Completion Report on the Production of Evapotranspiration Maps for Year 2004 for the Upper Klamath and Sprague area of Oregon using Landsat Images and the METRIC^{tm} Model

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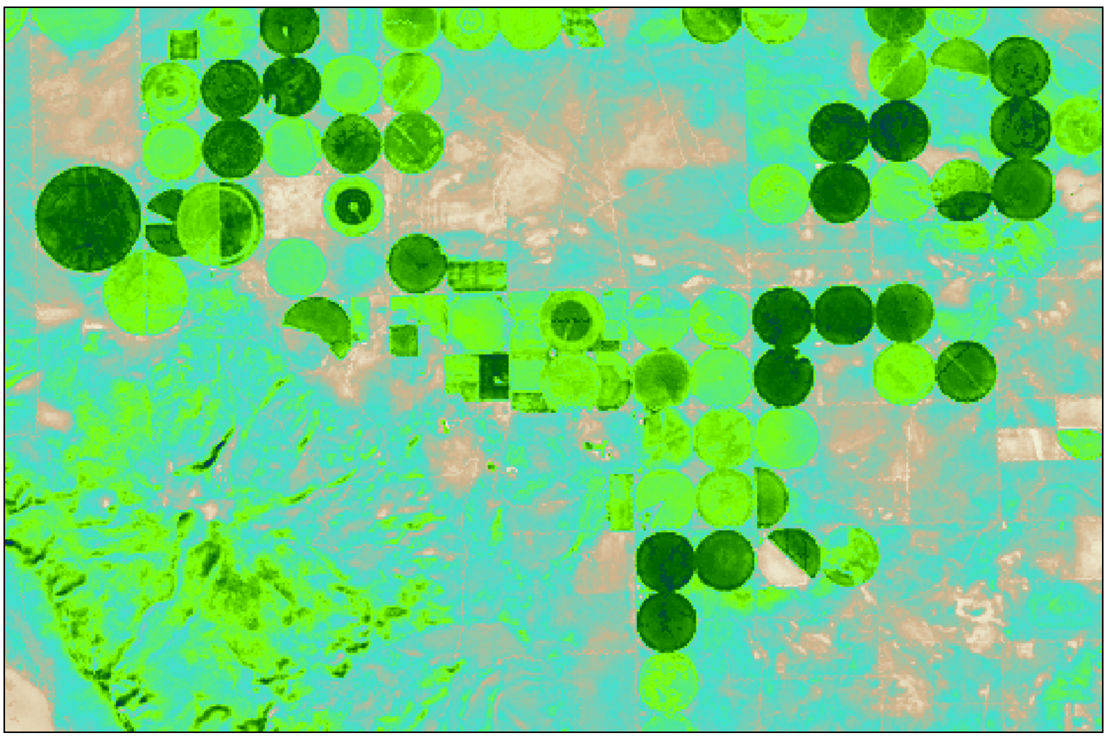

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1. Introduction

This report describes the procedures for and products from processing satellite, weather and land-use data for the Landsat World Reference System (WRS) Path 45 covering portions of south-central Oregon containing agricultural and mountain areas from near Crescent, Oregon south to the Oregon-California border and containing land areas in the upper Klamath and the Sprague River basins. The purpose of the application was the production of spatial and temporal maps of monthly and growing season evapotranspiration (ET) for the region for the years 2004 and 2006. In this first report, products for 2004, only, are reported.

The final products include 30 m resolution images of Actual Evapotranspiration (ET) and also images showing ET expressed as a fraction of Reference Crop ET (ETrF). ET was calculated at the same 30 m spatial resolution as the Landsat satellite images. Eight Landsat images were processed along Landsat WRS path 45 by combining portions of WRS rows 30 and 31 to produce estimates of monthly and growing season (April – October) ET.

ET was obtained using the METRIC model developed by the University of Idaho. The METRIC procedure utilizes the visible, near-infrared and thermal infrared energy spectrum bands from Landsat satellite images and weather data to calculate ET on a pixel by pixel basis. Energy is partitioned into net incoming radiation (both solar and thermal), ground heat flux, sensible heat flux to the air and latent heat flux. The latent heat flux is calculated as the residual of the energy balance and represents the energy consumed by ET. The topography of the region was incorporated into METRIC via a digital elevation model (DEM), and used to account for impacts of slope and aspect on solar radiation absorption. METRIC was calibrated for each image using ground based meteorological information and identified ‘anchor’ conditions (the cold and hot pixels of METRIC) present in each image. A detailed description of METRIC can be found in Allen et al. (2007a,b; 2010).

Work by the University of Idaho (UI) during this project included further development of the METRIC model to perform more accurately under the specific conditions of the study area. Specific enhancements included a new cloud gap filling procedure for ET_rF[1] images that allows the operator to adjust for background evaporation occurring from recent precipitation to better reflect total evaporation over longer (monthly) periods, the generation of gridded ET_r maps used to estimate monthly and seasonal ET, improved computation of surface reflectance and albedo in mountainous areas to improve estimations of ET on sloped terrain. For Landsat 5 images, sharpening of the thermal band provided spatial refinement to the final ET products.

Figure 1 shows the domain of the Landsat images processed by METRIC for years 2004 and 2006. The image is a ‘false composite’ of bands 2, 3 and 4, where ‘green vegetation’ shows as a red color. Forest vegetation in mountainous areas show as dark red and broadleaf vegetation, including agricultural crops generally shows as a lighter red color.

[1] ET_rF is the fraction of alfalfa reference ET_r as calculated by the standardized ASCE-EWRI Penman-Monteith equation (ASCE-EWRI, 2005) and represents the relative amount of reference ET occurring on any particular pixel of an image. ET_rF is a direct product from METRIC. ET_r is also used to calibrate the METRIC process and is calculated using hourly meteorological information from a weather station. Typical ranges for ET_rF are 0 to about 1.1. ET_rF is synonymous with the crop coefficient.

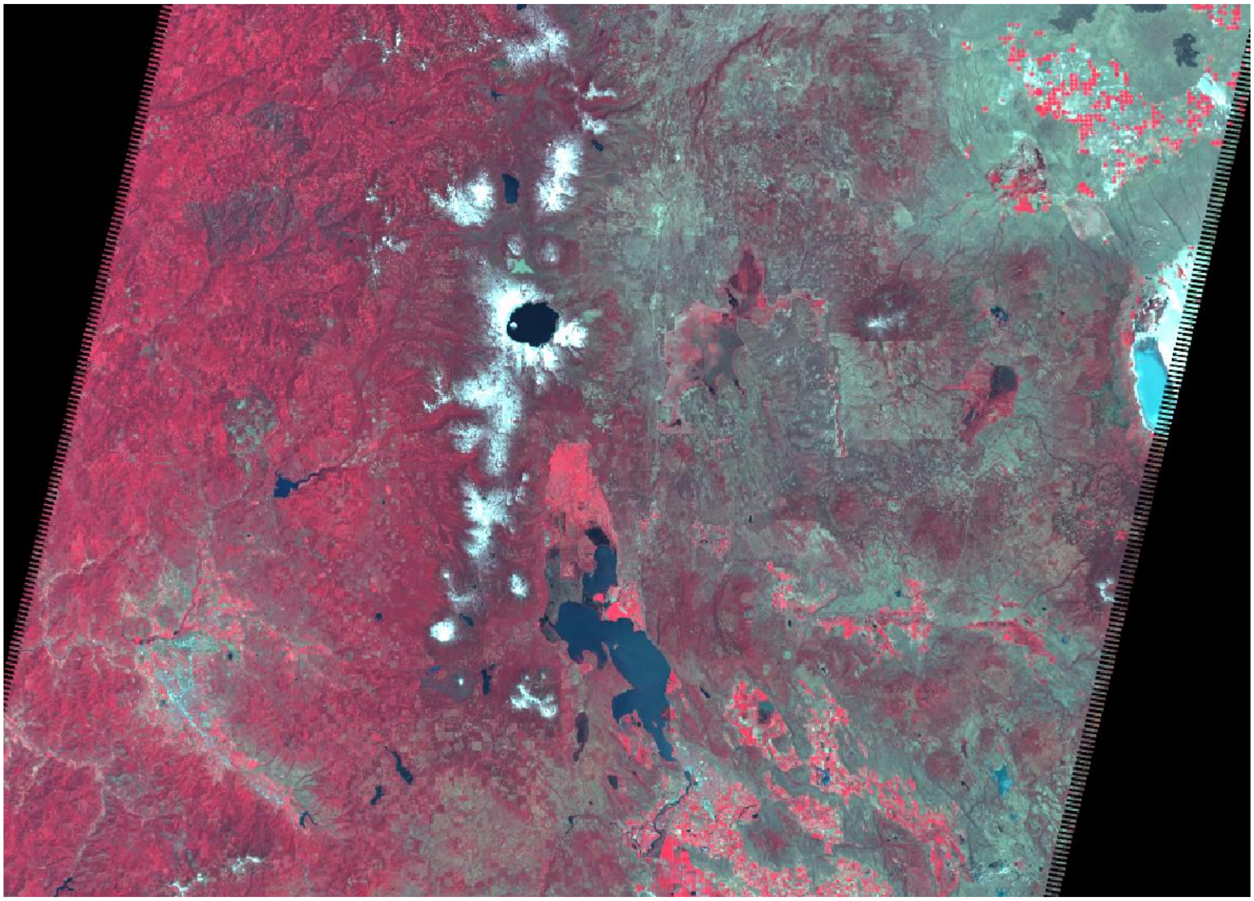

Figure 1. False color composite Landsat image of path 45, rows 30 and 31 corresponding to 06/17/2004 showing the study area processed by METRIC processing.

Figure 2 shows an overlay on Landsat path 45, row 30 (southern portion) for the water basins of Williamson, Wood River/Upper Klamath Lake and Sprague, which are of interest to the USGS studies. The portion of row 31 of path 45 lying south of row 30, to the California state line, was added to the total area processed. That additional area, shown in Figure 1a, covers nearly all of the river basin domains shown in Figure 2. The exception is a portion of the upper Sprague system that lies in path 44, east of path 45. That portion was estimated separately from METRIC using more simple vegetation index-based ET relationships that were derived from sampling of METRIC products from path 45. Landsat imagery was used in all cases.

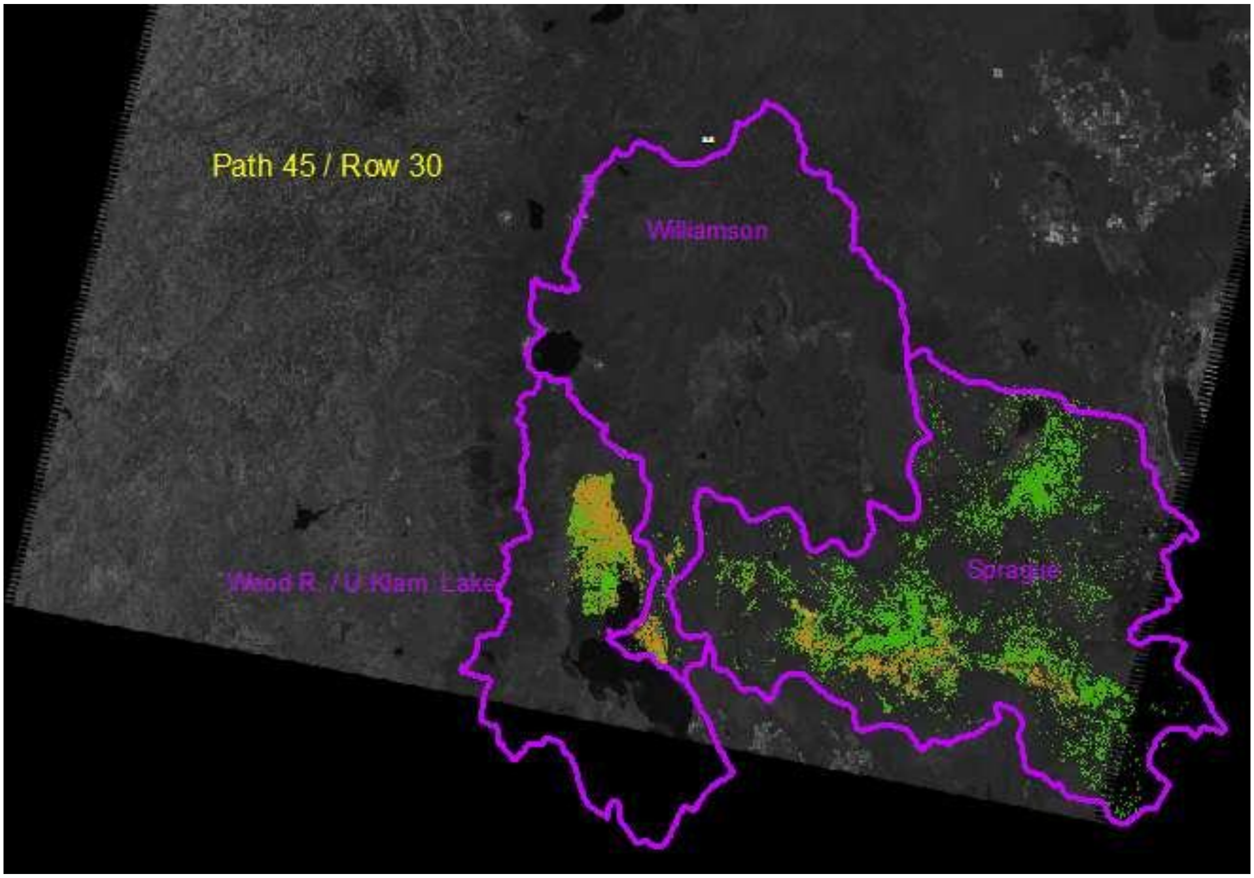

Figure 2. Overlay of area of interest (purple lines) for ET processing and southern half of Landsat path 45, row 30 (courtesy of Daniel Snyder, USGS).

2. Image Selection and pre-processing

For this application, images from Landsat 5 and Landsat 7 satellites were utilized due to their high resolution and presence of a thermal band. The image archive for Landsat 5 dates back to 1984 and the satellite is still in operation. Landsat 7 was launched in 1999.

Landsat 7 images acquired after May 2003, although from a newer satellite than Landsat 5, are less preferred than Landsat 5, due to an anomaly with the Landsat 7 satellite caused by the malfunction of the scan line corrector (SLC). As a result, Landsat 7 images processed for years 2004 and 2006 are "SLC-off" images containing wedge shaped gaps extending from the edges of the image and stretching towards the centers. To obtain as complete coverage as possible, the gaps in ET_rF maps produced by METRIC are generally filled in during post processing using the natural neighbor tool of Arc-GIS. The Landsat 7 images were only used during periods when Landsat 5 images were not available due to clouds.

The most important criteria for the image selection is an assessment of cloud conditions at the time of the satellite overpass. The occurrence of conditions impeding the clearness of the atmosphere, such as clouds (including thin cirrus clouds and jet contrails), smoke, haze and similar over the study area may render parts of an image unusable for processing in METRIC. Even very thin cirrus clouds have a much lower surface temperature than the ground surface and because METRIC needs surface temperature estimates to solve the energy balance, areas with cloud cover cannot be used in the surface energy balance estimations. In addition, in cases of partial cloud cover, land areas recently shaded by clouds may be cooler as they have not yet reached a thermal equilibrium corresponding to the clear sky energy loading, and will also have to be masked out.

A total of 9 Landsat image dates were selected for METRIC processing for year 2004. These dates are shown in Table 1.

Table 1 – Dates of the Landsat 5 satellite images used for METRIC processing in 2004.

#	Date	Image Type
1	04/30/2004	Landsat 5 TM
2	06/01/2004	Landsat 5 TM*
3	06/17/2004	Landsat 5 TM
4	07/11/2004	Landsat 7 ETM+
5	08/04/2004	Landsat 5 TM
6	08/20/2004	Landsat 5 TM
7	09/21/2004	Landsat 5 TM
8	10/07/2004	Landsat 5 TM
9	11/08/2004	Landsat 5 TM

Dem and Land Use maps used for METRIC processing

To enable processing with METRIC, other basic input files are needed besides the satellite images. METRIC requires the use of DEM (Digital Elevation Model) and LU (Land Use) files as inputs. A digital elevation map (DEM) is used during METRIC processing to adjust surface temperatures for lapse effects caused by elevation variation. Maps of slope and aspect (aspect is the cardinal direction of an inclined surface) are also derived from the DEM at 30 m resolution and are used in estimating solar radiation on slopes. These images were created using the tools of the ERDAS Imagine processing system based on the DEM.

A land use (LU) map was used to support the estimation of aerodynamic roughness and soil heat flux during METRIC processing. The NLCD (National Land Cover Database) Land Use map was obtained from the USGS-seamless webpage (http://seamless.usgs.gov/). The 30 m DEM was downloaded from the same website.

3. The METRIC Model

METRIC™ (Mapping Evapotranspiration with high Resolution and Internalized Calibration) is an ERDAS coded model that bases the ET estimate on the evaluation of the energy balance at the earth's surface. METRIC™ processes instantaneous remotely-sensed digital and weather data and estimates the partitioning of energy into net incoming radiation, heat flux into the ground, sensible heat flux to the air, and latent heat flux. The latent heat flux, which is computed as a residual in the energy balance, represents the energy consumed by ET:

$$LE = Rn - G - H$$

where LE=latent energy consumed by ET; Rn=net radiation; G=sensible heat flux conducted into the ground; and H=sensible heat flux convected to the air. One very strong advantage of using energy balance is that actual ET rather than potential ET based on amount of vegetation is computed so that reductions in ET caused by a shortage of soil moisture are captured. A disadvantage of the energy balance approach is in the complexity of calculations. In traditional applications of energy balance, the computation of LE is only as accurate as the summed estimates for Rn, G, and H. METRIC attempts to overcome this disadvantage by focusing the internal calibration on LE and with H used to absorb all intermediate estimation errors and biases.

METRIC™ utilizes spectral raster images from the visible, near infrared, and thermal infrared energy spectrum to compute the energy balance on a pixel-by-pixel basis. In METRIC, Rn is computed from the satellite-measured narrow-band reflectance and surface temperature; G is estimated from Rn, surface temperature, sensible heat flux and vegetation indices; and H is estimated from surface temperature ranges, surface roughness, and wind speed using buoyancy corrections. Figure 3 shows a general schematic of the METRIC process.

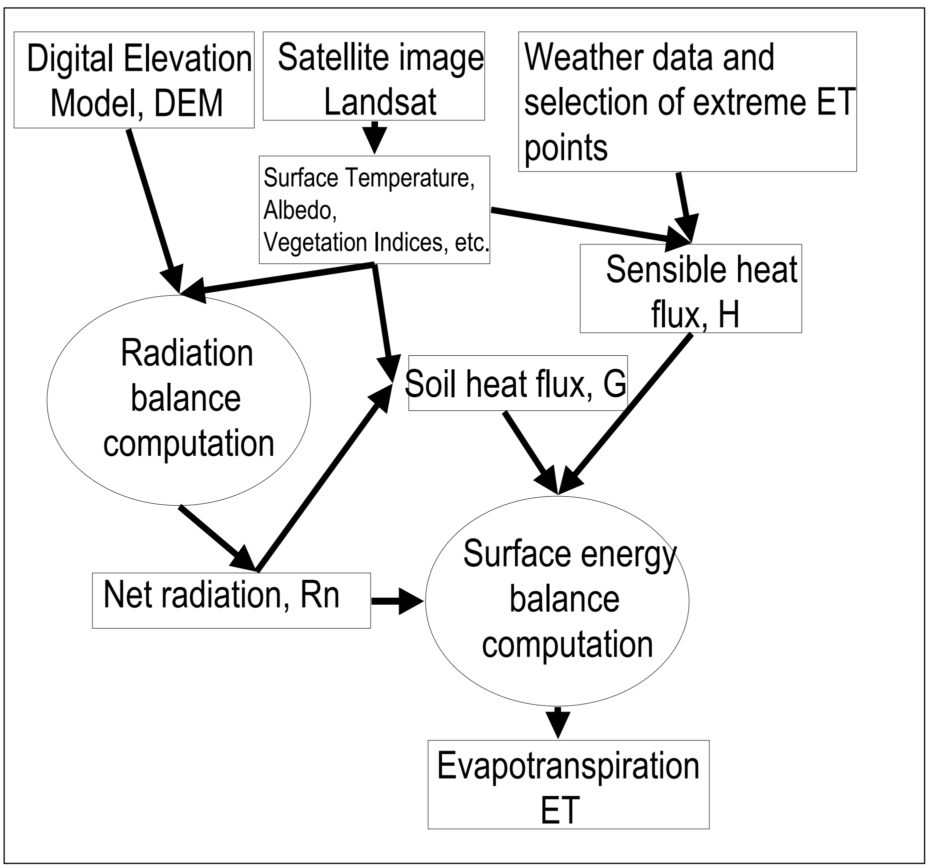

Figure 3. General schematics of the METRIC process.

