agriwater

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Introduction

The Simple Algorithm for Evapotranspiration Retrieving (SAFER), which presents itself as a tool for the management of water resources, is based on the modeling of the $\frac{ET_a}{ET_0}$ ratio.

The surface albedo (α_0) was obtained from the reflectivity for each band (α_{pb}). For Landsat images was necessary to obtain the planetary albedo (α_{pb}) applying this equation for each band:

$$\alpha_{pb} = \frac{L_b \pi d^2}{R cos\phi}$$

Where L_b ($W\ m^{-2}\ sr^{-1}\ \mu m^{-1}$) is the spectral radiance for the wavelenghts of the band (b from 1 to 7), d (m) is the relative earth-sun distance, R ($W\ m^{-2}\ \mu m^{-1}$) is the mean solar irradiance at the top of the atmosphere for each band and ϕ the solar zenith angle.

The broadband α_p was calculated as the total sum of the differenct reflectivities α_{pb} values according to the weights for each band (w_p):

$$\alpha_p = \sum w_p \alpha_{pb}$$

The data of α_p was atmospherically corrected to obtain the value of surface albedo (α_0):

$$\alpha_0 = 0.61 \times \alpha_p + 0.08$$

The normalized difference vegetation index (NDVI) was calculated through the ratio of the difference between the planetary reflectivities of the near infrared (ρ_{nir}) and red (ρ_{red}) and their sum.

Net radiation ($R_N, W\ m^{-2}\ sr^{-1}\ \mu\ m^{-1}$) was obtained by the Slob's equation:

$$R_N = (1 - \alpha_0) R_G - \alpha_L \tau_{sw}$$

The ratio between actual evapotranspiration and reference evapotranspiration ($ET_a\ ET_0^{-1}$) was calculated according to:

$$\frac{ET_a}{ET_0} = exp\left[a + b\left(\frac{T_0}{\alpha_0 NDVI}\right)\right]$$

Actual evapotranspiration ($ET_a, mm\ day^{-1}$) was obtained according to:

$$ET_a = ET_0 \left(\frac{ET_a}{ET_0}\right)$$

Latent heat flux ($LE, MJ\ day^{-1}$) was obtained by:

$$LE = ET_a \times 2.45$$

Heat flow in the soil ($G, MJ\ day^{-1}$) was estimated through its realtionship with the net radiation:

$$\frac{G}{R_N} = 3.98\ exp(-31.89\alpha_0)$$

Sensible heat flux ($H, MJ\ day^{-1}$) was obtained as a residue of the energy balance:

$$H = R_N - LE - G$$

Loading package "agriwater" and dependencies

```
library(agriwater)
library(raster)
library(sp)
library(rgdal)
```

Sentinel-2

Data base preparation using a single agrometeorological station

In the workspace must be the following files:

- "B2.tif" - Blue - with wavelength between 0.439 - 0.535 micrometers - 10 m of resolution
- "B3.tif" - Green - with wavelength between 0.537 - 0.582 micrometers - 10 m of resolution
- "B4.tif" - Red - with wavelength between 0.646 - 0.685 micrometers - 10 m of resolution
- "B8.tif" - Near Infrared (NIR) - with wavelength between 0.767 - 0.908 micrometers - 10 m of resolution
- "mask.shp" - Shapefile of study area to mask digital images

All must have the same projection in decimal degrees (geographical)

Data base preparation using a grid of agrometeorological data

In the workspace must be the following files:

- "B2.tif" - Blue - with wavelength between 0.439 - 0.535 micrometers - 10 m of resolution
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- "B4.tif" - Red - with wavelength between 0.646 - 0.685 micrometers - 10 m of resolution
- "B8.tif" - Near Infrared (NIR) - with wavelength between 0.767 - 0.908 micrometers - 10 m of resolution
- "ET0.tif" - Reference evapotranspiration ($mm\ day^{-1}$) spatially interpolated by the user's preferred method.
- "RG.tif" - Solar radiation incident ($MJ\ day^{-1}$) spatially interpolated by the user's preferred method.
- "Ta.tif" - Average air temperature (Celsius degrees) spatially interpolated by the user's preferred method.
- "mask.shp" - Shapefile of study area to mask digital images

All must have the same projection in decimal degrees (geographical)

Modeling with a single agrometeorological station

Surface Albedo retrivieng at 10 m resolution

With Sentinel-2 bands in the workspace, run:

```
albedo_s2()
```

A raster file named "Alb_24.tif" will be generated with the same projection as the raster input.

