Final Report

Project Title: A framework for improving land surface hydrologic process representation in land surface model over California

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Project Summary

California's water supply systems are straining to keep up with economic growth and urban development. The state has experienced three major droughts and three major floods since 1980's, and California continues to grow and build. Combined, these regional changes pose an urgent need for accurate modeling and predictions of key hydrologic processes for the guidance for California's water management responses.

In this project, a series of strategies were employed to improve understanding the long-term hydrological processes such variations of soil moisture, ET, precipitation, surface runoff, deep-layer percolations, as well as snow water equivalent (SWE) etc. These strategies include: (1) implementing a realistic irrigation scheme, which is used in California agricultural irrigation practice, modified Noah LSM land surface model (LSM); (2) implementing the Utah Energy Balance (UEB) snow model into Noah LSM; and (3) assimilating remote-sensing soil moisture into Noah LSM using Sequential-Monte-Carlo Filters. Several research findings are summarized below:

- In comparison with in-situ observations and estimates from default model runs, the model results from modified Noah LSM are greatly improved and comparable with observations. The irrigation scheme is included based on the realistic irrigation scheme suggested by Hanson et al (2004) and the snow surface and snowpack temperature estimate scheme is modified based on the UEB model.
- Our ET long-term analysis also exhibits that agriculture irrigation results in ET decreasing in long-term partly due to solar radiation decrease, and the later may be due to cloud increase either due to SST increase or irrigation-induced water vapor increase.
- Our results also shows that deep-layer percolation due to agriculture irrigation can be estimated using our proposed method based on the comparisons between simulations and available field experiments reported.

- After the UEB model was integrated into Noah LSM, the simulations of snow water equivalent and snow melting time is improved in comparison with the SNOTEL observations in California and other state and control runs.
- Through this project, we have also explored the use of remote sensing soil moisture data and LSM to improve estimation of soil moisture at deep soil layers, ranging from 5-cm to 100-cm, using sequential Monte Carlo (SMC-PF) technique. Our results indicate that the proposed method works very well in comparison with observations.

In this project, we planned to use CLM as the physical model. During our data preparation, we find that more forcing fields are required to drive CLM, which are difficult to obtain. We finally used Noah LSM in the experiments instead.

1. *Highlighted Activities:*

- ***Implemented a realistic irrigation scheme into land surface model***

  A realistic irrigation scheme based on the California agricultural irrigation practices is implemented into Noah LSM. The results from modified model were validated against observations on soil moisture, soil temperature, 2-m air temperature and surface fluxes from different locations at irrigation regions (Sorooshian et al., 2011, 2012). Figure 1 is the example of comparisons of model soil moisture (MM5C/R/F represents soil moisture from control run, realistic irrigation run, and field capacity run, respectively) and observed soil moisture.

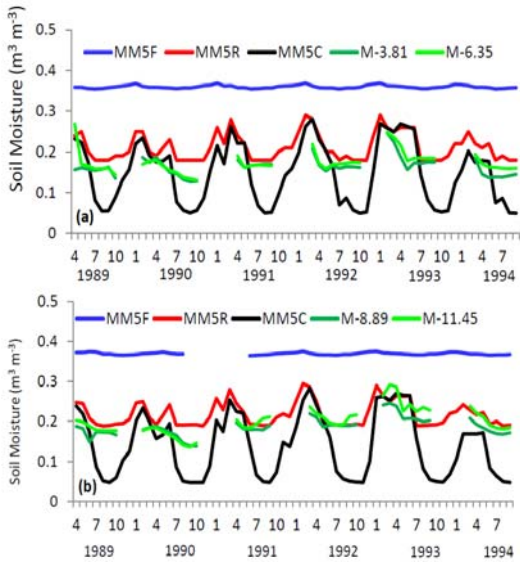

Figure 1a: Model simulations and observations of soil-moisture over the observation site: (a) first layer of the model, and (b) second layer of the model (no field observations available from November to February).

