11. APPLICATION OF A COMBINED DAILY RAIN GAUGES AND RAINFALL SATELLITE ESTIMATES SCHEME FOR BASIN MANAGEMENT

By: **Daniel Vila[1] and Cesar Luis Garcia[2]**

11.1. Relevance of the application

The spatial and temporal distribution of precipitation at regional scale is needed for a variety of scientific uses, such as climate diagnostic studies and societal applications such as water management for agriculture and power, drought relief, flood control, and forecasting floods and crops health. A very common aspect of hydrological monitoring in developing countries is the low density of rain gauge networks. Constrains of data in critical situations like drought and flood periods add an extra challenge to the people trying to mitigate and control the damages, also reducing the effectiveness of the measures. Also under normal situations, the availability of hydrological information can help to improve land productivity by allowing better farm and market managements. Having hydrological information is a valuable asset, but the task of quantifying the rainfall distribution is complicated by the fact that no single, currently available estimate of precipitation has the necessary coverage and accuracy.

Estimating daily rainfall over land, using a satellite-based algorithm and rain gauge networks involves two major issues: firstly to define the algorithm to derive the satellite based precipitation and secondly define and design a merging technique. In the first case, the "Hydroestimator" algorithm is used as the base algorithm for retrieving precipitation and it is available under the acronym "Rainfall Satellite" "RFS" in the GEONETCast feed. The second issue has been largely discussed in several papers over the last years, but the general assumption is that rain gauge observations have lower bias. Therefore they will prevail over any satellite retrievals in those regions with dense networks, while over the ocean (not analyzed in this application) and non-well gauged areas, the multi-satellite estimates have a larger weight in the final analysis.

11.2. Objectives of the application

The objectives of this application are to:

1. Develop a blended product based on the Hydroestimator algorithm (Vicente et al., 1998) and daily rain gauge values using the Combined Scheme (CoSch) technique (Vila et al., 2009);
2. Calculate rainfall statistics for any region of interest (ROI) that is provided by the user. This involves: daily mean areal rainfall, maximum rainfall of the day, area where rainfall is > 1mm, and daily mean areal rainfall considering only values > 1mm.;
3. Provide to GEONETCast users an automatic function for data processing in order to obtain daily products from the near real-time information. The resulting products will be: Daily precipitation estimates from the 15min Hydroestimator algorithm and Daily Combined Scheme corrected precipitation.

This application can be used in manual, batch or automated mode. The manual step by step procedure is the best way to really understand the methods adopted and see how the application works. For exercising purposes, the manual mode for a given day will be explained in this chapter. But you can integrate this application into your work using batch or automated mode operations. Batch mode allows to process entire months or time series of any length, while automated mode is to obtain daily results directly from the satellite feed.

[1] INPE-CPTEC, Brazil, email: Daniel.vila@cptec.inpe.br

[2] CREAN-UNC and Catholic University of Cordoba, Argentina, email: cesarnon@gmail.com

11.3. Data used

11.3.1. Geo-temporal boundaries

The development of this application will be carried out inside the geographical limits of the INPE RFS product, and for exercising purposes a ROI containing the major catchments of South America will be provided. However, the application can be replicated and adapted to any other ROI. For this application we used a daily gauge dataset that is freely available for the entire world, and which determines the temporal resolution of the exercise as daily. The Combined Scheme (CoSch) technique (Vila et al., 2009), can be applied to other regions of the world and in different geo-temporal resolutions, depending upon data availability.

11.3.2. Local / regional (in-situ) data

The local data needed for this application is the ground information on rainfall. The Combined Scheme (CoSch) technique offers a better accuracy due to the integration of data from different sources (satellite and ground). In this case, the rainfall information will be obtained from NOAA's Climate Prediction Centre Unified Gauge-Based Analysis of Global Daily Precipitation. The advantage of this data source is that it is freely available for download from: ftp://ftp.cpc.ncep.noaa.gov/precip/CPC_UNI_PRCP/GAUGE_GLB/.

With a daily global coverage and a spatial resolution of 0.5 degrees, it contains information from 1st January, 1979 to the present. The number of gauges varies, the Retrospective Version, from 1979 – 2005, uses 30K+ gauges. From 2006 – till the present day, the so called Real-time version uses approximately 17K gauges. For any given day, 2 images are available: 1 layer containing the number of rain gauges with observations per pixel, and another image with the mean precipitation value of the gauges.

Other local data required are the Regions of Interest (ROI), over which the aggregated rainfall statistics will be computed. Here some of the biggest catchments of South America are used.

11.3.3. Data from GEONETCast – DevCoCast

The data used in this application is part of the stream of DevCoCast America. The product is provided by CPTEC - INPE and it is released under the acronym "Rainfall Satellite - RFS". The data is in GEOTIFF format, about 200KB in size, with a temporal resolution of 15 minutes and a spatial resolution of 4km. Basically, the RFS is the result of applying an adapted version of the Hydroestimator algorithm to transform the GOES East thermal images into precipitation.

11.4. Methodology

The proposed scheme, hereafter called Combined Scheme (CoSch), combines two approaches in a single method to remove the bias of satellite estimates. In this way, it overcomes some limitations of both schemes used separately and it produces spatially continuous rainfall fields. Figure 11.1 represents the flowchart of this procedure.

Those pixels with no gauges (this information is also provided in the CPC product) will be removed from this part of the analysis, since no ground truth can be used to correct them. The change of resolution to 0.25 degree and a buffer zone will produce a group of pixels for the same station.

