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Infrared Thermometer (IRT) Instrument Handbook

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ARM CLIMATE RESEARCH FACILITY

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Acronyms and Abbreviations

AAF	ARM Aerial Facility
AERI	atmospheric emitted radiance interferometer
AMF	ARM Mobile Facility
ARM	Atmospheric Radiation Measurement
ASTM	American Society for Testing and Materials
DOE	U.S. Department of Energy
ENA	Eastern North Atlantic
GNDRAD	ground radiometers on stand for upwelling radiation
IRT	infrared thermometer
IRTSST	infrared thermometer for sea-surface temperature
MWR	microwave radiometer
MWRP	microwave radiometer profiler
MWR3C	microwave radiometer, 3 channel
NSA	North Slope of Alaska
OLI	Oliktok Point, NSA
PIR	precision infrared radiometer
PNNL	Pacific Northwest National Laboratory
QC	quality control
SGP	Southern Great Plains
SKYRAD	sky radiometers on stand for downwelling radiation
TWP	Tropical Western Pacific

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1.0 General Overview

The Infrared Thermometer (IRT) is a ground-based radiation pyrometer that provides measurements of the equivalent blackbody brightness temperature of the scene in its field of view. The downwelling version has a narrow field of view for measuring sky temperature and for detecting clouds. The upwelling version has a wide field of view for measuring the narrowband radiating temperature of the ground surface.

The infrared thermometer for sea-surface temperature (IRTSST) is a ship-based radiation pyrometer that provides measurements of the temperature of the sea surface. The upwelling infrared emission is determined with two IRTs for over-ocean field campaigns.

Figure 1. Heitronics infrared radiation pyrometer.

Figure 2. Infrared thermometer setup at the Southern Great Plains (SGP) observatory.

Figure 3. Exterior of the infrared thermometer enclosure.

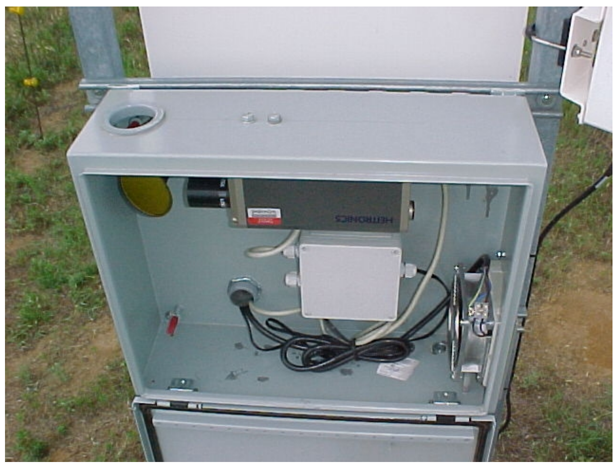

Figure 4. Interior of the infrared thermometer enclosure.

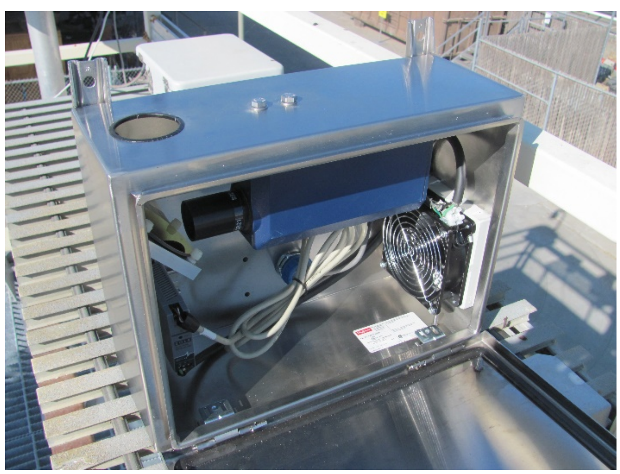

Figure 5. Second view of infrared thermometer enclosure interior.

2.0 Contacts

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2.2 Vendor/Instrument Developer

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3.0 Instrument Description

The Infrared Thermometer (IRT) deployed at the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility is a Heitronics GmbH KT19.85 Infrared Radiation Pyrometer.

4.0 Historic Background of the Instrument

The DOE ARM Facility currently operates a total of 31 IRTs at its fixed sites (in Oklahoma, Alaska, and the Azores) and mobile and aerial facilities. Initially, one downwelling and two upwelling Heitronics KT19.85 Type I Infrared Radiation Pyrometers were deployed at the ARM Southern Great Plains (SGP) site in 1993. The same model IRT was integrated with the sky and ground radiometers at the Tropical Western Pacific (TWP) and North Slope of Alaska (NSA) sites from 1996 to 2002. Heitronics KT19.85 Type II IRTs were deployed at the SGP extended facilities, the three ARM Mobile Facilities (AMF), and the ARM Aerial Facility (AAF) from 2005 to 2010. The Type I models were upgraded to Type II at the SGP, TWP, and NSA central facilities in 2013. IRTs were also deployed with the sky and ground radiometers at the Eastern North Atlantic (ENA) site in 2013. The IRTs were separated from the sky and ground radiometer systems at NSA, ENA, and AMF sites and configured with a dedicated data acquisition system from 2017 to 2018.

The current deployment locations of the IRTs are listed in Table 1. Note: This information was current as of January 1, 2018. Please contact the instrument mentor for the latest version. See also “IRT Sensor” components in the ARM Operations Status System.

Table 1. IRT current status and locations.

Serial Number	Property Number	Function	Location	Installation Date	Status
517	WD11383	downwelling	Wintronics	--	decommissioned
863	WD17512	GNDRAD (TWP)	SGP	--	spare
864	WD17513	GNDRAD (TWP)	PNNL	--	spare
865	WD17514	GNDRAD (TWP)	PNNL	--	spare
866	WD17515	SKYRAD (TWP)	NSA	--	spare
867	WD17516	SKYRAD (TWP)	ENA	--	spare
868	WD17517	SKYRAD (TWP)	PNNL	--	decommissioned
1026	WD18682	upwelling (25m)	SGP	--	spare
1029	WD18683	upwelling (10m)	SGP	--	spare
1250	WD20062	GNDRAD (NSA)	Wintronics	--	decommissioned
1251	WD20064	GNDRAD (NSA)	NSA	--	spare
1252	WD20063	GNDRAD (NSA)	AMF3	--	spare
1253	WD20065	SKYRAD (NSA)	NSA	--	spare
1254	WD20066	SKYRAD (NSA)	PNNL	--	spare
1255	WD20067	SKYRAD (NSA)	NSA	--	spare
1553	WD23001	SKYRAD	SGP	--	spare
1628	WD23029	GNDRAD	SGP	--	spare
1832	WD26623	downwelling (AML)	PNNL		operational
1845	WD26738	upwelling (AML)	PNNL	--	spare
1938	WD33301	SKYRAD	LASF	--	spare
2271	WD44843	downwelling	AMF1	--	spare
2272	WD44844	downwelling	Wintronics	--	repair
2273	WD44845	downwelling	SGP/E11	2005/08/25	operational
2274	WD44846	downwelling	SGP/E13	2016/04/22	operational
2275	WD44847	downwelling	SGP/E32	2011/08/25	operational
2276	WD44848	downwelling	SGP/E39	2015/10/15	operational
2301	WD45256	SKYRAD	PNNL	--	decommissioned
2302	WD45257	GNDRAD	PNNL	--	decommissioned
2326	WD54726	upwelling (AAF)	PNNL	--	spare
2327	WD54727	upwelling (AAF)	PNNL	--	spare
2384	WD49278	downwelling	SGP/E15	2008/01/29	operational
2385	WD49279	SKYRAD	AMF1	--	spare
2386	WD49280	downwelling	SGP/E31	2011/09/16	operational
2387	WD49281	downwelling	SGP/E40	2015/10/20	operational
2388	WD49282	downwelling	SGP/E37	2015/10/26	operational
2389	WD49283	downwelling	SGP/E21	2013/10/02	operational
2390	WD49284	downwelling	SGP/E41	2016/04/26	operational
2391	WD49285	downwelling	PNNL	--	spare
2392	WD49276	downwelling	SGP	--	spare
2655	WD58073	downwelling	SGP	--	spare
2656	WD58074	downwelling	SGP/E35	2011/09/01	operational
2657	WD58075	downwelling	SGP	--	spare
2658	WD58076	downwelling	SGP/E36	2015/01/06	operational
2659	WD58077	downwelling	SGP/E38	2017/11/09	operational