Calibration of METRIC

METRIC version 2.0.5 was used for the UI processing, but with some modifications during 2010 and early 2011. The 2.0.5 version was released by the University of Idaho in January 2010. A detailed description of METRIC can be found in Allen et al. (2007a,b) and Allen (2008).

The main focus for the processing was to generate estimates of ET from lands having agricultural production, so that METRIC was calibrated with primary focus on accurate estimation of ET from the agricultural areas. However, because the full Landsat images were processed, efforts were made to minimize uncertainty in ET estimates from other land cover types present within the image, including forests, riparian vegetation and rangeland.

Calibration Philosophy.

METRIC uses a vertical near surface-to-air difference, dT, to estimate sensible heat flux. Sensible heat flux (H) is the amount of heat that is convected from a surface into the air, thereby reducing the amount of available energy for evaporation. The dT function is modeled as linearly proportional to surface temperature and is defined using the properties of two user selected anchor pixels, the "cold" and the "hot" pixels, that represent the extreme conditions encountered within the image (a condition having nearly complete conversion of available energy into evapotranspiration and a condition having nearly zero conversion of available energy into evapotranspiration). The cold anchor pixel generally represents a fully vegetated and actively transpiring vegetation, while the hot anchor pixel represents a bare and dry or nearly dry agricultural soil with little or no vegetation. The selection of cold and hot anchor pixels by the user is described by Allen et al., (2007b) and Allen (2008). These pixels are generally selected from agricultural fields for consistency and to match assumptions made in the estimation of soil heat flux, for example, where that algorithm was developed for agricultural soils. The surface temperature used to estimate dT was 'delapsed' to account for differences in surface temperature occurring as a result of elevation differences.

During the internal calibration of sensible heat flux in METRIC, a fraction of ET_r, ET_rF, is assigned to the hot and cold conditions. ET_rF is equivalent to the crop coefficient (K_c) based on full-cover alfalfa as the reference crop. ET_rF at the cold pixel is normally assigned a value of 1.05 (Allen et al., 2007a,b) unless vegetation cover is insufficient to support this assumption (for example, early in spring and during winter when full, robust vegetation cover is rare). The 1.05 assignment to ET_rF is used to account for the variation in ET inherent within a large population of fully vegetated fields. Previous applications of METRIC and comparisons against lysimeter measurements of ET at Kimberly, Idaho show that the "nearly coldest", or wettest, agricultural fields having full vegetation cover tend have ET rates that are typically 5% higher than that of the alfalfa reference ET_r. This is because, for a large population of fields, some fields may have a wet soil surface beneath the canopy, or the canopy may be wet from recent (sprinkler) irrigation or precipitation, that tend to increase the total ET rate to about 5% above ET_r. In addition, when viewing a large population of fields containing full cover alfalfa, a specific subpopulation of fields will have somewhat wetter conditions and therefore slightly higher ET and slightly cooler temperature than the "mean" full cover condition represented by the alfalfa reference. When the METRIC image is calibrated using an ET_rF of 1.05 at the cold pixel, sampling of ET_rF over a large population of full cover, irrigated fields tends to produce, on average, an ET_rF value of 1. The cold pixel is selected from a population of fields having full cover and relatively cold temperatures. Ideally, an alfalfa field is preferred for calibration, since the ASCE Penman-Monteith equation is calibrated to an alfalfa reference. However, Wright (1982) has shown that most agricultural crops, when at full cover, transpire at levels very similar to those of alfalfa. Therefore, the selected location for the cold pixel does not need to be alfalfa, but can be any pixel from within the interior of a fully vegetated, cool, field (crop type is generally unknown when applying METRIC).

During calibration of METRIC via the assignment of ET_rF values for the cold and hot pixel conditions, normally only a single weather station is utilized in the calibration. A single station is used during calibration for several reasons. One, the locations for the cold and hot conditions are selected as close as possible to the single calibration weather station (usually within 20 km) so that wind speed and reference ET from the station can be assumed to closely approximate that for the selected calibration pixels. The internal calibration of the sensible heat flux function within METRIC is tied to the wind speed occurring at the calibration locations. Secondly, the internal calibration of the sensible heat flux function within METRIC generally requires the use of the same wind speed as was used in its determination, throughout the image. Third, the assignment of the ET_rF at the hot pixel is closely tied to any recent precipitation occurring at the calibration weather station. Fourth, the assignment of ET_rF at the cold and hot pixel conditions and the application of the METRIC process to the image should create (if calibrated and applied correctly) an ET_rF surface over the image that has general limits of 0 and 1, and that can be later applied to an ET_r surface that may vary over the image.

Special Calibration Cases.

For the November 8, 2004 image, we were unable to locate fields that appeared to have full vegetation cover, as evidenced by no fields having normalized difference vegetation index (NDVI) near the 0.7 to 0.8 typical for full cover. NDVI generally ranges from about 0.1 to 0.2 for bare soil to 0.75 to 0.85 for full vegetation cover. Therefore, the maximum ET from agricultural fields on that date and for the location assigned as the cold pixel is expected to be less than that from the alfalfa reference. ET_rF for the cold pixel on 11/8/2004 was calculated using the following relationship between ET_rF and the NDVI as ET_rF_{cold} = 1.25NDVI (Tasumi et al., 2005). For 11/8/2004, maximum NDVI values were around 0.72 so ET_rF_{cold} = 0.9.
Table 2 contains locations, NDVI and ETrF values assigned for cold and hot pixel conditions.

For 11/8/2004, results from the surface soil water balance indicated values of ETrF=0.5 for bare soil conditions due to recent antecedent rain events near the Agency Lake weather station. Therefore, this value was used to represent the driest bare soil conditions in the image area surrounding the calibration weather station (Agency Lake) to account for the presence of background evaporation.

Table 2. ET_rF values assigned to and locations (X, Y coordinates in UTM meters zone 10 WGS1984) for the hot and cold pixels for each image date.

Date		X	Y	NDVI	ETrF
4/30/2004	cold	630768	4671645	0.81	1
	hot	634714	4652405	0.14	0.1
6/01/2004	cold	587757	4706613	0.84	1.05

	hot	590053	4704492	0.15	0.1
6/17/2004	cold	587510	4703321	0.82	1.05
	hot	633960	4699000	0.14	0.1
7/11/2004	cold	589444	4679435	0.86	1.05
	hot	625774	4685165	0.13	0.1
8/04/2004	cold	599170	4657756	0.83	1.05
	hot	639951	4673031	0.14	0.05
8/20/2004	cold	626001	4688034	0.83	1.05
	hot	618819	4707417	0.18	0.1
9/21/2004	cold	608020	4666789	0.84	1.05
	hot	647589	4658023	0.16	0.1
10/07/2004	cold	605764	4661015	0.81	1.05
	hot	630724	4654175	0.15	0.1
11/08/2004	cold	678318	4783885	0.72	0.9
	hot	589139	4704133	0.13	0.5

4. Weather data processing

METRIC utilizes alfalfa reference ET (i.e., ET_r) as calculated by the American Society of Civil Engineers (ASCE) standardized Penman-Monteith equation (ASCE-EWRI 2005) for calibration of the energy balance process and to establish a daily soil water balance to estimate residual soil evaporation from bare soil following precipitation events (Allen et al., 2007a). The ET_r is used as a means to 'anchor' the surface energy balance by representing the ET from locations having high levels of vegetation and cooler surface temperatures. Therefore, high quality estimates of ET_r are needed, which, in turn, require high quality weather data. Therefore, before processing the satellite images, the quality and accuracy of the meteorological data were assessed.

Hourly weather data time steps are needed to produce ET_r for calibration of the METRIC energy balance estimation process at the time of the Landsat overpasses. The hourly ET_r values are summed to daily totals to provide a basis for producing daily and monthly ET. ET_r was calculated using the RefET software (version 3) of the University of Idaho (Allen, 2008).

Quality Assessment and Quality Control of the Weather Data

To apply METRIC, reference ET is calculated from weather data sets having the following parameters, plus some of these parameters are used in the METRIC calibration:

- Wind speed (hourly average): for computation of sensible heat flux (wind speed at satellite overpass time is required) and reference evapotranspiration (ETr) with the REFET software.
- Precipitation (24 hour): to evaluate evaporative soil moisture conditions at the satellite overpass time.
- Dew point temperature (hourly average): for calculation of atmospheric transmissivity and instantaneous incident solar radiation (clear sky) at satellite overpass time. Also used for reference ET calculation.
- Incident solar radiation (hourly average): for reference ET calculation

- Air temperature (hourly average): maximum and minimum temperature for reference ET calculation.

Before being used for these calculations, QA (Quality Assessment) and QC (Quality Control) procedures as recommended by ASCE-EWRI (2005) were applied to investigate the general quality of data. In the case of solar radiation, for example, measured values (hourly or daily) were compared to estimated clear sky solar radiation taken as the upper bound for measured. Sensor malfunctioning, calibration problems, low maintenance and other issues can lead measured values to have systematic bias. Such systematic errors can be corrected based on expected clear sky conditions. Adjustments are applied by means of appropriate coefficients. In Figure 4 good agreement between registered solar radiation (Rs) and theoretical clear-sky solar radiation (Rso) indicates appropriate calibration of the sensor at Agency Lake for the date shown.

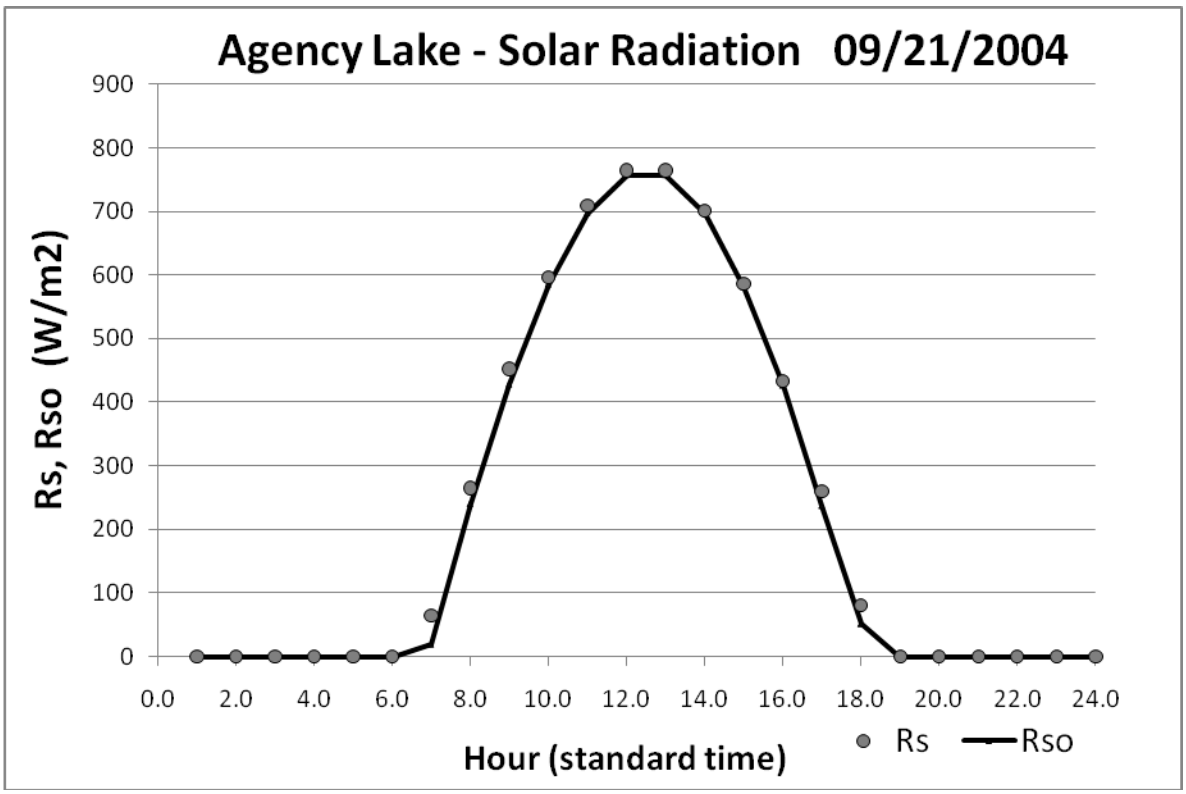

Figure 4. Solar radiation (Rs) plotted against theoretical clear-sky solar radiation (Rso).

In Figure 5 a plot of hourly mean air temperature and dewpoint is shown for a 24-hour period. In agricultural settings one can expect the recorded minimum temperature to be close to the dewpoint temperature observed at the same time, as in the case in the figure shown for 09/21/2004.

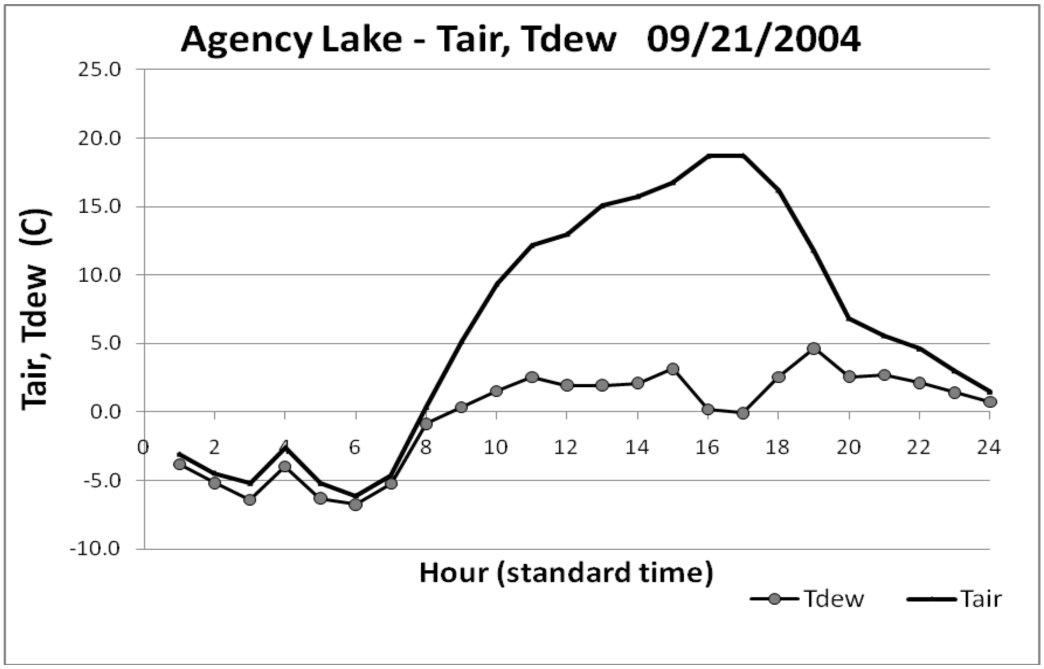

Figure 5. Air temperature and dew point temperature registered at AGENCY LAKE on 9/21/2004

5. Using a daily soil water balance model for METRIC calibration.

A daily soil water balance was applied to the 2004 period using precipitation and ET_r data from the Agency Lake weather station. The water balance estimates residual evaporation from a bare soil surface on each image date as shown in Figure 6. The soil water balance is based on the two-stage daily soil evaporation model of the United Nations Food and Agriculture Organization's Irrigation and Drainage Paper 56 (Allen et al., 1998). Fig. 6 shows a simulation of evaporation from the upper 0.125 m of soil at Agency Lake.

During the drying cycle after a wetting event, a typical bare agricultural soil can be expected to continue to evaporate at a small rate beyond the first several weeks due to diffusion of liquid water and vapor from beneath the upper soil layer. This evaporation can continue at very low rates for several additional weeks, provided no new wetting events occur, especially from tilled soils that have a moderate amount of water stored within the soil profile. This is typical of agriculture.

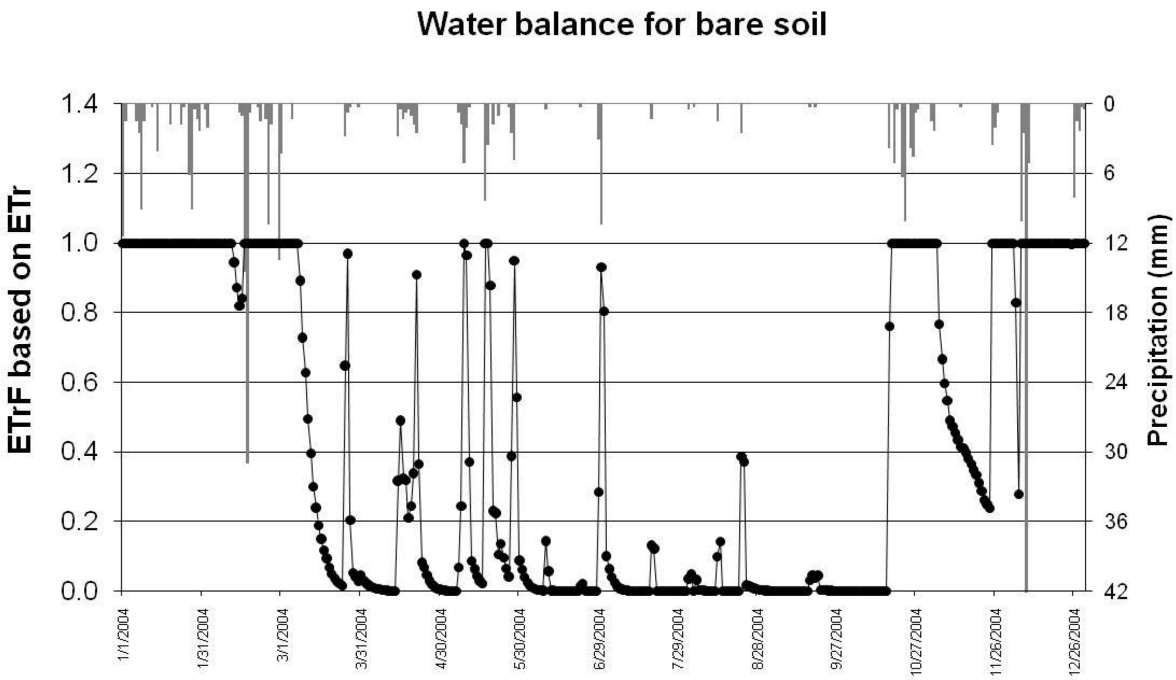

Figure 6. Daily ET_rF for bare soil estimated from the soil water balance for 2004 using weather data from the Agency Lake weather station.

6. METRIC™ processing and results

METRIC produces 30x30 m spatial resolution maps of both ETrF (Fraction of Reference Evapotranspiration) and actual ET. The main products produced by METRIC are:

- Instantaneous ETrF and ET maps, at satellite time for every image.
- Daily ETrF and ET maps, for every image.
- Monthly ETrF and ET maps .
- Seasonal ETrF and ET maps.

Intermediate Products

During the METRIC™ process, dimensionless vegetation indices (NDVI, LAI and NDWI), surface reflectance (albedo), and surface and DEM-delapsed temperature maps are created. NDVI (normalized difference vegetation index) and LAI (leaf area index) maps are used in METRIC™ as indicators of biomass and aerodynamic roughness, and as predictors of ratios of soil heat flux to net radiation or sensible heat flux. The LAI is defined as the total one-sided green leaf surface area per unit ground surface area. The typical range for LAI is zero to six, where zero represents bare soil and greater than four represents dense vegetation. LAI values above three represent "full cover" conditions, and generally imply maximum ET in well irrigated areas.

