Do internals of neural networks make sense in the context of hydrology

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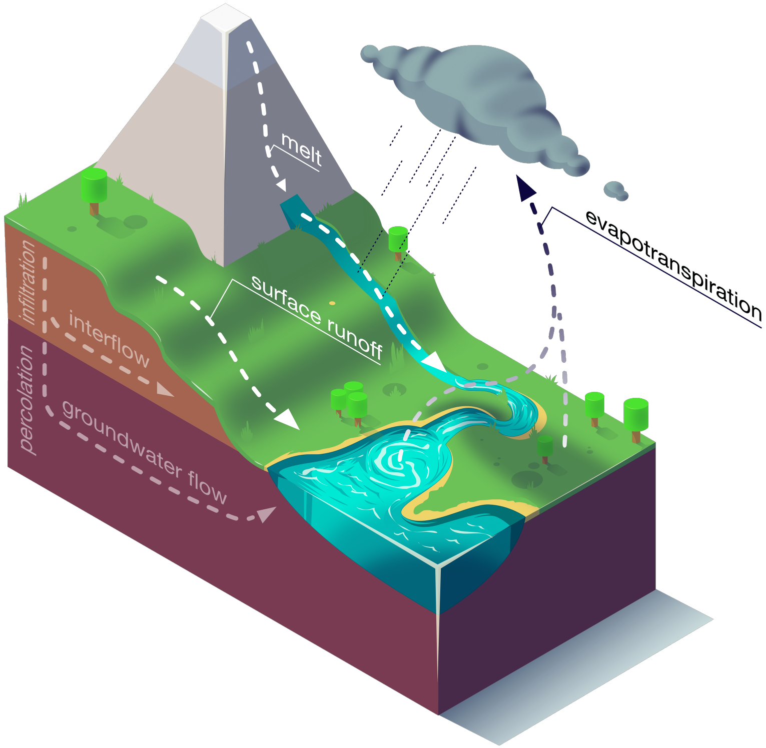
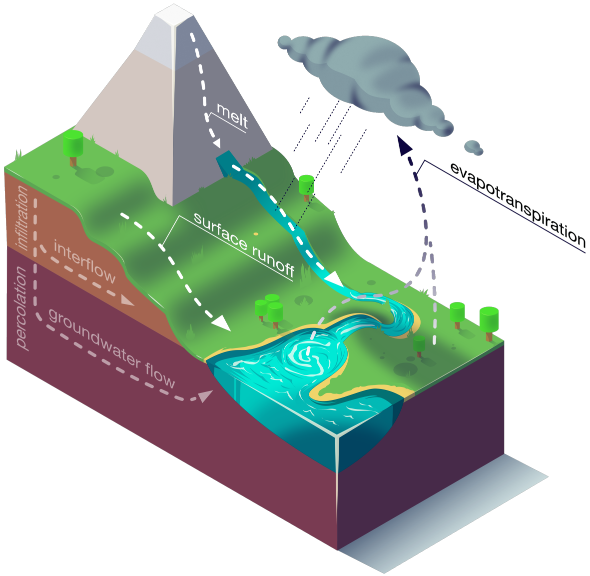
Rainfall-runoff modeling with LSTMs

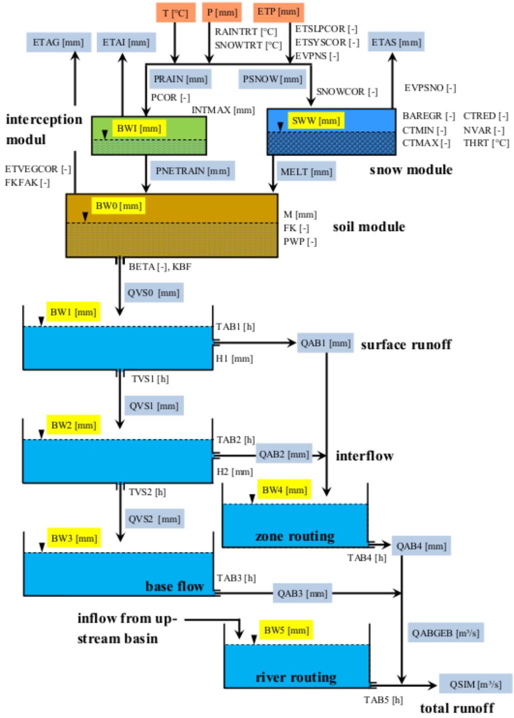


Classical modeling approach



State-(space)-model formulation:

$$\boldsymbol{S}_t = f(\boldsymbol{I}_t, \boldsymbol{S}_{t-1}, \Theta_i)$$
$$\boldsymbol{O}_t = f(\boldsymbol{I}_t, \boldsymbol{S}_t, \Theta_j)$$



