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Recursive neural networks for application-focussed emulation of groundwater models

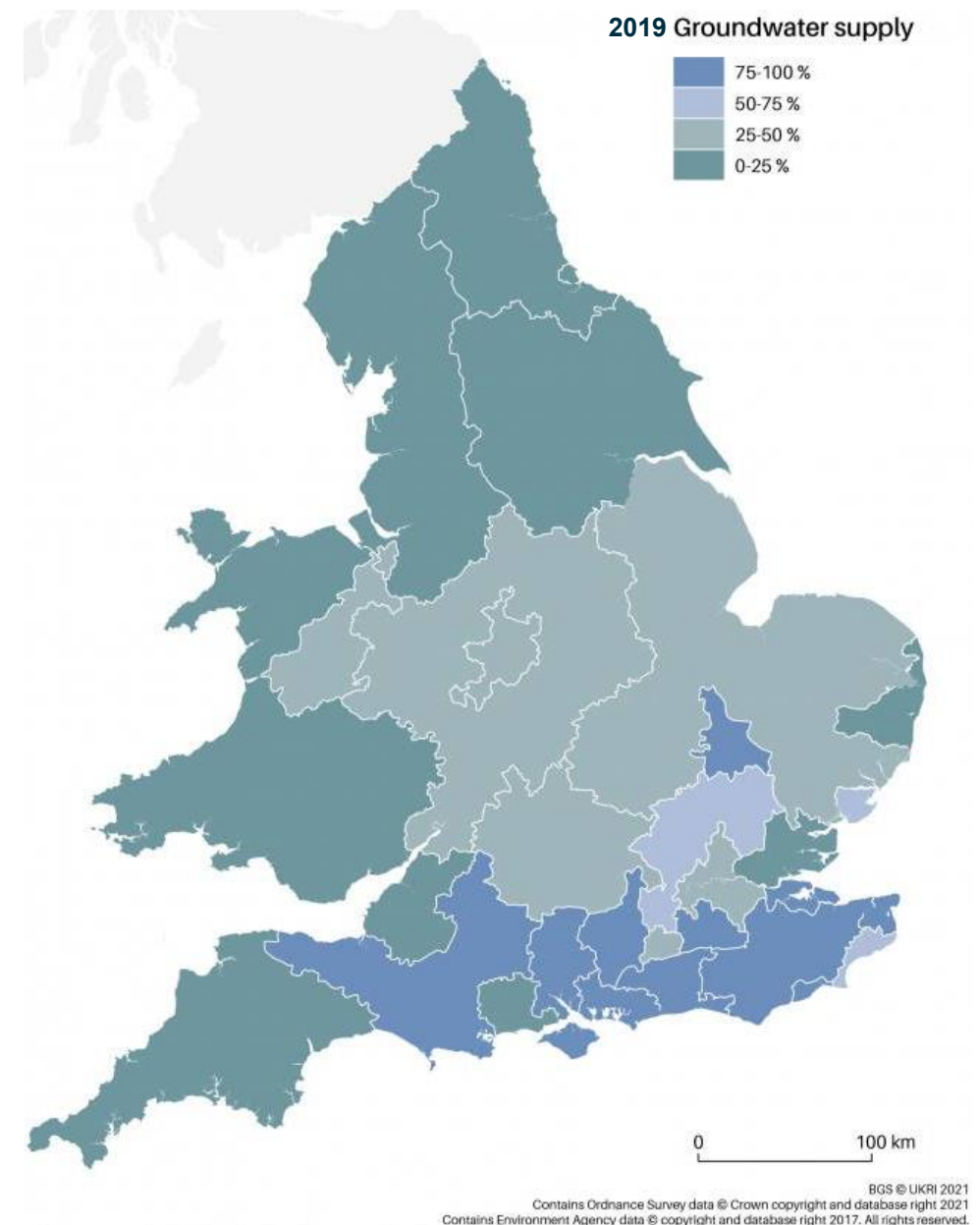
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British
Geological
Survey