Serial Number	Property Number	Function	Location	Installation Date	Status
2660	WD58078	downwelling	Wintronics	--	repair
2661	WD58079	downwelling	SGP/E33	2012/03/01	operational
2662	WD58080	downwelling	SGP	--	spare
2663	WD58081	downwelling	SGP	--	spare
2753	WD58258	downwelling	SGP/E34	2011/08/26	operational
2754	WD58259	downwelling	PNNL	--	spare
2769	WD59083	downwelling	LASF	--	spare
2770	WD59084	downwelling	AMF1	--	spare
2771	WD59085	downwelling	LASF	--	spare
2772	WD59086	downwelling	AMF2	2017/10/16	operational
2773	WD59087	upwelling	AMF2	2017/10/16	operational
2774	WD59088	upwelling	AMF2	--	spare
2948	WD56375	downwelling	AMF2	--	spare
3145	WD79424	SKYRAD	AMF3	2013/08/30	operational
3146	WD79452	downwelling	ENA/C1	2013/10/01	operational
3147	WD79432	GNDRAD	AMF3	2013/08/30	operational
3148	WD79453	upwelling	ENA/C1	2013/10/01	operational
3259	--	upwelling	SGP	--	spare
3337	--	SKYRAD	NSA/C1	2014/02/26	operational
3338	--	downwelling	SGP/E9	2015/11/19	operational
3339	--	downwelling	SGP/E12	2016/10/27	operational
3350	--	upwelling (10m)	SGP/C1	2013/09/17	operational
3351	--	GNDRAD	NSA/C1	2014/04/10	operational
3352	--	GNDRAD	AMF1	--	spare
3353	--	upwelling	AMF1	--	spare
3354	--	upwelling (25m)	SGP/C1	2013/09/19	operational

5.0 Measurements Taken

The downwelling IRT measures the infrared radiation emitted by the sky or cloud base and transforms it into a standardized output signal that is proportional to temperature in Kelvins. The upwelling IRT measures the ground-surface temperature in Kelvins.

6.0 Links to Definitions and Relevant Information

See ARM Glossary.

6.1 Data Object Description

The IRT produces the following datastreams:

irt200ms – 5-Hz instantaneous sky temperature
irt – 1-min-averaged sky temperature
gndirt – 1-min-averaged surface temperature
irt10m – 1-min-averaged surface temperature from 10 m
irt25m – 1-min-averaged upwelling irradiance and surface temperature from 25 m
irtsst – 1-sec instantaneous sky and surface temperature for sea-surface temperature retrieval

Table 2. Primary variables.

Variable Name	Quantity Measured	Unit
sky_ir_temp	Sky infrared temperature	K
sfc_ir_temp	Surface infrared temperature	K

Table 3. Secondary Variables

Variable Name	Quantity Measured	Unit
time	Time offset from midnight	seconds
ref_ir_temp	Internal reference infrared temperature	K

Table 4. Diagnostic variables.

Variable Name	Quantity Measured	Unit
time_offset	Time offset from base time	seconds
logger_temp	Logger temperature	C
logger_volt	Logger voltage	V
logger_libat	Internal logger battery voltage	V

Table 5. Dimension variables.

Variable Name	Quantity Measured	Unit
base_time	base time in Epoch	seconds
lat	north latitude	degrees
lon	east longitude	degrees
alt	altitude	meters above mean sea level

Table 6. Global attributes.

Attribute Name	Quantity Measured	Unit
model_number	IRT model number	none
serial_number	IRT serial number	none
calibration_factor	IRT calibration factor	none
emissivity	IRT emissivity	none
response_time	IRT response time	seconds

6.2 Data Ordering

The IRT data are available from the ARM Archive.

6.3 Data Plots

Daily quick look plots are available for the ARM data files.

6.4 Data Quality

The ARM Data Quality Office produces plots, tables, and other tools that contain techniques used by data quality analysts, instrument mentors, and site scientists to monitor and diagnose data quality.

On a weekly basis, the instrument mentor inspects plots of the data from the downwelling and upwelling IRTs at the ARM sites. Time series and scatter plots are produced and inspected to compare sky temperature measured by the IRT and atmospheric emitted radiance interferometer (AERI) and the surface temperature measured by the IRT and precision infrared radiometer (PIR). Data Quality Problem Reports and Data Quality Reports are submitted when needed.

Most datastream fields contain a corresponding, sample-by-sample, automated quality check field in the b1 level datastreams. These flags are named **qc_<fieldname>**. For example, the **sky_ir_temp** field also has a companion **qc_ sky_ir_temp** field. Possible values for each sample of the **qc_<fieldname>** are shown in the table below.

Table 7. Data quality flags.

Value	Definition
0	All QC checks passed
1	Sample contained 'missing data' value
2	Sample was less than prescribed minimum value
3	Sample failed both 'missing data' and minimum value checks
4	Sample greater than prescribed maximum value
5	Sample failed both minimum and maximum value checks (highly unlikely)
7	Sample failed minimum, maximum, and missing value checks (highly unlikely)
8	Sample failed delta check (change between this sample and previous sample exceeds a prescribed value)
9	Sample failed delta and missing data checks
10	Sample failed minimum and delta checks
11	Sample failed minimum, delta, and missing value checks
12	Sample failed maximum and delta checks
14	Sample failed minimum, maximum, and delta checks
15	Sample failed minimum, maximum, delta, and missing value checks

The minimum and maximum thresholds are currently defined as follows for datastreams **irt200ms**, **irt**, and **irtsst**:

Table 8. Data quality thresholds for downwelling IRT.

Field Name	Units	Min	Max	Delta
sky_ir_temp	K	173	303	50
sky_ir_temp_max	K	173	303	50
sky_ir_temp_min	K	173	303	50
sky_ir_temp_std	K	0	20	--
ref_ir_temp	K	253	333	10

The minimum and maximum thresholds are currently defined as follows for datastreams **gndirt**, **irt10m**, **irt25m**, and **irtsst**:

Table 9. Data quality thresholds for upwelling IRT.

