

CALIFORNIA DEPARTMENT OF WATER RESOURCES

Machine Learning for Long-Range Streamflow Forecasting: Feather River Case Study

CWEMF Annual Meeting, May 13, 2025



CALIFORNIA DEPARTMENT OF
WATER RESOURCES

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Overview

- Overview
- Methodology
- Preliminary Results and Dashboard
- Summary
- Future Directions



Overview

❑ Overarching goal

Forecast streamflow up to 9 months
(Jan.-Sep.)

❑ Why long-range streamflow forecasting matters?

- Water year typing
- Water allocation
- Reservoir operations
- Drought preparedness

❑ Challenges

Uncertainty/inter-annual hydrologic variabilities



Methodology

❑ Study location

Feather River at Lake Oroville

❑ Study data

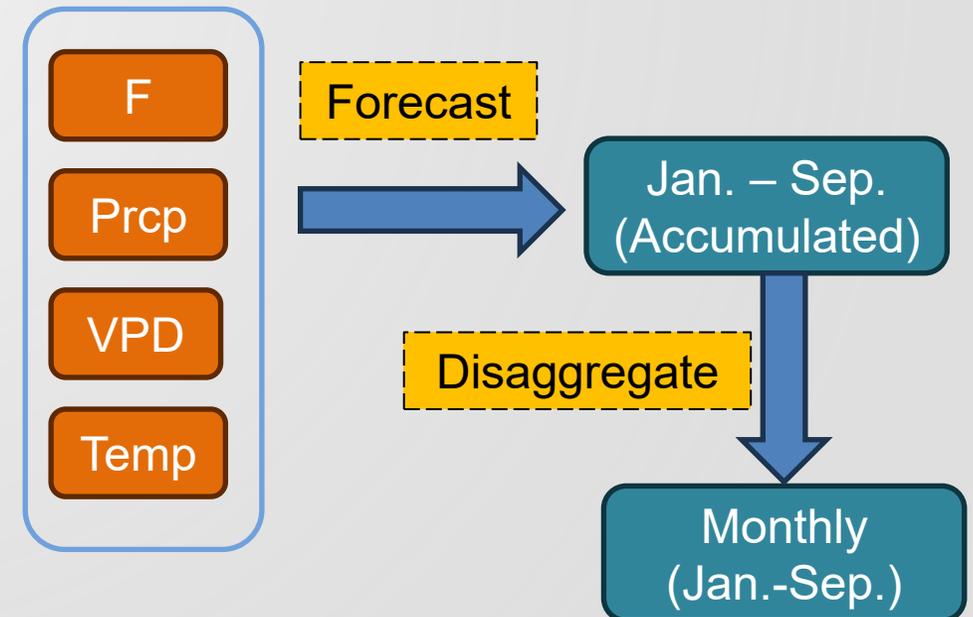
Monthly precipitation (Prcp), temperature (Temp), vapor pressure deficit (VPD), and streamflow (F)

❑ Study period

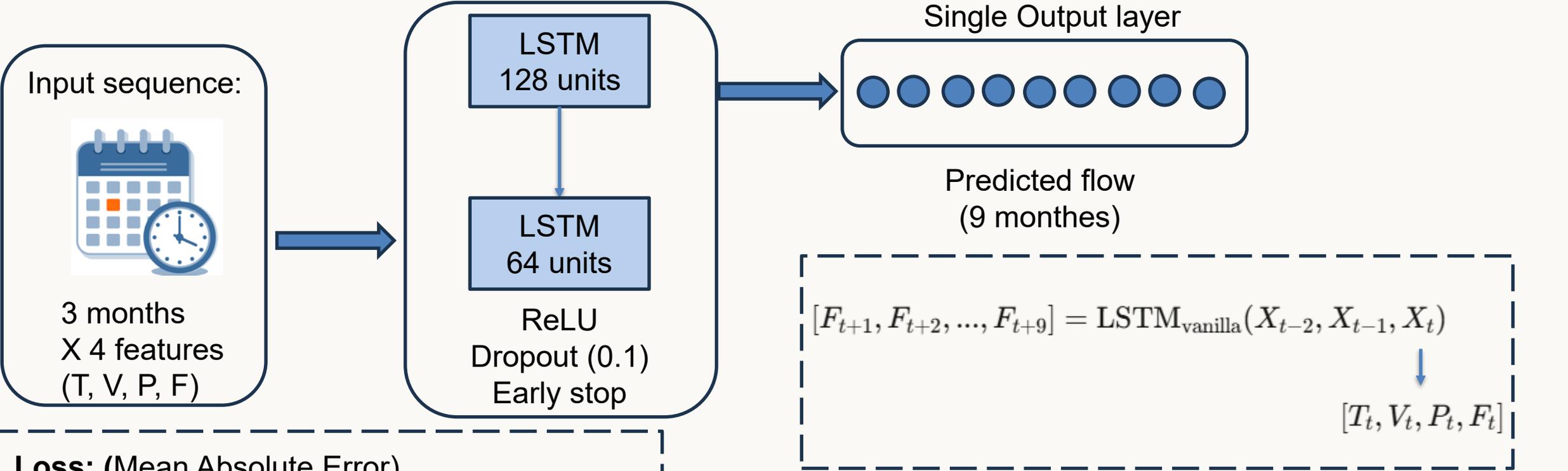
Water year 1922-2021 (100-year)

❑ Study models

Statistical model (benchmark)
Long-Short Term Memory (LSTM)



Methodology: Vanilla LSTM



Loss: (Mean Absolute Error)

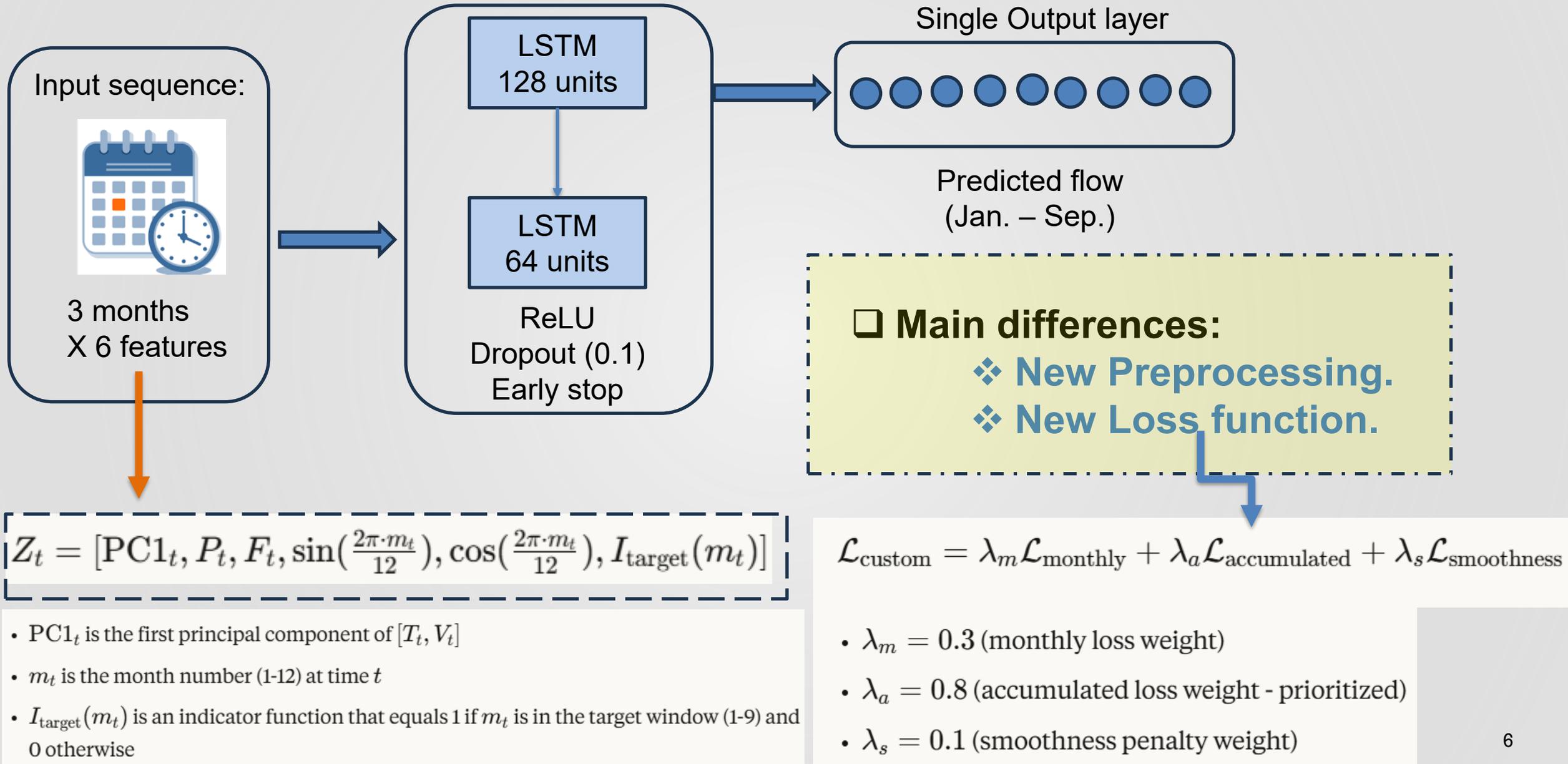
$$\mathcal{L}_{\text{vanilla}} = \frac{\sum_{i=1}^N w_i \sum_{j=1}^9 |F_{i,j}^{\text{pred}} - F_{i,j}^{\text{true}}|}{9 \cdot \sum_{i=1}^N w_i}$$

