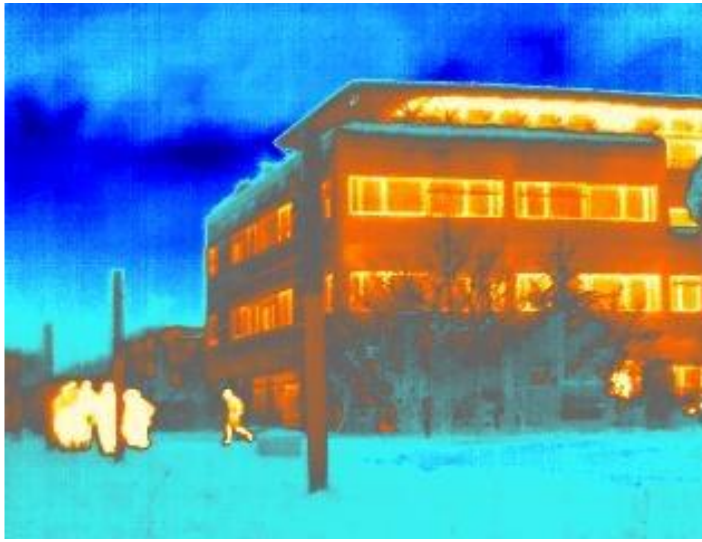
Photo: A. Black, UBC

07 Long-wave radiation.

Learning objectives

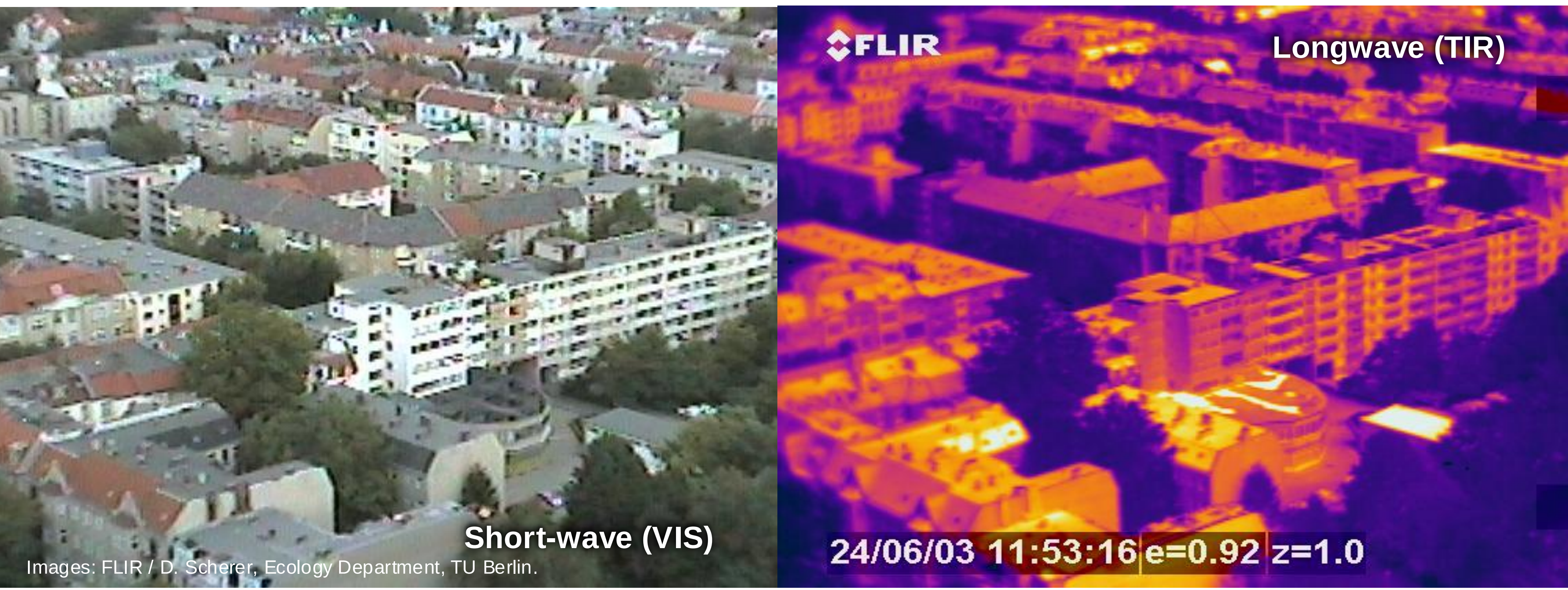
- Explain how radiation laws apply to long-wave radiative exchange as well.
- Describe how long-wave radiation can interact with surfaces.
- Explain how we can calculate longwave outgoing radiation, and how it relates to surface emissivity.



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)



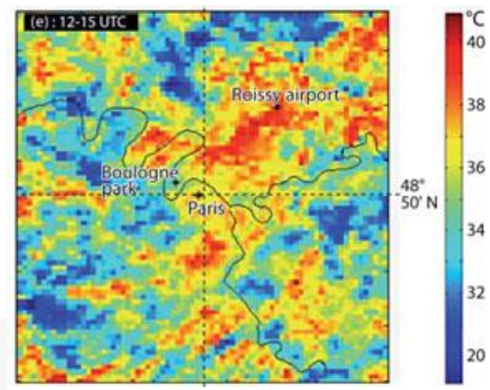
Images: FLIR / D. Scherer, Ecology Department, TU Berlin.

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

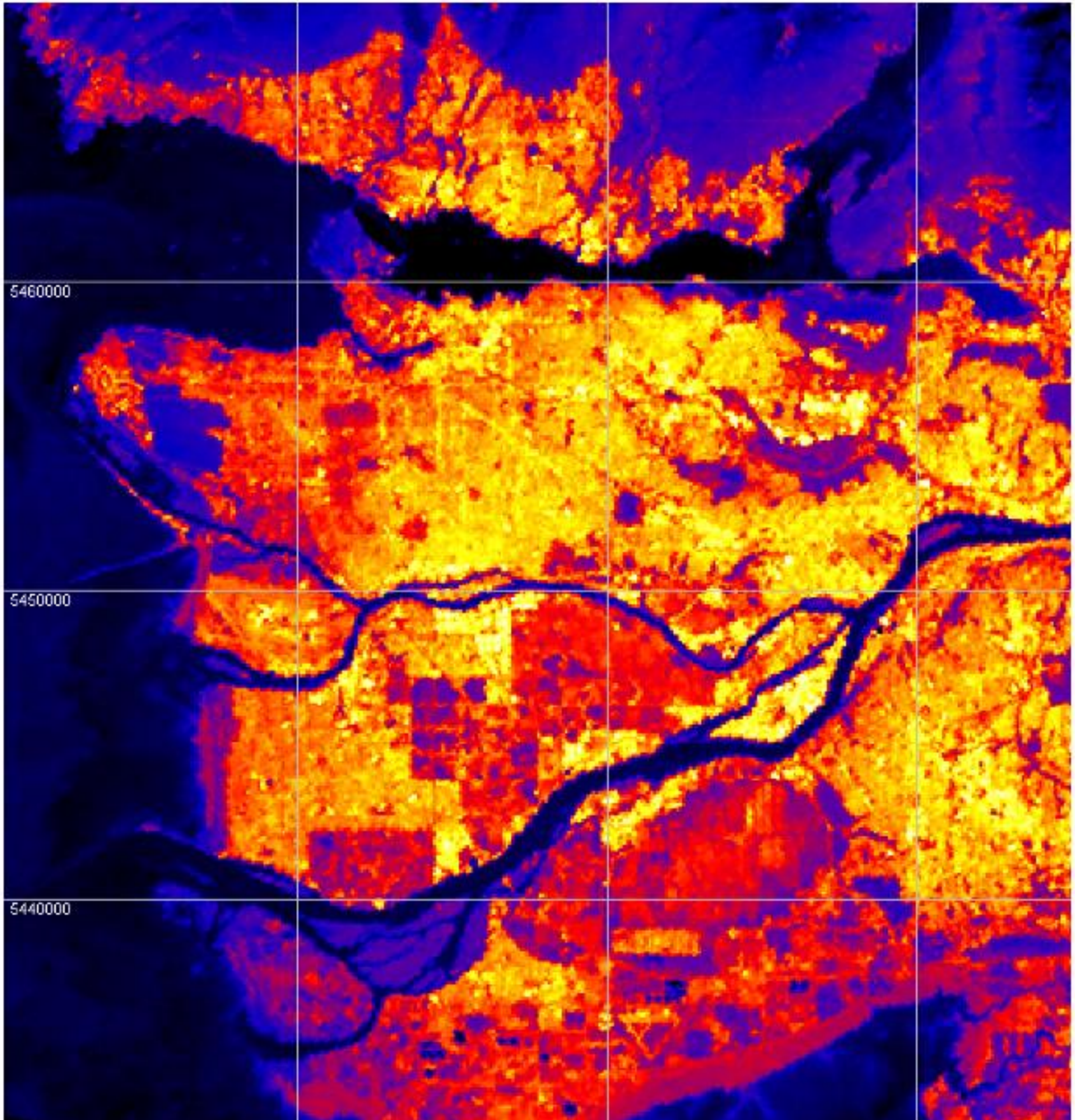
$$\boxed{E_g = \varepsilon \sigma T^4 \quad \star}$$

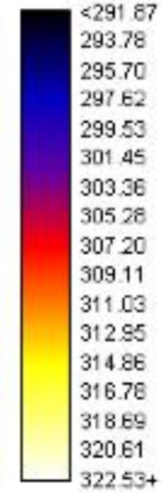
where ε is their **surface emissivity**. Emissivity is the ratio of the actual emission to that of a blackbody (i.e. ε = 1.0).