Crop coefficient retrivieng at 10 m resolution

With Sentinel-2 bands in the workspace, run:

```
kc_s2(doy, RG, Ta, a, b)
```

Where:

- doy is the Day of Year (DOY)
- RG is the global solar radiation ($MJ\ day^{-1}$)
- Ta is the average air temperature (Celsius degrees)
- a is one of the regression coefficients of SAFER algorithm
- b is one of the regression coefficients of SAFER algorithm

Raster files named "Alb_24.tif", "NDVI.tif", "LST.tif", "Rn_MJ" and "kc.tif" will be generated with the same projection as the raster input.

Atual evapotranspiration retrivieng at 10 m resolution

With Sentinel-2 bands in the workspace, run:

```
evapo_s2(doy, RG, Ta, ET0, a, b)
```

Where:

- doy is the Day of Year (DOY)
- RG is the global solar radiation ($MJ\ day^{-1}$)
- Ta is the average air temperature (Celsius degrees)
- ET0 is the reference evapotranspiration ($mm\ day^{-1}$)
- a is one of the regression coefficients of SAFER algorithm
- b is one of the regression coefficients of SAFER algorithm

Raster files named "Alb_24.tif", "NDVI.tif", "LST.tif", "Rn_MJ", "kc.tif" and "evapo.tif" will be generated with the same projection as the raster input.

Radiation and energy balance at 10 m resolution

With Sentinel-2 bands in the workspace, run:

```
radiation_s2(doy, RG, Ta, ET0, a, b)
```

Where:

- doy is the Day of Year (DOY)
- RG is the global solar radiation ($MJ\ day^{-1}$)
- Ta is the average air temperature (Celsius degrees)
- ET0 is the reference evapotranspiration ($mm\ day^{-1}$)
- a is one of the regression coefficients of SAFER algorithm

- b is one of the regression coefficients of SAFER algorithm

Raster files named “Alb_24.tif”, “NDVI.tif”, “LST.tif”, “Rn_MJ”, “kc.tif” , “evapo.tif”, “LE_MJ.tif”, “H_MJ.tif” and “G_MJ.tif” will be generated with the same projection as the raster input.

Modeling with a grid of agrometeorological data

Surface Albedo retrivieng at 10 m resolution

With Sentinel-2 bands in the workspace, run:

```
albedo_s2()
```

A raster file named “Alb_24.tif” will be generated with the same projection as the raster input.

Crop coefficient retrivieng at 10 m resolution

With Sentinel-2 bands and agrometeorological data in the workspace, run:

```
kc_s2_grid(doy, a, b)
```

Where:

- doy is the Day of Year (DOY)
- a is one of the regression coefficients of SAFER algorithm
- b is one of the regression coefficients of SAFER algorithm

Raster files named “Alb_24.tif”, “NDVI.tif”, “LST.tif”, “Rn_MJ” and “kc.tif” will be generated with the same projection as the raster input.

Atual evapotranspiration retrivieng at 10 m resolution

With Sentinel-2 bands and agrometeorological data in the workspace, run:

```
evapo_s2_grid(doy, a, b)
```

Where:

- doy is the Day of Year (DOY)
- a is one of the regression coefficients of SAFER algorithm
- b is one of the regression coefficients of SAFER algorithm

Raster files named “Alb_24.tif”, “NDVI.tif”, “LST.tif”, “Rn_MJ”, “kc.tif” and “evapo.tif” will be generated with the same projection as the raster input.

Radiation and energy balance at 10 m resolution

With Sentinel-2 bands and agrometeorological data in the workspace, run:

```
radiation_s2_grid(doy, a, b)
```

Where:

- doy is the Day of Year (DOY)
- a is one of the regression coefficients of SAFER algorithm
- b is one of the regression coefficients of SAFER algorithm

Raster files named “Alb_24.tif”, “NDVI.tif”, “LST.tif”, “Rn_MJ”, “kc.tif” , “evapo.tif”, “LE_MJ.tif”, “H_MJ.tif” and “G_MJ.tif” will be generated with the same projection as the raster input.

