Radiometer Test Report

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General Description

Four radiometers were tested against each other to determine measurement consistency among instruments. The comparisons were done over a few test dates between various combinations of the sensors (while the instruments were swapped out among field sites). The following instruments and associated calibrations were tested:

Hukseflux NR01 4-band radiometer (s/n 1720) – new sensor
- $SW_{incoming}$: 13.71 mV / (W m^{-2})
- $SW_{outgoing}$: 13.36 mV / (W m^{-2})
- $LW_{incoming}$: 10.30 mV / (W m^{-2})
- $LW_{outgoing}$: 10.84 mV / (W m^{-2})

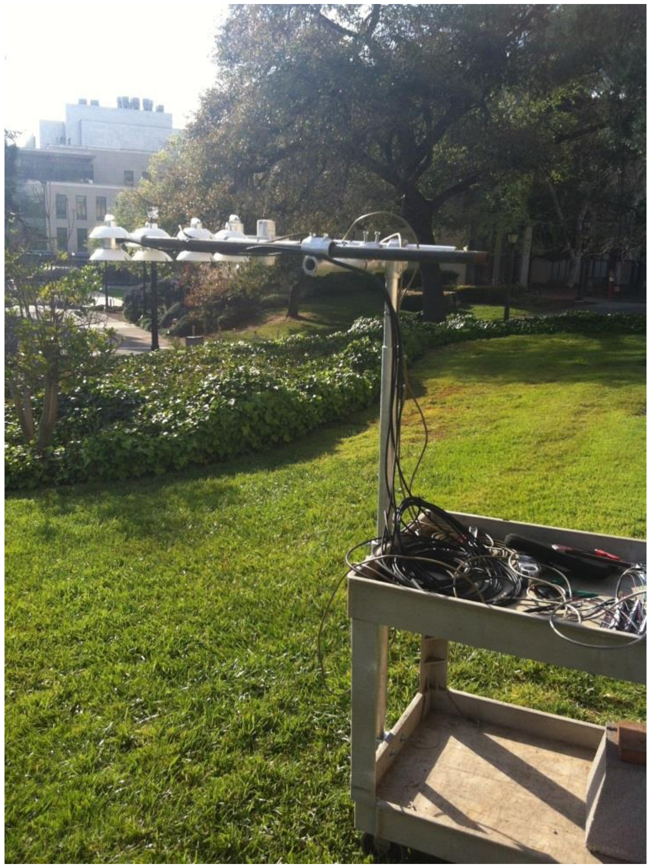
Hukseflux NR01 4-band radiometer (s/n 1570)
- $SW_{incoming}$: 13.33 mV / (W m^{-2})
- $SW_{outgoing}$: 15.00 mV / (W m^{-2})
- $LW_{incoming}$: 10.87 mV / (W m^{-2})
- $LW_{outgoing}$: 10.47 mV / (W m^{-2})

Kipp & Zonen CNR1 4-band radiometer (s/n 990181) – recalibrated by 3rd party some years ago
- $SW_{incoming}$: 9.94 mV / (W m^{-2})
- $SW_{outgoing}$: 9.96 mV / (W m^{-2})
- $LW_{incoming}$: 9.66 mV / (W m^{-2})
- $LW_{outgoing}$: 9.58 mV / (W m^{-2})

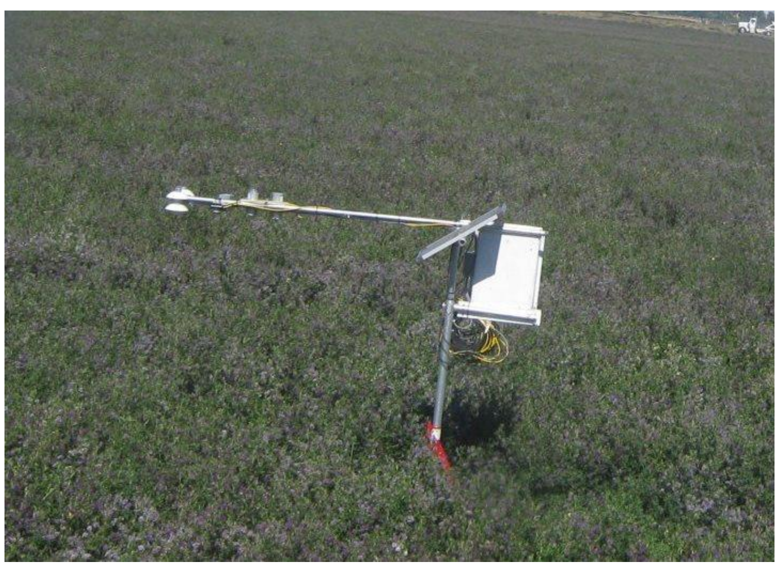
Kipp & Zonen CNR1 4-band radiometer (s/n 020476)
- $SW_{incoming}$: 10.27 mV / (W m^{-2})
- $SW_{outgoing}$: 10.27 mV / (W m^{-2})
- $LW_{incoming}$: 10.27 mV / (W m^{-2})
- $LW_{outgoing}$: 10.27 mV / (W m^{-2})

Incoming radiation refers to the upward pointing sensor. Outgoing radiation refers to the downward pointing sensor.

The sensors were mounted next to each other on a mobile cart (see picture below) and cantilevered out over either grass or asphalt. Data were measured every 10 seconds and averaged every minute. Sensors were also flipped periodically during the test runs to obtain a larger range of values and compare the upward and downward looking sensors on each instrument.



A final test between two sensors was conducted by mounting the sensors directly in-line with each other at the Twitchell Alfalfa site (see picture below). These data were measured every 10 seconds and averaged every half-hour.



