# 9. ESTIMATION OF ET FROM REMOTE SENSING AND METEOROLOGICAL DATA USING THE METHOD PROPOSED BY JACKSON

By: **Alfredo G. García[1], Carlos M. Di Bella [1] and Tomás Hartmann [1]**

## 9.1. Relevance of the application

The evapotranspiration (ET) is the term used to describe the amount of water, expressed in mm/day, which is effectively lost from the earth surface into the atmosphere by soil surface evaporation and plant transpiration. ET is an important component of the water cycle and its importance in the hydrological cycle makes necessary its accurate quantification both for use in the field of agricultural production and for planning and management of water resources. Thus, ET plays a key role in the calculation of the soil water balance, either for the detection of water stress conditions, their use as input variable in crop yield models or the study of ecosystem functioning and its relationship to local and regional climate, among others.

The estimation of ET using remote sensing is based on the evaluation of the surface energy balance (Paruelo, 2008). These models assume that the ET process uses some of the available energy (net radiation) to vaporize the water. The approach uses information derived from remote sensing to estimate surface properties such as albedo, leaf area index, vegetation indices, surface roughness, emissivity and surface temperature, and estimate ET as a residual from the surface energy balance equation (Gowda et al, 2007):

$$LE=Rn-G-H \qquad \text{(Eq. 1)}$$

where Rn is net radiation (Wm-2). LE, H and G are the latent heat, sensible and geothermal fluxes (all in Wm-2). LE is converted to ET (mmd-1) by dividing it by the latent heat of vaporization (~ 2.45 MJkg-1).

## 9.2. Objective of the application

In order to provide a useful tool in the calculation of water balances for fields of the central region of Argentina, the overall objective of this exercise is to provide a procedure for the estimation of evapotranspiration (ET) for clear sky conditions, combining information derived from remote sensing in conjunction with meteorological data.

## 9.3. Data used

### 9.3.1. Local / regional (in-situ) data

Initial data used to derive the evapotranspiration (ET) are:

- Land Surface Temperature (LST) derived from MODIS Land Surface Temperature and Emissivity product (Land Surface Temperature MOD11A2 product): mod11a2.2009145.LST_Day_1km.tif;

[1] Instituto Nacional de Tecnología Agropecuaria
(Corresponding author Alfredo García) email: aggarcia@agro.uba.ar

- Surface Spectral Reflectances derived from MODIS Surface Reflectances product (Surface Reflectance bands 1 and 2 MOD09A1 product): mod09a1.2009145.sur_refl_b01.tif (b01: band 1 - red and b02: band 2 - near infrared);
- Meteorological ground station air temperature data: airtemp.2009145.tif (produced using local ground meteorological station data by INTA);
- Digital elevation model derived from the Shuttle Radar Topography Mission (SRTM);
- Net radiation: netrad.2009145.tif (produced by INTA following the approach proposed by Kumar et al. (1997)).

Further details on the data used for this exercise are provided in table 9.1.

| Product | Temporal Resolution | Spatial Resolution | Units | Scaling Factor | Data Source |
|---|---|---|---|---|---|
| Land Surface Temperature | 8 days | 1 km | Kelvin | 0.02 | MODIS[1] |
| Surface Reflectance (bands 1 and 2) | 8 days | 500 m | Reflectance | 0.0001 | MODIS[1] |
| Air Temperature | 8days | 500 m | Celsius | - | INTA[2] |
| Net Radiation | 8 days | 500 m | $MJ.m^{-2}.d^{-1}$ | - | INTA[2] |

***Table 9.1 Data sets characteristics***

([1] Warehouse Inventory Search Tool available at https://wist.echo.nasa.gov/api/ and [2] produced at INTA)

### 9.3.2. Data from GEONETCast – DevCoCast

Although the methodology proposed here does not use data from GEONETCast at this moment, INTA plans to use products from the GEONETCast – DevCoCast data stream in future versions to derive the ET. It should be noted that some of the products do not cover the full geographic extent of the study area.

## 9.4. Methodology and description of the study area

### 9.4.1. Methodology

To estimate the ET at regional scale use will be made of the method originally proposed by Jackson et al. (1977), the so-called "Simplified Method", which calculates the daily ET ($ET_d$ in mmd-1) relating the net radiation received by the surface and its temperature difference with the near-surface air, based on the following equation:

$$ET_d = NR_d - B(T_s - T_a)^n \quad \text{(Eq. 2)}$$

where $NR_d$ ($mmd^{-1}$) is the daily net radiation, $T_s$ (K) is the surface radiant temperature, $T_a$ (K) is the air temperature (near surface), B ($mmd^{-1}K^{-1}$) and n are parameters that depend on the type and condition of vegetation.

Although it is a relatively simple method, it has been used successfully in estimating the evapotranspiration of agricultural crops, reforestations, natural forests and grasslands (Seguin and Itier 1983, Lagouarde and Brunet 1991, Courault et al., 1994, Caselles et al., 1998, Nosetto et al., 2005). The ET product will be generated at a spatial resolution of 1 km and is having a temporal resolution of 8 days. The overall methodology is presented in figure 9.1.
Net radiation, which can be separated in net short wave radiation ($S_n$) and net long wave radiation ($L_n$) is computed using calculations of incoming solar radiation ($S_t$) and satellite estimates of land surface albedo ($\alpha$). The net short wave radiation ($S_n$) is obtained semi-empirically as:

$$S_n = S_t (1-\alpha) \quad \text{(Eq. 3)}$$

where $S_t$ is the total incoming short wave radiation and $\alpha$ is land surface albedo.

