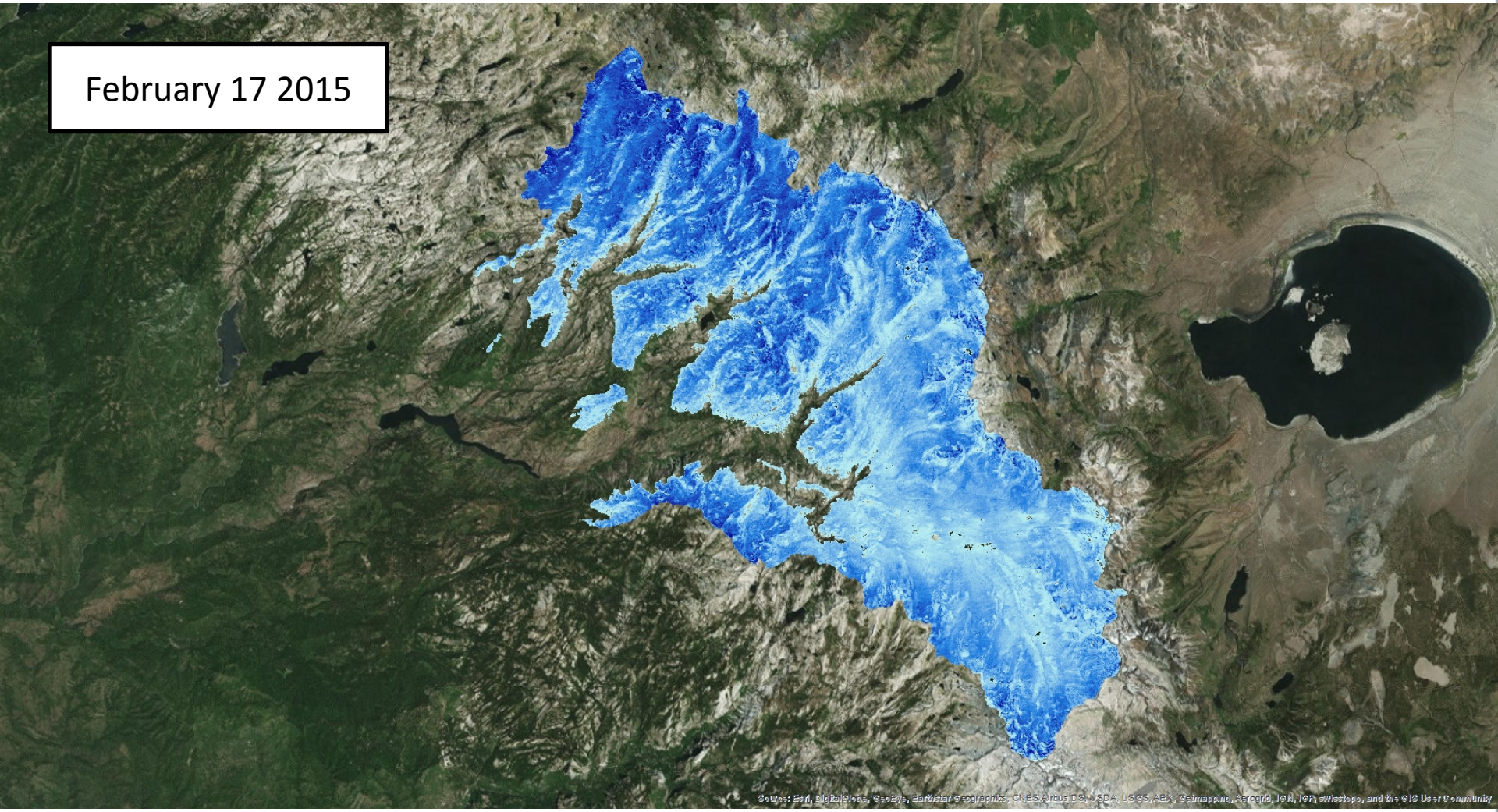
Using ASO Snow Estimates to Forecast Future Streamflows in the Tuolumne Basin

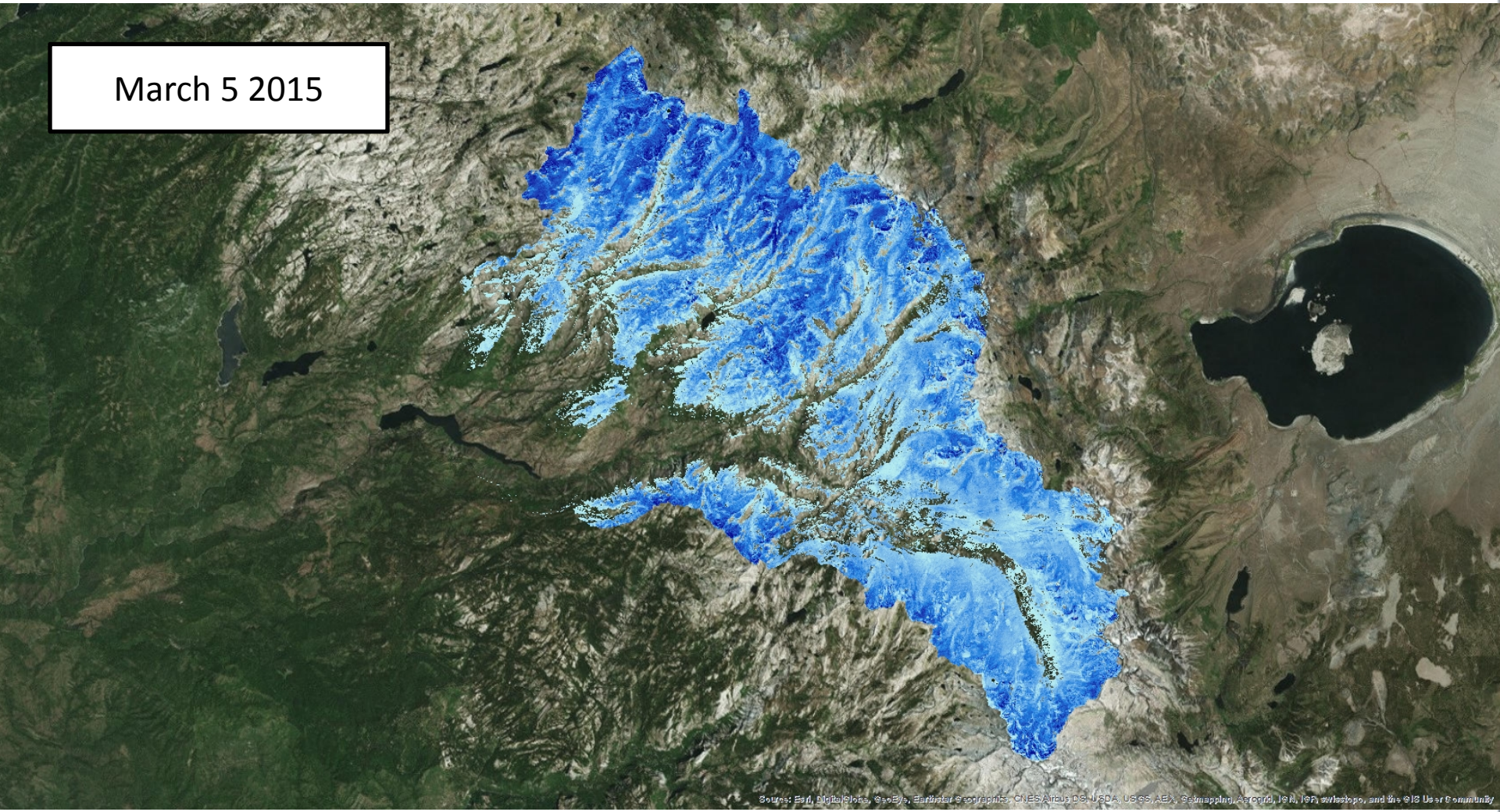
Chris B Graham

Water Operations Analyst / Hydrologist

Hetch Hetchy Water & Power

- Snow Distribution
- Relationship to Inflows
- Forecasting


February 17 2015
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community


March 5 2015
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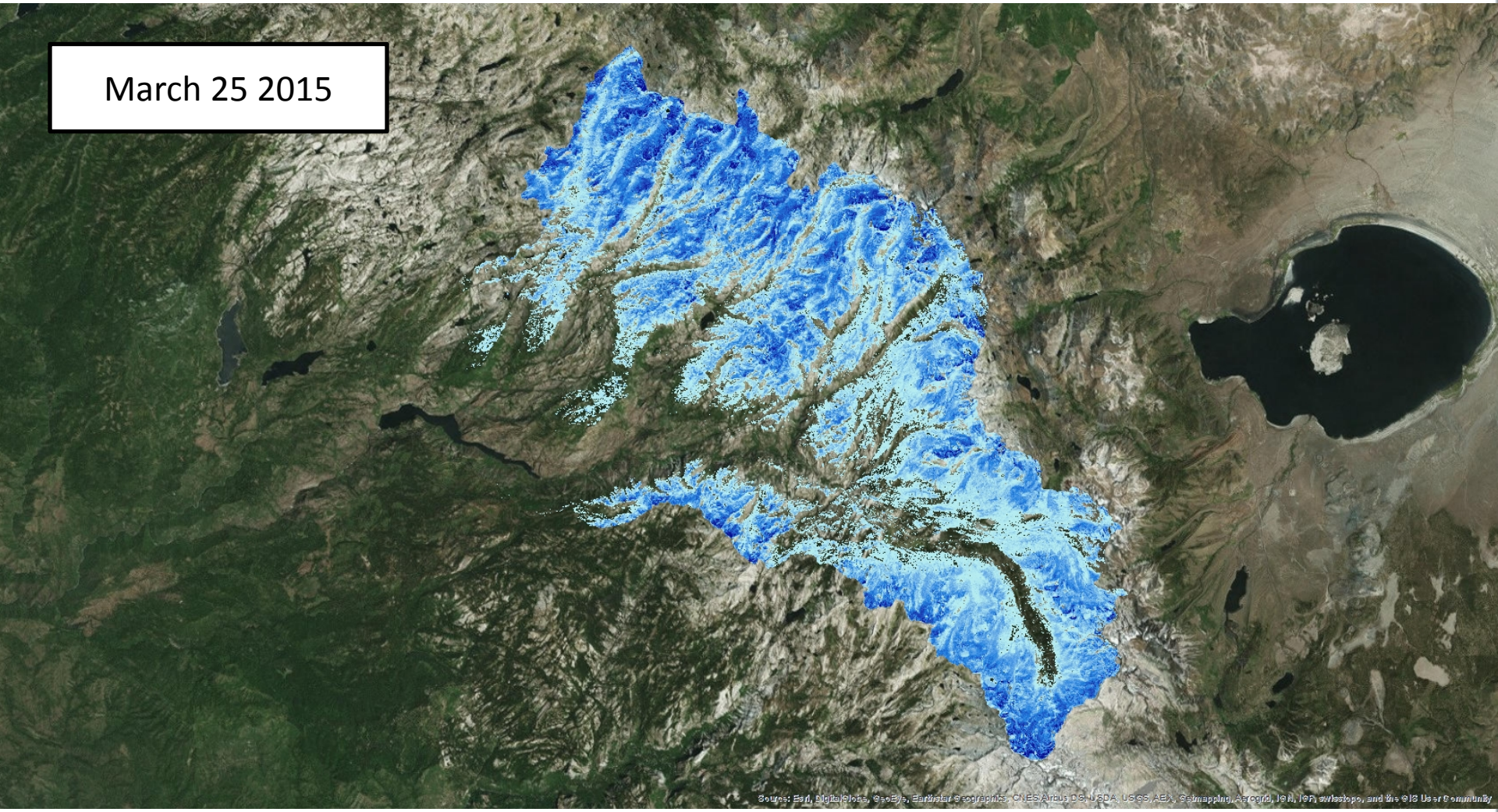
March 25 2015
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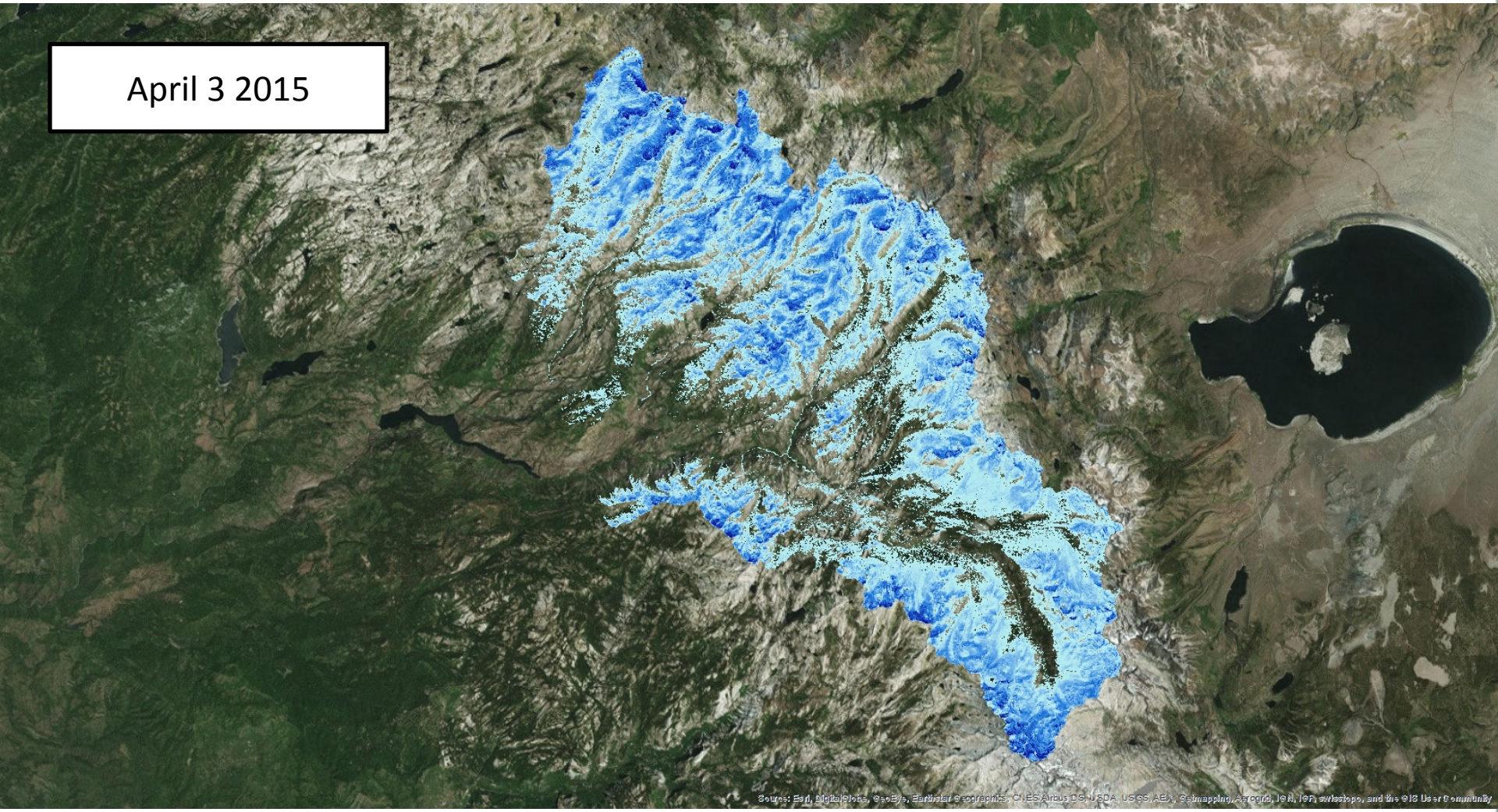
April 3 2015
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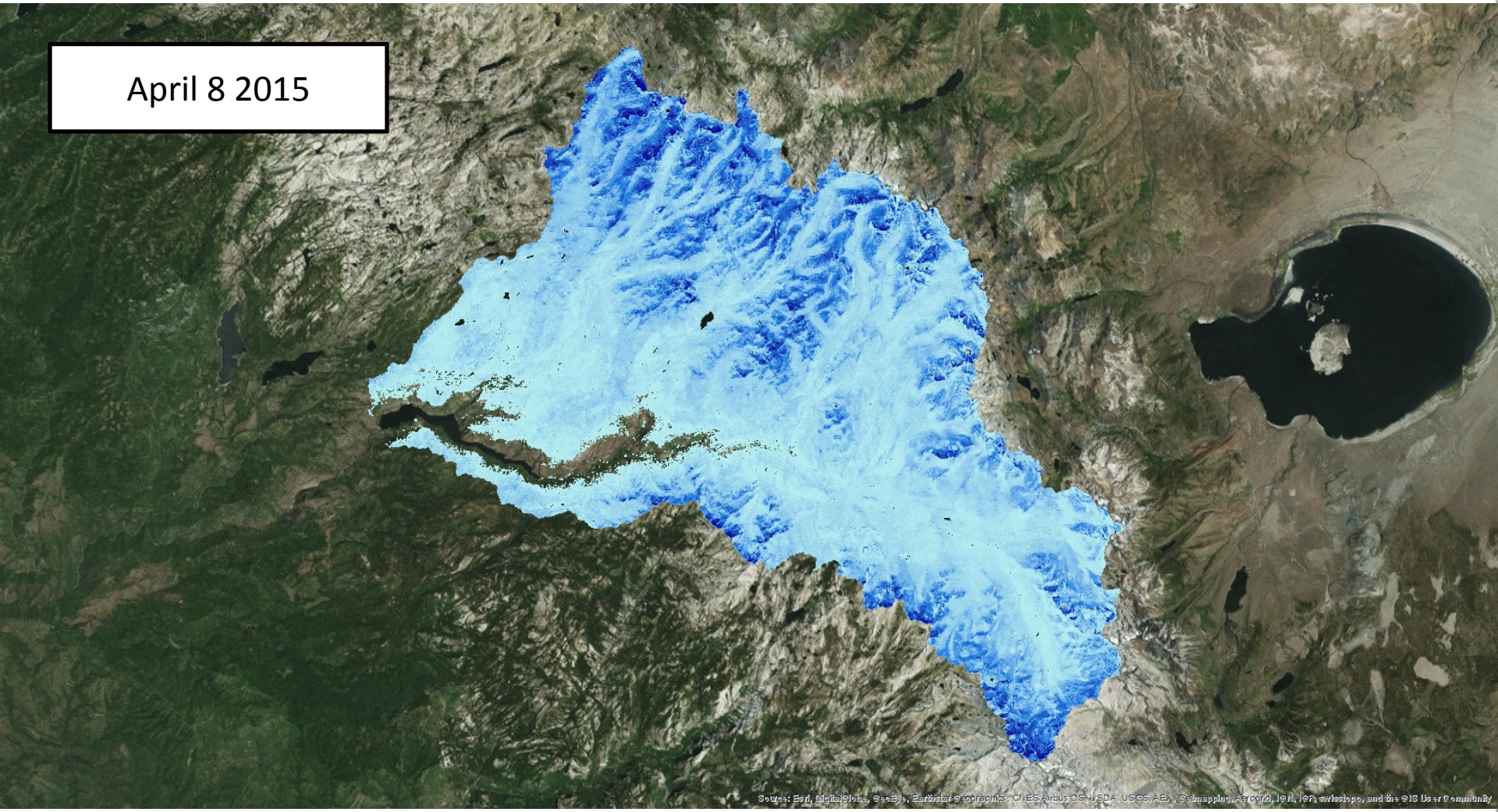
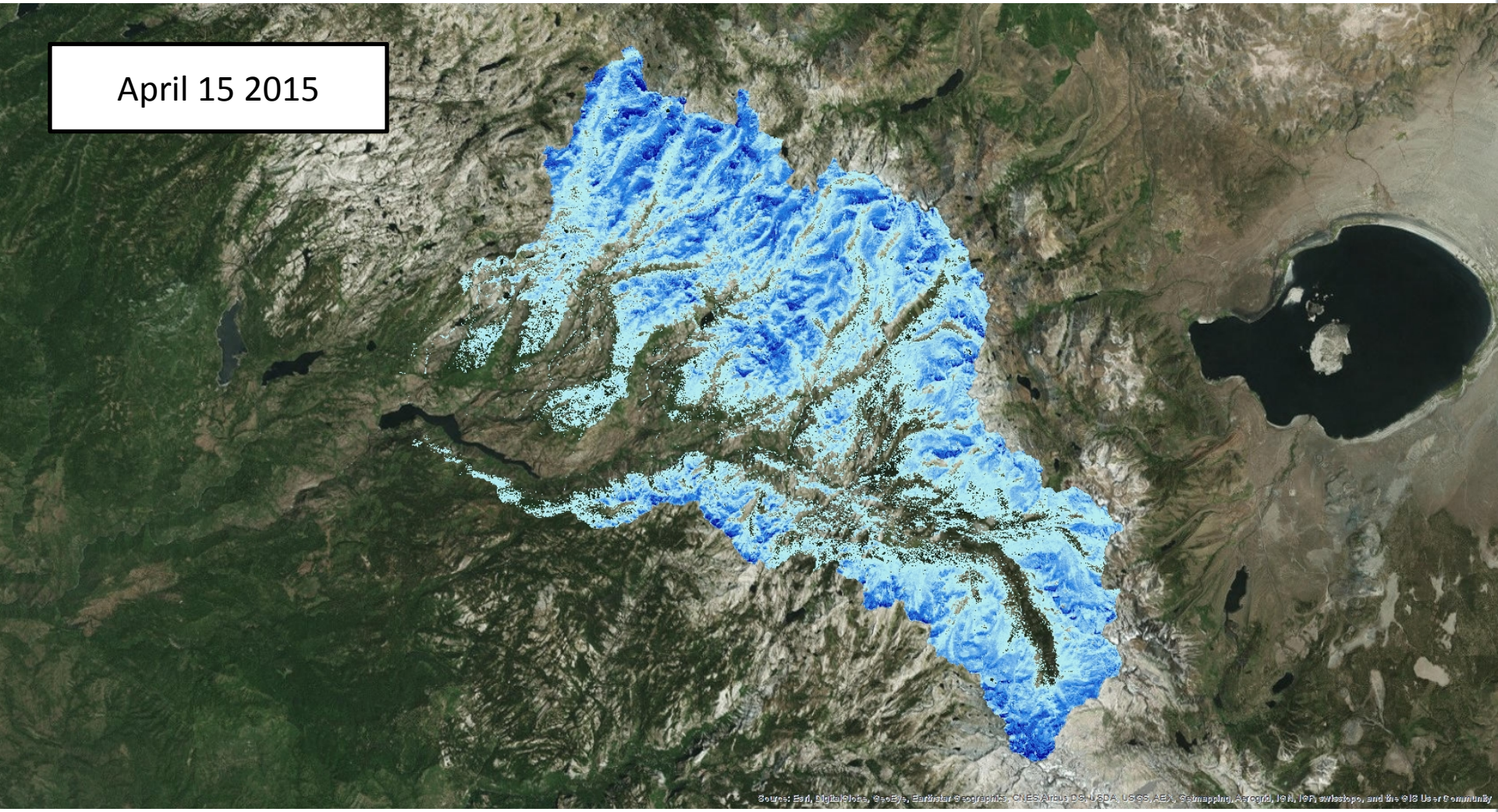

