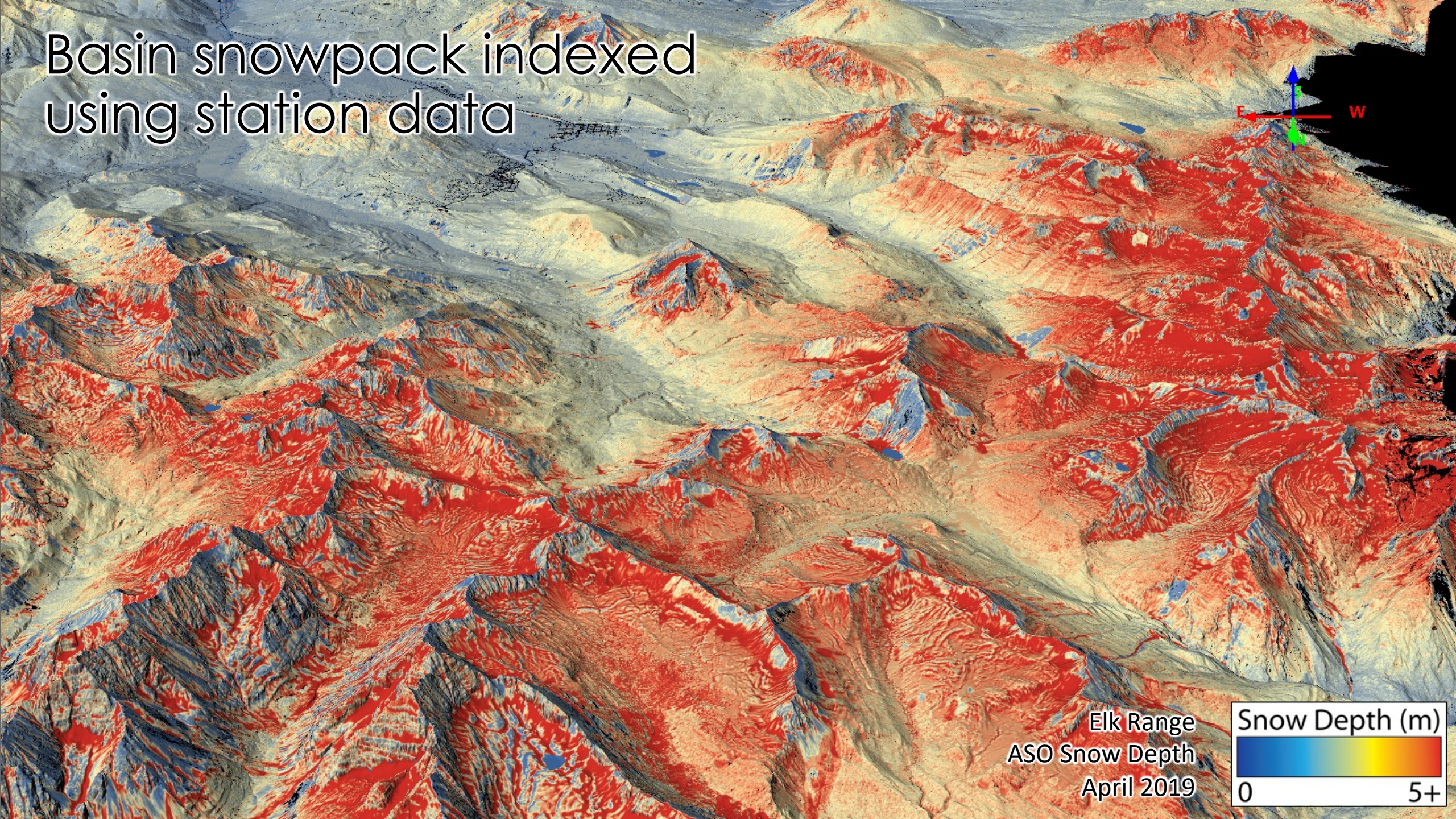
Colorado's Airborne Snowpack Monitoring Program

2023 operations & development update

Jeff Deems | Airborne Snow Observatories, Inc.

Basin snowpack indexed using station data



Basin snowpack indexed using station data

Elk Range
ASO Snow Depth
April 2019

Snow Depth (m)
0 5+

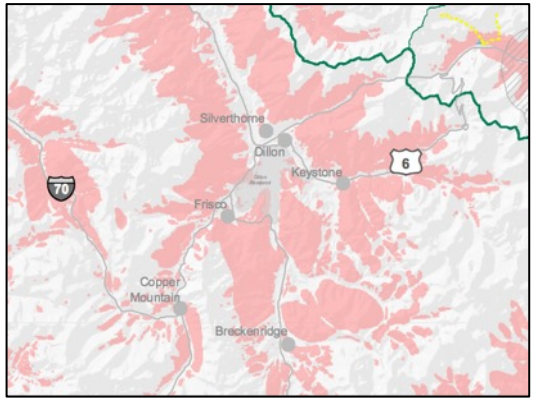
History is an increasingly poor guide to the future

- forecasts based on historic data assume a constant baseline
- forecast uncertainty requires a wide operating margin
- accurate & complete SWE monitoring is a foundation to minimize forecast uncertainty

Temperature & Precip changes

Dust-on-snow

Wildfire/Beetles



	April Forecast	Obs Inflow	% Difference
1999	120	197	-39%
2000	155	159	-2%
2001	150	146	3%
2002	59	57	4%
2003	170	173	-2%
2004	100	78	28%
2005	125	120	4%
2006	210	176	19%
2007	150	177	-15%
2008	200	195	2%
2009	180	192	-6%
2010	120	142	-15%
2011	225	272	-17%
2012	100	64	56%
2013	100	134	-25%
2014	250	242	3%
2015	166	202	-18%
2016	167	157	7%
2017	195	184	6%
2018	137	117	17%

Forecast > 10% Low | **Forecast > 10% High**

Airborne Snow Observatories, Inc.

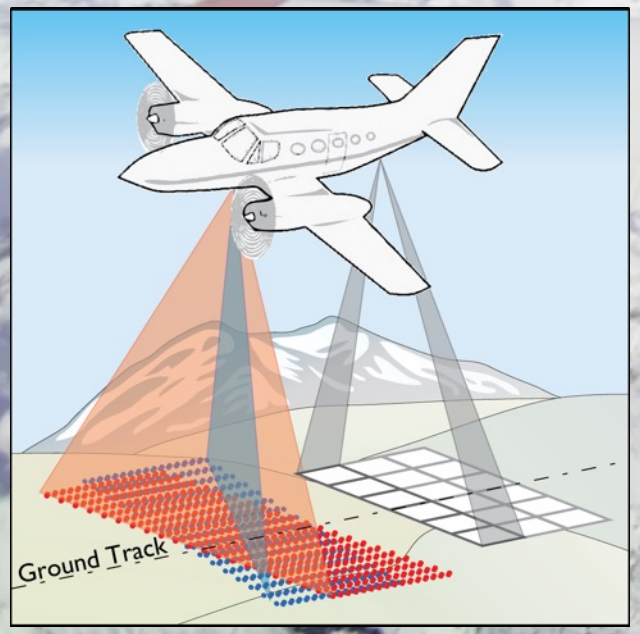
mapping the two most critical snow properties to forecast runoff volume & timing

Snow Water Equivalent

Snow depth from lidar elevation
SWE from coupling with obs & modeled density

Snow Albedo

HySpex VSWIR spectrometers
Albedo & surface properties



Physical Modeling

Coupled lidar & spectrometer
Physical snowpack & runoff modeling

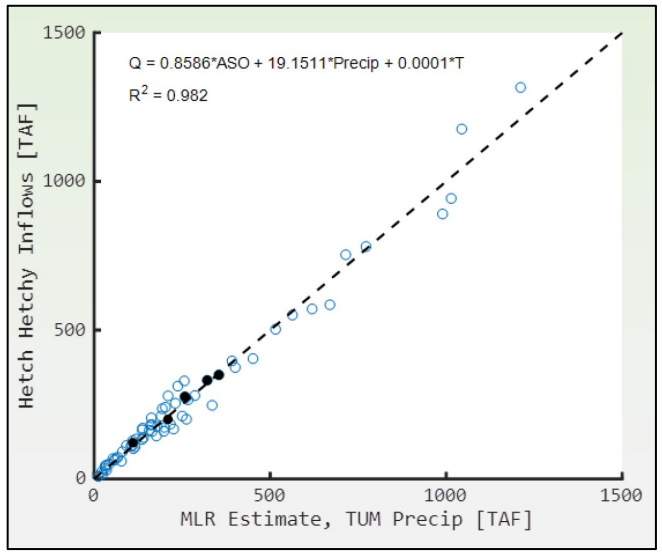
Operations

Unique high-altitude operations
Unique rapid product turnaround

Wide-range of decision-support applications

Multi-objective Reservoir operations

- Robust seasonal runoff predictor
- lower bound confidence allowed ecology flows in drought years



