Advancing Water Supply Forecasts in the Colorado River Basin for Improved Decision Making

Jay Day

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Statement of challenges / need

• To improve water supply forecasting in an area with high spatial variability in the snow accumulation and ablation process

Opportunity

• To leverage improved models, new data sources, and advanced data assimilation techniques to provide more skillful water supply forecasts with uncertainty estimates to water managers to support risk-based decision making
Current partners

<table>
<thead>
<tr>
<th>Role</th>
<th>Name(s)</th>
<th>Affiliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-I</td>
<td>Christian Kummerow</td>
<td>Colorado State University, Cooperative Institute for Research in the Atmosphere (CIRA)</td>
</tr>
<tr>
<td>Co-I</td>
<td>David Tarboton</td>
<td>Utah State University</td>
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<tr>
<td>Partner</td>
<td>Colorado Basin River Forecast Center</td>
<td>National Weather Service, NOAA</td>
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</tbody>
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User community

<table>
<thead>
<tr>
<th>Role</th>
<th>Organization Name</th>
<th>Organization Type</th>
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<tbody>
<tr>
<td>End-user</td>
<td>Denver Water</td>
<td>Public Water Utility</td>
</tr>
<tr>
<td>End-user</td>
<td>Dolores Water Conservancy District</td>
<td>Water Conservancy District</td>
</tr>
</tbody>
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RTI International team
Shaun Carney, Paul Micheletty, Gi-Hyeon Park, Jon Quebbeman, Abby Watson, Danielle Perrot
Partner communities you / your project could engage in the future

- Bureau of Reclamation
- Other municipalities
- State Department of Water Resources
- Other river districts
- Irrigation companies
- Other river basins
Key datasets, models, scientific, technical tools

• GPM, SNOTEL, MODSCAG, MODDRFS, NLDAS, Daymet, Airborne Snow Observatory

• Utah Energy Balance (UEB) model, NWS Research Distributed Hydrologic Model (RDHM) with SNOW-17 and Sacramento models

• Community Hydrologic Prediction System (CHPS), Ensemble Kalman Filtering, Non-dominated Sorting Genetic Algorithm (NSGA II)
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**Approach**

**Data and model workflow**

- **Model Inputs**
  - Topography
    - USGS DEM
  - Precipitation
    - CBRFC
    - GPM
    - Daymet
    - NLDAS
    - MERRA
  - Temperature
    - CBRFC
    - Daymet
    - NLDAS
    - MERRA
  - Other weather
    - Daymet
    - NLDAS
    - MERRA
  - Land Cover
    - NLCD
    - MODIS LC
  - Soils
    - SSURGO

- **Models / Processes**
  - Pre-processing
    - Hydro-DS
  - Snow 17
  - SACSIMA
  - Surface and River Routing

- **Observations**
  - SNOTEL SWE
  - MODSCAG
  - MODDRFS
  - USGS Q
  - Diversions

- **Post-processing**
  - Ensemble outputs
  - Deterministic outputs

**Notes**
- Model domain (watershed, HRAP grid, hill slope and channel representation) and terrain variables based on USGS DEM
- Precipitation and temperature from CBRFC
- Humidity, wind speed and radiation from national land data assimilation systems (Daymet, NLDAS, MERRA)
- Precipitation from satellite products (GPM)
- Land cover / vegetation data from national land cover and satellite products MODIS
- Soil data from SSURGO

**Additional Notes**
- Assimilate SNOTEL SWE, snow cover and snow radiative energy (albedo) from MODIS products into UEB/Snow 17 models
- Compare seasonal water supply forecasts to computed natural flow volumes
- Statistical post-processing of ensemble outputs to improve skill and ensure reliability
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Approach

• Provide ensemble forecast products to capture forecast uncertainty
• Generate reforecasts to assess forecast skill and reliability
• Work with decision makers to leverage probabilistic water supply forecasts
Impacts (achieved and anticipated)

- Improved Operational Water Supply Forecasts
  - Regionally Calibrated Satellite Precipitation Estimates
  - Distributed Hydrologic Modeling
  - Energy Balance Snow Model Evaluation
  - Snow Data Assimilation

- Improved Water Management Decision Making
  - Skillful Forecasts with Uncertainty Estimates
  - Reforecasting for Verification and Development of System Operating Rules
Transition Strategy

• Make CBRFC a Partner
  • Leverage local knowledge
  • Collect constant feedback
  • Shared ownership

• Work Closely with Water Managers
  • Understand system/tradeoffs/decision making process
  • Demonstrate value of the forecasts
Lessons Learned

Importance of Communication
• Project team members
• Users
Highlight:
A gauge-adjusted regionalized GPM satellite precipitation product has been produced for the Colorado River basin for the period September 2014 – August 2015.

Relevance:
The successful application of this methodology for the short time period shows that it can now be extended to produce a long-term regionalized GPM climatology for the Colorado River Basin.

Figure 4 Initial bias-corrected PMW data (far left) and gauge data (center left) used to produce the gauge adjusted precipitation (center right), as well as the difference between the gauge adjusted and bias-corrected data (far right).

ESD Applied Sciences – (Water Resources)
Highlight:
The Utah Energy Balance (UEB) model water balance at Cascade SNOTEL station in the Animas River Watershed

Relevance:
The UEB model produces a significantly different water balance in the Animas basin than the temperature index SNOW-17 model. The difference is that the UEB model estimates sublimation losses of about 200 mm/year.

An improvement in the ability of the UEB model to capture the actual water balance may impact the ability of the model to benefit from snow data assimilation.

Note: The UEB sublimation component was evaluated in Mahat et al., 2013 where in 2 months (March and April) 63 mm of sublimation was measured using Eddy-Covariance at a different site also in Rocky Mountains indicating 200 mm/year is reasonable.

Highlight:
- RTI developed a novel approach to estimate observed distributed SWE, and associated standard errors, through the merging of ground and satellite observations (figure 9)
- RTI implemented a distributed snow data assimilation framework around the distributed hydrologic model using an Ensemble Kalman Filter.

Relevance:
Approximately 85% of the annual runoff in the Colorado River Basin is produced from snowmelt. By leveraging remote sensing datasets, and this snow data assimilation framework, additional skill is added to the April-July water supply forecast compared to the open-loop control run and historical CBRFC forecast for the majority of sample years (figure 10).

Figure 9. Snow Data Assimilation Product

Figure 10. (a) displays a single trace (single ensemble member) comparison, figure (b) shows the full updated ensemble of traces, and (c) shows a cumulative distribution function of the April-July forecast volumes computed from the full ensemble.
Highlight:
Implementation of an Ensemble Kalman Filter to perform Snow Data Assimilation

Relevance:
An Ensemble Kalman Filter is used to propagate the uncertainty of the snowpack states and to update SWE based on gridded SWE estimated from SNOTEL SWE and MODSCAG.

The result is a more accurate ensemble forecast of water supply that reflects both model and future forcing uncertainty that can be used by water managers for risk-based decision making.
Publications/Presentations


• 2016 AGU Fall Meeting presentations –
  • “Assimilation of ground and satellite snow observations in a distributed hydrologic model to improve water supply forecasts in the Upper Colorado River Basin”, Session H057: Hydrologic Data Assimilation.
  • “Utilization of Expert Knowledge in a Multi-Objective Hydrologic Model Automatic Calibration Process”, Session H44B: General Surface Hydrology II.