DOWNSCALING MODIS LAND SURFACE TEMPERATURE USING SIMULATED SENTINEL-2 IMAGERY

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ABSTRACT

In this paper we tested a disaggregation method based on the relationship between NDVI (Normalized Difference Vegetation Index) and LST (Land Surface Temperature) to downscale the thermal information (TIR) of a coarse resolution satellite to the higher resolution of the visible and near infrared (VNIR) bands of a different satellite. The objective was to enable the application of these techniques to the coming Sentinel-2 satellite with 10-30 m spatial resolution in the VNIR bands in combination with a satellite offering TIR information at lower spatial resolution (MODIS, Sentinel-3, etc.). In this paper we used the VNIR bands of Landsat images due to its similarity to Sentinel-2, and the relationship between VNIR and TIR bands was extracted from MODIS images. An experimental campaign was carried out in the agricultural test site of Barrax (Albacete), Spain. Ground LSTs were measured at a variety of crop fields in 4 different dates in May 2015, concurrent with MODIS overpasses. Three Apogee MI-210 thermal radiometers were used. These ground measurements were used to validate the disaggregated LSTs from the MODIS–Landsat images. A bias of 0.13 ºC and a RMSE=±1.4 ºC were obtained. Results of this work show the potential of the exposed technique to derive land surface temperatures at high spatial resolution by merging coming Sentinel - 2 and Sentinel- 3 data.

INTRODUCTION

The compromise between spatial and temporal resolution is a constraint in many studies, especially when thermal infrared data (TIR) is needed. Usually the thermal bands have a lower spatial resolution than the visible and near infrared (VNIR) bands. Moreover, several satellites offering high spatial resolution do not include TIR sensors. In recent years, several disaggregation techniques have been developed to improve the spatial resolution of TIR data using the information from VNIR bands (1–5). Most disaggregation techniques are based on a relationship between VNIR and TIR bands at coarse spatial resolution, and the assumption that this relationship is independent of the spatial resolution. Thus, the relationship is obtained from low spatial resolution images and applied to high resolution VNIR bands. Furthermore, it can be applied to sensors on board two different satellites, with the high resolution sensor not necessarily containing thermal bands, as the case of the coming Sentinel-2. A comparison of different disaggregation methods using MODIS and Landsat 7 ETM+ images in the Barrax area was performed (6). The Landsat 7 thermal band was used to validate and compare the disaggregation procedures, also some ground LSTs were used for validation. The method using a linear regression between NDVI and LST led to the best results in terms of root mean square error (RMSE). The aim of this study is to further analyse the performance of this disaggregation method applied to two different satellites, using more ground data, and check its applicability to sensors without thermal bands as the imminent Sentinel-2. The spectral resolution of Sentinel-2 is similar to Landsat images, especially to Landsat 8 OLI. The spectral response functions for the Sentinel-2, Landsat 7, and Landsat 8 VNIR bands are presented in Figure 1. A comparison of the VNIR capabilities of Landsat, SPOT, and Sentinel-2 is included in Table 1.

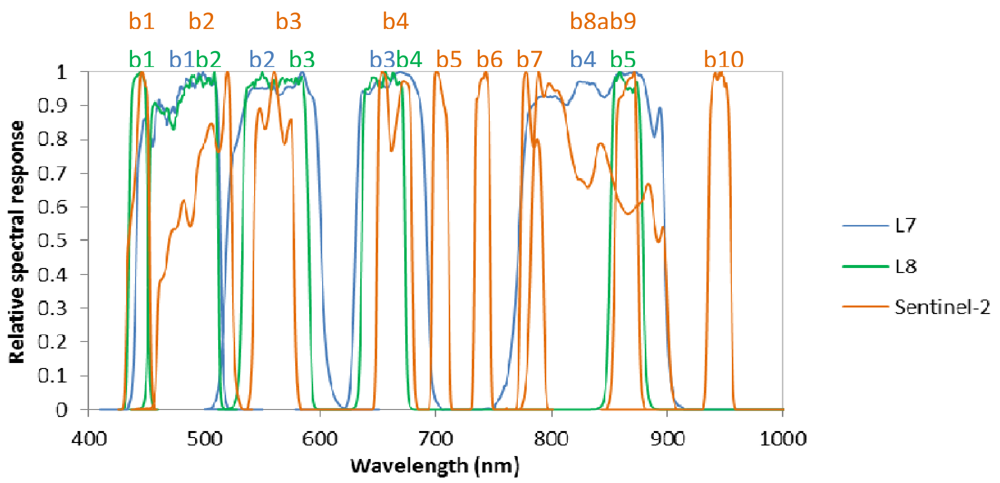


Figure 1. Spectral response function of Sentinel-2, Landsat 7 and Landsat 8 VNIR bands.

