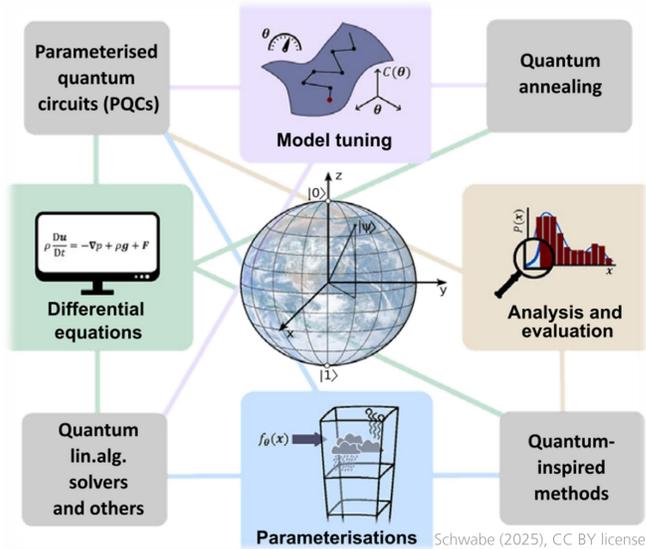


# Klim-QML

## Improving climate models with quantum computing

We improve climate models and their development process with quantum machine learning and quantum computing for robust technology assessment and mitigation recommendations.

- Applications
- Quantum machine learning

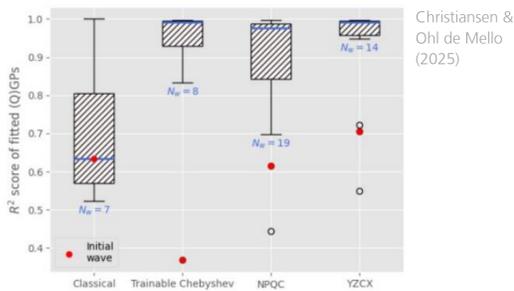


### Quantum computing has great potential to improve various components of Earth system models and their development

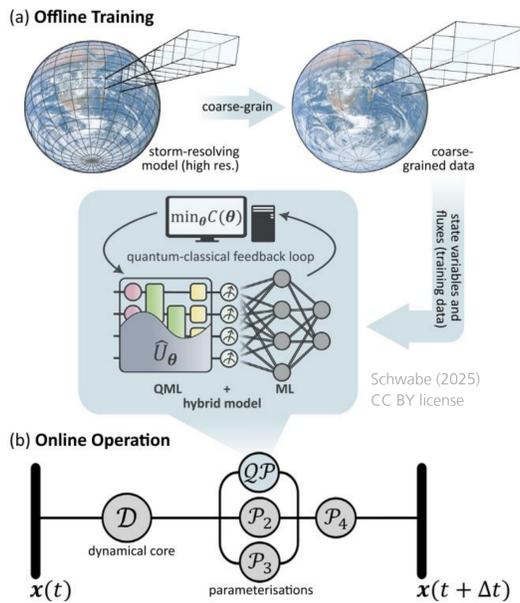
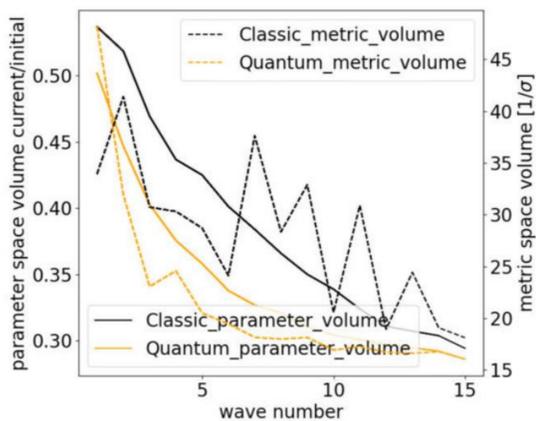
- Model tuning: Calibrating the model, currently often done manually, which is slow and subjective
- Differential equations: Form the core of the model, very compute intensive, could be accelerated with quantum methods
- Parameterizations: Describe subgrid-scale (unresolved) processes, not very accurate, could be improved by training QML models on high-resolution data

### Quantum-assisted pipeline for climate model tuning

- Automatic tuning pipeline based on history matching and Gaussian processes
- First step: Quantum-assisted tuning of toy model (Lorenz-96)



