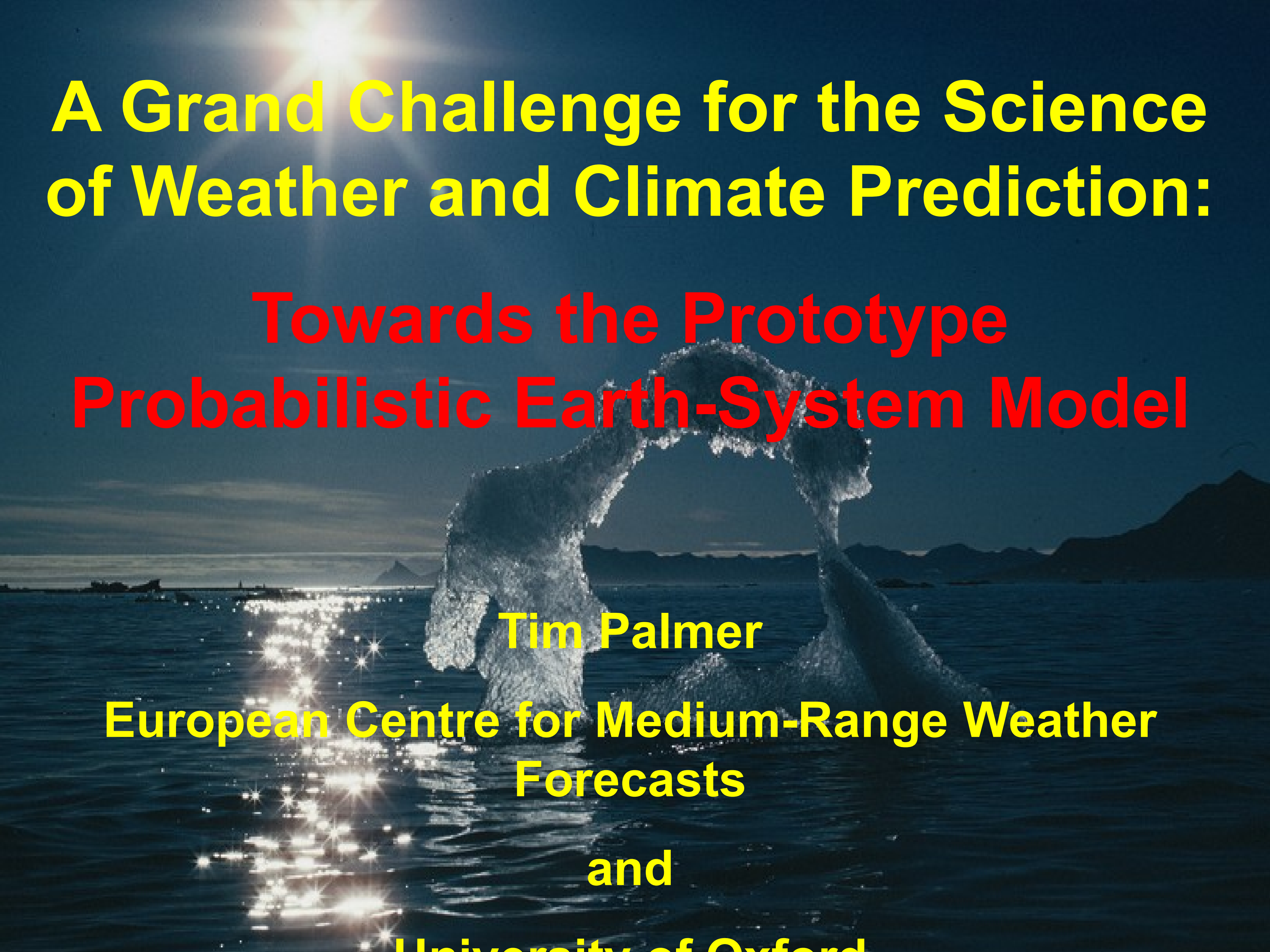


A Grand Challenge for the Science of Weather and Climate Prediction:

Towards the Prototype Probabilistic Earth-System Model

Tim Palmer

European Centre for Medium-Range Weather Forecasts

and

University of Oxford

There are essentially two types of climate model

1. Idealised models eg

$$\boxed{\pi(1-A)F_{\text{sun}} = 4\pi\sigma T_{\text{earth}}^4}$$

..or (idealised barotropic vorticity equation)

$$\frac{\partial}{\partial t}\nabla^2\psi + J\left(\psi, \nabla^2\psi + f\right) + \gamma J\left(\psi, h\right) + C\nabla^2(\psi - \psi^*) = 0$$

advection

orography

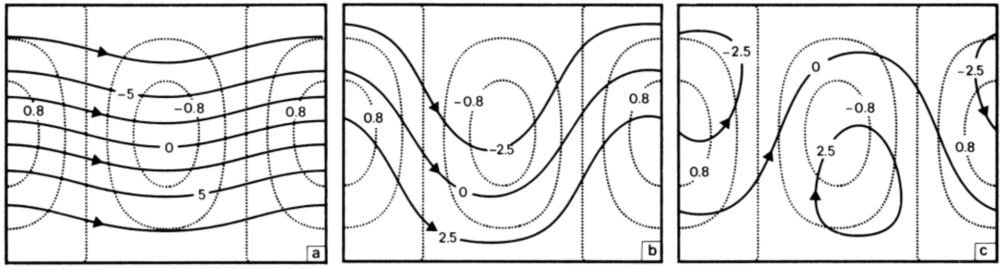
“equator-pole
temperature gradient”

$$\gamma x_3 - C(x_1 - x_1^*)$$

$$-\beta) x_3 \qquad - Cx_2$$

$$-\beta) x_2 \quad -\gamma x_1 \quad - Cx_3$$

Charney DeVore,
1979



Westerly/block flow regimes as multiple equlibria

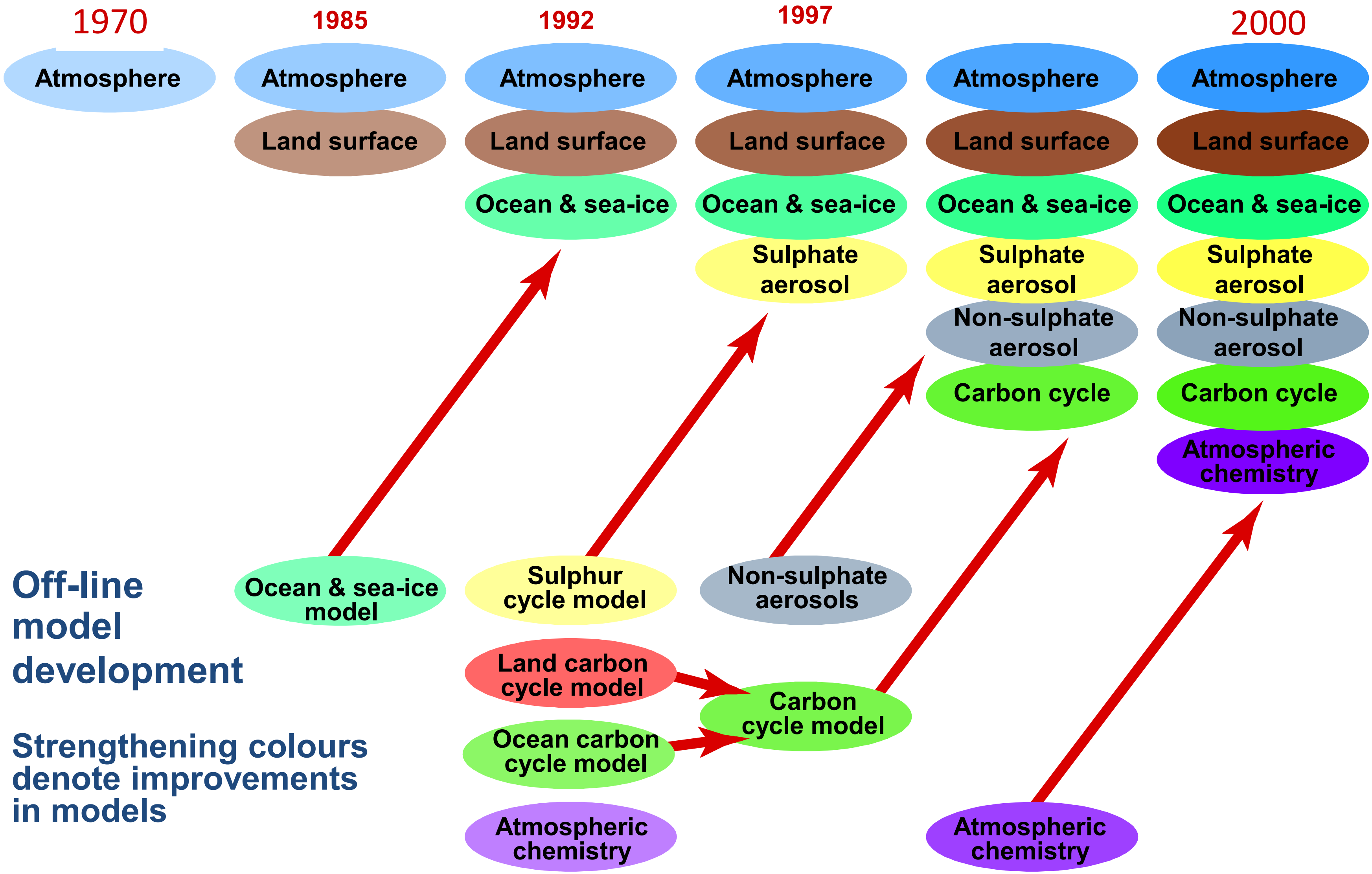
2. “*Ab initio*”[1] climate models eg based on

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

where the weather systems which characterise climate, are modelled explicitly from first principles.

[1] “Ab initio” models are sometimes, more pejoratively, referred to as “Brute force” models

Towards the Comprehensive Climate Model



1970
Atmosphere

1985
Atmosphere
Land surface

1992
Atmosphere
Land surface
Ocean & sea-ice

1997
Atmosphere
Land surface
Ocean & sea-ice
Sulphate aerosol

Atmosphere
Land surface
Ocean & sea-ice
Sulphate aerosol
Non-sulphate aerosol
Carbon cycle

2000
Atmosphere
Land surface
Ocean & sea-ice
Sulphate aerosol
Non-sulphate aerosol
Carbon cycle
Atmospheric chemistry

Off-line model development

Ocean & sea-ice model

Sulphur cycle model
Land carbon cycle model
Ocean carbon cycle model
Atmospheric chemistry

Non-sulphate aerosols
Carbon cycle model

Atmospheric chemistry

Strengthening colours denote improvements in models

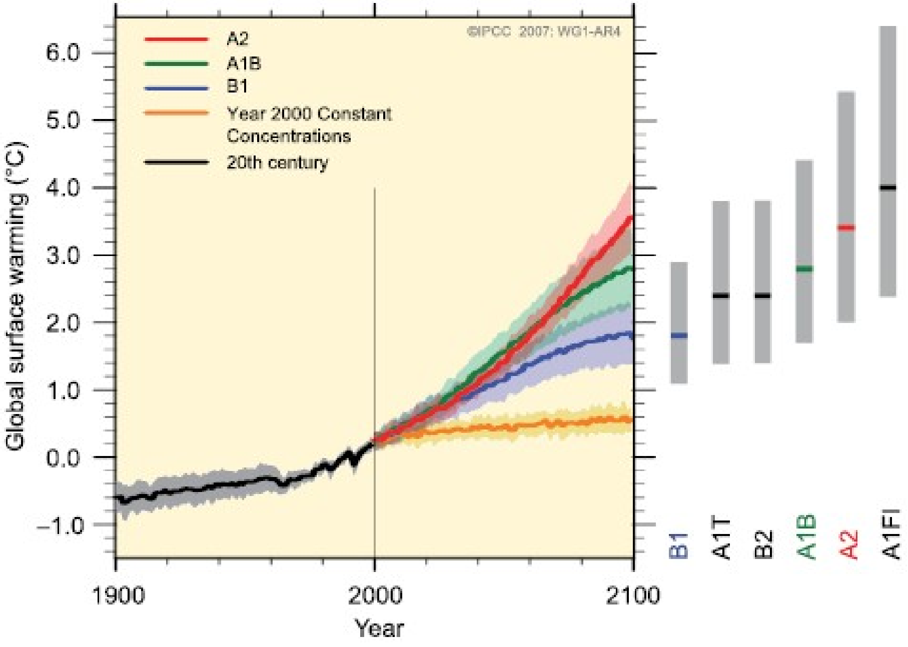
The Met.Office Hadley Centre

"*Ab initio*" models are important if we are to have confidence in predictions of global warming. Eg