Landsat-8 with thermal bands

Data base preparation using a single agrometeorological station

In the workspace must be the following files:

- "B1.tif" - Ultra Blue (coastal/aerosol) - with wavelength between 0.435 - 0.451 micrometers - 30 m of resolution
- "B2.tif" - Blue - with wavelength between 0.452 - 0.512 micrometers micrometers - 30 m of resolution
- "B3.tif" - Green - with wavelength between 0.533 - 0.590 micrometers - 30 m of resolution
- "B4.tif" - Red - with wavelength between 0.636 - 0.673 micrometers - 30 m of resolution
- "B5.tif" - Near Infrared (NIR) - with wavelength between 0.851 - 0.879 micrometers - 30 m of resolution
- "B6.tif" - Shortwave Infrared (SWIR) 1 - with wavelength between 1.566 - 1.651 micrometers - 30 m of resolution
- "B7.tif" - Shortwave Infrared (SWIR) 2 - with wavelength between 2.107 - 2.294 micrometers - 30 m of resolution
- "B10.tif" - Thermal Infrared (TIRS) 1 - with wavelength between 10.60 - 11.19 micrometers - 100 m of resolution
- "B11.tif" - Thermal Infrared (TIRS) 2 - with wavelength between 11.50 - 12.51 micrometers - 100 m of resolution
- "mask.shp" - Shapefile of study area to mask digital images
- ".txt" - a text file of metadata provided with Landsat-8 images

All must have the same projection in decimal degrees (geographical)

Data base preparation using a grid of agrometeorological data

In the workspace must be the following files:

- "B1.tif" - Ultra Blue (coastal/aerosol) - with wavelength between 0.435 - 0.451 micrometers - 30 m of resolution
- "B2.tif" - Blue - with wavelength between 0.452 - 0.512 micrometers - 30 m of resolution
- "B3.tif" - Green - with wavelength between 0.533 - 0.590 micrometers - 30 m of resolution
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- "mask.shp" - Shapefile of study area to mask digital images

- ".txt" - a text file of metadata provided with Landsat-8 images
- "ET0.tif" - Reference evapotranspiration ($mm\ day^{-1}$) spatially interpolated by the user's preferred method.
- "RG.tif" - Solar radiation incident ($MJ\ day^{-1}$) spatially interpolated by the user's preferred method.
- "Ta.tif" - Average air temperature (Celsius degrees) spatially interpolated by the user's preferred method.

All must have the same projection in decimal degrees (geographical)

Modeling with a single agrometeorological station

Reflectance at 30 m resolution

With Landsat-8 bands in the workspace, run:

```
reflectance_l8()
```

Raster files named from "B1_reflectance_landsat8" to "B7_reflectance_landsat8" will be generated with the same projection as the raster input.

Surface Albedo retrivieng at 30 m resolution

With Landsat-8 bands in the workspace, run:

```
albedo_l8()
```

A raster file named "Alb_24.tif" will be generated with the same projection as the raster input.

Crop coefficient retrivieng at 30 m resolution

With Landsat-8 bands in the workspace, run:

```
kc_l8t(doy, RG, Ta, a, b)
```

Where:

- doy is the Day of Year (DOY)
- RG is the global solar radiation ($MJ\ day^{-1}$)
- Ta is the average air temperature (Celsius degrees)
- a is one of the regression coefficients of SAFER algorithm
- b is one of the regression coefficients of SAFER algorithm

Raster files named "Alb_24.tif", "NDVI.tif", "LST.tif", "Rn_MJ" and "kc.tif" will be generated with the same projection as the raster input.

Atual evapotranspiration retrivieng at 30 m resolution

With Landsat-8 bands in the workspace, run:

```
evapo_l8t(doy, RG, Ta, ET0, a, b)
```

Where:

- doy is the Day of Year (DOY)
- RG is the global solar radiation ($MJ\ day^{-1}$)

- Ta is the average air temperature (Celsius degrees)
- ET0 is the reference evapotranspiration ($mm\ day^{-1}$)
- a is one of the regression coefficients of SAFER algorithm
- b is one of the regression coefficients of SAFER algorithm

Raster files named "Alb_24.tif", "NDVI.tif", "LST.tif", "Rn_MJ", "kc.tif" and "evapo.tif" will be generated with the same projection as the raster input.

