한국환경과학회 봄 학술발표회지 제15권(제1호), 159~163, 2006
Proceedings of the Korean Environmental Sciences Society Conference, May, 19~20, 2006

OE1)

Up- and Down-Scaling of Evapotranspiration Maps Derived from Landsat and MODIS Images

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1. INTRODUCTION

Remote sensing using satellite-based sensors has the potential to provide detailed information on land surface properties and parameters over large areas (e.g. Diak and Stewart.,1989; Kustas and Humes, 1996). Perhaps one of the most important land surface parameters that can be derived from optical remote sensing is evapotranspiration (ET). Since ET is an important component of the hydrologic cycle in arid environments, the determination of the spatial distribution of ET over a range of space and time scales is needed for sustainable management of water resources as well as for a better understanding of water exchange processes between the land surface and the atmosphere.

The scale or pixel size of remote sensing data is dependent upon the spatial resolution of its satellite imagery. In this study, two different satellite images will be used to examine the effect of scale transfer processes. The Landsat 7 Enhanced Thematic Mapper Plus (ETM+) launched in 1999 has 30m visible and 60m thermal band pixel size but poor temporal resolution (i.e. 16 days). More recently (2000), the Moderate Resolution Imaging Spectroradiometer (MODIS) is providing information of high temporal resolution (twice a day) but a coarse spatial resolution (250 to 500m in the visible and 1000x1000m in the thermal bands).

For an accurate prediction of water consumption at the field level homogeneous pixels with a single vegetation type are needed. Therefore, it seems that accurate estimates of water consumption can only be done using fine spatial resolution images like Landsat 7. However, Landsat 7 images are not suitable for global scale land surface characterization and monitoring. Although coarse resolution images like MODIS provide very useful opportunities to monitor the energy balance at meso scale, they cannot directly provide field specific data. Therefore, scaling transfer between Landsat 7 and MODIS is needed to take advantage of high temporal and various spatial resolutions of land surface parameters.

Many studies in the last decade have examined the effects of different pixel sizes (Hay

et al., 1997; Heuvelink and Pebesma, 1999). Since most of these studies addressed up-scaling only, there is a need for more information on down-scaling procedures. The first objective of this paper is to assess the possible discrepancy of daily ET rates estimated using SEBAL through Landsat 7 and MODIS. The second objective is to implement various scaling transfer approaches for investigating the effect of the scaling transfer between ET maps derived from Landsat 7 and MODIS images.

2. SCALING TRANSPER PROCESS

Although Landsat 7 and MODIS images differ in many ways, including wavelength of spectral bands, scanning system and sensitivity, the largest difference is in the spatial and temporal resolutions. One MODIS image can cover from the Gulf of California to the Gulf of Mexico while a Landsat image covers a much smaller area of about 160x160 km. The Landsat 7 images used in this study covered the Middle Rio Grande Basin (Path/Row: 34/36).

Scaling transfer means changing data or information from one scale to another. Upscaling consists of taking information at smaller scales to derive processes at larger scales, while downscaling consists of decomposing information at one scale into its constituents at smaller scales.

In the up-scaling process (Landsat 7 resolution to MODIS resolution on June 6, 2002), two different procedures were evaluated. The first consists of averaging 60 by 60m Landsat 7 pixels of the input parameter (radiance) to obtain 1000 by 1000 m pixels at the MODIS scale before SEBAL is applied. The second consists of first applying SEBAL and then averaging the output parameter (daily ET) from 60 m to 1000 m spatial resolution. In the averaging process, 60 by 60m pixels were broken into 10 by 10m pixels with the same pixel values and then were averaged into 1000 by 1000m pixels. The averaging process (aggregation) includes calculating arithmetic and geometric means.

In the down-scaling process (disaggregation MODIS resolution to Landsat 7 resolution on June 16, 2002), an earlier Landsat 7 image of May 31, 2002, was used to characterize the fine scale variability within the large MODIS pixels. Two down-scaling procedures were evaluated. The first consists of down-scaling the MODIS input parameter (radiance); the second of down-scaling the output parameter (daily ET) at MODIS resolution. Similar to up-scaling, 1000 by 1000m pixels were first down-scaled into 10 by 10m pixels and then averaged into 60 by 60m pixels.

3. SEBAL ALGORITHM

In this study, the Surface Energy Balance Algorithm for Land (SEBAL) (Bastiaanssen et al., 1998a) was used to derive evapotranspiration maps from Landsat 7 and MODIS

images. The SEBAL method has been used in various studies to assess ET rates in Idaho, Spain, Italy, Turkey, Pakistan, India, Sri Lanka, Egypt, Niger, and China (Bastiaanssen et al., 1998a,b; Timmermans et al., 2001; Wang et al., 1998). In this volume we have a companion paper by Hendrickx and Hong that describes an application of SEBAL in arid heterogeneous riparian areas of the southwestern United States

SEBAL is a physically based analytical method that evaluates the components of the energy balance and determines the ET rate as the residual

$$R_n - G - H = \lambda ET \quad (1)$$

where R_n is the net incoming radiation flux density (Wm^{-2}), G is the ground heat flux density (Wm^{-2}), H is the sensible heat flux density (Wm^{-2}), λET is the latent heat flux density (Wm^{-2}), and parameter λ is the latent heat of vaporization of water ($J\ kg^{-1}$). The ET rates are determined as $ET=\lambda ET/\lambda$.

