J5.13 APPLYING HIGH RESOLUTION LAND SURFACE DATA, MODELING AND ASSIMILATION TECHNIQUES TO WATER SUPPLY AND DEMAND FORECASTS

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1. INTRODUCTION

There is a critical need to improve water supply and demand forecasting for water resources managers in the Upper Columbia River Basin. The Bureau of Reclamation (Reclamation) teamed with the Land Data Assimilation System (LDAS) group at NASA's Goddard Space Flight Center (GSFC) to address this need. The objectives of the joint research include improving snowpack water supply forecasts, snowmelt runoff forecasts, and agricultural and riparian water consumptive use forecasts. The research integrates the improved water supply and demand forecasts into decision support tools to improve water resources management.

Reclamation is developing an Agricultural Water Resources Decision Support (AWARDS) - Evapotranspiration (ET) Toolbox system in portions of the Upper Columbia Basin for automatically inputting daily riparian/wetlands and crop water use estimates, open water evaporation estimates, and WSR-88D-based rainfall estimates to RiverWare, which is a daily river modeling and accounting system for decision makers. The rainfall estimates, as well as cool season precipitation estimates, are from the Reclamation-developed Precipitation Accumulation Algorithm (PAA). Recently consumptive use forecasts out to 72 hours have been added to the ET Toolbox. These forecasts are based on the NCEP Eta model (12-km grid) weather forecast parameters. This water resources decision support system is being used operationally.

The NASA GSFC LDAS group is heavily involved in the development and testing of the uncoupled North-America Land Data Assimilation System (NLDAS). The NLDAS uses four physically-based, land-surface models (LSMs) running on a common grid and driven by common surface forcing and observation-based precipitation and radiation fields. The study approach for the Upper Columbia River Basin is to incorporate NLDAS products into the ET Toolbox and RiverWare. Upon integration, then evaluate the resulting products and value added to the water operations in terms of additional conservation storage, and sustainable river basin ecosystems.

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There are two ways in which collaboration efforts between the LDAS team and Reclamation have to be made, viz., (1) the exchange of data to help each other evaluate the ability of the current LDAS and its suitability to fit into Reclamation's water management operations and decision support tools, and (2) through such validation, the LDAS team's main goal is to improve the parameterization and land surface model physics, incorporating the scaling issues, to render better output specific to water supply and demand forecasting needs. On the applications side, Reclamation's main goal is to improve water resources management through the development of decision support tools like the ET Toolbox and RiverWare.

2. AWARDS - ET TOOLBOX

The AWARDS - ET Toolbox system (ET Toolbox) is an automated information system to assist water users by providing easy access to rainfall and daily crop water use estimates (Hartzell et al., 2002). These estimates are based on real-time data obtained from WSR-88D (Weather Surveillance Radar - 1988 Doppler) radar systems and automated weather stations. The purpose of the ET Toolbox is to improve the efficiency of water management and irrigation scheduling by proving guidance on when and where to deliver water, and how much to apply.

Reclamation's Yakima, Columbia Basin and Umatilla projects in the Upper Columbia Basin are developing and deploying RiverWare, an object-oriented reservoir and river modeling framework for both planning and daily operational use. However, the current water supply and demand accounting systems in their RiverWare systems model fail to take advantage of the latest technologies for precipitation estimation, agricultural and riparian water use ET calculations, open water evaporation estimates, and meteorological model forecasts. This applied research effort will improve operational efficiency and water conservation for water deliveries, and help maintain reservoir levels and an equitable supply of water for in-stream flows and endangered species during periods of critically short water supplies. The goal of this ongoing research project is to improve the efficiency of water management by using the ET Toolbox to calculate daily crop ET estimates for input to RiverWare. As the decision support tools and products are being developed, they are posted on an Internet Web page for use by water managers (http://www.usbr.gov/rsmg/nexrad).

The primary purpose of the ET Toolbox is to estimate high-resolution (nominal 2km x 2km cells) radar-based daily rainfall and crop water depletions within specified subareas of irrigation projects (an example of such a project is shown in Figure 1). The rainfall estimates are based on Reclamation's Precipitation Accumulation Algorithm (PAA). The daily net crop water use requirements calculated by the ET Toolbox for each subarea are available for input for Depletion Requested values in RiverWare. A Data Management Interface (DMI) was developed to exchange data between the ET Toolbox and the Upper Columbia Area Office's (UCAO) Hydrologic Engineering Center - Data Storage System (HEC-DSS).

