



— BUREAU OF —
RECLAMATION

Enhancing Western United States Sub-Seasonal Forecasts: Forecast Rodeo Prize Competition Series

Kenneth Nowak

December 1, 2020

Overview

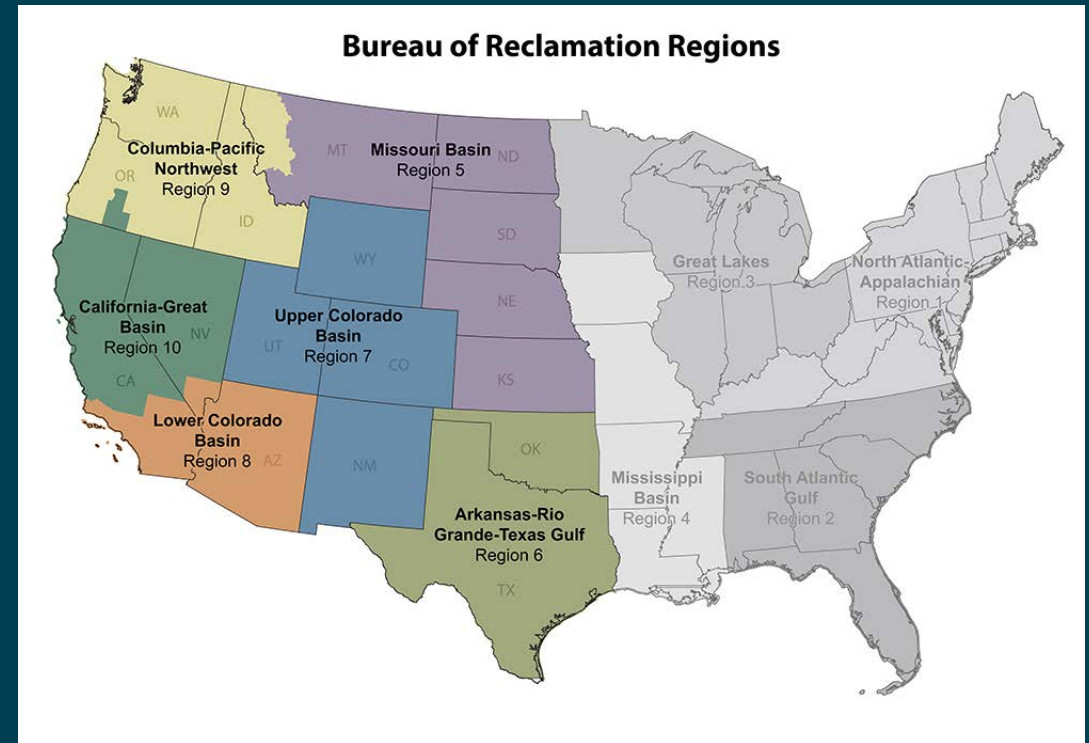
- **Bureau of Reclamation**
- **Sub-Seasonal Forecast Rodeo I**
- **Sub-Seasonal Forecast Rodeo II**
- **Looking Forward**



Bureau of Reclamation

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

- Manage water in 17 western states
- Operate 337 reservoirs
- Largest wholesaler of water in the country; provides 1 out of 5 Western farmers with irrigation water for 10 million farmland acres
- Second largest hydropower producer; 53 hydroelectric powerplants providing 14,000+ MW capacity; generate enough electricity to power 3.5M U.S. homes



