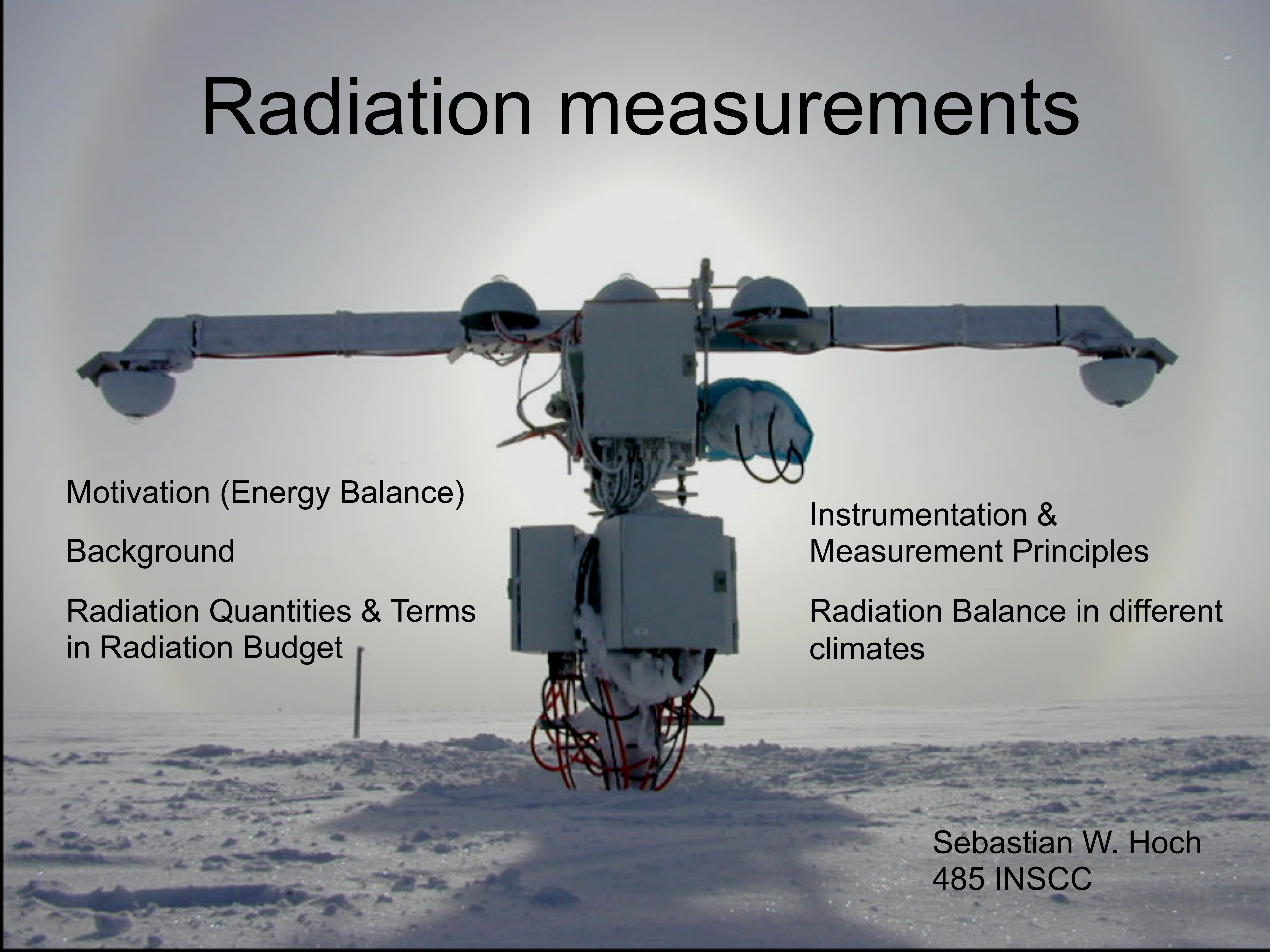
Radiation measurements



Motivation (Energy Balance)

Background

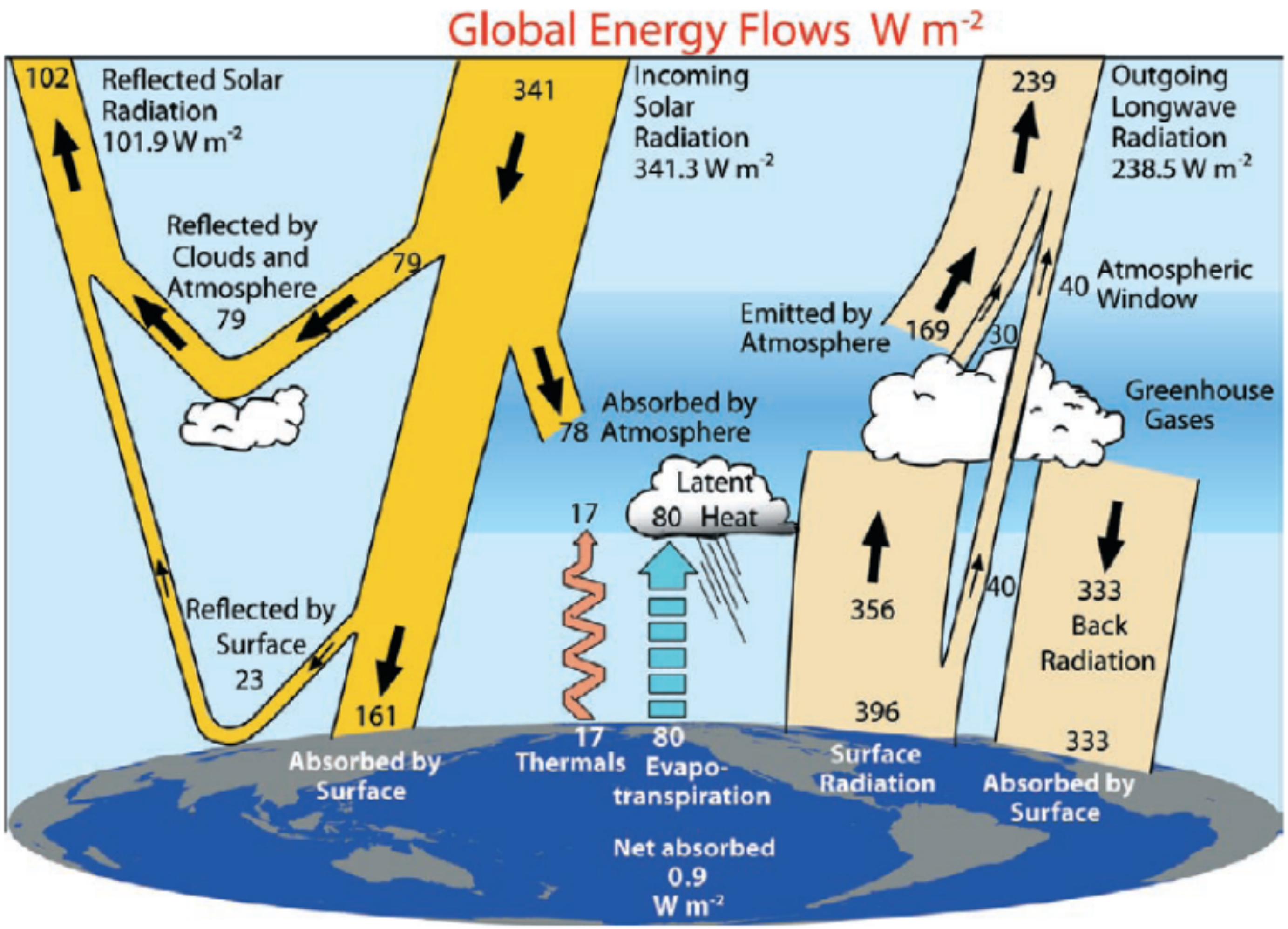
Radiation Quantities & Terms in Radiation Budget

Instrumentation & Measurement Principles

Radiation Balance in different climates

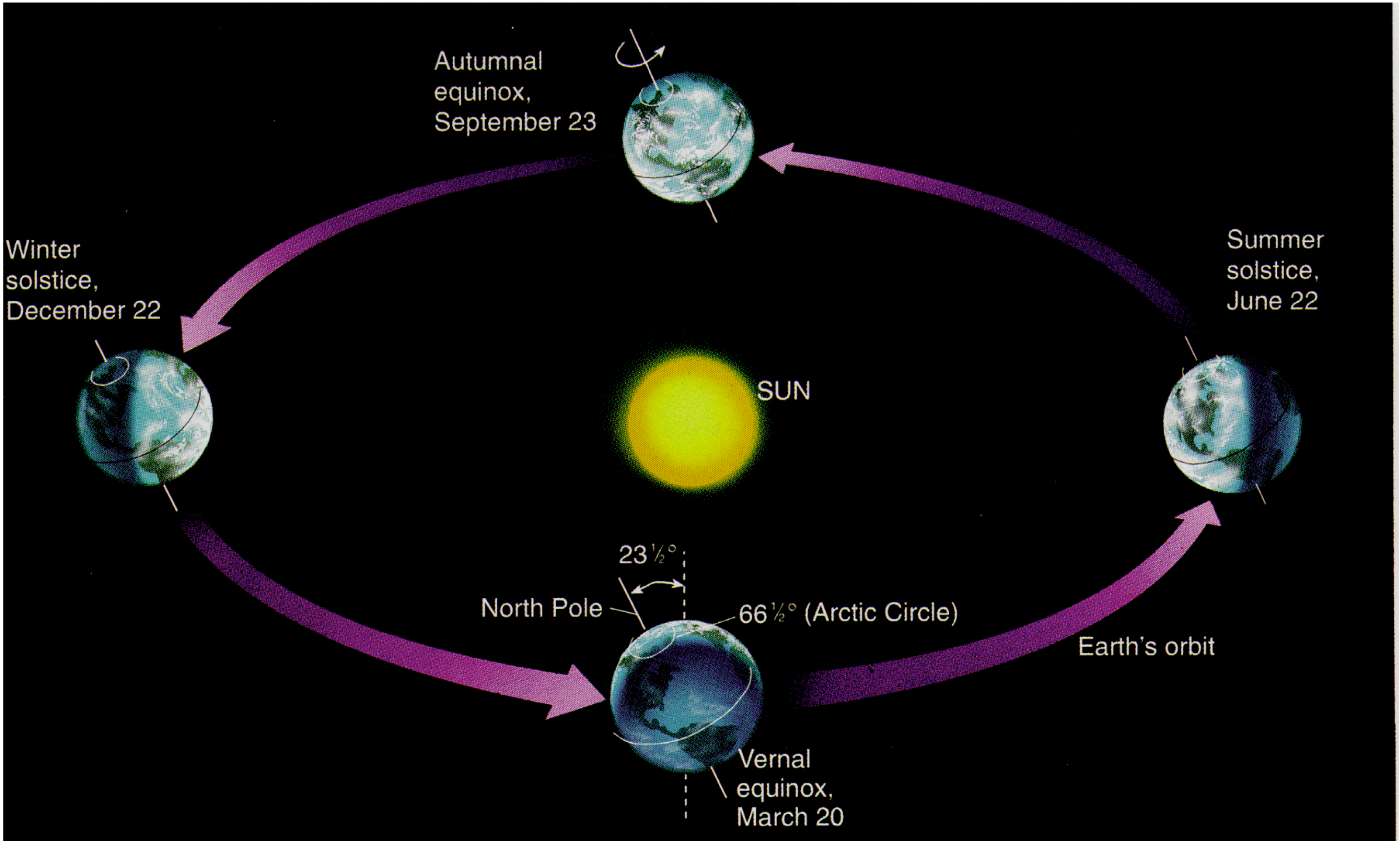
Sebastian W. Hoch
485 INSCC

Radiation and the Energy Budget



Trenberth et al. 2009 BAMS

Solar Radiation – Driver of Earth's Climate System



Northern Hemisphere terminology

Ahrens (1994)