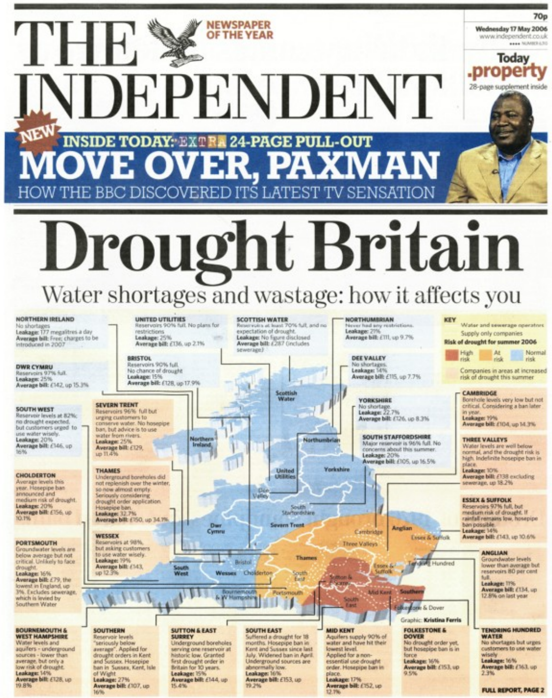
$$\boxed{\pi(1-A)F_{\text{sun}} = 4\pi\sigma T_{\text{earth}}^{4}}$$

Albedo depends on cloud cover, ice cover etc. Cannot be specified a priori, but depends on dynamics

IPCC AR4



Ab initio models are also needed, eg to guide adaptation strategies…



THE INDEPENDENT

NEWSPAPER OF THE YEAR

70p
Wednesday 17 May 2006
www.independent.co.uk

Today
.property
28-page supplement inside

NEW

INSIDE TODAY: EXTRA 24-PAGE PULL-OUT

MOVE OVER, PAXMAN

HOW THE BBC DISCOVERED ITS LATEST TV SENSATION

Drought Britain

Water shortages and wastage: how it affects you

NORTHERN IRELAND
No shortages
Leakage: 177 megalitres a day
Average bill: Free; charges to be introduced in 2007

DWR CYMRU
Reservoirs 97% full.
Leakage: 25%
Average bill: £142, up 15.3%

SOUTH WEST
Reservoir levels at 82%; no drought expected, but customers urged to use water wisely.
Leakage: 20%
Average bill: £146, up 16%

CHOLDERTON
Average levels this year. Hosepipe ban announced and medium risk of drought.
Leakage: 20%
Average bill: £156, up 10.1%

PORTSMOUTH
Groundwater levels are below average but not critical. Unlikely to face drought.
Leakage: 16%
Average bill: £79, the lowest in England, up 3%. Excludes sewerage, which is levied by Southern Water

UNITED UTILITIES
Reservoirs 90% full. No plans for restrictions
Leakage: 25%
Average bill: £136, up 2.1%

BRISTOL
Reservoirs 90% full.
No chance of drought
Leakage: 15%
Average bill: £128, up 17.9%

SEVERN TRENT
Reservoirs 96% full but urging customers to conserve water. No hosepipe ban, but advice is to use water from rivers.
Leakage: 25%
Average bill: £129, up 11.4%

THAMES
Underground boreholes did not replenish over the winter, so now almost empty. Seriously considering drought order application. Hosepipe ban.
Leakage: 32.7%
Average bill: £150, up 34.1%

WESSEX
Reservoirs at 98%, but asking customers to use water wisely.
Leakage: 19%
Average bill: £143, up 12.3%

SCOTTISH WATER
Reservoirs at least 70% full, and no expectation of drought.
Leakage: No figure disclosed
Average bill: £287 (includes sewerage)

NORTHUMBRIAN
Never had any restrictions.
Leakage: 21%
Average bill: £111, up 9.7%

DEE VALLEY
No shortages.
Leakage: 14%
Average bill: £115, up 7.7%

YORKSHIRE
No shortage.
Leakage: 22.7%
Average bill: £126, up 8.3%

SOUTH STAFFORDSHIRE
Major reservoir is 96% full. No concerns about this summer.
Leakage: 20%
Average bill: £105, up 16.5%

KEY
Water and sewerage operators
Supply only companies
Risk of drought for summer 2006
🟥 High risk 🟧 At risk 🟦 Normal risk
Companies in areas at increased risk of drought this summer

CAMBRIDGE
Borehole levels very low but not critical. Considering a ban later in year.
Leakage: 19%
Average bill: £104, up 14.3%

THREE VALLEYS
Water levels are well below normal, and the drought risk is high. Indefinite hosepipe ban in place.
Leakage: 10%
Average bill: £138 excluding sewerage, up 18.2%

ESSEX & SUFFOLK
Reservoirs 97% full, but medium risk of drought. If rainfall remains low, hosepipe ban possible.
Leakage: 14%
Average bill: £143, up 10.6%

ANGLIAN
Groundwater levels lower than average but reservoirs 80 per cent full.
Leakage: 11%
Average bill: £134, up 12.8% on last year

Graphic: **Kristina Ferris**

BOURNEMOUTH & WEST HAMPSHIRE
Water levels and aquifers – underground sources – lower than average, but only a low risk of drought.
Leakage: 14%
Average bill: £128, up 19.8%

SOUTHERN
Reservoir levels "seriously below average". Applied for drought orders in Kent and Sussex. Hosepipe ban in Sussex, Kent, Isle of Wight
Leakage: 27%
Average bill: £107, up 16%

SUTTON & EAST SURREY
Underground boreholes serving one reservoir at historic low. Granted first drought order in Britain for 10 years.
Leakage: 15%
Average bill: £144, up 15.4%

SOUTH EAST
Suffered a drought for 18 months. Hosepipe ban in Kent and Sussex since last July. Widened ban in April. Underground sources are abnormally low.
Leakage: 16%
Average bill: £153, up 19.2%

MID KENT
Aquifers supply 90% of water and have hit their lowest level. Applied for a non-essential use drought order. Hosepipe ban in place.
Leakage: 17%
Average bill: £152, up 12.1%

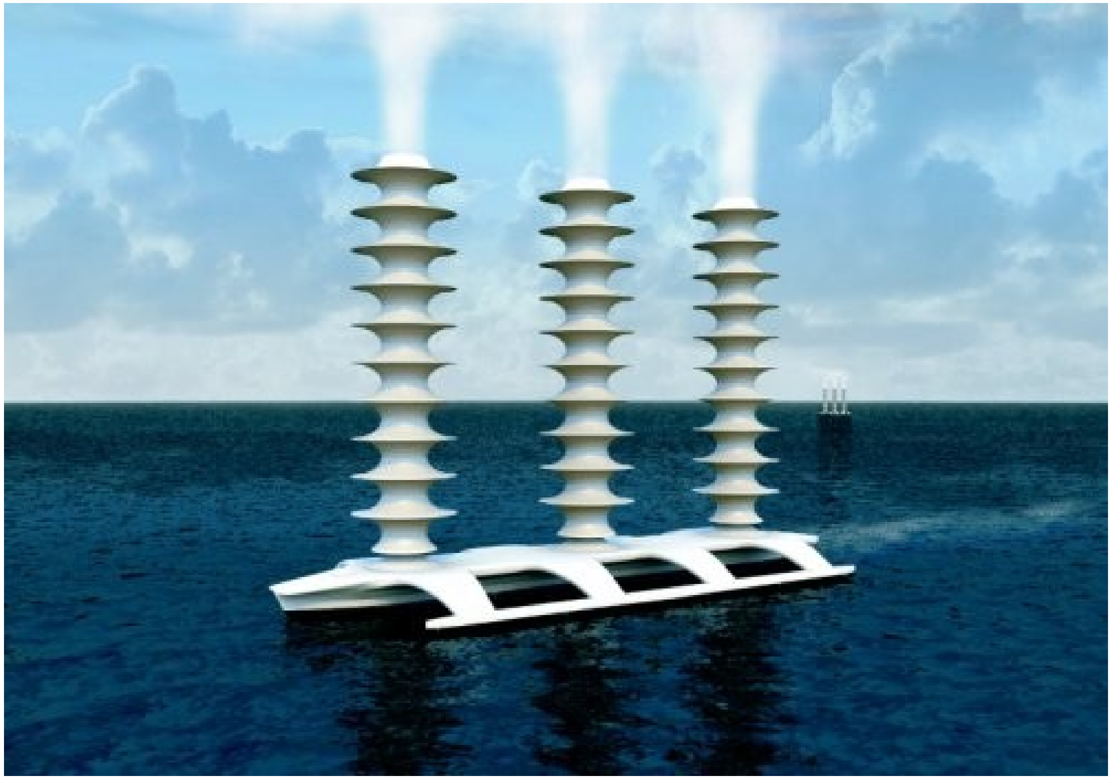
FOLKESTONE & DOVER
No drought order yet, but hosepipe ban is in force
Leakage: 16%
Average bill: £153, up 9.5%

TENDRING HUNDRED WATER
No shortages but urges customers to use water wisely
Leakage: 16%
Average bill: £163, up 2.3%

FULL REPORT, PAGE 2

Will blocking become more prevalent under climate change…more reservoirs, national water grid etc…..??

…and, increasingly, to assess regional impacts of climate geoengineering proposals



Permanent El Nino, shutoff in monsoons…..????

Frequently-heard paradigm (20th Century vintage):

- Mathematicians (the academic community more generally) develop the idealised, mathematically tractable, models for improved understanding

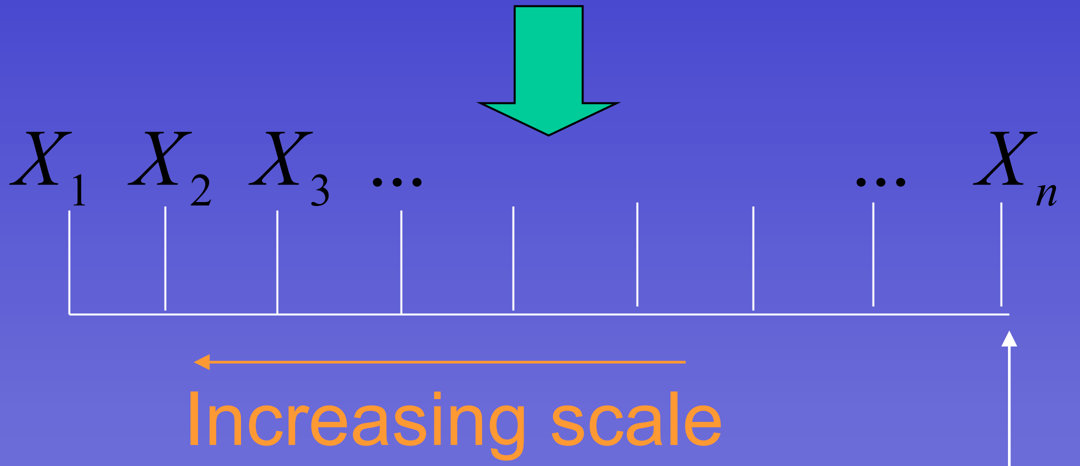
- "Software engineers in meteorological institutes develop the brute force models for quantitative predictions"

