02 INFORMATION ABOUT PRINCIPAL INVESTIGATORS/PROJECT DIRECTORS(PI/PD) and co-PRINCIPAL INVESTIGATORS/co-PROJECT DIRECTORS

Submit only ONE copy of this form **for each PI/PD and co-PI/PD** identified on the proposal. The form(s) should be attached to the original proposal as specified in GPG Section II.B. Submission of this information is voluntary and is not a precondition of award. This information will not be disclosed to external peer reviewers. ***DO NOT INCLUDE THIS FORM WITH ANY OF THE OTHER COPIES OF YOUR PROPOSAL AS THIS MAY COMPROMISE THE CONFIDENTIALITY OF THE INFORMATION.***

PI/PD Name: Enrique R Vivoni

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☒ Hispanic or Latino ☐ Not Hispanic or Latino

Race:
(Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☐ White

Disability Status:
(Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☐ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

Check here if you do not wish to provide any or all of the above information (excluding PI/PD name): ☒

REQUIRED: Check here if you are currently serving (or have previously served) as a PI, co-PI or PD on any federally funded project ☒

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Hispanic or Latino. A person of Mexican, Puerto Rican, Cuban, South or Central American, or other Spanish culture or origin, regardless of race.
Race Definitions:
American Indian or Alaska Native. A person having origins in any of the original peoples of North and South America (including Central America), and who maintains tribal affiliation or community attachment.
Asian. A person having origins in any of the original peoples of the Far East, Southeast Asia, or the Indian subcontinent including, for example, Cambodia, China, India, Japan, Korea, Malaysia, Pakistan, the Philippine Islands, Thailand, and Vietnam.
Black or African American. A person having origins in any of the black racial groups of Africa.
Native Hawaiian or Other Pacific Islander. A person having origins in any of the original peoples of Hawaii, Guam, Samoa, or other Pacific Islands.
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PI/PD Name: Mekonnen Gebremichael

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race:
(Select one or more)

- ☐ American Indian or Alaska Native
- ☐ Asian
- ☒ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☐ White

Disability Status:
(Select one or more)

- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☒ None

Citizenship: (Choose one) ☐ U.S. Citizen ☐ Permanent Resident ☒ Other non-U.S. Citizen

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Ethnicity Definition:
Hispanic or Latino. A person of Mexican, Puerto Rican, Cuban, South or Central American, or other Spanish culture or origin, regardless of race.
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List of Suggested Reviewers or Reviewers Not To Include (optional)

SUGGESTED REVIEWERS:
David J. Gochis
W. James Shuttleworth
Thomas J. Jackson
Witold F. Krajewski

REVIEWERS NOT TO INCLUDE:
Not Listed

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 04-23		FOR NSF USE ONLY
NSF 04-036	09/15/05	NSF PROPOSAL NUMBER
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.)		
OISE - GLOBAL SCIENTISTS & ENGINEERS		0553852

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856000411	☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE
New Mexico Institute of Mining and Technology

ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE
New Mexico Institute of Mining and Technology
801 Leroy Place
Socorro, NM. 878014796

AWARDEE ORGANIZATION CODE (IF KNOWN)
0026542000

NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE

ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE

PERFORMING ORGANIZATION CODE (IF KNOWN)

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions)
☐ SMALL BUSINESS ☐ MINORITY BUSINESS
☐ FOR-PROFIT ORGANIZATION ☐ WOMAN-OWNED BUSINESS
☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT
International: A US-Mexico Collaboration on Hydrological Studies of the North American Monsoon: A Synthesis of Field Experiments, Remote Sensing, and Hydrological Modeling

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 98,984	24 months	01/01/06	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW
- ☒ BEGINNING INVESTIGATOR (GPG I.A)
- ☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)
- ☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.B, II.C.1.d)
- ☐ HISTORIC PLACES (GPG II.C.2.j)
- ☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.D.1)
- ☐ VERTEBRATE ANIMALS (GPG II.D.5) IACUC App. Date ______
- ☐ HUMAN SUBJECTS (GPG II.D.6) Exemption Subsection ______ or IRB App. Date ______
- ☒ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j) MX
- ☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.G.1)

PI/PD DEPARTMENT
Earth & Environ. Science

PI/PD POSTAL ADDRESS
801 Leroy Place
MSEC 244
Socorro, NM 878014796
United States

PI/PD FAX NUMBER
505-835-6436

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME Enrique R Vivoni	PhD	2003	505-835-5611	vivoni@nmt.edu
CO-PI/PD Mekonnen Gebremichael	PhD	2004	505-835-5690	mekonnen@nmt.edu
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				

Electronic Signature

CERTIFICATION PAGE

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the individual applicant or the authorized official of the applicant institution is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, and lobbying activities (see below), as set forth in Grant Proposal Guide (GPG), NSF 04-23. Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U. S. Code, Title 18, Section 1001).

In addition, if the applicant institution employs more than fifty persons, the authorized official of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of Grant Policy Manual Section 510; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

Drug Free Work Place Certification

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Drug Free Work Place Certification contained in Appendix C of the Grant Proposal Guide.

Debarment and Suspension Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Debarment and Suspension Certification contained in Appendix D of the Grant Proposal Guide.

Certification Regarding Lobbying

This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure of Lobbying Activities,'' in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME **Lonnie Marquez**	**Electronic Signature**	**Sep 15 2005 2:50PM**

TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS	FAX NUMBER
505-835-5606	**smoore@admin.nmt.edu**	**505-835-5659**

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International Programs Cover Page Addendum

Country #1: Mexico
Country #2:
Country #3:

Proposal Category: Developing Global Scientists and Engineers (G)

Foreign Counterpart Investigator/Organizer/Host #1:

Name: Watts, Christopher J.
Department: Departamento de Física
Institution: Universidad de Sonora
Address: Blvd. Encinas y Rosales
Hermosillo, Mexico.
Phone: 52662259210
Fax: 52662259210
Email: watts@fisica.uson.mx

For Planning Visit or Joint Seminar or Workshop:

Location
City:
Country:
Start Date:
End Date:

Demographics(people that will be supported by this project):

- Number of senior U.S. scientists and engineers (excluding those within 6 years of their Ph.D. and graduate and undergraduate students): 0
- Number of U.S. scientists within 6 years of the Ph.D.(including the PI and/or Co-PI if applicable): 2
- Number of U.S. graduate students: 4
- Number of U.S. undergraduate students: 4
- Number of foreign scientists and engineers (including post-docs, graduate and undergraduate students) associated with the foreign institution. Include only those who will be supported under this NSF proposal. Do not count foreign participants who will be supported by non-NSF funds: 10

Project Summary

Relatively little is known about the North American monsoon despite the fact that this seasonal climate phenomenon controls the distribution of rainfall, streamflow and vegetation in the southwestern United States and northwestern Mexico. As the summer monsoon can account for up to 70% of the annual rainfall in the region, there is a pressing need for binational studies that properly characterize the spatial and temporal variability in hydrologic variables such as precipitation, soil moisture, and streamflow. Furthermore, the monsoon impacts areas that are typically composed of complex mountain ranges where orographic processes are poorly understood. Our current lack of understanding is due to various factors, including a paucity of ground observations, the high spatiotemporal variability of hydrologic processes, and limitations in remotely-sensing and modeling these landscapes. We argue that significant advances can be made with focused efforts that synthesize in-situ and remote sensing data with hydrologic models in these environments. Moreover, we believe that monsoon studies require joint binational efforts as the climate phenomenon equally affects semi-arid, mountainous regions in the American Southwest and northwestern Mexico. In this proposal, we present an International Research Experience for Students program that promotes binational research for early career scientists, stimulates learning of hydrologic field methods, and will result in an improved understanding of the spatiotemporal variability of hydrologic processes during the North American monsoon.

Intellectual Merit: We seek to address an identified gap in our current understanding of monsoon hydrology by integrating ground observations, remote sensing and hydrologic modeling in a semiarid, mountainous watershed of northern Sonora, México. Our major objectives are to: (1) Quantify the spatiotemporal variability of hydrologic variables through field and remotely-sensed data, and characterize it in terms of functional relations between scaling behavior and dynamic landscape indices; (2) Estimate the uncertainty of remotely-sensed hydrologic variables such as rainfall and soil moisture through field validation; and (3) Synthesize these observations and their uncertainty with a hydrologic model to understand interactions between the monsoon and the complex land surface properties and to assess the value and utility of remote sensing data in hydrologic models. In order to do so, we propose to use a distributed sensor network, spatial field campaigns, and the application of a distributed hydrologic model in a basin in northern Sonora, México. One unique contribution of this work is that it focuses on quantifying hydrologic variability in its true sense (full distribution function), and not only at the mean level, as it is common practice. The proposed network can form the basis for long-term measurements used to advance our understanding of the monsoon and validate remote sensing observations of precipitation, soil moisture and other variables in a complex, semiarid monsoon setting.

Broader Impacts: Our work will utilize the international setting as an educational tool to teach students of varying levels about binational hydrologic research. Through hands-on field experience with the distributed sensor network and field campaigns, we anticipate to inspire inquiry-based learning and promote development of global scientists enabled to study monsoon phenomena. We will encourage women and underrepresented minorities to participate in the international research experience with a contingent of students and researchers from México. Our program includes various components: (a) a field program in México for instrument deployment and data collection, (b) research training for undergraduate students prior to and after the field study, and (c) mentoring activities to promote hands-on, team-based learning in a field setting. Educational activities will expand collaborations between the Universidad de Sonora and New Mexico Tech to enhance the long-term impacts of the project. Dissemination of results through public presentations, web-based materials and research publications will be used to attract future funding for sustained, long-term activities in this monsoon-driven, semiarid mountain setting.

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For font size and page formatting specifications, see GPG section II.C.

Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

Project Description

1. Introduction

We propose to organize and conduct an International Research Experience for Students (IRES) program in hydrologic studies of the North American monsoon for U.S. students in México. This program builds on an earlier collaboration between research groups at New México Tech and the Universidad de Sonora in a two-week field campaign (summer 2004) in Sonora, México, and extends it to provide new opportunities for undergraduate and graduate students. Our two groups have complementary research expertise in hydrologic instrumentation, remote sensing and hydrologic modeling with a focus on semiarid, monsoon systems. In addition, each group has participated in binational research (NAME, SMEX04, SAHRA, SALSA) sponsored by various agencies. For this project, a group of four undergraduate and graduate U.S. students and two U.S. researchers will travel to México to work with a Mexican team comprising of four undergraduate and graduate students and two researchers. Each U.S. participant will work in a team with a Mexican participant, and will be mentored by researchers from the binational group on a particular project to be carried out during each field season. <u>This IRES program will provide U.S. students in science and engineering with a global perspective and opportunities for professional growth through international cooperative research training, networking and mentoring.</u>

On account of its complex topography and drastic changes in climate, geomorphology, and vegetation, the Sonora river basin in México provides a unique setting to examine different hydrological processes. The summer season in the basin (June-September) is punctuated by the North American monsoon, which is responsible for up to 70% of the annual rainfall. As a result, a summer field experiment creates an ideal opportunity to experience and learn firsthand about the space-time dynamics of rainfall variability and how it controls the basin hydrologic response (e.g. streamflow, soil moisture). The Sonora river basin also exhibits a dramatic and fast response in vegetation cover to rainfall forcing at the onset of the monsoon (see Figure 1). This uncommon 'greening of a desert' provides an exciting environment to study cause-effect relationships and to stimulate an interest in students for discovery-driven science. The importance of the basin for the study of monsoon dynamics and hydrologic responses is well-recognized, as demonstrated by an existing network of instruments that measure relevant hydrological and meteorological variables. In addition, the site is well-suited as a validation site for remote sensing data due to its complex setting and rural conditions. <u>More importantly, the Sonora basin is a unique natural laboratory to study hydrologic processes in a region of complex terrain dominated by a monsoon climate.</u>

Our plan to develop student research skills through an international research experience is organized into three major activities: (1) a field program in México for instrument deployment and data collection, (2) research training for summer undergraduate students prior to and after the field study, and (3) mentoring activities to promote hands-on, team-based learning in a field setting for students from both the U.S. and México. In the following, we first present a statement of the research problem, including the research objectives and plan. We then present a detailed discussion of research and educational hypothesis to be tested as part of the IRES program. We focus on describing the educational component to provide details on how the international research experience will be organized, conducted and evaluated over the two-year period. We then conclude by presenting detailed information on the project timeline, management plan and anticipated results from the proposed project. <u>In designing the IRES program, we have attempted to integrate the research and educational components seamlessly, as participant experiences are enhanced when involved in cutting-edge research activities of interest to researchers in the project and the scientific community at large.</u>

June 4, 2004 **August 4, 2004**

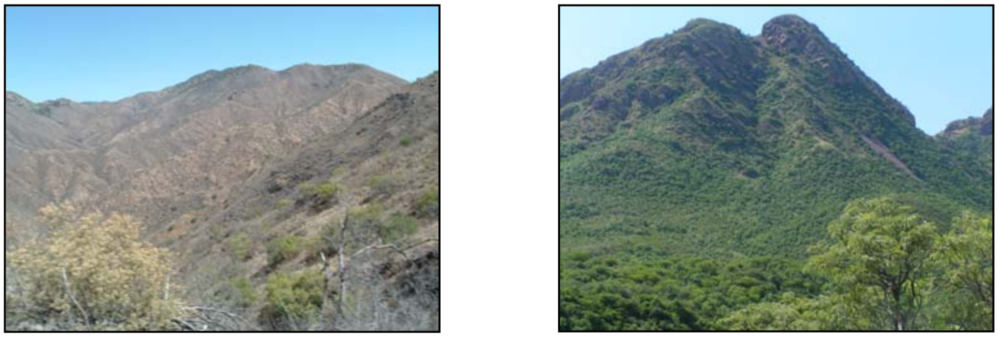

Figure 1. The study region in Sonora, México before (left) and after (right) the onset of the North American monsoon. Notice the dramatic response of vegetation to rainfall forcing.

