Integration of precision NASA snow products with the operations of the Colorado Basin River Forecast Center to improve decision making under drought conditions

Thomas H. Painter
JPL/Caltech

Water Resources – Project Summary

- **Title:** *Integration of precision NASA snow products with the operations of the Colorado Basin River Forecast Center to improve decision making under drought conditions*
- **Project PI**: Thomas H. Painter, JPL/Caltech
- **Solicitation**: A.34 Water Resources
- **Project Summary**: The primary objective of this project is to integrate real-time MODIS Snow Covered Area and Grain size (MODSCAG) fractional snow covered area (SCA) into CBRFC modeling and analysis systems and into stakeholder oriented data products, markedly reducing SCA uncertainties that have hampered forecasting operations for decades. A secondary objective is to ingest and study MODIS Dust Radiative Forcing in Snow (MODDRFS) radiative forcing imagery, to better understand its value as an input to modeling and forecasting approaches. CBRFC will offer a direct connection to stakeholders (End Users) and together with other linked NWS operational centers provides an institutional home to maintain the advances of this effort beyond project's end.
- **Geographic scope**: Colorado River Basin, Western USA
- **NASA products and modeling**: MODSCAG Snow Covered Area, MODDRFS Dust/BC Radiative Forcing in Snow + SNOW-17/Sac-SMA operational forecasting model, VIC+MODSCAG/MODDRFS, WRF+MODSCAG/MODDRFS

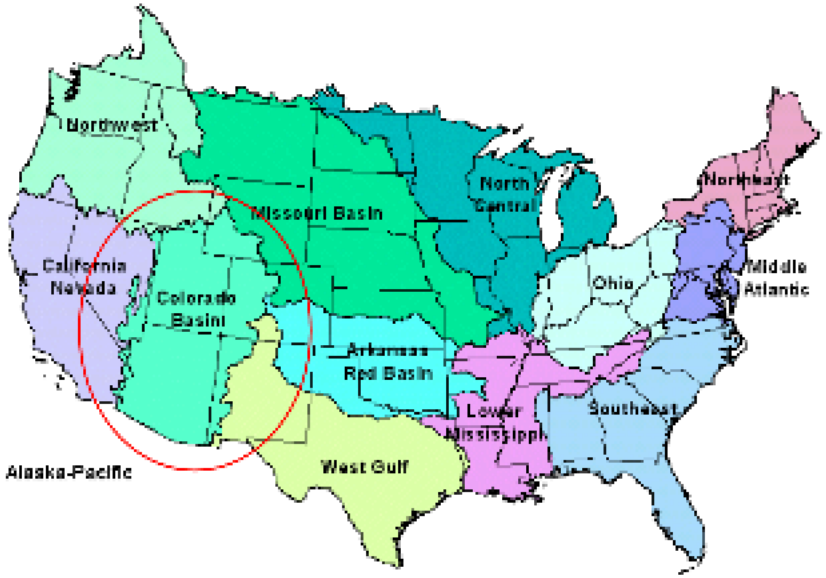
Colorado Basin River Forecast Center (CBRFC)

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

Vacancies:

- 1 hydro (now open on usajobs!)
- 1 mgmt (not yet open)

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



National Weather Service River Forecast Centers

Operational forecast types:

- daily streamflow
- seasonal peak streamflow
- seasonal runoff volume

www.cbrfc.noaa.gov

Operational Snow Model: SNOW17 (lumped)

- minimum inputs and 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 temperature
- 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

Integration NASA snow with CBRFC forecasting
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Accomplishments / Results

① Ongoing use and refinement of use of near real-time MODSCAG
② Introduction of near real-time canopy-adjusted MODSCAG fractional snow covered area into CBRFC operations
③ New use of near real-time MODDRFS dust radiative forcing to update snowmelt rates in CBRFC operations
④ Evaluation of CBRFC SNOW-17 forecasting errors across Colorado River Basin relative to dust radiative forcing anomalies from near real-time MODDRFS
⑤ Modeling of runoff at forecast points with VIC and MODSCAG
⑥ WRF modeling of snowmelt and dust-accelerated snowmelt in Colorado River Basin

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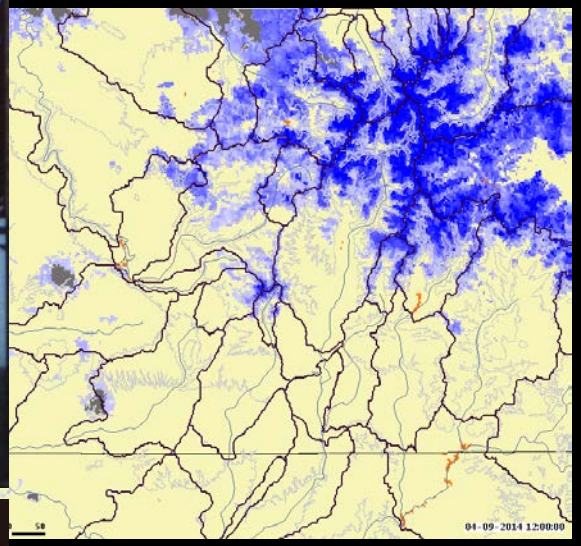
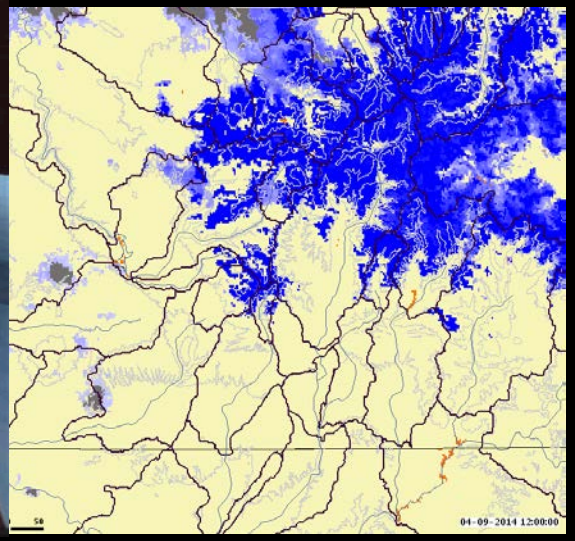


