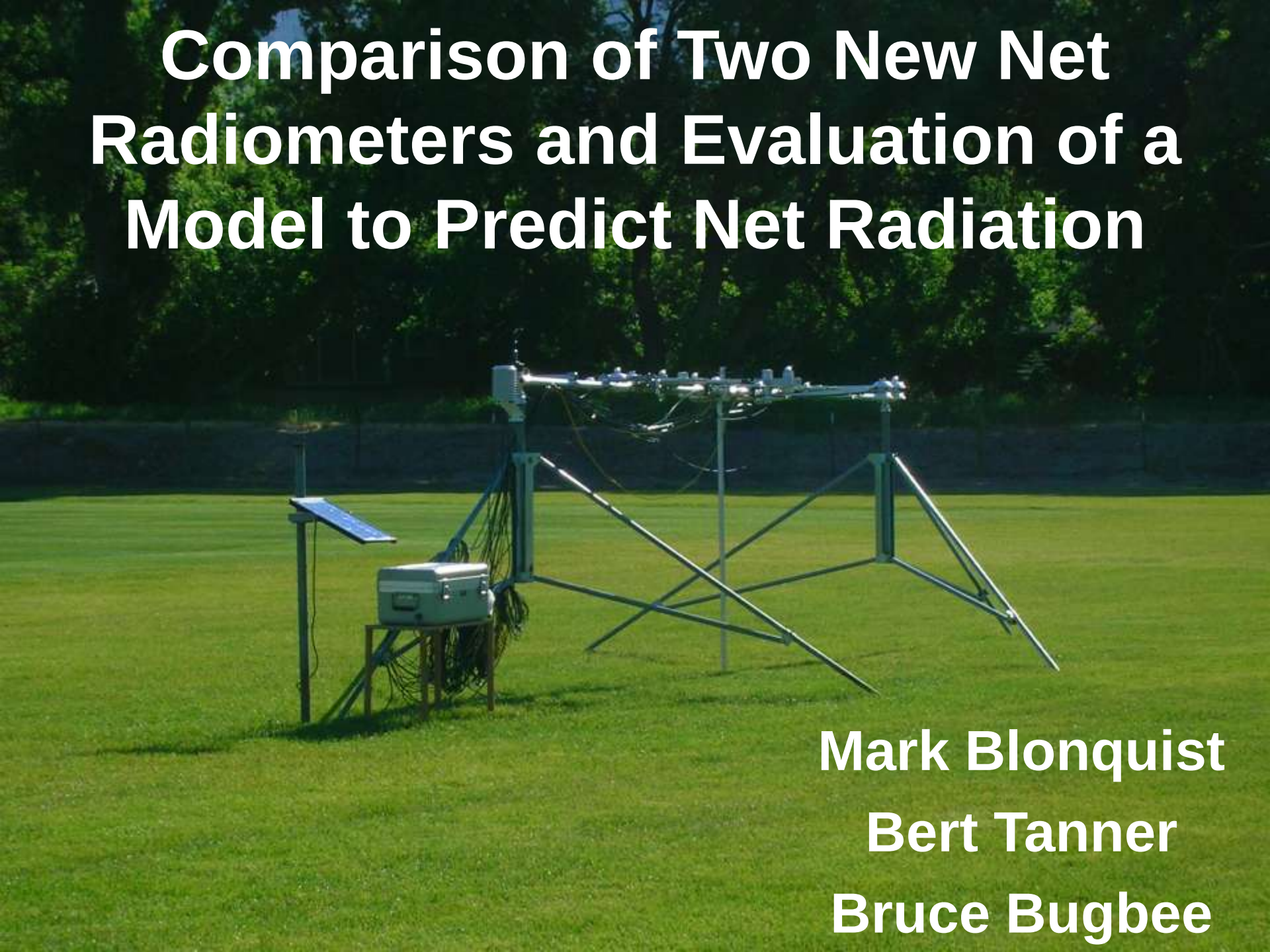
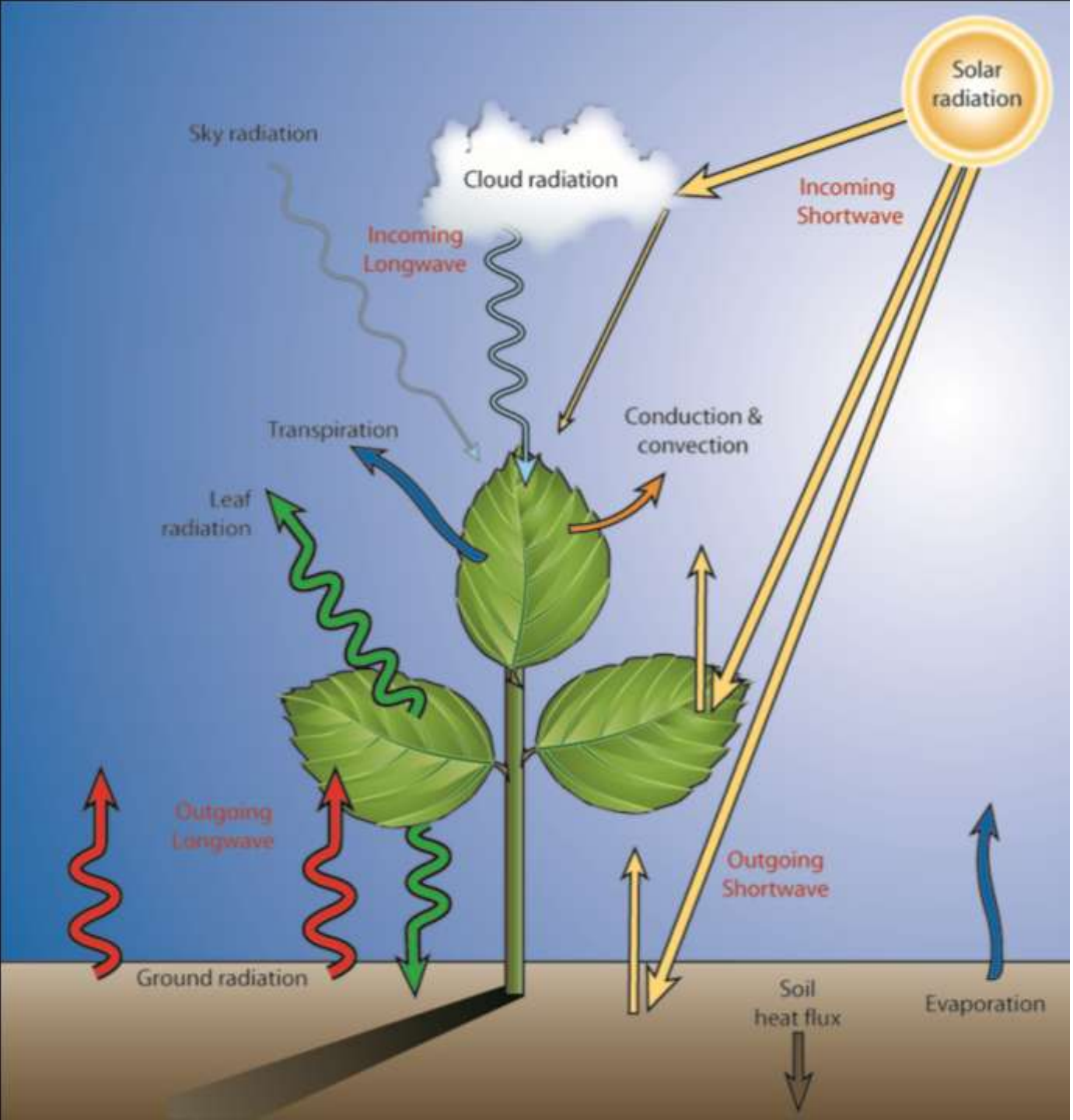
Comparison of Two New Net Radiometers and Evaluation of a Model to Predict Net Radiation