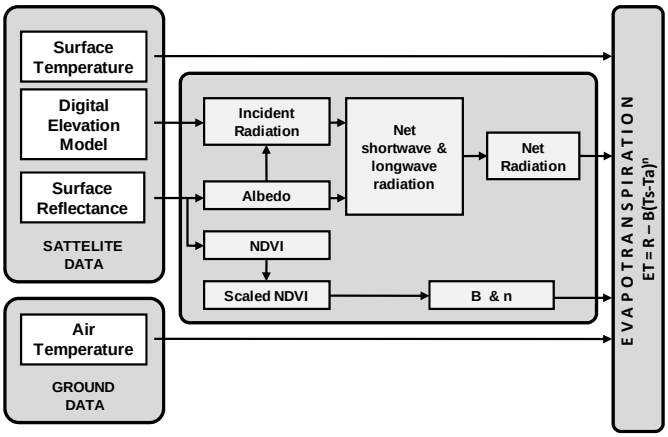


***Figure 9.1 Flow chart of the proposed ET processing chain***

Following Kumar et al. (1997), $S_t$ is computed as the potential solar radiation received under clear-sky conditions in response to latitude and elevation, using a digital elevation model and latitude data, to study the variation in radiation for different aspects and slopes. The model takes into account a simplified diffuse radiation. The surface albedo ($\alpha$) is estimated using the reflectance values from bands 1 (620-670 nm), 2 (841-876 nm), 3 (459-479 nm), 4 (545-565 nm), 5 (1230-1250 nm) and 7 (2105-2155 nm) of the MODIS-TERRA instrument, based on the approach outlined by Liang (2000) as:

$$\alpha = 0.160\alpha_1+0.291\alpha_2+0.243\alpha_3+0.116\alpha_4+0.112\alpha_5+0.081\alpha_7-0.0015 \qquad \text{(Eq. 4)}$$

where $\alpha_{(1 \text{ to } 7)}$ are the reflectance values from the respective MODIS-TERRA bands.

Net long wave radiation ($L_n$) is estimated empirically according to Granger and Gray (1990). Assuming that variations in atmospheric humidity are controlled by the energy supplied to the surface (NR), for clear sky conditions and at daily basis, $L_n$ can be estimated from incoming short wave radiation ($S_t$) as:

$$L_n = -4.25-0.24S_t \qquad \text{(Eq. 5)}$$

Due to the lack of validation for the methodology presented here, INTA is planning to use in the next versions of the ET product, data disseminated by GEONETCast (such as Downward Surface Short-wave Flux and Downward Surface Long-wave Flux) to estimate the net radiation following the method proposed by LSA-SAF in their evapotranspiration product (http://landsaf.meteo.pt). INTA will then compare these approaches and decide to use which method is best adjusted in comparison to the ground based meteorological net radiation data.

The surface radiant temperature ($T_s$) is obtained from the MODIS Land Surface Temperature and Emissivity product, while near surface air temperature ($T_a$) is derived from a reference height of 1.5 m using the air temperature registered by the meteorological ground stations located in the study area.

The parameter B represents the average bulk conductance for daily-integrated sensible heat flux and n is a correction factor for non-neutral static stability (Kalma et al., 2008). While the B value depends on the surface roughness, n depends on the atmospheric stability and both coefficients are closely related to the amount of vegetation or fractional vegetation cover, which can be estimated from a scaled vegetation index, the Scaled Normalized Vegetation Index or NDVI* (Carlson et al., 1995), where:

$$NDVI^* = (NDVI-NDVI_{min})/(NDVI_{max}-NDVI_{min}) \qquad \text{(Eq. 6)}$$

The Normalized Difference Vegetation Index (NDVI) can also be obtained from the MODIS Vegetation Index product. Finally, B and n will be calculated following the equations proposed by Carlson et al. (1995), where:

$$B = 0.0109+0.051(NDVI^*) \quad \text{(Eq. 7)}$$

$$n = 1.067-0.372(NDVI^*) \quad \text{(Eq. 8)}$$

### 9.4.2. Study Area

The area of interest (figure 9.2) includes the central portion of the Argentinean territory. This area partly consists of 9 provincial territories, including Buenos Aires, Entre Ríos, Santa Fe, Córdoba, La Pampa, San Luis, San Juan, La Rioja, Rio Negro and Neuquén. From east to west this region presents vast gradients in climate, soils and land use types. The main activities of the region are irrigated agriculture and livestock production to the west and rain-fed agriculture and livestock production to the east. There are at least two types of climates in this area: temperate humid to the east, and semi arid - arid to the west. The mean annual precipitation increases from southwest to northeast, ranging between 200 - 1200 mm. The mean annual temperature also increases from southwest to northeast, ranging between 14 - 20 ºC.

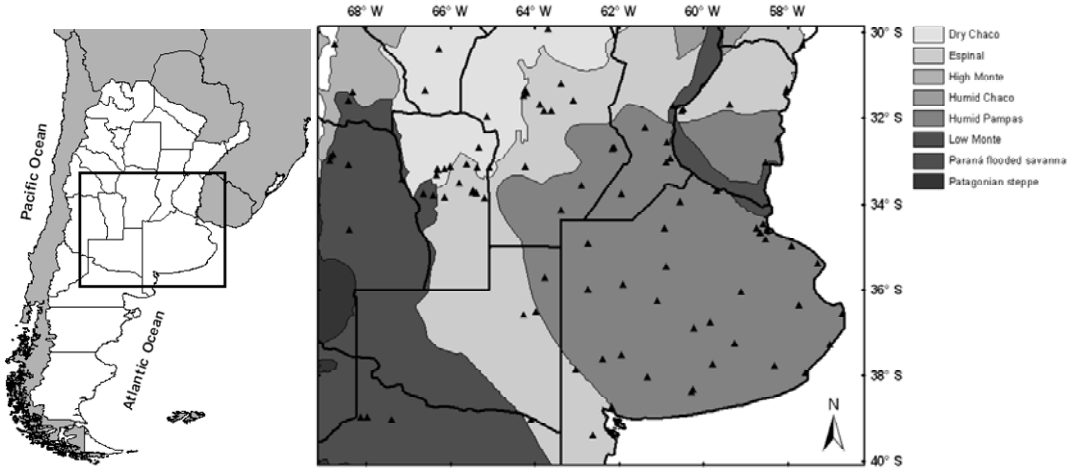


***Figure 9.2 Study area located at the central region of Argentinean territory. Triangles show the location of meteorological ground station used to estimate ET***

## 9.5. Data pre-processing

### 9.5.1. Satellite Remote Sensing data

As mentioned above, the surface temperature ($T_s$) in the ET equation, the NDVI (needed to calculate the B and n coefficients) and the surface spectral reflectance values (needed to compute the albedo in the net radiation estimate) are obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS-TERRA) products. Specifically, use is made of the Surface Spectral Reflectance 8-day L3 Global 500m (MOD9A1) and Land Surface Temperature/Emissivity 8-day L3 Global 1km (MOD11A2) products. Two tiles are used to cover the entire study area: h12v12 and h12v13. The images – products have been obtained from the MODIS receiving station located at INTA (Buenos Aires, Argentina). The Land Surface Temperature from MOD011A2 needs to be resampled to 500 m spatial resolution in order to obtain the same spatial resolution as the MOD09A1 product. First the necessary import and pre-processing has to be conducted before the ET can be derived. Copy the zipped exercise data file on your c:\ drive. Unzip the file chapter9.zip. On your C:\ drive you now should have a directory called "chapter9" containing the following sub directories: 'DataInput' and 'Working_Dir'. The folder DataInput is containing the following sub directories: '1_SufraceTemp', '2_SurfaceReflect', '3_AirTemp' and '4_NetRad'. Open ILWIS and use the ILWIS navigator to browse to the active working directory for this exercise, which is "C:\Chapter9\Working_Dir". In the ILWIS Catalog you find a table, double click the table to open it, look at the content and close the table. Close ILWIS and once more open ILWIS. ILWIS should open in your active working directory "C:\Chapter9\Working_Dir".

