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Abstract- Surface energy flux estimates over central Oklahoma, during the summer of 2001, are derived in two different ways from thermal infrared and visible-near infrared ASTER (Advanced Spaceborne Thermal Emission and Reflection radiometer) 90 m resolution observations. In one approach, surface flux estimates are computed using a two-source energy balance (TSEB) model, which distinguishes between soil and vegetation flux components. The benefit of TSEB is an improved surface representation over sparsely vegetated terrain, as compared to one-layer models. In the other approach, surface flux estimates are computed from the Surface Energy Balance Algorithm for Land (SEBAL) model, which computes meteorological variables using information contained within the spatial variability of convective fluxes. A major benefit of the SEBAL model is that estimates can be obtained solely from remote sensing observations. Both models compare reasonably well with surface flux measurements, but their relative sensitivities and biases are different for the same input data. Sources of these modeling sensitivities and biases will be discussed.

I. INTRODUCTION

Modeling surface energy fluxes is a way to estimate spatial distributions of evapotranspiration (ET). Knowledge of ET is important for both hydrologists and climatologists, but retrieving accurate ET estimates is difficult. ET varies rapidly and is strongly dependent upon land surface heterogeneity. Remote sensing based estimates are the only practical way to retrieve spatial ET estimates, as they excel at representing surface heterogeneity. Using well-calibrated visible- near infrared (VNIR) observations, in conjunction with recently available multi-band thermal infrared data from the ASTER sensor, allows modeling the surface energy balance under a wide range of conditions, including sparse and stressed vegetation. However, existing remote sensing models vary considerably in their approach and assumptions. Some approaches augment satellite observations with surface observations, while others attempt to be self-contained. In this study, we model surface energy fluxes over a single region using two approaches representing each of these cases.

II. THE TSEB MODEL

The Two-Source Energy Balance (TSEB) [1] model, a resistance network approach, can compute the four main surface energy flux components, sensible heat (H), latent heat (LE), soil heat (G), and net radiation (R_n), based upon separate contributions from soil and vegetation. The distinction between soil and vegetation is the prime characteristic of TSEB, and allows differences in radiative and aerodynamic properties of a heterogeneous surface to be accommodated. TSEB requires three remote sensing inputs: surface temperatures, vegetation indices and a land use classification. It also requires near surface meteorological observations of air temperature, humidity, wind speed and incoming solar radiation.

III. THE SEBAL MODEL

The Surface Energy Balance Algorithm for Land (SEBAL) [2], also a resistance approach, computes the surface flux components H, LE, G and R_n almost entirely from remote sensing based observations of surface temperatures, vegetation indices and surface albedo. SEBAL accomplishes this by computing wind speed and air temperature, which are determined by semi-empirical relationships and simplifications of the energy balance over dry and wet areas. Subsequent computations produce the four surface fluxes from a single source at the land surface.

Table I
Surface Meteorology at E19 Site, 10 June 2001

Overpass Time	11:34 CST
Air Temperature (2m)	28.9 °C
Relative Humidity	62%
Wind speed	5.1 m s^{-1}
Solar Radiation	814.9 W m^{-2}
Solar Zenith Angle	19.35 °
Pressure	964.5 mbar
Soil Temperature (2in)	21.6 °C
Volumetric Soil Moisture	30% (5)

Fig. 1. NDVI image over El Reno, Oklahoma extracted from ASTER scene, 10 June 2001. Light tones indicate high NDVI and thick vegetation, dark tones low NDVI and either bare soil or water bodies. The arrow points to the E19 flux station site. Image area is approximately 6x12km, with north towards the upper left direction

IV. SURFACE FLUXES AT EL RENO, OKLAHOMA

Comparison between TSEB and SEBAL was performed on a 10 June 2001 ASTER scene over central Oklahoma, a portion of which is shown in Fig. 1. The scene primarily includes grazing lands (light gray) and harvested winter wheat fields (dark gray). The box, pointed to by the arrow, indicates the location of the El Reno E19 Bowen Ratio site, which lies within the USDA El Reno Grazinglands Research center, an intensively studied site [3,4,5].