Field Name	Units	Min	Max	Delta
sfc_ir_temp	K	223	323	50
sfc_ir_temp_max	K	223	323	50
sfc_ir_temp_min	K	223	323	50
sfc_ir_temp_std	K	0	20	--
ref_ir_temp	K	253	333	10

In addition to the above data quality checks, the **qc_time** field is also supplied. The purpose of the qc_time field is to help detect duplicate samples, missing samples, or other sample time problems. The qc_time field contains a value for each sample time. Refer to the table below for details.

Table 10. Time quality flags.

Value	Description
0	Dt is within specified range
1	Dt is 0, duplicate sample
2	Dt is less than specified lower limit
4	Dt is greater than specified upper limit

Finally, the table below specifies the **qc_time limits** used for each of the irt datastreams.

Table 11. Limits for time.

Datastream	Lower Limit (s)	Upper Limit (s)
irt200ms	0.2	0.2
irt	60	60
gndirt	60	60
irt10m	60	60
irt25m	60	60
irtsst	1	1

6.5 Calibration

The calibration and testing of Heitronics Radiation Pyrometers are done according to the *Standard Test Methods for Radiation Thermometers (Single Waveband Type) E1256-88* of the American Society for Testing and Materials (ASTM).

6.5.1 Factory Calibration Procedures

By means of a blackbody calibration source, the display of the radiation pyrometer can be checked and recalibrated, if required. It is advisable to carry out the test under high temperature (80°-100°C). For this purpose, the radiation pyrometer is placed in front of a blackbody calibration source so that the IRT is focused on the radiator. The temperature of the blackbody radiator must be measured by means of a calibrated probe. On the indicator at the back of the device, press the left key for the menu, use the down key to choose "Calibration", press enter key to select, press left key to change "Cal.-Factor", enter the code, and press enter key to store. The calibration factor and measured temperature can be read from the display. Using the up and down keys, the factor can be changed so the temperature matches the blackbody temperature. By pressing the enter key, the new calibration factor is stored and the device will automatically be adjusted to this temperature.

6.5.2 Mentor Calibration Procedures

The ASTM method uses a blackbody radiator heated to 350°C (623 K). This is 350-400 degrees above the range of sky temperatures to be measured. For this reason, the mentor recommends calibrating the upward-looking instruments against a cryogenically cooled spectrometer such as the AERI spectrometer. This is accomplished as follows:

Collocate the IRT with the AERI to observe the same sky conditions. AERI provides a spectrally resolved measurement over the range of the IR thermometer's detector response. For each AERI spectrum, compute the narrowband radiance observed by the IRT:

$$L_{IRT} = \int L(l,T)S(l)dl$$

where l is the wavelength or wavenumber, L(l,T) is the AERI spectral radiance, and S(l) is the IRT spectral response function. Then iteratively solve the following expression for the blackbody radiating temperature T_{bb} until it agrees with the narrowband radiance computed from the AERI spectrum:

$$L_{IRT} = \int B(T_{bb},l)S(l)dl$$

where $B(T_{bb},l)$ is the Planck function.

Plotting the temperature reported by the IRT, T_{obs}, against the blackbody temperature computed from the AERI spectra, T_{bb}, for a wide range of sky temperatures (i.e., clear and cloudy skies, low to high precipitable water vapor) will permit the construction of a regression: $T_{bb} = a + b\ T_{obs}$. The IRT calibration can then be adjusted (see above) to match the AERI-derived values.

Although this is not an absolute calibration, it will reference the IRT to AERI and will permit the calibration to be tuned to the range of sky temperatures actually encountered. Additionally, one could use the AERI data to determine corrections for water vapor contribution (since what we hope to measure with the IRT is cloud base temperature). This will be significant during the summer at SGP and year-round at tropical AMF sites.

The calibration history of the IRTs is given in Table 12. Note: This information was current as of January 1, 2018. Please contact the instrument mentor for the latest version.

Table 12. Calibration history.

Serial Number	Calibration Date	Calibration Factor	Comments
517	1991/09/12	2263	Initial calibration by Heimann
	1996/10/28	2263	Lens replaced and compared with AERI (PIF 960809.2)
	1996/12/10	2263	Compared with SN 1254 by NREL (PIF 961203.2)
	1997/09/10	2263	Compared with AERI (PIF 970428.1)
863	1993/09/19	2440	Initial calibration by Pyrometrics
	2007/09/06	2562	Repaired and calibrated by Wintronics
	2016/04/22	2562	Checked with BB
	2017/05/19	2562	Compared with AERI, SN 2272, and BB
864	1993/09/19	2300	Initial calibration by Pyrometrics
	1999/04/07	2300	Compared with SN 517 and AERI
	2006/04/19	2274	Repaired and calibrated by Wintronics
	2016/04/22	2274	Checked with BB
865	1993/09/19	2640	Initial calibration by Pyrometrics
	2003/11/14	2628	Repaired and calibrated by Wintronics
	2006/08/07	2622	Repaired and calibrated by Wintronics
866	1993/09/19	1649	Initial calibration by Pyrometrics
	2006/04/19	1800	Repaired and calibrated by Wintronics
	2007/09/06	1806	Repaired and calibrated by Wintronics
867	1993/09/19	1847	Initial calibration by Pyrometrics
	1998/01/10	2358	Repaired and calibrated by Wintronics
	1999/04/07	2358	Compared with SN 517 and AERI
	2006/08/07	2396	Repaired and calibrated by Wintronics
	2007/09/06	2420	Repaired and calibrated by Wintronics
	2009/02/11	2420	Repaired and calibrated by Wintronics
	2010/06/13	2424	Repaired and calibrated by Wintronics
868	1993/09/19	2221	Initial calibration by Pyrometrics
	2007/09/06	2331	Repaired and calibrated by Wintronics
1026	1995/08/16	2276	Initial calibration by Pyrometrics
	2006/08/07	2396	Repaired and calibrated by Wintronics
	2014/04/17	2340	Repaired and calibrated by Wintronics
	2016/04/22	2340	Checked with BB
	2017/05/19	2340	Compared with AERI, SN 2272, and BB
1029	1995/08/16	2114	Initial calibration by Pyrometrics
	2016/04/22	2114	Checked with BB
	2017/05/19	2114	Compared with AERI, SN 2272, and BB
1250	1996/10/01	2214	Initial calibration by Wintronics
	1997/09/10	2214	Compared with SN 517 and AERI (PIF 970428.1)
	1999/04/07	2214	Compared with SN 517 and AERI
	2009/02/11	2214	Repaired and calibrated by Wintronics
1251	1996/10/01	2106	Initial calibration by Wintronics
1252	1996/10/01	2116	Initial calibration by Wintronics

