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A Hydrologic Flood Forecasting System for Mesoamerica

Jose E. Villalobos[1]
Department of Civil and Environmental Engineering
Louisiana State University, Baton Rouge, LA 70803-6405, USA
E-mail: jvilla3@lsu.edu

Vijay P. Singh
Department of Biological and Agricultural Engineering
Texas A and M University, College Station, Texas 77843-2117, USA
E-mail: vsingh@tamu.edu

ABSTRACT: Frequent flooding is a common occurrence in the Mesoamerica region, causing both death and destruction. With a flood forecasting system in place, the safety and security of both people and property in this region can be greatly improved. A Hydrologic Flood Forecasting System (HFFS) is developed for Mesoamerica. HFFS couples meteorological and hydrological models and creates flood inundation web-maps. Due to the poor availability of observed data in the region, the precipitation data are derived from satellite images, and combined with additional GIS data to determine watershed characteristics, such as land use distribution. A multivariate analysis of key variables is used to group the watersheds and delineate regions of similar hydro-meteorological performance. The obtained regionalization allows the use of regional parameters in the ungauged watersheds. The distinctiveness of HFFS is its applicability not only in the Mesoamerica region, but also in other flood-prone areas in the world with limited access to relevant data.

INTRODUCTION

The Mesoamerican territory covers nearly one million square kilometers, and has approximately 60 million inhabitants. The region includes the southern part of Mexico and the seven countries of Central America—Belize, Guatemala, El Salvador, Honduras, Costa Rica, Nicaragua, and Panama. Dominated by mountainous terrain, Mesoamerica has more than 100 large volcanoes, some more than 4,000 m high. Along the western front, the land surface slopes down rather abruptly from the mountain crests to a narrow coastal plain along the Pacific Ocean. On the opposite, eastern coast, the land descends more gradually from the mountains to a broad plain along the Caribbean Sea (see Figure 1).

Many small streams drain from the steep western slopes into the Pacific Ocean while the longest rivers in Mesoamerica flow through the broad eastern plains to the Gulf of Mexico and Caribbean Sea. Temperatures in Mesoamerica, which is situated between the Tropic of Cancer and the Equator, vary principally according to altitude rather than latitude. Wet tropical climate characterizes southern Mexico and also Central America. Precipitation is highly seasonal over Mesoamerica. Approximately 90% of its annual precipitation falls between May through October. It exhibits a bimodal distribution with maxima during June and September–October and a relative minimum during July and August, known as the midsummer drought (Magaña *et al.*, 1999). The Caribbean Coast and eastern mountain slopes generally receive twice as much annual precipitation as the western mountain slopes along the Pacific coast.

Although Mesoamerica is rich in terms of culture and biodiversity the region has poor social and economic conditions that are exacerbated by vulnerability to natural disasters. Flooding is a major problem along the coasts, particularly for the people who live in low lying areas. Just within the past decade, there have been numerous events where regional flooding has resulted in extensive death and damage to property, such as houses, buildings, plantations, and livestock.

One of these events occurred in October 1998, when Hurricane Mitch savaged Mesoamerica, killing at least 11,000 people, leaving thousands more missing, and displacing more than two million others. Nicaragua and Honduras absorbed the brunt of the damage, but El Salvador, Guatemala, Belize, and other countries in the region were also heavily impacted. Some observers have called Mitch the worst natural disaster ever to strike Mesoamerica. Most recently, Hurricanes Stan and Beta caused similarly devastating effects throughout

