SATELLITE-BASED ENERGY BALANCE TO ASSESS RIPARIAN WATER USE

USGS 104B Final Report

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Project Description

Our goal is to improve our ability to estimate riparian ET by utilizing satellite and air-bone remote sensing data on major watersheds in the North Platte River. A physically surface energy balance model, METRIC (Mapping Evapotranspiration at high Resolution using Internalized Calibration), was used to calculate ET from satellite remote sensing. Specific objectives of the proposal are:

1. Quantify daily and seasonal distributions of ET over riparian systems at selected watersheds along the North Platte River Basin in Nebraska.

   Expected outcome: The major outcome of this work would be quantitative surface energy balance algorithm for land estimates of ET for riparian systems.

2. Comparison of water use and water availability on riparian species by utilizing ET maps with existing air-bone based riparian species distribution map.

   Expected Outcome: The riparian species distribution map was used to identify location of species precisely. This map will be integrated into METRIC ET maps to quantify amount of ET flux from each riparian species.

This report describes the procedures used processing satellite images for year 2005 for Landsat Path 33 Row 31. The final product includes actual evapotranspiration (ET) as well as fraction of evapotranspiration in relation to a reference alfalfa crop. Individual ETrF images were generated from Landsat 5 and Landsat 7 satellite imagery using the METRIC model. This model was developed by the University of Idaho for use in Erdas Imagine® image processing software (Leica Geosystems Geospatial Imaging, LLC). Each satellite image for 2005 was processed on a pixel by pixel basis using METRIC to estimate ETrF (evapotranspiration in relation to a reference alfalfa crop) and actual evapotranspiration.

Meteorological Data: Weather data were acquired from the High Plains Regional Climate Center's (HPRCC) Automated Weather Data Network (AWDN) (Table 1). The AWDN stations record hourly data for air temperature, humidity, soil temperature, wind speed and direction, solar radiation, and precipitation. Reference ET (ETr) values were calculated using the ASCE-EWRI (2005) standardized Penman-Monteith equation for alfalfa reference.

Hourly precipitation and ETr data were summed together to create daily, 24-hour values. Data from the Scottsbluff, NE station were used for the generation of intermediate and final METRIC products from the individual images. The rest of the stations were used to create an interpolated (Inverse Weighted Distance) map of reference ET for the project area to be used with the monthly and seasonal ET maps.

Table 1. AWDN station coordinates and characteristics.

Station	Latitude	Longitude	Elevation (m)
Alliance-North, NE	42.18	102.92	1213
Alliance-West, NE	42.02	103.13	1213
Arapahoe Prairie, NE	41.48	101.85	1097
Arthur, NE	41.65	101.52	1097
Gordon, NE	42.73	102.17	1109
Gudmundsen, NE	42.07	101.43	1049
Mitchell Farms, NE	41.93	103.70	1098
Scottsbluff, NE	41.88	103.67	1208
Sidney, NE	41.22	103.02	1317
Sterling, CO	40.47	103.02	1200
Torrington, WY	42.03	104.18	1216

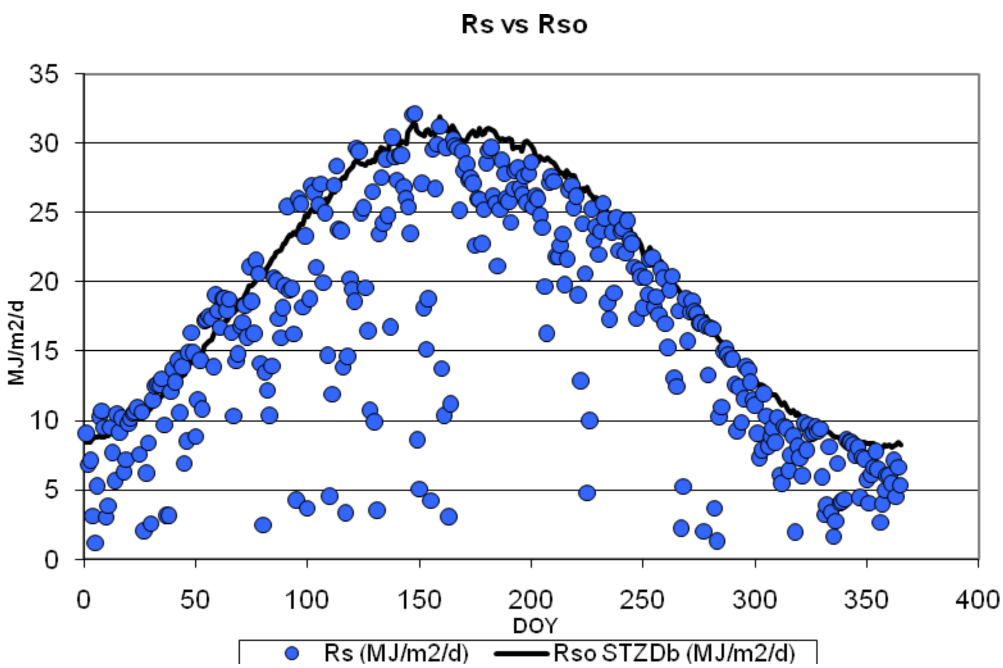

Figure 1. Observed solar radiation (MJ/m^2) and calculated clear sky solar radiation (MJ/m^2) in 2005 at Scottsbluff, NE.

Daily Soil Water Balance Model: A daily water balance model based on Allen et al. (1998) was employed to estimate residual evaporation from the hot pixel (Fig. 2). The satellite overpass times were acquired from the image meta data files to estimate zenith angle of the sun, instantaneous values of wind speed at 200 m, air humidity, and ETr.

