How Much Water is Evaporated Across California?: An Assessment Using a MesoNetwork of Eddy Covariance Sites, a Biophysical Model Forced with Satellite Remote Sensing and ECOSTRESS Data

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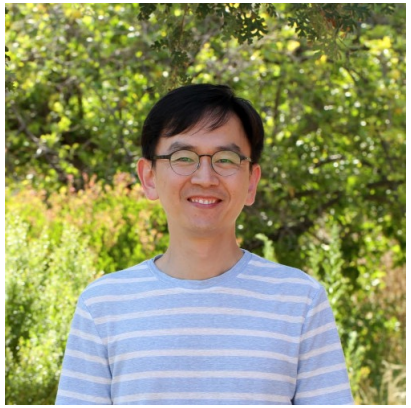
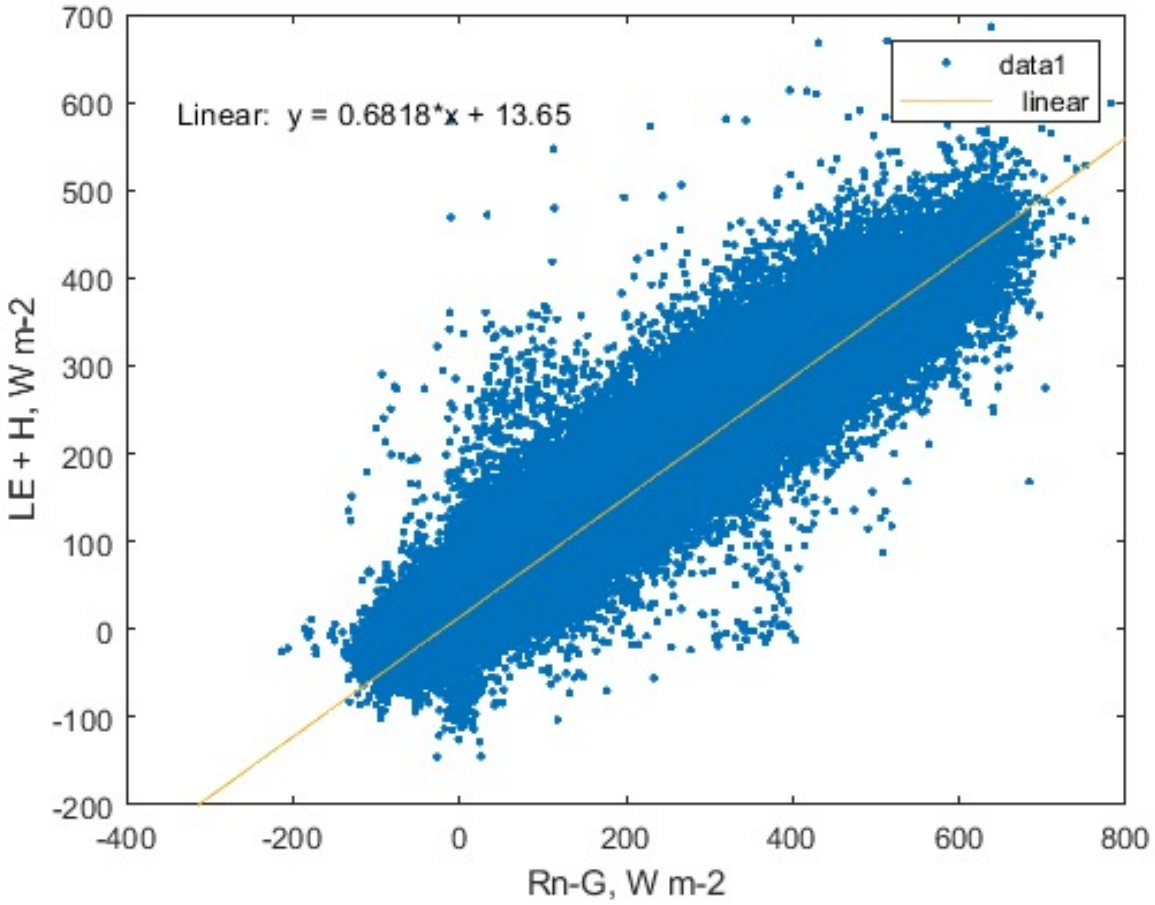
ECOSTRESS April 12-14, 2022, Ventura, CA



Topics

- Soil Heat Flux and Energy Balance Closure (???)
- Advection and Energy Balance Closure (??)
- CoSpectral Filtering and Energy Balance Closure (?!)
- Hand Shaking Remote Sensing, Eddy Covariance and Flux Footprints
- Diagnosing ECOSTRESS Products with CanVeg
- Diagnosing ECOSTRESS Products with Day-Night Temperature Differences

Mystery: Energy Balance is Not Closing



Toward Better Soil Heat Flux Measurements

$$\rho_s C_s \frac{\partial T}{\partial t} = \frac{\partial G}{\partial z} = -\frac{\partial (k \, \partial T_s / \partial z)}{\partial z}$$

$$G(0) = G(z) + \int_{z_1}^{z_2} \rho_s C_s \frac{\partial T}{\partial t} dz$$

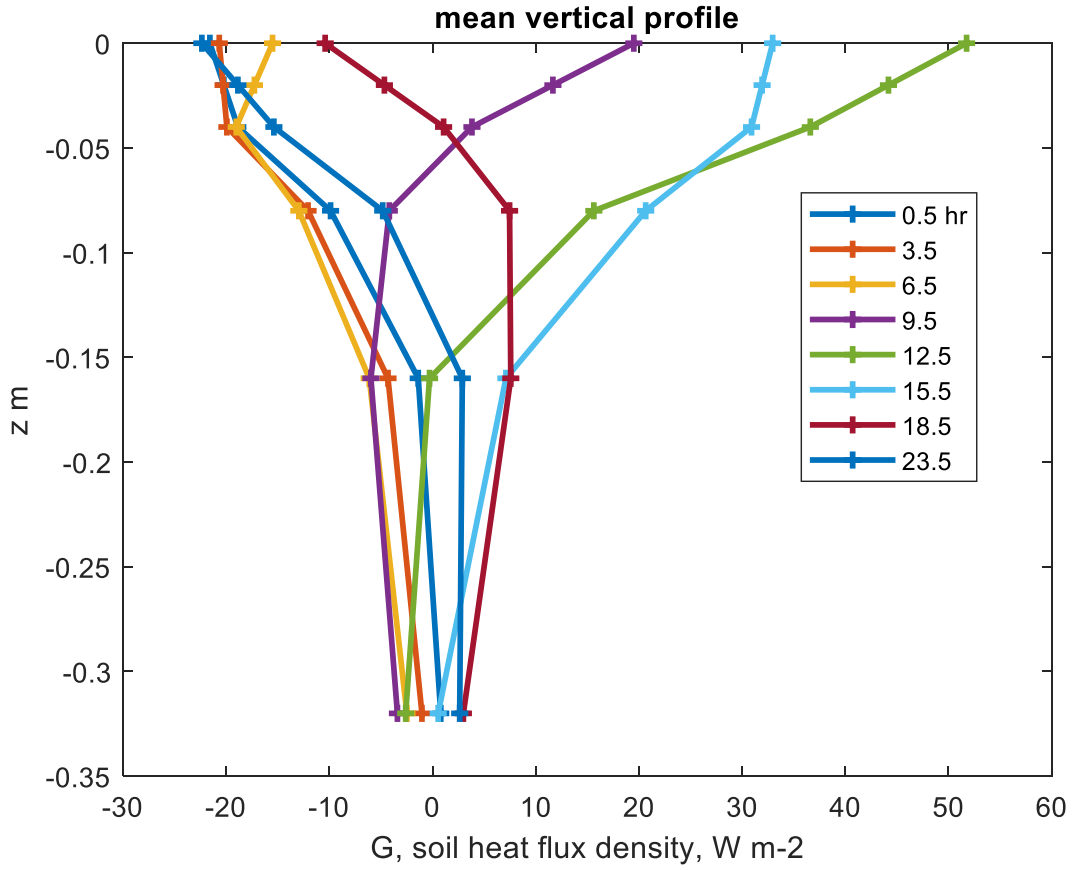
$$G_{storage} = \frac{T_s(t+1) - T_s(t)}{\Delta t} \Delta z \, \rho_s \, C_s$$

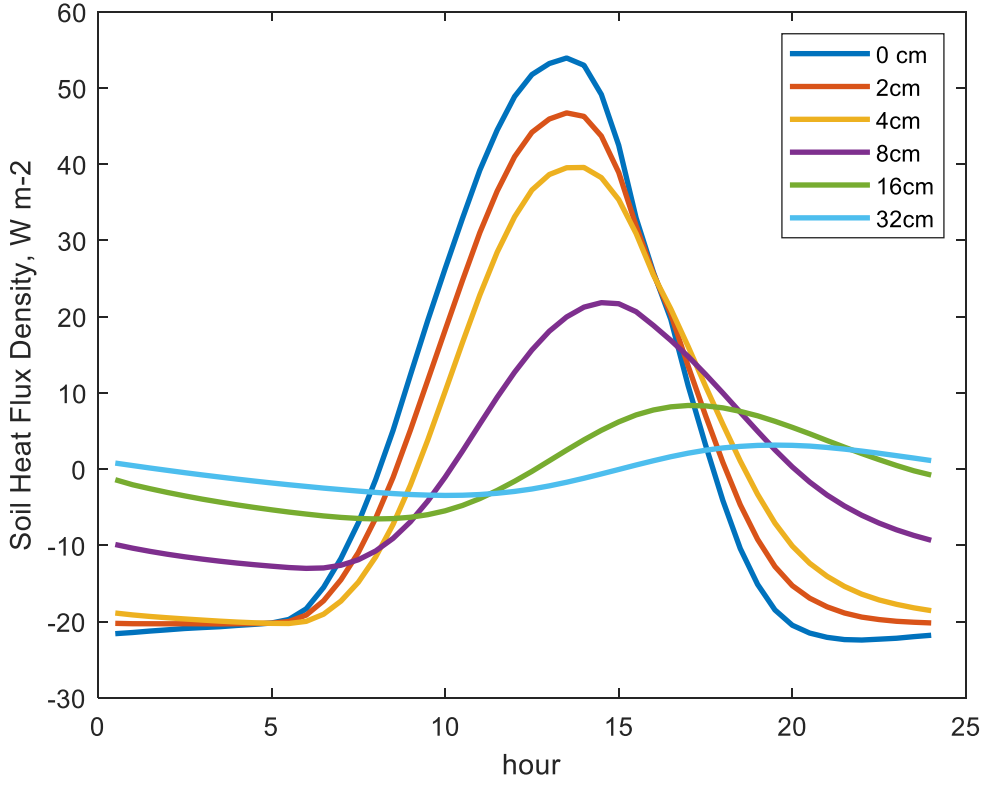
$$\rho_s C_s = \phi_m \rho_m C_m + \phi_o \rho_o C_o + \theta_w \rho_w C_w$$

Difficult to Assess Precisely

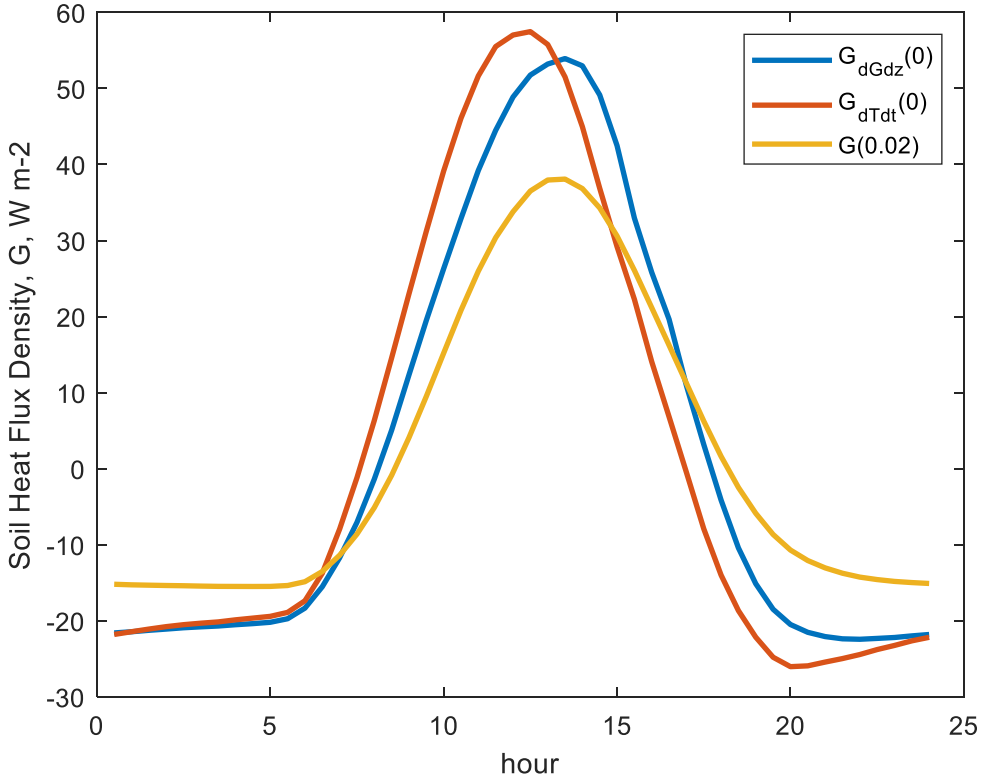
Measure G Flux Divergence!

