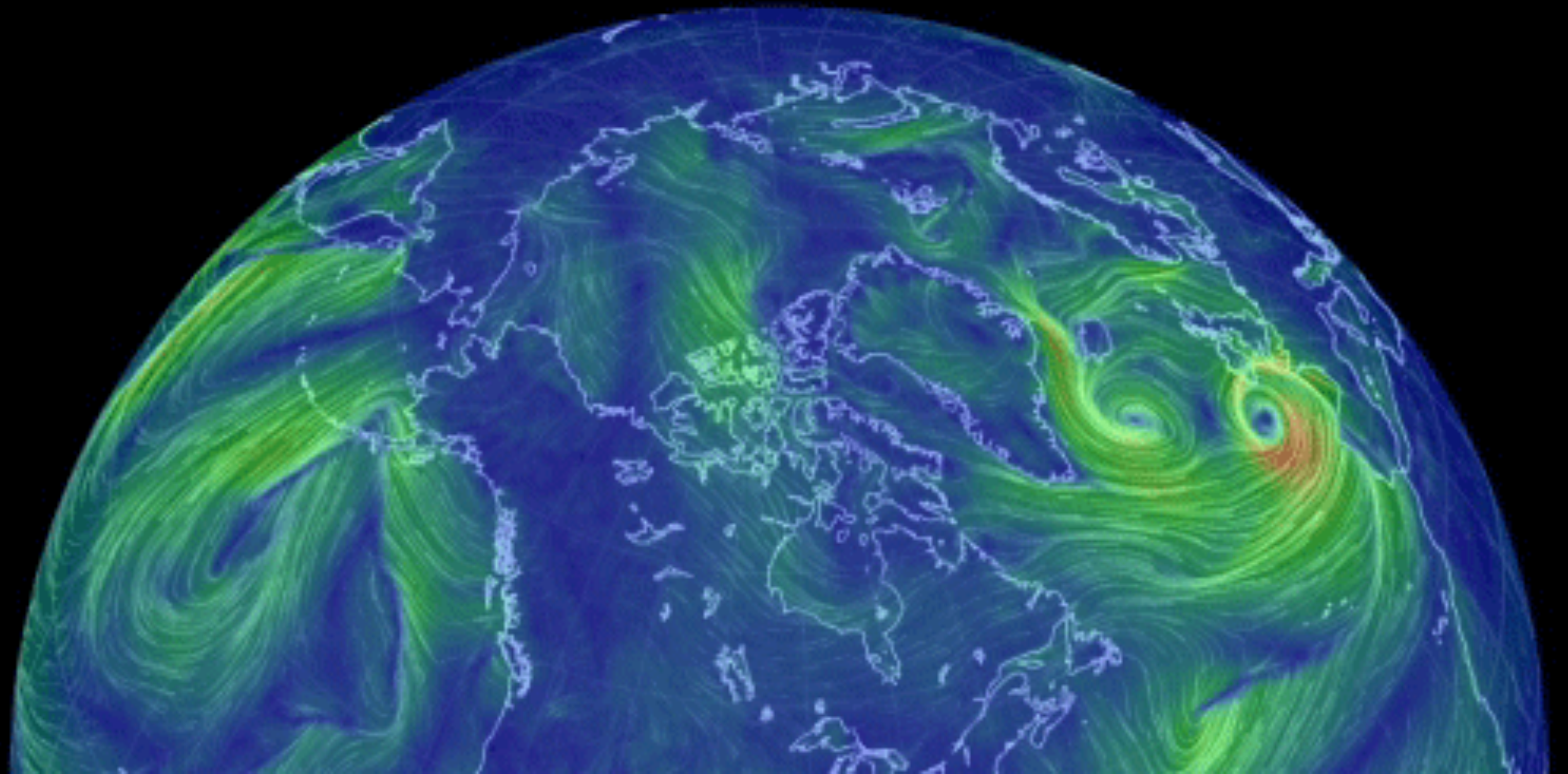


Tackling Climate Challenges with Quantum Computing

NSTF Discussion Forum: Quantum Science & Technology

20 November 2025



About Me



Shivani Pillay

- PhD Candidate in Computer Science @ University of KwaZulu-Natal
- CEO and Co-Founder of Fraqtal Technologies

<https://www.fraqtaltechnologies.ai/>

- Developer of PINN-kit, an open source Python package for solving differential equations with Physics-Informed Neural Networks

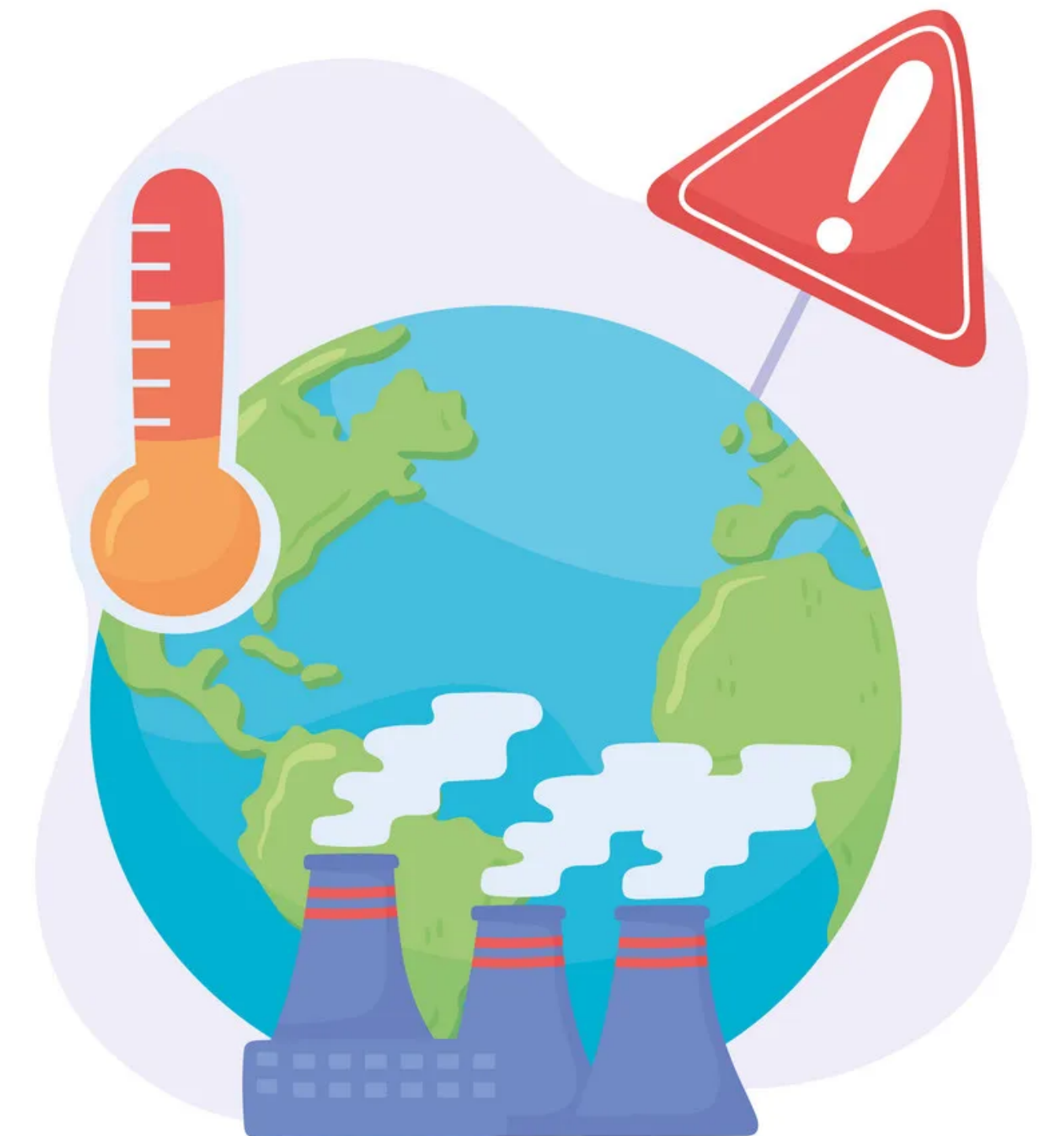
<https://fraqtal-technologies.github.io/PINN-kit/>

