Stochastic Parametrisation and Extreme Rainfall Prediction

Tim Palmer

University of Oxford

Stochastic parametrisation is not some *ad hoc* method to represent model uncertainty.

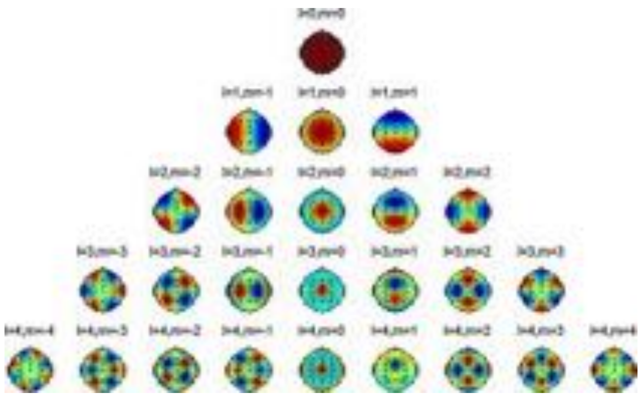
It is an approach to represent unresolved processes in a way which respects the symmetries of the underlying equations of motion better than does conventional deterministic parametrisation.

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

Resolved scales ← The Canonical Approach → Unresolved scales

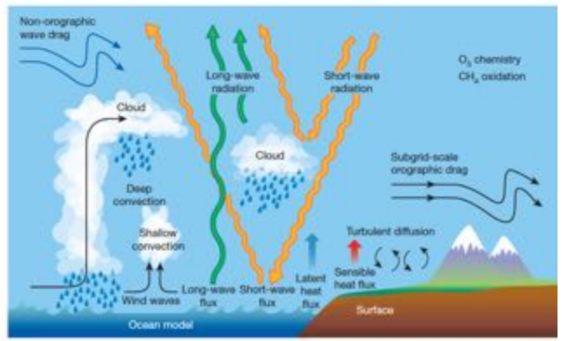
Dynamical Core

$$\zeta=\sum_{m\ l}^{\infty}\zeta_{ml}e^{im\lambda}P_l^m(\phi)$$

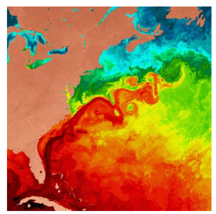


Parametrisations

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

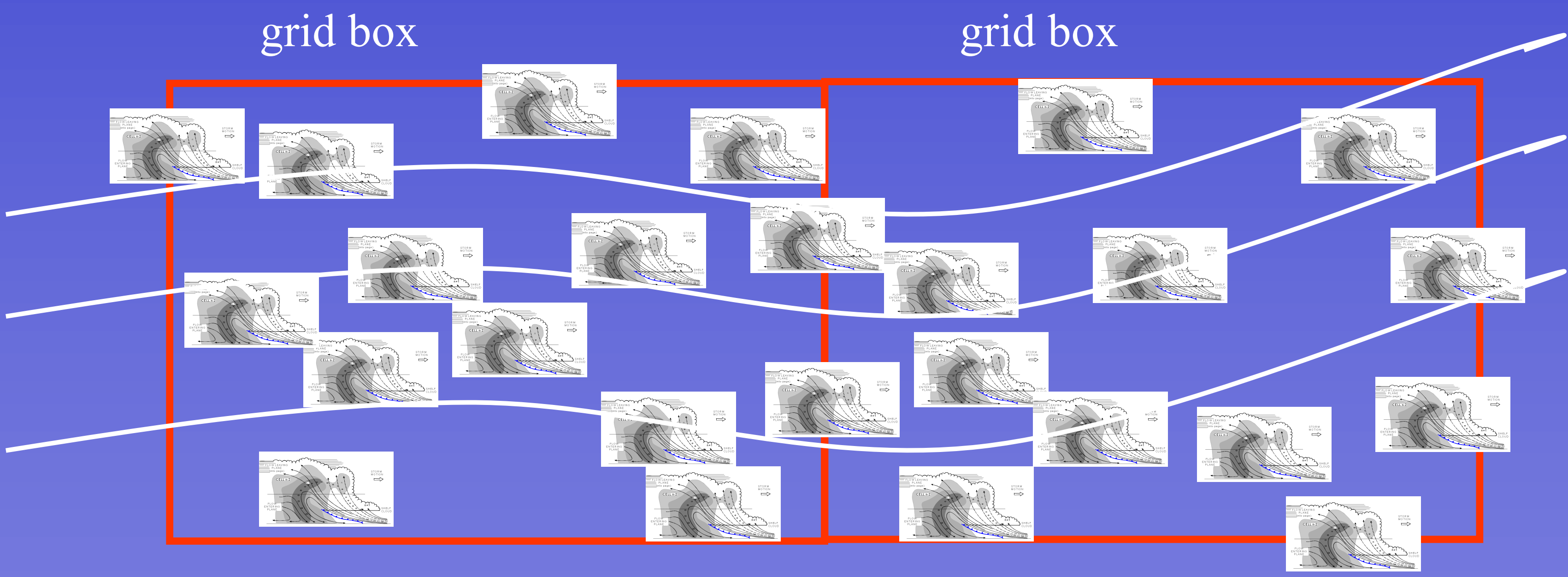


$$D=P$$



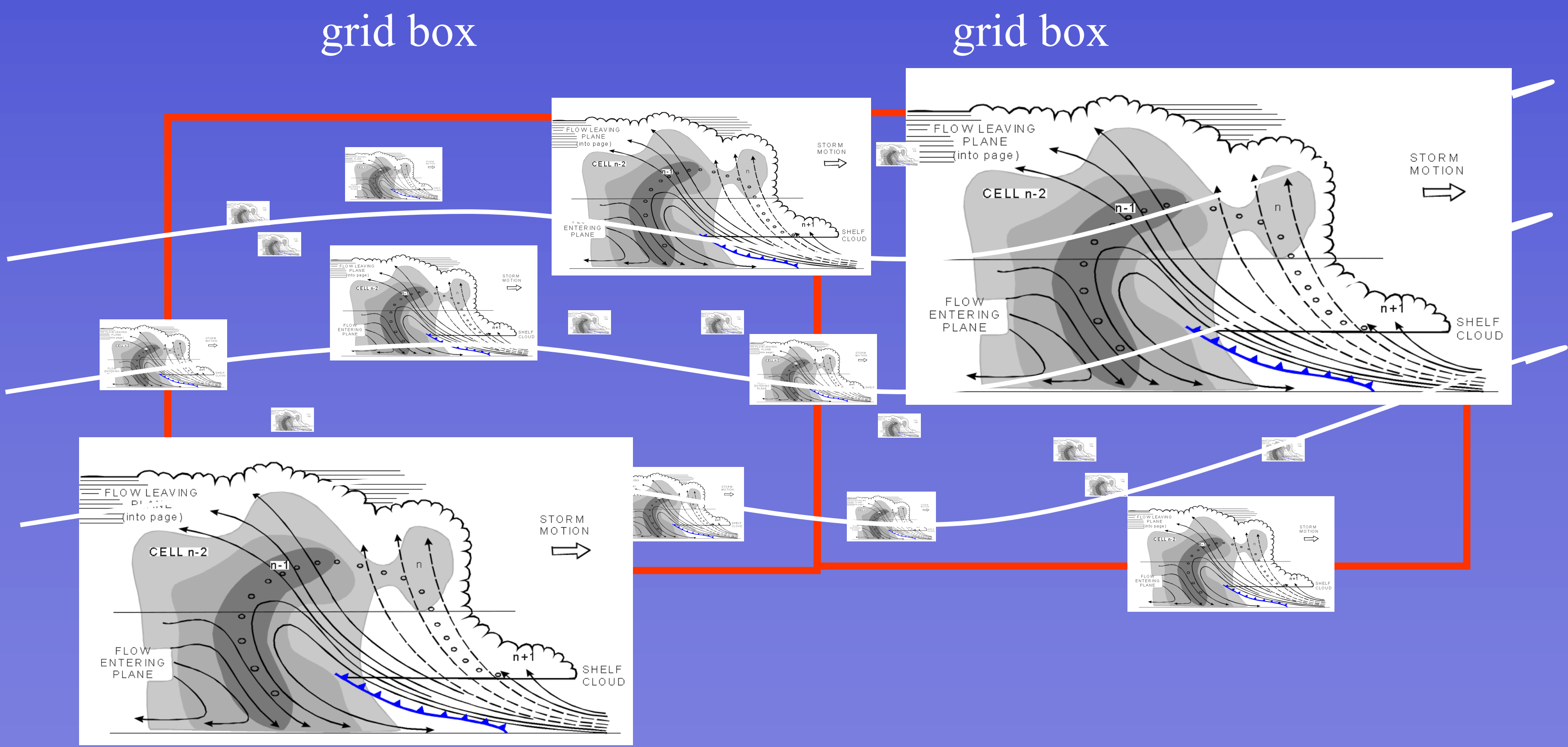
>50% compute time

Convective parametrisation is based on the assumption that the world looks like this…



