Long-range forecasting

Anca Brookshaw

Outline

- What is predictable at long range (and where does predictability come from)?
- Uncertainty in long-range predictions: sources and ways of estimating it
- Skill of long-range prediction systems
- Issues ‘specific’ to long-range predictions (e.g. reference period, temporal and spatial representativity, bias)

- Met Office monthly and seasonal prediction systems and derived products

What is a seasonal forecast?

It is not a weather forecast

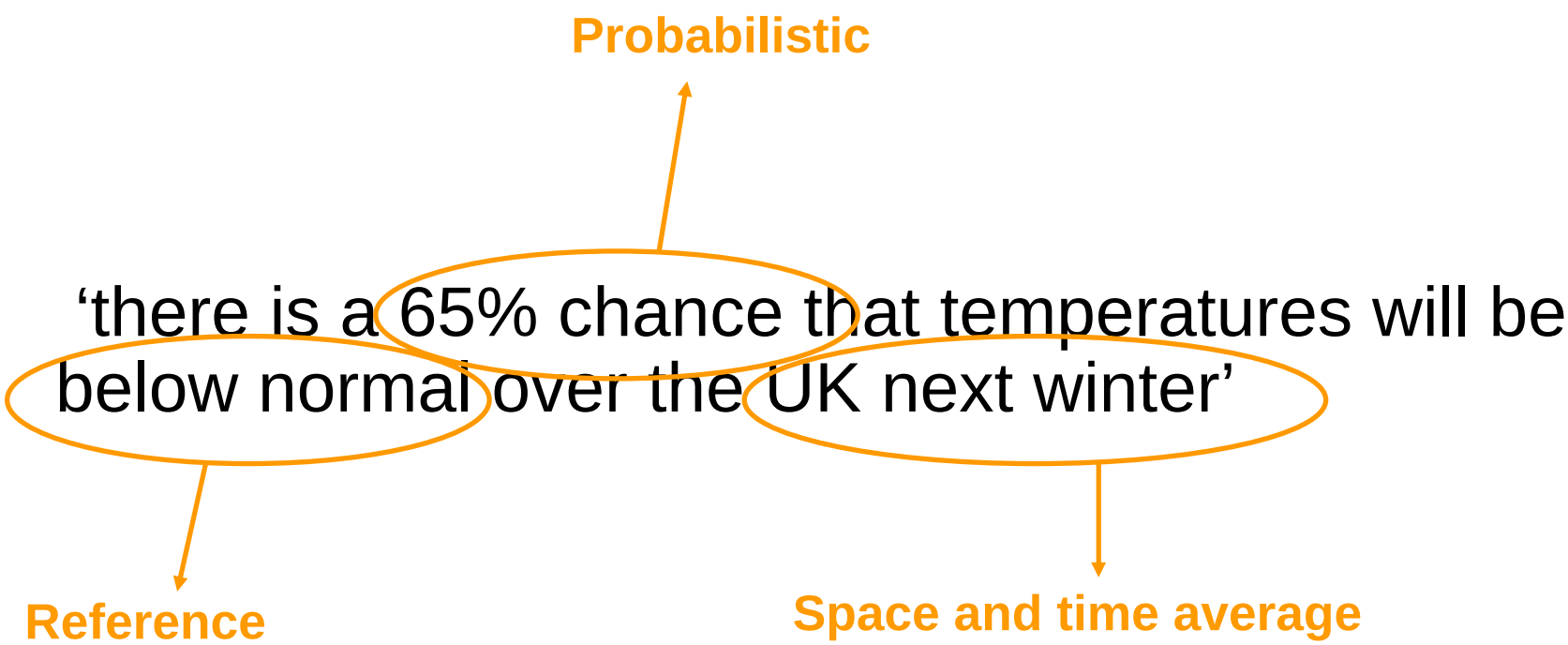
beyond a few days ahead we cannot predict conditions for a particular day

beyond a (very) few weeks ahead we cannot predict conditions for a particular week

It is a prediction of conditions averaged over several weeks/months

e.g. ‘there is a 65% chance that temperatures will be below normal over the UK next winter’

What is a seasonal forecast?

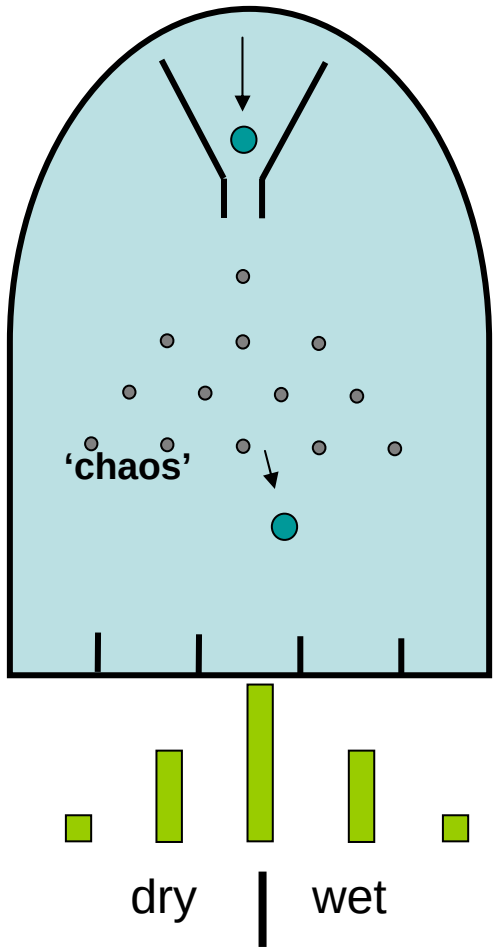


Seasonal: Probabilistic forecast

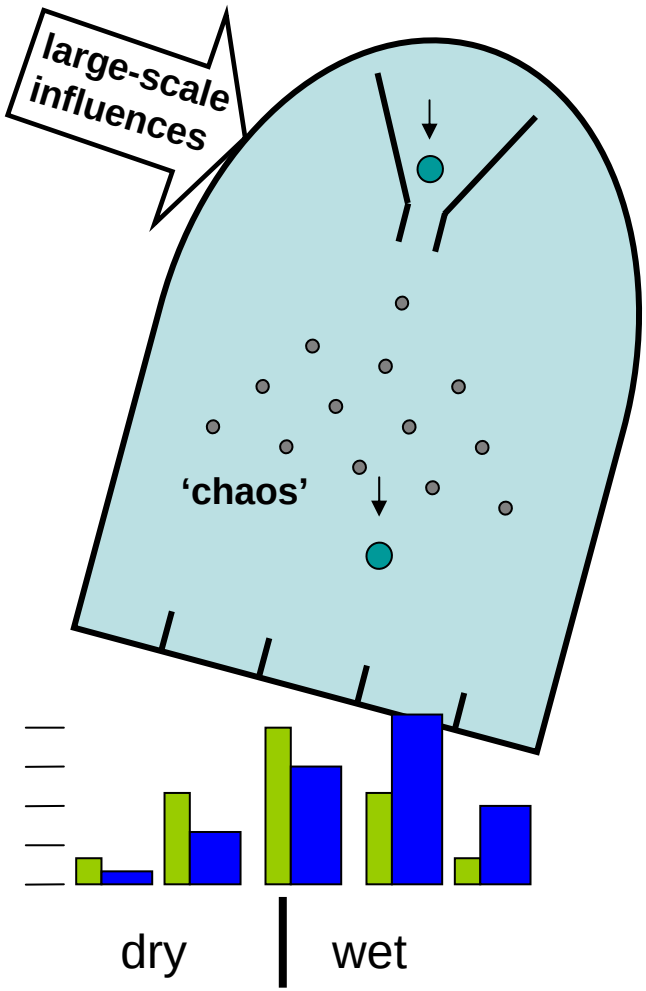
Uncertainties and chaos limit the range of predictability after a few days …..

….. Is there any hope for seasonal forecasting?

Predictability and chaos

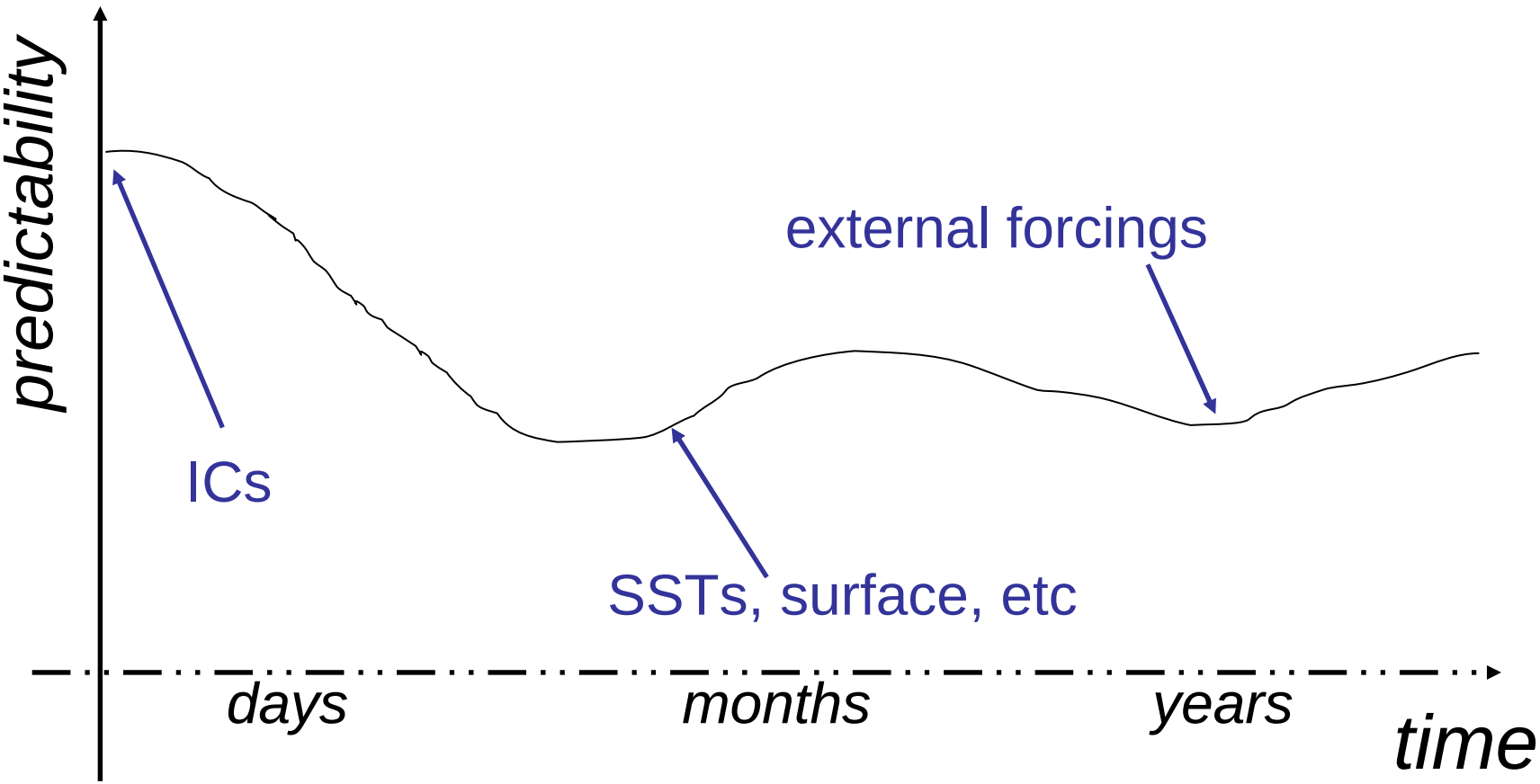


Predictability and chaos

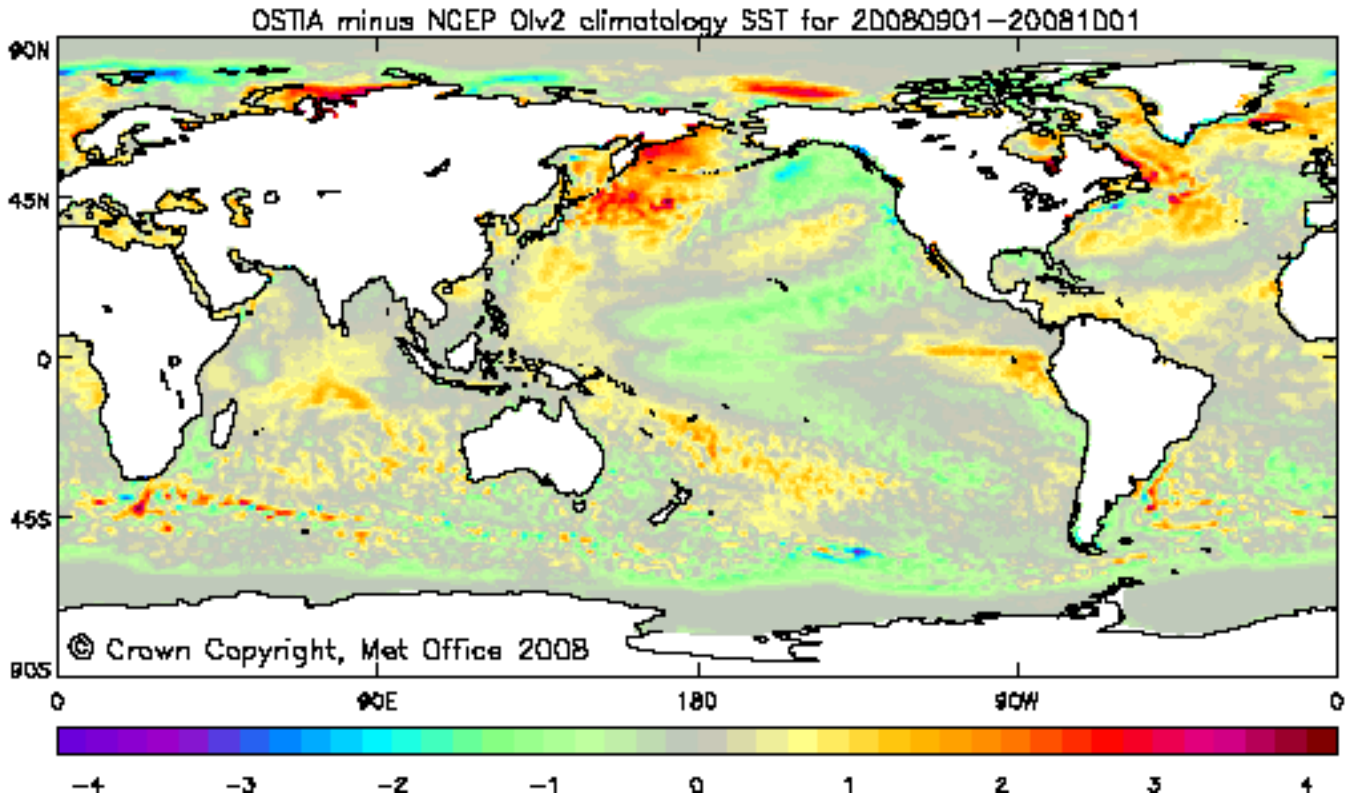


Seasonal: Probabilistic forecast

Sources of predictability:
Boundary conditions (SST, soil moisture, etc);
External forcing (emissions, etc)

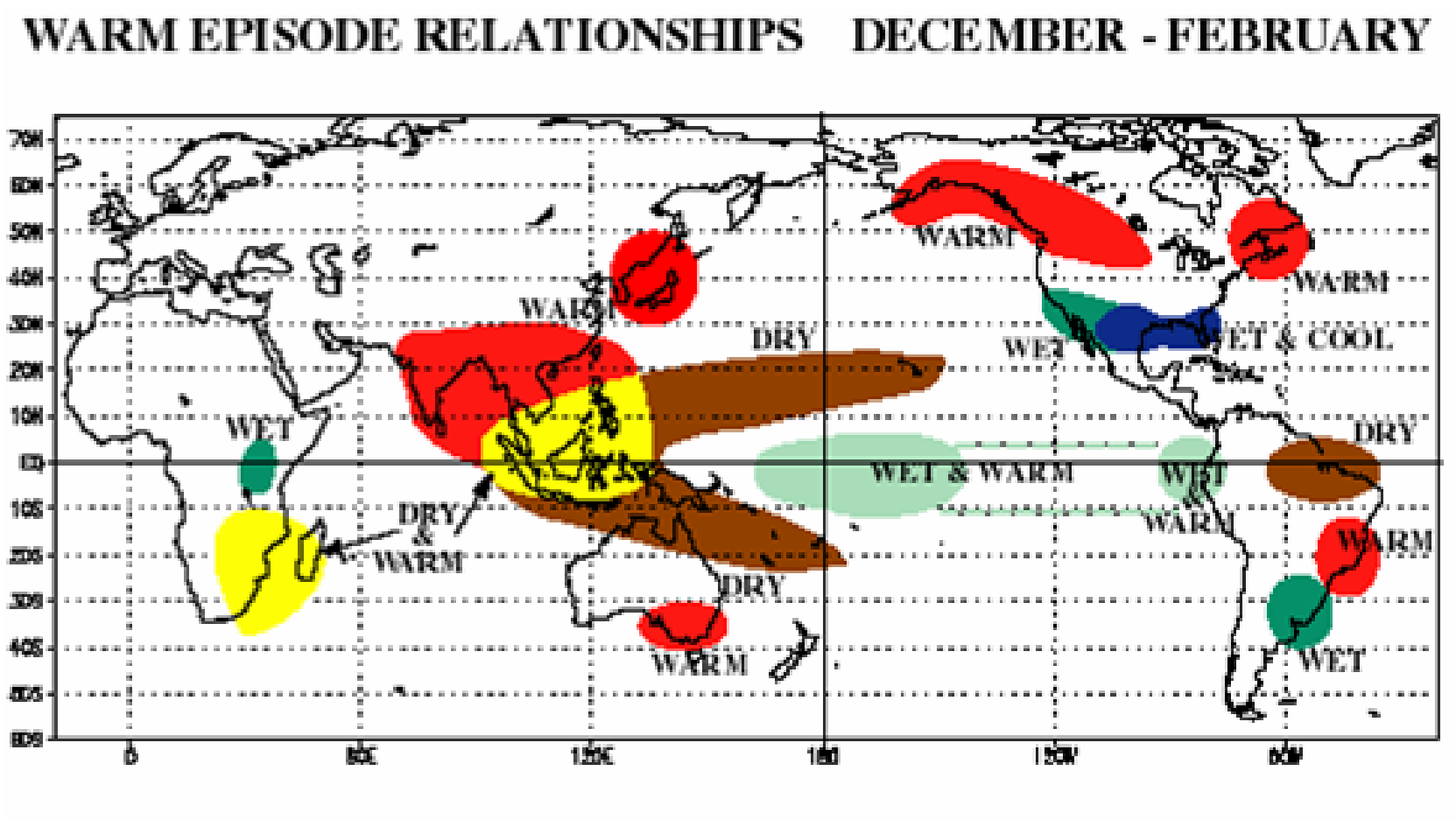


Example: sea surface temperature anomalies

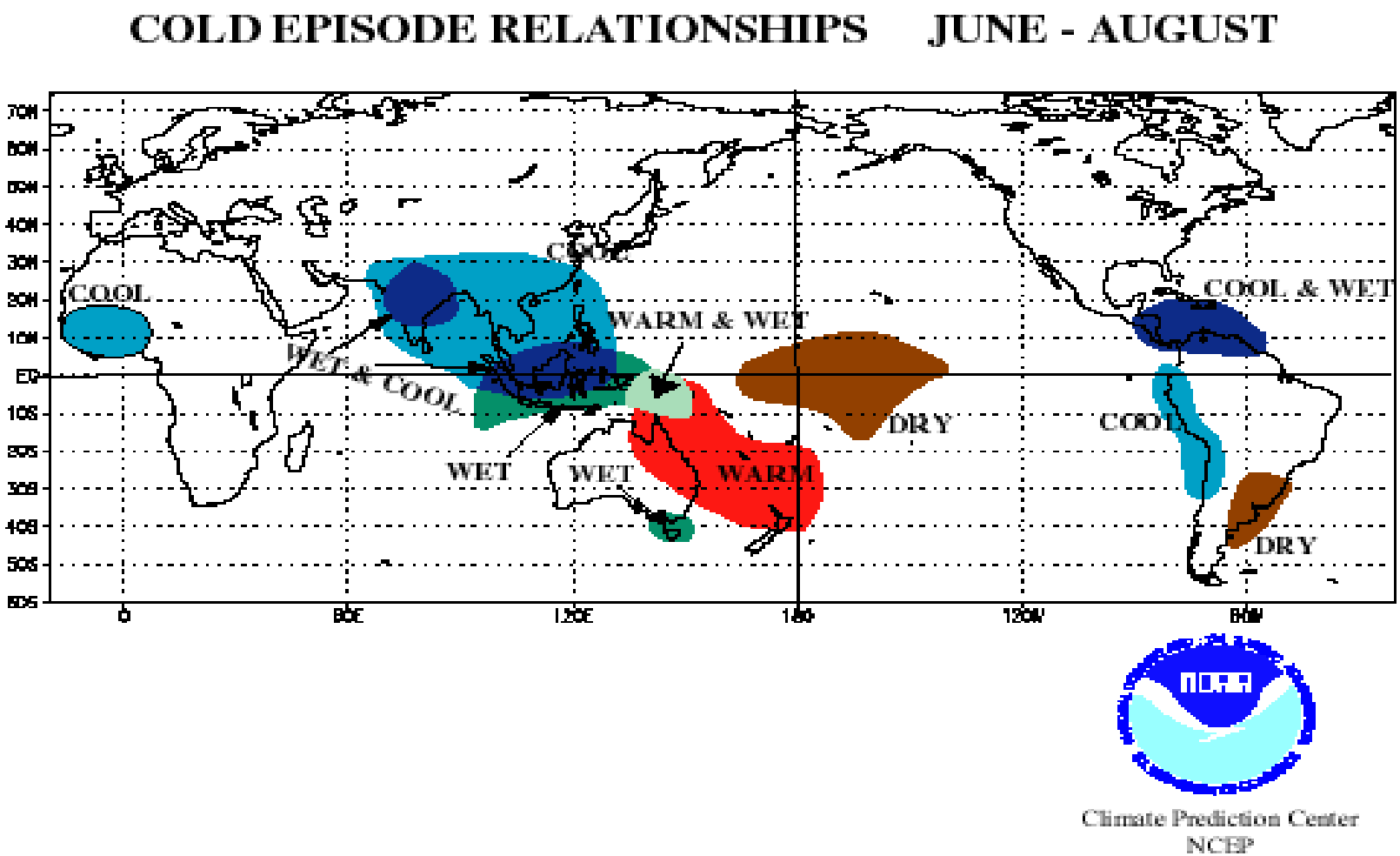


The pattern is large scale and slow-varying in time

Teleconnections
Typical El Niño Impacts



Teleconnections
Typical La Niña Impacts



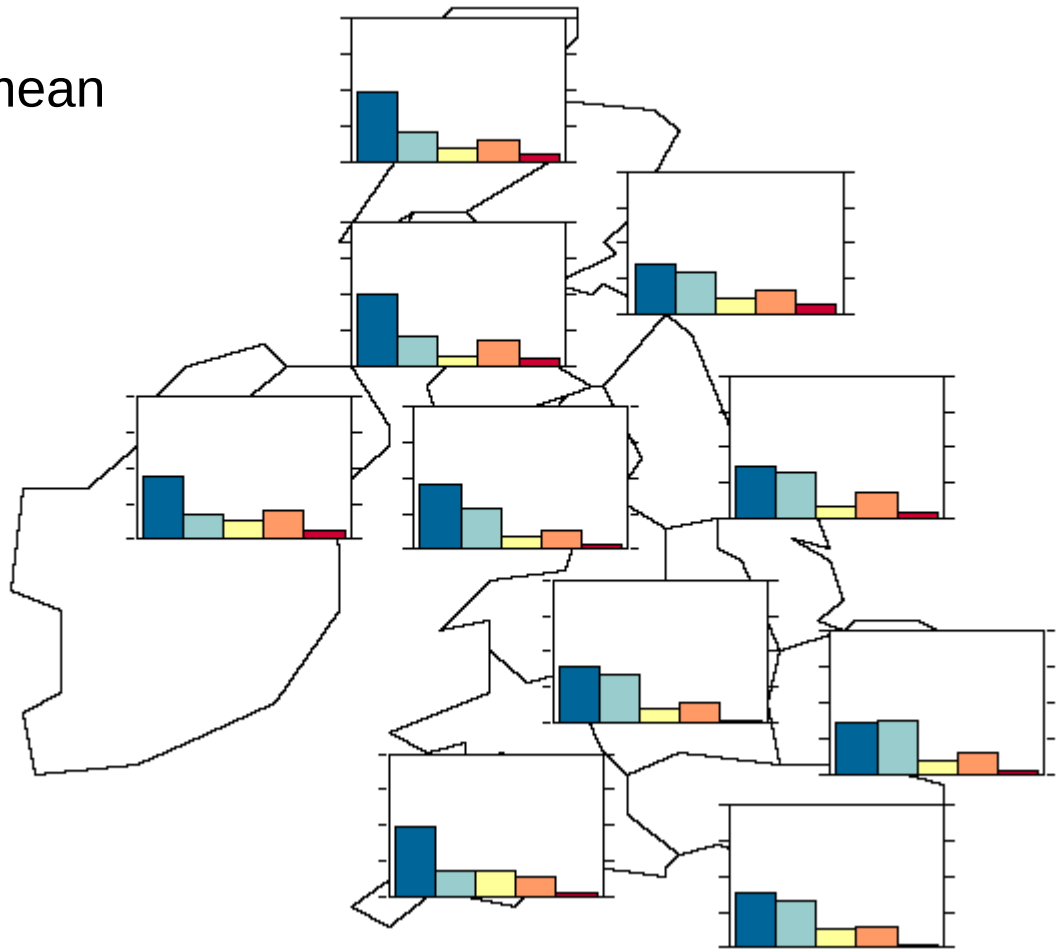
What is a seasonal forecast?