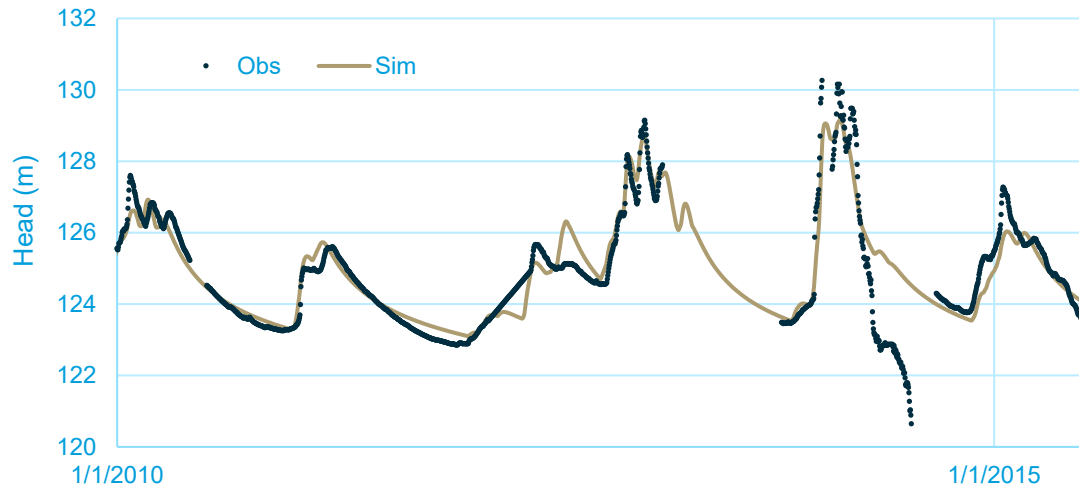
Motivation

- Groundwater provides a third of England's public water supply
 - Around 1,400 licenced abstraction boreholes
 - Total abstraction around 1.7 billion cubic metres per year
- Ensuring sustainable supply requires rapid scenario investigation:
 - How will groundwater levels react to abstraction this summer?
 - What abstraction rates would be sustainable in future droughts?
- Water companies need rapid, easy-to-use models

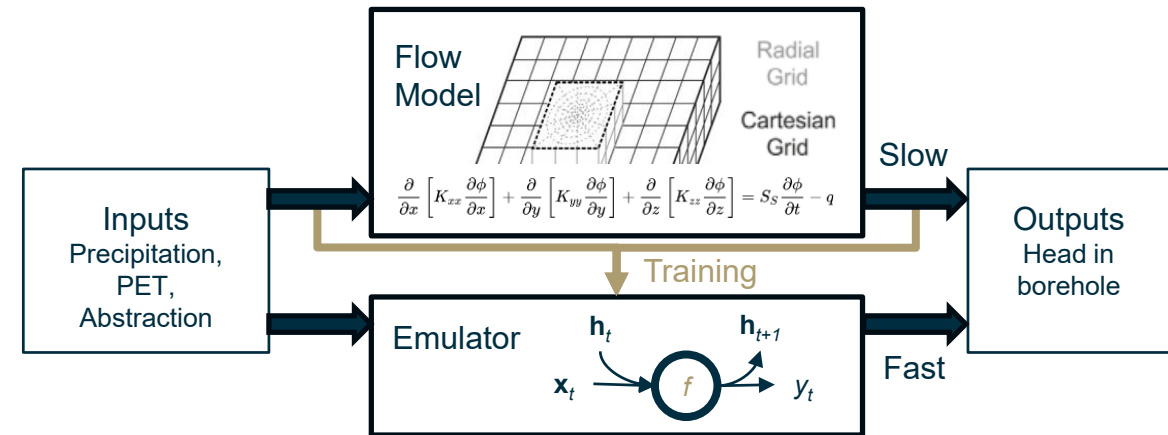


Aim

- BGS has validated and widely applied physics-based models:
 - AquiMod: lumped catchment model for groundwater recharge and discharge
 - SPIDERR: 3D Radial-Cartesian Darcy-Forchheimer solver for near-well flow
- Running physics-based models requires time and expertise
- We want an ‘emulator’, to simply and rapidly approximate such predictions



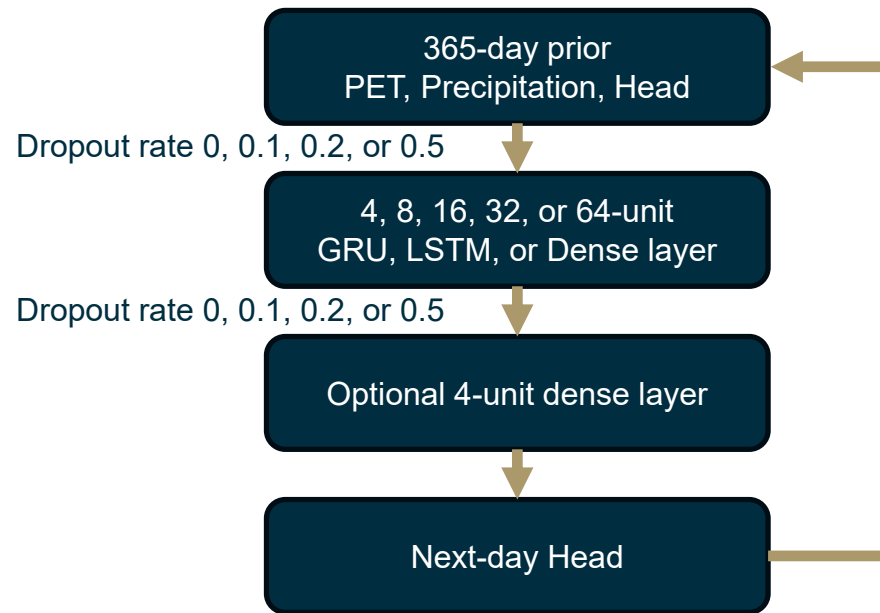
Comparison of AquiMod-SPIDERR simulations to observations at Marlborough borehole