I think this paradigm is outdated. In this lecture I wish to promote a new paradigm for the 21st Century

Standard ansatz for “*ab initio*” weather/climate models

Eg

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



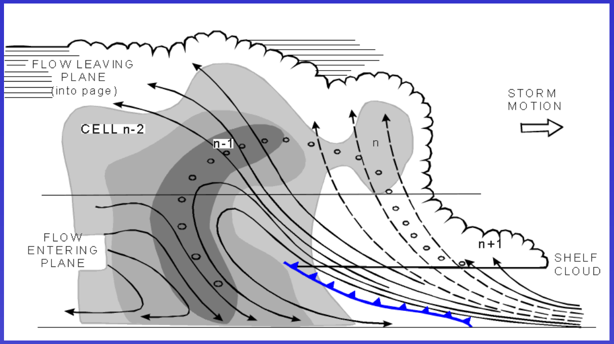
Increasing scale

Eg momentum“transport” by:

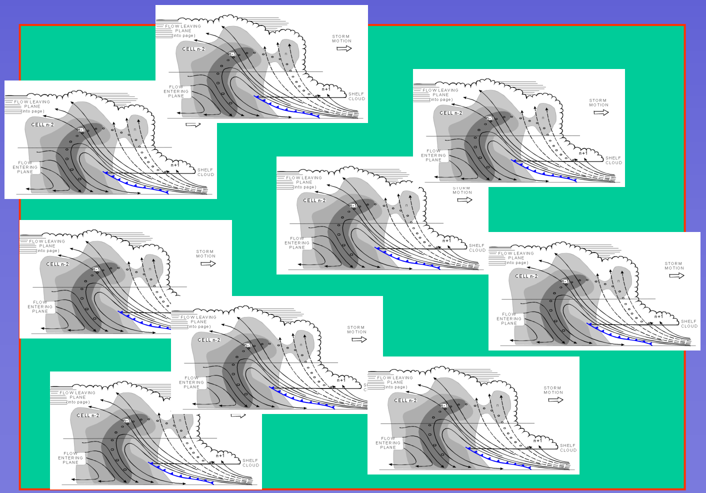
- Turbulent eddies in boundary layer
- Orographic gravity wave drag.
- Convective clouds

Deterministic local bulk-formula parametrisation

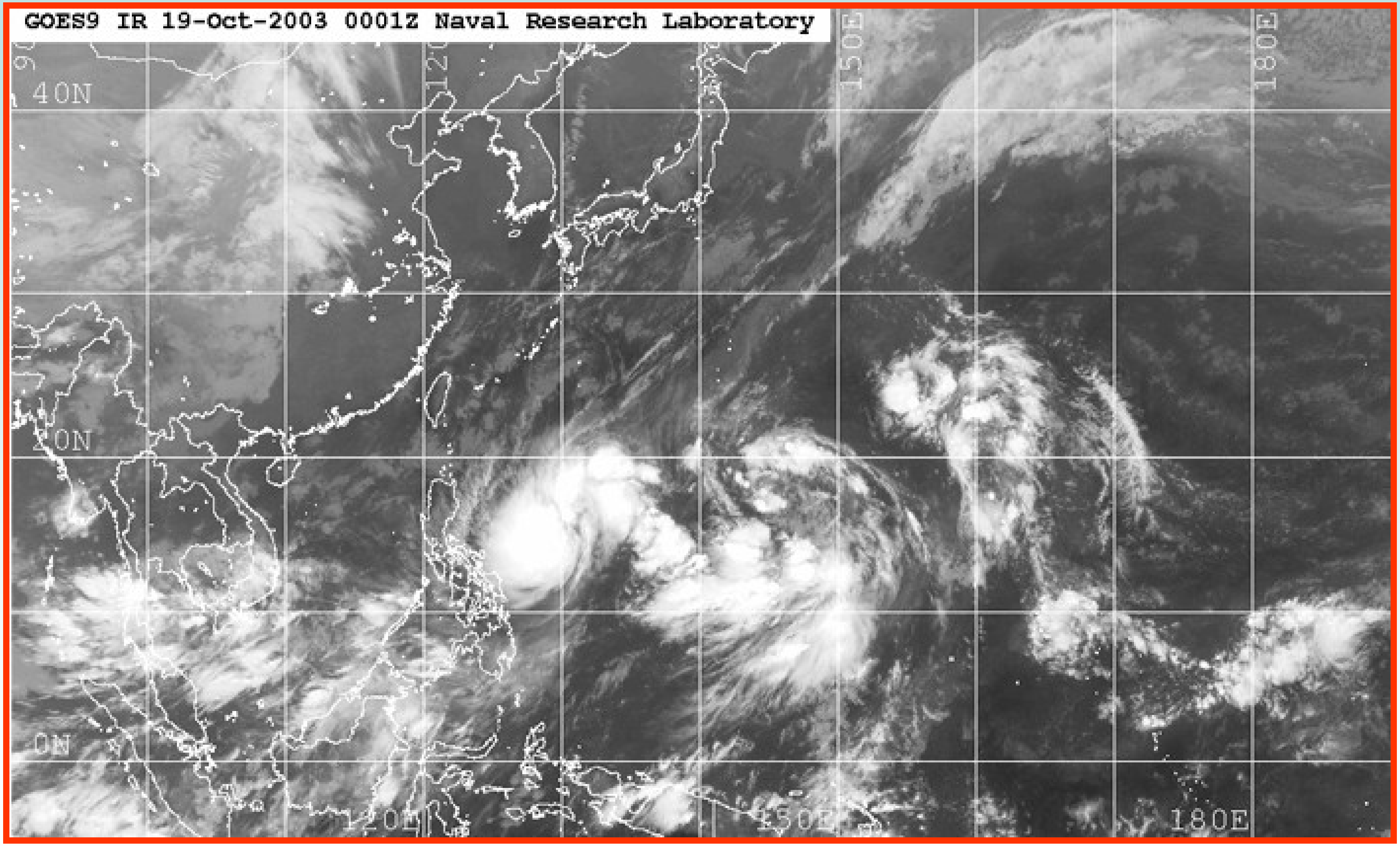
$$P\left(X_n;\alpha\right)$$



Standard bulk-formula parametrisation assumes the existence of a large ensemble of eg convective cloud systems within a grid box, in quasi-equlilibrium with the large-scale flow.

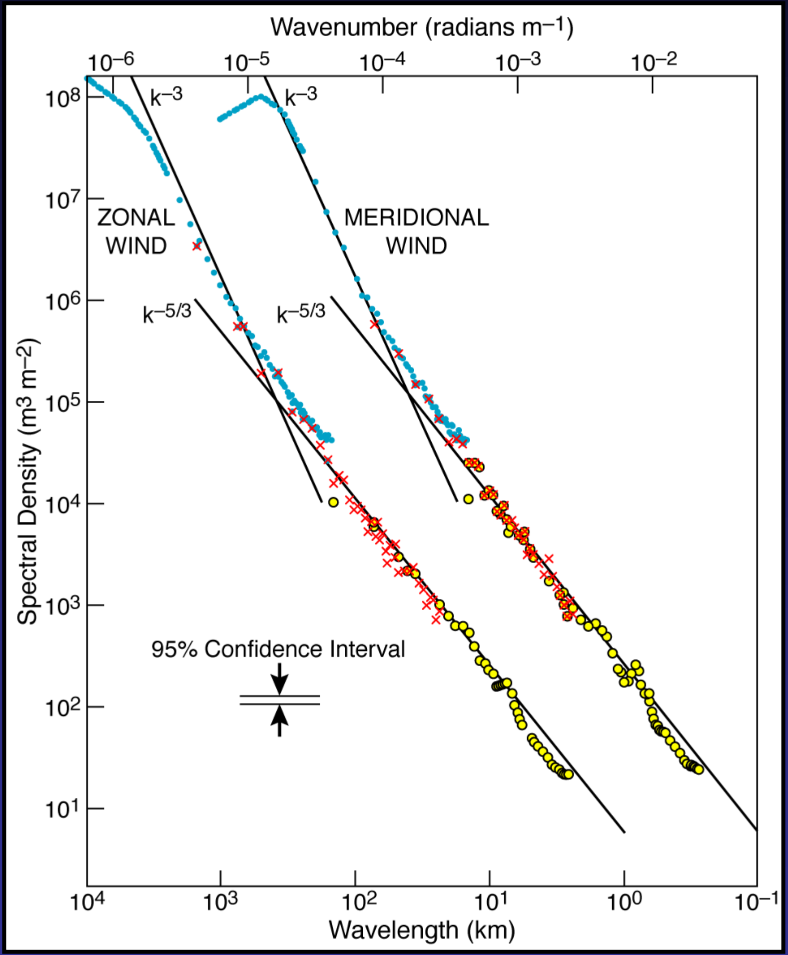


Similar considerations for other parametrised processes, eg orographic gravity wave drag


GOES9 IR 19-Oct-2003 0001Z Naval Research Laboratory
40N
20N
0N
120E
150E
180E

Parametrisations motivated by statistical mechanics (eg molecular diffusion), but…

Wavenumber spectra of zonal and meridional velocity composited from three groups of flight segments of different lengths. The three types of symbols show results from each group. The straight lines indicate slopes of –3 and –5/3. The meridional wind spectra are shifted one decade to the right. (after *Nastrom et al,* 1984).

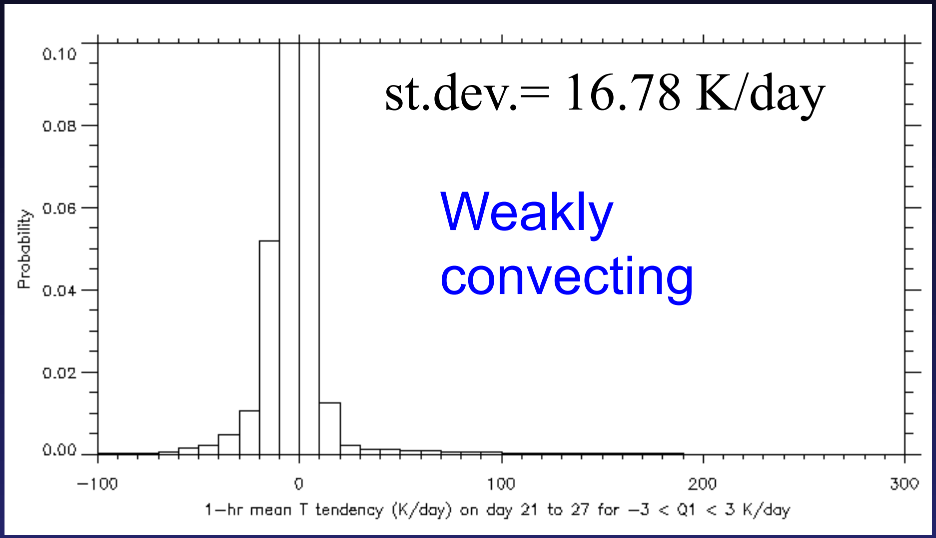


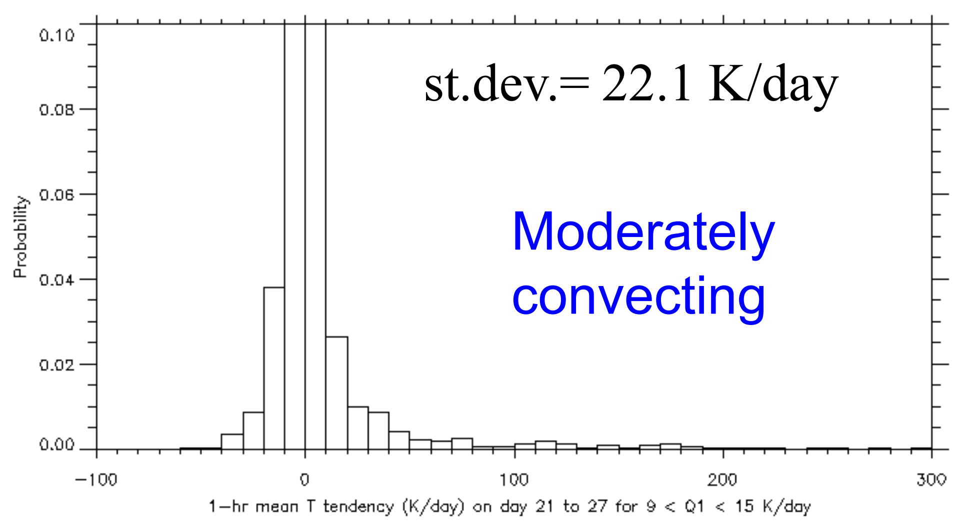
…there is no scale separation between resolved and unresolved scales at NWP truncations (eg convection, orography)

