Mapping land-surface fluxes of carbon, water and energy from field to regional scales

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Abstract A multi-scale and multi-sensor framework for routine mapping of land-surface fluxes of carbon, water, and energy at the field to regional scales has been established in an effort to improve drought monitoring, water resource management, and agricultural monitoring capabilities. The framework uses the ALEXI/DisALEXI suite of land-surface models in conjunction with remotely sensed data from Landsat, MODIS (MODerate resolution Imaging Spectroradiometer), and GOES (Geostationary Operational Environmental Satellite). In order to obtain high resolution in both space and time, we employ the use of the Spatial and Temporal Adaptive Reflectance Fusion Model (STARFM) to obtain time-continuous datasets of land-surface fluxes at Landsat spatial resolution using Landsat (30 m) high spatial and MODIS high temporal resolutions. Thermal infrared (TIR) data provides valuable information about the sub-surface moisture status, and land-surface temperature can be an effective substitute for in-situ surface moisture observations and a valuable metric for constraining land-surface fluxes at sub-field scales. The adopted multi-scale thermal-based land surface modeling framework facilitates regional to local downscaling of carbon, water and energy fluxes by using a combination of shortwave reflective and TIR imagery from GOES, MODIS and Landsat. In addition biophysical vegetation properties are retrieved at 30 m resolution using a surface reflectance dataset as input to the REGularized canopy reFLECtance (REGFLEC) tool. REGFLEC facilitates retrievals of leaf chlorophyll (Cab), a biophysical parameter that has been recognized as a key parameter to quantify variability in photosynthetic efficiency. Cab is used here to estimate spatio-temporal variations in nominal light-use-efficiency (LUEn), a fundamental parameter that modulates the fluxes of carbon and water in the land-surface model. The integrated thermal-based modeling system has been applied to regions of rain fed and irrigated soy and corn agricultural landscapes within the continental U.S. and flux simulations have been compared with flux tower observations.

Motivation and methods

Agriculture and water resource management require information about soil moisture/ET over a wide range of temporal and spatial resolutions. There is no one satellite currently in orbit that can accommodate such requirements. Fortunately there are multiple current and future imaging systems that provide data at coarse spatial and high temporal resolution from geostationary platforms such as Geostationary Operational Environmental Satellite (GOES), moderate resolution at daily intervals from sensors such as the Moderate Resolution Imaging Spectroradiometer (MODIS), and higher spatial resolution but lower temporal resolution from systems like Landsat.

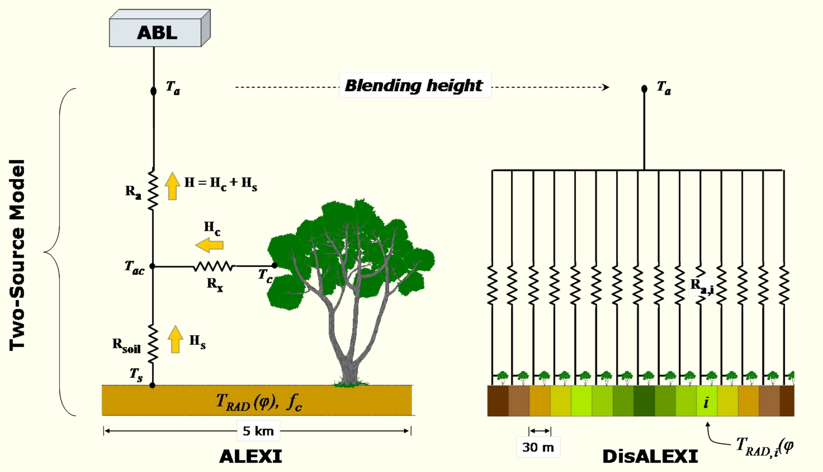
Here we present a modeling suite for fusing ET information derived from multiple sensors and platforms with varying revisit times and spatial resolutions to create hourly/daily ET maps at spatial resolutions of 10 km using GOES down to 30 m over localized regions using sensors such as Landsat. Multi-scale ET products are generated with a physically based inverse model of Atmosphere-Land Exchange (ALEXI) and an associated flux disaggregation technique (DisALEXI), a modeling framework for synthesizing multi-scale, multi-platform TIR imagery into useful end-products for operational monitoring of evaporative water loss and drought over a wide range of spatial and temporal scales [1].

ALEXI/DisALEXI model suite

The **ALEXI** is a surface energy balance model that estimates ET by partitioning radiation available at the surface into sensible and latent heat fluxes.