#### 9.5.1.1. Import and scale MODIS LST product

To import all necessary MODIS Land Surface Temperature (mod11a2*.tif) data in order to estimate ET for a long time period using the ILWIS menu can be cumbersome. Use Windows Explorer to check the content of the sub directory: "C:\chapter9\DataInput\1_SurfaceTemp". There are 4 files. The file "SurfaceTemp.rar" contains the original Land Surface Temperature images in TIF format for 4 consecutive dates. In order to import these images there are two batch files, "multi_import_SurfaceTemp_start.bat" and "multi_import_SurfaceTemp.bat", respectively. The content of these batch files is also provided in figure 9.3 and 9.4. Right click with the mouse the file "multi_import_SurfaceTemp_start.bat", select "Edit" from the context sensitive menu to examine the file content.

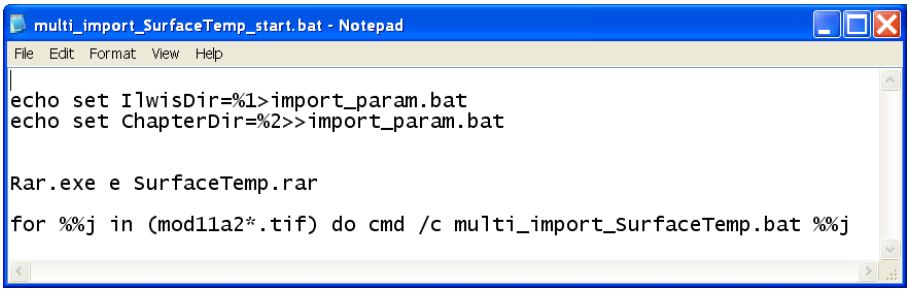


***Figure 9.3 Batch file 1 to start the multi temporal import routine***

This batch routine states in the first line that it has to create a new batch file, called "import_param.bat" specifying the location of your ILWIS directory. The second line adds another line to the batch file "import_param.bat", specifying the location of the directory where you have unzipped the exercise data. Line 3 specifies that the content of the "SurfaceTemp.rar" file should be extracted and the content should be written in the same directory. The last line indicates that for all (now decompressed) images containing the string "mod11a2*.tif" another instance of a batch file, called "multi_import_SurfaceTemp.bat" should be executed. The listing of this batch file is provided below.

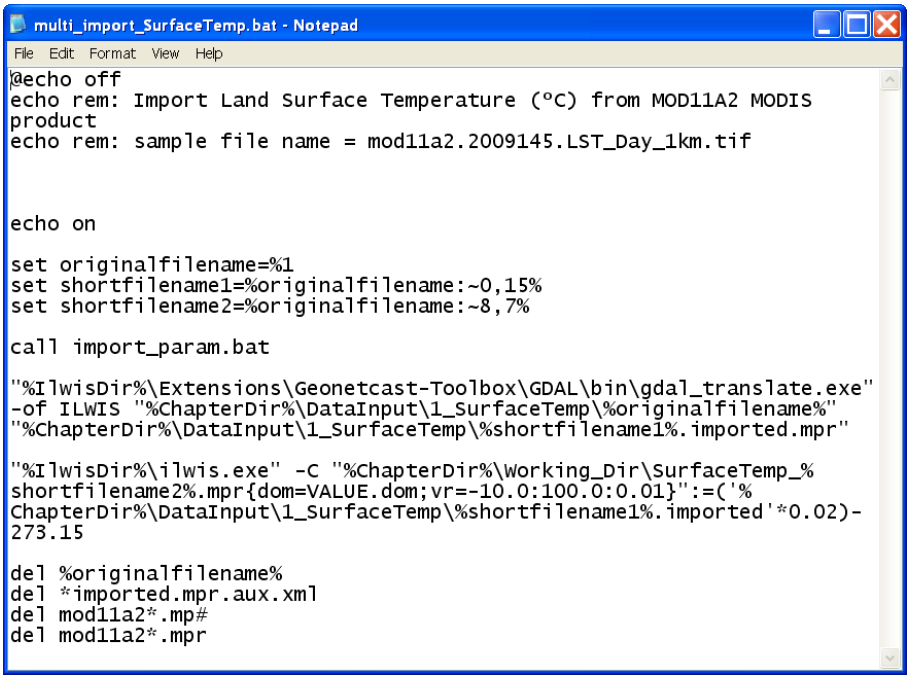


***Figure 9.4 Batch file 2 for importing the Land Surface Temperature data***

This batch routine, which is executed after all data is decompressed, starts with a 'set' command. The file is passed to the second batch by its file name, here addressed as %1. Two portions of the filename string are being use, namely

the filename without the extension ('shortfilename1') and the date of the product ('shortfilename2'). Next command is calling the batch file "import_param.bat" that has been created during execution of the first batch file, defining the locations of the "IlwisDir" and "ChapterDir". The next line is executing the 'gdal_translate.exe' utility, taking the *.tif image and writing the output file in ILWIS format in the same directory. Next command is scaling and converting the previously imported map and is applying a scaling factor (0.02) and offset, here a value of '273.15' is used to convert from Kelvin to Celsius, respectively. Also note that the final converted image in ILWIS format will be located in the "Working_Dir (in this case C:\Chapter9\Working_Dir).

Now activate from Windows the 'Start' menu and select 'Run'. You are going to use the Windows 'command.exe' utility to run the batch files. In the new command window that appears navigate to your active working directory (in this case 'C:\chapter9\DataInput\1_SurfaceTemp') and execute the Land Surface Temperature import batch file. For commands to navigate to your working directory and other DOS command syntax, see also figure 9.5.

