An Exercise on

Calculating Surface Temperature with Thermal Imagery

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Geographical Location of the Twitchell Island Flux Tower from the website:
Latitude: 38.1087204
Longitude: -121.65310

Growing Season:

The growing season of the study area was identified from the supplied twitchell_ET_2011.xls spreadsheet. In the 'crop.type' column, 'RI' values indicated rice crop was in the field from planting to harvest.

Start: 9 May 2011
End: 14 Oct. 2011

Satellite images:

Nine Landsat-7 ETM+ images (Path = 44, Row = 33) images of nine dates within the growing season were downloaded from the USGS Earth Explorer website (Table 1).

Table 1. Nine Landsat-7 ETM+ images from nine dates during the crop growing period in Twitchell Island, California

Sl. No	Image Collection Date	File Name (.tar.gz)
1.	21-05-2011	LE07_L1TP_044033_20110521_20160914_01_T1
2.	22-06-2011	LE07_L1TP_044033_20110622_20160913_01_T1
3.	08-07-2011	LE07_L1TP_044033_20110708_20160913_01_T1
4.	24-07-2011	LE07_L1TP_044033_20110724_20160913_01_T1
5.	09-08-2011	LE07_L1TP_044033_20110809_20160913_01_T1
6.	25-08-2011	LE07_L1TP_044033_20110825_20160913_01_T1
7.	10-09-2011	LE07_L1TP_044033_20110910_20160913_01_T1
8.	26-08-2011	LE07_L1TP_044033_20110926_20160912_01_T1
9.	12-10-2011	LE07_L1TP_044033_20111012_20160912_01_T1

Q.1. Compare the radiance values to the DNs in the image

Landsat 7 ETM+ thermal 6-2 bands are converted from digital numbers (0-255) to top of atmosphere radiance (3.16-12.65 W·m-2·sr-1·μm-1) using Equation 1 in the practical. The summary statistics between DN values and TOA radiance of each image is represented in Table 2. The summary statistics were calculated with the Raster Zonal Statistics tool in QGIS. The DN values ranges from 0 to 255 in each image except 12 October 2011. The range of TOA radiance values were between 3.16 to 12.65, and the mean radiance and standard deviation were 6.73 and 3.29, respectively (Table 2).

Table 2. Comparison of radiance value and DN image value

	DN Values				**Calculated TOA Radiance**			
Image Date	Minimum	Maximum	Mean	Stdev	Minimum	Maximum	Mean	Stdev
21-May-11	0	255	85.84	80.36	3.16	12.65	6.36	2.99
22-Jun-11	0	255	105.93	97.65	3.16	12.65	7.1	3.63
8-Jul-11	0	255	105.75	97.35	3.16	12.65	7.1	3.62
24-Jul-11	0	255	99.16	91.34	3.16	12.65	6.85	3.4
9-Aug-11	0	255	102.57	94.33	3.16	12.65	6.98	3.51
25-Aug-11	0	255	100.15	92.5	3.16	12.65	6.89	3.44
10-Sep-11	0	255	98.47	91.96	3.16	12.65	6.83	3.42
26-Sep-11	0	255	85.31	78.15	3.16	12.65	6.34	2.91
12-Oct-11	0	219	79.65	73.21	3.16	12.65	6.13	2.72
Average	**0.00**	**251.00**	**95.87**	**88.54**	**3.16**	**12.65**	**6.73**	**3.29**

Q. 2. Compare your TOA radiance and brightness temperatures to those provided in the subfolders: LS TOA and LS Brightness Temperature

The values of calculated TOA radiance and brightness were found similar to supplied TOA radiance and brightness (Table 3 and 4).

Table 3. Comparison between TOA radiance and supplied TOA radiance at Twitchell Island during 2011

Image Date	Calculated TOA Radiance				Supplied TOA Radiance			
	Minimum	Maximum	Mean	Stdev	Minimum	Maximum	Mean	Stdev
21-May-11	3.16	12.65	6.36	2.99	3.16	12.65	6.36	2.99
22-Jun-11	3.16	12.65	7.1	3.63	3.16	12.65	7.11	3.63
8-Jul-11	3.16	12.65	7.1	3.62	3.16	12.65	7.1	3.62
24-Jul-11	3.16	12.65	6.85	3.4	3.16	12.65	6.85	3.4
9-Aug-11	3.16	12.65	6.98	3.51	3.16	12.65	6.99	3.52
25-Aug-11	3.16	12.65	6.89	3.44	3.16	12.65	6.89	3.44
10-Sep-11	3.16	12.65	6.83	3.42	3.16	12.65	6.83	3.42
26-Sep-11	3.16	12.65	6.34	2.91	3.16	12.65	6.34	2.91
12-Oct-11	3.16	12.65	6.13	2.72	3.16	11.31	6.13	2.72
Average	**3.16**	**12.65**	**6.73**	**3.29**	**3.16**	**12.50**	**6.73**	**3.29**