Effects of eccentricity

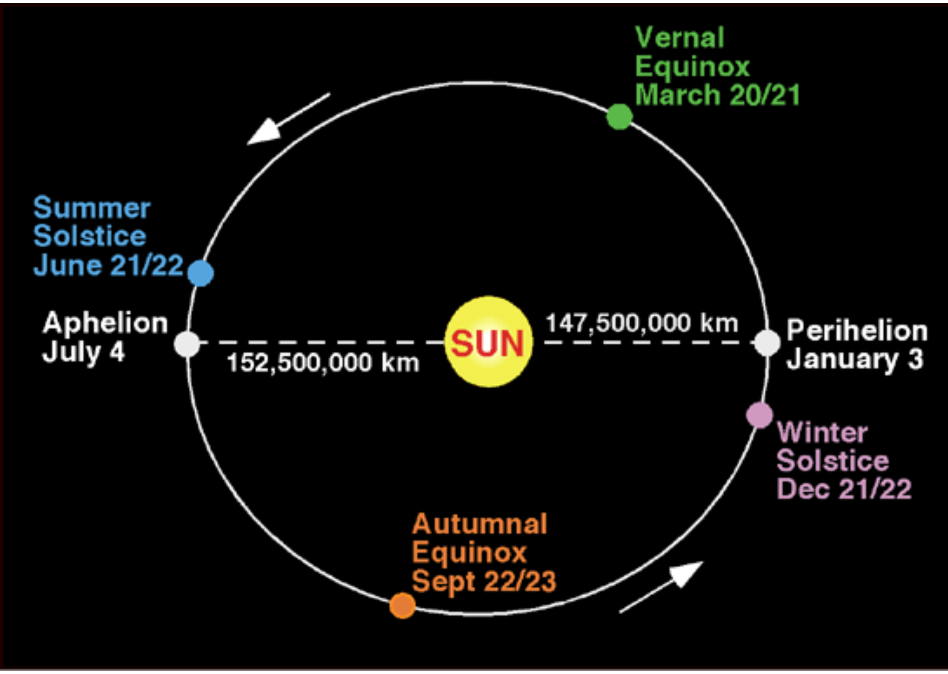
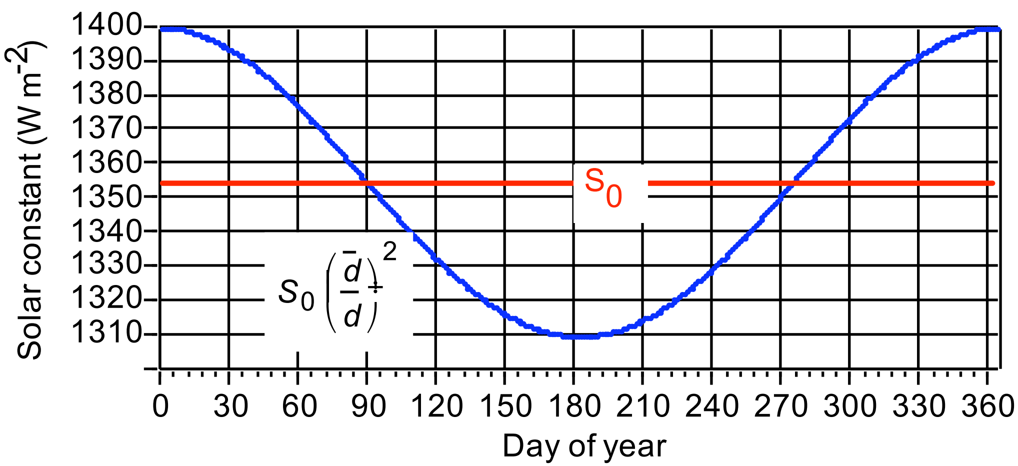


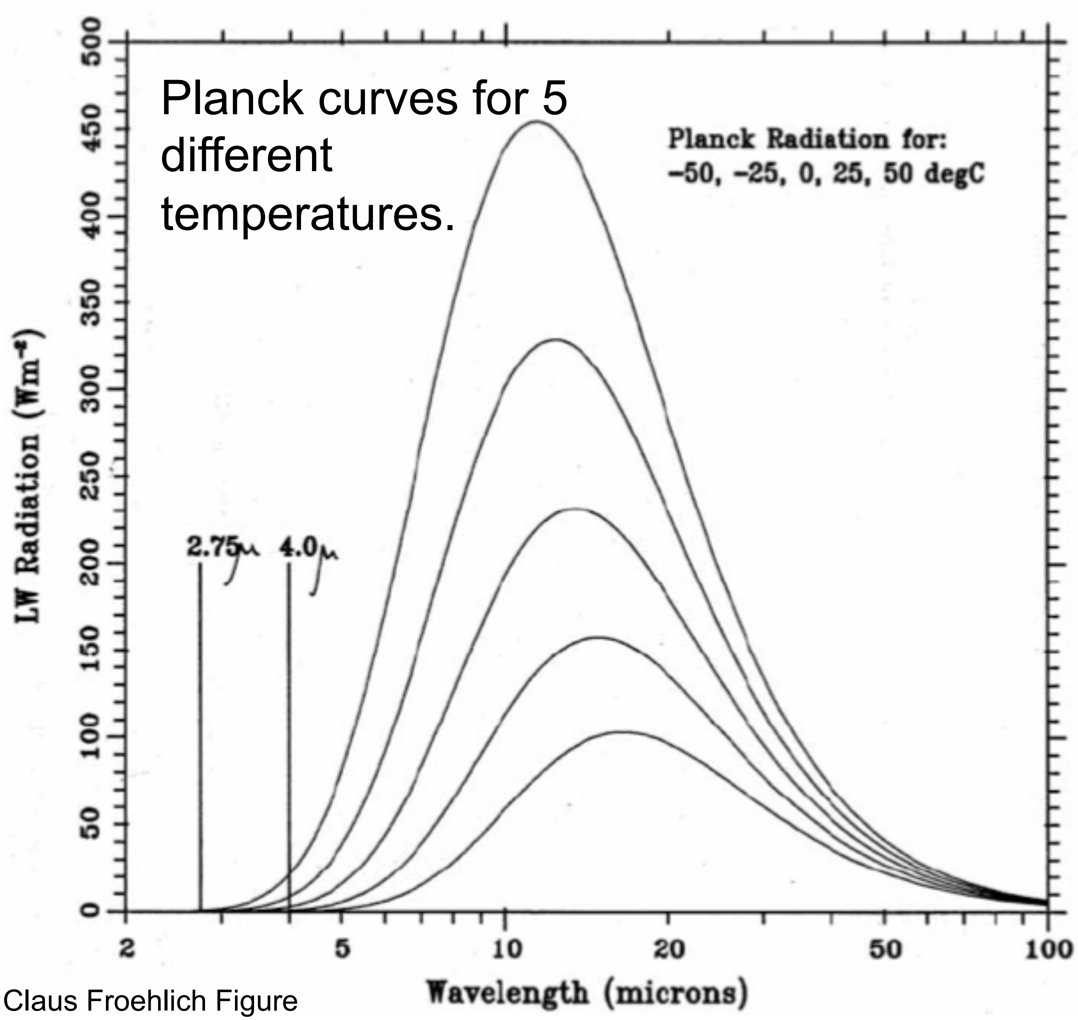
Image Credit & Copyright: Ian Griffin (Otago Museum)
https://apod.nasa.gov/apod/ap200109.html

Solar "constant"



7% annual variation
in TOA insolation

Why Shortwave Radiation and Longwave Radiation?



Claus Froehlich Figure

Planck Function

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5 \left(e^{hc/k\lambda T} - 1\right)}$$

$h = 6.626\,068\,96(33) \times 10^{-34}$ J s

c: *speed of light*

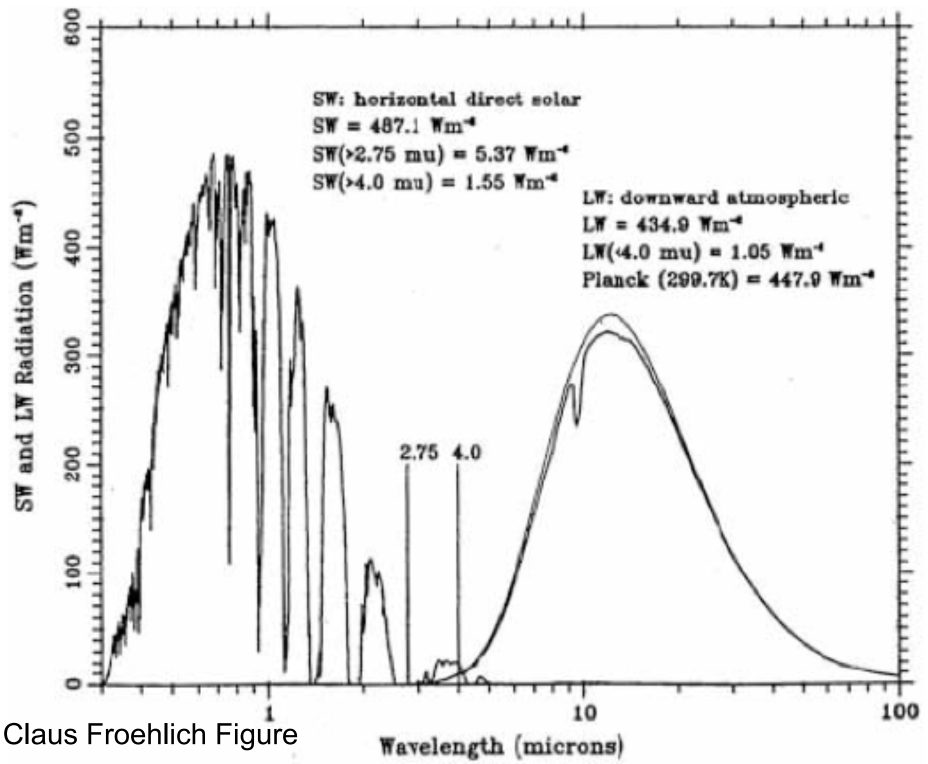
λ : *wavelength*

Everything emits radiation – depending on the temperature!