COSERO model, taken from official handbook

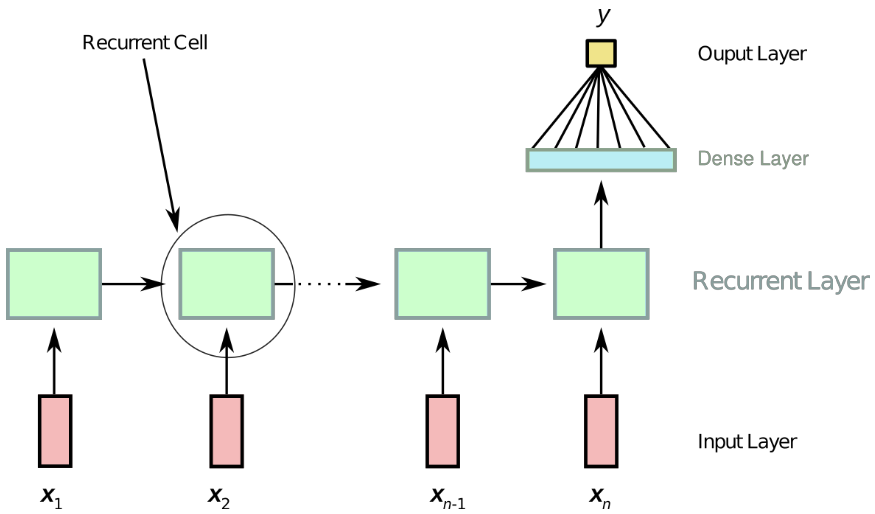
Long Short-Term Memory (LSTM)

- Recurrent neural network with explicit memory [1]
- State of the art for many applications
  - Used e.g. in Siri, Google Assistant, Alexa
- Works very well for rainfall-runoff modeling [2]

[1] Hochreiter, S., & Schmidhuber, J. (1997). Long short-term memory. Neural computation, 9(8), 1735-1780.

[2] Kratzert, F., Klotz, D., Brenner, C., Schulz, K., and Herrnegger, M.: Rainfall–runoff modelling using Long Short-Term Memory (LSTM) networks, Hydrol. Earth Syst. Sci., 22, 6005-6022.

Long Short-Term Memory (LSTM)

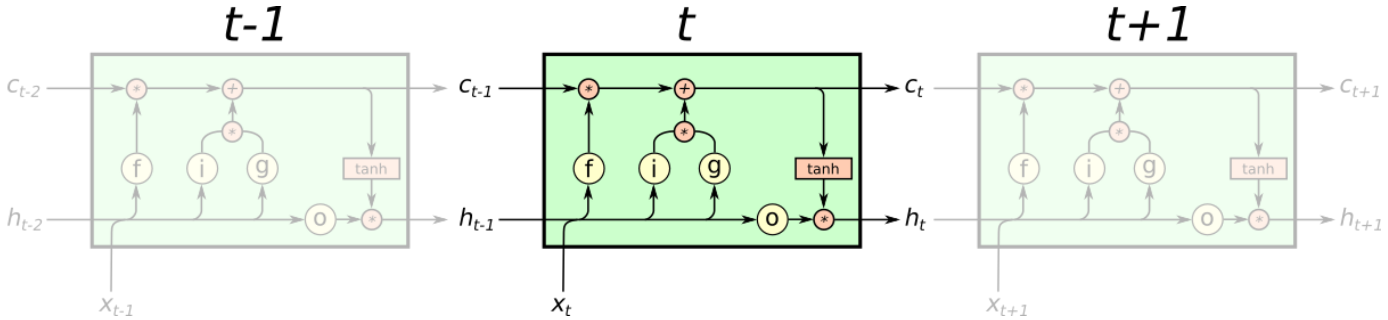


Hyd. State-(space)-model formulation:

$$\boldsymbol{S}_t = f(\boldsymbol{I}_t, \boldsymbol{S}_{t-1}, \Theta_i)$$
$$\boldsymbol{O}_t = f(\boldsymbol{I}_t, \boldsymbol{S}_t, \Theta_j)$$

