LONG-TERM DAILY FIELD-SCALE EVAPOTRANSPIRATION ESTIMATION USING MULTI-SATELLITE DATA FUSION IN AN INTENSIVELY DRAINED AGRICULTURAL AREA IN SOUTH DAKOTA, USA

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ABSTRACT

Subsurface tile drainage is a widely used agricultural practice in Midwestern USA to remove excess water to improve crop yield. Research shows an increasing trend of baseflow over the last 60 years and may be due to this artificial drainage activity. The influence of tile drainage on streamflow has been studied using in situ measurements and hydrological models. Evapotranspiration (ET) is an important component of hydrologic cycle. However, the impact of tile drainage on ET, or on other components of the water budget, is not well documented. In this study, we applied an energy balance based multi-sensor (GOES, MODIS, and Landsat) data fusion method to estimate daily 30 m ET over an intensively drained area in South Dakota, USA to assess the model performance and further explore the spatial and temporal ET patterns through 2004-2013 and their relationship to drain installation.

Index Terms—Evapotranspiration, tile drainage, data fusion, thermal infrared

1 INTRODUCTION

Subsurface tile drainage plays an important role in poorly drained agricultural areas, especially in Midwestern USA, to remove excess water for earlier crop planting, better field accessibility and higher yields. Tile flow is found to be 23% of annual precipitation in central Indiana [1] and between 9.5% to 23% of annual precipitation at an Iowa site [2]. Research has shown an increasing trend of baseflow over the last 60 years in Iowa rivers [3] and upper Mississippi River [4]. One reason for the increasing baseflow is thought to be artificial drainage [3]. Many recent studies have investigated the influence of subsurface tile drainage on streamflow using field observed data [5][6] and hydrological models, such as DRAINMOD [7] and SWAT [8][9], and on nitrogen load [10][11] which causes water pollution and nutrient loss from agricultural fields.

Evapotranspiration (ET), as a major part of the water balance, connecting hydrologic and biologic processes. However, the impact of rapid expansion in subsurface tile drainage on ET or on the local hydrology has not been well documented. This research employs an energy balance based ET modeling system, which uses a multi-satellite data fusion approach and has been successfully applied to many agricultural sites in USA and around the world [12][13][14], to estimate long-term (2004-2013) daily field-scale (30 m) ET in an intensively drained agricultural area in South Dakota, USA. The estimated 30 m daily ET data are compared with flux tower observations and analyzed to better understand the impact of tile drainage on ET.

2 METHODS

2.1. Two Source Energy Balance (TSEB) based multi-satellite fusion method

2.1.1. ALEXI/DisALEXI multi-scale energy balance

The regional Atmosphere-Land Exchange Inverse (ALEXI) [15] and the associated flux disaggregation model (DisALEXI) [16] are based on the Two Source Energy Balance (TSEB) land-surface representation [17] (Figure 1). Rather than treating the land-surface as a homogeneous surface, TSEB partitions modeled surface fluxes and observed directional radiometric surface temperature between soil and vegetation components [17]. Latent heat is estimated as a residual of the system. Combining TSEB in time-differential mode with an atmospheric boundary layer model, ALEXI estimates regional ET at coarse scales (3-10km) supported by thermal infrared (TIR) imagery from geostationary satellites. These regional fluxes can be spatially disaggregated in DisALEXI to estimate ET at finer scales with corresponding MODIS/Landsat thermal data, which can be sharpened to 1km and 30m, respectively. More details regarding TSEB and ALEXI/DisALEXI can be found in Norman et al. [1995][17] and Anderson et al. [2007][18].
2.1.2. Fusion of multi-satellite derived ET

ET retrievals generated with DisALEXI using TIR data from MODIS (near daily, at 1 km resolution) and Landsat (periodic, sharpened to 30 m resolution) are gap-filled and then fused into a daily time series at 30 m. The major components of the processing stream include a Data Mining Sharpener (DMS; [19]) tool that is used to improve the spatial resolution of the LST inputs to DisALEXI; a method to estimate Landsat-scale LAI [20], the Spatial and Temporal Adaptive Reflectance Fusion Model (STARFM; [21]), which is used to combine temporally sparse Landsat and dense MODIS ET maps to produce daily Landsat-scale ET time series; and a gap-filling procedure that is applied to ALEXI and MODIS and Landsat DisALEXI retrievals prior to disaggregation and fusion. The gap-filling and fusion processes are shown schematically represented in Figure 2.

