Met Office
Hadley Centre

30 years
Leading climate science and services in our changing world

Ensembles and probabilities in the 1980s

Pioneering the use of dynamical ensembles in real-time monthly predictions

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30 Years of Ensemble Forecasting and Symposium for Prof. Tim Palmer

Department for Environment Food & Rural Affairs
Department for Business, Energy & Industrial Strategy
Met Office Hadley Centre
Environment Agency

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Ensembles and probabilities

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1. Reflections on monthly predictions in the 1980s

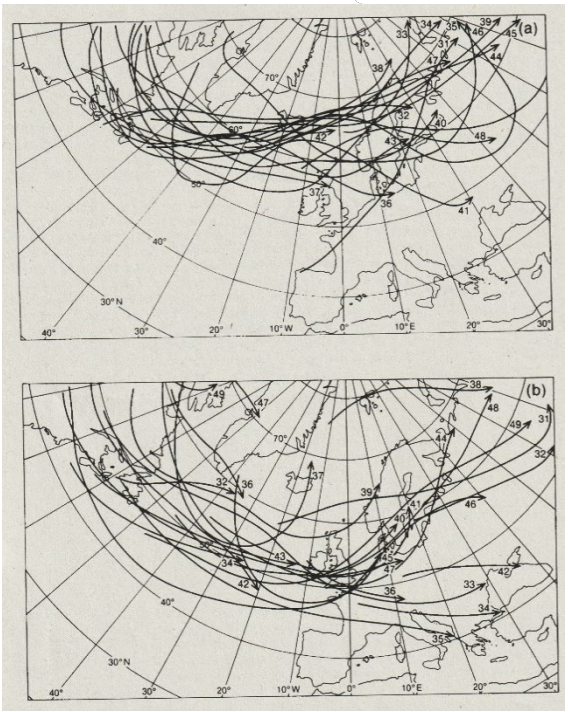
- *Carried out in the Synoptic Climatology Branch of the (Bracknell) Met Office*
- *Operational monthly forecasts based on statistical methods (Chris Folland and colleagues)*
- *Pioneering dynamical ensembles (Tim, myself and colleagues)*
- *Uncertainty recognised as a fundamental component of these forecasts, from the start*

2. UK climate change projections

- *Providing ensembles and probabilities to support climate risk assessments and adaptation decisions*

Met Office monthly forecasts: 1960s to 1980s

- Regular operational forecasts started in 1963, motivated by the extreme winter of 1962-63
- Issued publicly till 1980, then to commercial and corporate users through the 1980s
- Focused on predicting spells of weather associated with persistent long-wave patterns.
- Presented probabilistically and with subjective assessments of confidence, recognising the non-deterministic nature of the task

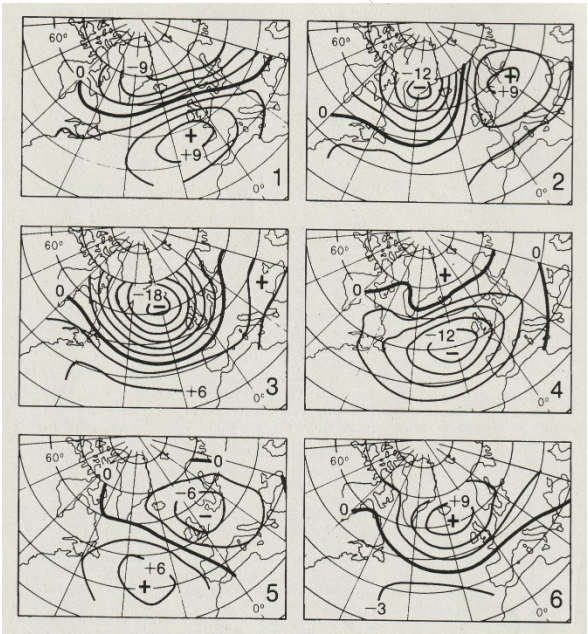


500hPa jet stream speeds for 5-day periods during summer 1983 (top), 1985 (bottom)

Folland and Woodcock (1986), Met. Mag. 115, 301-318.

