Infrared Radiometer Calibration Center

of the WRC/PMOD

-IRC-

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Tasks within the Workplan

1h) Develop further the establishment of a World Standard Group of absolute longwave radiometers

task: Collaborate with PMOD/WRC on the establishment of a World Standard Group of absolute long-wave radiometers

Deliverable: A World Standard Group of absolute long-wave radiometers established

Deadline May 2006: Not yet achieved!

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Tasks within the Workplan

1i) Coordinate the dissemination of the World Radiometric Reference factors to regional and national radiation standards

task: Develop proposal for the dissemination of IR factors to regional and national radiation standards *–centers(?)*

Deliverable: Report to Members

Deadline May 2006: Calibration Center is operational and in use

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Overview

- History of the IRC
- Instrumentation (overview)
- Stability of the longwave infrared reference
- Pyrgeometer calibration procedure
- Absolute longwave reference
    - ASR
        - Uncertainty budget
- Current developments / outlook

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History

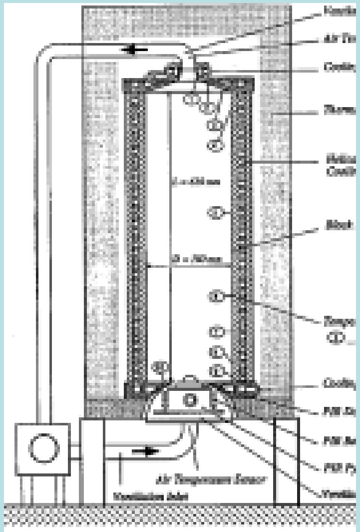
- Official starting date 1 January 2004
- One Absolute sky scanning Radiometer (ASR)
- Comprises 4 pyrgeometers
  - 2 modified Eppley PIR, 31463, 31464
  - 2 Kipp&Zonen CG4, FT004, 010535

„World Infrared Standard Group of pyrgeometers“

- WISG -

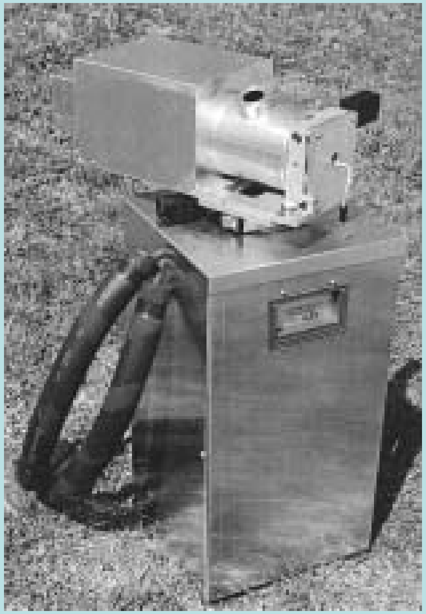
This standard group is based on the Absolute Sky-Scanner Radiometer (ASR) developed by R. Philipona

Instrumentation of IRC



Black Body

WISG



ASR

World Infrared Standard Group
of pyrgeometers

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The WISG coefficients are based on IPASRC-I results with a small adjustment for conditions at PMOD/WRC (Philipona, 2005 private communication).

September 1999, Great Plains, Oklahoma, US

Table 1. Pyrgeometer Inventory and Calibration and Correction Factors

			FACT	User		CMDL		PMOD					FIELD				
Serial	Owner[a]	T_D	C	C	K	C	K	C	k_1	k_2	k_3	K	C	k_1	k_2	k_3	K
PIR13678F3	BoM Australia	1	4.13	4.29	4.0	3.97	4.0						4.27		0.997		4.0
PIR28492F3	SUNYA USA	1	3.74	3.74	4.0	3.49	4.0						3.43		0.994		4.0
PIR28898F3	University of Maryland USA	1	4.00	4.00	4.0	3.91	3.0						3.90		1.003		3.0
PIR29255F3	NOAA/SRRB USA	1	3.82	4.00	4.0	4.01	3.0						3.97		1.002		3.0
PIR30555F3	NOVA/CMDL USA	1	3.57	3.57	4.0	3.52	3.5						3.69		1.000		3.5
PIR31195F3	NREL USA	1	3.56	3.56	4.0	3.49	3.5						3.41		1.003		3.5
PIR32227F3	Eppley USA	1	3.90	3.90	4.0	3.93	3.5						3.83		1.003		3.5
PIR32690F3	Saudi Arabia	1	4.00	4.00	4.0	4.19	3.5						4.10		1.002		3.5
PIR26036mod	NASA USA	3	(4.14)	3.84	3.48	3.78	4.0	4.36	0.1218	1.0038	3.58		4.42	0.1218	1.0000	3.58	
PIR28146mod	AES Canada	3	(3.88)	3.69	3.42	3.67	4.0	4.34	0.1510	1.0024	3.61		4.32	0.1510	1.0024	3.61	
PIR29143mod	DOE/ARM USA	3	(3.30)	3.38	3.51	3.33	4.0	4.28	0.2360	1.0050	3.64		4.37	0.2360	1.0020	3.64	
PIR30175mod	DWD Germany	3	(3.91)	3.63	3.13	3.63	3.5	3.95	0.0733	1.0014	3.11		4.05	0.0733	1.0000	3.11	
PIR31463mod	PMOD Switzerland	3	(3.63)	3.32	3.53	3.34	4.0	3.71	0.0766	0.9974	3.30		3.80	0.0766	0.9974	3.30	
PIR32205mod	JMA Japan	3	(4.04)	3.92	2.66	3.80	3.5	4.25	0.1112	1.0031	2.75		4.26	0.1112	1.0031	2.75	
CG4-4	K&Z Netherlands	1	—	12.29	0.3	12.2	1.4	12.29				0.3	12.50		1.004		0.3

[a] BoM, Bureau of Meteorology; SUNYA, State University of New York at Albany; SRRB, Surface Radiation Branch; NREL, National Renewable Energy Laboratory; AES, Atmospheric Environmental Service; DOE/ARM, Department of Energy Atmospheric Radiation Measurement Program; DWD, Deutsche Wetter Dienst; PMOD, Physikalisch-Meteorologisches Observatorium Davos; JMA, Japanese Meteorological Agency; K&Z, Kipp & Zonen.

