Two important roles for AI in weather/climate prediction.

Tim Palmer

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University of Oxford

Oxford Physics

THE ROYAL SOCIETY

erc

European Research Council

Established by the European Commission

Model Hierarchy

Gill model of tropical atmosphere.

Stommel box model of thermohaline circulation

Cane-Zebiak model of El Nino

Charney Quasi-geostrophic model of midlatitude flow

Intermediate complexity

Simple

$$\frac{dX}{dt} = -10X + 10Y$$
$$\frac{dY}{dt} = -XZ + 28X - Y$$
$$\frac{dZ}{dt} = XY - \frac{8}{3}Z$$

Complex

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

We need comprehensive climate models for:

- **Understanding** (Of course!)
- **Mitigation** (How to transition to a decarbonised society.)
- **Adaptation** (How to make society more resilient to changing extremes of weather?)
- **Attribution** (Were observed weather events caused by climate change – will they become more frequent in the future?)
- **Geoengineering** (Is there a Plan B?)

Are we primarily adapting to

or

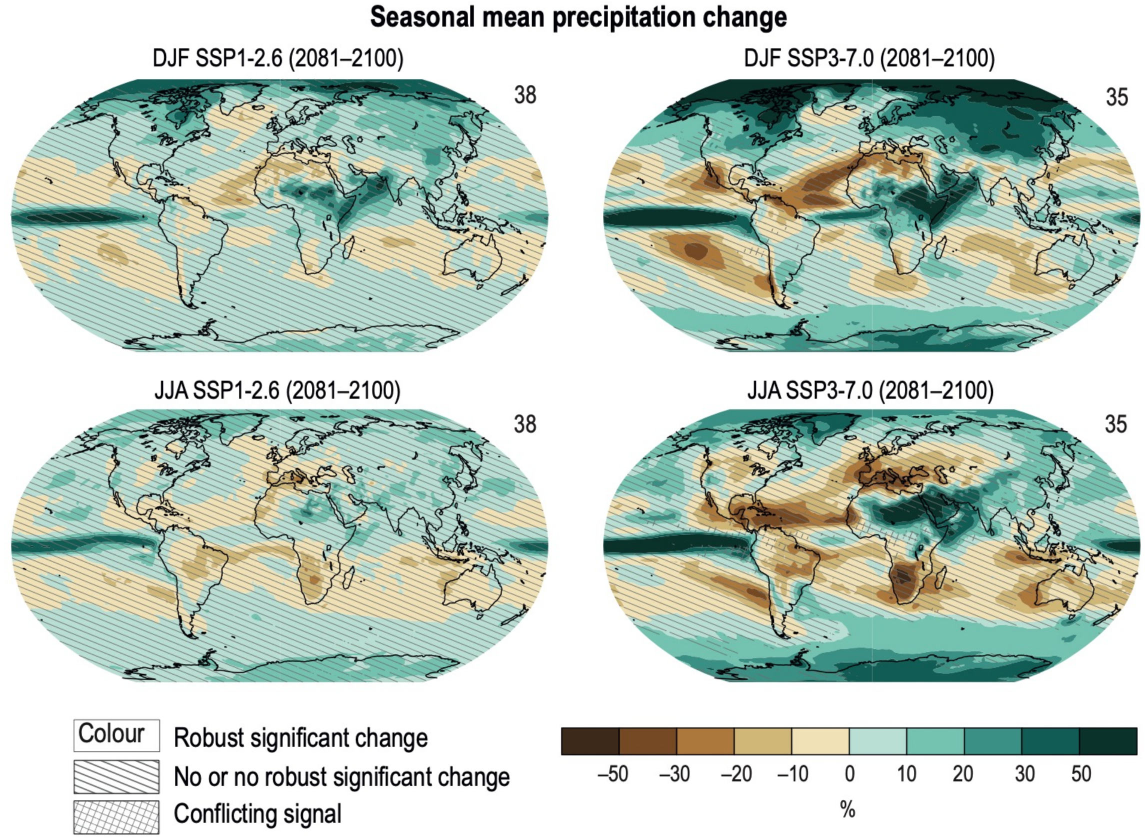

Figure 4.24 | Long-term change of seasonal mean precipitation. Displayed are projected spatial patterns of multi-model mean change (%) in **(top)** December–January–February (DJF) and **(bottom)** June–July–August (JJA) mean precipitation in 2081–2100 relative to 1995–2014, for (left) SSP1-2.6 and (right) SSP3-7.0. The number of models used is indicated in the top right of the maps. No map overlay indicates regions where the change is robust and *likely* emerges from internal variability, that is, where at least 66% of the models show a change greater than the internal-variability threshold (Section 4.2.6) and at least 80% of the models agree on the sign of change. Diagonal lines indicate regions with no change or no robust significant change, where fewer than 66% of the models show change greater than the internal-variability threshold. Crossed lines indicate areas of conflicting signals where at least 66% of the models show change greater than the internal-variability threshold but fewer than 80% of all models agree on the sign of change. Further details on data sources and processing are available in the chapter data table (Table 4.SM.1).

