# Use of a Dual Temperature-Difference Two-Source Energy Balance Model to Estimate Turbulent Fluxes under Strongly Advective Conditions during BEAREX08

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## Introduction:

- Many TSEB models require meteorological inputs including wind speed and air temperature; often local measurements of these inputs are not available or are collected under non-ideal conditions.
- The uncertainty associated with the inputs to the model, for example air and radiometric temperature, can result in significant errors in the estimates of the turbulent heat and moisture fluxes.
- The Dual-Temperature Difference (DTD) approach, developed by Norman et al. (2000) uses a double difference of the air ($T_a$) and radiometric surface temperature ($T_r$) to minimize the effects of measurement uncertainty when calculating the temperature gradient between the land surface and the atmosphere.
- Since it should be less sensitive to bias and other measurement errors, it is hypothesized that the DTD approach will produce more robust estimates of the sensible ($H$) and latent ($\lambda E$) heat fluxes in inhomogeneous landscapes such as agricultural environments containing a mosaic of irrigated and non-irrigated fields.
- To test this hypothesis, data collected as a part of the 2008 Bushland Evapotranspiration and Agricultural Remote Sensing Experiment (BEAREX08) from 12 May to16 July was used.

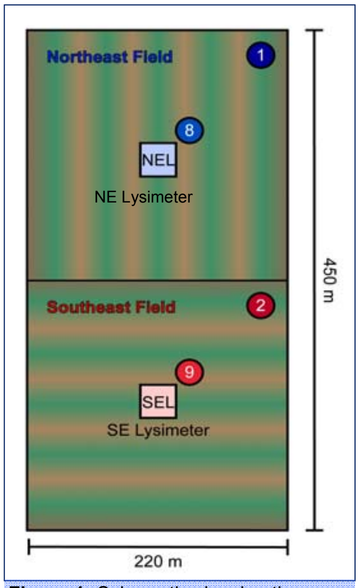
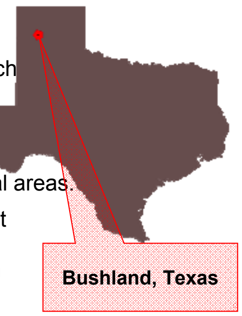



**Figure 1:** Schematic showing the location of the EC systems and lysimeter in each of the cotton fields

## BEAREX08:

- The Bushland Evapotranspiration and Agricultural Remote Sensing Experiment (BEAREX08) was conducted from May through August 2008 at the USDA-ARS Conservation and Production Research Laboratory (CPRL) near Bushland, Texas.
- The overarching objective of the field campaign was to develop improved methods of monitoring and modeling evaporative water loss in agricultural areas.
- The study presented here focuses on two adjacent cotton fields (Fig. 1). Two eddy covariance (EC) micrometeorological stations and a large weighing lysimeter was deployed in each field.
- Both fields were irrigated and the same in all respects except row orientation. The crop rows in the Northeast Field ran north to south while the crop rows in the Southeast field ran west to east.



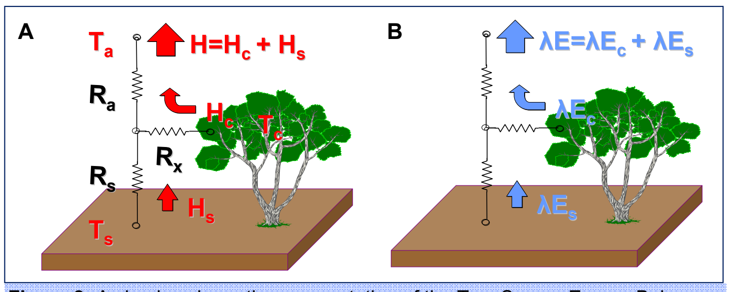




**Figure 2:** A simple schematic representation of the Two-Source Energy Balance Model. Panel A shows the sensible heat flux while Panel B shows the latent heat flux .