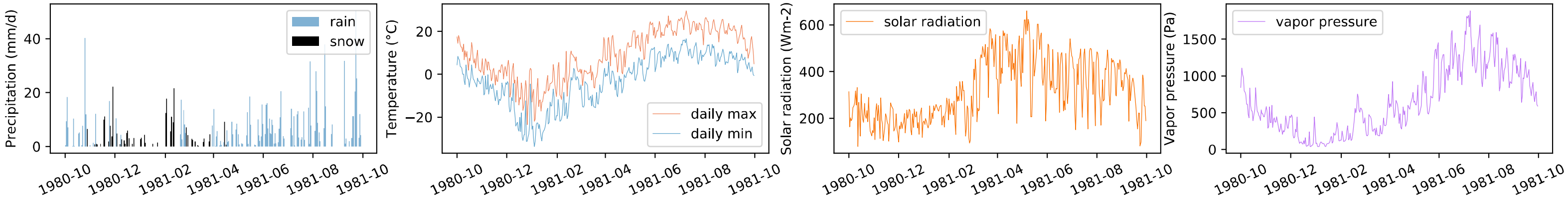
Analogous for the LSTM:

$$\{\boldsymbol{c}_t, \boldsymbol{h}_t\} = f_{\mathrm{LSTM}}(\boldsymbol{x}_t, \boldsymbol{h}_{t-1}, \boldsymbol{c}_{t-1}, \Theta_k)$$
$$y_t = f_{\mathrm{Dense}}(\boldsymbol{h}_t, \Theta_l)$$



Data + Setup

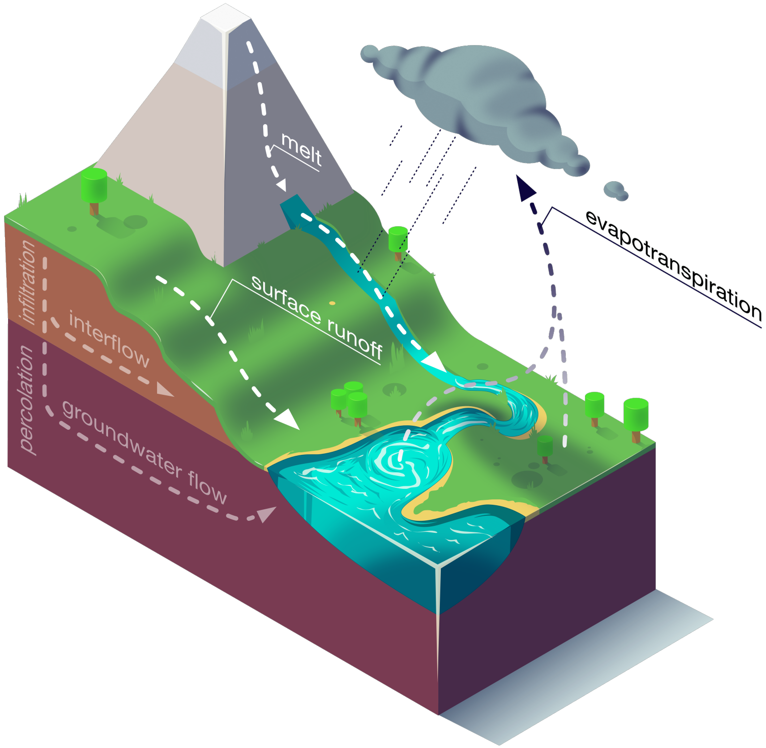
- 47 humid & snow-influenced basins [3]
- 20 yrs for training, 5 yrs for validation, remaining ~7 yrs for final evaluation
- Task: predict discharge of single day from previous 365 daily meteorological observations