PERSPECTIVE

The scientific challenge of understanding and estimating climate change

Tim Palmer[a,1] and Bjorn Stevens[b,1]

Edited by Jagadish Shukla, George Mason University, Fairfax, VA, and accepted by Editorial Board Member Robert E. Dickinson October 21, 2019 (received for review May 21, 2019)

Given the slow unfolding of what may become catastrophic changes to Earth's climate, many are understandably distraught by failures of public policy to rise to the magnitude of the challenge. Few in the science community would think to question the scientific response to the unfolding changes. However, is the science community continuing to do its part to the best of its ability? In the domains where we can have the greatest influence, is the scientific community articulating a vision commensurate with the challenges posed by climate change? We think not.

climate change | climate models | high resolution

The idea that the science of climate change is largely "settled," common among policy makers and environ- how this warming plays out regionally, and what it implies for the likelihood of surprises. In our view,

Even when climate models agree, are they trustworthy on the regional scale?

BIAS SIGNAL

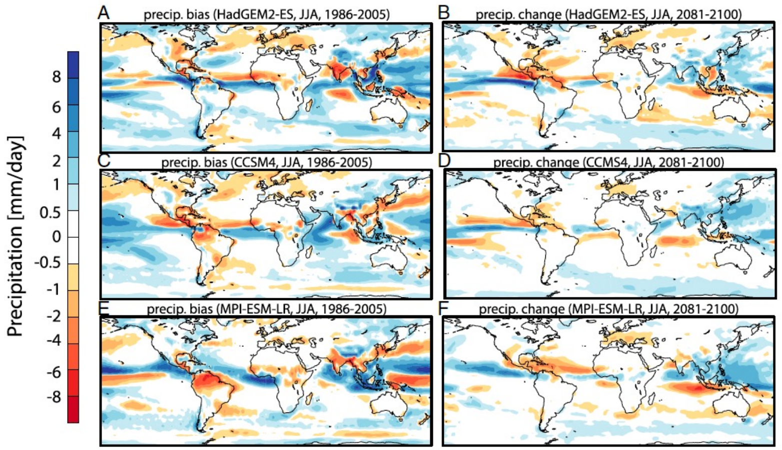

Fig. 3. *A*, *C*, and *E* show the systematic error of the 3 CMIP5 models in Fig. 2 for June, July, and August (JJA) mean precipitation (based on GPCP observational data) computed using ensemble integrations and observations for the same period as in Fig. 2. *B*, *D*, and *F* show the same 3 models' response to climate change forcing based on differences between ensemble integrations for the same period and scenario as in Fig. 2. The same scale is used for *A*–*F*. There are widespread regions where the systematic error exceeds the climate change signal (in some regions by more than a factor of 20).

world weather attribution

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Climate change likely increased extreme monsoon rainfall, flooding highly vulnerable communities in Pakistan

14 September, 2022

EXTREME RAINFALL

From mid-June until the end of August 2022, large parts of Pakistan experienced record-breaking monsoonal rainfall, leading to large parts of the country being flooded.

Full study

- Download the full study: Climate change likely increased extreme monsoon rainfall, flooding highly vulnerable communities in Pakistan, pdf (36 pages, 4.3 MB)

ot

Our study:

Early phases of climate change (thermodynamic) – Pakistan floods become more likely.

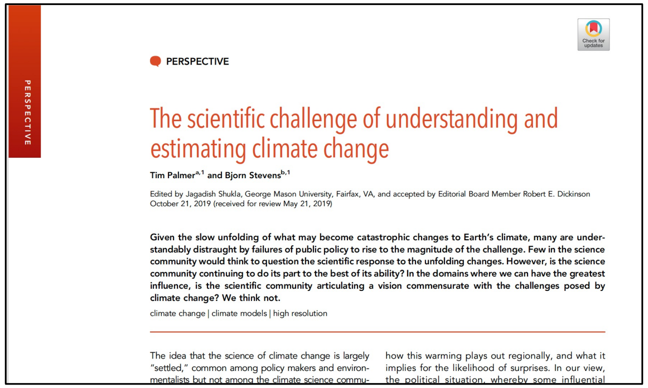
Later phases of climate change (dynamic and thermodynamic) – Pakistan floods become less likely.

