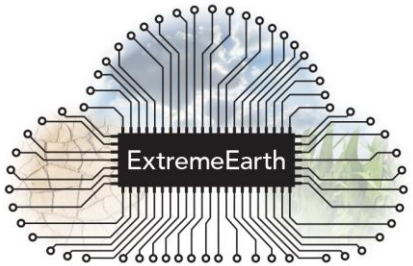
Climate models will play an increasingly important role in modern society

- Seasonal/decadal prediction
- Scientific input for decisions on decarbonising world economy
- Guidance on infrastructure investment for regional climate adaptation
- To foresee regional consequences of geoengineering proposals
- Attribution of current weather events
- Synthesising observations
- Scientific Understanding – vital for communicating weather/climate science

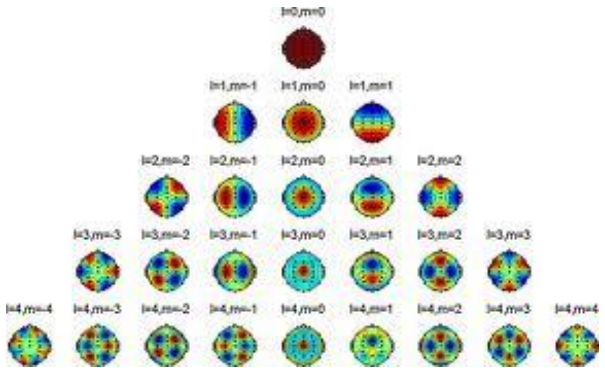


$$r\left(\frac{\partial}{\partial t}+\mathbf{u}.\nabla\right)\mathbf{u}=r\mathbf{g}-\nabla p+m\nabla^2\mathbf{u}$$

Resolved scales ⟵ | ⟶ Unresolved scales

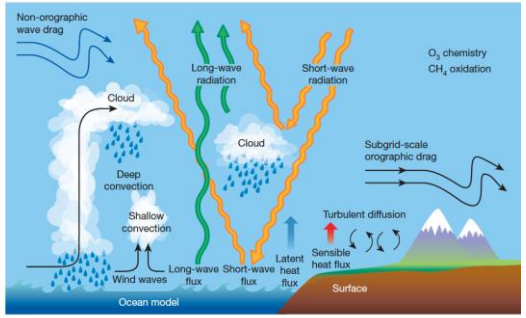
Dynamical Core

$$z=\sum_{m}^{\infty}\sum_{l} z_{ml}e^{iml}P_l^m(f)$$

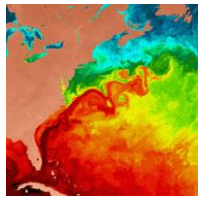


Parametrisations

$$P\left(X_{\mathrm{Tr}};a\right)$$



$$D=P$$



>50% compute time

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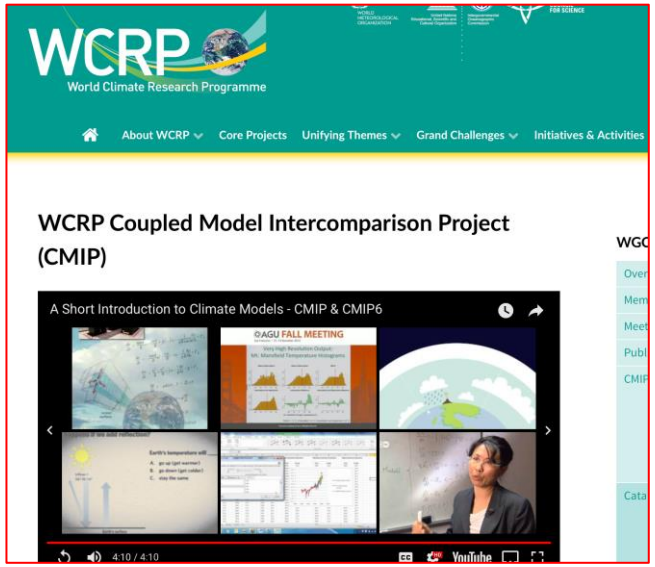

CMIP3 23 Models
CMIP5 54 Models
CMIP6 >70 Models

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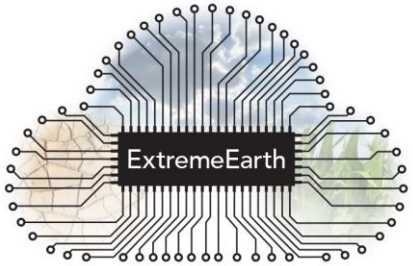
CMIP models are not getting better.