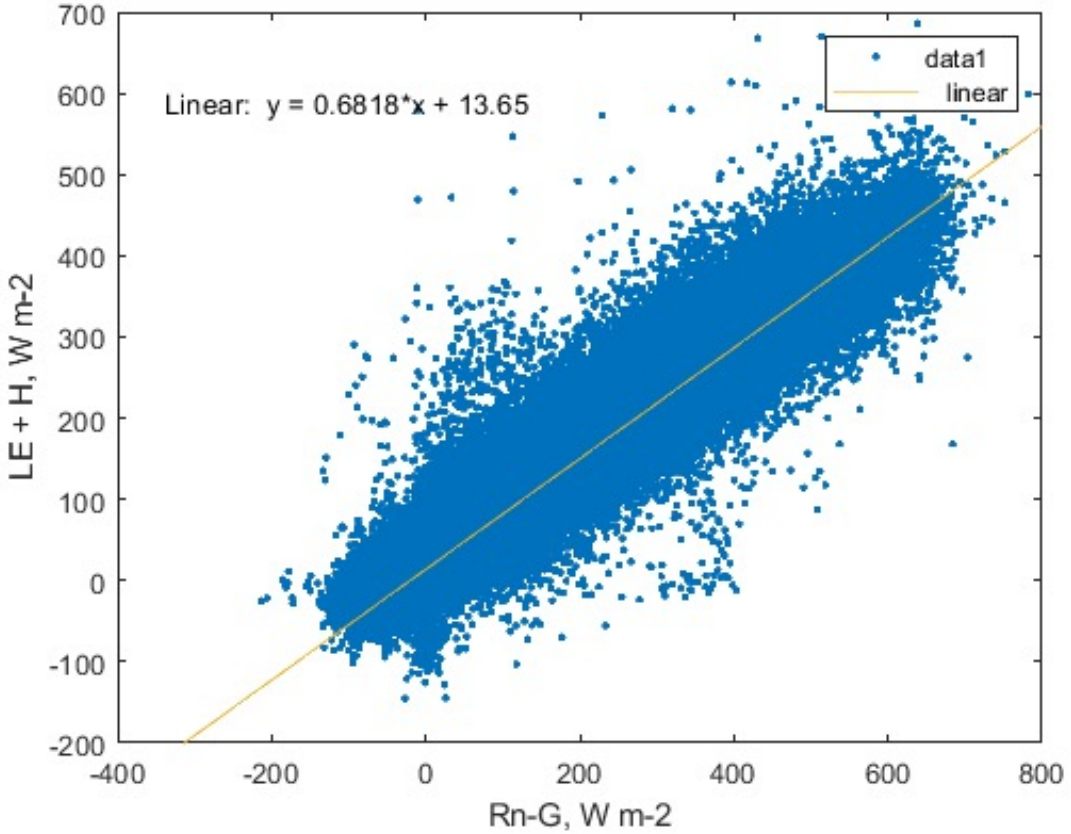
$$G_{dGdz}(0) = G_{soil}(z) + \int_{z}^{0} \frac{\partial G_{soil}}{\partial z} dz \approx (G(z_1)z_2 - G(z_2)z_1)/(z_2 - z_1)$$



