MOGREPS
Met Office Global and Regional Ensemble Prediction System

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Ensemble Forecasting Manager

Outline

- Introduction to Ensemble Forecasting
- Examples from
  - ECMWF Medium-range EPS
  - Met Office short-range ensemble (MOGREPS)
- Probability forecasts
  - What do they mean
  - Decision-making

The Met Office has a World-leading forecasting system, but nevertheless…

- All forecasts are uncertain
- High-profile forecast failures are now rare, but do still occur (eg Dec '99 European storms)
- Less severe errors are much more common, e.g.
  - medium-range forecasts
  - finer details such as timing of rainfall
  - E-W position of snow over recent weekend
- Ensembles turn weather forecasts into Risk Management tools

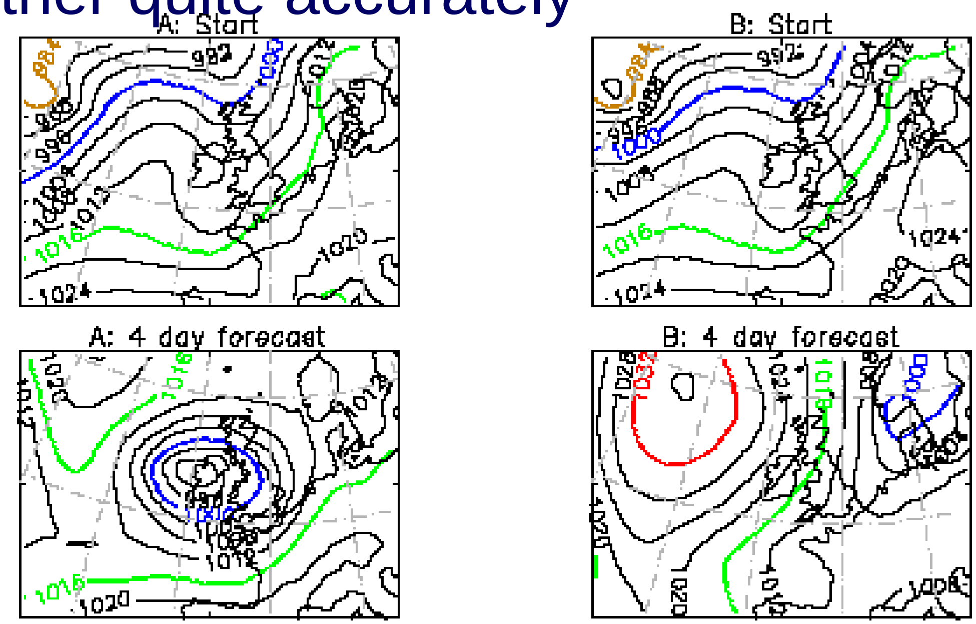
The Effect of Chaos

- The atmosphere is a chaotic system: *"… one flap of a seagull's wing may forever change the future course of the weather"*, (Lorenz, 1963)

- Up to about 3 days ahead we can *usually* forecast the general pattern of the weather quite accurately

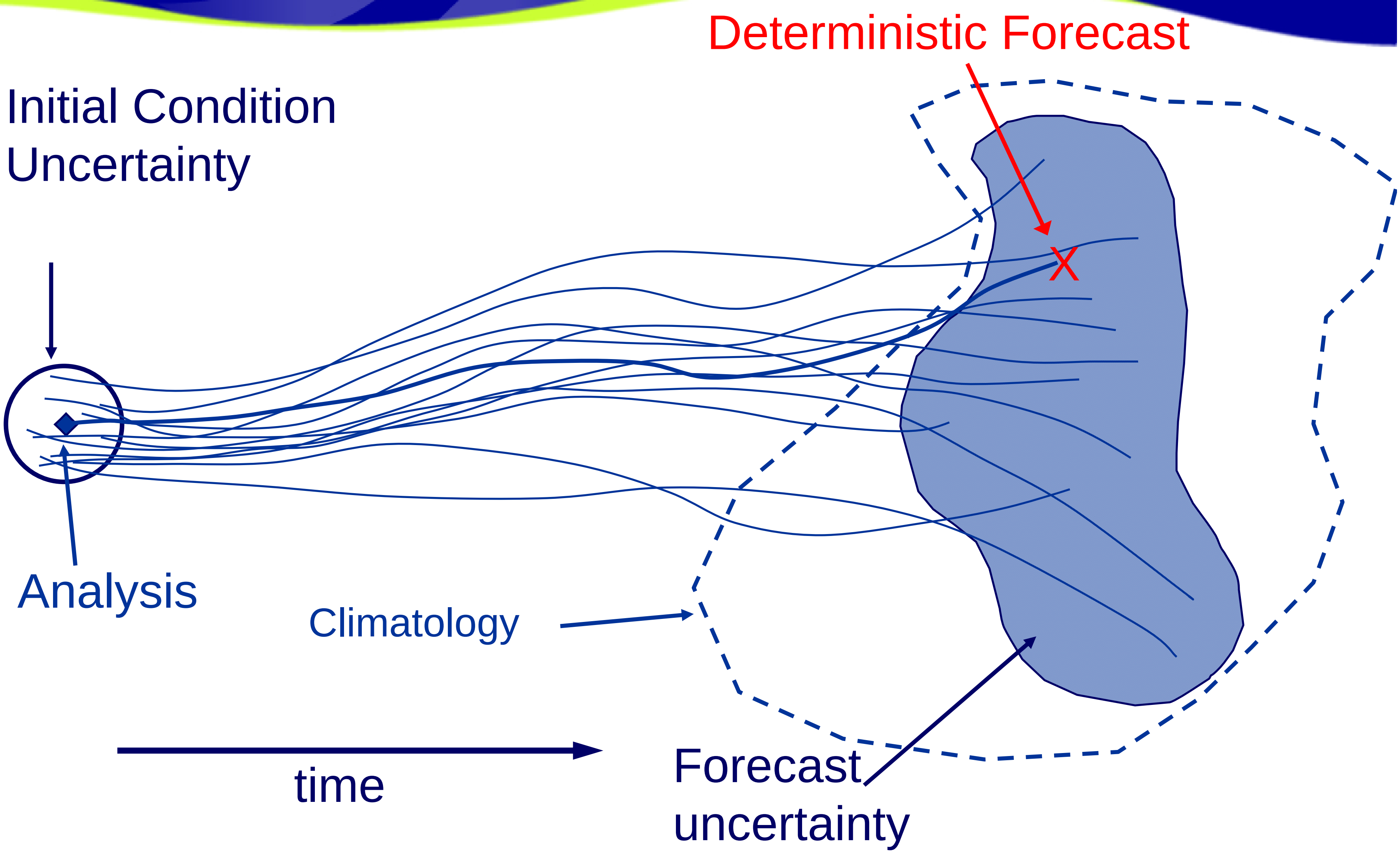
- Beyond 3 days Chaos becomes a major factor

Tiny errors in how we analyse the current state of the atmosphere lead to large errors in the forecast – these are both equally valid 4-day forecasts!



- Fine details (eg rainfall) have shorter predictability

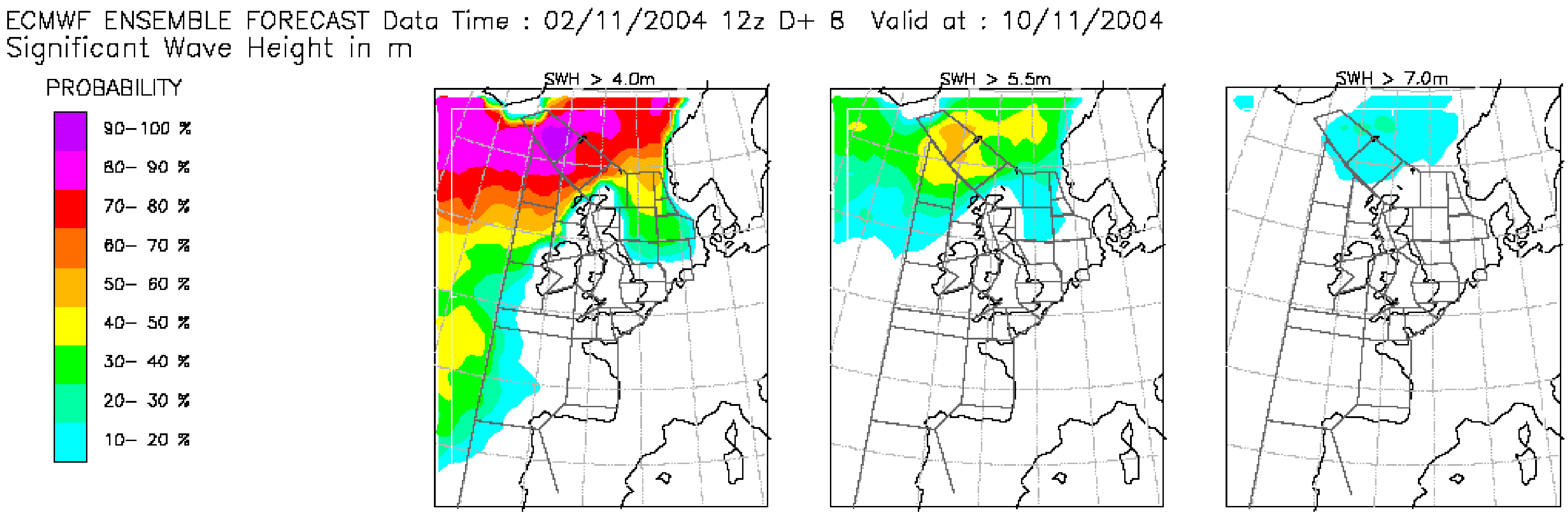
Ensembles...


Deterministic Forecast
Initial Condition Uncertainty
X
Analysis
Climatology
time
Forecast uncertainty

Ensembles – estimating risk

By running model(s) many times with small differences in initial conditions (and model formulation) we can:

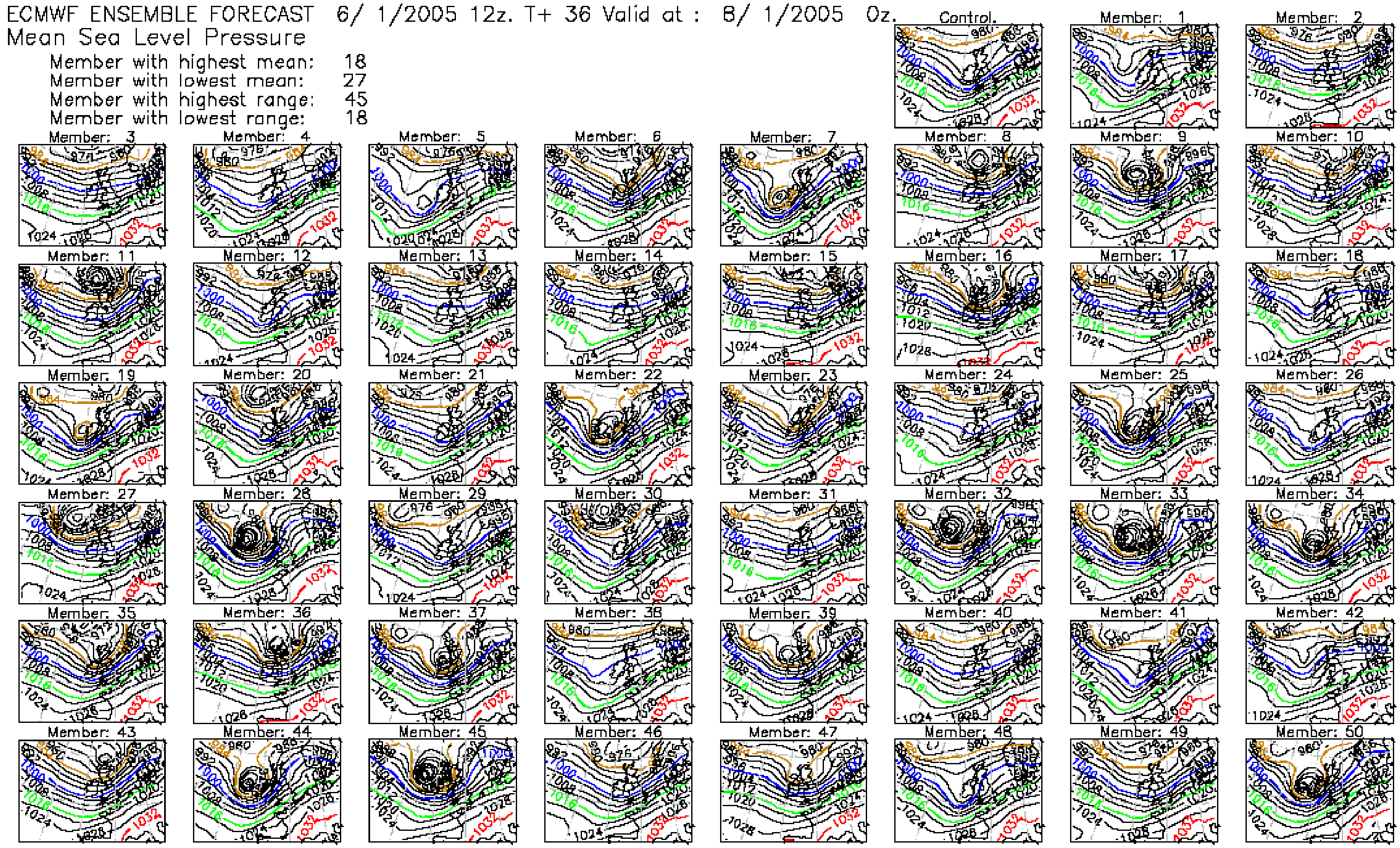
- take account of uncertainty
- estimate probabilities and risks
    - eg. 10 members out of 50 = 20%



ECMWF Ensemble (EPS)

- 51 members
  - Control (unperturbed) + 25 pairs formed by adding and subtracting a perturbation
- T_L319 Resolution (approx 60km)
- Designed for use beyond 48h
- Perturbations are linear combinations of Forward and Evolved Singular Vectors
- Includes Stochastic Perturbations to model physics

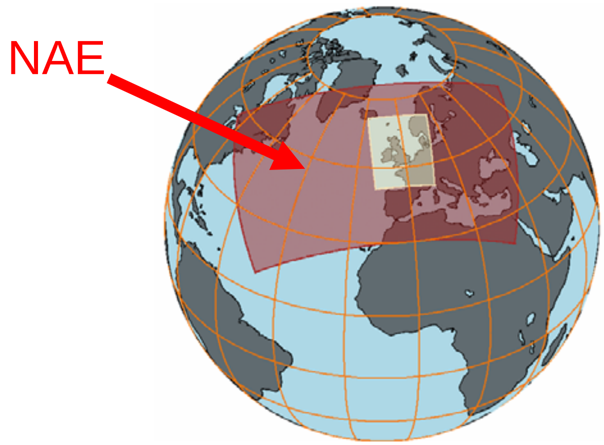
ECMWF Ensemble prediction System (EPS)



Carlisle storm, Jan 05, from ECMWF 51-member medium-range ensemble

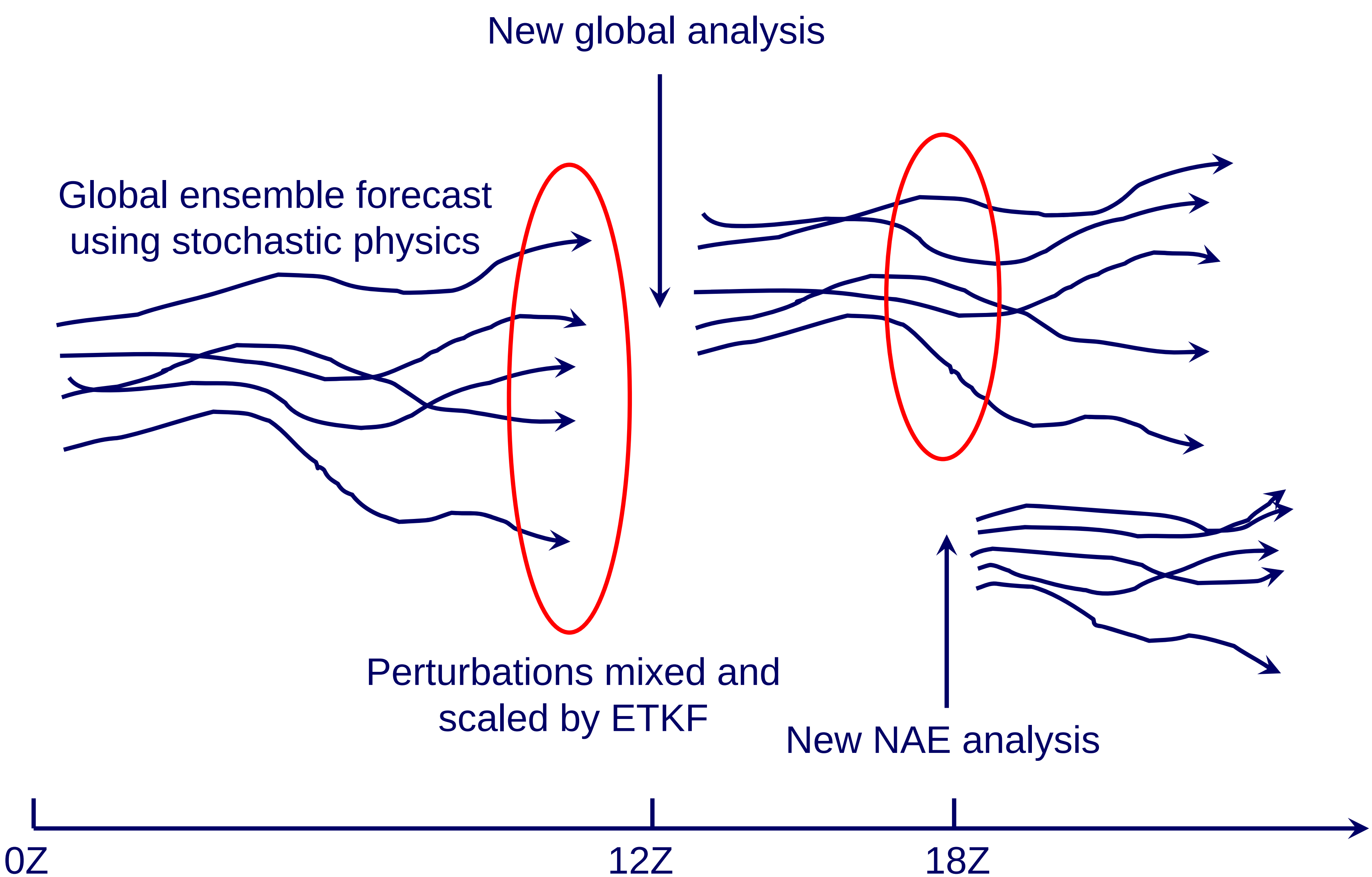
MOGREPS – The Met Office short-range ensemble

- 24-member ensemble designed for short-range forecasting
  - Regional ensemble over N. Atlantic and Europe (NAE) (24km resolution, 38 levels) to T+54
  - Global ensemble (~90km resolution, 38 levels) to T+72
    - Also runs to 15 days at ECMWF for THORPEX
  - ETKF for initial condition perts
  - Stochastic physics
  - Global run at 0Z and 12Z. Regional run at 6Z & 18Z



MOGREPS has successfully completed a 1-year Operational Trial. Scheduled to become operational by Dec 2007.

MOGREPS Operational System diagram



Desirable Properties and how we achieve them

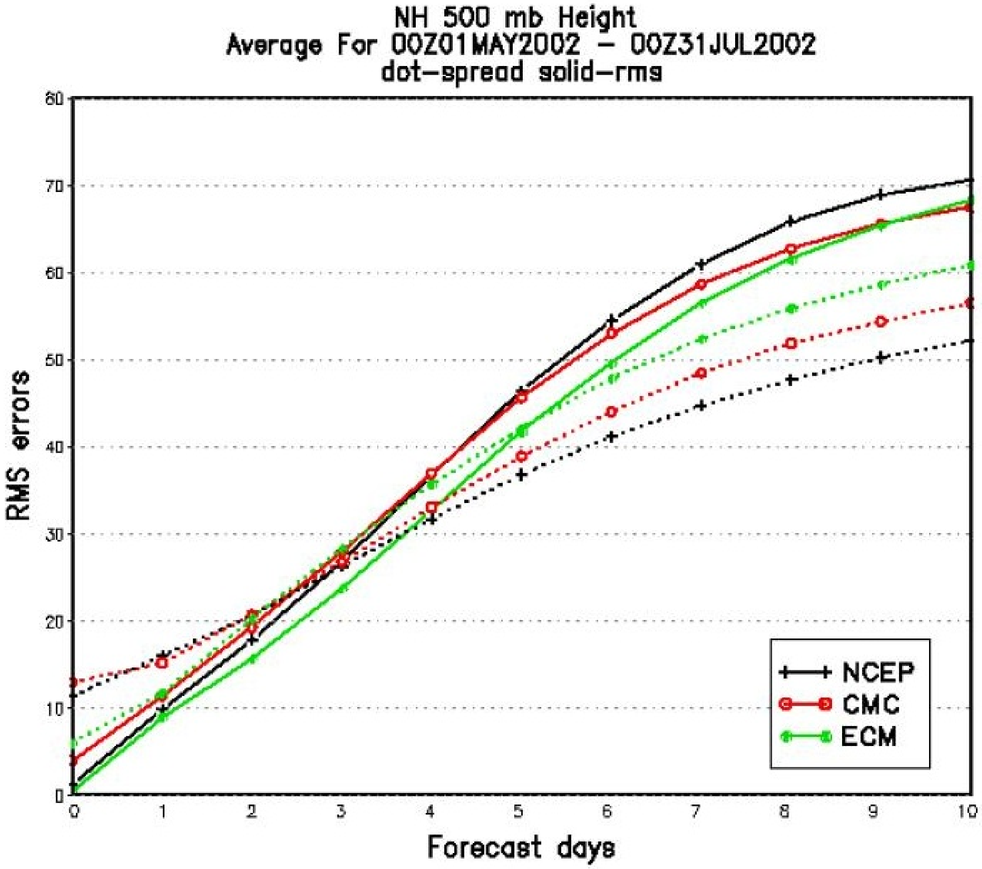
Desirable properties of an ensemble:

- All members must be equally likely
- RMS spread ~ RMS error of Ens.mean
- Ensemble spread should include observations (most of the time! ~ 2(100/n)%)
- Spread-skill relationship:
    - Small spread should indicate high probability … but large spread not necessarily mean low skill!

