SAFARI 2000 MODIS Water and Heat Fluxes, Maun, Botswana, Dry Season 2001

Abstract

Estimation of regional evapotranspiration is of major importance in hydrological modeling, where the partitioning of available energy into sensible and latent heat fluxes is crucial. Point-based measurements are routinely obtained with micrometeorological methods using a combination of radiometers and eddy-covariance instruments. Notwithstanding closure problems, these are considered to yield reliable point source flux values. However, when dealing with heterogeneous semi-arid terrain, these point estimates are not representative for regional estimation.

MODIS image data was used along with micrometeorological measurements to model and map the energy and water balances of a heterogeneous land surface in a savanna environment on the southern fringe of the Okavango Delta, near Maun, Botswana. Despite its semi-arid character, fresh floodwaters arrive through the Delta seasonally and therefore part of the area's vegetation is always transpiring at a potential rate.

The physically-based model, Energy: Surface Towards Atmosphere (ESTA), was developed as an improvement over existing models used previously over the southern African continent. ESTA is governed by remotely sensed values of surface temperature, reflection, and vegetation density.

Background Information

Investigator:
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Project: SAFARI 2000

Data Set Title: SAFARI 2000 MODIS Water and Heat Fluxes, Maun, Botswana, Dry Season 2001

Site: Okavango Delta, Botwana
  Westernmost Longitude: 21.49465° E
  Easternmost Longitude: 24.5004° E
  Northernmost Latitude: -17.99465° S

Southernmost Latitude: -21.0004° S

Data Set Citation:

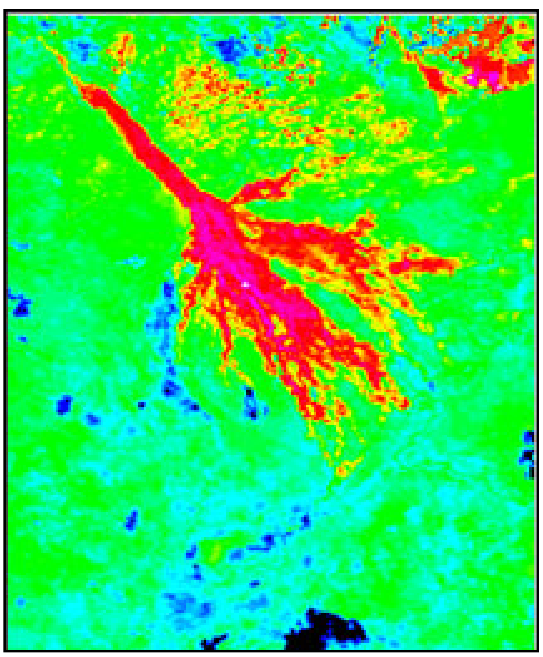
Timmermans, W. J. 2004. SAFARI 2000 MODIS Water and Heat Fluxes, Maun, Botswana, Dry Season 2001. Data set. Available on-line [http://daac.ornl.gov/] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U. S.A.

Data File Information

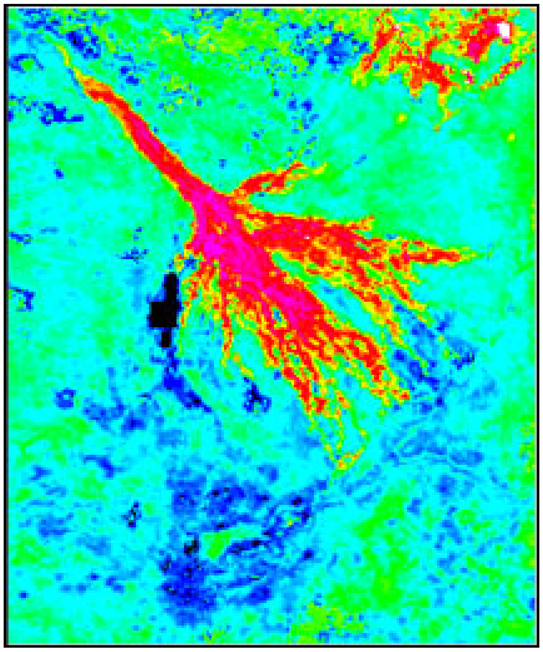
This data set consists of 3 separate gridded binary image files. The floating point image files are 234 columns by 281 rows in size, each pixel is 32-bits, representing daily evapotranspiration (mm/day) for the Okavango Delta region. Data are provided for September 2, September 13, and September 29, 2001. The data files are named:

modis_eta_2001-09-02.dat
modis_eta_2001-09-13.dat
modis_eta_2001-09-29.dat

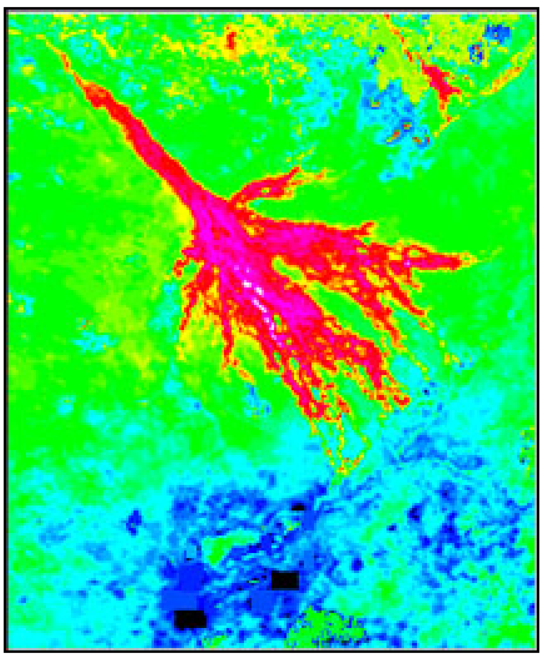
Samples of modeled evapotranspiration images for the Okavango Delta are displayed below:



September 2, 2001



September 13, 2001



September 29, 2001

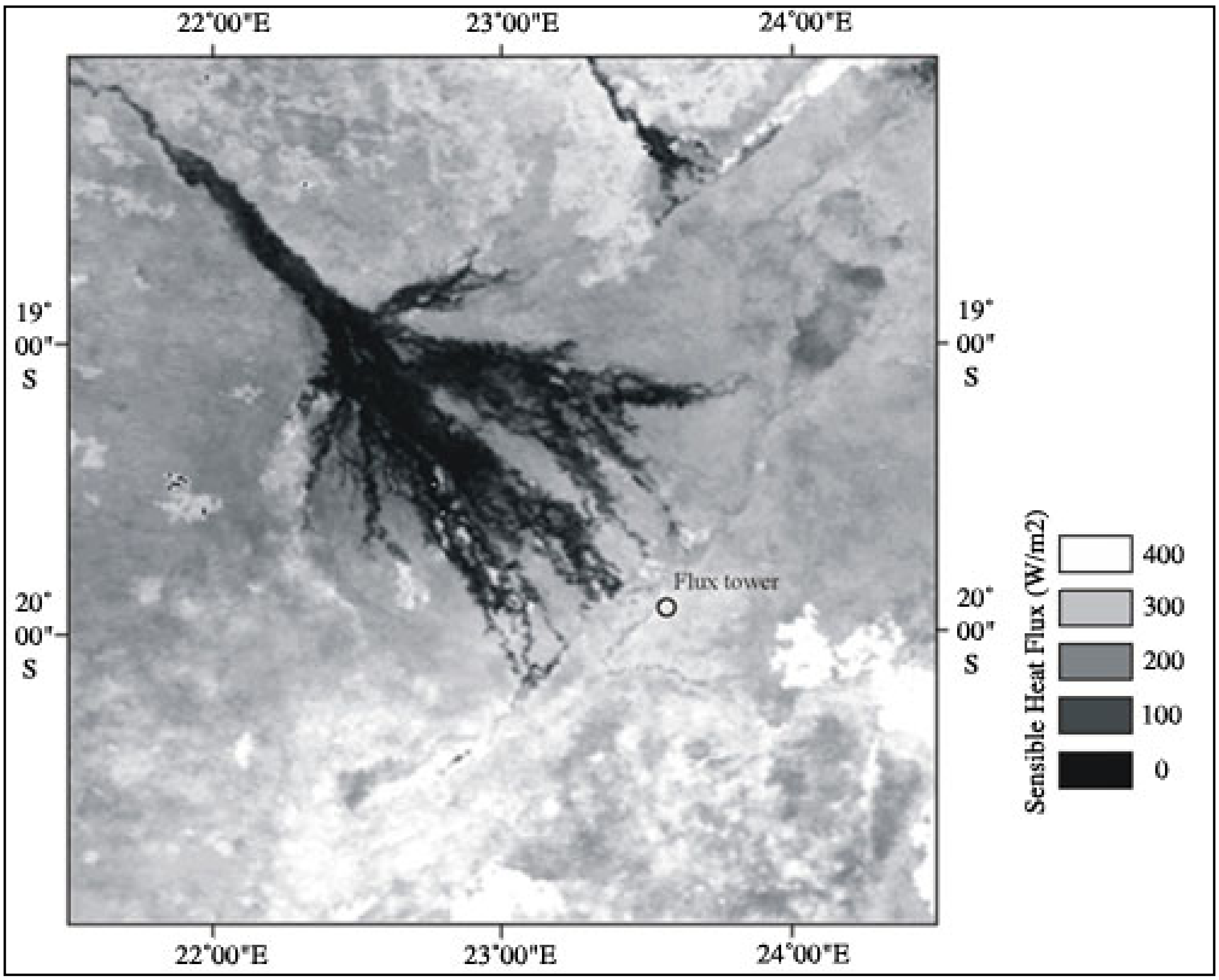
MODIS ETA Image Parameters

file format	flat binary
data type	32-bit float
image size	281 lines, 234 cols

geographic projection	Geographic, latlong
upper left corner, x	21.49875° E
upper left corner, y	17.9974305° S
pixel size	1120 meters at image center
units	mm/day

Study Area

The Okavango Delta region, near Maun, Botswana, is very heterogeneous, comprising densely vegetated swamps and grasslands, as well as woodlands surrounded by a savanna environment.



Typical model output for sensible heat for September 29, 2001, using the ESTA algorithm over the delta region. Note the light tones near the Maun flux tower indicating sensible heat flux over 300 W/m^2.

Data input to the model include near-surface meteorological observations. These observations are continuously recorded at a micrometeorological flux tower located near Maun, Botswana. The tower is mutually operated by the Max Planck Institute, Jena, Germany and the Harry Oppenhiemer Okavango Research Center (HOORC) of the University of Botwana. The tower site is located in a broad-leaved *Colophospermum mopane* (Kirk ex Benth.) savanna woodland, about 20 km east of Maun. The long-term climate of the site is semi-arid, with a mean annual rainfall of 464 mm. There is a distinct dry season during the winter months from May to September. Appreciable rainfalls are normally limited to the period between December and March.

Satellite Data

Reflectance data from the MODIS sensor aboard the Terra satellite were obtained for the Okavango Delta region, near Maun, Botswana, for September of 2001. The area extracted, roughly 300 by 400 kilometers, is very heterogeneous and is comprised of densely vegetated swamps, grasslands, and woodlands, in a savanna environment.

The images were acquired during the mid to late morning hours, local time. Additional data input included meteorological conditions measured at the tower site at the time of the Terra platform overpass. Image data acquisition times and micrometeorological data at these times are indicated in the table below.

Date	Time (LST)	Air Temper-ature (° C)	Relative Humidity (%)	Wind Speed (m/s)	Solar Radiation (W/m2)	Atmospheric Pressure (mbar)
September 2, 2001	11:08	26.5	7	4.3	778	910
September 13, 2001	10:46	17.7	17	5.3	814	909
September 29, 2001	10:46	25.8	38	3.6	853	912

Use was made of the visible, near infrared, and thermal bands of the MODIS surface reflectance product (MOD09), a configuration that allows discrimination of broad-band surface albedo, vegetation indices, and surface temperature. Although not absolutely necessary for the algorithm, a crude land cover classification image was also created. The original spatial resolution of the visible and near infrared imagery of 250 and 500 meters, respectively, was reduced to 1 km to be compatible with the resolution of the thermal imagery.

Despite the fact that the remote sensing observations provided almost all the necessary data needed for the model, they could not provide vegetation canopy heights. Although the model appears not to be a very sensitive to this parameter, it is used for the estimation of aerodynamic resistance. A crude land cover classification image was developed, comprising the main land use types in the area: riparian vegetation, floodplain, shrub- and open savanna and bare soil.

