1.7 COMPARISON OF AIRCRAFT- AND TOWER-MEASURED FLUXES ACQUIRED DURING SMACEX WITH PREDICTIONS FROM A REGIONAL ATMOSPHERE-LAND EXCHANGE MODEL

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1. INTRODUCTION

The Soil Moisture - Atmosphere Coupling Experiment (SMACEX) was conducted 15 June – 13 July 2002 in the Walnut Creek Watershed near Ames, Iowa – an agricultural region dominated by corn and soybean production. A primary goal in SMACEX was to study the role of heterogeneity in soil moisture and vegetation cover in influencing land-atmosphere exchanges of energy, water and carbon over a range in spatial scales. During the experiment, fluxes were measured continuously at 14 eddy covariance towers distributed across the watershed, and periodically along tracks over flown by the NRC Twin Otter atmospheric research aircraft (MacPherson et al., 2003). Together, tower and aircraft observations sampled flux footprints on the order of 100 to 1000 m. Surface vegetation and temperature observations were collected in situ: at the 1 m pixel resolution with the Utah State University Piper Seneca remote sensing aircraft (Neale et al., 2003), and at 30 to 5000 m pixel resolutions with the Landsat, MODIS, AVHRR and GOES satellites. Further details regarding the SMACEX experiment are given by Kustas et al. (2003).

This multi-scale dataset, representing a mixture of point, linear, and gridded coverages, will be synthesized, aggregated and used to evaluate spatial scaling techniques and assumptions inherent in turbulent transport modeling. This paper will compare flux measurements aggregated to the watershed scale with predictions from the regional-scale Atmosphere-Land Exchange Inverse (ALEXI) model – a coupled land-surface-atmospheric boundary layer model based on satellite estimates of vegetation cover and surface radiometric temperature change.

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2. MODEL DESCRIPTION

The ALEXI model (Anderson et al., 1997; Mecikalski et al., 1999; see also emily.soils.wisc.edu/~anderson/alexi) was developed as an auxiliary means for estimating surface fluxes over large regions using primarily remote-sensing data. This flux model is unique in that no information regarding antecedent precipitation or moisture storage capacity is required - the surface moisture status is deduced from a radiometric temperature change signal. Therefore, ALEXI can provide independent information for updating soil moisture variables in more complex regional models.

ALEXI is a two-source (soil and canopy) land-surface model (Norman et al., 1995) coupled with a 1-dimensional atmospheric boundary layer (ABL) model (McNaughton and Spriggs, 1986). The lower boundary conditions for the two-source model are provided by thermal IR observations taken at two times during the morning hours from a geostationary platform such as GOES (the Geosynchronous Operational Environmental Satellite). The ABL model then relates the rise in air temperature above the canopy during this interval and the growth of the ABL to the time-integrated influx of sensible heating from the surface. Use of time-differential measurements of surface radiometric temperature reduces model sensitivity to errors in sensor calibration, and atmospheric and surface emissivity corrections.

The two-source land-surface model embedded in ALEXI allows the soil and canopy energy budgets to be solved independently. Thus soil and canopy latent heating can be compared with potential rates based on radiation load, atmospheric demand and vegetation cover, and used as indicators of available water content in the soil surface and root zone (see e.g., Campbell and Norman, 1998).

ALEXI is constrained to operate on spatial scales of 5-10 km – scales at which atmospheric forcing by uniform land-surface behavior becomes effective. A flux disaggregation algorithm (DisALEXI) has been developed by Norman et al. (2003) to scale 5 km flux estimates from ALEXI down to the 30 – 250 m scale for direct comparison with ground-based flux measurements.

3. MODEL INPUT DURING SMACEX

Throughout the SMACEX experiment, ALEXI was run daily on a 5 km grid including Iowa and environs, with the Walnut Creek study region occupying approximately 20 grids cells within the modeling domain (see Fig. 1). We concentrate here on model inputs and results for 1 July 2002. This day was particularly clear, and thus comparison data from several satellite and aircraft platforms are available (see also Kustas et al., 2003).