If these criteria are met the ensemble may be used to estimate probabilities

Desirable Properties of Ensembles

- RMS Spread of members similar to the RMS Error of the control forecast



We can verify the spread of the ensemble

The Talagrand diagram

With only one ensemble member (|)
all observations (•) will fall "outside"

• | •

With two ensemble members two out of
three observations (2/3=67%) will fall outside

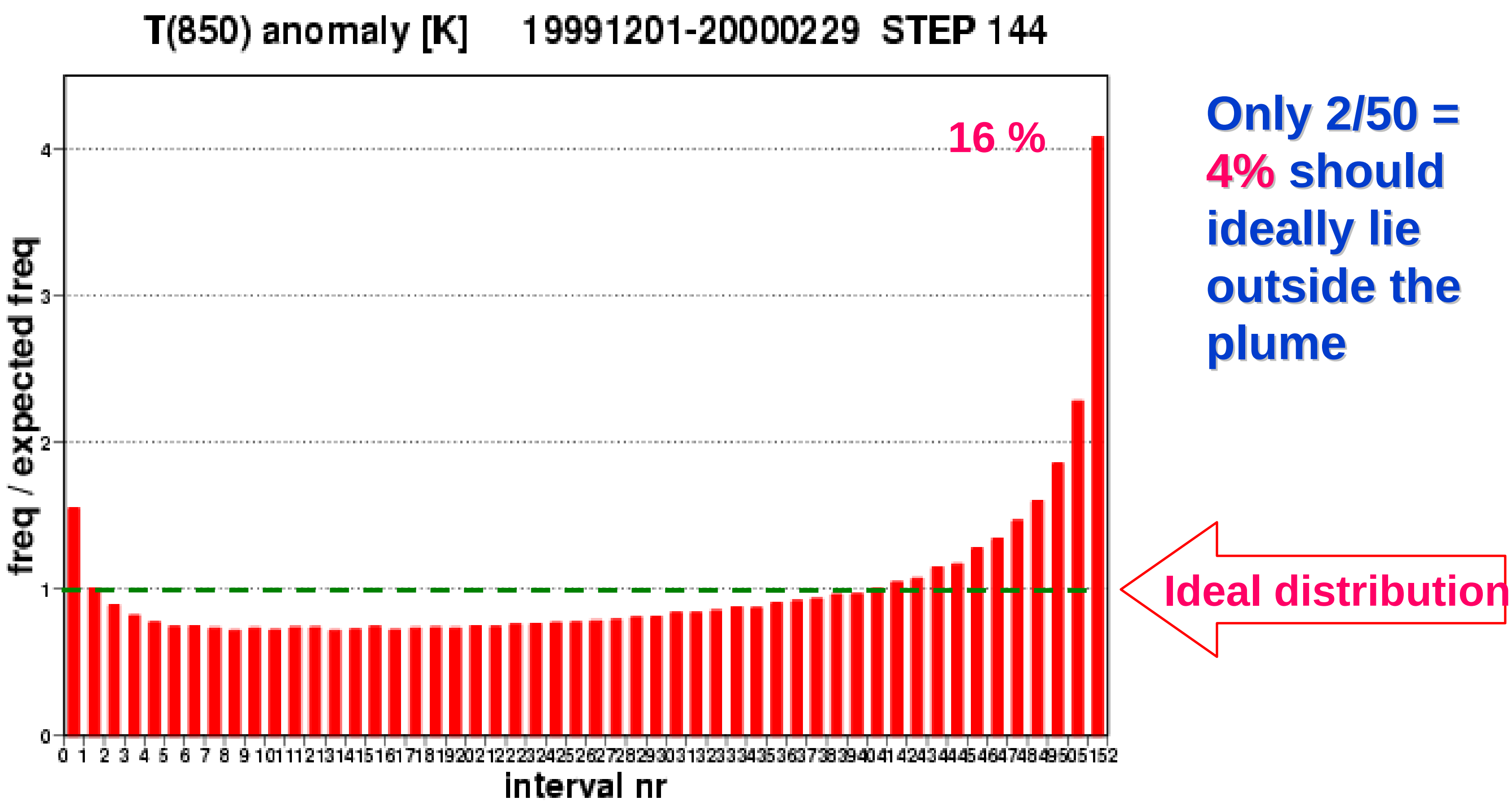
• | • | •

With three ensemble members two out of
four observations (2/4=50%) will fall outside

• | • | • | •

Two observations out of N will always fall outside yielding a proportion of 2 / N outside

The Rank Histogram



Only 2/50 = 4% should ideally lie outside the plume

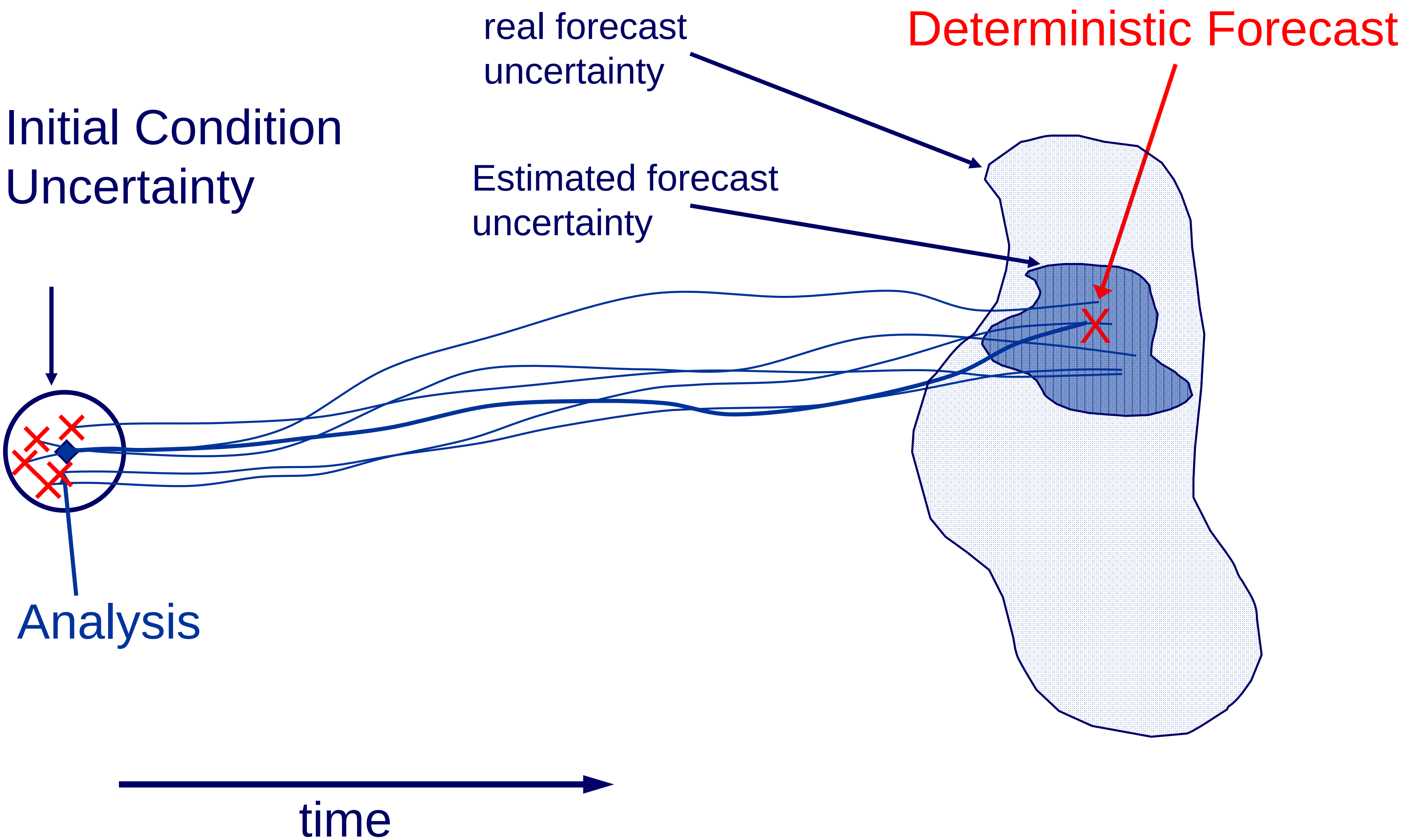
Initial Condition Perturbations

Uncertainty in the IC

- Getting different ICs that estimate the analysis error is not enough …
  - **not all errors in the analysis are likely to grow**
  - **Limited computing resources**

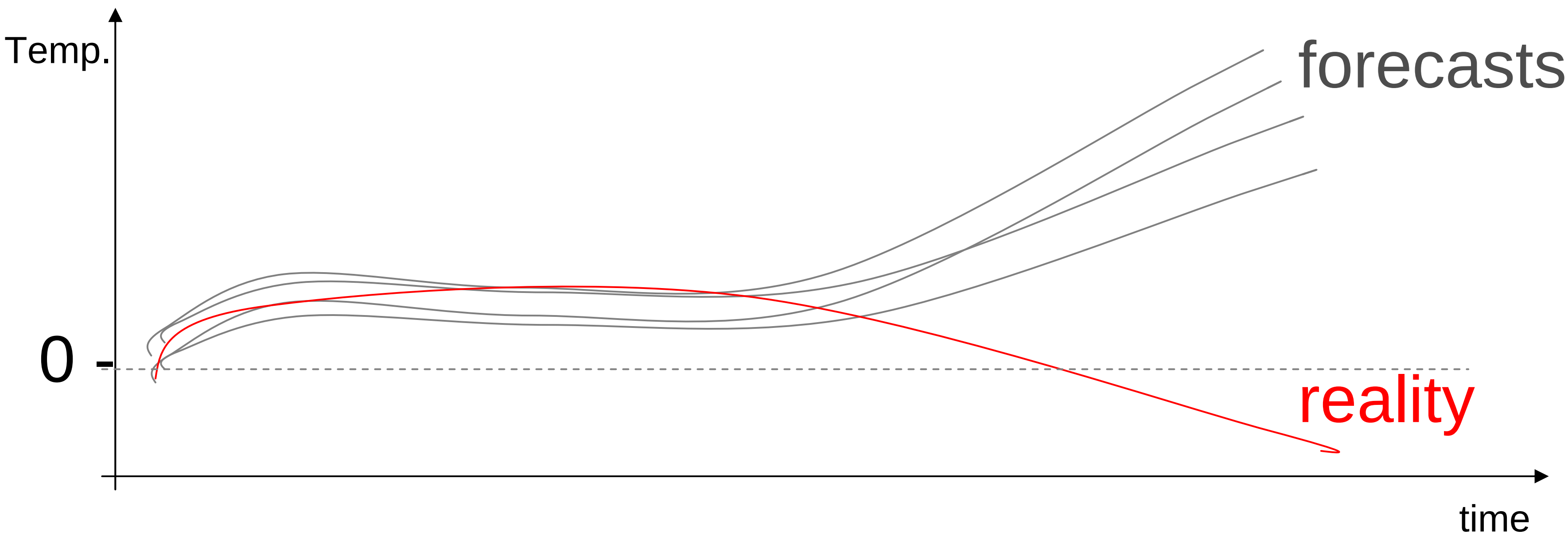
We need to focus on those perturbations that rapidly diverge

Initial conditions: Bad sampling!



Underdispersion

What does under-dispersion mean?



The ensemble capture reality less often than it should

- **Dangerous: false sense of security!**

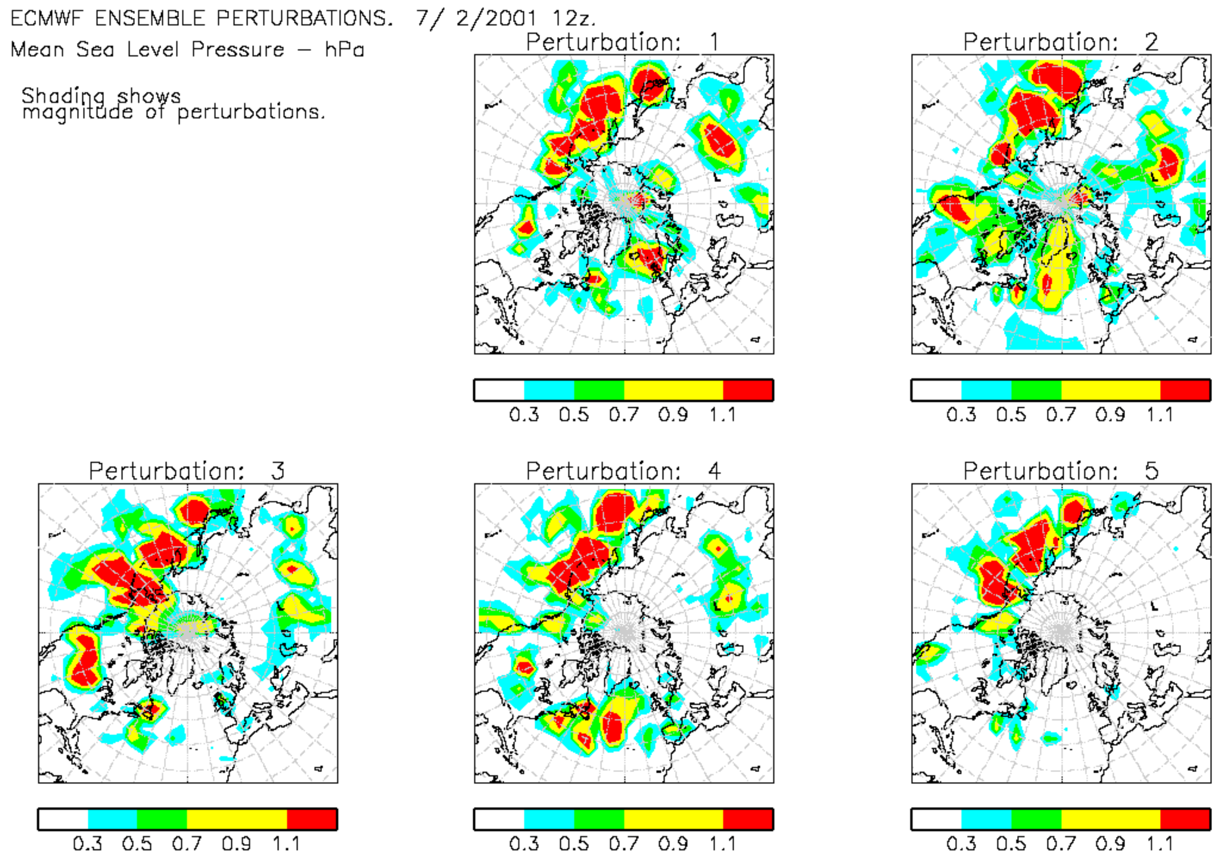
Initial conditions

Singular Vectors
(ECMWF; Molteni et al., 1996)

- SV try to identify the dynamically most unstable regions of the atmosphere by calculating where small initial uncertainties would affect a 48 hour forecast most rapidly. It needs an adjoint model.
  - SV perturbations are very small at initial time – grow rapidly
  - Expensive to calculate – done at low resolution (T63)

SV Perturbations

- Each perturbation is a linear combination of:
  - 25 NHem SVs
  - 25 SHem SVs
  - 25 Tropical moist SVs targetted on
    - Caribbean
    - TCs
  - Evolved SVs
    - Calculated 48h previously
    - larger



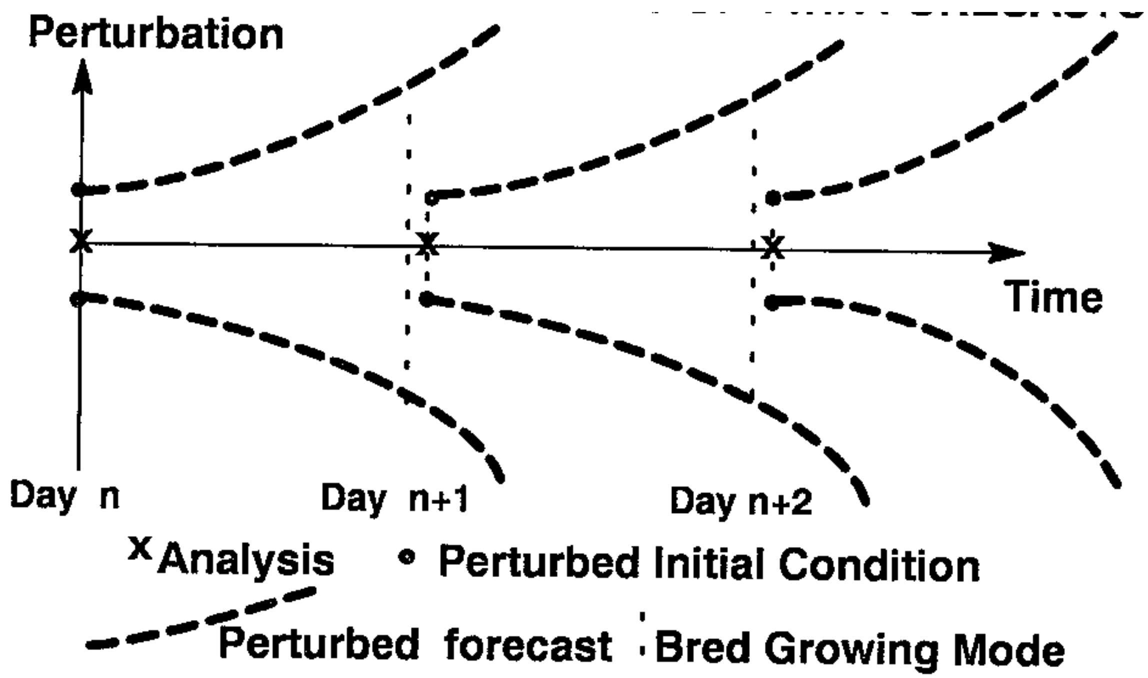
Error Breeding

Start with random perturbation - allow to grow in forecast

Rescale bred mode to analysis errors (fixed climatological rescaling factor)

Use for perturbation in next cycle

Cycle "breeds" the rapidly growing modes in the analysis cycle



Toth and Kalnay (1997), MWR 125, 3297-3319

Analysis Perturbations - Error Breeding

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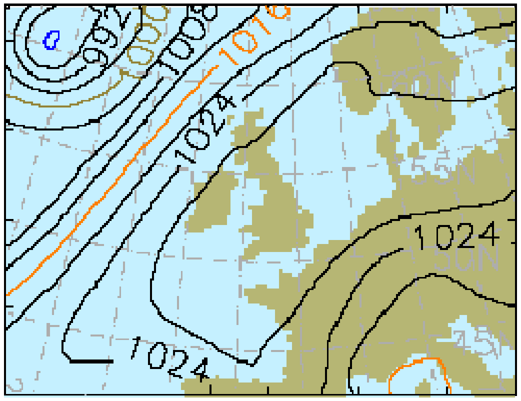

T+12 perturbed forecast

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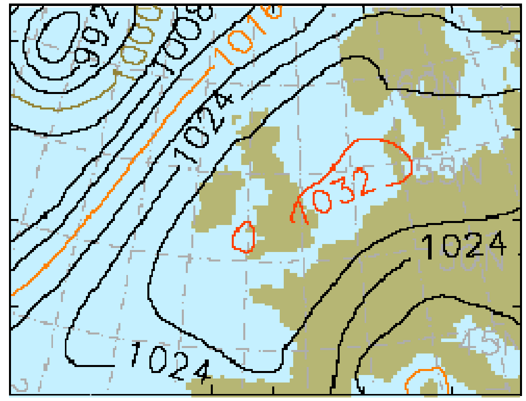

T+12 control forecast

)*F

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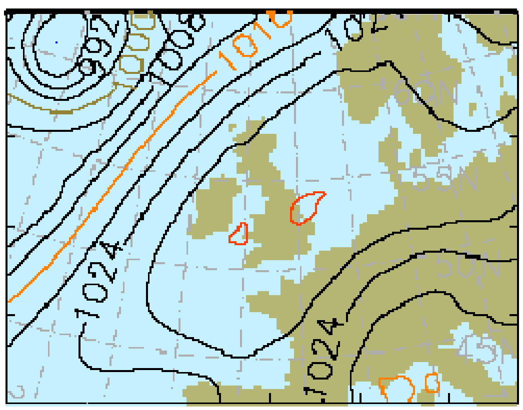

Control analysis

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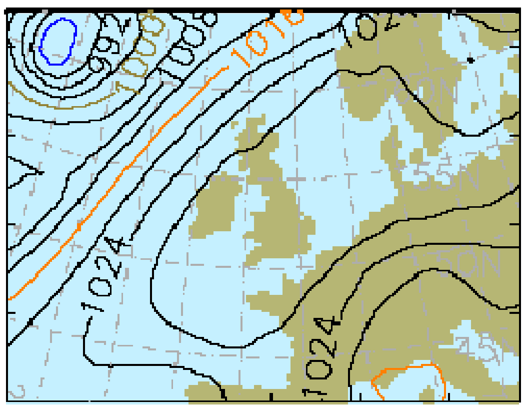
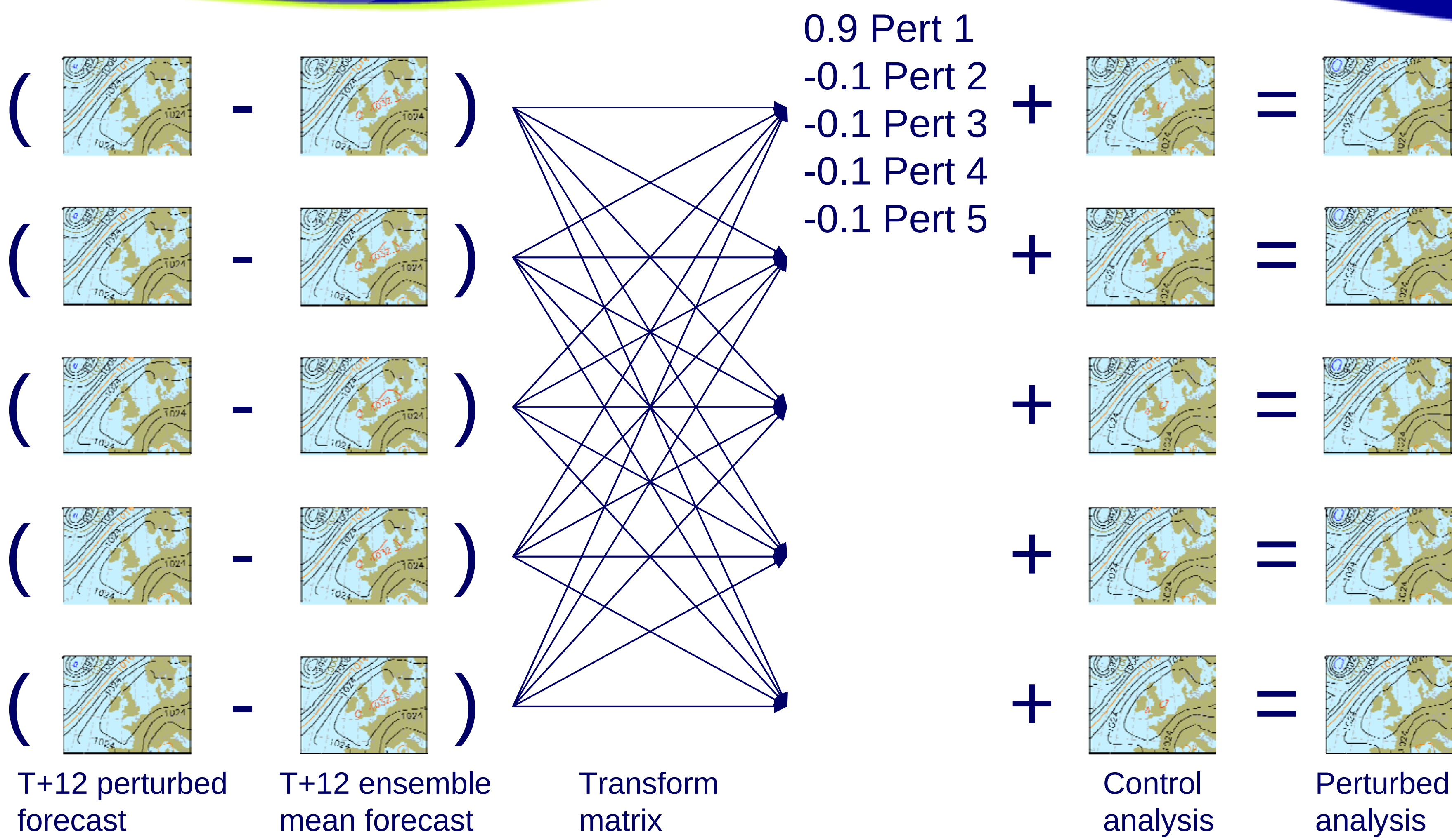


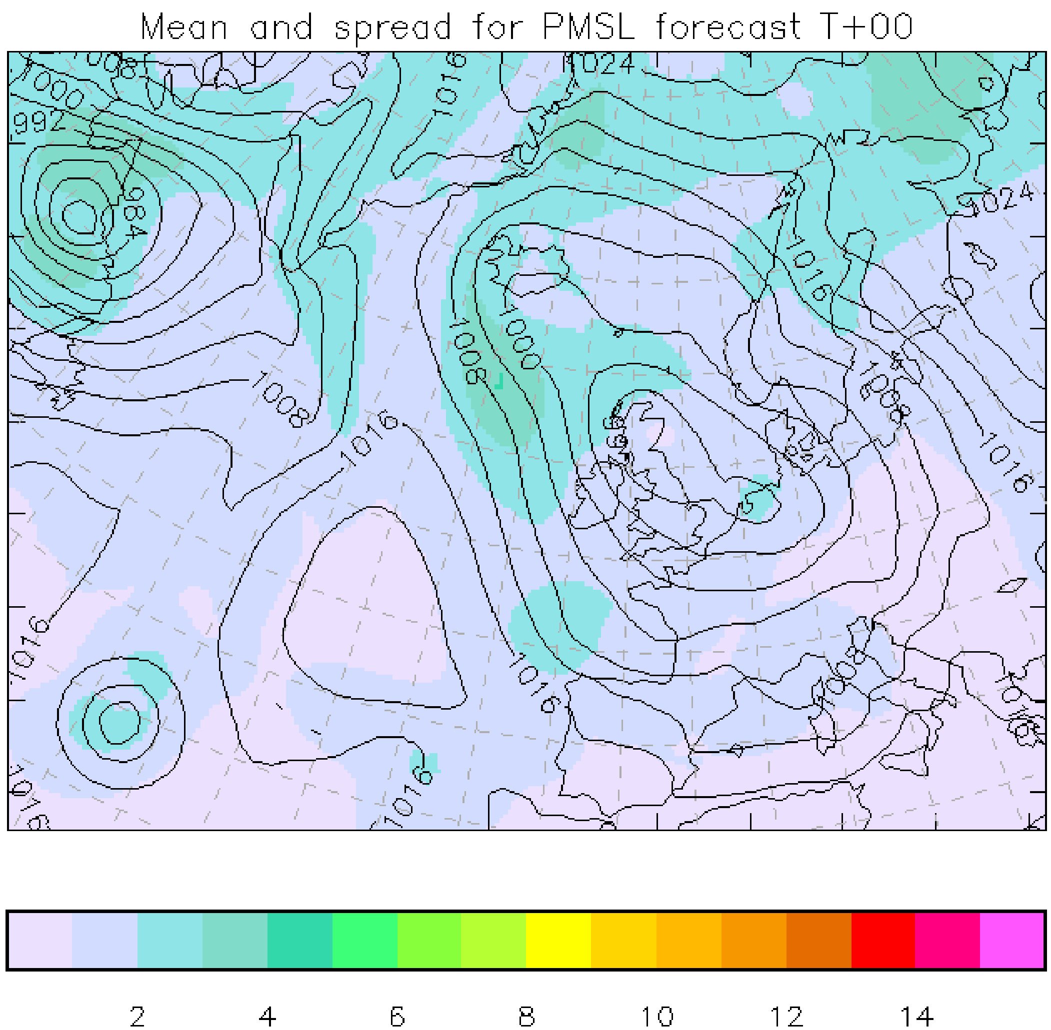
Perturbed analysis

Ensemble Transform Kalman Filter (ETKF)



