99 YEARS OF GLOBAL RADIATION OBSERVATIONS IN STOCKHOLM 1922-2020

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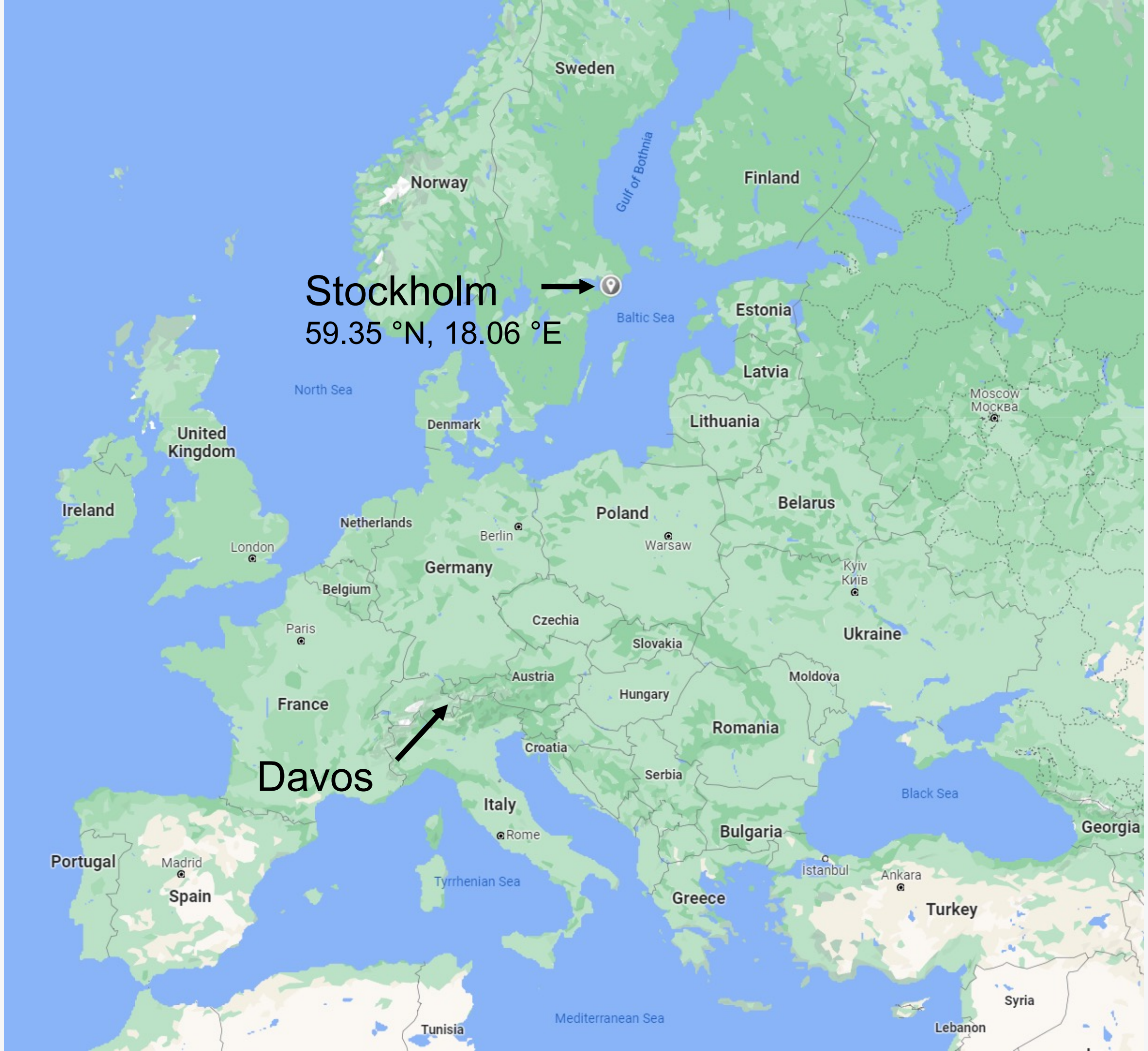
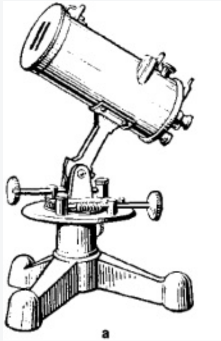
IPC-XIII Symposium, Davos, Switzerland 2021.


Stockholm
59.35 °N, 18.06 °E
Davos
Sweden
Norway
Finland
Gulf of Bothnia
Baltic Sea
Estonia
Latvia
Lithuania
North Sea
Denmark
United Kingdom
Ireland
Netherlands
Berlin
Poland
Warsaw
Belarus
Moscow
Москва
London
Germany
Belgium
Kyiv
Київ
Czechia
Paris
Slovakia
Ukraine
Austria
Moldova
Hungary
France
Romania
Croatia
Serbia
Italy
Black Sea
Bulgaria
Georgia
Rome
Portugal
Madrid
Spain
Tyrrhenian Sea
Istanbul
Ankara
Greece
Turkey
Syria
Mediterranean Sea
Tunisia
Lebanon

Where it all began…

SMHI



The Ångström electrical compensation pyrheliometer invented by Knut Ångström 1893 in Uppsala

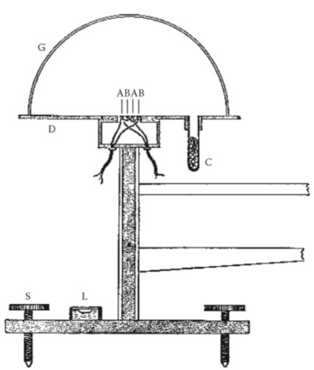


FIGURE 3.7 Schematic diagram of the Ångström electrical compensation pyranometer with white thermopile strips (A), black thermopile strips (B), glass hemisphere (G) mounted in a supporting disk (D), desiccant chamber (C), adjusting screws (S), and spirit level (L), (After Coulson, K. L., *Solar and Terrestrial Radiation, Methods and Measurements*, Academic Press, New York, 1975.)

The Ångström pyranometer was developed by Anders Ångström 1919

3.4.4 Ångström Pyranometer (1919)

Anders Knutsson Ångström, Swedish physicist and meteorologist and son of Knut Ångström, used his father's principle of electrical compensation developed for the Ångström pyrheliometer as the basis for his pyranometer nearly two decades later. As shown in the schematic diagram in Figure 3.7, the Ångström pyranometer detector consisted of two white strips and two black strips mounted on an insulating framework at the end of a nickel-plated cylinder. A glass hemisphere was mounted to a metal disk to protect the detector from the weather. Thermojunctions were attached to the backs of the strips in good thermal contact and electrically isolated. The operation of the pyranometer was based on maintaining the temperature of the white strips by supplying a measured electrical heating to match the amount of radiant energy absorbed by the black strips (Coulson, 1975). In spite of some attractive design attributes, the Ångström pyranometer was never put into widespread use.

From **Solar and Infrared Radiation Measurements**
By Vignola, Michalsky and Stoffel, 2012

