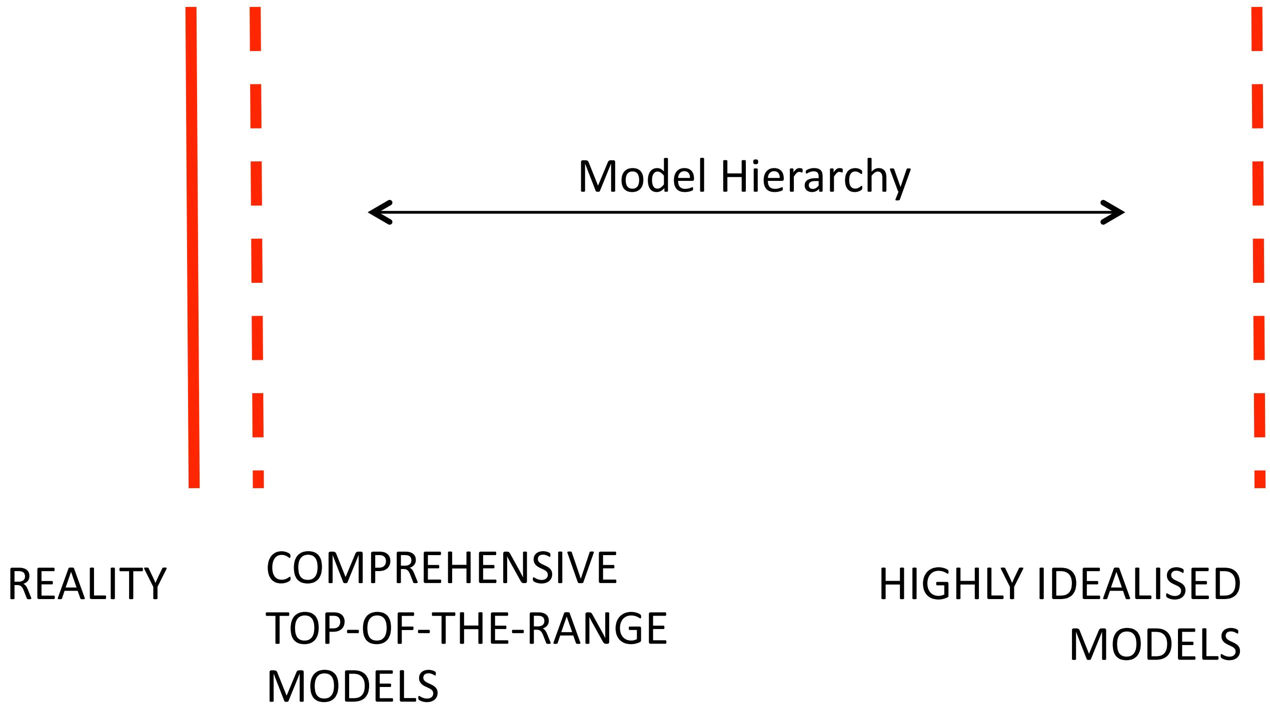
The Hierarchical Paradigm for Climate Science: Fit for purpose?

Tim Palmer

The "Hierarchy Paradigm"

What we hope is the case:



The "Hierarchy Paradigm"

What may actually be the case:

Model Hierarchy

REALITY

COMPREHENSIVE TOP-OF-THE-RANGE MODELS

HIGHLY IDEALISED MODELS

Multiple Flow Equilibria in the Atmosphere and Blocking[1]

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(Manuscript received 22 September 1978, in final form 28 February 1979)

ABSTRACT

A barotropic channel model is used to study the planetary-scale motions of an atmosphere whose zonal flow is externally driven. Perturbations are induced by topography and by a barotropic analogue of thermal driving. The use of highly truncated spectral expansions shows that there may exist a multiplicity of equilibrium states for a given driving, of which two or more may be stable. In the case of topographical forcing, two stable equilibrium states of very different character may be produced by the same forcing: one is a "low-index" flow with a strong wave component and a relatively weaker zonal component which is locked close to linear resonance; the other is a "high-index" flow with a weak wave component and a relatively stronger zonal component which is much farther from linear resonance. It is suggested that the phenomenon of blocking is a metastable equilibrium state of the low-index, near-resonant character. The existence of the two types of equilibria has been confirmed by numerical integration of a grid-point model with many more degrees of freedom than the spectral model.

It has also been found spectrally and for a grid-point model that oscillations may occur when one of the equilibrium states is stable for the lowest order spectral components but unstable for the next higher order components. The oscillation apparently is due to a barotropic instability of the topographic wave of the kind discussed by Lorenz and Gill.

Thermal forcing also produces multiple, stable equilibria in a spectral model but confirmation with a grid-point model has so far not been obtained.

Harvey, Methven and Ambaum JFM 2016.

RW propagation – smooth PV step

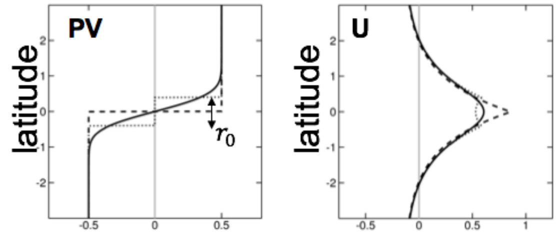
www.ncas.ac.uk

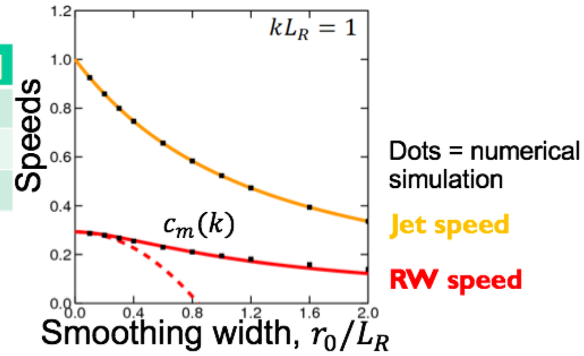
$$c_m \approx \int (U_s(y) - \phi_s(y))w(y)\,dy$$