Synopsis of Results

The older NR01 (s/n 1570) showed a nearly identical response in all channels (shortwave and longwave) to the new NR01 (s/n 1720). No changes to the calibrations of the NR01 (s/n 1570) for the shortwave channels or the incoming longwave channel are recommended. The greatest deviation of the older NR01 compared to the newer NR01 was a 0.97:1 slope and +11 W m-2 offset in the outgoing longwave channel. This calibration could probably stand as-is. However, since it was used as the baseline in testing another instrument, a new calibration for the outgoing longwave channel was found. The new set of calibration factors for the NR01 (s/n 1570) are as follows:

Hukseflux NR01 4-band radiometer (s/n 1570)

$SW_{incoming}$: 13.33 mV / (W m^{-2}) – no change
$SW_{outgoing}$: 15.00 mV / (W m^{-2}) – no change
$LW_{incoming}$: 10.87 mV / (W m^{-2}) – no change
$LW_{outgoing}$: 10.12 mV / (W m^{-2}) – new calibration

The CNR1 (s/n 990181) showed a nearly identical response in both the shortwave channels to the NR01 sensors, but the longwave channels showed an approximately 0.93:1 slope and +30 W m^{-2} offset from the new NR01 sensor. Therefore, no change to the CNR1 shortwave channel calibrations are recommended, but the longwave channel calibrations were re-determined. The new set of calibration factors for the CNR1 (s/n 990181) are as follows:

Kipp & Zonen CNR1 4-band radiometer (s/n 990181) – new calibrations

$SW_{incoming}$: 9.94 mV / (W m^{-2}) – no change
$SW_{outgoing}$: 9.96 mV / (W m^{-2}) – no change
$LW_{incoming}$: 8.90 mV / (W m^{-2}) – new calibration
$LW_{outgoing}$: 8.76 mV / (W m^{-2}) – new calibration

The CNR1 (s/n 020476) showed notable deviations in all channels compared to the NR01 sensor (s/n 1570), most often showing lower values than the NR01. New calibrations for all channels were determined and are as follows:

Kipp & Zonen CNR1 4-band radiometer (s/n 020476)

$SW_{incoming}$: 10.0 mV / (W m^{-2}) – new calibration
$SW_{outgoing}$: 9.6 mV / (W m^{-2}) – new calibration
$LW_{incoming}$: 11.15 mV / (W m^{-2}) – new calibration
$LW_{outgoing}$: 8.6 mV / (W m^{-2}) – new calibration

Plots and commentary for each set of tests are shown in the following pages.

NR01 (s/n 1570) vs. CNR1 (s/n 990181) vs. NR01 (s/n 1570)
Test date: 29 March 2013 (partly cloudy)
Follow-up test: 2 May 2013 (cloudless)

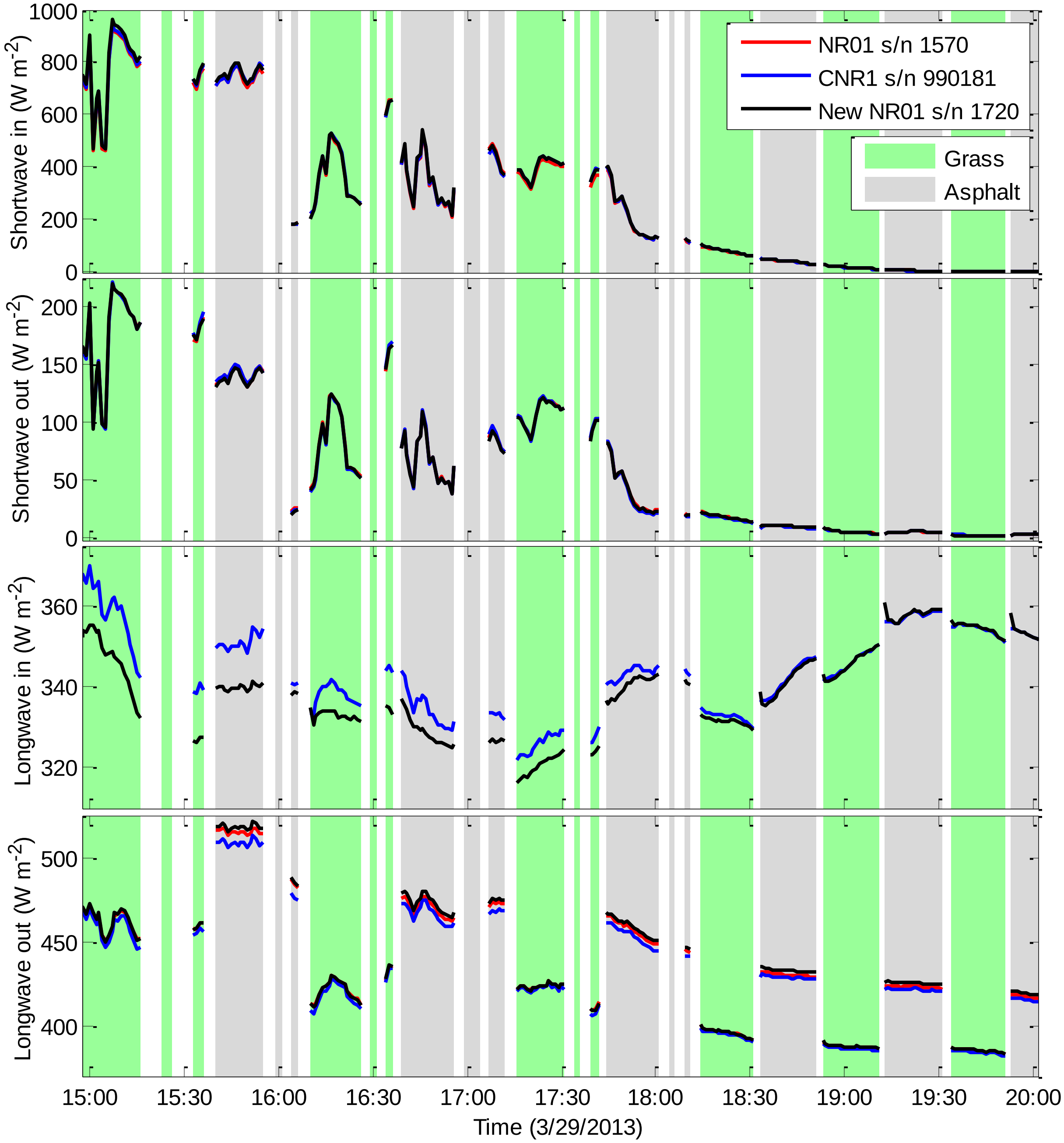


Fig. 1. Time series of the 3/29/2013 test comparing the two NR01 sensors and one CNR1 sensor. Each of the four bands is plotted in a separate subplot. The sensors were positioned over grass and asphalt, corresponding to the different colored periods. Only data for the normally oriented sensors are shown here (flipped periods and transition times were excluded). Note that the incoming longwave channel for NR01 s/n 1570 was not working at this time. It was later fixed

and tested again on 5/2/2013 (Figs. 6 & 7). The sensors all show relatively good correspondence with each other, although some differences are apparent. Differences among sensors appear larger in the longwave channels, but note that the scale on these readings is much narrower. The flip tests (below) help to generate a larger range of compared values.