Table 1: Comparison of the VNIR capabilities of Landsat, SPOT and Sentinel-2.

	L7	**L8**	**SPOT 5**	**SPOT 6**	**Sentinel-2**
Launch Date – End mission	04/15/1999 - ...	02/11/2013 - ...	05/04/2002 – 03/31/2015*	09/09/2012 -...	06/23/2015 - ...
Revisit time (days)	16	16	1-3	1	5
Swath (km)	185	185	60	60	290
Multispectral bands	4	5	3	4	10
Spatial Resolution	30 m	30 m	10 m	6 m	4(10m) 4(20m) 2(60m)

METHODS

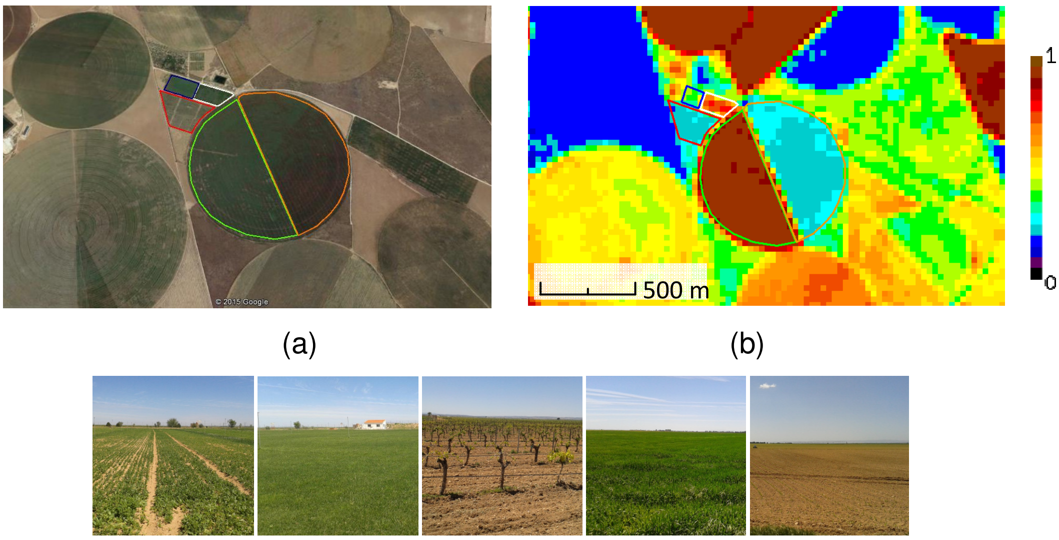
Study area and ground measurements

The study area is the agricultural test area of Barrax (Albacete), including "Las Tiesas" experimental farm (39° 03' 35'' N, 2° 06' W). In this area numerous experimental campaigns have been carried out in recent years related to water management in agriculture (7, 8). Since early May 2015, ground temperatures have been measured in different fields covering a variety of crops and vegetation fraction: poppy, festuca, vineyard, corn and barley. LST transects were concurrent with MODIS overpasses. An overview of the study area and the crop fields is shown in Figure 2. The temperatures were measured using hand-held infrared radiometers (IRTs) Apogee MI-210, pointing nadir view at 1.5-2 m height above the ground surface. These radiometers have a broad thermal band (8-14 µm) with an accuracy of ±0.3 °C and 22° field of view. IRTs measurements were corrected from atmospheric and emissivity effects.

Satellite images

Images from MODIS and Landsat satellites on the same or close dates were used in this study. Only MODIS images with a low view angle (<20º) were considered, as high angles lead to higher errors, especially in the TIR band. Both, Landsat 7 and Landsat 8 were used. When no Landsat satellite overpass coincided with a MODIS one (with low view angle), a close Landsat image was used under the assumption that the NDVI remained constant. The VNIR bands of Landsat 7 ETM+ and Landsat 8 OLI were obtained from the Landsat Surface Reflectance Climate Data Record (CDR) product (https://espa.cr.usgs.gov/). Moreover, the TIR data from Landsat 7, when concurrent with a MODIS overpass, was used for a further comparison between Landsat and disaggregated LSTs. The Landsat 7 TIR data was atmospherically corrected using the radiative transfer equation (9) and the atmospheric parameters obtained from the 'Atmospheric Correction Tool' from (10, 11).