- Many of the available state-of-the-art climate models struggle to simulate these rainfall characteristics. Those that pass our evaluation test generally show a much smaller change in likelihood and intensity of extreme rainfall than the trend we found in the observations. This discrepancy suggests that long-term variability, or processes that our evaluation may not capture, can play an important role, rendering it infeasible to quantify the overall role of human-induced climate change.

As a conclusion, models are unable to provide a basis to confidently quantify the change in the monsoon season rainfall intensity with climate change up to now. Qualitative statements are however possible.

Move to km-scale grids?

- More accurate representation of underlying laws of physics.
- No parametrization of deep convection, orographic gravity wave drag and ocean eddy mixing.
- Smaller systematic errors.
- Better representation of extremes (vital for adaptation applications).
- Better assimilation of observations (ocean and atmosphere) and hence more accurate initial conditions.
- Better reanalysis products for climate diagnostics.
- Improved (stochastic) parametrisations for CMIP-class models.



PERSPECTIVE

Check for updates

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how this warming plays out regionally, and what it implies for the likelihood of surprises. In our view, the political situation, whereby some influential

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Destination Earth

ot

Destination Earth (DestinE) and its development of digital earth twins are key to predicting the effects and building resilience to climate-change.

PAGE CONTENTS

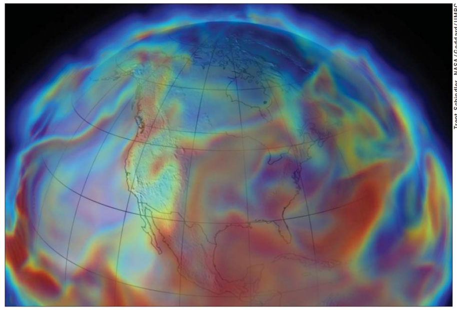
Destination Earth system

Implementation

Destination Earth (DestinE) aims to develop – on a global scale - a highly accurate digital model of the Earth to monitor and predict the interaction between natural phenomena and human activities. As part of the European Commission's Green Deal and Digital Strategy, DestinE will contribute to achieving the objectives of the twin transition, green and digital.

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



Trent Schindler, NASA/Goddard/UMBC

A global approach to a global problem Modelling the climate may require a unified strategy for computing.

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-

hot

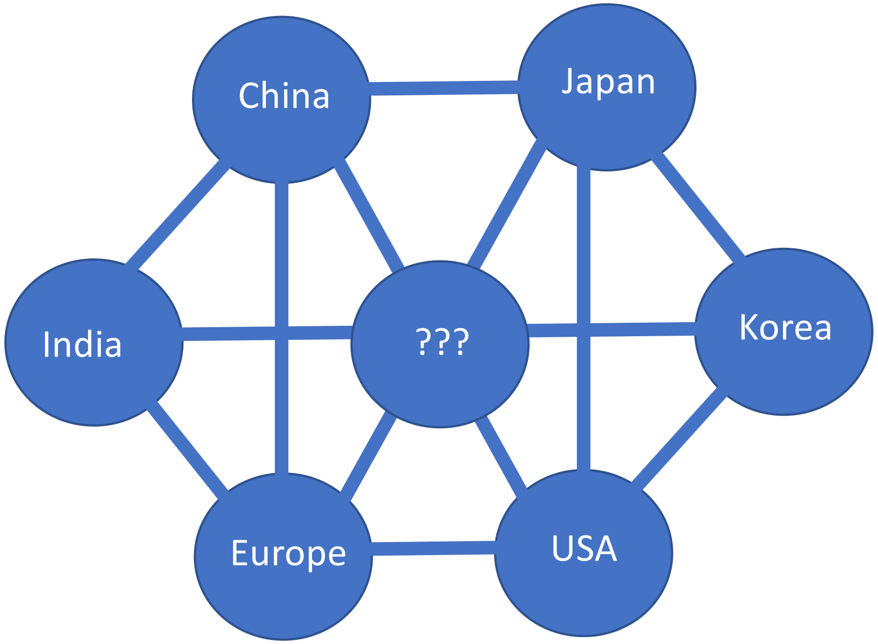
Comment | Published: 16 June 2022

Ambitious partnership needed for reliable climate prediction

Julia Slingo, Paul Bates, Peter Bauer, Stephen Belcher, Tim Palmer, Graeme Stephens, Bjorn Stevens, Thomas Stocker & Georg Teutsch