Reclamation R&D

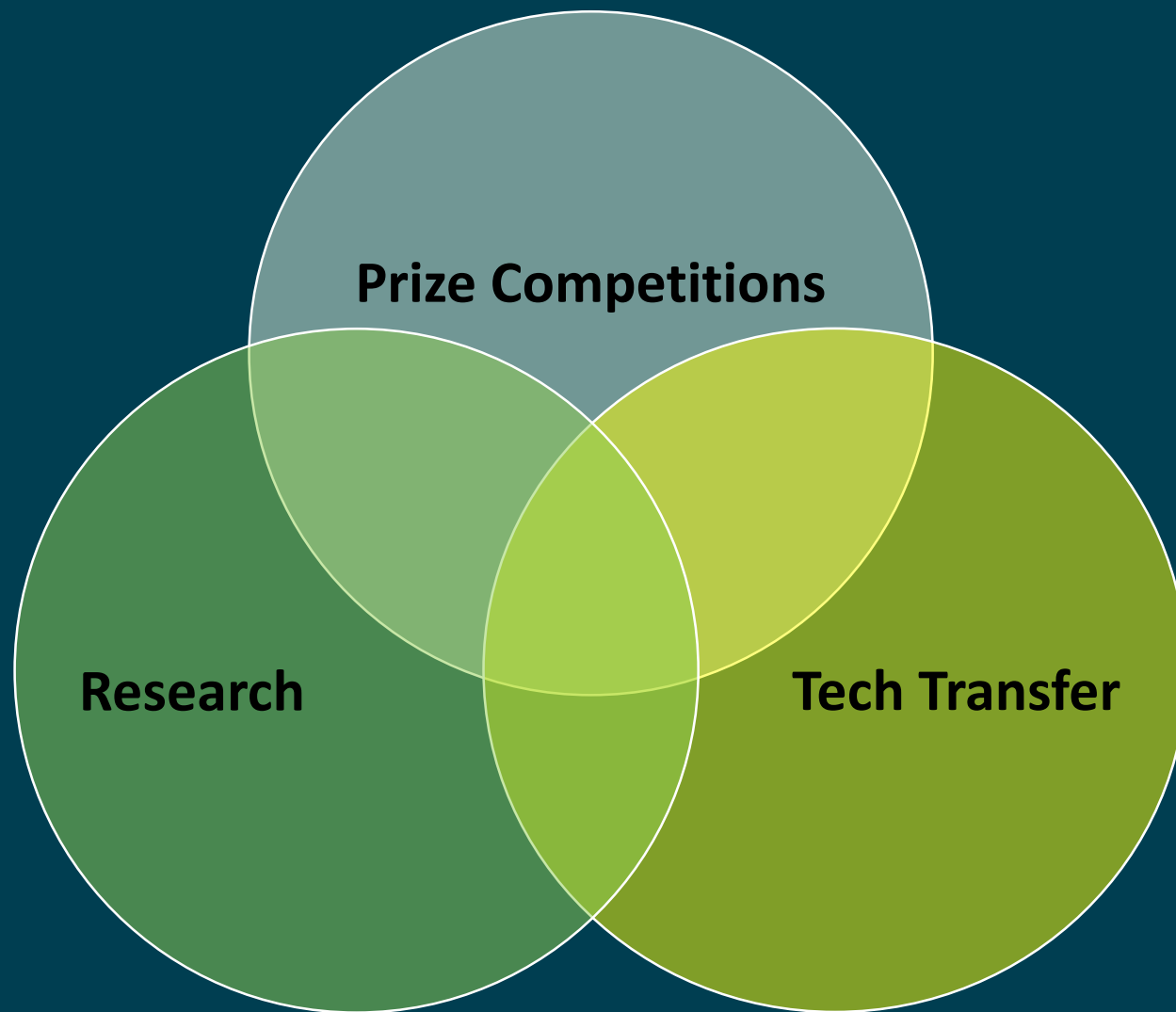
- Address Technical Challenges in:
 - Water infrastructure
 - Power and energy
 - Environmental issues for water management
 - Water operations and planning
 - Developing water supplies
- Customers
 - Reclamation facility and resource managers, customers, stakeholders, private sector, public