It is found that there is virtually no improvement in all these measures [of tropical circulation] from the CMIP3 ensemble to the CMIP5 ensemble models…. No progress can be identified in the sub-ensembles of five best models from CMIP3 to CMIP5 even though more models participated in CMIP5, the systematic errors of excessive precipitation and overestimated SST in southeastern Pacific are even worse in the CMIP5 models.

Zhang et al, GRL 2015

Wintertime blocking frequency is heavily underestimated by almost all [CMIP5] models. This is particularly the case for the Euro-Atlantic sector, where the mean deficit is greater than 1⁄2 of the total daily frequency, in accordance with CMIP3 results

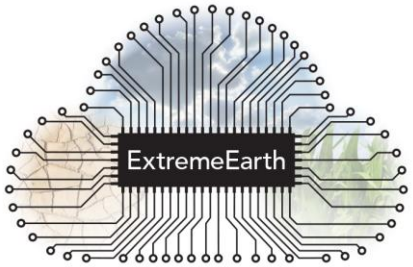
Masato et al 2015



We Must Do Better!

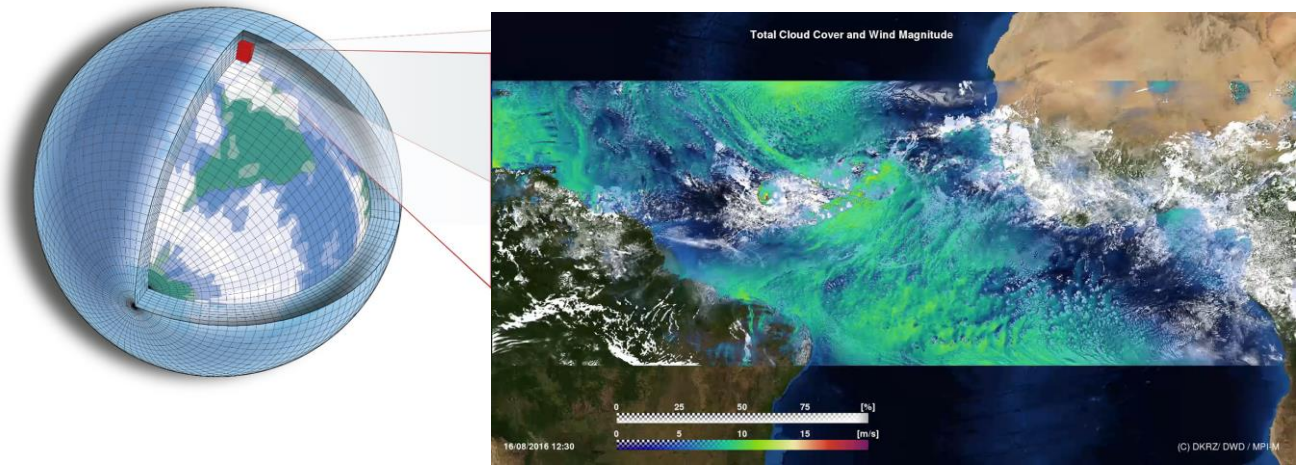
In a profoundly nonlinear system like climate, a systematic misrepresentation of small-scale processes can lead to a systematic misrepresention of large-scale processes.

Three key parametrisations can be eliminated from climate models (deep convection, orographic gravity wave drag, mixing by ocean mesoscale eddies) if we can get down to a horizontal resolution of 1km.

