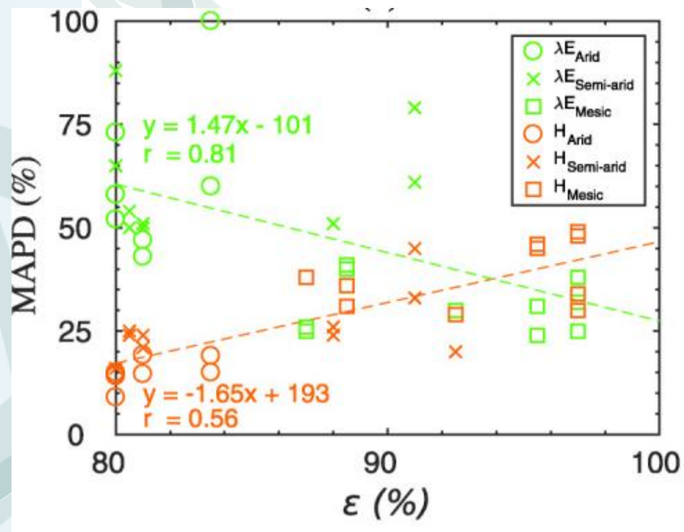
Evapotranspiration mapping across an aridity gradient in conterminous US by combining thermal remote sensing with Penman-Monteith and Shuttleworth-Wallace model



Kanis(h)ka Mallick[1], Nishan Bhattarai[2], Nathaniel Brunsel[3], Ge Sun[4], Meha Jain[2]

[1]Water Safety and Security Research Unit, Department ERIN, Luxembourg Institute of Science and Technology (LIST)

[2]School for Environment and Sustainability, University of Michigan, USA

[3]Geography and Atmospheric Science, University of Kansas, USA

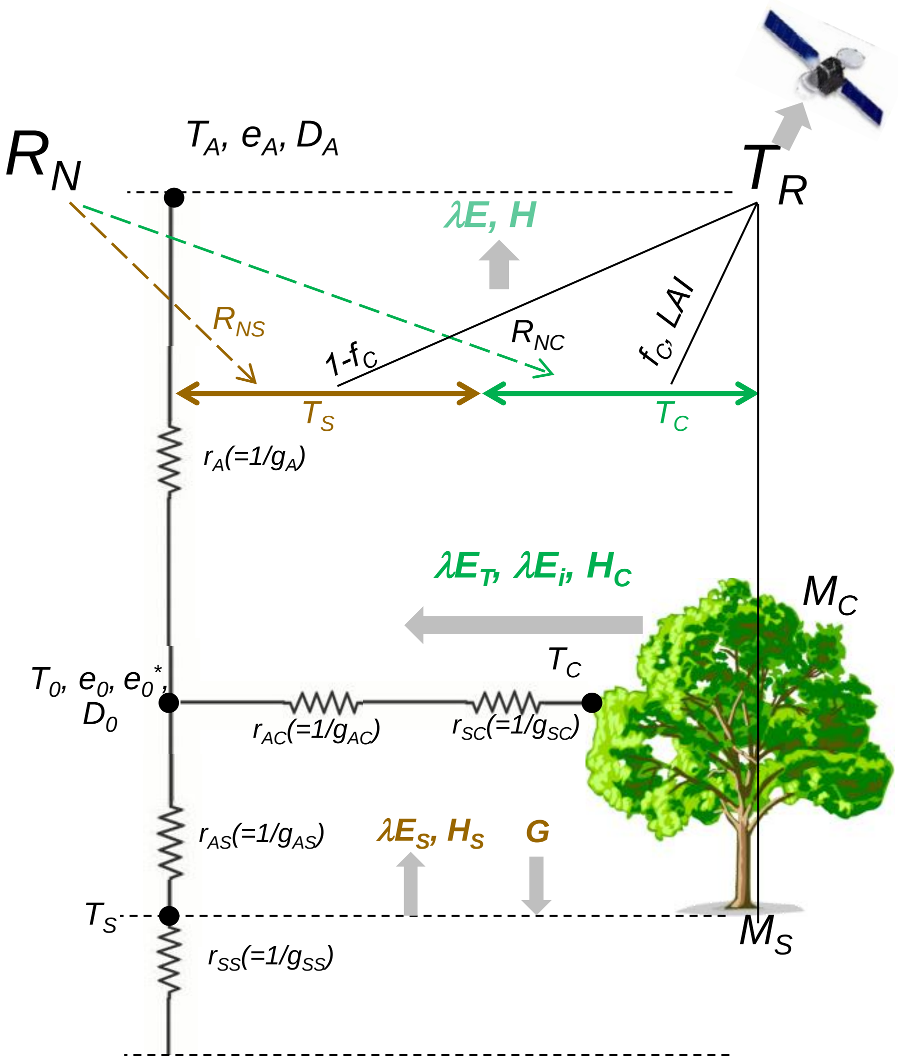
[4]Eastern Forest Environmental Threat Assessment Center, Southern Research Station, US Department of Agriculture Forest Service, Raleigh, USA

[kaniska.mallick@gmail.com; kaniska.mallick@list.lu]

