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Measurement of the Reference Surface Air Temperature from Brightness Temperature of Atmospheric Radiation

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Summary

- We have performed a field intercomparison:
  - A shielded thermometer
  - Two types of instruments using the brightness temperature of atmospheric radiation as candidates for measuring the reference surface air temperature
  - Other candidates
    - A very thin handmade thermocouple
    - Two ultrasonic anemometer and thermometers
- Our preliminary analysis indicates that radiometers have great potential for measuring the reference surface air temperature.

Acknowledgment: This work was supported by JSPS KAKENHI Grant Number JP17K20051.

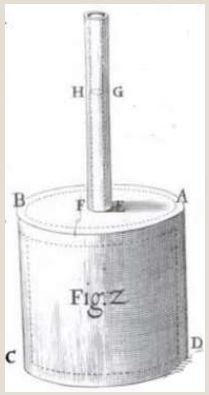
Air temperature has been measured by thermometers over 300 years, but a thermometer measures only “a temperature of a thermometer”

Heat budget of a thermometer (Kondo, 1982)

T_s: Temperature of a thermometer
T: Air Temperature

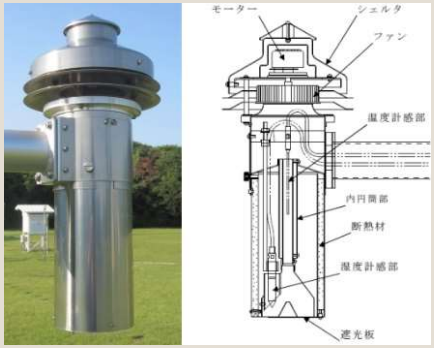
$$\frac{dT_s}{dt}=\frac{S}{c_0 M}\{R-\sigma T_s^4-c_p\rho(C_h U)(T_s-T)\}$$

- energy from outside sources
- radiation emitted by a thermometer
- heat exchange between air and a thermometer



Hooke, 1665

- Solar radiation is majority of energy from outside sources.
- Numerous types of thermometer screens/shields has been developed to minimize the impact of radiation.



Japan Meteorological Agency

Many intercomparisons have been performed to evaluate their characteristics…

WMO field intercomparison of thermometer screens/shields and humidity measuring instruments: Ghardaia, Algeria, November 2008-October 2009

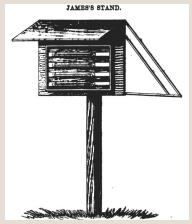
18 types of screens/shield (11 naturally ventilated, 7 Artificially ventilated)

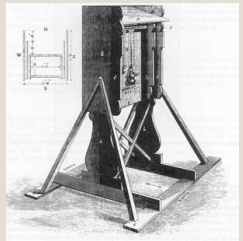
Meterorological Instrument Centre, Japan Meteorological Agency, Tsukuba, Japan, August, December 2009-September 2010

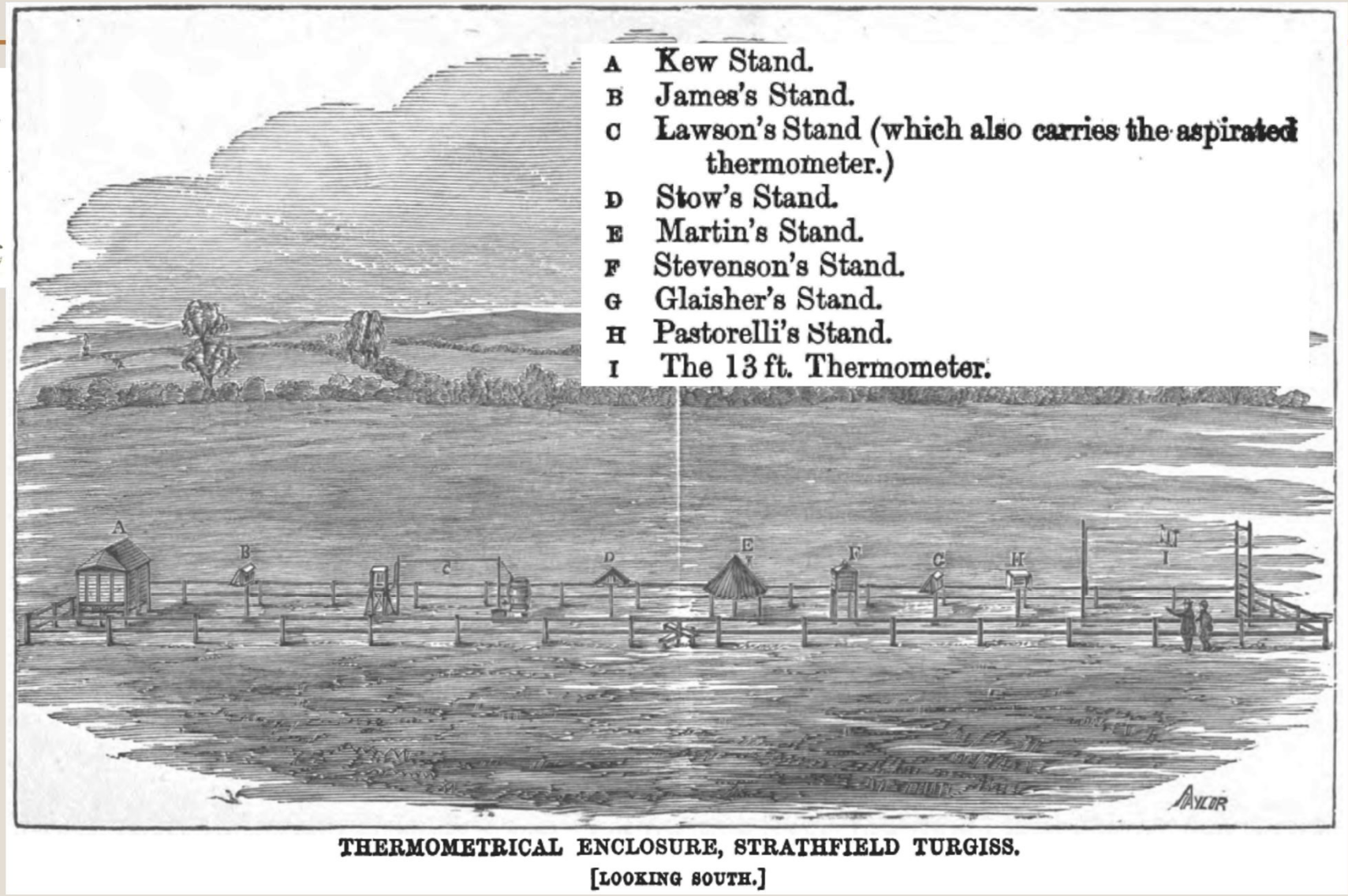
11 types of screens/shield (4 naturally ventilated, 7 Artificially ventilated)