Probabilistic

‘there is a 65% chance that temperatures will be below normal over the UK next winter’

Seasonal: probabilistic forecast

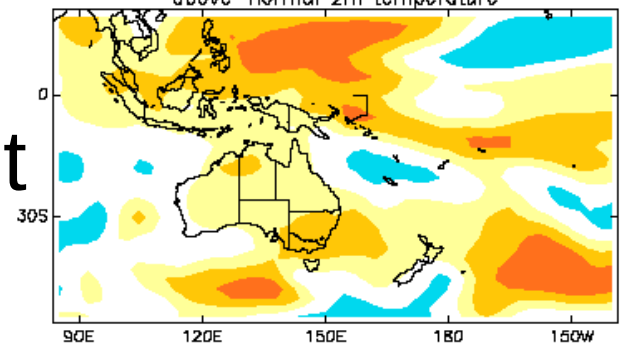
Tmean



Seasonal: probabilistic forecast

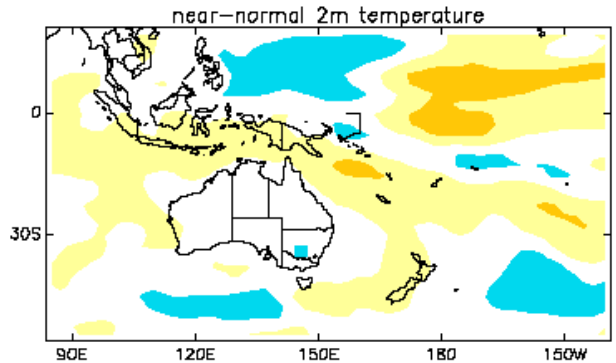
EURO–SIP : Probability of tercile categories Sep/Oct/Nov Issued Aug 2005

above–normal 2m temperature



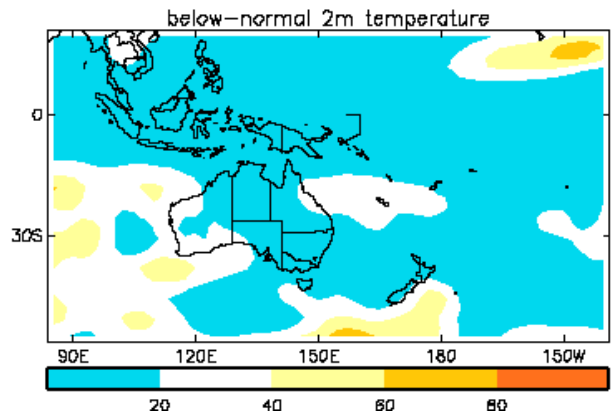
P(above)

near–normal 2m temperature



P(average)

below–normal 2m temperature



P(below)

Tercile categories (probabilities)

What is a seasonal forecast?

‘there is a 65% chance that temperatures will be below normal over the UK next winter’

Reference

Reference

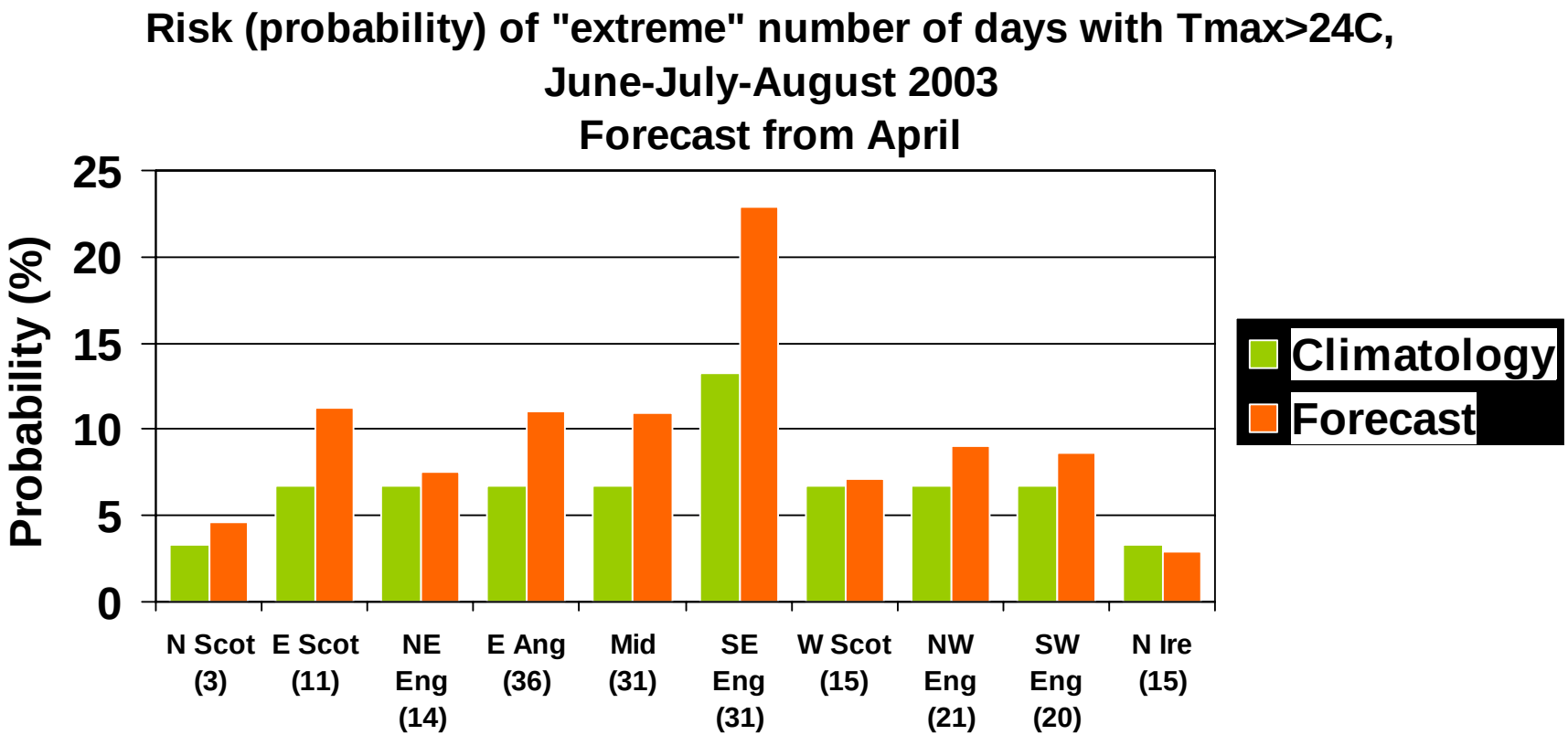
- **All probabilistic forecast need a reference**

50% prob. of rain tomorrow …. ***You have no idea!***

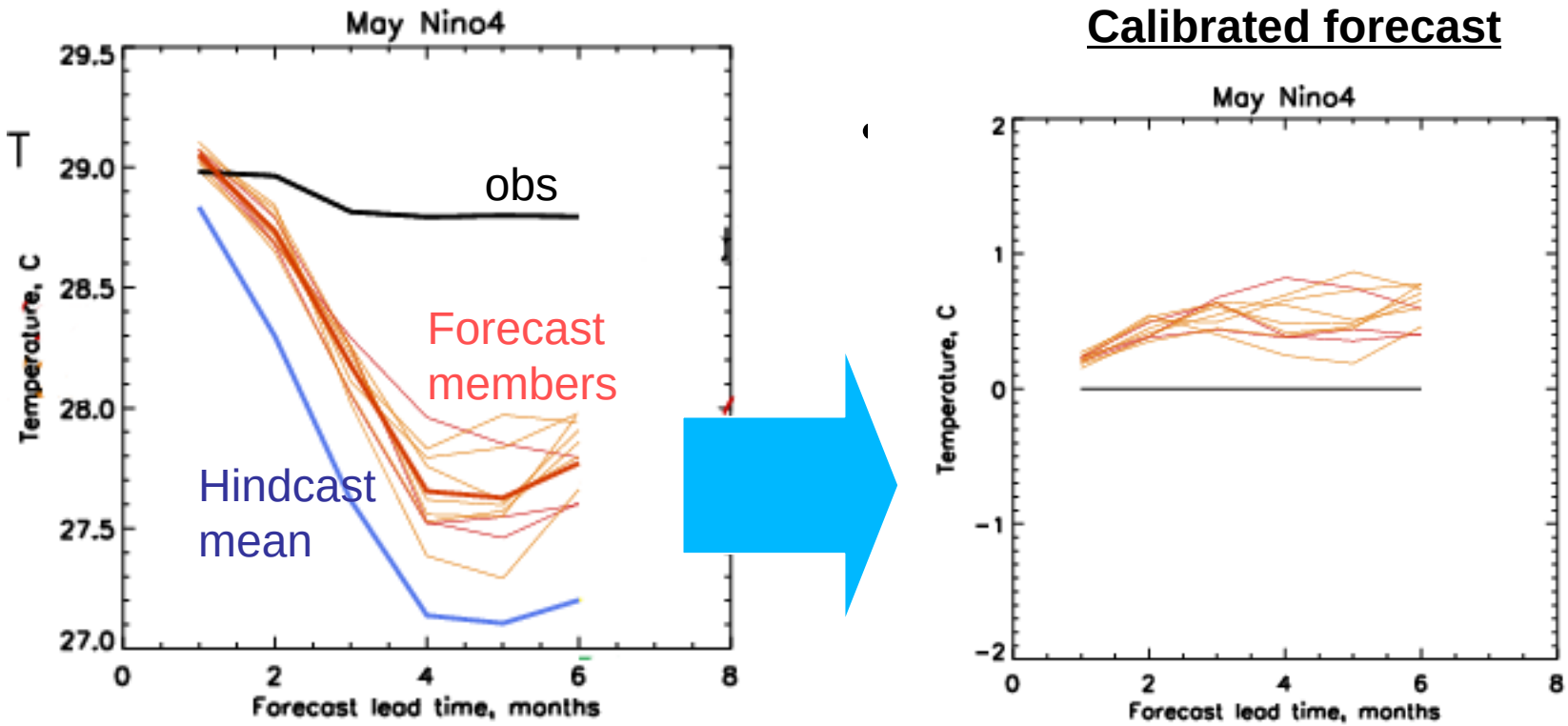
London climatology: 80% | Seville climatology: 10%

Low risk High risk

Reference



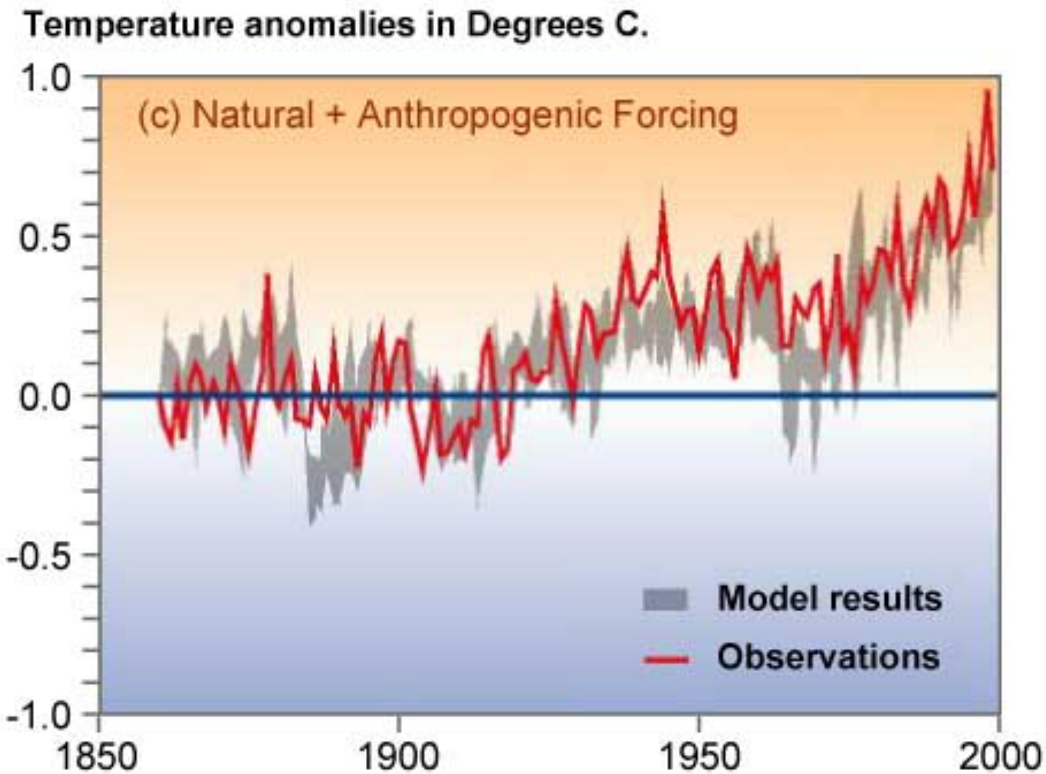
Model bias



At long range, predict anomalies

Reference period

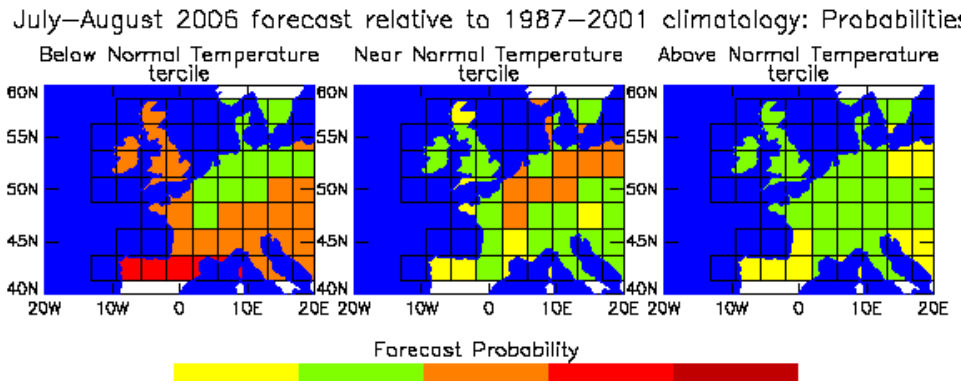
- **PROBLEM**:
- *What does "climate" mean under climate change?*



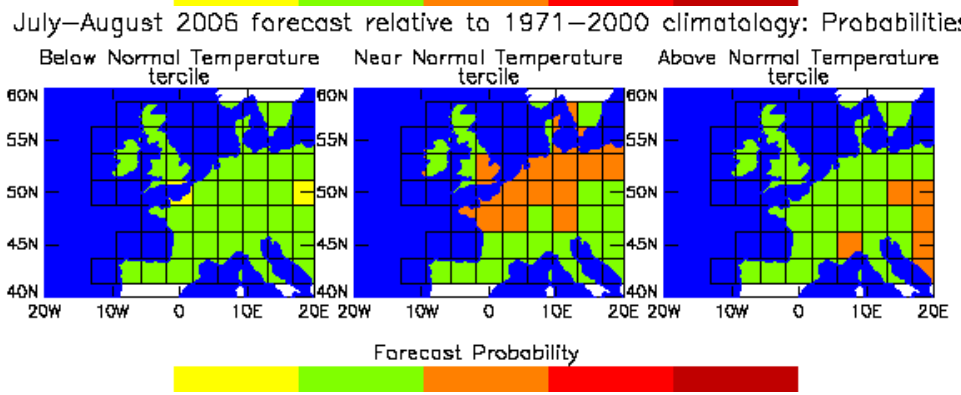
Reference period

Statistical forecast for summer 2006 from Jan-Feb SST relative to 3 climatologies

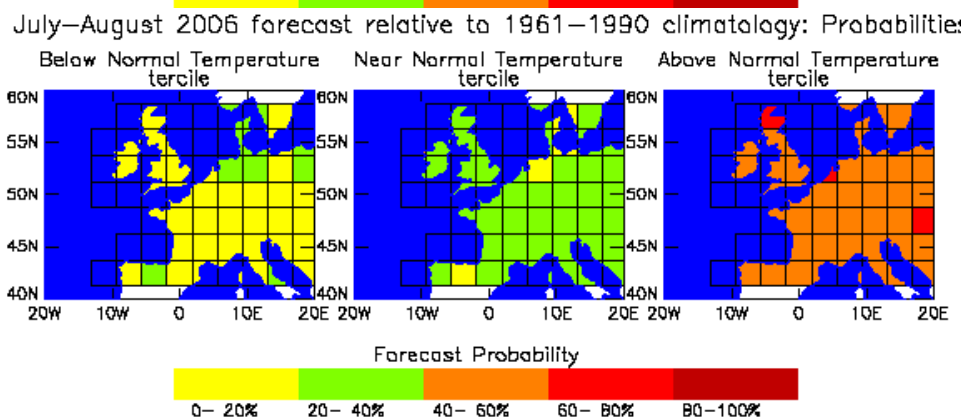
1987-2001



1971-2001

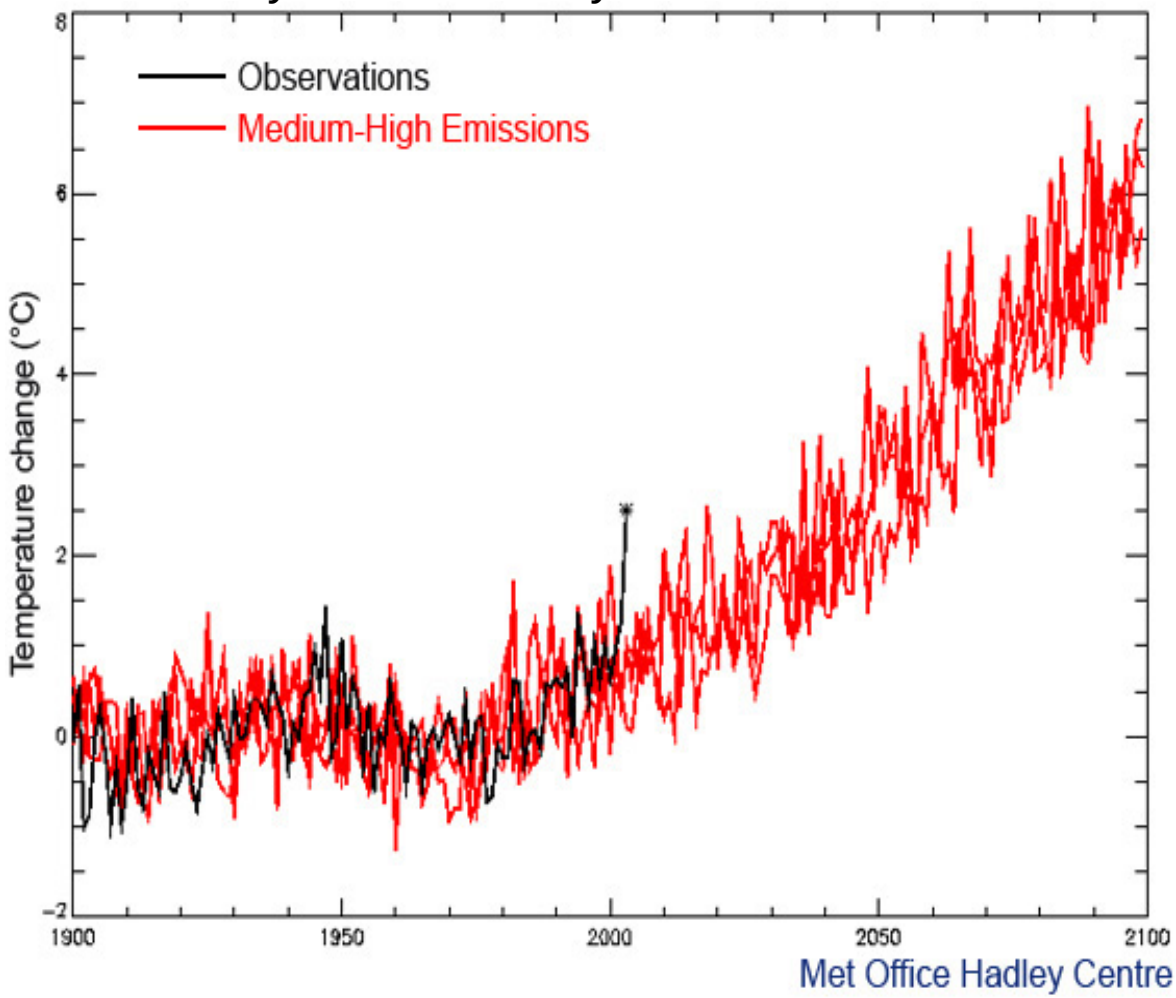


1961-1990



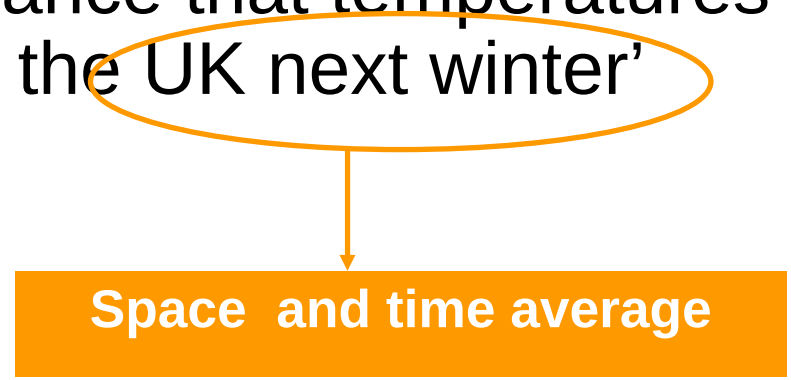
Reference period and climate change

European 2003 summer temperatures could be normal by 2040s, cool by 2060s



What is a seasonal forecast?

