QUANTUM FOR ENVIRONMENT

TQT Transformative Quantum Technologies

Sponsored by: Quantum Valley Ideas Lab, Angstrom Engineering, Canada NRC·CNRC, Ambature

Quantum for Environment Design Challenge

Launched in June 2023, design submissions due March 2024.

Open to all students and post-doctoral fellows at the University of Waterloo. Must apply as a team. Opportunity to receive mentorship.

Awards up to $5,000 CAD.

tqt.uwaterloo.ca/q4e

QUANTUM
FOR
ENVIRONMENT

WHAT IS THE CHALLENGE

Transformative Quantum Technologies (TQT) presents a design challenge to search for opportunities where quantum technology can advance environment (monitoring, stewardship). This challenge is open to University of Waterloo undergraduate and graduate students, and postdocs.

WHY QUANTUM FOR ENVIRONMENT

Quantum technologies allow us to perform tasks with more efficiency and greater precision than is possible in the classical world. Quantum solutions can achieve what would otherwise be impossible. It is compelling to mate these exciting new technologies with the pressing need to advance environmental monitoring and stewardship. Through this challenge, TQT aims to uncover new ways that quantum technologies might have impact in both the near and long term.

Quantum computing – select computational tasks may be exponentially faster.
Quantum simulation – obtain new insights into nature.
Quantum communications – absolute information security.
Quantum sensing – more efficient, more sensitive, more versatile, more tailorable.

The focus is to bring forth ideas that expand the potential reach of quantum technologies, there is no need to reduce ideas to practise to participate in this challenge.

Quantum technology is rapidly emerging (as we will see with the case studies in a moment). The challenge asks that you assume that the quantum technology you need exists, including fault tolerant quantum computers, versatile quantum simulators, secure quantum communication systems, and quantum sensors capable of preparing and using entanglement.

WHO SHOULD PARTICIPATE IN QUANTUM FOR ENVIRONMENT

The Q4Environment challenge is looking for well-motivated, quantum-based ideas that can lead to innovation.

The focus is on the impacts that new technologies can have.

In the design proposal, the technology side should be well founded, but the expectation is that it will not have been reduced to practise. No prototype is required, but the design document should be convincing that the proposed future is possible.

We take a broad view of the environment to include climate change, energy as well as oceans, and the north, for example.

Teams need not have deep knowledge in either the quantum or environment fields, but should have explored what is in general possible. TQT will run a series of short courses to provide introductions to both quantum concepts and environment needs.

All design submissions must be team based, with a minimum of two people (up to any number).

The proposal must demonstrate basic knowledge and creativity in environment and in quantum.

Speakers

Chris Fletcher

Associate Professor and Chair

Department of Geography and Environmental management

Jennifer Lynes

Associate Professor

School of Environment, Enterprise and Development (SEED)

John Donohue

Senior Manager, Scientific Outreach

Institute for Quantum Computing

Michael Grabowecky

Quantum Technology Coordinator

Transformative Quantum Technologies

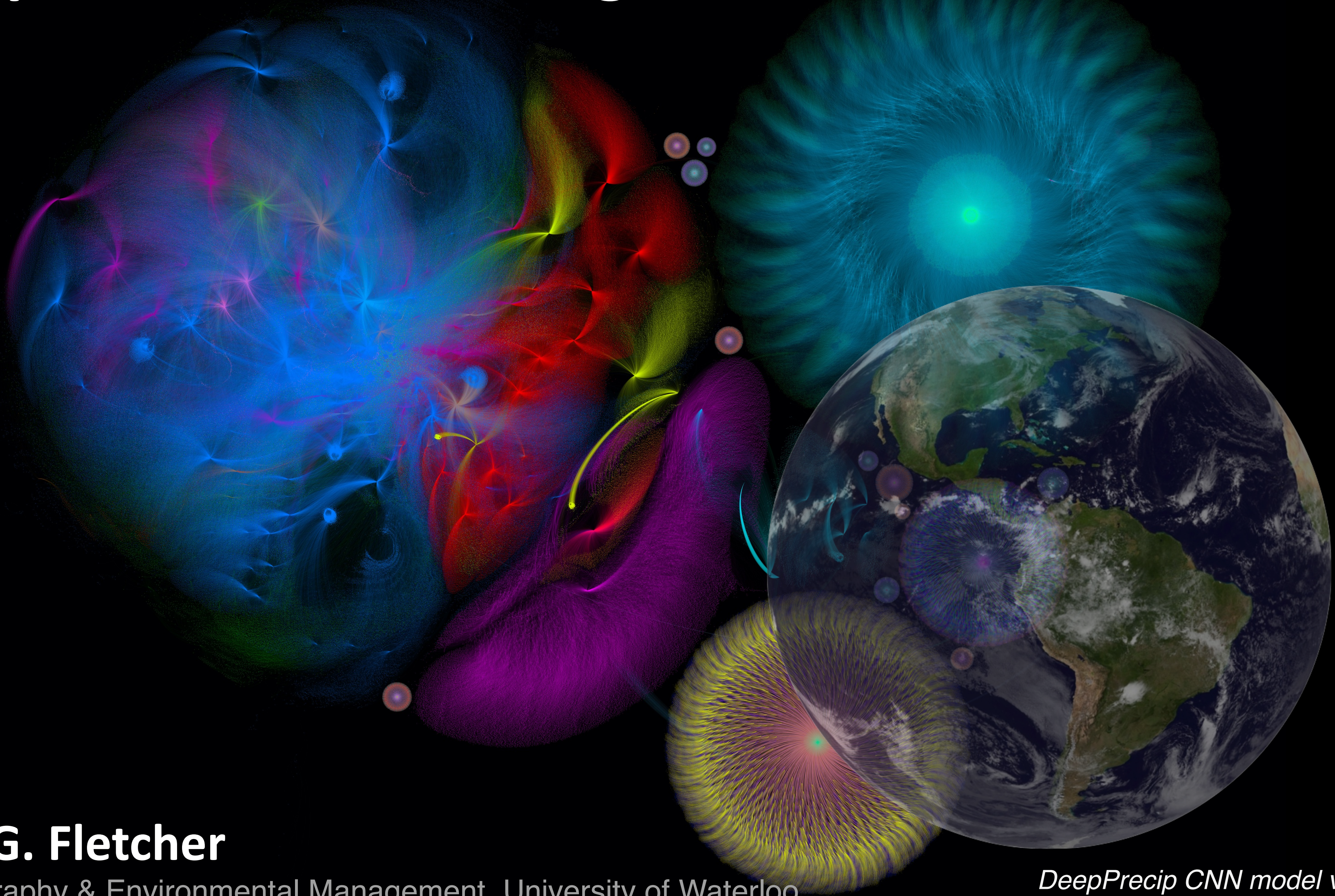
Fatemeh Fani Sani

Research Associate

Transformative Quantum Technologies

QUANTUM FOR ENVIRONMENT

Computational challenges for climate science

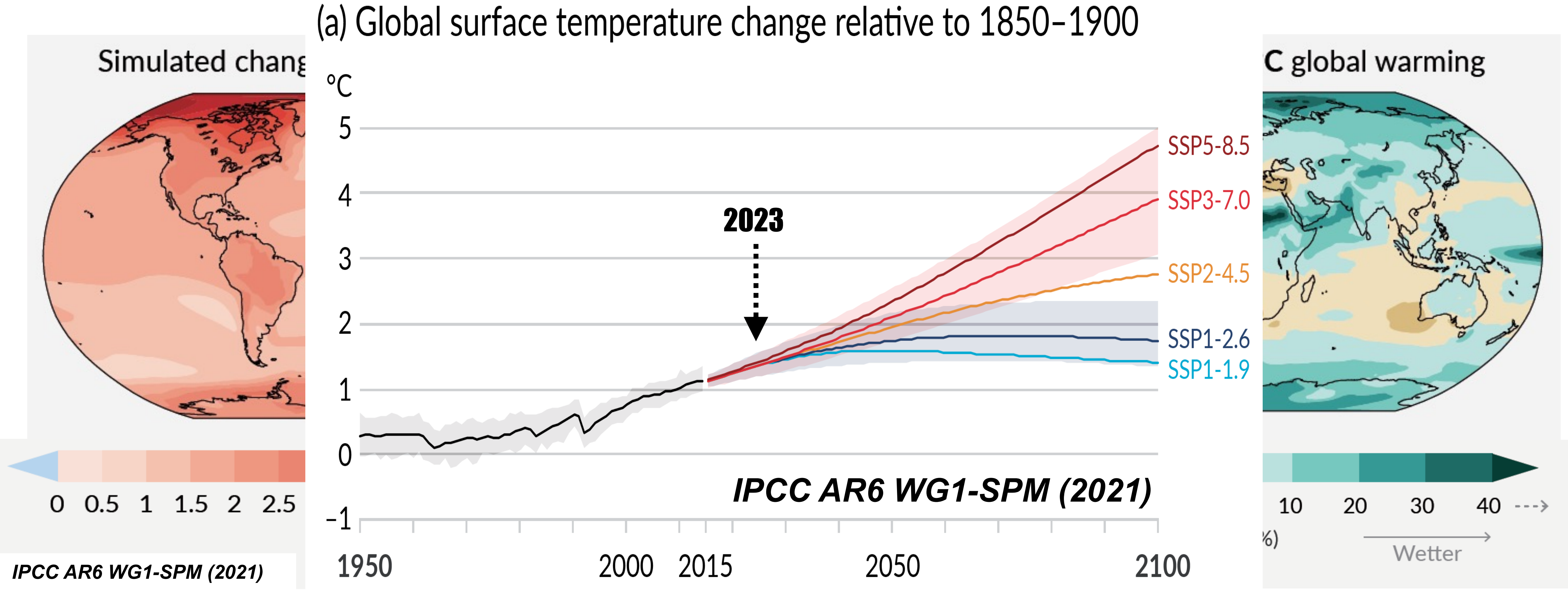


Christopher G. Fletcher

Department of Geography & Environmental Management, University of Waterloo.

DeepPrecip CNN model visualization by Fraser King using Graphcore IPUs.