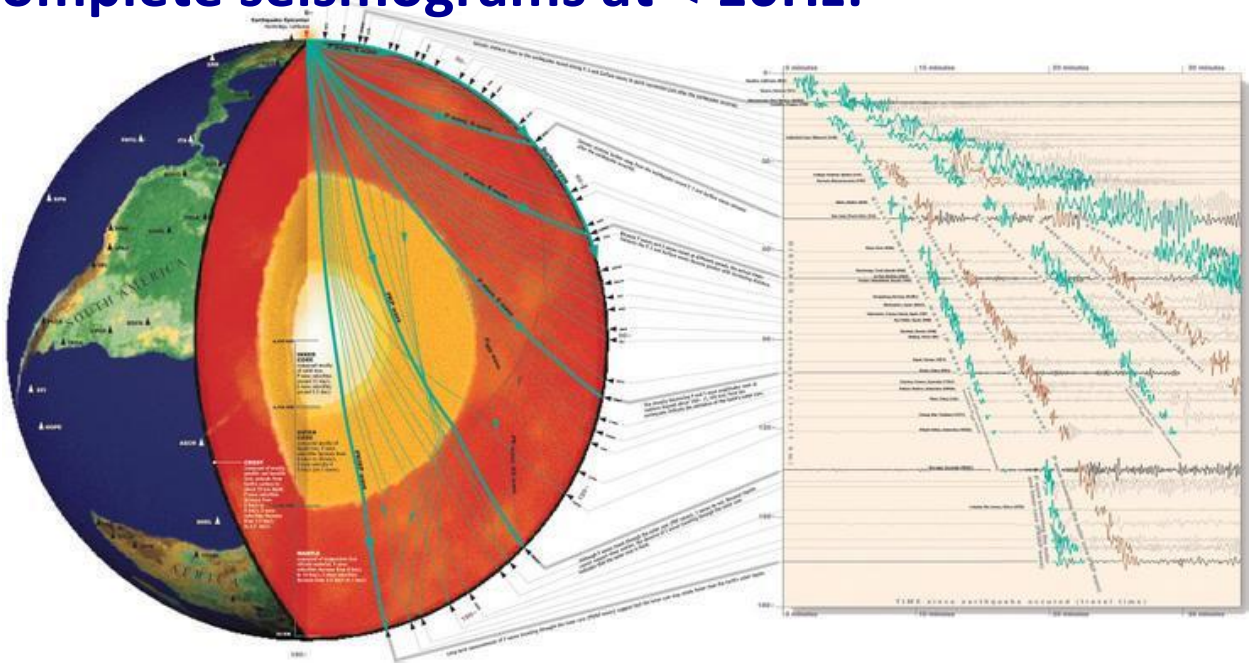


Science Challenge → Technology Requirement

Global Earth-system simulations at < 1km:



Complete seismograms at < 10Hz:



= x1000 bigger computing and simulation data handling problem than feasible in 2020!

→ mathematics and AI