2. Statement of the Proposed Research

The North American monsoon can account for up to 70% of the annual rainfall available for water supply, irrigation and ecosystem function over large areas of the southwestern United States and northwestern México. Characterizing the spatiotemporal variability of monsoon precipitation and its hydrologic response is of practical concern for water resource planners and hydrologic forecasters, among other stakeholders, of the region. Rainfall in the monsoon is associated with convective activity with small scale spatiotemporal variability. For example, precipitation may fall in concentrated convective periods over limited areas of a few square kilometers. Furthermore, the monsoon impacts complex mountainous areas where orographic processes are poorly understood. How this spatiotemporal variability in rainfall interacts with the spatial heterogeneity of landscape properties to produce complex, dynamic fields of runoff and soil moisture is an area where the scientific community currently lacks understanding. We argue that significant advances can be made with focused efforts that synthesize in-situ and remote sensing data with hydrologic models in these environments.

Hydrologic variability is usually monitored with in-situ networks, remote sensors, and hydrologic models. In-situ observations are essentially point observations, and hence are typically inadequate to capture the intrinsic spatial variability. This is illustrated in Figure 2, where 17 rain gauge stations well spread across an area of 4 km^2 introduce an error of 6% in the areal average rainfall estimate. Despite this limitation, in-situ sensors remain the only instruments that give direct measurement of hydrologic states and fluxes, and hence are often used to validate remote sensing estimates. Gebremichael et al. (2003, 2005a) provided a framework that addresses point-area discrepancy problems when validating remote sensing data based on point observations.

Remote sensors have the distinct advantage of observing over a large range of spatial scales, from a few kilometers to the entire globe. However, their spatial resolutions are still insufficient to capture the spatiotemporal variability of monsoon hydrologic processes over complex terrain that can take place at spatial scales shorter than a few kilometers. They are also constrained by temporal gaps in observations (30 minutes to 1 day, depending on the satellite). The processing of remotely sensed signals into hydrologic variables via retrieval algorithms can also introduce errors. Research is therefore needed to quantify the error associated with the spatiotemporal variability of precipitation and soil moisture derived from remote sensing data, in particular for such challenging environments as convection-dominated rugged landscapes.

Physically-based, distributed models have the advantage of reproducing spatial fields in the hydrologic response (soil moisture, evapotranspiration, streamflow) by utilizing best available data on topographic distributions, soil and land-cover properties, and atmospheric forcing fields (precipitation, radiation, air temperature). As predictive tools, hydrologic models also serve the purpose of experimentation. For example, physically-based models can be indispensable to study

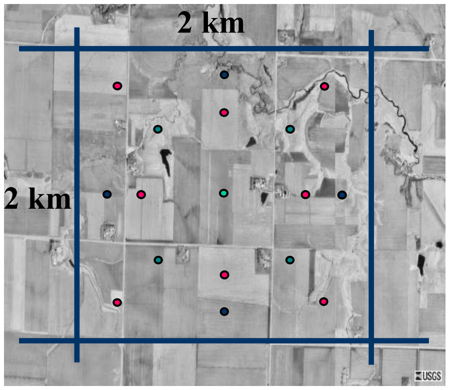

Figure 2. An example demonstrating the point-area discrepancy problem, using 17 rain gauges (circles) well spread across an area of 4 km^2. For a convective rainfall with a correlation distance of 5-km, the average of data from 17 stations introduces an error of 6% in the rainfall estimate.

scenarios, such as the impact of land cover change on hydrology. Because of the uncertainty in model inputs (measurement errors, inadequacy of space-time resolution), model parameters and model structure, the outputs of a hydrologic model are also subject to error in their spatial and temporal predictions. A useful method, to assess the potential and value of remote sensing data and to identify gaps in our measurements, is to quantify the errors in the hydrologic model output due to space-time resolutions of the remote sensors. Equally important is the potential use of hydrologic models to transfer remote sensing observations into spatiotemporal predictions of unobserved, but simulated, hydrologic processes, such as aquifer recharge and evapotranspiration.

It is clear from the above that significant advances can be achieved in the understanding of hydrologic variability with an appropriate synthesis of in-situ networks, remote sensing observations and hydrological modeling. A particular challenge exists in understanding complex semiarid terrain forced by convective monsoon precipitation as the spatial and temporal scales of heterogeneity can be quite small. To address this issue, we follow a three-pronged approach: (1) strengthen an existing instrument network in northern Sonora, México, (2) apply cutting-edge statistical techniques, such as a multifractal framework, to exploit the scale-invariance properties in hydrologic processes, and (3) employ a fully-distributed hydrological model with physically interpretable and measurable parameters using remotely-sensed and field sampled data sets.

Research Objectives – The overall scientific objectives of the proposed research are to:

(1) Characterize the spatiotemporal variability of hydrological variables through field data collection and remote sensing imagery using statistical techniques,

(2) Identify the large-scale (climate) and local factors (vegetation, topography) that affect the spatiotemporal variability, and establish functional relationship between these factors,

(3) Quantify the error in the spatiotemporal variability of precipitation and soil moisture estimated from remote sensing data; and

(4) Synthesize observations and their uncertainty with a hydrologic model to assess the value of remote sensing data and analyze the spatiotemporal hydrologic response.

The proposed research pursues these objectives by using observations across a range of scales which can lead to a greater understanding of causality. The research plan, described in the next two sections, is organized into three activities: (1) summer field campaigns for instrument deployment and surveys; (2) synthesis, analysis, and evaluation of field observations and remote sensing data; and (3) a modeling study integrating the field and remotely-sensed data sets to assess spatial patterns in hydrologic response. In the following, we discuss four research and one educational hypotheses as integrating themes addressed during our international activities.

3. Research and Educational Hypotheses

It is recognized that to accurately characterize the North American monsoon will require coordinated data collection, modeling efforts, and analyses that consider the broad range of time and space scales over which hydrological processes are active. Monsoons do not follow political boundaries, and hence, constitute an ideal opportunity for providing international research and education experiences to students. The unique landscape properties of semiarid, mountainous terrains (drastic changes in climate, terrain, ecosystems) also provide an exciting environment for educational activities designed to stimulate interest in discovery-driven science.

Hypothesis I: *Multifractal models can describe the complex spatiotemporal variability of hydrological variables in a manner consistent with regional climate and physiography.*

Motivation and Previous Work: A multifractal framework will allow us to characterize the spatiotemporal hydrological variability using a few parameters, which can be interpreted directly in terms of the physical processes involved. It will also allow us to characterize the variability in its truest sense (i.e. full distribution function). The working assumption for this investigation is that the spatial and temporal patterns of hydrologic variables (e.g. precipitation, soil moisture, and runoff), or of their simple transformations, possess scale-invariant properties.

Recently, Gebremichael et al. (2005c) investigated the presence of scale-invariance in spatial rainfall fields across the entire tropics using three years of TRMM-PR (Tropical Rainfall Measuring Mission – Precipitation Radar) data. They reported that the majority of the spatial rainfall scenes (>70% over ocean; >80% over land) are scale-invariant, which points to the universality of the scale-invariance property of tropical rainfall. For the small number of events that are not scale-invariant, simple transformations of the precipitation field can lead to scale-invariance (Harris et al. 1998; Menabde et al. 1999). Moreover, Perica and Foufoula-Georgiou (1996) found a strong correlation the scaling parameter and an index of convective potential in a squall-line storm in Oklahoma and Kansas.

After examining soil moisture data from Washita'92 and Washita'94 experiments, Peters-Lidard et al. (2001) reported that the soil moisture patterns are scale-invariant. They showed that the scaling parameters depend on the mean soil moisture. Veitzer and Gupta (2001) reported that the maximum of the width function (an important landscape property) obeys scale-invariance as well. Troutman and Over (2001) suggested that streamflow obeys scale-invariance, and its scaling behavior mirrors that of rainfall if storm intensity is highly variable, and that of the network structure in the case of uniform rainfall. In summary, several studies have suggested that different hydrologic variables exhibit scale-invariance, and that the scaling behavior can be explained in terms of physical processes. We hypothesize that this property is well preserved in monsoon, mountain regions, and that the scaling behavior is linked to surface properties such topography and vegetation. This sort of analysis has not been performed in the proposed setting.

Testing Hypothesis I: The main objective is to verify the presence of scale-invariant fields, identify scaling regimes and parameters, and investigate the functional relations with large/local-scale dynamical indices. In addition to the existing network of instruments, we will employ additional instruments to measure precipitation and soil moisture. We will use these observations to obtain precipitation and soil moisture data at the smallest scale, and observations from satellites to obtain data at larger scales. The hydrological variables of interest include rainfall, soil moisture, and streamflow. The dynamical indices to be examined include variables that affect the large and small-scale processes, such as terrain properties (topography, vegetation, soil moisture), atmospheric properties (divergence, velocity potential), and precipitation properties (storm height, vertical profile of precipitation). The terrain properties will be obtained from a Digital Elevation

Model, remote sensing imageries, and hydrologic model outputs, while the atmospheric properties will be obtained from NCEP reanalysis, and the precipitation properties from TRMM.
Hypothesis II: *Mountainous terrain and vegetation patterns play an important role in the spatiotemporal variability of monsoon precipitation and hydrologic response*.

Motivation and Previous Work: The notion that complex gradients of moisture and energy across a landscape are associated with regional weather patterns over a wide range of spatial and temporal scales is the basis for land-atmosphere interaction studies (Dickinson 1995). Studies have shown that land surface heterogeneity patterns in soil moisture, vegetation and topography trigger changes in convective stability, locally altering pre-storm environmental conditions and subsequently affecting cloud and precipitation pattern regionally (Pielke 2001). Changes in the land surface, for example as occurring during deforestation, have also been shown to affect the patterns of shallow clouds in tropical rain forests (Chagnon et al. 2004). In regions of complex terrain, evidence exists for convection and precipitation processes to be controlled by the spatial organization of elevation (Roe 2005). As topographic distributions are equally important in determining the spatial patterns of runoff and soil moisture (Beven and Kirkby 1979), we anticipate that these phenomena are intrinsically linked over a range of space and time scales.

Fabry (1996) examined the character of precipitation variability over a large range of scales, using high-resolution rain gauge data. Converting the time scale into an equivalent space scale, he reported four regimes in rainfall variability: 50m–100m, 100m–20km, 20km–50km and 50km–300km. Small scales were directly associated with local factors, while the large scales with midlatitude cyclones. Carbone et al. (2002) examined the radar-based climatology of warm season precipitation "episodes". They defined episodes as time-space clusters of heavy precipitation that often result from sequences of organized convection such as squall lines, mesoscale convective systems, and mesoscale convective complexes. Their results showed that the ensemble of episodes exhibits a globally phase-locked behavior, consistent with the effects of thermal and topographical forcing and subsequent propagation. These studies point to the potential for identifying relevant space scales over which monsoon convection can interact and be controlled by complex landscape characteristics, such as topography, and its potential temporal variation during changes in surface conditions (e.g. greening of vegetation).

Testing Hypothesis II: We will first delineate different ecosystems based on vegetation and soil properties obtained from field surveys, existing maps and remote sensing interpretation. We will take representative measurements of rainfall and soil moisture over each ecosystem during the field campaign and with the instrument network. Using these observations, remote sensing data and a distributed hydrologic model, we will investigate for each ecosystem: (1) the relations among the spatiotemporal variability of rainfall, hydrologic response and terrain, and the temporal dynamics of these relations during the monsoon (with associated changes in rainfall and vegetation) using pattern covariance functions and regression analysis, and (2) the extent to which the distribution of rainfall translates into the distribution of hydrologic response.