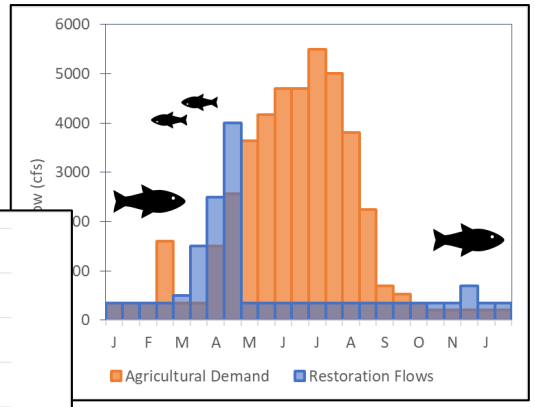
Proactive flood management

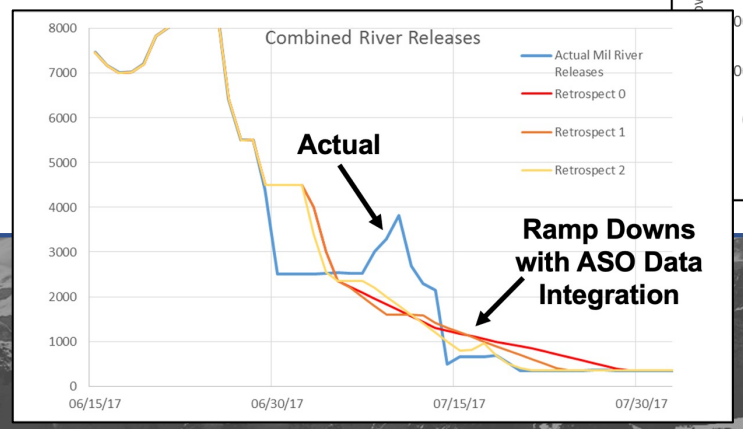
- Kings River, CA – 2019: flood designation avoided using ASO SWE volume guidance
- met water supply obligations
- avoided $100M water lease

Forecasts	Apr-Jul Runoff Forecast Exceedance		
	10%	50%	90%
CA DWR	2.1 MAF	1.8 MAF	1.6 MAF
NOAA RFC	2.3 MAF	2.1 MAF	1.9 MAF
ASO		2.5 MAF	

Ecologic & In-stream flows

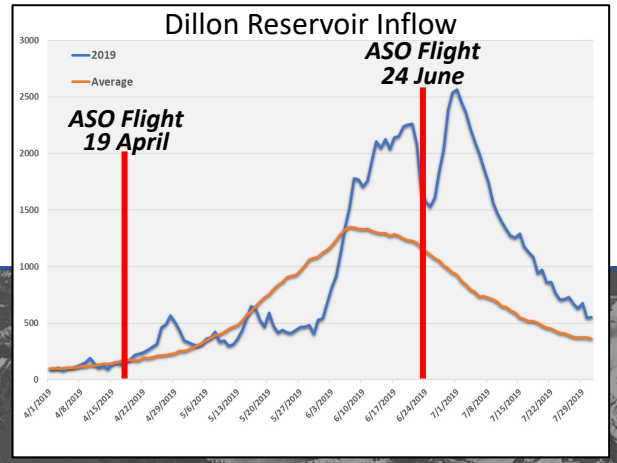
- fish flow timing
- dam release ramping

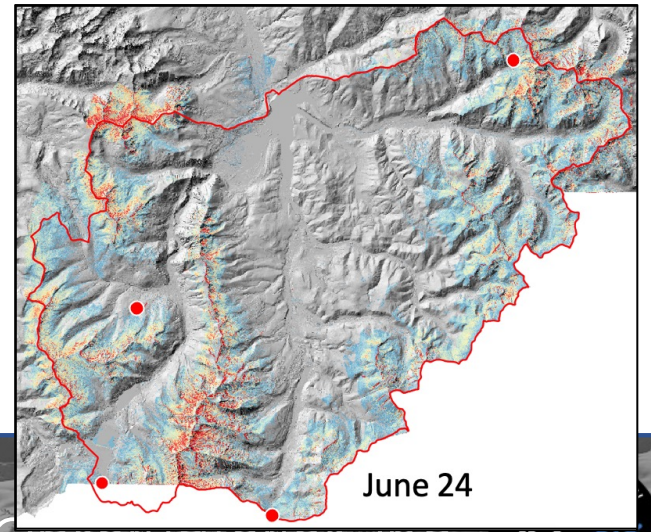




Reservoir operations timing

- Dillon Reservoir 2019
- captured 2nd runoff peak





ASO + CASM:
Building & sustaining the Colorado program

ASO → ASO, Inc.

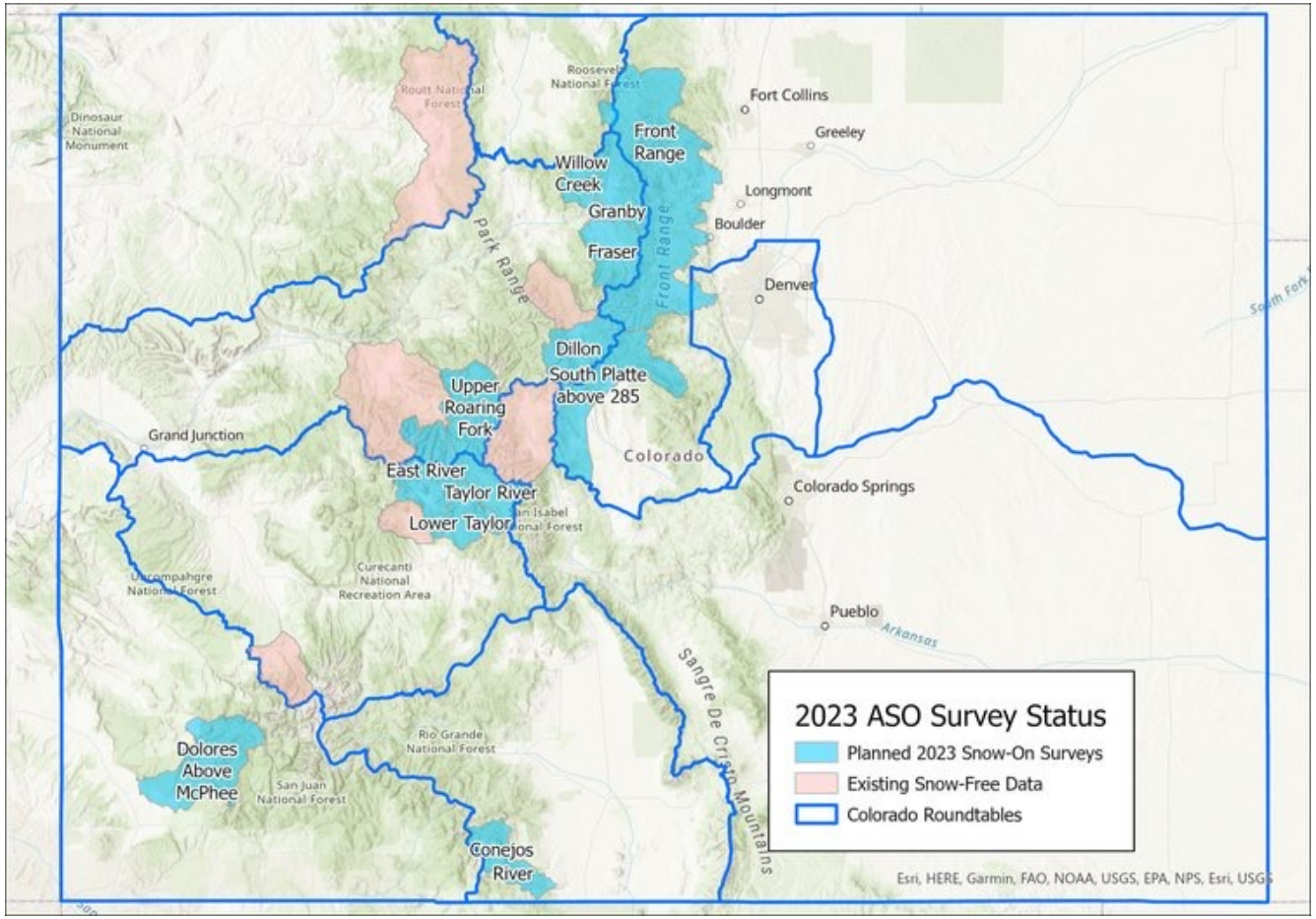
- CO legacy since 2013
- Forecast Improvement Project began 2015