Where it all began in 1922

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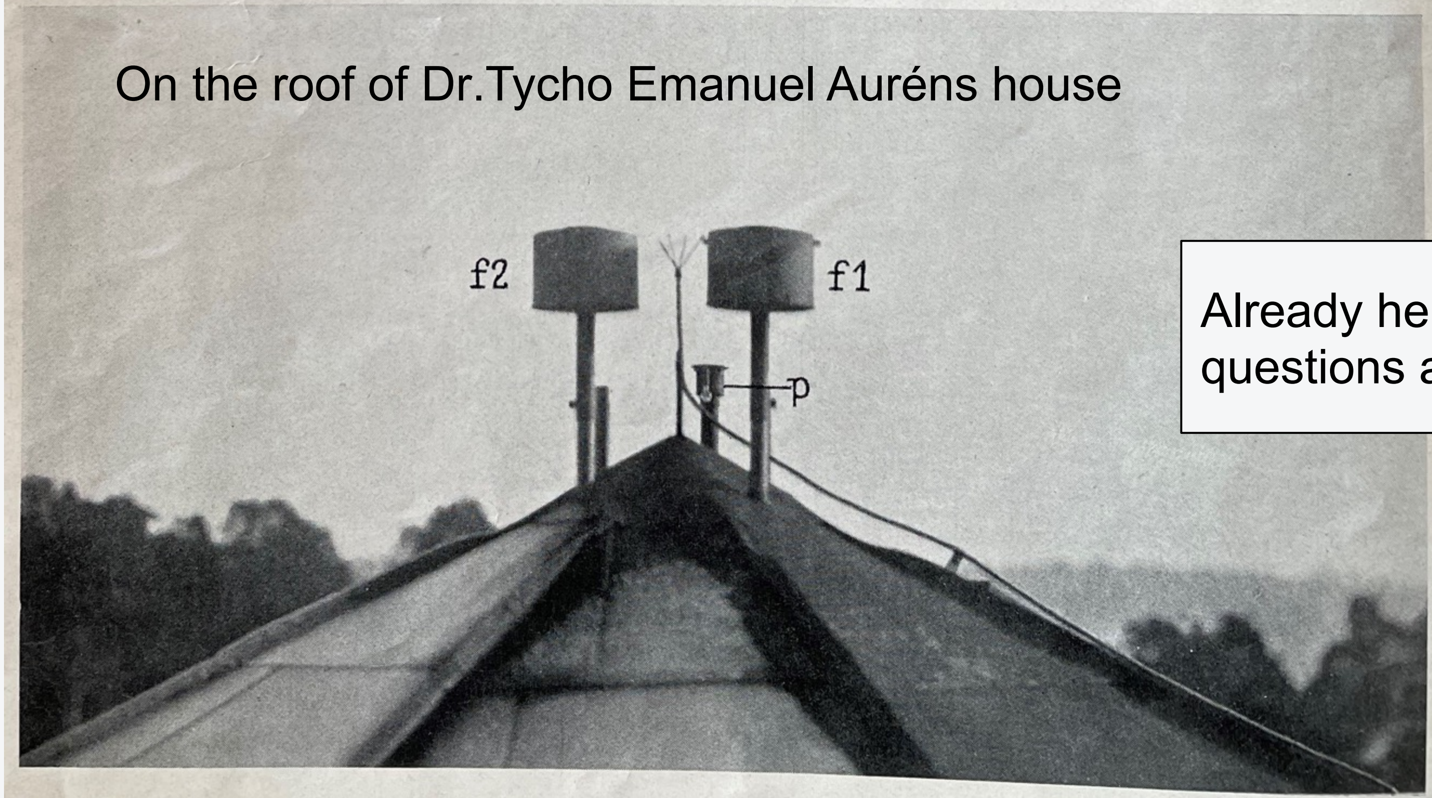

Description: p = pyranometer mounted on the roof of the observatory. f_1 and f_2 = photoelectric cells mounted for the researches of Dr. Aurén.

Already here the first questions arise…

Where it all began in 1922

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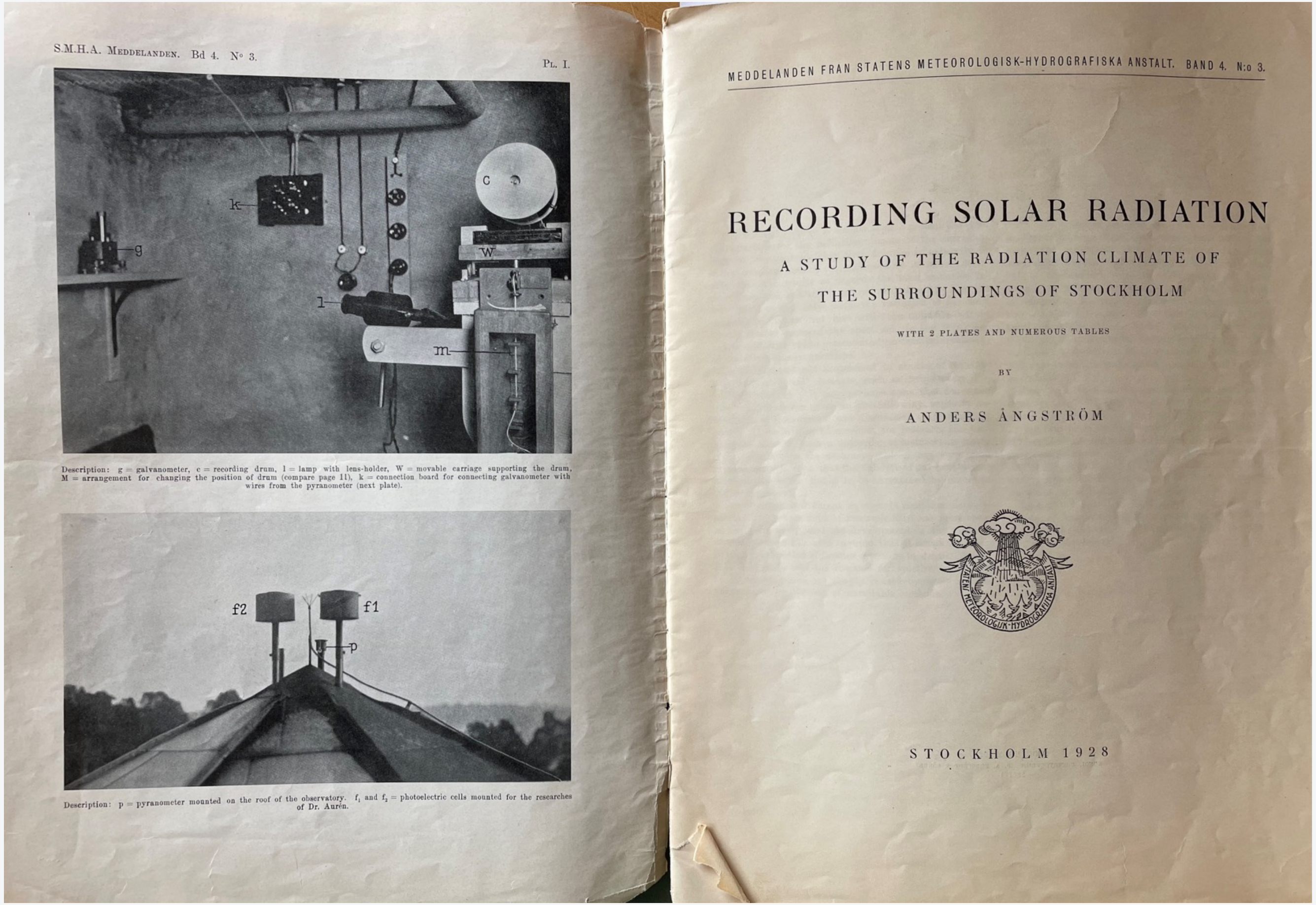
S.M.H.A. Meddelanden. Bd 4. N° 3.

Pl. I.

Description: g = galvanometer, c = recording drum, l = lamp with lens-holder, W = movable carriage supporting the drum, M = arrangement for changing the position of drum (compare page 11), k = connection board for connecting galvanometer with wires from the pyranometer (next plate).

Description: p = pyranometer mounted on the roof of the observatory. f_1 and f_2 = photoelectric cells mounted for the researches of Dr. Aurén.

MEDDELANDEN FRAN STATENS METEOROLOGISK-HYDROGRAFISKA ANSTALT. BAND 4. N:o 3.

