

10. FROM CLOUD TOP TEMPERATURE TO RAINFALL; BLENDING MSG AND TRMM-TMI

By: **Ben Maathuis**¹

10.1. Relevance of the application

Continuous rainfall estimates at high temporal and spatial resolution is of great importance in climate variability monitoring, Numerical Weather Prediction and in hydrological model inputs amongst other applications. Precipitation is one of the most variable quantities in space and time. The existing rain gauge network is sparse and available data are insufficient to characterize the high spatial variable rainfall distribution. Combined with the uneven distribution of rain gauges, weather radars and the relative lack of rainfall measurements over the oceans have therefore significant limitations.

Rainfall measurements from space are based on the interpretation of the electromagnetic (EM) radiation that is scattered or emitted from clouds, precipitation and underlying surface, and is monitored by the satellite instruments at discrete spectral regions. Several studies have focussed on usage of visible and infrared (10.5 - 12.5 μ m) portions of the EM spectrum. Rainfall estimation methods using these spectral regions can be classified into cloud-indexing, spectral life history and cloud model-based methods. Each of the categories stresses a particular aspect of the sensing of cloud physical properties using satellite imagery. The primary drawback of the VIS/IR techniques is that the observations only relate to the characteristics of the cloud tops, rather than the precipitation reaching the surface. Clouds are opaque in the VIS and IR spectral range and precipitation is inferred from the cloud top structure. At passive MW frequencies precipitation particles are the main source of attenuation of the upwelling radiation. MW techniques are thus physically more direct than those based on VIS/IR radiation. The emission of radiation from atmospheric particles increases the signal received by the satellite sensor while at the same time the scattering due to hydrometeors reduces the radiation stream. Type and size of the detected hydrometeors depend upon the frequency of the upwelling radiation (Levizzani et al, 2002, 2007). Research is on-going to blend - combine observations from different sensors - spectral regions in an attempt to improve accuracy, coverage and resolution of the satellite derived rainfall estimates.

10.2. Objective

The main objective of this exercise is to make use of the TRMM-TMI derived rain rates to calibrate a collocated Meteosat-9 Cloud Top Temperature image (10.8 micron band) and subsequently transform a time series of MSG images into precipitation.

10.3. Methodology and study area

10.3.1. Methodology adopted

A flowchart of the overall procedure is presented in figure 10.1. All required data is provided in the zipped exercise data file. The import procedures for the TRMM TMI data are described as well to allow application of the methodology to retrieve rainfall for other events.

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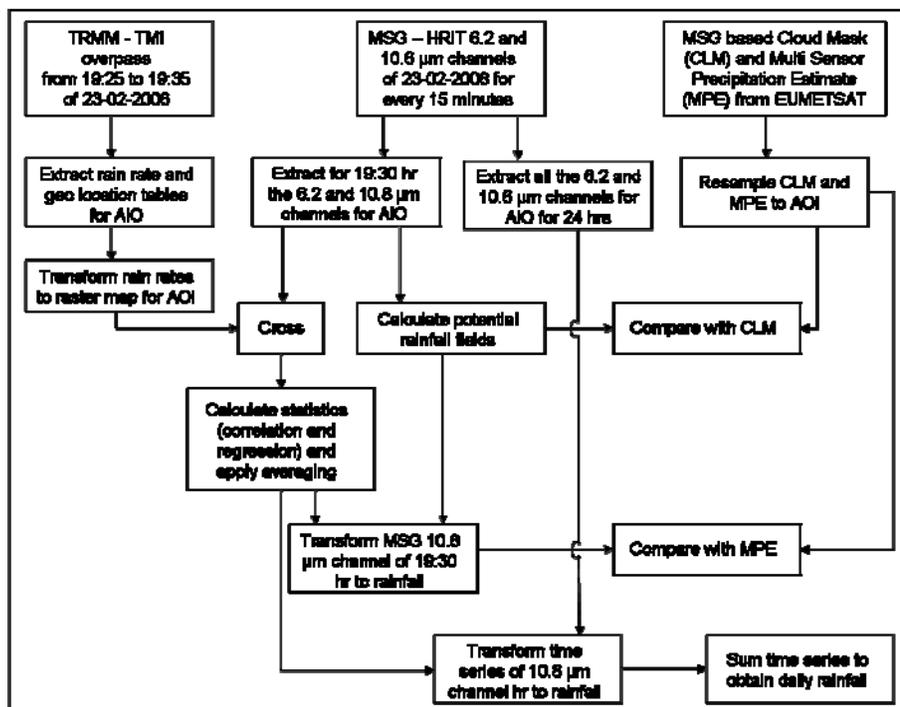


Figure 10.1 Flowchart of methodology adopted

10.3.2. Study area

The study area selected is covering the central and southern part of Africa. The bounding coordinates are from 25 degrees south to 10 degree north latitude and from 10 degree west to 50 degree east longitude. Most of the rainfall in these regions is attributed to convective precipitation as during this time of the year the ITCZ is situated over this region. The methodology applied is more suited towards deriving this type of precipitation. The frontal and orographic rainfall regions are not appropriately extracted due to the fact that these cloud top temperatures are not as cold as the cloud tops from cumulonimbus clouds.

10.4. Data preprocessing

Download the exercise data and unzip the file into your active working directory. Note that your working directory name should not contain spaces in the name. Note furthermore that there is a sub-directory (“\23febr2008”) containing the raw time series MSG HRIT data for the 6.2 and 10.8 micron channels.

10.4.1. TRMM TMI rainfall data retrieval

The period selected for this exercise is 23-02-2008. The TRMM data provided in the exercise was retrieved from the website: <http://mirador.gsfc.nasa.gov/cgi-bin/mirador/homepageAlt.pl?keyword=TRMM>.

If you want to retrieve the data yourself load the website indicated above, select from tab “Available”: TRMM, subsequently select from the “TRMM Data Group”: *Orbital* and finally select as “Data Set”: *2A12 (Version 006): Hydrometeorprofile (TMI)*. Select the appropriate date and time: “2008-02-23” and “18:14:28”, you can also have a look at the preview of the image using the “View Image” option, see also figure 10.2. Note once more that this file is already provided and is situated in your active working directory.

Download this data file and unzip it. To inspect the various data layer of the downloaded 2A12 data file you can use “Orbit Viewer”. Orbit Viewer is a tool for displaying the HDF data of the Tropical Rainfall Measuring Mission (TRMM). To download Orbit Viewer, follow the link below and press “Download the Orbit Viewer” option from http://disc.sci.gsfc.nasa.gov/precipitation/additional/tools/trmm_ov.shtml.

