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Surface Energy Balance System (SEBS) Instrument Handbook

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Acronyms and Abbreviations

ARM	Atmospheric Radiation Measurement
DQ	Data Quality
DQ Explorer	Data Quality Explorer
DQR	Data Quality Report
ECOR	Eddy Correlation Flux Measurement System
EF	extended facility
EFSCO	EF Surface Conditions Observations
ENA	Eastern North Atlantic
IMMS	Instrument Mentor Monthly Summaries
IR	infrared
MET	Surface Meteorological Instrumentation
netCDF	Network Common Data Form
NSA	North Slope of Alaska
PRTD	platinum resistance temperature detector
QC	quality control
REBS	Radiation and Energy Balance Systems, Inc.
RMS	root mean square
SEBS	Surface Energy Balance System
SGP	Southern Great Plains
TWP	Tropical Western Pacific
VAP	value-added product
WMO	World Meteorological Organization
WPL	Webb, Pearman, Leuning

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1.0 General Overview

A surface energy balance system (SEBS) has been installed collocated with each deployed eddy correlation flux measurement system (ECOR) at the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) user facility Southern Great Plains (SGP) observatory, North Slope of Alaska (NSA) observatory, first ARM Mobile Facility (AMF1), second ARM Mobile Facility (AMF2), and third ARM Mobile Facility (AMF3) at Oliktok Point (OLI). A SEBS was also deployed at the Tropical Western Pacific (TWP) site, before it was decommissioned. Data from these sites, including the retired TWP, are available in the ARM Data Center. The SEBS consists of upwelling and downwelling solar and infrared radiometers within one net radiometer, a wetness sensor, and soil measurements. The SEBS measurements allow the comparison of ECOR sensible and latent heat fluxes with the energy balance determined from the SEBS and provide information on wetting of the sensors for data quality purposes.

2.0 Contacts

2.1 Mentor

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2.2 Instrument Developer

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3.0 Deployment Locations and History

Table 1. SEBS status.

Facility	Location	Date Installed	Status
SGP/EF14	Lamont, OK	10/18/2010	Operational
SGP/EF21	Okmulgee, OK	10/20/2010	Operational
SGP/EF31	Anthony, KS	11/03/2011	Operational
SGP/EF33	Newkirk, OK	11/03/2011	Operational
SGP/EF37	Waukomis, OK	11/04/2011	Operational
SGP/EF38	Omega, OK	11/02/2011	Operational
SGP/EF39	Morrison, OK	09/29/2015	Operational
SGP/EF41	Peckham, OK	04/26/2016	Operational
ENA	Azores, Portugal	07/23/2014	Operational
AMF1	Various	01/02/2011	Operational
AMF2	Various	11/01/2010	Operational
AMF3	Oliktok, AK	06/25/2014	Operational
TWP/E30	East Arm	08/11/2010	Removed 01/10/2015
TWP/E31	Beatrice Hill	08/13/2010	Removed 01/03/2015
TWP/E32	Berrimah	08/02/2010	Removed 01/10/2015
NSA/E10	Barrow	09/13/2011	Operational
NSA/E11	Point Barrow	06/03/2012	Operational

4.0 Near-Real-Time Data Plots

To view near-real-time plots of SEBS data, visit the NCVweb page at http://dq.arm.gov/ncvweb/ncvweb.cgi or DQ HandS page at http://plot.dmf.arm.gov/plotbrowser/.