- Putting some numbers in…
  - $r_0 = \frac{\Delta PV}{\max PV_y} \approx \begin{cases} 308\ km\ (analysis) \\ 381\ km\ (forecast) \end{cases}$
  - Also use: $L_R = 700\ km\ , \Delta PV = 4PVU$
  - Result:

	U_{max} [m/s]	c_m [m/s]	$c_{m,g}$ [m/s]
Sharp PV front:	70.0	20.5	45.3
$r_0 = 308\ km$:	50.9	17.7	38.2
$r_0 = 381\ km$:	47.6	16.8	36.0

  - Typical phase error after 5 days = O(400km)





PV Gradient Across Tropopause

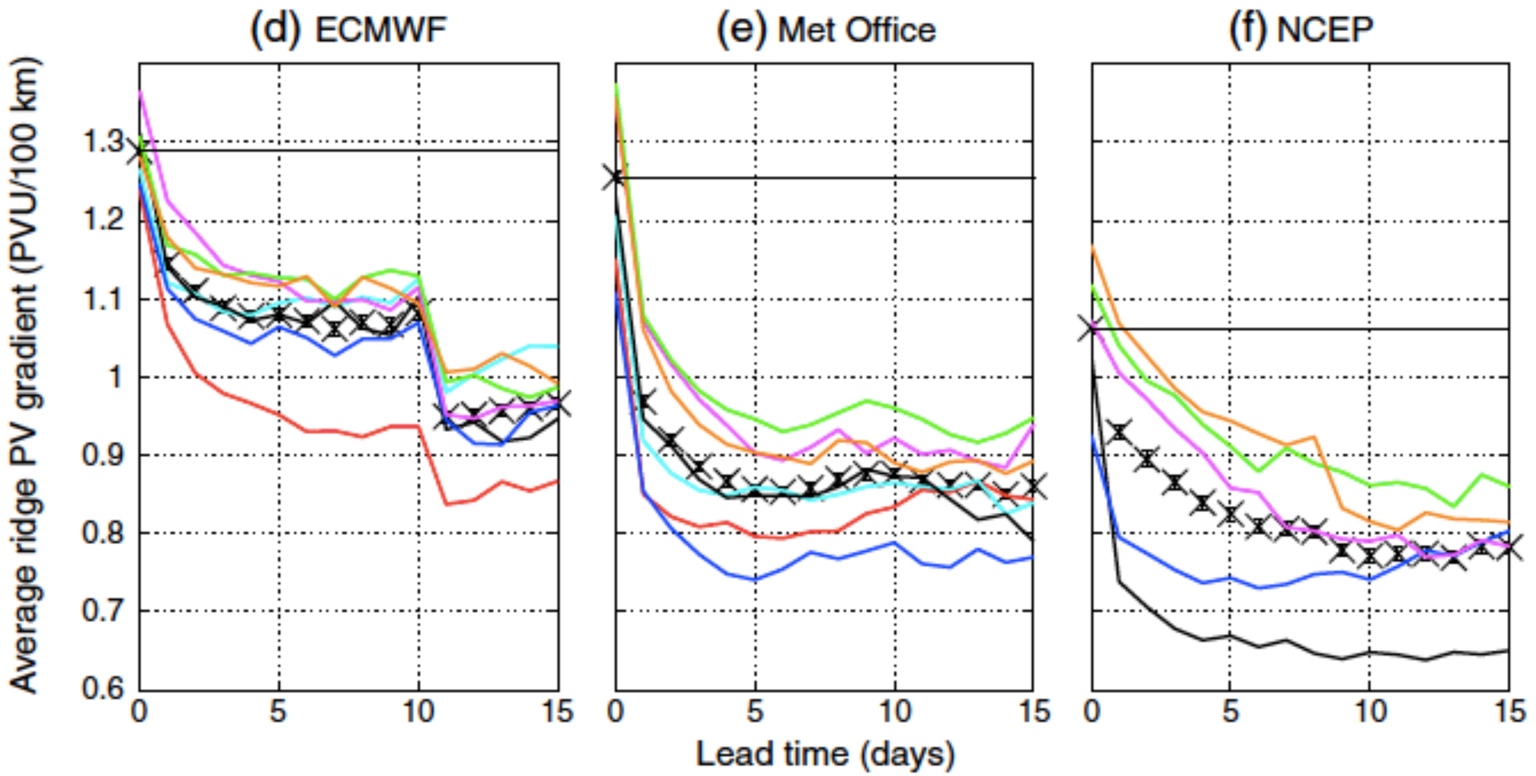


Figure 5. (a–c) Average ridge area and (d–f) the isentropic PV gradient flanking ridges as a function of forecast lead time for ECMWF, Met Office, and NCEP. Black markers with error bars (standard errors) are averages over all winter seasons with horizontal lines extending across all lead times from the analysis values. Colored lines are averages for the individual seasons where red is 2006/2007, cyan is 2007/2008, black is 2008/2009, blue is 2009/2010, magenta is 2010/2011, green is 2011/2012, and orange is 2012/2013. Note (as an example) that a fraction of the Northern Hemisphere of 0.05 is equivalent to an area of 1.275×10^7 km^2.