Nature Climate Change 12, 499–503 (2022) | Cite this article

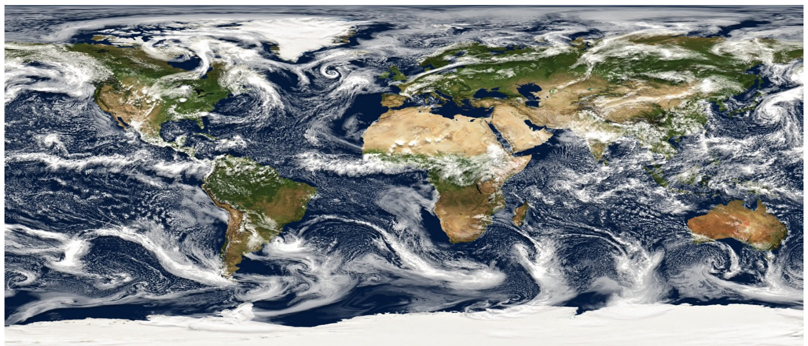
Current global climate models struggle to represent precipitation and related extreme events, with serious implications for the physical evidence base to support climate actions. A leap to kilometre-scale models could overcome this shortcoming but requires collaboration on an unprecedented scale.

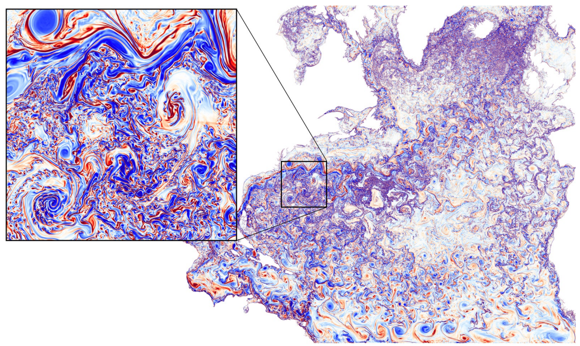


A coordinated international network of climate-dedicated exascale computing institutes.

And what would we do with such a distributed facility?

Coordinated km-scale (K-scale) global ensembles for multi-decadal climate prediction





