CCAFS FUNDED WORKSHOP ON "METHODOLOGICAL APPROACHES IN CLIMATE DOWNSCALING AND WEATHER DATA RECONSTRUCTION"

Executive summary of presentations and discussions

Date: March 21–22, 2011

Venue: CIP-HQ Lima, Peru

Objectives

- To discuss methodological approaches used by different institutions on analyses of rainfall patterns at different time and space domains
- To identify research gaps in rainfall data generation and climate downscaling
- To select research sites for testing rainfall daily data generation and downscaling methods
- To search for synergies among research groups, and
- To define a strategy for collaborative research within CCAFS and other funding opportunities

Expected outputs

- An executive summary of presentations, discussions and recommendations
- An outline of a proposal to study South American monsoon system (by-product)

Program

March 21

Welcome to CIP: P. Monneveux, DDG-Research

Introductory remarks: R. Quiroz (on behalf of CCAFS)

Morning session—Approaches to assess precipitation characteristics

Assessing precipitation characteristics in the South American Monsoon System from different data sets: C. Jones (UCSB, ICESS, CA, USA).

Characterizing daily rainfall signals with the Wavelet Transform Modulus Maximum—Multifractal approach: A. Posadas (CIP), presented by Roberto Quiroz

Afternoon Session—Daily rainfall generation

Generating historical time series of daily rainfall by combining satellite rainfall estimates and rain-gauge measurements: T. Dinku (IRI, NY, USA)

Improving daily rainfall estimations using a wavelet-based multi-resolution approach: data gap filling, TRMM correction, and generation from NDVI: R. Quiroz (CIP)

March 22

Morning session—Spatial downscaling

Downscaling of climate predictions: Experiences in Peru: E. Silvestre (SENAMHI), presented by Delia Acuña

Spatial downscaling of future climate predictions for Agriculture: J. Ramirez (CIAT)

Climate downscaling techniques for end users: a proposal for a non-linear downscaling methodology: A. Posadas (CIP)

Afternoon Session—Impact of extreme events

Changes in the South American Monsoon and potential regional impacts: L. Carvalho (UCSB, Department of Geography)

Presentation Abstracts and summary of discussions

Theme 1: Approaches to assess precipitation characteristics

Presentation Summaries

South American Monsoon System from different data sets

Charles Jones, Leila M. V. Carvalho, Adolfo N. D. Posadas, Roberto Quiroz, Bodo Bookhagen, and Brant Liebmann

Abstract

The South American Monsoon System (SAMS) is characterized by intense convective activity and precipitation that peaks in tropical South America during the austral summer (December–February). Many studies have demonstrated that SAMS varies over broad ranges of temporal and spatial scales, and important local and remote linkages controlling its variability have been identified. A significant challenge to understand past and future changes in SAMS is related to the availability of precipitation datasets. While a few stations in South America have precipitation records going back several decades, the majority of those stations are not located over the core of the monsoon (e.g., over the northeast Brazil). Only a few stations over the Amazon have precipitation records beginning in the early 1980s. In addition, the sparseness of the stations in some parts of the continent poses serious problems to accurately characterize mesoscale precipitation systems.

The objective of this work was to investigate the statistical properties of precipitation in different datasets with different spatial resolutions. The following gridded precipitation data sets were analyzed: 1) Earth System Research Laboratory (ESRL), 2.5° lat/lon, 2) Global Precipitation Climatological Project (GPCP), 1.0° lat/lon, Climate Prediction Center unified gridded precipitation (CPCu), 0.5° lat/lon, National Centers for Environmental Prediction Climate Forecast System Reanalysis (CFSR), 0.5° lat/lon, NASA Modern Era Retrospective-Analysis for Research and Applications (MERRA), 0.5° lat/0.3° lon and NASA Tropical Rainfall Measurement Mission (TRMM), 0.25° lat/lon. Daily precipitation averages for the 1 January 1998–31 December 2008 period were studied.

Several statistical properties were analyzed: empirical orthogonal function (EOF) analysis, cross-correlations, power spectrum, mean, gamma frequency distributions and percentiles. The EOF analysis allows the characterization of the onset, demise, duration and amplitude of SAMS. The first and second EOFs represent the large-scale patterns of precipitation over the core of the monsoon and the South Atlantic Convergence Zone (SACZ), respectively. The first EOF is reasonably represented among all data sets, while the second EOF derived from CFSR data differs significantly from the other data and indicates deficiencies in representing precipitation variability over the western South America. In addition, the onset, demise and duration of SAMS are largely consistent among ESRL, GPCP, CPCu and TRMM, whereas CFSR and MERRA appear to have problems in capture the timing of the monsoon. Figure 1 compares the mean precipitation during the monsoon season from all data sets. While the spatial patterns and intensities are reasonably consistent among the observed precipitation data sets (ESRL, GPCP, CPCu and TRMM), the reanalysis products show some obvious inaccuracies. Both CFSR and MERRA exhibit excessive precipitation over the Andes. In addition, MERRA shows mean precipitation above 6 mm day-1 too far north relative to the spatial patterns derived from the other data sets. Significant spatial and magnitude differences in the parameters of gamma frequency distributions and percentiles were determined among all datasets, which indicates additional challenges for the investigation of extreme precipitation.

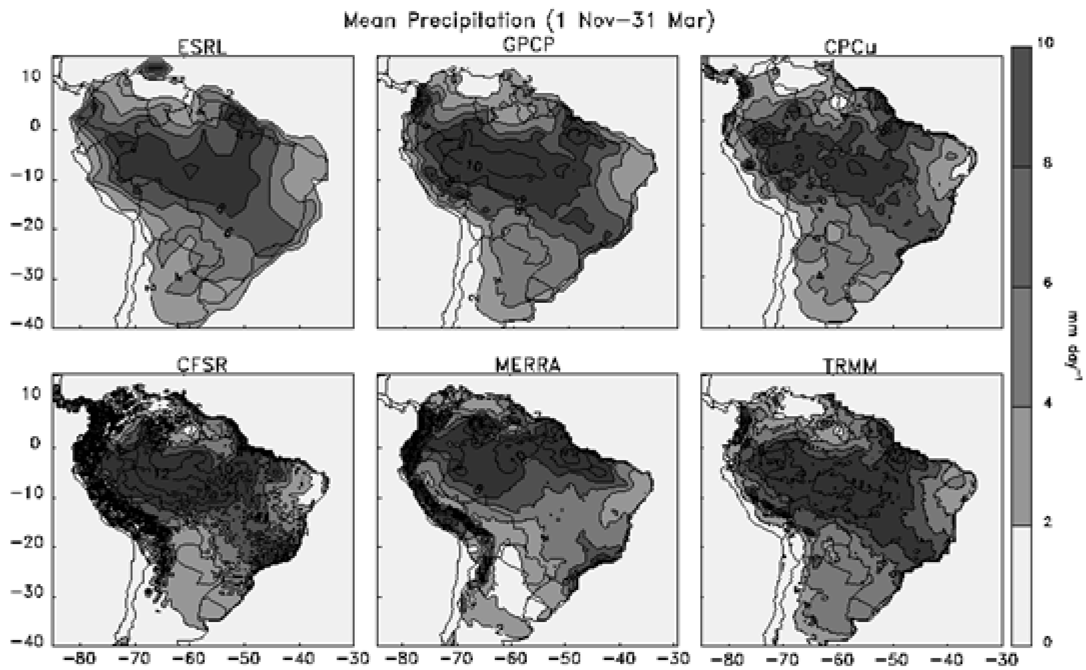

Figure 1. Mean daily precipitation during 1 November–31 March, 1979–2010. Contour interval and shading: 2 mm day-1. Data sets are indicated on top of each panel.