(a)



(b)

	Snow-free
	>= 1
	>= 10
	>= 20
	>= 30
	>= 40
	>= 50
	>= 60
	>= 70
	>= 80
	>= 90
	Non-snow, non-cloud (>101)
	Edge of sin proj (230)
	Not processed by JPL (235)
	Clouds (250)
	Detector Saturated (254)

influence has been reduced.

Figure 1:
Graphical display of MODSCAG (a) "viewable" and (b) "canopy-adjusted" gridded fSCA over southwestern Colorado, April 9, 2014, as viewed by CBRFC forecasters within CHPS.

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Highlight: During 2013-2014, CBRFC forecasters more closely monitored the MODDRFS datasets as snowmelt occurred.

Relevance:
<u>Dust-on-snow information from MODDRFS</u>

CBRFC operational snow model = SNOW17, a temperature-index model.

Air temperature = primary consideration at CBRFC for snowmelt rates

MODDRFS data provide *supporting* information about the potential for acceleration of snowmelt rates to CBRFC forecasters

Given air temperature and dust-on-snow information, CBRFC forecasters can forcibly increase or decrease snowmelt initially simulated by SNOW17 through the use of "melt factor corrections" (MFCs)

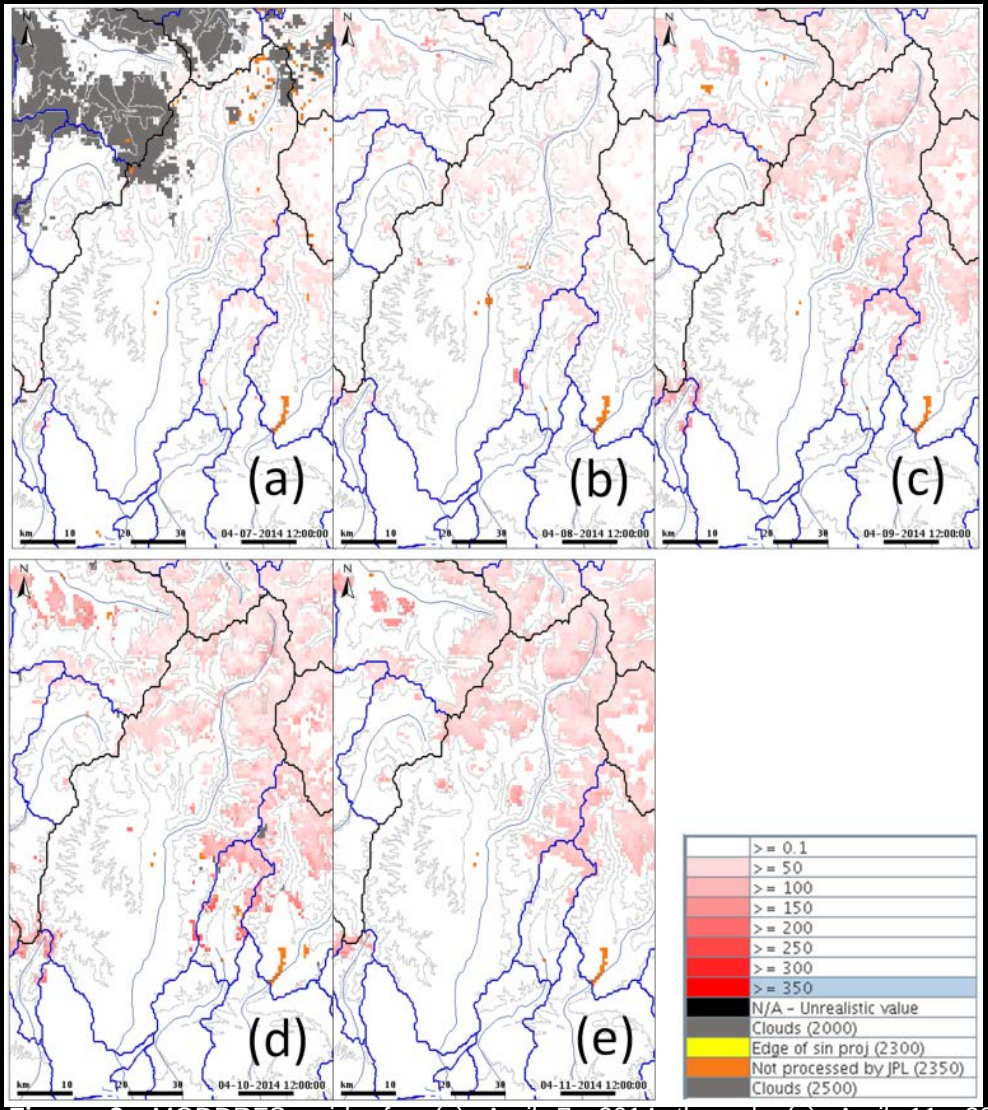

Figure 2: MODDRFS grids for (a) April 7, 2014 through (e) April 11, 2014, for southwestern Colorado, including the Animas River headwater basin near Durango, CO (indicated by the green star), as viewed by CBRFC forecasters within CHPS.