Hypothesis III: *Field measurements can be used to quantify the errors in remote sensing estimates of precipitation and soil moisture, and other hydrological variables.*

Motivation and Previous Work: Remote sensors measure the emission and/or reflectance of radiative energy, and use these measurements to estimate precipitation and soil moisture through what is referred to as 'retrieval algorithms' (Elachi and van Zyl 1987). This process introduces errors at the measurement scale. There are also issues associated with its coarse measurement scale (spatial resolution) and the temporal gap between successive measurements (time-integrated scale) (Bell and Kundu 1996). Spatially distributed measurements, which can directly measure hydrologic states and fluxes, such as rain gauges, are often used to quantify the error in remote sensing estimates. This working assumption that has led to the establishment of various ground validation sites around the world. Examples of field experiments in support of remote sensing, and hydrology include catchments such as Little Washita, OK, Walnut Creek, IA and Walnut Gulch, AZ (Jackson et al. 1995). Examples of validation sites, established and maintained by the NASA TRMM office, to evaluate rainfall products include Florida; Texas; Darwin, Australia, and Kwajalein Atoll. Our previous work has also focused on the evaluation of remote sensing data using ground observations (Vivoni et al. 2005c and Gebremichael et al. 2003, 2005b).

Testing Hypothesis III: We will select two or three sub-sites, each covering an area of 5-km by 5-km, where dense measurements of rainfall and soil moisture will be taken. To collect rainfall data, we will employ event-based rain gauges to augment the continuous stations deployed during the campaign. To collect soil moisture data, we will take measurements using hand-held probes to augment the continuous stations. By aggregating these data over larger and larger scales (the largest scale being 5-km × 5-km), we will seek to identify the scaling relation between the values at the point scale and those at the largest scale. We use this scaling relation to upscale the point station data to the spatial resolution of the remote sensing estimates. Once we address the scale-discrepancy problem, we will compare the spatial structures of the remote sensing estimates and those of the field observations. The comparisons will be based on scale-invariance property, scaling regimes, multifractal parameters, and the full distribution functions.

Hypothesis IV: *Hydrologic models can be used to assess the potential and utility of remote sensing data and identify scaling properties in simulated spatial patterns.*

Motivation and Previous Work: One of the major uses of remote sensing data is in predicting floods and other hydrologic responses. The error in remote sensing estimates, or the limitation in spatiotemporal resolutions, will propagate to the hydrologic model in a non-linear way (Ogden and Julien 1994; Winchell et al. 1998). As it propagates, the error might dampen or amplify in the hydrologic response as a function of catchment scale and its scale-dependent properties. While this has long been recognized, few studies have addressed this topic using remote sensing data and distributed hydrologic models. The error propagation will usually determine the usability of remote sensing data in these applications and the level of confidence in the model outputs. In a recent study, Hossain and Anagnostou (2004) studied the sensitivity of satellite retrieval and sampling error on flood prediction uncertainty for a week-lasting rainfall event over a medium-sized watershed of a typical sensor footprint size (~100 km^2). Their results seem to suggest that there is not much difference between an hourly sampled rainfall and a three-hourly sampled rainfall in terms of predicting a flood response. We argue that the effect of sampling error varies with the spatiotemporal distribution of rainfall and the land surface characteristics.

Testing Hypothesis IV: We will create a reference rainfall and soil moisture dataset for the Sonora basin by combining field observations and remote sensing using the scaling relations previously described. This dataset will be used as input to a distributed hydrologic model that can provide spatial patterns of basin response as model outputs. We will use these model outputs as a reference for further experimentation. We will run the model using remote sensing precipitation and soil moisture data (without augmenting by field observations), and judge the performance by comparison with the reference outputs. The comparisons will be focused on the distribution functions, scaling relationships, and consistency between water and energy fluxes. We will also assess the impact of spatial resolution and temporal sampling on model outputs by constructing realizations from the reference dataset. For example, to assess the effect of spatial resolution, we will aggregate the input data to higher spatial scales. To assess the effect of temporal sampling, we will perform resampling experiments from the data. This approach allows us to select any satellite sampling strategy, and hence the results might be useful for designing future hydrology space missions. The resampling experiment using a moving block technique has been shown to be a robust tool for hydrological data analysis (Gebremichael and Krajewski 2004).

Hypothesis V: *The semiarid, monsoon mountain region in México provides a unique setting for an international research and educational experience for undergraduate and graduate students.*

Motivation and Previous Work: A field-based, international learning experience will provide a framework for introducing undergraduate students to hydrological sciences and the advancement of graduate students in the study of the monsoon and its hydrologic response. The semiarid mountain setting will be exploited as an educational tool for its unique environment. This strategy is based on the concept of inquiry-based learning in the field promoted for earth science instruction at various levels (Woltemade and Stanitski-Martin 2002; Salvage et al. 2004; May and Gibbons 2004). In addition, our strategy is based on developing team-based learning skills for participants from the U.S. and México. One approach successfully applied in field-based team learning is the concept of peer mentorship where students and researchers at various levels provide instruction to fellow students at the same level or below (Simila et al. 2004). In two recent field experiments documented by Vivoni et al. (2004) and Mendez-Barroso et al. (2005), the concepts of team-based field learning have been successfully used in mountain regions. These field studies employed undergraduate and graduate students from multiple institutions. Research training was provided prior to the field exercise and data analysis performed after the data collections efforts were completed. The bonding established between participants helped to cement the learning experiences in hydrologic instrumentation, data collection methods and field observations. Peer-mentorship naturally arises in these situations as more experienced graduate students will lead efforts and train novice undergraduates. In addition, participants emphasized the unique instruction that occurred during field campaigns as hydrologic processes are witnessed in person and hands-on learning is achieved in a challenging physical setting.

Testing Hypothesis V: The main objective is to test the hypothesis that an international field experience will lead to enhanced student learning across a broad range of educational levels. The ultimate goal of the international research and education program is to make significant advances to the recruitment, retention and advancement of students in hydrological science in both the U.S. and México, with a particular focus on women and underrepresented minorities. We contend that the proposed study region is well suited for testing this hypothesis for several reasons. First, the area is characterized by dramatic changes in topography, soil properties and hydrologic processes, along with seasonal vegetation changes, which can be reasonably explored during a short-term field campaign. Second, the monsoon phenomenon of interest equally affects semiarid, mountain regions in the Southwestern U.S. and northwestern México, establishing a conducive environment for binational collaboration. Finally, we have a strong commitment from the host country with regards to intellectual contributions, student participation, and a set of existing field instrument networks in the study region. Team-based learning and peer mentorship will be tested by promoting interactions between U.S. and Mexican participants from multiple levels through team projects, field activities and cultural exchanges. As the proposed field research involves 'hands-on' training in hydrologic instruments, data collection and analysis of hydrologic observations, we will be able to gauge the learning achieved through direct contact with the monsoon and its hydrological response. Finally, we will evaluate the project progress at various stages using tools such as weekly meetings, and use indicators such as student presentations and publications as a measure of the success of the International Research Experience for Students (IRES) program.

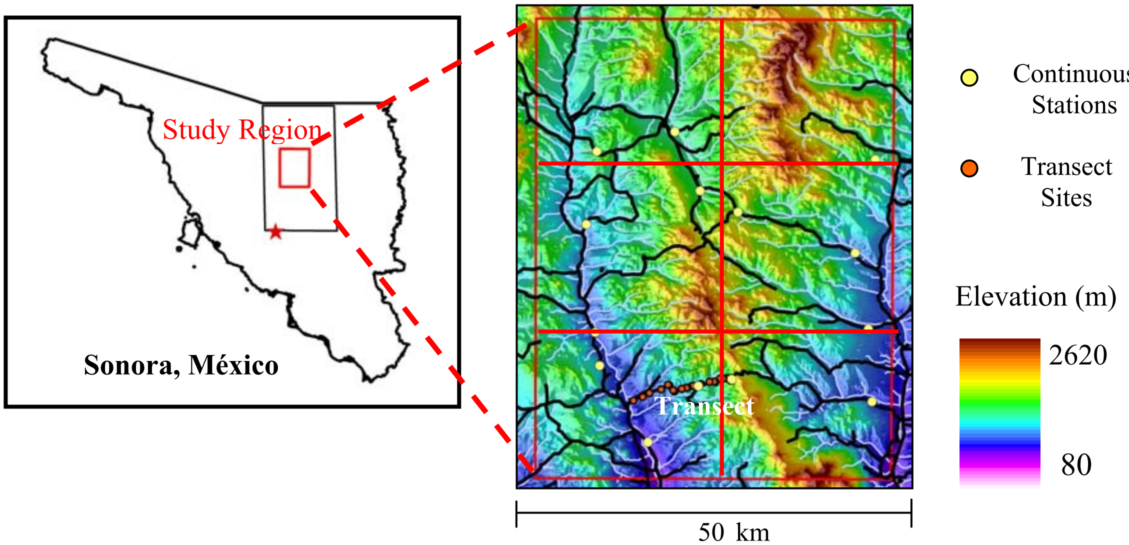

Figure 3. A description of the study area, a 75-km by 50-km box in northern Sonora, and its topographic characteristics. (left) The study area in the state of Sonora (Hermosillo highlighted with a star). (right) A digital elevation model (DEM) of the study region and the location of continuous sampling stations and daily sampling sites along a topographic transect. Note the extent of the six remote sensing pixels.

4. Research Approach

Our approach relies on a combination of the following major elements: (1) a distributed sensor network designed for continuous measurements at selected locations, and intensive field surveys to expand sampling during short periods; (2) synthesis, analysis and evaluation of field observations and remote sensing data; and (3) the application of a distributed hydrologic model to characterize hydrologic responses and to assess the potential and utility of remote sensing data in hydrologic models. The ultimate purpose is to improve understanding of monsoon rainfall and its hydrologic response and assess the role played by the land surface in the climate phenomena.

4.1 Study Region and Existing Network

Recognizing the gap in understanding monsoon rainfall variability and the hydrological response over complex terrain, a field campaign (SMEX04 – Soil Moisture Experiment 2004) was conducted in the Sonora basin in northern México during the 2004 monsoon season, which P.I. Vivoni organized and conducted. The study location was determined through several factors including: (1) the requirements and footprint of a remote sensor AMSR-E used to derive a soil moisture product, (2) the topographic variability within the monsoon-driven region, and (3) the accessibility to sampling locations via rural roads and other amenities for field work. A 75-km (north-south) by 50-km (west-east) box was selected as our regional sampling area to represent six individual remotely-sensed pixels (each 25-km by 25-km). Within each sub-domain, sampling locations were determined for continuous soil moisture and rainfall measurements over the summer period. Fifteen continuous stations were installed by collaborator Watts at sites selected based upon elevation, ecosystem distribution, and overall spatial distribution. In addition to the permanent sites, ten teams of two students sampled soil moisture and soil temperature at various locations within each of the six remote sensing pixels. Each team was equipped with portable sensors and carried out daily sampling at a number of pre-selected sites, typically on the order of 10 per team. The teams consisted of undergraduate and graduate students from U.S. and Mexican institutions. Based on the combination of permanent stations and daily sampling sites, a density of approximately twenty sites per remote sensing pixel was obtained (or about 1 sample per 30 km^2).

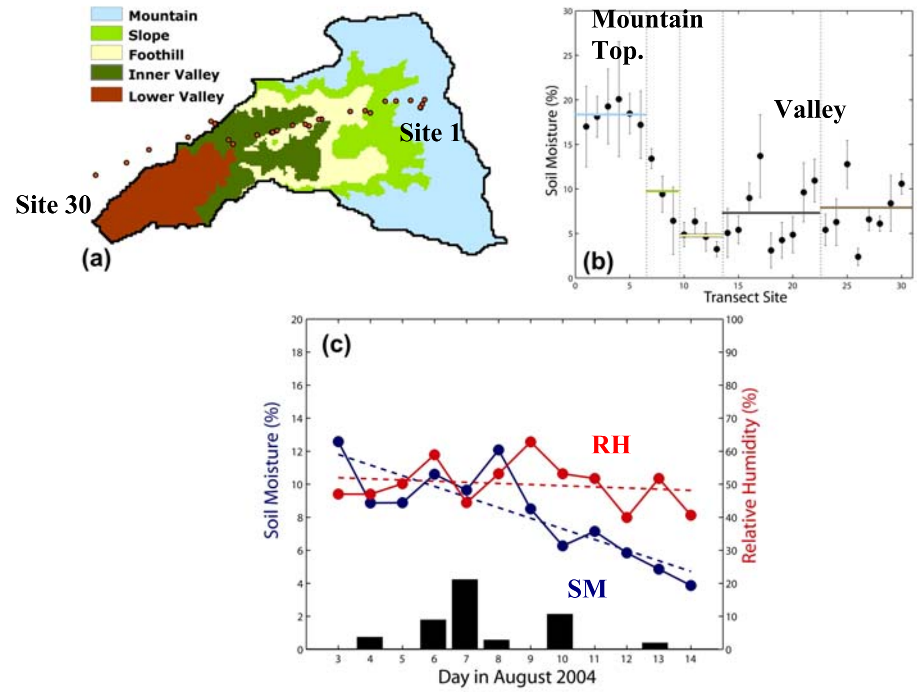

Figure 4. Daily soil moisture, soil temperature, and meteorological data taken at transect locations. Many locations shown in (a) were in a single watershed (100 km^2). Watershed averaging was conducted using a hypsometric technique as shown in (b). Averages for each elevation band were then weighted by the percent of the basin at each elevation interval. The time series of basin-averaged soil moisture and relative humidity is shown in (c), as well as the average rainfall for the watershed. Basin mean quantities can be compared to AMSR-E, TRMM and other remote sensing products over the region.

