2nd Protocol: Longwave

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Contents

1 Motivation

All bodies with a temperature above the absolute zero emit electromagnetic radiation. The wavelength and intensity of this radiation depends on the temperature of the body. Within the temperature range of the earth surface, the emitted radiation has a wavelength between 3 and 100 mm and it is defined as longwave.

Emitting longwave radiation is the only way for the plant to cool itself down, making it a crucial aspect in maintaining a steady climate. In fact climate change is caused by green house emissions, which capture part of the longwave radiation emitted by the planet surface and then re-emit in back towards the Earth. This results in a bigger amount of radiation reaching the earth surface, hence increasing its temperature [1].

Contrary to shortwave radiation, that is zero at night, longwave is a constantly present in terrestrial ecosystem. Especially during night the longwave radiation can have a substantial impact on the surface temperature.

2 Background

Longwave radiation has an important impact on the research and measurement of the global energy balance. Longwave radiation implements big changes energy budget when modeling land surface. The measurement of longwave radiation is more complicated in comparison with shortwave radiation. This fact is due to the variables that are measured to estimate shortwave radiation such as vapor pressure and air temperature. Thus, longwave radiation estimation will differ according to the atmospheric emissivity and temperature [2].

The changes produced in the radiation balance of the atmosphere are induced by global warming as an adaptation to this process. These changes are mainly caused by the variation in the level of water vapor present in atmosphere. This is regularized with the absorbed solar radiation and the emitted longwave radiation coming from atmosphere to the surface of earth [3].

In the paper written by Sridhar & Elliott. (2002), some equations are explained for the calculation of incoming longwave radiation.

Through the use of infrared sensors the calculation of outgoing calculation can also be measured. Areas situated close to the ecuador line will present higher amount of outgoing longwave radiation but also higher temperature rates.

Longwave radiation is emitted by all bodies on the Earth, with the total intensity depending on the temperature as described by the *Steffan-Boltzman law.*

$$E = \varepsilon \sigma T^4$$

Where:

- E is the radiation intensity in W/m^2
- ε an adimensional coefficient that represents the emissivity of the body. This depends on the material, a perfect black body has a ε of 1, while other materials have a lower emissivity
- σ is the Steffan-Boltzman constant $5.67 \times 10^{-8} W m^{-2} K^{-4}$
- T is the body temperature in K

As mentioned previously , green house gases emission are constantly increasing. This is causing a higher levels of net temperature, process induce by human known as global warming.

Other part that constitutes longwave radiation are the following terms:

[1] J. E. Harries, The greenhouse Earth: A view from space, 1996 https://doi.org/10.1002/qj.49712253202

[2] Sridhar, V., & Elliott, R. L. (2002). On the development of a simple downwelling longwave radiation scheme. Agricultural and Forest Meteorology, 112(3-4), 237-243.

[3] Stephens, G. L., Wild, M., Stackhouse Jr, P. W., L'Ecuyer, T., Kato, S., & Henderson, D. S. (2012). The global character of the flux of downward longwave radiation. *Journal of Climate*, *25*(7), 2329-2340.

- *Atmospheric longwave radiation:* the emitted flux coming from clouds and water vapor particles present at atmosphere.
- *Surface longwave radiation:* (E), the reflected radiant flux from the planet's surface.

$$E = \varepsilon \sigma T^4$$

- *Reflected longwave radiation:* (R_{lw}) is the reflected radiation occurring when the heat flux heats the surface.

$$R_{lw} = (1 - \varepsilon) * A$$

- *Longwace radiation balance:*

$$Q_{lw} = A - E - R_{lw}$$

The principle followed to calculate the net radiation balance of the planet is based on the sum of Q_{sw} and Q_{lw}. Thus;

$$Q_n = Q_{sw} + Q_{lw}$$
$$Q_n = (1 - r_{sw})G + \varepsilon \sigma T_{atm}^4 - \varepsilon \sigma T_s^4$$

Net radiation (Rn) is defined by Bonan (2019), as the solar and longwave radiation absorbed by the land surface. Another equation used to calculate the land surface energy balance is known as:

$$Rn = (S_{incoming} - S_{outgoing} + (L_{incoming}) - L_{outgoing})$$

Also, emissivity can be defined as (1-τ) and thus, the fraction of longwave radiation that is reaching the earth surface and being bounced back, can be explained (Bonan,2019). [4].

