SALSA-MEX: A Large Scale
Semi-Arid Land-Surface-Atmospheric Mountain Experiment

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ABSTRACT

Quantification of water and energy fluxes in mountain environments presents significant scientific challenges that must be addressed in a multidisciplinary manner due to the complex interaction of the ecosystem with hydrology and meteorology in areas with large topographic gradients. Conceptualization of a multidisciplinary, regional-scale, mountain experiment to be conducted in the near future is presented to address a subset of these challenges for a semiarid region. A site description with preliminary scientific objectives and a discussion of other important site characteristics for an investigation of this type are included. A primary goal of the presentation is to generate feedback from the portion of the scientific community interested in land-atmosphere interactions in mountain regions.

INTRODUCTION

Regional-scale experiments in several different biome types have been completed or are currently in early stages of execution or planning (HAPEX-MOBILY, FIFE, EFEDA, HAPEX-SAHEL, BOREAS, LAMBADA, TUNDRA Experiments). These experiments address the effects at the local scale of regional advection on land surface-atmosphere and hydrologic processes over relatively flat terrain. However, the applicability of the findings from these experiments in mountain regions must be tested. The strong influence of mountain topography (heights greater than 1 km) on local and regional atmospheric stratification is well known but subsequent impacts on surface water and energy balances requires further investigation. Increased understanding of the eco-hydro-atmospheric interactions of mountain areas is important as these regions cover more than 20% of the continents and have a marked influence on atmospheric circulation as well as the local water and energy cycles. Mountains areas are also often the primary source of available water in arid and semiarid regions of the world. Enhanced understanding of processes that are influenced by topography, such as precipitation, snowmelt, and recharge to groundwater aquifers, is essential for population sustainability in these regions. Therefore mountain experiments, such as *SALSA-MEX* (Semi-Arid Land-Surface-Atmospheric Mountain Experiment), must be formulated to measure and predict land-atmosphere interactions and to address the profound effects of topography on hydrological and meteorological processes over many scales.

In contrast to a number of past experiments which concentrated considerable resources in a temporally intensive (short term) field campaign, *SALSA-MEX* will be formulated to acquire data and carry out analysis over a long period of time (3 to 10 years with even longer-term monitoring in existing research watersheds). In a fashion analogous to the compilation of long term spaced-based data sets via the EOS Pathfinder Program, the *SALSA-MEX* study area may serve as a Terrestrial Pathfinder data set for smaller scale; process-based investigations and validation of land-surface-atmosphere interactions. This concept would entail long-term monitoring at a number of sites within the study area and the acquisition of remotely sensed aircraft or satellite data on a target of opportunity basis with limited ground support. In addition, retrospective compilation of existing historical, regional-scale, remotely sensed data sets would be undertaken. Limited intensive field campaigns also could be carried out if they significantly enhanced scientific understanding and were within budgetary constraints.

SITE DESCRIPTION

The semiarid mountainous region of the San Pedro basin, straddling the U.S.-Mexico border in southeastern Arizona and northern Sonora, Mexico, offers an exceptional location to conduct a regional-scale experiment to challenge and expand the current status of scientific knowledge in mesoscale hydrometeorology and land-atmosphere interactions. The basin encompasses an area of roughly 12,000 km^2 with the headwaters near Cananea, Sonora, and the outlet near Winkelman, Arizona. The "upper San Pedro" portion of the basin (Figure 1; Note: A full color image of this figure is available on the IGARSS'94 CD-Rom files) is approximately 50 km east-west and 150 km north-south (drainage area of 7600 km^2 at the USGS gage near Reddington, AZ, with 1800 km^2 in Mexico). Elevation ranges from roughly 900 to 2900 m in the upper basin, providing exceptional ecological and climatic diversity in a relatively compact area. The major biome types represented in the basin are: Chihuahuan Desert, Semi-Arid Grasslands, Oak Savannah Chaparral, Pinyon-Juniper, and Coniferous Forest; all of which are traversed in a horizontal distance as short as 20 km from the main drainage stem of the San Pedro to the top of the Huachuca Mountains (Figure 1).

