Uncertainty of Surface Turbulence Flux Measurements and Its Impacts to the Derived Large-Scale Forcing at the ARM SGP Site

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Motivation

Two instruments, ECOR and EBBR, are deployed at SGP to measure surface latent (LH) and sensible (SH) heat fluxes over different surface types. In this study, we would like to understand:

- How large do ECOR and EBBR differ in measuring surface fluxes, what are the possible sources of the difference?
- How large will it impact the large-scale forcing derived by variational analysis (VARANAL) that uses surface fluxes as part of the constraints?

ECOR and EBBR

ECOR (Eddy Correlation Flux Measurement System)

Vertical flux can be presented as a covariance of the vertical wind velocity (w) and the concentration of the entity of interest. E.g.: $SH = \rho c_p \overline{\theta' w'}$

Error source:

- Spectral losses (10 Hz frequency and 30 min averaging time window)
- Assumption of stational atmospheric condition
- Surface heteogeneity

Flux shortfalls of 10% to 25% are often seen in ECOR results; 35% shortfalls are less common, but can occur. (ECOR handbook)

QCECOR (quality controlled ECOR data):

- Flux corrections from instrument mentor. Daytime LH increases by 10% - 30%, SH increase by 10%
- Remove suspicious data. E.g.: data outliers

EBBR (Energy Balance Bowen Ratio Station)

Flux estimates are calculated from the energy balance of local surface.

Q + G + LH + SH = 0

The Bowen ratio (B = LH/SH) is measured as the ratio of the gradients of temperature and water vapor pressure (calculated by RH and T)

Error source:

- Assumption on equal diffusivities for water and heat
- Errors in measurements of net radiation Q
- No canopy storage
- Surface heteogeneity

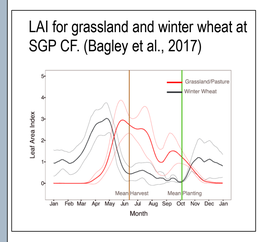
This technique is only suitable for less disturbed surface.

BAEBBR: replaces the data with Bulk Aerodynamic calculated latent and sensible heat fluxes when B is within the range -1.6 to -0.45.

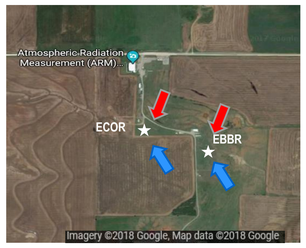
Comparison of ECOR and EBBR

The only collocated ECOR and EBBR stations before 2015 are at the Central Facility (CF). In north or northeast (NE) wind direction, both systems view the same grass surface. In south or southeast (SE) wind direction, ECOR is looking at cropland (primarily winter wheat in most of the year) while EBBR is looking at grassland. Winter wheat has very different growth cycle from grass.

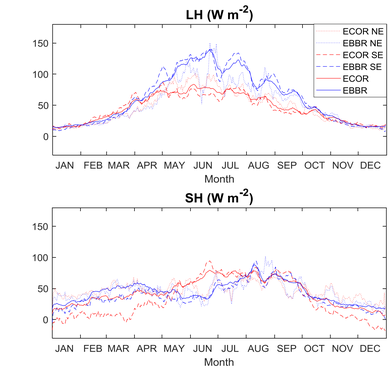
LAI for grassland and winter wheat at SGP CF. (Bagley et al., 2017)



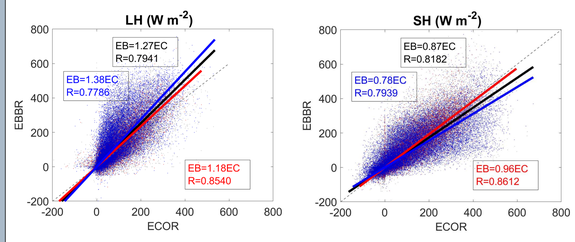
SGP Central Facility



Comparison of 2004-2015 daily-mean ECOR and EBBR measured turbulence fluxes at CF



- Under NE wind direction when ECOR and EBBR see the same surface type, the differences are small.
- Under SE wind direction when ECOR and EBBR see different surface types, the flux differences are large.