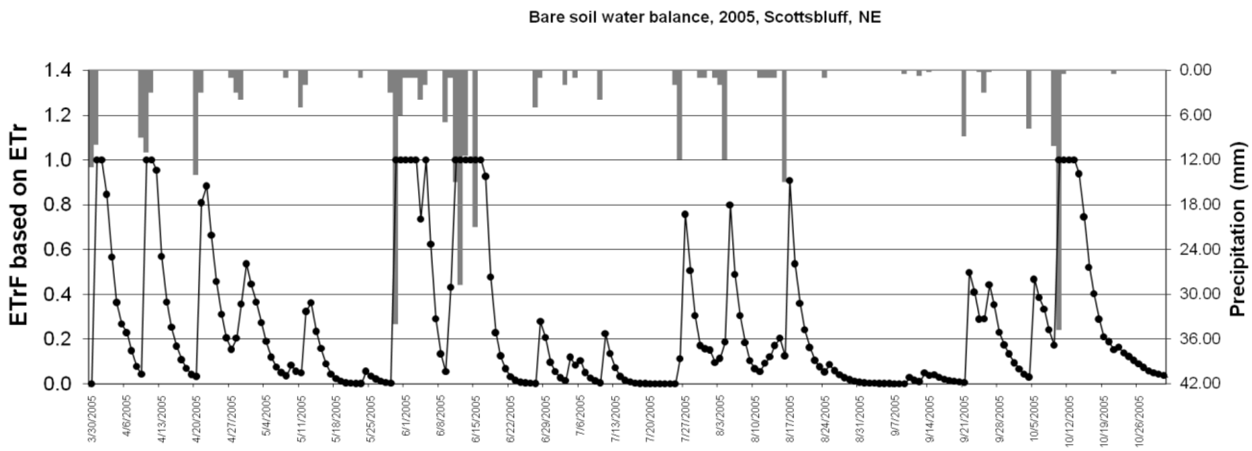

Figure 2. Soil water balance for bare soil calculated from meteorological data from Scottsbluff, NE 2005. Soil water balance is used to determine ETrF for hot pixel selection.

Satellite Imagery: A total of 10 Landsat images were purchased for 2005 of the Nebraska Panhandle region. Table 3 lists the dates of the imagery. Landsat images were ordered for path 33, row 31 as systematic terrain-corrected (Level 1T), 30 meter spatial resolution, with nearest neighbor resampling method. The thermal band was resampled by USGS to 30 meters. UTM zone 13, NAD 1983 was the projection and datum used.

Table 3. Landsat imagery of Nebraska Panhandle acquired for 2005.

Date	Satellite	Path	Row
13 April 2005	Landsat 5	33	31
15 May 2005	Landsat 5	33	31
31 May 2005	Landsat 5	33	31
02 July 2005	Landsat 5	33	31
10 July 2005	Landsat 7	33	31
19 August 2005	Landsat 5	33	31
28 August 2005	Landsat 5	32	31
20 September 2005	Landsat 5	33	31
14 October 2005	Landsat 7	33	31
23 November 2005	Landsat 5	33	31

Seasonal Actual ET (from May 01 through september 30) for riperian species

Figure 3 shows the riparian species on flight #3 on NE Panhandle. This map was integrated with seasonal ET maps obtained with METRIC model (see fig. 1.5. on Appendix A). Figure 4 through 8 show seasonal actual ET (from may 01 through september 30) for each riperian species. The y axis on each figure (histogram) shows number of landsat pixels for each riparian species while x axis shows corresponding actual ET values in mm. For instance, the seasonal water use (from May 01 through september 30) of saltcedar ranged from as low as 350 mm to as high as 961 mm depending on the density and age of saltcedar tree. On average, the water use of saltcedar was 680 mm. The details of METRIC ET processing were explained in Appendix A.