- Above all, someone who cares **deeply** about the world we live in and the world we're leaving behind

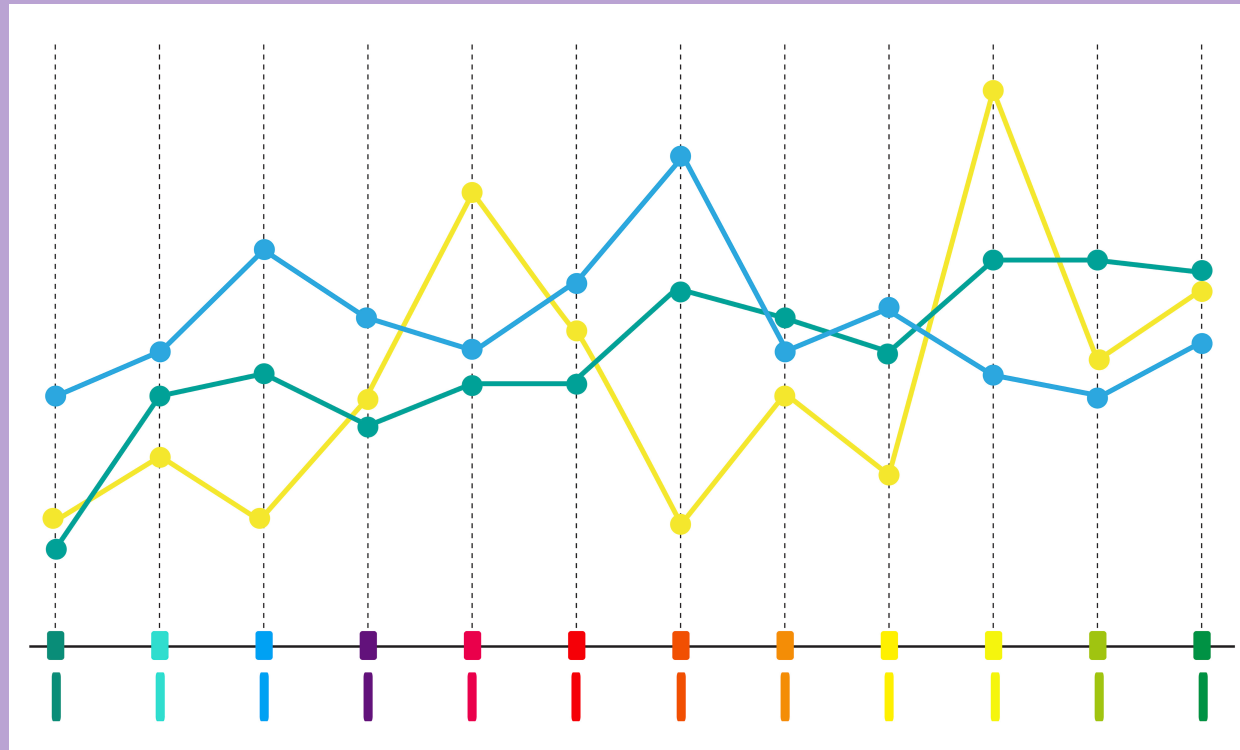
Climate Change

The Defining Problem of our Century

- Climate Change refers to **long-term shifts** in Earth's **average temperatures and weather patterns**
- While natural processes can influence climate, the rapid warming we see today is driven **primarily by human activity** — especially the burning of coal, oil, and gas
- This releases greenhouse gases (like CO₂ and methane) that trap heat in the atmosphere, causing the planet to **warm faster** than ever before
- The Result: **more extreme weather**, rising sea levels, **shifting ecosystems**, and increasing pressures on food, water, and energy systems