NDVI is calculated as the relative difference in reflectance between the shortest near infrared band (band 4) and the red band (band 3), respectively:

$$NDVI = \frac{\rho_4 - \rho_3}{\rho_4 + \rho_3}$$

where $\rho 3$ and $\rho 4$ are the at-satellite reflectances in bands 3 and 4 respectively. NDVI is somewhat sensitive to the color of the soil, spectral bandwidth, and atmospheric attenuation. Typically, NDVI varies between 0.1 and 0.8, with the higher value indicating dense vegetation and values less than about 0.2 associated with soil/rocks. Negative NDVI values typically indicate water bodies and snow, which reflect more energy in the red spectrum than in the near infrared.

NDWI (normalized difference water index) is calculated as the relative difference at satellite reflectance between bands 5 and 2

$$NDWI = \frac{\rho_5 - \rho_2}{\rho_5 + \rho_2}$$

where $\rho 5$ and $\rho 2$ are the at-satellite reflectances in bands 5 and 2 respectively. This is an index defined for the identification of water bodies. A value lower than zero indicates the presence of water bodies. In combination with NDVI, NDWI produces a good map of watery areas.

Lapse rate

In METRIC, the simulation of DEM delapsed temperature is necessary for estimating the near surface temperature gradient (dT) used to estimate sensible heat flux. This requires the establishment of an atmospheric lapse rate. For the area of study a unique lapse rate was used on each image date for elevations less than 1750 m, to represent lapsing trends along the agricultural valleys inside the image; this lapse rate is called the "flat" lapse rate during METRIC processing. Another lapse rate was used for elevations greater than 1750 m that represents mountainous conditions; this one is called the "mountain" flat rate. Unique values were sometimes required for specific images, determined by operator observation of surface temperature trends. Common (standard) values for the lapse rates are 6.5 K/1000 m for the 'flat' rate and 10 K/1000 m for the 'mountain' rate where K is degrees Kelvin.

Sharpening

Although the final products from METRIC are of high spatial quality when produced from Landsat imagery, an even finer resolution for the images is often desirable, especially when ET within individual field parcels is needed. Landsat 5 images have 120 m spatial resolution of longwave (thermal) band that is coarser than the 30 m for coincident shortwave bands, and the 120 m thermal information tends to dominate the resolution of the final ET product. To improve the quality of the results, a procedure known as *sharpening* was applied to the final individual

ETrF images generated with the METRIC code. This procedure is described in the METRIC manual (Allen et al., 2010) and in a paper by Trezza et al. (2008).

The basic sharpening philosophy and procedure followed is based on the application of an established Surface Temperature (Ts) vs NDVI relationship to produce a first estimate of Ts at every short wave pixel, assuming a linear relationship and correspondence between NDVI and Ts. Later, to preserve original Ts information, this first estimate of Ts is adjusted so that Ts averaged over all shortwave pixels lying within an original thermal pixel matches the original average Ts of that thermal pixel. In most of the cases the redistribution of the bias between the original thermal Ts and the estimate Ts is an iterative process.

Figure 7 shows an example of an ETrF map, before and after sharpening surface temperature. This procedure was applied to all Landsat 5 images to enhance the resolution of the final ETrF product. Landsat 7 images were not sharpened because they are already at 60 m resolution.

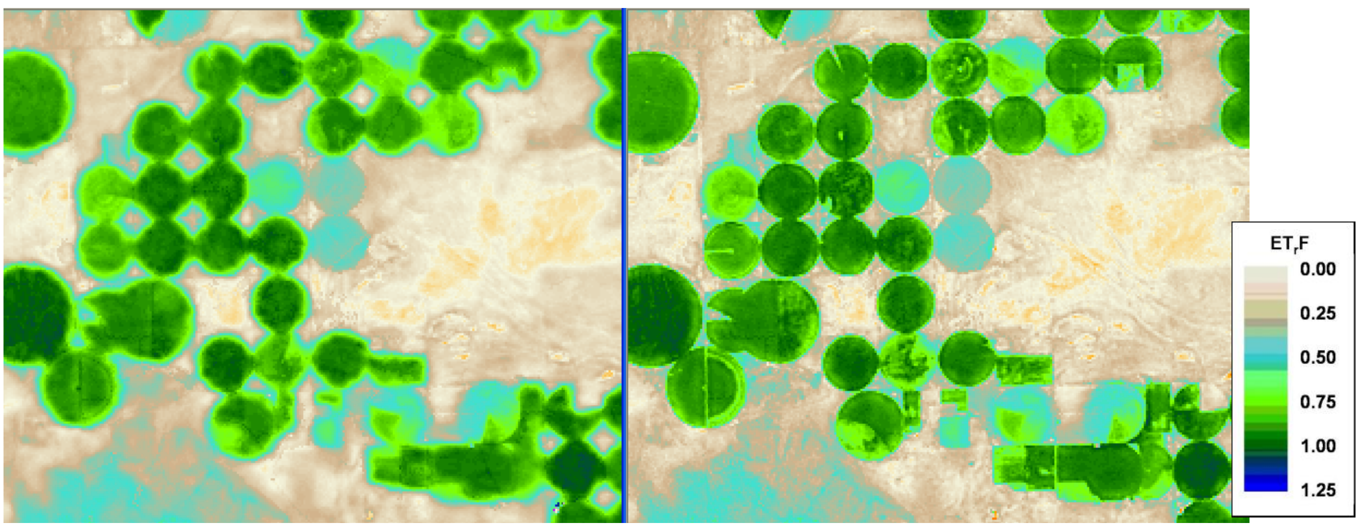

Figure 7. Left: Close-up of ETrF image from path 45 corresponding to June 17th 2004; the area is close to Christmas Valley, OR. Right: The same ETrF map but using sharpened surface temperature.

Gapfilling for Landsat 7 images

Landsat 7 images acquired after May 2003 have information gaps caused by the malfunction of the scan line corrector. As a result, Landsat 7 images processed for year 2004 and 2006 are "SLC-off" images where wedge shaped gaps exist in the images, extending from the edges of the image and stretching towards the centers. To obtain as complete coverage as possible, the gaps in ET_rF maps produced by METRIC were filled in during post processing using the natural neighbor tool of Arc-GIS. Figure 8 shows a close-up of an area along the Sprague River where the natural neighbor interpolation procedure was applied. The quality of the interpolation depends on the location of the gap, being better over homogenous landscapes.

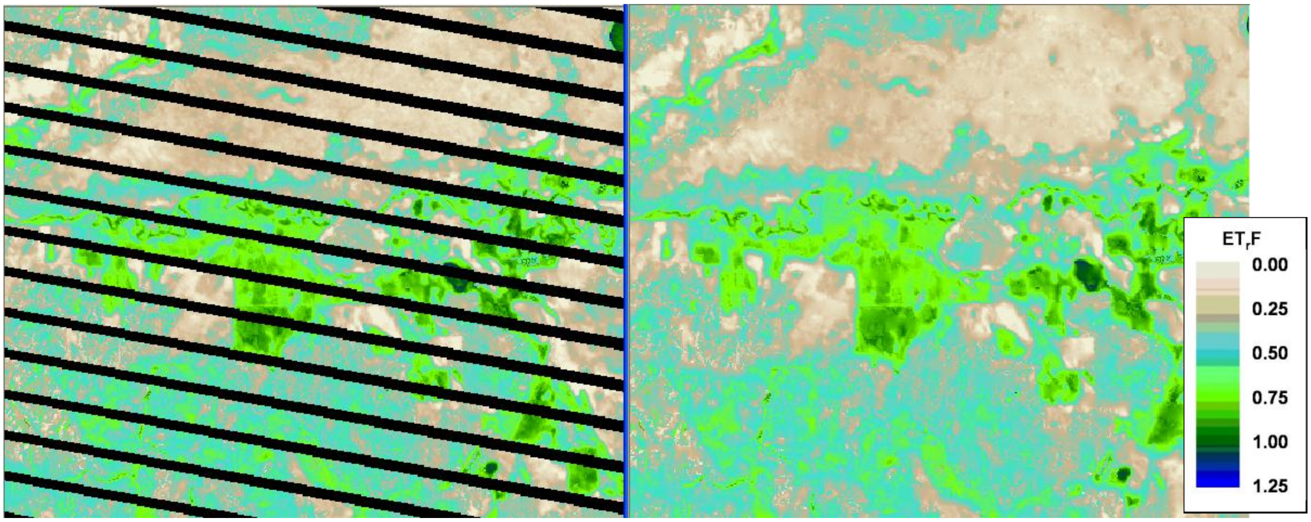

Figure 8. Left: Close-up of ETrF image corresponding to July 11th 2004, showing gaps (stripes) originated from the Landsat 7 image; the area is close to Sprague River. Right: The same ETrF map, after gaps were filled using natural neighbor interpolation.

Daily ETrF products

METRIC was applied for every image included in Table 1 to obtain instantaneous (at satellite) and daily ETrF maps. As previously discussed, a total of 9 images were processed (Table 1).

Maps of reflectance of short wave radiation, vegetation indices (NDVI and LAI), surface temperature, net radiation and soil heat flux were generated as intermediate products during METRIC processing. The final output from the METRIC energy balance model were images showing instantaneous ET_rF (fraction of alfalfa based reference ET, ET_r) at the satellite overpass time. For land covers other than rangeland, the estimate of daily ET_rF was set equal to the instantaneous at the satellite overpass time, based on extensive ET measurements made using precision weighing lysimeters at Kimberly, Idaho (Allen et al., 2007b; Allen, 2008).

The following section provides a discussion of each image (figures 9 – 17).

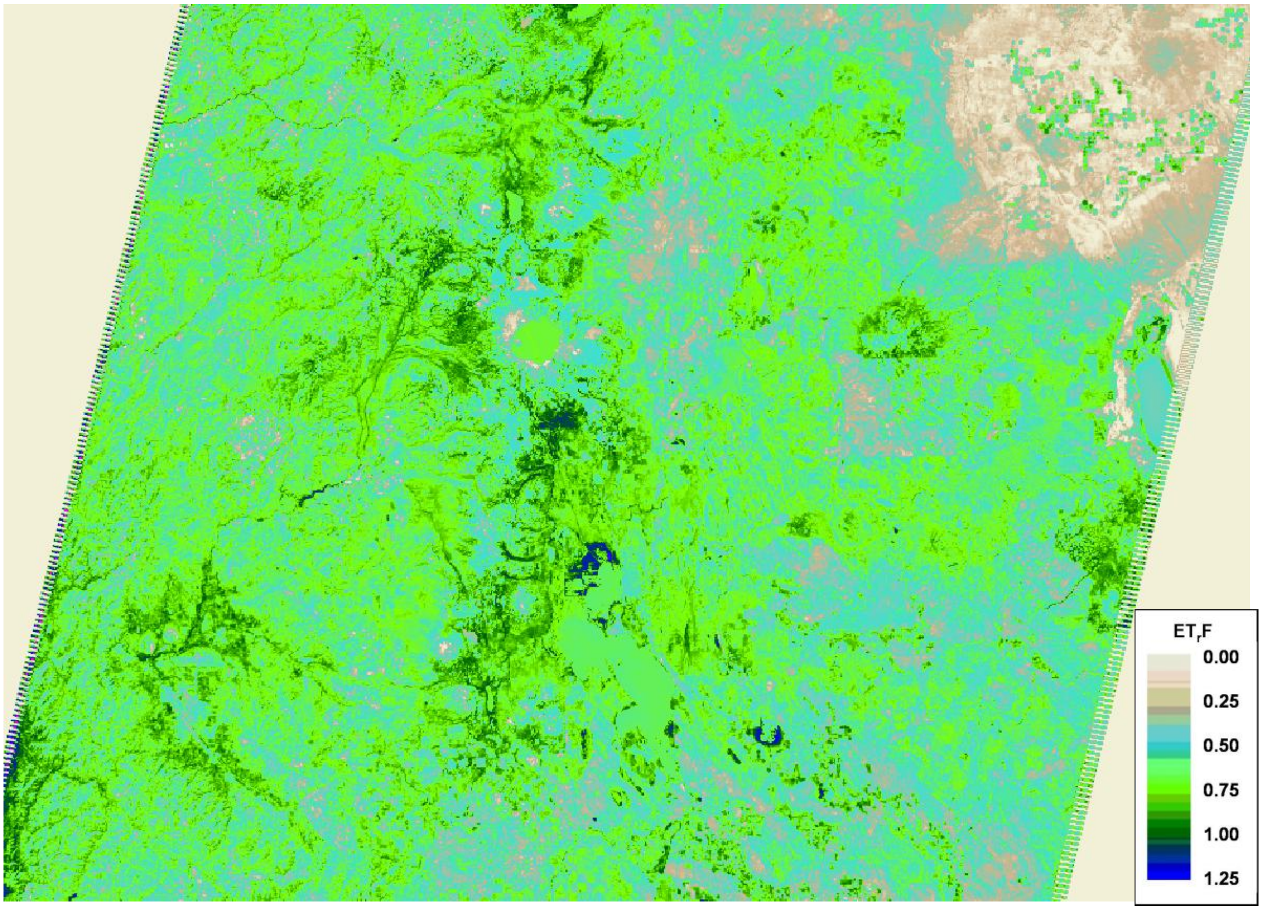

Figure 9. ETrF map for 04/30/2004. Masked cloudy areas are identified as black.

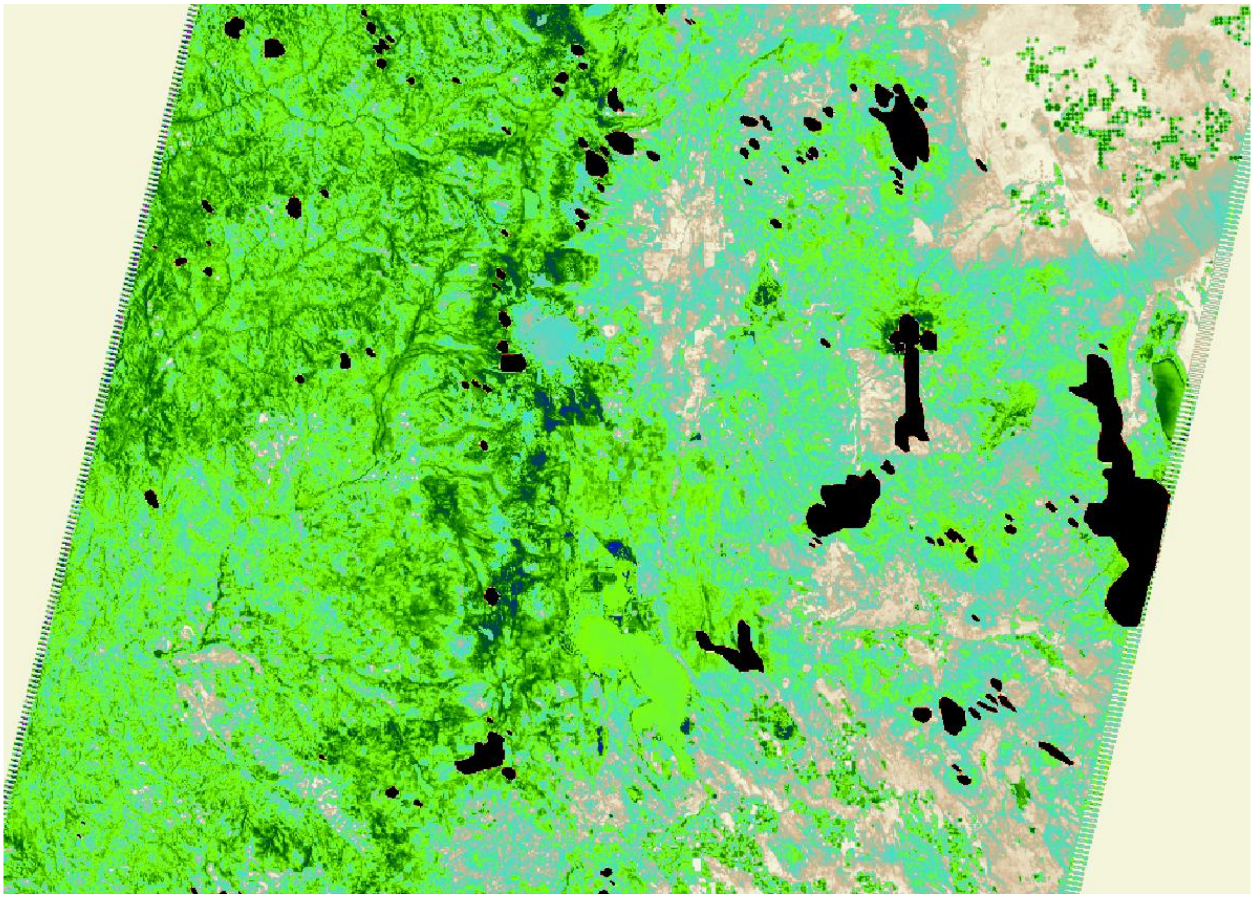

Figure 10. ETrF map for 06/01/2004. Masked cloudy areas are identified as black.

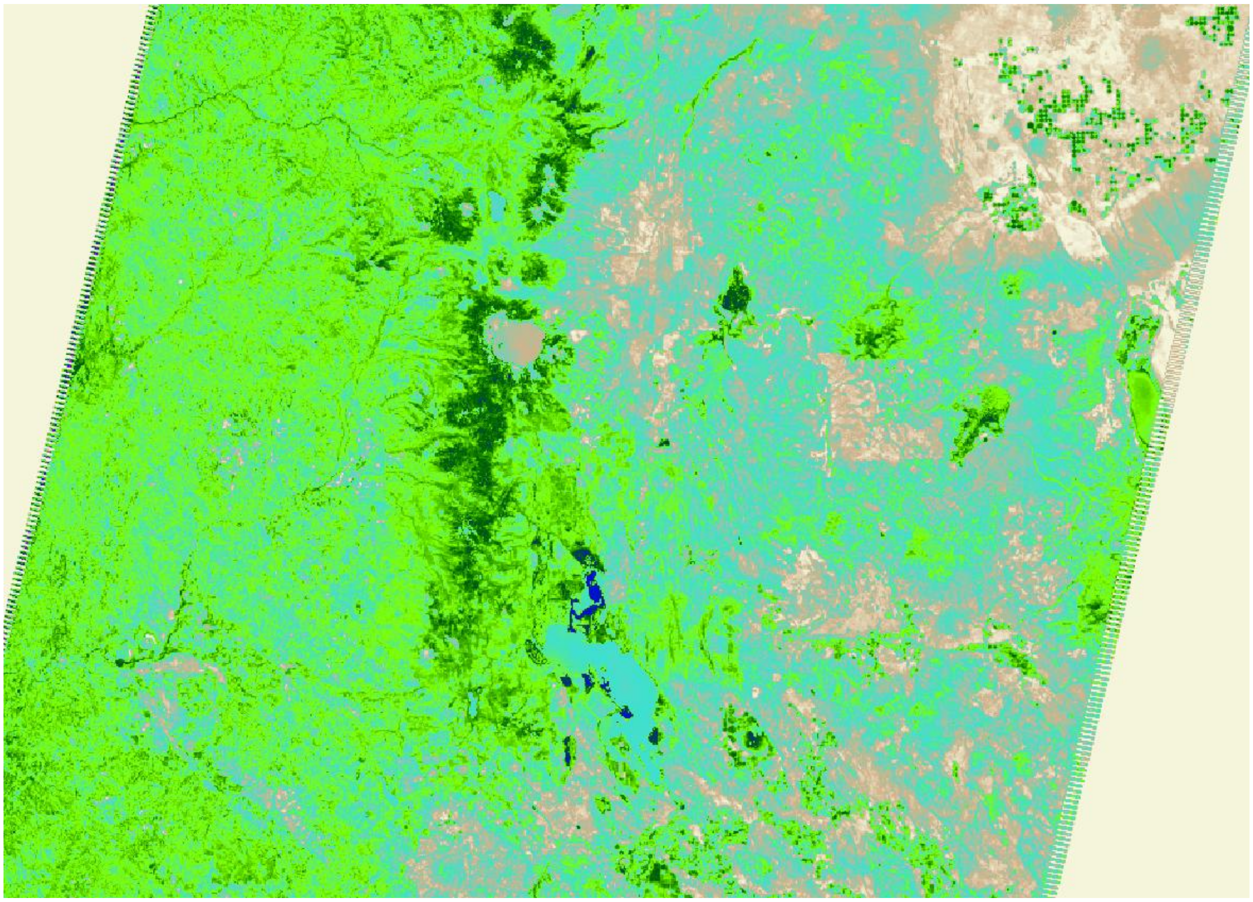

Figure 11. ETrF map for 06/17/2004. Masked cloudy areas are identified as black.

