3.5 IMPROVED WATER DEMAND FORECASTING FOR WATER RESOURCES MANAGERS

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1. INTRODUCTION

Water resources in the Middle Rio Grande are increasingly in demand for such diverse uses as agriculture, municipal and industrial, maintaining healthy habitats for endangered species, and recreation. Because of competing water demands, there is a critical need for rapid improvement in calculating and forecasting daily agricultural and riparian water consumptive use. Evapotranspiration (ET) from irrigated crops and riparian vegetation, and evaporation from open-water surfaces are the primary consumers of the surface water in the basin. To address these problems, the U.S. Bureau of Reclamation (Reclamation) has developed and implemented the Agricultural Water Resources Decision Support (AWARDS) system, and automated information system to assist water managers and users by providing easy access to rainfall and daily crop water use estimates. Building on the AWARDS system, Reclamation has been developing an Evapotranspiration Toolbox (ET Toolbox) which estimates the daily surface water use requirements at a resolution useful for implementation in the Upper Rio Grande Water Operations Model (URGWOM).

At NASA Goddard Space Flight Center, a Land Data Assimilation System (LDAS) has been developed to integrate and assimilate various observation datasets into comprehensive, distributed land surface models (LSMs) in near-realtime or retrospectively. Recently, the LDAS has been enhanced with the incorporation of the Land Information System (LIS) modeling framework where the LSMs can be run at moderately and very high temporal and spatial resolutions on parallel computing machines (Peters-Lidard *et al*., 2004). The main goal of this study is to incorporate remotely sensed and in-situ observation data into LDAS to improve the parameterization of its LSMs and ultimately improve the estimates of evapotranspiration. Those improved values, when used within the AWARDS and ET Toolbox systems, are expected to improve water management decision making. This project is currently being conducted for the Middle Rio Grande River Basin area.

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2. BACKGROUND OF AWARDS ET TOOLBOX

To help improve the efficiency of water management and irrigation scheduling, Reclamation created the Agricultural Water Resources Decision Support (AWARDS) system. Through its Evapotranspiration (ET) Toolbox interface, the AWARDS system provides guidance to local farmers on when and where to deliver water to the crops. The ET Toolbox estimates water usage (evapotranspiration and open water evaporation) on a grid cell basis. Based on the ET daily values, vegetation and open water Daily Consumptive Use (DCU) is generated for each hydrological rainfall analysis project (HRAP, areas of approximately 4 km x 4 km) grid cell following equation (1),

$$(1)\quad DCU_{total} = \frac{\left[\sum_{k=1}^{N} ET_k \frac{acres_k}{12}\right] - rain}{1.98347}$$

with $acres_k$ being the acreage of the surface type k of a given grid cell, and $rain$ the NEXRAD estimated daily accumulated rainfall. DCU_{total} is a flow in units of $[ft^3 \cdot s^{-1}]$. These estimates are monitored on a daily basis for the different irrigation district divisions (Fig. 1). Currently, the ET Toolbox relies on a modified Penman equation to obtain the ET estimates for each crop.

Within the ET Toolbox, and for each crop, the evapotranspiration, ET , is calculated as,

$$(2)\quad ET = K_c ET_0$$

where $ET_0\,[mm \cdot day^{-1}]$ is the reference evapotranspiration and is calculated with a modified Penman equation. Crop coefficients K_c are used in calculating ET_0 and are obtained using either the *Month* method (based on monthly coefficients) or the

** Note: Dr. David Matthews is currently retired from the U.S. Bureau of Reclamation

Growing Degree Days (GDD) method. In the former case, daily coefficients are interpolated from monthly values. In the latter case, crop coefficients, for vegetation or open water, are dependent on temperature, producing a lower coefficient for cooler

