

SUPPLEMENTARY FILE S1

Tutorial: using the ATl_c method

The tutorial presented below is aimed to show, step by step, how to produce an ATl_c map based on the approach presented in the manuscript. The main steps consist of: data acquisition (I), production of albedo map (II), production of temperature difference map (IV), topographic correction of albedo and temperature difference maps (III and V) as well as atmospheric correction and production of the final apparent thermal inertia map (IX and X). We provide below the specific instructions for SAGA GIS and ArcGIS, but the steps will be similar for most of GIS softwares. The output ATl_c map is provided in the GeoTIFF format.

The data used in the tutorial are those used in Section 3 (Application) of this article:

THEMIS IR Day: I17277013 and I07967021

THEMIS IR Night: I16872020 and I08186009

CTX: P01_001417_1718_XI_08S085W and P01_001351_1717_XI_08S084W

HRSC DTM: h0380_0001.da4.53.tif

- I. **Acquire the pair of THEMIS thermal images** (day and nighttime) for your area of interest
 1. Check the data availability for particular regions on Mars in JMARS software
 - a) Use the following parameters to search for **high-quality images** only:
 - minimum and maximum “summing” parameters set to 1 (full-resolution images)
 - the minimum and maximum “image rating values” set to 4 and 7 respectively (subjective assessment of image quality ranging from 1-unusable, to 7-very good)
 - b) Daytime image acquisition time should be as close as possible to the moment of the maximum daily temperature for your area of interest
 - Use the **MARSTHERM** model to find the time of maximum daily temperature for the selected solar longitude and latitude
 - ✓ Create an account on <https://marstherm.boulder.swri.edu>
 - ✓ In the *Models* section, click *New Model*
 - ✓ Set: *Lowest Latitude*, *Latitudes Per Run*, *Latitude Increment*, *Mode*, *Solar Longitude*. Settings used in our manuscript for THEMIS I17277013: -10.5, 1, 5, Diurnal, 319.1, respectively
 - c) Nighttime image – the acquisition time is not that crucial as daytime
 - Select images taken between 4 and 7 AM
 2. Copy the THEMIS image IDs to **process the images** in <http://thmproc.mars.asu.edu/> in order to yield the **brightness temperature** data
 - You can use either all Standard Processings (but without Unrectify) or only the UDDW (The Undrift-Dewobble filter) processing to save time (better for large images)
 - Select the projection you need

- Select output format, in the manuscript, we use Brightness Temperature – 32-bit ISIS Cube – 9th band
- Download the image once the process is complete

II. Make an **albedo map based on CTX**

1. [Find CTX images covering your area of interest via JMARS](#)

2. [Process them in http://pilot.wr.usgs.gov/](http://pilot.wr.usgs.gov/)

- Select Mars/MRO/CTX/Mapped
- Go to the ‘Advanced’ lap
- In ‘Identifier Text Match’ select ‘product id’ and insert your CTX image ID (for instance P01_001417_1718_XI_08S085W, as in our Application)
- Select the image in the box next to it and click the ‘download to process’ option (the down arrow sign in the upper right corner)
- Select ‘Projection on the Web (POW)’ and click ‘Go!’
- Click ‘Submit’ (you have to create an account in the Astrology Science Center and login)
- Complete the data fields, remember that the albedo and thermal data should be in the same coordinate system and have the same resolution
- After this operation, you will receive the referenced albedo data of the fixed spatial resolution

III. **Topography correction of A**

- Calculate slopes and aspects from DTM (in degrees), for example using HRSC/MEx (High Resolution Stereo Camera onboard Mars Express orbiter)
 - In SAGA GIS (free software): Terrain Analysis / Morphometry / Slope, Aspect, Curvature
 - In ArcGIS: Spatial Analyst Tools / Surface / Aspect (or Slope)
- Calculate the equation for $\cos(i)$ presented below (Eq. 7 adapted to GIS in the Supplementary file 2) by copy and paste to any Raster/Grid Calculator tool in the selected GIS software

$$\cos(0.017453*(s))*(\cos(0.017453*(i)))+\sin(0.017453*(s))*((1-(\cos(0.017453*(i)))^2)^{0.5}*\cos(0.017453*((-57.29674*(\cos(((\cos(0.017453*(i)))*\sin(0.017453*(\varphi)))-0.4256*\sin(0.017453*(L_s)+0.093*\sin(0.017453*(L_s-251)))))/((1-(\cos(0.017453*(i)))^2)^{0.5}*\cos(0.017453*(\varphi))))))-0.017453*((180-e)))$$

where i is incidence angle ($^{\circ}$), L_s is the solar longitude ($^{\circ}$), φ is latitude ($^{\circ}$), s is slope angle ($^{\circ}$), e is aspect ($^{\circ}$) and t is local solar time (h). φ represents the range of -90, 90. Note that: a) negative pixels values were converted to zero; b) where $t < 12$, the constant number 57.29674 is positive, otherwise – negative.