- $F_{i,j}^{\text{pred}}$ is the predicted flow for sample i and month j
- $F_{i,j}^{\text{true}}$ is the actual flow for sample i and month j
- w_i is the weight for sample i (0 for test years, 1 for training years)



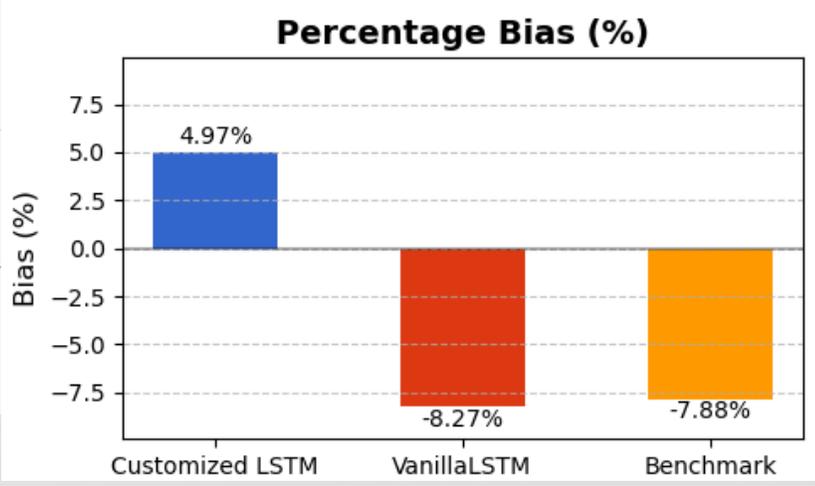
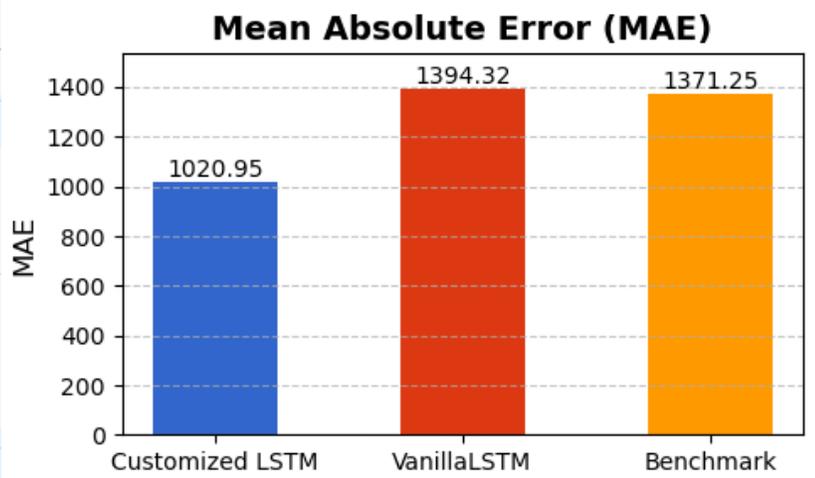
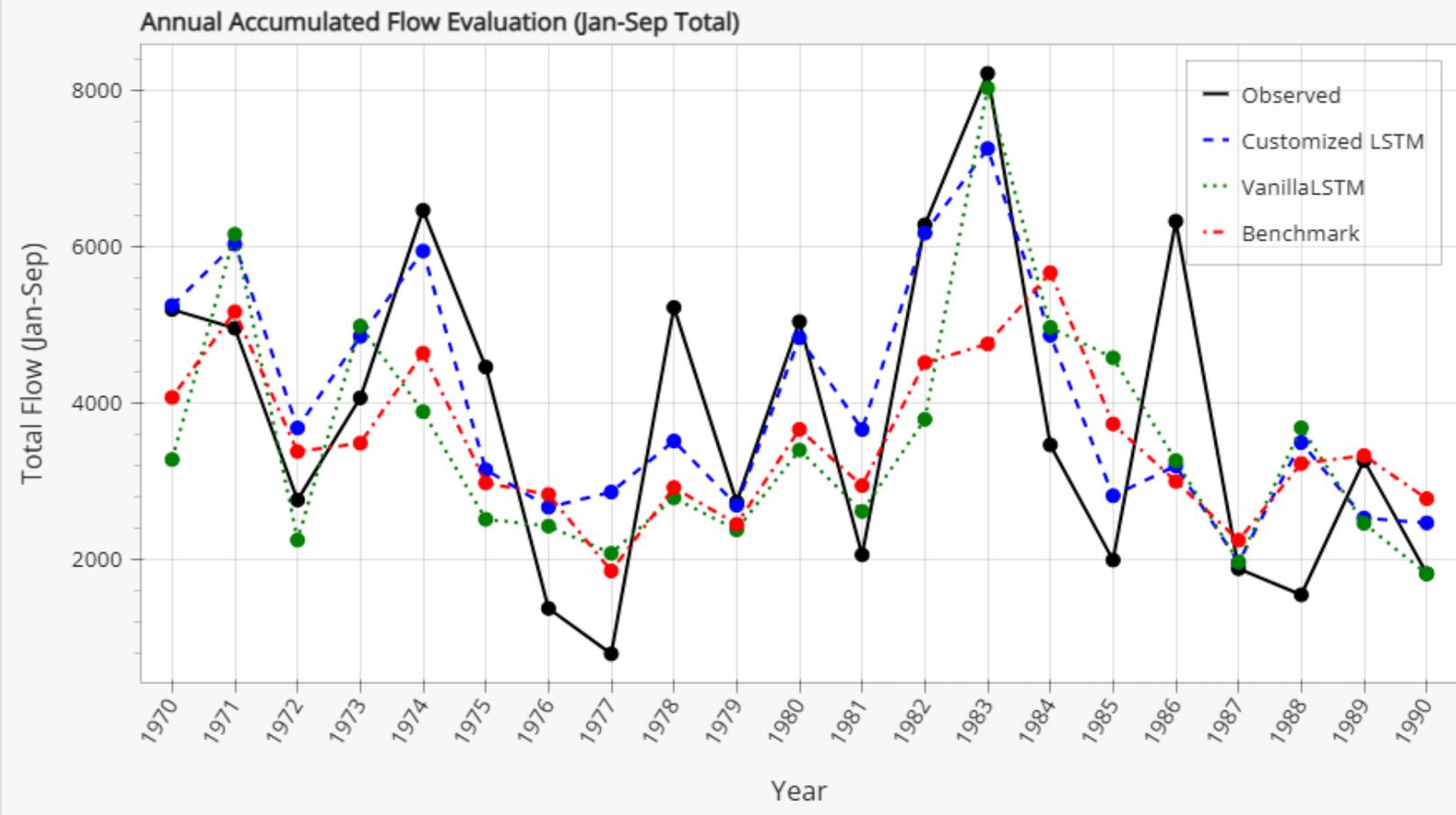
Slicing method