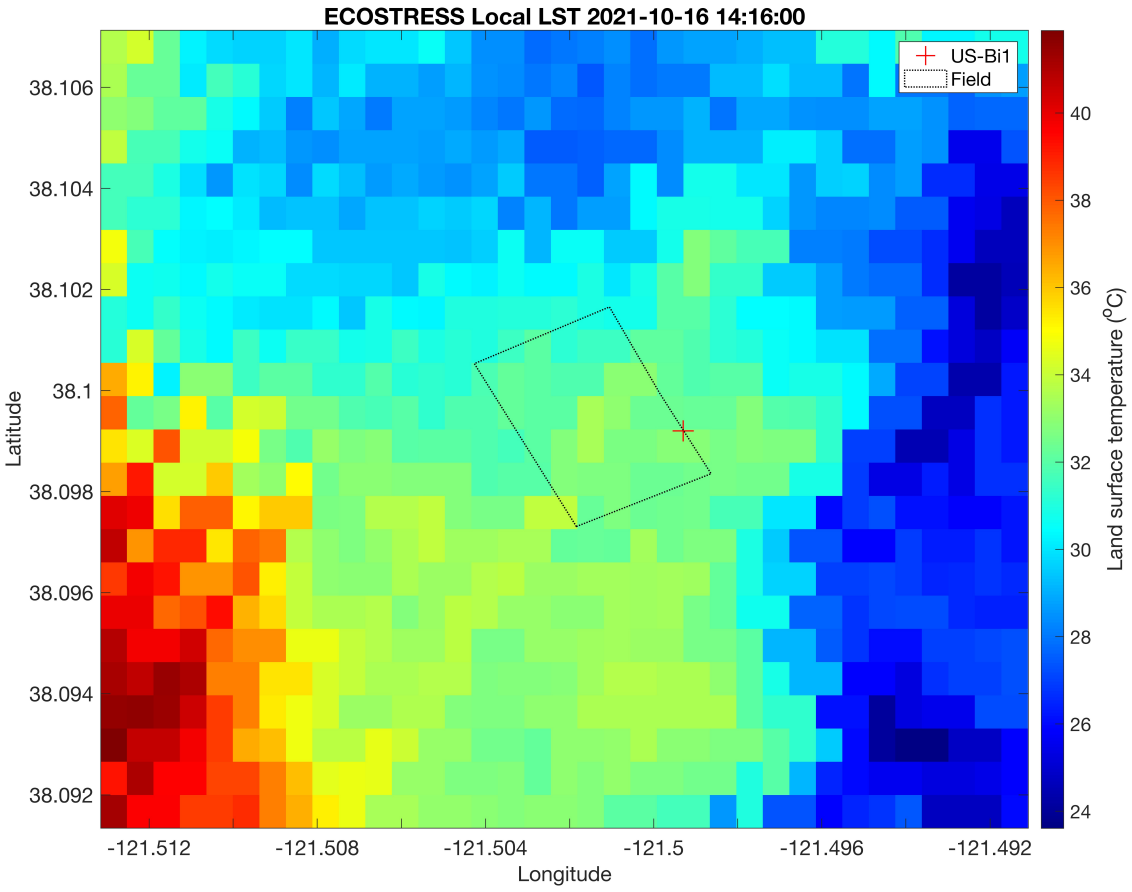


Better G measurements Did Not Improve Energy Balance Closure

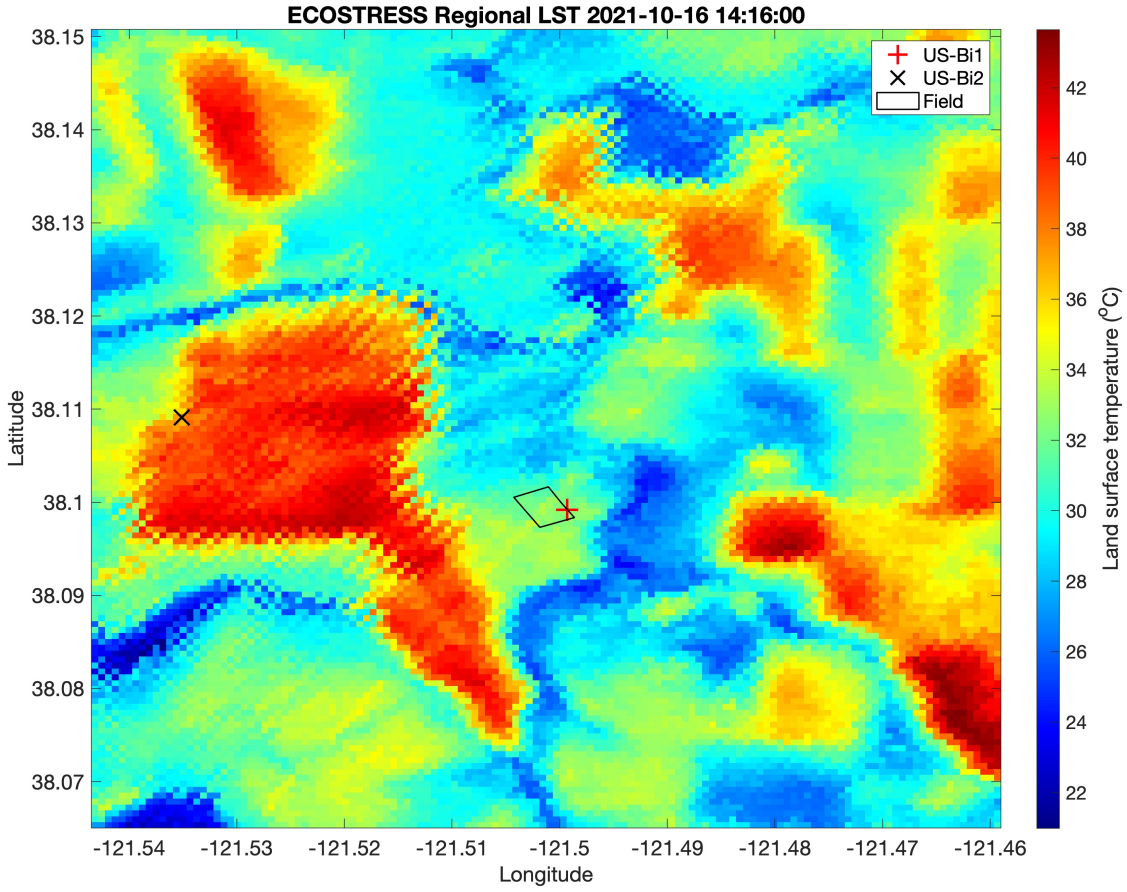




What About Advection?: Strong T Gradients over Ideal Fields with Great Fetch

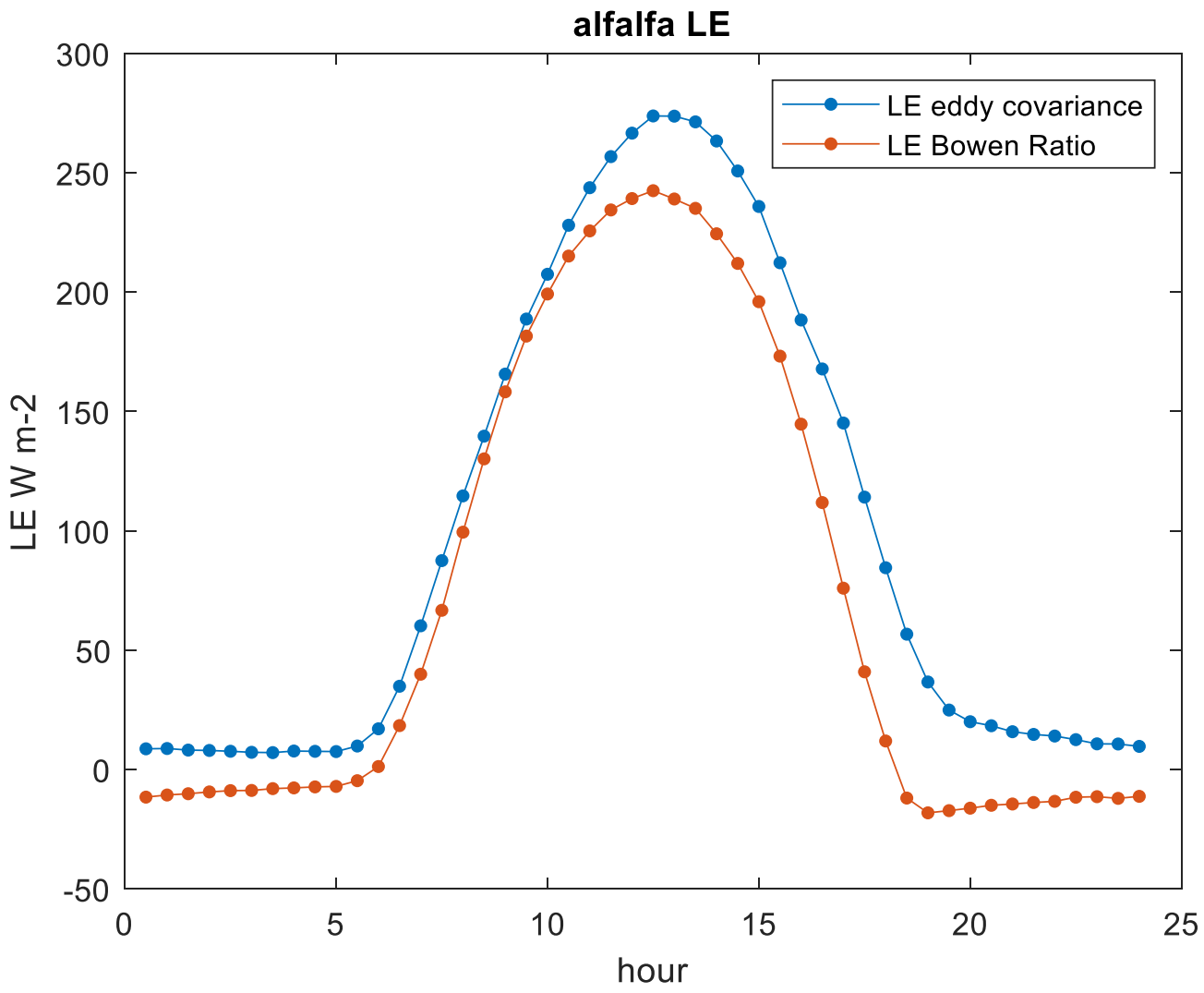


Intra-field advection with gradient
2021-10-16
WGS 1984

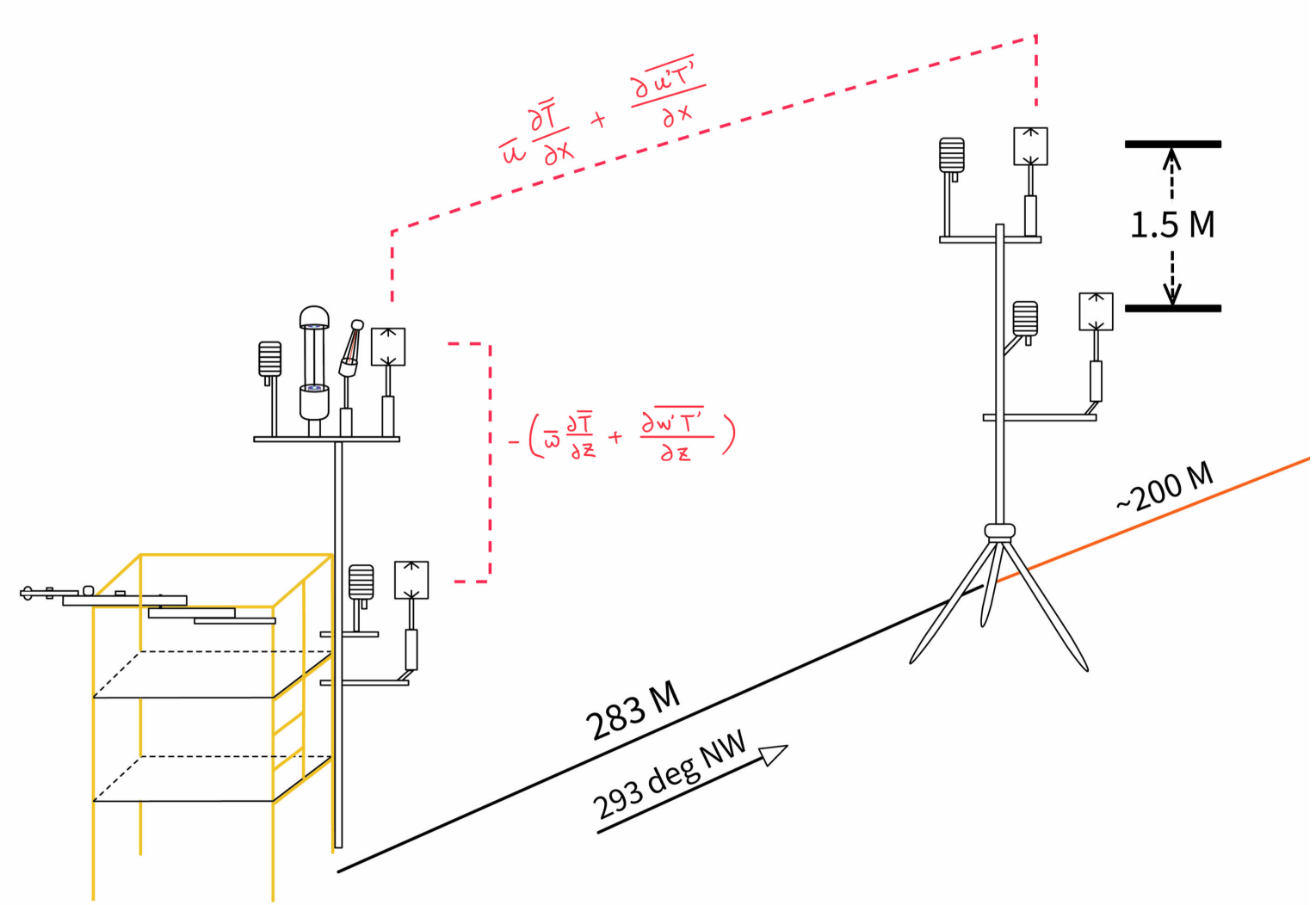


Regional advection with gradient
2021-10-16
WGS 1984

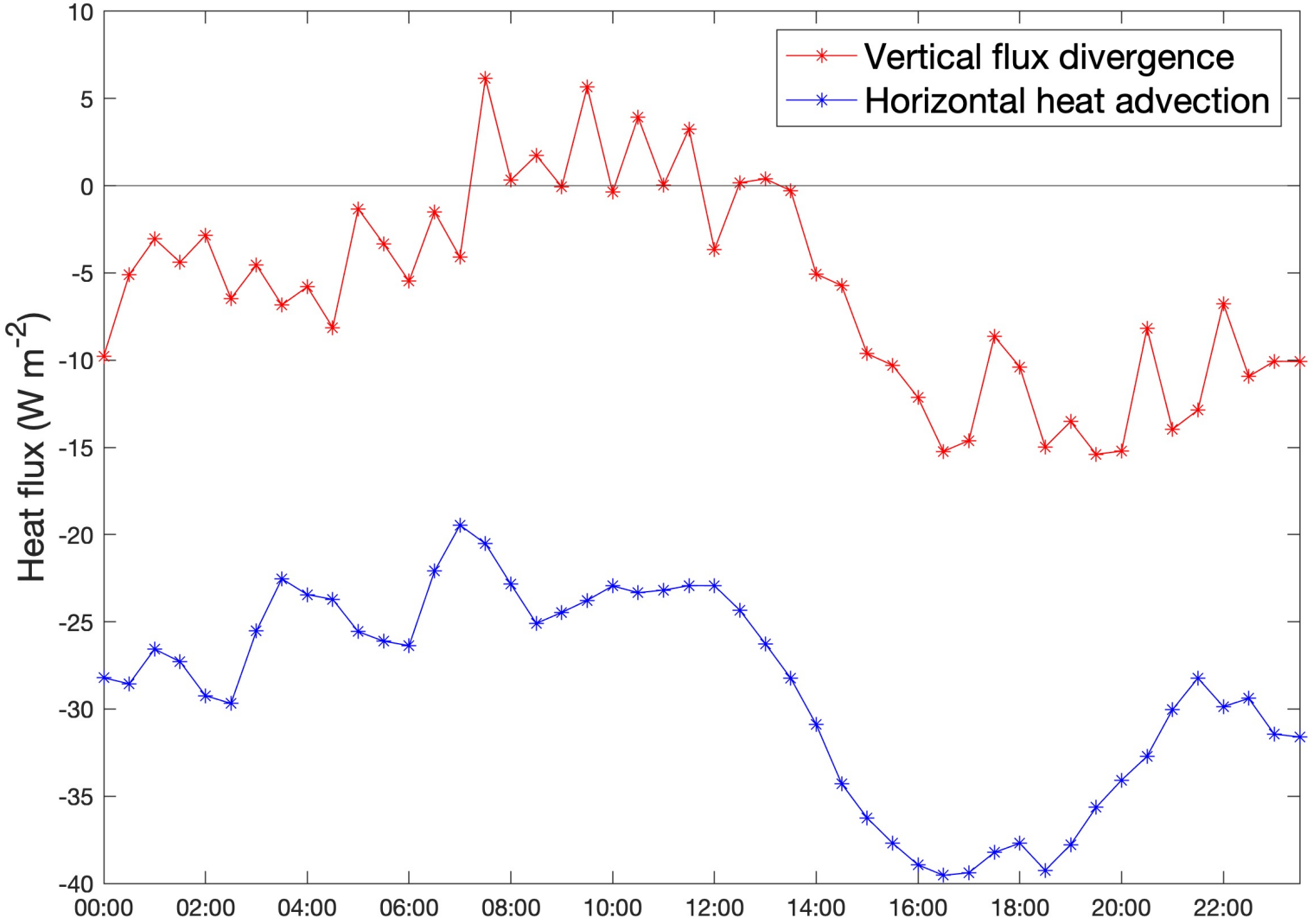
Evaporative Enhancement by Advection?



Flux Divergences over Alfalfa



Diel H Vertical Flux Divergence and Horizontal Advection: Real But Small



$$-\left(\int_0^z \overline{u}\cdot\frac{\partial T}{\partial x}dz\right) \neq \int_0^z \frac{\partial \overline{w'T'}}{\partial z}dz$$

What about LE?

