Snow-related Measurements in Operational Streamflow Forecasting at NOAA/CBRFC

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Western Water Assessment
Snowpack Monitoring Workshop

Broomfield, CO

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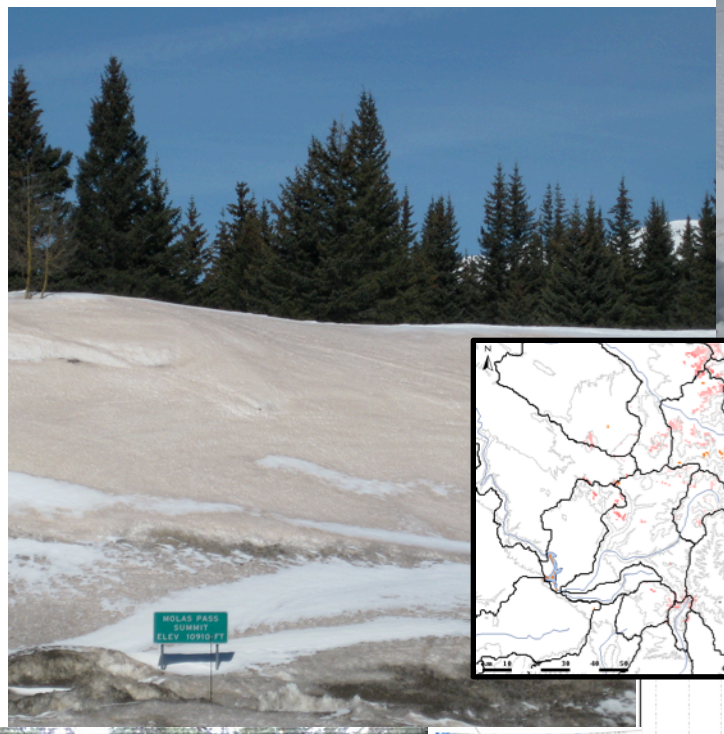
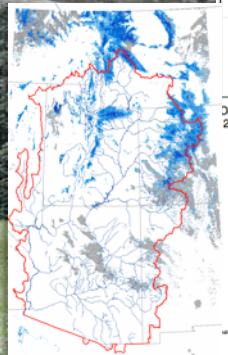
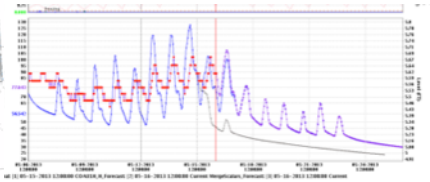






NWS RFCs

NOAA/National Weather Service River Forecast Centers (RFCs)

Operational streamflow forecasts across the United States

Colorado is covered by four RFCs:

CBRFC (Salt Lake City, UT)

- 67% of RFC forecast points in CO

MBRFC (Pleasant Hill, MO)

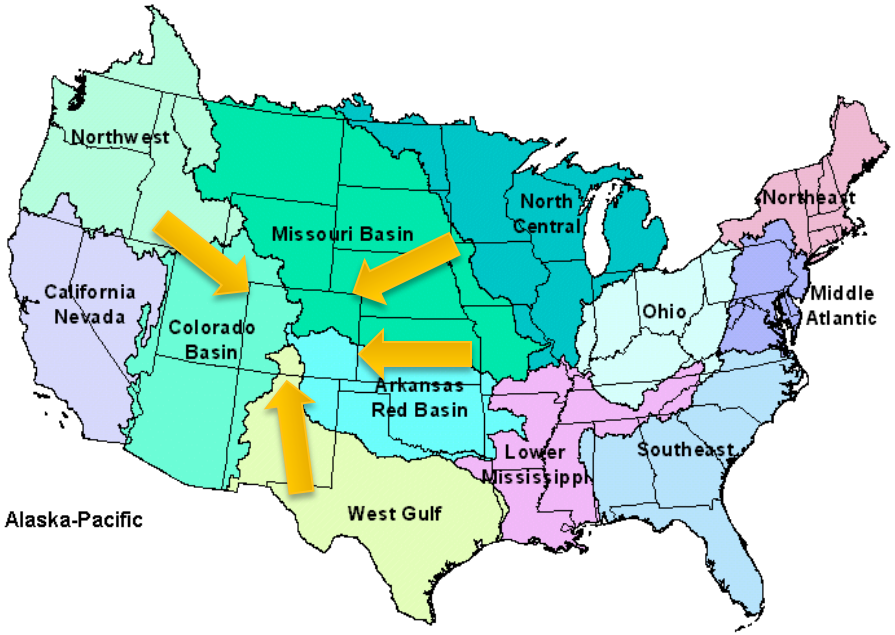
- 16% of RFC forecast points in CO

ABRFC (Tulsa, OK)

- 15% of RFC forecast points in CO

WGRFC (Fort Worth, TX)

- 2% of RFC forecast points in CO



National Weather Service River Forecast Centers

Forecast types:

- short-term streamflow, out 5-10 days
- seasonal runoff volume
- seasonal peak streamflow (CB only)

CB: www.cbrfc.noaa.gov
MB: www.weather.gov/mbrfc/
AB: www.srh.noaa.gov/abrfc/
WG: www.srh.noaa.gov/wgrfc/

CBRFC

Colorado Basin River Forecast Center (CBRFC)

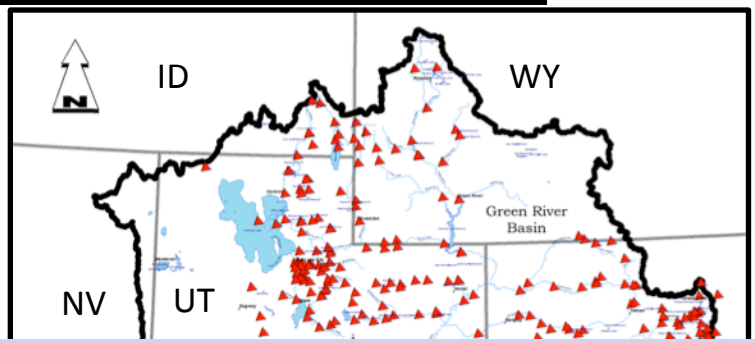
Hydrologic regimes:

- snow-dominated and flash flood hydrology
- natural and regulated

500+ streamflow forecast points across 7 states

(~100 in Colorado)

~1150 modeling units (snow and soil moisture model run on each unit)



Stakeholders dependent upon snowmelt-driven streamflow forecasts:

- NWS Weather Forecast Offices
- US Bureau of Reclamation
- water conservation districts
- municipalities
- recreational community
- others

CBRFC Stakeholder Forum: Oct 20-21, 2015
http://www.cbrfc.noaa.gov/present/2015/forum/2015forum.htm

Importance of Snow Info

RFCs

Importance of Snow Info

Operational CBRFC Modeling

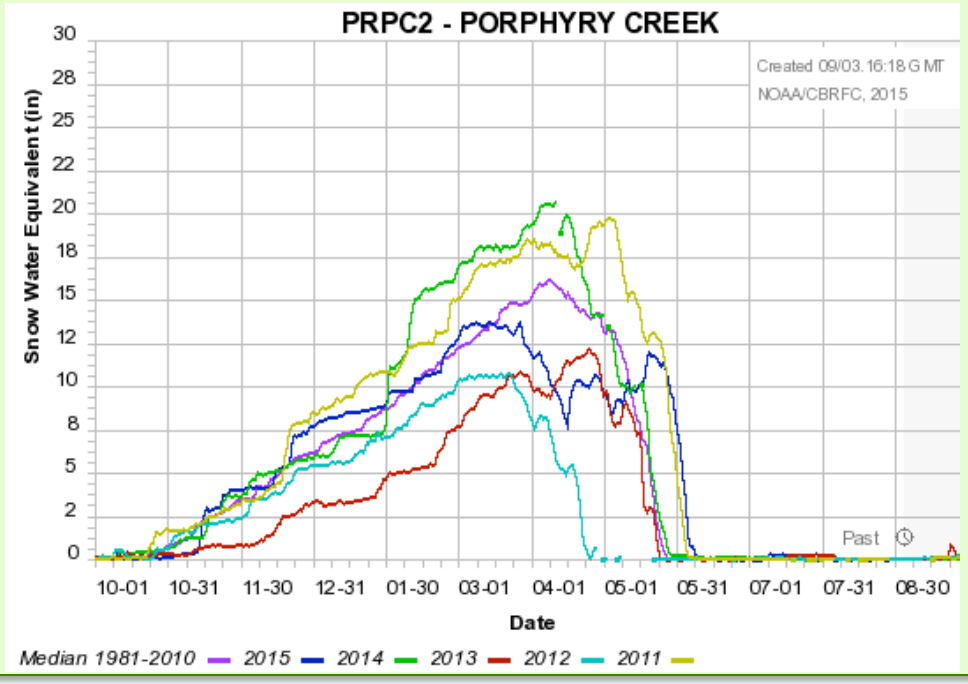
CBRFC Uses of Surface Observations

CBRFC Uses of Remote Sensing

What's Next?