The ET estimation process involves fusion of data from three major geostationary and polar orbiting satellite systems: GOES, MODIS and Landsat. Land-surface temperature (LST) data from the GOES Imager instruments were used to run ALEXI over the continental U.S. for 2004–2013 at 4 km resolution. MODIS tile data (NDVI (MOD13A2), LAI (MCD15A3), Albedo (MCD43GF) and Landcover (MCD12Q1), downloaded from Reverb NASA website), MODIS swath LST data (MOD11_L2, downloaded from Reverb NASA website) and Landsat 5, Landsat 7 and Landsat 8 thermal reflectance data from 2004 to 2013 (tile 029029, downloaded from USGS Global Visualization Viewer) were also obtained to run DisALEXI. Around 140 Landsat scenes were downloaded and atmospherically corrected. Meteorological data used to run ALEXI and DisALEXI (primarily insolation, wind speed, air temperature and vapor pressure) were extracted from North American Regional Reanalysis dataset [22]. DisALEXI inputs also include a Digital Elevation Map (DEM) obtained from USGS at 30 m resolution and land cover type information from the 2006 National Landcover Dataset (NLCD), which is also at 30 m. Flux observations at around 27°C in July. The average annual precipitation as rainfall is around 616 mm, which mainly occurs between May and September. The average annual precipitation as snowfall is around 84 cm, which mainly occurs between November and next March. The Brooking AmeriFlux tower (USBkg, 44.3453N, 96.8362W) is located in a private pasture in this study area, planting grasses for grazing. The canopy height around the flux tower is 0.2 to 0.4 m and the tower height is 4 m.

![Figure 2](image-url)
Brooking flux tower site at 30-min time steps were downloaded from AmeriFlux website.

![Figure 3. Study area – South Dakota Site with NLCD 2006 Landcover map.](image)

### 4. RESULTS

#### 4.1. LAI Values around the Flux Tower

As an important parameter in calculation of surface roughness, bulk leaf boundary layer resistance (Rx in Fig. 1) and canopy radiation interception, LAI was extracted from both MODIS LAI product at 1km resolution and our estimated Landsat-scale LAI at 30 m resolution around the Brooking flux tower site from 2005 to 2009 (Figure 4). It was interesting to find that at 30 m resolution, LAI is showing a double-peak pattern in all the years, which may relate to periodic grazing within the pasture site. This double-peak is not apparent in the 1-km MODIS LAI data, encapsulating phenological cycles of multiple sub-pixel crop fields within each pixel. This behavior is also reflected in a comparison between ET observations at the flux tower site and the 4-km ALEXI ET estimates over this site (see an example from 2006 in Fig. 5).

![Figure 4. Time series of LAI values extracted from MODIS LAI at 1 km resolution and Landsat LAI at 30 m resolution around the Brooking flux tower.](image)

#### 4.2. Daily 30 m ET Estimation

Figure 6 shows daily high spatial resolution ET mapping results generated with the data fusion system, exemplifying typical seasonal water use patterns over the growing season. The heterogeneous spatial pattern of ET shows strong structure over this agricultural landscape, and can clearly exhibits differences in ET between agricultural management units.

![Figure 5. Time series plot of observed ET at the Brookings tower site (blue dots) and 4 km ALEXI ET (gray line) in 2006.](image)

![Figure 6. Spatial time series of example 30 m ET retrieved from Landsat data.](image)

### 5. NEXT STEPS

The tile drain permits data is available from USGS and contains locations of drainage tile permits and application dates back from 1986 to 2013 in many counties in South
Dakota. Statistical analysis will be applied to study the difference between ET values before and after tile drainage installation to further explore the impact of tile drainage on ET patterns.

6. CONCLUSIONS

A daily 30 m scale multi-sensor data fusion method to mapping ET was applied to an intensively drained agricultural area in SD, USA. Both LAI values and ET values at 1 km and 30 m scales show the heterogeneous characteristics of this study area and suggest the importance of high resolution ET mapping for heterogeneous study areas. The comparison between flux tower ET observation and 4 km ALEXI ET suggest that an appropriate spatial resolution is needed to compare modeled with observed fluxes, especially for the more heterogeneous land surfaces.

In ongoing work, the 30 m ET estimates will be evaluated in comparison with long-term flux observations at the Brookings site, and this long-term data cube will be used to further explore the impact of tile drainage on trends in ET and hydrological variables.

7. REFERENCES