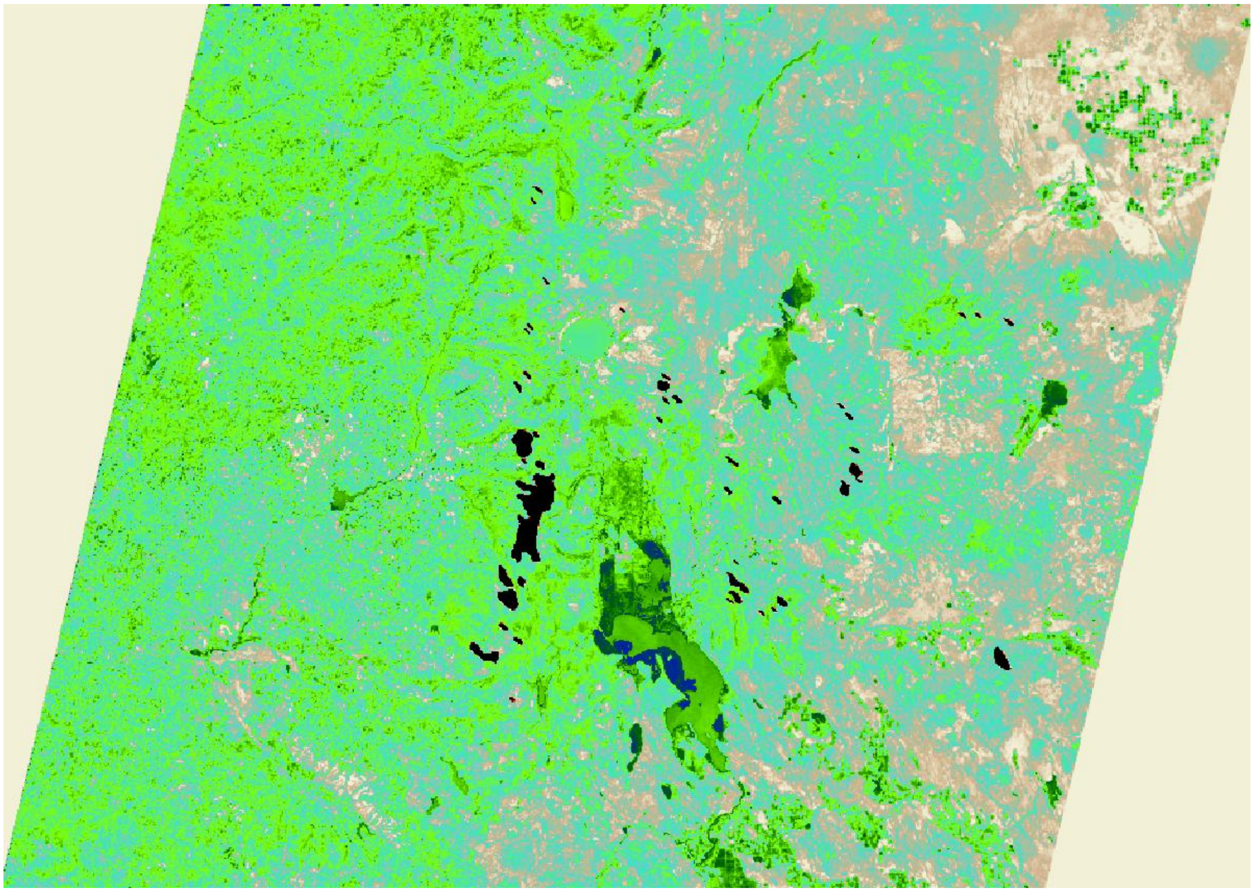

Figure 12. ETrF map for 07/11/2004. Masked cloudy areas are identified as black. The image shows the product after filling the gaps from the Landsat 7 image.

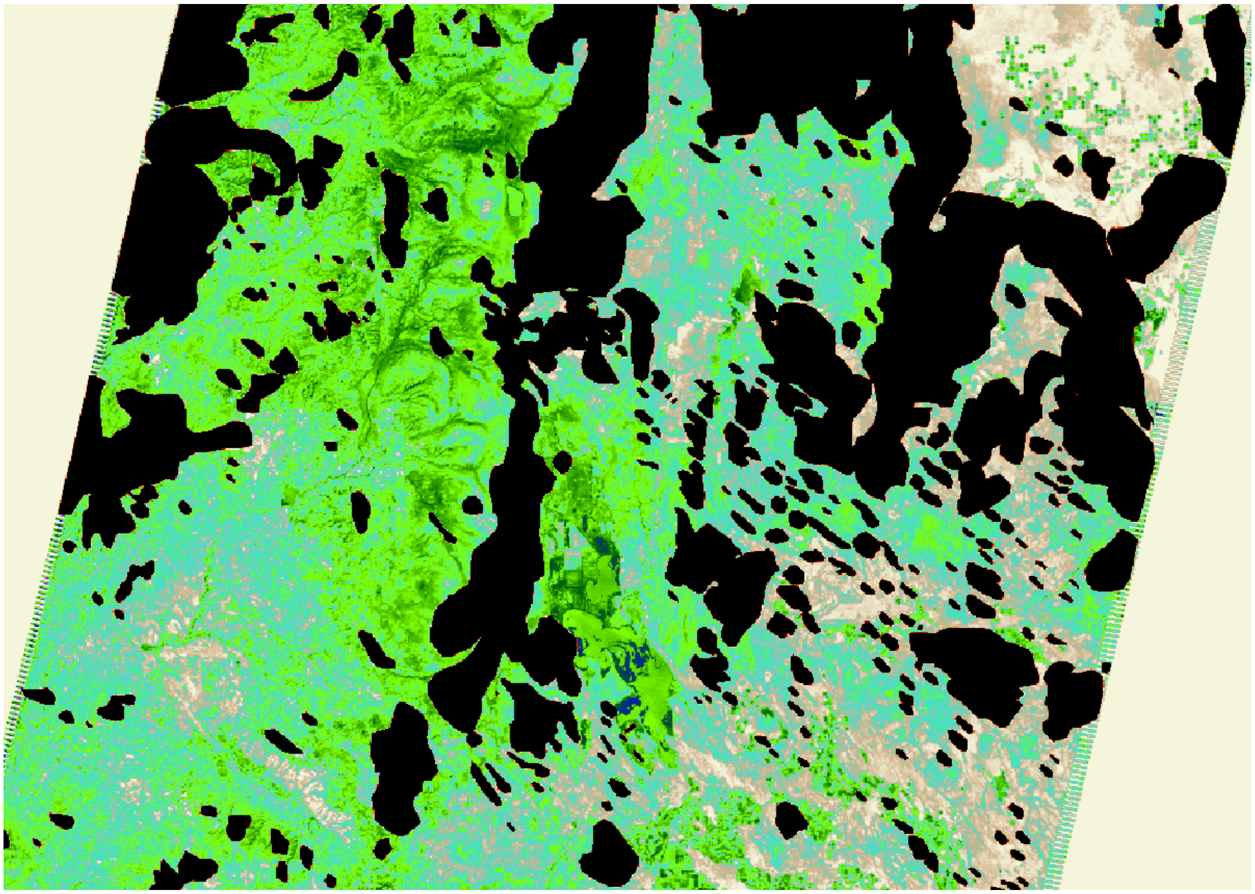

Figure 13. ETrF map for 08/04/2004. Masked cloudy areas are identified as black.

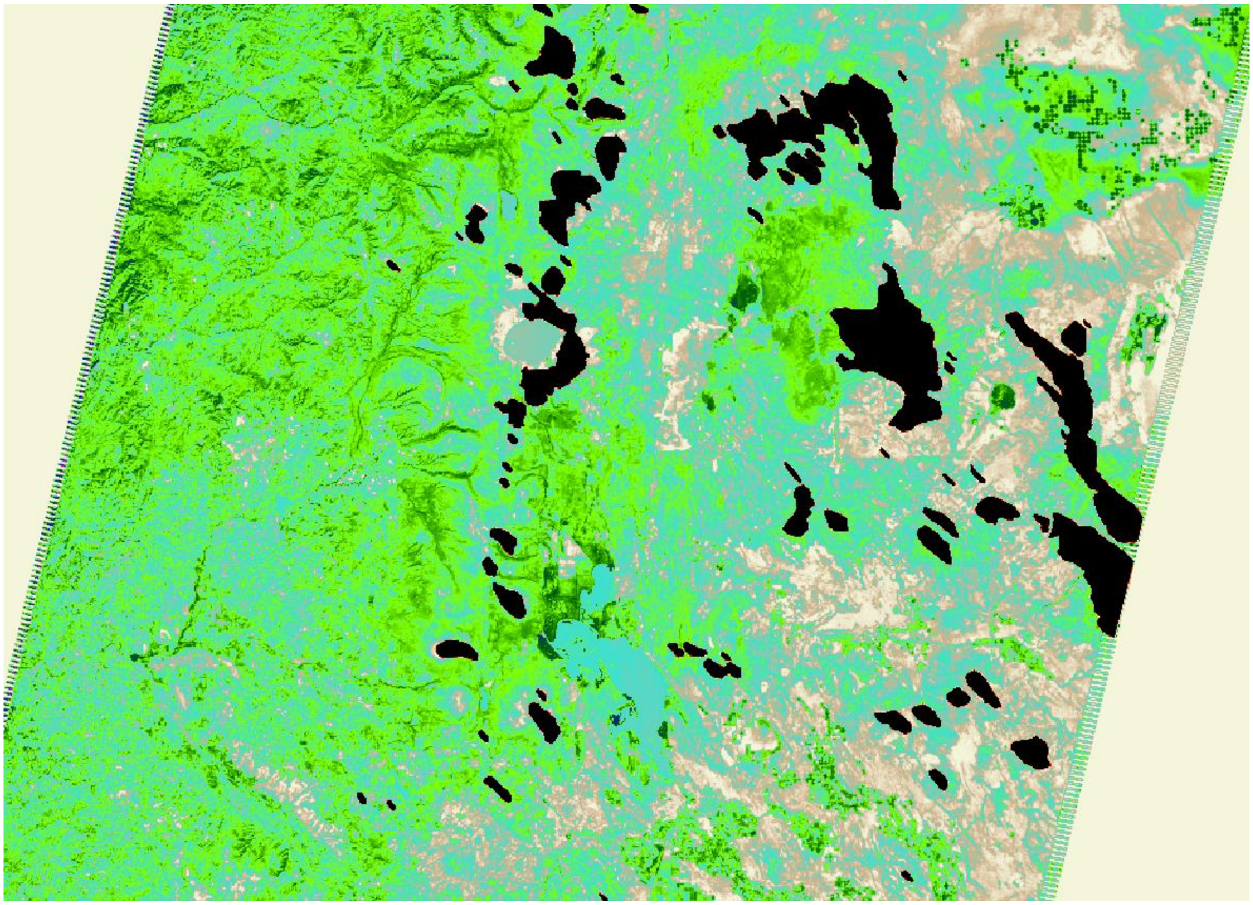

Figure 14. ETrF map for 08/20/2004. Masked cloudy areas are identified as black.

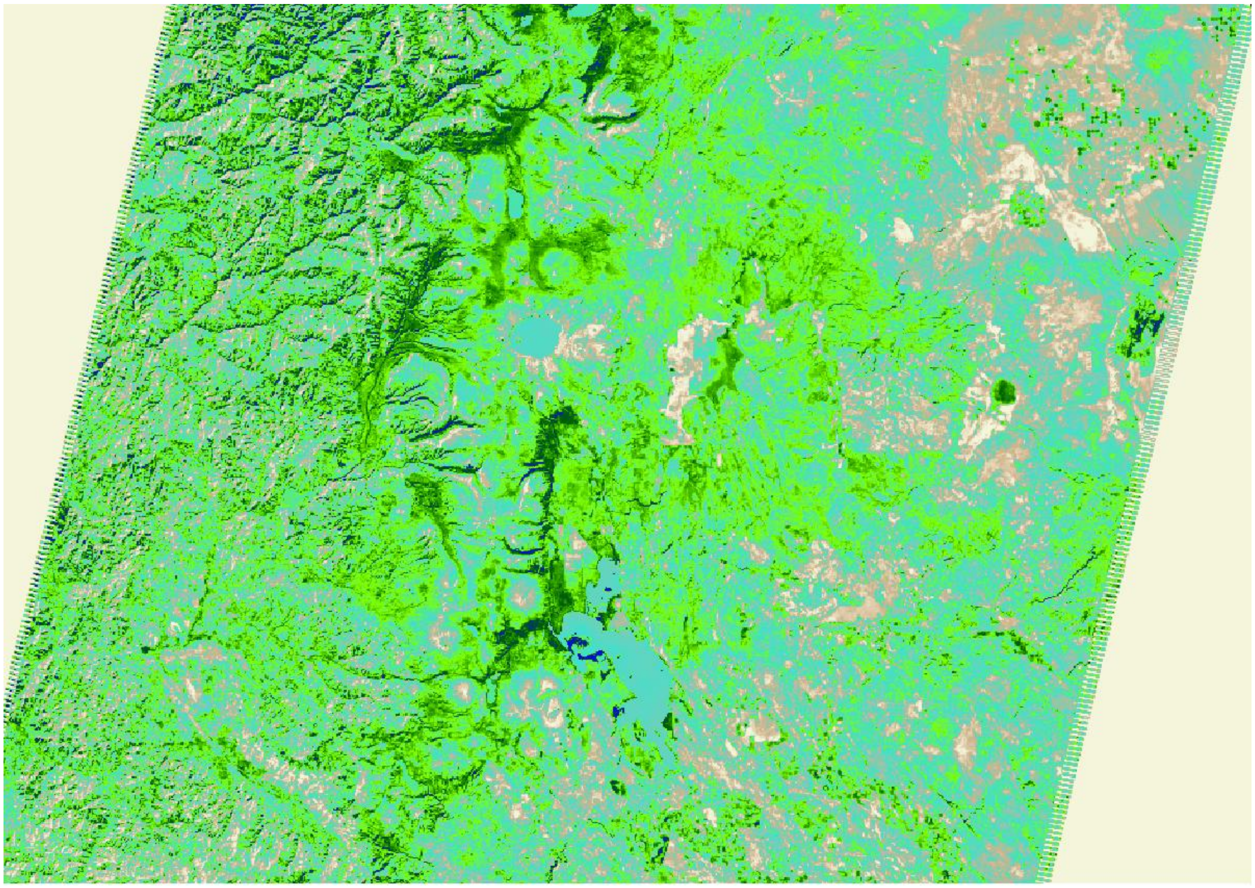

Figure 15. ETrF map for 09/21/2004. Masked cloudy areas are identified as black.

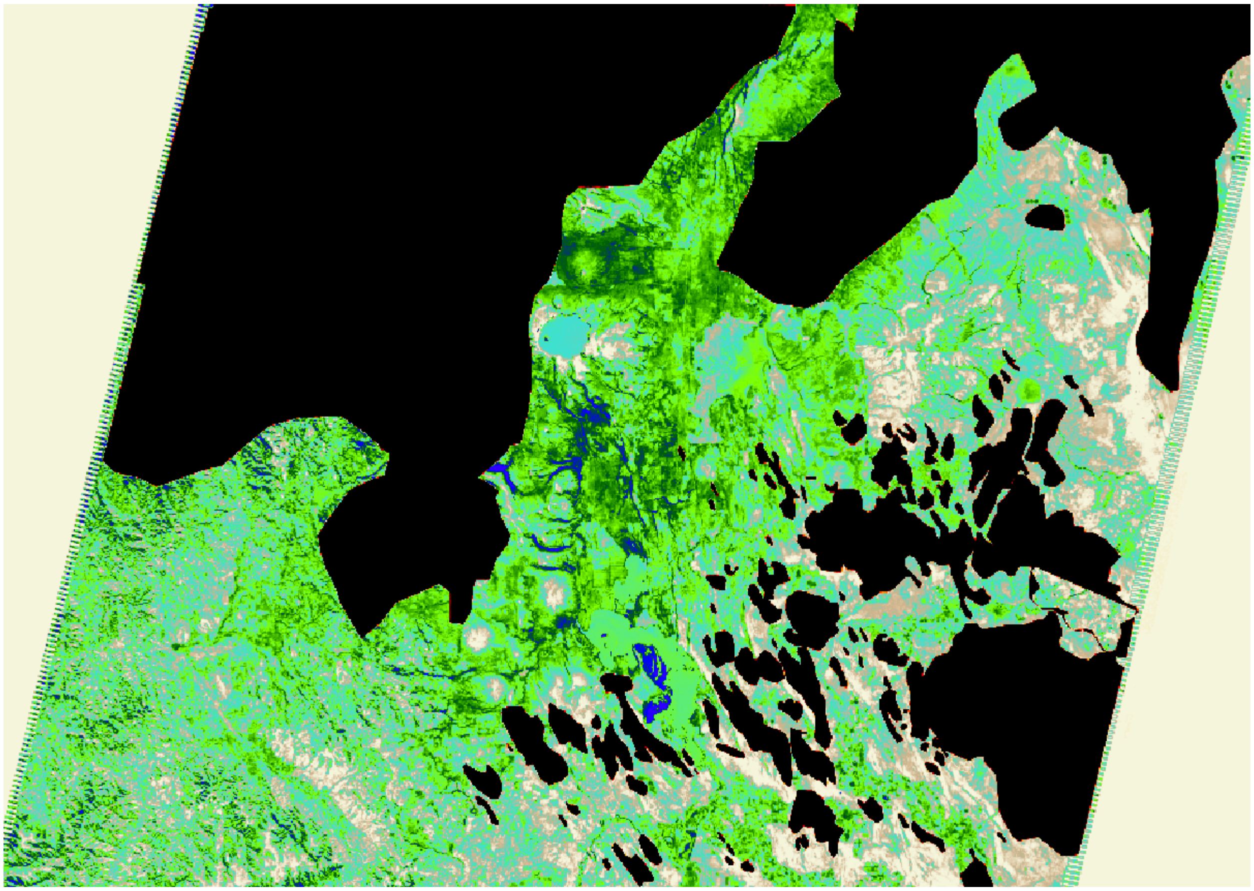

Figure 16. ETrF map for 10/07/2004. Masked cloudy areas are identified as black.