…from 150 Years ago

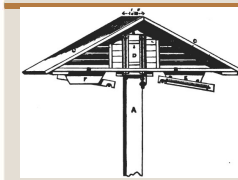
Intercomparison of thermometer stands in England 1868-1870







THERMOMETRICAL ENCLOSURE, STRATHFIELD TURGISS.
[LOOKING SOUTH.]



Symons's Monthly Meteorological Magazine (1869)

Which one is “true”?

Daily maximum temperature of artificially ventilated screen

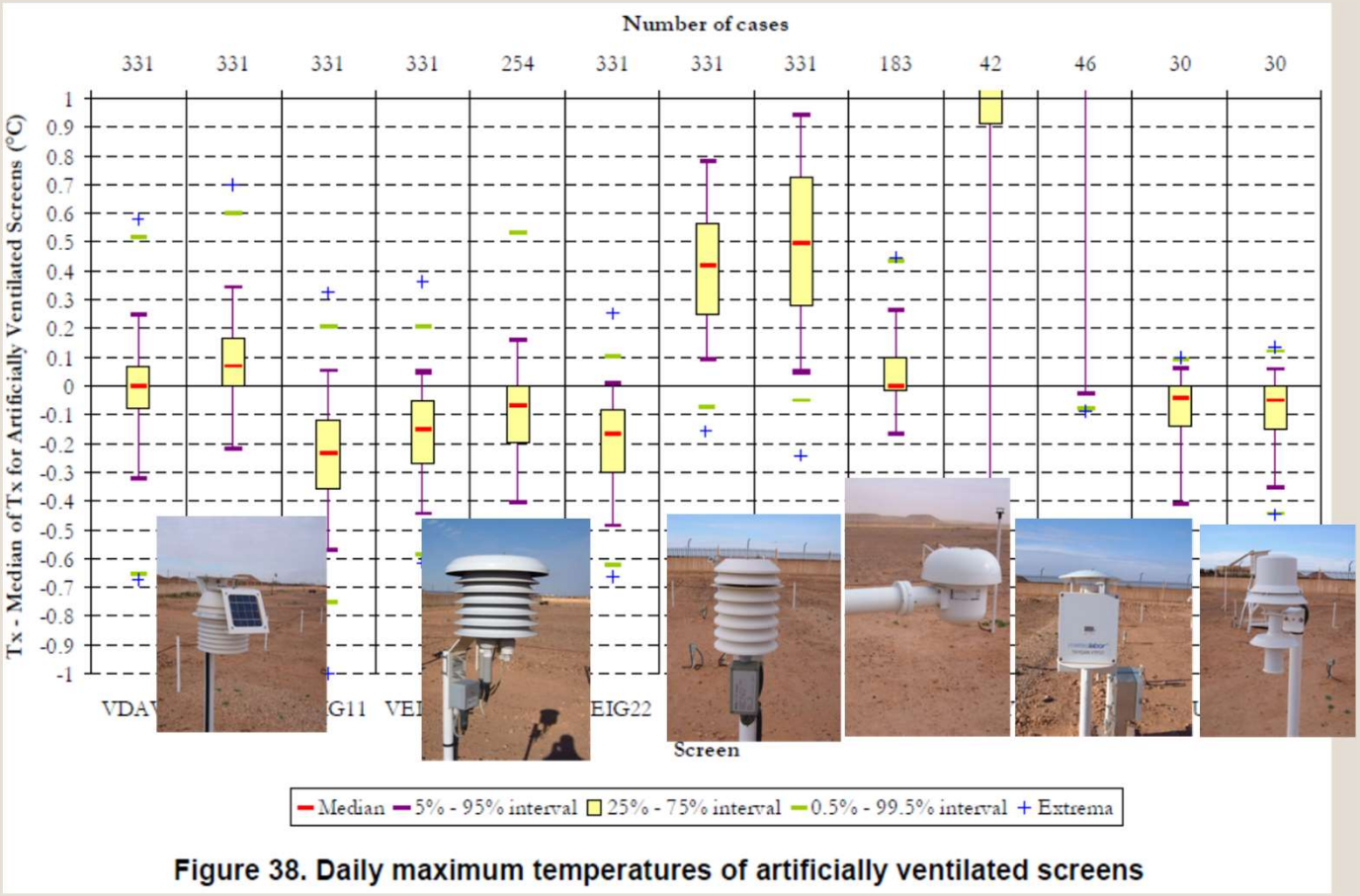


Figure 38. Daily maximum temperatures of artificially ventilated screens

Lacombe et al. 2011)

Intercomparison is only a relative evaluation.