Philipona et al., Atmospheric longwave irradiance uncertainty: Pyrgeometers compared to an absolute sky-scanning radiometer, atmospheric emitted radiance interferometer, and radiative transfer model calculations, JGR, 106, 2001..

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Stability

WISG

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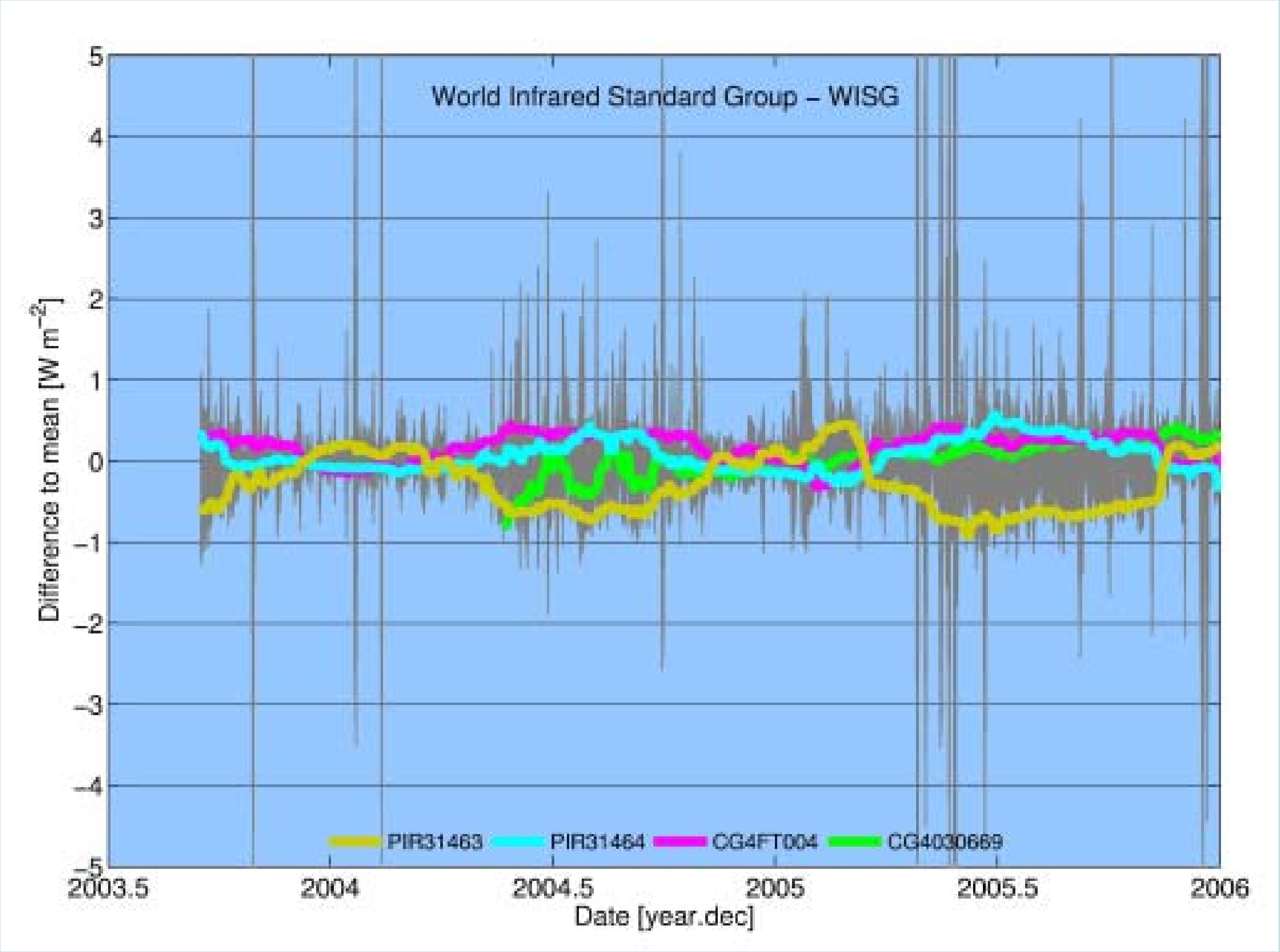
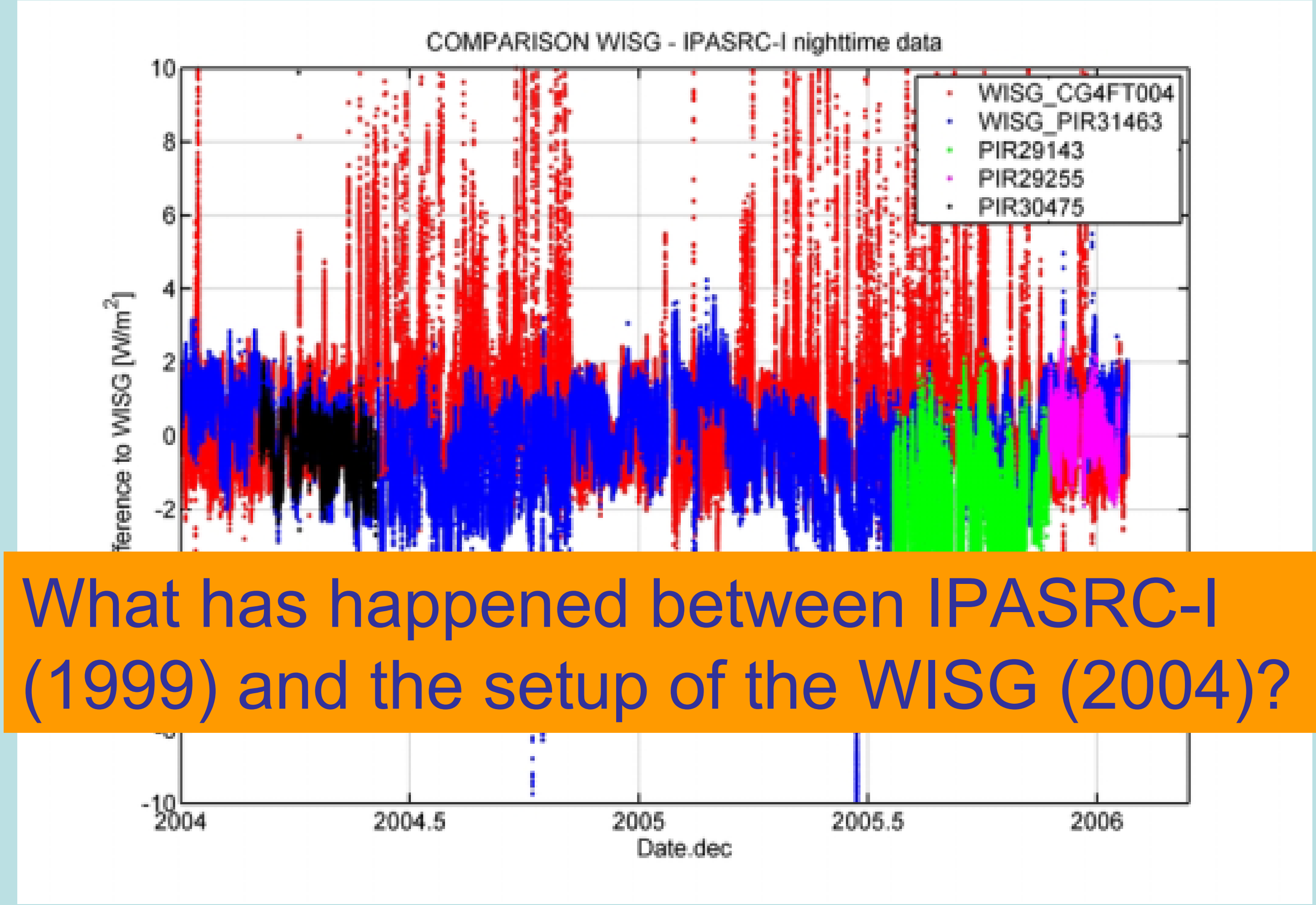