Serial Number	Calibration Date	Calibration Factor	Comments
	1999/04/07	2116	Compared with SN 517 and AERI
	2001/03/22	2138	Repaired and calibrated by Wintronics
1253	1996/10/01	1300	Initial calibration by Wintronics
	1998/01/10	4600	Repaired and calibrated by Wintronics (PIF 980918.3)
	1999/04/07	4600	Compared with SN 517 and AERI
	2009/09/24	2770	Repaired and calibrated by Wintronics
1254	1996/10/01	1307	Initial calibration by Wintronics
	1997/09/10	1307	Compared with SN 517 and AERI (PIF 970428.1)
	1997/12/19	1281	Calibrated by Wintronics
	1999/04/07	1281	Compared with SN 517 and AERI
	2008/06/17	1281	Compared with AERI
	2008/11/21	1281	Checked with BB (DQPR-1948)
	2010/04/14	1281	Compared with AERI, SN 2386, and BB
1255	1996/10/01	1255	Initial calibration by Wintronics
	1998/07/13	1207	Repaired and calibrated by Wintronics
	2002/10/17	1145	Repaired and calibrated by Wintronics
	2006/04/19	1163	Repaired and calibrated by Wintronics
1553	1998/01/10	1260	Initial calibration by Wintronics
	1999/04/07	1260	Compared with SN 517 and AERI
1628	1998/03/04	4226	Initial calibration by Wintronics
	1999/02/05	4226	Repaired and calibrated by Wintronics
	1999/04/07	4226	Compared with SN 517 and AERI
1832	2000/11/08	3912	Initial calibration by Wintronics
	2010/04/14	3912	Compared with AERI, SN 2386, and BB
	2011/02/15	3928	Repaired and calibrated by Wintronics
1845	2000/12/18		Initial calibration by Wintronics
	2003/03/21	4190	Repaired and calibrated by Wintronics
	2010/04/14	4190	Compared with AERI, SN 2386, and BB
1938	2001/09/01	5086	Initial calibration by Wintronics
	2010/01/18		Repaired and calibrated by Wintronics
	2014/03/25	5170	Repaired and calibrated by Wintronics
	2017/05/23	5170	Checked with BB
2271	2003/10/31	1.4607	Initial calibration by Wintronics
	2005/02	1.4607	Repaired and calibrated by Wintronics
	2005/08/23	1.4607	Repaired and calibrated by Wintronics
	2013/01/10	1.4834	Repaired and calibrated by Wintronics
2272	2003/10/31	1.3963	Initial calibration by Wintronics
	2005/07/10	1.3963	Compared with AERI (ECO-345)
	2008/06/06	1.3962	Repaired and calibrated by Wintronics
	2008/06/17	1.3962	Compared with AERI, SN 1254, and BB
	2013/01/31	1.4120	Repaired and calibrated by Wintronics
	2017/05/19	1.4120	Compared with AERI and BB
2273	2003/10/31	1.4951	Initial calibration by Wintronics
	2005/07/10	1.4951	Compared with AERI (ECO-345)
2274	2003/10/31	1.2873	Initial calibration by Wintronics
	2005/07/10	1.2873	Compared with AERI (ECO-345)
	2016/04/22	1.2873	Checked with BB
	2017/05/19	1.2873	Compared with AERI, SN 2272, and BB
2275	2003/10/31	1.3548	Initial calibration by Wintronics
	2005/07/10	1.3548	Compared with AERI (ECO-345)
	2010/07/15	1.3668	Repaired and calibrated by Wintronics
2276	2003/10/31	1.3184	Initial calibration by Wintronics

Serial Number	Calibration Date	Calibration Factor	Comments
	2005/07/15	1.3184	Compared with AERI (ECO-345)
2301	2004/03/17	1.7262	Initial calibration by Wintronics
	2010/04/14	1.7262	Compared with AERI, SN 2386, and BB
	2011/08/16	1.8000	Calibrated with RCF
2302	2004/03/17	2.2165	Initial calibration by Wintronics
2384	2005/06/10	1.2600	Initial calibration by Wintronics
	2005/07/10	1.2600	Compared with AERI (ECO-345)
	2006/12/13	1.2600	Repaired and calibrated by Wintronics
2385	2005/06/10	1.1817	Initial calibration by Wintronics
	2005/07/10	1.1817	Compared with AERI (ECO-345)
	2008/09/29	1.2311	Repaired and calibrated by Wintronics
	2009/11/05	1.2898	Repaired and calibrated by Wintronics
2386	2005/06/10	1.2172	Initial calibration by Wintronics
	2005/07/10	1.2172	Compared with AERI (ECO-345)
	2007/09/06	1.4100	Repaired and calibrated by Wintronics
	2008/06/19	1.4100	Compared with AERI, SN 1254, and BB
	2008/11/21	1.4100	Checked with BB (DQPR-1948)
	2010/04/14	1.4100	Compared with AERI and BB
	2011/08/17	1.4320	Calibrated with RCF
2387	2005/06/10	1.2295	Initial calibration by Wintronics
	2005/07/10	1.2295	Compared with AERI (ECO-345)
	2008/09/29	1.2457	Repaired and calibrated by Wintronics
2388	2005/06/10	1.2171	Initial calibration by Wintronics
	2005/07/15	1.2171	Compared with AERI (ECO-345)
	2005/08/05	1.2171	Compared with AERI and SN 1254 (ECO-345)
	2006/08/07	1.2171	Repaired and calibrated by Wintronics
	2015/05/11	1.2799	Repaired and calibrated by Wintronics
2389	2005/06/10	1.3719	Initial calibration by Wintronics
	2005/07/15	1.3719	Compared with AERI (ECO-345)
	2005/08/05	1.3719	Compared with AERI and SN 1254 (ECO-345)
	2013/01/10	1.4330	Repaired and calibrated by Wintronics
2390	2005/06/10	1.1817	Initial calibration by Wintronics
	2005/07/15	1.1817	Compared with AERI (ECO-345)
2391	2005/06/10	1.1464	Initial calibration by Wintronics
	2005/07/15	1.1464	Compared with AERI (ECO-345)
	2016/04/22	1.1464	Checked with BB
2392	2005/06/10	1.3178	Initial calibration by Wintronics
	2005/07/15	1.3178	Compared with AERI (ECO-345)
	2010/07/15	1.3247	Repaired and calibrated by Wintronics
	2016/04/22	1.3247	Checked with BB
2655	2008/06/06	1.0113	Initial calibration by Wintronics
	2008/06/18	1.0113	Compared with AERI, SN 1254, and BB
	2010/04/15	1.0113	Compared with AERI, SN 2386, and BB
	2016/04/22	1.0113	Checked with BB
	2017/05/18	1.0113	Compared with AERI, SN 2272, and BB
2656	2008/06/06	0.9837	Initial calibration by Wintronics
	2008/06/19	0.9837	Compared with AERI, SN 1254, and BB
	2010/04/15	0.9837	Compared with AERI, SN 2386, and BB
2657	2008/06/06	1.0646	Initial calibration by Wintronics
	2008/06/17	1.0646	Compared with AERI, SN 1254, and BB
	2010/04/15	1.0646	Compared with AERI, SN 2386, and BB
	2012/05/09	1.0770	Repaired and calibrated by Wintronics