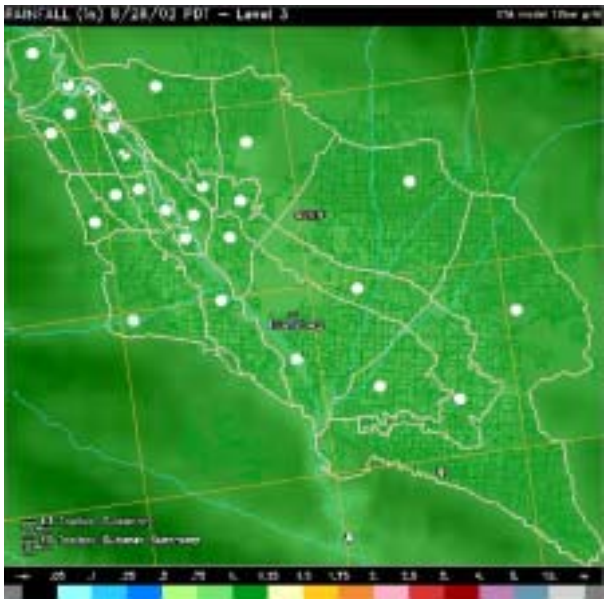

Figure 1. Kittias Division showing canals and drains for irrigation water, field polygons, and 12-km NCEP Eta model grid. Clicking on the white dots will pop up a table with daily water use by individual crop and in total for the subareas.

3. ETA MODEL FORECASTS

There are irrigation projects within the Upper Columbia Basin (e.g. see Figure 1) that do not have a representative real-time automatic weather station to provide the meteorological parameters needed for the calculation of daily reference ET. In these areas, the ET Toolbox system is using the National Centers for Environmental Prediction (NCEP) Eta model weather forecast parameters at 12-km grid resolution. The ET Toolbox uses the Eta model 0600 UTC (2300 PDT) run's 3-hr forecasts for temperature, relative humidity, and wind speed, plus the forecast cumulative solar radiation and precipitation for 0600-0600 UTC. From the 3-hr forecast values, the ET Toolbox selects the maximum and minimum temperatures, and calculates the average relative humidity and wind speed. The same Eta model runs are also used to calculate 48-hr ET forecasts.

Figure 2 shows a comparison of the forecast total solar radiation, maximum and minimum temperatures, and average relative humidity, with measurements from the Lind, WA AgriMet weather station (elevation 1475 ft) located within the 12-km Eta grid cell (mean elevation 1539 ft). The Lind AgriMet weather station is shown in Figure 3.

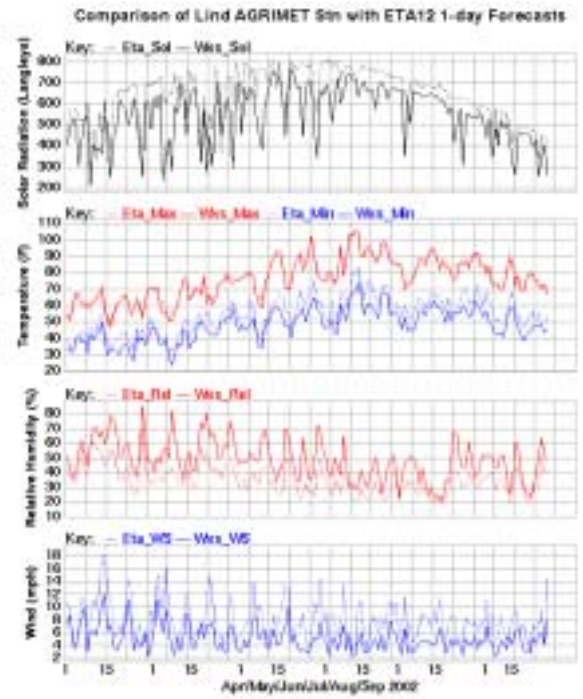

Figure 2. Example of a comparison of one Eta model 12-km grid cell forecast parameters with measurements from a weather station located within the grid cell.

Figure 3. Lind, Washington AgriMet weather station.

The data sample used in the comparison was 166 days from April 1 through September 29, 2002 (there were a few days with missing Eta model data). Table 1 shows the results of a comparison of data from the Lind, WA AgriMet weather station and the 12-km Eta Model grid cell it is located in. The comparison numbers are average daily values for the 166 day sample.