Methodology: Customized LSTM



Preliminary Results

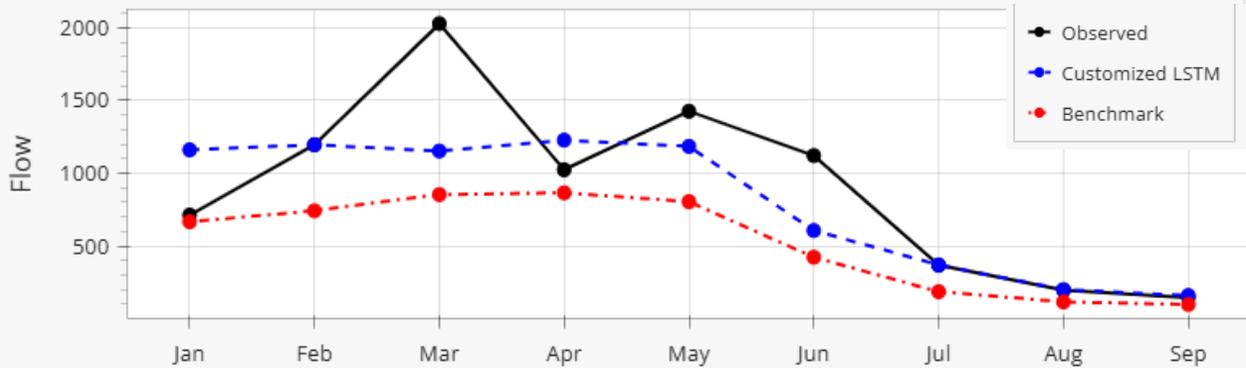
Jan.-Sep. accumulated flow



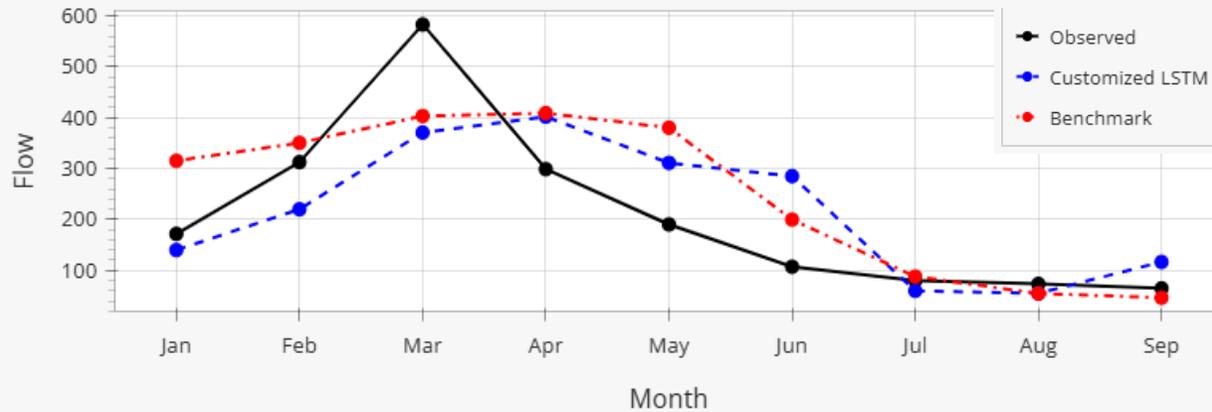
Preliminary Results

Jan.-Sep. monthly flow

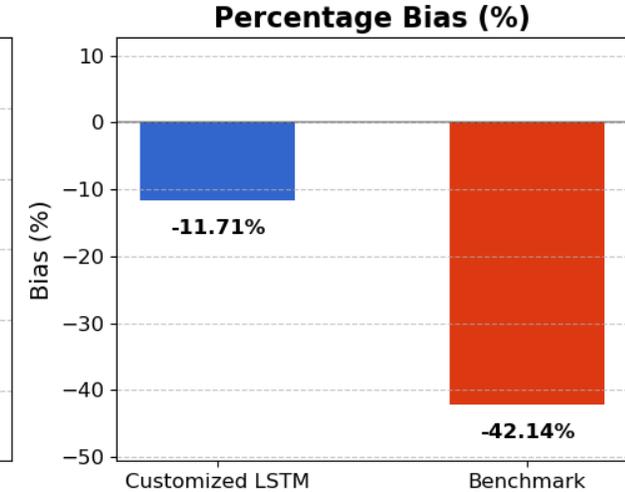
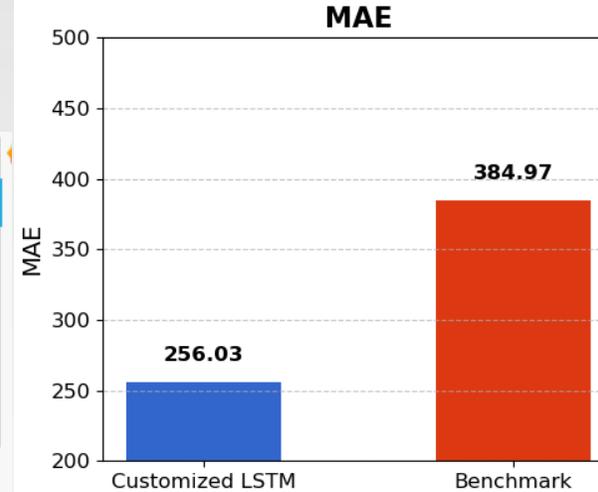
Monthly Flow Evaluation - Year: 1983 (WYT: W)