WISG traceability to IPASRC-I



What has happened between IPASRC-I (1999) and the setup of the WISG (2004)?

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Stability

Conclusion

- The WISG together with additional instruments have remained stable as a group since the IPASRC-I campaign in September 1999.
- No apparent
  - -Drift
  - -offset

Pyrgeometer Calibration procedure

- Based on Philipona et al. formula:

$$E = \frac{U_{emf}}{C}(1 + k_1 \sigma T_b^3) + k_2 \sigma T_b^4 - k_3 (T_d^4 - T_b^4)$$

- C, k_1, k_2,k_3 are unknown coefficients and are retrieved from the calibration.

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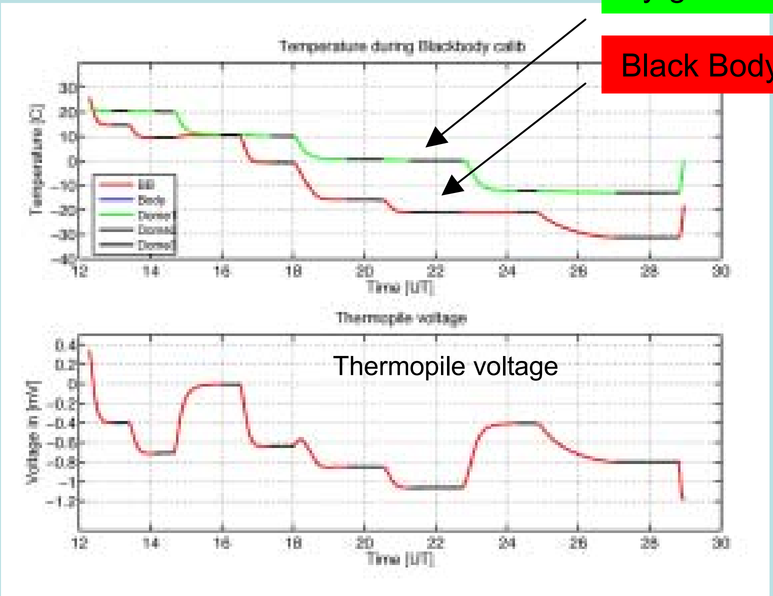
Calibration procedure
First Step

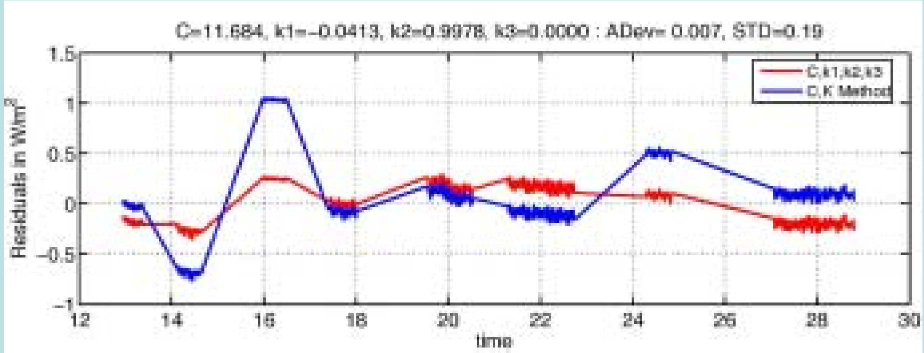
- Characterisation in the black body to retrieve k_1, k_2,k_3. C is retrieved but not used as calibration constant.