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)



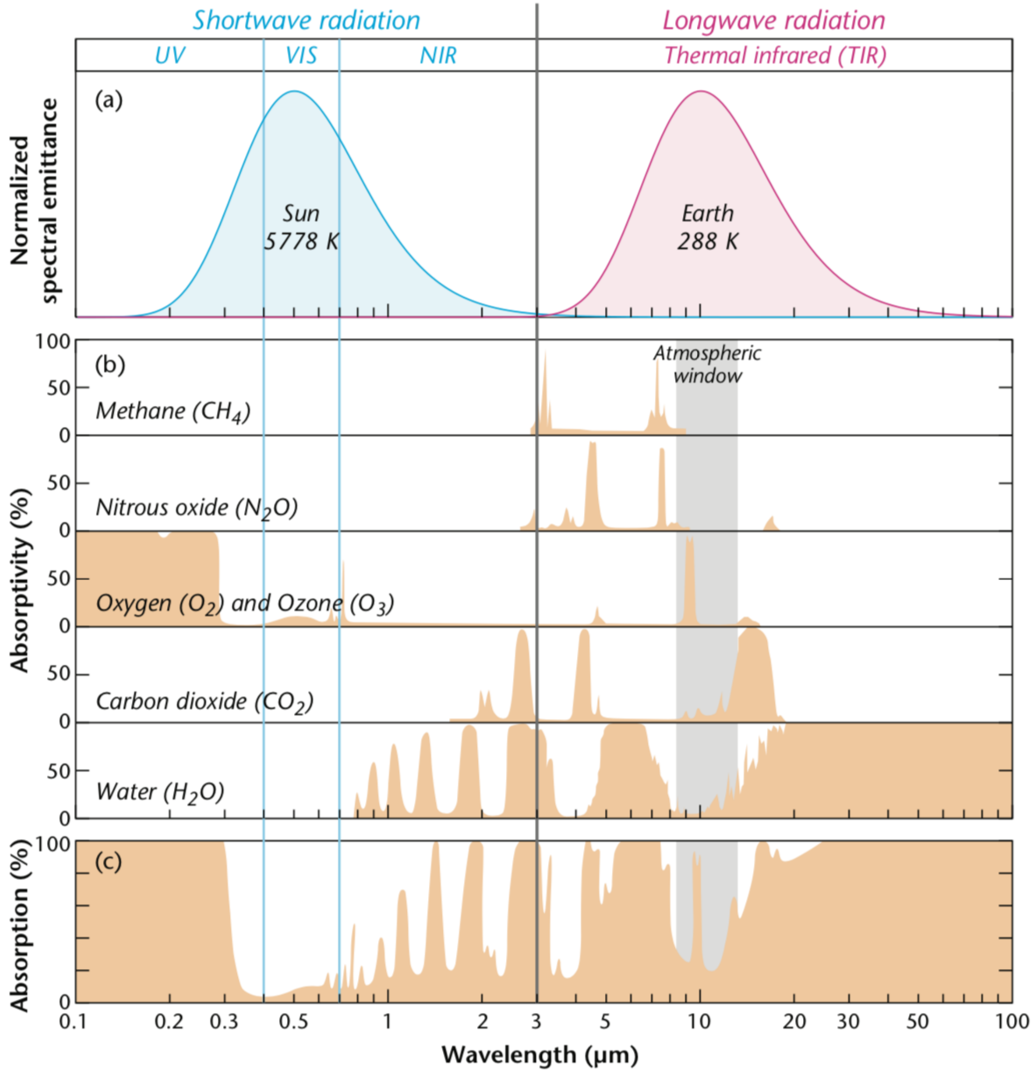


W m^{-2}

Sept 3 2010
12:24 PDT

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

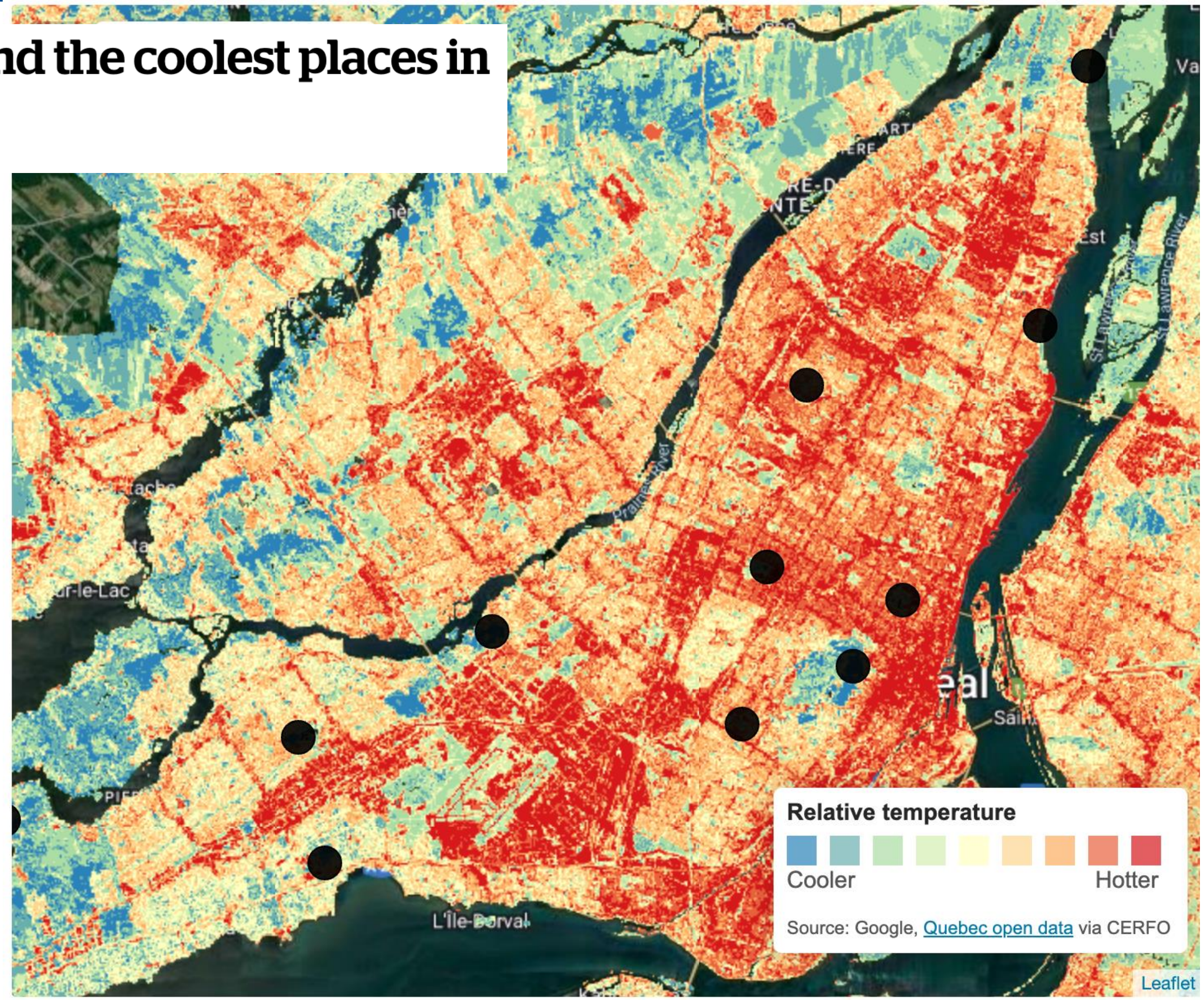
Atmospheric window & remote sensing in the TIR



From emittance we can estimate surface temperature

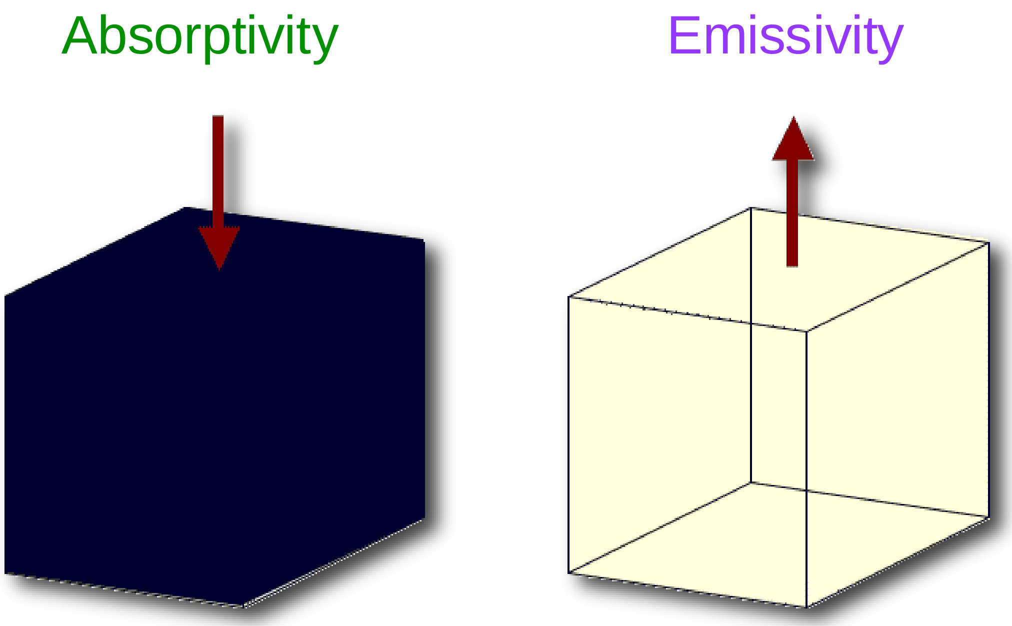
Where are the warmest and the coolest places in Montreal?

