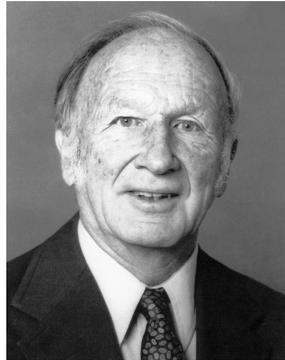
The background of the slide features a green Lorenz attractor, a mathematical plot that resembles a butterfly or a pair of wings. It is set against a dark blue background with a subtle grid pattern.

*With applications to climate change, pure mathematics  
and foundations of quantum physics:*

Six important properties of the amazing  
(nonlinear) Lorenz attractor.

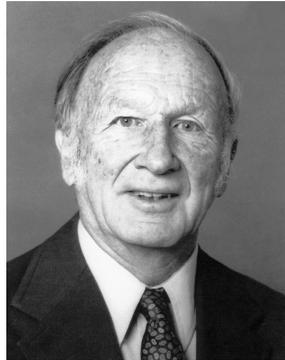
Tim Palmer  
Department of Physics  
University of Oxford

**New Directions in Theoretical Physics 2026**

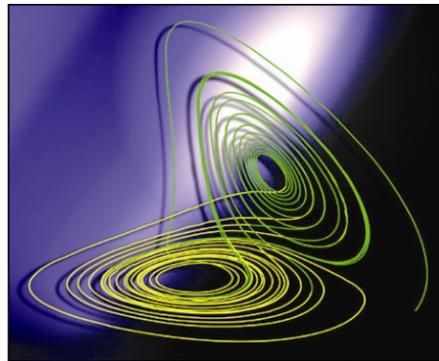
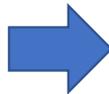


$$\begin{aligned}\dot{X} &= -\sigma X + \sigma Y \\ \dot{Y} &= -XZ + rX - Y \\ \dot{Z} &= XY - bZ\end{aligned}$$

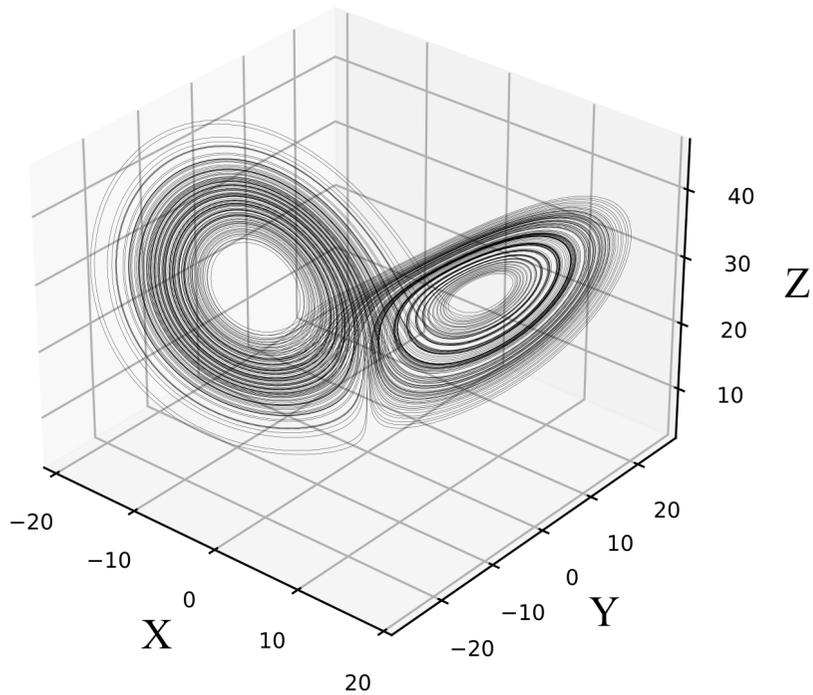
Lorenz (1963)



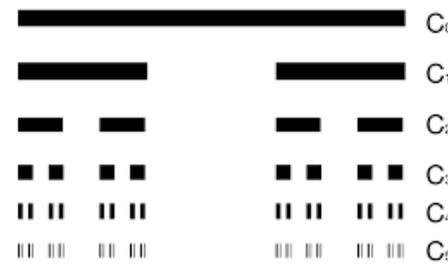
$$\begin{aligned}\dot{X} &= -\sigma X + \sigma Y \\ \dot{Y} &= -XZ + rX - Y \\ \dot{Z} &= XY - bZ\end{aligned}$$



# The Lorenz Attractor



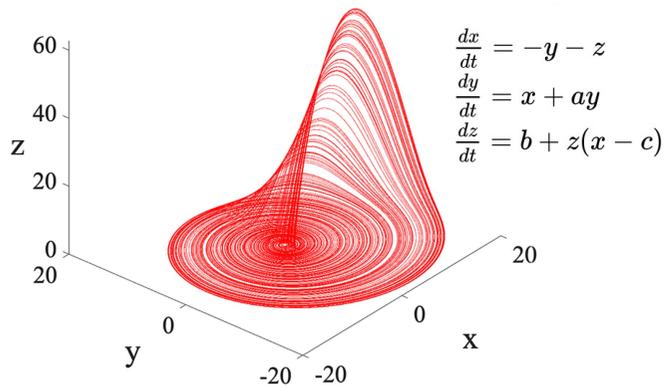
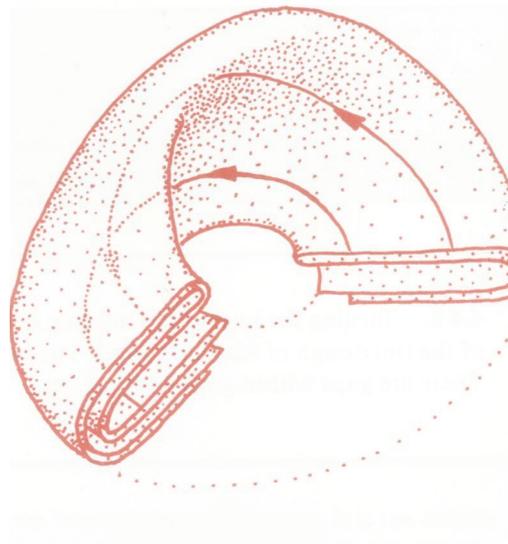
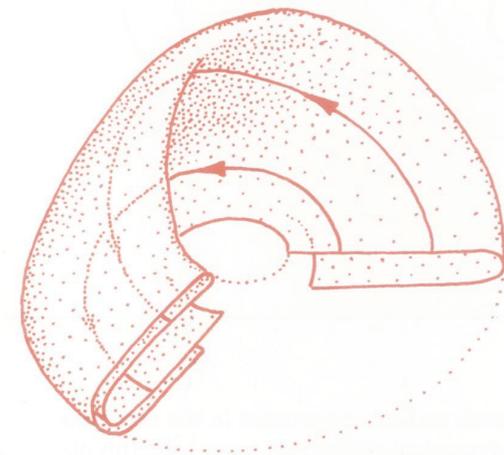
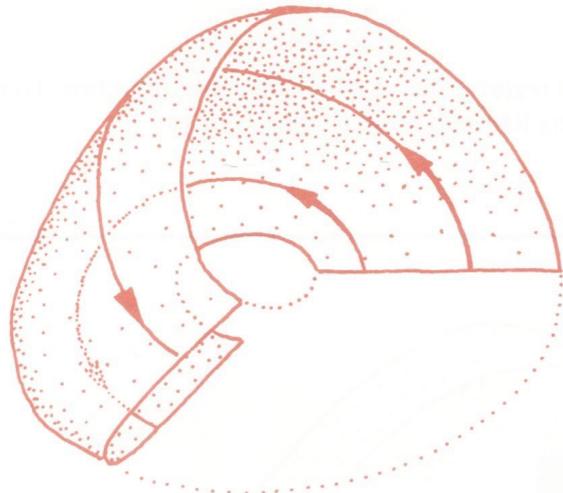
“We see that each surface is really a pair of surfaces, so that when they appear to merge, there are really four surfaces. Continuing this process for another circuit, we see there are really eight surfaces, etc, and we finally conclude that there is an infinite complex of surfaces , each extremely close to one or the other of two merging surfaces”. **Lorenz 1963.**



