Better Together?

Multi-task process-guided deep learning for predicting streamflow and stream temperature

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Stream temperature and flow predictions

help answer key questions

Is the water cold enough?

Is the water warm enough?

Will we have enough to drink?

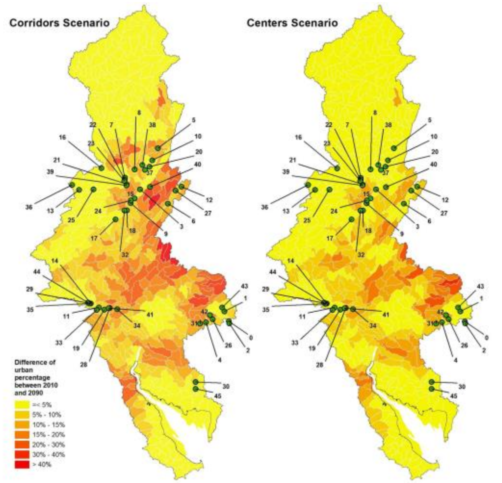
Will the river flood?

Stream temperature and flow predictions

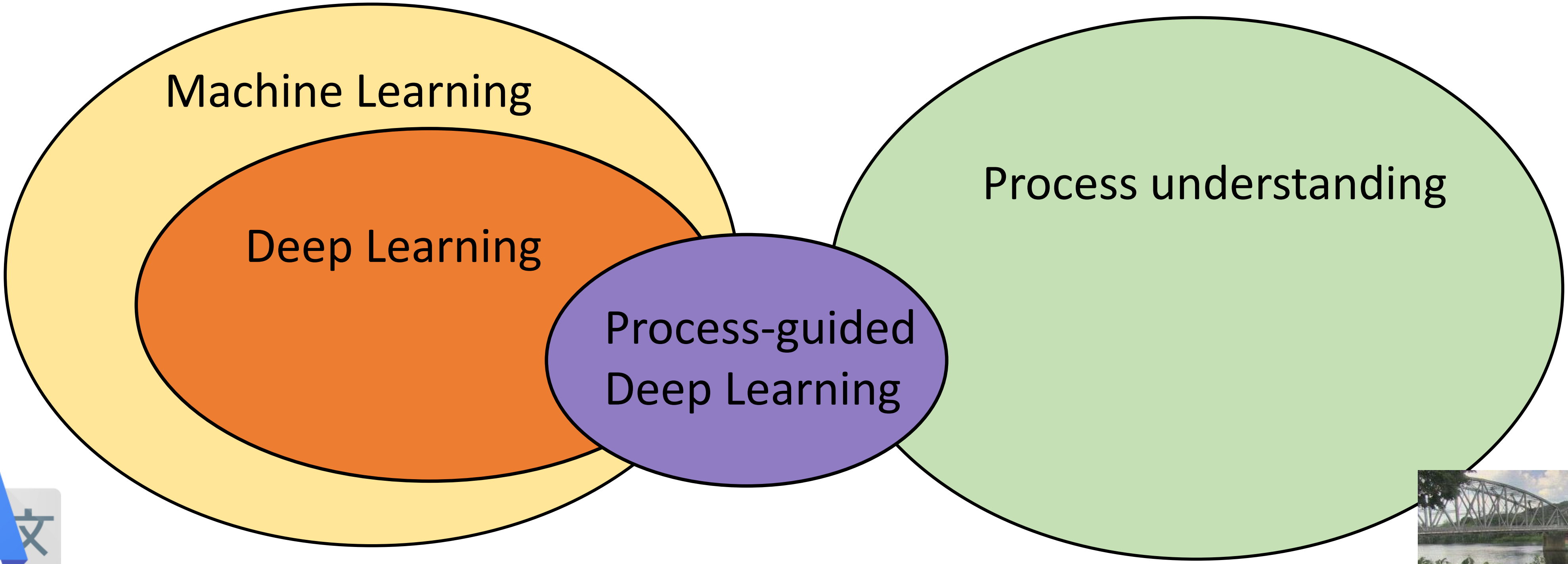
inform key decisions

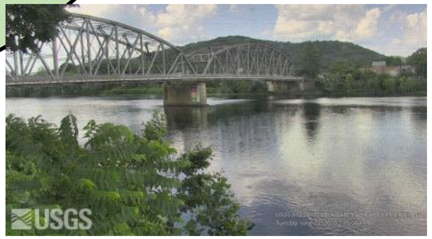
How much water should we release today to meet stakeholders' short-term and long-term needs?

What long-term policies can we focus on now given anticipated climate and land use change?