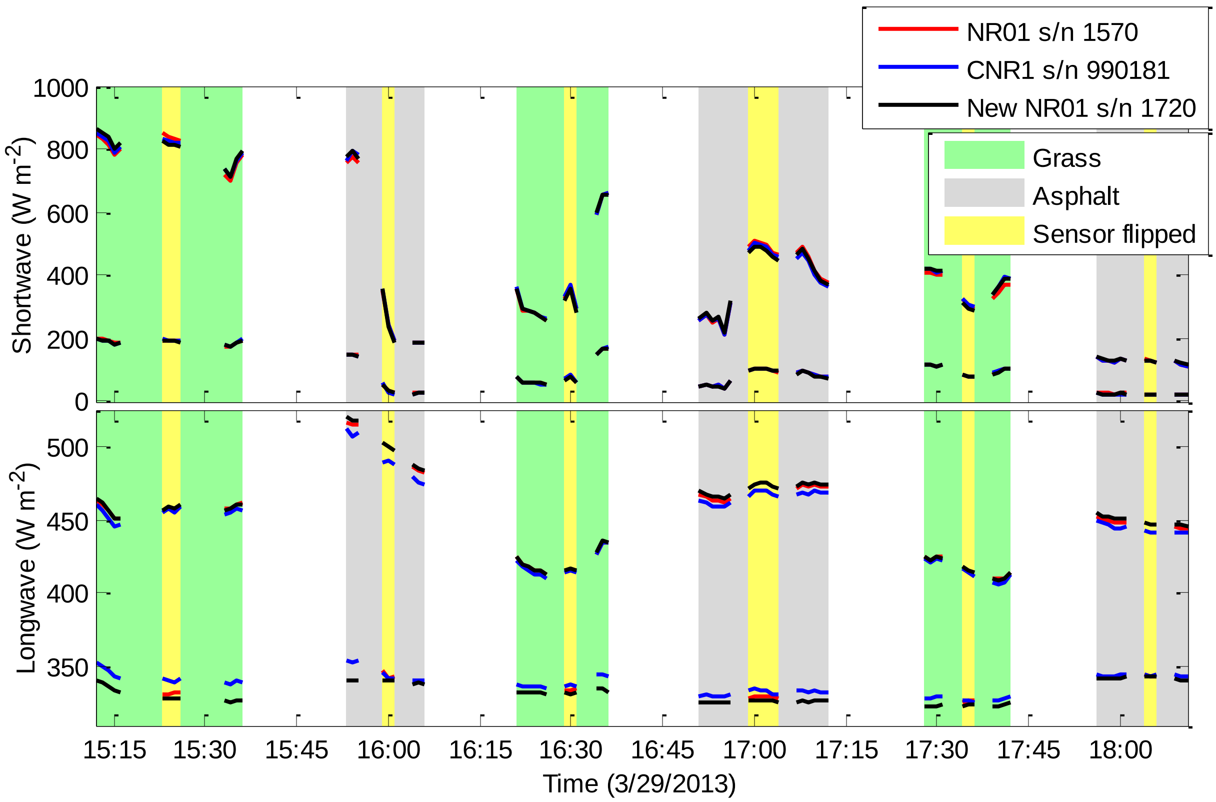


Fig. 2. Time series showing the flip tests for the 3/29/2013 comparison. In the yellow shaded regions the sensor was flipped so that what appears to be incoming radiation is being read from the downward looking sensor, and vice versa.

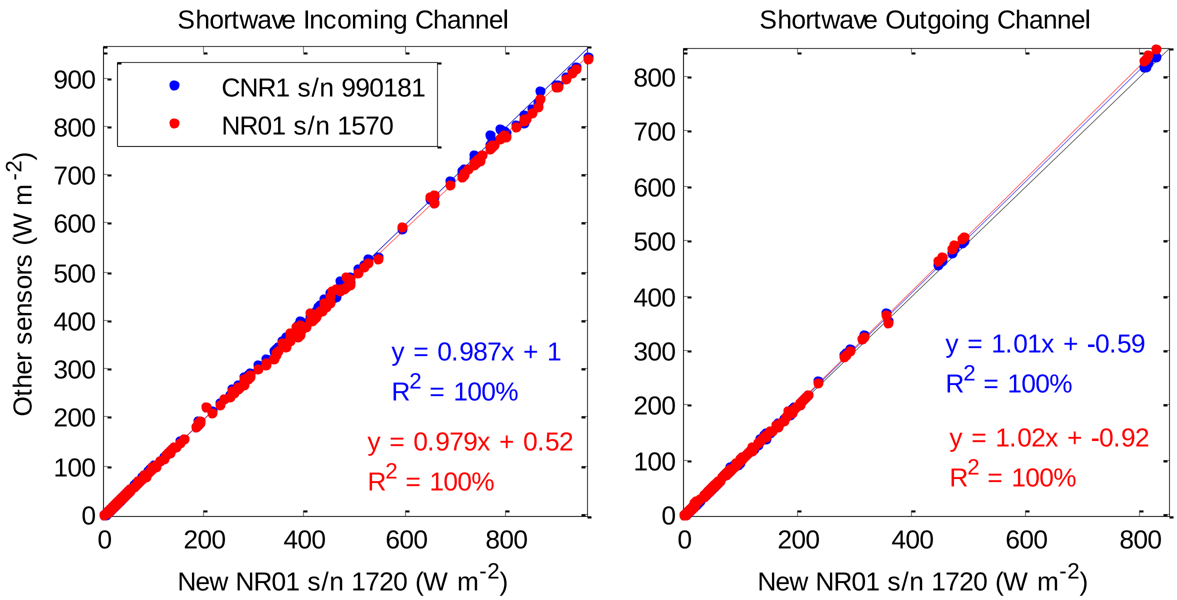


Fig. 3. Regressions of shortwave channels among the three radiometers for the test on 3/29/2013. The older NR01 and the CNR1 are both plotted against the new NR01. The comparisons include the periods in which the sensors were flipped, which is why the ranges of the incoming and outgoing channels are similar. Correspondence among the instruments for the incoming and outgoing shortwave channels was near 1:1. Calibration coefficients should remain as is.