Estimate Evaporation with **V**ariance Modified **B**owen Ratio

$$\beta = \frac{H}{\lambda E} \approx \frac{\overline{w'T'}}{\overline{w'q'}} = \frac{r_{wT}\sigma_w\sigma_T}{r_{wq}\sigma_w\sigma_q} \approx \frac{\sigma_T}{\sigma_q}$$

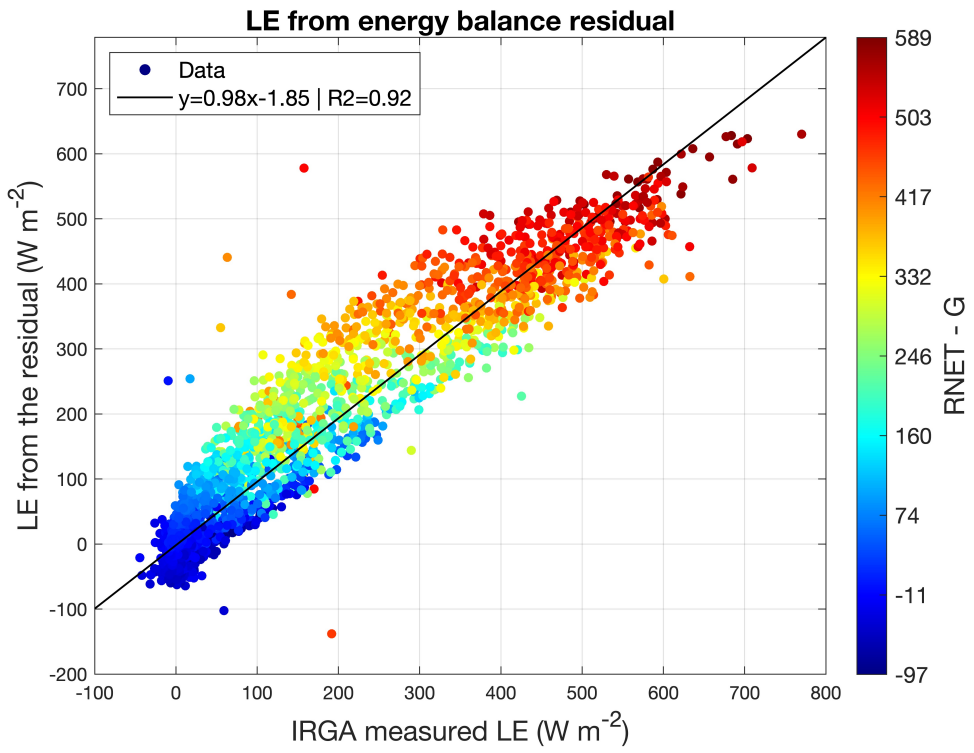
$$\overline{w'T'} = \frac{\overline{w'T_s'}}{1 + \frac{0.51Cp\overline{\overline{T}}}{\lambda\beta}}$$

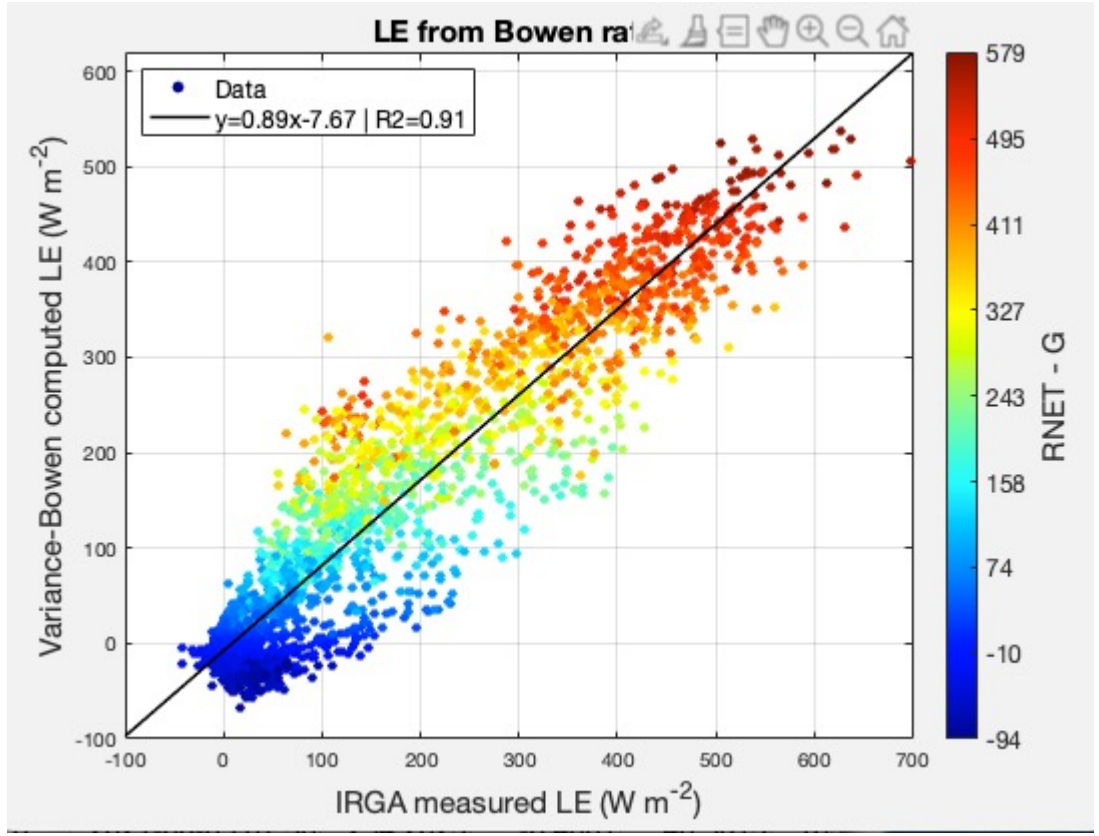
$$H_{VB} = \rho_a \cdot C_p \cdot \overline{w'T'}$$

$$\lambda E = R_{NET} - G - H_{VB}$$

$$\lambda E = \frac{Rn - G}{1 + \beta}$$

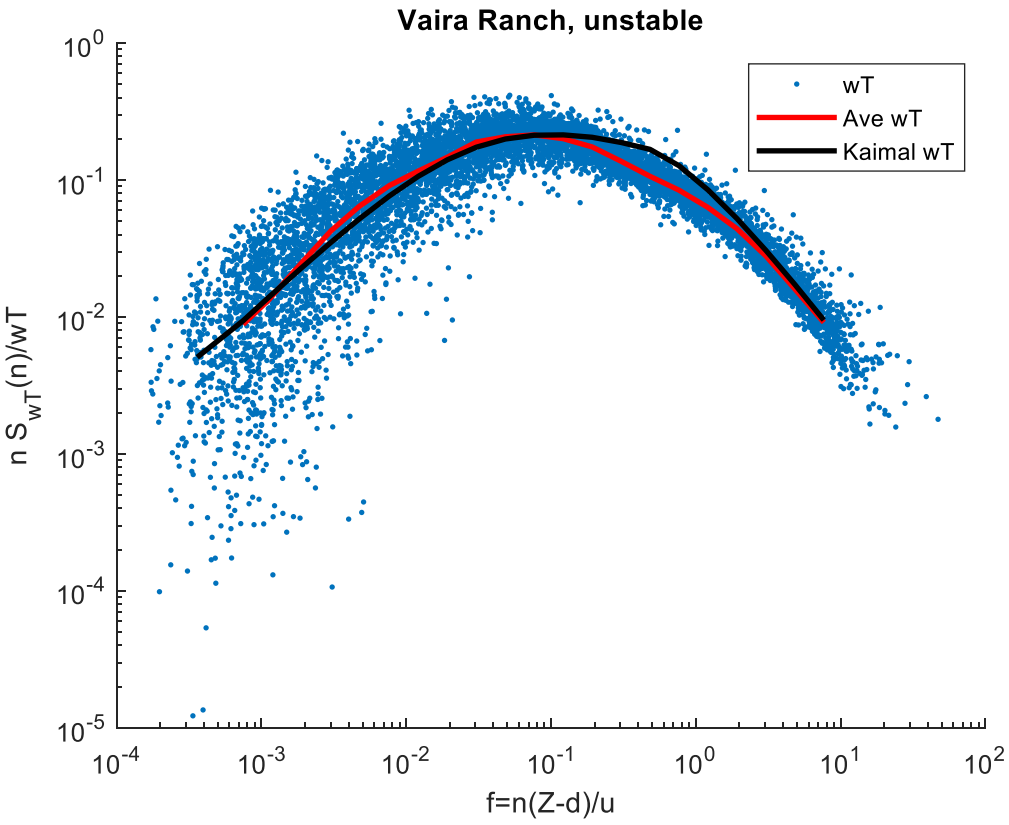
New, Inexpensive and Simple Way to Estimate LE