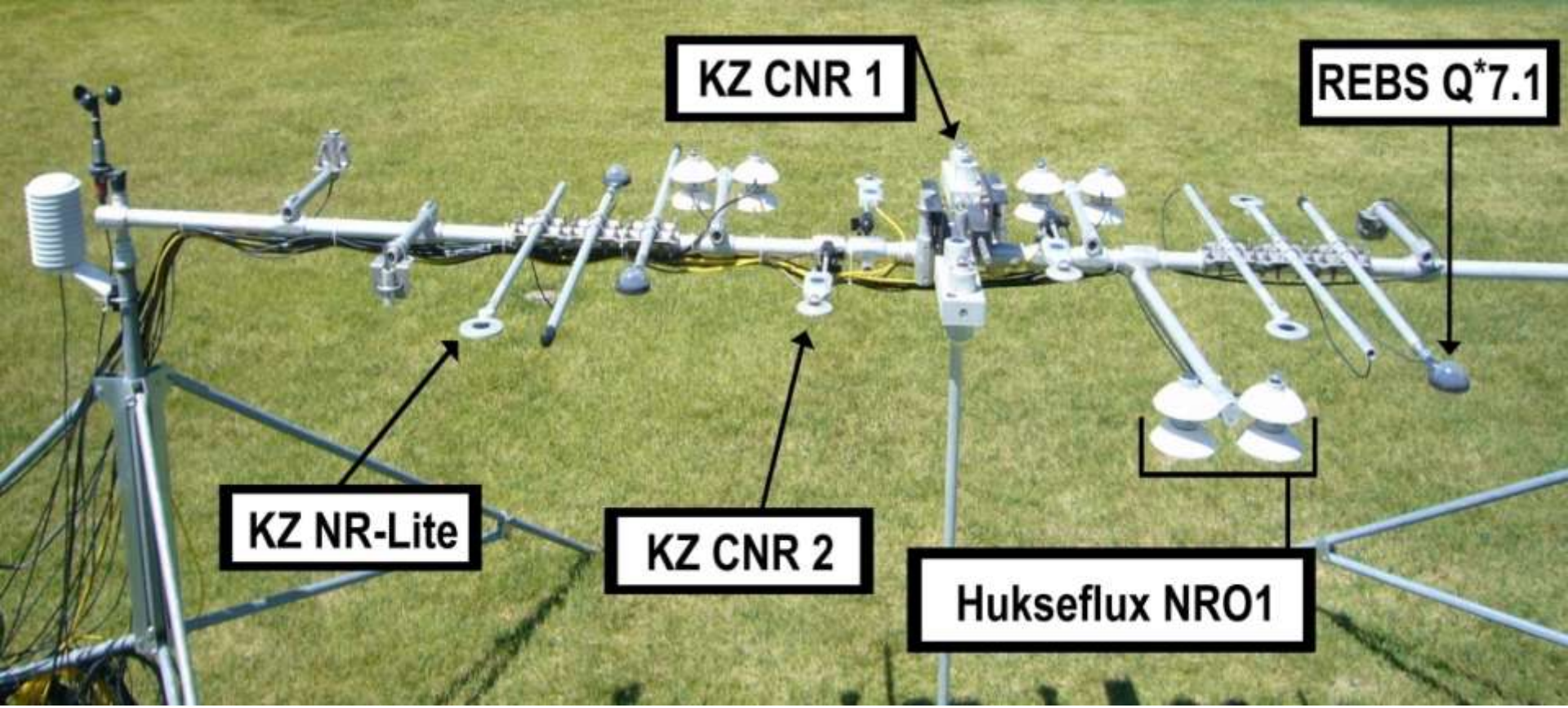


Mark Blonquist
Bert Tanner
Bruce Bugbee



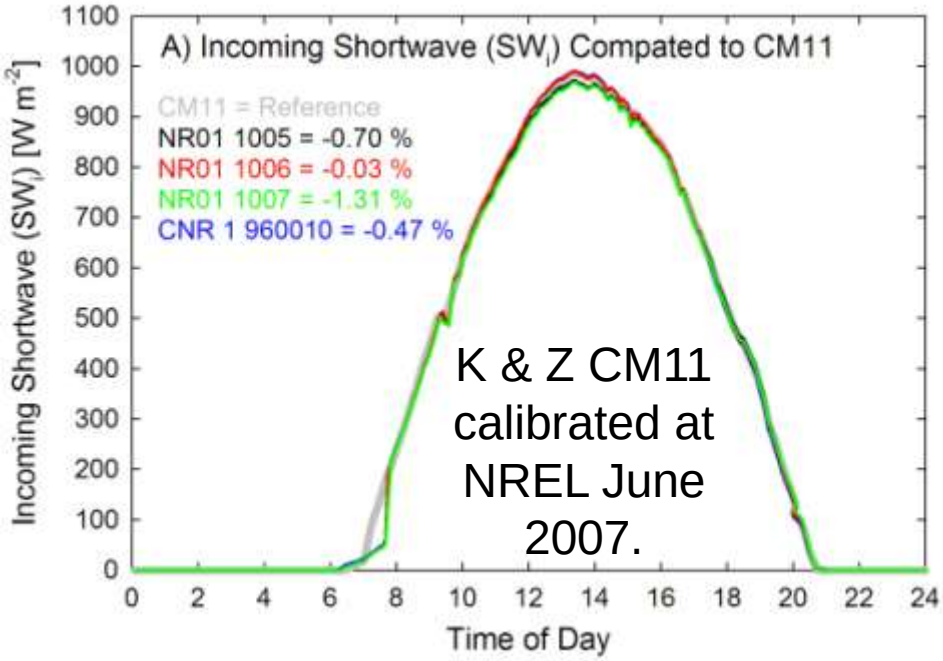
Energy Balance:

$R_n = \lambda E + H + G$

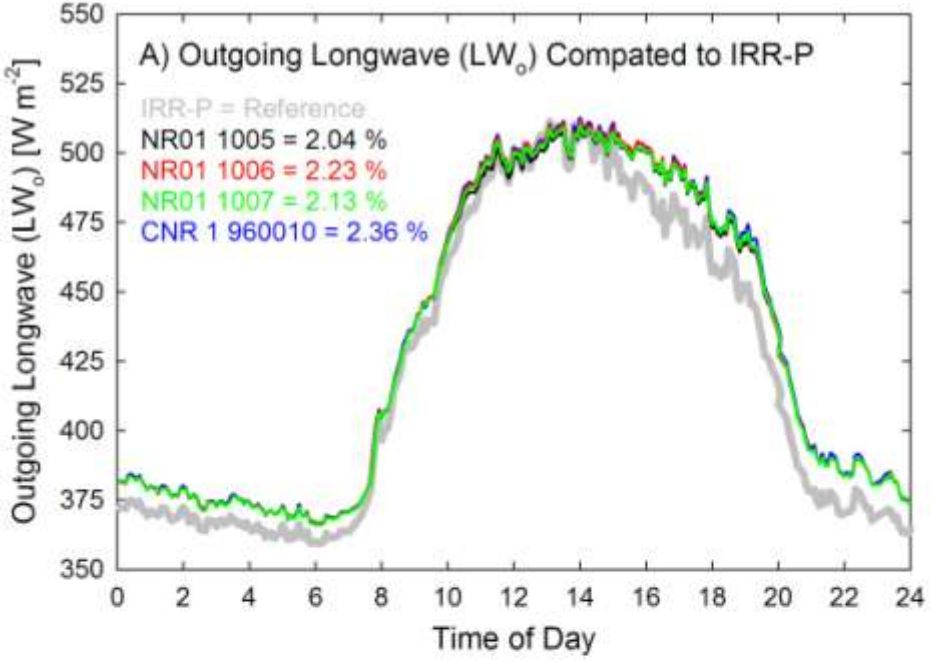


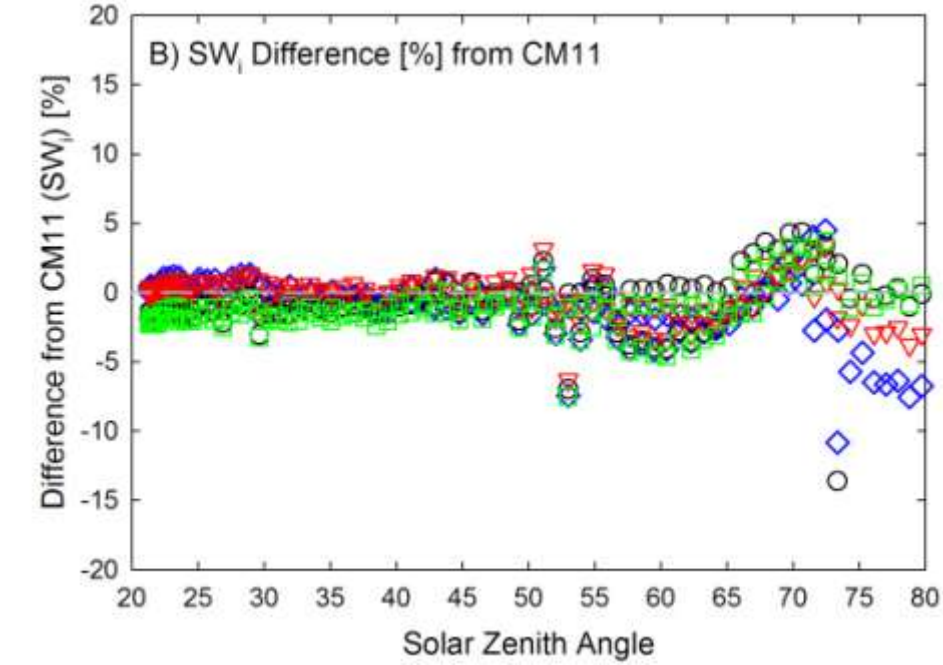
Manufacturer	Model	Cost [$]	Replicates	Output
Kipp & Zonen	CNR 1	6195	2	SW_i, SW_o, LW_i, LW_o
Hukseflux	NR01	4200	3	SW_i, SW_o, LW_i, LW_o
Kipp & Zonen	CNR 2	2600	3	SW_n, LW_n
Kipp & Zonen	NR-Lite	1630	3	R_n
REBS	Q*7.1	1250	3	R_n

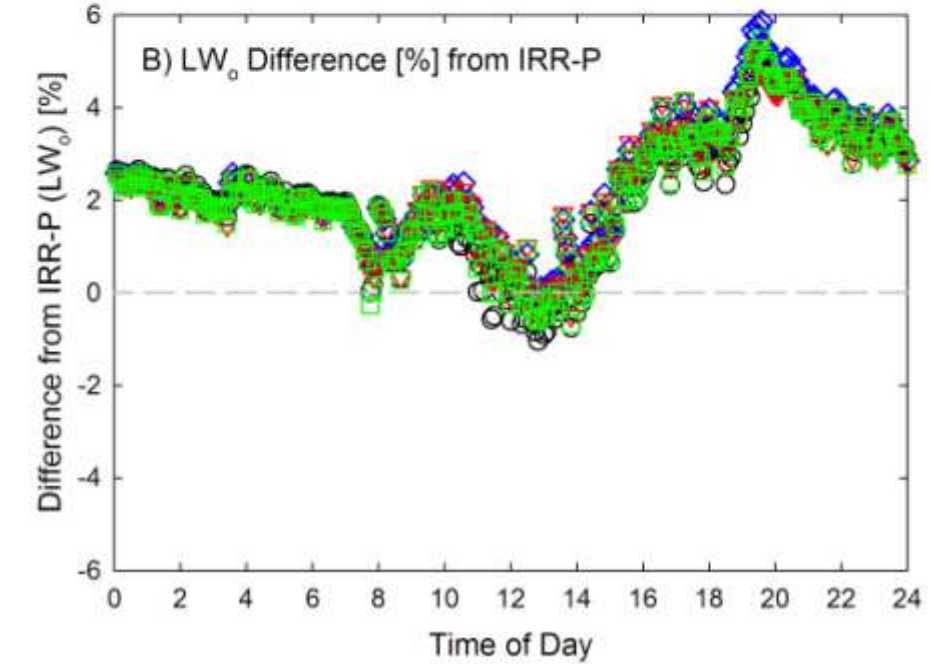
- Radiometers were cleaned and leveled following each irrigation (approximately every two days).
- Data during and following irrigation events (previous to cleaning and re-leveling) was filtered out.

