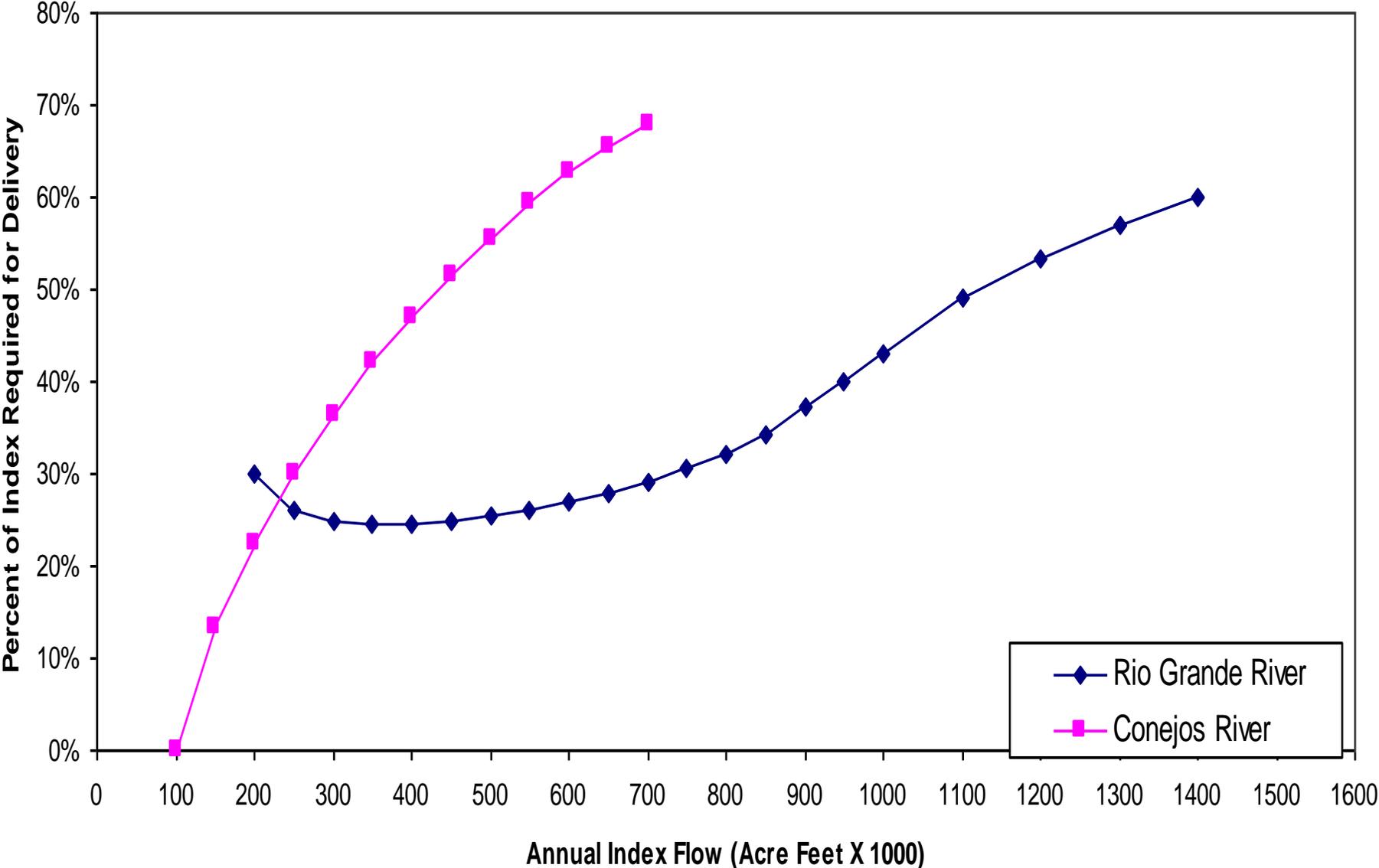


Rio Grande Basin Forecasting Project

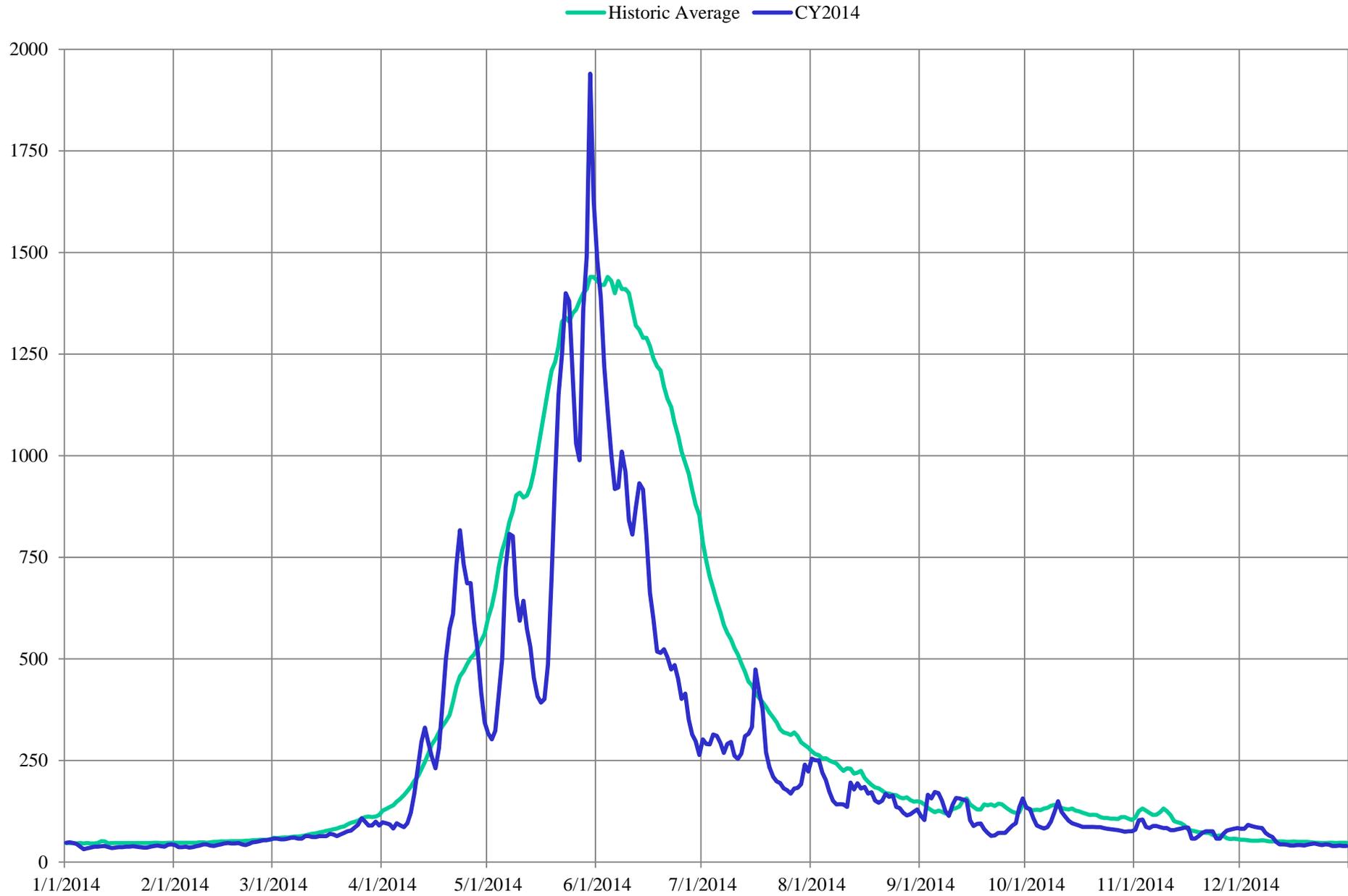
Workshop on snowpack monitoring for
streamflow forecasting and drought planning
Sep. 9, 2015



Rio Grande Compact Delivery Requirements as a Percentage of Annual Index Flows

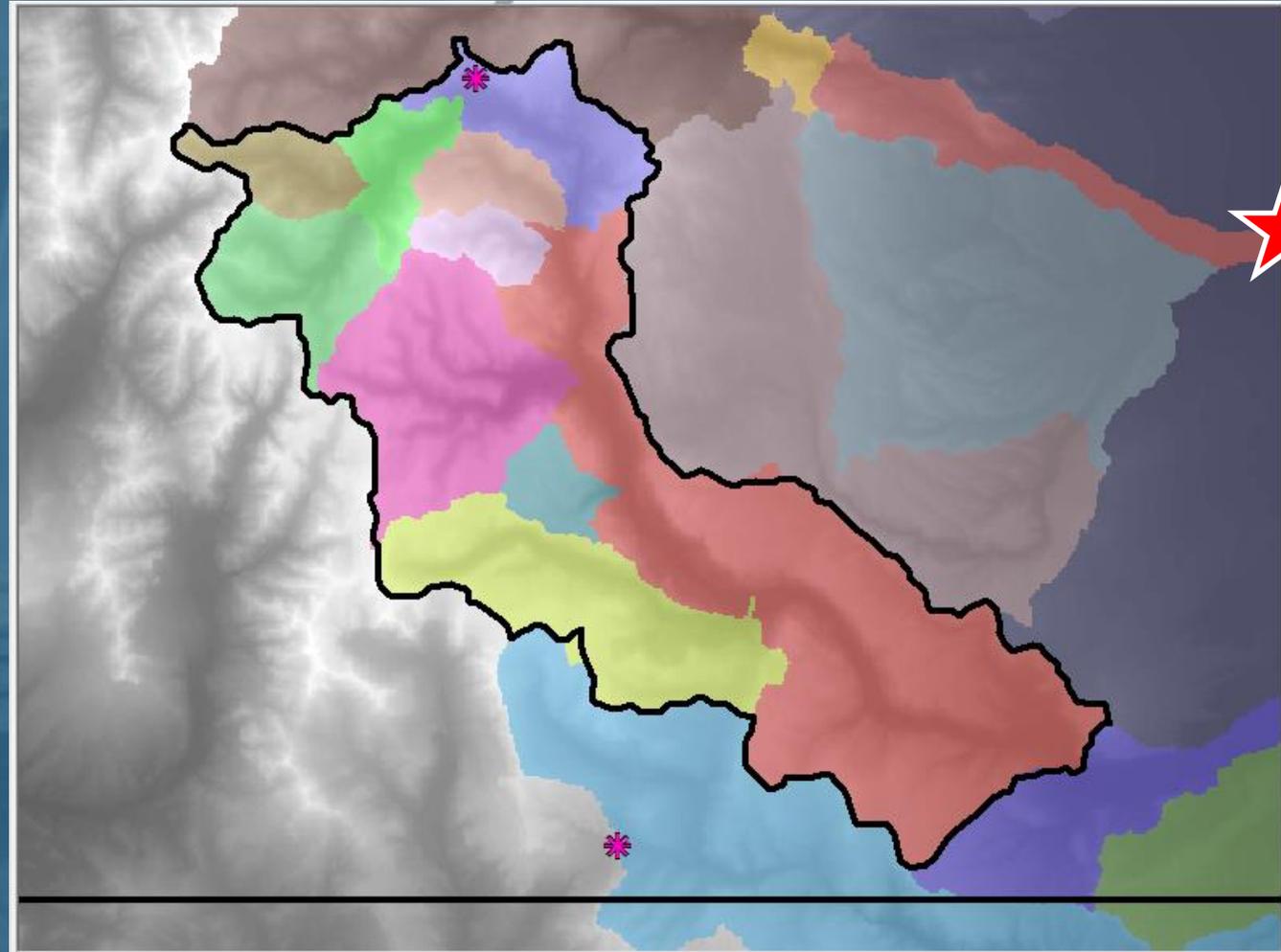


Conejos River near Mogote



Project Motivation and Goals

- Project Motivation:
 - Need better skill in water supply forecasts to better meet Compact requirements
 - Build on demonstrated capabilities of ‘radar in the mountains’ (6 years)
 - Limited information on snowpack, snowmelt and tributary streamflow conditions leads to uncertainty in snowpack conditions
 - SNODAS
 - Hydro models
 - Other snowpack analyses