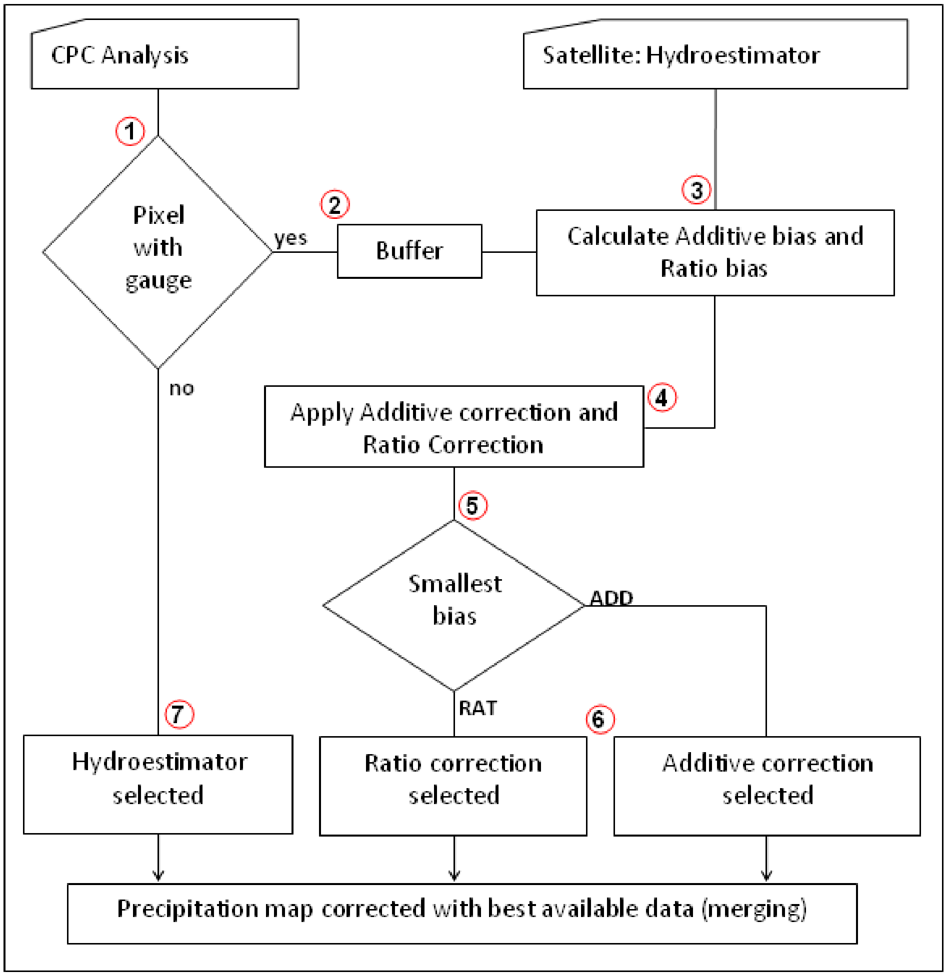

Figure 11.1 Methodology followed in this application

The additive bias correction (ADD) is defined as follows:

$$ADD = rr\_sat + \overline{(rr\_obs - rr\_sat)} \qquad \text{Eq. 1}$$

Where rr_sat is the satellite based retrieval and the second term represents the gridding average of the (additive) bias between the observed rainfall (rr_obs, CPC analysis) and the satellite retrieval (Hydroestimator, in this case) for each pixel group.

The ratio bias correction (RAT) is defined as follows:

$$RAT = rr\_sat * \overline{\left(\frac{rr\_obs}{rr\_sat}\right)} \qquad \text{Eq. 2}$$

Where the same conventions as those described for the additive bias correction are used.
In the next step, the difference between additive/multiplicative bias correction and values obtained from CPC analysis is performed. One particular scheme (additive or ratio) is selected for each pixel based on the minimum difference between that particular bias correction and the observation. For each non-masked pixel one particular method is assigned and for the rest of the pixels the original hydroestimator value is set.
After deriving the daily precipitation using the Combined Scheme the next step is to obtain the statistical values for every ROI and export them into a table.

11.5. Data analysis

11.5.1. Data collection and pre-processing

Before starting with the analysis, there are some pre-processing steps required to obtain the final 3 maps that will enter into the process (RFS, CPC and ROIs). All maps have different boundaries and a different resolution, we are going to use the full extent of the RFS product, but we are going to aim for a 0.25 degree product.

An example area of interest map is provided for this exercise, it is basically a class map containing ROIs with the same coordinate system as the RFS data and having a 0.25 degree resolution.

The RFS images are downloaded at a rate of one every 15 minutes, and need to be integrated into a daily image. A very important point to consider is with respect to the start/end time of the daily integration, these should be the same for the ground and satellite datasets. In this case, for South America, the daily integration period of today will start from yesterday at 12:15 hrs UTC time to today at 12:00 hrs UTC time. The units of the RFS product are mm/hr and the daily integration procedure adopted here is: average of all images during the full day and multiply the result by 24. This is the best way of distributing the errors produced by missing images, something very common in this kind of data. In order to perform the daily integration, an automated processing routine can be adopted on a daily basis using the online data stream; also batch routines can be applied on archived data.

For this exercise the daily RFS image containing the rainfall estimation of the hydroestimator algorithm for the 3rd of January of 2011 is provided, called "*hydro_20110103*".

Unzip and copy the exercise data to your active working directory. Start ILWIS and use the navigator to move to this working directory. Now close ILWIS and open it again. In the catalogue of the main ILWIS window you should see the map "*hydro_20110103*". Double click on the map name to open it, use as Representation "*mpe_sum*" and press "*OK*". Note the map values and inspect the coordinate system used. Double click on the "*Properties*" item, available in the left legend window of the map. Add the country boundaries "*country_02*" as well, using as display option "*Info*" off and "*Boundaries Only*". Note that the southern parts of Chile and Argentina are not covered as the product only provides rainfall data up to 45 degree south latitude.

The next step is to resample this data to get a 0.25 degree resolution. This is done using the Resample option available from the ILWIS main menu "*Operations*" > "*Spatial Reference Operations*" > "*Raster*". Resample details are given in figure 11.2 (left) as well as the output results (figure 11.2, right). Display the output map created and check the results.

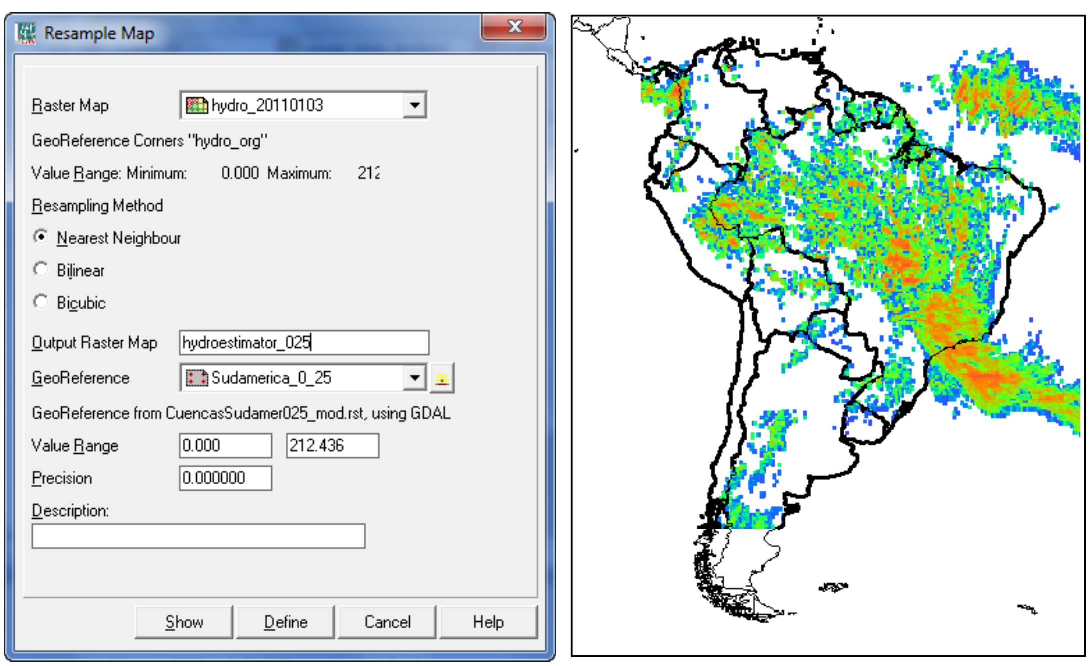

Figure 11.2 Map resampling settings and resulting RFS map

The CPC data can be downloaded via ftp (see address above) and the gauge map should be processed to match the resolution and geographic boundaries of the daily RFS. The CPC images have a spatial resolution of 0.5 degree and have global coverage, but here only a part is required covering the South American region with a resolution of 0.25 degrees. If you have an internet connection you can go to CPC ftp site and check the data available for the day we are working in. In the folder RT (stands for Real-Time) you will be able to find the file: "*PRCP_CU_GAUGE_V1.0GLB_0.50deg.lnx. 20110103.RT*". This file is also available in your working directory.
The procedure to import this image requires a closer look at the meta data provided:

- The file format is binary, real (float) values in a little Endian byte order (no 'swap' required) where undefined / no data = -999.0;
- header size = 0, data is stored in a band sequential (BSQ) file structure
- Number of Rows / Columns = 360 / 720;
- Minimum / maximum Latitude of corner coordinates -90 / 90; Minimum / maximum Longitude of corner coordinates 0 / 360;
- Number of bands is 2: Rain = the grid analysis (0.1mm/day) and Gnum = the number of gauges.

Although in the current version of ILWIS the scrip command allows to include more options for the import of a generic raster map(s), enter the following command line in the main ILWIS window to import the two CPC gauge map layers:

```
cpc_temp:=maplist(prcp_cu_gauge_v1.0glb_0.50deg.lnx.20110103.rt,genras,Convert,720,2,0,BSQ,Real,4,
NoSwap,CreateMpr)
```

When import is completed, a maplist is created, open the maplist called "*cpc_temp*" consisting of 2 bands. Open from the maplist the map "*cpc_temp1*", choose Representation "*Pseudo*" and your map should resemble the one given in figure 11.3.

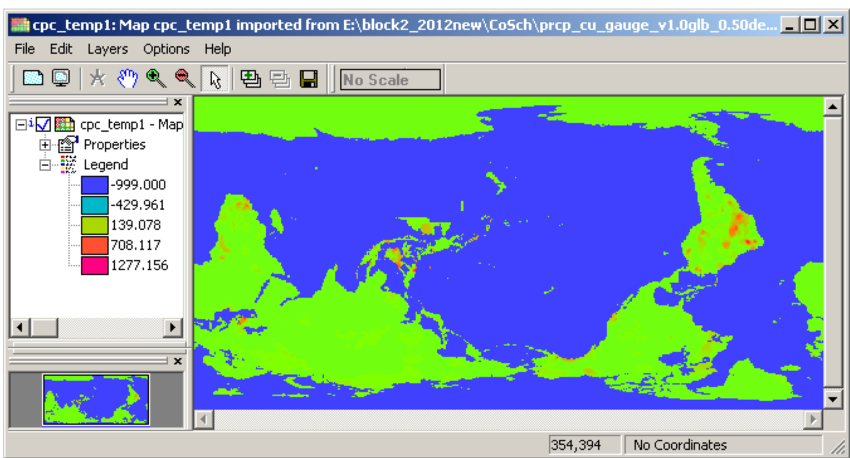

Figure 11.3 Resulting map layer 1after import of the CPC gauge data

The CPC maps are written and read from West to East and then from South to North, while other software packages use a North to South procedure. Right click using the mouse button the map layer "*cpc_temp1*", select from the context sensitive menu the option "*Spatial Reference Operations*" > "*Raster*" > "*Mirror Rotate*", choose the option: "*Mirror Horizontal*" and specify as output raster map "*cpc_temp1_mirror*". Your output should resemble figure 11.4. Note that there are no coordinates assigned to the map.

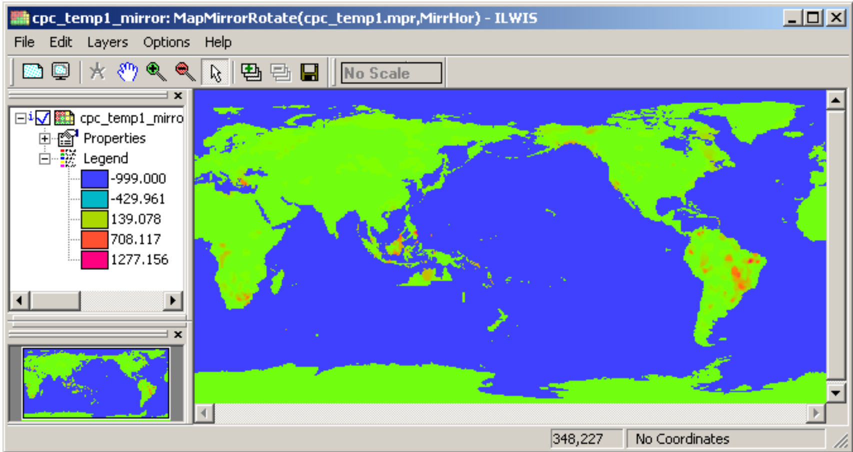

Figure 11.4 Resulting map using the Mirror Rotate - Mirror Horizontal option

Repeat the procedure for the other band: "*cpc_temp2*" and note the gauge distribution around the globe. Instead of using the menu you can also type the following expression into the command line of the main ILWIS window and press "*enter*" and "*OK*":

cpc_temp2_mirror.mpr:=MapMirrorRotate(cpc_temp2,MirrHor)

Display the map using and "Inverse" Representation; stretch the map from "0" to "1".

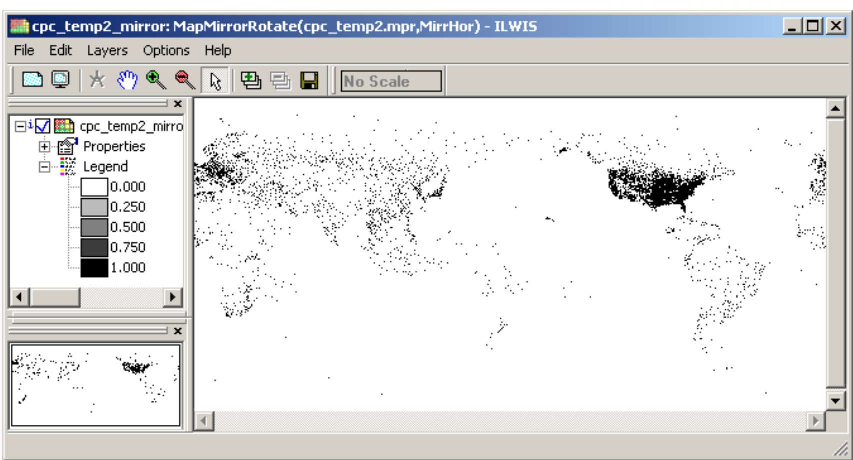

Figure 11.5 Resulting map using the Mirror Rotate - Mirror Horizontal option of layer 2

The next step is to geo-reference the maps and this presents a challenge as the world coordinate system is commonly having America on the left (west) and Africa-Asia situated in the east. In this case only South America is needed, but here the whole world extent is taken so if you are interested in some other area you can repeat the procedure. The method to adopt is: cut the world in an eastern and western hemisphere and then switch the order.