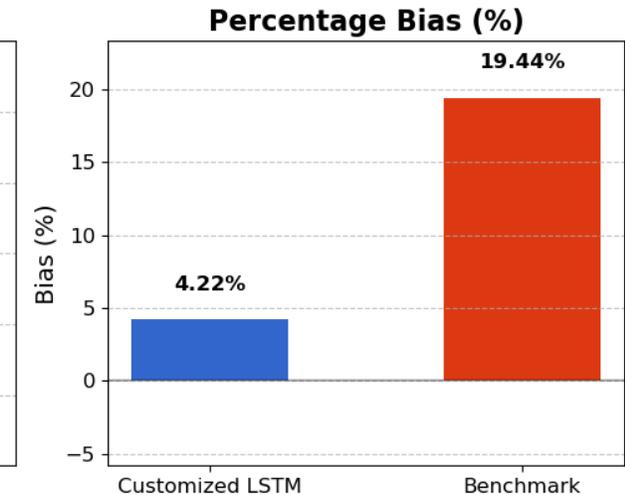
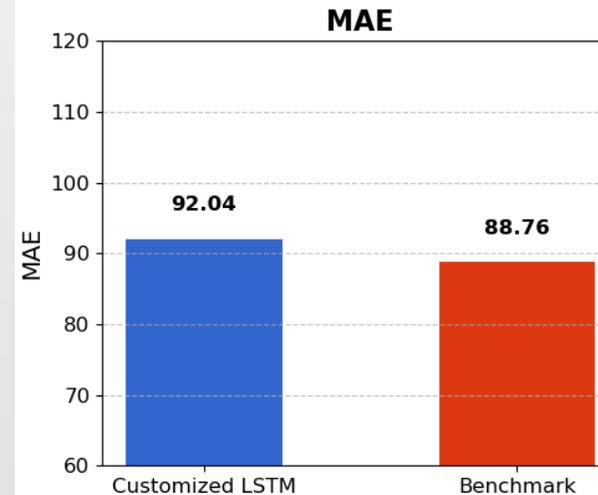
Monthly Flow Evaluation - Year: 1987 (WYT: D)