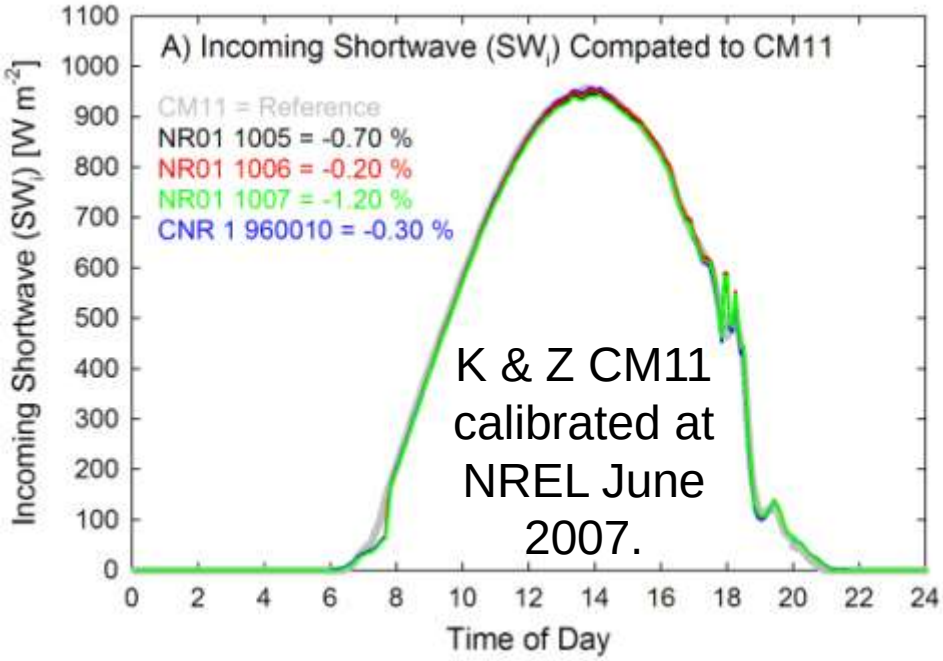


K & Z CM11 calibrated at NREL June 2007.









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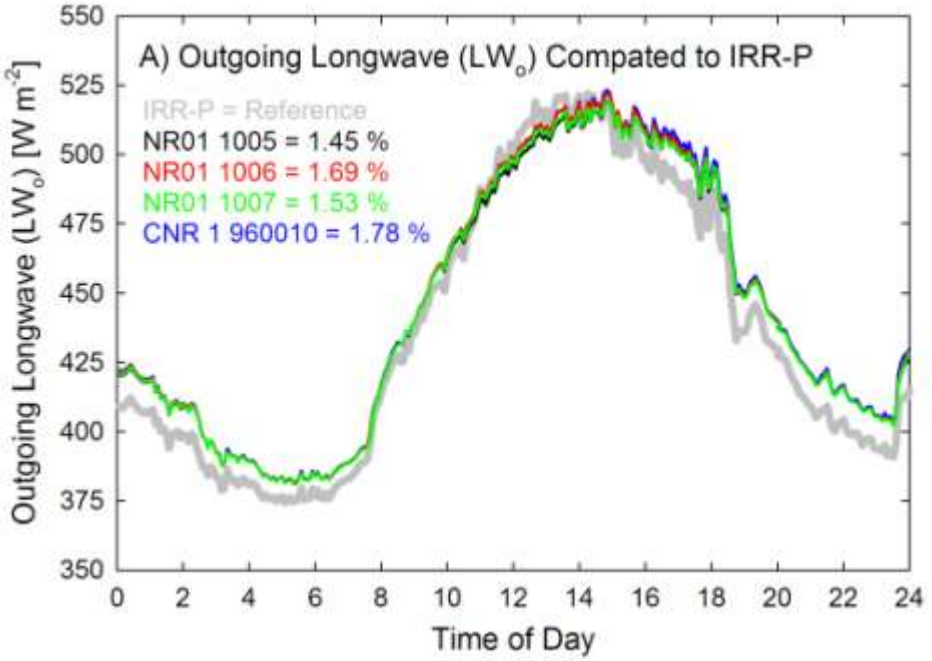