The nature of the problem: Global Climate Projections



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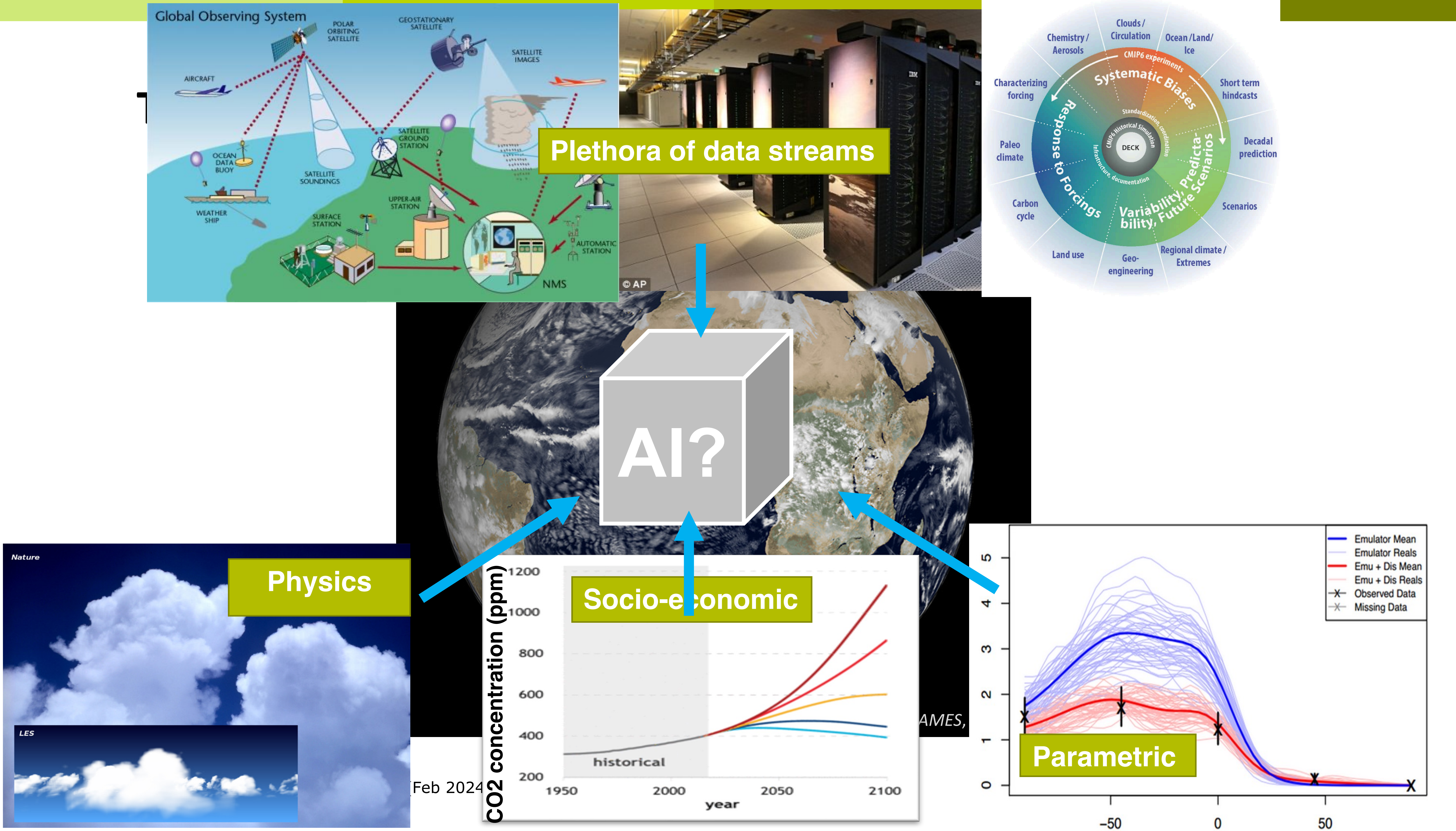
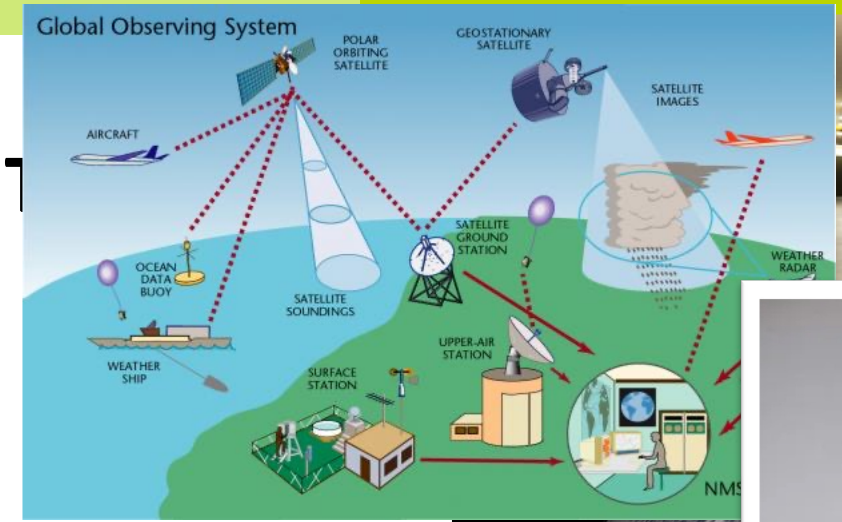
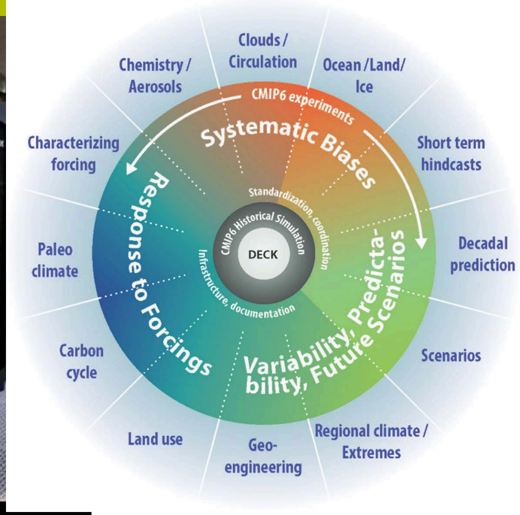
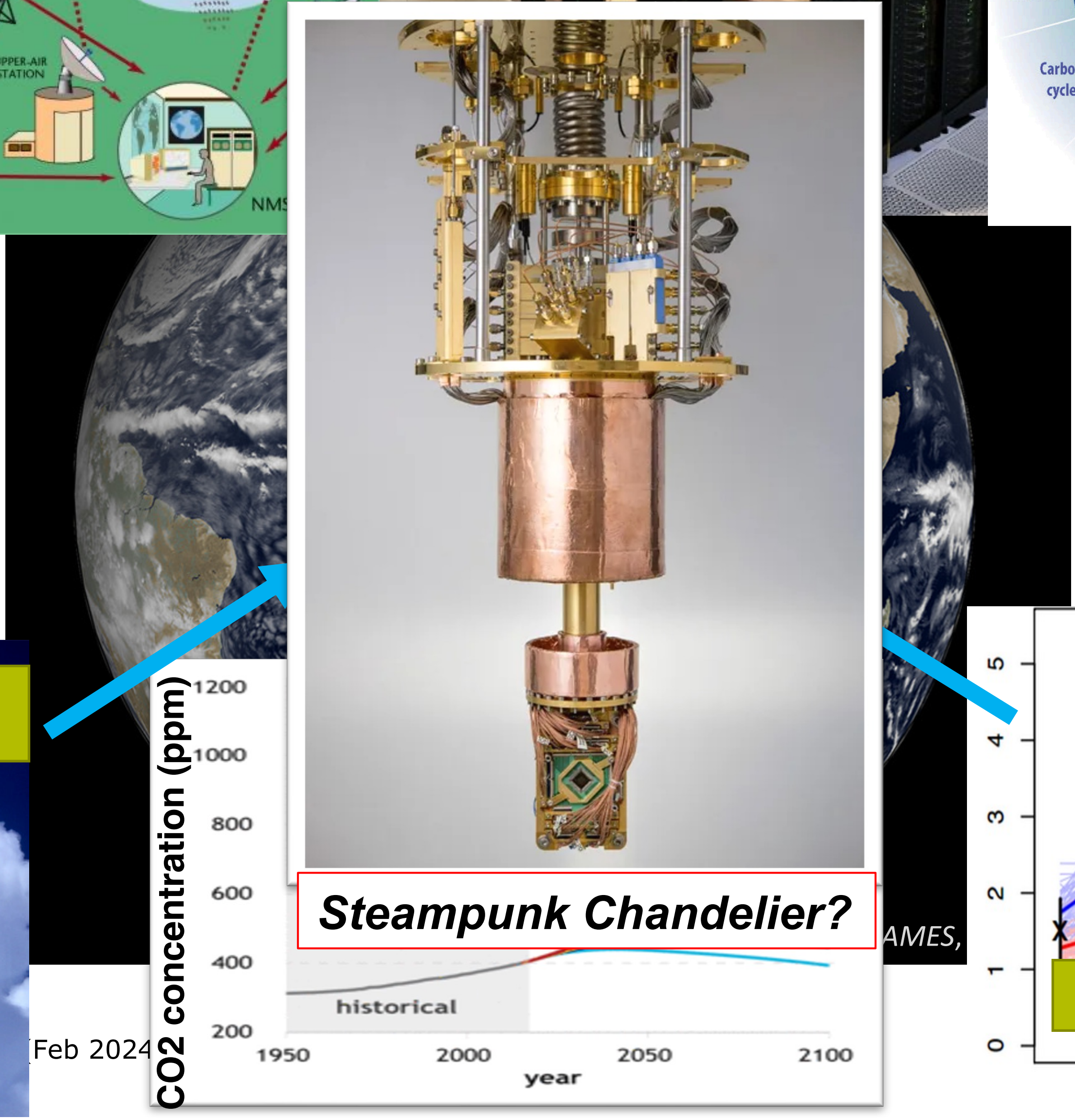
Meyer et al. (2022) 10.3389/frym.2022.682759

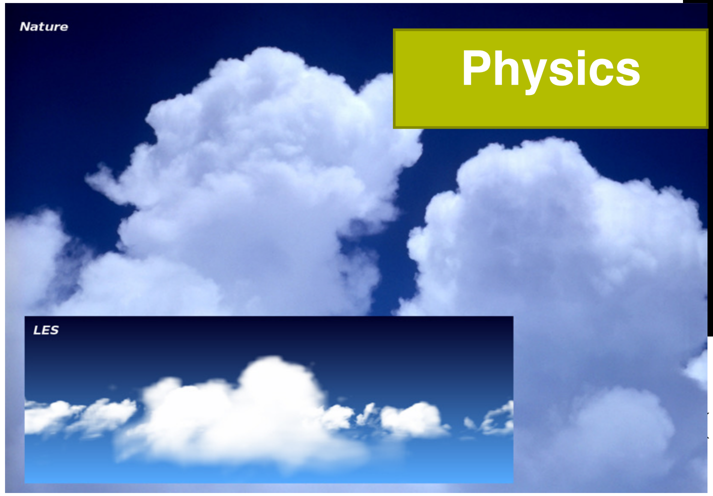

Global Observing System
POLAR ORBITING SATELLITE
GEOSTATIONARY SATELLITE
SATELLITE IMAGES
AIRCRAFT
OCEAN DATA BUOY
SATELLITE SOUNDINGS
SATELLITE GROUND STATION
UPPER-AIR STATION
WEATHER SHIP
SURFACE STATION
AUTOMATIC STATION
NMS
© AP
Plethora of data streams
Clouds / Circulation
Chemistry / Aerosols
Ocean / Land / Ice
CMIP6 experiments
Systematic Biases
Characterizing forcing
Short term hindcasts
Response to Forcings
DECK
Paleo climate
Decadal prediction
Variability, Predictability, Future Scenarios
Carbon cycle
Scenarios
Land use
Geo-engineering
Regional climate / Extremes
AI?
Physics
Nature
LES
Socio-economic
CO2 concentration (ppm)
year
historical
Parametric
Emulator Mean
Emulator Reals
Emu + Dis Mean
Emu + Dis Reals
Observed Data
Missing Data
[Feb 2024
AMES,

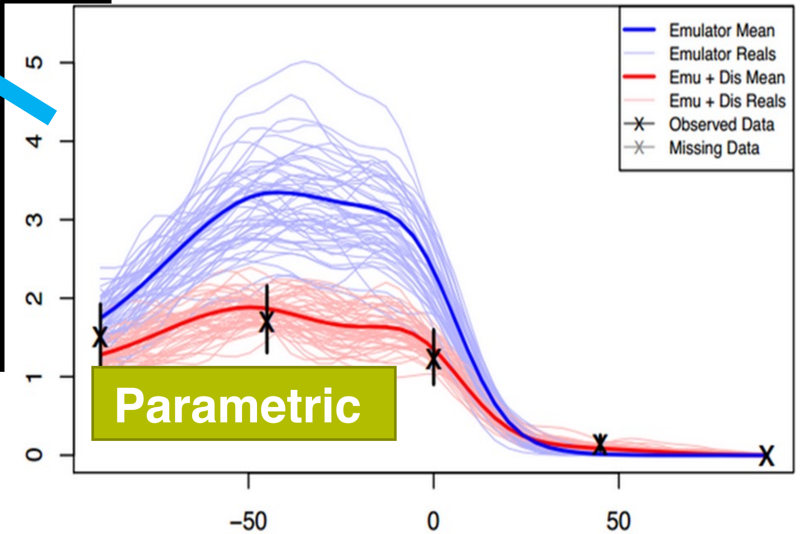






Steampunk Chandelier?