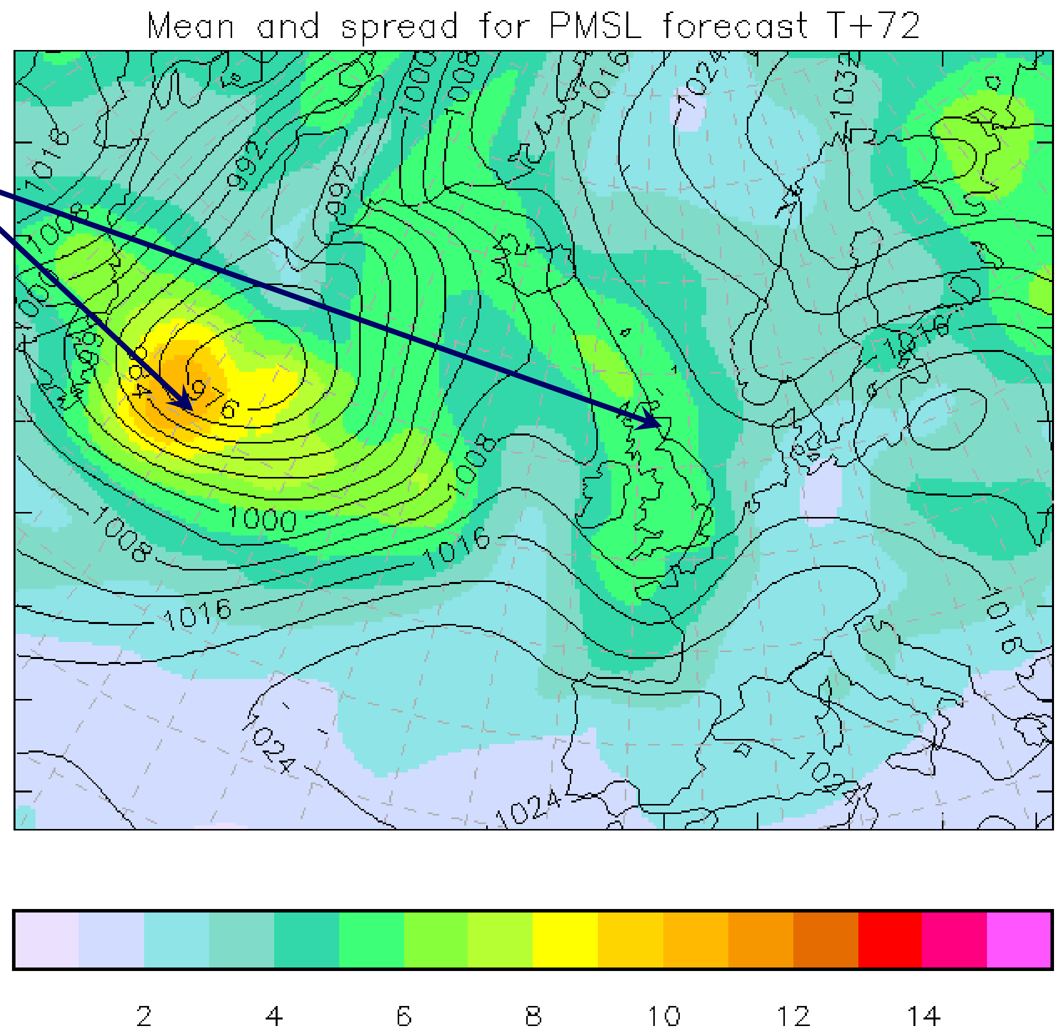
Perturbation structure

Perturbation Structures –
Mean and spread PMSL



Perturbation Structures –
Mean and spread PMSL

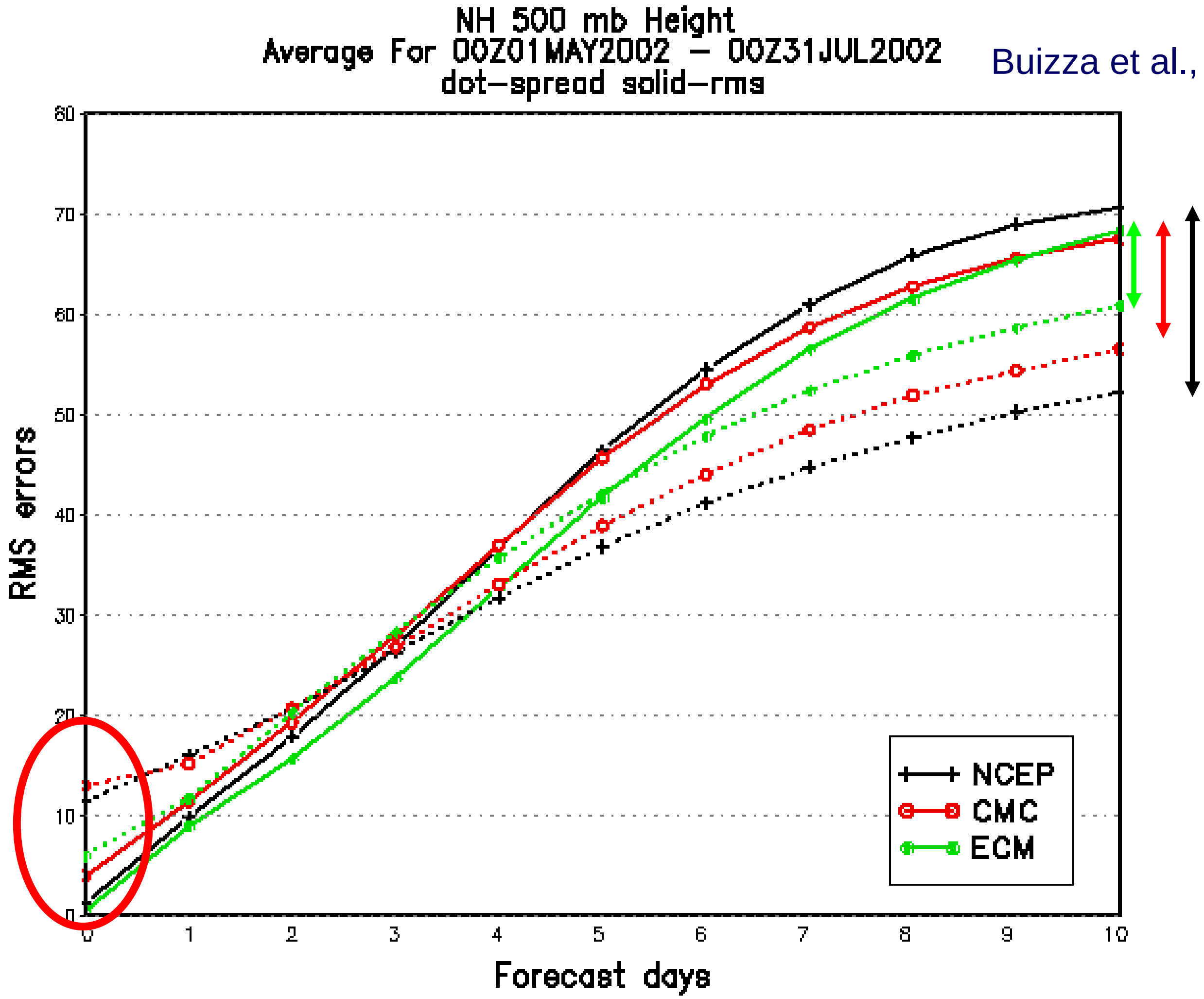
- Spread tends to be concentrated around fronts and sharp gradients
- Perturbation is non-zero everywhere (in contrast to SVs)



Stochastic Physics

Stochastic physics

…. the quest to increase spread!



Buizza et al., MWR, 2004

All three systems are under-dispersive!!

Stochastic physics in MOGREPS

MOGREPS employs three schemes to address different sources of model error:

- **Random Parameters (RP)**
  - Error due to approximations in parameterisation
- Stochastic Convective Vorticity (SCV)
  - Unresolved impact of organised convection (MCSs)
- Stochastic Kinetic Energy Backscatter (SKEB)
  - Excess dissipation of energy at small scales

Impact is propagated to next cycle through the ETKF

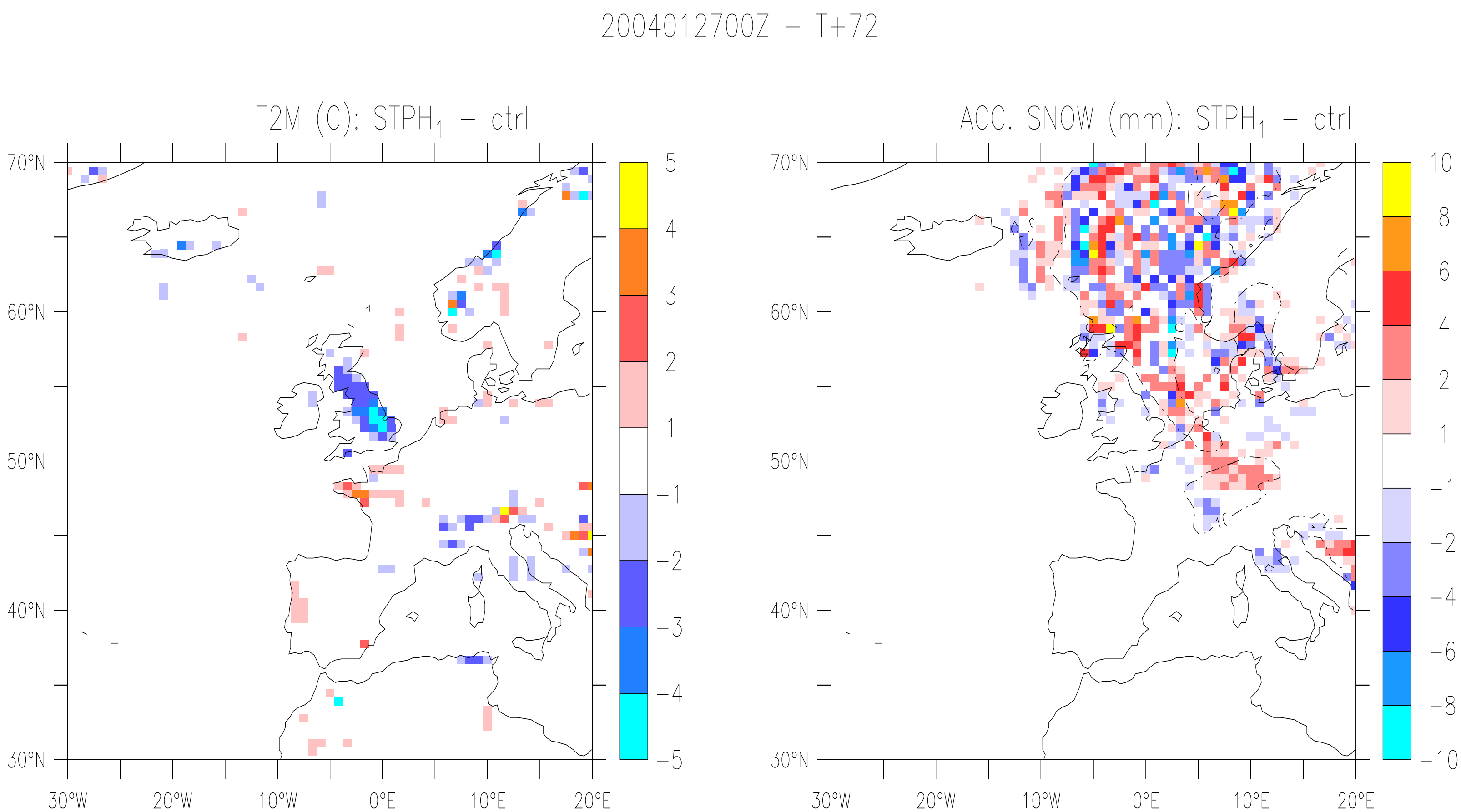
Model error: using a single-model

Random parameters

- QUMP (Murphy et al., 2004)
- Initial stoch. Phys. Scheme for the UM (Arribas, 2004)

Parameter	Scheme	min/std/Max
Entrainment rate	CONVECTION	2 / 3 / 5
Cape timescale	CONVECTION	30 / 30 / 120
Rhcrit	LRG. S. CLOUD	0.6 / 0.8 / 0.9
Cloud to rain (land)	LRG. S. CLOUD	1E-4/8E-4/1E-3
Cloud to rain (sea)	LRG. S. CLOUD	5E-5/2E-4/5E-4
Ice fall	LRG. S. CLOUD	17 / 25.2 / 33
Flux profile param.	BOUNDARY L.	5 / 10 / 20
Neutral mixing length	BOUNDARY L.	0.05 / 0.15 / 0.5
Gravity wave const.	GRAVITY W.D.	1E-4/7E-4/7.5E-4
Froude number	GRAVITY W.D.	2 / 2 / 4

RP+SCV in MOGREPS



SKEB

Stochastic Kinetic Energy Backscatter (SKEB)

- Based on original idea and previous work by Shutts (2004)
- Related to new scheme for ECMWF EPS

- **Aim:** To backscatter (stochastically) into the forecast model some of the energy excessively dissipated by it at scales near the truncation limit

- In the case of the UM, a total dissipation of 0.75 Wm-2 has been estimated from the Semi-lagrangian and Horizontal diffusion schemes. *(Dissipation from Physics to be added later on)*

- Each member of the ensemble is perturbed by a different realization of this backscatter forcing

SKEB

- **Streamfunction forcing:**

$$F_{\psi} = \frac{1}{2}\alpha \cdot K \cdot R(\lambda,\phi)\frac{\sqrt{\Delta\tau \cdot D}}{\Delta\tau}$$

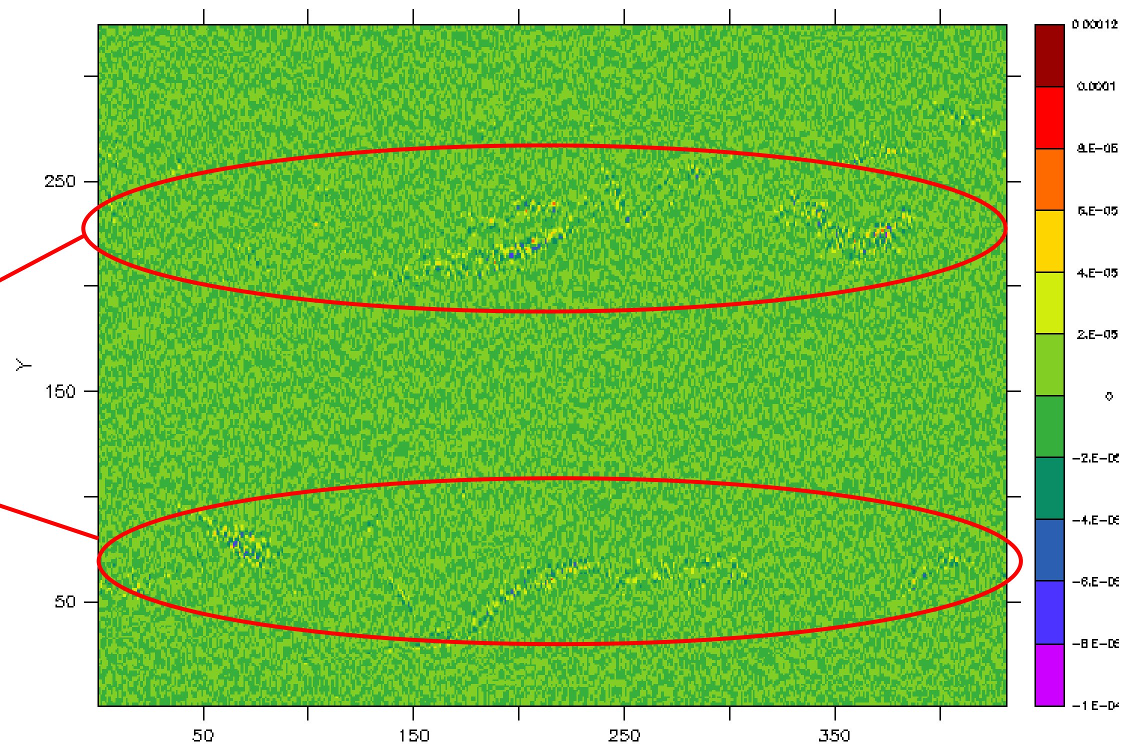
K.- Kinetic En.; *R*.- Random field;
$\Delta\tau D$.- Dissipated en. in a time-step

R is designed to reproduce some statistical properties found with CRMs

Example:

u increments at H500

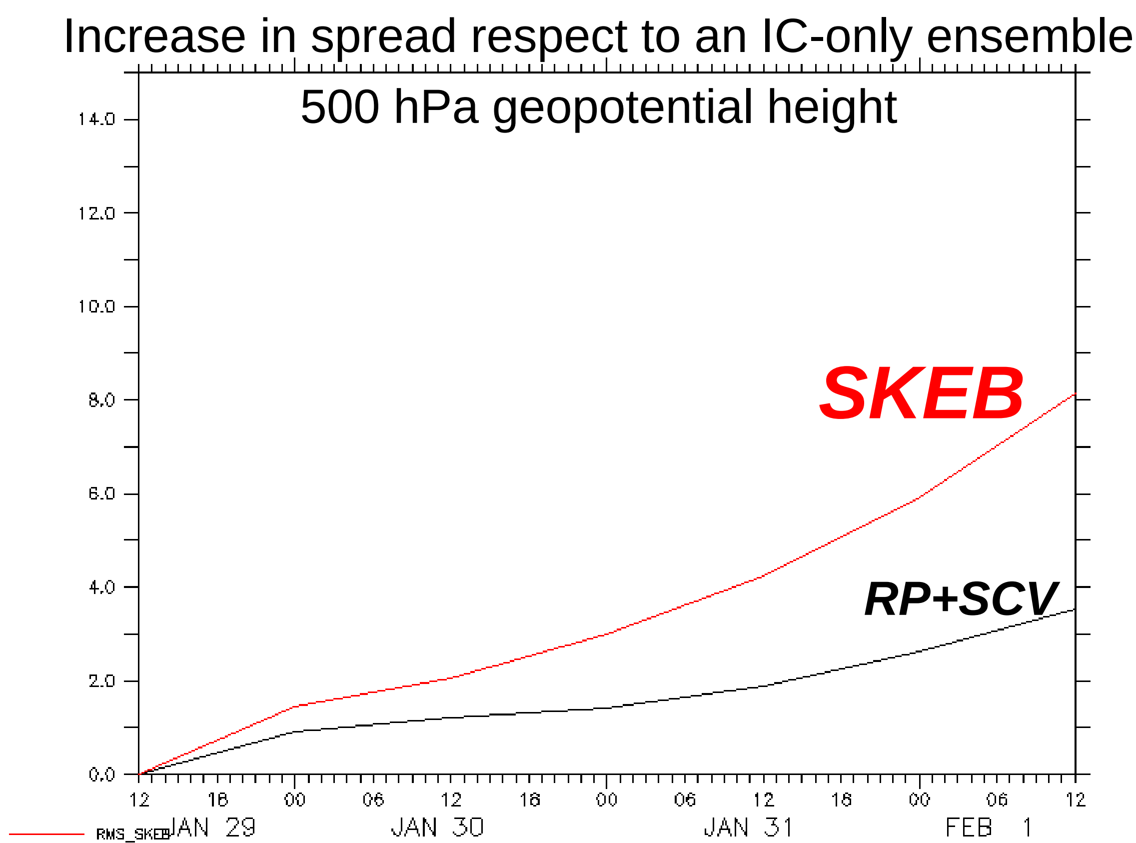
- Largest at the jets/storm track



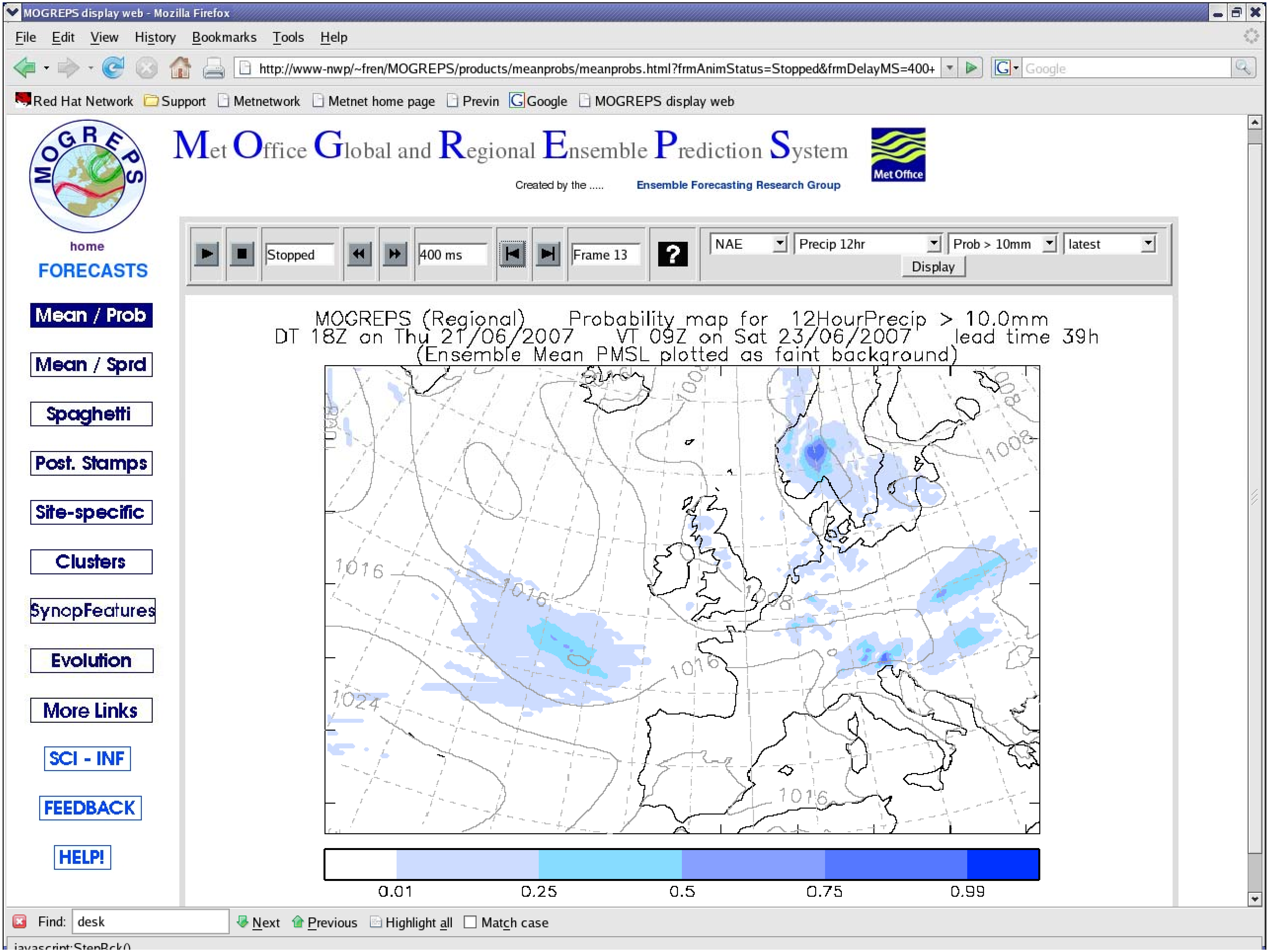
SKEB

Preliminary results:

- Positive increase in spread (comparable to that seen at ECMWF)