April 8 2015
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community


April 15 2015
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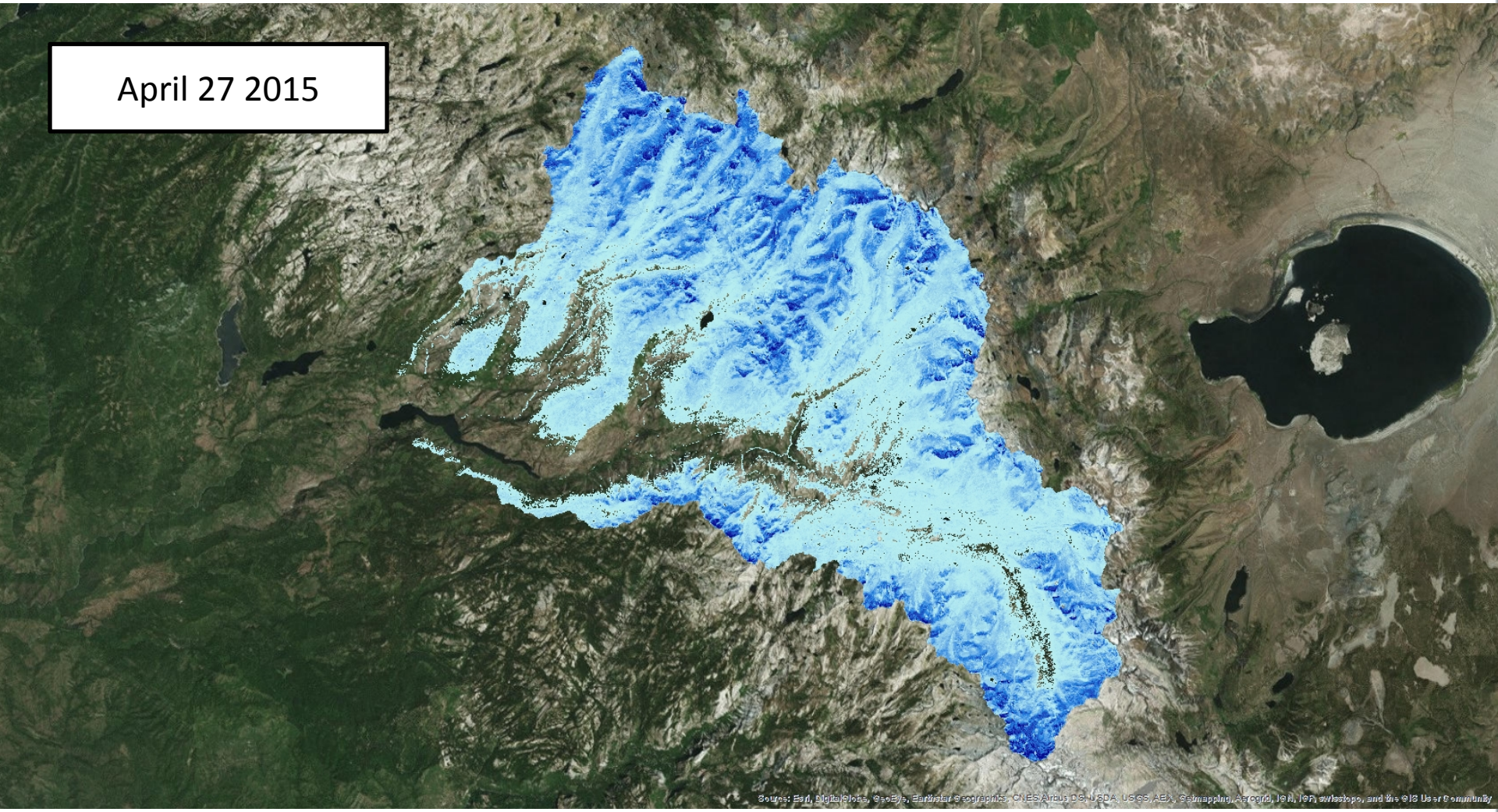
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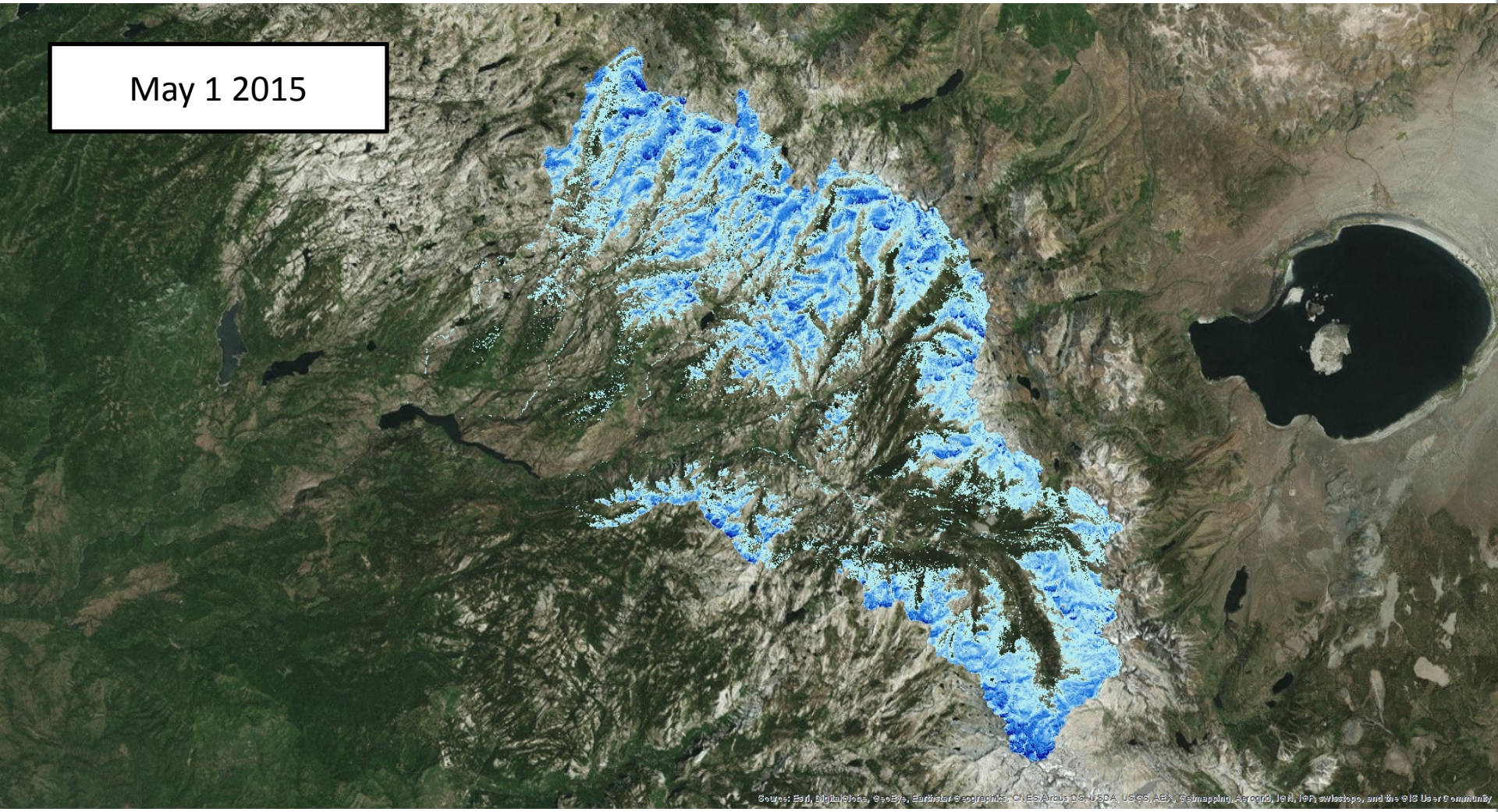
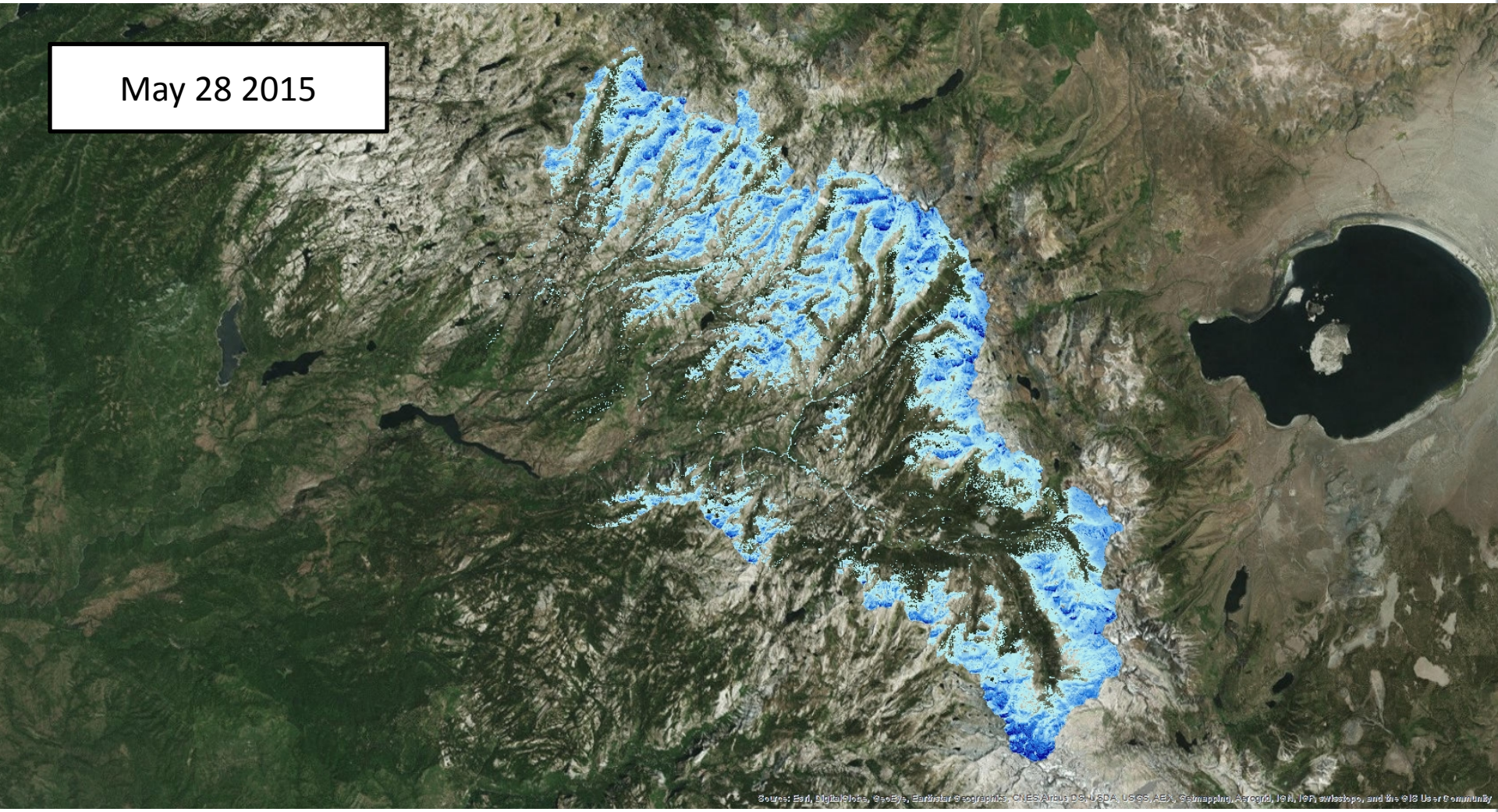

May 1 2015
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community


May 28 2015
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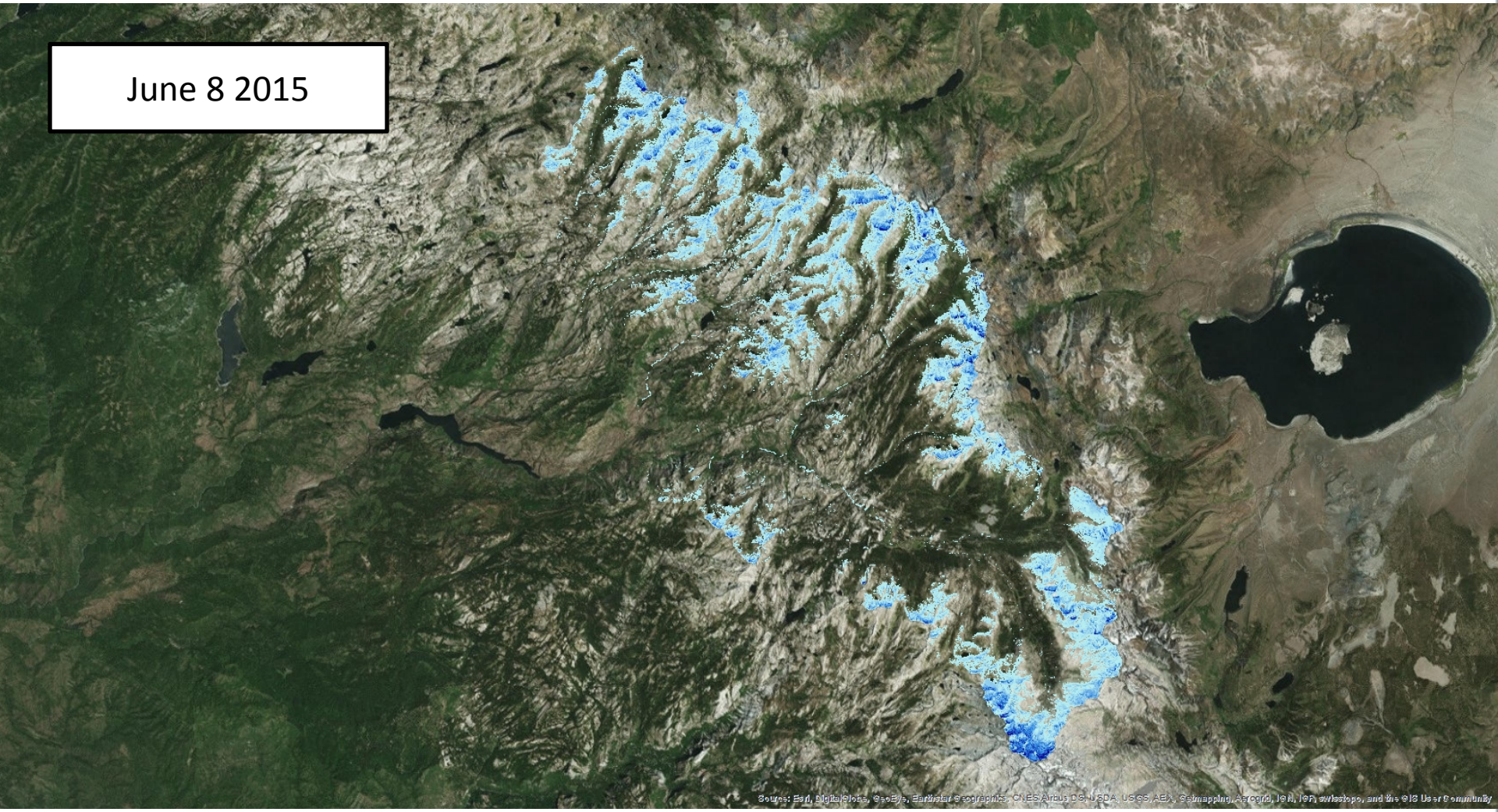
June 8 2015
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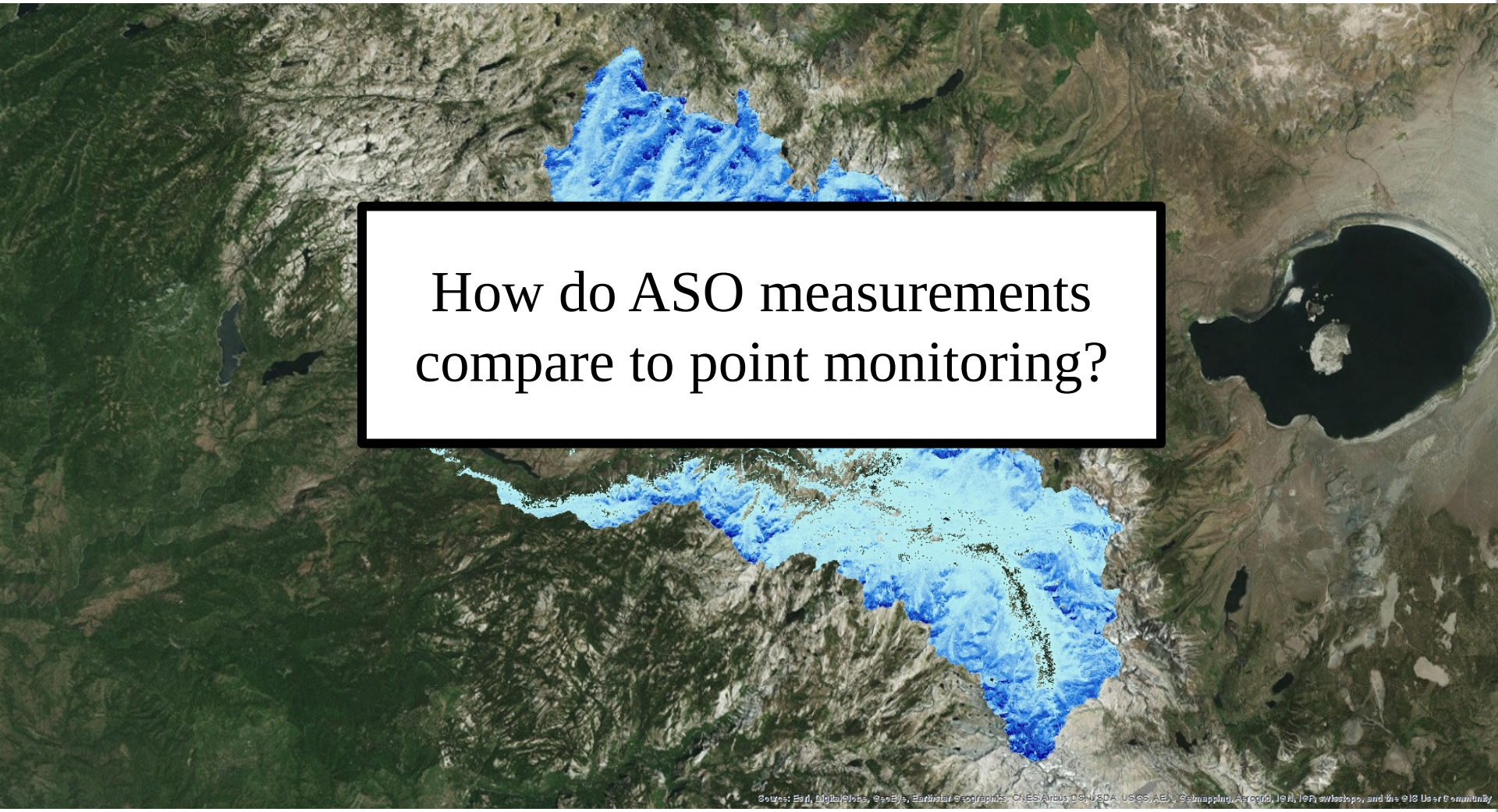
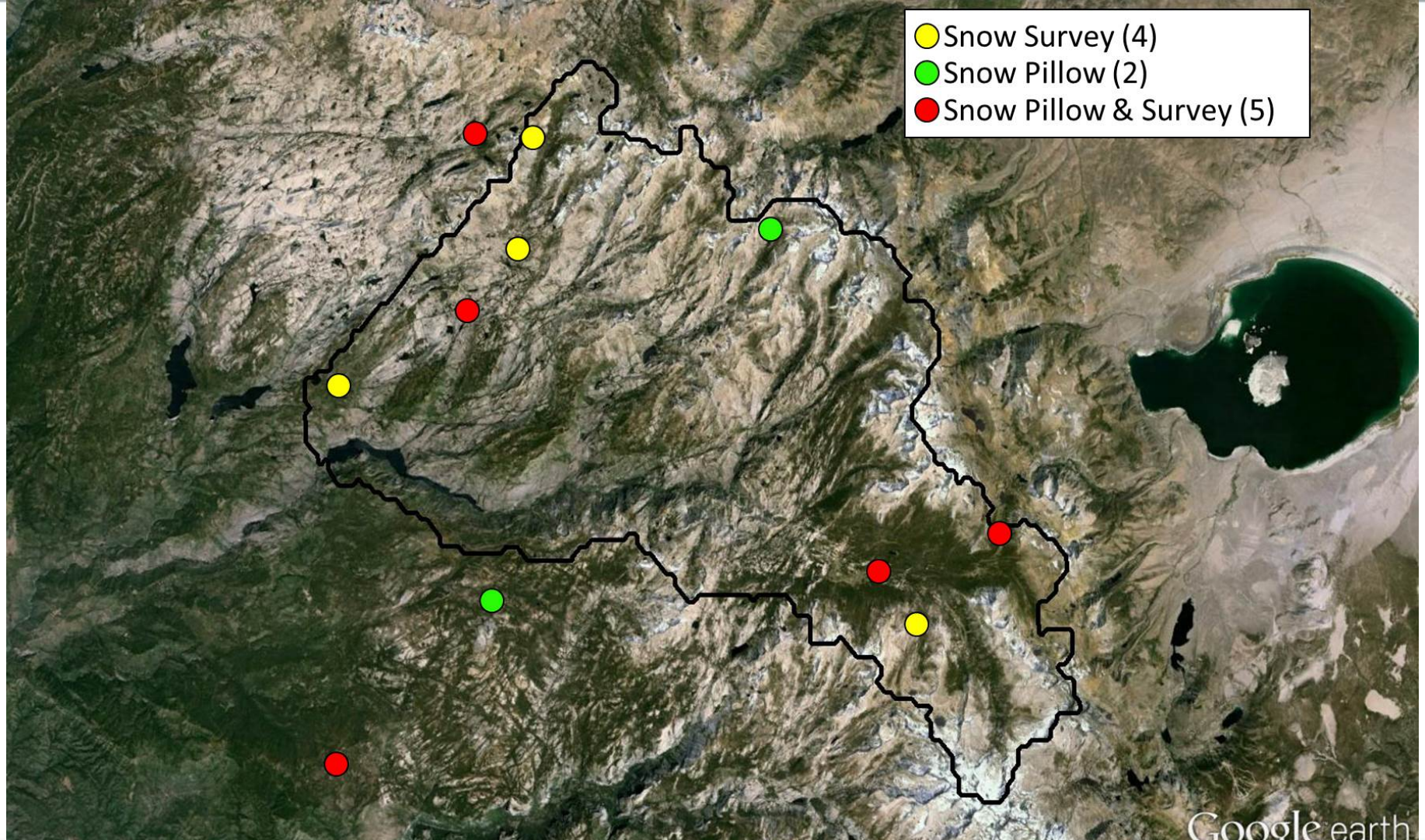
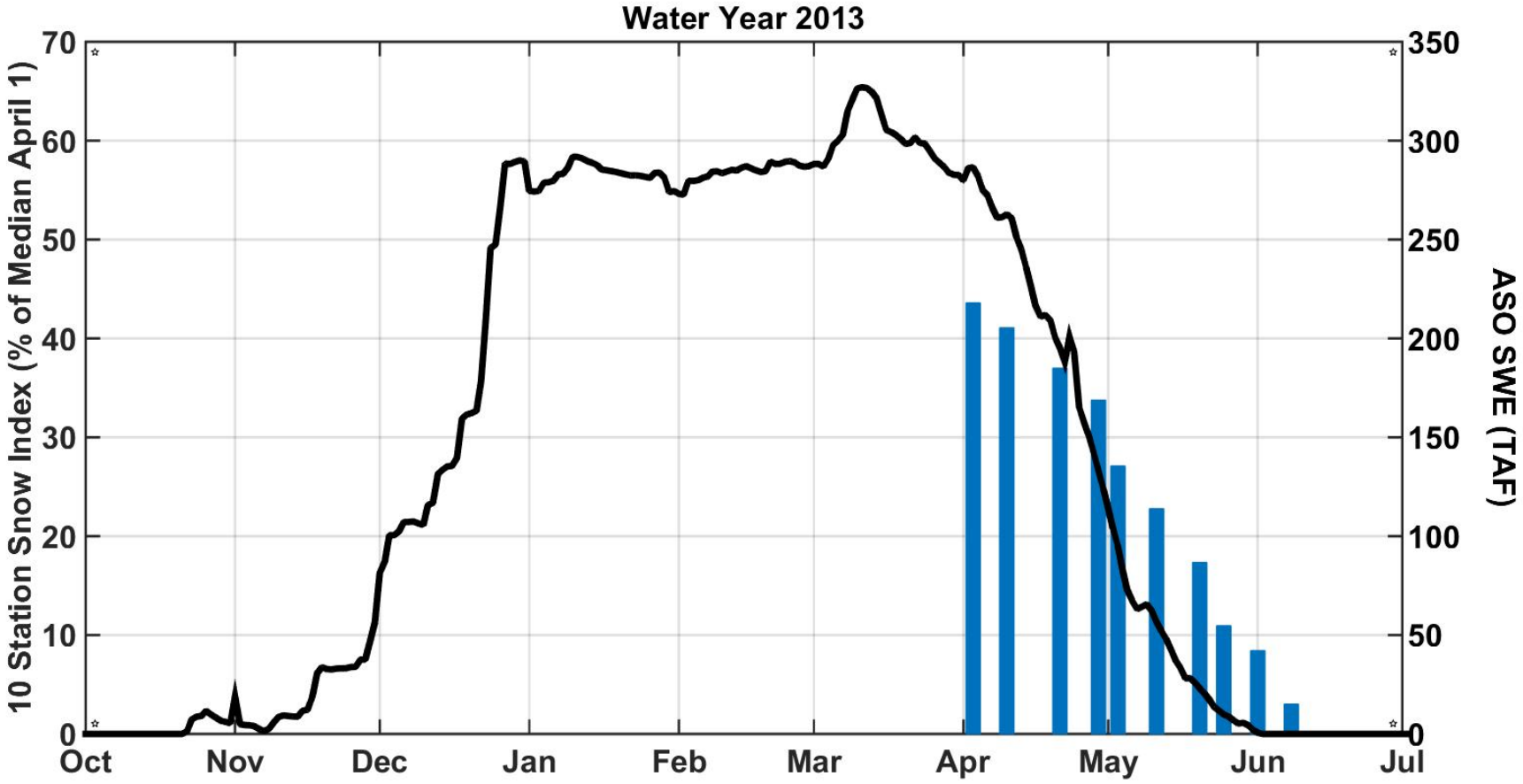
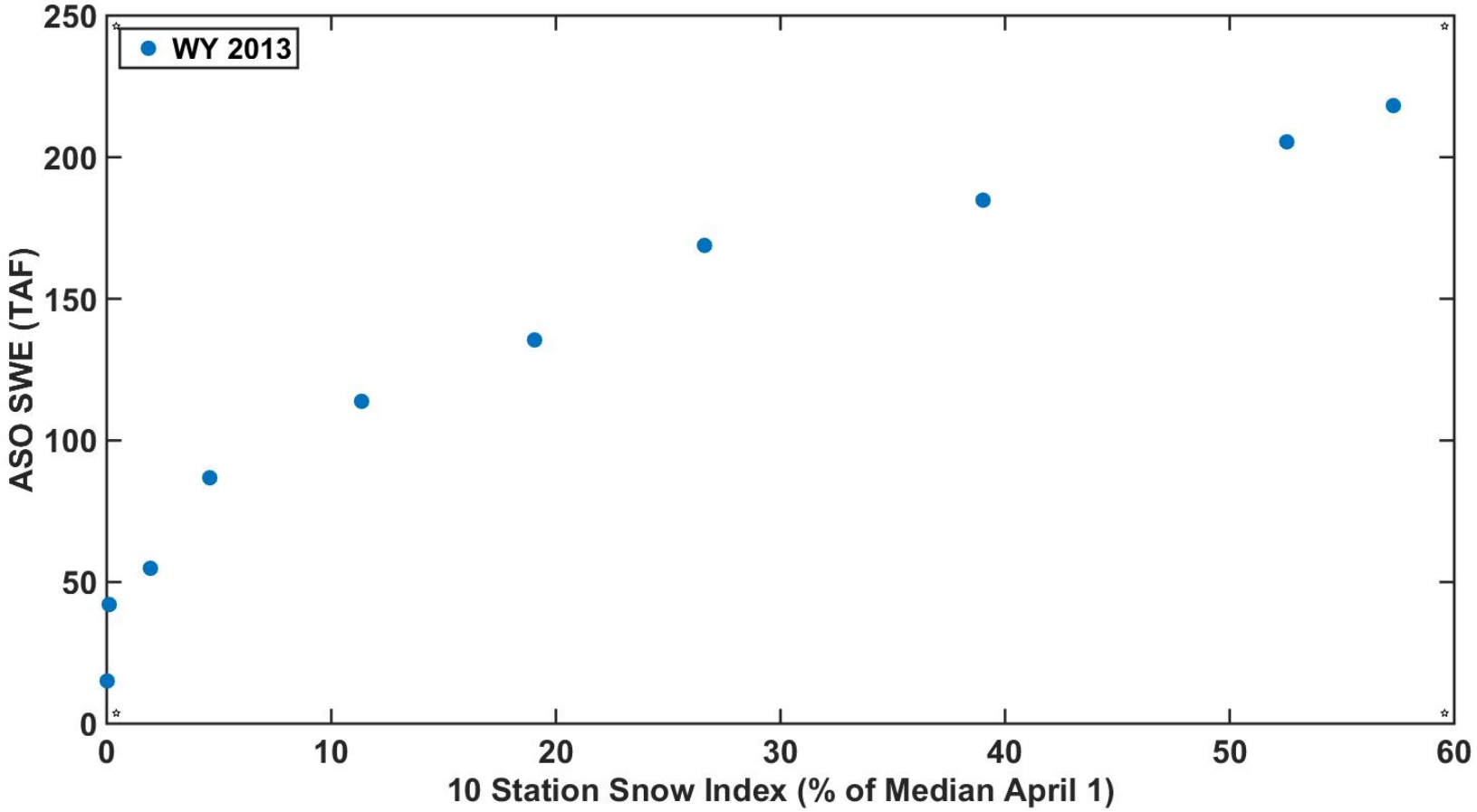
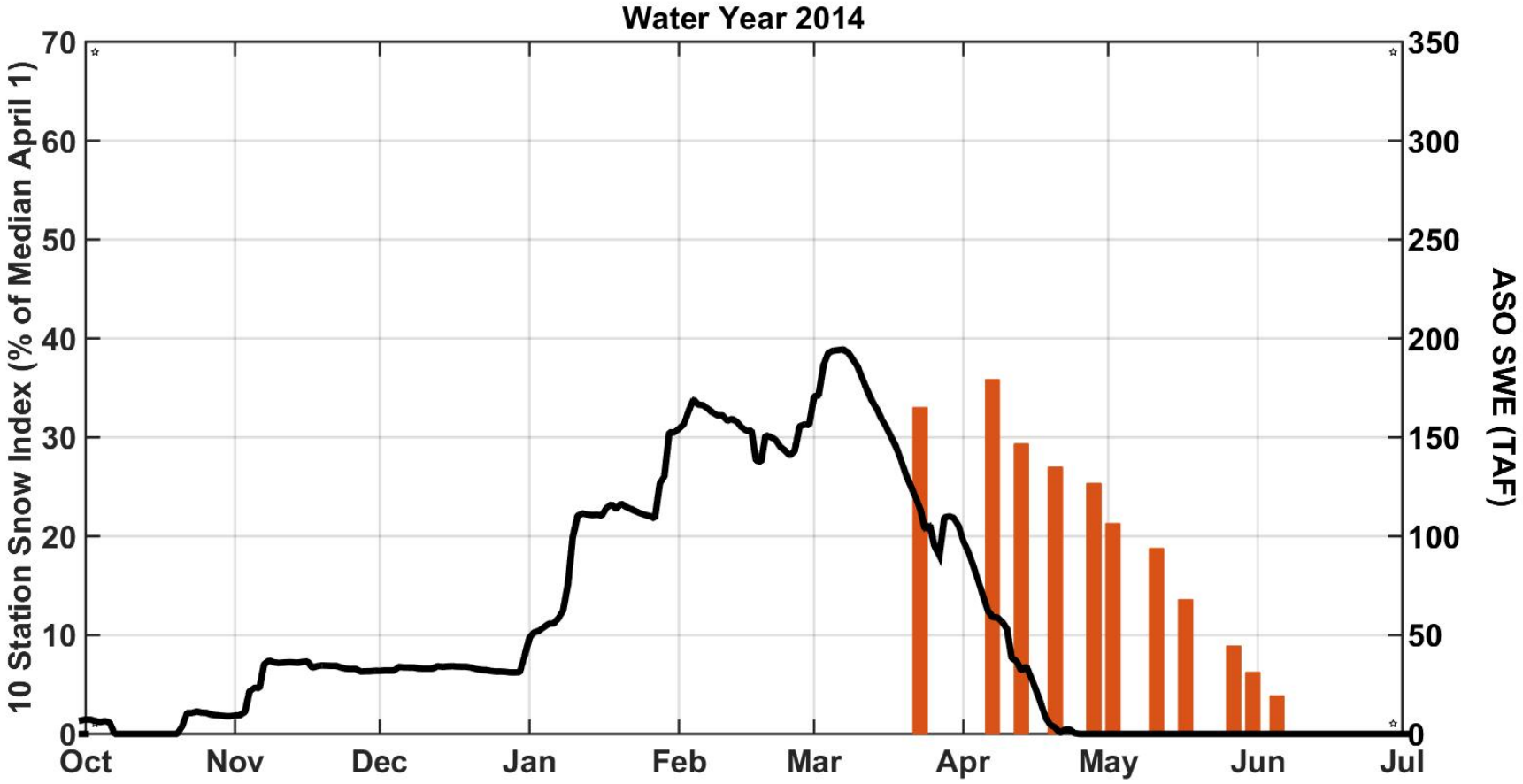