In addition to significant heterogeneity across biome types, the San Pedro is characterized by a high degree of heterogeneity within a biome type over a wide range of spatial scales. At the large scale (100-1000 km^2), different land use practices in the U.S. and Mexico give rise to land-surface changes that are readily apparent in satellite multi-spectral images (Bryant et al., 1990). These differences provide an opportunity to evaluate the effects of anthropogenic changes on land surface parameters that control various hydrologic processes, and surface-atmosphere interactions. Cross border analysis can be further facilitated by examination of the adjacent upper Santa Cruz Basin (213 km^2 at Lochiel, AZ - see Figure 1), which in contrast to the San Pedro, flows south from the United States into Mexico. This headwater basin is relatively undisturbed due to its isolated location. Another large scale heterogeneity exists in the relatively linear, narrow riparian area of the San Pedro River (50-300m wide). This line source of water, sustained during many times of the year by the regional groundwater aquifer, and the associated concentration of lush vegetation are surrounded by sparse desert brush. Such riparian systems represent an important component of the water and energy flux interactions of semiarid regions worldwide. At the small scale (1-10 km^2), heterogeneity exists in the basin in the form of numerous small irrigated fields and tailings ponds of the Cananea copper mines in Mexico. Significant micro-scale (1-10 m^2) variability exists in the desert brush complexes where scattered vegetation with incomplete canopy cover is typical. In these complexes, surface temperatures of vegetation and dry bare soil differ by more than 25^o K. during the hot, dry summer months. This diverse range of heterogeneity in a relatively compact area will facilitate the study of the impacts of this variability on bio-hydro-atmospheric interactions.

The summer monsoon weather of the region also produces substantial heterogeneity of spatial, and temporal, wet-dry patterns within the basin. The majority of annual precipitation (~ 30 cm in the 1200-1700 m elevation range) and virtually all infiltration-excess runoff occurs during the monsoon season from high intensity air-mass convective thunderstorms, many of which are of limited spatial extent (5-10 km diameter). An increase in annual precipitation by a factor of three or more at the high elevations within the basin (> 2800 m) is common. Sparse vegetation in the lower desert areas