$$q = 2.44 \frac{mm}{d}$$

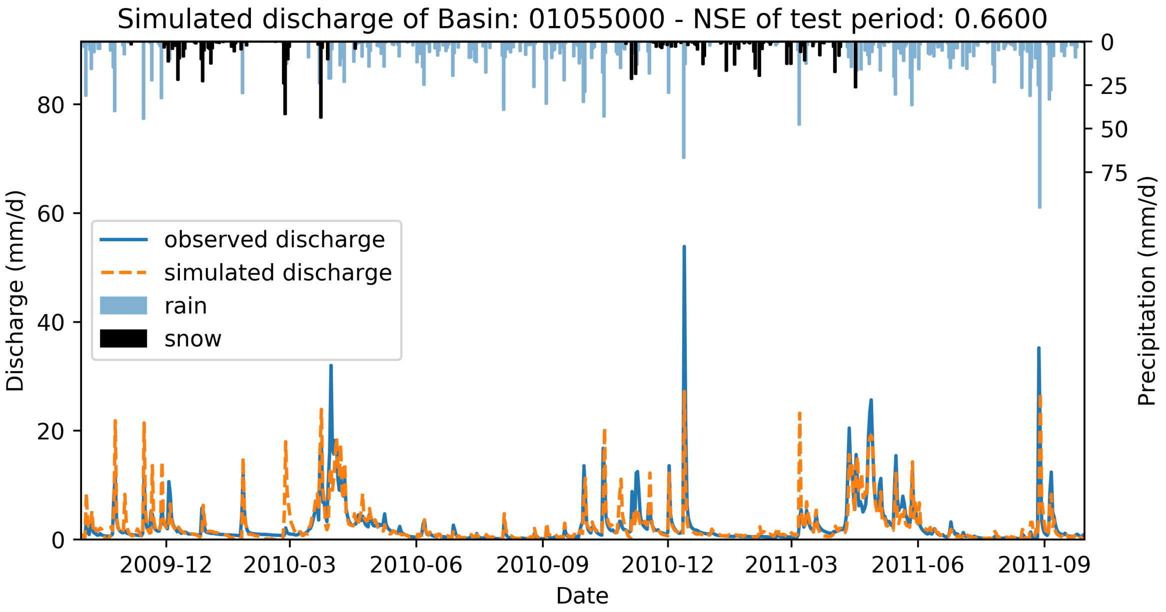
[3] A. Newman; K. Sampson; M. P. Clark; A. Bock; R. J. Viger; D. Blodgett, 2014. A large-sample watershed-scale hydrometeorological dataset for the contiguous USA. Boulder, CO: UCAR/NCAR.