“There is no recognised reference system for measuring the true air temperature.” (ISO 17714:2007)

Reference surface air temperature measurement is effective to evaluate characteristics of screens/shields

- Some potential candidates for measuring the reference surface air temperature have been suggested.
- Candidates:
  - Very thin resistive wire（ISO 2007)
  - Ultrasonic anemometer（Lacombe et al. 2011）
  - **Radiometer** (Yamamoto 2016)

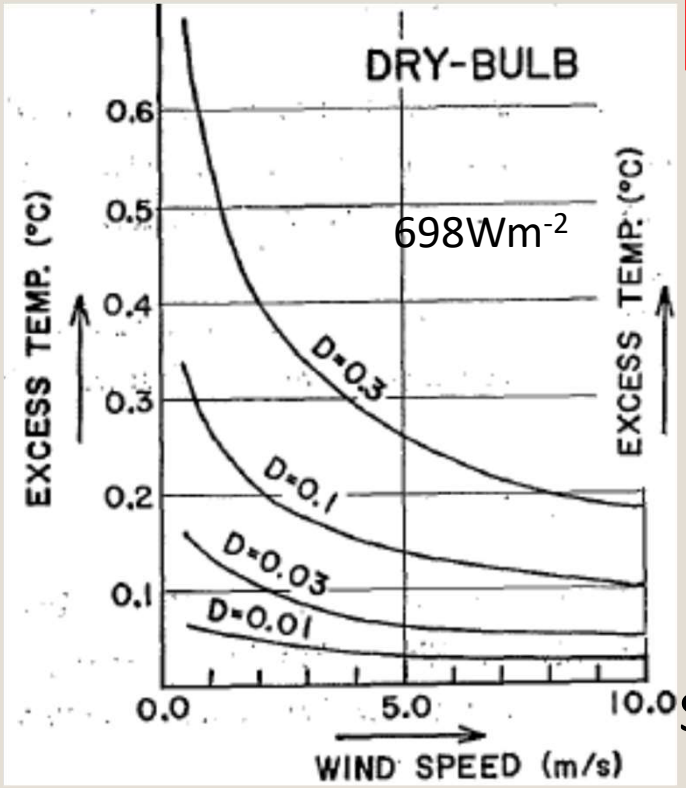
Very thin wire

- The very thin wire (diameter < around 10μm) exposed to the air with no radiation screen may has little radiation effect less than 0.1K.
- We introduced very thin "handmade" thermocouples after Moriwaki et al. (2003) that are a less expensive and readily available. Those of diameter 13μm was adopted.

Heat Budget of thermometer (Kondo 1982)

$$\frac{dT_s}{dt}=\frac{S}{c_s M}\{R-\sigma T_s^4-c_p\rho(C_h U)(T_s-T)\}$$

$$C_h U = aN/L$$



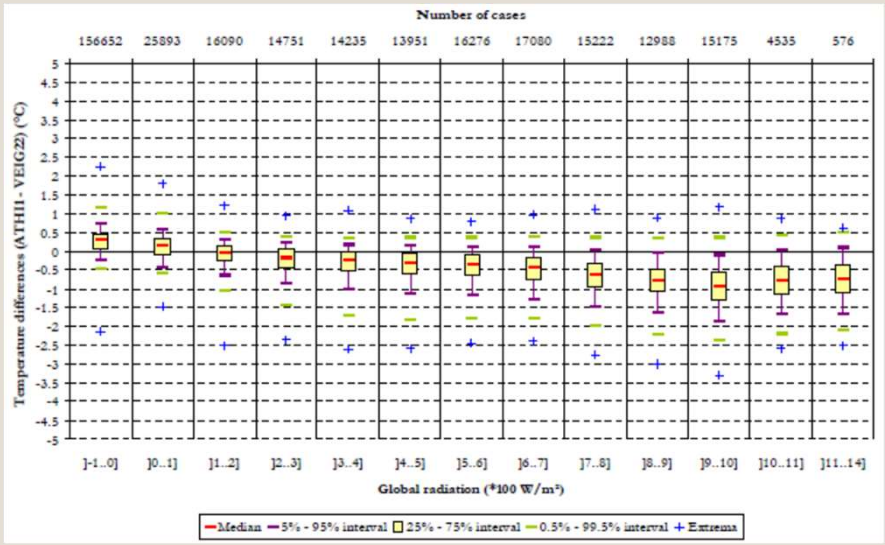
Sahashi (1973)

Smaller diameter (L) brings larger Heat transfer coefficient

Ultrasonic Anemometer and Thermometer (UAT)

- Sonic anemometers measure the acoustic virtual temperature (no influence from solar radiation).
- Air temperature can be calculated using additional relative humidity and pressure information.

Ultrasonic anemometer
2D THIES CLIMA



Larger solar radiation, THIES Ultrasonic measured lower temperature the LAM630 screen.
Ultrasonic has calibration problem.

Working reference:
LAM 630
EIGENBRODT

Lacombe et al. 2011

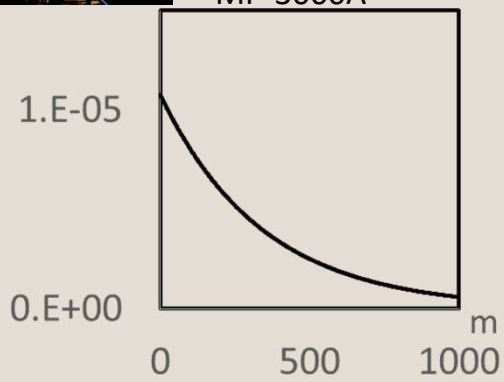
Radiometer

- Electromagnetic waves were absorbed and emitted at some absorption bands of atmosphere, and brightness (power of electromagnetic waves) is proportional to the temperature of atmosphere.
- Practical use in microwave radiometer (MWR) for measuring temperature profile.
- It is difficult to measure horizontal brightness by a radiometer directly, because of aperture angles and antenna siderobes.

$$B = \frac{2kT_B}{\lambda^2}\Delta f$$

B: Brightness
T_B: Brightness temperature
k: Boltzmann constant
λ: wavelength
Δf: band width