‘there is a 65% chance that temperatures will be below normal over the UK next winter’



Space and time average

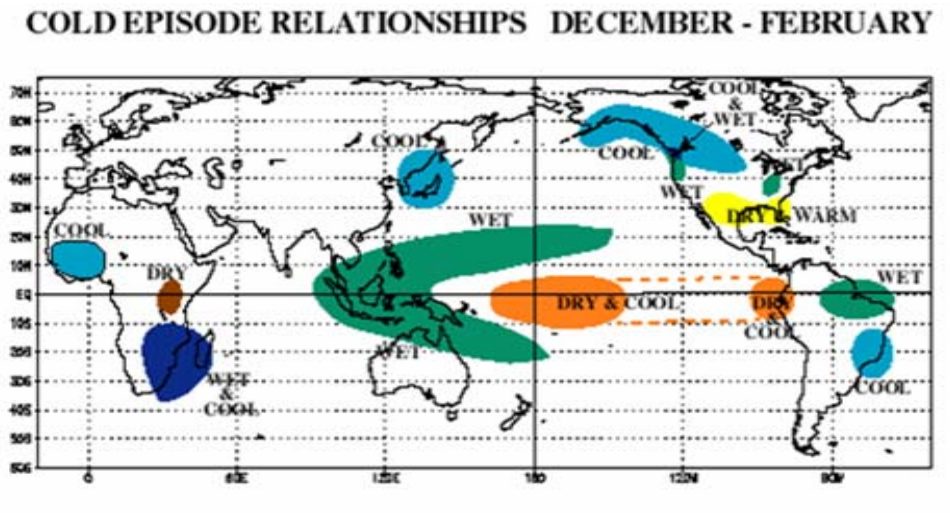
- Beyond a few days ahead we cannot predict conditions for a particular day

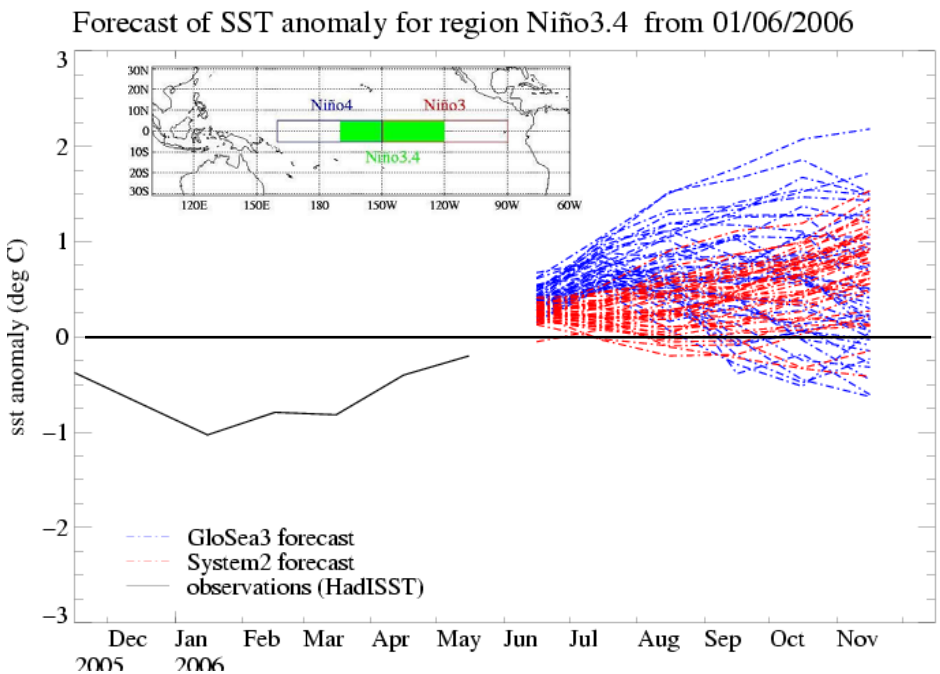
- Beyond a (very) few weeks ahead we cannot predict conditions for a particular week

Space and time average

Met Office Hadley Centre

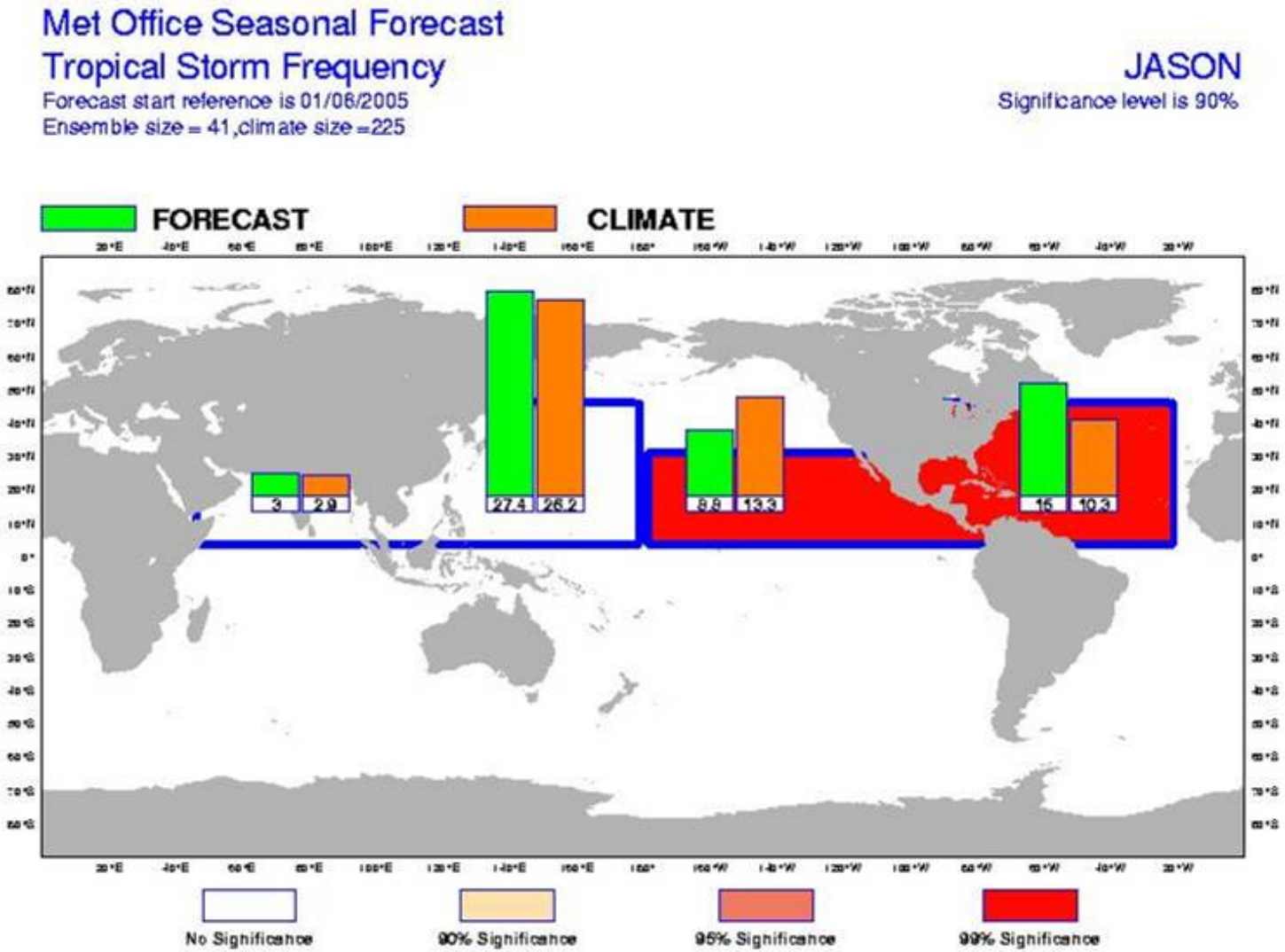
ENSO



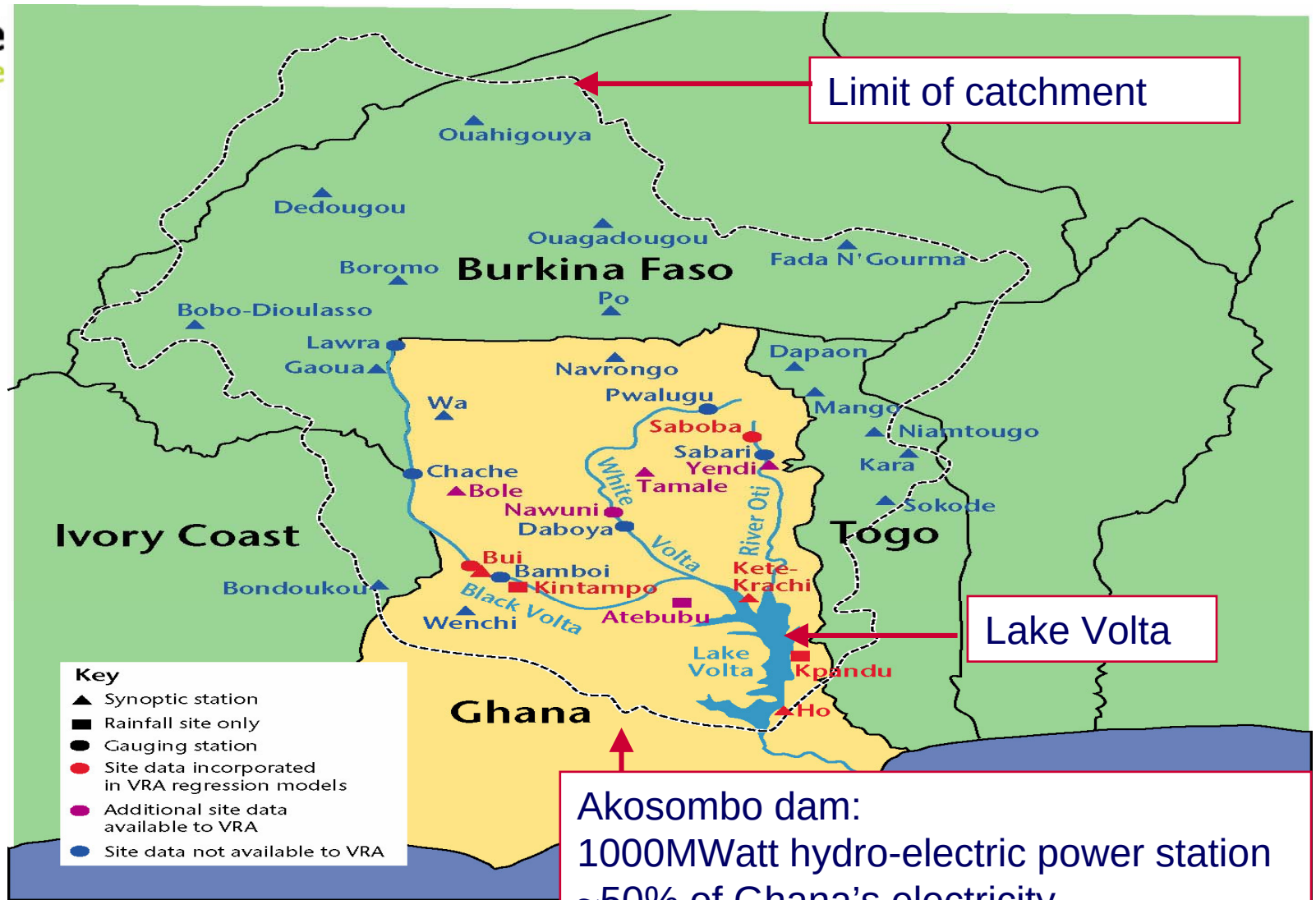


Space and time average

Tropical storm frequency: July-November, issued June



Space-time averaged



What is predictable at long range (and why)

- ‘climate’, not ‘weather’
- large-area averages, not localised events
- range of outcomes, with probabilities attached to them

Sources of predictability

- initial conditions
- slow-varying boundary conditions (SST, soil moisture, etc)
- external forcings (solar radiation, volcanoes, greenhouse gases)

Uncertainty in long-range predictions

Sources of uncertainty

- ‘measuring’ initial state
- model error
- internal variability (noise)
- evolution of external forcings
- methodology used for post-processing (bias removal, downscaling, etc)

To quantify uncertainty in the predictions: ensembles

Skill of long-range predictions

Is not meaningful for individual forecasts (which are probabilistic).

Skill scores specifically designed for probabilistic forecasts are used; they reflect average skill of the system.

It varies with

- region
- lead time
- time of year
- variable

Met Office long-range prediction systems and products

Long-range predictions systems

Monthly range

- 51-member ensemble, global coupled ocean-atmosphere model, 32-day range (ECMWF)

Seasonal range

- global coupled ocean-atmosphere model, version of HadGEM3 climate model
  - weekly 14-member ensembles, 6-month range (Met Office), combined into seasonal products once a month
  - monthly EUROSIP multi-model (Met Office, ECMWF, Meteo-France)
- statistical/empirical methods

  tropical rainy seasons, European summer temperatures, winter North Atlantic Oscillation (NAO), annual global temperature
- combinations of dynamical model and empirical methods

Decadal range

- Initialised predictions run 10+yrs ahead, 10 member ensemble (Met Office)

Long-range forecasting products and customers

Monthly:

- "The Monthly Outlook" for UK
- global forecast products

for energy traders, utilities, retail, MoD, used in Public Weather Service (PWS) seasonal forecasts for Europe/UK

Seasonal (PWS):

- global and regional seasonal forecasts, updated monthly

for world's National Meteorological Services, Regional Climate Outlook Forums, Drought Monitoring Centres of Africa, MoD, DfID, public. (*Met Office is one of 9 centres (GPCs) recognised by WMO*).

Seasonal and decadal (business/commercial/consultancy):

- energy industry, DfID, EA, MoD, Volta River Authority Ghana.

Product formats (general)

Expected conditions averaged over a time period (or event counts eg. tropical storms)

- weekly periods out to 1 month ahead
- 3-month periods from 1 to 6 months ahead
- multi-year averages from 1+ year ahead

Probability format, ‘broad-brush’ events eg.

- probabilities for 3 equi-probable (tercile) categories

  below/near/above climate average for the location and time of year
- probabilities for outer-quintile categories (20^{th}/80^{th} percentiles)

Availability:

- every week to 1-month range
- every month to 6-month range
- every year to decadal range

Monthly forecasting system

Model used: ECMWF 51-ensemble coupled VarEPS system, run once each week to 32 days ahead

- atmosphere resolution: first 10 days TL399 62L, then TL255 62L (coupled)

Range of global and UK products generated at Met Office

- Tmean, Tmax, Tmin, precip, sunshine (UK only)
- averages for Monday-Sunday (‘working week’) periods:

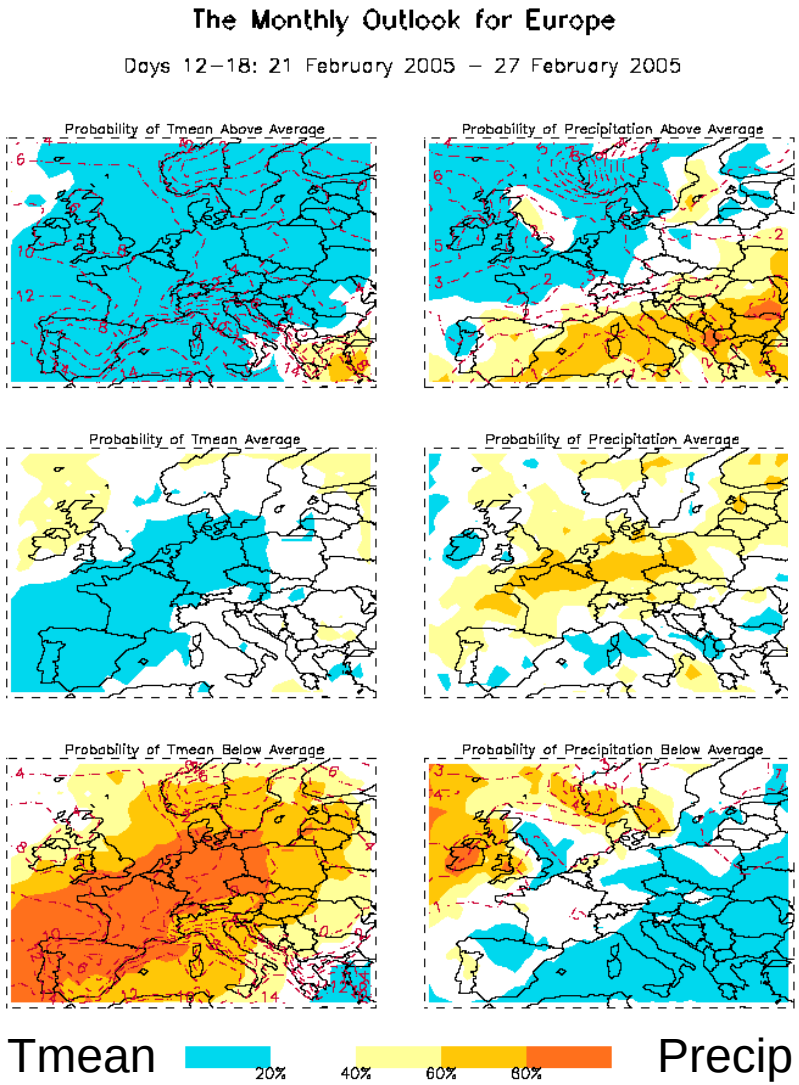
  two 7day periods (5-11 & 12-18 days ahead)

  one 14-day period (19-32 days ahead)

Issued in probabilistic and (for UK) deterministic format

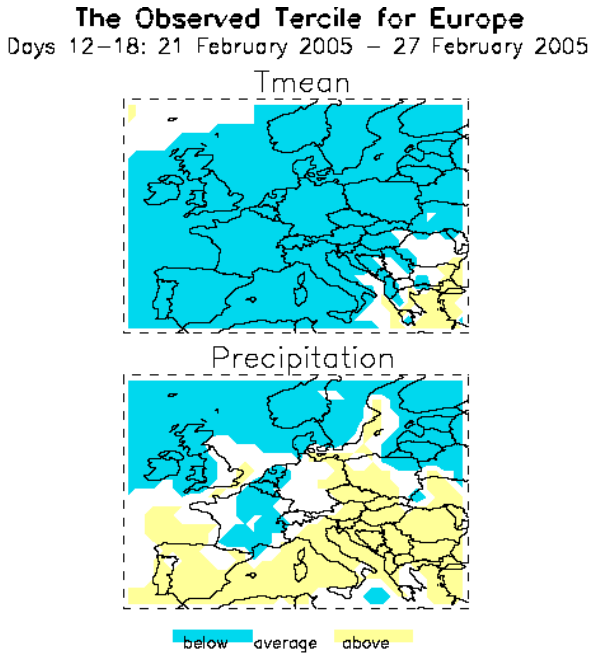
Frequency: weekly from initial conditions 00GMT Thursday

Example global capability tercile probability forecast – Europe, days12-18



Verification

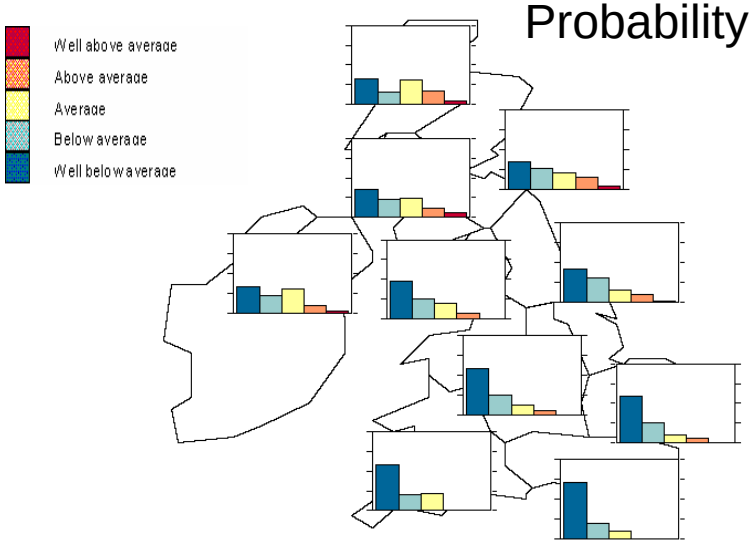
(ECMWF operations)



The Monthly Outlook

Example UK 12-18 day temperature forecast

Probability forecast



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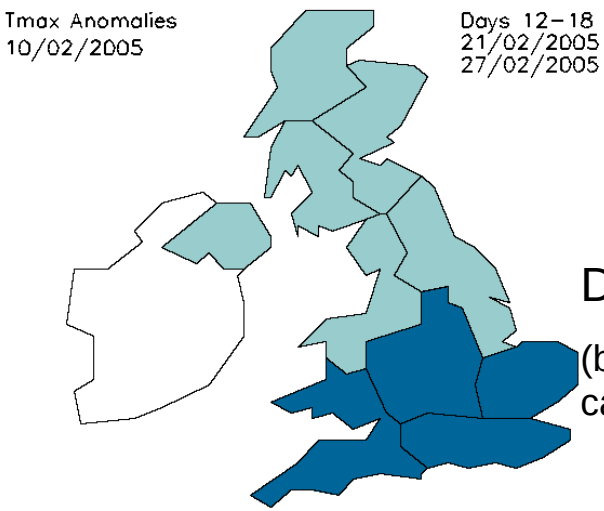
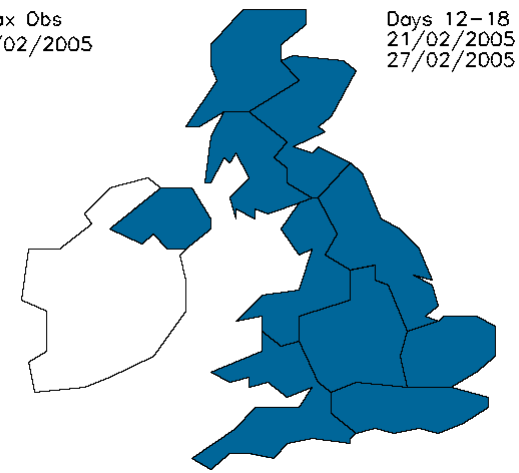