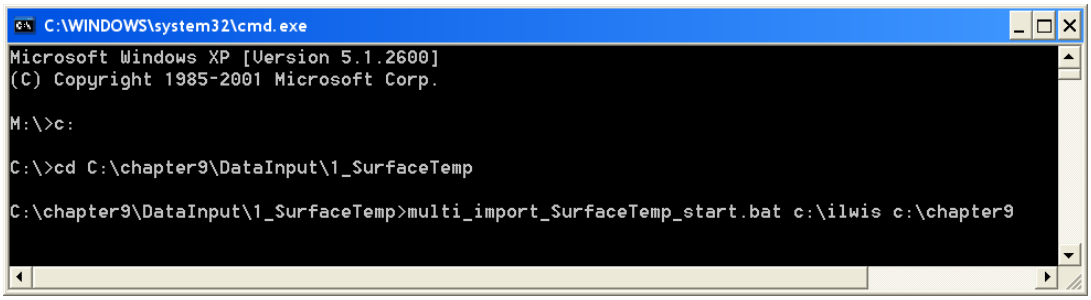


***Figure 9.5 Starting the batch processing from a CMD window***

Note that on the command line the batch file "multi_import_SurfaceTemp_start.bat" will be executed using two parameters. The first parameter specified is "C:\Ilwis". This parameter is the location of your ILWIS directory; in your case this might be different as you might have installed ILWIS using a different folder. In that case specify the appropriate folder. The second parameter is "c:\chapter9"; this is the location of your exercise data directory. If you have installed the exercise data as described before you don't need to change it over here, else specify the appropriate folder. After the correct string has been typed on the command line press "enter" from the keyboard to execute this batch process.

When the import has finished select from the main ILWIS menu the option "Window => Refresh" and you will note that four surface temperature maps have been created, using as time stamp "year" and "Julian day". Double click one of the maps, e.g. "SurfaceTemp_2009145", use as Representation "Pseudo" and press "OK" to display the map. Note the map values by moving the mouse over the active map window, keeping the left mouse button pressed. Display also another surface temperature map.

#### 9.5.1.2. Import and scale MODIS Surface Reflectance product

To import all necessary MODIS Surface Reflectance images (mod09a1*.tif) repeat the procedure described above and now use the data from the sub directory 'C:\chapter9\DataInput\2_SurfaceReflect'. Note that in this case the command line should be specified as "multi_import_SurfaceReflect_start.bat c:\ilwis c:\chapter9". The "multi_import_SurfaceReflect.bat" batch file is importing the TIF file into ILWIS format and subsequently is scaling the reflectance values by a scale factor of 0.0001 (see also Table 9.1 and Figure 9.6).

When the import has finished select from the main ILWIS menu the option "Window => Refresh" and you will note that four mod09a12009***_b01 and mod09a12009***_b02 maps (*** = Julian day) have been created. Double click one of the maps, e.g. "mod09a12009145_b01", use as Representation "Pseudo" and press "OK" to display the map. Note the map values by moving the mouse over the active map window, keeping the left mouse button pressed. Display also the band 2 image of the corresponding time: "mod09a12009145_b02".

multi_import_SurfaceReflect.bat - Notepad

File Edit Format View Help

```
@echo off
echo rem: Import Surface Reflectance from MOD09A1 MODIS product
echo rem: sample file name = mod09a1.2009145.sur_refl_b01.tif

echo on

set originalfilename=%1
set shortfilename1=%originalfilename:~0,15%
set shortfilename2=%originalfilename:~25,3%
set shortfilename3=%originalfilename:~0,7%
set shortfilename4=%originalfilename:~8,7%

call import_param.bat

"%IlwisDir%\Extensions\Geonetcast-Toolbox\GDAL\bin\gdal_translate.exe"
-of ILWIS "%ChapterDir%\DataInput\2_SurfaceReflect\%originalfilename%"
"%ChapterDir%\DataInput\2_SurfaceReflect\%shortfilename1%.%
shortfilename2%.imported.mpr"

"%IlwisDir%\ilwis.exe" -C "%ChapterDir%\Working_Dir\%shortfilename3%%
shortfilename4%_%shortfilename2%.mpr
{dom=VALUE.dom;vr=0.0:1.0:0.001}":=('%ChapterDir%
\DataInput\2_SurfaceReflect\%shortfilename1%.%
shortfilename2%.imported'*0.0001)

del %originalfilename%
del *imported.mpr.aux.xml
del mod09a1*.mp#
del mod09a1*.mpr
```

***Figure 9.6 Batch file 2 for importing the Surface Reflectance data***

### 9.5.2. Meteorological Data

#### 9.5.2.1. Import of the INTA air temperature product

Use is made of air temperature recordings from 100 meteorological ground stations located in the study area, recorded at a reference height of 1.5 m. The air temperature at daily temporal resolution is averaging for each 8-days period. This information is interpolated covering the full extent of the study area in order to obtain air temperature data at the same spatial resolution as the variables derived from remote sensing (1 km).

To import all necessary INTA Air Temperature images (airtemp*.tif) repeat the procedure described above for the MODIS products and now use the data from the sub directory 'C:\chapter9\DataInput\3_AirTemp'. Note that in this case the command line should be specified as "multi_import_AirTemp_start.bat c:\ilwis c:\chapter9". In this case the batch routine "multi_import_AirTemp.bat" is only converting the images from TIF to ILWIS format (see Figure 9.7).

When the import has finished select from the main ILWIS menu the option "Window => Refresh" and you will note that four air temperature maps have been created, using as time stamp "year" and "Julian day". Double click one of the maps, e.g. "airtemp_2009145", use as Representation "Pseudo" and press "OK" to display the map. Note the map values by moving the mouse over the active map window, keeping the left mouse button pressed. Display also another air temperature map.

multi_import_AirTemp.bat - Notepad

File Edit Format View Help

```
@echo off
echo rem: Air Temperature (°C) product from ground meteorological
stations
echo rem: sample file name = airtemp.2009169.tif

echo on

set originalfilename=%1
set shortfilename=%originalfilename:~0,15%
set shortfilename1=%originalfilename:~0,7%
set shortfilename2=%originalfilename:~8,7%

call import_param.bat

"%IlwisDir%\Extensions\Geonetcast-Toolbox\GDAL\bin\gdal_translate.exe"
-of ILWIS "%ChapterDir%\DataInput\3_AirTemp\%originalfilename%" "%
ChapterDir%\Working_Dir\%shortfilename1%_%shortfilename2%.mpr"

del %originalfilename%
del "%ChapterDir%\Working_Dir\*.mpr.aux.xml"
```