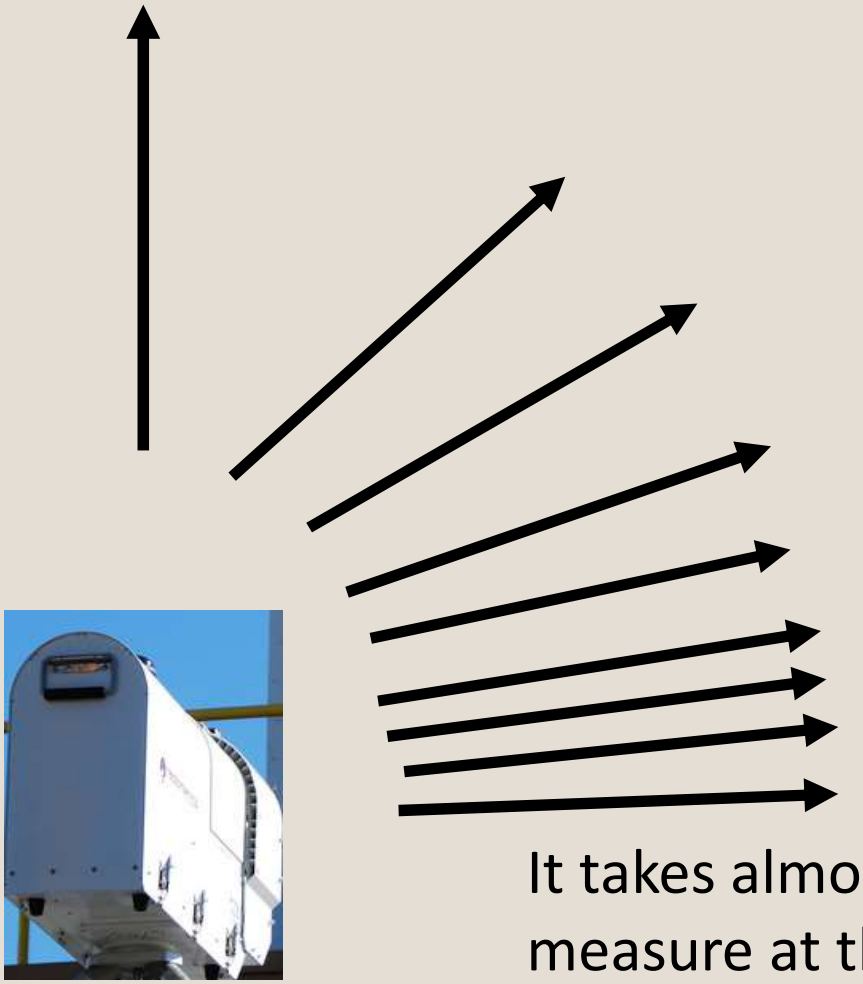
Radiometrics
MP-3000A



An example of weighting function.

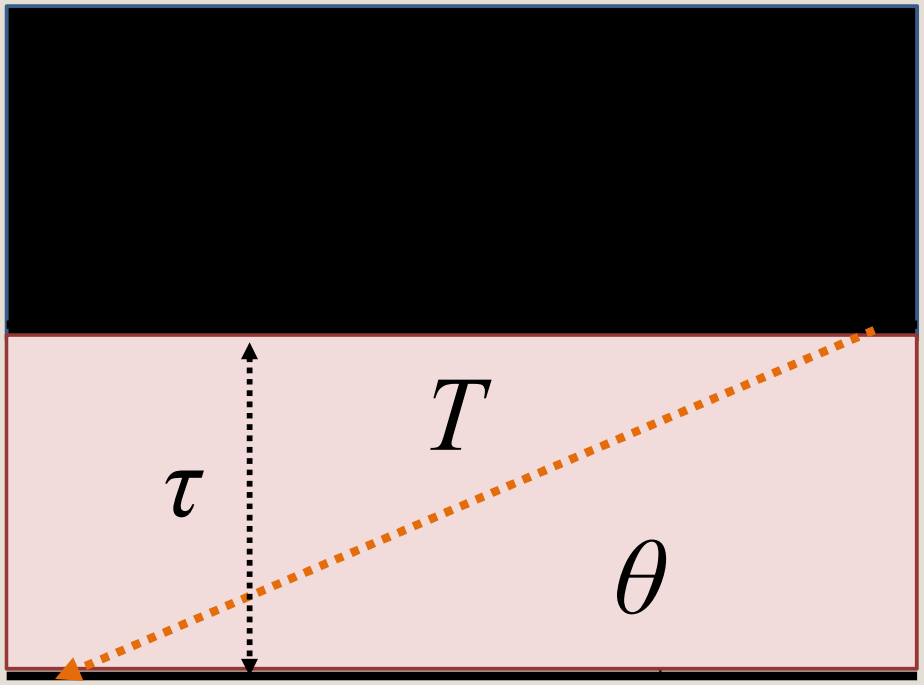
Elevation scan measurements were performed at this observation for nine elevation angles.

178.65°
177.75
175.5
170.55
165.6
160.65
149.85
138.15
90



It takes almost several minute to measure at these angles.

To estimate surface temperature, low-elevation data were extrapolated to an angle of zero



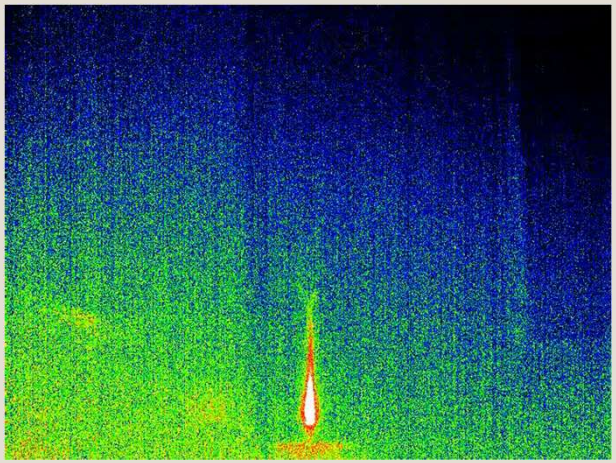
$$B_{obs}(T,\theta) = B(T)(1 - e^{-\frac{\tau}{\sin\theta}})$$

- Considering virtual layer with a temperature T optical thickness τ
- At Elevation angle $\theta = 0$, Brightness temperature $B_{obs} = B(T)$ is measured
- τ is determined to statistically ensure that B_{obs} varies linearly with $e^{-\frac{\tau}{\sin\theta}}$ at lower three elevation angles.
- τ=0.05 was obtained.
- B_{obs} at lower three elevation angles for each measurement were linear regressed by $e^{-\frac{\tau}{\sin}}$, then intercept was obtained.

