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14. ABSTRACT

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Report Title

REMOTE SATELLITE SOIL MOISTURE MAPPING FOR THE ERDC COUNTERMINE SIMULATION TEST BED

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List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Number of Papers published in peer-reviewed journals: 0.00

(b) Papers published in non-peer-reviewed journals or in conference proceedings (N/A for none)

Number of Papers published in non peer-reviewed journals: 0.00

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Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts): 0

Peer-Reviewed Conference Proceeding publications (other than abstracts):

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(d) Manuscripts

Number of Manuscripts: 0.00

Number of Inventions:

Graduate Students

NAME	PERCENT_SUPPORTED
Frank Gambardella	0.25
FTE Equivalent:	**0.25**
Total Number:	**1**

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
Matthias Falk	0.30
FTE Equivalent:	**0.30**
Total Number:	**1**

Names of Faculty Supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

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Names of Personnel receiving masters degrees

NAME
Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED	
Graciela Hendrickx-Rodriguez	0.04	No
FTE Equivalent:	**0.04**	
Total Number:	**1**	

Sub Contractors (DD882)

Inventions (DD882)

REMOTE SATELLITE SOIL MOISTURE MAPPING FOR THE ERDC COUNTERMINE SIMULATION TEST BED

A STIR Project funded by
Terrestrial Sciences at the Army Research Office

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March 2010

REMOTE SATELLITE SOIL MOISTURE MAPPING
FOR THE ERDC COUNTERMINE SIMULATION TEST BED
Final Report, February 2010

ABSTRACT

The Countermine Simulation Test Bed needs reliable initial conditions on short notice from denied areas. The most important initial conditions are soil moisture and soil temperature. Our research on remote satellite soil moisture mapping for the ERDC Countermine Simulation Test Bed has proved the concept that soil moisture maps with a resolution of 30 m can be produced in Afghanistan from operational Landsat images. Soil and canopy temperature are determined by the incoming global radiation. Our research on remote satellite global radiation mapping for the ERDC Countermine Simulation Test Bed has proved the concept that global radiation maps with a resolution of 2 km can be produced in Afghanistan from operational METEOSAT images. In addition, our research has shown that soil moisture conditions are strongly correlated to the digital values of Landsat Bands 1-4. Therefore, there is a high likelihood that a Landsat soil moisture map with resolution of 30 m can be downscaled to 2.7 using QuickBird Bands 104. Two research needs are identified: 1. Validation of the Landsat soil moisture product on roads and in river beds, deserts, riparian areas and forests; 2. Development of a reliable downscaling procedure for Landsat soil moisture maps (30 m) to Quickbird maps (2.7 m).

RESEARCH OBJECTIVES

The research objectives for this project were as follows:

1. Use the METRIC approach on two clear days for the preparation of two soil moisture maps of an area in Afghanistan chosen by ERDC. In addition, maps will be prepared of all components of the energy balance (latent and sensible heat fluxes, soil heat flux, net radiation and its four components) as well as land surface temperature, albedo, and NDVI. This objective serves to "proof the concept" of using the METRIC approach for operational army use in Afghanistan.
2. Install an automatic weather station in the Middle Rio Grande Valley to validate all ground measurements that are taken under similar conditions in New Mexico for validation of the remote sensing algorithms.
3. Test and validate existing algorithms that derive global incoming radiation under cloudy and partially cloudy conditions from GOES and METEOSAT images. This objective serves to "proof the concept" of using GOES and METEOSAT images for quantification of hourly energy input to the land surface under all weather conditions (clear, cloudy, partially cloudy) to constrain the model runs with the Countermine Simulation Testbed. Validation radiation measurements from Afghanistan (METEOSAT 8 or 7), Suriname (METEOSAT 8 or GOES), Panama (GOES), and New Mexico (GOES) will be used for this objective. The sites in Suriname and Panama are Yuma Proving Grounds sites.

RESEARCH RESULTS

The research results will be discussed with reference to each objective. Due to logistical constrains some of the objectives had to be modified but the overall effort was not compromised. We will present the "proofs of concept" for remote satellite soil moisture mapping using Landsat imagery with the METRIC approach in Helmand Province of Afghanistan and for remote satellite quantification of regional distributions of incoming solar radiation using GOES and METEOSAT imagery over, respectively, New Mexico and Afghanistan under all weather conditions (clear, cloudy, partially cloudy). Our research results clearly demonstrate the great potential of optical imagery (Landsat, MODIS, GOES, METEOSAT, QUICKBIRD and other platforms) for reliably initializing and constraining model runs with the Countermine Simulation Test Bed.

Objective I. Use the METRIC approach for the preparation of soil moisture maps in Afghanistan.
We have prepared two soil moisture maps: one from a Landsat5 image (Path 155, Row 038) of October 15, 2000, and one from a Landsat7 Image (Path 155, Row 038) of April 23, 2009. The latter soil moisture map with a spatial resolution of 30 m has been downscaled to a soil moisture map with 2.7 m resolution using a QuickBird image of April 24, 2009, that was kindly made available to us by the Topographic Engineering Center.

We will shortly discuss the METRIC application on the Landsat7 image of April 23, 2009, and the Quickbird image of April 24, 2009, covering a typical area in Helmand Province, Afghanistan (Figs. 1 and 2). Since the images are only one day apart, we assume that soil moisture conditions are the same except perhaps for a few fields that received irrigation water between Landsat and Quickbird overpasses.

The Landsat image was analyzed for the retrieval of the energy balance and root zone soil moisture in each 30×30 m pixel. METRIC uses all seven bands of Landsat and needs at least one thermal band. The METRIC root zone soil moisture map is shown in Fig. 5. Similar soil moisture maps have been validated quantitatively (Ahmad and Bastiaanssen, 2003; Bastiaanssen et al., 2000; Fleming et al., 2005; Hendrickx et al., 2006; Scott et al., 2003).

METRIC cannot be used with QuickBird images because QuickBird doesn't have a thermal band. QuickBird has four bands that are identical to Bands 1-4 of Landsat. These bands are in the visual and near-infrared wavelengths. The pixel size (2.7 m) of QuickBird is about one order of magnitude smaller than Landsat pixels (30 m). Therefore, we wanted to investigate whether the METRIC root zone soil moisture map at 30 m resolution can be downscaled to 2.7 m resolution using QuickBird images since m-scale resolution is critical for the optimal use of the Countermine Simulation Testbed.

First we checked whether there exists a significant linear regression between Landsat Bands 1-4 and Landsat root zone soil moisture. Figure 3 shows that a highly significant relationship does exist between Landsat Bands 1-4 and Landsat root zone soil moisture with R2=0.96. Therefore, we conclude that there is sufficient information in Bands 1-4 to predict root zone soil moisture. In other words, one can predict root zone soil moisture from visible and near-infrared bands without using the thermal band.

Next we determined the linear regression between QuickBird Bands 1-4 and the Landsat soil moisture product. This regression also is highly significant and has R2=0.85. Figure 4 is somewhat misleading; it does show the strong relationship between QuickBird Bands 1-4 and Landsat soil moisture but it also shows several outliers. Here, one has to keep in mind that Figure 4 is based on 33,000 pixels most of which are located in the solid blue areas. The outliers are only a very small percentage of the total number of pixels. The outliers are expected since we regress 2.7 m QuickBird pixels against soil moisture in a 30 m Landsat pixel. Each dry spot of 2.7×2.7 m in a moist 30×30 m Landsat pixel and each wet spot of 2.7×2.7 m in a dry 30×30 m Landsat pixel will become an outlier.

Figures 5 and 6 show the Landsat (30 m) and QuickBird (2.7 m) soil moisture maps side by side. The agreement is quite striking with moist pixels (light blue and green) and dry pixels (red and yellow) located at the same locations on both maps. The QuickBird soil moisture map looks very crisp since it has a resolution of 2.7. However, on the sandbars in the river the QuickBird soil moisture seems to be too low (Figures 7, 8, 9, 10, 11, 12) while on the asphalt road the soil moisture is estimated too high (13, 14, 15, and 16). This is a consequence of not taking into account sufficiently the effect of albedo on the soil moisture prediction. On the sand bars the soils are highly reflective which drives the soil moisture estimate down while on the asphalt road the black color of the asphalt (low reflectivity) drives the soil moisture estimate up.