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Relevance:

MFCs - needed when energy input to the snowpack deviates from typical conditions, as implied by air temperature as an index, and MODDRFS albedo information and field reports as supplemental information

Example case from mid April 2014:

- air temperatures up to +8C (Fig. 3)
- MODDRFS indicated elevated potential for accelerated snowmelt rates (Fig. 2)
- Field reports from the Colorado Dust-on-Snow (CODOS) program mentioned an emerging dust layer and the potential for enhancement of snowmelt rates

Combination of above information gave forecasters confidence when they used MFCs to manually increase the snowmelt rate.

Better streamflow forecasts after the MFC was applied using sources of information listed above (Fig. 4)

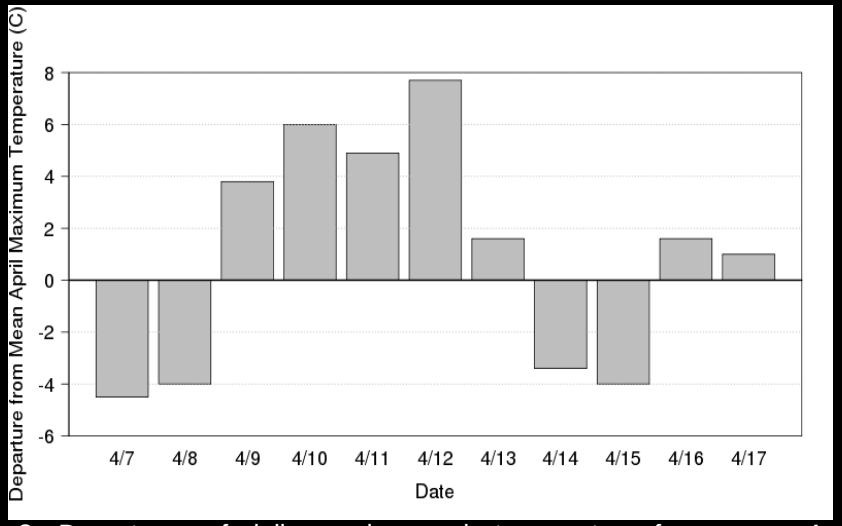

Figure 3: Departures of daily maximum air temperature from mean April maximum temperature (gray) for Silverton, CO (NWS ID: SLVC2) in mid April 2014

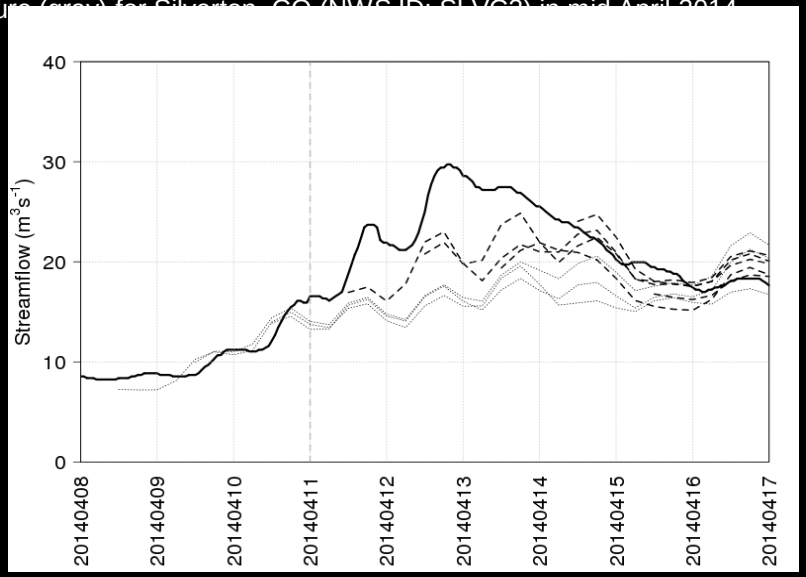

Figure 4: Observed streamflow (bold line), streamflow forecasts issued *before* MFC by CBRFC forecaster (dotted lines), and streamflow forecasts issued *after* MFC by CBRFC forecaster (dashed lines), for the Animas River at Durango, CO.