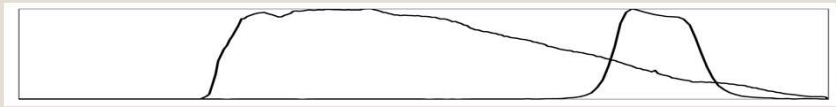
Far Infrared camera

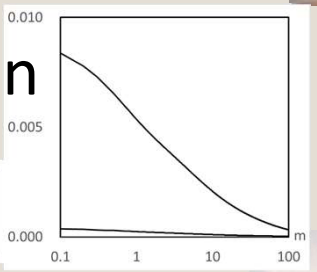
- Far Infrared camera with a 14-16 µm bandpass filter has been newly developed for this intercomparison
- Strong absorption band of carbon dioxide exists in 14-16 µm wavelength.

candle

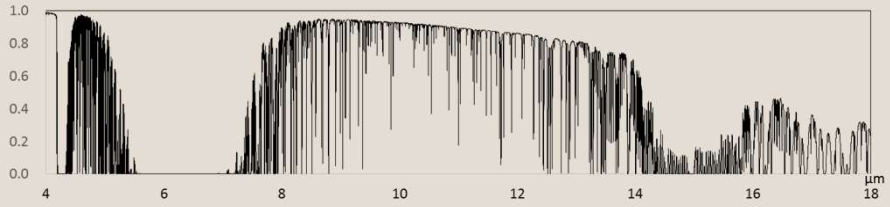


Weighting function

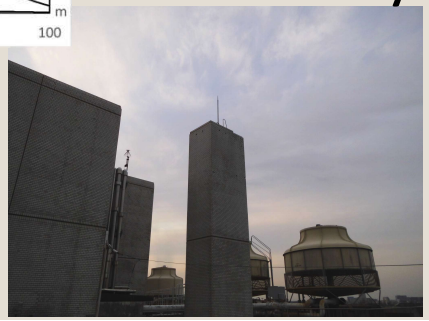


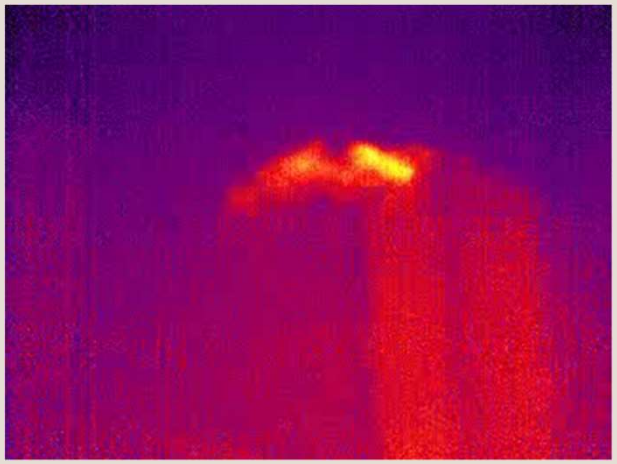


horizontal 1000m transmittance



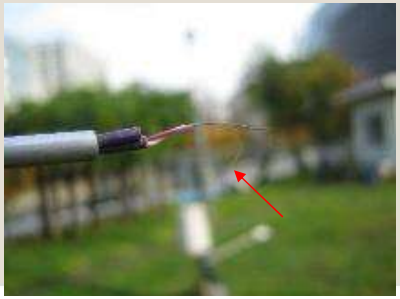
chimney

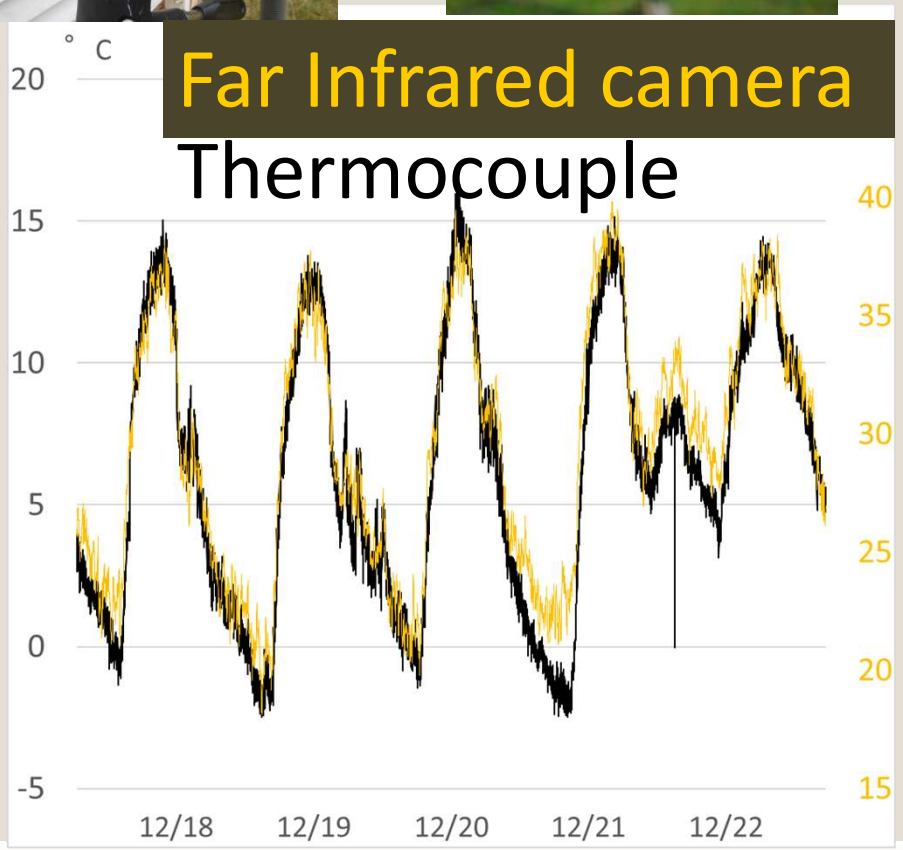


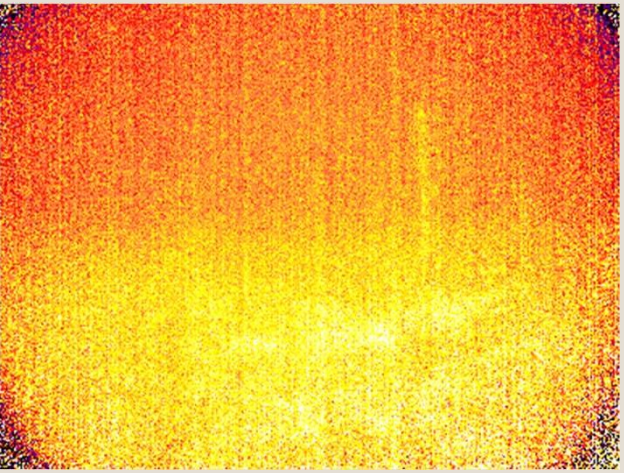


Far Infrared camera with a 14-16 μm bandpass filter detect the emitted radiation from carbon dioxide in the air

Power of the radiation should be proportional to the temperature of air, but we have many challenges to solve to get reasonable temperature data.