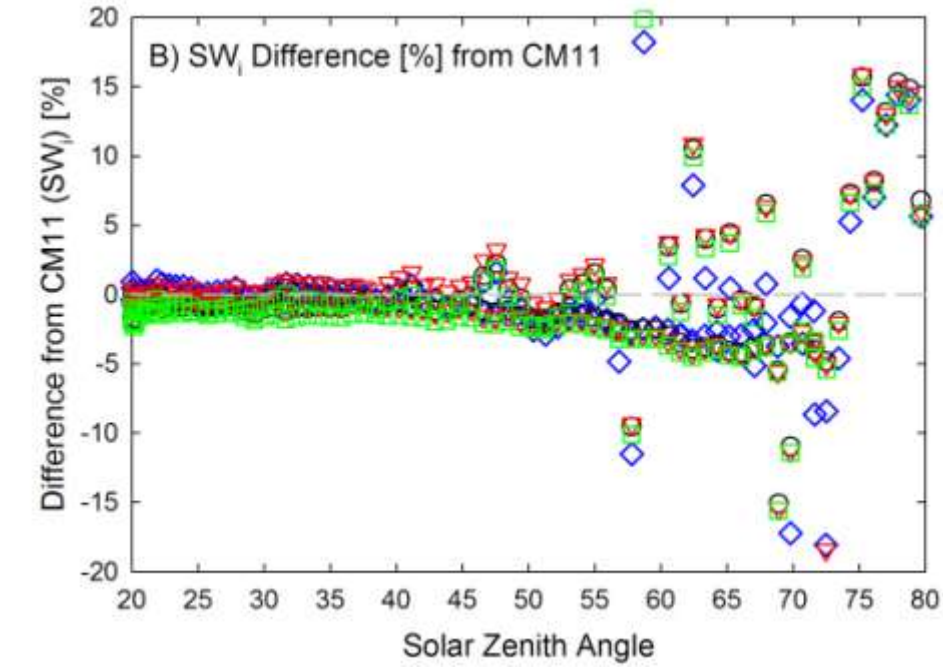

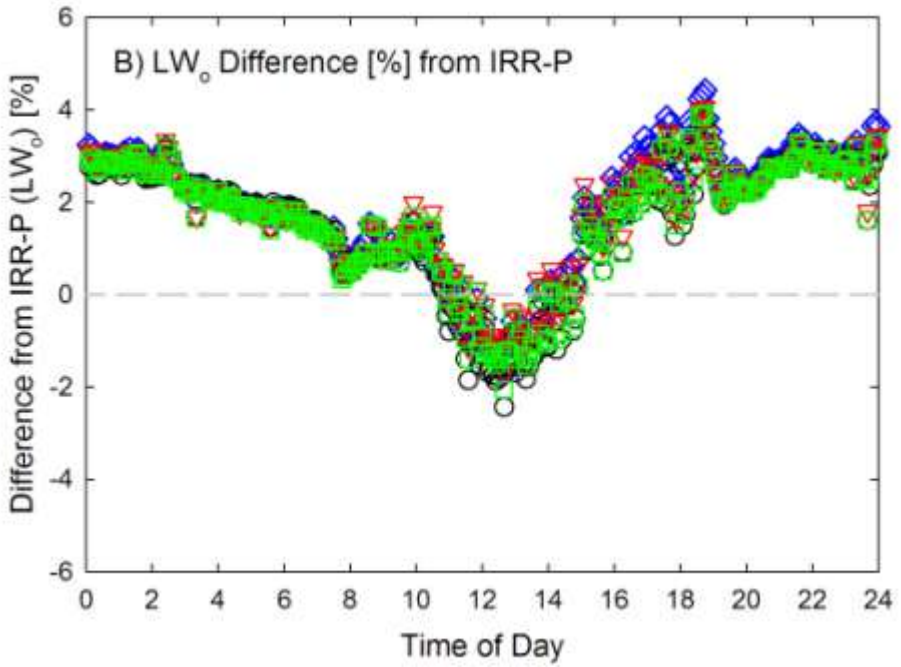

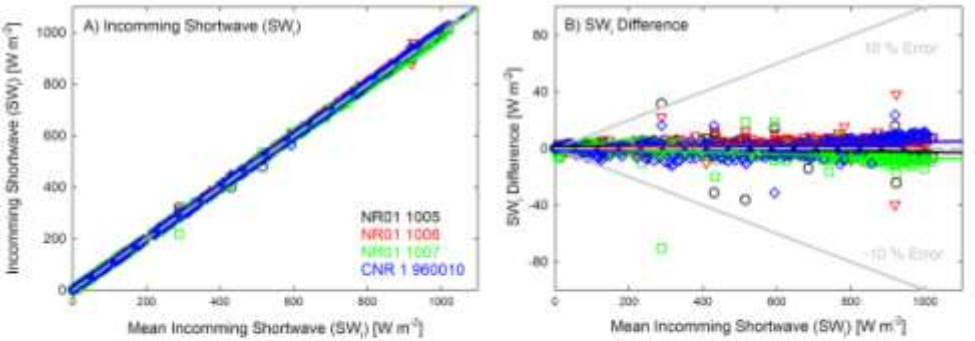

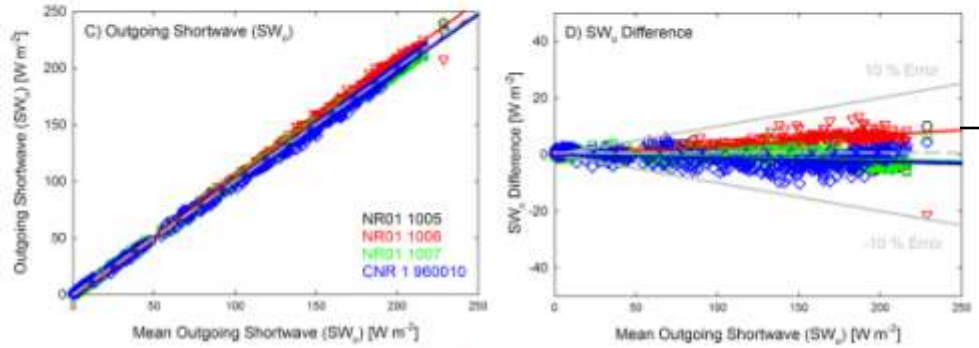

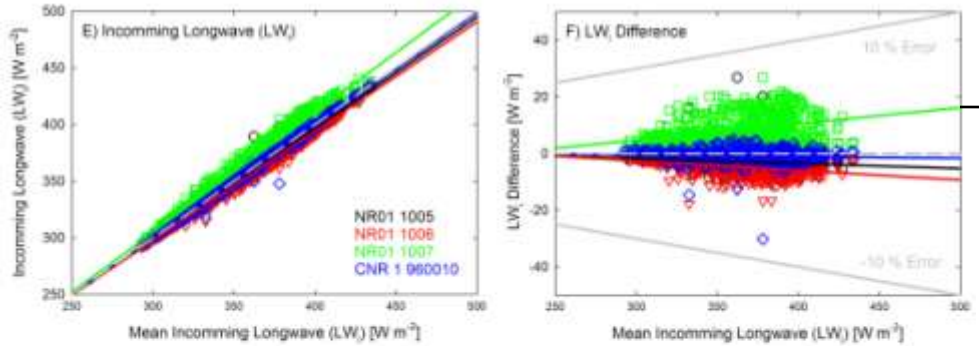

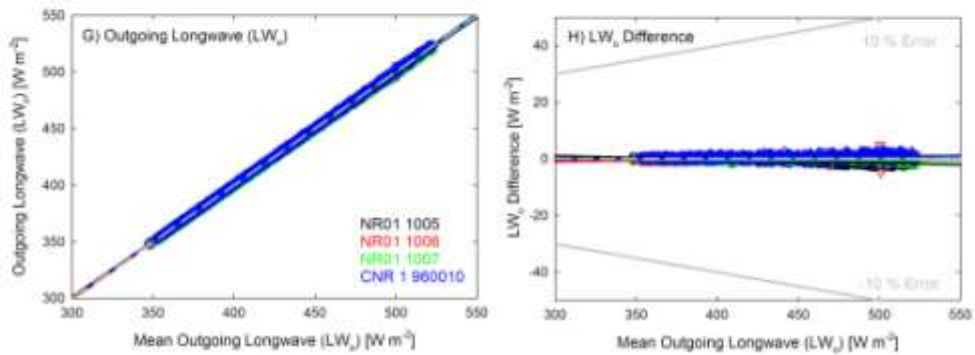

Blue = K & Z CNR 1

Black = HF NR01

Red = HF NR01

Green = HF NR01

→ **Sent back to Hukseflux for calibration check.**

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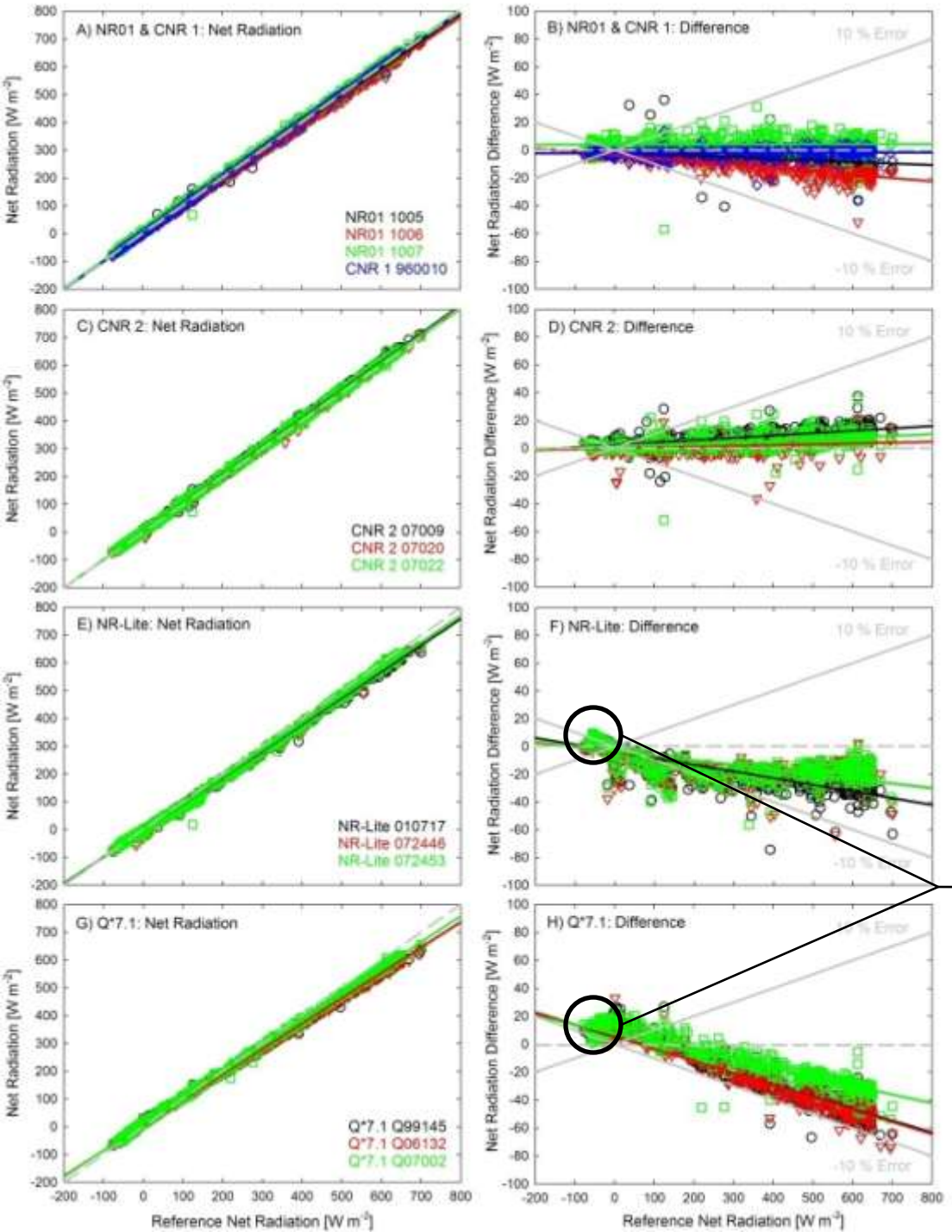
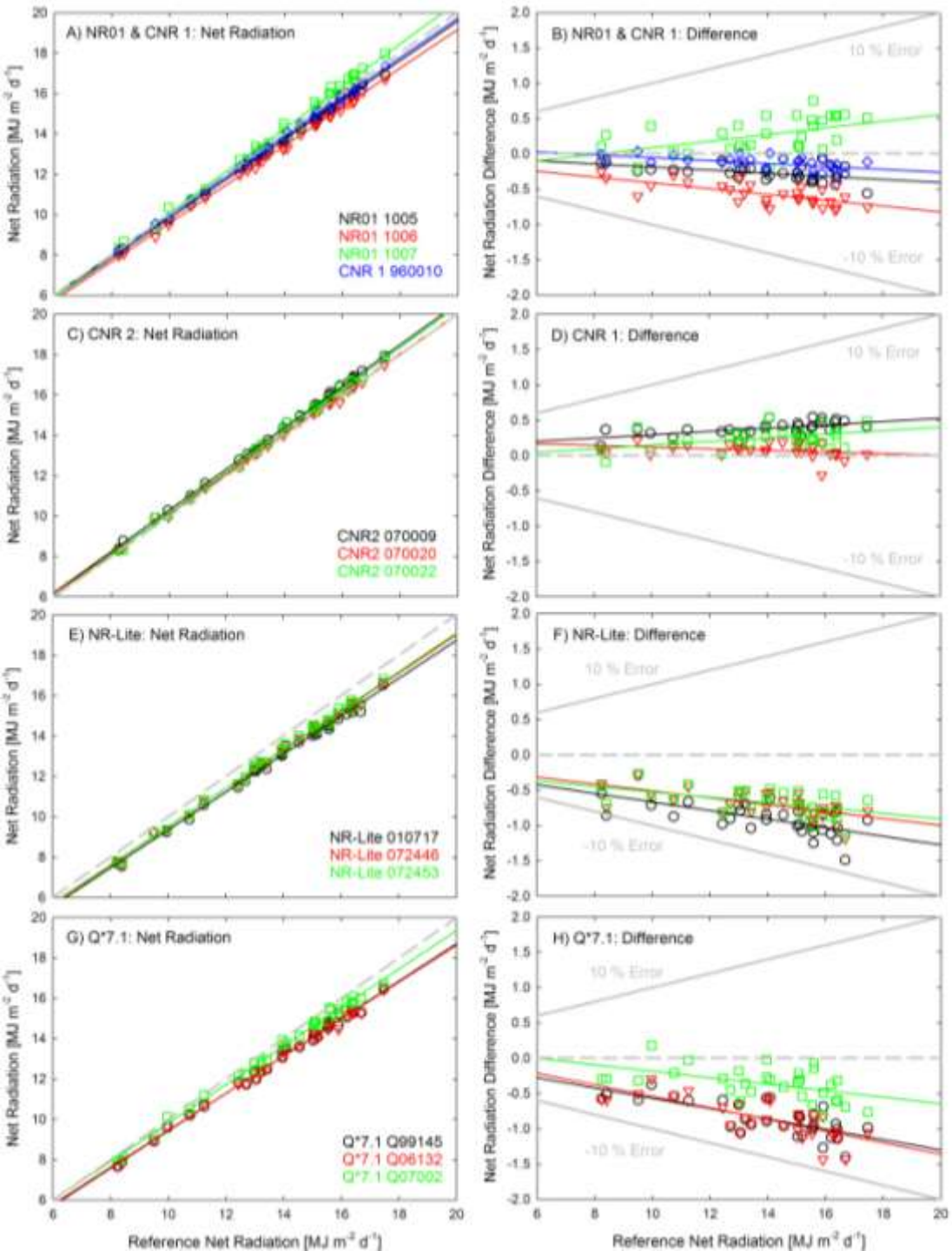


No standard for R_n measurement; reference for comparison is average of CSI CNR 1, 3 NR01s, and 3 CNR 2s.