Forecast Methods

- Forecast periods: Days 1-5, 6-15 and 16-30
- ECMWF and Met Office medium-range forecasts informed days 1-5.
- Statistical forecast methods were the main basis for extended-range periods.
- Principal method was MVA (MultiVariate Analysis):
  - Predictors: Hemispheric eigenvectors of mslp and 1000-500hPa thickness during the preceding two months, and monthly SST anomalies from a set of worldwide regions
  - Predictands: Probabilities of half-monthly sea-level pressure clusters (six patterns), predicted using linear discriminant analysis



Sea-level pressure anomaly clusters for January-February, used in MVA

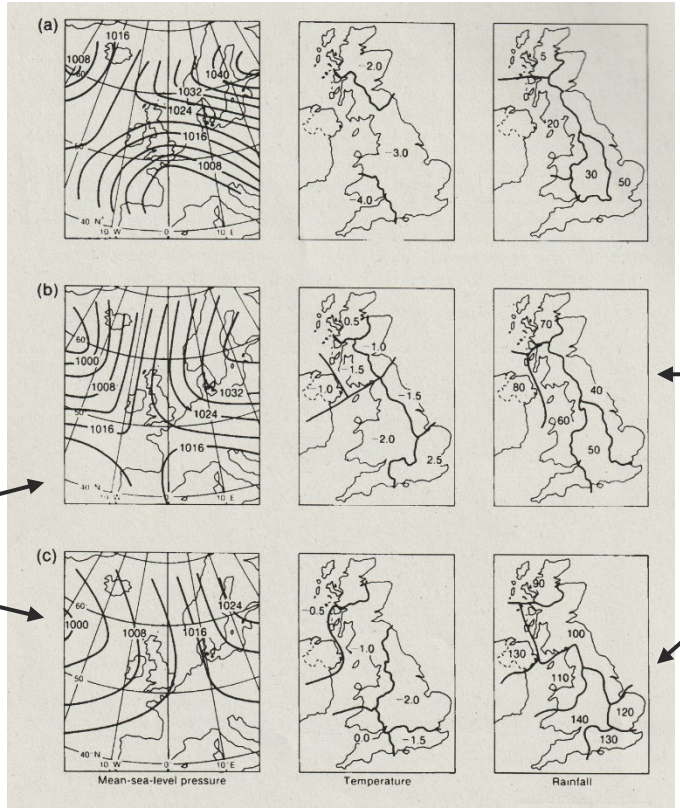
Best-estimate forecast, February 1986

Days 1-5

Days 6-15

Most probable cluster, modified in a second regression step

Days 16-30



Temperature and rainfall derived from slp using analogue and regression methods

Sea-level pressure

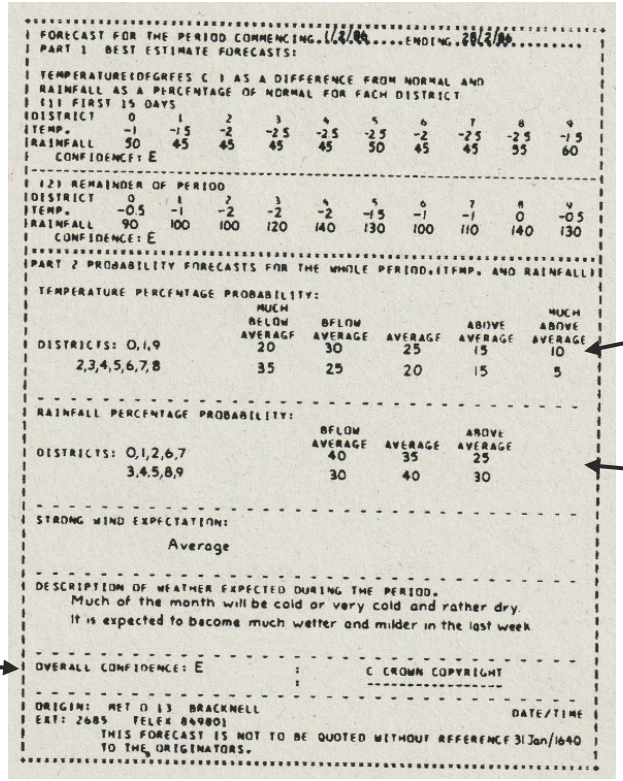
Temperature

Rainfall

Probabilistic forecast, February 1986

Probability forecasts shown to possess modest skill on average (better in 1980s than during 1970s)

Folland et al. (1986), Met. Mag. 115, 377-395.



FORECAST FOR THE PERIOD COMMENCING 1/2/86 ....ENDING 28/2/86

PART 1 BEST ESTIMATE FORECASTS:

TEMPERATURE(DEGREES C) AS A DIFFERENCE FROM NORMAL AND RAINFALL AS A PERCENTAGE OF NORMAL FOR EACH DISTRICT

(1) FIRST 15 DAYS

DISTRICT	0	1	2	3	4	5	6	7	8	9
TEMP.	-1	-1.5	-2	-2.5	-2.5	-2.5	-2	-2.5	-2.5	-1.5
RAINFALL	50	45	45	45	45	50	45	45	55	60

CONFIDENCE: E

(2) REMAINDER OF PERIOD

DISTRICT	0	1	2	3	4	5	6	7	8	9
TEMP.	-0.5	-1	-2	-2	-2	-1.5	-1	-1	0	-0.5
RAINFALL	90	100	100	120	140	130	100	110	140	130

CONFIDENCE: E

PART 2 PROBABILITY FORECASTS FOR THE WHOLE PERIOD.(TEMP. AND RAINFALL)

TEMPERATURE PERCENTAGE PROBABILITY:

	MUCH BELOW AVERAGE	BELOW AVERAGE	AVERAGE	ABOVE AVERAGE	MUCH ABOVE AVERAGE
DISTRICTS: 0,1,9	20	30	25	15	10
2,3,4,5,6,7,8	35	25	20	15	5

RAINFALL PERCENTAGE PROBABILITY:

	BELOW AVERAGE	AVERAGE	ABOVE AVERAGE
DISTRICTS: 0,1,2,6,7	40	35	25
3,4,5,8,9	30	40	30

STRONG WIND EXPECTATION:

Average

DESCRIPTION OF WEATHER EXPECTED DURING THE PERIOD.

Much of the month will be cold or very cold and rather dry. It is expected to become much wetter and milder in the last week

OVERALL CONFIDENCE: E

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ORIGIN: MET O 13 BRACKNELL DATE/TIME

EXT: 2685 TELEX 849801

THIS FORECAST IS NOT TO BE QUOTED WITHOUT REFERENCE 31 Jan/1640 TO THE ORIGINATORS.

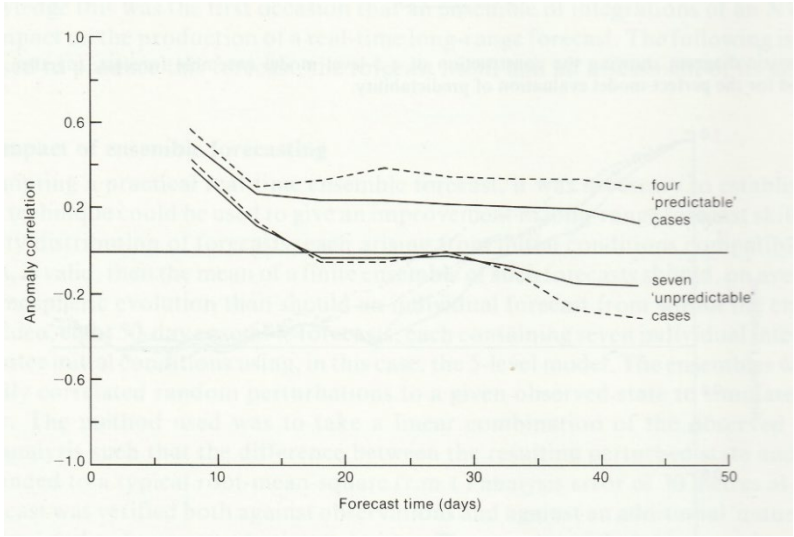
Temperature probabilities for quintiles of historical distribution

