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The QCECOR Value-Added Product: Quality-Controlled Eddy Correlation Flux Measurements

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ARM

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Acronyms and Abbreviations

ANL	Argonne National Laboratory
ARM	Atmospheric Radiation Measurement
BAEBBR	Bulk Aerodynamic Technique EBBR value-added product
EBBR	energy balance Bowen ratio
ECOR	eddy correlation flux measurement system
LH	latent heat
LLNL	Lawrence Livermore National Laboratory
MAO	ARM's Mobile Facility site at Manacapuru, Brazil during GoAmazon 2014/15
MASRAD	Marine Stratus Radiation Aerosol and Drizzle field campaign
netCDF	Network Common Data Form
NSA	North Slope of Alaska
PYE	ARM's Mobile Facility site at Point Reyes, California during MASRAD (2005)
QC	quality control
QCECOR	Quality-Controlled ECOR value-added product
SEBS	surface energy balance system
SGP	Southern Great Plains
SH	sensible heat
TWP	Tropical Western Pacific
VAP	value-added product

Contents

Figures

1.0 Overview

Eddy correlation flux (ECOR) measurement system stations are used by the U.S. Department of Energy Atmospheric Radiation Measurement (ARM) user facility to provide surface turbulence flux measurements. In recent years, ARM has significantly enhanced its ECOR systems and made them available at all its primary research observatories and mobile facilities. However, the original ECOR data were not corrected through common eddy correlation corrections and still contain suspicious data due to instrument and measurement uncertainties. Such uncertainties in the ECOR surface turbulence fluxes hampered their uses by the user community. To improve the ECOR data, we develop a value-added product (VAP) — **the Quality-Controlled Eddy Correlation Flux (**QCECOR) — by applying the following necessary corrections and quality control (QC) procedures:

1. Eddy correlation corrections.
2. Determination of the quality-controlled energy fluxes from the corrected ECOR fluxes.
3. Stringent QC checks.
4. Flagging possible incorrect fluxes due to hydrometeor impacts using the collocated surface energy balance system (SEBS) wetness measurements.

The QCECOR VAP currently contains two variables: surface latent heat flux (LH) and sensible heat flux (SH), together with their QC flags. When SEBS are collocated with ECOR, the wetness measurements from SEBS are used to flag the LH that may be incorrect due to hydrometeors such as precipitation, dew, or frost. An indeterminate flag is given to those that fail the wetness test.

The QCECOR data are currently available at the Southern Great Plains (SGP) atmospheric observatory for the ARM extended facilities of E1, E3, E5, E6, E10, E14, E16, E21, E24, E31, E33, E37, E38, E39, and E41 updated to 2018. The data are also available at the following AMF sites: PYE (Point Reyes, 2005), NIM (Niamey, Niger, 2006), FKB (Black Forest, Germany, 2007), HFE (Shouxian, China, 2008), GRW (Azores, 2009 to 2010), and MAO (Manacapuru, Brazil, 2014-2015). The algorithm is now in the process of moving to production mode. After that, QCECOR will run automatically for all available ARM sites.

2.0 Corrections and QC Procedures

The protocol for the QCECOR VAP workflow is shown in Figure 1. It includes the following flux corrections and QC procedures:

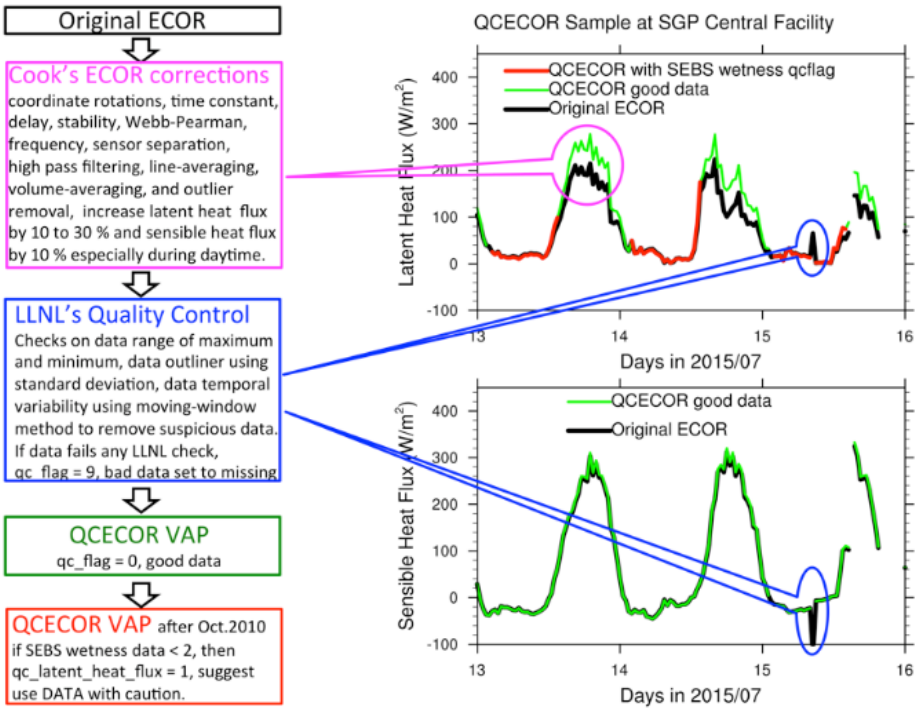

Figure 1. The protocol for the QCECOR VAP workflow.

Eddy correlation corrections include stability correction, Webb-Pearman correction, frequency correction, sensor separation correction, filtering correction, line-averaging correction, and volume-averaging correction (Cook et al. 2008, Fuehrer and Friehe 2002).

LLNL further quality controls include:

1. Data range check on maximum and minimum values.
2. Outlier check using standard deviation. If data departures from the mean are larger than four times standard deviation, the data are rejected.
3. Temporal variability check using moving window method. This method is applied with a moving window of ± 3 hours centered at the data point. In the time window, two temporal variabilities with and without the data are calculated. If the difference of the two temporal variabilities is larger than a threshold, the data are considered as an outlier and rejected.

Wetness flagging is applied to the LH fluxes with available collocated SEBS measurements.

Based on our initial analysis (Figure 1), these corrections generally increase the latent heat flux by 10 to 30 % and the sensible heat flux by 10 % from the original data, especially during the daytime, while a much smaller increase is noticed during nighttime. The LLNL QC checks effectively reject suspicious data points due to instrument or measurement uncertainties.

QC flag setting: Before SEBS wetness data were used to provide an indeterminate QC flag, there were only two QC flags for the surface turbulent flux data: flag = 0 represents good data while flag = 1 represents bad data. This flag setting is applied for QCECOR products at PYE, NIM, FKB, HFE, and GRW. After applying the SEBS wetness check, there were three QC flags: flag = 0 represents good data,

flag = 1 represents indeterminate data that fails the SEBS wetness check, and flag = 2 represents bad data. This flag setting is applied for QCECOR products at SGP and MAO. Note that flag = 1 has different meanings in these two settings. All the future updates of QCECOR products will use the 0/1/2 QC flag setting, and we will reprocess the QCECOR data with the 0/1 QC flag setting into the 0/1/2 setting in the future.

3.0 Comparison of Turbulent Fluxes between QCECOR and BAEBBR

Besides ECOR, there is another type of instrument, the energy balance Bowen ratio system (EBBR), installed at the broad ARM SGP region, with a VAP available as the Bulk Aerodynamic Technique EBBR (BAEBBR). Most of the ECOR and EBBR instruments are located at different facilities within the SGP extended site, except two collocated facilities: the Central Facility (since 2004) and Extended Facility 39 (EF39, since 2015). At the SGP Central Facility, the two instruments are within a few hundred meters apart. The turbulence fluxes measured from ECOR and EBBR are found to have quite significant differences (Figure 2). Overall, BAEBBR has similar LH and larger SH compared to QCECOR during spring, but it has much larger LH and smaller SH during summer.