Characterizing daily rainfall signals with the Wavelet Transform Modulus Maximum - Multifractal approach

A. Posadas, H. Heidinger, C. Yarlequé, L. Carvalho, C. Jones, R. Bombardi, and **R. Quiroz**

Abstract

Daily rainfall is the most complex climatic variable, due to the combination of high-frequency/low-magnitude and low-frequency/high-magnitude events. Rainfall is commonly described at low temporal resolution and through statistical parameters or dynamical equations supported by the classical theory. Notwithstanding the usefulness of such characterizations, these techniques omit key attributes that could be useful in characterizing spatial and temporal differences—for example, extreme events (singularities), scalability, and the like. The Multifractal (MF) methodology is a plausible option to assess the variability in high-resolution temporal rainfall signals and understand the conservative properties of the processes across temporal scales. By analyzing these events at several time scales, physical processes governing rainfall can be inferred. To guarantee an adequate description of the true multifractality of high-temporal resolution signals, the Wavelet Transform Modulus Maximum (WTMM) was applied. The advantages of this methodology include (1) the removal of the non-stationarities that mask the true "fluctuations" in the signal; (2) access to the whole range of singularities; (3) efficient and robust estimation of singularities by using the ridges of the maxima; and (4) direct estimation of the MF spectrum. Consequently, the ridges of the maxima connect the occurrence of rainfall events across scales (Fig. 2) thus permitting the detection of changes—regardless of their size—in several time dimensions (hours, days, weeks, months, seasons, years). We hypothesize that this methodology can facilitate the analysis of rainfall differences in topo-climates and thus help develop hypothesis on how the physical parameters varies in topographically heterogeneous terrains. Another attractive feature is the possibility of linking local land properties with high resolution climatic variables.

This work aims at (1) applying the WTMM-MF to characterize rainfall stations in different regions; (2) correlating the MF parameters with those of the climate; and (3) defining a "filter" matrix that represents the heterogeneity of rainfall in space. In the preliminary phase (results are presented for discussion in the workshop), several gauged stations from five countries were processed with the WTMM-MF technique. In this preliminary phase we want to see whether the technique could tell apart differences even in weather stations proximal to each other (see Fig. 3). It seems that the methodology is sensitive to small changes and thus the user must be cautious about the interpretation. For instance, the data from two weather stations in Addis Ababa presented different spectrum, albeit rather close. Similar differences were found elsewhere with apparent minor changes in the surroundings. These preliminary results, although stimulant, demand concerted efforts among disciplines to better explain differences and hopefully will contribute to the search for the understanding of physical parameters that characterize rainfall in micro-zones.

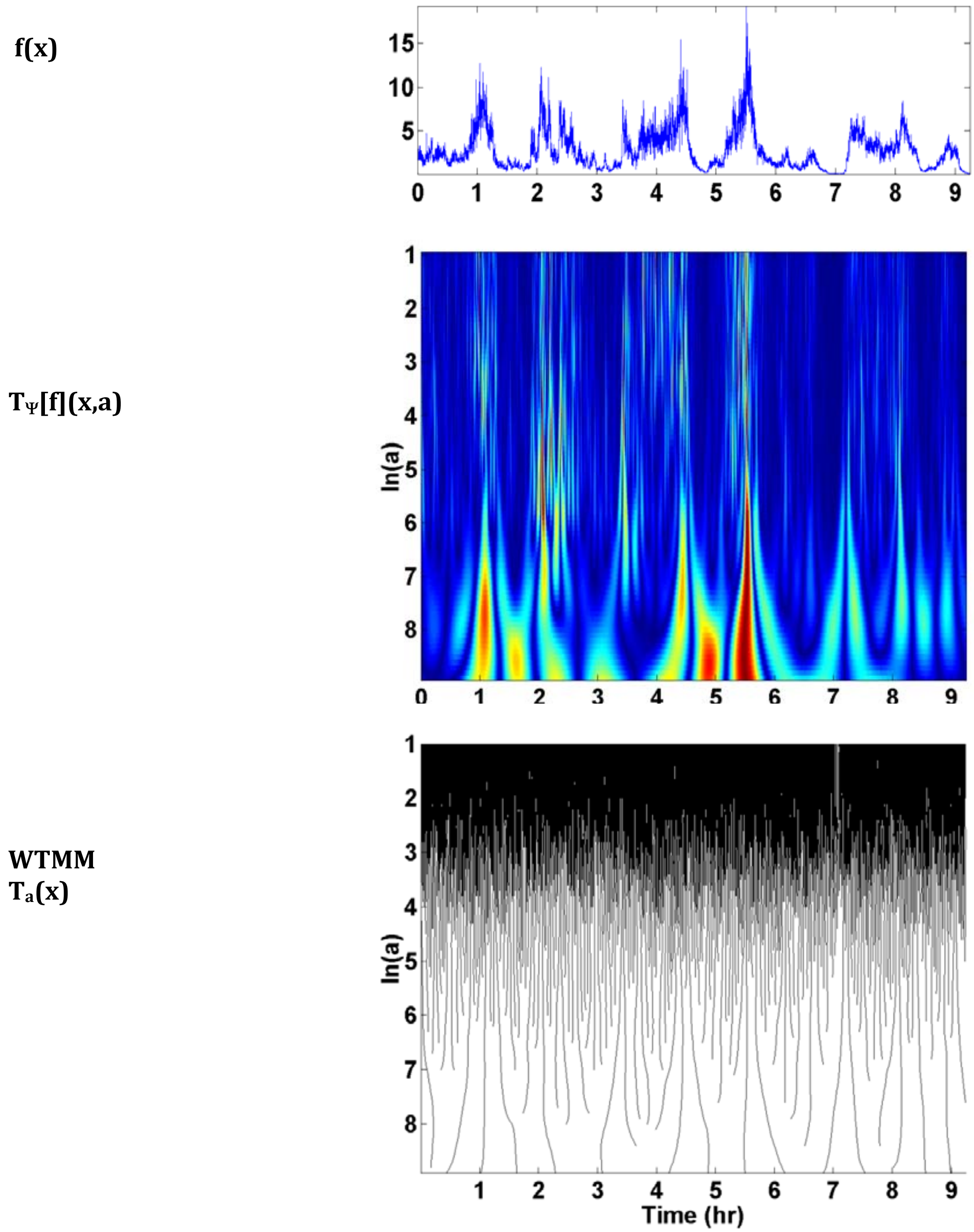

Figure 2. Graphical portray of a high temporal resolution rainfall signal, the wavelet transform and the ridges of the maxima.

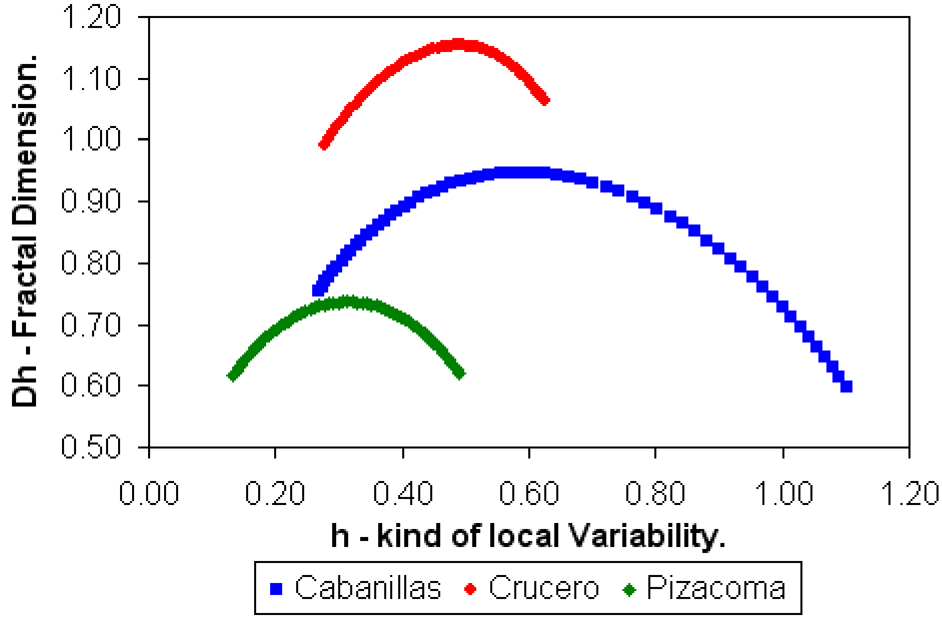

Figure 3. Multifractal spectra of three contrasting rainfall signal in the high plateau, a region deemed as "homogeneous" rainfall wise.