3 Sensors and measuring principle

Longwave radiation is an important flux to understand how climatology works in earth and understand processes such as global. Thus, some instruments have been developed as well to measure longwave radiation.

The pyrgeometer measures this type of radiation from the atmosphere and the Earth's surface. This device is based on a sensitive range with infrared radiation between of 4.5 and 40 micrometer. It includes a thermal detector (64 thermocouple thermophile) based on giving a voltage output that then is needed to convert into radiative flux of energy units (W m-2). The way it works is basic, calculating the difference between the longwave radiation coming from the atmosphere and the longwave produced by the sensor. This is represented by the next equation:

$$L_A = L_{net} + \sigma T_{sensor}^4$$

Another device that allows to measure longwave radiation is the pyrometer. The pyrometer measures longwave radiation and converts it into a temperature based on the Stefan Boltzmann principle. Besides, it exists

[4] Bonan, G. (2019). *Climate change and terrestrial ecosystem modeling.* Cambridge University Press.

other types of sensor based on the measurement of net radiation. One of them is known as CNR4, based on 4 components (G, Rsw, A, E) which gives an output value for each of these. The other instrument that can be used for the same application is NR-Lite2. It is based on a thermophile that measures net radiation (G+A) in the upper side, whether in the other side it is measuring the net outgoing radiation (Rsw+E). These last two are similar instruments, but the last one (NR-Lite2) only gives one value as output in shape of voltage which is proportional to the Rn or net radiation.

4 Analysis

```
rad <- read_csv("../Data_lectures/2_Longwave_radiation/LW_SW_TSoil_BotGarten.csv")
names(rad) <- c("datetime", "t_sens", "sw_in", "sw_out", "lw_in_sens", "lw_out_sens", "t_soil")
```

```
# Utlitity funcs
sigma <- 5.67e-8

lw2temp <- function(lw) (lw/ sigma)^(1/4)
temp2lw <- function(temp)  return (sigma * temp^4)

c2k <- function(c) c + 273.15
k2c <- function(k) k - 273.15
```

```
#calculate from input data the real lw and the soil/surface temperature
rad <- rad %>%
  drop_na() %>%
  mutate(
    lw_sens = temp2lw(c2k(t_sens)),
    lw_in = lw_in_sens + lw_sens,
    lw_out = lw_out_sens + lw_sens,
    t_sky = lw2temp(lw_in) %>% k2c,
    t_surface = lw2temp(lw_out) %>% k2c,
    net_rad = lw_in - lw_out + sw_in - sw_out,
    net_sw = sw_in - sw_out,
    net_lw = lw_in - lw_out
  )
```

```
# for making aggregation easier we are going to consider data only for one calendar year
rad <- rad %>%
  filter(datetime < as_datetime("2020-12-31"))
```

```
# weekly average data
rad_w <- rad %>%
  as_tsibble(index = datetime) %>%
  index_by(week = ~ yearweek(.)) %>%
  summarise_all(mean, na.rm = TRUE)
```