Pyrgeometer temperature range: +20ºC to -10ºC

Black Body temperature range:+15ºC to -30ºC



Results from the regression -> C, k_1,k_2,k_3



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Black-Body coefficients C, k1,k2,k3

Typical uncertainties from black-body measurements and retrieval procedure:

$\delta C/C = \pm 0.02$ -> $\delta E/E = \pm 0.01$

$\delta k_1 = \pm 0.02$

$\delta k_2 = \pm 0.0002$ $\delta E = \pm 0.1\ W/m^2$ (T=300 K)

$\delta k_3 = \pm 0.05$ $\delta E = \pm 0.3\ W/m^2$ (T=300 K, δT=1K)

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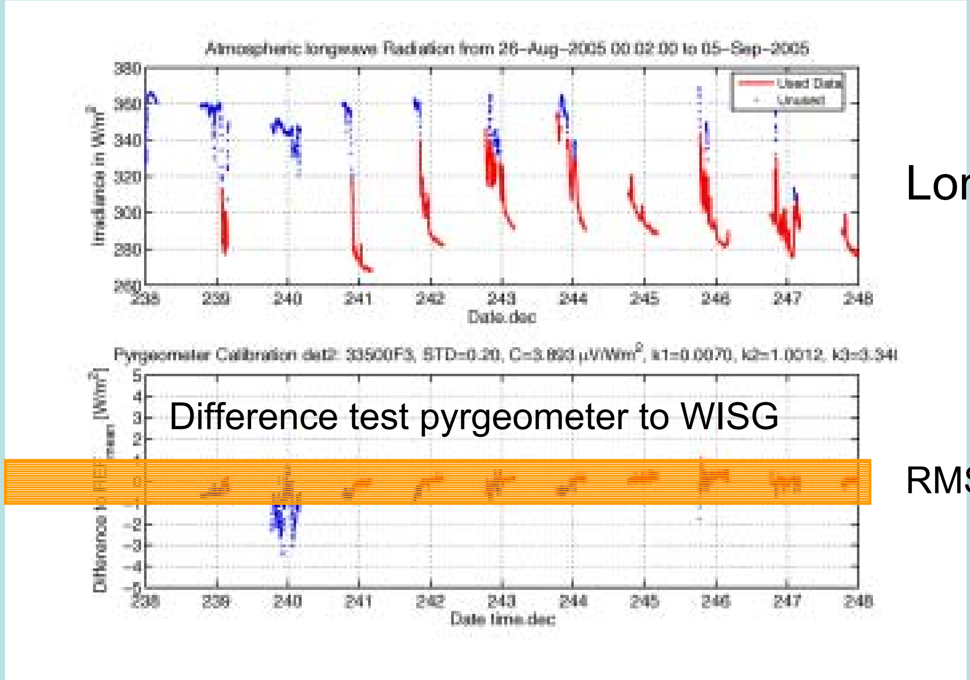
Calibration procedure
Second Step

- Comparison to the WISG using atmospheric infrared radiation to determine the pyrgeometer sensitivity C.



Longwave radiation

±1 W

RMS 0.2 W/m²

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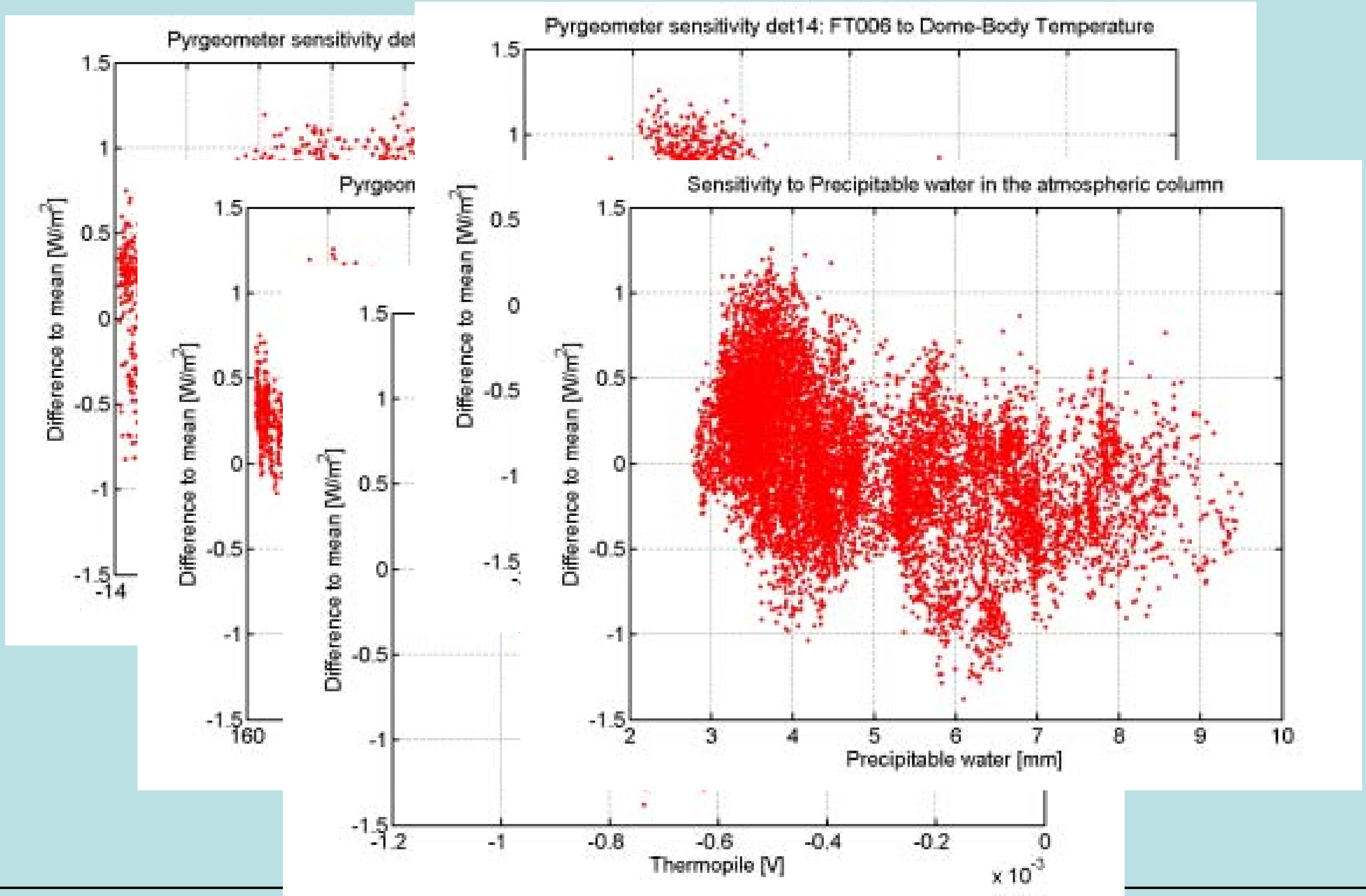
Sensitivity studies



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Calibration procedure Conclusion

- k_1,k_2,k_3 are retrieved from the black body characterisation
- Sensitivity C is obtained from direct comparison to the WISG and thus traceable to ASR.