Overall the QuickBird soil moisture map looks quite good in the areas away from the sand bars and the asphalt road. The downscaling regression breaks down for highly reflective sands and dark asphalt roads. This indicates that the global approach that we took for the downscaling regression from Landsat to QuickBird scale is not correct. Instead, we need to test regressions that are constrained by the true Landsat soil moisture maps either on a pixel by pixel basis or after an unsupervised classification to partition the area in a number of land cover classes that have each their own downscaling regression.

Conclusions:
1. METRIC can be used to prepare root zone soil moisture maps in Afghanistan (Figure 5).
2. METRIC root zone soil moisture based on a Landsat image can be predicted from the visual and near-infrared bands (Landsat bands 1-4) (Figure 3).
3. Using the Landsat regression for prediction of root zone soil moisture from the visual and near-infrared bands of QuickBird yields soil moisture maps of m-scale resolution. However, initial results indicate that one needs to develop a stratification procedure to do the regression.

Research Needs:
1. The METRIC Landsat root zone soil moisture product has been rigorously validated on irrigated fields similar to those found in Helmand Province. However, a validation in riparian area, forests, and deserts still needs to be conducted although visual observations by PI Hendrickx in New Mexico and the Volta Basin in West Africa indicate a high degree of reality.

2. The QuickBird m-scale root zone soil moisture product needs to be validated, especially its reliability on dirt roads or on the tracks next to the dirt roads. Director Bert Davis of the Cold Regions Laboratory emphasized in a February 2010 workshop the importance of better characterizing road and road corridor conditions in Afghanistan.

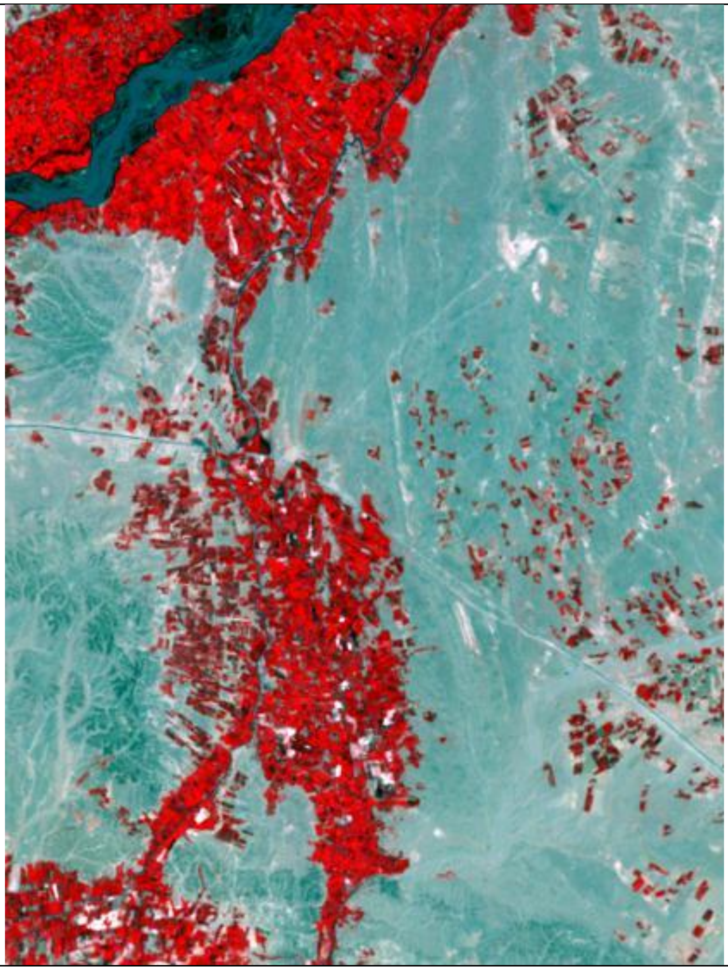


Figure 1. Landsat7 Image on April 23, 2009, in false colors. Vegetation is colored red. Spatial resolution is 30 m pixel size. Image area is about 16x12 km.

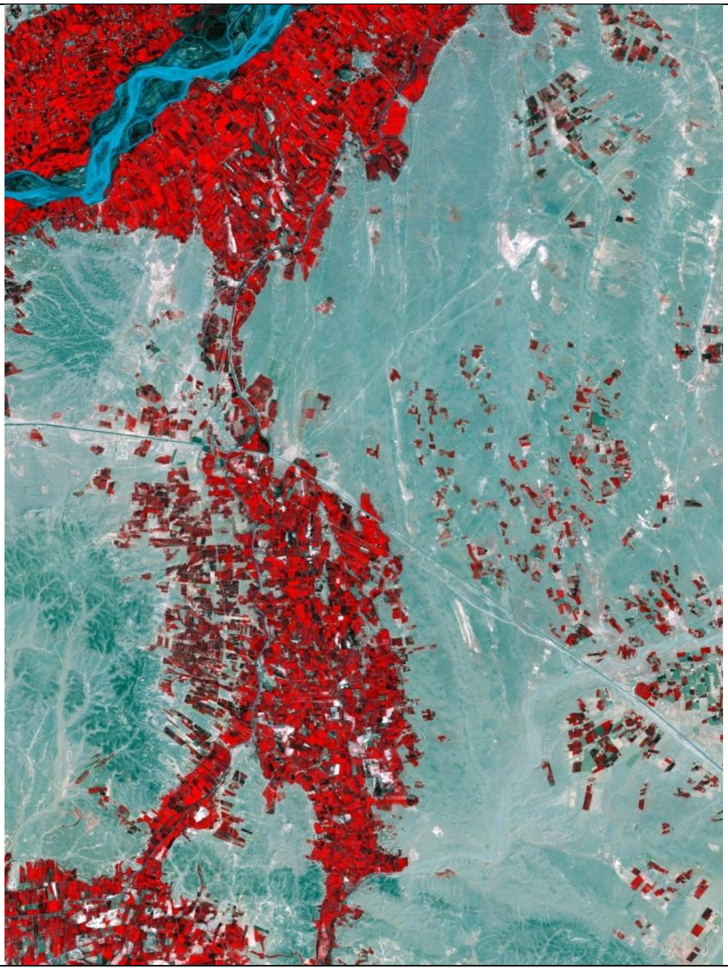


Figure 2. Quickbird Image on April 24, 2009, in false colors. Vegetation is colored red. Spatial resolution is 2.7 m pixel size. Image area is about 16x12 km.