Rainfall probabilities for terciles of historical distribution

Confidence assessed subjectively, and used to determine sharpness of probability forecasts

Dynamical monthly forecasts in the 1980s at the Met Office

- Encouraged by pioneering work motivating ensemble methods as a practical way of exploring uncertainty both before (Epstein, 1969; Leith, 1974) and beyond the limit of deterministic predictability – In particular, by early evidence of dynamical predictability on the monthly time scale (Shukla, 1981; Miyakoda et al., 1983)…
- … We initially used a 5-level hemispheric atmosphere model to show potential skill in 50-day hindcasts arising from SST anomalies (Palmer and Sun, 1985; Mansfield, 1986) and use of ensembles (Murphy, 1988).



ACC for 15-day mean winter forecasts of 500hPa anomaly fields in N Hemisphere extratropics, for individual forecasts (solid) and ensemble-means (dashed).

First operational monthly dynamical forecast

Murphy and Palmer (1986), Met. Mag. 115, 337-349.

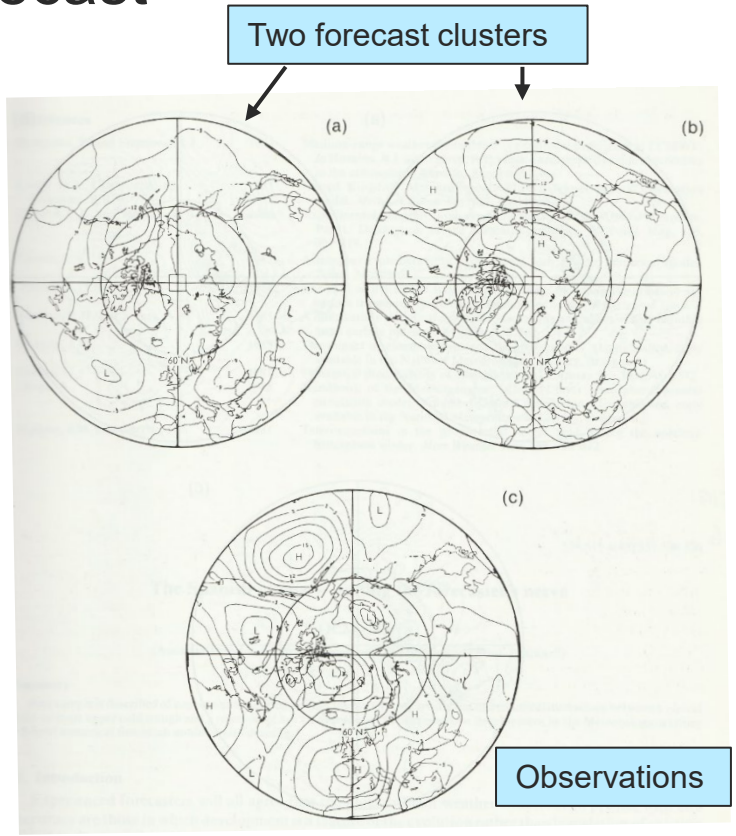
- Tim and I contributed a dynamical extended-range forecast (DERF) to the monthly forecast made in mid-September 1985
- Used a more sophisticated 11-level global AGCM designed for climate simulations (Slingo, 1985: ~300km horizontal resolution)
- 7-member ensemble initialised using lagged operational analysis with persisted SST anomalies
- First use of a DERF in real-time monthly prediction
- Ensemble-mean showed some skill beyond medium-range, to ~20 days