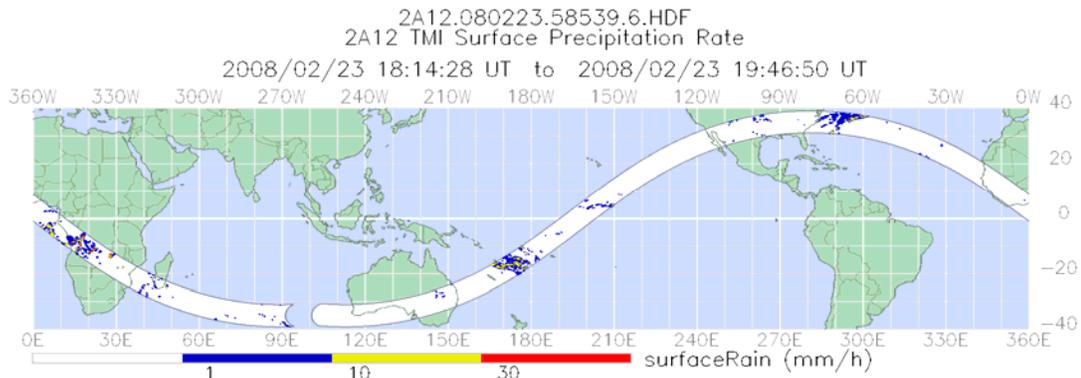


Figure 10.2 TMI Surface Precipitation rate.

For the purpose of this exercise you can use the following Orbit Viewer version: “*orbit_1.3.5_win.exe*”. Eventually download the “*tutorial.pdf*” as well. After download you can install the utility by double clicking on the file: “*orbit_1.3.5_win.exe*” or by right clicking with the mouse on the filename and selecting from the context sensitive menu “*Run as Administrator*”. After specifying an appropriate output directory the self-extractor is unzipping all required files. Browse to the specified directory.

Activate the Orbit Viewer by double-clicking on the “*setupWIN.exe*” program. Then, double-click on the “*orbitWIN.exe*” program (in the sub directory \TSDISorbitViewer) or use the “*orbit*” shortcut on your systems’ desktop.

10.4.2. TRMM TMI rainfall data extraction of central Africa

To view the downloaded HDF file you need to use the Orbit Viewer. The example provided here is using the file “*A12.080223.58539.6.HDF*” containing information about the surface rain (mm/hr) for the evening overpass, on 23 February 2008 (using version 6 of the TRMM rainfall estimation algorithm) over Central Africa, see also figure 10.3. Start Orbit and open from the menu “*File*” > “*Open File*”, browse to the directory containing the file “*2A12.080223.58539.6.HDF*” (unzipped!). From the left hand “*Arrays*” options select “*Surface Rain*” and from the bottom global orbit zoom in on “*central – southern Africa*”. Note that as indicated in figure 10.3 a zoom resolution is used of “*30 degree Longitude*” (from the Menu, under “*Option*” > “*Zoom Resolution*”).

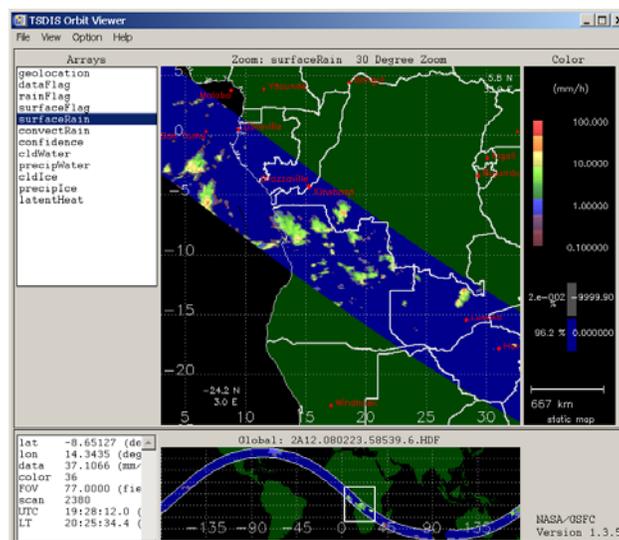


Figure 10.3 Orbit Viewer surface rain rate

To get the time-date and rainfall intensity information, click with the mouse on a rainfall area, note the values in the lower left-hand corner. Also check the time stamps on both ends of the swath over Southern Africa. Note that when

you select different locations the time is changing (in this window roughly from 19:25 to 19:35 UTC, from NW to SE respectively).

To export the selected frame to Ascii tables use the option “File” > “Save Data” and select as Output Format “Swath: ASCII (ARC/INFO)”, see also figure 10.4. Specify an appropriate output directory and filename. The file with the extension “TXT” is containing the rainfall intensities and the “GEO” file is providing the corresponding GEO location information. In general two TRMM overpasses over a specific area per day exist! Note that these files have already been created for you and are contained in the exercise data zip file. The extracted rainfall and geolocation files are called “*surfaceRain.txt*” and “*surfaceRain.geo*” respectively.

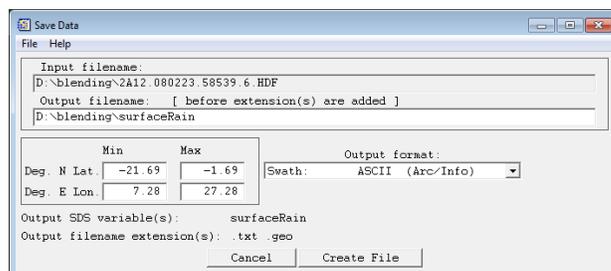


Figure 10.4 Export to ascii tables using Orbit Viewer

10.4.3. Extracting thermal channel from MSG for central Africa

To relate the cloud top temperature with the rain rates, you have to import for the corresponding period the Meteosat-9 thermal image, so select 23 February 2008, 19:30 UTC, for band WV_062 and IR_108, convert the image to temperature (in Kelvin), select the appropriate area and export it as an ILWIS file.

Open ILWIS, select “Geonetcast” > “Toolbox” > “MSG-HRIT” > “MSG Data Retriever”. Start the Data Retriever by pressing the button “Start MSG Data Retriever”. First check the “Data Sources” (from the Menu select the “File” option). If there is an existing data source specified, select it and use the option “Delete” and confirm the deletion. Select the option “New” and press “Browse”, navigate to the sub-directory “23febr2008”. Select the option “Data resides directly under the source folder specified”, press the “auto-detect” button, the first and last day of data should now indicate “2/23/2008”, press “OK” and “Close”.

To get the settings as of the figure 10.5 below also use can be made of the ‘msg-project settings’. In the Meteosat Second Generation Data Retriever, select from the Menu “File” > “Open” and select from the exercise working directory the file: “*msg_cal1930.msg1project*” and press “Open”. With these project settings the MSG Data Retriever should look identical to figure 10.5 below and now execute the import (note the output file folder, if needed change this to your appropriate working directory). The file prefix is assigned with cal (for calibration) as the IR_108 will be used to determine the relation between cloud top temperature and the rainfall intensity from TRMM. Make sure that the imported TRMM geo and txt files are located in the same working directory as the MSG files which have been imported.