Primary remote sensing inputs to ALEXI include the morning time-rate-of-change in surface radiometric temperature, downwelling solar and longwave radiation (to compute net radiation), and fractional vegetation cover (to deconvolve the composite surface temperature measurements into soil and canopy contributions). A landcover classification map derived from multi-spectral satellite data is used in conjunction with the cover-fraction map to assign class-dependent surface properties, such as surface roughness, albedo and emissivity. Ancillary surface and atmospheric data required include an estimate of the wind speed field at 50 m and an early-morning analysis of synoptic radiosounding profiles of temperature and vapor pressure across the modeling domain, here performed within the framework of a mesoscale forecast model. Mecikalski et al. (1999) review input requirements for regional-scale application of the ALEXI model.

In this experiment, surface radiometric temperature maps were obtained at 1.0 hr past local sunrise and 1.5 hrs before local noon from the GOES-8 imager band 4, nominally at 5 km resolution. Band 4 brightness temperatures were corrected for atmospheric effects using a simple technique described by French et al. (2003), based on a modification of work presented by Price (1983).

Downwelling short- and long-wave radiation was also mapped using data from the GOES-8 satellite. The shortwave radiation model is described by Diak and Gautier (1983); the longwave model by Diak et al. (2000). Net radiation was computed using a landcover class-dependent albedo and the model-diagnosed radiometric soil and canopy temperatures.

Vegetation cover maps were created from a bi-weekly-composited Normalized Difference Vegetation Index (NDVI) product (Eidenshink, 1992), created at 1 km resolution from images collected by the Advanced Very High Resolution Radiometer (AVHRR). The fraction of vegetation cover derived for 1 July 2002 is shown in Fig. 1.

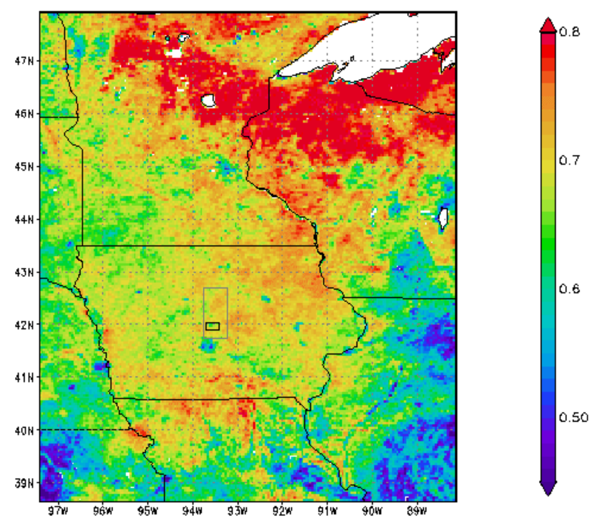

Figure 1. Fractional vegetation cover over the ALEXI modeling domain for 1 July 2002. The small black box indicates the location of the Walnut Creek watershed; the larger gray box designates the extent of a regional-scale study associated with SMACEX.

4. PRELIMINARY RESULTS

4.1 Comparison with antecedent precipitation

The ratio of actual to potential evapotranspiration (ET) is an indicator of system stress: for conditions