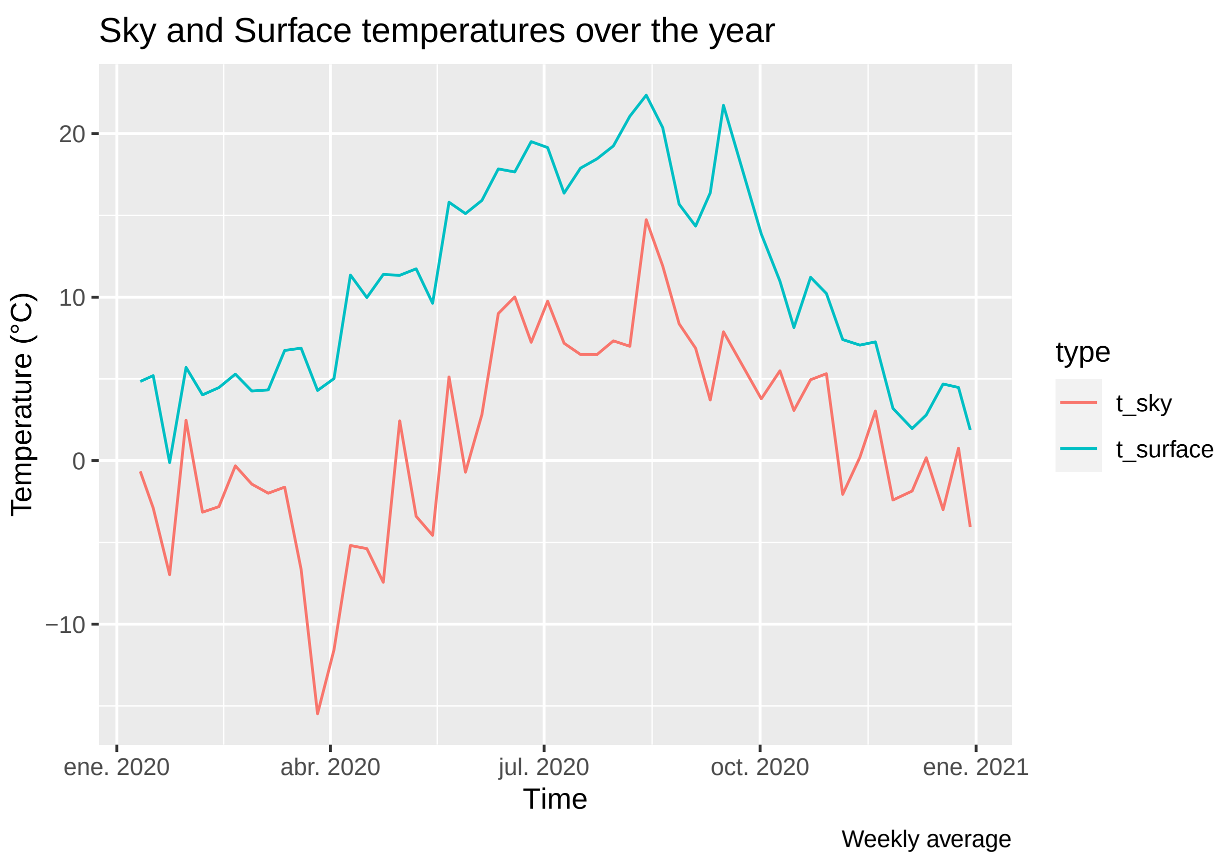
```
# daily average data
rad_d <- rad %>%
  mutate(yday = yday(datetime)) %>%
  group_by(yday) %>%
  summarize_all(mean, na.rm = TRUE)
```