Serial Number	Calibration Date	Calibration Factor	Comments
	2016/04/15	1.0944	Repaired and calibrated by Wintronics
	2017/05/18	1.0944	Compared with AERI, SN 2272, and BB
2658	2008/06/06	1.0097	Initial calibration by Wintronics
	2008/06/17	1.0097	Compared with AERI, SN 1254, and BB
	2010/04/15	1.0097	Compared with AERI, SN 2386, and BB
	2012/05/09	1.0000	Repaired and calibrated by Wintronics
	2014/03/25	1.0092	Repaired and calibrated by Wintronics
2659	2008/06/06	1.0135	Initial calibration by Wintronics
	2008/06/17	1.0135	Compared with AERI, SN 1254, and BB
	2010/04/15	1.0135	Compared with AERI, SN 2386, and BB
	2016/04/15	1.0135	Repaired and calibrated by Wintronics
	2017/05/18	1.0135	Compared with AERI, SN 2272, and BB
2660	2008/06/06	0.9858	Initial calibration by Wintronics
	2008/06/17	0.9858	Compared with AERI, SN 1254, and BB
	2011/08/22	0.9891	Repaired and calibrated by Wintronics
	2013/01/31	1.0018	Repaired and calibrated by Wintronics
	2016/09/06	1.0052	Repaired and calibrated by Wintronics
2661	2008/06/06	1.0777	Initial calibration by Wintronics
	2008/06/19	1.0777	Compared with AERI, SN 1254, and BB
	2010/04/15	1.0777	Compared with AERI, SN 2386, and BB
2662	2008/06/06	1.0485	Initial calibration by Wintronics
	2008/06/19	1.0485	Compared with AERI, SN 1254, and BB
	2015/07/28	1.1231	Repaired and calibrated by Wintronics
	2017/05/18	1.1231	Compared with AERI, SN 2272, and BB
2663	2008/06/06	1.0110	Initial calibration by Wintronics
	2008/06/19	1.0110	Compared with AERI, SN 1254, and BB
	2012/05/09	1.0168	Calibrated by Wintronics
	2016/04/22	1.0168	Checked with BB
	2017/05/18	1.0168	Compared with AERI, SN 2272, and BB
2753	2009/03/09	1.0033	Initial calibration by Wintronics
	2010/04/15	1.0033	Compared with AERI, SN 2386, and BB
2754	2009/03/09	0.9428	Initial calibration by Wintronics
	2010/04/15	0.9428	Compared with AERI, SN 2386, and BB
	2016/04/15	0.9743	Repaired and calibrated by Wintronics
2769	2009/05/12	0.9013	Initial calibration by Wintronics
	2015/06/23	0.9013	Checked with BB
	2017/05/23	0.9013	Checked with BB
2770	2009/05/12	0.9244	Initial calibration by Wintronics
	2015/06/23	0.9244	Checked with BB
2771	2009/05/12	0.9249	Initial calibration by Wintronics
	2015/06/23	0.9249	Checked with BB
	2017/05/23	0.9249	Checked with BB
2772	2009/05/12	0.9360	Initial calibration by Wintronics
	2015/06/23	0.9360	Checked with BB
	2015/07/14	0.9401	Repaired and calibrated by Wintronics
	2017/05/23	0.9401	Checked with BB
2773	2009/05/12	1.1752	Initial calibration by Wintronics
	2010/11/12	1.1812	Repaired and calibrated by Wintronics
	2015/06/23	1.1812	Checked with BB
	2017/05/23	1.1812	Checked with BB
2774	2009/05/12	1.2905	Initial calibration by Wintronics
	2015/06/23	1.2905	Checked with BB

Serial Number	Calibration Date	Calibration Factor	Comments
	2016/09/06	1.3025	Repaired and calibrated by Wintronics
	2017/05/23	1.3025	Checked with BB
2948			Initial calibration by Wintronics
	2010/11/22		Repaired and calibrated by Wintronics
	2015/06/23	1.3615	Checked with BB
	2015/07/14	1.3556	Calibrated by Wintronics
	2017/05/23	1.3556	Checked with BB
3145	2012/05/26	1.0593	Initial calibration by Wintronics
3146	2012/05/26	1.3538	Initial calibration by Wintronics
	2016/05/26	1.3538	Repaired and calibrated by Wintronics
	2017/06/05	1.3538	Checked with BB
3147	2012/05/26	1.4264	Initial calibration by Wintronics
3148	2012/05/26	1.4724	Initial calibration by Wintronics
	2017/06/05	1.4724	Checked with BB
3259	2013/01/24	1.3250	Initial calibration by Wintronics
	2016/04/22	1.3250	Checked with BB
	2017/05/19	1.3250	Compared with AERI, SN 2272, and BB
3337	2013/09/09	1.2413	Initial calibration by Wintronics
3338	2013/09/09	1.1044	Initial calibration by Wintronics
3339	2013/09/09	1.1575	Initial calibration by Wintronics
	2016/04/22	1.1575	Checked with BB
3350	2013/09/09	1.4641	Initial calibration by Wintronics
3351	2013/09/09	1.4056	Initial calibration by Wintronics
3352	2013/09/09	1.4714	Initial calibration by Wintronics
3353	2013/09/09	1.4933	Initial calibration by Wintronics
3354	2013/09/09	1.4565	Initial calibration by Wintronics

Table 13. Specifications.

Parameter	KT19.85 Type I (SN < 2000)	KT19.85 Type II
Spectral Sensitivity	9.6 to 11.5 μm	9.6 to 11.5 μm
Temperature Measuring Range	213 to 673 K	173 to 473 K
Temperature Resolution (emissivity = 1)	±1.10 K at 223 K; ±0.45 K at 293 K (response time = 1.0 s)	±1.85 K at 223 K; ±0.70 K at 293 K (response time = 0.1 s)
Accuracy	±0.5 K + 0.7% of temperature difference	±0.5 K + 0.7% of temperature difference
Operational Ambient Temperature	0° to 60°C	-20° to +60°C
Storage Temperature	-20° to +70°C	-20° to +70°C
Weight	1.5 kg	2.4 kg
Analog Output Resolution	12 bit	12 bit
Optical Field of View (at 3 m)	downwelling (S921 lens, f = 120 mm): 2.64° upwelling (M6 lens, f = 20 mm): 30.51°	downwelling (S921 lens, f = 120 mm): 2.64°
Operating Voltages	24 V AC (±10%) at 48 to 400 Hz or 26 V DC (±15%)	24 V AC (±10%) at 48 to 400 Hz or 26 V DC (±15%)
Current Consumption	80 mA	80 mA

6.6 Units

The temperature measurements are in Kelvins.

6.7 Range

The temperature measuring range is from 173 to 473 K.

6.8 Accuracy

The accuracy is the greater value of a) ±0.5 K + 0.7% of the temperature difference between the internal reference temperature and the object measured or b) the temperature resolution.

6.9 Repeatability

Unknown.

6.10 Sensitivity

The spectral sensitivity is from 9.6 to 11.5 µm.

6.11 Uncertainty

For a 0-1 volt output range and 100 K span, the temperature uncertainty is 0.0244 K.