Georg Cantor

**Only proven rigorously in 1999.**

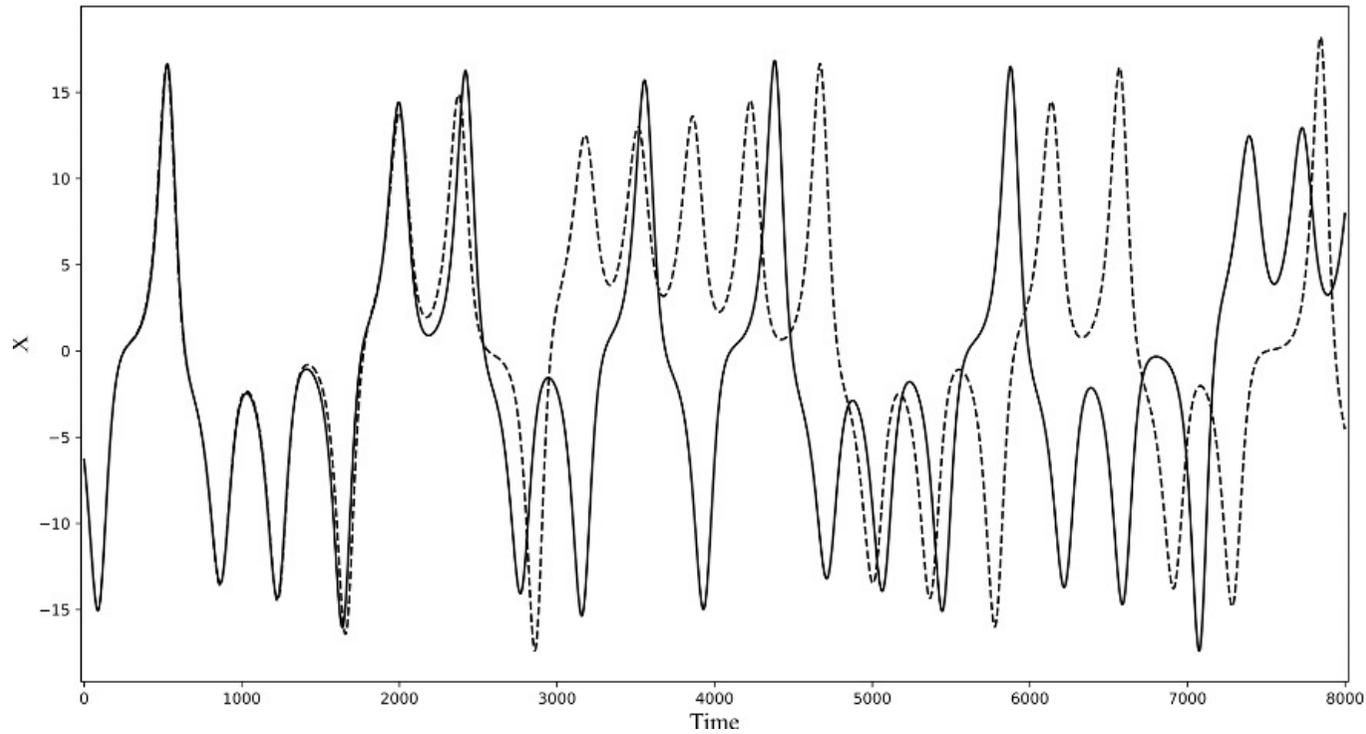
# The Essential Idea: Stretch and Fold



Rössler Attractor

Abraham and Shaw, 1984

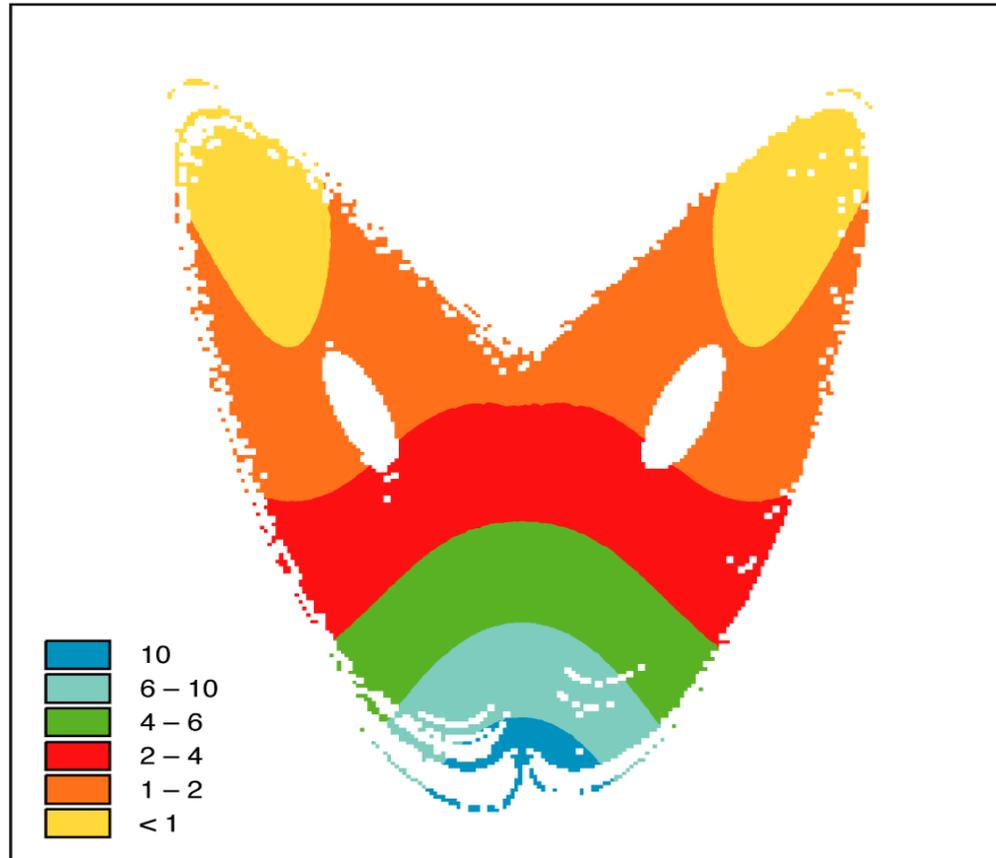
# The Butterfly Effect



**Boring! We all know this.**

1.

