Use of Snow Data from Remote Sensing in Operational Streamflow Prediction

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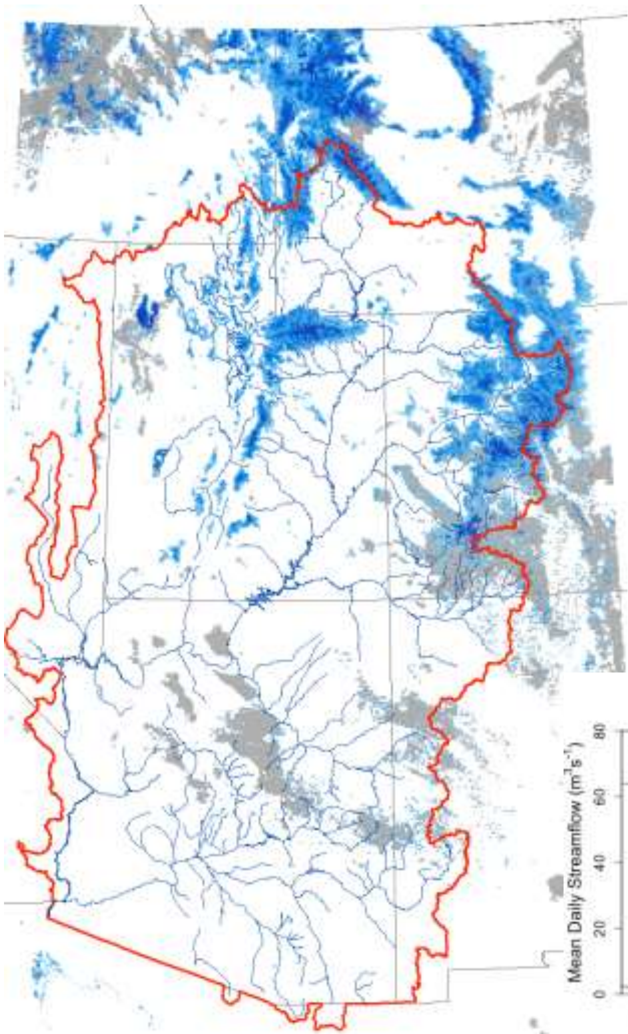
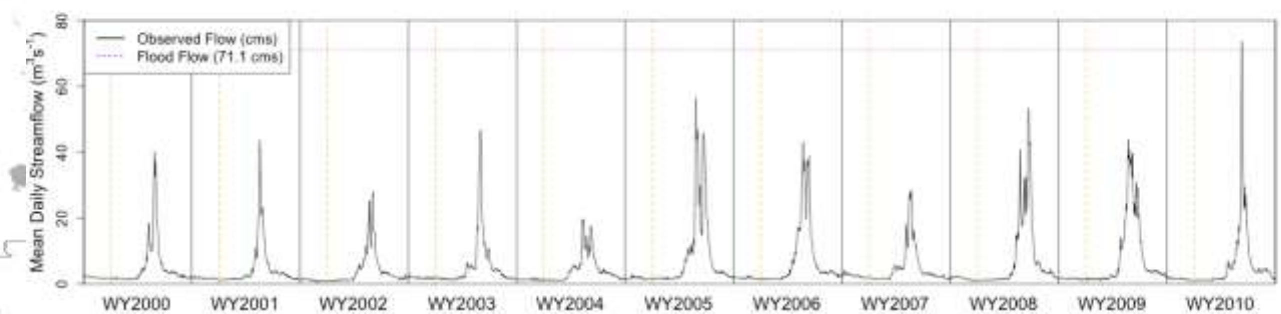




CBRFC

Colorado Basin River Forecast Center (CBRFC)

Full staff: 3 mgmt, 9 hydrologists, 1 admin, 1 IT

Vacancies: 1 mgmt, 1 hydro

Operational streamflow forecasts across the Colorado River basin and eastern Great Basin

Operational forecast types:

- daily streamflow
- seasonal peak flow
- seasonal water supply volume

National Weather Service River Forecast Centers

www.cbrfc.noaa.gov

CBRFC

CBRFC

The R2O Gap

Project Goals and Motivation

MODSCAG & DRFS Datasets

Uses of NASA/JPL Data at CBRFC

Future Directions

Emphasizing the Importance of Collaboration

Summary

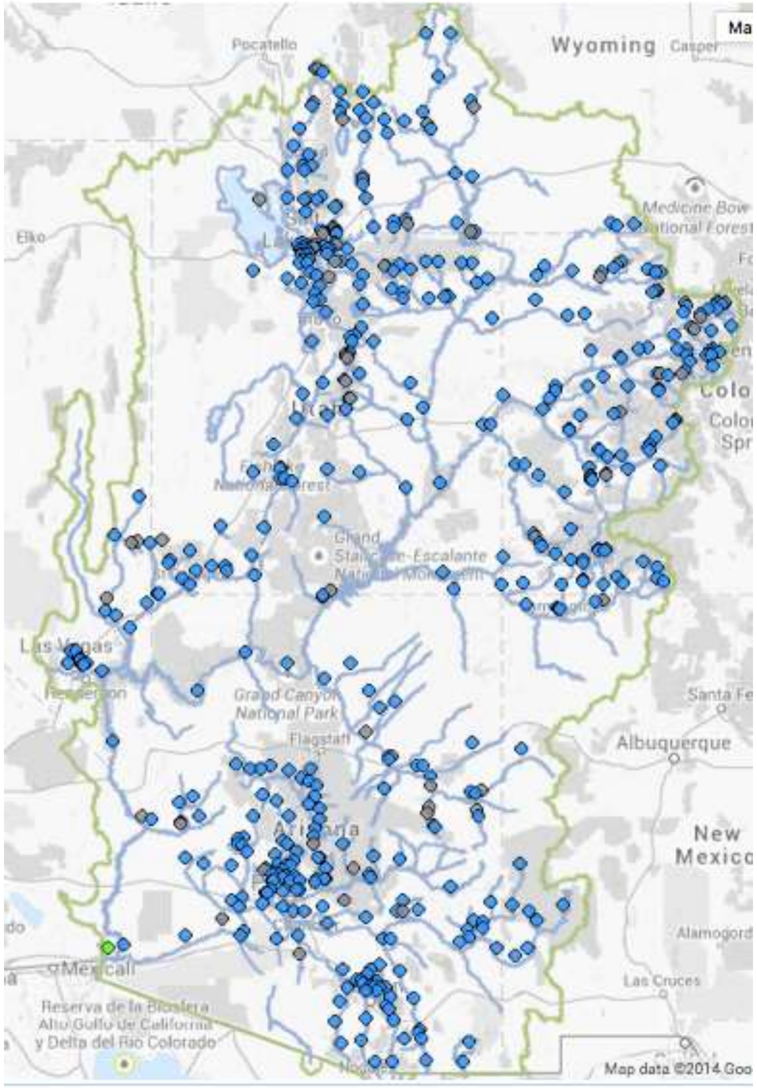
Colorado Basin River Forecast Center (CBRFC)