Discussions Highlights

The presentations addressed precipitation characteristics from different but complementary angles. On the one hand, precipitation characteristics were analyzed at the continental scale using a series of geospatial data sets from different sources and spatial resolutions. These data sets included gridded gauged data, reanalysis, and precipitation derived from remotely sensed information. On the other hand, gauged precipitation was characterized using non-linear approaches. The challenge is to find a suitable way of combining the two sources of data and generate better quality temporal & spatial rainfall data for data scarce environments.

In spite of the improvement in the quality of gridded precipitation data, the assessment of the precipitation characteristics is quite challenging. Although the resolution of geospatial rainfall data is improving with the aid of remotely sensed data, the topographic variations—often encountered in developing countries where data scarcity is the common denominator—are still limiting the quality of outputs. This is particularly important when studying the impact of extreme events such as the South American Monsoons at the local level (e.g., glaciers, hydrology, and agriculture). One approach is to use downscaling tools (see discussion below); nonetheless, initial parameters based on a better understanding of the physics is still lacking. The conventional way of eliciting physical parameters is through a dense network of gauge data with long-enough records to account for weather extremes.

The characterization of gauged precipitation data with MF analysis was an alternative discussed. The rational is that since the MF parameters are associated with well-explained thermodynamics concepts, by association, hypothesis of physical drivers could be generated. Although the results are very preliminary, the group is interested in further exploring this alternative and compare results with conventional tools. A possible way to implement this recommendation is to find a data-rich spot to conduct the comparative analysis prior to its implementation in target developing countries. Participants also recommended testing this approach in different research sites and associate the entropy, internal energy, asymmetry, and other MF parameters with, for example, rainfall intensity, length of the rainy season, extreme events, shifts in rainy seasons, orography, and connectivity. One thing was evident: the method is very sensitive to changes in patterns that could be associated to local topography or human error. There are a lot of researchable issues; one of the key ones is the selection of the wavelet most suitable for a particular signal and how the physical interpretation varies when different filters suit better different gauged data.

A third group of comments dealt with packaging results of rainfall characterization for predicting purposes. The intended end users of the information generated have to be kept in mind, since they may have different expectations and time horizons, particularly when dealing with weather/climate forecasts. In this context, differences between short- and long-term prediction skills must be highlighted.

A characterization of gauge data will be done in the Highlands of Peru and in Brazil, to respond to questions raised and to compare with conventional characterization. SENAMHI, UCSB and CIP showed interest in searching for funds and collaborating in this endeavor.

Theme 2: Daily rainfall generation

Presentation Summaries

Constructing Daily Rainfall Time Series by Combining Rain gauge Measurements and Satellite Rainfall Estimates

Tufa Dinku

Abstract

The importance of historical climate time series cannot be overemphasized. Long-term temporally homogeneous time series of climate data with good spatial coverage are critical in many applications, including assessing climate-related baseline or static risks, putting observed and anticipated climate into context, understanding and modeling impact of climate on different socioeconomic activities, and producing useful climate atlases. The conventional source of climate data has been measurements at weather stations. The number and quality of weather stations in Africa, however, has been declining. The available stations are unevenly distributed with most of the stations located in cities and towns along the main roads. This imposes severe limitations to the availability of climate information and services to the rural community where, arguably, these services are needed most. Data available in the cities and towns also suffer from shortness of time series and severe data gaps.

Remote sensing data are very critical to overcome spatial and temporal gaps in ground observations, both for historical data and current observations. The main advantage of satellite proxies is continuous spatial coverage. Satellite rainfall estimates now go back over 30 years. However, current satellite rainfall estimates suffer from some shortcomings. These include heterogeneous time series, short time period, and poor accuracy particularly at higher temporal and spatial resolutions. Most of these shortcomings could be overcome by optimally combing the satellite estimates with station measurements. Though the accuracy is not very reliable at daily time scale, satellite rainfall estimates can provide information about the occurrence and spatial structure of rainfall. These characteristics are used for interpolation of station measurements. This has been tested over Ethiopia and parts of West Africa. National rain gauge measurements were combined with rainfall estimates from Meteosat thermal infrared data using regression Kriging.

Figures 4 and 5 present sample outputs. Figure 4 compares rain gauge data (A), satellite estimate (B), interpolated gauge-only data (C), and interpolated gauge with satellite estimate used as a secondary variable (D) over Ethiopia for 7 July 2003. The satellite product overestimates rainfall over some parts of the country, but does capture the spatial extent and structure of the rainfall. The gauge-only product (C) looks reasonable over data-rich parts of the country, but gives rainfall over the dry, and data-sparse, part of the country. This is a typical problem with interpolation of daily rainfall. The combined product (D) is better than both the satellite estimates and the gauge-only product. The false rainfall over southern and southeastern low lands is no more there, and there are more areas of high rainfall compared to the gauge-only product. Figure 5 presents an example from West Africa. Here we also have a product generated by a regional center (AGRHYMET) at a spatial resolution of 0.5^{o} lat/long (as opposed to 0.1^{o} for the other products). In this case, even the satellite estimate by itself is better than the gauge-only products (C and E). The combined product (D) brings the satellite estimate closer to the gauge values. Figures 4 and 5 underscore the value of the satellite proxies. The satellite estimates contribute more over data-sparse regions. The satellite estimate used here is not the best in terms of accuracy; it has been selected only because of its consistency. Work is underway to produce better satellite rainfall estimates, which will further improve the combined product. Then the satellite estimates and rain gauge measurements will be used to generate 30-year rainfall time series at spatial resolution of 10 km.