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.

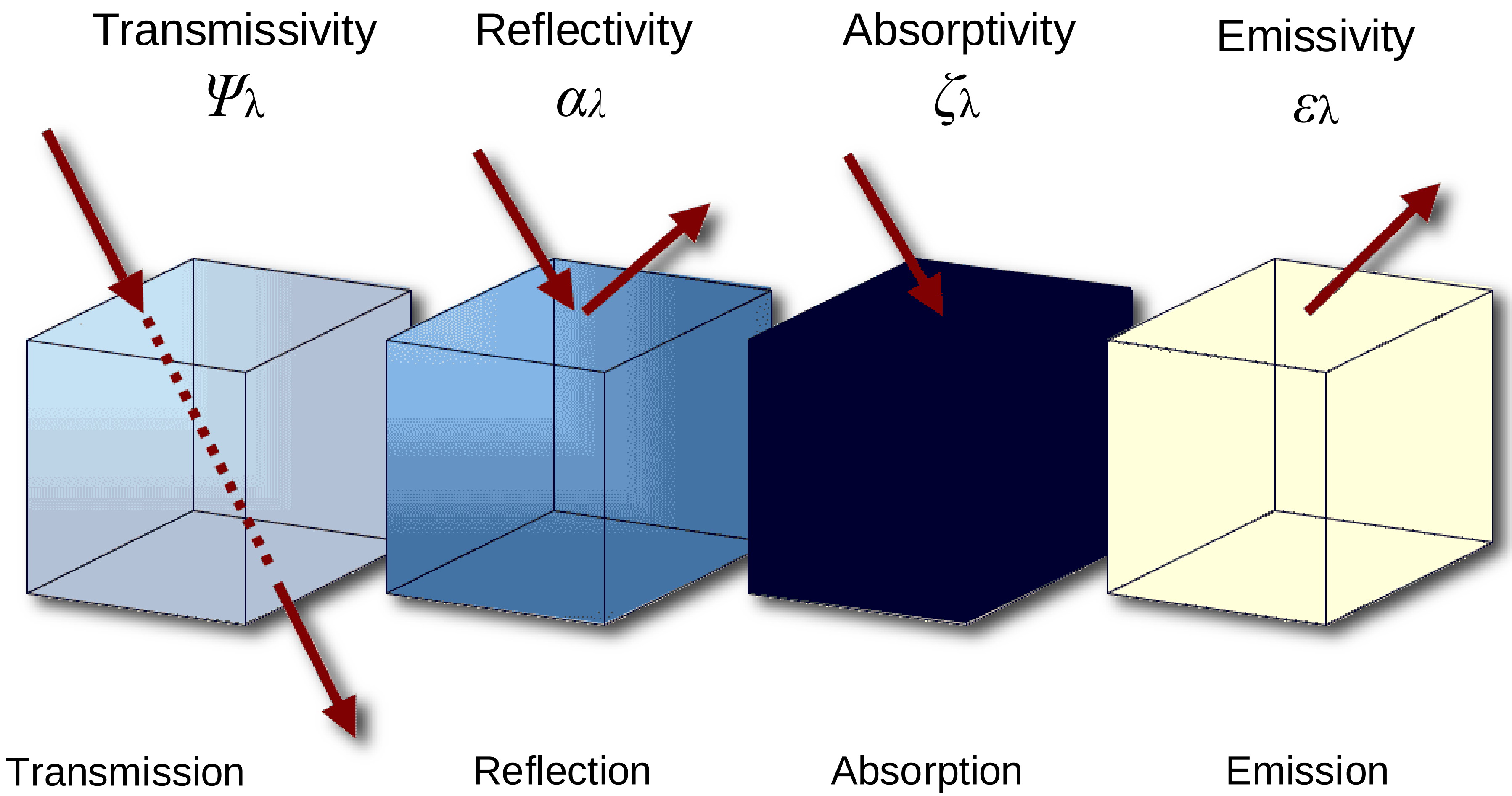
A good absorber is a good emitter

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

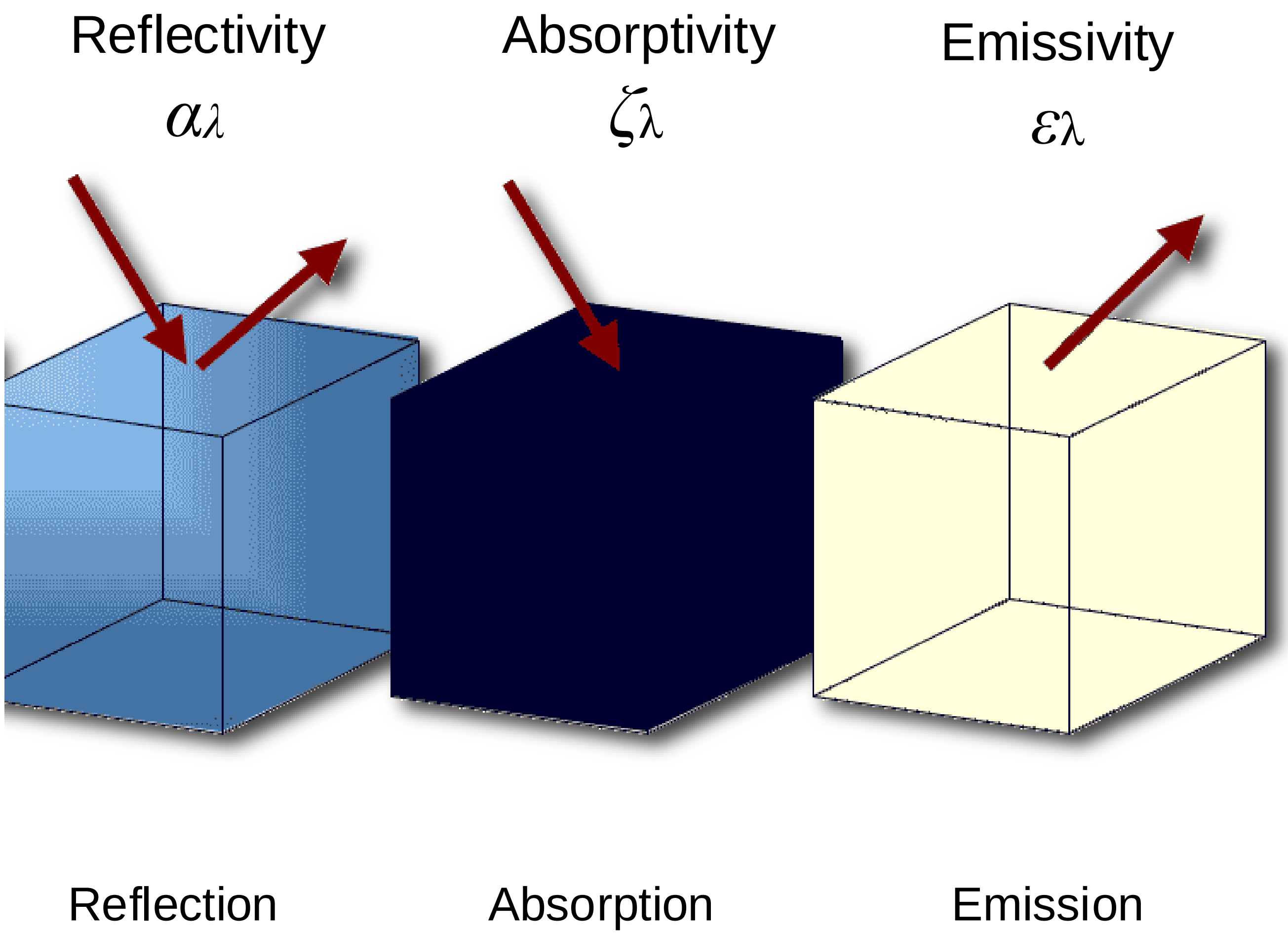
Kirchhoff's law of thermal radiation

- 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



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)

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

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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'

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$$\alpha_{o,LW} = 1 - \varepsilon_{o,LW}$$

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Since $\varepsilon_{o,LW} > 0.95$ it means $\alpha_{o,LW}$ is usually small (< 0.05).

