Improving snow water equivalent prediction with a hybrid SNOW17-LSTM model

Aamir Raj Lamichhane and Andrew Bennett
Hydrology and Atmospheric Sciences

Why a hybrid approach?

- Snow models are essential for predicting water availability.
- Traditional process-based models, like SNOW-17, require site-wise calibration and struggle to generalize across regions.
- Unlike SNOW-17, which has to be calibrated site-wise, the hybrid model can be trained using spatial holdouts to evaluate generalization ability.
- Recent advances in machine learning strongly indicate its potential to improve parameter estimation.

Research questions

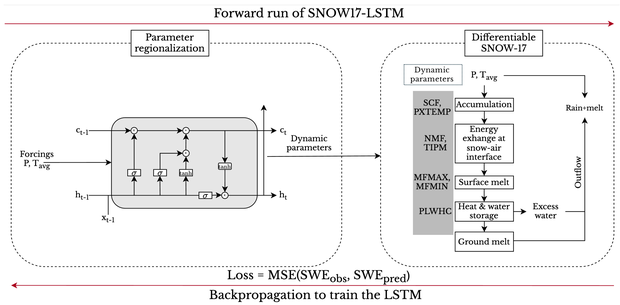
We aim to answer the following questions:

- Can an LSTM based parameterization enhance SNOW-17's ability to predict SWE?
- How does the standalone SNOW-17 fare against our hybrid model in capturing key snowpack metrics?
- Does performance vary across snow years, elevations, and regions?

Data and study area

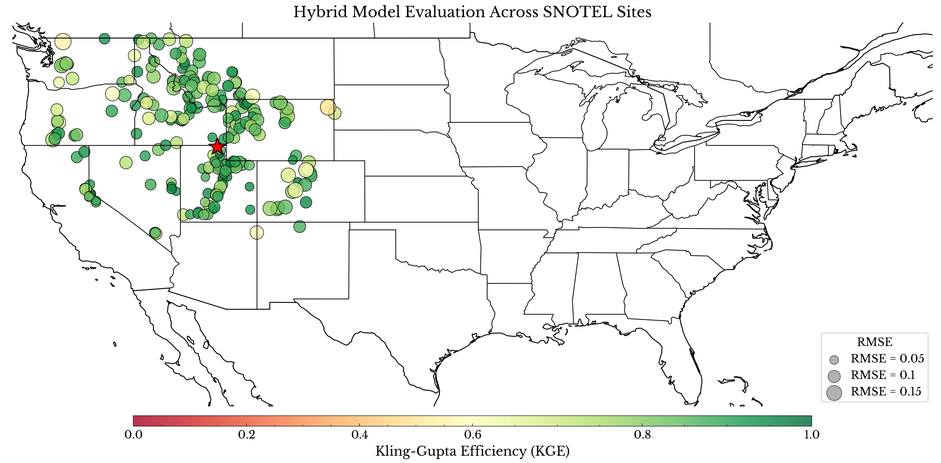
- Daily precipitation and average temperature from 250 SNOTEL stations across the western US spanning varied climate zones.
- Evaluation metrics used are KGE, NSE, RMSE, and Bias.

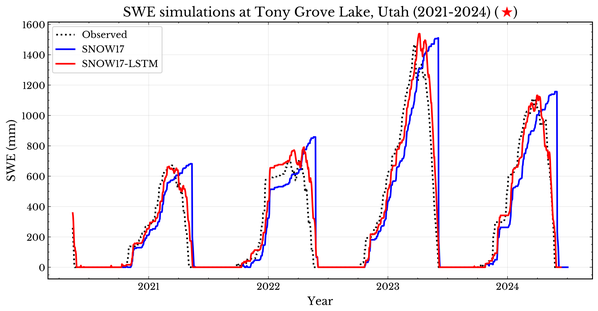
Hybrid modeling framework

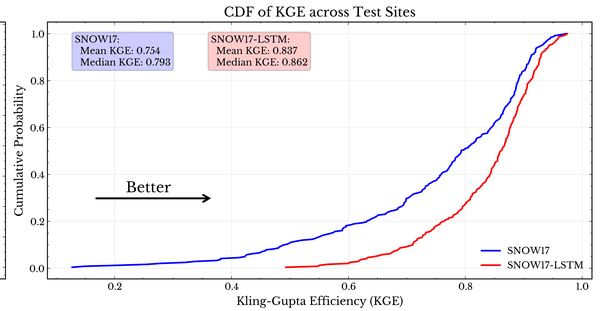


Results and discussion

- **SNOW17-LSTM improves SWE predictions across SNOTEL sites**
- **The hybrid approach provides significant improvement in the simulation of snow-melt**



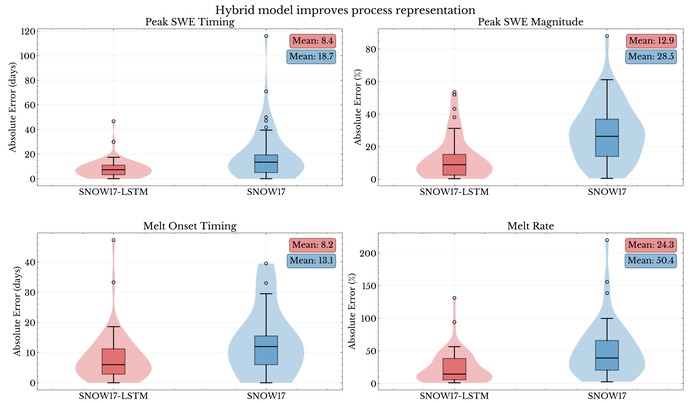




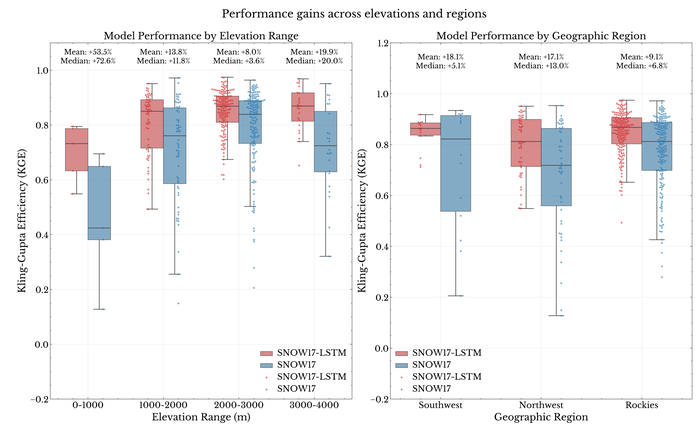
- **Hybrid model outperformed SNOW17 in all snow conditions**

Snow Year	NSE Increase	SNOW17 Bias	SNOW17-LSTM Bias	Sites Improved
Low	+9.90%	-16.0%	-4.8%	57.3%
Medium	+6.03%	-19.3%	-0.9%	63.2%
High	+5.96%	-16.1%	-2.9%	67.6%

- **Hybrid model improves process representation and better simulates evolution of snowpack**



- **Performance gains across elevations and regions**



Conclusions

- SNOW17-LSTM model consistently performed better than standalone SNOW17 for all metrics with up to 9.9% NSE improvement and significant bias reduction.
- The hybrid model shows greatest performance gains in the Northwest and the Rockies, and at high-elevations ranging 3000-4000 m.
- Integrating ML with process-based models better captures snowpack evolution while maintaining physical consistency, as demonstrated by the improvement in site performance across all snow conditions.