It doesn't…

The reality of the situation



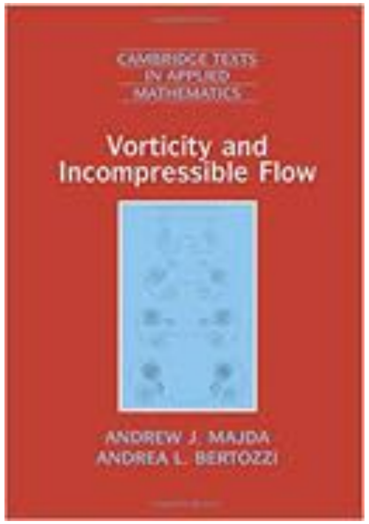
$$\rho\left(\frac{\partial}{\partial t}+\mathbf{u}.\nabla\right)\mathbf{u}=\rho\mathbf{g}-\nabla p+\mu\ \nabla^{2}\mathbf{u}$$

If $u(x,t)$ is the velocity field and $p(x,t)$ is the pressure field associated with a solution to the Navier-Stokes equations, then so is

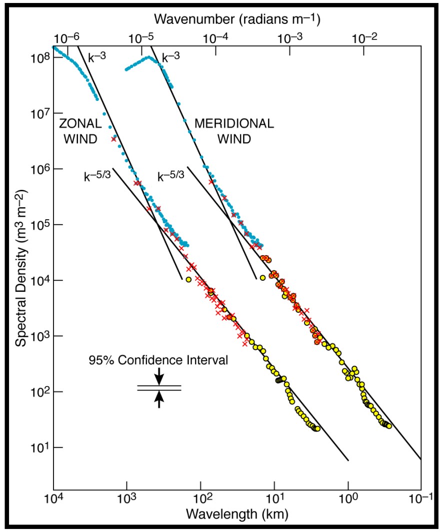
$$u_{\tau}(x,t)=\tau^{-1/2}u\left(\frac{x}{\tau^{1/2}},\frac{t}{\tau}\right),$$

$$p_{\tau}(x,t)=\tau^{-1}p\left(\frac{x}{\tau^{1/2}},\frac{t}{\tau}\right)$$

where $\tau>0$ is a dimensionless scaling parameter.



Scaling Laws for the Navier-Stokes Equations



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

Resolved scales

Unresolved scales

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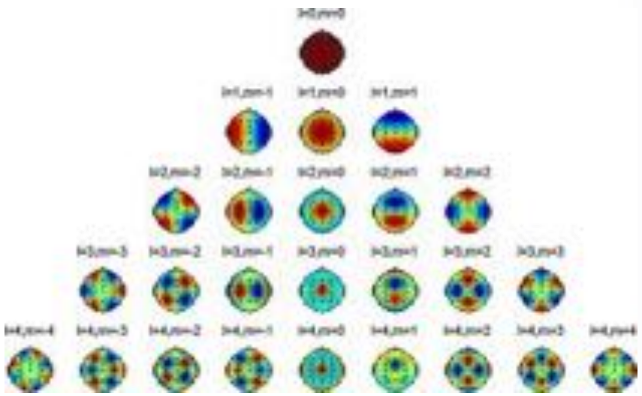
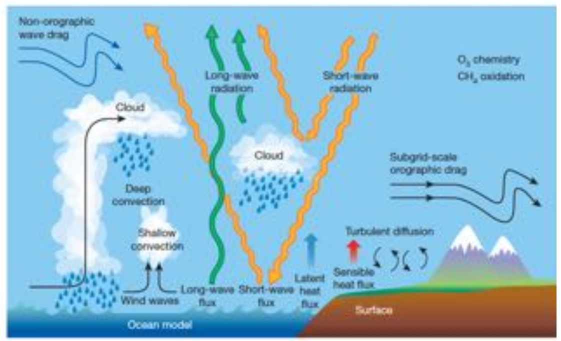
$$\zeta=\sum_{m}^{\infty}\sum_{l}\zeta_{ml}e^{im\lambda}P_l^m(\phi)$$



