Estimating Terrestrial Evaporation: Algorithm background for the new MOD16 product

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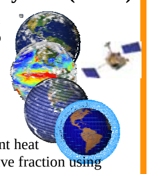
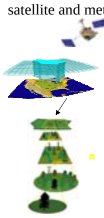
Introduction

Evaporation provides the link between the energy and water budgets at the land surface. Accurate measurements of evaporation rates at large spatial scales are central to understanding the feedback mechanisms and coupling between the land and the atmosphere. The paucity of available surface observations for many portions of the globe makes the use of modeled evaporation using satellite-based remotely sensed inputs a viable surrogate. The Surface Energy Balance System (SEBS) estimates atmospheric turbulent heat fluxes and evaporative fraction using a minimum of near-surface meteorological variables, satellite derived land surface temperature (LST) and insolation, and other remote sensing products such as vegetation information. An issue in using MODIS-based satellite measurements to force SEBS is the low temporal sampling. Therefore, estimates of daily evaporation may be based on as few as one surface temperature measurement per day. A method is shown to overcome this problem which assumes that the evaporative fraction is constant over daylight hours and so daily evaporation may be estimated using a single measurement. Here, the basis of the SEBS algorithm is outlined, with particular reference to input data requirements, model assumptions and planned products. Also provided is an overview of both current and future evaluation programs.

Surface Energy Balance System (SEBS)



The Surface Energy Balance System (SEBS) (Su, 2002) was developed to provide improved estimates of land surface fluxes using a minimum of satellite and meteorological data.



SEBS estimates atmospheric turbulent heat fluxes and evaporative fraction using satellite derived surface temperature and insolation, and near surface meteorological variables, along with other remotely sensed variables. The SEBS-MODIS product is aimed at providing an estimate of the evaporative fraction occurring at the land surface. The product will be limited primarily by the availability of surface temperature data from the MOD-11 product, with uncertainty correlated with the LST quality. A strategy for having a MODIS-based insolation product is being pursued.

* *(Su et al., Hydrol. Earth. Syst. Sc., 6, 2000).*

SEBS Operation and Data Requirements

The temporal resolution of SEBS is only limited by the availability of forcing data. For MODIS surface temperature data, morning (10:30am – Terra) and afternoon (1:30pm – Aqua) platforms provide two daytime measurements. For the continental United States, the availability of the North American Land Data Assimilation System (N-LDAS) offers a variety of data forcings suitable for SEBS. Such data is also available at the global scale (G-LDAS), although at a reduced spatial resolution.

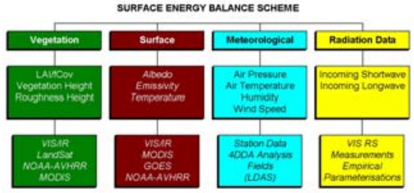


Figure 1. SEBS forcing data requirements

Progress towards a high resolution (1km) forcing data set, a component of the Land Information System (LIS) (http://lis.gsfc.nasa.gov) will offer a global data set suitable for incorporation with the SEBS.

Remote Sensing Variables	*MODIS Land Products*
Surface temperature (K)	MOD-11: Land Surface Temperature
Surface emissivity	MOD-11: Emissivity
Surface albedo	MOD-43: Surface reflectance
Leaf Area Index	MOD-15: Leaf Area Index & FPAR
Fractional Vegetation Cover	MOD-13: Gridded NDVI & MVI
Roughness Height and Displacement Height (m)	MOD-12: Land Cover

Meteorological and Radiative Forcing	*Data Source*
Surface Pressure (Pa) 2m air temperature (K) Surface specific humidity (kg/kg) Surface wind speed (m/s)	GLDAS surface fields from 4DDA analysis fields
Incoming short-wave radiation (W/m^2) Downward longwave radiation (W/m^2) Net short & longwave radiation (W/m^2)	ISCCP (3-Hrly), Air Force Weather Agency (Hrly) or NOAA-NESDIS

Figure 2. Potential data sources from MODIS and ancillary products

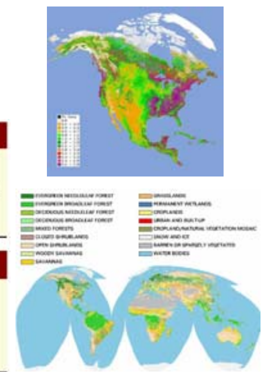


Figure 3. MODIS LAI and Land Cover Types

Theoretical Basis, Model Assumptions and Development

To determine surface heat fluxes and evaporation, SEBS uses measurements of surface temperature from satellite remote sensing. Since MODIS data may only pass over a given point once per day, the full diurnal cycle of these fluxes can not be estimated. It is proposed that this problem may be overcome by assuming that the evaporative fraction ($\lambda E/(R_n - G)$) is constant over daylight hours (Shuttleworth et al., 1989; Brutsaert and Sugita, 1992, Crago, 1996) and therefore it may be possible to estimate daily evaporation from a single daily observation of surface temperature.