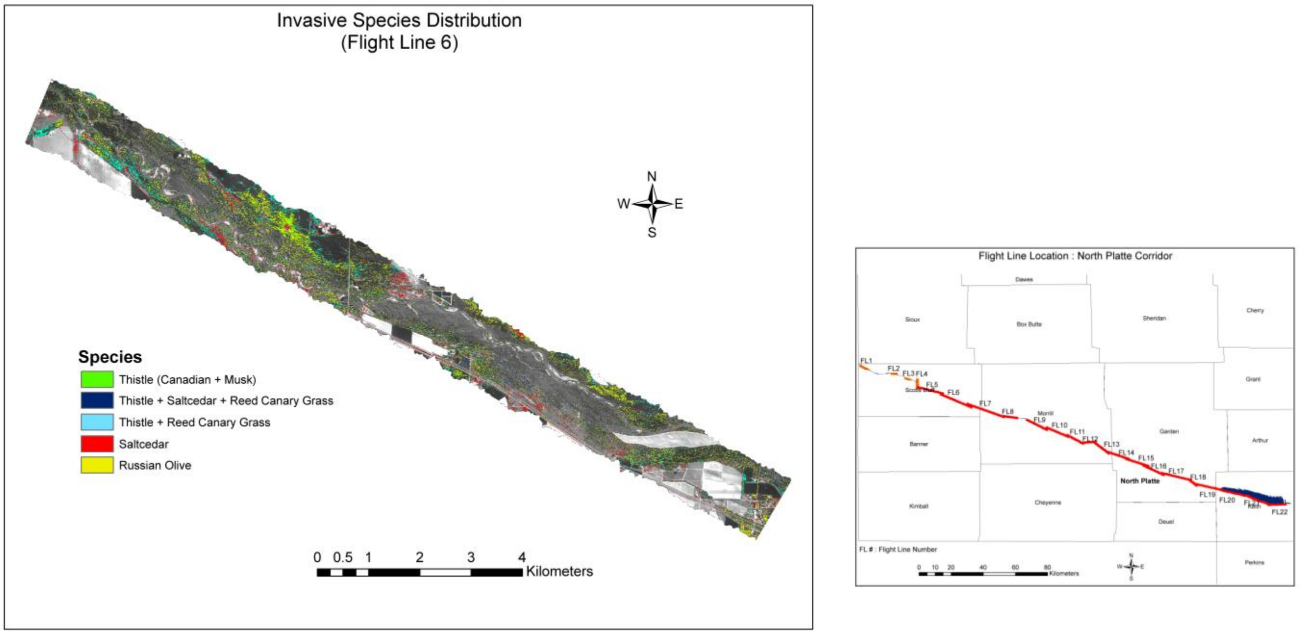

Figure 3. Invasive species distribution in 2005 for flight line #3 on Path 33, Row 31.

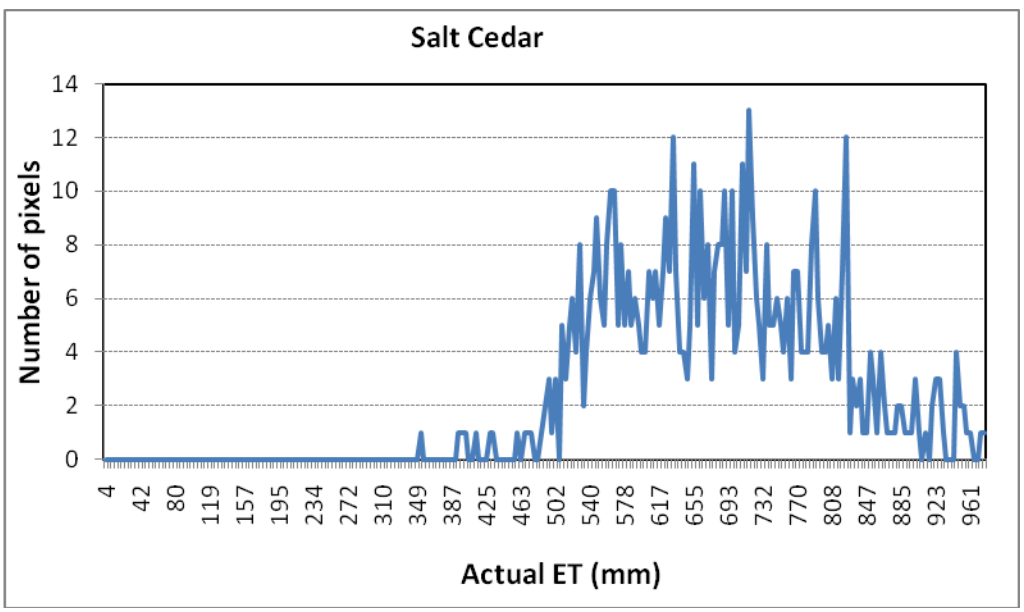

Figure 4. Histogram of seasonal ET (from May 01 through September 30) in 2005 for salt cedar.

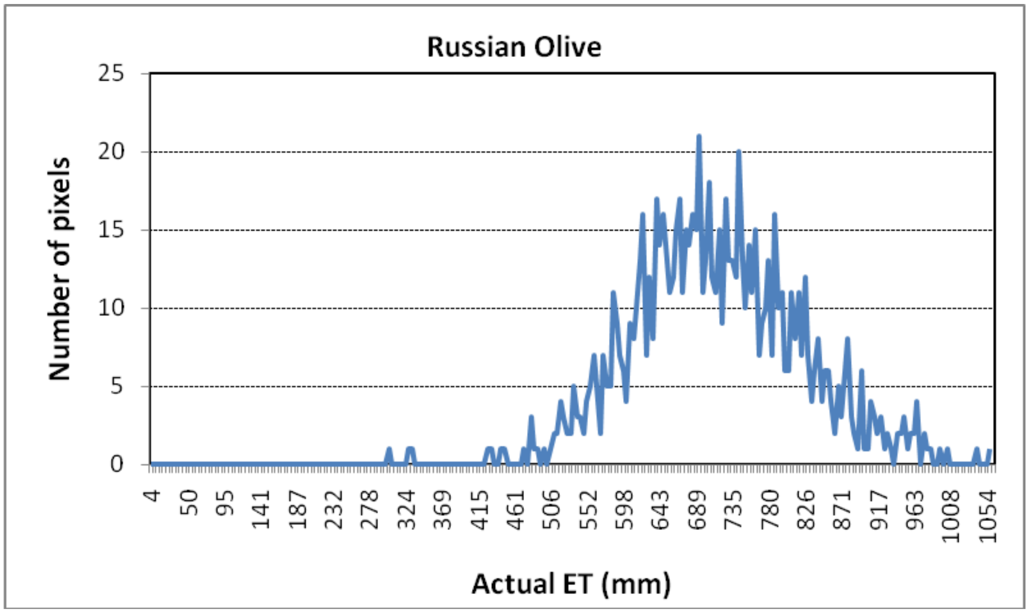

Figure 5. Histogram of seasonal ET (from May 01 through September 30) in 2005 for Russian olive.