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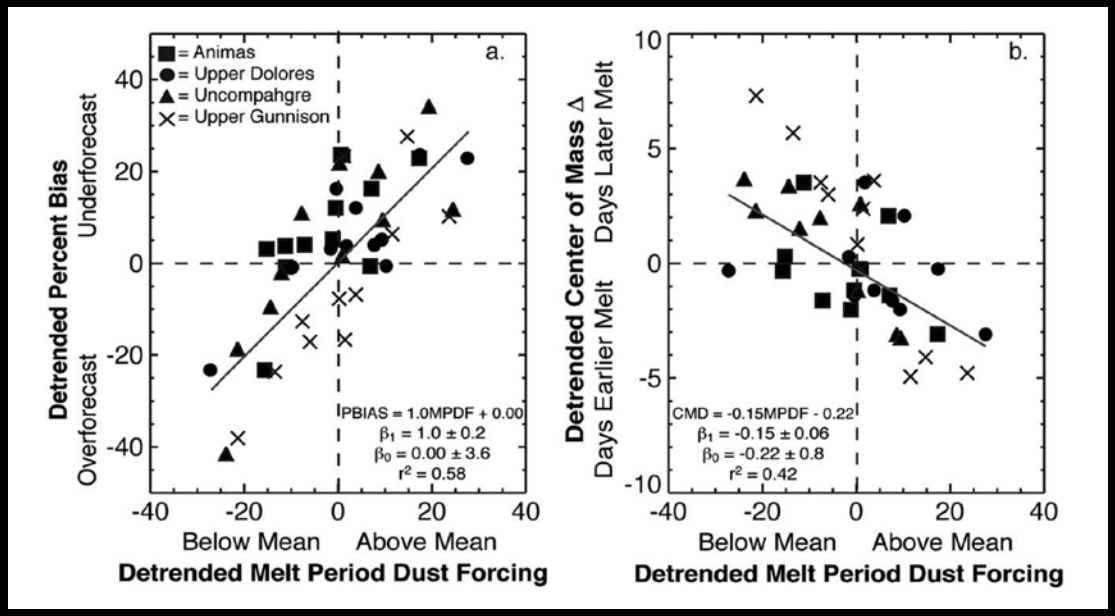
Highlight: Analysis of CBRFC Snow-17 forecasting of rising limb of hydrograph relative to dust radiative forcing in snow from MODDRFS

Dust absorption of sunlight in snow has been increasing across entire Colorado River Basin since 2000.

Bigger rising limb forecast errors and range at CBRFC where dust absorption range is greater

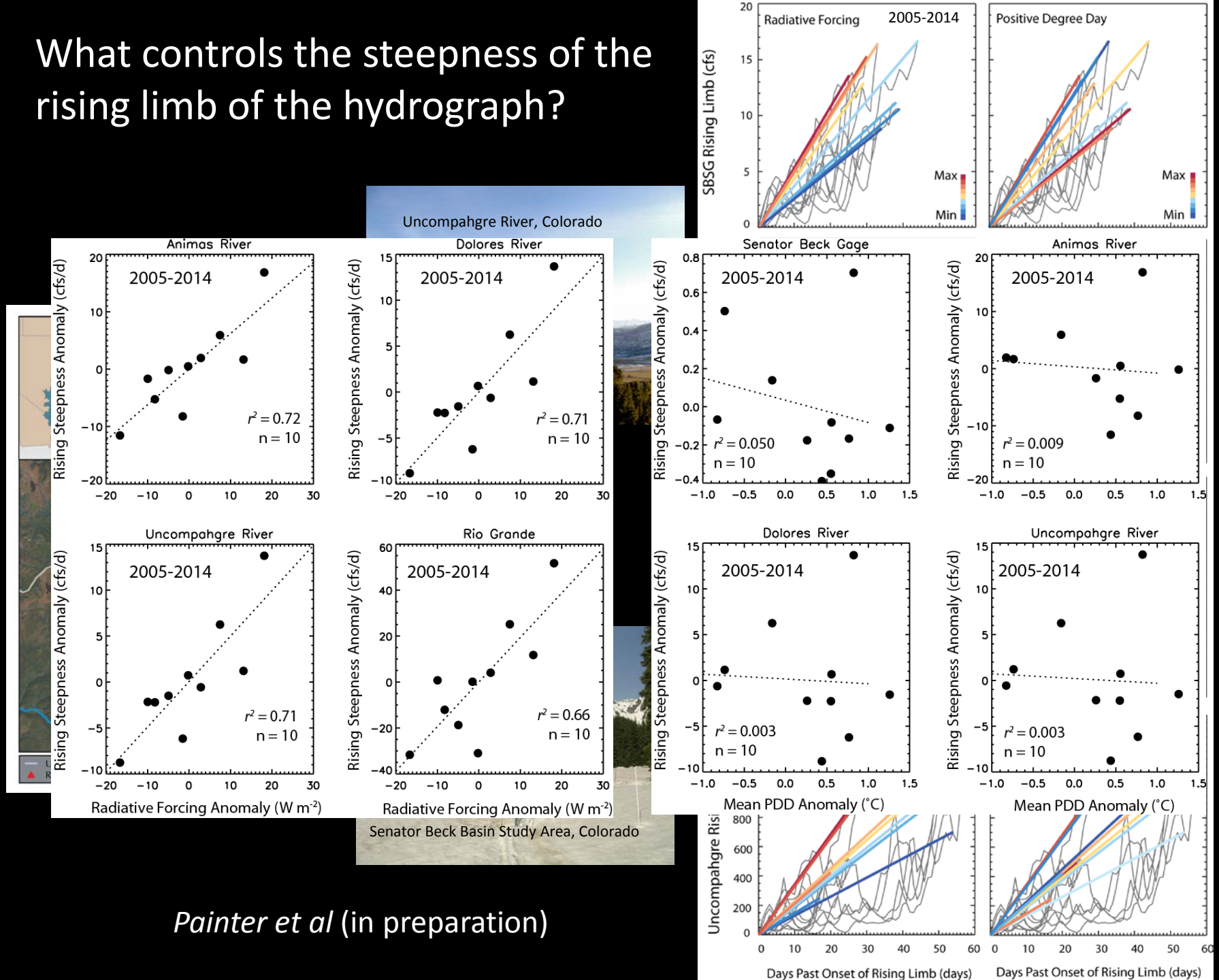
Smaller magnitude of forecast errors where lower dust radiative forcing and lower interannual variability



