



# Short-Range Ensemble Prediction Systems at the Met Office

MOGREPS – Met Office Global and Regional Ensemble Prediction System

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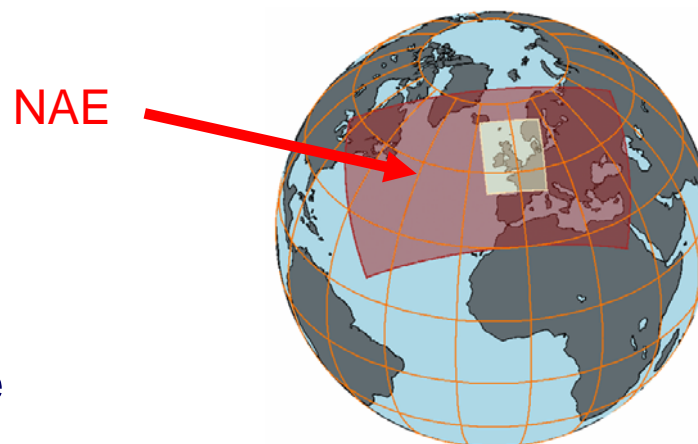
Ensemble Forecasting Research

Thanks also to: Kelvyn Robertson, Dave Goddard, Tim Legg, Ian Pearman,  
Clare Bysouth, Paul Maisey and many others!

# MOGREPS – The new Met Office short-range EPS



- Ensemble designed for short-range
  - Regional ensemble over N. Atlantic and Europe (NAE)
  - Nested within global ensemble
  - ETKF perturbations
  - Stochastic physics
  - T+72 global, T+36 regional
  - Aim to assess uncertainty in short-range, eg.:
    - Rapid cyclogenesis
    - Local details (wind etc)
    - Precipitation
    - Fog and cloud



MOGREPS is on Operational Trial for 1 year from September 2005

# ETKF Initial Condition Perturbations



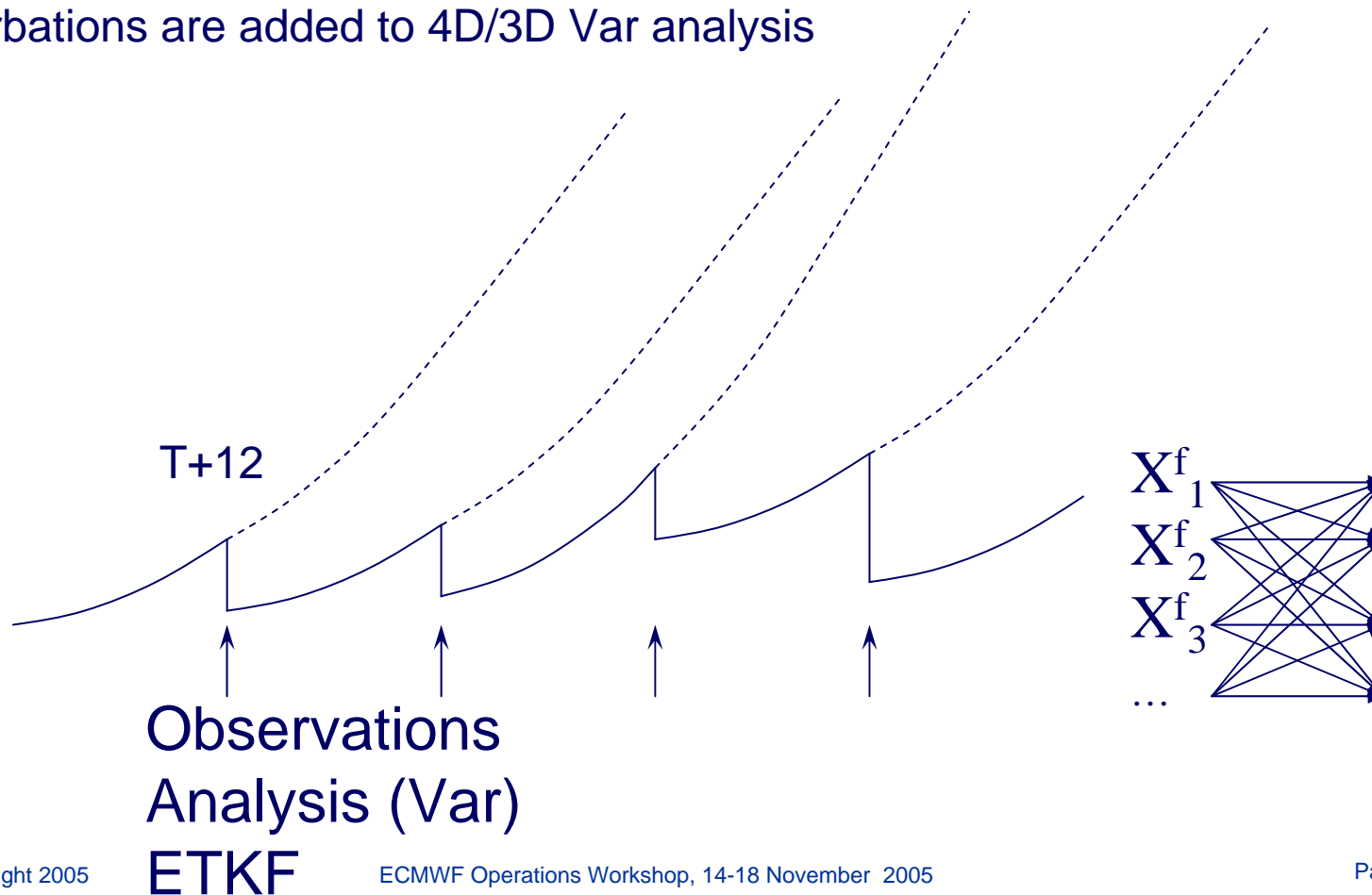
- ETKF – Simplified version of Ensemble Kalman Filter  $\mathbf{X}^a = \mathbf{X}^f \mathbf{T}$
- ETKF similar to Error Breeding
  - Perturbations are linear combination of forecast perturbations from previous cycle, formed by matrix transformation
  - Transforms calculated using same set of observations as used in 4D-Var (including all satellite obs) within +/- 3 hours of data time



# ETKF Initial Condition Perturbations



- ETKF – Simplified version of Ensemble Kalman Filter
  - Cannot update mean state – covariance information only
  - Perturbations are added to 4D/3D Var analysis



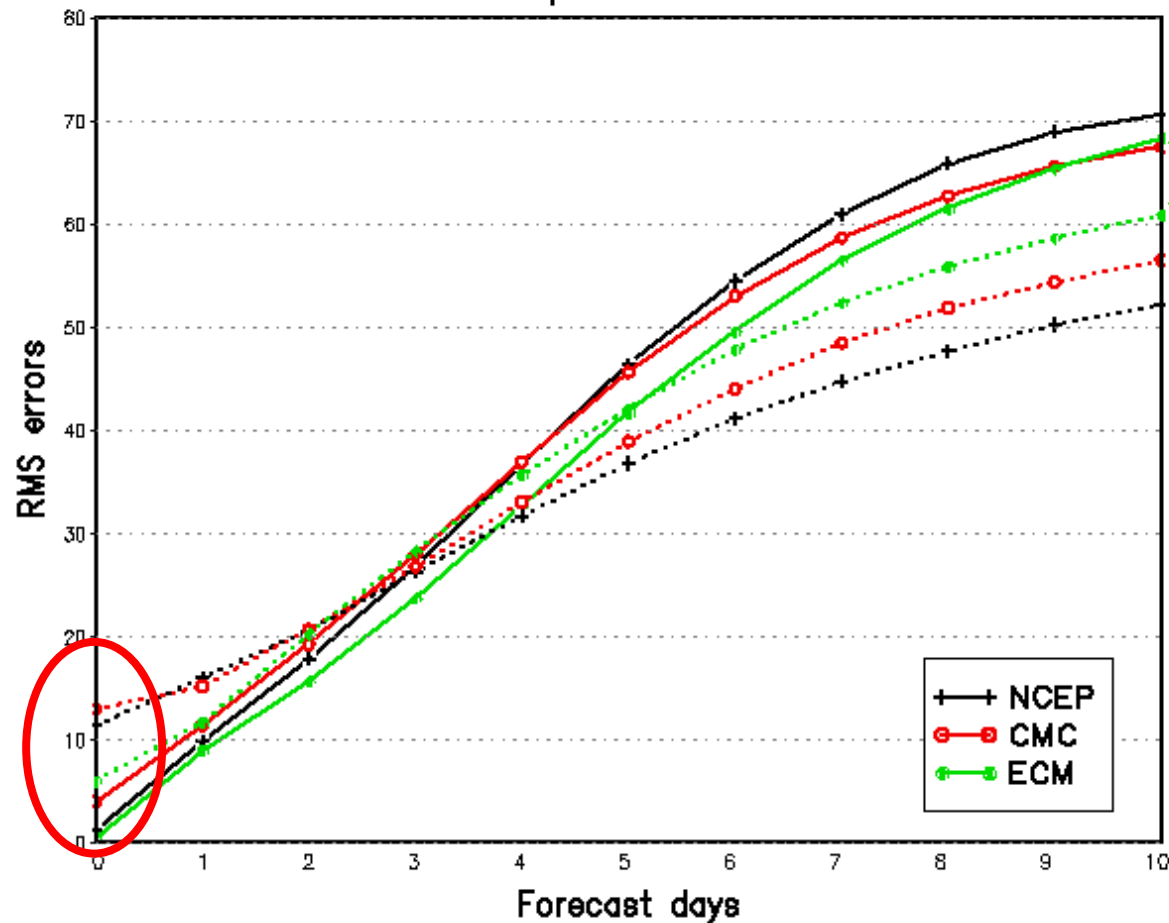
# Stochastic physics



.... the quest to increase spread!

NH 500 mb Height  
Average For 00Z01MAY2002 - 00Z31JUL2002  
dot-spread solid-rms

Buizza et al., MWR, 2004



All three systems are under-dispersive!!

