Integrating Remote Sensing Data on Evapotranspiration and Leaf Area Index with Hydrological Modeling: Impacts on Model Performance and Future Predictions

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Objective
The goal of this research, which uses the Connecticut River Basin as a case study, is to incorporate satellite remote sensing data for ET and LAI into the VIC model to improve the model performance. Specific objectives are:
1) Assess the extent to which remote sensing data helps improve hydrological modeling
2) How the integration of remote sensing data might influence future hydrological trends
3) Characterize the model-related uncertainties in hydrological predictions

VIC Model and Data Sets
The model used is the Variable Infiltration Capacity (VIC) model (Liang et al 1994). The historic simulation was driven by the NASA Land Data Assimilation System phase-2 (NLDAS-2) forcing data for the period 1980-2011 (Parr & Wang, 2014), and future projections for the period 2046-2065 were driven by output from three North American Regional Climate Change Assessment Program (NARCCAP) models (Parr et al. 2015).

Evapotranspiration (ET) Data
This monthly data spans 1986-1995 at 0.5-degree spatial resolution and is from Fischer et al. (2008). As ET cannot be directly measured, it is estimated according to a surface radiation budget algorithm.

Leaf Area Index (LAI) Data
Derived from Moderate Resolution Imaging Spectroradiometer (MODIS) sensors aboard the polar-orbiting Terra and Aqua satellites. The LAI data has an 8 day temporal resolution and a 1 km spatial resolution matching our land cover data set.

Methodology of Adapting the Model:
VIC calculates each component of ET (canopy evaporation, transpiration, bare ground evaporation, canopy sublimation) separately and requires a minimum of daily forcing (VIC, VICET, VIC+VEG).

Model Improvements
The primary method for determining the model simulated ET and LAI into the VIC model to improve the model performance is by comparing the various simulated discharges to observation at USGS stations at Thompsonville, CT, and West Lebanon, NH. The river flow was simulated using the default model (VIC) as well as each data-enhanced version (VICET, VICVEG, VICET+VEG).

- The model-simulated ET components were overwritten to correct the ET bias identified based on the comparison of a default model simulation with ET data derived from remote sensing.

- Due to the nature of the alterations made to the various model versions, the impact on model results is expected to manifest at different temporal scales

- The most dominant improvements are to the seasonal discharge (particularly summer and fall months) for VICET and VICET+VEG (above)

- There are also significant improvements on the daily and bimonthly time scale for VICET and VICET+VEG

- The greatest improvements to VICVEG occur on the inter-annual scale

- Correlations (high significant at p<0.01, Nash-Sutcliffe Efficiency, Root Mean Square Error, and Standard Deviation for all model versions is provided below.

Experimental Design

The Combination Model (VIC+VEG)
- We have also developed and run simulations for the combination model with prescribed ET and Dynamic Vegetation
- VIC+VEG produces its largest enhancements to inter-annual variability, particularly in the winter and spring
- VIC+VEG model performance is assessed using VICET as a “static vegetation” baseline

Impacts on Future Predicted

- Evaluating the historic and future (2046-2065) hydrological changes and long term trends comparing the default model (VIC) and VICET
- Interestingly, results from VIC and VICET differ not only qualitatively (in magnitude) but also qualitatively (in directionality)

- Changes of some water cycle variables
- Minimum Discharge
- VICET: Past: 2,734 cfs; Future: 3,443 cfs (increase of 12 cfs/year)
- VICET: Past: 1,592 cfs; Future: 607 cfs (decrease of 13 cfs/year)

Conclusions

- The incorporation of the remotely sensed ET data produced statistically significant improvements of model performance towards estimations of river flow
- VICVEG produces its largest enhancements to inter-annual variability, particularly in the winter and spring
- The VICET+VEG combination model was able to find a balance between the other two enhanced versions displaying the most significant increases on the seasonal, bi-weekly, and daily scales
- VICET and VIC produced future predictions that differ in not only magnitude but also direction of some hydrological changes
- VICET suggested an increase in longer and more frequent drought as supported by a soil moisture drought analysis, decreasing minimum river flows, and a large step increase/decrease in future JJA ET and soil moisture respectively
- Integrating remote sensing data with hydrological modeling has helped characterize the range of model-related uncertainties and more accurately reconstruct historic river flow estimates, which leads to presumably more accurate prediction of hydrological response to future climate changes
- Follow-up study: to apply the ET bias correction algorithm to the whole NLDAS domain and to CLM

References
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This study has been documented in the following publications:

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