RECORDING SOLAR RADIATION

A STUDY OF THE RADIATION CLIMATE OF THE SURROUNDINGS OF STOCKHOLM

WITH 2 PLATES AND NUMEROUS TABLES

BY

ANDERS ÅNGSTRÖM

STOCKHOLM 1928

The early recordings on photographic plates

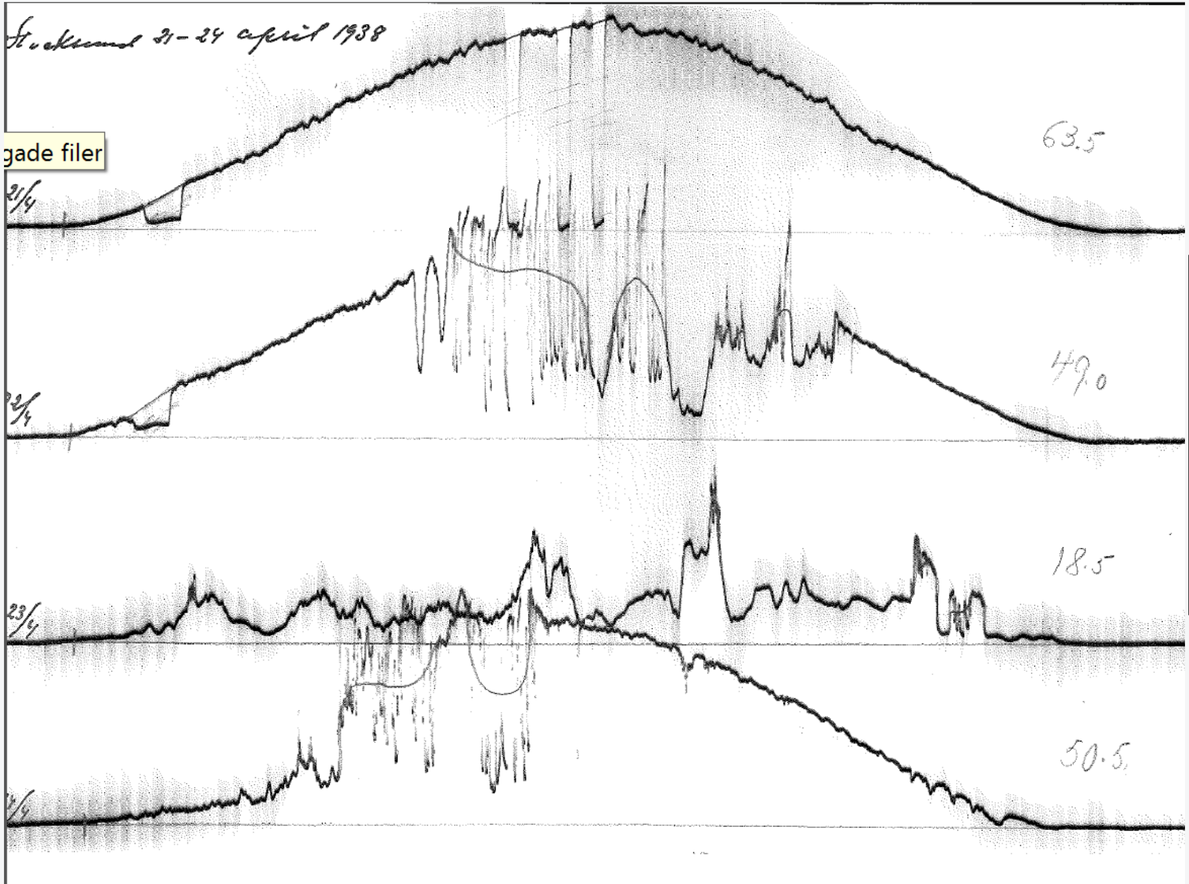

Figure 3.1 A photo found in the archive of SMHI showing the registration of four days 21-24 April 1938. Note the averaging during periods with strong and rapid variations. Some dips are interpolated e.g. in the top one there is an obscuring object causing a false dip to the left and during the day there has probably been a calibration using a shading disc at three occasions.

All original photographic plates have been lost.

The sites

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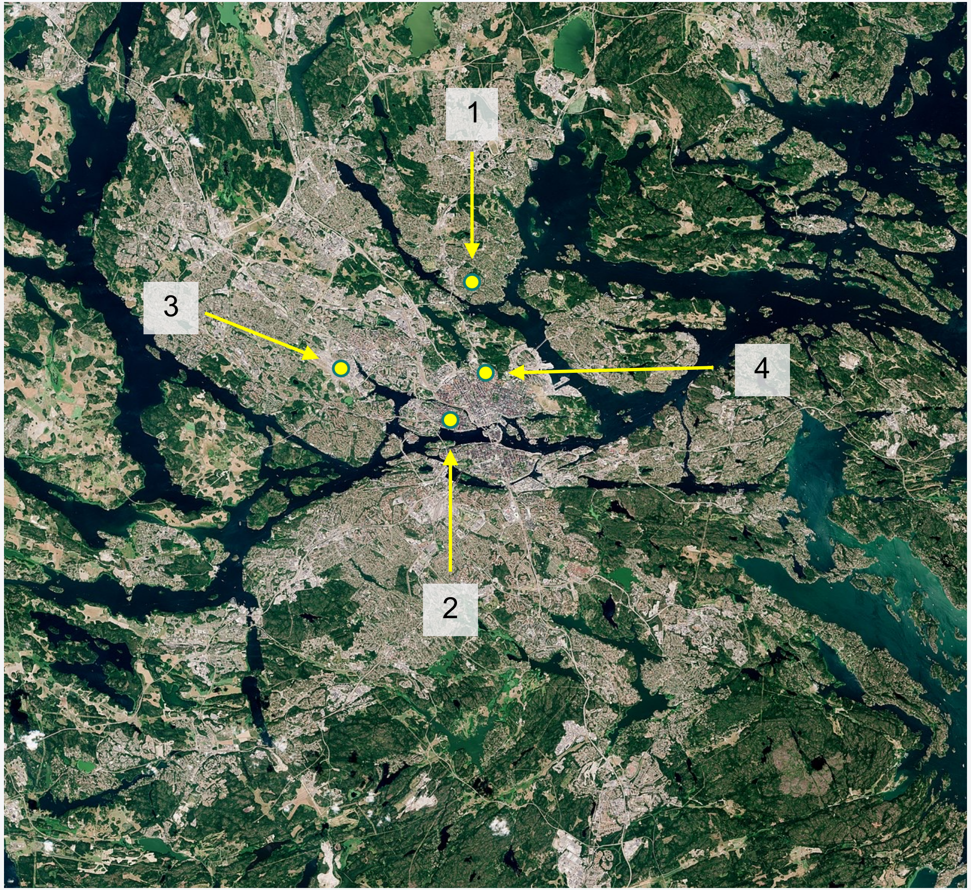
Nr	Name	Start
1	Stocksund	July 1922
2	Fridhemsplan SMHI	Oct 1945
3	Bromma Airport	June 1975
4	KTH Royal Institute of Technology	Jan 1983

Maximum distance [1,3]: 7 km

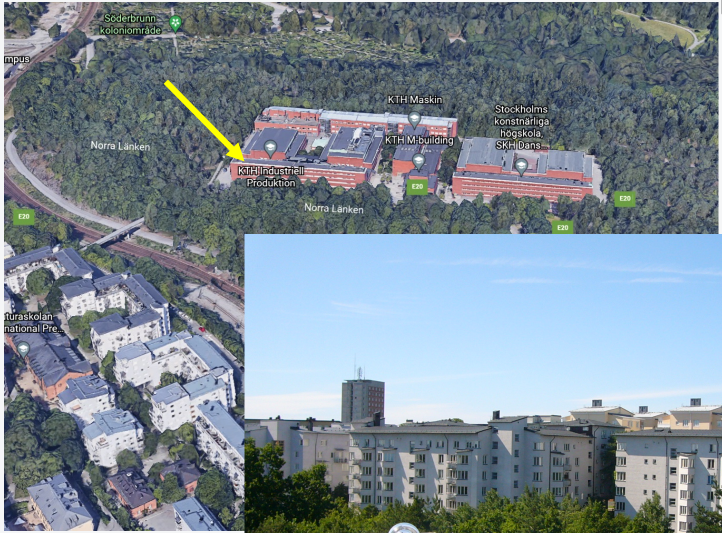
No significant difference in monthly (<0.3 %) or annual (<0.15 %) irradiation according to STRÅNG



SMHI

1. Stocksund

4. KTH



3. Fridhemsplan

Workflow – A long list...