Relevance:

- Gives understanding of SNOW-17 errors relative to forcings in the basin
- Indicates regional sensitivities and needs for dust forcing information and snow water equivalent information
- Provides initial foundation for protocols of usage of dust forcing information in SNOW-17 forecasting and error corrections

What controls the steepness of the rising limb of the hydrograph?



Painter et al (in preparation)

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Successfully assimilated snow cover fraction satellite observations into a hydrology model

Demonstrated the value of the MODSCAG data product for estimating snow mass over the entire Upper Colorado River basin

Developed the framework for providing initial SWE conditions informed by satellite observations for streamflow forecasting

Improve forecast skill for inflows to reservoirs therefore allowing for more efficient releases

Relevance:

Assimilation of snow covered area into physically-based snow model

Converges toward modeled snow water equivalent from physically based snow model to improve SNOW-17 SWE nudging

Important step in remote sensing constrained modeling in operational forecasting

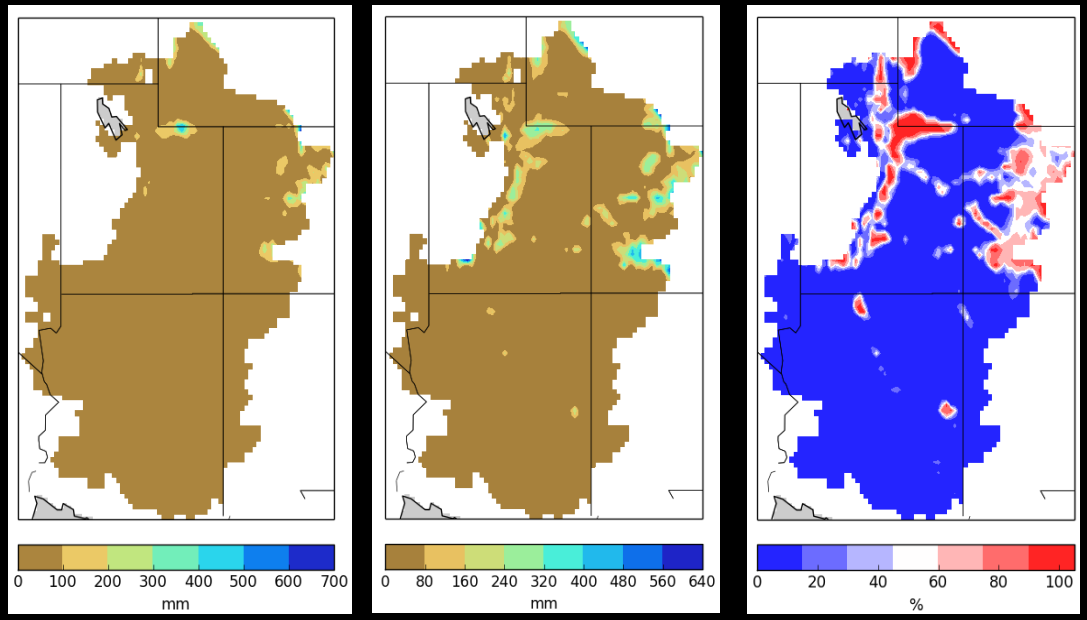

Figure 1: Simulated snow water equivalent with (middle) and without assimilation (left), along with MODSCAG observations (right).