WRF-Hydro runoff forecasting

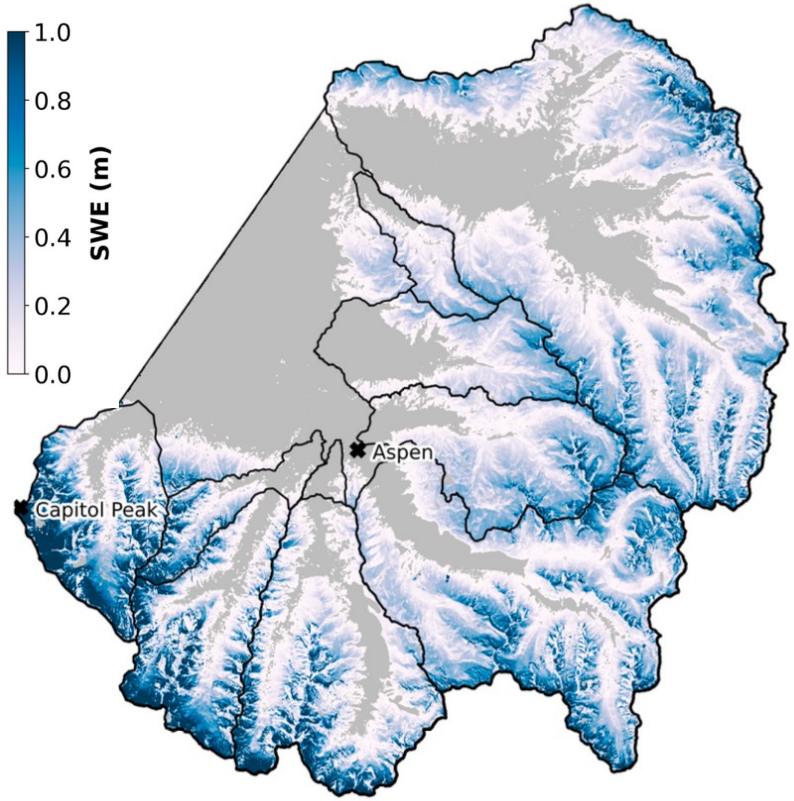
- CWCB support

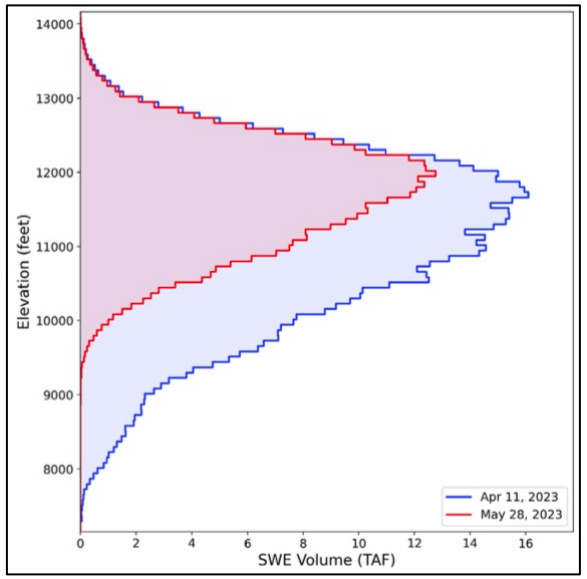
Colorado Airborne Snow Measurement Program (CASM)

- define & implement a sustained ASO program in CO
- stakeholder coordination
- survey schedule coordination
- coloradosnow.org