Hydrologic regimes:

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

500+ streamflow forecast points

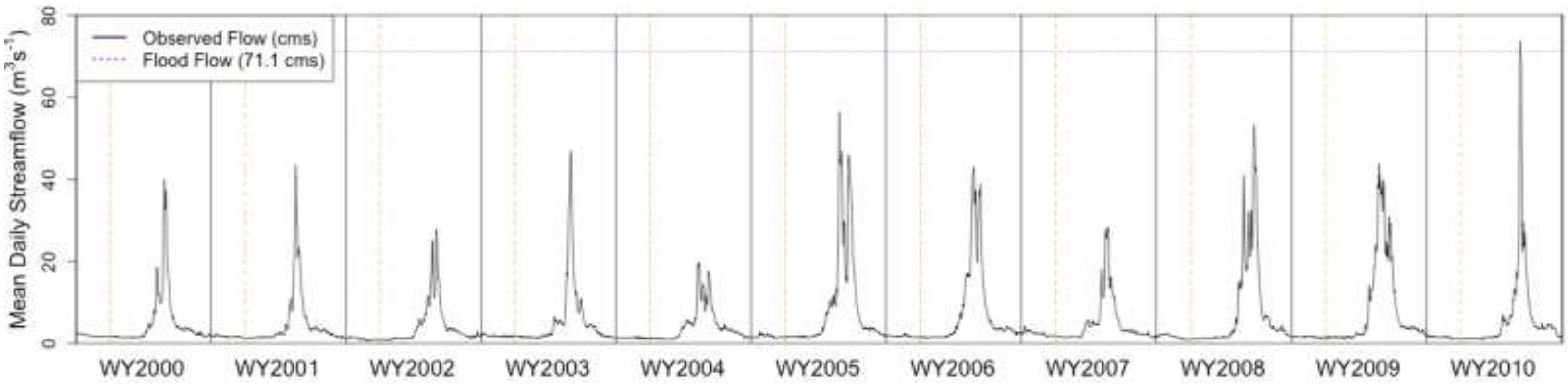
~1150 modeling units (snow and soil moisture model run on each)



Importance of Snow

Annual streamflow:

→ primarily snowmelt-driven in CBRFC area of responsibility



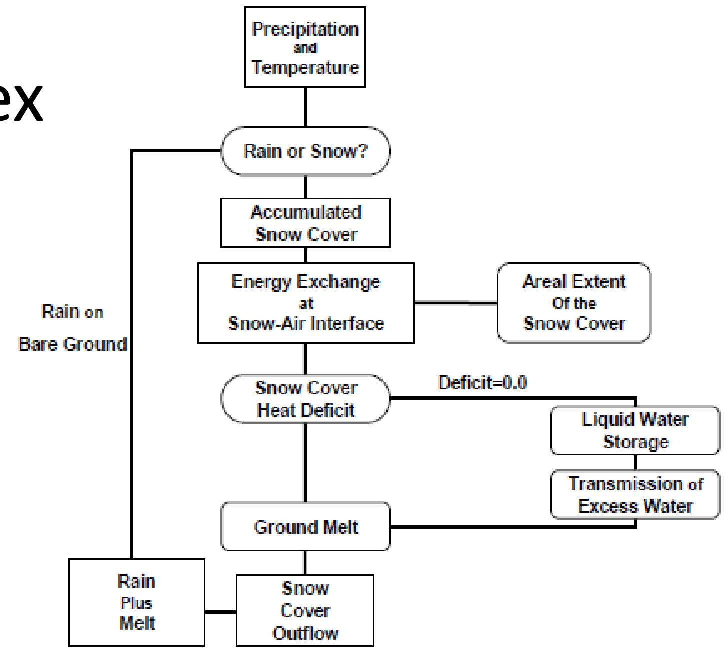
Annual hydrographs for the Weber R. headwater basin (northern Utah), water years 2000 to 2010

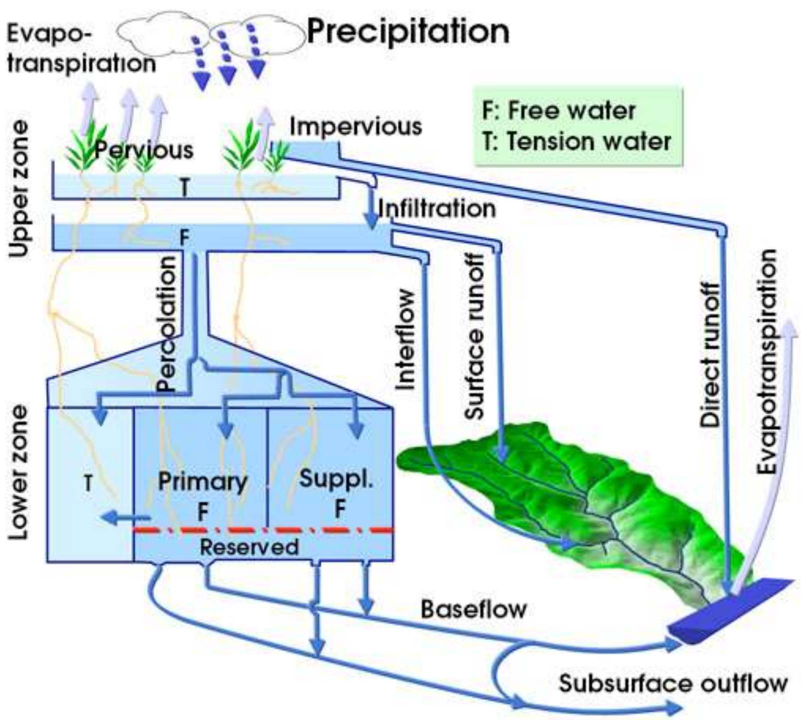
Streamflow forecast users then, in turn, depend on snow:

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

Operational CBRFC Models

Operational Snow Model: SNOW17 (temperature-index model)





Operational Soil Moisture Model: Sac-SMA

Operational CBRFC Models

Operational Snow Model: SNOW17

- minimum inputs: precip and temperature
- minimal computational power needed
- decades of NWS experience
- calibrated to streamflow using the 1981-2010 historical period (manual process at CBRFC)
- temperature-index model
  → "melt factor" to relate snowmelt to air temp.
- forecasts snowmelt pretty well under near-normal conditions of the calibration period
- *doesn't* do so hot when conditions deviate from near-normal – manual adjustments needed

Snow and the CBRFC Operational Forecasting Process

CBRFC Operational Hydrologic F

Ultimately driven by CBRFC fore
deadlines and who need foreca

❄ where snow improvements may potentially lead to streamflow prediction improvements

Input Datasets:
Must be reliably available in a timely manner

CBRFC Hydrologic Model
Computing = local Linux boxes (no supercomputer available)

CBRFC Hydrologist / Forecaster (the “human component”)
Given information about hydrologic conditions, the forecaster may modify the forecast that initially comes directly from the model (including manual adjustment of snow and/or soil model states)

Official CBRFC Streamflow Forecasts

CBRFC Forecast Users and Stakeholders:
NWS Weather Forecast Offices, Bureau of Reclamation, Water Conservation Districts, Recreational River Community, others

Bridging the R2O Gap

Collaborative partnerships among operational and research-oriented groups

→intended to accelerate the improvement of snowmelt-driven streamflow predictions at CBRFC

Productive research and academic communities

≠

automatic and easy transfer of research to operations (R20)

Bridging the R2O Gap

<u>Some reasons for the notoriously difficult-to-bridge R20 gap:</u>

Cultural - both sides need to understand their counterparts
→ researchers – usually have a specialty
→ NWS operational hydrologists - jacks/jills of many trades

Differences in hydrologic science and models used

Operational time constraints

- forecasting agency needs input datasets available in NRT
- forecast users need info quickly and reliably → decisions

Scale of datasets (space and time)

- field experiments vs. datasets with long period of record
- dedicated experimental basins vs. results across a large area

IT Issues

- computing power (no supercomputer for NWS hydro)

Project Goals and Motivations

Expanding info available to the CBRFC forecaster:

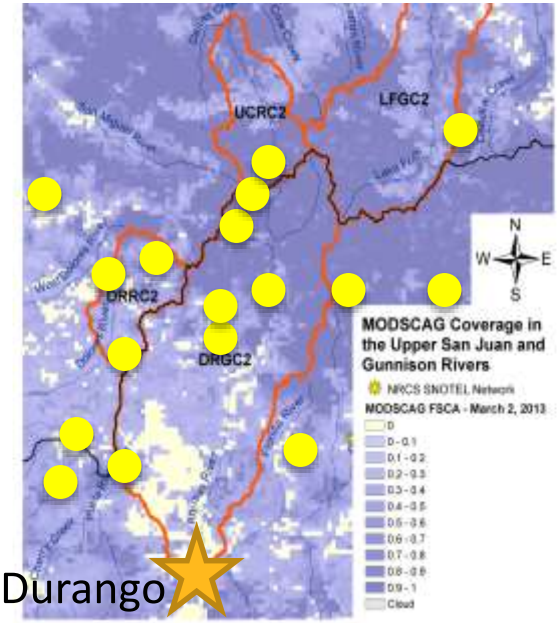
Snowpack observations → crucial to improving CBRFC streamflow prediction

Point networks (SNOTEL) =the backbone and remain crucial to CBRFC ops.

Remote sensing (RS) data can fill in gaps between point stations, especially at high elevations, in mountainous terrain.

Jet Propulsion Laboratory
California Institute of Technology

RS of SW CO snow cover from MODIS, with SNOTEL station locations (yellow)



Past (pre-2013):

Point networks ***only***

Present and future:

Point networks + Remote sensing (MODIS, VIIRS) = More robust set of snowpack observations

Project Goals and Motivations

<u>Establish a multi-year CBRFC/JPL collaboration:</u>

Actually get across the R2O gap!

More efficiently integrate RS snow datasets into CBRFC forecasting

Improve overall understanding and communication between operational and research groups

Develop beneficial relationships specifically among snow and remote sensing science researchers and operational hydrologic forecasters

RS Snow Datasets

CBRFC

The R2O Gap

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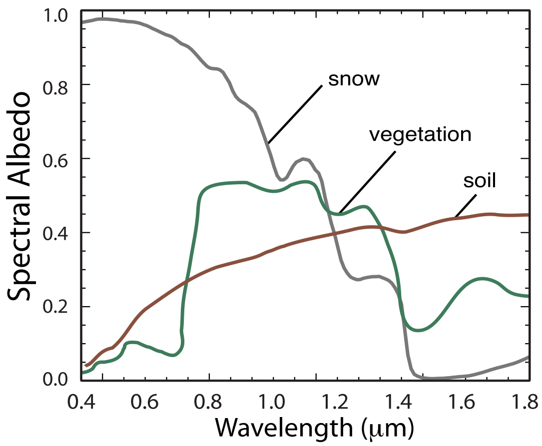
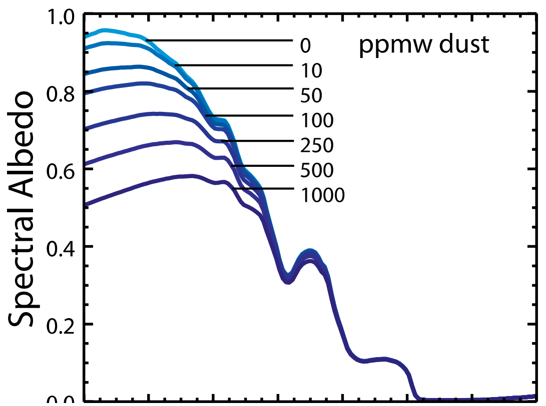
Summary

Exploit differences in spectral characteristics of snow in the VIS and NIR to derive snow cover and dust information

- MODSCAG provides per-pixel (500 m) fractional snow cover (%)
- MODDRFS provides per-pixel (500 m) radiative forcing by dust in snow (W m^{-2})



Both gridded datasets are available from JPL server in near-real time and over the MODIS period of record (2000-present)



REFERENCES:

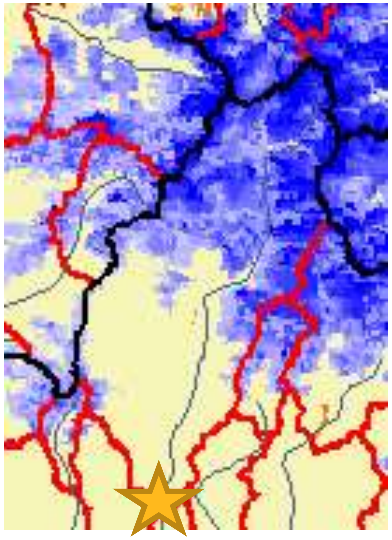
Painter, T. H., K. Rittger, C. McKenzie, R. E. Davis, and J. Dozier, Retrieval of subpixel snow-covered area and grain size from MODIS reflectance data, *Remote Sensing of Environment,* 113, 868-879, doi:10.1016/j.rse.2009.01.001.