Select the option "*Sub Map*", from "*Operations*" > "*Spatial Reference Operations*" > "*Raster*". Specify the settings as indicated in the figure below and create the two 'hemispheres'.

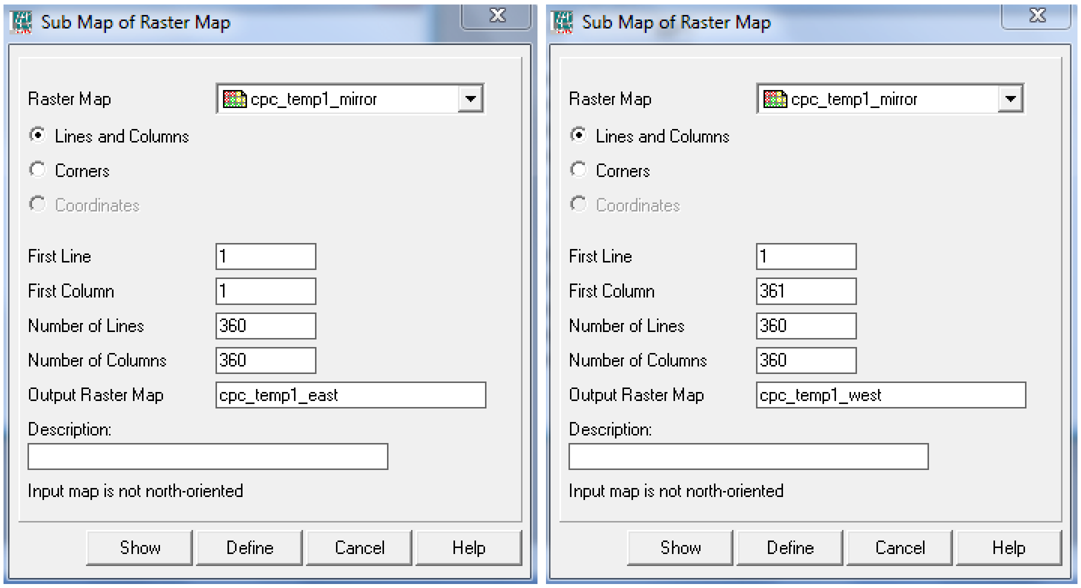

Figure 11.6 Creating eastern and western hemisphere sub maps

Check if your sub maps are OK. Note that you will see something very strange in Australia, if you haven't noticed before, a portion of the country is having no data. Always check the results of your operations carefully; a visual inspection can save lots of time, prevent problems and wrong conclusions! In this case it will not have an impact because it is not in our study area.

To combine the maps in the proper order it is necessary to geo-reference the 2 pieces and then glue the maps to obtain a global coverage having the Greenwich meridian in the map centre. From the ILWIS main menu select "*Create*" > "*GeoReference*" and create two geoereferences called "*east*" and "*west*", see details in figure 11.7.

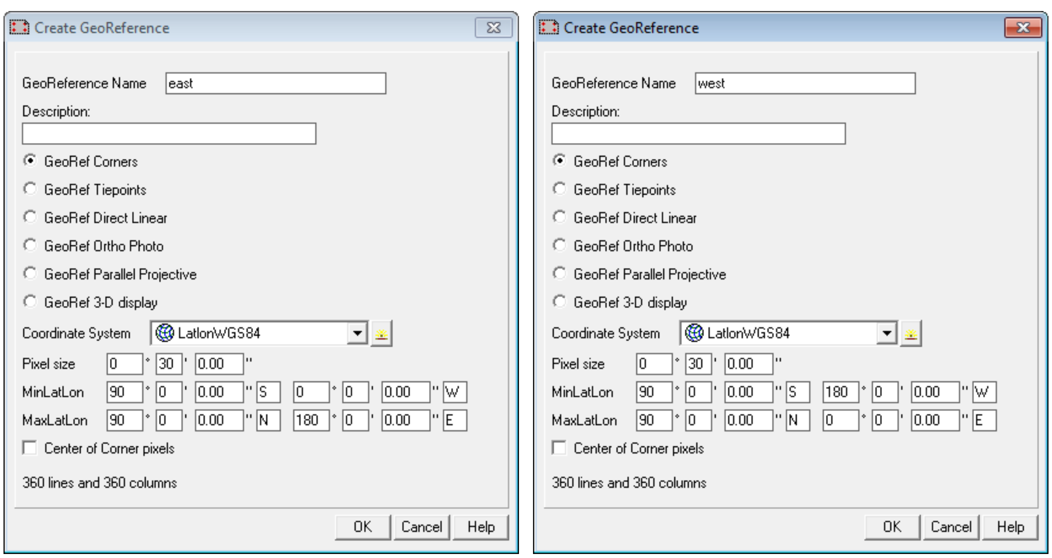

Figure 11.7 Georeference details for the eastern and western hemisphere

Right click the mouse over the map "*cpc_temp1_east*", from the context sensitive menu select "*Properties*". From the properties dialog box select the tab "*Dependency*" and press the button "*Break Dependency Link*" and confirm with "*Yes*". Once more right click with the mouse the map "*cpc_temp1_east*", and now as georeference specify "*east*" and press "*OK*". Display the map and add the layer "*country_02*", using as display options "*Info*" off and "*Boundaries Only*". Check your results, especially the coordinate information provided in the lower right hand corner of the map display. Repeat this procedure for the western hemisphere; use the map "*cpc_temp1_west*". After the georeference for the western part is assigned, select from the main ILWIS menu the option "*Operations*" > "*Raster Operations*" > "*Glue Maps*". As 1st and 2nd map use "*cpc_temp1_east*" and "*cpc_temp1_west*" respectively, as Georeference specify "*full_WtoE*" and call the Output Raster Map "*prcp_20110103*". Your results should resemble those of figure 11.8.

Repeat the procedure as indicated above to the second band (gauges) of the CPC imported map, here called "*cpc_temp2_mirror*". As output name from the Glue Maps operation, use "*gauges_20110103*". Note that to visualize this map an "Inverse" Representation can be used and stretch the map from "0" to "1".