SEBAL is based on the computation of energy balance parameters from multi spectral satellite data. Table 1 shows the spectral bands of Landsat 7 and MODIS in the visible, near infrared and thermal infrared wavelength regions used in this study. The original spatial resolution of the visible and near infrared imagery of 30m in Landsat 7 and 250 and 500m in MODIS, was reduced to 60m and 1000m to be compatible with the resolution of the thermal imagery. Table 2 shows the spatial resolution of MODIS and Landsat 7.

Since MODIS bands 1, 2, 3, 4, 6 and 7 are compatible with Landsat 7 bands 3, 4, 1, 2, 5 and 7, most of the SEBAL algorithms using MODIS are similar to the Landsat 7 algorithms. The only difference is the algorithm for surface temperature calculations. SEBAL uses one thermal band for surface temperature estimation through the Landsat 7 while two thermal bands are used for the MODIS application.

4. RESULTS AND DISCUSSION

Comparison of SEBAL ET rates derived from Landsat 7 and MODIS images

The SEBAL algorithms were applied to one Landsat 7 image and one MODIS image acquired on June 16, 2002, to estimate daily ET rates. Both the overall ET maps as well as the ET histograms match each other quite well which is an indication that the spatial resolution of an image doesn't affect much SEBAL derived ET rates. In the next section we will quantify some of the differences between the two ET maps.

Both of the ET images clearly show the high ET rates in the irrigated fields and riparian areas in the Rio Grande Valley and the low ET rates in the adjoining desert areas. The city of Albuquerque has a somewhat higher ET rate than its surroundings. The irrigated fields underneath the center pivot systems in the Estancia basin have a

much higher ET than the bare fields surrounding them. The ET map derived from the Landsat 7 image shows a slightly higher ET mean and standard deviation than the one derived from the MODIS image. Many small areas (length scale on the order of 10 to 100 m) along the river and in the mountains have peak ET rates that are captured well in the Landsat derived ET map with spatial resolution of 30 m. However, these peak ET rates are averaged out on the MODIS derived ET map with spatial resolution of 1000 m.

Effect of up- and down-scaling

The scale transferred ET maps have good agreement with the original ET maps. The effect of up- and down-scaling as absolute ET difference maps between the original ET map derived directly from Landsat 7 and MODIS imagery and the one generated from scaling transfer. A few lines with apparently high ET differences are observed along the Rio Grande River riparian areas. These anomalies are due to errors with image registrations since the registration of two maps with spatial resolutions differing more than one order of magnitude is not trivial. It causes abrupt ET changes at the boundaries between riparian (high ET) and desert (low ET) areas. For example, to obtain completely accurate down-scaling results, the image registrations among the MODIS image of June 16, 2002, and the Landsat 7 images of May 31 and June 16, 2002, should be perfect.

In the up-scaling results, means of the ET difference range from 0.45 to 0.60 mm/day and standard deviations range from 0.42 to 0.60 mm/day. Means and standard deviations of the down-scaling results are slightly higher and range from 0.54 to 0.60 mm/day and 0.51 to 0.65 mm/day, respectively. In the up-scaling procedures only a slight difference exists between arithmetic and geometric means. In both up- and down-scaling procedures, output scaling transfer performs better. All histograms of ET differences show similar shapes and the dominance of zero values.

The areas having zero ET in the original map are assigned to be 100% relative errors [$(ET_{original} - ET_{scaled})/ET_{original}*100$]. Large relative errors ($> \sim 75\%$) occur in areas having low ET ($< \sim 2$ mm/d) while areas having ET greater than 2 mm/d exhibit relative errors less than 25%. For the downscaling procedure there are some points having 100% relative error with high daily ET. However, these points are the result from the anomalies resulting from registration errors as discussed above.

5. SUMMARY AND CONCLUSIONS

In this study, first daily evapotranspiration rates were calculated using SEBAL algorithms with Landsat 7 and MODIS imagery and second, up- and down-scaling procedures were used to investigate the effect of scaling transfer on evapotranspiration maps. Preliminary results are:

1. Good agreement exists between SEBAL evapotranspiration maps derived from

Landsat 7 and MODIS images.

2. Up-scaling produces better results than down-scaling and output scaling transfer performs better than input scaling transfer.
3. Large relative errors occur in desert areas with low to zero ET rates; areas having high ET rates show small relative errors.
4. Overall, the up- and down-scaled ET maps over the Middle Rio Grande Basin are in good agreement with ET maps directly derived from Landsat 7 and MODIS images.

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