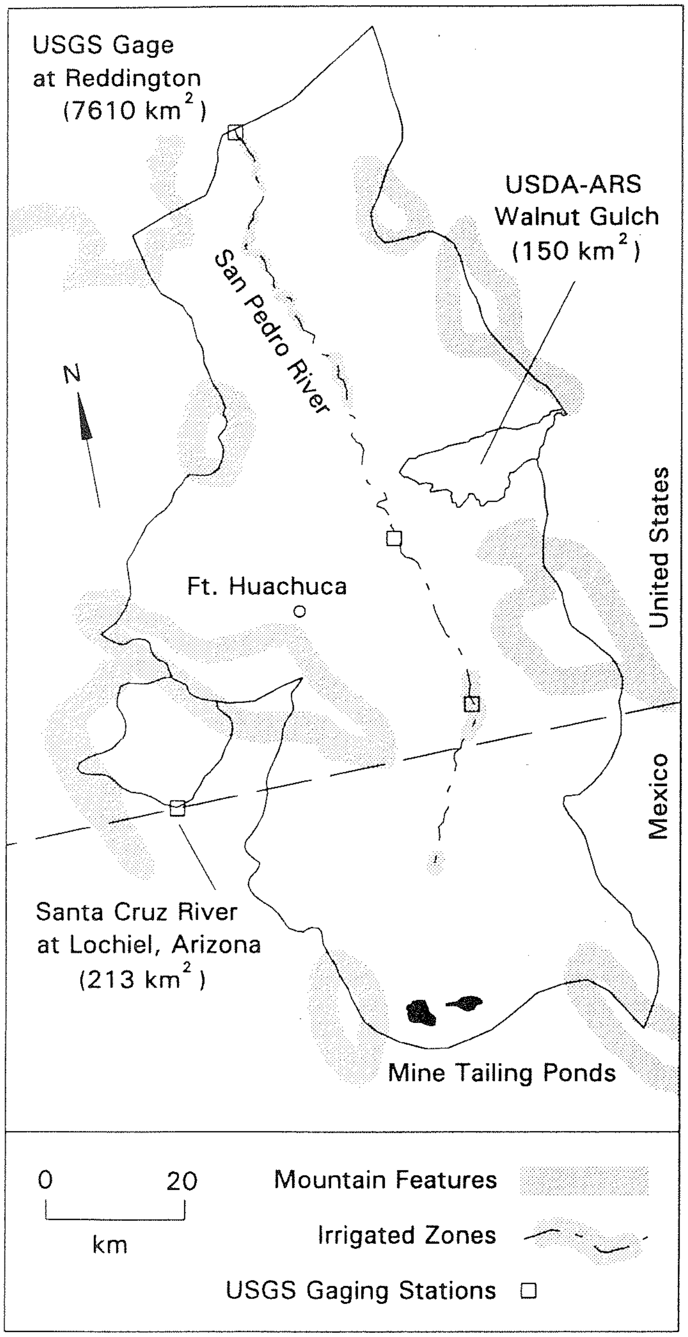

Figure 1. Upper San Pedro Basin

enables ready identification of moist areas with microwave remote sensing (Kustas et al., 1991). Frequent thunderstorms during the monsoon, coupled with very high potential evapotranspiration, often provides the ability to observe frequent wetting and drying cycles in a short period of time. Net transport of moisture from wet to dry areas and the effects of wetted storm footprints on boundary layer development are also evident in this region. The site also provides significant seasonal contrasts between the monsoon season (July-Sept., 65% of annual rainfall) and the very dry pre-monsoon season (April-June, 6% of annual rainfall) which exhibits little or no rainfall and senescent vegetation outside riparian and irrigated areas. Less frequent winter rainfall (Oct-March, 29% of annual rainfall) from frontal systems typically produces lower intensity rainfall over larger areas and significant snowfall at high elevations.

The topographically induced steep spatial gradients in biome types, the heterogeneities in land use, management and the associated spatial variations in fluxes of moisture and energy in the Upper San Pedro provide a unique opportunity for investigating bio-hydro-atmospheric interactions in a relatively compact area with high topographic relief.

EXPERIMENTAL OBJECTIVES

The following initial experimental research objectives are proposed for *SALSA-MEX*.

1. Quantify hydrologic fluxes and identify the dominant hydrologic processes as a function of time-space scales in regions with high topographic relief with particular emphasis on: a) surface-ground water interactions in the San Pedro riparian area, and b) the role of near surface soil moisture in infiltration and runoff generation.

2. Evaluate evaporation and transpiration and their relationships to the water balance in topographically rough terrain over a range of canopy-soil-understory conditions represented by the biome types in the San Pedro basin.

3. Assess the utility of remotely sensed data for regional land-surface characterization and for incorporation into hydrologic and energy balance models utilized for objectives 1 and 2.

4. Test the ability of mesoscale meteorologic models to realistically simulate a broad range of land-atmosphere interactions in heterogeneous domains with significant topographic relief.

5. Determine the spatial and temporal patterns of carbon uptake and release by the vegetation-soil continuum. In addition to seasonal trends, the effects of water availability, particularly from precipitation, on these fluxes will be evaluated.

6. As part of the above objectives, observe and model state variables and fluxes over a range of scales to formulate scaling relationships for aggregation and disaggregation.