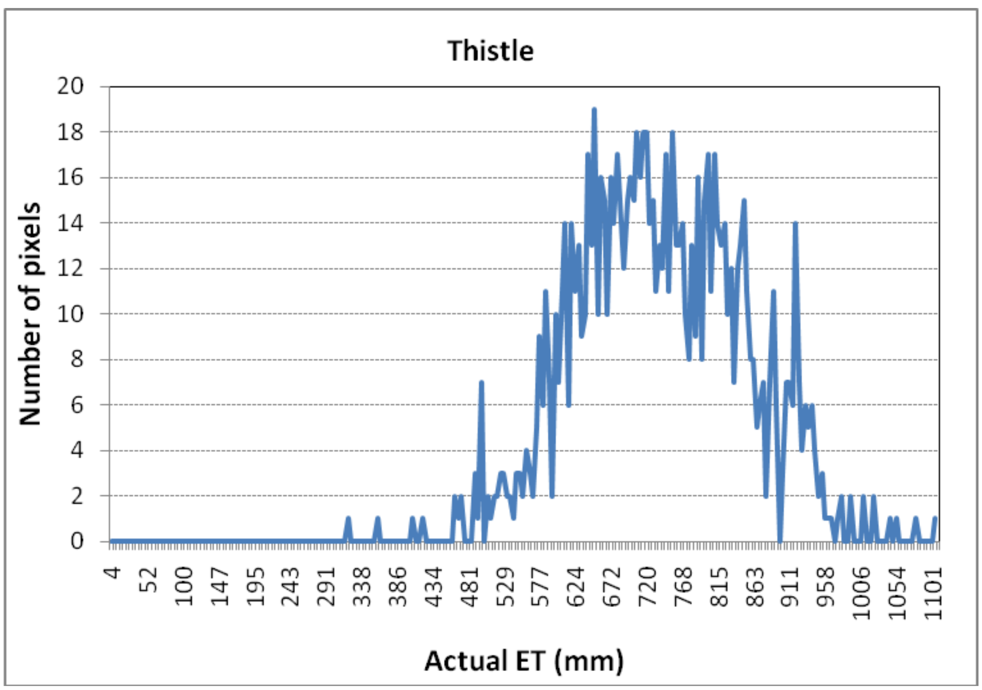

Figure 6. Histogram of seasonal ET in 2005 for Thistle.

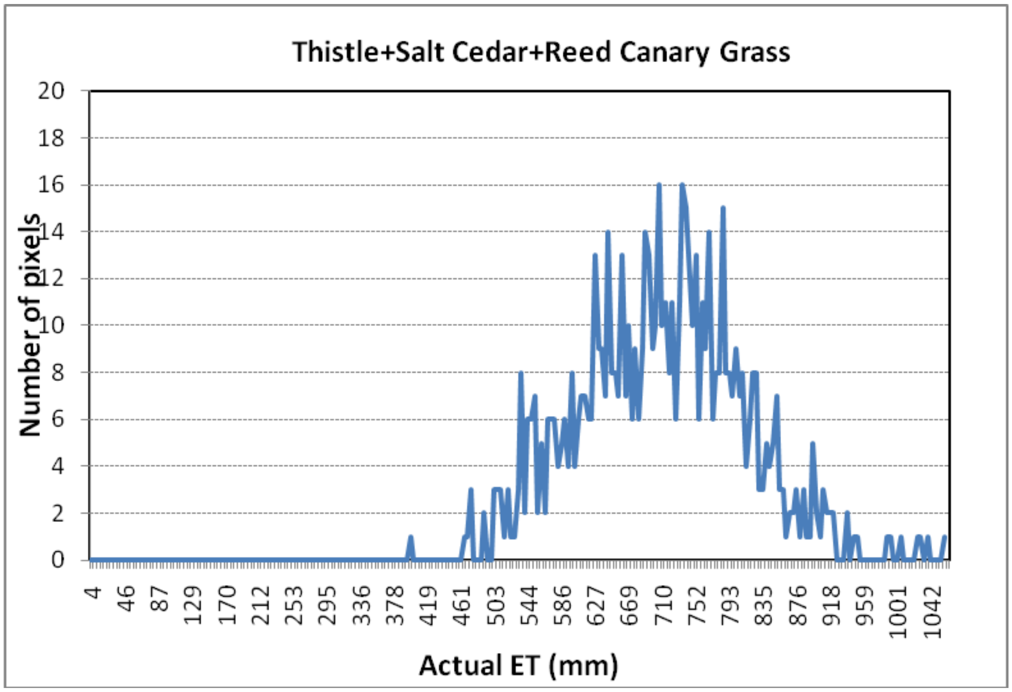

Figure 7. Histogram of seasonal ET in 2005 for land use class of thistle + salt cedar +reed canary grass.