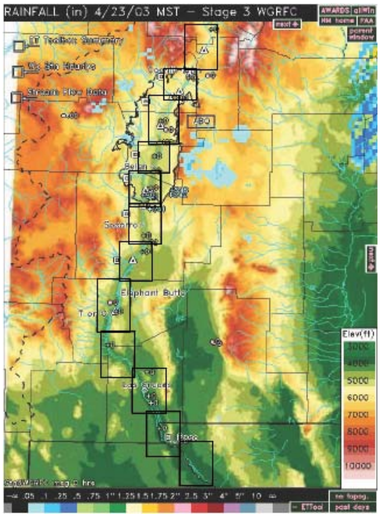


Figure 1. ET Toolbox NEXRAD rainfall map identifying the irrigation district divisions (black boxes) along the Rio Grande River.

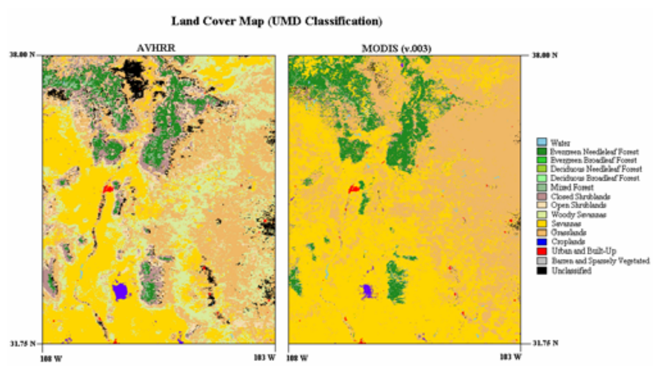
temperatures and higher coefficient for warmer temperatures (Brower, 2004). These methods are tested in the state of New Mexico (Fig. 2), with a particular emphasis given to the Middle Rio Grande area, extending from the Cochiti Reservoir to Elephant Butte Dam.

3. LAND DATA ASSIMILATION SYSTEM (LDAS)

The uncoupled North American Land Data Assimilation System (NLDAS) project is characterized as a real-time, hourly, distributed, uncoupled, land-surface simulation system on different domains. NLDAS simulations use the LIS modeling framework and are run at a 1 km domain with a 900 second timestep. The suite of different LSMs in NLDAS and LIS are used in the comparisons and testing with AWARDS ET Toolbox. Two of the LSMs being used for the initial studies and validation include the Noah LSM, the main land surface scheme for the National Oceanic and Atmospheric Administration (NOAA) and other agencies, and the Community Land Model, version 2.0 (CLM2.0), mainly developed at the National Center for Atmospheric Research (NCAR) (Bonan et al. 2002; Dai et al., 2003). The two LSMs create output fields that are used in energy and water balance calculations. NLDAS models, forcing and parameters files have been setup on common geographic or UTM projections at various resolutions.

The hourly NLDAS surface forcing files include several fields from both observed and model-derived products which are placed on a common eighth degree domain. The model data used for surface forcing data come from the 40-km, NCEP **E**ta-based 4-D **D**ata **A**ssimilation **S**ystem (EDAS) analyses. The EDAS surface fields are also interpolated to the LDAS grid by accounting for terrain-height differences between the EDAS and finer resolution LDAS grid. This is accomplished using a standard lapse rate to adjust the 2-m air temperature, specific humidity, downward longwave radiation and surface pressure variables. The LDAS precipitation field merges "Stage II" WSR-88D, Climate Prediction Center (CPC) gage precipitation, and EDAS total precipitation in areas that lack the radar and gage data. For the observed incoming shortwave radiation, NLDAS uses NESDIS (National Environmental Satellite, Data, and Information Service) GOES satellite-retrieval of hourly 0.5 degree surface solar radiation (including photosynthetically active radiation (PAR) and diffuse), using the retrieval algorithm of Pinker et al. (2003).