Table 1. Comparison of 12-km Eta model 24-hr forecasts with surface weather station data.

Label	Tmx F	Tmn F	RH %	Solar L	WS mph
12 Eta	76.6	54.5	35.1	641.5	7.9
Wx Stn	75.9	48.2	48.8	544.2	5.1
Diff (%)	0.9	13.1	-28.1	17.9	54.9
Corr (r)	0.982	0.958	0.873	0.790	0.829

The Eta positive bias in surface solar insolation was expected as it has been documented by a number of Eta model verification studies (Mitchell, et al., 2000). For this sample, the maximum temperatures were in good agreement, there was a positive bias in the minimum temperature, and a negative bias in the average relative humidity. The difference in relative humidity is likely due to the mean height of the Eta grid cell being about 64 feet higher than the weather station. The bias in wind speed (ws) is due to comparing 10-m Eta model wind forecasts with 2-m weather station measured data. Adjusting the 10-m ws forecast to 2 m using: $ws_2 = (ws_2/ws_{10})^{0.2}$ where the exponent is an estimate of the surface roughness, reduces the 7.9 mph average to 5.7 mph, which compares closely with the measured 5.1 mph average.

4. PRECIPITATION ESTIMATES

High resolution rainfall estimates based on WSR-88D Level 3 data are incorporated into the AWARDS - ET Toolbox system to offset vegetation water use and open water evaporation. The 24-hr rainfall for each HRAP grid cell located over the irrigated and riparian/wetlands acreage along river systems in the Upper Columbia Basin is used in the water use calculations.

The accuracy of standard WSR-88D precipitation products such as Stage III, based on the default $Z_e = 300R^{1.4}$ relationship with no range correction, was found to be insufficient for Reclamation's operational needs. Therefore, a $Z_e = \alpha R^{\beta}$ precipitation accumulation algorithm (PAA) based on WSR-88D Level 3 base reflectivity data was developed to improve the quantitative precipitation estimates (QPE). The first version of the PAA developed for the Pacific Northwest allowed site specific selected α and β values, minimum and maximum precipitation thresholds, and range correction factor (Hartzell et al., 2001).

Improvements were made to the PAA that restores the range correction function with a true vertical profile of reflectivity, based on clearance between a radar beam center and the terrain. Also, the precipitation type in the radar beam is classified as dry snow, melting snow, and rain, based on model soundings. The three classes will have a different α, but β will remain 2.0 (Hunter and Holroyd, 2002). This version of the PAA was implemented for operational testing in the Upper Columbia Basin (and elsewhere) during late April 2002. An example of the PAA-based QPE is shown in Figure 3.

PAA research work is ongoing to refine parameters within the algorithm and to adapt it for the Upper Columbia Basin area. Specifically, PAA QPE are being compared against 24-hr precipitation amounts from Reclamation's AgriMet weather station network and the National Weather Service Cooperative Observing network within the Spokane, Washington WSR-88D (KOTX) radar umbrella. This comparison will enable accurate QPE in the Upper Columbia Basin area.

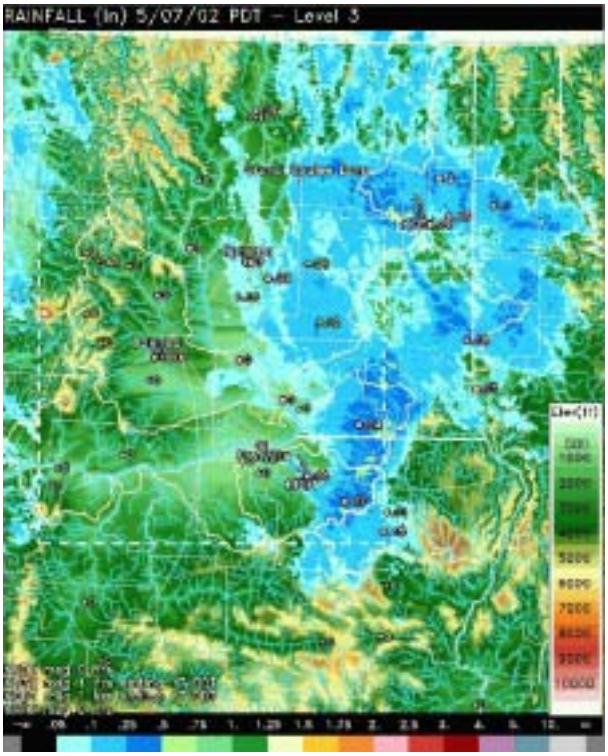

Figure 4. Example of the PAA-based 24-hr QPE for the Upper Columbia Basin area. For this image, QPEs from four WSR-88Ds (Spokane, Pendleton, Portland, Seattle) are merged; 24-hr gage accumulations are plotted for comparison.