Model Performance Comparison - Year 1983

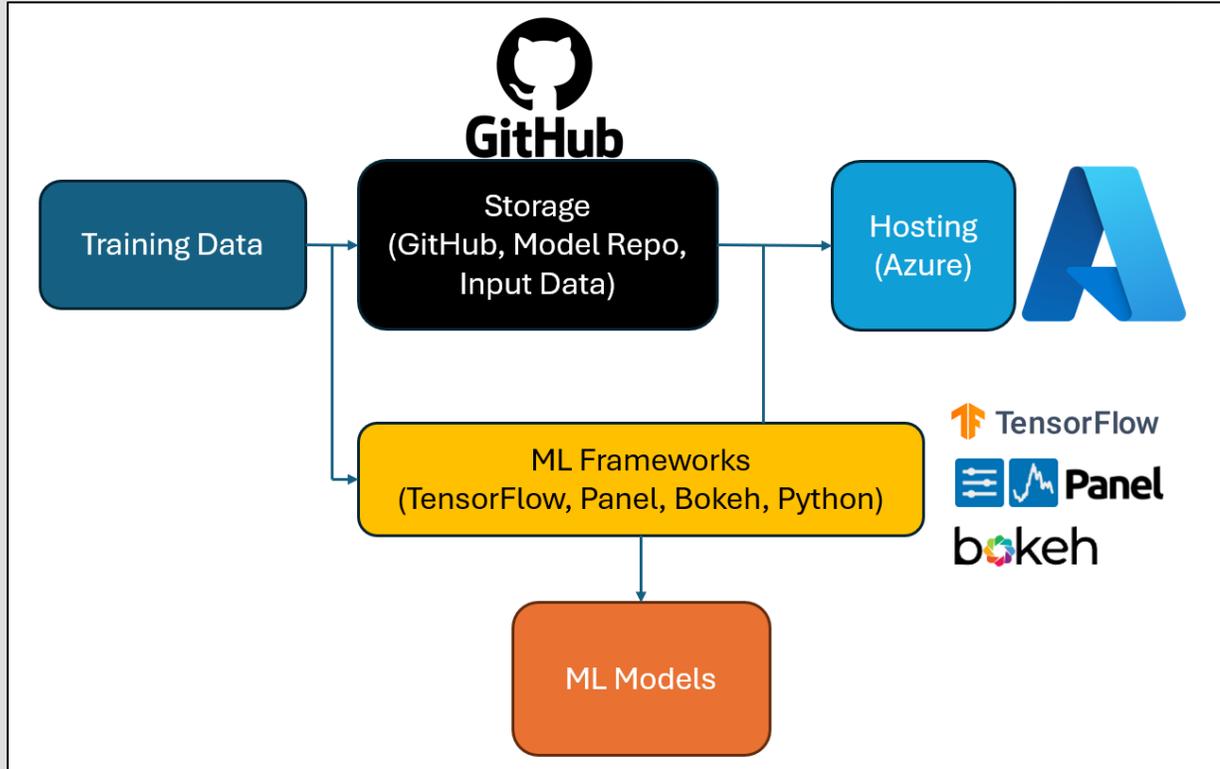


Model Performance Comparison - Year 1987



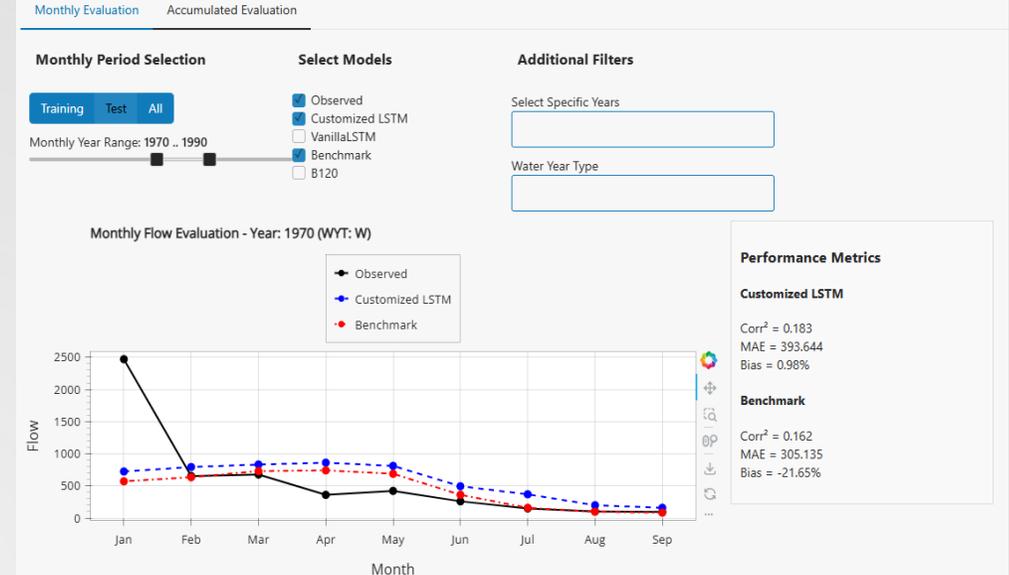
Preliminary Results

Interactive Dashboard

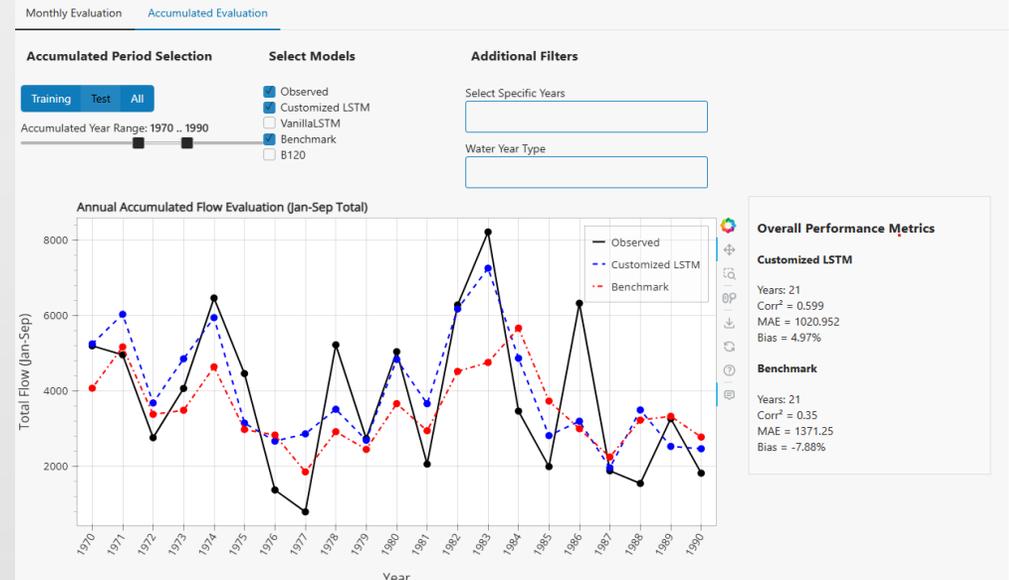


https://floworv9-hwfte2fta9gcbdeg.westus2-01.azurewebsites.net/Dashboard_HF9M

Flow Forecast Model Evaluation Dashboard

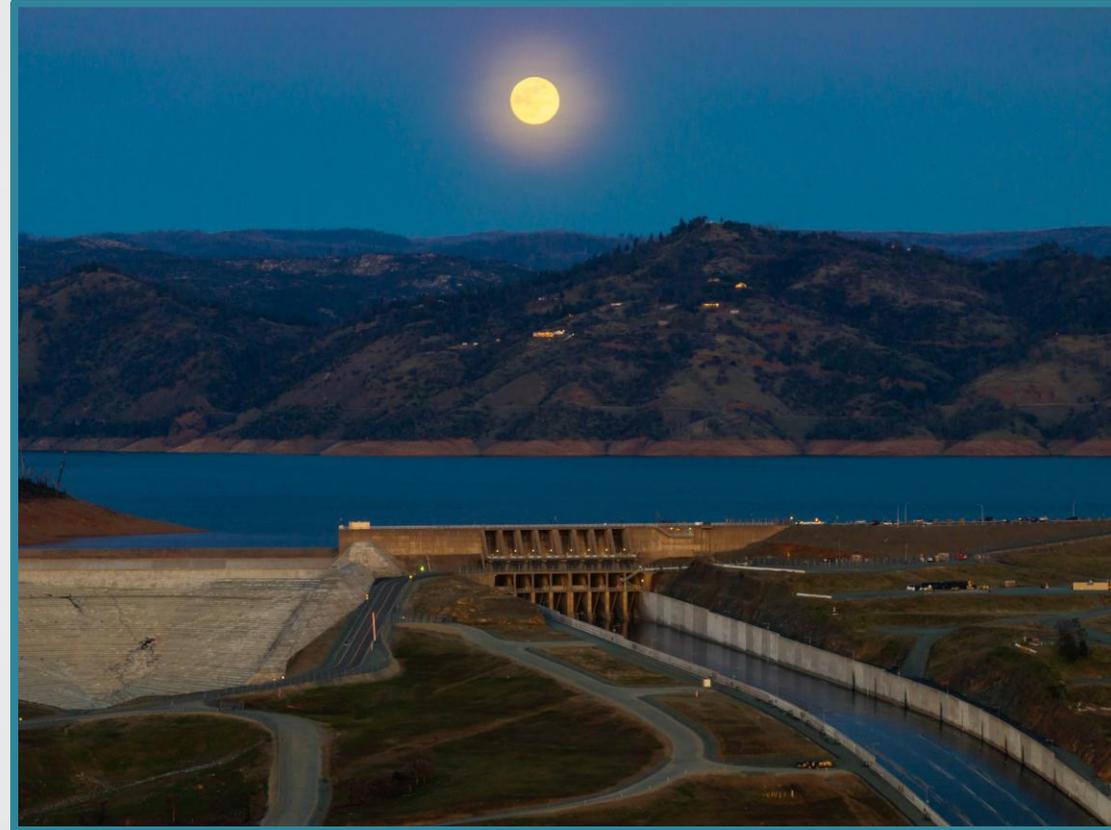


Flow Forecast Model Evaluation Dashboard



Summary

- ❑ LSTM can outperform the traditional statistical model in long-term (9-mth) streamflow forecasting
- ❑ Customized LSTM offers flexibility to leverage domain knowledge
- ❑ Both models have difficulties in capturing extreme wet years; LSTM doing better



Future Directions

- ❑ Enhance LSTM to target more on extremes
- ❑ Incorporate additional inputs (e.g., snow index)
- ❑ Expand to other lead times (e.g., Feb./ Mar. / Apr. /May – Sep.)
- ❑ Expand to other basins



Questions?



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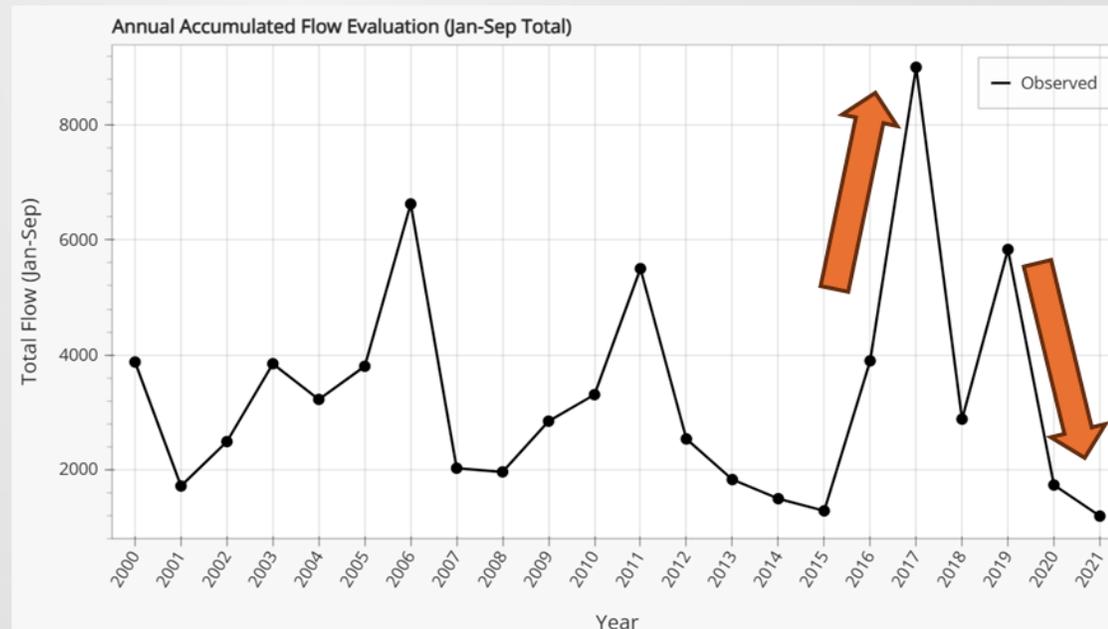
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Overview

Forecasting Challenges:

- **Long-range uncertainty:** **9-month** predictions far exceed typical weather forecast horizons (days)
- **Hydrologic variability:** Limited predictability of **extreme weather events**
- **Year-to-year transitions:** **Difficulty capturing shift patterns from dry to wet or wet to dry years**