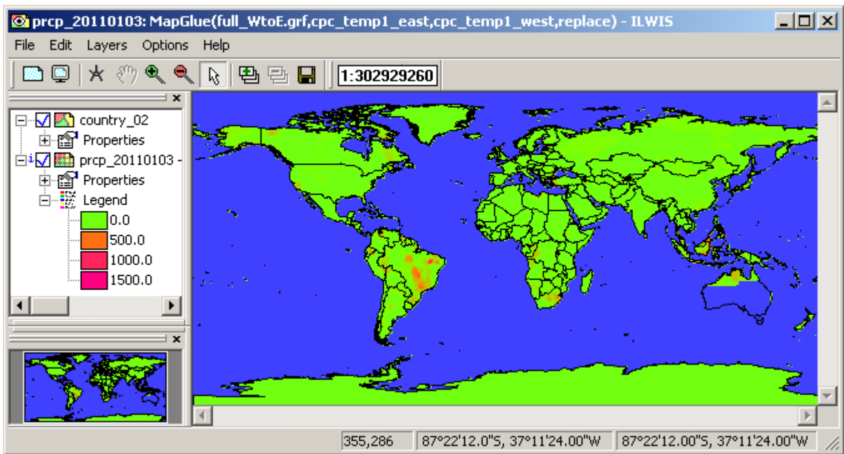

Figure 11.8 Final map showing the CPC interpolated gauge rainfall fields

Last step is to resample the "*prcp_20110103*" and "*gauges_20110103*" CPC maps so that these can be used in conjunction with the Hydroestimator map at 0.25 degrees resolution. Check the resampling settings as of figure 11.2 (left) and call the output maps "*prcp_20110103_025*" and "*gauges_20110103_025*" respectively. See also figure 11.9, showing the results of this operation. Note that for the visualization of the precipitation map the ocean area has been assigned 'no-data'.

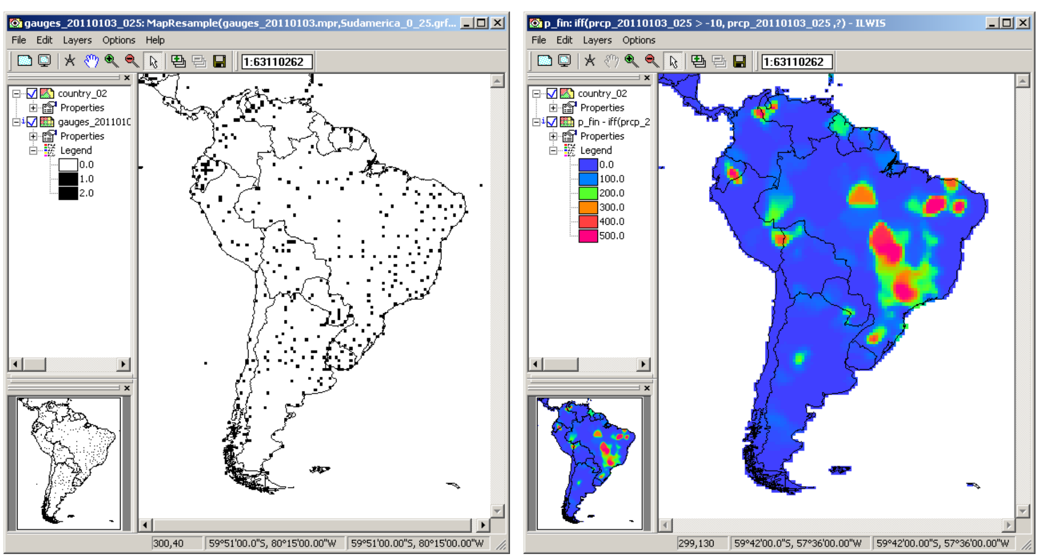

Figure 11.9 Resampling of the CPC precipitation and gauge data for South America

The necessary pre-processing has now been completed. Check the flowchart of figure 1 once more, note that now you are at the beginning of the flowchart, with everything ready to start the process. With respect to the values of the

gauge based precipitation map "*prcp_20110103_025*", you may have noticed that these are too high; this is because the precipitation amounts are multiplied by a factor of 10. This is often done to keep the decimals in an integer image: a value of 12.6 is represented as 126. This correction will be applied later.
Before you start the next series of calculations, first carefully look at the explanation and figure 11.10 below. The computations required will be conducted using an ILWIS script to calculate the additive bias and ratio bias corrections as given by equation 1 and 2 respectively.

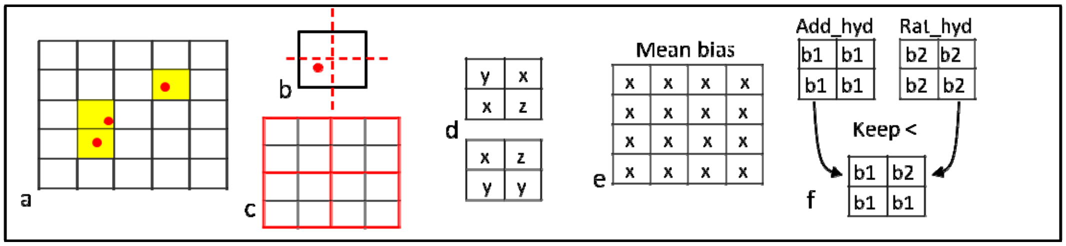

Figure 11.10 Method adopted to select the smallest bias

To start, only use those pixels from the cpc_gauge map that contain at least 1 gauging station **(a)**. This map is resampled from 0.5 degrees to 0.25 degrees **(b).** The hydroestimator map is resampled to 0.25 degrees **(c)** by aggregation. Subsequently the 2 bias images (additive and ratio) are calculated **(d)** and a filter is applied to obtain the mean additive and ratio bias (which can also be assigned to neighbouring pixels) **(e)**. These mean bias maps are used to correct the hydroestimator. One particular scheme (additive or ratio) is selected for each pixel based on the minimum difference between that particular bias correction and the observation (cpc_precipitation) and the best estimate is selected **(f)**. Pixels in ungauged areas will remain untouched and the original estimated value will be retained.

11.5.2. Calculation of bias

In order to perform the computations given in the flowchart as steps 1 to 4 an ILWIS script is at your disposal, called "*bias*". Select the script "bias" from the catalogue and open it. Inspect the content carefully as additional explanation is provided there as well. To run the script, press the "*Run Script*" icon ▶ and in the next popup script parameter window specify the appropriate input maps. See also figure 11.11 below and press "*OK*" to execute the script.

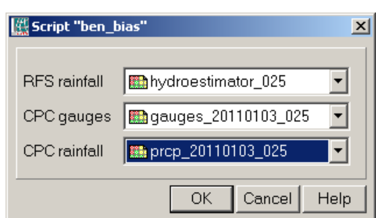

Figure 11.11 Input maps to compute the bias

After the computation has finished open the map "*hydro_add*", use as Representation "*mpe_sum*". From the map window, select the option "*File*" > "*Open Pixel Information*" and from the Pixel Information Window select the options "*File*" > "*Add Map*" and add all maps that have been computed for the additive bias calculation:

- Input maps: hydroestimator_025, gauges_20110103_025, prcp_20110103_025;
- Input gauge rainfall: prcp_temp, gauge_boolean, prcp_masked;
- Rainfall difference: bias_add_temp, bias_add_for_sum, bias_add_for_count;
- Filter results: add_sum and add_count;
- Average bias: average_add and bias_add.

Move the mouse over the map "*hydro_add*" and check the values of the intermediate maps. Eventually use a calculator to check the results. The output should resemble those given in figure 11.12.