The differences between ECOR and EBBR are mainly due to the different surface vegetation types the instruments are representing. At the Central Facility, ECOR is located at the edge of cropland and grassland, and measuring fluxes over cropland under prevailing southerly winds, while EBBR is located and measuring fluxes over grassland. For all ECOR and EBBR stations at SGP, all EBBR stations are located over grassland while ECOR stations are mostly sampling over cropland, with others sampling over grassland and forest. Users need to be careful about the surface type representation when using the turbulent flux measurements from ECOR and EBBR. More information about the comparison of ECOR and EBBR at SGP can be found in Tang et al. 2019.

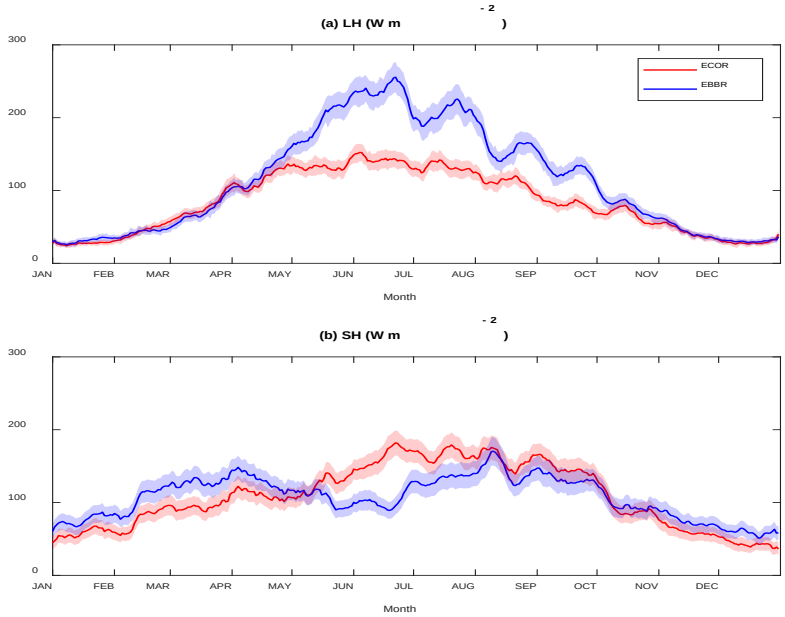

Figure 2. The seasonal variation of 2004–2015 daytime (06–18 local time, UTC-6) mean (a) LH and (b) SH from QCECOR (red) and BAEBBR (blue) at the SGP Central Facility.

4.0 Output Data

The primary variables in QCECOR are surface latent heat flux and sensible heat flux and their QC flags. A detailed list of the output variables is given in Appendix A. The VAP produces a single output file per day, named with the following convention:

XXX30qcecorFF.s1.YYYYMMDD.hhmmss.cdf

where:

XXX = the location of the instrument (nsa, sgp, twp, pye, etc.)
30qcecor = identifies that this is QCECOR VAP with 30min time resolution
FF = facility (e.g., C1)
s1 = identifies the data level
YYYYMMDD = year, month, and day
hhmmss = hour, minute, second

Currently we do not have quick plots for this VAP. Figure 3 gives an example of the final QCECOR products with QC flag.