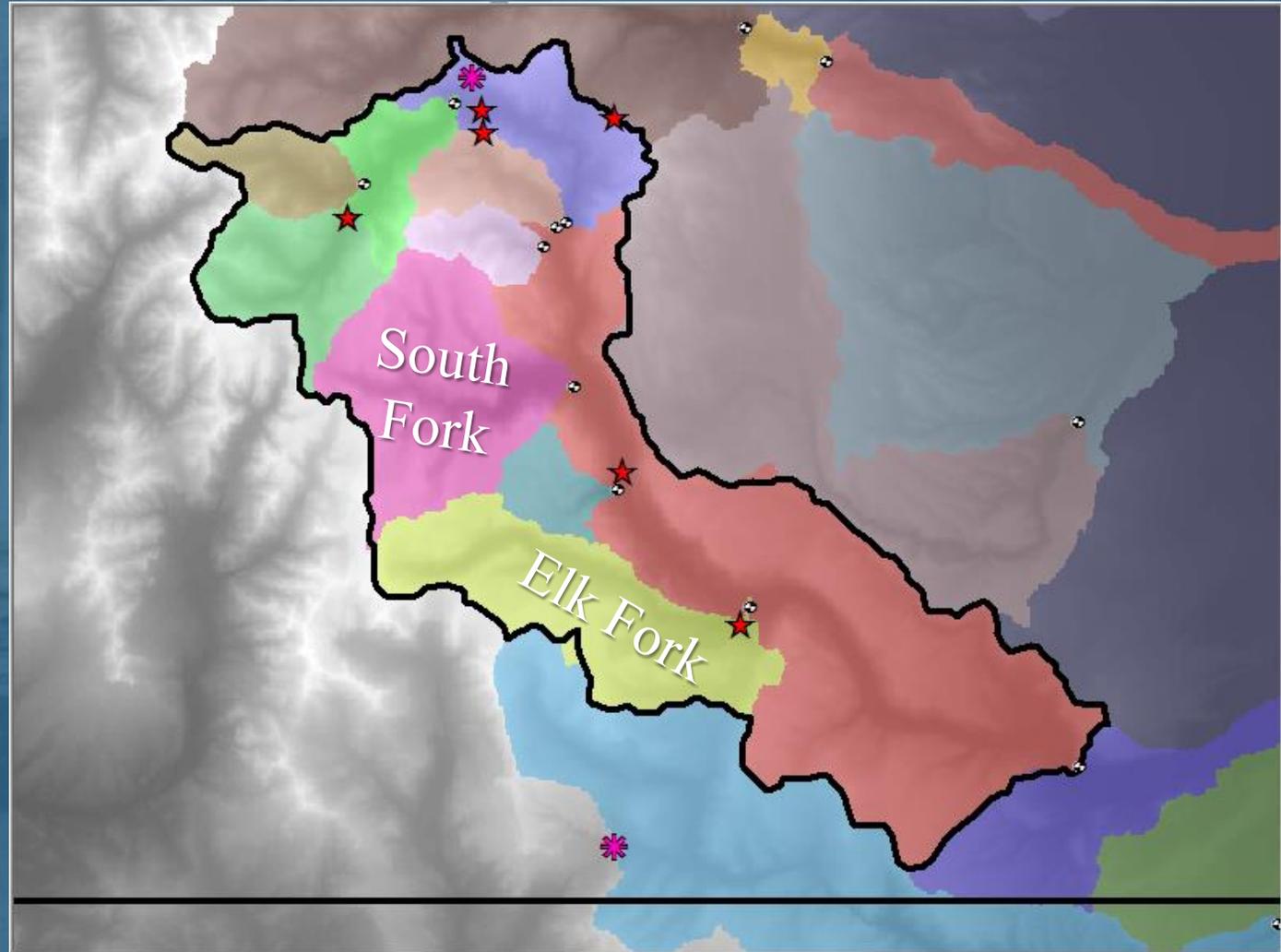


Overarching Questions:

- What are the biases in operational precipitation, temperature, humidity, wind and insolation forcing?
- Can operational forcing data errors be corrected with local data?
- How are model biases in simulated snowpack (accumulation and depletion phases) related to errors in forcing data?
- How are the model biases in simulated streamflow (timing and total seasonal volume) related to forcing data and simulated snowpack errors?

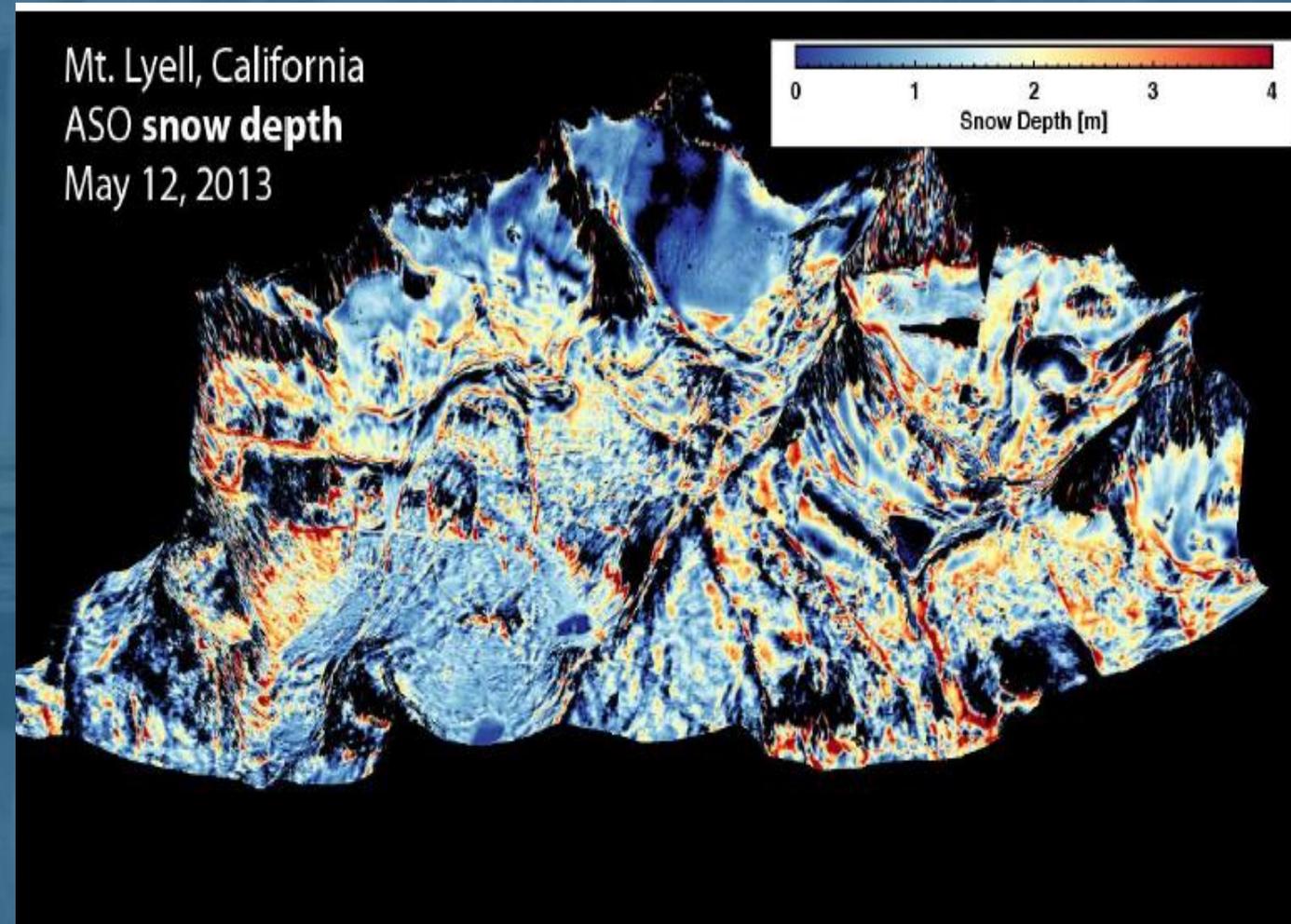
Project Motivation and Goals

- Project Goals:
 - Strategic enhancement of precipitation and snowpack observations
 - Evaluate value of new measurements compared to existing analyses
 - Use enhanced observations to evaluate distributed modeling system (WRF-Hydro)
 - Develop new experimental water supply forecast methodologies



Hydrologic Monitoring and Seasonal Streamflow Prediction in the Upper Rio Grande River Basin

- NSSL - NOXP (Xband) radar
 - Snowfall retrieval based on past radar in mountains experiments
- NCAR met. stations (6 stations in Conejos Basin)
- NCAR streamflow (4 sites in the Conejos basin)
- NASA Airborne Snow Observatory
- Operational: NRCs/SNOTEL, CDWR, NWS/SNODAS, MODIS/SCA



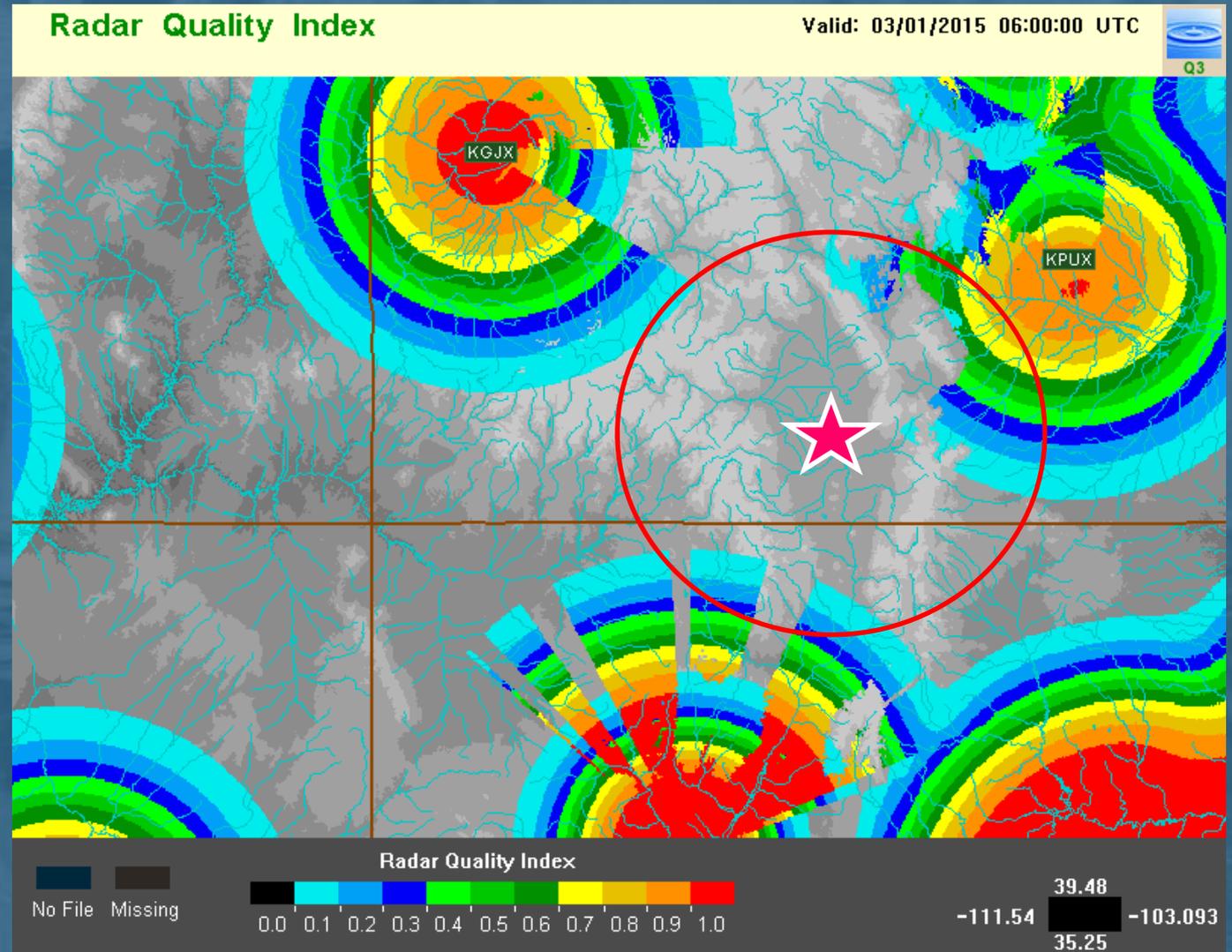
Community Engagement in the San Luis Valley and State of Colorado