Radiation and energy balance at 30 m resolution

With Landsat-8 bands in the workspace, run:

```
radiation_l8t(doy, RG, Ta, ET0, a, b)
```

Where:

- doy is the Day of Year (DOY)
- RG is the global solar radiation ($MJ\ day^{-1}$)
- Ta is the average air temperature (Celsius degrees)
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- b is one of the regression coefficients of SAFER algorithm

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Modeling with a grid of agrometeorological data

Reflectance at 30 m resolution

With Landsat-8 bands in the workspace, run:

```
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```

Raster files named from "B1_reflectance_landsat8" to "B7_reflectance_landsat8" will be generated with the same projection as the raster input.

Surface Albedo retrivieng at 30 m resolution

With Landsat-8 bands in the workspace, run:

```
albedo_l8()
```

A raster file named "Alb_24.tif" will be generated with the same projection as the raster input.

Crop coefficient retrivieng at 30 m resolution

With Sentinel-2 bands in the workspace and agrometeorological data, run:

```
kc_l8t_grid(doy, a, b)
```

Where:

- doy is the Day of Year (DOY)
- a is one of the regression coefficients of SAFER algorithm
- b is one of the regression coefficients of SAFER algorithm

Raster files named "Alb_24.tif", "NDVI.tif", "LST.tif", "kc.tif" will be generated with the same projection as the raster input.

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With Landsat-8 bands in the workspace and agrometeorological data, run:

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Landsat-8 without thermal bands

Data base preparation using a single agrometeorological station

In the workspace must be the following files:

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- "B4.tif" - Red - with wavelength between 0.636 - 0.673 micrometers - 30 m of resolution
- "B5.tif" - Near Infrared (NIR) - with wavelength between 0.851 - 0.879 micrometers - 30 m of resolution
- "B6.tif" - Shortwave Infrared (SWIR) 1 - with wavelength between 1.566 - 1.651 micrometers - 30 m of resolution
- "B7.tif" - Shortwave Infrared (SWIR) 2 - with wavelength between 2.107 - 2.294 micrometers - 30 m of resolution
- "mask.shp" - Shapefile of study area to mask digital images
- ".txt" - a text file of metadata provided with Landsat-8 images

All must have the same projection in decimal degrees (geographical)

Data base preparation using a grid of agrometeorological data

In the workspace must be the following files:

- "B1.tif" - Ultra Blue (coastal/aerosol) - with wavelength between 0.435 - 0.451 micrometers - 30 m of resolution
- "B2.tif" - Blue - with wavelength between 0.452 - 0.512 micrometers - 30 m of resolution
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- "Ta.tif" - Average air temperature (Celsius degrees) spatially interpolated by the user's preferred method.

All must have the same projection in decimal degrees (geographical)

Modeling with a single agrometeorological station

Surface Albedo retrivieng at 30 m resolution

With Landsat-8 bands in the workspace, run:

```
albedo_l8()
```

A raster file named "Alb_24.tif" will be generated with the same projection as the raster input.

Crop coefficient retrivieng at 30 m resolution

With Landsat-8 bands in the workspace, run:

```
kc_l8(doy, RG, Ta, a, b)
```

Where:

- doy is the Day of Year (DOY)
- RG is the global solar radiation ($MJ\ day^{-1}$)
- Ta is the average air temperature (Celsius degrees)
- a is one of the regression coefficients of SAFER algorithm
- b is one of the regression coefficients of SAFER algorithm

Raster files named "Alb_24.tif", "NDVI.tif", "LST.tif", "Rn_MJ" and "kc.tif" will be generated with the same projection as the raster input.

Atual evapotranspiration retrivieng at 30 m resolution

With Landsat-8 bands in the workspace, run:

```
evapo_l8(doy, RG, Ta, ET0, a, b)
```

Where:

- doy is the Day of Year (DOY)
- RG is the global solar radiation ($MJ\ day^{-1}$)
- Ta is the average air temperature (Celsius degrees)
- ET0 is the reference evapotranspiration ($mm\ day^{-1}$)
- a is one of the regression coefficients of SAFER algorithm
- b is one of the regression coefficients of SAFER algorithm

Raster files named "Alb_24.tif", "NDVI.tif", "LST.tif", "Rn_MJ", "kc.tif" and "evapo.tif" will be generated with the same projection as the raster input.

Radiation and energy balance at 30 m resolution

With Landsat-8 bands in the workspace, run:

```
radiation_l8(doy, RG, Ta, ET0, a, b)
```

Where:

- doy is the Day of Year (DOY)
- RG is the global solar radiation ($MJ\ day^{-1}$)
- Ta is the average air temperature (Celsius degrees)
- ET0 is the reference evapotranspiration ($mm\ day^{-1}$)
- a is one of the regression coefficients of SAFER algorithm
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Raster files named "Alb_24.tif", "NDVI.tif", "LST.tif", "Rn_MJ", "kc.tif" , "evapo.tif", "LE_MJ.tif", "H_MJ.tif" and "G_MJ.tif" will be generated with the same projection as the raster input.

Modeling with a grid of agrometeorological data

Reflectance at 30 m resolution

With Landsat-8 bands in the workspace, run:

```
reflectance_l8()
```

Raster files named from "B1_reflectance_landsat8" to "B7_reflectance_landsat8" will be generated with the same projection as the raster input.

Surface Albedo retrivieng at 30 m resolution

With Landsat-8 bands in the workspace, run:

```
albedo_l8()
```

A raster file named "Alb_24.tif" will be generated with the same projection as the raster input.

Crop coefficient retrivieng at 30 m resolution

With Sentinel-2 bands in the workspace, run:

```
kc_l8_grid(doy, a, b)
```

Where:

- doy is the Day of Year (DOY)
- a is one of the regression coefficients of SAFER algorithm
- b is one of the regression coefficients of SAFER algorithm

Raster files named "Alb_24.tif", "NDVI.tif", "LST.tif", "Rn_MJ" and "kc.tif" will be generated with the same projection as the raster input.

Atual evapotranspiration retrivieng at 30 m resolution

With Landsat-8 bands in the workspace and agrometeorological data, run:

```
evapo_l8_grid(doy, a, b)
```

Where:

- doy is the Day of Year (DOY)
- a is one of the regression coefficients of SAFER algorithm
- b is one of the regression coefficients of SAFER algorithm

Raster files named "Alb_24.tif", "NDVI.tif", "LST.tif", "Rn_MJ", "kc.tif" and "evapo.tif" will be generated with the same projection as the raster input.

Radiation and energy balance at 30 m resolution

With Landsat-8 bands and agrometeorological data in the workspace, run:

```
radiation_l8_grid(doy, RG, Ta, ET0, a, b)
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Where:

- doy is the Day of Year (DOY)
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Raster files named "Alb_24.tif", "NDVI.tif", "LST.tif", "Rn_MJ", "kc.tif" , "evapo.tif", "LE_MJ.tif", "H_MJ.tif" and "G_MJ.tif" will be generated with the same projection as the raster input.

MODIS

Data base preparation using a single agrometeorological station

In the workspace must be the following files:

- "B1.tif" - Red - with wavelength between 0.620 - 0.670 micrometers - 250 m of resolution
- "B2.tif" - Near Infrared (NIR) - with wavelength between 0.841 - 0.876 micrometers - 250 m of resolution
- "mask.shp" - Shapefile of study area to mask digital images

All must have the same projection in decimal degrees (geographical)

Data base preparation using a grid of agrometeorological data

In the workspace must be the following files:

- "B1.tif" - Red - with wavelength between 0.620 - 0.670 micrometers - 250 m of resolution
- "B2.tif" - Near Infrared (NIR) - with wavelength between 0.841 - 0.876 micrometers - 250 m of resolution
- "mask.shp" - Shapefile of study area to mask digital images
- "ET0.tif" - Reference evapotranspiration ($mm\ day^{-1}$) spatially interpolated by the user's preferred method.
- "RG.tif" - Solar radiation incident ($MJ\ day^{-1}$) spatially interpolated by the user's preferred method.
- "Ta.tif" - Average air temperature (Celsius degrees) spatially interpolated by the user's preferred method.