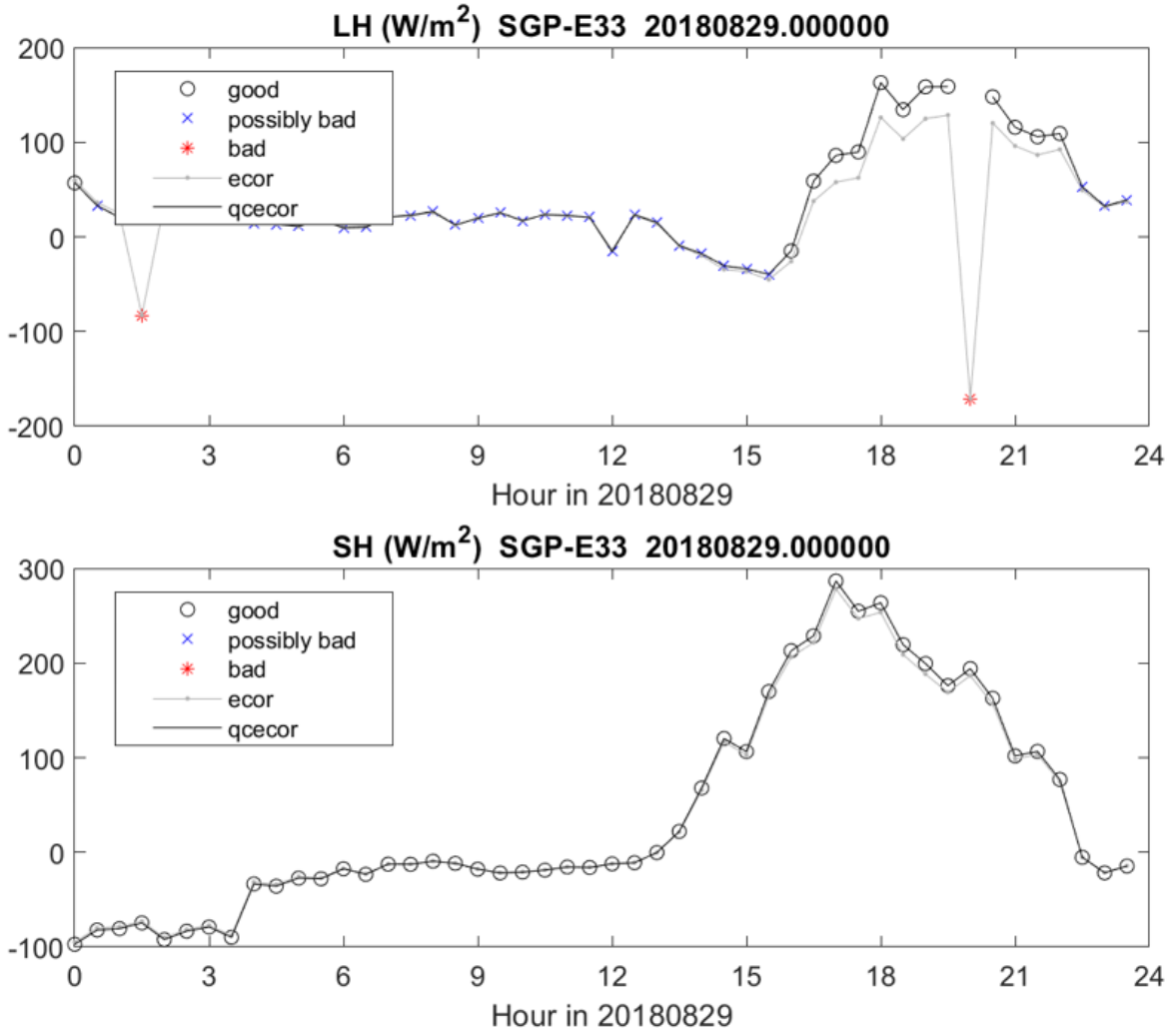

Figure 3. Time series of SH and LH from ECOR and QCECOR VAP at SGP E33 on August 29, 2018. The gray line and dots are original ECOR data. The black line represents corrected QCECOR data, with blue crosses representing failing on SEBS wetness check, and circles indicate good data. Red stars indicate bad data and are set as missing value (-9999) in QCECOR.

5.0 References

Cook, DR, M Franklin, and DJ Holdridge. 2008. "ECOR VAP Flux Corrections, Gap-Filling, and Results." Poster presented at the Eighteenth Atmospheric Radiation Measurement Program Annual Science Team Meeting, Norfolk, Virginia.

