WRF-Hydro/ASO Ensemble Seasonal Water Supply Forecasting for California, Colorado and Utah: WY 2024

Airborne Snow Observatories, Inc.

June 3, 2024
Outline & Acknowledgements:

- Overview of forecasting domains
- Forecasting Process using NoaMP/WRF-Hydro
- Sample results for 2024 to date...

- ASO Hydrologic Prediction/Modeling Team:
  - Logan Karsten
  - Dave Gochis
  - Broader ASO team for snow products...

- WRF-Hydro team at NCAR:
  Y. Zhang, M. Casali, J. Grim, A. Gaydos, R. Rozenswieg-Abolafia, A. Dugger, K. Sampson
WY2024 Supported WRF-Hydro Forecast Basins

- Feather River Basin
- Truckee River Basin
- Yuba River Basin
- Carson River Basin
- Tuolumne River Basin
- Merced River Basin
- San Joaquin River Basin
- King’s River Basin
- Tracking ASO snowpack assimilation in:
  - American River Basin
  - Kaweah River Basin

Model domain extent
WRF-Hydro Colorado ESP: WY2024 Seasonal Water Supply Forecasts
WY2024 Supported WRF-Hydro Forecast Basins

- Provo River Basin
- West Fork Duchesne River Basin
- Duchesne River Basin
- Rock Creek Basin
- Currant Creek Basin
- Strawberry River Basin
WRF-Hydro based forecast process:

- **Assimilation-Prediction Workflow:**
  1. Downscale and bias correct long-term meteorological data records (hourly downscaled observed analyses of meteorological data)
  2. Calibrate model to hourly streamflow/inflow at over unregulated stations across CO/CA headwater basins
  3. Regionalize model parameters from calibration basins to rest of CA/CO domains
  4. Execute long-term retrospective run for spin-up and for statistical referencing (homegrown optimal-blend analysis forcings)
  5. Assimilate ASO-observed snowpack (past: direct insertion, next: AEnKF-like)
  6. Execute operational and research ensemble water supply forecasts and products (enhanced ensemble generation and weighting)
WRF-Hydro-ASO Data Assimilation: California Example

1. Direct Insertion Process:

1. 50m ASO SWE&depth
2. 1km SWE & depth

3. Insert and re-initialize WRF-Hydro/NoahMP snow States into “cold-start” version

- Init: depth & SWE
- Derive density
- Re-derive layers
- Re-initialize temperature

4. Insert updated states into full regional forecast domain

• **Pros:** Simple, fast, computationally-lean, preserves ASO survey values
• **Cons:** Model likely not fully equilibrated, can have large mass-discontinuities across assimilation
• Will do additional manual DA when large assimilation increments are present…
• **Moving to an ensemble DA process…**

2. Ensemble DA Process: *(see also Lahmers et al., 2021, Tuolumne)*

- Robust ensemble: parameters, forcings, physics
- LIS-based AEn-KF
- DART-based AEn-KF
- Optimal analysis from ensemble
- Blend into full domain with other Basins…
Airborne Snow Observatories, Inc. is a public benefit corporation with a mission to provide high-quality, timely, and accurate snow measurement, modeling, and runoff forecasts to empower the world's water managers to make the best possible use of our planet's precious water.

Historical data and reports can be found at: data.airbornesnowobservatories.com

WY2024 WRF-Hydro Forecast Reports

TUOLUMNE RIVER BASIN
FEB. 6, 2024 HYDROLOGIC FORECAST

Snowpack Status:

Table 1.

<table>
<thead>
<tr>
<th>Basin</th>
<th>Estimated SWET volume [kac-F]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNODAS</td>
<td>52.2 340</td>
</tr>
<tr>
<td>ASO-optimized</td>
<td>52.9 318</td>
</tr>
<tr>
<td>Openair</td>
<td>51.8 343</td>
</tr>
</tbody>
</table>

Modeled Evapotranspiration:

Summary of evapotranspiration consumption:

**[PLACEHOLDER ...narrative... narrative]**

Figure 1. WRF-ASO model forecasted net evapotranspiration (mm) for the month of February 2024.
Snowpack Analyses: Yuba River Basin...
Snowpack Analyses: Yuba River Basin

Figure 1. Left: WRF-Hydro/ASO-assimilated, Right: OpenLoop 1km gridded Snow Water Equivalent (SWE - inches). Valid: Apr. 23, 2024
Snowpack Analyses: Yuba River Basin

**Figure 4.** Basin-avg SWE from WRF-Hydro OpenLoop, ASO-assimilated and SNODAS (kac-ft)

**Figure 6.** WRF-Hydro model analyzed and ensemble mean forecasted SWE. Valid: Apr. 23, 2024

<table>
<thead>
<tr>
<th>Basin</th>
<th>Estimated SWE volume (kac-ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNODAS</td>
<td>766.163</td>
</tr>
<tr>
<td>ASO-assimilated</td>
<td>554.154</td>
</tr>
<tr>
<td>OpenLoop</td>
<td>379.611</td>
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</tbody>
</table>
Snowpack Analyses: Yuba River Basin...