Feb 2024

AMES,

Medium Search Write

Quantum Computing and Climate Change: A Match Made in Sci- Fi Heaven

B Belen Perez-Wicht Bravo de Rueda · Follow
7 min read · Oct 16, 2023

AMS Journals JOURNALS BROWSE PUBLISH SUBSCRIBE ABOUT Sign in

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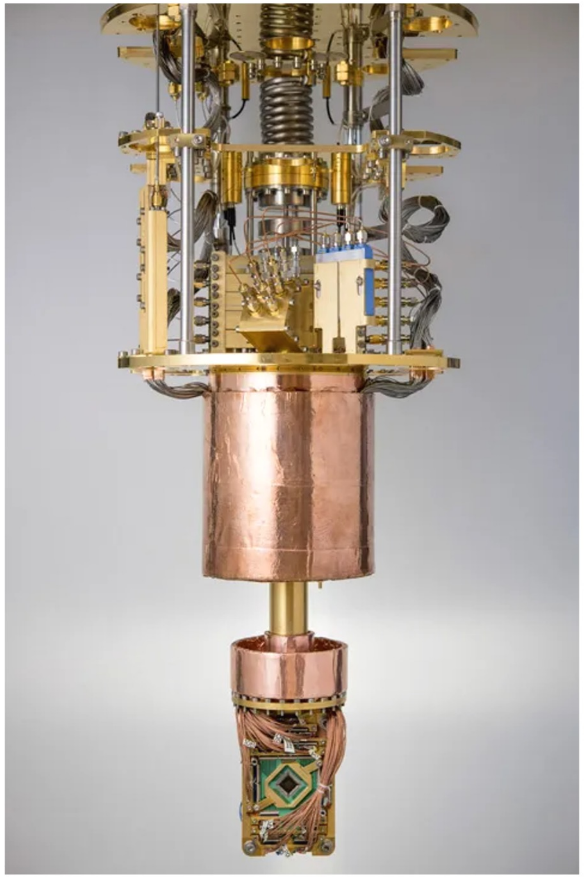
Article Type: Research Article

Quantum Computers for Weather and Climate Prediction: The Good, the Bad, and the Noisy

F. Tennie and T. N. Palmer

Online Publication: 27 Feb 2023
Print Publication: 01 Feb 2023
DOI: https://doi.org/10.1175/BAMS-D-22-0031.1
Page(s): E488–E500



Steampunk Chandelier?

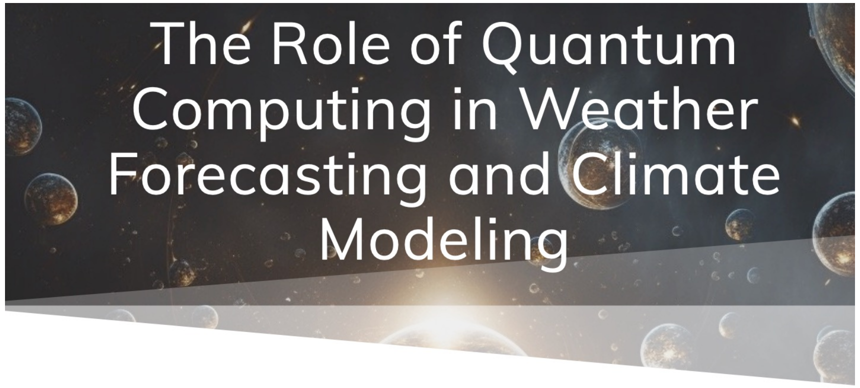
Eos

ABOUT SPECIAL REPORTS TOPICS PROJECTS NEWSLETTER SUBMIT TO *EOS*

How Quantum Computing Can Tackle Climate and Energy Challenges

The day is coming when quantum computers, once the stuff of science fiction, will help scientists solve complex, real-world problems that are proving intractable to classical computing.

By Annarita Giani and Zachary Goff-Eldredge 21 October 2022

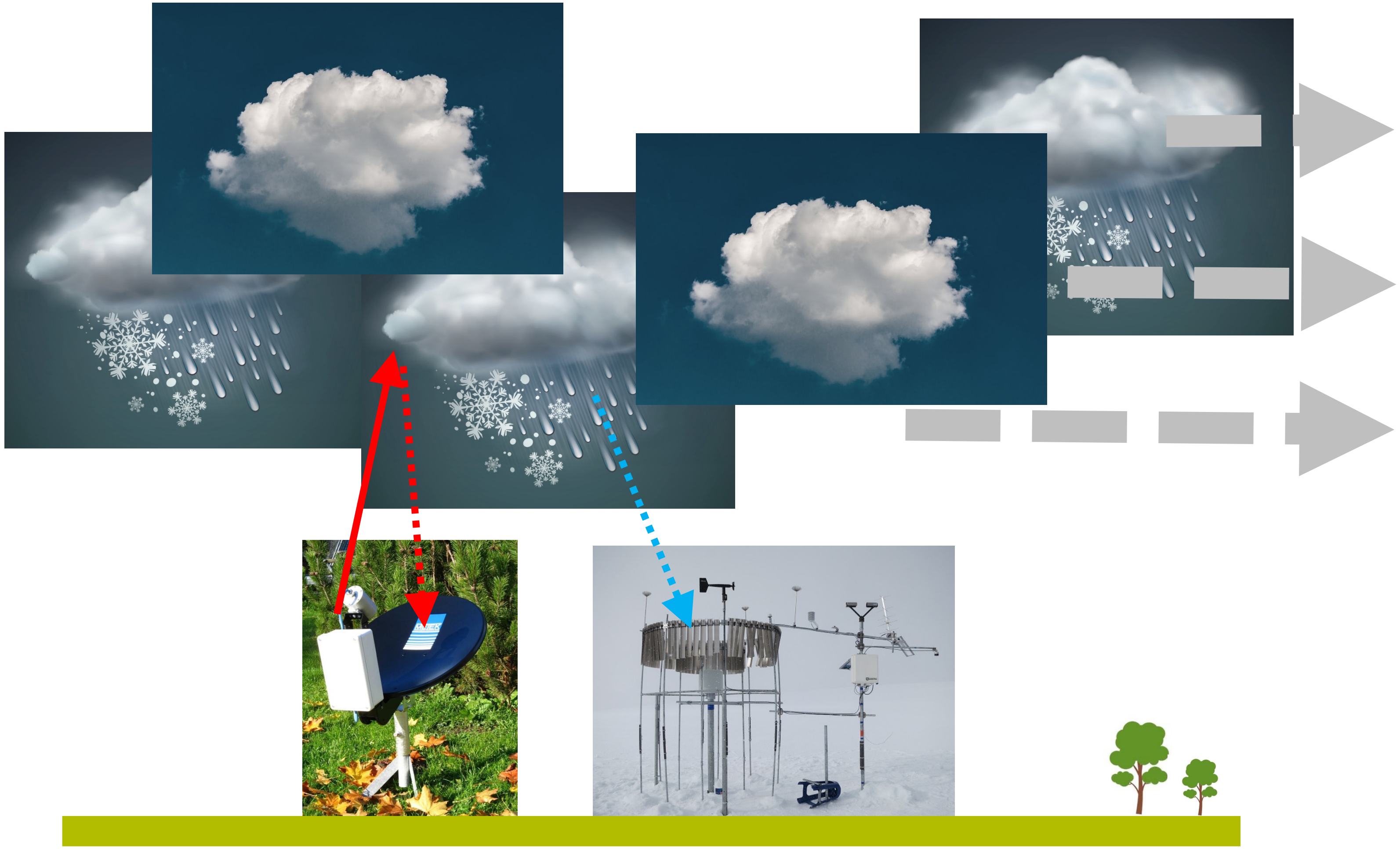


The Role of Quantum Computing in Weather Forecasting and Climate Modeling

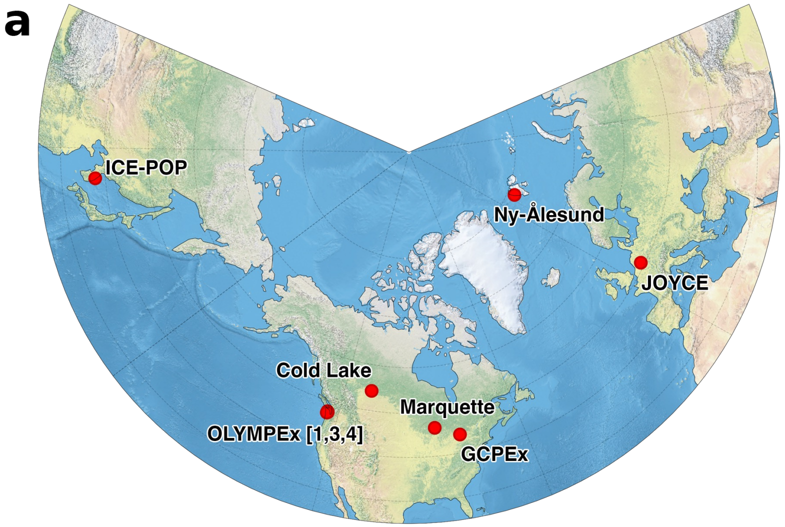
by Marcin Frąckiewicz in Artificial intelligence, TS2 Space on 29 March 2023 0

EXTRA SLIDES

Training data: use reflectivity to predict accumulation



- Nine sites across the northern hemisphere with Micro Rain Radar (MRR) and Pluvio2 gauge (2012-2021).
- All data aggregated to 20-min temporal resolution.



- Traditional methods make assumptions about cloud properties and relate Z-R through strict, location-specific statistical relationships.