MODIS images are provided atmospherically corrected. MOD09GQ images and MOD09GA products for VNIR, and the MOD11_L2 product for TIR, were downloaded (http://reverb.echo.nasa.gov/). These MODIS images were re-scaled to 240 m (VNIR) and 960 m (TIR) to have multiple dimensions of the Landsat images. In addition VNIR images were added to the spatial resolution of the TIR for the application of the disaggregation techniques. This aggregation was conducted by averaging the reflectivity values of all the high resolution pixels within a corresponding coarse resolution pixel. Finally, a normalization process of the Landsat bands was performed to correct any temporal and spectral differences between Landsat and MODIS images. This process consists in aggregating the Landsat images to the spatial resolution of MODIS and obtaining a linear regression between the two images for each band, then the equation obtained is applied to the Landsat bands at their original spatial resolution (12).



(a) (b)

(c) (d) (e) (f) (g)

Figure 2: a) Google maps image of the study area including the fields selected: poppy (blue), festuca (white), vineyard (red), barley (green) and corn (orange) b) NDVI image for date 05/07/2015, c-g) pictures of the different fields on 05/07/2015: poppy, festuca, vineyard, barley and corn.

Disaggregation procedure

In (6) various disaggregation methods from the literature were tested in the Barrax area. A modification of the method presented by Agam et al. (2) led to the best results. This method consists in adjusting a linear regression between NDVI and LST (Eq. 1) at the coarse resolution using the most homogeneous pixels as suggested by Kustas et al. (1).

$$LST = a_0 + a_1 NDVI \tag{1}$$

This equation is then applied separately at both, the coarse and high resolution. From the coarse resolution, difference between the disaggregated and the original MODIS LSTs is obtained and this is considered as the residual. Subsequently, these residuals are added to the disaggregated LST at high resolution (same residual for all high resolution pixels belonging to the same coarse pixel).

The residuals may cause a 'boxy effect' in the disaggregated images. Applying a Gaussian filter reduces this effects and also reduces the RMSE (6). The disaggregation procedure is applied to concurrent Landsat and MODIS images when available, if not, a close Landsat image is used under the assumption that NDVI changes are minimum in close dates. Four MODIS images were used in this work: 7, 12, 14, and 21 May 2015. Ground temperatures were measured for a time range of 10 minutes centered in the MODIS overpass time (around 11:00 UTC) each date. The Landsat images used for the disaggregation of the different dates were 6 (L8), 13 (L8), 13 (L8), and 21 (L7) May 2015, respectively.

RESULTS

Figure 3 shows an example (7 May) of a disaggregated LST image (30x30 m^2 spatial resolution) compared to the original MODIS LST product (1x1 km^2). The potential of the disaggregation technique is more than evident.

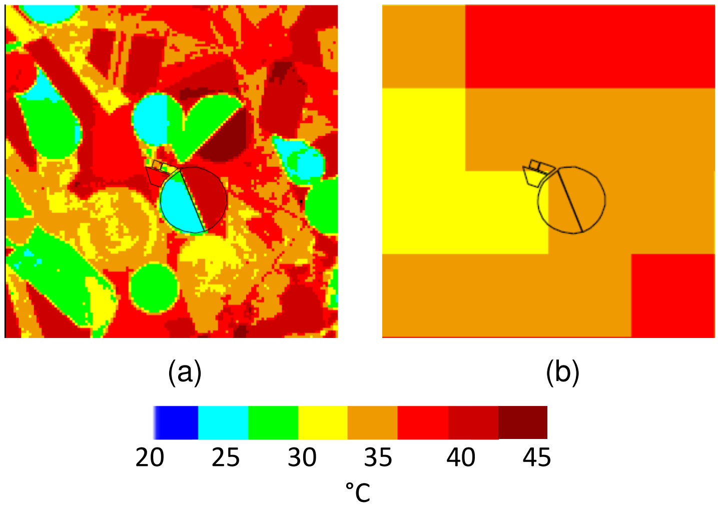


Figure 3: Disaggregated (a) and MODIS (b) temperature corresponding to date 7 May.