LUXEMBOURG INSTITUTE OF SCIENCE AND TECHNOLOGY | LIST

Summary

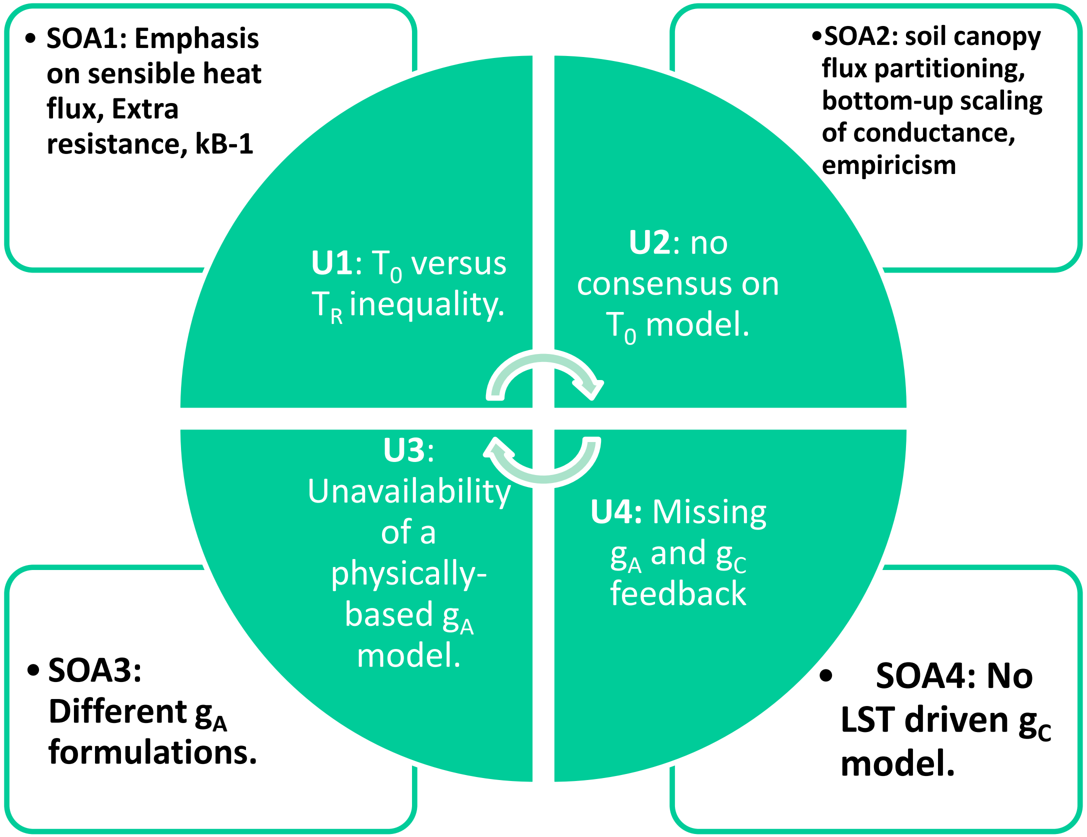
- Challenges in thermal remote sensing of ET.
- Why Penman-Monteith (PM) and Shuttleworth-Wallace (SW)?
- Proposed modeling scheme and characteristics
- Study region and data
- Results
- Conclusion



Explicit surface energy balance representation

State-of-the-art uncertainties / challenges

- Inequality between aerodynamic temperature (T_0) and T_R ($T_0 \neq T_R$)
- Non-unique relationship between T_0 and T_R
- universally agreed T_0 model: unavailable
- Aerodynamic conductance (g_A): Semi-empirical
- Canopy conductance (g_C): oversighting the role of LST on g_C.

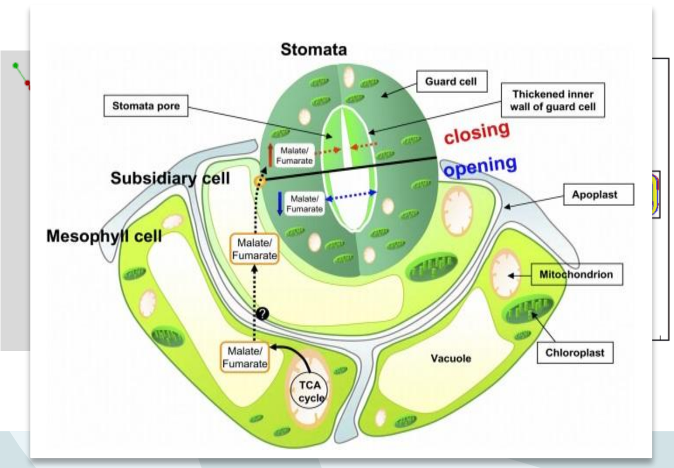


Why PM and SW?

Penman-Monteith (Monteith, 1965, 1981)

$$\lambda E_{PM} = \frac{s\phi + \rho c_P g_A D_A}{s + \gamma\left(1 + \frac{g_A}{g_C}\right)}$$

$\phi = R_N - G$, $s = f\{T_A\}$



Shuttleworth-Wallace (Shuttleworth and Wallace, 1985)

$$\lambda E_{SW} = \frac{s\phi_C + \rho c_P g_A^C D_0}{s + \gamma\left(1 + \frac{g_A^C}{g_S^C}\right)} + \frac{s\phi_S + \rho c_P g_A^S D_0}{s + \gamma\left(1 + \frac{g_A^S}{g_S^S}\right)}$$