[1]Conference speaker

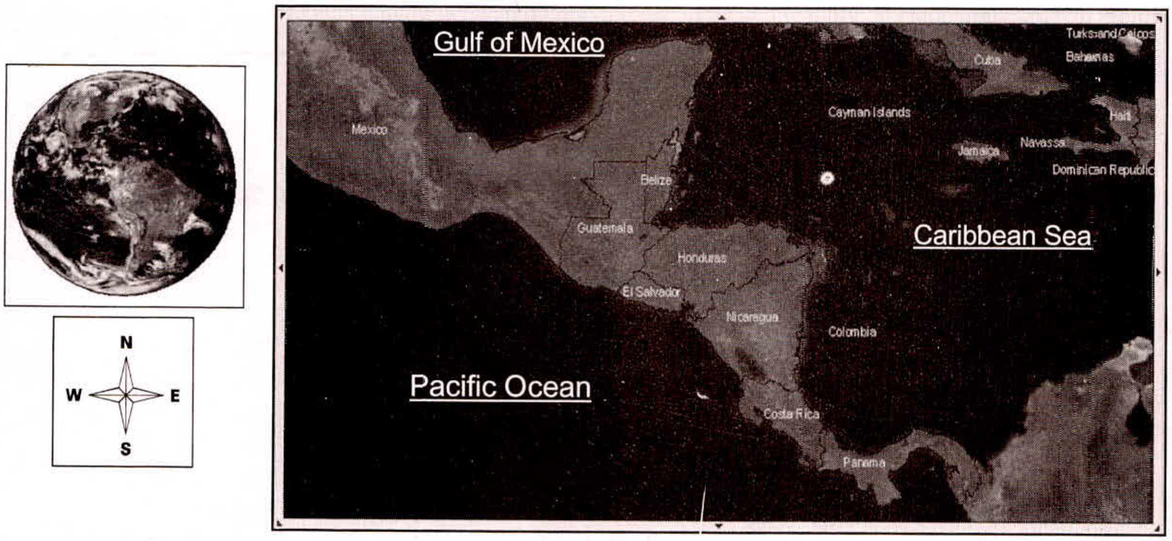

Fig. 1: A map of Mesoamerica and the Caribbean obtained from the SERVIR

the region in October of 2005, causing many deaths and displacing hundreds of thousands of people. Associated with floods, during the hurricane season mountain regions are affected by different soil mass movement processes, such as rotational landslides and debris flows.

Due to the frequency and extent of flood hazards described above, a system to predict the location of flooding using real-time forecasting is very desirable for the region. Such a system would require a real-time prediction of storm runoff. This can be achieved with the use of recent and forecasted precipitation maps along with river basin characteristics, to process a combination of meteorological and hydrologic models capable of identifying areas susceptible to flooding. The key issue in real-time flood prediction is the availability of accurate precipitation information. There are only a few operational rain gauges, so dependable rainfall estimation is a major challenge. However, satellite remote sensing measurements, providing a detailed display and information of precipitation, currently exist, reliably estimating precipitation in the Mesoamerican region. In addition, the system would use watershed characteristics, such as land use and elevation that can be obtained from remote sensing methods and managed in a Geographic Information System (GIS). With the satellite derived precipitation and watershed characteristics determined, hydrologic models will then be able to process the information to predict areas of flooding.

DATA PROCESSES AND MODELS

Here it is presented the sources of data, demonstrated how that data is processed, and discuss the modeling techniques that will be used to predict flooding. This section describes the core components and structure of the Hydrologic Flood Forecasting System.

Remote Sensing and GIS Data

Clearly, in the last decade, a great increase in the availability of geospatial technologies has been proven to aid human efforts to prevent natural hazards. According to Waser (2002), the power of geospatial technologies comes from their ability to enable the acquisition of massive quantities of data, linked by geo-referencing to specific physical locations on the planet's surface, with the ability to retrieve, analyze, and distribute this data in a variety of combinations and permutations that can be tailored to meet a diverse array of end-user needs. Bennett (1997) affirms that in fully integrated systems GIS users should have access to simulation models through software 'hooks' and/or built in macro-languages. This integration strategy can also provide access to a consistent user interface and data structure, but software available at that time did not support model development, or user interaction, during simulated events. He continues with the assertion that such integrated system software must support the construction, execution, and manipulation of geographical simulation models in a seamless, user-friendly environment. Finally, he emphasizes that users should be able to visualize ongoing simulations and suspend the simulation process to query intermediate results, investigate spatial/temporal relations, and even modify the underlying models used to simulate geographical processes.