Product Examples


MOGREPS display web - Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://www-nwp/~fren/MOGREPS/products/meanprobs/meanprobs.html?frmAnimStatus=Stopped&frmDelayMS=400+
Google
Red Hat Network
Support
Metnetwork
Metnet home page
Previn
Google
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SynopFeatures
Evolution
More Links
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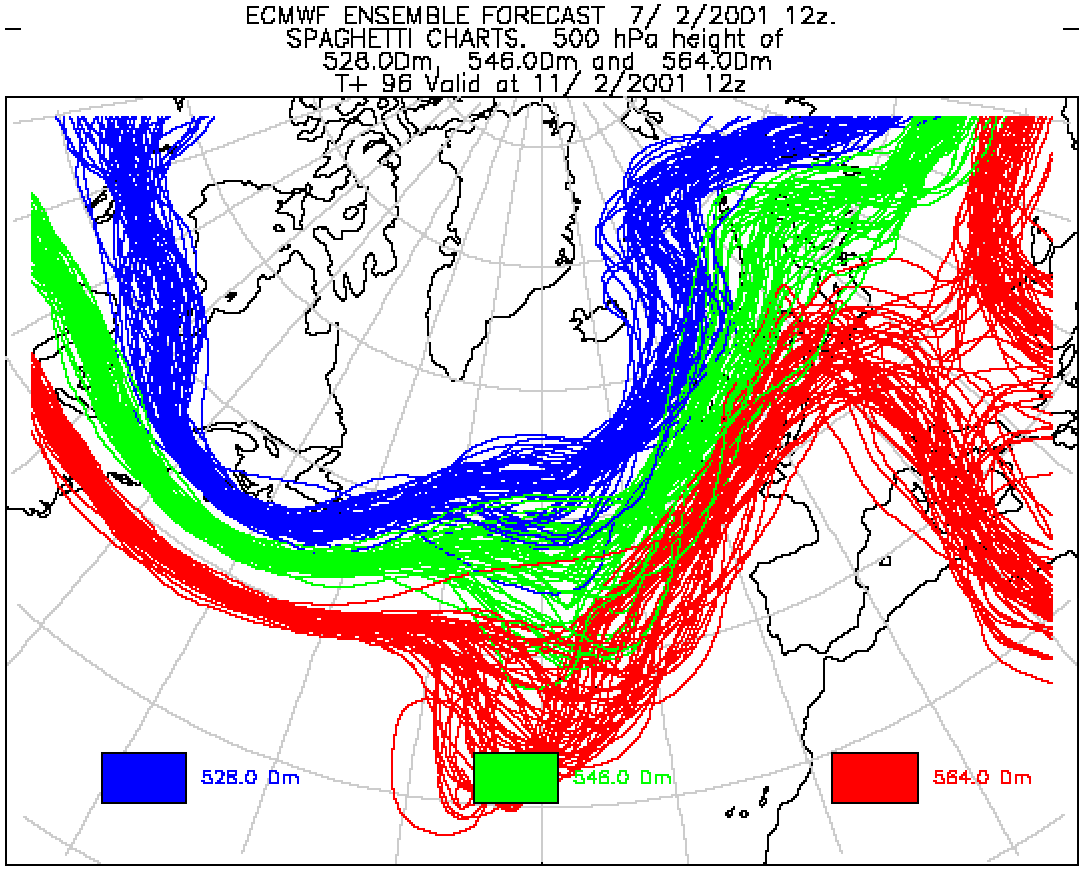
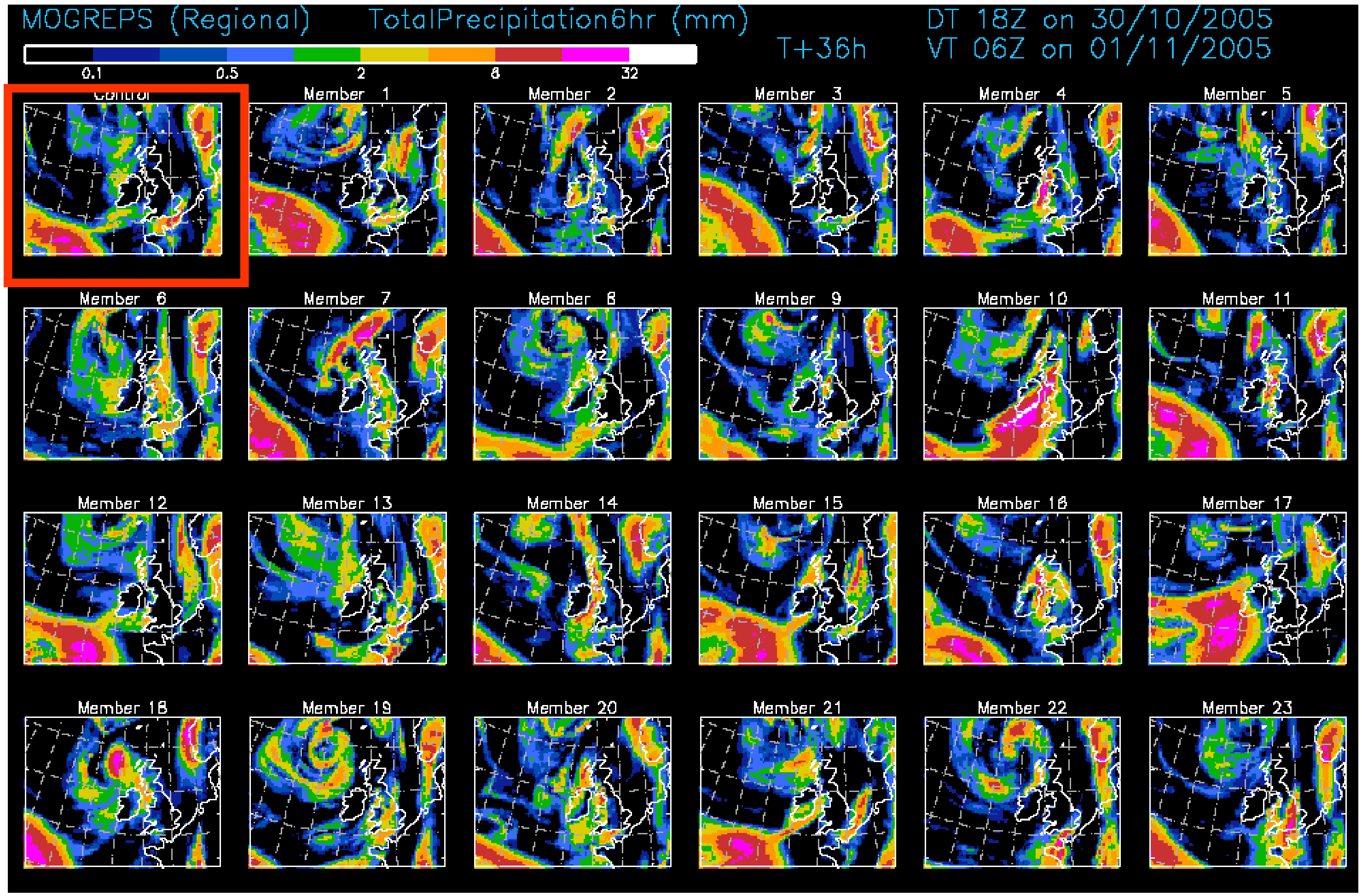
HELP!
Met Office Global and Regional Ensemble Prediction System
Created by the .....
Ensemble Forecasting Research Group
Met Office
Stopped
400 ms
Frame 13
?
NAE
Precip 12hr
Prob > 10mm
latest
Display
MOGREPS (Regional) Probability map for 12HourPrecip > 10.0mm
DT 18Z on Thu 21/06/2007 VT 09Z on Sat 23/06/2007 lead time 39h
(Ensemble Mean PMSL plotted as faint background)
1016
1016
1024
1008
1016
1016
1008
0.01
0.25
0.5
0.75
0.99
Find: desk
Next
Previous
Highlight all
Match case
javascript:StepBck0

Spaghetti Chart

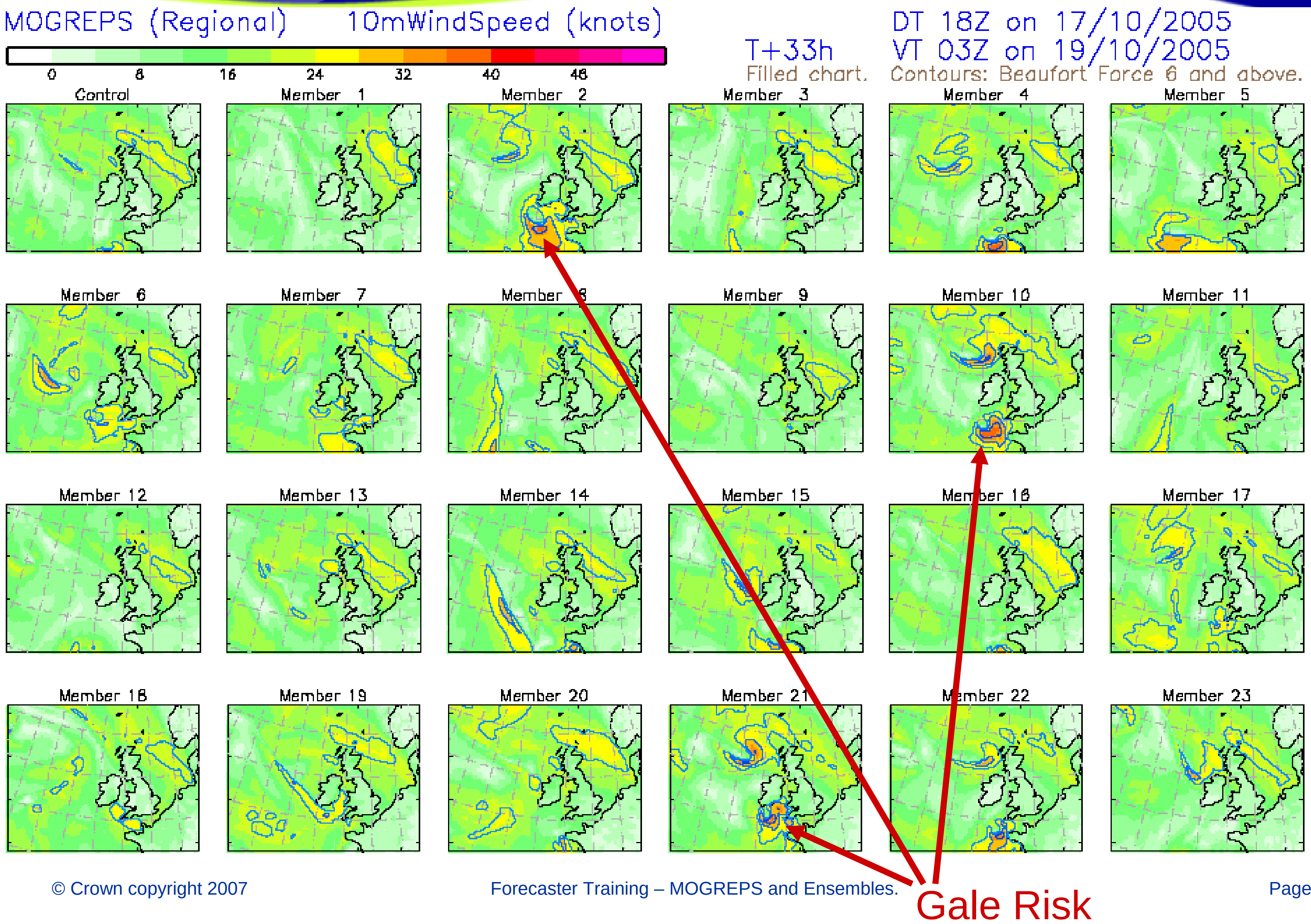


Example MOGREPS 33h Rainfall forecast

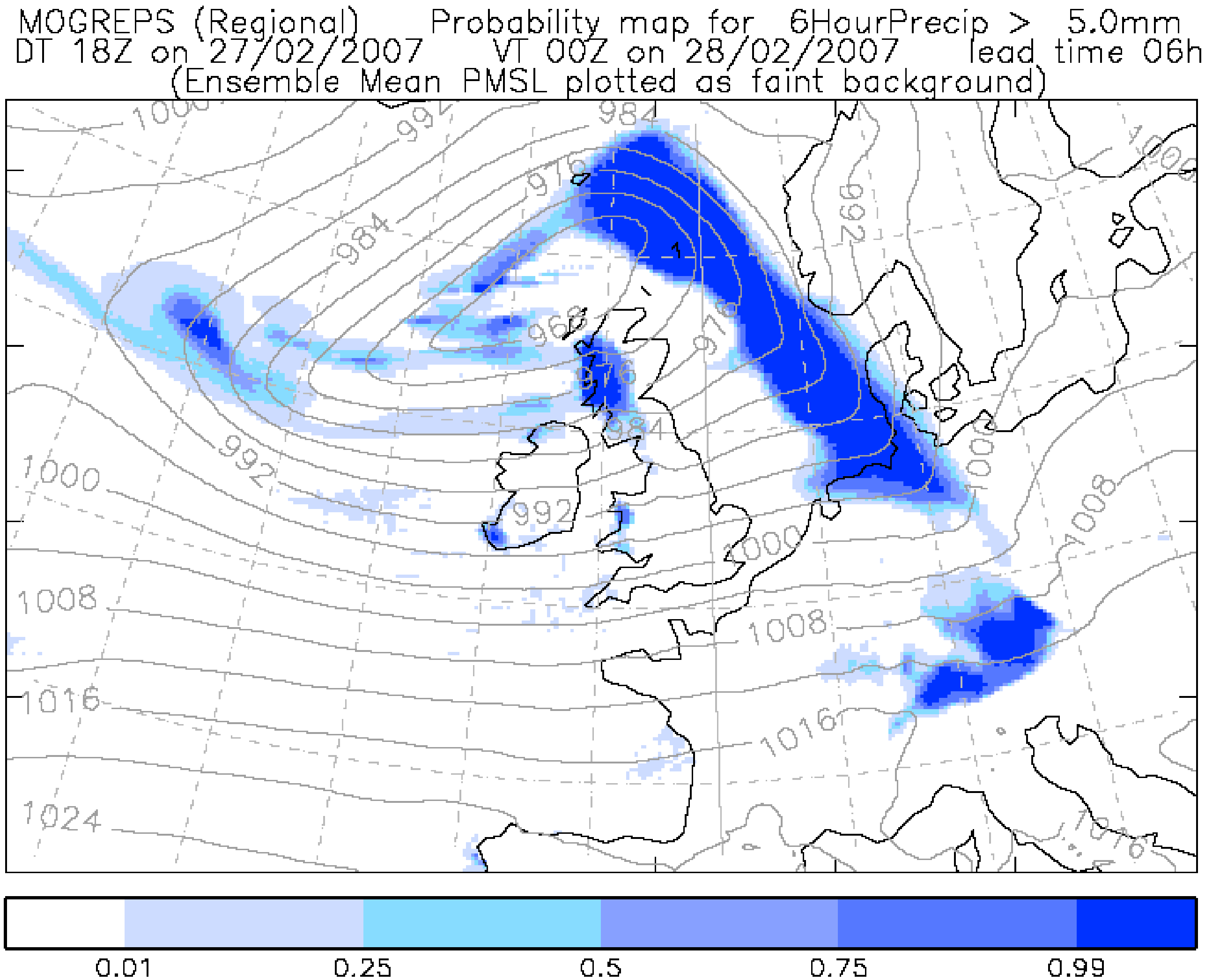
- Standard deterministic forecast
- Ensemble offers much more information on
  - areas at risk
  - intensity



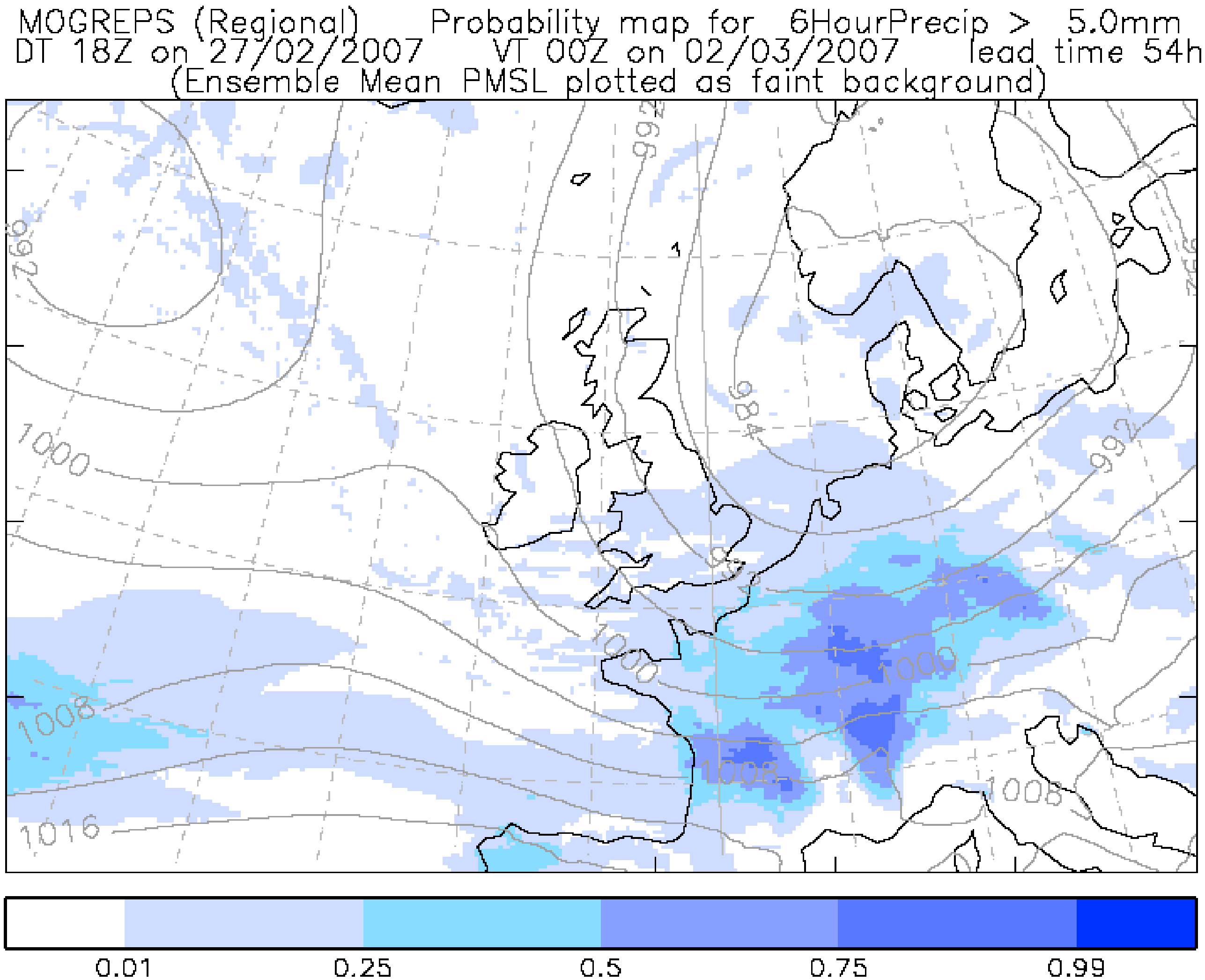
Example MOGREPS 33h 10m WS forecast



Products – Probability charts

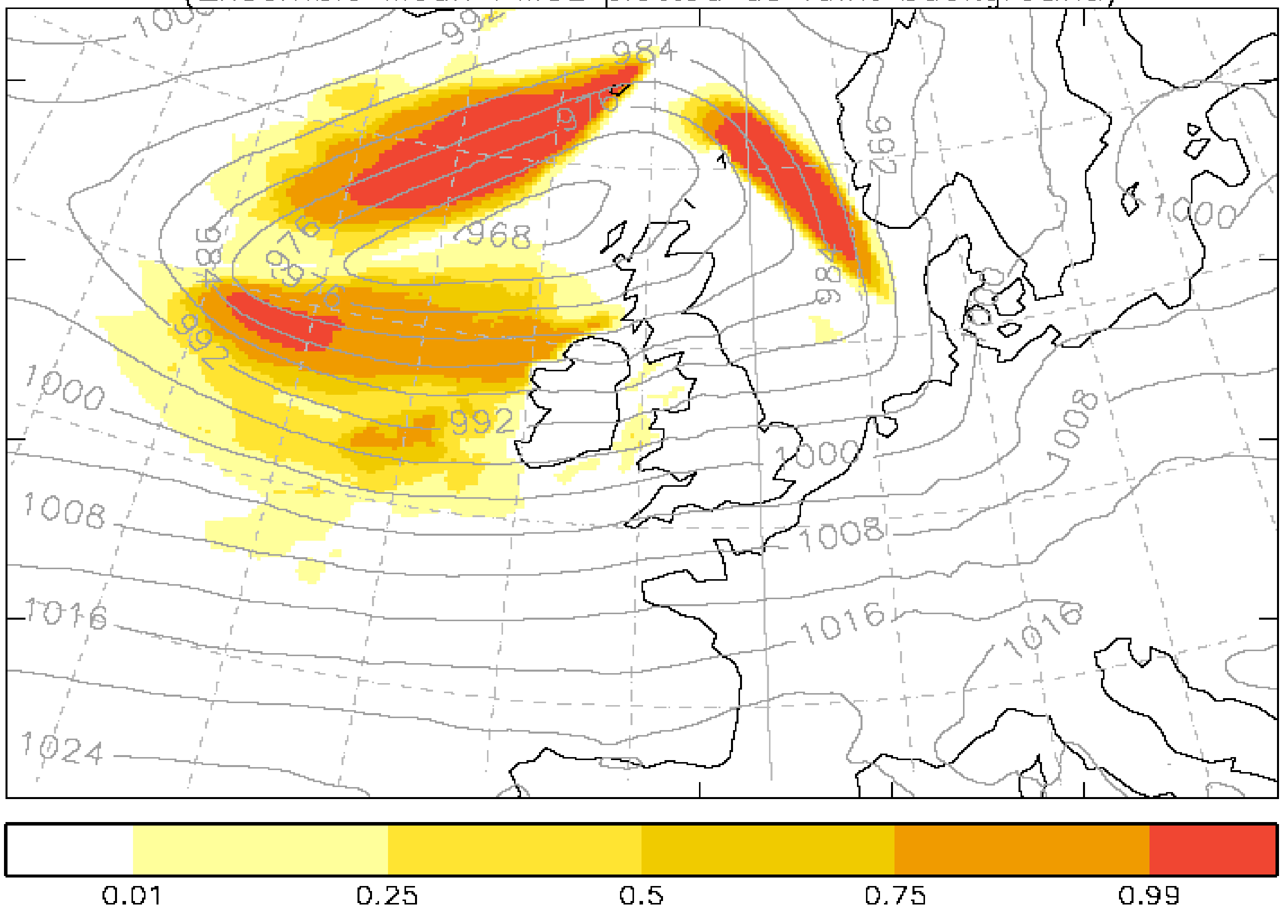


Products – Probability charts

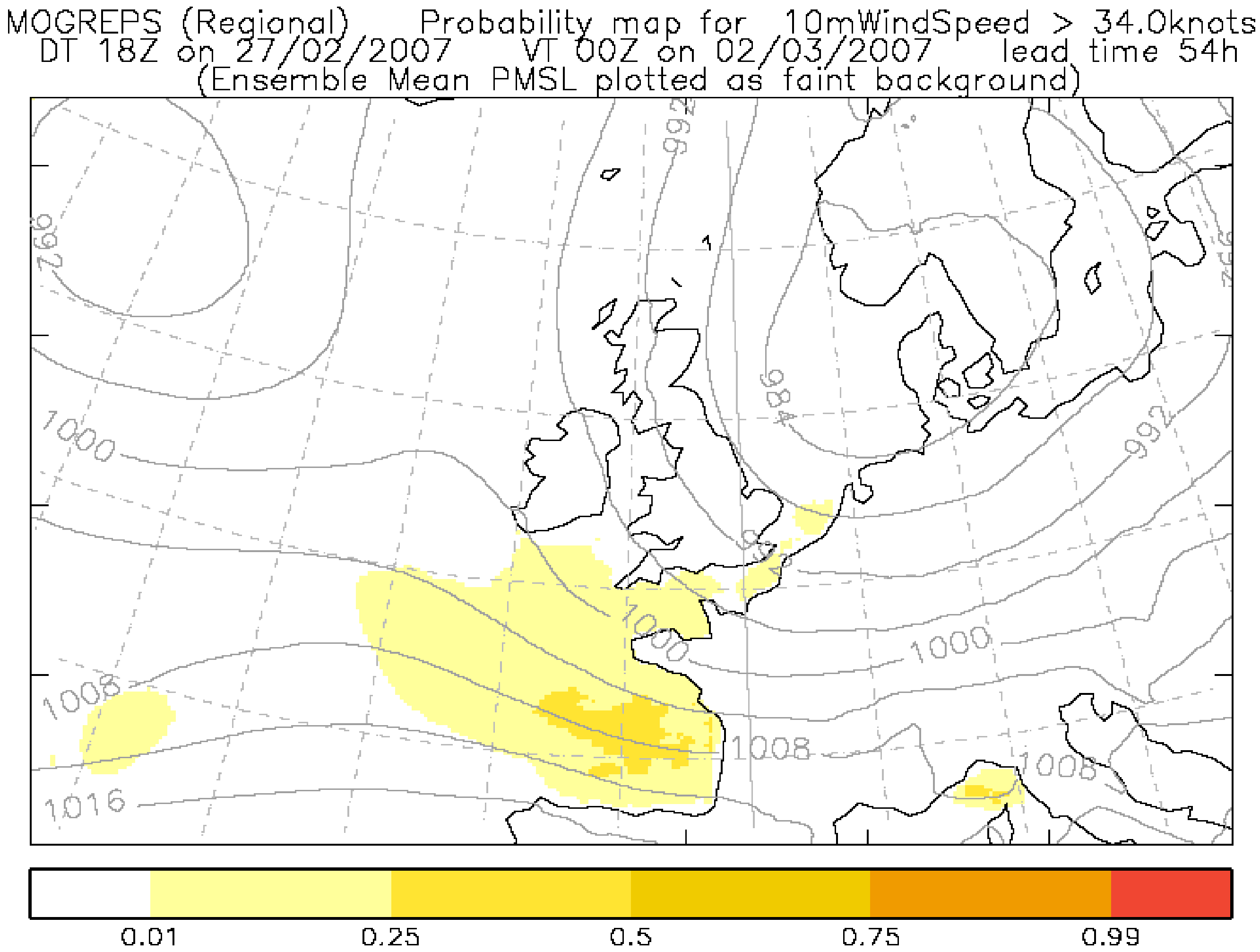


Products – Probability charts

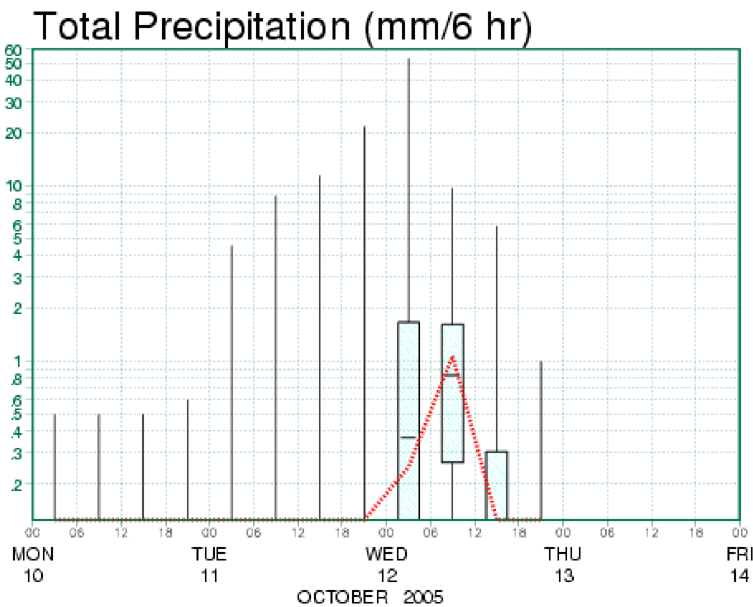
MOGREPS (Regional)   Probability map for 10mWindSpeed > 34.0knots
DT 18Z on 27/02/2007   VT 21Z on 27/02/2007   lead time 03h
(Ensemble Mean PMSL plotted as faint background)



