The SEBAL Remote Sensing tool for water consumption

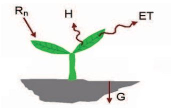
Wim Bastiaanssen*, Grant Davids** and Rick Allen

About SEBAL

SEBAL (Surface Energy Balance Algorithm for Land) uses spectral radiances recorded by Landsat or other thermal infrared satellite images, plus routine weather data, to solve the energy balance at the earth's surface (illustrated below). The instantaneous ET_{act} flux is calculated for each pixel of the image as a 'residual' of the surface energy budget equation:

$$ET = R_n - G - H$$

where; ET is the latent heat flux (W/m^2), R_n is the net radiation flux at the surface (W/m^2), G is the soil heat flux (W/m^2), and H is the sensible heat flux to the air (W/m^2).



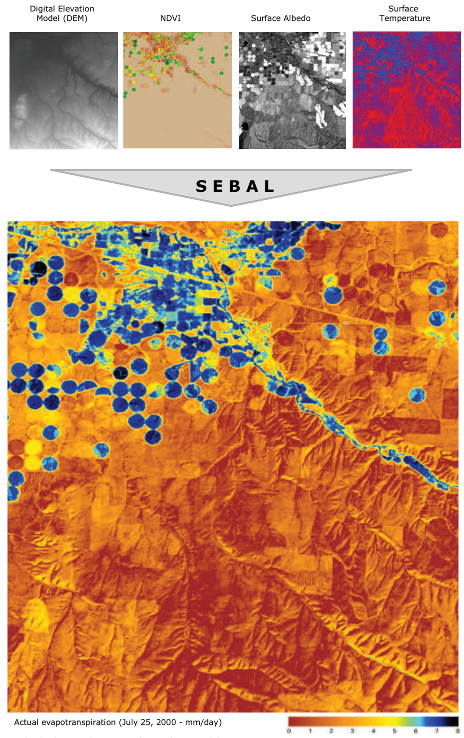
The result is a digital ET image that can be imported into GIS for analysis, in combination with land use and other data. There are a few major characteristics that make SEBAL different from other Remote Sensing flux algorithms:

The first characteristic is that the sensible heat flux is fixed at the so called "hot" and "cold" pixel. These two points should "anchor" the range of sensible heat flux or evaporative fraction, thus these two pixels should be divided between very dry terrain (where latent heat flux is small to zero) and very moist terrain (where sensible heat flux is small to zero).

The second characteristic is that ΔT (i.e. the vertical difference in air temperature) is computed from inversion of the sensible heat flux at the anchor points. This implies that neither radiometric surface temperature, nor air temperature measurements are involved in the computation of ΔT.

The third characteristic is that ΔT is linearly related to radiometric surface temperature. This relationship depends on the satellite image chosen (area, climate, time of overpass) and is often referred to as the "self-calibration" approach.

The fourth characteristic is the temporal constancy of surface heat flux fractions throughout the day. Different fractions can be thought of, such as the evaporative fraction and the relative ET, i.e. ET_a/ET_{ref}. A simple correction can be added to correct for advection effects on the evaporative fraction.



Actual evapotranspiration (July 25, 2000 - mm/day)

Colombia basin, Echo, Oregon (119°12'W; 45°40'N)

Accuracies

In the U.S., SEBAL has been tested and validated by dr. Rick Allen of the University of Idaho/Kimberly, with excellent results as compared to lysimeter measurements of monthly and seasonal crop water use. Error cancellation occurs when daily ET-fluxes of sugar beets are integrated over time. The lysimeter gave a total ET value of 705 mm per season, and the independent SEBAL estimates predicted a value of 714 mm (see figure 1).

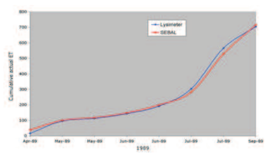


Figure 1: Cumulative ET for irrigated sugar beets grown on a USDA lysimeter in Kimberly, Idaho, from April 1 to September 30, 1989 (data from Dr. James Wright)

A research in the Middle Rio Grande Valley towards vegetation and vadose zone processes compared the SEBAL-based ET fluxes for 7 different dates between October 1999 and March 2003 for 6 types of riparian vegetation. The flux sites were covering cottonwood, salt-cedar, shrub, grass and mixed vegetation. The overall agreement across a wide range of ET fluxes (range is 0 to 7.8 mm/d) for sparse vegetation is good. The average measured ET for images acquired in March, April, May, June, September and October was 2.25 mm/d and the SEBAL estimated value was 2.19 mm/d, being an error of 2.7% (see figure 2).