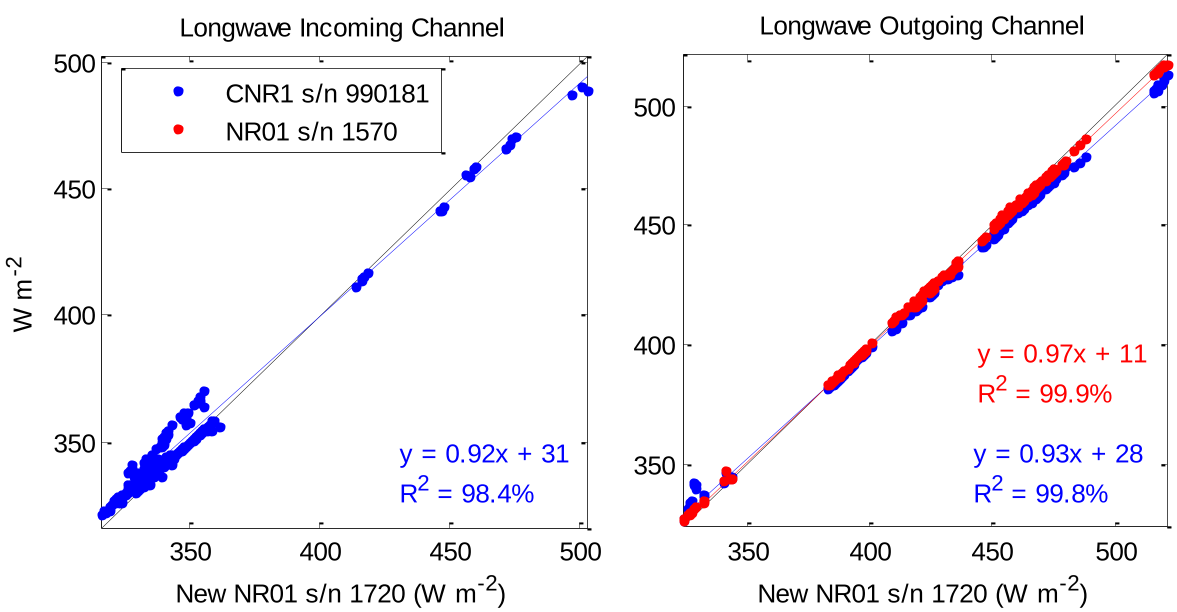


Fig. 4. Comparison of longwave channels among the three radiometers for the test on 3/29/2013. The older NR01 (s/n 1570) and the CNR1 (s/n 990181) are both plotted against the new NR01. Note that incoming longwave channel on the NR01 s/n 1570 was not working on 3/29/2013. See

Figs. 6 & 7 below for its evaluation. The comparisons include the periods in which the sensors were flipped, which is why the ranges of the incoming and outgoing channels are similar. The incoming and outgoing CNR1 longwave channels both show a < 1:1 slope and positive offset compared to the new NR01 (s/n 1720). Note that the relationships between the sensors are more variable over the short range, but closer to 1:1 over the larger range (when including the flipped periods). This probably has to do with poorer short term accuracy of sensor heating. New calibration factors for the CNR1 longwave channels were found (Fig. 5). The outgoing longwave channel on the older NR01 (s/n 1570) is close enough to the new NR01 (s/n 1720) that it could be within the margin of leveling error. However, when the incoming longwave channel on this instrument was fixed and another test done (see Figs. 6 & 7), the same offset was noted and a correction to the calibration remained consistent between the two tests. Therefore, a new calibration was found for the outgoing longwave channel of the NR01 (s/n 1570) (Fig. 5), especially since this instrument was used as the baseline to test another instrument.

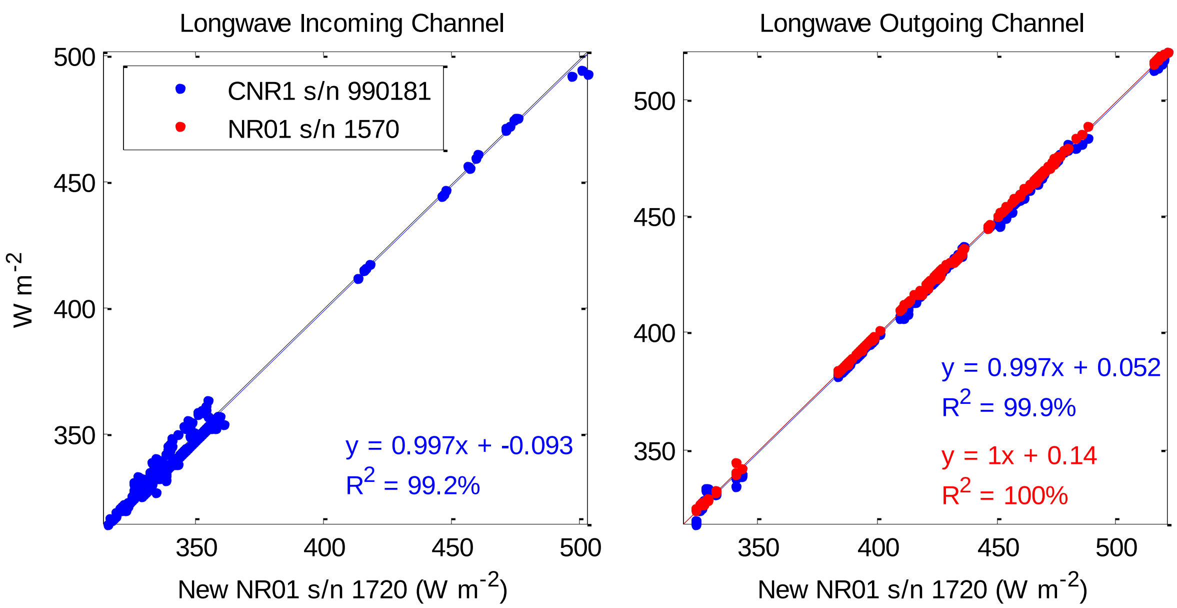


Fig. 5. Comparison of longwave channels between the new NR01 (s/n 1720) and the older instruments CNR1 (s/n 990181) and NR01 (s/n 1570) after iteratively adjusting the calibrations for the older instruments. New calibration coefficients for the CNR1 are: $LW_{incoming}$ = 8.90 mV / (W m^{-2}); $LW_{outgoing}$ = 8.76 mV / (W m^{-2}). New calibration for the NR01 (s/n 1570) outgoing longwave is: $LW_{outgoing}$ = 10.12 mV / (W m^{-2}). Note the slightly better R^2 values after adjusting the calibrations.