Gray et al, GRL, 2014

The resolution sensitivity of Northern Hemisphere blocking in four 25-km atmospheric global circulation models

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Matthew S. Mizielinski and Malcolm J. Roberts

Met Office Hadley Centre, Exeter, United Kingdom

Mio Matsueda

Center for Computational Sciences, University of Tsukuba, Japan, and Department of Physics, University of Oxford, United Kingdom

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Thomas Jung

ECMWF, Reading, United Kingdom, and AWI, Bremerhaven, Germany

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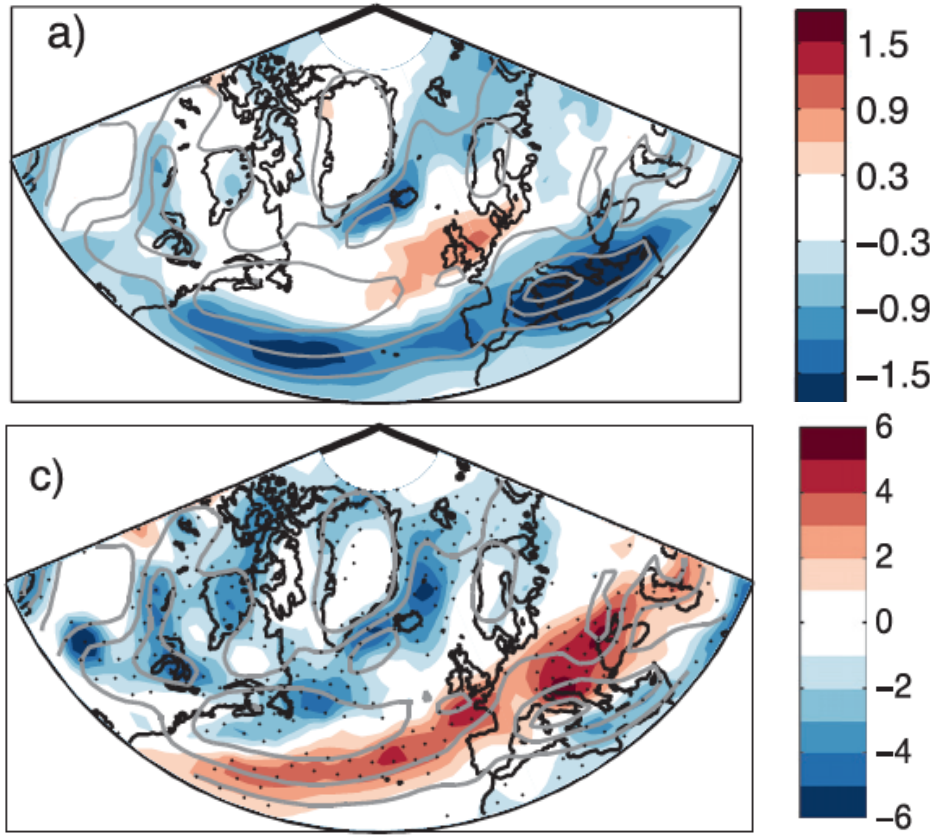
ABSTRACT

The aim of this study is to investigate if the representation of Northern Hemisphere blocking is sensitive to resolution in current-generation atmospheric global circulation models (AGCMs). An evaluation is conducted of how well atmospheric blocking is represented in four AGCMs whose horizontal resolution is increased from a grid spacing of more than 100 km to about 25 km. It is shown that Euro/Atlantic blocking is simulated overall more credibly at higher resolution, i.e. in better agreement with a 50-year reference blocking climatology created from the ERA-40 and ERA-Interim reanalyses. The improvement seen with resolution depends on the season and to some extent on the model considered. Euro/Atlantic blocking is simulated more realistically at higher resolution in winter, spring and autumn, and robustly so across the model ensemble. The improvement in spring is larger than that in winter and autumn. Summer blocking is found to be better simulated at higher resolution by one model only, with little change seen in the other three models. The representation of Pacific blocking is not found to systematically depend on resolution. Despite the improvements seen with resolution, the 25-km models still exhibit large biases in Euro/Atlantic blocking. For example, three of the four 25-km models underestimate winter northern European blocking frequency by about one third. The resolution sensitivity and biases in the simulated blocking are shown to be in part associated with the mean-state biases in the models' mid-latitude circulation.

Climate models do suggest **a strengthening of the wintertime storm track over the UK** (shown here by track density)

- However: model biases are not small; mechanisms are not understood; and not detected in obs; leads to **low confidence**



Mean CMIP5 response to RCP 8.5 in late 21st century

Mean CMIP5 bias

Zappa et al. (2013 J. Clim.)

CAN WE EVEN TRUST THE SIGN OF THIS RESPONSE?

With thanks to Ted Shepherd

A Nonlinear Dynamical Perspective on Climate Prediction

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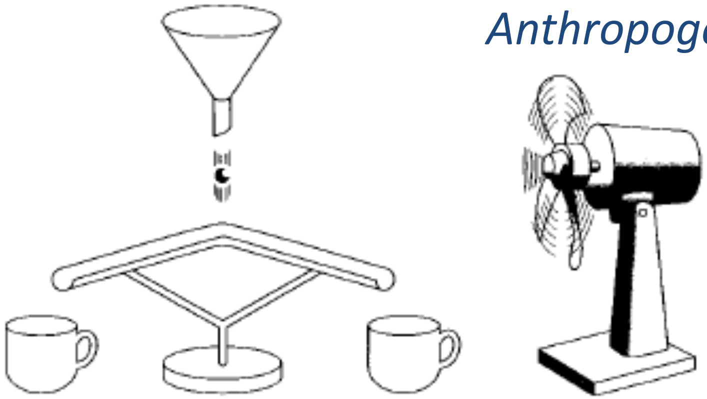
(Manuscript received 7 October 1997, in final form 26 February 1998)