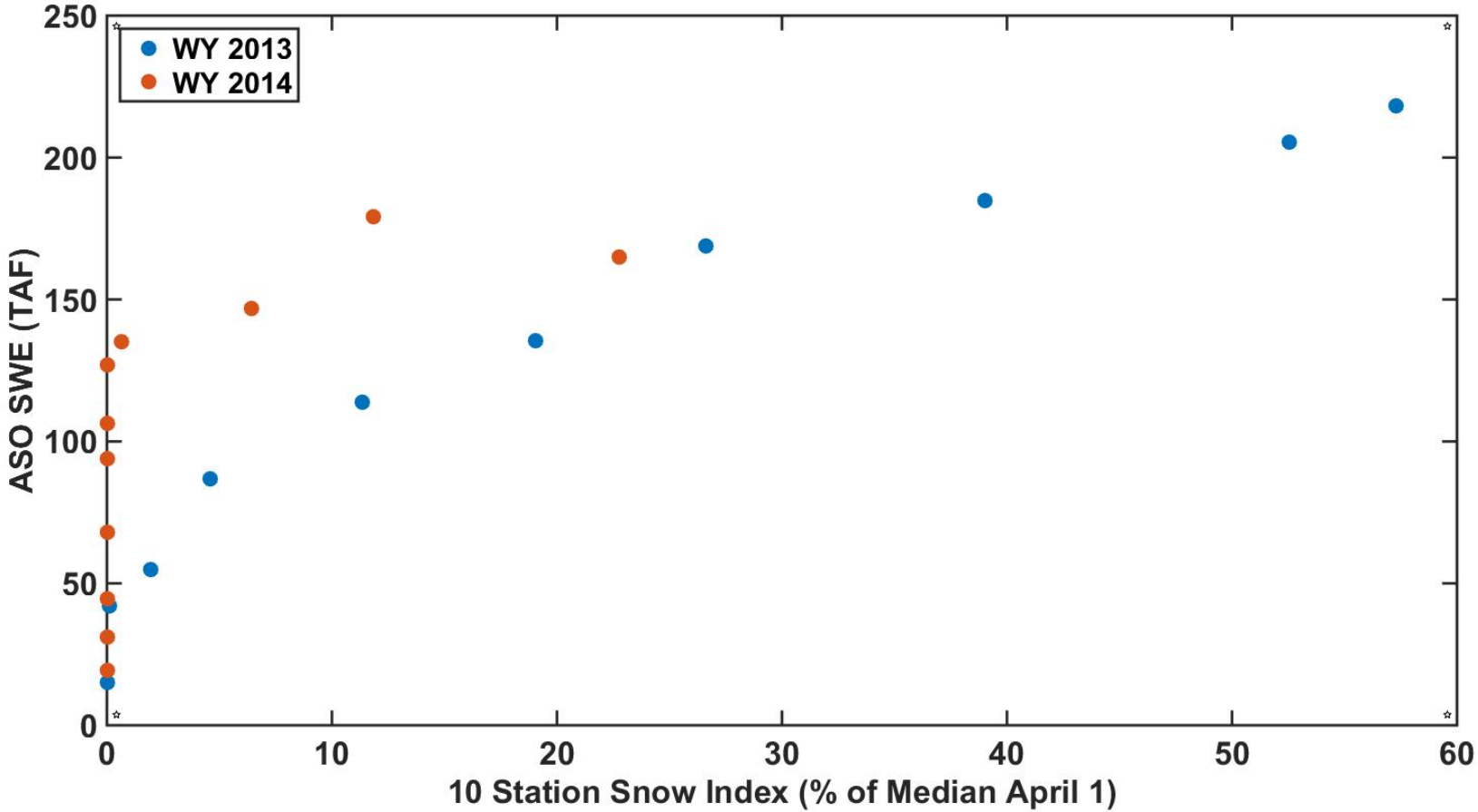
How do ASO measurements compare to point monitoring?

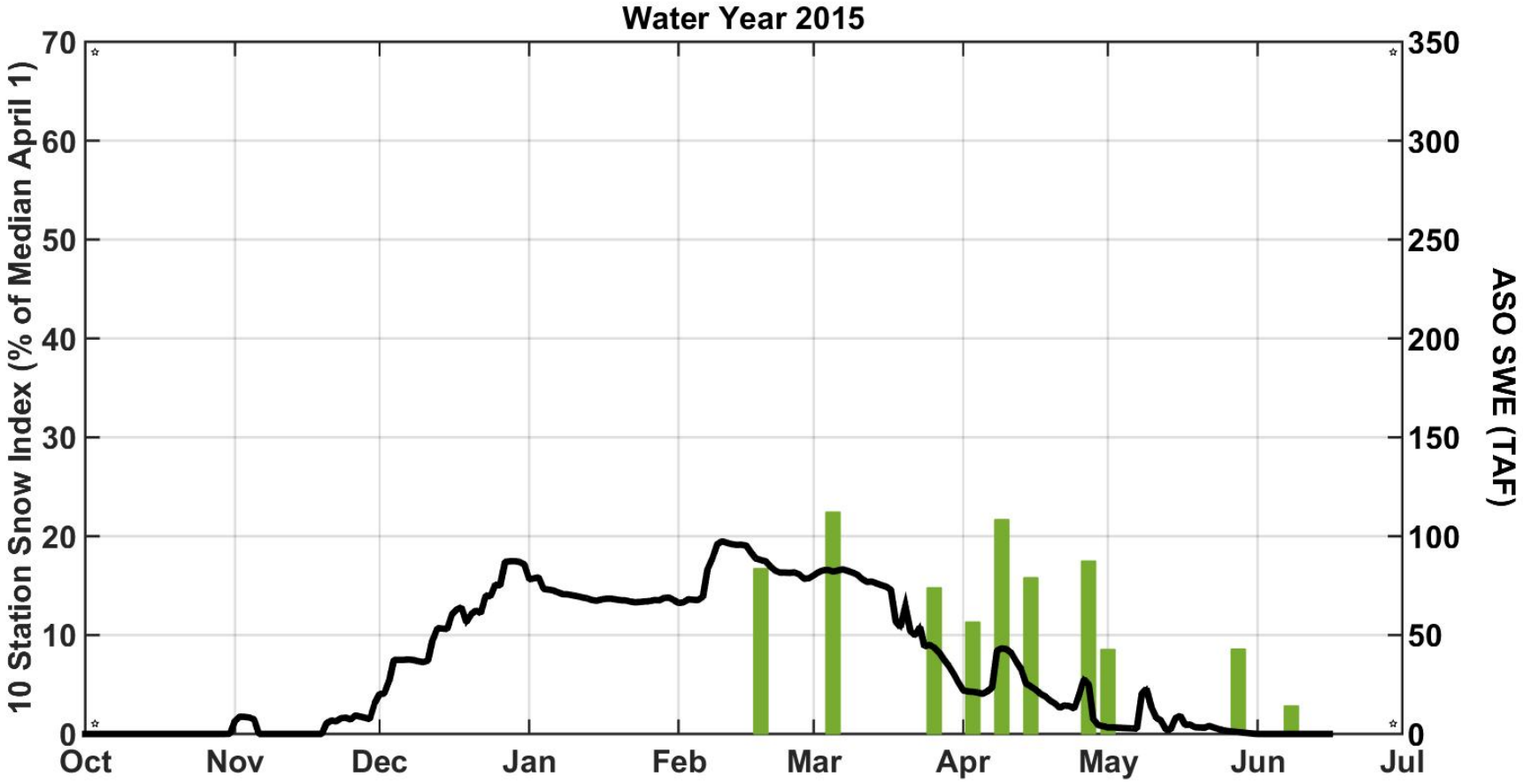

Snow Survey (4)
Snow Pillow (2)
Snow Pillow & Survey (5)
Google earth

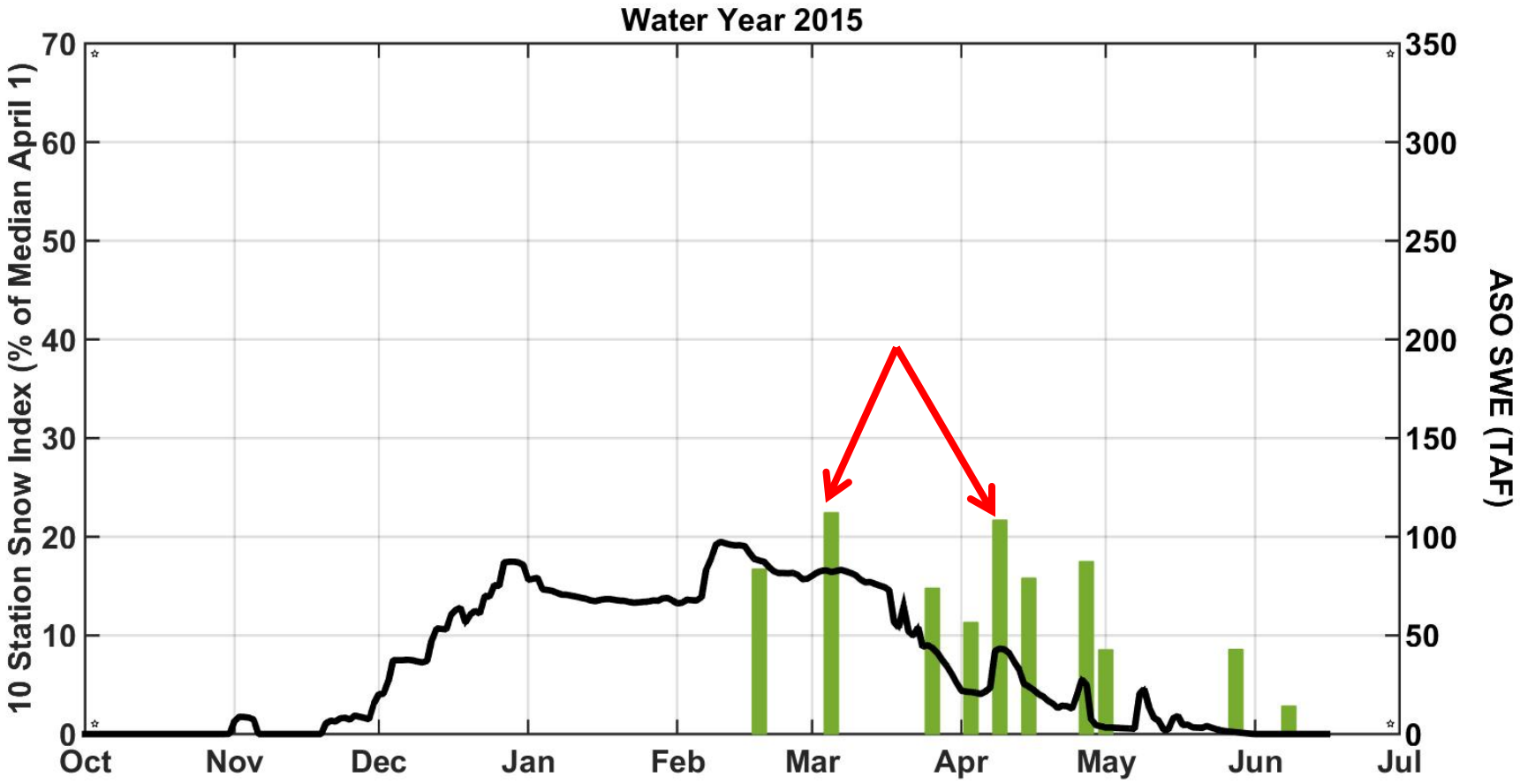

Water Year 2013
10 Station Snow Index (% of Median April 1)
ASO SWE (TAF)
0
10
20
30
40
50
60
70
0
50
100
150
200
250
300
350
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul