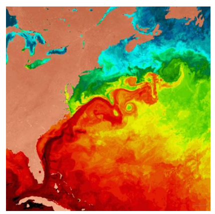
Stochastic Parametrisations

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

Buizza et al, 1999

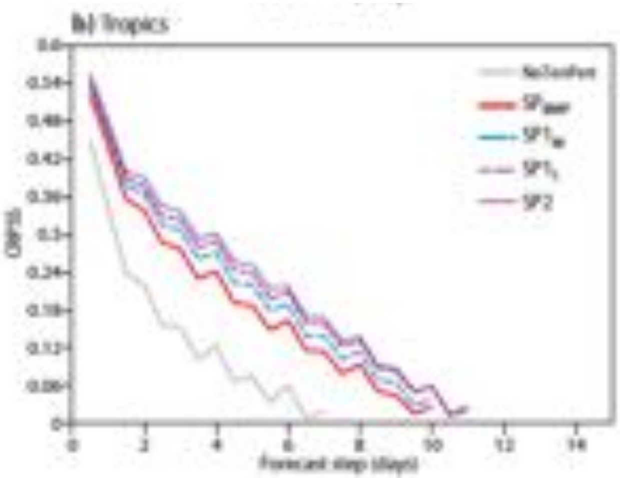


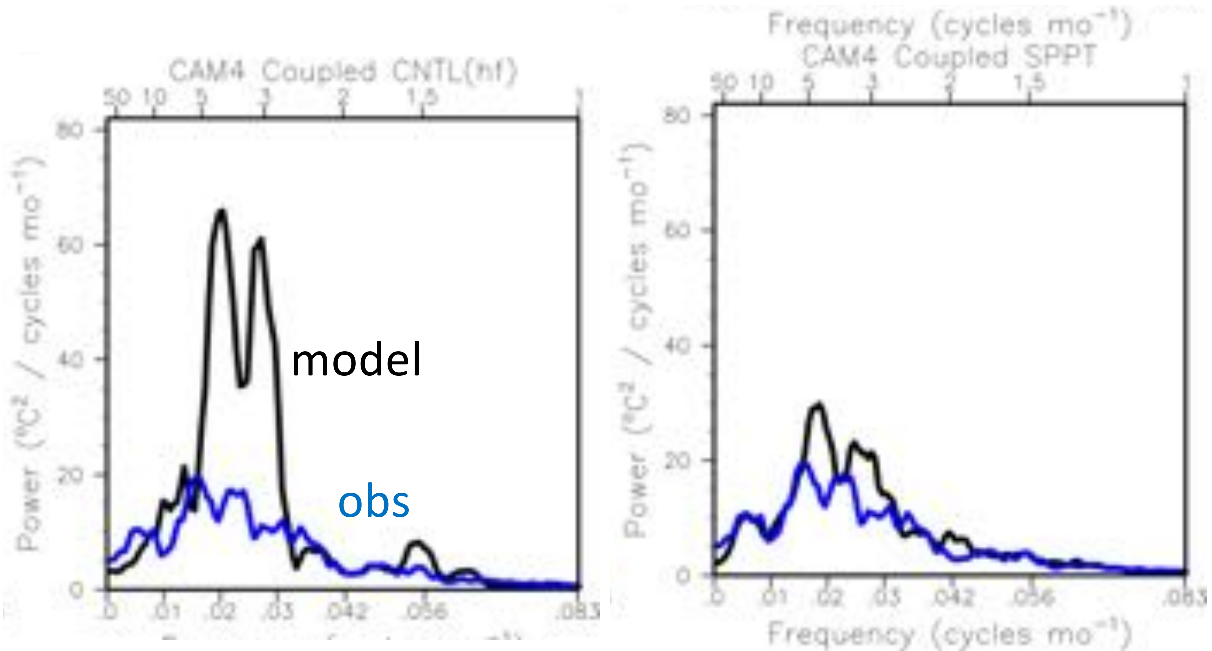
$$D=P$$



Some of the benefits of stochastic parametrisation

Weather Forecast Skill Scores without (grey) and with (colour) stochastic parametrization.





NCAR, CAM4 ENSO without and with stochastic parametrization.
Christensen et al, 2017

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

10.1002/2016JD026386

Key Points:

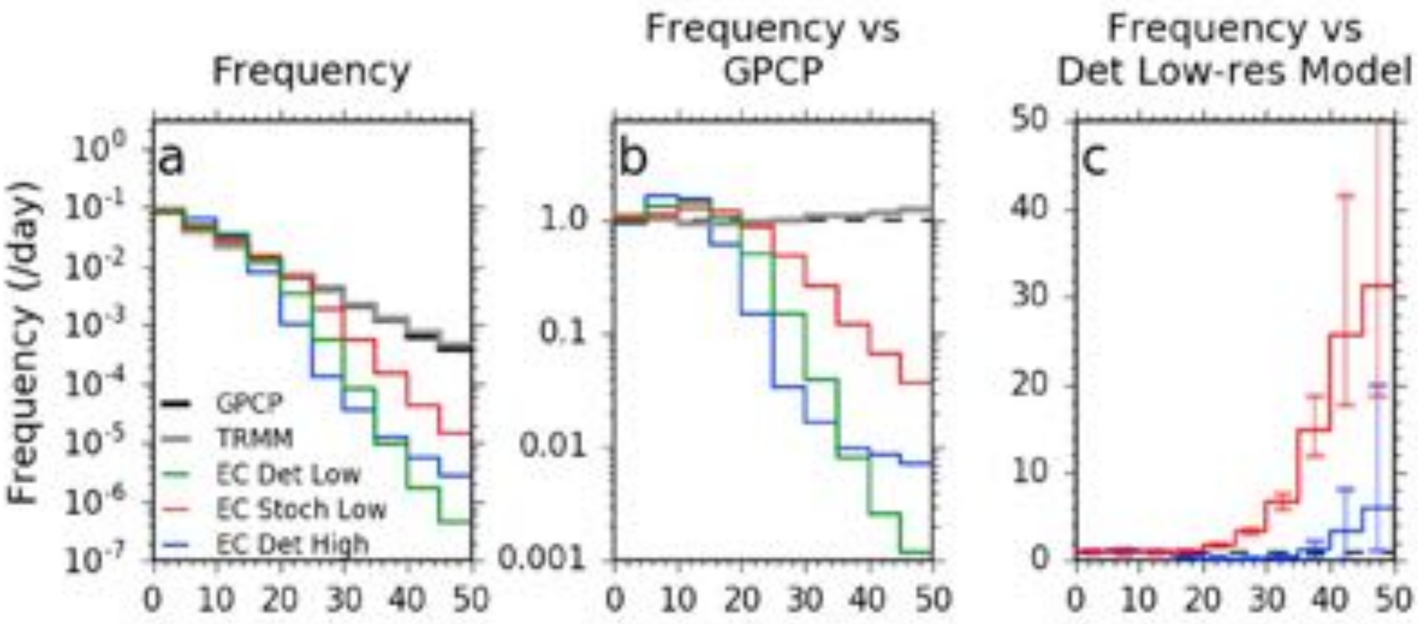
- Stochastic physics schemes improve simulated tropical precipitation variability on daily to weekly time scales in climate models
- Large improvements are found in simulating extreme event frequency, persistence, and power spectra of precipitation
- Small-scale variability has an important role in determining tropical climate variability statistics on scales larger than ~100 km

The impact of stochastic physics on tropical rainfall variability in global climate models on daily to weekly time scales

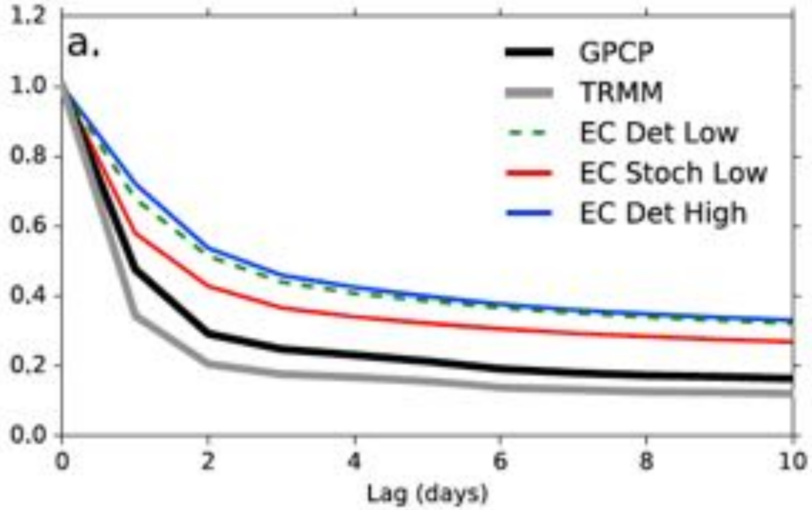
Peter A. G. Watson[1], Judith Berner[2], Susanna Corti[3], Paolo Davini[4], Jost von Hardenberg[5], Claudio Sanchez[6], Antje Weisheimer[1,7,8], and Tim N. Palmer[1]

[1]Atmospheric, Oceanic and Planetary Physics, University of Oxford, Oxford, UK, [2]National Center for Atmospheric Research, Boulder, Colorado, USA, [3]Institute of Atmospheric Sciences and Climate (ISAC-CNR), Bologna, Italy, [4]Laboratoire de Météorologie Dynamique/IPSL, Ecole Normale Supérieure, Paris, France, [5]Institute of Atmospheric Sciences and Climate (ISAC-CNR), Torino, Italy, [6]Met Office, Exeter, UK, [7]European Centre for Medium-Range Weather Forecasts, Reading, UK, [8]National Centre for Atmospheric Sciences, University of Oxford, Oxford, UK

Impact of SPPT in EC-Earth



Rate (mm/day) Rate (mm/day) Rate (mm/day)