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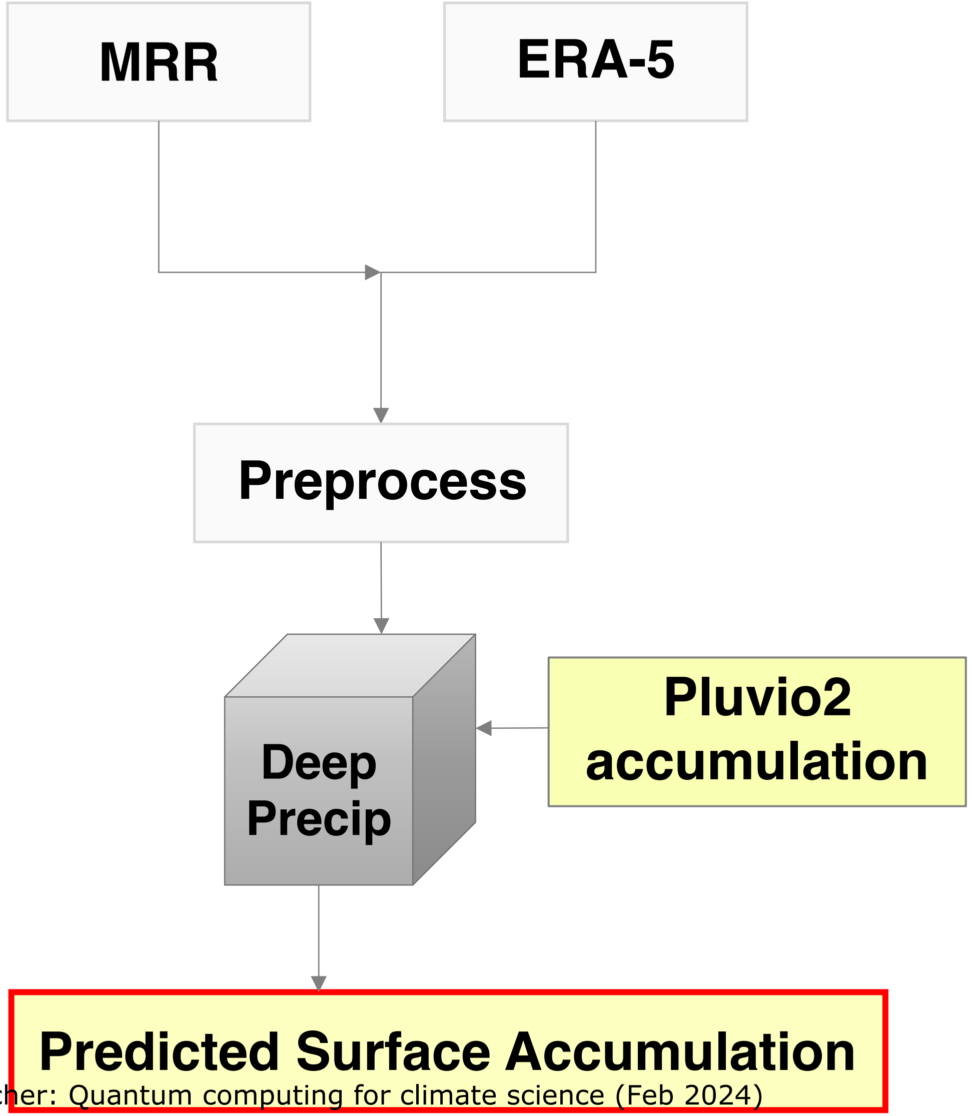
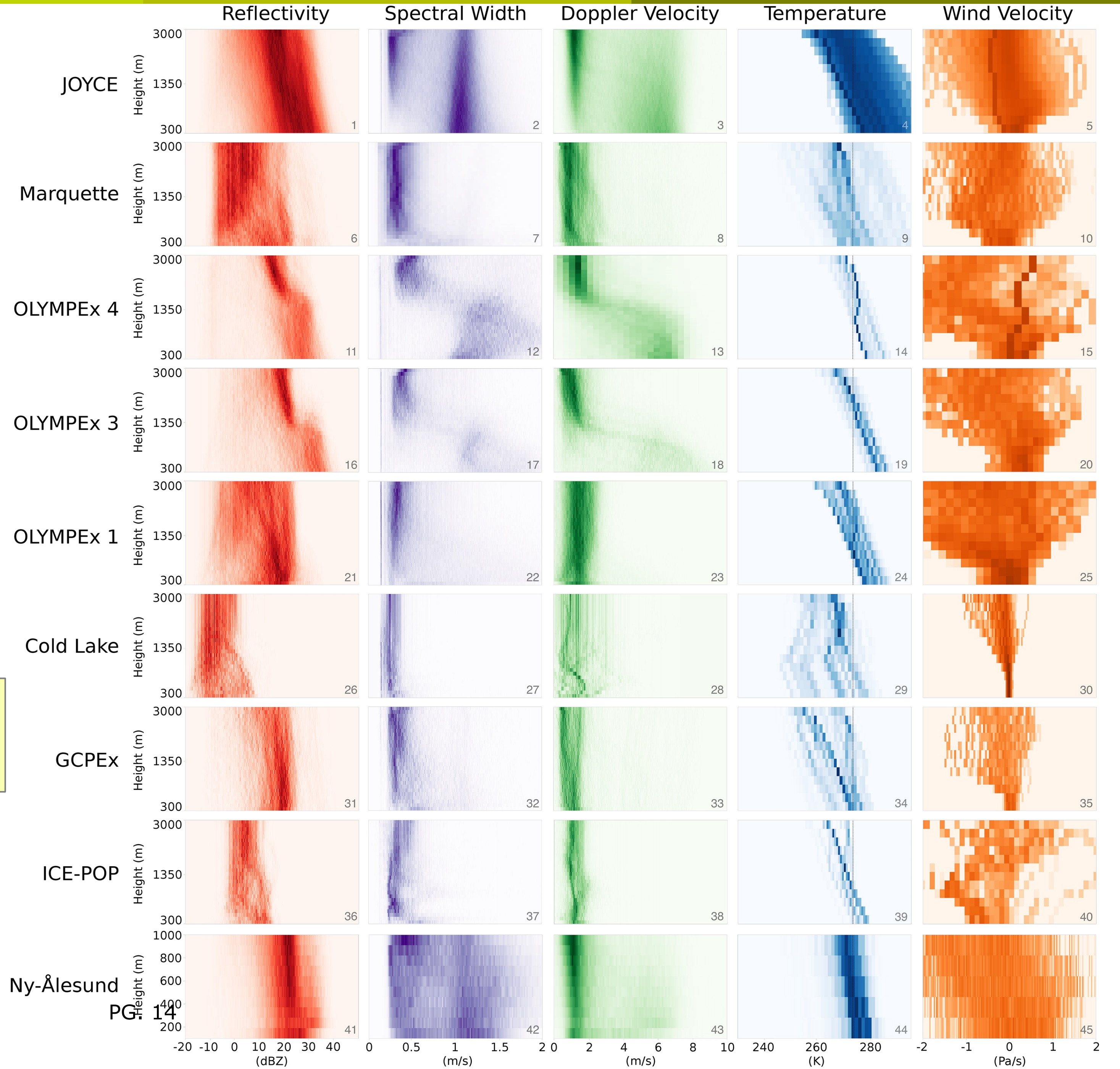
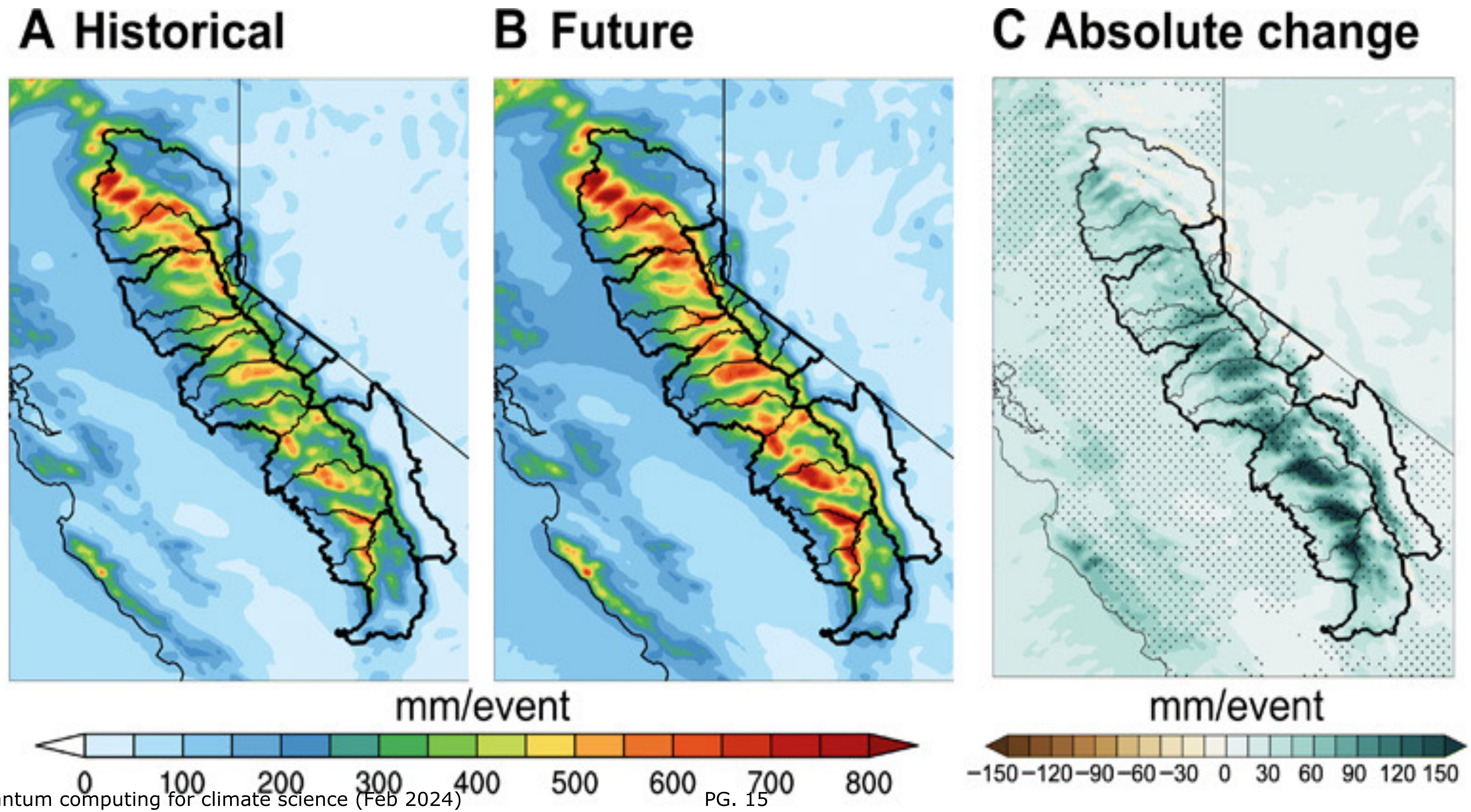
Data Pipeline





The nature of the problem: Regional Climate Projections



Huang et al., Science, (2020)

ATERLOO
NMENT

Geophysical models of the climate system

ESMs solve a system of PDEs to track "stuff" moving between towers of boxes:

Navier–Stokes Equations
3 – dimensional – unsteady

NASA — Glenn Research Center

Coordinates: (x,y,z)
Velocity Components: (u,v,w)
Time : t
Density: ρ
Total Energy: Et
Pressure: p
Stress: τ
Heat Flux: q
Reynolds Number: Re
Prandtl Number: Pr

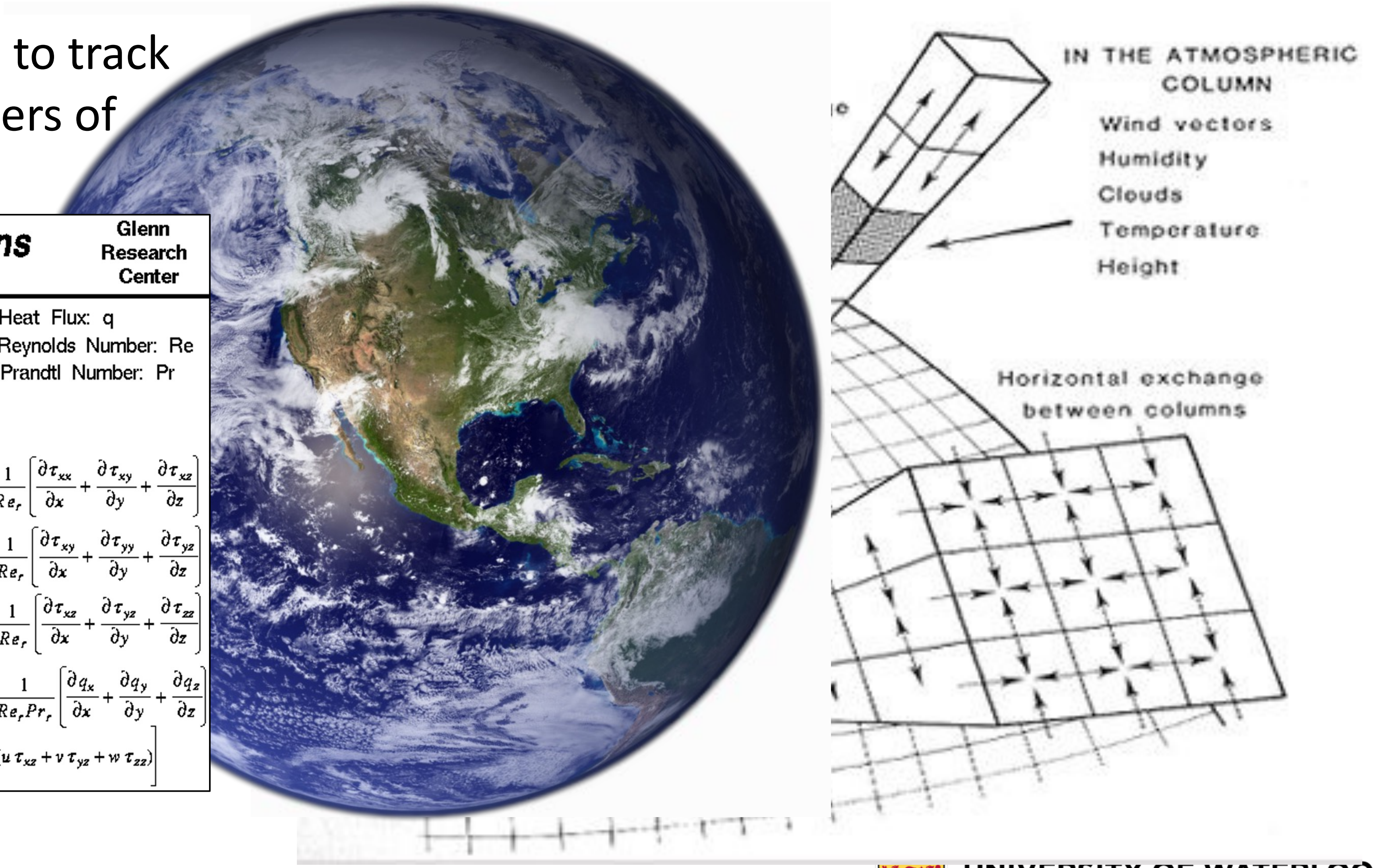
Continuity:
$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0$$

X – Momentum:
$$\frac{\partial(\rho u)}{\partial t} + \frac{\partial(\rho u^2)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} + \frac{\partial(\rho uw)}{\partial z} = -\frac{\partial p}{\partial x} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z}\right]$$