$$D_0 = D_A + \frac{\{s\phi - (s + \gamma)\lambda E_{PM}\} g_A}{\rho c_P}$$

g_A = aerodynamic conductance
g_C = canopy (surface) conductance

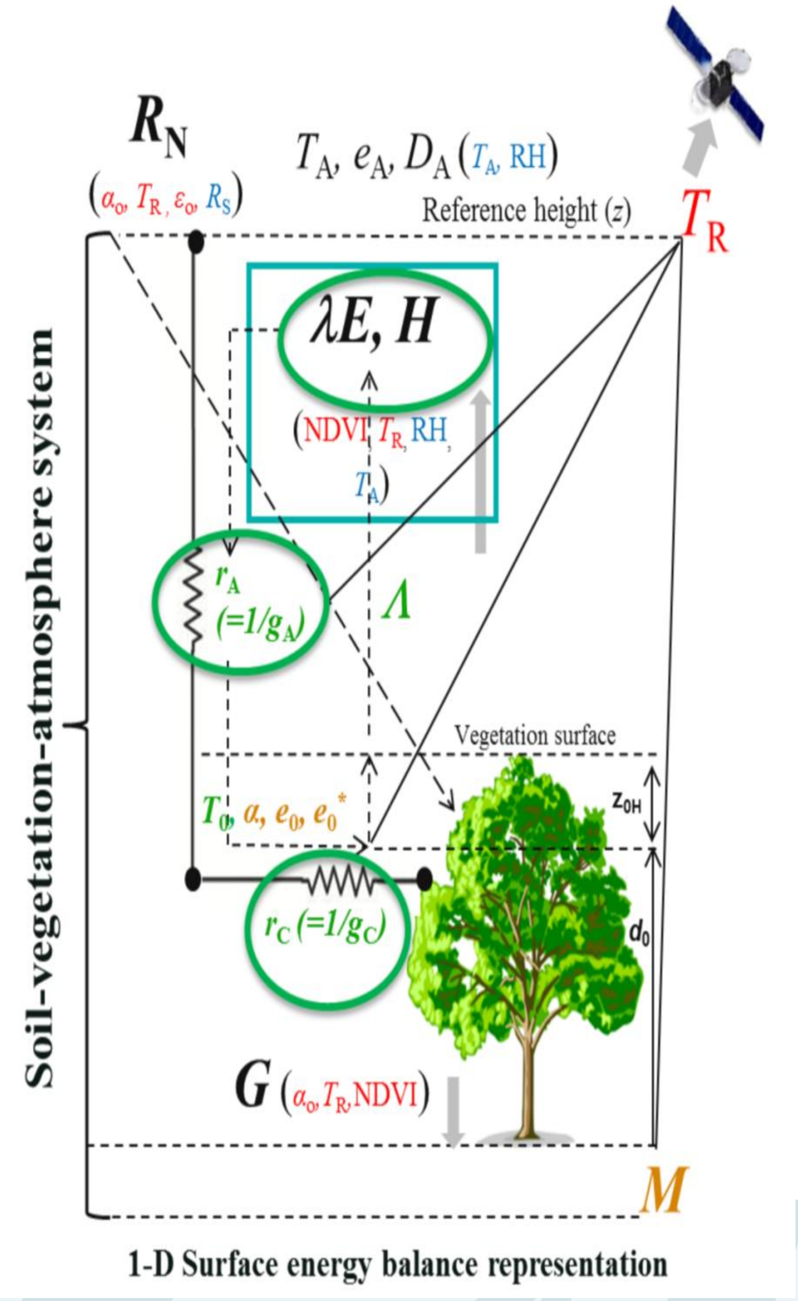
Integrating LST into PM-SW

STIC (Surface Temperature Initiated Closure)

$$\lambda E_{PM} = \frac{s\phi + \rho c_P g_A D_A}{s + \gamma\left(1 + \frac{g_A}{g_C}\right)}$$

$$sv_1 = f\{c_1, c_2, c_3, v_1, v_2, v_3, v_4, sv_3, sv_5\}$$
$$sv_2 = f\{v_3, v_4, sv_1, sv_5, sv_6\}$$
$$sv_3 = f\{c_3, v_3, v_4, sv_4, sv_5\}$$
$$sv_4 = f\{c_3, v_3, sv_1, sv_2, sv_7, sv_8\}$$

$$sv_5 = f\{c_1, c_2, c_3, v_1, v_2, v_3, v_4, sv_1, sv_2, \lambda E_{PM}\}$$
$$sv_6 = f\{c_1, c_2, c_3, v_3, v_4, sv_1, sv_2, \lambda E_{PM}\}$$
$$sv_7 = f\{c_1, c_2, c_3, v_3, v_4, sv_1, sv_2, sv_3, sv_6, sv_8\}$$
$$sv_8 = f\{v_3, v_4, v_5, sv_1, \lambda E_{PM}\}$$



Bhattarai et al., 2018; Mallick et al., 2016, 2018

Characteristics

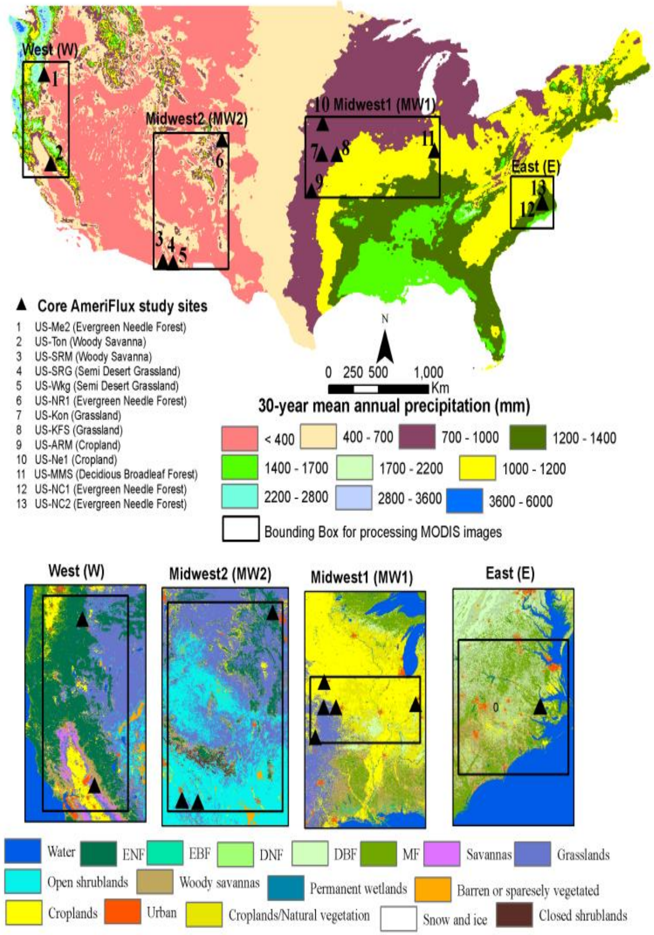
Functional

- Fully analytical
- LST, aerodynamic conductance and vapor pressure feedback
- Simultaneous ET partitioning
- Application potential: both LEO and GEO

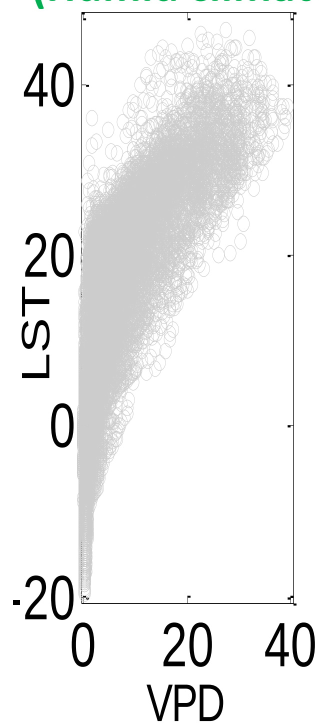
Structural

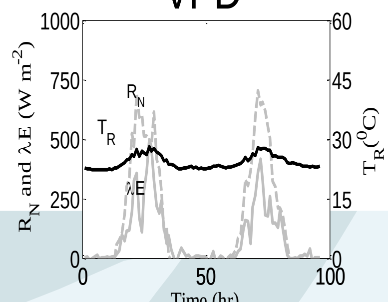
- Physical integration of LST: combining PM and SW to solve D_0
- No land surface parameterization for the conductances
- Direct estimation of ET and H
- Numerical estimation: Conductances, Priestley-Taylor α (as a time varying quantity, instead of a fixed value), canopy-air stream properties.
- Inputs: R_N, G, T_A, R_H or e_A, and LST (or TR).