Table 4. Comparison between TOA Brightness temperature and supplied TOA Brightness temperature at Twitchell Island during 2011

Image Date	Calculated Brightness Temperature (^{0}C)				Supplied Brightness Temperature (^{0}C)			
	Minimum	Maximum	Mean	Stdev	Minimum	Maximum	Mean	Stdev
21-May-11	-33.6	48.93	-2.25	29.06	-33.6	48.93	-2.23	29.06
22-Jun-11	-33.6	48.93	3.24	33.73	-33.6	48.93	3.26	33.73
8-Jul-11	-33.6	48.93	3.22	33.64	-33.6	48.93	3.23	33.64
24-Jul-11	-33.6	48.93	1.47	32.09	-33.6	48.93	1.49	32.09
9-Aug-11	-33.6	48.93	2.39	32.86	-33.6	48.93	2.47	32.92
25-Aug-11	-33.6	48.93	1.71	32.41	-33.6	48.93	1.72	32.41
10-Sep-11	-33.6	48.93	1.2	32.2	-33.6	48.93	1.22	32.2
26-Sep-11	-33.6	48.93	-2.29	28.56	-33.6	48.93	-2.27	28.56
12-Oct-11	-33.6	40.28	-3.92	27.19	-33.6	40.28	-3.91	27.19
Average	**-33.60**	**47.97**	**0.53**	**31.30**	**-33.60**	**47.97**	**0.55**	**31.31**

Q.3. Visualize TOA brightness temperature side by side with a true colour or visible-NIR image composite. A colour infrared (CIR) or agriculture composite is quite useful here. CIR displays near infrared (5), red (4) and green (3) as Red-Green-Blue. Similarly, an agriculture composite uses SWIR-1, NIR and blue.

A clipped image of Cropscape, a classified map of crop types for the entire United States, was supplied with the exercise problems (Figure 1). The red dot in the figure represents the eddy covariance flux tower. The rice field is located immediately west of the tower. The CropScape classified image showing alfalfa, corn, rice, wheat, and water with pink, yellow, blue, brown, and dark blue color, respectively.

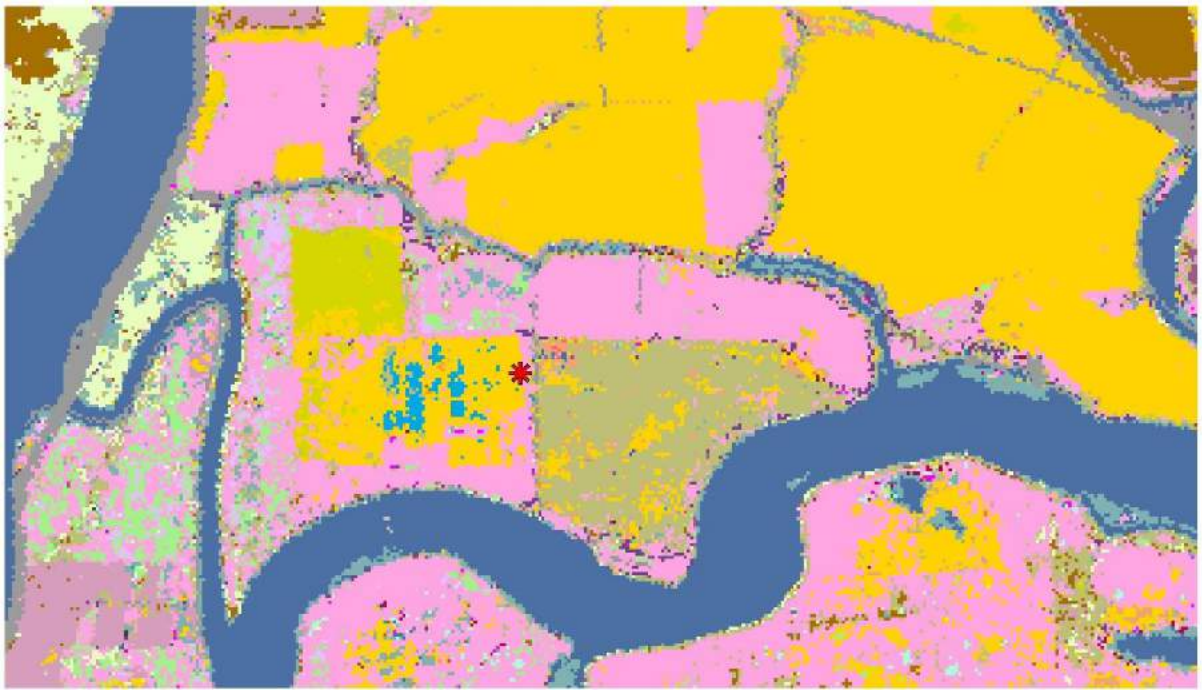

Figure 1: CropScape classification of Twitchell Island, Central Valley of California. Red star (*) indicates the location of Twitchell Island Flux Tower.