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- Digitize raw data (if available) otherwise irradiance values
- List applied calibration constants
- If possible find out how and when calibrations were done
- Find out which unit and radiations scale that has been used
- Check that the digitizing was done correct
- Find out which data has been interpolated, corrected
- List instruments and periods when they were used
- Try to find instrument characteristics
- If possible correct for systematic errors caused by instrument characteristics
- Digitizing ancillary data; sunshine duration, precipitable water, air-temperature
- Compute extraterrestrial global irradiation and length of the day
- Quality check. Correct if necessary. ← Largest impact on the updated data series
- Uncertainty estimate

Digitizing, control and correction

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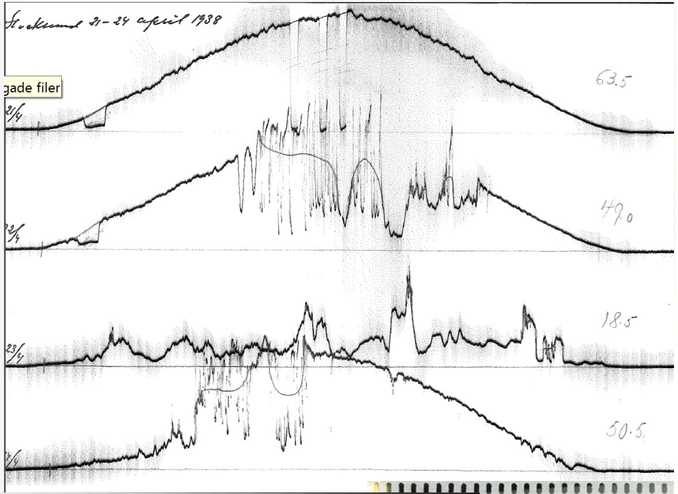
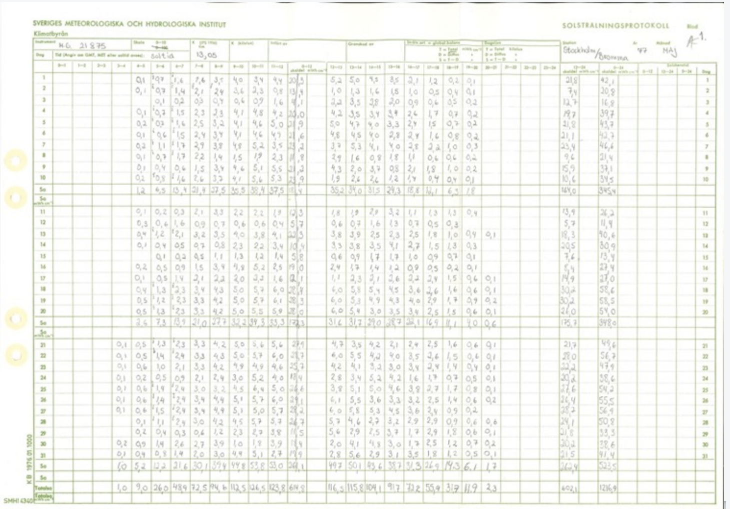


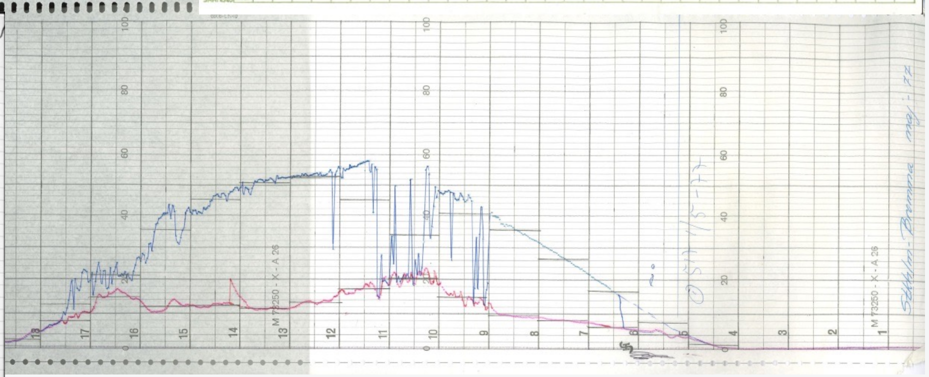



St 179

Total instrålning Stockesund aprilmånad 1938

K = 1/4 – 5/4 5.12
6/4 – 30/4 7.09

	Y		Q
1	54.2		278
2	59.5		305
3	22.5		115
4	51.5		264
5	66.5		340
6	28.0		199
7	32.0		227
8	38.8		275
9	28.5		202
10	42.0		298
11	25.5		181
12	36.5		259
13	36.5		259
14	41.5		294
15	41.5		294
16	10.5		74
17	35.5		252
18	44.5		316



Instruments, calibrations and time resolution in data

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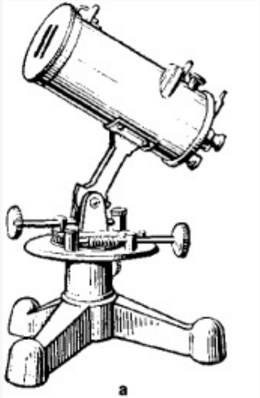
• Ångström pyranometer	monthly and daily values
• Aurén pyranometer	(used to fill in missing data)
• Kimball-Eppley pyranometer	hourly values
• Kipp and Zonen CM 2/3	
• Kipp and Zonen CM5	
• Kipp and Zonen CM11	six-minute values
• Kipp and Zonen CM21	minute values

Calibrations

Ångström's (Aurén's) pyrheliometer 1922 to about 1990-ties
Reference pyranometer Bromma 1975-1983
Absolute cavity pyrheliometers -> Thermopile references 1990-ties -



Ancillary data

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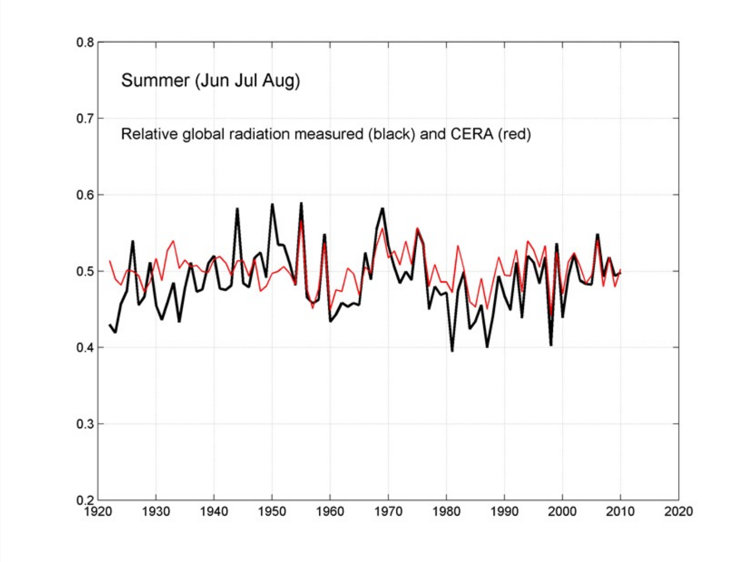
- Extraterrestrial radiation
- **Sunshine duration**
- Cloudiness
- Modelled data from ECMWFs CERA-20C
- Other stations measuring global radiation

… far … far away



Instrument characteristics

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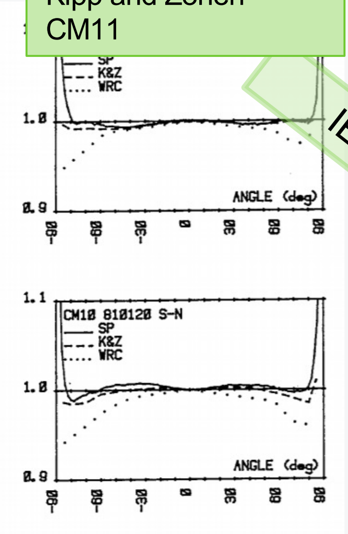
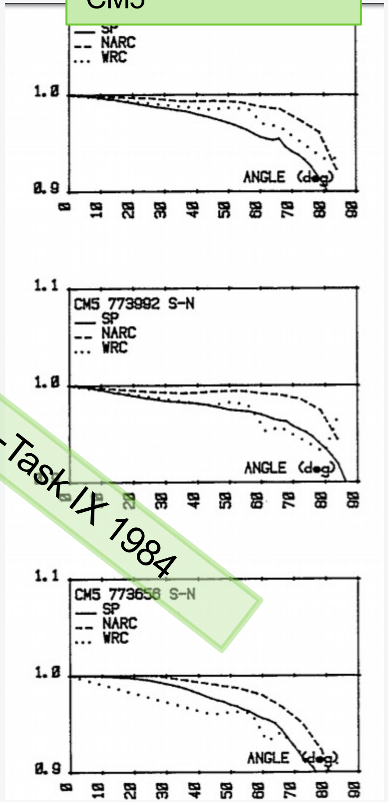
- Electrical and thermal offset
- Non-linearity
- Temperature dependence
- Directional responsivity (cosine and azimuth)
- *Calibration ….*