Y – Momentum:
$$\frac{\partial(\rho v)}{\partial t} + \frac{\partial(\rho uv)}{\partial x} + \frac{\partial(\rho v^2)}{\partial y} + \frac{\partial(\rho vw)}{\partial z} = -\frac{\partial p}{\partial y} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{yz}}{\partial z}\right]$$

Z – Momentum
$$\frac{\partial(\rho w)}{\partial t} + \frac{\partial(\rho uw)}{\partial x} + \frac{\partial(\rho vw)}{\partial y} + \frac{\partial(\rho w^2)}{\partial z} = -\frac{\partial p}{\partial z} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z}\right]$$

Energy:
$$\frac{\partial(E_T)}{\partial t} + \frac{\partial(uE_T)}{\partial x} + \frac{\partial(vE_T)}{\partial y} + \frac{\partial(wE_T)}{\partial z} = -\frac{\partial(up)}{\partial x} - \frac{\partial(vp)}{\partial y} - \frac{\partial(wp)}{\partial z} - \frac{1}{Re_r Pr_r}\left[\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + \frac{\partial q_z}{\partial z}\right]$$
$$+ \frac{1}{Re_r}\left[\frac{\partial}{\partial x}(u\,\tau_{xx} + v\,\tau_{xy} + w\,\tau_{xz}) + \frac{\partial}{\partial y}(u\,\tau_{xy} + v\,\tau_{yy} + w\,\tau_{yz}) + \frac{\partial}{\partial z}(u\,\tau_{xz} + v\,\tau_{yz} + w\,\tau_{zz})\right]$$



Unresolved processes: parameterization

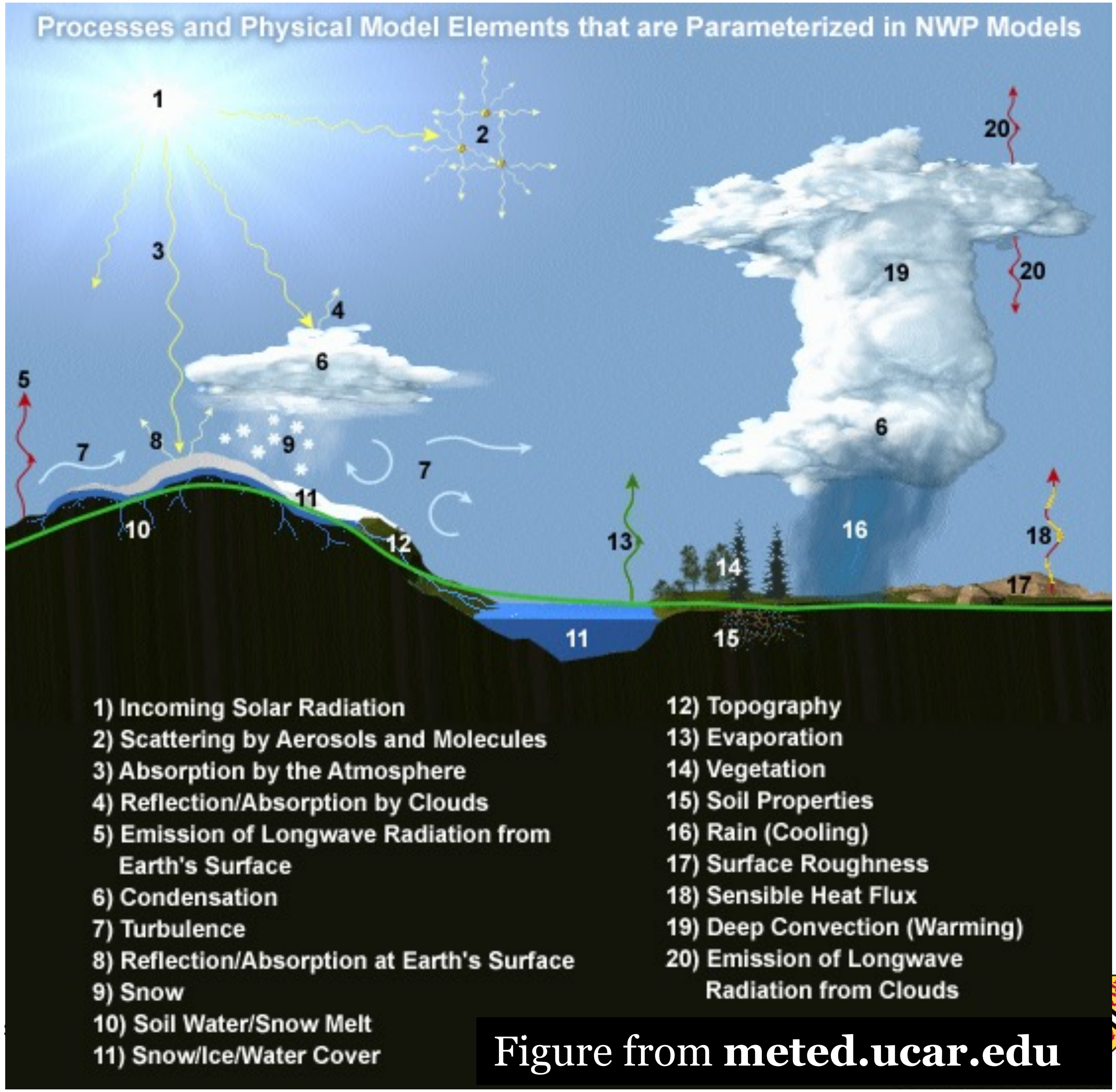
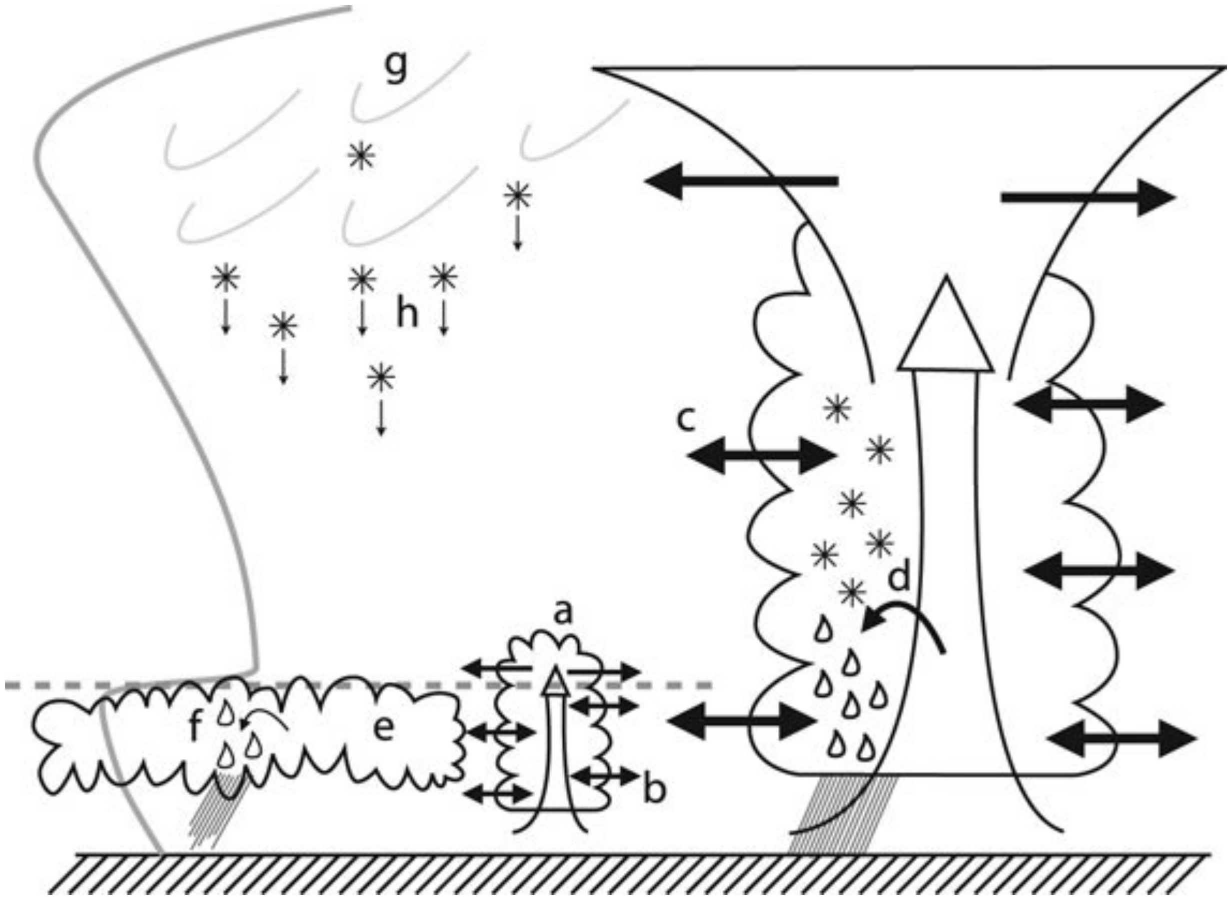


Figure from **meted.ucar.edu**

Model calibration (aka Tuning)

- Unresolved (sub-grid scale) processes involve poorly constrained parameters
- E.g., clouds, precipitation, radiation.



Mauritsen et al., JAMES, (2012)

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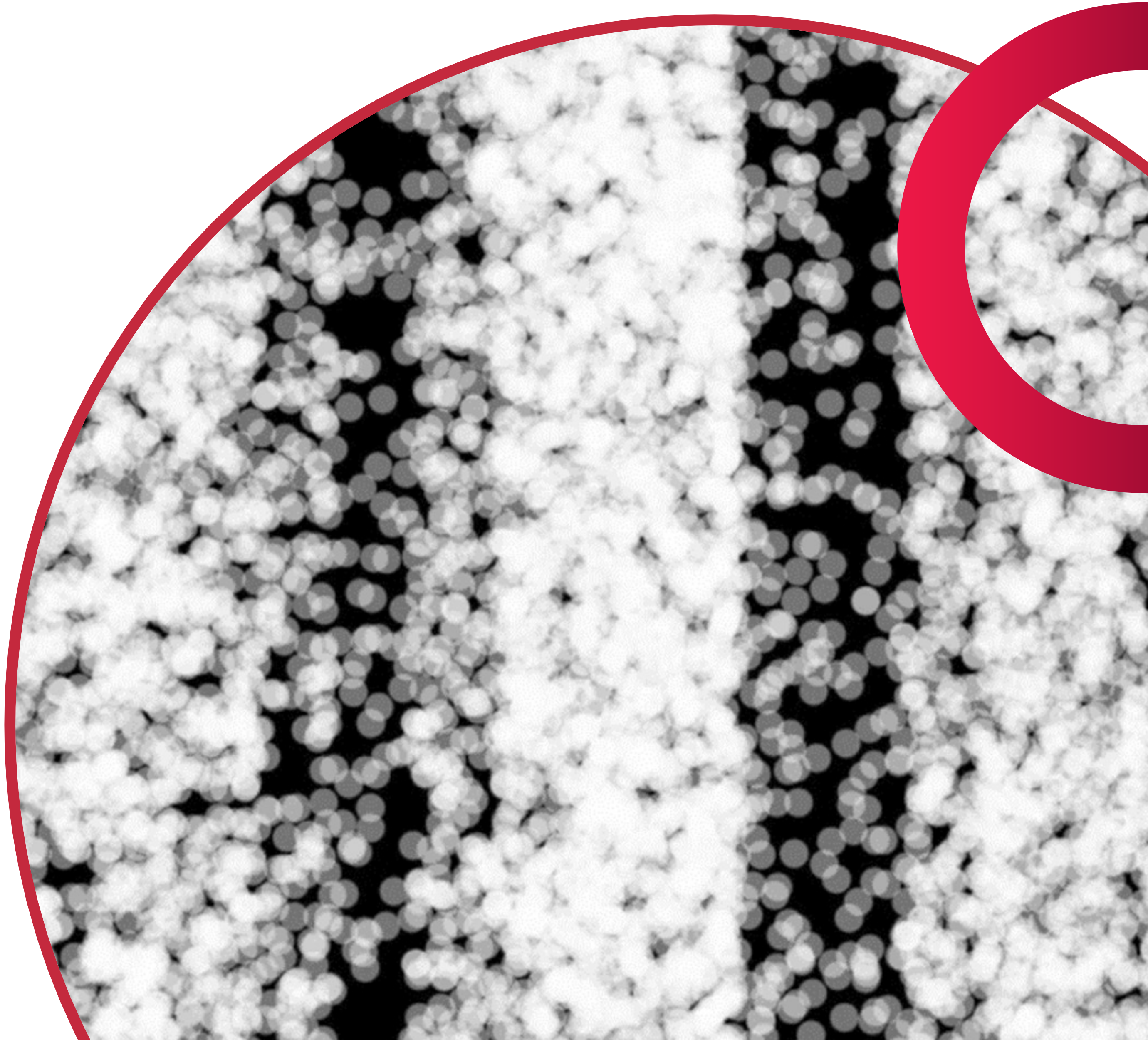
A QUICK QUANTUM LANDSCAPE

John Donohue

Senior Manager, Scientific Outreach
Institute for Quantum Computing
University of Waterloo



What is quantum?