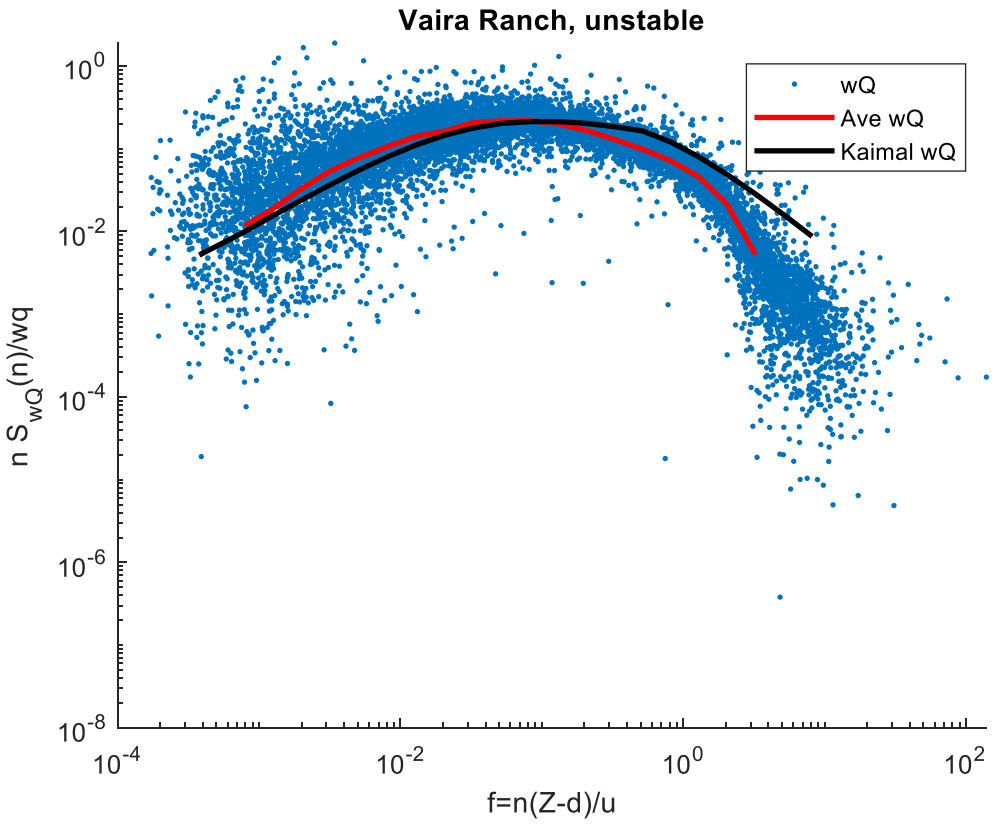
CoSpectral Filtering, 2 m Tower

Heat Flux



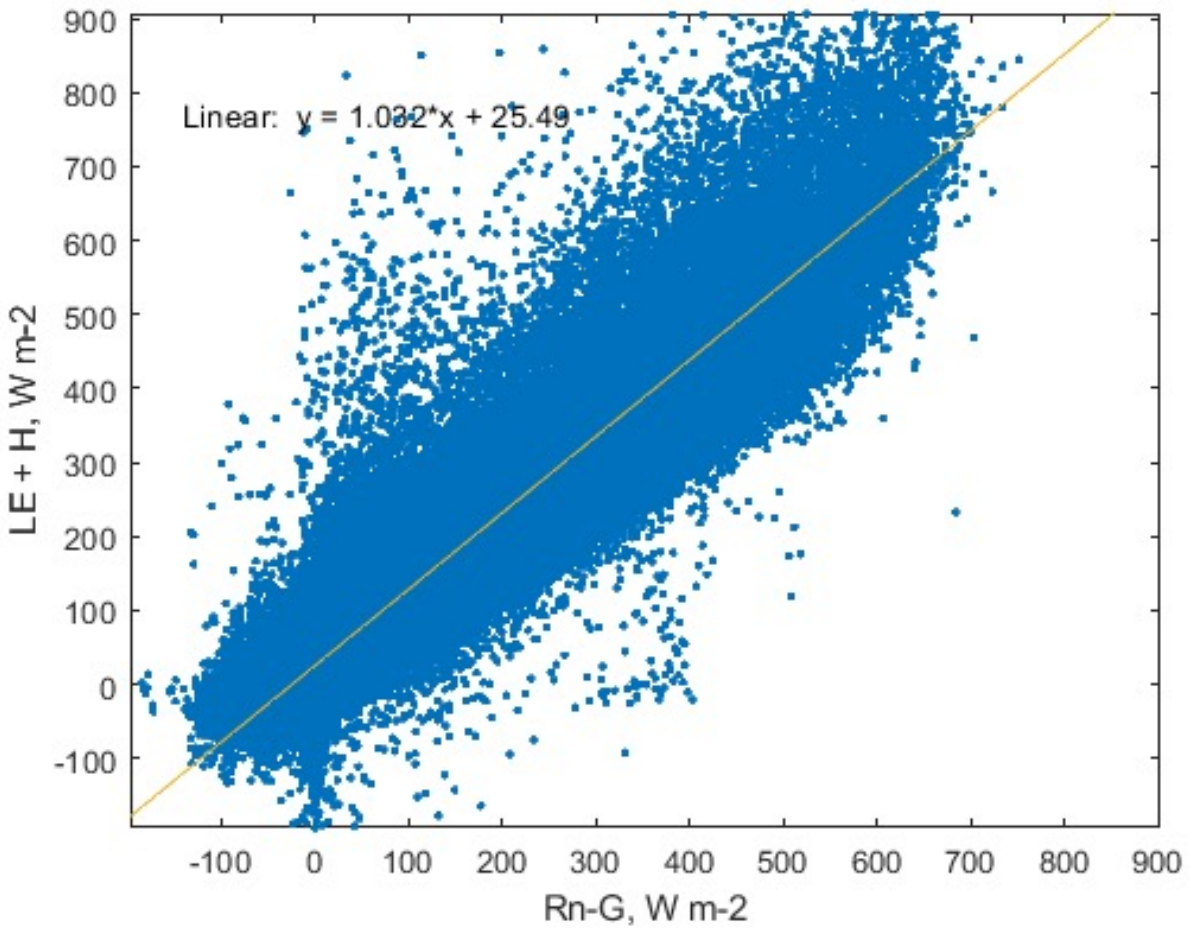
Spectral Filtering= 0.81

Water Flux

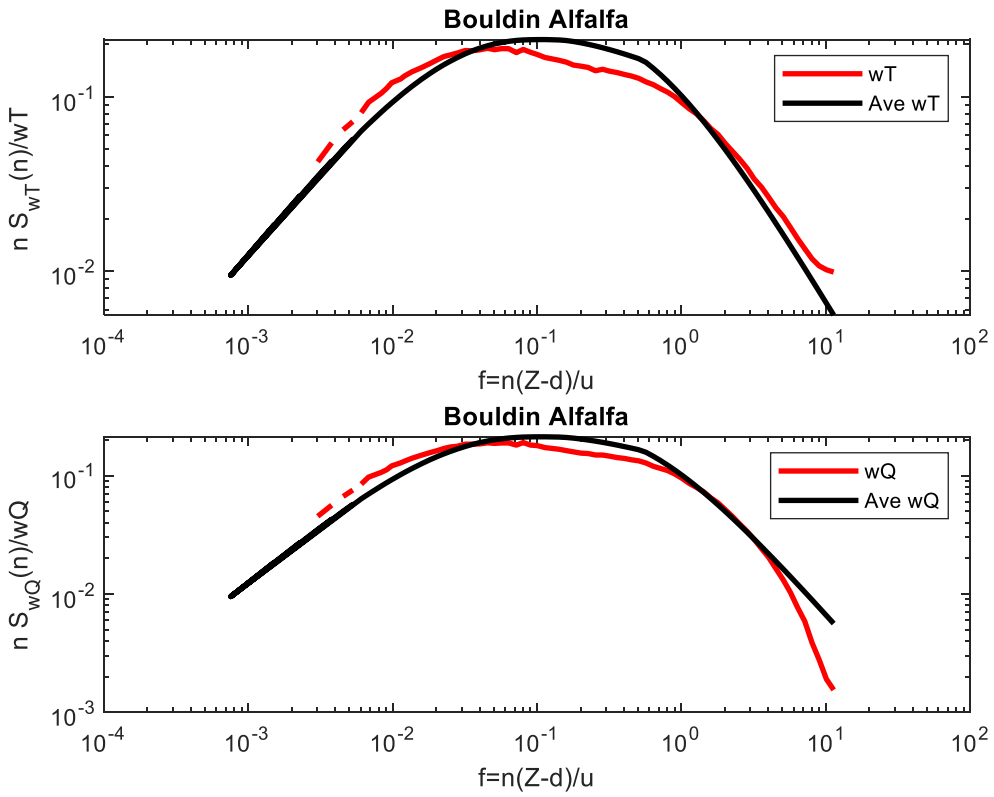


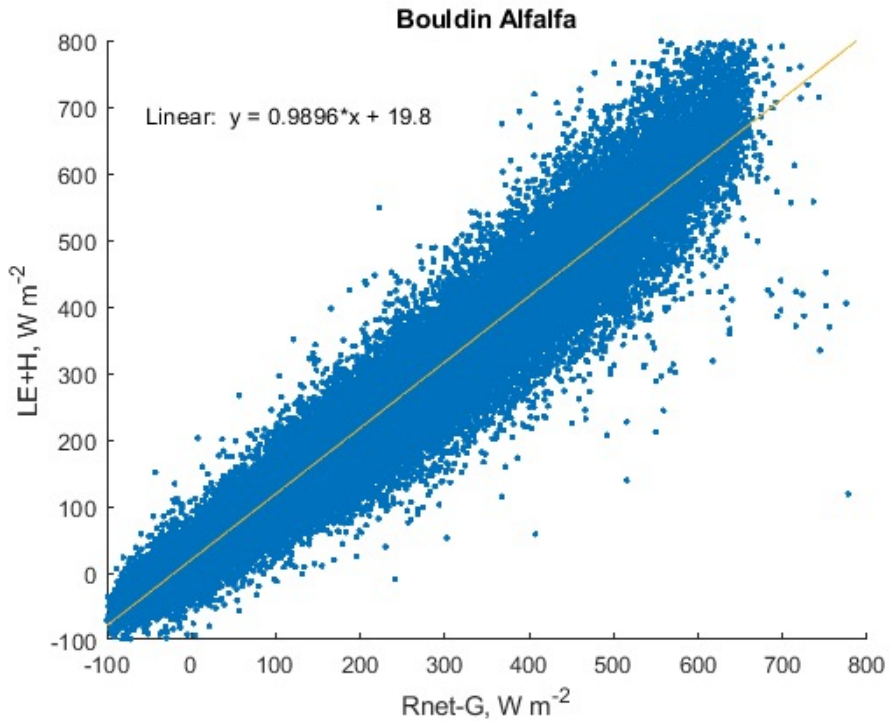
Spectral Filtering= 0.48

Better Energy Balance Closure with Spectral Corrections!!