Figure 3 illustrates the study region in northern Sonora, its topographic variability, and the location of the 15 permanent stations and 30 of the daily sampling sites. The topographic variability is significant and well-organized into north-south mountain ranges which form the Sierra Madre Occidental. As a result of the tectonic setting, two major rivers traverse the region in a north-south orientation: Río San Miguel (west) and Río Sonora (east). As both rivers have a confluence south of the study region, both belong to the Sonora river basin, which is a major water supply to the capital Hermosillo. Note that not all of the sampling locations are depicted in the diagram as we emphasize a subset of the measurements obtained over a topographic transect which had a range of elevation of nearly 600 m over a 22-km rural, mountain road. Two teams from New México Tech sampled the transect daily for rainfall, soil moisture, soil temperature and meteorological variables (e.g. air temperature, relative humidity) across a range of ecosystems. Results from the study have been documented by Vivoni et al. (2004) and Vivoni et al. (2005c).

As an example of the spatial and temporal variability in the rainfall and soil moisture processes during the monsoon, we present in Figure 4 the results from measurements along the topographic transect. Many of the transect sites fell within a single watershed (100 km^2, Figure 4a) and were used to obtain time series of basin-averaged relative humidity and soil moisture. The spatial variability in soil moisture is shown in Figure 4b where the topographic control is evident. Transect measurements show high soil moisture for mountain areas and highly variable soil moisture in the lower valley. The temporal variability of the mean basin quantities (rainfall, soil moisture and relative humidity) illustrates a pattern of land surface drying while the high relative humidity conditions characteristics of the monsoon airflow are sustained. Note also the basin-averaged responses of soil moisture to individual rainfall events (Figure 4c). As shown by this work, the field campaign in the complex monsoon terrain provided some significant and new insights into the hydroclimatology of the region. Nevertheless, the current infrastructure alone, as described previously (~1 sample per 30 km^2), is insufficient to address the spatial and temporal variability of hydrologic processes as proposed in this study. We plan on strengthening the existing network with additional equipment, utilizing remote sensing as a tool to address the large scale variations, and synthesizing observations through a distributed model capable of providing spatial patterns of hydrologic response. As a result, this proposal builds upon existing research and integrated new research and educational experiences for binational students and scientists.

4.2 Proposed Research Elements

Hydrometeorological Station Installation and Field Campaign

We will deploy five stations per year in the study site shown in Figure 3 (right panel) designed to measure rainfall and soil moisture variations. The sensors involved are tipping-bucket rain gauges and soil water content reflectometers. The station locations will be determined based upon field investigation and data analysis accounting for topographic and vegetation variability, summer rainfall distributions, and the existing instrument network. During the field campaign, we will deploy a network of inexpensive, non-recording gauges, over two or three selected areas (5-km × 5-km) in order study the small-scale variability. We will also take dense measurements of soil moisture using hand-held probes. The tasks to be performed during the field campaign will be divided into mini-projects assigned to teams composed of two students (one from each country). Examples of mini-projects to be performed over the course of two field campaigns include: (a) Assessing the small-scale variability in rainfall using event and recording rain gauges, (b) Assessing the small-scale variability of soil moisture in a set of representative ecosystems using hand-held probes, (c) Verification of topographic and vegetation maps using global positioning system, and (d) Determining the regional variability in rainfall and soil moisture based on permanent station data. These mini-projects serve an educational purpose for undergraduate and graduate students by helping to stimulate discovery-driven research and interest in field research.

Synthesis, Analysis and Evaluation of Field Observations and Remote Sensing Data

The proposed work relies on a multifractal framework to characterize the spatiotemporal variability of rainfall and soil moisture, and to match the scales between ground observations and remote sensing data. Multifractals are mathematical generalizations of fractals, objects displaying scale-invariance. The specific analysis that will be done include: (i) detection of scale-invariance through power spectrum (Korner 1988), (ii) estimation of multifractal parameters through the double trace moment method (Lovejoy and Schertzer 1995), (iii) investigation of the linkage between multifractal (scaling) parameters and large-scale forcing (such as climate) or small-scale forcing (such as topography or vegetation), using pattern covariance function and regression analysis (Wilks 1995), and (iv) comparison of the field observations and remote sensing data, after matching up the scales. These analyses will be carried out to test each research hypothesis based upon the results of field campaigns, remote sensing data and hydrologic modeling.

Integration of Observations into a Distributed Hydrologic Model

We will utilize the TIN-based Real-time Integrated Basin Simulator (tRIBS) model developed by the P.I. to assess the potential and utility of remote sensing data, and to understand how the spatiotemporal variability in rainfall interacts with spatial heterogeneity of landscape properties to produce complex, dynamic fields of runoff and soil moisture. tRIBS is a physically-based model based on a triangulated irregular network (TIN) developed for hydrologic simulation in regions of complex terrain using precipitation data from rain gauges and remote sensing. The model encapsulates the hydrologic and software developments from Garrote and Bras (1995) and Tucker et al. (2001). Ivanov et al. (2004a,b) and Vivoni et al. (2005a,b) document the various model components and capabilities. The distributed hydrologic model will first be applied with detailed measurements from the distributed sensor network and spatial field campaigns. Spatial data on mountain properties such as topography, soils and vegetation from field measurements and remote sensing are used to parameterize the model. After model setup, spatial simulations of soil moisture, evapotranspiration, and runoff, among others, can be compared to observational fields. After gaining confidence in the simulations, the physical processes are represented at a sufficient level of accuracy for model experimentation. We will then integrate field observations and remote sensing data into the hydrologic model. The resulting model outputs will be compared with those obtained by using different sets of inputs tailored to address specific problems. Remote sensing data of precipitation and soil moisture (without augmented by field observations) will be used to assess the impact of these data on hydrological model outputs. By aggregating the assimilated input data into higher spatial scales, we will conduct sensitivity studies to elucidate how the spatial resolution of input forcing affects the simulated runoff, soil moisture, and evapotranspiration. We will also examine the effect of temporal sampling by resampling from the input data, according to a specified sampling pattern. Finally, we will apply the spatiotemporal multifractal analysis to the spatial patterns produced by the hydrologic model.

5. Educational Approach

Integrating the international research activities described previously into educational opportunities for students at various levels and across the U.S./México border requires a multi-tiered approach. Three major educational program elements are to be developed as part of this proposal: (1) an international field campaign where graduate and undergraduate students from the U.S. and México will obtain research experiences; (2) an undergraduate summer research program for training prior to and after the field campaign and (3) mentoring activities to stimulate team-based learning across multiple student levels. Our goal is to closely integrate research and education activities to stimulate learning through experimentation. Participant experiences are enhanced when involved in cutting-edge research activities of interest to researchers in the project and the scientific community at large. The mountainous monsoon setting will also be exploited as an educational tool for its unique environment and perspective on the hydrology of semiarid regions. This strategy is based on the concept of inquiry-based learning in the field promoted for earth science instruction at various levels (Woltemade and Stanitski-Martin 2002; Salvage et al. 2004; May and Gibbons 2004). In addition, our strategy is based on tiered and peer mentorship where students at various levels provide instruction to fellow students at the same level or below. The ultimate purpose of the coordinated educational elements is to make significant advances to the recruitment, retention and advancement of students in the hydrologic sciences, particularly women and underrepresented minorities. In the following, we discuss the approach to address the hypothesis that mountain settings provide an effective environment for experiential learning.

5.1 International Field Campaign

As described in the research approach, a three-week international field campaign will be conducted each summer in northern Sonora, México with the intent to deploy and install research equipment, conduct field surveys and augment permanent measurements with daily sampling. The intent of the international field campaign is to provide research, educational and cultural exchange opportunities for U.S. students via interactions with Mexican researchers and students. The field campaign is the cornerstone of the IRES program and will serve to galvanize the planning, data analysis and modeling efforts conducted prior to and after the campaign. Our host institution, the Universidad de Sonora in Hermosillo, is excited about providing its students with equally stimulating interactions with U.S. researchers and students. As both regions of each country share a similar climate phenomenon and landscape setting, we believe that the field campaign will serve toward developing research and educational skills across the U.S./México border, providing our students with necessary skills for transboundary and global research.

For the international field campaign to be an educational success, we have carefully evaluated the scientific rationale for the proposed studies and the necessary resources to conduct them in an efficient manner. Housing, transportation, meals, insurance and other logistics have been considered with the help of the foreign partnering institution. As we have conducted a prior field campaign in the region, we have gained significant experience in providing the necessary facilities for successful student involvement. We plan on having students involved in 'hands-on' training in hydrologic instruments, field data collection and hydrologic observations that are unattainable in a classroom for U.S. participants. Similarly, for Mexican students, involvement in cutting-edge research with U.S. investigators is a unique opportunity. To maximize this shared experience, we will team one U.S. and one Mexican student (4 total teams) and assign them mini-projects that they are responsible for over the course of the campaign. Both U.S. and Mexican researchers will guide the tasks and provide mentorship. By having two summer seasons, we ensure project continuity; allow for research results to be produced and published; and provide flexibility to adjust techniques, methods or questions. New undergraduate and graduate students will be encouraged each summer with the same team of U.S. and Mexican investigators.

5.2 Undergraduate Summer Research Program

The primary audience for the IRES program is undergraduate students recruited each summer to participate in an eight-week research program, with three weeks dedicated to the field campaign. At the undergraduate level, the recruitment and training of underrepresented minorities and women into geoscience careers, including hydrology, can be significantly enhanced by providing research opportunities at an early stage. Well-designed summer research programs that integrate field activities, data analysis and computing exercises have proven to be successful nationwide (Slater et al. 2004). As a strategy for teaching young investigators, 'learning by doing' in a field setting is a hallmark for inspiring enthusiasm and discovery-driven research. As part of this proposal, two undergraduates will be hired during each summer period to participate in the field campaigns, data collection from remote sensing and hydrologic modeling. The students will be recruited from regional institutions without a strong undergraduate hydrology program (UTEP, NMSU, UNM, NMT) and selected based on academic performance, scientific inquisitiveness, and openness to cultural exchange and team-based activities. Recruitment activities will include department mailings, web posting and personal visits/contacts. We will place special emphasis on recruiting women and underrepresented minorities. We have had previous success in this respect due to our diverse cultures in New México. For this project, we anticipate that the opportunity to work on research in México will attract minority students, particularly Hispanics. The two selected students will work closely with the P.I., co-P.I. and graduate students, receiving mentorship and guidance from various perspectives. The result of the summer experience is expected to provide students with a good introduction to hydrologic science while their efforts will provide important contributions to the project. Activities prior to and after the campaign will focus on data analysis and modeling to establish a well-balanced mix with field activities.

5.3 Mentoring Activities

Mentorship is an essential activity in the program and merits individual attention. We have a strong commitment at New México Tech and Universidad de Sonora on student mentoring as it promotes recruitment, retention and advancement in the hydrologic sciences. Both U.S. and Mexican researchers have had joint experiences in mentoring students through a collaborative field campaign in summer 2004 and through continued interaction. Individually, we also mentor students in our research groups (at the undergraduate and graduate level) and perform mentoring through teaching activities. The challenge for mentoring in the IRES program will be that many of the participating students will be of very different levels, ranging from early undergraduate to doctoral candidates, and also have different cultural experiences in each country. We will address this by promoting tiered and peer mentorship, with students at higher levels mentoring students at equal or lower levels. Since we anticipate some of the U.S. participants having strong cultural and language ties with México (of Hispanic decent), we expect that the tiered and peer mentorship will promote greater student learning. It is important to note, however, that both P.I. Vivoni and collaborator Watts are bilingual, bicultural and well versed in the nuances of each country. This is primarily due to their experiences in both the U.S. and México. Our focus on mentoring is primarily because we want to provide participating students with unique opportunities that can form a link or bridge towards future steps along a hydrological science career.