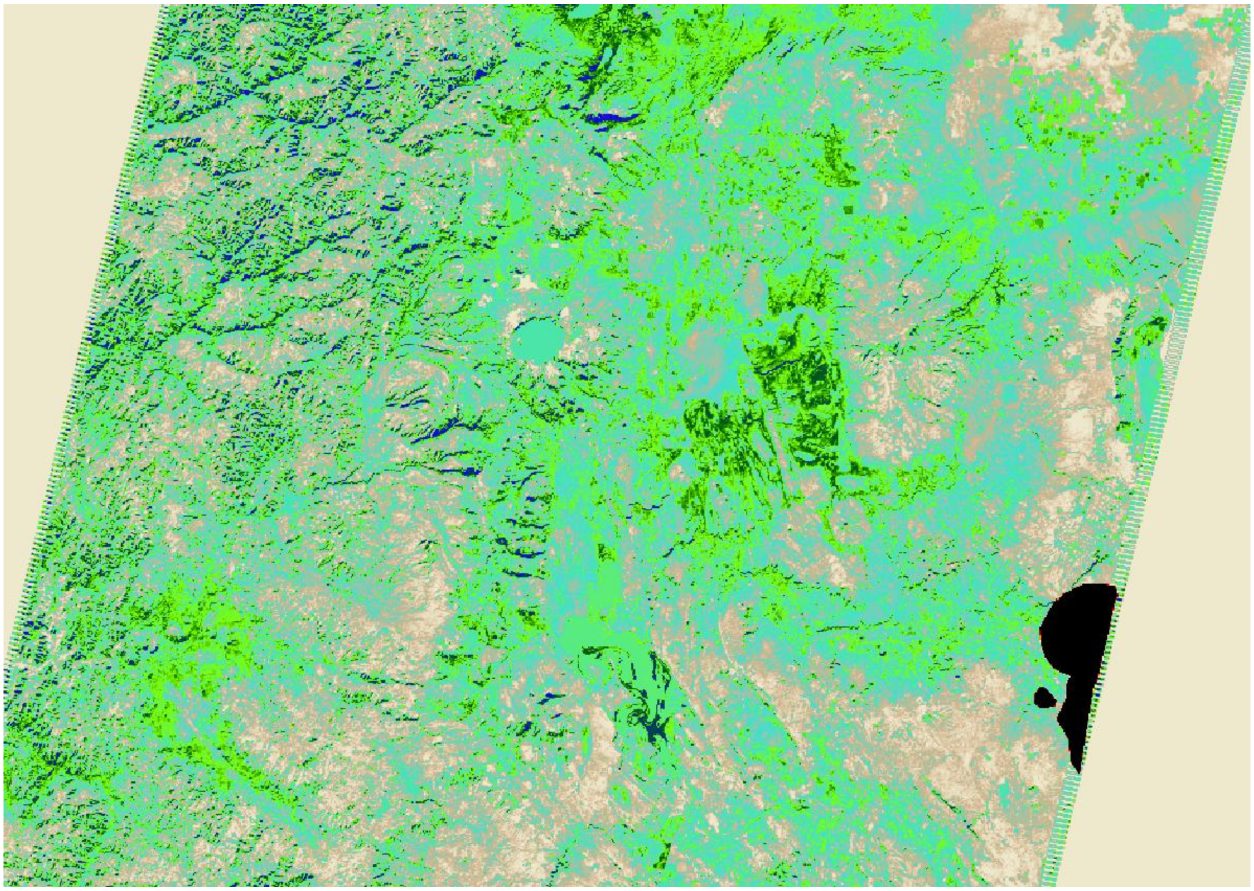

Figure 17 ETrF map for 11/08/2004. Masked cloudy areas are identified as black.

Monthly ET and ETrF

Individual satellite images processed using METRIC yield daily maps of ETrF for the image dates only. Because the available satellite images are obtained relatively infrequently, ETrF is likely to change with time between images as vegetation develops or matures or as surface water availability varies. A common and useful objective of METRIC applications is to produce monthly and seasonal ET based on the information provided by the individual images. This is done by interpolating ETrF information among individual satellite image dates to following the trends caused by vegetation development and evaporation from precipitation and multiplying by daily reference ET for each day to account for impacts of weather on potential ET demand.

Cubic spline interpolation of ETrF values between satellite dates

METRIC uses a cubic spline interpolation method to describe a smoothed variation in ETrF between images. This methodology was found to work better than a simple linear interpolation. For illustration of the cubic spline interpolation method, the figure 18 below shows an example (from another region) of point values of ETrF sampled from a single pixel from multiple images processed using METRIC. The values on each image date are connected using linear interpolation between image dates.

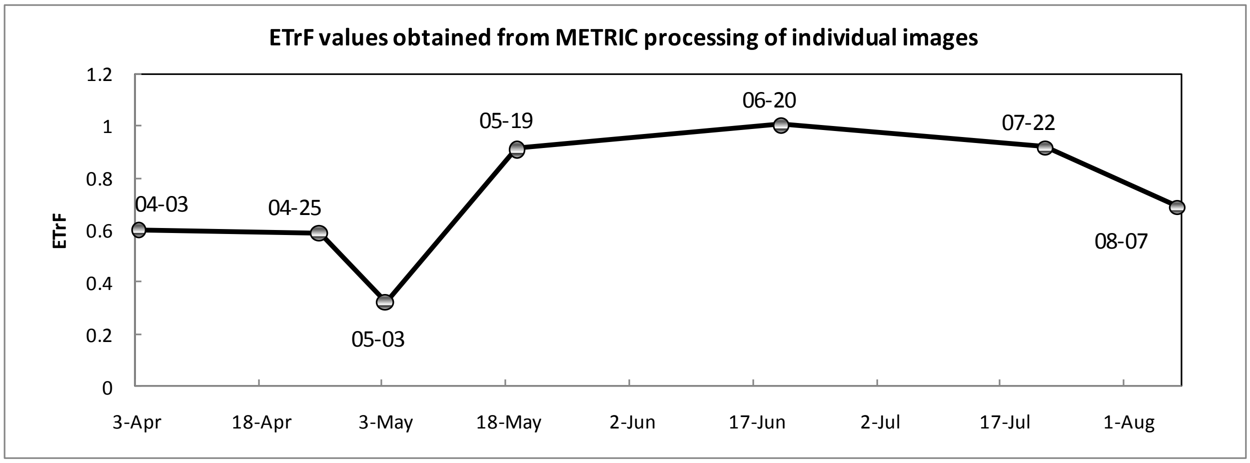

Figure 18. Interpolated ET_rF using linear interpolation between images dates.

Relatively abrupt changes in slope occur between dates. Figure 19 shows the application of a spline interpolation method for the same image dates. This smoother interpolation is in most cases a better representation the development of ET_rF for vegetation compared to the linear interpolation.

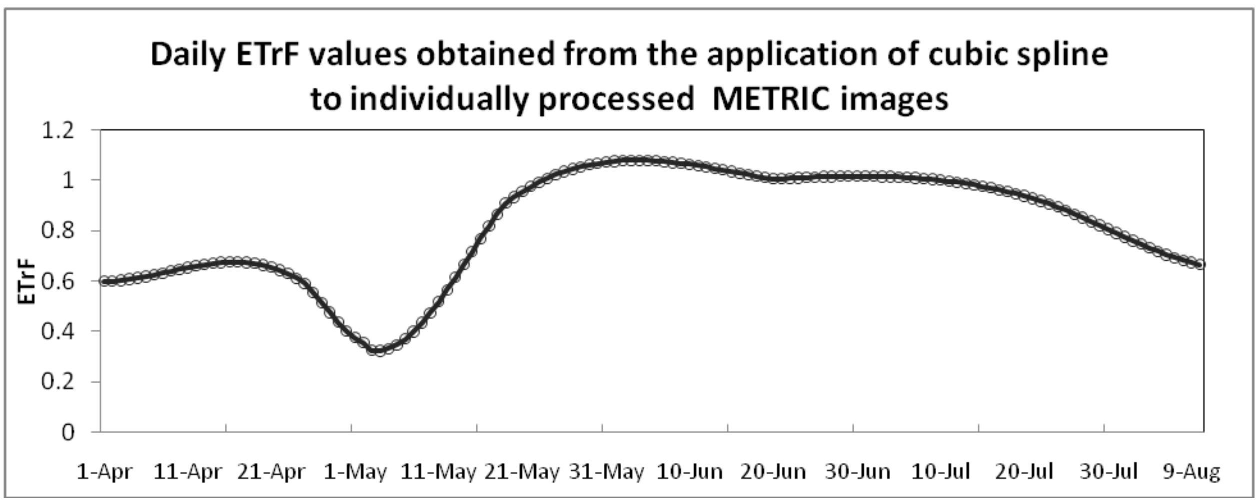

Figure 19. Interpolated ET_rF using cubic spline interpolation between images dates.

The application of the cubic spline procedure to derive monthly and seasonal ET_rF and ET is applied one month at a time. Once the daily images for ET_rF for each day of the month are created, for each day, the ET_rF for every pixel in an image is multiplied by the reference ET (ET_r), computed for each specific day according to weather data:

$$ET_{daily} = ET_rF_{daily} \text{ x } ET_{r\ daily}$$

Following the computation of daily ET for each day of the month, the ET_{daily} was summed to produce ET_{month}. The average monthly ET_rF_{month} was then determined by dividing the ET_{month} by the summed $ET_{r\ month}$:

$$ET_rF_{month} = ET_{month} / ET_{r\ month}$$

Because ET_r can change spatially within an image domain, an inverse distance interpolation procedure of Arc-GIS with standard default parameters was used to produce a daily ET_r surface using twelve Agrimet weather stations to create daily maps of ET_r. The resolution of the daily ET_r images was coarser than that for ET_rF, since ET_r changes only gradually in space. Location information for the Agrimet stations is listed in Table 3. Description of some stations is provided in Appendix A.

Once ET and ETrF images for all months (April through October) were produced, the same concept as above was applied for the generation of the seasonal images, by summing the monthly ET and dividing by summed ETr to generate the average seasonal ETrF.

As such the final generated products were the monthly ET and ETrF images from April through October and the seasonal total ET and average ETrF images for both considered paths. All ETrF images were generated as a Float Single Data Type and the ET images were generated as 16-bit Signed data type previously rounded to avoid data truncation.

Table 3. Agrimet stations used to calculate daily reference ET during 2004 and 2006, including daily ETr surfaces for use during splining and integrating METRIC ET over monthly periods.

Station	State	Latitude, dec.	Longitude, dec.	Latitude	Longitude	Elevation, ft
Christmas_Valley	OR	43.24139	120.728	43° 14' 29"	120° 43' 41"	4305
Agency_Lake	OR	42.56528	121.983	42° 33' 55"	121° 58' 57"	4150
Beatty	OR	42.47806	121.274	42° 28' 41"	121° 16' 26"	4320
Lakeview	OR	42.12222	120.523	42° 07' 20"	120° 31' 23"	4770
Lorella	OR	42.07778	121.224	42° 04' 40"	121° 13' 27"	4160
Klamath_Falls	OR	42.16472	121.755	42° 09' 53"	121° 45' 18"	4100
Worden	OR	42.0125	121.788	42° 00' 45"	121° 47' 15"	4080
Medford	OR	42.33111	122.938	42° 19' 52"	122° 56' 16"	1340
Cedarville	CA	41.58528	120.171	41° 35' 07"	120° 10' 17"	4600
Powell_Butte	OR	44.24833	-120.95	44° 14' 54"	120° 56' 59"	3200
Hills_Creek_Dam	OR	43.70972	122.421	43° 42' 35"	122° 25' 17"	1560
Lookout_Point_Dam	OR	43.91556	122.752	43° 54' 56"	122° 45' 08"	940

Dealing with clouded parts of images

Satellite images often have clouds in portions of the images, and the Path 45 images of Oregon for years 2004 and 2006 were no exception. ETrF cannot be directly estimated for clouded areas using surface energy balance because cloud temperature masks surface temperature and cloud albedo masks surface albedo. ETrF for clouded areas must be filled in before splining of monthly ET. Because clouded (or 'missing') portions of an image generally result in long periods between valid ETrF data (sometimes longer than several months), a special cloud-filling procedure was used.

ETrF for cloud masked areas is filled in for individual Landsat dates prior to splining ET_rF between images. The ET_rF data inserted into masked areas are 'borrowed' from adjacent images in time, but with adjustment for background evaporation occurring from precipitation events, and, in some cases, adjusting total ETrF to account for substantial changes in image-wide vegetation amounts, for example during early spring. The cloud mask-gap filling and interpolation of ET between image dates entails interpolating the ET_rF for the missing area from the previous and following images.

An ERDAS Imagine Modelmaker code was created by the University of Idaho METRIC group to conduct the 'filling' of cloud masked portions of images. The procedure is explained in details in Appendix 19 of the METRIC manual (Allen et al, 2010).

Results of monthly ETrF maps

Figures 20 to 26 show monthly ETrF maps for the period between April and October 2004 that were produced by cloud-filled images for individual dates and splining.