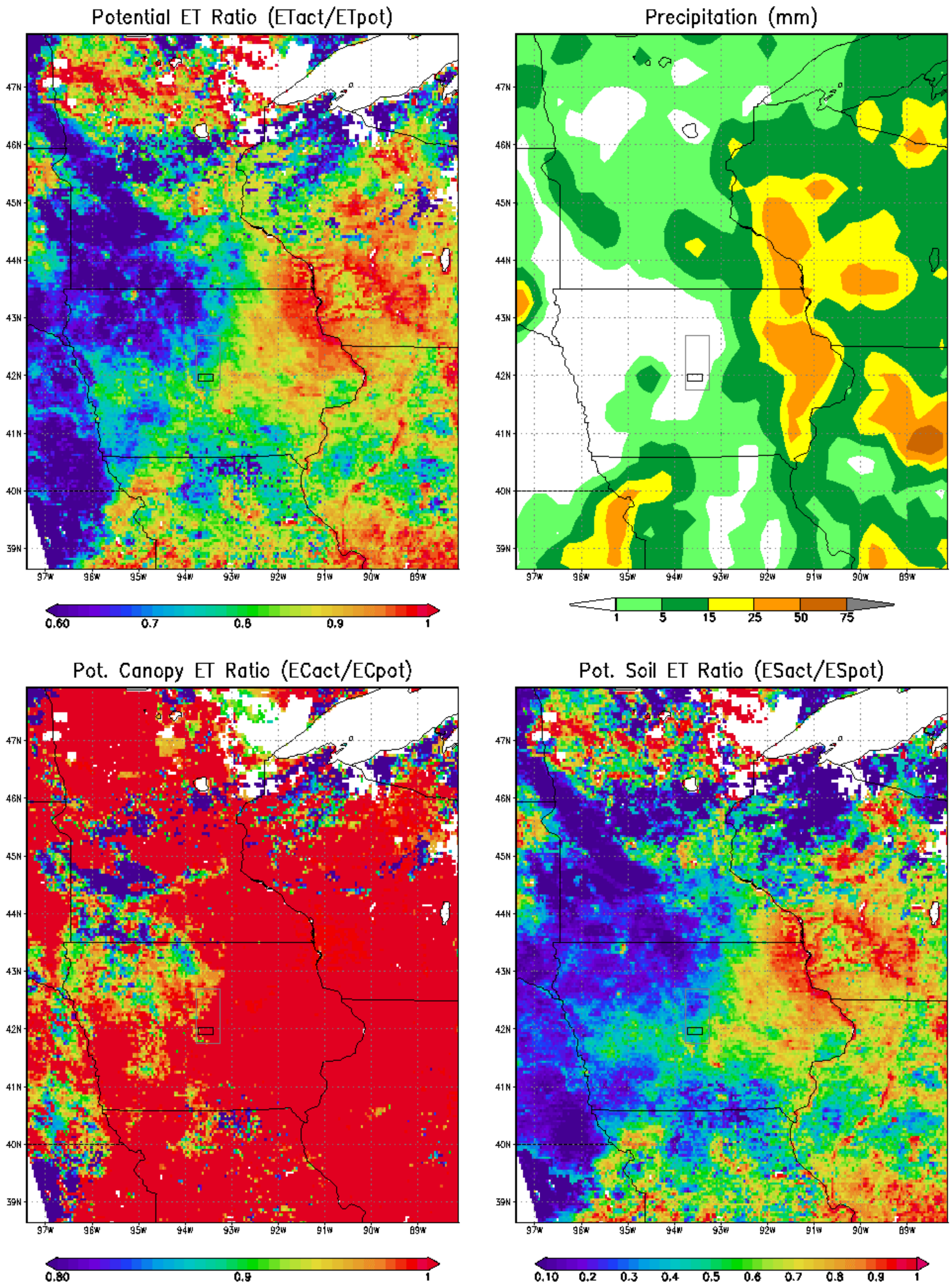

Figure 2. a) 6-day composite of system (soil+canopy) potential ET ratio estimates from the ALEXI model, ending 1 July 2002. The nominal time associated with this image is 1.5 hours before local noon, the time of the second GOES image used to compute surface radiometric temperature change. b) 6-day accumulated precipitation, based on the NCEP daily precipitation analysis product. c) canopy potential ET ratio. d) soil potential ET ratio.

prevailing during SMACEX, potential ET ratios less than unity suggest a paucity in water available for evaporation from the soil surface and/or canopy transpiration. Comparisons between maps of ET and antecedent precipitation can be confused by variations in vegetation cover – typically only water in the top 5 cm of the soil profile contributes to evaporation from bare soil, while plants can extract water down to several meters. Normalizing by the potential rate expected for a given cover fraction improves the correlation between ET and precipitation fields.

Figure 2a shows a 6-day composite ending 1 July 2002 of potential system (soil+canopy) ET ratio predicted by the ALEXI model. The compositing procedure consisted of a weighted time-average at each pixel, implemented to increase grid coverage (only the clear portion of the domain can be mapped on a given day) and to reduce noise. Image weights were assigned to emphasize conditions on the nominal composite date.

For comparison, Fig. 2b shows a 6-day accumulation of precipitation, generated from the National Centers for Environmental Prediction (NCEP) Climate Prediction Center daily precipitation analysis product. These precipitation estimates are based on hourly objective analyses of station data from the National Weather Service and Cooperative Observers networks.