→ programming
→ processor technology

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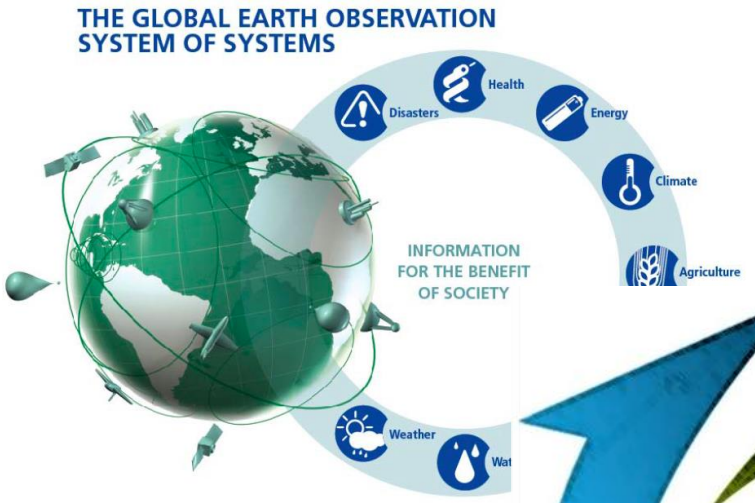
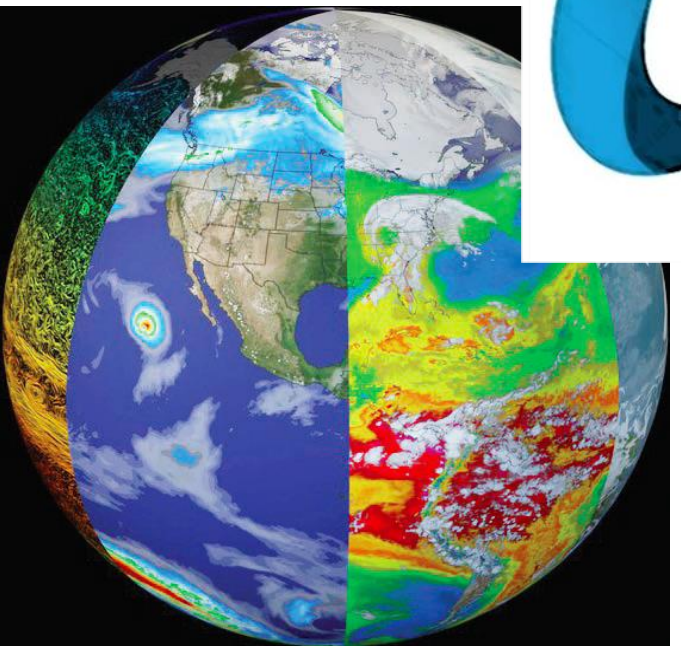
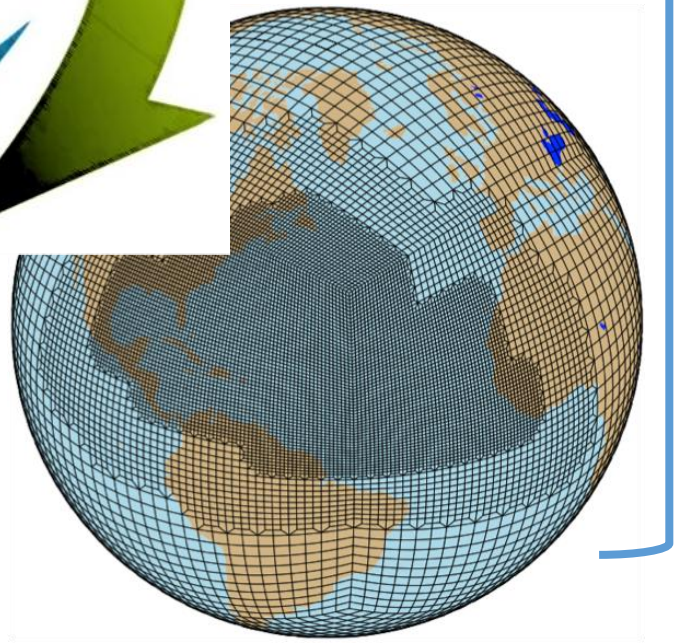
Science Challenge → Technology Requirement