Evaluation: across an aridity gradient
([Bhattarai, Mallick et al., 2018](#))



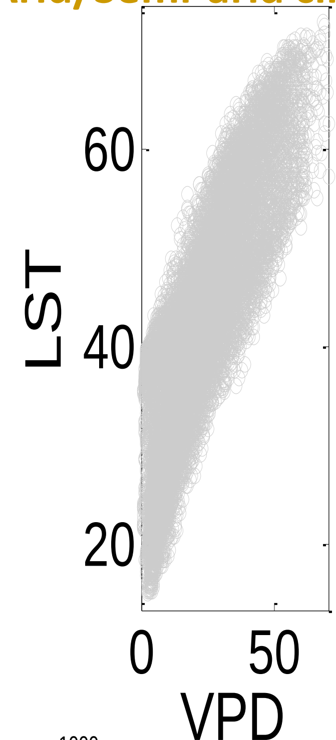
Radiation controlled (Humid climate)

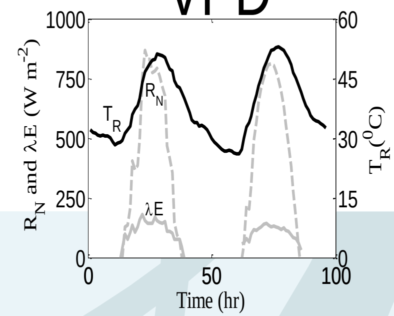




ET : 60 to 80% of R_N

Water controlled (Arid/Semi-arid climate)