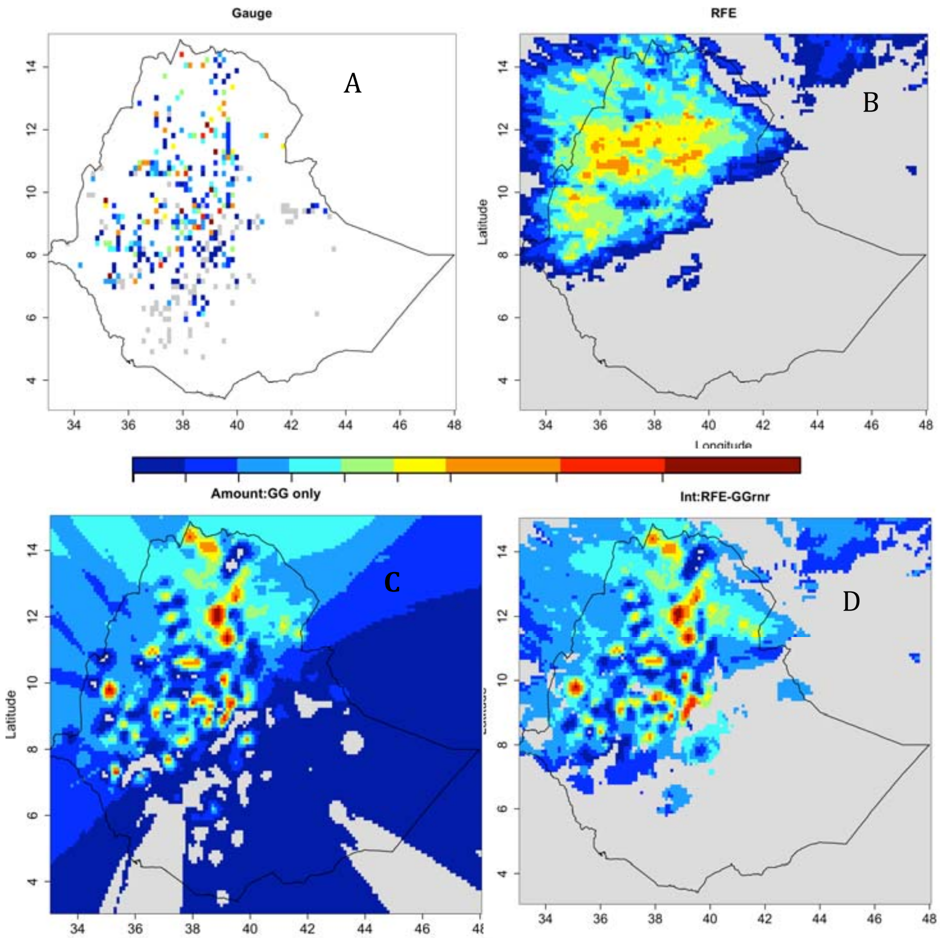

Figure 4: Comparison of rain gauge data (A), satellite estimate (B), gauge-only gridded products (C), and combined gauge-satellite product (D), over Ethiopia for 7 July 2003. All products have spatial resolution of 0.1^{o} lat/long.

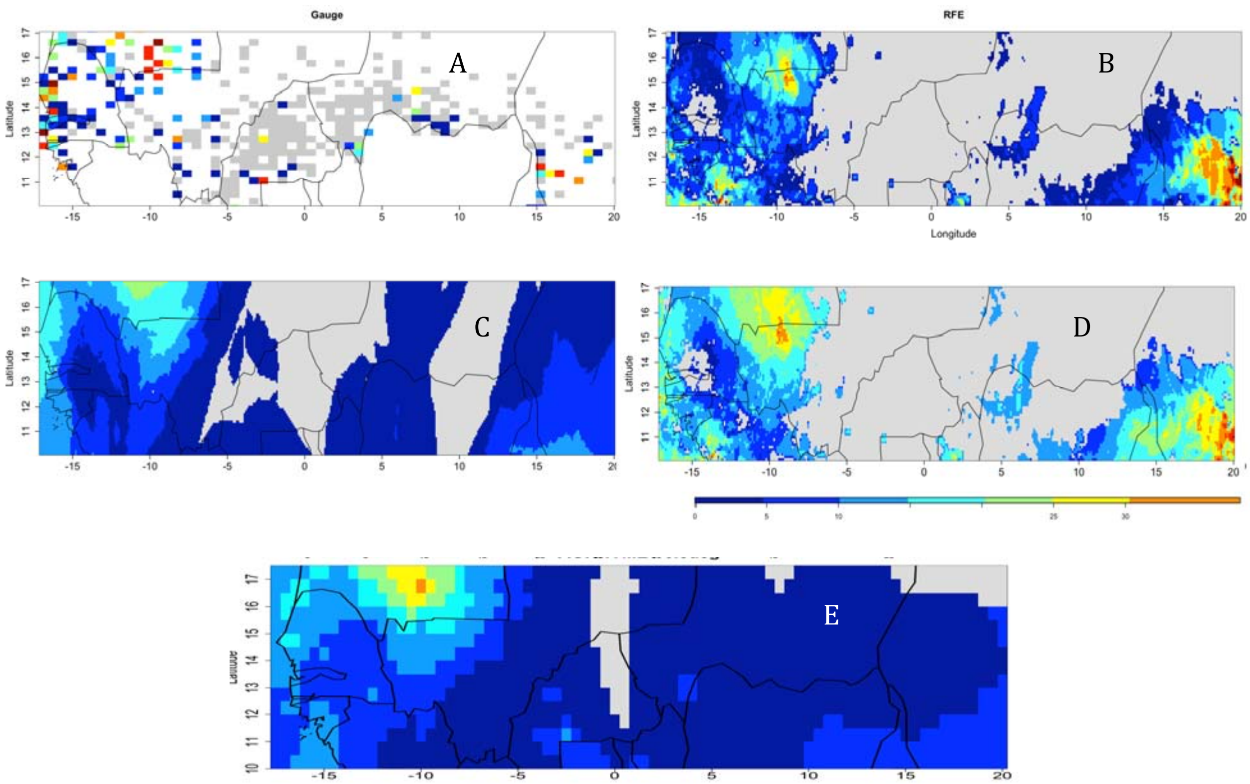

Figure 5: Same as Figure 4, but over West Africa for 10 AUG 2001. Here we also have a product generated at the AGRHYMET center at 0.5^o spatial resolution (E).

Improving daily rainfall estimations using a wavelet-based multi-resolution approach: data gap filling, TRMM correction, and generation from NDVI

R. Quiroz, A. Posadas, M. Carbajal, H. Heidinger, and C. Yarlequé

Abstract

Accurate rainfall data with sufficient spatial resolution are of key importance in assessing the impact of a changing climate on agriculture and other related economic activities. Unfortunately, gauged rainfall data in developing countries present several limitations. The spatial coverage is limited, particularly in terrains with high topographical heterogeneity, where a higher density of stations is required. Long-term (~ 30 years) rainfall time series, needed to assess land-atmosphere interactions, are seldom available and, when available, it is common to find a large amount of missing values. Remote sensing can provide spatial precipitation patterns and thus provide a proxy for quantitative assessments at spatial and temporal scales in regions where meteorological stations are scarce.

A Wavelet transform (WT)-based Multi-Resolution Analysis (MRA) was implemented to combine remotely sensed data with the distinctive feature of local rainfall variability extracted from gauged measurements (Quiroz et al. 2010). This approach was programmed in the freeware Wavelet Transform for Estimating Rainfall (WATER), which can be used to run the applications described below (downloadable from http://inrm.cip.cgiar.org; go to download and then to simulation models). Multiresolution analysis (Mallat and Zhong 1992), as implied by its name, comprises the evaluation of the signal at different frequencies with different resolutions. The MRA allows the decomposition of a signal into various resolution levels which retain the main features of the original signal. The filtering approach to multiresolution WT is to form a series of half-band filters that divide a spectrum into a high-frequency band (retain information about the higher-frequency components) and a low-frequency band (contain information about lower-frequency components). It is formulated on a scaling function or low-pass filter (LP) and a wavelet function or high-pass filter (HP). These filters initially act on the entire signal band at the high frequencies (small-scale) filters and gradually reduce the signal band at each stage (see Fig. 6). The algorithm extracts information from the process through the decomposition or up-scaling of both signals; and then uses it to reconstruct the signal with the initial high resolution through the inverse process. The reconstructed signal retains the statistical properties of the local rainfall variability thus improving the quality of the remotely sensed data.