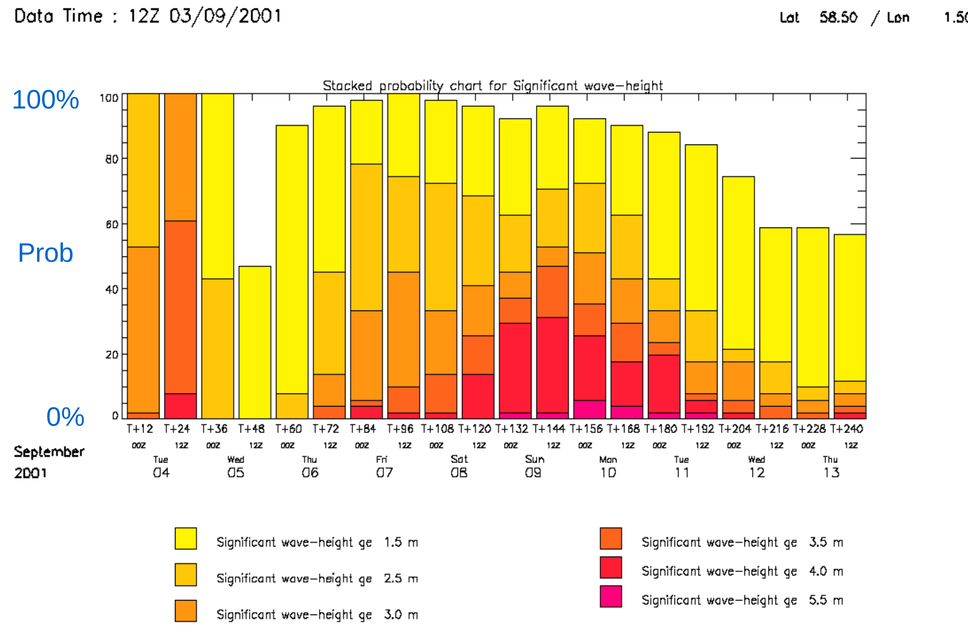
Products – Probability charts



Products for the Risk Manager

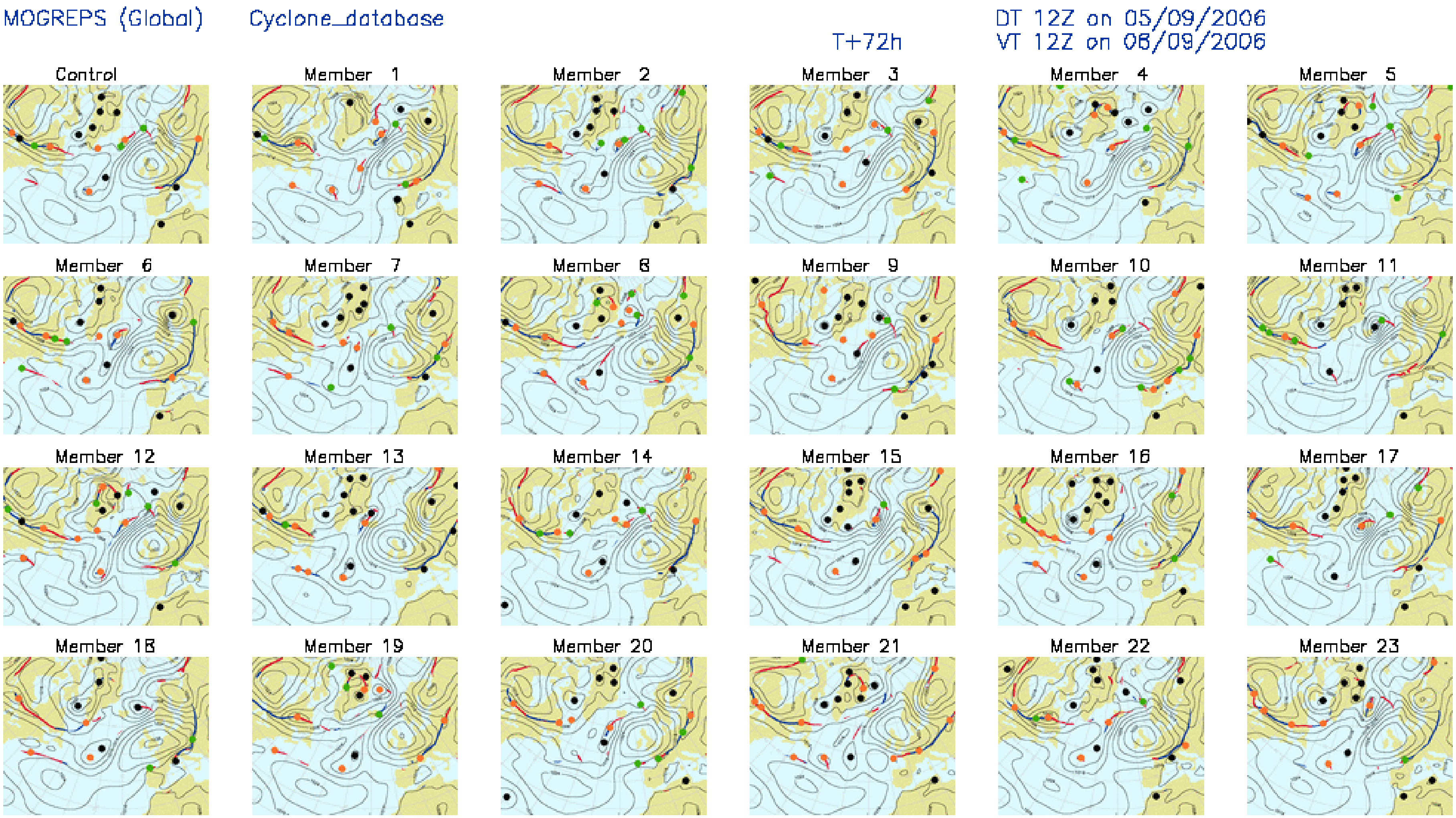


- Plot of ensemble spread
  - Range of uncertainty

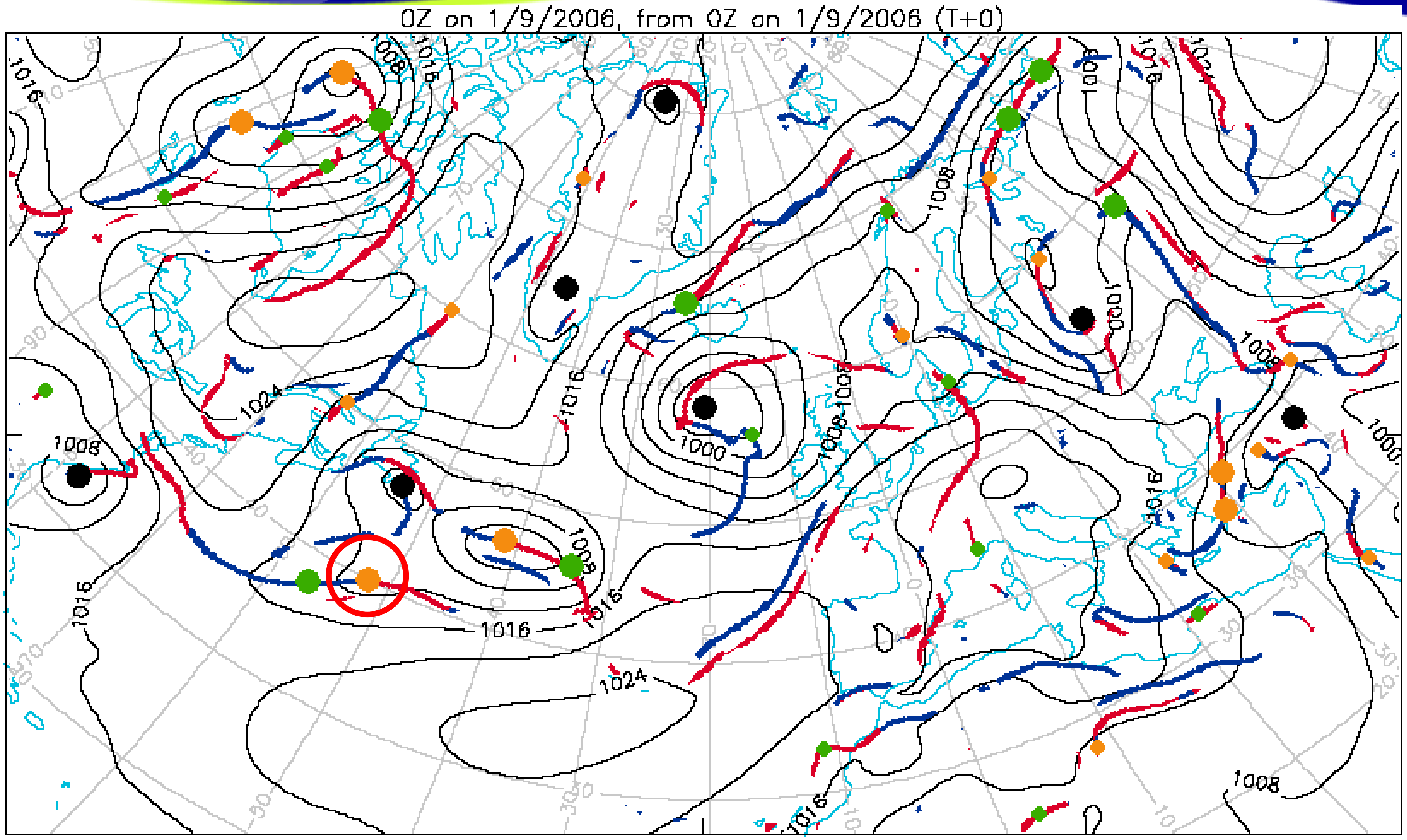


- Probability graph for multiple severity thresholds
  - Example of use for risk management in offshore oil industry

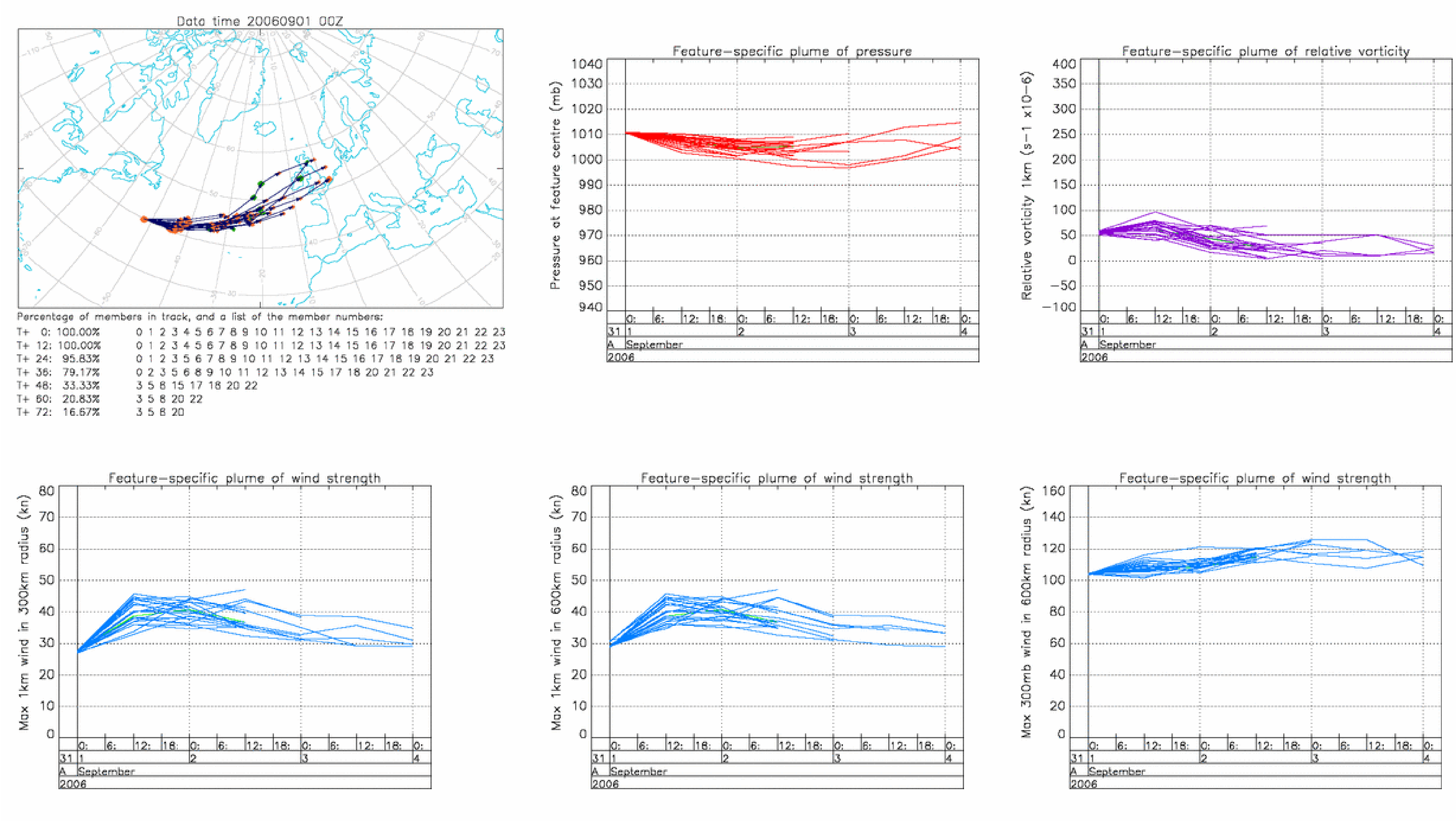
Synoptic Features (from Cyclone Database)



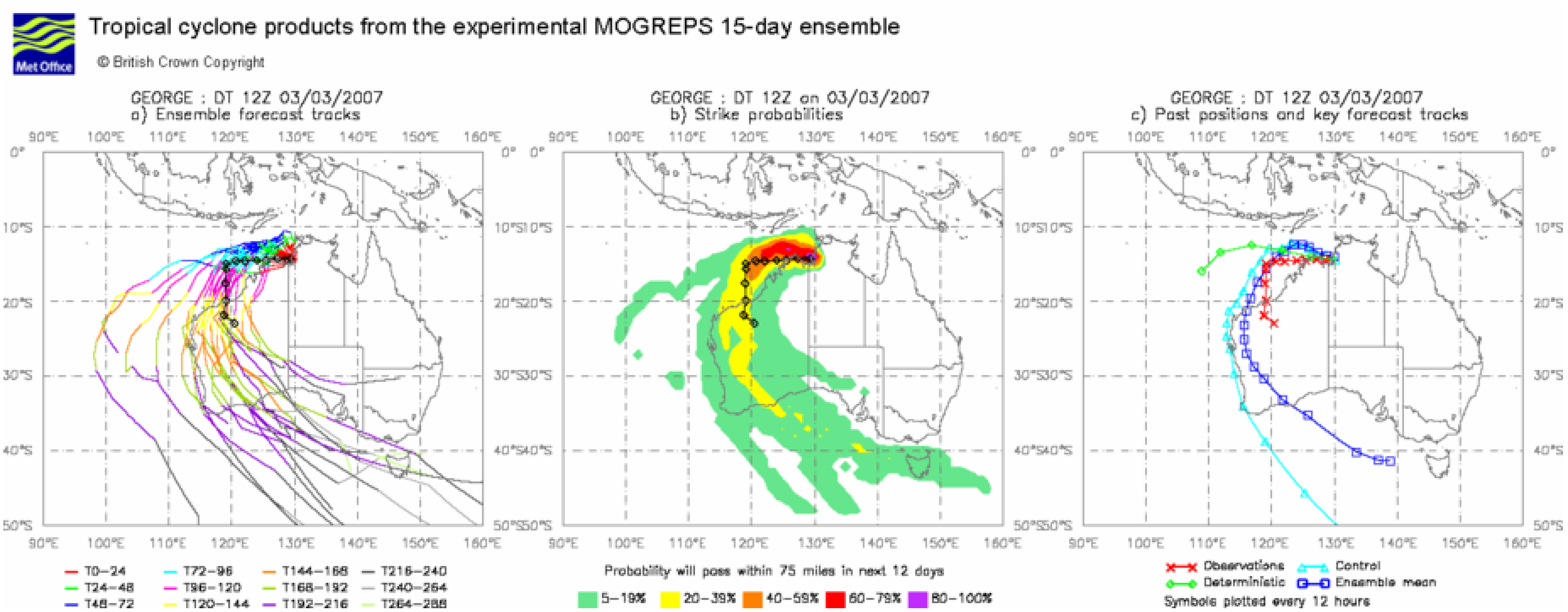
Click on Feature at T+0…



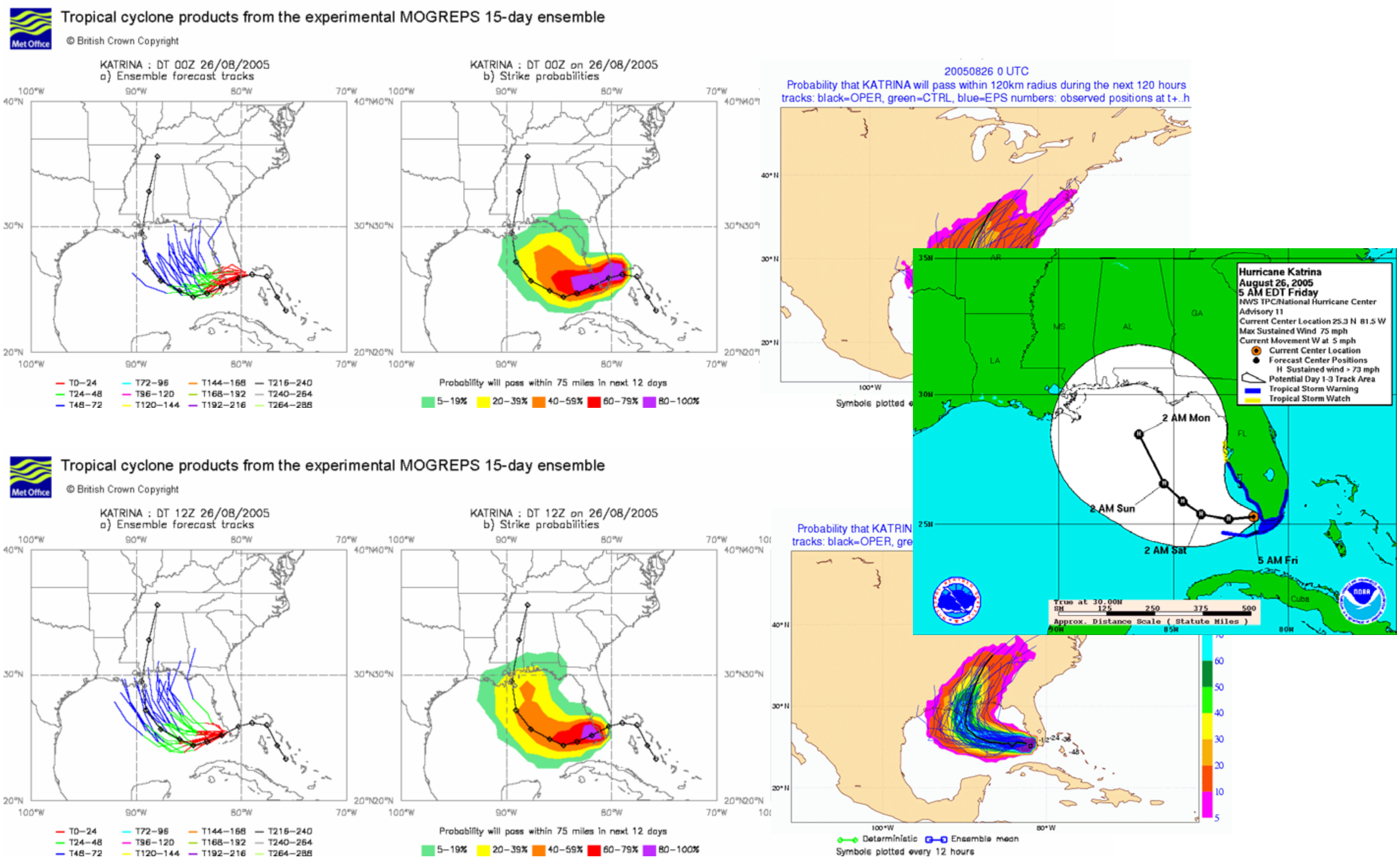
Forecast plumes for feature characteristics



Example tropical cyclone chart

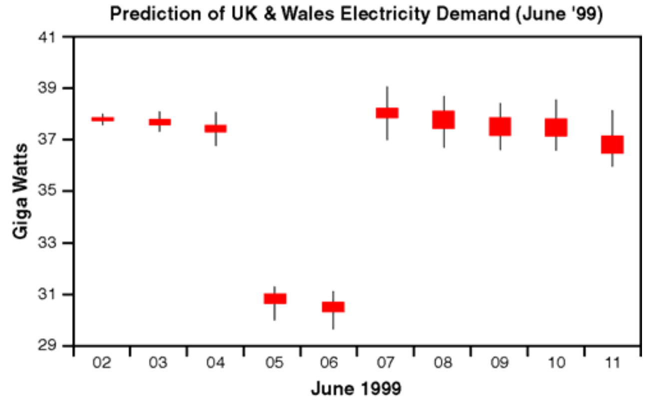


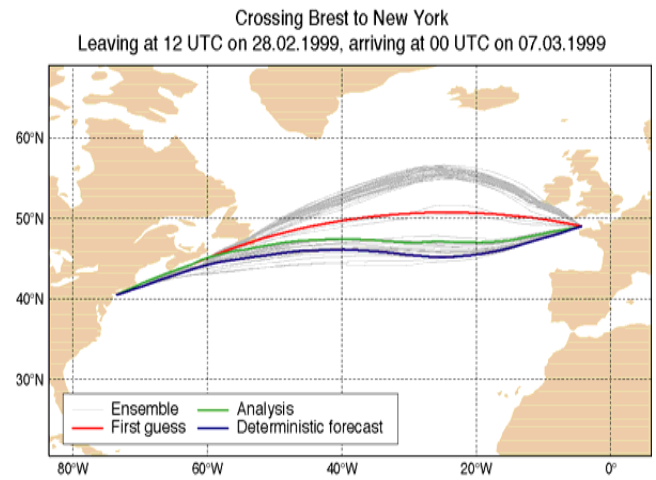
Hurricane Katrina



End-to End Outcome Forecasting

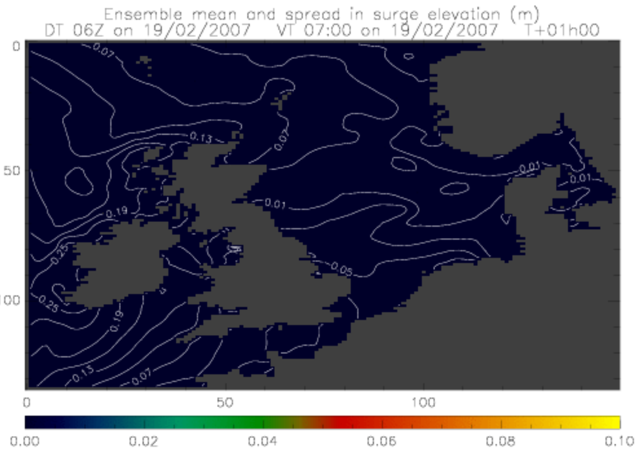
- An ensemble weather forecast can be used to drive an ensemble of outcome models, eg.:
  - Tidal surge
  - Ocean waves
  - Wind power output
  - Energy demand
  - Hydrology – flood risk
  - Ship or aircraft routes