4.1 Surface and Sky temperature

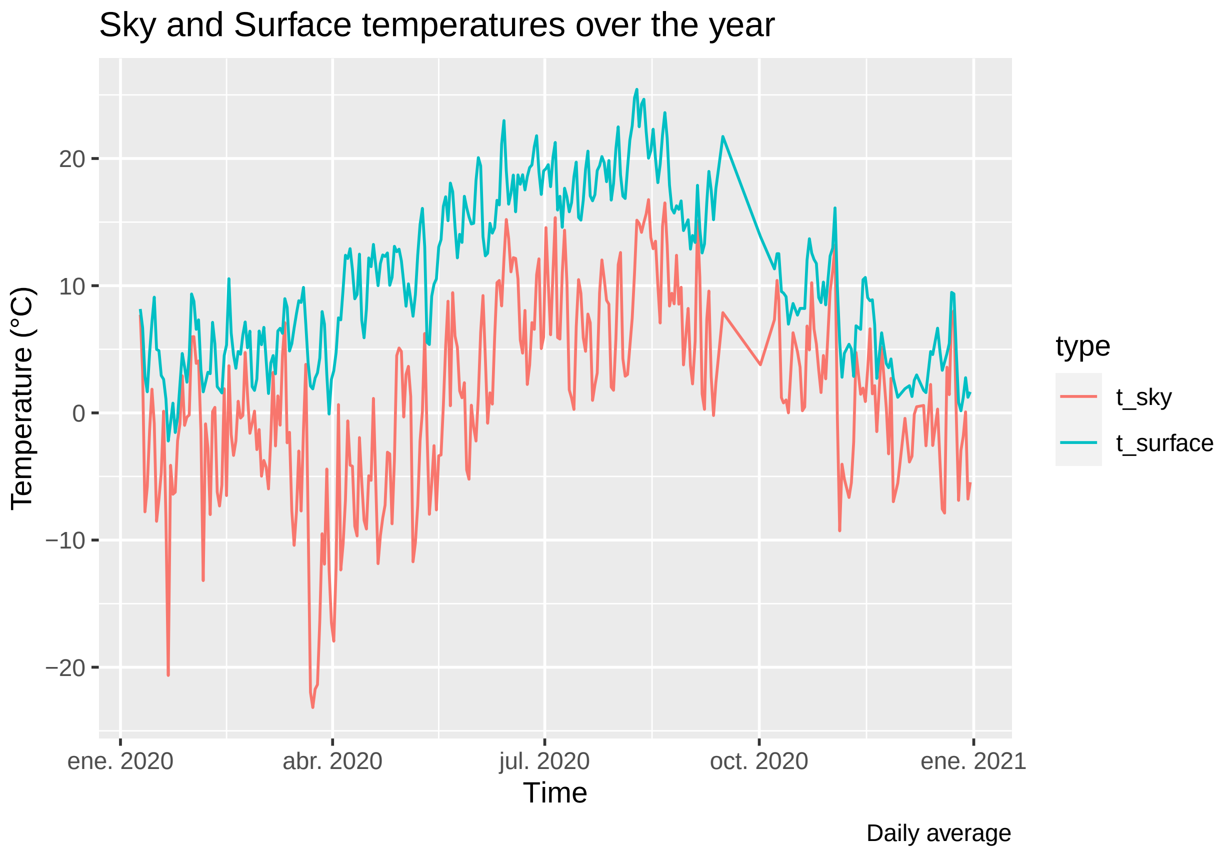
Derive the sky and surface temperature from the longwave radiation components. How do they differ and why? Discuss! During which periods of the year sky and surface temperature differ the most and the less?

The two temperature are analyzed at different timescales

```
rad_w %>%
  gather(key="type", value="temp", t_sky, t_surface) %>%
ggplot(aes(x=datetime, y=temp, colour=type)) +
  geom_line() +
  labs(caption="Weekly average", y="Temperature (°C)", x="Time",
       title="Sky and Surface temperatures over the year")
```