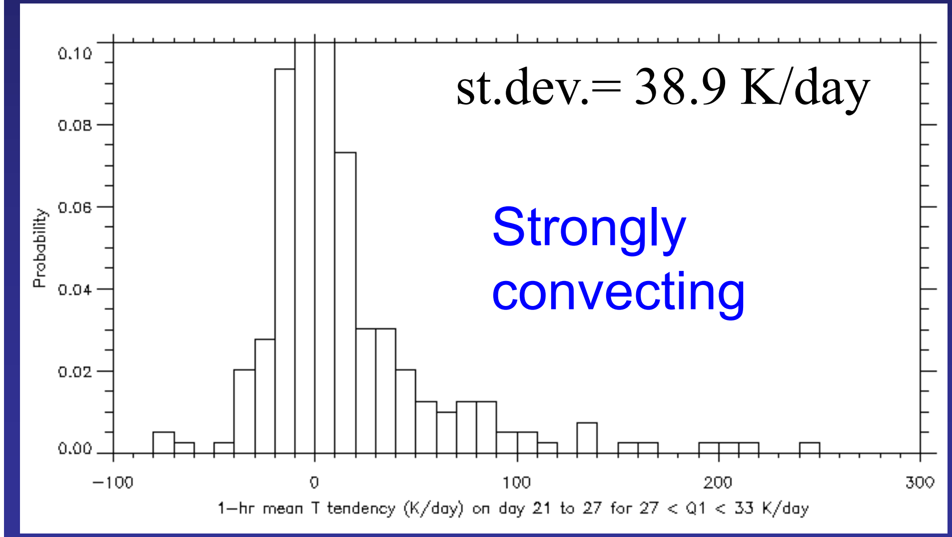
- Calculate exact PDF of sub-grid temperature tendencies in a coarse-grained (**~50km**) grid box based on output from a cloud-resolving (**~1km**) model treated as “truth”.

- PDFs are constrained such that parametrised tendencies based on coarse-grain input fields lie within boxes of width **6K/day**.

Shutts and Palmer, J.Clim, 1987







Width of pdf ∝ parametrised tendency

From Schertzer and Lovejoy, 1993

Definitions of Parametrisation

Traditional definition (Jacob 2010):

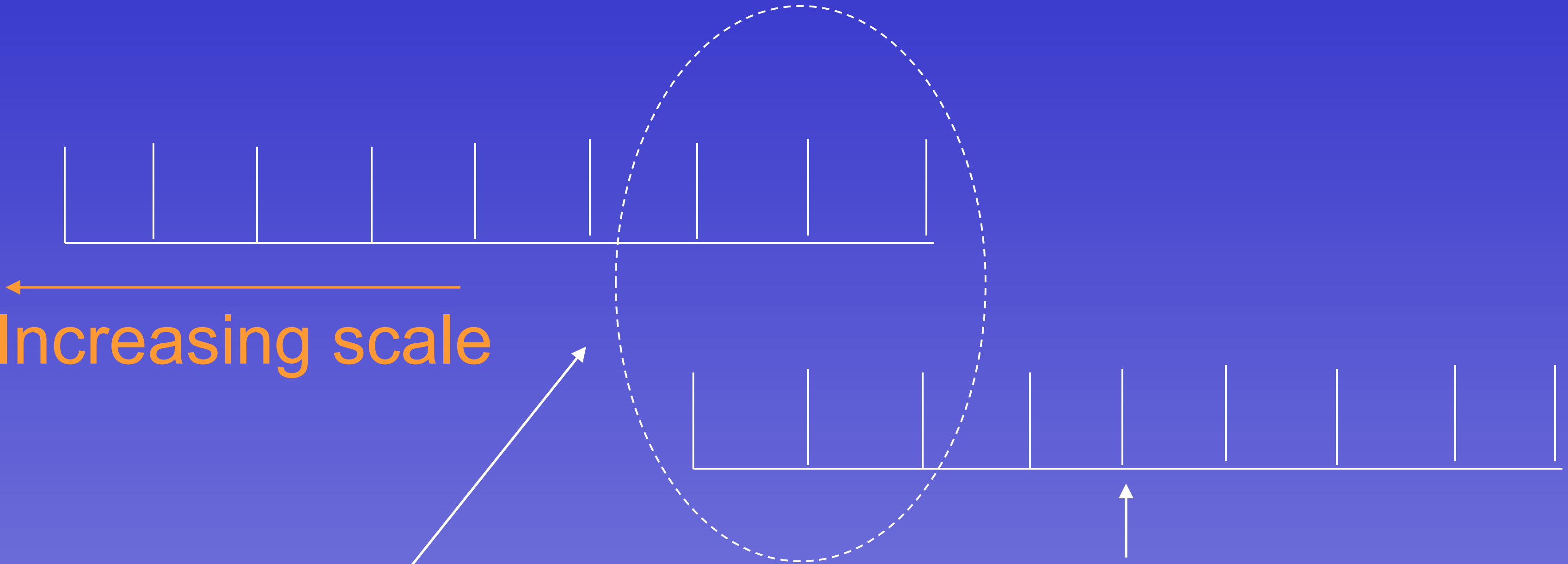
"Despite ..computational advances..many of the processes occurring in the atmosphere..remain unresolved. It is therefore necessary to represent those subgrid-scale processes **as a function**[*] of the grid-scale variables. The technique to achieve this…is ..referred to as parametrization. "

[*] Wikipedia: The mathematical concept of a function expresses the idea that one quantity (the argument of the function) completely determines another quantity (the value of the function).

Consider replacing with

…..It is therefore necessary to consider how grid-scale variables might constrain some prior probability distribution of sub-grid processes. The technique to achieve this is referred to as stochastic parametrization.

A stochastic-dynamic paradigm for a Probabilistic Earth-System Model



Potentially Coupled over a range of scales

(Palmer, 1997; 2001)

Computationally-cheap nonlinear <u>stochastic</u>-dynamic models (potentially on a secondary grid) providing specific realisations of sub-grid motions rather than sub-grid bulk effects.

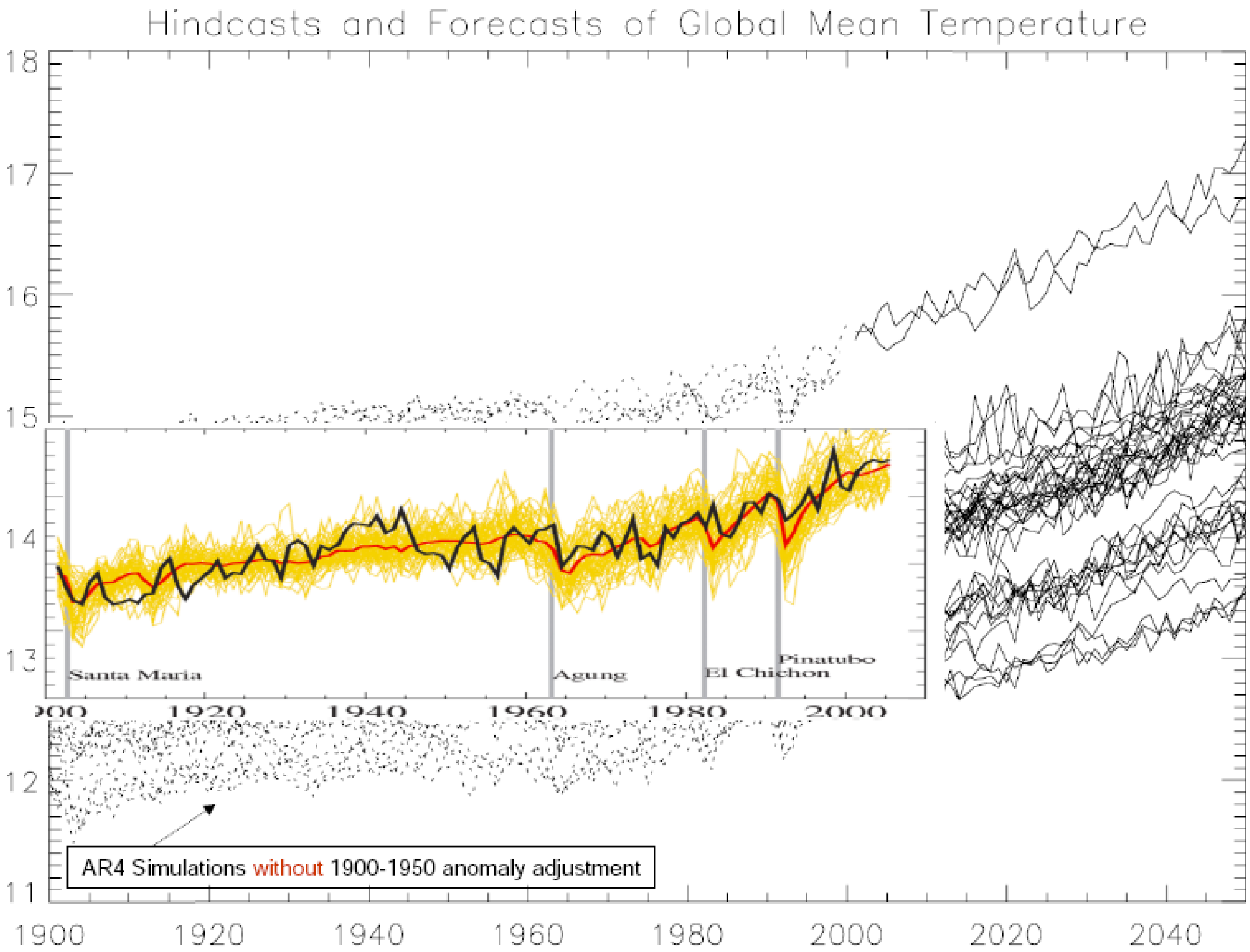
Examples :

- Multiplicative Noise (Stochastically Perturbed Parametriatsion Tendencies; SPPT - Buizza et al, 1999)
- Stochastic Backscatter (Stochastic Spectral Backscatter Scheme; SPBS, Shutts, 2005, Berner et al 2010)
- Cellular Automata (Palmer 1997, Berner et al 2010)
- Stochastic lattice models (Majda et al, 2010)
- Dual grid, stochastic mode reduction (Majda et al, 2010: Allen et al, 2010)
- Statistical mechanics of finite sized cloud ensembles (Plant and Craig 2008)
- (Perturbed Parameters; Stainforth et al, Smith et al)
- (Superparametrisation; Randall et al, 2003)