Wien's Displacement Law

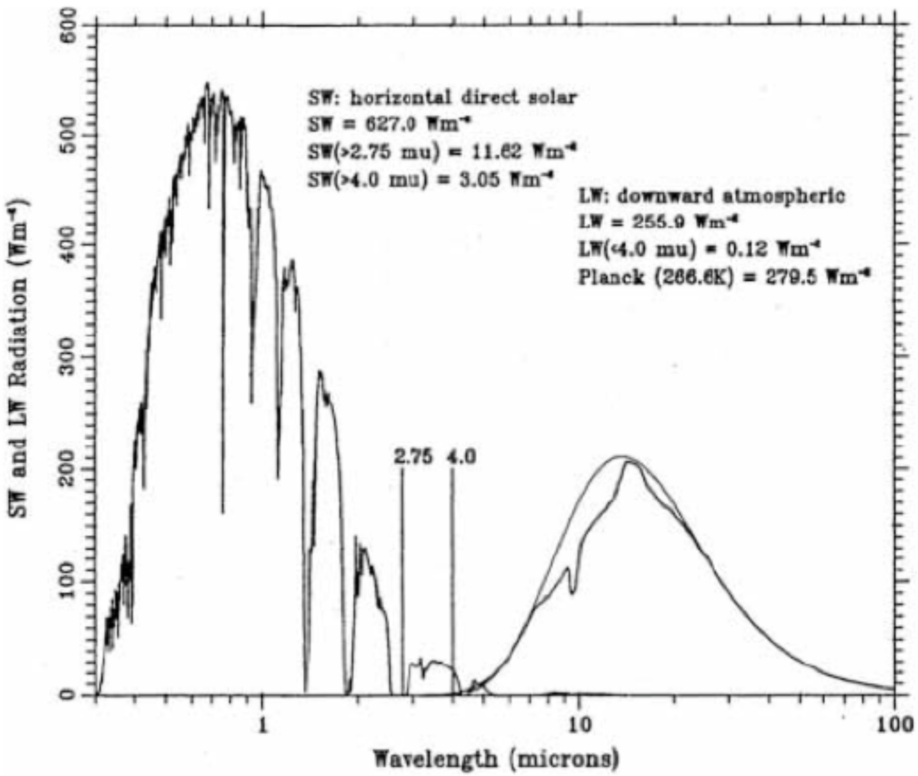
$$\lambda_{\max} = \frac{a}{T} \quad \text{with} \quad a = 2.89776 \times 10^{-3}\ \mathrm{m\,K}$$

Longwave or ***Terrestrial*** or ***Infrared*** Radiation and ***Shortwave*** or ***Solar*** Radiation



Claus Froehlich Figure

Tropical atmosphere



Midlatitude Summer, 1600 m (ASL)

Other quantities defined by spectral range:

- UV Radiation (A, B, C)
- PAR: Photosynthetically Active Radiation; 400 - 700 nm

There's an overlap at times ...

Radiation Quantities

Quantity	Symbol	SI unit	Abbr.	Notes
Radiant energy	Q	joule	J	energy
Radiant flux	Φ	watt	W	radiant energy per unit time, also called *radiant power*
Radiant intensity	I	watt per steradian	$W \cdot sr^{-1}$	power per unit solid angle
Radiance	L	watt per steradian per square metre	$W \cdot sr^{-1} \cdot m^{-2}$	power per unit solid angle per unit *projected* source area. called *intensity* in some other fields of study.
Irradiance	E, I	watt per square metre	$W \cdot m^{-2}$	power incident on a surface. sometimes confusingly called "intensity".
Radiant exitance / Radiant emittance	M	watt per square metre	$W \cdot m^{-2}$	power emitted from a surface.
Radiosity	J or J_λ	watt per square metre	$W \cdot m^{-2}$	emitted plus reflected power leaving a surface
Spectral radiance	L_λ or L_ν	watt per steradian per metre^3 *or* watt per steradian per square metre per hertz	$W \cdot sr^{-1} \cdot m^{-3}$ *or* $W \cdot sr^{-1} \cdot m^{-2} \cdot Hz^{-1}$	commonly measured in $W \cdot sr^{-1} \cdot m^{-2} \cdot nm^{-1}$
Spectral irradiance	E_λ or E_ν	watt per metre^3 *or* watt per square metre per hertz	$W \cdot m^{-3}$ *or* $W \cdot m^{-2} \cdot Hz^{-1}$	commonly measured in $W \cdot m^{-2} \cdot nm^{-1}$

Source: Wikipedia

The Radiation Balance – the terms (Irradiances W m^{-2})

Direct Solar Radiation S↓

Diffuse (Solar) Radiation D↓

Global Radiation (K↓, Gl) = S↓+ D↓

Shortwave Reflected Radiation K↑

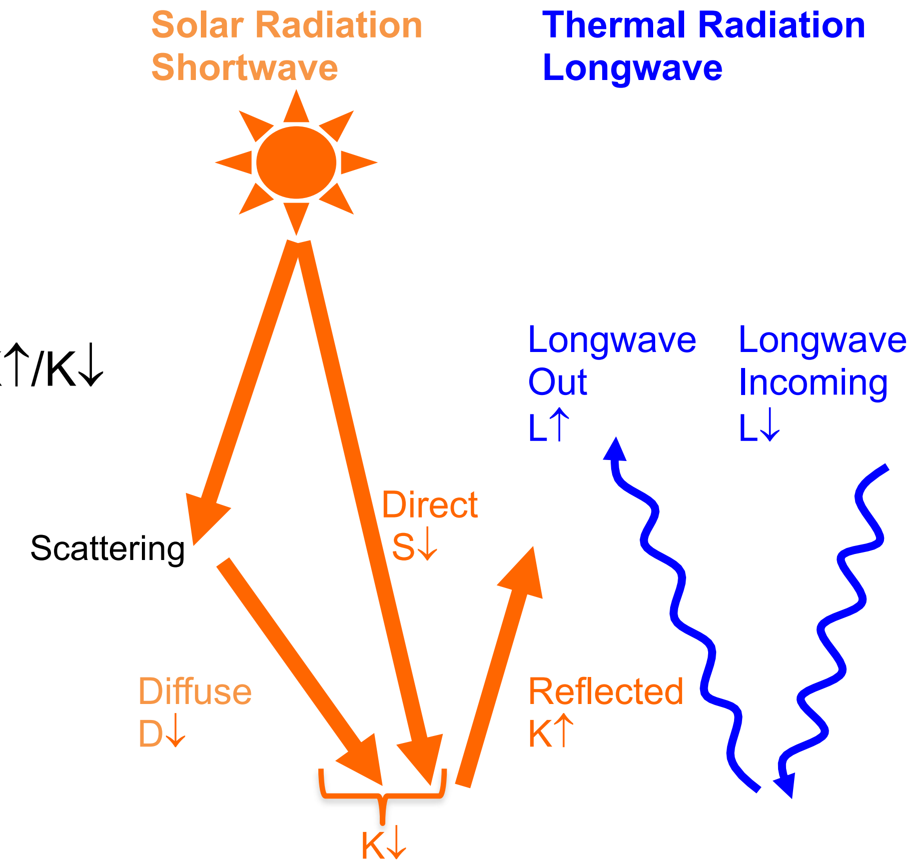
Shortwave Net Radiation K*

Albedo α = K↑/K↓

Longwave Incoming L↓

Longwave Outgoing Radiation L↑

Longwave Net Radiation L*



Net Radiation Q*

Q* = K* + L*

= K↓ – K↑ + L↓ – L↑

= (1 –α) * K↓ + L*

$L\uparrow = \varepsilon_{surf} \cdot \sigma \cdot T^4_{surf}$

$L\downarrow = \varepsilon_{atmos} \cdot \sigma \cdot T^4_{atmos}$

Stefan-Boltzmann Constant
σ: $5.67 \cdot 10^{-8}$ J s^{-1} m^{-2} K^{-4}

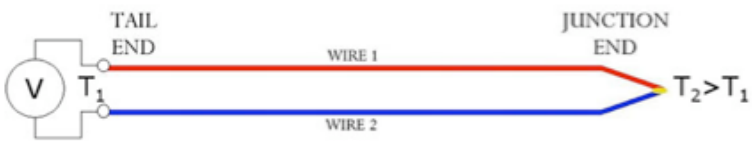
Measurement Principles

Thermopile

- converts thermal energy into electrical energy
- composed of thermocouples (usually in series)
- output voltage proportional to a local temperature difference
- range of tens or hundreds of millivolts.

Thermocouple

- temperature measurement based on the *Seebeck Effect*: a result of a difference in *thermoelectric power* of two materials



$$Emf = \int_{T_1}^{T_2} S_{12} \cdot dT = \int_{T_1}^{T_2} (S_1 - S_2) \cdot dT$$

- Emf is the Electro-Motive Force or Voltage; T_1 and T_2: Temperatures of reference (T_1) and measuring end (T_2)
- S_{12}, S_1, S_2: **Seebeck coefficients** of the thermocouple and thermo-elements
- null voltage:
    - same materials
    - no temperature difference

Radiation observations in Climate Science - Instrumentation

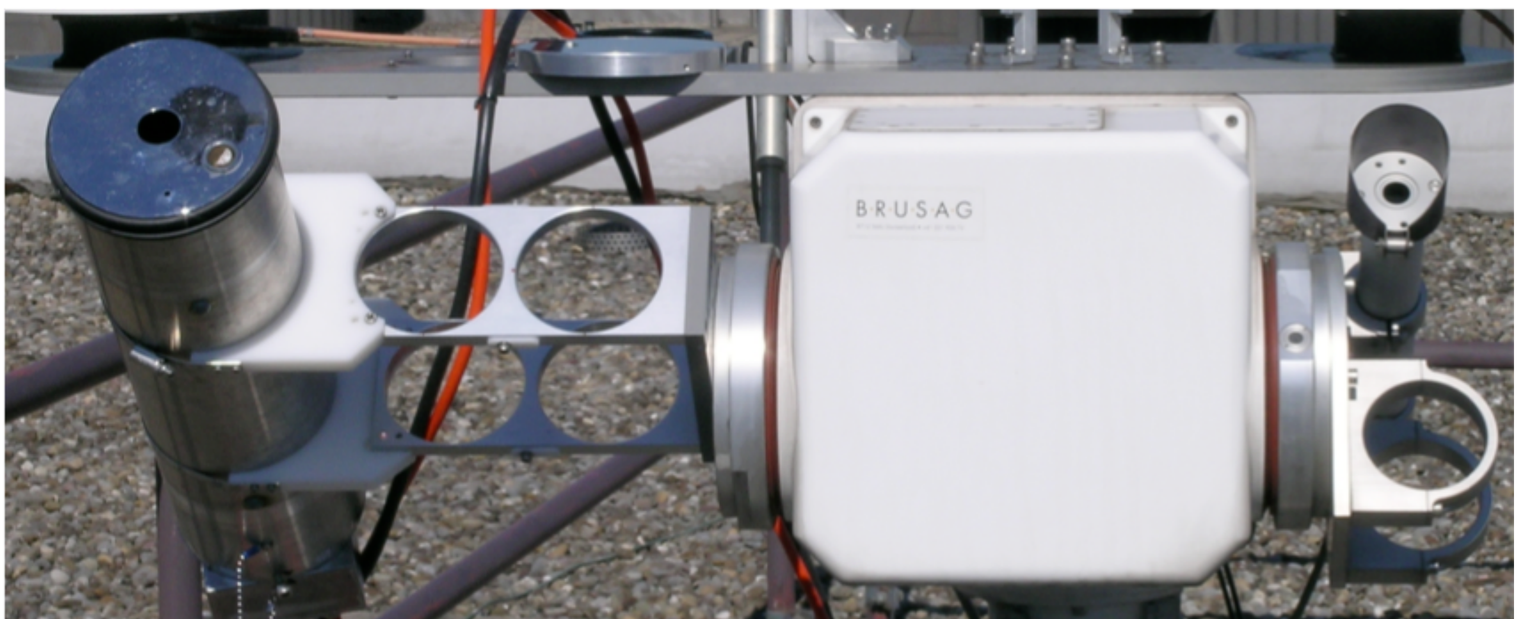
Pyrheliometer

- Direct Solar Radiation
- World Standard Instruments
- (Compensation Type / Thermopile)
- Open / with window ...