Kipp and Zonen
CM11



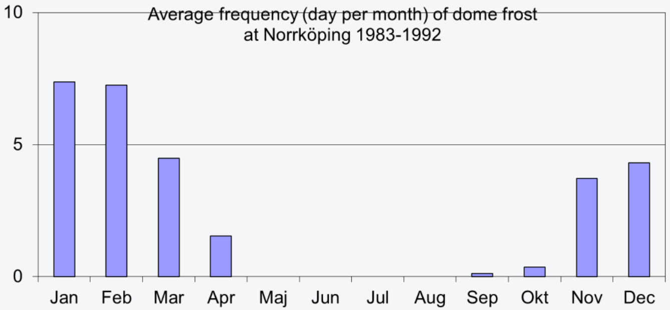
Kipp and Zonen
CM5

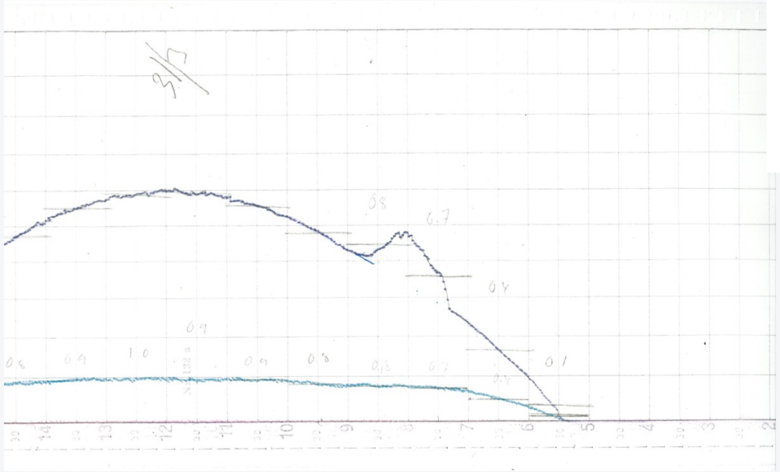


IEA-Task IX 1984

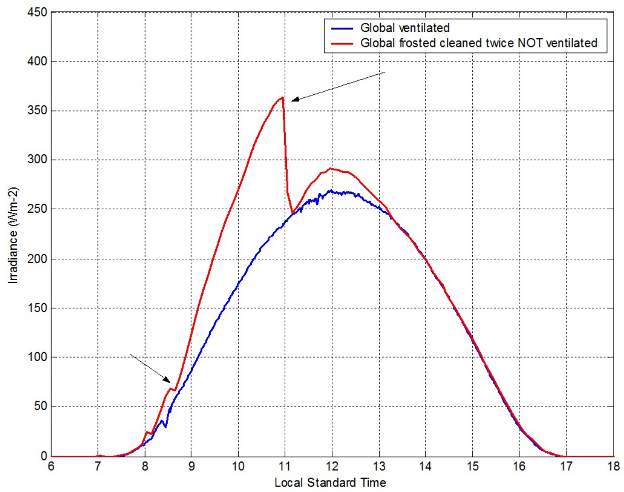
Ref.: IEA Task IX Recent Advances in Pyranometry 198

Gross errors in the evaluation e.g. rime / frost





Effect of rime 31 March 1957



Ångström-Prescott relation $G/G_{ex} = A * S/S_{max} + B$

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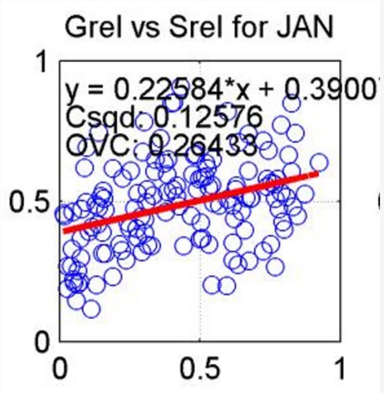
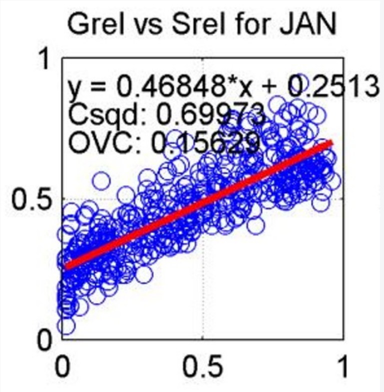
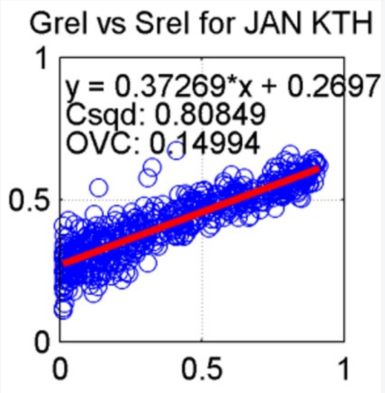
Daily values