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Table 1. Institutes traceable to the IRC; Calibrations performed since January 2004)

- Deutscher Wetterdienst, Germany
- Eidgenössische Technische Hochschule Zürich, Switzerland
- Meteo France, France
- Optimare, Germany
- Alfred-Wegener Institut, Germany
- National Ocean and Air Administration (NOAA), U.S.
- NASA Langley Research Center, U.S.
- Arsenal Research, Austria
- Meteo Swiss, Switzerland
- Royal Netherlands Meteorological Institute (KNMI), the Netherlands
- National Renewable Energy Laboratory, U.S.
- Met Office, U. K.
- ENEA, Italy
- Bureau of Meteorology, Australian Government, Australia
- Kipp&Zonen, the Netherlands
- Swedish Meteorological and Hydrological Institute (SMHI), Sweden
- China Meteorological Administration, China

Total 17

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Calibration uncertainty based on:

$$u = std(PIR) + std(REF) + u_{ASR}$$

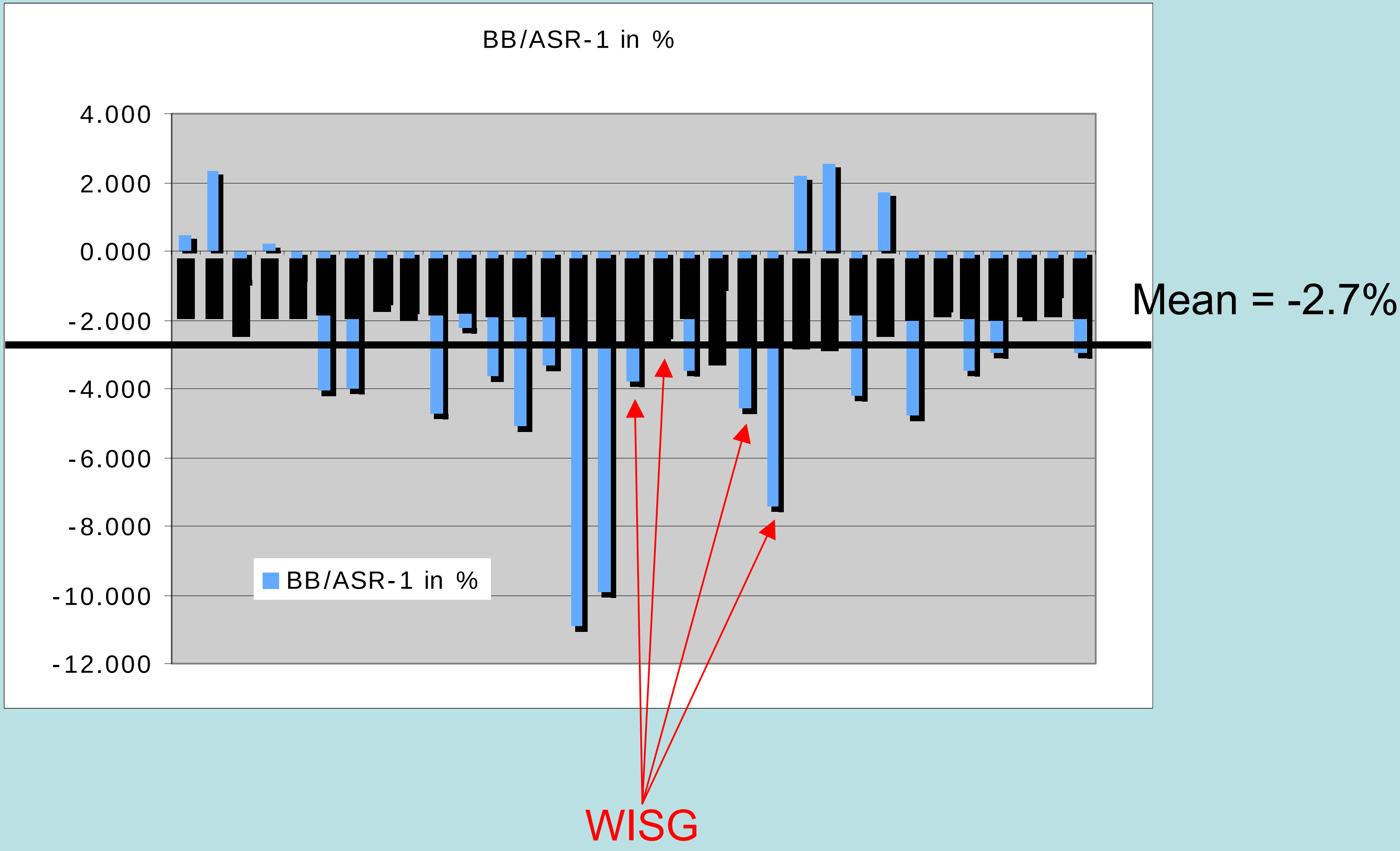
Absolute ASR uncertainty estimated at ±1 W/m^2 (Philipona et al. 2001)

Example:

- C (*1e-6)=4.293
- Irradiance Variation from 175.1 to 354.1 W/m^2
- Residuals from -2.0 to 2.5 W/m^2
- Body Temperature (only night) from -12.26 to 21.39
- Uncertainty REF 0.835 W/m^2 , rel. = 0.33 %
- Uncertainty PIR 0.693 W/m^2 , rel. = 0.27 %
- Relative standard Uncertainty of C = 0.89 %
- Expanded uncertainty (k=2) of C = 0.076 microV/W