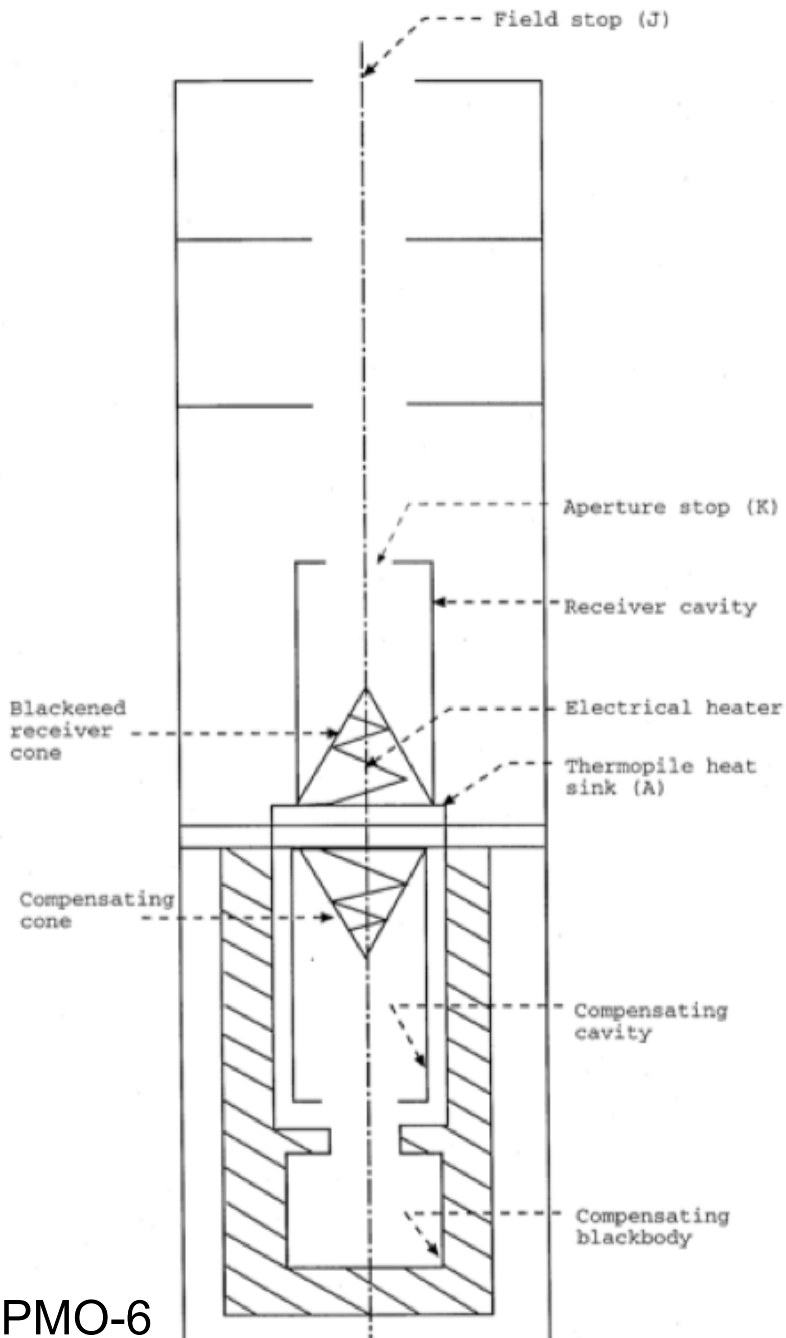
pyro-, pyr- +
(Greek: fire, burn; heat, produced by heating; and sometimes "fever")

Ἥλιος (Helios) is derived from the noun ἥλιος, "sun" in ancient Greek

PMO-6



Kipp & Zonen CH1



PMO-6

PMO-6 Absolute Cavity Radiometer

$$S = k * (P_{closed} - P_{open})$$

pmod/wrc

Other System:
Eppley Hickley-Frieden (HF)

Thermopile Pyrheliometer (NIP / CH1)

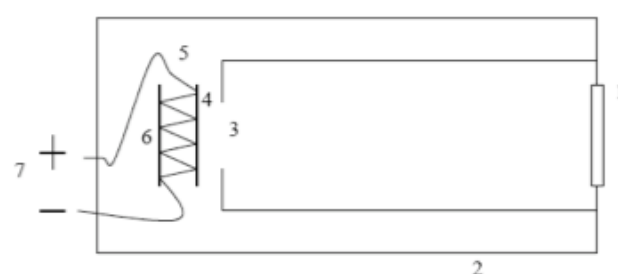
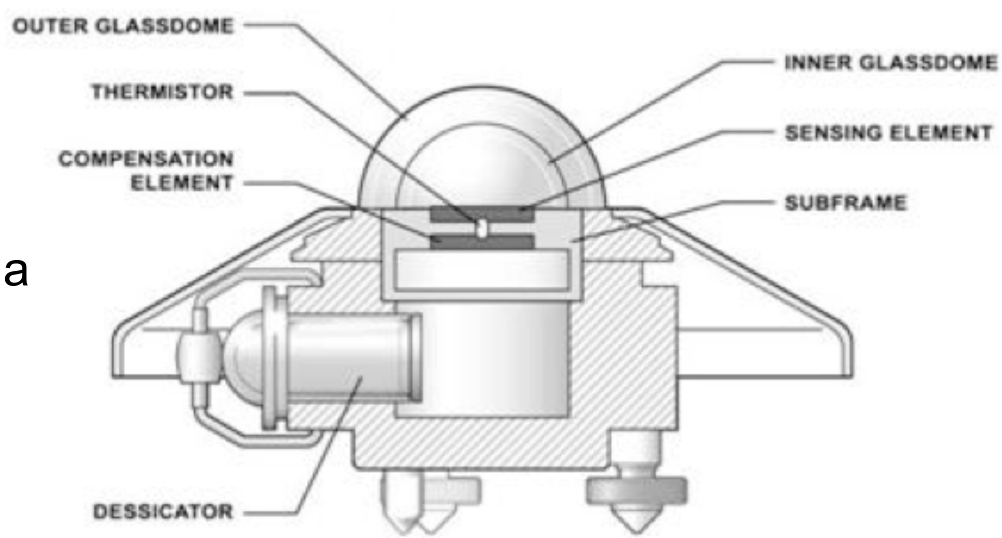
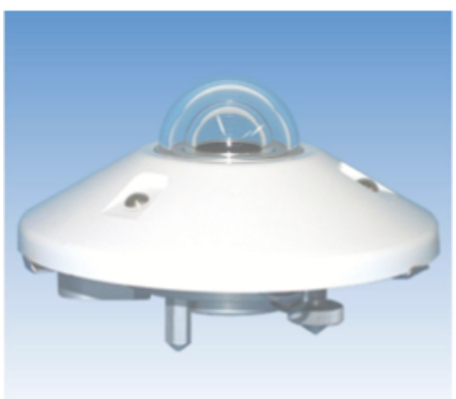


Fig. 1. Pyrheliometer schematic showing entrance window (1), thermal shield (2), detector aperture (3), light absorber (4), thermopile (5), heat sink (6), and thermopile output (7).

Pyranometer

- Global Radiation
- Shortwave Reflected Radiation
- Diffuse Radiation (in conjunction with a shading disk or shadow-band)
- Glass or quartz dome





Standard

Black & White Type

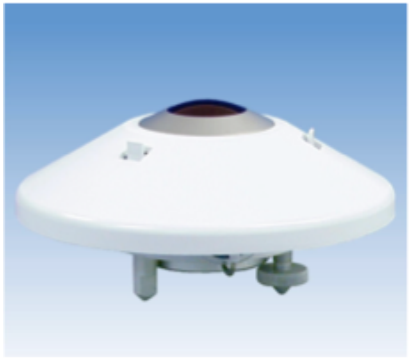
Photodiode Type

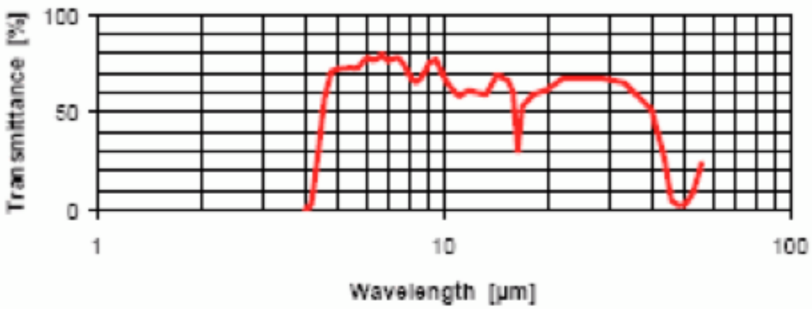
Shading – Shadowbands and Shading disks

Pyrgeometer

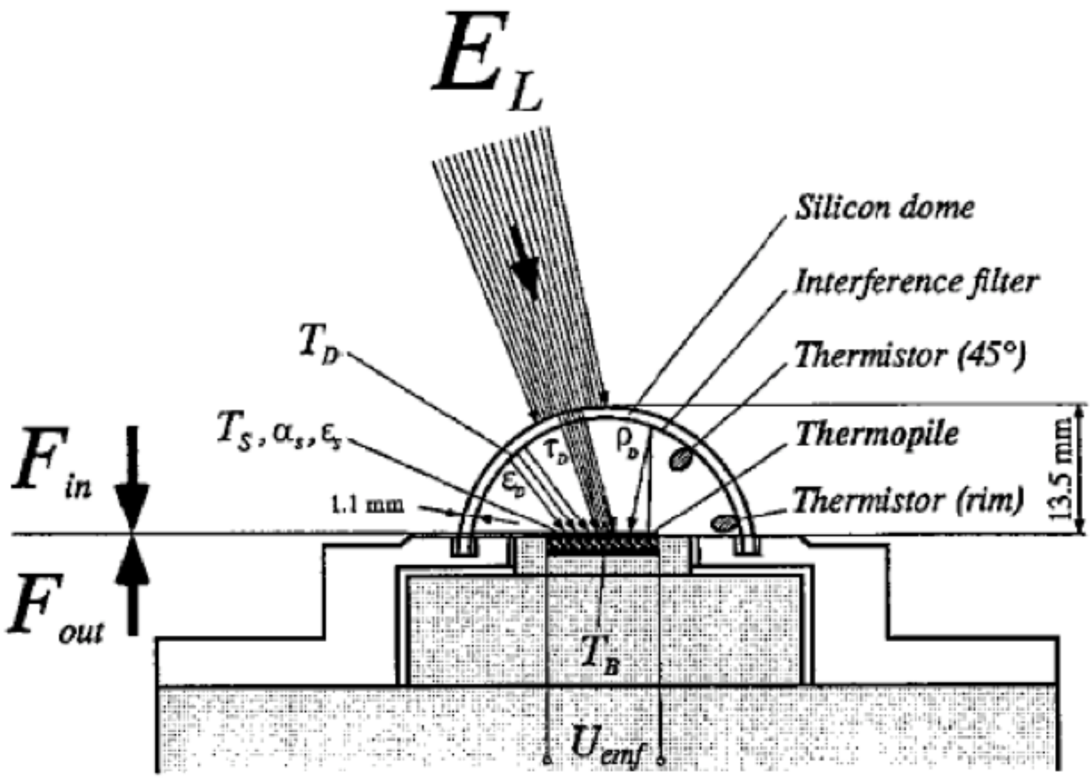
- Longwave Radiation
- Thermopile
- Silicon (Si) dome

geo-, ge- +
(Greek: earth, land, soil; world)