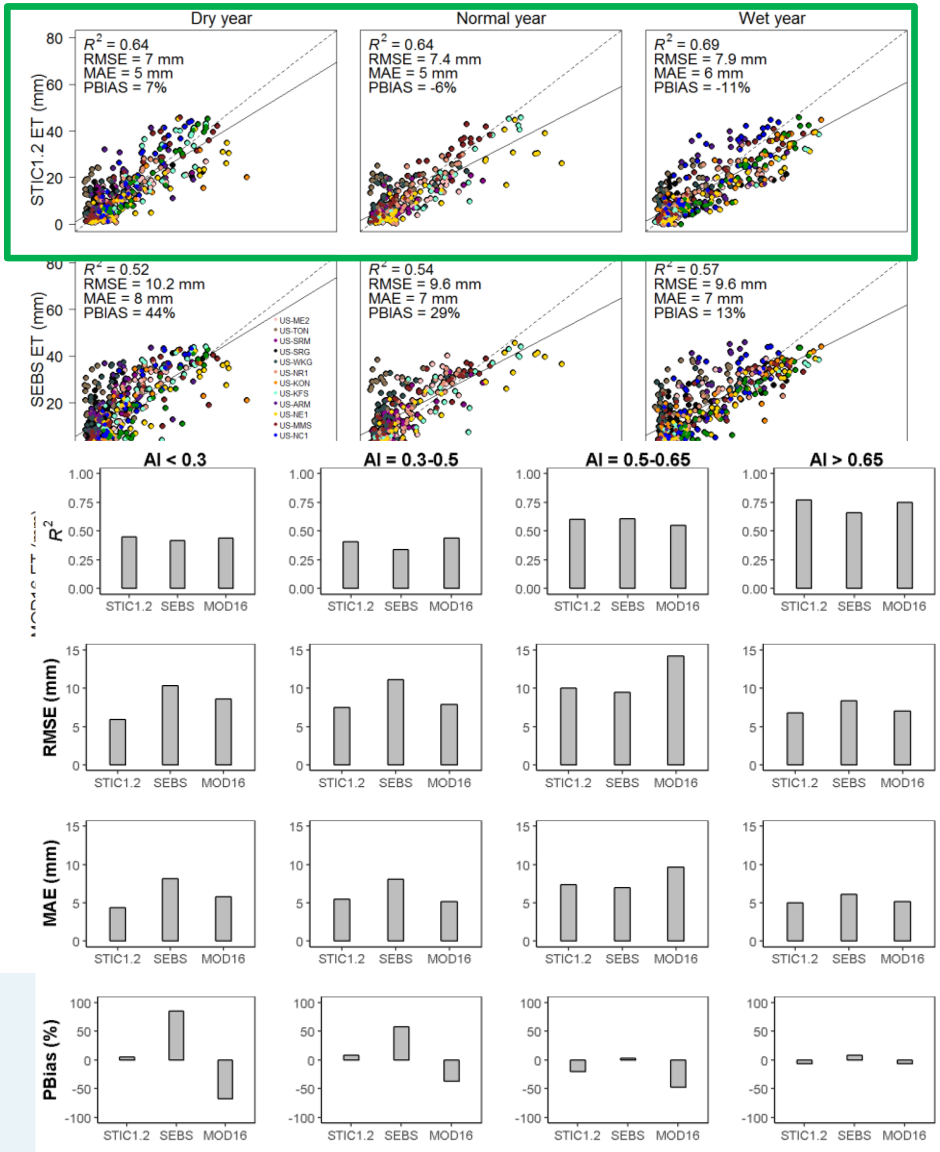


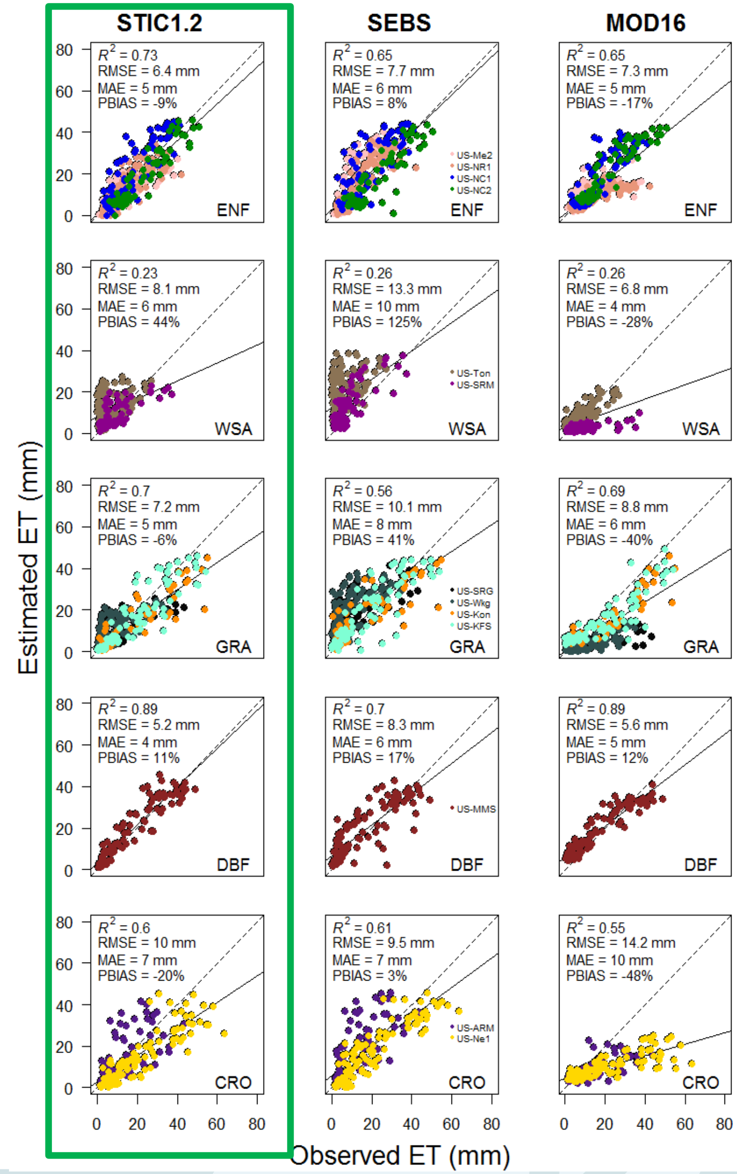
ET : 15 to 30% of R_N

Data : MODIS LST, surface reflectances, NLDAS meteorology

Evaluation and model intercomparison

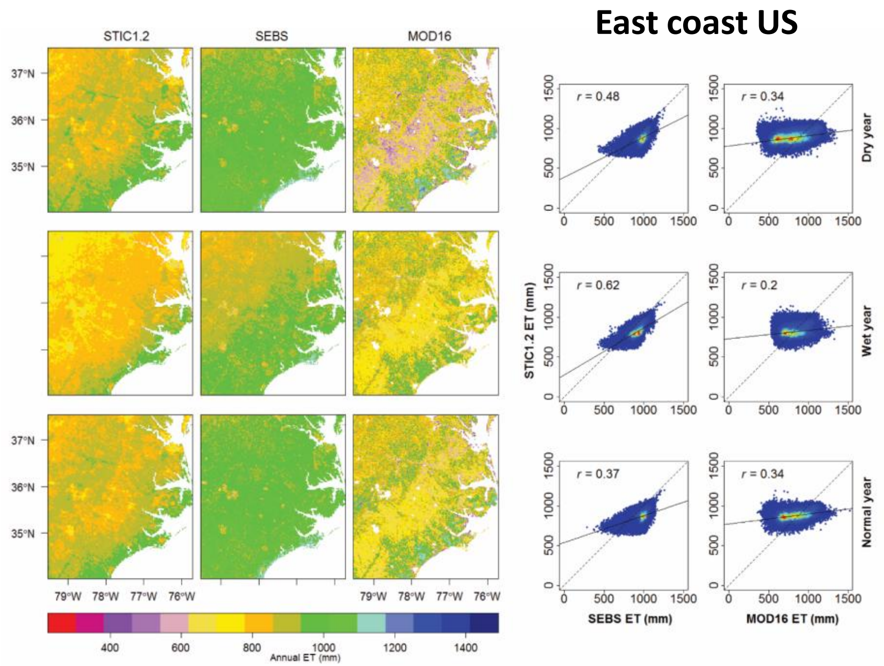
(Precipitation extreme, biome, aridity)