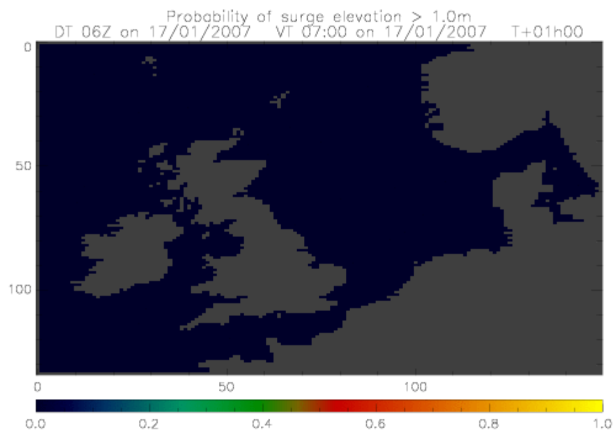


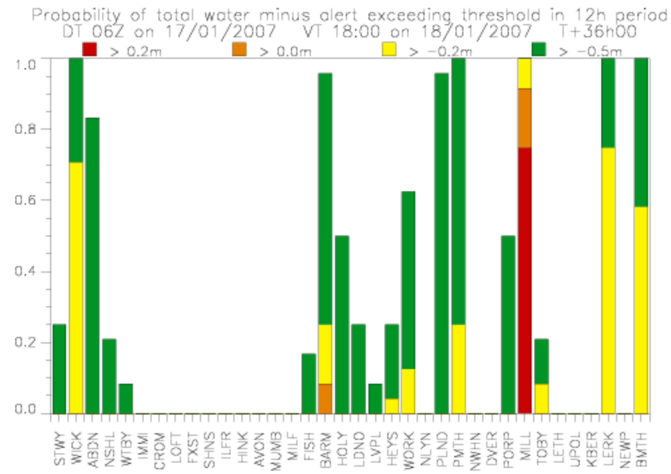


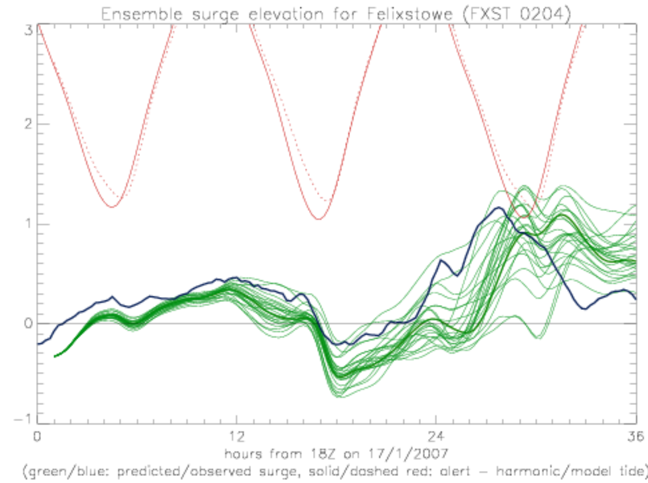
Storm surge Ensemble – contract for EA

- CS3 Storm surge model coupled to MOGREPS NAE



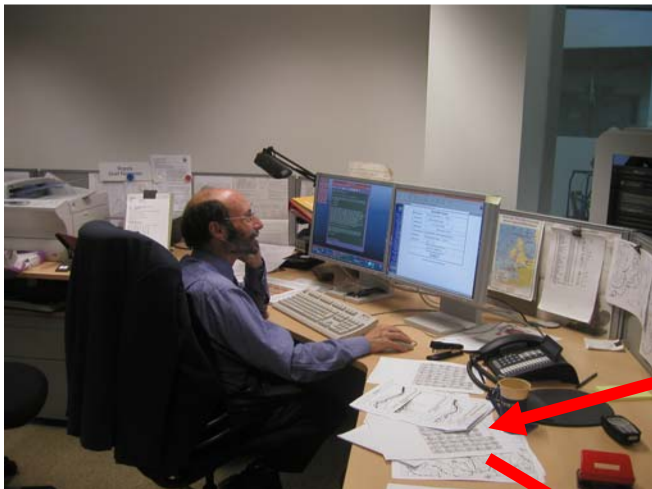


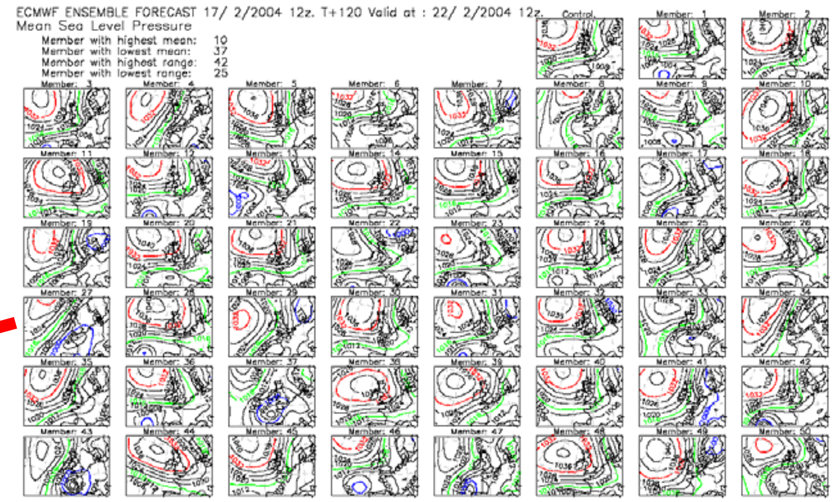


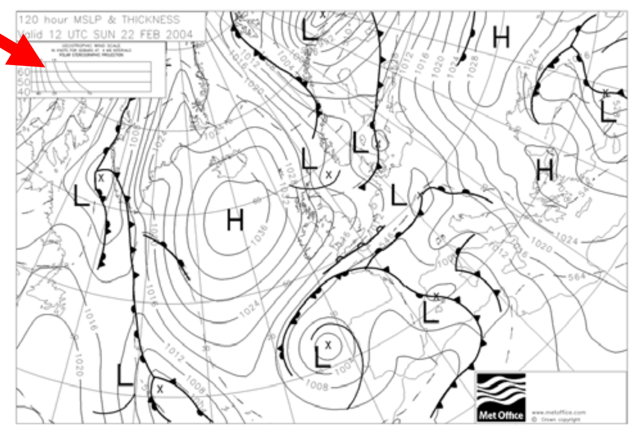


Using Ensembles

Met Office Operations Centre





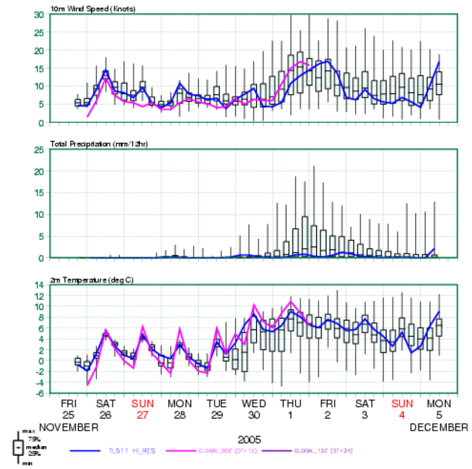


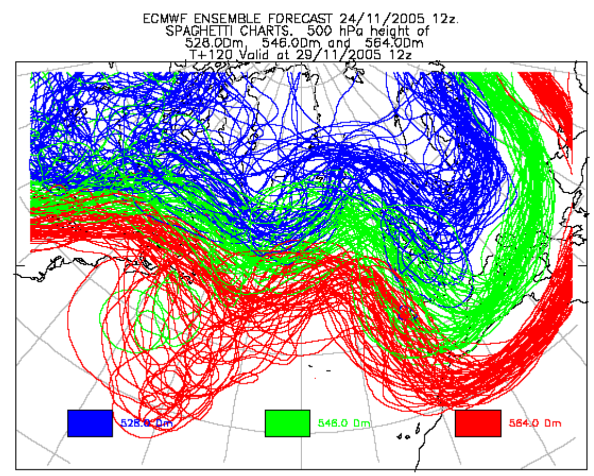
Ops Centre forecaster uses the ensemble to assess the *most probable outcome* before creating the medium-range forecast charts…

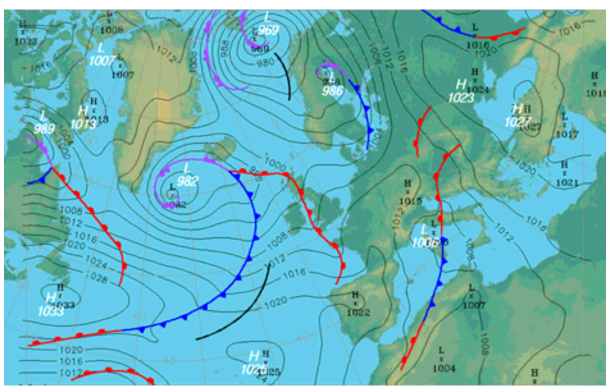
…and assess risks

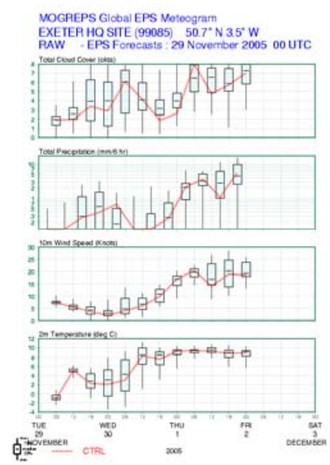
Example – low spread, high confidence

- Snowy period in SW, Nov 2005
- ECMWF EPS very high confidence of blocking breakdown
  - Allowed issue of high confidence of return to mild conditions on Wed 30th 5 days ahead
  - Analysis of 0600 on 30th confirms this was correct

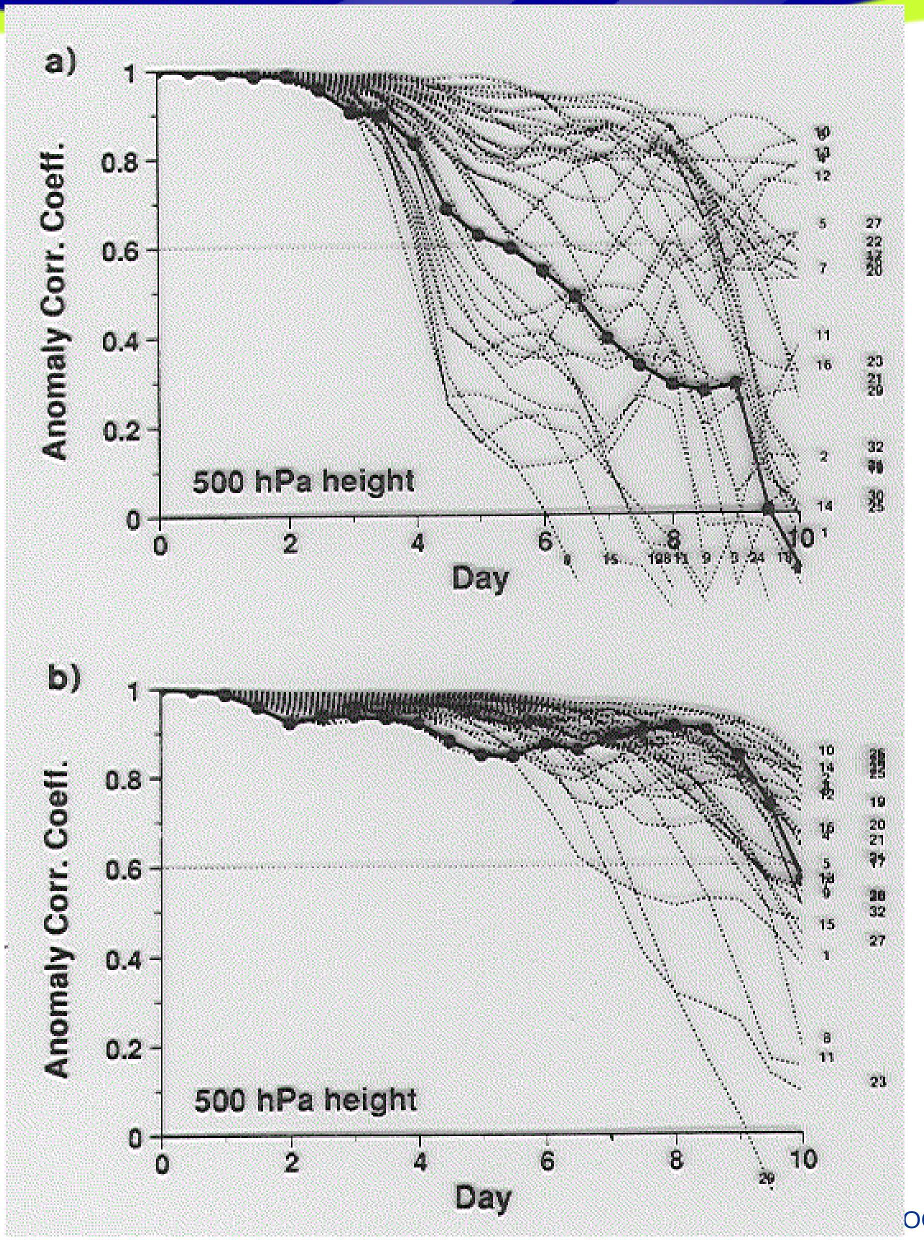








Variable Predictability in EPS



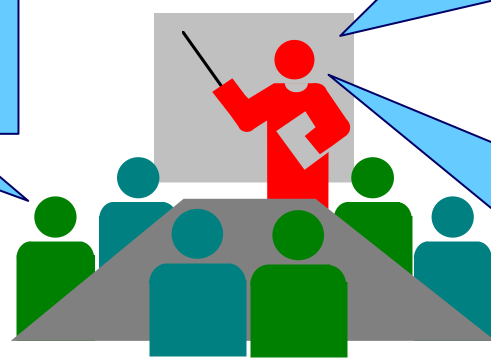
- ACC>0.6 indication of useful forecast
- Two graphs show variable predictability
- Many EPS members more skilful than control (solid line)
- Need to develop ways to extract information from best members, without knowing which they are
- Ensemble prediction systems (EPS) allow us to assess the *flow-dependent* predictability

Figure from Molteni *et al*, 1996

Expressing uncertainty

- Forecasters have always dealt with uncertainty.

When?
Where?
How much?
Are you
sure?



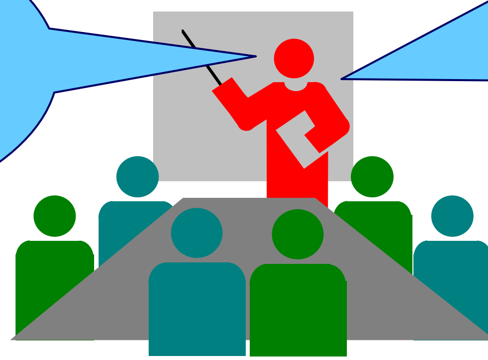
It's going to rain!

…at times
…mainly in the NW
…up to an inch in places
…risk of heavy bursts

- Uncertainty expressed in many ways , mostly subjective.

How can we improve on subjective description?

People in London have a 50% chance of seeing a light shower this afternoon...



…but in the NW you have an 80% risk of a shower with a 20% chance of over an inch

This is much more informative, but only if the figures are meaningful!

Use of probability forecasts - Clear Definition

What does this mean?

- 30% probability of rain in Scotland
    - 30% in Edinburgh City Centre?
    - 30% somewhere along the M8?
    - or 30% “somewhere in Scotland”?
    - How much?
        - A trace? 5mm? heavy downpour?

Probabilities must be *unambiguous* and *relevant* to the end user

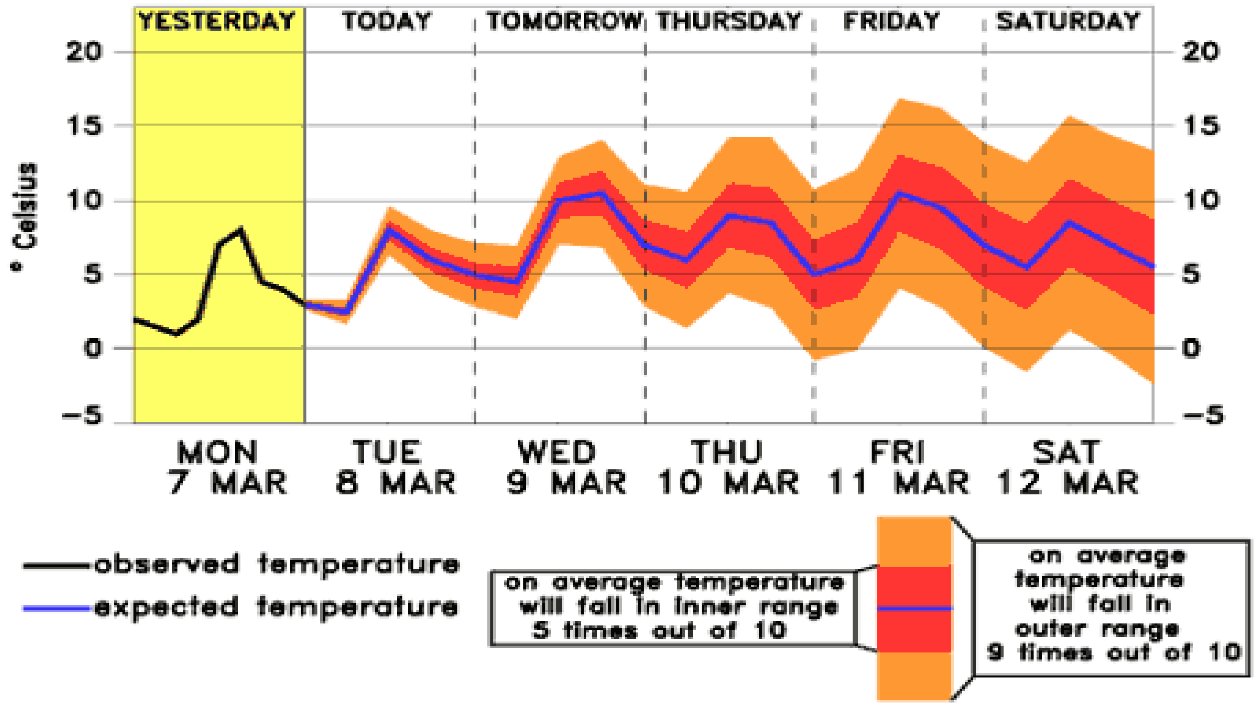
Clear Definition

Examples of well-defined probability forecasts could be:

- 30% probability of more than 5mm of rain at Edinburgh Airport between 1200 and 1800.
- 70% probability of wind reaching gale force in at least one place in Scotland on Tuesday.
- 10% probability of wind sufficient to cause severe structural damage in Edinburgh overnight.

The last example shows how a low probability can give useful warning of a serious event

Communicating uncertainty



- Improved presentation of meteogram information

Verification

A single Probability Forecast cannot be right or wrong. Consider:

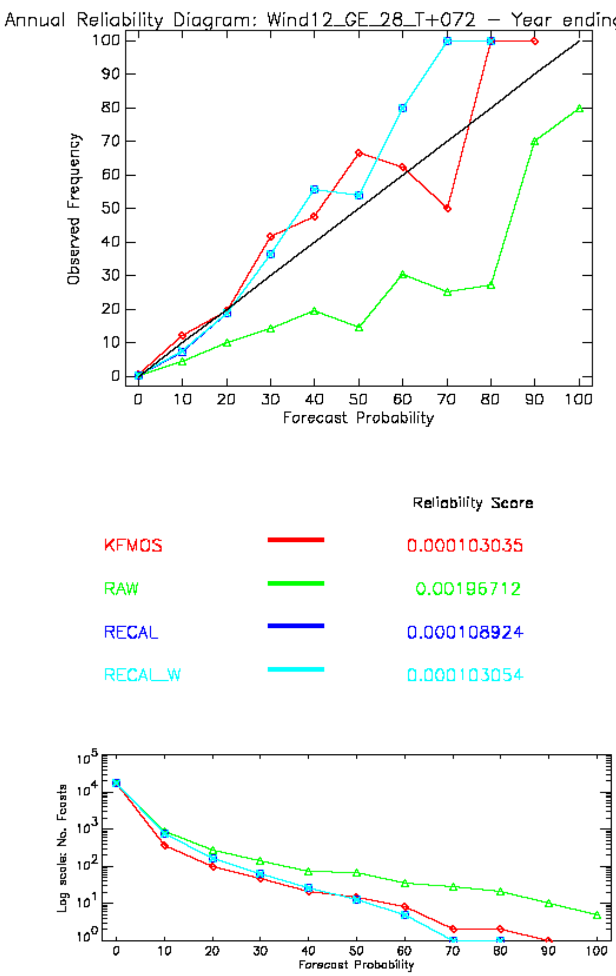
- Probability of *X* is 30%

If *X* happens, is this right? Or wrong?

But… out of 100 such forecasts, *X* should happen 30 times.

Verification must be done over many forecasts

Verification



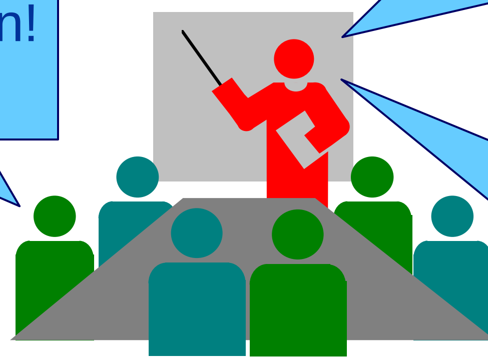
- Reliability diagram shows how well probability relates to frequency of occurrence
  - Demonstrates benefit of bias correction (red) compared to raw (green) for ECMWF wind forecasts

Probabilities in Context

- Sometimes probabilities need to be compared to climatology to be properly understood.

50% ? You mean you don't know what will happen!

There's a 50% prob of snow in London tomorrow



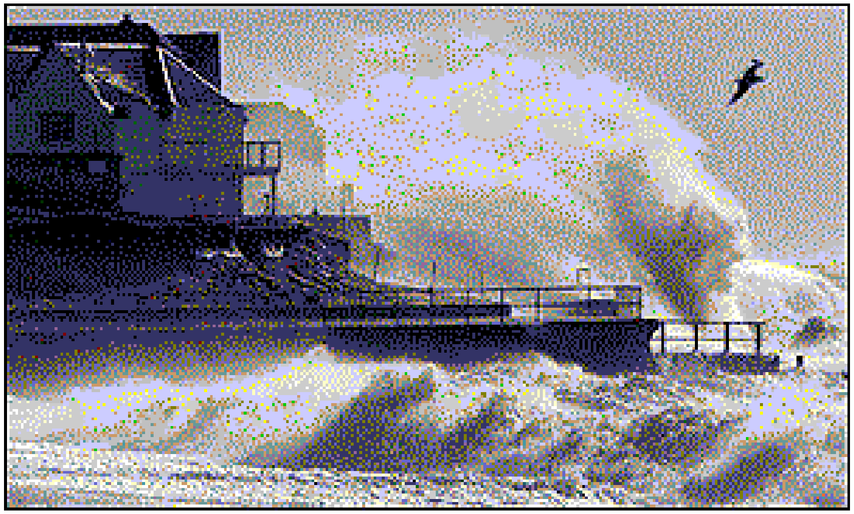
Normally it only snows one day in 50 at this time of year - so 50% is a strong signal.

