1. About LandMOD ET mapper

The LandMOD ET mapper is a Matlab based GUI for implementation of SEBAL and METRIC models on Landsat and MODIS. Because the derived remote sensing inputs (NDVI, albedo, LST, and emissivity) are used, the toolbox can be easily implemented on other thermal sensors such as ASTER and ECOSTRESS. This work is a modified form of the code used in a recent automation of SEBAL/METRIC work (Bhattarai et al., 2017) (check Page 182, method #2 out of 3). Here, there is no need to specify reference station pixel and a distance matrix. The code works best on images with large agricultural pixels, as these models are mostly applicable for agricultural crops. The LandMOD ET mapper download folder "The LandMOD ET mapper" includes fully automated versions of METRIC and SEBAL models and all associated functions to run these models smoothly. Some data preprocessing is required (as in the case of all other model implementations), which is detailed in "Definition of all input variables". The input variables are minimized at best in the LandMOD ET mapper toolbox.

This toolbox is free to download and use. However, the authors are not liable for any results/conclusion from the model outputs. Because these models are highly sensitive to the accuracy of input variables, careful consideration should be given during the preparation of input variables. If you use this tool please cite following if you use this data:

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Main Functions

1) FindCandidate_Ag_pixels.m – finds candidate pixels
2) FindHotColdPixelsImage.m – selects hot and cold pixel
3) NetImageTimeSolarRadiation.m – comutes net radiation at the image time
4) METRIC.m – main METRIC model.
5) SEBAL.m – main SEBAL model
6) hourlyREF_ET_image.m – calculates hourly reference ET
7) DailyREF_ET_image.m – calculates daily references ET
8) Psih_SEBAL.m and Psim_SEBAL.m – run stability corrections during *H* iteration.

Contact:
Nishan Bhattarai, PhD
Currently at University of Michigan, Ann Arbor,
Email: nbhattar@syr.edu/nbhattar@umich.edu
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2. How to run the toolbox?

1> Download entire folder with GUI and all associated .m and .mat files (keep all files in the same folder).
2> Type following
cd 'FOLDERPATH' % this is your current folder
run LandMODETmapper.m
3> The toolbox will pop up
4> Load all inputs files, parameters (see "Definition of all input variables" for details).
5> Choose models (SEBAL, METRIC, or both), define output path, output formats, and select the visualization options.
6> After all inputs and parameters are set, click *RUN*.
7> A process bar will show the progress
8> Close the message box when asked and check the output folder.

3. Definition of all input variables

3.1 Image Metadata Inputs

yeardoy = year and day of the year.

landsattype = 5, 7 or 8 for Landsat, use 0 or 5 for MODIS.

b = sun elevation angle

imghr = local hour of image acquisition

imgmm = local minute of image acquisition

Descriptions: b, imghr, and imgmm are available in MTL file of Landsat image metadata. For MODIS, these are available in image format within MODIS LST data (MOD11A1, MOD11A2, MYD11A1, MYD11A2). All must have the same spatial extent (same size) and the same pixel size.

3.2 Remote sensing inputs

lst= land surface temperature (K) in GEOTIFF format

albedo= albedo (unitless)

ndvi= = NDVI (unitless)

emissivity= emissivity (unitless)

Descriptions: For MODIS, readily available MODIS products (e.g., MOD11A1; MOD09A1; MCD43A3) could be used. For Landsat, USGS has started distributing LST and emissivity products recently (https://landsat.usgs.gov/landsat-surface-temperature. NDVI is available within surface reflectance products (https://landsat.usgs.gov/landsat-science-data-products). LST and albedo can be derived from multiple ways from Landsat ((Jiménez-Muñoz and Sobrino, 2003; Liang, 2001; Tasumi et al., 2008).

3.3 Surface and Cloud Cover information

z0m = surface roughness (m)

Igood = binary image (1= no cloud, and 0= cloud).

Iwater = binary image (1= water, and 0= no water).

Ag_filter = binary image (1= agriculture, and 0 = non agriculture).

Descriptions: z0m can be derived using multiple ways (Allen et al., 2007; Paul et al., 2014; Van der Kwast et al., 2009; Waters et al., 2002) based on NDVI and vegetation height. Igood and Iwater can be created using F-mask products for Landsat (https://landsat.usgs.gov/landsat-science-data-products). Igood can be obtained from MODIS LST or cloud products. Simple land cover classification could be performed or readily available classified maps can be used to create Ag_filter and Iwater (e.g. https://www.mrlc.gov/tools, https://modis.gsfc.nasa.gov/data/dataprod/mod12.php).

3.4 Weather Inputs

rh_inst = relative humidity (%) at the image time

t_inst = air temperature (K) at the image time

u_inst = wind speed (m s^{-1}) at the image time

solar_inst = incoming solar radiation (W m^{-2}) at the image time

tmax_daily = max daily air temperature (K)

tmean_daily = mean daily air temperature (K)

tmin_daily = min daily air temperature (K)

solar_daily = daily mean solar radiation (W m^{-2})

rh_daily = daily mean relative humidity (%)

u_daily = daily mean wind speed (m s^{-1})

Descriptions: For small regions, single station data or mean of a network of stations could be used. Gridded weather data could be prepared using IDW, spline, krigging, or other interpolation methods. solar_inst could be estimated using doy, altitude, latitude, and sun elevation angle (see function: NetImageTimeSolarRadiation.m). solar_daily could also be estimated using FAO equations under clear sky conditions (ASCE-EWRI, 2005).