Si-Dome and interference filters



Schematic view of Eppley PIR (Philipona et al. 1995)

Pyrgeometer Formula:

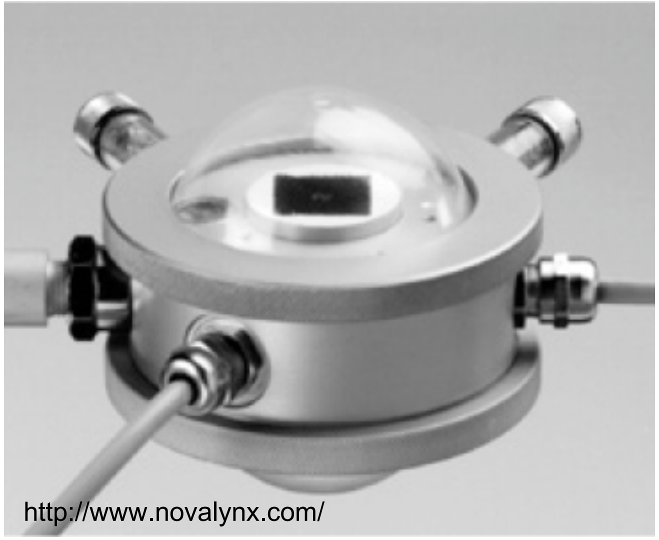
$$E_L = \frac{U_{\text{emf}}}{C}(1 + k_1\sigma T_B{}^3) + k_2\sigma T_B{}^4 - k_3\sigma(T_D{}^4 - T_B{}^4).$$

LWin_a LWin_b LWin_c

We neglect k_1, set k_2 to 1.0, and k_3 to a mean value of 3.5.

Pyrradiometer

- "All-wave" Radiation
- Thermopile measurements
- Polyethylene Dome
- Double domes: Net-Radiometer
- "Wind Speed Error"



Different response to short- and longwave fluxes!

Birds like to destroy them, too...

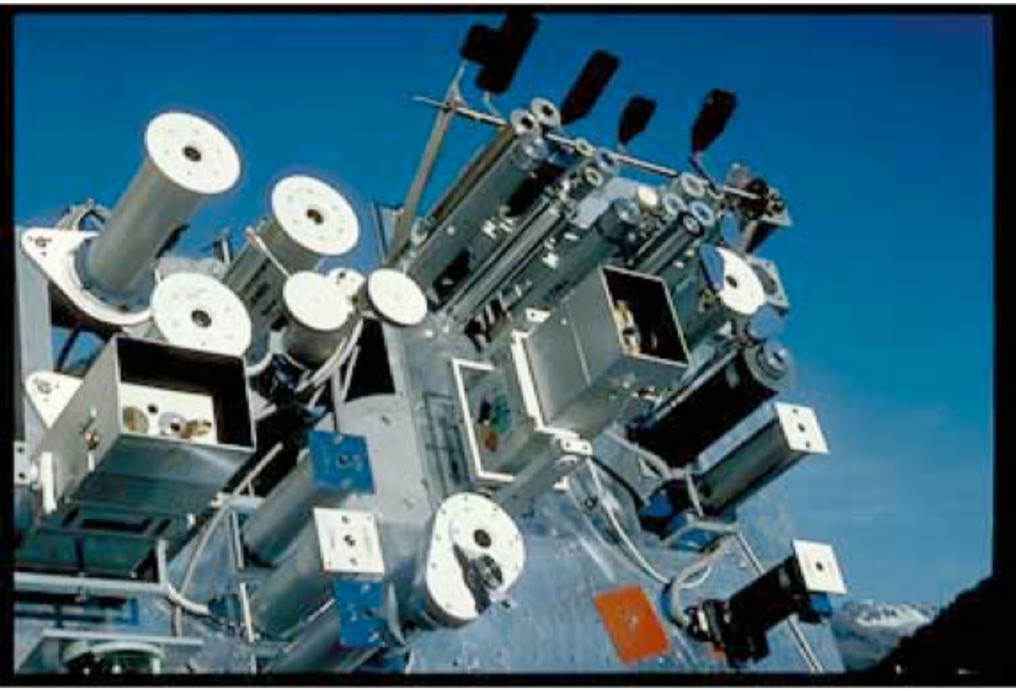
Heliograph / Sunshine Duration Sensor

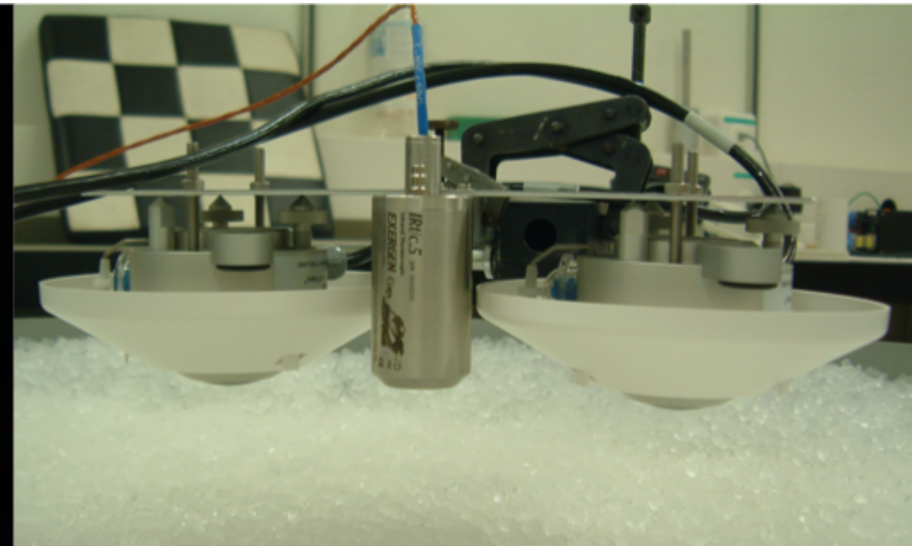
Campbell-Stokes Sunshine Recorder

“Sunshine”: Flux > 120 Wm^{-2}

One end of an optical fiber revolves around the sun axis. The opening angle is limited by an optical diaphragm. At the other end, a photovoltaïc detector receives the light pulse when the fiber window meets the sun. The detected signal is compared to a threshold. A pulse is generated when the radiation intensity exceeds 120 W/m².

Calibrations and Errors





WSG (World Standard Group)
Davos, Switzerland

Absolute Calibration Error
(Comparison to World Standard)

Spectral Response Errors

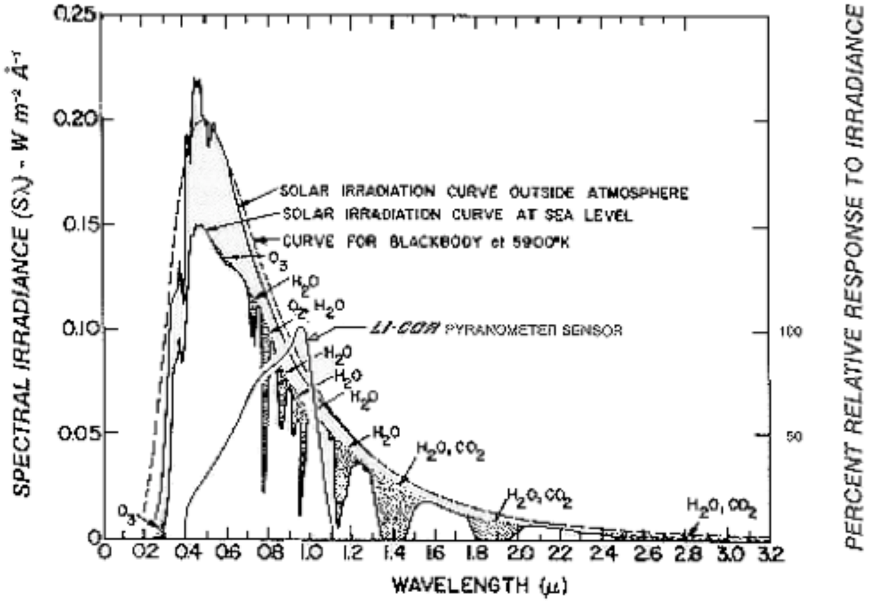
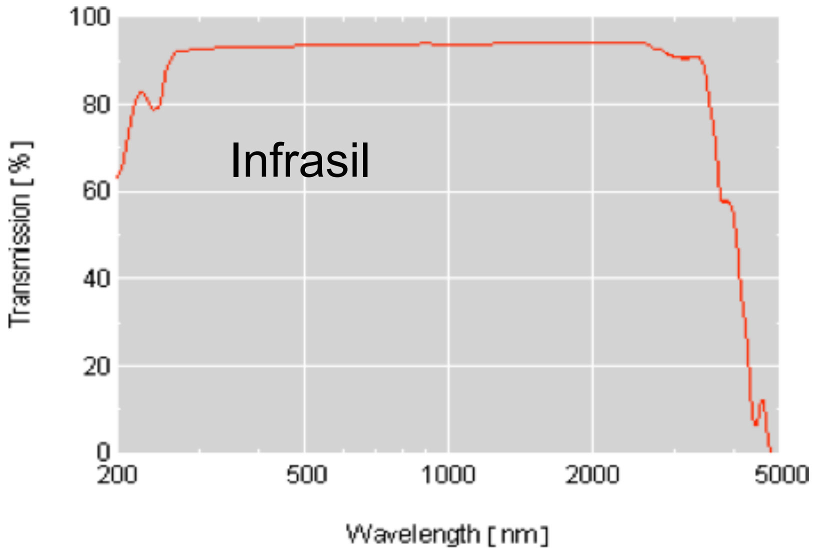
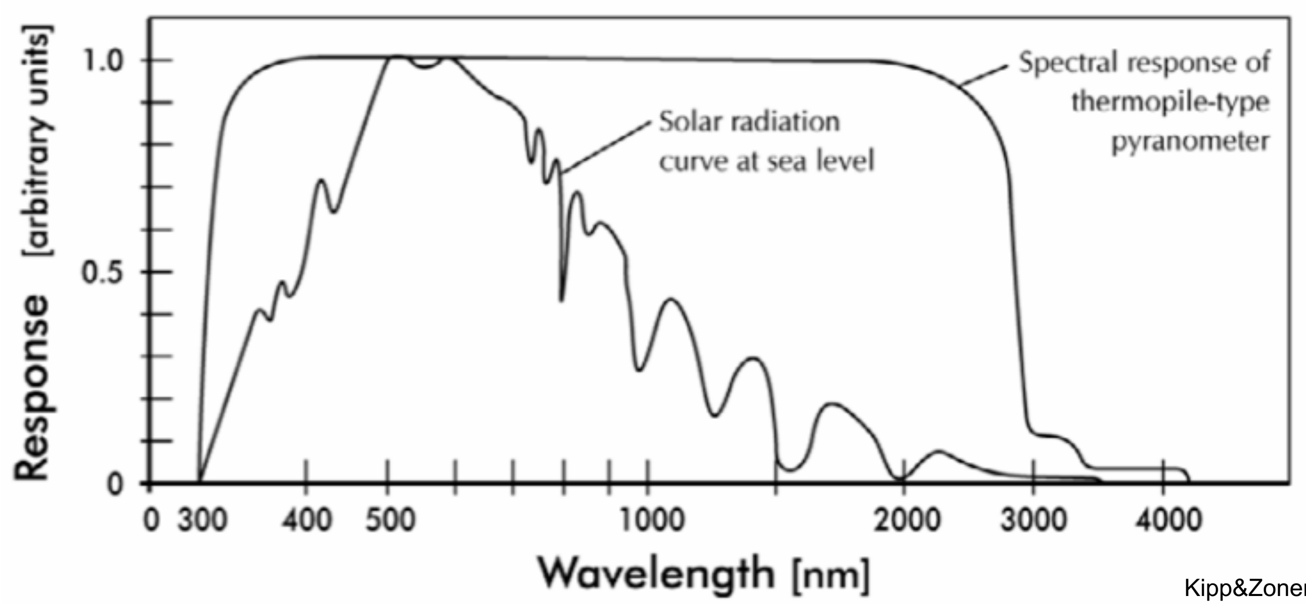