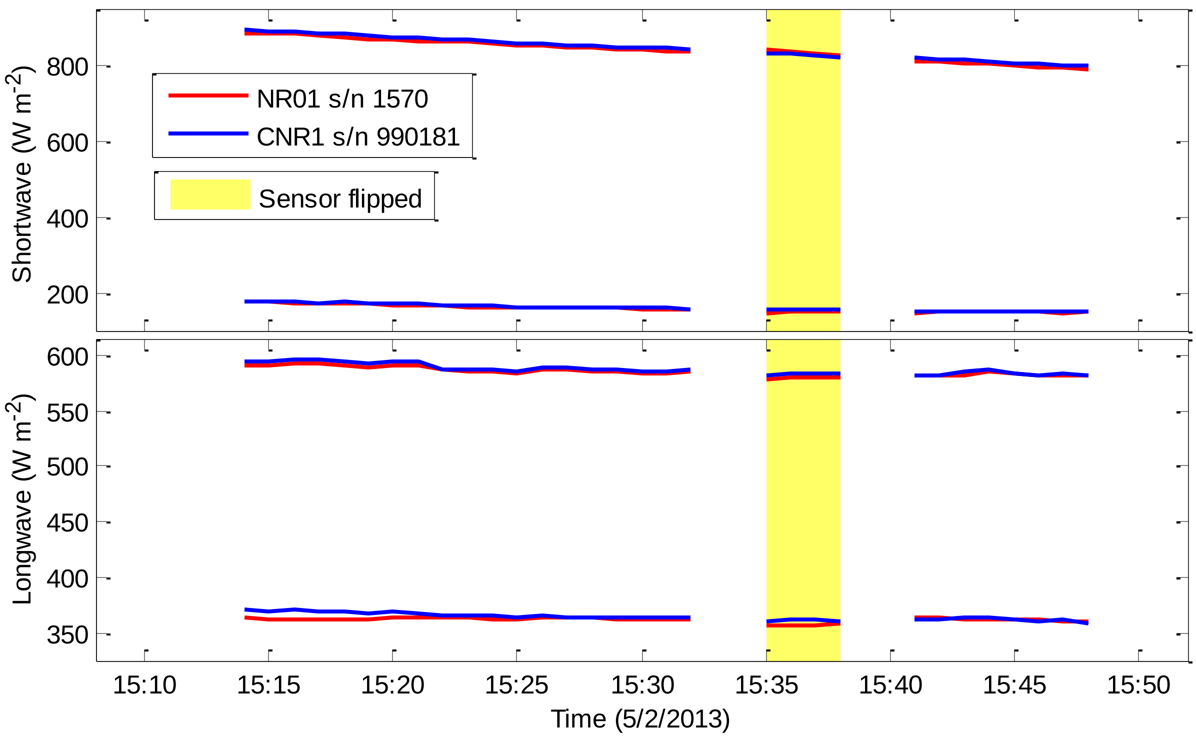


Fig. 6. Flip test (over asphalt) after the incoming longwave channel on the NR01 s/n 1570 was fixed. Readings include all updated calibrations (see Fig. 5). The new NR01 (s/n 1720) was installed at Tonzi between the 3/29 and 5/2 tests. Therefore, only the older NR01 (s/n 1570) and the CNR1 (s/n 990181) were compared. The reason for the NR01 fix is not entirely clear. I noted that the sensor began working when the sensor housing was loosened. I disassembled the sensor and reassembled it, and the sensor worked fine. I think it likely that there was a pinched wire inside the sensor somewhere.

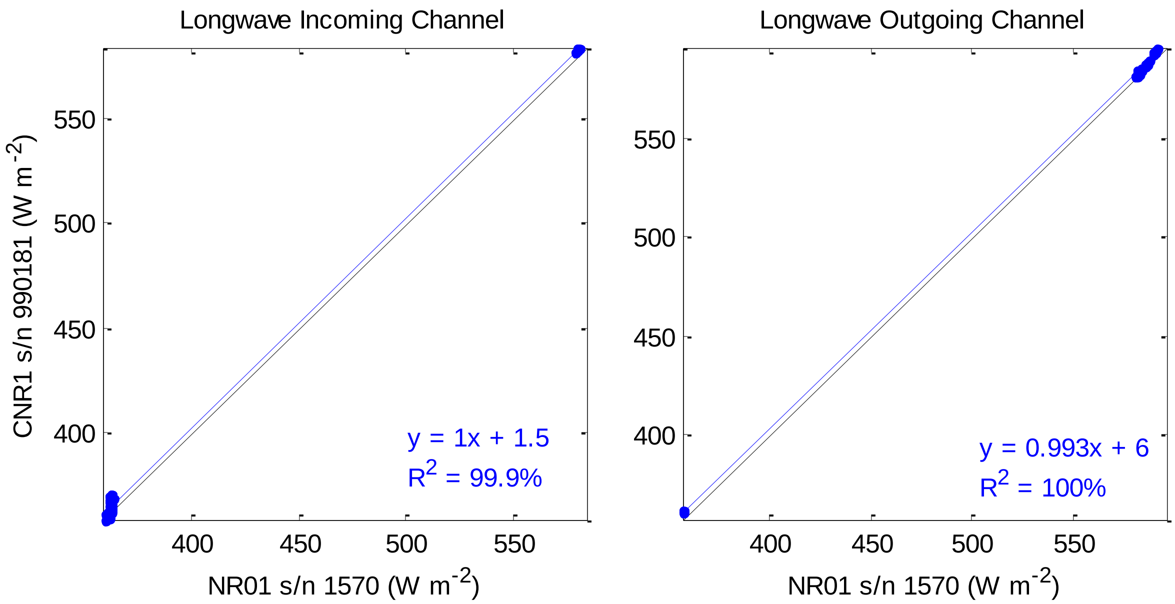


Fig. 7. Comparison of longwave channels after the incoming longwave channel on the NR01 s/n 1570 was fixed. Readings include all updated calibrations (see Fig. 5). The comparisons include the periods in which the sensors were flipped, which is why the ranges of the incoming and outgoing channels are similar. Note that the NR01 s/n 1720 on the x-axis (from Fig. 4) has been replaced by the NR01 s/n 1570 (including new cal for outgoing longwave), and the relationship between the NR01 and the CNR1 channels are nearly 1:1 with minimal offset. Therefore, the updated cals seem verified and no adjustment to the incoming longwave channel on NR01 s/n 1570 is needed. The high R^2 values are probably overestimated due to clumped values at the range extremes.