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

- **Stochastic Convective Vorticity (SCV)**
  - Unresolved impact of organised convection (MCSs)
  - Not used in the higher resolution regional ensemble
- **Random Parameters (RP)**
  - Structural error due to approximations in parameterisation
- **Stochastic Kinetic Energy Backscatter (SKEB)**
  - Excess dissipation of energy at small scales
  - SKEB not yet implemented

Impact is propagated to next cycle through the ETKF

## The Random Parameters (Arribas, 2004)

- All parameterizations include a number of empirical-adjustable parameters and thresholds (with somewhat arbitrary values!)
- These parameters are treated as stochastic variables, and, each 3-h, their values are calculated using a first-order auto regression model:

$$P_t = \mu + r(P_{t-1} - \mu) + \varepsilon \quad \text{with } r = 0.95$$

- Same value at all grid points (i.e. spatial corr. = 1)

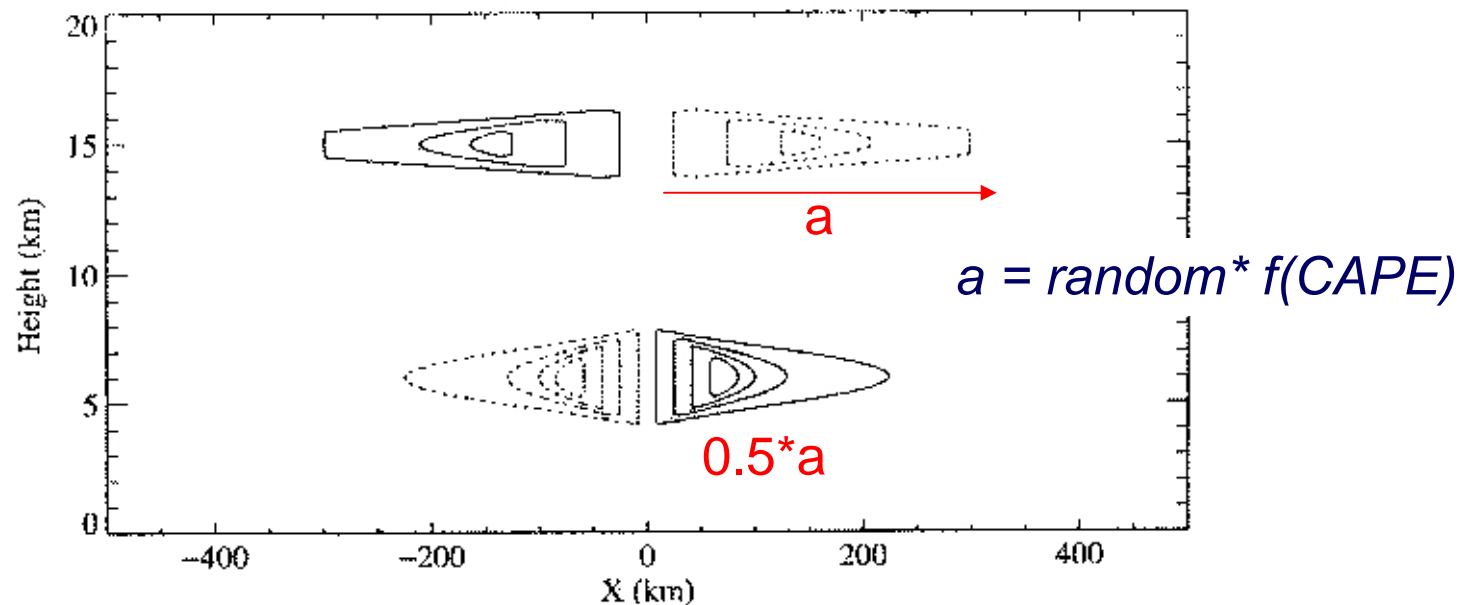
# Stochastic scheme for the UM



## The Random Parameters

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

## The SCV component



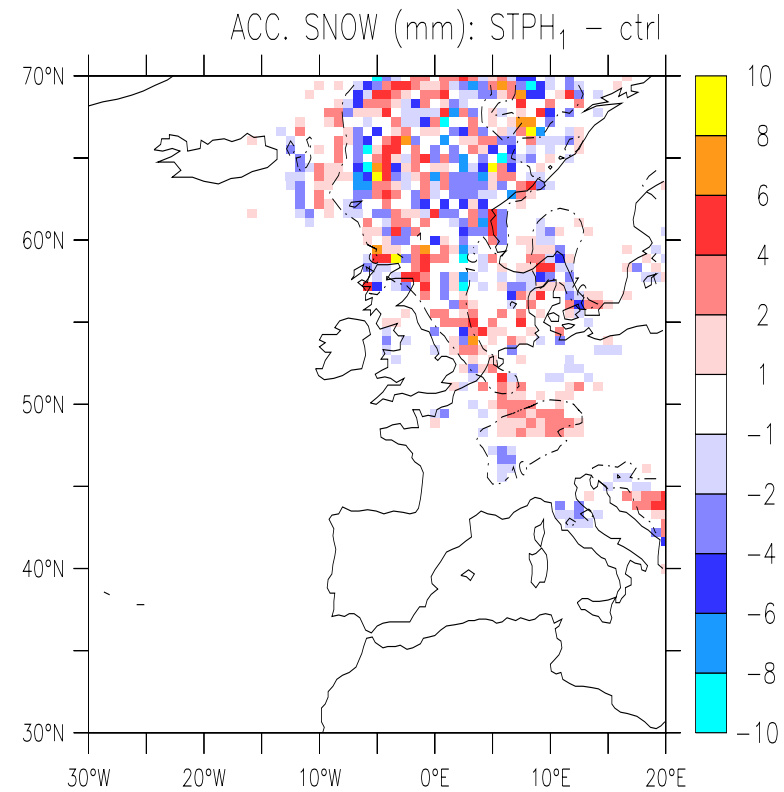
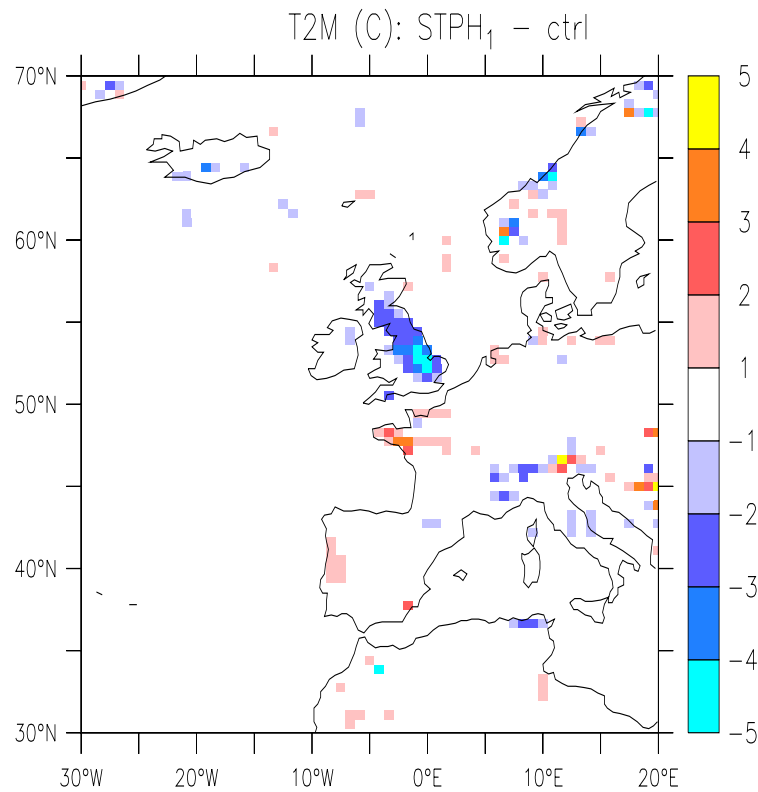
- In the SCV scheme the PV dipole is formed by two vortices which scales are determined by a randomised function

# RP+SCV in MOGREPS



Covered in previous MOSAC – sample of impact

2004012700Z – T+72



## Stochastic Kinetic Energy Backscatter

(Arribas and Shutts, 2005)

- **Aim:** To backscatter (stochastically) into the forecast model some of the energy excessively dissipated by it at scales near the truncation limit.  
(similar to ECMWF's CASBS by Shutts)
- A total dissipation of  $0.75 \text{ Wm}^{-2}$  has been estimated from the Semi-lagrangian and Horizontal diffusion schemes.
- Each member of the ensemble is perturbed by a different realization of this backscatter forcing