A variety of satellite datasets are used to help parameterize and drive the models, including data from NOAA's Advanced Very High Resolution Radiometer (AVHRR) and NASA's Terra and Aqua's MOderate Resolution Imaging Spectroradiometer (MODIS) instrument. In this study, we parameterize the LSMs with satellite derived land cover and leaf area index (LAI) products from both sensors, in a twin experiment that attempts to assess the sensitivity of the different models to these parameters. In addition to those two variables, different AVHRR and MODIS products are being evaluated and tested in the LSMs of NLDAS to better understand how and where they can improve the models' energy and water budget variables. The LSMs are run currently at 0.01 degree (~1 km) resolution for the New Mexico region, focusing on the Upper and Middle Rio Grande Basins and the Pecos River Basin.



(a) (b)

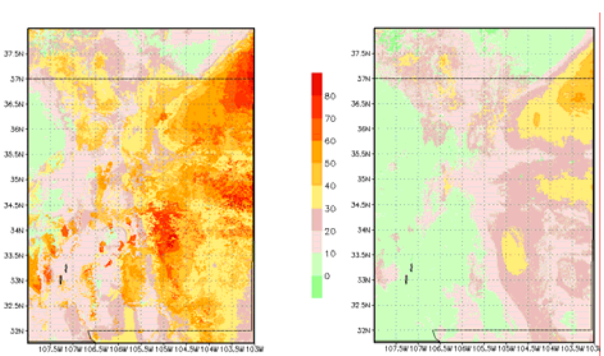
Figure 2. (a) The AVHRR and (b) MODIS land cover maps which correspond to the LDAS model runs.

3.1 LDAS SIMULATED ET

Part of the work being conducted for this project involves evaluating the differences between land surface model schemes and the input parameters to those models. Currently, several simulations are being performed with different land cover datasets, derived from remote sensing data, with the two LSMs, Noah and CLM2.0. The two land cover types being examined at this time are based on the University of Maryland's (UMD) land cover type scheme and are derived from measurements from NOAA's AVHRR and NASA's MODIS instruments.

Figures 2a and 2b show the differences in the two different satellite-derived land cover types subsetted to our study area. These datasets are used in the LIS modeling system a at 1 km spatial resolution. The runs were generated with a five-year spin-up (from 9/30/1996 to 9/30/01) and a 15-minute time step in the four final years (9/30/1997 to 9/30/01). Some preliminary results are discussed and shown here from two of the experiments which include a comparison between the Noah LSM run with the AVHRR and MODIS UMD land cover classifications. These two runs only incorporate the satellite-derived land cover files. Future runs with the CLM2 LSM will incorporate the LAI climatology files. AVHRR monthly greenness fraction files were used at this time in the Noah LSM runs. Figures 3a and 3b show an initial comparison between latent heat fluxes for the Noah LSM with AVHRR land cover and MODIS land cover datasets, respectively. The AVHRR land cover based run predicts more enhanced latent heat flux values (in W m^{-2}) than the MODIS simulation case. The MODIS land cover run also tends to reduce the higher spatial variability of the latent heat flux field, which is also shown in other variable comparisons between the two runs.

These results demonstrate the sensitivity of the Noah LSM to land cover type and the impact this parameter has on the estimated surface energy and water fluxes. An updated and accurate knowledge of land cover and land use (in particular over the cultivated areas) is therefore crucial to obtain reliable estimates of ET.



(a) (b)

Figure 3. Latent heat flux predictions (W m^{-2}) from the Noah LSM simulations using (a) AVHRR and (b) UMD land cover classification datasets, for June 1, 2002 (12Z).