Surface temperatures were obtained from 90 m ASTER thermal infrared observations in bands 10-14, and a temperature-emissivity separation algorithm [6]. Correction of atmospheric effects used NCEP [7] profiles and MODTRAN simulations [8]. Surface reflectance values, obtained from ASTER bands 1-8, were used to determine NDVI and albedo. They were computed at 90 m resolution by using the 6S model [9] with the same NCEP profiles, plus observations provided by the Aeronet Project [10]. Land use was determined from a supervised classification of 15 m resolution ASTER data (bands 1-3), which was subsequently resampled to match the 90 m surface temperature imagery.

Unstable aerodynamic conditions prevailed at the time of the satellite overpass. Radiometric temperatures over the grazing lands were ~36°C, while 2 m air temperature and southerly wind were ~29°C and 5 m s^{-1} (Table I). NDVI values ranged between 0.0 and 0.65, and indicated that grazing land vegetation LAI ranged between 1.0 and 3.0. The NDVI- surface temperature relationship was reasonable (Fig. 2), with complete cover showing low variability in temperature, while bare soil surfaces had high surface temperature variability.

Table II.
Surface Parameters & Fluxes, 10 June 2001
Means and Standard Deviations (W m^{-2})

Source	H	LE	G	R_n
E19	129	405	19	552
TSEB	126 (11)	370 (14)	70 (4)	566 (4)
SEBAL	108 (37)	385 (45)	70 (3)	563 (8)

Both TSEB and SEBAL models returned surface energy flux components in close agreement with ground level observations at the E19 Bowen ratio site (Table II.). Means and standard deviations are based on nine 90 m pixels.

Net radiation (R_n) estimates were within 14 W m^{-2} of the observation at site E19. Although TSEB and SEBAL use the same value for both incoming solar and atmospheric radiation, they estimate R_n in different ways. TSEB estimates R_n from separate streams of visible and near infrared radiation, while SEBAL uses a one layer approach along with integrated values over the considered spectral ranges.

Soil flux (G) estimates from TSEB and SEBAL are identical, and exceed the E19 observation by 51 W m^{-2}. Agreement in G is coincidental. TSEB's G is estimated as a fraction (0.3) of net radiation at the soil level. SEBAL's G is estimated from an empirical formulation of heat transfer over bare soil and a vegetation extinction coefficient.

The most informative comparison between TSEB and SEBAL lies with the turbulent flux component, H. TSEB's H estimate is 18 W m^{-2} greater than SEBAL's and is within 3 W m^{-2} of the E19 observation. The observed wind speed, used by TSEB, and SEBAL's estimated wind speed values are similar (5.1 vs. 3.8 m s^{-1}). Momentum roughness lengths are also similar (0.13 vs. 0.10 m). Therefore, the chief reason for differing H estimates is the surface air temperature gradient. TSEB assumes a spatially uniform air temperature at measurement height. SEBAL, on the other hand, spatially varies air temperature according to surface heterogeneities. In the current instance, TSEB appears to produce a slightly better H estimate, with half the variability of SEBAL's estimate.

The latent heat flux (LE) estimates show a similar relationship to the H estimates. Both TSEB and SEBAL LE fluxes are less than E19 observations by 35 and 20 W m^{-2}, respectively. The TSEB LE shows 1/3 the variability of the SEBAL LE, and results from using a constant near surface air temperature.

V. CONCLUSIONS

The comparison between two surface energy balance models using remote sensing data has just begun. Both the TSEB and the SEBAL approach produce estimates in close agreement with measurements from a single ground observation site. Future work will analyze imagery that includes multiple ground observation sites, for example in the Jornada Experimental Range in southern New Mexico.