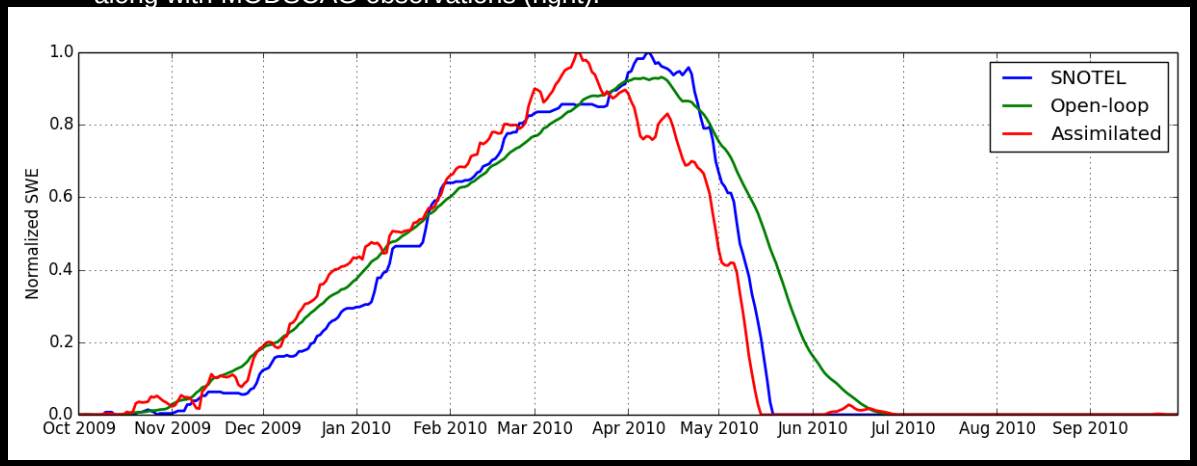

Figure 2: Simulated snow water equivalent with (red line) and without assimilated MODSCAG observations, compared with in-situ measurements from the SNOTEL network at Columbine, CO for the 2010 water-year.

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Highlight:

Weather Research and Forecasting (WRF) modeling of basin water cycle with explicit treatment of dust radiative forcing and optics (SNICAR optical model)

Snowmelt production readied for more robust flow routing in next year (courtesy Famiglietti group)

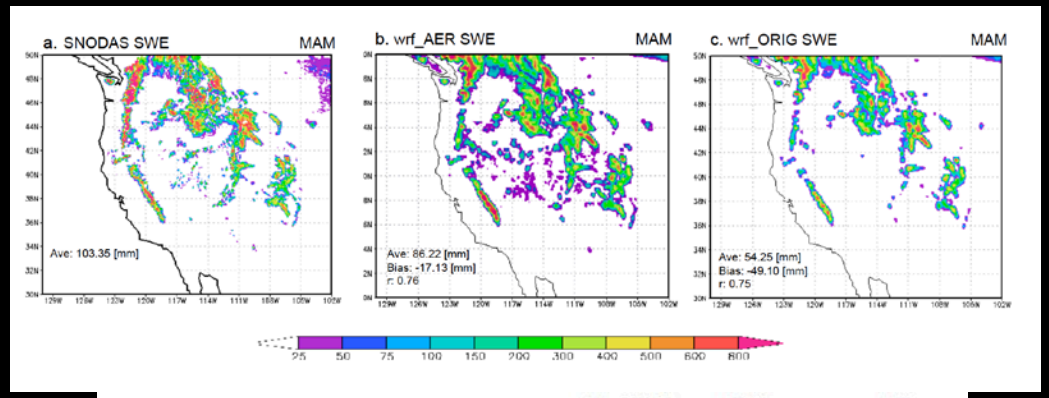
Guidance on physical processes in Colorado River Basin and Great Basin

Relevance:

Provides physical understanding of processes controlling water cycle in CRB and Great Basin to guide modifications to SNOW-17 model usage

Sets evaluation of mesoscale modeling that will be incorporated with VIC modeling for physically based snowmelt runoff modeling

This is a fundamental goal of this project



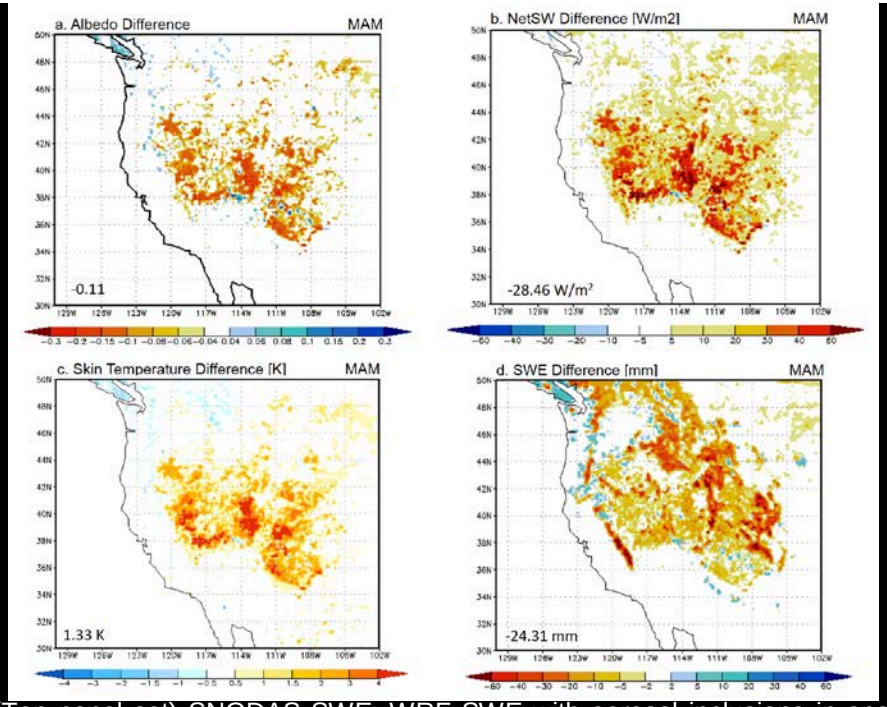


Figure (Top panel set) SNODAS SWE, WRF SWE with aerosol inclusions in snowpack, WRF SWE without aerosol inclusions in snowpack as handled by SNICAR soft coupled model. (Bottom panel set) Differences in albedo, net shortwave, skin temperature, and SWE between WRF with aerosols (SNICAR) and WRF without aerosols.