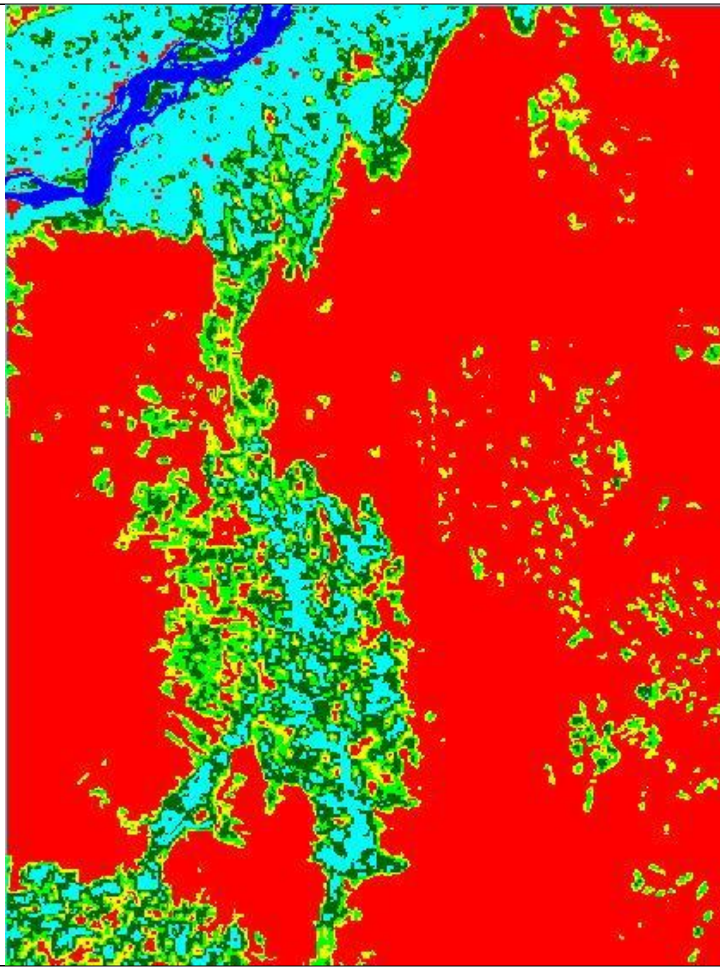


Figure 3. Landsat7 Soil Moisture Map on April 23, 2009. Spatial resolution is 30 m pixel size. Image area is about 16x12 km.

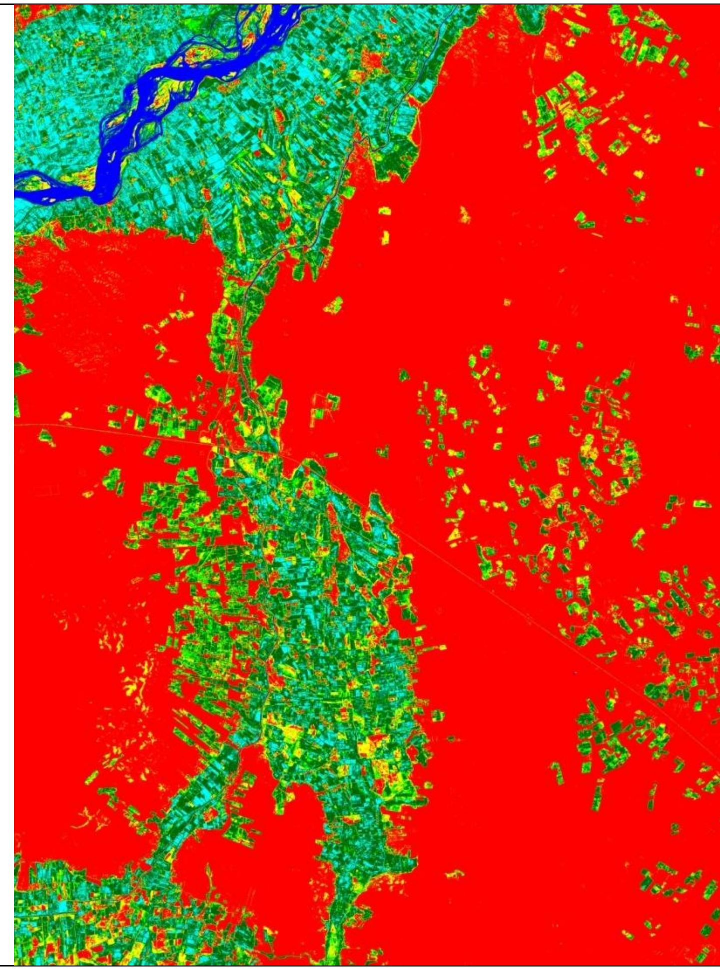


Figure 4. Quickbird Soil Moisture Map on April 24, 2009. Spatial resolution is 2.7 m pixel size. Image area is about 16x12 km.

Saturation	0.0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	0.8-1.0	Open Water
Color						

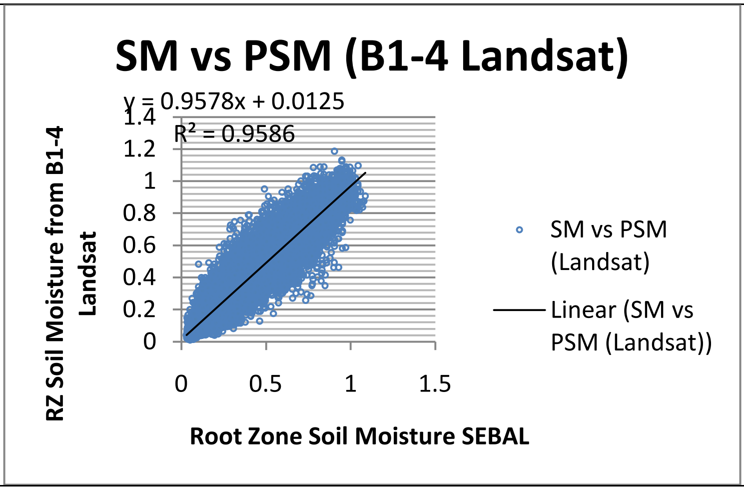
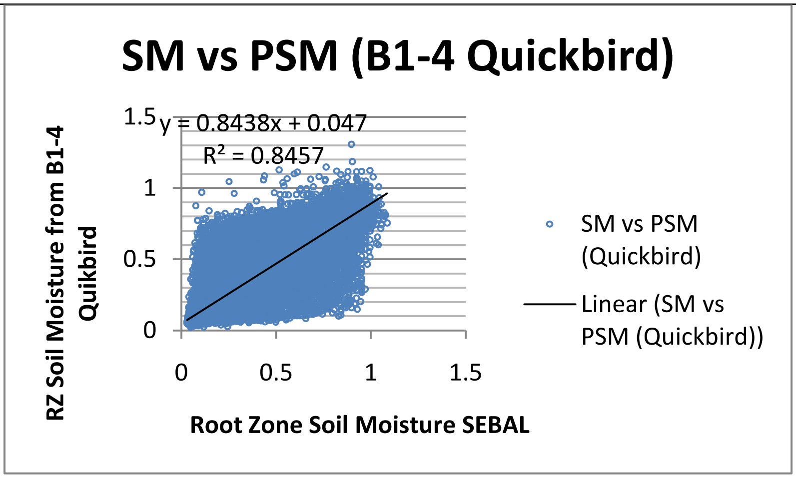
	

Figure 3. Regression between Root Zone Soil Moisture from SEBAL and its prediction (PSM) using bands 1-4 of Landsat.	Figure 4. Regression between Root Zone Soil Moisture from SEBAL and its prediction (PSM) using bands 1-4 of QuickBird.

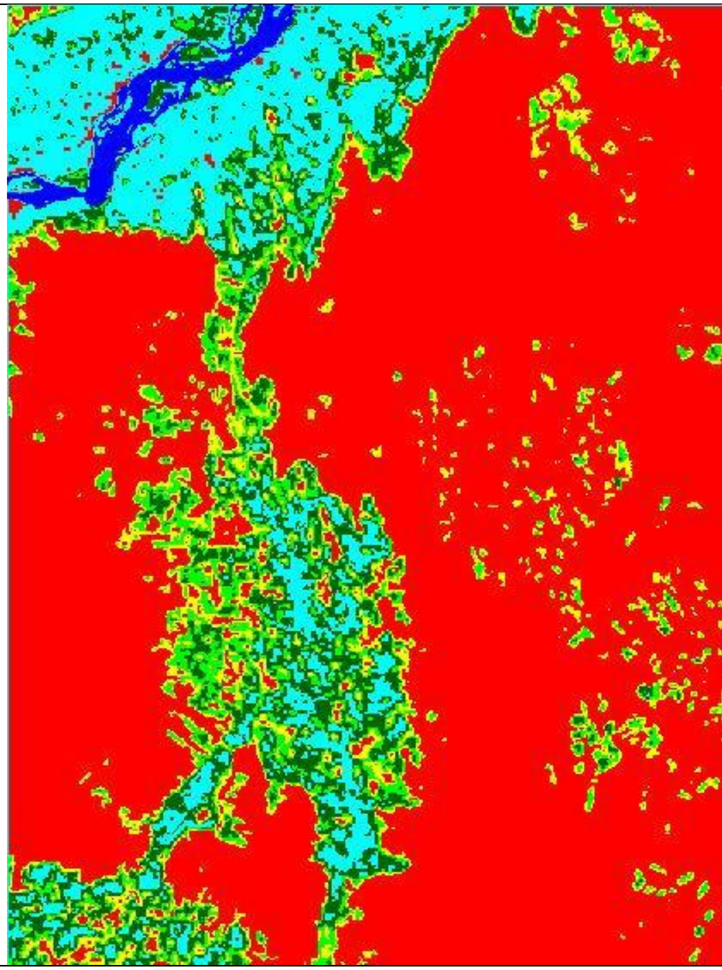


Figure 5. Landsat7 Soil Moisture Map on April 23, 2009. Spatial resolution is 30 m pixel size. Image area is about 16x12 km.