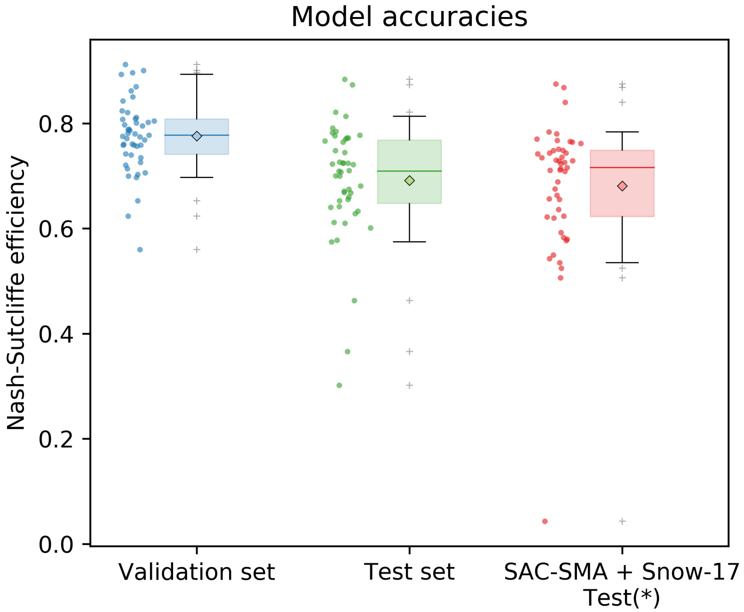
Results and network inspection



Model accuracy

- Comparable performance to SAC-SMA + Snow-17

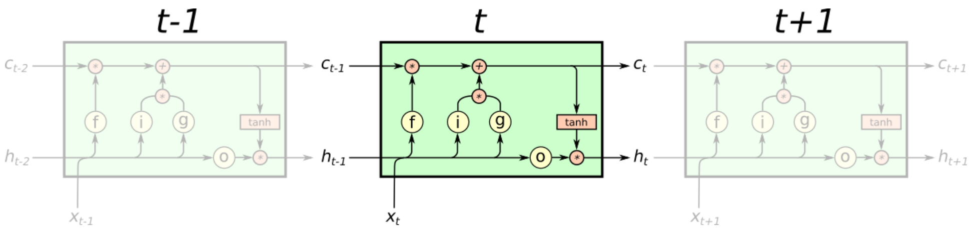




(*) covers not the exact same period.
Only meant for rough comparison

First glimpse into the LSTM

Found on the last days before submitting HESS paper



First glimpse into the LSTM

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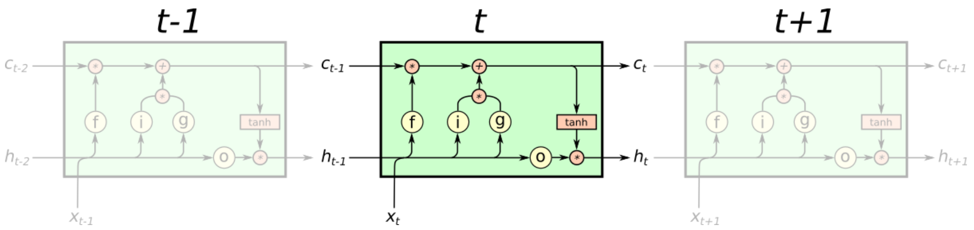
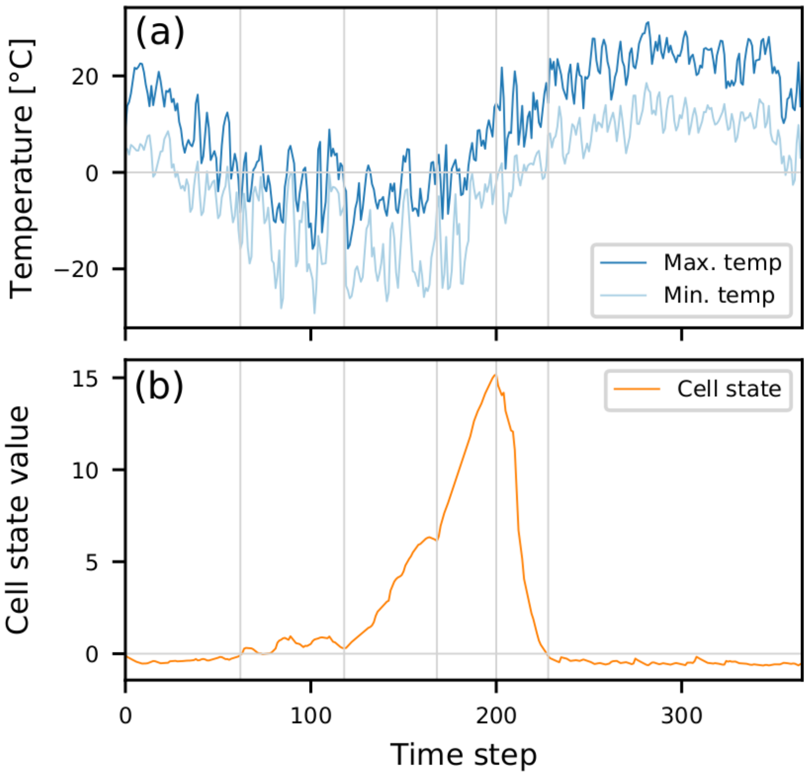
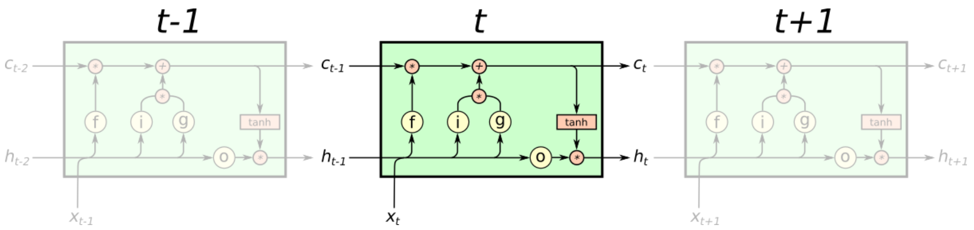
➔ Coincidence?