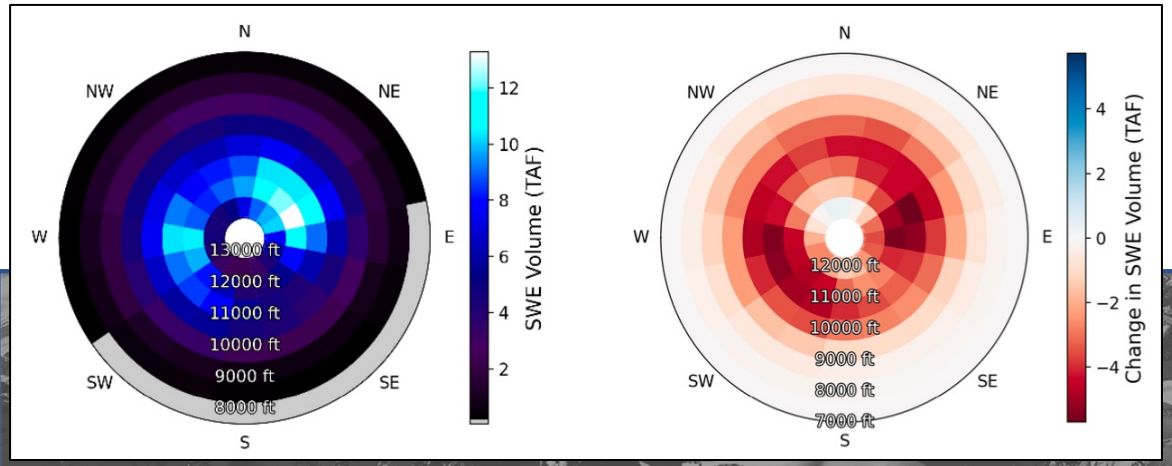


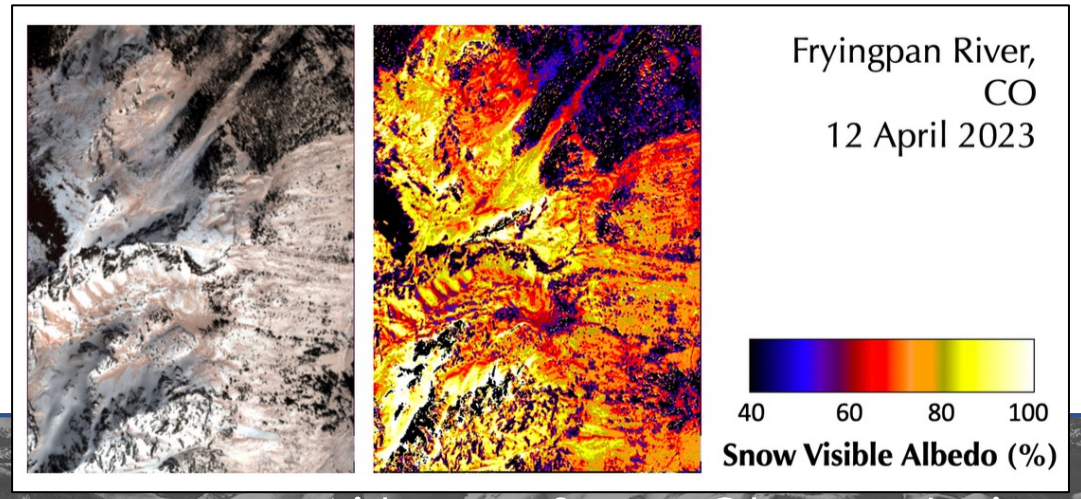
Roaring Fork Headwaters



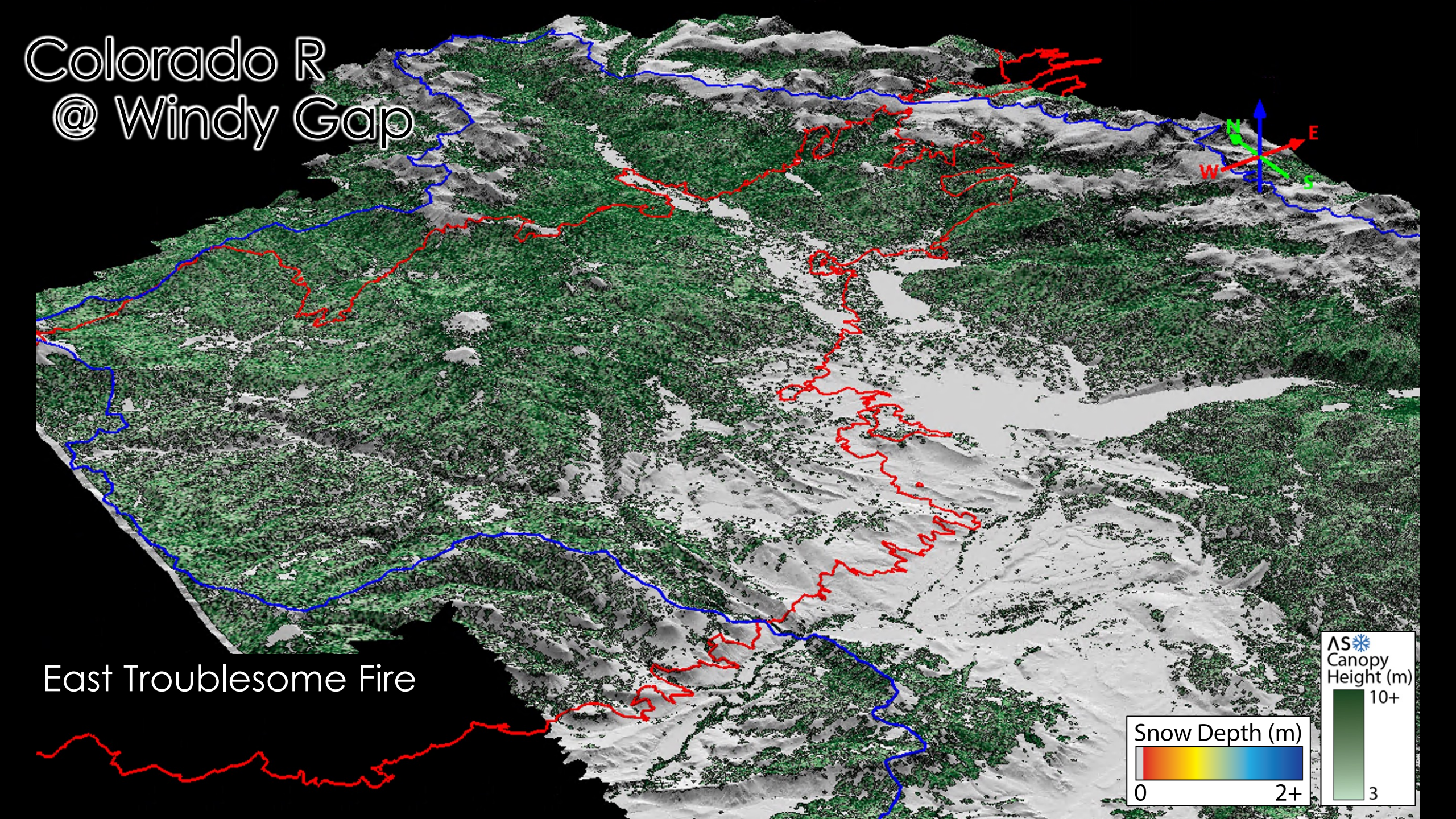


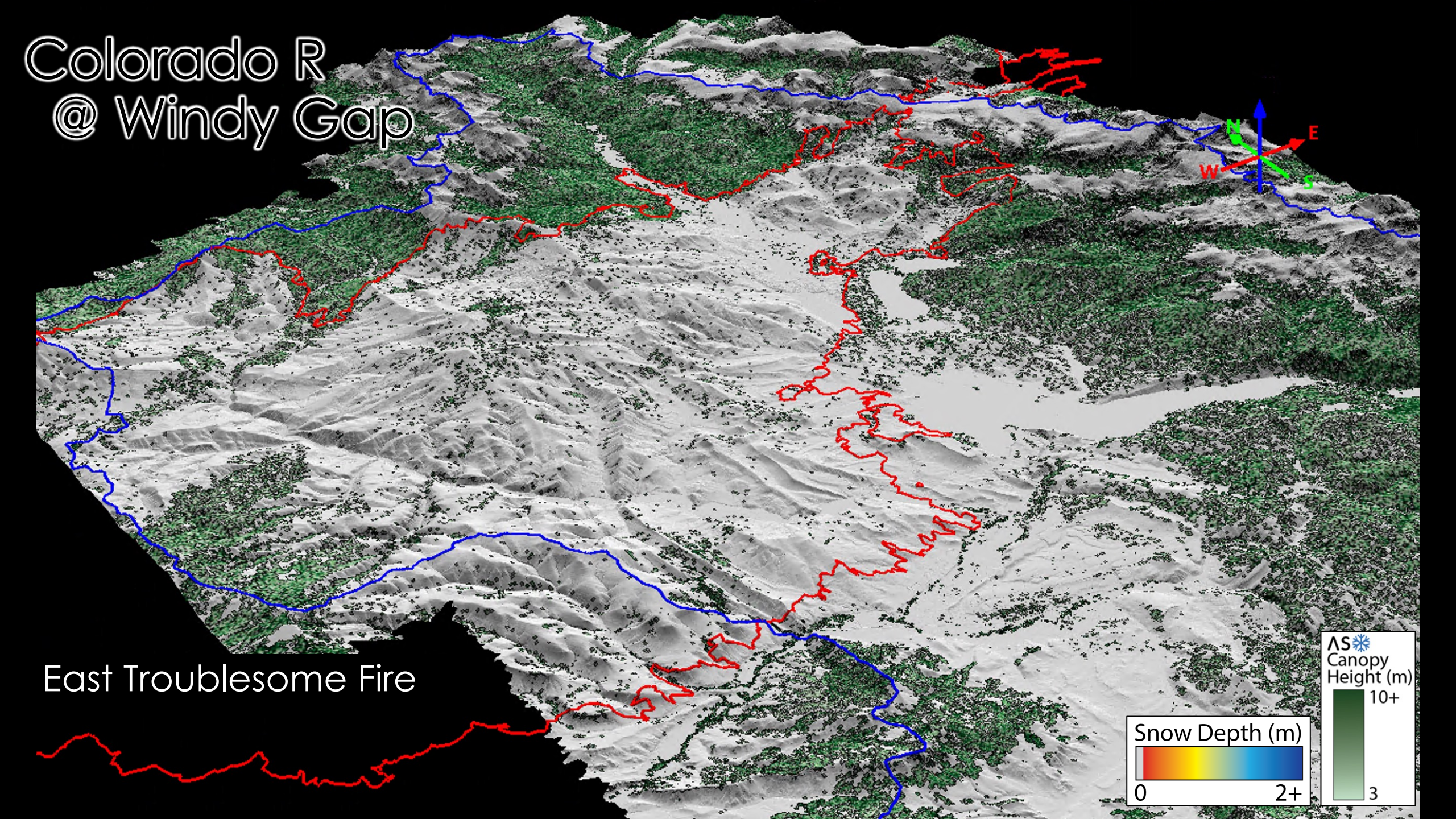
Basin	Estimated SWE (TAF) April 11-12	Estimated SWE (TAF) May 28
Roaring Fork & Fryingpan Headwaters	589	315
Uncertainty Range	*562 - 616*	*293 - 337*
Castle Creek above Aspen Diversion	66	37
Castle Creek at Highway 82	67	37
Fryingpan River above Reudi	187	86
Hunter Creek at Aspen	39	22
Maroon Creek above Aspen Diversion	58	35
Maroon Creek at Highway 82	74	45
Roaring Fork near Aspen	94	62
Rocky Fork Creek	10	4
Snowmass Creek	61	42
Woody Creek below Collins Creek	25	11





Airborne Snow Observatories, Inc.
A Public Benefit Corporation


Colorado R
@ Windy Gap
East Troublesome Fire
N
E
W
S
ΛS
Canopy
Height (m)
10+
3
Snow Depth (m)
0
2+


