Validation, Calibration and Improvement of Remote Sensing ET Algorithms in Mountainous Regions

Jan Hendrickx, New Mexico Tech

Project descriptors: remote sensing, mountain hydrology, evapotranspiration

PROBLEM AND RESEARCH OBJECTIVES

Accounting of key reservoirs and fluxes associated with the global water cycle, including their spatial and temporal variability, are crucial goals of water resource managers. Advancements in satellite optical remote sensing have resulted in the development of several operational remote sensing evapotranspiration (ET) algorithms. While these algorithms typically give accurate ET predictions over flat terrain, significant difficulties have been encountered in mountainous regions which are characterized by heterogeneous soil and topography and high elevation changes. However, mountain runoff represents more than 90% of the total runoff in the semi-arid basins of the Rio Grande, Oranje, Colorado, and Rio Negro rivers. Thus improving ET estimates in the mountains is crucial for determining the regional water balance in the southwestern U.S. and in many mountainous regions worldwide. The following objectives will be pursued:
1) validate sensible and latent heat fluxes estimated from SEBALNM using ground measurements over mountainous landscapes in New Mexico; 2) calibrate SEBALNM satellite ET maps using ET measurements over scintillometer transects in near real time; and 3) develop improvements for SEBALNM and other remote sensing ET algorithms for better ET estimates in mountainous areas. To achieve this we will incorporate shade effects, lapse rates, advection, and air flow effects into SEBALNM.

METHODOLOGY

Most remote sensing algorithms obtain ET as the residual of the energy balance after measuring and/or modeling net radiation, ground heat flux, and sensible heat flux H. Among these fluxes, H is the most complex to estimate and its value is associated with the greatest uncertainty. We will use novel measurement techniques, such as scintillometers, together with spatially dense meteorological measurements and archived ETA numerical weather model data to measure H and determine how it is related to temperature lapse rate, wind speed, water vapor deficit, and boundary layer height. Two protected sites with idealized topographical shape will be considered in the field study: the Magdalena Ridge and the Valles Caldera National Park in New Mexico. First, the measured H will be used to validate estimates derived from the Surface Energy Balance over Land (SEBAL) algorithm applied on data from synchronous ASTER and MODIS satellite overpasses. Second, techniques for calibration of the SEBAL algorithm in near-real time using surface measurements of H will be developed. Third, parameterizations in the SEBAL algorithm for mountain lapse rates, wind speeds, and surface roughnesses will be critically reviewed and improved by considering meteorological measurements and archived numerical weather model data. Through this work we will make a lasting contribution to ET estimation from SEBAL and other remote sensing algorithms for current and future satellite missions.

PRINCIPAL FINDINGS

For the validation of SEBALNM we have used the new technology of scintillometry. Since no other research group had established a network of six scintillometers over an area of 315,000 km2 we have spent considerable effort to test the performance of scintillometers under the mountainous conditions of New Mexico.

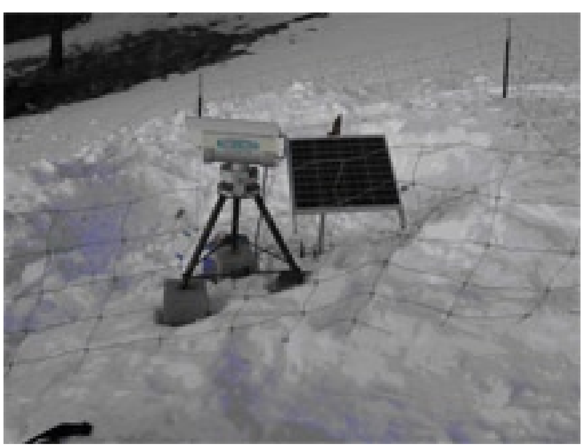
We performed first two field studies with six large aperture scintillometers (LASs) using horizontal and slant paths. The accuracy of this novel and increasingly popular technique for measuring sensible heat fluxes was quantified by comparing measurements from different instruments over nearly identical transects. Random errors in LAS measurements were small, since correlation coefficients between adjacent measurements were greater than 0.995. However, for an ideal set-up differences in linear regression slopes of up to 21% were observed with typical inter-instrument differences of 6%. Differences of 10% are typical in more realistic measurement scenarios over homogeneous natural vegetation and different transect heights and locations. Inaccuracies in the optics, which affect the effective aperture diameter, are the most likely explanation for the observed differences (Kleissl et al., 2008b). The quantification of the instrument error of large aperture Kipp & Zonen scintillometers is critical information for all hydrologists using scintillometer worldwide. These results are relevant for Objective One.

We also established in New Mexico a first-of-its-kind network of seven Large Aperture Scintillometer (LAS) sites to measure sensible heat fluxes over irrigated fields, riparian areas, deserts, lava flows, and mountain highlands. Wireless networking infrastructure and auxiliary meteorological measurements facilitate real-time data assimilation. LAS measurements are advantageous in that they vastly exceed the footprint size of commonly used ground measurements of sensible and latent heat fluxes (~100 m2), matching the pixel-size of satellite images or grid cells of hydrologic and meteorological models (~0.1-5 km2). Consequently, the LAS measurements can be used to validate, calibrate, and force hydrologic, remote sensing, and weather forecast models. We have published initial results for: (1) variability and error of sensible heat flux measurements by scintillometers over heterogeneous terrain and (2) the validation of the Surface Energy Balance Algorithm for Land (SEBAL) applied to MODIS satellite imagery (Hendrickx et al., 2007; Kleissl et al., 2008a). The findings from this study are relevant for our first two objectives .

In another recently submitted publication, we present our experiences with the emerging method of scintillometry for hydrologic studies include the use of SEBALNM. Large aperture scintillometers are employed to derive the sensible heat flux over irrigated fields, riparian areas, deserts, lava flows, and mountain highlands in New Mexico. The theory and technical aspects of the setup, operation, and analysis of LAS data are discussed. The advantages of a larger flux footprint, compared with other measurement techniques for the sensible heat flux, are explained, particularly in the context of the calibration and validation of remote sensing surface energy balance algorithms, and hydrologic and meteorological models. The scintillometer transects were used to explore this measurement technique as a potentially useful tool in hydrological applications. Evapotranspiration rates for hydrologic applications can be obtained at scales of the pixel-size of satellite images or grid cells of hydrologic and meteorological models (0.1-10 km2) (Gomez et al., 2008). The findings from this study are relevant for our first two objectives.

Finally, in another recent publication we discuss why scintillometer measurements cannot be used directly for the calibration and validation of SEBALNM since the sensible heat flux determined by SEBALNM absorbs biases caused by its assumptions and atmospheric conditions (Hong et al., 2008). This was somewhat of a surprise to us and is very relevant for practitioners worldwide; it is relevant for our objective two.

We have already taken many measurements relevant for the third objective such as air temperature and humidity measurements along elevation gradients and scintillometer measurements over snow in the Valles Caldera (Figures 1 and 2). These measurements still need to be analyzed. Since a new PhD student withdrew from the project in the fall semester of 2007 this work has been delayed and, therefore, we will request a no-cost extension of one year.



Transmitter in Valles Caldera transect in January 2008. The tough field work makes the project less attractive for some graduate students.

Figure 2. Waist-deep snow posed severe access problems. After one failed attempt on snow shoes the Valles Caldera National Park made their snowmobiles available to access the scintillometer.