Just as the Upper San Pedro basin provides a wide range of ecological diversity, it also is an exemplary site in terms of providing hydrologic process diversity to address objective (1). Perennial flow sustained by the regional groundwater aquifer exists in the riparian area. This flow is augmented by runoff generated primarily from convective summer rainfall via saturation excess within the riparian area and by infiltration excess from more distant semiarid upland areas where runoff must traverse ephemeral channels. Thus, with proper subwatershed selection, perennial-ephemeral stream systems can be studied in isolation or in combination. In high elevation basin areas, snowfall can be significant (snowpacks over 600 cm occurred in the winters of 1992 and 1993). The snowpack sustains flow in high elevation streams well into early summer, as well as providing water for mountain front groundwater recharge.

In regard to objective (2), methods for estimation of evapotranspiration and other energy balance components for homogeneous targets, such as mature agricultural crops or bare soil, are relatively well-understood and robust. The challenge in this experiment will be to estimate a regional energy balance for a heterogenous landscape with diverse and sometimes sparse vegetation, and variable topography. A related objective is to link the results of energy balance evaluation with attempts to evaluate regional water balance. Considering that potential evaporative water is often many times greater than annual rainfall and that actual evaporative water loss is often the dominant component of the water balance in semiarid regions, this objective is both reasonable and imperative.

Remote sensing provides the only feasible means of implementing objectives (1) and (2) at regional scales in such heterogeneous landscapes. The implementation of objective (3) will require the assessment of remotely sensed data by two methodologies. First, the *SALSA-MEX* experiment will provide the opportunity to test the utility of remote sensing for characterization of such land surface parameters as a) soil type and moisture content, b) vegetation type, cover and density, and c) surface and aerodynamic roughness. Secondly, with the water and energy flux research conducted in Objectives (1) and (2), it will be possible to determine the symbiotic links between remote sensing and modeling that will advance the application of both mediums at the regional scale. The site of the *SALSA-MEX* experiment is most conducive to this research due to the generally clear sky conditions, the monsoon storm patterns (in time and space), and the distinct, elevation-related vegetation communities.

A state of the science mesoscale model (Avissar and Pielke, 1989) may prove to be a powerful tool to study land-atmosphere interactions at the San Pedro basin scale to address objective (4). Because of the difficulties in observing atmospheric phenomena at the spatial and temporal resolution required to identify the various components of the complex land-atmosphere interactions found in such domains (i.e. mountain-valley flow, sea-breeze like circulations induced by vegetation contrast) the application of the mesoscale model will be an integral part of the overall multidisciplinary experimental data collection. As such, we propose preliminary site analyses using the mesoscale meteorological model initialized with available topography, approximate land-surface characteristics, and radiosondes relevant to the San Pedro. An immediate application of this type of model sensitivity analysis will greatly enhance field experimental design by providing initial indications of where and when we can expect to find predominantly forced mesoscale land-atmosphere interactions and thus aid in location of data collection instrumentation. Furthermore, the data collected over the course of the investigation will then be used to evaluate the ability of the model to simulate land-atmosphere interactions at the mesoscale. This is a crucial task since these models are expected to be used widely in even larger scale situations in diverse terrain in the context of future GEWEX and BAHC efforts.

Examination of the carbon cycle in semiarid regions warrants further study and comparison to other carbon cycle studies elsewhere in the world due to the relative uncertainty of carbon cycling in these regions. Little is known of the contributions of vegetation and soils in semiarid areas to the global carbon balance. Although semiarid plant density is low, the global area of similar semiarid biome complexes is large. In addition, inadequate understanding exists of the magnitudes and duration of carbon fluxes from vegetation and soils following convective precipitation events (via increased water availability and through water intrusion into soils). For objective (5) carbon fluxes to or from the vegetation-soil continuum will be determined by a variety of means ranging from eddy correlation flux techniques to chambers and with models using soil gas concentration profiles. To apply these techniques over an ecologically and topographically diverse region, point and aircraft measurements would be combined with modeling techniques. In addition, methodology to delineate and characterize the various biomes for consistent land-atmosphere model parameterizations from both ground and remotely based methods would be an important component of the investigation.