Severe Weather Warnings

Example: Early Warnings of Severe Weather

Met Office issues Early Warnings up to 5 days ahead -
when probability ≥60% of disruption due to:

- **Severe Gales**
- **Heavy rain**
- **Heavy Snow**

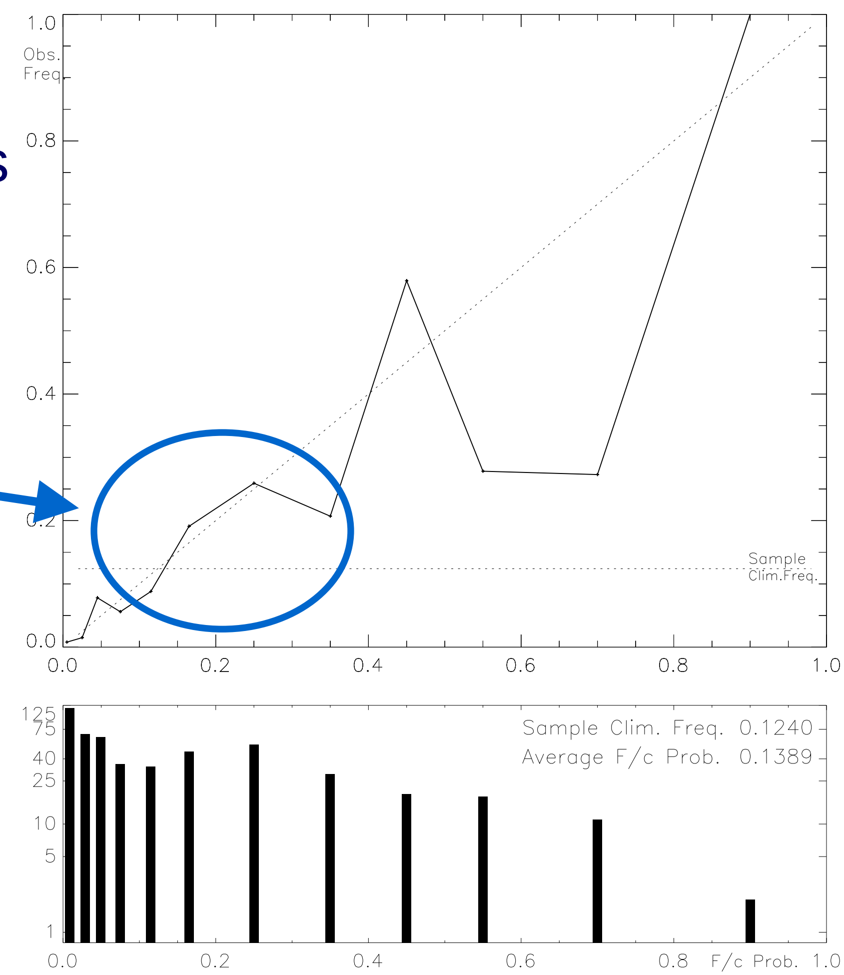


- Forecasters Provided with alerts and guidance from EPS
- Challenges:
  - Severe events not fully resolved
  - Combination of effects
  - Few events so difficult to verify

Verification of Heavy Rainfall Warnings

- Good relationship between forecast probability and frequency of occurrence
- Most severe events *can be* forecast, but at *low probabilities*
- False alarms
  - For each correct low probability warning, several false alarms are also issued
  - Need suitable response levels to cope

Obs freq



f/c prob

Can we use low probabilities?

Most extreme events are inherently improbable - how should we respond to low probabilities?

Event probability must be related to "climatology" for decision-making, eg.

- 5% risk that a plane will crash - ***would you board it?***
- 5% risk of rain ***– would you play golf?***
- 50% prob of heavy snow in London tomorrow

Decisions must be based on user's Cost/Loss ratio

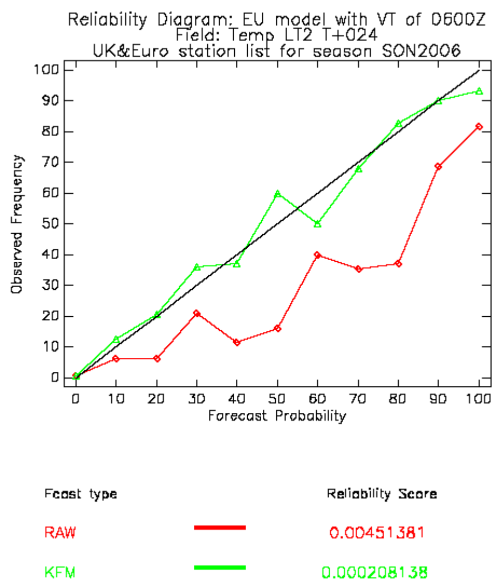
- users with low C/L should protect at low probabilities

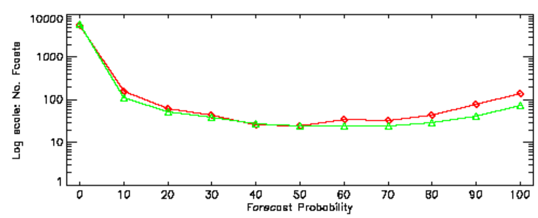
MOGREPS Verification

(Time permitting!)

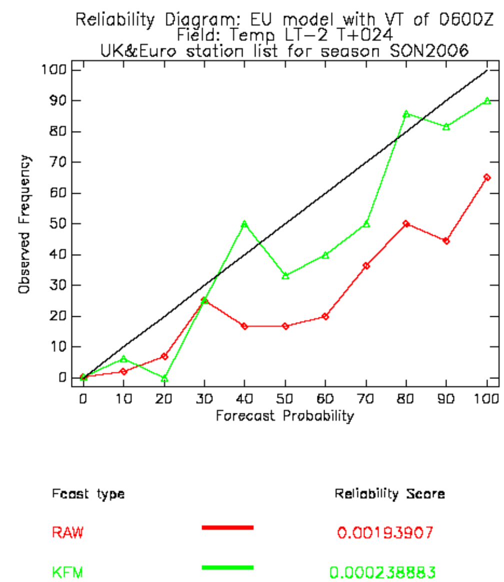
Temp SON06 (79 sites UK & Europe)

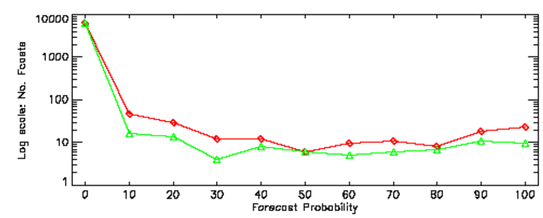
Temp<2C T+24



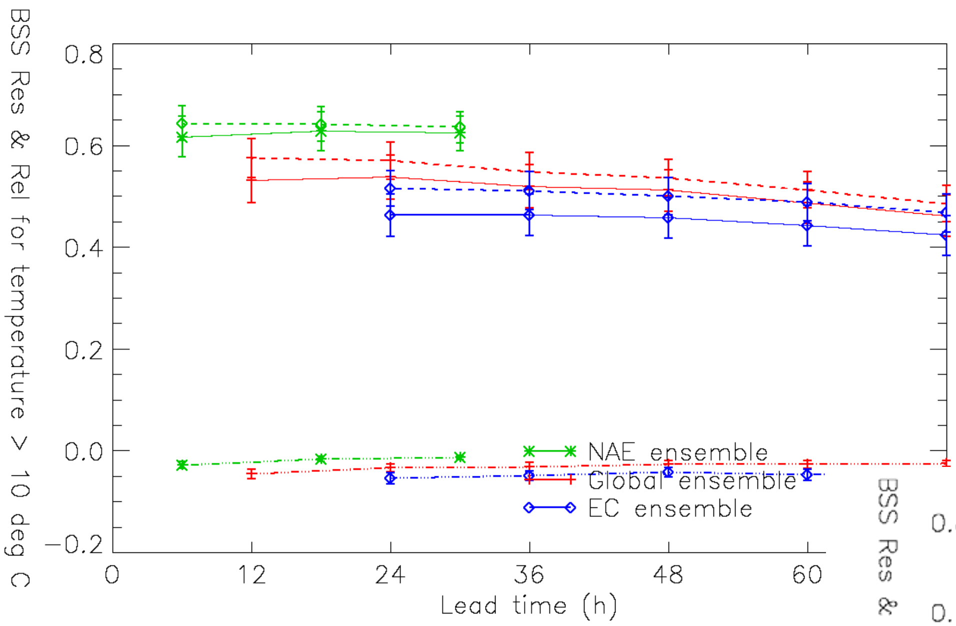


Temp<-2C T+24

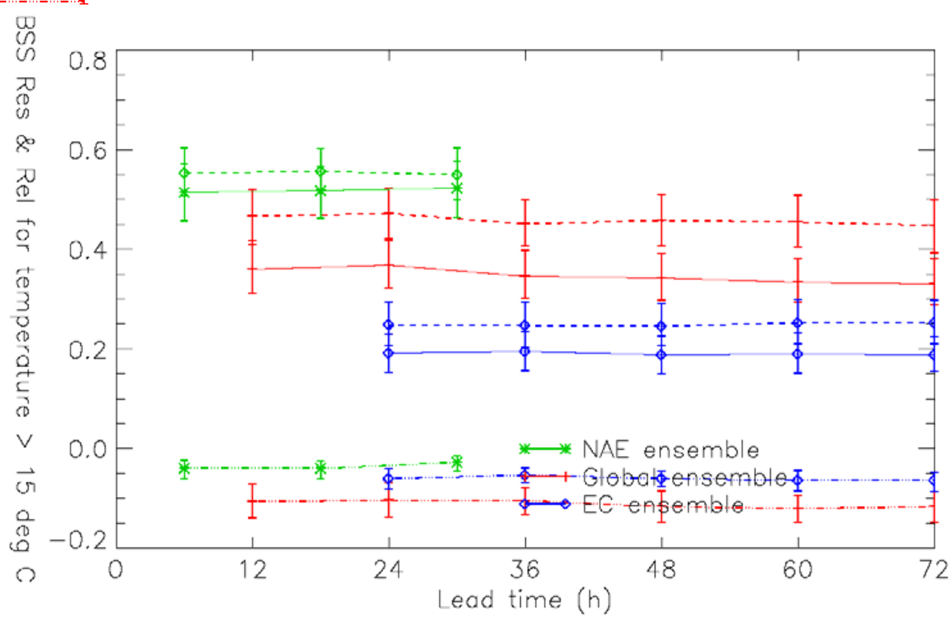




Brier Skill Score components for Temperature



Temp>10C

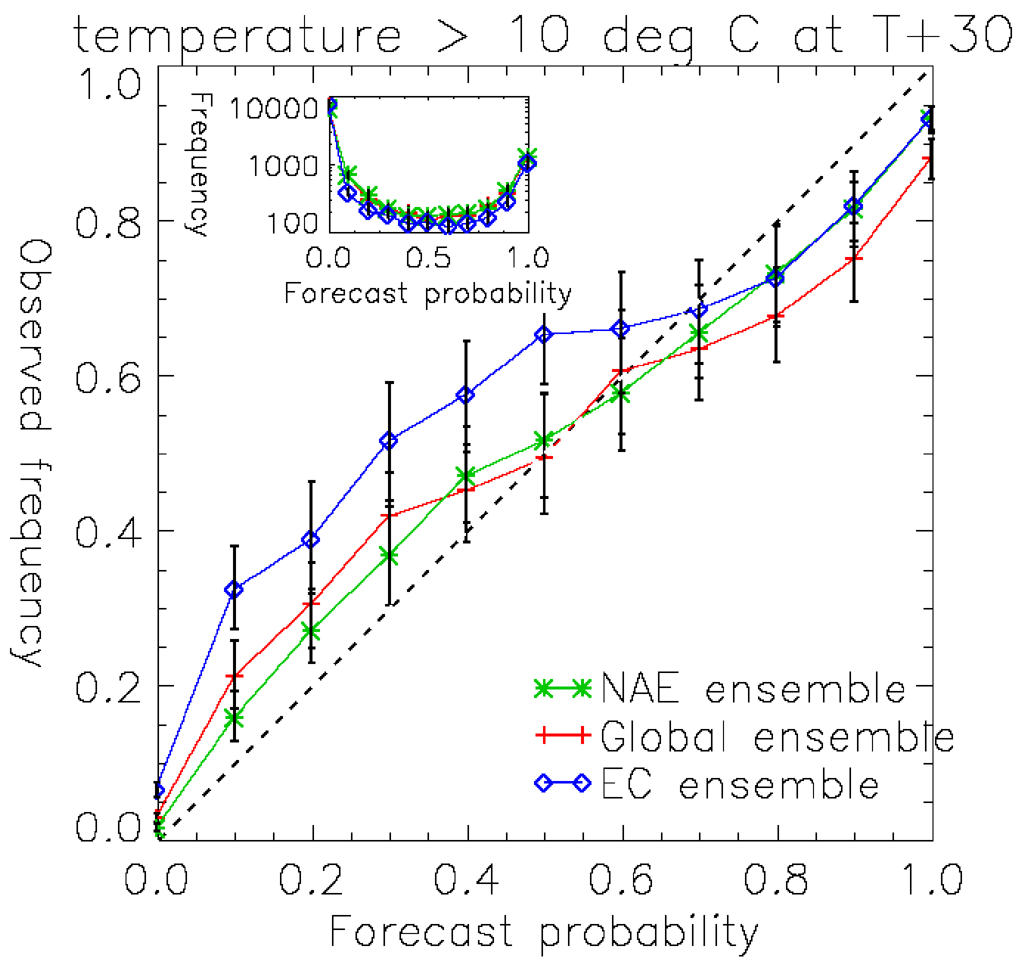


- 79 sites UK & Europe
- 6 Nov 2006 – 28 Feb 2007

Temp>15C

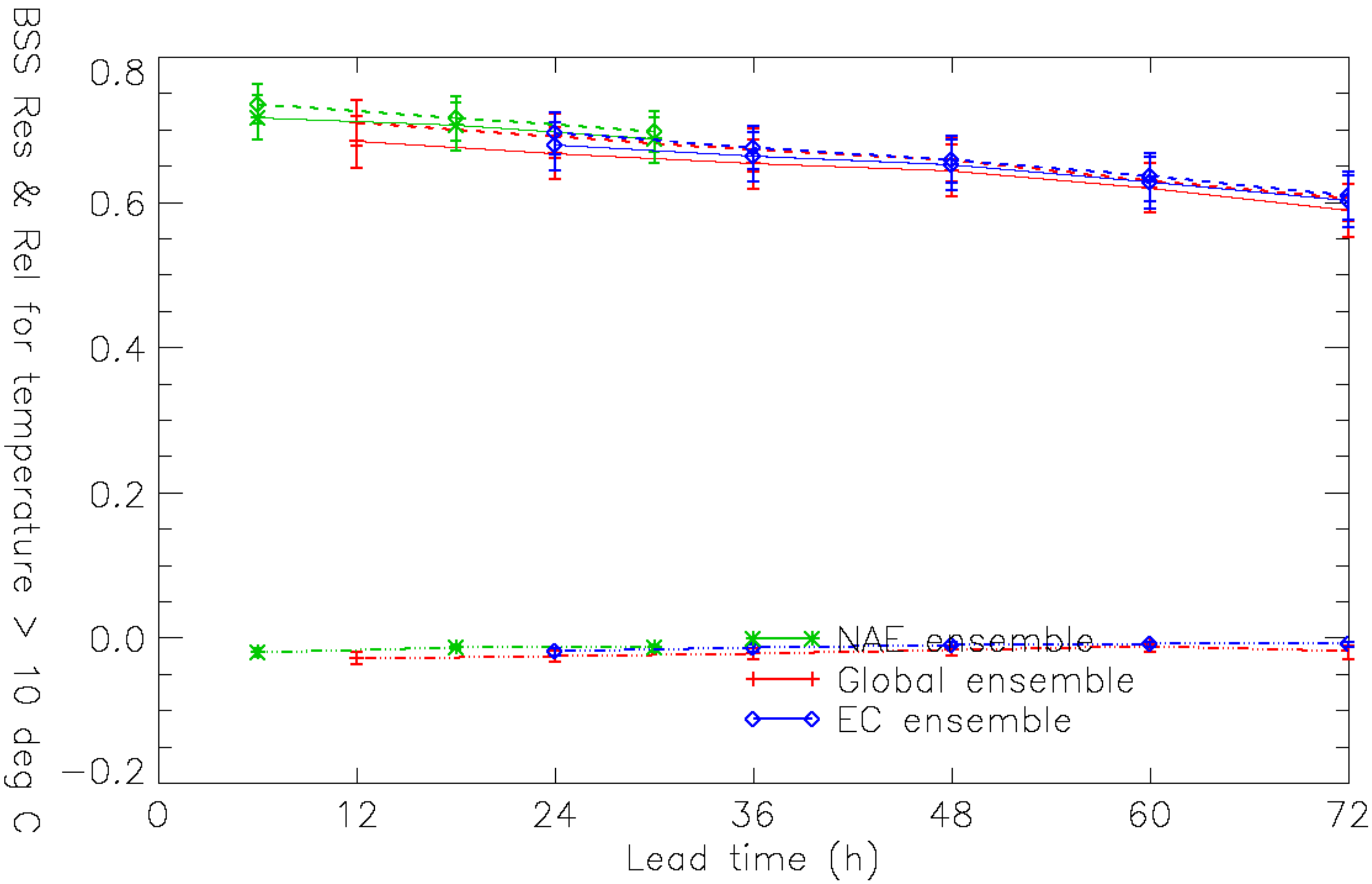
Reliability diagram for surface temperature

- Reliability diagram for Temp>10C
- 79 sites UK & Europe
- 6 Nov 2006 – 28 Feb 2007

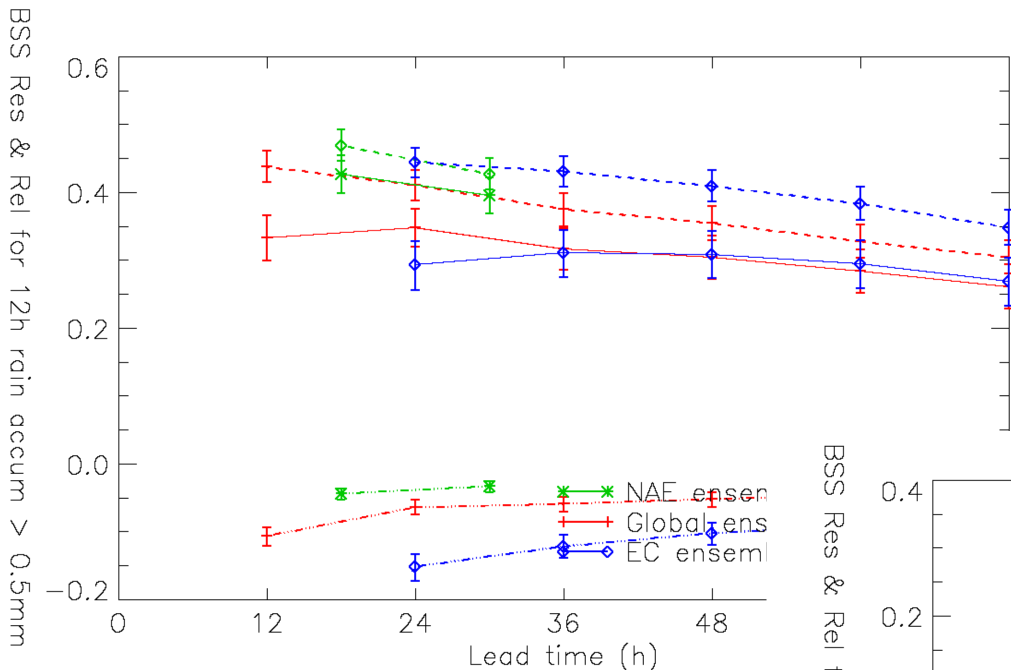


Temperature > 10ºC KFMOS

Kalman-filter bias-corrected forecasts.



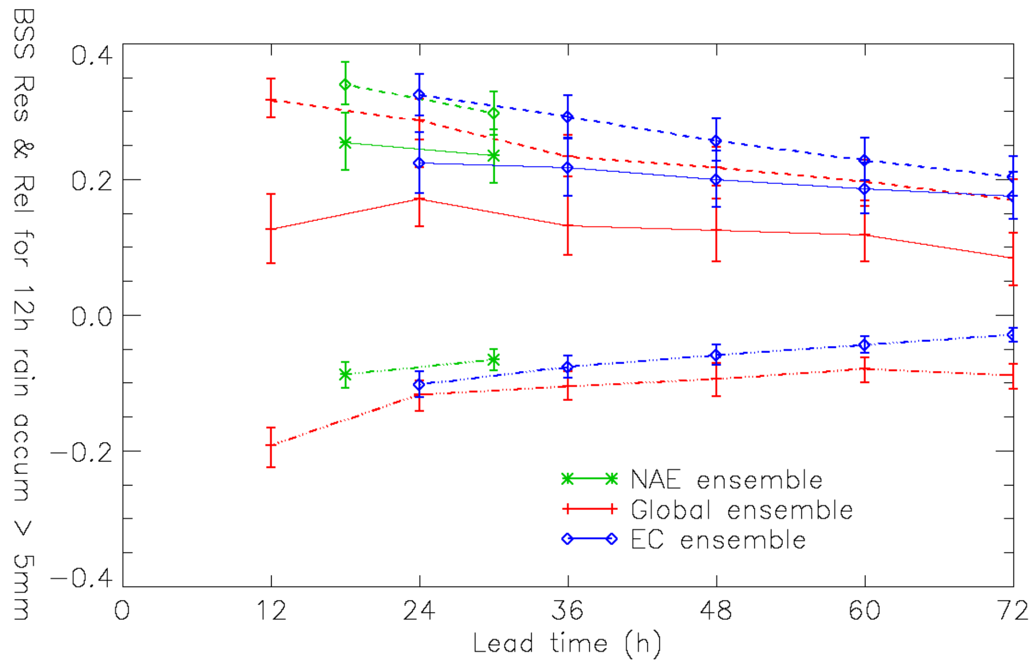
Brier Skill Score components for Precipitation



12-hour precip>0.5mm

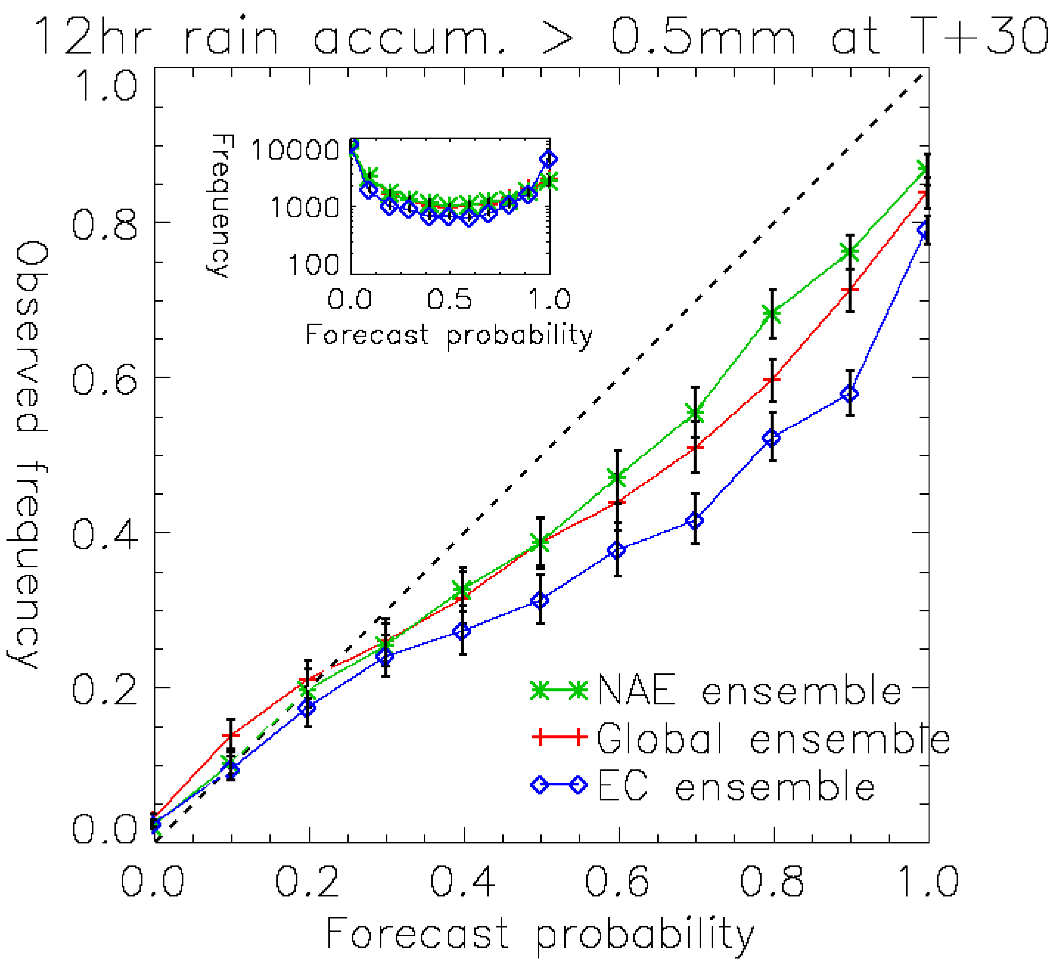
- 79 sites UK & Europe
- 1 July 2006 – 31 March 2007