### Leading Singular Value



Optimization interval 60 dt (dt = 2 x 10<sup>-3</sup>)

$$\frac{dX}{dt} = F[X]$$

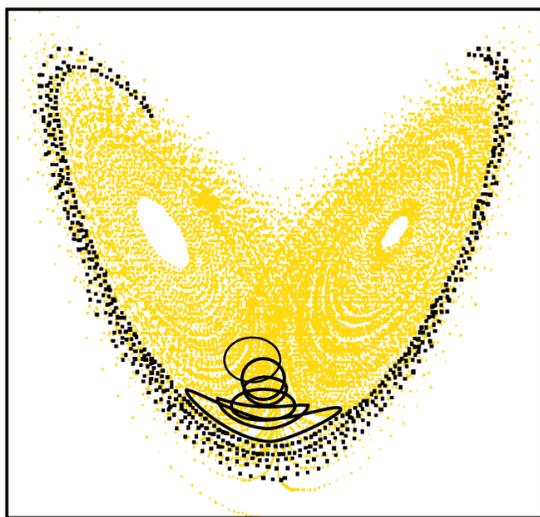
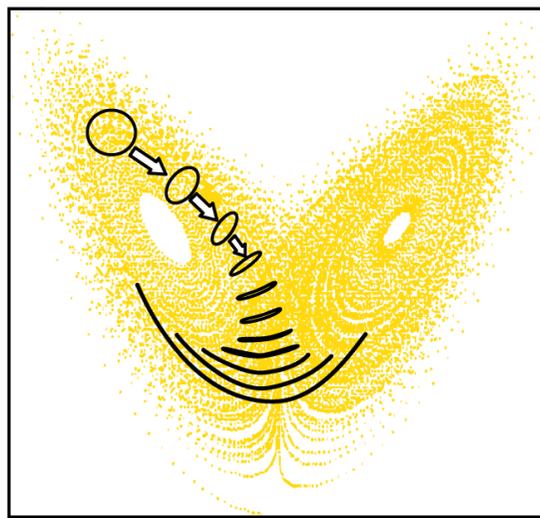
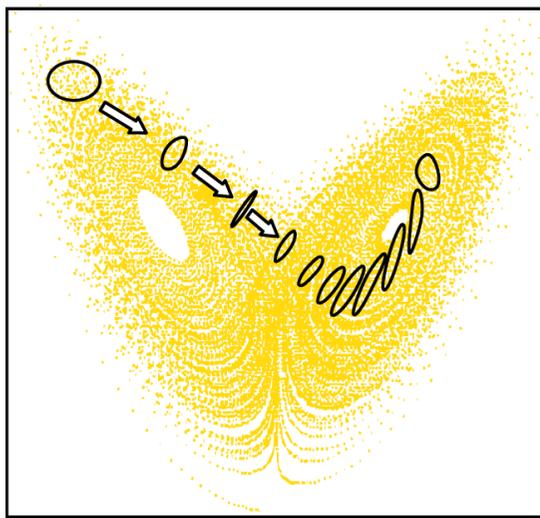
⇒

$$\frac{d \delta X}{dt} = \frac{dF}{dX} \delta X$$

⇒

Growth of small perturbations depends on  $X$ .

Leading Singular Value of Lorenz (1963) – leading eigenvalue of symmetrised Jacobian



The scientific  
basis for  
ensemble  
weather  
prediction

# A Traditional Weather/Climate Model

$$\rho \left( \frac{\partial}{\partial t} + \mathbf{u} \cdot \nabla \right) \mathbf{u} = \rho \mathbf{g} - \nabla p + \mu \nabla^2 \mathbf{u}$$

Resolved scales  
←

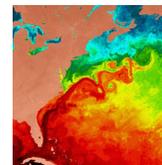
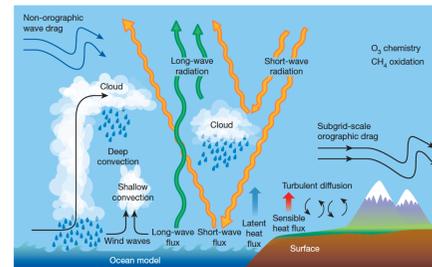
Dynamical Core



→ Unresolved scales

Deterministic  
Parametrisations

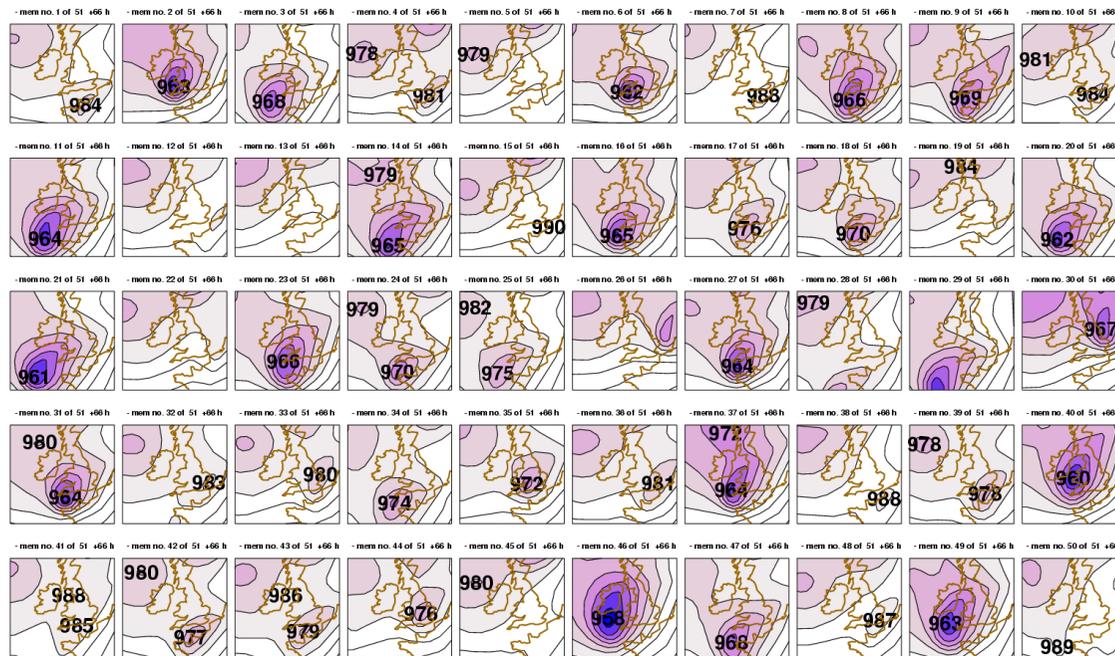
$$P(X_{Tr}; \alpha)$$



$$D = P$$

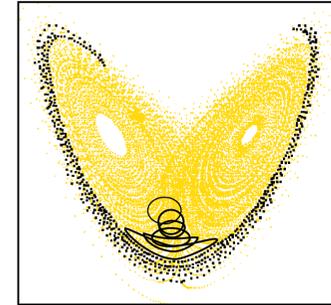
# October 87 “Michael Fish” Storm: Very Unpredictable – Very Chaotic!

“I mean if you can’t forecast the worst storms for several centuries – three hours before they happen – what are you doing?” Michael Buerk. 16 October 1987.