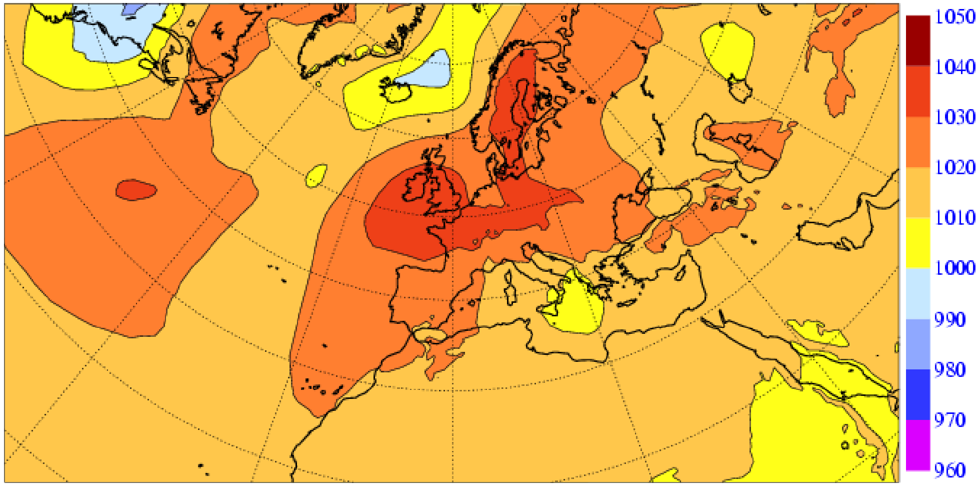
Five motivational reasons for stochastic parametrisation

1. As a new approach to reducing model biases

Lenny Smith, personal communication

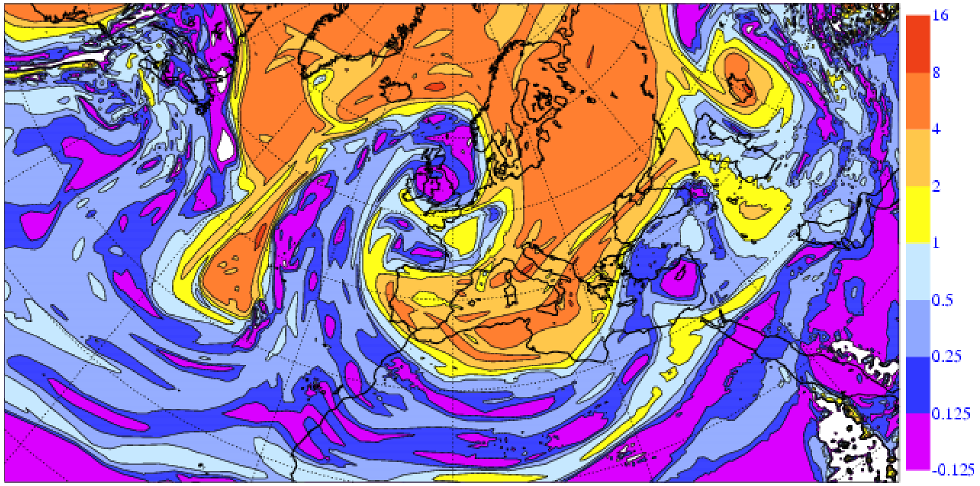


Surface Pressure



Persistent Blocking Anticyclone

Potential Vorticity on 315K

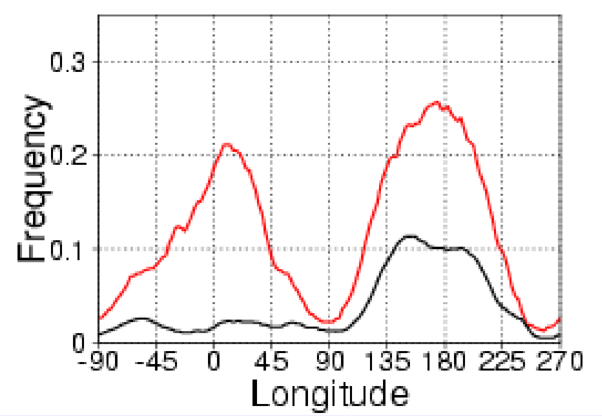


Blocking frequency in DEMETER hindcasts

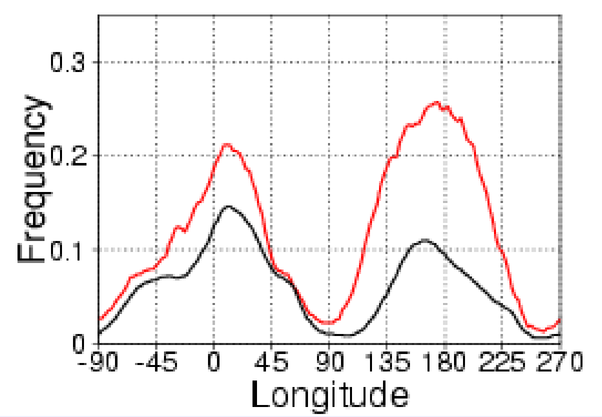
November start, 1959-2001, 9-member ensembles

January (third month)

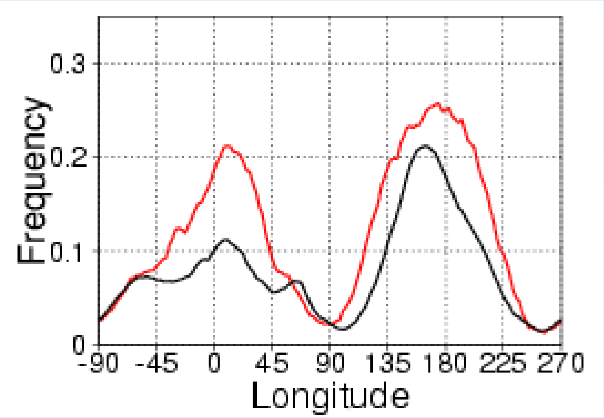
ERA40 **Single models**



CNRM



ECMWF



Met Office

From
UKCP09

UK CLIMATE PROJECTIONS

“The mechanisms for atmospheric blocking are only partially understood, but it is clear that there are complex motions, involving meso-scale atmospheric turbulence, and interactions that climate-resolution models may not be able to represent fully.”

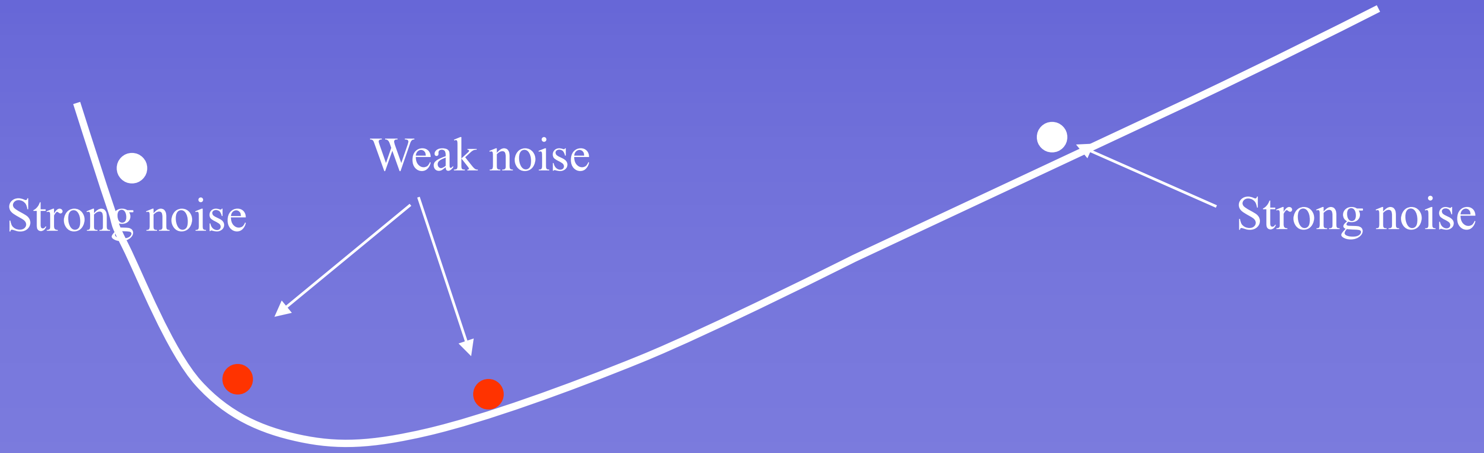
“In developing the UKCP09 projections it was decided not to include probabilistic projections for future wind due to the high level of associated uncertainty.”

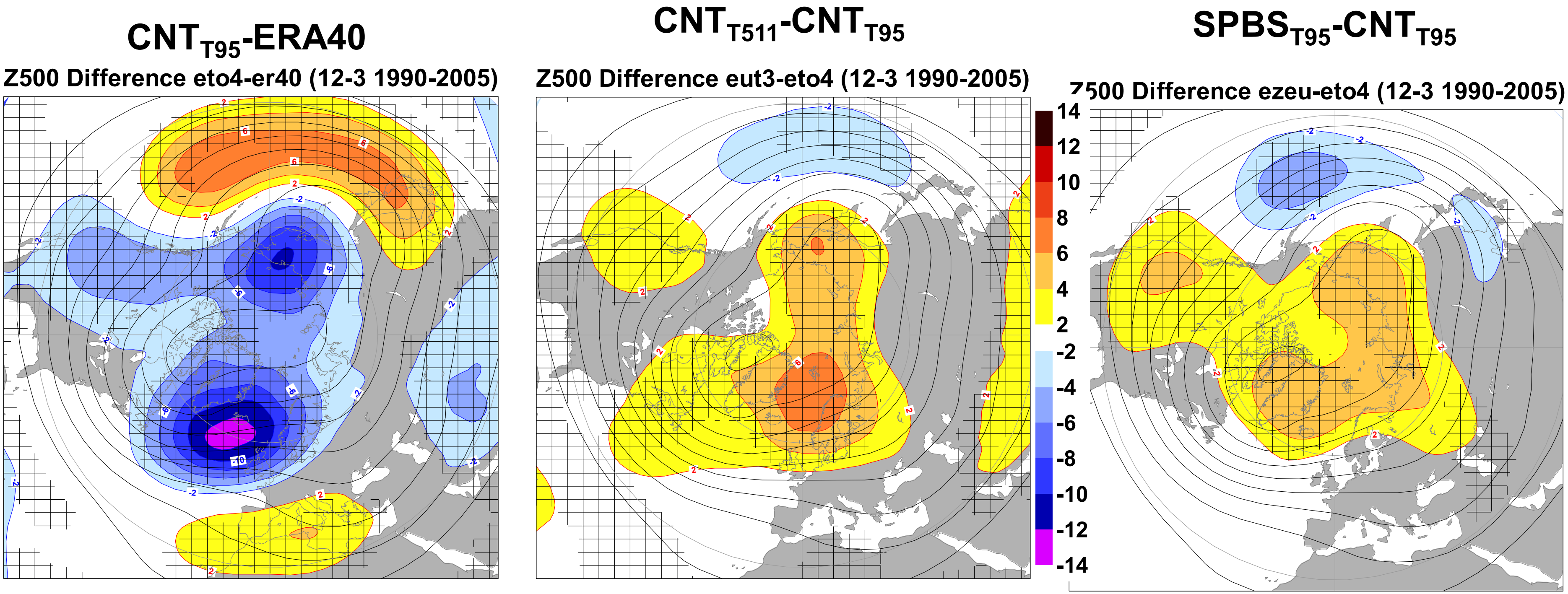
Will future UK offshore winds be strong enough to provide projected energy needs from renewables?

We don’t know!

Stochastic parametrisation has potential to alter the mean state of the (nonlinear) model.

Eg ball bearing in potential well.