One can conclude that current remote sensing and geographic information system technologies provide sources for rapid collection of field data and prompt data processing. These sources of data are proposed to be employed in this project to obtain the input rainfall and watershed characteristics necessary for hydrologic modeling. To make some of the powerful geospatial technologies for Mesoamerica accessible, an internet based Regional Monitoring and Visualization System (SERVIR initials in Spanish) was recently launched. This system is funded mainly by NASA and the United States Agency for International Development (USAID). Utilizing satellite imagery and other data sources, this system is designed to aid in environmental management and disaster prevention. SERVIR (see Figure 2) provides data at no cost to scientists, educators, and policymakers to monitor and forecast environmental changes and disaster response. This study attempts to obtain GIS data and satellite images from SERVIR and other public domain web sites to determine watershed characteristics (elevation, land use, stream network) for the HFFS.

Meteorological Data and Modeling

Hong and others (2004) assert that rainfall measurements derived from meteorological satellites have become an attractive option because of their high spatial and temporal sampling frequencies. In this context, it is worth noting that the Global Precipitation Measurement (GPM) Mission, which is a partnership between the United States National Aeronautics and Space Administration (NASA), the Japanese Aerospace Exploration Agency (JAXA) and other international agencies, is developing a constellation of satellites exclusively for measuring precipitation. This system is being designed to provide data with more frequency, and greater accuracy than any system or satellite currently in operation (Berger, 2005).

Hou (2006) states that the GPM Mission uses advanced precipitation radar, with a constellation of passive microwave radiometers, to improve the accuracy, sampling, and coverage of global precipitation measurements. It is a scientific mission with integrated application goals focusing on (1) advancing the knowledge of the global water/energy cycle variability and freshwater availability; and (2) improving weather, climate, and hydrological prediction capabilities through more frequent measurements of global precipitation with increased accuracy. He also anticipates that the GPM Core satellite, which carries a JAXA-provided dual-frequency precipitation radar and NASA-provided microwave radiometers with high-frequency capabilities for light rain and frozen precipitation measurements, is expected to be launched in the 2010 timeframe. The GPM Core will serve as a precipitation physics laboratory and a calibration system for improved precipitation measurements by creating a heterogeneous constellation of dedicated and operational microwave radiometers. NASA also plans to provide an additional "wild card" constellation member with a copy of the radiometer carried on the GPM Core to be placed in an orbit to maximize the coverage and sampling of the constellation.

Fig. 2: SERVIR Website and data portal

Anticipating the operational status of the GPM Mission, the proposed HFFS intends to employ the precipitation measurement algorithm, called Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN). This is a satellite-based algorithm used to estimate rainfall with a nearly global coverage. The PERSIANN system uses a neural network function classification and approximation procedures to estimate the rainfall rate from the infrared brightness temperature image provided by geostationary satellites at a scale of 0.25° × 0.25°. Sorooshian *et al.* (2005) explain and discuss this algorithm in detail, and they point out that its precipitation predictions have been successfully used over the years in a number of hydrologic research and application studies. This data is available to the public through the Hydrologic Data and Information System (HyDIS). HyDIS (see Figure 3) is a river basin and country-based internet GIS system that includes a global precipitation-mapping server (Sorooshian *et al.*, 2005). Until the GPM mission is in operation, the HFFS will use hourly satellite precipitation measurements from the HyDIS database.

Meteorological models are used to predict weather patterns and movement. They use universal laws of atmospheric physics and empirical relationships to estimate or simulate precipitation, wind flow, temperature, humidity, and vertical air mixing in time and space throughout the modeled area. In these models, the main links between the land surface and the atmosphere are formulated on the basis of the energy balance, heat balance, and moisture balance. In the early 1970's, researchers started developing an atmospheric prediction model derived from remote sensing. At that time, Anthes and Warner (1978) started developing a predictive, hydrostatic meteorological model, which has since evolved into the Fifth-Generation Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesoscale Model (MM5). This version of the model has been operational since 1999.