## Backscatter forcing:

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

$\alpha$ .- Tunable amount of energy feedback

$KE$ .- Kinetic Energy

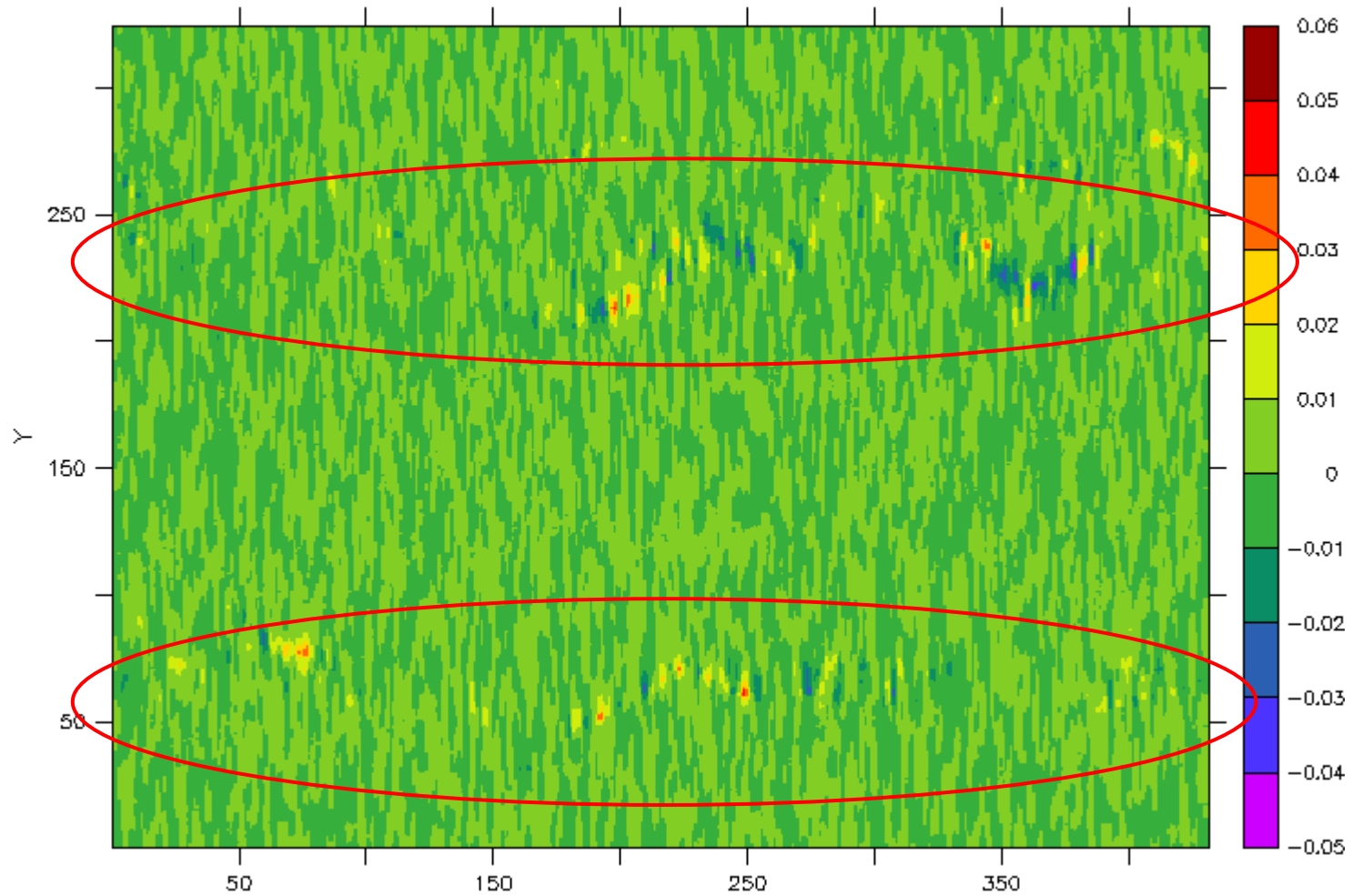
$R$ .- Random field

$D$ .- Dissipation rate

$\Delta \tau$ .- Time-step

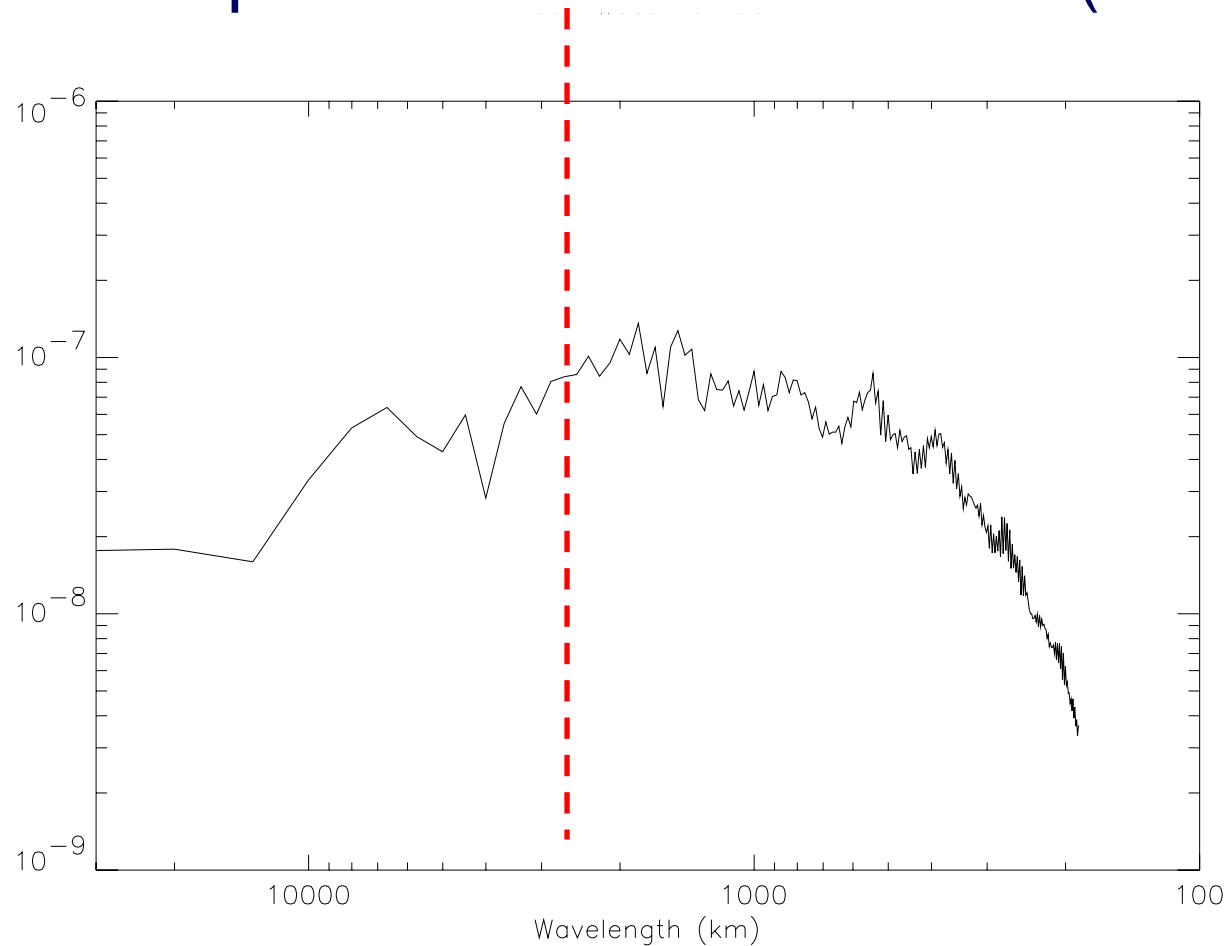
$R(\lambda, \phi) \rightarrow$  3D random pattern in which horizontal, vertical and temporal correlations can be imposed to reproduce CRM statistics

## Aspect of the forcing: u incr. at 500 hPa



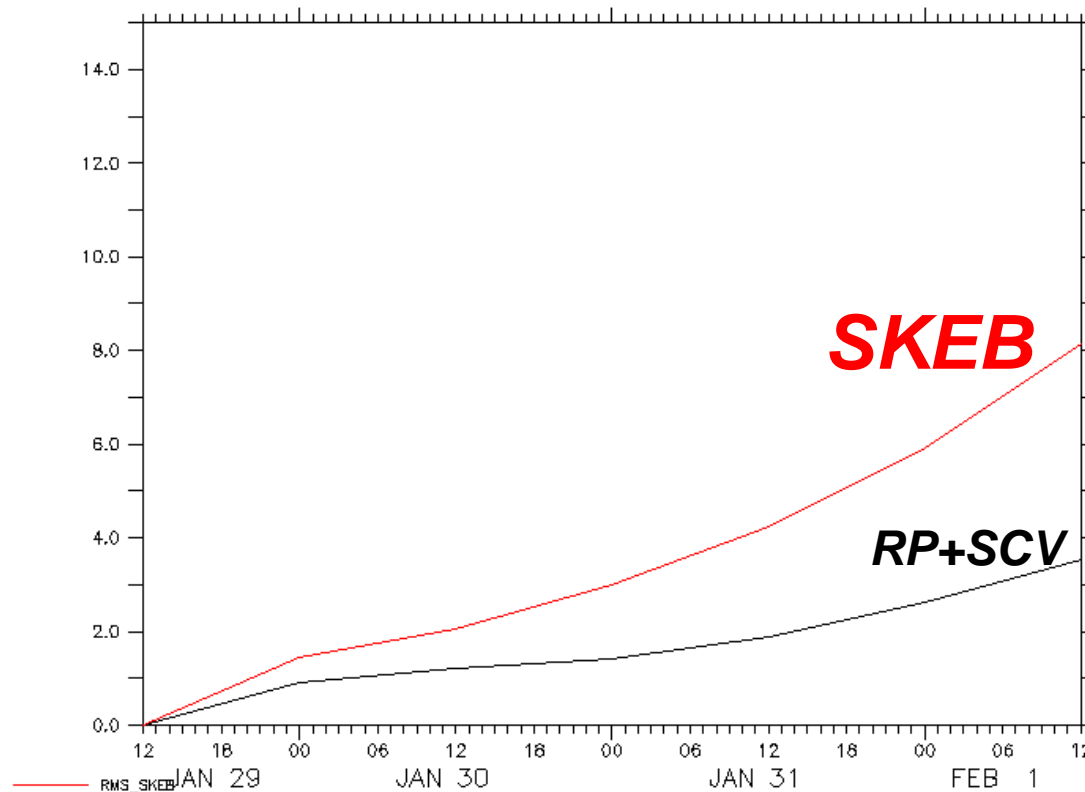
## Spectra of the forcing (KE at 500 hPa)

– agrees with spectra from CRM studies (Shutts)