CNT_{T95}-ERA40

Z500 Difference eto4-er40 (12-3 1990-2005)

CNT_{T511}-CNT_{T95}

Z500 Difference eut3-eto4 (12-3 1990-2005)

$SPBS_{T95}$-CNT_{T95}

Z500 Difference ezeu-eto4 (12-3 1990-2005)

T95

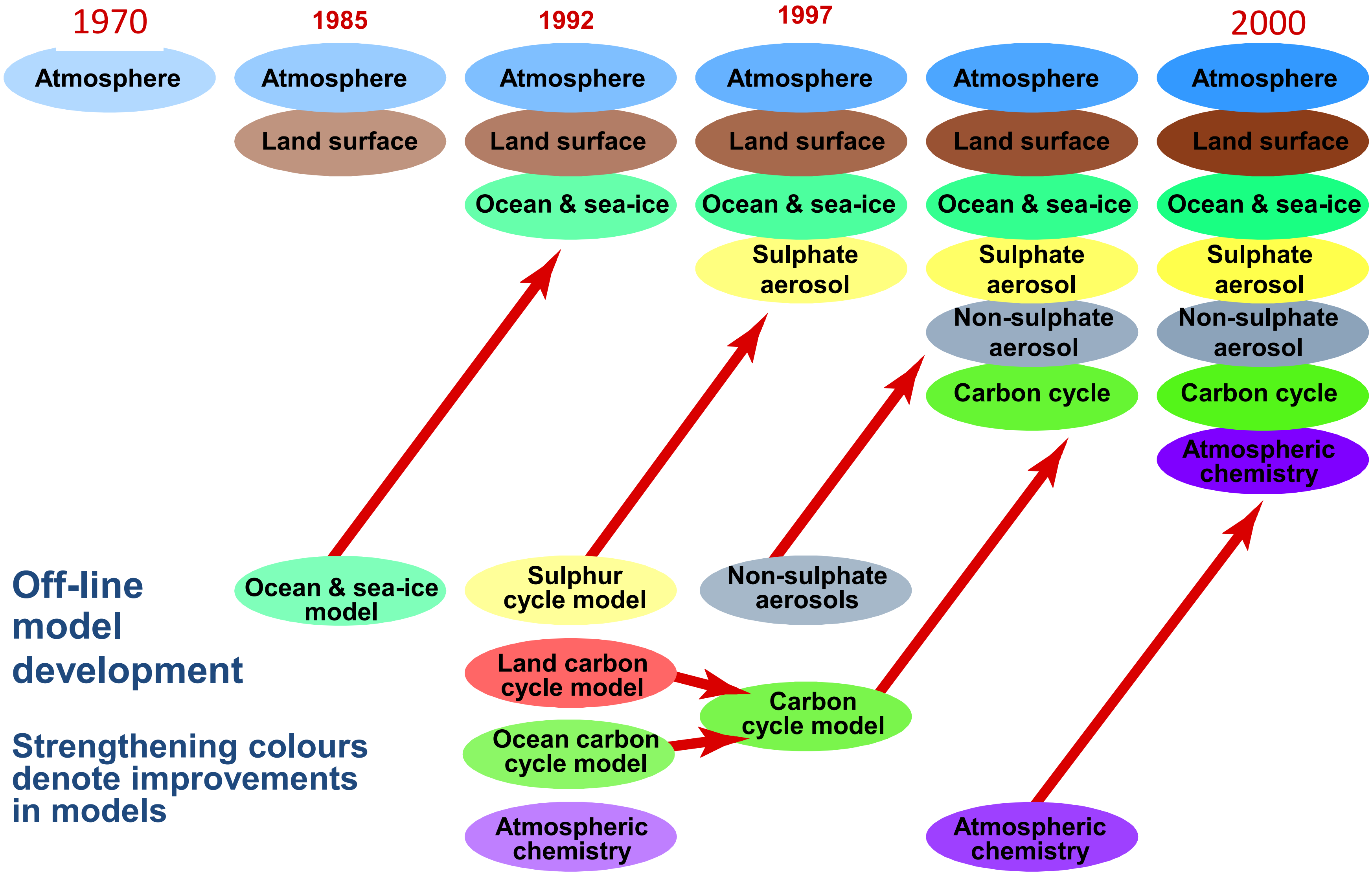
T511

T95+Stochastic parametrisation

- Experiments with model cycle 31R1
- Experiments with Berner et al (JAS 2009) stochastic backscatter scheme
- Winters (Dec-Mar) of the period 1990-2005

2. As a new approach to representing model uncertainty in ensemble forecasting

Towards Comprehensive Earth System Models



1970

Atmosphere

1985

Atmosphere

Land surface

1992

Atmosphere

Land surface

Ocean & sea-ice

1997

Atmosphere

Land surface

Ocean & sea-ice

Sulphate aerosol

Atmosphere

Land surface

Ocean & sea-ice

Sulphate aerosol

Non-sulphate aerosol

Carbon cycle

2000

Atmosphere

Land surface

Ocean & sea-ice

Sulphate aerosol

Non-sulphate aerosol

Carbon cycle

Atmospheric chemistry

Off-line model development

Ocean & sea-ice model

Sulphur cycle model

Non-sulphate aerosols

Land carbon cycle model

Ocean carbon cycle model

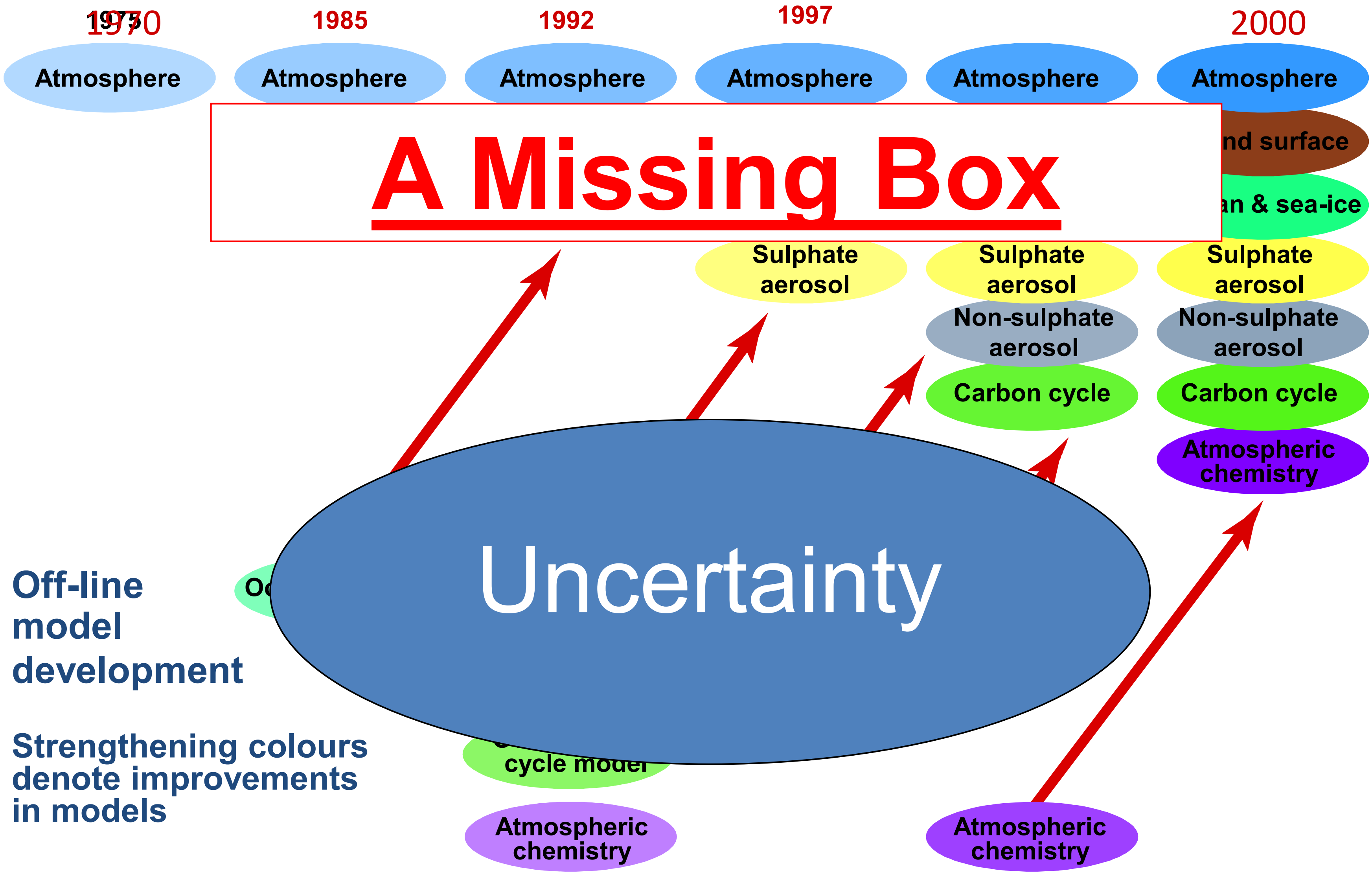
Carbon cycle model

Atmospheric chemistry

Atmospheric chemistry

Strengthening colours denote improvements in models

The Met.Office Hadley Centre



1970 1975

1985

1992

1997

2000

Atmosphere

Atmosphere

Atmosphere

Atmosphere

Atmosphere

Atmosphere

A Missing Box

nd surface

an & sea-ice

Sulphate aerosol

Sulphate aerosol

Sulphate aerosol

Non-sulphate aerosol

Non-sulphate aerosol

Carbon cycle

Carbon cycle

Atmospheric chemistry

Uncertainty

Oc

cycle model

Atmospheric chemistry

Atmospheric chemistry

Off-line model development

Strengthening colours denote improvements in models

The Met.Office Hadley Centre

Met Office

IFM-GEOMAR
Leibniz-Institut für Meereswissenschaften
an der Universität Kiel

Centro Euro-Mediterraneo
per i Cambiamenti Climatici

METEO
FRANCE

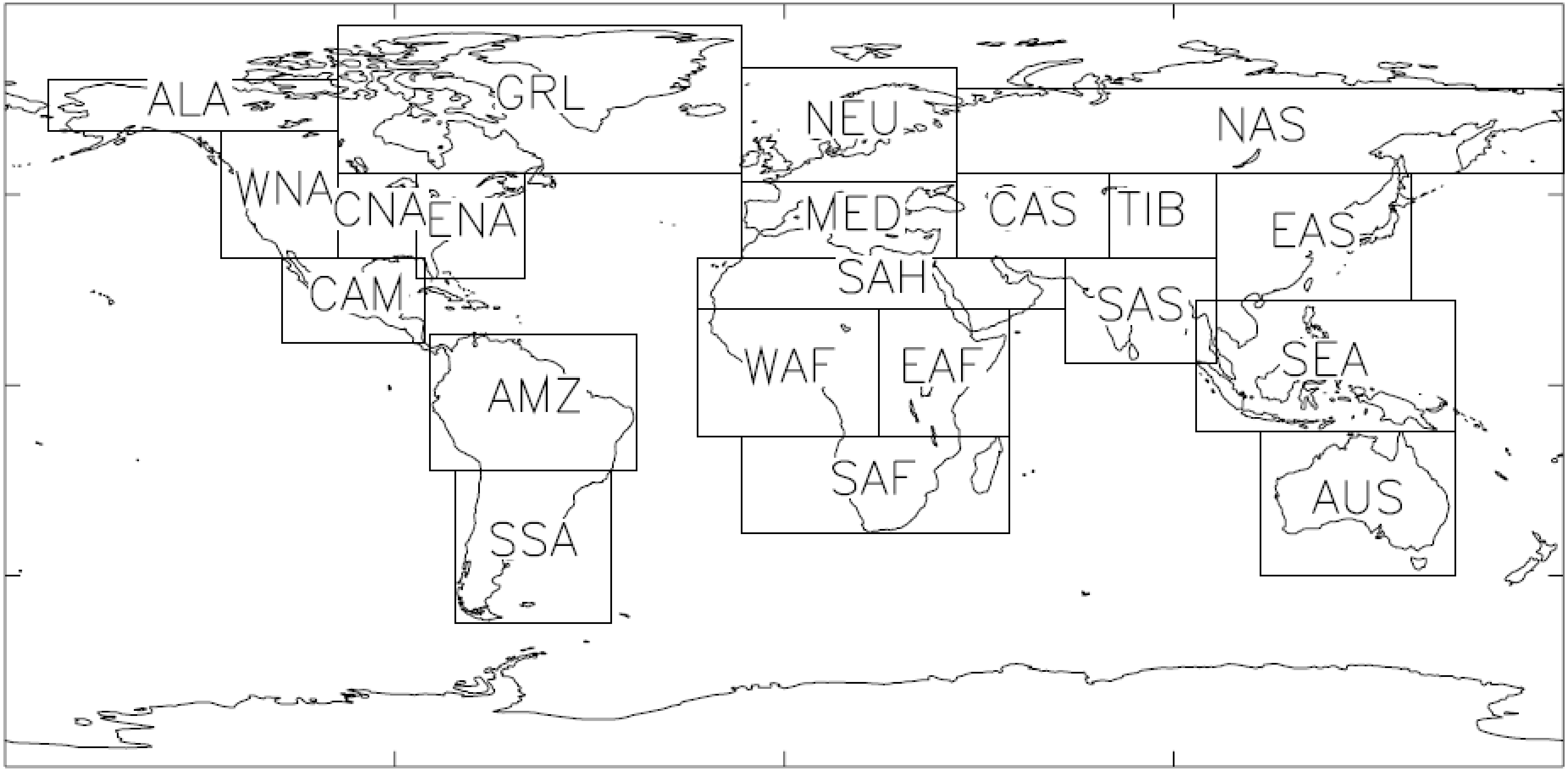
Multi-model ensemble

ENSEMBLES

In ENSEMBLES the relative ability of these different representations of uncertainty has been tested:

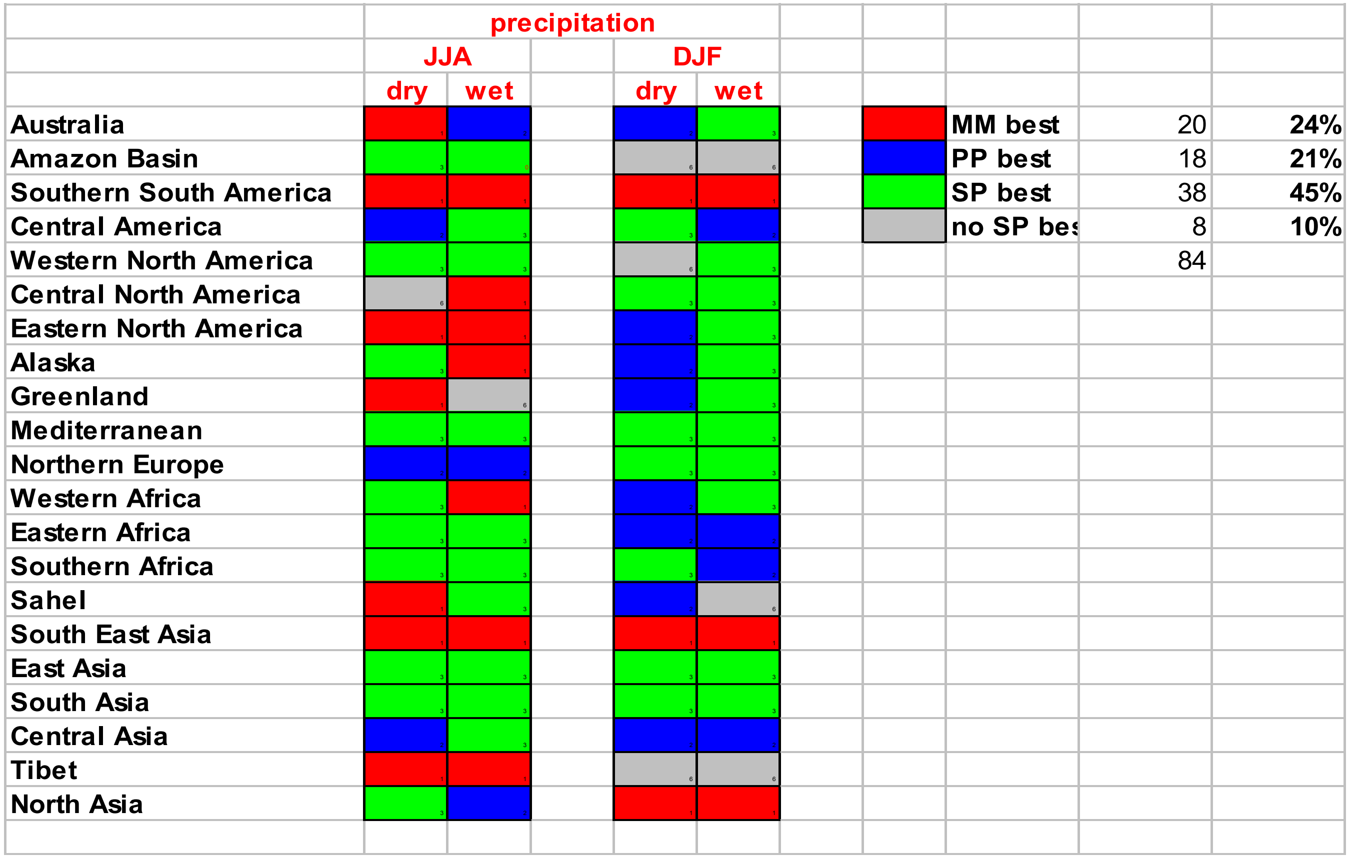
Multi-model ensembles
Perturbed parameters
Stochastic parametrisation (SPPT+SPBS)

by making probabilistic seasonal climate predictions.



“Giorgi” Regions

Comparison of the BSS(∞) for precipitation over land regions: ENSEMBLES multi-model ensemble (MM), perturbed parameter ensemble (PP), ECMWF stochastic physics ensemble (SP) and ECMWF control ensemble (noSP)



	precipitation									
	JJA			DJF						
	dry	wet		dry	wet					
Australia	🟥 1	🟦 2		🟦 2	🟩 3		🟥	MM best	20	24%
Amazon Basin	🟩 3	🟩 0		⬜ 6	⬜ 6		🟦	PP best	18	21%
Southern South America	🟥 1	🟥 1		🟥 1	🟥 1		🟩	SP best	38	45%
Central America	🟦 2	🟩 3		🟩 3	🟦 2		⬜	no SP bes	8	10%
Western North America	🟩 3	🟩 3		⬜ 6	🟩 3				84	
Central North America	⬜ 6	🟥 1		🟩 3	🟩 3					
Eastern North America	🟥 1	🟥 1		🟦 2	🟩 3					
Alaska	🟩 3	🟥 1		🟦 2	🟩 3					
Greenland	🟥 1	⬜ 6		🟦 2	🟩 3					
Mediterranean	🟩 3	🟩 3		🟩 3	🟩 3					
Northern Europe	🟦 2	🟦 2		🟩 3	🟩 3					
Western Africa	🟩 3	🟥 1		🟦 2	🟩 3					
Eastern Africa	🟩 3	🟩 3		🟦 2	🟦 2					
Southern Africa	🟩 3	🟩 3		🟩 3	🟦 2					
Sahel	🟥 1	🟩 3		🟦 2	⬜ 6					
South East Asia	🟥 1	🟥 1		🟥 1	🟥 1					
East Asia	🟩 3	🟩 3		🟩 3	🟩 3					
South Asia	🟩 3	🟩 3		🟩 3	🟩 3					
Central Asia	🟦 2	🟩 3		🟦 2	🟦 2					
Tibet	🟥 1	🟥 1		⬜ 6	⬜ 6					
North Asia	🟩 3	🟦 2		🟥 1	🟥 1					

lead time: 2-4 months, hindcast period: 1991-2005
SP version 1055m007

A Weisheimer, Work in progress

Comparison of the BSS(∞) for temperature over land regions: ENSEMBLES multi-model ensemble (MM), perturbed parameter ensemble (PP), ECMWF stochastic physics ensemble (SP) and ECMWF control ensemble (noSP)

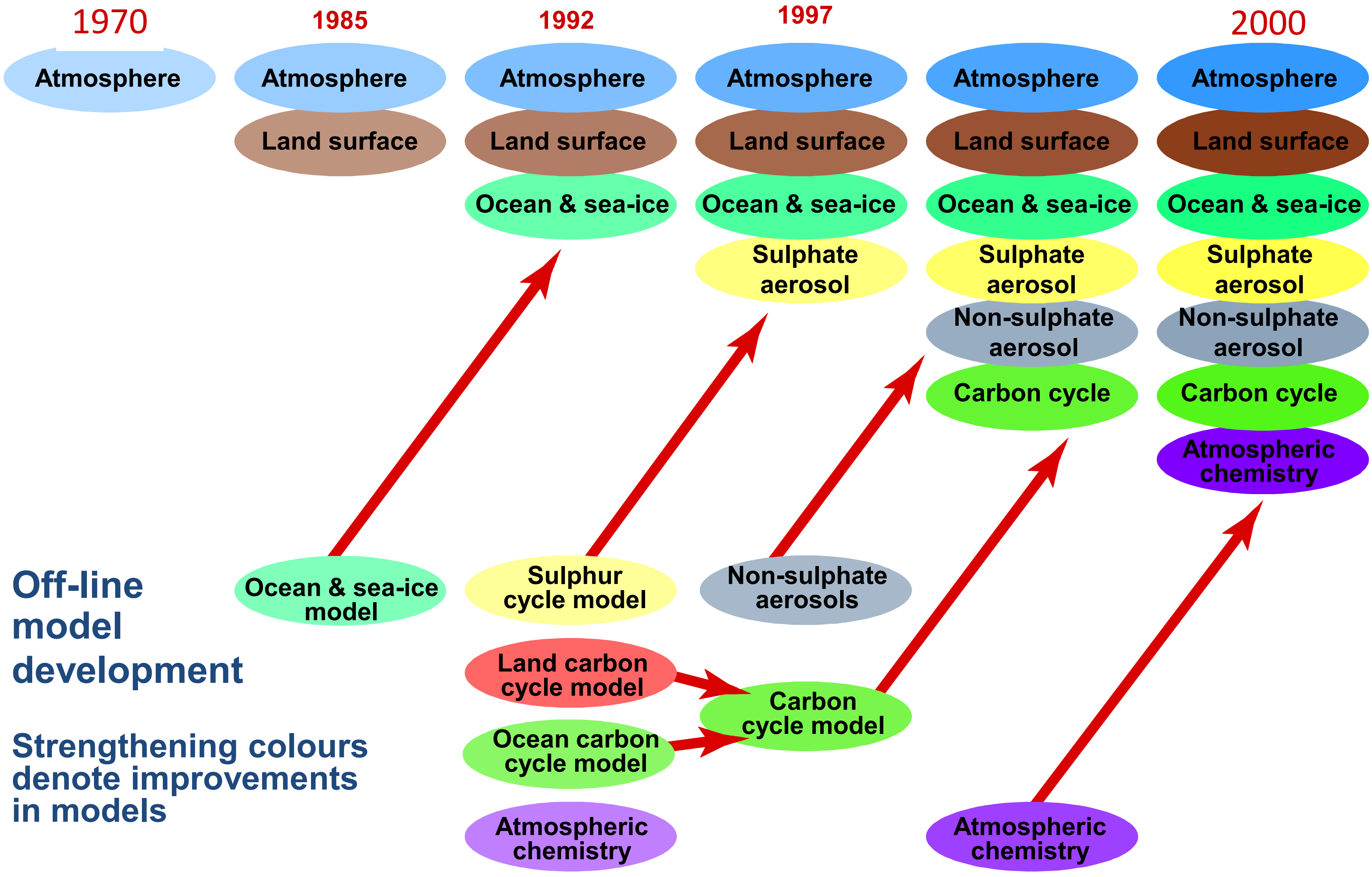
	temperature				
	JJA			DJF	
	cold	warm		cold	warm
Australia	🟩 3	🟩 3		🟩 3	🟥 1
Amazon Basin	🟩 3	🟥 1		🟥 1	🟥 1
Southern South America	🟥 1	🟥 1		🟩 3	🟦 2
Central America	🟩 3	🟥 1		🟩 3	🟥 1
Western North America	🟥 1	🟥 1		⬜ 6	⬜ 6
Central North America	🟥 1	🟥 1		🟦 2	🟦 2
Eastern North America	🟩 3	🟩 3		🟦 2	🟩 3
Alaska	🟩 3	🟩 3		🟦 2	🟦 2
Greenland	🟥 1	🟥 1		🟦 2	🟦 2
Mediterranean	🟩 3	⬜ 6		🟥 1	⬜ 6
Northern Europe	🟦 2	🟦 2		🟩 3	🟩 3
Western Africa	🟥 1	🟥 1		🟩 3	🟩 3
Eastern Africa	🟥 1	🟥 1		🟦 2	🟩 3
Southern Africa	🟥 1	🟦 2		🟥 1	🟥 1
Sahel	🟥 1	🟦 2		⬜ 6	⬜ 6
South East Asia	🟥 1	🟥 1		🟦 2	🟥 1
East Asia	🟩 3	🟦 2		🟥 1	⬜ 6
South Asia	🟩 3	🟥 1		🟩 3	🟩 3
Central Asia	🟥 1	🟦 2		🟩 3	🟦 2
Tibet	🟩 3	🟥 1		🟩 3	⬜ 6
North Asia	🟥 1	🟦 2		🟥 1	🟦 2