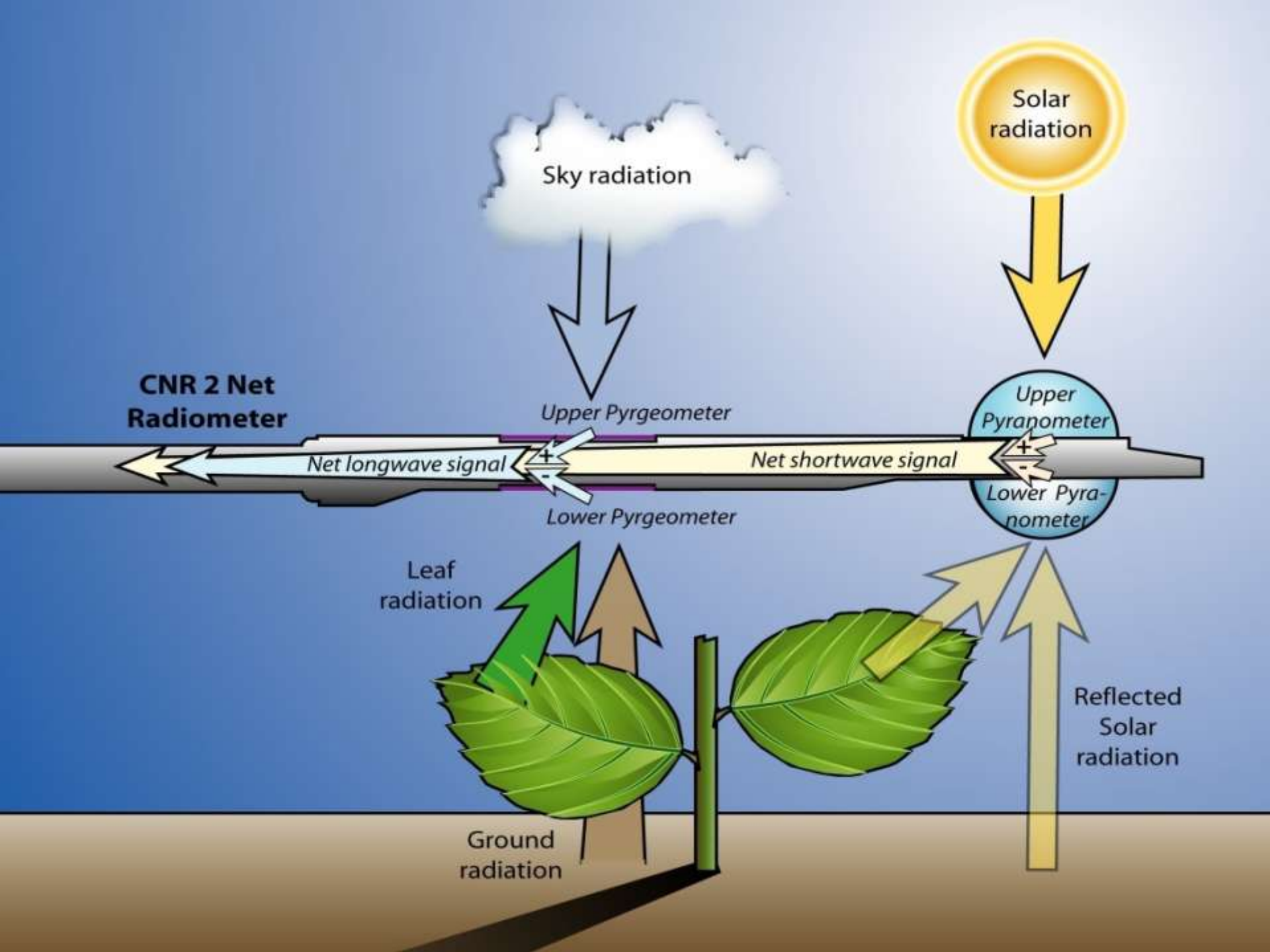
Offsetting error at night; indicates lesser sensitivity to longwave.



Model	Mean Slope	St. Dev. Slope
NR01	0.995	0.047
CNR 2	1.012	0.021
NR-Lite	0.951	0.012
Q*7.1	0.933	0.019

Kipp & Zonen CNR 2 Net Radiometer

- Four-way radiometer (four detectors), two net outputs (two thermopiles).
- NR-Lite and Q*7.1 are two-way radiometers (two detectors) with one net output (one thermopile).


Solar radiation
Sky radiation
CNR 2 Net Radiometer
Upper Pyrgeometer
Upper Pyranometer
Net longwave signal
Net shortwave signal
Lower Pyrgeometer
Lower Pyra-nometer
Leaf radiation
Reflected Solar radiation
Ground radiation

Inversion Test Results

		Net Radiation Component						
Model	**Serial Number**	**SW_i**	**SW_o**	**LW_i**	**LW_o**	**SW_n**	**LW_n**	**R_n**
CNR 1	960010	0.28	0.00	0.58	0.87	0.35	1.73	0.06
	990212	-0.74	1.03	0.94	0.20	-1.19	-1.88	-1.05
NR01	1005	-0.08	-0.91	1.45	0.30	0.14	-3.35	0.83
	1006	1.01	-2.06	-0.20	0.00	1.91	0.56	2.23
	1007	-0.82	-0.52	5.69	-0.85	-0.90	-17.87	3.11
CNR 2	070009					-6.69	6.35	-9.53
	070020					-2.07	2.50	-3.01
	070022					-8.34	2.11	-10.51
NR-Lite	010717							0.18
	072446							-0.18
	072453							0.54
Q*7.1	Q99145							-2.23
	Q06132							-1.77
	Q07002							-2.51

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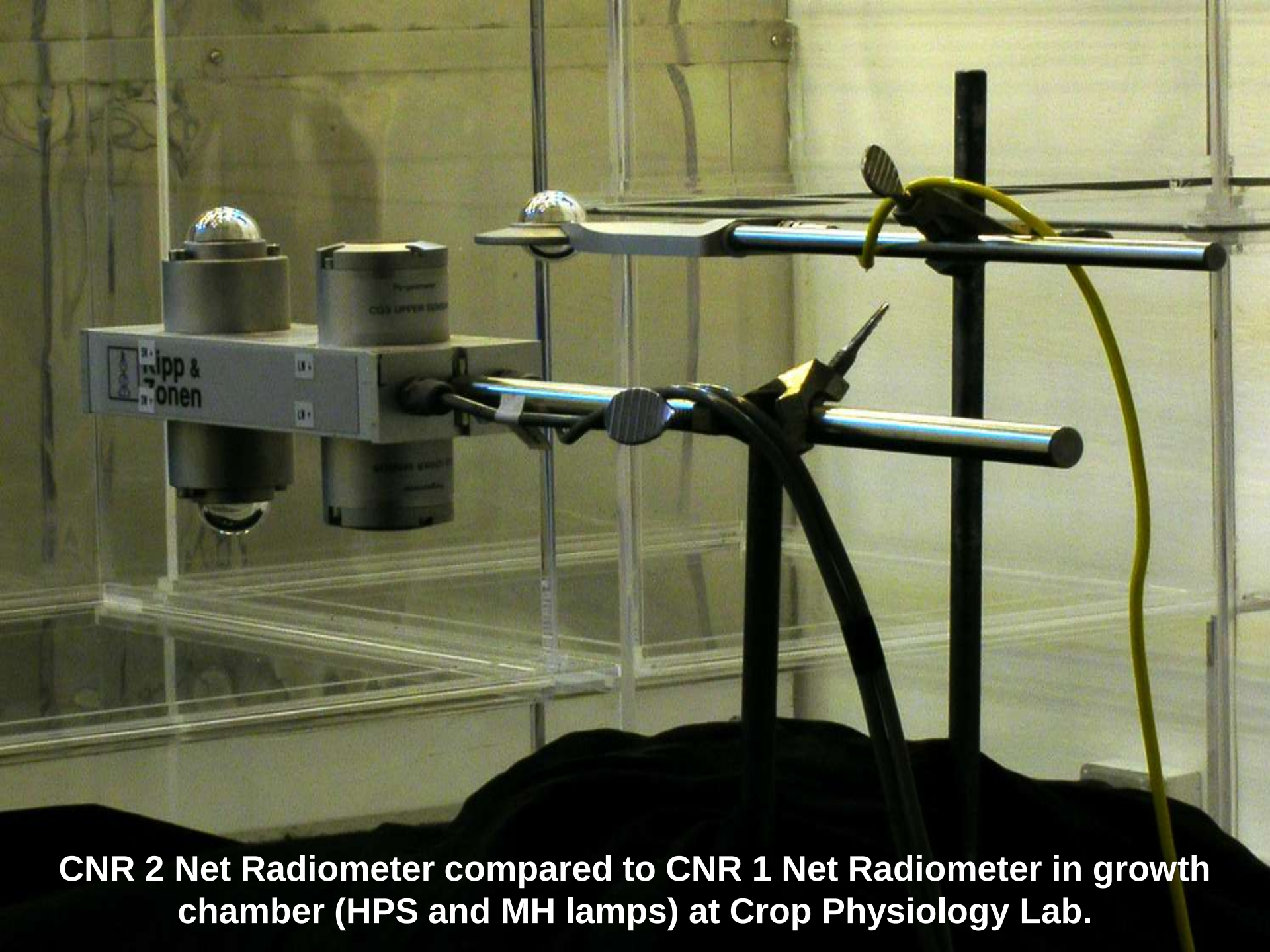
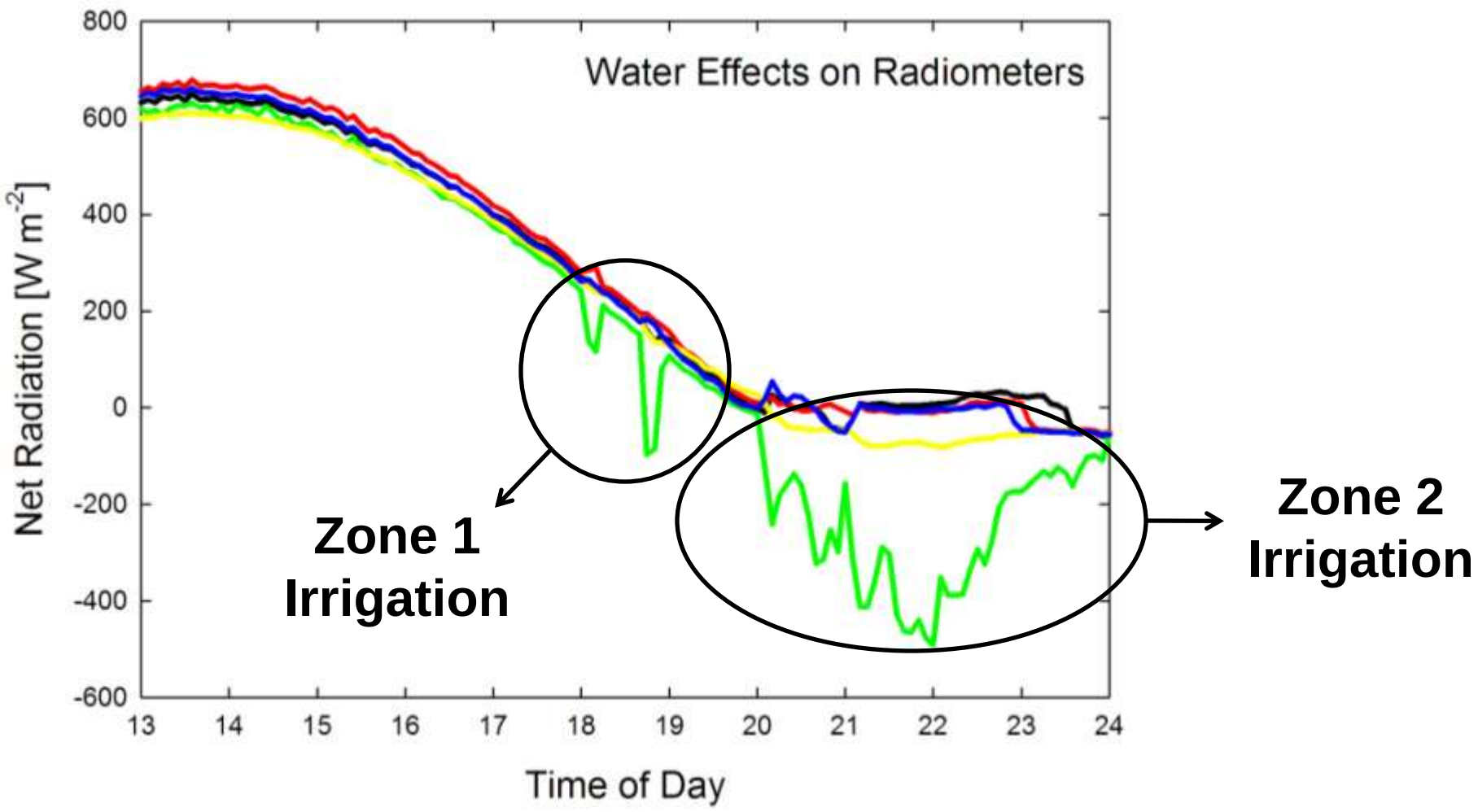