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Highlight:

- Preparation of near real-time fractional snow cover from NPP VIIRS (VIIRSSCAG)
- Comparisons with standard VIIRS snow product and MODSCAG
- Delivery and testing of VIIRSSCAG in CBRFC setting for ultimate transition to NPP VIIRS and JPSS VIIRS

Relevance:

The ultimate sustained adoption of fractional snow products by CBRFC will carry on through the end of MODIS products and into VIIRS for polar orbiting

This specifically targets the goal of this project.

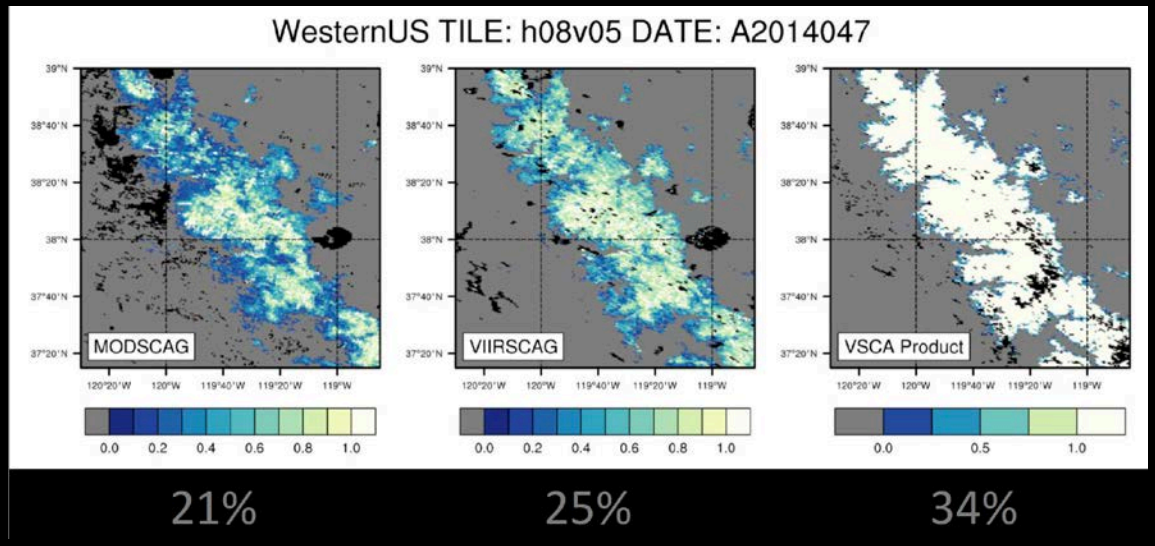


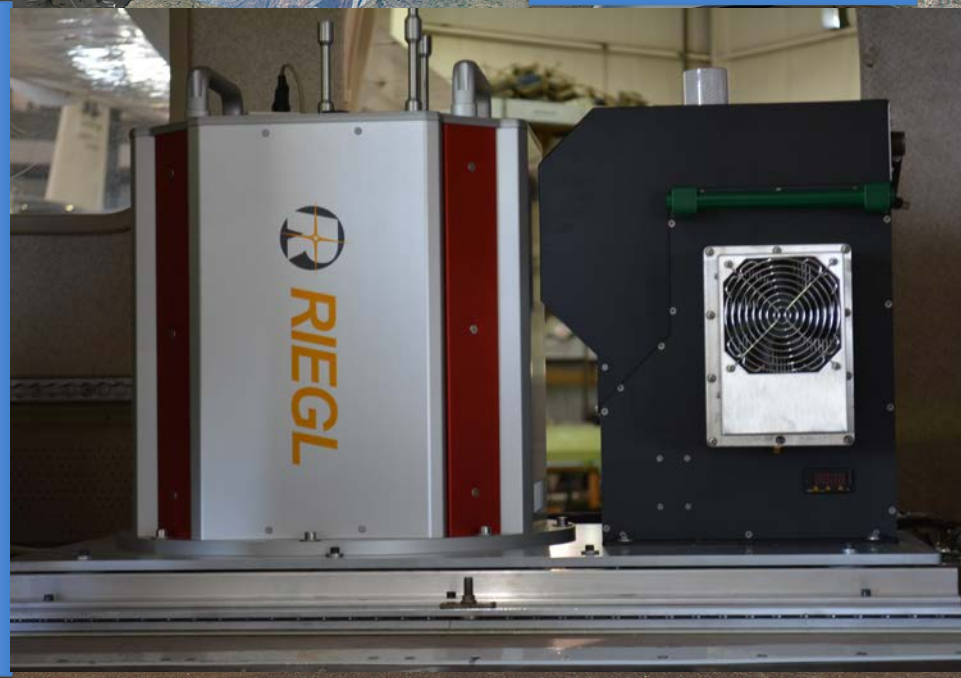
Figure: MODIS tile h08v05 (Left) MODSCAG fractional snow cover (viewable), (Middle) VIIRSSCAG fractional snow cover (viewable), (Right) VIIRS standard fractional product (2 by 2 averaging), showing its large overestimate.