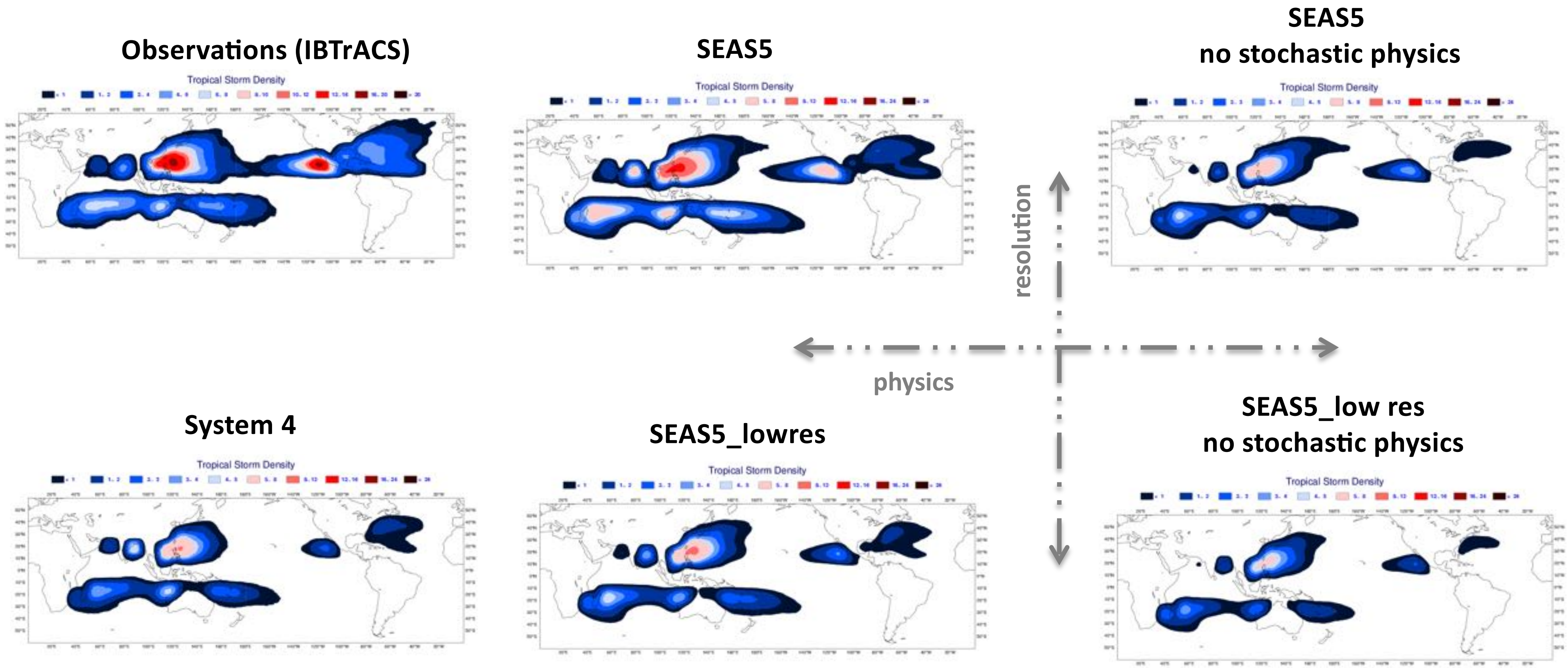
Precipitation Autocorrelation

Watson et al (2017)