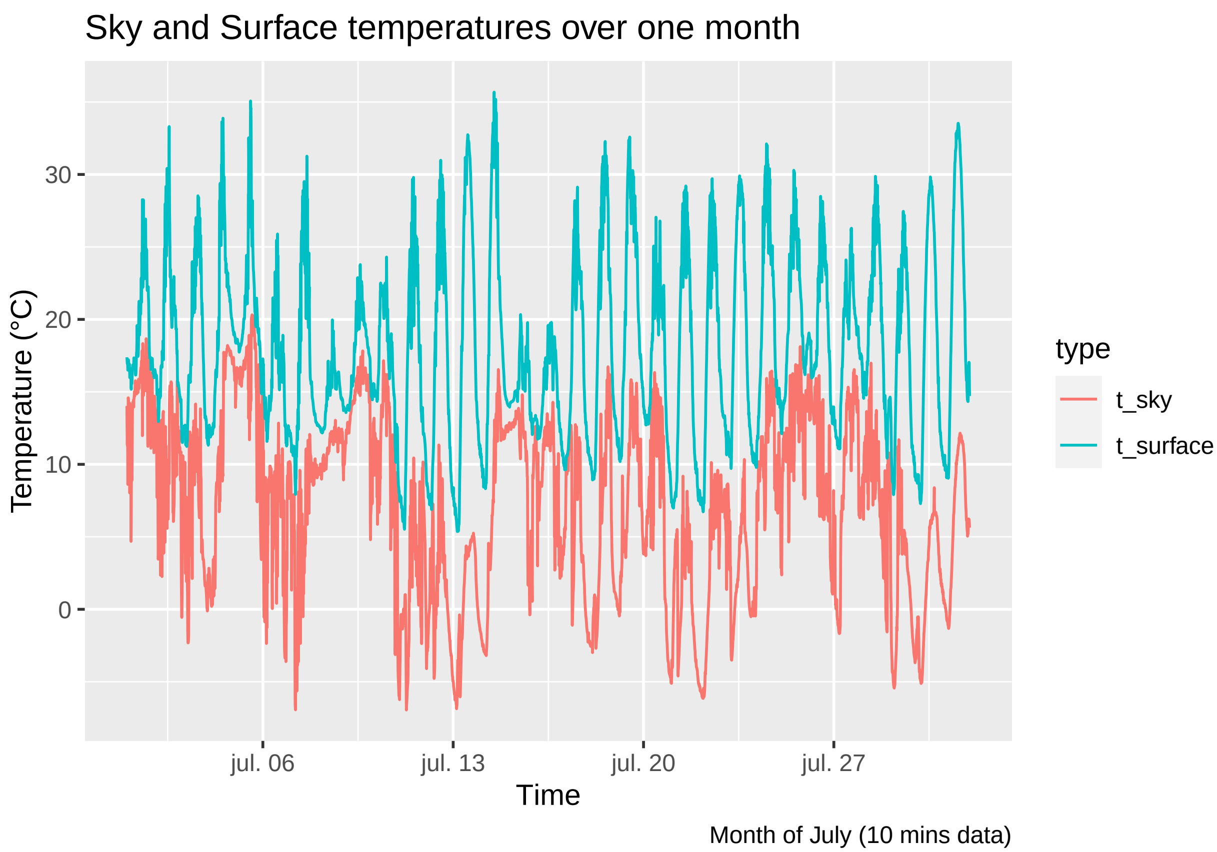


```
rad_d %>%
  gather(key="type", value="temp", t_sky, t_surface) %>%
ggplot(aes(x=datetime, y=temp, colour=type)) +
  geom_line()  +
  labs(caption="Daily average", y="Temperature (°C)", x="Time",
       title="Sky and Surface temperatures over the year")
```