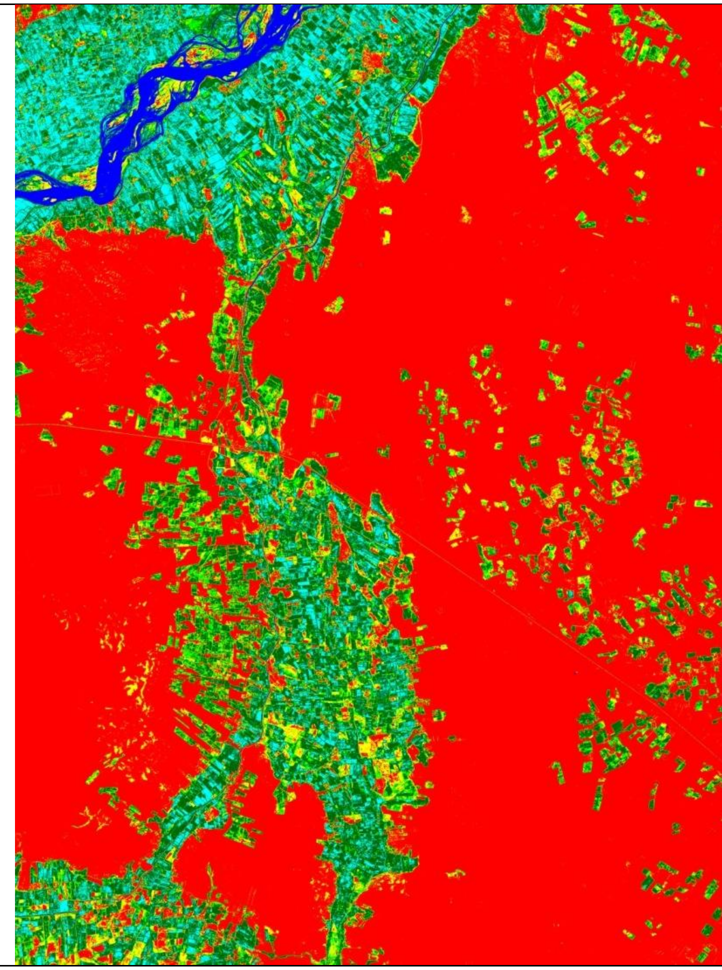
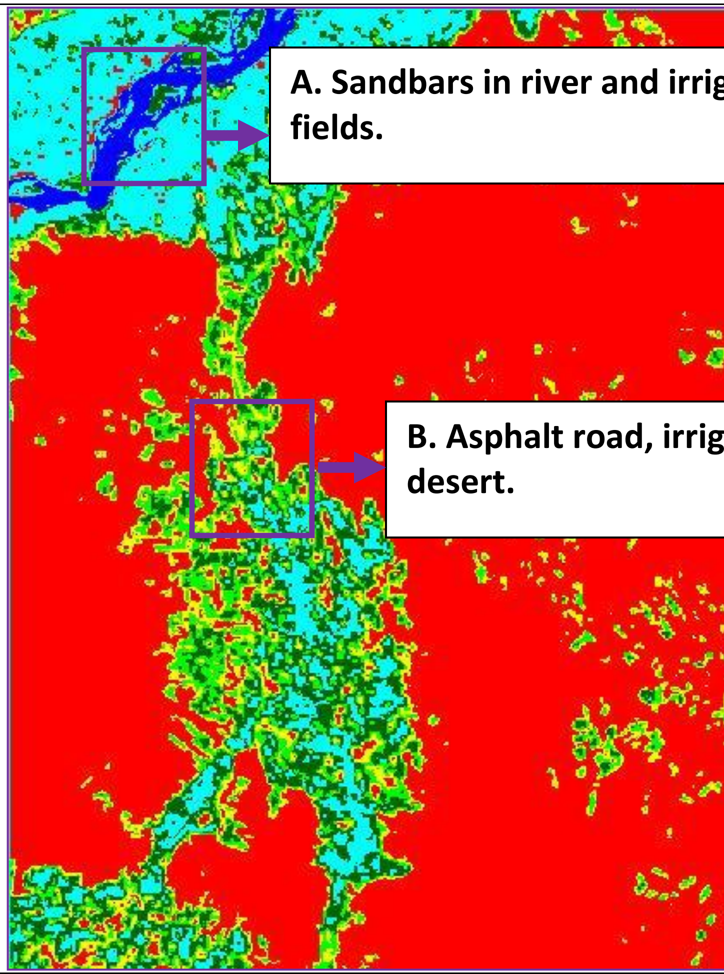


Figure 6. Quickbird Soil Moisture Map on April 24, 2009. Spatial resolution is 2.7 m pixel size. Image area is about 16x12 km.

Saturation	0.0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	0.8-1.0	Open Water
Color						



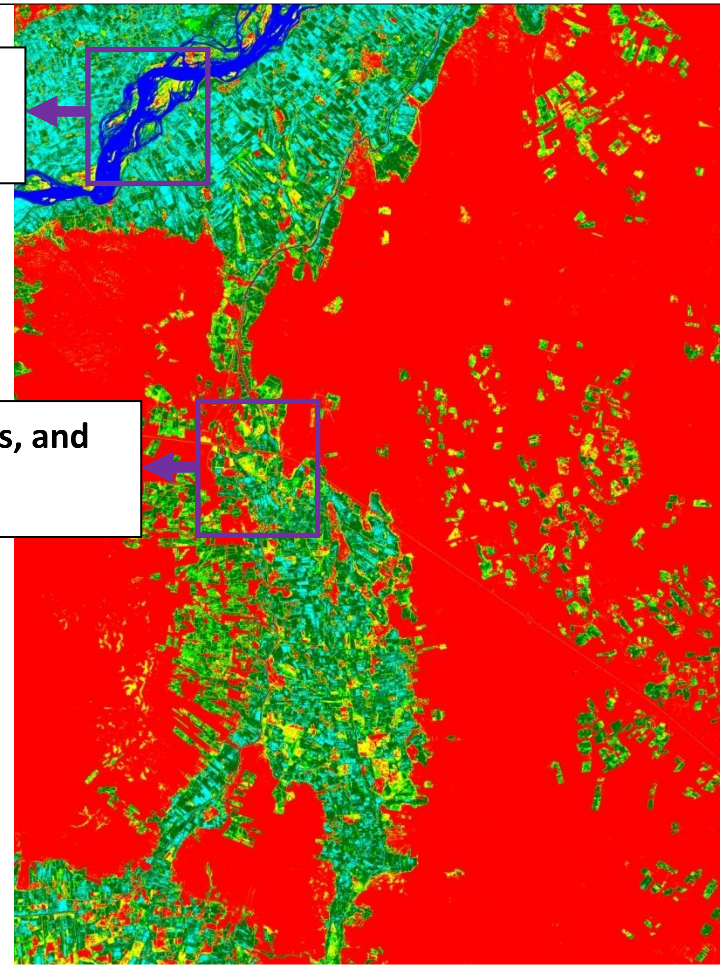


Figure 7. Landsat7 Soil Moisture Map on April 23, 2009. Spatial resolution is 30 m pixel size. Image area is about 16x12 km.