7.0 Instrument System Functional Diagram

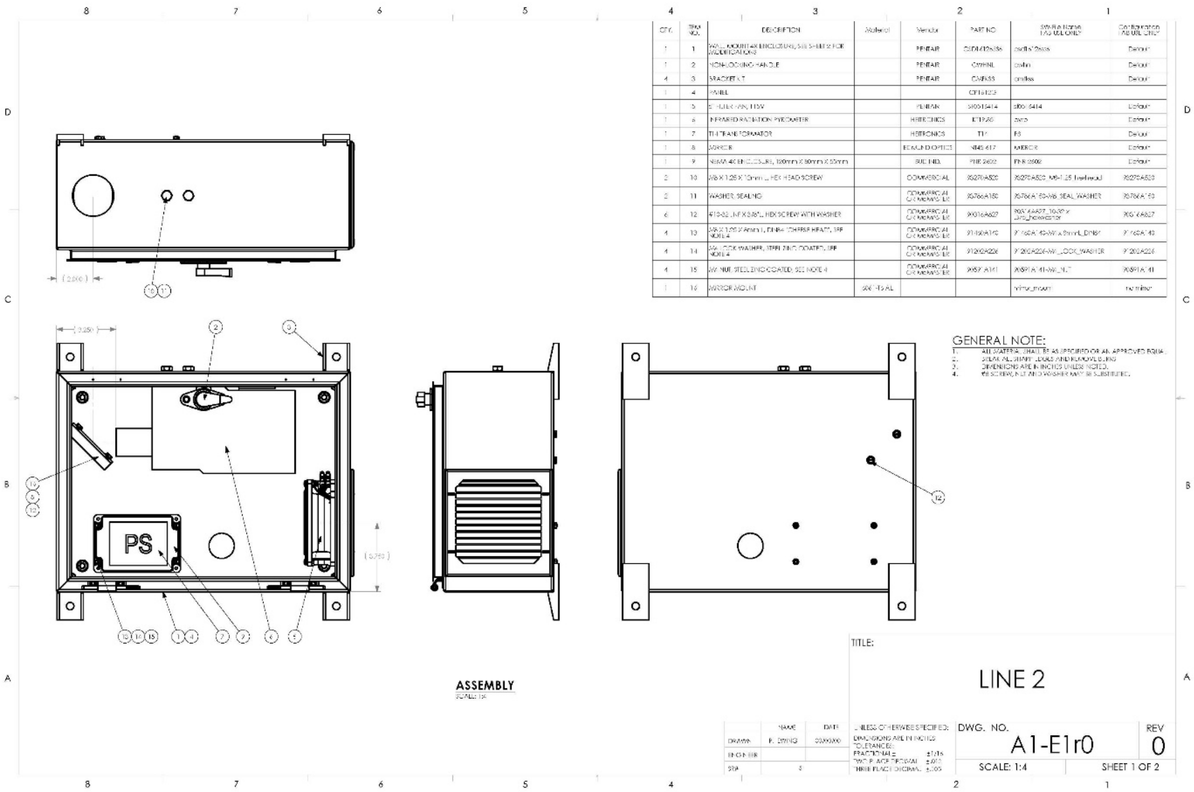

Figure 6. Downwelling IRT enclosure diagram.

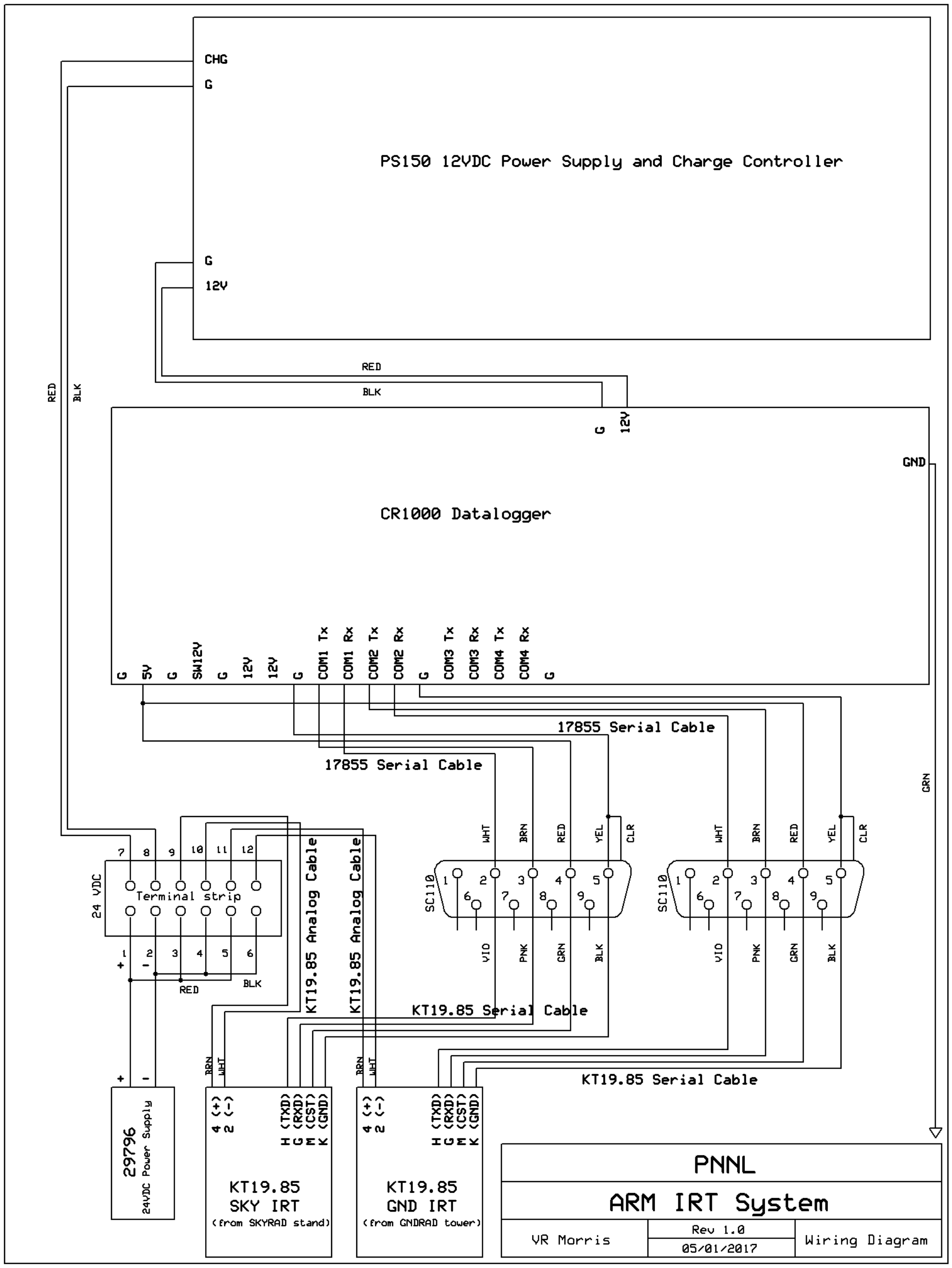

Figure 7. IRT data acquisition system wiring diagram.

8.0 Instrument/Measurement Theory

It is well known that radiation emitted by objects can be felt by the thermal sensors of our skin. “Temperature radiation” is emitted by all material objects at temperatures above the absolute zero point. Temperature radiation is primarily emitted at wavelengths in the invisible infrared region, but at high temperatures also in the visible spectrum. Instruments capable of measuring this radiation and providing an output signal calibrated in temperature units are called radiation thermometers, radiation pyrometers, or simply pyrometers. The scientific study of the determination of temperatures by the noncontact measurement of self-emitted surface radiation is called radiation pyrometry.

A radiation thermometer measures the radiance power from the target area. The self-emitted radiant power is smaller than the radiant power from a blackbody surface at the same temperature. The reflected and transmitted radiant powers are emitted by the foreground and the background, respectively. The sum of emissivity, reflectance, and transmittance is always 1. In accordance with Planck's law, the radiances are clearly related to the temperatures, provided the relative spectral response (determined by the optical system and the radiation detector) is known. The output signal of a linear detector is proportional to the measured radiance. It is thus permissible to read the measured radiance in terms of a "measured temperature" and to calibrate the indicating meter for the output signal in temperature units (i.e., in Kelvins).