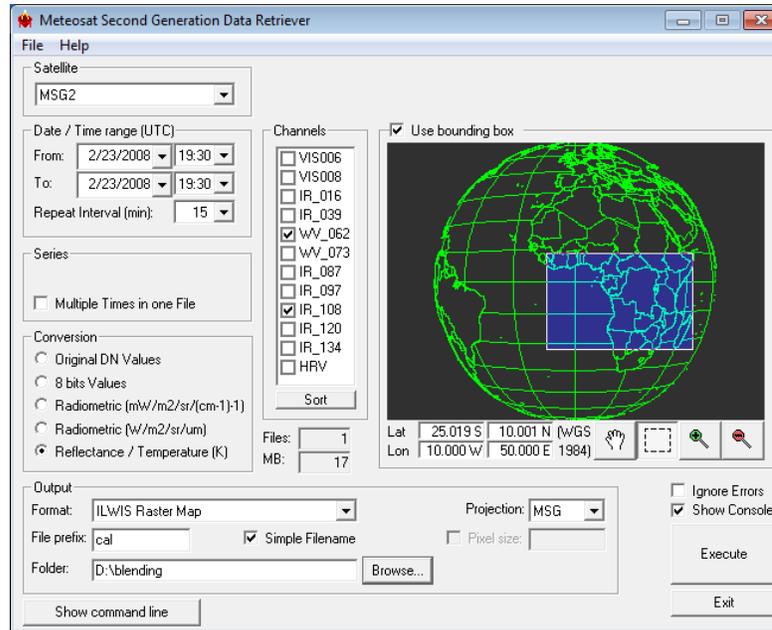


Figure 10.5 MSG Data Retriever settings

10.5. Data analysis

10.5.1. Retrieving the potential rainfall fields

Activate ILWIS and navigate to the appropriate directory where you stored the tables and the MSG image files. Display the individual images and check the values and the differences between the Water Vapour and the Thermal Infrared channels, also have a look at the coordinates (MSG projection). You can use an “Inverse” Representation for display of the images, use from the Map Window, “File” > “Open Pixel Information”, in the Pixel Information Window, select “File” > “Add Map”. Now select the other image and per pixel an idea can be obtained of the brightness temperature in these two channels. Select pixels that have cloud conditions and select also pixels that are not cloudy. Note that the colder areas (clouds) will have a white tone and the warmer areas are darker toned when using an inversed grey scale lookup table Representation. From the main exercise directory you can add to the image the country boundaries (“Add layer”, select the file “country_02”, uncheck the option “Info” and check the option “Boundaries only” and press “OK”).

Note that you have imported 2 channels, the water vapour (6.2 micron) and the thermal IR (10.8 micron). Water Vapour has an absorption band around 6 microns and therefore it absorbs radiation from below but emits radiation according to the 2nd Kirchoff law. Therefore the water vapour channels are indicative of the water vapour content in the upper part of the troposphere. The maximum signal from WV_062 is at 350 hPa, and for WV_073 at 500 hPa (assuming normal pressure at sea level approximate elevation is at 8980 m and 5965 m amsl respectively), see also figure 10.6. If there is no water vapour radiation from far below can reach the satellite (V. Zwatz-Meise, ZAMG).

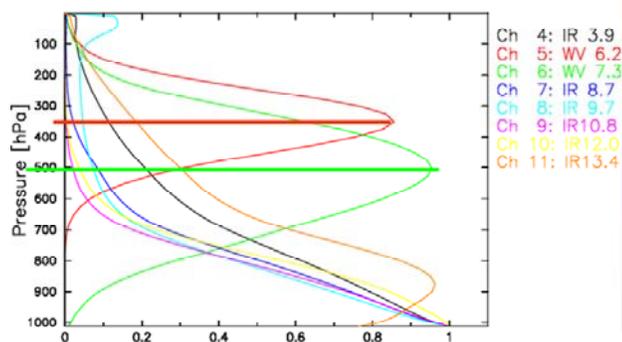


Figure 10.6 MSG channel normalised weighting functions

The thermal channel records the emitted energy from the Earth surface itself. Based on a classification using MSG channel 108 and 062, applying a threshold on the temperature difference of less than 11 Kelvin an approximation of the clouds that have a high likelihood of precipitation can be obtained. This is an empirically determined threshold reported by Kidder, *et al.* (2005).

To calculate the potential precipitating clouds, type the following algorithm on the command line in the main ILWIS window:

```
pcloud:=iff(cal0000_band_2-cal0000_band_1<11,1,0)
```

Use the default Raster map definition and press “*Show*”. Compare this map with the WV and IR image data. Display the map: “*clm20080223_1930*”. This is the Cloud Mask Product of the same time obtained from EUMETSAT. The Cloud Mask (CLM) product is an image-based product in full pixel resolution that displays information on the presence of cloud. When possible, each pixel is classified as one of the following three types: clear sky over water (value=0), clear sky over land (value=1) and cloud (value=2). Right click with the mouse the map “*clm20080223_1930*”, select “*Spatial Reference Operations*” and “*Resample*”. As resampling method use “*Nearest Neighbour*”, as georeference “*Cal0000*” (the georeference from the WV and TIR MSG bands) and specify an appropriate output map name, e.g. “*clm1930*”. Press “*Show*”. Now you can integrate the Pcloud map with the CLM, type the following statement on the command line in the main ILWIS menu and execute it using the default map definition:

```
combine:=pcloud+clm1930
```

Have a look at the location of the areas that have been classified as precipitating clouds in the pcloud map (note that precipitating clouds have a value of 3 and are all situated within the cloud masked areas).

10.5.2. Import the two TRMM tables

To import the file with the geo location information, here called “*surfaceRain.geo*” use the option from the main ILWIS menu: “*File*” > “*Import*” > “*ILWIS*” > “*Table*” > “*Comma Delimited*”, use the browse button to specify appropriate input and output file and press “*OK*” > “*Next*”. Check the table configuration and the meaning of each of the columns and modify the Column names according to figure 10.7 (left) presented below (Column2 to “*X*” and Column3 to “*Y*”), press “*Finish*” and “*OK*”. Repeat the same procedure (figure 10.7, right) for the Ascii table with the Rainfall intensities (here called: “*surfaceRain.txt*”).

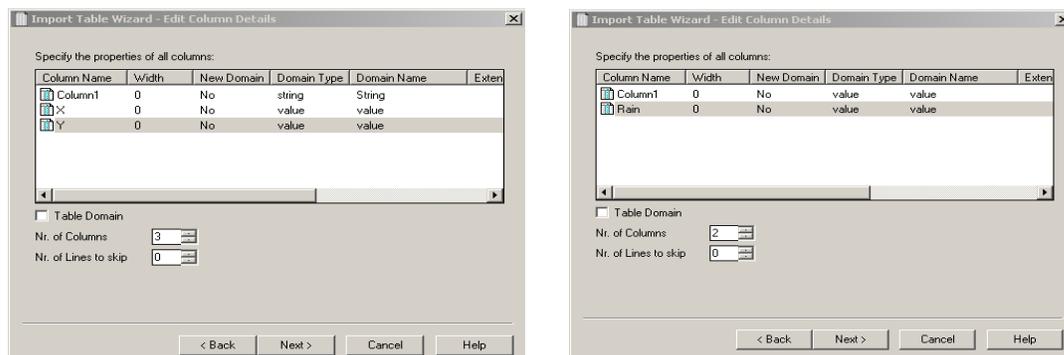


Figure 10.7 Import table windows for the TMI locations and rain rates

After the tables have been imported, open both the tables and check the content. Activate the table with the geo location information. Select now from the table menu the option “*Column*” and “*Join*”. Specify the rainfall intensity table and select the column containing these values (here column2 called “*Rain*”). Specify an appropriate output column name, e.g. “*rainfall*” and execute the operation (using the default data type, range, precision, etc). The results

should be like those given in figure 10.8, note that here only a few records are displayed and that each set of XY coordinate pairs has a rainfall value assigned, in case of no rainfall the value is 0.