www.usbr.gov/research

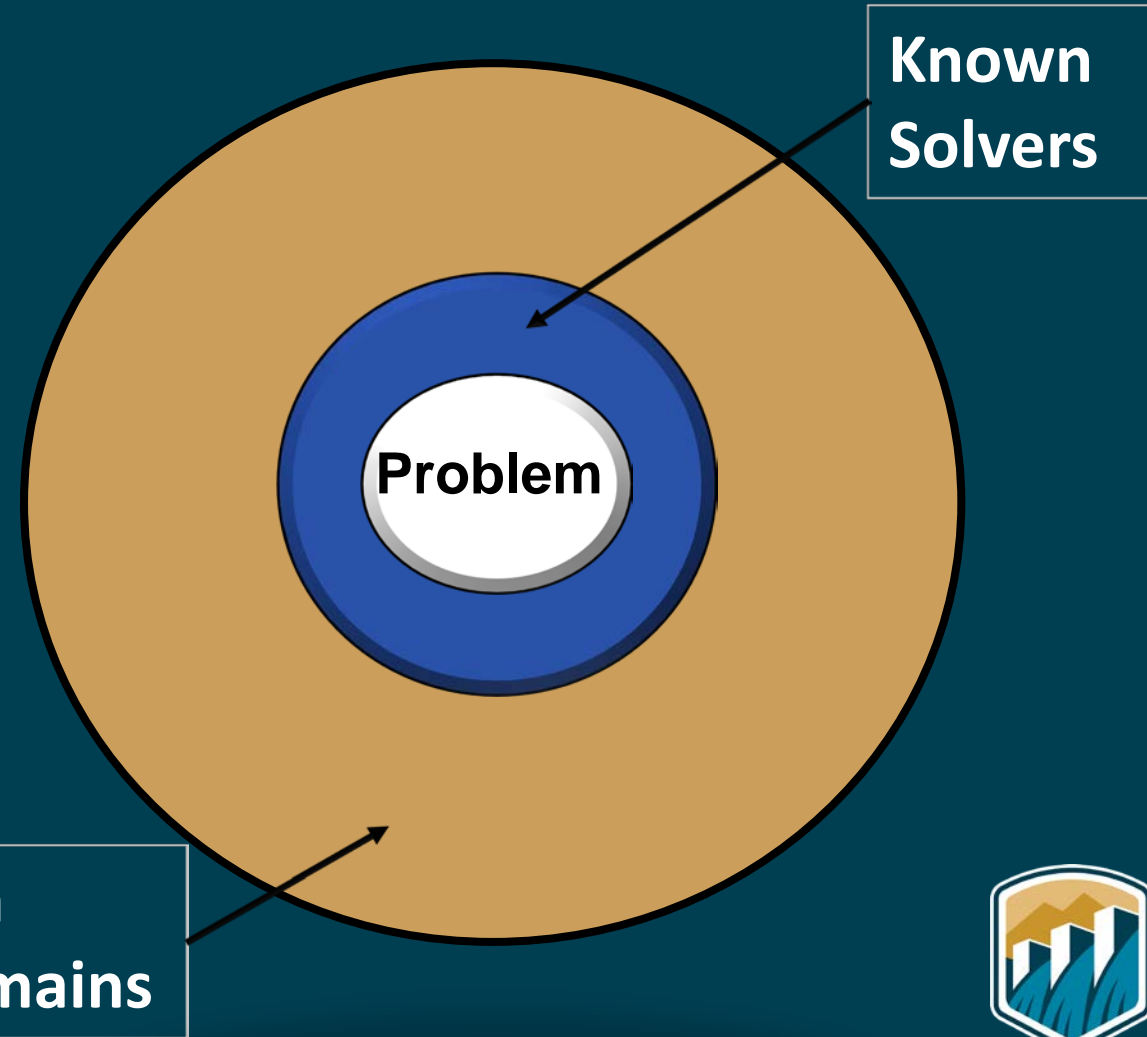


R&D Tools



Prize Competition Program

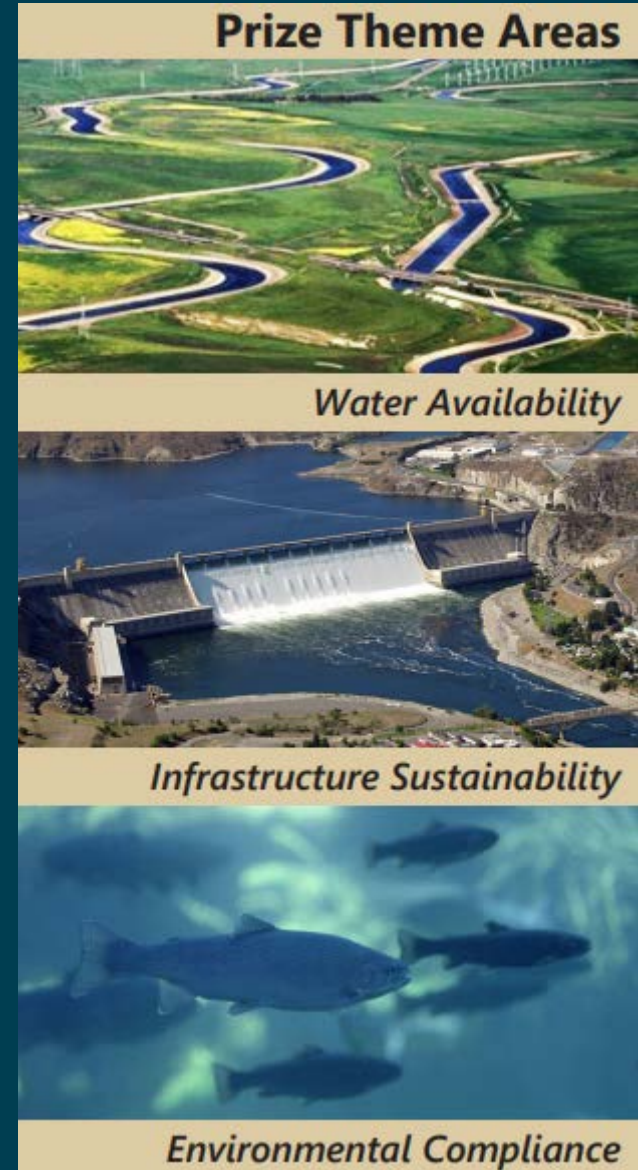
- A tool for addressing tough issues and advancing research through crowdsourcing
- Since 2014, Reclamation has:
 - Launched 27 competitions
 - Awarded nearly \$1.5 million for winning solutions
- Collaboration is vital



Prize Competition Program

- Pay for Results
- New Starting Point for Research
- Tackle Long-Standing Issues
- Accelerate Research
- Prototype Development
- Promote Growth
- New Partnerships
- New or Novel Ideas

Jennifer Beardsley
Prize Competition Coordinator
jbeardsley@usbr.gov



Forecast Rodeo I

A year long, real-time sub-seasonal forecasting competition

WATER
PRIZE COMPETITION CENTER

\$800,000 in prize \$\$\$!

March 2, 2016 Forecast (in) 0.1 10 25 50 1 2 3 4 5 7.5 10 15

Saddle up for the Sub-Seasonal Climate Forecast Rodeo!

usbr.gov/research/challenges

Competition Sponsor: **RECLAMATION** Managing Water in the West

Competition Partners: NOAA, US Army Corps of Engineers, USGS

- Genesis: Drought
 - Definition
 - Agricultural
 - Meteorological
 - Hydrological
 - Others
 - Common Ground
 - Temperature
 - Precipitation
- Objectives
 - Advance Science
 - Raise Awareness
 - Provide Evaluation Platform



Forecast Rodeo I

- Forecasts

- Resolution: a $1^{\circ} \times 1^{\circ}$ grid
- Variables: Temperature and Precipitation
- Outlooks: Weeks 3&4 and 5&6
- Frequency: 2 Weeks
- Duration: 13 Months
- Domain: 17 Western States

- Benchmarks

- CFSv2 (32-member ensemble)
- Damped persistence

- Metric

- Spatial anomaly correlation

- Schedule

- Announced: Dec 12, 2016
- Pre-Season: Mar 21, 2017
- Regular Season: Apr 18, 2017
- Final Submission: May 3, 2018
- Winners Announced: March 7, 2019