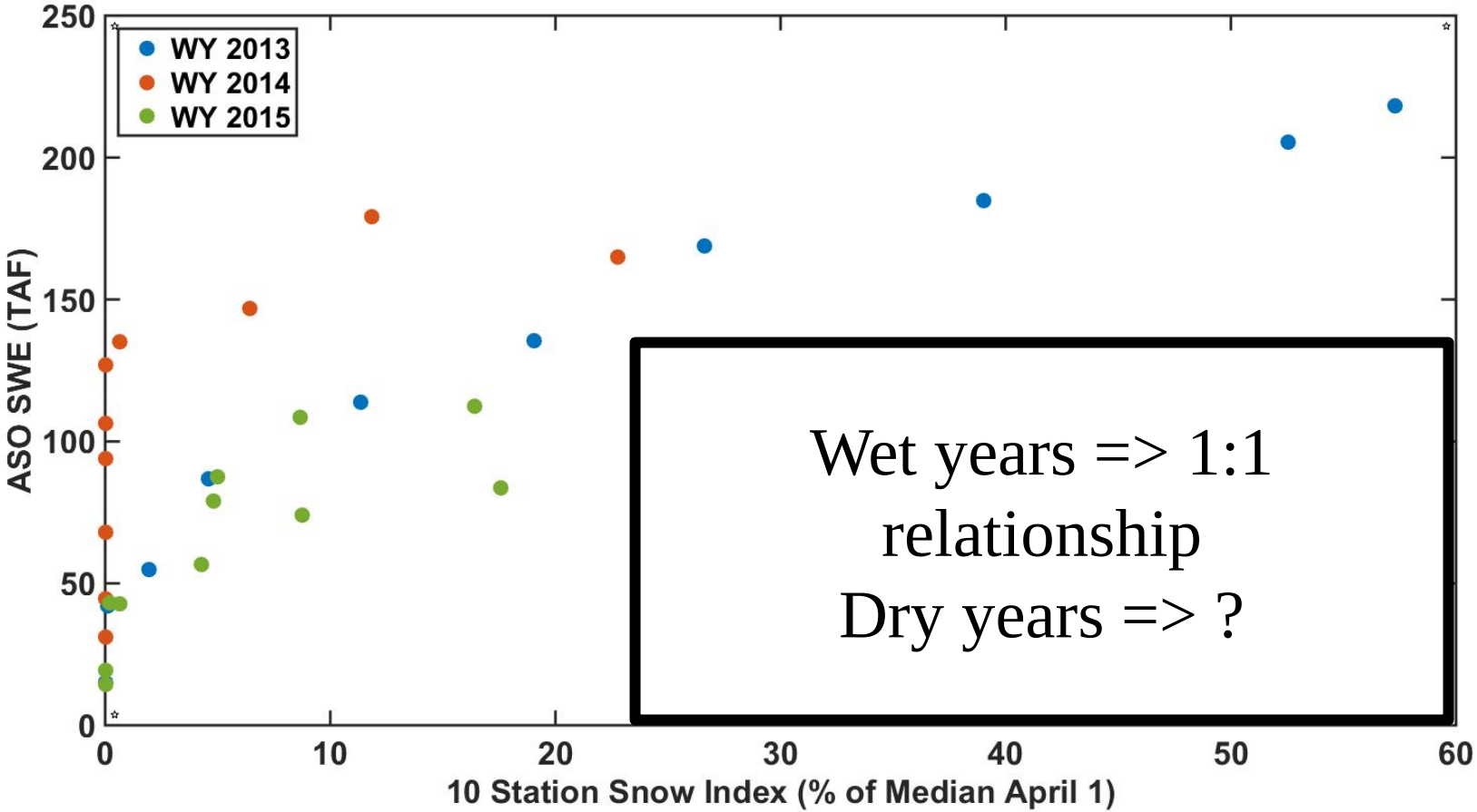

WY 2013
ASO SWE (TAF)
250
200
150
100
50
0
0
10
20
30
40
50
60
10 Station Snow Index (% of Median April 1)


Water Year 2014
10 Station Snow Index (% of Median April 1)
ASO SWE (TAF)
0
10
20
30
40
50
60
70
0
50
100
150
200
250
300
350
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul


WY 2013
WY 2014
ASO SWE (TAF)
10 Station Snow Index (% of Median April 1)
0
50
100
150
200
250
0
10
20
30
40
50
60


Water Year 2015
10 Station Snow Index (% of Median April 1)
ASO SWE (TAF)
0
10
20
30
40
50
60
70
0
50
100
150
200
250
300
350
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul

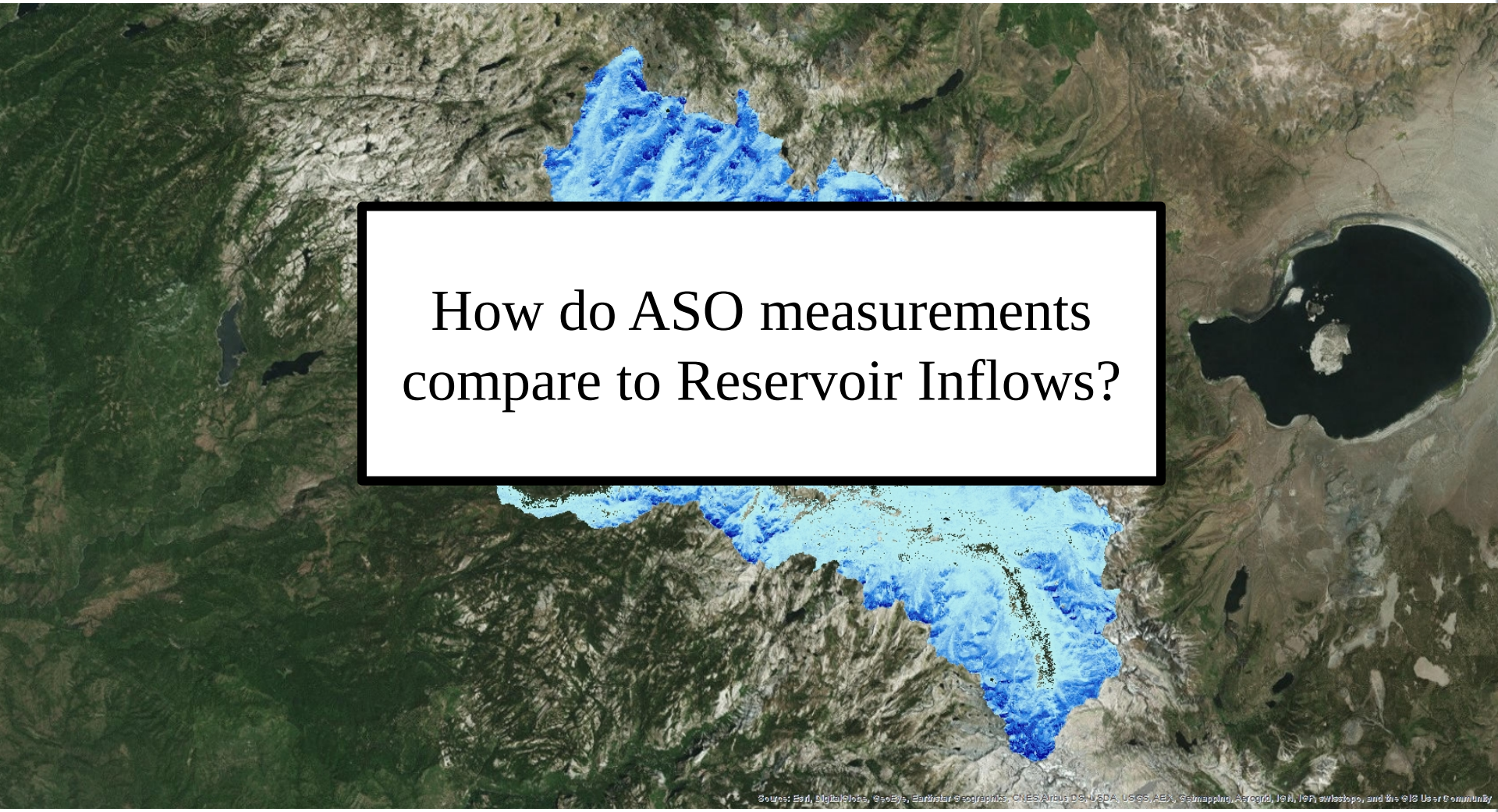

Water Year 2015
10 Station Snow Index (% of Median April 1)
ASO SWE (TAF)
0
10
20
30
40
50
60
70
0
50
100
150
200
250
300
350
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul

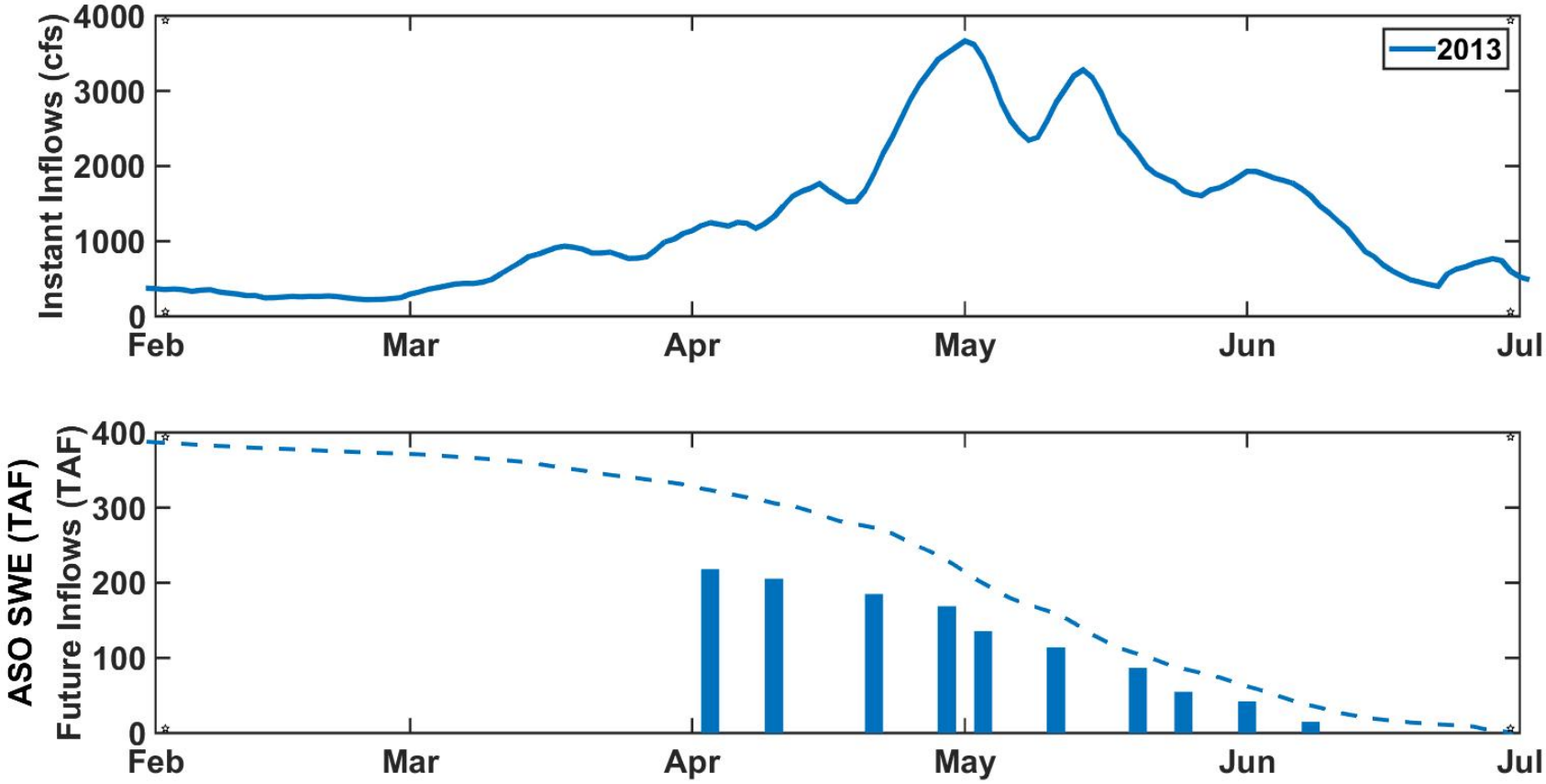


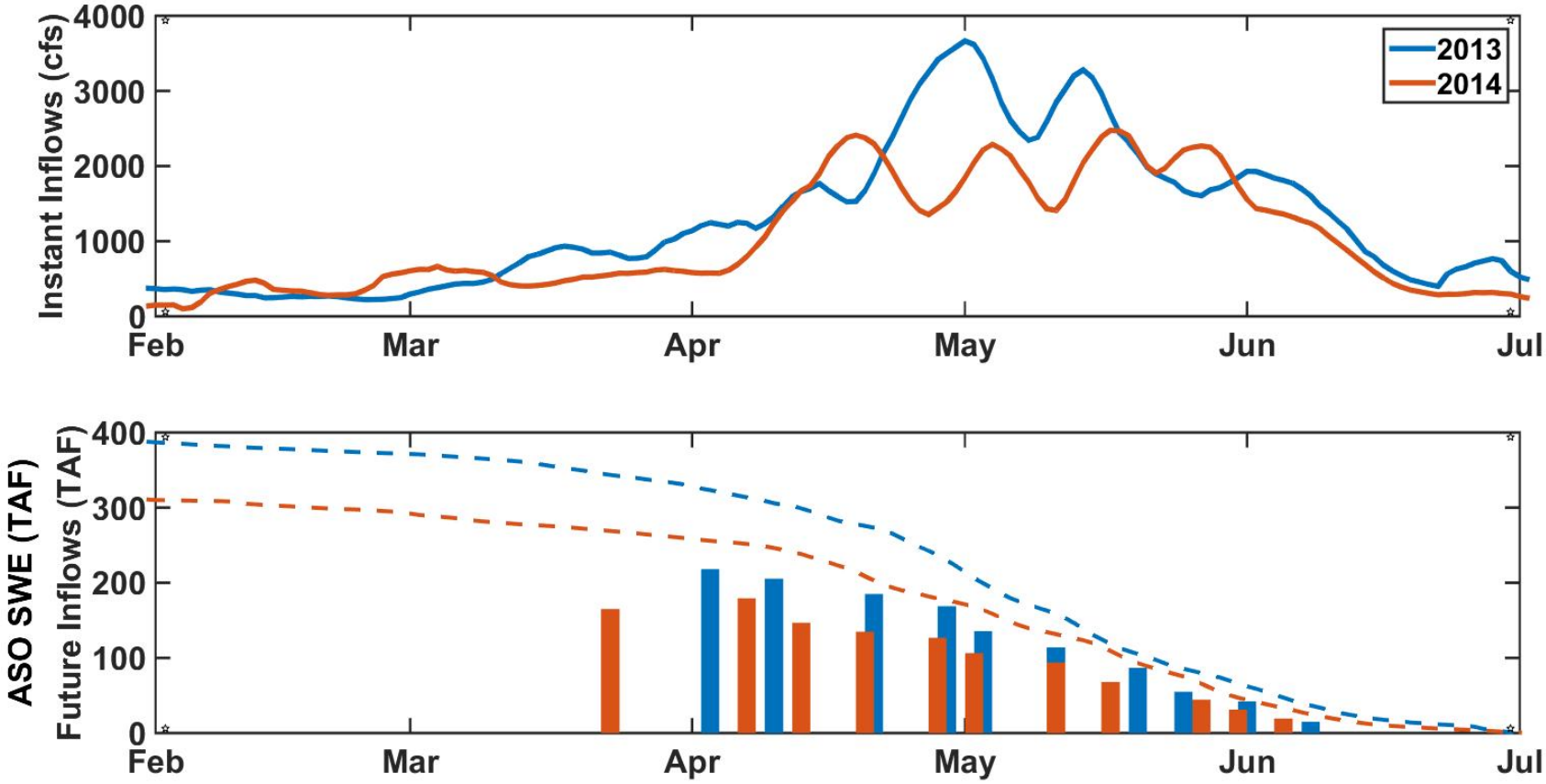
Wet years => 1:1 relationship

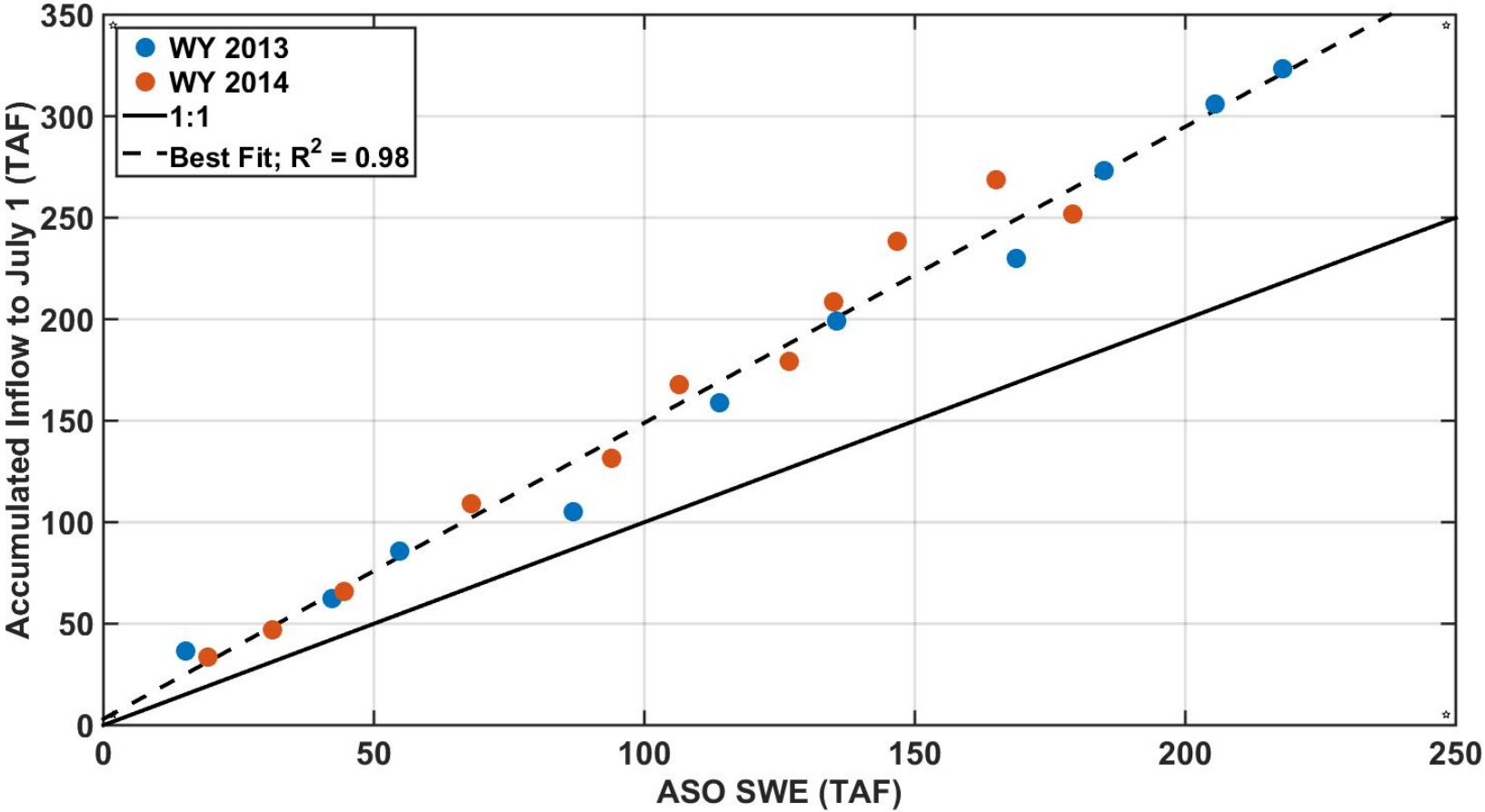
Dry years => ?

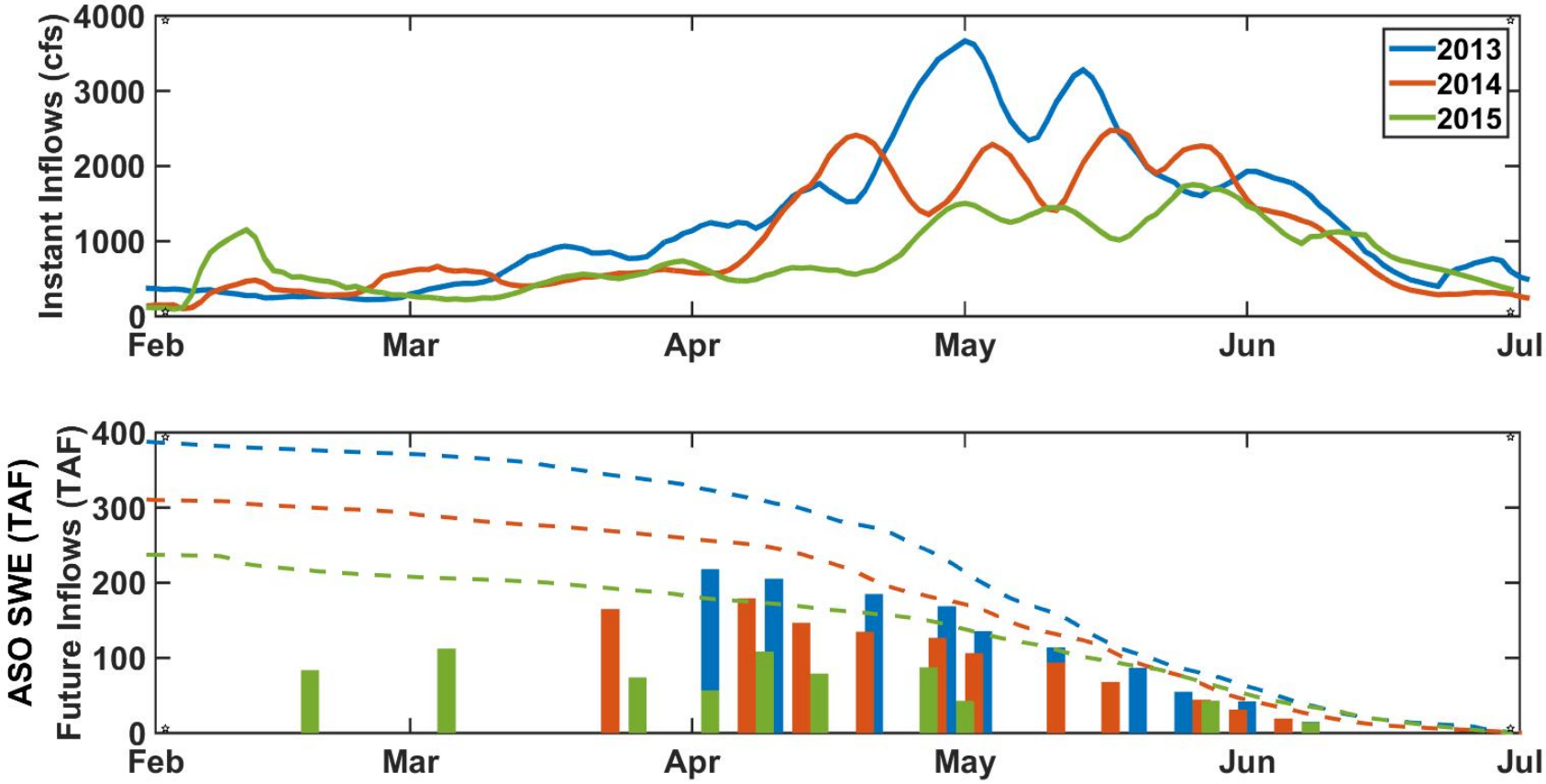
How do ASO measurements compare to Reservoir Inflows?