Major scientific challenges include the development and testing of methods to disaggregate large area Global Climate Model (GCM) output to subgrid scales, and the inverse methods to aggregate small area land-atmosphere feedback interactions to GCM's, especially in mountainous regions. Recent results from the FIFE experiment (Sellers and Hall, 1992) indicate the existence of scale invariance properties for aggregation of a surface energy balance model for the relatively flat, uniform FIFE site. Development and testing of methodologies for both aggregation and disaggregation under much more severe heterogeneity and elevation gradients of mountainous terrain would be a critical aspect of the *SALSA-MEX* experiment.

OTHER IMPORTANT SITE ADVANTAGES AND FACTORS

The USDA-ARS Walnut Gulch Experimental Watershed (150 km^2, see Figures 1 and 2), operated by the Southwest Watershed Research Center (SWRC), is a tributary to the Upper San Pedro. This watershed contains examples of the Chihuahuan Desert and Semi-Arid Grasslands biomes and offers an unparalleled historical database and data collection instrumentation for semiarid rainfall and runoff analysis (Renard et al., 1993). Within this watershed, an operational network of 85 recording raingages, and 23 runoff flumes (subwatersheds from 0.004 to 150 km^2) exists. The watershed is equipped with fixed cross-section, critical depth, runoff measuring flumes specifically designed to accurately measure sediment laden runoff in ephemeral semiarid channels. The majority of the rainfall-runoff network was completed in 1966. In addition, near continuous energy flux measurements, vegetation production and characterization, and soil moisture monitoring in profile at two watershed locations has been carried out since 1990. Few, if any other,

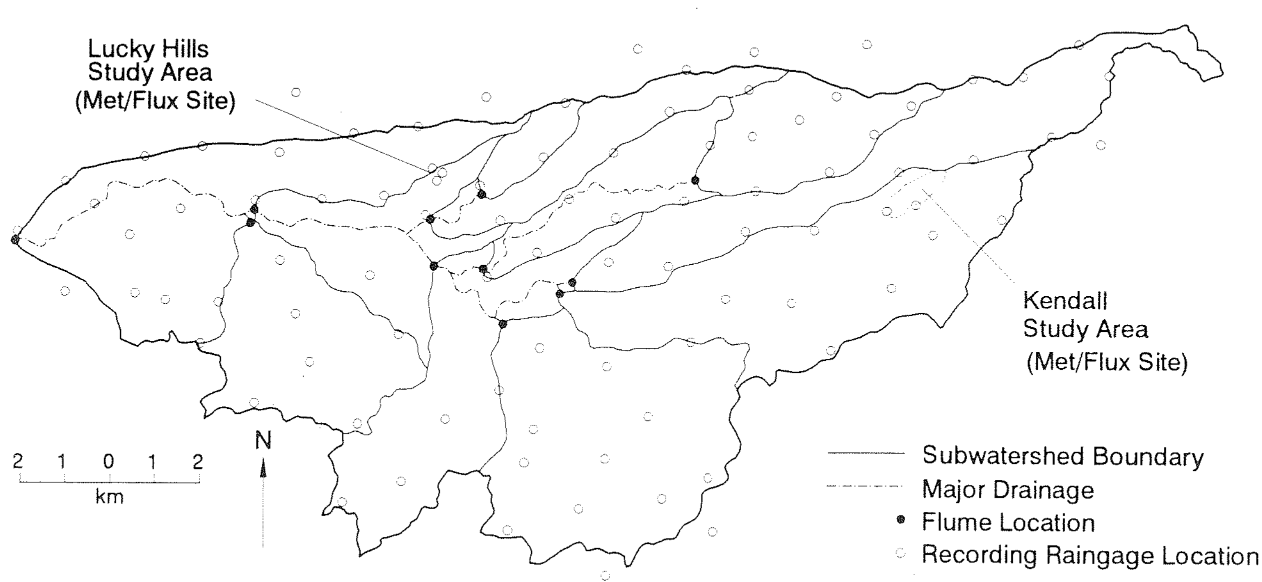

Figure 2. USDA-ARS Walnut Gulch Experimental Watershed

semiarid watersheds in the world exist with comparable hydrologic instrumentation in time and space.