- 12-hour precip>5mm

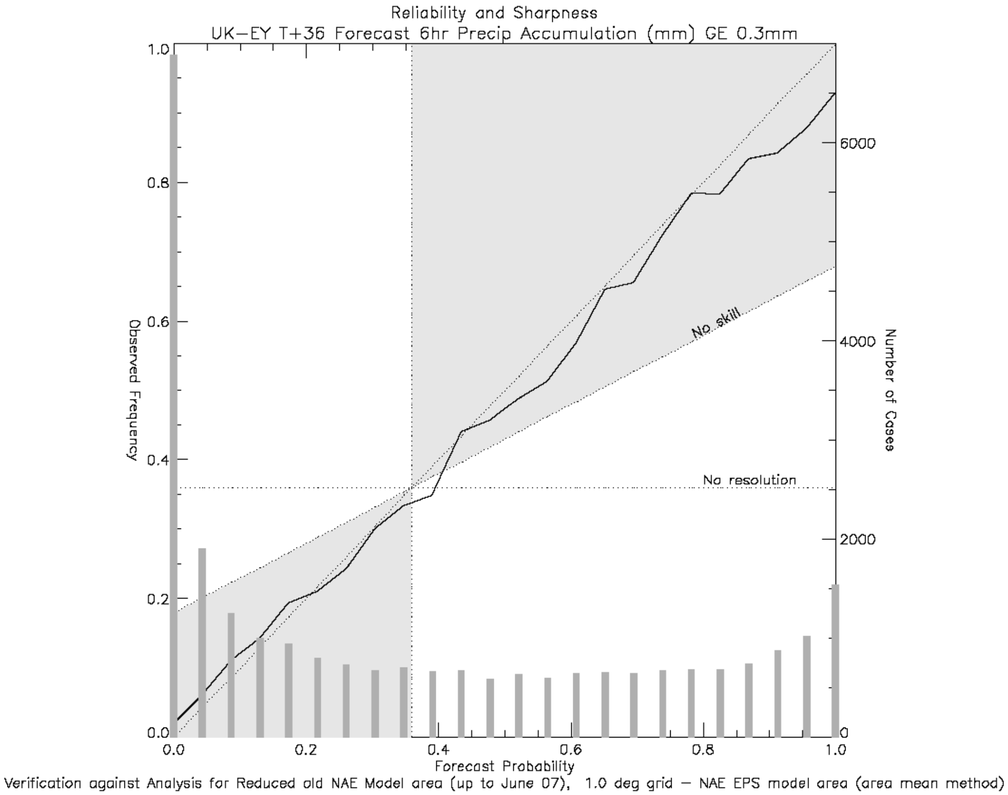


Reliability diagram for precipitation

- Reliability diagram for 12h precip>5mm
- 79 sites UK & Europe
- 1 July 2006 – 31 March 2007

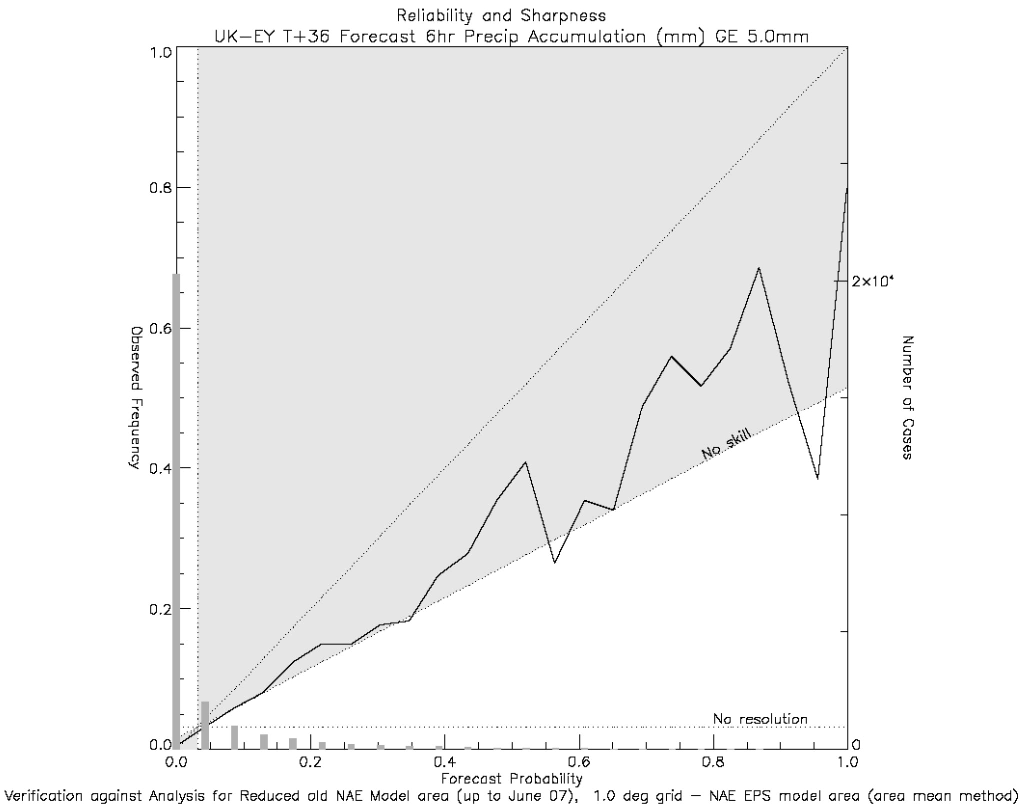


6hr precip > 0.3mm against gridded analysis



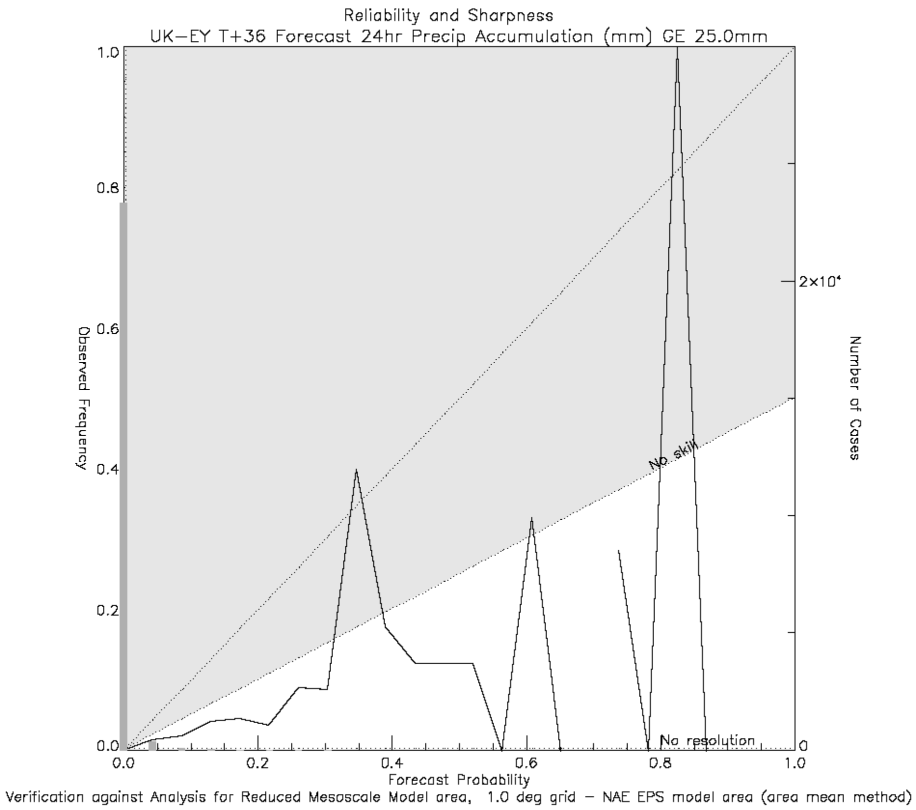
- Reliability and sharpness diagram for T+36 forecast.
- 6h precip > 0.3mm
- Verification against Nimrod Analysis over the UK at 1.0 degree resolution.

6hr precip 5mm against gridded analysis



- Reliability and sharpness diagram for T+36 forecast.
- 6h precip > 5mm
- Verification against Nimrod Analysis over the UK at 1.0 degree resolution.

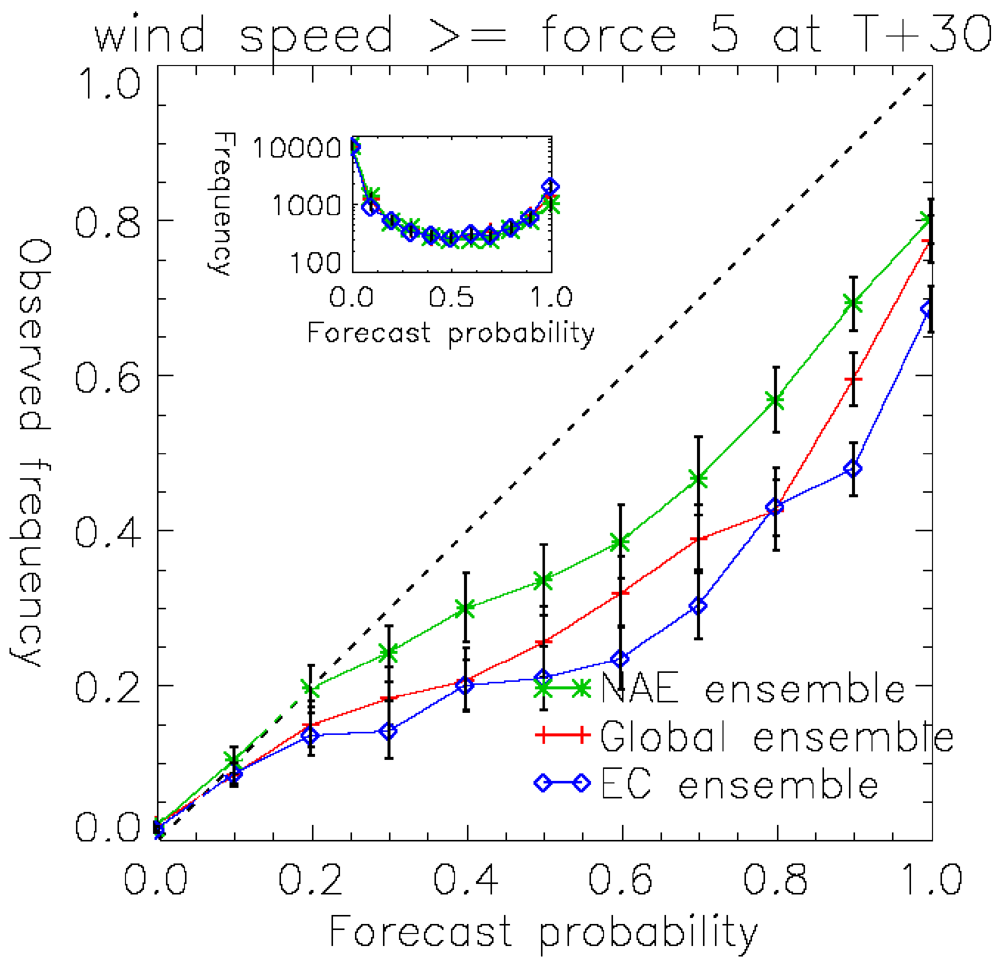
6hr precip 25mm against gridded analysis



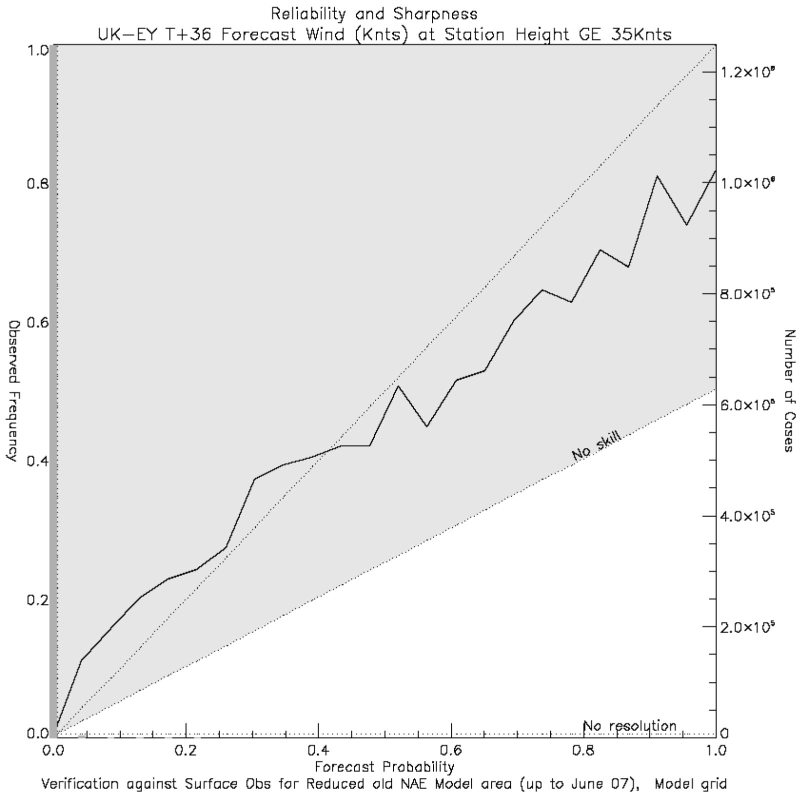
- Reliability and sharpness diagram for T+36 forecast.
- 6h precip > 5mm
- Verification against Nimrod Analysis over the UK at 1.0 degree resolution.

Reliability diagram for wind speed

- Reliability diagram for wind speed >F5 at T+30
- 79 sites UK & Europe
- 6 Nov 2006 – 31 March 2007

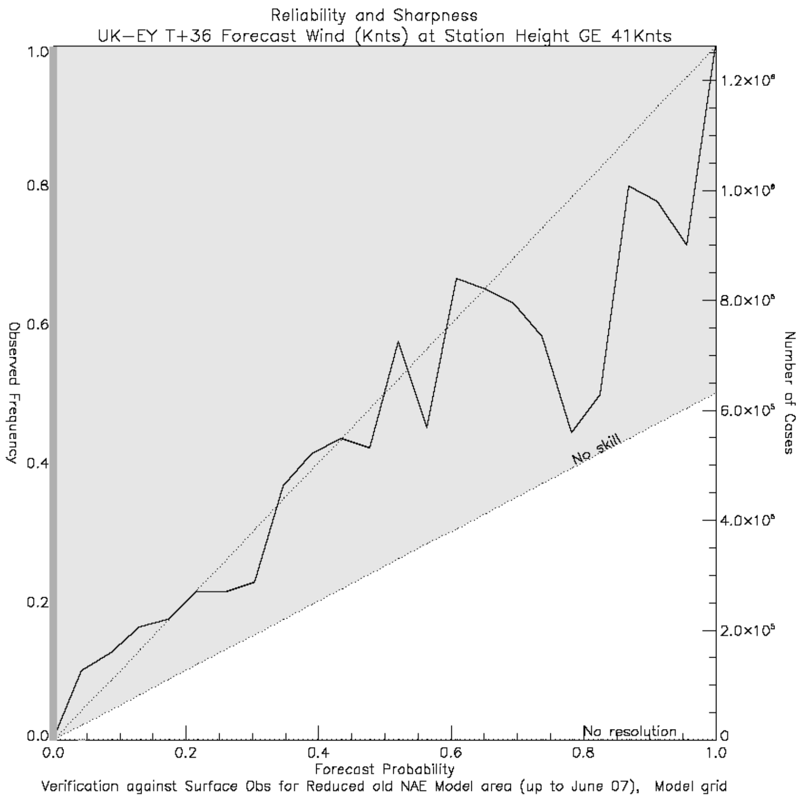


Wind speed at least gale force 8



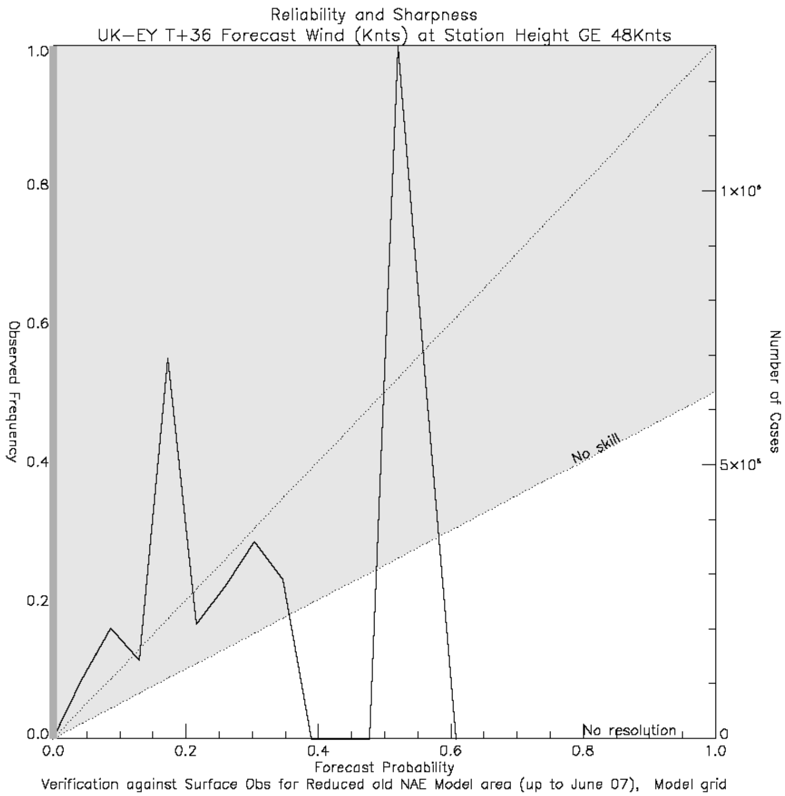
- Reliability and sharpness diagram for T+36 forecast.
- 10m Wind > F8
- Verification against surface obs over UK and Europe.
- 1 Jan 06 – 28 Feb 07

Wind speed at least severe gale force 9



- Reliability and sharpness diagram for T+36 forecast.
- 10m Wind > F9
- Verification against surface obs over UK and Europe.
- 1 Jan 06 – 28 Feb 07

Wind speed at least storm force 10

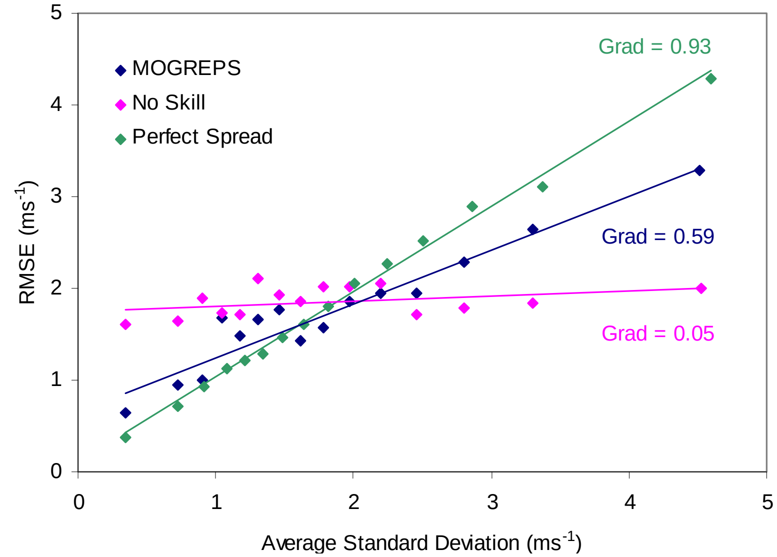


- Reliability and sharpness diagram for T+36 forecast.
- 10m Wind > F10
- Verification against surface obs over UK and Europe.
- 1 Jan 06 – 28 Feb 07

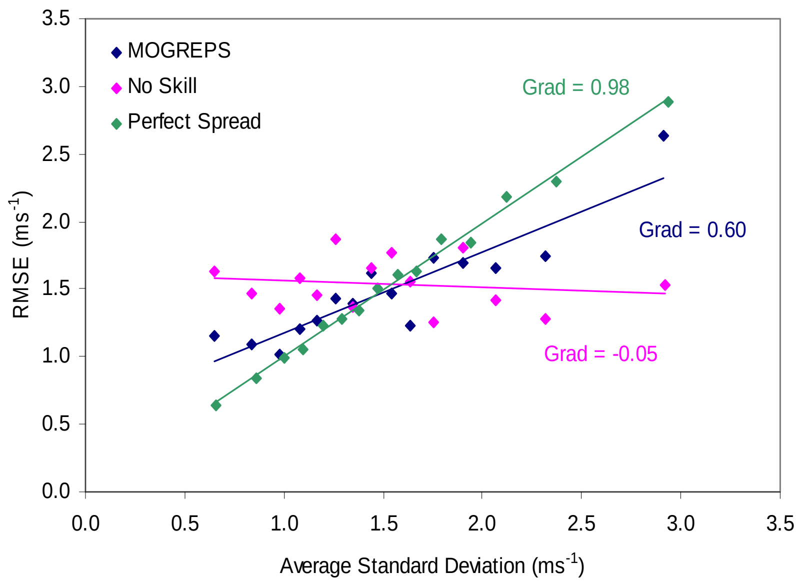
Spread-skill relationship – wind speed

- Spread-skill for wind-speed binned into equal population bins by spread
  - Skill corrected for observation error

- Blue – MOGREPS
- Pink – No Skill
- Green – Perfect



DJF

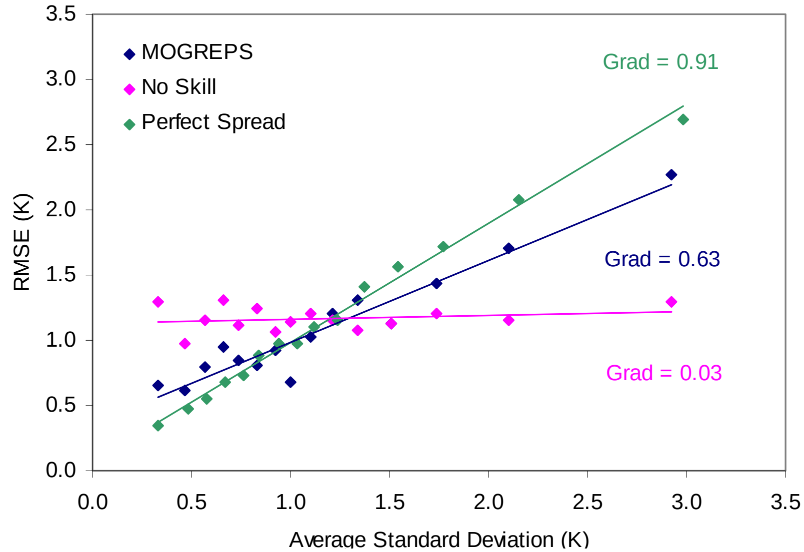


JJA

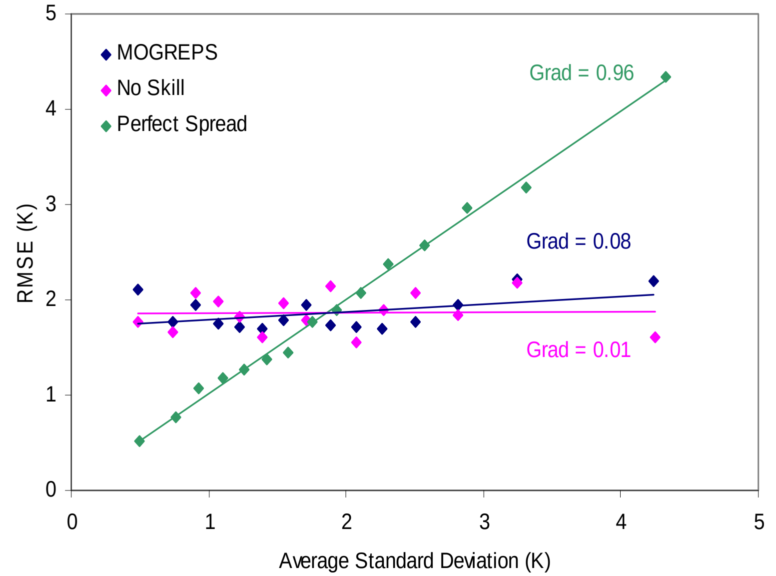
Spread-skill relationship – temperature

- Spread-skill for temperature binned into equal population bins by spread
  - Skill corrected for observation error

- Blue – MOGREPS
- Pink – No Skill
- Green – Perfect



DJF



JJA

Conclusions

- Ensemble forecasting is now a mature tool for medium-range forecasting
  - New development in the short-range
- Ensembles provide extra information on
  - Uncertainty
  - Risks, particularly for High Impact weather
- We are learning how to use probability forecasts for improved decision-making

Useful Web Addresses

- MOGREPS Operational display system:
- http://www-nwp/~fren/MOGREPS/products/home.shtml
- Met Office ECMWF Ensemble display system (PREVIN): http://ukmet/OPER_PRODUCTS/ensembles/ensembles.html
- ECMWF Website forecasts: http://www.ecmwf.int/products/forecasts/d/charts
- Ensemble pages on external web: http://www.metoffice.com/research/nwp/ensemble/index.html
- NWP Gazette article on MOGREPS: http://www.metoffice.com/research/nwp/publications/nwp_gazette/feb06/mogreps .html
- Lecture notes from ECMWF Predictability Training Course: http://www.ecmwf.int/services/training/rcourse_notes/general_circulation.html
- Slides from 2002 ECMWF Seminar on Predictability: http://www.ecmwf.int/publications/library/ecpublications/proceedings/seminar2002_predictability/index.html
- Ken Mylne's page of www sites (includes links to ECMWF and NCEP pages): http://www-nwp/~frkm/Ensemble_sites.html
- Ken Mylne's home page: http://www-nwp/~frkm/index.html
- Any questions? Email: ken.mylne@metoffice.com

Accreditation

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Questions & Answers