What is quantum?

It's not magic

Quantum mechanics is the rulebook of the sub-microscopic universe

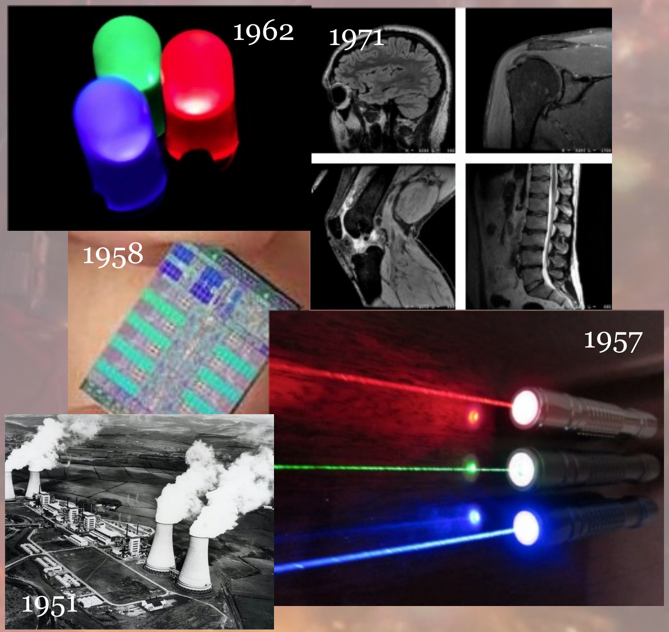
Energy is quantized, not continuous

Objects obey certain rules like the uncertainty principle and the Schrödinger equation

We must be careful about classical concepts like locality and determinism

It's not new

Understanding quantum has enabled many important modern technologies



It's still evolving

Popular modern research has focused on *quantum information*

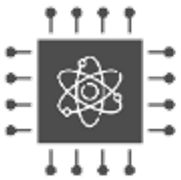
QUANTUM INFORMATION SCIENCE

A field that uses principles like superposition to transform information in new ways, with elements of:

- Computer Science
- Mathematics
- Cryptography
- Chemistry
- Physics
- Engineering

and more!

Applications include...



Computing

Communication

Sensors

Materials

Foundations

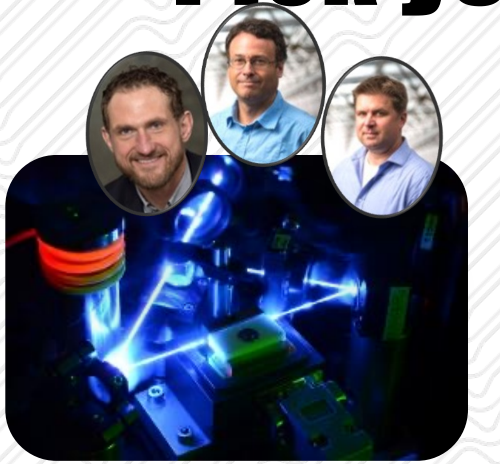
Pick your system

Atoms & Ions

Isolate a atoms and use their electron energy to encode information.

Applications
Atomic clocks, gravitational sensors, quantum simulators, memories

QUANTINUUM
ColdQuanta
AQT
atom computing
IONQ

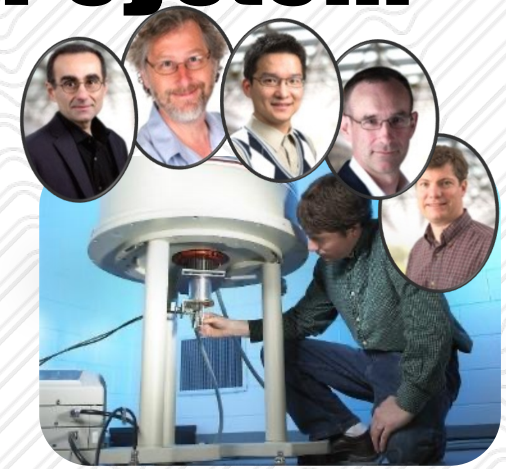


Photons

Create photons and encode information in polarization, color, etc.

Applications
Quantum communication, bosonic QC, imaging, networks, interferometers

IDQ FROM VISION TO TECHNOLOGY
XANADU
PSIQUANTUM

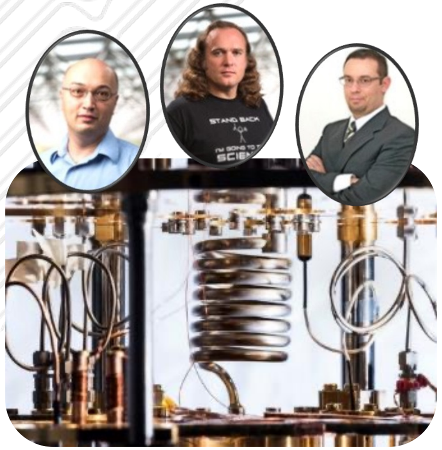


Spin

Use the magnetic properties of electrons and molecules and address with EM fields.

Applications
NMR spectrometry, imaging, QC, spintronics, magnetometry

intel
photonic
SILICON QUANTUM COMPUTING



Superconducting Circuits

Cool circuits to near absolute zero and measure wave properties of electrons.

Applications
QC, microwave quantum radar, magnetometry, photon detection

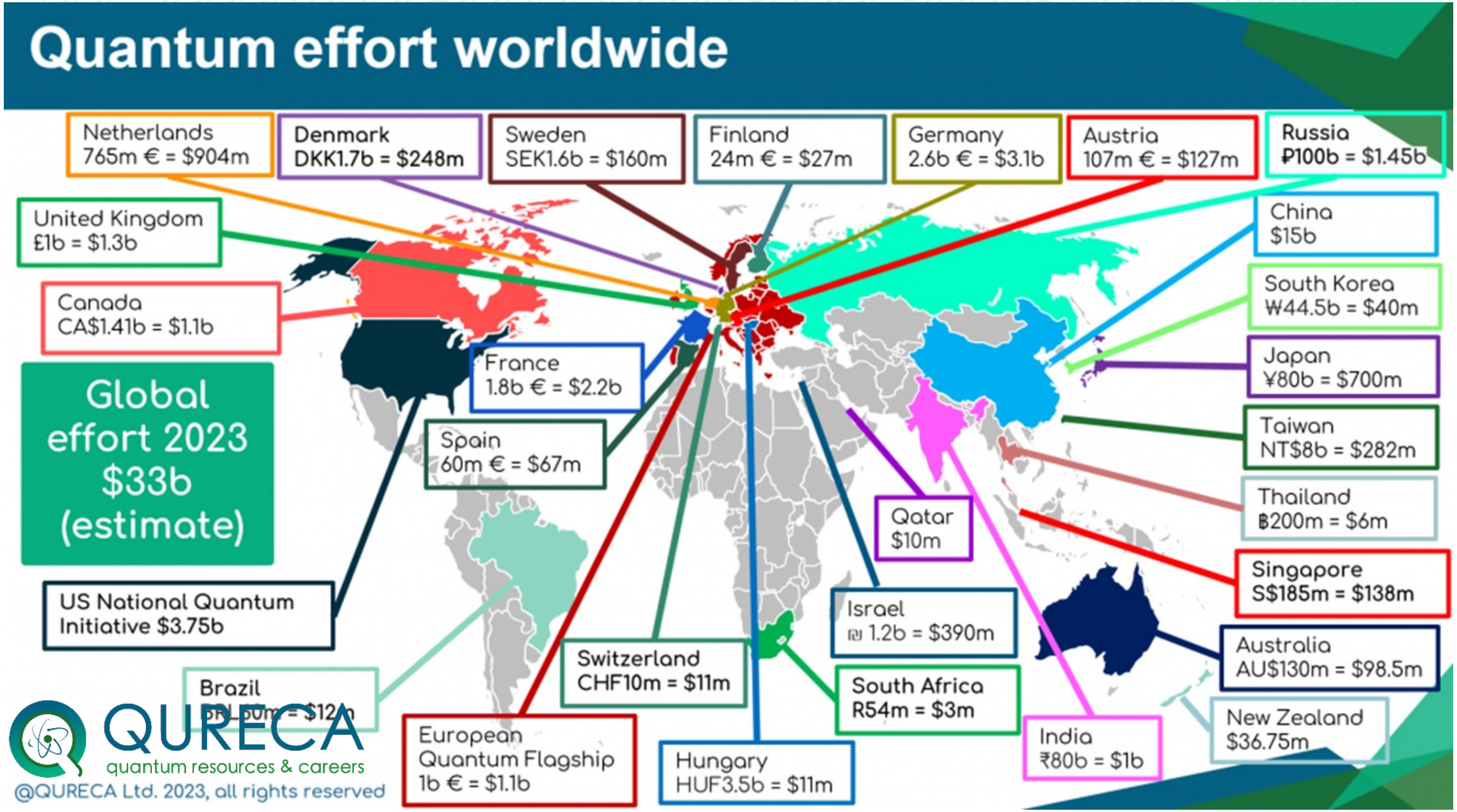
D:WAVE
Google
rigetti
IBM Q

Quantum in Canada

Canada announced a $360M national quantum strategy in January 2023, supporting:

- Research
- Talent
- Commercialization

Global Investments in Quantum Research



What can quantum do for you?

Quantum for environment

Michael Grabowecky, mgrabowe@uwaterloo.ca

UNIVERSITY OF WATERLOO | Department of Physics and Astronomy

IQC Institute for Quantum Computing

TQT Transformative Quantum Technologies

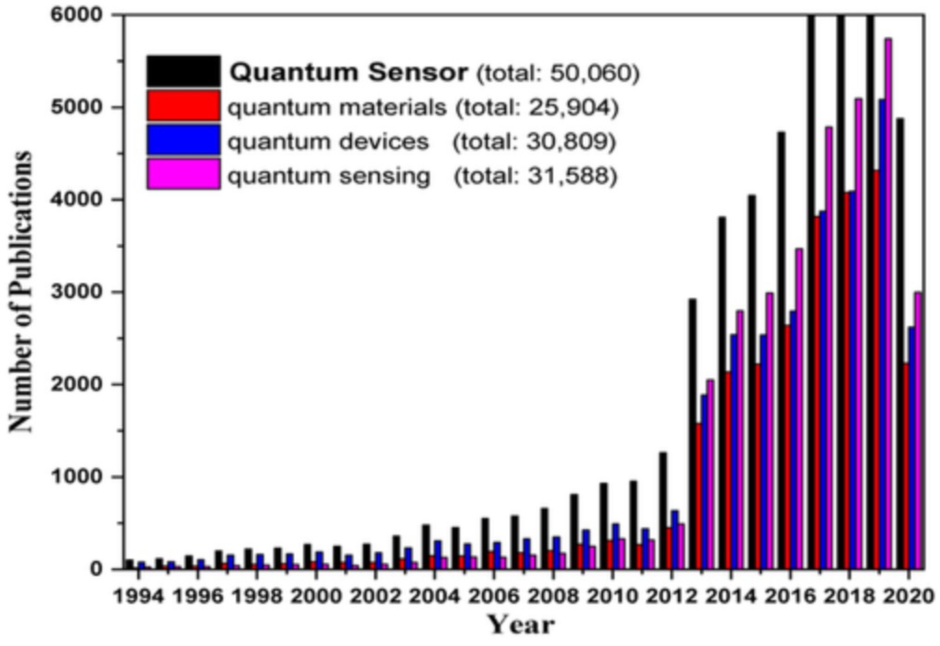
Quantum Exploration Space

Supported Activities

- **3 core experimental courses for the MSc in Quantum Technologies program**
  - Emphasis on hands-on learning using industry relevant quantum devices
- **Undergraduate School for Experimental Quantum Information Processing (USEQIP)**
  - Two week-long summer school including lectures and hands-on experiments designed for undergraduate students
- **Quantum School for Young Scientists (QSYS)**
  - Two week-long summer school aimed at high-school students for gaining hands on experience in QIP
- **Undergraduate Co-op opportunities**
- **Training**
  - Quantum sensing with nitrogen vacancy centers

Why choose quantum?