- Project participants:
 - U. Oklahoma (radar)
 - Adams State U. (radar)
 - Colorado State U. (survey)
 - U. of Colorado (snow pits)
 - Conejos Water Conservancy (site maint.)
 - NRCS, CWCB, NSSL, NASA, NCAR

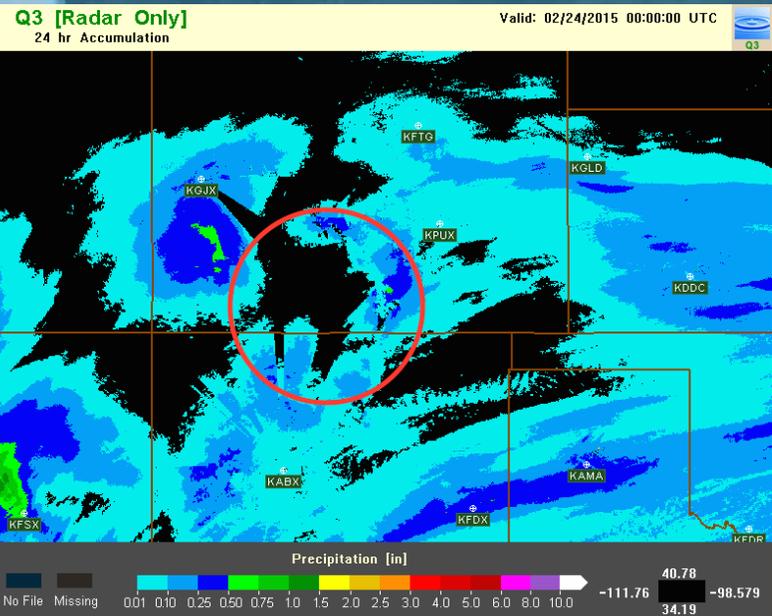


NSSL Radar Products: Filling the gap

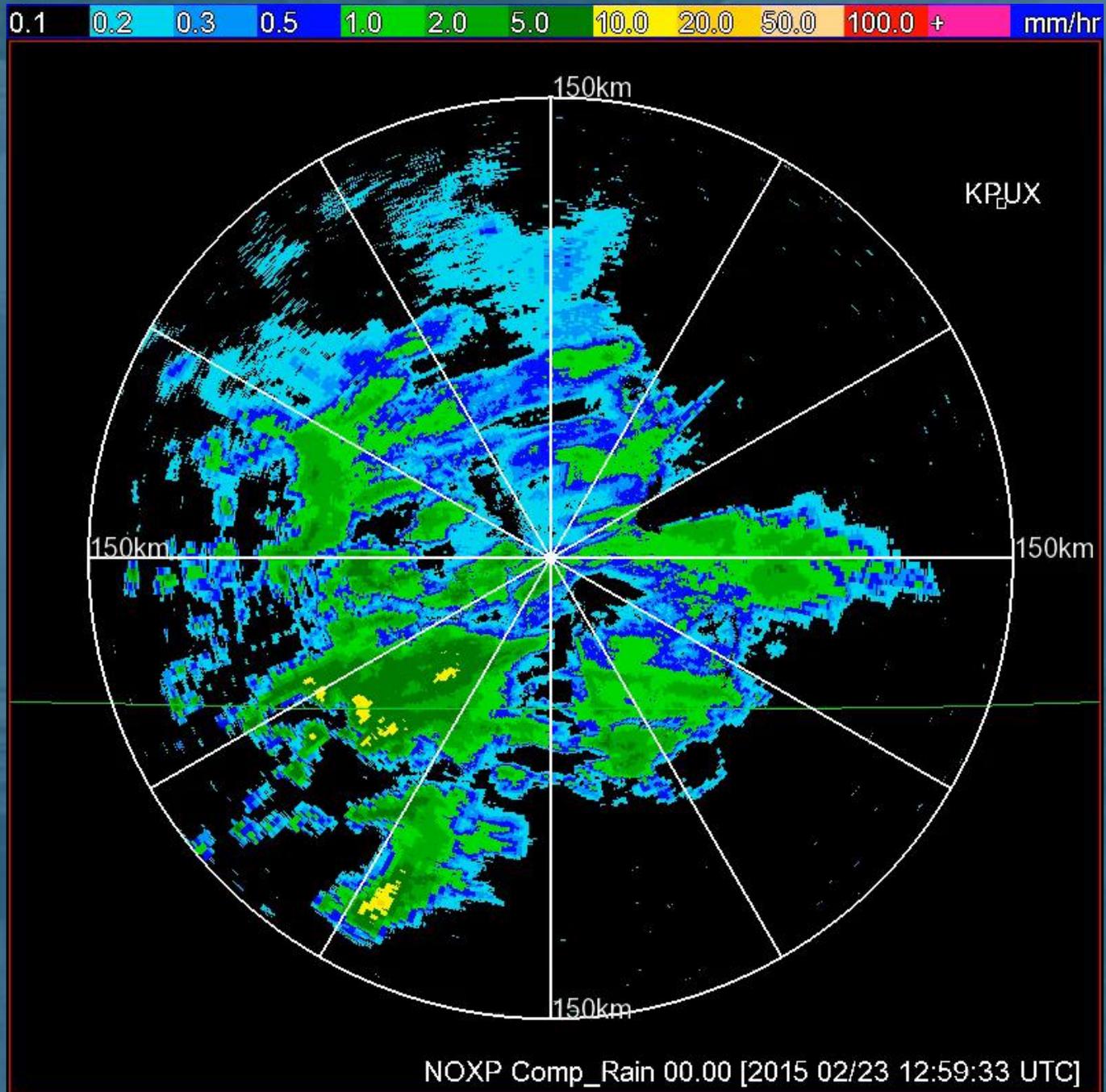
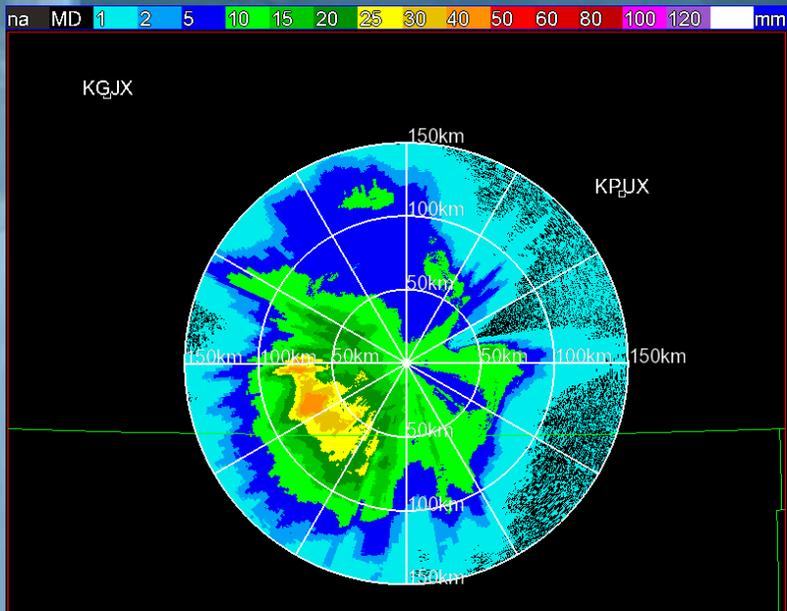
- No quality coverage in upper Rio Grande
- NSSL radar in Alamosa provides 360 deg coverage out to 100km radius
- Estimates of precipitation rate and rain/snow partition
- Operated during all major events Dec.-Apr.



Operational National Radar Mosaic

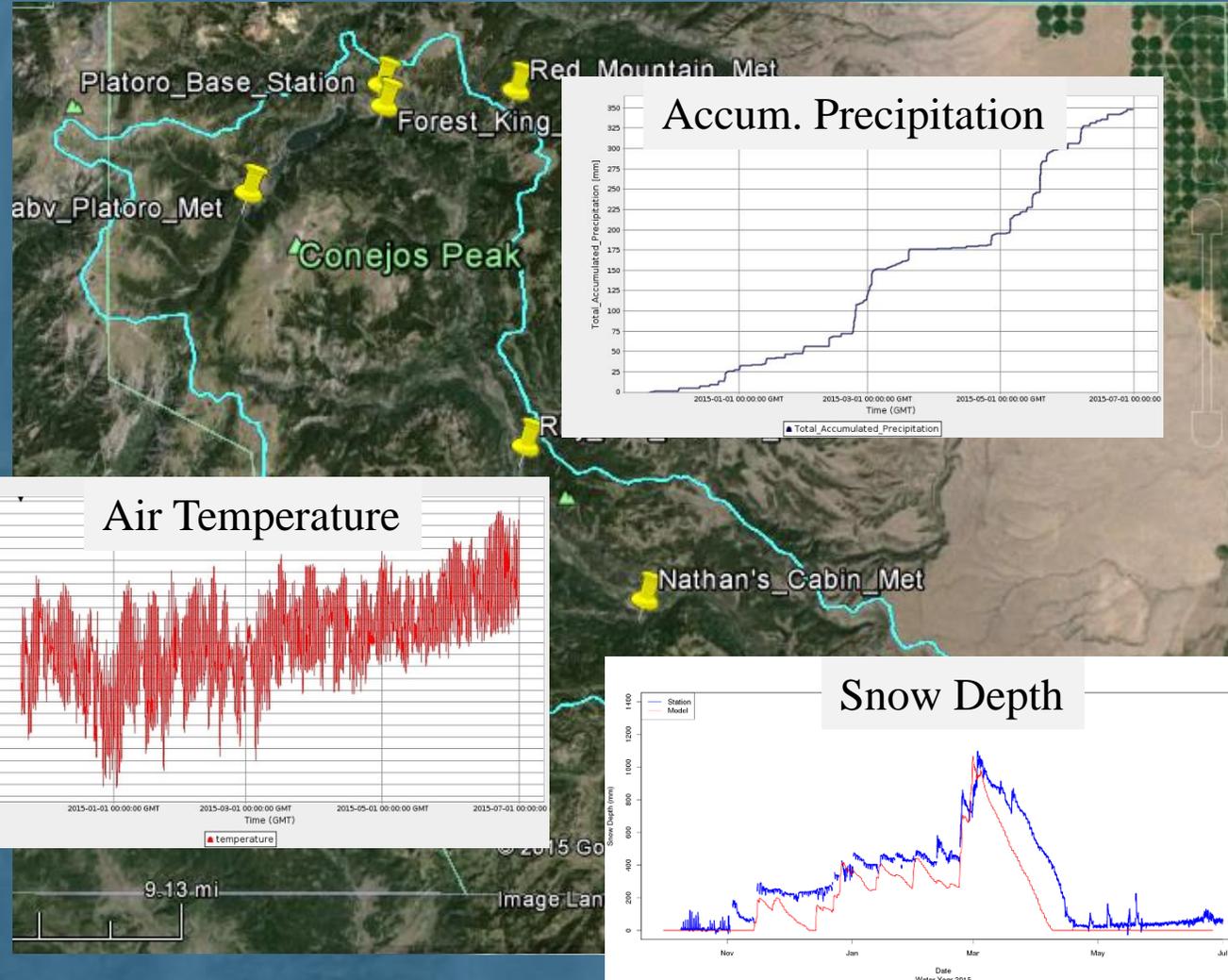


NOXP-Alamosa



On-the-ground Measurements in the Conejos

- 6 stations:
 - Temperature
 - Humidity
 - Wind
 - Incoming solar radiation
 - Snow depth
 - Soil moisture/temperature
- 3 stations
 - Precipitation