## Model Overview:

- The TSEB model estimates the turbulent fluxes by simultaneously solving the energy balance relationships for both the canopy and the vegetation:

$$R_{n_c} = H_c + \lambda E_c$$
$$R_{n_s} = H_s + \lambda E_s + G$$

- The net radiation ($R_n$) is partitioned between the canopy and soil using either a physically-based model or a Beer's Law-type relationship and the soil heat flux ($G$) is estimated as a function of the soil level net radiation.
- At the canopy level, the sensible heat flux ($H_c$) is calculated using a modified Priestly-Taylor formulation:

$$H_c = R_{n_c}\left[1 - \alpha f_g \frac{\Delta}{\Delta + \gamma}\right]$$

and the latent heat flux ($\lambda E_c$) is calculated as a residual.

- At the soil, traditional TSEB models determine the sensible heat flux ($H_s$) according to:

$$H_s = \frac{\rho C_p (T_r - T_a) - f(\theta) H_c R_A}{(1 - f(\theta))(R_A - R_s)}$$

- Rather than using the absolute difference between the $T_r$ and $T_a$, DTD approach calculates $H_s$ as function of the relative change in the temperature gradient as follows:

$$H_s = \rho C_p \left[\frac{(T_r - T_{r_0}) - (T_a - T_{a_0})}{(1 - f(\theta))(R_A + R_s)}\right] + H_c\left[1 - \frac{f(\theta) R_A}{(1 - f(\theta))(R_A + R_s)}\right]$$

Again, the latent heat flux ($\lambda Es$) is calculated as a residual.

- $T_{r_0}$ and $T_{a_0}$ are the radiometric and air temperature, respectively, measured within one hour after sunrise.

### Results of the DTD Approach Using Large Footprint Measurements of Radiometric Surface Temperature:

- A large footprint, i.e. area of view, estimate of $T_r$ was calculated from measurements of upwelling longwave radiation collected with a pyrgeometer with a hemispherical view.
- A comparison of the flux measurements from the four EC systems indicated there was spatial variability in the partition of the surface energy budget over the two cotton fields, particularly during mid-day. The inter-site standard deviations were 30 W m$^{-2}$, 68 W m$^{-2}$, and 24 W m$^{-2}$, respectively, for *H*, $\lambda E$, and *G*.
- A comparison of the model output using the DTD approach forced with data collected at each EC site yielded similar results for the turbulent fluxes. The inter-site standard deviations were 31 W m$^{-2}$ and 44 W m$^{-2}$, respectively, for *H* and $\lambda E$.
- A site-by-site analysis showed good agreement between the modeled and observed fluxes (Fig. 3, Table 1). For *H*, the correlation between the modeled and observed flux ranged between 0.8377 and 0.8712; for $\lambda E$, it ranged between 0.8267 and 0.9383.
- The differences between the modeled and observed turbulent fluxes can be attributed to, at least, two factors. These are:
  - The tendency of the model to overestimate *G*.
  - The high fraction of vegetation cover ($f(\theta)$) at Site 8 NE and Site 9 SE near the end of the study period, approached the threshold where the model be becomes computationally unstable.

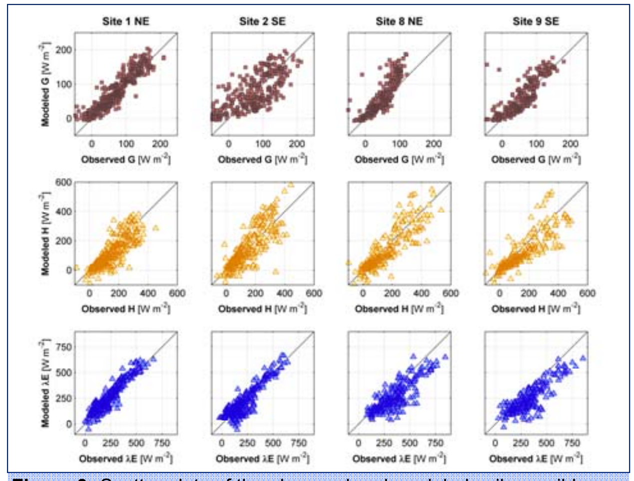



**Figure 3:** Scatter plots of the observed and modeled soil, sensible, and latent heat fluxes are shown for each of the study sites. The estimates of radiometric temperature where derived from measurements of upwelling longwave radiation.