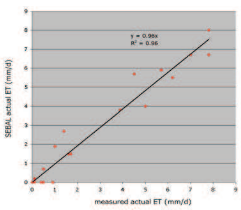


Figure 2: Validation of SEBAL-based ET estimates for riparian and irrigated vegetation under arid conditions in New Mexico (data from Dr. Jan Hendrickx)

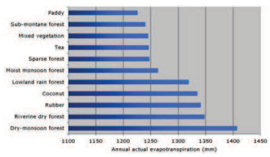


Figure 3: Annual ET for various agro-ecosystems commonly present on the island of Sri Lanka between June 1999 and June 2000

Catchment-scale studies in Pakistan, Sri Lanka and Sudan reveal an overall deviation of 4.6% between SEBAL annual ET values and the annual total ET derived from water balance closures between precipitation, inflow and outflow. It is unlikely that these accuracies will ever be improved much further in the short term, because most regional scale hydrological databases (of precipitation, stream flow, weather, etc.) lack sufficient accuracy.

Country	Size catchment (km^2)	ET-field data (mm)	ET-SEBAL (mm)	Difference (%)
Rechan Doab, Pakistan	30,000	935	940	+1
Kelani Ganga, Sri Lanka	2,292	1,328	1,310	-1
Gin Ganga, Sri Lanka	932	1,506	1,333	-11
Kirindi Oya, Sri Lanka	256	1,295	1,356	+5
Sudd, Sudan	38,600	1,669	1,636	-2
Baher El Ghazal, Sudan	59,270	1,574	1,499	-5
Sobat, Sudan	42,900	1,364	1,287	-6
AVERAGE				**4.6**

Potential applications

The high resolution images enable analysis within irrigated fields, such as to assess water use uniformity, and integration across fields, up to the watershed level, for hydrologic water balances and the like. SEBAL can generate GIS databases (spatial coverages) of water consumption for different crops and fields within agricultural areas and for various land types within river basins (see figures 3 and 4). This enables assessment of irrigation management practices within and among fields and improves the degree of confidence in development and interpretation of water balances at various spatial scales. Additional applications of SEBAL are listed in the table below.

Theme	Location	Objective
Water rights	Idaho State	Identification of farmers whose water consumption exceeds entitlement
Crop ET	Washington State	Compare crop ET by SEBAL to crop ET computed from conventional means
Runoff prediction	Panama	Predict runoff to fill the sluices of Panama Canal on the basis of catchment surplus
Irrigation performance	Argentina	Identification of non-uniformity in water availability
Irrigation scheduling	Brazil	Identifying pumping units that lift insufficient water for potential growth of fruit crops
Groundwater mining	Mexico	Identification of farms that intensively use groundwater
Water accounting	Sri Lanka	Quantify consumptive use, beneficial and non-beneficial use of water resources
Groundwater withdrawals	Pakistan	Estimate difference between extraction and recharge in rice-wheat cropping systems
Crop water productivity	India	Identify head-tail differences and effect on productive use of water resources
Integrated water management	India	Conjunctive use of surface and groundwater in Warabandi systems
Basin scale efficiency	Pakistan	Demonstrate the impact of water recycling on irrigation efficiency
Water user associations	China	Characterize the impact of management transfer from Government to User Groups on the utilization of water resources
Sustainability	Iran	Quantifying changes in soil salinity in head and tail end of the basin
Water use bird parks	Turkey	Estimation of water use of environmental systems
Uniformity in water use	Egypt	Expressing uniformity of access to surface water resources
Soil salinity	Syria	Allocate areas with insufficient drainage capacity

Land cover wise evaporative depletion in river basins

Figure 4 shows the results of using GIS to superimpose the land cover map on the annual ET map in Sri Lanka. Although paddy (rice) cultivation is generally believed to consume large quantities of water, SEBAL revealed that paddy is the least water consuming land cover type. This is explained by the short growing season of rice (240 growing days in a year under typical double cropped conditions). SEBAL revealed that "dry zone" forests found in the leeward side of seasonal monsoon weather systems consume more water than irrigated agriculture. This is because they are exposed to a larger doses of solar radiation (less cloud cover) and draw their supply from shallow groundwater, especially near the downstream end of open river basins.