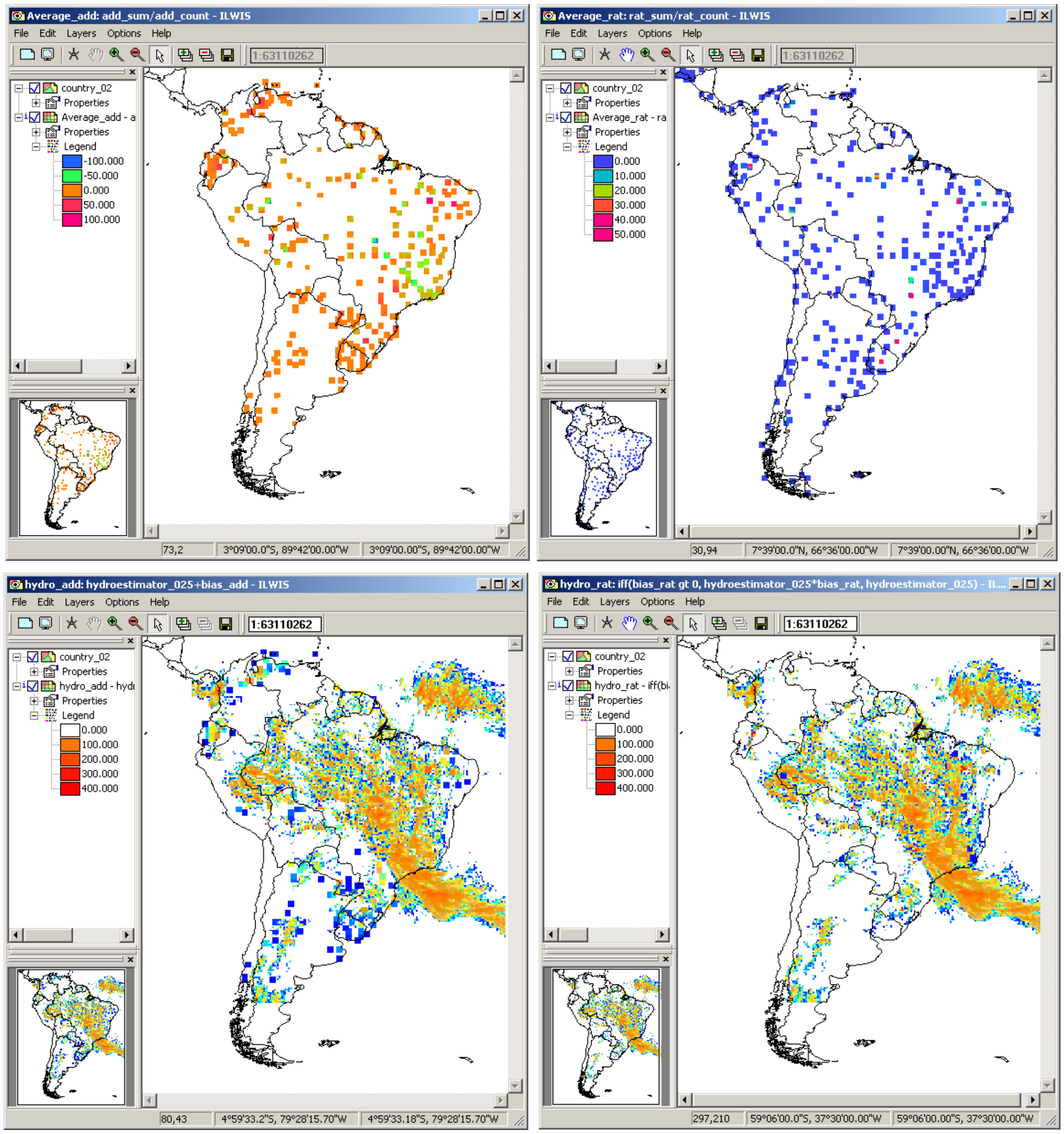

Figure 11.12 Average additive and ratio bias and resulting hydro_add and hydro_rat maps

In the process the size of the bias correction window was increased; the gauge location areas have been expanded by one pixel! Note that what looks like single 0.5 degrees pixels are in fact 4 pixels of 0.25 degrees. You can use transparency to display "*bias_add*" and "*bias_add_temp*" in the same map window, and you should see the effect of the filter. See also figure 11.13. At this resolution this is the smallest area increase that you can make. A bigger area means more continuity but this also depends on your study area and rainfall systems. Consider that having a gauge measurement, taken from a sampling area of about 30 cm in diameter, then distributing this value over an area of 50 km radius 'is already a big leap of faith'.

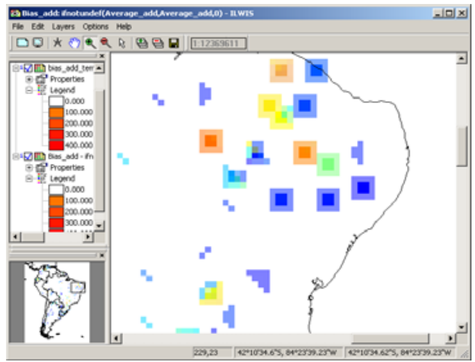

Figure 11.13 Expansion of gauge location window

11.5.3. The decision process and calculation of the CoSch

Now we can determine which method presents the smallest difference between the corrected estimate and the original ground measurement. This difference can be either positive or negative. Either way we want the smallest and so we have to take this into consideration. For this, we use the abs function which will give us the absolute value.

The precipitation file we need to use to make the comparison is "*prcp_masked*", because those were the only areas that have the real observations. But, if you remember well, the sum3x3 filter that was used increased our area of bias correction by a pixel. Here you can choose to neglect the bias correction by one pixel and continue to use prcp_masked. Type the following expressions in the command line of the main ILWIS menu and press "*OK*" to execute the operation:

diff_abs_add:=abs(prcp_masked-hydro_add)
diff_abs_rat:=abs(prcp_masked-hydro_rat)

You may also want to keep the 3x3 increased filter in order to gain a bit more of continuity in your final map:

gauge_temp_mask:=MapFilter(gauge_boolean,RankOrder(3,3,9),value)
prcp_masked_big:=gauge_temp_mask * (prcp_temp/10)

diff_abs_add_big:=abs(prcp_masked_big-hydro_add)
diff_abs_rat_big:=abs(prcp_masked_big-hydro_rat)

Display the maps calculated and use pixel information to check your results. Now that the absolute differences are known, the map with the lowest bias can be selected. The expression provided here uses the first set of equations as input:

cosch_temp:=iff(diff_abs_add ge diff_abs_rat,abs(hydro_rat),abs(hydro_add))

Repeat the procedure using the increased area of bias correction by one pixel as input and call the output map "*cosch_temp_big*". Display the maps, using as Representation "*mpe_sum*" and check your results.