Forecast Rodeo I Final Standings

Weeks 3&4 Temperature

Team	Newest Score	Average Score ▼
bgzimmerman	-0.0994	0.2855
prxwx	-0.1821	0.2265
StillLearning	0.029	0.217
DampedPersistence	-0.0794	0.1952
CFSv2	-0.3997	0.1589
asanteko2000	-0.1117	0.0909
lupoa13	-0.2187	0.0895
Salient	0.05	-0.1365

Weeks 5&6 Temperature

Team	Newest Score	Average Score ▼
bgzimmerman	-0.4472	0.2357
CFSv2	0.5267	0.2192
StillLearning	0.1436	0.2044
prxwx	0.3105	0.2026
lupoa13	-0.5854	0.1675
asanteko2000	-0.1046	0.0897
DampedPersistence	0.1084	-0.0762
Salient	-0.8229	-0.09

Weeks 3&4 Precipitation

Team	Newest Score	Average Score ▼
Salient	0.7758	0.2144
prxwx	0.0921	0.1711
lupoa13	-0.1367	0.1246
CFSv2	0.1837	0.0713
StillLearning	0.7987	0.0227
bgzimmerman	0.1087	-0.0221
asanteko2000	-0.7981	-0.0612
DampedPersistence	-0.7996	-0.1463

Weeks 5&6 Precipitation

Team	Newest Score	Average Score ▼
Salient	0.5897	0.2162
prxwx	0.0995	0.1208
StillLearning	0.5816	0.0941
lupoa13	0.0916	0.0931
bgzimmerman	0.303	0.0773
CFSv2	0.0692	0.0227
asanteko2000	-0.5561	-0.0879
DampedPersistence	-0.4375	-0.1613

Image from National Integrated Drought Information System (NIDIS) Leaderboard



Forecast Rodeo I Winning Solutions

Category	1 st Place (\$100,000)	2 nd Pace (\$50,000)	3 rd Place (\$25,000)	Hind-Cast (\$25,000)
Weeks 3&4 Temperature	StillLearning	-	-	StillLearning
Weeks 5&6 Temperature	-	-	-	StillLearning
Weeks 3&4 Precipitation	Salient	Lupoa13	-	Salient
Weeks 5&6 Precipitation	Salient	StillLearning	Lupoa13	Salient



Forecast Rodeo I Winning Solutions

- StillLearning
 - Backwards stepwise local linear regression with feature selection shared across grid points
 - Analog technique for periods exhibiting strong similarity to historical conditions
- Salient
 - Artificial neural network model trained on sea surface temperature data
- Lupo13
 - Analog periods from the historical record identified based on global pressure anomalies



Members of winning Rodeo I teams are honored at the symposium with NOAA and Reclamation leadership. L-R: Gary Matlock, NOAA Deputy Assistant Administrator for Science; Lester Mackey; Ernest Frankel; Judah Cohen; Ray Schmitt; Joseph Renken; and David Palumbo, Reclamation Deputy Commissioner.



Still Learning

- Primary Approach
 - Backward stepwise local linear regression using a diverse pool of predictor datasets (meteorological observations, NMME models, and climate indices)
- Secondary Method
 - Analog forecast technique when similarity criteria were satisfied

Improving Subseasonal Forecasting in the Western U.S. with Machine Learning

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²Atmospheric and Environmental Research

³Microsoft Research New England

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Abstract

Water managers in the western United States (U.S.) rely on longterm forecasts of temperature and precipitation to prepare for droughts and other wet weather extremes. To improve the accuracy of these longterm forecasts, the Bureau of Reclamation and the National Oceanic and Atmospheric Administration (NOAA) launched the Subseasonal Climate Forecast Rodeo, a year-long real-time forecasting challenge, in which participants aimed to skillfully predict temperature and precipitation in the western U.S. two to four weeks and four to six weeks in advance. Here we present and evaluate our machine learning approach to the Rodeo and release our `SubseasonalRodeo` dataset, collected to train and evaluate our forecasting system.

Our system is an ensemble of two regression models. The first integrates the diverse collection of meteorological measurements and dynamic model forecasts in the `SubseasonalRodeo` dataset and prunes irrelevant predictors using a customized multitask model selection procedure. The second uses only historical measurements of the target variable (temperature or precipitation) and introduces multitask nearest neighbor features into a weighted local linear regression. Each model alone is significantly more accurate than the operational U.S. Climate Forecasting System (CFSv2), and our ensemble skill exceeds that of the top Rodeo competitor for each target variable and forecast horizon. We hope that both our dataset and our methods will serve as valuable benchmarking tools for the subseasonal forecasting problem.

The current availability of ample meteorological records and high-performance computing offers the opportunity to blend physics-based and statistical machine learning (ML) approaches to extend the skillful forecast horizon.

This data and computing opportunity, coupled with the critical operational need, motivated the U.S. Bureau of Reclamation and the National Oceanic and Atmospheric Administration (NOAA) to conduct the Subseasonal Climate Forecast Rodeo (Nowak et al. 2017), a year-long real-time forecasting challenge, in which participants aimed to skillfully predict temperature and precipitation in the western U.S. two to four weeks and four to six weeks in advance. To meet this challenge, we developed an ML-based forecasting system and a `SubseasonalRodeo` dataset (Hwang et al. 2018) suitable for training and benchmarking subseasonal forecasts.