In Fig 2, the TOA brightness temperature has been presented as cold (blue) to hot (red) pixels in degrees Celcius. Most of the pixels are reddish during May and June since this period were the initial growth stage of the crop. The north and northeast corner of the images are more reddish meaning high temperature probably due to exposed or bare soil during planting time. At this stage bare soil absorbs more sensible heat, hence evapotranspiration is lower which leads to higher brightness temperature.

During July and August reddish fields turned fade which means lower lower temperature. Which is so because during this time plants are at peak growing season when transpiration rate is much higher. So, due to higher evapotranspiration latent heat is much more than sensible heat.

At the later stage of the growing season (September and October), the fields turning to high temperatures. The color turns brown meaning the ripening stage when photosynthesis and

evapotranspiration is lower as a result high brightness temperature occurred in the field. The waterbody in all images were dark blue in color.

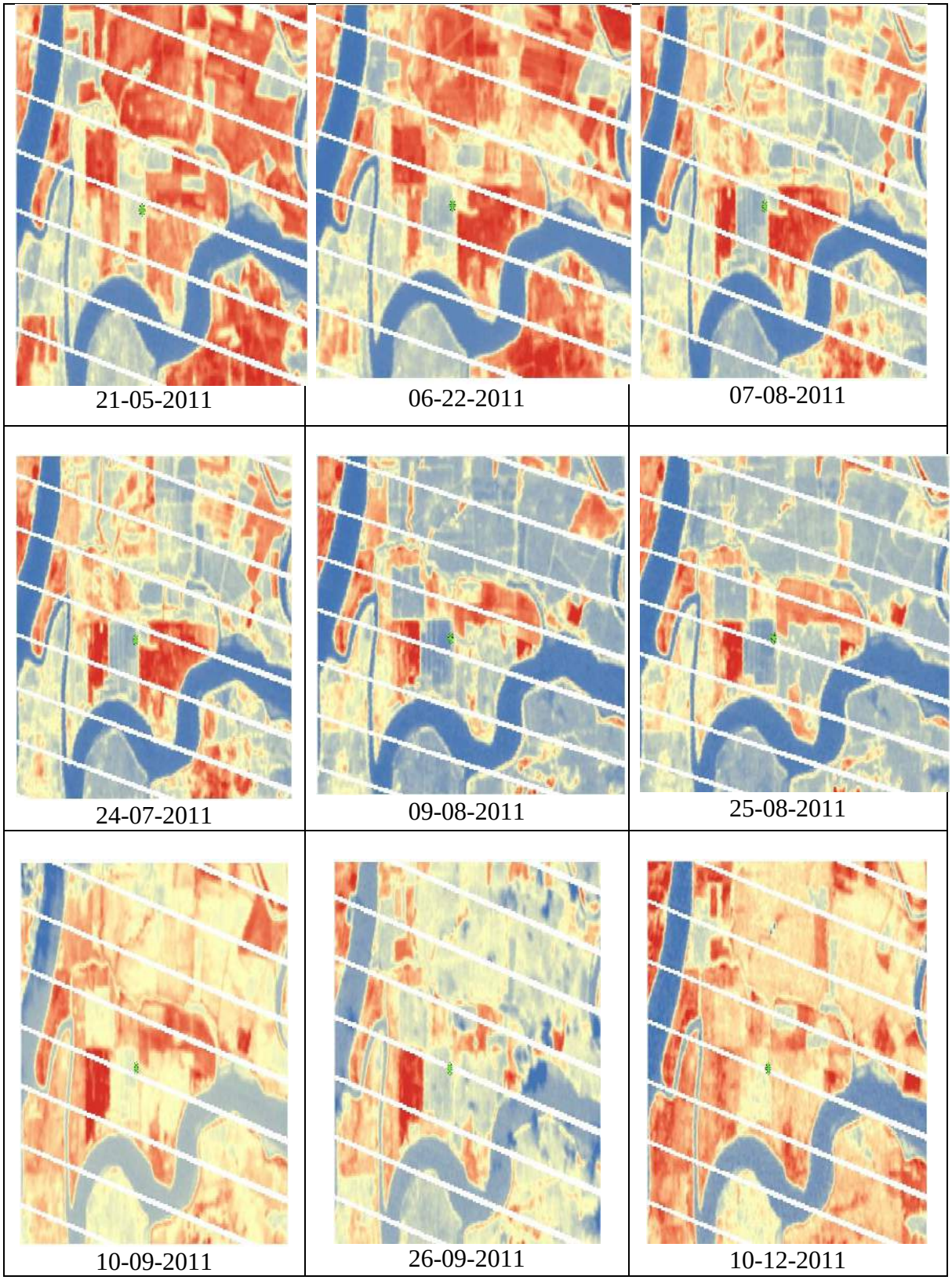

Fig 2: TOA Brightness Temperature at Twitchell Island as cold (blue) to hot (red).

Q. 4. Look at different targets (water bodies, agricultural fields, urban areas, etc.). Differentiate differences by land cover type.

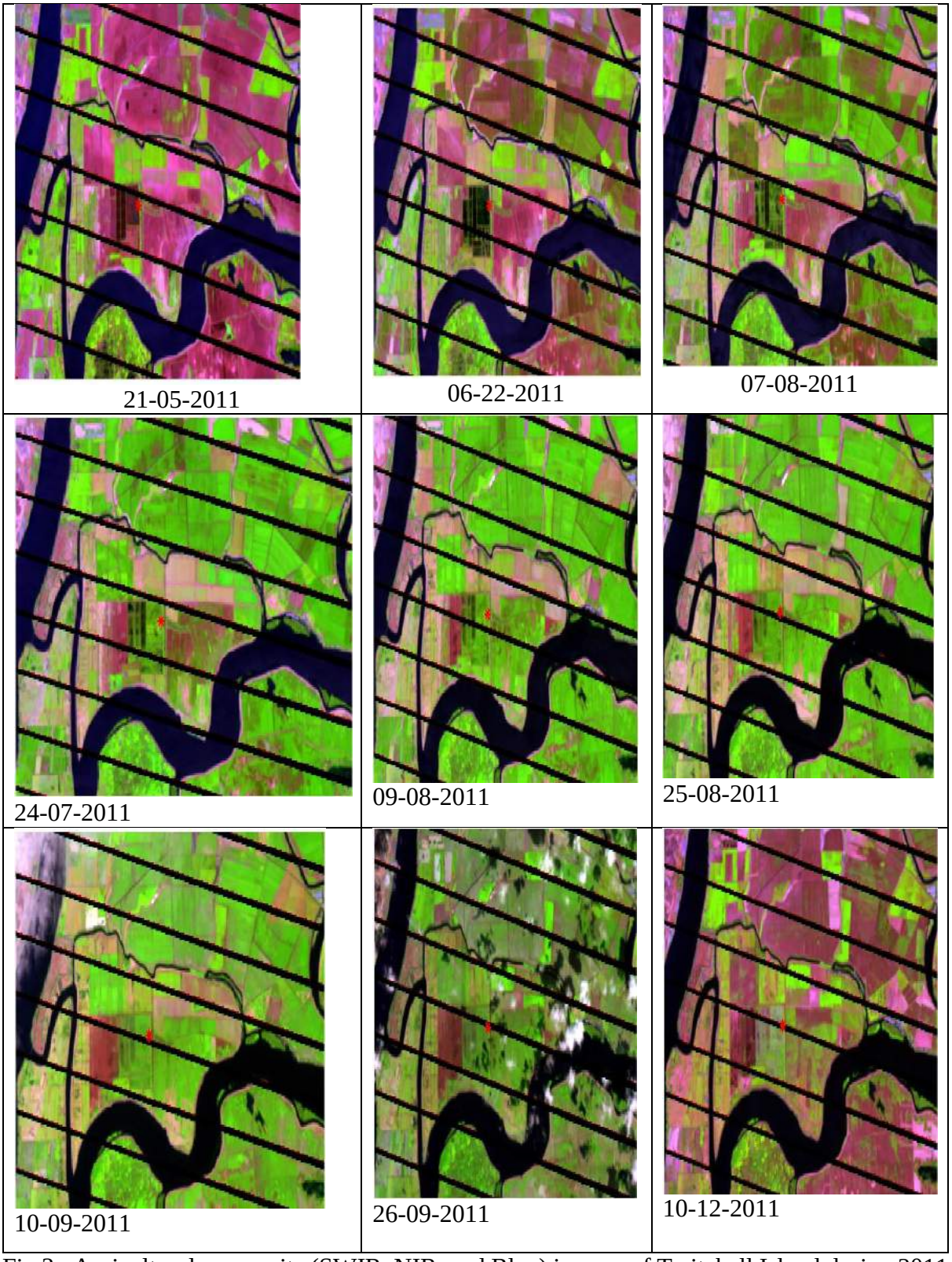

Fig 3: Agricultural composite (SWIR, NIR, and Blue) images of Twitchell Island during 2011