Questions & Comments

Snow (especially water equivalent) = primary predictor of seasonal runoff volume



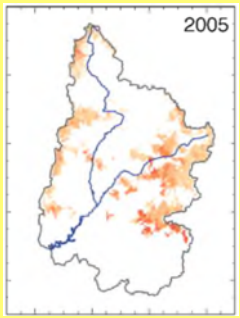
Recent years' snowpack - extremes in both directions

→ mostly dry (☹)

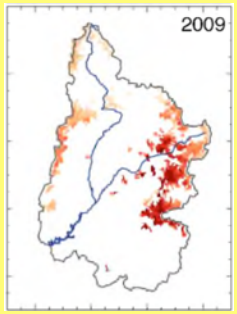
→ sometimes, wet (generally ☺)

→ variability in "dust on snow"

"Dust on snow" images for 2005 (light dust) and 2009 (heavy dust)



Map credit: Bryant-Burgess, 2014



Map credit: Bryant-Burgess, 2014

Precip type = primarily snow

- ~60-80% of precipitation shows up as SWE

SNOTEL site	Precip through April 30, on average (inches)	May 1 SWE, on average (inches)	SWE/precip (%)
Porphyry Creek (NWS id: PRPC2)	18.1	13.6	75%
Slumgullion (NWS id: SLMC2)	15.8	13.7	87%

Importance of Snow Info

Additional datasets and information about snowpack conditions assist CBRFC hydrologists with more informed forecasting decisions.

Expanding CBRFC's use of snow-related measurements is key.

Past (through 2009):

Surface-based networks (SNOTEL) only, SNOTEL sites w/ < 30 year period of record

Past (through 2010-2012):

Surface-based networks (SNOTEL) only, *** most SNOTEL now w/ 30 yr period of record ***

Present and into the future (2013 to present):

Surface-based networks (SNOTEL, CSAS field obs) + Remote sensing (MODIS, VIIRS, ASO) = More complete set of snowpack observations

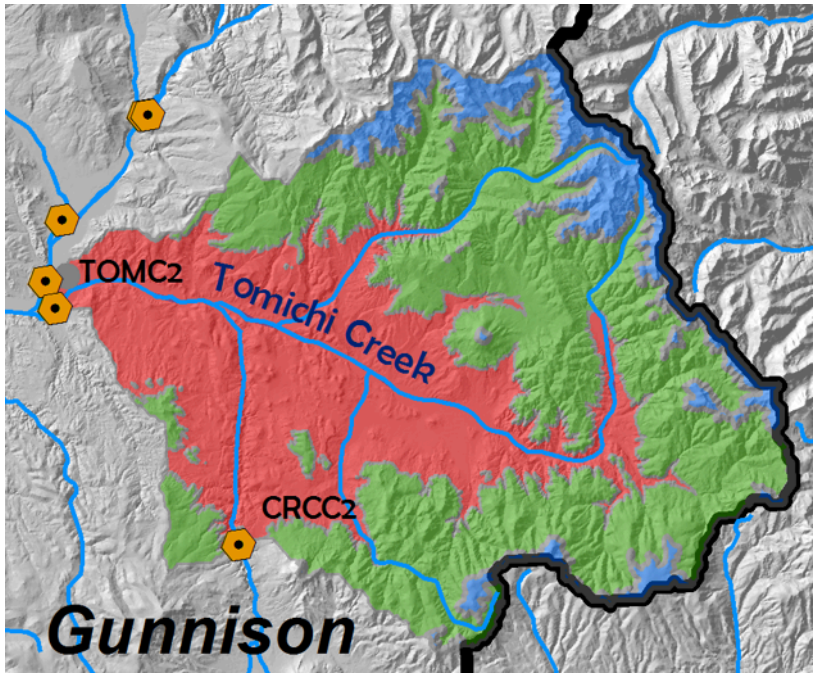
Note: Remote sensing datasets are *NOT* intended to replace surface-based observations in CBRFC modeling and forecasting but rather to complement surface-based observations.

Operational CBRFC Modeling

- → each watershed is sliced & diced into multiple areas
- → modeling units = elevation bands or zones
- → snow and soil moisture models are run daily for each "zone"

EXAMPLE: Tomichi Creek in CO (NWS ID = TOMC2)

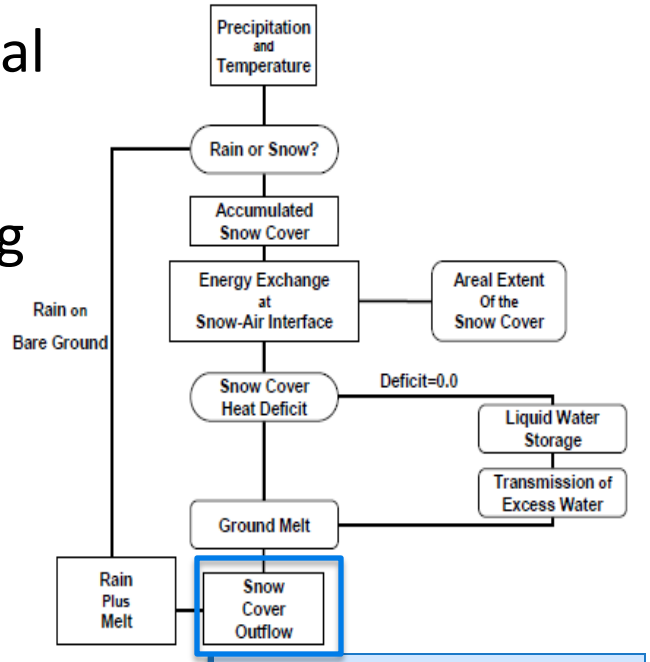
Elevation Zone	Mean Elevation (ft)
TOMC2LUF (Upper)	11519 ft
TOMC2LMF (Middle)	9899 ft
TOMC2LLF (Lower)	8447 ft



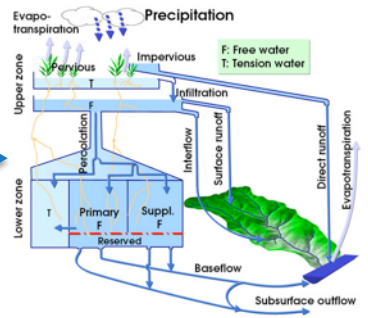
Operational CBRFC Modeling

Operational Snow Model at CBRFC: SNOW17

- minimum inputs and computational power needed
- manually calibrated at CBRFC using 1981-2010 historical data
- temperature-index model (air temperature used as proxy for energy/radiation)
- forecasts snowmelt pretty well under near-normal conditions of the calibration period
- *doesn't* do so hot when conditions deviate from near-normal – adjustments needed (manual, auto)



Water output from SNOW17 is then input to the soil moisture model (Sac-SMA)



Surface Measurements

NRCS's SNOTEL network = primary source of surface-based snowpack information for CBRFC

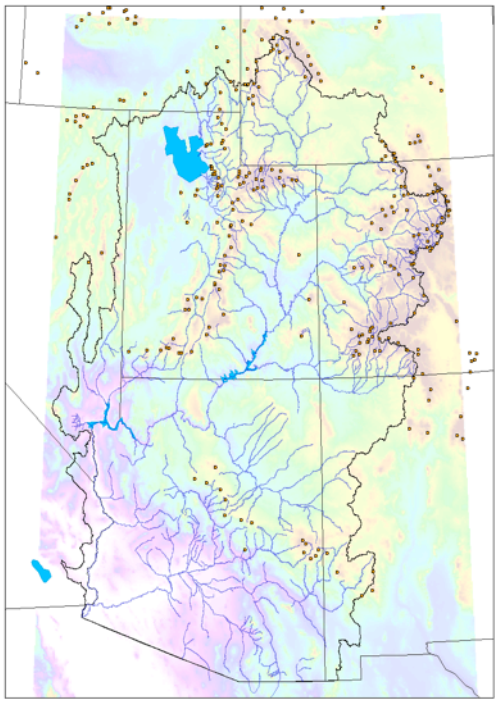
- 1st-of-month SWE data - statistical modeling for runoff volume forecasts
- SNOTEL precipitation data :
  - Real-time hourly – initially build the simulated snowpack in SNOW17
  - QC'd monthly values – "update" the snowpack simulated by SNOW17

Additional surface based info: field observations from the Center for Snow and Avalanche Studies/Colorado Dust-on-Snow Program

More details on next few slides!

Photo (right): Clean snow over a dust layer, April 2014.