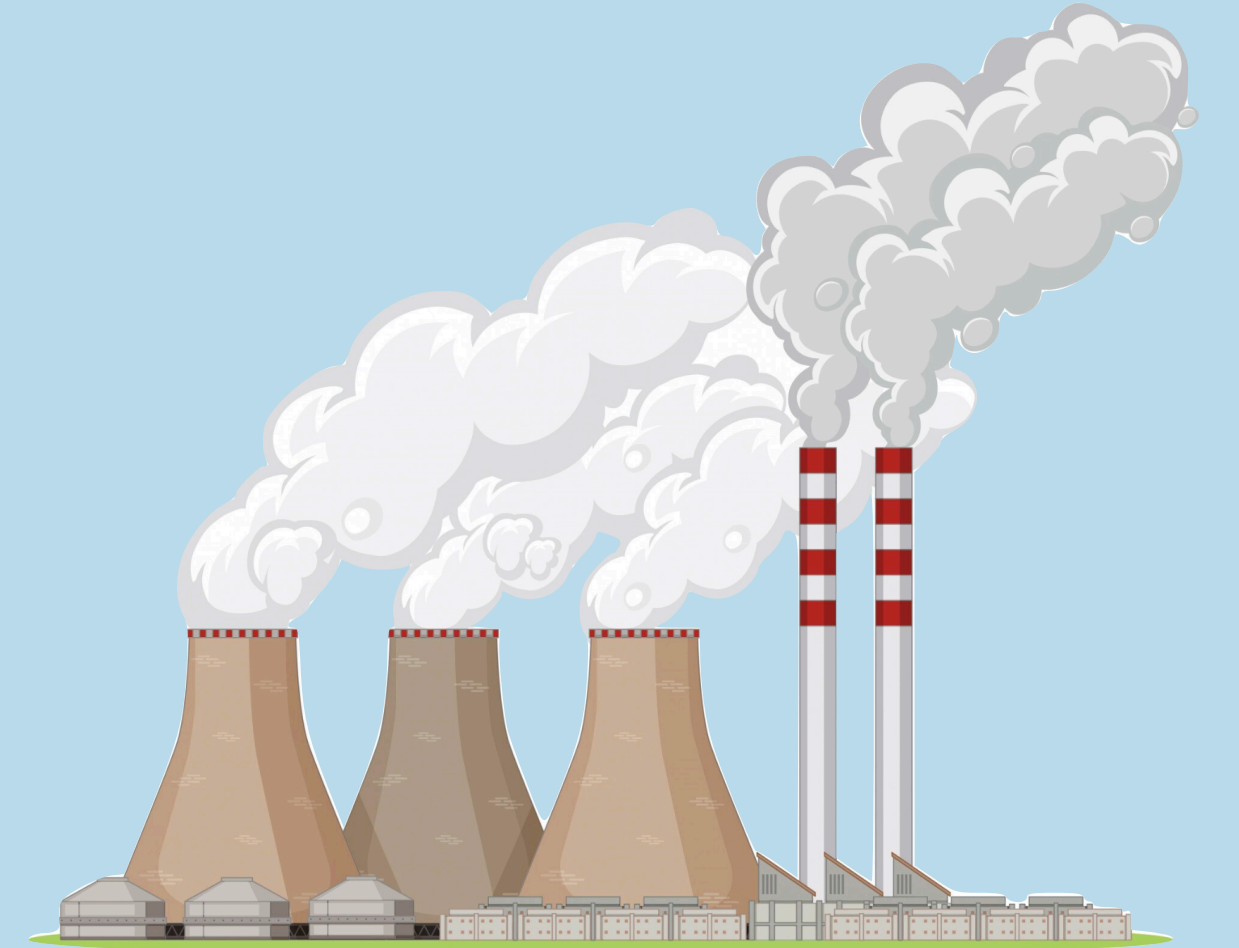
Climate Challenges



Climate Modelling



**Predicting Extreme
Weather Events**

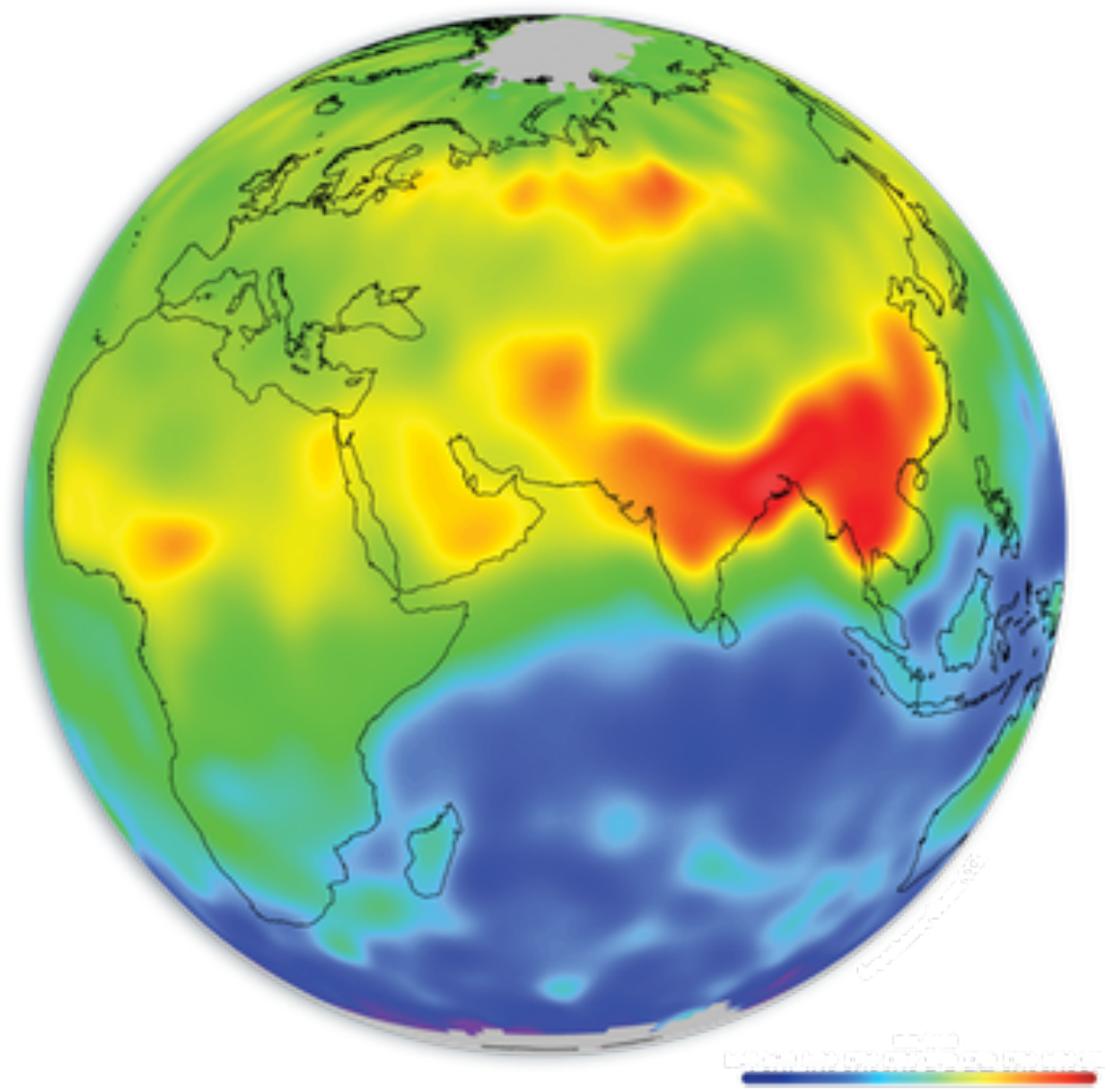


**Reducing Energy
Consumption**

Climate Modelling

Climate Modelling involves **simulating the physical processes** of the **atmosphere and oceans** to understand global climate dynamics.

Practically, this involves **solving a set of non-linear, partial differential equations** like the infamous Navier-Stokes Equations.



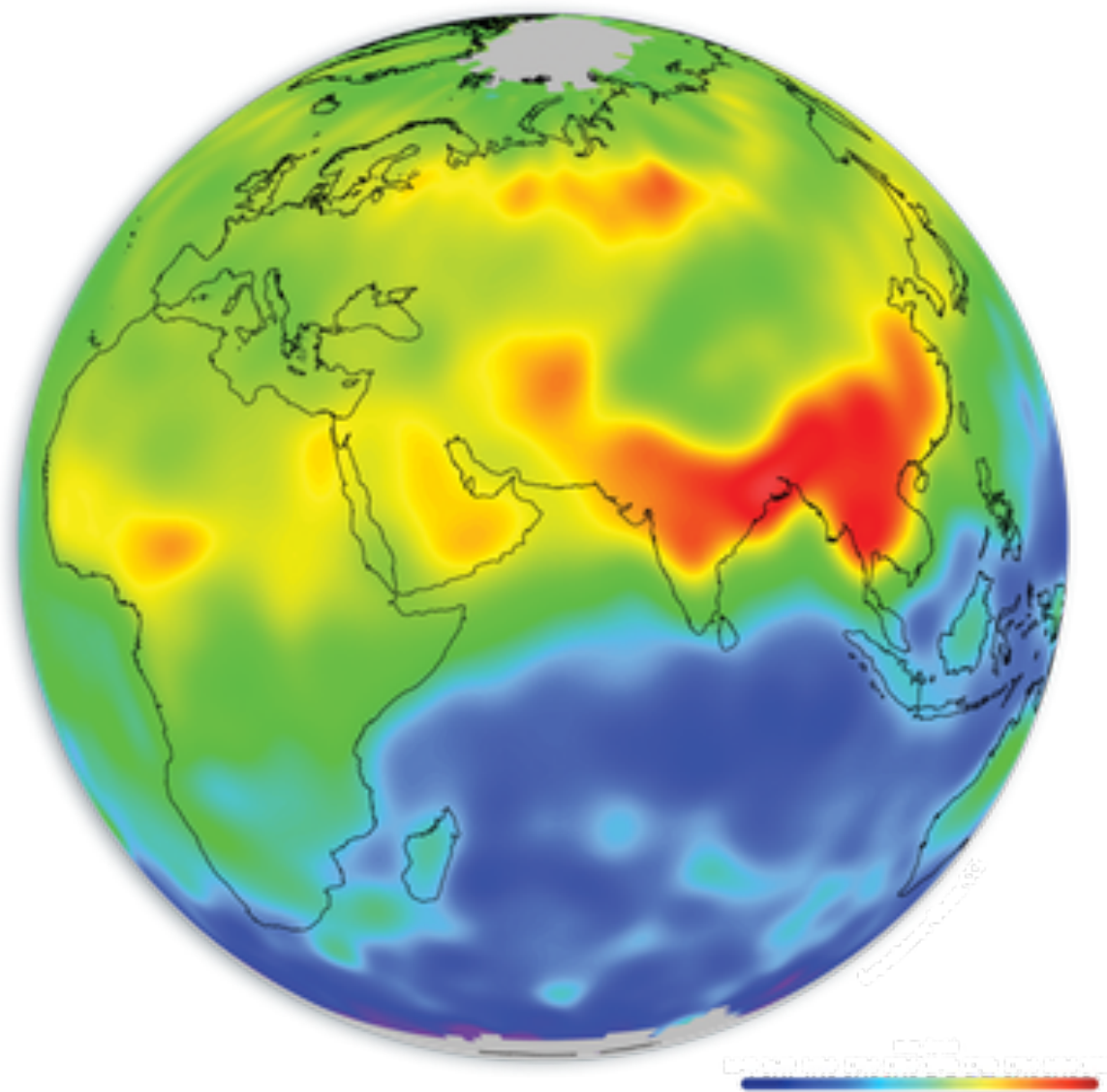
Significance

- Finding accurate solutions to these equations allows us to **make predictions** using our mathematical models
- This allows us to predict global temperature rise, sea-level changes, and shifts in regional climate patterns
- These predictions are essential for **informing national and international policy as well as infrastructure planning**

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Challenges

- Grid Resolution Limits
- Computational Cost
- Non-Linearity in Governing Equations

Predicting Extreme Weather Events

This focuses on **forecasting** specific, high-impact meteorological events such as **hurricanes**, **heatwaves**, and **heavy precipitation** that leads to **flooding**.

It requires the **rapid assimilation of real-time satellite and sensor data** to predict the trajectory and intensity of dynamic weather systems.