Models that simulate the Earth system indistinguishable from observations:







= x1000 bigger computing and observational data handling problem than feasible in 2020!

→ mathematics and AI
→ edge and cloud computing
→ IoT

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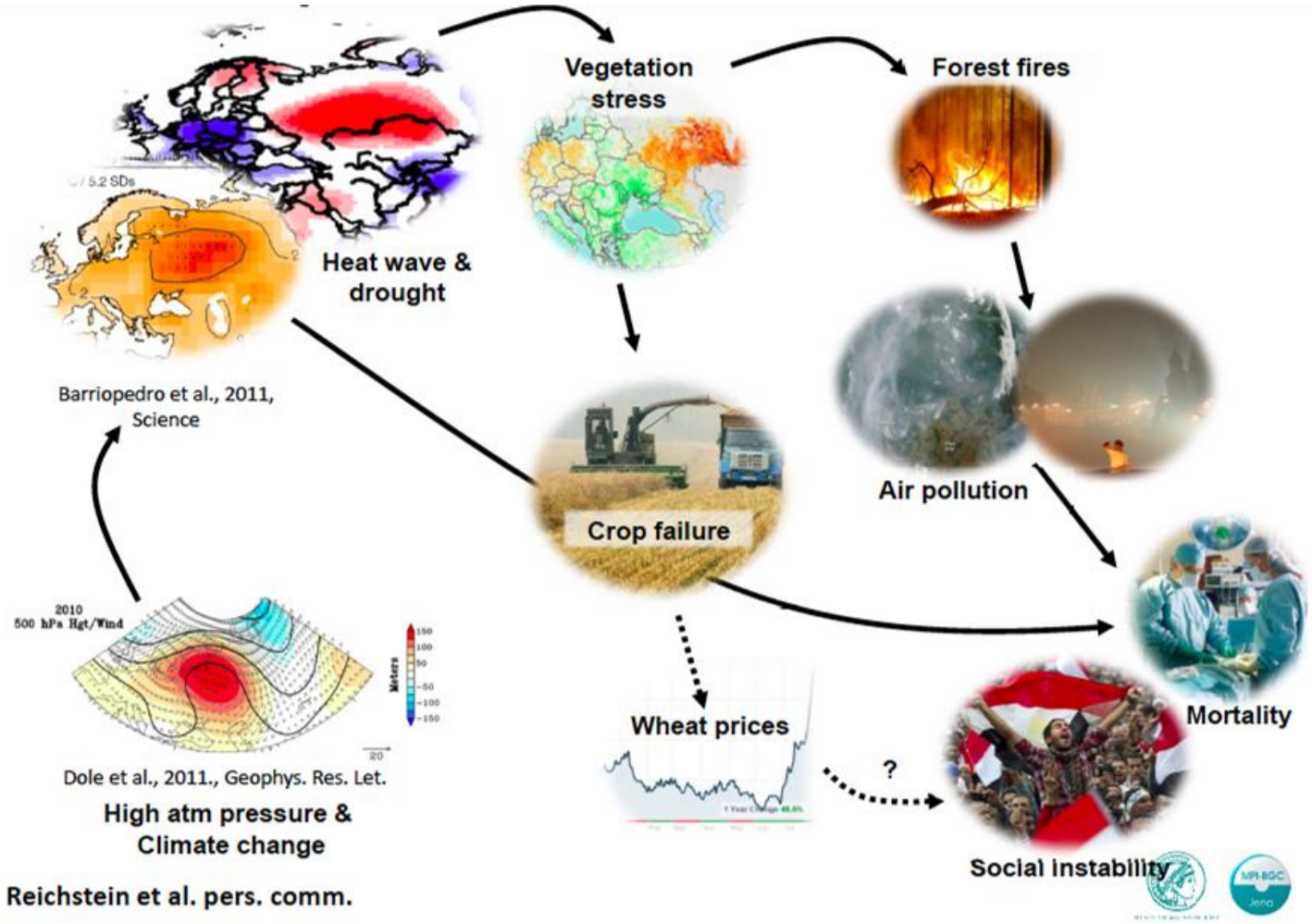
Science Challenge → Technology Requirement