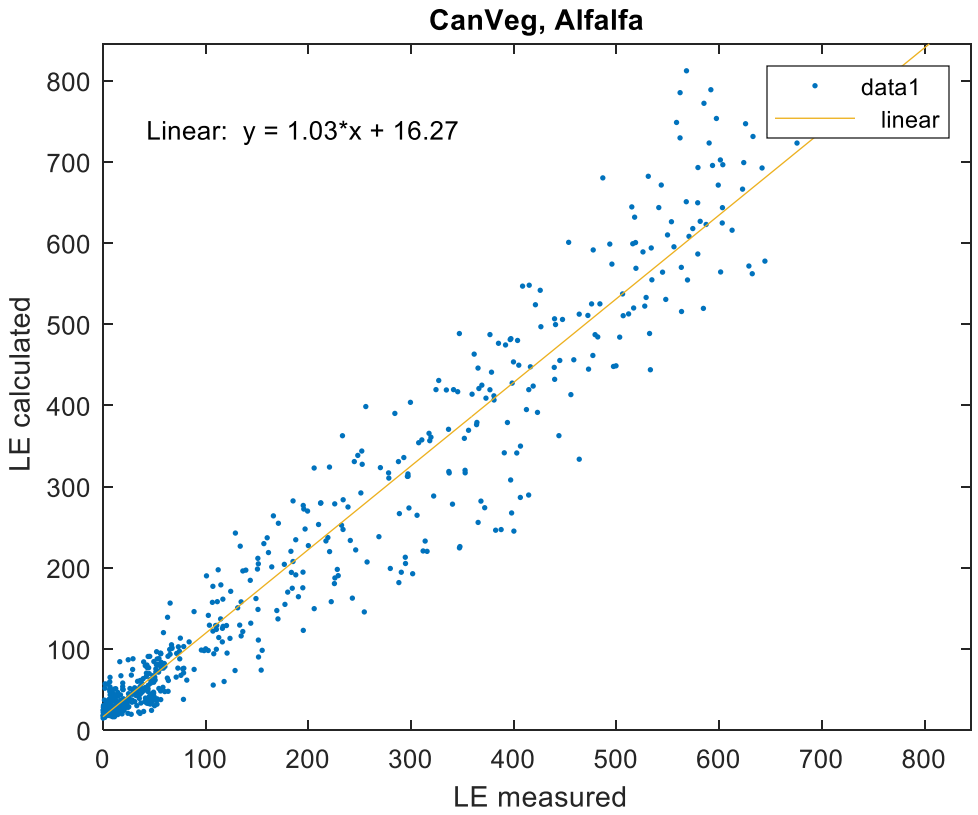


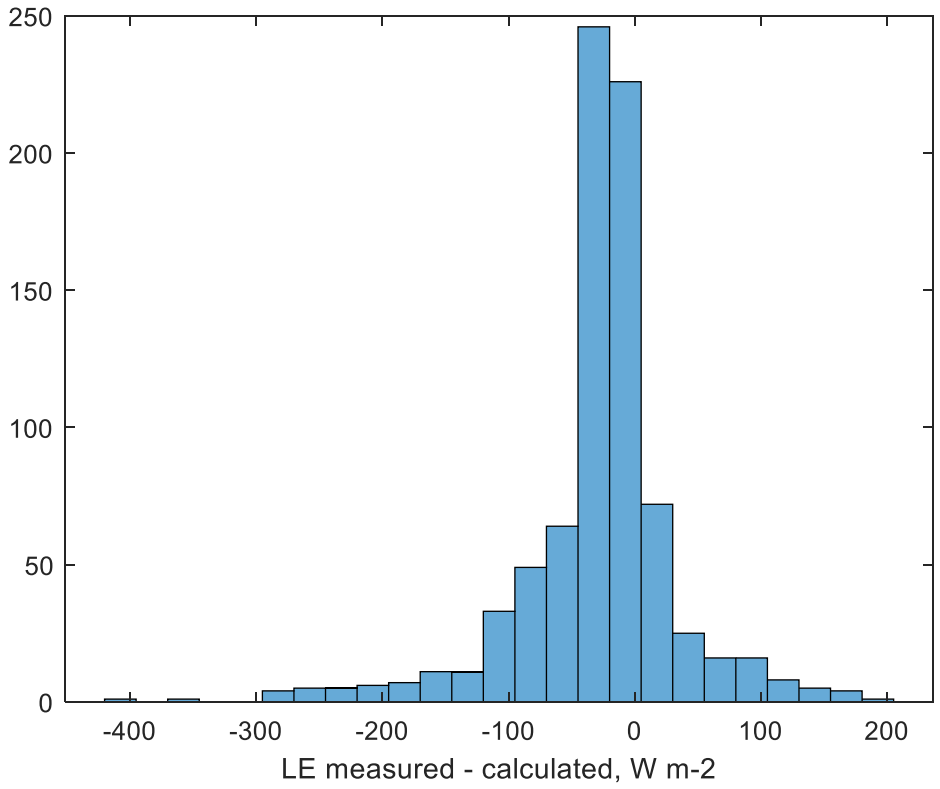
CoSpectral Filter, 4 m Tower



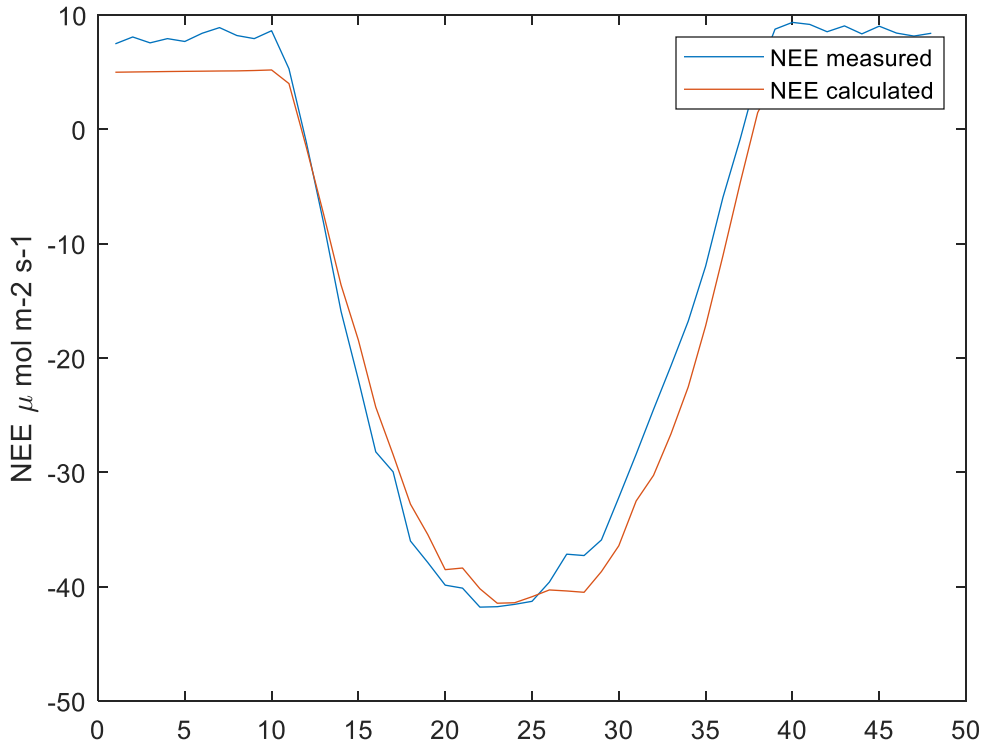


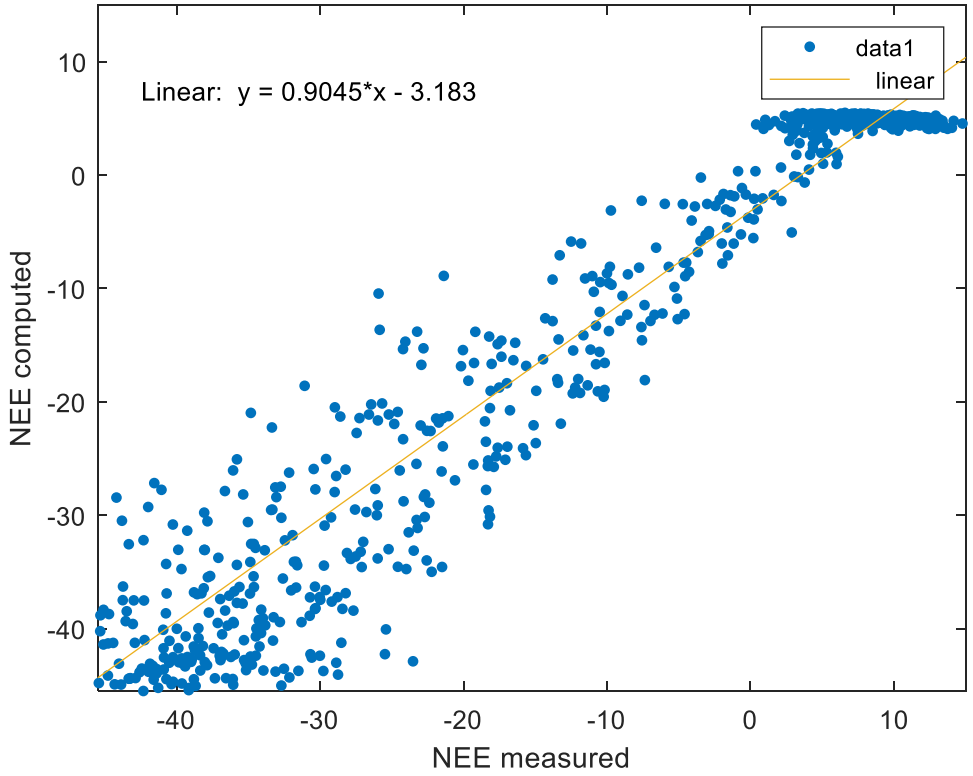
CanVeg Model Test with w'q' spectral correction



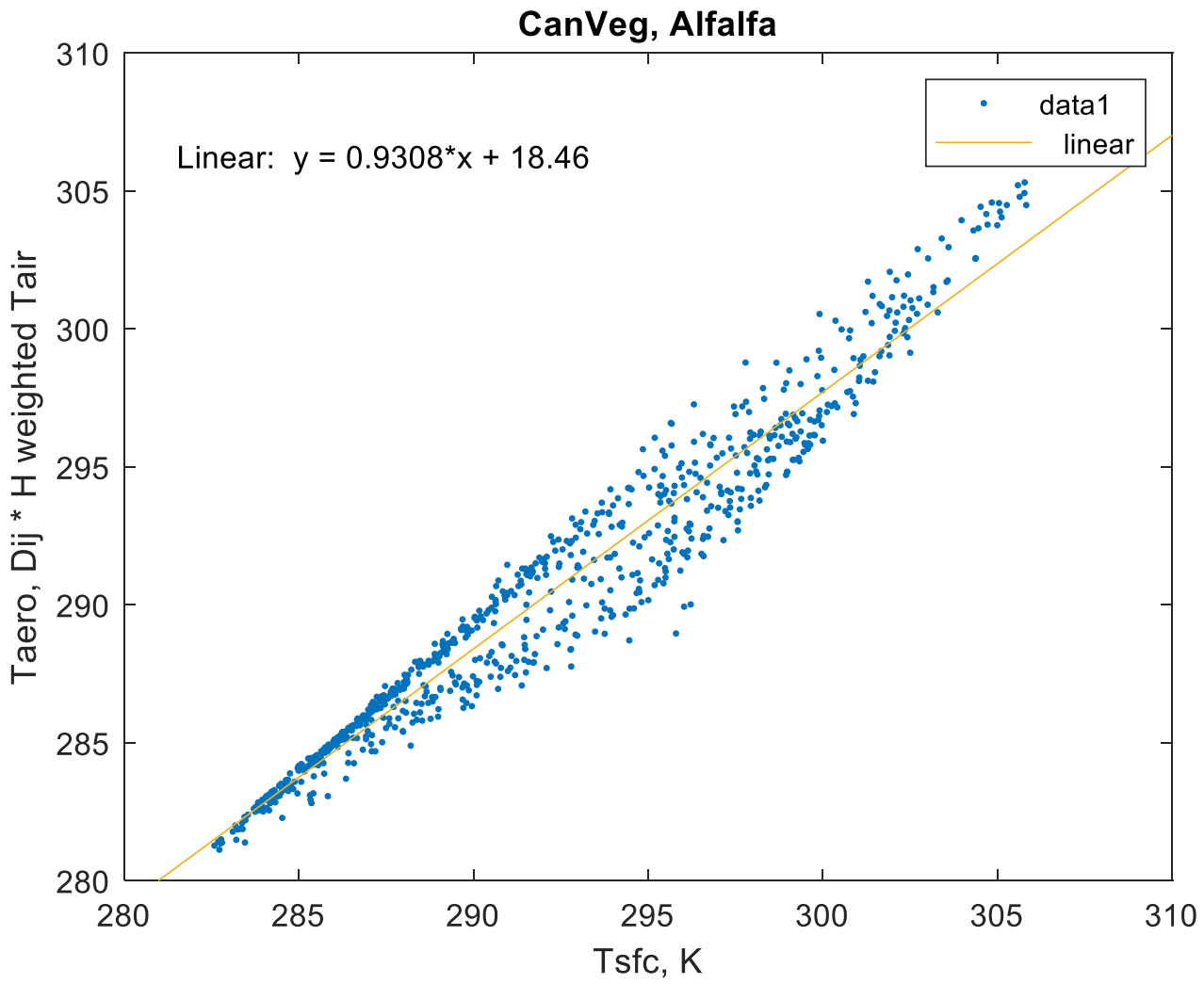


We also Match CO2 Fluxes
Only Inputs Met, LAI and Vcmax…No Tuning…All First Principles and Mechanisms

