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Some scientific results from the SALSA programme

ABDEL GHANI CHEHBOUNI*, **CHRIS J. WATTS**
IRD/IMADES, Reyes & Aguascalientes, Hermosillo, Sonora 83190, Mexico
e-mail: ghani.chehbouni@cesbio.cnes.fr

DAVID C. GOODRICH, SUSAN MORAN
USDA-ARS, Tucson, Arizona 85719, USA

YANN KERR, GERARD DEDIEU
CESBIO (CNES-CNRS-IRD-UPS), F-31401 Toulouse cedex 4, France

WILLIAM G. KEPNER
US EPA, Office of Research and Development, Las Vegas, Nevada, USA

WILLIAM J. SHUTTLEWORTH & SOROOSH SOROOSHIAN
University of Arizona, Department of Hydrology and Water Resources, Tucson, Arizona 85821, USA

Abstract The objective of this paper is to present an overview of preliminary results obtained during the SemiArid Land–Surface–Atmosphere (SALSA) programme. It highlights some of the findings in the fields of remote sensing and surface–atmosphere interaction.
Key words hydrology; land degradation; LAS (large aperture scintillometer); moisture; semiarid; SALSA; SVAT; temperature; vegetation

INTRODUCTION

Regions classified as semiarid or arid are under increasing pressure for development and many landscapes have been permanently altered by activities that have modified the water cycle, such as rapid urbanization, groundwater mining and overgrazing. In this context, a consortium of universities, research laboratories and government agencies from the United States, Mexico and France designed the SemiArid Land–Surface–Atmosphere (SALSA) programme. The primary goal for SALSA is: *to understand, model and predict the consequences of natural and human-induced change on the basin-wide water balance and ecological diversity of semiarid regions at event, seasonal, interannual, and decadal time scales.* The programme focuses on the binational San Pedro River basin, which originates in Sonora, Mexico and flows north into Arizona, USA (Fig. 1). However, since the ecological, hydrological, and meteorological processes involved are not specific to the San Pedro basin, the results obtained and the expertise gained during SALSA can also be applied to other semiarid regions of the world. The objective of this paper is to provide an overview of some of the scientific results obtained in the course of the first three years of the SALSA programme. More details are available in Goodrich *et al.* (2000).

**Correspondence address*: CESBIO18, av. E. Belin, F-31401 Toulouse cedex 4, France

VEGETATION DYNAMIC AND SURFACE ATMOSPHERE INTERACTION

Changes in vegetation cover in the San Pedro basin have been studied (Kepner *et al.*, 2000) using the North American Landscape Characterization (NALC) project database that incorporates triplicate Landsat Multi-Spectral Scanner (MSS) imagery from the early 1970s, mid 1980s, and the 1990s. The changes in land cover observed for the study period indicate that extensive, highly connected grassland and desert scrub areas are the ecosystems most vulnerable to encroachment of mesquite woodland. Grasslands and desert scrubs not only decreased in areal extent but also became more fragmented. In contrast, the mesquite woodland patches increased in size, number and connectivity.

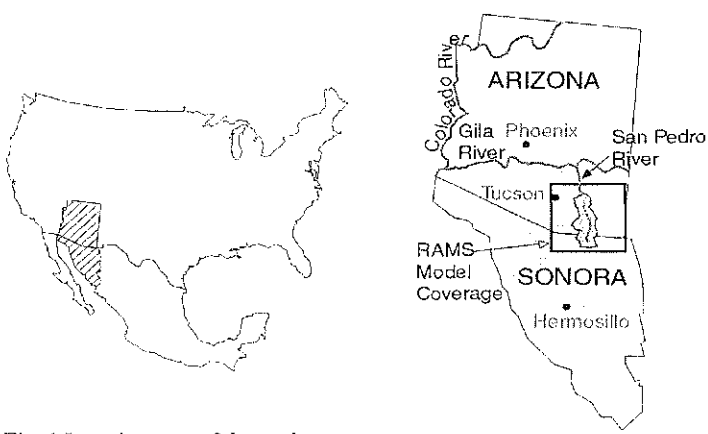

Fig. 1 Location map of the study area.