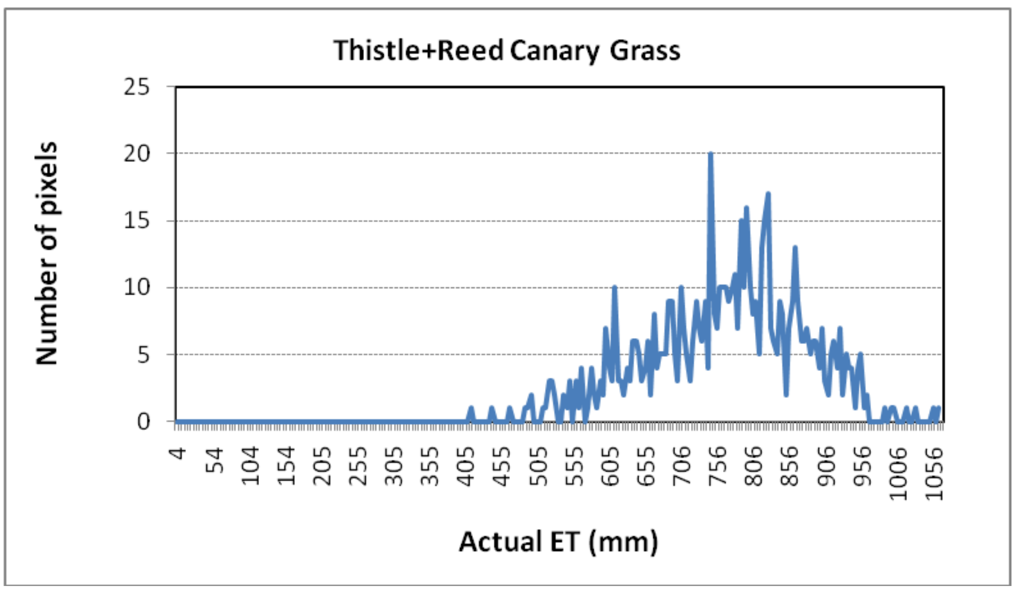

Figure 8. Histogram of seasonal ET in 2005 for thistle+ reed canary grass.

APPENDIX A:

Gap-filling of Landsat 7 ETM+: On 31 May 2003, image data from the ETM+ sensor onboard the Landsat 7 satellite began exhibiting "striping" artifacts (USGS, 2008). It was determined that the problem was a result of the failure of the Scan Line Corrector (SLC) which compensates for the forward motion of the satellite. The post-SLC failure images of Landsat 7 are termed as SLC-off images. Due to the SLC failure, about 22% of the scene area is missing in SLC-off images. Processing of SLC-off images requires replacing the missing data. Various approaches are used for filling the missing data. Some of these approaches use data from the previously acquired images to replace the missing pixels. However, this approach is not very useful for agricultural applications due to temporal dynamics. Because Landsat 7 was still able to acquire imagery, the USGS developed new image products to fix the striping problem by combining two separate dates or by interpolation to fill in the data gaps.

We carried out our own correction to the scan line correction for Landsat7 datasets by using convolution filtering (nearest neighborhood method) with a 5X5 pixels majority function (Singh et al., 2008). In our application, we have used the approach of gap filling utilizing same time images with spectral information from the neighboring pixels. For this, the convolution filtering algorithm with majority function has been used to replace the missing data. The majority function is preferred due to our overall objective of estimating ET from the agricultural fields. This technique works perfectly for the inner missing lines. However, the missing pixels at the edges of the image scene are not well represented due to large gaps. Hence, it is advisable to subset the images leaving the outer edges.

Thermal shift in Landsat 5 Imagery: Inspection of Landsat 5 L1T NLAPS images, ordered through the AmericaView Project, indicates a systematic vertical downward shift of 30 to 90 m in the resampled band 6 (thermal band). Band 6 was resampled during the L1T process from the original 120 m to 30 m. The shift problem seems to occur for both cubic convolution and nearest neighbor resampling schemes. This shift has been evident in Landsat 5 images for p33r31 and p32r31 from 1997, 2002, and 2005. A shift of band 6 was not obvious in Landsat 7 images that were ordered. We have concluded that manually shifting the thermal band north 60 meters (2 pixels) rectified the problem.

Preparation of Digital Elevation Model and Land Use Map: The Digital Elevation Model (DEM) was obtained from the EROS Data Center Seamless Data Distribution System. The DEM was downloaded as 1 arc second and reprojected to NAD 83 GRS 1980 UTM 13 using cubic convolution.

METRIC does not require a land cover map but is recommend in order to improve the parameterization and estimation of the surface roughness parameter (Allen et al., 2007). The land use maps are a composite of (1) the 1991-1993 Nebraska Gap Analysis Program (GAP), (2) the 1997, 2001, or 2005 Nebraska Cooperative Hydrology Study (COHYST), and (3) the 2001 National Land Cover Dataset (NLCD). Three land use maps were created for the Nebraska Panhandle: 1997, 2001, and 2005. These maps correspond to the years the COHYST land use maps were generated. The land use maps were reprojected into NAD 83 GRS 1980 UTM 13 using nearest neighbor resampling.

Processing Individual ETrF Images and Managing Cloud Cover in Imagery

ETrF (relative ET fraction) cannot be directly estimated for cloud covered land surfaces. Even thin cirrus clouds can lower the values in the satellite thermal band and cause large errors in the calculation of sensible heat fluxes. Therefore, it is essential that all satellite imagery be checked for cloud cover and shadows, and be masked out. A suggestion made by Allen and Burnett (2009) involves the use of daily MODIS 250 m, NDVI products to provide information on the development of vegetation during the cloud cover period. This method was applied to cloud cover areas for image dates of May 15th, May 31st, and July 2nd.

MODIS/Terra Surface Reflectance Daily L2G Global 250m SIN Grid V005 data were ordered from the NASA Warehouse Inventory Search Tool (WIST) website. Only MODIS dates within 5 days of the Landsat date were considered. Cloud-free MODIS images (23 April, 18 May, 28 May, 06 July) in 2005 were run through the MODIS Reprojection Tool (MRT) software provided by the USGS LP DAAC. The data were reprojected to UTM zone 13, NAD83, using nearest neighbor resampling. The files were output as HDFEOS format. Reprojected MODIS files were then imported into ERDAS Imagine where the data was converted to reflectance and NDVI was calculated. Figure 1.3 shows ETrf for individual Landsat dates by utilizing data from Landsat and MODIS.