CNR 2 Net Radiometer compared to CNR 1 Net Radiometer in growth chamber (HPS and MH lamps) at Crop Physiology Lab.


SENSOR
OUTPUT
THERM &
HEATER
Multiplier = 12.7
LONG WAVE
SHORT WAVE
Kipp & Zonen
Net Radiometer

		High Light ΔT = 2-5 ^{o}C (500 W m^{-2})	Low Light ΔT = 2-5 ^{o}C (250 W m^{-2})	Upside Down (250 W m^{-2})	Dark 1 ΔT = 2-5 ^{o}C (0 W m^{-2})	Dark 2 ΔT = 0 ^{o}C (0 W m^{-2})
CNR 1	Net Short-Wave	427.0	225.0	-222.0	1.1	-0.5
	Net Long-Wave	-2.0	-8.5	8.9	-9.8	-1.1
	Net Radiation	425.0	216.5	-213.1	-8.7	-1.6
CNR 2	Net Short-Wave	422.0	218.0	-188.0	-5.9	0.8
	Net Long-Wave	8.0	-7.5	11.2	-13.1	1.1
	Net Radiation	430.0	210.5	-176.8	-19.0	1.9



Blue = CNR 1, Black = NR01, Red = CNR 2,
Green = NR-Lite, Yellow = Q*7.1

Net Radiation Model From ASCE Standardized Reference ET Equation

$$R_n = SW_n + LW_n$$

$$SW_i = measurement$$

$$SW_o = \alpha SW_i;\ \alpha = 0.23$$

$$SW_n = SW_i - \alpha SW_i$$

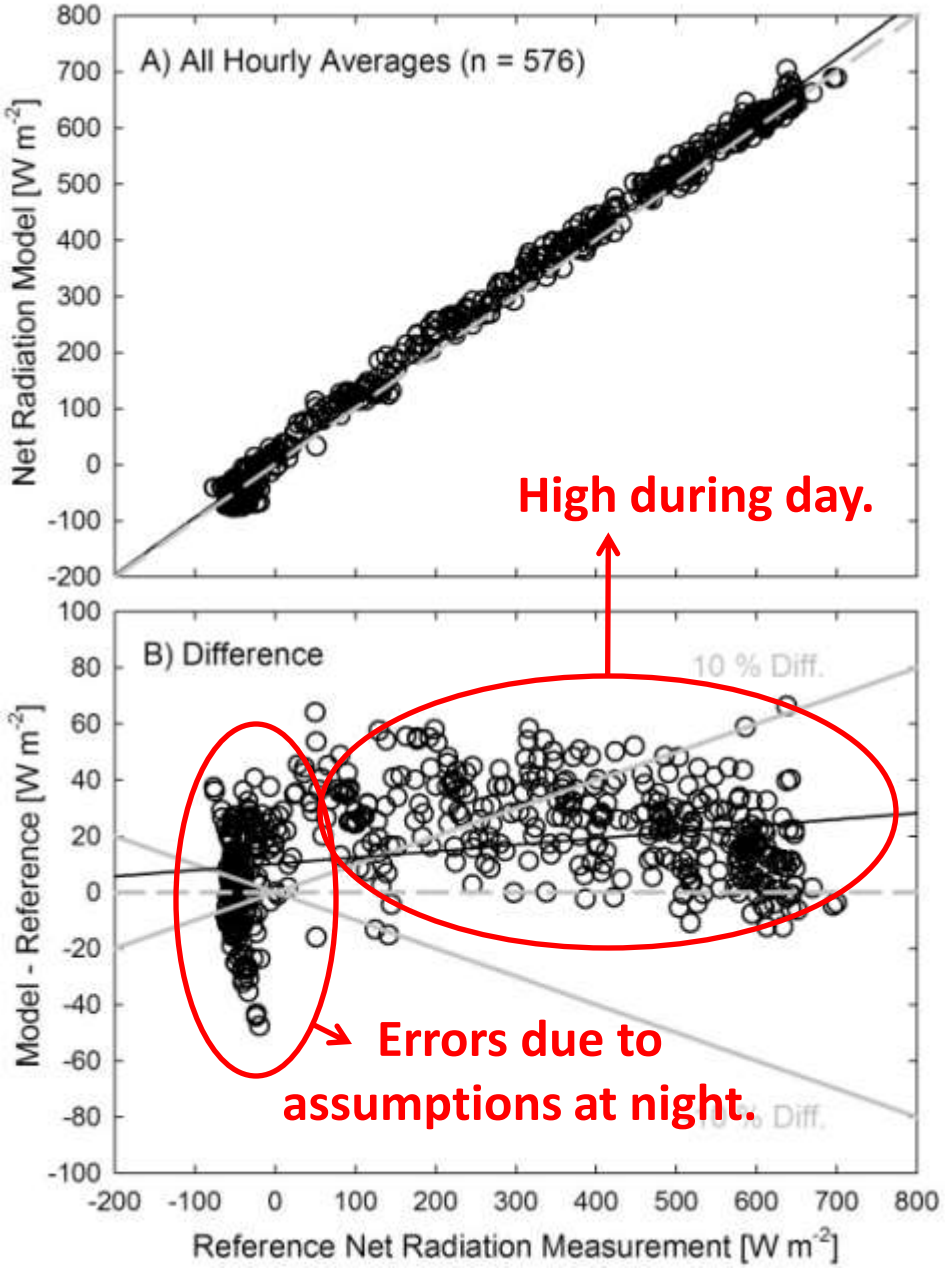
$$LW_n = -\sigma f_{cd}\left(0.34 - 0.14\sqrt{e_a}\right)T_a^{\,4}$$