NR01 (s/n 1570) vs. CNR1 (s/n 020476)

Test date: 18 June – 28 June Installed at Twitchell Alfalfa site

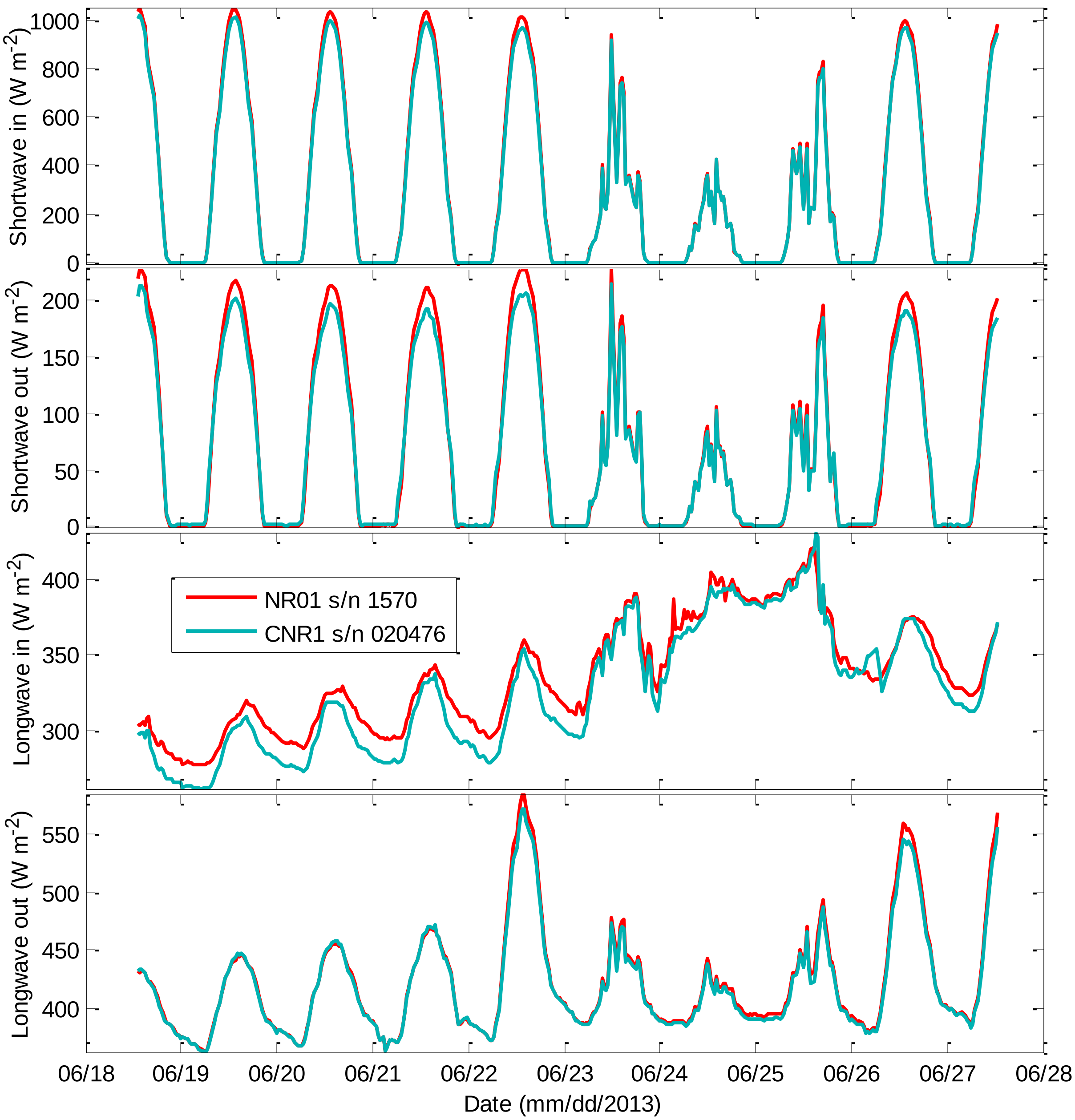


Fig. 8. Time series of the multi-day test at Twitchell Alfalfa comparing the older NR01 (s/n 1570) sensor (including updated cal to outgoing longwave) to a CNR1 (s/n 020476). Each of the four bands is plotted in a separate subplot. The sensors were positioned in-line over alfalfa, and there were no flip tests done. The sensors showed fairly good correspondence in readings but the CNR1 generally showed lower readings in all channels compared to the NR01.

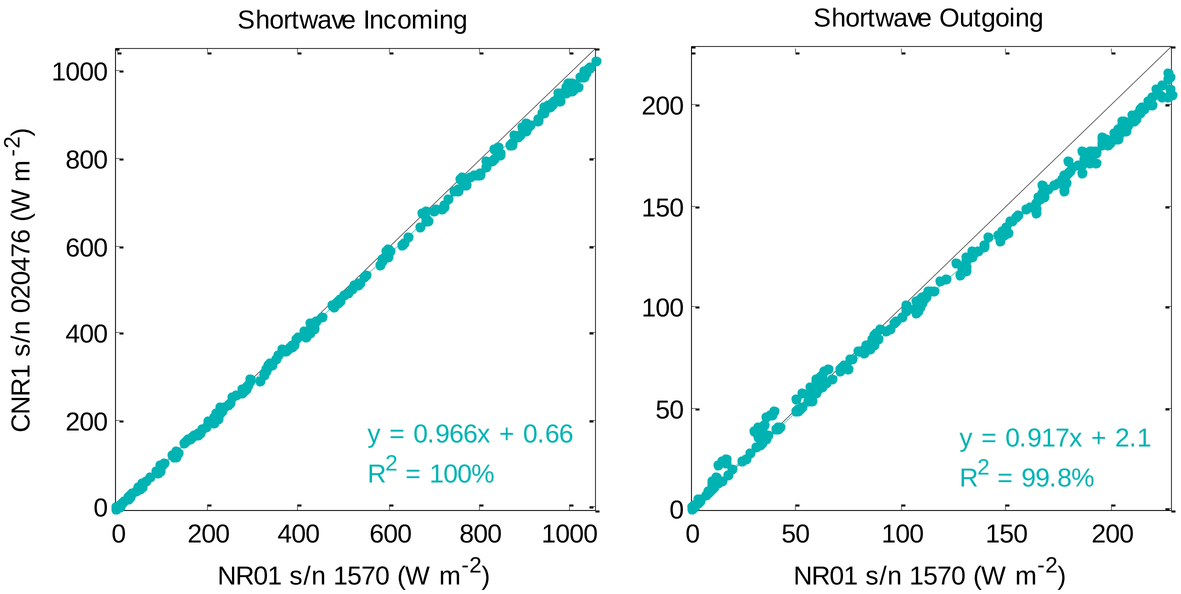


Fig. 9. Comparison of shortwave channels among the NR01 (s/n 1570) and CNR1 (s/n 020476) for the multi-day test at Twitchell Alfalfa. The CNR1 is plotted against the older NR01 which showed nearly identical readings to the new NR01 (Fig. 3). The incoming shortwave channel on the CNR1 (s/n 020476) showed a ~3% lower response compared to the NR01 and a new calibration was determined (Fig. 10). The outgoing shortwave channel on the CNR1 (s/n 020476) showed a substantially lower response compared to the NR01. A new calibration was determined (Fig. 10).