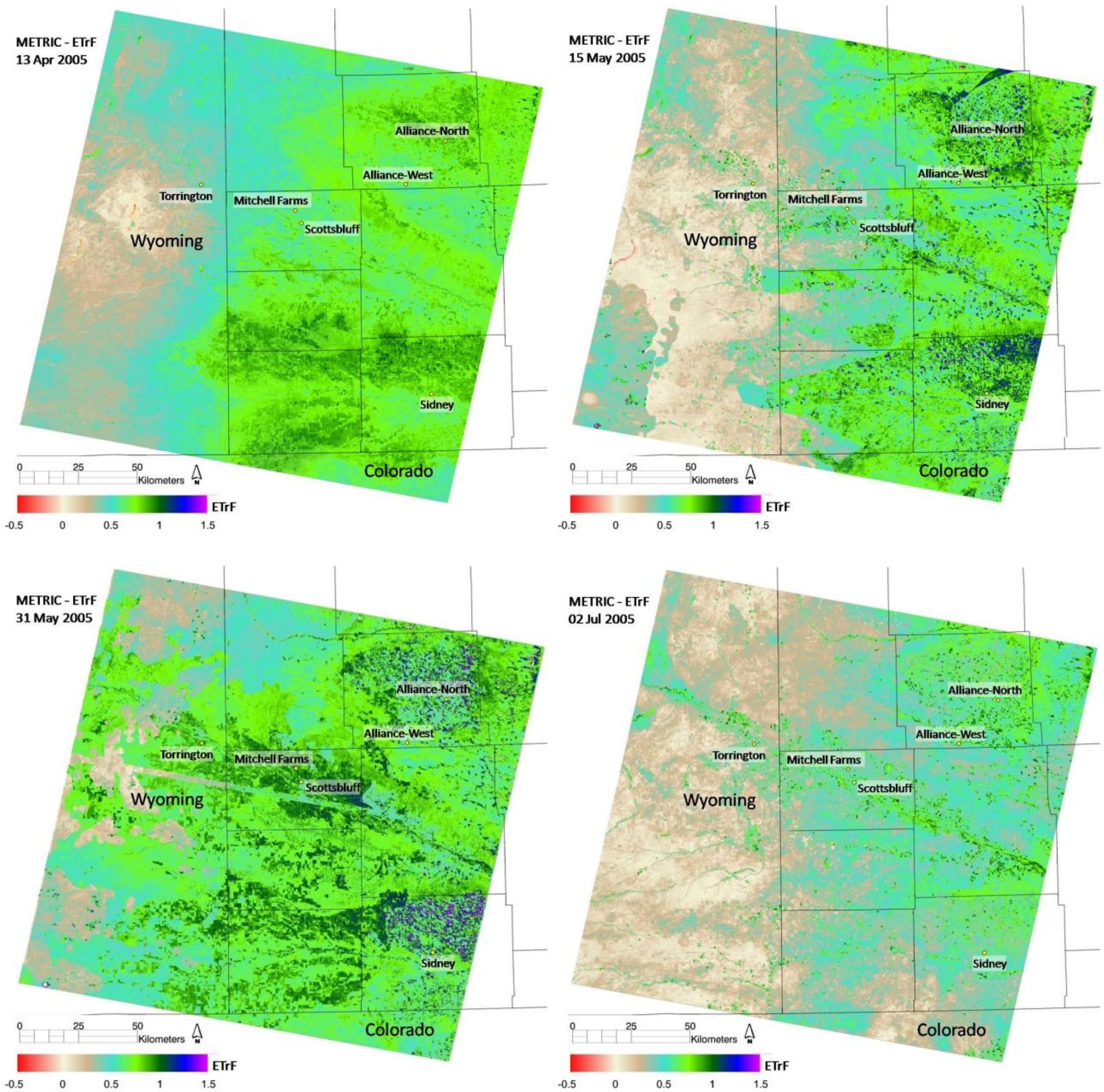

Figure 1.3. Calculated ETrf (reference ET faction) for individual Landsat dates in 2005 path 33, row 31.