In general, there is good qualitative agreement between these two fields. The model has captured the effects of an extended dry spell that occurred in northwest Iowa, southwest Minnesota and eastern Nebraska, where the potential ET ratio is significantly reduced. A series of rainfall events along the Iowa-Wisconsin border, central Wisconsin and in Illinois have kept ET at near potential rates in these areas. The Illinois, Wisconsin, Platte and Mississippi river basins are discernible in Fig 2a.

The most marked discrepancy occurs in northern Minnesota, where little rainfall accumulated over 6 days yet the model predicts near potential ET. This is primarily an artifact of the compositing procedure. A large rainfall occurred in this area on 23-24 June, it was clear on 26 June, then cloudy throughout the rest of the composite interval (26 June – 1 July). This underscores one liability in working with thermal infrared satellite data – large portions of the modeling domain may be unimageable on any given day.

4.2 Comparison with aircraft fluxes

On several days between 15 June and 6 July 2002, the Twin Otter aircraft flew transects over the Walnut Creek Watershed, collecting energy, momentum and carbon flux measurements at a height of 40m (MacPherson et al., 2003). The flight lines were designed to intersect several of the ground-based eddy correlation towers operating within the region.

Figure 3 shows flux data collected on 16, 23, 25 June and 1 July, compared with predictions from the ALEXI model. Net radiation (*Rn*) and soil heat (*G*) data are averages over ground-based measurements made at several towers within the watershed at the time of the second GOES image used in ALEXI (about 10:45 CST). The "measured" latent (*LE*) and sensible heat (*H*) fluxes were derived from aircraft Bowen ratio measurements, averaged over midday transects on these days and used to fill the energy budget given the tower-average available energy (*RN*-*G*).

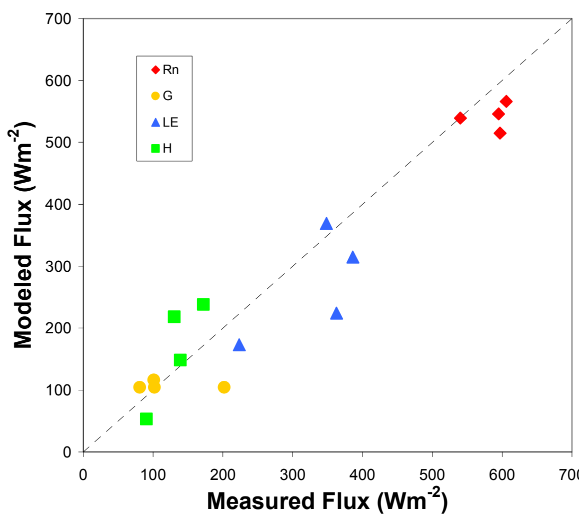

Figure 3. Estimates of net radiation (Rn), soil heat (G), latent (LE) and sensible (H) heat fluxes from the ALEXI model compared with fluxes derived from a combined ground-based and aircraft measurement set (see text).

The root-mean-square-deviation between modeled and measured fluxes is 60 Wm^{-2}, or 20% of the average measured flux – comparable to the expected accuracy of eddy correlation flux measurements (Norman et al., 1995). The combined aircraft-surface measurement set will be refined as data from additional towers are processed.

5. FUTURE WORK

High-resolution thermal and visible/near-infared images from Landsat and aircraft (Neal et al., 2003) platforms are currently being processed. These images will be used to disaggregate 5 km ALEXI flux fields over the Walnut Creek watershed down to the 1 – 30 m scale using the DisALEXI algorithm. At this scale, flux estimates can be reaggregated using analytical techniques (e.g., Schuepp, 1990) to match the flux footprints of individual eddy-correlation towers and compared directly to ground-based flux measurements. Agreement between measured and disaggregated fluxes will provide additional validation of the largescale ALEXI flux estimates.

Recent experiments in implementing an analytical light-use efficiency technique for estimating carbon assimilation into the DisALEXI algorithm have been encouraging. DisALEXI predictions of net carbon flux agree well with fluxes measured by aircraft over pasture and grasslands in central Oklahoma. This model will be applied to the patchwork of C_3 (soybean) and C_4 (corn) fields that largely comprise the Walnut Creek landscape and compared to aircraft and tower carbon fluxes. The ability to reliably map carbon and water fluxes at 30 m resolution has wide application in the fields of agricultural and hydrological management.

6. ACKNOWLEGEMENTS

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