Painter, T. H., A. C. Bryant, and S. M. Skiles, Radiative forcing of dust in mountain snow from MODIS surface reflectance data, *Geophysical Research Letters,* doi: 10.1029/2012GL052457.

Limitations of MODIS-derived Snow Data

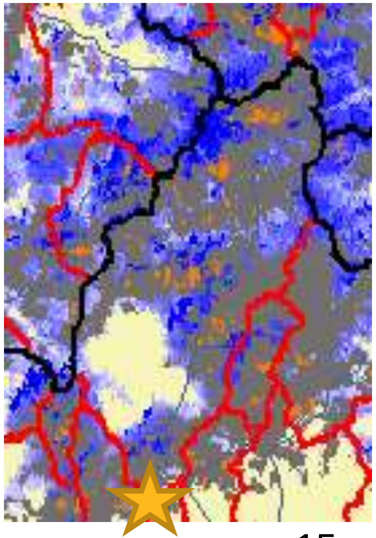
1. No direct SWE information
2. Limited seasons of usefulness (fSCA values bounded by 0 to 100%)
3. Impacts of vegetation
4. Clouds, especially during stormy periods

MODSCAG fSCA
April 11, 2014



MODSCAG fSCA
April 12, 2014

(clouds = gray)



Timeline of MODSCAG and DRFS Use at CBRFC

2012: initial exploratory phase

- CBRFC set up NRT processing of data from JPL
- both groups began learning what they had gotten themselves into

2013:

- semi-quantitative use of MODSCAG fSCA at CBRFC
  - → binary indicator of snow presence (or lack of)
  - → add/subtract small amount of SWE
- historical analysis of patterns in streamflow prediction errors and MODDRFS dust-on-snow data (Annie Bryant PhD work)
- 3 week visit to CBRFC during melt season by JPL's Annie Bryant

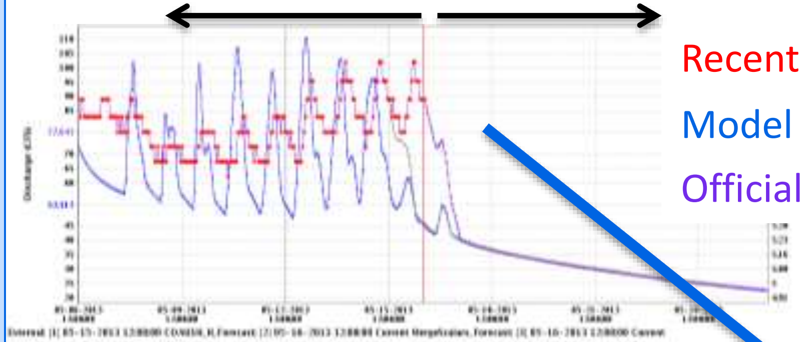
2014:

- added another version of MODSCAG fSCA to toolbox
- automated alerts of model vs. MODSCAG "fSCA differences"
- more extensive use of MODDRFS dust data in 2014 than 2013
- began refining semi-quantitative method of treating of fSCA and dust info in CBRFC forecasting and modeling

May 16, 2013 CBRFC forecast modifications due to MODSCAG (snow cover)

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

Before small SWE adjustment:

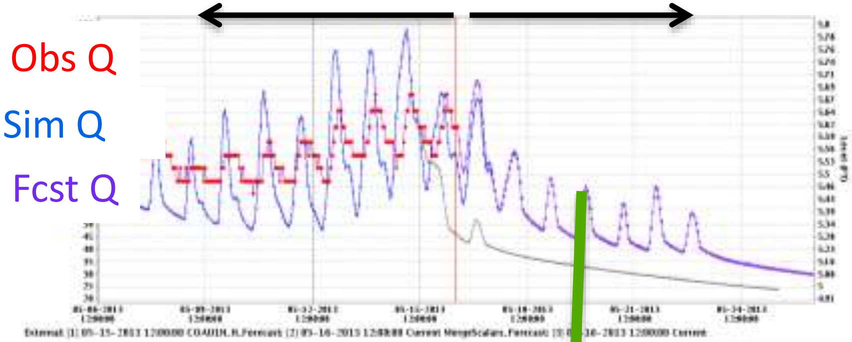


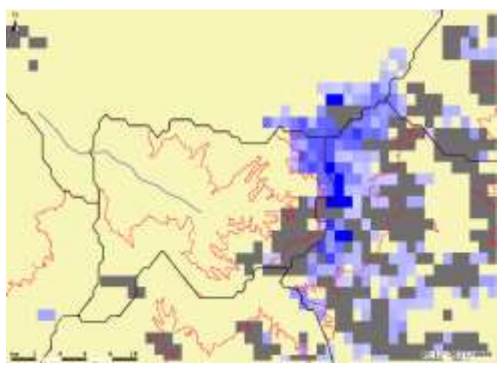
Recent Obs Q

Model Sim Q

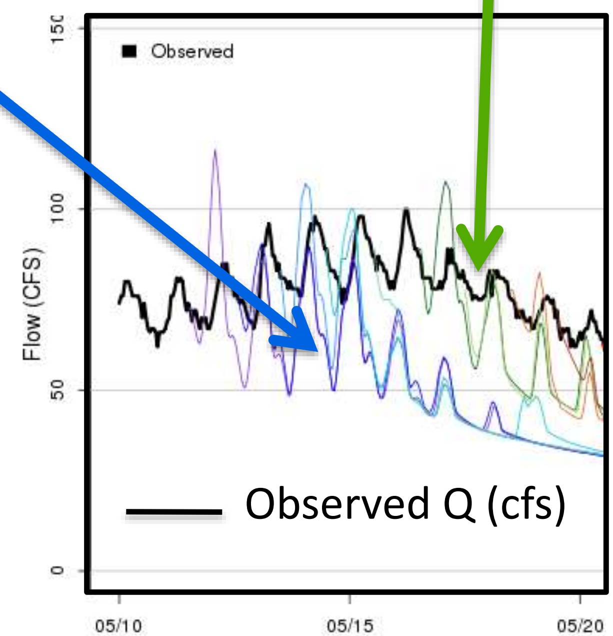
Official Fcst Q

After small SWE addition:





MODSCAG Snow Cover

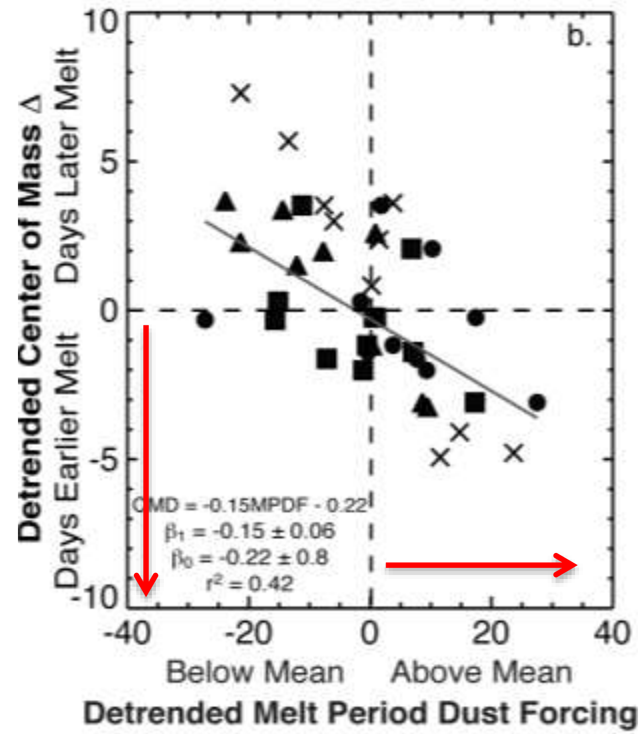


MODDRFS and CBRFC Q Error Patterns

Dust in the snowpack primarily impacts timing of snowmelt (and timing of subsequent snowmelt-driven streamflow peaks)

Analysis shows that a dustier than average snowpack results in center of mass that is observed *earlier* than predicted (esp. SW CO)

Very dusty years coincide with larger streamflow prediction errors



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.

Multiple MODSCAG fSCA Products

<u>"Viewable" MODSCAG fSCA</u>

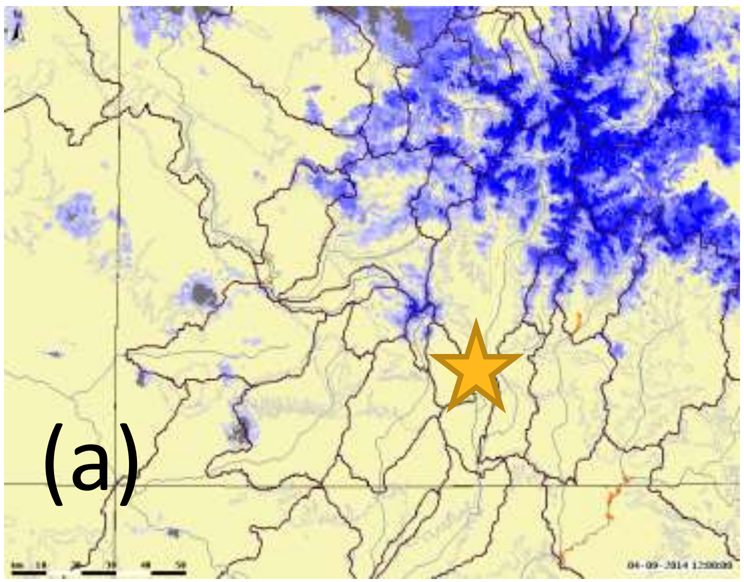
- what the MODIS instrument "sees"
  → if trees are snow-free but a snowpack exists under them, MODIS will not observe that snowpack
- more accurate in a remote sensing aspect
- MODSCAG fSCA product used by CBRFC during 2013 melt

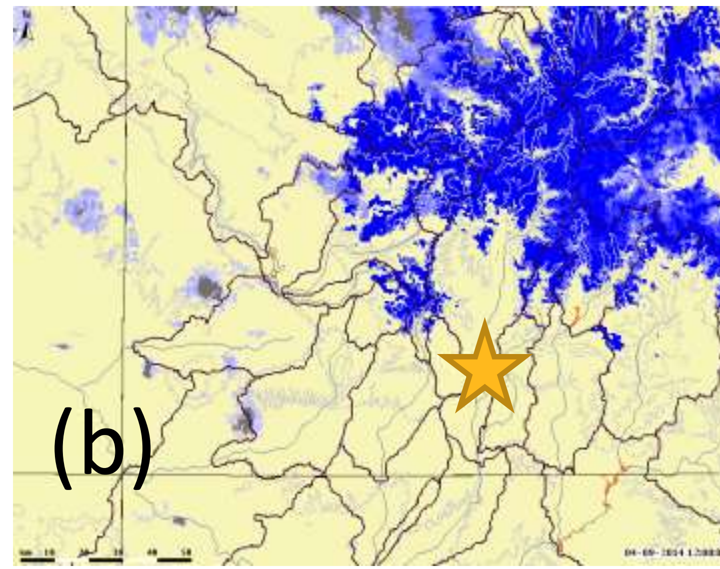
<u>"Canopy-adjusted" MODSCAG fSCA – new for 2014 melt</u>

- In a nutshell: if MODSCAG algorithm detects snow *and* green vegetation in the same pixel, the fSCA value is reset to 100%
- higher fSCA value than "viewable" MODSCAG fSCA
- less accurate in a remote sensing sense but more hydrologically useful
- closer to SNOW17 values of snow cover extent

Multiple MODSCAG fSCA Products

MODSCAG (a) “viewable” and (b) “canopy-adjusted” fSCA over southwestern Colorado, April 9, 2014, as viewed by CBRFC forecasters.