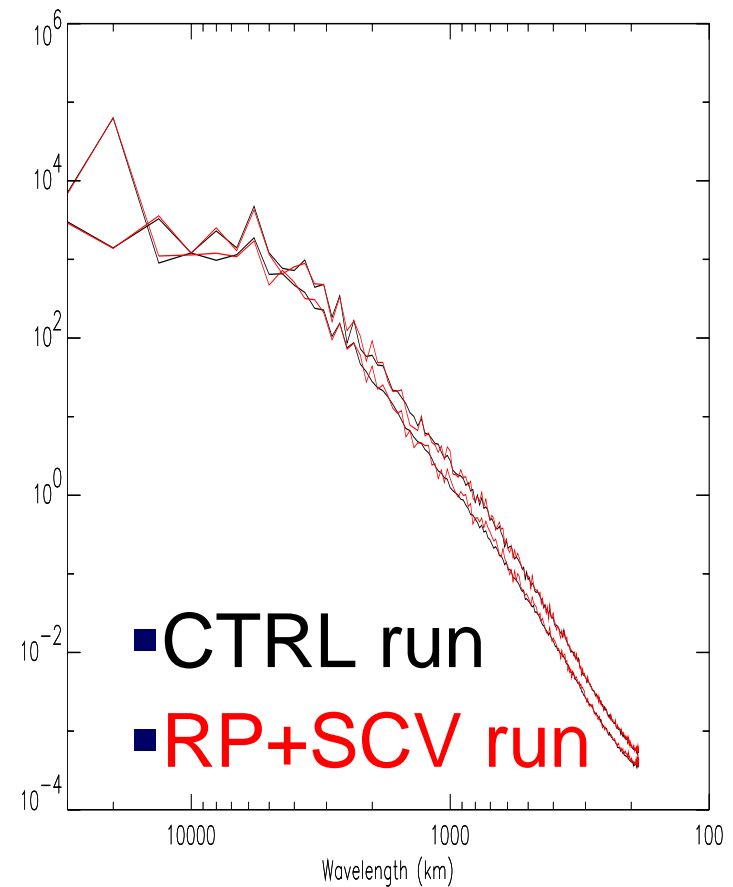
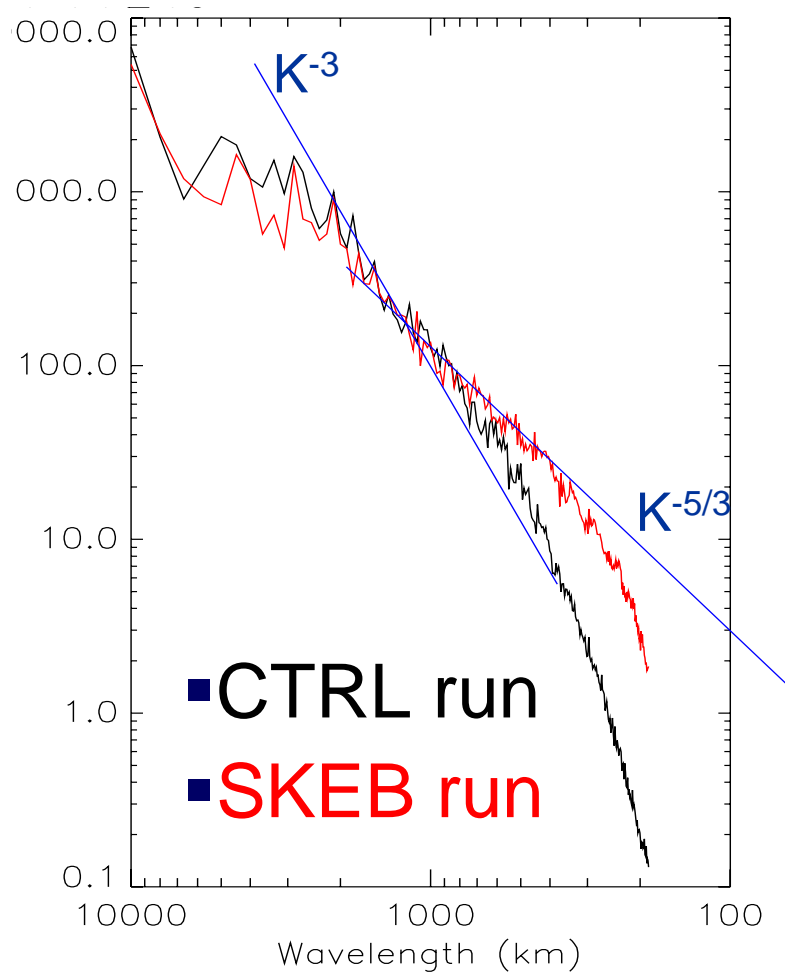
## Preliminary results:

- Positive increase in spread (comparable to that seen at ECMWF)  
 Increase in spread respect to an IC-only ensemble  
 500 hPa geopotential height

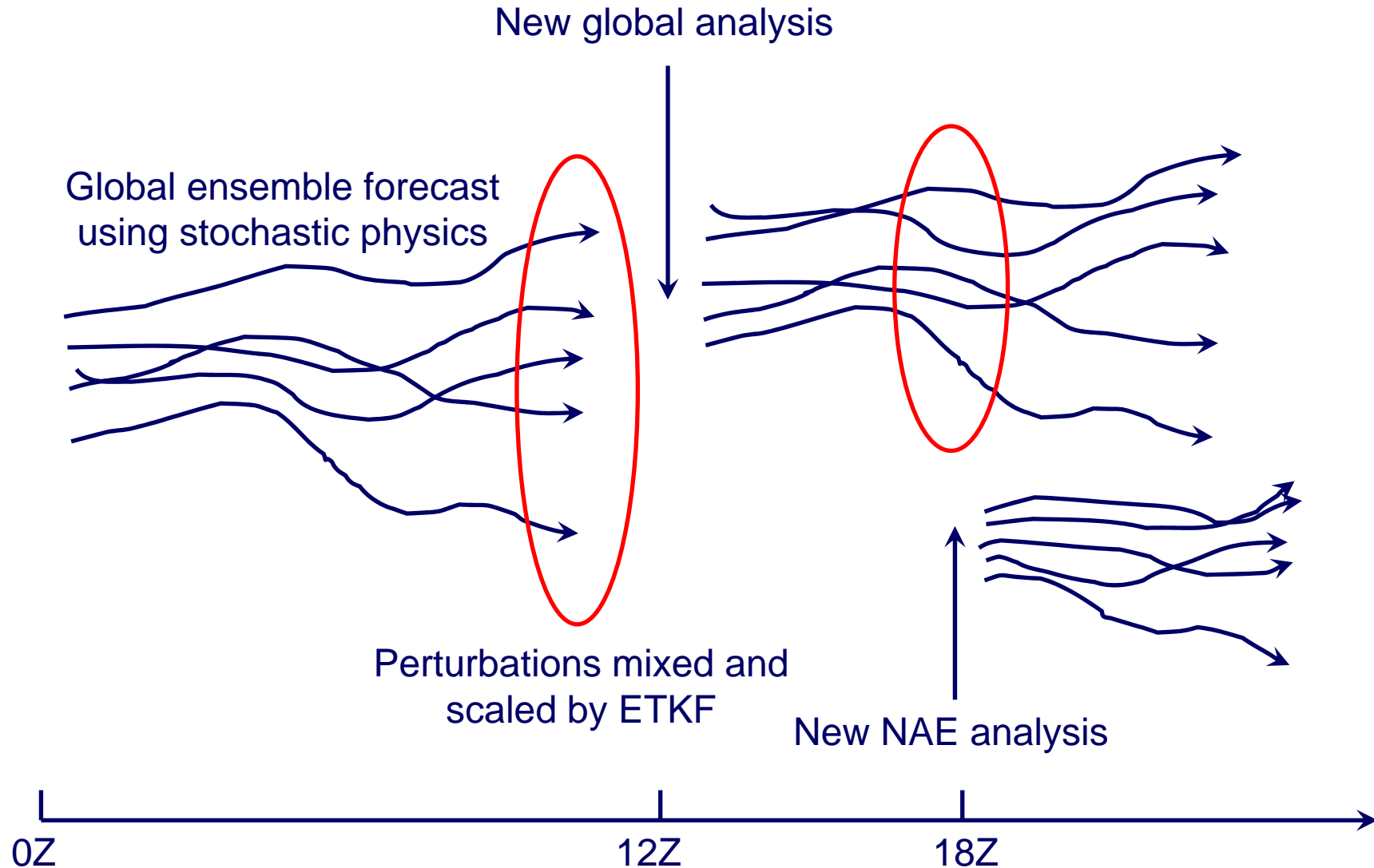


## Preliminary results:

- Better representation of forecast spectra



# MOGREPS Operational System diagram





# Met Office Global and Regional Ensemble Prediction System



**BEWARE: Site still under development**

Created by the .... Ensemble Forecasting Research Group

## FORECASTS

[Mean / Prob](#)

[Mean / Sprd](#)

[Spaghetti](#)

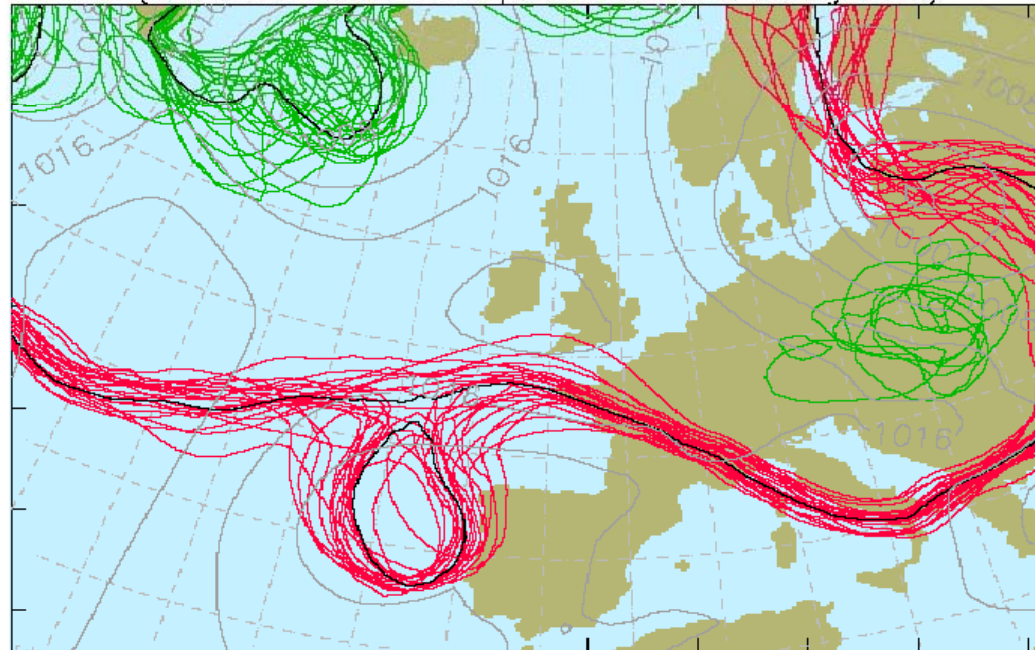
[Post. Stamps](#)