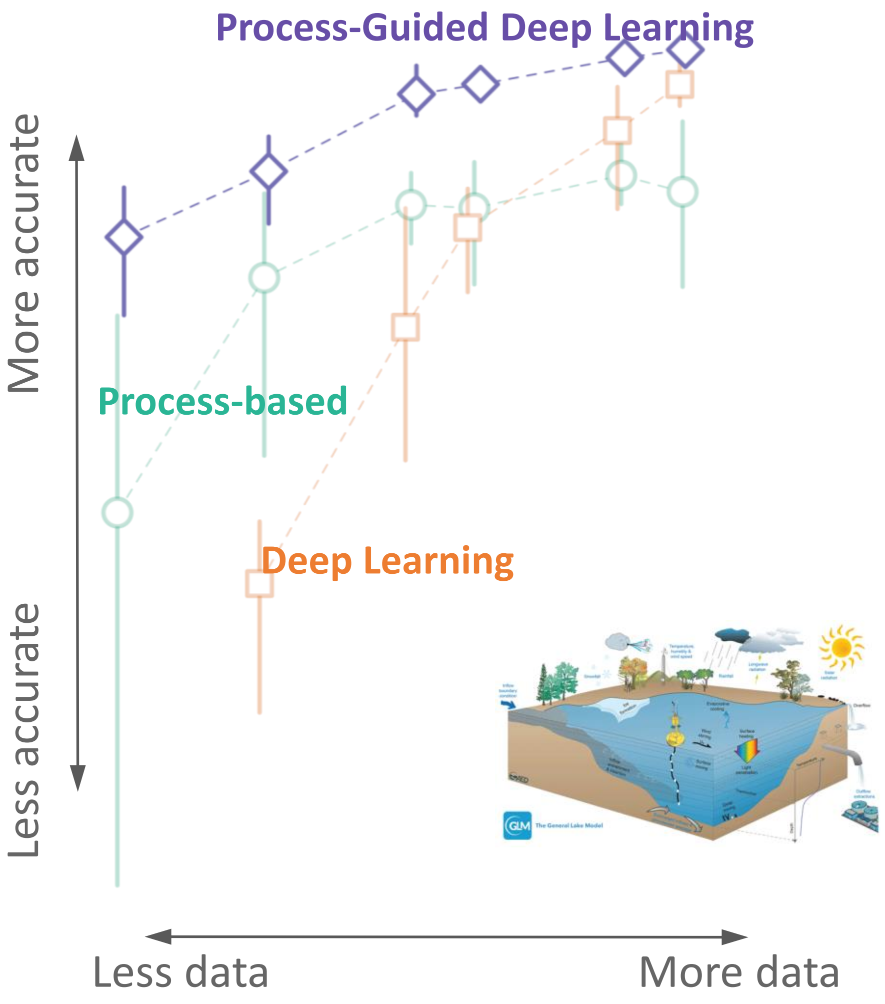
Process-guided Deep Learning



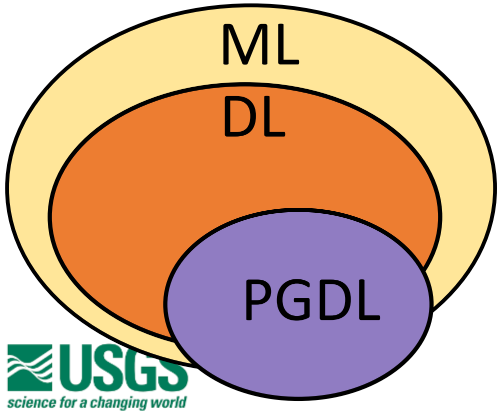


How do we incorporate process-understanding?

1. **Time aware modeling**
   - (yesterday affects today)
2. **Energy budget constraint**
   - (penalty for physically impossible predictions)
3. **Pretraining with a process-based model**
   - (physically consistent starting point)
4. **Space aware modeling (for streams)**
   - (upstream affects downstream)

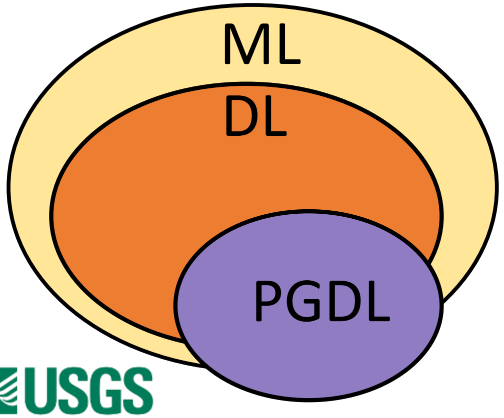


Adapted from Read et al. 2019



How do we incorporate process-understanding?

1. Time aware modeling
2. Energy budget constraint
3. Pretraining with a process-based model
4. Space aware modeling (for streams)
5. **Multi-task modeling of related variables**



multi-task deep learning

Primary objective: learn to read (unseen books)

multi-task deep learning

Primary objective: learn to read (unseen books)

Single-task

- Read the words

VS

Multi-task

- Read the words
- Describe the picture

multi-task deep learning

Primary objective: predict streamflow (in unseen conditions)

Single-task

- Predict streamflow

VS

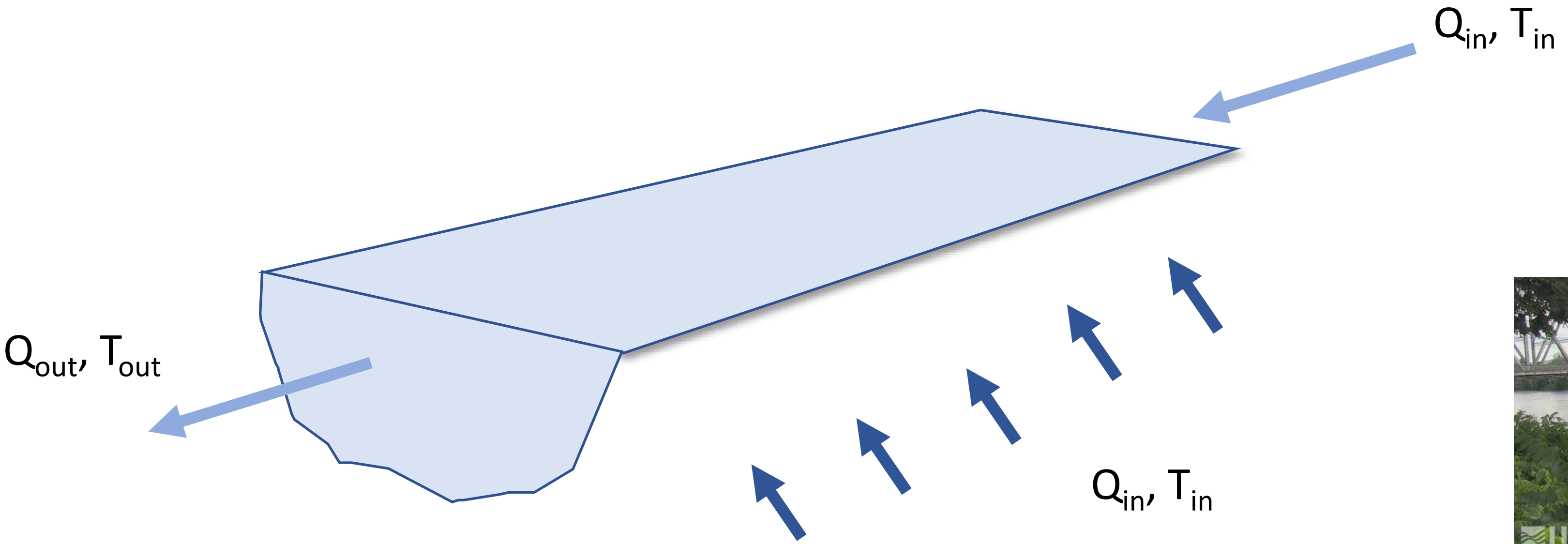
Multi-task

- Predict streamflow
- Predict temperature

Why Streamflow and Stream temperature

Both part of the energy transfer process

Incoming water flowing from surface runoff or groundwater brings energy into a stream segment. This affects changes in streamflow and stream temperature.