Example: April 2014 Storm

CBRFC

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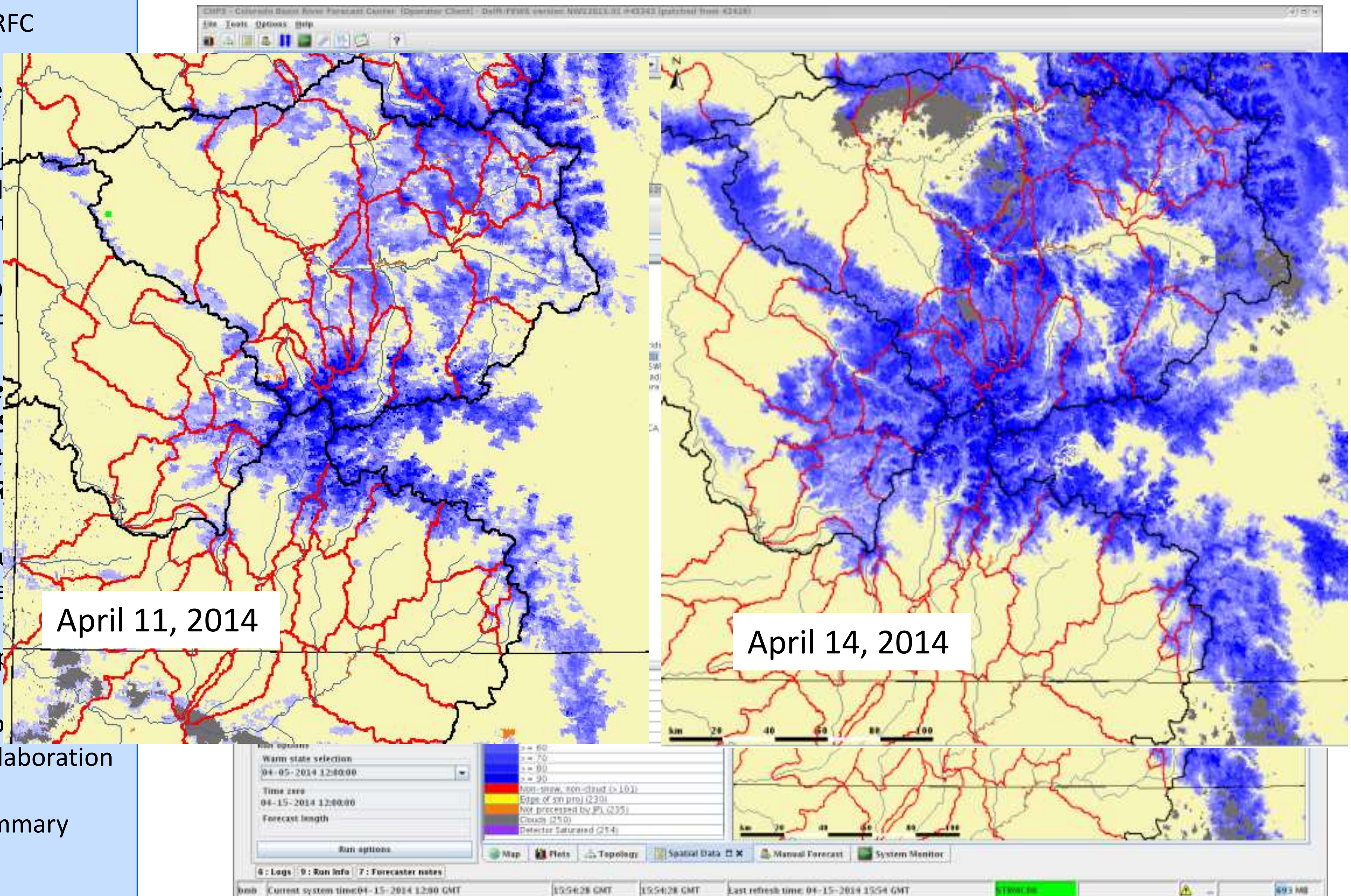
Collaboration

Summary

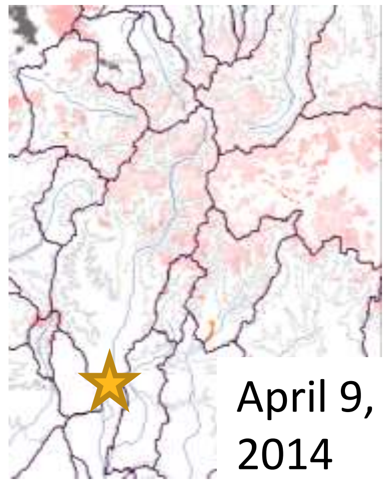


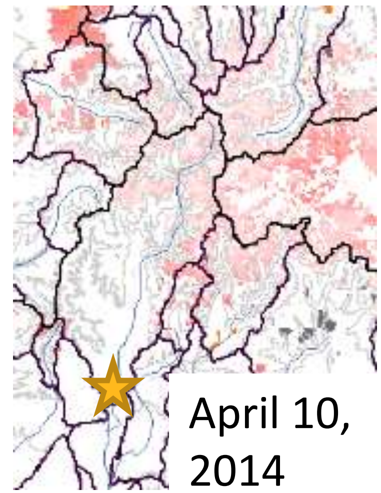
NRT Dust Conditions

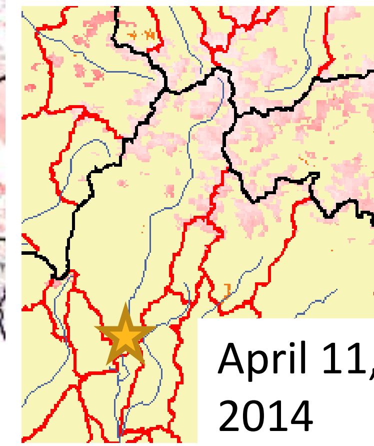
- CBRFC
- The R2O Gap
- Project Goals and Motivation
- MODSCAG & DRFS Datasets
- ***Uses of NASA/JPL Data at CBRFC***
- Future Directions
- Emphasizing the Importance of Collaboration
- Summary

CODOS, April 4: “… dust layer D4 may emerge in the coming week, absorbing solar radiation and accelerating the warming of the underlying snowcover at higher elevations, or enhancing snowmelt rates at lower elevations where the snowcover was already isothermal.”