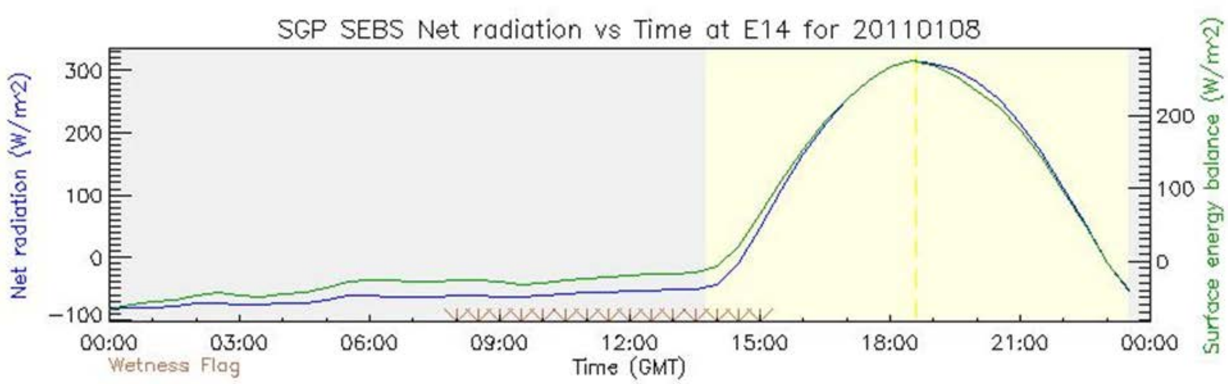

Figure 1. Sample plot showing net radiation versus time.

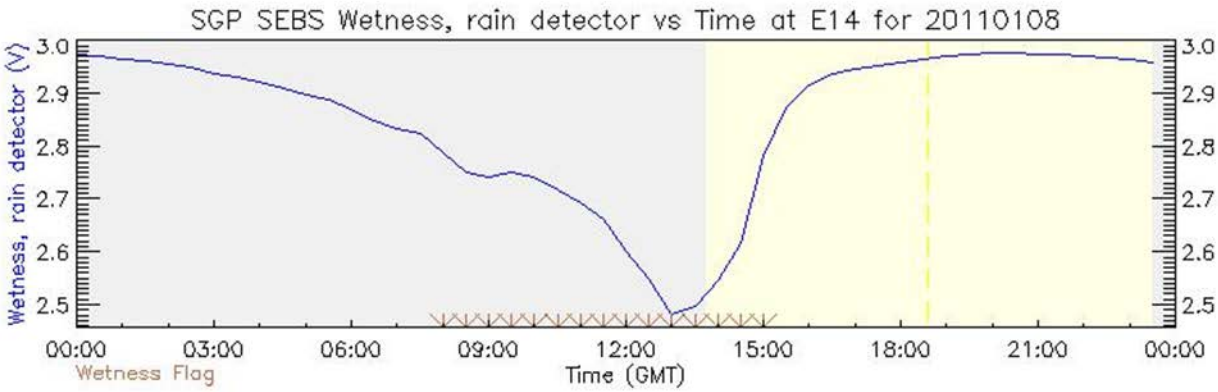

Figure 2. Sample plot showing wetness measured by the SEBS.

5.0 Data Descriptions and Examples

5.1 Data File Contents

5.1.1 Primary Variables and Expected Uncertainty

30 minutes:
surface_energy_balance: 5% uncertainty
surface_soil_heat_flux_avg: 10% uncertainty
net radiation: 5% uncertainty
wetness: 5% uncertainty

Definition of Uncertainty

We define uncertainty as the range of probable maximum deviation of a measured value from the true value within a 95% confidence interval. Given a bias (mean) error B and uncorrelated random errors characterized by a variance σ^2, the root-mean-square error (RMSE) is defined as the vector sum of these,

$$RMSE = \left(B^2 + \sigma^2\right)^{1/2}.$$

(B may be generalized to be the sum of the various contributors to the bias and σ^2 the sum of the variances of the contributors to the random errors). To determine the 95% confidence interval we use the Student's *t* distribution: $t_{n;0.025} \approx 2$, assuming the RMSE was computed for a reasonably large ensemble. Then the *uncertainty* is calculated as twice the RMSE.

5.1.2 Secondary/Underlying Variables

30 minutes:
time_offset
time
down_short_hemisp

up_short_hemisp
down_long
up_long
surface_soil_heat_flux_1
surface_soil_heat_flux_2
surface_soil_heat_flux_3
soil_moisture_1
soil_moisture_2
soil_moisture_3
soil_temp_1
soil_temp_2
soil_temp_3
soil_heat_flow_1
soil_heat_flow_2
soil_heat_flow_3
corr_soil_heat_flow_1
corr_soil_heat_flow_2
corr_soil_heat_flow_3
soil_heat_capacity_1
soil_heat_capacity_2
soil_heat_capacity_3
energy_storage_change_1
energy_storage_change_2
energy_storage_change_3
albedo
temp_net_radiometer
DOY
gmthour

5.1.3 Diagnostic Variables

battery_voltage

5.1.4 Data Quality Flags

The b1 data file contains basic data quality flags for most important variables; the flags indicate the variable status (bit values), as follows:

- 0x0 = value is within the specified range
- 0x1 = value is equal to “missing_value”
- 0x2 = value is less than “valid_min”
- 0x4 = value is greater than “valid_max”
- 0x8 = value failed the “valid_delta” check.