- **Quantum sensors offer improved accuracy/sensitivity for measuring:**
  - Changes in Motion
  - Strength of, and changes in electric and magnetic fields
  - Identifying trace levels of contaminants in materials
- **Quantum entanglement is a resource for:**
  - Enhanced computation & simulation
  - Improving the capacity, speed, and security of communication networks
  - Achieving finer sensitivity in measurements (entanglement enhanced sensing)
- **Photonic quantum systems offer:**
  - Improved imaging capabilities
  - Advantages for light detection and ranging systems (LIDAR)
- **And much more…**



Review | Open Access

Quantum Sensing for Energy Applications: Review and Perspective

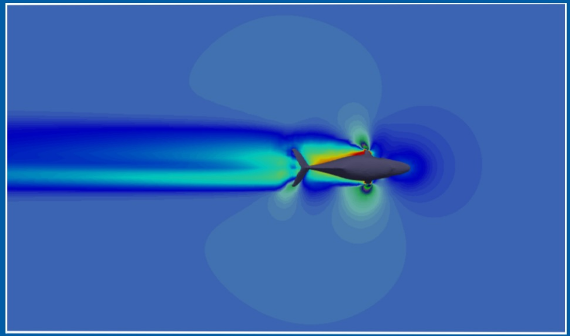
Scott E. Crawford, Roman A. Shugayev, Hari P. Paudel, Ping Lu, Madhava Syamlal, Paul R. Ohodnicki, Benjamin Chorpening, Randall Gentry, Yuhua Duan

First published: 15 June 2021 | https://doi.org/10.1002/qute.202100049 | Citations: 13

What quantum could do for you

Models from C-Core.ca

- **Quantum technologies for energy applications**
  - Quantum batteries
  - Improved energy production utilizing novel photovoltaic cells.
- **Quantum sensing for environmental monitoring**
  - Marine gravimetry (changes in ocean temperature, salinity, ice melt rates etc.)
  - Water quality, identifying contaminants
  - Changes in magnetic fields with sensitive magnetometers (Earth's field for climate monitoring, migration patterns of marine mammals



SQUIDS (Superconducting Quantum Interface Devices) can detect tiny changes in a magnetic field. C-CORE's modelling shows the changes in a magnetic field induced by a whale moving. Truly using SQUIDS to detect whales.

Much of this work is in its infancy, which is why we need ideation challenges such as Q4E!

RESEARCH ARTICLE | PHYSICS

Superabsorption in an organic microcavity: Toward a quantum battery

JAMES Q. QUACH, KIRSTY E. MCGHEE, LUCIA GANZER, DOMINIC M. ROUSE, BRENDON W. LOVETT, ERIK M. GAUGER, JONATHAN KEELING, GIULIO CERULLO, DAVID G. LIDZEY, AND TERSILLA VIRGILI Authors Info & Affiliations

SCIENCE ADVANCES • 14 Jan 2022 • Vol 8, Issue 2 • DOI: 10.1126/sciadv.abk3160

28,708 31

Conferences > OCEANS 2015 - MTS/IEEE Washin...

Quantum sensing in the maritime environment

Publisher: IEEE Cite This PDF

Marco Lanzagorta ; Jeffrey Uhlmann ; Salvador E. Venegas-Andraca All Authors

11 Cites in Papers | 712 Full Text Views

PAPER • OPEN ACCESS

An environmental monitoring network for quantum gas experiments and devices

T J Barrett[3,1], W Evans[1], A Gadge[1,2], S Bhumbra[1], S Sleegers[1], R Shah[1], J Fekete[1], F Oručević[1] and P Krüger[1]

Published 1 February 2022 • © 2022 The Author(s). Published by IOP Publishing Ltd

Quantum Science and Technology, Volume 7, Number 2

Citation T J Barrett *et al* 2022 *Quantum Sci. Technol.* **7** 025001

DOI 10.1088/2058-9565/ac3385

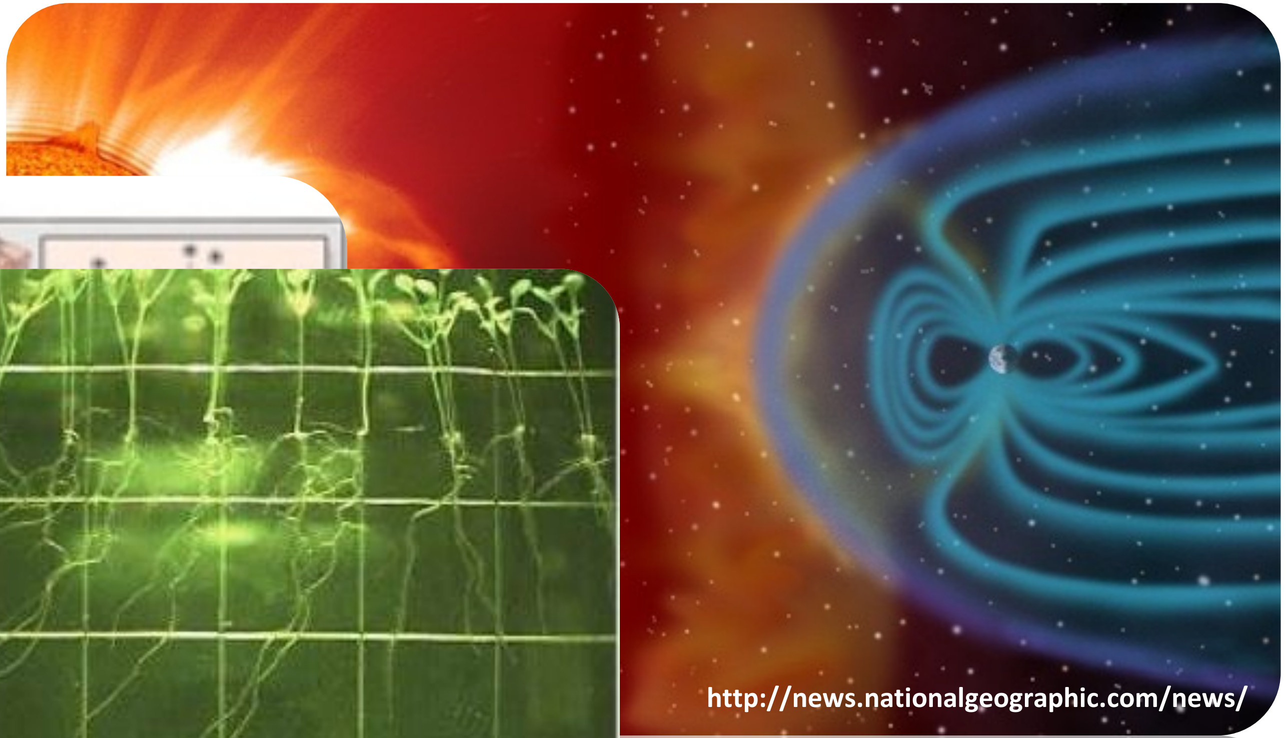
Quantum for Environment

F. Fani Sani

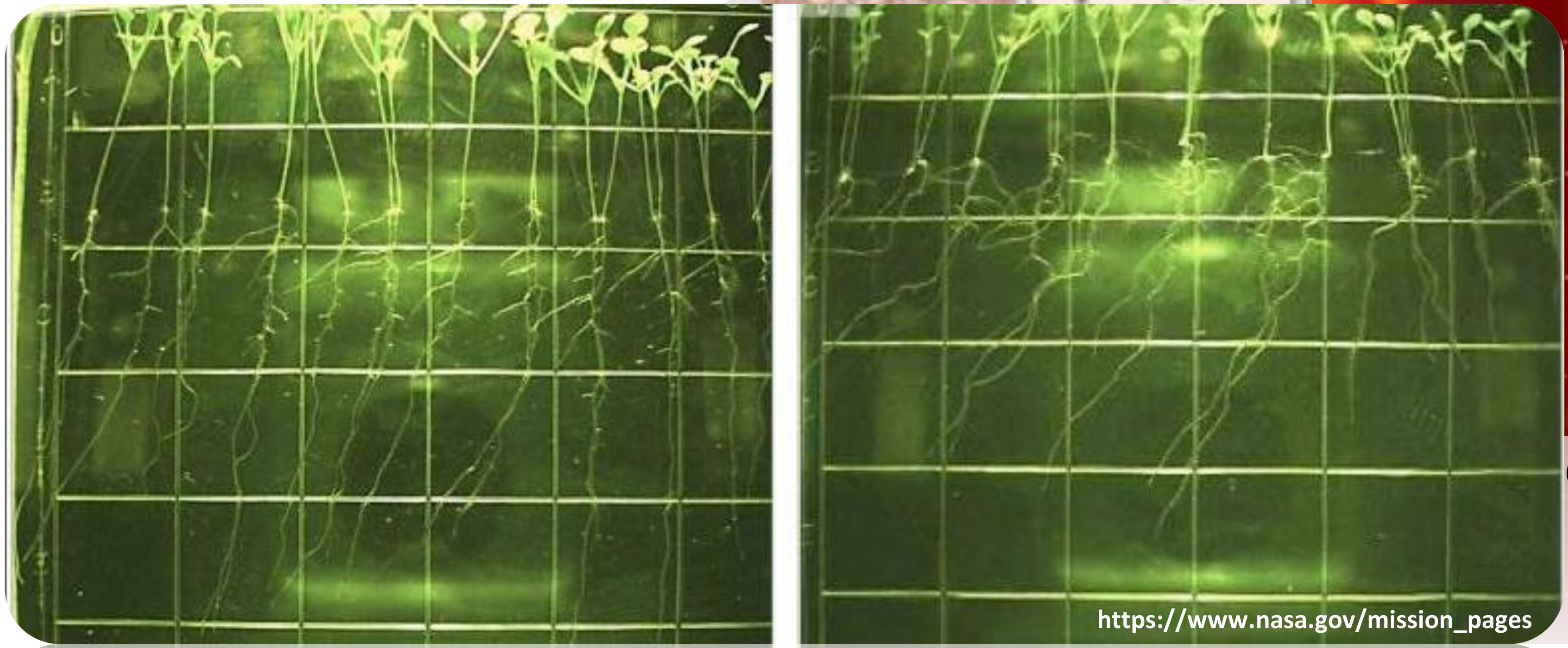
15 Feb 2024

Magnetism; a sense of mystery

- Perplexing phenomena related to magnetic interactions…

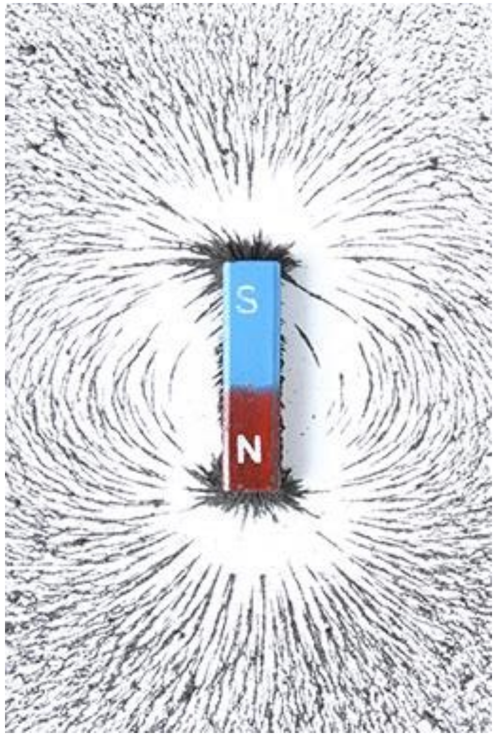


Cracks Found (2008)



Space Station Study Seeks How Plants Sense 'Up' and 'Down' (2014)