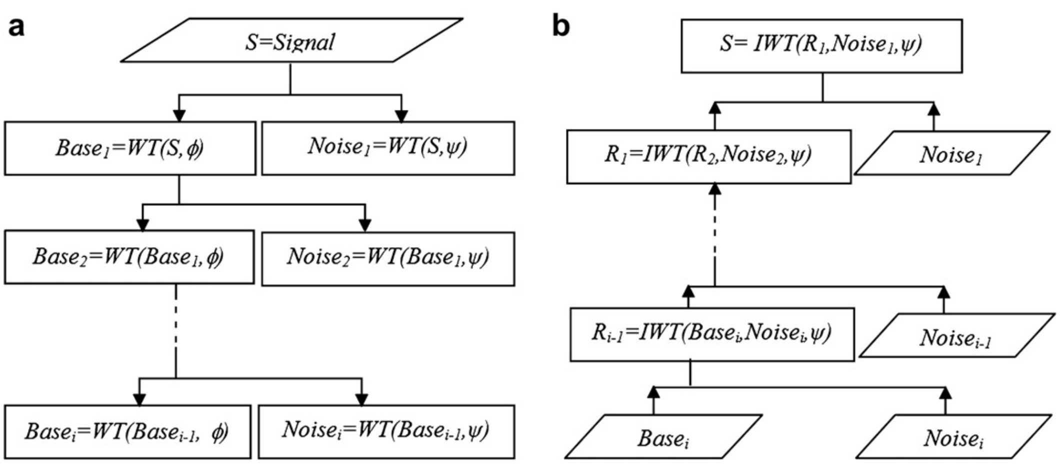

Figure 6. Multi-resolution analysis processes. ***a*** *Decomposition or "up-scaling" process.* ***b*** *Reconstruction or "down-scaling" process. The algorithm and the mother wavelet (ψ) for both processes is the same; i = 0,1,2,. is the finite process level [decomposition (**a**) and reconstruction (**b**)] which define the scale as $\lambda=2^i$ and φ is the scaling function associated to ψ.*

Three applications of the MRA methodology were presented: (1) rainfall data gap infilling based on Carbajal et al. 2011; (2) daily rainfall estimation from Normalized Difference Vegetation Index (NDVI), based on Quiroz et al. 2010; and (3) TRMM correction, based on Heidinger et al. 2011. It was shown that the methodology produced good results in contrasting areas of the world (e.g., Ethiopian highlands, the Indo-Gangetic plains, Sao Paulo, Brazil, and the Andean Plateau). The feasibility of generating long-term daily rainfall data was also discussed (Fig. 7).

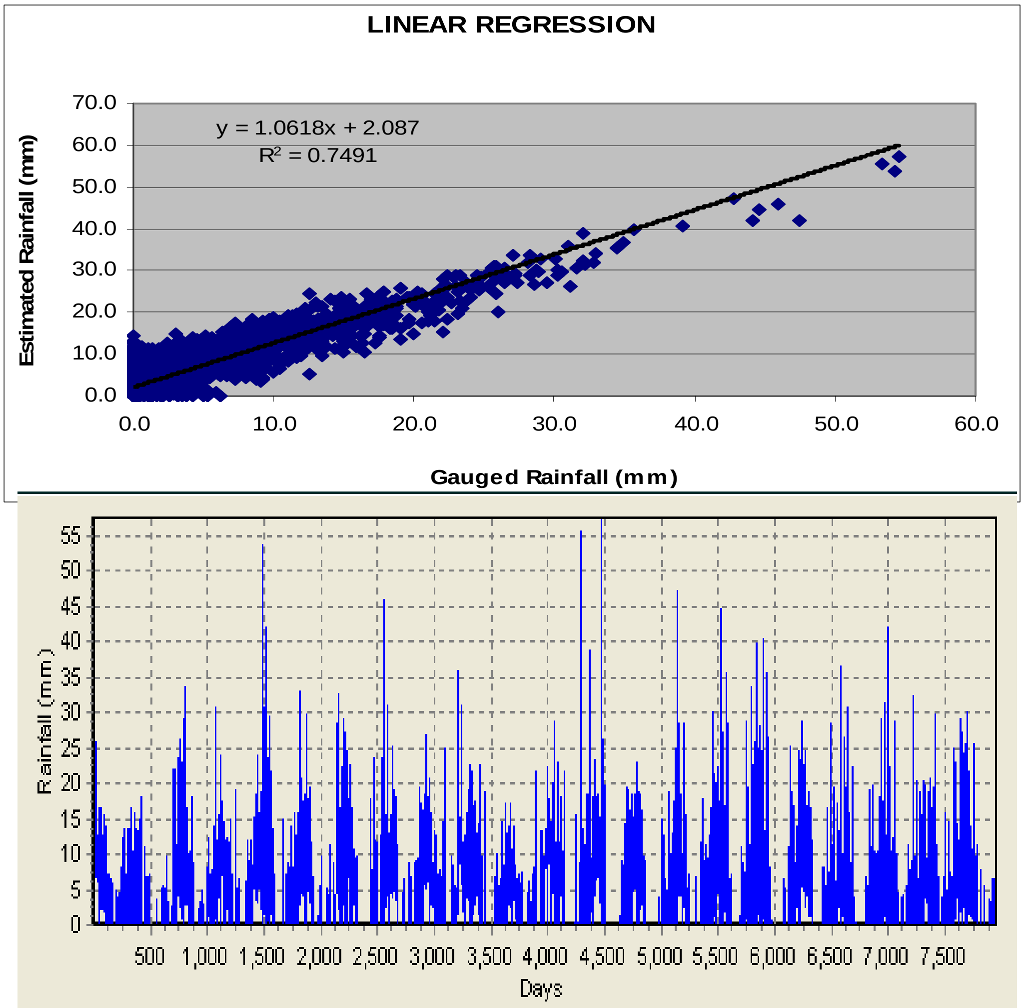

Figure 7. Thirty years daily rainfall reconstruction in the Andean plateau using NDVI with the MRA methodology.

References

Carbajal, M., Yarlequé, C., Posadas, A., Silvestre, E., Mejía, J., and Quiroz, R. 2010. Reconstrucción de datos faltantes de precipitación pluvial diaria mediante la Transformada Wavelet. *Revista Peruana Geo-Atmosférica (RPGA)* 2: 76–88.

Heidinger, H., Yarlequé, C., Posadas, A., and Quiroz, R. 2010. TRMM rainfall correction over the Andean Plateau using wavelet multi-resolution analysis. *International Journal of Remote Sensing* (in press).

Quiroz, R., Yarlequé, C., Posadas, A., Mares, V., and Immerzeel, W.W. 2011. Improving daily rainfall estimation from NDVI using wavelet transform. *Environmental Modelling & Software* 26(2): 201–209.

Discussions Summary

Long-term (~30 years) homogeneous rainfall data at acceptable spatial and temporal resolutions are needed in data scarce environments for many applications, including the calibration of GCM outputs. Several approaches were discussed. There seem to be great potential in combining the tools presented and existing geospatial data resources to maximize synergy. This theme seems to be a fertile area for a wide collaboration where most participating institutions showed interest.

Remotely sensed data useful as rainfall proxies are available for most data scarce environments in the world and new resources with improved spatial and temporal resolutions are being made available. METEOSAT, GOES, NOAA, TRMM, INSAT, and others are examples of meteorological resources accessible to most researchers. Reanalysis data constitute a valuable and amply used (and sometimes misused) resource as well. Notwithstanding, good quality gauged data is required to either test the quality of the rainfall estimate or implement appropriate correction of the remotely sensed proxies. This is particularly crucial when daily or sub daily estimates are required for the research or development application. A crucial aspect of gauged data is the quality. It is thus important to work closely with national meteorological institutions to guarantee the quality of the data and to institutionalize the methodological developments achieved.

The wavelet-based rainfall correction methodology presented seems to be a promising one. The participants agreed on a joint effort to improve the methodology. The following aspects will be prioritized as the focus of the research:

- Conduct a comparative analysis in contrasting sites using different geospatial data resources (reanalysis and different meteorological satellites). Ethiopia, Indo-Gangetic plains, and a virtual transect from Sao Paulo to the high plateau (virtual since we doubt there is available quality gauged data y throughout the transect).
- A comparative analysis among conventional selected published methods (e.g., connectivity) to characterize weather stations and the wavelet-MF approach presented in theme 1. This analysis will include selecting types of wavelets and a strong emphasis on the physical interpretation of the MF parameters.
- From weather stations to gridded rainfall data; test most suitable spatial interpolation methods.
- Improving existing rainfall estimates from remotely sensed proxies and reanalysis with gauged measurements; aiming at generating long-term daily rainfall information of adequate quality for the research sites.
- Make a first attempt to infer about the physics of the topo- and micro-climates based on the theoretical foundations of MF parameters.