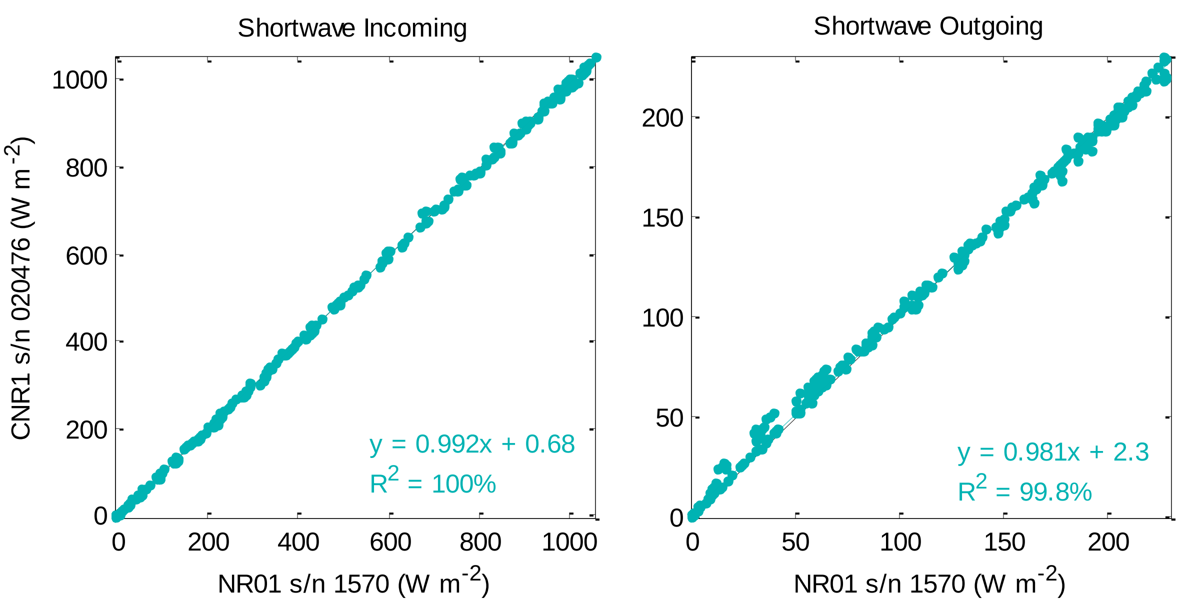


Fig. 10. Comparison of shortwave channels between the old NR01 (s/n 1570) and the CNR1 (s/n 020476) after iteratively adjusting the calibrations for the CNR1. New calibration coefficients for the CNR1 are: $SW_{incoming}$ = 10.0 mV / (W m^{-2}); $SW_{outgoing}$ = 9.6 mV / (W m^{-2}).

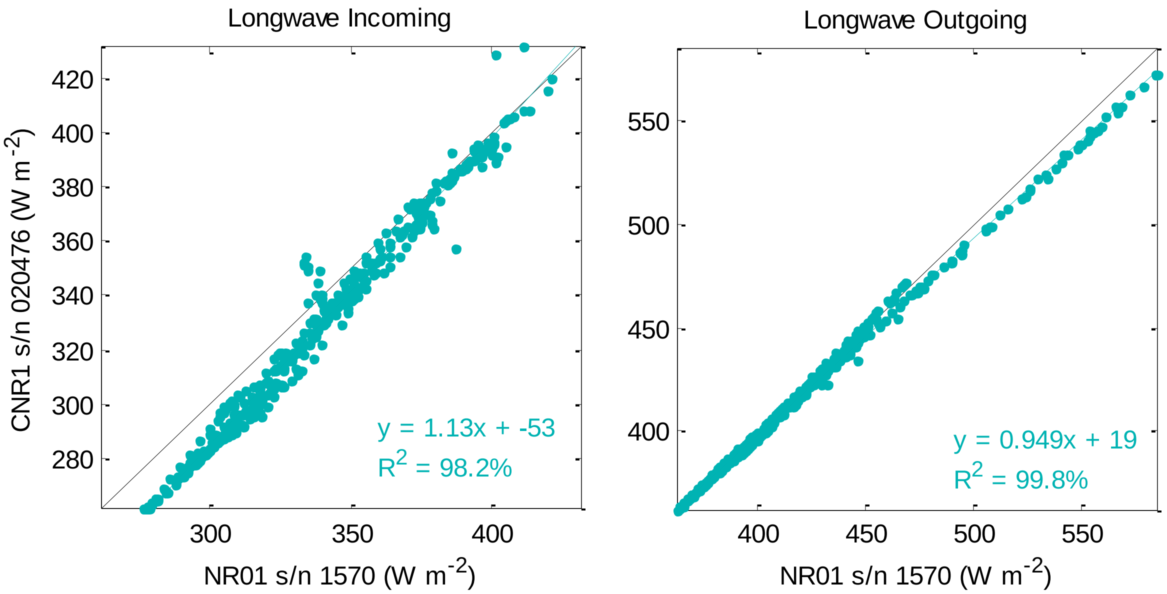


Fig. 11. Comparison of longwave channels between the older NR01 (s/n 1570) and CNR1 (s/n 020476) for the multi-day test at Twitchell Alfalfa. The CNR1 is plotted against the older NR01 (including updated outgoing longwave cal). The incoming CNR1 longwave channel showed a negative bias at the low end of the incoming longwave radiation range. A new calibration coefficient was determined (Fig. 12). The outgoing longwave channel on the CNR1 showed a ~5% lower response than the NR01, and a new calibration was determined (Fig. 12).