From agricultural composites of Twitchell Island showing higher photo-active dark to light green pixels (Figure 3). Water bodies are blue and violet in color while purple or pink color represents bare soil, built-ups, or some other no photosynthesizing surface. Most of the images are either pink or purple from May to June due to lots of exposed soils in the fields. From July through September the crop reach almost maturity stage hence fields are dark to light green. In the West and Northeast of the study area representing alfalfa fields, which are harvested multiple times during the growing season. It is used to feed cattle and provides a continuous source of supplemental income for farmers during the growing season. Probably alfalfa has been recently harvested leading to either pink or purple color. At the end of the season, most of the images are either pink or white, indicating crops ripening stage or harvested.

Q.5. Plot the TOA brightness temperatures against the NDVI (or EVI) and ET provided. In conditions where soil moisture is a constraint on plant health, we would expect a proportional response of NDVI (vegetation) to latent heat (energy equivalent of ET). Due to the conservation of energy, we would expect an increase in latent heat to lead to a decrease in sensible heat and land surface temperature. Do you see an inverse relationship between TOA brightness temperature and ET? Explain your answer.

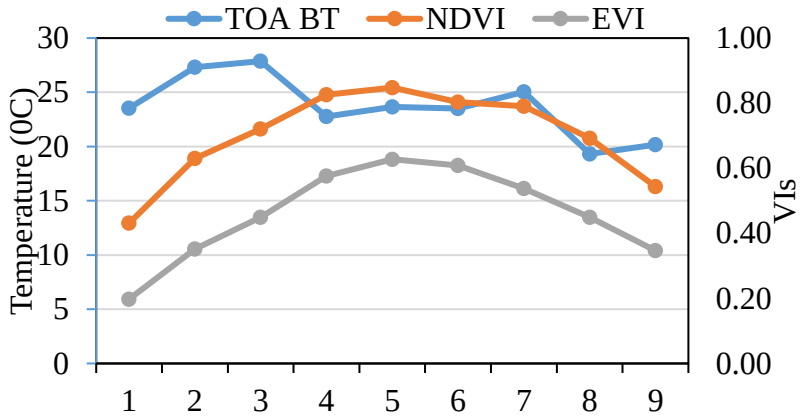

Fig. 4. Estimated TOA BT Vs Vegetation indices (NDVI, EVI)

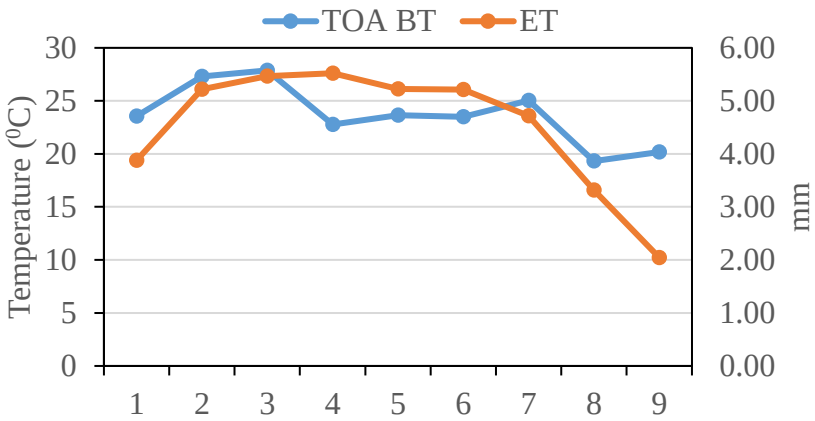

Fig. 5. Estimated TOA BT Vs ET

At the early growing season, the rice is either absent in the field or emerging (“green-up”). Moreover, it may be flooded or not. Evapotranspiration is lower due to low productivity (NDVI, EVI) and higher sensible heat increases brightness temperatures. However, the converse is true during the peak productivity in June-August. As the rice is drying out ("browning down") and the fields may be drained resulting in relationship will reverse further at the end of growing season. It may be because of brightness temperature limitations (e.g., susceptibility to atmospheric water vapors/clouds), which have already been discussed.