Courtesy Center for Snow and Avalanche Studies, Colorado Dust-on-Snow Program, Silverton, CO



Map: NRCS SNOTEL network for CBRFC AOR

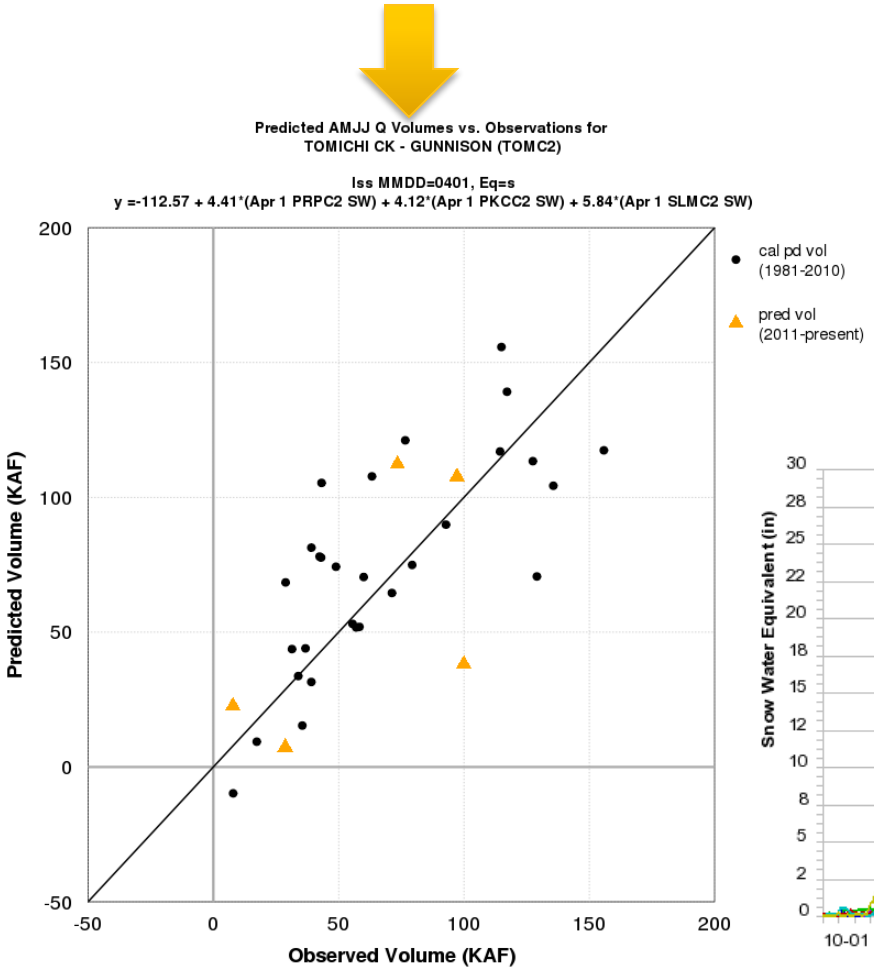
Surface Measurements: SNOTEL SWE

- RFCs
- Importance of Snow Info
- Operational CBRFC Modeling
- ***CBRFC Uses of Surface Observations***
- CBRFC Uses of Remote Sensing
- What's Next?
- Questions & Comments

SNOTEL SWE: used on the 1st of the month for water supply forecasting

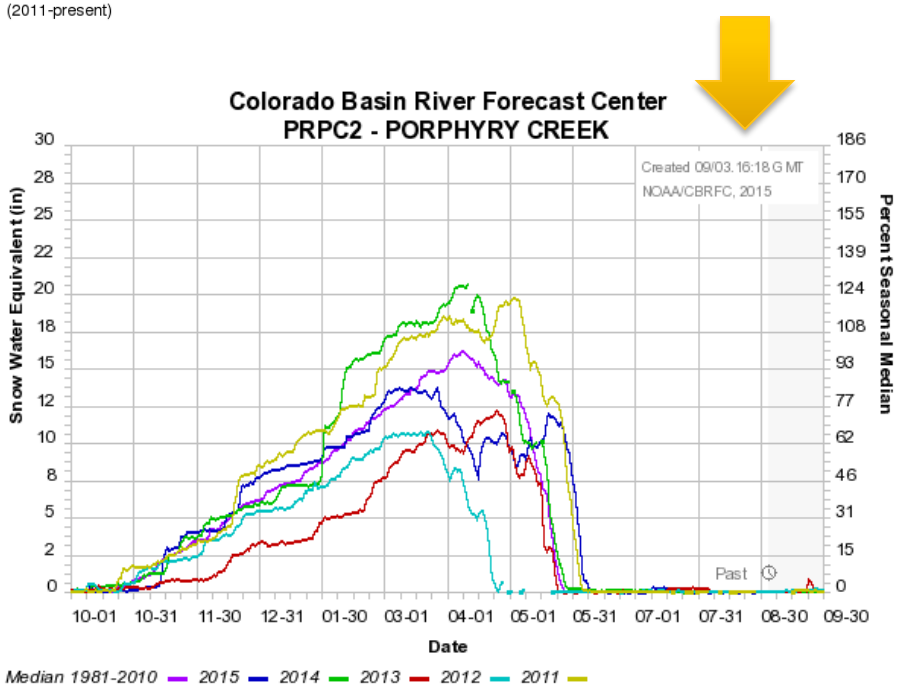
Quantitative use:

as a predictor in statistical regression models



Qualitative use:

forecaster awareness of general snowpack conditions (above/ below average, median, determine analog years, etc.)



Surface Measurements: SNOTEL Precip

SNOTEL Precipitation Uses:

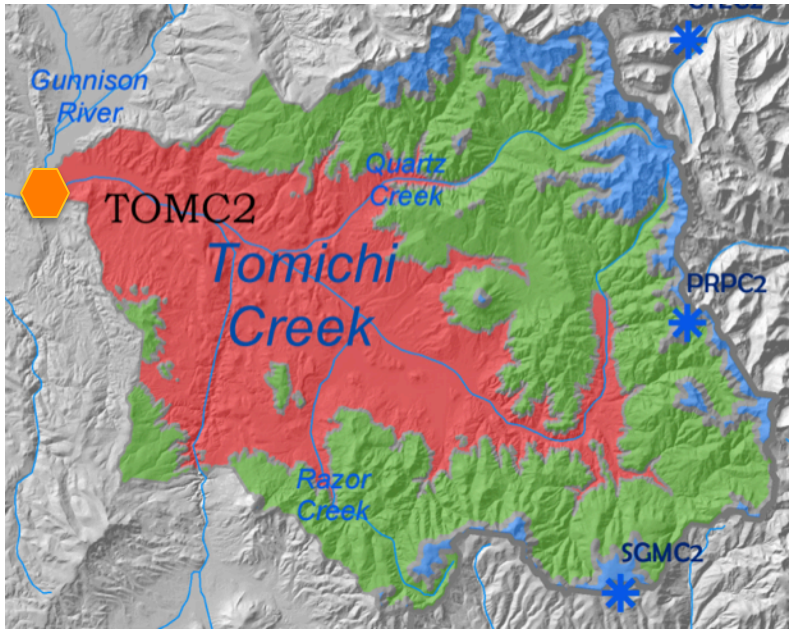
- real-time precipitation - build the SNOW17-simulated snowpack in the deterministic CBRFC hydro model (run daily)
  - Note: SNOW17 builds snowpack w/ precip data, *not SWE data*
- monthly precipitation – "update" the SNOW17-simulated snowpack
- seasonal accumulated precipitation – statistical models for water supply forecasting

Surface Measurements: SNOTEL Precip

Building the simulated snowpack with real-time SNOTEL precipitation

SNOTEL (point) precip → Build mean areal precip (MAP) values over elevation zones → Run SNOW17 for each elevation zone with MAP inputs → SNOW17 adds MAP as snow to simulated SWE (or types precip as rain)