Significance

- Accurate short-term forecasting is critical for **disaster risk reduction**
- It enables timely **evacuation** orders, optimised deployment of **emergency resources** and protection of **critical infrastructure** during extreme conditions

Predicting Extreme Weather Events

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Challenges

- Time Constraints
- Processing of Large Datasets
- Ensemble Limitations

Reducing Energy Consumption

This challenge is two-fold: **developing materials** to make energy storage and industrial production more efficient, and **addressing the growing energy footprint of high-performance computing** itself.



Significance

- Industrial processes (like fertiliser production) and data centres are major global energy consumers
- **More Energy Consumption → More Greenhouse Gas Emissions → Accelerated Global Warming**

Reducing Energy Consumption

This challenge is two-fold: **developing materials** to make energy storage and industrial production more efficient, and **addressing the growing energy footprint of high-performance computing** itself.



Challenges

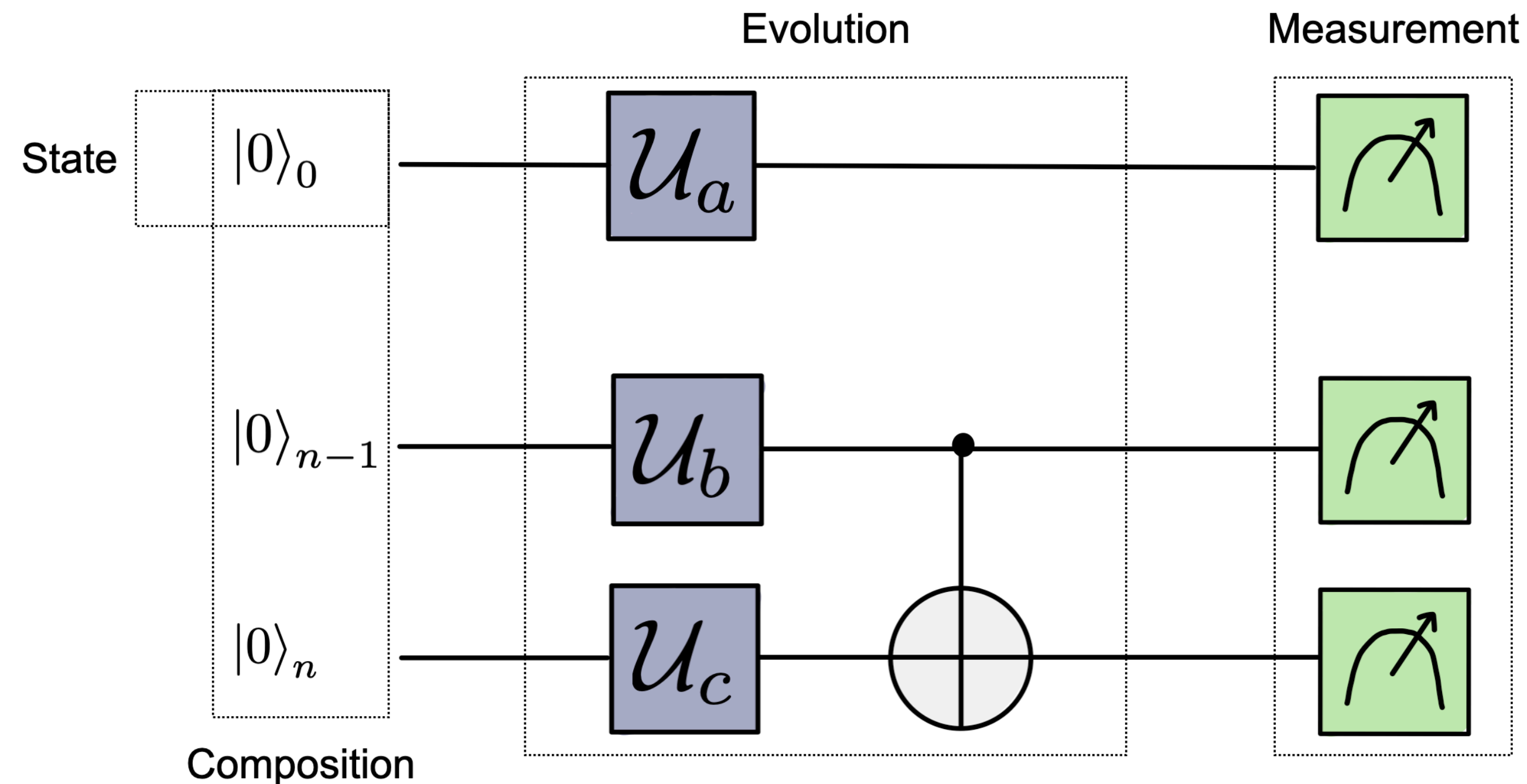
- Material/Chemical Simulation Limits
- Growing Demand for Compute Power
- Power Constraints