Figure 8. Quickbird Soil Moisture Map on April 24, 2009. Spatial resolution is 2.7 m pixel size. Image area is about 16x12 km.

Saturation	0.0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	0.8-1.0	Open Water
Color						

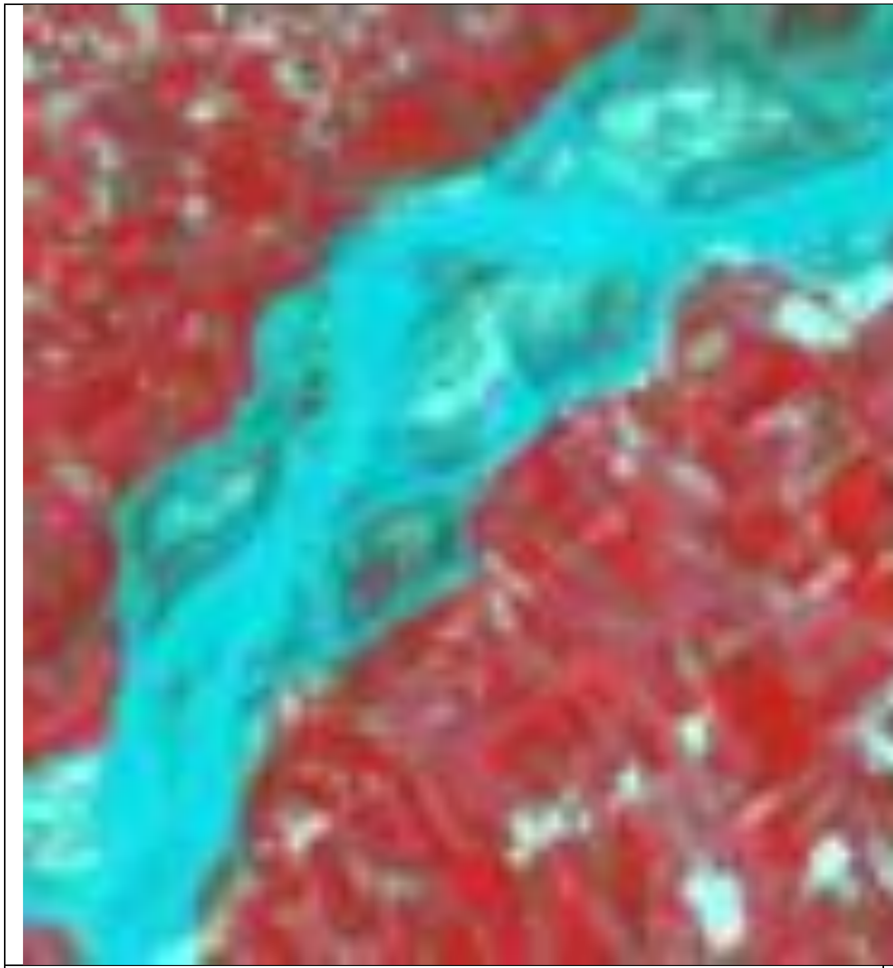


Figure 9. Section A: Landsat7 Image on April 23, 2009. Spatial resolution is 30 m pixel size. Image area is about 3x3 km.

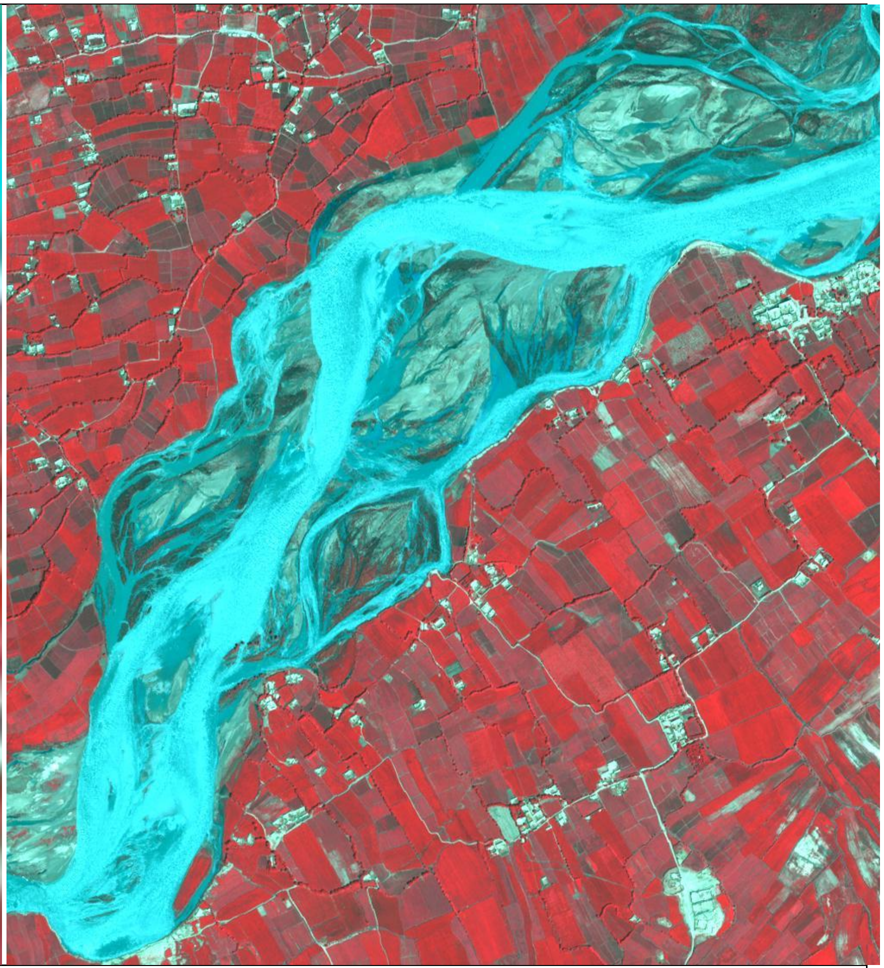


Figure 10. Section A: Quickbird Image on April 24, 2009. Spatial resolution is 2.7 m pixel size. Image area is about 3x3 km.