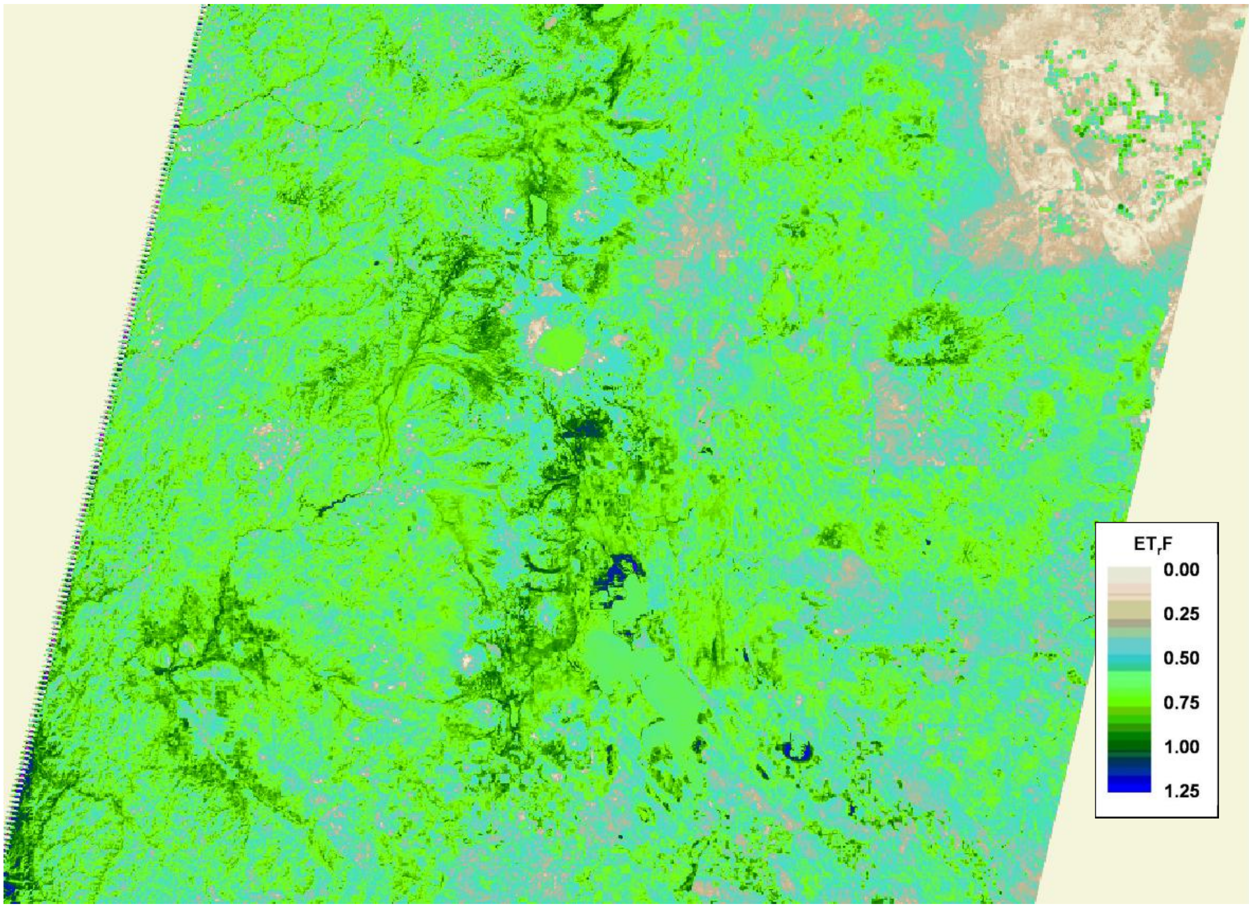

Figure 20. Average ETrF map for April 2004

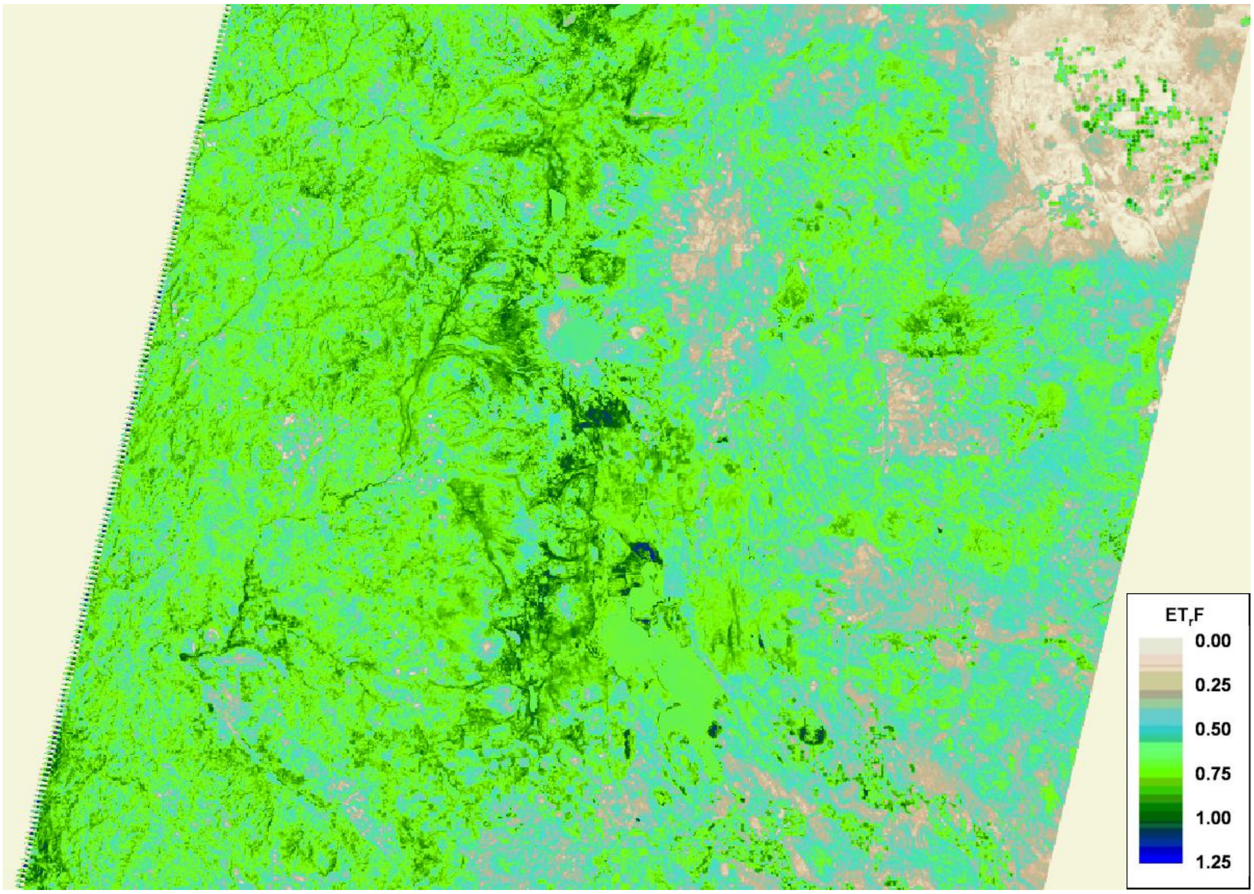

Figure 21. Average ETrF map for May 2004

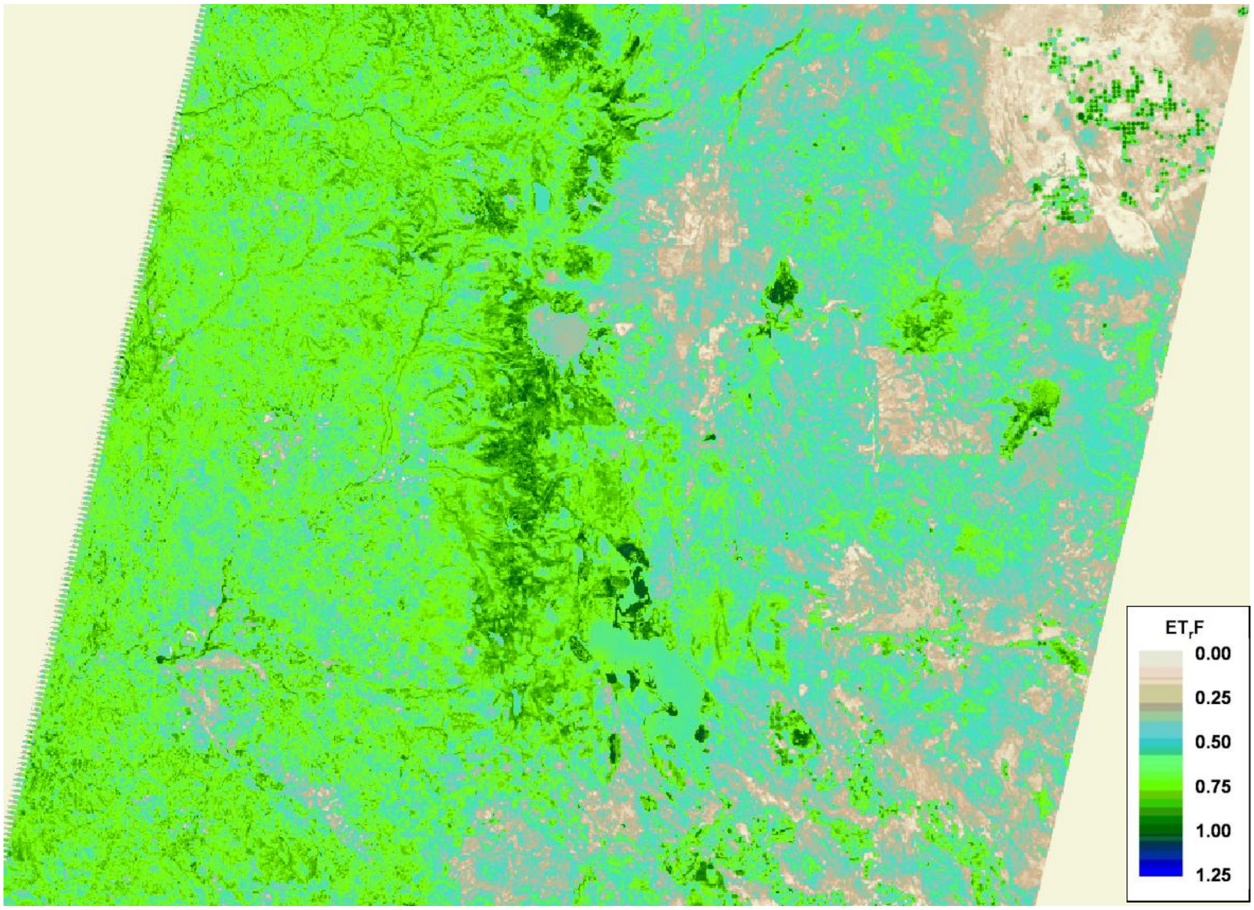

Figure 22. Average ETrF map for June 2004

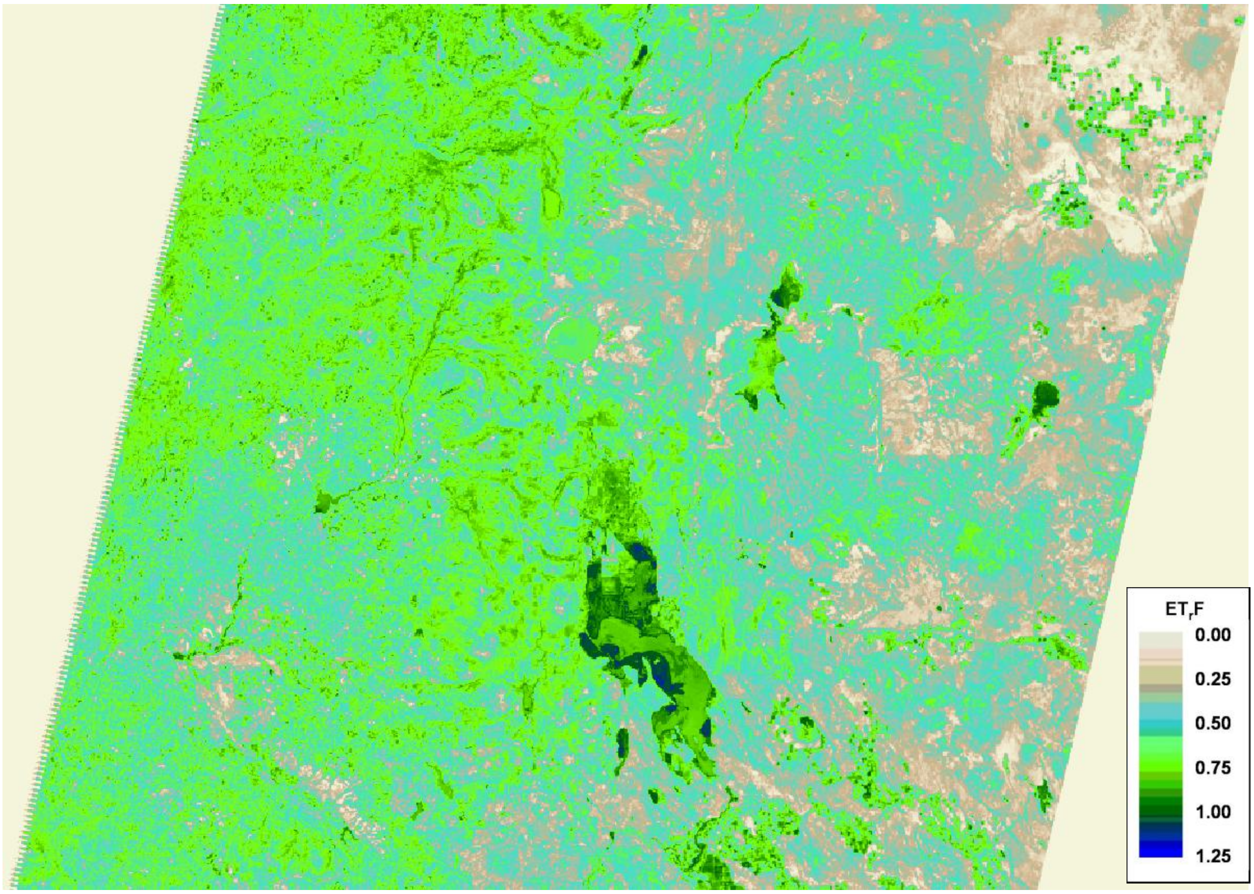

Figure 23. Average ETrF map for July 2004

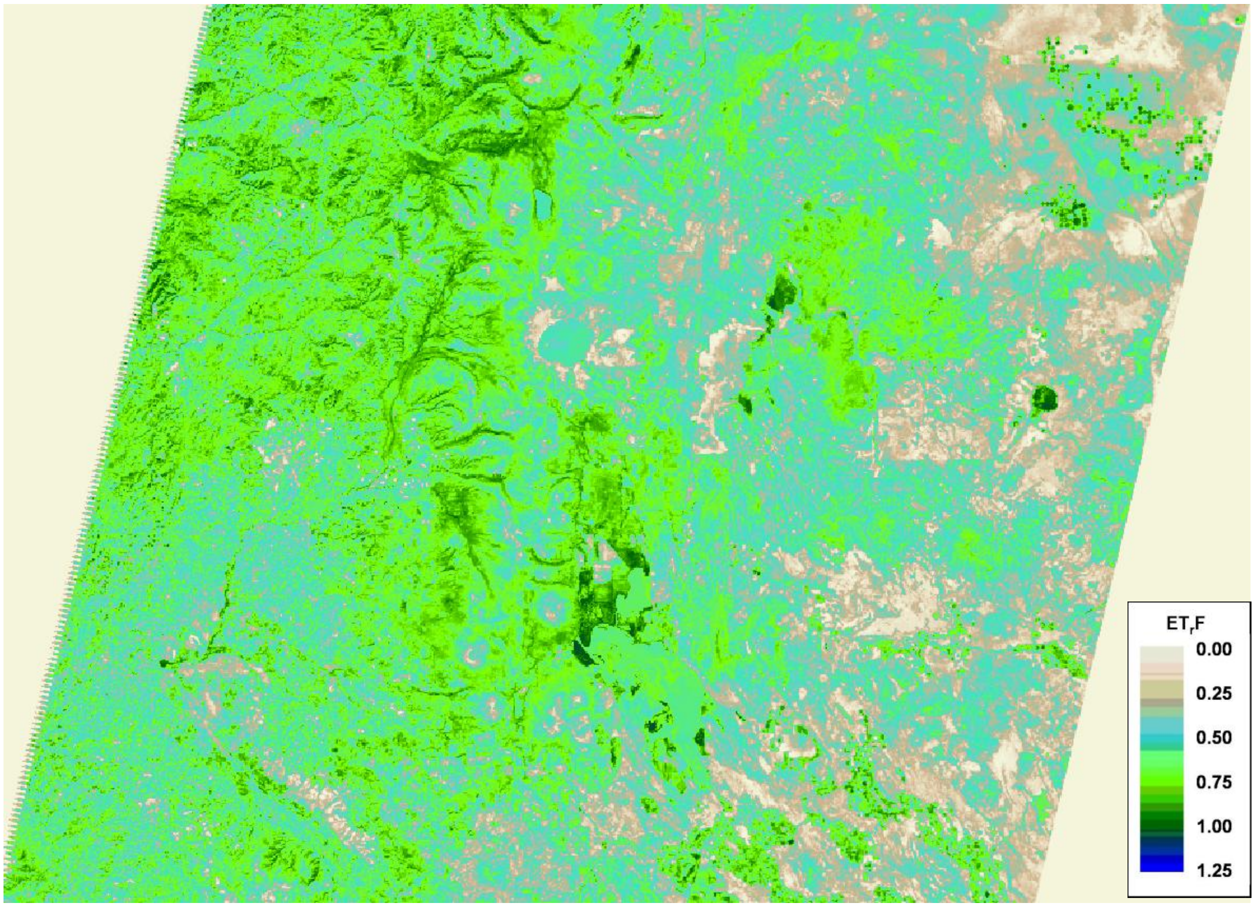

Figure 24. Average ETrF map for August 2004

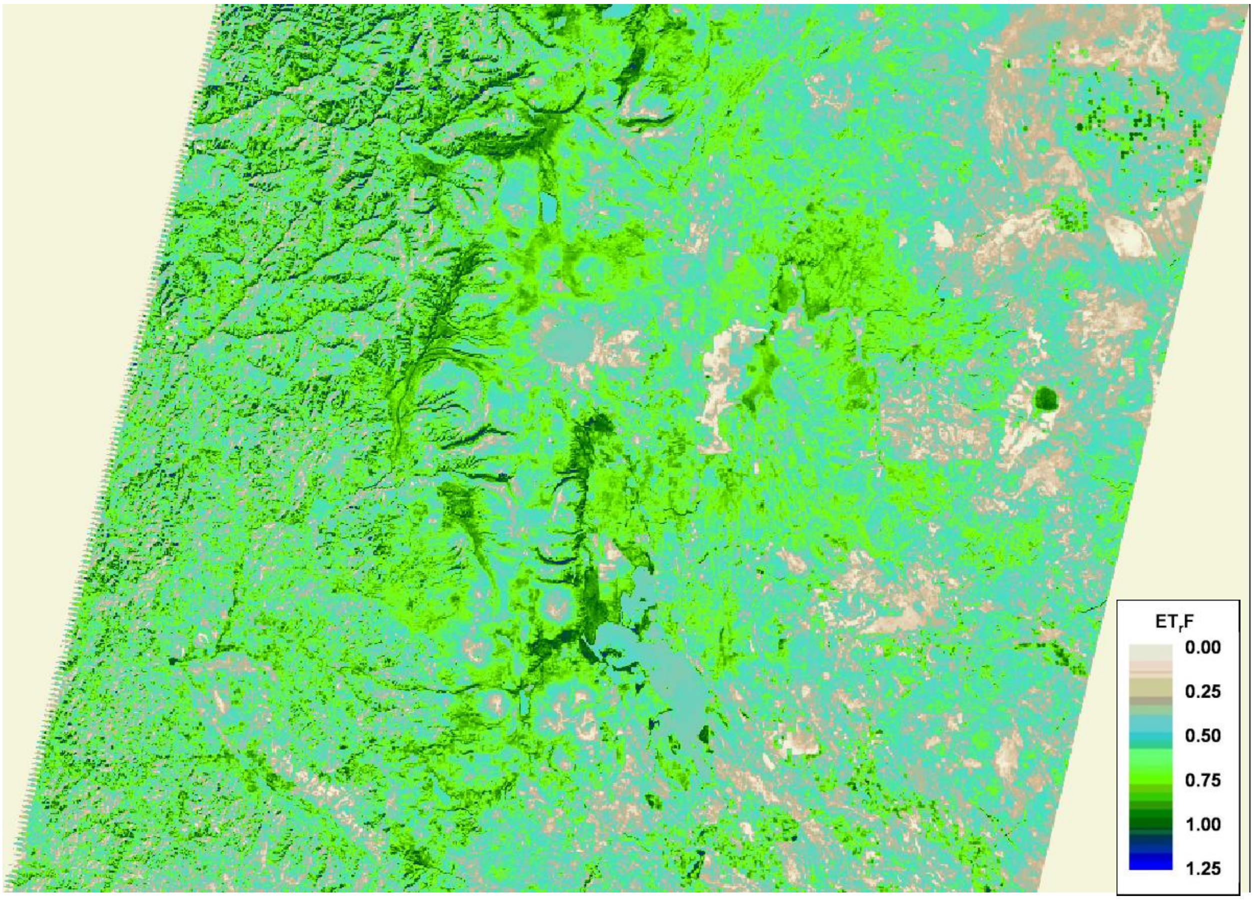

Figure 25. Average ETrF map for September 2004

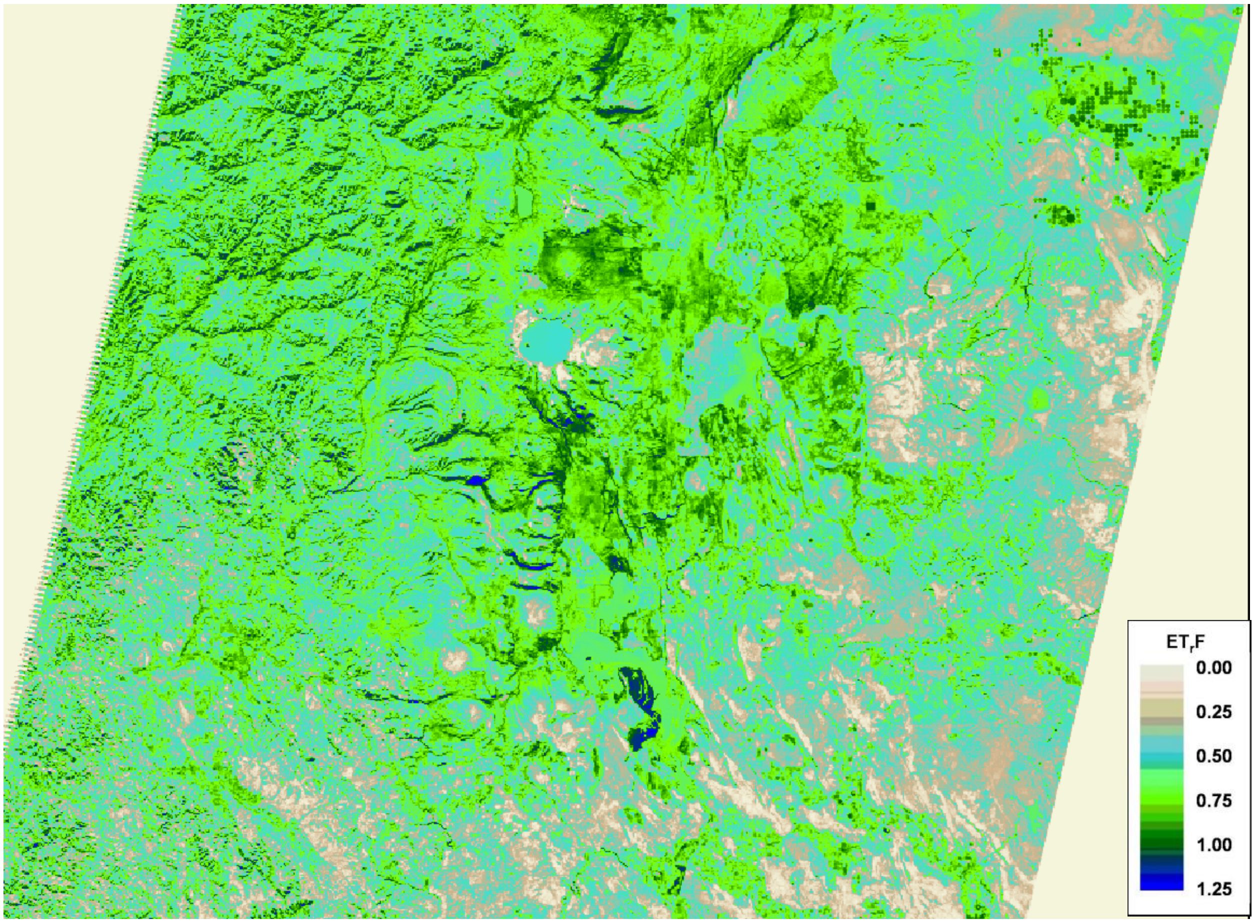

Figure 26. Average ETrF map for October 2004

Seasonal ET and ETrF

Seasonal ET from April to October 2004 was calculated by summing ET from each month. Finally an average ETrF map was generated by dividing the seasonal ET by the total ETr for the same period. The average seasonal ETrF map is shown in Figure 27. A close up of seasonal ETrF is shown in Figure 28 for the Sprague River area and in Figure 29 for the Klamath Falls area.

Total ET from nonirrigated areas, as computed by the METRIC process, was generally in the range of annual precipitation. Table 4 is a summary of ranges of ET estimated from METRIC for nonirrigated areas near noted weather station locations. April-October 2004 ET is compared to precipitation from January-December, 2004. The annual period was summed to consider winter precipitation that may have been stored in soil. ET ranged considerable due to land use type. Some error in both growing season ET and precipitation exists, with the former occurring during temporal interpolation between satellite images and the latter occurring from spatial interpolation.

Table 4. Ranges of ET estimated from METRIC for nonirrigated areas near noted locations during 2004.