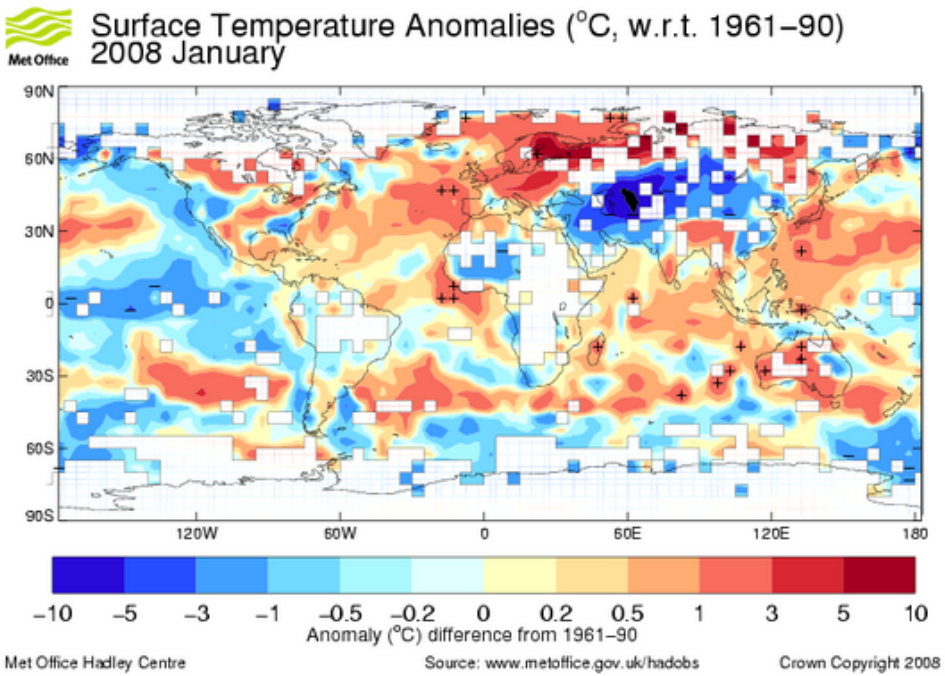
Deterministic forecast

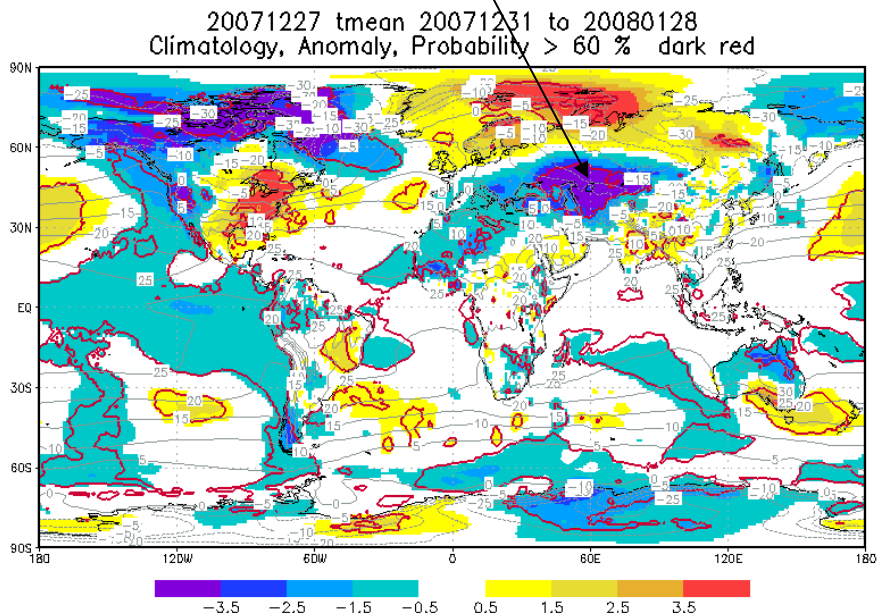
(based on most probable category or ensemble mean)



Monthly forecasting: example: January 2008

High probability (>60%) of lower quintile





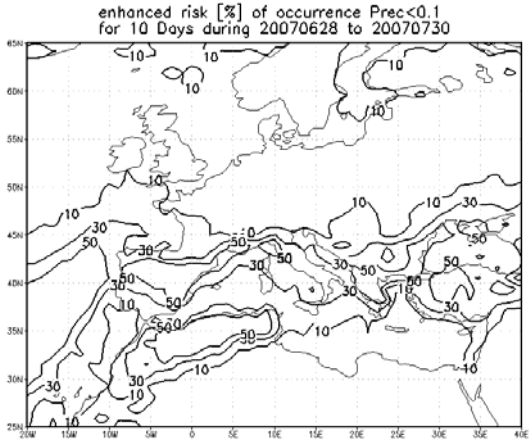
Lowest global-mean January temperature since 1998: impacts in China

Forecast product generated using ECMWF varEPS initialised 27 December 2007

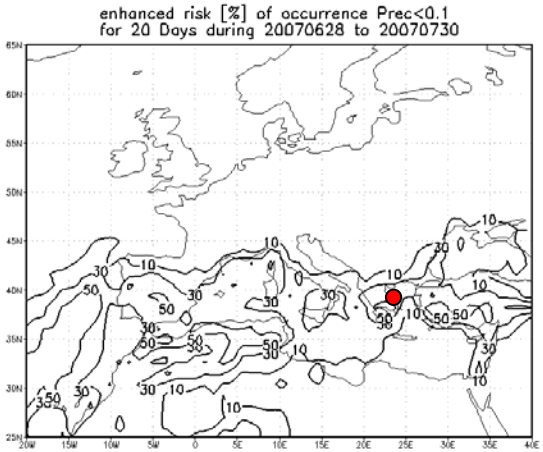
Monthly prediction informing drought risk:

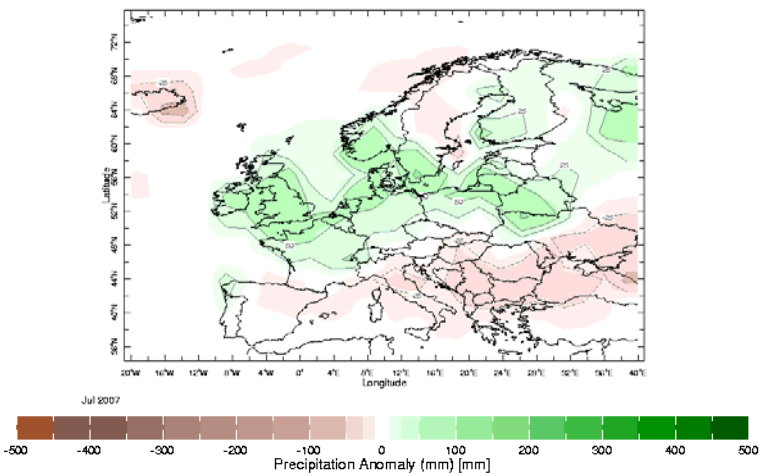
Example: southern Europe, July 2007

Enhanced risk of >10 consecutive days with pp<0.1mm

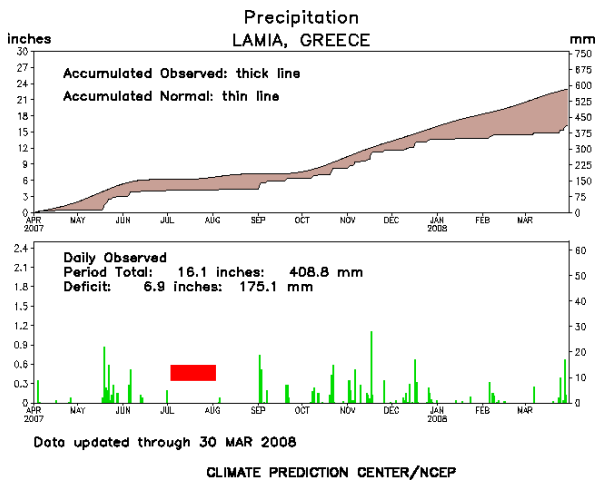


Enhanced risk of >20 consecutive days with pp<0.1mm





CAMS_OPI

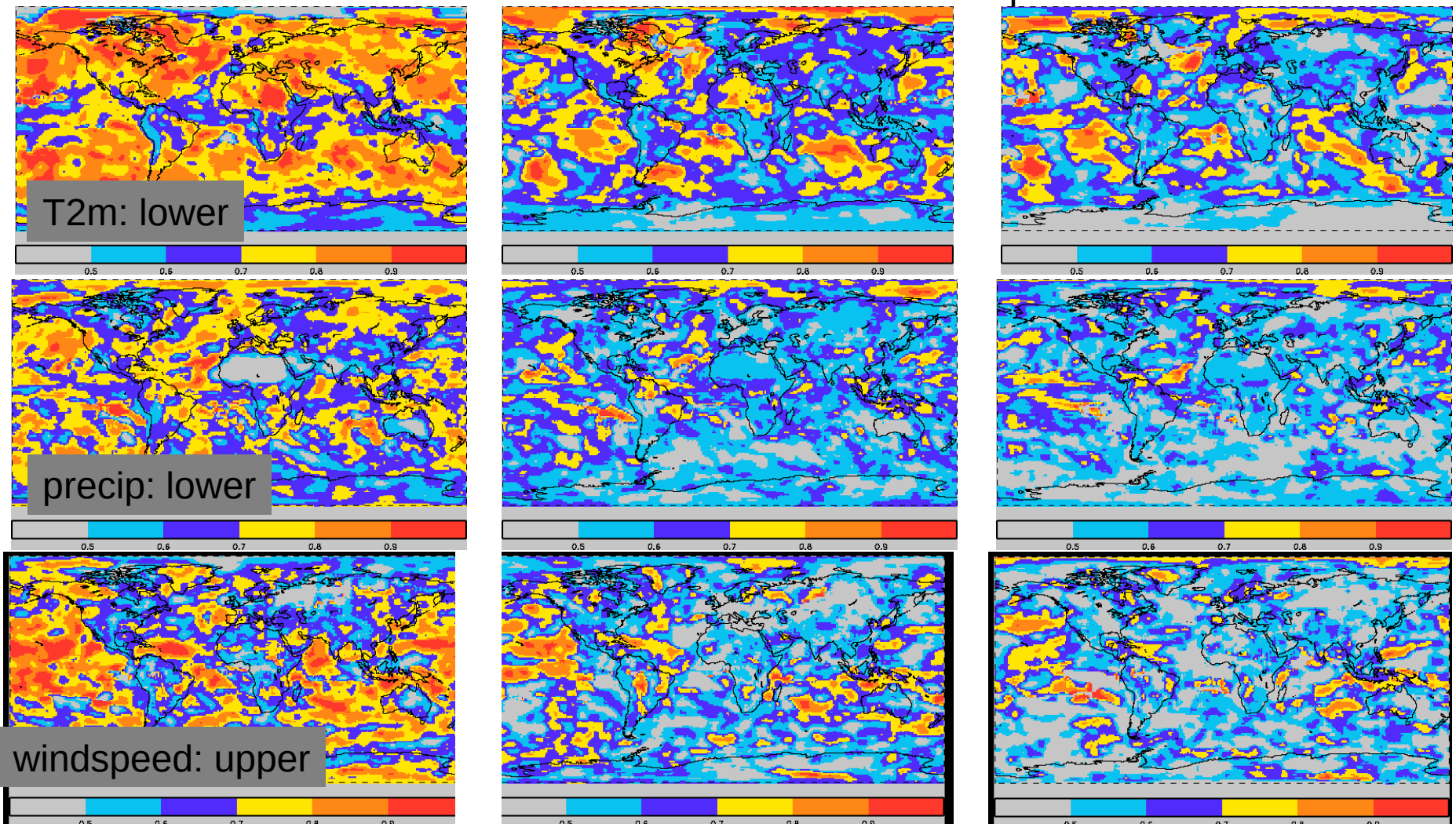


NOAA CPC

Global ROC scores for quintile categories of period-mean temperature, rainfall, windspeed

Met Office

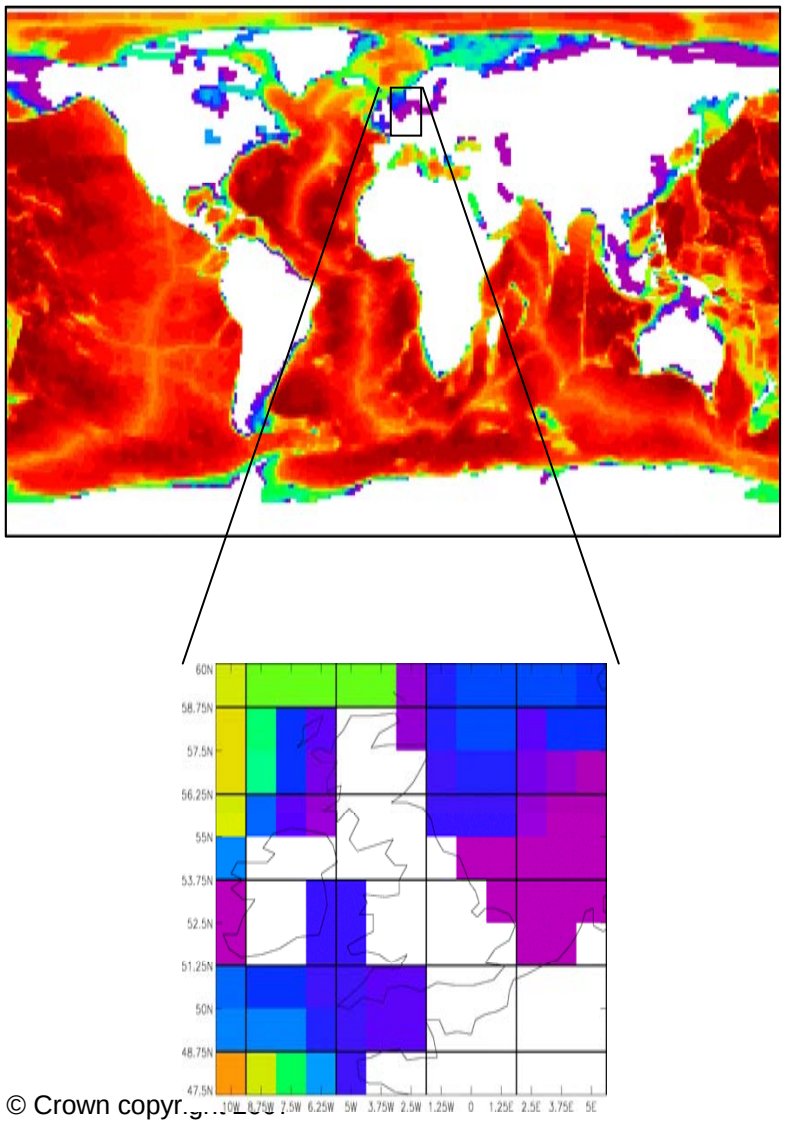
Calculated over all forecasts issued in the period December - February



Met Office

seasonal

Met Office seasonal forecasting system : GloSea

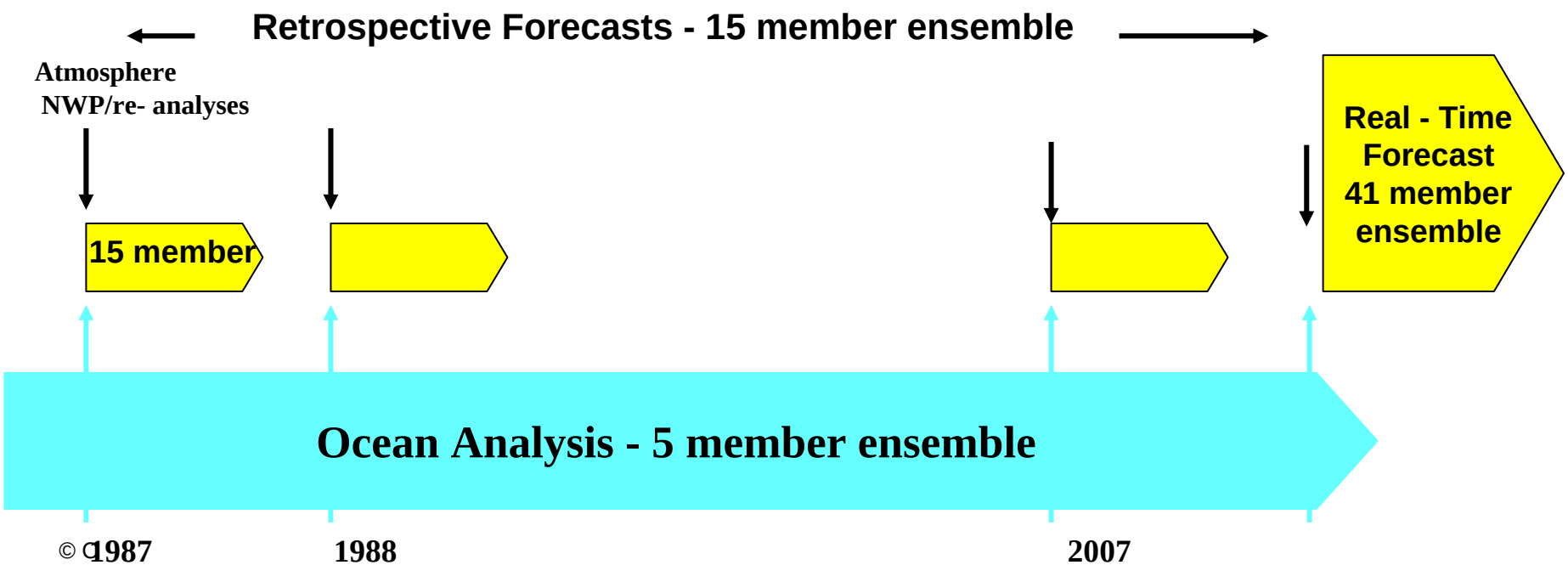


HadCM3 climate model physics and dynamics:

- 2.5° x 3.75° x 19L AGCM
- (1.25° to 0.3°) x 1.25° x 40L OGCM
- coastal tiling scheme

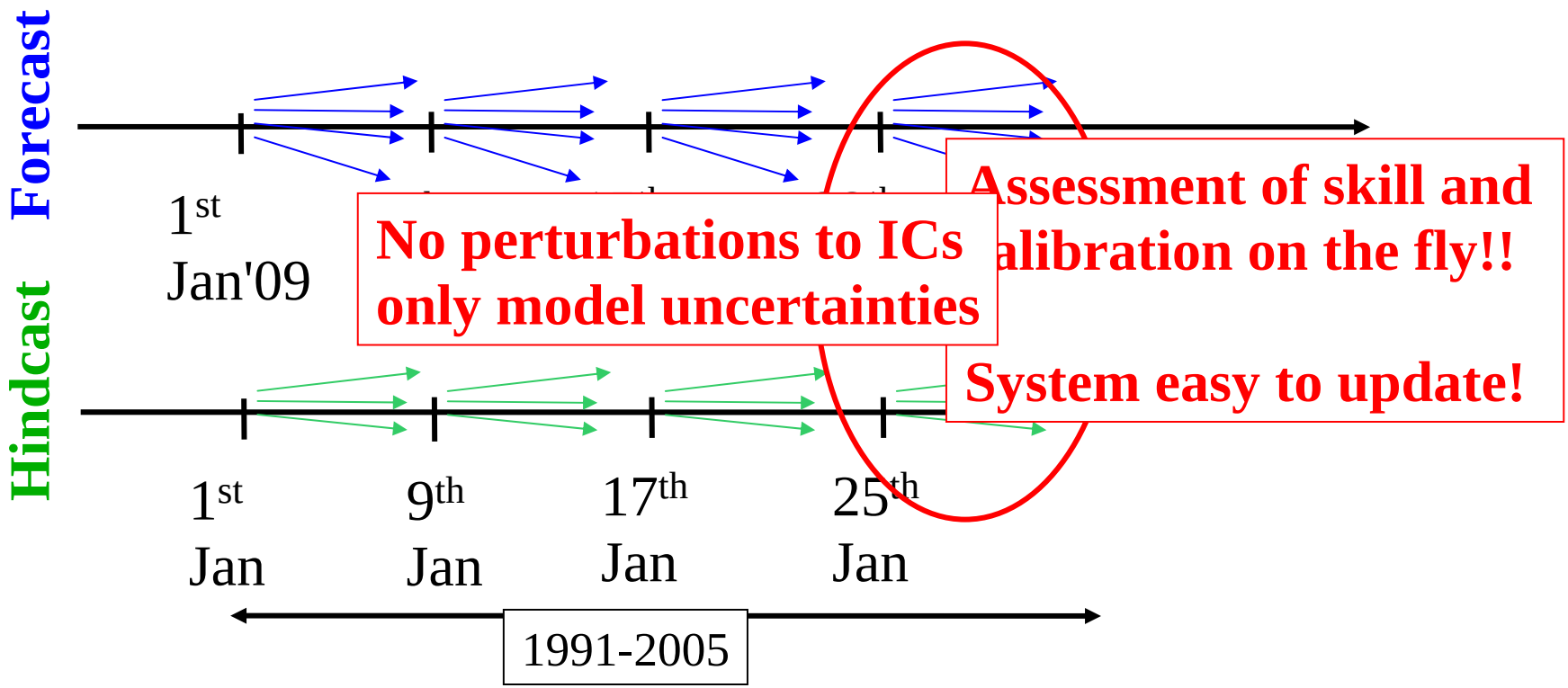
Seasonal forecasting system : GloSea

- enhanced version of the Hadley Centre Climate model HadCM3
- 41-member ocean-atmosphere global forecast ensemble
- run to 6 months ahead from initial conditions on 1st of each month
- 5 ocean analyses from perturbed wind stresses
- ocean analyses further perturbed with instantaneous SST perturbations
- hindcast period, 1987-present (1987-2001 used for calibration)
- run at ECMWF as part of developing European multi-model – EUROSIP



New system **(GloSea4)**

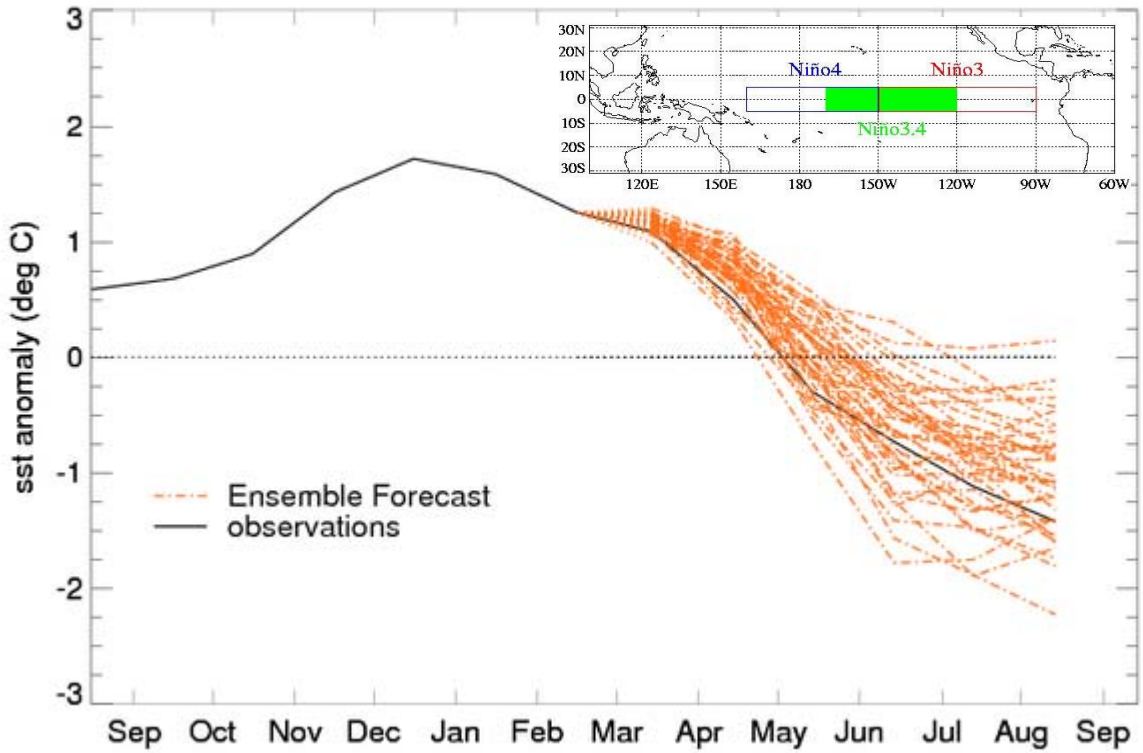
- **Hindcast:** Run **real time**; ~ 15 yrs, ~3 members/week, 6-months fcst
- **Forecast:** Run real-time **weekly;** ~10 members/week, 6-months fcst.