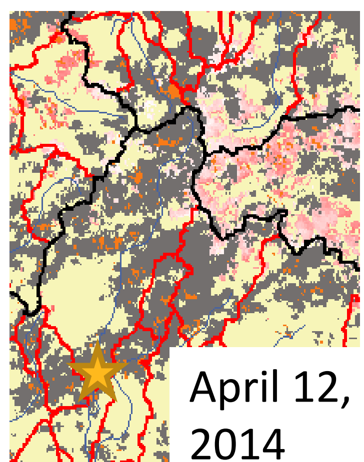

April 8, 2014


April 9, 2014


April 10, 2014


April 11, 2014

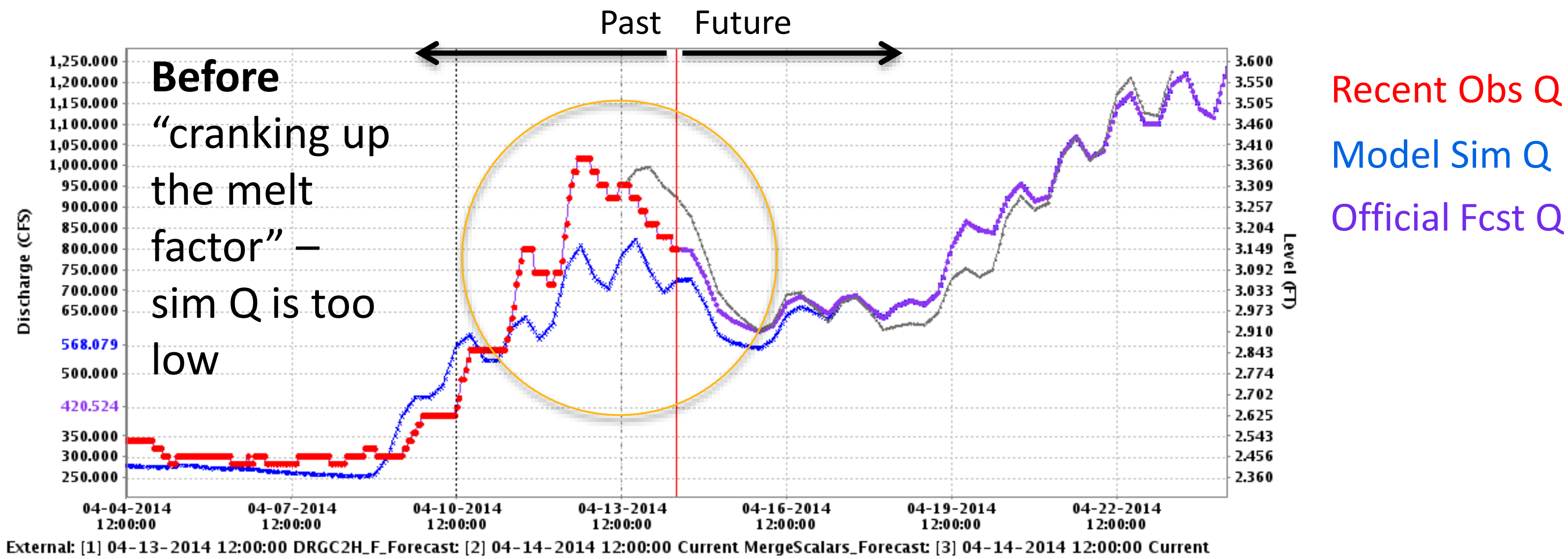
(white)	>= 0.1
(light pink)	>= 50
(pink)	>= 100
(pink)	>= 150
(red)	>= 200
(red)	>= 250
(red)	>= 300
(red)	>= 350
(black)	N/A – Unrealistic value
(grey)	Clouds (2000)
(yellow)	Edge of sin proj (2300)
(orange)	Not processed by JPL (2350)
(grey)	Clouds (2500)