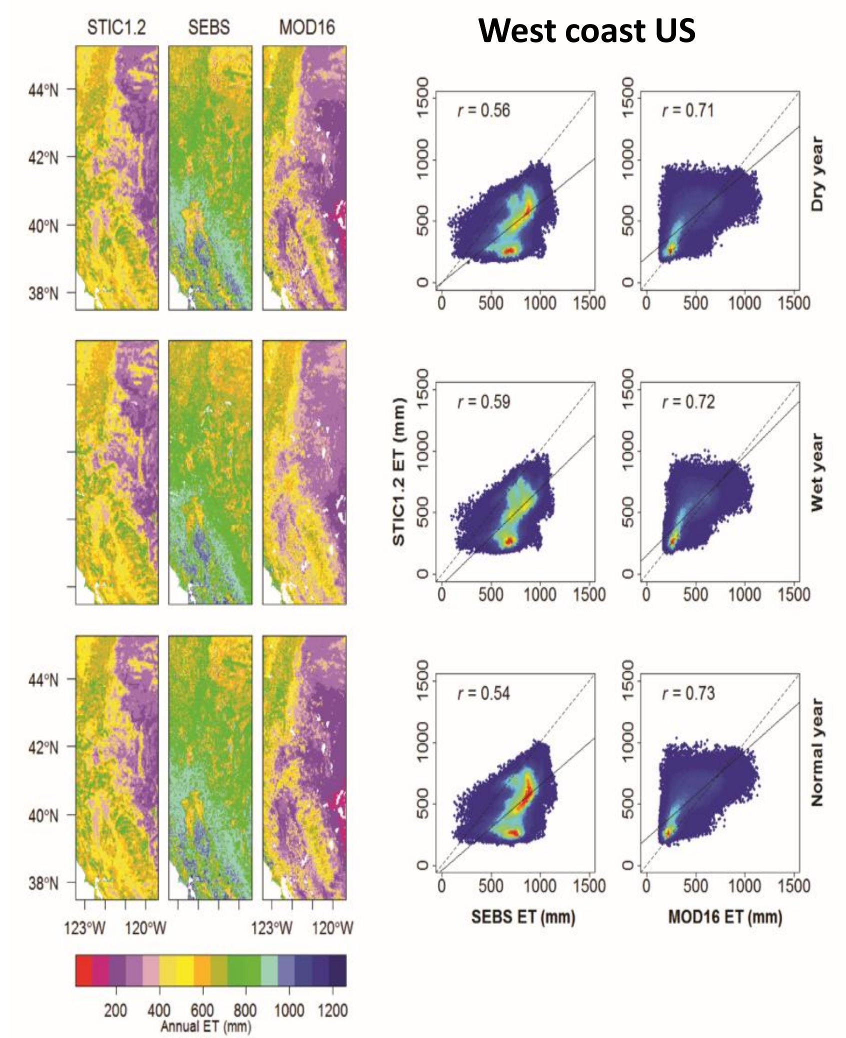


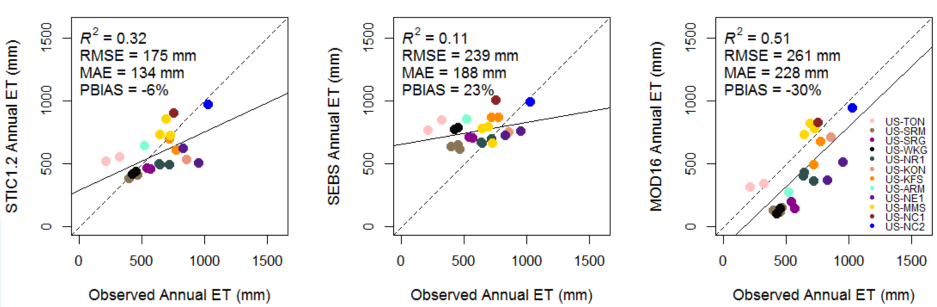


Bhattarai, Mallick et al., 2018

Annual ET distribution and evaluation

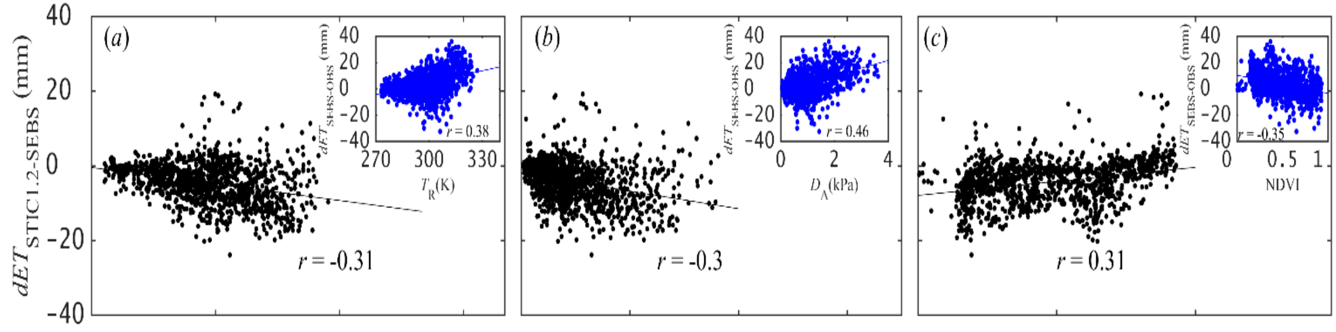




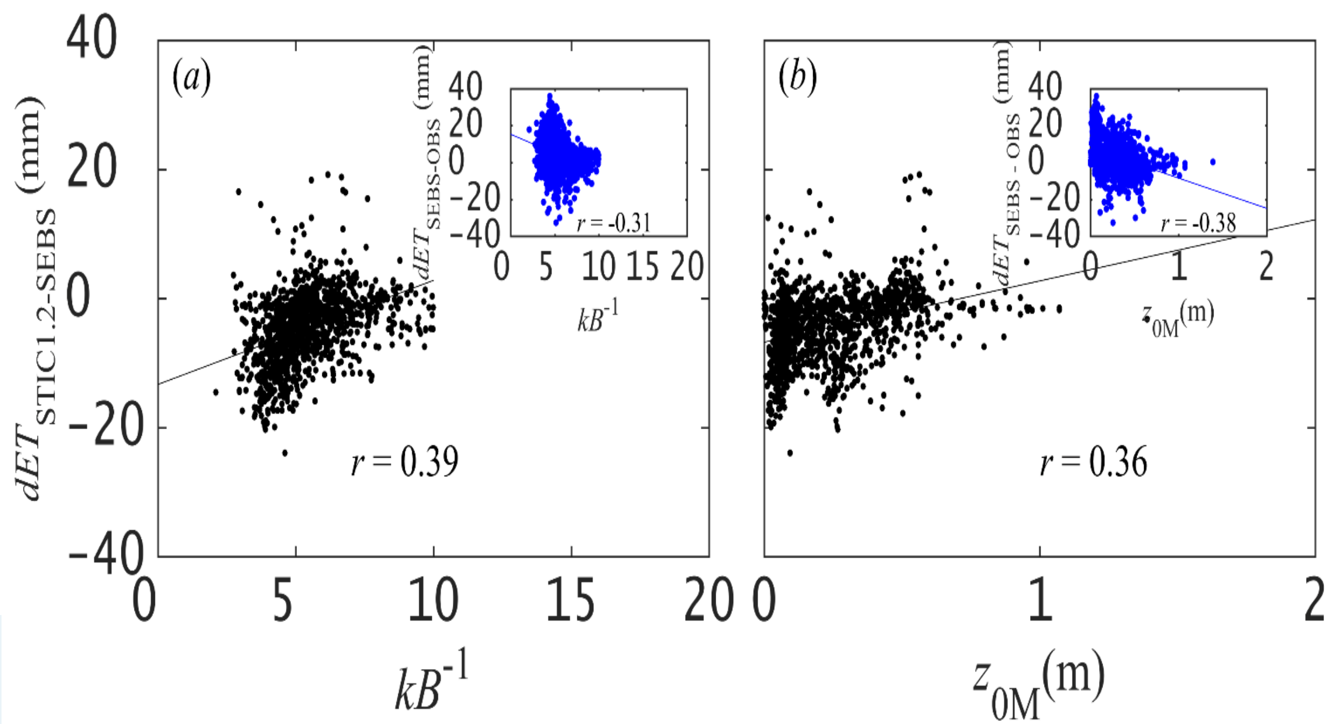


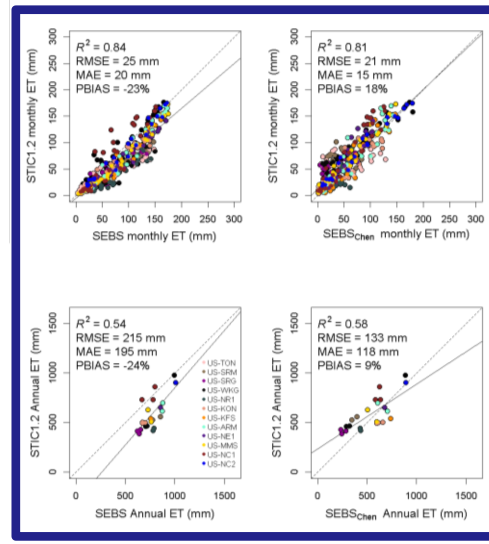
Model differences: Forcings versus parameterizations

(**Bhattarai, Mallick et al., 2018**)



- Overestimation SEBS: high T_R and D_A, low NDVI.
- Major ET difference: kB^{-1} (2 – 6)





Interpretation

- STIC1.2 explained significant variability in the observed 8-day cumulative ET, RMSE<1 mm/d
- Smallest errors in forests, followed by grassland, cropland, and woody savannas.
- Underestimation of ET in croplands: spatial-scale mismatch between a MODIS pixel and the flux tower footprint
- Overestimation of ET in woody savannas: large uncertainties in the MODIS LST product, SEB closure correction of EC ET observations, single-source approximations.
- Difference between STIC1.2 and SEBS: Differences in g_A estimation between the two models.
- Empirical characterization of z_{0M} and kB^{-1} in SEBS: major factors creating uncertainties in aerodynamic conductance and ET estimations.

Thank you!!

Hydrol. Earth Syst. Sci., 22, 2311–2341, 2018
https://doi.org/10.5194/hess-22-2311-2018

Hydrology and Earth System Sciences
Open Access
EGU

Regional evapotranspiration from an image-based implementation of the Surface Temperature Initiated Closure (STIC1.2) model and its validation across an aridity gradient in the conterminous US

Nishan Bhattarai[1], Kaniska Mallick[2], Nathaniel A. Brunsell[3], Ge Sun[4], and Meha Jain[1]

[1]School for Environment and Sustainability, University of Michigan, Ann Arbor, MI 48109, USA
[2]Remote Sensing and Ecohydrological Modeling, Water Security and Safety Research Unit, Dept. ERIN, Luxembourg Institute of Science and Technology (LIST), 4422 Belvaux, Luxembourg
[3]Geography and Atmospheric Science, University of Kansas, Lawrence, KS 66045, USA
[4]Eastern Forest Environmental Threat Assessment Center, Southern Research Station, US Department of Agriculture Forest Service, Raleigh, NC 27606, USA

Correspondence: Nishan Bhattarai (nbhattar@umich.edu)

Received: 30 August 2017 – Discussion started: 11 September 2017
Revised: 19 March 2018 – Accepted: 19 March 2018 – Published: 18 April 2018