GloSea3 vs. GloSea4

	GloSea3 (current system)	**GloSea4** (new system)
Model	HadCM3 (N48L19 – 1/3L40)	HadGEM3 (N96L38-ORCA1L42)
Initialization	atmosphere/soil: ECMWF ocean: UM-ocean 3D-OI	atmosphere/soil/sea-ice: Met Office Ocean: NEMO 3D-OI
IC uncertainties	wind stress and SST perturbations added to a central analysis	weekly lagged approach
Model uncertainties	None	RP + SKEB2
Forecast ensemble	41-members (monthly bursts from 1st)	~ 10 members per week
Hindcast ensemble	Run *a priori* off-line 15-members / 15-years (1987-2001) ERA-40	Run on real-time ~12-members / ~15-years (1991-2005) ERA-interim

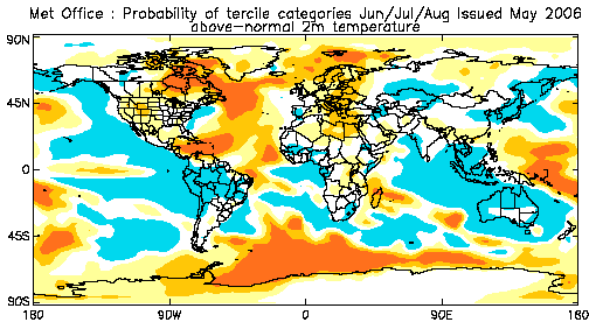
Example seasonal products from GloSea
(sea-surface temperature – Niño indices)



Products available at:
http://www.metoffice.gov.uk/science/specialist/seasonal/

Example seasonal products from GloSea
(probabilities of tercile and quintile categories)

Met Office



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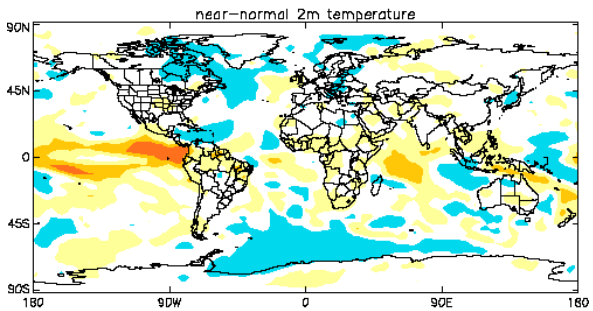
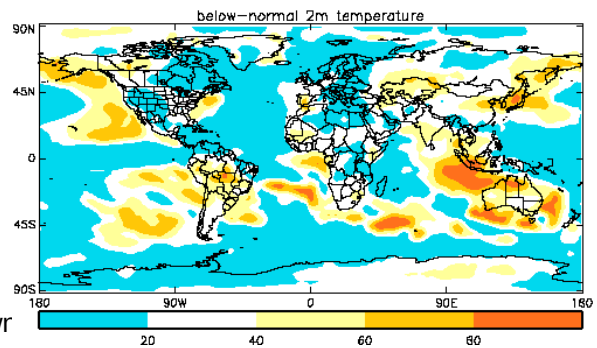
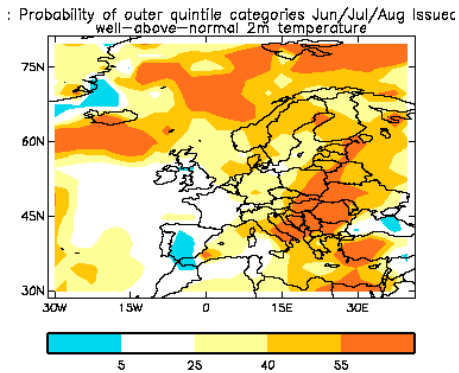


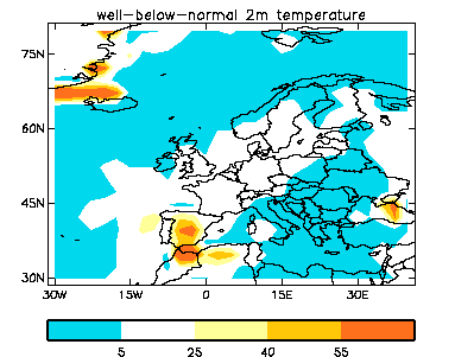
P(average)



P(below)



P(well-above)



P(well-below)

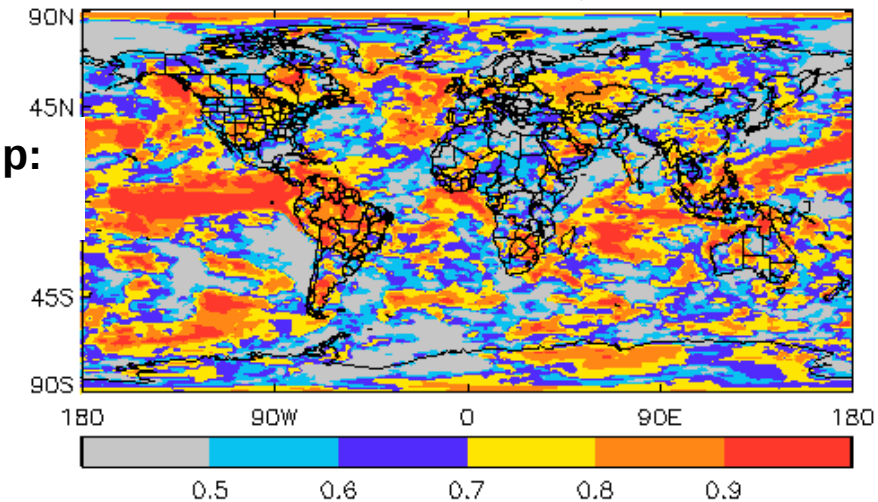
Example: skill of seasonal forecasts

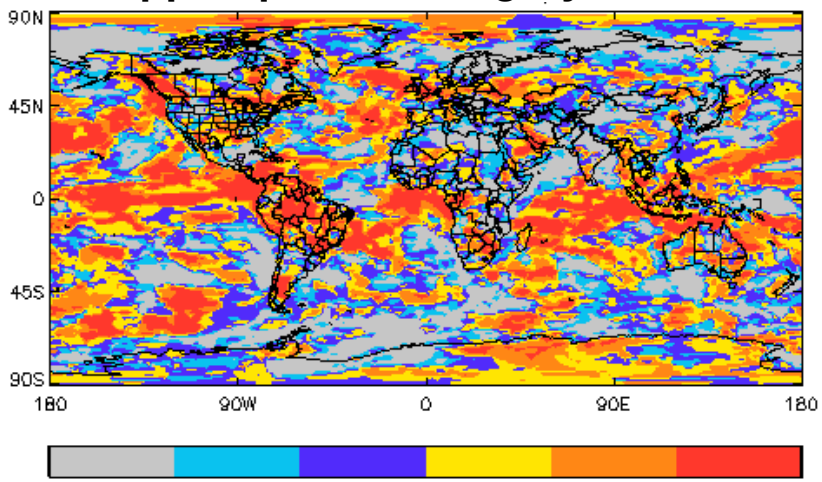
ROC scores for 1-month-lead predictions

Upper tercile category

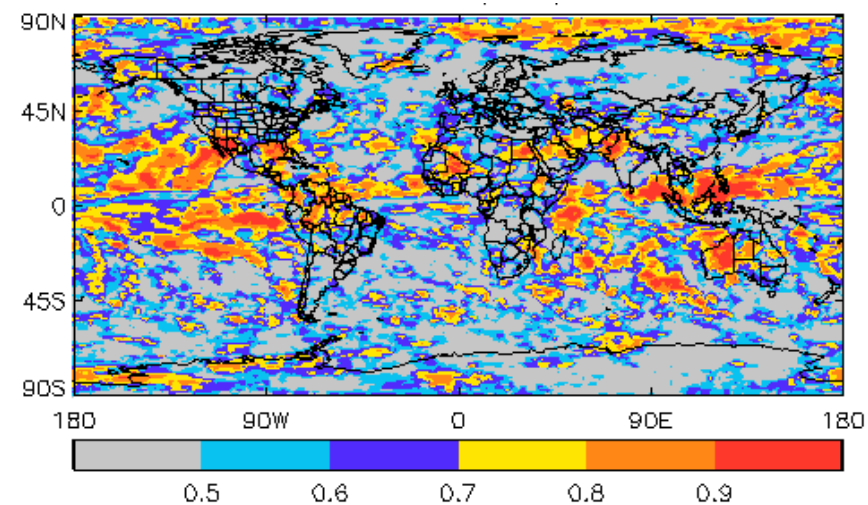
Upper quintile category

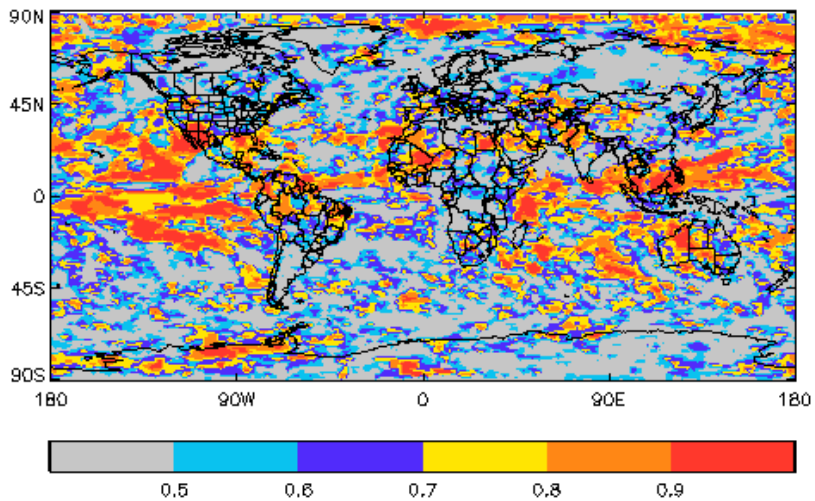
Temp: DJF



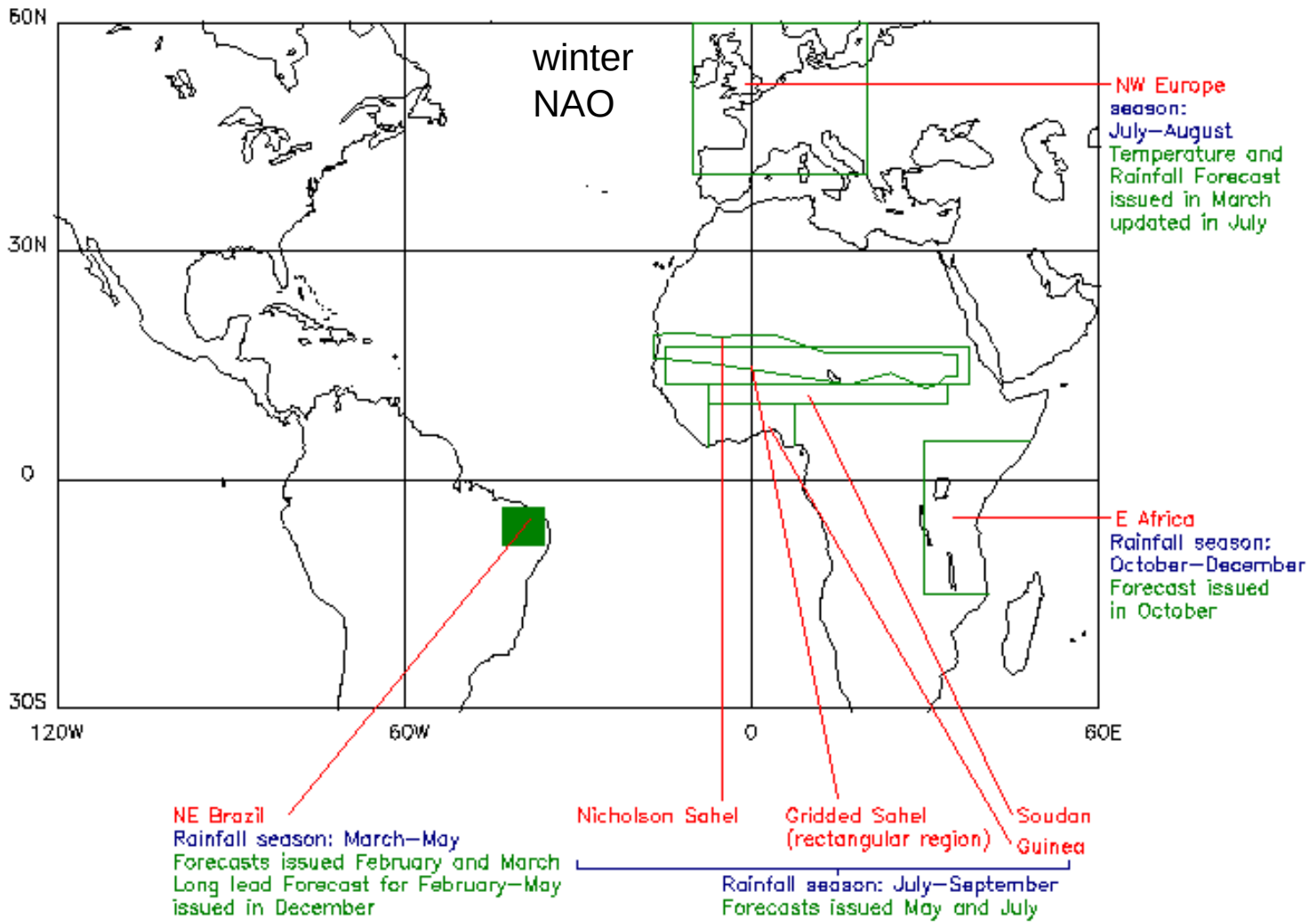


Precip: JFM



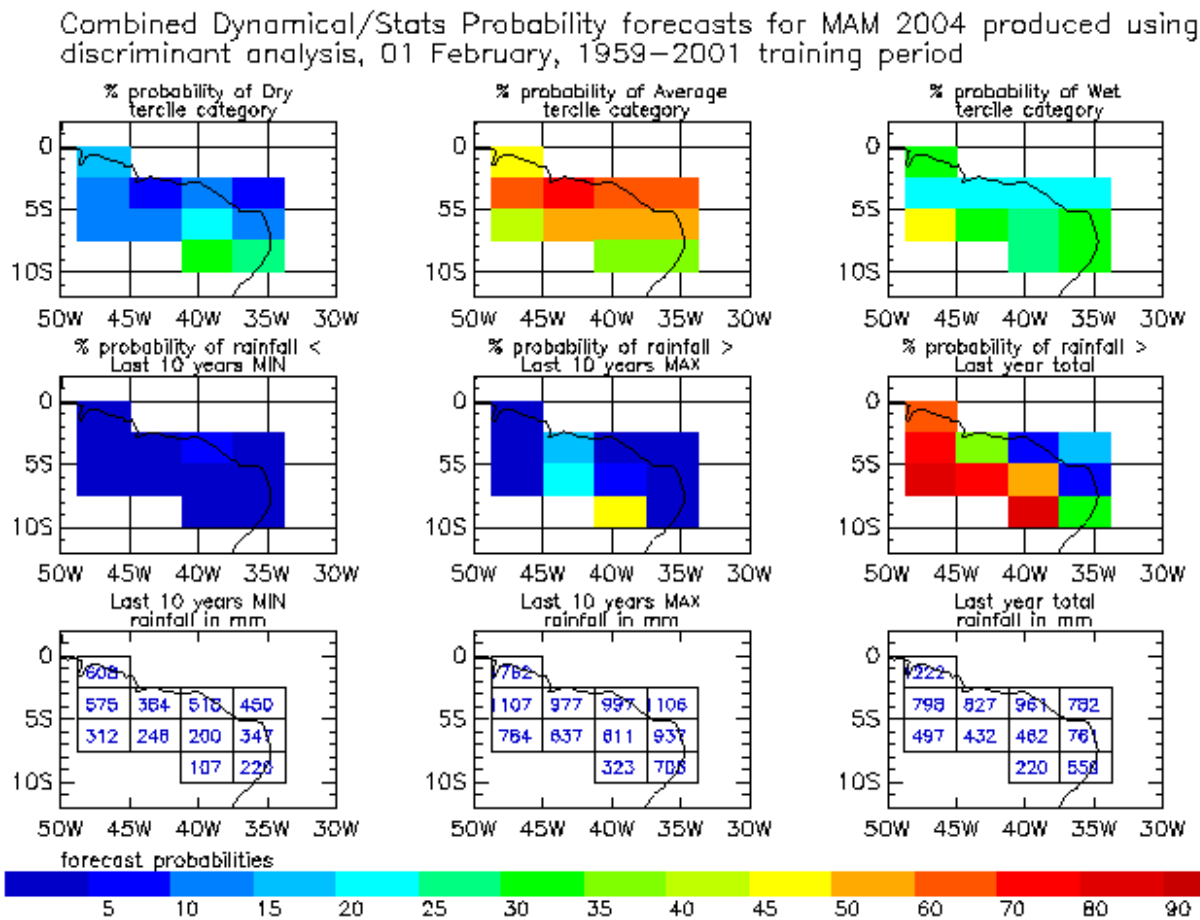


Statistical forecasts for specific regions



Combined dynamical/statistical products

North East Brazil: March-May precipitation



probabilities for tercile categories

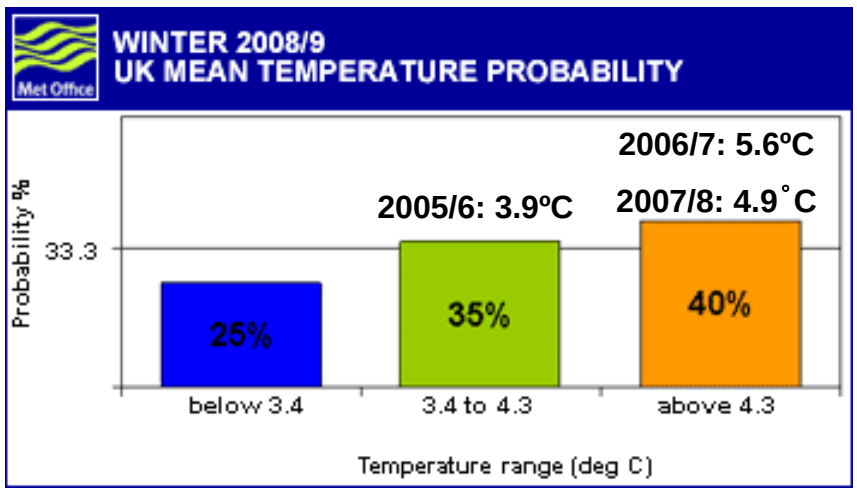
risk of ‘extreme’

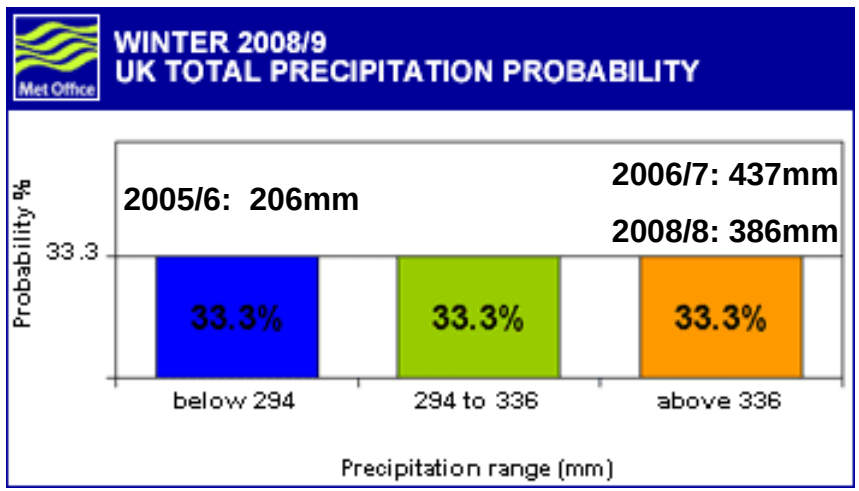
reference (climatological) data

UK-mean temperature, precipitation

Probability of tercile categories, Dec-Jan-Feb

tercile categories defined to be equally likely on 1971-2000 climatology



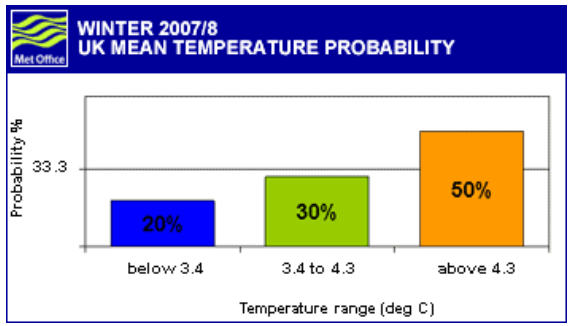


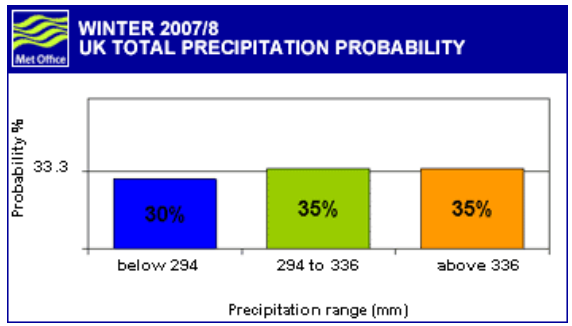
temperature
(1971-2000 mean = 3.7˚C)

precipitation
(1971-2000 mean = 332mm)

Public and business UK seasonal forecast products

Public service

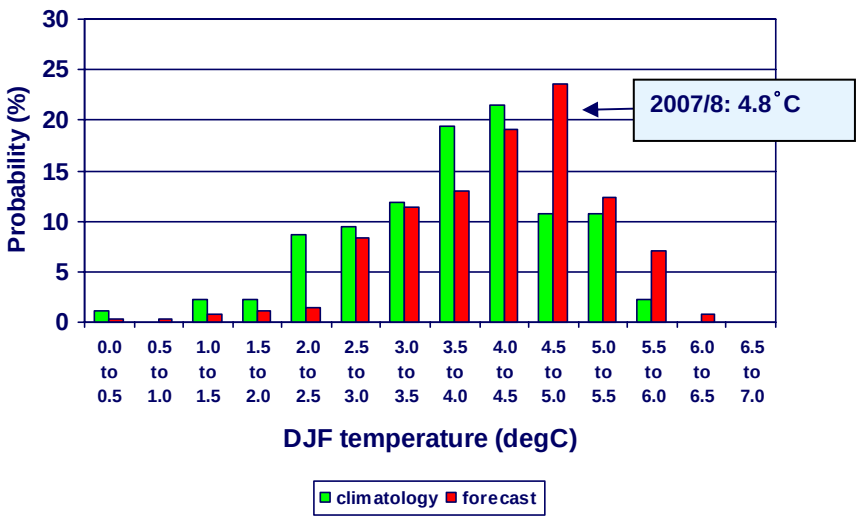


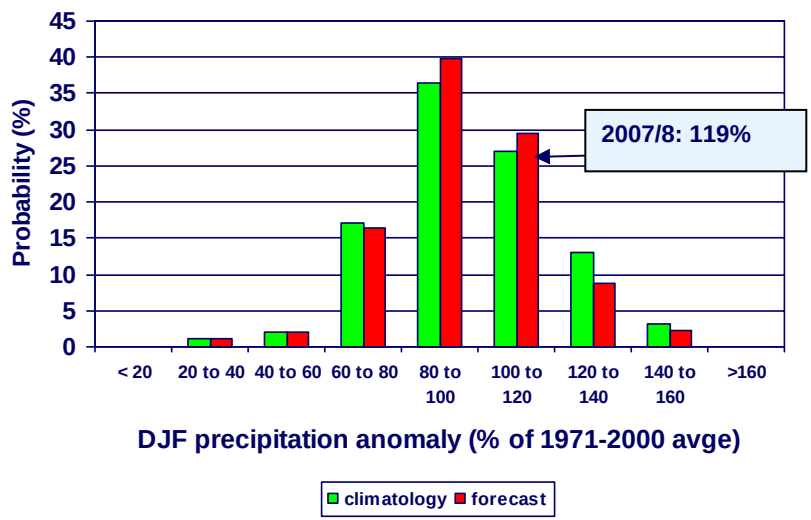


Use 'coarse' predicted pdf to skew climate pdf

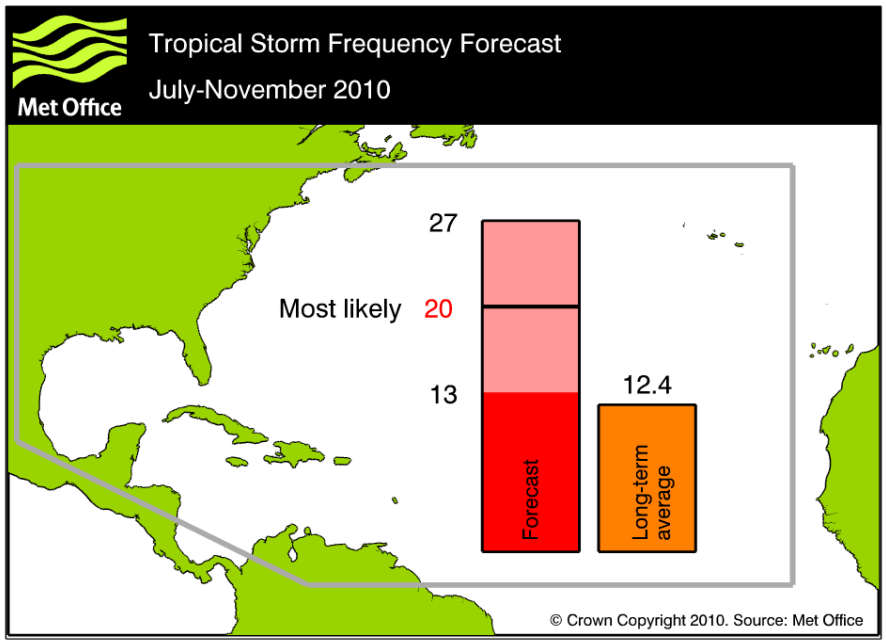
Use 'coarse' predicted pdf to skew climate pdf