[Site-specific](#)

[SCI - INF](#)

[FEEDBACK](#)

MOGREPS (Global) Spaghetti chart for 1000–500hPaThickness  
 DT 00Z on 08/08/2005 VT 06Z on 10/08/2005 lead time 54h  
 510/528/546/564dam (Black lines represent Control member)  
 (Ensemble Mean PMSL plotted as faint background)




MOGREPS display web - Mozilla

File Edit View Go Bookmarks Tools Window Help


Back Forward Reload Stop <http://www-nwp.gov/MOGREPS/products/meanprobs/meanprobs.html?frmAnimStatus=Running&frmDelayMS=400+ms&frmFraNu> Search Print

Home Bookmarks Red Hat Network Support Metnetwork Metnet home page Previn Google MOGREPS

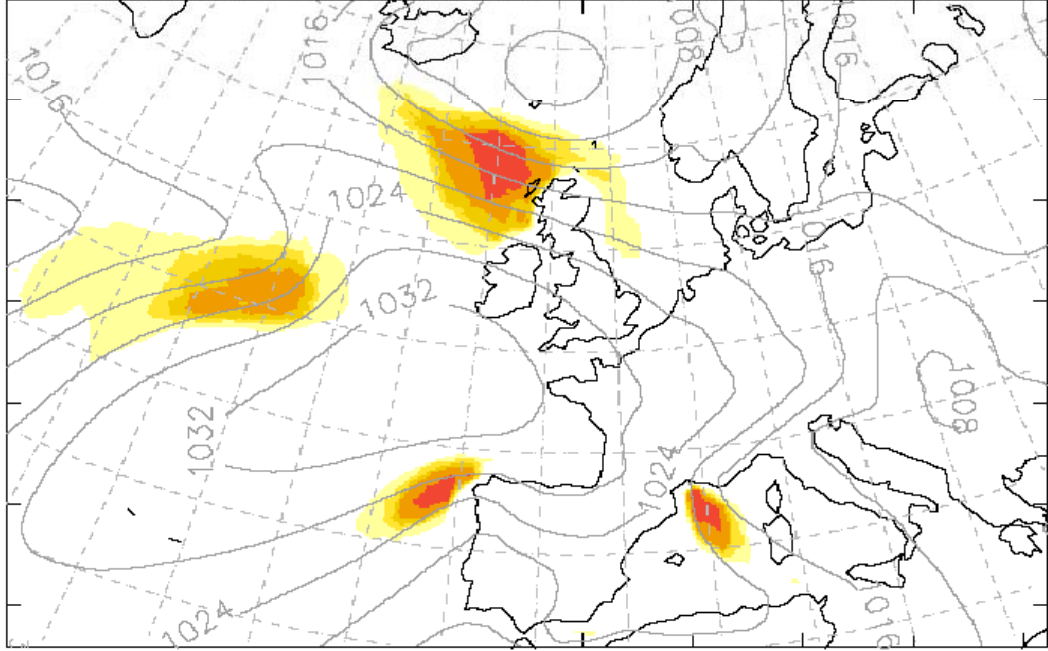



# Met Office Global and Regional Ensemble Prediction System

**BEWARE: Site still under development** Created by the ..... Ensemble Forecasting Research Group



MOGREPS (Global) Probability map for 10mWindSpeed > 22.0knots  
 DT 12Z on 02/08/2005 VT 00Z on 04/08/2005 lead time 36h  
 (Ensemble Mean PMSL plotted as faint background)