The historical and research infrastructure available in Walnut Gulch was the foundation for a NASA/ARS sponsored multidisciplinary ground, aircraft and satellite campaign in the north central portion of Walnut Gulch in 1990 (MONSOON '90, Kustas et al., 1991). This experiment was quite successful in utilization of remote sensing for modeling the water and energy balance at the subbasin scale. A series of papers pertaining to this experiment for a special section of *Water Resources Research* will be available in May 1994 (Kustas and Goodrich, 1994). This experiment initiated further acquisition of ground, aircraft, and satellite remotely sensed data with ground support at a greater temporal and spatial resolution in 1991, and 1992 (Walnut Gulch '92 campaign; Moran et al., 1993). Much of this imagery extends beyond Walnut Gulch and covers between 60 and 90 percent of the Upper San Pedro adding to historical satellite coverage of the area (7 TM, 3 SPOT, and 5 ERS-1 scenes in 1992 alone). In addition, Walnut Gulch is also one of the focus areas for a NASA/EOS Interdisciplinary Study effort by Kerr and Sorooshian (1990).

Cross border research will be facilitated by ongoing cooperation between the USDA-ARS SWRC and Mexican research investigators. The Ft. Huachuca Meteorological Team (Figure 1) also operates ongoing data collection in the Upper San Pedro, including daily radiosonde launches and operation of 16 automated meteorological sites (10 stations since 1987) that collect rainfall, wind speed, relative humidity, pressure, solar radiation and soil temperature at locations ranging in elevation from 1200 to 2400 m. This team is also involved in the regional meteorological Southwest Area Monsoon Project (SWAMP). Both the Jet Propulsion Laboratory (JPL) and the French organization ORSTOM are actively pursuing research planning in anticipation of the *SALSA-MEX* experiment.

Other favorable factors of the San Pedro site include coverage of the basin by National Weather Service doppler radar (scheduled for early 1995) and the potential to acquire TRMM (Tropical Rainfall Measuring Mission) satellite data. In addition, due to the extraordinary ecological diversity present in the San Pedro riparian area, it was selected as one of the "12 Great Places of the Western Hemisphere" by The Nature Conservancy and has been designated as the first Riparian National Conservation Area by the U.S. Congress (administered by the USDI-BLM).

CONCLUSIONS

Significant scientific challenges exist in understanding hydrologic, ecologic and atmospheric interactions in mountainous regions. Meeting these challenges is important as these regions cover more than 20% of the continents and they have a significant influence on atmospheric circulation and the local water and energy cycles. In addition, numerous mountains regions are the primary source of water resources to sustain food production and human populations. The great diversity and complexity of the land-atmosphere interface induced by steep topographic gradients necessitates multidisciplinary experimentation to meet the scientific challenges. Conceptualization for a long-term multidisciplinary investigation (*SALSA-MEX*) in a semiarid mountain region spanning the Mexico-United States border is presented with a preliminary set of research objectives to generate feedback from the scientific community. The site contains significant heterogeneities in land cover and use at a variety of scales and provides exceptional ecological and climatic diversity in a relatively compact area. In addition, cross-border land use differences may facilitate the study of anthropogenic impacts on local climate. A considerable history of hydrologic and remote sensing research and substantial instrumentation infrastructure also exists within portions of the study basin. The study basin and the *SALSA-MEX* investigation offer a realistic avenue to begin to meet the challenges associated with understanding and quantifying the hydrologic, ecologic and atmospheric interactions in a semiarid mountain region.

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