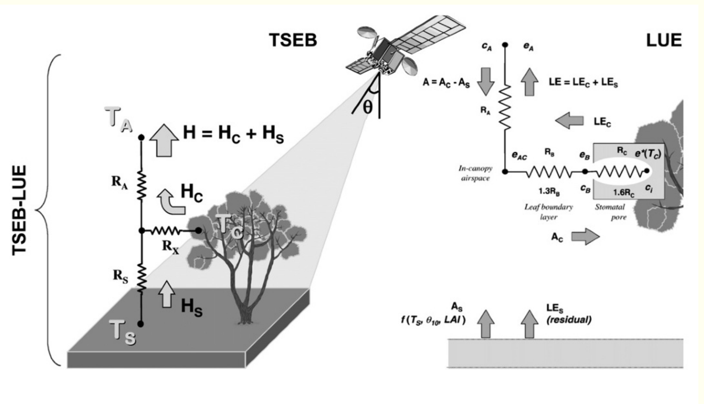
- ALEXI uses TIR and LAI data to partition sensible and latent heat fluxes into their soil and canopy components
- Air temperature at the blending height is estimated using an atmospheric boundary layer (ABL) model.

Given TIR, insolation and longwave radiation from GOES and LAI from MODIS, ET can be estimated at 10 km.Using the air temperature calculated in ALEXI and insolation and longwave from GOES along with high resolution TIR, LAI and albedo **DisALEXI** estimates ET at higher resolutions such as MODIS (1 km) or Landsat (30 m). A schematic of the modeling suite is shown below [1].



TSEB-LUE

The ALEXI/DisALEXI suite calculates ET using a modified Priestly-Taylor approach for estimating canopy transpiration. The Two Source Energy Balance (TSEB-LUE) model is a remote sensing model of carbon, water and energy exchange that uses satellite-based measurements of land-surface temperature as a proxy for soil moisture status. A LUE-based submodel of canopy resistance is used to simulate the coupled flux of transpiration and **carbon** uptake by the canopy component of the satellite pixel area. A schematic diagramming the TSEB LUE-based canopy resistance submodel is shown below [2].



Routine flux mapping

Satellite acquisition and data preparation

Landsat reflectance (30 m)

Landsat TIR (60/120 m)

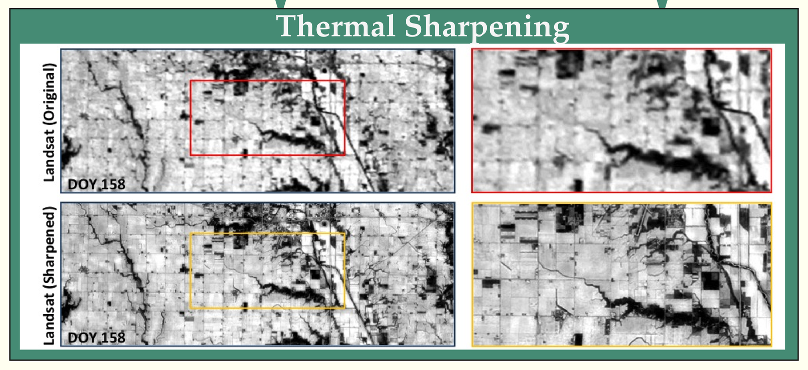
GOES (10 km)

MODIS LAI (1 km)

MODIS TIR (1 km)

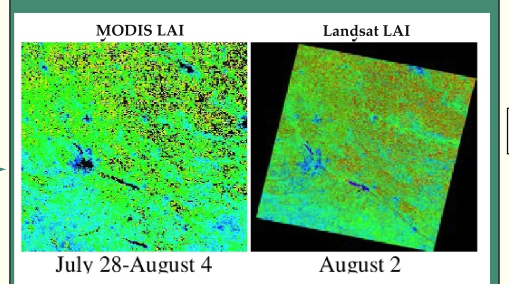
MODIS Albedo (1 km)