Tropical Cyclones in ECMWF seasonal forecast system

Number of tropical cyclones: Impact of resolution vs stochastic physics

- Stochastic physics and resolution have similar impact

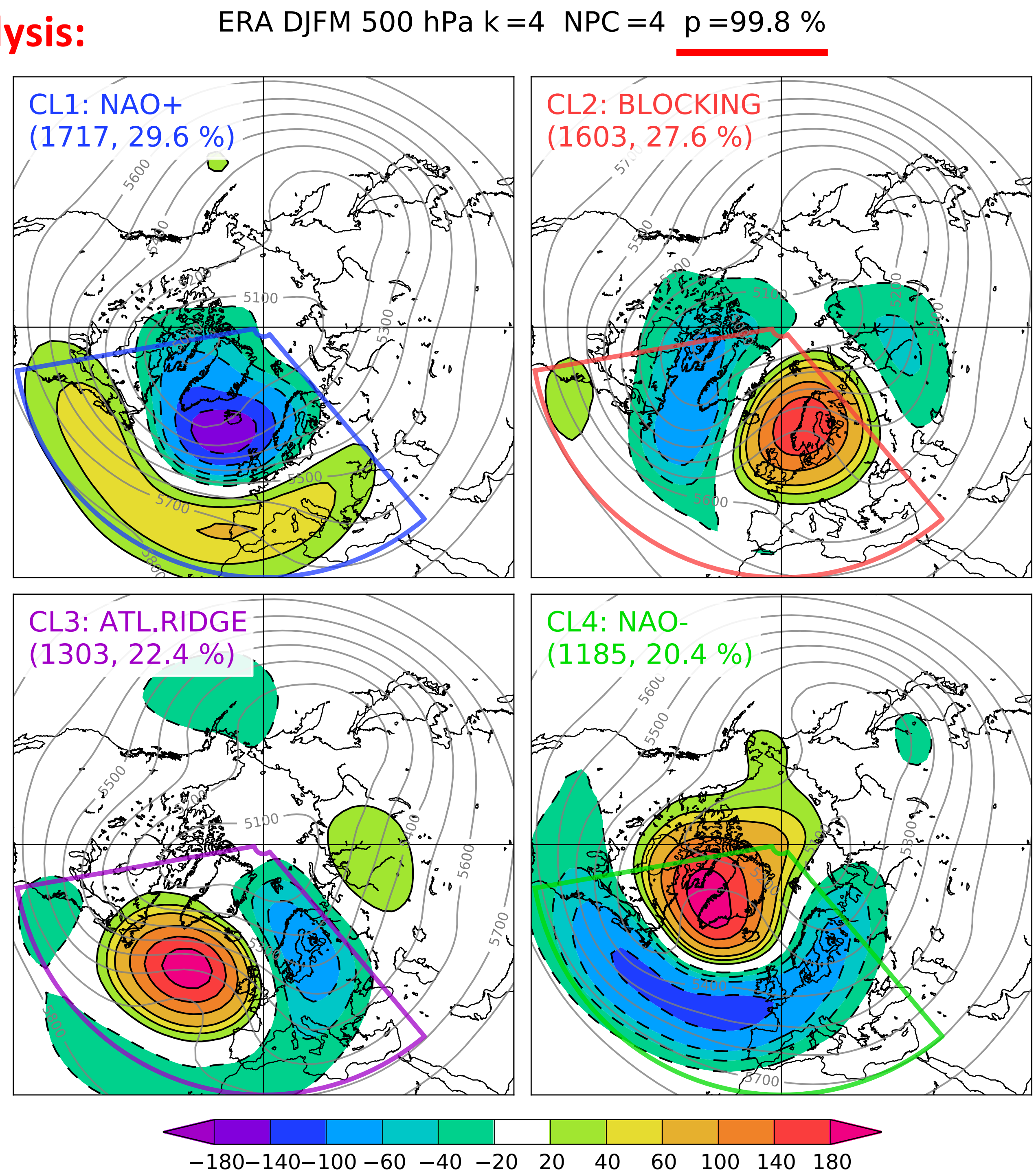


Thanks to Antje Weisheimer

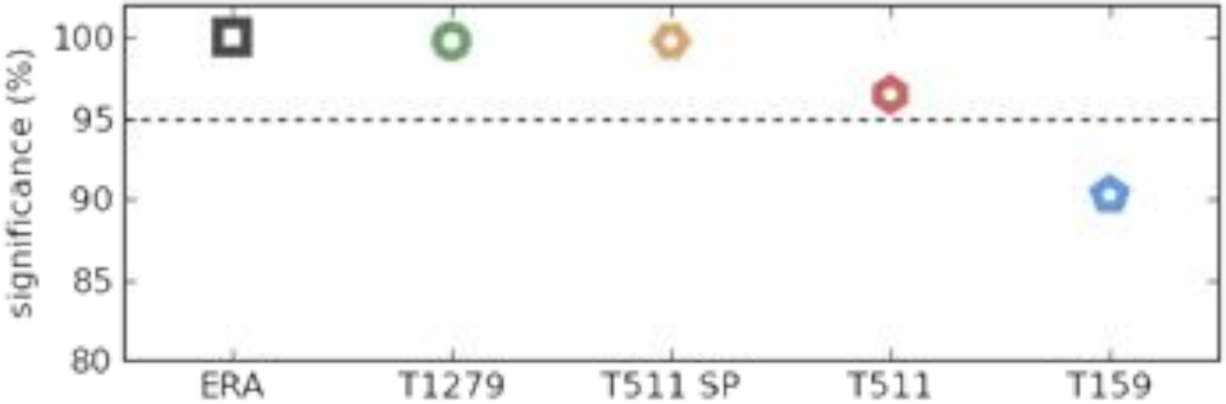
Winter Flooding in UK. Often persistent heavy rain over several days/weeks/months.

Indication of persistent circulation regime (e.g. +NAO)