1922-1950 | 1951-1982 | 1983-2018

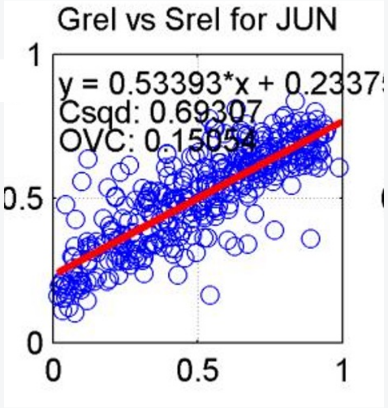
January

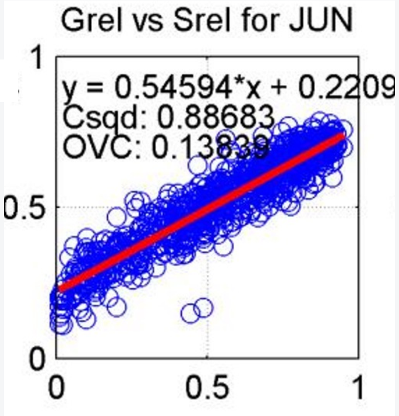


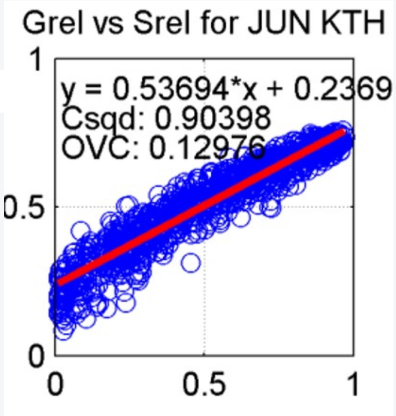




June







Uncertainty estimate

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	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
7		needs corr for			for daily value							standard unc.		divided by their degrees of freedom			
8	**Uncertainty**	systematic	Magnitude				**relative**		**degrees of freedom**		sensitivity coeff		**squared st unc**				
9	**Component**	component	of syst.comp.	**Unit**	**A or B**	**Distribution**	**u or a**	**Divisor**	**vi**	**u(x)**	**c**	**u(y)=c*u(x)**	**u(y)^2**	**u(y)^4 / vi**			
10																	
11	Abs calibration	No			B	rectangular	0.03	1	556	0.03	1	0.03	0.0009	1.458E-09			
12	spectral resp	No			B	normal	0.01	1	5000	0.01	1	0.01	0.0001	2E-12			
13	non-linearity	Yes			B	normal	0.005	1	20000	0.005	1	0.005	0.000025	3.125E-14			
14	temperature resp	Yes			B	normal	0.005	1	20000	0.005	1	0.005	0.000025	3.125E-14			
15	cosine	Yes			B	normal	0.025	1	800	0.025	1	0.025	0.000625	4.883E-10			
16	azimuth	Yes			B	normal	0.025	1	800	0.025	1	0.025	0.000625	4.883E-10			
17	time-const	No			B	normal	0.0025	1	80000	0.0025	1	0.0025	6.25E-06	4.883E-16			
18	non-stability between calibr	No			B	normal	0.015	1	2222	0.015	1	0.015	0.000225	2.278E-11			
19	offset	Yes			B	normal	0.01	1	5000	0.01	1	0.01	0.0001	2E-12			
20																	
21																	
22	error in time	No			A	normal	n/a				1						
23	unc in registration	No			B	rectangular	0.005	2	20000	0.0025	1	0.0025	6.25E-06	1.953E-15			
24																	
25	evaluation of registration																
26	method of evaluation	no			A	normal	0.005	2	20000	0.0025	1	0.0025	6.25E-06	1.953E-15			
27	significant digits	no			B	rectangular											
28	rounding in integrated values	no			B	rectangular	0.005	1	20000	0.005	1	0.005	0.000025	3.125E-14			
29																	
30	other suorces of uncertainty																
31	rime, frost, dew, rain, dirt				B	rectangular	n/a										
32	humidity inside				B	rectangular	n/a										
33	tilt of instr				B	rectangular	n/a										
34	missing value /interpolation				A	normal	n/a										
35																	
36	**CONCLUSION**																
37	Daily values measured by the Kipp and Zonen CM5 pyranometer have an uncertainty (95%) of about **±10 %**										**Sums**		**0.002669**	**2.461E-09**			
38											**Combined standard uncertainty**		**0.051660**		sqrt of sum		
39											**Effective degrees of freedom**		**2894**		From Welch-Sattertwaite equat		
40											**Coverage factor (95%) k=**		**1.96**		Student's t-table gives this from		
41											**Expanded uncertainty**		**0.10125**				
42																	

Methodology and worked examples described in Cook (2002) and JCGM 100 (GUM, 2008)

Results

Final output is a report and some data sets

”Raw data” 1922-1983 in Excel-files including comments

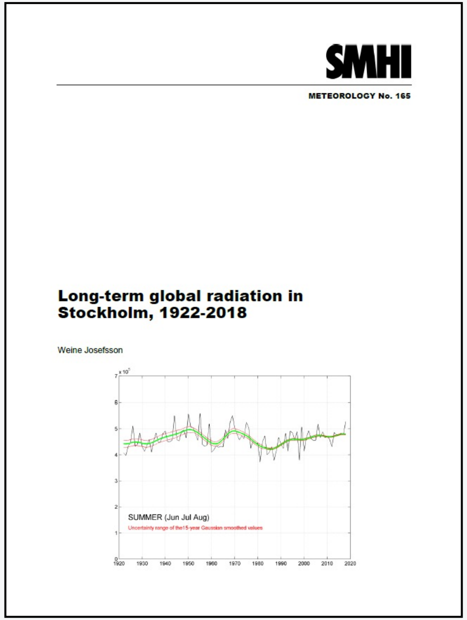
Hourly data, 1945 X -- in yearly files including some ancillary data

Daily data files (available on the web)

Monthly data files (available on the web)

Report (available on the web)

https://www.smhi.se/kunskapsbanken/meteorologi/long-term-global-radiation-stockholm-1.141870



Was there a change after the re-evaluation?

YES!

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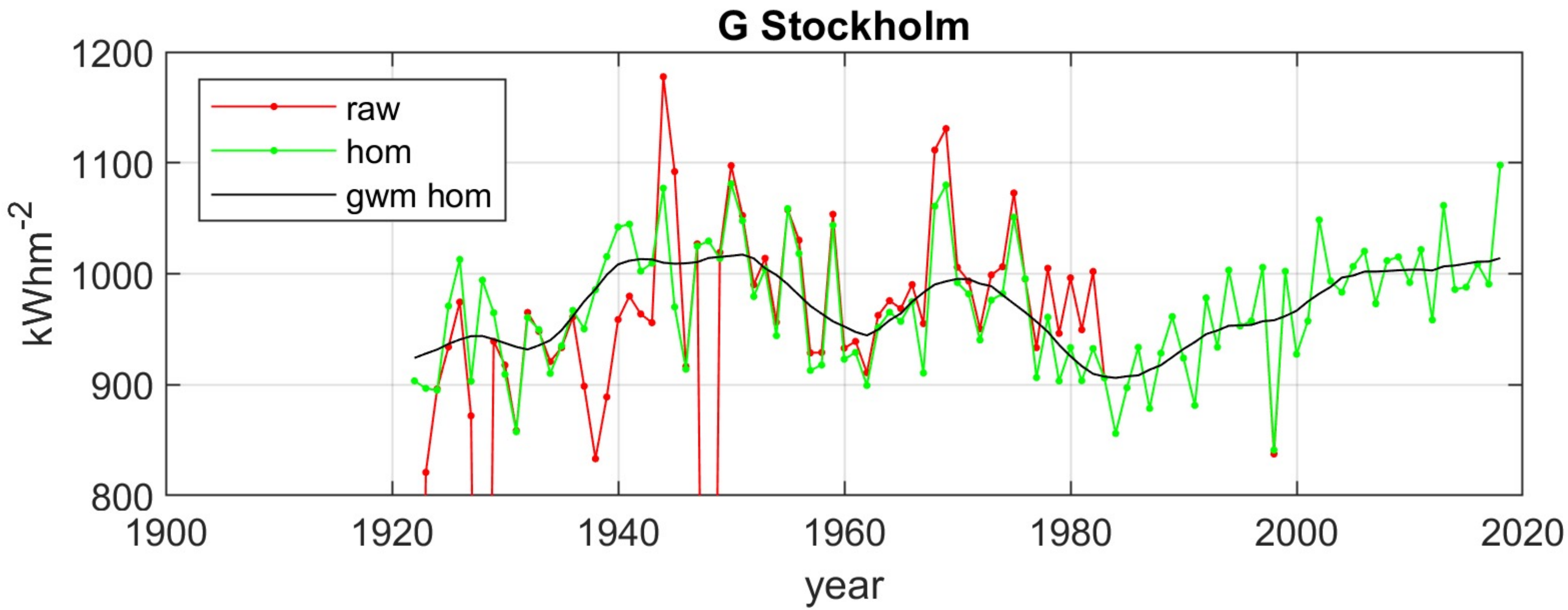
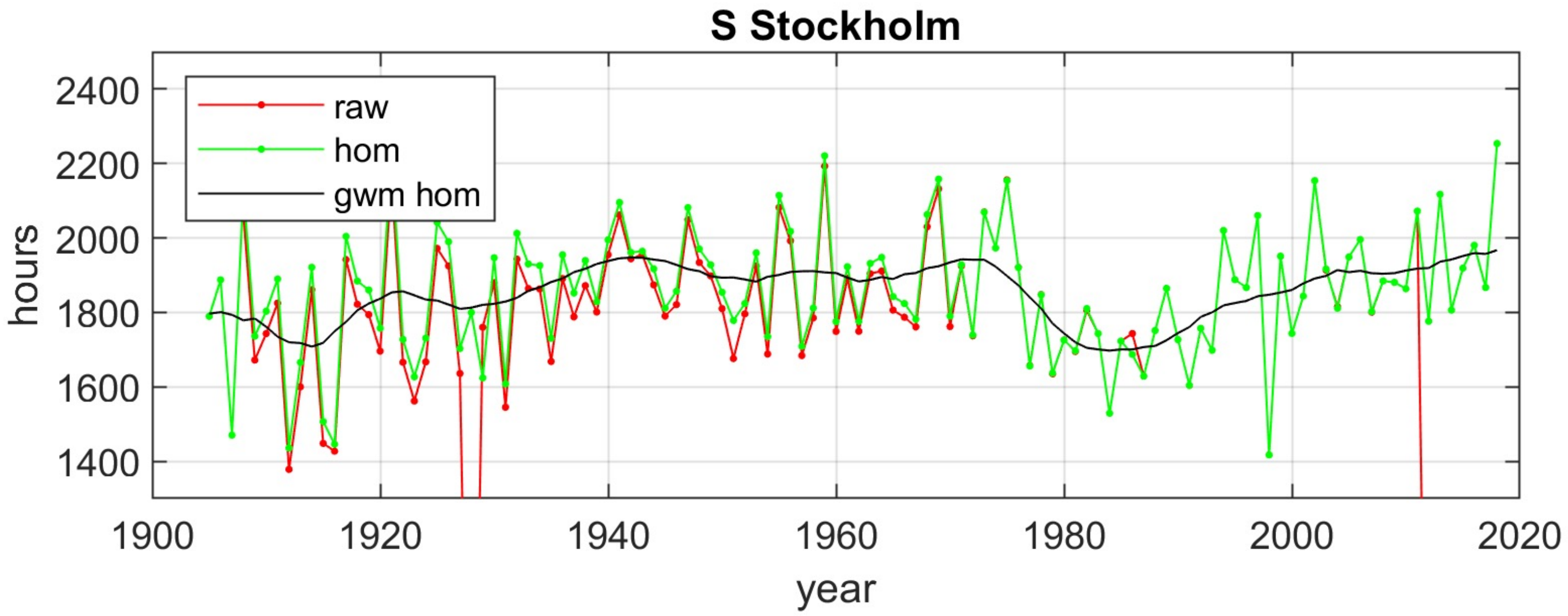
Annual global irradiation



Was there a change after the re-evaluation?