ABSTRACT

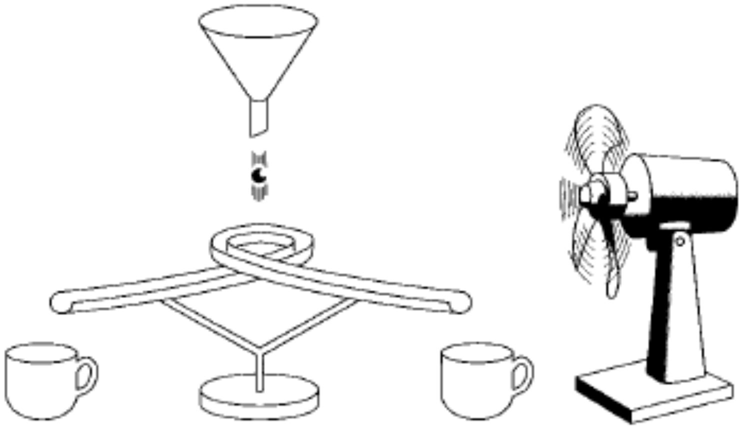
A nonlinear dynamical perspective on climate prediction is outlined, based on a treatment of climate as the attractor of a nonlinear dynamical system *D* with distinct quasi-stationary regimes. The main application is toward anthropogenic climate change, considered as the response of *D* to a small-amplitude imposed forcing **f**.

Anthropogenic CO_2



zonal *blocked*

Model Word

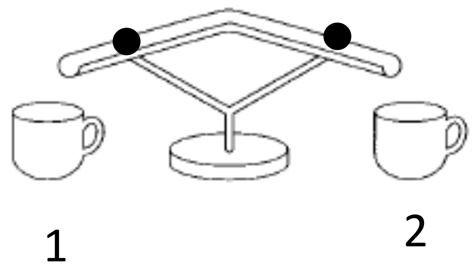


Real World (more complicated than model)?

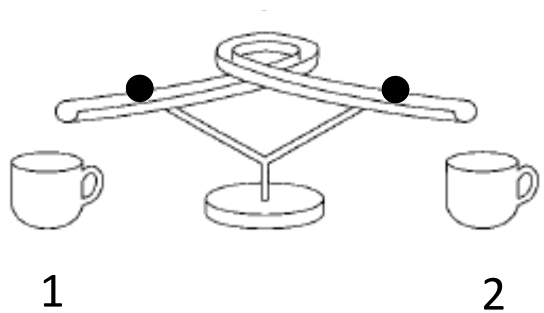
Societal implications enormous

Diagnose forcing errors by looking at the reliability of probabilistic initial value predictions

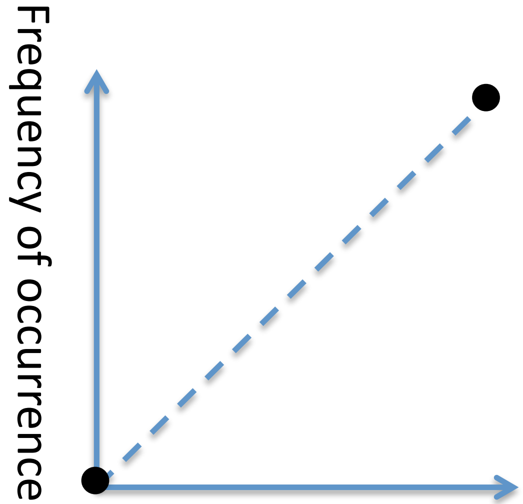
model

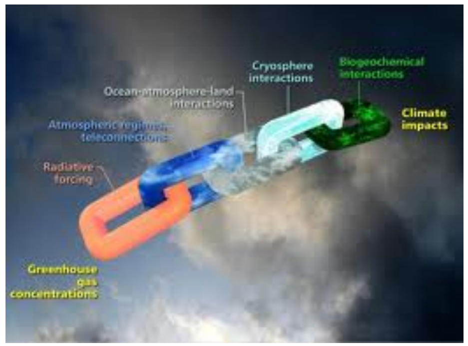


“real world”