5.4 Program Evaluation

Evaluation of the educational program will be conducted via two major components: qualitative and quantitative assessments. The qualitative evaluation occurs throughout the project duration and provides an assessment of how well the program activities have met the stated goals. The quantitative evaluation occurs by utilizing questionnaires for project participants in various activities. Culturally-aware and bilingual (where applicable) evaluations will be conducted for program elements involving underrepresented minorities and participants from México. An example of the quantitative evaluations is a questionnaire for Mexican students participating in the field program prior to (to assess expectations) and after (to assess outcomes) the activities. Examples of the qualitative evaluations are weekly meetings with undergraduate and graduate students designed to evaluate progress during the pre-trip, field campaign and post-trip phases. Another tool to be used to evaluate project progress will be the number of public presentations, journal manuscripts and collaborative proposals conducted by students and researchers that arise as a result of this project. A successful international collaboration is one that continues to evolve, attract new participants, and advance hydrologic science with answers to unresolved questions.

6. Host Participation

The participation of the host institution in México, the Universidad de Sonora, is critical for the success of the educational and research components of the IRES program. We have a strong commitment from our collaborator Prof. Christopher Watts (see attached Support Letter). Dr. Watts and his students have experience in hydrologic instrumentation, hydrometeorology and monsoon studies in northern México. In particular, their research group has deployed, managed and archived long-term data from two rain gauge networks, four meteorological flux towers and a soil moisture network, available to the proposed project. Their research expertise significantly complements the strengths in the New México Tech group, primarily field campaigns, data analysis, remote sensing and hydrologic modeling. The local contact in México is particularly important for obtaining data sets from government and research agencies; establishing logistical details such as housing arrangements, transportation support, laboratory space, office facilities and field instruments; recruiting students from local universities for participation in the program and government permitting issues. Our institutions have had productive collaboration experiences in the past, including field studies, workshops, conference sessions and manuscripts under preparation. We anticipate that the host institution, Universidad de Sonora, will be able to provide the support outlined above. Resources from New México Tech available to the project are fully described in the Facilities and Equipment section. Of additional note, however, is the availability of Spanish language instruction and cultural activities at NMT for the participating U.S. students; and use of the NMT Distance Education program to provide instruction to Mexican participants.

7. Research and Education Integration and Work Plan

During the two-year period covering the proposed project, the research and educational program tasks include the following:

Year 1: *Field Campaign, Instrument Deployment, Remote Sensing Analysis*. During the summer of Year 1 we will focus on the deployment of five instrument stations during the field campaign and on post-campaign data analysis and remote sensing activities: **(a)** Procurement and deployment of five hydrologic stations in Sonora; **(b)** Design and execution of field activities related to detailed data collection; **(c)** Collection and processing of remote sensing data over study region; **(d)** Assessment of uncertainty in remote sensing products; and **(e)** Spatiotemporal analysis of observations in a multifractal framework.

Year 2: *Field Campaign, Instrument Deployment, Hydrologic Modeling*. During the summer of Year 2 we will focus on the deployment of a second set of five stations during the field campaign and on post-campaign data analysis and hydrologic modeling activities: **(a)** Procurement and deployment of five hydrologic stations in Sonora; **(b)** Design and execution of field activities related to detailed data collection; **(c)** Collection and processing of geographic data for model setup; **(d)** Assessment of value and utility of remote sensing data in hydrologic model; and **(e)** Spatiotemporal analysis of simulated hydrologic patterns in a multifractal framework.

8. Anticipated Results and Expected Significance

Several fundamental questions will be addressed in this proposed project concerning the spatiotemporal variability of hydrologic processes during the North American monsoon in regions of complex terrain. We have identified three major approaches to achieving new understanding: field campaign activities, remote sensing data analysis and the integration of these products in a distributed hydrological model. Advances in this project will help address critical science questions related to the spatial and temporal variability of observed hydrologic variables and their representation in a physically-based model. The proposed study site has advantages in terms of its characteristics and existing facilities that will enable careful measurements and model simulations to be conducted in an unprecedented level of integration. Our foreign collaborators will be providing expertise in hydrologic instrumentation and in studies of monsoon dynamics, as well as logistical and participant recruiting support. The application of distributed sensor networks and distributed hydrologic modeling to the study of semiarid monsoon hydrology in this complex terrain can form the basis for long-term measurements that can provide future opportunities to propose a validation site for remote sensing measurements of precipitation, soil moisture and other hydrologic variables. In this respect, we anticipate to use this proposed project as leverage for other proposals and efforts both in the U.S. and México to improve the instrument network, obtain sustained researcher participation and generate scientific results.

We anticipate making significant advances in providing students with an international research experience which is cutting-edge in its science and educational approach. Participating students from both the U.S. and México will receive 'hands-on' training on field methods in a unique field setting. The mountain region will be used as an educational tool designed to inspire inquiry-based learning at multiple levels from each country. While the three-week field campaign is the primary component of the project, other educational activities, including a summer undergraduate research program and mentorship activities, will be used to provide additional research training that complements field work. We consider that the proposed efforts will advance the recruitment, retention and advancement of students into hydrologic science, in particular for women and underrepresented minorities attracted to the program. Program evaluation of the educational and research components will ensure continual project review and identify potential limitations for corrective action. Ultimately, the significance of the project will lie in our success to inspire students to have a binational perspective on monsoon studies, to pursue further studies in hydrologic science and to develop as global scientists prepared for future challenges.

9. Management Plan and Collaborations

Prof. Enrique Vivoni will serve as the Principal Investigator for the project in the Department of Earth and Environmental Science at New México Tech (NMT). The co-P.I. for the project is Dr. Mekonnen Gebremichael, a Post-Doctoral Research Associate at NMT, who will lead the project planning, execution and analysis. We plan on inviting two graduate students (M.S. or Ph.D. level) from the Hydrology Program at NMT to participate in the International Research Experience for Students (IRES) program. The graduate students will be selected each year based on the relation of their current research with the proposed work. In addition, two undergraduate researchers will be hired each year through a recruitment effort to identify candidates from regional universities without a strong hydrology undergraduate curriculum. The four students will participate in a 3-week field season in addition to working on various project aspects including equipment preparation, data analysis and model applications. Extensive educational and research exchanges between the P.I., co-P.I., graduate and undergraduate students are anticipated in the project. We will also interact with researchers from our foreign partnering institution, the Universidad de Sonora in Hermosillo, Sonora, México, as part of the IRES program. Two researchers, Prof. Christopher Watts and Mr. Julio César Rodríguez, will lead a group of four undergraduate and graduate students from México, selected to participate in the field season each project summer (see attached Support Letter). Collaborator Watts has significant research experience in instrumentation, hydrometeorology and monsoon studies by binational teams such as SALSA, NAME, SMEX04 and SAHRA (see attached CV). We plan on recruiting the students from universities in Sonora based on their academic interests and research experience. The IRES program will present a unique opportunity to expand an on-going collaboration between New México Tech and Universidad de Sonora. Past collaborations have included the SMEX04 field campaign; two field trips during June 2004 and 2005; several joint presentations and manuscripts based on the project results; and organization of a joint session for a national conference. Funding of the IRES program will substantially improve our current collaboration which has been accomplished with limited to no funds, and allow for a new focused research and educational effort in the study region. This proposal is part of a long-term effort to increase our understanding of semiarid, mountain hydrology in a monsoon region of northern Sonora through field observations, remote sensing, and model applications. Additional funding to support new measurements and researcher involvement is currently being sought via both U.S. and México funding agencies. The proposed work will further the research and educational efforts in a unique, semiarid monsoon environment with the future objective of proposing the region as a field validation site for remote sensing measurements of precipitation, soil moisture and other hydrological variables. We anticipate presenting project results at national conferences, as well as several publications from this effort.

10. Results from Prior NSF Support

High-Performance, Multiple-Resolution Modeling of Semiarid Hydrology at Regional Scales, EAR-0342526, $128,346, 03/2004 – 02/2006. A two-year project was funded by NSF with the goal of adapting a fine-resolution hydrologic model for simulations in semiarid basins. The project is focused on the parallelization the tRIBS model and the development of new modules for use in the Río Grande. This project involves ongoing collaborations with the Los Alamos National Laboratory and the NSF Science and Technology Center SAHRA (Sustainability of semiArid Hydrology and Riparian Areas). It also has a funded an REU component for minority participation and outreach. During its first project year, the major accomplishments made were: (1) Model Parallelization: The tRIBS model was successfully parallelized using reach-based domain decomposition. Initial tests suggest that the model performance will improve on high performance cluster computers; (2) Fine-Resolution Modeling Requirements: Collaborations with SAHRA have led to using tRIBS as the hydrologic model to address effects of vegetation change on basin water balance; (3) Model Applications and Field Campaigns: Detailed data collection and model simulations are being conducted in the Valles Caldera National Preserve and a two-week field campaign has been carried out to obtain observations of hydrometeorological variables at seventy-two sites; and (4) Minority Participation: An REU program and faculty involvement have increased minority participation in hydrologic sciences through recruitment and retention both at New México Tech and SAHRA. As this project is on-going, no peer-reviewed publications have yet arisen. We have made several conference presentations at national conferences (AGU 2004, SACNAS 2004, GEM 2005), local university activities and as part of a Traveling Lecture Series (Cottonwood School, Las Cruces Learning Center). We anticipate several publications from the project documenting the model developments and field campaign studies.

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Gebremichael, M., W.F. Krajewski, M.L. Morrissey, G.J. Huffman, and R.F. Adler. 2005a: A Detailed Evaluation of GPCP 1° Daily Rainfall Estimates over the Mississippi River Basin**.** *J. Appl. Meteor.,* **44**(5), 665–681.

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Ivanov, V.Y., E.R. Vivoni, R.L. Bras, and D. Entekhabi, 2004b: Preserving high-resolution surface and rainfall data in operational-scale basin hydrology: A fully-distributed, physically-based approach. *J. Hydrol.,* **298**(1-4), 80–111.

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Méndez-Barroso, L.A., A.J. Rinehart, C.A. Aragón, G. Bisht, M.B. Cardenas, E. Engle, B. Forman, M.D. Frisbee, H.A. Gutiérrez-Jurado, S.-H. Hong, K. Tai, R.L. Wyckoff, and E.R. Vivoni, 2005: Spatial and Temporal Analysis of Hydrometeorological Conditions in the Valles Caldera, New México during the North American Monsoon. *American Geophysical Union, Fall Conference,* San Francisco, CA.

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Veitzer, S.A., and V.K. Gupta, 2001: Statistical self-similarity of width function maxima with implications to floods. *Adv. Water Resour.,* **24**(9-10), 955–965.

Vivoni, E.R., Gutiérrez, H.A., Aragón, C.A., Rinehart, A., Wyckoff, R., Watts, C.J., Rodríguez, J.C., and Jackson, T.J. 2004: Landscape Controls on Monsoon Soil Moisture Distribution in Northern Sonora, México. *American Geophysical Union, Fall Conference*, San Francisco, CA.

Vivoni, E.R., V.Y. Ivanov, R.L. Bras, and D. Entekhabi, 2005a: On the effect of triangulated terrain resolution on distributed hydrologic modeling. *Hydrol. Proc.,* **19**(11), 2101–2122.

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Enrique R. Vivoni

PROFESSIONAL PREPARATION

Massachusetts Institute of Technology	Environmental Engineering Science	B.S. 1996
Massachusetts Institute of Technology	Civil and Environmental Engineering	M.S. 1998
Massachusetts Institute of Technology	Hydrology	Ph.D. 2003

APPOINTMENTS

New Mexico Institute of Mining and Technology, Dept. of Earth and Environmental Science

2003 to present — Assistant Professor of Hydrology.

2003 to present — Research Hydrologist. Geophysical Research Center.

Massachusetts Institute of Technology, Dept. of Civil and Environmental Engineering

2005-present — Research Affiliate

INTERESTS

Hydrometeorology, Watershed Modeling, Surface Hydrology, Ecohydrology, GIS, Remote Sensing

AWARDS

Visiting Scientist, NCAR (2005), Young Investigator Program, US Army (2005-2008), UA Promising Young Scientist Lecturer (2005), Los Alamos National Lab, University Research Program (2005-2006), Sandia National Lab, University Research Program (2004-2006), CUAHSI Cyberpioneer Distinguished Lecture Series (2003), American Geophysical Union Outstanding Student Paper Award (2002), URISA Horwood Critique Student Prize (2002), National Research Council, Ford Foundation Dissertation Fellowship (2002-2003), National Science Foundation, Graduate Fellowship (1997-2000), Graduate Minority Education, Graduate Fellowship (1996).