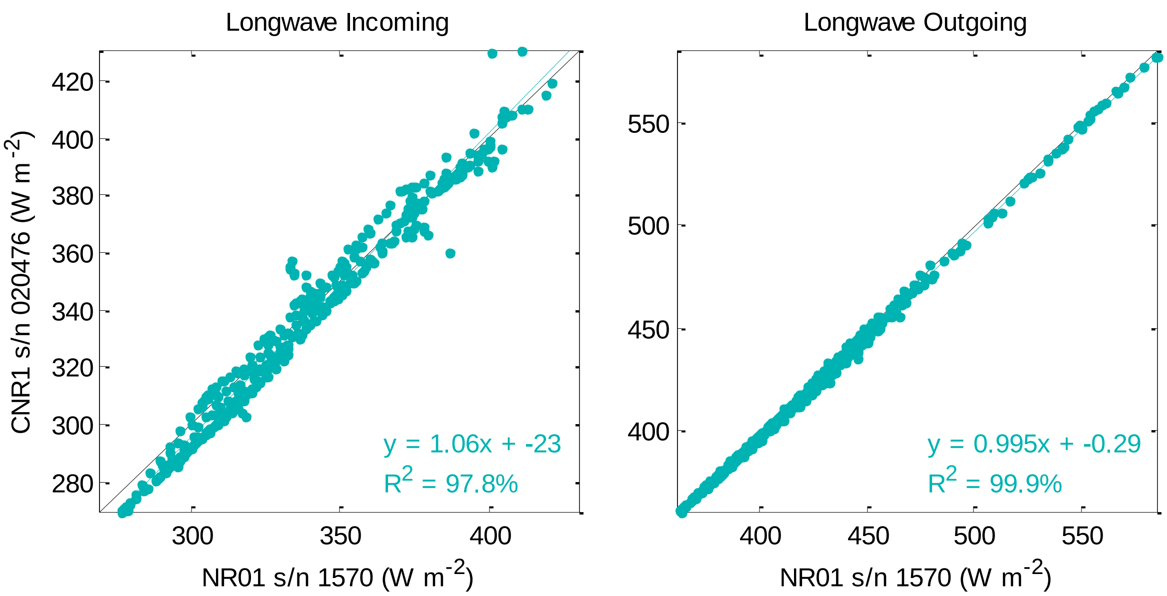


Fig. 12. Comparison of longwave channels between the old NR01 (s/n 1570) and the CNR1 (s/n 020476) after iteratively adjusting the calibrations for the CNR1. New calibration coefficients for the CNR1 are: $LW_{incoming}$ = 11.15 mV / (W m^{-2}); $LW_{outgoing}$ = 8.6 mV / (W m^{-2}). The updated cal for the CNR1 incoming longwave channel still showed remaining bias. However, I did not adjust the calibration further because doing so resulted in greater bias at the high range of incoming

longwave radiation. The new cal resulted in the best possible correspondence between the CNR1 and NR01 at both extremes of the incoming longwave radiation range. Fig. 13 below shows the time series after the adjustments to all channels on the CNR1.

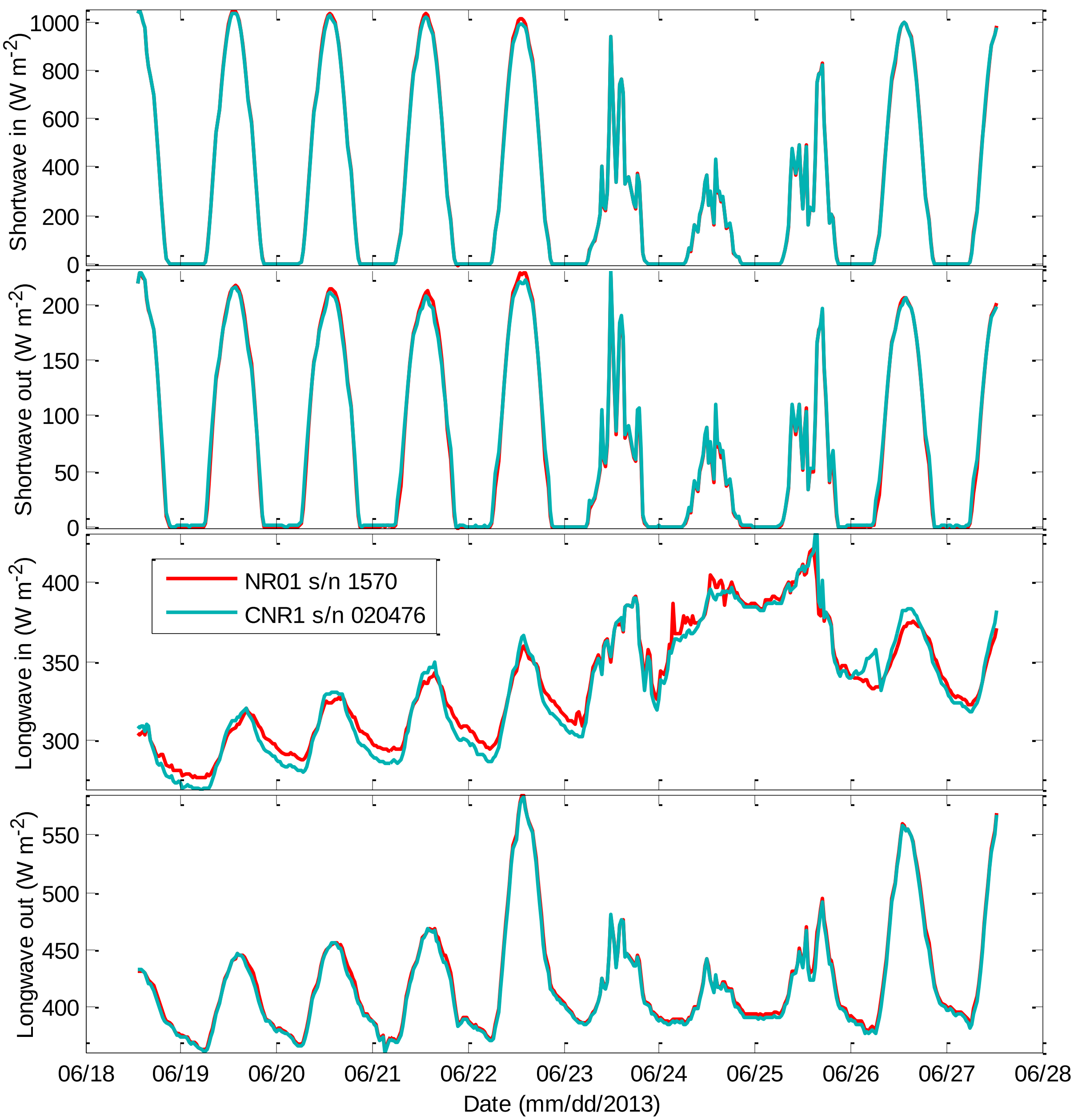


Fig. 13. Time series of the multi-day test at Twitchell Alfalfa comparing the older NR01 (s/n 1570) sensor (including updated cal to outgoing longwave) to the CNR1 (s/n 020476) after applying all updated calibrations to the CNR1. Note that bias still remained in the incoming longwave channel of the CNR1, but the bias was relatively equal at both extremes of the radiation range.