A reliable, real time quantitative precipitation forecast has long been recognized as a prerequisite to hydrologic forecasting for flash-floods (Georgakakos, 2002a). The MM5 is a limited-area, non-hydrostatic, terrain-following sigma-p coordinate model designed to simulate and predict mesoscale atmospheric circulation. The model is supported by several pre- and post-processing programs, which are referred to collectively as the MM5 modeling system. The MM5 modeling system software is mostly written in Fortran, and has been developed at Pennsylvania State University and National Center for Atmospheric Research (NCAR) as a community mesoscale model, with additional contributions from users worldwide. The MM5 modeling system software is freely provided and supported by the Mesoscale Prediction Group in the Mesoscale and Microscale Meteorology Division, NCAR. The HFFS will use the rainfall predictions using MM5 of the *Centro del Agua del Trópico Húmedo para Ámerica Latina y el Caribe* (CATHALAC initials in Spanish).

Hydrologic Modeling

Flooding is a critical subject of study in hydrology, and such events can be predicted with the use of hydrological models. According to Singh & Frevert (2006), watershed models simulate natural processes, such as the flow of water, sediment, chemicals, nutrients, and microbial organisms within watersheds, as well as quantify the impact of human activities on these processes. Generally, watershed models are used to predict the output (streamflow) of a system (watershed or river basin) in response to some amount of input (precipitation). The temporal and spatial variations of both system and input have recently been the driving factors in the development of more physically based, spatially explicit approaches to hydrologic modeling. Watershed models can be classified based on: process description, timescale, techniques of solution, land use, and model use. In 1996, the American Society of Civil Engineers also separated flood analysis models into four categories: Event-based precipitation-runoff models, Continuous

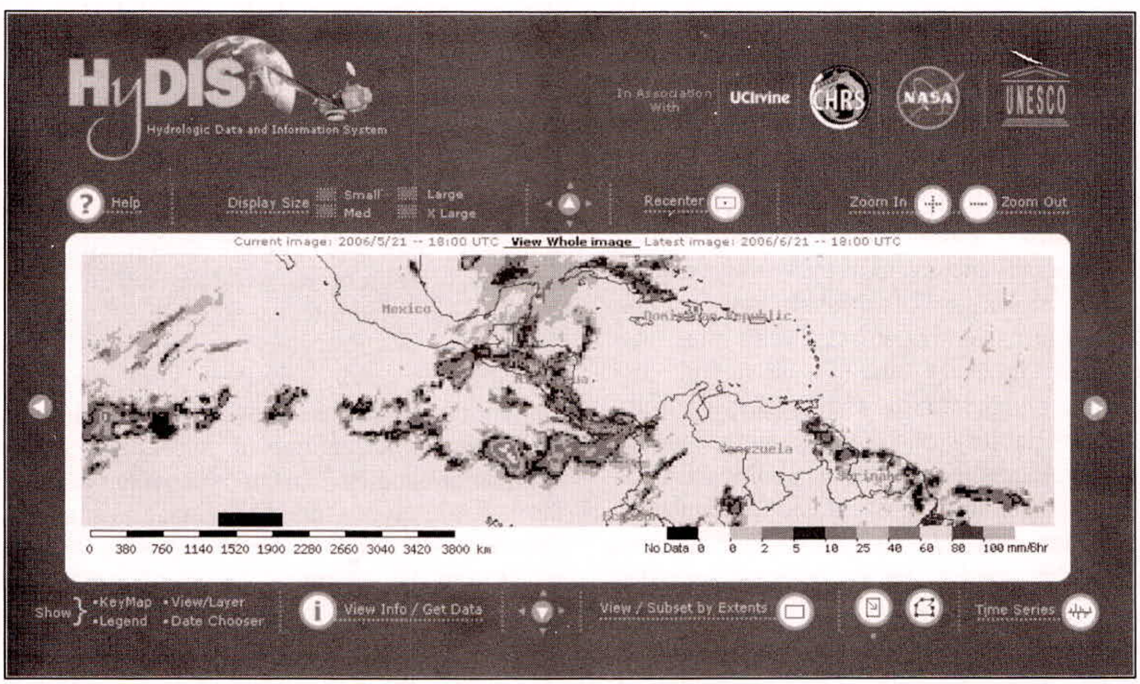

Fig. 3: The Hydrologic Data and Information System (HyDIS) Interactive Website displaying a six hour precipitation map encompassing Mesoamerica

precipitation-runoff-models, Reservoir regulation models, and Flood frequency analysis models (Singh and Frevert, 2002). HFFS considers both lumped and distributed models for determining flood forecasting. This is a classification based on the description of the hydrologic process that contributes to the system output in conjunction with the system characteristics, established by Singh (1995).