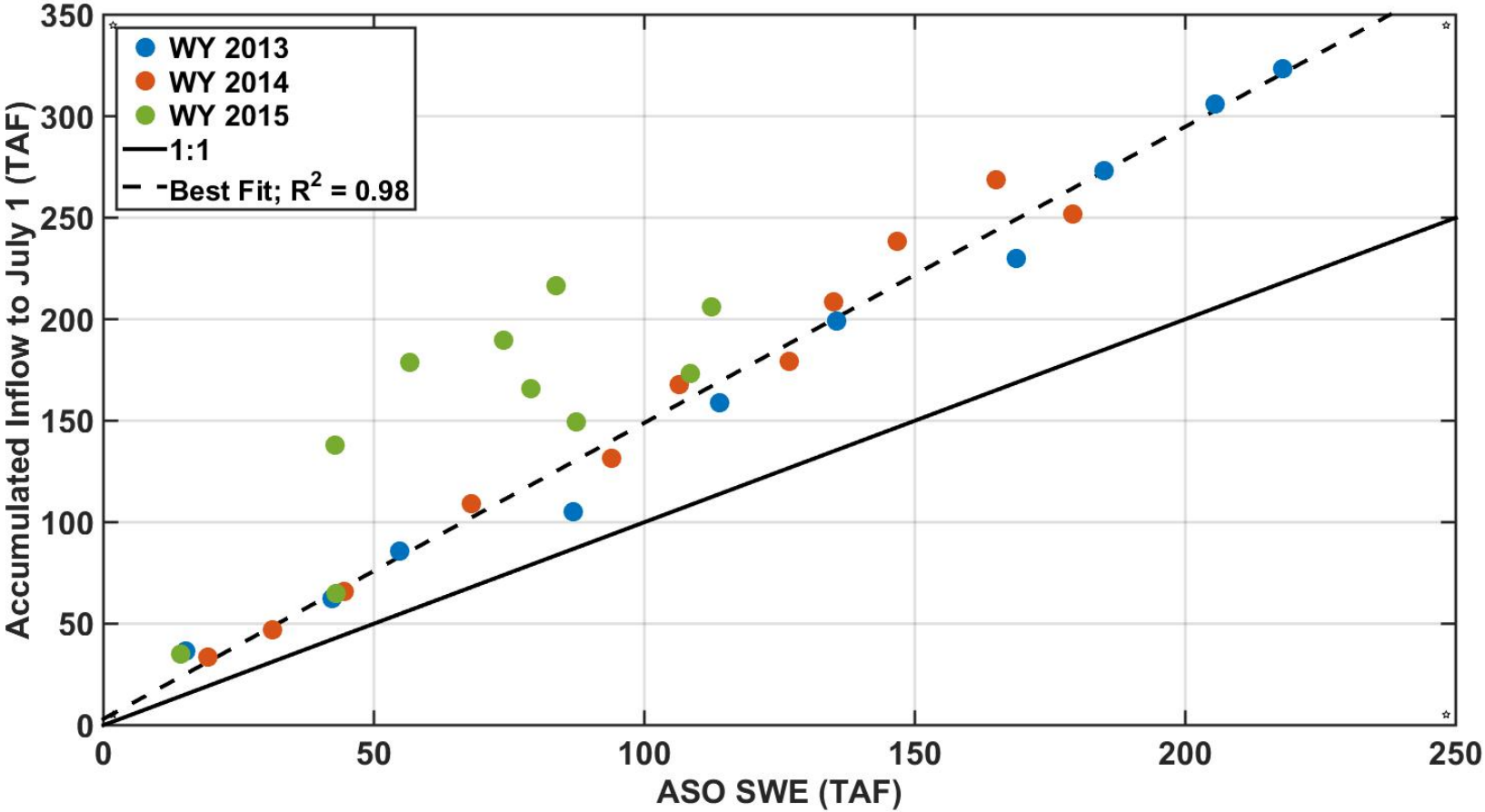


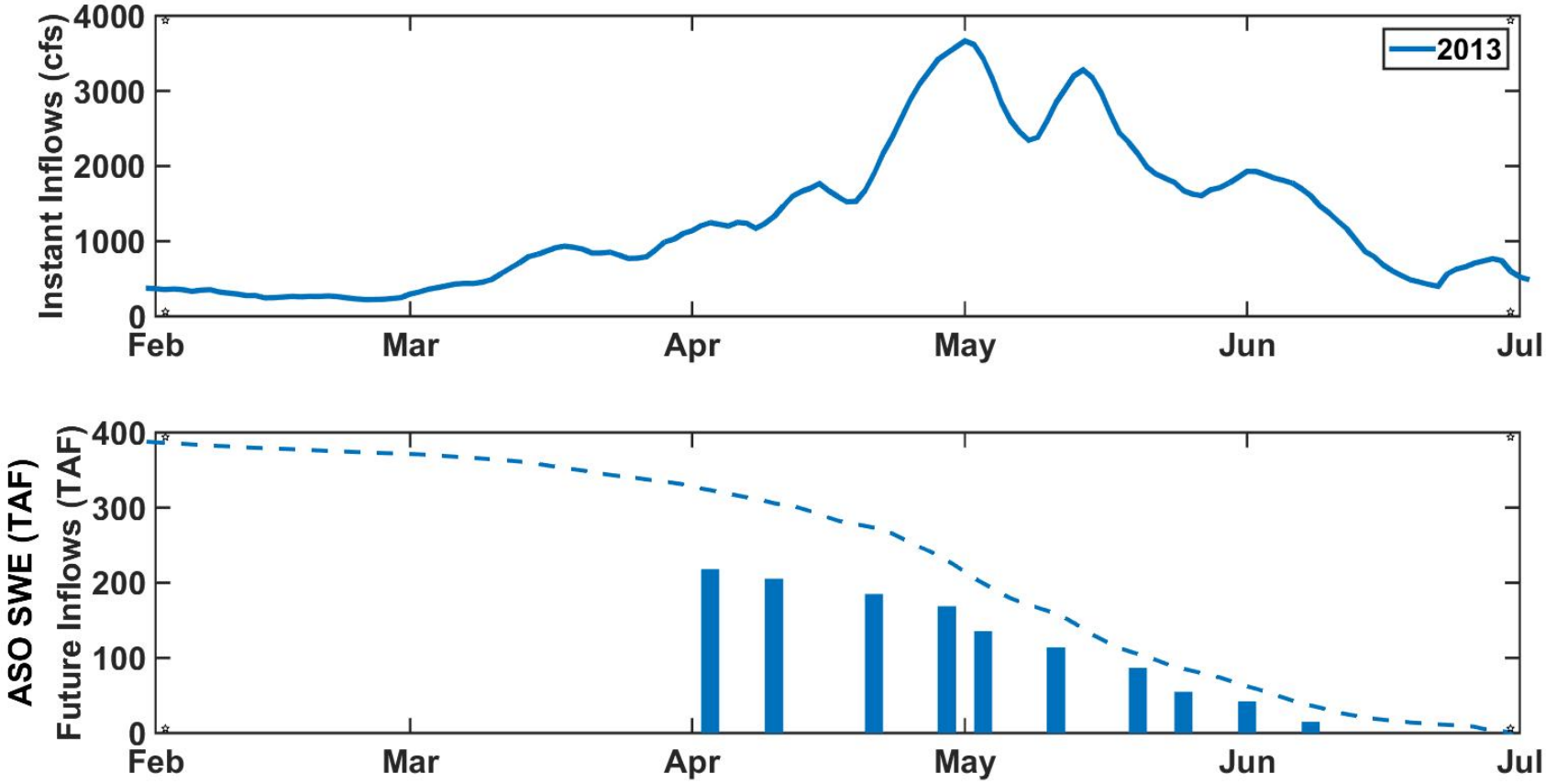

Instant Inflows (cfs)
4000
3000
2000
1000
0
2013
Feb
Mar
Apr
May
Jun
Jul
ASO SWE (TAF)
Future Inflows (TAF)
400
300
200
100
0
Feb
Mar
Apr
May
Jun
Jul

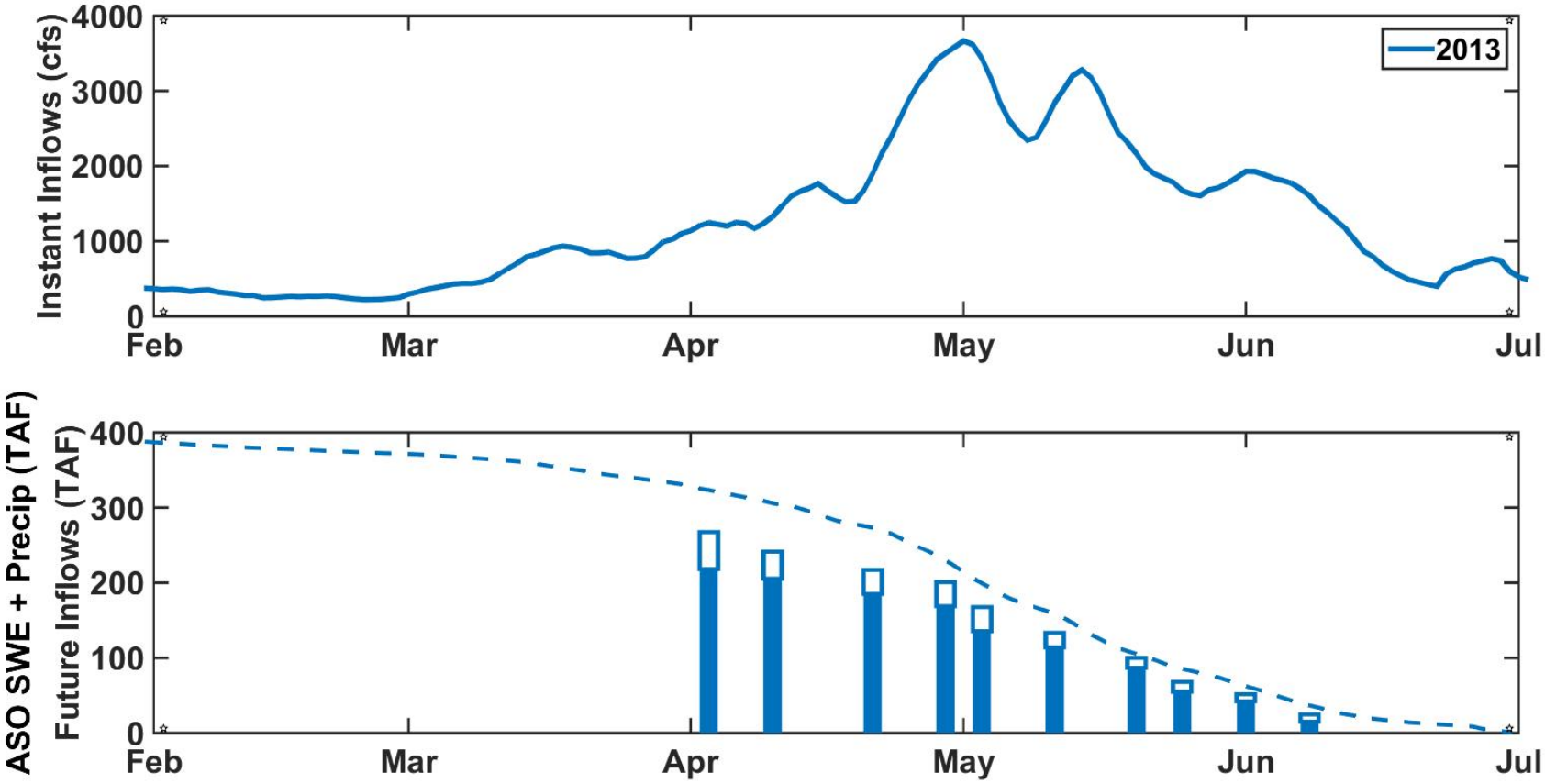

Instant Inflows (cfs)
4000
3000
2000
1000
0
2013
2014
Feb
Mar
Apr
May
Jun
Jul
ASO SWE (TAF)
Future Inflows (TAF)
400
300
200
100
0
Feb
Mar
Apr
May
Jun
Jul

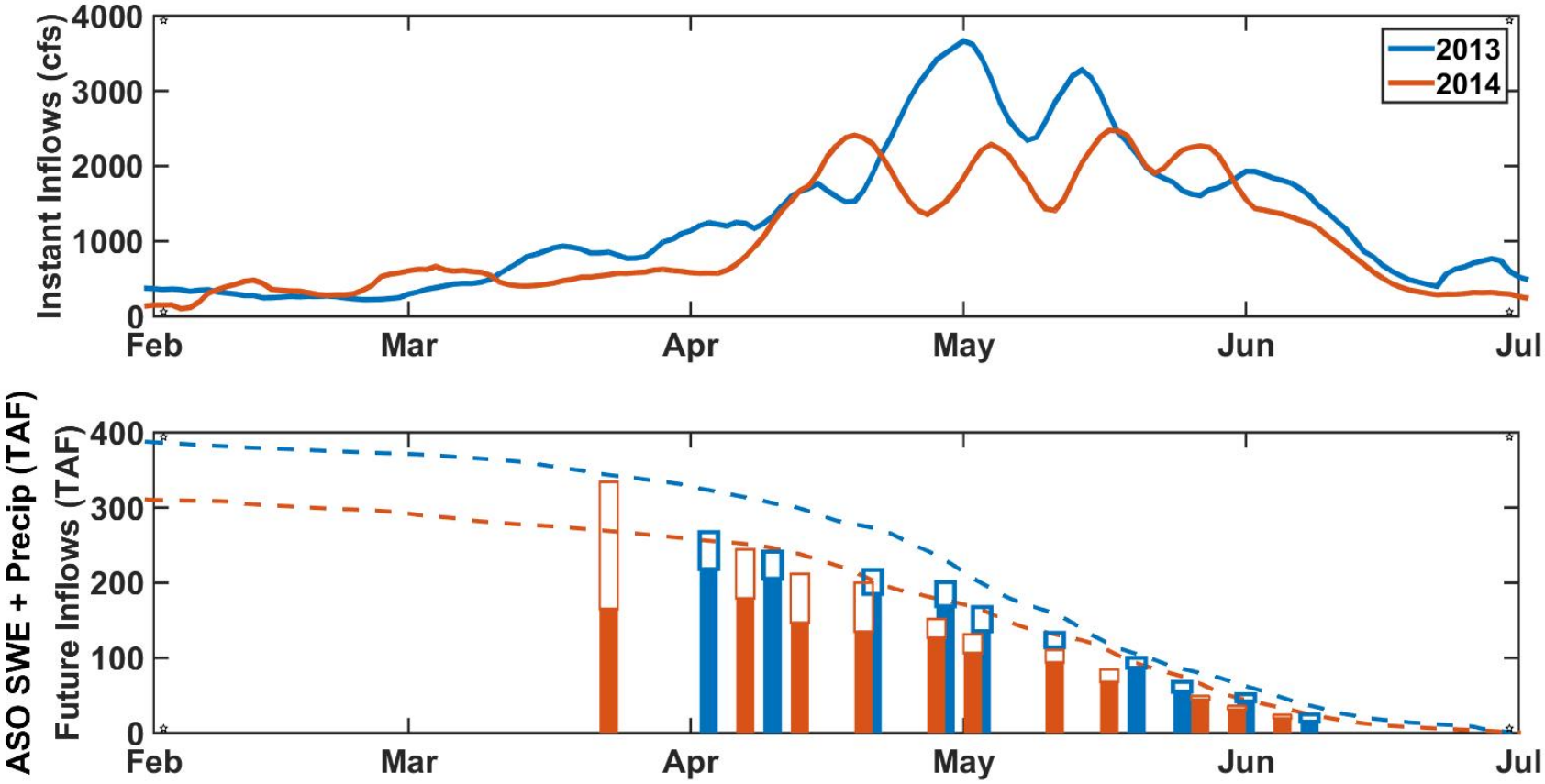

WY 2013
WY 2014
1:1
Best Fit; R^2 = 0.98
Accumulated Inflow to July 1 (TAF)
ASO SWE (TAF)
0
50
100
150
200
250
300
350

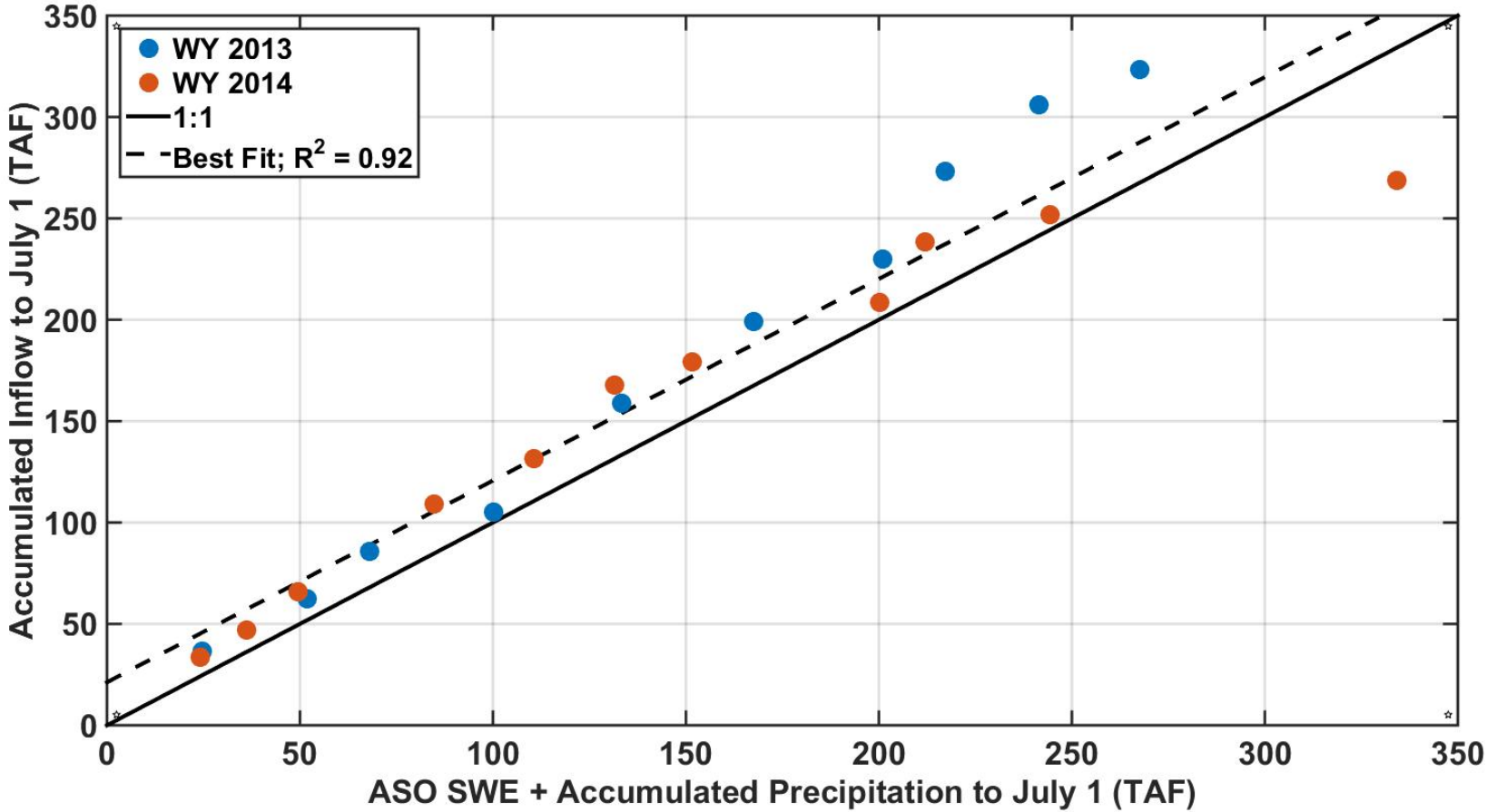

Instant Inflows (cfs)
4000
3000
2000
1000
0
Feb
Mar
Apr
May
Jun
Jul
2013
2014
2015
ASO SWE (TAF)
Future Inflows (TAF)
400
300
200
100
0
Feb
Mar
Apr
May
Jun
Jul

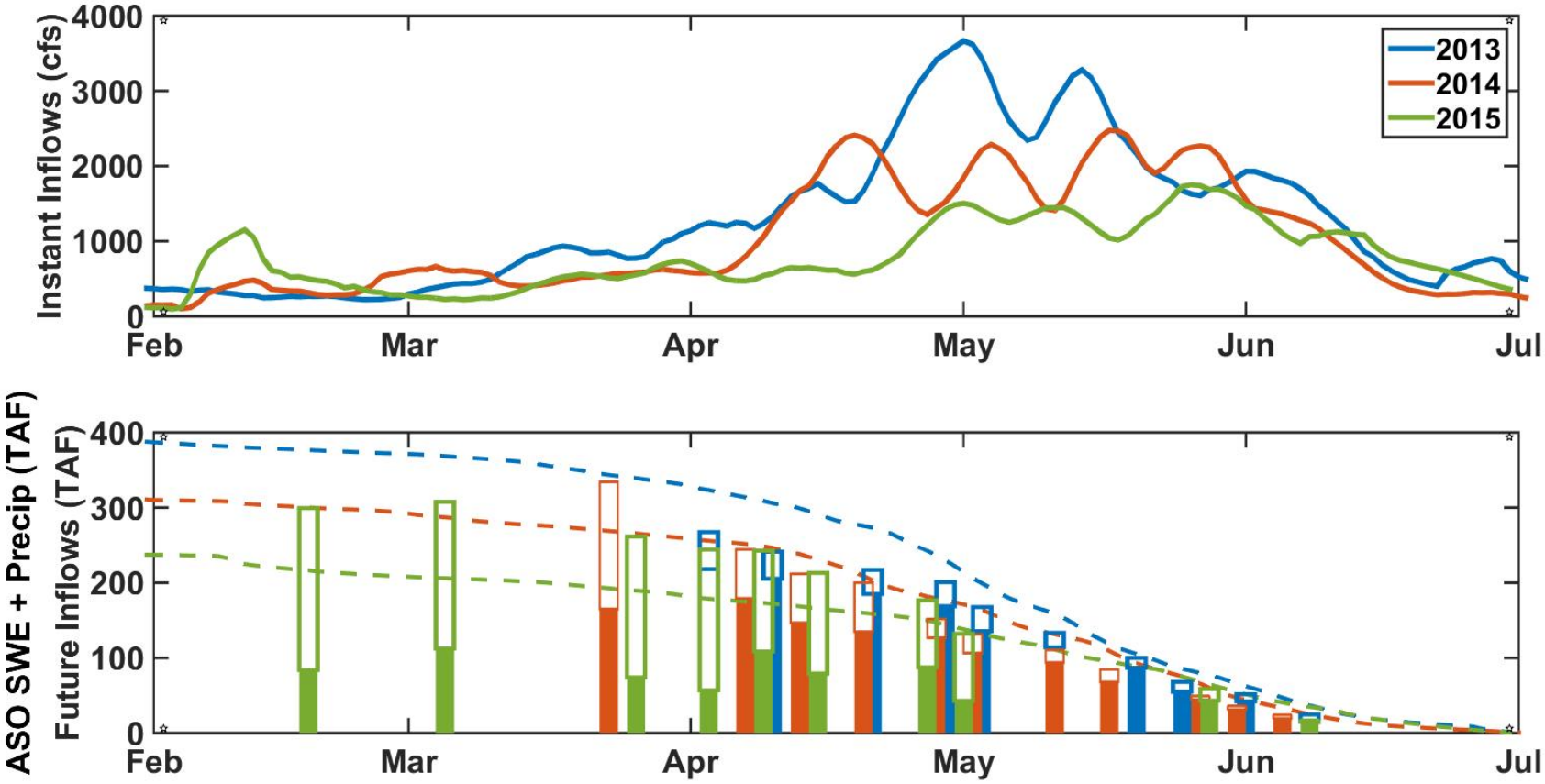

WY 2013
WY 2014
WY 2015
1:1
Best Fit; R^2 = 0.98
Accumulated Inflow to July 1 (TAF)
ASO SWE (TAF)
0
50
100
150
200
250
300
350