0.1      0.3      0.5      0.7      0.9

**FORECASTS**

**Mean / Prob**

Mean / Sprd

Spaghetti

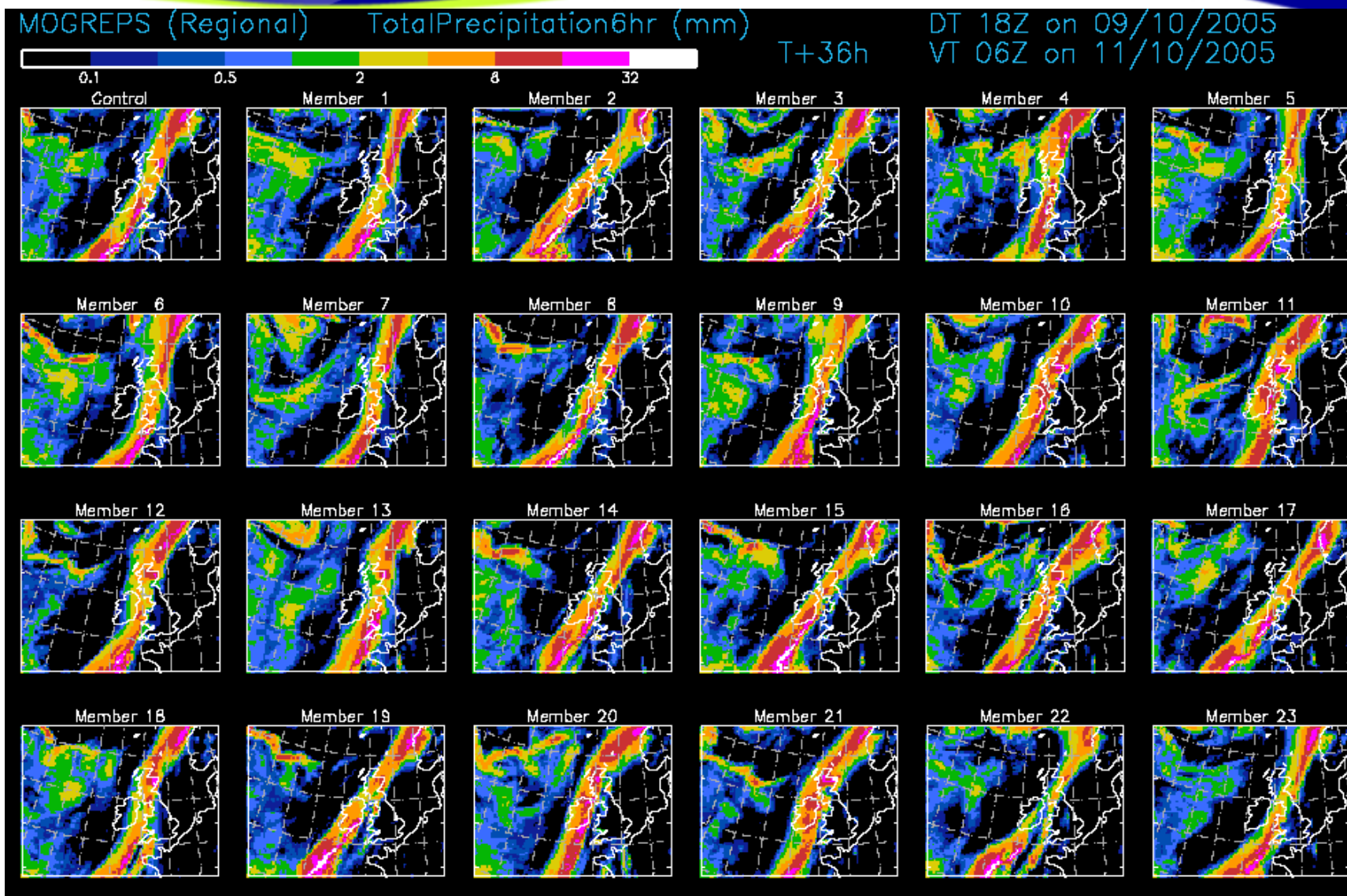
Post. Stamps

Site-specific

SCI - INF

FEEDBACK

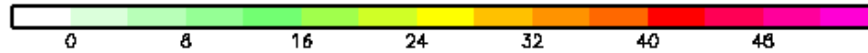
# Example MOGREPS 36h Rainfall forecast



# Example MOGREPS 33h 10m WS forecast

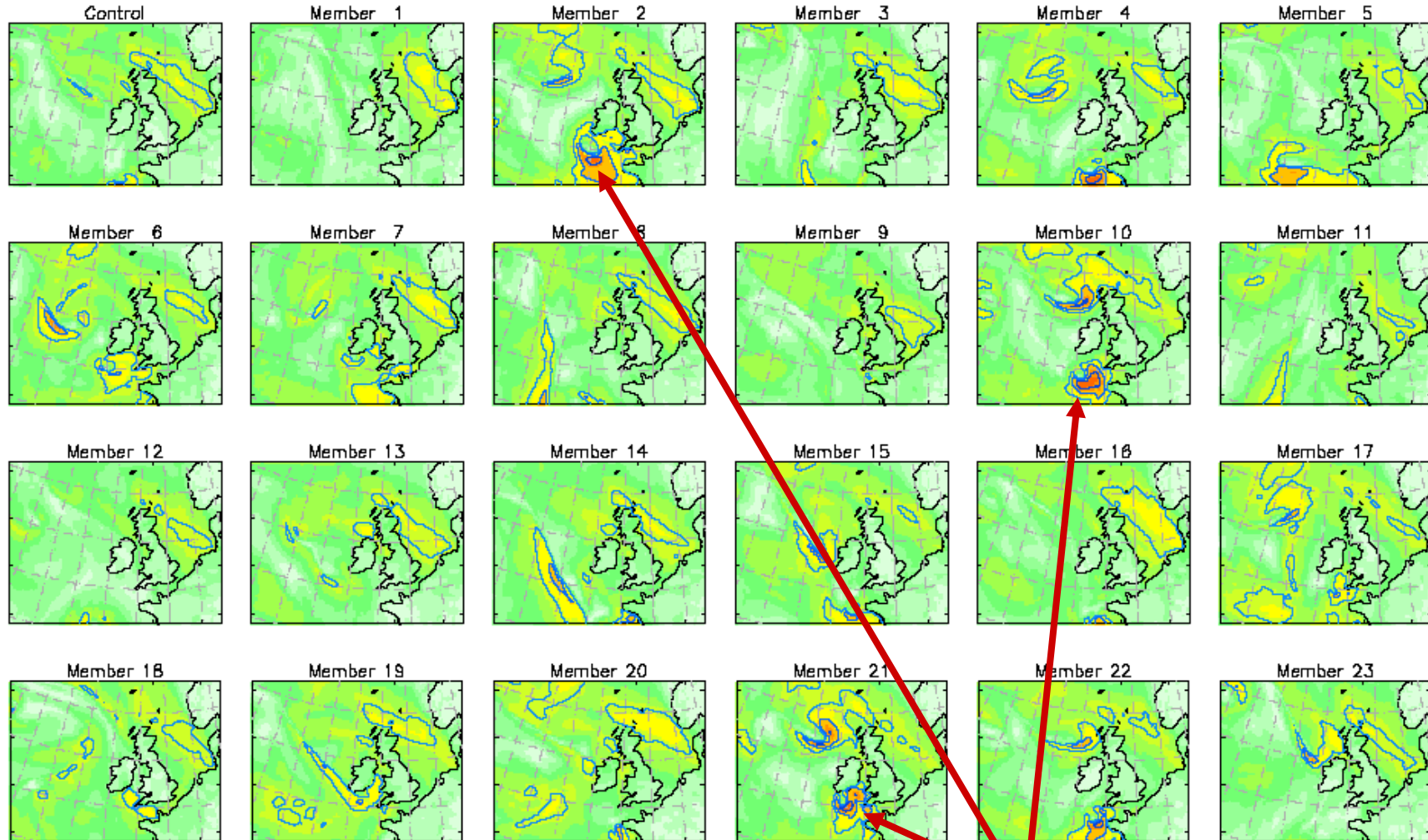


MOGREPS (Regional) 10mWindSpeed (knots)



T+33h  
Filled chart.

DT 18Z on 17/10/2005  
VT 03Z on 19/10/2005  
Contours: Beaufort Force 6 and above.

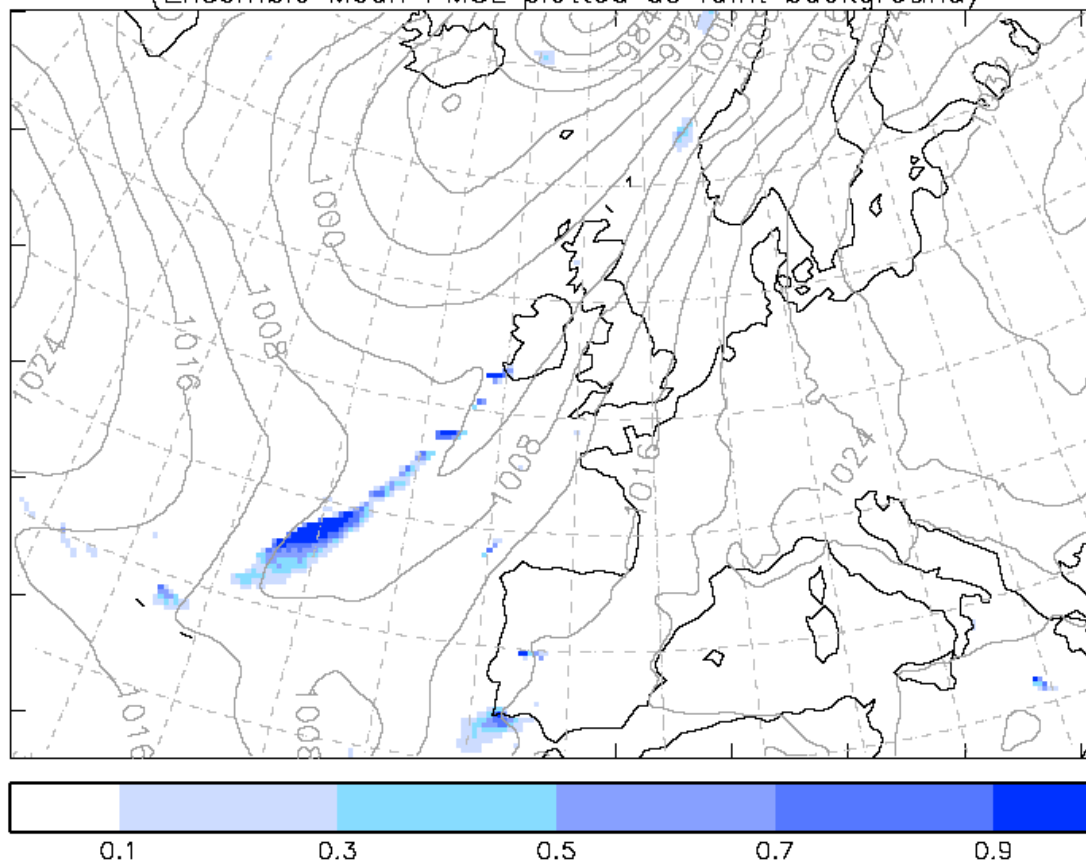


# Probability of $>10\text{mm}/6\text{h}$ T+06



Proportion of ensemble members gives estimate of probability

MOGREPS (Regional) Probability map for 6HourPrecip  $> 10.0\text{mm}$   
DT 06Z on 10/10/2005 VT 12Z on 10/10/2005 lead time 06h  
(Ensemble Mean PMSL plotted as faint background)

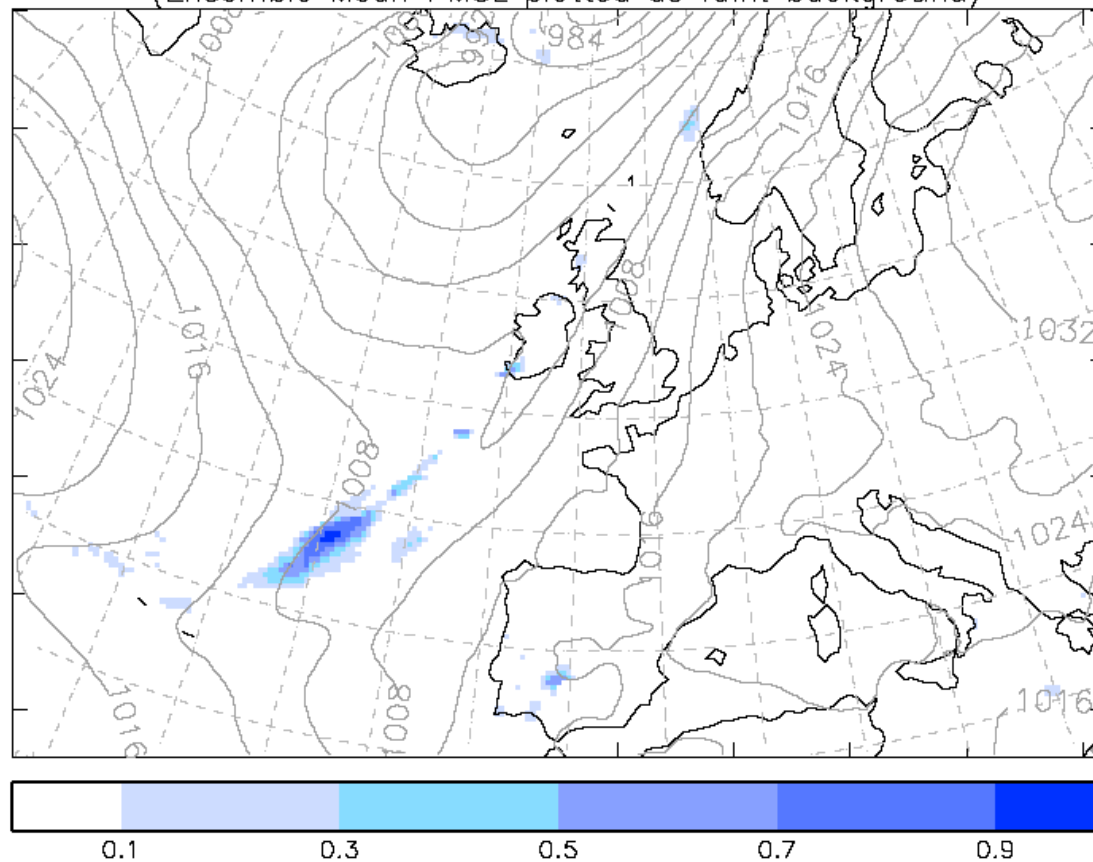


# Probability of >10mm/6h T+09



Proportion of ensemble members gives estimate of probability

MOGREPS (Regional) Probability map for 6HourPrecip > 10.0mm  
DT 06Z on 10/10/2005 VT 15Z on 10/10/2005 lead time 09h  
(Ensemble Mean PMSL plotted as faint background)