5.1.5 Dimension Variables

The global attributes section of the netCDF data file contains geographic coordinates (location) of the SEBS system and the altitude of the ground where the instrument is deployed; the "sensor location" parameter refers to the height of the instrument above the ground. The time variables denote the end of the 30-minute measuring period.

The sign convention for radiometer, net radiation, change of energy storage, and soil heat flux measurements is: positive towards the soil surface and negative away from the surface.

The net radiometer is pointed due south.

5.2 Annotated Examples

Not available at this time.

5.3 User Notes and Known Problems

The upwelling and downwelling solar radiation measurements often exhibit small negative values at night; these values are not physically real.

The wetness values go below the lower limit when icing occurs, and spikes above the upper limit after the ice melts. The condition most frequently occurs at NSA and OLI, but can occur at other locations where icing, snow, and frost occur (including SGP).

5.4 Frequently Asked Questions

Where do I get more information about SEBS systems?

Contact the instrument mentor at rcsullivan@anl.gov.

6.0 Data Quality

6.1 Data Quality Health and Status

The following links go to current data quality health and status results.

- DQ Explorer (http://dq.arm.gov/dq-explorer/cgi-bin/main)
- NCVweb for interactive data plotting (https://plot.dmf.arm.gov/ncvweb/ncvweb.cgi)

The tables and graphs at these sites are used by ARM's data quality analysts, instrument mentors, and site scientists to monitor and diagnose data quality.

6.2 Data Reviews by Instrument Mentor

- Visual QC frequency: Daily to weekly
- QC delay: Typically 1–3 days
- QC type: Instrument mentor routinely views graphic displays that include plots (day courses) of all calculated quantities and comparison plots (time series or scatter plots) of relevant parameters with data from collocated ECOR, SEBS, EBBR (SGP CF and EF39 only), and surface meteorological instrumentation (MET) (Cook et al., 2006).

Monthly reviews of the SEBS data were prepared by the mentor and submitted to the Instrument Mentor Monthly Summary (IMMS) report database until late 2014; these reports are available at "Related Documents" on the SEBS web page.

Data Quality Reports (DQRs) are not written for missing data or for situations when QC flags clearly show that the data are incorrect (this is true for most of the conditions listed below). DQRs are written for periods when data are incorrect, when the situation is not represented by QC flags in the data, and it is not obvious that the data should have been flagged as incorrect.

6.3 Data Assessments by Site Scientist/Data Quality Office

The following guidance has been provided by the SEBS mentor for use by the Data Quality Office in preparing their weekly assessment report for the SEBS systems.

SEBS Data Quality Guidance
David R. Cook
1/10/2011

Introduction: The best way to tell someone what to look for in assessing the SEBS data is to describe conditions that reflect correct and incorrect data. For the most part, the QC checks provide adequate guidance. However, there are conditions for which the QC flags may not provide the needed guidance to be able to interpret the correctness of the data. Therefore, please use the information below as further guidance.

Primary Measurements: surface_energy_balance, surface_soil_heat_flux_avg, and net radiation are calculated quantities, whereas wetness is a direct measurement. The QC limits set in the ingest are appropriate for the measurements (primary and otherwise), although there are times when legitimate values fall outside the QC limits (particularly for upwelling and downwelling solar radiation).

Nuisance QC Flags: The upwelling and downwelling minimum solar radiation flags are frequently tripped at night, exhibiting small negative values that are not physically real; these are instrument offsets.

Comparison of Data at Adjacent SEBS Sites: Only some measurements can be favorably compared with those at adjacent sites, keeping in mind that climate conditions from one side of the ARM site to another can differ sharply. Particular caution must be used in making comparisons between two adjacent sites when they see different vegetation surfaces (Cook et al. 2006). The upwelling radiometer and surface soil heat flux measurements from two sites may not be similar, unless the ground is snow-covered.