Table 2 shows the average ground temperatures (T_g), including standard deviation, measured with the Apogees in each field and date. NDVI values from the Landsat images are also listed. δ L'-T_g represents the differences between disaggregated and ground measured temperatures. The festuca and poppy fields were affected by the Landsat 7 scan line corrector failure on 21 May, thus no information could be extracted from these fields. Differences within ±2ºC are obtained in the festuca and barley fields, whereas important differences are observed in the corn field. A limitation of the disaggregation methods is that local drops in LST, consequence of some irrigation practices such as the use of pivots or sprinklers cannot be captured, yielding dramatic temperature overestimations in these areas. These deviations are stressed under low vegetation cover conditions, and may be larger than 10 ºC. This is the reason of the results obtained in the corn field (very small plants, see Fig. 2g) and also 12 and 14 May in the poppy field (intermediate NDVI values). Disaggregated LSTs in the vineyard, provided with a drip irrigation system instead, are quite close to those ground-measured despite the large values of standard deviation in this crop produced by its heterogeneity. Festuca and barley are more homogenous crops in terms of vegetation coverage and consequently also in terms of temperature. To sum up, if we focus on the set of 11 punctual data non-affected by the irrigation issue mentioned above, a Bias of 0.13 ºC and a RMSE=±1.4 ºC are obtained. These results are in agreement with those shown in (6).

Differences with the original MODIS LSTs are also included in Table 2 to highlight the improvement after the disaggregation procedure. A comparison between LSTs disaggregated and obtained directly from Landsat TIR band was possible only for 21 May, when concurrent MODIS and Landsat 7 images were available. Differences were -0.4, -0.8, and -1.6 ºC for the vineyard, barley and corn, respectively.

Results in this work are promising although further research is required and the dataset needs to be completed. For example, note that some differences may arise as a consequence of estimating NDVI from Landsat 8 or Landsat 7. Whether these differences have a significant impact or not is something that needs to be explored.

Table 2: Landsat NDVI values, ground measured temperatures (T_g), difference between disaggregated and ground temperatures (δ L'-T_g), difference between MODIS original LST and ground temperatures (δ T_{rMOD}-T_g).

Field	Day	NDVI	T_g (ºC)	δ L'-T_g (ºC)	δ T_{rMOD}-T_g (ºC)
Festuca	05/07	0.74	28.0 ± 1.2	1.3	6.6
	05/12	0.64	35.0 ± 0.7	0.4	1.6
	05/14	0.62	30.9 ± 1.7	-2.1	4.6
*	05/21		29.2 ± 1.1		
Poppy	05/07	0.38	33.9 ± 1.7	0.7	0.7
	05/12	0.47	35.7 ± 2.4	6.0	0.9
	05/14	0.45	29.1 ± 0.7	4.7	6.4
*	05/21		21.4 ± 1.0		
Vineyard	05/07	0.23	39.5 ± 2.4	-1.7	-6.7
	05/12	0.32	47 ± 4	-1	-11
**	05/14	0.30			
	05/21	0.21	40 ± 5	-1	-10
Barley	05/07	0.92	22.9 ± 0.4	2.0	10.5
	05/12	0.75	29.0 ± 1.4	0.9	7.6
	05/14	0.74	25.7 ± 0.9	-0.1	9.8
	05/21	0.9	18.8 ± 0.7	2.0	11.2
Corn	05/07	0.25	31 ± 3	8	2
	05/12	0.3	40 ± 3	4	-3
	05/14	0.27	28.9 ± 0.6	10.9	6.6
	05/21	0.21	28.0 ± 0.7	8.5	2.0

* Scan line corrector failure effect. ** Experimental issues.

CONCLUSIONS

A temperature disaggregation method using two different satellites has been evaluated in this work, using ground LST data, with the further aim of applying it to imminent Sentinel-2 images. The method used disaggregates the MODIS 1 km thermal resolution to the Landsat 30 m VNIR resolution. LST values from five agricultural fields with different crop types and coverage conditions, and measured in 4 different dates, were used to compare ground and disaggregated surface temperatures. Results obtained are encouraging, especially for non-irrigated fields, with differences within ±2 ºC, and an average estimation error of ±1.4 ºC. A longer time series of disaggregated images is required. The experimental campaign that began early May is planned to continue along the summer. Moreover we plan to use a set of SPOT 5 images from the SPOT 5 (Take 5) experiment, which simulates Sentinel-2 images, for the disaggregation of MODIS images.

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