Assuming Thermopile = 0.5 mV → δE= 2.1 W/m^2

Ratio between ASR-based and Black-Body based calibration



Spectral mismatch, effect of water in the atmospheric column

Example atmospheric LIR spectra, spectral dome transmissions

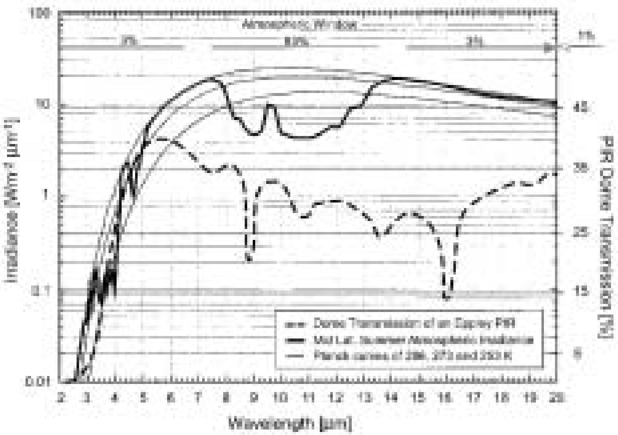
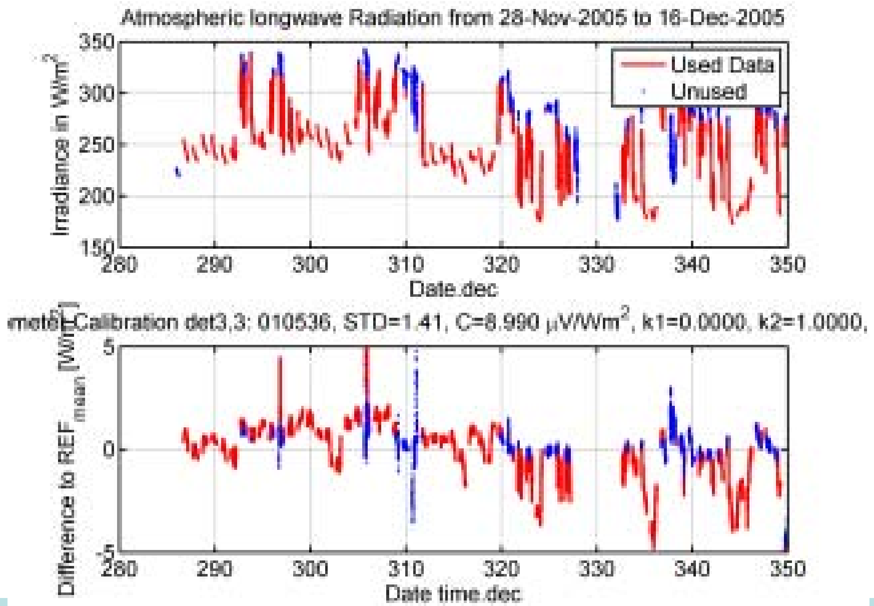


Fig. 1. Inhomogeneous PIR dome transmission (right scale) and significant differences between pyrgeometer calibration Planck curves and real atmospheric irradiance spectra, which cause considerable uncertainties in long-wave downward irradiance measurements.

Difference test Pyrgeometer to WISG



Irradiance measurements – Angular response of pyrgeometers

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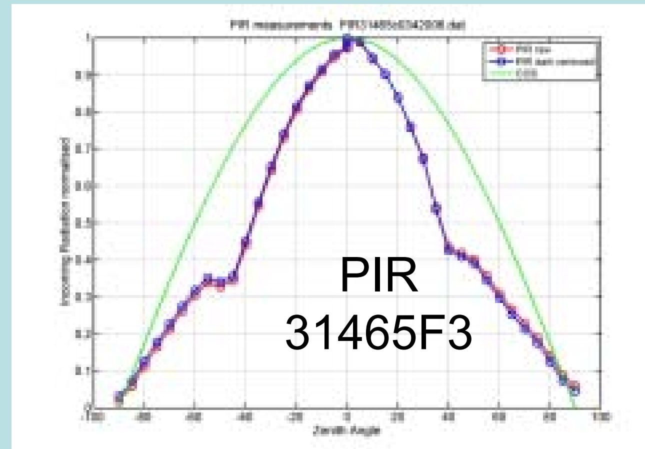

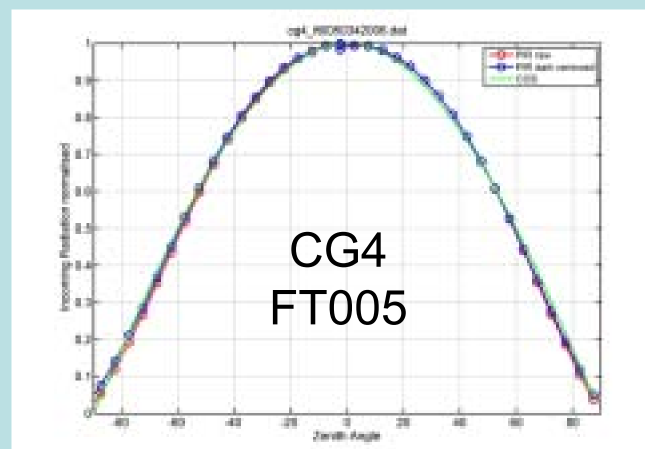

Absolute sky scanning radiometer (ASR)

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Absolute sky scanning radiometer (ASR)

Features:

- Pyroelectric detector
- Flat spectral response
- Calibration based on low temperature black-body
- Irradiance obtained from gaussian integration of 5º sky radiance measurements

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Absolute sky scanning radiometer (ASR)

Table 2. Uncertainties due to Errors on ASR Absolute Long-Wave Irradiance Measurements

Uncertainties	Error	Measured Unit ($W m^{-2}$)
Type		
Uncertainty of temperature of blackbody (at 260 K)	± 0.15 K	± 0.6
Uncertainty of chopper temperature during calibration	± 0.05° K	± 0.2
Uncertainty of blackbody emittance	0.999 ± 0.0005	± 0.14
Mismatch due to pyroelectric detector sensitivity	(100 $W m^{-2}$) ± 0.5%	± 0.5
Field-of-view beam stray light	(100 $W m^{-2}$) ± 0.5%	± 0.5
Ambient air passage	(100 $W m^{-2}$) ± 0.5%	± 0.2
Combined standard uncertainty (rss)		± 0.98
Maximum uncertainty (worst case)		± 2.15

±1 $W m^{-2}$

Uncertainty budget for ASR as published in Philipona, Appl. Opt., 40, 2001.