	x	y	rainfall
29700	6.672	2.421	0.000
29703	6.718	2.431	0.000
29710	6.764	2.440	0.000
29711	6.811	2.449	0.000
29712	6.857	2.457	0.066
29713	6.904	2.465	1.990
29714	6.950	2.472	2.265
29715	6.997	2.479	3.621
29716	7.043	2.485	4.873
29717	7.090	2.491	4.794
29718	7.137	2.496	3.642
29719	7.184	2.501	0.571
29720	7.231	2.505	0.603
29721	7.278	2.509	2.707
29722	7.325	2.512	0.183
29723	7.372	2.515	0.000
Min	-10.050	-28.494	-9999.900
Max	45.333	12.550	52.538
Avg	15.911	-7.618	-3.481
Std	14.475	10.333	193.214
Sum	1704363.001	-816021.190	-372900.498

Figure 10.8 Resulting table using the join operation

Using Table calculation, from the table command line calculate a new column in which only those locations are used that have actual precipitation. Type the following command in the table command line:

```
rain_more0:=iff(rainfall>0, rainfall,?)
```

Execute this statement. For those records that have no rainfall a question mark is returned, in ILWIS this is assigned undefined (see the ILWIS help function for more details). Close the table.

The next step is to transform this table into a point map, so it can be crossed with the Meteosat image at a later stage to calculate if there is a correlation with the cloud top temperature and if so, to find a suitable regression function to transform the cloud top temperature into rainfall intensity.

With the mouse, right click the table (with the X,Y and rainfall columns), select “Table Operations” > “Table to PointMap”. Modify the options such that they represent those as given in figure 10.9 below. The X and Y columns are used for the location; the coordinate system assigned is an ILWIS system coordinate system (LatLonWGS84). Make sure that you use the column rainfall for assignment of the point values in your output map.

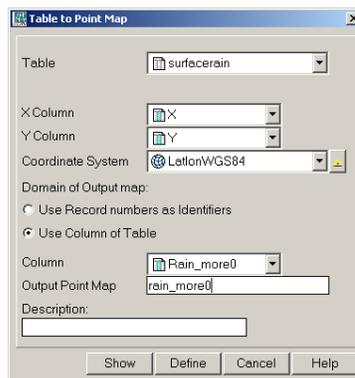


Figure 10.9 Table to point map settings

Execute the operation and display the resulting point map, here called “rain_more0”. Check the values and zoom in on some of the rainfall points. Use the measuring tool option from the map display window menu and measure the distance between the points to get an idea of the spatial distribution of the TRMM measurements. Use the option “Layer” > “Add Layer” and display the MSG 108 band (here “cal0000_band_2”) and the map “Combine” in the same window. Zoom in on the image and check the results obtained. The image view should represent the results as given

in figure 10.10, here a “pseudo” colour representation is used. Select from the display window, under “File” the option “Open Pixel Information”. Roam the mouse over the image and check the temperature and rainfall values that are presented in the pixel information viewer. You can check and uncheck in the legend the layers to furthermore visually inspect the relation between the precipitating clouds and the TRMM rainfall locations.

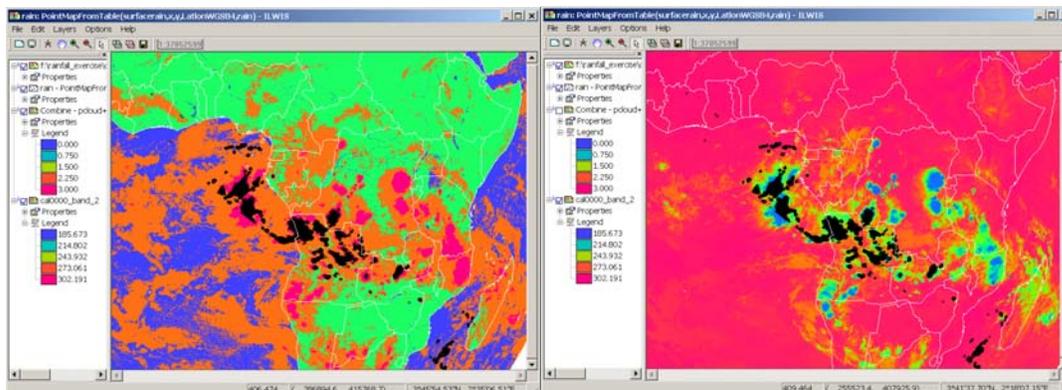


Figure 10.10: TRMM point observations over the (precipitating) clouds and MSG TIR image

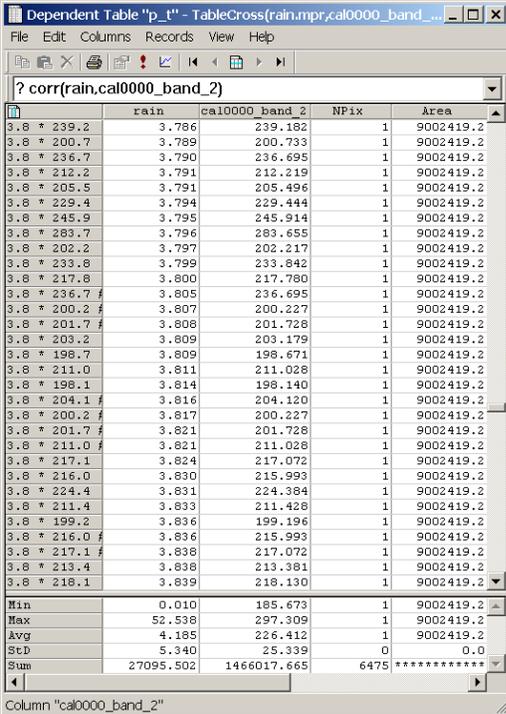
This process completes the integration of TRMM data with MSG. Now the relations between the two sets of sensor data – products has to be further investigated. Do you have an idea of the type of rainfall; is it orographic, convective, etc? How about the matching of precipitating clouds and the TRMM rainfall locations?

10.5.3. Correlation of TRMM rainfall point measurements with MSG

To determine if there is a correlation with rainfall intensities and MSG cloud top temperature first the TRMM point rainfall map has to be transformed into a raster map. Next step is to cross both maps and the resulting cross table can be used to compute the correlation between the two.

To transform the point map to a raster map right click the point map using the mouse button and select the option “Rasterize” > “Point to Raster”. Select as georeference the one given for the MSG image, here “cal0000”. Use the default output map name, point size, value range and precision. Display the results, zoom in and use the measurement tool to measure the distance between the raster elements that have obtained a value. Display the point map on top of this map, using “Layer” > “Add Layer” and note the effect of this resampling procedure.

Next cross the two maps to obtain the cross table. To do so select from the main ILWIS menu “Operations” > “Raster Operations” > “Cross”, select the appropriate two input maps and specify an output table name. There is no need to generate an output map. Make sure that both input maps have the “Ignore Undef” option active. Display the resulting table, see also figure 10.11. Select from the table menu the option “Columns” > “Statistics”, as function select “Correlation” and select the rainfall and temperature columns, press “OK” to derive the correlation coefficient which is about -0.4.