Integration	Forecast period						
	16–20 Sept. (day 1–5)	21–25 Sept. (day 6–10)	26–30 Sept. (day 11–15)	1–5 Oct. (day 16–20)	6–10 Oct. (day 21–25)	11–15 Oct. (day 26–30)	16–20 Oct. (day 31–35)
1 (00 GMT 12 Sept.)	0.31	0.03	0.21	0.10	−0.03	−0.01	−0.05
2 (12 GMT 12 Sept.)	0.47	0.02	0.01	0.03	−0.08	0.11	−0.17
3 (00 GMT 13 Sept.)	0.44	0.07	0.24	0.26	−0.21	0.05	0.05
4 (12 GMT 13 Sept.)	0.73	0.22	0.22	0.08	−0.19	0.03	−0.11
5 (00 GMT 14 Sept.)	0.75	0.40	0.34	0.27	0.23	0.04	−0.25
6 (12 GMT 14 Sept.)	0.82	0.46	0.28	0.06	0.23	−0.07	−0.10
7 (00 GMT 15 Sept.)	0.82	0.30	0.34	0.07	−0.02	0.10	0.08
1–7 average individual forecast	0.62	0.21	0.23	0.12	−0.01	0.04	−0.08
1–7 ensemble-mean forecast	0.73	0.30	0.32	0.16	−0.01	0.05	−0.10

ACC scores for successive pentads: 500hPa anomaly fields, 15-90°N.

Clusters in the dynamical forecast

- The ensemble developed two distinct clusters in the Pacific/north American region
- Three members showed a PNA-like pattern, that developed early in the forecast and then persisted
- Four members showed a broad cyclonic anomaly over Alaska and the eastern seaboard
- An example of how monthly ensemble forecasts might support probabilistic statements about predicted circulation regimes
- Real-time dynamical integrations continued during the 1980s, contributing to the monthly forecasts alongside the statistical methods.