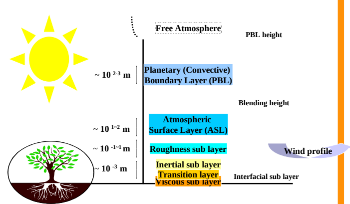
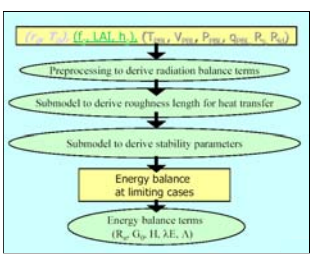


Figure 4. SEBS vertical extent (PBL-ASL)



$$
\begin{cases}
u = \dfrac{u_*}{k}\left[\ln\left(\dfrac{z-d_0}{z_{0m}}\right) - \Psi_m\left(\dfrac{z-d_0}{L}\right) + \Psi_m\left(\dfrac{z_{0m}}{L}\right)\right] \\
L = -\dfrac{\rho C_p u_*^3 \theta_v}{kgH} \\
H = ku_*\rho C_p(\theta_0 - \theta_a)\left[\ln\left(\dfrac{z-d_0}{z_{0h}}\right) - \Psi_h\left(\dfrac{z-d_0}{L}\right) + \Psi_h\left(\dfrac{z_{0h}}{L}\right)\right]^{-1}
\end{cases}
$$

$$R_n = G_0 + H + LE$$

$$R_n = (1-\alpha)\cdot R_{swd} + \varepsilon \cdot R_{lwd} - \varepsilon \cdot \sigma \cdot T_0^4$$

$$G_0 = R_n \cdot [\Gamma_c + (1-f_c)\cdot(\Gamma_s - \Gamma_c)]$$

Figure 5. SEBS process description and some governing equations

The algorithm is designed as follows: The available energy is partitioned into sensible and latent heat fluxes for two end conditions: (i) dry surface where the latent heat flux is assumed to be zero (minimum) due to soil-vegetation controls and (ii) wet surface where the atmospheric evaporative demand can be fully met (i.e. the maximum evaporation rate , often referred to as the 'potential rate'. For the dry case, the sensible heat is assumed to be the available energy and for the wet case a Penman-Monteith type combination equation is solved using a suitably parameterized surface resistance to account for both meteorological and surface roughness conditions.

Using a Bulk-Aerodynamic approach, the sensible heat *H* is estimated for the current conditions. This estimate of *H*, along with the two constraining end conditions (H_{dry} and H_{wet}) allows for the estimate of the relative evaporation Λ_r. The relative evaporation can be related to the evaporative fraction Λ, which can be related to the latent heat for the current conditions given the available energy. To estimate total daily latent heat (i.e. evaporation) from the evaporative fraction, the total daily available energy (Rn - G) is required. For relatively clear sky days, it is reasonable to assume that the diurnal cycle of available energy varies only in its amplitude between days and location.

Knowing H, solve for Λ_r

$$\boxed{\Lambda_r = 1 - \frac{H - H_{wet}}{H_{dry} - H_{wet}}}$$

Knowing Λ_r, solve for Λ

$$\boxed{\Lambda = \frac{\lambda E}{R_n - G} = \frac{\Lambda_r \cdot \lambda E_{wet}}{R_n - G}}$$

Re-write H and LE

$$\boxed{\begin{aligned} H &= (1-\Lambda)\cdot(R_n - G) \\ \lambda E &= \Lambda \cdot (R_n - G) \end{aligned}}$$

Estimate daytime ET

$$\boxed{E_{daytime} = \Lambda \times \int_{daytime} \frac{R_n - G_0}{\lambda \rho_W}}$$

Comparison of Model Simulated Energy Fluxes with Measurements

To determine how well SEBS simulates surface energy fluxes, comparisons are to be made with observations derived over a variety of unique land surface types and conditions. These model evaluations will be undertaken over both the continental United States as well as other areas of the globe where quality data sets are available.

Work being undertaken at Princeton University includes the assessment of scale on the evapotranspiration, from the point to regional scales. Data from both the 1km and 5km MODIS-LST product are being assessed to determine the influence of temperature scaling on the proposed product.

Previous work assessing SEBS has been undertaken over the Oklahoma Mesonet and also recently over Iowa as part of the Soil Moisture Atmosphere Coupling Experiment (SMACEX 02) *(Su et al, 2004 J. Hydrometeorology, submitted).* Future field scale examination is expected as part of the SMEX-NAME experiment occurring summer 2004.

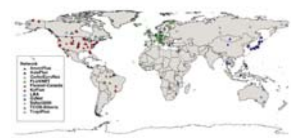


Figure 5. AmeriFlux and COEP sites provide a network of tower and field measurements.

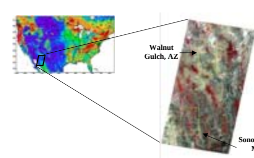


Figure 6. The 2004 Soil Moisture Experiment (SMEX) will provide additional surface flux observations for an arid environment

As well as examining the ability of SEBS to reproduce land surface fluxes at a variety of scales and surface types in the United States, analysis will be undertaken at selected locations around the globe as part of a plan to expand SEBS evaluation. Data from the GEWEX Coordinated Observing Period (CEOP) towers and selected AmeriFlux sites will be used to assess the algorithm.

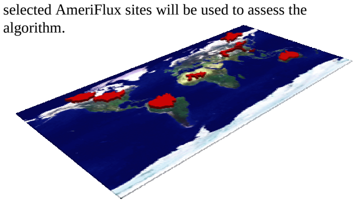


Figure 7. Globally distributed flux tower sites as part of the Global Energy Water Cycle Experiment (GEWEX)

Project Schedule

- **July 2004**: Initiation of the project. As of July 1, 2004 the final grant documents have not yet been finalized from NASA. Pre-award funding has been approved.
- **Year 1**: In collaboration with Steve Running, UMT, identify a set of Ameriflux towers for algorithm intercomparisons. UMT is taking the lead in compiling these data and associated MODIS data. Carry out scaling studies using high resolution Thermatic Mapper-based surface temperatures to understand the impact of MODIS-scale surface temperatures.
- **Year 2**: Initiate regular retrievals for selected domains. The extent of these areas will depend on the results from year 1. Carry out continued product evaluation and comparisons to tower based surface heat flux estimates.
- **Year 3**: Expand the domain for the retrievals, and provide uncertainty estimates for the retrievals.