PUBLICATIONS

Publications most closely related to proposed project

1. Vivoni, E.R. and Camilli, R. 2003. Real-time Streaming of Environmental Field Data. *Computers & Geosciences*. 29(4): 457-468.
2. Grassotti, C., Hoffman, R.N., Vivoni, E.R. and Entekhabi, D. 2003. Multiple Timescale Intercomparison of Two Radar Products and Rain Gauge Observations over the Arkansas-Red River Basin. *Weather and Forecasting*. 18(6): 457-468.
3. Xie, H., Zhou X., Vivoni, E.R., Hendrickx, J.M.H. and Small, E.E. 2005. GIS-based NEXRAD Stage III precipitation database: Automated approaches for data processing and visualization. *Computers and Geosciences*. 31(1): 65-76.
4. Ivanov, V.Y., Vivoni, E.R., Bras, R.L. and Entekhabi, D. 2004. Catchment Hydrologic Response with a Fully-Distributed Triangulated Irregular Network Model. *Water Resources Research*. 40(11): W11102, 10.1029/2004WR003218.
5. Vivoni, E.R., Ivanov, V.Y., Bras, R.L. and Entekhabi, D. 2005. On the Effect of Triangulated Terrain Resolution on Distributed Hydrologic Modeling. *Hydrological Processes*. 19(11): 2102-2122.

Other significant publications

1. Nepf, H.M. and Vivoni, E.R. 2000. Flow Structure in Depth-Limited, Vegetated Flow. *Journal of Geophysical Research, Oceans*. 105(C12): 28,547-28,558.

2. Vivoni, E.R., Ivanov, V.Y., Bras, R.L., Entekhabi, D. 2004. Generation of Triangular Irregular Networks based on Hydrological Similarity. *Journal of Hydrological Engineering*. 9(4): 288-303.
3. Vivoni, E.R., Teles, V., Ivanov, V.Y., Bras, R.L. and Entekhabi, D. 2005. Embedding Landscape Processes into Triangulated Terrain Models. *International Journal of Geographical Information Science*. 19(4): 429-457.
4. Falorni, G., Teles, V., Vivoni, E.R., Bras, R.L. and Amaratunga, K.S. 2005. Analysis and characterization of the vertical accuracy of digital elevation models from the Shuttle Radar Topography Mission. *Journal of Geophysical Research, Earth Surface.* 110(F2): F02005. doi:10.1029/2003JF000113.
5. Ivanov, V.Y., Vivoni E.R., Bras, R.L. and Entekhabi, D. 2004. Preserving high-resolution surface and rainfall data in operational-scale basin hydrology: A fully-distributed, physically-based approach. *Journal of Hydrology*. 298(1-4): 80-111.

SYNERGISTIC ACTIVITIES

1. Formulated and taught an MIT course on environmental field data collection through the development of mobile, wireless and Internet technology and its field trials in Australia.
2. Patent-pending computational algorithm for the incorporation of hydrologic and geomorphic process behavior (through terrain indices) into triangulated terrain models.
3. Copyrighted a distributed hydrologic model (software code) utilizing triangulated irregular networks and coupling the surface and subsurface rainfall response.
4. Advisor for New Mexico Tech Society of Hispanic Professional Engineers.
5. Steering Committee on New Mexico Alliance for Graduate Education and the Professoriate.
6. Undergraduate advisor for environmental sciences with hydrology concentration.
7. Diversity outreach activities through SACNAS, GEM and SAHRA.
8. Reviewer for *Water Resources Research*, *Journal of Hydrometeorology*, *Hydrological Processes*, *Geophysical Research Letters*, *Journal of Geophysical Research – Earth Surface*; National Science Foundation, NASA Earth-Sun System Science, US Army Research Office

COLLABORATORS & OTHER AFFILIATIONS

Collaborators: Rafael L. Bras, Valeri Y. Ivanov, Dara Entekhhabi (MIT), Ross N. Hoffman, Chris Grassotti (AER, Inc), Everett Springer, Brent Newman (LANL), Vince Tidwell (Sandia National Laboratory), Christopher Watts (Universidad de Sonora), Robert S. Bowman, John Wilson (New Mexico Tech), Tom Jackson (USDA), Salvatore Grimaldi (CNR- IRPI, Italy), Fernando Nardi (University of Rome), Venkat Lakshmi (U. South Carolina).

Graduate Advisors: (1) Rafael L. Bras, Massachusetts Institute of Technology.
(2) Dara Entekhabi, Massachusetts Institute of Technology.
(3) Heidi M. Nepf, Massachusetts Institute of Technology.

Thesis Advisor*:* 6 current graduate students: Hugo Gutierrez, Luis Mendez (Ph.D.), Alex Rinehart, Carlos Aragón, Robert Wyckoff, Bill Tai (M.S.), none graduated.

Mekonnen Gebremichael

EDUCATION

Alemaya University (Ethiopia),	Agricultural Engineering	B.S. 1992
International Institute for Geo-information Science and Earth Observation (the Netherlands),	Water Resources	M.S. 1999
University of Iowa (USA)	Civil and Environmental Engineering	Ph.D. 2004

PROFESSIONAL APPOINTMENTS

2005-present	Postdoctoral Research Associate, Dept. of Earth and Environmental Science, New Mexico Institute of Mining and Technology
2004-2005	Postdoctoral Research Associate, Dept. of Civil and Environmental Engineering, Duke University
1995–1997	Design Engineer and Team Leader, Commission for Sustainable Agriculture & Environmental Rehabilitation, Ethiopia
1993–1994	Soil and Water Conservation Expert, Ministry of Natural Resources, Ethiopia.

INTERESTS

Hydrometeorology, Hydrological Modeling, Ecohydrology, Remote Sensing, Stochastic Modeling, Nonlinear Dynamics, Uncertainty

AWARDS

2003-2004	NASA Earth System Sciences Fellowship
1999-2000	International Institute for Aerospace Survey and Earth Sciences (ITC) Fellowship
1997-1999	Netherlands Government Fellowship
1997	Outstanding Performance Award, awarded by the Tigray State Government, Ethiopia

PUBLICATIONS

Publications most closely related to proposed project

1. **Gebremichael, M.,** W.F. Krajewski, T.M. Over, Y.N. Takayabu, P. Arkin, and M. Katayama, "Geographical variation in scaling of tropical rainfall as seen by TRMM PR", Journal of Climate, 2005 (in review).
2. **Gebremichael, M.,** T.M. Over, and W.F. Krajewski, "Comparison of the scaling properties of rainfall derived from space- and surface-based radars", Journal of Hydrometeorology, 2005 (in review).
3. **Gebremichael, M.,** and W.F. Krajewski, "Characterization of the temporal sampling error in space-time averaged rainfall estimates using parametric and non-parametric approaches," Journal of Geophysical Research–Atmospheres, 109, D11110, doi:10.1029/2004JD004509, 2004.
4. **Gebremichael, M.,** and W.F. Krajewski, "Assessment of the statistical characterization of small-scale rainfall variability from radar: Analysis of TRMM ground validation datasets," Journal of Applied Meteorology, **43**(8), (1180-1199), 2004.
5. **Gebremichael, M.,** W.F. Krajewski, M. Morrissey, D. Langerud, G. Huffman, and R. Adler, "Error uncertainty analysis of GPCP monthly rainfall products: A data-based simulation study," Journal of Applied Meteorology, **42**(12), 1837-1848, 2003.

Other significant publications

1. **Gebremichael, M.,** and A.P. Barros, "Evaluation of MODIS gross primary productivity (GPP) in regions of complex terrain and monsoon climates," Remote Sensing of Environment, 2005 (in review).
2. **Gebremichael, M.,** and W.F. Krajewski, "The effect of temporal sampling error on inferred rainfall spatial statistics," Journal of Applied Meteorology, 2005 (in press).
3. **Gebremichael, M.,** W.F. Krajewski, M. Morrissey, G. Huffman, and R. Adler, "A detailed evaluation of GPCP one-degree daily rainfall estimates over the Mississippi River Basin," Journal of Applied Meteorology, 44(5), 665-681, 2005.
4. **Gebremichael, M.,** and W.F. Krajewski, "On the distribution of temporal sampling errors in the area-time averaged rainfall estimates derived from satellites," Atmospheric Research, **73**, 243-159, 2005.
5. **Gebremichael, M.,** and W.G.M. Bastiaanssen, "A new simple method to determine crop coefficients for water allocation planning from satellites: results from Kenya," Irrigation and Drainage Systems, **14**, 237-256, 2000.

SYNERGISTIC ACTIVITIES.

Reviewer for *Journal of Hydrology*, *IEEE Transaction on Geoscience and Remote sensing*, *Advances in Water Resources*, *Journal of Applied Meteorology*

GRADUATE ADVISORS

(1) Witold F. Krajewski, University of Iowa
(2) Wim Bastiaanssen, International Institute for Geo-information Science and Earth Observation
(3) Alland Meijerink, , International Institute for Geo-information Science and Earth Observation

Christopher J. Watts

PROFESSIONAL PREPARATION

University of York, U.K.	Chemistry	B.A.	1971
University of Sheffield, U.K.	Chemistry	Ph.D	1976

APPOINTMENTS.

University of Southern California, Dept. Chemistry	Postdoctoral Fellow	1977-78
University of Arizona, Dept. Hydrology	Research Associate	1979-80
Instituto Tecnológico de Sonora, Dept. Water Resources	Associate Professor	1981-91
Instituto del Medio Ambiente de Sonora, Director of Water Resources		1992-2002
University of Sonora, Dept. Physics	Professor	2002-present

INTERESTS

Hydrometeorology, Energy Balance, Ecohydrology, GIS, Remote Sensing

AWARDS

Group Honor Award for the SALSA Program USDA

PUBLICATIONS

Publications most related to this proposed project

1. Gochis, DJ, A Jimenez, CJ Watts, J Garatuza-Payán, and WJ Shuttleworth, 2004, Analysis of 2002 and 2003 Warm-Season Precipitation from the North American Monsoon Experiment Rain Gauge Network, *Monthly Weather Review,* 132: 2938-2953.

2. Scott, RL, EA Edwards, WJ Shuttleworth, TE Huxman, CJ Watts and DC Goodrich, 2004, Interannual and seasonal variation in fluxes in water and carbon dioxide from a riparian woodland ecosystem, *Agricultural and Forest Meteorology,* 122: 65-84.

3. Scott, RL, CJ Watts, J Garatuza Payan, E Edwards, DC Goodrich, D Williams and WJ Shuttleworth, 2003, The understory and overstory partitioning of energy and water fluxes in an open canopy, semiarid woodland, *Agricultural and Forest Meteorology,* 114: 127-139.

4. Gochis, DJ, JC Leal, WJ Shuttleworth, CJ Watts and J Garatuza-Payan, 2003, Preliminary Diagnostics from a New Event-Based Precipitation Monitoring System in Support of the North American Monsoon Experiment, *Journal of Hydrometeorology,* 4: 974–981.

5. Hoedjes JCB, RM Zuurbier and CJ Watts, 2002, Large Aperture Scintillometer Used Over A Homogeneous Irrigated Area, Partly Affected By Regional Advection, *Boundary-Layer Meteorology* 105(1): 99-117.

Other significant publications

1. Kepner WG, CJ Watts, CM Edmonds, JK Maingi, SE Marsh, G Luna, 2000, A Landscape Approach for detecting and evaluating change in a semi-arid environment, *Environmental Monitoring And Assessment*, 64:179-195.

2. Watts CJ, A Chehbouni, JC Rodriguez, YH Kerr, O Hartogensis, HAR de Bruin, 2000, Comparison of sensible heat flux estimates using AVHRR with scintillometer measure-ments over semi-arid grassland in northwest Mexico, *Agricultural and Forest Meteorology,* (105)1-3:81-89.

3. Chehbouni A, CJ Watts, J.-P. Lagouarde, Y.H. Kerr, J.-C. Rodriguez, J.-M. Bonnefond, F. Santiago, G. Dedieu, D.C. Goodrich, C. Unkrich, 2000, Estimation of heat and momentum fluxes over complex terrain using a large aperture scintillometer, *Agricultural and Forest Meteorology*, (105)1-3:215-226.

4. Garatuza-Payan J, RT Pinker, WJ Shuttleworth, CJ Watts, 2001, Solar radiation and evapotranspiration in northern Mexico estimated from remotely sensed measurements of cloudiness, *Hydrological Science Journal* ,46(3): 465-478.

SYNERGISTIC ACTIVITIES

1. Coordinator of field activities in Mexico for the SALSA program.
2. Member of Scientific Working Group for the North American Monsoon Experiment (NAME).
3. Co PI for the Soil Moisture EXperiment 2004 (SMEX04) in the Sonora river basin.
4. Co PI for the NAME Enhanced Rainfall Network (NERN).
5. Co PI for the NAME study vegetation-atmosphere feedbacks NW Mexico.
6. Member of scientific oversight committee for CONACyT projects in Sonora, Mexico.