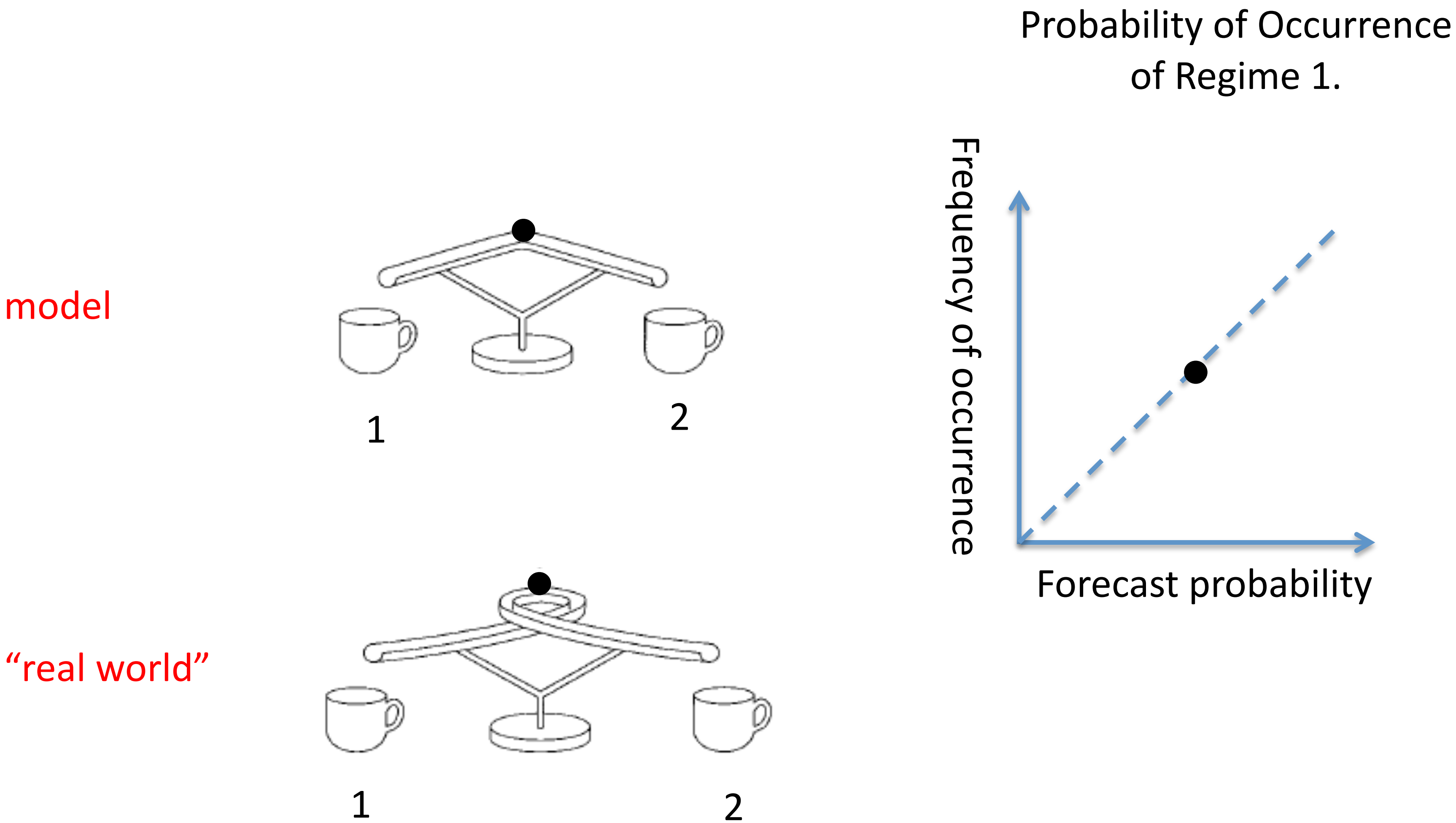


Probability of Occurrence of Regime 1.

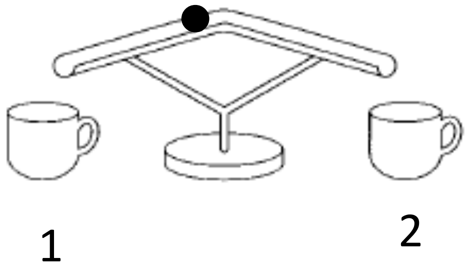




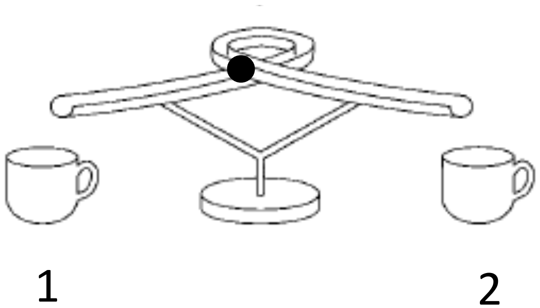
BAMS 2008


Probability of Occurrence
of Regime 1.
model
1
2
"real world"
1
2
Frequency of occurrence
Forecast probability

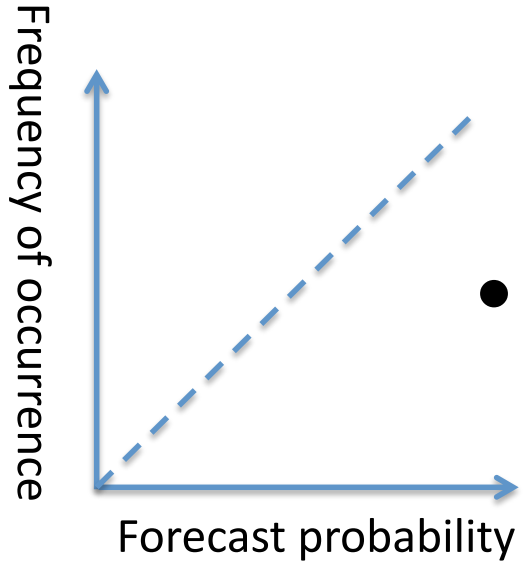
model



“real world”



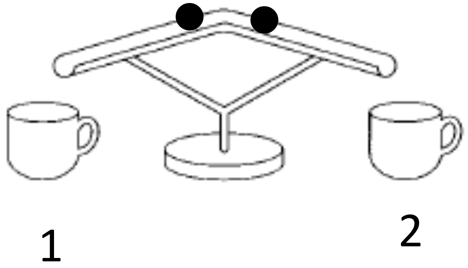
Probability of Occurrence
of Regime 1.