Location	ET range, mm during April-October	Precipitation, mm during January-December
Christmas Valley	180 – 300	280
Mountains in NW Image	400 – 800	1400
Timbered areas west of Crater Lake	600 – 900	1250
West of Agency Lake	250 – 500	550
Upper Sprague basin	150 – 500	300 - 450
South of Klamath	100 – 400	350

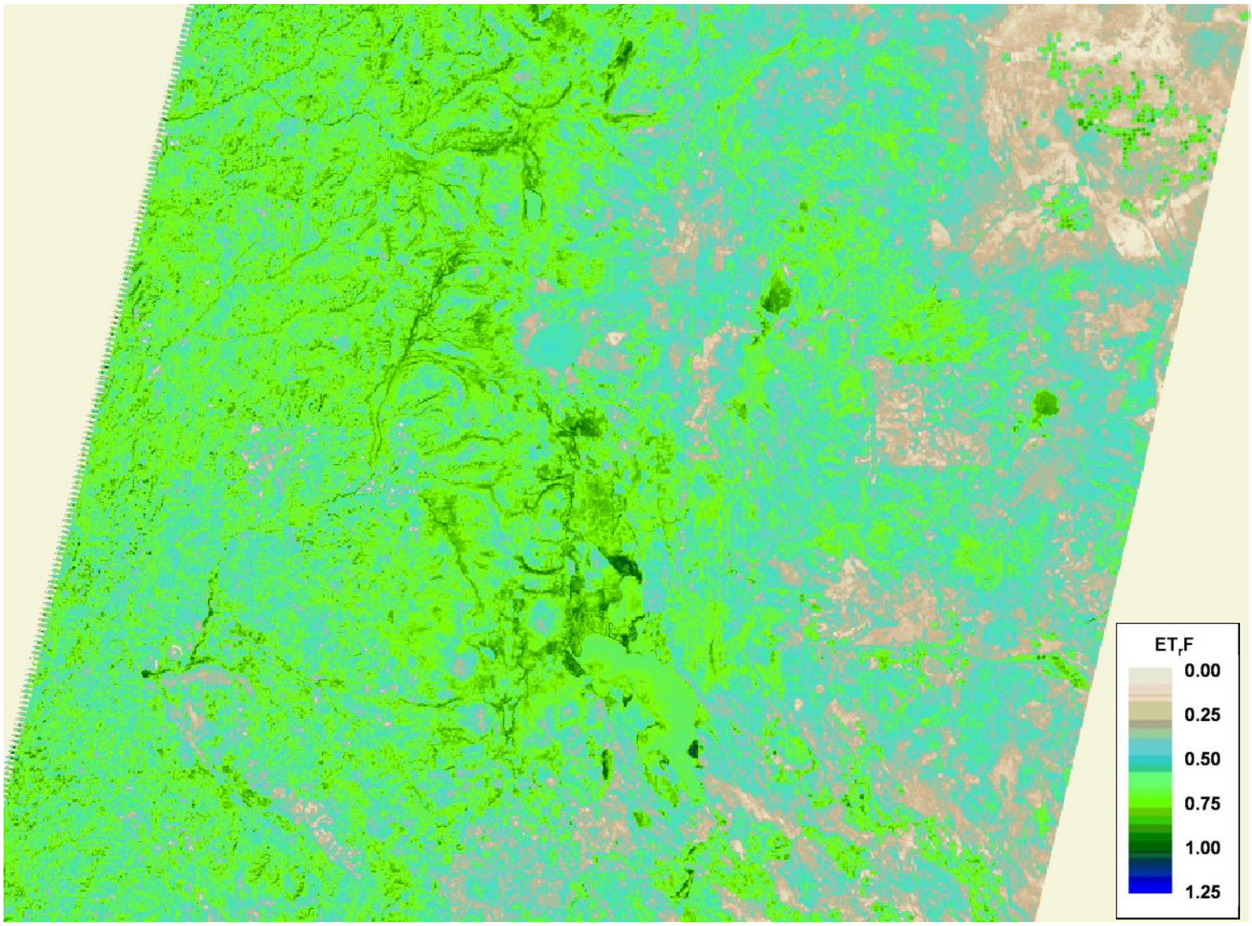

Figure 27. Average seasonal ETrF map for the period between April to October 2004

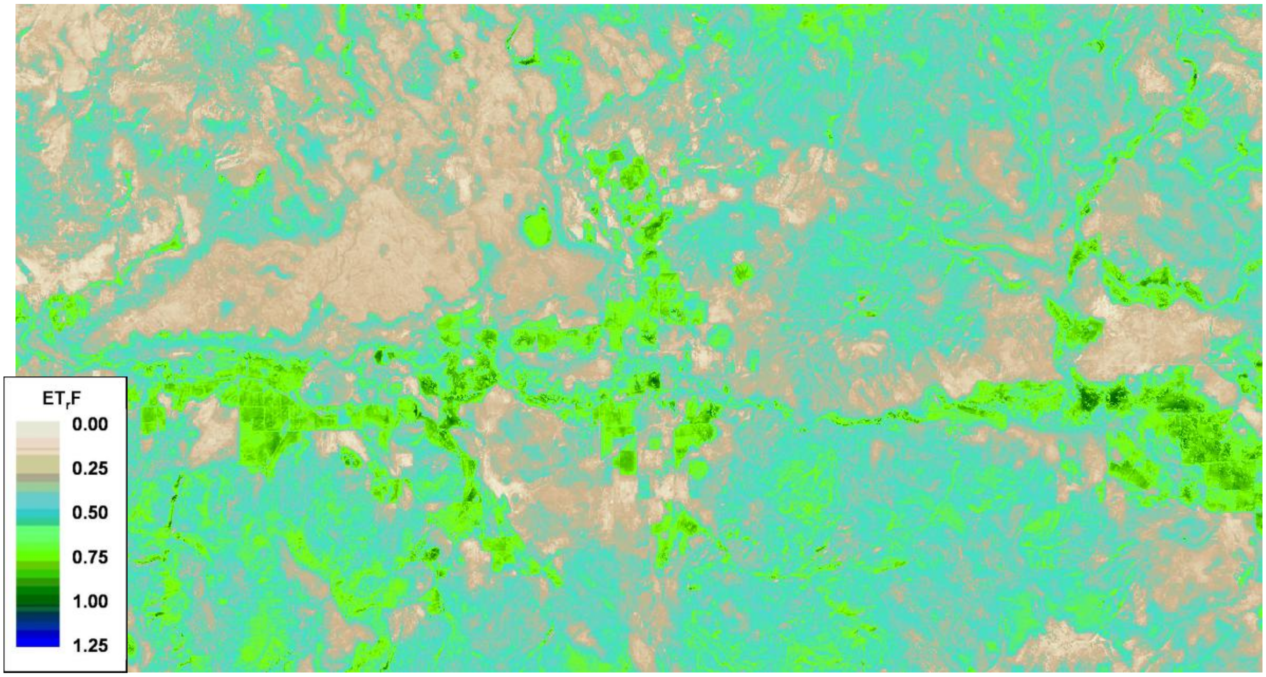

Fig. 28. Close up of average seasonal ETrF for the period April-October in the Sprague River area for 2004.

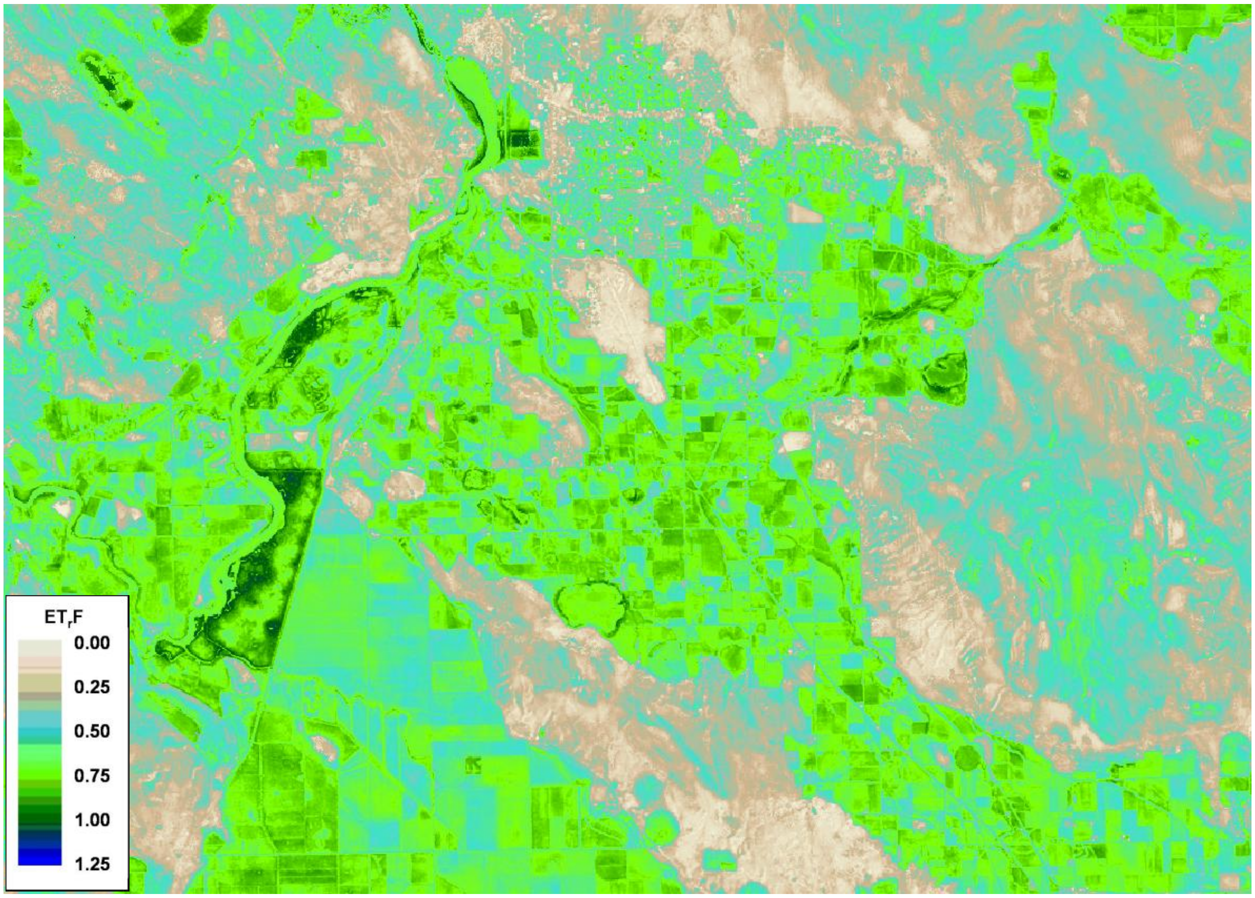

Fig. 29. Close up of average seasonal ETrF for the period April-October near Klamath Falls, 2004.

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Appendix A. Descriptions of weather stations within the project area

On November 13 - 16, 2010, Rick Allen, Ricardo Trezza and Eric Kra toured the upper Klamath and Sprague River basins to review general land-use and agricultural production conditions and to review Agrimet weather stations. Of the 12 Agrimet stations used to estimate reference ETr (Table A-1 below), the Klamath Falls, Beatty, Lakeview, Lorella and Medford stations were visited. We were unable to reach the Agency Lake site due to locked access.

Table A-1. Agrimet stations used to calculate daily reference ET during 2004 and 2006, including daily ETr surfaces for use during splining and integrating METRIC ET over monthly periods.

Station	**State**	**Latitude, dec.**	**Longitude, dec.**	**Latitude**	**Longitude**	**Elevation, ft**
Christmas_Valley	OR	43.24139	120.728	43° 14' 29"	120° 43' 41"	4305
Agency_Lake	OR	42.56528	121.983	42° 33' 55"	121° 58' 57"	4150
Beatty	OR	42.47806	121.274	42° 28' 41"	121° 16' 26"	4320
Lakeview	OR	42.12222	120.523	42° 07' 20"	120° 31' 23"	4770
Lorella	OR	42.07778	121.224	42° 04' 40"	121° 13' 27"	4160
Klamath_Falls	OR	42.16472	121.755	42° 09' 53"	121° 45' 18"	4100
Worden	OR	42.0125	121.788	42° 00' 45"	121° 47' 15"	4080
Medford	OR	42.33111	122.938	42° 19' 52"	122° 56' 16"	1340
Cedarville	CA	41.58528	120.171	41° 35' 07"	120° 10' 17"	4600
Powell_Butte	OR	44.24833	-120.95	44° 14' 54"	120° 56' 59"	3200
Hills_Creek_Dam	OR	43.70972	122.421	43° 42' 35"	122° 25' 17"	1560
Lookout_Point_Dam	OR	43.91556	122.752	43° 54' 56"	122° 45' 08"	940

Klamath Falls Agrimet

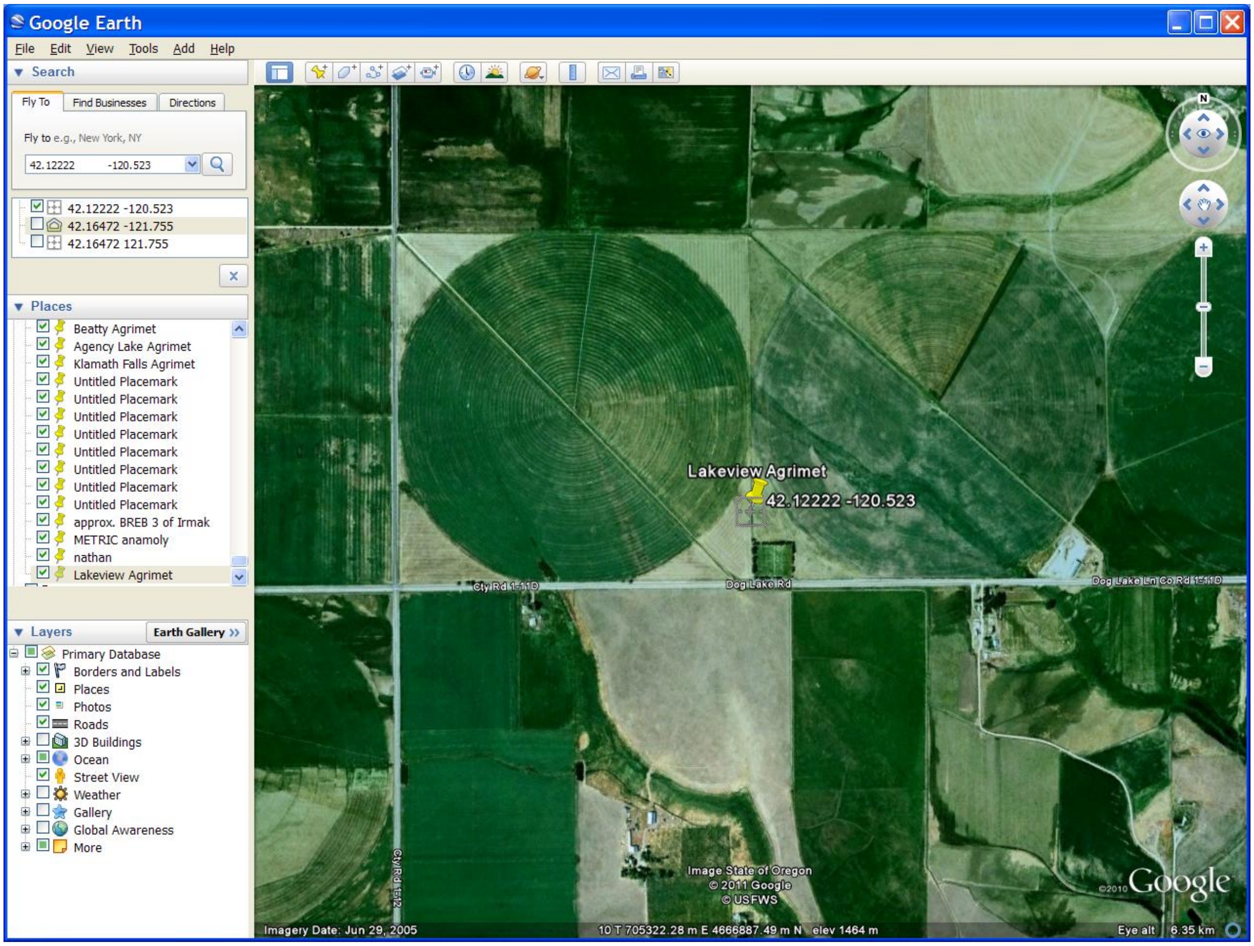
The Klamath Falls Agrimet weather station is located at the Oregon State University Research Center south of Klamath Falls. The area is mostly agricultural with some residential and industrial development. Windbreaks to the south and west of the station may impact air flow at times, as might proximity of research buildings to the weather station.


Klamath Falls Agrimet from the hiway, looking SW


Closeup of Klamath Falls Agrimet looking SW.

Lakeview Agrimet

The Lakeview Agrimet station is located near two center pivots and north of an irrigated cemetery. The very local landcover is dry grass, however, fetch is predominately irrigated.



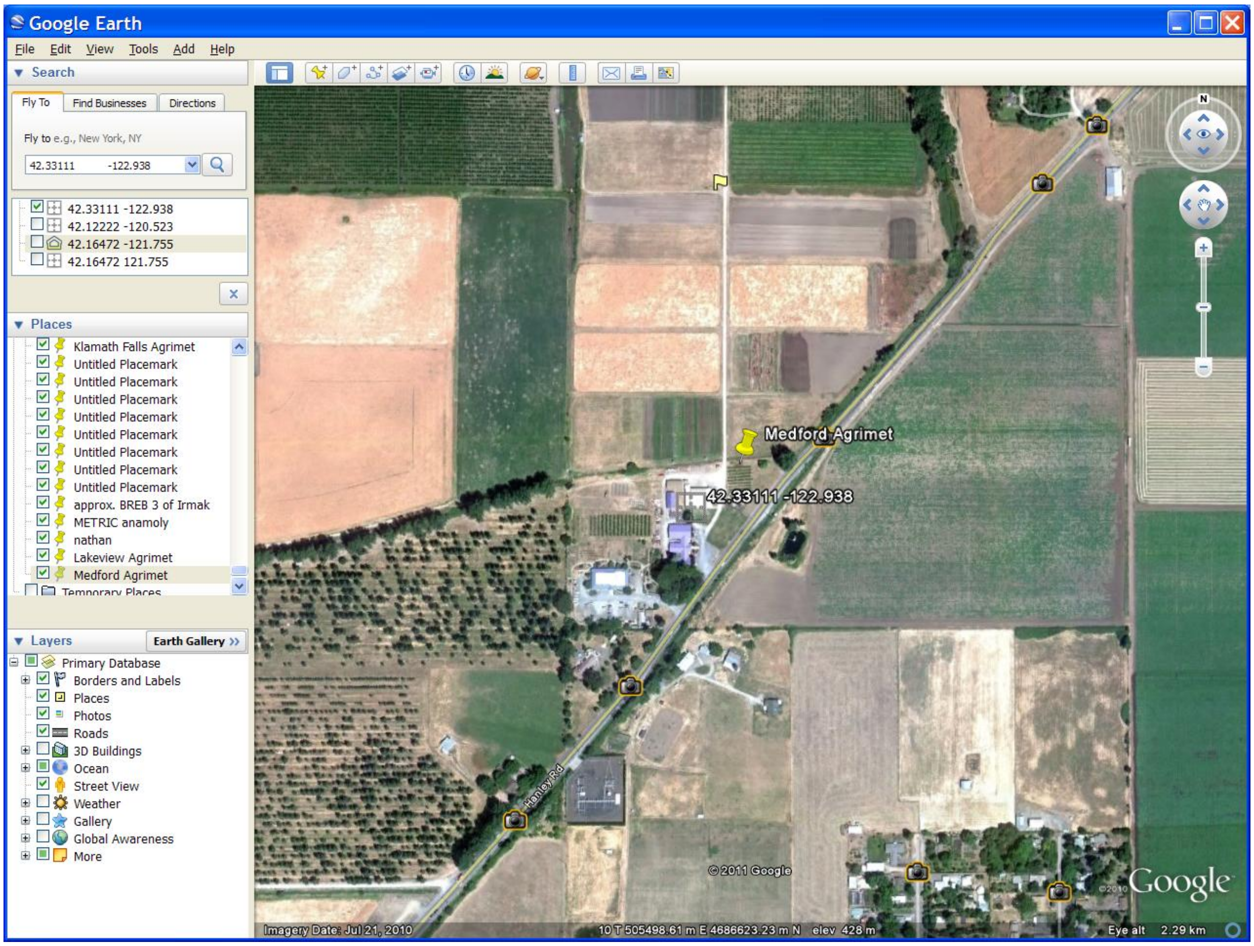
Lakeview Agrimet looking NW

Lakeview Agrimet looking NW, with Allen


Closeup of Lakeview Agrimet station

Medford Agrimet Station

The Medford Agrimet station is located at the Oregon State University Research Center west of Medford. The area is partially agricultural with some residential and industrial development. The station itself is located just north of research buildings and just north of a small grapevine study. The area to the north and east is mostly open. The buildings to the south and the grapevines probably impact air flow at times. It would be helpful on all Agrimet stations if anemometers were set at 3 m height above ground rather than the current 2 m height.




Medford Agrimet station with Trezza and Allen

Medford Agrimet Station looking East

Medford Agrimet Station looking North.

Appendx B
Generation of Precipitation and Reference ETr surfaces

Daily precipitation surfaces were created using precipitation (P) information from 45 COOP stations and 7 Agrimet stations located within and adjacent to the scene processed. Data for COOP stations were downloaded from the NOAA National Climatic Data Center (NCDC) web site. Agrimet data were obtained from the USBR Agrimet web site. A shapefile indicating the COOP and Agrimet station locations was created and is available. An Inverse Distance Weighting function was used for the interpolation of P and ETr, which can create some discontinuities and some 'bulls eyes' around stations having higher or lower readings as compared to surrounding stations (figure B1). This is mostly an artifact from the interpolation method. Towards the center of the image is Crater Lake, where there is a COOP station on the mountain (Crater Lake is a lake inside a volcano) and the mountain receives substantially more P as compared to the surrounding areas.

The ETr surfaces are based on 9 (2004) or 10 (2006) Agrimet weather stations. We used a spline interpolation for the ETr surfaces where we increased the tension setting in Arc to 10 to prevent the spline from increasing ETr beyond reasonable values for areas in between weather stations. The process created an ERDAS file for each day of 2004 and 2006, and stacks of daily files by month and the monthly and seasonal sums, all in units of mm.