Missing: Calibration reproducibility

Comparison blackbody ASR with IRC nov 05

BB_{ASR}

BB_{IRC}

Comparison blackbody ASR with IRC results

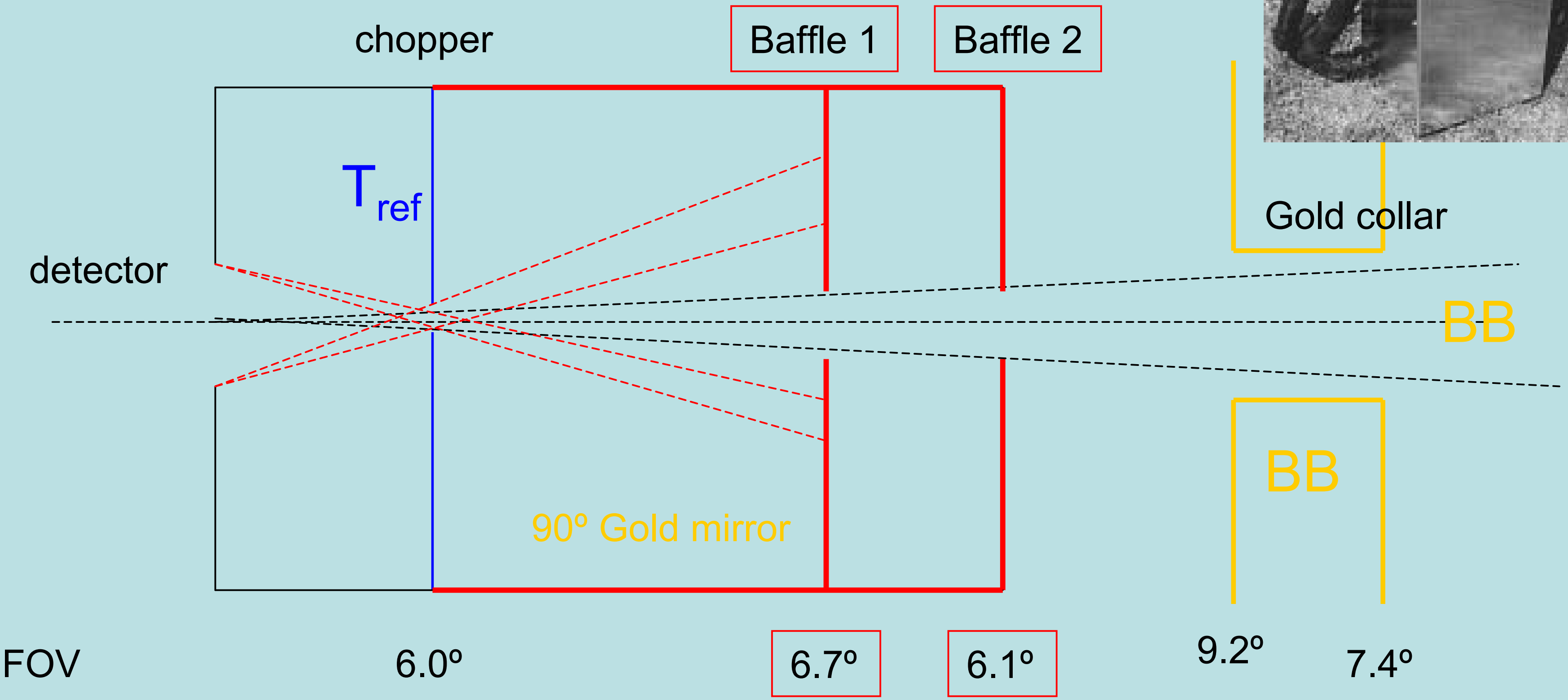
ASR Sensitivity and offset in mV/W

date	ASR	IRC
24 nov	9.19 +121	10.24+31
25 nov	9.57+86	10.26+52
29 nov	9.77-10	
30 nov		10.25-6.5
1 dec		9.84+0
5 dec	9.32+38 9.69-2	9.89+1

Inconsistent results, some unknown systematic?

ASR geometry

Dimensions not to scale!!



„straylight“ from Baffles and walls?