9.0 Setup and Operation of Instrument

The downwelling IRT is mounted at a height of 1-2 m above the ground, inside of a ventilated enclosure (Hoffman CSD16126SS6), oriented so the zenith view of the sky is reflected into the lens by a protected gold mirror (Edmund Optics 45-617). The upwelling IRT is mounted at a height of 2-25 m above the ground, inside a small enclosure, oriented so the mounting platform is not in the field of view and to ensure that the ground and vegetation cover are representative of the local area.

The following internal configuration is presently in use:

Table 14. Configuration.

Parameter	Downwelling	Upwelling
Target emissivity (EMI)	0.987	1.000
Temperature unit (UNIT)	Kelvins	Kelvins
Temperature span (ANALOG)	173-303 K	223-323 K
Analog output (ANALOG)	0-1 volt	0-1 volt
Digital output (COM)	9.6Kb/8NP/1S/LF	9.6Kb/8NP/1S/LF
Ambient temperature (AMB)	internal reference	internal reference
Response time (RESP)	0.3 second	3.0 seconds

The radiation pyrometer is a measuring transducer, which receives the infrared radiation emitted by the measuring object and transforms it into a standardized output signal. If the emissivity is known, the temperature of the object can be determined. The ARM IRTs use a constant emissivity of 0.987 for sky, to compensate for the reflectance of the gold mirror, and 1.0 for ground. The radiation pyrometer KT19.85 operates within the spectral range of 9.6 to 11.5 µm where the transmission of the atmosphere is very high. There is very little weakening of the infrared radiation due to CO_2 or to water vapor contained in the air.

The working principle of infrared radiation pyrometers uses optical modulation of thermal radiation intercepted by an infrared detector. In general, this is accomplished by an optical chopper (mechanical blades driven by an electric motor), which periodically interrupts the incident radiation from the measured target to the detector. During each interruption the detector is exposed to an internal blackbody reference source having a defined temperature. Infrared detectors of the pyroelectric type must be operated with the "chopped radiation" method because they respond to radiation differences and not to absolute radiation intensities. The detector intercepts infrared radiation emitted by the measured target and, at the same time, radiation emitted by the detector enclosure. During the short chopping cycles, in the millisecond range, the temperature of the pyrometer's housing does not change. The bias is thus eliminated and substituted by the reference signal, which can be easily measured or controlled within the specified reference accuracy over the operational ambient temperature range. Thus, the “chopped radiation” method eliminates thermal drift and automatically provides a modulated signal with a precisely defined frequency.

Each IRT has its own characteristics because of small deviation in filters, detector sensitivity, and lenses. These individual characteristics are compensated by comparing the temperature reading of the instrument with the blackbody radiation at several temperatures and adapting the linearization. The radiance can be calculated from the measured temperature by integrating Plank's law over the spectral range.

The downwelling IRT reports the effective blackbody temperature of the sky in the portion of the infrared spectrum sensed by the instrument. When there is no cloud within the field of view of the instrument, this temperature depends almost entirely on the amount of water vapor in the atmosphere above the instrument. When there is a lot of water vapor present (e.g., during summer at the SGP site), the sky temperatures may exceed 250 K. When there is very little water vapor present (e.g., during winter at the SGP site), the sky temperatures may fall below 180 K. When a cloud enters the field of view of the IRT, an increase in the reported temperature should be observed. How much the temperature will increase depends on how high the cloud is, how thick the cloud is, and how much water vapor is in the atmosphere between the instrument and the cloud. Low, heavy clouds will generally produce the largest increase in temperature, especially in winter when the clear-sky temperature is low; high, wispy clouds will produce a lesser increase. During the summer when the clear sky temperature is relatively large, high clouds may produce only a slight increase.

The narrowband radiating temperature reported by the upwelling IRT will be very close to the physical temperature of the ground/vegetation in its field of view. To the extent that the physical temperature varies in the course of a diurnal cycle, so too will the IR temperature reported by the instrument.

10.0 Software

The IRT measurements are currently acquired with a Campbell Scientific CR1000 Measurement & Control Datalogger, which executes program IRTSKYGND.CR1, and collected automatically with LoggerNet Datalogger Support Software.

11.0 Maintenance

Fine dust is removed from the lens by means of compressed air or a fine lens brush. If the lens is heavily soiled or has greasy deposits, it is cleaned with paper tissues, cotton swabs, and lens-cleaning solution (alcohol or water can also be used).

See Corrective Maintenance Reporting.

12.0 User Notes and Known Problems

Positive “spikes” are produced in the sky temperature measurements during daily preventative maintenance due to water and/or alcohol used to clean the gold mirror.

Positive “spikes” can also be produced in the sky temperature measurements near the time of local solar noon. These anomalies are due to the sun in the field of view of the IRT and occur at tropical sites near the time of the equinoxes.

An apparent warm bias of the surface temperature is exhibited by the upwelling IRT, compared to the PIR, at sites where the instrument is mounted on a tower 10 m above the ground, especially in summer. The PIR responds strongly to air temperature while the IRT responds strongly to ground temperature. The bias goes away or becomes very small at night because the ground temperature approaches equilibrium with the air. The bias is also small when it is raining or very overcast (as indicated by low solar values). The bias becomes large during the day when the sun is out. For example, on sunny days at TWP/CF3, the ground temperature as measured by the IRT was about 51°C while the PIR measured a temperature about 10°C cooler. The actual air temperature at Darwin in the afternoon is about 32°C. So it appears that the PIR was reporting a temperature approximately mid-way between the ground temperature and the air temperature. This effect was also experienced at Manus and Nauru but it was more pronounced at Darwin because the radiometers were further from the ground.

An apparent negative bias of the sky temperature is exhibited by the downwelling IRT, compared to the microwave radiometer profiler (MWRP) and microwave radiometer, 3 channel (MWR3C), because the characteristics of the IRTs are different. The downwelling IRT uses a lens with a field of view of 2.6° while the MWRP and MWR3C use a lens with a field of view of 30°, which can cause a bias of ~10°C.

A positive bias of the sky temperature is exhibited by the downwelling IRT, compared to the AERI, during clear-sky conditions when the sky temperature is less than ~180K. The effect depends on the characteristics of the individual IRT and the internal reference temperature of the IRT. The greatest difference compared to AERI will occur when the sky is very clear, dry, and cold and the ambient temperature is relatively hot, maximizing the difference in temperature between the sky and instrument, and the calibration of the IRT at the lower limit of 223K was not performed accurately. This bias is especially apparent at high-latitude sites (e.g., NSA, OLI, and AWR).

The internal reference temperature of the downwelling and upwelling IRTs at AMF3 (OLI/M1) in winter is frequently less than the minimum measurable value of -20°C.

The signals of the downwelling and upwelling IRTs were moved from the SKYRAD and GNDRAD datalogger to a dedicated data acquisition system (ENG0000990) at AMF2 on 5/25/2017 and at ENA/C1 on 6/5/2017.

The downwelling and upwelling IRTs were configured to provide measurements for retrieving sea-surface temperature for AMF2 deployments aboard a ship at MAG/M1 in 2012 and MAR/M1 in 2017.