🟥	MM best	32	38%
🟦	PP best	19	23%
🟩	SP best	25	30%
⬜	no SP bes	8	10%
		84	

lead time: 2-4 months, hindcast period: 1991-2005
SP version 1055m007

3. As a way to make more efficient use of human and computer resources

Towards Comprehensive Earth System Models



1970
- Atmosphere

1985
- Atmosphere
- Land surface

1992
- Atmosphere
- Land surface
- Ocean & sea-ice

1997
- Atmosphere
- Land surface
- Ocean & sea-ice
- Sulphate aerosol

- Atmosphere
- Land surface
- Ocean & sea-ice
- Sulphate aerosol
- Non-sulphate aerosol
- Carbon cycle

2000
- Atmosphere
- Land surface
- Ocean & sea-ice
- Sulphate aerosol
- Non-sulphate aerosol
- Carbon cycle
- Atmospheric chemistry

Off-line model development

- Ocean & sea-ice model
- Sulphur cycle model
- Non-sulphate aerosols
- Land carbon cycle model
- Ocean carbon cycle model
- Carbon cycle model
- Atmospheric chemistry
- Atmospheric chemistry

Strengthening colours denote improvements in models

The Met.Office Hadley Centre

A community-wide approach to the Climate Model development?

Standard argument against the “Airbus” paradigm:

“We need model diversity in order to be able to estimate prediction uncertainty”

This argument should not be considered dogma, but rather be open to objective scientific evalution.

The development of a skilful Probabilistic Climate Model allows this argument to be tested, potentially opening the door to greater integration of climate model development, and to much more efficient use of the enormous human and computational resources needed to develop reliable climate prediction models.

4. Emerging Probabilistic Computer Hardware?

A New type of chip: PCMOS (Probabilistic Complementary Metal-Oxide Semiconductor)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SPECIAL ISSUE

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WHO
Alex Zettl, University of California, Berkeley

DEFINITION
At the core of the nanoradio is a single molecule that can receive radio signals.

IMPACT
Tiny radio devices could improve cell phones and allow communication between tiny devices, such as environmental sensors.

CONTEXT
New nanotech tools are allowing researchers to fabricate very small devices. The nanoradio is one of the latest.

fewer electrons make the jump across the gap. The fluctuating electrical signal that results reproduces the audio information encoded onto the radio wave, and it can be sent to a speaker.

The next step for Zettl and his colleagues is to make their nanoradios send out information in addition to receiving it. But Zettl says that won't be hard, since a transmitter is essentially a receiver run in reverse.

Nano transmitters could open the door to other applications as well. For instance, Zettl suggests that nanoradios attached to tiny chemical sensors could be implanted in the blood vessels of patients with diabetes or other diseases. If the sensors detect an abnormal level of insulin or some other target compound, the transmitter could then relay the information to a detector, or perhaps even to an implanted drug reservoir that could release insulin or another therapeutic on cue. In fact, Zettl says that since his paper on the nanotube radio came out in the journal *Nano Letters*, he's received several calls from researchers working on radio-based drug delivery vehicles. "It's not just fantasy," he says. "It's active research going on right now."

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HARDWARE

Probabilistic Chips

KRISHNA PALEM THINKS INTRODUCING A LITTLE UNCERTAINTY INTO COMPUTER CHIPS COULD EXTEND BATTERY LIFE IN MOBILE DEVICES—AND MAYBE THE DURATION OF MOORE'S LAW, TOO. *BY ERIKA JONIETZ*

Krishna Palem is a heretic. In the world of microchips, precision and perfection have always been imperative. Every step of the fabrication process involves testing and retesting and is aimed at ensuring that every chip calculates the exact answer every time. But Palem, a professor of computing at Rice University, believes that a little error can be a good thing.

Palem has developed a way for chips to use significantly less power in exchange for a small loss of precision. His concept carries the daunting moniker "probabilistic complementary metal-oxide semiconductor technology"—PCMOS for short. Palem's premise is that for many applications—in particular those like audio or video processing, where the final result isn't a number—maximum precision is unnecessary. Instead, chips could be designed to produce the correct answer sometimes, but only come close the rest of the time. Because the errors would be small, so would their effects: in essence, Palem believes that in computing, close enough is often good enough.

Every calculation done by a microchip depends on its transistors' registering either a *1* or a *0* as electrons flow through them in response to an applied voltage. But electrons move constantly, producing electrical "noise." In order to overcome noise and ensure that their transistors register the correct values, most chips run at a relatively high voltage. Palem's idea is to lower the operating voltage of parts of a chip—specifically, the logic circuits that calculate the least significant bits, such as the *3* in the number *21,693*. The resulting decrease in signal-to-noise ratio means those circuits would occasionally arrive at the wrong answer, but engineers can calculate the probability of getting the right answer for any specific voltage. "Relaxing the probability of correctness even a little bit can produce significant savings in energy," Palem says.

Within a few years, chips using such designs could boost battery life in mobile devices such as music players and cell phones. But in a decade or so, Palem's ideas could have a much larger impact. By then, silicon transistors will be so small that engineers won't be able to precisely control their behavior: the transistors will be inherently probabilistic. Palem's techniques could then become important to the continuation of Moore's Law, the exponential increase in transistor density—and thus in computing power—that has persisted for four decades.

When Palem began working on the idea around 2002, skepticism about the principles behind PCMOS was "pretty universal," he says. That changed in 2006. He and his students simulated a PCMOS circuit that would be part of a chip for processing video, such as streaming video in a cell phone, and compared it with the performance of existing chips. They presented the work at a technical conference, and in a show of hands, much of the audience couldn't discern any difference in picture quality.

Applications where the limits of human perception reduce the need for precision are perfectly suited to PCMOS designs, Palem says. In cell phones, laptop computers, and other mobile devices, graphics and sound processing consume a significant

TR10 65

Krishna Palem – Rice University

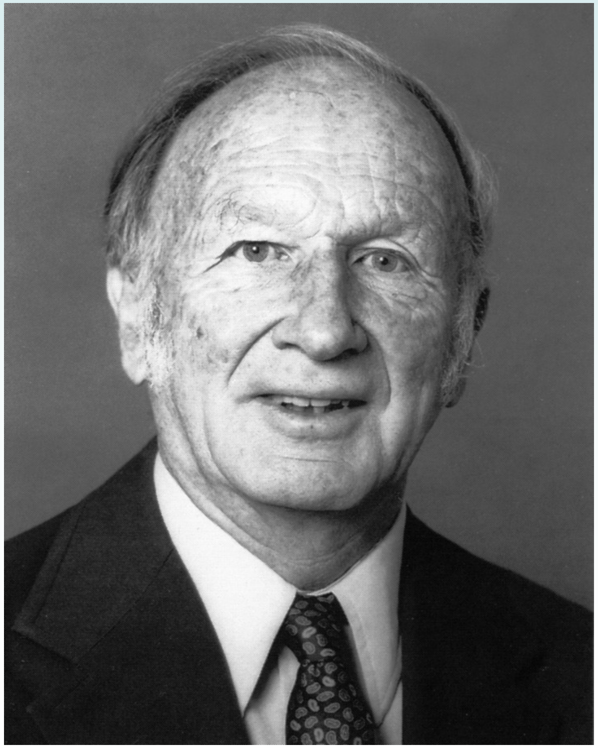
Technology to Enable 1,000X Performance Over Today’s Digital Processors

SANTA CLARA, Calif., and AUSTIN, Texas – August 17, 2010 – FLASH MEMORY SUMMIT and THE INTERNATIONAL SYMPOSIUM ON LOW POWER ELECTRONICS AND DESIGN – Lyric Semiconductor, Inc. a DARPA- and venture-funded MIT spin-out, today emerged from stealth mode to launch a new technology called probability processing, which is poised to deliver a fundamental change in processing performance and power consumption. With over a decade of development at MIT and at Lyric Semiconductor, Lyric’s probability processing technology calculates in a completely new way, enabling orders-of-magnitude improvement in processor efficiency. Lyric Error Correction (LEC™) for flash memory, the first commercial application of probability processing, offers a 30X reduction in die size and a 12X improvement in power consumption all at higher throughput compared to today’s digital solutions. Lyric Semiconductor has developed an alternative to digital computing. The company is redesigning processing circuits from the ground up to natively process probabilities – from the gate circuits to the processor architecture to the programming language. As a result, many applications that today require a thousand conventional processors will soon run in just one Lyric processor, providing 1,000X efficiencies in cost, power, and size.

For over 60 years, computers have been based on digital computing principles. Data is represented as bits (1s and 0s). Boolean logic gates perform operations on these bits. Lyric has invented a new kind of logic gate circuit that uses transistors as dimmer switches instead of as on/off switches. These circuits can accept inputs and calculate outputs that are between 0 and 1, directly representing probabilities - levels of certainty.

5. Cos the boss said so!

“*I believe that the ultimate climate models..will be stochastic, ie random numbers will appear somewhere in the time derivatives*” Lorenz 1975.



Where are we now with Stochastic-Dynamic Parametrisation?

Atmosphere	Partially (SPPT, SPBS)
Land surface	No
Ocean	No
Cryosphere	No
Biosphere	No

However, stochastic parametrisations are currently “bolt-on” extras, whereas the existence of finite sub-grid pdfs (even when constrained by gridscale variables) should be considered as primitive in the ab initio development of parametrisations

Let the time it could take some error at wavenumber $2k$ to infect wavenumber k, be proportional to the eddy turn over time $\tau(k) \ \sim \qquad {}^{1/2}(k)$

The time it could take for error to propagate N "octaves" to some large-scale wavenmber k_L of interest is

$$\Omega(N) = \sum_{n=0}^{N} \tau(2^n k_L)$$

If $E(k) \sim \qquad\qquad \sim$

$$\Omega(N) = \sum_{n=0}^{N} \tau(2^n k_L)$$

$$= \tau(k_L)\sum_{n=0}^{N} 2^{-2n/3} \sim \qquad\qquad N \to \infty$$

Hence scaling suggests it could take a finite time for small-scale truncation/parametrisation errors to infect any large scale of interest, no matter how small-scale these uncertainties are confined to.

Clay Mathematics Millenium Problems

- Birch and Swinnerton-Dyer Conjecture
- Hodge Conjecture
- Navier-Stokes Equations
- P vs NP
- Poincaré Conjecture
- Riemann Hypothesis
- Yang-Mills Theory

The Grand Challenge

Mathematicians (the academic community more generally) to help develop a new generation of *ab initio* Earth System Models, modifying or replacing the conventional bulk-formula parametrisation paradigm with innovative stochastic-dynamic mathematics, to aid our ability to predict climate, for the good of society worldwide.

The tools we have to work with:

- Observations
- Cloud resolving models (coarse grain budgets)
- Physics, mathematics and the power of pure reason!

A world-wide network of scientists interested in stochastic parametrisation is being set up, both as an email discussion forum and as the means to set up and promote workshops and conference sessions.

If you are interested in joining this network, please email Judth Berner (NCAR) at

berner@ucar.edu