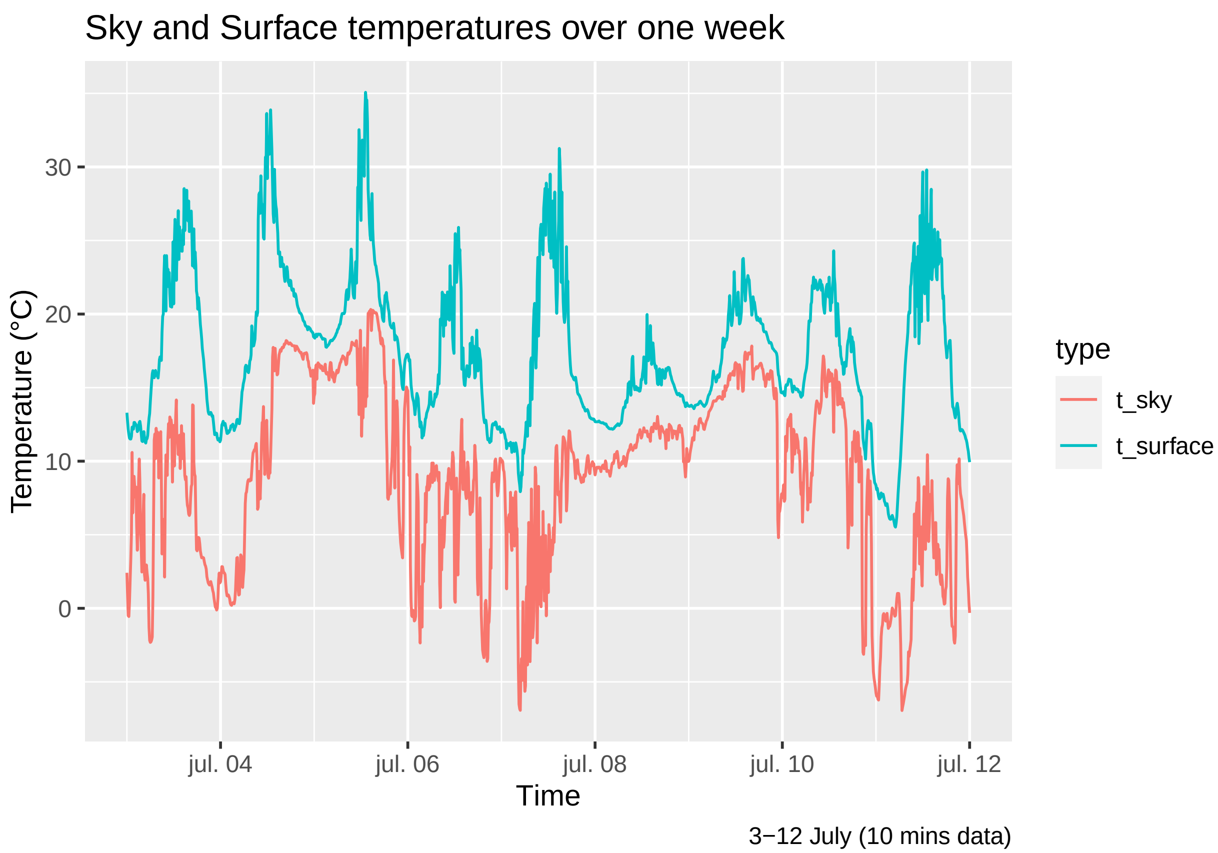


The sky temperatures is always lower than the surface one. The surface temperature ranges from -2 C to 25 C, while the sky temperature has a bigger range from -23 C to 17 C. The temperature of the sky mainly depends on the cloud cover and the temperature of the air.

```r
rad %>%
  filter( month(datetime) == 7 ) %>%
  gather(key="type", value="temp", t_sky, t_surface) %>%
ggplot(aes(x=datetime, y=temp, colour=type)) +
  geom_line()  +
  labs(caption="Month of July (10 mins data)", y="Temperature (°C)", x="Time",
       title="Sky and Surface temperatures over one month")
```



```r
filter(rad, between(datetime, as_datetime("2020-07-03"), as_datetime("2020-07-12"))) %>%
  gather(key="type", value="temp", t_sky, t_surface) %>%
ggplot(aes(x=datetime, y=temp, colour=type)) +
  geom_line()  +
  labs(caption="3-12 July (10 mins data)", y="Temperature (°C)", x="Time",
       title="Sky and Surface temperatures over one week")
```