Downwelling radiation and wetness measurements may be comparable, remembering that there are likely to be climatologically driven differences. No other measurements can be reliably compared. Comparisons cannot be reliably made of the measurements of upwelling radiometer and surface soil heat flux measurements at SGP site E21 (forest) versus other SEBS locations in SGP, because the surface vegetation types are so different; such comparisons are likely to show significant differences.

Comparison of Data with the EBBR: The only collocated EBBR and SEBS are at E13/E14 (SGP Central Facility). Caution must be used in the comparison of the two systems because they see different vegetation surfaces (Cook et al. 2006). The net radiation and surface soil heat flux measurements from the two will probably not be similar, unless the ground is snow-covered.

Comparison of Data with MET Instrumentation: MET systems are collocated with ECOR/SEBS systems at most of the ECOR sites (exceptions are SGP E10 and E16). However, there are no measurements of the two systems that can be directly compared. SEBS net radiometer temperature (the temperature of the body of the net radiometer) is normally expected to be higher than MET temperature; they can be expected to be considerably different, especially under warm weather conditions.

Comparison of Data with the ECOR: There are no measurements of the two systems that can be directly compared. SEBS net radiometer temperature (the temperature of the body of the net radiometer) is normally expected to be higher than ECOR sonic temperature, but may be lower than the LI-7500 CO_2/H_2O analyzer temperature; they can be expected to be considerably different under warm weather conditions, especially.

Common Conditions Reflecting Incorrect Data: Upwelling and downwelling solar radiation measurements normally exhibit negative offsets, which do not correspond with physical reality. Measurements exceeding maximum QC values or less than minimum QC values can generally be interpreted as incorrect. Measurements that do not change at all over several hours (particularly if flat-lined) may not be correct. The following sources of information can be helpful in determining the value of the SEBS data.

See the QC flags in the SEBS data.

IMMS Reports at http://www.db.arm.gov/IMMS/.

Conditions that commonly cause the SEBS downwelling radiation measurements to be incorrect include:

Periods of precipitation, fog, and dew (frost). This is caused by water lying on the upper domes of the net radiometer, thereby obstructing the passage of shortwave and longwave radiation (very light precipitation may have little or no effect). I do not write DQRs or indicate time periods in the monthly report for this wetting condition. The data user should look at the SEBS wetness measurement, the collocated or nearby MET rain gauges, or the DQ Explorer ECOR plots to determine times of precipitation and dew/frost. You can assume that offscale or spiked readings in the nighttime hours before dawn are normally caused by dew or frost on the upper net radiometer domes.

Large spikes (positive and negative) in surface_energy_balance and surface_soil_heat_flux_avg can occur when precipitation is heavy. The temperature of the water flowing into the soil from the soil surface (particularly during cold front passages), plus the effects of water/ice/snow on the net radiometer domes can cause such spikes.

6.4 Value-Added Products and Quality Measurement Experiments

SEBS data are included in the ECOR VAP and the Methane VAP. The VAPs perform corrections of ECOR fluxes for WPL buoyancy effects (Webb et al. 1980), sensor separation and frequency attenuation effects, outlier removal using the SEBS wetness measurement, and integrate SEBS net radiation and surface soil measurements. The Methane VAP also includes methane flux measurements made by the ECOR.

7.0 Instrument Details

7.1 Detailed Description

7.1.1 List of Components

Net Radiometer: CNR4/CNF4 by Kipp & Zonen
(http://www.kippzonen.com/?product/85182/CNR+4.aspx)
Spectral range: 300 to 2800 (shortwave) nm
Spectral range: 4500 to 42000 (longwave) nm
Sensitivity: 5 to 20 μV/W/m²
Temperature dependence of sensitivity (-10 ºC to +40 ºC): < 4%
Response time: < 18 s
Non-linearity: < 1 %
Operating temperature: -40 to 80 °C
International standards (WMO): Good Quality WMO
Ventilation power: 10 W

Wetness: DRD11A Rain Detector by Vaisala, Inc.
(http://www.vaisala.com/en/products/rainandprecipitationsensors/Pages/DRD11A.aspx)
Range: 1 to 3 V DC (3 V dry, 1 V wet)

Soil Heat Flow: HFT-3 by Radiation and Energy Balance Systems, Inc.
Range: +/- 10 mV

Soil Moisture: SMP1 by Radiation and Energy Balance Systems, Inc.
capacitive sensor measuring resistance ratio

Soil Temperature: STP-1 by Radiation and Energy Balance Systems, Inc.
100-ohm platinum resistance temperature detector (PRTD)

Data Logger: CR1000 by Campbell Scientific, Inc.