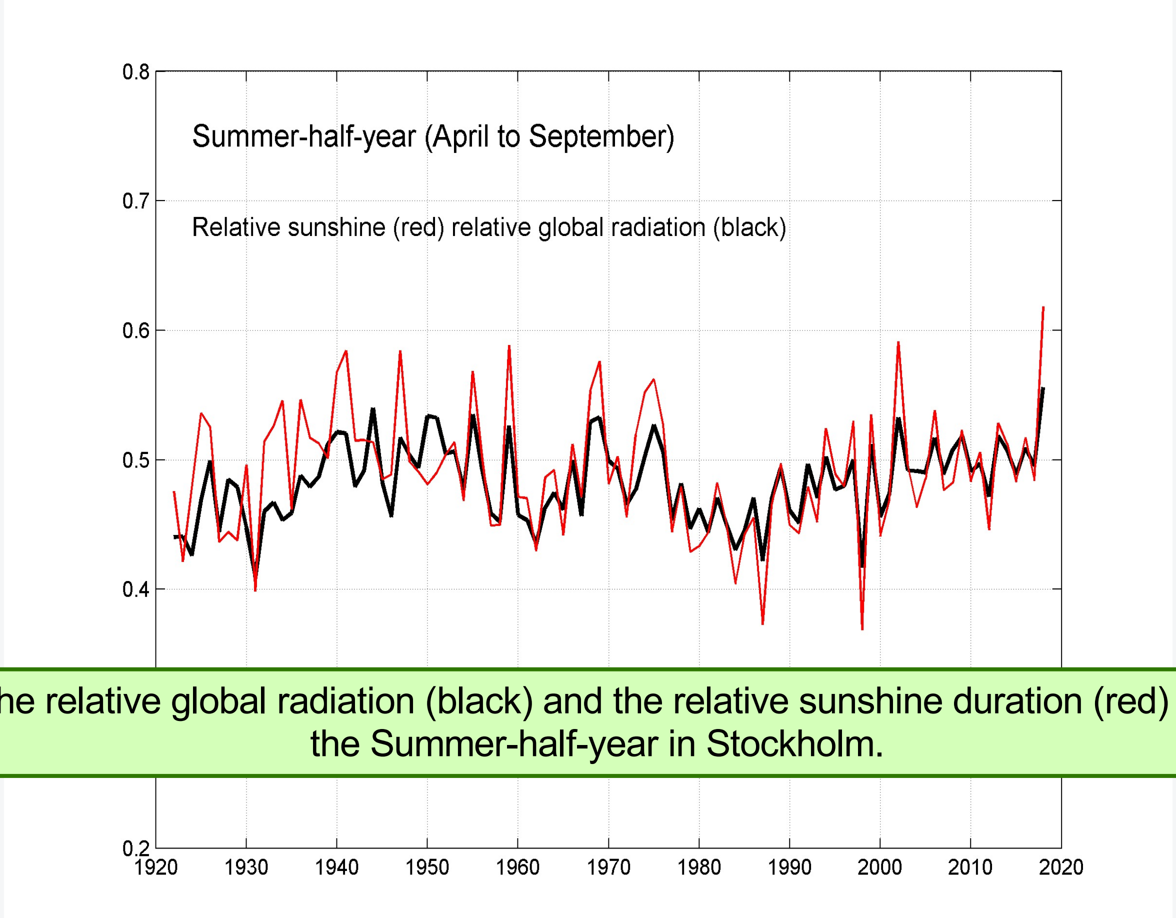
SMHI

Annual sunshine duration



Global radiation and sunshine duration combined

SMHI



The relative global radiation (black) and the relative sunshine duration (red) for the Summer-half-year in Stockholm.

Rough uncertainty estimate Daily values

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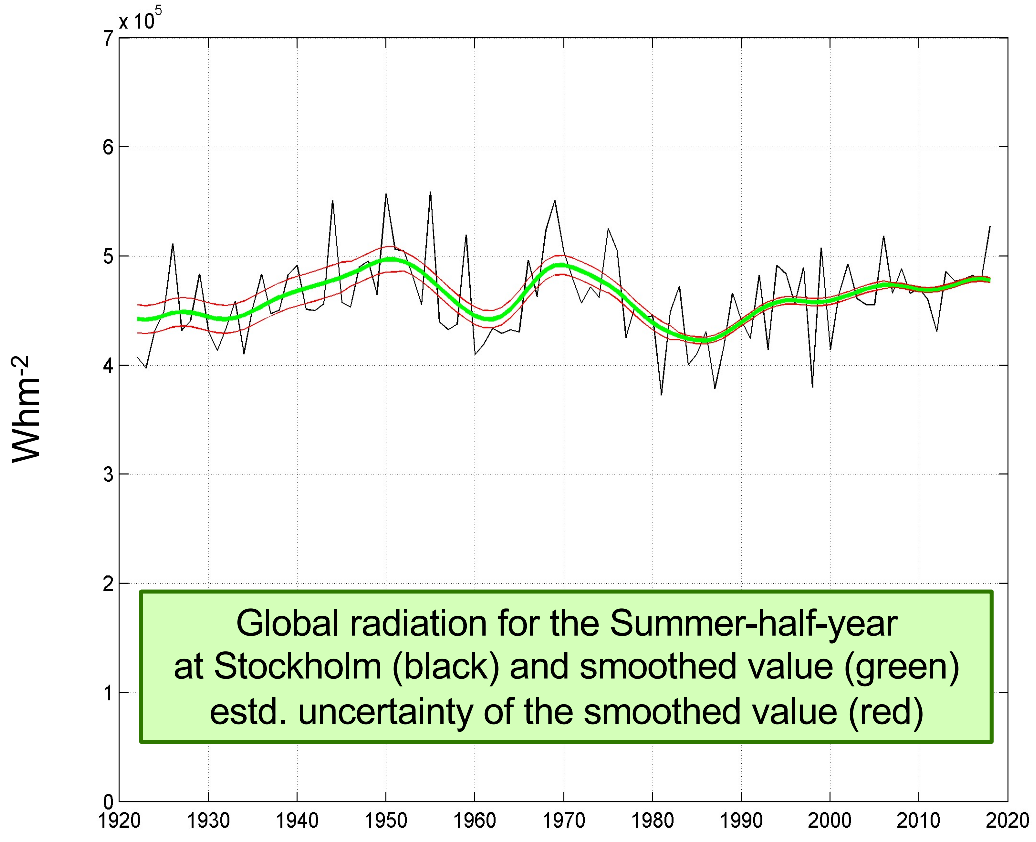
Table 7.1 Expanded absolute uncertainty (2σ) estimates for daily values measured at Stockholm 1922-2018 for days when everything operates as it should.

Instrument	Approx. period	Uncertainty (%)
Ångström #2	1922-1930	15
Ångström #40	1931-1945	15
Aurén solarimeter	(1938-1942)	15
Kimball-Eppley	1945-1951	13
CM2/3	1951-1975	11
CM5	1975-1983	10
CM11	1983-2006	5
CM21	2007 -	4

Summer half year global irradiation with uncertainty estimate



Some conclusions

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- There are still some loose ends prior to 1951
- The re-evaluated data series are hopefully better than the previous published
- There is no significant trend for the full period 1922-2018
- However, there is some notable decadal variation
- The quality of the measurements of global radiation has improved
- The introduction of ventilation and heating was a major improvement
- Most important for the quality is well educated and dedicated personal.