Impact prediction becomes integral part of Earth-system prediction:

Example Russian heat wave 2010



= x1000 bigger data handling and workflow problem than feasible in 2020!

→ mathematics and AI
→ edge and cloud computing
→ IoT

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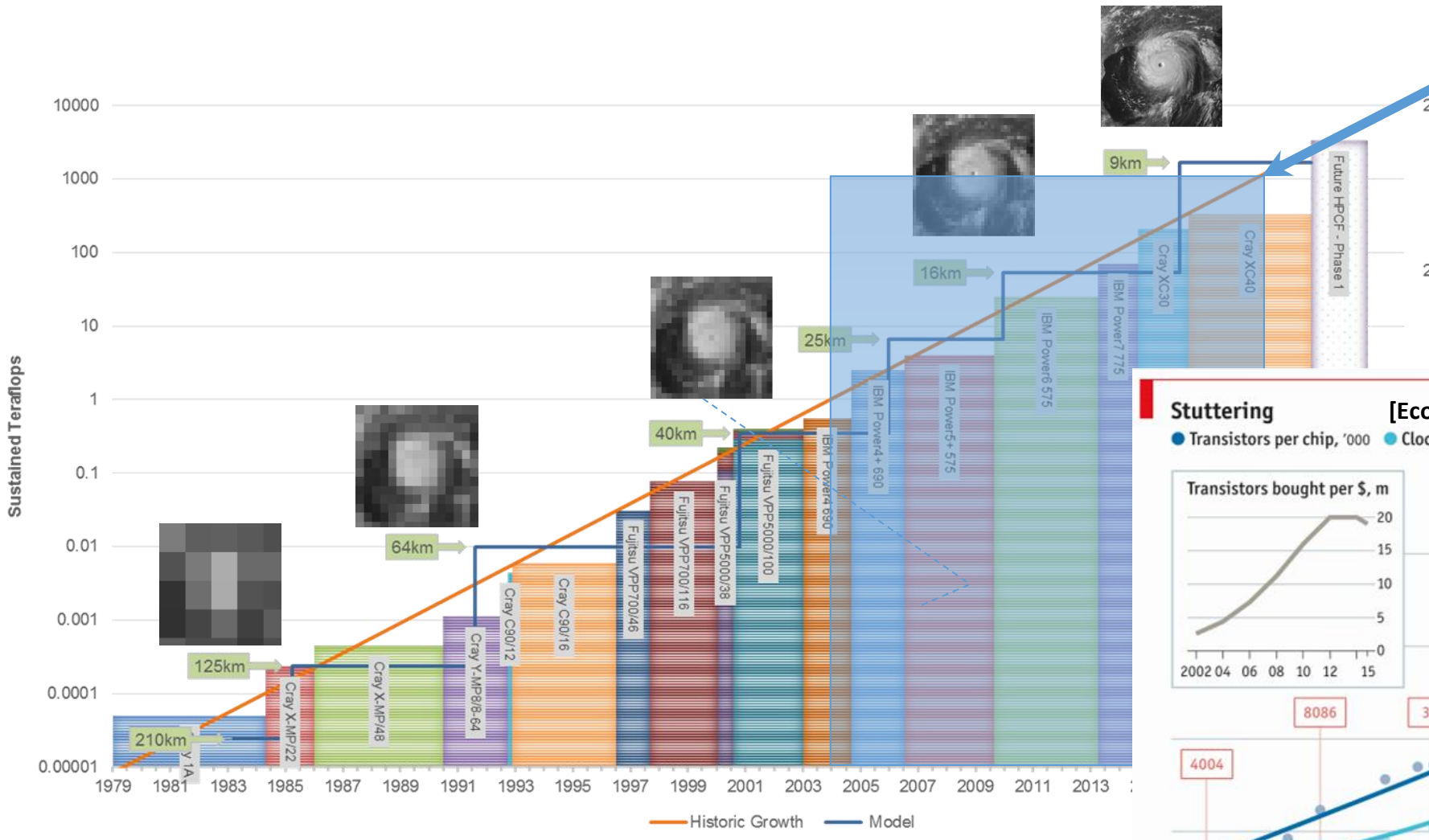
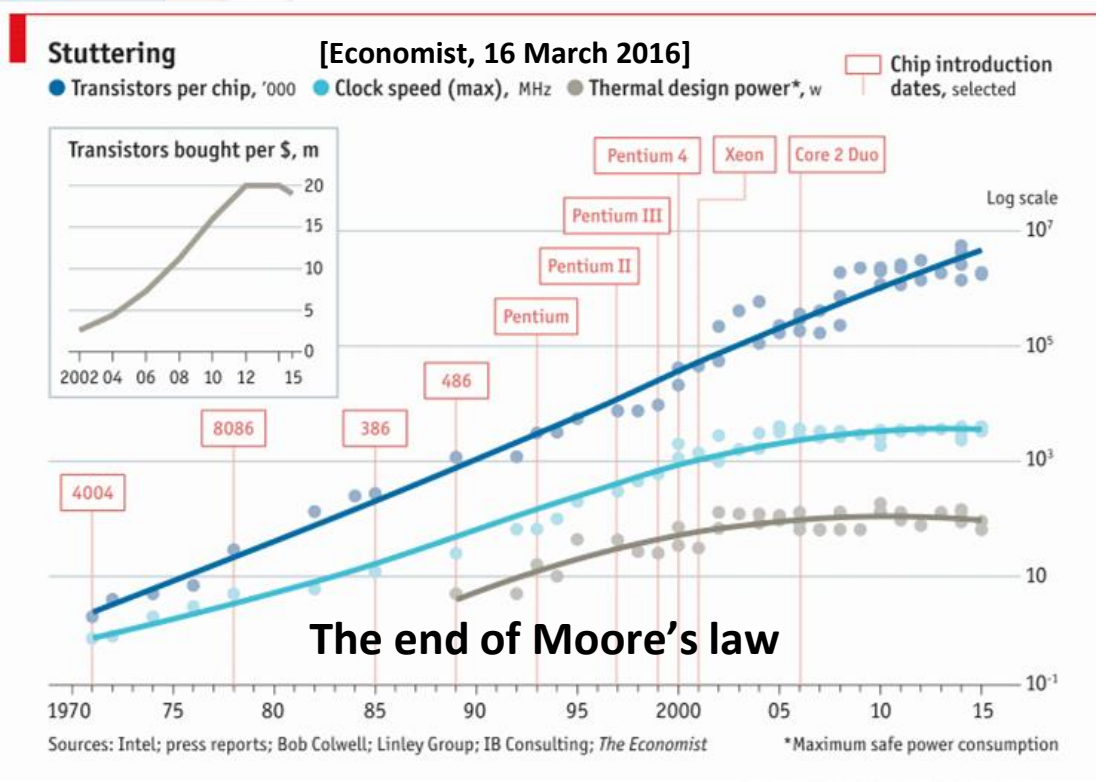
What does x1000 mean?