The COOP station P data were adjusted for the time-of-day (usually 7 am) of readings, so that if the precipitation was recorded before noon, we moved the data to the previous day, while if the precip was recorded after noon, we did not move it. For this reason, there is sometimes a one day 'shift' in precip between nearby stations, so that one station may have recorded say 10 mm one day and nothing on the next, while a neighboring station is the opposite. Later, in the process of adjusting the image date ETrF from METRIC for background evaporation, we therefore typically take the average of three days when estimating what the ETrF was at the satellite overpass date. The P surfaces have one file for each day of 2004 and 2006, and stacks by month and the seasonal sum, all in units of mm. At this point, the gridded precipitation data have not been used. They were assembled in case a gridded evaporation process model would have been needed to estimate total evaporation over monthly periods from bare soil conditions, to use to adjust Landsat images for background evaporation differences between image dates and surrounding monthly periods. However, review of ET data from METRIC did not indicate the need to make this adjustment. STATSGO soil maps for Oregon and California, and the derived water content at 15 bars and 1/3 bar, available water capacity and soil texture for Oregon in were assembled, but again, not required. Other input to the soil water balance model, included TEW (total evaporable water), REW (relative extractable water), initial depletion of the evaporation layer (De_initial) and effective precipitation (P_eff) defined as gross reported precipitation less estimated surface runoff.

The following two figures (figs. B1 and B2) show gridded precipitation summed over January – December 2004 for an area slightly larger than the processed image area and gridded reference ET summed for the April – October 2004 period for the nearly the same area.

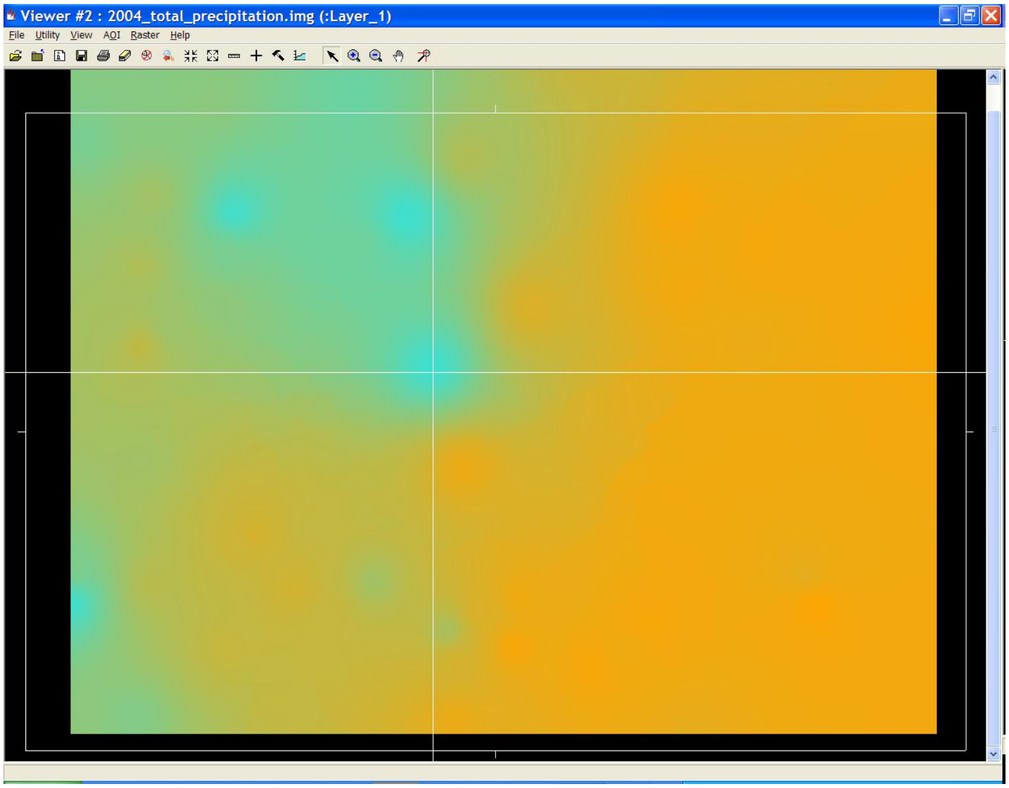


Fig. B1. Interpolation of total January – December, 2004 precipitation over the study area, with orange at 200 mm to blue at 1450 mm. The cross hair is centered over Crater Lake.

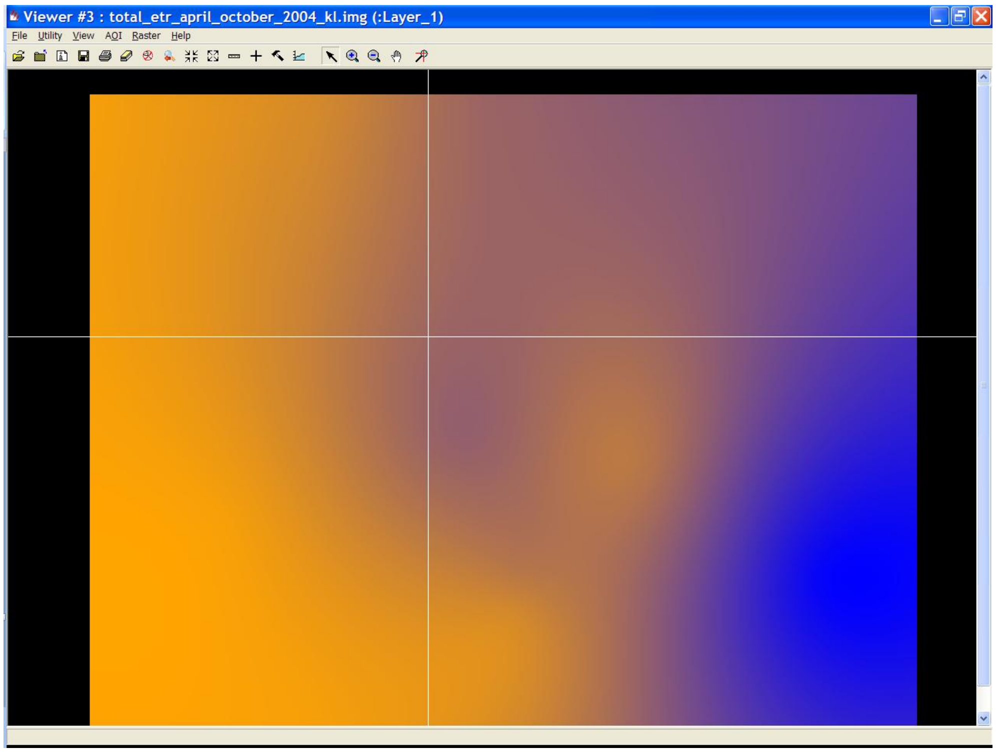


Fig. B2. Interpolation of total Alfalfa reference ETr from April to October, 2004 over the study area, with orange at 980 mm to blue at 1250 mm

Appendix C. Description of Products Produced during METRIC processing for Klamath, Oregon, Year 2004 and Provided to the USGS
March 2011

All spatial data files are presented in ERDAS Imagine data format (*.img). This format is a raster format that can contain multiple layers. Data are generally in 'float' (real) value expressions (including all images using mm depths and all ETrF), but some are expressed in integer form (DEM). The Imagine formatted files are readily read by all modern Arc-GIS systems. For some images, including the monthly ET and ETrF files, the data have been 'colorized' to display in ERDAS imagine in color. This helps with visualization to the person viewing the data, but do not impact the data themselves. The colorization may not transfer into the Arc-GIS system. The colorization is viewed in ERDAS by opening the files in 'pseudo color' mode. Each "img" file is accompanied by an 'rrd' file that is generated by ERDAS to facilitate rapid zooming and statistics. The rrd files are not important to Arc-GIS usage.

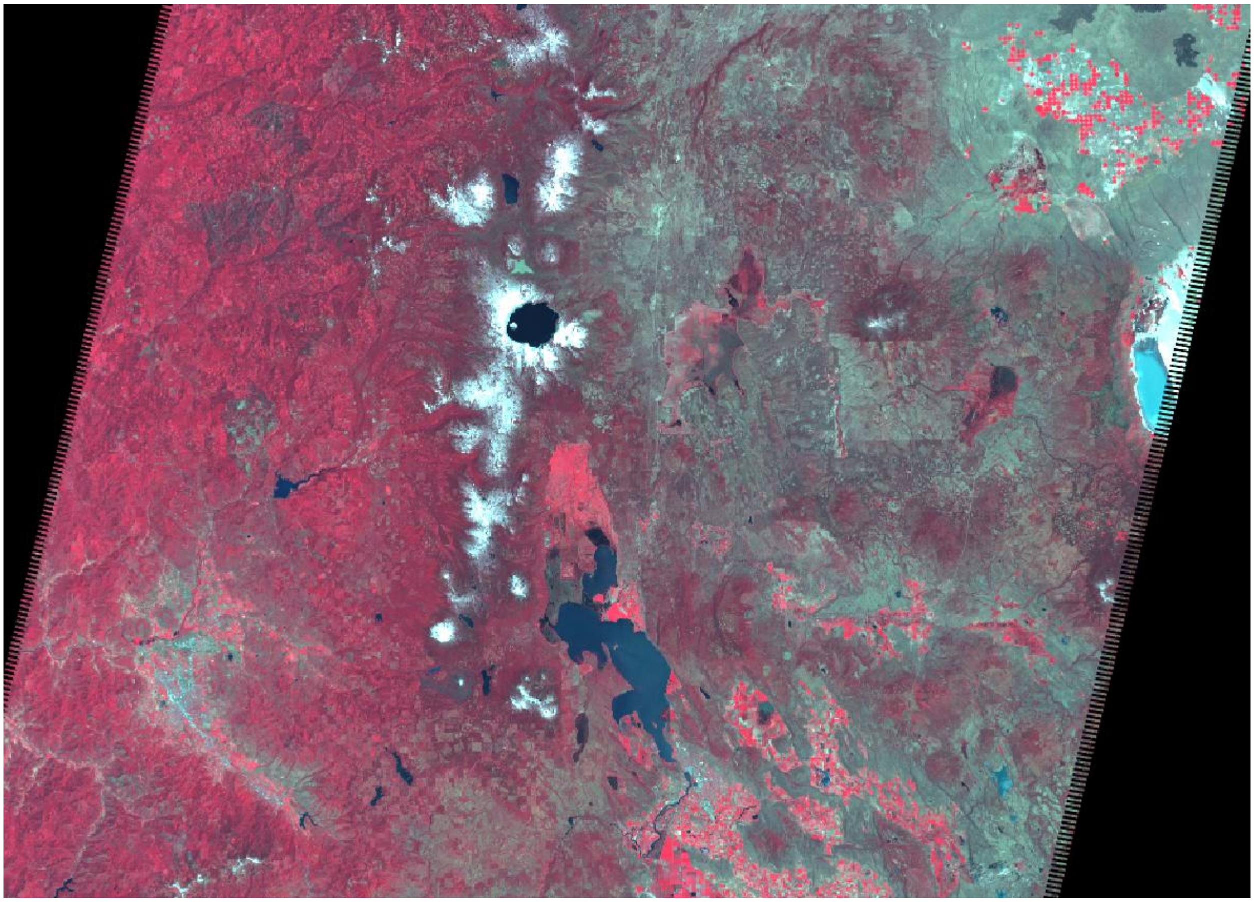
Folder: Landsat Images

This folder contains the original Landsat images(8 bit digital numbers (DN) (0-255)) used during METRIC processing. Each image is comprised of seven layers, where Layer 1 = Landsat Band 1; Layer 2 = Landsat Band 2; Layer 3 = Landsat Band 3; Layer 4 = Landsat Band 4; Layer 5 = Landsat Band 5; Layer 6 = Landsat Band 6 (thermal band); Layer 7 = Landsat Band 7.

Image Name	**Units**	**Description**
erosl1t_04302004_p45r30_l5_kl.img	DN	Landsat 5 image corresponding to 04/30/2004
erosl1t_06012004_p45r30_l5_kl.img	DN	Landsat 5 image corresponding to 06/01/2004
erosl1t_06172004_p45r30_l5_kl.img	DN	Landsat 5 image corresponding to 06/17/2004
erosl1t_07112004_p45r30_l7_kl.img	DN	Landsat 7 image corresponding to 07/11/2004
erosl1t_08042004_p45r30_l5_kl.img	DN	Landsat 5 image corresponding to 08/04/2004
erosl1t_08202004_p45r30_l5_kl.img	DN	Landsat 5 image corresponding to 08/20/2004
erosl1t_09212004_p45r30_l5_kl.img	DN	Landsat 5 image corresponding to 09/21/2004
erosl1t_10072004_p45r30_l5_kl.img	DN	Landsat 5 image corresponding to 10/07/2004
erosl1t_11082004_p45r30_l5_kl.img	DN	Landsat 5 image corresponding to 11/08/2004

The naming convention is "L1t" = level 1, terrain corrected, followed by MMDDYYYY for the date, followed by the path and center row, followed by the satellite type (Landsat 5 or 7), "_kl" for Klamath.

All of the images correspond to Landsat World Reference System (WRS) path 45, comprised mainly of row 30, plus some portions of row 31 residing north of the Oregon-California state line, as shown in the following figure. Spatial resolution of pixels is 30 m for all bands. However, original resolution of Landsat 5 band 6 (the thermal band) was 120 m and of Landsat 7 was 60 m. These bands were resampled, however, using cubic convolution, by the USGS EROS data center prior to dissemination.



The following table shows the seven bands and their wavelength range from each satellite.

Band Number	Original resolution (m)	Landsat 5 wavelength (µm)	Landsat 7 wavelength (µm)
B1 (blue)	30	0.452 – 0.518	0.452 – 0.514
B2 (green)	30	0.528 – 0.609	0.519 – 0.601
B3 (red)	30	0.626 – 0.693	0.631 – 0.692
B4 (NIR)	30	0.776 – 0.904	0.772 – 0.898
B5 (MIR)	30	1.567 – 1.784	1.547 – 1.748
B6 (thermal,TIR)	60 (LS7), 120 (LS5)	10.45 – 12.42	10.31 – 12.36
B7 (MIR)	30	2.097 – 2.349	2.065 – 2.346
B8 (panchromatic)*	10 (LS7 only)	NA	0.515 – 0.896

*Not used for ET and ETrF map generation.

Folder: landuse map

This folder contains the landuse map used for METRIC processing. The map was derived from the USGS NLCD (National Land Cover Database) Land Use map, and it was downloaded from the USGS-seamless webpage (http://seamless.usgs.gov/). The NLCD map is primarily used during determination of aerodynamic roughness values.

Image Name	**Description**
land_use_kl.img	Land use map

Folder: DEM

This folder contains the DEM map used for METRIC processing. The map was downloaded from the USGS-seamless webpage (http://seamless.usgs.gov/) and has 30 m resolution.

Image Name	**Description**
dem_kl.img	Map of pixel elevation, in meters.

Folder: daily_etrf_maps

This folder contains the daily images produced from METRIC and represents the ET estimate for each Landsat image date. The pixel values represent the ratio (ETrF) between actual evapotranspiration (ET) and alfalfa-reference evapotranspiration (ETr). A value of ETrF=0.6 means that ET is 60% of ETr. “Black” areas in these images are areas that were ‘cloud masked’ to delete those areas that were impacted by cloud cover.

Image Name	**Units**	**Description: ETrF = ET/ETr**
etrf24_04302004_p45r30_l5_kl_masked_color.img	fraction	ETrF map corresponding to 04/30/2004
etrf24_06012004_p45r30_l5_kl_masked_color.img	fraction	ETrF map corresponding to 06/01/2004
etrf24_06172004_p45r30_l5_kl_masked_color.img	fraction	ETrF map corresponding to 06/17/2004
etrf24_07112004_p45r30_l7_kl_masked_color_1.img	fraction	ETrF map corresponding to 07/11/2004
etrf24_08042004_p45r30_l5_kl_masked_color.img	fraction	ETrF map corresponding to 08/04/2004
etrf24_08202004_p45r30_l5_kl_masked_color.img	fraction	ETrF map corresponding to

		08/20/2004
etrf24_09212004_p45r30_l5_kl_masked_color.img	fraction	ETrF map corresponding to 09/21/2004
etrf24_10072004_p45r30_l5_kl_masked_color_1.img	fraction	ETrF map corresponding to 10/07/2004
etrf24_11082004_p45r30_l5_kl_masked_color.img	fraction	ETrF map corresponding to 11/08/2004

The naming convention is ETrF24 followed by the date expressed as MMDDYYYY, followed by the path row and satellite number.

Folder: monthly_et_maps

This folder contains the monthly ET maps (in millimeters) for every month, from April to October 2004. For example, a pixel value = 120 means that a total 120 mm of ET was calculated for that particular pixel for that particular month.

Image Name	**Units**	**Description**
et_april2004_kl.img	millimeters	Total ET in millimeters for April 2004
et_may2004_kl.img	millimeters	Total ET in millimeters for May 2004
et_june2004_kl.img	millimeters	Total ET in millimeters for June 2004
et_july2004_kl.img	millimeters	Total ET in millimeters for July 2004
et_august2004_kl.img	millimeters	Total ET in millimeters for August 2004
et_september2004_kl.img	millimeters	Total ET in millimeters for September 2004
et_october2004_kl.img	millimeters	Total ET in millimeters for October 2004

Folder: monthly_etrf_maps

This folder contains the average ETrF for every month, from April to October 2004. This average ETrF was obtained dividing the total ET by the total ETr for a particular month. The "monthly" average ETrF" was produced from the image date-specific ETrF by splining ETrF between image dates for each day between the images, multiplying by ETr of each day, summing the ET product over a month to produce the monthly ET in the previous table, and then dividing by monthly summed ETr to obtain a monthly average ETrF. ETr data were calculated using the University of Idaho REF-ET software using meteorological weather parameters from six Agrimet weather stations in the study area following extensive quality assessment/quality control. The standardized ASCE-EWRI (2005) Penman-Monteith reference ET equation for the tall alfalfa reference type was used.

Image Name	**Units**	**Description**
etrf_april2004_kl.img	fraction	Average ETrF for April 2004
etrf_may2004_kl.img	fraction	Average ETrF for May 2004
etrf_june2004_kl.img	fraction	Average ETrF for June 2004
etrf_july2004_kl.img	fraction	Average ETrF for July 2004
etrf_august2004_kl.img	fraction	Average ETrF for August 2004
etrf_september2004_kl.img	fraction	Average ETrF for September 2004
etrf_october2004_kl.img	fraction	Average ETrF for October 2004

Folder: seasonal_et_map

This folder contains the total ET maps (in millimeters) for the period between April to October 2004.

Image Name	Units	Description
total_et_april_october_2004_kl.img	millimeters	Total ET in millimeters for the period between April to October 2004

Folder: seasonal_etrf_map

This folder contains the average ETrF from April to October 2004. This average ETrF was obtained by dividing the total seasonal ET (from April to October) by the total seasonal ETr (from April to October).

Image Name	Units	Description
average_etrf_april_october_2004_kl_color.img	fraction	Average ETrF fraction for the period between April to October 2004

Folder: number of images with clouds

This folder contains an integer map that summarizes the number of images that a given pixel was cloudy. For example a number = 3 means that in 3 out of the 9 images (9 images were the total of images used) were cloudy for that specific pixel. This number can be taken as an indication of relatively uncertainty of the reported value on the seasonal ET map. The actual image dates having clouds can be determined by viewing each individual daily ETrF image file.

Image Name	Description
number_images_with_clouds_2004_kl.img	Number of cloudy images

Folder: Etr_maps

This folder contains the total alfalfa-reference evapotranspiration (ETr) maps for every month in 2004 and seasonal total April to October. ETr is expressed in millimeters.

Folder: RefET_results

This folder contains output results, generally for daily timesteps for ETr data calculated using the University of Idaho REF-ET software using meteorological weather parameters from six Agrimet weather stations in the study area following extensive quality assessment/quality control. The standardized ASCE-EWRI (2005) Penman-Monteith reference ET equation for the tall alfalfa reference type was used.