ML approaches have been successfully applied to both short-term (< 2 week) weather forecasting (Karstens et al. 2018; Ghosh and Krishnamurti 2018; Herman and Schumacher 2018) and longer-term climate prediction (Strobach and Bel 2016; Badr, Zaitchik, and Guikema 2014; Totz et al. 2017), but mid-term subseasonal outlooks, which depend on both local weather and global climate variables, still lack skillful forecasts (Robertson et al. 2015).

Our subseasonal ML system is an ensemble of two regression models: a local linear regression model with multitask model selection (`MultiLLR`) and a weighted local

809.07394v1 [stat.AP] 19 Sep 2018

<https://arxiv.org/pdf/1809.07394.pdf>



Salient

- NOAA Optimal Interpolation (OI) Sea Surface Temperature (SST) Dataset
 - Global, weekly, 4 degree
- Develop ensemble of 50 neural networks
- Forecast based on top 10, per validation performance
- Each network randomized on:
 - Inclusion of date as input
 - Network depth
 - Units per layer
 - Training epochs
 - Activation function



Forecast Rodeo I - Other Solvers

Rather than seek prize purses in exchange for their forecast methods, these teams elected to withdraw from the competition and formed a partnership to commercialize their techniques.

PRXWX

bgzimmerman

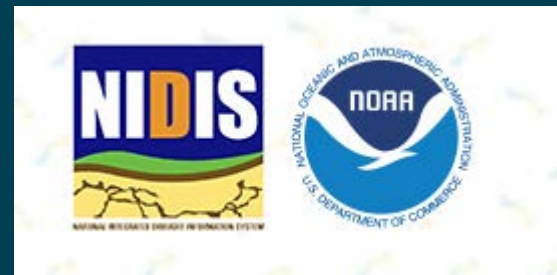
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Salient	0.05	-0.1365	Salient	-0.8229	-0.09

Weeks 3&4 Precipitation			Weeks 5&6 Precipitation		
Team	Newest Score	Average Score	Team	Newest Score	Average Score
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DampedPersistence	-0.7996	-0.1463	DampedPersistence	-0.4375	-0.1613



Forecast Rodeo II

- Same forecasts as Rodeo I
 - RMSE metric
- Prizes
 - Individual Forecast
 - Quarterly
 - Overall
- Benchmarks
 - CFSv2
 - Rodeo I winner Salient
 - NIDIS Leaderboard
- Schedule
 - First forecast: October 15, 2019
 - Concluded: November 17, 2020



Forecast Rodeo II

- 26 'Sprints' – each opens 2 weeks before forecast is due
- Teams can participate in as many/few sprints as desired
- Eligibility for quarterly and overall prizes
- Prizes – Per Category