All must have the same projection in decimal degrees (geographical)

Modeling with a single agrometeorological station

Surface Albedo retrivieng at 250 m resolution

With MODIS bands in the workspace, run:

```
albedo_modis()
```

A raster file named "Alb_24.tif" will be generated with the same projection as the raster input.

Crop coefficient retrivieng at 250 m resolution

With MODIS bands in the workspace, run:

```
kc_modis(doy, RG, Ta, a, b)
```

Where:

- doy is the Day of Year (DOY)
- RG is the global solar radiation ($MJ\ day^{-1}$)
- Ta is the average air temperature (Celsius degrees)
- a is one of the regression coefficients of SAFER algorithm
- b is one of the regression coefficients of SAFER algorithm

Raster files named "Alb_24.tif", "NDVI.tif", "LST.tif", "Rn_MJ" and "kc.tif" will be generated with the same projection as the raster input.

Atual evapotranspiration retrivieng at 250 m resolution

With MODIS bands in the workspace, run:

```
evapo_modis(doy, RG, Ta, ET0, a, b)
```

Where:

- doy is the Day of Year (DOY)
- RG is the global solar radiation ($MJ\ day^{-1}$)
- Ta is the average air temperature (Celsius degrees)
- ET0 is the reference evapotranspiration ($mm\ day^{-1}$)
- a is one of the regression coefficients of SAFER algorithm

- b is one of the regression coefficients of SAFER algorithm

Raster files named "Alb_24.tif", "NDVI.tif", "LST.tif", "Rn_MJ", "kc.tif" and "evapo.tif" will be generated with the same projection as the raster input.

Radiation and energy balance at 250 m resolution

With MODIS bands in the workspace, run:

```
radiation_modis(doy, RG, Ta, ET0, a, b)
```

Where:

- doy is the Day of Year (DOY)
- RG is the global solar radiation ($MJ\ day^{-1}$)
- Ta is the average air temperature (Celsius degrees)
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- a is one of the regression coefficients of SAFER algorithm
- b is one of the regression coefficients of SAFER algorithm

Raster files named "Alb_24.tif", "NDVI.tif", "LST.tif", "Rn_MJ", "kc.tif" , "evapo.tif", "LE_MJ.tif", "H_MJ.tif" and "G_MJ.tif" will be generated with the same projection as the raster input.

Modeling with a grid of agrometeorological data

Surface Albedo retrivieng at 250 m resolution

With MODIS bands in the workspace, run:

```
albedo_modis()
```

A raster file named "Alb_24.tif" will be generated with the same projection as the raster input.

Crop coefficient retrivieng at 250 m resolution

With MODIS bands in the workspace, run:

```
kc_modis_grid(doy, a, b)
```

Where:

- doy is the Day of Year (DOY)
- a is one of the regression coefficients of SAFER algorithm
- b is one of the regression coefficients of SAFER algorithm

Raster files named "Alb_24.tif", "NDVI.tif", "LST.tif", "Rn_MJ" and "kc.tif" will be generated with the same projection as the raster input.

Atual evapotranspiration retrivieng at 250 m resolution

With MODIS bands and agrometeorological data in the workspace, run:

```
evapo_modis_grid(doy, a, b)
```

Where:

- doy is the Day of Year (DOY)
- a is one of the regression coefficients of SAFER algorithm

- b is one of the regression coefficients of SAFER algorithm

Raster files named “Alb_24.tif”, “NDVI.tif”, “LST.tif”, “Rn_MJ”, “kc.tif” and “evapo.tif” will be generated with the same projection as the raster input.

Radiation and energy balance at 250 m resolution

With MODIS bands in the workspace, run:

```
radiation_modis_grid(doy, a, b)
```

Where:

- doy is the Day of Year (DOY)
- a is one of the regression coefficients of SAFER algorithm
- b is one of the regression coefficients of SAFER algorithm

Raster files named “Alb_24.tif”, “NDVI.tif”, “LST.tif”, “Rn_MJ”, “kc.tif” , “evapo.tif”, “LE_MJ.tif”, “H_MJ.tif” and “G_MJ.tif” will be generated with the same projection as the raster input.