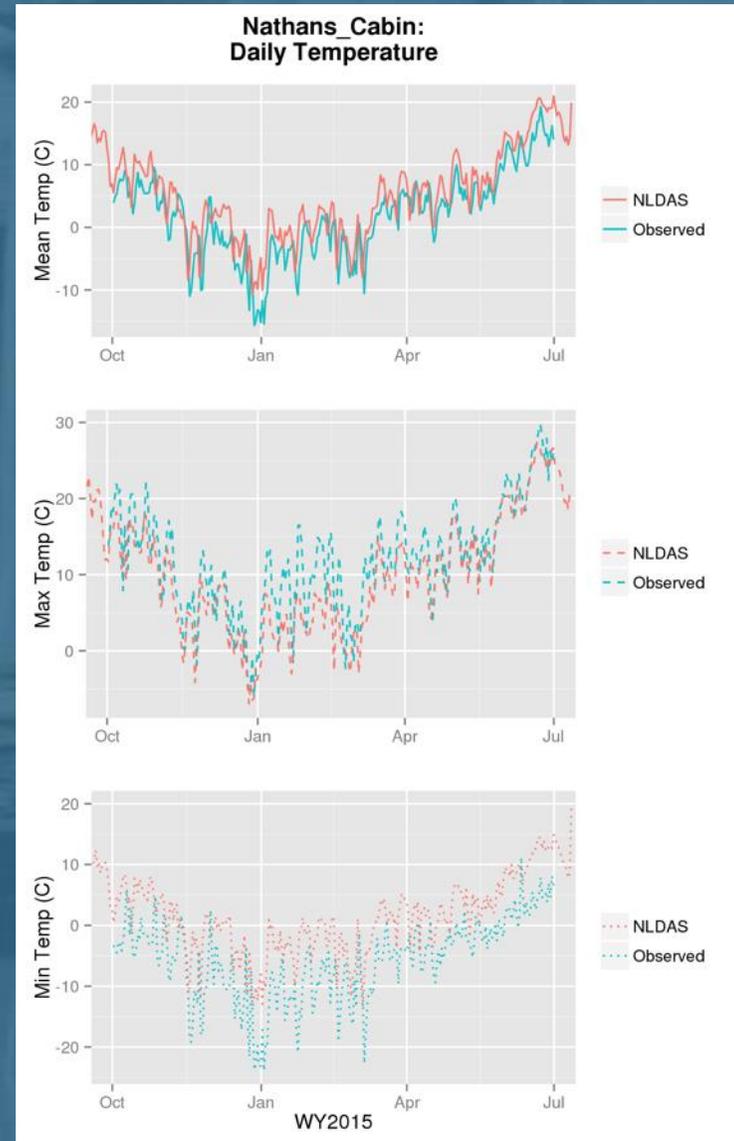




Results from Year 1 Monitoring

On-the-ground Measurements in the Conejos

- Comparing operational NLDAS met. data vs. local stations:
- Downscaled NLDAS lacks daily temperature range vs. local observations
- NLDAS has warm bias for valley stations
- NLDAS overestimates total daily insolation



On-the-ground Measurements in the Conejos

Percent Bias in NLDAS Forcing Variables

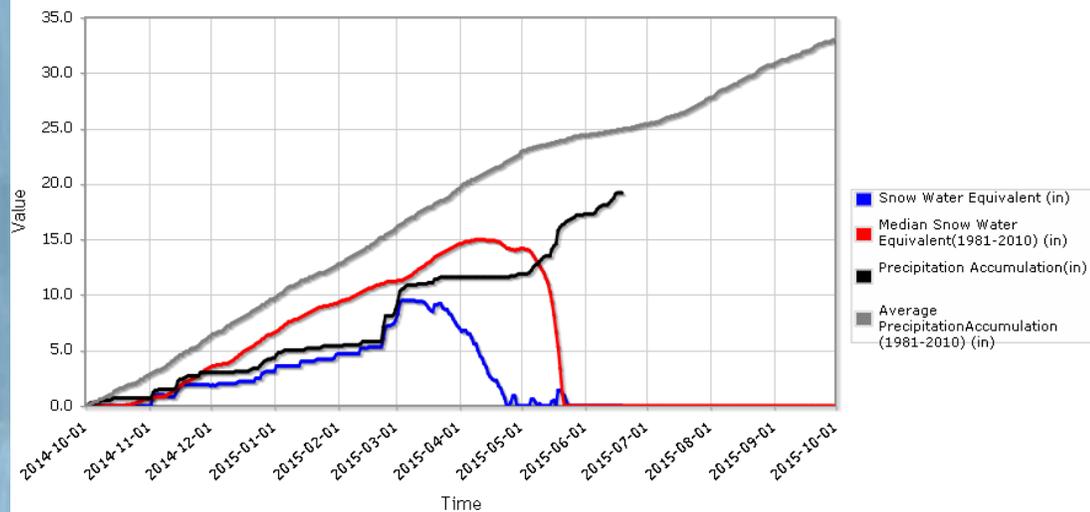
site_id	site_name	Temperature (K)	RelHum (0-1)	SurfPress (Pa)	Wind (m/s)	SWRad (W/m2)
1	Upper_Conejos_abv_Platoro	0.5	-26.7		1962.2	35.0
2	Red_Mountain	0.1	-10.5		536.1	23.6
3	Platoro_cabin	0.6	-26.8	-4.5	274.3	7.0
4	Nathans_Cabin	1.0	-29.9	-4.5	1032.6	14.2
5	Forest_King	0.2	-18.0		1005.5	353.9
6	Rcky_Mtn_Estates_estim	1.5	-33.2		595.2	27.7

- Comparison between operational NLDAS and local met station forcing *suggests too much 'available energy'* (temperature, radiation, humidity and wind) compared to station data

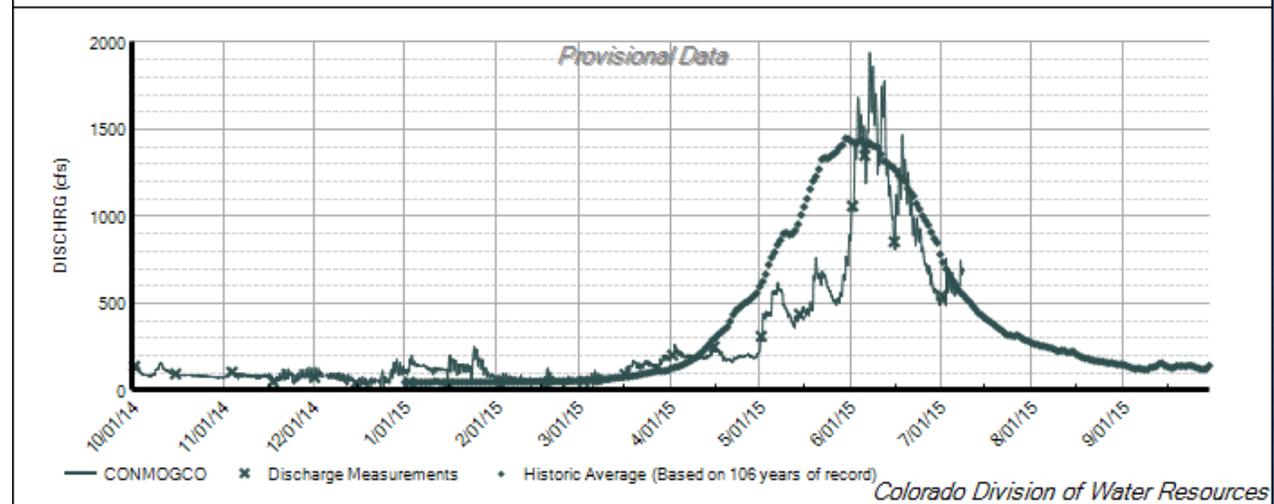
Summary of Findings to Date: Snowpack-streamflow relationships

1. Despite *well below median snowpack* at SNOTEL sites streamflow was reasonable. So where did runoff come from?...*likely higher elevations than most current SNOTEL sites* and late season precipitation

Lily Pond (580) Colorado SNOTEL Site - 11000 ft



CONEJOS RIVER NEAR MOGOTE (CONMOGCO)
Data Source: Co. Division of Water Resources



- *Melt out at SNOTEL sites (Lilly Pond) is 2 months earlier than peak flow...longer than channel travel time...*
- Additional work looking at SNODAS and NASA/ASO snowpack products is in progress....

Summary of Findings to Date: Streamflow variability

1. Tributary flows into Conejos River from ungauged Elk Fork, S. Fork branches form very significant fraction of total flow. *Unknown how fractional contribution varies from year to year.* This fact complicates management and suggests better monitoring of tributary flows is needed

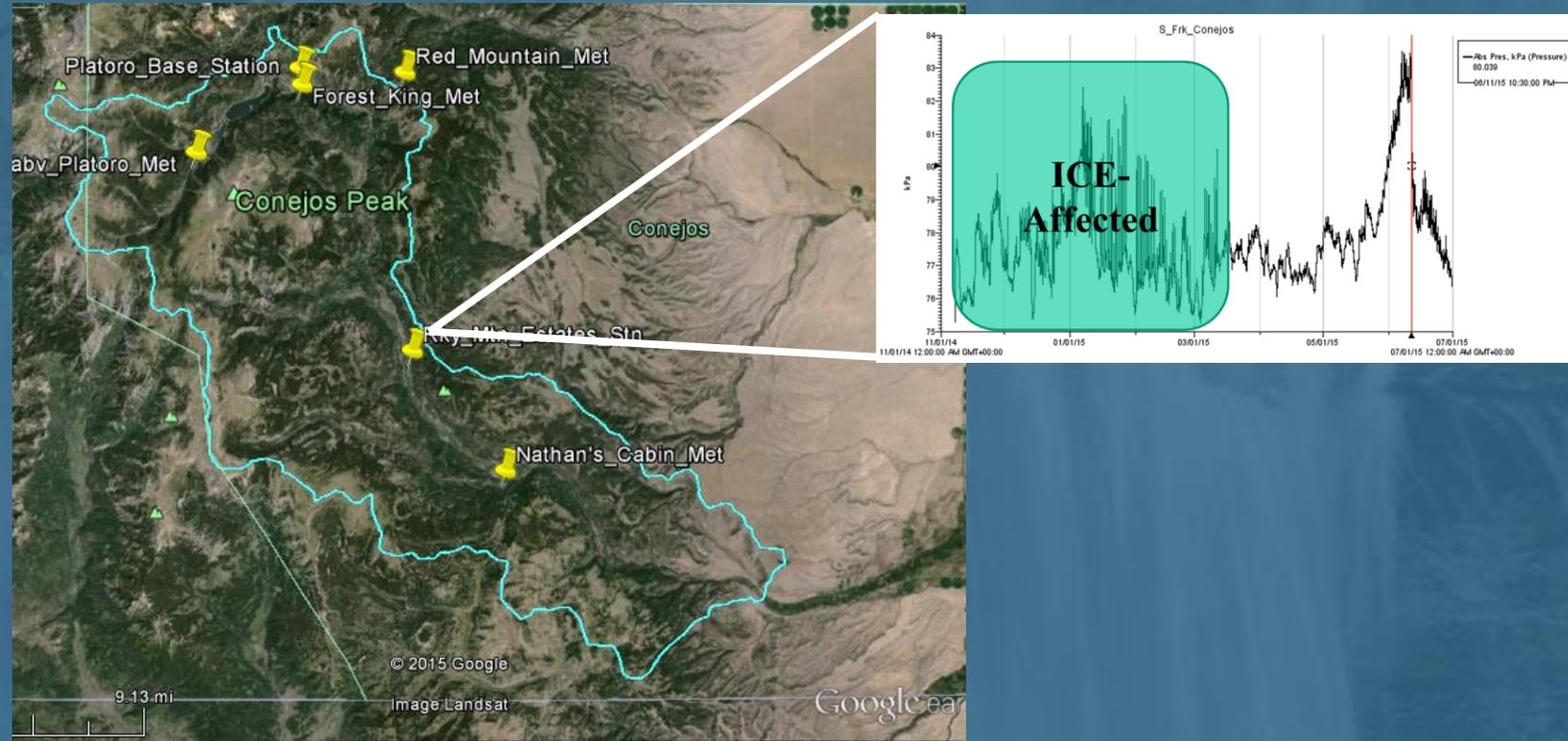
Dates of peak flow:

S. Fork Conejos: June 11

Elk Fork: June 12

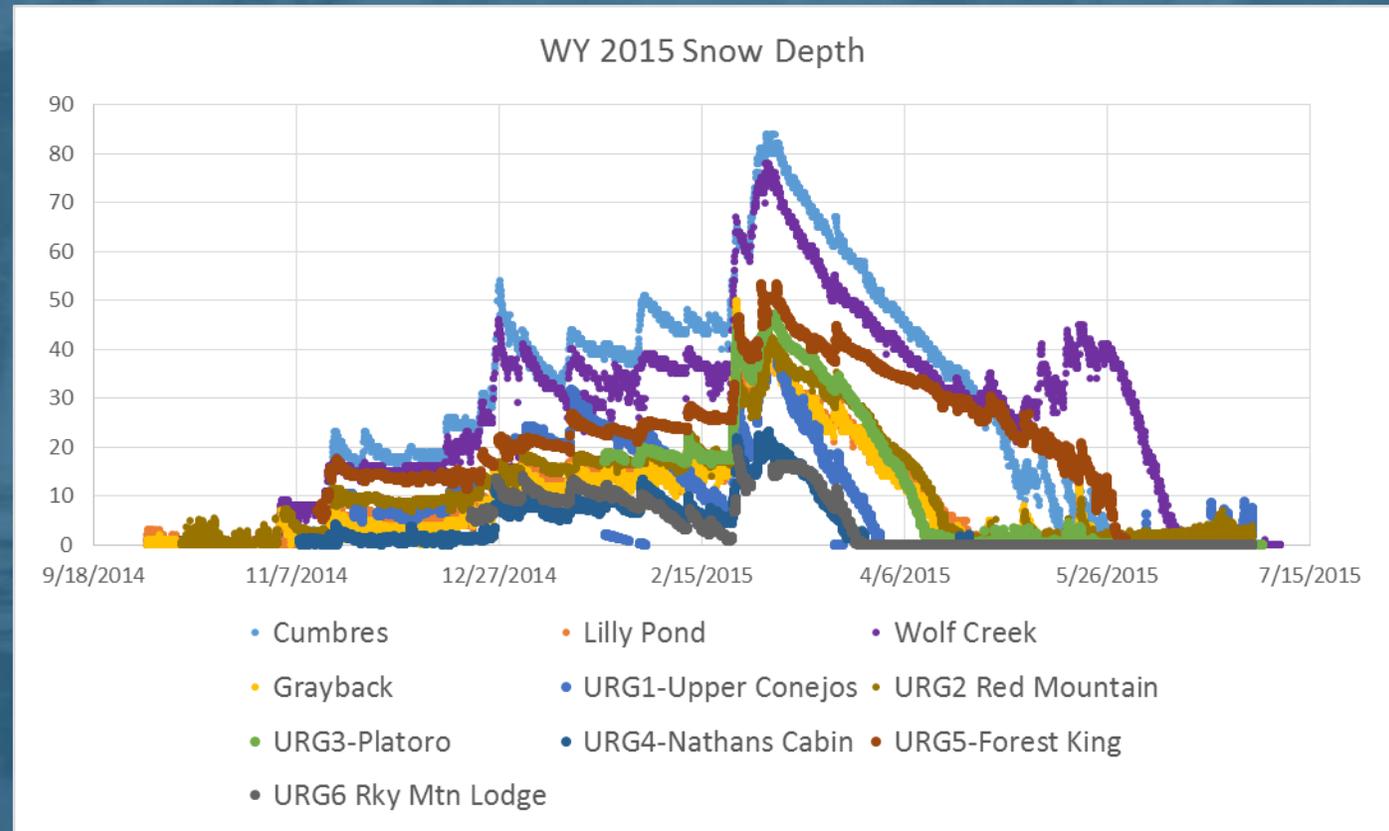
Lake Fork: June 7

Saddle Creek: June 10



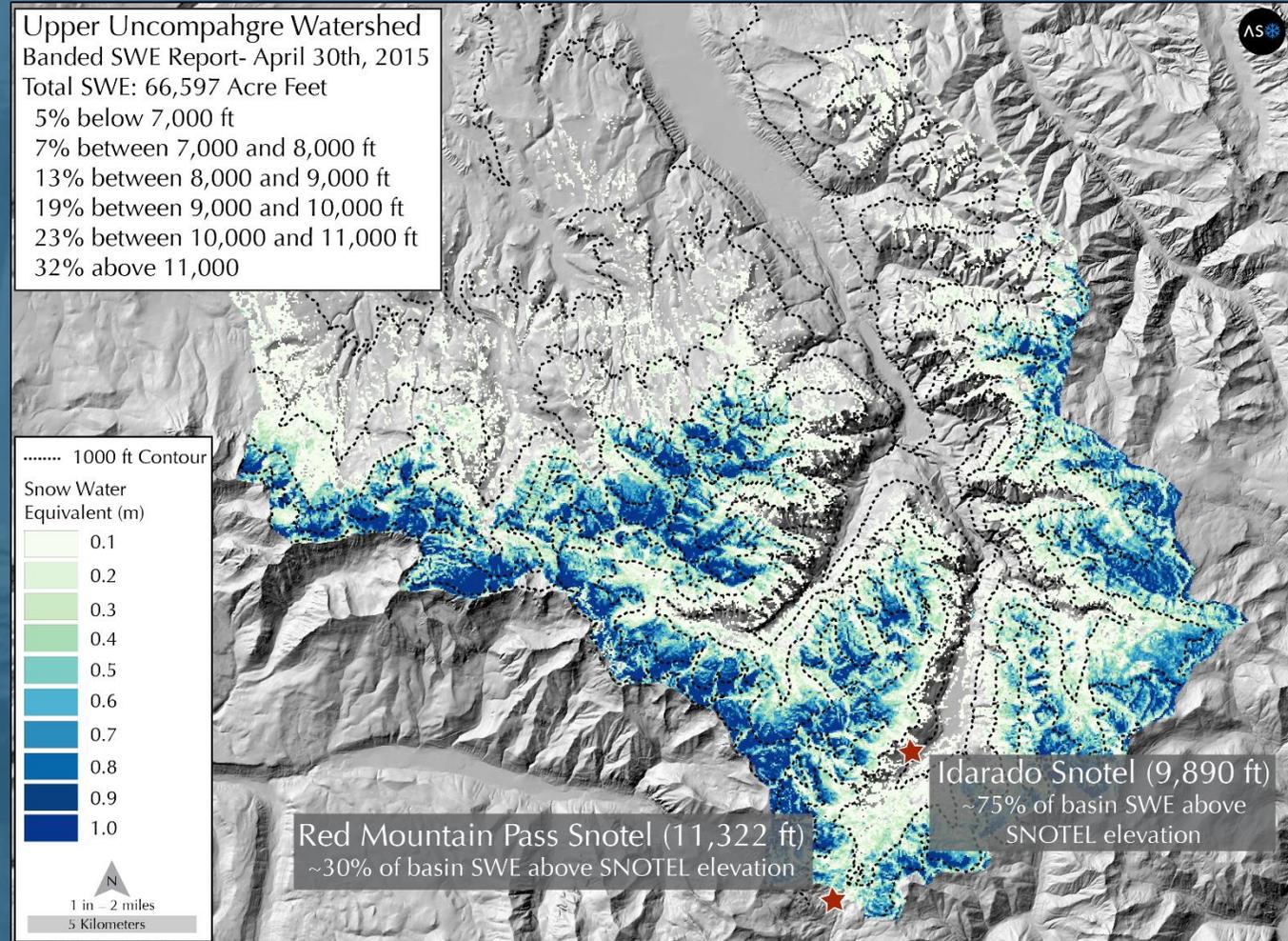
On-the-ground Snowpack Monitoring

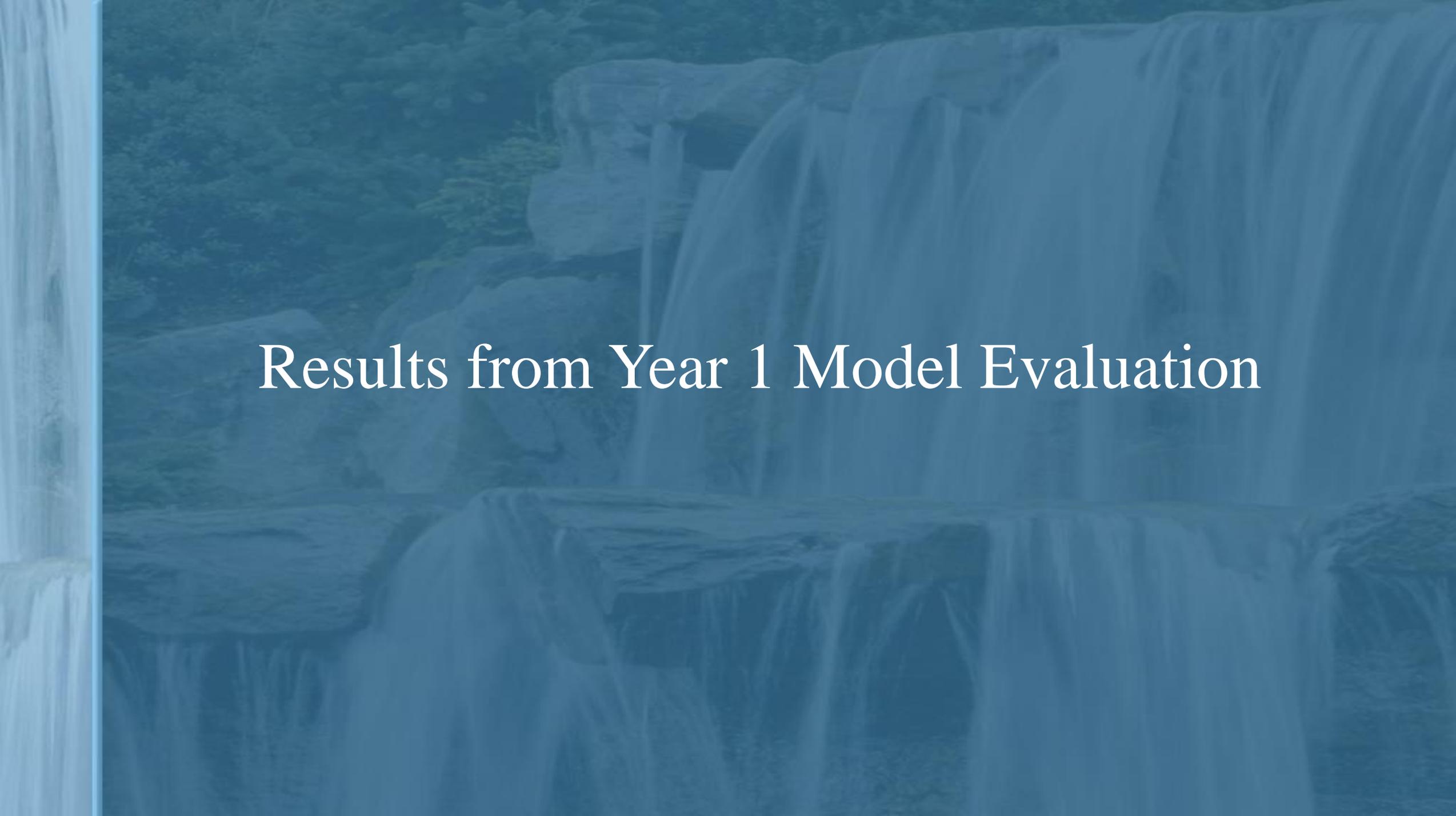
- Lilly Pond consistent with mid-elevation Conejos sites with late April melt out
- High elevation/north aspect sites (e.g. Forest King) holds snow much longer
- Forest King, Wolf Creek and Cumbres Trestle SNOTEL sites has many 'plus-ups' during spring