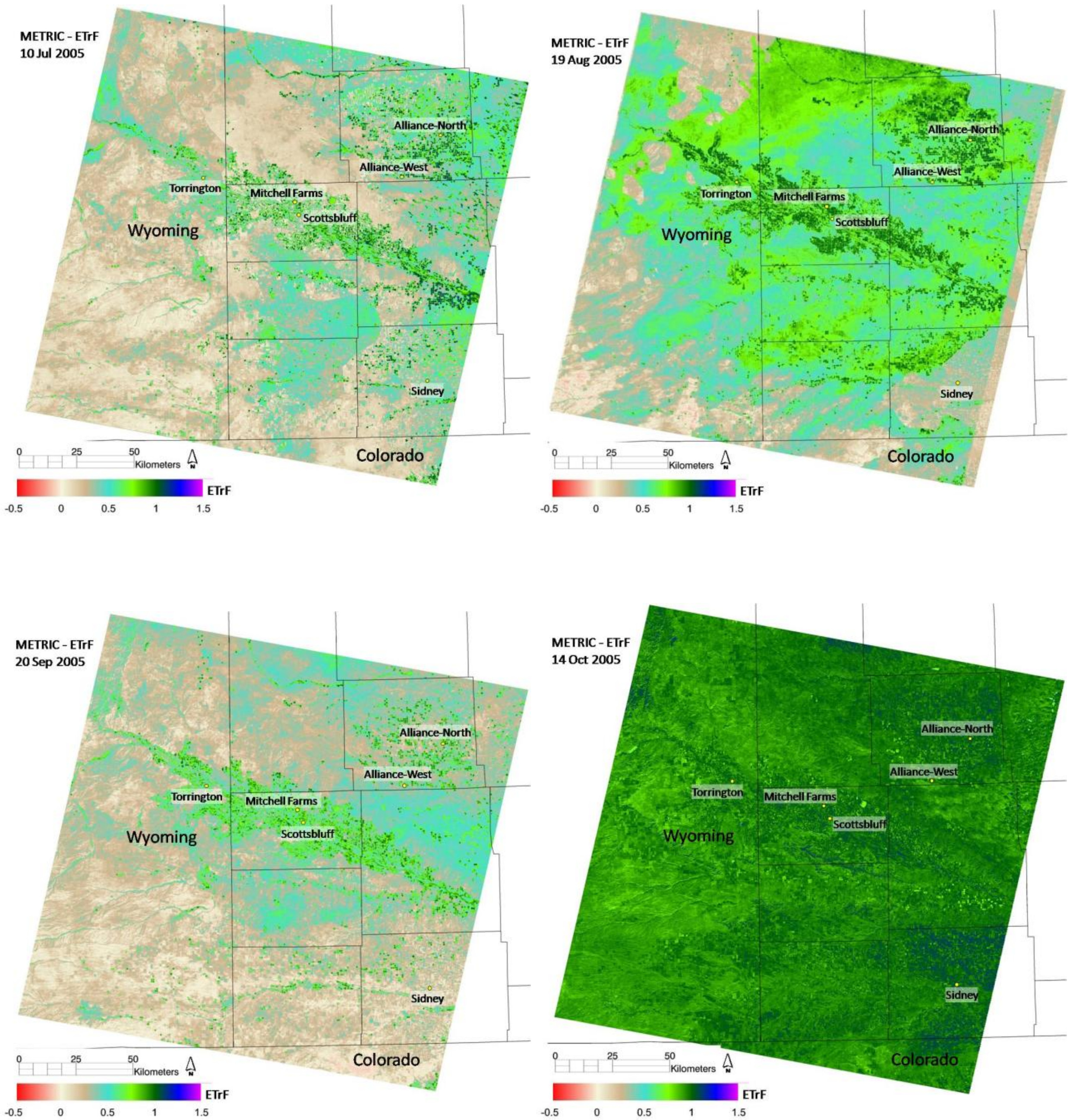

Figure 1.3. Continued. Calculated ETrf for individual Landsat dates in 2005 path 33, row 31.

Monthly and Seasonal ET Maps

Individual maps of ETrF generated from METRIC were interpolated using a spline model. Figure 1.4. shows monthly ET for path 33, row 31 in 2005. The spline model requires two images each in the preceding and subsequent months of the month to be interpolated. Because only one image was available for the month of April, a new ETrF image was created for April 23rd from MODIS 250m NDVI data. The methods used were the same as the cloud filling method using MODIS 250m NDVI data. Monthly ET maps were summed to obtain total seasonal ET for the study area (fig. 1.5.).