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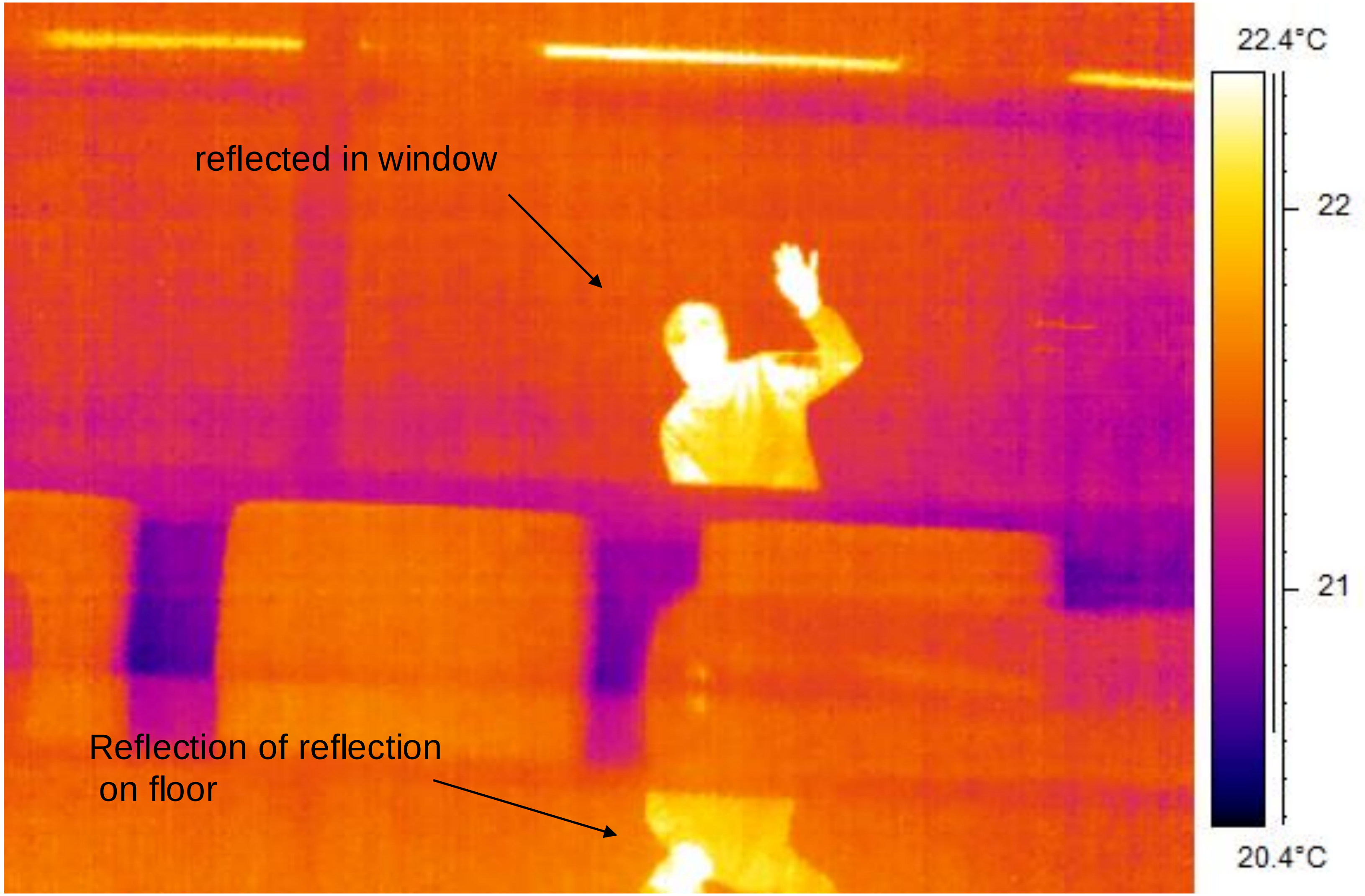
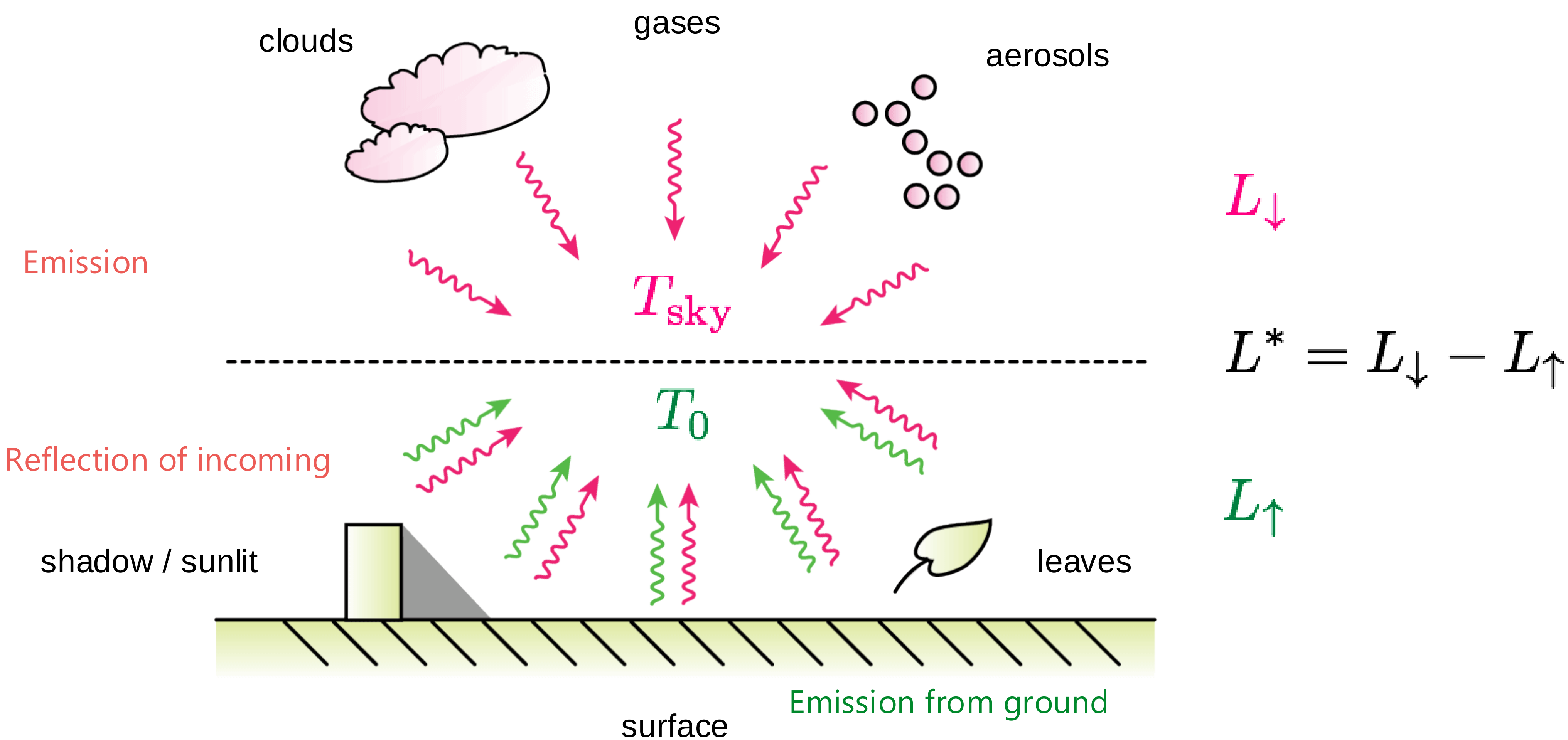
Long-wave reflection



Long-wave radiation exchange of a surface

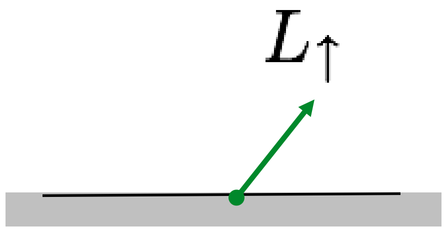


Calculating $L_\uparrow$

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

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

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



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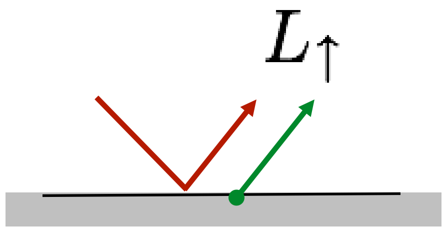

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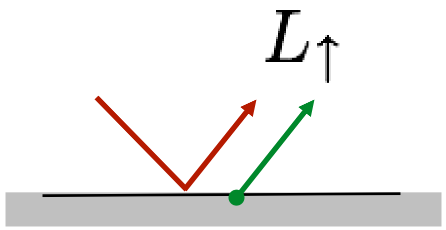

where ζ_o - absorptivity of surface in the long-wave, α_0 reflectivity of surface in the long-wave and from Kirchhoff's law ($\zeta_\lambda = \varepsilon_\lambda$):

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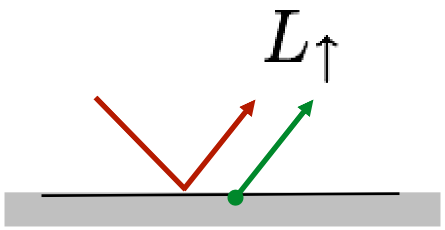

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$$L_\uparrow = \varepsilon_o \sigma T_o^4 + (1-\varepsilon_o) L_\downarrow \quad \star$$

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 $L_\downarrow$:

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

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 $L_\downarrow$:

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

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

Kirchhoff's Law

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

emitted

reflected

Question for discussion

What influences $L_\downarrow$?