Questions about the usefulness of wavelet-MF techniques for improving forecasting skills were raised. Nonetheless, they were not prioritized for immediate research. Another issue discussed was the need for user-friendly tools. As we learn about the process, tools will be developed within CCAFS

The participants agreed on searching for funds to implement the research summarized above. CIAT and CIP hope to contribute to these needs with CCAFS funding. Tufa Dinku will circulate the first draft of a concept note on the comparative analyses.

Theme 3: Spatial downscaling

Presentation Summaries

Spatial Downscaling of Future Climate Predictions for Agriculture

Julian Ramirez, Andy Jarvis, and Carlos Navarro

Abstract

Agricultural scientists, practitioners, and policy makers need to have an idea of what the expected changes in climate are in order to use those changes to assess agricultural systems. Hence, strong, reliable and accurate climate models and predictions need to be provided. Existing climate models, however, are not still able to accurately and consistently predict the climate system, partly because of our still limited understanding of the climate system and partly because these models are computationally very expensive. Processes such as cloud, deep moist convection, radiative transfer, turbulent mixing, boundary layer processes, precipitation, and gravity wave drag cannot be analyzed at coarse spatial resolutions (~100 km), thus are expressed as parameterization schemes. These parameterization schemes yield different responses, as they are based on different assumptions. Differences in predictions done by means of the different IPCC AR4 climate models are accounted to these processes.

Uncertainty in climate predictions plays an important role whenever future climate projections are to be used. In some regions, particularly in the tropical world, uncertainties in future predictions are rather large (Fig. 8). Policy making and agricultural development and research need to base their processes on the fact that there is an inevitable uncertainty level on any prediction of future climate and therefore on any prediction of expected effects of the phenomenon. Even short time weather forecasts still fail. Both the assessment of impacts of climate change on agriculture and the development and implementation of adaptation strategies depend upon the availability of climate predictions. Thus, uncertainties have to be properly managed, reported, and assessed whenever predictions of impacts of future climates are to be done.

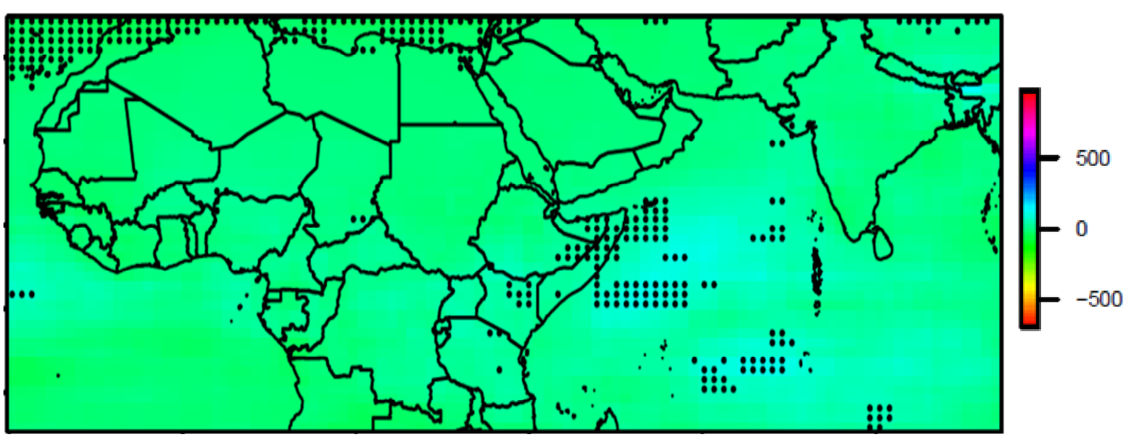

Figure 8. Average changes in annual precipitation (mm/year) by 2030s, under the SRES-A1B emission scenario as average of the 24 GCMs in the IPCC 4AR. Black dots indicate places where more than 80% of the GCMs agree in the same direction.

In addition, climate model outputs need to be relevant for agriculture and therefore need to be properly scaled in order to provide agricultural researchers, practitioners, and farmers with adequate conclusions and guide adaptation. Given the coarse resolution of climate models, downscaling has become a need whenever impact assessment is pursued. Different downscaling techniques exist up to now, and it is the matter of time and resources to use and validate them in different geographic areas. The different methods present advantages and caveats and the usage of their outputs needs to be assessed as per their validity and applicability for impact assessment (Table 1).

Table 1. Overview of Downscaling Methods Used at CIAT

Method	Pros	Cons
Delta	*Quick to implement * ↑ resolution *Applicable to ALL GCMs *Uniformise baselines	* Assumes changes only occur at broad scales * Assumes variables don't change relationships in time * ↓ variables
Delta-VAR	*Quick to implement *Applicable to ALL GCMs *Uniformise baselines * Reproduces GCM pattern	* Max. 50km resolution (CRU) * Reduces original variance in GCMs * ↓ variables
Delta-STATION	* Relatively quick to implement * More robust interpolation * Any resolution * Applicable to ALL GCMs	* Assumes changes only occur at broad scales * Assumes variables don't change relationships in time * Each station represents changes in a 400km range * ↓ variables
RCMs	* Most climatologically robust *Applicability depends upon availability of GCM BC *↑ variables	*Few platforms (PRECIS) *Massive storage and processing *Limited resolution (25-50km) *More development is required *Uncertainties difficult to assess

In general, CIAT and CCAFS Theme 1 are working towards the development of a climate database that includes the different methods and are also working towards the validation of both GCM and RCM predictions. This work is planned to be extended to other downscaling techniques such as those developed at CIP, so that the agricultural world is provided with the best available and tested methods for any further impact assessment planned to be carried out. For further information visit http://gisweb.ciat.cgiar.org/GCMPage.

Climate downscaling techniques for end users: a proposal for a non-linear downscaling methodology

Yarlequé, C., A. **Posadas**, L. Carvalho, Ch. Jones, R. Bombardi, and R. Quiroz

Abstract

General Circulation Models suggest that rising concentrations of greenhouse gases will have significant implications for climate at global and regional scales. Less certain is the extent to which meteorological processes at individual sites will be affected. So-called "downscaling" techniques are used to bridge the spatial and temporal resolution gaps between what climate modelers are currently able to provide and what impact assessors require.

How food production and security will be affected by climate change is one of the most important challenges facing regional-scale predictions. Regional-scale precipitation and temperature simulations are absolutely crucial in order to understand how global changes impact livelihoods. Precipitation and temperature downscaling improve the coarse resolution and poor local representation of global climate models and help end users to assess the likely impacts of climate change through the generation of more realistic scenarios. Among the requirements for downscaled climate to be useful for end users there should be (1) a reliable representation of intensities (precipitation in this example); (2) a sound assessment of the variability in time and space; and (3) physical consistency. The quality of the results should be independent of region and season. Notwithstanding, there are gaps and uncertainties arising from sparse data; a short list follows: representation of extreme summer precipitation, sub-daily precipitation, and full precipitation fields on fine scales; capturing changes in small-scale processes and their feedback on large scales; and errors inherited from the driving global climate model.

The aim of this work is to develop climate downscaling tools that can suit the need of end users cited above. For the workshop we address precipitation downscaling exclusively, but the methodology is expected to be generic for any climate variable.

A downscaling algorithm based on the multiplicative random cascade disaggregation method was developed. The principal objectives were the following: (1) generate a multiscaling random cascade disaggregation model that represents the precipitation as a Lognormal distribution using an MF technique; (2) use the Mandelbrot-Kahane-Peyriere function to characterize the process (Fig. 9); and (3) apply the model to simulate rainfall distribution in an Andean area (Peru-Bolivia) with high topographical and rainfall heterogeneities.