Intercomparison

at Meteorological Instrument Centre, Japan Meteorological Agency, Tsukuba, JAPAN

Thermometer with artificial ventilated screen

April 2018~

Very thin thermocouples

April 2018~

UATs

Vaisala WMT701

June 2018~

Sonic SAT600

April 2018~

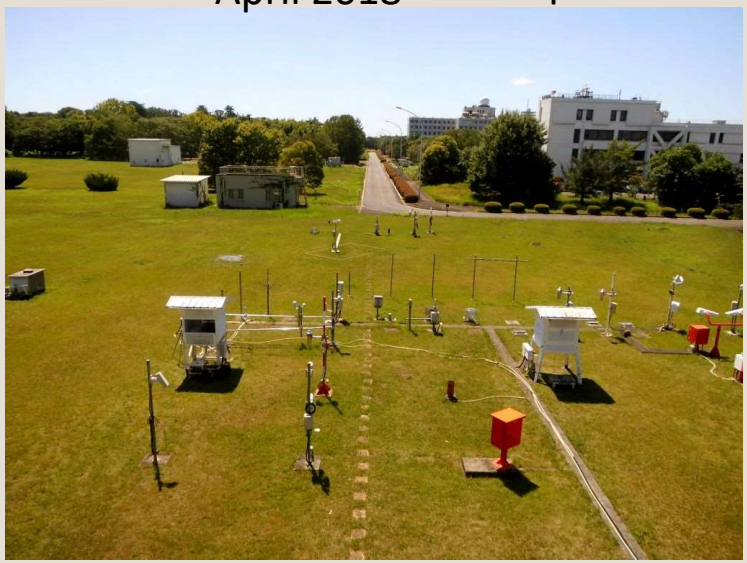
Radiometers

Far Infrared camera

April 2018~

Ground-based MWR
Radiometrics MP-3000A

August 2018~

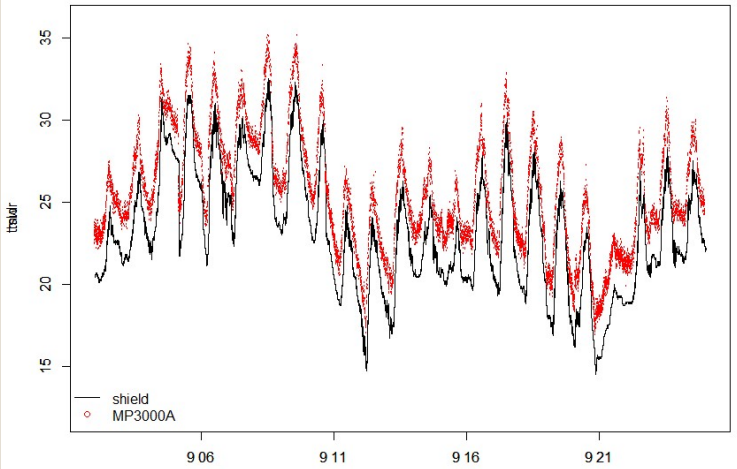


north to south view

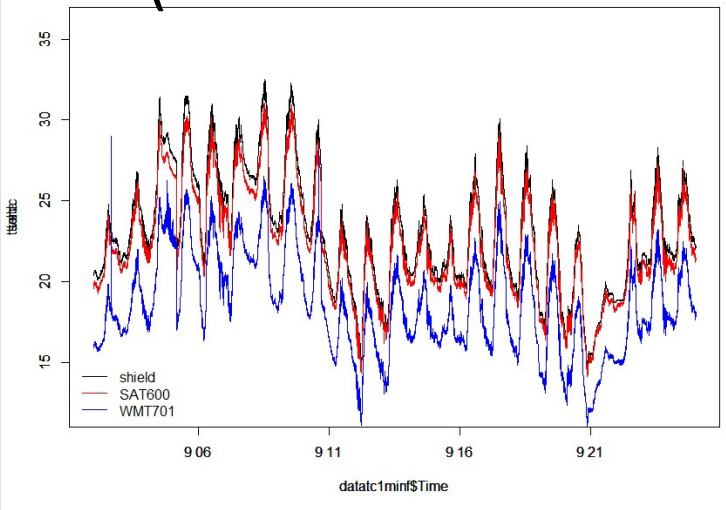
Preliminary results from Sept 2-24 2018

reference: shielded thermometer (black curves) , and

MWR

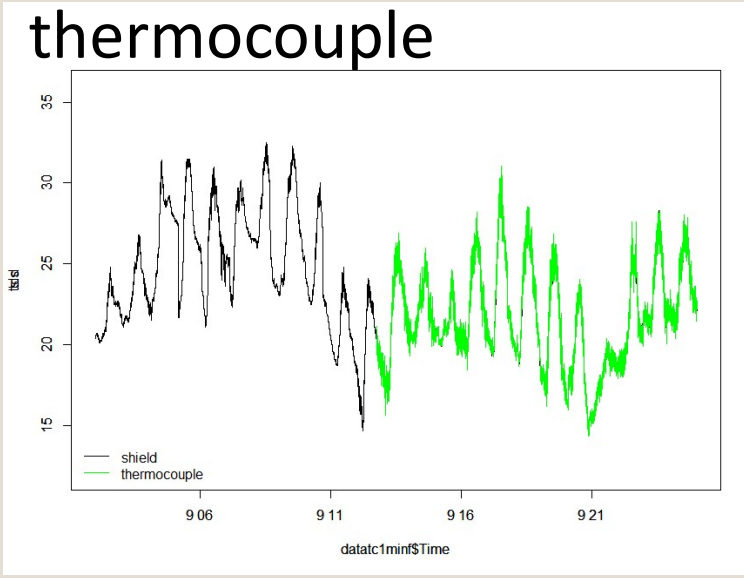


UATs (red: SAT600 blue: WMT701)