Fuehrer, PL, and CA Friehe. 2002. "Flux corrections revisited." *Boundary-Layer Meteorology* 102(3): 415–458, https://doi.org/10.1023/A:1013826900579

Massman, WJ. 2000. "A simple method for estimating frequency response corrections for eddy covariance systems." *Agricultural and Forest Meteorology* 104(3): 185–198, https://doi.org/10.1016/S0168-1923(00)00164-7

Tang, S, S Xie, M Zhang, Q Tang, Y Zhang, SA Klein, DR Cook, and RC Sullivan. 2019. "Differences in eddy-correlation and energy-balance surface turbulent heat flux measurements and their impacts on the large-scale forcing fields at the ARM SGP site." *Journal of Geophysical Research – Atmospheres* 124(6): 3301–3318, https://doi.org/10.1029/2018JD029689

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 Meteorological Society* 106(447), 85-100, https://doi.org/10.1002/qj.49710644707

Appendix A

Example of File Head of QCECOR

```
netcdf sgp30qcecorE33.s1.20180808.000000 {
dimensions:
      time = UNLIMITED ; // (48 currently)
variables:
      int base_time ;
            base_time:string = "2018-08-08 00:00:00 0:00" ;
            base_time:long_name = "Base time in Epoch" ;
            base_time:units = "seconds since 1970-1-1 0:00:00 0:00" ;
            base_time:ancillary_variables = "time_offset" ;
      double time_offset(time) ;
            time_offset:long_name = "Time offset from base_time" ;
            time_offset:units = "seconds since 2018-08-08 00:00:00
0:00" ;
            time_offset:ancillary_variables = "base_time" ;
            time_offset:calendar = "gregorian" ;
      double time(time) ;
            time:long_name = "Time offset from midnight" ;
            time:units = "seconds since 2018-08-08 00:00:00 0:00" ;
            time:calendar = "gregorian" ;
            time:axis = "T" ;
      float sensible_heat_flux(time) ;
            sensible_heat_flux:long_name = "Sensible heat flux at
surface" ;
            sensible_heat_flux:units = "W/m^2" ;
            sensible_heat_flux:standard_name =
"surface_upward_sensible_heat_flux" ;
            sensible_heat_flux:positive = "up" ;
            sensible_heat_flux:missing_value = -9999.f ;
            sensible_heat_flux:_FillValue = -9999.f ;
            sensible_heat_flux:valid_max = 1100.f ;
            sensible_heat_flux:valid_min = -300.f ;
            sensible_heat_flux:ancillary_variables =
"qc_sensible_heat_flux" ;
      int qc_sensible_heat_flux(time) ;
            qc_sensible_heat_flux:long_name = "Quality check results on
field: Sensible heat flux at surface" ;
            qc_sensible_heat_flux:units = "unitless" ;
```

```
           qc_sensible_heat_flux:description = "This field contains
integer values indicating the results of QC test on the data. Non-zero
integers indicate the QC condition given in the description for those
integers; a value of 0 indicates the data has not failed any QC
tests." ;
           qc_sensible_heat_flux:flag_method = "integer" ;
           qc_sensible_heat_flux:flag_2_description = "Value not
available or failed one or more quality control tests, value set to
missing_value." ;
           qc_sensible_heat_flux:flag_2_assessment = "Bad" ;
      float latent_heat_flux(time) ;
           latent_heat_flux:long_name = "Latent heat flux at surface"
;
           latent_heat_flux:units = "W/m^2" ;
           latent_heat_flux:standard_name =
"surface_upward_latent_heat_flux" ;
           latent_heat_flux:positive = "up" ;
           latent_heat_flux:missing_value = -9999.f ;
           latent_heat_flux:_FillValue = -9999.f ;
           latent_heat_flux:valid_max = 1100.f ;
           latent_heat_flux:valid_min = -300.f ;
           latent_heat_flux:ancillary_variables =
"qc_latent_heat_flux" ;
      int qc_latent_heat_flux(time) ;
           qc_latent_heat_flux:long_name = "Quality check results on
field: Latent heat flux at surface" ;
           qc_latent_heat_flux:units = "unitless" ;
           qc_latent_heat_flux:description = "This field contains
integer values indicating the results of QC test on the data. Non-zero
integers indicate the QC condition given in the description for those
integers; a value of 0 indicates the data has not failed any QC