5. NLDAS PRODUCTS

The greatest priority of water supply management is having accurate snowpack amounts and runoff forecasts. Water managers must have timely data from remote areas that are often inaccessible in winter, and they need a means of quickly analyzing the impacts of precipitation and snowmelt on streamflow for routine river system

management, and emergency responses to extreme events. Therefore, accurate estimates and forecasts of the snow water equivalent (SWE), antecedent soil moisture, surface energy budget forecasts, and the evolution of the snowpack into hydrologic runoff are very important for accurate flood forecasts.

Reclamation researchers are collaborating with scientists at the Hydrologic Sciences Branch, NASA's GSFC, on studies that support Reclamation priorities by assessing the importance of orographic processes on water cycle predictability through the use of snowfall remote sensing and data assimilation in the western United States and applications of model forecasts in water resources management decision making.

The objective of this research collaboration is to develop and demonstrate the value added from various satellite, radar, and other in-situ observations in the North American Land Data Assimilation System (NLDAS) to improve water supply forecasts for water resource managers, initially in the Columbia River Basin. This research partnership among scientists/researchers at NASA and Reclamation will test and evaluate different land surface models (LSMs) and hydrologic runoff models. These models will use satellite and radar data and conventional surface observations to demonstrate the value added to improved streamflow simulations and forecasts.

Figure 5 shows an example of the snow water equivalent (SWE) depth product from the Mosaic LSM (Koster and Suarez, 1996). Bi-monthly Snotel SWE data for two Natural Resources Conservation Service (NRCS) Snotel sites were used for comparison purposes. Manual versus pillow correlations for the two Snotel sites have high correlations being 0.963 and 0.952. So far the comparisons with the Mosaic near real-time and forecast runs have shown that the snow cover is reasonably captured, but snow depth proves to be the challenge due to SWE being underestimated when compared to the Snotel sites.

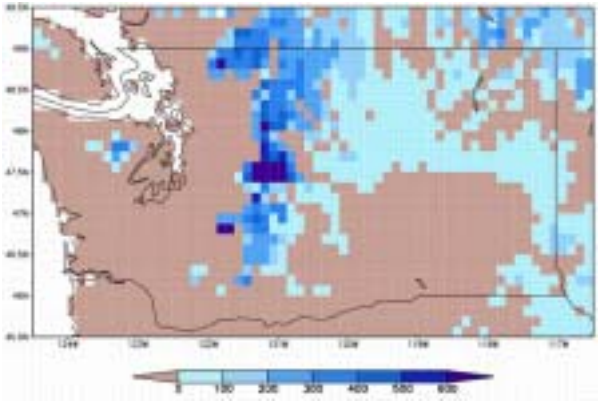

Figure 5. Mosaic LSM Snow Water Equivalent (mm) of the snowpack as of 00Z on 03/29/01.

The cooperative study is also evaluating how estimated soil moisture fields from NLDAS LSMs can be used to improve the efficiency of water management. Soil Moisture is crucial to land-atmosphere and surface water interactions, and hence to forecast models. In this study, forcing and output data for the Mosaic LSM retrospective model were compared to and correlated with actual soil moisture observations from the NRCS Soil Climate Analysis Network (SCAN) site near Lind, Washington (close to the Reclamation Lind AgriMet weather station). Figures 6 and 7 show LDAS-SCAN 1m depth soil moisture comparisons for Mar-May 2001 and Jun-Aug 2001, respectively. The correlations of 0.730 and 0.920 were fair to good.