Quantum Computing

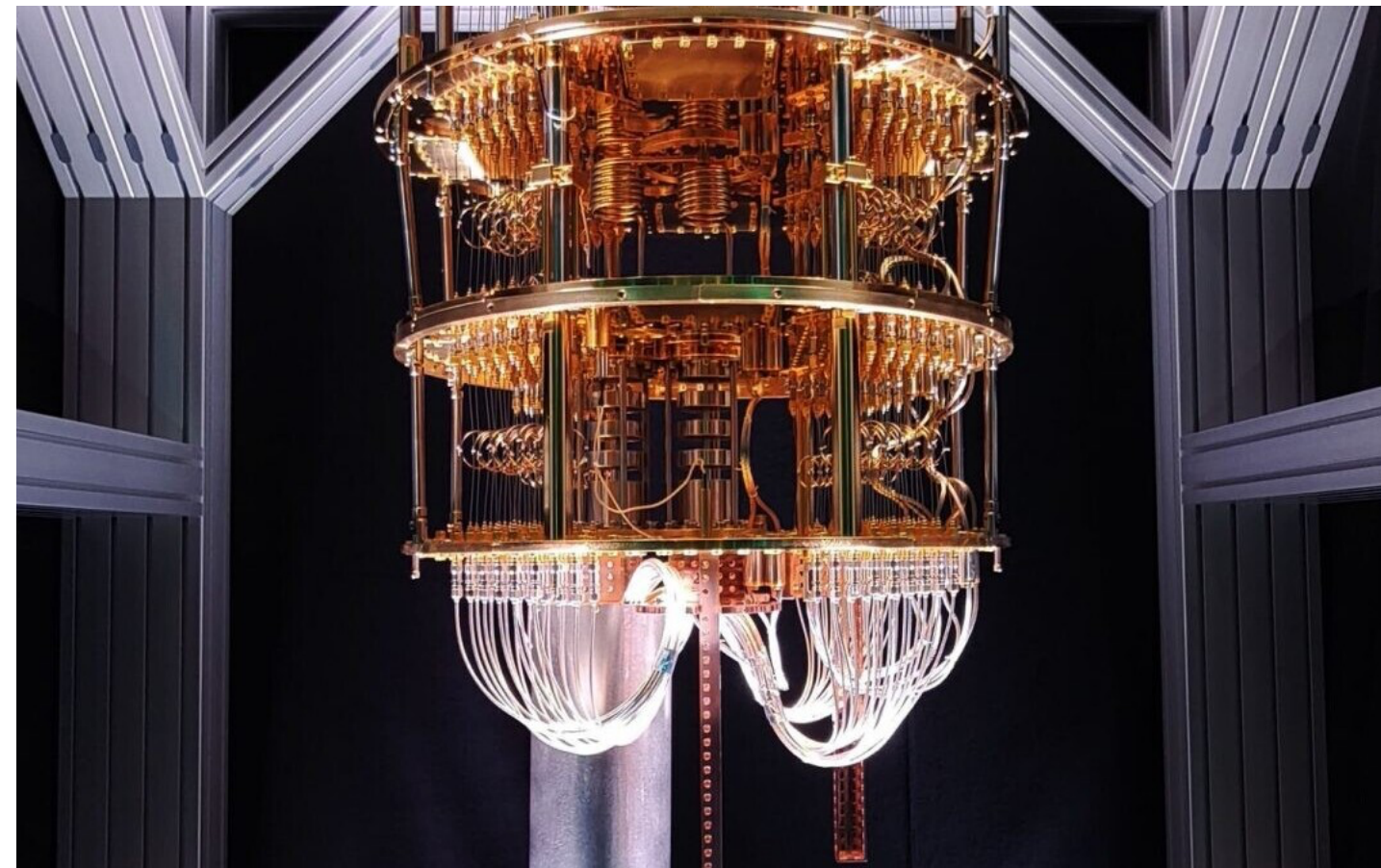
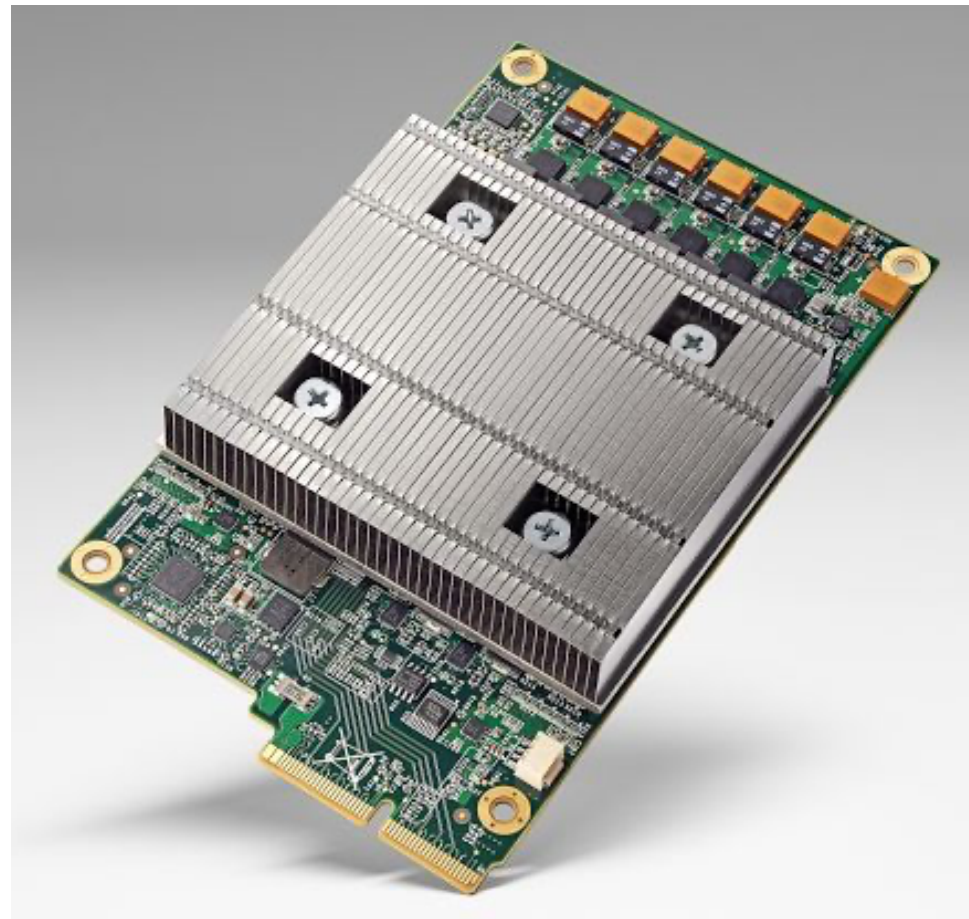
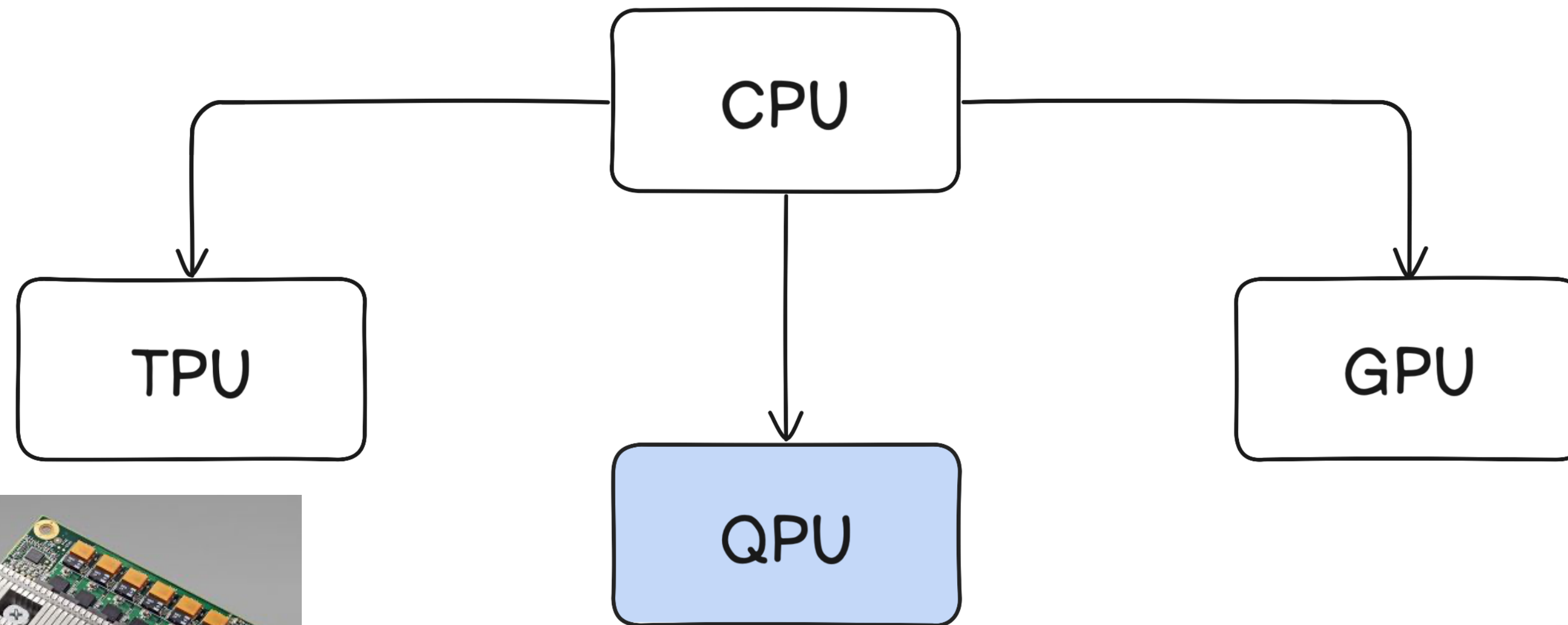
A New Computing Paradigm

Quantum computing is a new model of computing.

Quantum algorithms are developed to **leverage the principles of superposition, entanglement and interference.**