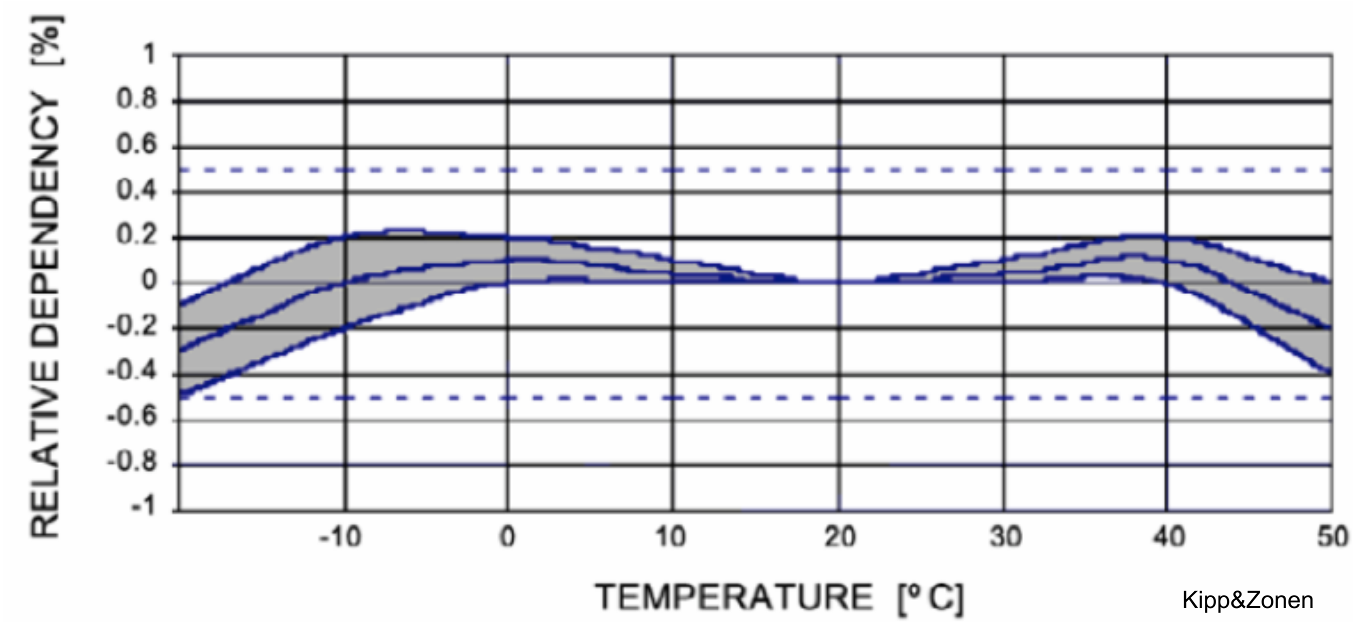
Figure 4. The LI-200SA Pyranometer spectral response is illustrated along with the energy distribution in the solar spectrum (8).



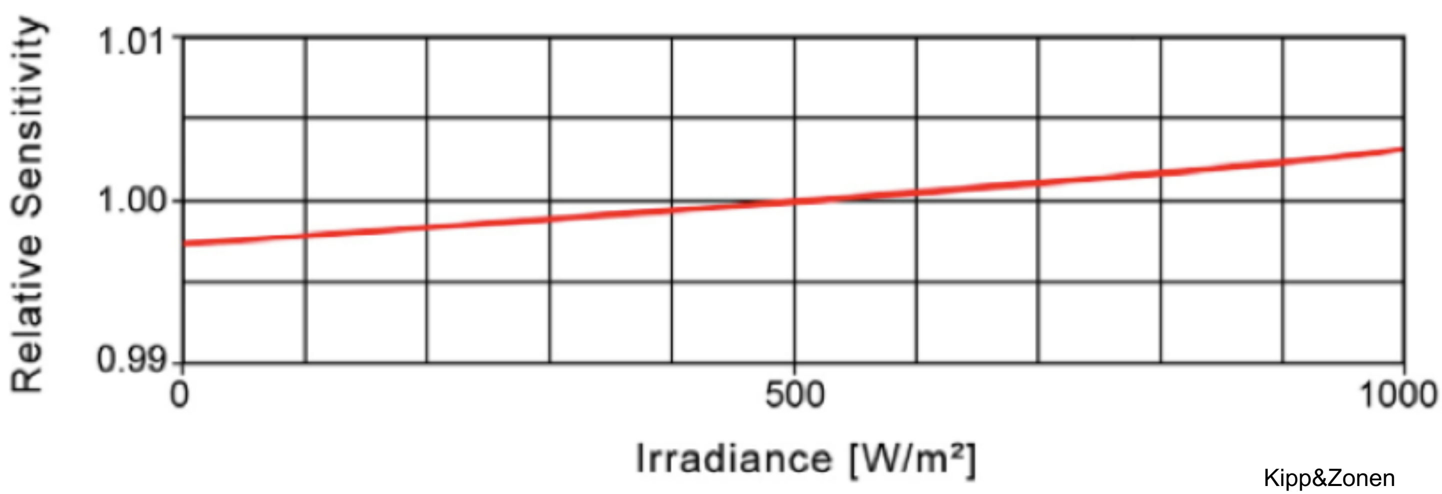


Kipp&Zonen

- Temperature Dependency



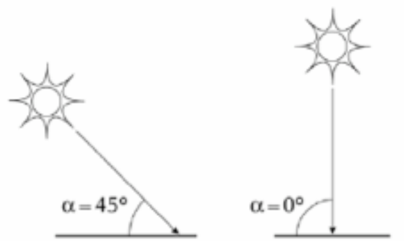
- Linearity

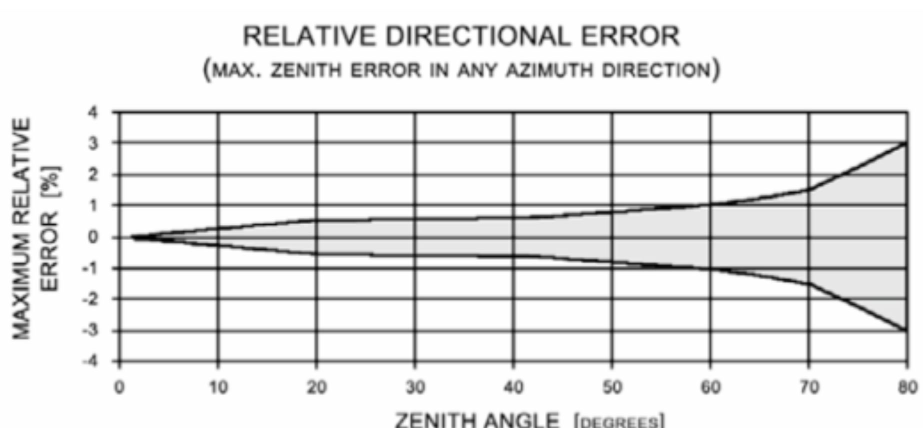


Geometric Errors:

- Cosine Response Error

  (low vs high incident radiation)
- Azimuth error (sensor geometry)





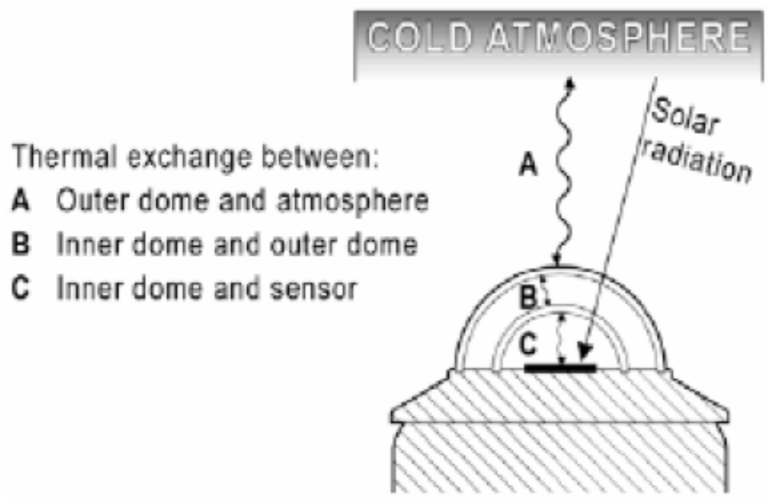
Kipp&Zonen

- Hysteresis
- Response Time Error
- Long Term Stability (aging of thermopile / paint / resistors / etc.)