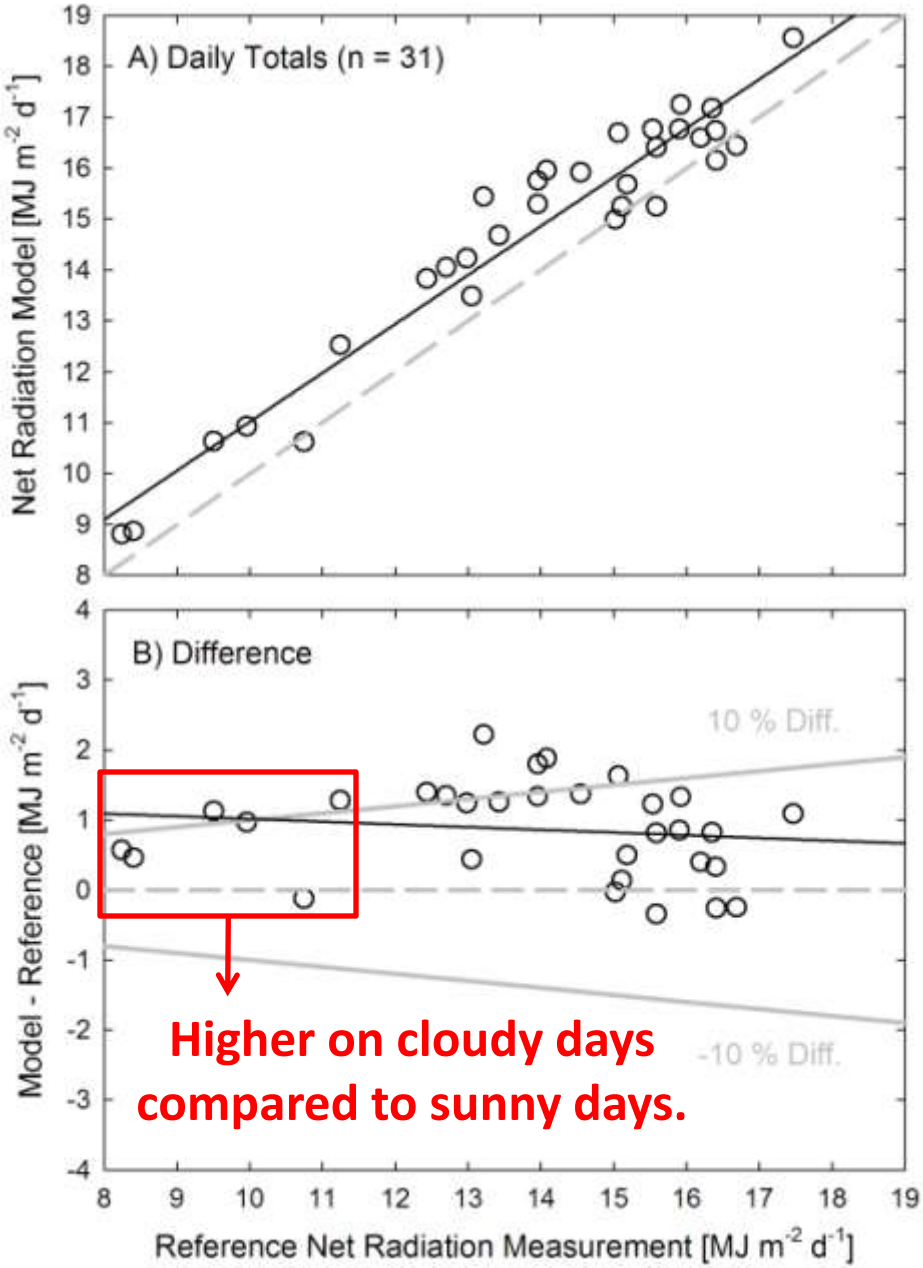
$$e_a = measurement$$

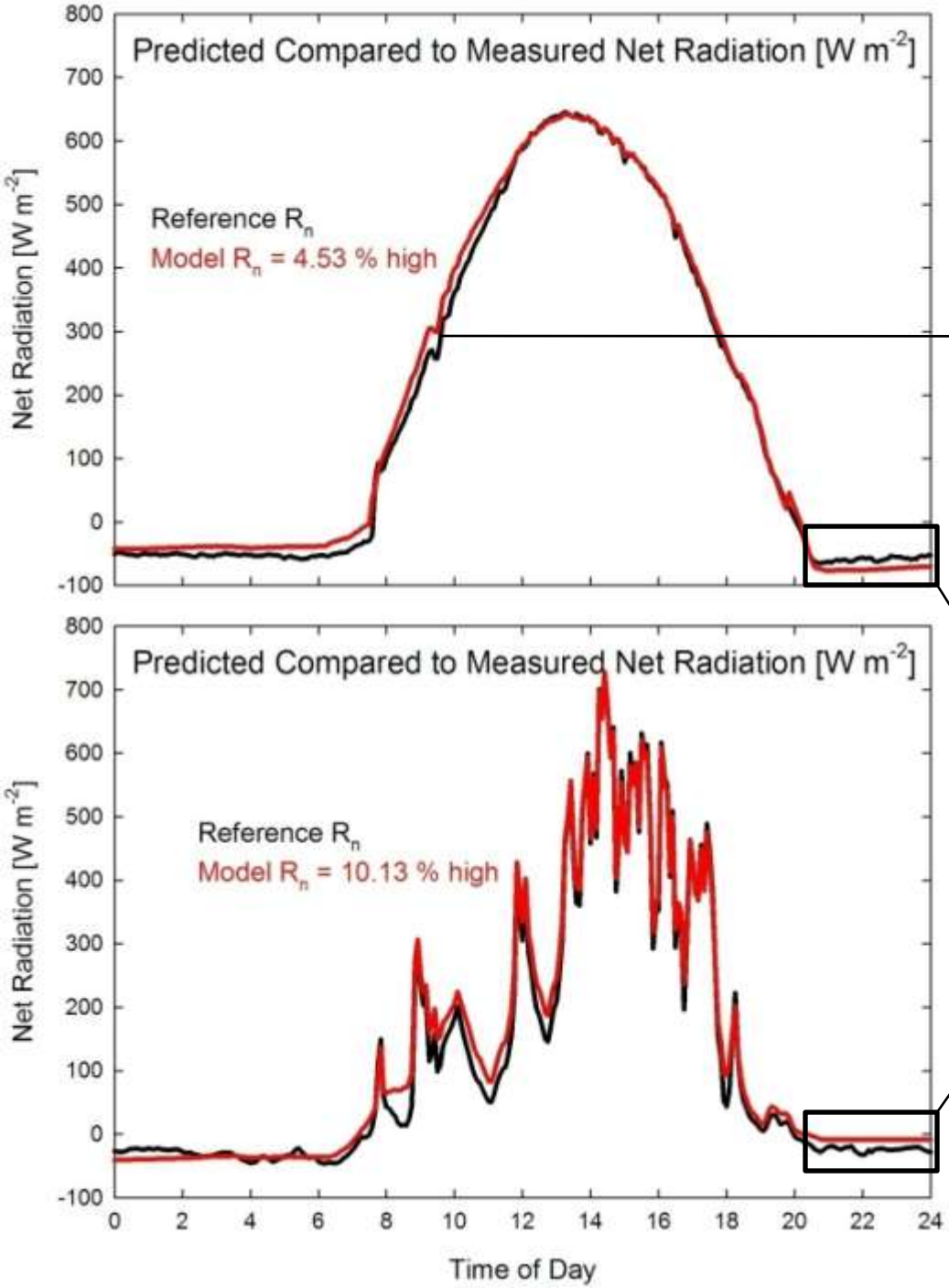
$$T_a = measurement$$

$$f_{cd} = 1.35\left(\frac{SW_i}{SW_{i-clearsky}}\right) - 0.35$$

Net Radiation Model Compared to Average of Net Radiometers

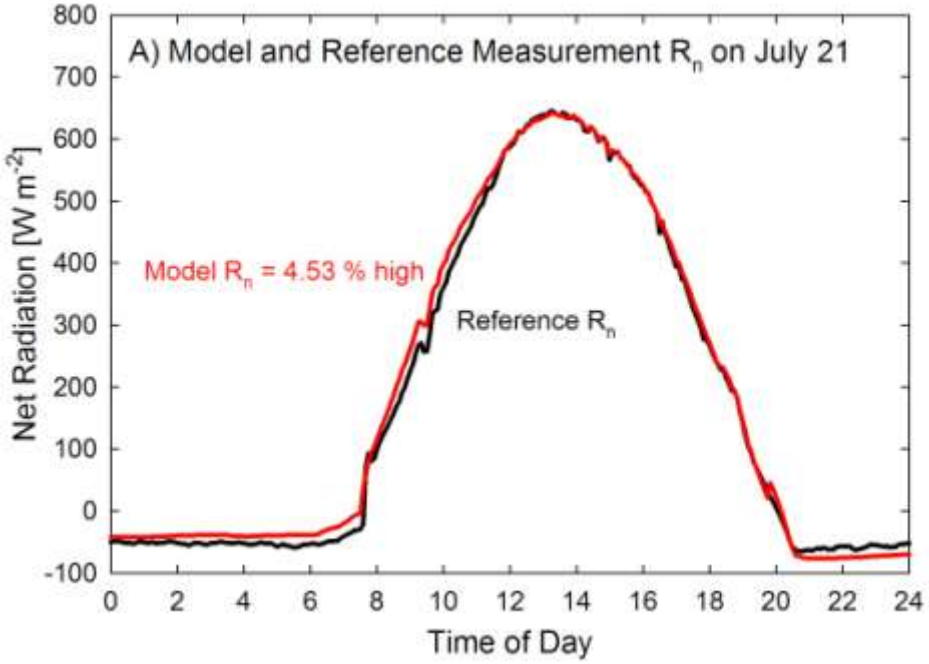


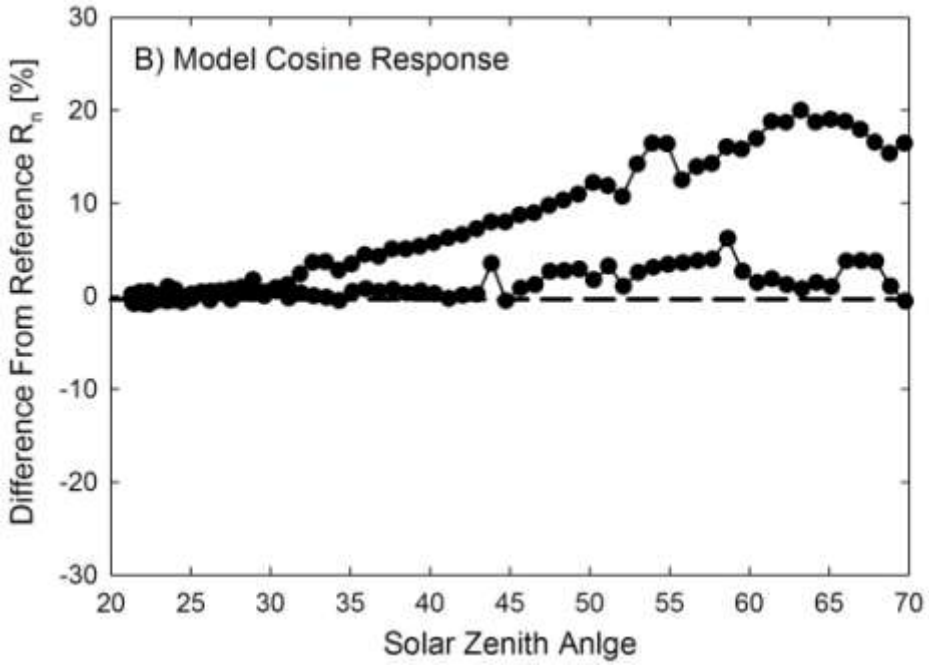


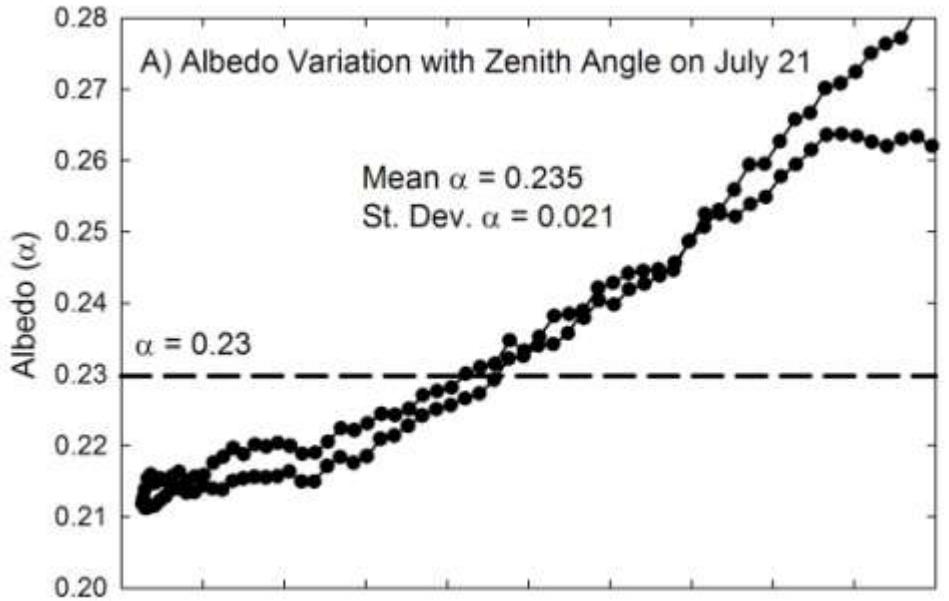


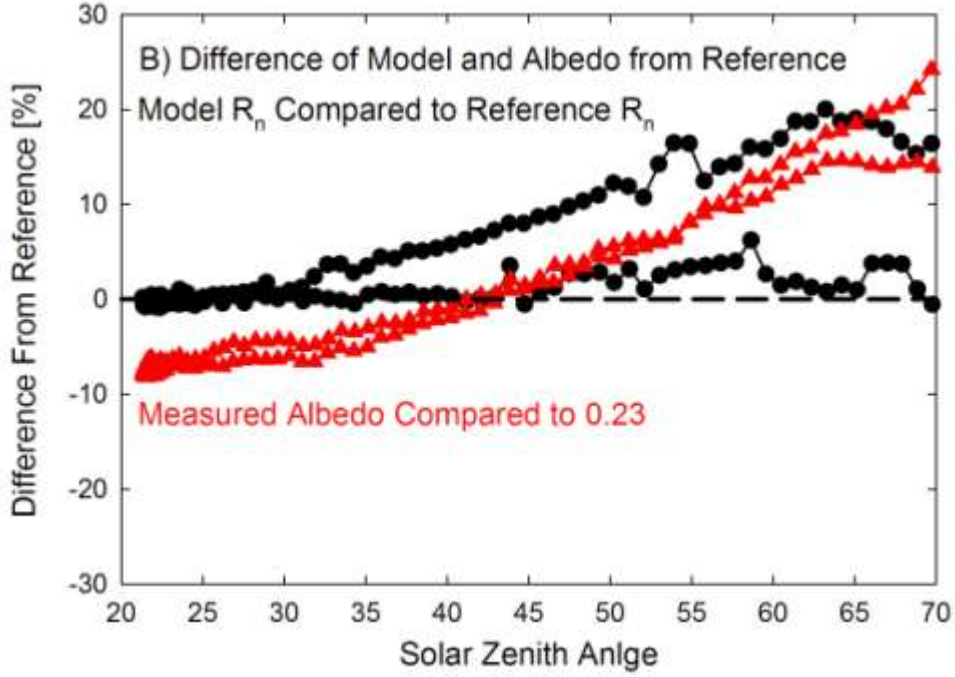
Appears to be a time offset.

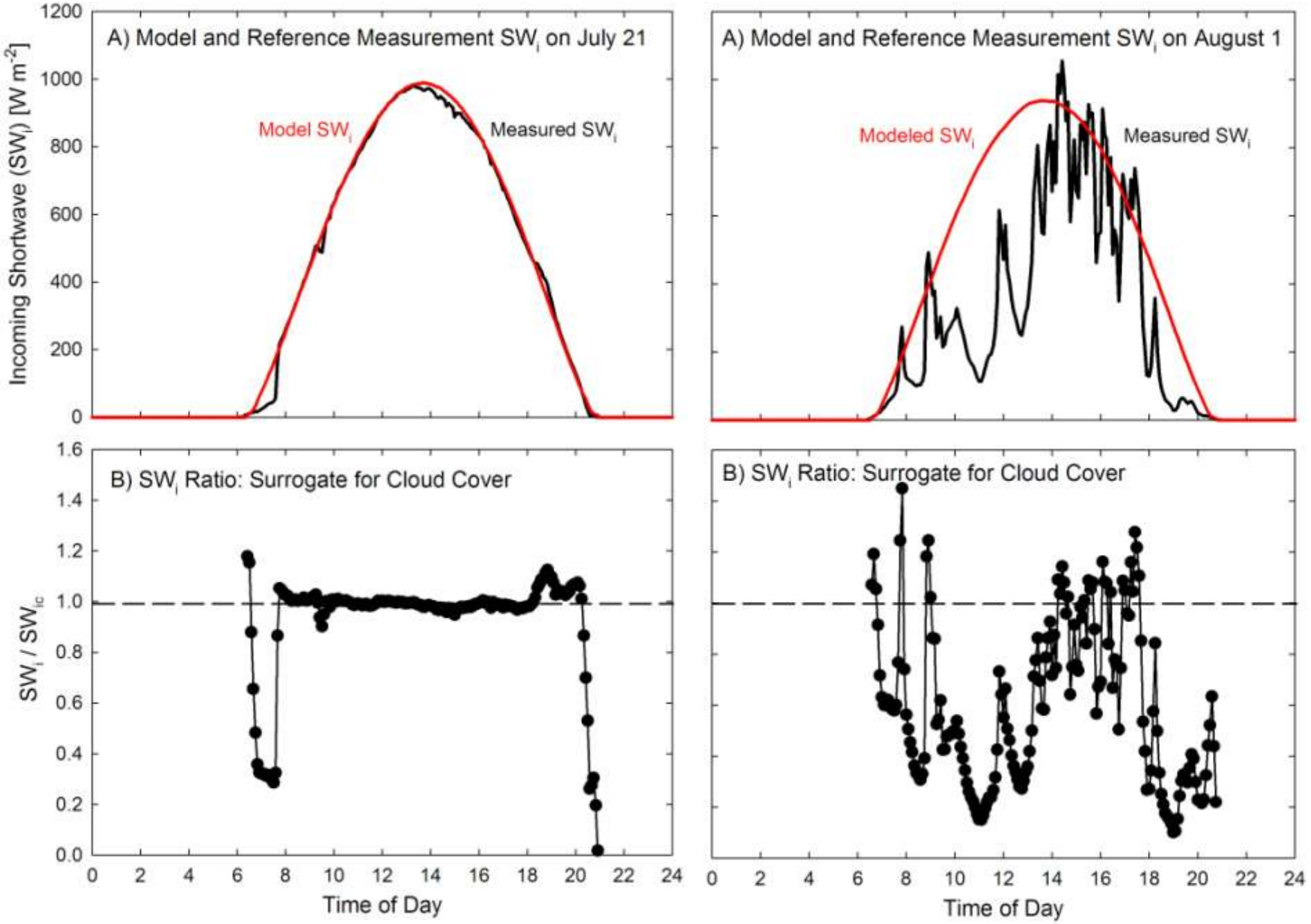
Assume f_{cd} from earlier in the day or next morning.


A) Model and Reference Measurement R_n on July 21
Net Radiation [W m^{-2}]
Time of Day
Model R_n = 4.53 % high
Reference R_n


B) Model Cosine Response
Difference From Reference R_n [%]
Solar Zenith Anlge


A) Albedo Variation with Zenith Angle on July 21
Mean α = 0.235
St. Dev. α = 0.021
α = 0.23
Albedo (α)


B) Difference of Model and Albedo from Reference
Model R_n Compared to Reference R_n
Measured Albedo Compared to 0.23
Difference From Reference [%]
Solar Zenith Anlge


A) Model and Reference Measurement SW$_i$ on July 21
Model SW$_i$
Measured SW$_i$
Incoming Shortwave (SW$_i$) [W m^{-2}]
1200
1000
800
600
400
200
0
A) Model and Reference Measurement SW$_i$ on August 1
Modeled SW$_i$
Measured SW$_i$
B) SW$_i$ Ratio: Surrogate for Cloud Cover
SW$_i$ / SW$_{ic}$
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0 2 4 6 8 10 12 14 16 18 20 22 24