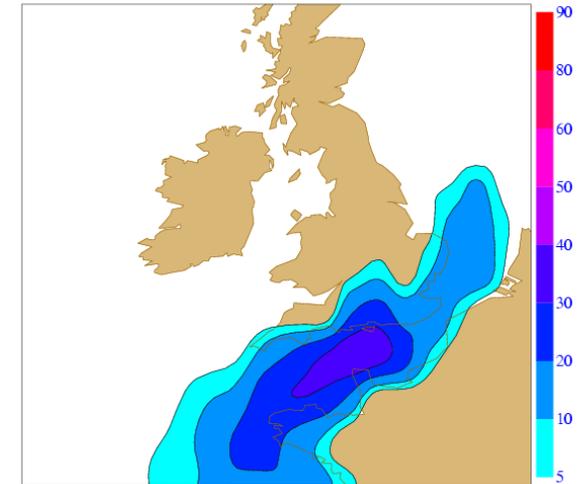


D+2.5 days

Ensemble of 50 forecasts with slightly different initial conditions.

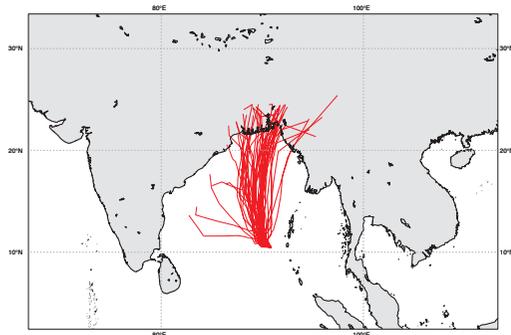


Tuesday 13 October 1987 12UTC ECMWF EPS Perturbed Forecast t=+66-72) VT: Friday 16 October 1987 12UTC  
Surface: \*\*wind gust at 10m (Exp: ep2b) - Ensemble member number 1 of 51

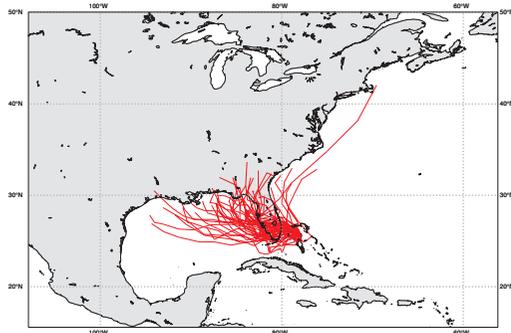
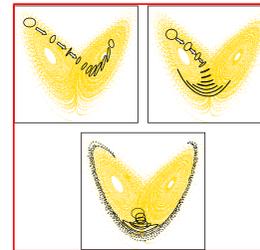


Probability of hurricane-force gusts on October 16<sup>th</sup> 1987

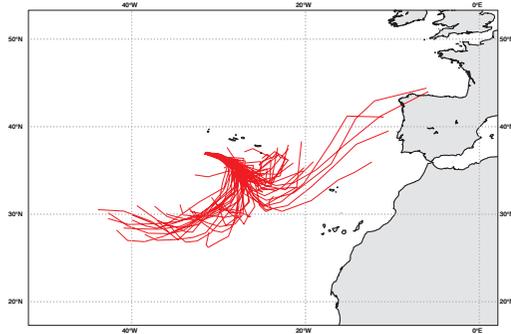
# c. 7-day Predictions of Tropical Cyclones



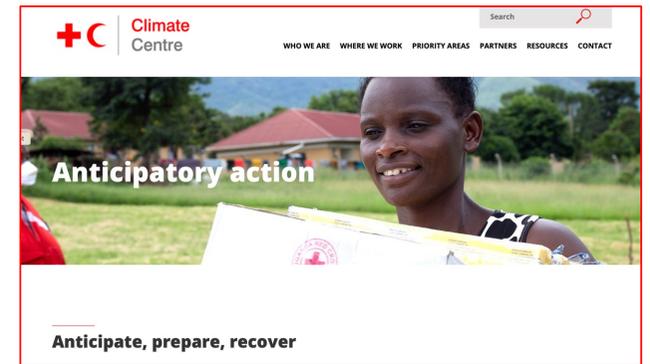
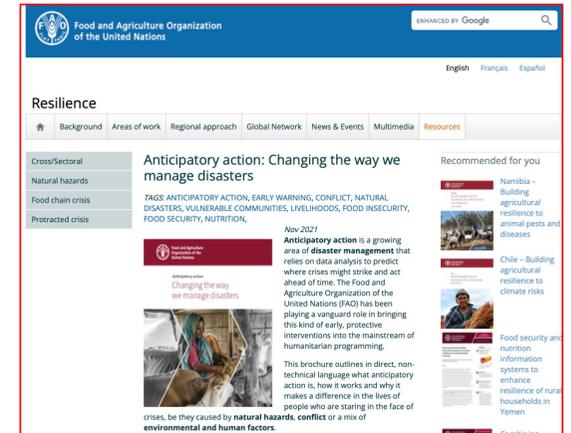
Cyclone Sidr  
(very predictable).



Hurricane Katrina  
(averagely predictable).

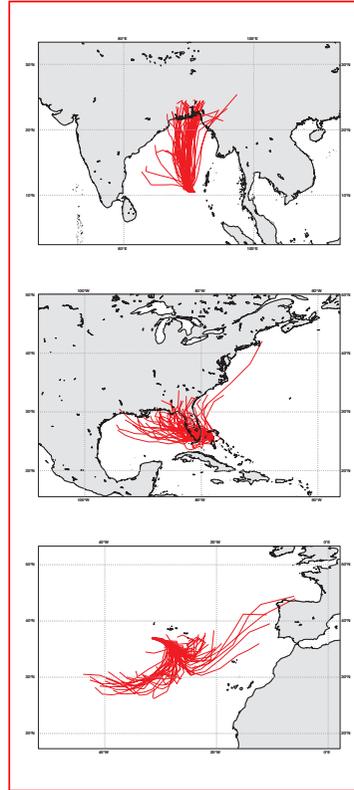
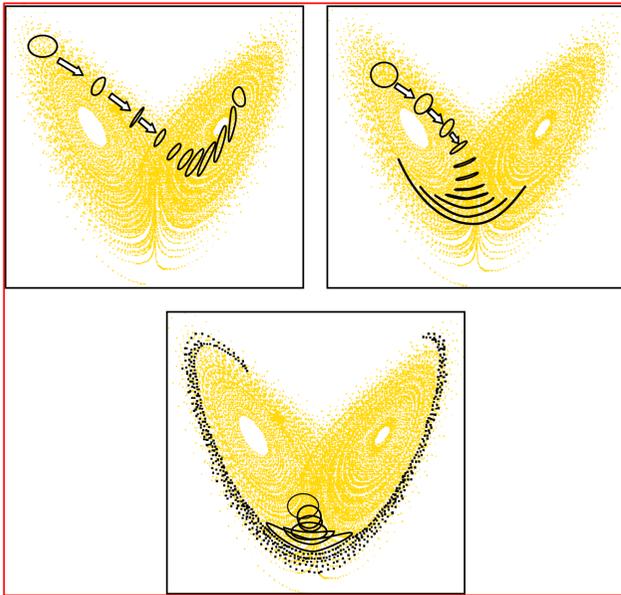


Hurricane Nadine  
(very unpredictable).