*Figure 9.7 Batch file 2 for importing the Air Temperature data*

### 9.5.2.2. Import of the INTA Net Radiation product

To import all necessary INTA Net Radiation images (netrad*.tif) repeat the procedure described above for the MODIS products and now use the data from the sub directory 'C:\chapter9\DataInput\4_NetRad'. The last command in the 'multi_import_NetRad.bat' batch file is also replacing the -999.9 pixel values by a no data value, called undefined, in ILWIS, represented by "?". The replace is done using an IFF function (see Figure 9.8).

multi_import_NetRad.bat - Notepad

File Edit Format View Help

```
@echo off
echo rem: Import Net Radiation (MJ/m2.d) product
echo rem: sample file name = netrad.2009145.tif


echo on


set originalfilename=%1
set shortfilename=%originalfilename:~0,14%
set shortfilename1=%originalfilename:~0,6%
set shortfilename2=%originalfilename:~7,7%


call import_param.bat


"%IlwisDir%\Extensions\Geonetcast-Toolbox\GDAL\bin\gdal_translate.exe"
-of ILWIS "%ChapterDir%\DataInput\4_NetRad\%originalfilename%" "%
ChapterDir%\DataInput\4_NetRad\%shortfilename%.imported.mpr"

"%IlwisDir%\ilwis.exe" -C "%ChapterDir%\Working_Dir\%shortfilename1%
_%shortfilename2%.mpr{dom=VALUE.dom;vr=0.0:100.0:0.001}":=IFF('%
ChapterDir%\DataInput\4_NetRad\%shortfilename%.imported'=-999.9,0,'%
ChapterDir%\DataInput\4_NetRad\%shortfilename%.imported')

del %originalfilename%
del *imported.mpr.aux.xml
del netrad.*.mpr
del netrad.*.mp#
```

*Figure 9.8 Batch file 2 for importing the Net Radiation data*

When the import has finished select from the main ILWIS menu the option "Window => Refresh" and you will note that four netrad maps have been created, using as time stamp "year" and "Julian day". Double click one of the maps, e.g. "netrad_2009145", use as Representation "Pseudo" and press "OK" to display the map. Note the map values by moving the mouse over the active map window, keeping the left mouse button pressed. Display also another air temperature map.

#### 9.5.2.3. Resampling the LST product

After import of all Land Surface Temperature maps to ILWIS format you need to resample these images to 500 m in order to obtain the same spatial resolution as the other products. To do this type the following expressions in the command line from the main ILWIS menu (note that you can use the command line history from the main ILWIS menu to quickly change the date string portions which change within each resampling procedure):

Surfacetemp_2009145r.mpr{dom=VALUE.dom;vr=-100.00:100.00:0.01}:=MapResample(SurfaceTemp_2009145,airtemp_2009145.grf,nearest)

Surfacetemp_2009153r.mpr{dom=VALUE.dom;vr=-100.00:100.00:0.01}:=MapResample(SurfaceTemp_2009153,airtemp_2009145.grf,nearest)

Surfacetemp_2009161r.mpr{dom=VALUE.dom;vr=-100.00:100.00:0.01}:=MapResample(SurfaceTemp_2009161,airtemp_2009145.grf,nearest)

Surfacetemp_2009169r.mpr{dom=VALUE.dom;vr=-100.00:100.00:0.01}:=MapResample(SurfaceTemp_2009169,airtemp_2009145.grf,nearest)

When the resampling of the LST maps has finished, double click one of the maps, e.g. "surfacetemp_2009145r", use as Representation "Pseudo" and press "OK" to display the map. Note the map values by moving the mouse over the active map window, keeping the left mouse button pressed. Display also another resampled land surface temperature map.

## 9.6. Computation of the ET

### 9.6.1. Compute Normalized Difference Vegetation Index (NDVI)

Compute the NDVI using the reflectance values of the red (b01) and near infrared bands (b02) obtained from the MODIS Surface Reflectance product. To do this select from the main ILWIS menu the options "Operations => Raster Operations => Map Calculation". Type the indicated algorithm as show the Figure 9.9 in the 'Expression' window, specify an output map name (in this case "ndvi_2009145"), select as Domain "Value", specify as Value Range: "0" and "1" and set the Precision to "0.001". Execute the command by pressing 'Show'. Display the map "ndvi_2009145" calculated, use as Representation 'NDVI1'.

Repeat the same procedure to compute the NDVI for the other dates: 153, 161 and 169. For efficient processing it is advised to make use of the command line history available from the main ILWIS menu. Change the Julian day string portions of the equation and press enter to execute the command and calculate a new ndvi map. You can of course keep using the menu option.

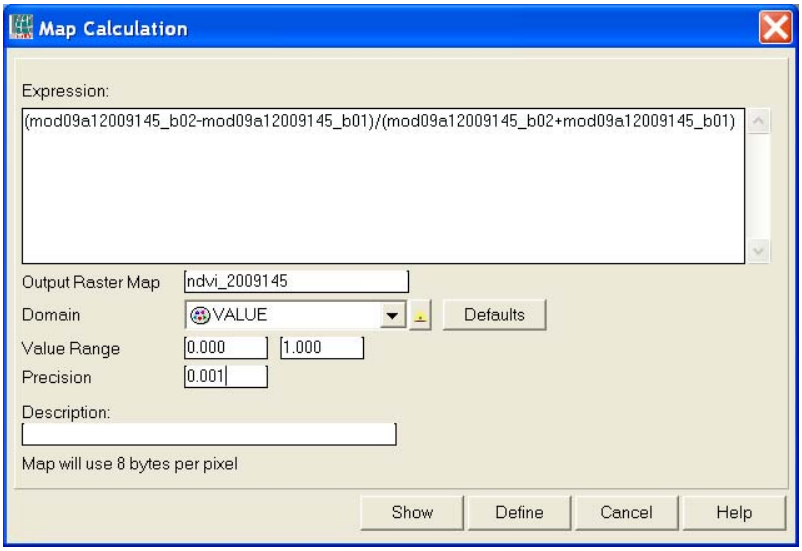


***Figure 9.9 Map calculation window to compute the NDVI***

### 9.6.2. Create Map Lists

To compute the ET for different time stamps it is more convenient to create maplists. In order to deal with the same operation over all time stamps within a maplist, you have to create a map list for each of the imported and resampled products (surfacetemp_resampled, ndvi, airtemp and netrad). To create a map list select from the main ILWIS menu the option "File => Create => Map List". Select the list of layers in the appropriate order to be included in the map list, press the ">" button to move the maps to the right hand listing, specify an output Map List name, here "ndvi" is used and execute the command by pressing "OK" (Figure 9.10). Repeat the same procedure to create a Map List for each data input, here "surftempr", "airtemp" and "netrad" is being used.