AGU100 ADVANCING EARTH AND SPACE SCIENCE

Water Resources Research

RESEARCH ARTICLE
10.1029/2017WR021357

Special Section:
Hydrology Delivers Earth System Sciences to Society (HESSS4): Improving and Integrating Knowledge Across Disciplines on Global Energy, Water and Carbon Cycles

Bridging Thermal Infrared Sensing and Physically-Based Evapotranspiration Modeling: From Theoretical Implementation to Validation Across an Aridity Gradient in Australian Ecosystems

Key Points:
- Thermal remote sensing of evapotranspiration is critical due to uncertainties in aerodynamic temperature and conductance estimation
- We integrated radiometric temperature into Penman-Monteith Shuttleworth-Wallace framework to directly estimate conductances and evapotranspiration
- Moderate to low systematic errors in evapotranspiration across an aridity gradient in Australia

Kaniska Mallick[1], Erika Toivonen[1,2,3,4], Ivonne Trebs[1], Eva Boegh[5,6], James Cleverly[7], Derek Eamus[7], Harri Koivusalo[2], Darren Drewry[8,9], Stefan K. Arndt[10], Anne Griebel[10], Jason Beringer[11], and Monica Garcia[12,13]

[1]Department of Environmental Research and Innovation, Luxembourg Institute of Science and Technology, Belvaux, Luxembourg, [2]Department of Built Environment, Aalto University School of Engineering, Espoo, Finland, [3]Climate System Research, Finnish Meteorological Institute, Helsinki, Finland, [4]Department of Physics, University of Helsinki, Helsinki, Finland, [5]Department of Science and Environment, Roskilde University, Roskilde, Denmark, [6]Now at Danish Agency for Data Supply and Efficiency, Copenhagen, Denmark, [7]Terrestrial Ecohydrology Research Group, School of Life Sciences, University of Technology Sydney, Broadway, NSW, Australia, [8]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, [9]Joint Institute for Regional Earth System Science and Engineering, University of California, Los Angeles, CA, USA, [10]School of Ecosystem and Forest Sciences, University of Melbourne, Melbourne, Vic, Australia, [11]School of Agriculture and Environment, University of Western Australia, Crawley, WA, Australia, [12]Department of Environmental Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark, [13]International Research Institute for Climate and Society, Earth Institute, Columbia University, Palisades, NY, USA