- Delete the $\cos(i)$ values < 0.188 (equivalent of incidence angle $> 79^{\circ}$)
- i , L_s and φ can be found in the Mars Image Explorer or another metadata available. Here are the examples of CTX images used in our application:

[#start](http://viewer.mars.asu.edu/planetview/inst/ctx/P01_001417_1718_XI_08S085W)

[#start](http://viewer.mars.asu.edu/planetview/inst/ctx/P01_001351_1717_XI_08S084W)

- Calculate: CTX (in I/F; result of point II) / $\cos(i)$ (result of point III.2)
- Calculate: $1 - A$ (albedo) in any Raster/Grid Calculator tool in GIS software

IV. Calculation of ΔT

1. $\Delta T = \text{THEMIS}_{\text{DAY}} - \text{THEMIS}_{\text{NIGHT}}$
 - a) In SAGA GIS: Grid / Calculus / Grid Calculator
 - b) In ArcGIS: Spatial Analyst Tools / Map Algebra / Raster Calculator
2. Convert negative values of ΔT to 0, if present

V. Topographic correction of ΔT

1. Use slopes and aspects from point III.1
2. Use the below equation to copy and paste to any Raster/Grid Calculator in the selected GIS software (Eq. 8 adapted to GIS in the Supplementary file 2)

$$\begin{aligned} & \{[\cos(0.017453*(s)) * (\cos(0.017453*(-t_1*15+180))) * \cos(\text{asin}(- \\ & 0.4256*\sin(0.017453*(L_s)+0.093*\sin(0.017453*(L_s- \\ & 251)))) * \cos(0.017453*(\varphi))+0.4256*\sin(0.017453*(L_s)+0.093*\sin(0.017453*(L_s- \\ & 251))) * \sin(0.017453*(\varphi)) + \sin(0.017453*(s)) * ((1-(\cos(0.017453*(-t_1*15+180))) * \cos(\text{asin}(- \\ & 0.4256*\sin(0.017453*(L_s)+0.093*\sin(0.017453*(L_s- \\ & 251)))) * \cos(0.017453*(\varphi))+0.4256*\sin(0.017453*(L_s)+0.093*\sin(0.017453*(L_s- \\ & 251))) * \sin(0.017453*(\varphi)))^2)^{0.5} * \cos(0.017453*((57.29674*(\cos(((\cos(0.017453*(- \\ & t_1*15+180))) * \cos(\text{asin}(-0.4256*\sin(0.017453*(L_s)+0.093*\sin(0.017453*(L_s- \\ & 251)))) * \cos(0.017453*(\varphi))+0.4256*\sin(0.017453*(L_s)+0.093*\sin(0.017453*(L_s- \\ & 251))) * \sin(0.017453*(\varphi))) * \sin(0.017453*(\varphi)) - \\ & 0.4256*\sin(0.017453*(L_s)+0.093*\sin(0.017453*(L_s-251)))) / ((1-(\cos(0.017453*(- \\ & t_1*15+180))) * \cos(\text{asin}(-0.4256*\sin(0.017453*(L_s)+0.093*\sin(0.017453*(L_s- \\ & 251)))) * \cos(0.017453*(\varphi))+0.4256*\sin(0.017453*(L_s)+0.093*\sin(0.017453*(L_s- \\ & 251))) * \sin(0.017453*(\varphi)))^2)^{0.5} * \cos(0.017453*(\varphi)))) - 0.017453*((180-e)))] / (t_d - t_1)\} + \end{aligned}$$