To all who have struggled to get and keep this long time series of global radiation running,

and to the current audience

Thank you!

https://www.smhi.se/kunskapsbanken/meteorologi/long-term-global-radiation-stockholm-1.141870

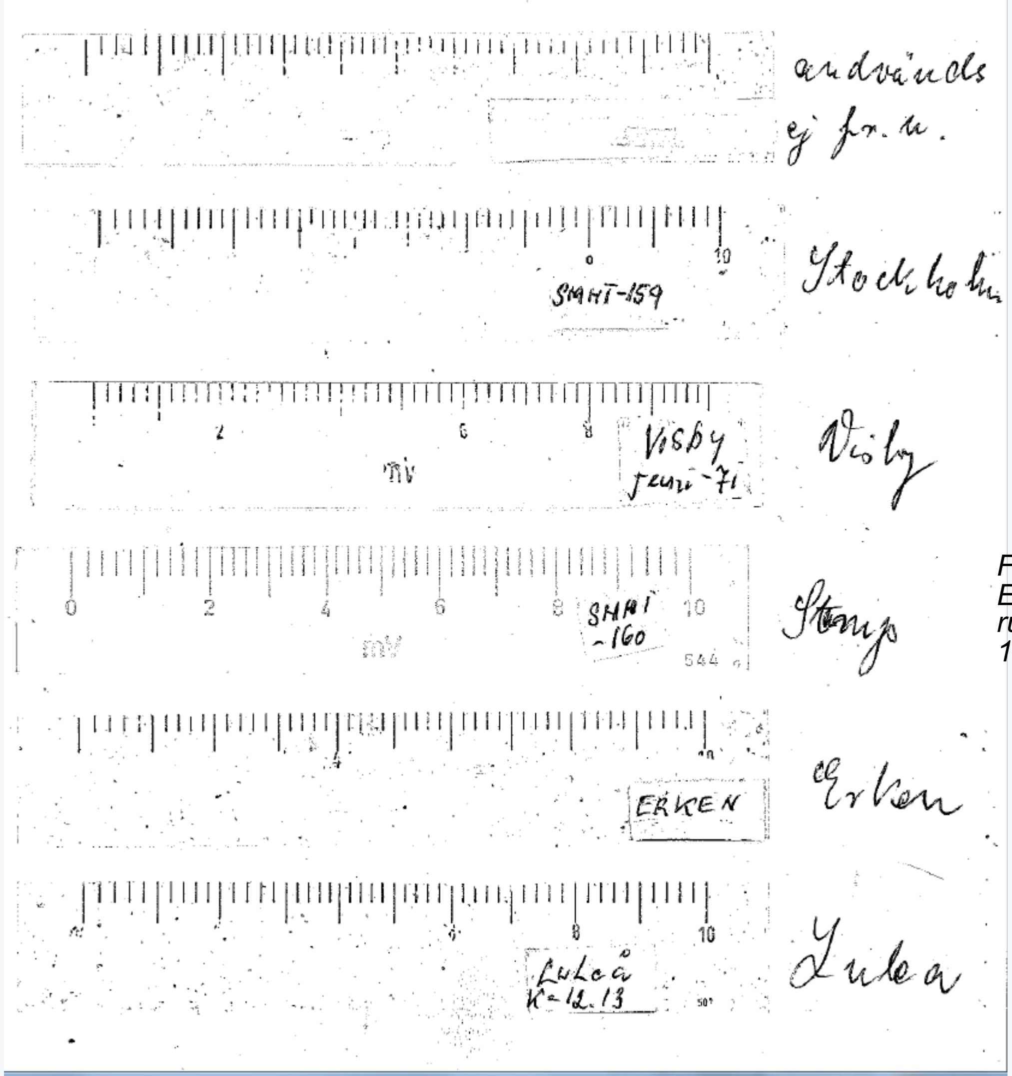
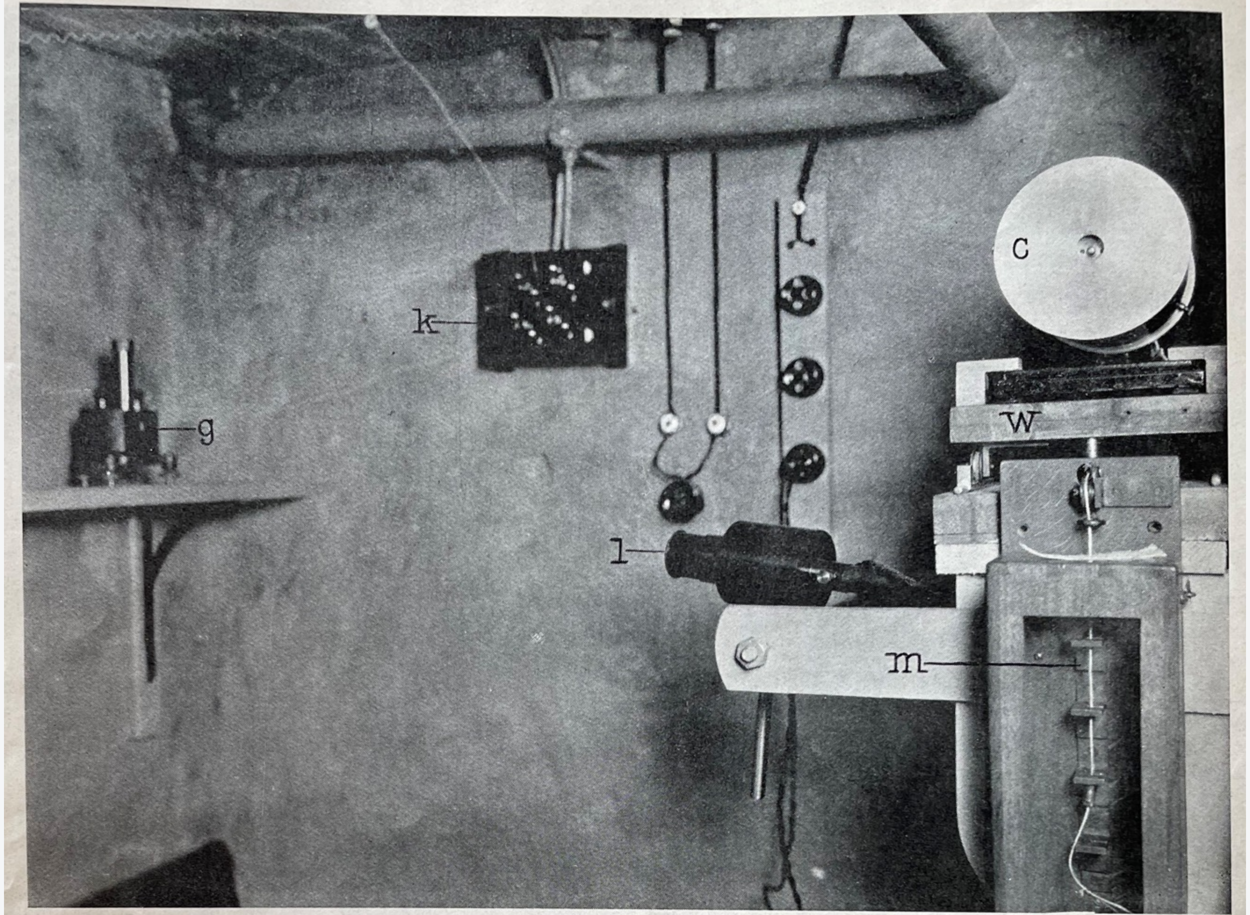


Figure 3.3 Examples of rulers used in 1973



Description: g = galvanometer, c = recording drum, l = lamp with lens-holder, W = movable carriage supporting the drum, M = arrangement for changing the position of drum (compare page 11), k = connection board for connecting galvanometer with wires from the pyranometer (next plate).

Older study comparing global radiation/SSRD from ERA40 and observations from some Swedish sites. (Carlund, EGU 20xx)