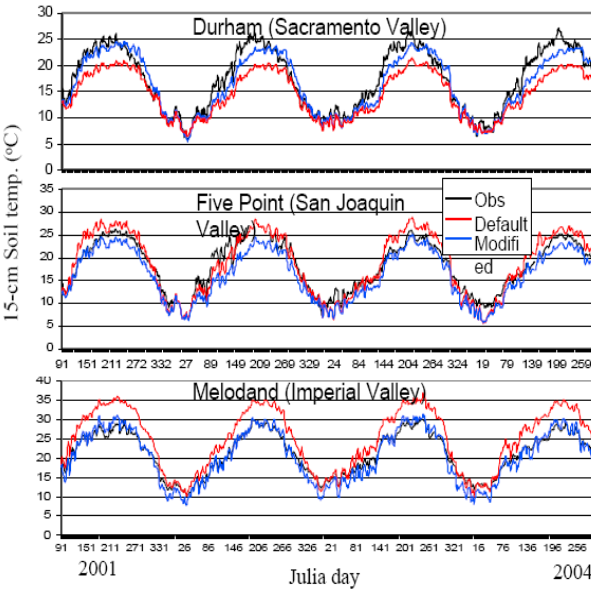

Figure 1b: The soil temp. comparisons between observation and model results at different Valleys. The dark, blue and read lines represent observation, model result with default run and model result with irrigation process added and wilting point changed

- ***Understanding hydrological processes at irrigation region***
  The modified Noah LSM and its coupling with atmospheric model can simulate the impact of irrigation on meteorology and hydrology from hourly scale/daily to decadal scales. Figure 2 is example of ET interannual variation comparisons (Sorooshian et al., 2014). The trend exhibited in ETo is reproduced by model.