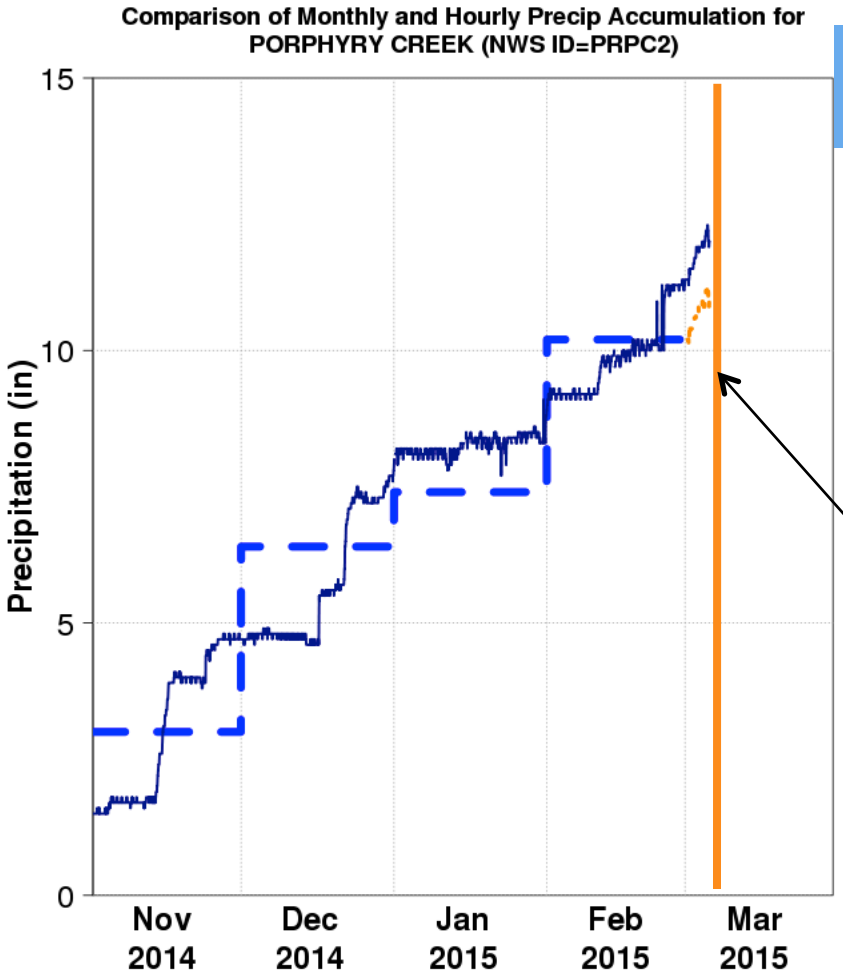
Elevation Zone	SNOTEL Stations Used to Compute MAP Value
TOMC2LUF (Upper)	PRPC2 (Porphyry Creek)
TOMC2LMF (Middle)	PRPC2 (Porphyry Creek)
TOMC2LLF (Lower)	No SNOTELs used (COOP station CCRC2 is used)



Surface Measurements: SNOTEL Precip

Building and updating the SNOW17-simulated snowpack

Daily model runs use **real-time**, hourly data – jumpy, can add uncertainty to sim. snowpack



So, when QC'd monthly precip obs become available, use those to "**update**" model SWE.

Example Update Date = Mar 4

accumulated full month MAPs (derived from QC'd ***monthly*** precip data)

+ accumulated MAPs for any partial months (derived from ***real time*** precip data)

= "updated" precipitation accumulation (using Mar 4 as an example)

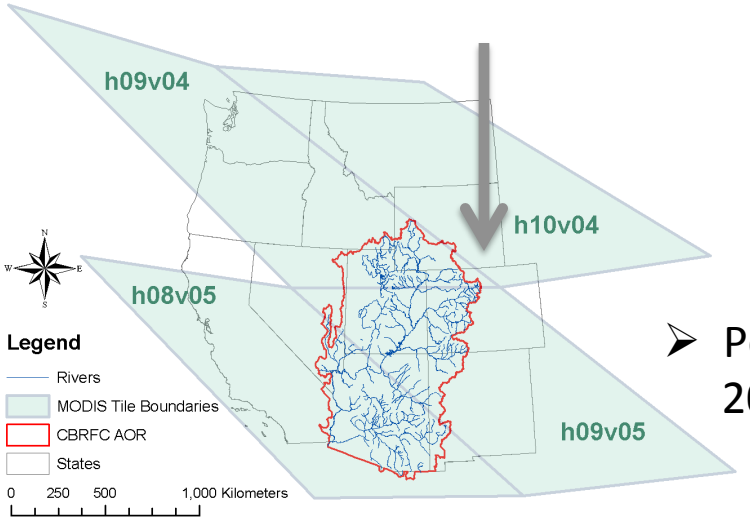
Model is then run forward in time with the new, "updated" estimate of SWE accumulation.

Measurements from Remote Sensing

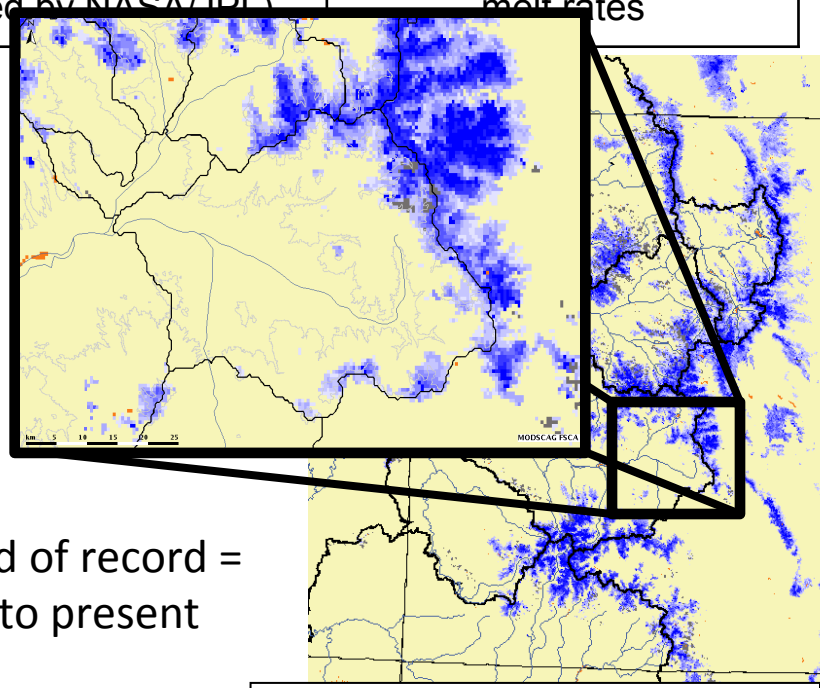
Remotely-sensed snow data used by CBRFC:

Snowpack Characteristic	Instrument	Algorithm	CBRFC Use
fractional snow-covered area (fSCA)	MODIS	MODSCAG (provided by NASA/JPL)	minor adjustments to SNOW17 model SWE as snowpack dwindles
dust-on-snow	MODIS	MODDRFS (provided by NASA/JPL)	adjustments to SNOW17 melt rates

- Data are available across all of CO (global datasets) – JPL has full original datasets, CBRFC can share mosaics for most of CO.



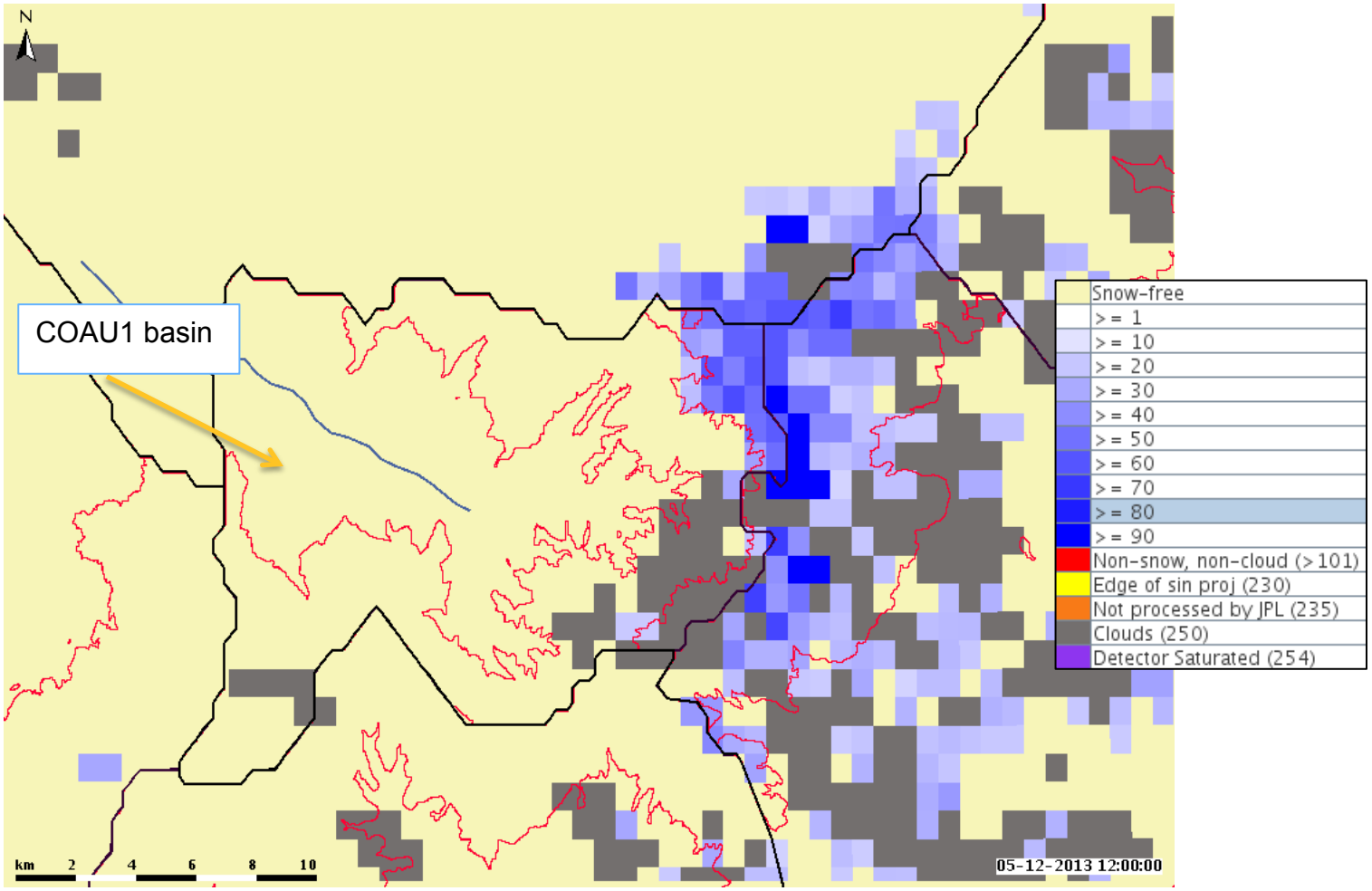
- Period of record = 2000 to present



MODSCAG fSCA April 29, 2015

MODSCAG fSCA Example

- RFCs
- Importance of Snow Info
- Operational CBRFC Modeling
- CBRFC Uses of Surface Observations
- ***CBRFC Uses of Remote Sensing***
- What's Next?
- Questions & Comments