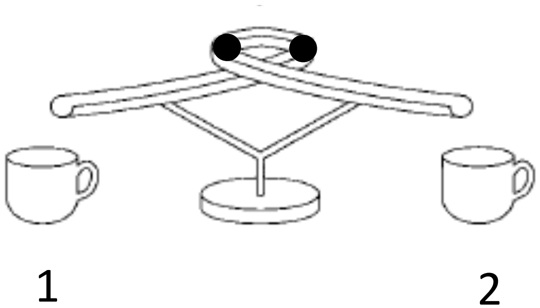
✗

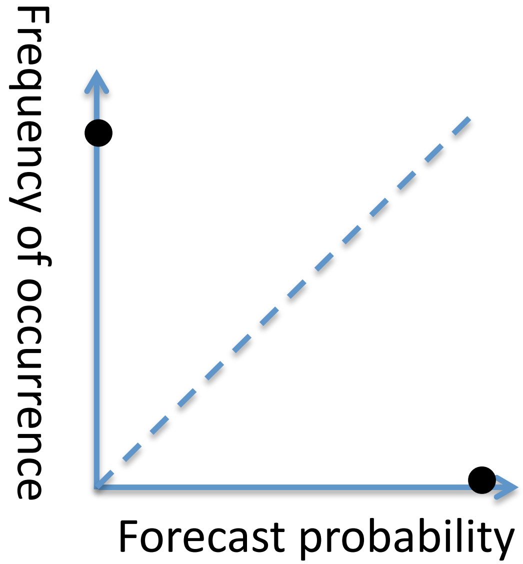
Probability of Occurrence
of Regime 1.

model



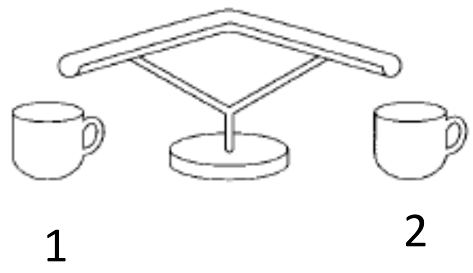
“real world”



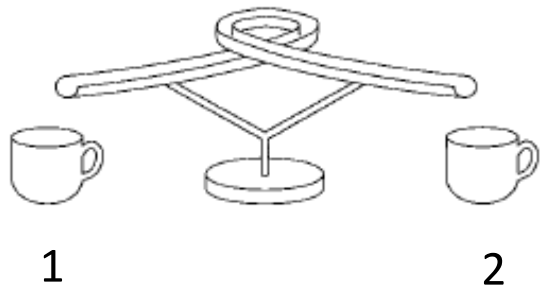


Putting it all together

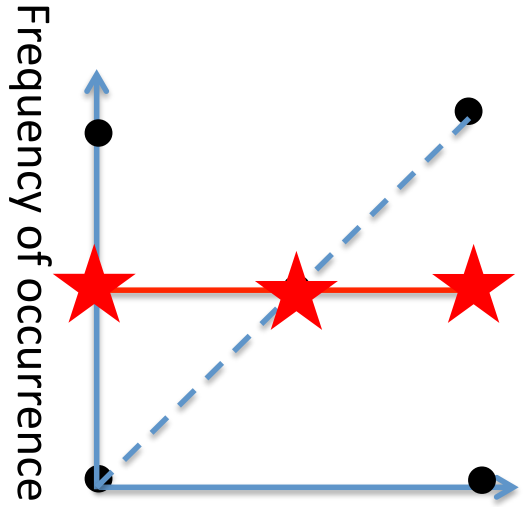
model



“real world”



Probability of Occurrence of Regime 1.



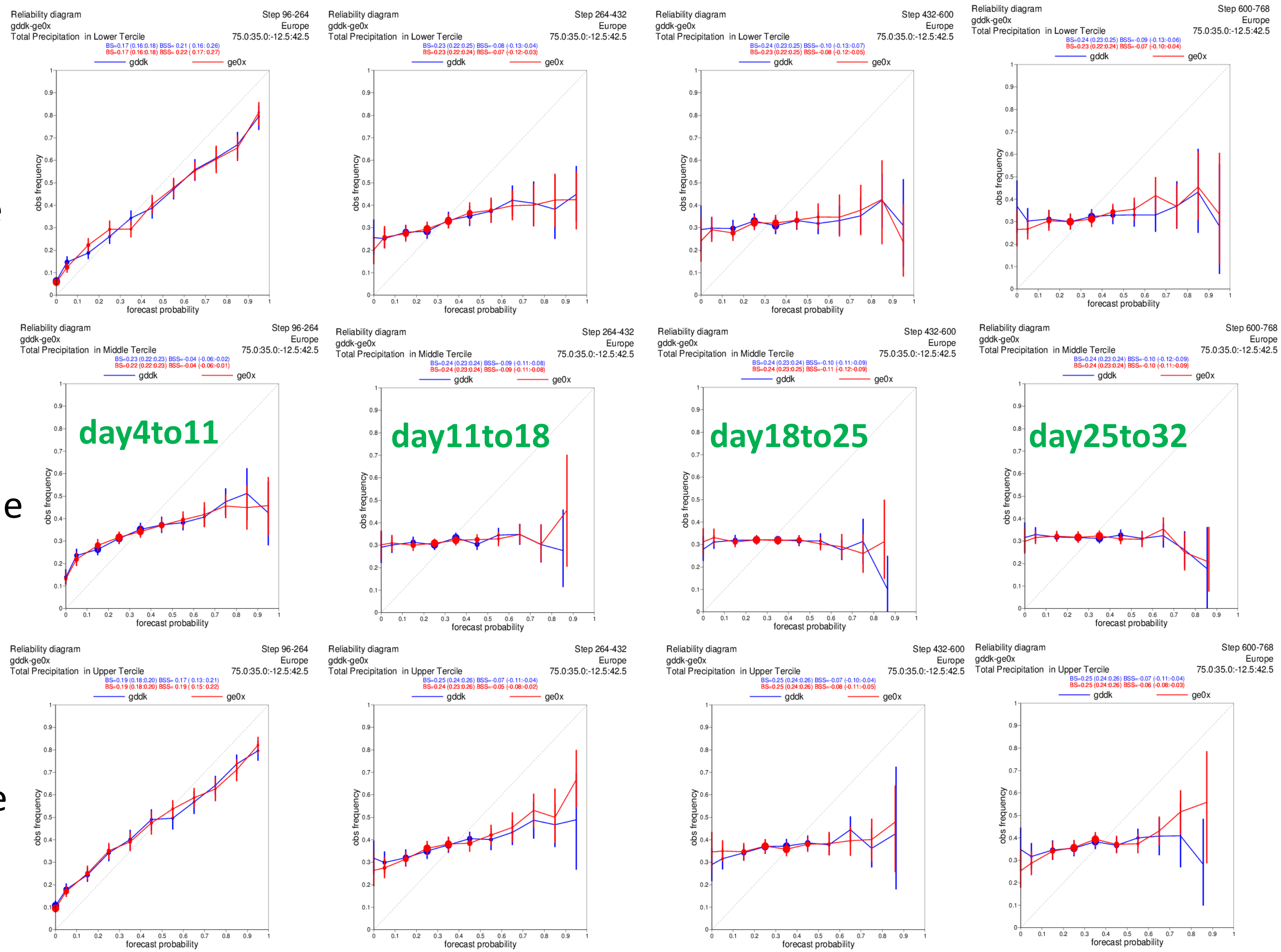
Reliable initial-value predictions is a necessary (but not sufficient) condition that the response to forcing is correct.