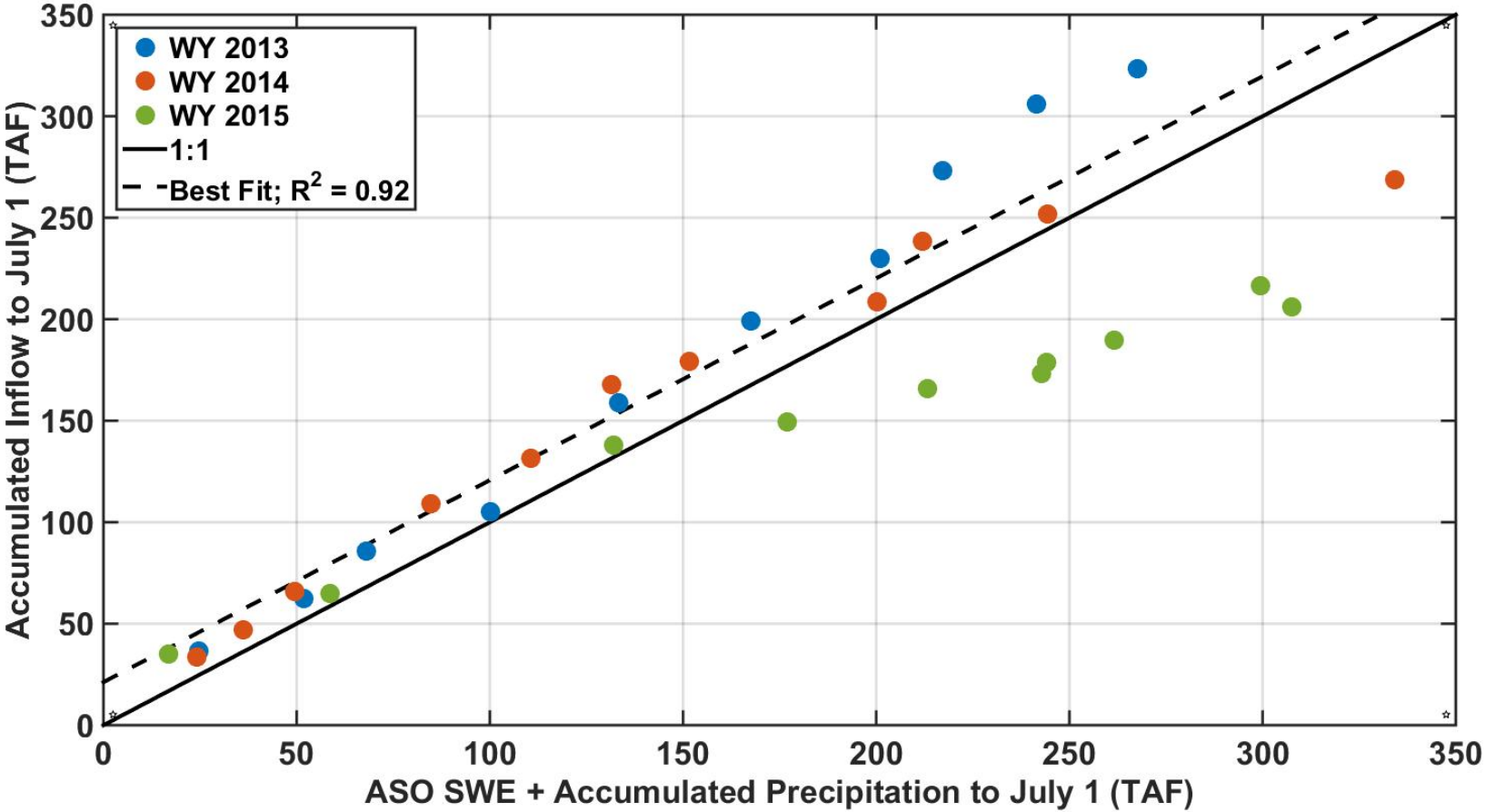

Instant Inflows (cfs)
4000
3000
2000
1000
0
2013
Feb
Mar
Apr
May
Jun
Jul
ASO SWE (TAF)
Future Inflows (TAF)
400
300
200
100
0
Feb
Mar
Apr
May
Jun
Jul

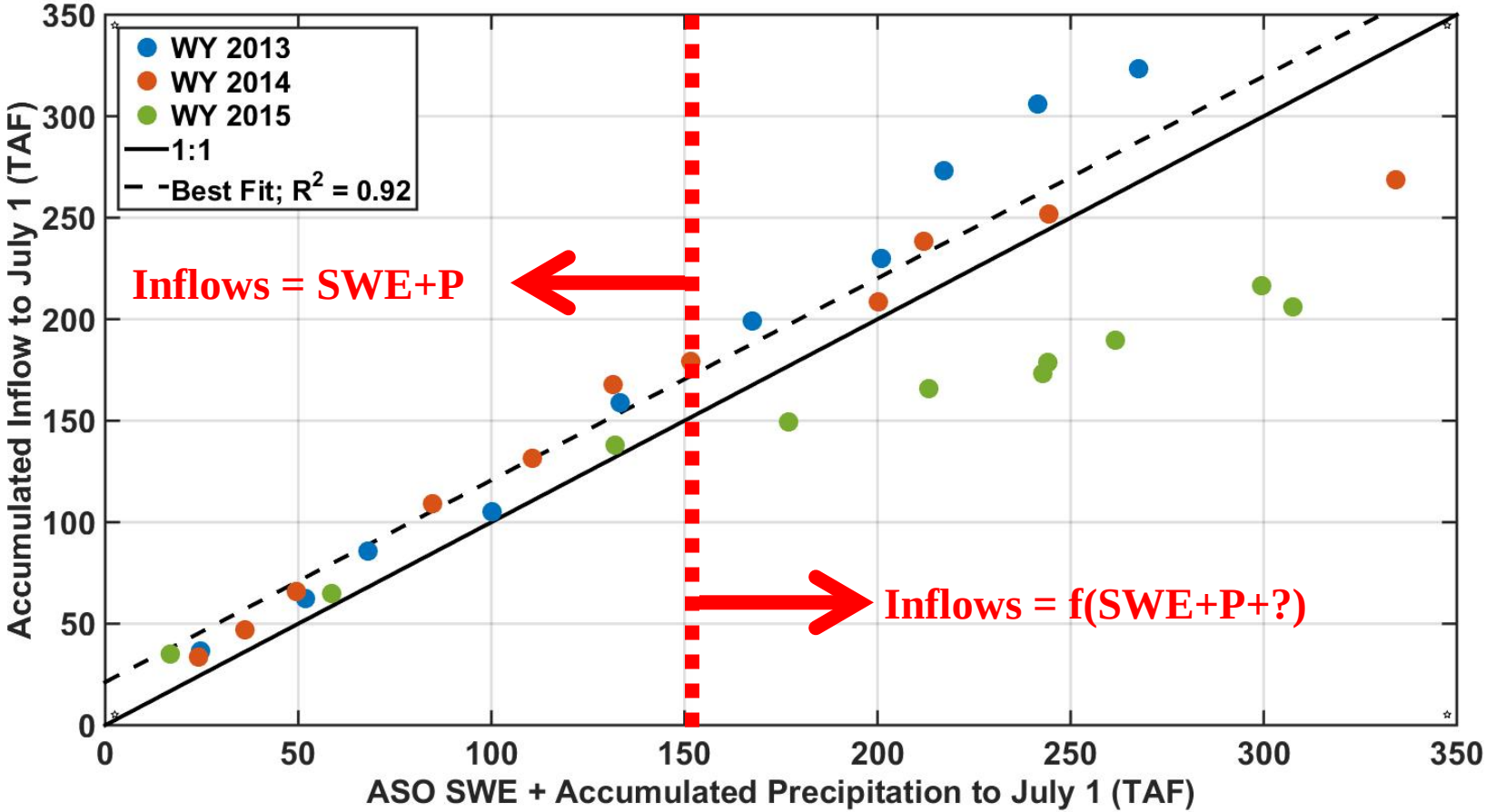

Instant Inflows (cfs)
4000
3000
2000
1000
0
2013
Feb
Mar
Apr
May
Jun
Jul
ASO SWE + Precip (TAF)
Future Inflows (TAF)
400
300
200
100
0
Feb
Mar
Apr
May
Jun
Jul

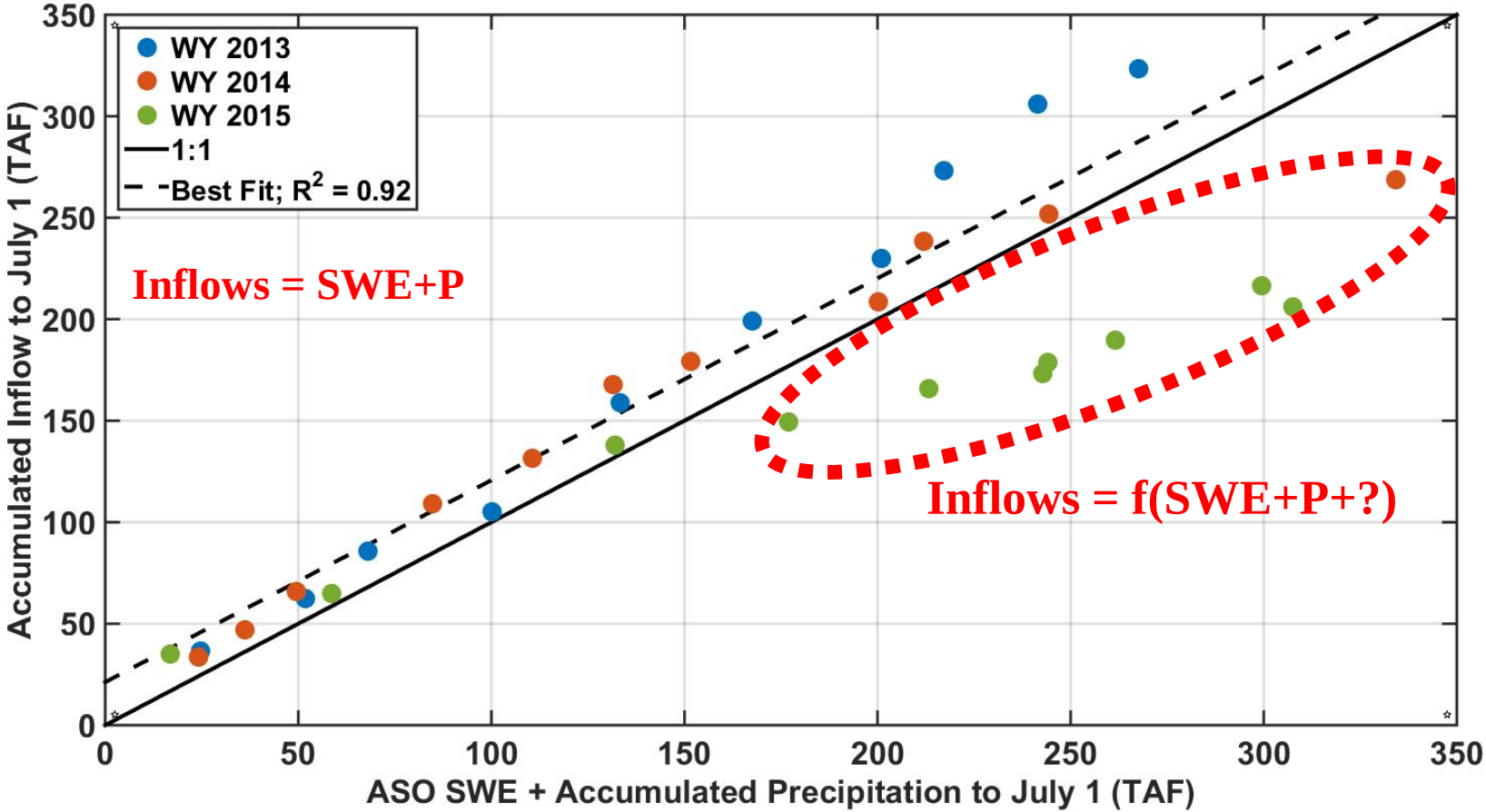

Instant Inflows (cfs)
4000
3000
2000
1000
0
Feb
Mar
Apr
May
Jun
Jul
2013
2014
ASO SWE + Precip (TAF)
Future Inflows (TAF)
400
300
200
100
0
Feb
Mar
Apr
May
Jun
Jul

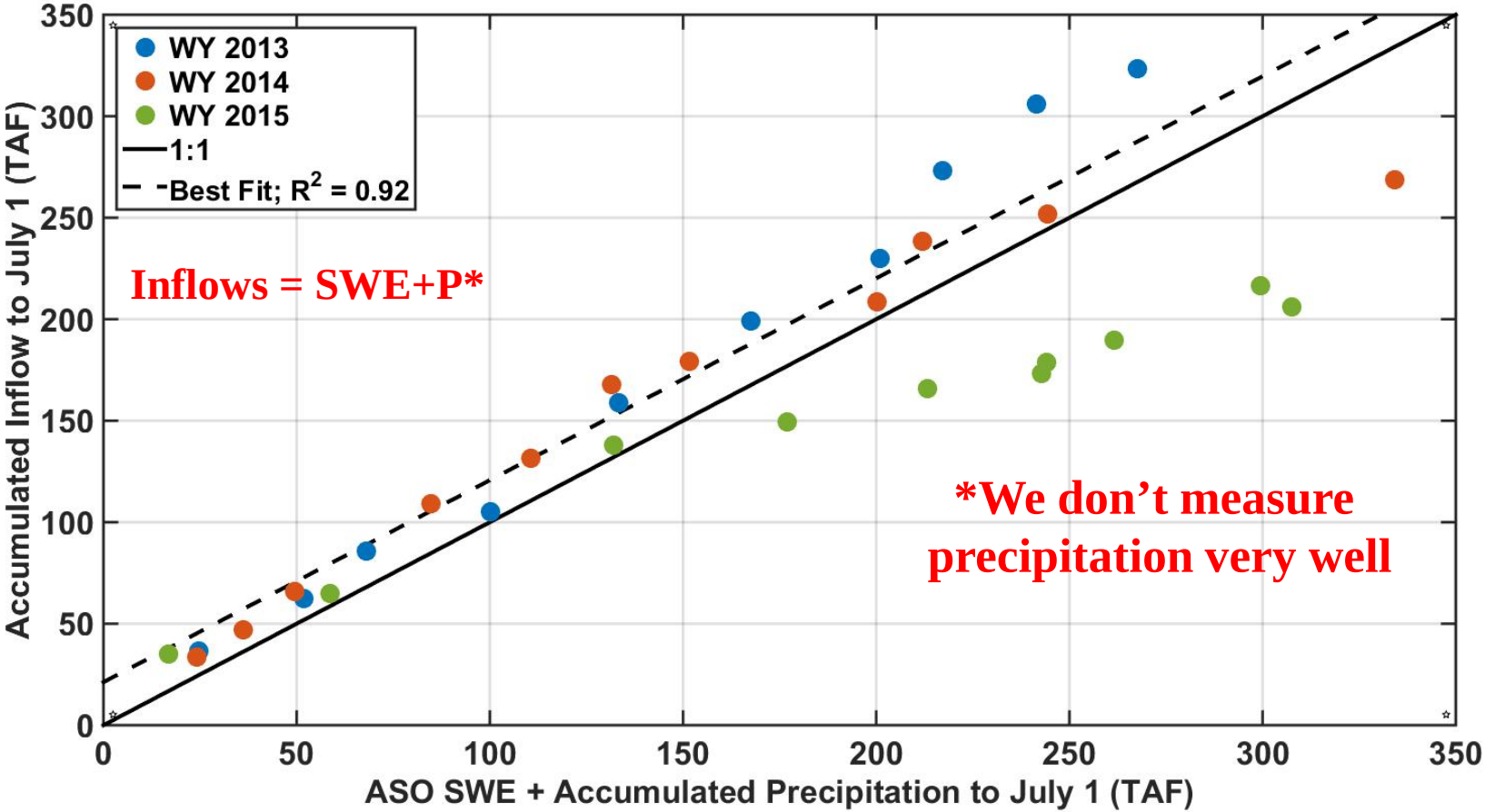

WY 2013
WY 2014
1:1
Best Fit; R^2 = 0.92
Accumulated Inflow to July 1 (TAF)
ASO SWE + Accumulated Precipitation to July 1 (TAF)
0
50
100
150
200
250
300
350

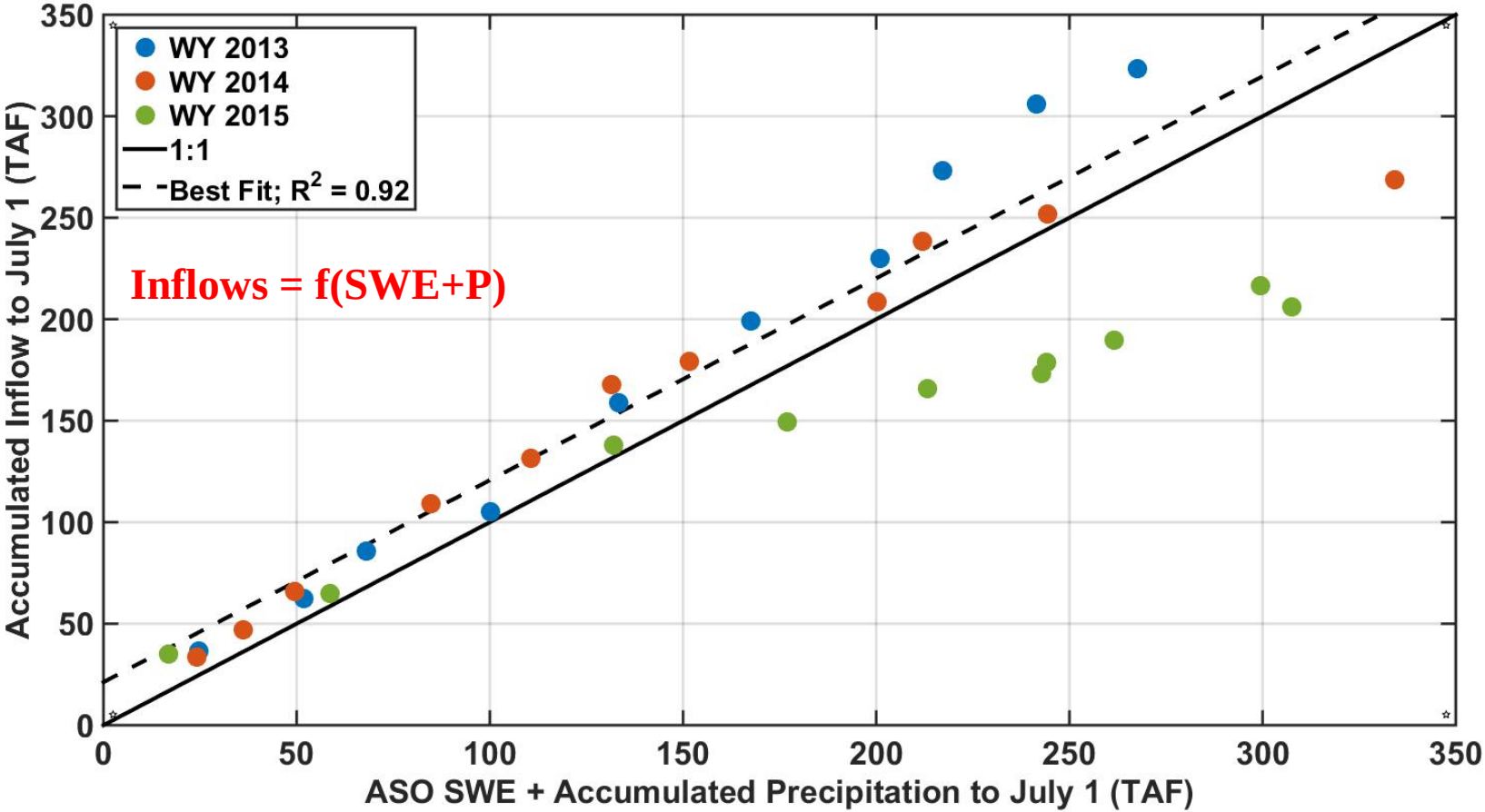

Instant Inflows (cfs)
4000
3000
2000
1000
0
Feb
Mar
Apr
May
Jun
Jul
2013
2014
2015
ASO SWE + Precip (TAF)
Future Inflows (TAF)
400
300
200
100
0
Feb
Mar
Apr
May
Jun
Jul

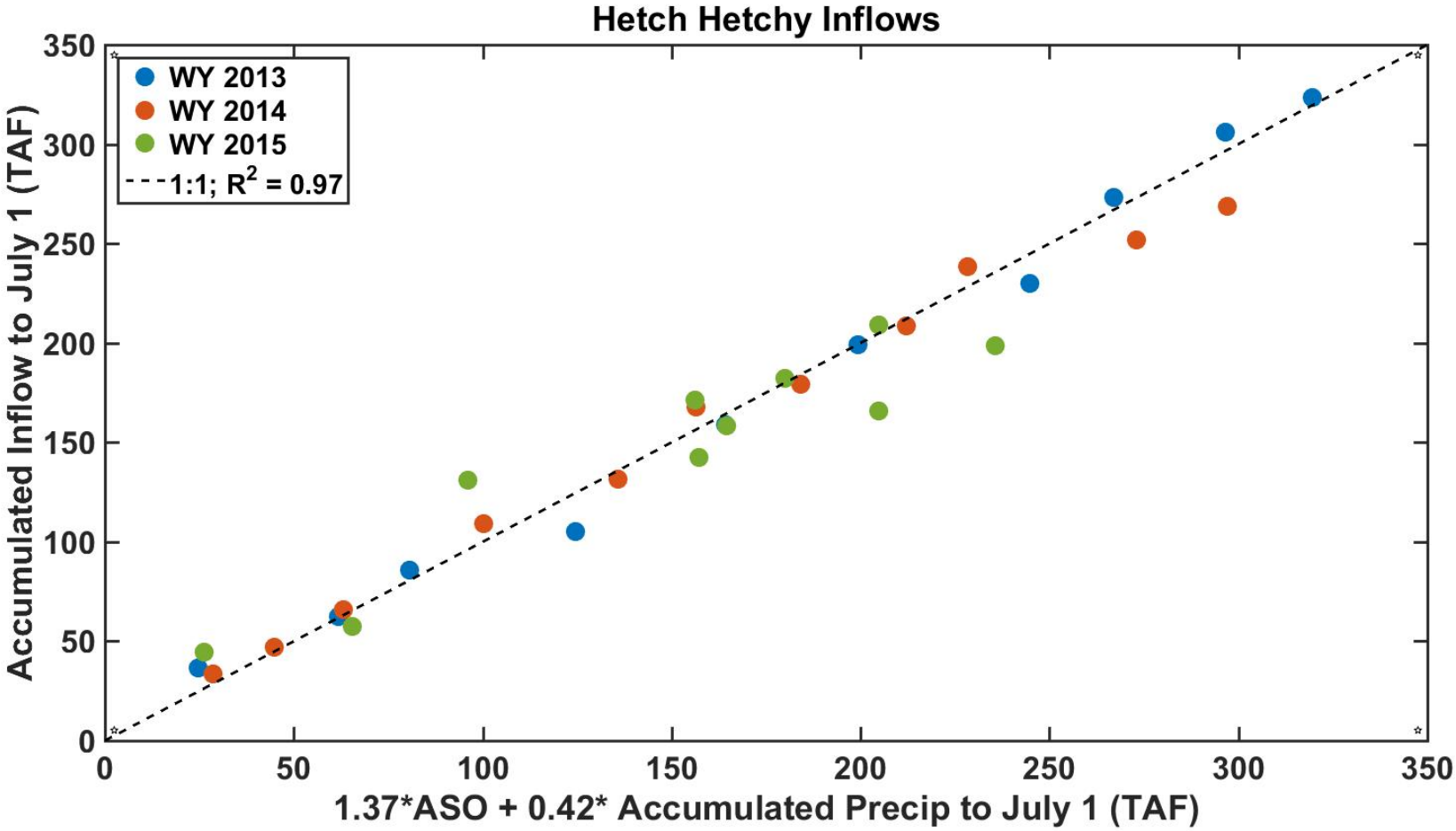

WY 2013
WY 2014
WY 2015
1:1
Best Fit; R^2 = 0.92
Accumulated Inflow to July 1 (TAF)
ASO SWE + Accumulated Precipitation to July 1 (TAF)
0
50
100
150
200
250
300
350