In general, winter precipitation controls woody plant growth by recharging deep soil moisture, while summer rains drive the annual grass production. This suggests that grasslands rely primarily on the summer precipitation while mesquite access moisture from deeper soil. This behaviour has been confirmed by studies on the flood plain near Lewis Springs (Scott *et al.*, 2000). However, another study, which was carried out over an extensive mesquite site at the top of an alluvial terrace in the Mexican part of the basin, revealed somewhat different behaviour. Over this site, the measured seasonal pattern of latent heat flux followed closely that of the surface soil moisture while at greater depth soil moisture content remained almost unchanged throughout the rainy season. Therefore it was concluded that the mesquite mostly used surface (rainfall) water, which implies that it is directly competing for water with the grass. As a result of these observations, a simple Soil Vegetation Atmosphere Transfer (SVAT) model was developed for the mesquite. This model is a one-layer model where the difference between aerodynamic and radiative surface temperature is taken into account and the bulk surface resistance is parameterized in terms of surface soil moisture. The results at 12:00 h local time for the period from 8 August to 7 October 1998 are shown in Fig. 2. It can be seen that the agreement is very good. Other SVAT models ranging from very simple to more complex, have been employed over different biomes in the San Pedro Basin. The results indicate that complex surface schemes might not be needed to accurately describe surface fluxes in semiarid regions.

The estimation of spatially distributed/averaged surface fluxes has been addressed in the course of SALSA from both measurement and modelling perspectives. A volume-imaging Raman Lidar has been used to derive maps of latent heat flux (Cooper *et al.*, 2000). A large aperture scintillometer (LAS) has been extensively used to estimate area-averaged sensible heat flux during the 1997, 1998 and 1999 seasons. LAS-based values of area-averaged sensible heat flux were compared to observations over different surfaces with encouraging results (root mean squared error (RMSE) of about 22 W m^{-2}). Additionally the LAS data has been used to validate estimates of area-averaged sensible heat flux derived using a physically based aggregation scheme described by Chehbouni *et al.* (2000). Figure 3 presents a comparison between LAS and model based fluxes.

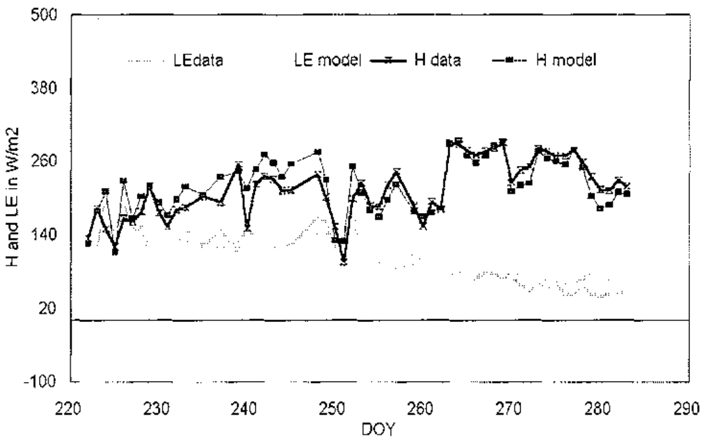

Fig. 2 Comparison between measured and simulated mid-day sensible and latent heat flux (Mesquite 1988).

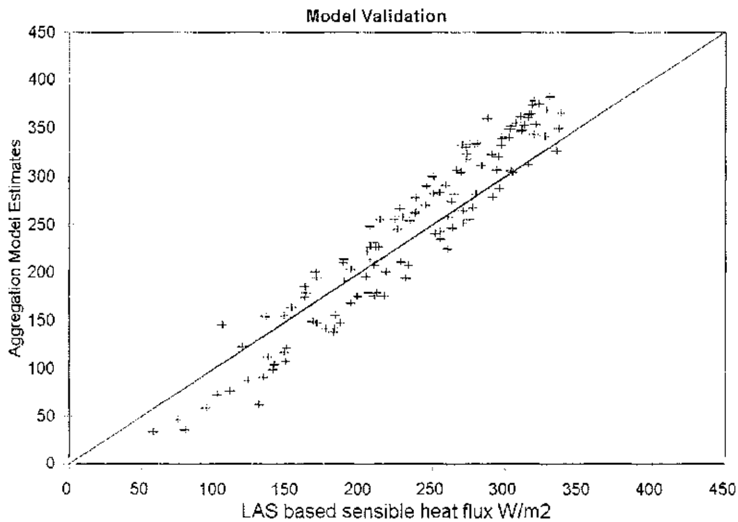

Fig. 3 Cross-plot of LAS-based and aggregation-scheme based estimates of area-averaged sensible heat flux.

REMOTE SENSING INVESTIGATIONS

The San Pedro basin has been selected as a validation site for several remote sensing programmes (NASA Earth Observing System ASTER and MODIS, ERS2/ATSR2, Landsat 7, ATLAS, SPOT4/VEGETATION). A wide range of remote sensing techniques were associated with SALSA investigations and only a few will be mentioned here.