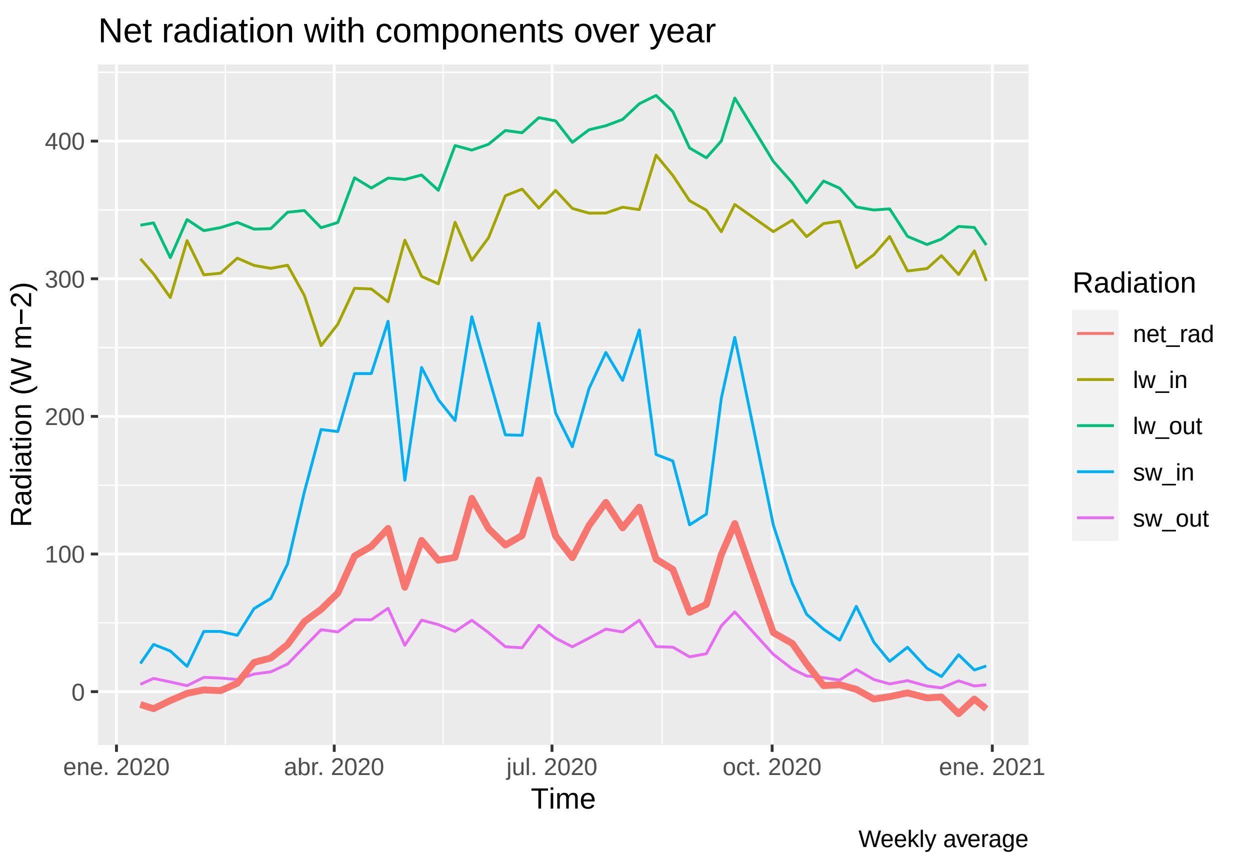


The surface temperature has a clear day cycle, while the sky temperature has little or no day pattern. Moreover, it can be clearly seen how cloudy days (eg. 9th of July) there is a high sky temperature, but a low surface temperature. Conversely, on sunny days (eg. 7th of July) the surface temperature is higher, but the sky temperature is low.

4.2 Net radiation

Calculate the net radiation over the meadow in the forest botanical garden and plot the four components. How do the four components change over the season and why? Which unexpected results you found? Discuss!

```
rad_w %>%
  gather(key="type", value="radiation", net_rad, lw_in, lw_out, sw_in, sw_out,
         factor_key = T) %>%
ggplot() +
  geom_line(aes(x=datetime, y=radiation, colour=type)) +
  geom_line(aes(x=datetime, y=net_rad), data=rad_w, size=1.2,
            colour=hue_pal()(1)) +
  labs(title="Net radiation with components over year ", y="Radiation (W m-2)",
       x="Time", caption = "Weekly average", colour="Radiation")
```



The net radiation has a yearly cycle. During the summer it has a relatively constant value at around $100W/m^2$, then it decrease and reach slightly negative values in January. The biggest driver of this yearly cycle is the incoming shortwave radiation, which during summer is much higher than in winter. The radiation from the sun has smooth variations, while the variation on the incoming shortwave during the summer can be explained by the different amount of cloud cover. You would expect a clearer peak of the shortwave radiation during the summer, Moreover the net radiation has an high peak in mid late September. This behavior can probably be explained by different amount of cloud cover.

The outgoing shortwave is the component with the smallest absolute value, it also has a yearly cycle being virtually zero in January but quickly reaching the max value during the spring and then remaining quite flat. Regarding the longwave the outgoing radiation is always bigger than the incoming, due to the higher temperature of the surface compared to the sky. The longwave components have a much smaller change during the year.

There is a notable low peak of incoming longwave in the last week of march, that is probably explained by clear skies but still low air temperature.