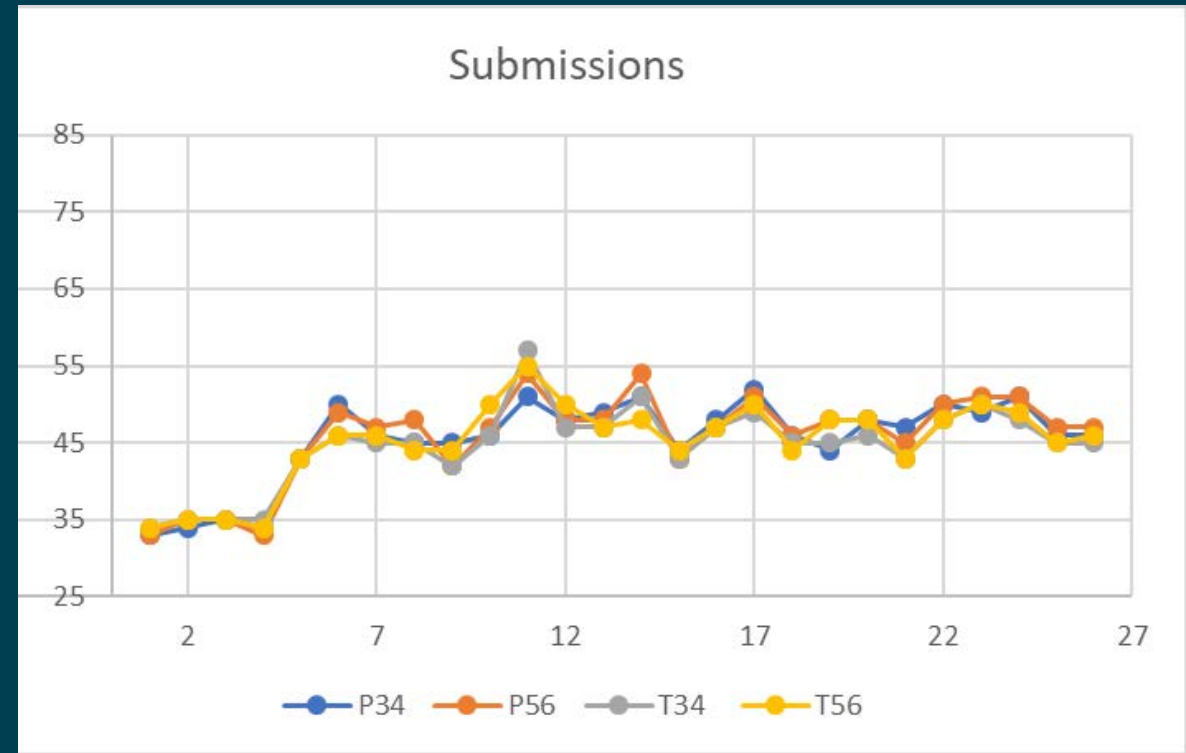
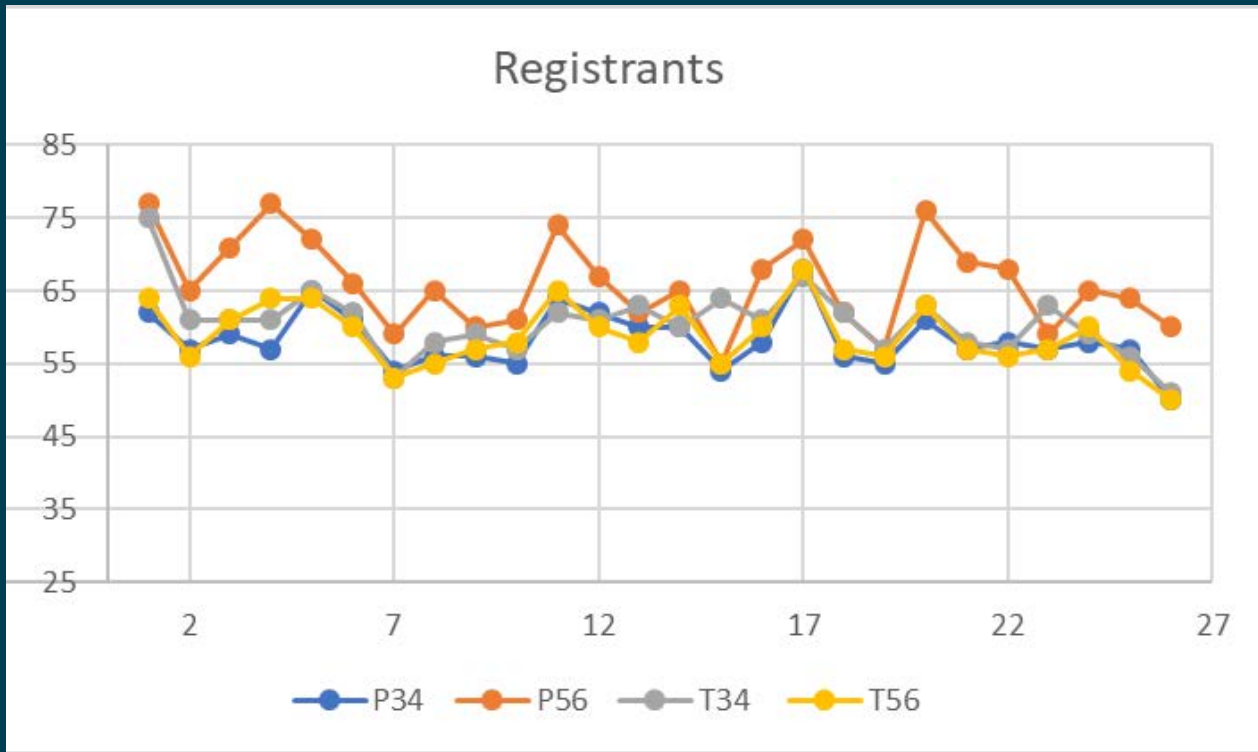
Sprints	
1st	\$500
2nd	\$350
3rd	\$250
4th	\$175
5th	\$100

Quarterly		Quarterly	
1st	\$6,000	6th	\$250
2nd	\$4,500	7th	\$250
3rd	\$3,000	8th	\$250
4th	\$2,000	9th	\$250
5th	\$1,000	10th	\$250

Overall		Overall	
1st	\$25,000	6th	\$2,500
2nd	\$17,500	7th	\$2,000
3rd	\$10,000	8th	\$1,500
4th	\$7,500	9th	\$1,250
5th	\$5,000	10th	\$1,000



Forecast Rodeo II Status – Participation



Forecast Rodeo II Final Standings

Temperature Weeks 3 and 4

<u>Position</u>	<u>Competitor</u>	<u>Average RMSE</u>
1st	n01z3	2.06363278
2nd	pfr	2.07484089
3rd	yypark	2.10454645
4th	gardn999	2.11879746
5th	J.Bogusz	2.12700364
24th	CFSv2	2.4898416

Precipitation Weeks 3 and 4

<u>Position</u>	<u>Competitor</u>	<u>Average RMSE</u>
1st	thothling	19.84037169
2nd	Rodeo I Winner	19.94010576
3rd	yypark	20.04744612
4th	m.rednaia	20.11177924
5th	n01z3	20.24233937
26th	CFsV2	22.42928926

• RMSE Scores

- Computed over 500+ points
- Average of 26 forecast 'scores'

Temperature Weeks 5 and 6

<u>Position</u>	<u>Competitor</u>	<u>Average RMSE</u>
1st	n01z3	1.96857967
2nd	pfr	1.99929408
3rd	gardn999	2.00219979
4th	yypark	2.01712998
5th	mouatadid	2.0261852
18th	CFSv2	2.15063171

Precipitation Weeks 5 and 6

<u>Position</u>	<u>Competitor</u>	<u>Average RMSE</u>
1st	m.rednaia	19.46179068
2nd	yypark	19.59005828
3rd	thothling	19.60888768
4th	Rodeo I winner	19.80460026
5th	tourist	20.0058885
23rd	CFSv2	21.30010766