$$\begin{aligned} & \{[\cos(0.017453*(s)) * (\cos(0.017453*(-t_2*15+180))) * \cos(\text{asin}(- \\ & 0.4256*\sin(0.017453*(L_s)+0.093*\sin(0.017453*(L_s- \\ & 251)))) * \cos(0.017453*(\varphi))+0.4256*\sin(0.017453*(L_s)+0.093*\sin(0.017453*(L_s- \\ & 251))) * \sin(0.017453*(\varphi)) + \sin(0.017453*(s)) * ((1-(\cos(0.017453*(-t_2*15+180))) * \cos(\text{asin}(- \\ & 0.4256*\sin(0.017453*(L_s)+0.093*\sin(0.017453*(L_s- \\ & 251)))) * \cos(0.017453*(\varphi))+0.4256*\sin(0.017453*(L_s)+0.093*\sin(0.017453*(L_s- \\ & 251))) * \sin(0.017453*(\varphi)))^2)^{0.5} * \cos(0.017453*((57.29674*(\cos(((\cos(0.017453*(- \\ & t_2*15+180))) * \cos(\text{asin}(-0.4256*\sin(0.017453*(L_s)+0.093*\sin(0.017453*(L_s- \\ & 251)))) * \cos(0.017453*(\varphi))+0.4256*\sin(0.017453*(L_s)+0.093*\sin(0.017453*(L_s- \\ & 251))) * \sin(0.017453*(\varphi))) * \sin(0.017453*(\varphi)) - \\ & 0.4256*\sin(0.017453*(L_s)+0.093*\sin(0.017453*(L_s-251)))) / ((1-(\cos(0.017453*(- \\ & t_2*15+180))) * \cos(\text{asin}(-0.4256*\sin(0.017453*(L_s)+0.093*\sin(0.017453*(L_s- \\ & 251)))) * \cos(0.017453*(\varphi))+0.4256*\sin(0.017453*(L_s)+0.093*\sin(0.017453*(L_s- \\ & 251))) * \sin(0.017453*(\varphi)))^2)^{0.5} * \cos(0.017453*(\varphi)))) - 0.017453*((180-e)))] / (t_d - t_2)\} + \\ & (\dots) \end{aligned}$$

where L_s - the solar longitude ($^\circ$), φ - latitude ($^\circ$), s - slope angle ($^\circ$), e - aspect ($^\circ$), t_{1-10} - middle points of the sub-intervals (we recommend the number of subintervals of 10,

but it might be variable), and t_d (a time when the daily image was taken). For sub-intervals where $t < 12$, the constant number 57.29674 is positive, otherwise – negative.

- a) To calculate the middle points of ten time intervals (t_1 - t_{10}) you can:
 - Either use the appended IDL routine (Supplementary file 4)
 - Or calculate intervals as follows:
 - ✓ Take the time gap between nighttime and daytime acquisition time
 - ✓ Divide this time period by 10
 - ✓ Start with the middle point of the interval
- b) L_s and ϕ can be found in the Mars Image Explorer or another metadata available. In our application described in the manuscript we have used:

<http://viewer.mars.asu.edu/planetview/inst/themis/I17277013#start>

<http://viewer.mars.asu.edu/planetview/inst/themis/I07967021#start>

<http://viewer.mars.asu.edu/planetview/inst/themis/I16872020#start>

<http://viewer.mars.asu.edu/planetview/inst/themis/I08186009#start>

- c) For every subinterval, convert negative pixel values to zeros.
 - d) Delete values < 0.188 (the equivalent of incidence angle $> 79^\circ$) from the latest subinterval that is t_{10} .
 - e) Sum up all the subintervals in e.g. Raster (Grid) Calculator in the selected GIS software
3. Find the summed up value for the flat areas (F), which is typically represented by the mode
 - a) In SAGA GIS e.g.: right click on the map and select *Histogram*
 - b) Find the mode value on the displayed histogram

VI. Calculation of ΔT_c

1. Apply the following equation: $\Delta T_c = \Delta T * F / F_0$, where ΔT_c is corrected ΔT , F is the sum of all subintervals and F_0 is the F value for flat areas

VII. Calculate ATI from $ATI = (1-A)/\Delta T$

VIII. Conversion of calories (cal) joules (J)

1. ATI from point 6 is in $(\text{cal cm}^{-2} \text{K}^{-1} \text{s}^{-1/2})$ units
2. To convert ATI values to SI units $(\text{J m}^{-2} \text{K}^{-1} \text{s}^{-1/2})$, multiply them by 41855

IX. Atmospheric correction and final ATI_c

1. Calculate the corrected ATI (ATI_c) from the formula $ATI_c = (0.913 - 0.244 * \tau) * ATI - 14 + 79 * \tau$ (Eq. 10 from the main text) where ATI is the result from point VII, τ is visible dust opacity (no units, scaling factor from 0 to 1)
 - a) To acquire visible dust opacity data, visit the website: http://www-mars.lmd.jussieu.fr/mars/dust_climatology/
 - b) Choose MY (martian year) you are interested in. Datasets are in NetCDF format

X. Apply horizontal surface correction (taking the horizons into account in calculating the incident flux on an inclined surface)

1. Applied for A and ΔT
2. We used Terrain Analysis/Lighting, Visibility/Analytical Hillshading tool in SAGA GIS to eliminate pixels where horizons reduce the total energy input due to shading for any interval (morning and evening intervals may be sensitive to such shading)
 - a) *North Azimuth* and *Height* parameters (90° – incidence angle) are imported from metadata of the images

b) Values >1.57 (in radians) are removed (they represent an angle $>90^\circ$) from our calculations

XI. The final ATl_c map may be exported from the GIS software to the most popular image file extension such as **GeoTIFF**