In the past:
x1000 = 15 years = 10^{15} scale
= 2 M€ electric power / year

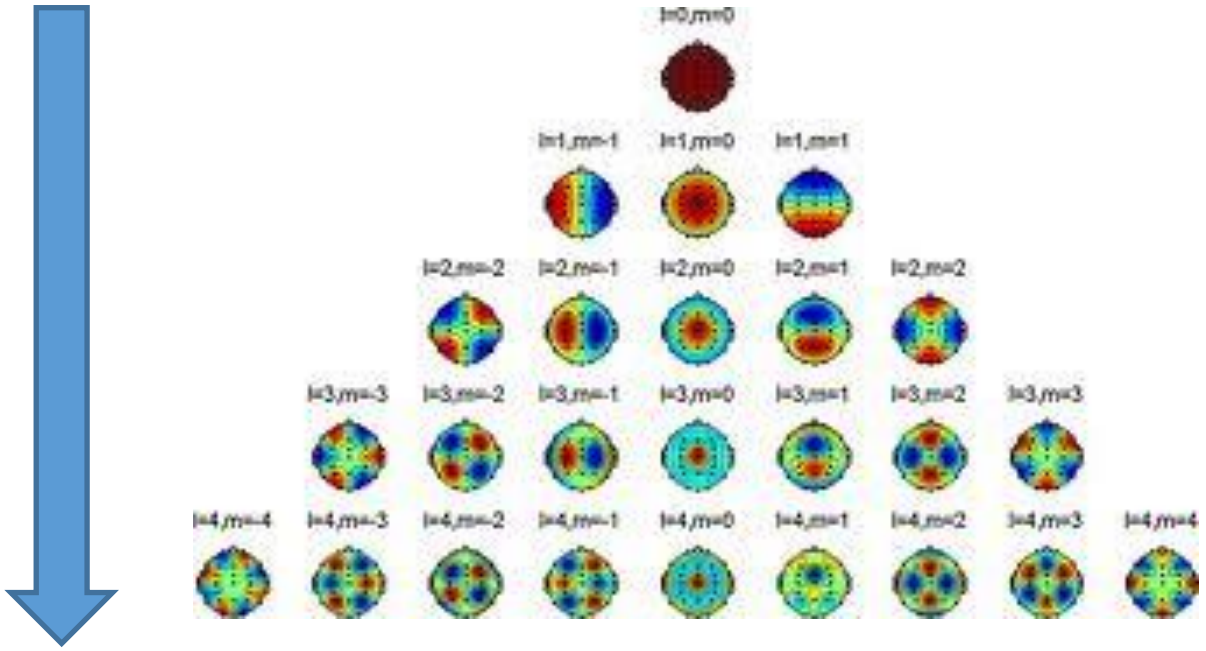
In the future:
x1000 = ?? years = 10^{18} scale
= ?? M€ electric power / year

Codes are only 5% efficient!





Reduced precision



Stochastic parametrisation

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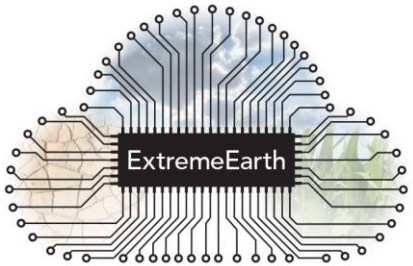
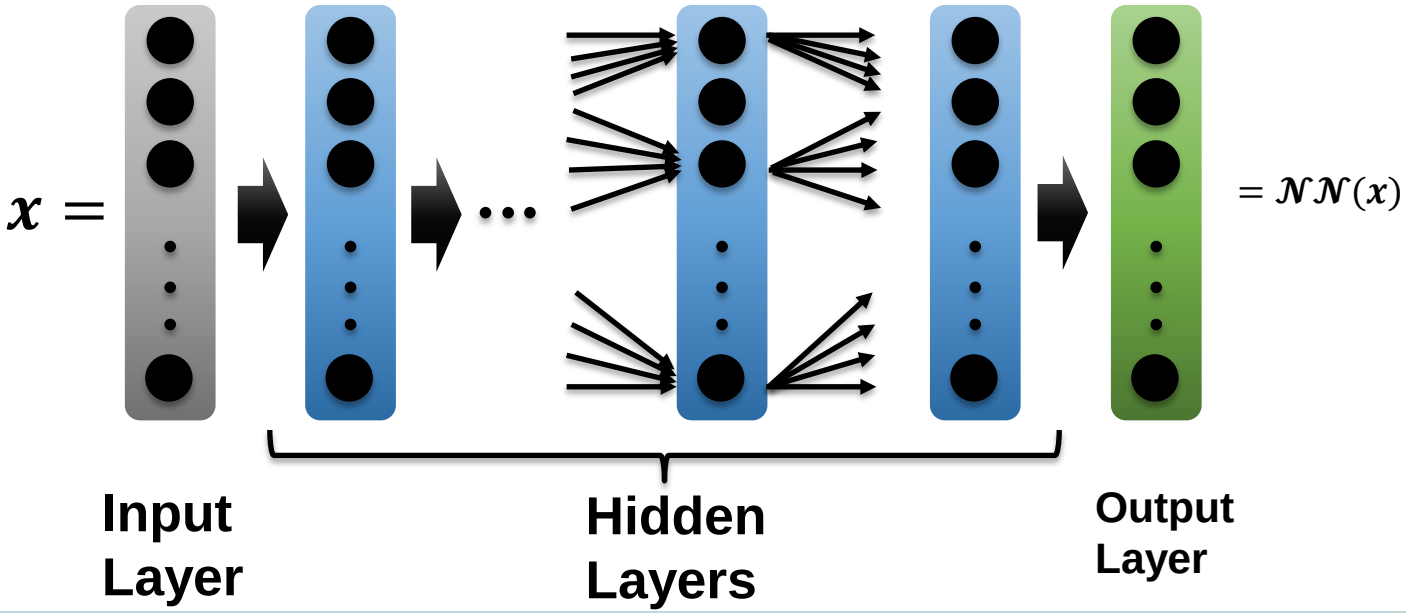
If parametrisations are stochastic and much of the model code can be run at reduced precision, could we replace the stochastic parametrisations with Neural Nets, trained on the parametrisations,and run on 16-bit processors without loss of simulation accuracy?