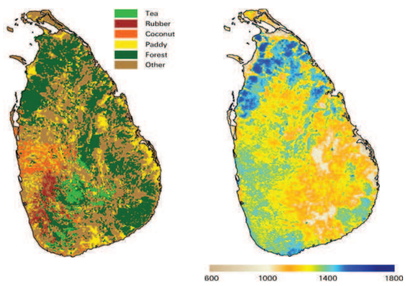


Figure 4: Land cover classification (left) and annual ET (mm/year - right) for all river basins in Sri Lanka

References

Allen, R.G., A. Morse, M. Tasumi, R. Trezza, W. G.M. Bastiaanssen, J.L. Wright, and W. Kramber, 2002. Evapotranspiration from a Satellite-BASED Surface energy balance for the Snake Plain Aquifer in Idaho, Proc. USCID conference San Luis Obispo, July 2002

Bastiaanssen, W.G.M., M. Menenti, R.A. Feddes and A.A.M. Holtslag, 1998. A remote sensing Surface Energy Balance Algorithm for Land (SEBAL), part 1: formulation, *J. of Hydr.*, 212-213: 198-212

Bastiaanssen, W.G.M., M. Ud-din-Ahmed and Y. Chemin, 2002. Satellite surveillance of water use across the Indus Basin, *Water Resources Research*, vol. 38, no. 12: 1273-1282

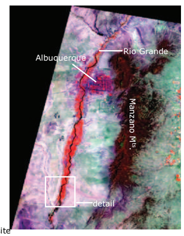
Bastiaanssen, W.G.M., E.J.M. Noordman, H. Pelgrum, G. Davids and R.G. Allen, 2003. SEBAL for spatially distributed ET under actual management and growing conditions, ASCE, *J. of Irrigation and Drainage Engineering* (submitted)

Scott, C.A., W.G.M. Bastiaanssen and M.D. ud-Din Ahmad, 2003. Mapping root zone soil moisture using remotely sensed optical imagery, ASCE, *J. of Irrigation and Drainage Engineering* (July issue)

SEBAL experiences in USA

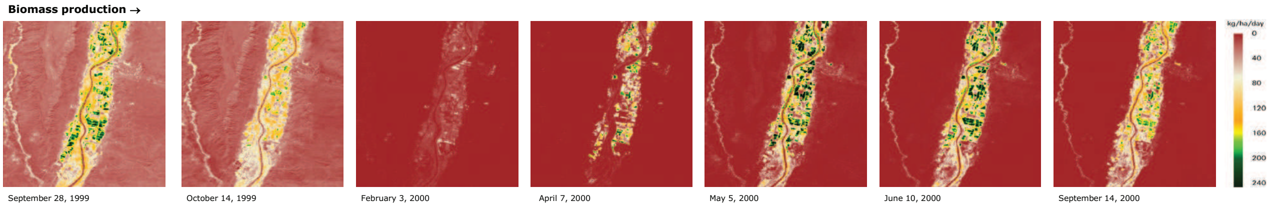
- 1995: Jornada Experimental Range, Chihuahuan Desert, New Mexico
- 1999: Middle Rio Grande, New Mexico, New Mexico Tech, Socorro
- 2000: Snake River Basin, Southern Idaho, University of Idaho
- 2001: Tampa Bay, Florida, Allen Engineering
- 2002: Boise Valley, Idaho Department of Water Resources, Boise
- 2002: San Juan basin, Najavo Nation, New Mexico, Keller-Bliesner Engineering
- 2003: Colombia basin, Benton Irrigation District, Washington State, Davids Engineering

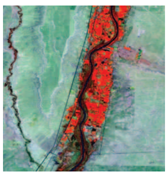
Rio Grande time series 1999–2000

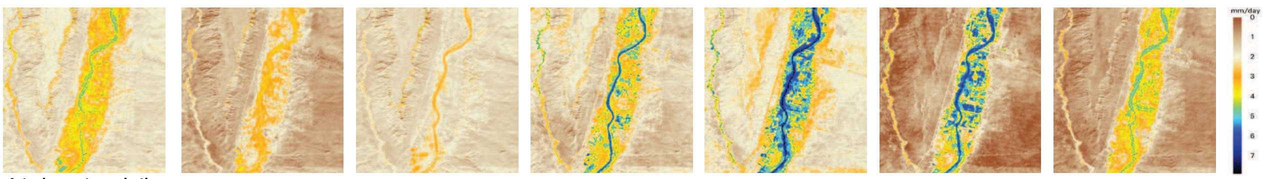


Landsat TM, June 10, 2000 false color composite rgb = b. 4,5,3

Biomass production →







Actual evapotranspiration →

SNA

Remote Sensing Services for Water Resources Management

** Grant Davids, Operations Manager
e-mail: grant@de-water.com

* Wim Bastiaanssen, Director of Technology
e-mail: w.bastiaanssen@waterwatch.nl

SEBAL North America (SNA)
1772, Picasso Avenue, Suite E
Davis, California
Phone: 530.757.6107 x14
Fax: 530.757.6118