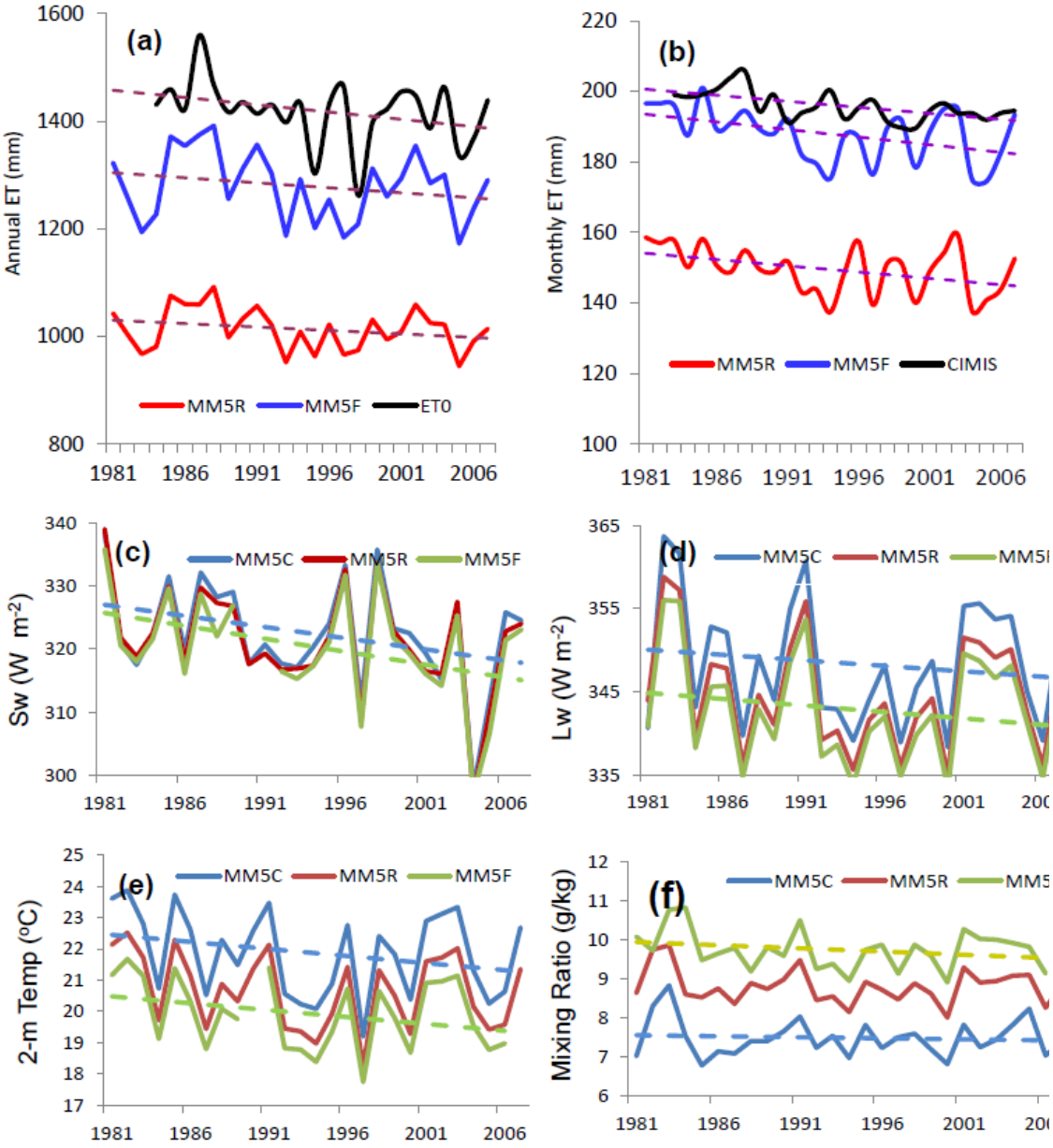

Figure 2: Mean irrigated-grid ET time series over California from 1981-2007. (top left): Annual total (mm), (top right): mean ET from July to August. ET0 is the average of 12 CIMIS sites where the data record starts before 1985. (middle): downward solar radiation, and (bottom): the corresponding 2-m annual temperature and mixing ratio time series

- ***Implemented the Utah Energy Balance model into Noah model***
  To improve snow water equivalent (SWE) simulation in the Noah LSM over the Sierra Nevada Mountains, the Utah Energy Balance (UEB) snow model is implemented in Noah to test alternate snow-surface temperature and snow-melt outflow schemes. Snow surface temperature was estimated using force-restore method and snow melt event is regulated by accounting for the internal energy of the snowpack. The modified Noah's SWE simulations are compared with the SWE observed at California's NRCS SNOTEL stations for seven water years: 2002- 2008, while the model's snow-surface temperature is verified with observed surface- temperature data at an observation site in Utah. The experiments show that modification in Noah's snow process substantially reduced SWE estimation bias while keeping the simplicity of the Noah LSM. The results suggest that the model did not benefit from the alternate temperature representation but primary improvement can be attributed to the substituted snow melt process (Sultana et al., 2014). Figure 3 is the example of SWE comparisons between observations and models at control runs (blue) and modified model runs.

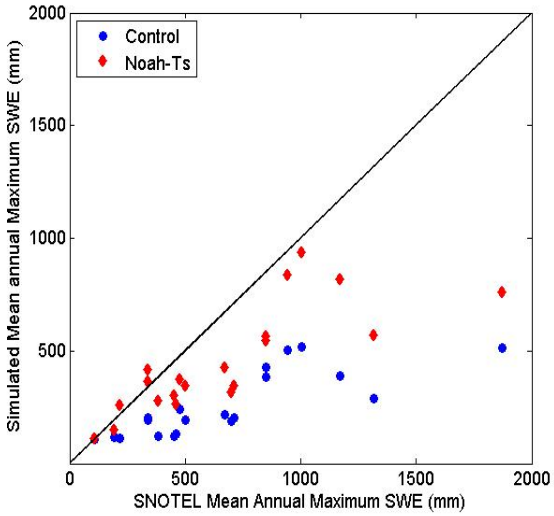

Figure 3: Comparison of mean annual maximum SWE between model simulations and SNOTEL measurements (mm).

- ***Soil moisture data assimilation using sequential Monet Carlo method***
  In this study, in-situ and remote sensing information of near-surface soil moisture is assimilated into the Noah land surface model to estimate deep-layer soil moisture variation. The sequential Monte Carlo particle filter (SMC-PF) technique, being well known for capability of modeling high nonlinear and non-Gaussian processes, is applied to assimilate surface soil moisture measurement to the deep layers.

  The experiments were carried out over several locations over the semi-arid region of the U.S. Comparing with in-situ observations, the assimilation runs show much improved from the control (non-assimilation) runs for estimating both soil moisture

and temperature at 5-, 20-, and 50-cm soil depths in the Noah Land Surface Model(LSM) (Hsu et al. 2011). Figure 4 is the example of assimilating AMSR-E soil moisture into Noah LSM using SMC-PF; data assimilation has improved soil moisture estimation at the top layer (see Figure 4a) as well as the deep-layers at 20-cm and 50-cm (see Figure 4b).

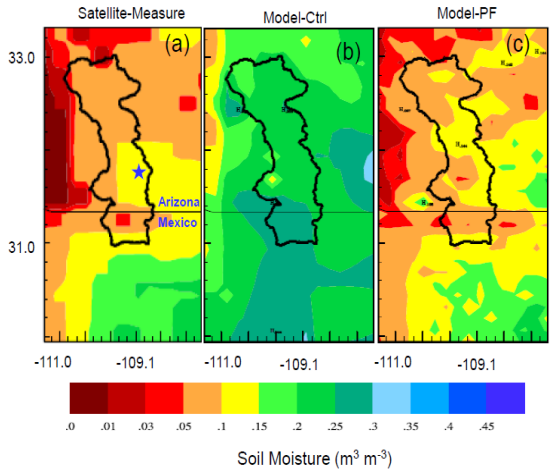

Figure 4a: Top layer mean soil moisture in August 14-17, 2005 from (a) remote sensing AMSR-E estimates, (b) Noah LSM control run, and (c) SMC-PF run.