Hydrol. Earth Syst. Sci., 20, 4237–4264, 2016
www.hydrol-earth-syst-sci.net/20/4237/2016/
doi:10.5194/hess-20-4237-2016

Hydrology and Earth System Sciences
Open Access
EGU

Canopy-scale biophysical controls of transpiration and evaporation in the Amazon Basin

Kaniska Mallick[1], Ivonne Trebs[1], Eva Boegh[2], Laura Giustarini[1], Martin Schlerf[1], Darren T. Drewry[3,12], Lucien Hoffmann[1], Celso von Randow[4], Bart Kruijt[5], Alessandro Araùjo[6], Scott Saleska[7], James R. Ehleringer[8], Tomas F. Domingues[9], Jean Pierre H. B. Ometto[4], Antonio D. Nobre[4], Osvaldo Luiz Leal de Moraes[10], Matthew Hayek[11], J. William Munger[11], and Steven C. Wofsy[11]

[1]Department of Environmental Research and Innovation, Luxembourg Institute of Science and Technology (LIST), L4422, Belvaux, Luxembourg
[2]Department of Science and Environment, Roskilde University, Roskilde, Denmark
[3]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, 91109, USA
[4]Instituto Nacional de Pesquisas Espaciais (INPE), Centro de Ciência do Sistema Terrestre, São José dos Campos, SP, Brazil
[5]Wageningen Environmental Research (ALTERRA), Wageningen, the Netherlands
[6]Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Belém, PA, Brazil
[7]Department of Ecology and Evolutionary Biology, University of Arizona, Tucson, AZ, USA
[8]Department of Biology, University of Utah, Salt Lake City, UT, USA
[9]Faculdade de Filosofia Ciências e Letras de Ribeirão Preto, Universidade de São Paulo (USP), São Paulo, SP, Brazil
[10]Centro Nacional de Monitoramento e Alertas de Desastres Naturais, São Paulo, SP, Brazil
[11]Department of Earth and Planetary Science, Harvard University, Cambridge, MA, USA
[12]Joint Institute for Regional Earth System Science and Engineering, University of California, Los Angeles, California, USA

Correspondence to: Kaniska Mallick (kaniska.mallick@gmail.com) and Ivonne Trebs (ivonne.trebs@list.lu)

Received: 30 December 2015 – Published in Hydrol. Earth Syst. Sci. Discuss.: 27 January 2016
Revised: 21 June 2016 – Accepted: 14 September 2016 – Published: 19 October 2016

AGU PUBLICATIONS

Water Resources Research

RESEARCH ARTICLE
10.1002/2014WR016106

Reintroducing radiometric surface temperature into the Penman-Monteith formulation

Key Points:
- Reintroducing radiometric surface temperature into Penman-Monteith (PM) model
- Holistic surface moisture availability framework to constrain the PM equation
- Numerical estimation of Priestley-Taylor parameter

Correspondence to:
K. Mallick,
kaniska.mallick@gmail.com;
kaniska.mallick@list.lu

Citation:
Mallick, K., E. Boegh, I. Trebs, J. G. Alfieri, W. P. Kustas, J. H. Prueger, D. Niyogi, N. Das, D. T. Drewry, L. Hoffmann, and A. J. Jarvis (2015), Reintroducing radiometric surface temperature into the Penman-Monteith formulation, *Water Resour. Res.*, *51*, 6214–6243, doi:10.1002/2014WR016106.

Received 7 JUL 2014
Accepted 9 JUL 2015
Accepted article online 14 JUL 2015
Published online 8 AUG 2015
Corrected 27 AUG 2015

Kaniska Mallick[1], Eva Boegh[2], Ivonne Trebs[1], Joseph G. Alfieri[3], William P. Kustas[3], John H. Prueger[4], Dev Niyogi[5], Narendra Das[6], Darren T. Drewry[6], Lucien Hoffmann[1], and Andrew J. Jarvis[7]

[1]Department of Environmental Research and Innovation, Luxembourg Institute of Science and Technology, Belvaux, Luxembourg, [2]Department of Environmental, Social and Spatial Change, Roskilde University, Roskilde, Denmark, [3]USDA-ARS, Hydrology and Remote Sensing Laboratory, Beltsville, Maryland, USA, [4]USDA-ARS, National Laboratory for Agriculture and Environment, Ames, Iowa, USA, [5]Department of Agronomy and the Department of Earth and Atmospheric and Planetary Sciences, Purdue University, West Lafayette, Indiana, USA, [6]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA, [7]Lancaster Environment Centre, Lancaster University, Lancaster, UK

Abstract Here we demonstrate a novel method to physically integrate radiometric surface temperature (T_R) into the Penman-Monteith (PM) formulation for estimating the terrestrial sensible and latent heat fluxes (H and λE) in the framework of a modified Surface Temperature Initiated Closure (STIC). It combines T_R data with standard energy balance closure models for deriving a hybrid scheme that does not require parameterization of the surface (or stomatal) and aerodynamic conductances (g_S and g_B). STIC is formed by the simultaneous solution of four state equations and it uses T_R as an additional data source for retrieving the "near surface" moisture availability (M) and the Priestley-Taylor coefficient (α). The performance of STIC is tested using high-temporal resolution T_R observations collected from different international surface energy flux experiments in conjunction with corresponding net radiation (R_N), ground heat flux (G), air temperature (T_A), and relative humidity (R_H) measurements. A comparison of the STIC outputs with the eddy covariance measurements of λE and H revealed RMSDs of 7–16% and 40–74% in half-hourly λE and H estimates. These statistics were 5–13% and 10–44% in daily λE and H. The errors and uncertainties in both surface fluxes are comparable to the models that typically use land surface parameterizations for determining the unobserved components (g_S and g_B) of the surface energy balance models. However, the scheme is simpler, has the capabilities for generating spatially explicit surface energy fluxes and independent of submodels for boundary layer developments.