Take anticipatory action only when the **probability of extreme weather** exceeds a predefined threshold – Anticipatory Action is now saving lives around the world

# What evolution equation do these probability distributions satisfy?



It is the Liouville Equation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (v\rho) = 0$$

or

$$\frac{\partial \rho}{\partial t} = \{H, \rho\}$$

for a Hamiltonian system.

The Liouville equation is linear because it describes conservation of probability.

The linearity of the Liouville equation says **nothing** about the nonlinearity of the dynamical system from which the probabilities are generated.

# A Stochastic Weather/Climate Model

$$\rho \left( \frac{\partial}{\partial t} + \mathbf{u} \cdot \nabla \right) \mathbf{u} = \rho \mathbf{g} - \nabla p + \mu \nabla^2 \mathbf{u}$$

Resolved scales  
←

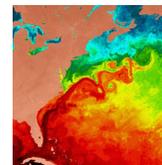
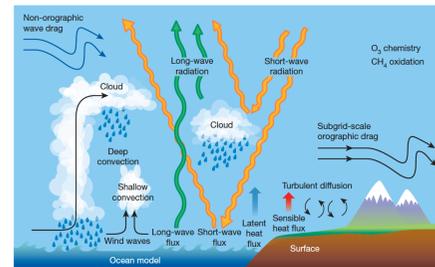
Dynamical Core



Unresolved scales  
→

Stochastic  
Parametrisations

$$(1 + r)P(X_{tr}; \alpha)$$

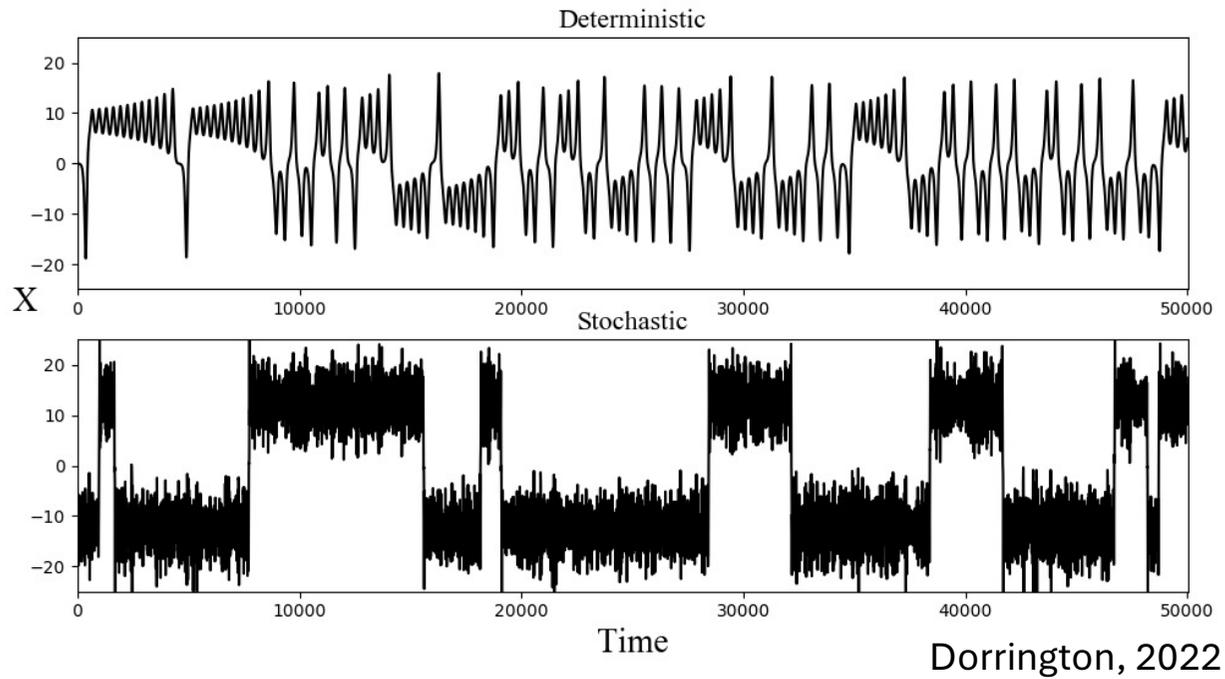


$$D = P$$

Buizza, Miller, Palmer, 1999;  
Palmer, 2001

2.

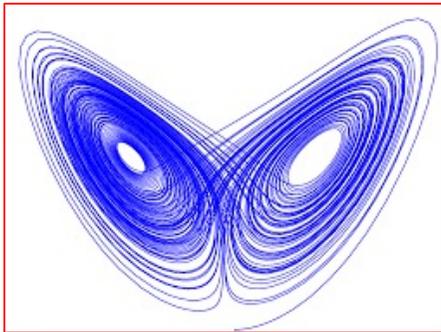
Adding noise to a nonlinear system can sharpen it, rather than blur it!



Adding noise to the Lorenz model stabilizes quasi-stationary regimes.

# 3. “Climate change” in the Lorenz Model.

$$\begin{aligned} \dot{X} &= -\sigma X + \sigma Y + f_0 \cos\theta \\ \dot{Y} &= -XZ + rX - Y + f_0 \sin\theta \\ \dot{Z} &= XY - bZ, \end{aligned}$$



The forcing does not shift the climate pdf, but instead increases the likelihood of one regime, decreases the likelihood of the other.

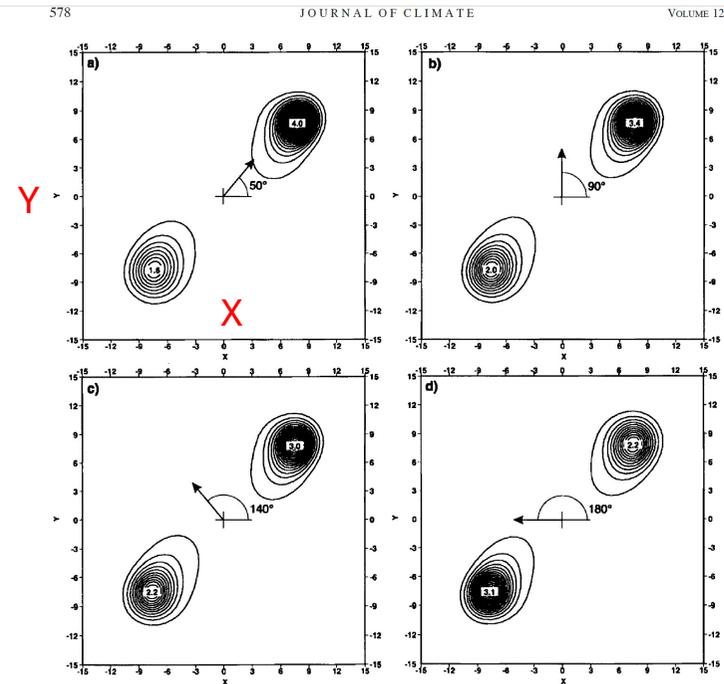
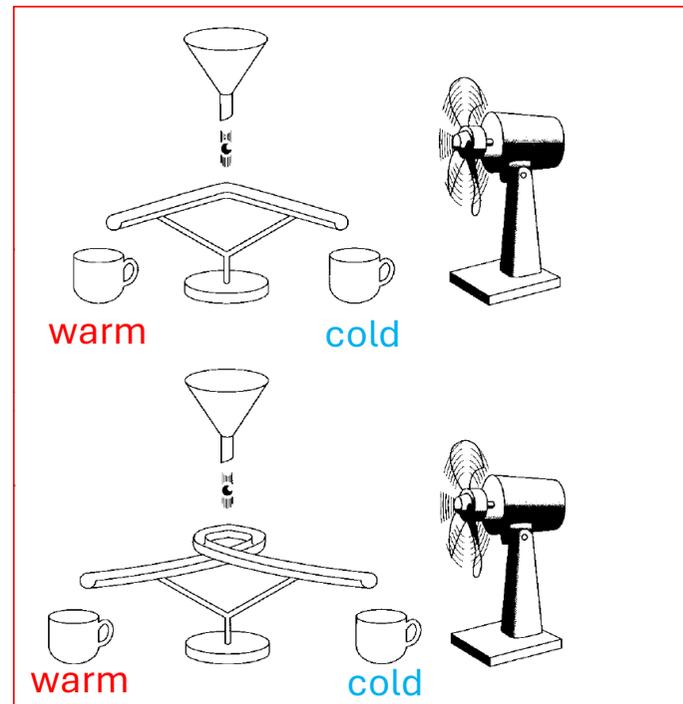