Dependent Table "p_t" - TableCross(rain.mpr,cal0000_band_2)

? corr(rain,cal0000_band_2)

	rain	cal0000_band_2	NPix	Area
3.8 * 239.2	3.786	239.182	1	9002419.2
3.8 * 200.7	3.789	200.733	1	9002419.2
3.8 * 236.7	3.790	236.695	1	9002419.2
3.8 * 212.2	3.791	212.219	1	9002419.2
3.8 * 205.5	3.791	205.496	1	9002419.2
3.8 * 229.4	3.794	229.444	1	9002419.2
3.8 * 245.9	3.795	245.914	1	9002419.2
3.8 * 283.7	3.796	283.655	1	9002419.2
3.8 * 202.2	3.797	202.217	1	9002419.2
3.8 * 233.8	3.799	233.842	1	9002419.2
3.8 * 217.8	3.800	217.780	1	9002419.2
3.8 * 236.7	3.805	236.695	1	9002419.2
3.8 * 200.2	3.807	200.227	1	9002419.2
3.8 * 201.7	3.808	201.728	1	9002419.2
3.8 * 203.2	3.809	203.179	1	9002419.2
3.8 * 198.7	3.809	198.671	1	9002419.2
3.8 * 211.0	3.811	211.028	1	9002419.2
3.8 * 198.1	3.814	198.140	1	9002419.2
3.8 * 204.1	3.816	204.120	1	9002419.2
3.8 * 200.2	3.817	200.227	1	9002419.2
3.8 * 201.7	3.821	201.728	1	9002419.2
3.8 * 211.0	3.821	211.028	1	9002419.2
3.8 * 217.1	3.824	217.072	1	9002419.2
3.8 * 216.0	3.830	215.993	1	9002419.2
3.8 * 224.4	3.831	224.384	1	9002419.2
3.8 * 211.4	3.833	211.428	1	9002419.2
3.8 * 199.2	3.836	199.196	1	9002419.2
3.8 * 216.0	3.836	215.993	1	9002419.2
3.8 * 217.1	3.838	217.072	1	9002419.2
3.8 * 213.4	3.838	213.381	1	9002419.2
3.8 * 218.1	3.839	218.130	1	9002419.2
Min	0.010	185.673	1	9002419.2
Max	52.538	297.309	1	9002419.2
Avg	4.185	226.412	1	9002419.2
StD	5.340	25.339	0	0.0
Sum	27095.502	1466017.665	6475	*****

Column "cal0000_band_2"

Figure 10.11 Resulting table from the cross operation

Note that the correlation coefficient has a negative tendency, meaning that with decreasing temperature there is an increase in rainfall intensity, but the overall correlation is weak. Figure 10.12 below shows some of the reasons for this low initial correlation and therefore the need for averaging (after Turk, *et al.*, 2003).

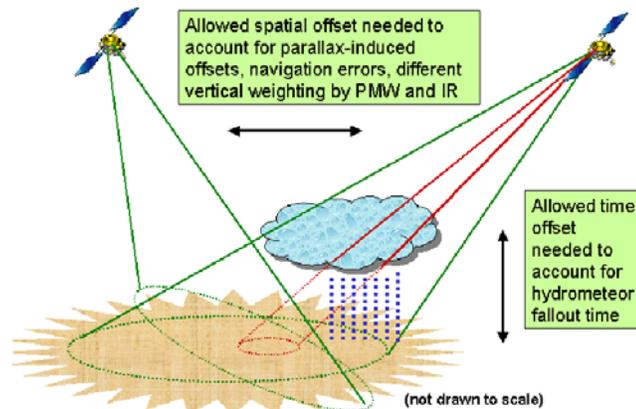


Figure 10.12 Collocating PMW and IR observations

With respect to the current data there are also alignment errors, e.g. the time (MSG requires 12 minutes to complete a full disk scan (3712 scan lines recorded from South to North start scan at 19:30, takes 6 minutes to scan the southern hemisphere of the field of view, compared with TRMM, recorded for this window from 19:25 to 19:35 UTC, from NW to SE respectively), looking angle (current MSG position is at 0 degree longitude over the equator, and original pixel size increases with increasing looking angles). TRMM has a relatively narrow swath. With respect to quickly changing phenomena like convective cloud system development and parallax offset it is not strange that there are low correlations. A method to average the data is presented below although there are more approaches possible to tackle this problem.

10.5.4. MSG averaging

As stated above there are more methods to improve the correlation. In literature approaches are described using larger areas (resampling of the IR data to account for spatial offset) or averaging two IR data acquisitions to compensate for timing offset. Here a slightly different procedure is proposed: the TRMM assigned rainfall pixels with corresponding rainfall intensities are averaged based on MSG-IR pixels having equal temperature (in classes of 0.5 or 1 degree Kelvin). This results in a temperature range, e.g. from 180 to 260 Kelvin, having for each temperature class interval a certain averaged corresponding rainfall intensity. These two variables are then used to determine the correlation and when satisfied a suitable regression function can be used for regionalization using the IR image as well as a short term IR time series of 15 minutes interval images (in the case of MSG).

To perform this operation in ILWIS first a new domain has to be created with the appropriate temperature intervals (in Kelvin). From the main ILWIS menu, select the option “Create” > “Domain”. Specify an appropriate input domain name, select the “Class” option and the “Group” function (see figure 10.13). By pressing the “insert” key a new class interval can be added as well as the associated code. After having finished inserting all the class intervals the domain editor can be closed. For your convenience this domain is available in the main exercise directory, called “temp_cl1”! Open this domain.

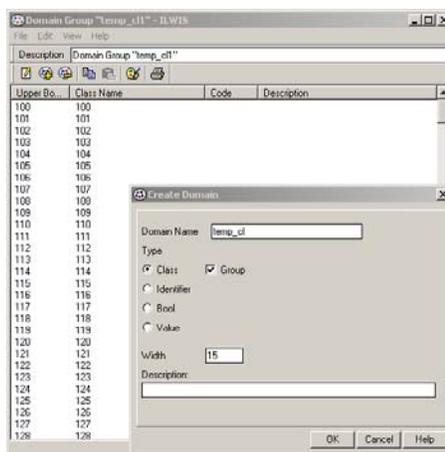


Figure 10.13 Creating a new class domain

Close the domain and open the cross table which was created previously by crossing the temperature image with the point rainfall raster map. Now you first have to classify the temperature column into 1 degree intervals. In the table menu, use the option “Columns” > “Column slicing”. Use as column name the temperature column and as domain the 1 degree temperature interval domain. Specify a name for the output column, e.g. “slicingT”. A new column is now created with these class intervals for each record.

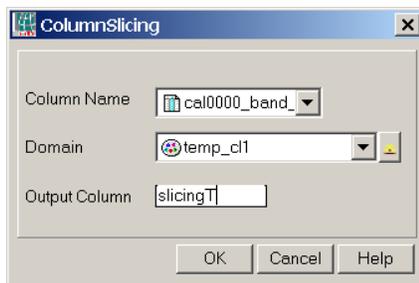


Figure 10.14 Column slicing operation

This newly created slicing column is now going to be used to create a new output table in which the average rainfall per temperature class interval is calculated. Select from the table menu “Columns” > “Aggregation”. Select the “rainfall” column for Column input, use the function “Average”, “Group” it by the column “slicingT”. Specify a name for the

new table that is going to be created and an appropriate output column name. Execute the operation and open the newly created table. Check the results of this operation.