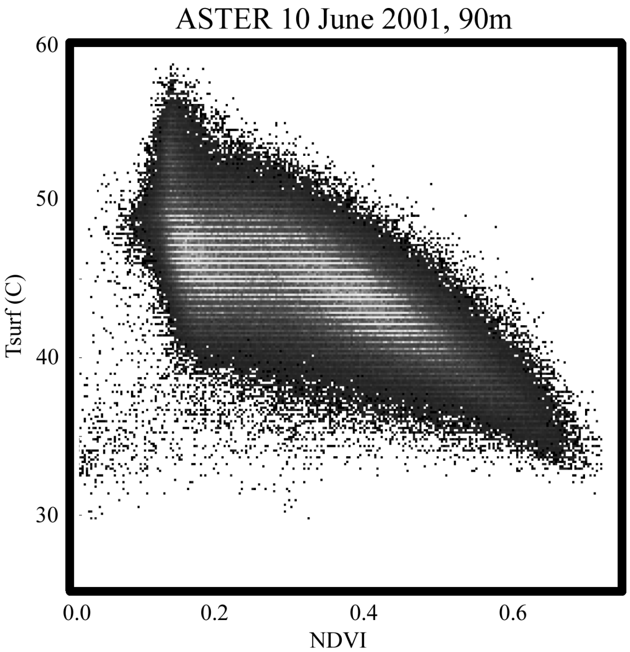

Fig. 2. Surface temperature vs. NDVI histogram over central Oklahoma from entire ASTER scene (60km x 60km) on 10 June 2001. Approximately 500,000 points are represented, with light tones indicating higher frequency and darker tones lower frequency.

VI. REFERENCES

[1] J. Norman, W. Kustas, and K. Humes, "A two-source approach for estimating soil and vegetation energy fluxes from observations of directional radiometric surface temperature," *Agric. For. Meteorol.*, vol. 77, pp. 263-293, 1995.

[2] W. Bastiaansen, M. Menenti, R. Feddes, and A. Holtslag, "A remote sensing surface energy balance algorithm for land (SEBAL)1. Formulation," *J. Hydrol.*, vol. 212-213, pp. 198-212, 1998.

[3] A. French, T. Schmugge, W.P. Kustas, "Estimating evapotranspiration over El Reno, Oklahoma with ASTER imaery," *Agronomie*, vol. 22, pp 105-106, January-February 2001.

[4] A. French, T. Schmugge, W.P. Kustas, "Estimating surface fluxes over the SGP site with remotely sensed data," *Phys. Chem. Earth (B)*, vol. 25, pp. 167-172, 2000.

[5] T.J. Jackson, D.M. LeVine, A.Y. Hsu, A. Oldak, P.J. Starks, C.T. Swift, J.D. Isham, and M. Haken, "Soil moisture mapping at regional scales using microwave radiometry: the Southern Great Plains hydrology experiment," *IEEE Trans. Geosci. Remote Sens.*, vol. 37, pp. 2136-2151, September 1999.

[6] A.R. Gillespie, S. Rokugawa, S.J. Hook, T. Matsunaga, and A.B. Kahle, "A temperature and emissivity separation algorithm for Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) images," *IEEE Trans. Geosci. Remote Sens.*, vol. 36, pp. 1113-1126, July 1998.

[7] National Centers for Environmental Prediction, http://wwwt.ncep.noaa.gov/

[8] A. Berk, L.S. Bernstein, G.P. Anderson, P.K. Acharya, D.C. Robertson, and J.H. Chetwynd, "MODTRAN cloud and multiple scattering upgrade with applications to AVIRIS," *Remote Sens. Environ.*, vol. 65, pp. 367-375, 1998.

[9] E.F. Vermote, D. Tanré, J.L. Deuzé, M. Herman, and J.-J. Morcrette, "Second Simulation of the Satellite Signal in the Solar Spectrum, 6S: an overview," *IEEE Trans. Geosci. Remote Sens.*, vol. 35, pp 675-686, May 1997.

[10] U.S. Department of Energy Atmospheric Radiation Program, Southern Great Plains Site. Data posted at http://aeronet.gsfc.nasa.gov/Aeroinfo.html.