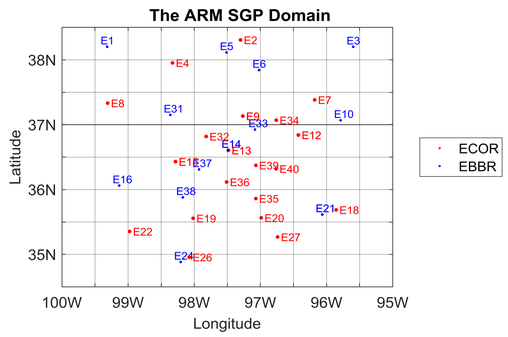


Red: NE wind, only instrument difference
Blue: SE wind, instrument difference + surface type difference

- Instrument difference: 18% for LH and 4% for SH
- Surface type difference: 20% for LH and 18% for SH

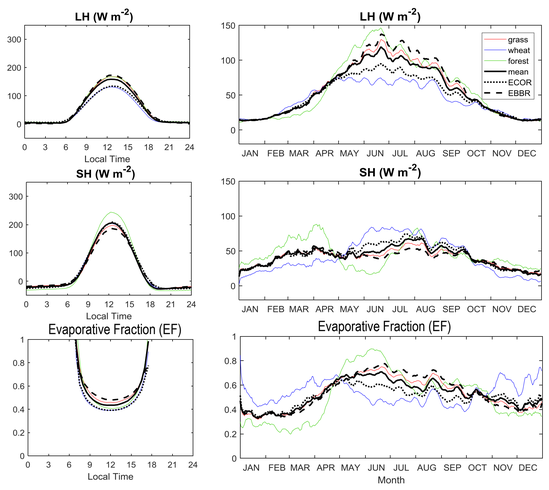
Instrument difference always exists while surface type difference depends on wind direction.

Domain-Mean LH and SH



Surface type (from ECOR and EBBR handbooks):
EBBR (18): all grassland (18)
ECOR (13): winter wheat (8), grassland (8), forest (1)

Comparison of domain-mean LH and SH (2004-2015)



Grass (red): normal growth cycle, EF increases from spring to summer.
Winter wheat (blue): EF decreases from spring to summer. LH slightly decreases and SH rapidly increases in May
Forest (green): small LH, large SH in spring and opposite in summer. Very rapid change in April.

- ECOR is closer to winter wheat while EBBR is closer to grass.
- Overall ECOR is smaller in LH and larger in SH.

Take-home Message

- Wind direction needs to be taken into account to properly interpret LH and SH measurements at SGP.
- Surface energy partitioning differs significantly for winter wheat and grass surfaces.

Acknowledgement

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Impacts to the Forcing

In VARANAL, large-scale forcing data are derived by conserving the column-integrated mass, moisture and energy budgets using surface and TOA measurements (including LH and SH) as constraints.

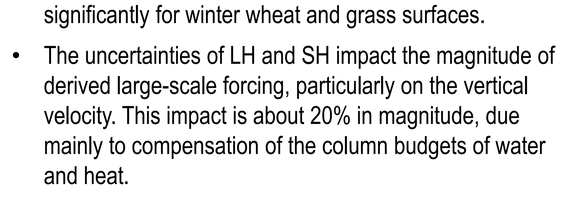
$$\langle \nabla \cdot \vec{V} \rangle = -\frac{1}{g}\frac{dP_s}{dt}$$

$$\frac{\partial \langle q \rangle}{\partial t} + \langle \nabla \cdot \vec{V} q \rangle = E_s - P_{rec} - \frac{\partial \langle q_l \rangle}{\partial t} \qquad E_s = \frac{1}{L_v} LH$$

$$\frac{\partial \langle s \rangle}{\partial t} + \langle \nabla \cdot \vec{V} s \rangle = R_{TOA} - R_{SRF} + L_v P_{rec} + SH + L_v \frac{\partial \langle q_l \rangle}{\partial t}$$

Large-scale forcing derived from merged, ECOR-only and EBBR-only surface LH and SH

2004-2015 Mean



Peak Diff: 21.7% 3.6% 5.6%

- The impacts are mainly on omega rather than on advection.
- The uncertainty of omega due to ECOR/EBBR differences is ~20%.
- Difference in specific season (e.g. summer) or case could be larger.

How do LH and SH impact the derived forcing

smaller LH and larger SH (ECOR) → more heat divergence and moisture convergence → stronger lower-level convergence and upper-level divergence → stronger upward motion

moisture decreases with height; static energy increases with height. Mass is conserved

Summary

- ECOR and EBBR are used at the ARM SGP site to measure surface turbulence fluxes over different surface types. Each has its own limitations.
- ECOR and EBBR may look at different surface types in different wind directions. When looking at the same surface, the differences between ECOR and EBBR are much smaller.
- At SGP, winter wheat has different growth cycle than the native vegetation. Surface energy partitioning differs significantly for winter wheat and grass surfaces.
- The uncertainties of LH and SH impact the magnitude of derived large-scale forcing, particularly on the vertical velocity. This impact is about 20% in magnitude, due mainly to compensation of the column budgets of water and heat.

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