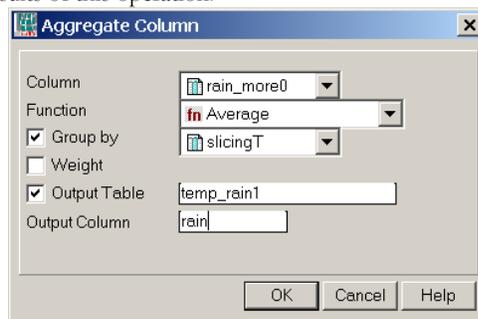


Figure 10.15 Aggregation function

In the newly created table (here called “temp_rain1”) there is only one column: the average rainfall, the temperature is given by the record ID. You can use the predefined variable, %K, to create a new column using these record numbers. Type in the table command line the following expression:

```
temperature:=%K
```

Use as domain the default domain and execute the expression. Using the right mouse button click on the name of the temperature column (the whole column is now blue) and select from the drop down list the option “Properties” and change the domain to a “Value” domain. You will note that the column content is now aligned at the right hand side of the column (as in figure 10.16).

rain	temperature	ID
2.753	253	253
1.730	254	254
1.640	255	255
1.901	256	256
2.475	257	257
1.751	258	258
1.587	259	259
1.329	260	260
1.361	261	261
1.325	262	262
2.569	263	263
1.887	264	264
1.705	265	265
2.432	266	266
2.108	267	267
1.209	268	268
1.564	269	269
0.000	270	270
2.628	271	271
1.355	272	272
1.103	273	273
1.070	274	274
1.363	275	275
1.046	276	276
1.356	277	277
0.930	278	278
0.777	279	279
1.179	280	280

Figure 10.16 Final rainfall and temperature table

From the table menu, select “Columns” > “Statistics”, from the drop down menu, the function “Correlation” and use as input the two columns of this table. As you can see the correlation by this type of averaging is already considerably improved (R is now nearly -0.8). To get a better idea of the characteristics of your data you can create a graph as well. Use the Graph button from the table menu, for the X-axis use the “temperature” column and for the Y-axis the “rain” column. Modify the X-axis range (from 150 to 300). The negative relation between temperature and rainfall intensity can be clearly depicted from this graph. To see if it is possible to obtain a least square fit through this data set, select from the Graph menu the option “Edit” > “Add Graph” > “Least Square Fit”. The example given below shows a “Polynomial” fit using “4” terms (3rd order). The associated properties of the line can be retrieved when double clicking the line representation in the left hand legend.

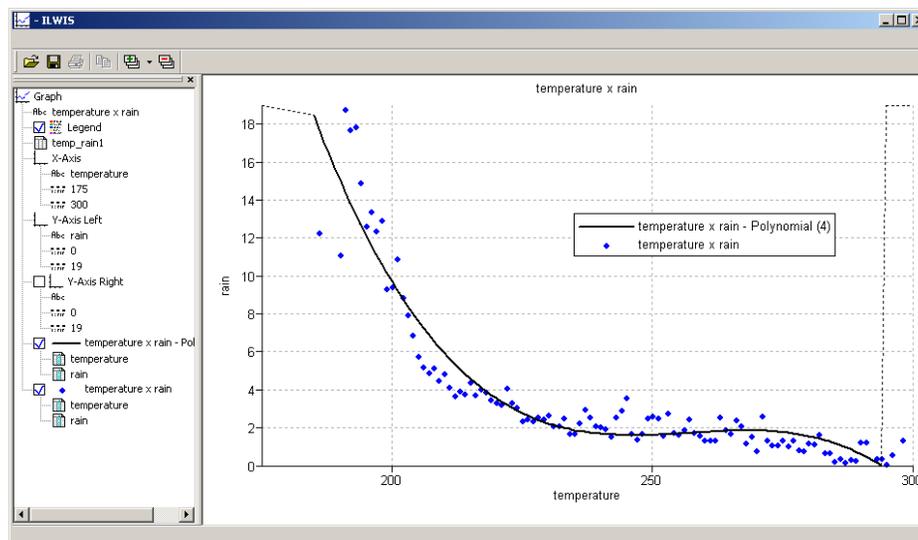


Figure 10.17 Graphical representation of relation temperature – rainfall and polynomial function

Close the graph window and from the table menu, select “Columns” > “Least Squares”. As X-axis “temperature”, as Y-axis “rain”, function is “Polynomial” and as number of terms “4”, now specify as output column “poly_3” and press “OK”. In the Column Properties window, press the option “Additional Info” and note the equation of the fitting function ($Y = 801.825646 + -9.357660 * X + 0.036419 * X^2 + -0.000047 * X^3$) and press “OK” twice. Check the values of the new column “poly_3” obtained and calculate the “correlation” between the “poly_3” and the “temperature” columns.

If satisfied with these results the fitting equation obtained can be used to transform a single thermal image (10.8 micron cloud top temperature) into a rainfall intensity map. You can enter the equation obtained into the command line of the main ILWIS window and conduct the transformation from temperature into rainfall:

```
rain1930:=iff(pcloud=1, 801.825646 + -9.357660 *cal0000_band_2+0.036419 * cal0000_band_2^2+-
0.000047 *cal0000_band_2^3,?)
```

Here we are going to follow a more generic approach as ILWIS is showing only a few decimals and for higher order polynomial functions the number of decimals is of critical importance. Copy and paste from the “temp_rain1” table the columns rain and temperature into an Excel worksheet. Only take for both columns the relevant data range as given by the temperature column from 190 to 296. Select from the Excel menu the “Chart Wizard”, as chart type select “XY (Scatter)” and as subtype “Scatter” (compares pairs of values), press “Next” and specify the appropriate data series (X=temperature and Y=rainfall) and press “Next” and “Finish”. The initial graph is shown in the active worksheet. Eventually change the X-axis data range (from 175 to 300). Right click with the mouse in the graph on the data points and from the context sensitive menu select the option “Add Trendline”, select “polynomial” and use as order “3”. From the “Options” tab, activate the options “Display equation on chart” and “Display R-Squared value on chart”, press “OK”. The equation of fit is given, activate the equation window, right click the mouse on this window again and from the context sensitive menu select the option “Format Data Labels”, from the “Number” tab, select “Number” and as “decimal places” specify “10” and press “OK”. Don’t activate the option ‘Use 1000 Separator (,)’. The chart, equation and correlation coefficient obtained should resemble the results of the graph presented below.