**Table 1:** The root mean square difference (RMSD) between the observed and modeled turbulent fluxes are given for each of the study sites. In addition to the model simulation conducted using the DTD approach, simulations were conducted at Site 1 NE and Site 2 SE using the standard two-source approach.

| | Site 1 NE | | | | Site 2 SE | | | | Site 8 NE | | Site 9 SE | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flux | DTD | | TSEB | | DTD | | TSEB | | DTD | | DTD | |
| | Large | Localized | Large | Localized | Large | Localized | Large | Localized | Large | Localized | Large | Localized |
| *H* | 64 | 71 | 74 | 90 | 72 | 81 | 80 | 99 | 78 | 81 | 84 | 87 |
| $\lambda E$ | 54 | 61 | 99 | 101 | 64 | 69 | 78 | 89 | 108 | 121 | 126 | 130 |

### Results of the DTD Approach Using Localized Footprint Measurements of Radiometric Surface Temperature:

- In order to ascertain the ability of the DTD approach to correctly estimate the turbulent fluxes when the available data may not fully reflect local conditions, additional model simulations were conducted using localized measurements of $T_r$.
- The localized measurements of $T_r$ were collected using a pair infrared thermometers with a total footprint area of 6.1 m$^2$. These measurements were between 0.5 K and 2 K less than the $T_r$ measurements with the larger footprint.
- As can be seen by comparing Figures 3 and 4, the results of these simulations were quite similar to the results discussed above. The model output agreed well with the observed fluxed and had correlations that ranged between 0.7761 and 0.8802 for *H* and between 0.8409 and 0.9312 for $\lambda E$.
- The similarity of the results is also evident from the modest increases in the root mean square difference (RMSD) between the observed and modeled flux (Table 1).
- A comparison of the model output using two different $T_r$ measurements showed that the RMSD, which ranged between 15 W m$^{-2}$ and 24 W m$^{-2}$ among the four sites, was the same at each site for both *H* and $\lambda E$.
- It also showed that model simulations conducted using the localized measurements of $T_r$ consistently partitioned more energy into $\lambda E$ than the simulations using large footprint measurements. The latter simulations yielded higher estimates of *H*.

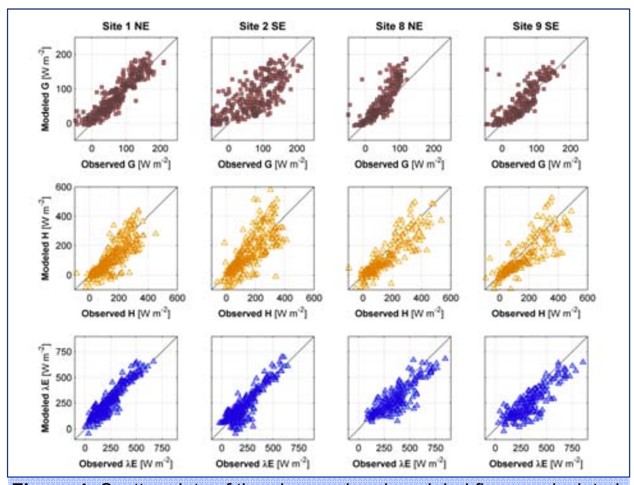



**Figure 4:** Scatter plots of the observed and modeled fluxes calculated using the localized measurements of radiometric temperature are shown for each of the study sites.

### Results with the TSEB Model:

- For comparison, simulations were also conducted using the data from Site 1 NE and Site 2 SE and a traditional TSEB model.
- The discrepancy between the observed and modeled fluxes tended to be larger with the this model than with the DTD approach (Table 1).
- TSEB tended to overestimate $\lambda E$ and underestimate *H* compared to the observational data. Theses differences were exacerbated by the use of the localized $T_r$ measurements. The difference between the observations and model output increased by 16% on average when the localized measurements were used.
- For the DTD approach, in contrast, the difference increased by less than 9%.

### Conclusions:

- The DTD approach is less sensitive to bias and errors in the estimate of the temperature gradient between the land surface and the atmosphere. As a result it produces more robust estimates of the turbulent fluxes.
- Nonetheless, the DTD approach shares some of the limitations of the TSEB model. It is applicable only during the day and for intermediate levels of vegetation cover.
- Discrepancies in the observed and modeled partition of the surface energy budget can also be linked to uncertainty in the empirically modeled *G*.