- Integration into tuning pipeline, successful tuning of coarse ICON climate model for two metrics and two parameters

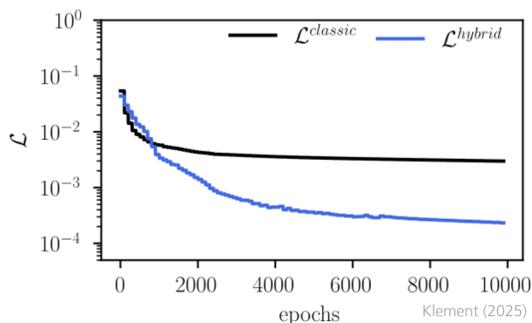


### Training QML models with high-resolution Earth system model (ESM) simulations

- Short high-res simulation as training data
- Calculate target variables at coarse (ESM resolution) scale
- Train hybrid ML-QML model
- Finally couple QML-based parameterization to ESM

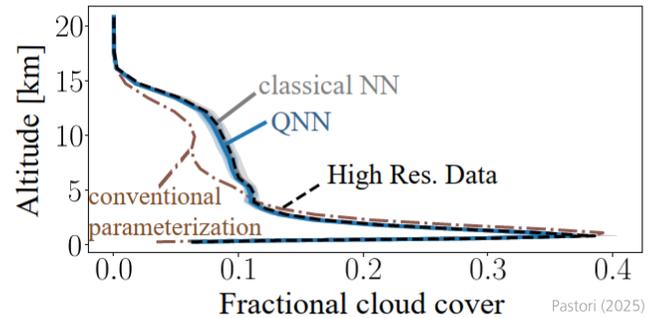
### Accelerate resolution of underlying partial differential equations (PDEs)

- Use QNN to solve PDEs (Klement 2025)
- NISQ ready
- Hybrid quantum-classical models train faster than purely classical



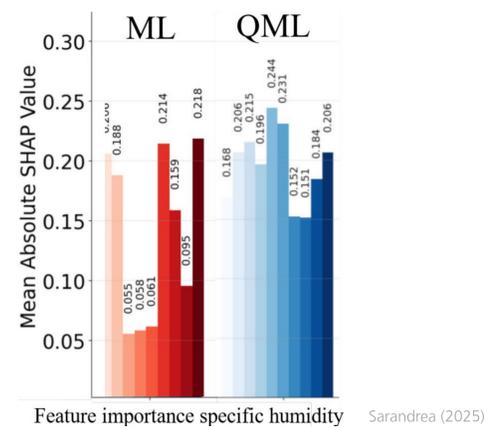
Loss during training of a classical (black) and hybrid (quantum-classical) model to learn the solution of PDEs

- Fault-tolerant methods (Häbel 2025)
- Classical linearization of the nonlinear equations
- Solution of the resulting linear systems with a quantum linear-system algorithm (QLSA) (e.g., HHL/QSVT)



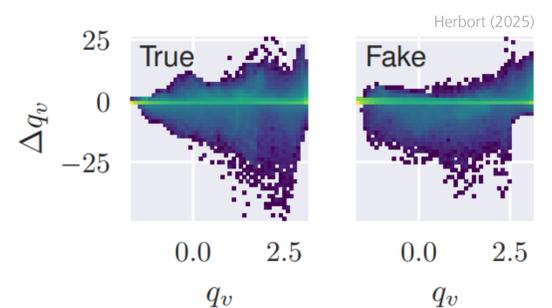
### Successful implementation of QML-based parameterization for cloud cover

- QML-based parameterization of cloud cover significantly better than conventional parameterization, on par with classical NN
- Training of quantum QML model more stable than training of classical ML model



### Parameterizations selected by use case of ship emissions

- Further parameterizations that we work on: Microphysics, turbulence, boundary layer height
- Develop generative model to represent distributions



### Upcoming:

- Coupling the QML-based parameterizations to the climate model ICON
- Tests on QC hardware

Session "Quantum Computing for Earth Observation and Climate Modelling" at the General Assembly of the European Geosciences Union (EGU) 2026 <https://s.dlr.de/qcegu26>



More information about the project on our website <https://qci.dlr.de/klim-qml/>



A project of



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