3.2 VALIDATION OF LDAS FORCING

Because the ET Toolbox evapotranspiration estimations rely heavily on meteorological data collected at the different stations along the Middle Rio Grande by the Middle Rio Grande Conservancy District (MRGCD), we assess the degree of agreement between the meteorological station forcing and the NLDAS forcing used to drive the LSMs. Results from a preliminary analysis of data collected at the Candelaria Farms station (lat: 35.13 deg N, lon: 106.68 deg W) in the Albuquerque area show that on an hourly basis, the agreement between these forcings varies considerably from variable to variable. Figure 4 shows scatter plots for (a) surface air temperature, (b) incident solar radiation, (c) air specific humidity and (d) wind intensity for the month of May 2003. Figure 4a suggests that the NLDAS forcing overestimates the station data with a fixed bias of about 3.5 K. If that bias is removed from the dataset, a good overall agreement is seen between both datasets (see Figure 5). Note that the NLDAS dataset used for this comparison does not reflect the elevation adjustment mentioned before (Section 3). Such adjustment for elevation differences between the original 0.125 degrees NLDAS data and the 1 km NLDAS data would lead on average to a 0.7 K bias, which is considerably lower that the observed bias. These values reflect probably local microclimates which are not captured by the coarser resolution forcing data.

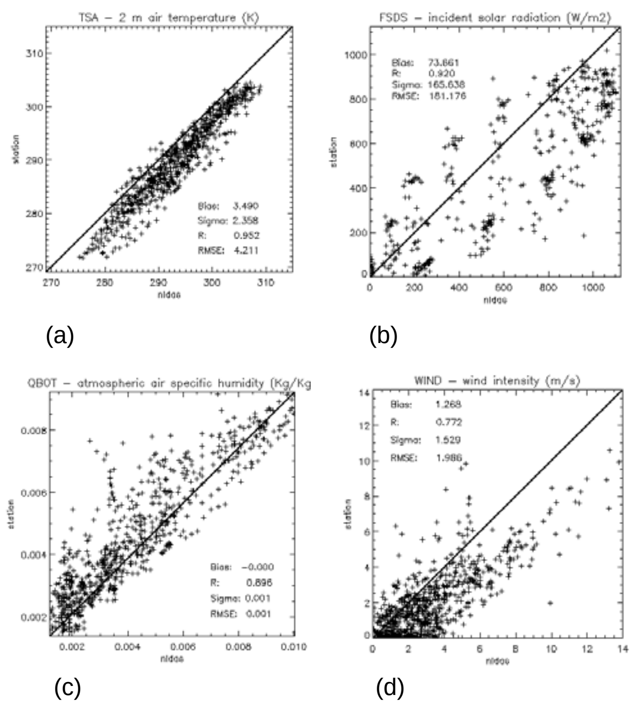


Figure 4. Scatter plot of a) surface air temperature (TSA); b) incident solar radiation (FSDS); c) air specific humidity (QBOT) and d) wind intensity (WIND), for NLDAS data vs. Candelaria Farms station data, for May 2003.

Regarding the incident solar radiation (FSDS), Figure 4b suggests very little agreement between both sources. However, by analysis of Figure 6, one can observe that the overestimation by NLDAS incident radiation occurs predominantly at mid day, and that a reasonable agreement is observed for most of the remaining diurnal cycle. An overestimation of this forcing variable, when compared to meteorological station data, has been found in previous studies, specifically by (Luo et al., 2003) over Oklahoma Mesonet stations.

A reasonably good agreement between both datasets was found for near surface air specific humidity, with very little bias observed for this particular month and station. The wind intensity scatter plot suggests however that the NLDAS forcing tends to overestimate the local data, in particular for higher values of wind intensity (above 10 m/s).

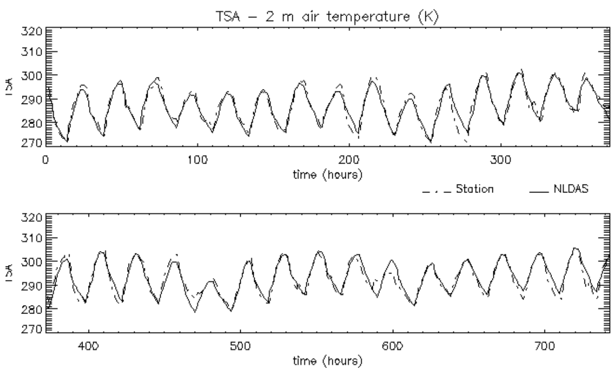


Figure 5: Surface air temperature (TSA) for NLDAS data and Candelaria Farms station data, for May 2003.