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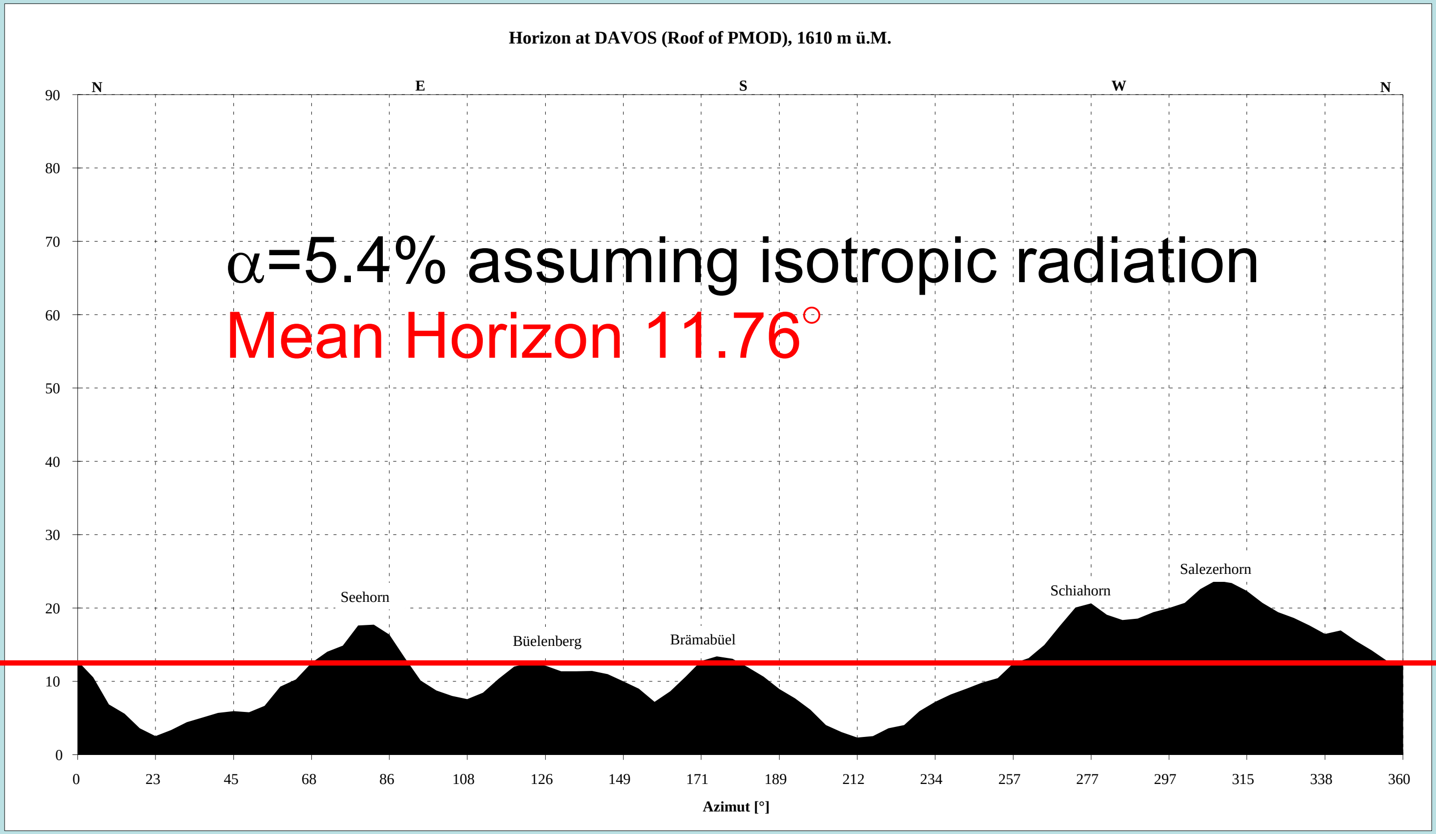
PMOD/WRC Horizon on IRC-Platform



α=5.4% assuming isotropic radiation

Mean Horizon 11.76°

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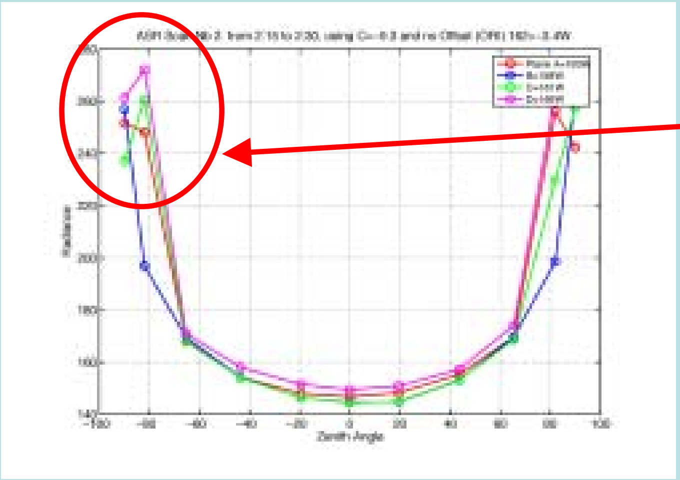
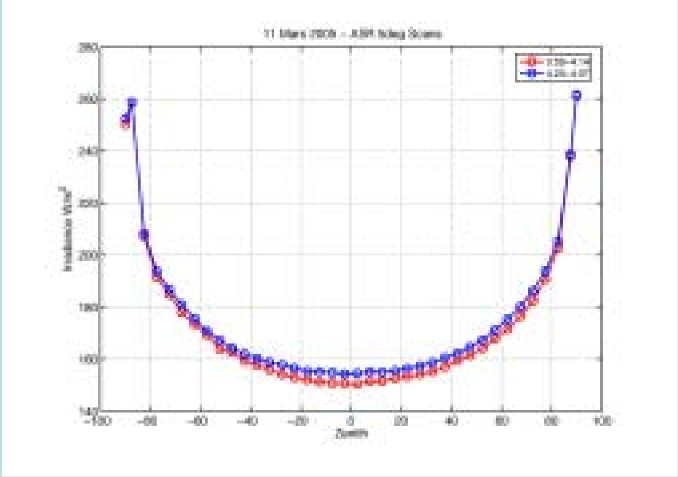
Sky-Scanning Radiometer (ASR)

Measurements from March, 11, 2005





Sky- or Horizon Temperature

-10° to -15° C (250-270 Watt)

With α=5.4%, this gives an uncertainty in the longwave irradiance of 1-3 Watt

Horizon correction at IRC for this specific case: **+2 W ± 1 W**

ASR / Conclusions

- Concept is sound:
  - Solves problems related to angular and spectral response.
- Prototype instrument
- Manual night-time operation
- Calibration reproducibility seems difficult
- Needs further characterisation

IRC achievements

- Creation of a stable group of pyrgeometers (WISG)
- Development of laboratory characterisations for pyrgeometers to determine:
  - Calibration coefficients (k_1 ,k_2 ,k_3) using a well characterised black-body
- Designed calibration procedure to transfer the calibration to test pyrgeometers

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ToDo / in Progress

- Construction of a second Black-body (in progress)
- Design and realisation of a second sky scanning radiometer based on an electric substitution pyroelectric detector (in progress)
- Perform comparisons between ASR and WISG
- Angular response measurement (in progress)
- Planning for a spectral response measurement facility for pyrgeometers