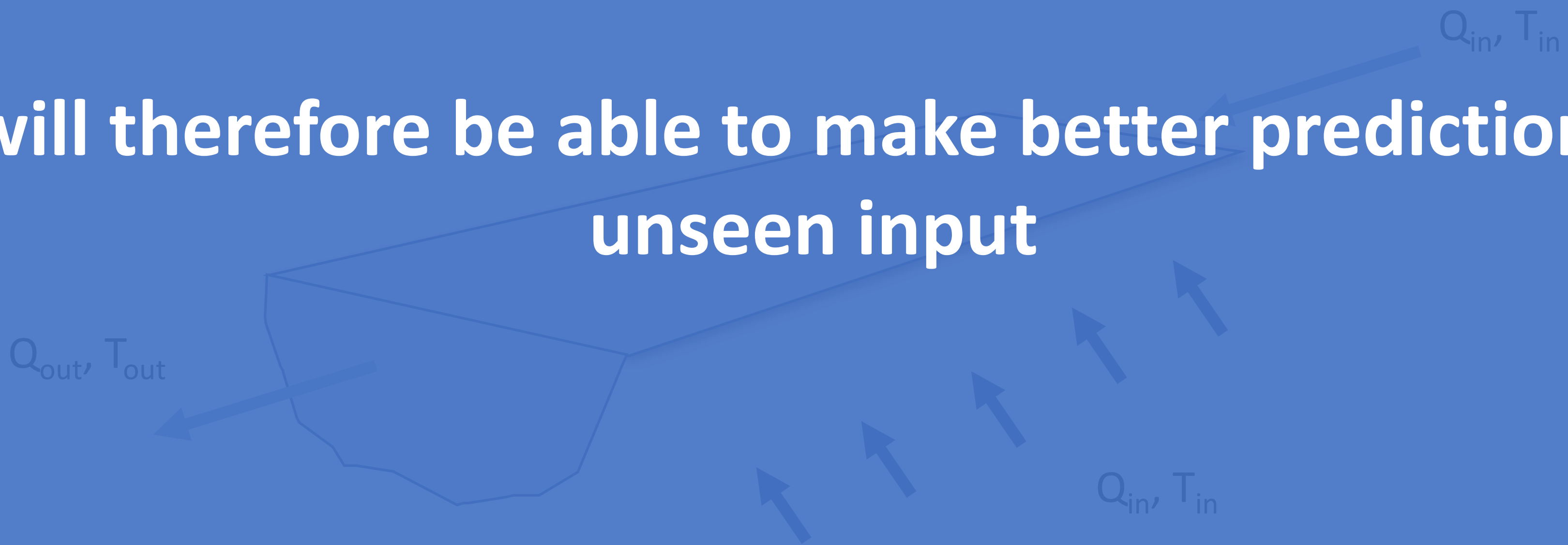
Why Streamflow and Stream temperature

Incoming water flowing from surface runoff or groundwater brings energy into a stream segment

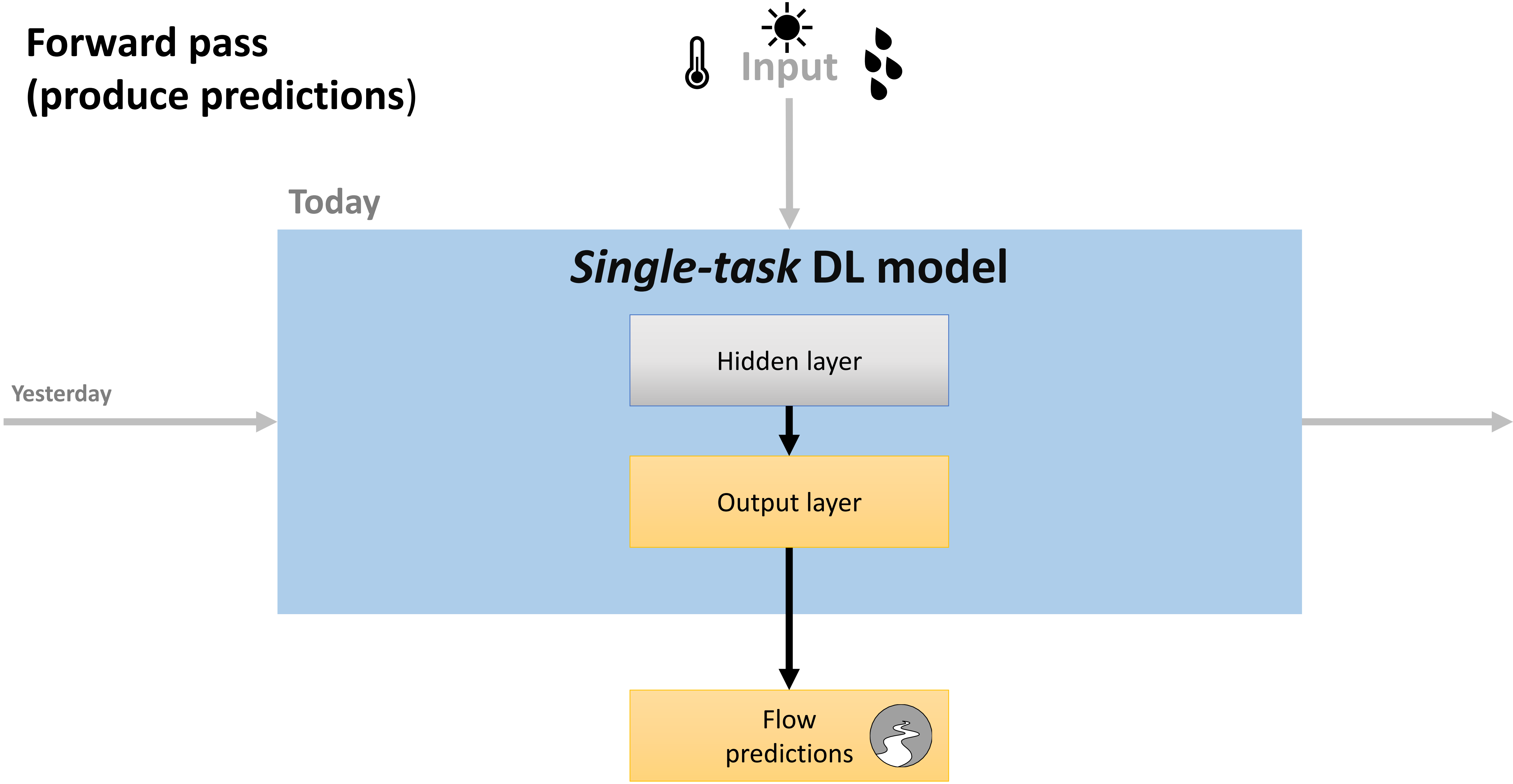
Intuition: If a model learns from two aspects of the energy transfer process (streamflow and water temperature),