Colorado R
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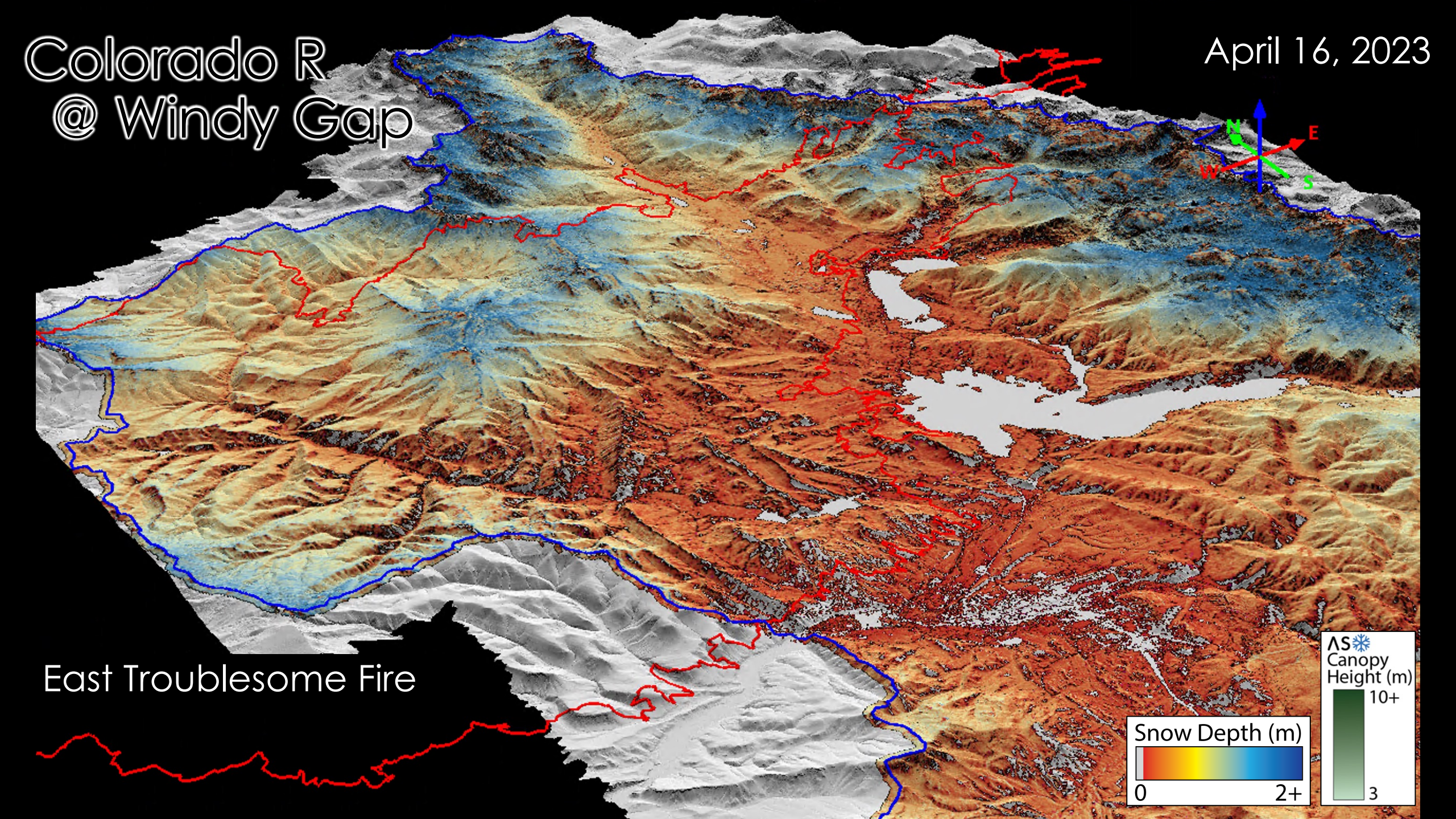
Colorado R
@ Windy Gap
April 16, 2023
N
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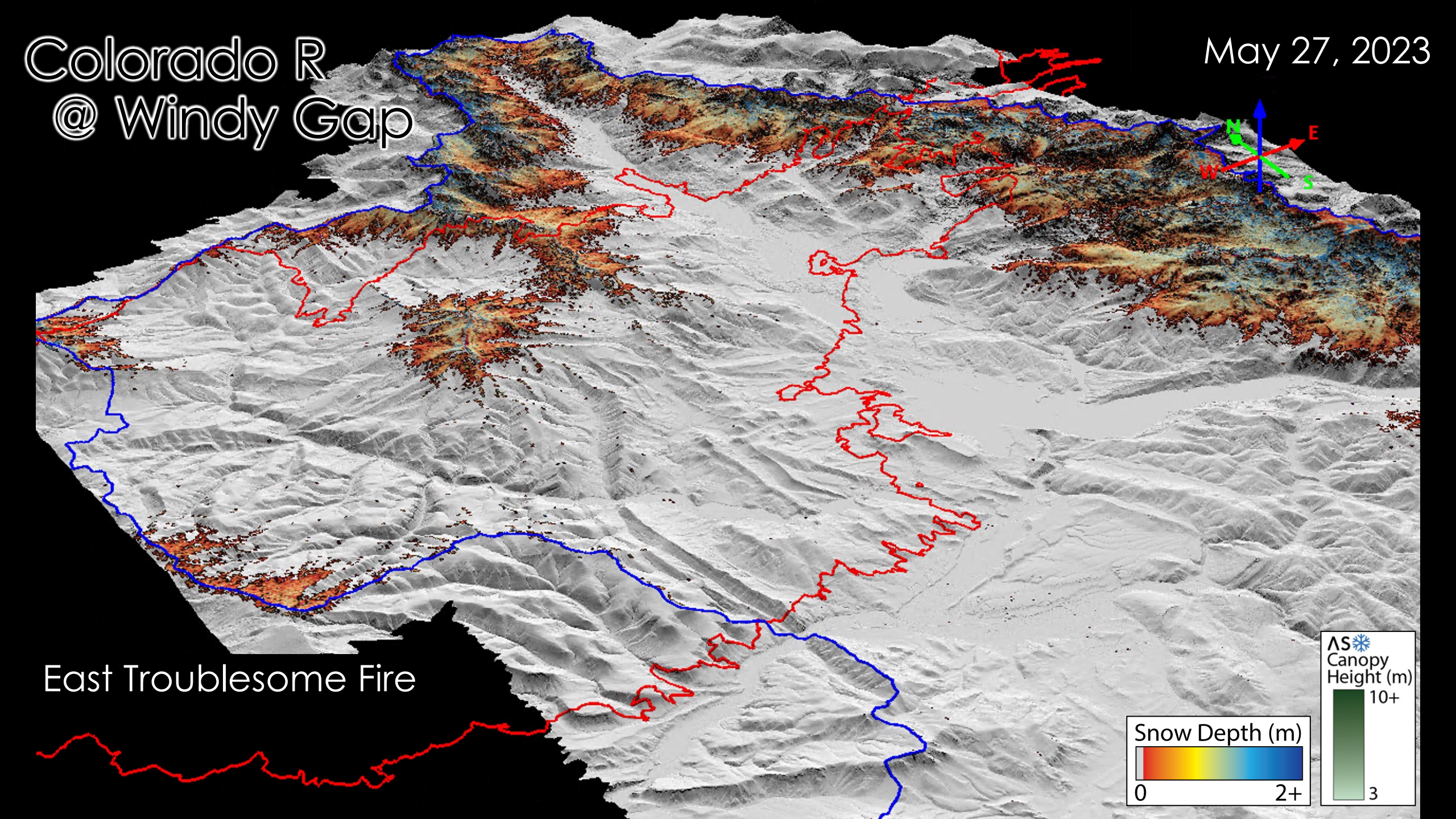
East Troublesome Fire
ΔS❄
Canopy
Height (m)
10+
3
Snow Depth (m)
0
2+