Net radiometer data from the Maun station were used both for crude atmospheric corrections, as well as for validating net radiation estimates. To validate the model output for soil and turbulent heat fluxes, a total of 5 soil heat flux plates, also in place at the tower site, were used in combination with an eddy-correlation system.

ESTA Model

With physically-based modeling of land surface-atmosphere interaction, especially over sparsely vegetated areas, one cannot ignore the completely different behavior of the two main surface types, soil and vegetation. Experience has taught us that when dealing with sparse canopies (LAI less than 0.4) and temperature differences between soil and canopy cover on the order of 20ºC, errors in net radiation modeling may reach up to 40% (Kustas and Norman, 1996). These are conditions that certainly prevail in the area under study. Therefore, the net radiation modeling is treated separately for soil and vegetation.

Because the reflection and absorption of radiation in the visible and near infrared wavelengths are significantly different for vegetation and soils, albedo is treated separately in these wavelength regions. Also, the beam and diffuse radiation components are computed separately. A multiple scattering radiation transfer model, following Campbell and Norman (1998), is implemented. The approach requires estimates of vegetation cover, in the vertical sense (vegetation density, or Leaf Area Index), for shortwave radiation modeling, and in the horizontal sense (fractional cover, derived from NDVI), for longwave modeling.

The algorithm requires measurements of incoming solar radiation, after which the transmission of shortwave radiation through the canopy is modeled following the formulations presented by Monteith and Unsworth (1990). The longwave radiation balance for the soil-vegetation-atmosphere system is performed by implementing a single exponential extinction factor to estimate the transmission for both the soil and the canopy. The longwave emissions from the soil, canopy and sky are computed from the Stefan-Boltzman equation, using estimates of soil temperature, canopy, and air temperature and vapor pressure, respectively.

The temperatures for the soil and vegetation components are obtained by partitioning the ensemble directional radiometric temperature into the soil and canopy components using the fraction of vegetation cover, following Becker and Li (1990).

The estimation of soil heat fluxes is linked directly to the net radiation component for soil. To account for the phase difference between net radiation and soil heat flux, a semi-empirical relation is implemented, using soil surface temperatures and the soil hemispherical reflection coefficient. The sensible heat flux is computed in steps from flux inversion at dry non-evaporating land units and at wet surface types. The surface roughness is determined following the approach described by Verhoef et al. (1997). Additional parameters needed here are the vegetation height (extracted from the crude land cover classification) and the displacement height (taken as a function of vegetation height). The friction velocity is determined by assuming a logarithmic wind profile using wind speed measurements at observation height and the wind speed at blending height. Near surface air temperature is calculated by inverting the sensible heat flux expression over dry and wet areas assuming a linear relation to surface temperature. The latent heat flux is finallly computed as the residual of the energy balance.

Additional Sources of Information

Related Data Sets

The Maun site was part of the Kalahari Transect which was the focus of several complementary studies by colleagues from Southern Africa and elsewhere. Many of these studies are archived by ORNL DAAC. A list of these data sets is available at: http://www.daac.ornl.gov/S2K/safari.html.

Lloyd, J., O. Kolle, E. Veenendaal, A. Arneth, and P. Wolski. 2004. SAFARI 2000 Meteorological and Flux Tower Measurements in Maun, Botswana, 2000. Data set. Available on-line [http://daac.ornl.gov/] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S.A.

References

Becker, F. and Z. L. Li. 1990. Temperature independent spectral indices in thermal infrared bands. Remote Sensing Environment, 32: 17-33.

Campbell, G. S. and J. M. Norman. 1998. An Introduction to Environmental Biophysics. Springer, New York, 286 pp.

Kustas, W. P. and J. M. Norman. 1996. Use of remote sensing for evapotranspiration monitoring over land surfaces. Hydrological Sciences, 41(4): 495-516.

Monteith, J. L. and M. H. Unsworth. 1990. Principles of Environmental Physics. Edward Arnold Publishers, London, 291 pp.

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Verhoef, A., K. G. McNaughton, and A. F. G. Jacobs. 1997. A parameterization of momentum roughness length and displacement height for a wide range of canopy densities. Hydrology and Earth Sciences, 1(1): 81-91.

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