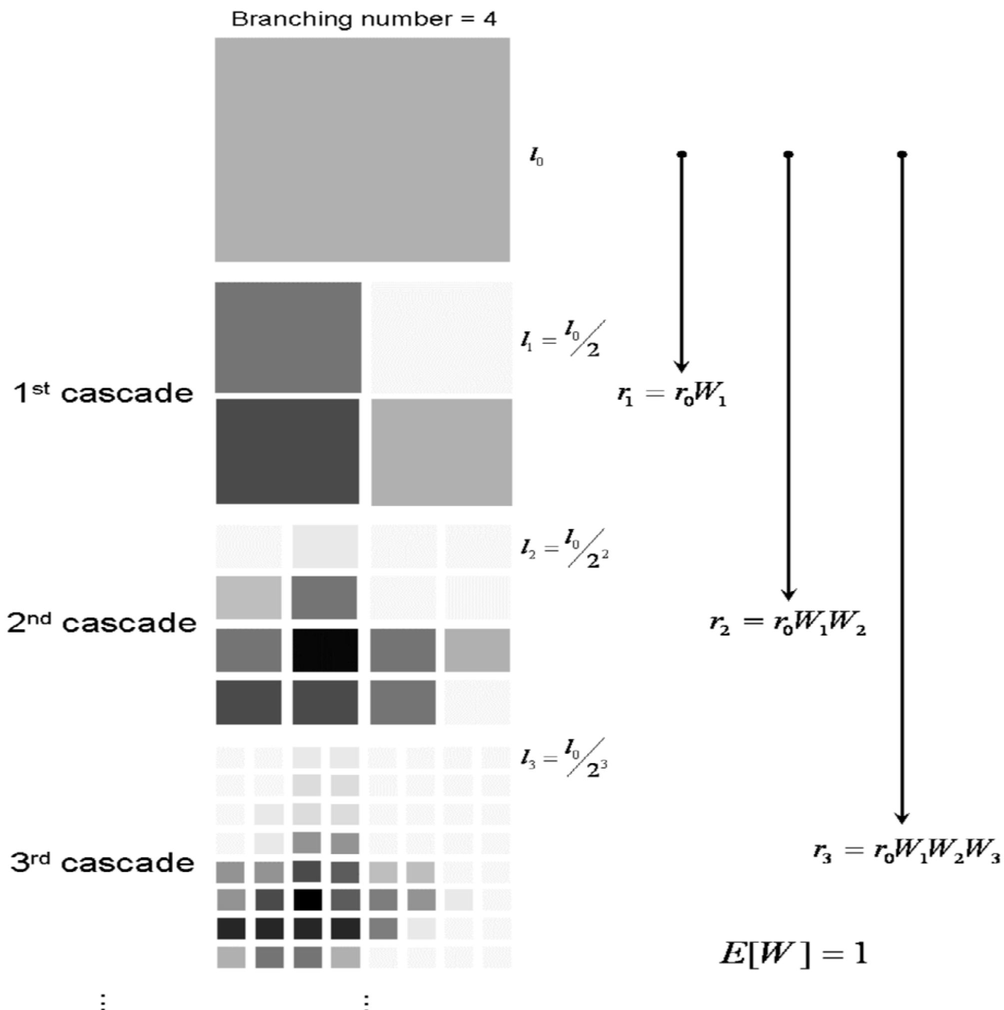

Figure 9. Schematic representation of the intermittent random cascade method. Model - r_0 is the initial (uniform) rainfall value over the square with side length l_0 (or average value); r_i is the offspring rainfall value over a cell with side length l_i; and W is the log-normal random generator obtained through the multifractal characterization.

This algorithm was tested and calibrated using TRMM precipitation data to generate the downscaling parameters. Daily TRMM 3B42 v6 data for the period 1998–2007 were obtained from TRMM Online Visualization and Analysis. Monthly rainfall snapshots were created by accumulating daily estimates. February, April, and August 2003 were used to represent the wettest, an intermediate, and the driest month in the high plateau and surroundings, respectively. A square area of 16 x 16 TRMM pixels (~ 430 x 430 km)—spanning an altitude gradient from around 2,000 to 6,500 masl and a rainfall gradient from ~ 400–3,000 mm y^{-1}—was selected. A rainfall ensemble over the entire square was downscaled—using the random cascade disaggregation model—to the individual pixels. Figure 10 portrays realizations of the downscaling for the three snapshots mentioned above. This seems to be a promising approach.

A

B

C

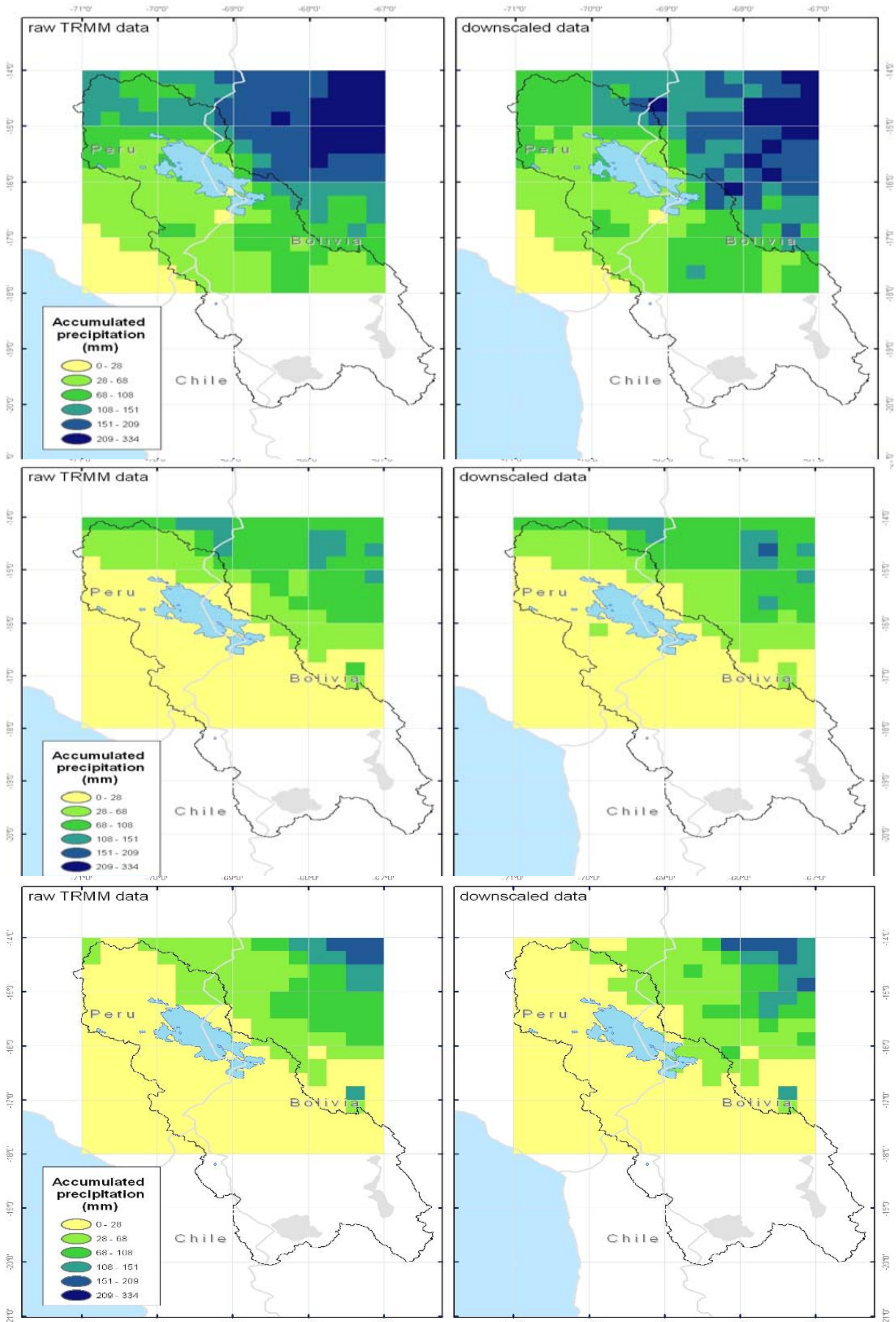

Figure 10. Measured TRMM rainfall versus downscaled: A. February—wettest month, B. April—intermediate, and C. August—driest month.