Time of Day
B) SW$_i$ Ratio: Surrogate for Cloud Cover
0 2 4 6 8 10 12 14 16 18 20 22 24
Time of Day

Conclusions

Radiometers

- CNR 1 was the most accurate relative to the reference; waiting on recalibration.
- NR01 was accurate relative to the reference, but outliers (SW_o on 1006 and LW_i on 1007) caused high variability among reps.
- CNR 2 was accurate relative to the reference, but SW detectors are not matched as closely as LW detectors.
- NR-Lite had offsetting errors for day and night, resulting in reasonable, but low, values for daily total. It is less sensitive to LW compared to SW. Water on the detector surface makes the measurement unusable until complete evaporation.
- Q*7.1 had larger offsetting errors than the NR-Lite, also resulting in low daily totals. It is less sensitive to LW compared to SW.

Model

- Generally high during the day.
- Errors in both directions at night due to assumption of SW_i / $SW_{i\text{-clearsky}}$ ratio.
- Under all conditions, model was less accurate than sensors.
- Even with accurate measurements of solar radiation, vapor pressure, and air temperature, sources of error in model are:
  - assumption of constant albedo,
  - use of surrogate variable (SW_i / $SW_{i\text{-clearsky}}$) for cloud cover characterization,
  - offset between logger clock and actual time of day.