Colorado Airborne Snow Measurement Program
Airborne Snow Observatory overview & 2022 data

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Airborne Snow Observatories, Inc.
Erik Skeie
Colorado Water Conservation Board

COLOrado Airborne Snow Measurement Program

ASO 3m Snow Depth
Quandry Peak, CO
18 April 2021
outline

CASM Working Group
Airborne Snow Observatory: why / what / how / where
2022 Colorado program results to-date
Upcoming activities & CASM program build-out
Colorado Airborne Snow Measurement Program

Formed in 2020
  • Leadership: Denver Water; Northern Water; Dolores WCD; Lynker; ASO, Inc.

WSRF funded to engage stakeholders & produce report
  • Letters of support from all Roundtables
  • >100 engaged stakeholders regularly participating
  • Report out soon: details program need & sustained pathway

2022 Water Plan Grant program expansion
  • Leveraging local & federal program match funds
  • Added snow-on flights in CO Headwaters, upper Gunnison, Dolores, Conejos
  • Snow-free data development in summer 2022 to expand “shovel-ready” basins
  • Outreach & data workshops

Foundation & pathway for a sustained program
  • State/federal partnership
  • Collaborations with forecast agencies
Decision-making with uncertainty

Rio Grande @ Del Norte
June Forecast & measured Apr-Sept Volumes

- Over-forecast: risk of compact shortage
- Under-forecast: unnecessary curtailment

<table>
<thead>
<tr>
<th>Year</th>
<th>June Forecast</th>
<th>Observed</th>
<th>Forecast - Obs</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>795</td>
<td>683</td>
<td>+112 16%</td>
</tr>
<tr>
<td>2006</td>
<td>350</td>
<td>412</td>
<td>-62 -15%</td>
</tr>
<tr>
<td>2007</td>
<td>450</td>
<td>593</td>
<td>-143 -24%</td>
</tr>
<tr>
<td>2008</td>
<td>655</td>
<td>623</td>
<td>+32 5%</td>
</tr>
<tr>
<td>2009</td>
<td>490</td>
<td>513</td>
<td>-23 -5%</td>
</tr>
<tr>
<td>2010</td>
<td>485</td>
<td>455</td>
<td>+30 6%</td>
</tr>
<tr>
<td>2011</td>
<td>435</td>
<td>415</td>
<td>+20 5%</td>
</tr>
<tr>
<td>2012</td>
<td>352</td>
<td>328</td>
<td>+24 7%</td>
</tr>
<tr>
<td>2013</td>
<td>230</td>
<td>344</td>
<td>-114 -50%</td>
</tr>
<tr>
<td>2014</td>
<td>420</td>
<td>519</td>
<td>-99 -24%</td>
</tr>
<tr>
<td>2015</td>
<td>385</td>
<td>556</td>
<td>-171 -31%</td>
</tr>
<tr>
<td>2016</td>
<td>475</td>
<td>566</td>
<td>-91 -16%</td>
</tr>
<tr>
<td>2017</td>
<td>535</td>
<td>574</td>
<td>-39 -7%</td>
</tr>
</tbody>
</table>

[Data courtesy Craig Cotton, CO DWR Division 3 Engineer]

Airborne Snow Observatories, Inc.
A Public Benefit Corporation
Snow stations used for statistical forecasting, not SWE volume
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Snow stations used for statistical forecasting, not SWE volume
Operational forecast models are vulnerable to changing conditions...

...and conditions are changing

Change factors include:
- Warming temperatures
- Snow season duration
- Rain/snow fraction
- Mid-winter melt
- Rain-on-snow
- Wildfire
- Beetle-kill
- Dust on snow

* Forecast methods based on historic data assume that calibrations apply to current conditions
Snowmelt timing & volume is controlled by SWE patterns & snow albedo

Accurate, full-basin SWE & albedo can reduce forecast uncertainty
• Decrease reliance on historic record
• Avoid assumptions about how stations represent basin water volume
• Put existing networks to work in new ways
Airborne Snow Observatories, Inc.
mapping the two most critical snow properties to forecast runoff volume & timing

**Snow Water Equivalent**
Snow depth from elevation mapping with Riegl VQ1560II-S
SWE from insertion of obs & modeled density

**Snow Albedo**
HySpex VSWIR Spectrometers
Snow properties retrieval

**Physical Modeling**
Coupled lidar & spectrometer measurements
Snowpack process modeling

**Operations**
Unique high-altitude operations
Unique rapid product turnaround
California & Colorado parallel applications development

**California**
- 350+ snow-on flights since 2013 in 10 basins
- *Operationally* mapping southern Sierra SWE volume
- Continuing program in southern & central Sierra, building to full-state coverage over next 2 years

**Colorado**
- Numerous NASA, State, & Local projects since 2013
- CASM Stakeholder group defining a sustainable statewide program

**Westwide & Global**
- WRF-Hydro assimilation & runoff forecasting
- USBR projects in NV, WY, AZ
- Norway hydropower
San Joaquin River: Restoration flows for salmon
- ASO data used in forecast for USBR Fish Recovery Program
- Improved accuracy enables restoration flows & re-watering lower San Joaquin
- Early forecast accuracy key to achieving flow factors & summer supply reliability

**Kings River 2019:**
Managing supply & flood risk
- Flood declaration: Army Corps takes over Pine Flat Dam ops & operates solely to protect infrastructure
- 2019: ASO forecast allowed KRWA to operate on 10% exceedance