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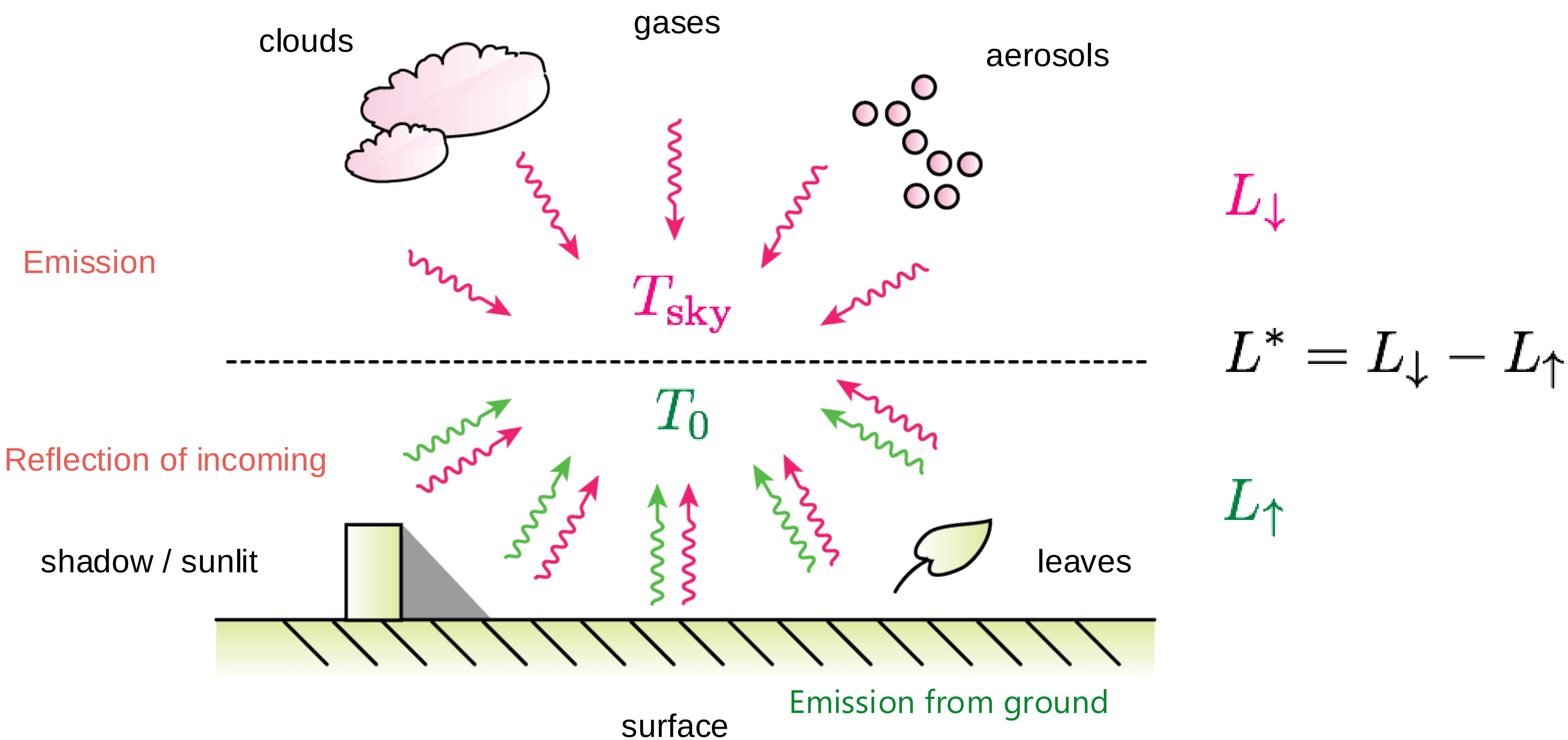
Long-wave radiation exchange of a surface