tests." ;
           qc_latent_heat_flux:flag_method = "integer" ;
           qc_latent_heat_flux:flag_1_description = "Use caution,
Value might be impacted by wetness issue of instrument based on SEBS
wetness data" ;
           qc_latent_heat_flux:flag_1_assessment = "Indeterminate" ;
           qc_latent_heat_flux:flag_2_description = "Value not
available or failed one or more quality control tests, value set to
missing_value." ;
           qc_latent_heat_flux:flag_2_assessment = "Bad" ;
      float lat ;
           lat:long_name = "North latitude" ;
           lat:units = "degree_N" ;
           lat:standard_name = "latitude" ;
           lat:valid_min = -90.f ;
           lat:valid_max = 90.f ;
      float lon ;
           lon:long_name = "East longitude" ;
           lon:units = "degree_E" ;
           lon:standard_name = "longitude" ;
           lon:valid_min = -180.f ;
```

```
            lon:valid_max = 180.f ;
      float alt ;
            alt:long_name = "Altitude above mean sea level" ;
            alt:units = "m" ;
            alt:standard_name = "altitude" ;

// global attributes:
            :Conventions = "CF-1.6" ;
            :title = "Quality Controlled Eddy Correlation Flux
Measurement (QCECOR) for surface sensible and latent fluxes" ;
            :description1 = "This VAP of surface latent and sensible
heat flux\n",
                  "is generated based on original ECOR data\n",
                  "by Yunyan Zhang and Shaocheng Xie (LLNL)\n",
                  "with help from ARM ECOR instrument mentor David R.
Cook (ANL)." ;
            :description2 = "Eddy correlation corrections applied: \n",
                  "Webb-Pearman correction, frequency correction,\n",
                  "sensor separation correction, stability corrections,
filtering correction,\n",
                  "and line-averaging and volume-averaging
corrections.\n",
                  "For data after the installation of Surface Energy
Balance System (SEBS) (Jan. 2011),\n",
                  "the SEBS wetness data are used to constrain heat
fluxes when processing.\n",
                  "Sonic anemometer height is set to be 3 meters,\n",
                  "except for SGP.E21 where it is set to be 4 meters." ;
            :description3 = "LLNL added QC includes: \n",
                  "data range check, outlier check, standard deviation
check, \n",
                  "and temporal variability check\n",
                  "Value is set to missing if it fails LLNL QC, qc flag
value is set to 2" ;
            :description4 = "Additional QC is added on latent heat flux
based on SEBS wetness data which become available after Oct. 2010.
\n",
                  "If SEBS wetness < 2, then latent heat flux qc flag is
set to 1.\n",
                  "However the value of latent heat flux is kept and NOT
set to missing.\n",
                  "This is because SEBS wetness < 2 happens so
frequently during night, for users\' benefit or interest\n",
                  "on diurnal cycle data, the value is kept. Please USE
with CAUTION!" ;
            :institution = "United States Department of Energy -
Atmospheric Radiation Measurement (ARM) program" ;
            :process_version = "adi-create_adi_project-1.15-0" ;
            :dod_version = "30qcecor-s1-1.1" ;
            :datastream = "sgp30qcecorE33.s1" ;
            :platform_id = "30qcecor" ;
            :data_level = "s1" ;
```

```
           :site_id = "sgp" ;
           :facility_id = "E33" ;
           :location_description = "Southern Great Plains (SGP),
Newkirk, Oklahoma" ;
           :authors = "Yunyan Zhang (zhang25@llnl.gov)" ;
           :qc_date = "Thu Jan 28 21:54:10 UTC 2016" ;
           :command_line = "idl -R -n adi_qcecor -s sgp -f E33 -b
20171001 -e 20190102 -D 2" ;
           :input_datastreams = "sgp30ecorE33.b1 : 13.4 :
20180808.000000\n",
                 "sgpsebsE33.b1 : 1.5 : 20180808.000000" ;
           :doi = "10.5439/1097546" ;
           :history = "created by user tang32 on machine lead at 2019-
02-13 00:10:04, using adi-create_adi_project-1.15-0" ;
}
```

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