A lumped parameter model does not clearly account for spatial relationships between model parameters and inputs or outputs. Distributed parameter models explicitly account for spatial relationships among model variables and parameters. The number of variables and parameters necessary to run a distributed model are far greater than for a lumped model of the same basin. This data demanding process generates difficulties in the parameterization, calibration and validation of the distributed model. Since comprehensive spatial data for the entire Mesoamerica region is not currently available, HFFS employs both lumped and distributed hydrologic models for flood forecasting. The intended approach is a top-down system (Klemes, 1983) that starts with the simplest conceptual model configuration that can gradually build process complexity.

In the end, the type of model to be used is often dictated by the availability of data. When the necessary data either do not exist or are not fully available, regionalization and synthetic techniques are useful (Singh and Frevert, 2002). The simplest regionalization approach is to fix watershed model parameters to average values for a region (Vogel, 2006). Shmagin and Kanivetsky (2006) have proposed a new integrative approach in regional hydrology following the conceptual systemic or system analyses. This approach uses a multilevel system for landscapes in which the watershed is a subsystem, taking the place of regional, dual scale (regional and basin), hydrological analysis for temporal and spatial variability of river stream runoff. They state that the conceptual systemic model of a watershed as a multidimensional area unit, reflecting quantitative and qualitative characteristics of all landscape properties, was developed, based on the cybernetic model of a geographic sphere reported by Krcho (1978).

Dominguez and others (1996) presented an interesting regional analysis for the Grijalva River basin in Chiapas, Mexico (part of Mesoamerica). In that study, they used the information available about maximum rainfall and runoff events, as well as a transformation function, to homogenize the sample and achieve regional equations to predict peak flows using the size of the river basin area. According to Vogel (2006), the transfer of hydrologic characteristics of watersheds from data-rich to data-poor environments is one of the most fundamental challenges in the field of hydrology. Since the Mesoamerican region has poor data availability, HFFS will employ a top-down approach (Klemes, 1983) that starts with a similar regional analysis configuration and gradually, as more data becomes available, descends to an individual basin scale.

Most processes that occur in nature are not completely understood, and therefore mathematical depictions of these processes contain different levels of uncertainty. Stochastic models explicitly account for uncertainty in model parameters. Deterministic models, on the other hand, characterize processes with specific values. Uncertainty is not considered in these processes, thus the same set of input values will always give the same set of output values. Since there exists scattered rainfall and runoff information in the Mesoamerican region, this project intends to employ stochastic models as complements of deterministic models in order to make flood forecasting a downward approach (Klemes, 1983). This process starts with a minimal data demanding model, and gradually, as more information is obtained, proceeds to increasingly data demanding models in search of the balance cited before.

Coupling Meteorological and Hydrological Models

In the meteorological sciences, the coupling of atmospheric and hydrologic models is seen as a tool to validate precipitation in atmospheric models through the integration of basin effects as an alternative to point-by-point verification of a highly variable field, with the aim of improving atmospheric simulation through a better representation of the surface water budget. In this context, and in regard to flood prediction, Tomassetti and others (2005) affirm that a strategic goal of applied meteorology is to try to predict with high spatial resolution the segments of a drainage network where floods may occur. One possible way to reach this goal is to couple the meteorological mesoscale model with high resolution hydrological models.

Bae and others (1995) were the first to report that coupled meteorological-hydrological models for simultaneous rainfall and flow prediction were in operational use at that time. Georgakakos (2002b) also confirmed that the formulation of the rainfall prediction component in integrated hydrometeorological models was expanded to incorporate the use of data from weather radars, generate spatially distributed rainfall predictions over large mesoscale domains with high resolution, use forecast fields from large-scale numerical weather prediction models, and to include mountain terrain effects on rainfall. He proposed a catchment-aggregate process-based model (rainfall prediction, soil moisture, and channel flow), complemented by a state estimator to update the model and make it suitable for real time flash flood prediction. The state estimator also creates the capability of probabilistic forecasting that quantifies uncertainties due to errors from observation sensors, model structure, parameters, or inputs (Georgakakos, 1987).