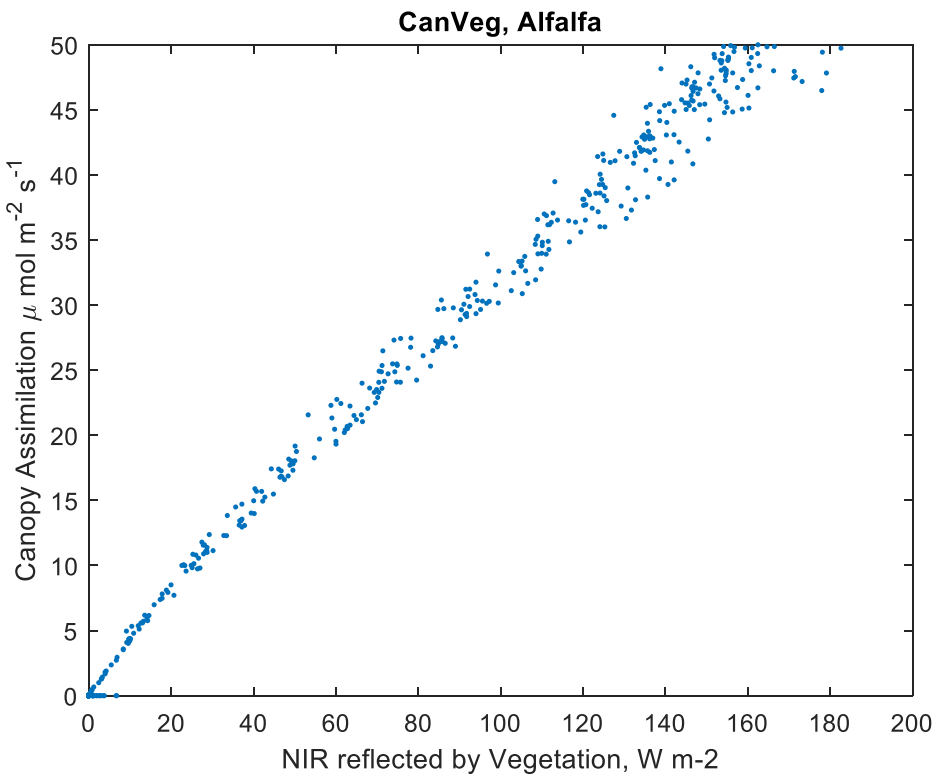


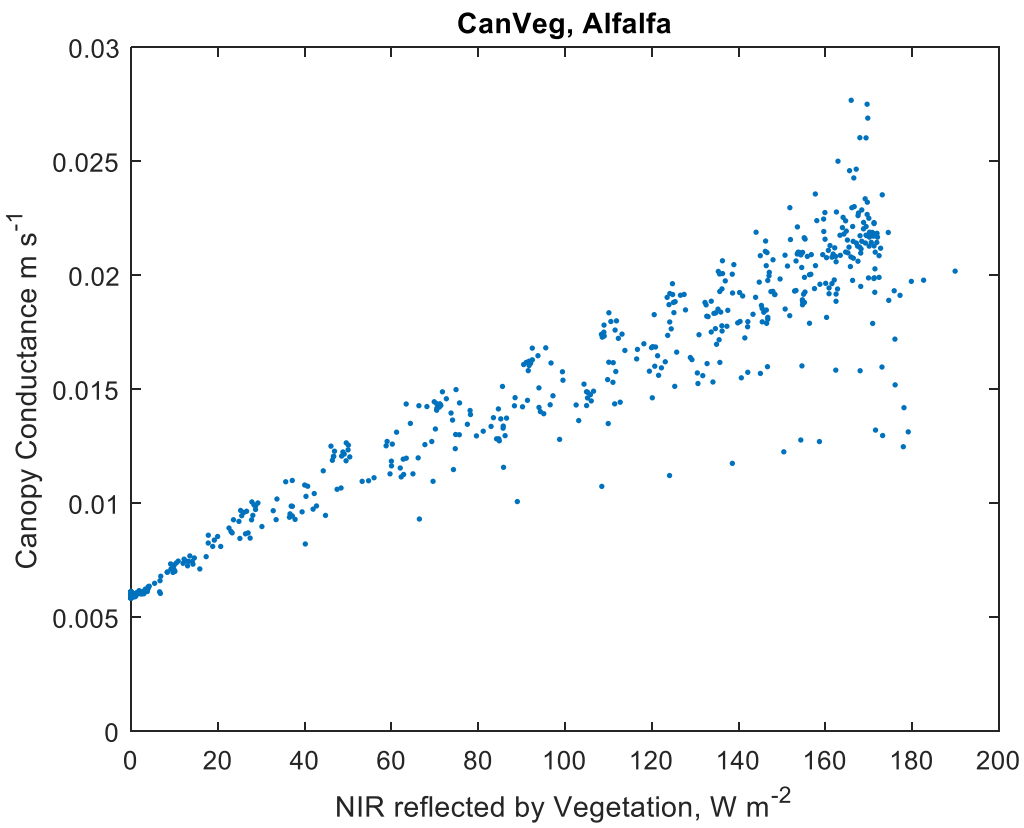


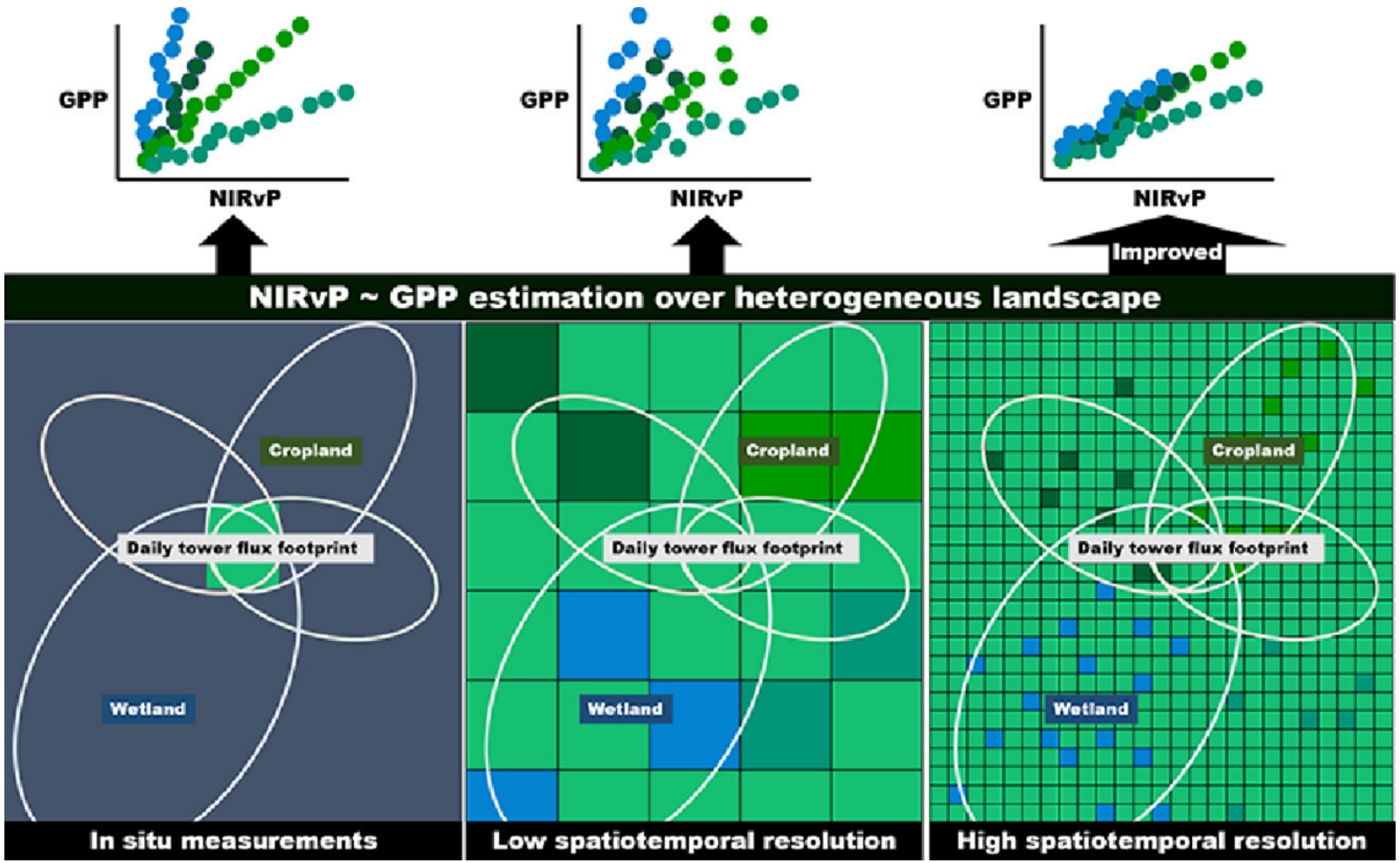
Now We Can Use CanVeg to Address Science Questions Regarding How and Why of Flux Measurements, e.g. Taero vs Tirt



Use Model to support GPP vs NIRv relation and Apply to Spatial Upscaling







Kong, Juwon, Youngryel Ryu, Jiangong Liu, Benjamin Dechant, Camilo Rey-Sanchez, Robert Shortt, Daphne Szutu, Joe Verfaillie, Rasmus Houborg, and Dennis D. Baldocchi. 2022. 'Matching high resolution satellite data and flux tower footprints improves their agreement in photosynthesis estimates', *Agricultural and Forest Meteorology, 316: 108878.*

Water Stress and Available Energy Limits for Terrestrial Evaporation using Day-night Land Surface Temperature

- 2 unknowns, Heat Capacity (Cp) and Available Energy, J_N=H + LE

$$\mathbf{Cp}\,\frac{dT_s(t)}{dt} = G(t) = R_N(t) - LE(t) - H(t)$$

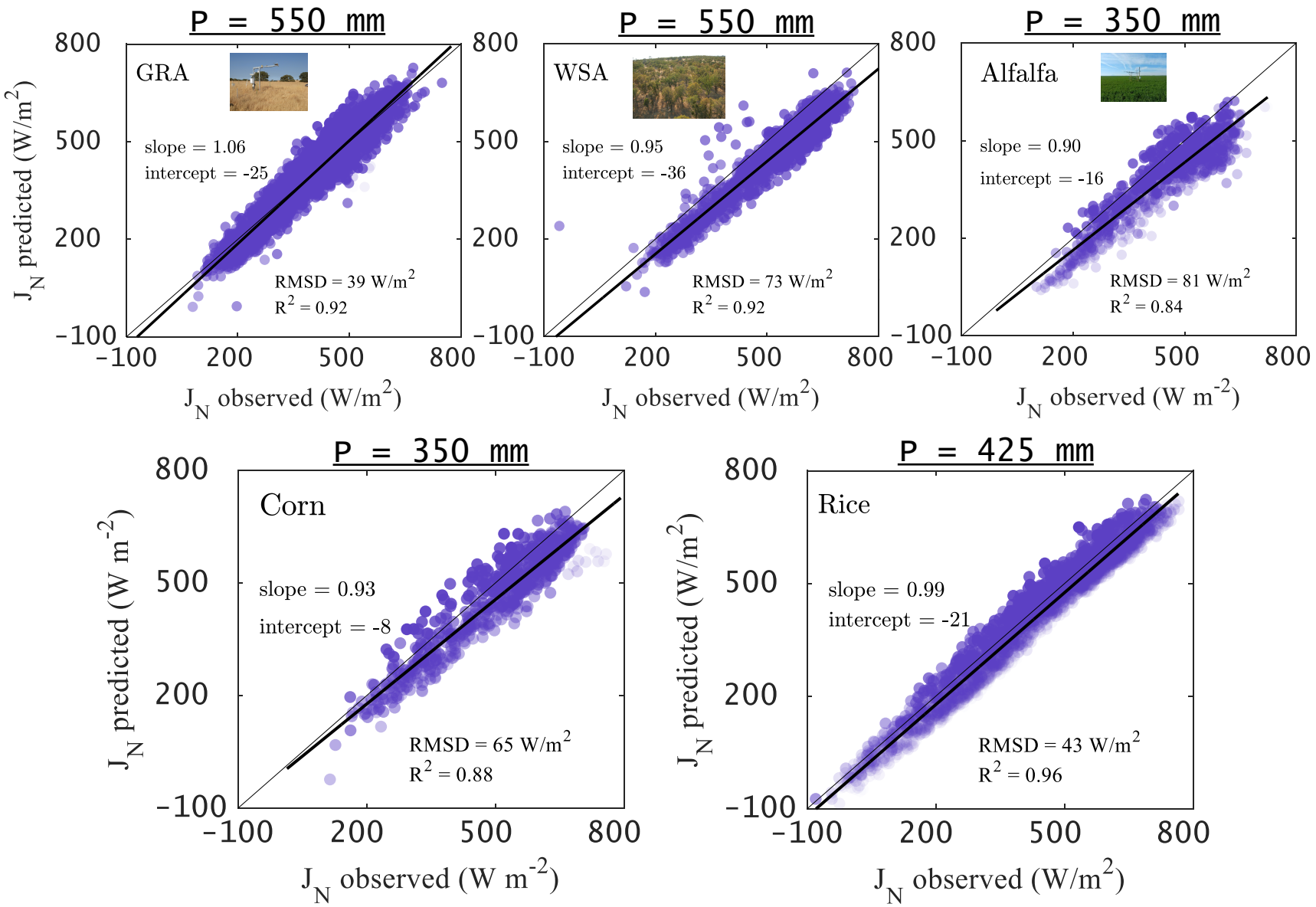
- 2 Equations

$$\Delta T_s(1300) = \frac{\Delta t}{C_p} R_n(1300) - \frac{\Delta t}{C_p} J_N \qquad -\Delta T_s(1300) = \frac{\Delta t}{C_p} R_n(0100)$$