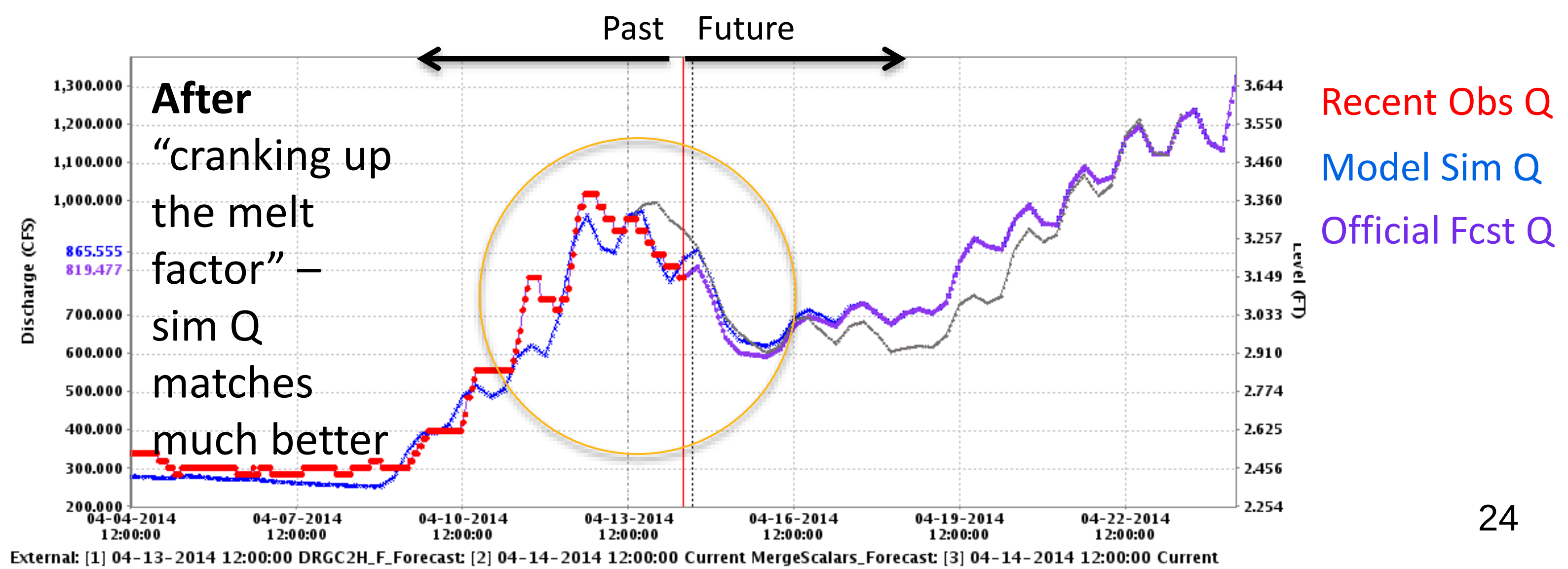

April 12, 2014

April 13, 2014 – storm/cloudy


April 14, 2014

Near Real-time Dust Impacts on Q Forecasts





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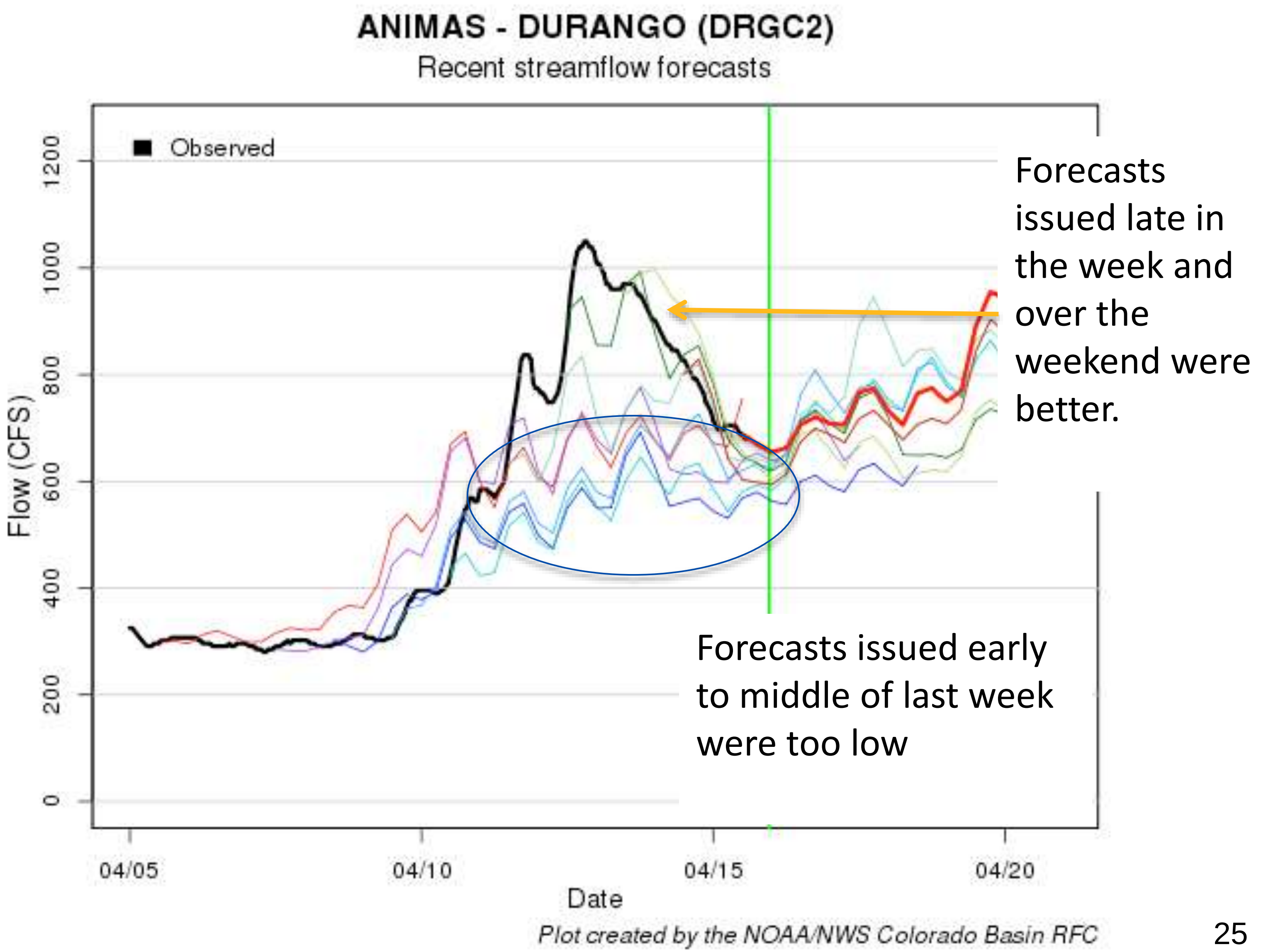

Near Future Directions

<u>For melt season 2015 (and beyond):</u>

* Continue to use information provided by NASA/JPL at CBRFC
  - → manual SWE adjustments from MODSCAG fSCA info
  - → "melt factor" (MF) adjustments from MODDRFS dust info
  - → Fine-tune the range of allowable SWE and MF adjustments

* Connect patterns in JPL MODIS snow data to patterns in snow model parameters, including calibrated SNOW17 areal depletion curves

* Adjustments to MODIS NASA/JPL datasets – estimates for cloudy pixels, vegetation adjustments (filling in gaps in the time series of data)

* Continue to explore pieces of the snowmelt forecasting puzzle – e.g., energy balance snow modeling

* Improve communication between CBRFC and users of CBRFC forecasts on snow remote sensing data at CBRFC and conditions as melt progresses.

* JPL continues to develop the Airborne Snow Observatory to map spatial distribution of SWE

CBRFC/NASA/JPL Collaboration

Collaboration and open exchange of information
→ **very beneficial** to both CBRFC and NASA/JPL

Jet Propulsion Laboratory
California Institute of Technology

CBRFC gains detailed knowledge of:

NASA/JPL snow cover and dust-on-snow data and remote sensing in general

How to overcome limitations in datasets (e.g., vegetation, clouds)

NASA/JPL gains awareness of:

CBRFC operational forecasting and modeling process (including the "human component")

Operational requirements for data availability and timeliness

People involved → KEY to the project's success.

Summary

CBRFC is using JPL's snow remote sensing data!

- MODSCAG fSCA for SWE adjustments
- MODDRFS dust info for "melt factor corrections"

Potential future uses of snow remote sensing data:

- Further analysis of historical MODIS datasets
- Improvements in JPL remote sensing datasets (estimating conditions on cloud days, further vegetation corrections, ASO)

People make the collaborative R2O wheels go round.

- Operational hydrologists
- Remote sensing science experts

Take Home Messages
Operational forecasting agencies CAN use snow remote sensing data.
Best, most robust way to use data in operational hydrology is still TBD.
Successful R2O collaborations are driven by dedicated people on the operations side AND the research side.

Contact Info:
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