Monitoring surface characteristics and inversion of biophysical parameters

Moran *et al.* (2000) used an approach that combines C-band ERS2-SAR and Landsat TM data to map surface soil moisture during the 1997 season. They used the difference between dry and wet season SAR backscatter to normalize roughness effects, and utilized surface reflectance from TM images to account for changes in vegetation density. They found that the combined SAR/TM approach greatly improves estimates of the spatial and temporal variation of surface soil moisture over semiarid rangeland. However, they also reported that the overall sensitivity of the SAR backscatter coefficient to soil moisture is limited and an accurate estimate of green leaf area index (GLAI) is required.

Cayrol *et al.* (2000) compared reflectance data in the red, near infrared (NIR), and short-wave infrared (SWIR) bands measured by the VEGETATION sensor onboard SPOT-4, after being corrected for atmospheric and directional effects, to observed biomass and LAI during the 1998 season. The results showed that the sensitivity of the SWIR and red bands to the amount of vegetation were rather similar. Since the SWIR band is less sensitive to atmospheric perturbations than the red, a combination of three bands may be more effective in characterizing vegetation status and dynamics than the usual two-band approach.

Remotely sensed surface temperature

The use of remotely sensed surface temperature for estimating surface fluxes has been much investigated. It has been shown here that radiative surface temperature can be successfully used to estimate instantaneous values of sensible heat flux if the difference between radiative and aerodynamic surface temperature is taken into account, and there are several empirical techniques that may be used. Watts *et al.* (2000) used AVHRR-based surface temperature in conjunction with the β approach (Chehbouni *et al.*, 1997) to derive sensible heat flux over a grassland site in Mexico. Estimates of sensible heat flux compared very well with the eddy correlation and scintillometer measurements. Chehbouni *et al.* (2000) extended the β approach to a surface composed of two adjacent patches (mesquite and grass). They concluded that a relationship between model and observational variables (radiative and aerodynamic surface temperature), that was developed and calibrated at a patch scale, should not be used for an application at a larger scale by simply scaling the parameters involved in its formulation. Therefore, future research should be directed towards building robust relationships between model and observational variables directly at the large scale.

In the framework of the ATSR investigation, the effect of view angle on radiative surface temperature has been studied. The relative contribution of soil and vegetation to radiative surface temperature measurements varies with the view angle and so the difference between nadir and off-nadir surface temperature increases with increasing contrast between soil and vegetation. Experimental data collected over a sparse grassland site in Mexico show differences in radiative surface temperature between nadir (0°) and off-nadir (45°) measurements of up to 5°C. The data also showed that, under constant vegetation conditions, this difference is well correlated with surface soil moisture. However, there is also a dependence on vegetation status and type. Current research is being directed towards quantifying this dependence on vegetation status using remotely sensed data in the visible, NIR and SWIR bands. Additionally, the impact of pixel heterogeneity on directional behaviour in the thermal infrared region needs to be investigated.

Finally it should be mentioned that, due to the presence of cloud, satellite data alone are not adequate for closely monitoring some important surface processes, such as turbulent fluxes. One solution is to combine the satellite data with surface process models. These models can provide continuous information about surface processes and should be able to incorporate satellite data when it is available. The approach here is to minimize the difference between a given set of variables measured by satellite and those simulated by the process model coupled to a radiative transfer model. This is accomplished by tuning some of the unknown (constant) parameters of the surface process model. This approach has been successfully tested during SALSA and elsewhere (Nouvellon *et al.*, 1998). However, this approach assumes that radiative transfer models are perfect which is far from being true. Research is currently underway for simultaneous four-dimensional assimilation of several streams of remotely sensed data, such those from NASA-EOS platforms, into a coupled land surface atmosphere model.

CONCLUSION

The SALSA programme has successfully employed a unique model of research collaboration and use of shared resources to accomplish a substantial amount of research. Our understanding of the processes controlling the hydrological cycle, the ecological diversity and the surface–atmosphere interactions in a semiarid basin has certainly been improved, but additional research questions have arisen and other unsolved issues have been identified. Last but not least, it is important to emphasize that hydrologists, atmospheric scientists, eco-physiologists and remote sensing specialists who were involved in the data collection effort, are now faced with the challenge of implementing integrated basin-scale hydrological, ecological and atmospheric models. Indeed, the building of such integrated models is crucial for answering the programme's primary question.

Future work should be directed toward developing, implementing and testing a near-real-time model-driven data assimilation system capable of ingesting EOS data.

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