then, it should learn to model the universal process better

and will therefore be able to make better predictions with unseen input



Forward pass
(produce predictions)



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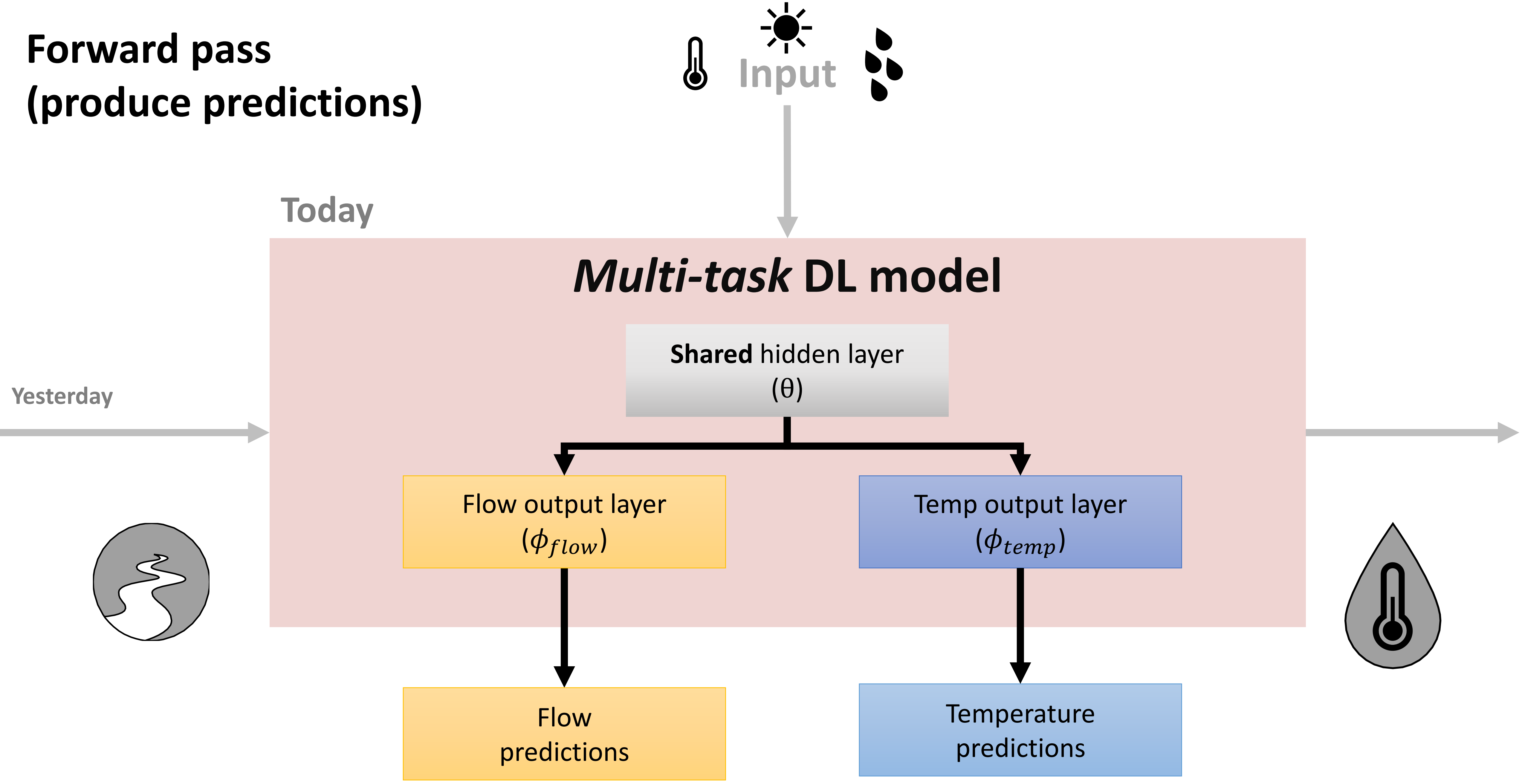
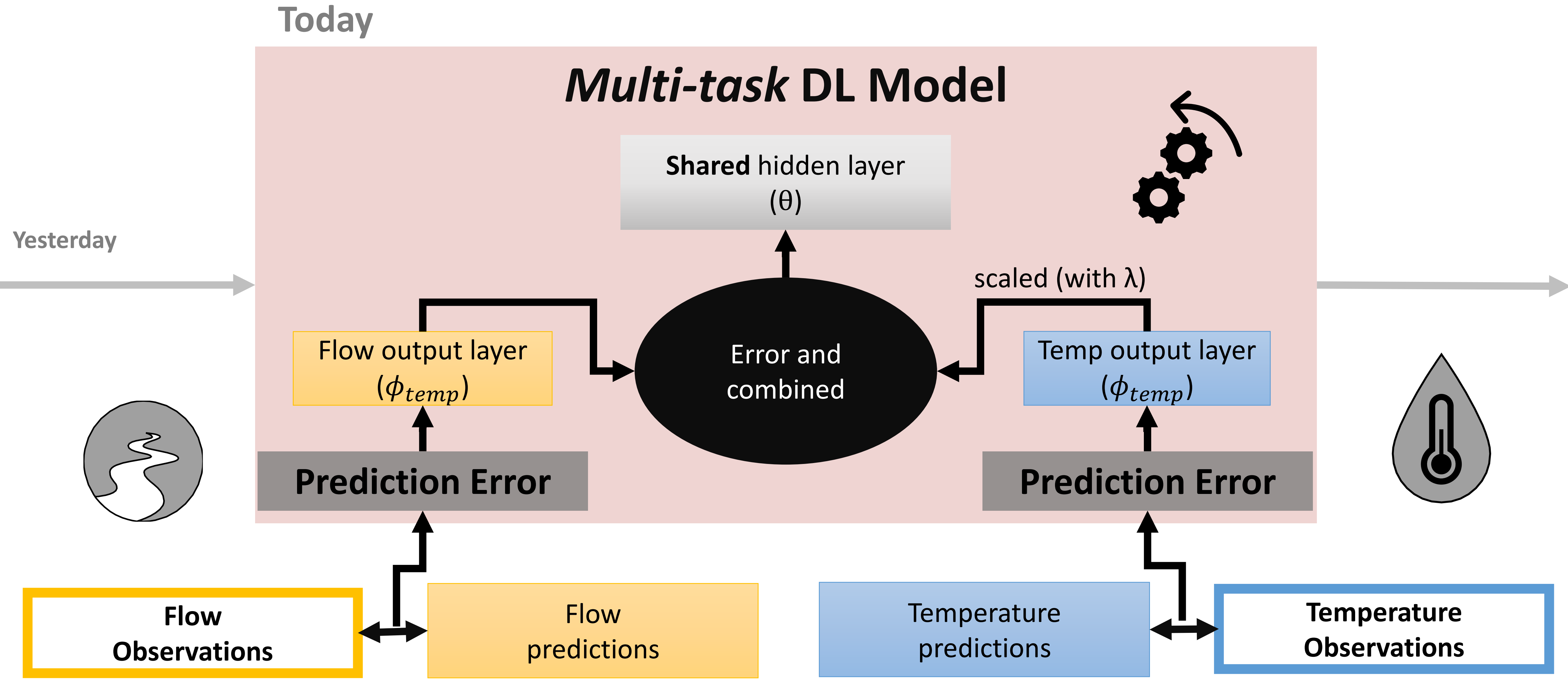