FIG. 2. The impact of various imposed forcings ( $f_0 \cos\theta, f_0 \sin\theta$ ) for  $\theta = 50^\circ, 90^\circ, 140^\circ, 180^\circ$ , on the PDF of the Lorenz-model state vector with running time mean, in the X-Y plane:  $\sigma = 10, r = 28, b = 8/3$ .

Palmer, 1998

# A conceptual model of the response to forcing in a nonlinear system

System is most susceptible to external forcing when it is in the unstable part of the attractor.



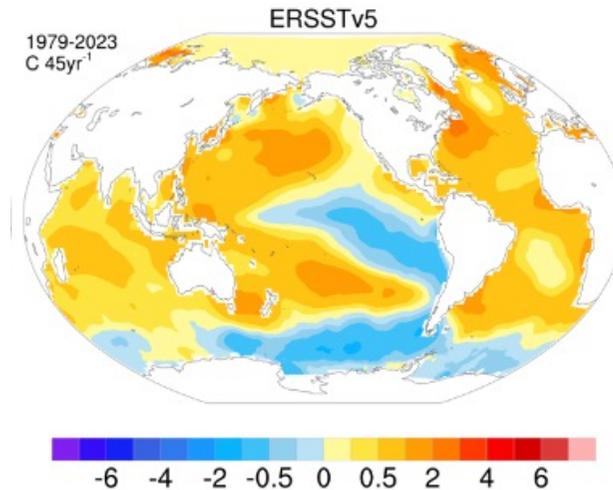
A forcing towards a warmer state could lead to cooling.

Palmer, Weisheimer, 2018

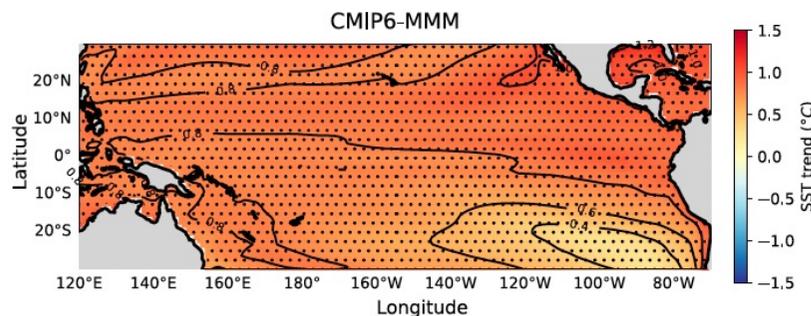
Predicting the impact of climate change reliably depends critically on modelling the climate attractor accurately.

One of the most important chaotic modes of climate variability is the **El Nino/Southern Oscillation (ENSO)**. ENSO affects weather around the globe.

Obs Sea surface  
Temp Trend

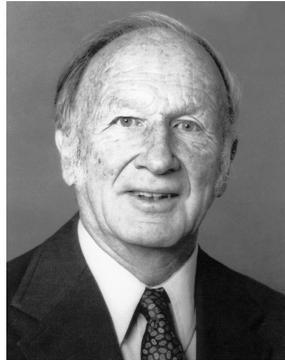


Predicted Temp  
Trend from IPCC-  
class models

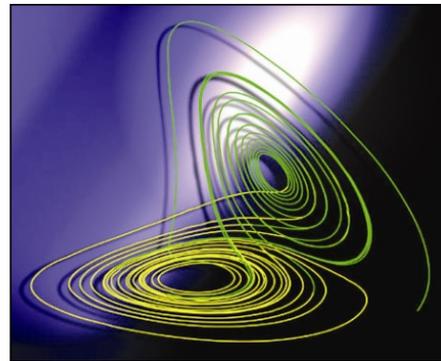
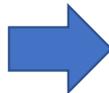


Current climate models' simulations of ENSO variability are poor (with many systematic errors). As a result, we are not predicting the impact of climate change on ENSO correctly. **This is almost certainly because of inadequate model resolution – Kang et al 2026.**

As a result, we can currently say **little with confidence** about climate change at the regional level (in terms of rainfall, wind patterns etc) around the globe. **What to do?**



$$\begin{aligned}\dot{X} &= -\sigma X + \sigma Y \\ \dot{Y} &= -XZ + rX - Y \\ \dot{Z} &= XY - bZ\end{aligned}$$



Great 20<sup>th</sup> Century Mathematicians

## Two Great Theorems of 20<sup>th</sup> Century Mathematics



The set of mathematical truths is much larger than those provable by algorithms.



The equation  $x^n + y^n = z^n$  has no solutions in positive integers if  $n > 2$ .

## 20th Century Maths and its relation to fractal geometry

4.



Uncomputable problems such as Hilbert's Entscheidungsproblem can be reformulated in terms of geometric properties of fractal attractors like Lorenz (1963).



Simant Dube (1993)

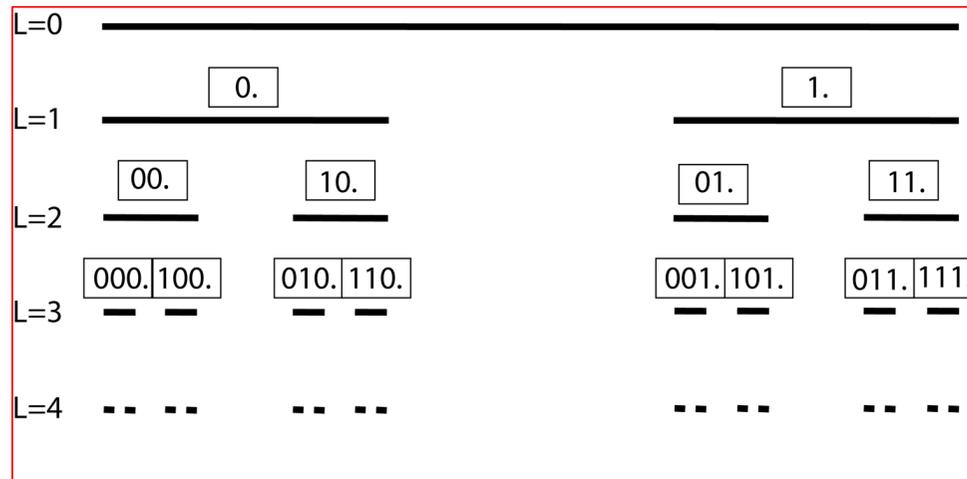
5.