COLLABORATORS & OTHER AFFILIATIONS

Collaborators: Russell Scott (USDA-ARS), David Gochis (UCAR), David Goodrich (USDA-ARS), Enrique Vivoni (NMT), Jim Shuttleworth (University of Arizona), Henk de Bruin (University of Wageningen, Netherands), Ghani Chehbouni (IRD, France), Jaime Garatuza (ITSON, Mexico), Miguel Cortez (SMN, Mexico)

Thesis Advisor*:* 13 MS graduated students; 2 current PhD graduate students: Julio Rodríguez and Fernando García.

SUMMARY PROPOSAL BUDGET — YEAR 1

ORGANIZATION New Mexico Institute of Mining and Technology			FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Enrique R Vivoni			AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Enrique R Vivoni - Assistant Professor	0.00	0.00	0.00	$ 0	$
2. Mekonnen Gebremichael - Postdoctoral Research Assoc.	1.00	0.00	1.00	3,083	
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (2) TOTAL SENIOR PERSONNEL (1 - 6)	1.00	0.00	1.00	3,083	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (2) GRADUATE STUDENTS				0	
4. (2) UNDERGRADUATE STUDENTS				7,000	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				10,083	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				1,127	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				11,210	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
Data Logger: CR10X-2M (5)			$ 4,475		
Enclosures: 15873 (5)			1,375		
Enclosures: Mounts (5)			275		
Others (See Budget Comments Page...)			5,881		
TOTAL EQUIPMENT				12,006	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				500	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ 3,360					
2. TRAVEL 3,680					
3. SUBSISTENCE 9,765					
4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (12) TOTAL PARTICIPANT COSTS				16,805	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				1,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				2,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				1,200	
5. SUBAWARDS				0	
6. OTHER				500	
TOTAL OTHER DIRECT COSTS				4,700	
H. TOTAL DIRECT COSTS (A THROUGH G)				45,221	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) Computer Services (Rate: 47.1000, Base: 1200) (Cont. on Comments Page)					
TOTAL INDIRECT COSTS (F&A)				4,121	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				49,342	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 49,342	$
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				

PI/PD NAME Enrique R Vivoni	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* Lonnie marquez	Date Checked	Date Of Rate Sheet	Initials - ORG

1 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET COMMENTS - Year 1

** D- Equipment
Mounting Brackets: 7840 (5)   (Amount: $ 275)
Rechargeable Batteries: PS100 (5)   (Amount: $ 1050)
Soil Water Reflectometers: Cable (210 ft)   (Amount: $ 143)
Soil Water Reflectometers: CS616-L (5)   (Amount: $ 750)
Solar Panels: MSX64R (5)   (Amount: $ 1825)
Tipping Bucket Raingauges: Cable (50 ft)   (Amount: $ 13)
Tipping Bucket Raingauges: TE525WS-L (5)   (Amount: $ 1825)
** I- Indirect Costs
Fringe Benefits (Rate: 47.1000, Base 987)
Materials and Supplies (Rate: 30.7000, Base 1000)
Other (Soil Analysis) (Rate: 47.1000, Base 500)
Publication Costs/Documentation/distrib (Rate: 47.1000, Base 2000)
Senior Personnel (Rate: 47.1000, Base 3083)
Travel (Rate: 30.7000, Base 500)

SUMMARY PROPOSAL BUDGET — YEAR 2

ORGANIZATION: New Mexico Institute of Mining and Technology	FOR NSF USE ONLY — PROPOSAL NO.	DURATION (months) Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: Enrique R Vivoni	AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Enrique R Vivoni - Assistant Professor	0.00	0.00	0.00	$ 0	$
2. Mekonnen Gebremichael - Postdoctoral Research Assoc.	0.00	0.00	1.00	3,238	
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (2) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	1.00	3,238	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (2) GRADUATE STUDENTS				0	
4. (2) UNDERGRADUATE STUDENTS				7,000	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				10,238	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				1,176	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				11,414	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
Data Logger: CR10X-2M (5) — $ 1,050					
Enclosures: 15873 (5) — 143					
Enclosures: Mounts (5) — 750					
Others (See Budget Comments Page…) — 10,063					
TOTAL EQUIPMENT				12,006	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				500	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ 3,360					
2. TRAVEL 3,680					
3. SUBSISTENCE 9,765					
4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (12) TOTAL PARTICIPANT COSTS				16,805	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				1,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				2,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				1,200	
5. SUBAWARDS				0	
6. OTHER				500	
TOTAL OTHER DIRECT COSTS				4,700	
H. TOTAL DIRECT COSTS (A THROUGH G)				45,425	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) Computer Services (Rate: 47.1000, Base: 1200) (Cont. on Comments Page)					
TOTAL INDIRECT COSTS (F&A)				4,217	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				49,642	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 49,642	$
M. COST SHARING PROPOSED LEVEL $ 0 — AGREED LEVEL IF DIFFERENT $					

PI/PD NAME: Enrique R Vivoni	FOR NSF USE ONLY — INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*: Lonnie marquez	Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET COMMENTS - Year 2

** D- Equipment
Mounting Brackets: 7840 (5)   (Amount: $ 1825)
Rechargeable Batteries: PS100 (5)   (Amount: $ 13)
Soil Water Reflectometers: Cable (210 ft.)   (Amount: $ 275)
Soil Water Reflectometers: CS616-L (5)   (Amount: $ 275)
Solar Panels: MSX64R (5)   (Amount: $ 1825)
Tipping Bucket Raingauges: Cable (50 ft.)   (Amount: $ 1375)
Tipping Bucket Raingauges: TE525WS-L (5)   (Amount: $ 4475)
** I- Indirect Costs
Fringe Benefits (Rate: 47.1000, Base 1036)
Materials and Supplies (Rate: 30.7000, Base 1000)
Other (Soil Analysis) (Rate: 47.1000, Base 500)
Publication Costs/Documentation/distrib (Rate: 47.1000, Base 2000)
Senior Personnel (Rate: 47.1000, Base 3238)
Travel (Rate: 30.7000, Base 500)

SUMMARY PROPOSAL BUDGET

Cumulative

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months)	
	Proposed	Granted
AWARD NO.		

ORGANIZATION
New Mexico Institute of Mining and Technology

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Enrique R Vivoni

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Enrique R Vivoni - Assistant Professor	0.00	0.00	0.00	$ 0	$
2. Mekonnen Gebremichael - Postdoctoral Research Assoc.	1.00	0.00	2.00	6,321	
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (2) TOTAL SENIOR PERSONNEL (1 - 6)	1.00	0.00	2.00	6,321	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (4) GRADUATE STUDENTS				0	
4. (4) UNDERGRADUATE STUDENTS				14,000	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				20,321	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				2,303	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				22,624	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) $ 24,012					
TOTAL EQUIPMENT				24,012	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				1,000	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 6,720 2. TRAVEL 7,360 3. SUBSISTENCE 19,530 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (24) TOTAL PARTICIPANT COSTS				33,610	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				2,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				4,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				2,400	
5. SUBAWARDS				0	
6. OTHER				1,000	
TOTAL OTHER DIRECT COSTS				9,400	
H. TOTAL DIRECT COSTS (A THROUGH G)				90,646	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				8,338	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				98,984	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 98,984	$
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				

PI/PD NAME
Enrique R Vivoni

ORG. REP. NAME*
Lonnie marquez

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

C *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

Budget Justification

Personnel: Academic salary is covered by NMT for P.I. Vivoni. No salary support is requested for P.I. following the proposal guidelines. The P.I. will be assisted by a Post-Doctoral Research Associate (Co-P.I. Gebremichael) who will participate at a level of effort of 1 summer months/year in all project activities. No salary support is requested for participating US graduate students (2 each summer) as these are currently funded by projects related to the proposed effort. The budget also includes salary for two undergraduate students as part of the international research experience for both summers. The estimated costs for undergraduate salary support are $3500 per student per summer period (8 weeks). At New Mexico Tech, fringe benefits are 32% for Staff and 2% for students. By design, the Post-Doctoral Associate, graduate and undergraduate students will work collaboratively on the field data collection, remote sensing and hydrological modeling portions of the project.

Participant Support Costs: Participant costs are the primary category of expenses in the proposed work. They consist of: (a) Lodging and meals for US participants, (b) Travel to field site by US participants, (c) Lodging and meals for Mexican participants, (d) Travel (gasoline costs) to field site by Mexican participants, and (e) stipend support for Mexican undergraduate students. The lodging ($4410/yr) and meals ($1575/yr) for US participants are computed based on a three-week field period at a rate of 70$/night/room for three rooms in vicinity to field site and $15/day for meals for five US participants. The lodging and meals for Mexican participants are similarly computed (3 hotel rooms at $50/night and meals for two participants). Supplemental funding from Universidad of Sonora will be used to cover additional Mexican costs. Both lodging and meals for US and Mexican participants are lumped into Subsistence costs in the proposed budget ($9765/yr). The travel to the field site by the US participants is estimated at $3050/yr based on using one 4WD vehicle rented from New Mexico Tech ($2000/yr), one 4WD vehicle rented locally in Mexico ($50/day) and miscellaneous vehicle expenses of $320/yr (gasoline for rental). We lump these US travel costs with Mexican travel expenditures (primarily gasoline expenses) of $630/yr to obtain the Travel costs in the proposed budget ($3680). Finally, we will provide stipends for the Mexican undergraduates to support participation in the three-week field campaign. Estimated costs for the stipends (4 students/year at 40$/day for 21 days) are $3360/yr. We include this cost as Stipends in the proposed budget.

Materials and Supplies: Materials and supplies can be divided into two categories: (a) field work and (b) soil sample analyses (classified as Other in the proposal budget). Field supplies include materials such as concrete, wiring, flagging, necessary for equipment installation. Field supplies are requested ($1000/year) each year since equipment will be purchased and installed each summer. The second category consists of costs for analyzing soil samples (hydraulic properties, texture) ($500/year).

Publication and Computing Services: Publication costs ($2000/year) and computing services ($1200/year) are requested. Publication costs will allow for graphics and page charges associated with journals, conferences and annual reports. In addition, we include costs for website preparation, advertisements for student recruitment efforts and poster preparation for dissemination of research results. The computing services costs are for the maintenance and upgrade of existing computing facilities at New Mexico Tech to be used for the project's remote sensing data analysis and modeling tasks. In addition, we will utilize the funds for software license renewals and field computing supplies.

<u>Travel Costs:</u> One additional trip is requested ($500/year) each year for the P.I., co-P.I. or foreign partner to visit each other's institution. This trip will be used for the purpose of disseminating research results, recruiting summer students and making valuable contacts to improve the US-Mexico collaboration.

<u>Equipment:</u> Equipment expenses are related to the installation of field instrumentation in the study region in northern Sonora. These equipment costs are essential to providing the students with the 'hands-on', international field experience as part of this educational program. Our proposed intent is that students from both US and Mexico collaborate on entire process of placing scientific instruments in field settings, including site selection, instrument set-up and deployment, sensor testing, data collection and analysis. The proposed field instrumentation is modest and is intended for instructional purposes in the field setting. The equipment will be purchased at New Mexico Tech and deployed in Sonora by the students during each field season. Five hydrometeorological stations will be deployed each year to measure the spatial and temporal variability in monsoon soil moisture and precipitation in the complex semiarid terrain. The students will get first hand experience in a field learning environment on hydrologic instrumentation, data collection and synthesis of observations with remote sensing and hydrological modeling. Each station will consist of the following equipment, which is similar in design to the existing network in Sonora: The following specifies the costs for each project year.

Measurements of Rainfall and Soil Moisture (5 stations)

	Component	*Cost*	*Quantity*	*Total Cost*
Tipping Bucket Raingauges	TE525WS-L	$365.00	5	$1,825.00
	Cable	$0.26/ft	50	$13.00
Soil Water Reflectometers	CS616-L	$150.00	5	$750.00
	Cable	$0.68/ft	210	$142.80
Data Logger	CR10X-2M	$895.00	5	$4,475.00
Enclosures	15873	$275.00	5	$1,375.00
	Mounts	$55.00	5	$275.00
Mounting Brackets	7840	$55.00	5	$275.00
Rechargeable Batteries	PS100	$210.00	5	$1,050.00
Solar Panels	MSX64R	$365.00	5	$1,825.00
Total				**$12,005.80**

All Prices Quoted from Campbell Scientific (August 2005)

<u>Indirect Costs:</u> Indirect costs are computed at a rate of 47.1% (2005-2006 Overhead rate for On-Campus activities) for the following: Salaries, Fringe benefits, Computer services, Publication costs, and Soil analysis. We utilize the rate of 30.7% (Off-campus rate) for Travel costs and Materials/Supplies. Following the budget instructions, we do not have overhead costs on Participant Costs. As our equipment expenses exceed $1,000 when purchased as integrated system, no Indirect Costs is applied.