- 2 inputs, Day and Night Thermal Temperature

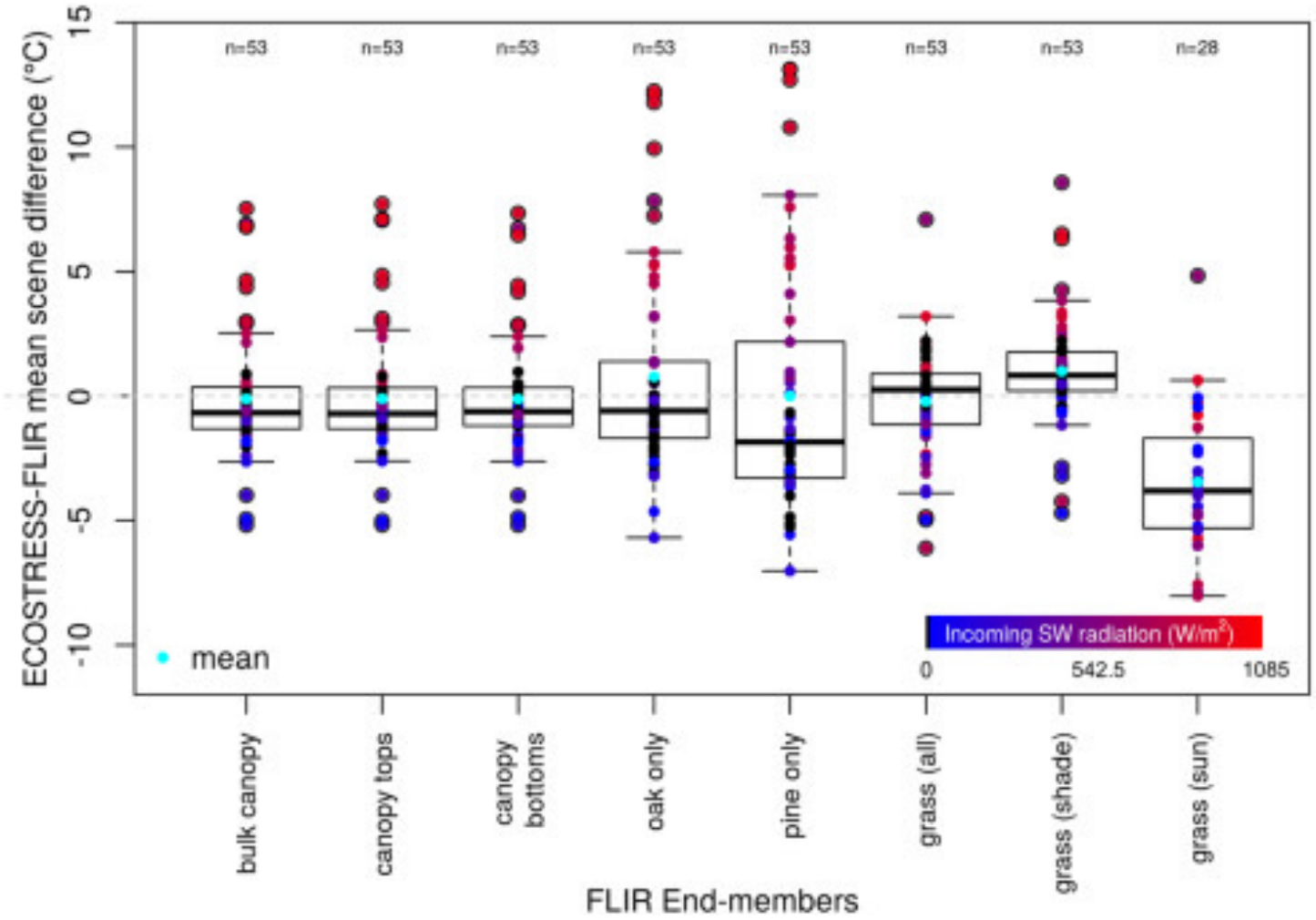
Net available energy (J_N)

- Slope 0.90 – 1.06 (+/- 0.05)
- Explained 84 – 96% variations in observed J_N.
- RMSD 12 – 18%
- Systematic underestimation tendency in some sites



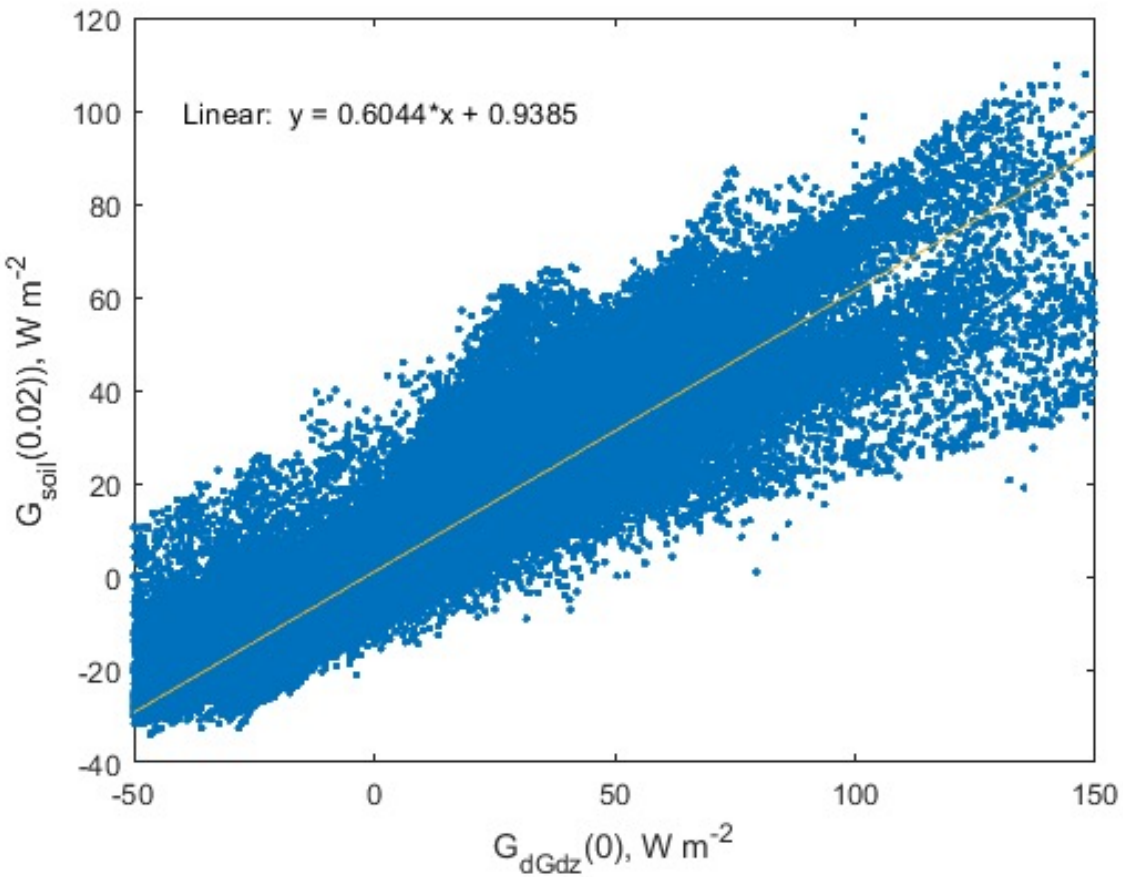
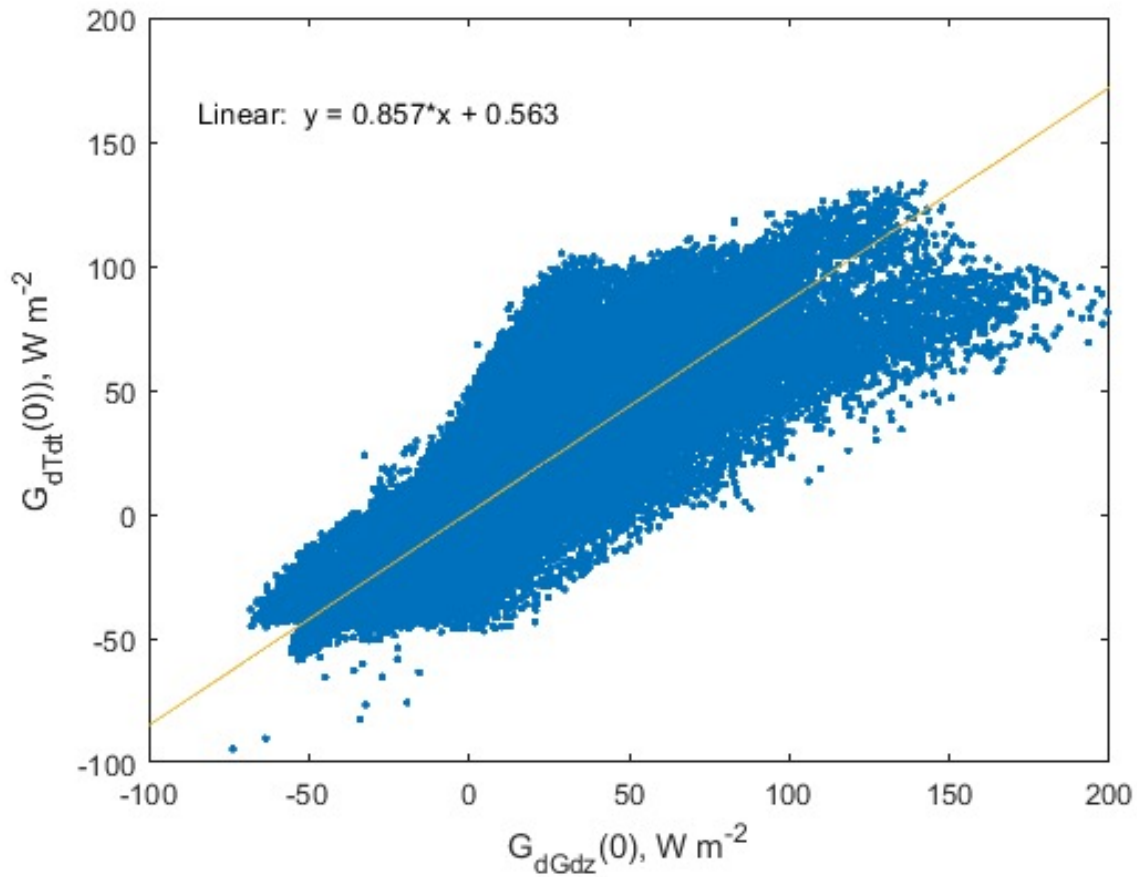
Take Aways

- We need to apply Co-Spectral Filter Correction to w'q' and w'T'
- Advection can be Ubiquitous in Ag Fields and Needs More Investigation
- High Resolution Remote Sensing Is Needed to Interrogate Flux Footprint, for Proper Validation
- Bowen Ratio Method can Be applied to increase Scope/Scale of Spatial Field to Validate ECOSTRESS
- Our Mechanistic, Biophysical Models Work, without Tuning, when Compared to Spectrally Corrected Fluxes
- NIRv has Much Promise to Estimate Gsfc and LE
- Day-Night Temperatures Give us Good information on Available Energy



Johnston, Miriam R., Ana Andreu, Joseph Verfaillie, Dennis Baldocchi, and Paul R. Moorcroft. 2022. 'What lies beneath: Vertical temperature heterogeneity in a Mediterranean woodland savanna', *Remote Sensing of Environment, 274: 112950.*

What Many Do, e.g. Wilson et al.



What We Should Do