NASA Airborne Snowpack Monitoring

- 2 flights conducted so far
- April 8, 2015
- May 16, 2015
- Final 'snow-off' flight forthcoming (September)

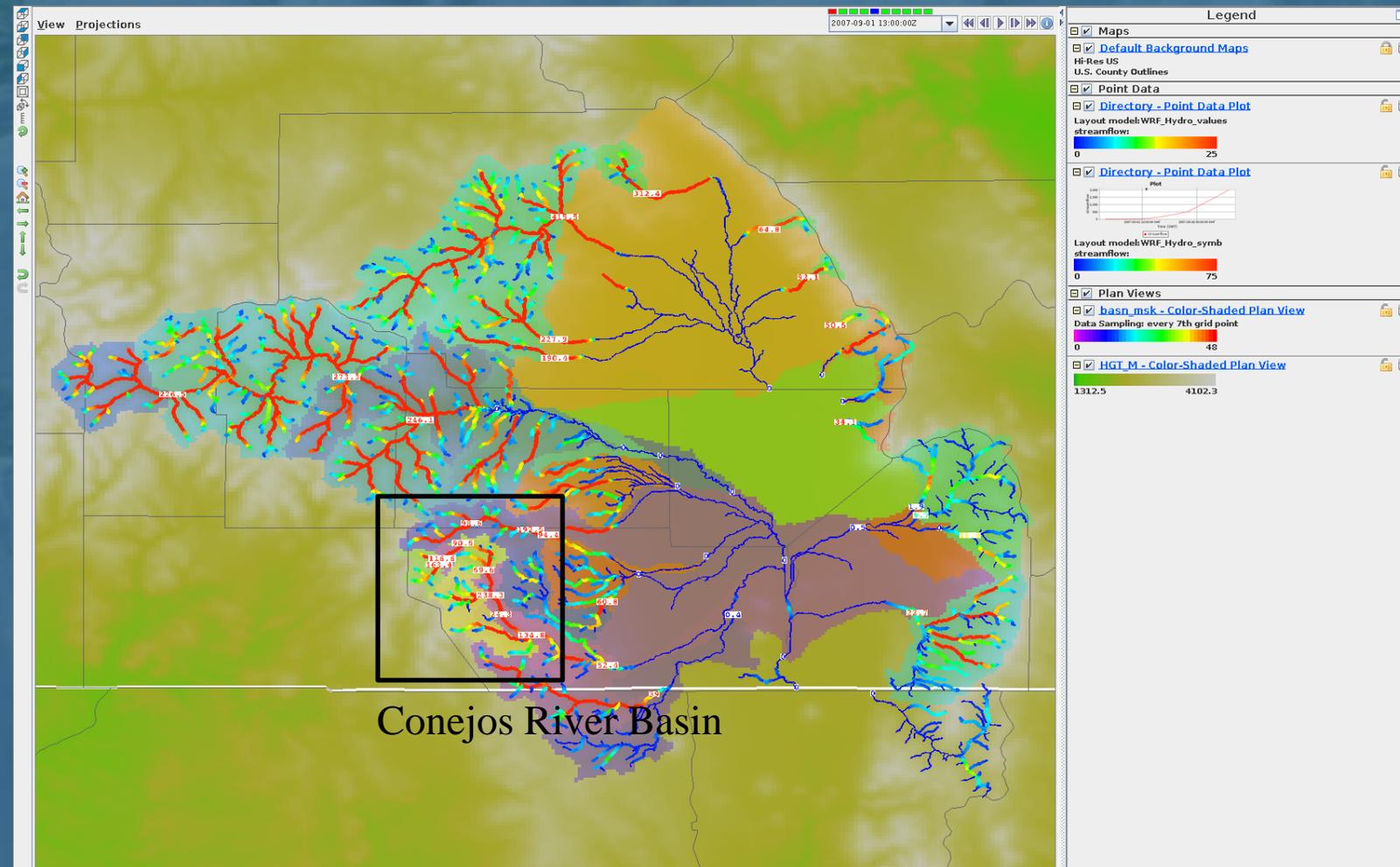




Results from Year 1 Model Evaluation

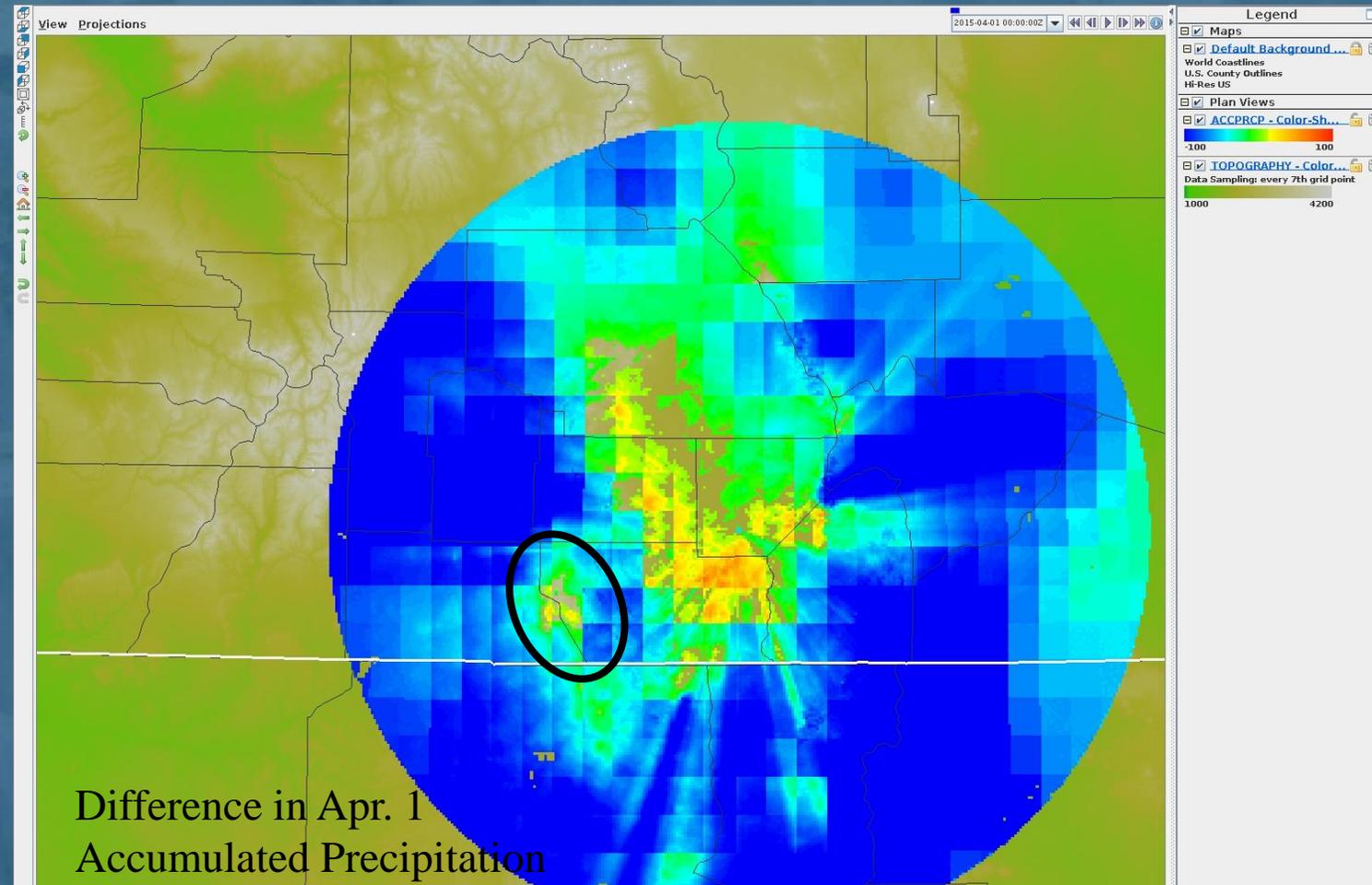
Seasonal Streamflow Prediction in the Upper Rio Grande River Basin: WRF-Hydro Modeling System

- High resolution (1km/100m) spatially-distributed physics
- Energy balance snowpack and physics-based runoff modeling
- In transition to become national streamflow prediction system with NWS



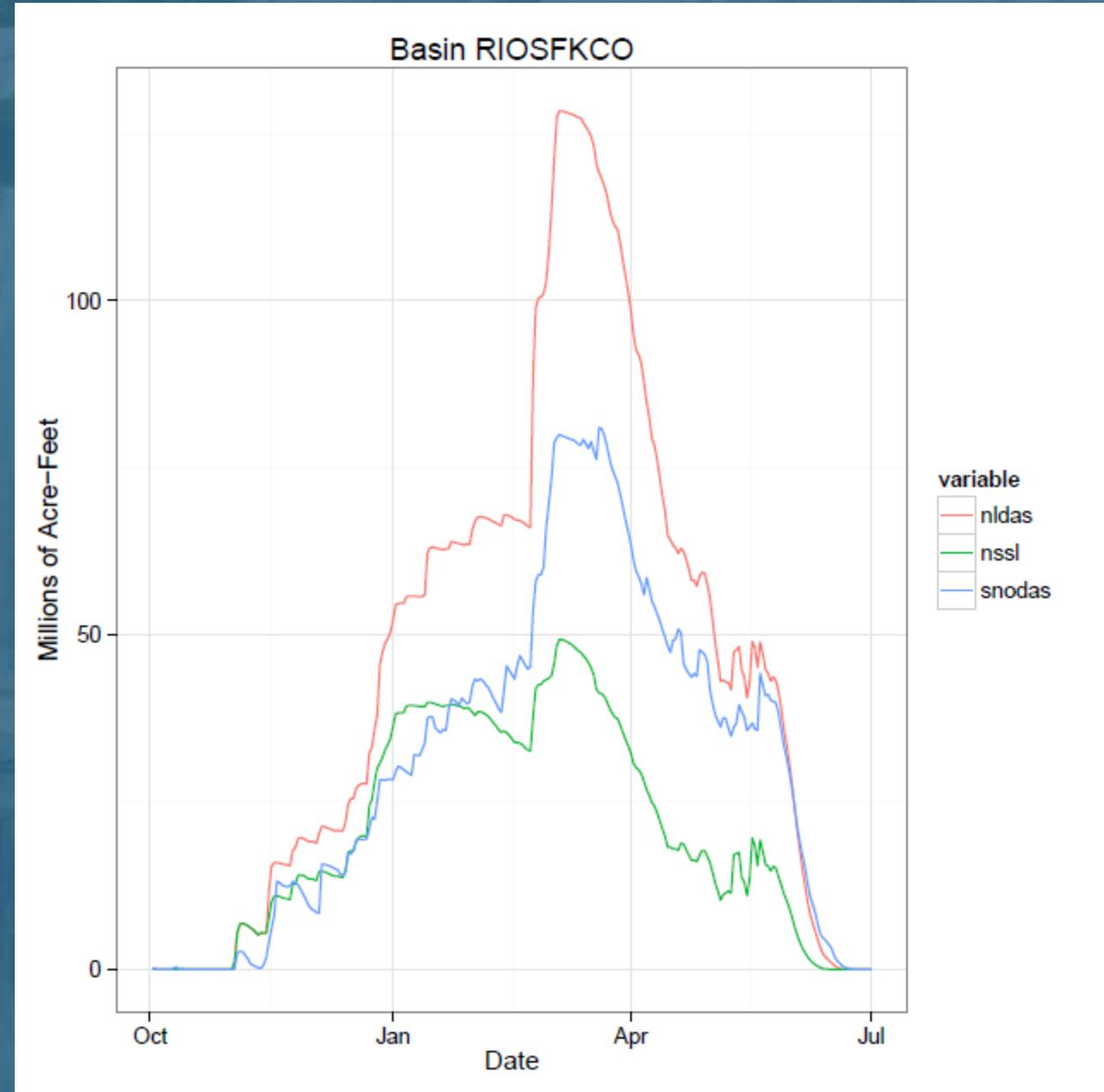
Impact of NSSL Radar Data:

- NSSL-NOXP radar tends to reduce area-wide precipitation vs. operational product
- More SLV precip. with NOXP product
- Exception is in Upper Conejos River Basin
 - NLDAS +54% bias
 - NOXP +24% bias



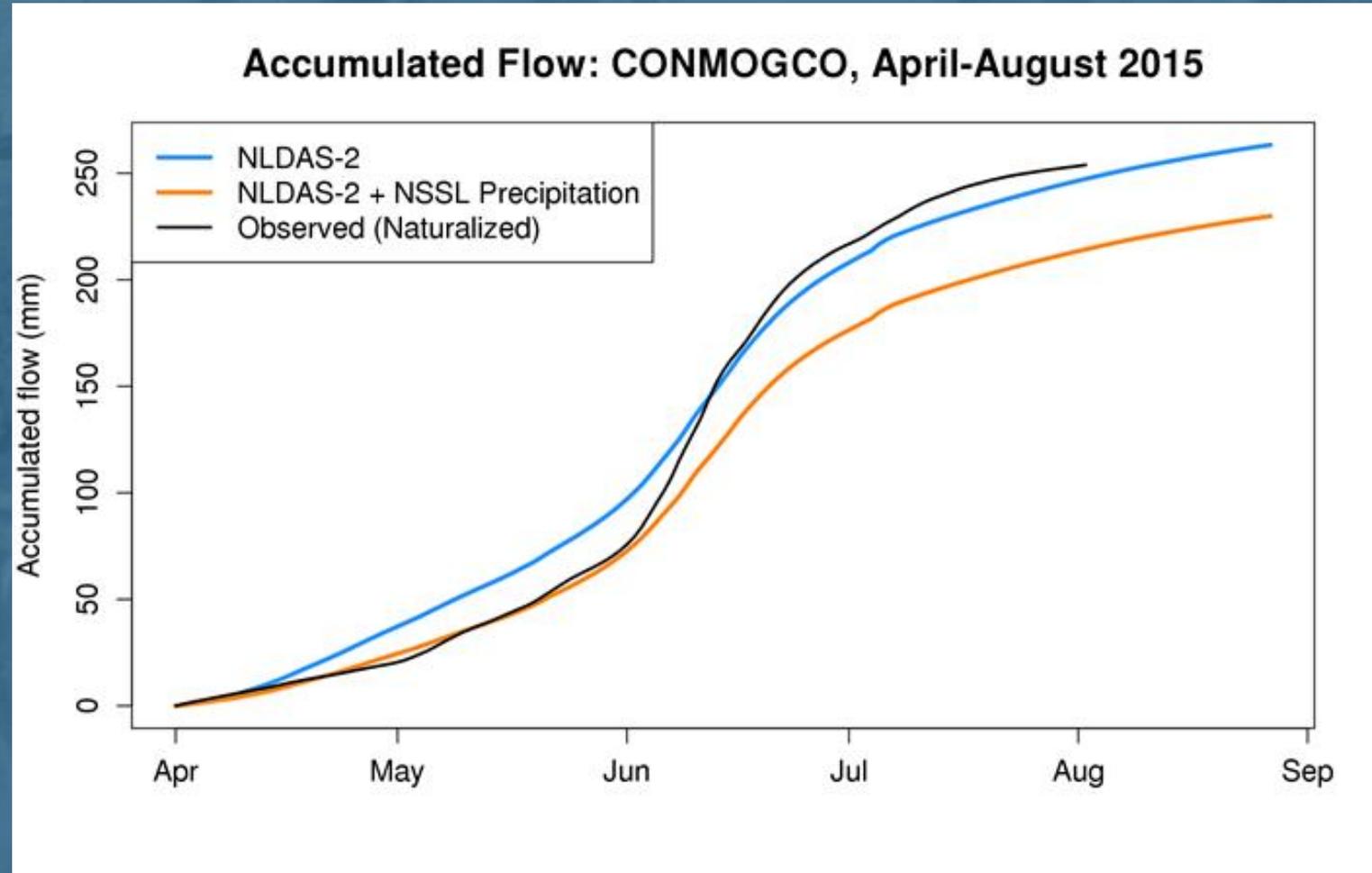
Impact of NSSL Radar Data: Basin averaged snowpack

- Most basins show better agreement between NOXP and SNODAS
- Problem basins:
 - Trinchera (accum. error)
 - Los Pinos (early melt)
 - S. Fork Rio (blockage?)

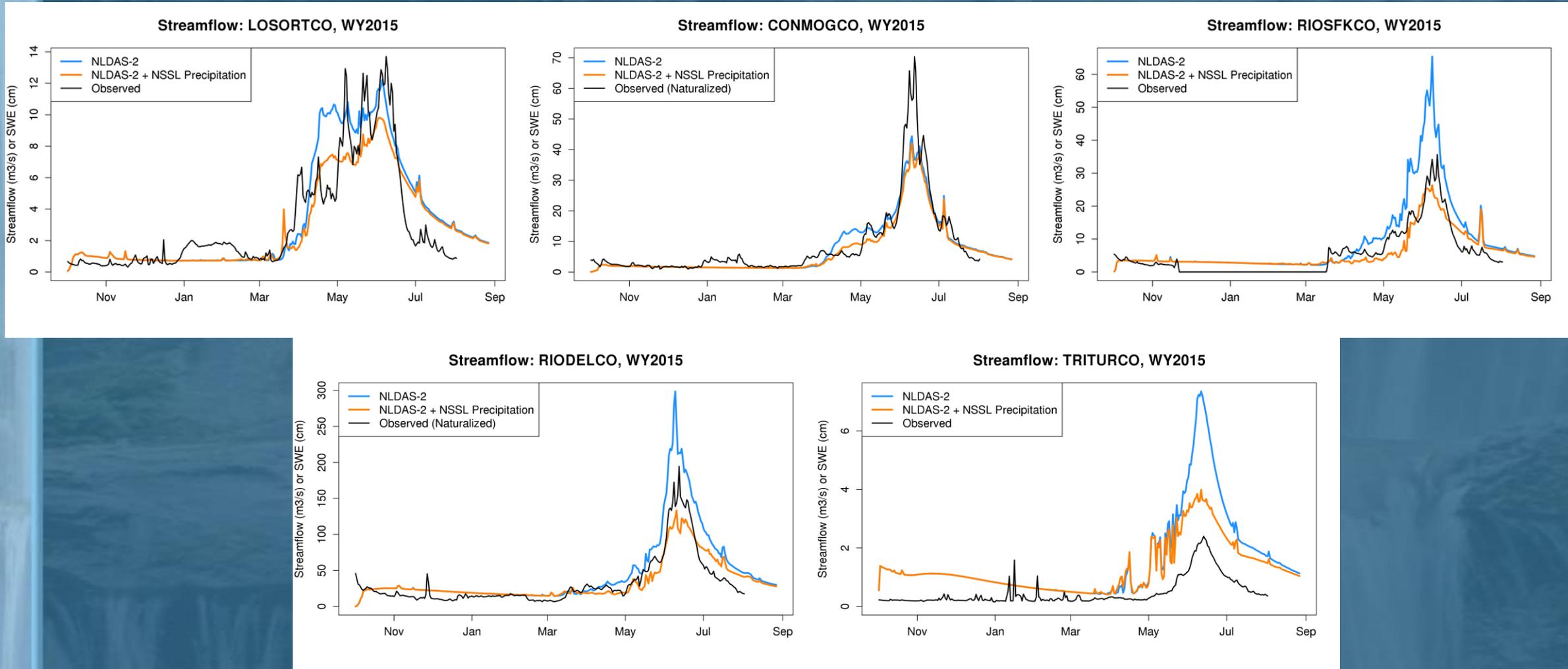


Hydrologic Modeling: Impact of Radar Data

- Radar precipitation product generally improves hydrologic simulation in URG
- Main impact is to reduce positive streamflow bias in operational forcing
- Rio Grande flows well simulated with NOXP radar data
- Conejos River shows early low bias error using radar...why?



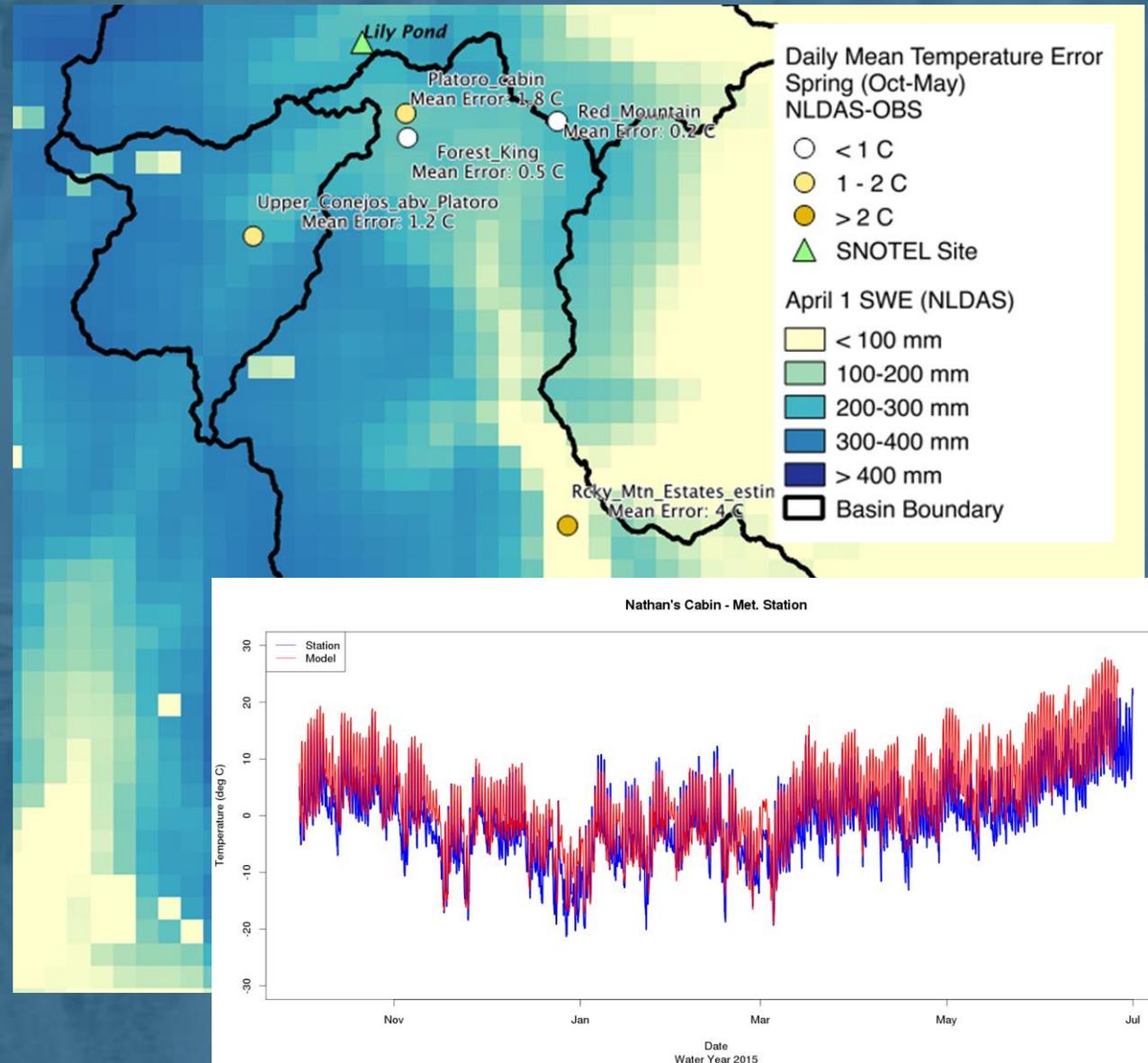
Hydrologic Modeling: Impact of Radar Data