Select Rodeo II Top Performers

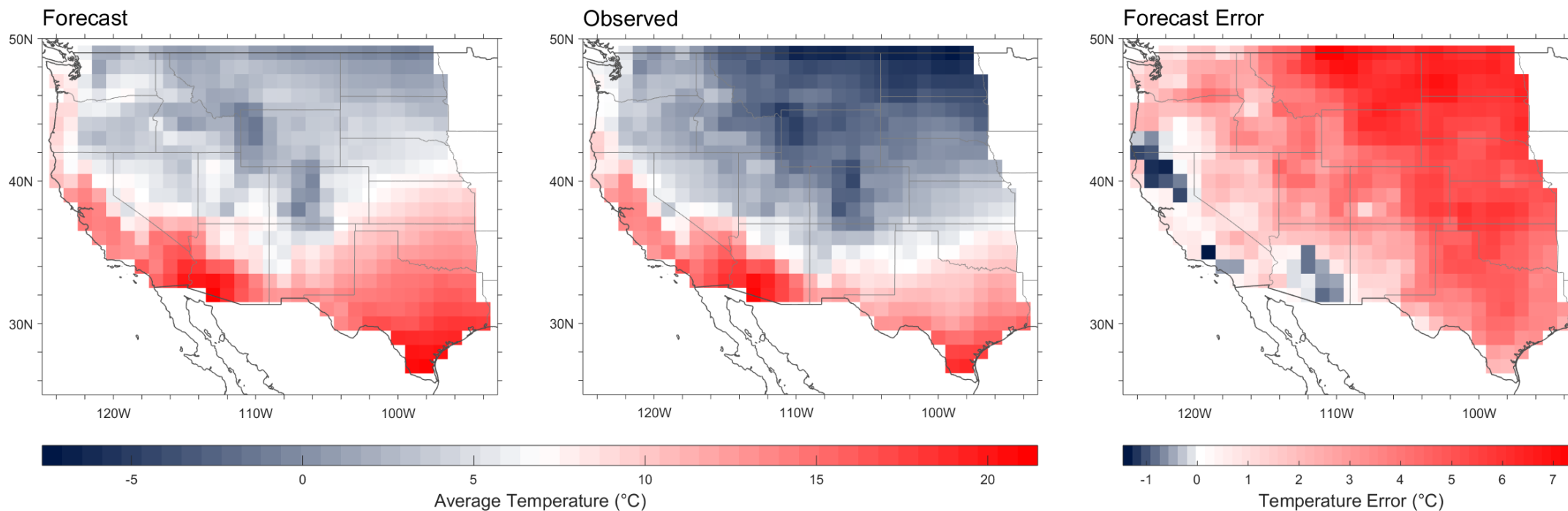
- Facebook additive regression model – ‘Prophet’
- Enhanced climatology (3)
- CFSv2 post-process
- Random forest machine learning algorithm



Rodeo II NIDIS Leaderboard

Team: **pfr**, Period: #1, Task: temp34

Week 3-4 Forecast Submitted 2019-10-15 (Prediction Range: Oct 29 - Nov 11)



<https://www.drought.gov/drought/forecast-rodeo-ii-leaderboard>



Forecast Rodeo II Leaderboard Scores

- Sprint 12, issued 3-17-20

TEMPERATURE 3-4 WEEKS

Rank	Team	Score
1	std	85.704814953245
2	chudan	85.503314577611
3	salmiaki	83.894364612922
4	jonas.neustock	82.351139085674
5	tcghanareddy	81.87127924982

PRECIPITATION 3-4 WEEKS

Rank	Team	Score
1	CFSv2	37.295798639707
2	tourist	36.86450855278
3	d_a_konovalov	36.851896471176
4	TheRealRoman	36.375893354869
5	salmiaki	36.241941986143



Looking Forward

- **Maturing Solutions – Partnership with SIO/CW3E**
 - **Meta analysis**
 - Data and methods
 - Performance regionally and seasonally
 - **Implementation and further evaluation of most promising methods**
 - **Enhancements/ensemble opportunities**