The next step is to retain the best corrected values for the areas close to the gauging stations and supplement them with the satellite based rainfall product where no ground observations are in the neighbourhood. To do so, type the following expression in the main ILWIS command line:

cosch:=ifundef(cosch_temp,hydroestimator_025)
cosch_big:=ifundef(cosch_temp_big,hydroestimator_025)

Your results should resemble those of figure 11.14, depending on the use of a filter. Explore the values of your image, you can overlay some of them and explore the difference between the measures and the estimated and corrected values for the same pixel. You can also make some maps to see which correction (ADD or RAT) scheme was selected for every pixel, or where the estimate was over or under estimating.

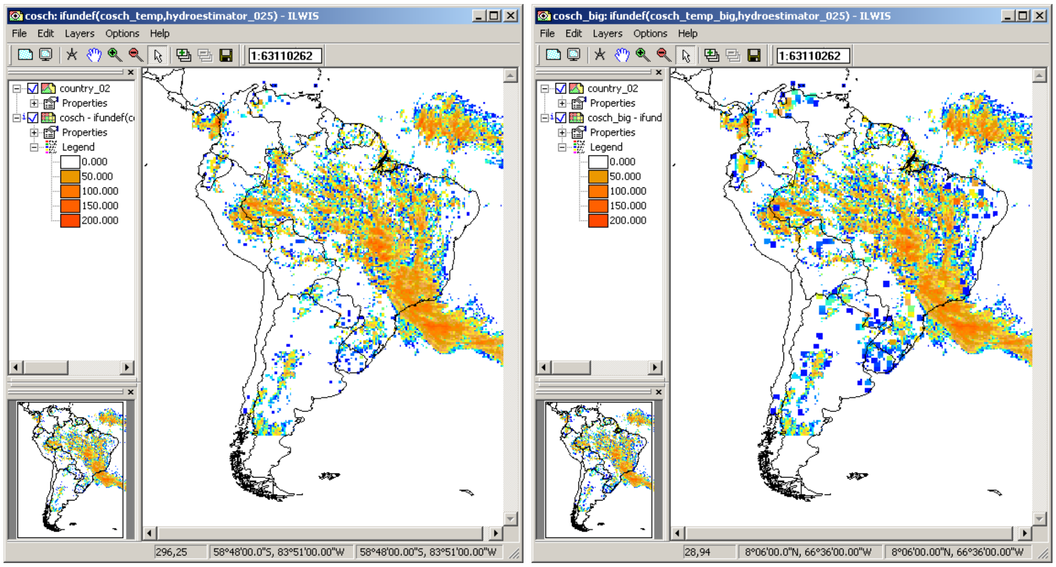

Figure 11.14 Combined Scheme results, without (left) and with filter (right) applied

Consider figure 11.15 showing a pluviometric interpolation and 2 different satellite estimates. Rain fields are not homogeneous like the interpolated. The bigger the area you are using to calculate the mean BIAS, the more errors will be incorporated into the correction. Hence, some places will end up with negative precipitation, which is of course impossible. This is a methodological trade-off, and should be carefully considered.

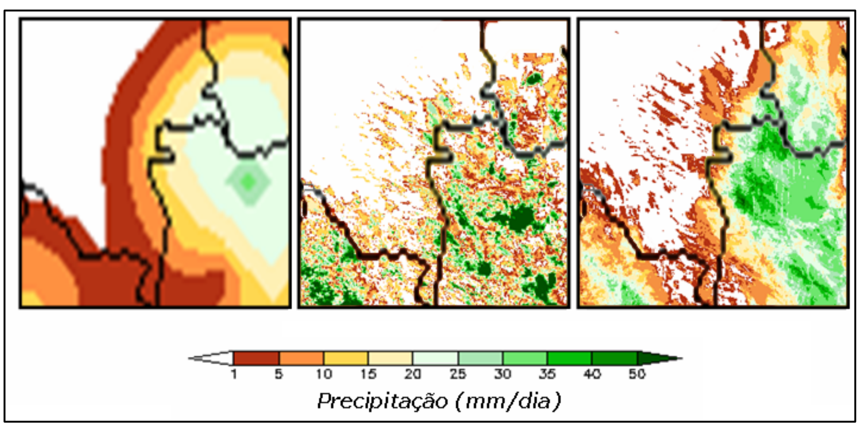

Figure 11.15 Comparison of pluviometric interpolation and satellite rainfall estimates

11.5.4. Retrieving rainfall statistics for basin management

Now it is a good time to check one of the maps we had provided with some sample Regions of Interest (ROIs). It is called "*Cuencas*", open the map and explore the content. See also figure 11.16.

You will notice that when you explore the map with the left mouse button pressed, you will get a tag with the catchment name. This class map will be crossed with our CoSch precipitation map. This operation will yield a table containing all possible combinations of pixels, also some information about how many pixels have the same combination and the area of this combination.

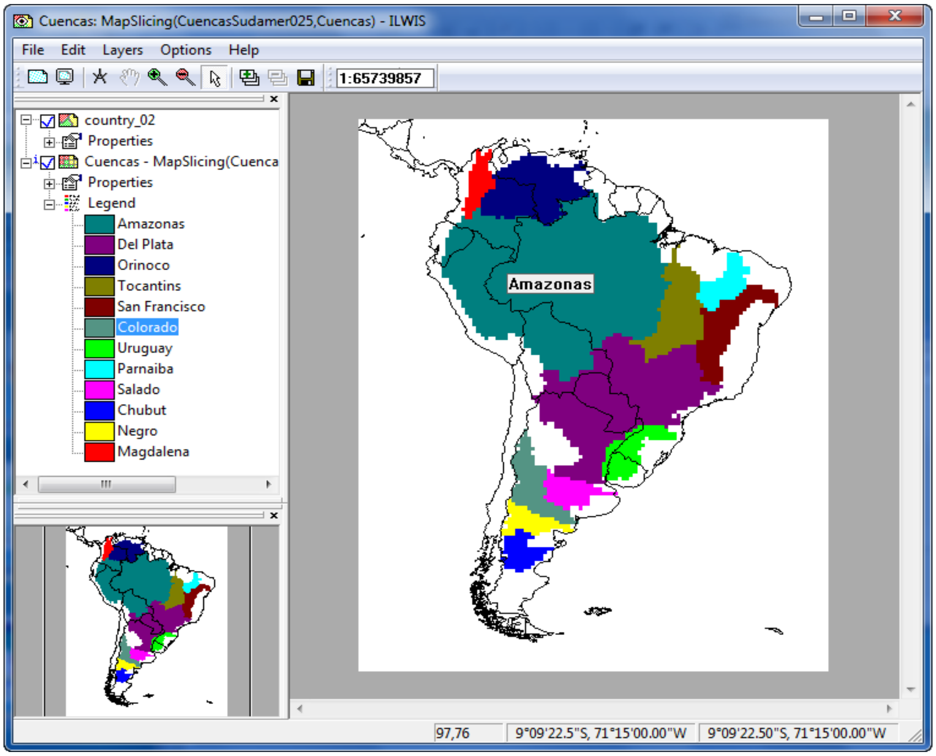

Figure 11.16 Class map showing main basin areas in Latin America

From the main ILWIS menu, select "*Operations*" > "*Raster Operations*" >"*Cross*", provide the details as indicated in figure 11.17 and press "Show". You can also type the following expression in the command line of the main ILWIS menu:

Rain_basin_cross.tbt:=TableCross(Cuencas, cosch,IgnoreUndefs)

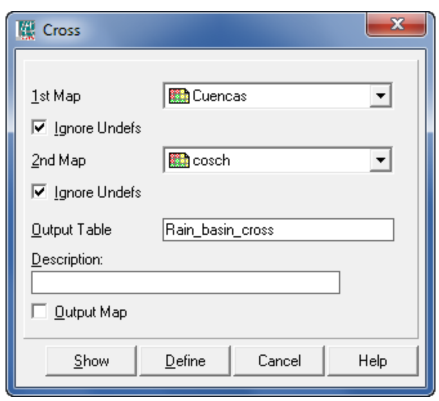

Figure 11.17 Cross operation details

Open the table "*rain_basin_cross*" and inspect the content.

Now you will create a new column retaining only the values of pixels where the precipitation is >= 1mm (Greater or Equal). We can use the 'iff' function in table calculation as well; the new column will be named "*cosch_GE_1mm*". Type the following expression in the table command line:

cosch_GE_1mm:=iff(cosch ge 1,cosch,?)

Now that we can obtain the mean rainfall for every basin, we will create a new table for our results; let's call it "*statistics*". From the table menu select "*Columns*" > "*Aggregation*", provide the details as indicated in figure 11.18 and press "*OK*".

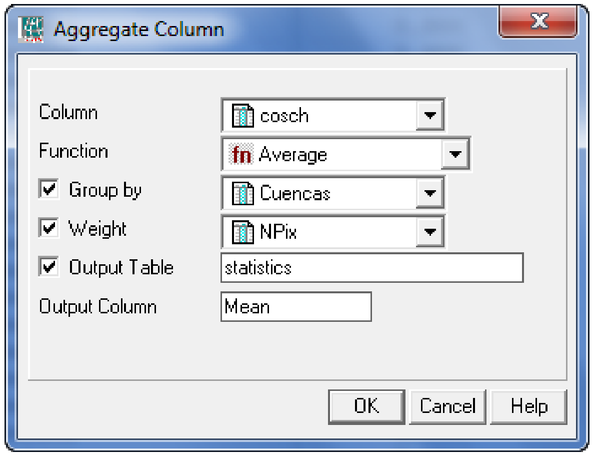

Figure 11.18 Calculation of aggregated basin rainfall statistics

Explore the resulting table "*statistics*" and the mean values. When working with these estimates it is sometimes very useful to obtain the mean rainfall for every basin, but only when rainfall is GE than 1mm. Close the tables. Now you will calculate the remaining statistics from the main ILWIS menu. Enter the following expressions directly in the command line from the main ILWIS menu.
To get the mean rainfall per basin greater or equals 1 mm:

tabcalc statistics cosch_ge_1mm:=ColumnJoinAvg(Rain_basin_cross.tbt,cosch_GE_1 mm, Cuencas,NPix)

To obtain the maximum rainfall per basin:

tabcalc statistics maximum:=ColumnJoinMax(Rain_basin_cross.tbt,cosch, Cuencas,1)

To obtain the area with rainfall GE 1mm per Basin normalized:

tabcalc rain_basin_cross.tbt NPix_GE_1mm:=iff(cosch ge 1,NPix,0)

crtbl Tabla_temp cuencas

tabcalc Tabla_temp sum_NPix:=ColumnJoinSum(Rain_basin_cross.tbt,NPix,Cuencas, 1)

tabcalc Tabla_temp sum_NPix_GE_1mm:=ColumnJoinSum(Rain_basin_cross.tbt,
NPix_GE_1mm,Cuencas,1)

tabcalc statistics area_GE_1mm:=Tabla_temp.tbt.sum_NPix_GE_1mm *100 / Tabla_temp.tbt.sum_NPix

Your final table should resemble the results as provided in table 11.1. Check also the temporary table created, called "*Tabla_temp*"!

Table "statistics" - ILWIS

	Mean	cosch_ge_1mm	maximun	area_GE_1mm
Amazonas	8.793	18.597	154.817	47.18
Del Plata	6.861	22.154	125.885	30.92
Orinoco	0.439	8.924	41.493	4.88
Tocantins	25.182	30.327	185.752	82.97
San Francisco	15.314	23.829	133.533	64.15
Colorado	1.844	10.007	42.857	18.22
Uruguay	2.694	7.656	31.271	34.77
Parnaiba	15.131	20.526	164.982	73.61
Salado	1.347	11.927	45.530	11.25
Chubut	4.801	8.035	31.743	59.51
Negro	1.594	6.923	36.923	22.89
Magdalena	0.465	6.555	16.034	7.01
Min	0.439	6.555	16.034	4.88
Max	25.182	30.327	185.752	82.97
Avg	7.039	14.622	84.235	38.11
StD	7.781	8.068	62.856	26.92
Sum	84.464	175.462	1010.821	457.36

Double click to change column properties of Mean: joinavg(Rain_basin_cross.tbt,Rain_basin_cross.cosch,Rain_basin_cross.Cuencas

Table 11.1 Final statistical results over the main basins of Latin America

As a final task have a look at the ILWIS script called "*script_auto_media*". This script allows performing the whole exercise conducted here in an automated manner.

11.6. Conclusion

The methodology provided here is being successfully applied to La Plata river Basin using other datasets as inputs. This is an adaptation to the DevCoCast data stream product and free CPC gauge data. Further work is needed at this time to test its precisions and limitations. The accuracy and impact of the correction will depend on the density of the gauge network, but also on the precipitation regime and size of the ROI's. Further research is required to study these relationships and establish safe boundaries.

Application of the Combined Scheme for other satellite rainfall estimates in conjunction with ground datasets is very easy following this methodological approach.

Here the proper areas could not be derived from an image that is not projected, but it is considered here a valid exercise. You can also get the area of your basins and then obtain a proportion of rain cover. Ultimately if you know your ROIs area (in Ha or km^2) you can use the proportion to obtain the rainfall area.

REFERENCES

Daniel A. Vila, Luis Gustavo G. de Goncalves, David L. Toll and Jose Roberto Rozante (2009): Statistical Evaluation of Combined Daily Gauge Observations and Rainfall Satellite Estimates over Continental South America. *American Meteorological Society*, DOI: 10.1175/2008JHM1048.1 Available at: http://cics.umd.edu/~dvila/web/CoSch/pdfs/CoSch.pdf

Vicente, G.A., R.A. Scofield and W.P. Menzel (1998): The operational GOES infrared rainfall estimation technique, *Bull. Am. Meteorol. Soc.*, 79, 1883-1898.