Global Weather Forecasting with Geometric Deep Learning

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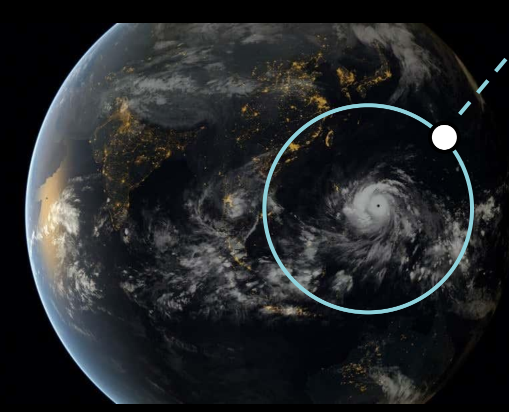
Abstract

Numerical weather prediction has historically focussed on the simulation of atmospheric physics across the Earth. Classical numerical weather forecasting methods are **physically motivated, highly interpretable but are prohibitively computationally expensive**, and **can induce parameterisation biases.** These biases can often be severe, particularly in forecasting of extreme precipitation events, which can lead to flash flooding. Recently, **deep learning** techniques have emerged as an alternative approach that is far **more efficient computationally, avoids parameterisation biases**, and **can model non-linear dynamics in a data-driven manner**. Importantly, deep learning approaches facilitate the generation of prediction ensembles, from which one may consider **probabilistic forecasting** and the construction of **digital twins**.

Recently proposed deep learning networks are constructed on **planar projections of the globe**, which inevitably **introduce both geometric distortions and latitudinal biases**. In this project we will develop networks which can forecast weather systems **natively over the spherical globe**, without the need for projections, leveraging very recent developments in the construction of scalable geometric deep learning approaches on the sphere. Such networks will be **geographically unbiased, scalable to sub-kilometre resolution, and robust**, with the potential to dramatically improve weather predictions. Given the importance of weather prediction, these next-generation geometric deep learning techniques will have **significant societal and scientific impact** in years to come.

Extreme Weather Prediction

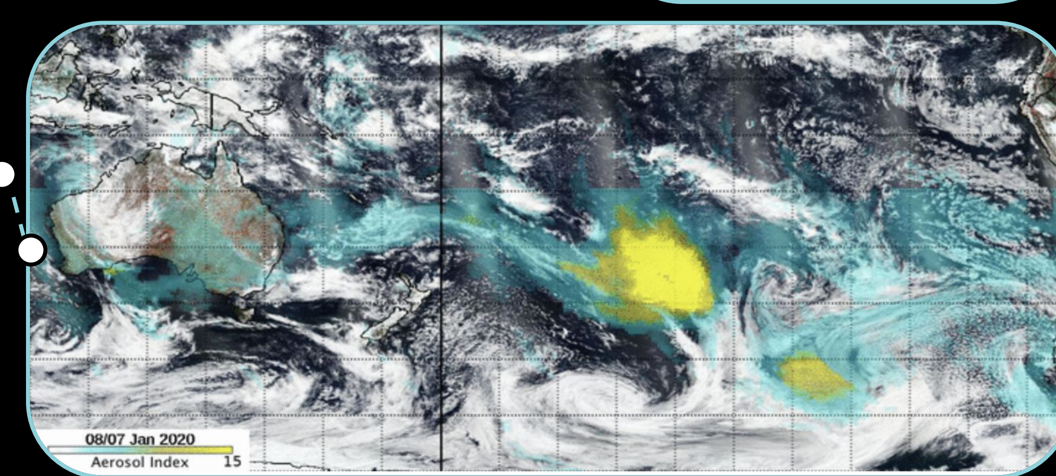


Super Typhoon Haiyan, 2013

- Category 5 storm.
- **14 million** people affected.
- Winds of up to **378 km/h**.

European Heatwave, 2022

- Up to 47°C in Pinhão, Portugal.
- Droughts **seen from space**.
- 3-fold increase in Wildfires.