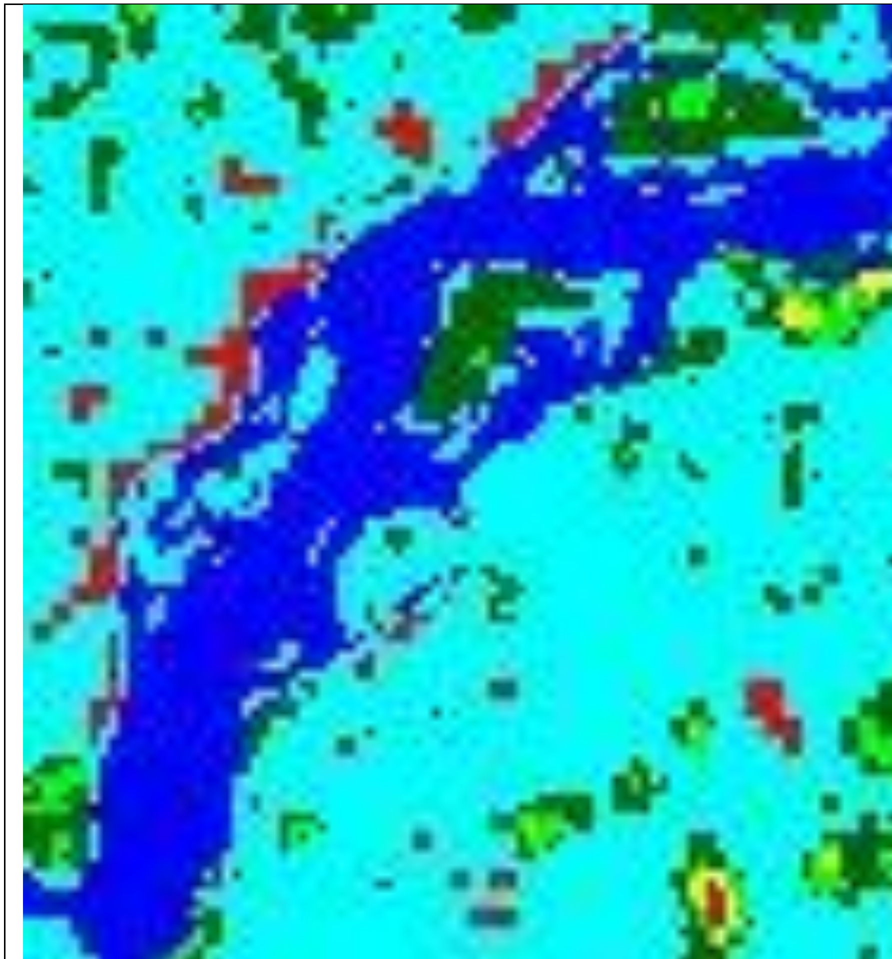


Figure 11. Section A: Landsat7 Soil Moisture Map on April 23, 2009. Spatial resolution is 30 m pixel size. Image area is about 3x3 km.

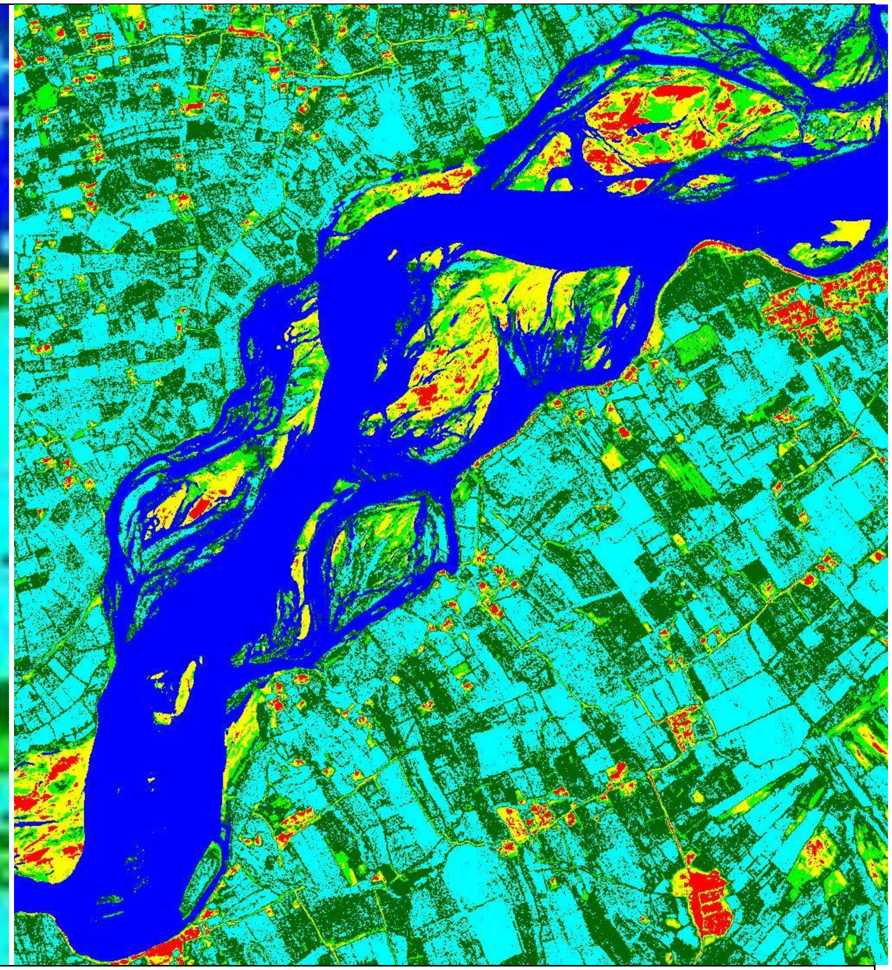


Figure 12. Section A: Quickbird Soil Moisture Map on April 24, 2009. Spatial resolution is 2.7 m pixel size. Image area is about 3x3 km.

Saturation	0.0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	0.8-1.0	Open Water
Color						

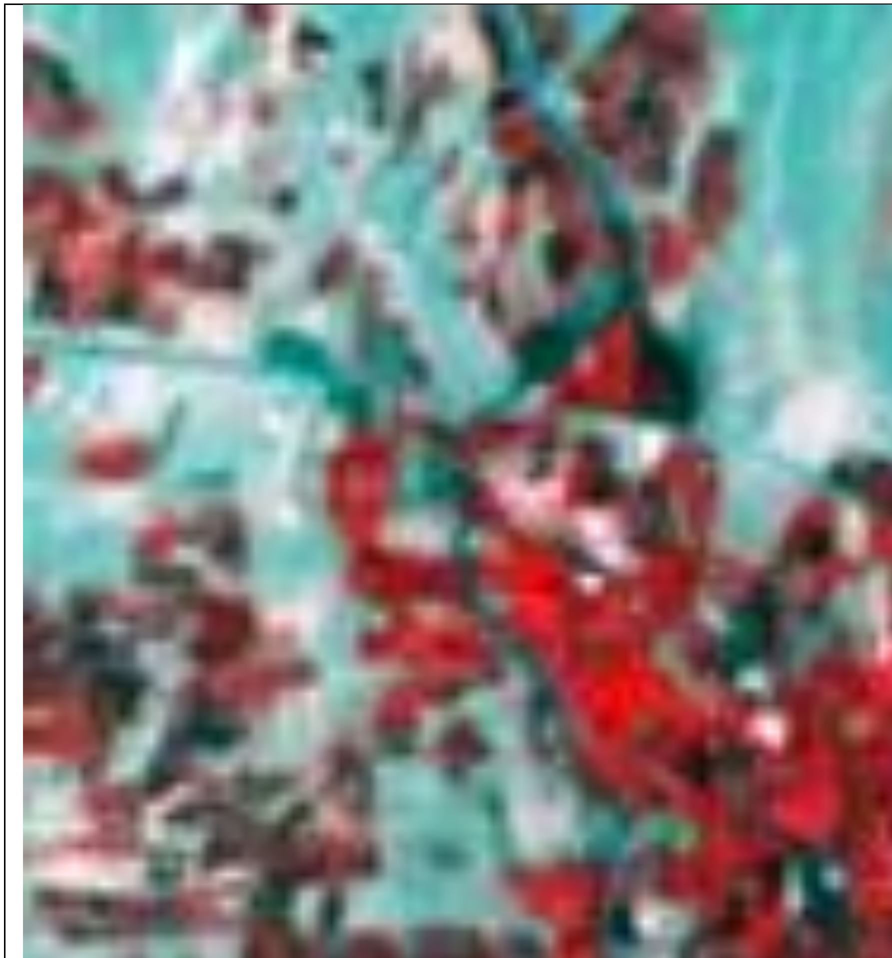


Figure 13. Section B: Landsat7 Image on April 23, 2009. Spatial resolution is 30 m pixel size. Image area is about 3x3 km.

Figure 14. Section B: Quickbird Image on April 24, 2009. Spatial resolution is 2.7 m pixel size. Image area is about 3x3 km.