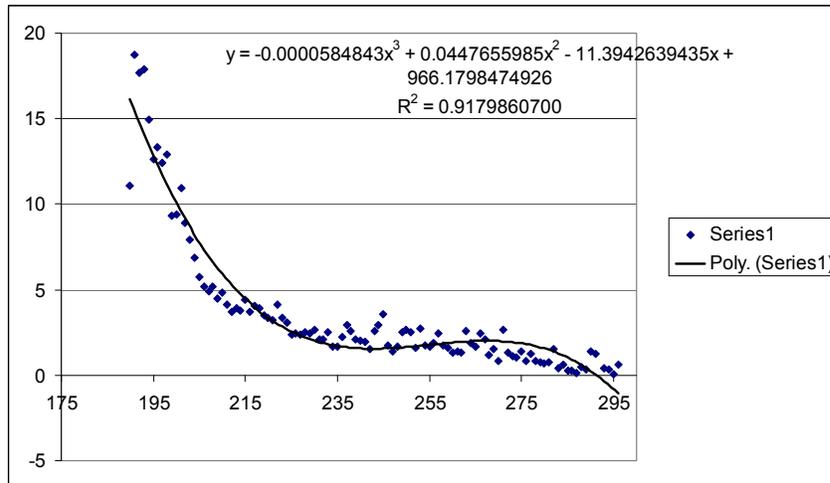


Figure 10.18 3rd order polynomial function and equation of fit

The resulting equation that can be typed in the command line of the main ILWIS menu now becomes:

```
rain1930_p3:=iff(pcloud=1, -0.0000584843*cal0000_band_2^3+ 0.0447655985* cal0000_band_2^2 -
11.3942639435*cal0000_band_2 + 966.1798474926,?)
```

Specify as value range “0” to “250”, precision of “0.01” and press “OK”. Note that “pcloud” is the precipitating cloud map calculated before and if there are no precipitating cloud pixels defined in this map an undefined is returned in the output map! Display the resulting map. Also calculate a 4th order polynomial function, a sample equation is provided below:

```
rain1930_p4:=iff(pcloud=1, 0.0000009548*cal0000_band_2^4 -0.0009862060*cal0000_band_2^3 +
0.3804618224*cal0000_band_2^2 - 65.0015824495*cal0000_band_2 + 4153.4825533355,?)
```

The resulting 3rd order polynomial function rainfall map should look like the figure presented below. Add also a vector layer with the country boundaries for visualization purposes. Use as representation the colour assignment as provided by “mpe_single”. Open from the map window the option “File” > “Pixel Information” and roam the cursor over your map, inspect the values obtained. Eventually add the point map with the TRMM rainfall locations. Repeat this procedure for the 4th order polynomial function.

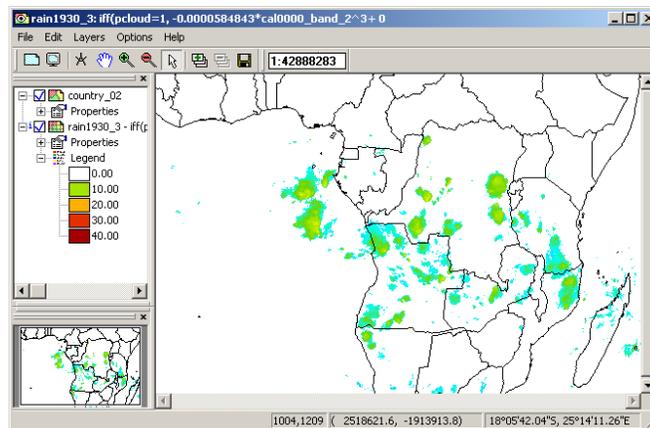


Figure 10.19 Rainfall map obtained derived from MSG Cloud Top Temperatures

The near real time multi sensor precipitation estimate (MPE) can be directly retrieved from the EUMETSAT Website (available: <http://oiswww.eumetsat.int/~idders/html/grib.html>, a rolling archive with files given for the last 24 hours). To derive the MPE use is made of the relationship between cloud temperature and rainfall intensity, as colder clouds are likely to produce more rainfall as seen in the relationship determined before. The MPE uses a statistical matching algorithm in temporal and geographical windows to correlate the SSM/I instrument derived rain rates with Meteosat IR brightness temperature images. The obtained relationship is later-on converted to the full Meteosat-9 temporal resolution and a MPE product is generated each 15 minutes. The algorithm performs well for the tropical and subtropical convection areas. The relationship is based upon SSM/I – Meteosat co-located pixels from 40 degree North to 40 degree South (Heinemann, et al, 2002). With the DMSP program (two satellites in polar-orbit array), a given location on Earth is revisited every 6 hours, allowing 4 brightness temperature versus rain rate calibration events on a 24 hr basis. The data is provided in GRIB format and other functionality in the GEONETCast toolbox allows one to import these files.

Open the map “*mpe20080223_1930*” to see the results of the MSG rainfall product (MPE) for the full field of view of the geostationary satellite. “*Resample*” this map, from the option “*Spatial Reference Operations*”, using the thermal image georeference “*cal0000*”.

Visually check the differences between the two maps and also calculate the difference between the two rainfall maps (keep the undefined pixels in mind!). You can also determine the correlation between the two maps (R of 0.8 or higher) using the “*Cross*” operation. What can be concluded when comparing your own calculated results with those from the multi sensor precipitation estimate (MPE)?

10.5.5. Compute rainfall intensities for a time series of thermal images

Once more retrieve the data for channels WV_062 and IR_108 of Meteosat-9. Use the MSG data retriever with the settings as indicated in the figure below (File, open and load the “*msg_tday.msg1project*” file). Note that for 23 February 2008 all data is retrieved on a 15 minutes basis, transformed into two ILWIS map lists (multiple times in one file), and converted to temperature for an identical window as was used previously. Note the folder settings for the output files! Use your active working directory.

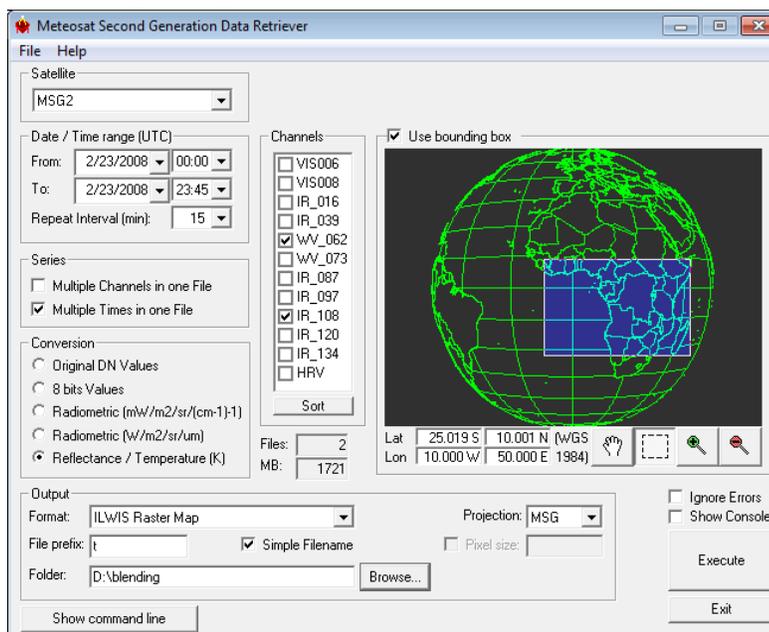


Figure 10.20 MSG import setting for time series retrieval

To visualize the time series created, move to your working directory and right click the maplist icon, select “*Open*” from the drop down menu and select the option “*As Slide Show*”. Also study the naming convention of the different

times used (instead of 'Band_n' it should be interpreted as 'Time_n'). Use an "Inverse" representation, use the default stretch and click "OK", in the display options set the refresh rate to a higher value, e.g. "150" and press "OK".