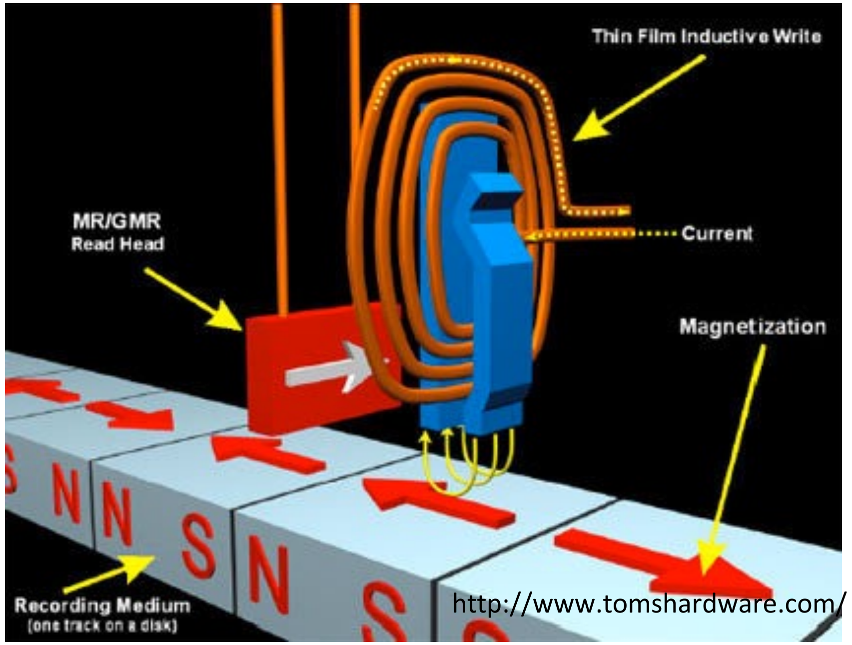
First magnetometer



http://www.compass-cbs.com/
https://www.uu.nl/nieuws/

Magnetism; human technologies

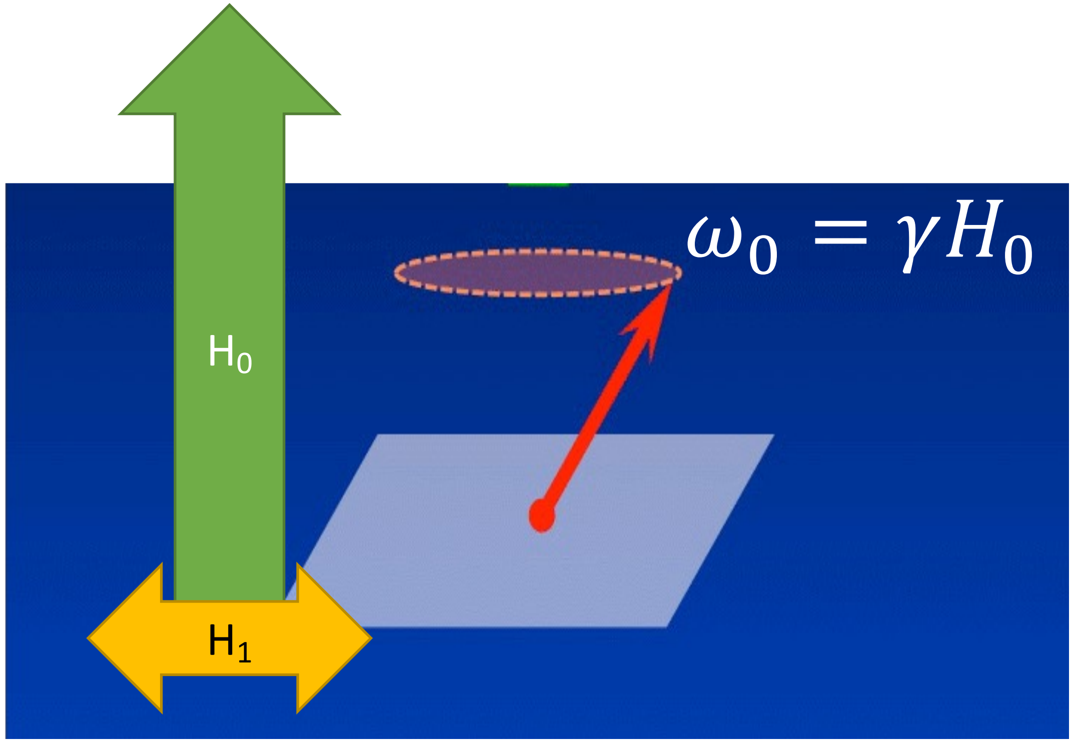
- Sound projectors; microphone
- Data reading and recording; memory
- Detection; MRI



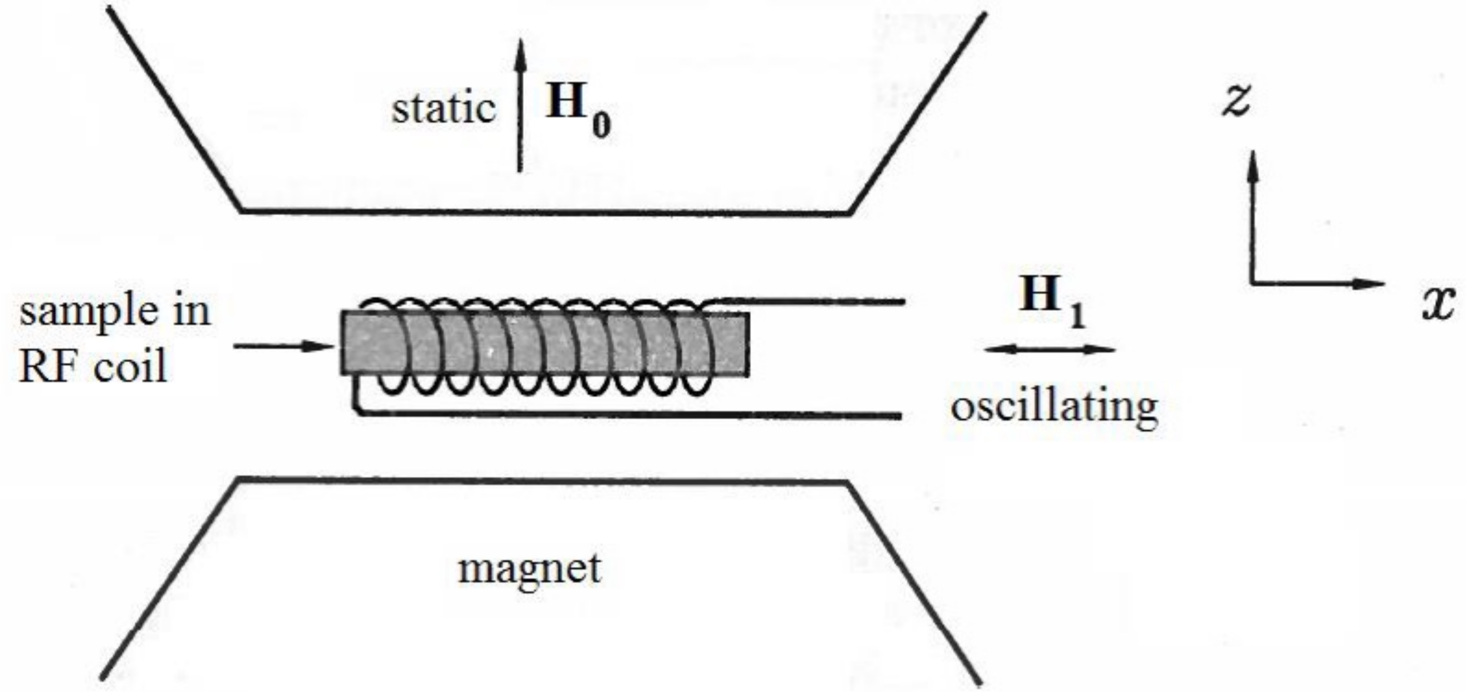
Hitachi's 7K1000 Terabyte Hard Drive (2007)

http://www.musiciansfriend.com

Magnetic resonance



Magnetic resonance

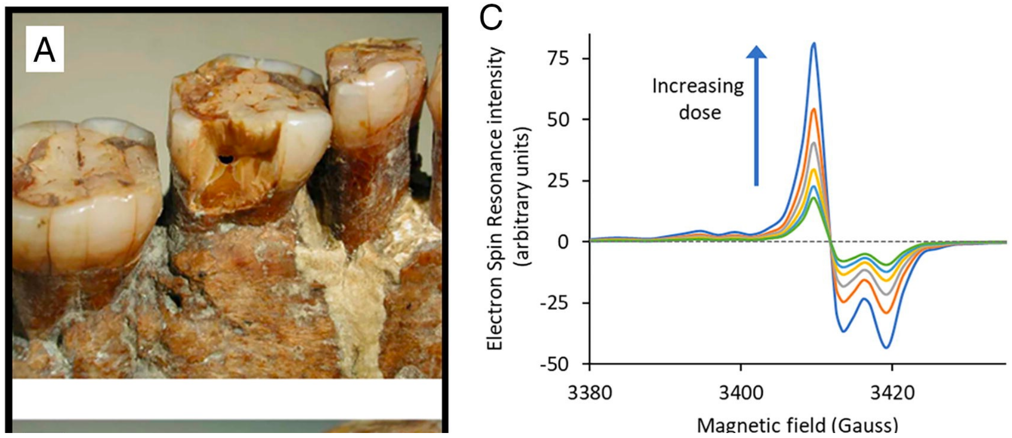


After S. Blundell, *Magnetism in Condensed Matter (2011)*.

Environmental Application of ESR

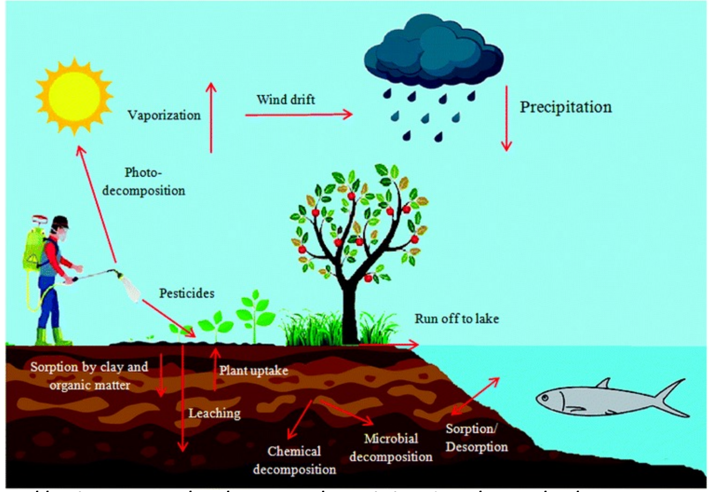
- Air and Water Quality Monitoring
- Understanding Climate Change
- Soil Health Assessment
- Monitoring Pollutant Degradation
- Dating of Paleolethic site

Sience.org/NEWS/SCIENCEINSIDER, 24 April 2023



https://www.pnas.org/doi/10.1073/pnas.2109324119?doi=10.1073/pnas.2109324119

https://atlas-scientific.com/blog/types-of-environmental-monitoring/



https://pubs.rsc.org/en/content/articlelanding/2020/ra/c9ra11025a

Thank you!

If you would like to tour or discuss any of the quantum devices in this room, don’t hesitate to reach out during the discussion session.

Important Dates

- Q4Environment Design Submissions Due: **March 4, 2024**
- Q4Environment Awards Announced: **April, 2024**

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Criteria

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Each team will submit a design document describing the form, operation, application and proposed impact of their idea.

Submissions will be judged on:

- the problem being addressed and its significance;
- team composition that reflects the expertise required to deliver on the interdisciplinary nature of the solution and best practices in equity, diversity and inclusion;
- impact of the proposed solution;
- market potential and economic feasibility.

A prototype is not required, but evidence of technical feasibility and manufacturability would be viewed favourably. Technical feasibility may refer to existing science and the novel application thereof in environment. References are not required but advantageous when describing a narrow aspect of science that may not be well known.

The design document shall be roughly five (5) pages in length and speak to both the quantum and environment communities (there will be reviewers drawn from both communities). The inclusion of at least one figure is desirable. The structure should follow the criteria bulleted above.

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Q&A/Discussion

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