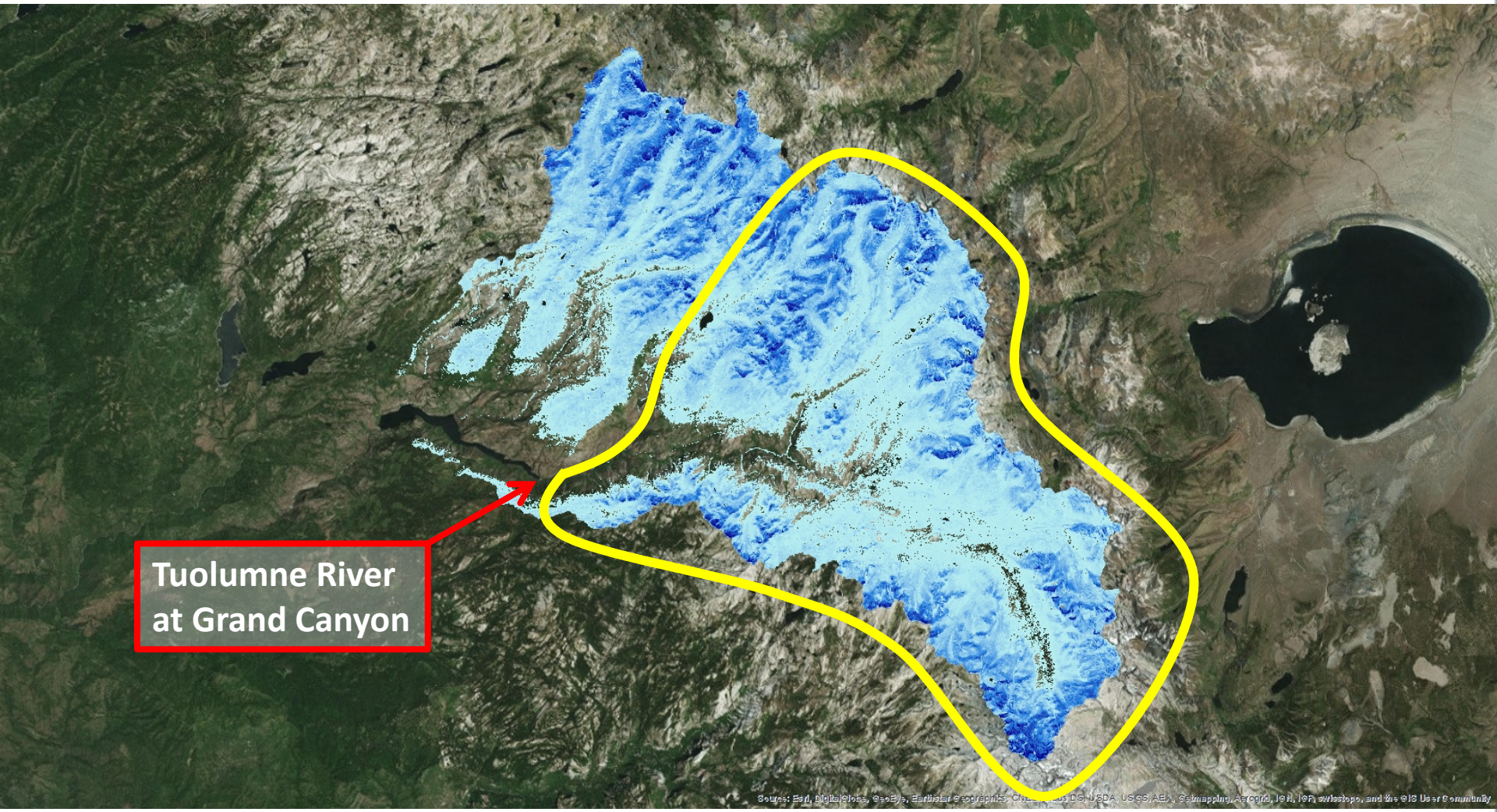

WY 2013
WY 2014
WY 2015
1:1
Best Fit; R^2 = 0.92
Inflows = SWE+P
Inflows = f(SWE+P+?)
Accumulated Inflow to July 1 (TAF)
ASO SWE + Accumulated Precipitation to July 1 (TAF)
0
50
100
150
200
250
300
350

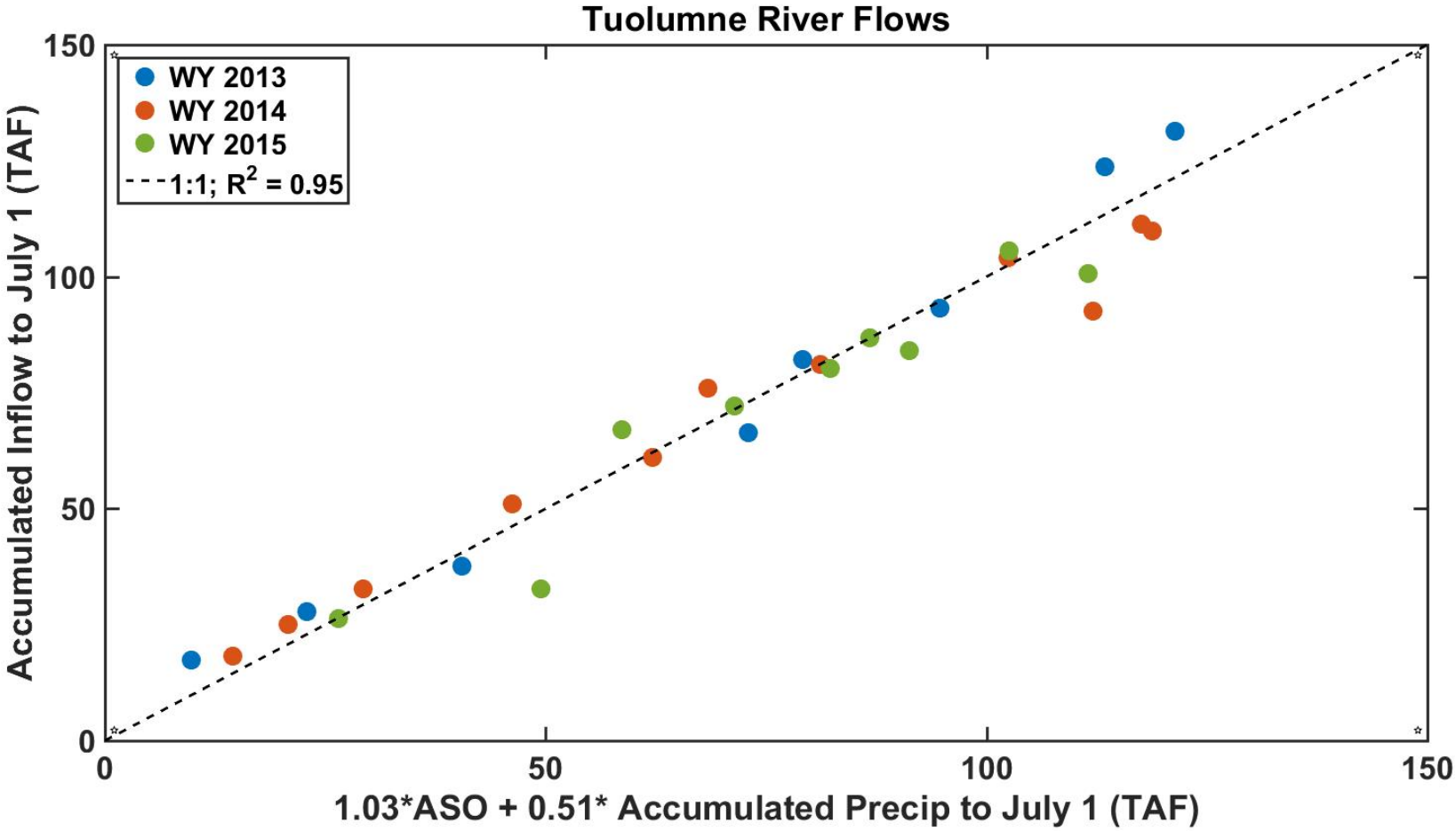

WY 2013
WY 2014
WY 2015
1:1
Best Fit; R^2 = 0.92
Inflows = SWE+P
Inflows = f(SWE+P+?)
Accumulated Inflow to July 1 (TAF)
ASO SWE + Accumulated Precipitation to July 1 (TAF)
0
50
100
150
200
250
300
350


WY 2013
WY 2014
WY 2015
1:1
Best Fit; R^2 = 0.92
Inflows = SWE+P*
*We don't measure precipitation very well
Accumulated Inflow to July 1 (TAF)
ASO SWE + Accumulated Precipitation to July 1 (TAF)
0
50
100
150
200
250
300
350


WY 2013
WY 2014
WY 2015
1:1
Best Fit; R^2 = 0.92
Inflows = f(SWE+P)
Accumulated Inflow to July 1 (TAF)
ASO SWE + Accumulated Precipitation to July 1 (TAF)
0
50
100
150
200
250
300
350


Hetch Hetchy Inflows
WY 2013
WY 2014
WY 2015
1:1; R2 = 0.97
Accumulated Inflow to July 1 (TAF)
1.37*ASO + 0.42* Accumulated Precip to July 1 (TAF)
0
50
100
150
200
250
300
350


Tuolumne River
at Grand Canyon

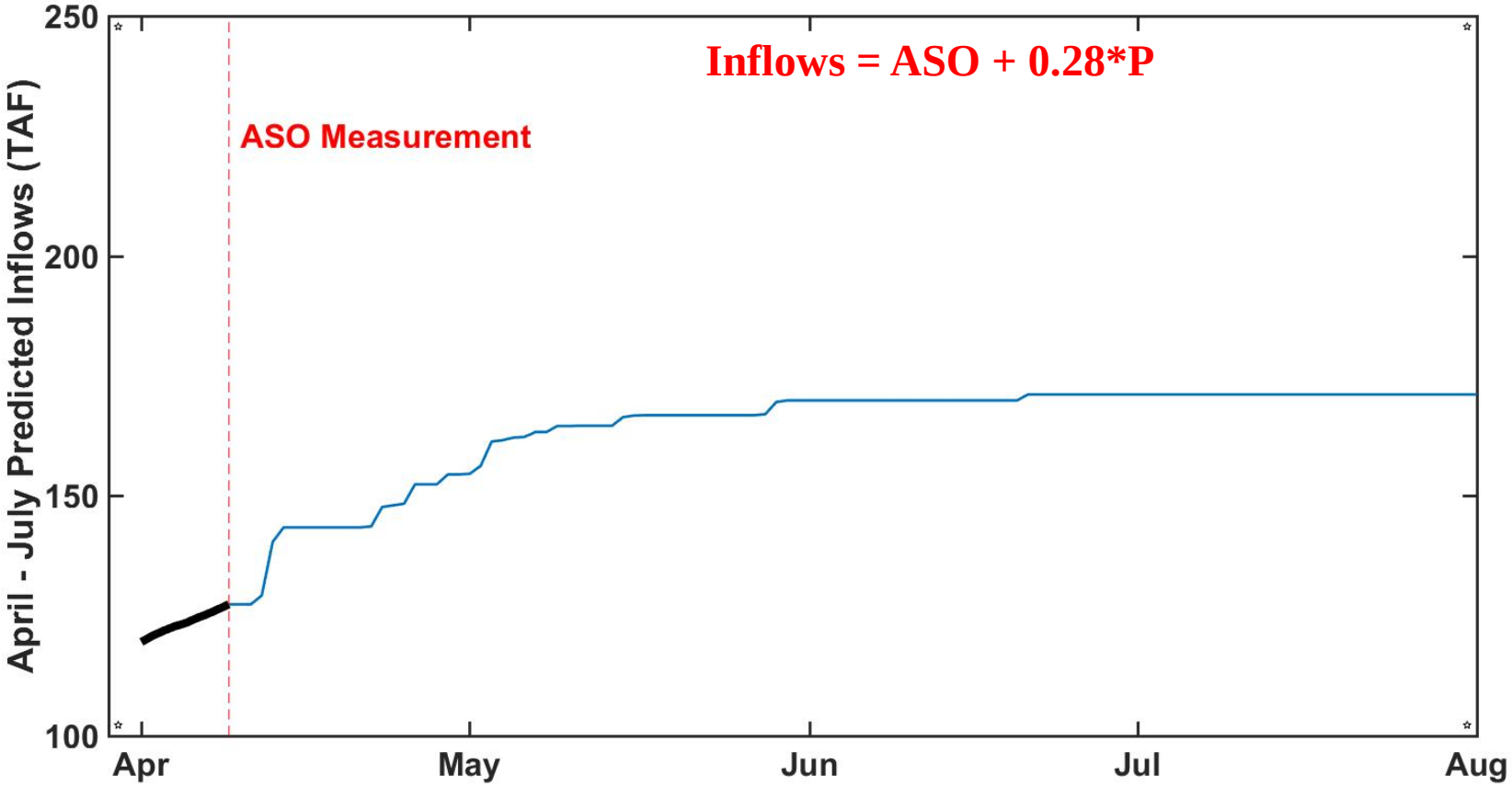

Tuolumne River Flows
WY 2013
WY 2014
WY 2015
1:1; R2 = 0.95
Accumulated Inflow to July 1 (TAF)
1.03*ASO + 0.51* Accumulated Precip to July 1 (TAF)
0
50
100
150
0
50
100
150

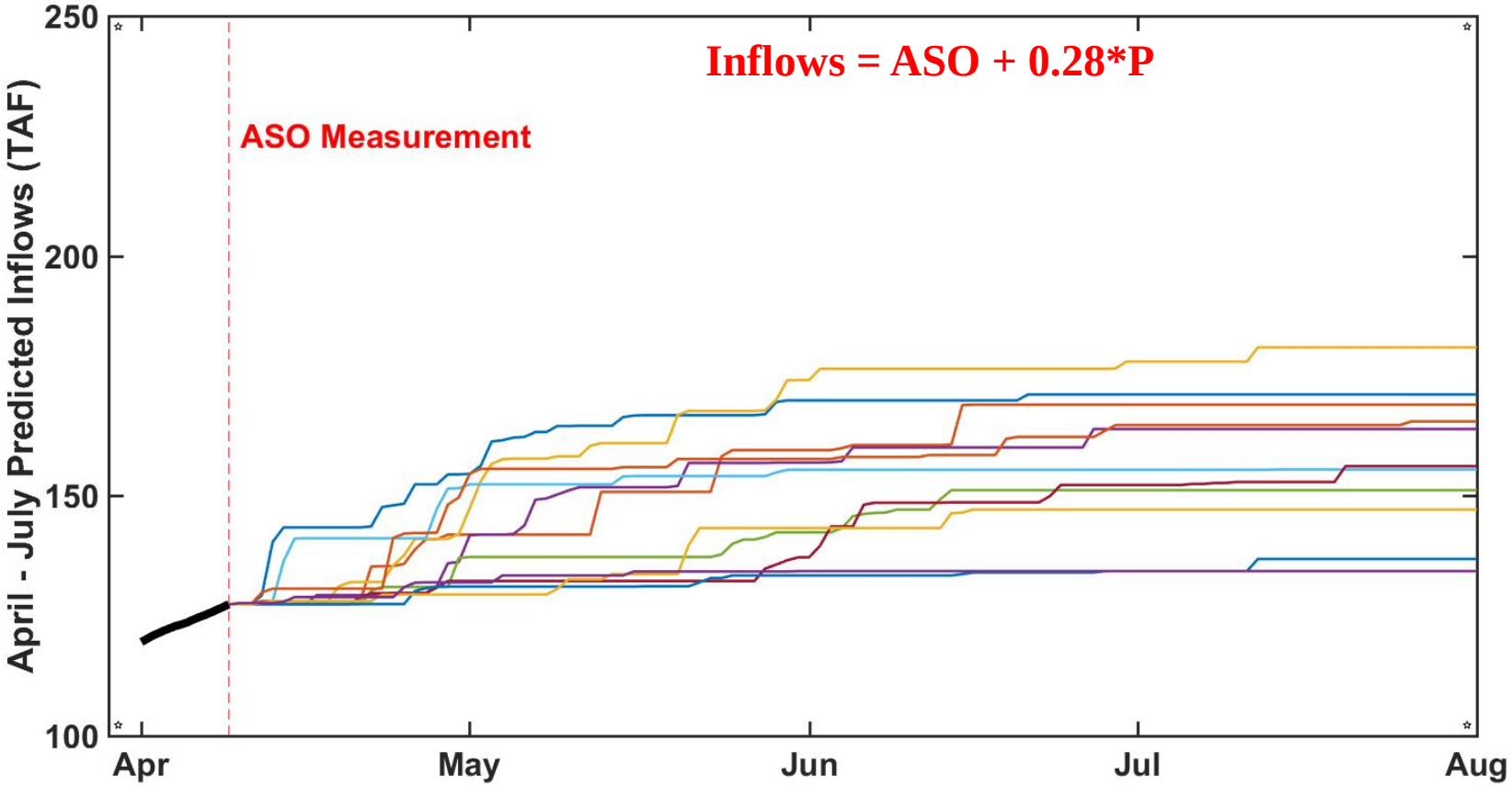
Conclusions

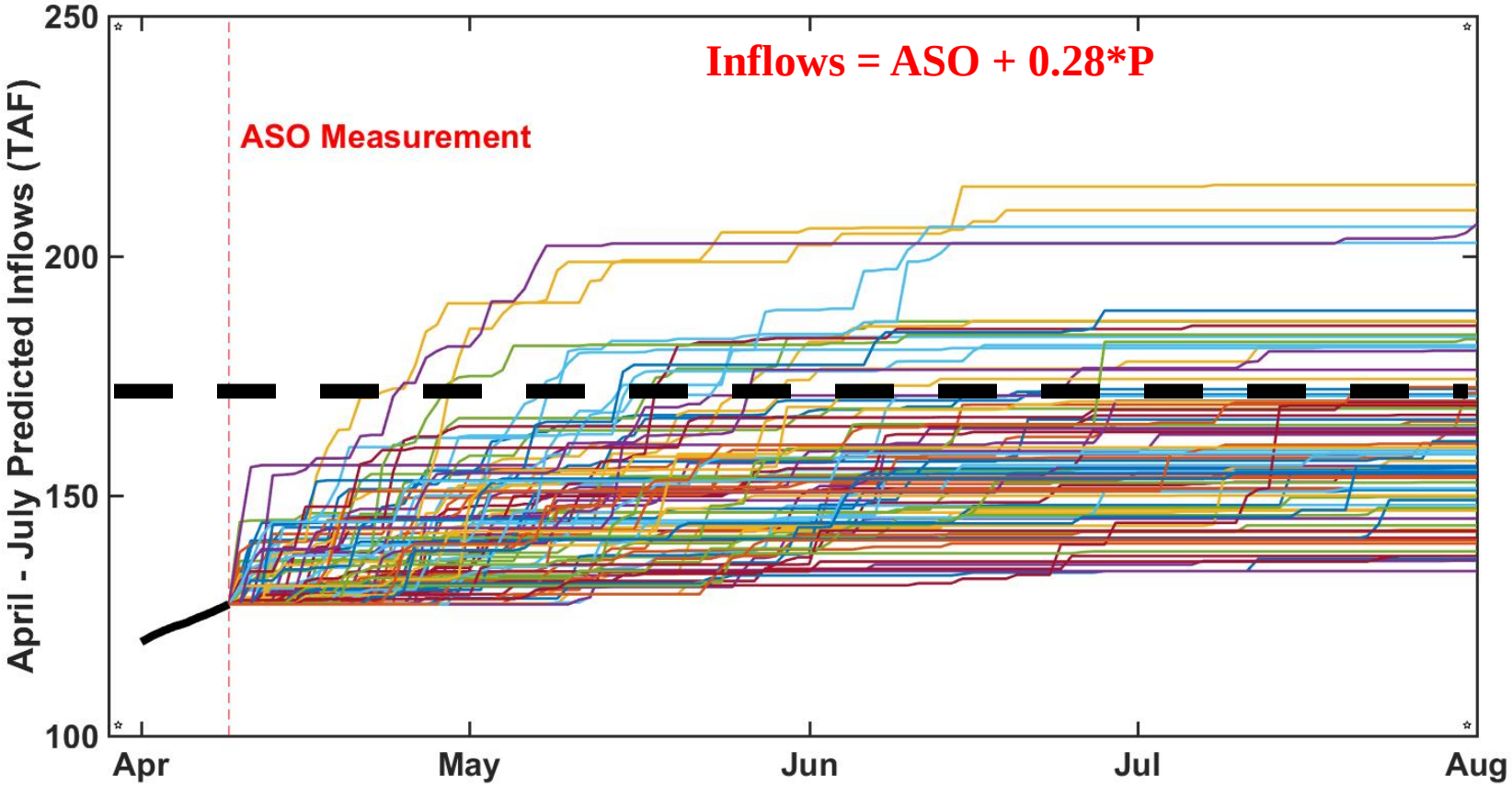
- ASO reveals snow accumulation and melt patterns that are different than suggested by snow pillows
- ASO is well correlated with seasonal reservoir inflows (streamflow)
  - Especially when combined with future precipitation

Questions?

How can we use ASO measurements to improve forecasting?