MODSCAG fSCA (percent) over southwestern Utah (Coal Creek near Cedar City, NWSID = COAU1), May 12, 2013, as viewed by CBRFC forecasters. The COAU1 basin is outlined in black, with the division between CBRFC elevation zones in red.

May 16, 2013 CBRFC forecast modifications informed by MODSCAG fSCA

RFCs

Importance of Snow Info

Operational CBRFC Modeling

CBRFC Uses of Surface Observations

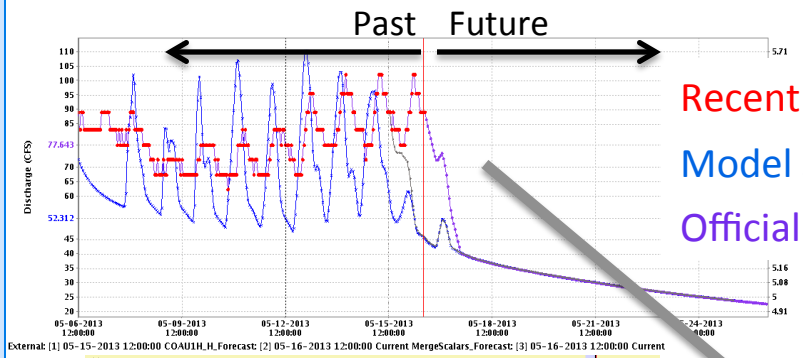
CBRFC Uses of Remote Sensing

What's Next?

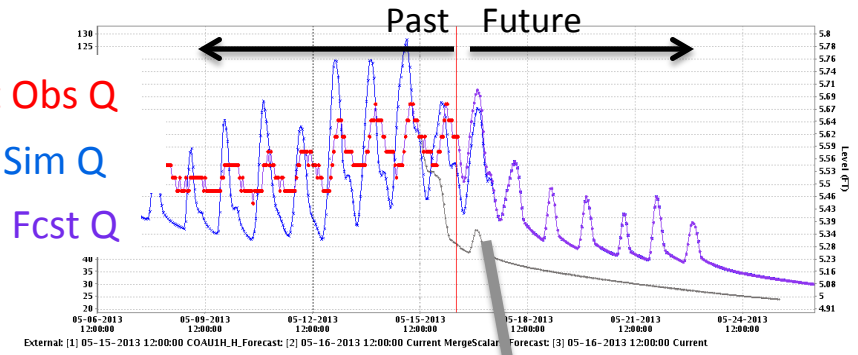
Questions & Comments

Coal Creek, near Cedar City, UT, NWS ID: COAU1/USGS ID: 10242000

Before small SWE adjustment:



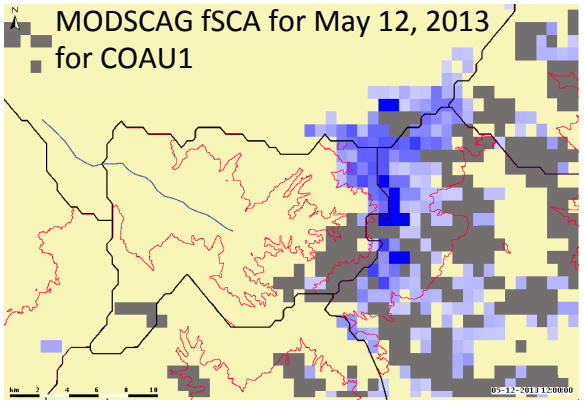
After small SWE addition:

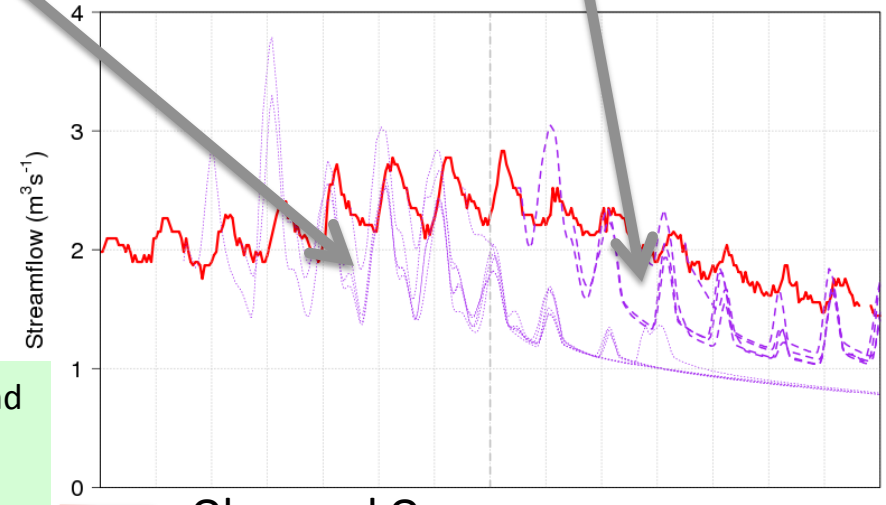


Recent Obs Q

Model Sim Q

Official Fcst Q





Observed Q

Q Fcsts issued prior to adjustment

Q Fcsts issued after adjustment

Currently: MODSCAG fSCA = most useful at end of melt as pseudo-binary indicator of snow presence.

Future: likely need more advanced snow model to fully quantitatively use MODSCAG fSCA (snow model research projects in progress).

2014 Dust-on-snow Example

Current operational CBRFC forecasting system:

- allows (and usually requires) manual adjustment to model simulation by CBRFC hydrologists

To address snowmelt potentially accelerated by dust-on-snow, <u>consider and combine information</u> from:

1. Historical analysis
2. Field observations
3. Remote sensing
4. CBRFC forecaster experience and knowledge of future weather possibilities

Better informed forecaster
→ improved Q forecasts

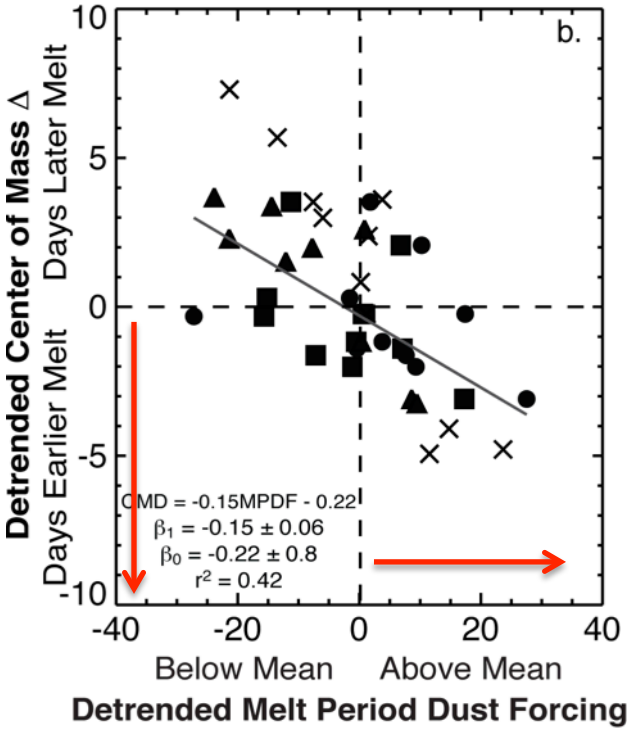
Historical + Real-time Info

Historical Remote Sensing Data:

Dustier than average snowpack

→ *earlier* snowmelt than what SNOW17 predicts

Very dusty years → typically larger streamflow prediction errors (timing)



Real-time Field Observations:

Provide information about

→ Whether or not dust layers exist within the snowpack

→ How close the dust layers are to the sfc

→ Whether or not the dust layers have emerged

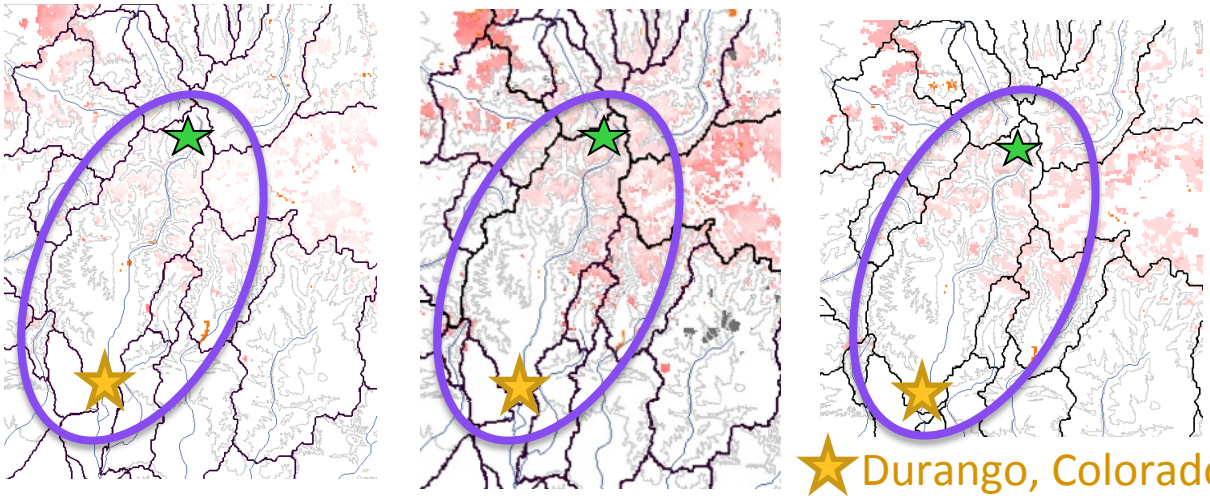
Photo (right): Several inches of clean snow above D4 dust layer, as of the morning of April 4. Courtesy Center for Snow and Avalanche Studies, Colorado Dust-on-Snow Program, Silverton, CO (http://www.codos.org/sbb-4-04-14)

REFERENCE:

Bryant, A. C., T. H. Painter, J. S. Deems, and S. M. Bender (2013), Impact of dust radiative forcing in snow on accuracy of operational runoff prediction in the Upper Colorado River Basin, Geophys. Res. Lett., 40, 3945–3949, doi:10.1002/grl.50773.

Remote Sensing + Field Obs

Consistency between new-to-CBRFC datasets and information → confidence in both datasets



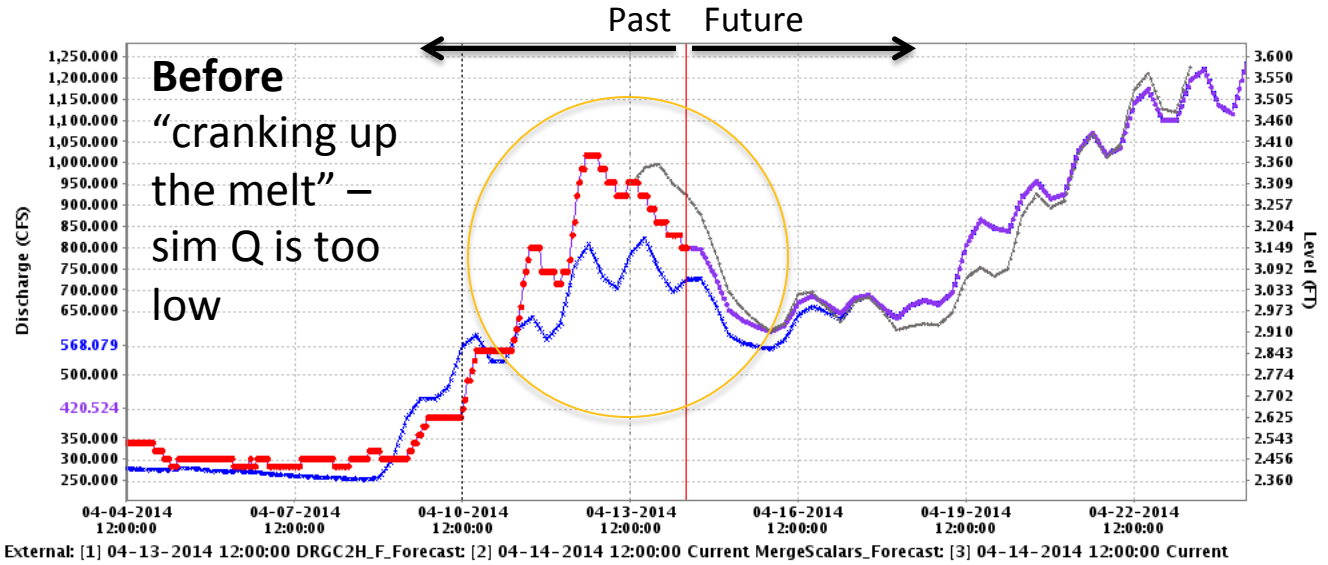
April 8, 2014

April 10, 2014

April 11, 2014

Photos: D4 emerging in the upper Animas watershed proper (along Hwy 550 south of Red Mountain Pass). Courtesy Center for Snow and Avalanche Studies, Colorado Dust-on-Snow Program, Silverton, CO