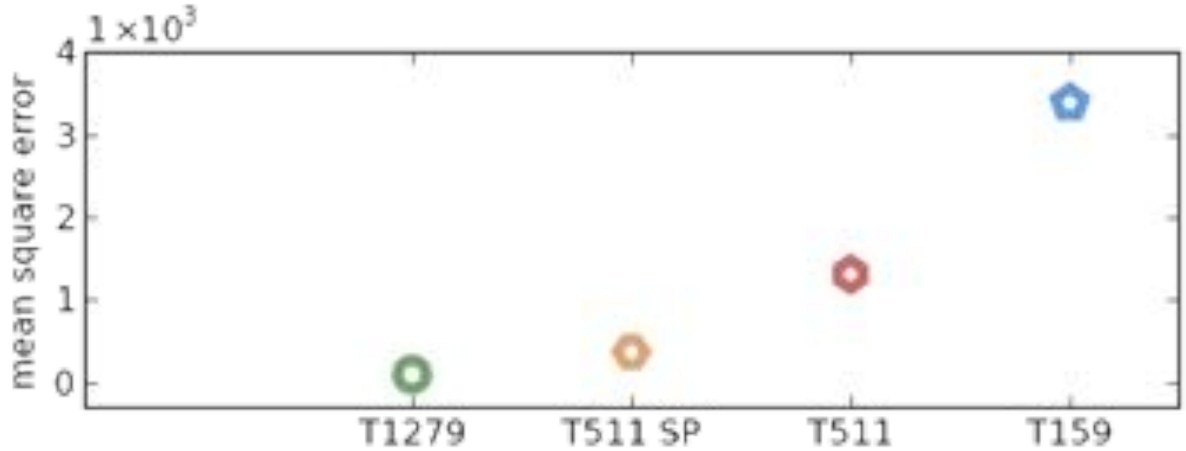
Regime Analysis: k-means clustering



Athena: AMIP runs

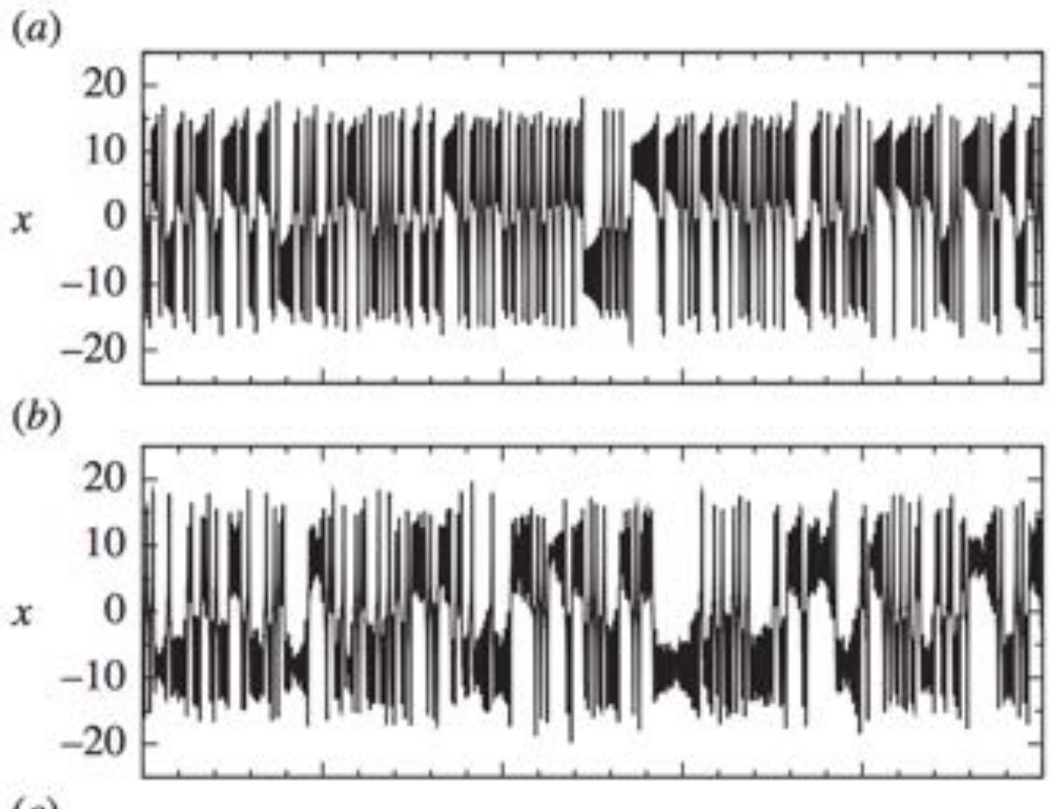


Probability that clusters are not produced from a chance sampling of a gaussian



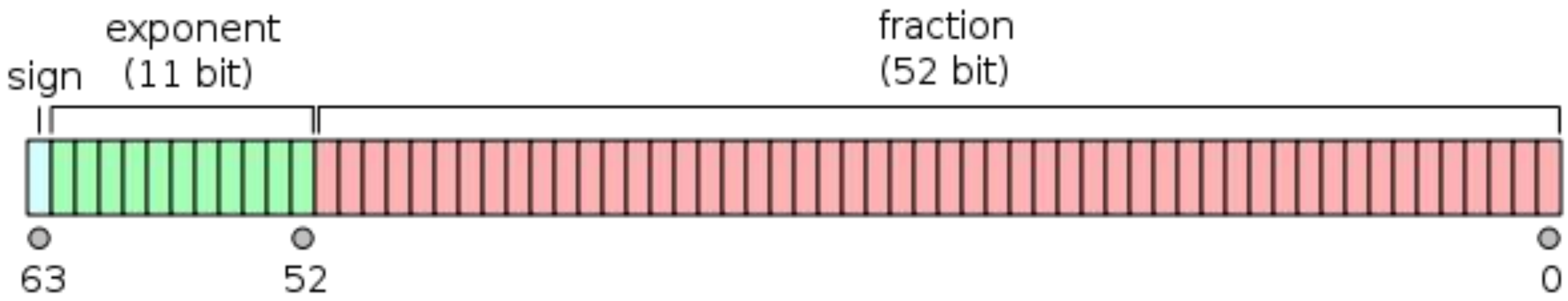
Dawson,
Corti Palmer,
GRL 2012

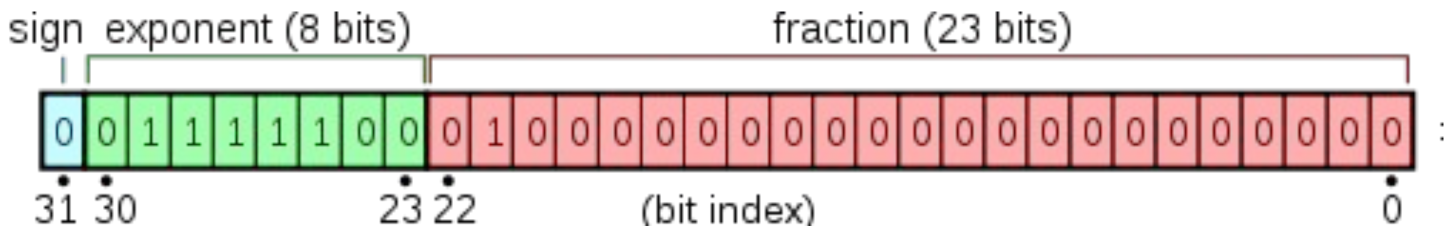
RMS error of simulated clusters against ERA

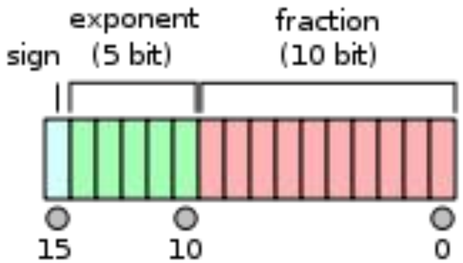


Lorenz 63

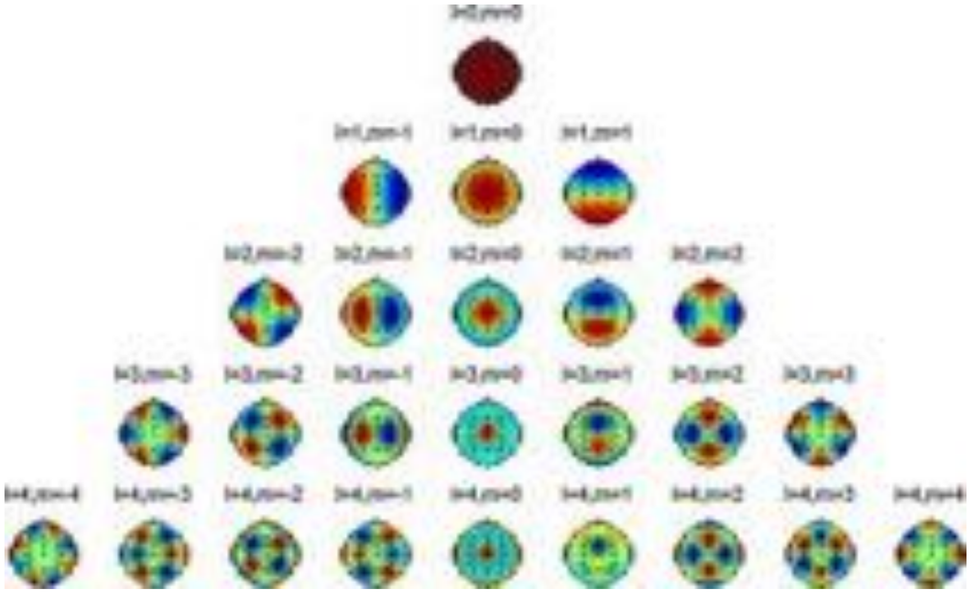
Lorenz 63 + stochastic noise (Kwasniok, 2014)


sign
exponent
(11 bit)
fraction
(52 bit)
63
52
0


sign
exponent (8 bits)
fraction (23 bits)
0 0 1 1 1 1 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
31 30
23 22
(bit index)
0