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

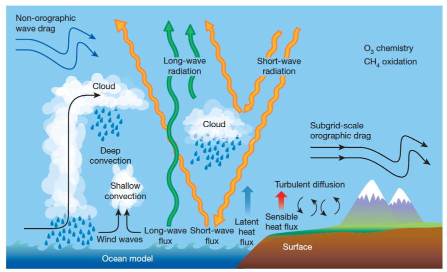
Resolved scales

Unresolved scales

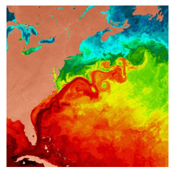
Dynamical Core

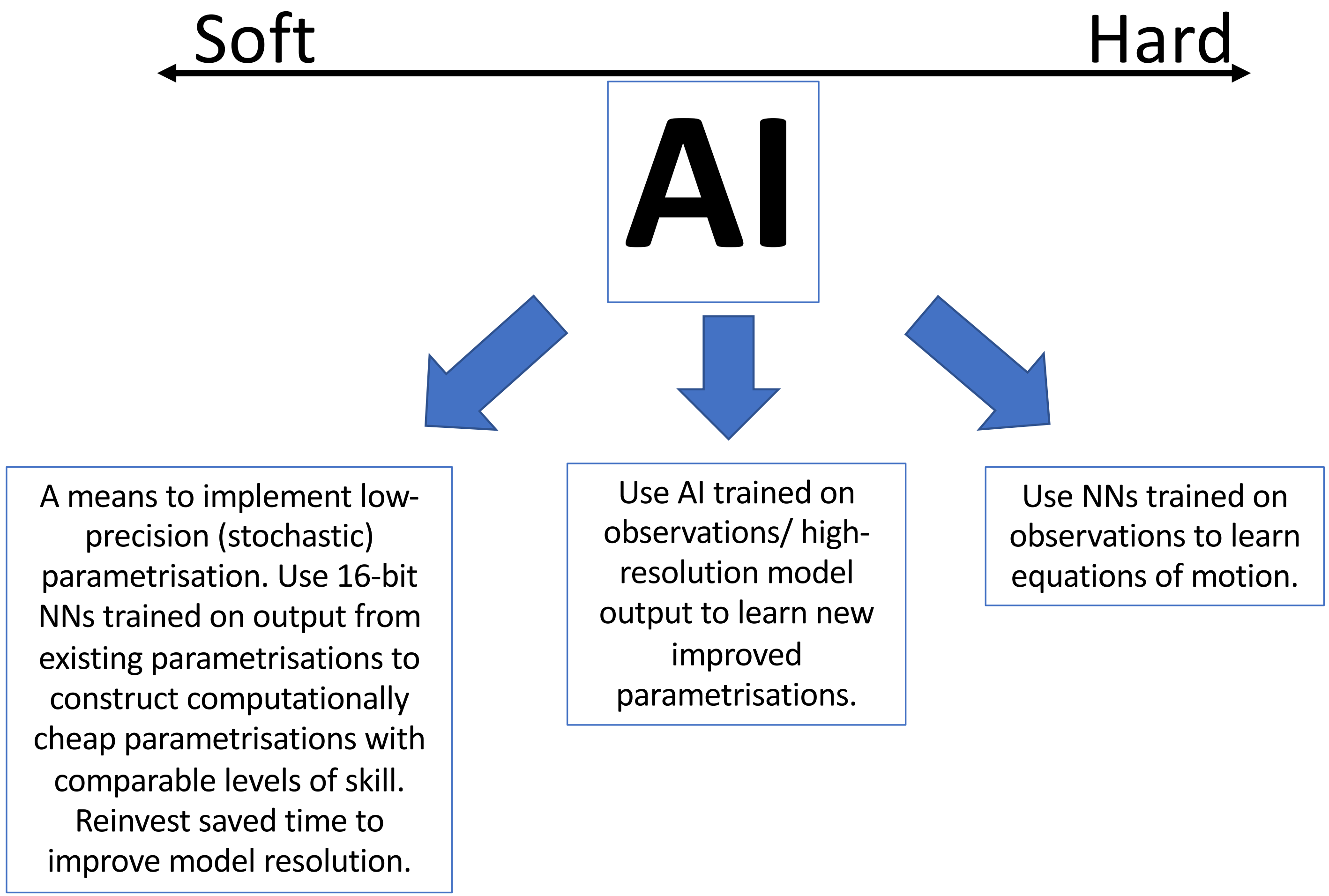
Stochastic Parametrisations

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

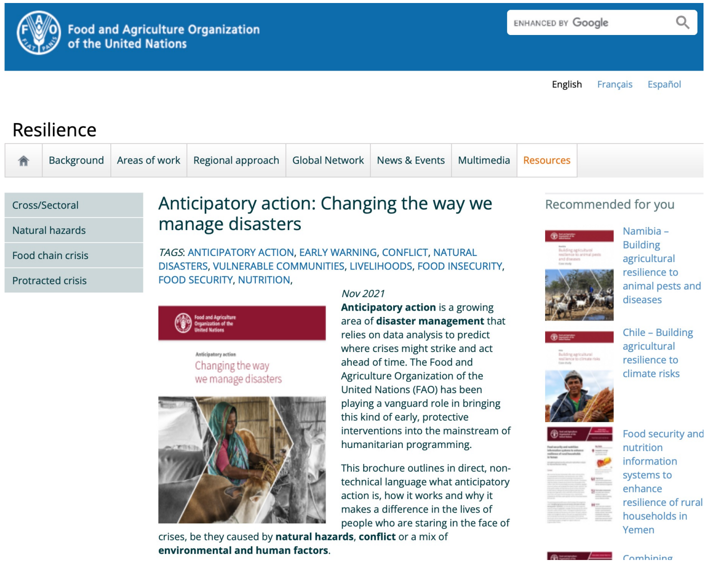


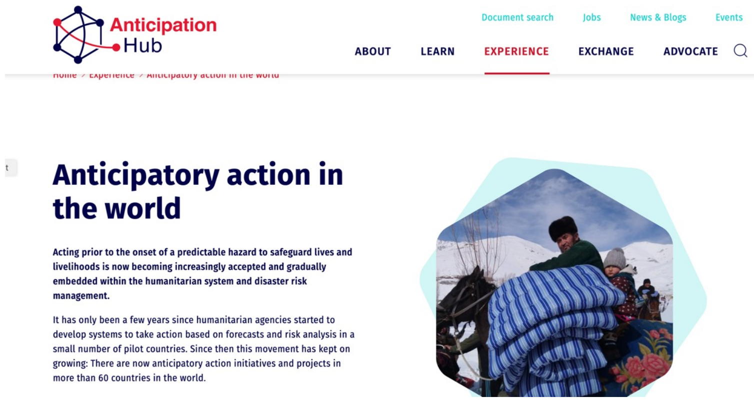
$$D=P$$



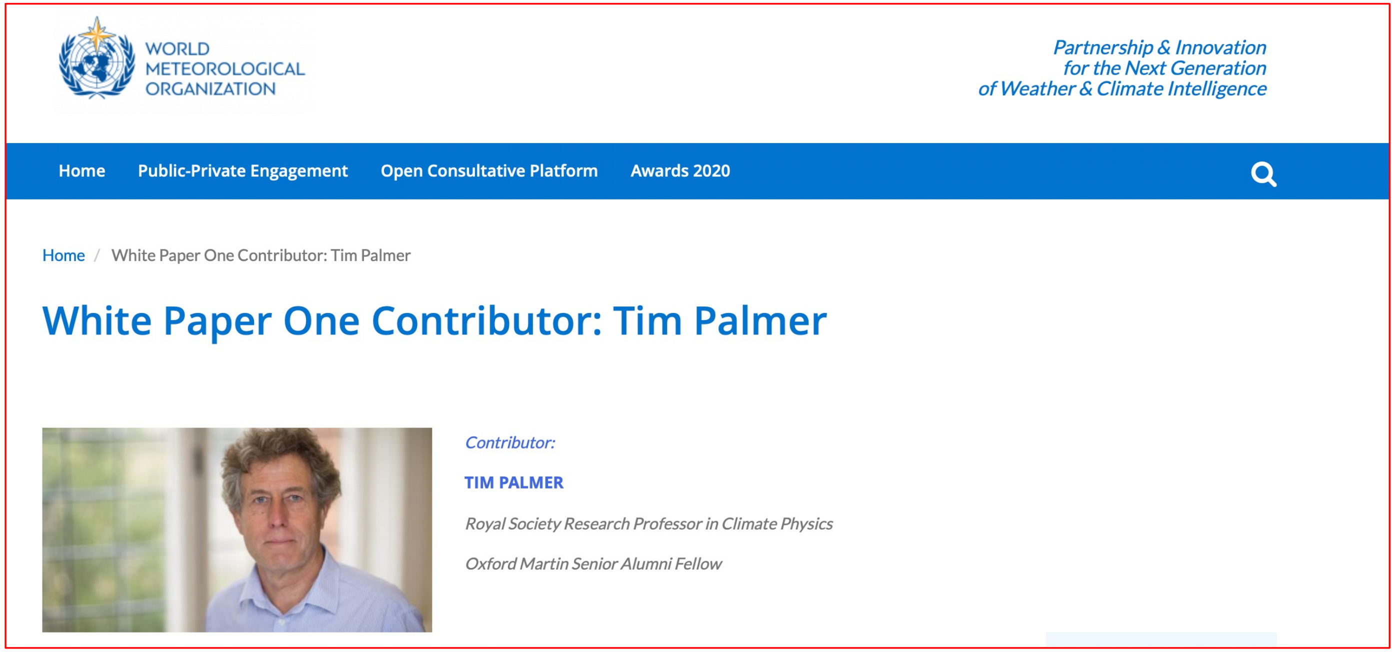

Soft
Hard
AI
A means to implement low-precision (stochastic) parametrisation. Use 16-bit NNs trained on output from existing parametrisations to construct computationally cheap parametrisations with comparable levels of skill. Reinvest saved time to improve model resolution.
Use AI trained on observations/ high-resolution model output to learn new improved parametrisations.
Use NNs trained on observations to learn equations of motion.

Take anticipatory action when probabilities of extreme weather exceed a predetermined threshold.





"There's a real, real change," Dirk-Jan Omtzigt, chief economist at the UN Office for the Coordination of Humanitarian Affairs (OCHA), told The New Humanitarian in an interview after the conference. "Anticipatory action has always been niche and technical. Now it's moving into the mainstream… It's now being embraced by the community at large."



- National Met Services (NMSs) use Limited Area Models (LAMs) to downscale global ensemble forecasts
- They can typically only afford to run a few LAM members and only out to a few days ahead
- Downscaling global ensembles with AI could allow them to run out to two weeks with “superensembles”
- And it would give the NMSs a reason to maintain their local observational network