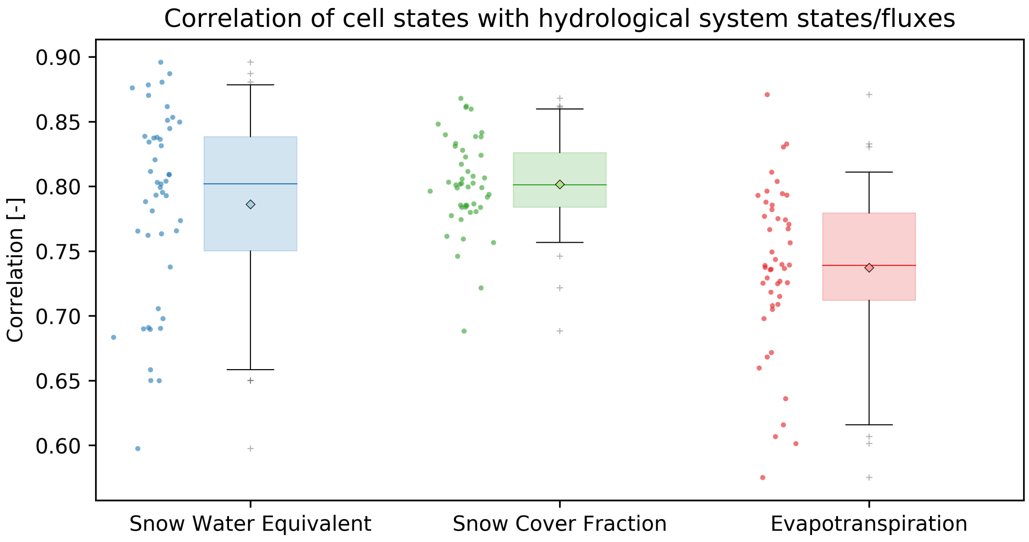




Correlations

- LSTM memory cell (c_t) & cell output (h_t) vs. hydrological states/fluxes
  - SCF + ET from MODIS
  - Modeled SWE from SAC-SMA/Snow-17

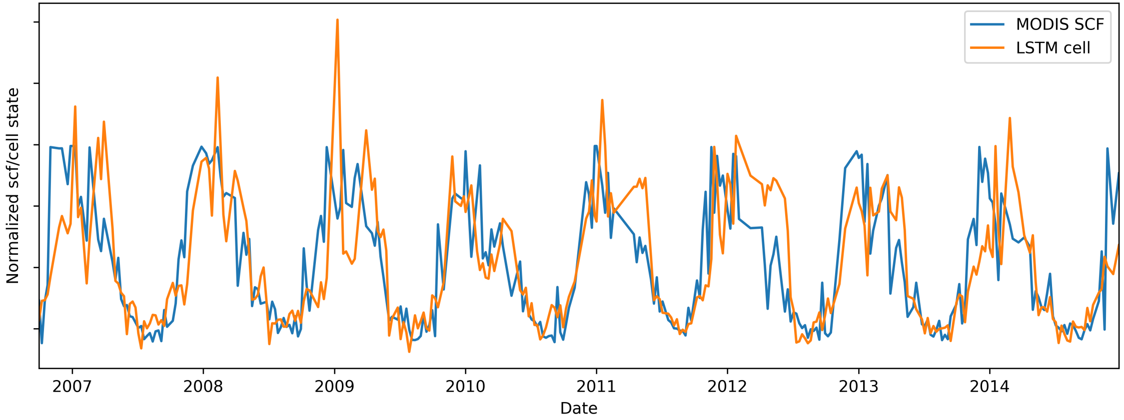




Some examples

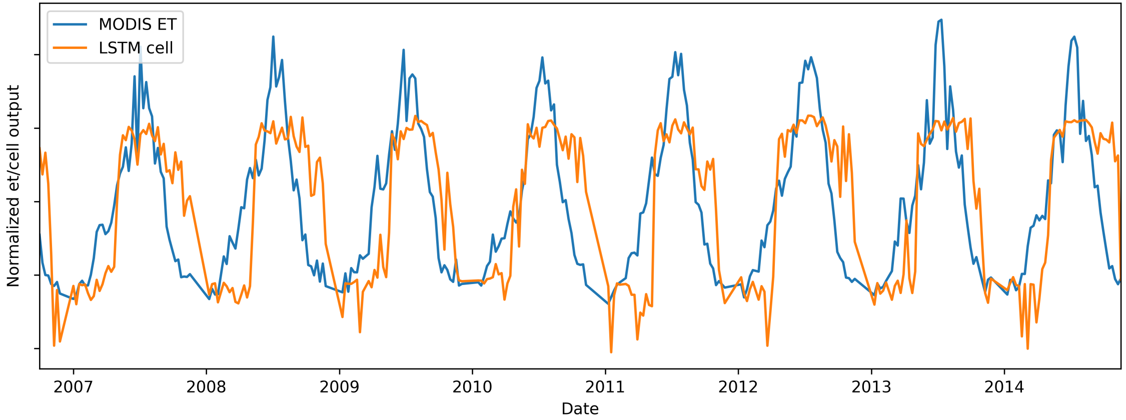
- **SCF:** Plot of basin most similar to median correlation