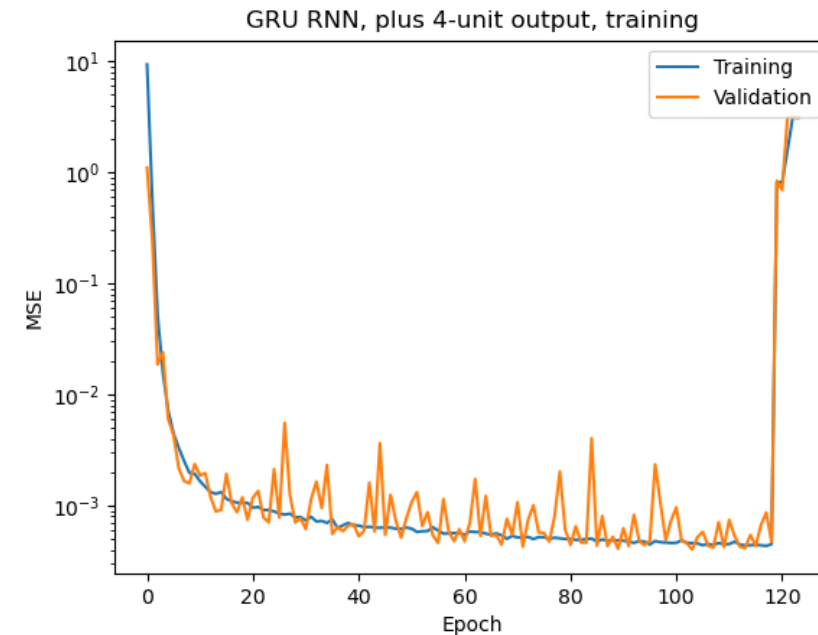
Conceptual schematic of emulator

Approach

- Run a coupled Aquimod-SPIDERR model for the Marlborough site for a wide range of scenarios:
 - Random, synthetic abstractions, with a range of moving averages, values, gradients
 - Historical PET with precipitation at 75%, 100%, 125% of historical values
 - 12 Regional Climate Model (RCM) 100-year scenarios for future PET and precipitation
- Use the (input, output) pairs to train a Recursive Neural Network (RNN) for iterative next-day prediction
 - Use held-out scenarios for early stopping and grid search hyperparameter tuning