Artificial Neural Network (NN)

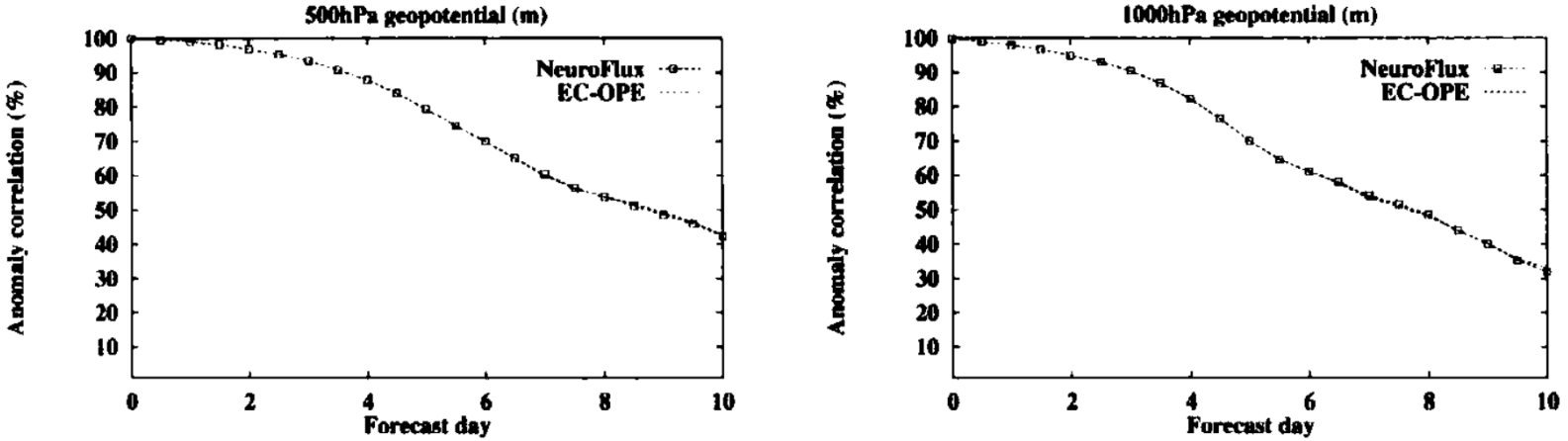


Summary of Chevallier et al., 1998:

- Replaced long-wave radiation budget from top to surface (20 pressure levels) by a NN
- The NN computed longwave flux profiles for clear and cloudy situations
- This part of the physics made up 10% of the computing time in the ECMWF GCM
- Two $\mathcal{F}(x;p)$ were approximated by ANNs:
  a. ECMWF wideband operational scheme (Morcette 1991, Zhong and Haigh 1995)
  b. Line-by-line model 4A (Scott and Chédin 1981, Tournier et al. 1995)
- Resulting ANN-a and ANN-b were 22 times faster than the wideband model and 10**6 times faster than the line-by-line model

Art

- The accuracy of the new scheme was comparable to the accuracy of the original scheme



Chevallier et al. QJRMS (2000)

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AI and Extreme Earth: Getting the extra computational efficiency needed

For our 1km global climate model, parametrisation schemes can be replaced with NNs trained on parametrisation output.

The cost of the parametrisation schemes can be reduced by at least an order of magnitude without loss of accuracy.

This can be extended to represent Earth System complexity too.