From the perspective of flood forecasting in real time, the HFFS requires the use of interactive meteorological and hydrological models. These models should be coupled in such a manner that permits the prediction of the time and space distribution of both rainfall and the resultant flooding. To do so, these tools must take advantage of existing and new developments in data acquisition, processing and management.

Flood Modeling

Flood models, such as WetSpa or DBSIM, comprise a combination of hydrologic and hydraulic models. The hydrologic model determines the runoff that occurs following an individual precipitation event. The primary outputs from the hydrologic model are hydrographs at varying locations along the stream network describing the quantity, rate and timing of streamflow resulting from precipitation events. These hydrographs then become a key input into the hydraulic model. The hydraulic model simulates the movement of flood waters through stream reaches, storage elements, and hydraulic structures. The hydraulic model calculates flood levels and flow patterns while modeling the complex effects of backwater, overtopping of embankments, waterway confluences, bridge constrictions and other hydraulic structure behaviors.

Creutin and Borga (2003) indicate that flash floods develop at space and time scales that conventional observation systems of rain and discharge in rivers are unable to monitor. They proceed to describe the three main problems that hamper the progress of flash-flood research as: 1) downscaling due to the incoherent space and time scales between atmospheric models and the flash-flood triggering processes, 2) small basins prone to flash-floods are seldom gauged and must be modeled without calibration, and 3) knowing the soil retention limits of runoff under the range of accumulated precipitation considered. Finally they considered the development of integrated hydro-meteorological approaches for flash-flood real-time hazard assessment as one of two key developments in the future of flash flood research. This project aims to integrate satellite rainfall estimation and regional hydrology parameters into the hydrologic/hydraulic (flood) models to confront the flash flood monitoring problem.

Web Mapping

Loucks and others, cited in Garrote and Bras (1995), state that a real-time flood forecasting system must combine a data acquisition system and state of the art hydrologic modeling to provide the decision maker with the best information possible. Since the decision making process must be carried out in real-time, the availability of an adequate software environment is very important in facilitating the task of model users, especially if the operation involves the use of complex, data-intensive distributed models.

This project proposes to use a web mapping application aimed towards decision-makers with some GIS and/or hydrological training and experience. Scientists, educational institutions, and government officials will be the target audience of the HFFS, although it will also be available to the public at large. This assumes that the users will range anywhere from beginners in computerized mapping, to having some GIS exposure, to experts in the field. This range in user experience will require several levels of complexity in the HFFS in order to face one of the ubiquitous deficiencies pointed out by Singh and Frevert (2006), which is the lack of user-friendliness of watershed models.

CALIBRATION OF MODELS

Calibration is a key component in producing accurate, reliable model results. However, performing this process in ungauged or data poor areas, such as in much of Mesoamerica, is extremely difficult. This section explains and discusses several statistical techniques that can be used for calibration in areas with insufficient information. It is important to note that these methods are still being developed and need to be explored more fully to determine the procedure that produces the most accurate results and predictions for this system. There is no definitive method for determining this procedure, and it will take many trials and user/model feedback to develop a working tool for this type of evaluation. Therefore, this section of the HFFS will be created after the initial setup of the system to improve model outputs in watersheds with few observational resources.

Regional Parameter Estimation

As it has previously stated, the region of Mesoamerica is characterized by poor hydrometeorological data availability. However, since the main goal of this project is to predict floods in this location, it is necessary to research techniques for determining model parameters that can be employed with limited amounts of data. In this context, Kundzewicz (2002) argues that if there is no data observed in a catchment, one has to use methods which do not require the availability of a lengthy time series of hydrological records. Even if there are only a few gauged sites among many similar and adjacent catchments, one can try to establish regionally valid laws. Models can then be developed for gauged catchments and used to link their parameters to physical characteristics (e.g., by not-very-illuminating linear regression). Once this is completed, the regional approach can be applied to ungauged basins, and the necessary physical characteristics can be determined.