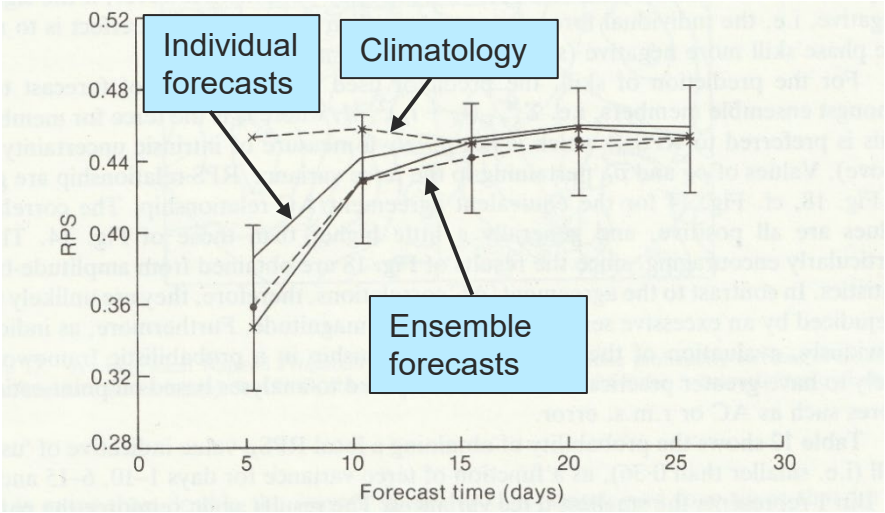


500 hPa height anomalies for 3-17 October, 1985

Probabilistic forecast verification

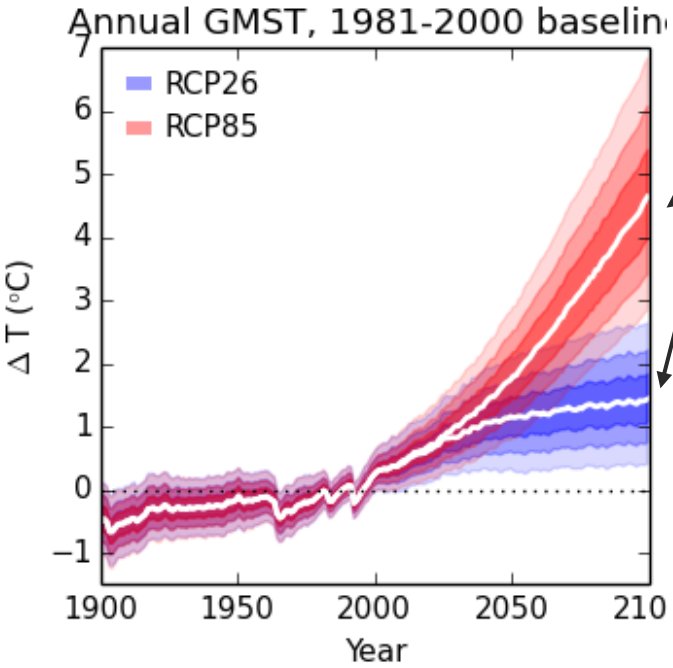
- Palmer et al. (1986) introduced a novel parameterisation of gravity wave drag to remove a westerly bias in the northern hemisphere mid-latitude flow.
- I ran a set of lagged-average ensemble hindcasts with this improved version, to assess its capabilities in monthly probabilistic prediction.
- The results showed skill relative to climatology out to ~20 days, with clear benefits for the ensemble approach over use of single-member forecasts.
- By the late 1980s, Tim had moved to ECMWF and myself to the Met Office Hadley Centre.
- From the 1990s ensemble prediction systems for seasonal and longer time scales grew in sophistication, moving firmly into the multi-model realm (e.g. Doblas-Reyes et al.,2009; Smith et al., 2013; Eyring et al., 2016).
- My focus switched to predictions of climate variability and change on annual to centennial time scales.

Ranked Probability Scores for forecasts of 10-day averages of sea-level pressure, 30-90°N



Murphy (1990), QJRMS 116, 89-125.

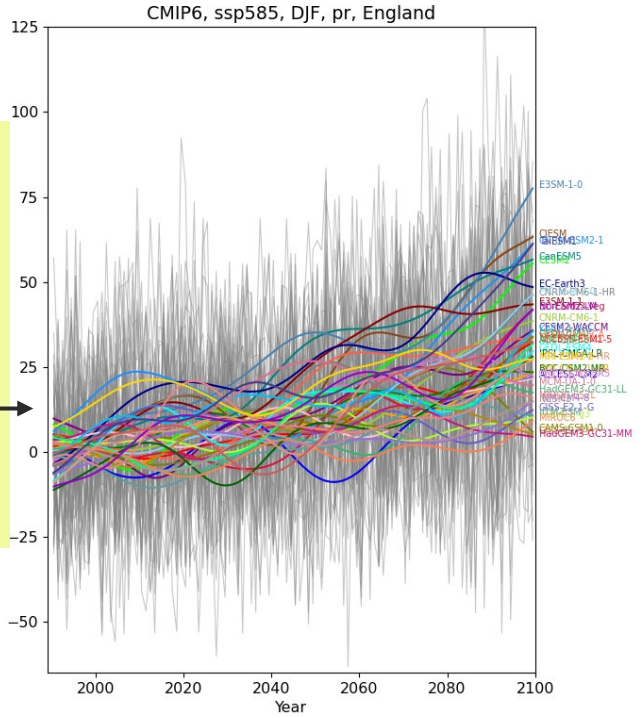
Uncertainties in climate change projections



Changes in global mean surface temperature from UKCP18 projections, for RCP2.6 and 8.5 emissions

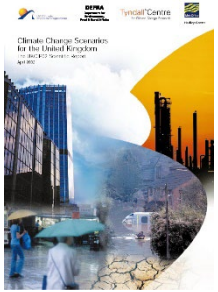
Future greenhouse gas emissions are uncertain