The Future of Computing is Hybrid

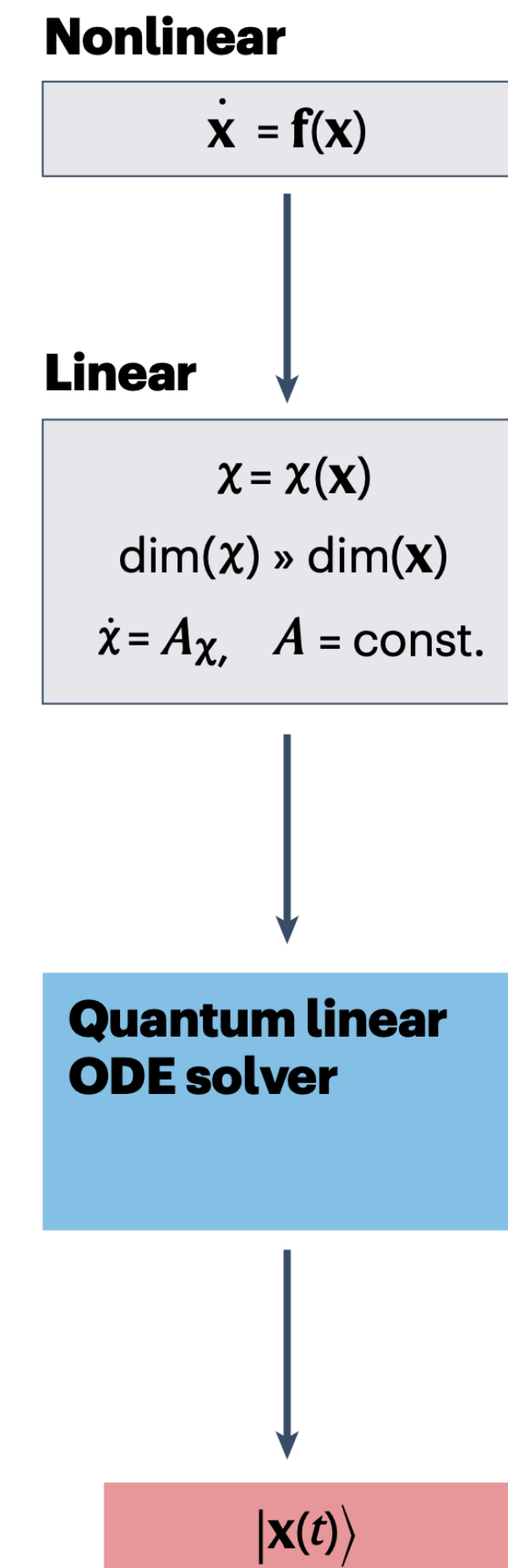


Climate Modelling with Quantum Computers

This requires quantum algorithms for solving non-linear, partial differential equations with quantum computers. There are 2 approaches that should be highlighted.

1. Linearisation-Based Quantum Algorithms

Given a system of non-linear differential equations $\dot{\mathbf{x}} = f(\mathbf{x})$, we can first linearise the system using Carleman Linearisation and then solve the system using a quantum linear system algorithm.

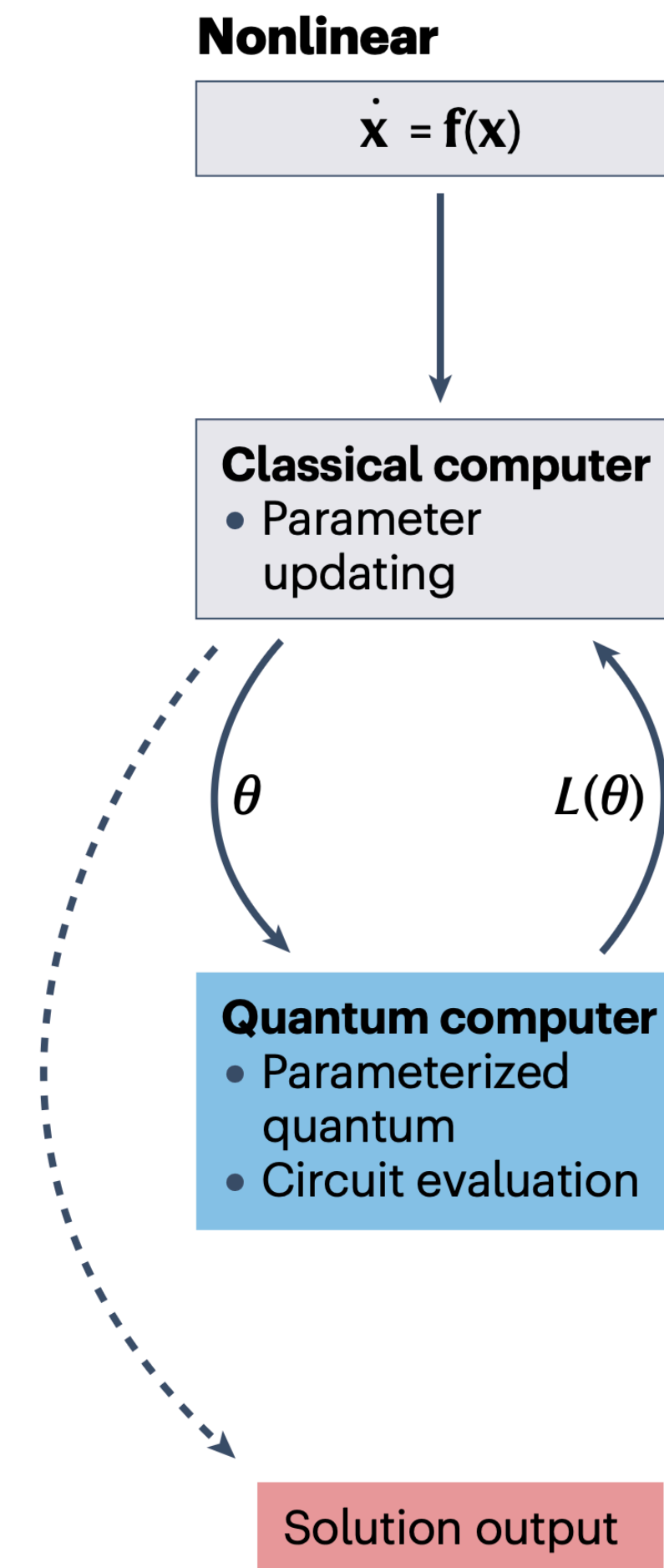


Climate Modelling with Quantum Computers

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2. Hybrid Quantum-Classical Algorithms

Given a system of non-linear differential equations $\dot{\mathbf{x}} = f(\mathbf{x})$, we represent a 'trial solution' as the output of a parametrised quantum circuit. We then use a classical computer to optimise those parameters, minimising a loss function that tells us exactly how well that trial solution obeys the differential equations.



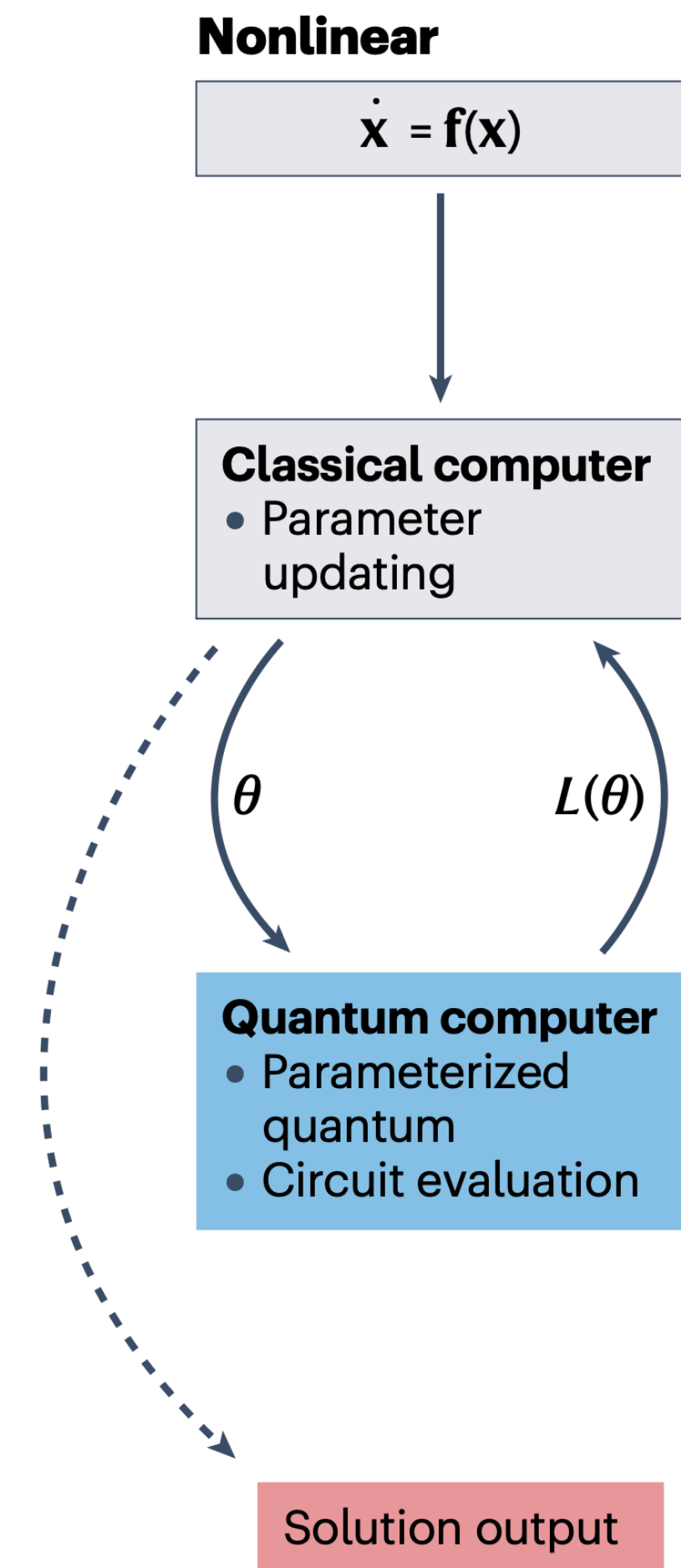
Climate Modelling with Quantum Computers

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2. Hybrid Quantum-Classical Algorithms

Example: in Jaderberg, Ben, et al. "Potential of quantum scientific machine learning applied to weather modeling." Physical Review A 110.5 (2024): 052423, the authors utilised a hybrid quantum-classical algorithm to solve the Barotropic Vorticity Equation (BVE), a 3rd order, non-linear PDE which serves as a simplified model of the atmosphere.

