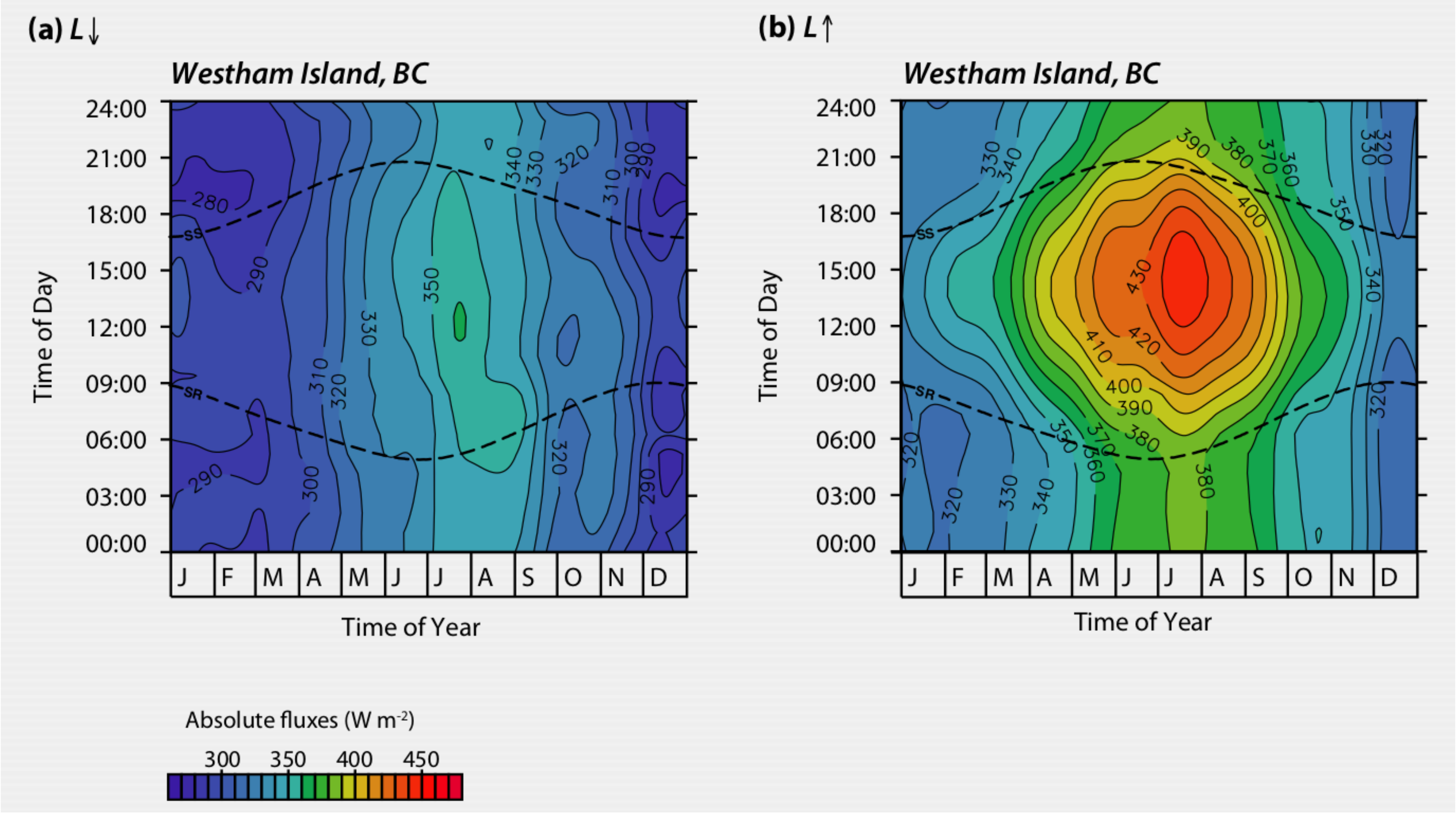


Signal is a mixture from 0º to +10ºC

Monthly totals of L↓, L↑ and L* in Vancouver



‘Fingerprint’ of L↓ and L↑ measured in Vancouver



Take home points

- Radiation laws apply the same way to the longwave part of the spectrum - but **Kirchhoff's law** and the concept of **emissivity** become relevant.

- The net-long wave radiation is driven by the difference in apparent sky and surface temperatures and hence **clouds and thermal surface properties** are controlling radiative exchange in the long-wave.