Springtime Elevation Evolution...

ESP - California: Yuba Basin, 2024-04-23 06z

- Model - OL
- Model - ASO DA
- SNODAS
Snowpack Thermal analysis: Yuba River...

Snowpack Temperature Animation

03/03/2024 00:00 UTC

[Map showing temperature distribution along the Yuba River]
Snow Albedo (VIZ): San Joaquin Basin
Snowpack Analyses: Yuba River Basin...

**Figure 7.** WRF-Hydro model forecasted basin-integrated ensemble mean accumulated snowmelt (inches) from OpenLoop and ASO-assimilated version.
ASO WRF-Hydro Ensemble Seasonal Runoff Forecasts:

Ensemble Traces...

2024 Yuba R nr Smartville DWR ID: YRS

Accumulated Flow (thousands of acre-feet)

Forecast (Days)

January, March, May, July, September
ASO WRF-Hydro Ensemble Seasonal Runoff Forecasts:

Runoff/Inflow Forecast Information...

Forecast Tables...

<table>
<thead>
<tr>
<th>Forecast Date</th>
<th>Mean</th>
<th>Q90</th>
<th>Q75</th>
<th>Q50</th>
<th>Q25</th>
<th>Q10</th>
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</thead>
<tbody>
<tr>
<td>Apr 05, 2024 (OLI)</td>
<td>915.654</td>
<td>729.438</td>
<td>809.662</td>
<td>890.272</td>
<td>1032.979</td>
<td>1131.911</td>
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<tr>
<td>Apr 08, 2024 (ASO)</td>
<td>1012.847</td>
<td>821.302</td>
<td>908.147</td>
<td>988.378</td>
<td>1132.819</td>
<td>1229.371</td>
</tr>
<tr>
<td>Apr 14, 2024 (OLI)</td>
<td>868.537</td>
<td>746.133</td>
<td>780.322</td>
<td>838.608</td>
<td>924.063</td>
<td>1034.854</td>
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<tr>
<td>Apr 14, 2024 (ASO)</td>
<td>973.616</td>
<td>850.908</td>
<td>881.866</td>
<td>942.575</td>
<td>1030.029</td>
<td>1140.814</td>
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<tr>
<td>Apr 23, 2024 (OLI)</td>
<td>870.642</td>
<td>782.928</td>
<td>805.889</td>
<td>823.211</td>
<td>883.638</td>
<td>1019.130</td>
</tr>
<tr>
<td>Apr 23, 2024 (ASO)</td>
<td>993.234</td>
<td>901.591</td>
<td>928.188</td>
<td>944.817</td>
<td>1095.707</td>
<td>1141.692</td>
</tr>
</tbody>
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Dot plots...
ASO WRF-Hydro Ensemble Seasonal Runoff Forecasts:

More Dot plots...
Soil Moisture Analyses: San Joaquin Basin

WRF-Hydro Soil Saturation  Apr. 1 – May 28, 2024

ESP - California: San Joaquin Basin, 2024-05-28 06z

Basin-averaged Soil Saturation
San Joaquin
ASO WRF-Hydro Projected Seasonal ET:

WRF-Hydro ET Forecast ending Jul 31, 2024:

Basin-averaged Evapotranspiration Yuba

Evapotranspiration (KAF)

Apr 2024 May 2024 Jun 2024 Jul 2024 Aug 2024 Sep 2024

Model OL
Model ASO
OL - 04/23 00z
ASO - 04/23 00z

0 in 11.81
Thank you

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ASO, Inc.
david.gochis@airbornesnowobservatories.com
WY2024 WRF-Hydro Forecast Report: San Joaquin Basin

Table 1. Valid: May 28, 2024

<table>
<thead>
<tr>
<th>Basin</th>
<th>Estimated SWE volume (kac-ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNOCAS</td>
<td>206,837</td>
</tr>
<tr>
<td>ASO-assimilated</td>
<td>376,144</td>
</tr>
<tr>
<td>OpenLoop</td>
<td>327,640</td>
</tr>
</tbody>
</table>

Snow Water Equivalent (Apr 1 – May 28)