Backpropagation (adjust parameters)



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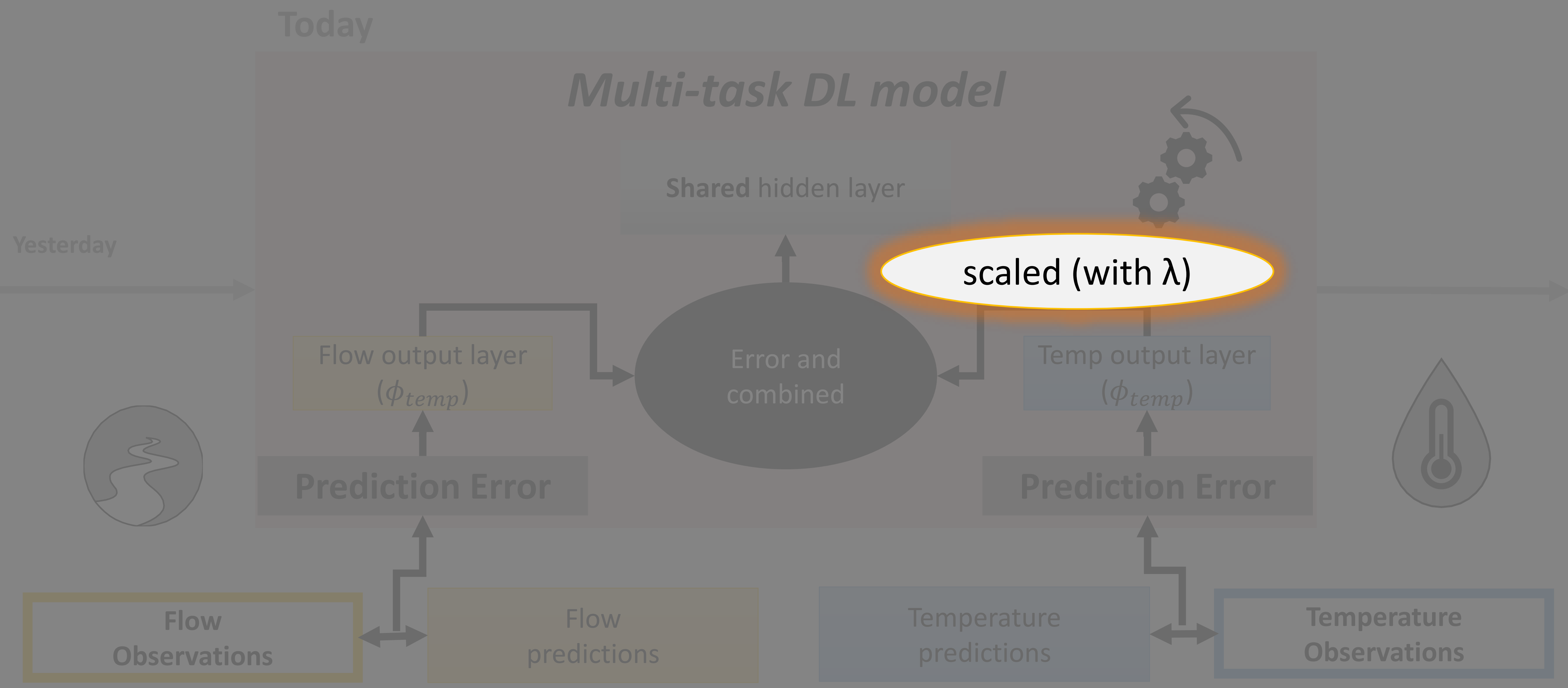