Have a look at the animation and close the animation window afterwards. Now calculate for each time step in the time series the precipitating clouds in a similar way as has been done previously for the 19:30 hr image. In order to do so select from the Main ILWIS menu "Operations" > "Raster Operations" > "Maplist Calculation". Select the appropriate map lists and enter the expression as indicated in figure 10.21 below (note that t0000 is representing the WV channel and t0001 is representing the TIR channel).



Figure 10.21 Map list calculation for time series computation

Now you can use the 3rd order polynomial formula as used for the 19:30 hr UTC image to transform the whole time series of the 23rd of February to rainfall intensities. Once more select "Maplist Calculation". Select the appropriate map lists and enter the expression using the coefficients for the previous obtained 3rd order polynomial fit, see also figure 22. Now each image in the maplist is transformed into a new maplist with rainfall intensities. Display this maplist as a slide show using as representation "mpe_single", add the country boundary vector layer as well.

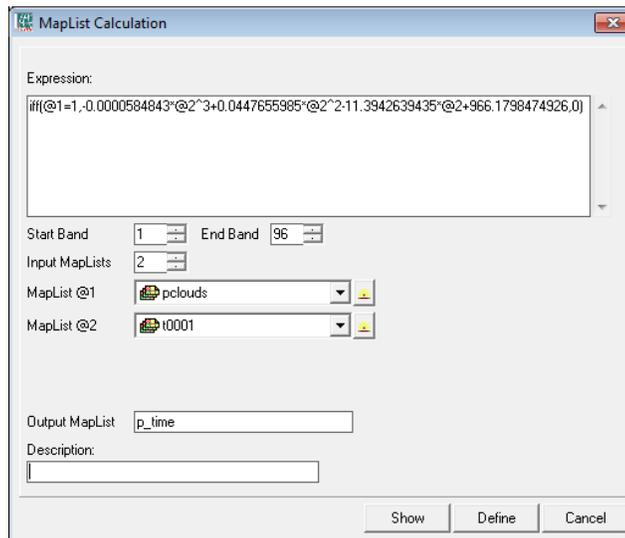


Figure 10.22 Transforming a maplist of thermal images into rainfall intensities

Double click the rain maplist and select image band_79 (which is actually the 19:30 hr UTC image) and display this image. Keep the map display window open. Close the maplist. Now select the maplist icon again using the right mouse button and select from the drop down list "Statistics" > "Map List Graph". Activate the fix stretch option and assign "0" to the minimum and "20" to the maximum, activate the "continuous" button as well. Now roam the mouse over the map display window and check the temporal activity of the rainfall over certain pixels during the 23rd of

February, note that the X-axis is the time (1=00:00 – 96=23:45 hr UTC) and the Y-axis is the rainfall intensity in mm/hr.

Now you have obtained a continuous rainfall record consisting of 96 observations over the day, transformed in a similar way as the 19:30 hr UTC image which was calibrated using a TRMM single overpass observation.

10.5.6. Compute total daily rainfall

To compute the total rainfall the Maplist statistics Sum function can be used. Right click with the mouse the maplist “*p_time*”, select “*Statistics*” > “*Maplist Statistics*” and specify the appropriate settings, as statistical function use “*Sum*”. Execute the operation and display the resulting map.

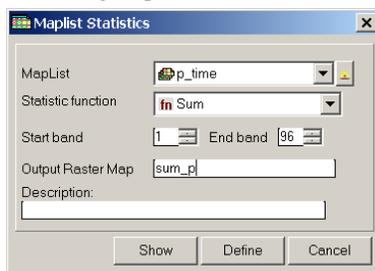


Figure 10.23 Summation of the 96 precipitation events

As the initial unit per timestamp is in mm/hr and we have 4 events on an hourly basis a final correction needs to be applied to obtain the total precipitation per day in mm. Type the following expression in the command line of the main ILWIS menu:

```
Rain_day20080223:=sum_p/4
```

Use the default map definition settings, display the resulting map and check the values. For better visualization you can use the representation “*mpe_sum*”. Your results should resemble those of figure 10.24.

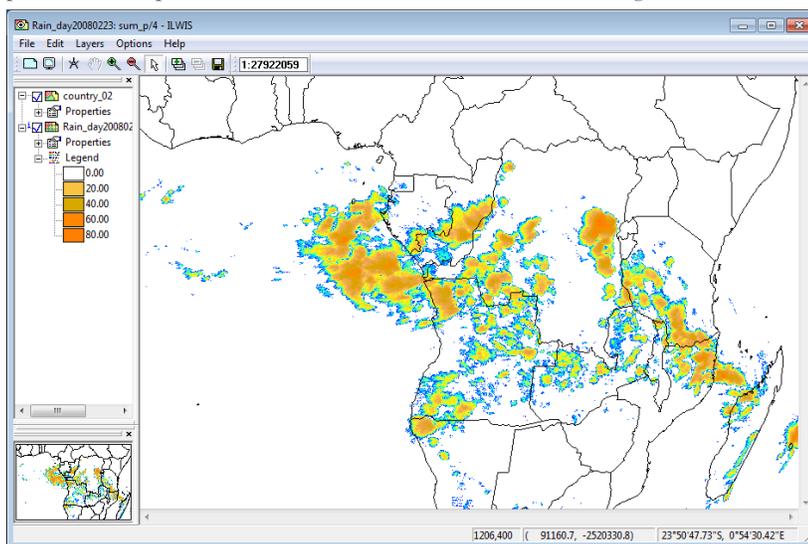


Figure 10.24 Precipitation calculated over central Africa for 23-02-2008

Leave the map “*Rain_day20080223*” open. To check the temporal distribution of the rainfall, right click with the mouse on the map list icon “*p_time*”. From the context sensitive menu, select the options “*Statistics*” > “*Maplist Graph*”, use a fixed stretch from “*0*” to “*20*”, activate the options “*Continuous*” and “*Always on Top*”. Now browse with the mouse over the map “*Rain_day20080223*” and check the rainfall details in the Maplist Graph window (note that the unit is mm/hr!).

10.6. Concluding remarks

The purpose of the exercise is to show how information obtained from other sensors can be used in conjunction with the cloud top temperature from geostationary satellites. Here the evening TRMM TMI overpass is used to calibrate a whole day of MSG 15 minutes interval images; you could use other overpasses from different satellites as well.

Here a statistical curve fitting procedure is adopted for the sake of simplicity to demonstrate the procedures. This adopted methodology is not able to cope with all miss-alignment issues. Furthermore the function applied to perform the averaging is resulting in the fact that the high precipitation events are not well taken into consideration and therefore under-estimation occurs, which could clearly be observed when comparing the rain rates derived with the '*mpe*' precipitation product. It should furthermore be noted that for this product another sensor, the Special Sensor Microwave Imager (SSM/I) onboard the polar orbiting DMSP satellites, is used as well as another overpass time.

More complex procedures are currently in place to obtain satellite derived rain rates, also incorporating gauge based ground observations. The timing for the total daily rainfall most likely deviates from the one that is presented by the meteorological organization of your country. To compare the obtained results with real rain gauge measurements one needs to know the time when the reading is done and use the same temporal settings for the MSG derived images!

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