Inflows = ASO + 0.28*P
ASO Measurement
April - July Predicted Inflows (TAF)
250
200
150
100
Apr
May
Jun
Jul
Aug


Inflows = ASO + 0.28*P
ASO Measurement
April - July Predicted Inflows (TAF)
250
200
150
100
Apr
May
Jun
Jul
Aug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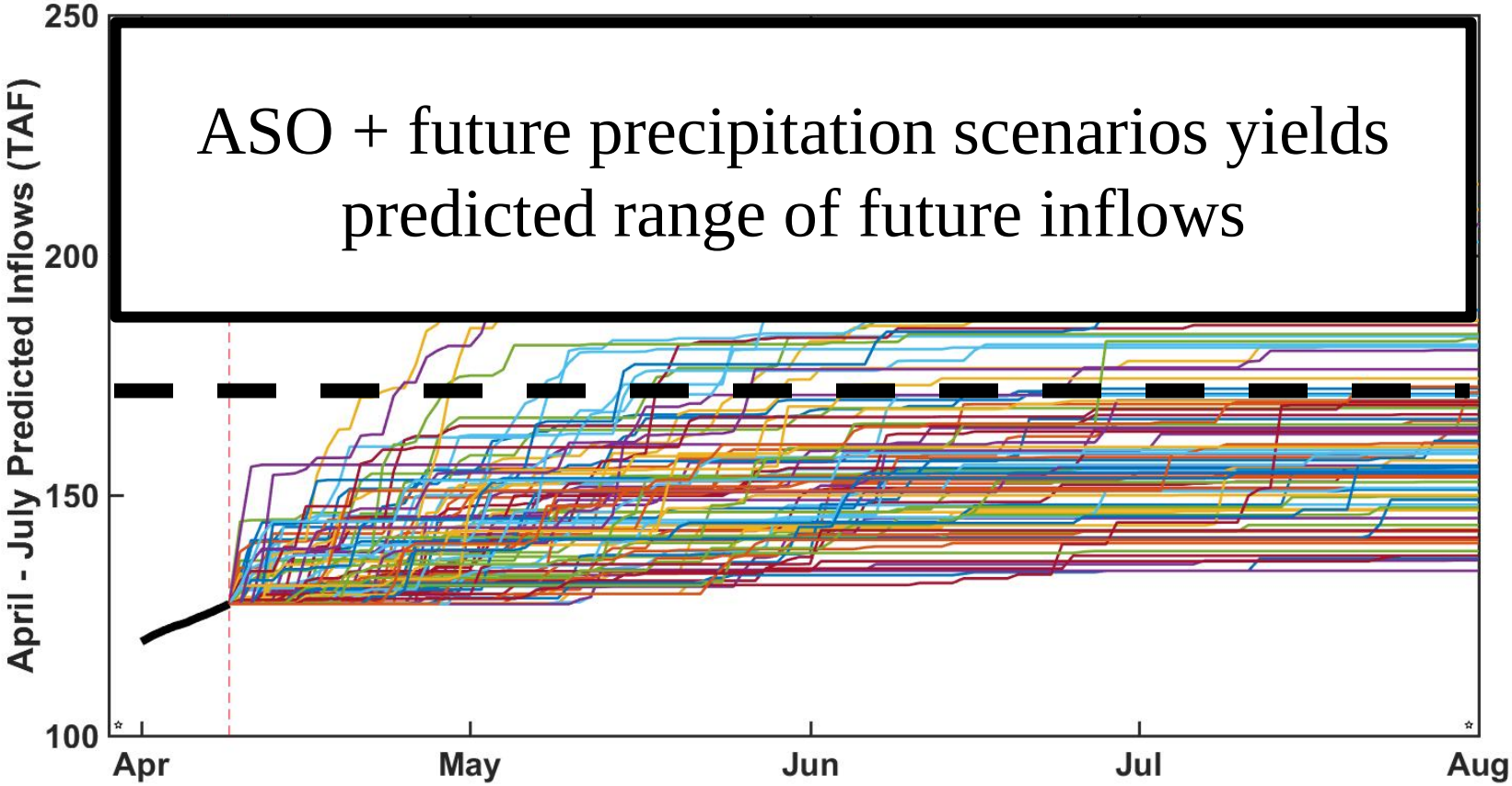
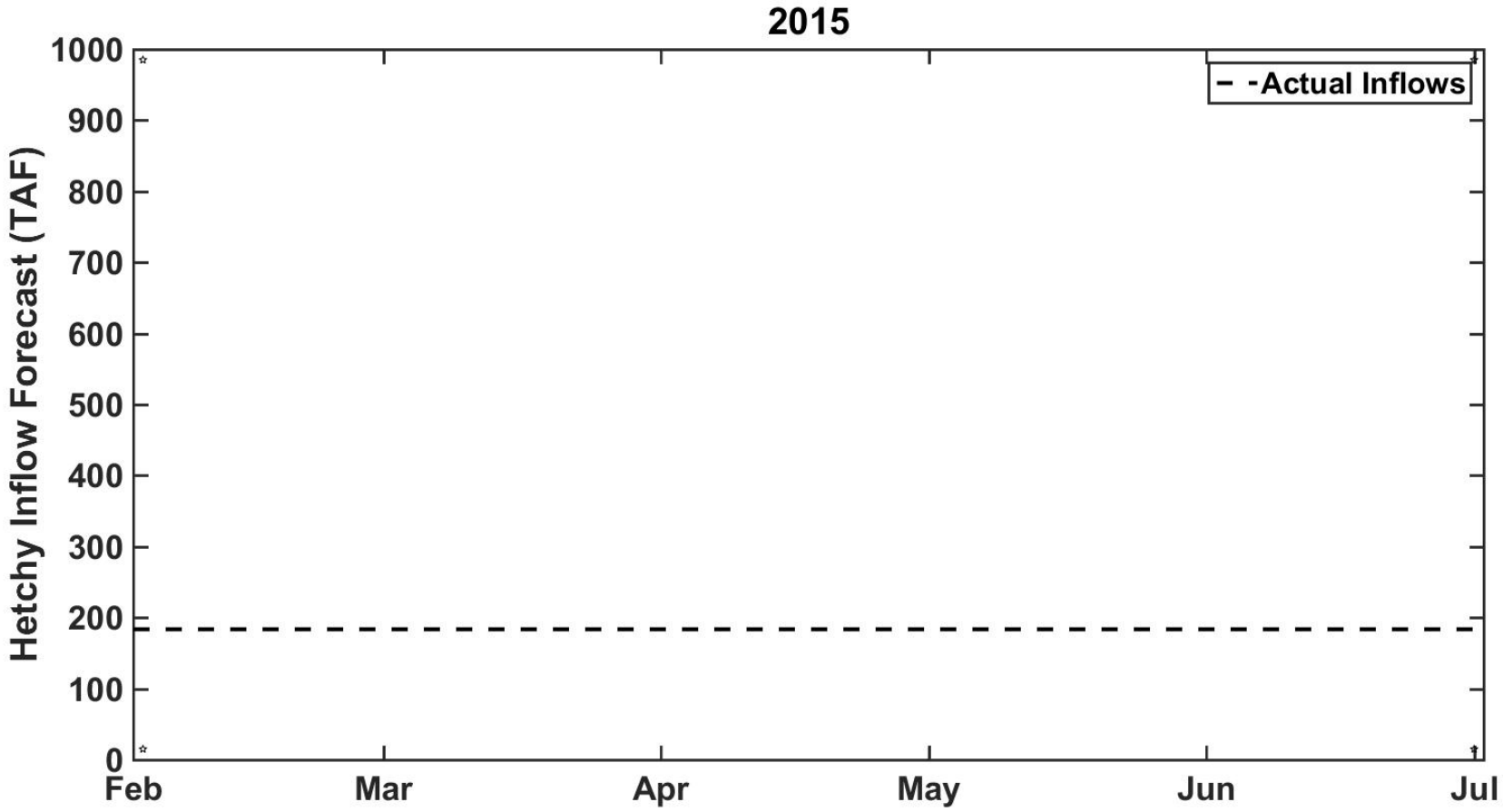
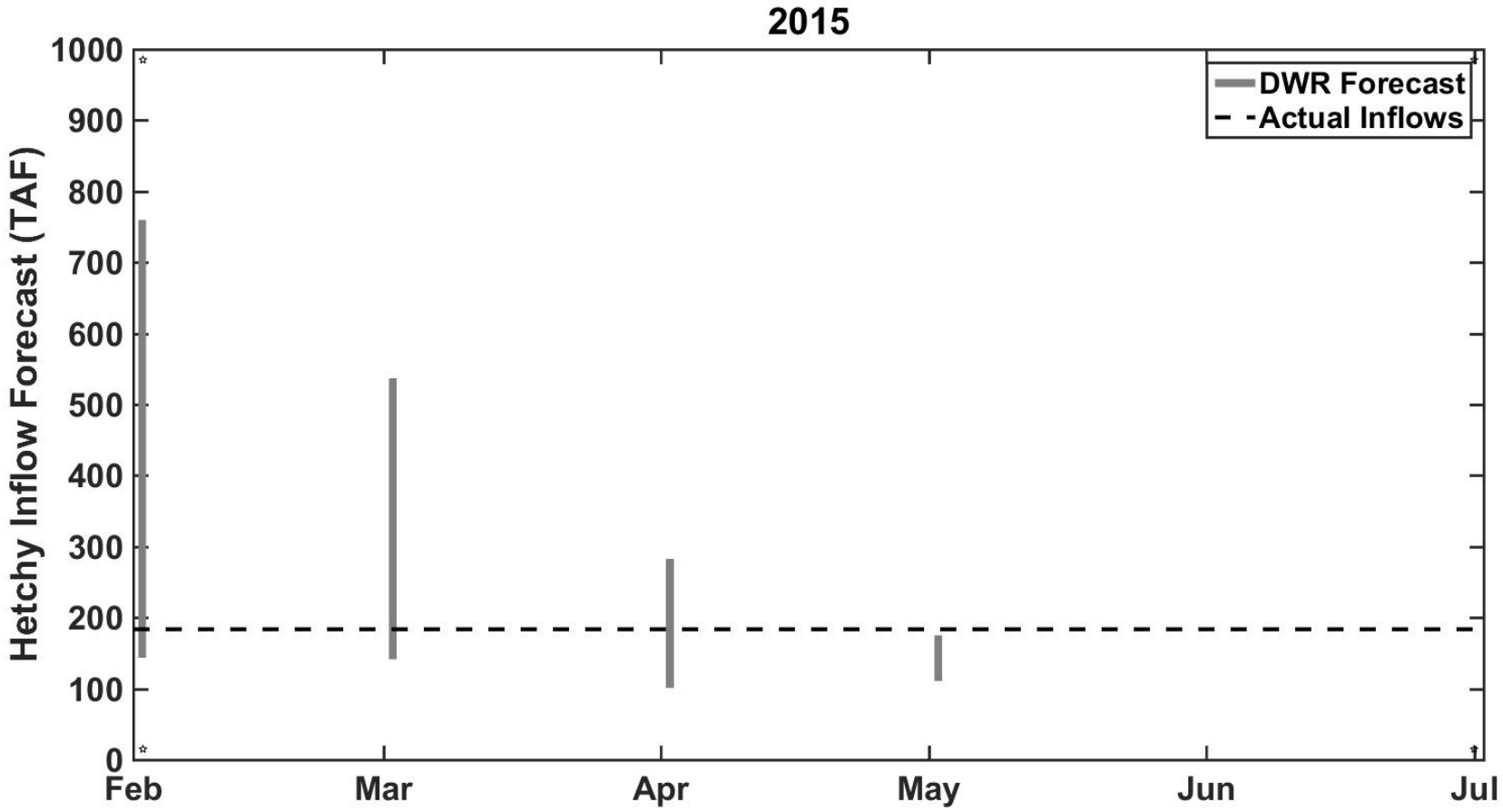
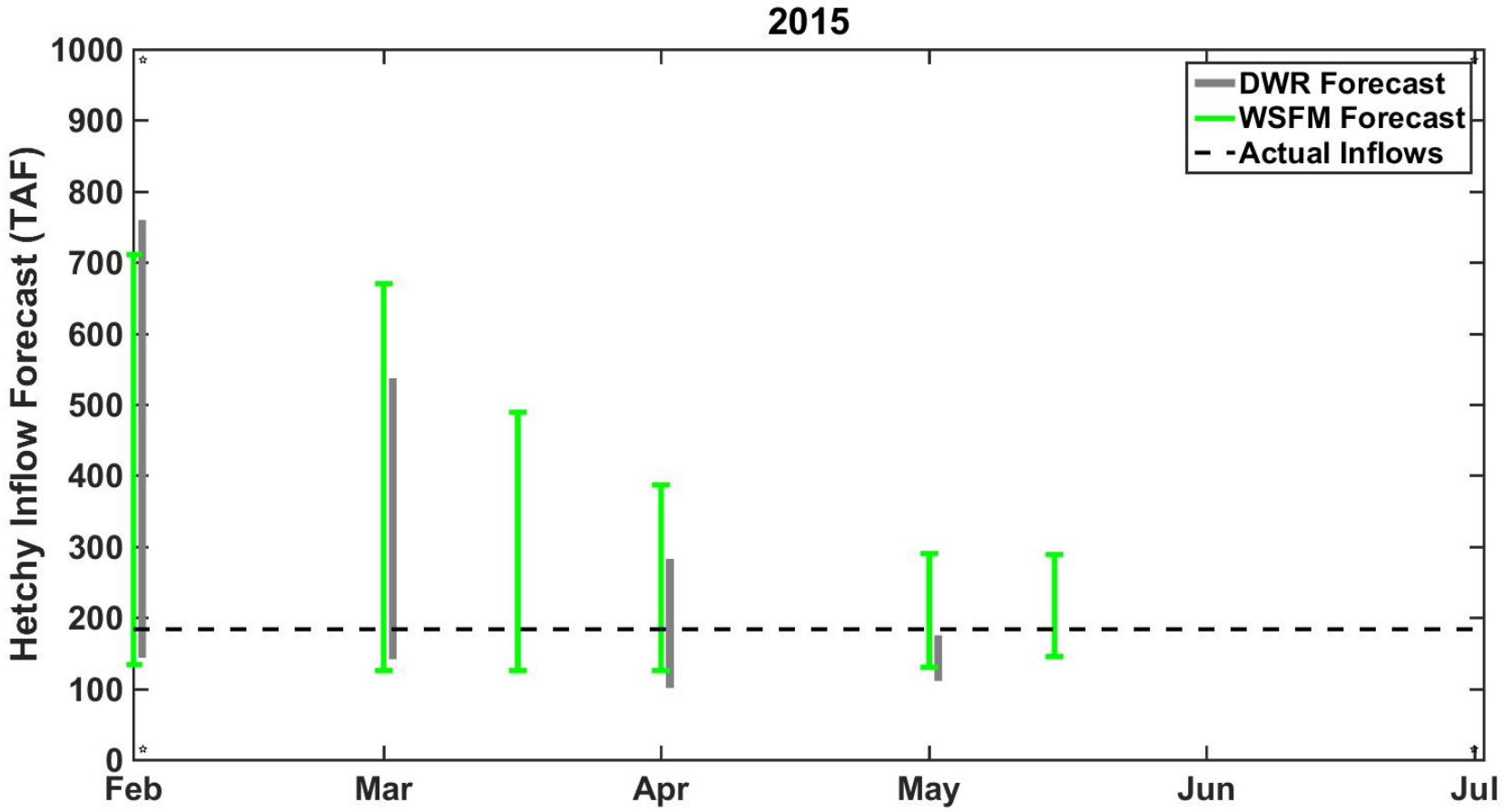

ASO + future precipitation scenarios yields predicted range of future inflows
April - July Predicted Inflows (TAF)
250
200
150
100
Apr
May
Jun
Jul
Aug

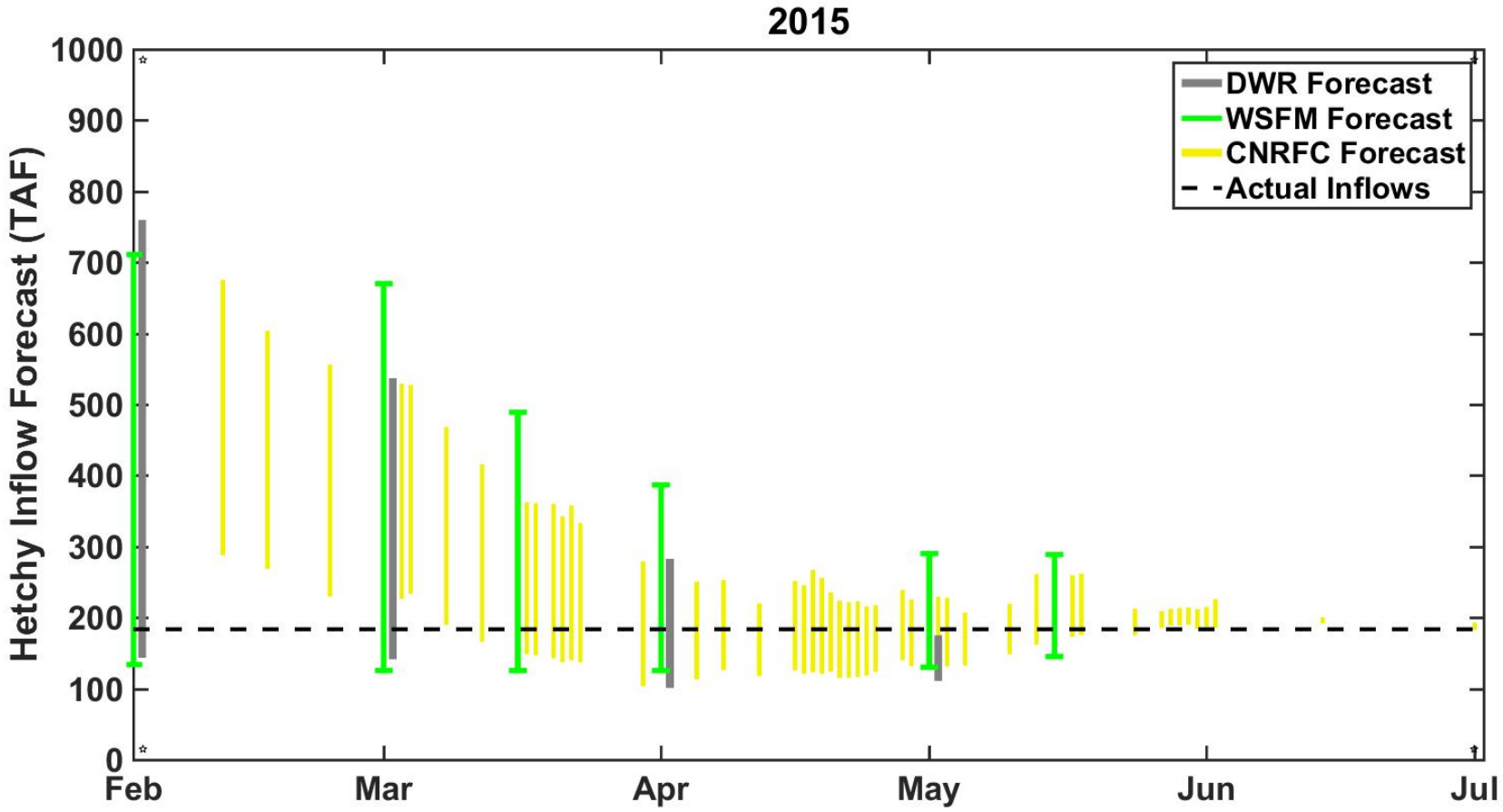
Current Forecasting Tools

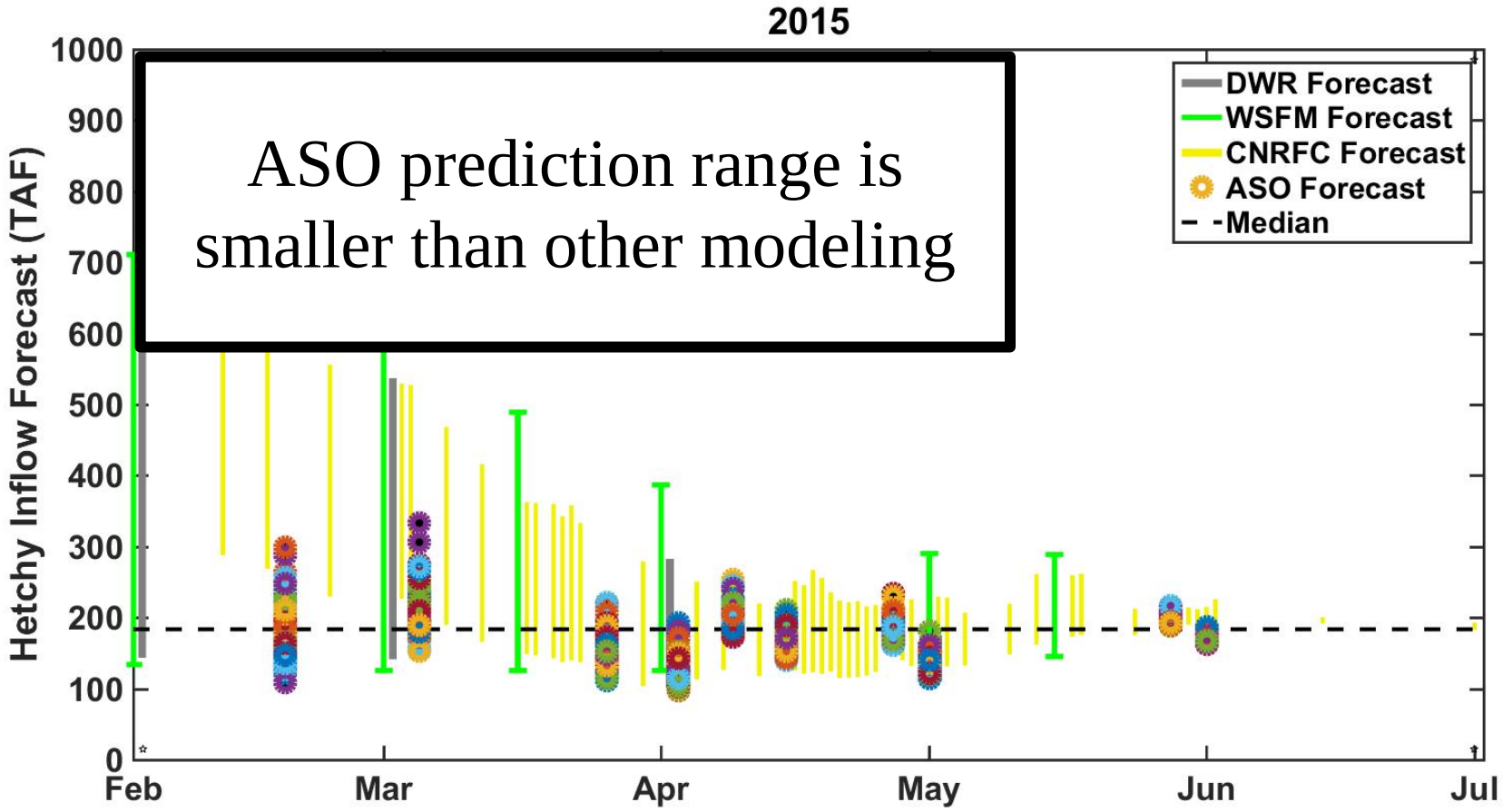
- California – Nevada River Forecasting Center
  - Deterministic Model (Snow Hydro 17 Sacramento Soil Moisture)
- Department of Water Resources
  - Seasonal Statistical Model
- Water Supply Forecasting Model
  - SFPUC Monthly Statistical Model
- Airborne Snow Observatory
  - Relationship between ASO measurement and future precipitation and future inflows.


2015
Hetchy Inflow Forecast (TAF)
1000
900
800
700
600
500
400
300
200
100
0
Feb
Mar
Apr
May
Jun
Jul
Actual Inflows


2015
Hetchy Inflow Forecast (TAF)
1000
900
800
700
600
500
400
300
200
100
0
Feb
Mar
Apr
May
Jun
Jul
DWR Forecast
Actual Inflows


2015
Hetchy Inflow Forecast (TAF)
1000
900
800
700
600
500
400
300
200
100
0
Feb
Mar
Apr
May
Jun
Jul
DWR Forecast
WSFM Forecast
Actual Inflows


2015
Hetchy Inflow Forecast (TAF)
1000
900
800
700
600
500
400
300
200
100
0
Feb
Mar
Apr
May
Jun
Jul
DWR Forecast
WSFM Forecast
CNRFC Forecast
Actual Inflows



ASO prediction range is smaller than other modeling

Conclusions

- ASO reveals snow accumulation and melt patterns that are different than suggested by snow pillows
- ASO well correlated with seasonal reservoir inflows (streamflow)
  - Especially when combined with future precipitation
- ASO can provide more precise forecasts of seasonal inflows.

Questions?