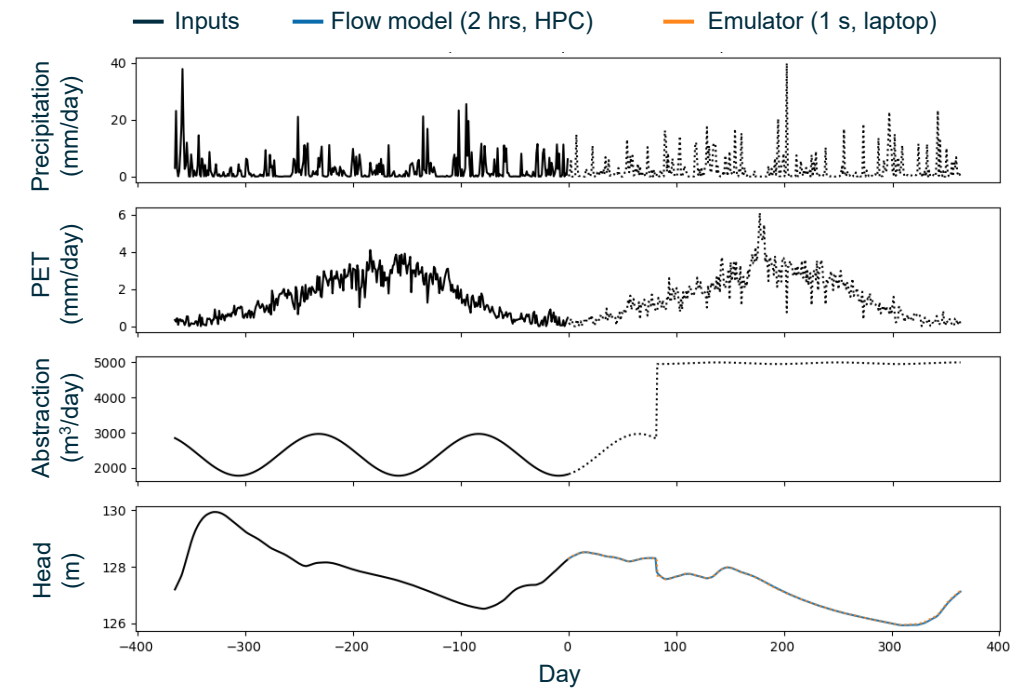
Schematic of RNN architecture



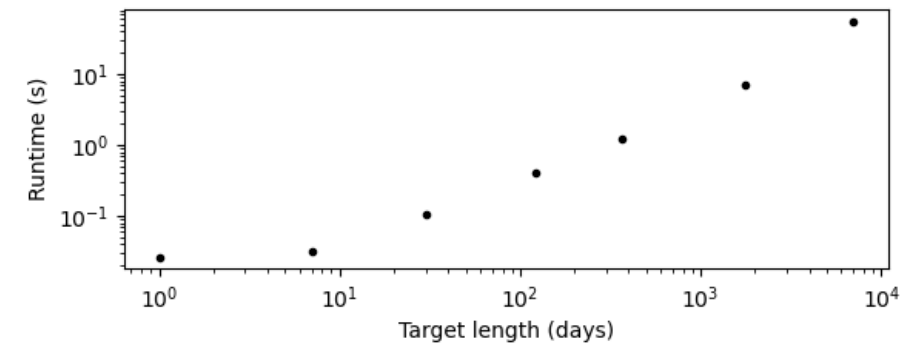
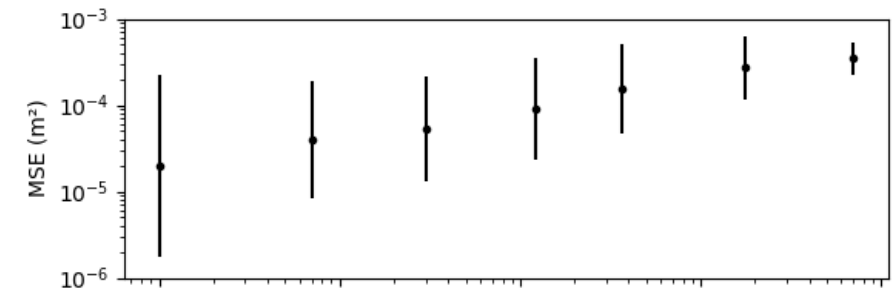
Mean squared error of predictions during training

Results

- Optimum RNN:
 - 32 GRUs, 10% output dropout, summary layer
- RMS 1-year approximation error over test scenarios:
 - Approximately lognormally distributed
 - Median 1.2 cm, $\sigma = 0.6$
- Variation with forecast horizon:
 - Error grows sub-linearly
 - Example average runtime ~ 1 second / year



Predictions for example from test dataset



Application

Deploy ⋮

Select data

Model scenario

Calculate DO curve

Select data

Data selection

Which emulator would you like to use?

AS demo

▼

Which meteorological data would you like to use as the basis for modelling?

Uploaded point data

▼

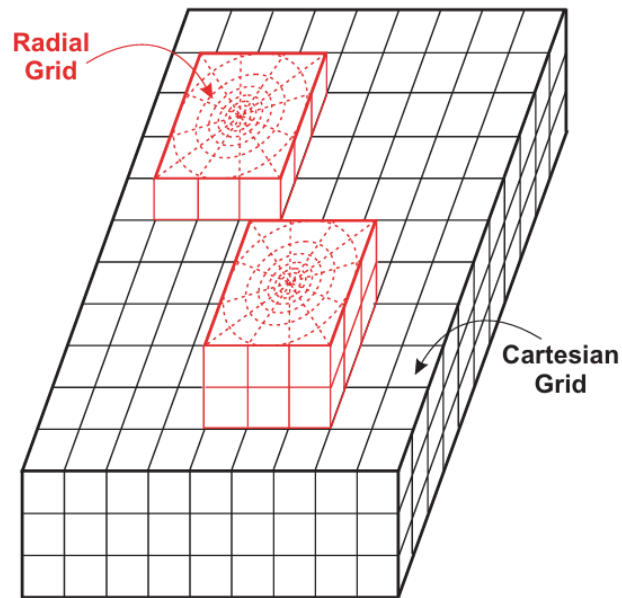
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Conclusions

- Our RNN is effective at rapidly emulating the Aquimod-SPIDERR flow model's predictions
- The emulator facilitates both short-term forecasts and long-term projections
- Our approach is generalisable to more complex, multiple-well sites
- Machine-learning-based emulators can make physics-based models accessible to stakeholders



Schematic of multiple-well flow model



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