Colorado R
@ Windy Gap
May 27, 2023
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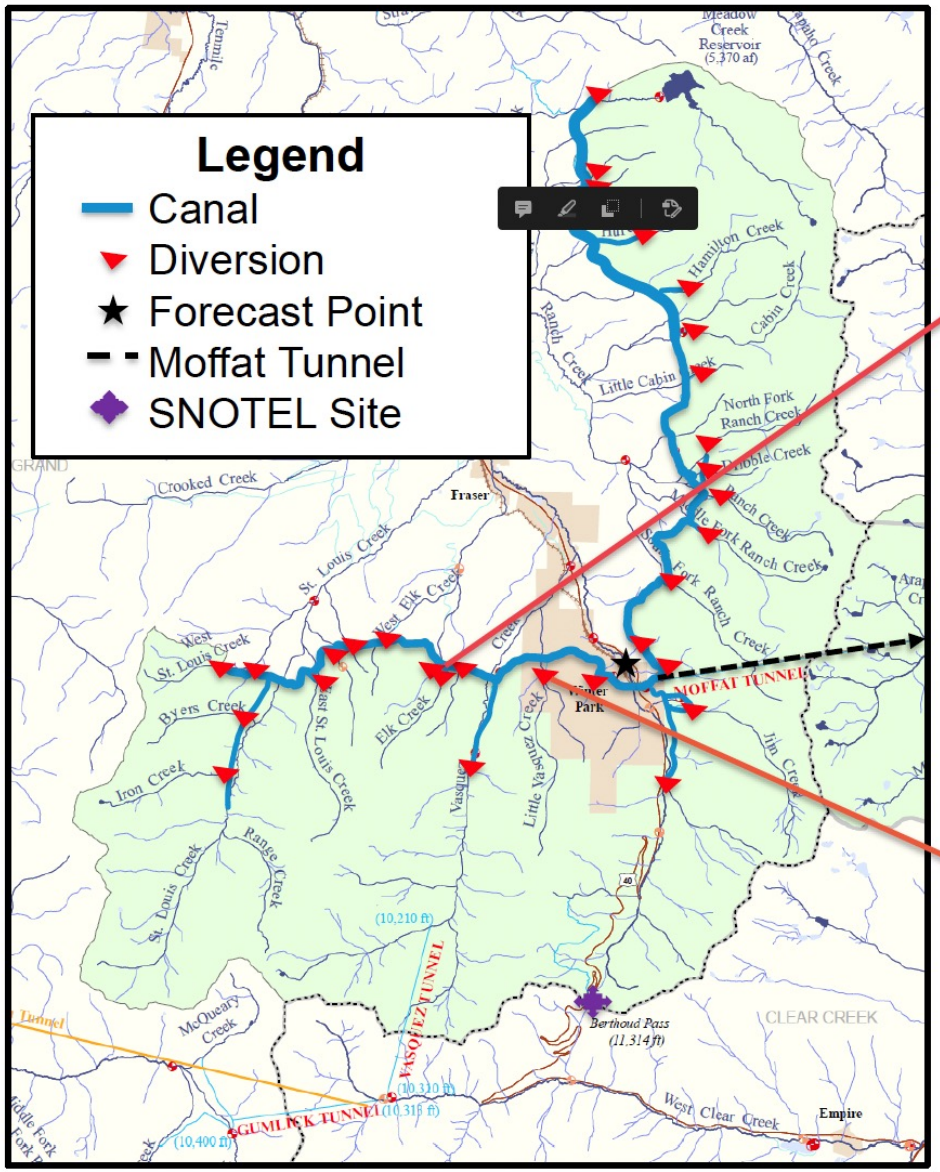
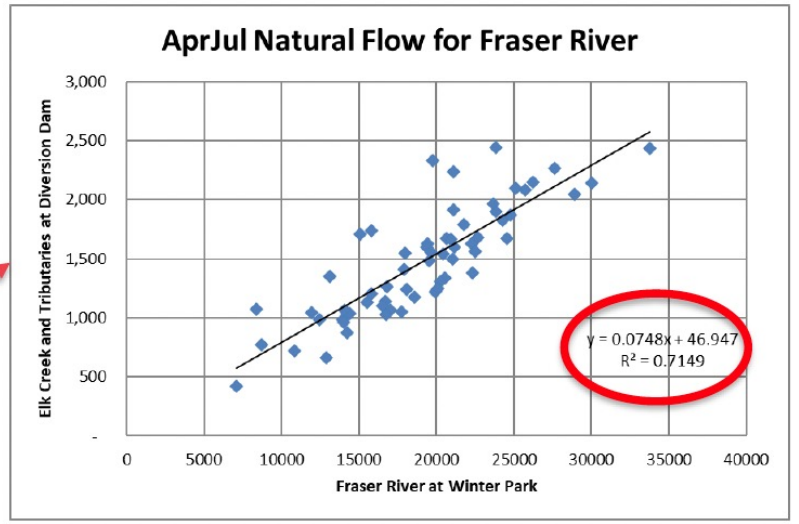
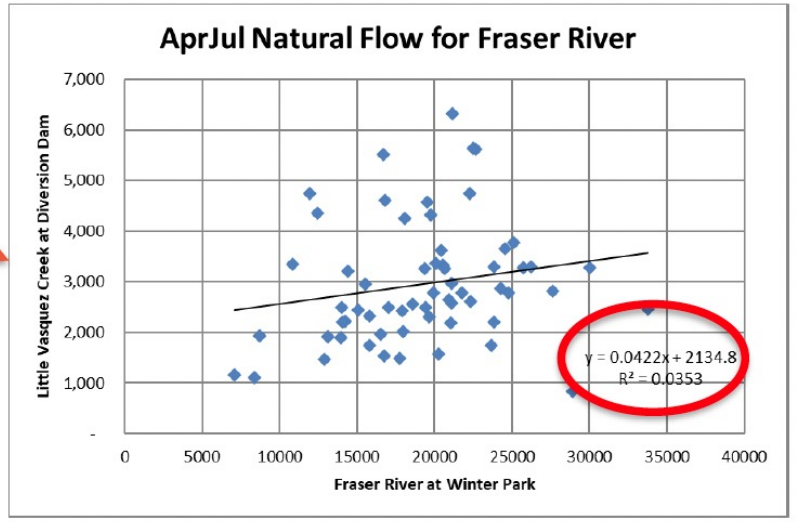
East Troublesome Fire
ΛS
Canopy
Height (m)
10+
3
Snow Depth (m)
0
2+