sign
exponent
(5 bit)
fraction
(10 bit)
15
10
0

Increasingly reduced precision



Stochastic parametrisation

650 MONTHLY WEATHER REVIEW VOLUME 147

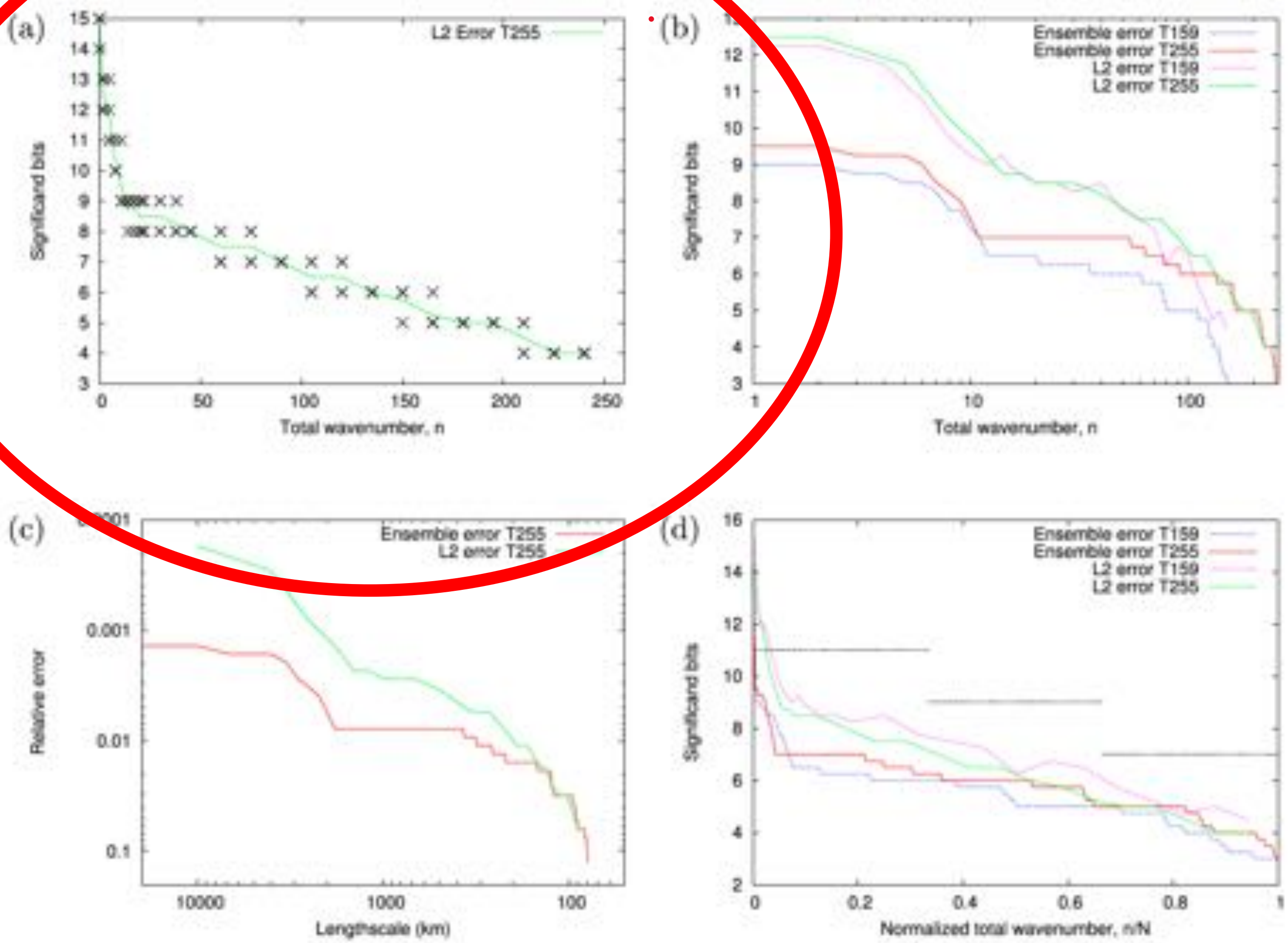
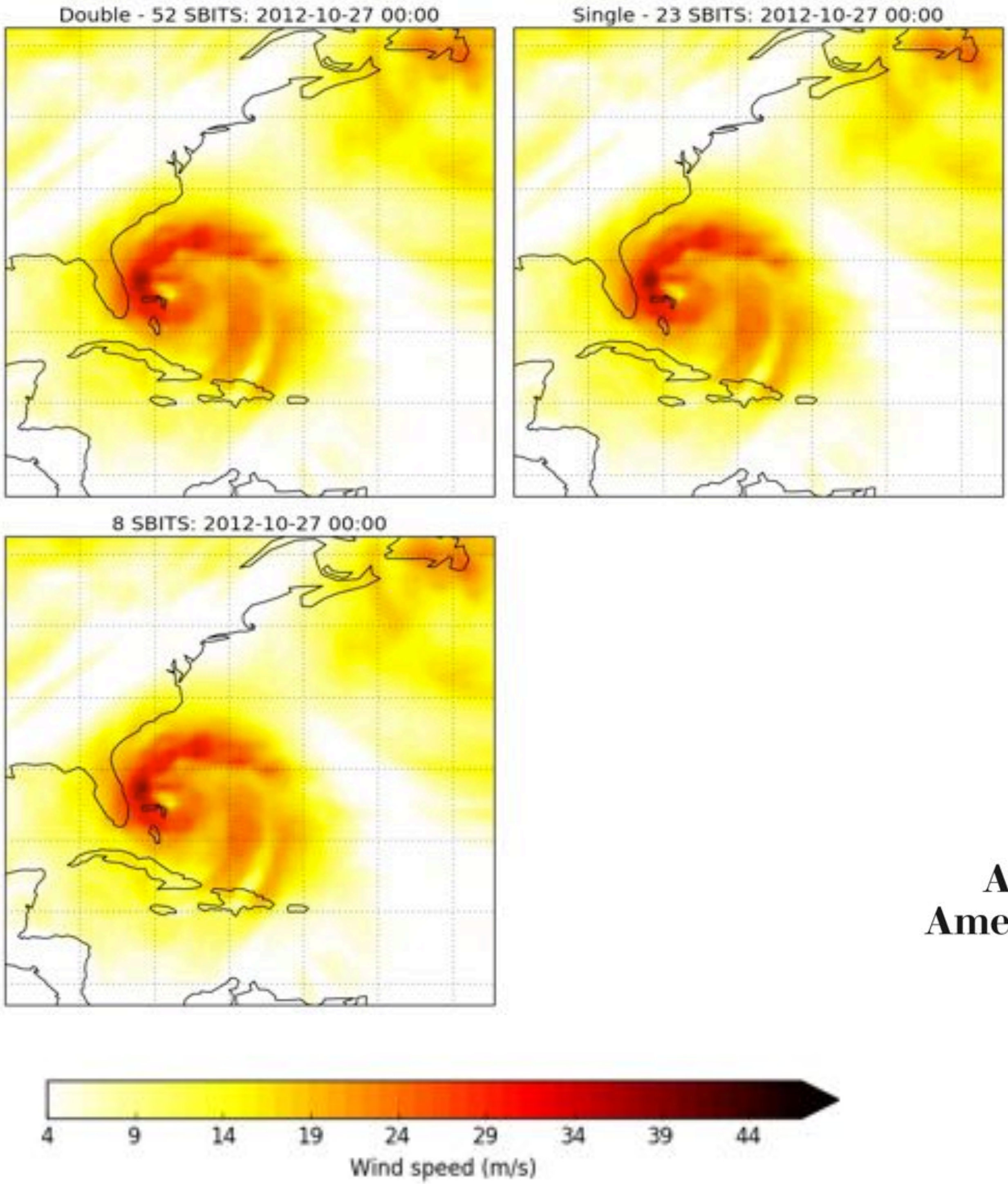


FIG. 3. (a) Precision needed to represent total wavenumbers $\geq n$ for an L_2 norm error less than two. Crosses represent four start dates at T255 resolution, with the line denoting the average. (b) Average precision for European ensemble error or L_2 error measures at resolutions T159 and T255. (c) Replotted T255 data as relative error against length scale. Please note that the x and y axes are reversed. (d) Total wavenumber is normalized by the truncation wavenumber to collapse the data for each measure. Gray dotted lines indicate scale-selective precision used for the decadal runs (see section 4d).

Chantry et al, Monthly Weather Review, 2019

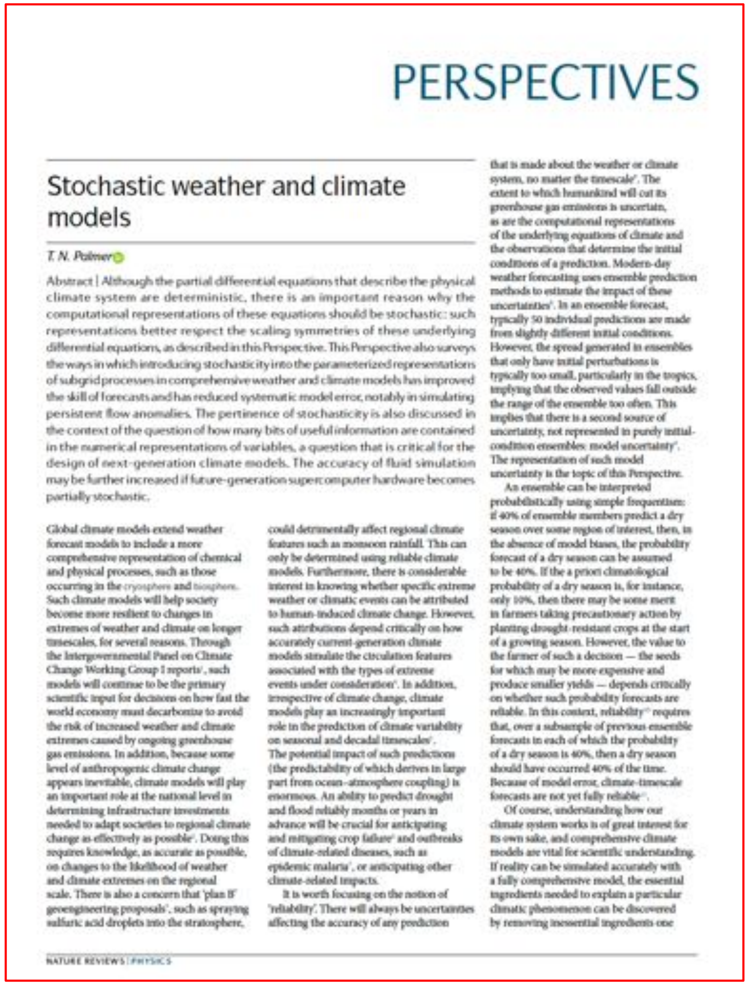


Hurricane Sandy

27/10/12 00:00
850hP wind speed
T255L91 ~ 80km

SUSTAINABILITY

Are Europeans Better Than Americans at Forecasting Storms?