The quantum model achieved high accuracies.



Predicting Extreme Weather Events with Quantum Computers

Classical Machine Learning has already been applied to the problem of detecting wildfires from images, flood prediction, etc.

There are quantum analogues to these classical machine learning methods that can also be applied to the same problems. For example, the **Quantum Convolutional Neural Network** could also be used to detect wildfires in images, the **Quantum Recurrent Neural Network** could be used to predict rainfall as a time series.



(a) Fire



(b) No Fire



(c) Smoke

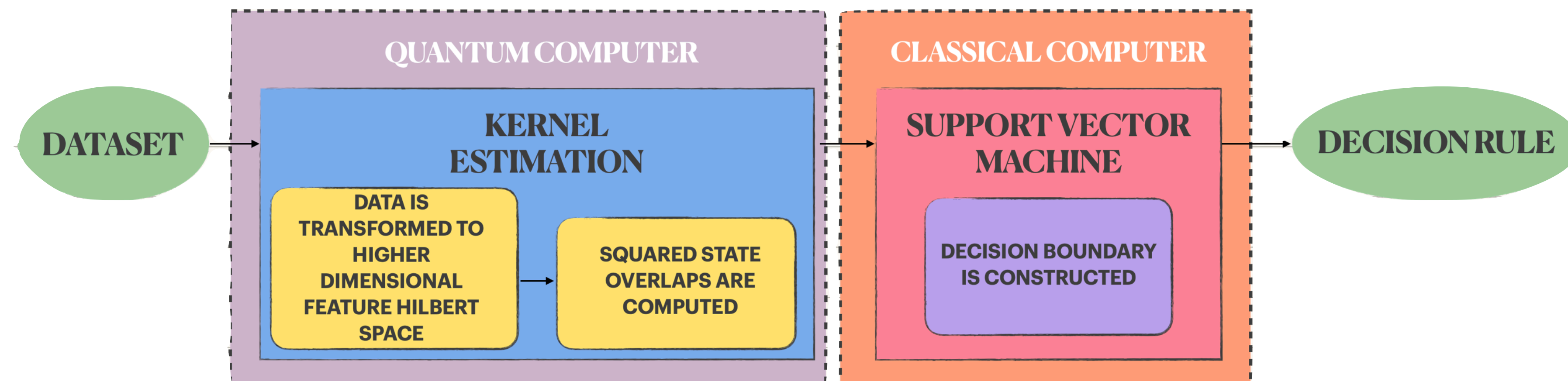


(d) Smoke Fire

Predicting Extreme Weather Events with Quantum Computers

In Grzesiak, Marek, and Param Thakkar. "Flood prediction using classical and quantum machine learning models." arXiv preprint arXiv:2407.01001 (2024), the authors trained a number of different quantum models to classify a given set of hydrological conditions into one of two categories: Flood or No Flood.

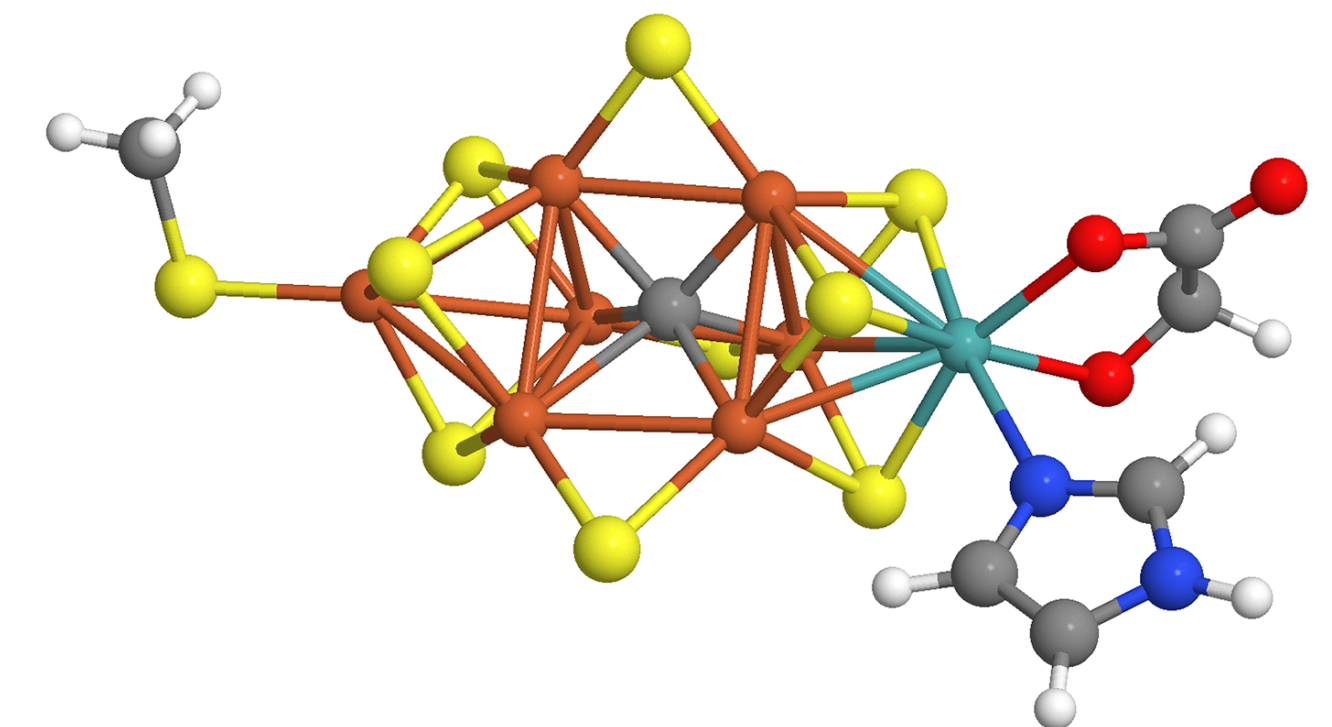
A number of different quantum machine learning methods achieved high accuracies for this task including **The Quantum Support Vector Machine** and The Quantum-Enhanced Decision Tree.



Reducing Energy Consumption with Quantum Computers

The Problem:

- Currently, the industrial process (the Haber-Bosch process) to convert nitrogen into ammonia (for fertiliser) requires **high temperatures and pressures**, making it **incredibly energy-intensive**
- In contrast, bacteria use the enzyme **nitrogenase** to perform this exact same reaction at **room temperature and standard pressure**
- If we could understand exactly how the active site of this enzyme (**FeMoco**) breaks nitrogen bonds so efficiently, we could design artificial catalysts to mimic it, saving massive amounts of global energy.
- However, this problem is intractable for classical methods.