Fraser River Regression Forecasts

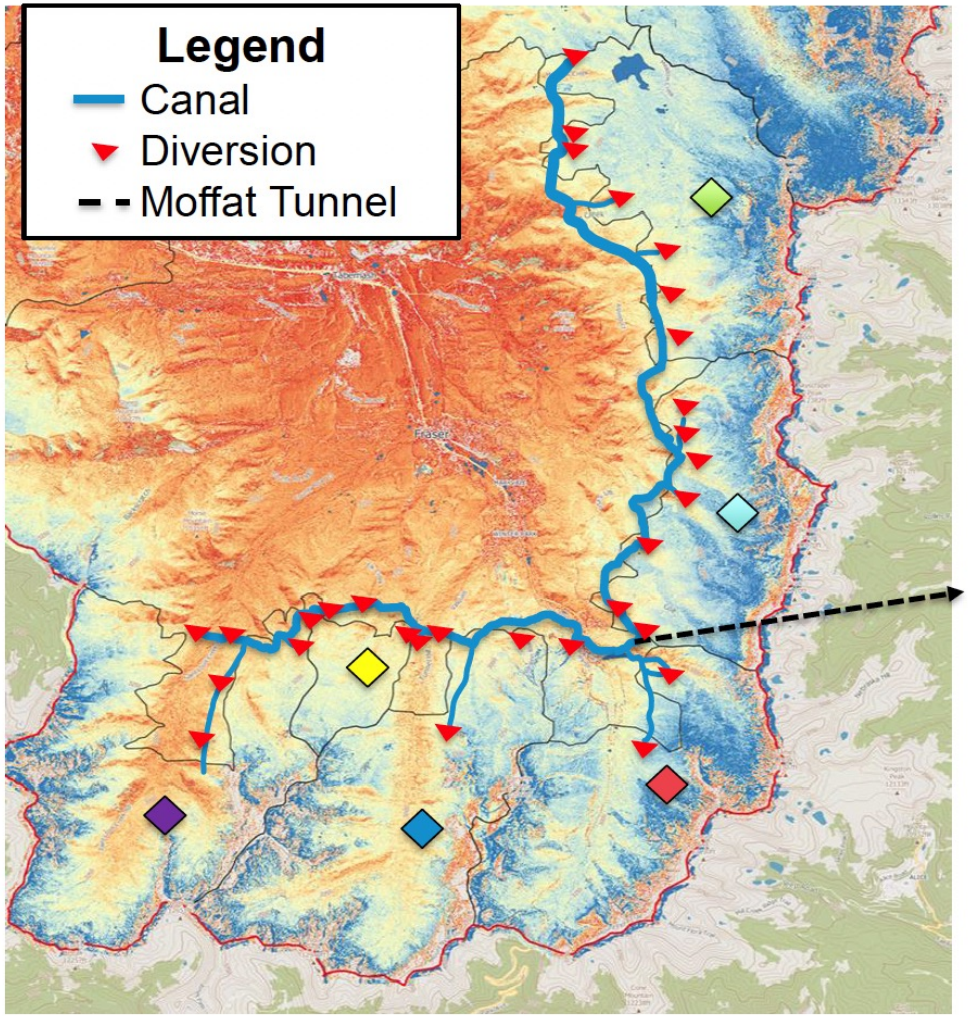






courtesy
Nathan Elder
Denver Water

Where to Spill? Fraser River ASO Applied

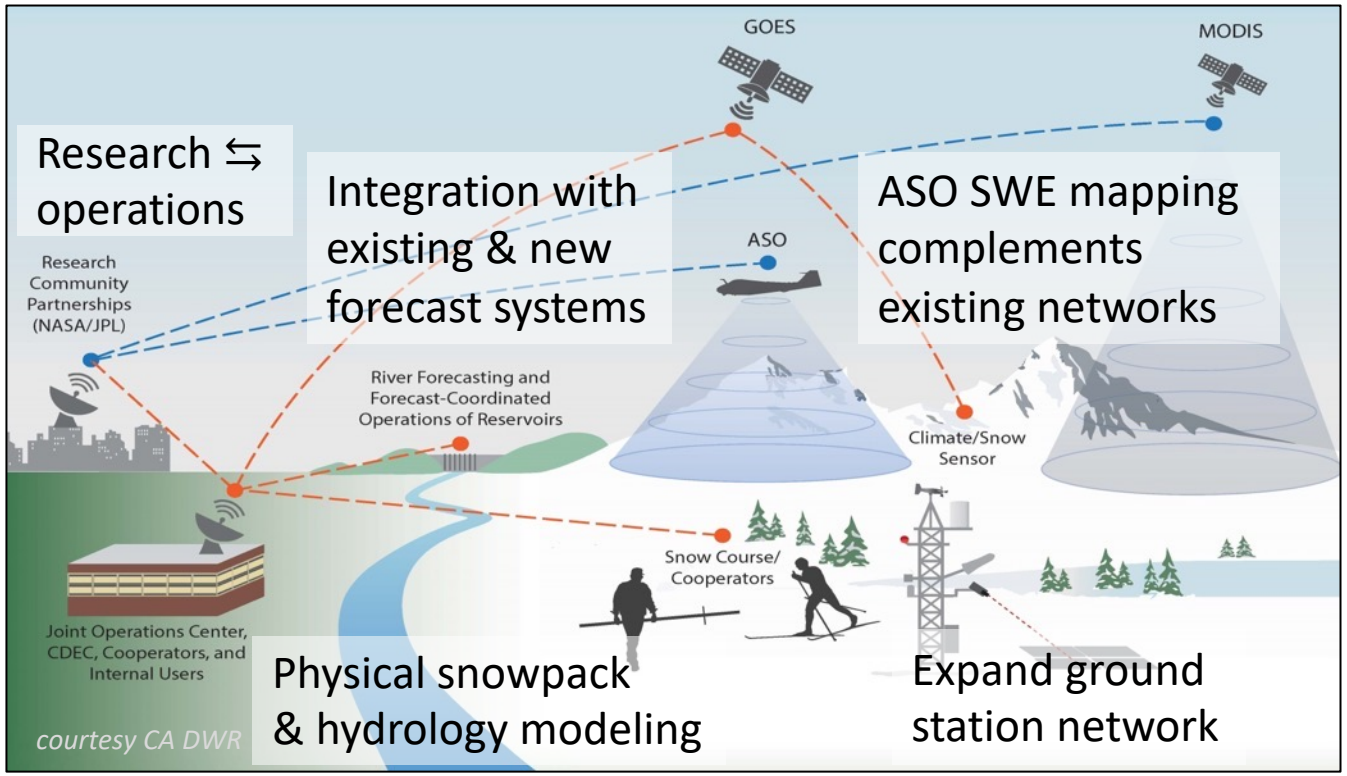


Basin	Estimated SWE (TAF) April 16
Colorado River at Windy Gap	533
Uncertainty Range	*514 - 552*
Colorado River below Lake Granby	262*
Elk Creek	3
Fraser River above Parry Creek	19
Fraser River at Granby	167*
Fraser River below Crooked Creek	141
Meadow Creek	17
Moffat Collection System	104*
Ranch Creek	14
St Louis Creek	20
Vasquez Creek	19
Willow Creek above Willow Creek Reservoir	93

courtesy
Nathan Elder
Denver Water

Enabling Next Generation Water Management

An integrated monitoring & forecasting system



Evolving challenges & programs

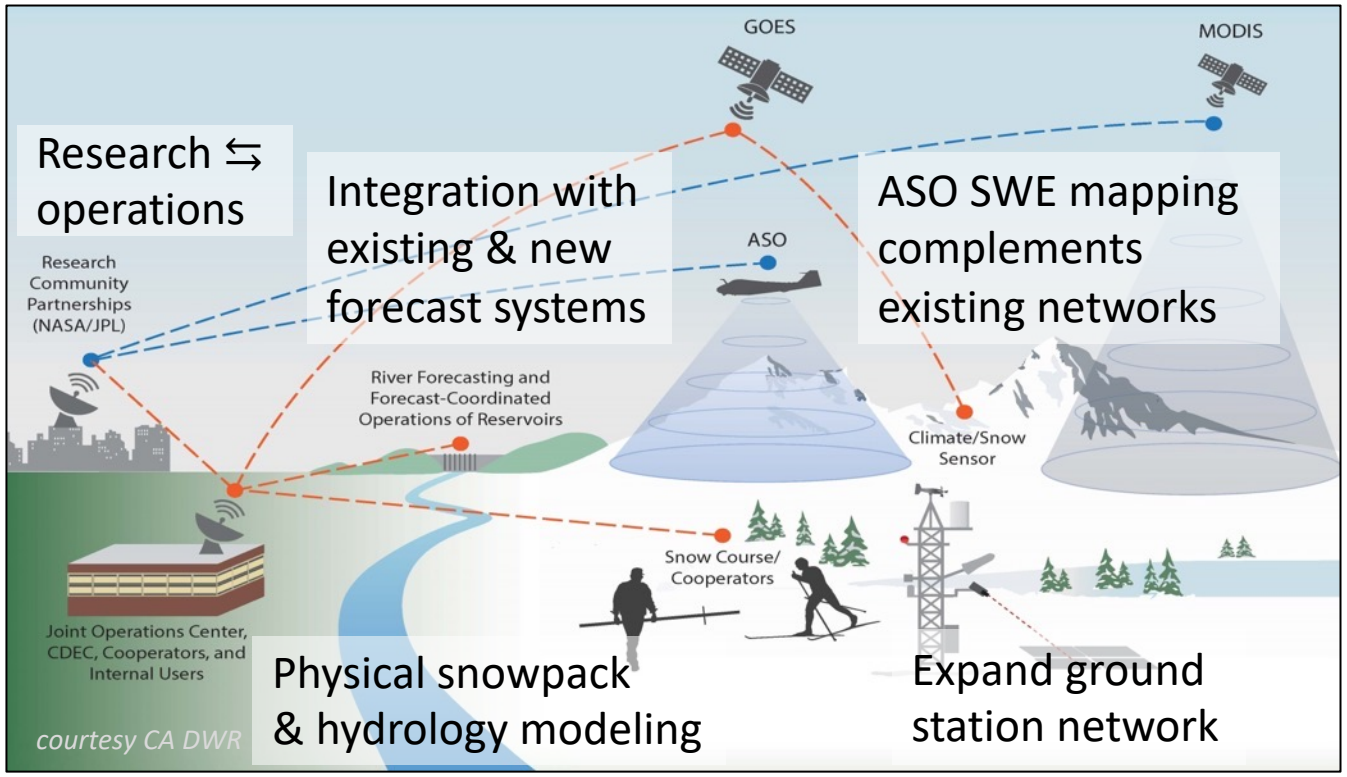
- **adaptation** to rapidly changing hydroclimate & watershed conditions
- adding critical spatial data to existing networks
- providing best snowpack data to experienced Federal forecast agencies
- enabling advanced forecast model systems

ASO is a cornerstone of this vision

- the **only, highly-accurate, full-watershed measurement of snow depth, SWE, & albedo**