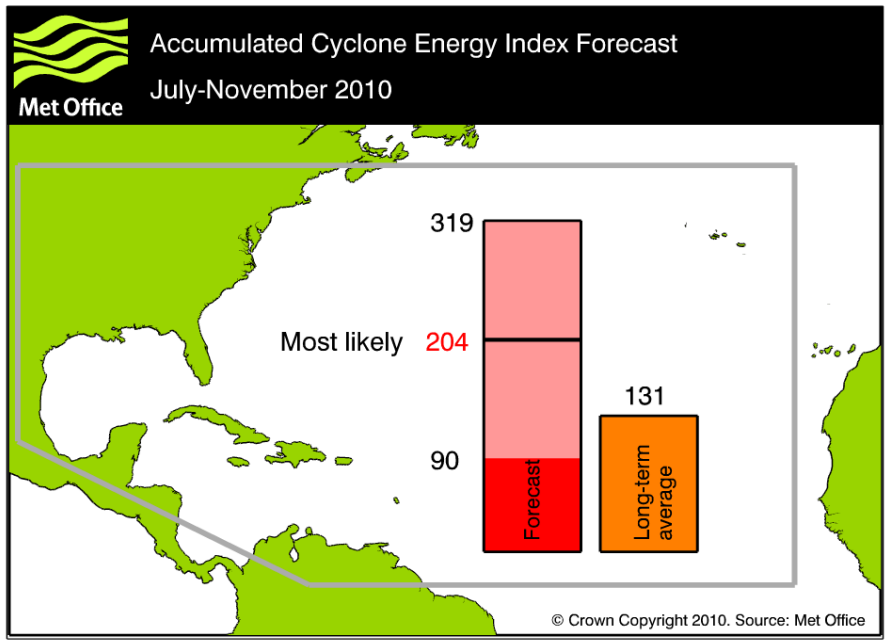
Business consultancy





Tropical storm seasonal forecasts for the North Atlantic: 2010 Met Office forecast



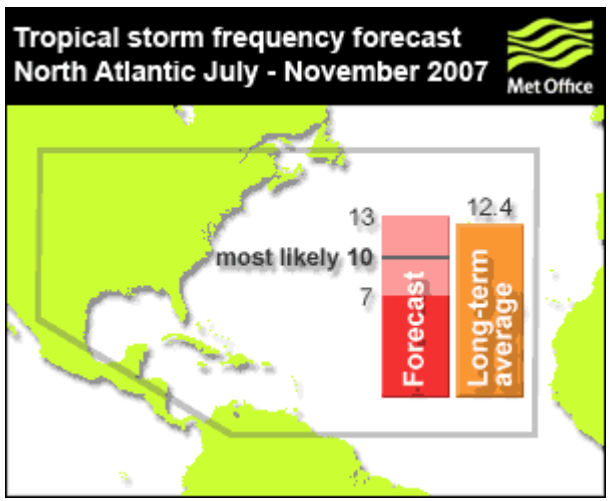


2010 public forecast is a multi-model forecast using output from the Met Office and ECMWF forecasting systems

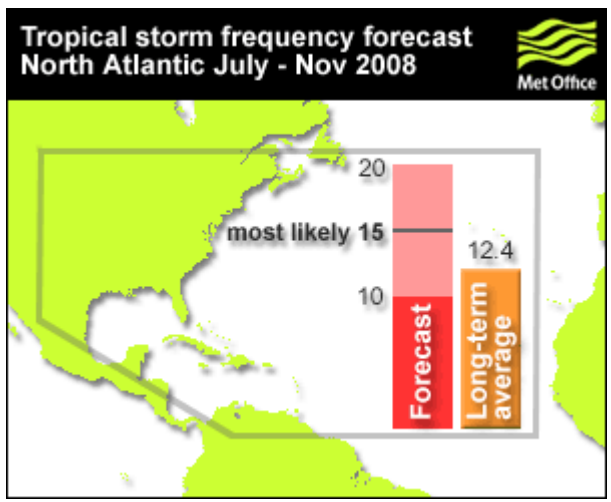
Forecasts are for above-normal activity in 2010

ACE index is a measure of the collective strength and duration of storms in the season.

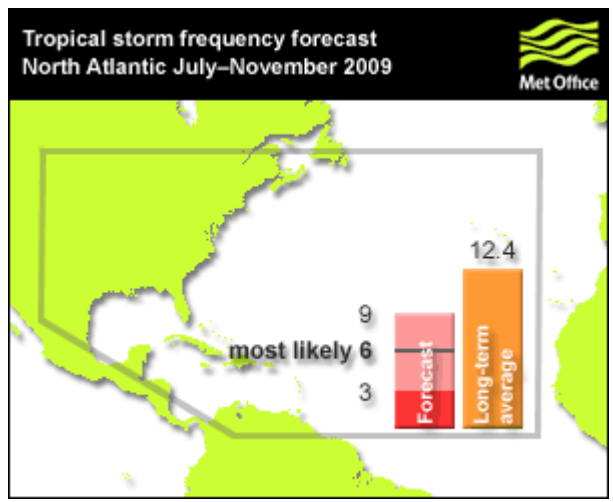
Tropical storm seasonal forecasts for the North Atlantic



2007
Observed: 12



2008
Observed: 15

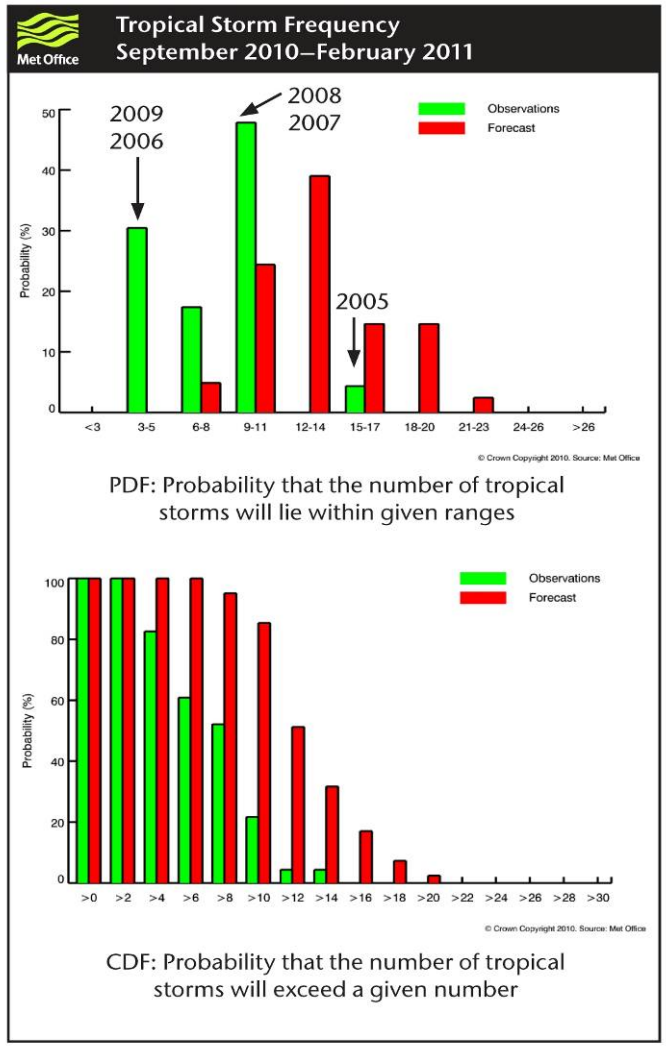


2009
Observed: 9

Tropical storm seasonal forecasts for the North Atlantic: probabilistic forecasts

- **Probabilistic forecasts**
- A detailed forecast report with information on:
  - **probabilities** and
  - the **strength and credibility** of signals within the forecast
- is produced alongside the headline storm number prediction each season.

- Forecasts are also produced for the Accumulated Cyclone Energy

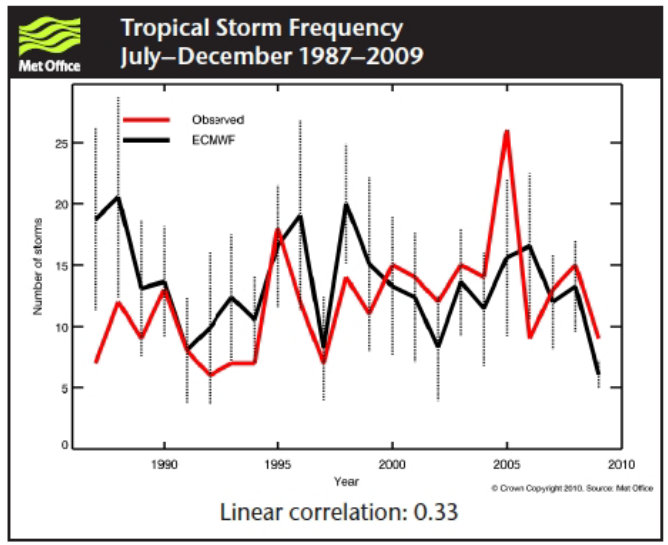


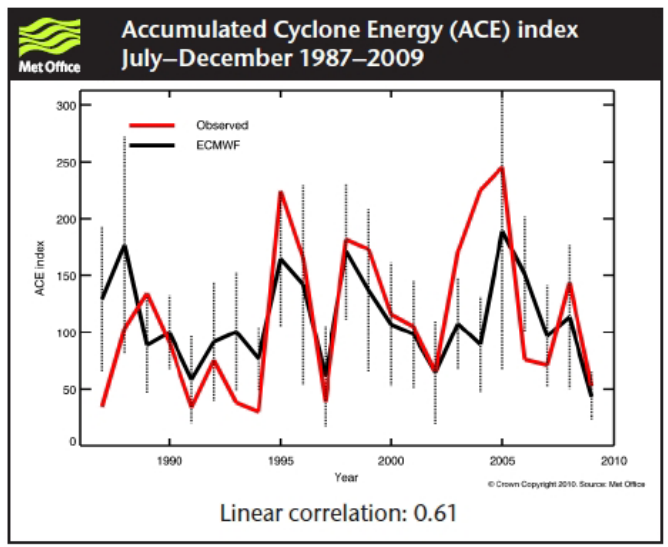
Seasonal forecast skill 1987–2009

- **Forecasts are generated monthly using data from GloSea4 and ECMWF**
- Skill (linear correlation) of 6-month forecasts from March to September are detailed below

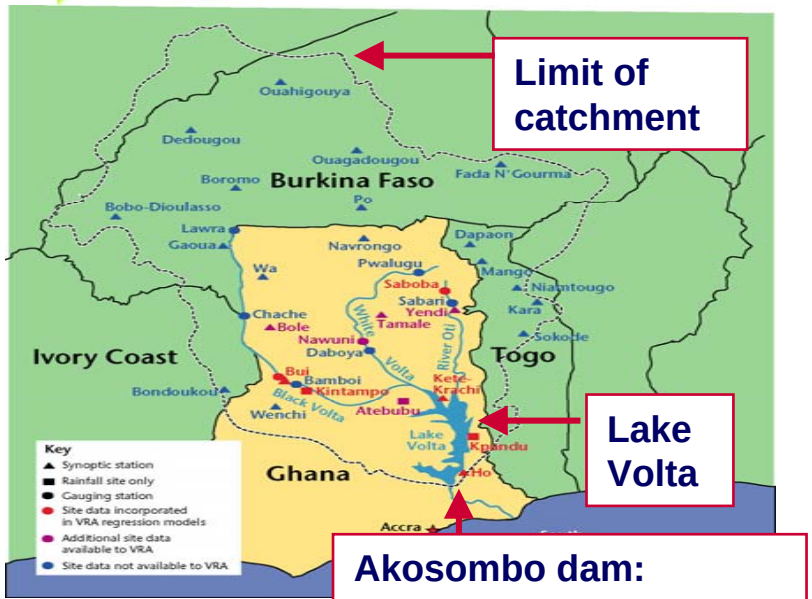
	Skill (linear correlation)						
	Mar	Apr	**May**	Jun	Jul	Aug	Sep
TS	0.26	0.49	**0.59**	0.33	0.55	0.50	0.42
ACE	0.14	0.25	**0.74**	0.61	0.56	0.46	0.17

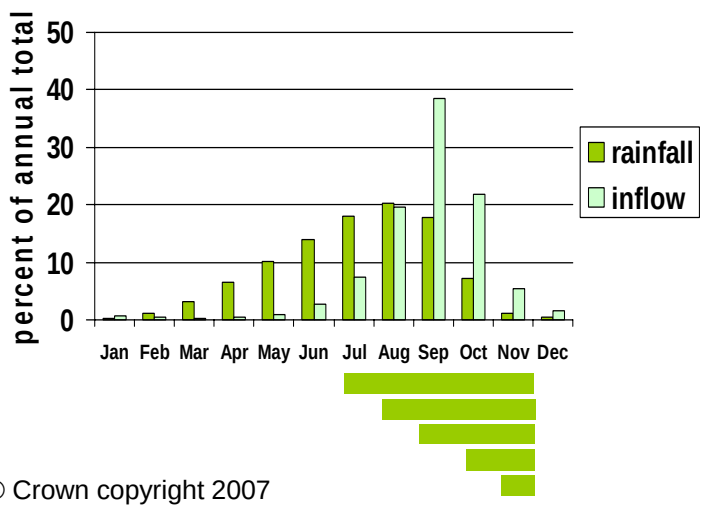
Perfect forecasts would have a skill of 1.0



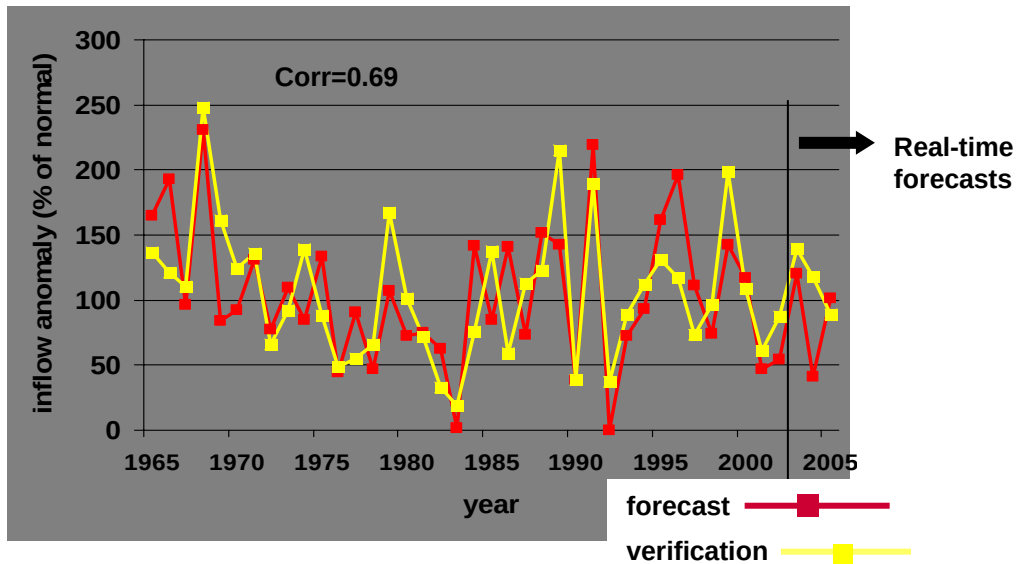


Water volume inflow, lake Volta





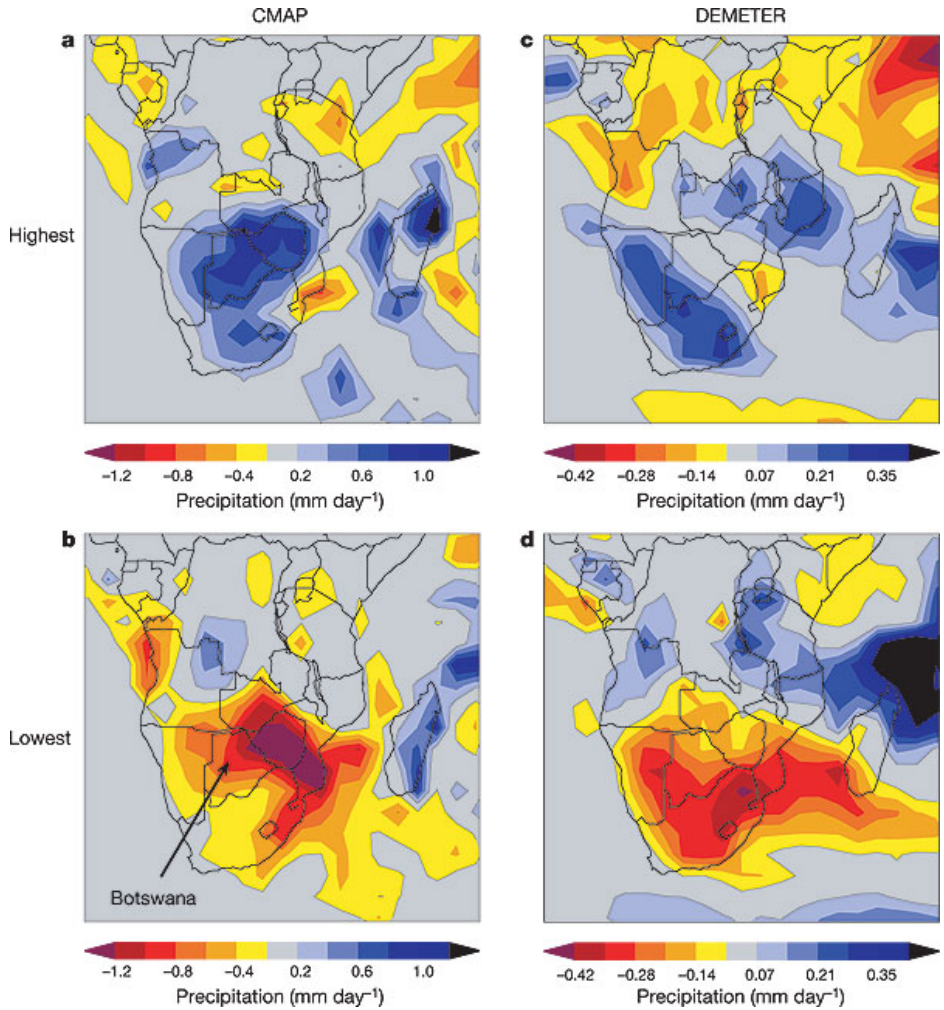
June issue forecasts of Jul-Oct inflow



Regression:GloSea+statistical+catchment observations

Malaria prediction – Botswana

Observed (left) and predicted (right) rainfall for 5 years with highest (top) and lowest (bottom) malaria incidence in Botswana



(Thomson et al, Nature, Feb 2006)

Met Office long-range systems and products

Seasonal forecasts to 6-months ahead, every month

Forecasts to one month ahead, every week

Decadal forecasts, when deemed necessary

A range of methods is used:

- ECMWF monthly ensemble system
- Met Office (and multi-model) seasonal ensemble prediction systems
- empirical/statistical methods
- combined dynamical/statistical
- DePreSys decadal prediction system
- ‘expert judgement’

Forecast products have different characteristics from weather forecasts: probabilistic, period average (or frequency counts), broad categories

Key future development areas

Improve seasonal prediction skill (new prediction system, using new Hadley Centre climate model, HadGEM3) - July 2009:

- particular research focus on regional predictions
- ensemble initialisation.

Increase range of forecast products (eg. storminess, frequency counts, ‘extremes’).

Increase spatial detail (downscaling).

Work with users to improve usefulness and communication of long-range forecasts.

Link with application models – crops, health, hydrology.

Link with present day climate stresses.

Build capability to deliver climate products on monthly, seasonal, decadal (and beyond) timescales.