Long-wave radiation - example of measurements

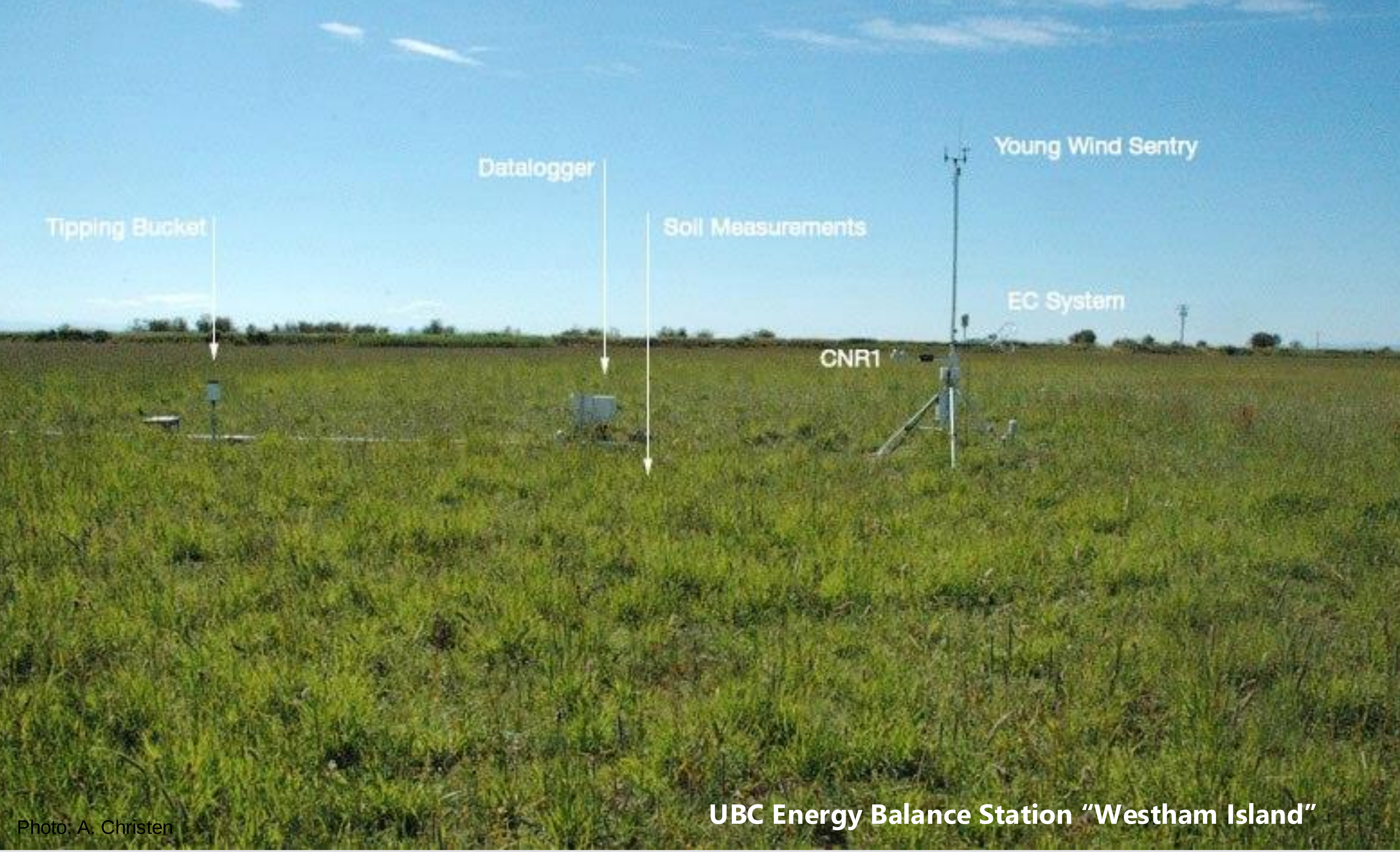
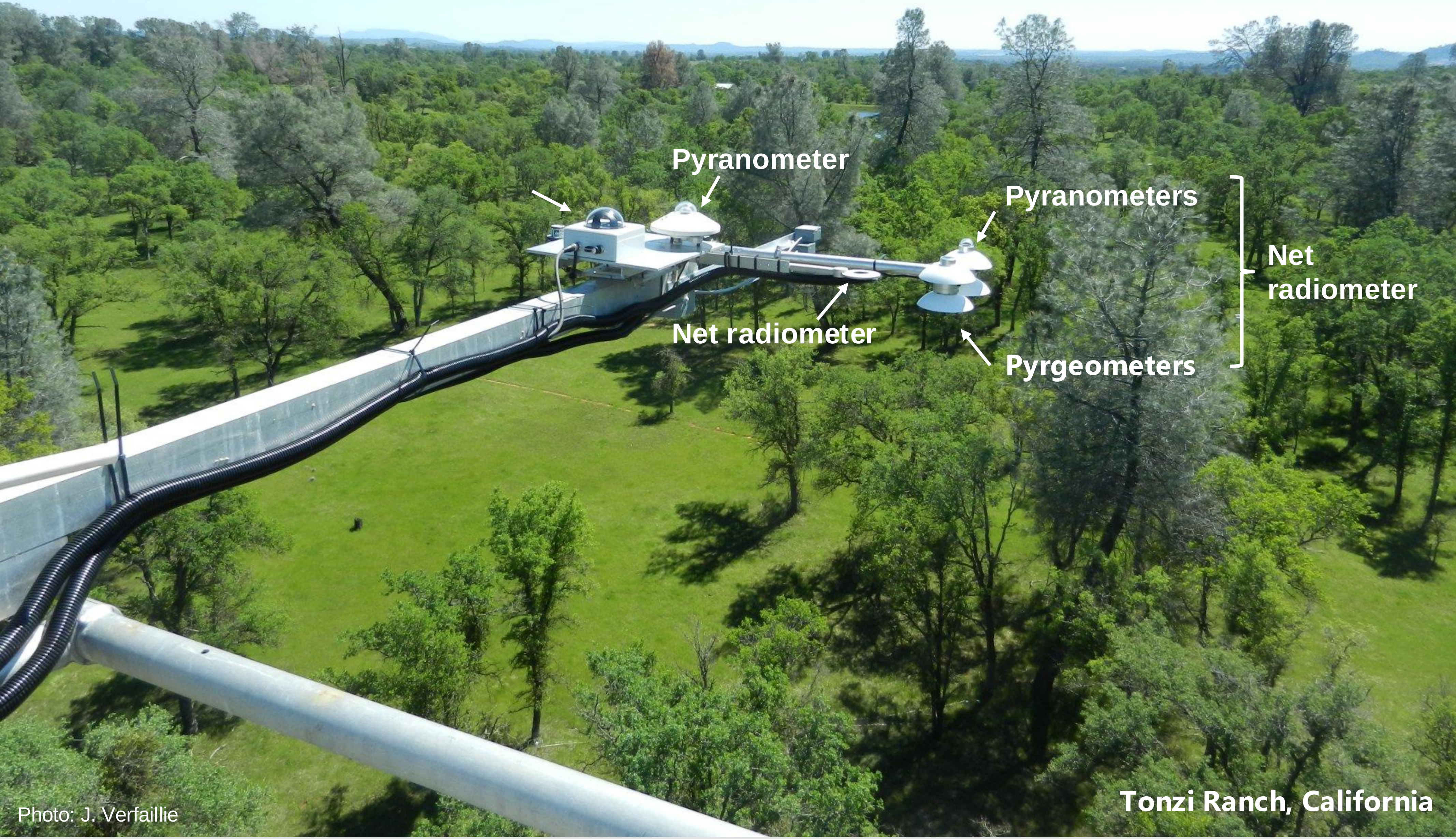
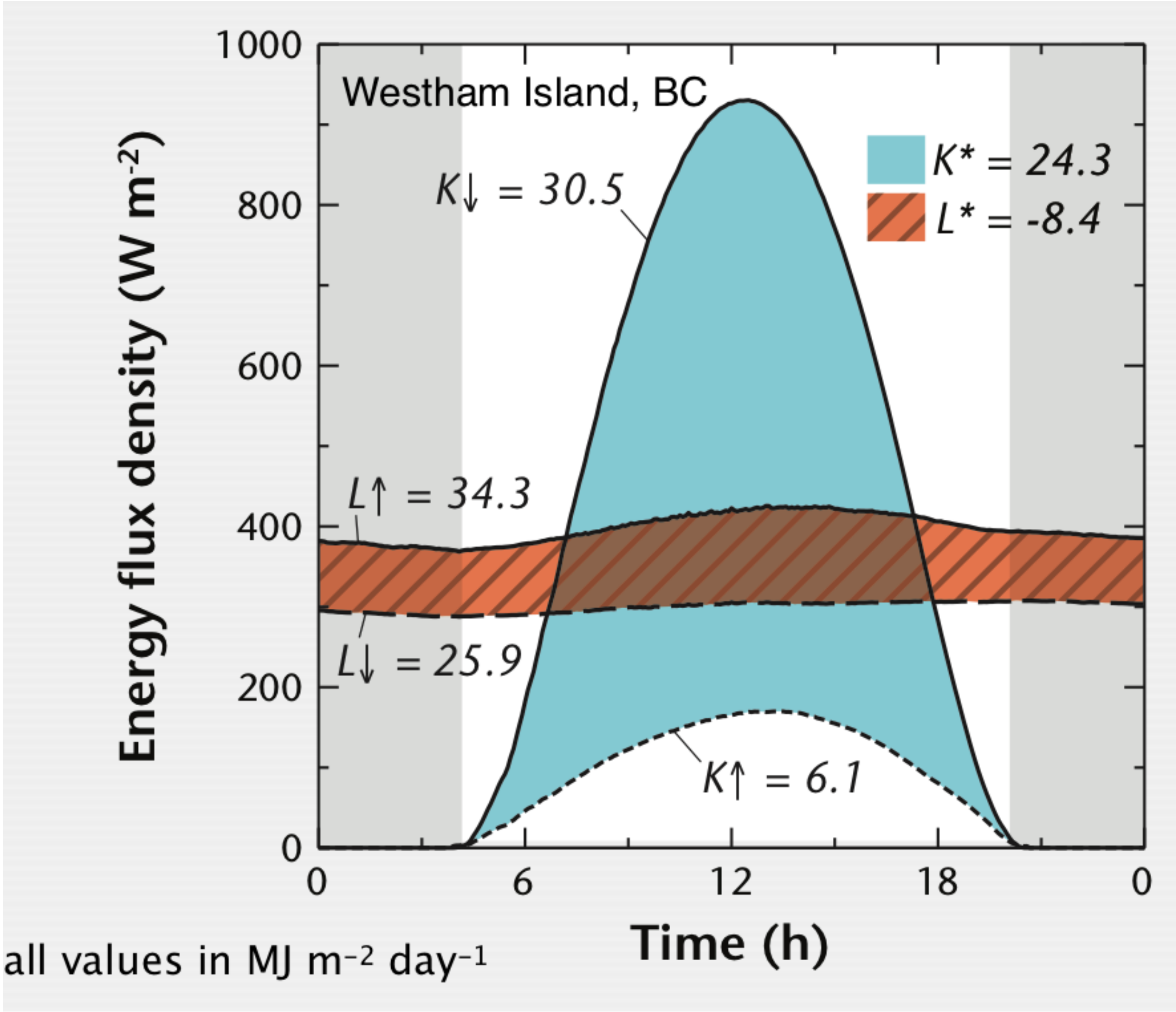


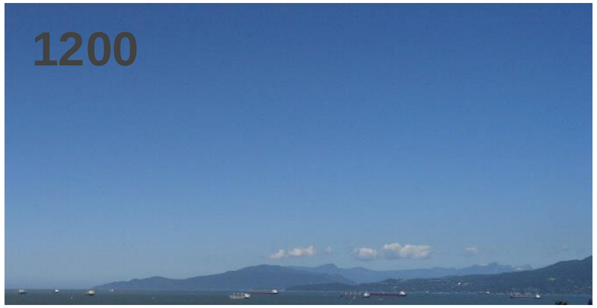
Photo: A. Christen

Long-wave radiation - example of measurements



Diurnal course of radiation - clear sky day





Images from Katkam in Vancouver

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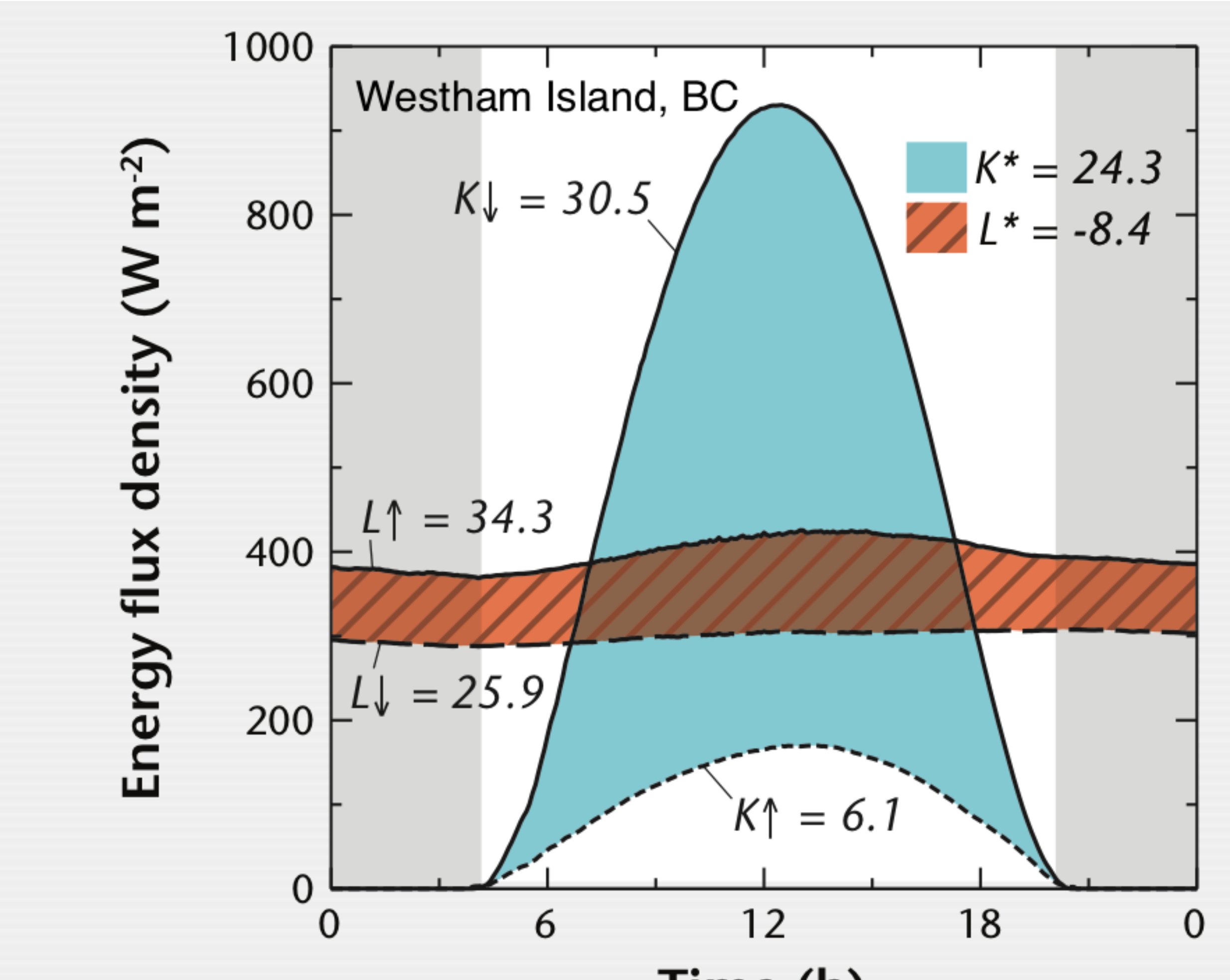
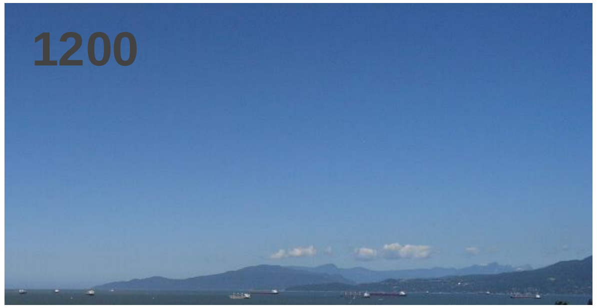
Class activity - Why is $L_{up} > L_{down}$?