Enabling Next Generation Water Management

An integrated monitoring & forecasting system



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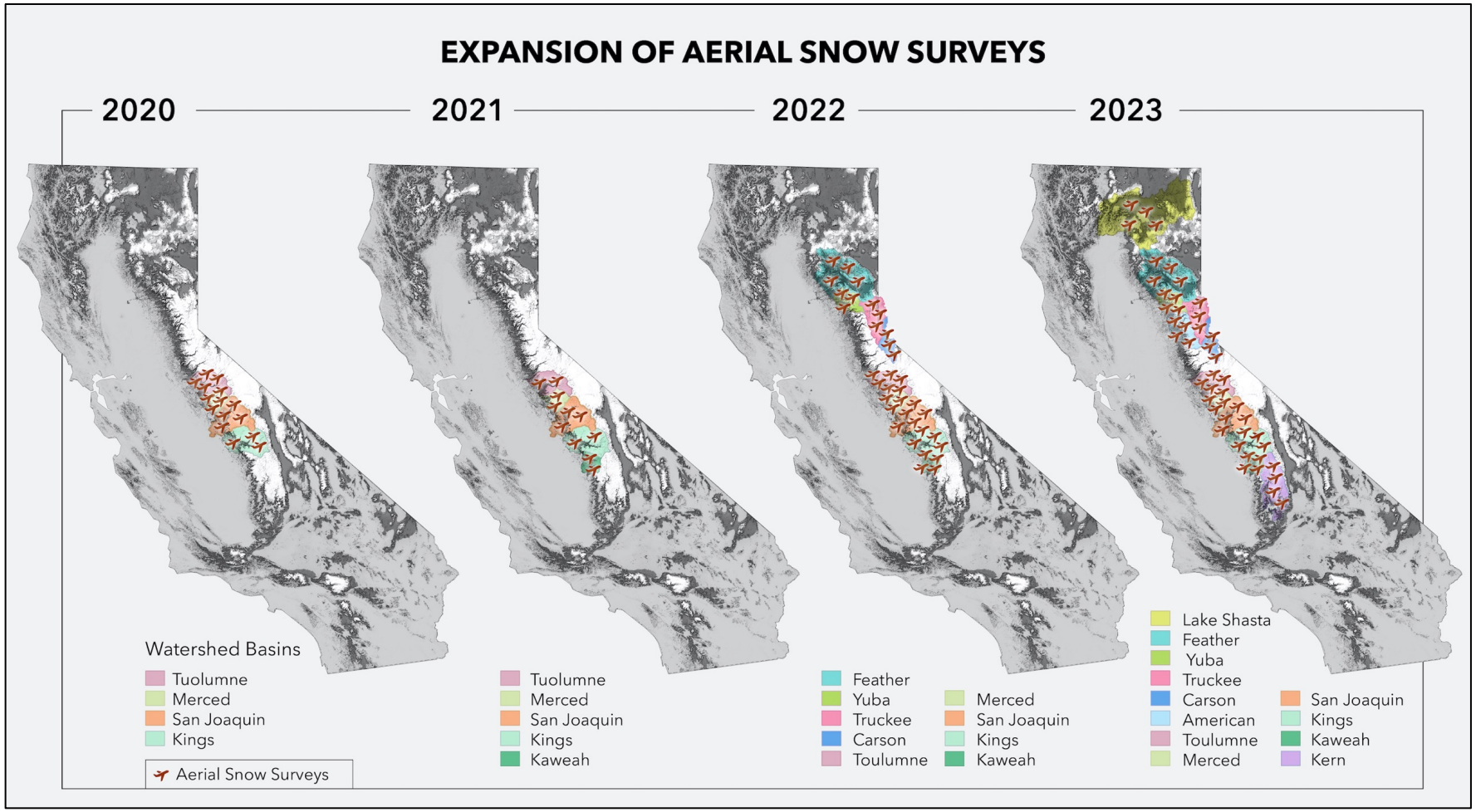
California Cooperative Snow Survey members estimate value of ASO forecast improvements

> $600M annually for water supply only (40:1 ROI)

> $1.25B annually for supply, power gen, recharge, ecosystem, operational flexibility (80:1 ROI)

Building towards a sustained California program

- program growth reflects stakeholder demand
- local, state, & federal $
- science & decision support
- 2023: base funding for sustained program
  - 4 flights/basin in 2023
- 2025: build towards full program
  - add remaining basins
  - 8 flights
- *benefits for expansion in CO & westwide*



ASO + CASM:

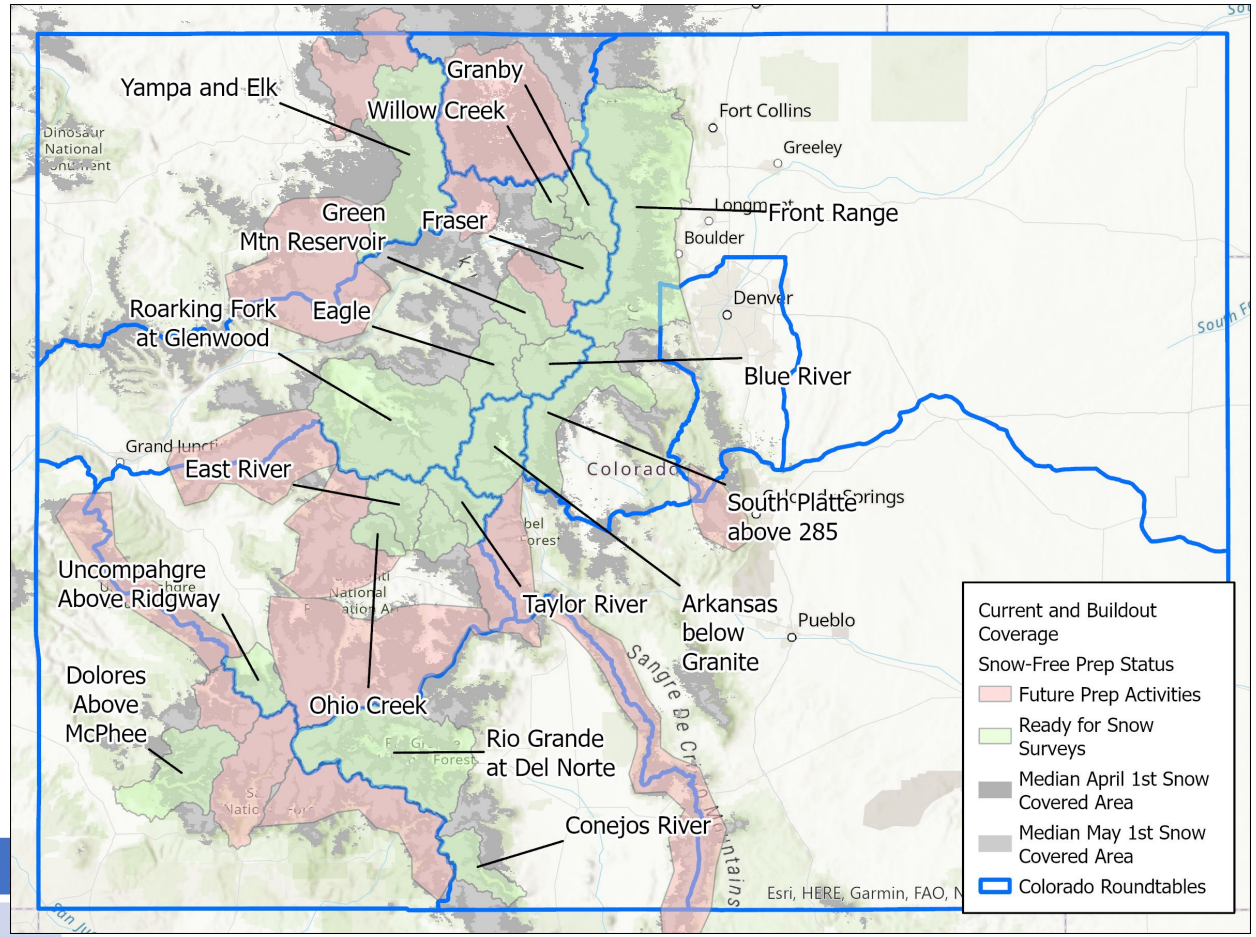
Building & sustaining the Colorado program

Notable support to-date:

- $1.9M CO Water Plan grant
- Roundtables & state WSRF grants
- Projects Bill
- Local & regional agencies
- USGS, USBR, DoE

Current & future development

- Federal opportunities
- State/CWCB support & management
  - Projects Bill
- Stakeholder capacity-building



Phase	Timeline	Flights Per Year
Phase 1	2022	14
Case Study Building	2023	30 (2 surveys in all prepped basins)
Widespread Adoption	2024-26	64 (3 surveys in all prepped basins)
Program Buildout	2026-28	214 (6 surveys across all headwaters)

"The information gained from ASO flights allows for a finer level of water management and provides more opportunity to benefit more users and get the maximum benefit out of every drop."

Nathan Elder
Raw Water Operations Manager
Denver Water

"ASO data can provide Colorado with a better ability to meet compact obligations while also fully utilizing the water that is allocated to Colorado users under the compact."

Craig Cotten
Colorado Division 3 Engineer

"What you've done is created new reservoir space and water supply without any impacts to the current physical or environmental paradigms."

Wes Monier
Chief Hydrologist
Turlock Irrigation District

"Having used this technology, it is hard to imagine a future without it."

Dave Rizzardo
Chief of Snow Surveys & Water Supply Forecasting
CA DWR

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