<table>
<thead>
<tr>
<th>Environmental Flow Factor</th>
<th>Important Water Years</th>
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<tbody>
<tr>
<td>1) Restoration Flow Scheduling</td>
<td>Critical through Normal-Wet</td>
</tr>
<tr>
<td>2) Temperature Management</td>
<td>Normal-Dry through Wet</td>
</tr>
<tr>
<td>3) Flood Flow Ramp-Down</td>
<td>Normal-Wet, Wet</td>
</tr>
<tr>
<td>4) Groundwater Management</td>
<td>Normal-Wet, Wet</td>
</tr>
</tbody>
</table>

**Operational guidance: California**

<table>
<thead>
<tr>
<th>Forecasts</th>
<th>Apr-Jul Runoff Forecast Exceedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA DWR</td>
<td>10%: 2.1 MAF, 50%: 1.8 MAF, 90%: 1.6 MAF</td>
</tr>
<tr>
<td>NOAA RFC</td>
<td>10%: 2.3 MAF, 50%: 2.1 MAF, 90%: 1.9 MAF</td>
</tr>
<tr>
<td>ASO</td>
<td>10%: 2.5 MAF</td>
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</table>

**Saved 100 TAF or ~$100M of water**

“ASO provides invaluable information that is not otherwise available, most importantly information about the rate of melt that provides a real opportunity to optimize reservoir operations for water supply, flood control, and instream requirements.”

Steve Haugen, Watermaster, Kings River Water Association
Water Year 2019
Blue River Basin

Denver Water

- 2019 Flights: April 19 & June 24
- May + June storms maintained high elevation snowpack
- SNOTELs snow-free on June 28
- June 24 flight SWE volume: 115 TAF
  - half of total inflow left to melt
  - enabled response to double flow peak

ASO Blue River: SWE by Elevation

SNOTEL Snowpack above Dillon Reservoir

Dillon Reservoir Inflow (cfs)
WY 2022 Colorado Program

Surveys Completed To-date:
- Dolores River: April 15 & May 10
- Conejos River: April 15 & May 10
- CO River @ Windy Gap: April 18
- Blue River @ Dillon: April 19
- East R. @ Almont: April 21 & May 18*
- Taylor R. @ TPR: April 21

Data freely accessible at: data.airbornesnowobservatories.com
2022 April ASO Flights

<table>
<thead>
<tr>
<th>April 18-21 Surveys</th>
<th>CO River @ Windy Gap</th>
<th>Blue River @ Dillon</th>
<th>East River @ Almont</th>
<th>Taylor River @ Taylor Park Res</th>
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<tr>
<td>Basin SWE (TAF)</td>
<td>369</td>
<td>150</td>
<td>177</td>
<td>119</td>
</tr>
<tr>
<td>Uncertainty range</td>
<td>351-387</td>
<td>146-154</td>
<td>168-186</td>
<td>113-125</td>
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Conejos River
April 15

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<thead>
<tr>
<th>Basin</th>
<th>Estimated SWE volume (TAF) April 15</th>
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<tr>
<td>Full Basin</td>
<td>169</td>
<td>60</td>
</tr>
<tr>
<td>Uncertainty range</td>
<td>161 - 177</td>
<td>56 - 64</td>
</tr>
<tr>
<td>Platoro Reservoir Inflow</td>
<td>51</td>
<td>27</td>
</tr>
<tr>
<td>Lower Basin</td>
<td>118</td>
<td>33</td>
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April 15

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<tr>
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<td>182 - 194</td>
<td>56 - 66</td>
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Dolores River
May 10

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SWE Volume (TAF)

April 15

May 10
Dolores River
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CASM Stakeholder engagement

Outreach & program planning survey *(detailed in report)*

- Highly engaged stakeholders
- Agreement that ASO will add value
- Strong interest in creating/funding program
- ASO would add confidence to annual operations and planning
- Incorporating ASO into forecasting is important
- Strong interest in stakeholder-led flight planning group
Expanding ASO applications: *operational models*

**NOAA River Forecast Center testing/evaluation**
- ASO SWE data nudges RFC forecast close to observed AJRO 2 months earlier than manual tuning

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<th>Source / Run Type</th>
<th>Volume</th>
<th>Percent of USGS</th>
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<td>USGS AJRO Volume (target)</td>
<td>29.1 KAF</td>
<td>100%</td>
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<td>35.2 KAF</td>
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**WRF-Hydro applications data assimilation**
- High elevation snow data from 24 May ASO assimilation reduces low forecast bias in ESP AJRO forecast

East River @ Almont

Taylor River @ Taylor Park

*courtesy Dave Gochis, NCAR*

*courtesy Pat Kormos, CBRFC*
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*East River @ Almont*  
*Taylor River @ Taylor Park*
Next Generation Water Management in CO

An integrated monitoring & forecasting system

Supporting evolving challenges & programs

- decision support information
- providing best snowpack data to experienced forecast teams
- realizing full potential of advanced model systems
- accurate SWE inventory for equitable decision-making
Colorado Airborne Snow Measurement Program

*Program Build-Out*

- Colorado’s Water Plan
- Stakeholder engagement
- New funding partnerships
- Federal collaboration
- Snow & runoff model refinement
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erik.skeie@state.co.us