Antje Weisheimer

lower tercile

middle tercile

upper tercile



Reliability of precip forecasts over Europe in the monthly forecasting system (T399-T255)

And then there's the tropics!

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

OPEN ACCESS
IOP PUBLISHING ENVIRONMENTAL RESEARCH LETTERS
Environ. Res. Lett. 8 (2013) 024018 (12pp) doi:10.1088/1748-9326/8/2/024018

Implications of regional improvement in global climate models for agricultural impact research

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[2] CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Denmark
[3] Institute for Climate and Atmospheric Science (ICAS), School of Earth and Environment, University of Leeds, Leeds, UK
[4] International Livestock Research Institute (ILRI), Nairobi, Kenya

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Abstract
Global climate models (GCMs) have become increasingly important for climate change science and provide the basis for most impact studies. Since impact models are highly sensitive to input climate data, GCM skill is crucial for getting better short-, medium- and long-term outlooks for agricultural production and food security. The Coupled Model Intercomparison Project (CMIP) phase 5 ensemble is likely to underpin the majority of climate impact assessments over the next few years. We assess 24 CMIP3 and 26 CMIP5 simulations of present climate against climate observations for five tropical regions, as well as regional improvements in model skill and, through literature review, the sensitivities of impact estimates to model error. Climatological means of seasonal mean temperatures depict mean errors between 1 and 18 °C (2–130% with respect to mean), whereas seasonal precipitation and wet-day frequency depict larger errors, often offsetting observed means and variability beyond 100%. Simulated interannual climate variability in GCMs warrants particular attention, given that no single GCM matches observations in more than 30% of the areas for monthly precipitation and wet-day frequency, 50% for diurnal range and 70% for mean temperatures. We report improvements in mean climate skill of 5–15% for climatological mean temperatures, 3–5% for diurnal range and 1–2% in precipitation. At these improvement rates, we estimate that at least 5–30 years of CMIP work is required to improve regional temperature simulations and at least 30–50 years for precipitation simulations, for these to be directly input into impact models. We conclude with some recommendations for the use of CMIP5 in agricultural impact studies.

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A personal perspective on modelling the climate system

T. N. Palmer

Published 13 April 2016. DOI: 10.1098/rspa.2015.0772

Article Figures & Data Info & Metrics eLetters PDF

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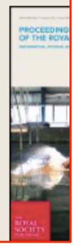
April 201
Volume 4



Abstract

Given their increasing relevance for society, I suggest that the climate science community itself does not treat the development of error-free *ab initio* models of the climate system with sufficient urgency. With increasing levels of difficulty, I discuss a number of proposals for speeding up such development. Firstly, I believe that climate science should make better use of the pool of post-PhD talent in mathematics and physics, for developing next-generation climate models. Secondly, I believe there is more scope for the development of modelling systems which link weather and climate prediction more seamlessly. Finally, here in Europe, I call for a new European Programme on Extreme Computing and Climate to advance our ability to simulate climate extremes, and

A Flagship European Programme on Extreme Computing and Climate

Contribution received to the FET Flagships consultation: A Flagship European Programme on Extreme Computing and Climate Author(s): Tim Palmer + 20 Leading European Climate Scientists You can add your comments on this topic at: ... Read more

Reporter: Carla Moris - *European Commission*
Last update: Tuesday, 3 May, 2016 15:05

Tags: FET Flagships, FET Flagships consultation, FET, consultation, Future and Emerging Technologies, emerging technologies

c. $1 billion

Model Hierarchies Workshop

Princeton University, New Jersey, USA, 2-4 November 2016

The Modeling Hierarchies Workshop will be held on the campus of Princeton University, New Jersey, USA. The meeting will run from 13:00, 2 November 2016 to 17:00, 4 November 2016. This meeting is held in conjunction with WGCM-20, which runs from 1-2 November 2016.