Snow cover fraction (SCF) cell: corr=0.80, p=2.17e-66



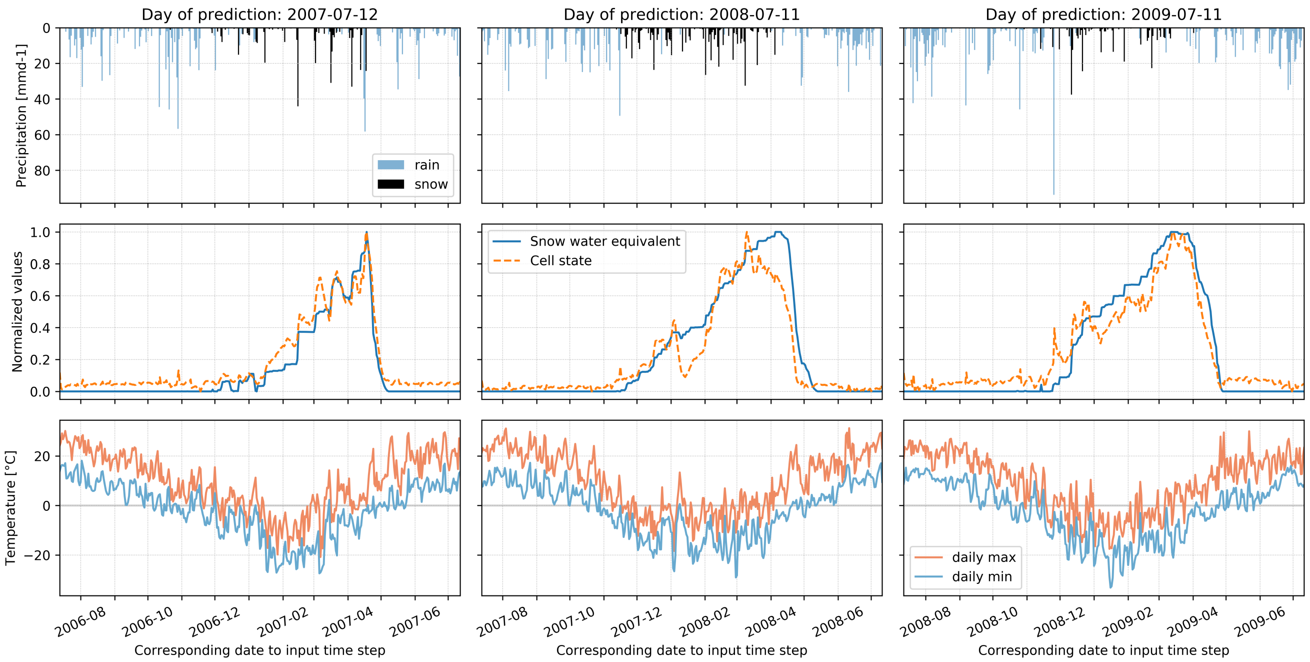
- **ET:** Plot of basin most similar to median correlation

Evapotranspiration (ET) cell: corr=0.73, p=8.21e-55



Snow cell

Remember: LSTM has never seen SWE data. Purely learned from rainfall-runoff task.



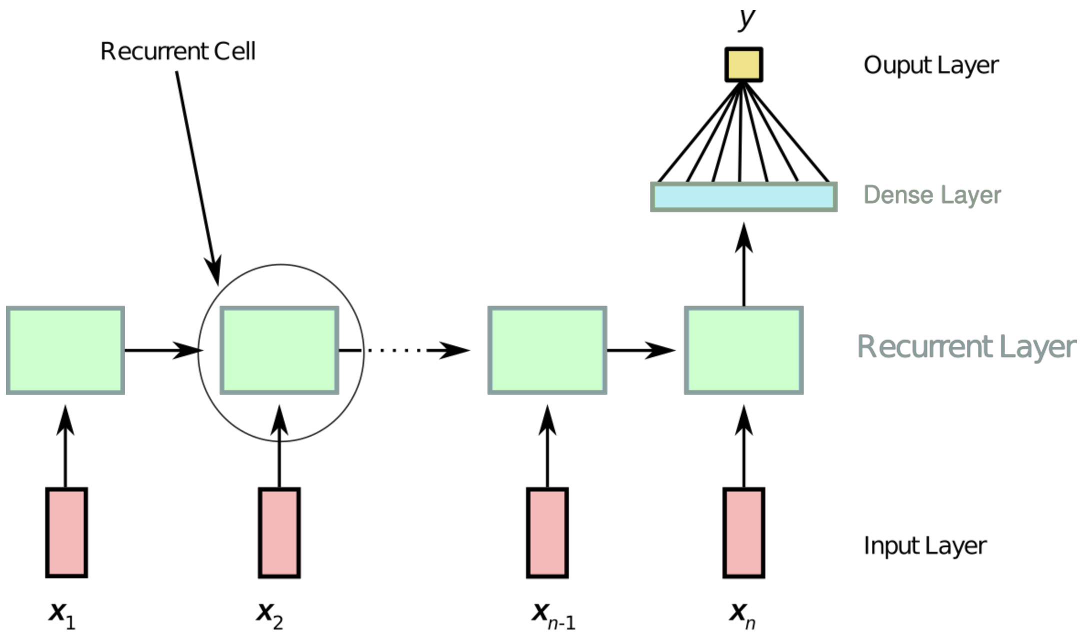
Questions?