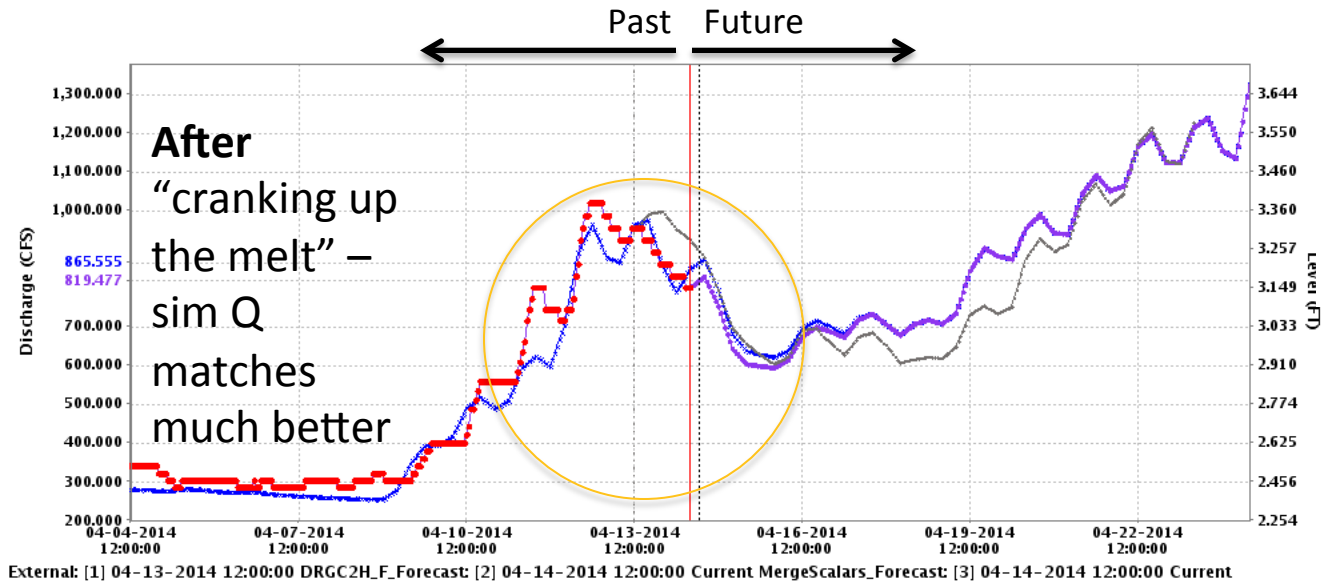
Manual Adjustments by Forecasters



Recent Obs Q

Model Sim Q

Official Fcst Q



Recent Obs Q

Model Sim Q

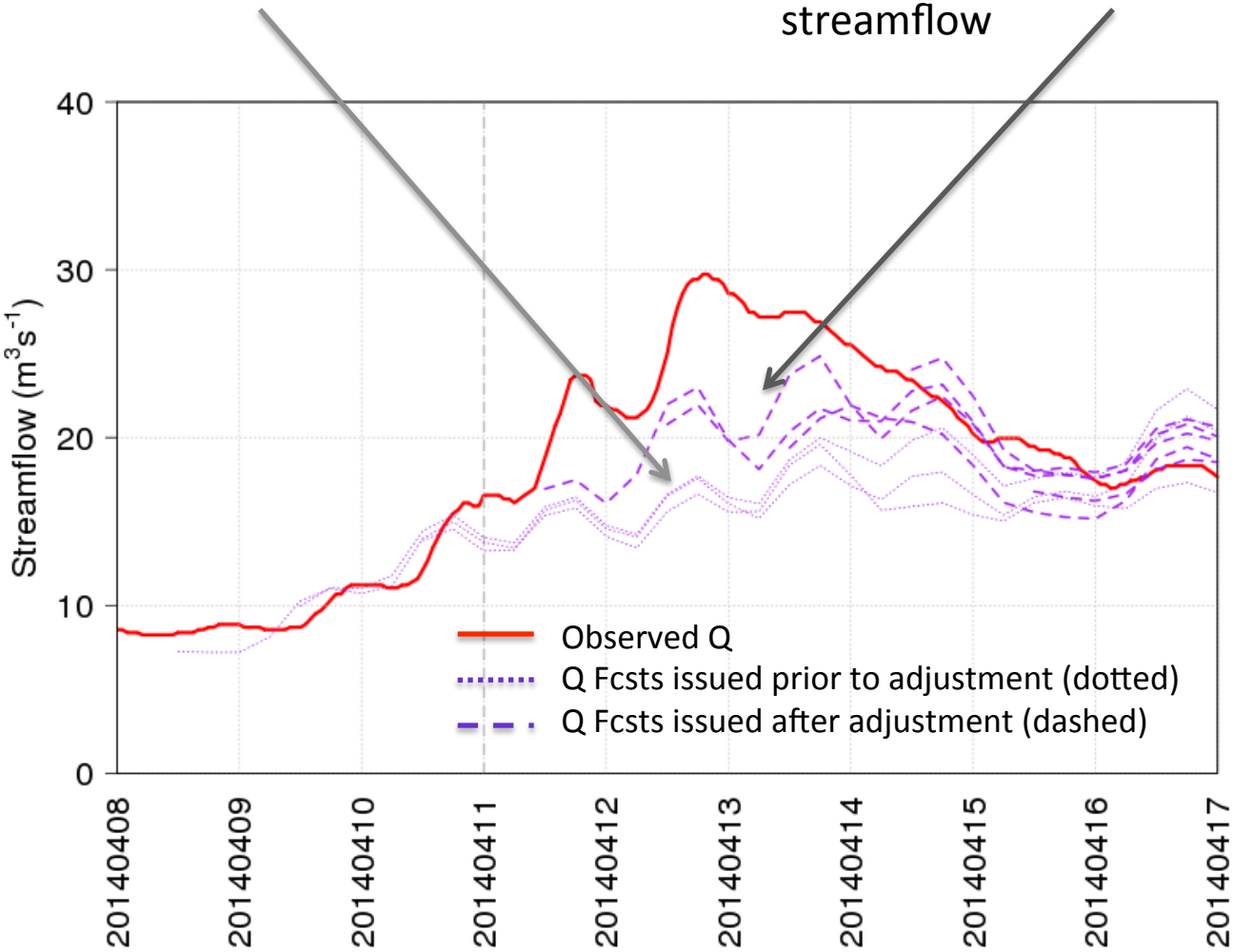
Official Fcst Q

Credit: plots courtesy B. Bernard (CBRFC)

How did we do in this April 2014 case?

Before informed manual adjustment (dotted): fcsts too low

After informed manual adjustment (dashed): fcsts closer to observed streamflow



Perfect? No.

Though, still an improvement!

Improving the Adjustment Process

MODDRFS-informed manual adjustments to snowmelt rate by CBRFC forecasters are:

1. helpful (see previous example)
2. but subjective and time-consuming

- Need a more efficient, objective method of incorporating MODDRFS "dust-on-snow" data into CBRFC forecasting

- MODDRFS → use it to tweak temperatures that are input to snow model (SNOW17, which is a temperature-index snow model)

DRFS-informed MAT Adjustments

RFCs

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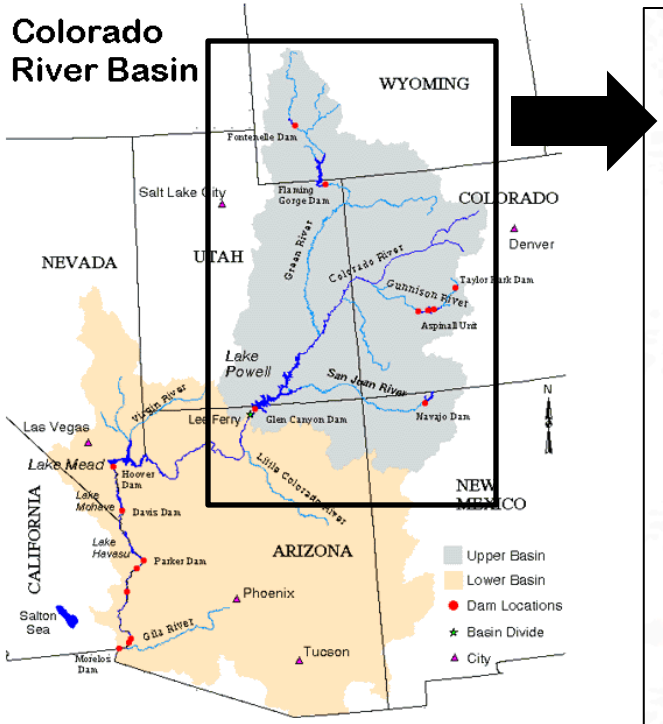
CBRFC Uses of Remote Sensing

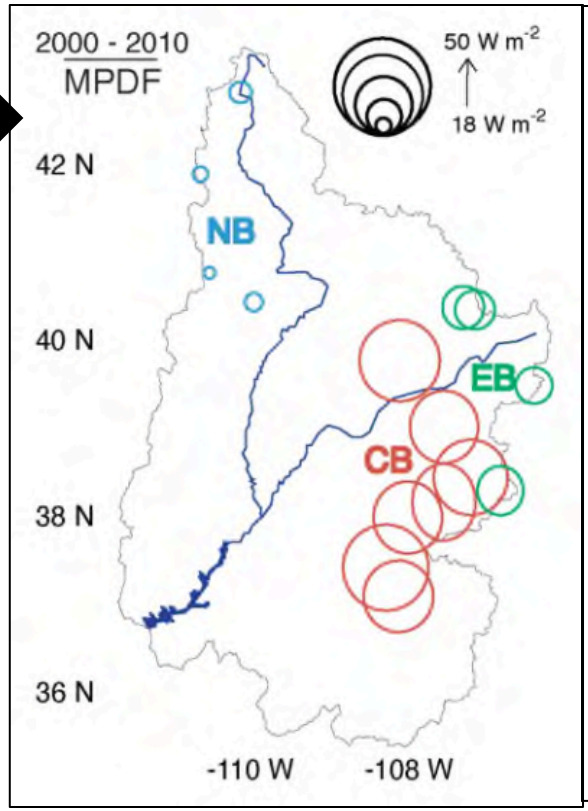
What's Next?

Questions & Comments

Where to start experiments w/ DRFS-informed SNOW17 MAT-adjustment method?



Map credit: Colorado River Commission of NV, available via http://crc.nv.gov/images/colorado_river_basin.gif)



Mean 2000-2010 melt period dust forcing, where colors denote the **Central Basin** region, **Eastern Basin** region, and **Northern Basin** region (Bryant-Burgess, 2014)

Nutshell:
Larger circles indicate more dust, on average

→ **Initial focus area = southwestern Colorado (most impacted by dust events)**

- UT and WY are less-impacted by dust events (differences in weather events, dust sources, dust deposition event characteristics…)

DRFS-informed MAT Adjustments

Methodology, in a nutshell**:

** → If you want details, just ask!

Original, unadjusted MATs **+** DRFS values (remote sensing of dust-on-snow) **+** Land Cover Info (coniferous veg.) **=** DRFS-informed, adjust MATs that can be input to SNOW17

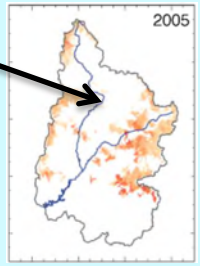
Preliminary Results for Uncompahgre R. in SW CO – NWS id = UCRC2:

- Minimal (+/- 3%) impacts on water year and seasonal runoff **volumes** (Apr-Jul)
- **Timing** of melt (and snowmelt-driven streamflow) *within the April-July runoff period* is altered by incorporation of MODDRFS data into SNOW17