A MWR and UATs have calibration problem.

thermocouple

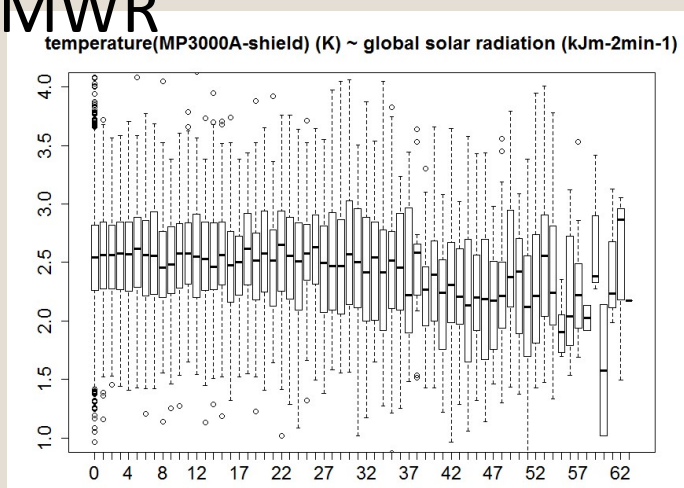


Thermocouples are installed after Sept. 12 because of logistical reason

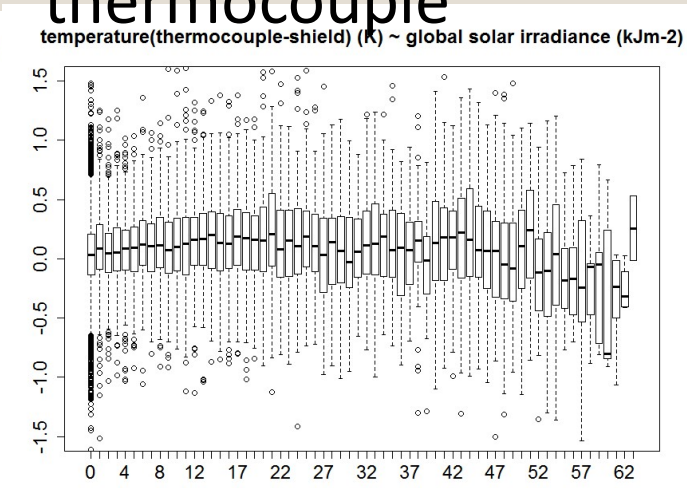
Preliminary results from Sept 2-24 2018

reference: shielded thermometer
global solar radiation (kJ m^{-2} min^{-1})

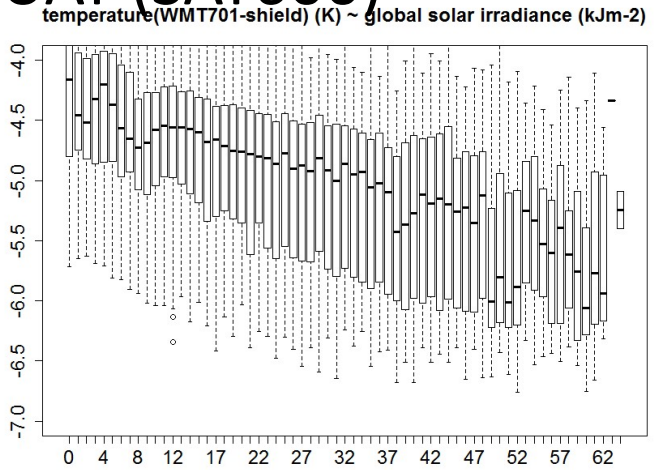
MWR



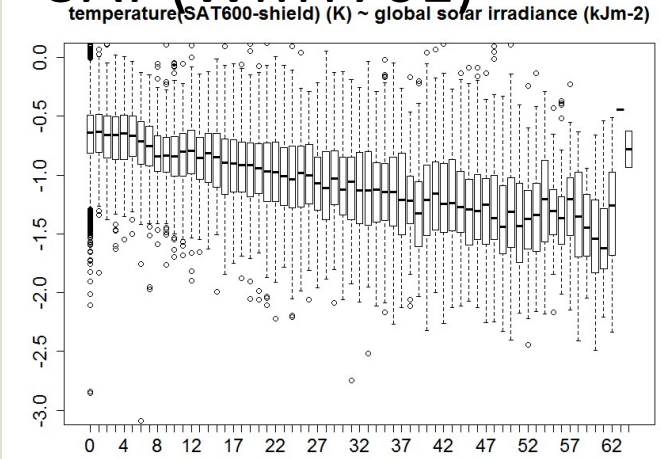
thermocouple



UAT (SAT600)



UAT (WMT701)



The difference from the shielded thermometer is larger when solar radiation is larger.

Major cause of these dependency is radiation effect on shield.

Dependency of UATs are quite large because of temperature dependency.