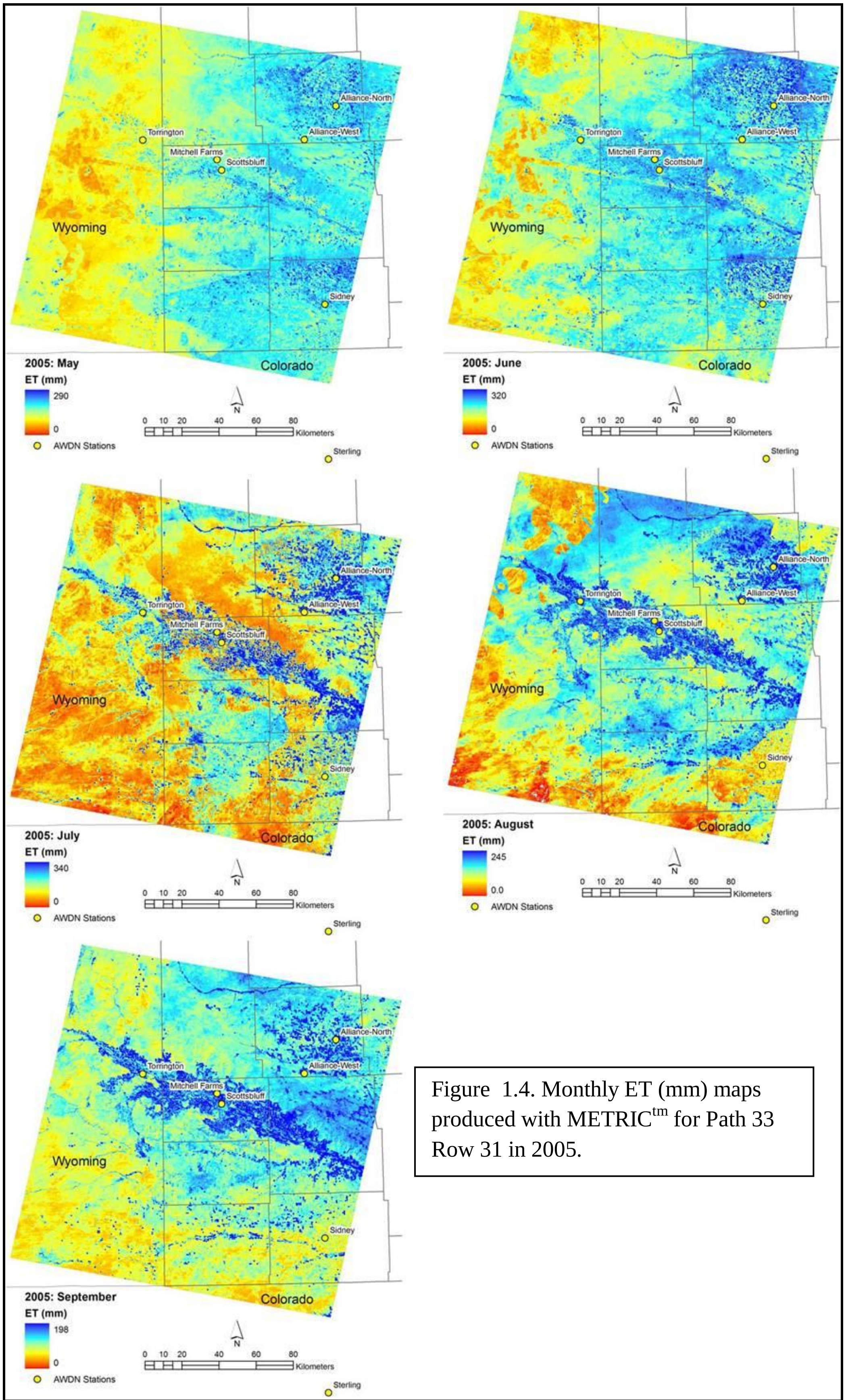

Figure 1.4. Monthly ET (mm) maps produced with METRIC^{tm} for Path 33 Row 31 in 2005.

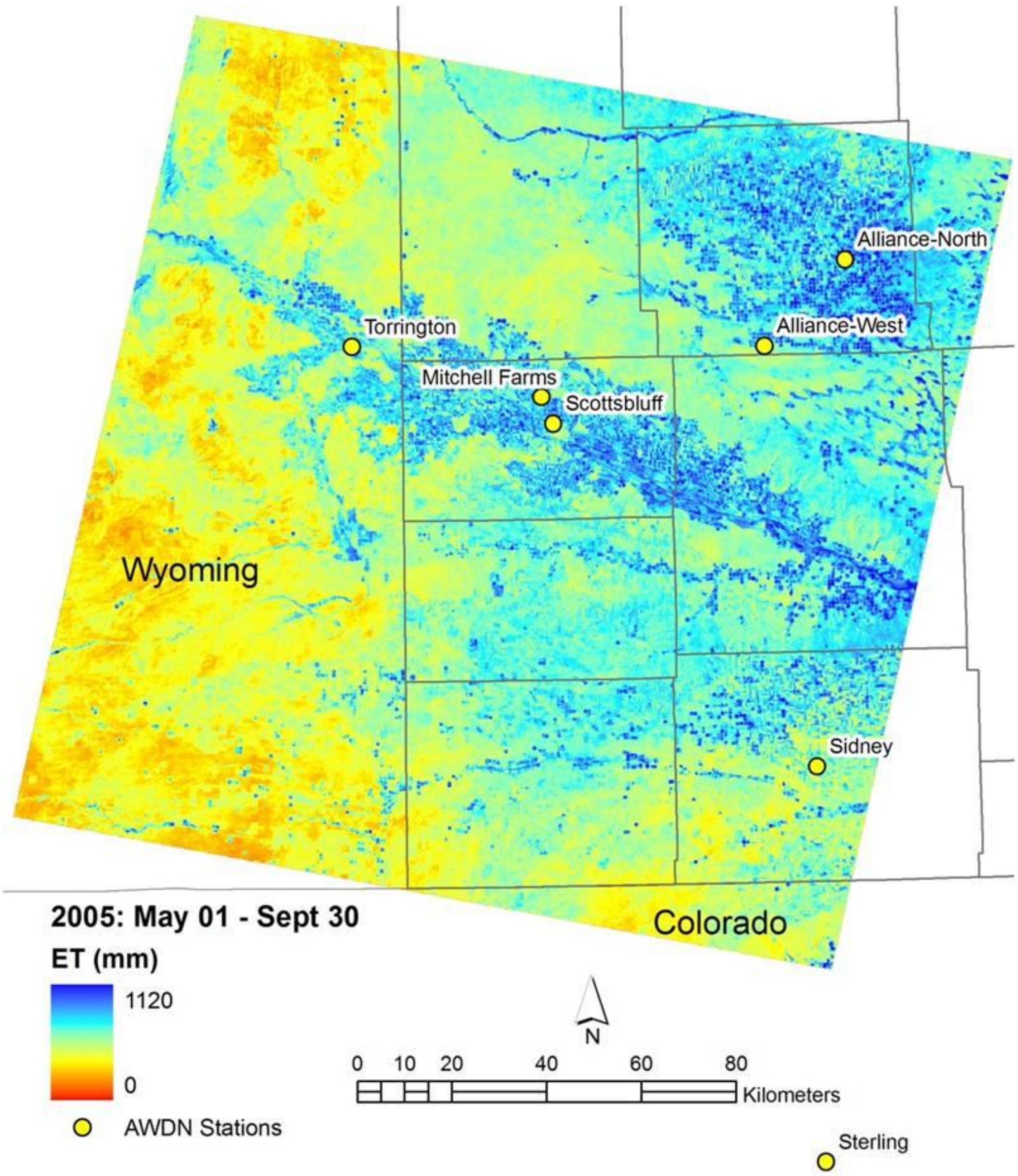

Figure 1.5. Seasonal ET (mm) map from May 01 through September 30 in 2005 for Path 33 Row 31.