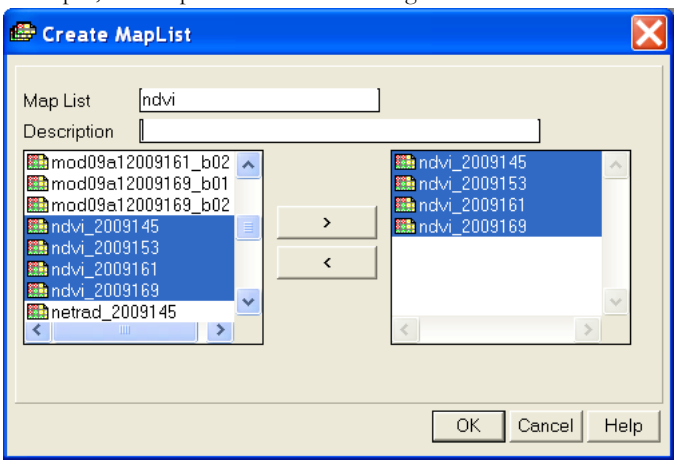


***Figure 9.10 Create Map List window***

### 9.6.3. Compute Scaled Normalized Difference Vegetation Index (SNDVI)

To compute SNDVI from the 'ndvi' map list, select from the main ILWIS menu the option "Operations =>Raster Operations => Map List Calculation". Type the algorithm as indicated in Figure 9.11: (@1-MAPMIN(@1))/(MAPMAX(@1)-MAPMIN(@1)). Specify an output Map List name (in this case "sndvi") and execute the command by pressing 'Show'.

When the calculations of the scaled NDVI maplist has finished, double click one of the maps, e.g. "sndvi_1", use as Representation "NDVI1" and press "OK" to display the map. Note the map values by moving the mouse over the active map window, keeping the left mouse button pressed. Display also another sndvi map. Note also that the map layer sndvi_1 represents Julian day 145, etc.!

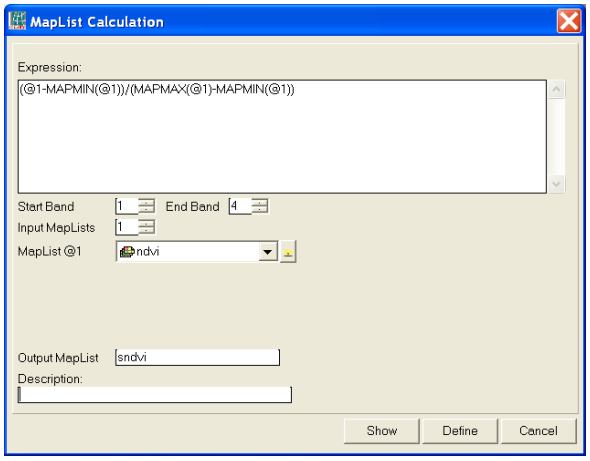


***Figure 9.11 Map List calculation window to compute the SNDVI***

### 9.6.4. Compute B and n

To compute B from the 'sndvi' map list, select from the main ILWIS menu the option "Operations => Raster Operations => Map List Calculation". Type the algorithm as indicated in Figure 9.12 (left): 0.0109+(0.051*@1). Specify an output Map List name (in this case "B") and execute the command by pressing 'Show'. Repeat the same procedure to compute "n", but now apply the following formula as given in figure 9.12 (right): 1.067-(0.372*@1). Check the results obtained, using as Representation "Pseudo".

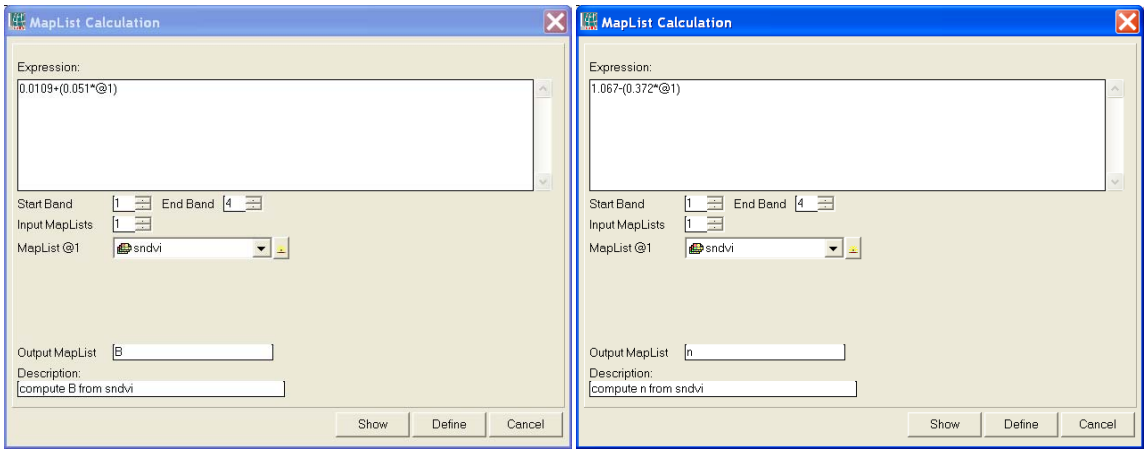


***Figure 9.12 Map List calculation window to Compute B (left) and n (right)***

### 9.6.5. Compute temperature differences

Follow the same procedure as used above to compute the difference between the resampled Surface Temperature maplist ("surftempr") and Air Temperature maplist ("airtemp"). Apply the following formula (figure 9.13): @1-@2. Select from the main ILWIS menu the option "Operations =>Raster Operations =>Map List Calculation". Type the algorithm as indicated in Figure 9.13, use now two Input MapLists. For Maplist 1, select "surftempr" and as maplist 2 select "airtemp". Specify an output MapList name (in this case "diftemp") and execute the command by pressing 'Show'. Check the results obtained, using as Representation "Pseudo".