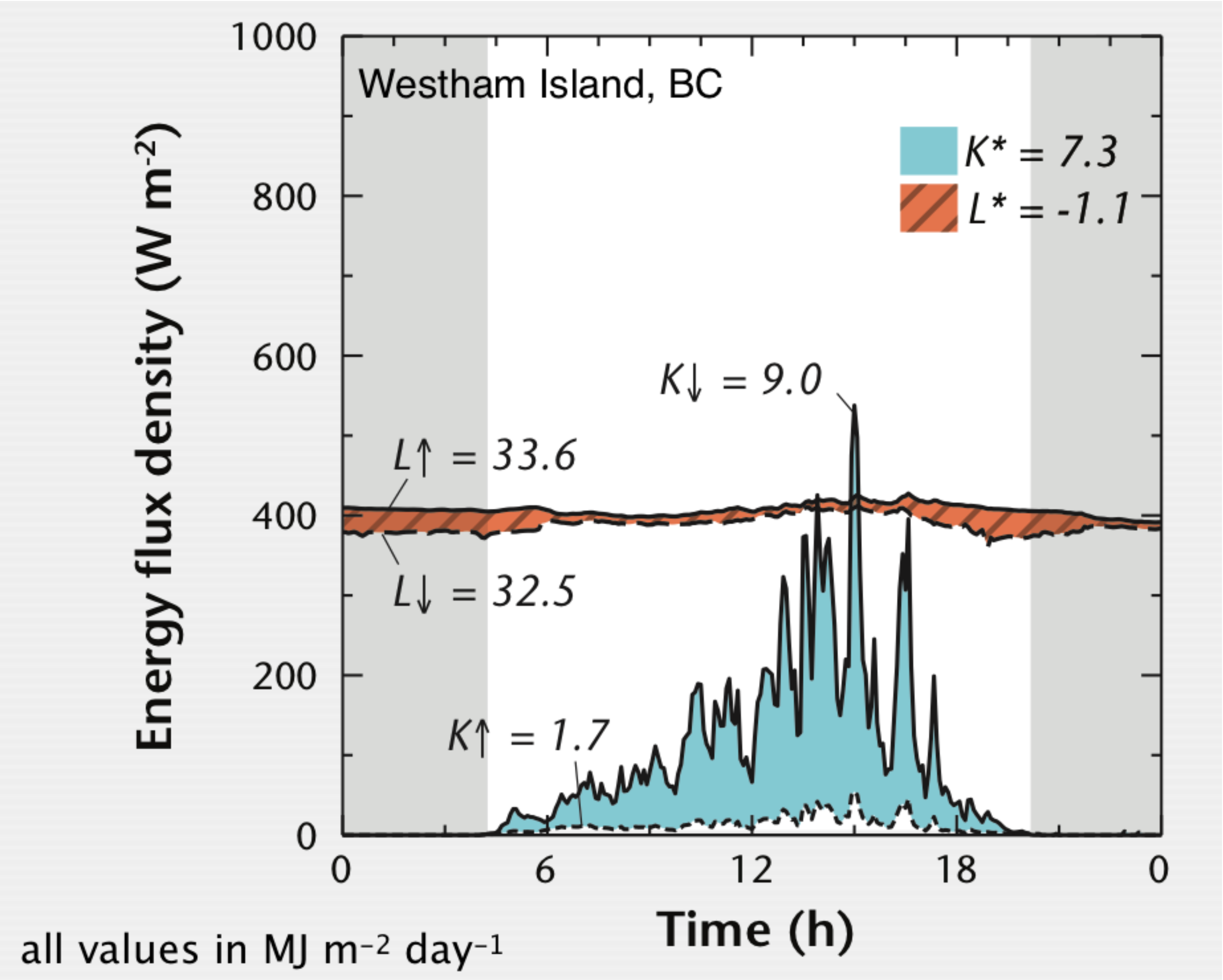


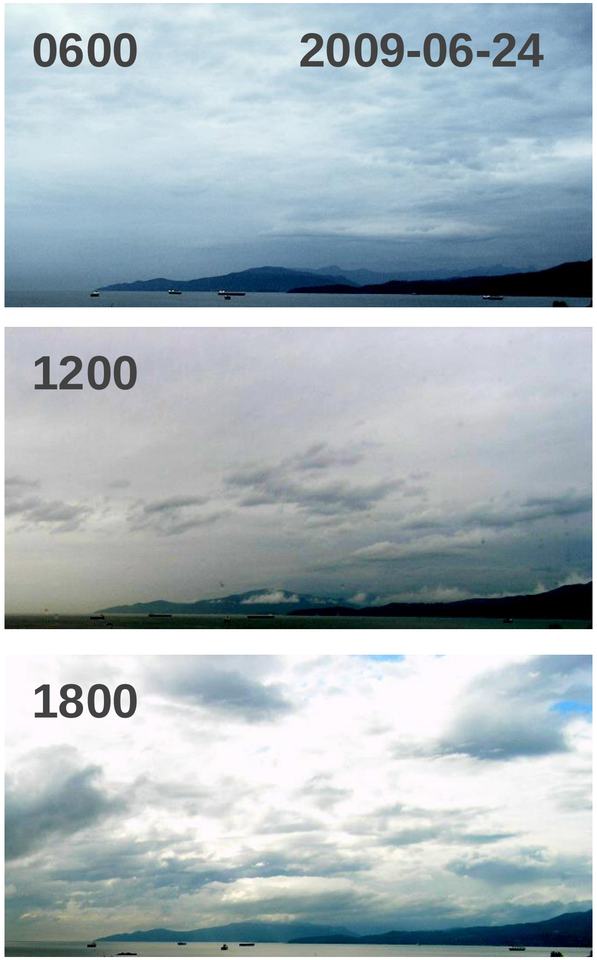
all values in MJ m^{-2} day^{-1}



Images from Katkam in Vancouver

Diurnal course of radiation - overcast / broken sky day



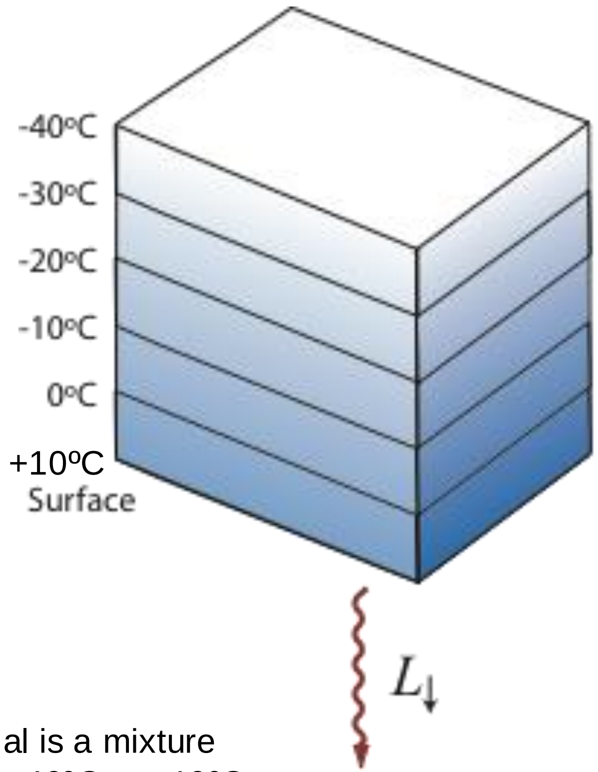


Images from Katkam in Vancouver