Pointing error

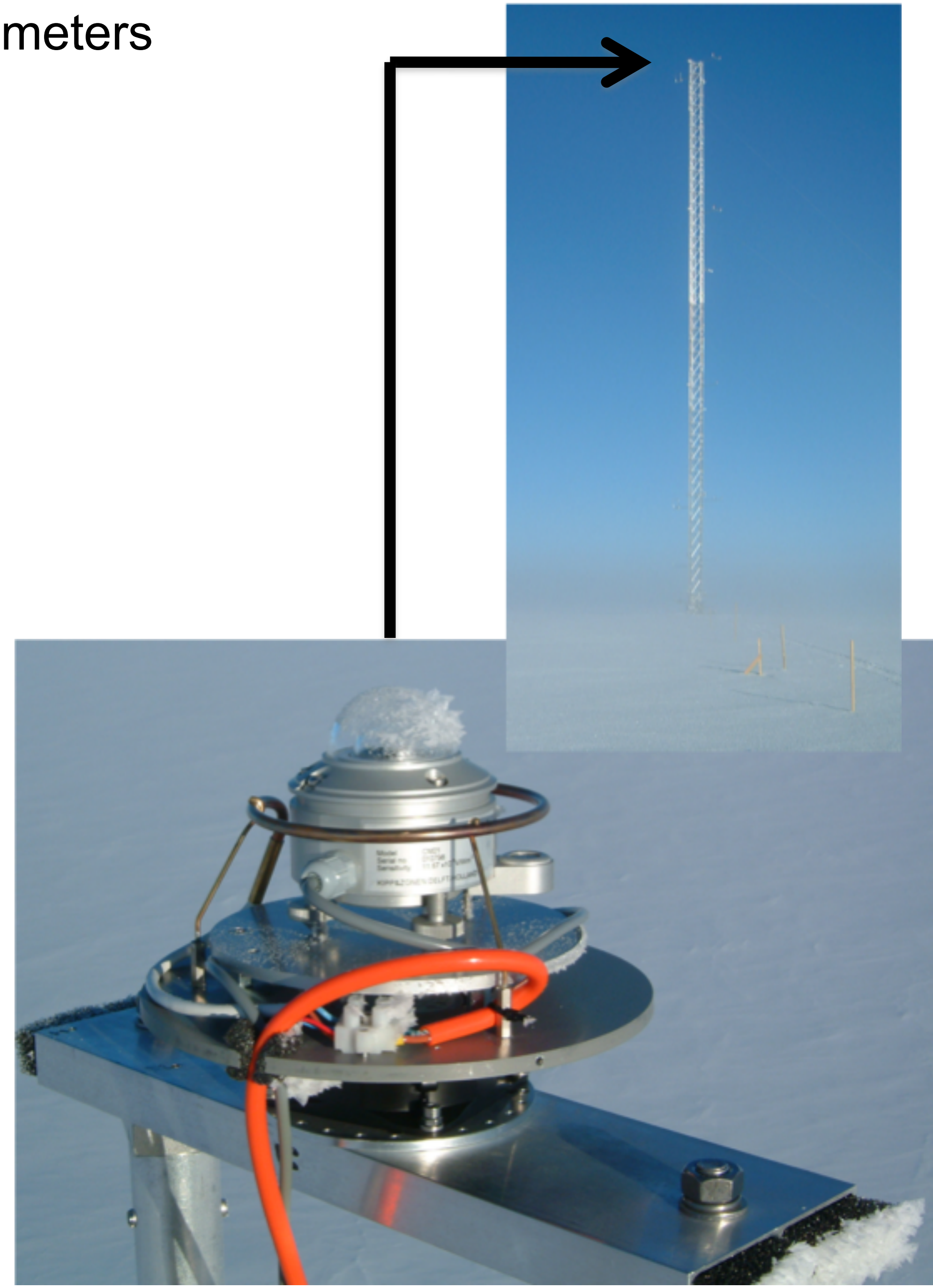
Condensation

Negative-Night-Time-Offset of Pyranometers



Kipp&Zonen

Ventilation and Heating!

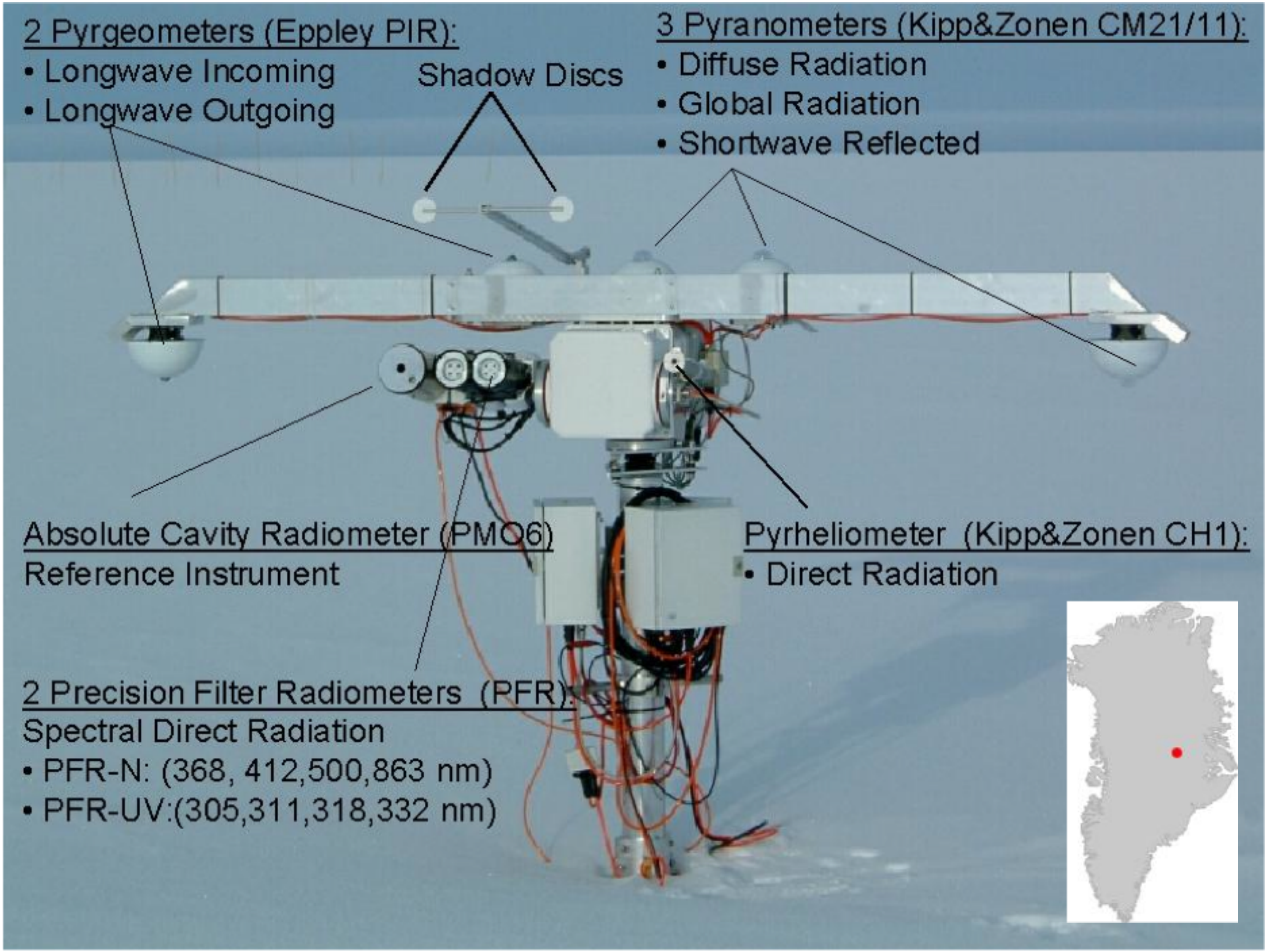


"Wind-Correction" of Pyrradiometers and Net-Radiometers

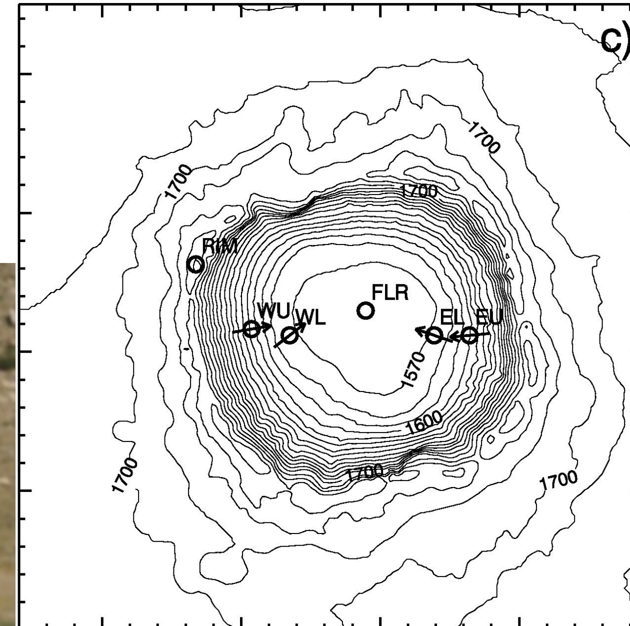
Dome material (polyethylene, lupolene) heats up. Ventilation reduces the heating effect.

Environmental impacts

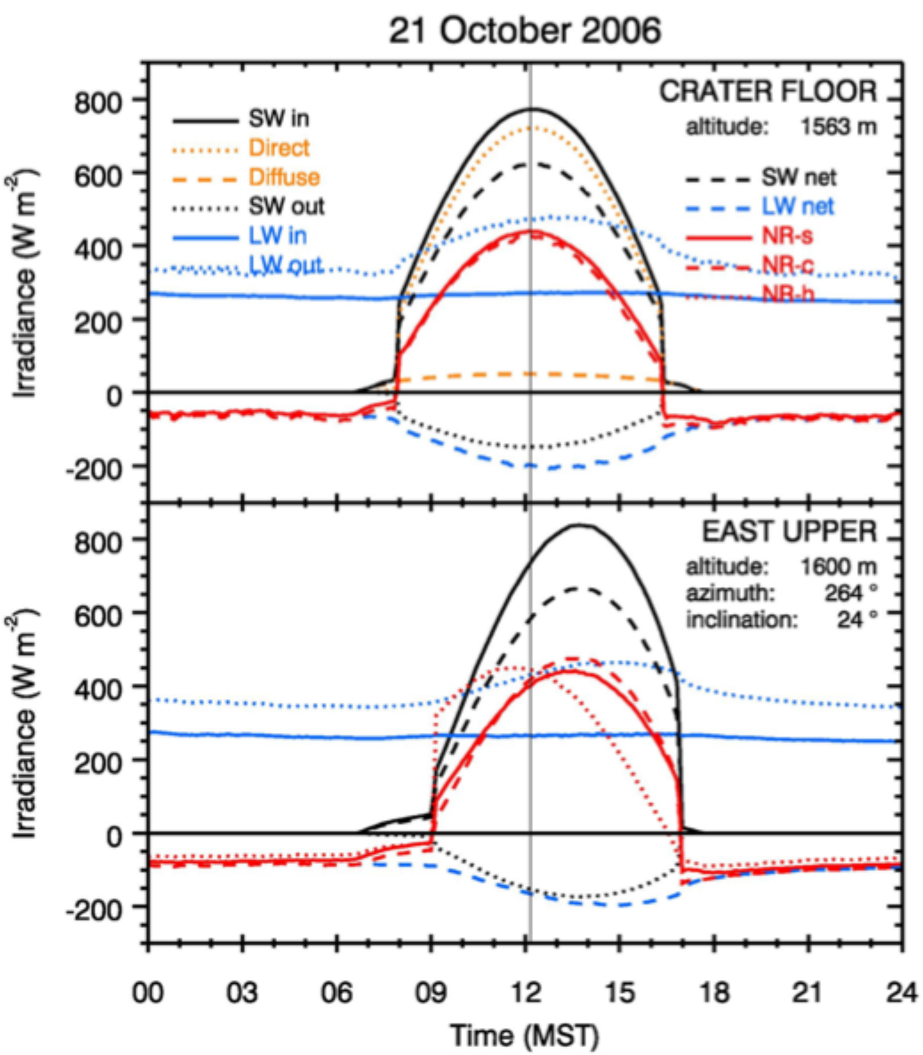
Radiation balance measurement at Summit, Greenland