4.3 Change emissity in the sensor

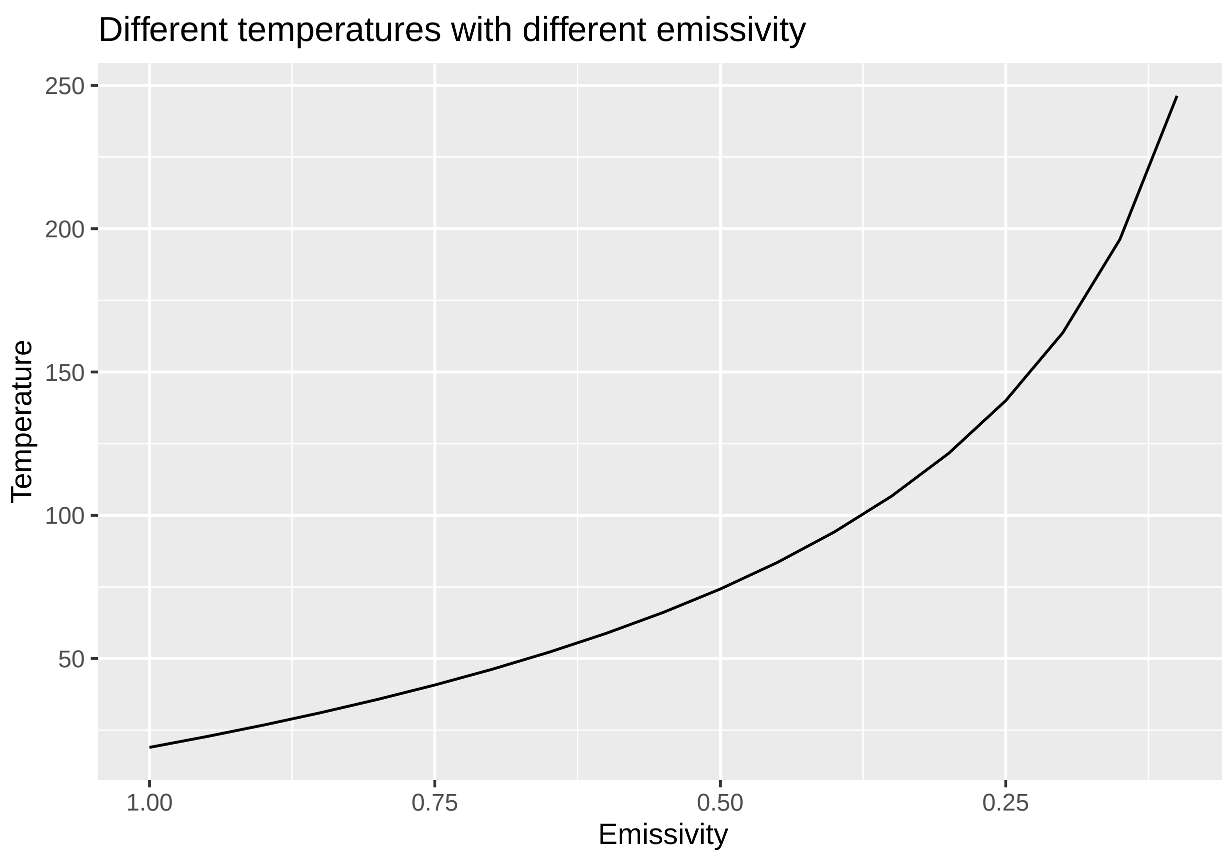
In the field activity we tried to measure the temperature of the surface by using different emissivity settings in the sensor and see how that could influence the readings. However, there have been some issues with the sensor, so the data has been generated using the formula from the theory

In this virtual experiment the real temperature is set to 19řC and the emissivity is changed, resulting in different temperature estimates.

```
t_0 <- 19 # temperature with emissivity 1
rad_0 <- c2k(t_0) %>% temp2lw # connected radiation

temps <- tibble(
  em = seq(1, .1, -.05),
  t = (rad_0 / (em * sigma))^(1/4)  %>% k2c
)
```

```
ggplot(temps, aes(em, t)) +
  geom_line() +
  scale_x_reverse() +
  labs(x="Emissivity", y="Temperature", title="Different temperatures with different emissivity")
```



It can be seen that the emissivity has a big influence on the temperature estimate. The emissivity of material can change drastically from 0.03 for aluminum foil to 0.97 for ice. This clearly shoes the importance of a correct estimation of the emissivity for temperature measurements.