Example cases of runoff timing for SW CO: 2005, 2009

2005 Dust:
→ Lighter/less than normal

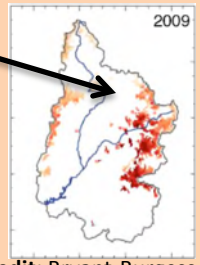
2005 AMJJ runoff volume:
→ 111% average



Map credit: Bryant-Burgess, 2014

2009 Dust:
→ Heavier/more than normal

2009 AMJJ runoff:
→ 118% average



Map credit: Bryant-Burgess, 2014

DRFS-informed MAT Adjustments

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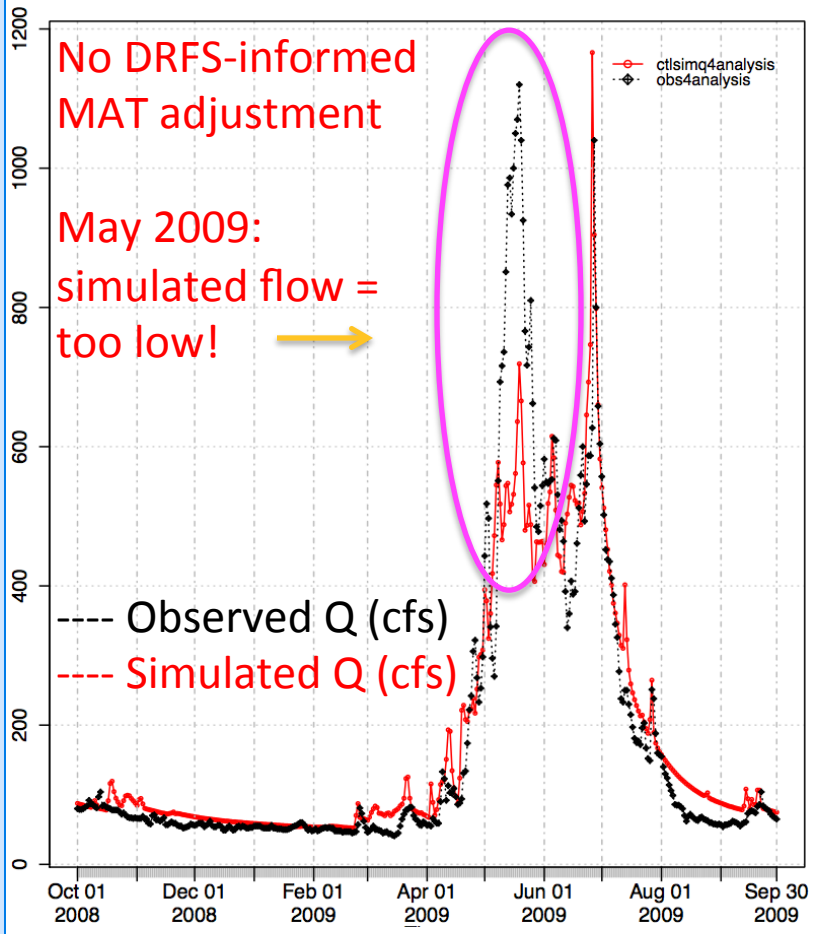
CBRFC Uses of Remote Sensing

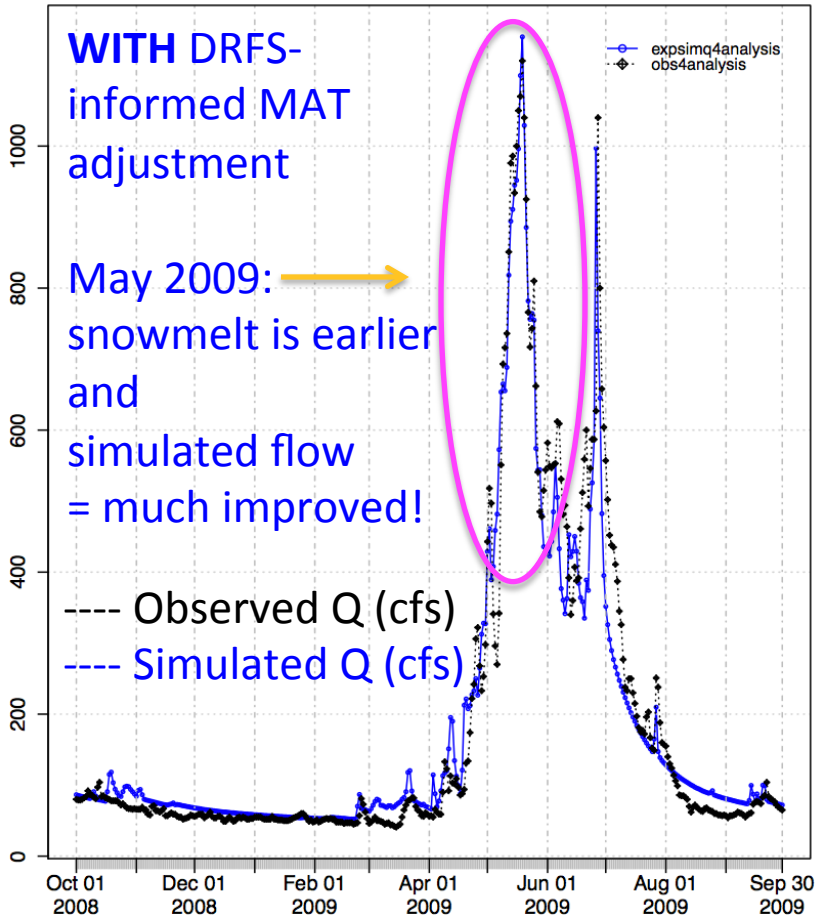
What's Next?

Questions & Comments

Example from initial results:

- Uncompahgre River in southwestern CO (NWS ID = UCRC2)
- WY2009 – "heavy dust" year





DRFS-informed MAT Adjustments

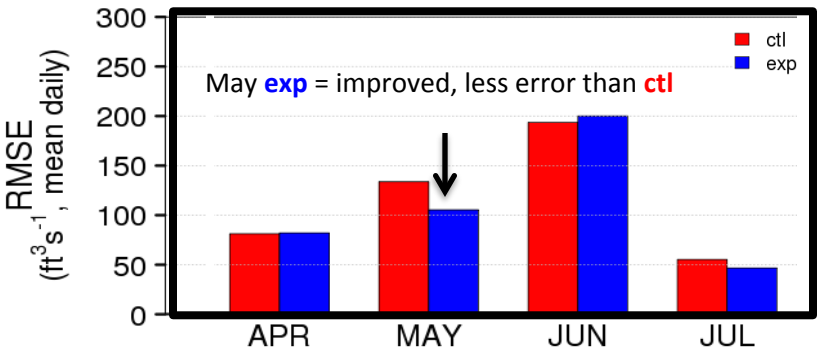
Breaking down results <u>within</u> the April-July runoff period:

2005 (minimal dust) Case:

Including "dust on snow" remote sensing info → <u>slight delay in melt</u>

- less runoff in May
- slightly more in June and July

➢ May = **most** improvement in error

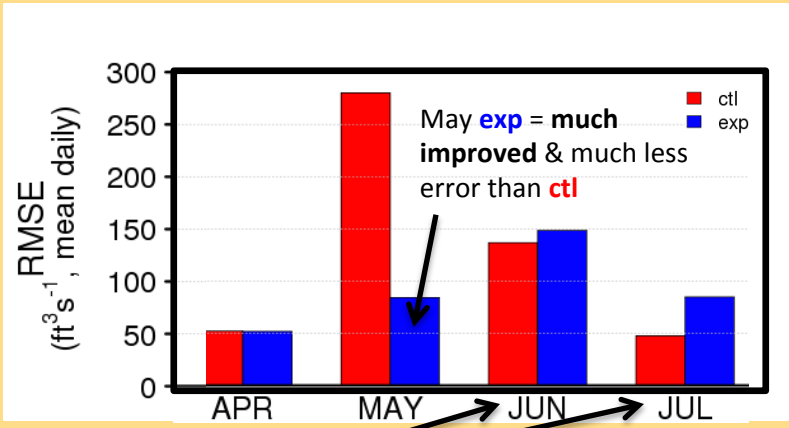


2009 (heavy dust) Case:

Including "dust on snow" remote sensing info → <u>accelerated melt</u>

- much more runoff in May
- much less in June and July

➢ May = **most** improvement in error



<u>Note</u>: for 2009: Jun-July (esp July) = **exp** simulation has larger error than **ctl**
→ need to check further into other error sources

What's Next?

For the rest of 2015 (and beyond):

- Work with stakeholders, forecast users, and water managers to share knowledge of snow observations and measurements from perspectives external to CBRFC
- Evaluation of snow model state updating methods (including documentation)
  - SNOTEL-based methods
  - Remote sensing-based methods
- Continue to support expansion of NRCS SNOTEL and other surface-based networks
- Review additional remote sensing datasets (more MODIS datasets, VIIRS, ASO from NASA/JPL) and investigate their best uses at CBRFC
- Investigate more advanced modeling (especially snow)
  - VIC work ongoing at NASA/JPL
  - RTi-Colorado State-Utah State distributed SNOW17, UEB, alternative model forcings project

Questions, Comments, and Acknowledgements

RFCs

Importance of Snow Info

Operational CBRFC Modeling

CBRFC Uses of Surface Observations

CBRFC Uses of Remote Sensing

What's Next?

Questions & Comments

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