Wiles' proof of FLT uses the fact that there are two ways to complete (Cauchy sequences of) rational numbers: with the Euclidean metric (real numbers) or with the  $p$ -adic metric ( $p$ -adic numbers).

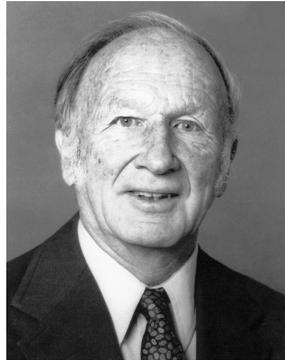
**p-adic numbers are to fractal geometry as real numbers are to Euclidean geometry.**

Labelling  $C$  with 2-adic numbers

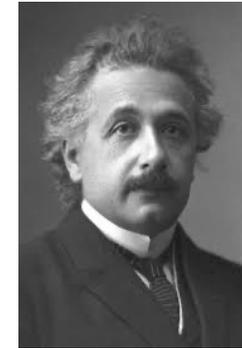
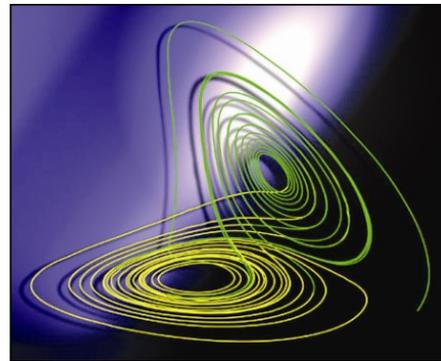


Can add, subtract, multiply and divide on  $C$  using 2-adic numbers  $\in \mathbb{Z}_2$ , e.g.,  $\dots 011. + \dots 111. = \dots 010.$  Can't do this with real numbers  $\in \mathbb{R}$ .

Irrational reals (like  $\sqrt{2}, \pi, e$ ) are infinitely far from the rational numbers in the p-adic perspective.



$$\begin{aligned}\dot{X} &= -\sigma X + \sigma Y \\ \dot{Y} &= -XZ + rX - Y \\ \dot{Z} &= XY - bZ\end{aligned}$$



Great 20<sup>th</sup> Century Physicists

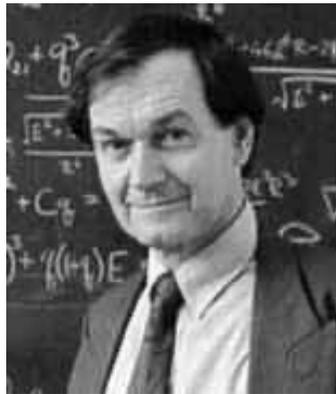


Great 20<sup>th</sup> Century Mathematicians

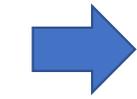
GR and Quantum Gravity



Dennis Sciama



Roger Penrose



Pre PhD

4 mentors on  
whose  
shoulders I  
have stood.



Post PhD

Climate and Chaos



Raymond Hide



Ed Lorenz

## “It from bit”



John Wheeler

Grandfather of modern  
quantum information  
theory  
**but**  
a critic of quantum  
mechanics.

“The familiar probability function and wave equation of quantum theory provide mere continuum idealizations and by reason of this circumstance conceal the information source from which they derive.”

# A model (RaQM) of QM based on discretised Hilbert Space

arXiv > quant-ph > arXiv:2510.02877

Search... Help |

Quantum Physics

[Submitted on 19 Sep 2025 (v1), last revised 2 Dec 2025 (this version, v2)]

## Testing Quantum Mechanics with Quantum Computers: Qubit Information Capacity

Tim Palmer

Motivated in part by John Wheeler's assertion that the continuum nature of Hilbert Space conceals the information-theoretic character of the quantum wavefunction, a specific discretisation of complex Hilbert Space is proposed. Although the Schrödinger equation is not modified, the bases in which the quantum state is mathematically defined must satisfy certain 'rationality conditions'. This leads to the notion of Qubit Information Capacity  $N_{\max}$ . For any  $N > N_{\max}$  - qubit state, there is insufficient information in the  $N$  qubits (linearly growing in  $N$ ) to allocate even one bit to each of the  $2^{N+1} - 2$  degrees of freedom demanded by complex Hilbert Space (exponentially growing in  $N$ ) and hence unitary quantum mechanics (QM, where  $N_{\max} = \infty$ ). Here, state reduction to the classical limit corresponds to a steady coarsening of the discretisation with time. Using the Diósi-Penrose model for gravitised state reduction, it is estimated that  $N_{\max}$  lies between about 200 and 400 for current qubit technologies, and will never exceed 1,000. It is therefore predicted that the exponential advantage of Shor's algorithm over classical algorithms, will have saturated at 1,000 qubits. Hence, insofar as a classical computer will never factor a 2048-bit RSA integer, neither will a quantum computer. This predicted breakdown of QM is potentially testable in a few years. Importantly, the proposed QIC is not itself due to gravitational or other types of state collapse.

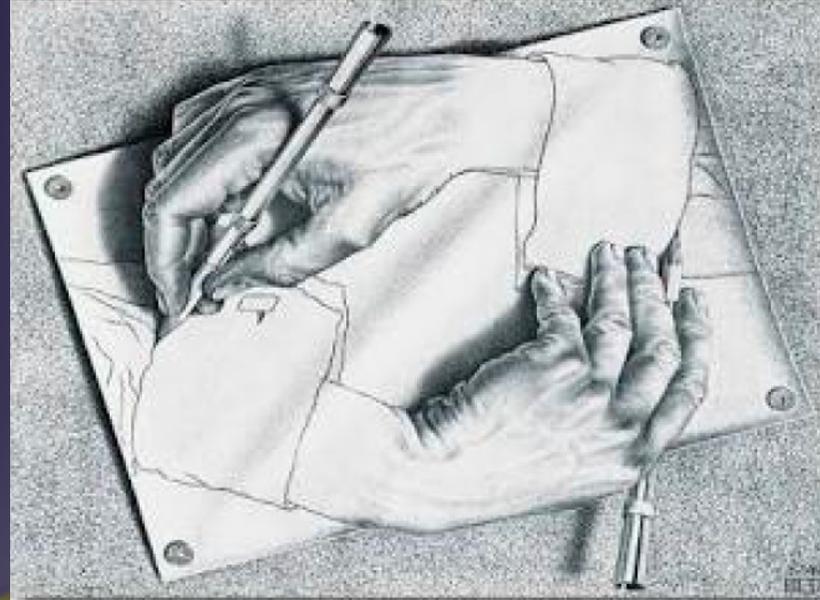
Comments: Proceedings of the National Academy of Sciences: Resubmission after review  
Subjects: Quantum Physics (quant-ph)  
Cite as: arXiv:2510.02877 [quant-ph]  
(or arXiv:2510.02877v2 [quant-ph] for this version)

In review in PNAS

- Gravity is the physical process discretising Hilbert Space. Because gravity is so weak, discretisation is very fine scale.
- Discrete Hilbert Space provides an explicit information-theoretic description of  $|\psi\rangle$ . Information content grows linearly with the number  $n$  of entangled qubits in  $|\psi\rangle$ .
- Quantum states are only defined in bases with rational-number (squared) amplitudes and/or complex phases. This only makes mathematical sense in the p-adic perspective.
- Gravitised discretisation of Hilbert Space leads to a specific prediction of the breakdown of unitary QM. When  $n > 1,000$ , it is not possible to allocate even one bit of information to each of the  $2^n$  dimensions of Hilbert Space.
- Solves the measurement problem as a nonlinear chaotic evolutionary process (c.f. fractal riddled basins of attraction).
- Provides comprehensible explanations of "quantum weirdness"

## Bell's Theorem

Fundamental theories of physics (e.g. quantum gravity) **will not be** EPR/Bell nonlocal but **will be** underpinned by holistic principles (like Mach's Principle – inertia here is due to mass there).