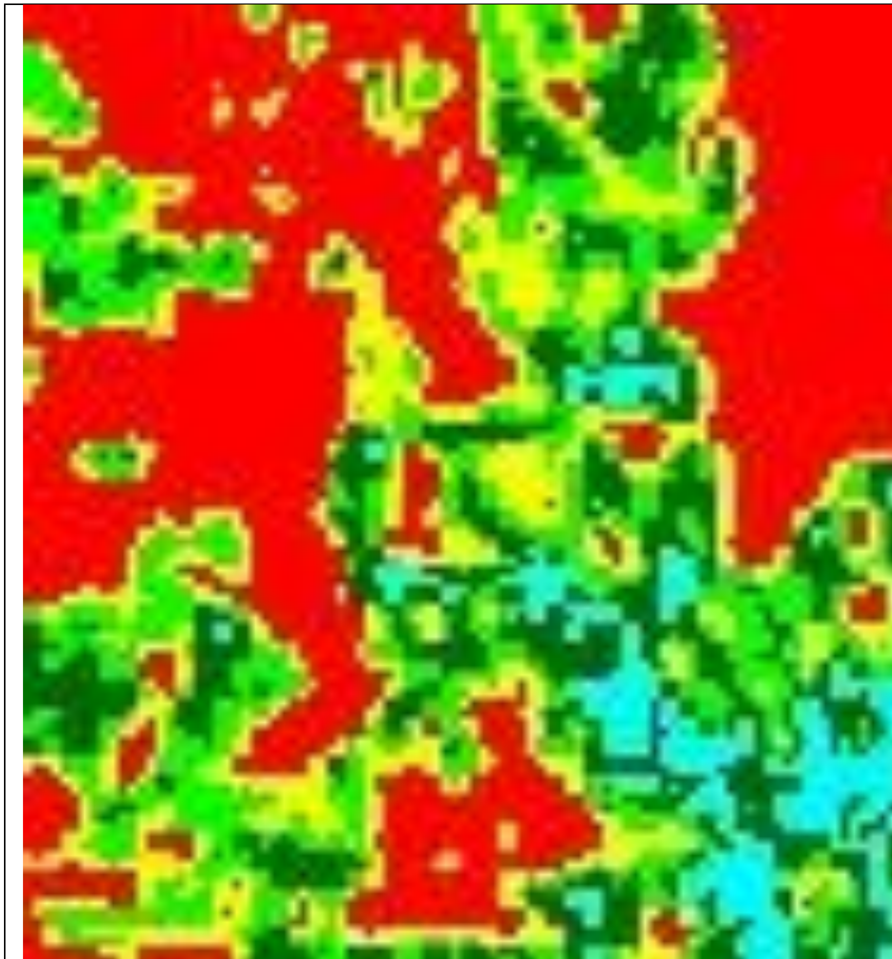


Figure 15. Section B: Landsat7 Soil Moisture Map on April 23, 2009. Spatial resolution is 30 m pixel size. Image area is about 3x3 km.

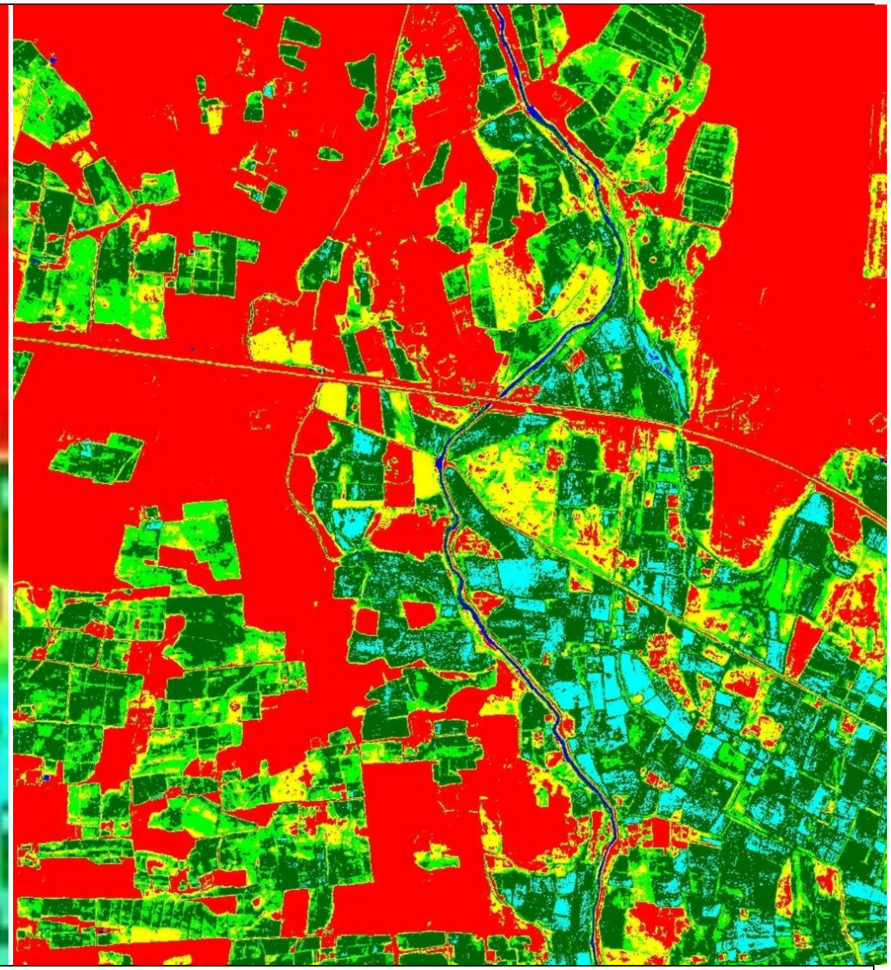


Figure 16. Section B: Quickbird Soil Moisture Map on April 24, 2009. Spatial resolution is 2.7 m pixel size. Image area is about 3x3 km.

Saturation	0.0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	0.8-1.0	Open Water
Color						

Objective II. Install an automatic weather station to validate ground measurements.

The original idea was to install an ERDC weather station –similar to the ones ERDC employs in Afghanistan– in the Middle Rio Grande Valley but due to non-availability of such a station on short notice this activity was abandoned. However, for a water use study PI Hendrickx and his students did install an automatic weather station in the Salt Basin during the summer of 2009 to measure all parameters needed for the calculation of the reference evapotranspiration. Figure 17 shows the daily measured incoming solar radiation at the station and the clear sky radiation that is calculated for that day taking into account the absorption of incoming solar radiation by water vapor in the atmosphere. These data are used for the validation of the GOES incoming solar radiation product in the next section.

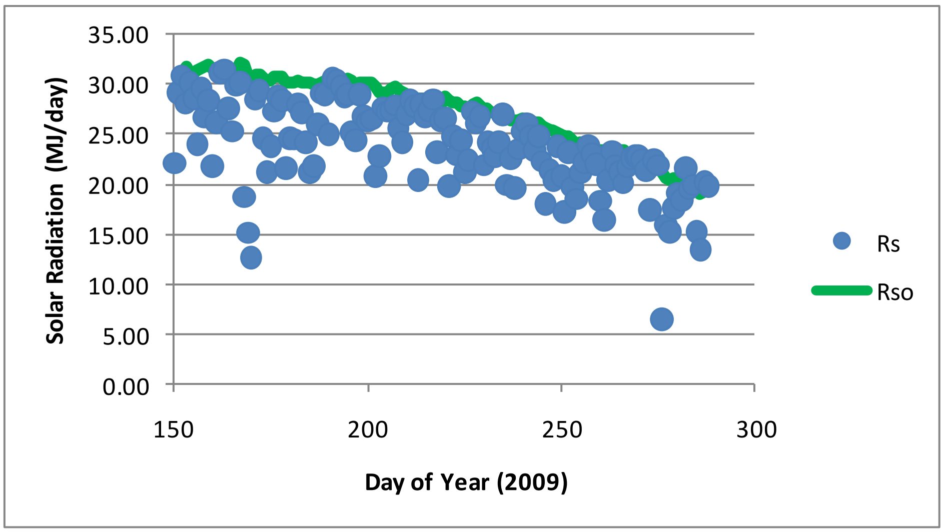


Figure 17. Incoming solar radiation (Rs, MJ/(m^2 day)) measured in the Salt Basin and clear sky radiation (Rso, MJ/(m^2 day)) calculated from air temperature and relative humidity measured at the station. Location of the weather station: 32.022 N, -105.108 W, elevation 1118 m.

Objective III. Test and validate existing algorithms that derive global incoming radiation under cloudy and partially cloudy conditions from GOES and METEOSAT images.