Australian Wildfires, 2019

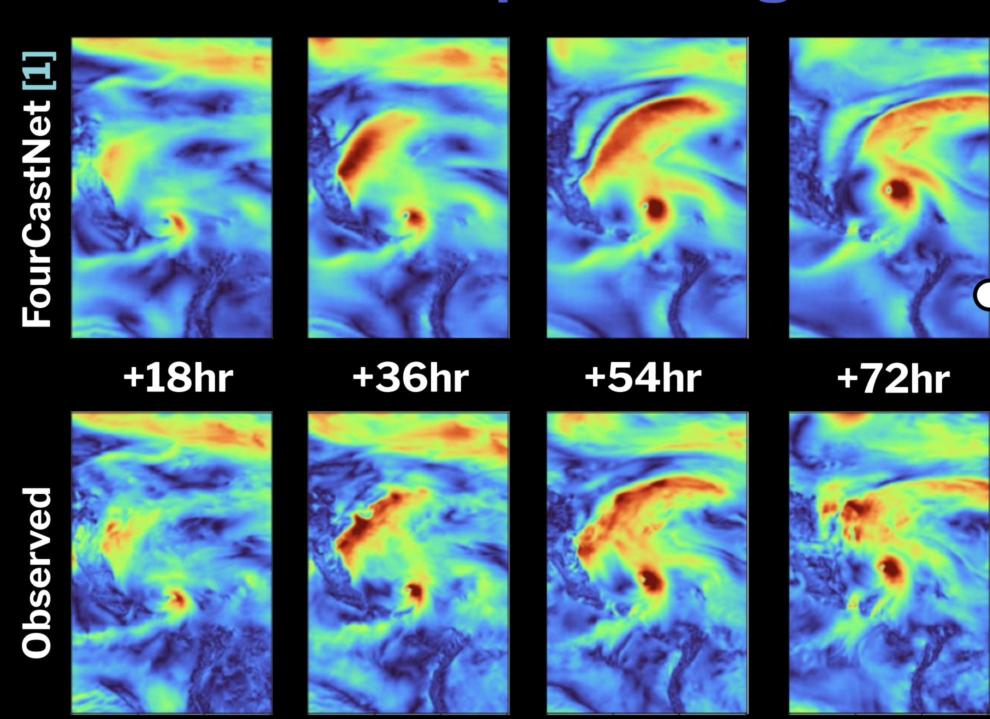
- 46 million acres burnt.
- **Aerosols circled the Earth**.
- Dramatic increase in fire generated thunderstorms.
- **3 billion animals affected**.
- Cost over £11 billion.

Classical Methods

Fully Physics-Based Simulation

- Accurately model the **physics** of the weather system.
- Straightforward to interpret predictions.
- Prohibitively **computationally expensive**.
- Implicit model bias can be difficult to account for.

Euclidean Deep Learning



Encode Spherical Symmetry

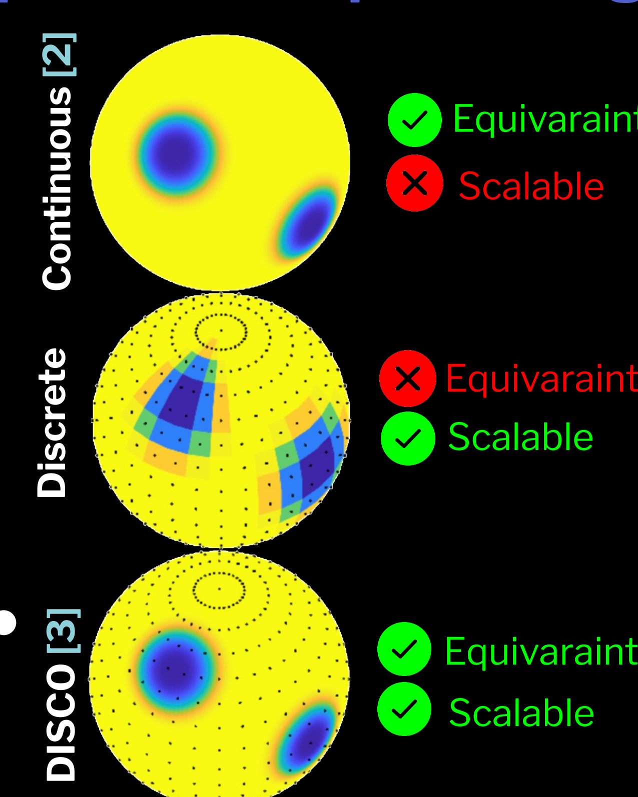
Euclidean Networks

- Cannot avoid significant **projection effects**.
- Exhibit **latitudinal bias**.
- Require significant data augmentation to train.

Spherical Networks

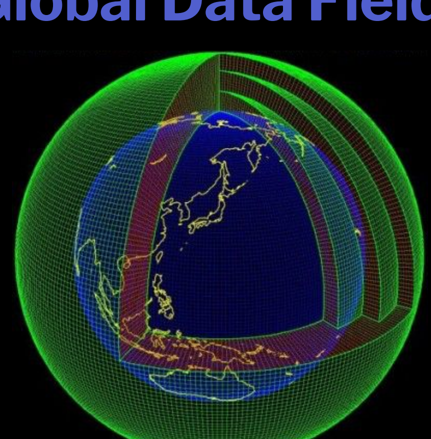
- **Exact** representation of global signals.
- Are **unbiased** across the entire globe.
- Learn all rotations from a **single** training datum.