Discussions Highlights

The limitations of existing downscaling methodologies were discussed and they reflect the general consensus found in the literature. So we will not repeat the disadvantages of existing options, since they are part of the public domain. Notwithstanding, users need to benefit from the best tools available, provided they have access to the computational resources needed for their choice. Otherwise they will have to restrict themselves to use what they can use.

The multiscaling random cascade disaggregation method introduced in this section might be an alternative worth exploring. All the participants in the workshop are interested in being part of a comparative analysis in the sites described in the previous section. The sites present samples of the spatial variability found around the globe and thus could be a robust test.

Again, participants raised the issue of keeping in mind the end users when researching downscaling methods. Regarding funding, proof of concepts can be initiated with CCAFS funding to CIP and CIAT and we will try raising funds through joint projects to fully include all the participants.

Theme 4: Impact of extreme events

Presentation Summaries

Changes in the South American Monsoon and Potential Impacts in the Andean Region

Leila M. V. Carvalho Charles Jones (UCSB), Adolfo Posadas (CIP), Roberto Quiroz (CIP), Bodo Bookhagan (UCSB), David Carr (UCSB), and Brant Liebmann (CIRES-NOAA)

The South American Monsoon System (SAMS) is the most important climatic feature that affects millions of people in South America. SAMS is characterized by pronounced seasonality in rainfall along with a seasonal reversal of the large-scale circulation when annual mean is removed. Other important features of SAMS during the wet season are the South Atlantic convergence zone (SACZ), an upper level anticyclone (the Bolivian High) and trough (the Northeast Trough) and a low level thermal low (the Chaco Low). Regional and remote factors influence the life cycle of SAMS on a broad range of time-scales. Examples of regional factors affecting SAMS are complex terrain such as the Andes and the Brazilian high plain, land use and change, biosphere-atmosphere, and soil-atmosphere interactions. Remote factors affecting SAMS have been associated with the Atlantic and Pacific sea surface temperatures patterns, and tropical and extra-tropical modes such as the North Atlantic Oscillation, the Madden-Julian Oscillation, and the Southern Annular Mode, among others. The onset of intense convective activity and heavy precipitation over most of the Amazon and central and southeastern Brazil in the present climate is between October and November; it peaks in the austral summer (December–February). The end of the rainy season over central and southeast Brazil is between the end of March and mid-April as intense precipitation gradually migrates from the south Amazon and central Brazil toward the equator. This study uses NCEP/NCAR reanalysis (1948–2010) and several distinct precipitation datasets and shows evidence that SAMS duration and amplitude have increased in the last 62 years (Fig. 11). Combined Empirical Orthogonal Functions (CEOF) of circulation, temperature, specific moisture, and precipitation is used as a metric to represent variations in SAMS (Silva and Carvalho 2007, Carvalho et al. 2010a, Carvalho et al. 2010b). The observed changes in SAMS are related to increase (decrease) of moisture transport and precipitation from eastern Andes to central-eastern Brazil (northern tropical South America) (Fig. 12). Moreover, there is evidence that, owing to the equatorward geographical extent of South America, the warming of recent decades has been more pronounced in the lower troposphere of tropical regions compared with the subtropics, with large rates of temperature increase over high elevations such as the Bolivian Andes and the Brazilian high plains. These changes have affected the temperature gradient between the South Atlantic and the continent resulting in intensified easterly moisture transport over eastern and central Brazil and weakened easterly transport over Northern tropical South America. Regional changes in precipitation and moisture transport, along with temperature and circulation in the Peruvian and Bolivian Andes and Amazon, need to be further addressed in order to understand the importance of SAMS variations on the deposition of snow, on runoff, and extreme events. These changes may significantly impact agriculture and water supply in the future with relevant economic and social consequences.

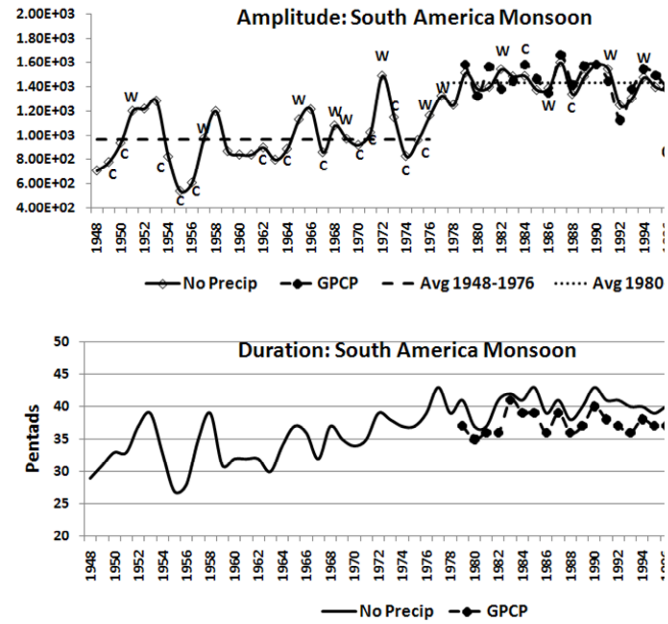

Figure 11 (top). Amplitude of SAMS based on the integral of the Large-scale Index for the South American Monsoon (LISAM) (Carvalho et al. 2010a). "W" ("C") indicates simultaneous El Nino (La Nina) events. (Bottom) SAMS duration based on LISAM

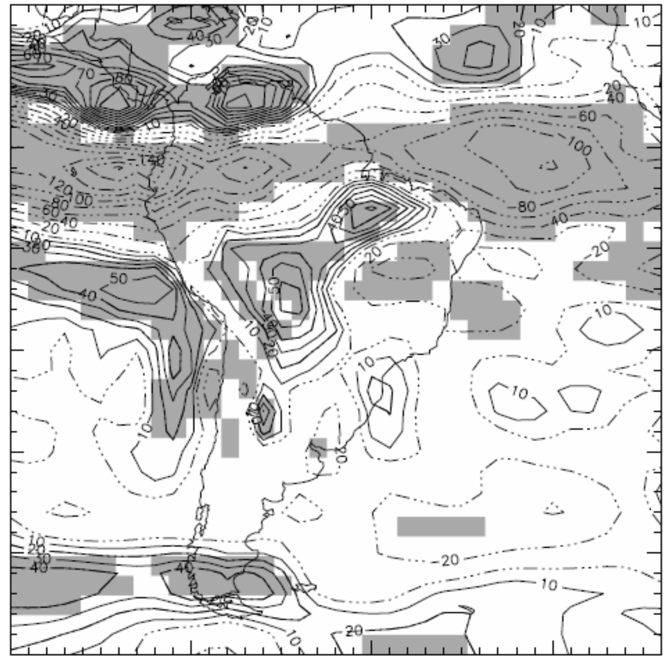

Figure 12. Linear trends (1977–2008) of the integrated moisture transport from the onset to the end of the monsoon (kg m^{-1} s^{-1}). See Carvalho et al. (2010b) for details.

References

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Discussions Highlights

Given the importance of SAMS, more research is needed on understanding their impact on natural and human systems. The Central Andes seems to be the area impacted the most and the SAMS can probably help explaining changes such as glacier retreats and severe changes in agriculture.

The participants agreed on putting together a joint proposal where the methods and tools discussed can be tested. Leila Carvalho will lead the process.

Participants

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