- Runoff timing and relative magnitude of runoff is reasonable...

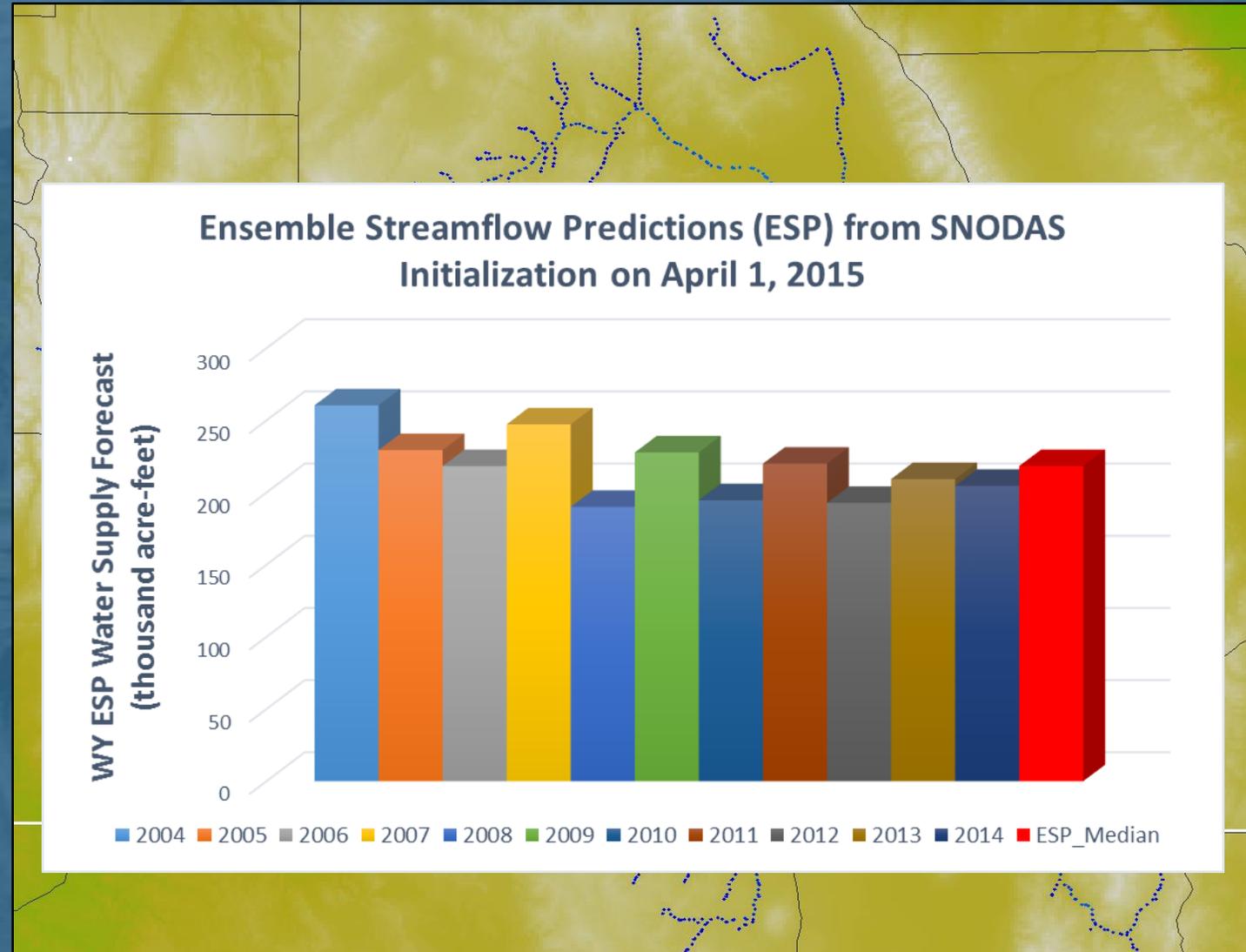
Hydrologic Modeling: Why is Conejos Runoff early?

- Low elevation stations in Conejos basin show strong *POSITIVE* temperature bias (+2-4 deg C) in operational forcing data
- NLDAS *overestimates* daily insolation
- Contributes excess basin sublimation and evaporation
- Not previously diagnosed due to lack of observations
- Other variables still being evaluated...



Hydrologic Modeling: Forecast Evaluation

- Forecast research is ongoing
- Incorporating new observations
- Initial Apr. 1 ESP forecasts were low, mostly due to biases in ESP forcings
- Additional model enhancements *and bias corrections to forcings* developed in WY2015
- New climate forecast method being evaluated (operational in WY2016)



Take Home Points:

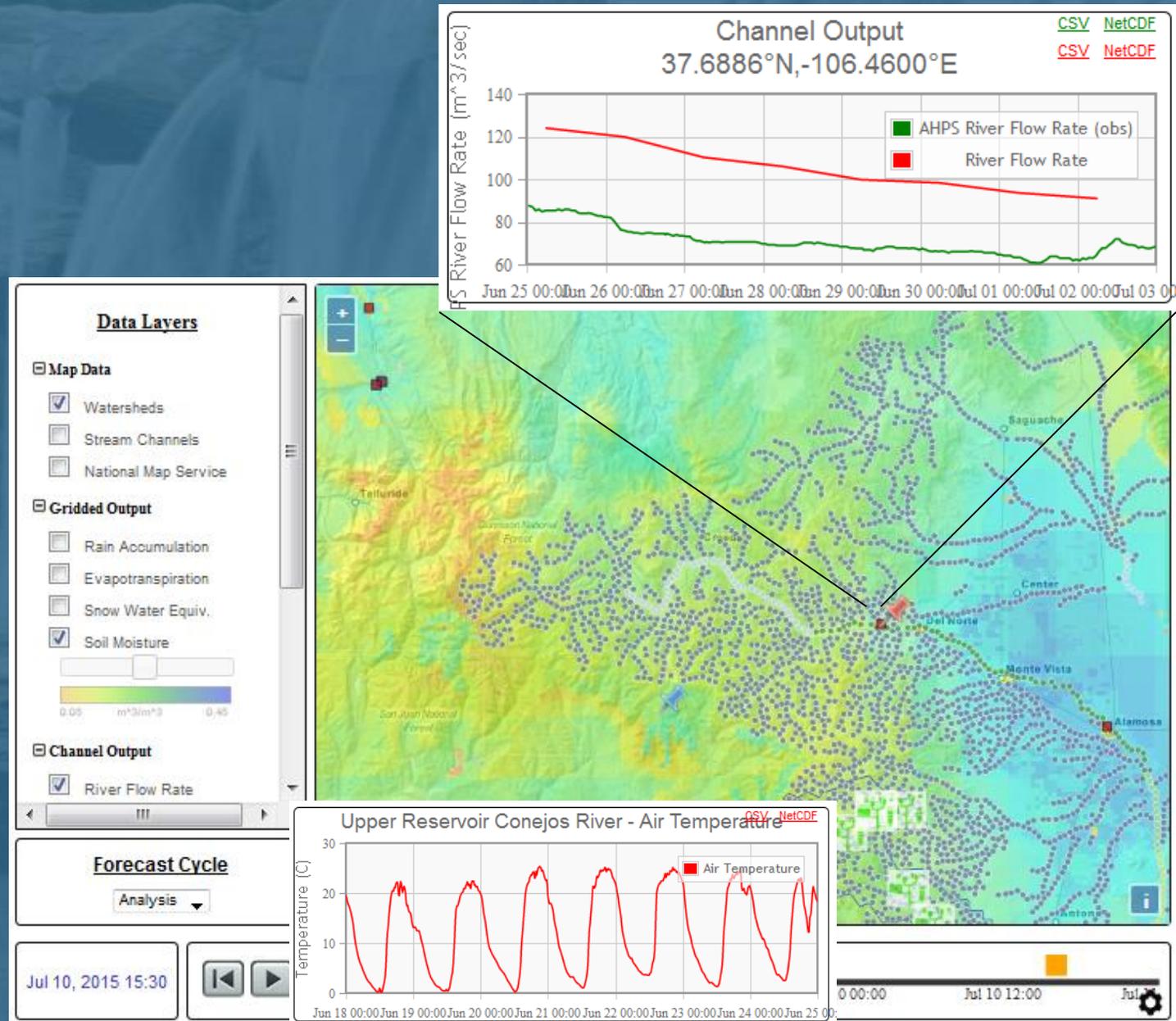
- Research radar adds value by reducing some strong forcing biases in model simulated runoff and providing *more local information in non-SNOTEL* areas (e.g. Conejos)
 - Significant potential for better representing spring rain vs. snow
- Additional snowpack monitoring revealed issue of out of phase timing between SNOTEL snow depletion and major runoff periods
 - More/better monitoring is needed at elevations above 11,000 ft. and in areas with greater/persistent snowpack
 - *Excellent opportunity for ASO and satellite data input*

Take Home Points:

- In-situ data identified *significant biases* in operational meteorological forcing datasets...correction methods now being developed
- Tributary flows into Conejos River form very significant fraction (+40%) of total flow suggests better monitoring of tributary flows is needed
- High resolution hydrologic modeling showing good simulation skill in snowpack conditions and in capturing relative contributions of tributary (non-gauged) flows...good flow timing in all basins
- Comparison and use of NASA ASO snowpack and albedo is forthcoming

Ongoing work

- Real-time monitoring/forecast web mapping service for Conejos and Upper Rio Grande basin for *experimental* products



Real-time display of station observations & model output

Ongoing work

- Expanded experimental WRF-Hydro water supply forecasting:
 - Bias-corrected, downscaled ESP-based forcings
 - Assimilation of real-time CDWR beginning in March 2016
 - Addition of 30-day downscaled NOAA Climate Forecast System forecast data (operational from NWS/NWC starting in May 2016)
- Opportunities for broader interaction:
 - Evaluation of past snowpack conditions (MODIS, MODSCAG)
 - ASO data comparisons against modeled snowpack and albedo
 - Addition of monitoring data to NCAR Web Mapping Service
 - El Nino event coming in 2016...???

End – Thank you.

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