Information and operational products

Seasonal forecast information pages:

http://www.metoffice.gov.uk/science/specialist/seasonal

Information on monthly forecasting system and products:

contact bernd.becker@metoffice.gov.uk

The end

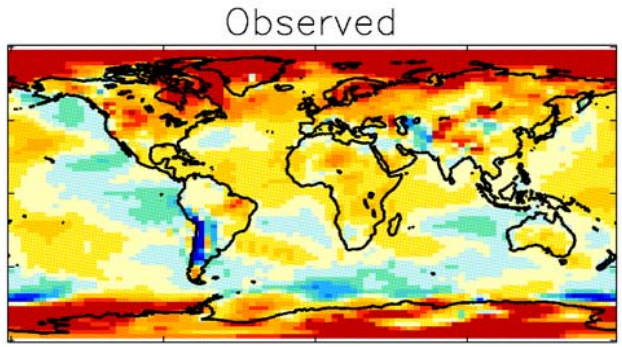
Met Office

decadal

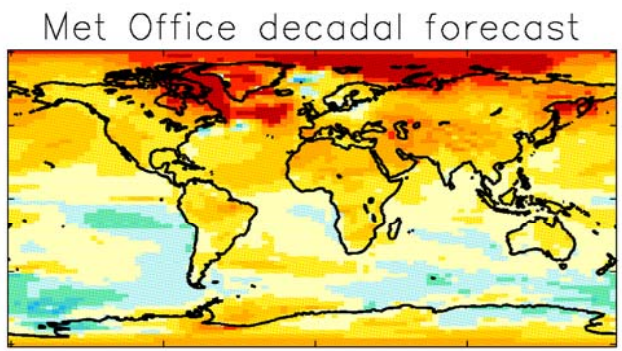
Decadal prediction system (DePreSys)

- HadCM3 (coupled global climate model)
- Include changes in greenhouse gases and sulphate aerosols (SRES B2 scenario – intermediate changes)
- Repeat previous 11-year solar cycle in forecasts
- Decay volcanic aerosol from the start of a forecast
- Include initial condition information:
  - Atmospheric winds, temperature and surface pressure
  - Ocean temperature and salinity
  - Assimilate as anomalies to avoid model drift

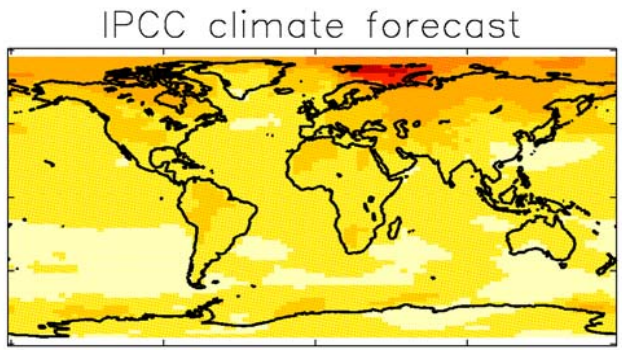
DePreSys: assimilation of observed state improves prediction skill relative



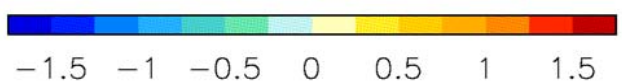
Observed surface temperature anomalies June 2005 to February 2008 (relative to 1979-2001 baseline)



Decadal system prediction, from June 2005:
includes greenhouse gases
AND influence of initial ocean-atmos. state
(data assimilation)

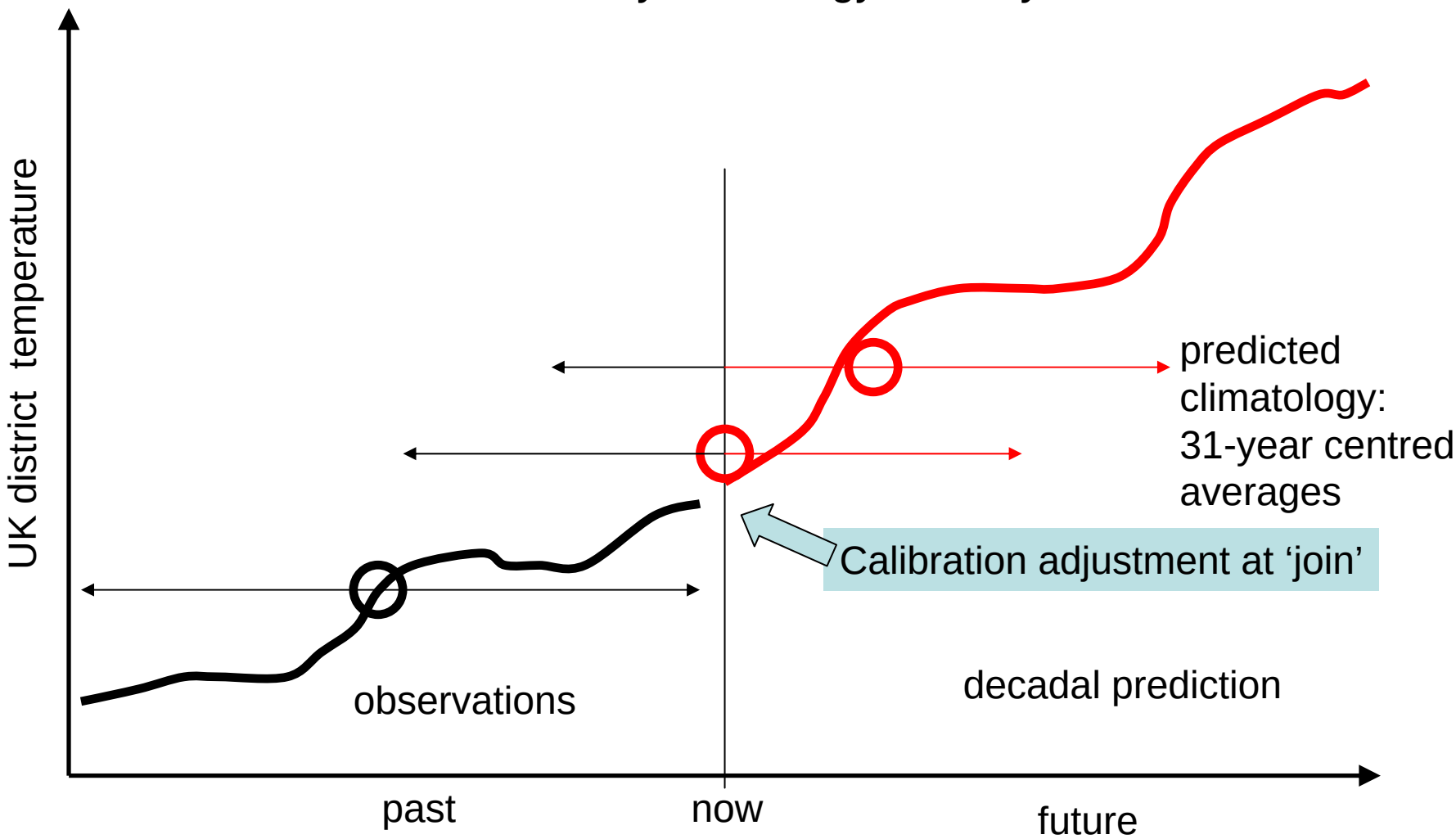


Equivalent prediction from IPCC AR4:
impact of greenhouse gases only

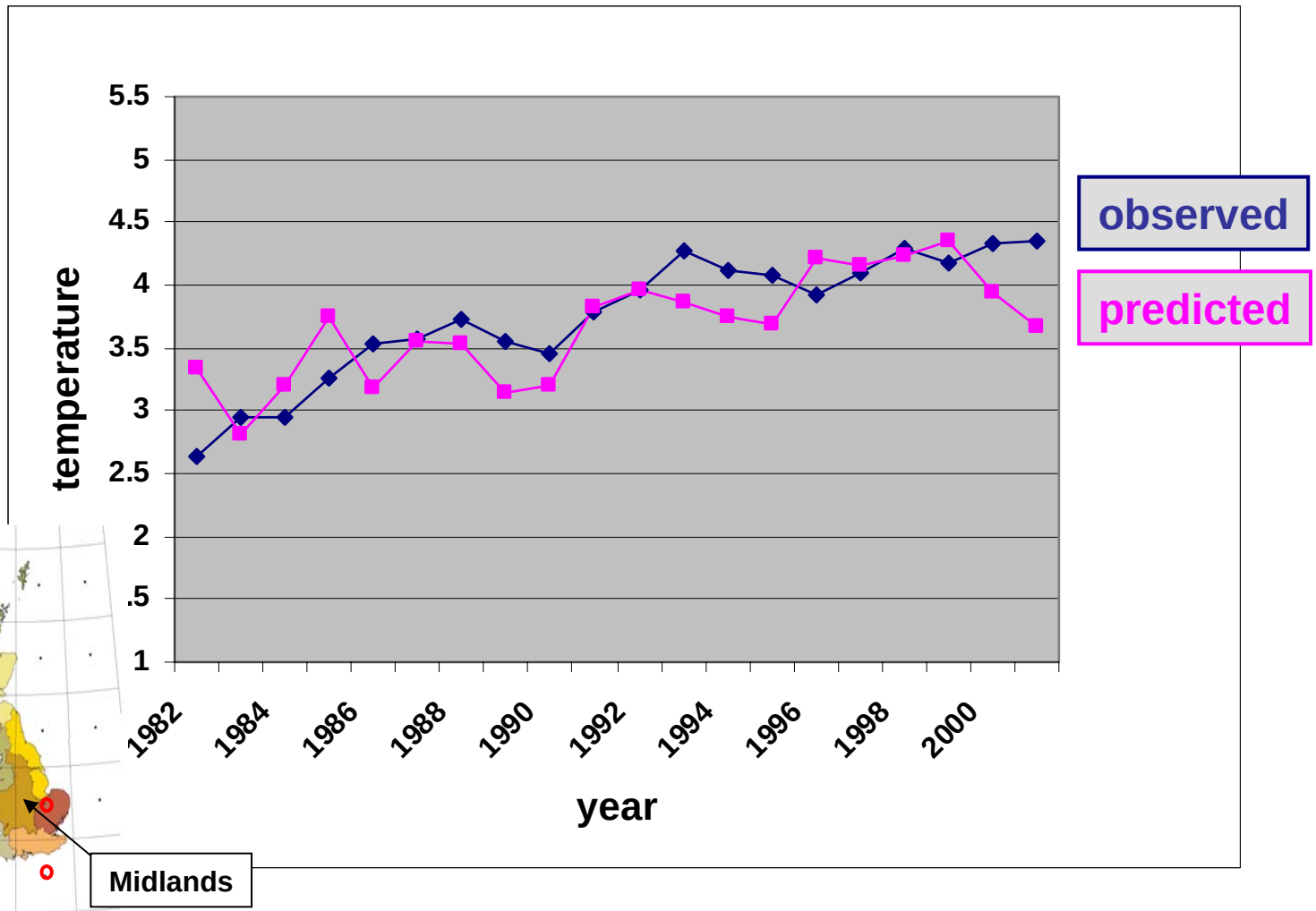


Predicted climatological averages: mix of observations and predictions

work commissioned by UK energy industry



Evaluation on period 1982-2001
3-year ahead prediction of January climate: mean temperature, Midlands



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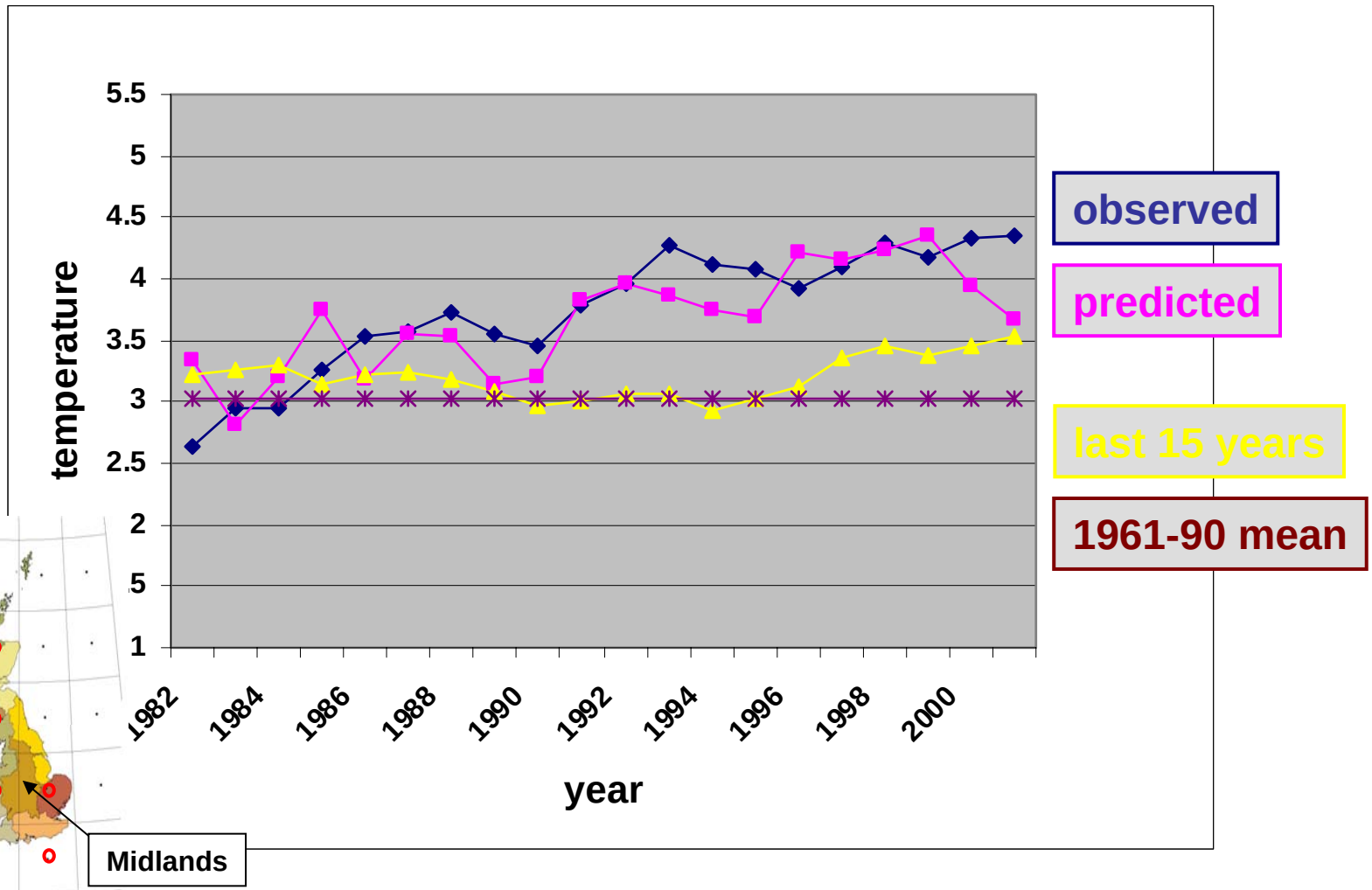
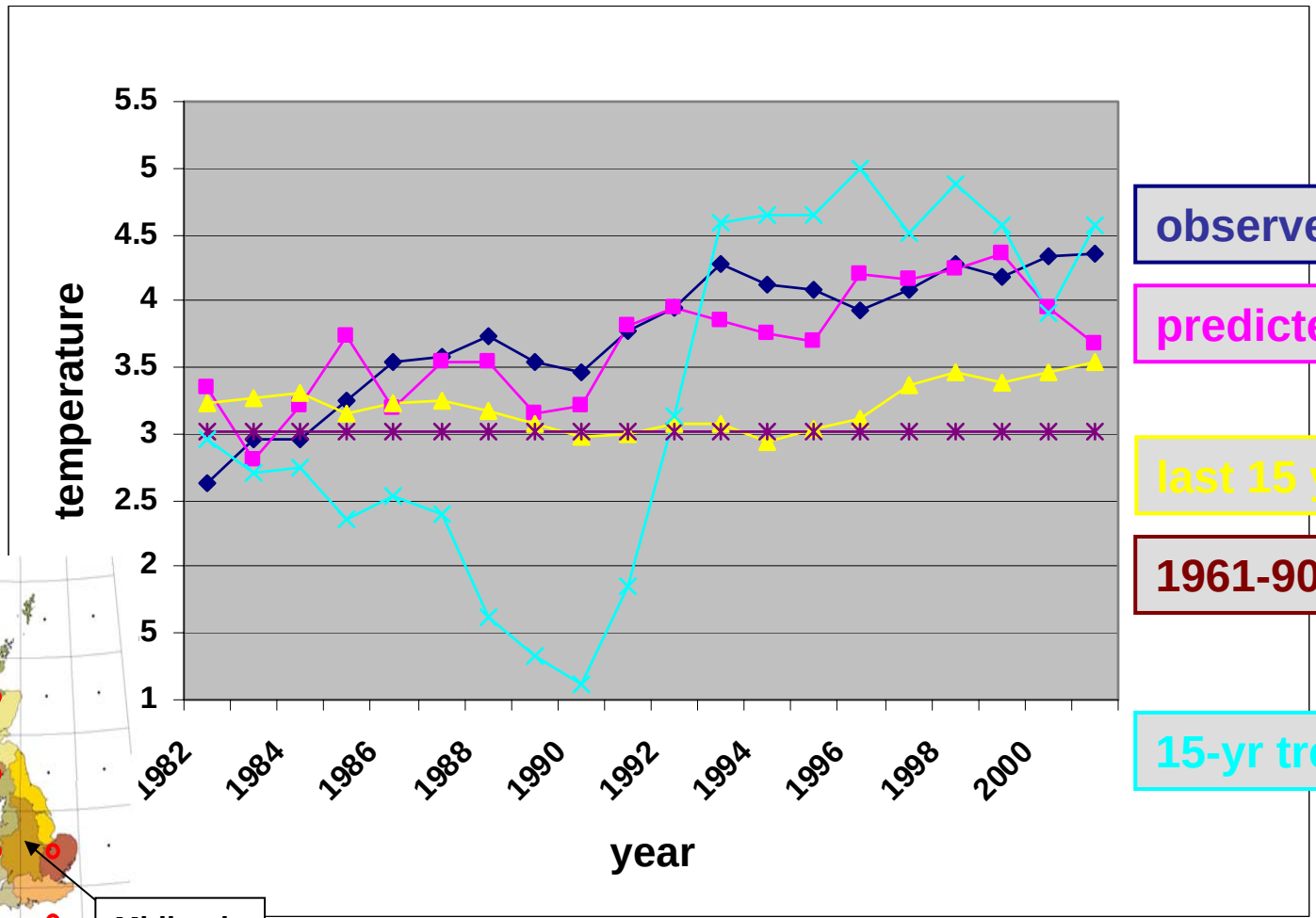


Evaluation on period 1982-2001
3-year ahead prediction of January climate: mean temperature, Midlands



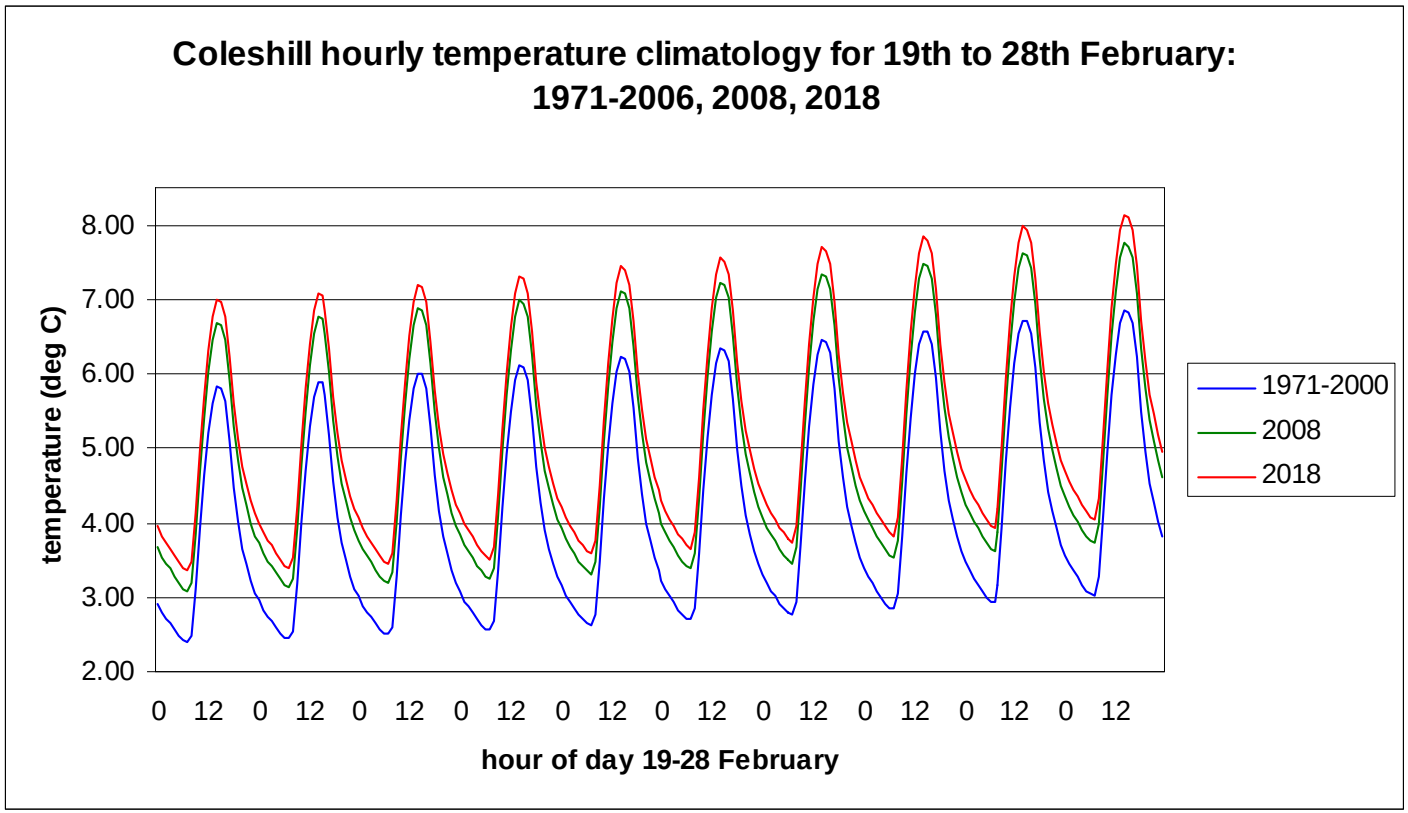
Skill benefit of 3-year-ahead predictions of UK district mean temperature climatology

Conventional method	Benefit of predicted climatology (RMSSS)
Last available observed 15-year mean	32.7%
3-year projection of linear trend over last 15 years	43.1%
Standard 30-year climatology	45.7% (1951-80) 43.2% (1961-90)

Adjustments needed to 1971-2006 mean temperature climatology: Midlands

	2008	2012	2018
July	+0.8	+0.9	+1.2
January	+0.6	+0.7	+0.9
July-Jan difference	+0.2	+0.2	+0.3

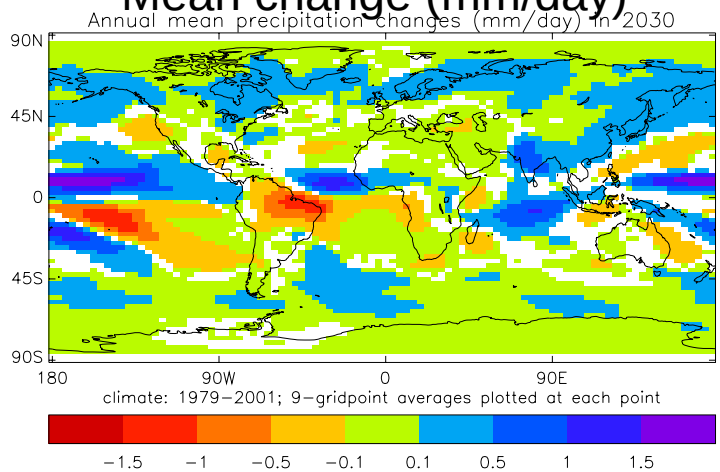
Energy Phase 2 product: constructed site-specific daily cycle of 30yr temperature averages (relative to 1971-2006), 2008, 2018



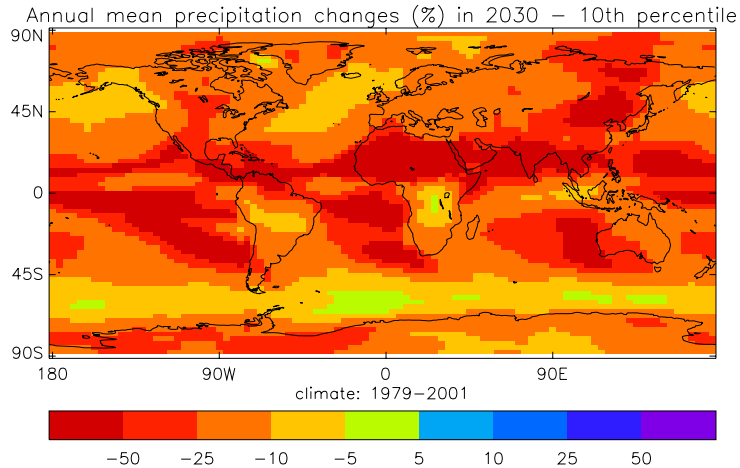
DePreSys predicted annual rainfall change (9-year mean centred on 2030)