PERSPECTIVES

Stochastic weather and climate models

T. N. Palmer

Abstract | Although the partial differential equations that describe the physical climate system are deterministic, there is an important reason why the computational representations of these equations should be stochastic: such representations better respect the scaling symmetries of these underlying differential equations, as described in this Perspective. This Perspective also surveys the ways in which introducing stochasticity into the parameterized representations of subgrid processes in comprehensive weather and climate models has improved the skill of forecasts and has reduced systematic model error, notably in simulating persistent flow anomalies. The pertinence of stochasticity is also discussed in the context of the question of how many bits of useful information are contained in the numerical representations of variables, a question that is critical for the design of next-generation climate models. The accuracy of fluid simulation may be further increased if future-generation supercomputer hardware becomes partially stochastic.

Global climate models extend weather forecast models to include a more comprehensive representation of chemical and physical processes, such as those occurring in the cryosphere and biosphere. Such climate models will help society become more resilient to changes in extremes of weather and climate on longer timescales, for several reasons. Through the Intergovernmental Panel on Climate Change Working Group I reports, such models will continue to be the primary scientific input for decisions on how fast the world economy must decarbonize to avoid the risk of increased weather and climate extremes caused by ongoing greenhouse gas emissions. In addition, because some level of anthropogenic climate change appears inevitable, climate models will play an important role at the national level in determining infrastructure investments needed to adapt societies to regional climate change as effectively as possible. Doing this requires knowledge, as accurate as possible, on changes to the likelihood of weather and climate extremes on the regional scale. There is also a concern that 'plan B' geoengineering proposals, such as spraying sulfuric acid droplets into the stratosphere, could detrimentally affect regional climate features such as monsoon rainfall. This can only be determined using reliable climate models. Furthermore, there is considerable interest in knowing whether specific extreme weather or climatic events can be attributed to human-induced climate change. However, such attributions depend critically on how accurately current-generation climate models simulate the circulation features associated with the types of extreme events under consideration. In addition, irrespective of climate change, climate models play an increasingly important role in the prediction of climate variability on seasonal and decadal timescales. The potential impact of such predictions (the predictability of which derives in large part from ocean–atmosphere coupling) is enormous. An ability to predict drought and flood reliably months or years in advance will be crucial for anticipating and mitigating crop failure and outbreaks of climate-related diseases, such as epidemic malaria, or anticipating other climate-related impacts.

It is worth focusing on the notion of 'reliability'. There will always be uncertainties affecting the accuracy of any prediction that is made about the weather or climate system, no matter the timescale. The extent to which humankind will cut its greenhouse gas emissions is uncertain, as are the computational representations of the underlying equations of climate and the observations that determine the initial conditions of a prediction. Modern-day weather forecasting uses ensemble prediction methods to estimate the impact of these uncertainties. In an ensemble forecast, typically 50 individual predictions are made from slightly different initial conditions. However, the spread generated in ensembles that only have initial perturbations is typically too small, particularly in the tropics, implying that the observed values fall outside the range of the ensemble too often. This implies that there is a second source of uncertainty, not represented in purely initial-condition ensembles: model uncertainty. The representation of such model uncertainty is the topic of this Perspective.

An ensemble can be interpreted probabilistically using simple frequentism: if 40% of ensemble members predict a dry season over some region of interest, then, in the absence of model biases, the probability forecast of a dry season can be assumed to be 40%. If the a priori climatological probability of a dry season is, for instance, only 10%, then there may be some merit in farmers taking precautionary action by planting drought-resistant crops at the start of a growing season. However, the value to the farmer of such a decision — the seeds for which may be more expensive and produce smaller yields — depends critically on whether such probability forecasts are reliable. In this context, reliability requires that, over a subsample of previous ensemble forecasts in each of which the probability of a dry season is 40%, then a dry season should have occurred 40% of the time. Because of model error, climate-timescale forecasts are not yet fully reliable.

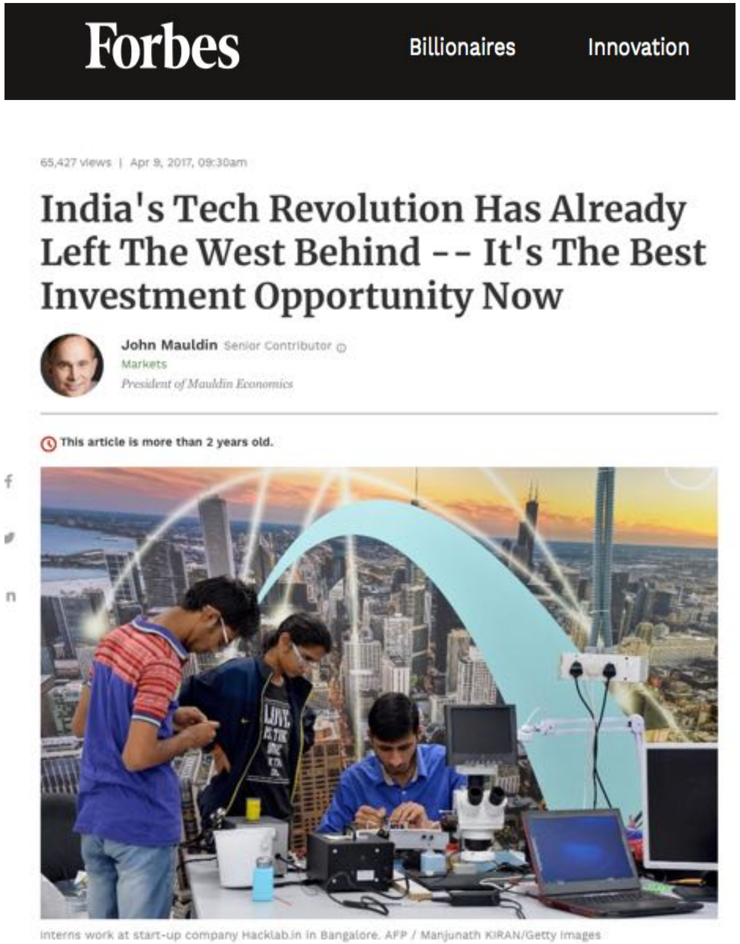
Of course, understanding how our climate system works is of great interest for its own sake, and comprehensive climate models are vital for scientific understanding. If reality can be simulated accurately with a fully comprehensive model, the essential ingredients needed to explain a particular climatic phenomenon can be discovered by removing inessential ingredients one

Palmer, T.N. Stochastic weather and climate models. *Nat Rev Phys* **1,** 463–471 (2019) doi:10.1038/s42254-019-0062-2

Conclusions

- Stochastic parametrization respects the scaling symmetries of the laws of motion better than deterministic parametrization
- Stochastic parametrization shows improvements in extreme rainfall prediction, not only for individual events, but also in relation to persistent events.
- Stochastic parametrization provides a benchmark for reducing numerical precision (a major bottleneck for improving computational efficiency

India is an advanced hi-tech country.


Forbes | Billionaires | Innovation

65,427 views | Apr 9, 2017, 09:30am

India's Tech Revolution Has Already Left The West Behind -- It's The Best Investment Opportunity Now

John Mauldin Senior Contributor
Markets
President of Mauldin Economics

This article is more than 2 years old.

Interns work at start-up company Hacklab.in in Bangalore. AFP / Manjunath KIRAN/Getty Images

India is an advanced hi-tech country.

- To make further advances in predicting precipitation extremes require us to resolve deep convective systems in global weather/climate models and abandon attempts to parametrize them.

- India could now be leapfrogging over ECWMF, NCEP etc by building the first global 1km ensemble forecast system for medium-range and intraseasonal prediction.

- Such models should be stochastic, with mixed precision numerics (single or half where possible) and with computationally cheap AI-based parametrisations.

- All run on dedicated Exascale hardware.