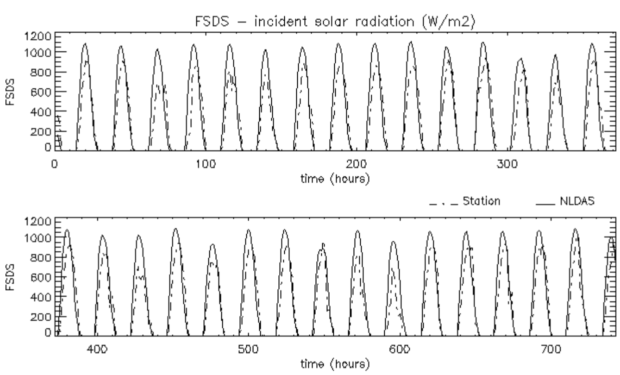


Figure 6: Incident solar radiation (FSDS) for NLDAS data and Candelaria Farms station data, for May 2003.

Further analysis is required to fully evaluate the agreement between both datasets, in particular when applied to different seasons and years. However, this preliminary analysis suggests good overall agreement between the datasets.

4. CONCLUSION AND FUTURE WORK

Reclamation has developed and implemented the AWARDS and ET Toolbox systems to assist water managers and users in assessing the amount of precipitation accumulation and water losses through ET and open-water evaporation. To help further improve these estimates, NLDAS and LIS data and tools are being customized specifically for the New Mexico region and to be used and compared with the AWARDS ET Toolbox. Thus far, the parameters and forcing being used in the NLDAS system are being evaluated against in-situ measurements. Also, multiple LSM runs are being generated to investigate the impacts of satellite-based land cover and other land surface parameter datasets on modeled ET predictions, which will be compared with in-situ observations in the future.

Two Noah LSM experiments have been run with different satellite-based land cover datasets, AVHRR and MODIS. The results show that the modeled ET is very sensitive to land cover type and how important it is to have updated and accurate land cover information. The forcing variables used to drive the LSMs in NLDAS show overall good agreement with local meteorological station data for near surface air temperature and specific humidity, although a fixed bias appears to exist in the air temperature field. The downward shortwave radiation however is overestimated, especially during midday, compared to the station measurements.

The LDAS approach relies heavily on land surface data assimilation, which has shown significant potential to improve realistic representation of the land surface (Arsenault, et. al., 2003). The objective of assimilation is to obtain the best estimate of the state of the system by combining observations with the forecast model first guess (Radakovich et. al., 2001). Remotely sensed land surface temperature (LST), defined as the effective kinetic temperature of the earth surface “skin,” indicates the surface energy state. Although LST is not currently assimilated in CLM2.0, we will assimilate LST products directly into the model’s surface radiative temperature prognostic variable by implementing an EnKF approach (Evensen, 2003). We will focus on MODIS LST product assimilation, with particular emphasis to the product generated by the MODIS Rapid Response system (Pinheiro et. al., 2003) This product is available approximately within four hours after satellite overpass allowing a near-real time estimate of ET for the region. We expect this will significantly improve estimates of soil moisture at the root zone and estimates of evapotranspiration. We will assess the improvement of the proposed system by comparing our results against the ET Toolbox evapotranspiration equivalent estimates.

Further, we will attempt to calibrate the model using extensive field data from the region. These data will be collected at selected sites within the state of New Mexico. Specifically, two eddy covariance flux towers were installed during the summer of 2004 and will soon be fully instrumented and deployed for use in our studies in the Middle Rio Grande agricultural and riparian areas. These will complement the existing 18 meteorological sites run by the MRGCD. Measurements will include profiles of soil moisture and temperature, surface net radiation, surface radiometric temperatures, CO2 and water fluxes estimates, and general meteorological observations.

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