Background

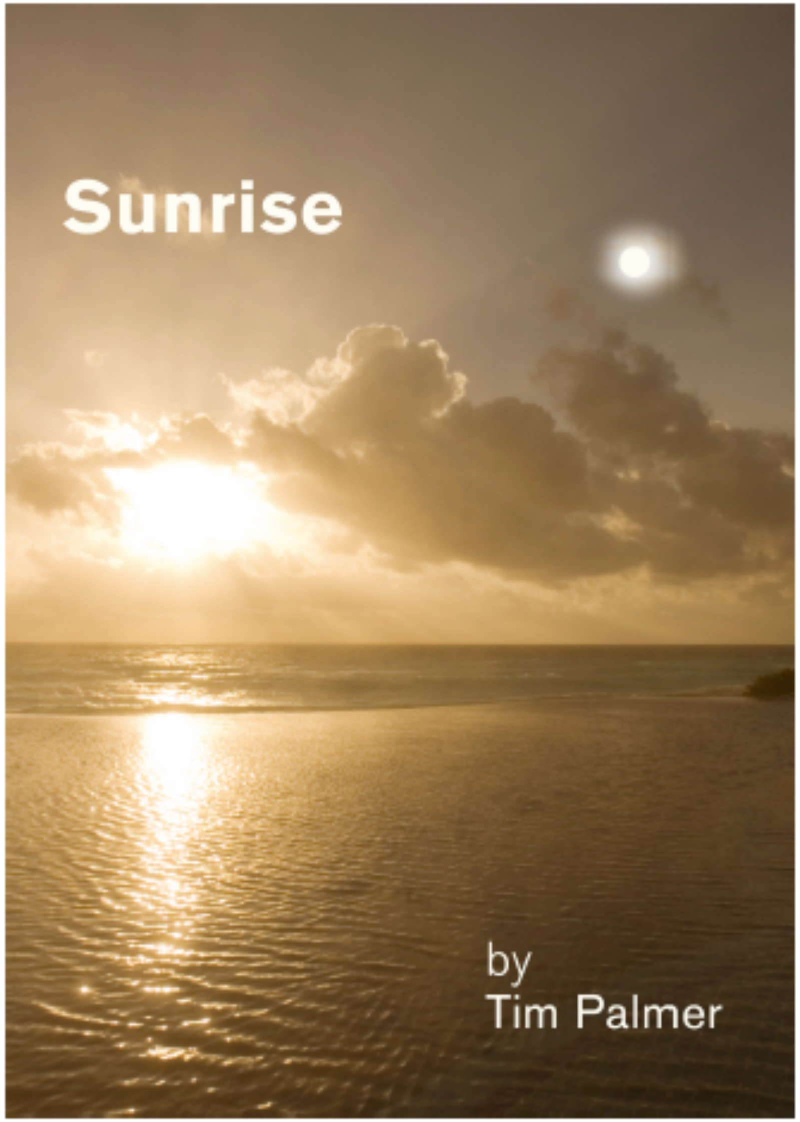
In "On Exactitude in Science", the Argentinian writer Borges tells the parable of a nation bankrupted by its cartographers, who endeavoured to create a map of the country on the scale of the country itself. It is sometimes argued that builders of Earth System models, which continue to grow in resolution and complexity, somewhat resemble Borges' mapmakers. Models so intricate that their behaviour is as rich and mysterious as the planet's itself, may not advance the science of climate as much as we would like.

Venue

PRINCETON UNIVERSITY

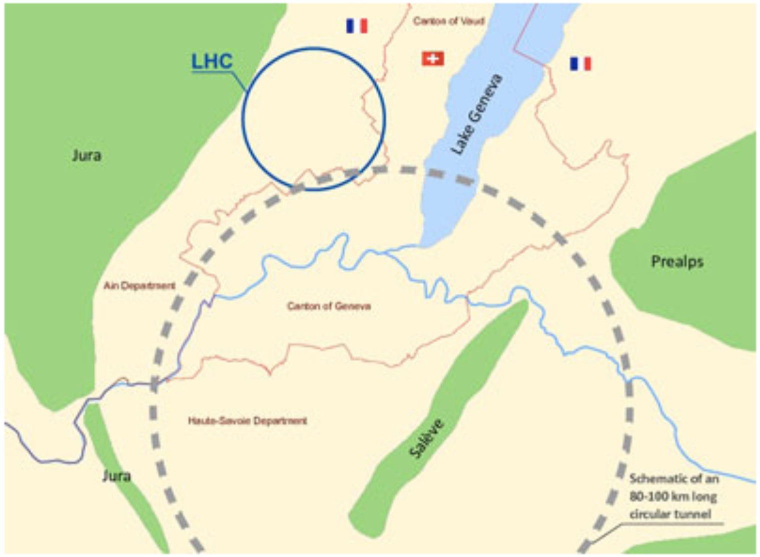
Princetown University
McDonnell Hall
Auditorium
Princeton, NJ

My own "sci-fi" short story about why we need reliable models for adapting to climate change



http://www2.physics.ox.ac.uk/research/predictability-of-weather-and-climate

CERN kicks off plans for LHC successor



Blueprint for the future

$ 100 billion?

Conclusions

- Hierarchical thinking should be second nature for all weather/climate scientists (of course). However, we are kidding ourselves if we think the current top-end of the hierarchy adequately represents reality. As such, the hierarchical paradigm, as the means to understand the real climate system, cannot today be applied with any degree of confidence.
- The top-end models are the central conduit through which society benefits from our research. However, we do not stress enough to funders and society the challenges in developing reliable top-end models (it's up there with finding evidence for supersymmetry). We are not ambitious enough (compared with the particle physicists) in proposing the means to address this issue.
- This is not helped by the relative detachment of some of our theoreticians (NOT ISAAC!). Development of top-end models shouldn't be thought of as a "brute force" activity, not worthy of their attention – there is a real educational problem here. Theoreticians who work on simplified models should also (be required to?) contribute to the development of top-end models and engage actively with operational weather/climate centres.

Conclusions

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