Gradient descent: updating the shared hidden layer parameters (θ)

$$\theta(i+1) \coloneqq \theta(i) - \alpha[\boxed{\nabla_\theta \mathcal{L}_{flow}(\theta(i), \phi_{flow}(i))} + \lambda\boxed{\nabla_\theta \mathcal{L}_{temp}(\theta(i), \phi_{temp}(i)}]$$

Gradient from errors in flow predictions

Gradient from errors in temp predictions

Gradient descent: updating the shared hidden layer parameters (θ)

$$\theta(i+1) \coloneqq \theta(i) - \alpha[\boxed{\nabla_\theta \mathcal{L}_{flow}(\theta(i), \phi_{flow}(i))} + \lambda \boxed{\nabla_\theta \mathcal{L}_{temp}(\theta(i), \phi_{temp}(i))})$$

Gradient from errors in flow predictions

Multi-task scaling factor

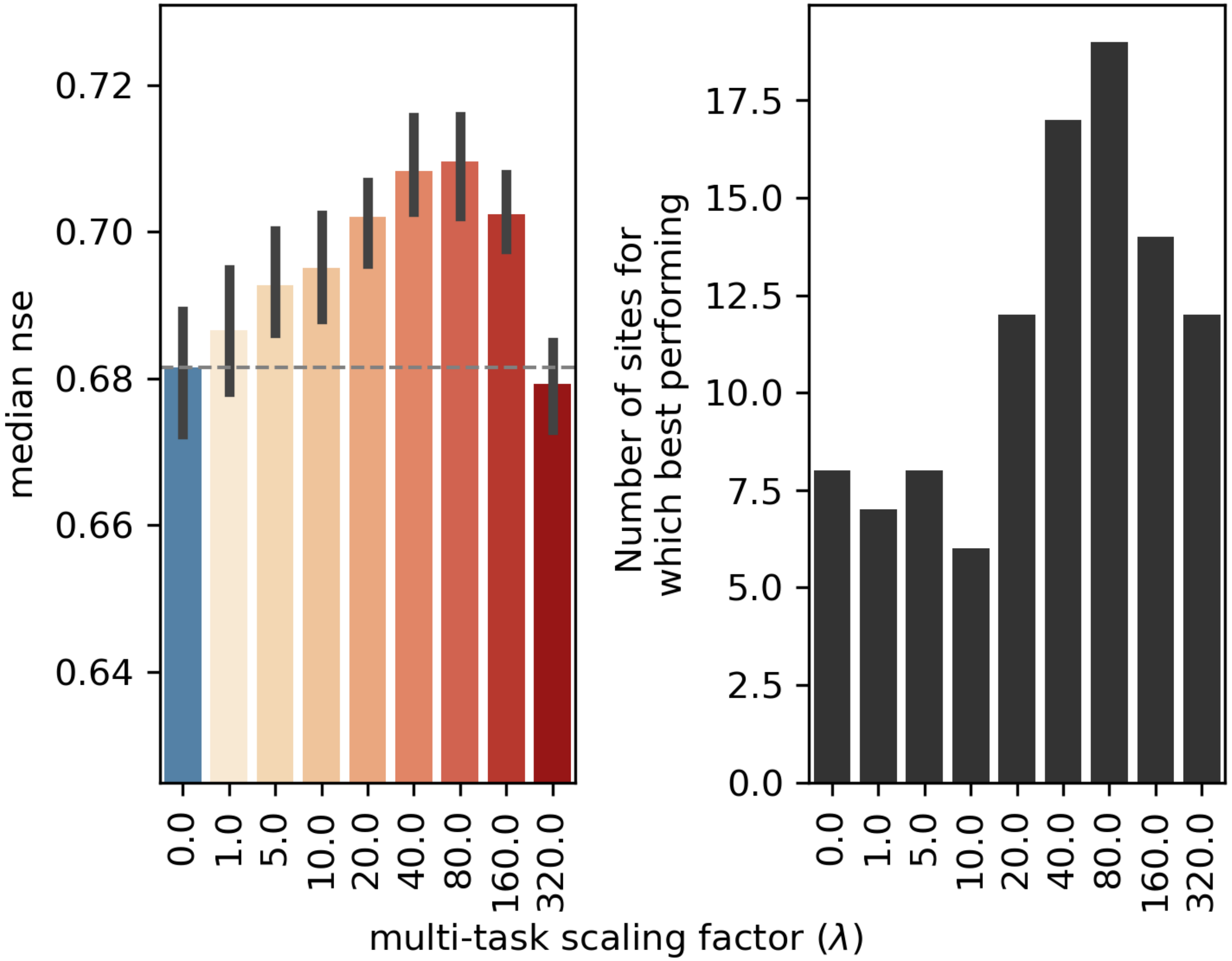
Gradient from errors in temp predictions