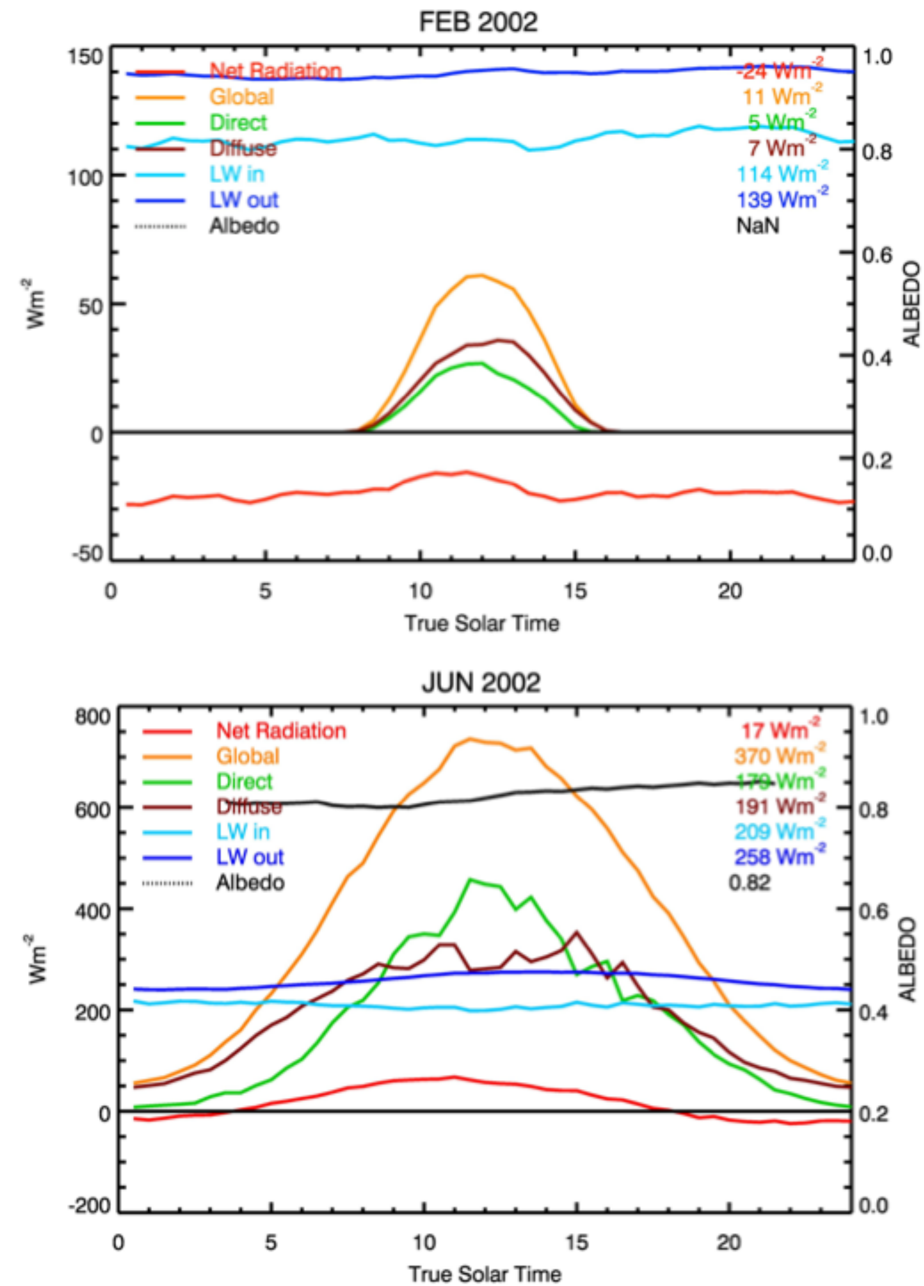
Radiation Balance Measurements during METCRAX 2006



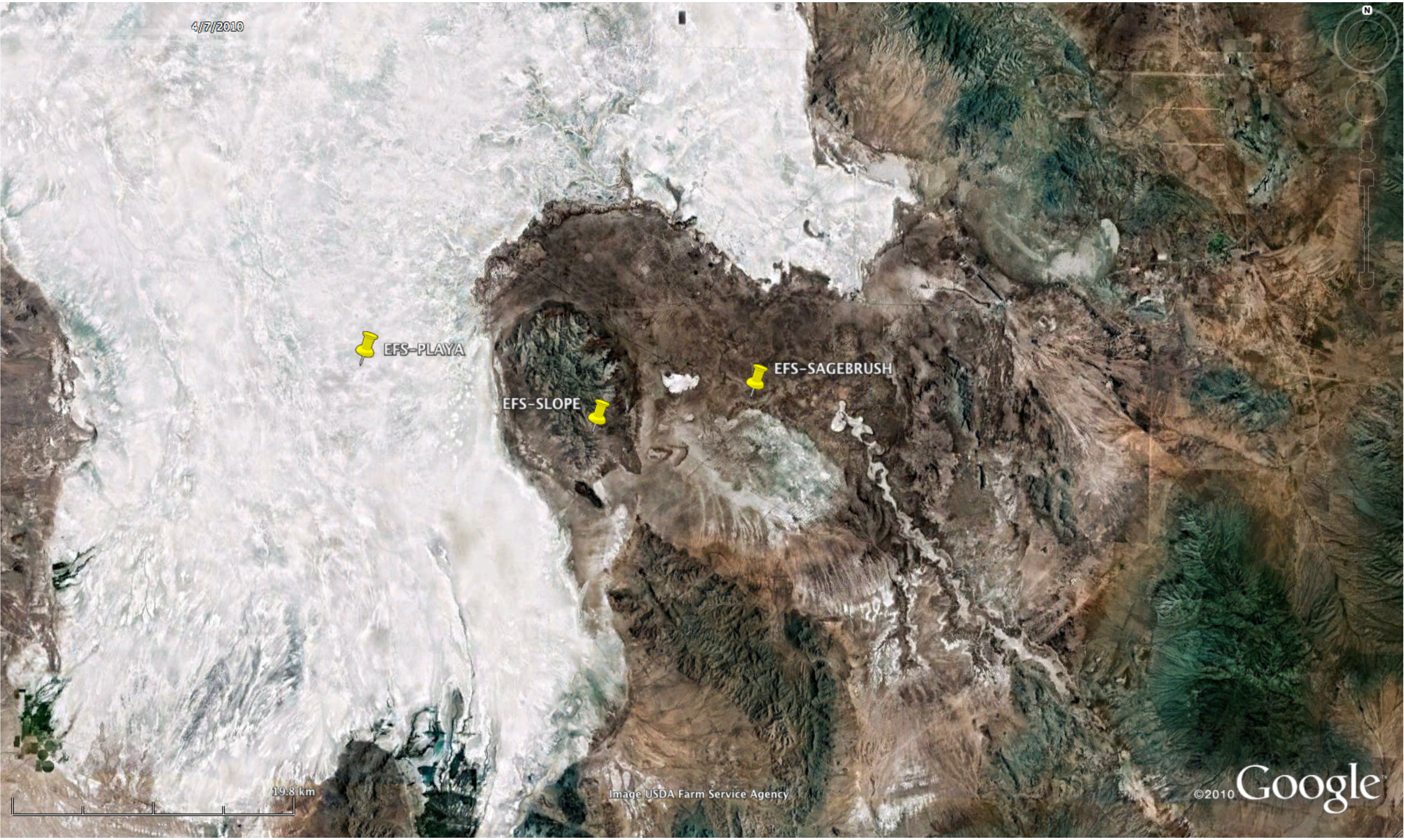
Meteor Crater, Arizona



Summit, Greenland (72˚N; 3200 m)



MATERHORN (Mountain Terrain Modeling and Observation Program)



Radiation measurements during MATERHORN

EFS-Playa

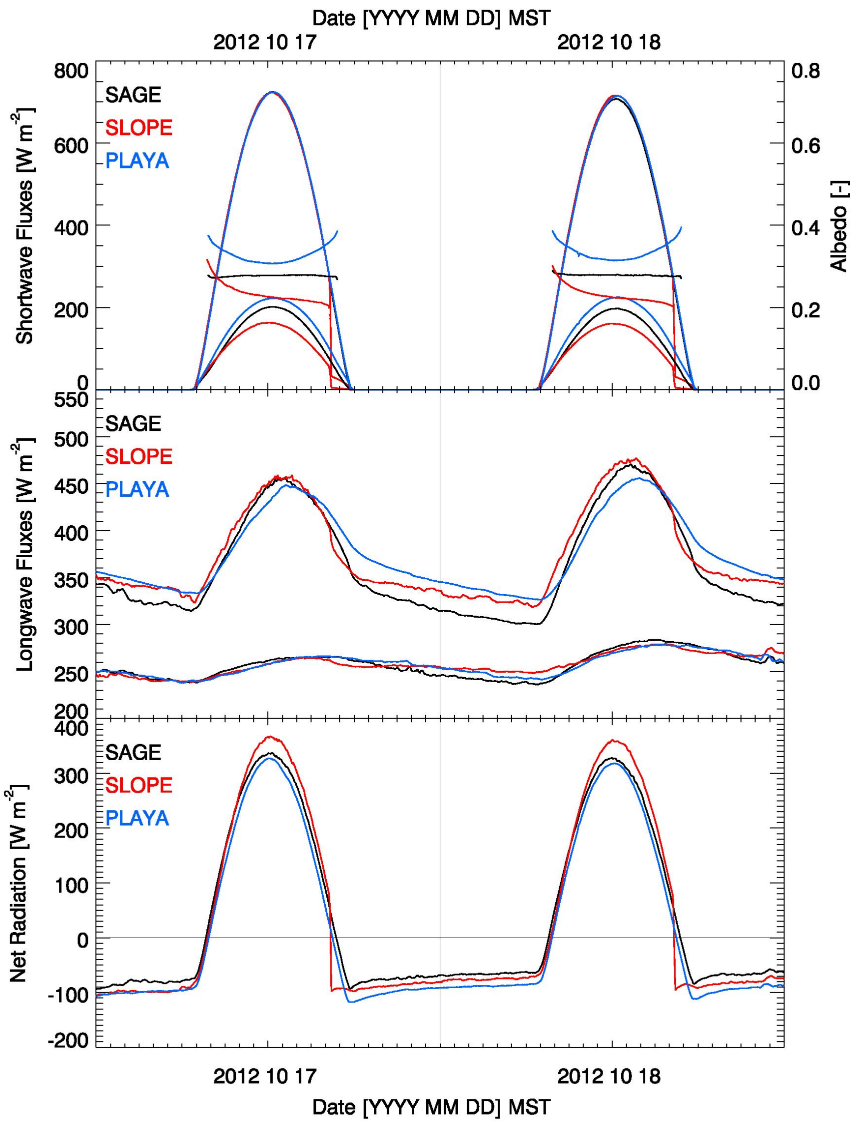
EFS-Sagebrush

EFS-Slope

Detailed View – 4 components

Radiation Balance at EFS-Sites

NR = SW↓ – SW↑ + LW↓ - LW↑



- Same shortwave energy input SW↓
- Albedo controls SW↑
- Same daytime NR at EFS-Sage and EFS-Playa
- Differences in SW* are compensated by differences in LW↑
- NR differences (Playa – Sage) are larger at nighttime, pointing to differences in soil thermal properties.

	Albedo [-] (min & max daily means)	Thermal Conductivity [W / (m K)]
EFS-Sage	**0.27** (0.18-0.29)	0.58
EFS-Slope	0.23 (0.17-0.24)	0.44
EFS-Playa	**0.31** (0.24 -0.35)	0.89

“Wer misst, misst Mist!”

English: “Those who measure, measure m&^%$!@# !”

Credits & Acknowledgements

Lecture notes of Prof. Claus Froehlich, Davos: ftp://ftp.pmodwrc.ch/pub/Claus/Vorlesung2009/

Notes on ETH Feldkurs Rietholtzbach by Reto Stoeckli

Kipp & Zonen: http://www.kippzonen.com/?downloadcategory/551/Pyranometers.aspx

Wikipedia articles