Current and Pending Support

(See GPG Section II.C.2.h for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Enrique Vivoni**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Dynamic Hydrology and Ecosystem Modeling in Semi-Arid Complex Terrain using NASA EOS Observations from TERRA and AQUA**

Source of Support: **NASA**

Total Award Amount: $ **252,786** Total Award Period Covered: **09/01/04 - 08/31/07**

Location of Project: **Socorro, NM**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.50**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **High-Performance, Multiple-Resolution Modeling of Semi-Arid Hydrology at Regional Scales**

Source of Support: **NSF**

Total Award Amount: $ **128,346** Total Award Period Covered: **03/01/04 - 02/28/05**

Location of Project: **Socorro, NM**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.50**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **New Mexico EPSCoR Phase II**

Source of Support: **NSF EPSCoR Program**

Total Award Amount: $ **794,831** Total Award Period Covered: **03/01/05 - 02/28/07**

Location of Project: **Socorro, NM**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.50**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Interdisciplinary Science for the Environment: Research Experience for Undergraduates at New Mexico Tech.**

Source of Support: **NSF REU Programs**

Total Award Amount: $ **261,945** Total Award Period Covered: **01/01/05 - 12/31/07**

Location of Project: **Socorro, NM**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.00**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Linking Atmospheric Dynamics with Land-Surface Hydrology over Complex Terrain: A Multiple Resolution Modeling Approach**

Source of Support: **Army Research Office**

Total Award Amount: $ **148,474** Total Award Period Covered: **01/01/05 - 12/31/07**

Location of Project: **Socorro, NM**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Summ: **0.50**

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.C.2.h for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Enrique Vivoni**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Spatial Scaling of Soil Moisture and Evapotranspiration in the Upper R o Grande Basin**

Source of Support: **LANL-NMT Collaborative Research Program**

Total Award Amount: $ **49,961** Total Award Period Covered: **09/01/04 - 08/31/06**

Location of Project: **Socorro, NM**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.00**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Distributed Watershed Modeling for Water Resources Planning: A GIS-based System Dynamics Approach**

Source of Support: **Sandia University Research Program**

Total Award Amount: $ **80,000** Total Award Period Covered: **10/01/03 - 09/30/06**

Location of Project: **Socorro, NM**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.25**

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Catchment-Based Ensemble Modeling and Data Assimilation using Remote Sensing Observations for Diagnosis and Forecasting of Regional Hydrologic Processes**

Source of Support: **NASA Energy and Water Cycle**

Total Award Amount: $ **248,924** Total Award Period Covered: **09/01/05 - 08/31/08**

Location of Project: **Socorro, NM**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.50**

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Interactions between Hydrology and Biogeochemistry in Complex Semi-Arid Landscapes: Seasonal Fluxes, Storage and Pulses**

Source of Support: **NSF**

Total Award Amount: $ **444,671** Total Award Period Covered: **09/01/05 - 08/31/08**

Location of Project: **Socorro, NM**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.50**

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Mountain-Centric Observations and Modeling of Water Cycle Processes in Semiarid Regions**

Source of Support: **NSF Career Award**

Total Award Amount: $ **499,964** Total Award Period Covered: **06/01/06 - 05/30/11**

Location of Project: **Socorro, NM**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Summ: **0.50**

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

FACILITIES, EQUIPMENT & OTHER RESOURCES

FACILITIES: Identify the facilities to be used at each performance site listed and, as appropriate, indicate their capacities, pertinent capabilities, relative proximity, and extent of availability to the project. Use "Other" to describe the facilities at any other performance sites listed and at sites for field studies. USE additional pages as necessary.

Laboratory: **The Department of Earth and Environmental Science at NMT maintains a suite of laboratory facilities for hydrologic field studies, soil physical properties and isotopic and chemical analyses. In addition, the New Mexico Bureau of Geology and Mineral Resources (http://www.geoinfo.nmt.edu),**

Clinical:

Animal:

Computer: **The Department of Earth and Environmental Science (E&ES) at the New Mexico Tech (NMT) maintains a computing facility, which includes UNIX and PC workstations. Recent funding from the NSF EPSCoR program will significantly expand the available computing resources in the Department**

Office: **The Department of Earth and Environmental Science at NMT provides office and laboratory space for P.I. Vivoni and his research group (6 graduate students and co-PI Gebremichael in the Mineral Science and Engineering Complex (MSEC). Currently, the available space for the project includes**

Other: **The Department of Earth and Environmental Sciences at NMT has extensive hydrological field research instrumentation that can be deployed during field experiments as part of the proposed work. Field equipment including surveying instrumentation, differential global positioning system, electromagnetic induction probes, portable theta probes for moisture**

MAJOR EQUIPMENT: List the most important items available for this project and, as appropriate identifying the location and pertinent capabilities of each.

OTHER RESOURCES: Provide any information describing the other resources available for the project. Identify support services such as consultant, secretarial, machine shop, and electronics shop, and the extent to which they will be available for the project. Include an explanation of any consortium/contractual arrangements with other organizations.

LABORATORY FACILITIES (continued):

housed at NMT, has numerous facilities for soil and water testing, as well and mineral, organic and inorganic analysis. These facilities are available to faculty and staff in the E&ES Department. For the proposed work, we anticipate conducting soil characterization (e.g., texture analysis, hydraulic properties); vegetation above and below ground biomass measurements (e.g. biomass, leaf area index); and soil water analysis (e.g. gravimetric soil moisture, infiltration properties). These measurements will (a) provide baseline data describing the soil and vegetation properties in the study region, (b) provide critical data allowing for new process understanding, and (c) allow for model simulations applied to the semiarid monsoon watershed. Laboratory facilities have also been identified and are available at the Universidad de Sonora in Hermosillo, Mexico. In past collaboration with the Mexican investigators, we have used the soil analysis lab and the hydrologic field facilities at both Universidad de Sonora and IMADES, a state ecological and hydrological agency. We propose to conduct laboratory analysis of soil samples in Mexico for time-critical measurements (e.g. where the delay between sample collection and analysis should be short), while more extensive analysis with less time constraints will be performed in the Department of Earth and Environmental Science at New Mexico Tech. We already have obtained federal government permission for the import of materials, such as soil and vegetation, from Mexico into the United States, via US Agricultural Service.

COMPUTER FACILITIES (continued):

of Earth and Environmental Science. P.I. Vivoni will be purchasing a multi-node cluster for parallel computing applications, upgrading a server room for this purpose, and purchasing application and web servers for data distribution and delivery. Data visualization, analysis and processing software for both remote sensing imagery and geographical information system (GIS) data are also currently used and developed in-house to complement numerical models. The distributed hydrologic model (tRIBS) proposed to integrate monsoon observations was developed by the proponent while at MIT and simulates high-resolution water cycle processes in regions of complex terrain. Permission to use and continue the development high-performance model for research and educational purposes has been granted to NMT to the proponent. Access to remote sensing data sets has been obtained and specific software necessary for processing is available to the project. Co-PI Gebremichael has expertise in the analysis, processing and interpretation of the remote sensing imagery and computing software proposed for this project. For the field experiments, portable computing equipment is available (2 laptops) as part of the currently available resources in the Department of Earth and Environmental Science. Necessary software for these computers (GIS, remote sensing, data analysis) is available and currently loaded onto the laptop computers.

OFFICE FACILITIES (continued):

offices for the all personnel (P.I., co-I, graduate students, and undergraduate REU students each 140 square feet), a computer room facility for workstations (~ 240 square feet), a server room for a cluster computer and web servers (~ 180 square feet) and a field equipment staging and storage room (~ 270 square feet). In addition, the E&ES Department has a number of shared resources for faculty use including storage rooms, secretarial, graphics and web publishing support, system administration staff and equipment and facilities personnel. We have identified office facilities and working space at the Universidad de Sonora, Hermosillo, Sonora, Mexico, in the Physics Department, and at IMADES (Instituto del Medio Ambiente y Desarrollo Sustentable del Estado De Sonora), in the Hydrological Resources branch.

OTHER FACILITIES (continued):

measurements, double ring infiltrometers, soil augers and sampling equipment, portable weather stations and associated equipment for field campaigns. P.I. Vivoni is currently instrumenting several sites in New Mexico for hydrologic studies including a small catchment study in the Sevilleta National Wildlife Refuge, and a regional watershed study in the Valles Caldera National Preserve (e.g. rainfall gauges, meteorological observations, soil moisture sensors, runoff measurements) providing experience in instrument selection, installation and maintenance. Our Mexican collaborators have significantly more experience in instrument deployments as they currently manage three separate networks in Sonora, Sinaloa and Chihuahua, including: (1) The North American Monsoon Experiment (NAME) Event Rain Gauge Network (~100 sites), (2) The Soil Moisture Experiment (SMEX04) Soil Moisture and rain Gauge Network (~15 sites); and (3) The NAME Meteorological Flux Tower Network (~4 sites). The field equipment of most relevance for this propose project are the 15 SMEX04 soil moisture and rain gauge stations and 1 meteorological flux tower, as these are currently placed in the study region of interest. Both Universidad de Sonora and IMADES also have field supplies, portable sensors, ancillary equipment and expertise in hydrologic instrumentation that will be fully available to the proposed collaboration. Purchases of additional equipment for field hydrologic measurements are detailed in the project budget. As our intent is to provide students with the field-based experience of selecting an instrument site, deploying sensors, testing their performance and collecting relevant data sets, we consider the purchase of this equipment (10 stations over a two year period) as an essential part of the educational and cultural exchange. Additional proposal efforts are underway to supplement our available field equipment for deployment as part of the International Research Experience for Students.

UNIVERSIDAD DE SONORA
DEPARTAMENTO DE FÍSICA

EL SABER DE MIS HIJOS HARÁ MI GRANDEZA

Tels. (662) 259 21 44,
259 21 08
259 21 14
Fax (662) 259 21 09
dir@fisica.uson.mx

Apartado Postal 1626
Hermosillo, Sonora, México. C.P. 83000

September 9, 2005

Dr. Harold Stolberg
Program Officer
Office of International Science and Engineering (OISE)
National Science Foundation
4201 Wilson Boulevard
Arlington, Virginia 22230, USA

Dear Dr. Stolberg,

It is my great pleasure to write this letter of endorsement on behalf of the NSF proposal to the program *Developing Global Scientist and Engineers* by Dr. Enrique R. Vivoni (P.I.) of the New Mexico Institute of Mining and Technology (NMT). The title of the proposal "International: A US-Mexico Collaboration on Hydrological Studies of the North American Monsoon: A Synthesis of Field Experiments, Remote Sensing, and Hydrological Modeling" appropriately describes the intended international research and educational exchange between the United States and México.

We are extremely pleased that Dr. Vivoni and his collaborators at NMT have proposed this international collaborative project. In the summer of 2004, Dr. Vivoni's research group participated with researchers from the Universidad of Sonora (UniSon) and IMADES (Instituto del Medio Ambiente y Desarrollo Sustentable del Estado de Sonora) on a large field campaign in northern Sonora, México. As part of the field study, hydrological measurements were taken by undergraduate and graduate students from the U.S. and México to complement aircraft and satellite remote sensing imagery and a network of continuous hydrologic stations.

As a result of this successful field study, our two institutions are seeking methods to stimulate further international collaboration. First, we both value the learning experiences provided to students from the U.S. and México when performing joint research on the summer monsoon and its hydrological impact. Second, we consider that one of the best approaches for teaching hydrologic science is via 'hands-on' experimentation in a field setting. Finally, we recognize that our institutions have complementary expertise in hydrologic science (e.g. instrumentation, hydrological modeling) and can advance each other's research program through our interactions.

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259 21 14
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Due to our strong interest in this program, we are prepared to help Dr. Vivoni and his collaborators in obtaining the necessary logistical support (housing arrangements, field vehicles, supplies), in recruiting Mexican students for participation in the program, and in organizing and conducting the proposed research tasks during the two summer field seasons. To this end, we have already made available an extensive data set of precipitation and soil moisture measurements from an existing network of 15 sites in the study region. We also plan to interact with Dr. Vivoni throughout the year to properly prepare for the field studies, to process, analyze and interpret field data in the context of the remote sensing and hydrological modeling studies, and to disseminate research results via public presentations and publications.

Finally, we would like to mention that support for this international research experience will offer long-term benefits in the potential opportunities available for participating students in both the United States and México. It also serves to strengthen existing ties between the two programs which can ultimately lead the establishment of a long-term hydrologic research facility in a monsoon area characterized by complex topography.

If you have any additional questions or require further details, please do not hesitate to contact me at watts@fisica.uson.mx or 011 52 (662) 259 2108.

Sincerely,

Christopher J. Watts
Professor
Departamento de Física
Universidad de Sonora
Hermosillo, Sonora, México