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

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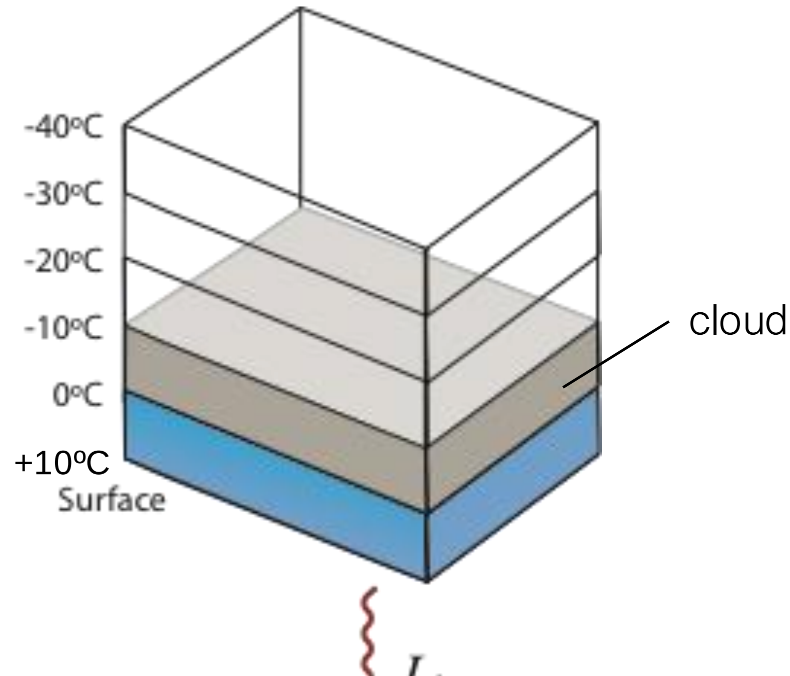
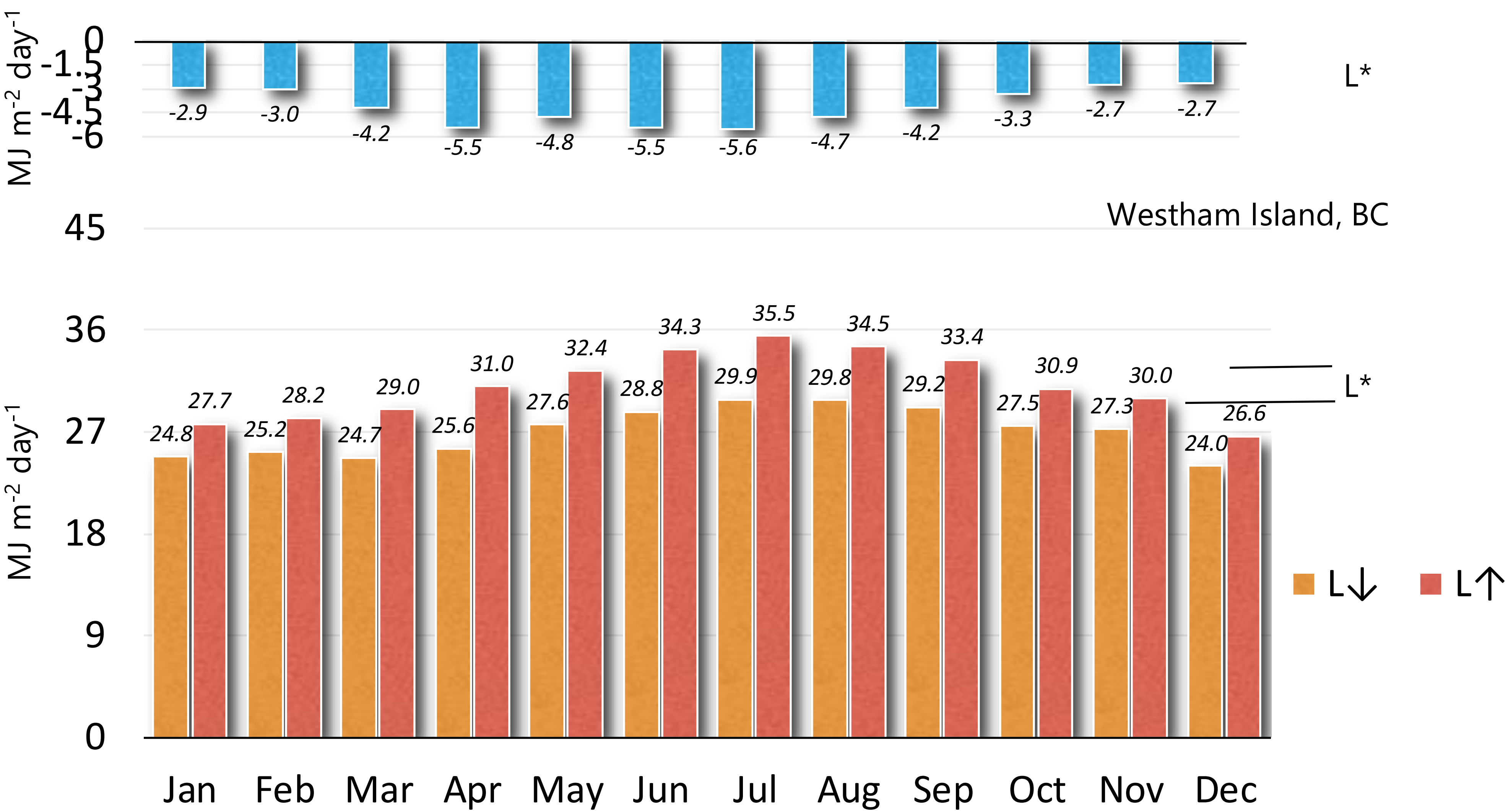
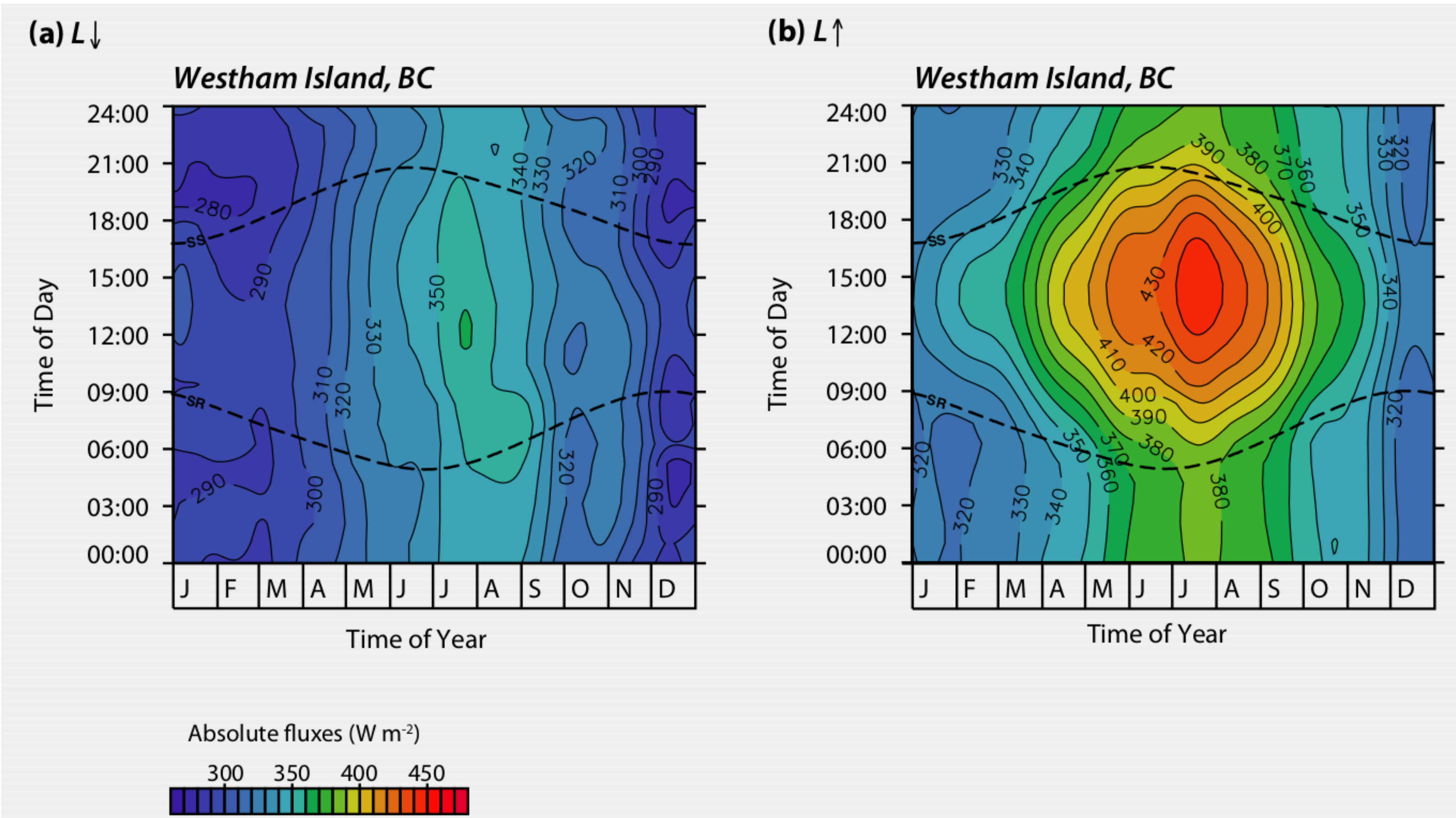


Signal is a mixture from 0º to +10ºC

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.