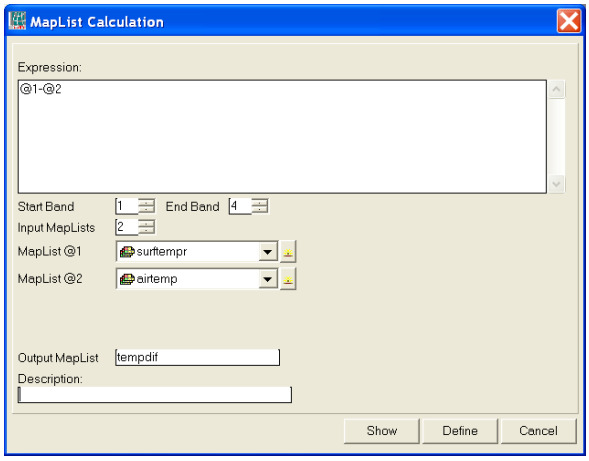


***Figure 9.13 Map List calculation window to compute temperature differences***

### 9.6.6. Compute ET

Using the Map List calculator apply the following formula to compute evapotranspiration in $mm.d^{-1}$ (figure 9.14): (@1*0.408)-(@2*(POW(@3,@4))). Note that for the net radiation values a transformation factor is applied (the reverse of vaporization latent heat) to convert from $MJ.m^{-2}.d^{-1}$ to $mm.d^{-1}$.

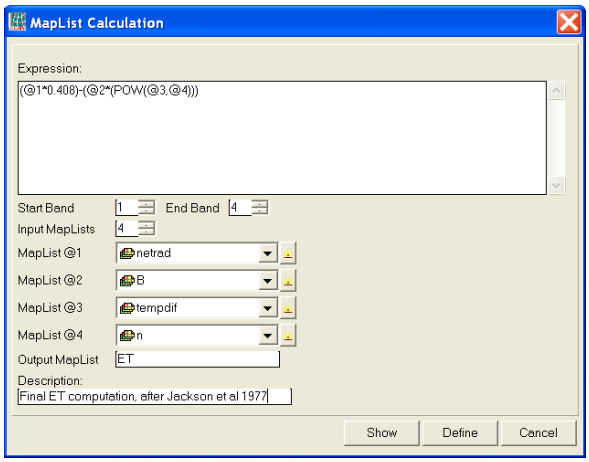


***Figure 9.14 Map List calculation window to compute the ET***

Check the results obtained, using as Representation "Pseudo". These should resemble for Julian day 153, or map layer "ET_2" of your time series "ET", the map as presented in figure 9.15. From the active map window, select the option "Layers => Add Layer", browse to your ILWIS directory, select the sub directory "Extensions\Geonetcast-Toolbox\util\maps" and select as vector layer "country_02", uncheck the option "Info" and activate the option "Boundary Only" and press "OK". Don't close the map window.

## 9.7. Checking the ET results

Validation of the actual ET is a difficult matter. To at least assess whether the results make some sense the potential evapotranspiration (PET) for each meteorological station following the Penman and Thornthwaite methodology have been computed. For this purpose, use was made of daily data of air temperature, wind speed at a reference height of 2 m., relative humidity and effective heliophany. The maximum daily PET value for each identical 8-days period was calculated and this can now be compared with the remote sensing derived ET estimations.

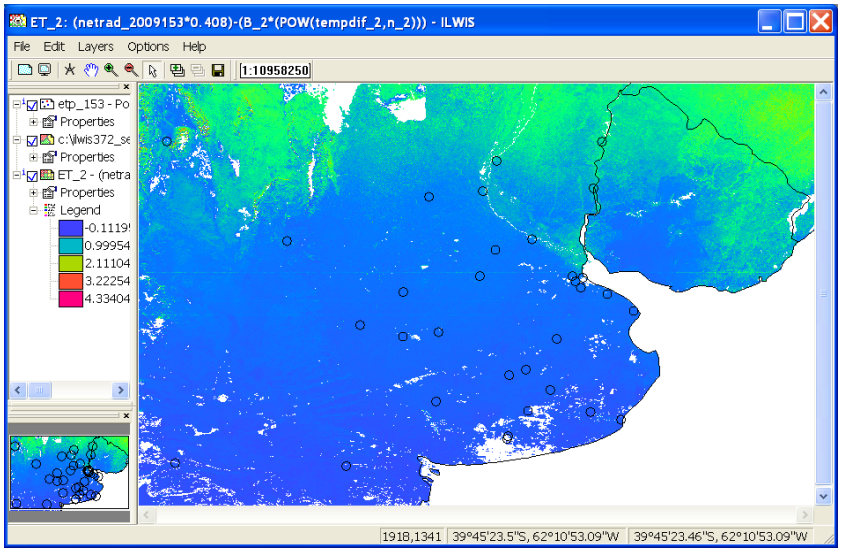


***Figure 9.15 Resulting ET map for Julian day 153 of 2009***

Open once more the table "etp_153" and check the content. You will note that there are sometimes remarkable differences between the two PET approaches used. In this case only those stations where the PET is similar will be used.

Type the following equation in the table command line: finalPet:=iff(mean_ETP_Penman-mean_ETP_Thornthwaite<0.5,mean_ETP_Penman,?). Press enter to execute the operation and accept the defaults, press "OK" once more. A new column is created and the values of this column will be crossed with the estimated ET for Julian day 153, or ET_2 from your map list. Close the table.

Convert the table to a point map. To do so right click with the mouse the table "etp_153", select from the context sensitive menu the options "Table Operations => Table to Point Map", as Coordinate System select "airtemp_2009145" and as output Point Map specify "etp_153". Press "Show" to execute the operation. Look at the point map created and close the map. From the active map window used to display the map "ET_2 select the option "Layers=> Add Layer", browse to your ILWIS directory, select the point map "etp_153" and activate from the Display Options menu the check box "Attribute", select the column "finalPET" and press "OK". From the active map window, select "File => Open Pixel Information", move the mouse cursor over the points on the map and check the results from the pixel information table. Close the active map layer.

Convert the point map "etp_153" to Raster. Right click with the mouse the point map "etp_153", select from the context sensitive menu the options "Rasterize => Point to Raster", as Georeference select "airtemp_2009145" and as output Raster Map specify "etp_153". Press "Show" to execute the operation. You might need to zoom in to the new raster map created to see the results!

From the main ILWIS menu, select the options "Operations => Raster Operations => Cross", as first map specify "ET_2", as second map select the attribute column "finalPet". To do so, click on the "+" sign in front of the raster map "etp_153" to select the appropriate column. As Output Table specify "compareETp_Eta and press "Show". From the menu of the newly created cross table select the Graph icon, as X-Axis specify map2 (note that this is the resulting value of the attribute table, representing the potential ET according to Penman), and as Y-Axis select "ET_2"and press "OK". Double click in the left hand legend of the graph the X-Axis and specify as Min-Max range "0" to "2", Interval of "0.5" and press "OK". Do this also for the left hand Y-Axis. Uncheck the Legend option. Double click the attribute "map2 * ET_2" and change the Color from Transparent to "Red". Your results should resemble those presented in figure 9.16.