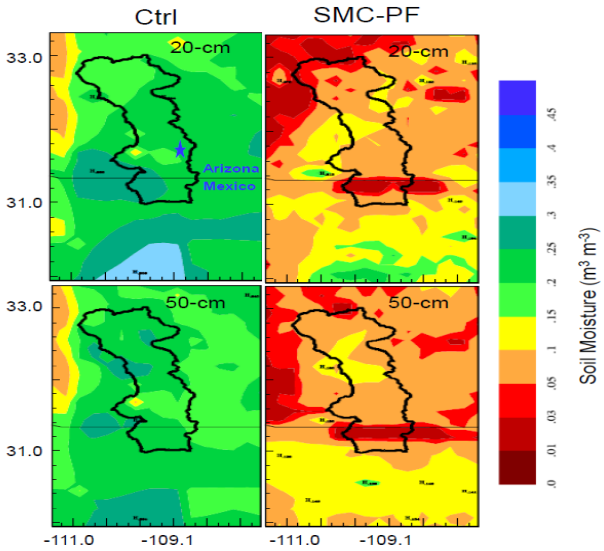

Figure 4b: Average soil Moisture at 20-cm and 50-cm depths from Noah control run (Ctrl) and SMC run (SMC-PF) during the period of August 14-17, 2005.

2. Education

One Ph.D. student (Rebecca Sultana) is supported from this grant. She graduated in 2013 and is currently served as an Assistant Professor at the Civil Engineering and Construction Engineering Management, California State University at Long Beach.

3. Publications from This Research:

Peer Reviewed Publications:

- Sorooshian, S. J. Li, K. Hsu, and X. Gao, 2011: How significant is the impact of irrigation on local hydroclimate in California's Central Valley? Comparison of model results with ground observation and remote-sensing data. J. Geophs., Res. 116, D06102, doi:10.1029/2010JD014775.
- Hsu, K., J. Li, and S. Sorooshian, 2011: Improve soil moisture estimation in arid/semi-arid region using In-situ and remote sensing information. Paddy and Water Environment Journal, DOI10.1007/s10333-011-0308-9.
- Sorooshian, S., J. Li, K. Hsu, and X. Gao, 2012: Influence of irrigation schemes used in RCMs on ET estimation: Results and comparative studies from California's Central Valley agricultural regions. J. Geophys. Res., 117, D06107, doi:10.1029/2011JD016978.

- Sultana, R., Hsu, K.-L., Li, J., and Sorooshian, S., 2014: Evaluating the Utah Energy Balance (UEB) snow model in the Noah land-surface model, Hydrol. Earth Syst. Sci., 18, 3553-3570, doi:10.5194/hess-18-3553-2014.
- S. Sorooshian, A. AghaKouchak, and J. Li, 2014: Influence of Irrigation on Land Hydrological Processes over California. Revised manuscript submitted to Journal of Geophysical Research-Atmos. (In press)

Conference Presentations:

- Hsu, K., J. Li., R. Sultana, and S. Sorooshian: Improving soil moisture and snow water equivalent estimation of Noah Model by Effective data assimilation and process modification. Asia Oceanic Geosciences Society 8th Annual Meeting, Taipei, Taiwan, August 8-12, 2011.
- Sultana, R., K. Hsu, J. Li, and S. Sorooshian 2014: Evaluating Utah Energy Balance's (UEB) snow model in Noah Land Surface model. HESS: in revision.
- Jaw, T., J. Li, K. Hsu, S. Sorooshian, and F. Driouech, 2014: Evaluation for Mroccan Dynamically Downscaled Precipitation from GCM CHAM5 and Its Regional Hydrologic Response. Submitted Journal of Hydrology-Regions.
- Nguyen, P., S. Sorooshian, K. Hsu, A. AghaKouchak, and B. Sander, Evaluating the Performance of a Coupled Distributed Hydrologic-Hydraulic Model for Flash Flood Modeling Using Multiple Precipitation Data Sources, American Geophysics Meeting, 9-13 December, 2013. San Francisco, 2013.
- Thorstensen, A., P. Nguyen, K. hsu, S. Sorooshian, and W. Krajewski, Comparison of Multiple Precipitation Products over a Densely Gauged Basin through Distributed Hydrologic Modeling, American Geophysics Meeting, 9-13 December, 2013. San Francisco, 2013.

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