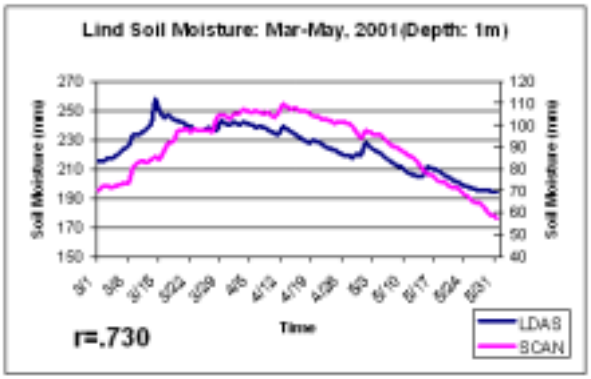

Figure 6. NLDAS Mosaic LSM vs Lind SCAN 1m soil moisture comparison for March - May 2001.

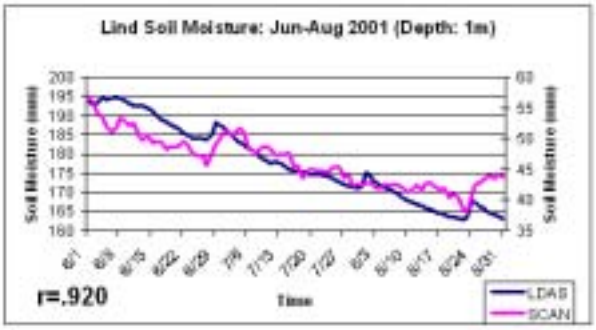

Figure 7. NLDAS Mosaic LSM vs Lind SCAN 1m soil moisture comparison for June - August 2001.

The future course of the cooperative research will include continuing to evaluate the near real-time and forecast run output from the Mosaic LSM and potentially output from other LSMs at Reclamation facilities. For both operational and forecast settings, various NLDAS LSM variables will be tested and used in Reclamation's water resource and river management support tools.

6. SUMMARY

- The AWARDS - ET Toolbox system being developed for the Upper Columbia Basin demonstrates a methodology that integrates high resolution WSR-88D 1-hr rainfall estimates from Reclamation's PAA, weather station data, atmospheric model forecasts, crop and riparian/wetlands ET requirements, GIS

information, and land usage, with modern computer communication, and Internet technologies for improved water resources management.

- The land use data are combined with the NCEP 12-km Eta model data-based ET estimates as calculated using the Kimberly-Penman equation to develop agricultural water use estimates in acre-feet (and as flows in cfs). When available, weather station data are used in place of the Eta model data.
- A Data Management Interface (DMI) was developed to exchange data between the ET Toolbox and a database. Currently, only an aggregated output from the ET Toolbox to the Upper Columbia Area Office's (UCAO) Hydrologic Engineering Center - Data Storage System (HEC-DSS) DMI exists. There is a need to build a prototype RiverWare model with a data object to transmit the ET Toolbox daily net water use requirements for the subareas - thus creating one time series each.
- Pop-up charts and graphs of weather station data, streamflow and river stage, and the 1-hr radar-based PAA images are updated in near real time.
- Forecast parameters at 12-km grid resolution from the NCEP Eta model are being used in the ET Toolbox for calculating daily ET, and to make 24-hr and 48-hr subarea consumptive use forecasts.
- The PAA is being operationally tested. It appears that the PAA is presently over-forecasting precipitation during light events, but is doing well during widespread moderate to heavy events. Case studies using 24-hr accumulations from AgriMet weather stations and NWS Cooperative observation sites are in progress. Results from these studies will be used to improve the PAA-based QPE for the Upper Columbia Basin.
- Reclamation AgriMet weather station measurements were compared with NLDAS Mosaic LSM near real-time and 00Z forecast simulations. The results show strong correlations for maximum and minimum temperatures, and good correlations for relative humidity, downward shortwave radiation, and wind speed. The forecast runs reveal a certain amount of accuracy, but with weaker correlations for precipitation and downward shortwave radiation when compared with the near real-time runs.
- Comparisons were made between snow depth (SWE) and soil moisture outputs from the NLDAS Mosaic LSM to observed data. The SWE are being underestimated when compared to Snotel data, but there are good correlations with soil moisture.

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Data from the AgriMet automated weather stations are provided by the Pacific Northwest Cooperative Agricultural Weather Network (Peter Palmer). The WSR-88D Level 3 data are obtained via FTP from the NWS TGFTP server (Alan Darling). The 12-km Eta model forecast parameters are obtained via FTP from NCEP's Environmental Modeling Center (Dr. Geoff DiMego).

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