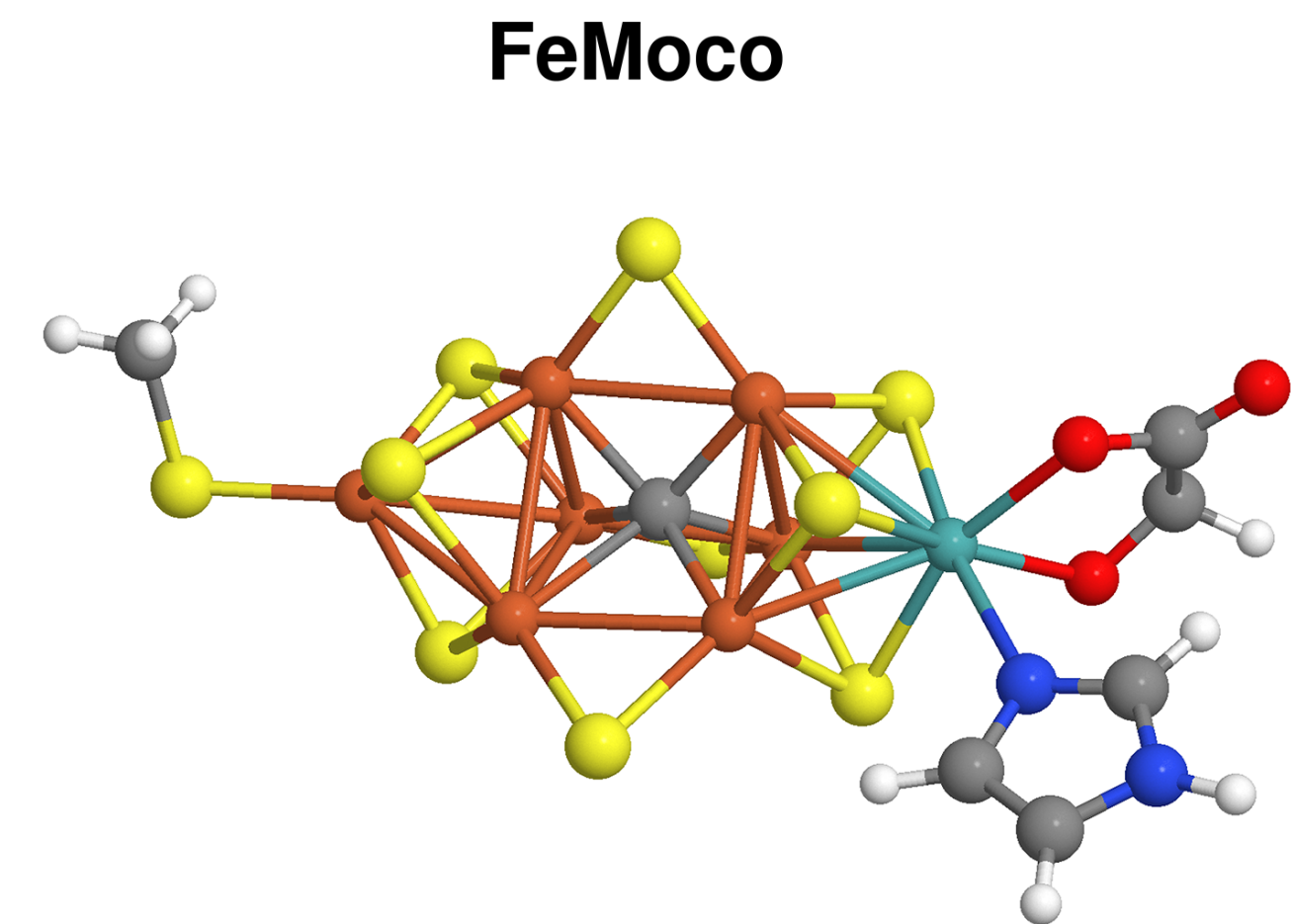
Reducing Energy Consumption with Quantum Computers

The Solution:

Reiher, Markus, et al. "Elucidating reaction mechanisms on quantum computers." Proceedings of the national academy of sciences 114.29 (2017): 7555-7560.

This paper demonstrates that quantum computers can reveal the reaction mechanism of nitrogen fixation at FeMoco. They achieve this by calculating reliable activation energies—data that is **currently impossible to obtain with traditional quantum chemical methods**.

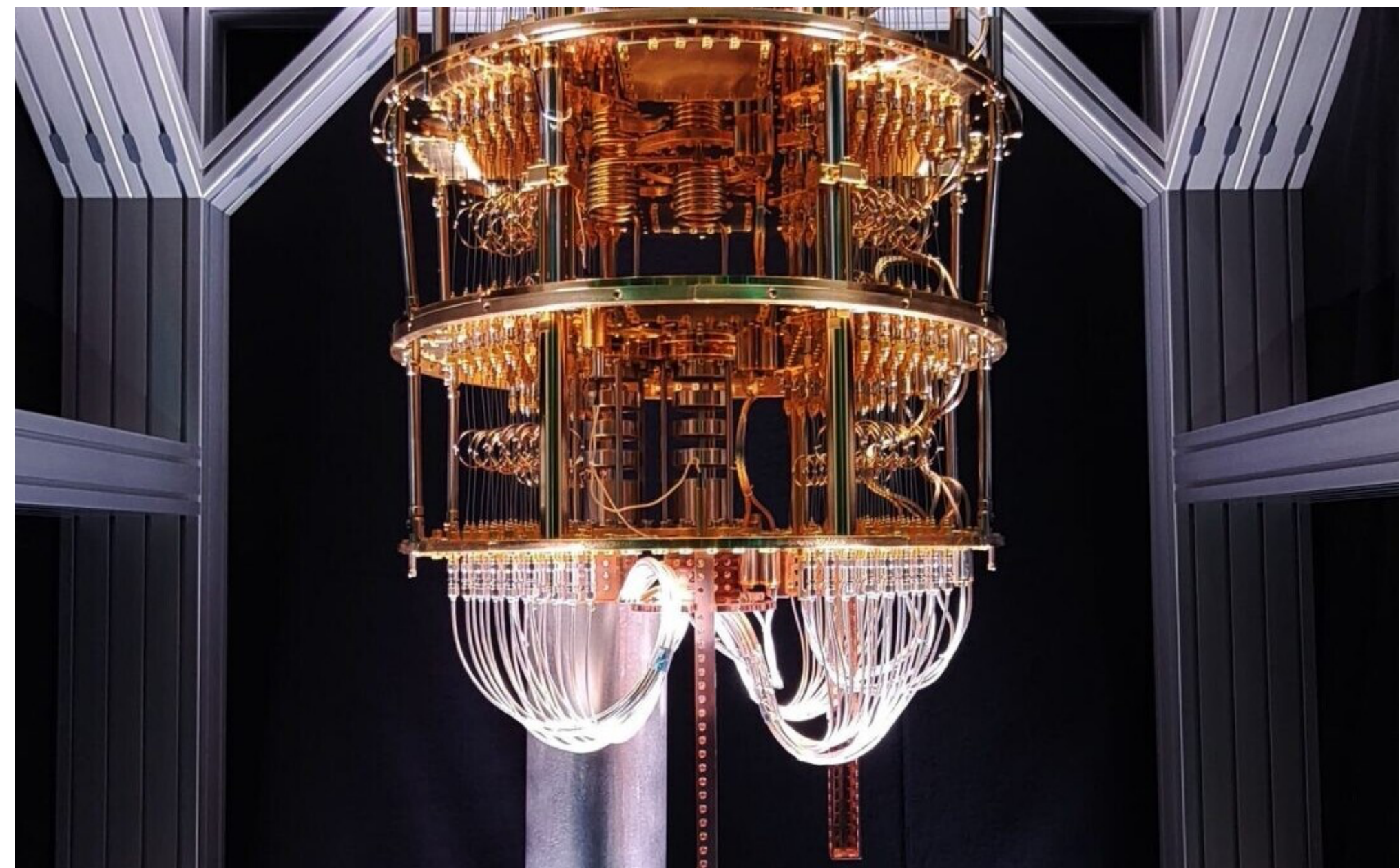
The authors also conducted a resource analysis and estimated that a quantum computer with around **only 111 logical qubits** could perform the necessary simulation.



Limitations

We have explored the transformative potential of quantum computing applied to various climate challenges. However, there are currently significant engineering and theoretical hurdles that stand between us and the widespread use of quantum computers in this domain. There are 4 limitations that need to be highlighted:

- **Hardware Limitations**
- **The Data Loading Bottleneck**
- **Quantum Advantage**
- **Verification**



Tackling Climate Challenges with Quantum Computing

Thank you.

Any Questions?