Met Office

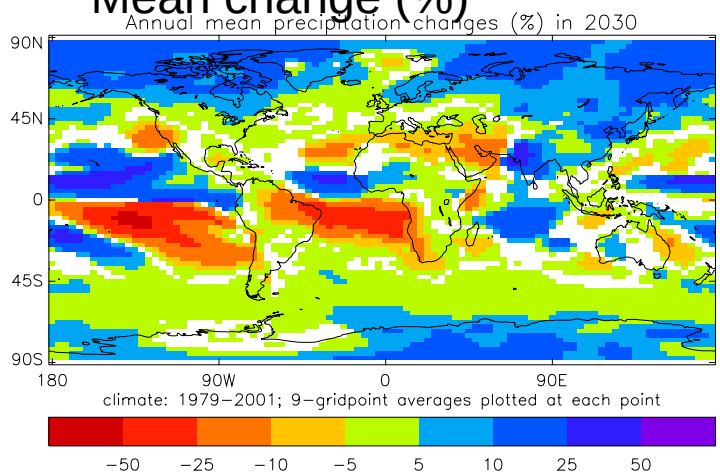
Mean change (mm/day)



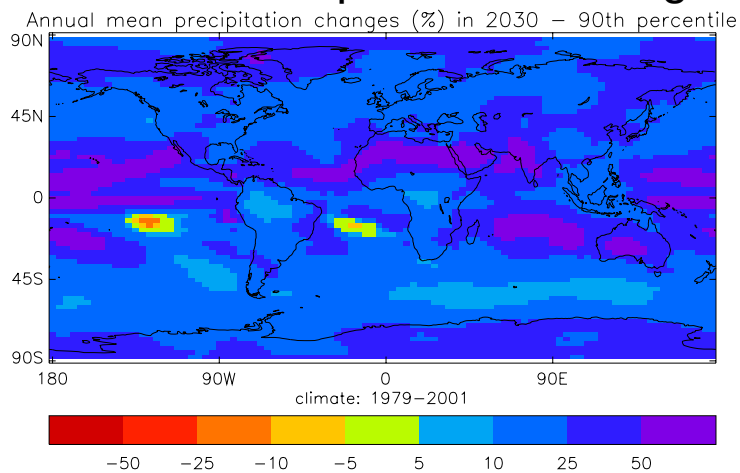
10% percentile change



Mean change (%)

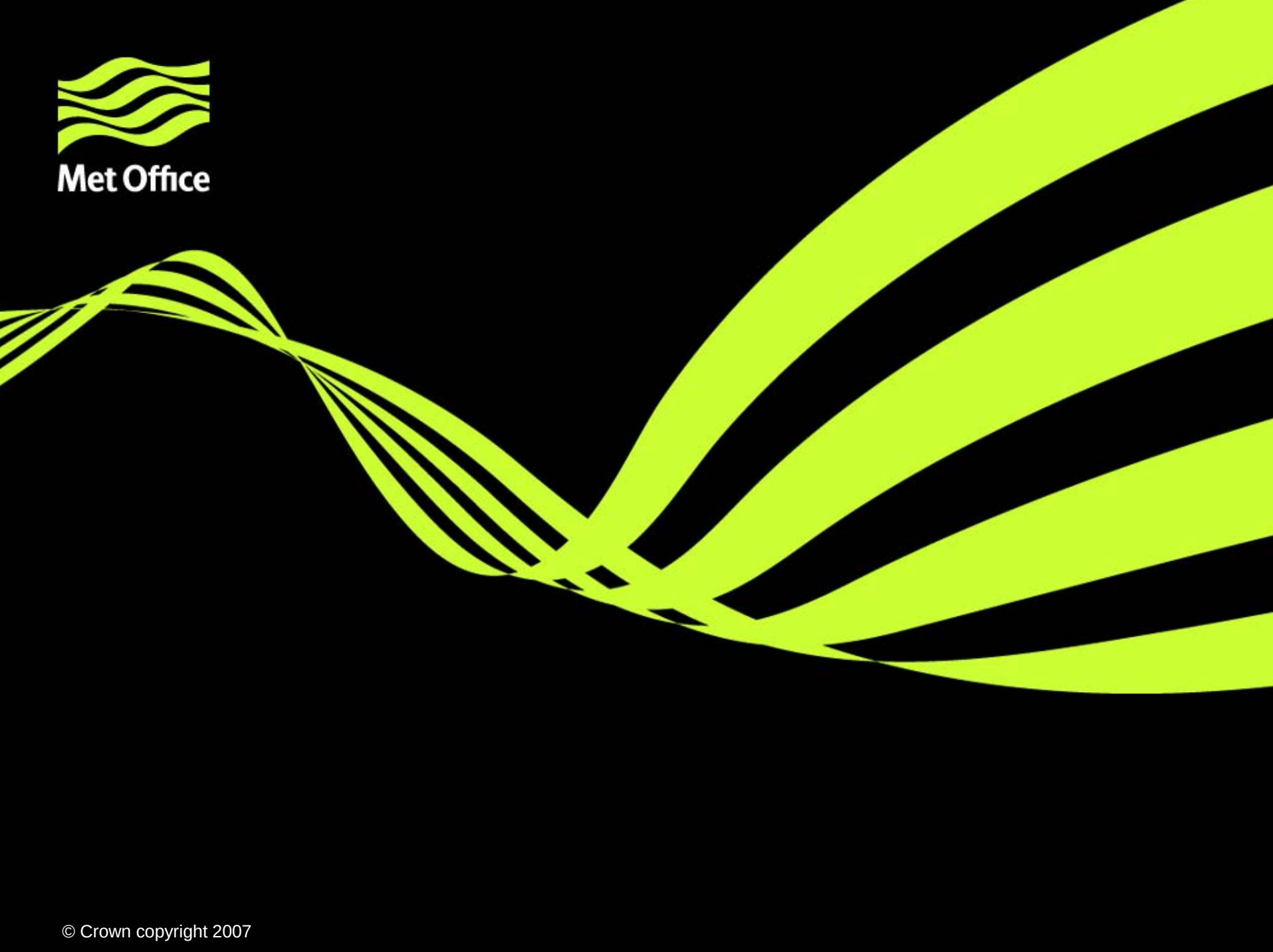


90% percentile change



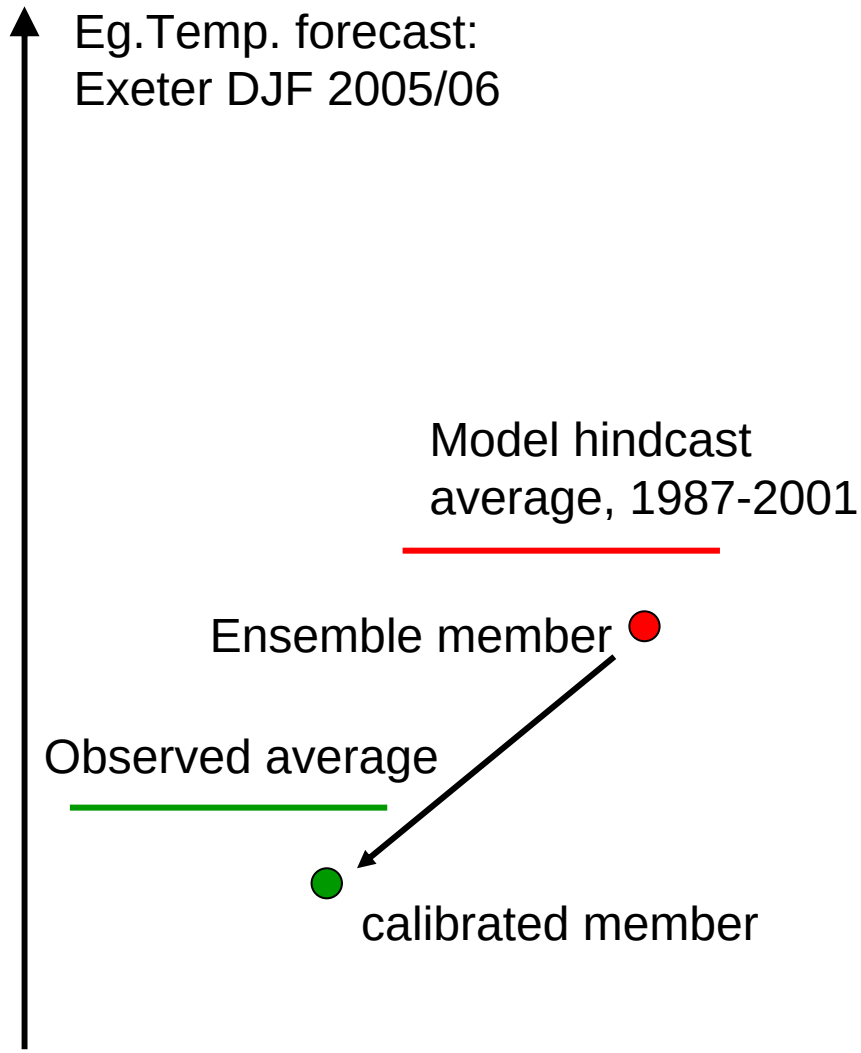
Mean change

Uncertainty



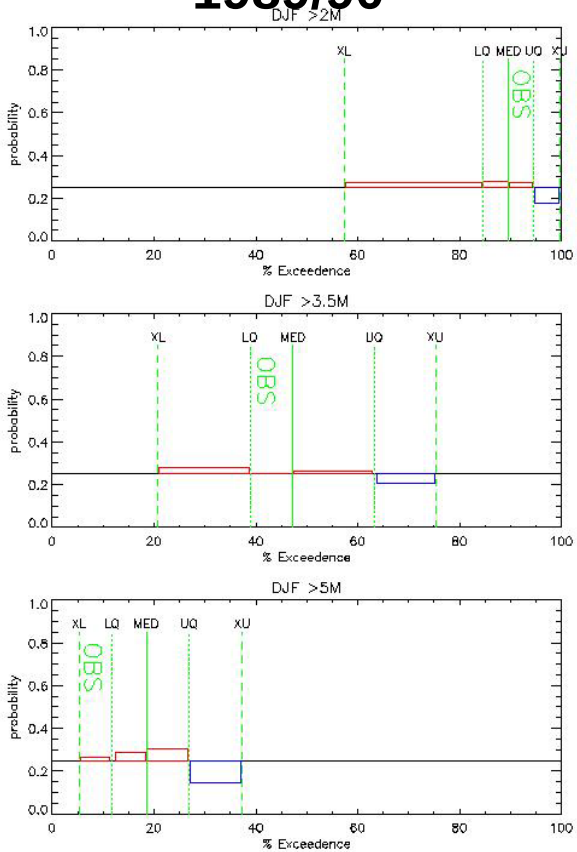
Forecast calibration, using hindcasts

- In the course of a long integration, the model tends to converge to 'its own climatology'
  - model climate will differ from real climate
- Need to express the forecast relative to its own climatology
- Many retrospective forecasts ('hindcasts') are performed to 'sample' the model climatology.
- Currently, hindcasts for the period 1987-2001 (15 years)
- Problem with representativeness of hindcast period in a changing climate

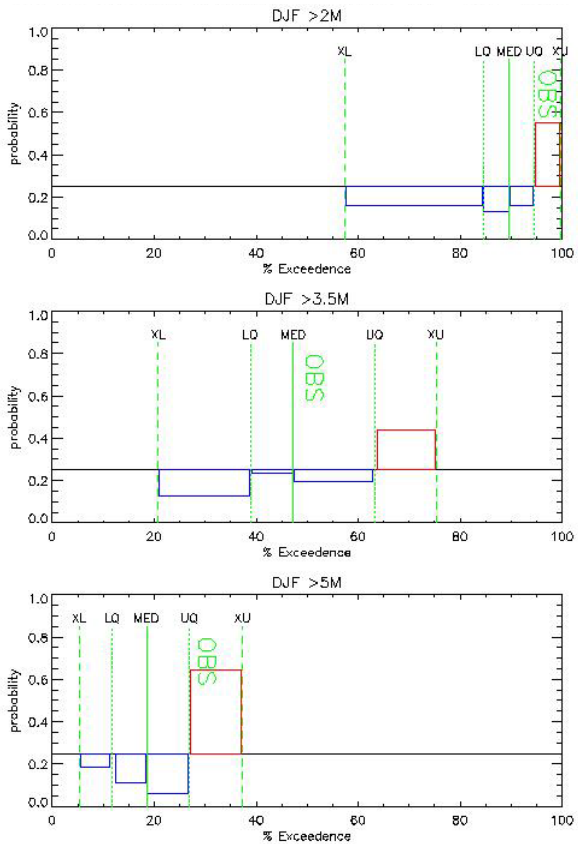


Use of NAO predictor to forecast of North Sea winter storminess

1989/90



2007/08



Forecast probability for quartiles of storminess

Andrew Colman, Erika Palin

Seasonal forecasts: products

Seasonal forecasting system (GloSea):
Tropical storms are identified and tracked in GloSea, using a TS tracking algorithm developed by Vitart and Stockdale, 2001.

GloSea is a coupled ocean-atmosphere model (based on HadCM3):

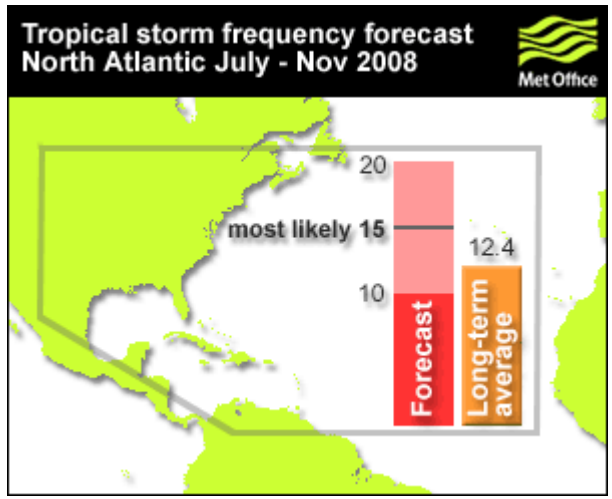
- AGCM: 2.5° x 3.75° x 19 levels
- OGCM: (1.25° to 0.3°) x 1.25° x 40 levels

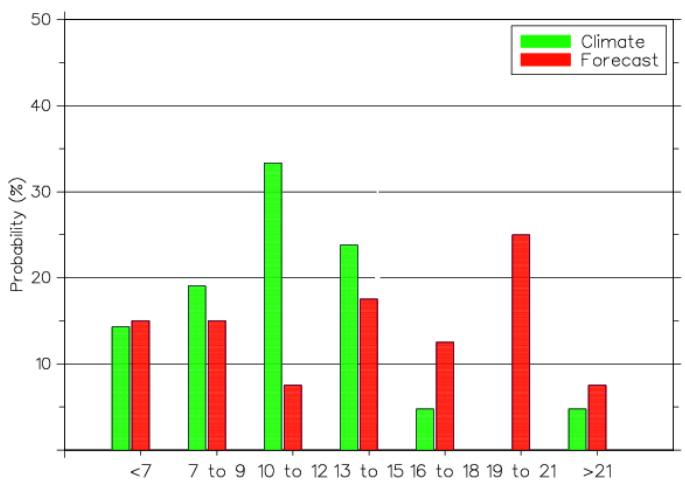
Real-time monthly forecasts: 41-member ensemble; 6 month range. June forecasts, covering July–November period, used for TS prediction.

Products:

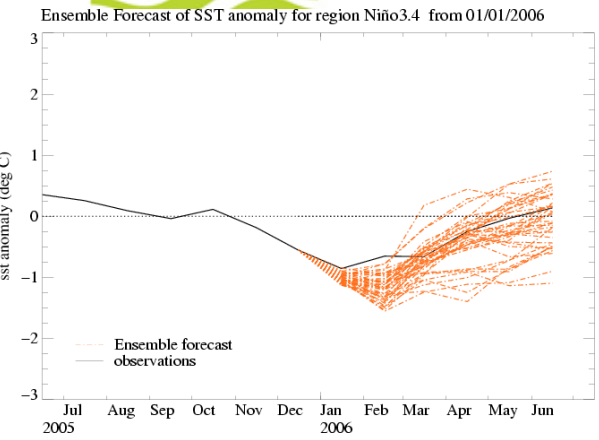
a) **Deterministic forecasts:** for the Public Weather Service (PWS) since 2007. Forecast available on Met Office Website.

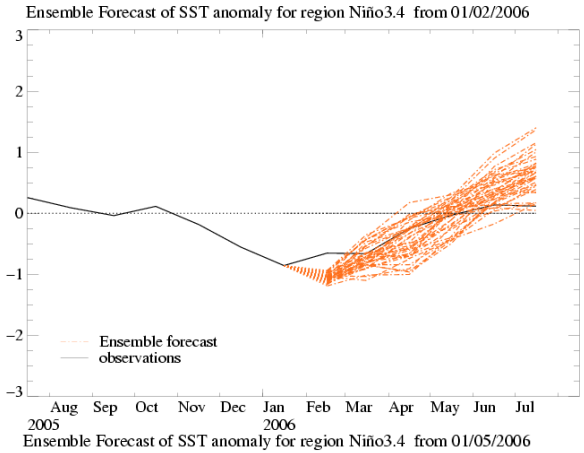
b) **Probabilistic forecasts**: probabilities that the number of storms and ACE will lie within pre-defined ranges. Product available as a commercial report.

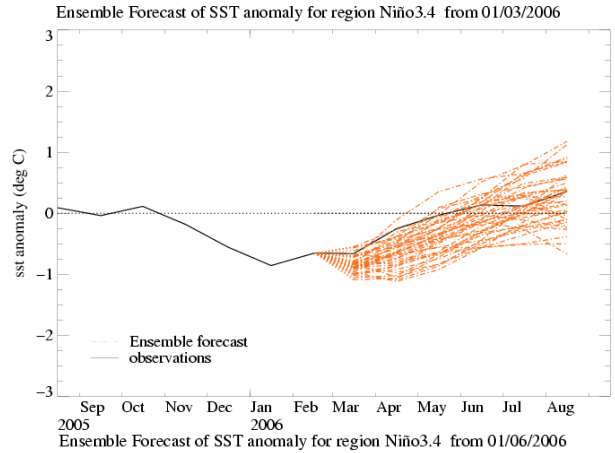


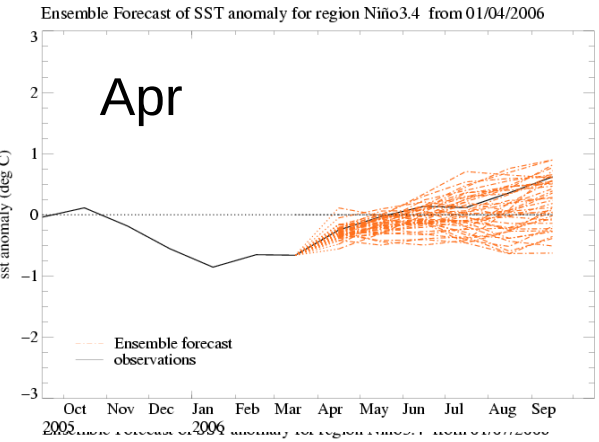


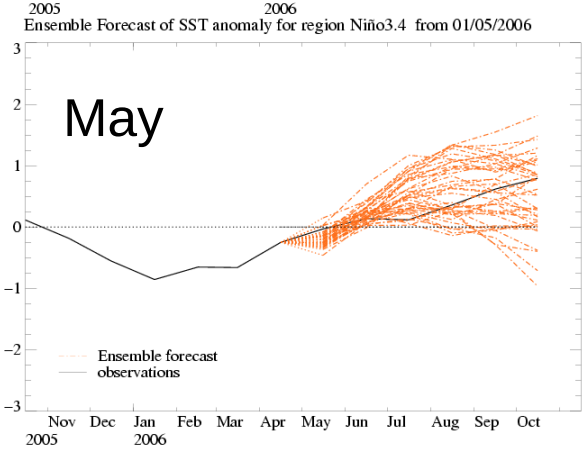
GloSea3 Niño3.4 prediction 2006-2007

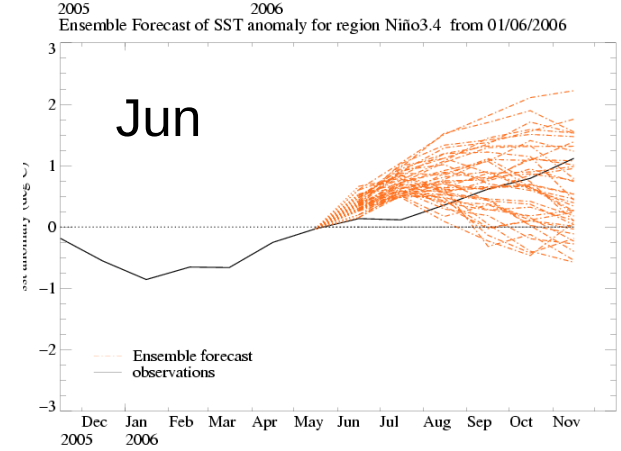


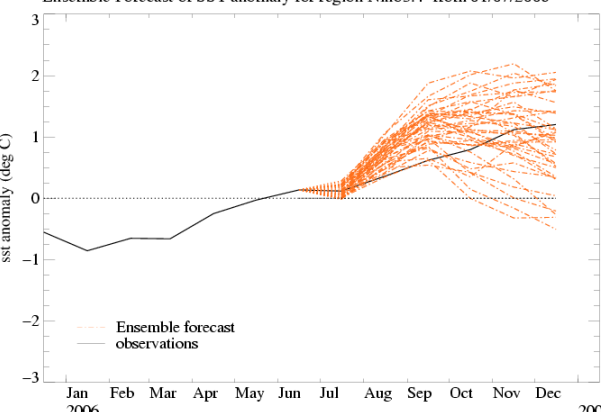


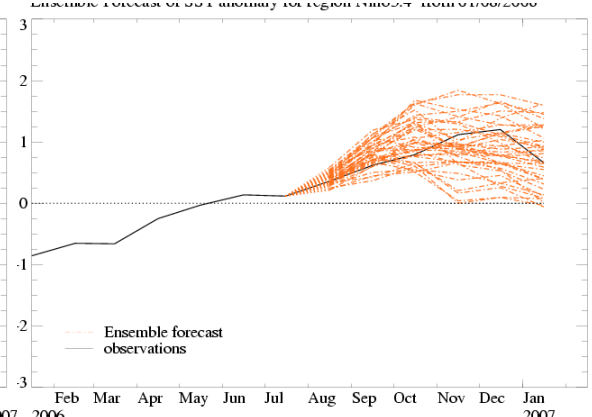


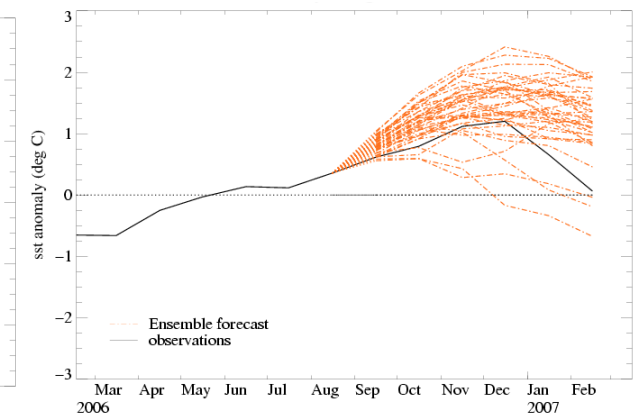




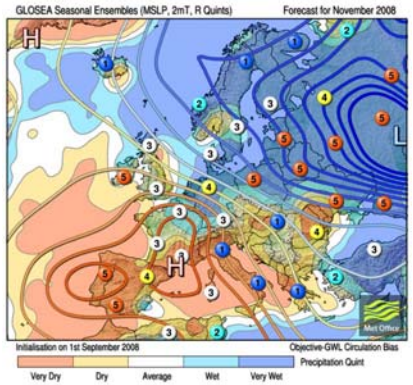








Grosswetterlagen (GWL) products: example November 2008 circulation anomalies, from GloSea Sep run



Also produced for medium range, monthly (and decadal) forecasts – giving potential 'seamless' presentation