3.5 Reference and Weather information

Compute_kr = option to run skin evaporation to assign an ETrF value for the cold pixel in the METRIC Model

P_year (mm) = stacked image (1 to 365/366) of all daily precipitation (mm) within the study year

Eto_year (mm) = stacked image (1 to 365/366) of all daily ET0 (mm) within the study year

Soil = soiltype (codes: 1 to 9, described later)

kr = ETrF value for the cold pixel in METRIC, use 0 if Compute_kr is checked as No.

kr_max = Kr_max is the maximum ETrF value allowed for hot pixel (default is 0.15).

z_st_veg (m) = the grass height (m) from weather stations

zref = wind speed measurement height (m)

t_interval = length of the calculation period [hour]: i.e., 1 for hourly periods or 0.5 for 30-minute periods.

Lapse = lapse rate (0.0065 K per m)

zb (m) = blending height (m); default 200 m

dem = elevation (m)

Descriptions: Compute_kr will run skin evaporation to assign an ETrF value for the cold pixel in the METRIC Model. If this is yes then three more inputs must be provided: P_year (mm), stack of daily precipitation and (geotiff) from day 1 to day 365 (or 366); Eto_year, stack of short grass reference ET (GEOTIFF) from day 1 to day 365 (or 366); and soil type map. These stacked images don't have to be same dimensions as the input RS images (e.g. LST), as for Landsat image it'd be a very large file to process. However, these images should have geo-reference info (use GEOTIFF format) to link values with Input GRIDs. The soil codes (GEOTIFF) to be used are:

Code	**Soil type**
1	Sand
2	Loamy sand
3	Sandy loama
4	Loam
5	Silt loam
6	Silt
7	Silt clay loam
8	Silty clay
9	Clay

For US, soil info can be obtained from
https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053627

For more details, please read Allen et al. (1998) and Allen (2011).

3.6 Processing Parameters/Constants

kdaj = adjustment factor used for cold pixel ET (1.05)

k = Von Karman's constant (0.41)

3.7 Hot and cold pixel selection parameters

ff_open =number of pixels for removing small areas; if the pixelsize is large, this value is smaller, the default is 50 (Landsat), 10 for MODIS

lstlowerlimit =min value of lst (K), default is 275 K
lstupperlimit =upper max value of lst (K), default is 335K
lststep = bin value of lst used to create LST histograms (default is 0.5 K)
ndvistep = bin value of NDVI used to create LST histograms (default is 0.01)
pixellimit_bins = min number of pixels to be considered as a valid NDVI/lst bin
pixellimit_counts = min number of pixels (# hot and cold pixels) to be considered as a hot or cold pixel
lstwindow = a small buffer to incorporate pixels that have values that satisfy the search criteria values for LST, default is 0.25K
ndviwindow = a small buffer to incorporate pixels that have values that satisfy the search criteria values for NDVI, default is 0.01

Descriptions: The defaults parameters are automatically populated. Modify default parameters if needed. Try few images and calibrate against manually selected hot and cold pixels. But these parameters should work in almost all conditions.

4. Definition of all Outputs

The model outputs can be saved in defined output folder (i.e., *output path*) and output files are named based on the parameter (e.g., "le" for LE appended with model type and yeardoy of the input image). The outputs are saved in GEOTIFF and/or .mat formats. The output variables are listed below:

det_modelname_yeardoy (daily ET in mm)

inset_modelname_yeardoy (instantaneous ET mm hr^{-1})

h_modelname_yeardoy (instantaneous sensible heat flux in W m^{-2})

le_modelname_yeardoy (instantaneous latent heat flux in W m^{-2})

These two variables are specific to each model (ef to SEBAL and ETrF to METRIC).

ef_sebal_yeardoy (evaporative fraction)

etrf_metric_yeardoy (reference ET fraction)

There is also an option to save Rn and G outputs, which are common for both models.

Rn_yeardoy (instantaneous net radiative flux in W m^{-2})

G_yeardoy (instantaneous soil heat flux in W m^{-2})

The toolbox also allows for the visualization of key model outputs (LE and daily ET).

Make sure to change *output path* if MODIS and Landsat input have same yeardoy. Otherwise the output files will be replaced with the latest ones.

5. Batch processing

The toolbox is designed to run a single scene. In order to iterate the tool over a large number of images, a for loop can be used. All the required functions are provided in the downloaded folder. Following steps are recommended:

- Have all inputs ready with a unique identifier (e.g., yeardoy)
- Run a for loop over the list of identifier (e.g., list of yeardoys).
- Run Models
- Save output and append the unique identifier

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