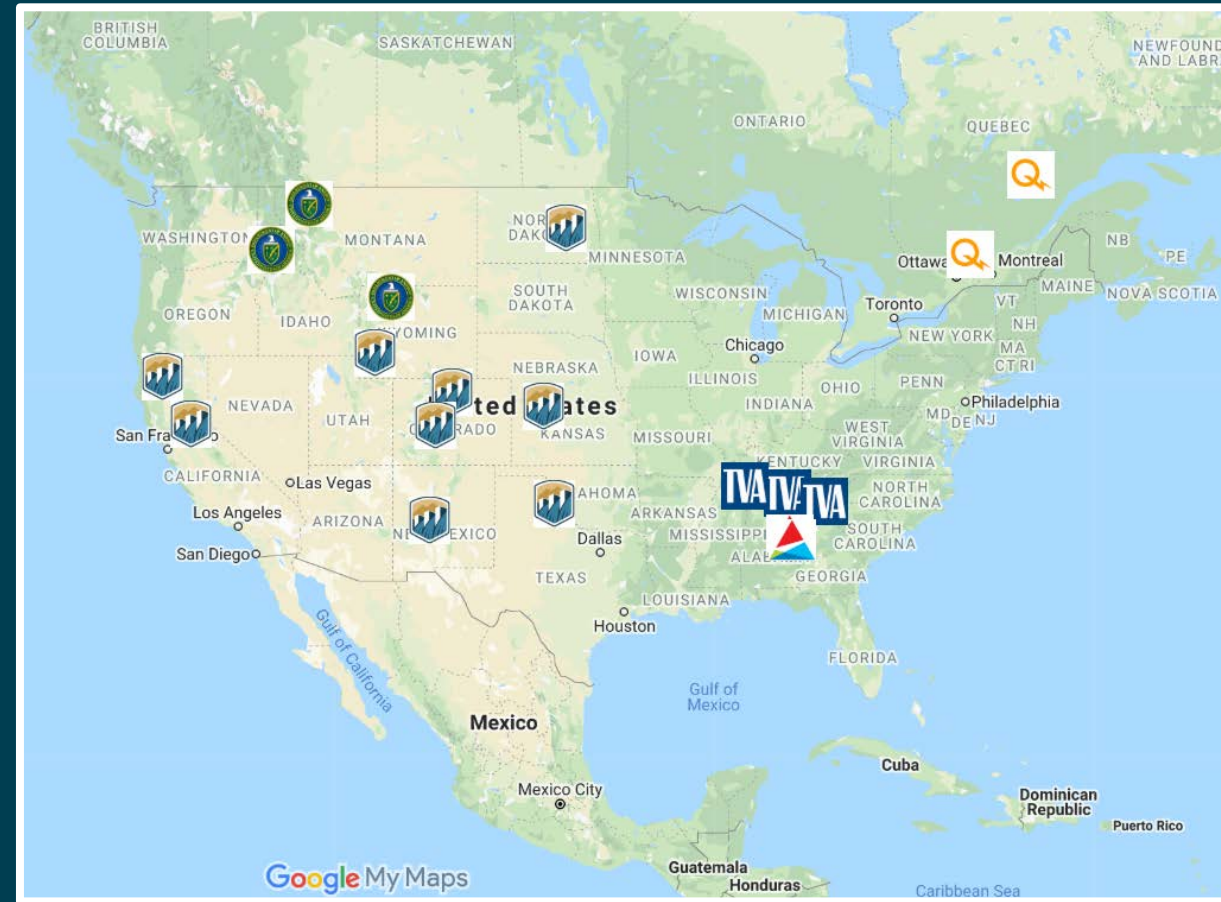
Reflections

- Data
 - Availability
 - Standardization
 - Documentation
- Requirements
 - Need well formulated problem
 - Deliverables specification
- Game plan for what's next



Streamflow Forecast Rodeo – WY 2021

- Hybrid
 - Technology Evaluation - CEATI
 - 19 sites across North America
 - TVA, DOE, Hydro Quebec, Southern Company, Reclamation
 - RFC, NWM, in-house, and Upstream Tech Forecasts
 - RTI as referee
 - Prize Competition
 - Open to general public
 - 9 Reclamation + 1 Reclamation/DOE sites
 - Hosed by Topcoder
 - Participants to be evaluated along tech evaluation forecasts

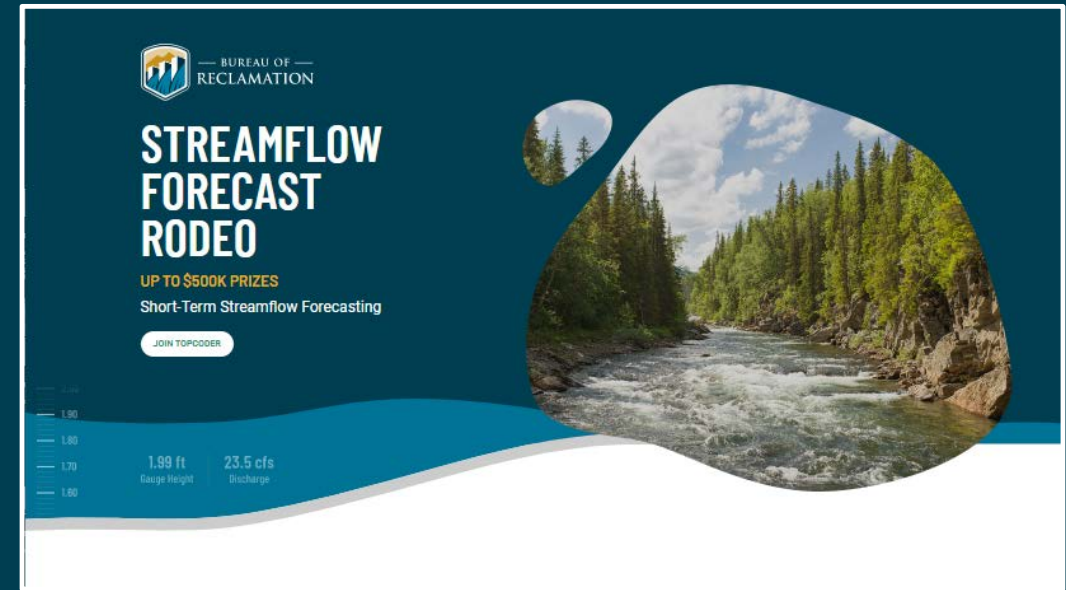


Map Courtesy of Curt Jawdy, TVA



Streamflow Forecast Rodeo

- 10-day streamflow forecasts
- Issued daily for WY 2021
- Technology Evaluation
 - Mix of 6-hour time-step and daily time-step (cfs/cms)
- Prize Competition
 - All forecasts are 6-hour timestep (cfs)
- Leaderboard
 - <https://www.topcoder.com/community/streamflow>



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