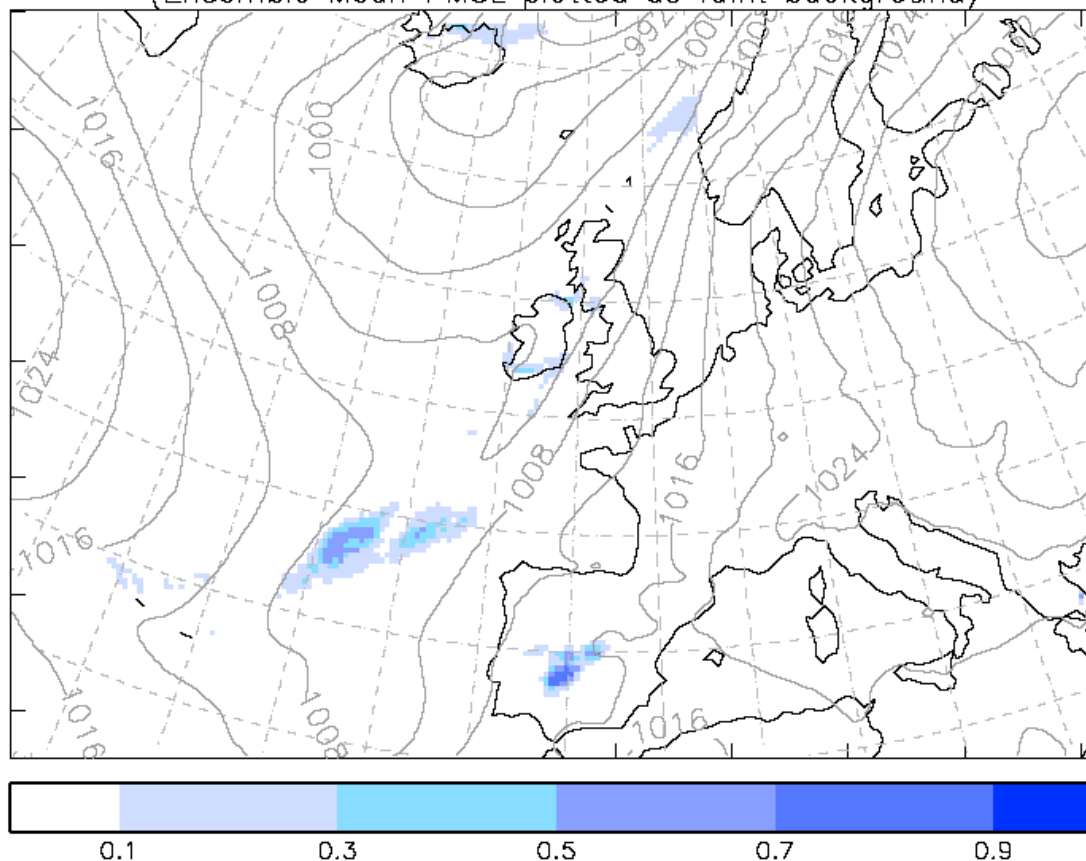


# Probability of $>10\text{mm}/6\text{h}$ T+12



Proportion of ensemble members gives estimate of probability

MOGREPS (Regional) Probability map for 6HourPrecip  $> 10.0\text{mm}$   
DT 06Z on 10/10/2005 VT 18Z on 10/10/2005 lead time 12h  
(Ensemble Mean PMSL plotted as faint background)

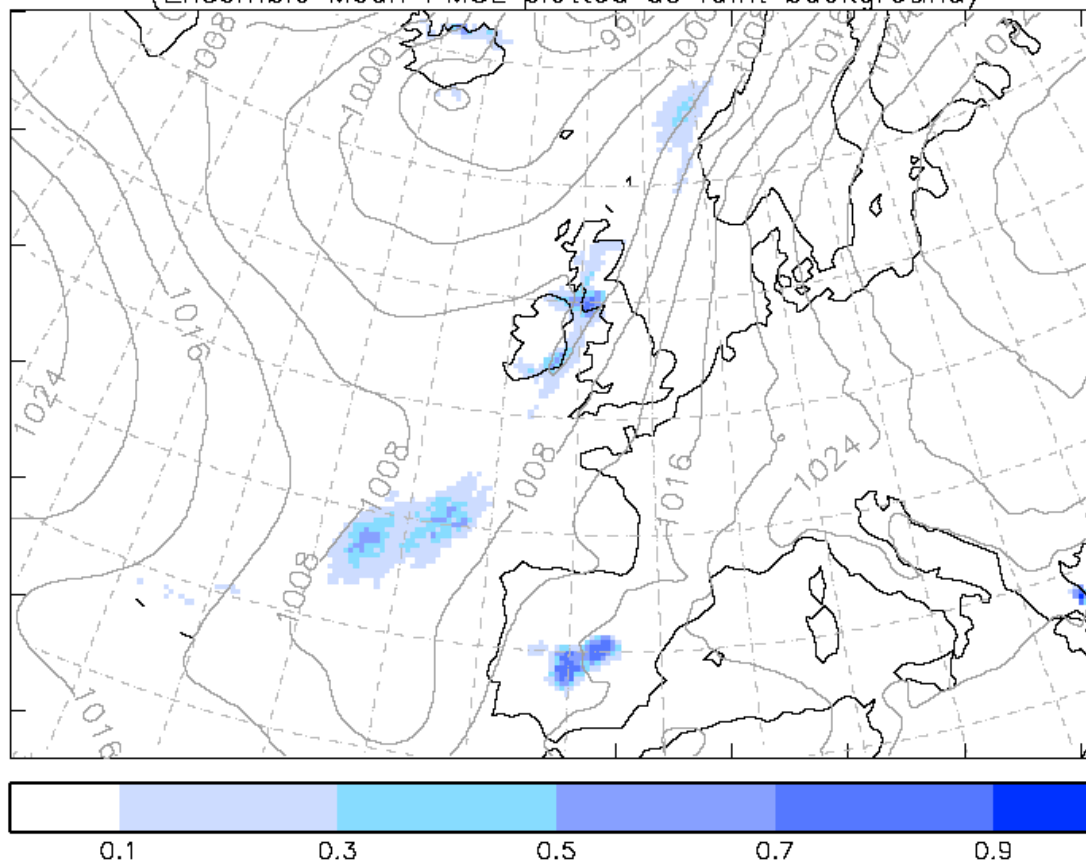


# Probability of $>10\text{mm}/6\text{h}$ T+15



Proportion of ensemble members gives estimate of probability

MOGREPS (Regional) Probability map for 6HourPrecip  $> 10.0\text{mm}$   
DT 06Z on 10/10/2005 VT 21Z on 10/10/2005 lead time 15h  
(Ensemble Mean PMSL plotted as faint background)

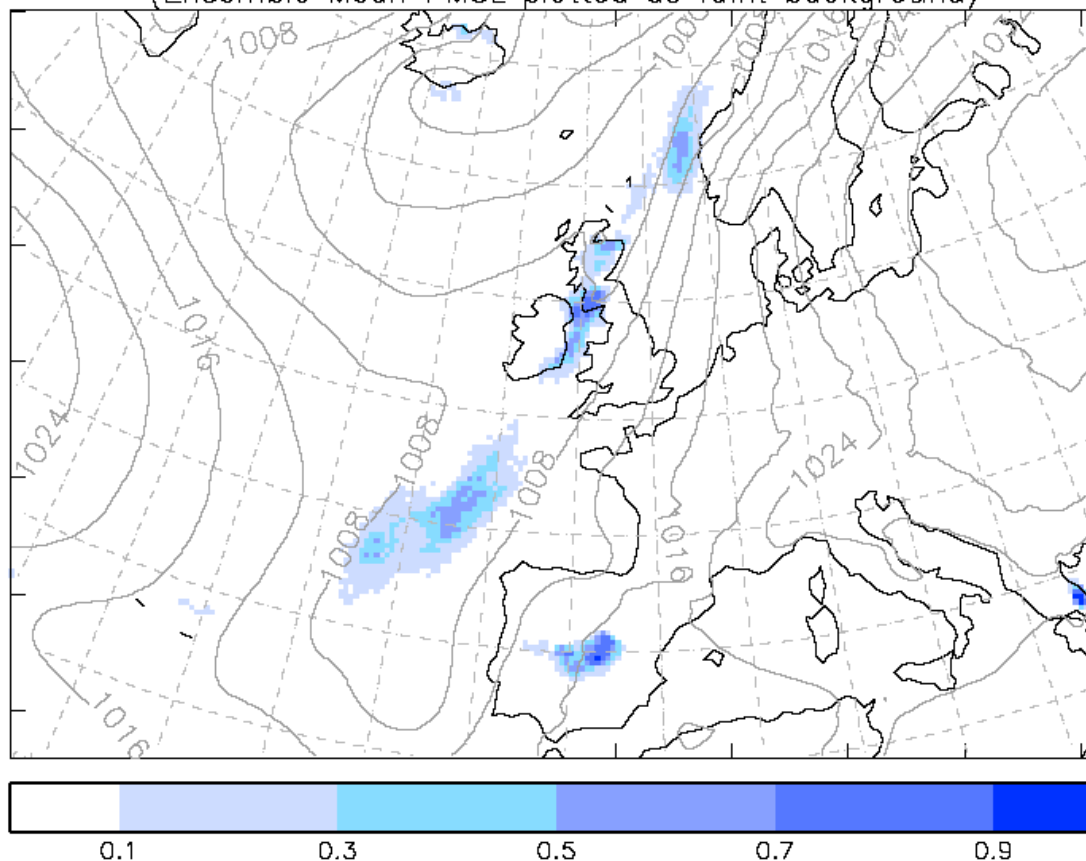


# Probability of $>10\text{mm}/6\text{h}$ T+18



Proportion of ensemble members gives estimate of probability

MOGREPS (Regional) Probability map for 6HourPrecip  $> 10.0\text{mm}$   
DT 06Z on 10/10/2005 VT 00Z on 11/10/2005 lead time 18h  
(Ensemble Mean PMSL plotted as faint background)