Building bigger particle colliders to probe yet smaller regions of space will not uncover such theories.

6. The Lorenz attractor may be telling us something deep about the holistic nature of the quantum universe. The (p-adic) laws of physics describe the geometry of a cosmological invariant set.

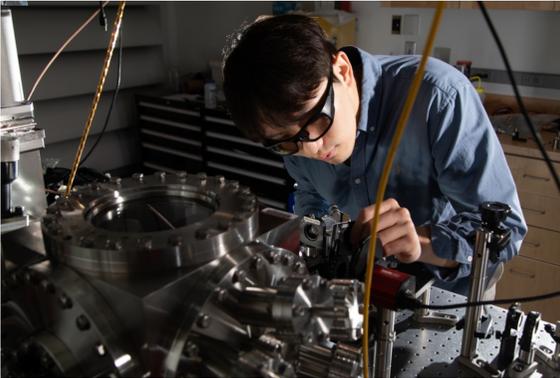
*"I think there is some reason to believe the true quantum theory of gravity is non-computable" (Roger Penrose, 1997).*

# New Directions: If the Future Circular Collider is not funded, then what?

**MIT News**  
ON CAMPUS AND AROUND THE WORLD

**A cool new way to study gravity**  
A technique developed at MIT enables a new class of experiments that could finally let physicists test whether gravity needs to be described by quantum theory.

Anne Wilson | Department of Mechanical Engineering  
May 20, 2025



One of the most profound open questions in modern physics is: "Is gravity quantum?"

Table-Top Quantum Gravity to study role of role of gravity on entanglement and during measurement.

NEWS | COMPUTING

**PsiQuantum Plans Quantum Supercomputer That Runs on Light** > The company plans to scale to a million qubits

BY EDD GENT | 07 OCT 2025 | 6 MIN READ | □  
Edd Gent is a contributing editor for IEEE Spectrum.



The cryogenic cabinet for PsiQuantum's upcoming quantum supercomputer is delivered to the company's new facility in Milpitas, Calif. COLBY MACRI/PSIQUANTUM

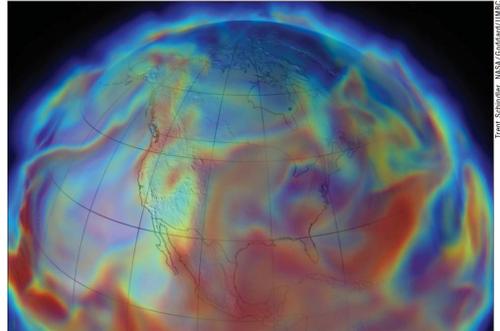
A million-qubit quantum computer to study the breakdown of unitary QM.

Comment: Forum

physicsworld.com

## A CERN for climate change

Providing reliable predictions of the climate requires substantial increases in computing power. **Tim Palmer** argues that it is time for a multinational facility fit for studying climate change



This winter has seen unprecedented levels of travel chaos across Europe and the US. In particular, the UK experienced some of the coldest December temperatures on record, with snow and ice causing many airports to close. Indeed, George Osborne, the UK's Chancellor of the Exchequer, attributed the country's declining economy in the last quarter of 2010 to this bad weather. A perfectly sensible question to ask is whether this type of weather will become more likely under climate change? Good question, but the trouble is we do not know the answer with any great confidence.

The key point is that the cold weather was not associated with some "global cooling" but with an anomalous circulation pattern that brought Arctic air to the UK and other parts of Europe. This very same circulation pattern also brought warm temperatures to parts of Canada and south-east Europe. Global mean temperatures were barely affected.

Weather-forecast models, which only have to predict a few days ahead at a time, are able to represent this level of detail very well. Global climate models, however, such

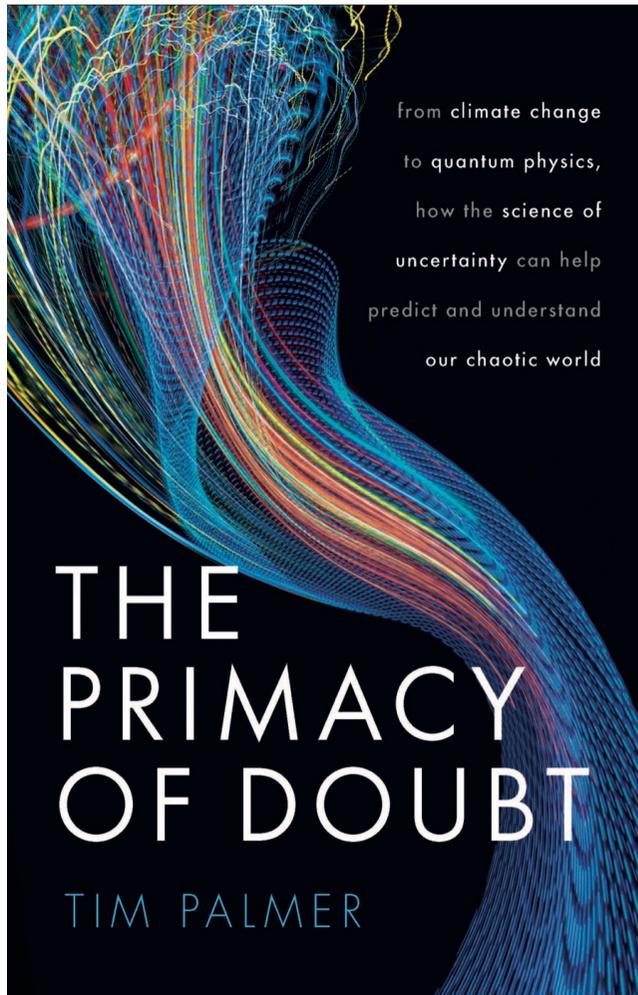
adapt to. This uncertainty arises, primarily, not because we do not know the relevant physics of the problem, but rather because we do not have the computing power to solve the known partial differential equations of climate science with sufficient accuracy.

In a nonlinear system, which the climate certainly is, getting the detail right can be important for understanding the large-scale structures. A manifestation of this problem is that no contemporary climate model can

to be able to resolve deep convective cloud systems, known to be crucial in transporting heat moisture and momentum from the planet's surface into the high troposphere, a climate simulator needs to have a grid-point spacing of at least 1 km. But we cannot say, short of actually doing the numerical experiments with such a grid, how much more accurate a climate simulator would be if these deep convective clouds could be properly represented by the laws of physics, ra-

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