For a given emissions pathway, climate model ensembles project ranges of change influenced by internal variability and modelling uncertainty

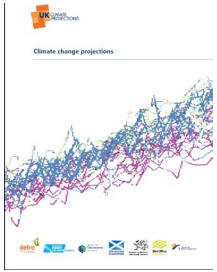


Winter precipitation changes (%) for England in winter, projected by CMIP6 multi-model ensemble

Ensembles and probabilities in UK climate scenarios



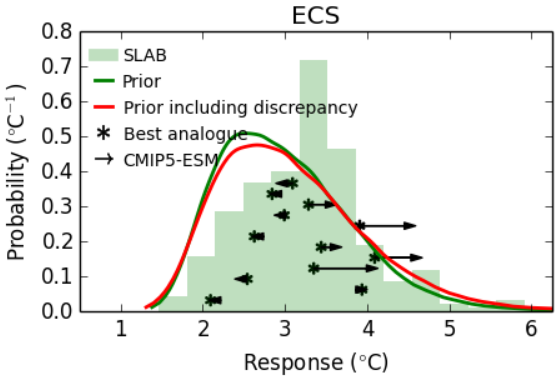
- UKCIP02: Scenarios of “what might happen” using three simulations from one climate model. Modelling uncertainties known about, but not included in the data.



- UKCP09: Probabilistic projections based on ~350 climate model simulations. Uncertainties quantified in the data, but only available for a limited set of variables.

- UKCP18: Probabilistic projections, plus ensembles of global, regional and local projections for flexible analysis of impacts.

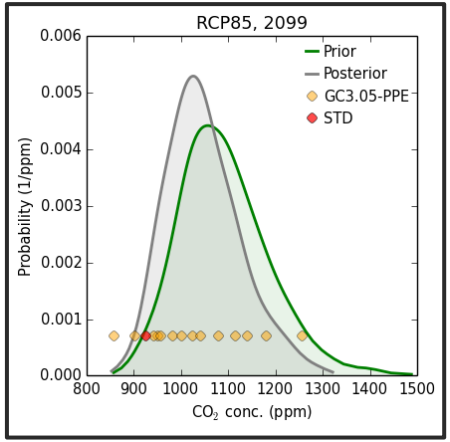
Ingredients for Bayesian probabilistic projections in UKCP18



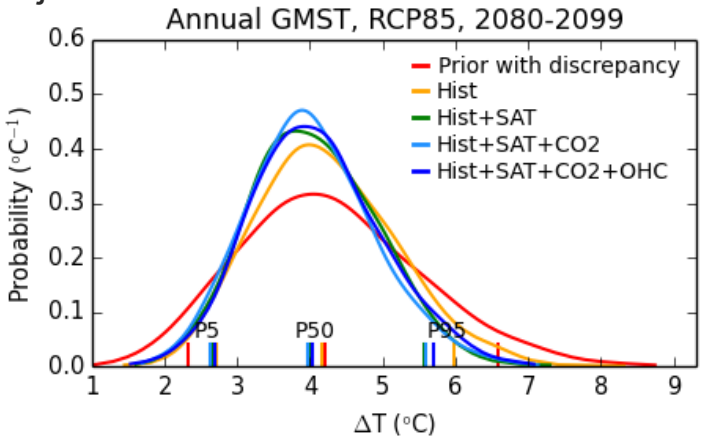
Perturbed parameter ensemble (PPE) simulations (green histogram)

Multi-model ensemble simulations (arrows)

Emulators (red prior)

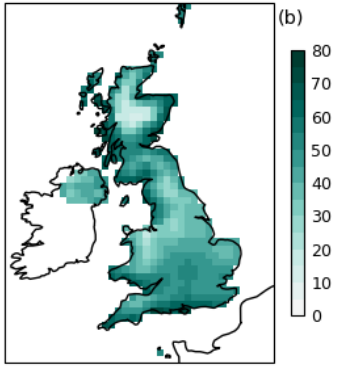


Earth system complexity (carbon cycle feedbacks)