Albedo

CASI-1500 Imaging Spectrometer
0.35-1.05 µm
2 m spatial resolution from 4000 AGL

Snow Water Equivalent

Riegl Q1560 3D Scanning lidar
1064 nm, canopy penetration
1 m spatial resolution



- Retrieve topography snow-free and snow-on
- Difference gives snow depth
- SWE comes from assimilation of modeled density field constrained by observations
- SWE variation primarily from depth

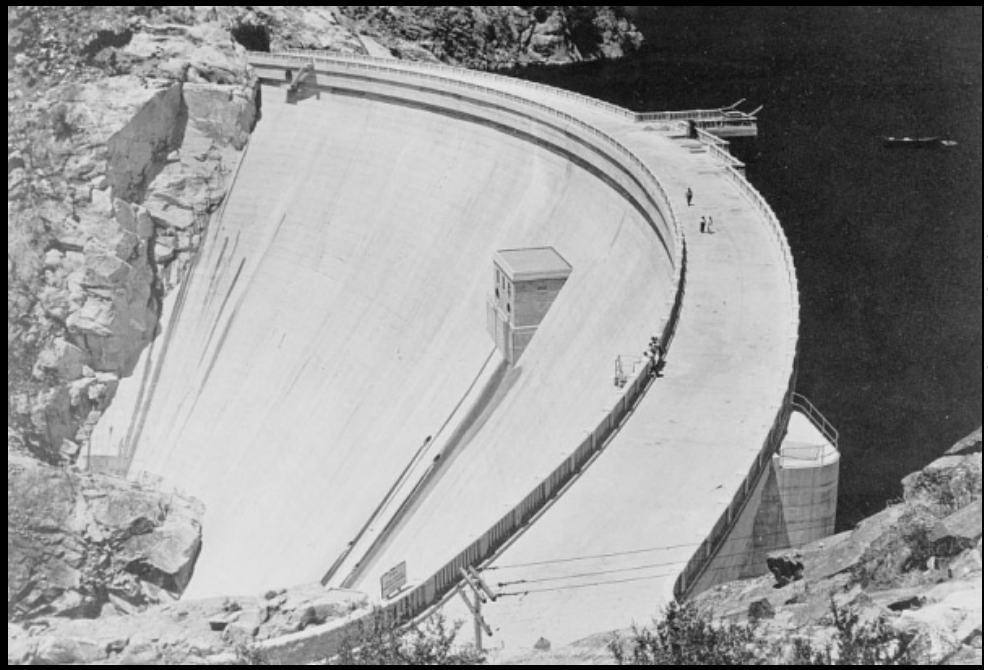
Th The way we se want to see it in the Tuolumne

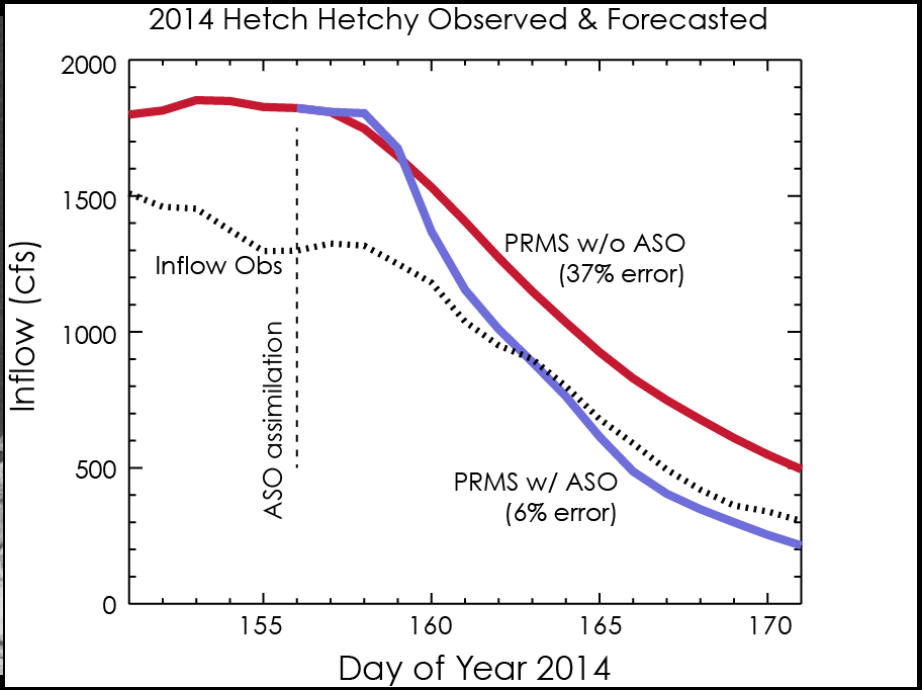
(3600x expanded)

…. 39 million times more coverage

Runoff Forecasting

Hetch Hetchy – Tuolumne River Basin





Snowmelt runoff forecasting with USGS Precipitation/Runoff Modeling System (PRMS)

Joint efforts

- CA DWR
- California Cooperators
- City of SFO HH operation
- Bureau of Reclamation Research Office – ASO Value of Information activity
- CWCB
- Wyoming State Engineer's office
- SNWA
- Physically-based modeling with MODIS/VIIRS/ASO and partnering with National Water Center

Training

- Colorado River Basin management community – online – 2013
- California – Sacramento-San Joaquin water management community – 2 days in person – 2014
- Colorado River Basin water management community – 2 days in person – TBD 2015