Thermal Sharpening



ALEXI

LAI fusion



DisALEXI

T_A

ET (10 km) Daily

T_A

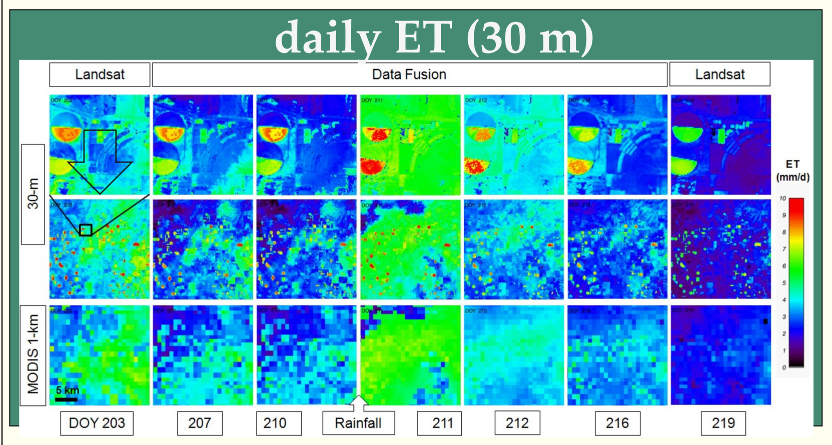
DisALEXI

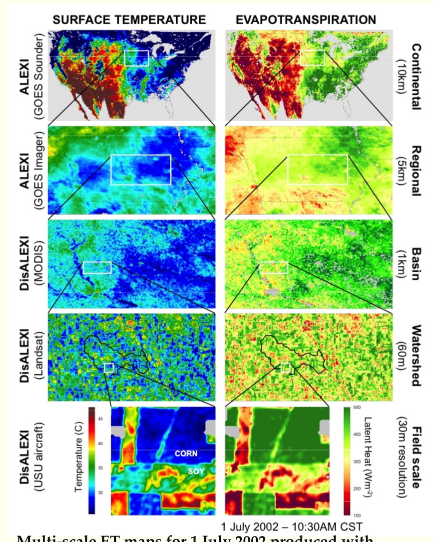
ET (30 m) 16-day

STARFM

ET (1 km) daily

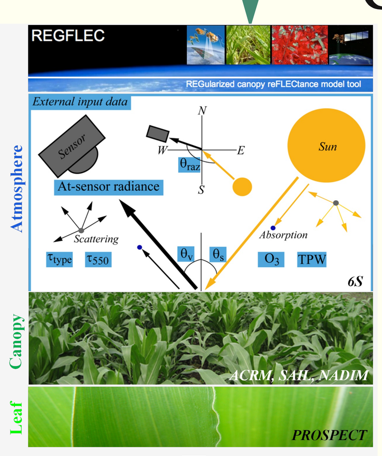
daily ET (30 m)



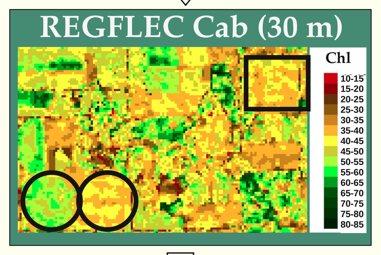


Multi-scale ET maps for 1 July 2002 produced with ALEXI/DisALEXI using surface temperature data from aircraft (30-m resolution), Landsat (60-m), MODIS (1-km), GOES Imager (5-km) and GOES Sounder (10-km), zooming into the Walnut Creek Watershed near Ames, Iowa, site of the SMEX02 Soil Moisture Experiment. The continental-scale ET map is a 14-day composite of clear-sky model estimates [1].

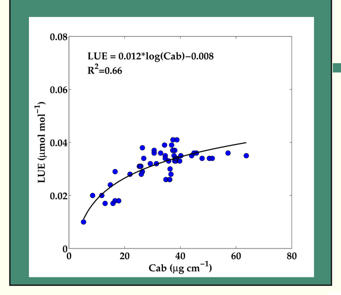
Carbon flux modeling



REGFLEC Cab (30 m)