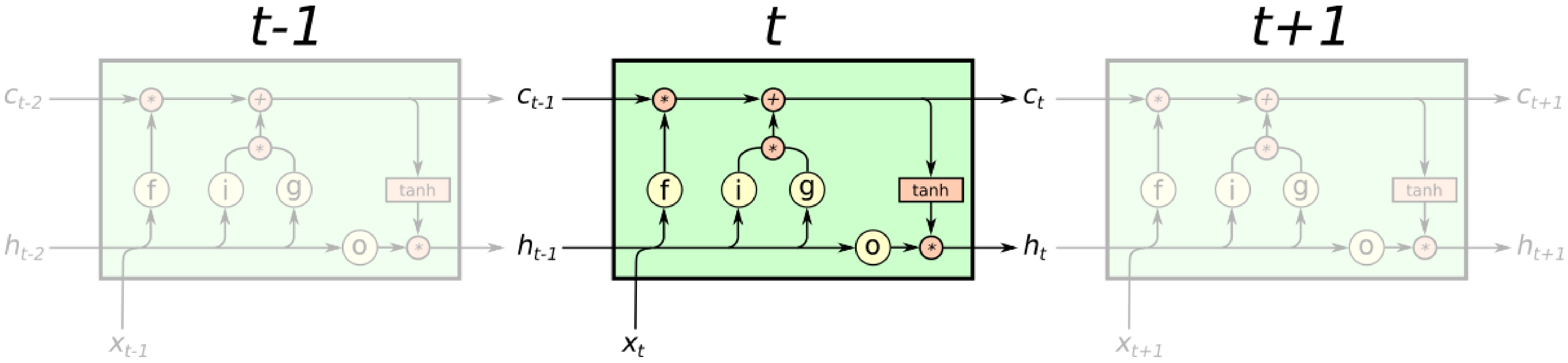
Slides + Code for reproducing results:
https://github.com/kratzert/AGU2018

@fkratzert

$$
\begin{aligned}
\mathbf{f}_t &= \sigma(\mathbf{W}_f \mathbf{h}_{t-1} + \mathbf{U}_f \mathbf{x}_t + \mathbf{b}_f) \\
\mathbf{i}_t &= \sigma(\mathbf{W}_i \mathbf{h}_{t-1} + \mathbf{U}_i \mathbf{x}_t + \mathbf{b}_i) \\
\mathbf{g}_t &= \tanh(\mathbf{W}_g \mathbf{h}_{t-1} + \mathbf{U}_g \mathbf{x}_t + \mathbf{b}_g) \\
\mathbf{o}_t &= \sigma(\mathbf{W}_o \mathbf{h}_{t-1} + \mathbf{U}_o \mathbf{x}_t + \mathbf{b}_o)
\end{aligned}
$$

$$
\begin{aligned}
\mathbf{c}_t &= \mathbf{f}_t \odot \mathbf{c}_{t-1} + \mathbf{i}_t \odot \mathbf{g}_t \\
\mathbf{h}_t &= \mathbf{o}_t \odot \tanh(\mathbf{c}_t)
\end{aligned}
$$





A glimpse into the Unobserved: Runoff simulation for ungauged catchments with LSTMs

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Workshop on Modeling and Decision-Making in the Spatiotemporal Domain, 32nd Conference on Neural Information Processing Systems (NIPS 2018), Montréal, Canada.

https://openreview.net/pdf?id=Bylhm72oKX