Experiments

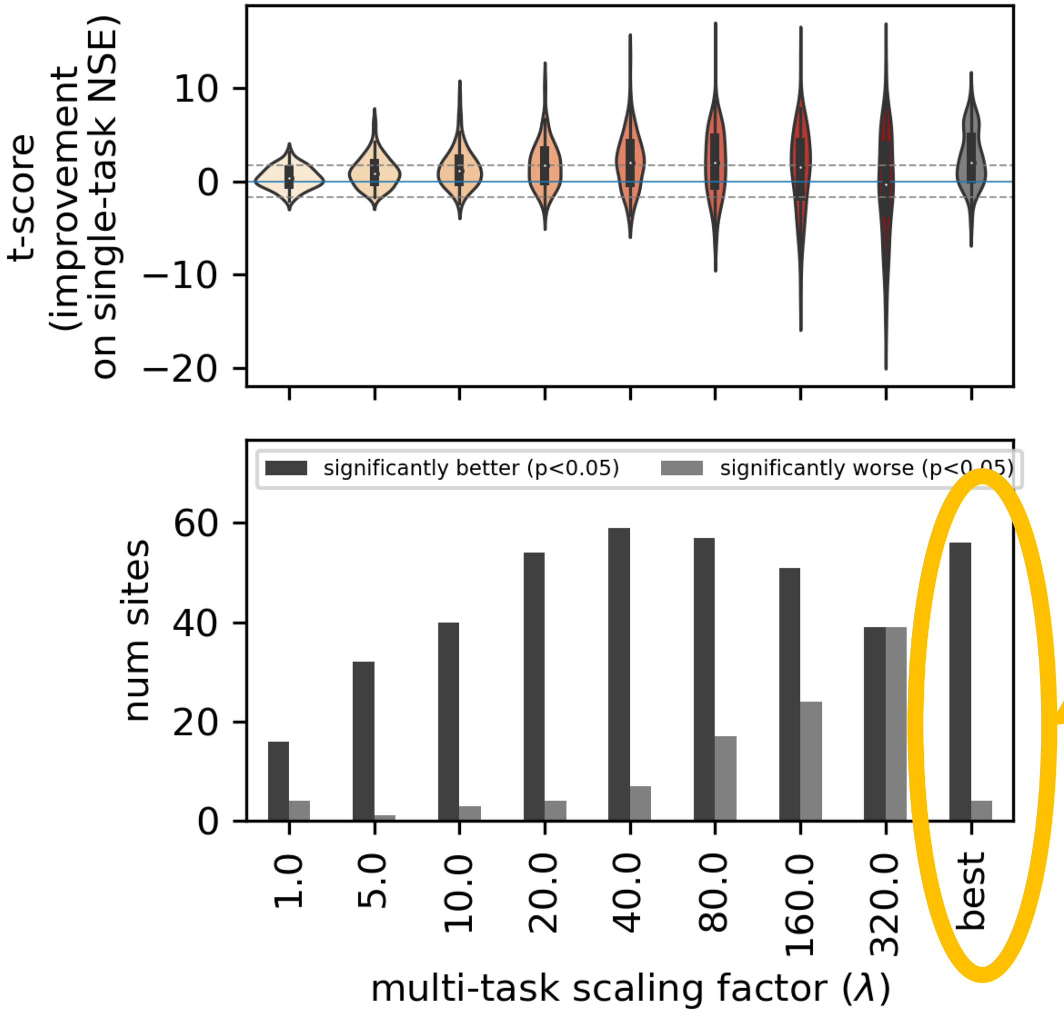
103 sites across the US

Part of CAMELS dataset (preprocessed flow/weather/attribute data)

Results: Effect of multi-task scaling factor



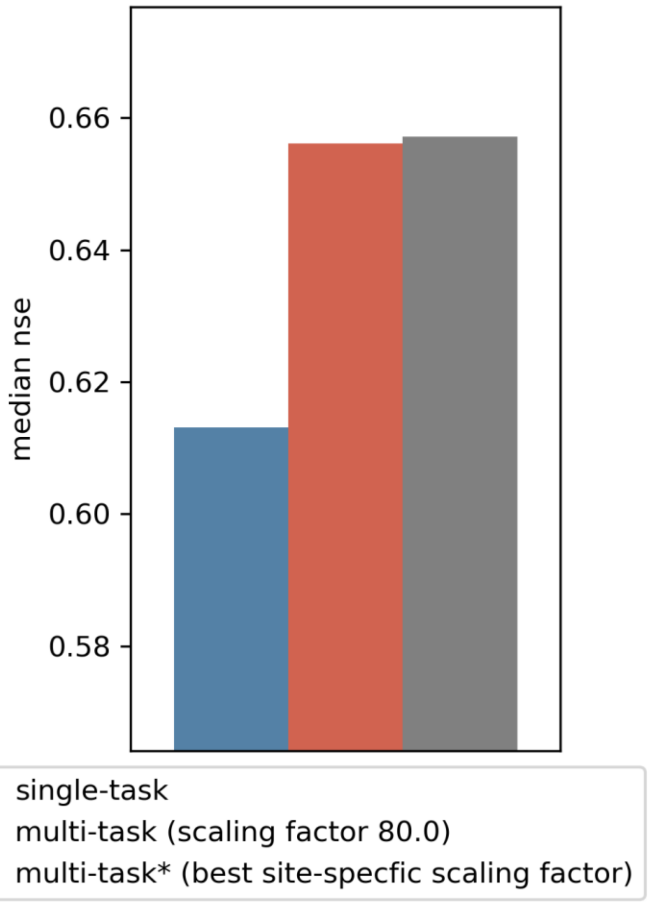
Results: Effect of multi-task scaling factor



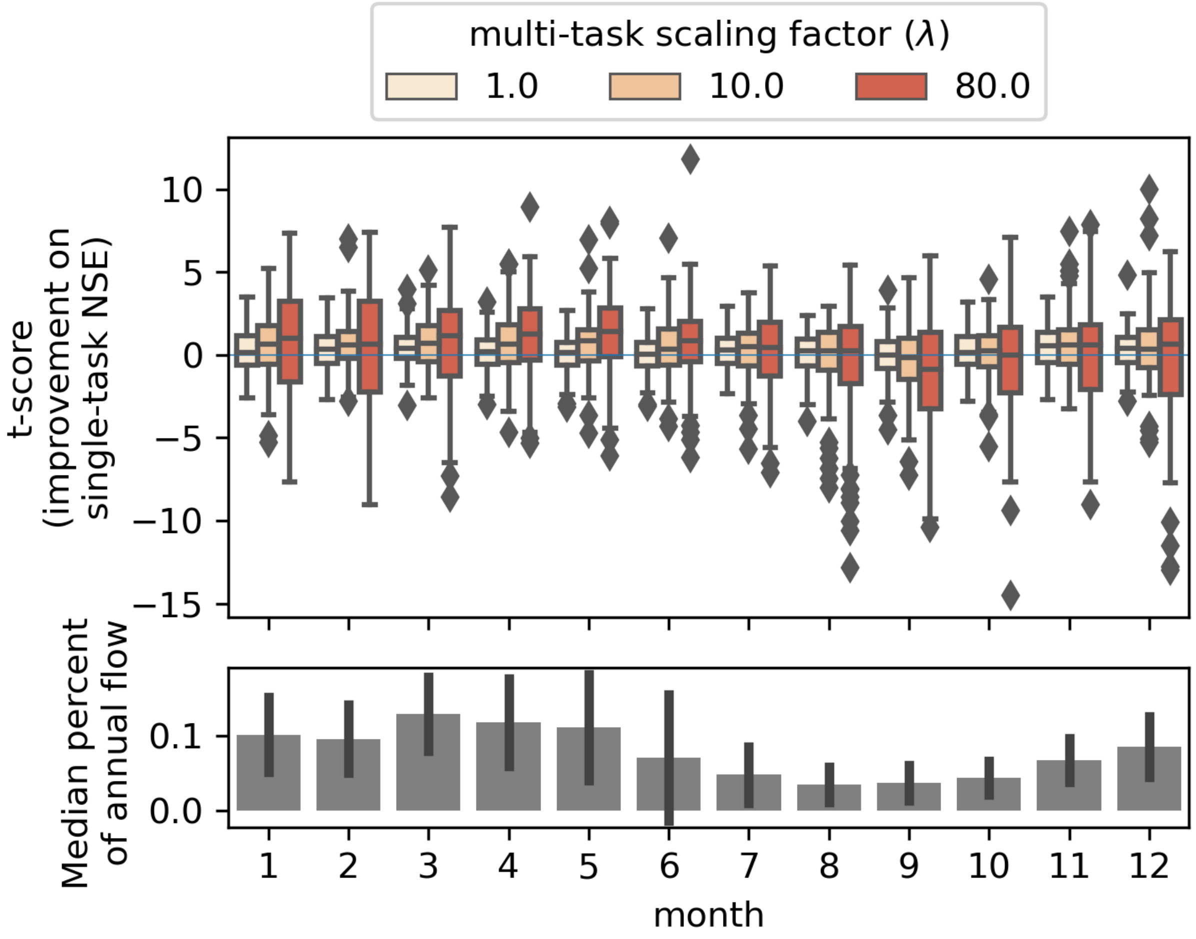
When the multi-task scaling factor was tuned on a site-by site basis:

- majority of sites significantly improved
- very few sites were significantly worse

Results: Multi-task is overall more accurate

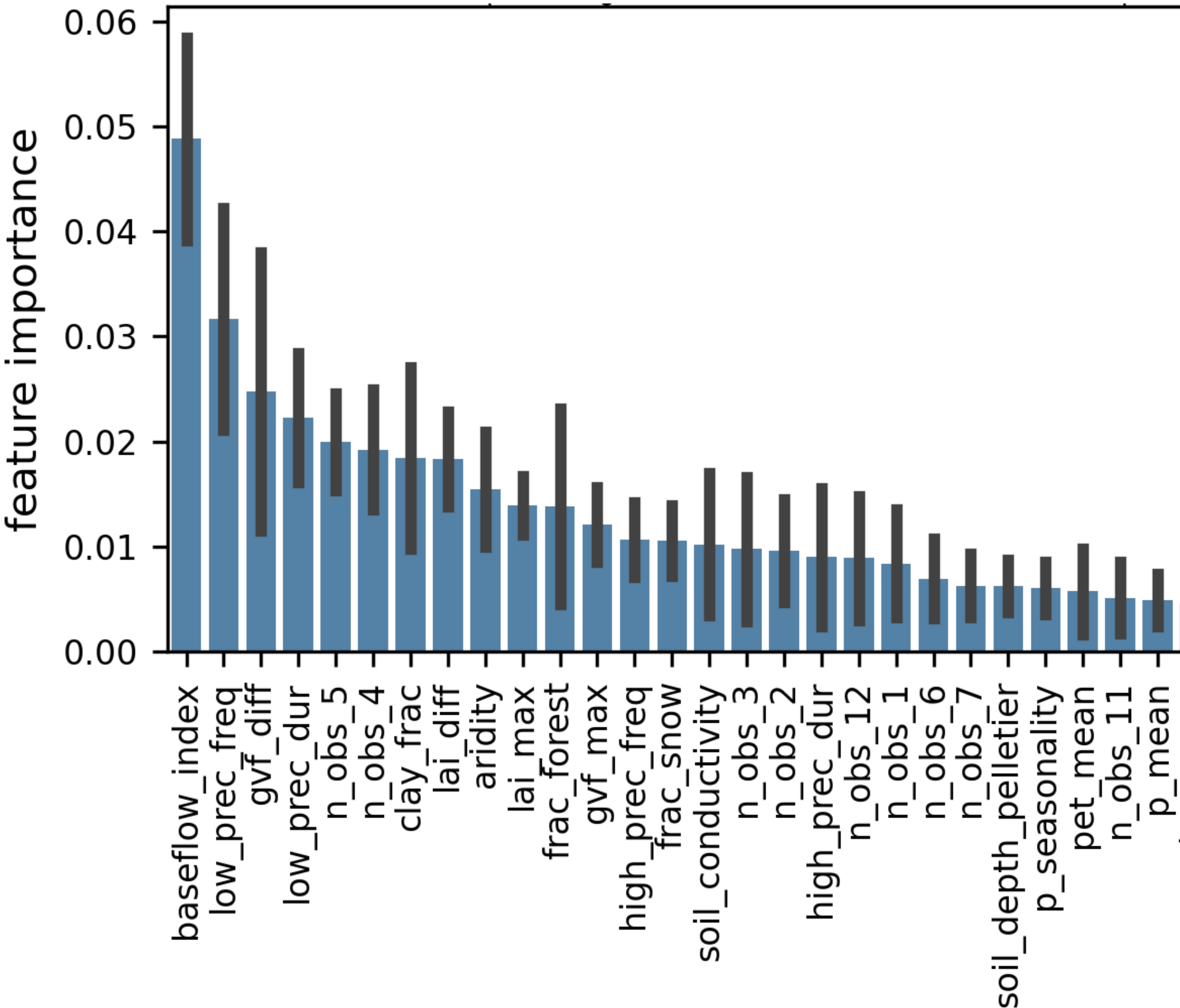


Results: Seasonality



Results: Seasonality

- Feature importances for predicting t-scores of multi-task model with scaling factor of 80
- $R2 = 0.27$
- Baseflow index was by far the most important variable



Stream temperature and flow predictions

inform key decisions

- ~28k - either streamflow **or** water temperature
- 19% - flow **and** temp*
- 78% - only flow

*Measuring temperature continuously costs less than 1/6 of measuring discharge

If properly configured, multi-task models could be an effective way to leverage these data to improve streamflow predictions

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