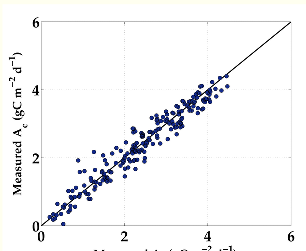


Cab-LUE functions



TSEB-LUE

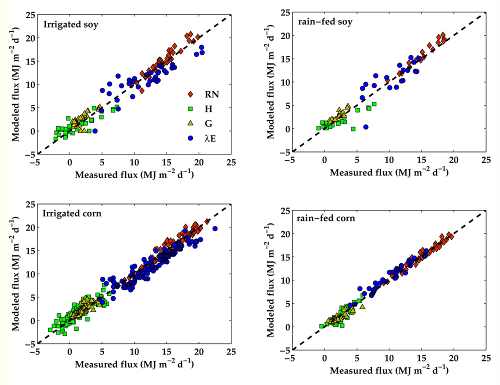
ET,carbon (30 m) 16-day



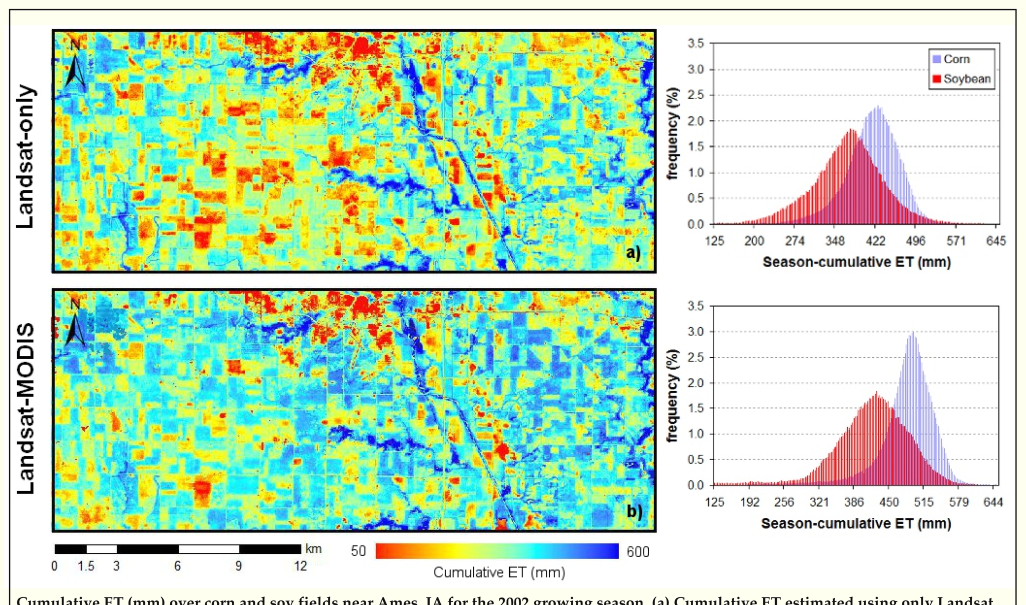
(upper panel) Daily CO2 flux measurements vs modeled fluxes over all (rain-fed+irrigated) fields of corn and soy in Nebraska incorporating the daily LUE estimated from the Cab-LUE relationships. Daily CO2 fluxes are calculated as the sum of hourly CO2 fluxes from sunrise to sunset.

(lower panels) Daily fluxes of water and energy for all (irrigated+rain-fed) fields of corn and soy from 2002-2005. Daily fluxes are taken as the average hourly flux from sunrise to sunset.

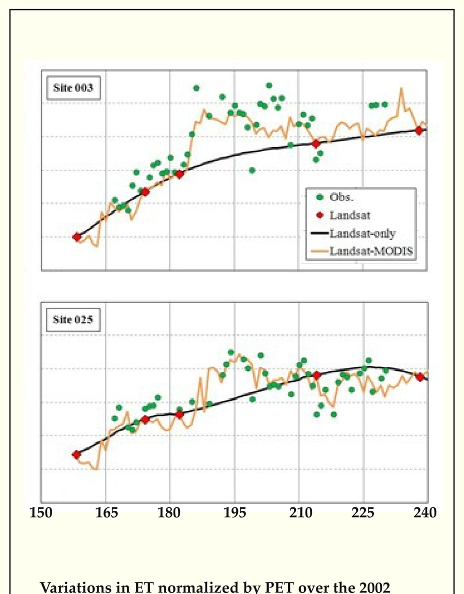
Spatial and temporal variations in nominal LUE due to varying plant conditions can be accommodated by leaf Cab calculated in REGFLEC [6]



ET fusion validation



Cumulative ET (mm) over corn and soy fields near Ames, IA for the 2002 growing season. (a) Cumulative ET estimated using only Landsat dates. (b) Cumulative ET estimated using fused Landsat-MODIS dates.



Variations in ET normalized by PET over the 2002 growing season for (a) irrigated and (b) rainfed fields of soy (003) and corn (025) near Ames,IA.

- Estimates of seasonal distributions in cumulative ET over fields of corn and soybean are improved by incorporating the Landsat-MODIS fusion techniques [3,4,5] as seen in the left-hand figure above.

- A general improvement in the agreement with in-situ measurements over spline interpolation was observed by fusing MODIS (daily, 1-km) data with Landsat (15 days, 30-m) maps if compared to Landsat-only case as illustrated in the right-hand figure above.

Conclusions

The modeling framework appears to be a successful approach for routine estimates of carbon and water fluxes from regional to continental scales.

- The fusion of Landsat and MODIS data using STARFM allows us to reduce errors on modeled fluxes in the gaps between consecutive Landsat acquisitions, as demonstrated by the comparison with flux tower measurements.

- The TSEB-LUE model is shown to be able to provide coupled transpiration and carbon fluxes over temporal and spatial scales.

- Incorporating Cab-LUE realtionships will allow for improved estimates of carbon over stressed conditions.

Future directions

- Incorporate 250 m ET into the ALEXI/disALEXI framework

- Improve thermal sharpening techniques

- Update the modeling to improve area of complex morphology

- Improve ET modeling over snow

- Incorporate LUE-based submodel of canopy resistance into the ALEXI/DisALEXI framwork to simulate the coupled flux of transpiration and canopy uptake of carbon

- Enhance carbon fluxes through the use of hyperspectral data

Acknowledgements

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