Additionally, Vogel (2006) states that as watershed models become increasingly sophisticated and useful, there is a need to extend their applicability to locations where they cannot calibrated or validated. He also emphasizes that without streamflow data a watershed model cannot be calibrated or validated, hence regional methods are needed which relate easily measured watershed characteristics to watershed model parameters. Inside his literature review about methods for the regional calibration of watershed models, he highlights several promising approaches:

1. Methods for grouping catchments on the basis of their hydrologic homogeneity,
2. The hybrid method, where first cluster analysis and principal components analyses are employed to break the region into homogeneous sub-regions, in which similar drainage basins that are close to ungauged basins are used to develop regional flow duration curve models, and subsequently used to calibrate watershed models at ungauged locations, and
3. The regional calibration methodology, which attempts to calibrate the model at all sites in a region simultaneously, while concurrently attempting to achieve the best possible regional relationships among watershed model parameters and watershed characteristics.

Finally, he underlines a recommendation that a hybrid regionalization method should combine recent advances in regional hydrologic statistics and the determination of hydrologically homogeneous regions with the regional calibration methodology. Included is a need to enable proper accounting of the impacts of both serial and spatial covariance structures of watershed models residuals.

Determination of Watershed Similarity

Statistical multivariate techniques provide a rational framework for analyzing the similarity of units, which vary with respect to numerous characteristics. Regarding the determination of hydrologically homogeneous regions, this project proposes to use the properties of Mesoamerica's catchments (area, mean altitude, average precipitation, drainage density, land use) through both ordination and classification (classifying units into discrete subsets) techniques described by Omi and others (1979) as follows:

1. The dimensionality of the problem is reduced using factor analysis. This ordination technique reduces the original number of variables to a smaller number of "factors" which are linear combinations of the original data set. The factor loadings, which are correlations between the original variables and the new factors, are then used to calculate the "scores" for each unit along each factor. These factor scores are used in place of the original variables in the subsequent analysis.
2. Initially, groups of similar units are identified by a cluster analysis of the factor scores. This classification process involves the determination of the units that are most alike, based on systematic comparisons of the factor scores for all units. The cluster analysis could be performed on the raw data, thus eliminating the need for the factor analysis. However, the factor analysis clarifies relationships between measured characteristics, mitigates the effect of redundant or correlated variables, and helps infer the structure and importance of phenomena that underlie the raw data.
3. The initial groups are tested, and units are reclassified using discriminant function analysis. Linear combinations of the factor scores, which maximize the distinction between groups, enable a unit to be placed into the group to which it has the highest probability of membership.

To investigate the possibility of identifying homogeneous precipitation areas, this project also plans to use the simple model (S-model) of the Principal Components Analysis (PCA) in order to have a better understanding of the complex atmospheric phenomena resulting in the seasonal rainfall distribution over Mesoamerica—as was used in Austria by Ehrendorfer (1987). According to this author, by using PCA—which can be considered a simple data-descriptive method—it is possible to describe a given data set completely by means of new variables (principal components or PCs), which have two fundamental properties: (a) two different uncorrelated components and (b) each component is derived from an empirical orthogonal variable, accounting for a maximum in residual total variance of the original data set. As stated by Johnson and Wichern (2002), a PCA is concerned with explaining the variance-covariance structure of a set of variables through a few linear combinations of these variables, with the general objectives of data reduction and interpretation. They also affirm that an analysis of principal components often reveals relationships that were not previously suspected, and thereby allows interpretations that would not have been shown otherwise.

One method that accounts for both the spatial covariance among flow, climate and watershed characteristics, as well as the temporal covariance associated with flow, climate and model residuals, is the generalized least squares method (Vogel, 2006). As indicated by Hofrichter and others (2006), annual maxima of the discharge of a river are commonly used to predict flood waters. Annual maxima from several rivers can then be modeled to predict flood levels for rivers where little or no discharge data is available. In order to explore the capability of creating a state estimator for the Mesoamerica region used for updating the models that will be utilized in the HFFS, this project plans to use an approach similar to the one successfully applied in Austria by Hofrichter and others (2006).