The downwelling and upwelling IRTs were upgraded from Heitronics KT19.85 Type I to the Type II model (BCR-1958) at SGP/C1 10m on 9/17/2013 and 25m on 9/19/2013, TWP/C3 on 10/28/2013, TWP/C1 on 2/1/2014, and at NSA/C1 on 2/26/2014.

The mounting configuration of the SKYRAD IRT was moved from a Radiometrics MP3965 Case and MP3964 Saddle and Edmund 32-089 elliptical gold mirror to a Hoffman CSD16126SS6 Filter-fan Enclosure and Edmund 45-617 round gold mirror (ECO-616, BCR-1884) at AMF1 (PVC/M1) on 10/18/2012, TWP/C3 on 4/4/2013, TWP/C1 on 11/6/2013, and at NSA/C1 on 2/26/2014.

The downwelling IRT at SGP/CF1 was replaced with an extended-range IRT (ECO-345, BCR-1131) at SGP/E13 on 1/4/2006.

The downwelling IRT at SGP/CF1 was removed from the Microwave Radiometer (MWR) and associated datastreams (ECO-267, BCR-581) on 11/5/2002.

The TWP SKYRAD IRT rain detector/shutter/enclosure assemblies were replaced with a gold mirror/solar cover assembly (ECO-170) at TWP/C1 on 10/19/2001 and at TWP/C2 on 10/29/2001.

The upwelling 10m and 25m IRTs at SGP/CF1 were removed from the MFR dataloggers and associated datastreams (ECO-149, BCR-306) on 9/26/2001 and 9/27/2001, respectively.

13.0 Frequently Asked Questions

How is the IRT compared with AERI?

See Section 6.5, Calibration.

What is the difference between the skin temperature, the effective ground radiating temperature measured with the upwelling IRTs, and the radiative temperature determined with the upwelling PIRs?

The skin temperature is the actual temperature of the ground surface, as measured with a thermometry device. The effective ground radiating temperature measured with IRTs is the temperature equivalent, using the Stefan-Boltzmann law, of the infrared radiant energy from the ground, assuming it acts as a blackbody with an emissivity of 1. The radiative temperature measured with the PIRs is longwave irradiance emitted and reflected by the ground surface.

What is the spectral response function of the IRT?

Table 15. Spectral response function.

Wavelength µm	Spectral Response %
9.40	0.000000
9.46	4.580252
9.58	12.273370
9.70	29.645053
9.82	48.180234
9.94	56.015325
10.06	59.592843
10.18	59.582579
10.30	61.141282
10.42	63.120466
10.54	64.794606

Wavelength µm	Spectral Response %
10.66	66.224009
10.78	67.286336
10.90	66.575086
11.02	65.575695
11.14	65.601176
11.26	66.965032
11.38	67.696559
11.50	42.629668
11.62	14.432280
11.74	4.815956
11.80	0.000000

In what datastream are the surface temperature measurements at the SGP Central Facility?

The "sfc_ir_temp" data are found in datastreams sgpmfr10mC1.a1 and sgpmfr25mC1.a1 from 5/19/1997 to 3/31/2001, sgpmfrirt10mC1.a1 and sgpmfrirt25mC1.a1 from 4/1/2001 to 9/26/2001, sgpirt10mC1.a1 and sgpirt25mC1.a1 from 9/26/2001 to 12/18/2003, and sgpirt10mC1.b1 and sgpirt25mC1.b1 from 12/18/2003 to present.

How is the IRT signal sampled simultaneously to provide data for both irt200ms and skyrad60s datastreams?

The IRT has both an analog and a serial port. At all sites except SGP, the downwelling analog signal of the IRT is connected to the SKYRAD datalogger and the serial signal is connected to a computer running a serial communication program.

14.0 Citable references

Morris V, L Rihimaki, and M Ritsche. 2013. Measuring Sea-surface Temperature for the MAGIC Field Campaign. Presented at 4th Atmospheric System Research (ASR) Science Team Meeting. Potomac, Maryland.

Morris V, C Long, and D Nelson. 2006. Deployment of an infrared thermometer network at the Atmospheric Radiation Measurement Program Southern Great Plains Climate Research Facility. In *Proceedings of the Sixteenth Atmospheric Radiation (ARM) Science Team Meeting*, Richland, Washington: U.S. Department of Energy.

15.0 Historical Changes

See Section 13, User Notes and Known Problems.

Appendix A

Calibration Data Sheet (Example)

Wintronics, Inc.
50 Division Avenue
Millington, NJ 07946
Phone: (908) 647-0144 Fax: (908) 647-8379

Certificate of Calibration

ANSI/NCSL Z540-1-1994

Certificate No.: J0097535

Manufacturer:	**Heitronics**	Description:	**Infrared Thermometer**
Model No:	**KT19.85-II**	Serial No:	**3147**

Customer:	Battelle Pacific Northwest Div 790 6th St Richland, WA 99354	Customer PO: Customer Asset No:	177863
Temperature (C):	23	Technician:	PLW
Humidity (%):	46	Date Cal:	5/26/2012
Procedure:	W60985, Rev 1	Date Due:	5/26/2013

The manufacturer's specifications of the above instrument have been confirmed by comparison to standards which are regularly calibrated using accepted values of natural physical constants, ratio type self-calibrating techniques, comparison to standards which are traceable to NIST, or compared to consensus standards. Wintronics' calibration procedures comply with ANSI/NCSL Z540-1 & MIL-STD-45662A. Wintronics' Quality program is registered to ISO9001:2008.

As received condition: In Tolerance
As shipped condition: In Tolerance
Type of Calibration: Normal

Calibration Standards

Manufacturer	Model	Description	Asset #	Calibration Date	Date Due	Cert. No.
Heitronics	TRT3.82	Transfer Infrared Pyrometer	W185	11/4/2011	11/4/2012	J0093158

Peter Winter
President

Certified By

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CERT–02/2012-pg 1 of 1
DOC#: W20029

Wintronics, Inc. Calibration Report

Wintronics, Inc., P.O. Box 337, Millington, NJ 07946 (908) 647-0144

Job: J0097535

Company: Battelle Pacific Northwest Div | Mfg: Heitronics | Model: KT19.85(-II) | Date: 05/26/12

S/N: 3147 | Cust. Asset #: | Tech: PLW

Function or Range	Nominal Value or Cal Range	As Received	Outgoing	Tolerance	TUR
Degrees C	0.0°C	+0.2	No Change	±0.71°C	
	10.0°C	10.1	No Change	±0.64°C	
	20.0°C	20.2	No Change	±0.57°C	
	30.0°C	30.1	No Change	±0.50°C	
	40.0°C	40.3	No Change	±0.57°C	
	50.0°C	50.3	No Change	±0.64°C	
	60.0°C	60.3	No Change	±0.71°C	
	70.0°C	70.5	No Change	±0.78°C	
	80.0°C	80.5	No Change	±0.85°C	
	90.0°C	90.6	No Change	±0.92°C	
	100.0°C	100.5	No Change	±0.99°C	
	Cal Factor	1.42643	No Change	No Tolerance	

Additional Comments: Any Test Uncertainty Ratio (TUR) that is less than 4:1 will appear under the "TUR" heading. If the TUR meets or exceeds 4:1, the field is left blank.
Standards listed used to monitor temperature of Mester ME20.03 Blackbody Calibration Source.

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