Originally, the plan was to conduct tests on hourly incoming solar radiation in Afghanistan (METEOSAT 7), Suriname (METEOSAT 8 or GOES), Panama (GOES), and New Mexico (GOES) but due to unforeseen difficulties with the acquisition and reformatting of the images, we have focused on daily incoming radiation in Afghanistan and New Mexico. Figure 18 shows two examples of daily incoming solar radiation (direct and diffuse) over Afghanistan on a clear (August 27, 2009) and a cloudy (September 17, 2009) day. Similar daily data are available over the period July through September, 2009. The daily data are sums of the hourly images for a specific data. Therefore, we do have the hourly data available for simulations with the Countermine Simulation Testbed if needed.

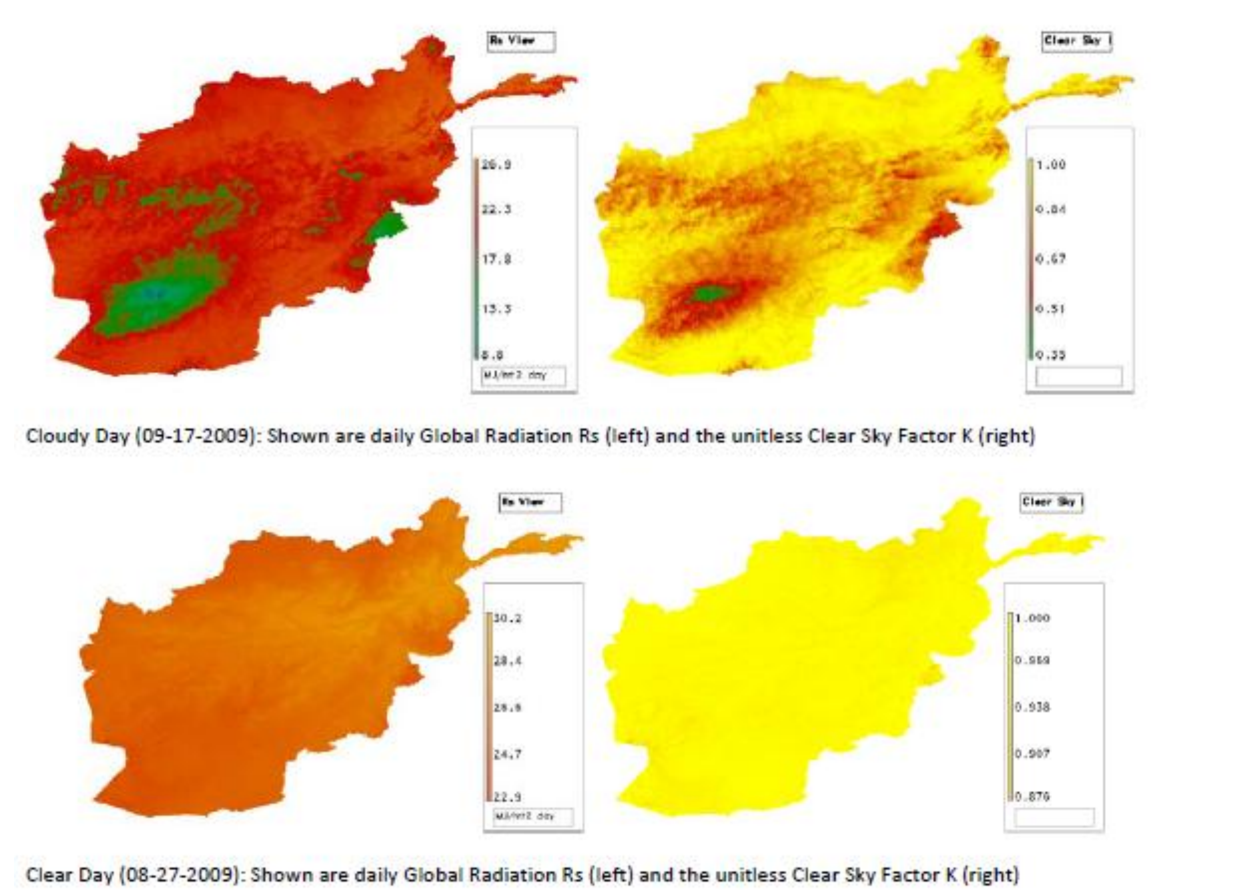


Figure 18. Daily global radiation, i.e. incoming solar radiation (direct and diffuse), on a cloudy and clear day over Afghanistan on, respectively, September 17 and August 27, 2009.

Since no radiation measurements from Afghanistan could be obtained we used some of the measurements in the Salt Basin of New Mexico for a first validation of the GOES and METEOSAT products. Figure 19 shows that the quality of the predicted incoming solar radiation is quite good but a more thorough validation will be conducted using a series of weather stations in New Mexico at different elevations.

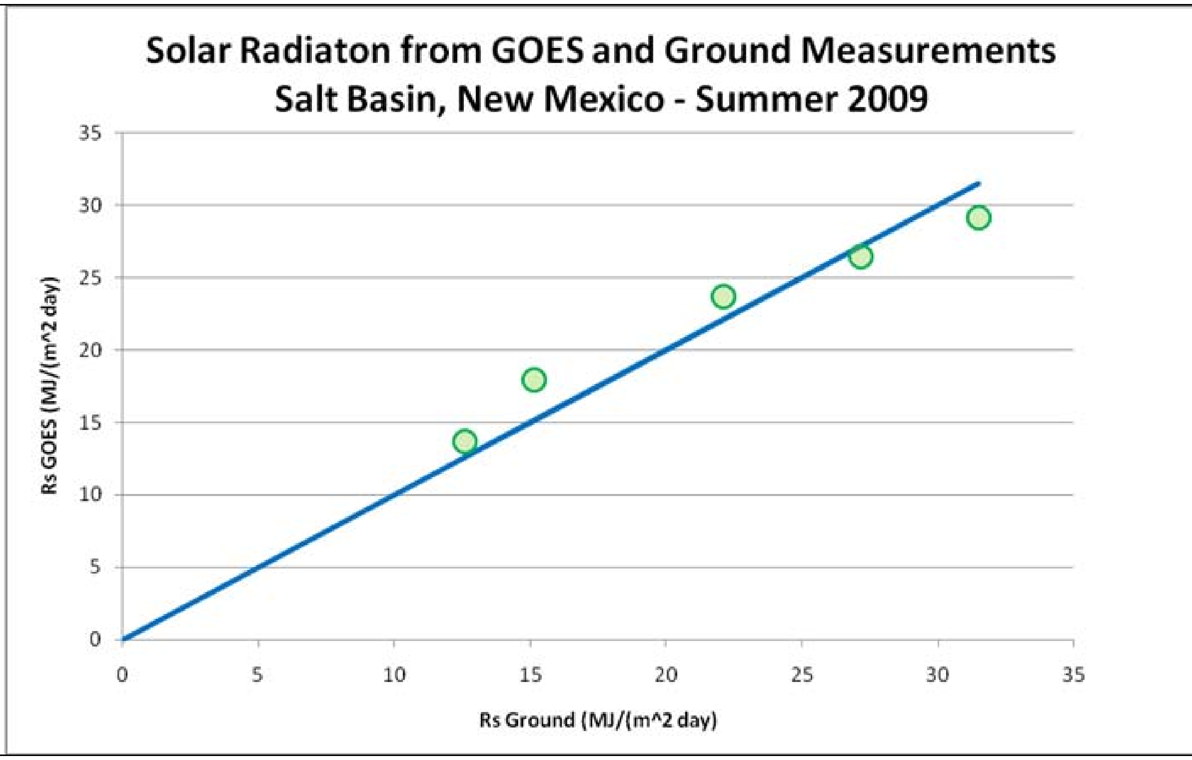


Figure 19. Validation of GOES incoming solar radiation product against daily incoming solar radiation measurements in the Salt Bassin, New Mexico, during spring and summer of 2009.

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