Multiplexers (2): AM16/32B by Campbell Scientific, Inc.

7.1.2 System Configuration and Measurement Methods

In a typical arrangement, the ECOR/SEBS system is placed on the north side of a crop field; the net radiometer is attached to the end of the ECOR boom, beneath the mount that holds the sonic and CO_2/H_2O sensor heads, at approximately 3 m above ground level (15 m height at SGP site EF21 forest). The wetness sensor is mounted on the top of the boom, midway between the two ends of the boom. The soil sensors are buried in the soil under the sonic and CO_2/H_2O sensor heads. The data logging equipment is installed in an enclosure attached to the ECOR tower.

Thirty-minute average measurements are stored within the CR1000 data logger and retrieved by the ECOR computer. The SEBS timestamp is the end of the half hour. The CR1000 data files are transferred to the site data system for ingest (conversion into the netCDF format and incorporation of QC flags) and shipment to the ARM Data Center.

7.1.3 Specifications

See instrument specifications in Section 7.1.1.

7.2 Theory of Operation

The surface energy balance is determined from the net radiometer and soil sensor measurements. Upwelling and downwelling solar and infrared radiation measurements are combined to determine net radiation. The net radiometer measurements are adjusted to compensate for the temperature of the net radiometer body. Soil measurements are performed by three sets of soil heat flow (5 cm depth), soil temperature (0–5 cm average), and soil moisture (centered at 2.5 cm) probes. Soil heat flow is adjusted for the effect of soil moisture above the soil heat flow plate. The storage of energy in the soil above the soil heat flow plate is determined from the change in soil temperature with time.

Measurements from the three sets of soil probes are combined to give an average soil surface heat flux. Under vegetation canopies (particularly tall vegetation), the soil surface heat flux probably underestimates the heat flux from the top of the canopy. Soil surface heat flux and net radiation are combined to produce an estimate of the surface energy balance.

7.3 Calibration

7.3.1 Theory

All sensors are factory calibrated. Periodic in situ checks of the net radiometer calibrations are possible, but are not normally needed for years.

7.3.2 Procedures

All sensors would be returned to the vendor for factory calibration, if needed.

7.3.3 History

Not applicable.

7.4 Operation and Maintenance

7.4.1 User Manual

No single comprehensive user manual for the SEBS system is available for general use; rather, vendor-supplied documentation on sensors and a collection of procedures prepared by the mentor are provided for internal use by Site Operations.

7.4.2 Routine and Corrective Maintenance Documentation

7.4.3 Software Documentation

SEBS preventive maintenance procedures and reports are stored in the Operations Status System (OSS) and are available to instrument mentors. Please contact the instrument mentor for more information.

7.4.4 Additional Documentation

Not applicable.

8.0 Glossary

See the ARM Glossary at http://www.arm.gov/about/glossary.

9.0 Citable References

Cook, DR, ML Fischer, and DJ Holdridge. 2006. "Comparison of ECOR, EBBR, and CO2FLX System Fluxes." *Sixteenth ARM Science Team Meeting*, Albuquerque, New Mexico.

Kyrouac, J, and Y Hamada. 2018. "Comparison between co-located soil moisture measurements at the ARM Southern Great Plains (SGP) Central Facility." Poster, *2018 ARM/ASR PI Meeting*, Vienna, Virginia, 19–24 March.

Webb, EK, GI Pearman, and R Leuning. 1980. "Correction of flux measurements for density effects due to heat and water vapour transfer." *Quarterly Journal of the Royal Meteorology Society* 106(44): 85–100, doi:10.1002/qj.49710644707.

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