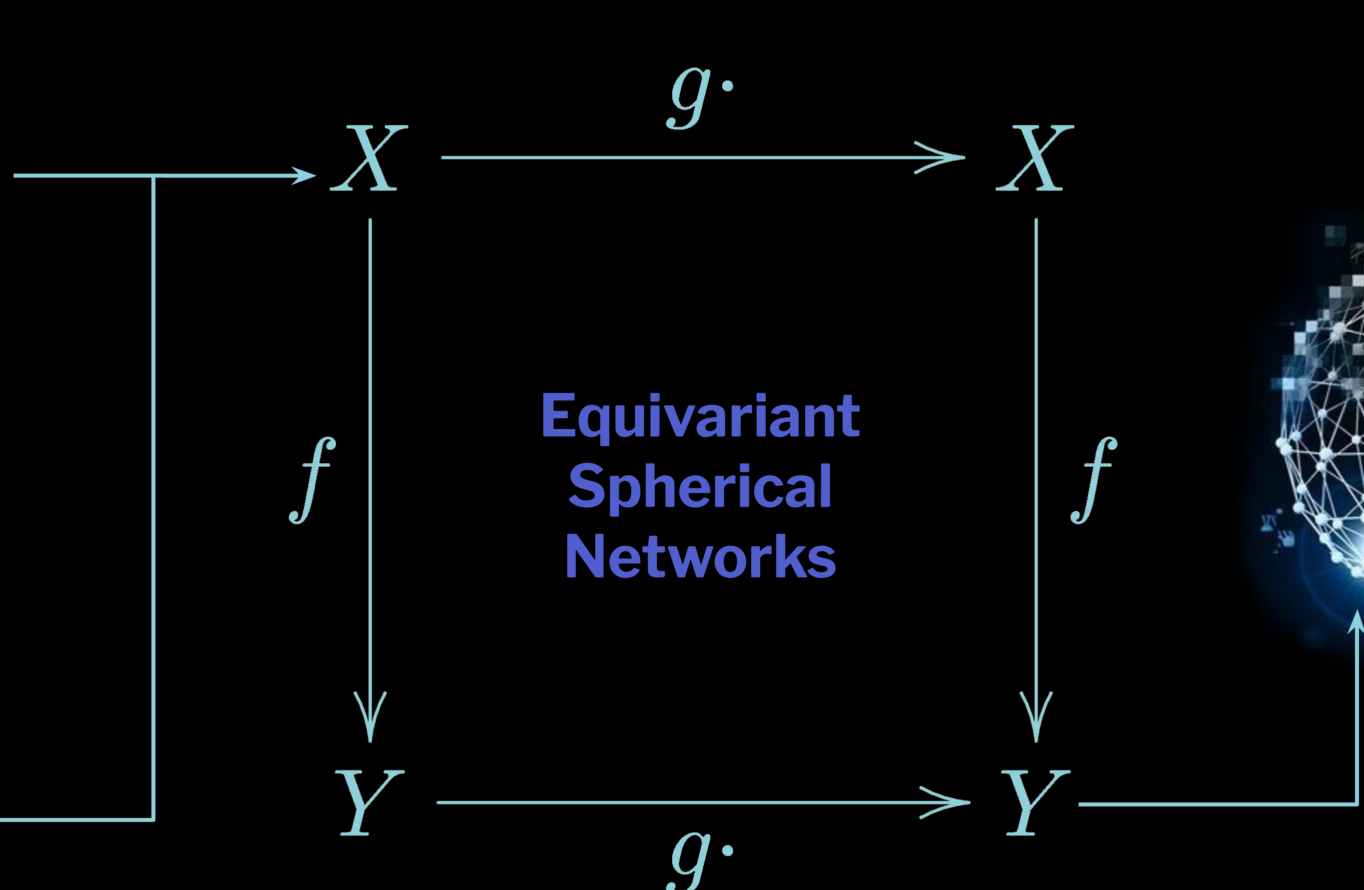
Spherical Deep Learning

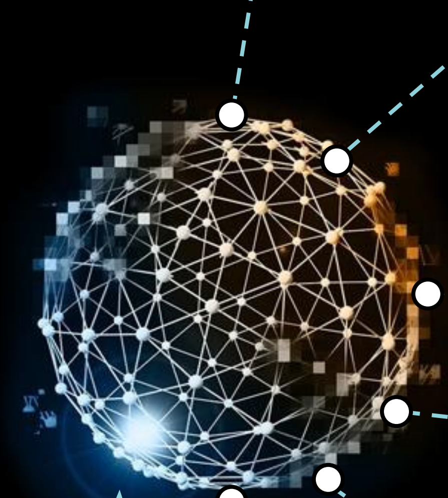


Meteorological Satellites

Global Data Fields







Reliable Global Data Analysis
Network outputs are **robust to spherical rotations** and do not exhibit a latitudinal bias.

Data-Driven Decision Making
Overcome implicit biases in classical numerical weather prediction models.

Real Time Predictions
Up to date early warning systems and facilitate **reliable digital twins**.

Enhanced Generalisability
Robust global predictions over time despite **climate induced evolution** in data.

Sub-Kilometre Resolution
Efficient and scalable algorithms to zero in on extreme weather events.

Increased Data Efficiency
Equivariant networks require **substantially less data** to train.

Supervisors

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Collaborators

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[1] Pathak et al. 2022, "*Fourcastnet: A global data-driven high-resolution weather model using adaptive fourier neural operators*", arXiv:2202.11214.

[2] Cobb et al. 2020, "Efficient generalized spherical CNNs", International Conference on Learning Representations, 2021, arXiv:2010.11661.

[3] Ocampo et al. 2022, "*Scalable and Equivariant Spherical CNNs by Discrete-Continuous (DISCO) Convolutions*", submitted to International Conference on Learning Representations 2023, arXiv:2209.13603.