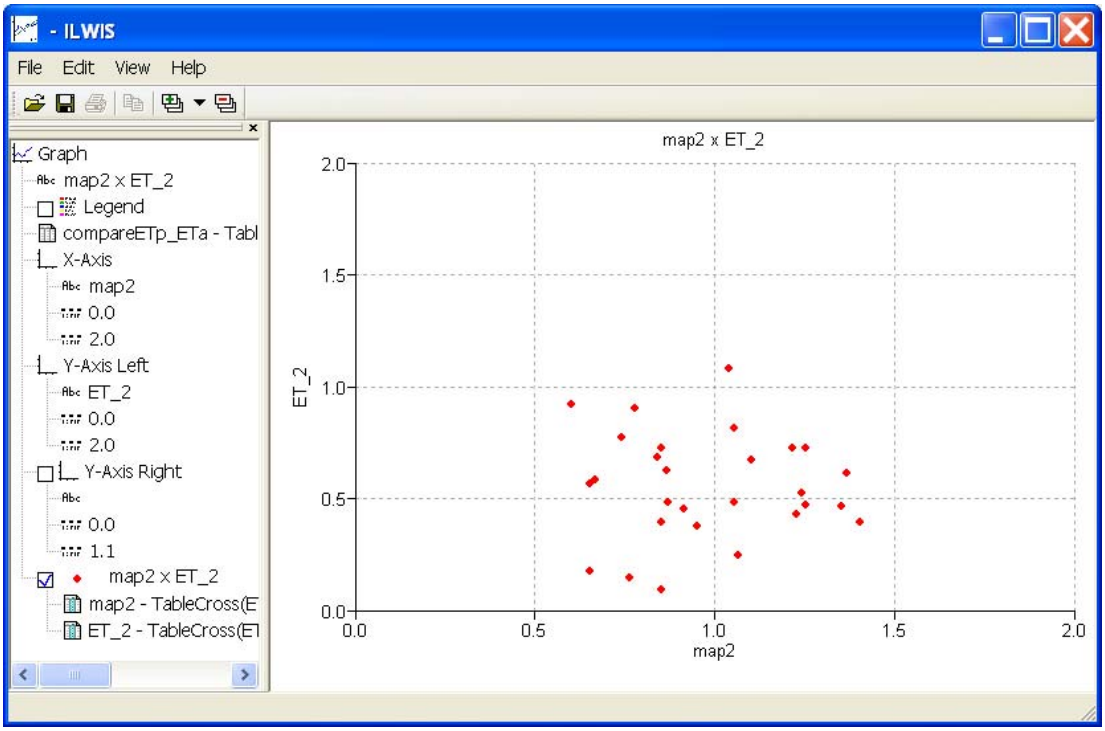


***Figure 9.16 Comparing estimated ET for Julian day 153 with PET***

## 9.8. Conclusions

From figure 9.16 it is clear that the computed ET is less than the potential ET which is according to expectation. In order to validate the ET estimates based on remote sensing, INTA will use more detailed ET data derived from eddy covariance based towers measurement and estimates based on meteorological ground station data. INTA at this moment has access to ET measurements from four eddy covariance flux towers located in representative dominant land use types in the study area (forest, agriculture, commercial tree plantations and dry forest).

In conjunction to this the near future additional information can be used from 150 meteorological stations that are currently being installing all around the Argentinean territory by INTA.

To account for possible errors on input variables (NR, B, n and $T_s$-$T_a$), INTA will test the ET estimates sensitivity by exploring the effects of extreme values of these variables.

Acknowledging the uncertainties in the air temperature due to the interpolation from low density of meteorological ground stations, INTA will furthermore explore the possibility of using the air temperature data derive from the MODIS atmospheric profile product.

# REFERENCES

Carlson TN, W.J. Capehart, R.R. Gillies (1995): A new look at the Simplified Method for remote sensing of daily evapotranspiration. *Remote Sensing of Environment*, 54: 161-167.

Caselles V, M.M. Artigao, E. Hurtado, C. Coll, and A. Brasa (1998): Mapping actual evapotranspiration by combining Landsat TM and NOAA-AVHRR images: Application to the Barrax Area, Albacete, Spain. *Remote Sensing of Environment* 63:1-10.

Courault D, B. Seguin, A. Olioso (2003): Review to estimate evapotranspiration from remote sensing data: some examples from the simplified relationship to the use of mesoscale atmospheric models. ICID. Workshop on Remote sensing of ET for large regions. 17 Sept 2003.

Gowda P.H, Chavez J.L, Colaizzi P.D, Evett S.R, Howell T.A and Tolk J.A (2007): Remote sensing based energy balance algorithms for mapping ET: current status and future challenges. *Trans Am Soc Agric Biol Engineers* 50(5):1639–1644

Granger R, D.M. Gray (1990): A net radiation model for calculating daily snowmelt in open environments. *Nordic Hydrology*, 21: 217–234.

Jackson R.D., R.J. Reginato, S.B. Idso (1977): Wheat canopy temperature: a practical tool for evaluating water requirements. *Water Resources Research*, 13, 651–656.

Kalma J.D, T.R McVicar and M.F McCabe. 2008. Estimating Land Surface Evaporation: A Review of Methods Using Remotely Sensed Surface Temperature Data. *Surv Geophys* (2008) 29:421–469.

Kumar L, K.A. Skidmore and E. Knowles (1997): Modelling topographic variation in solar radiation in a GIS environment. *Int. J. Geographical Information Science*, 1997, vol. 11, no. 5, 475-497.

Lagouarde J.P, and Y. Brunet (1989): Spatial integration of surface latent heat flux and evaporation mapping. *Advances in Space Research* 9:259-264.

Nosetto M, EG Jobbágy, y JM Paruelo (2005): Land use change and water losses: The case of grassland afforestation across a soil textural gradient in Central Argentina. *Global Change Biology* 11:1101-1117.

Paruelo J.M. (2008): Functional characterization of ecosystems using remote sensing. *Ecosistemas* 17 (3).

Seguin B, and B. Itier (1983): Using midday surface temperature to estimate daily evaporation from satellite thermal IR data. *International Journal of Remote Sensing* 4:371-383.