Observational constraints (red prior cf dark blue posterior)

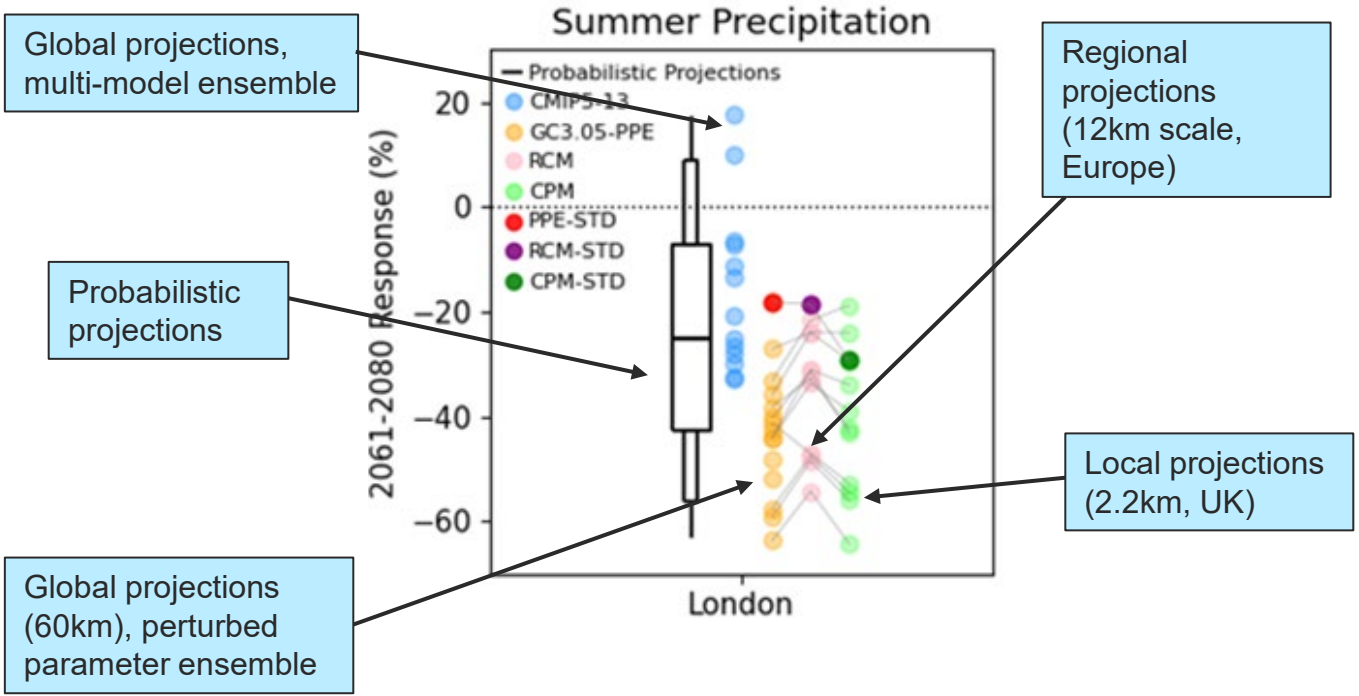
Regional climate model ensemble



90th percentile of winter precipitation changes (%), for 2061-80 relative to 1981-00, RCP8.5

Components of the UKCP18 land projections

Changes for 2061-2080 relative to 1981-2000 for London, RCP8.5 scenario



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In conclusion …

- During the 1980s, the Met Office produced monthly forecasts in a probabilistic format, using statistical methods and subjective judgements that explicitly accounted for uncertainties.
- This provided a natural framework for Tim & I to introduce dynamical monthly predictions, as a new contribution to the real-time forecasts.
- Since the 1980s, usage of ensemble methods in extended range predictions (seasonal, decadal, multidecadal) has grown in scope, including both single- and multi-model approaches.
- As an example, UK climate change scenarios are now based on ensembles using several climate model configurations, and include a probabilistic presentation.