Due to the non-normal distribution of the annual maxima, Hofrichter and others (2006) did not consider linear regression models. Instead, they ran the modeling within the context of quasi-likelihood estimation in the Generalized Linear Model (GLM) framework. Additionally, to take the correlation among observations of different rivers at one year periods into account, the model was augmented with a random effect, which lead to the broad class of Generalized Linear Mixed Models (GLMMs). The first analysis of the annual maxima indicates that it was reasonable to assume temporal independence over the years. Therefore, only spatial dependency of the data was considered. The fitted values were plugged into the method of moment estimator of the parameters in the extreme value distribution (Gumbel Distribution) to obtain estimates of certain quantiles. These quantiles are commonly used to predict flood levels of rivers. The authors concluded that this approach provides satisfactory estimates of flood levels, and can be applied for rivers where the only data available are the catchment properties.

Alternatively, for the establishment of the state estimator inside of the HSSF, the method used in Australia by Post (2004) will also be considered. Using this method, Flow Duration Curves (FDC) are represented using a logarithmic transformation. The FDCs have been defined using two parameters: (1) the 'cease to flow' point, and (2) the FDC slope. These two parameters defining the FDC have been related to the area, mean annual precipitation, drainage density and total stream length of the catchments under consideration. Finally, a regionalization procedure has been developed whereby the FDC for an ungauged catchment can be predicted based upon the attributes of that catchment. The author concludes that this simple model is sufficient to adequately define the flow duration curve in a variety of catchments. It is therefore compatible with the 'top-down' approach, where additional levels of complexity are added to a model only when the necessary data becomes available. Lastly, he states that the mirror-image nature of the FDC may imply that it is possible to predict high flows upon analysis of low flows in the same catchment.

HFFS DESIGN

The modular design of the HFFS enables the final user to select modules in custom combinations. The application of the HFFS is based upon satellite-based algorithm rainfall data to create flood inundation maps, which then becomes internet accessible. The system is geospatially integrated over Mesoamerica and contains: 1) an interface with the SERVIR and HyDIS and CATHALAC servers; 2) a central GIS database to integrate watershed characteristics; 3) simulation models (public domain) available for flood analysis; and 4) the proper interfaces to relay the input data to the models, and the resulting outputs to the final users and decision-makers through both data tables and maps (see Figure 4).

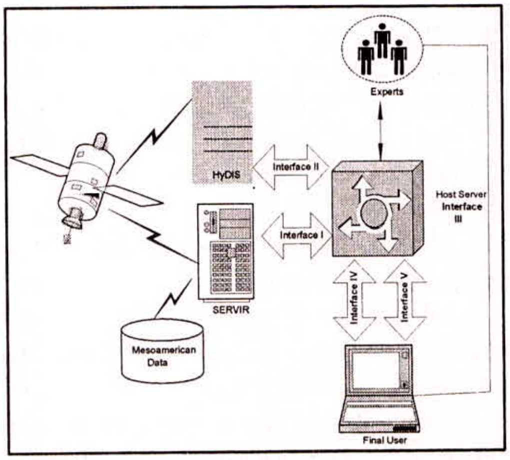

Fig. 4: Schematic of the Hydrologic Flood Forecasting System

CONCLUSIONS

Mesoamerica has been shown to be an area susceptible to heavy rains and coastal flooding that has resulted in many deaths and much destruction over the past decade. To help mitigate the losses resulting from these floods, we propose a real-time Hydrologic Flood Forecasting System. This system uses publicly available satellite remote sensing and geographic information to obtain the data necessary to process hydrologic models with the ability to predict flooding in Mesoamerica.

The development of the HFFS proves to be a great asset in the planning and prevention of the frequent flood related disasters that inundate Mesoamerica. It is not only be a technological achievement, as one of the first modeling applications to incorporate satellite rainfall estimations, but it also has the potential to positively affect the lives of the many people that live in this region. The results of this system can then be used to implement a similar setup in the many other areas of the world that have limited observed data. Concisely, the HFFS aims to contribute for an integrated water resources management, promoting sustainable development, and improve the understanding of the integrated hydro-meteorological models used in forecasting.

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