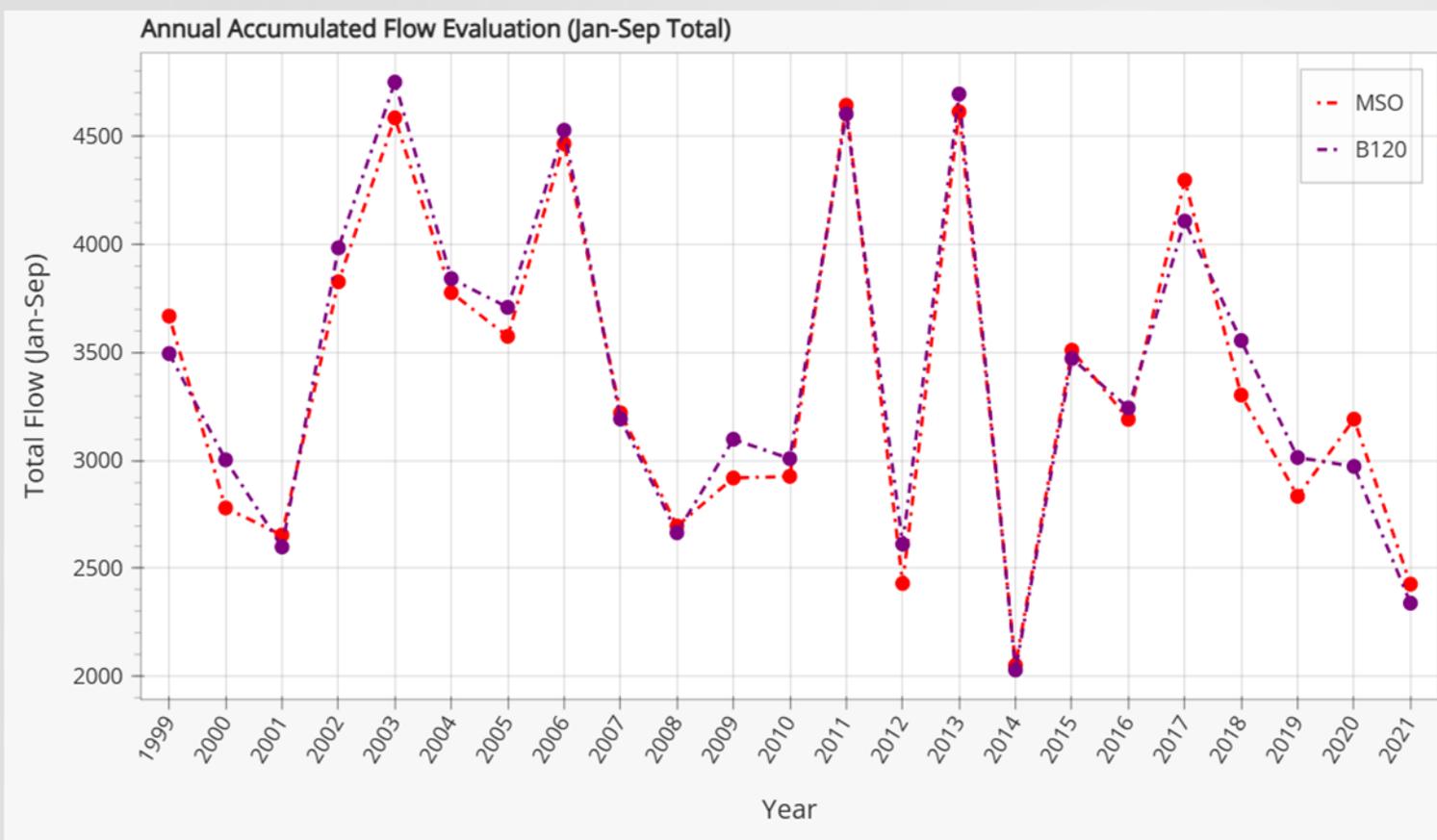
| CALIFORNIA DATA EXCHANGE CENTER CALIFORNIA DEPARTMENT OF WATER RESOURCES | | | | | |
|--|-------|-------|-------|-------|----|
| 2000 | 12.06 | 5.96 | 18.90 | 8.94 | AN |
| 2001 | 5.64 | 3.46 | 9.81 | 5.76 | D |
| 2002 | 9.32 | 4.57 | 14.60 | 6.35 | D |
| 2003 | 10.71 | 7.74 | 19.31 | 8.21 | AN |
| 2004 | 10.95 | 4.40 | 16.04 | 7.51 | BN |
| 2005 | 8.40 | 9.28 | 18.55 | 8.49 | AN |
| 2006 | 18.06 | 13.09 | 32.09 | 13.20 | W |
| 2007 | 6.59 | 3.04 | 10.28 | 6.19 | D |
| 2008 | 5.90 | 3.82 | 10.28 | 5.16 | C |
| 2009 | 7.05 | 5.30 | 13.02 | 5.78 | D |
| 2010 | 7.45 | 7.78 | 16.01 | 7.08 | BN |
| 2011 | 12.68 | 11.53 | 25.21 | 10.54 | W |
| 2012 | 5.69 | 5.46 | 11.84 | 6.89 | BN |
| 2013 | 8.52 | 3.01 | 12.19 | 5.83 | D |
| 2014 | 4.29 | 2.59 | 7.46 | 4.07 | C |
| 2015 | 6.91 | 1.77 | 9.23 | 4.00 | C |
| 2016 | 12.24 | 4.60 | 17.48 | 6.71 | BN |
| 2017 | 26.17 | 10.69 | 37.82 | 14.14 | W |
| 2018 | 7.09 | 5.05 | 12.86 | 7.14 | BN |
| 2019 | 13.11 | 10.66 | 24.77 | 10.34 | W |
| 2020 | 4.91 | 4.13 | 9.71 | 6.12 | D |
| 2021 | 3.52 | 2.26 | 6.37 | 3.80 | C |
| 2022 | 6.71 | 3.49 | 10.79 | 4.55 | C |
| 2023 | 13.11 | 10.07 | 24.11 | 9.33 | W |



Overview

❑ Evaluating Current Forecasting Approaches:

➤ MSO vs B120:



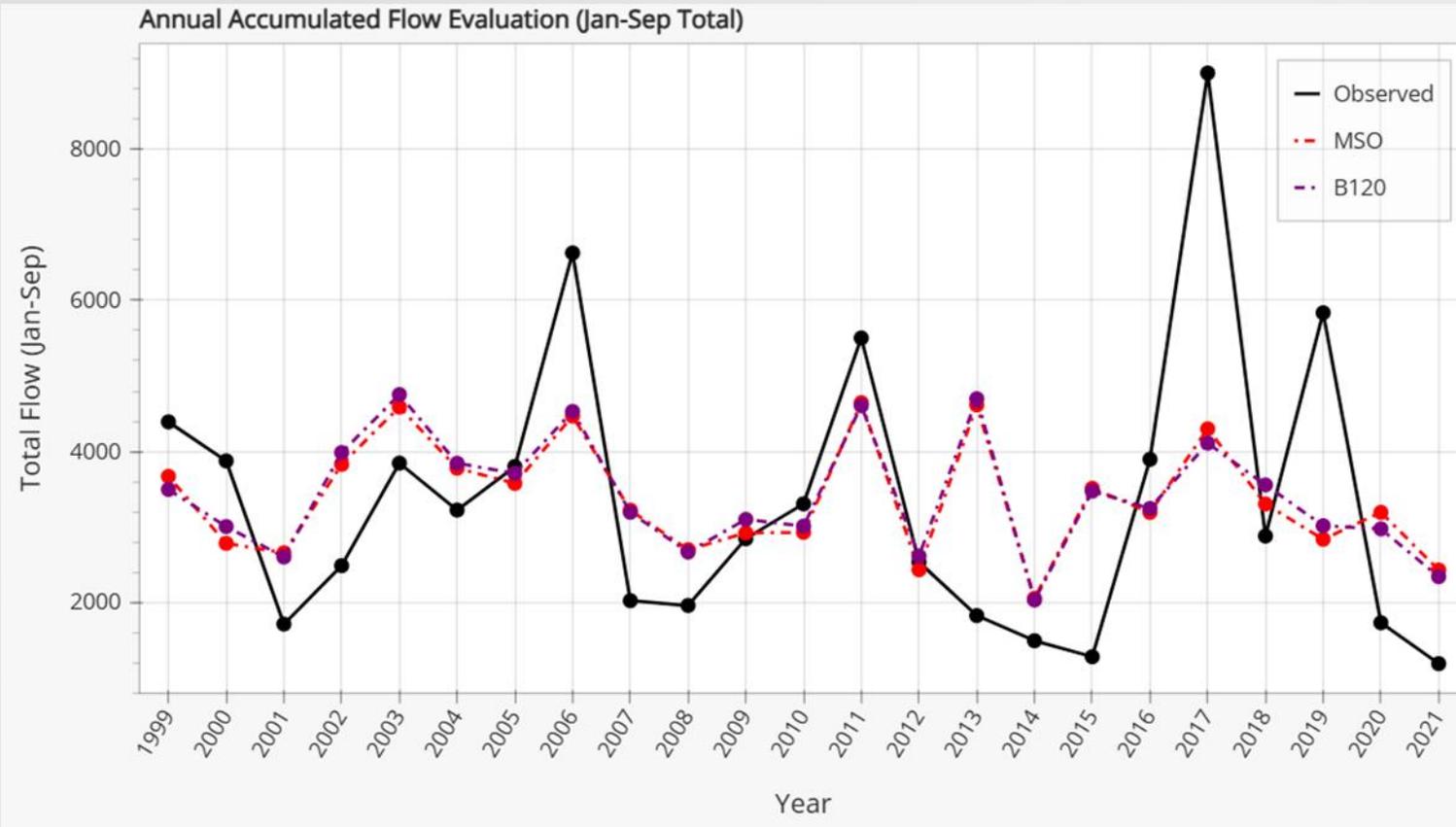
❑ Objectives:

- ✓ MSO forecasts closely match B120 forecasts
- ✓ Validate MSO's technical approach reproduces B120 characteristics
- ✓ MSO successfully creates an **automated alternative** to B120

Overview

❑ Evaluating Current Forecasting Approaches:

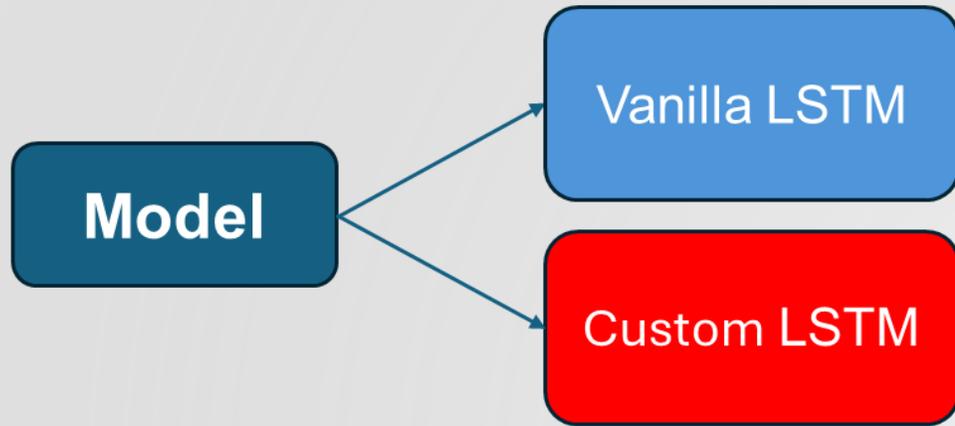
➤ MSO and B120 vs Observed:



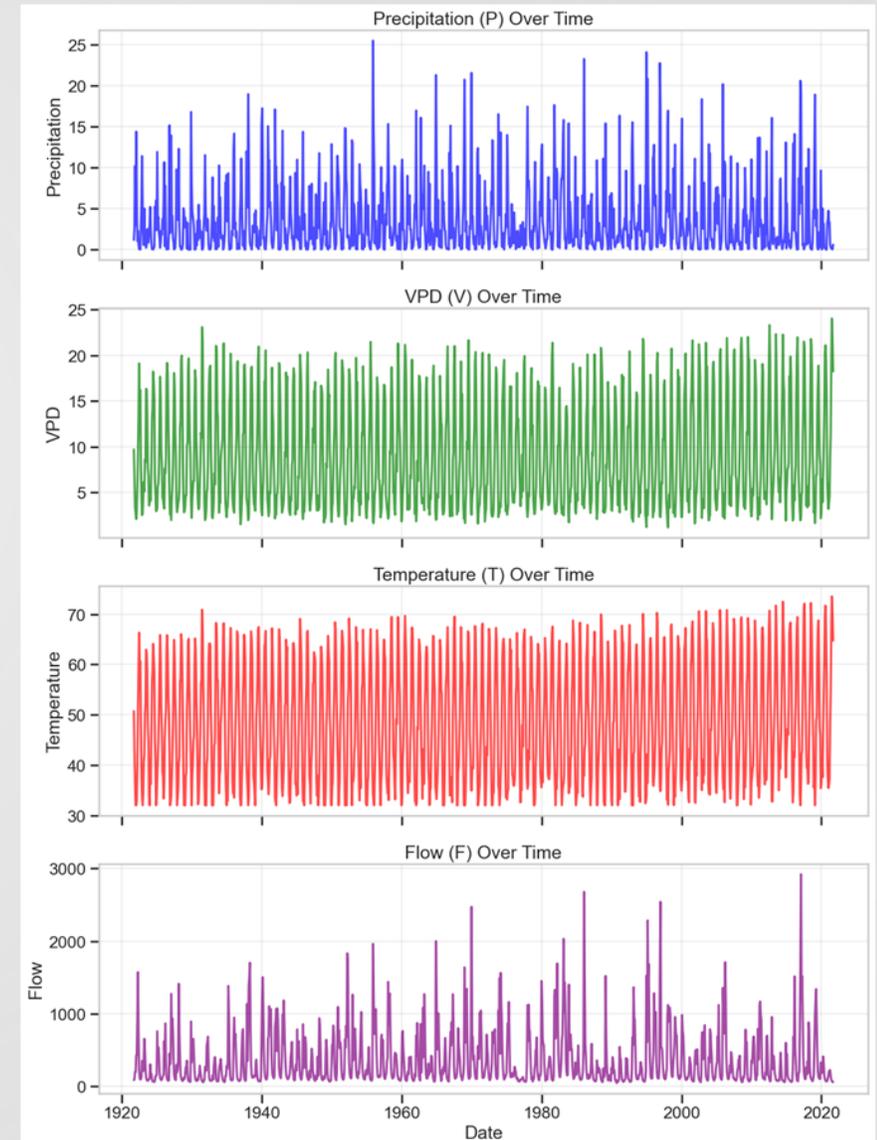
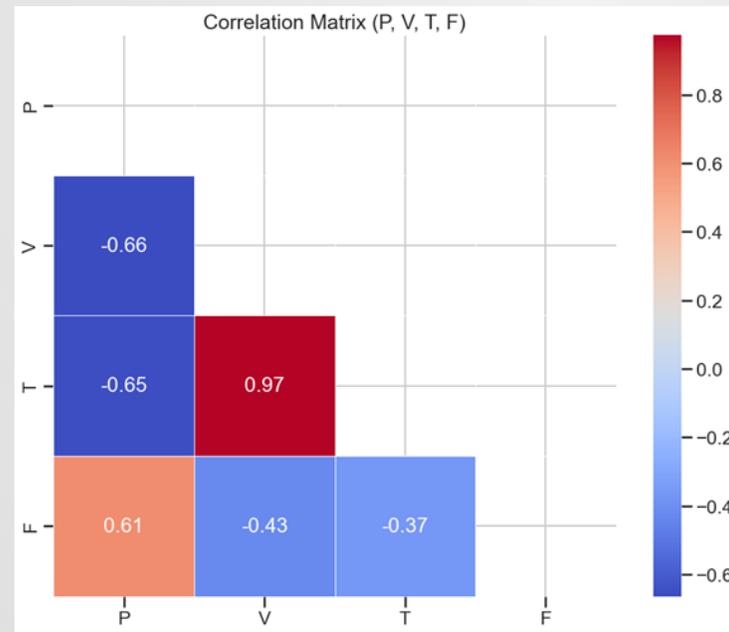
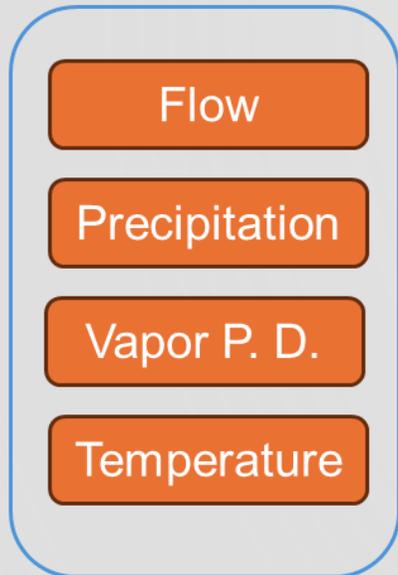
❑ Objectives:

- ✓ Forecast-observation gap
- ✓ Significant divergence in **wet years** (2006, 2017).
- ✓ Over-estimation in **dry periods**
- ✓ Limitations of current forecasting methods
- ✓ Justify **machine learning** approach targeting observed flows.

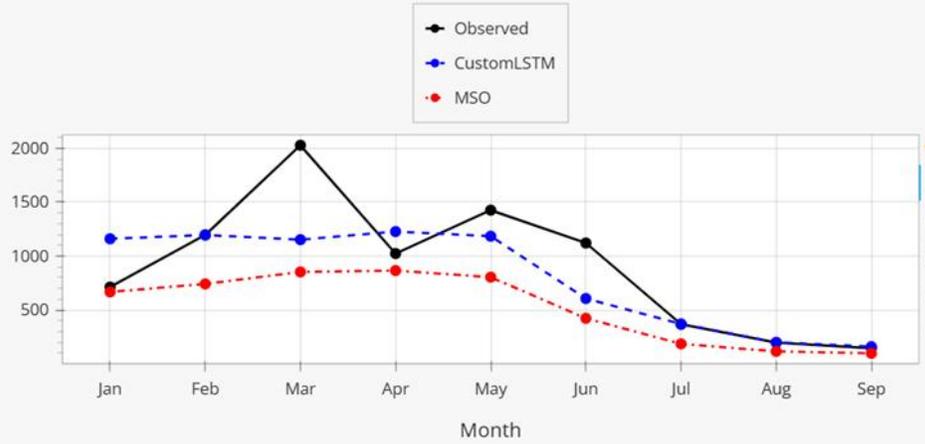
Modeling



Predictors:



Monthly Flow Evaluation - Year: 1983 (WYT: W)



Performance Metrics

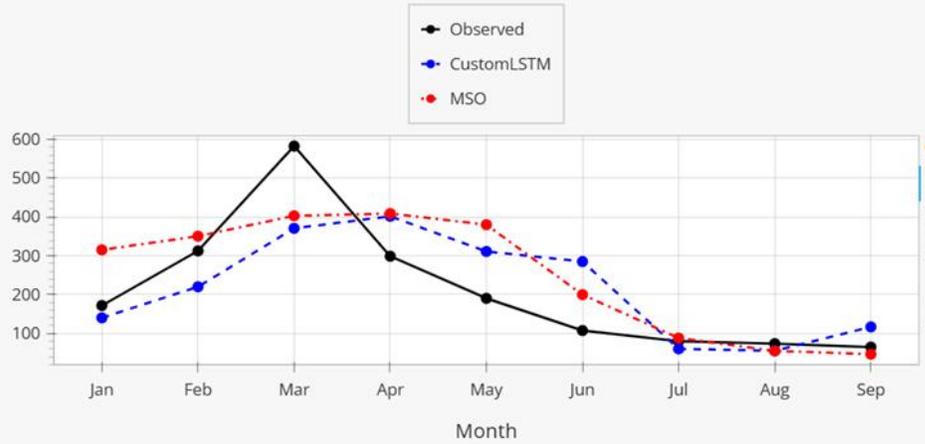
CustomLSTM

Corr² = 0.601
 MAE = 256.034
 Bias = -11.71%

MSO

Corr² = 0.715
 MAE = 384.97
 Bias = -42.14%

Monthly Flow Evaluation - Year: 1987 (WYT: D)



Performance Metrics

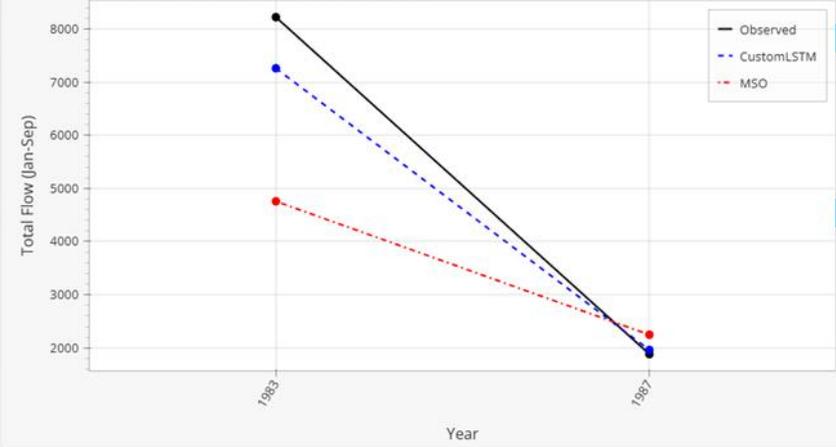
CustomLSTM

Corr² = 0.502
 MAE = 92.041
 Bias = 4.22%

MSO

Corr² = 0.592
 MAE = 88.764
 Bias = 19.44%

Annual Accumulated Flow Evaluation (Jan-Sep Total)



Overall Performance Metrics

CustomLSTM

Years: 2
 Corr² = 1.0
 MAE = 521.067
 Bias = -8.74%

MSO

Years: 2
 Corr² = 1.0
 MAE = 1915.205
 Bias = -30.67%

❖ CustomLSTM Loss Function

$$\mathcal{L}_{\text{custom}} = \lambda_m \mathcal{L}_{\text{monthly}} + \lambda_a \mathcal{L}_{\text{accumulated}} + \lambda_s \mathcal{L}_{\text{smoothness}}$$

- $\lambda_m = 0.3$ (monthly loss weight)
- $\lambda_a = 0.8$ (accumulated loss weight - prioritized)
- $\lambda_s = 0.1$ (smoothness penalty weight)

$$L_{(\text{monthly})} = (1/N) \sum_{i=1}^N w_i \cdot (1/9) \sum_{j=1}^9 (F_{(i,j)}^{\text{pred}} - F_{(i,j)}^{\text{true}})^2$$

$$L_{(\text{accumulated})} = (1/N) \sum_{i=1}^N w_i \cdot (\sum_{j=1}^9 F_{(i,j)}^{\text{pred}} - \sum_{j=1}^9 F_{(i,j)}^{\text{true}})^2$$

$$L_{(\text{smoothness})} = (1/N) \sum_{i=1}^N w_i \cdot (1/8) \sum_{j=1}^8 (F_{(i,j+1)}^{\text{pred}} - F_{(i,j)}^{\text{pred}})^2$$