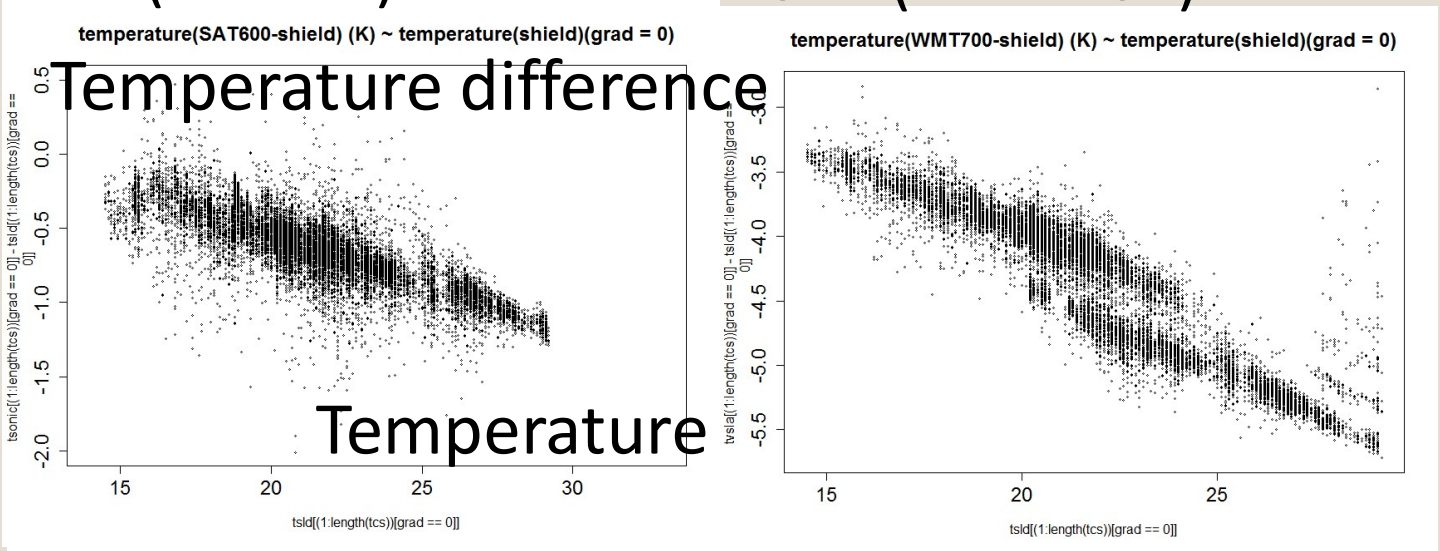
Preliminary results from Sept 2-24 2018

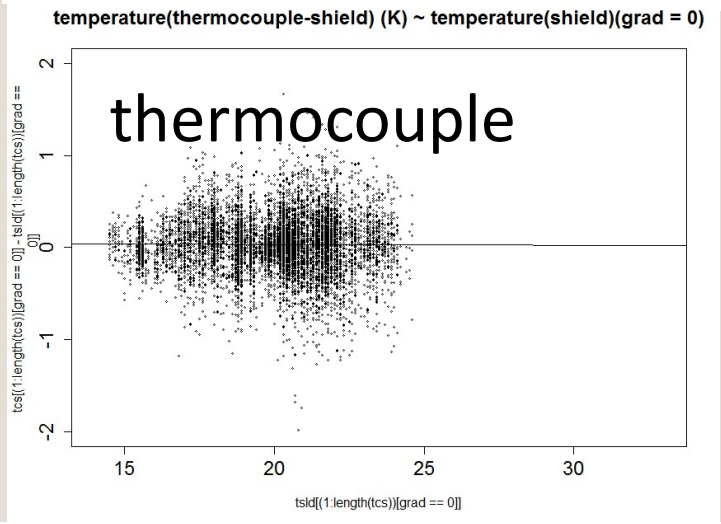
reference: shielded thermometer

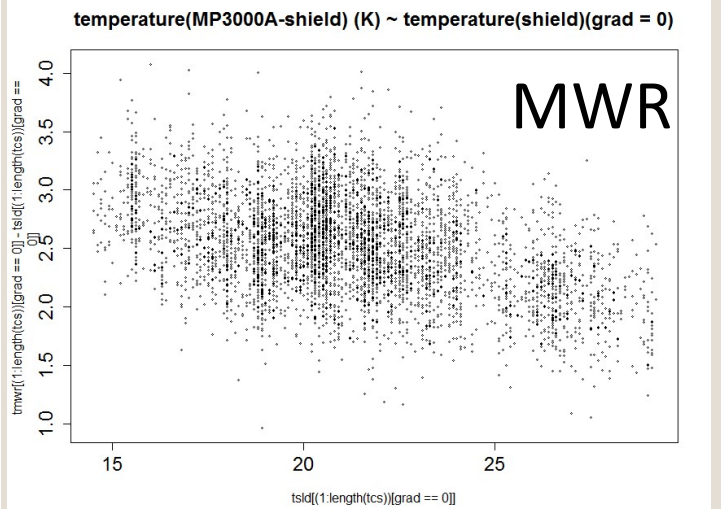
global solar radiation=0

UAT (SAT600)

UAT (WMT701)







UATs has strong dependency on (body) temperature. (Richiardone et al. 2012)

MWR has weak unexplained dependency on temperature.

Thermocouple has no dependency.

Summary of preliminary results

	☺	☹	Max. rad. Effect
MWR	Stable	Arbitrary extrapolation method Not measured In rain Very expensive Several mimutes interval Calibration Dependency on temperature(?)	~0.0K?
Far infrared camera	Great potential	Not measured In rain Many challenges	--
Artificial ventilated screen	Stable All weather	Radiation effect	~0.3K
Very thin (D = 13μm) thermocouples	Cost effective	Weak, feasible Dependency on wind speed	~0.1K
UAT	Stable	Expensive **Dependency on temperature** Calibration Humidly data needed	~0.0K?

References

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