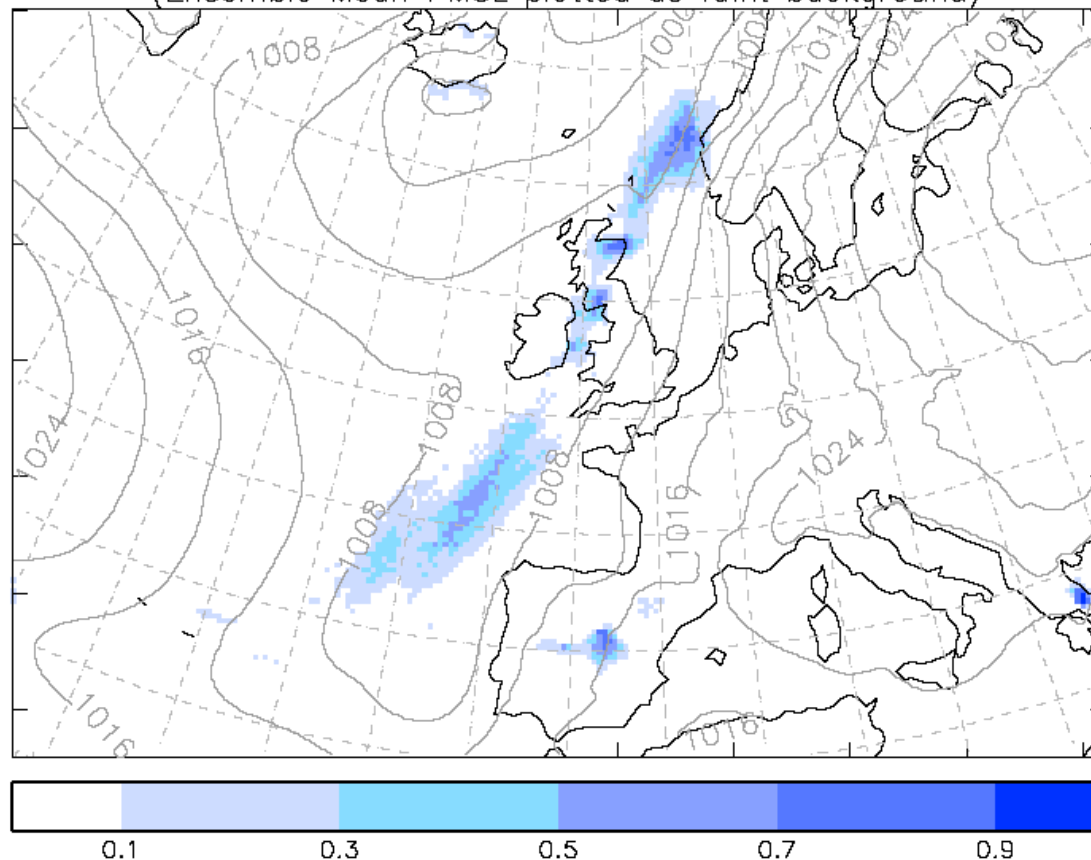


# Probability of >10mm/6h T+21



Proportion of ensemble members gives estimate of probability

MOGREPS (Regional) Probability map for 6HourPrecip > 10.0mm  
DT 06Z on 10/10/2005 VT 03Z on 11/10/2005 lead time 21h  
(Ensemble Mean PMSL plotted as faint background)

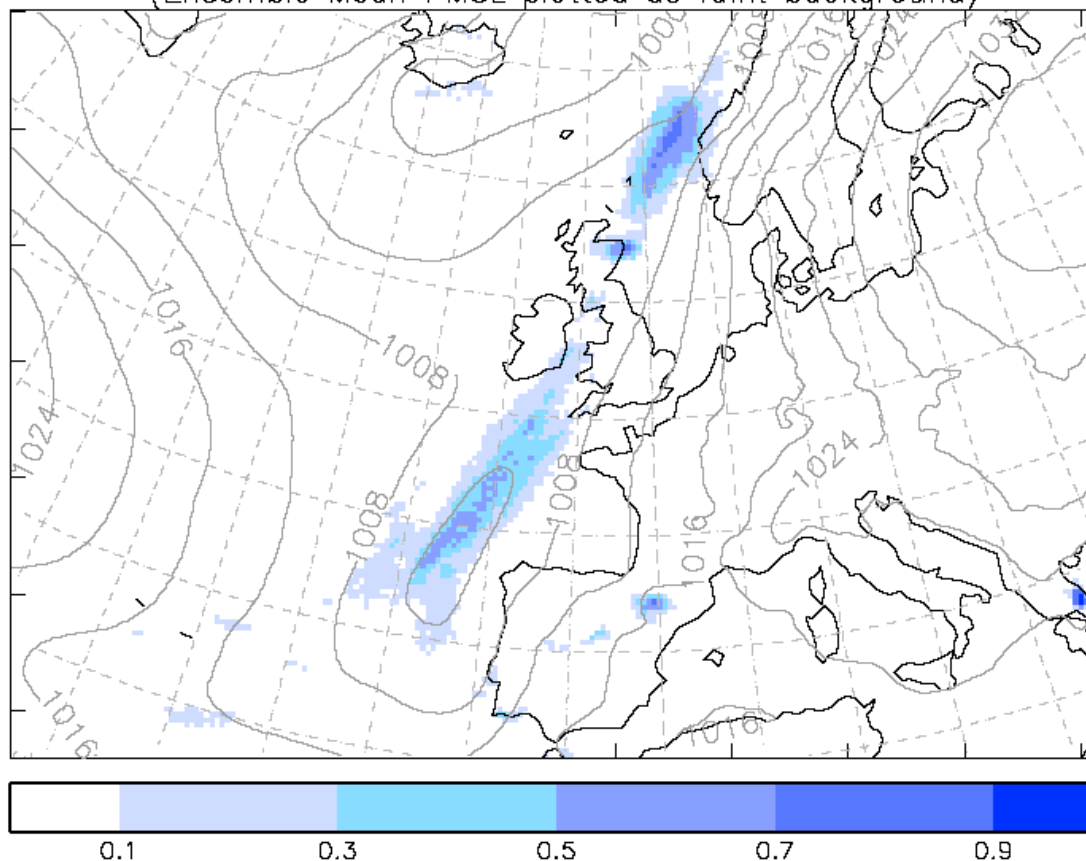


# Probability of $>10\text{mm}/6\text{h}$ T+24



Proportion of ensemble members gives estimate of probability

MOGREPS (Regional) Probability map for 6HourPrecip  $> 10.0\text{mm}$   
DT 06Z on 10/10/2005 VT 06Z on 11/10/2005 lead time 24h  
(Ensemble Mean PMSL plotted as faint background)

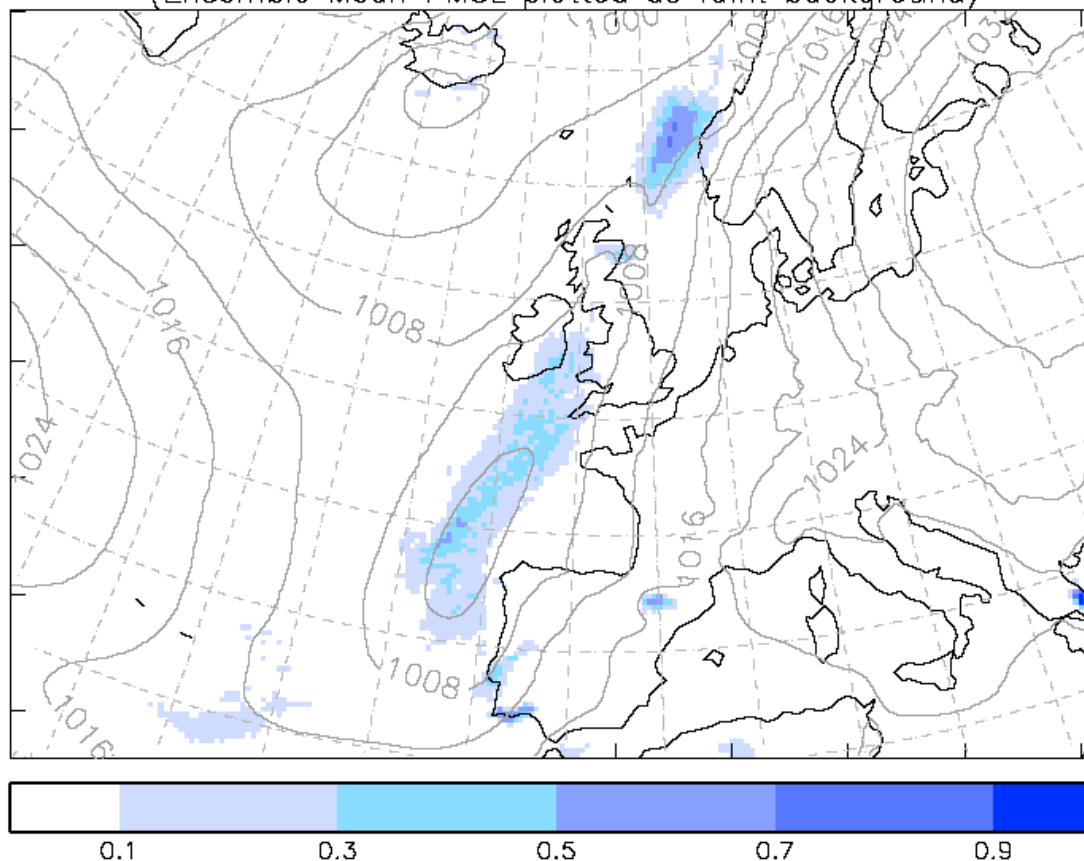


# Probability of >10mm/6h T+27



Proportion of ensemble members gives estimate of probability

MOGREPS (Regional) Probability map for 6HourPrecip > 10.0mm  
DT 06Z on 10/10/2005 VT 09Z on 11/10/2005 lead time 27h  
(Ensemble Mean PMSL plotted as faint background)

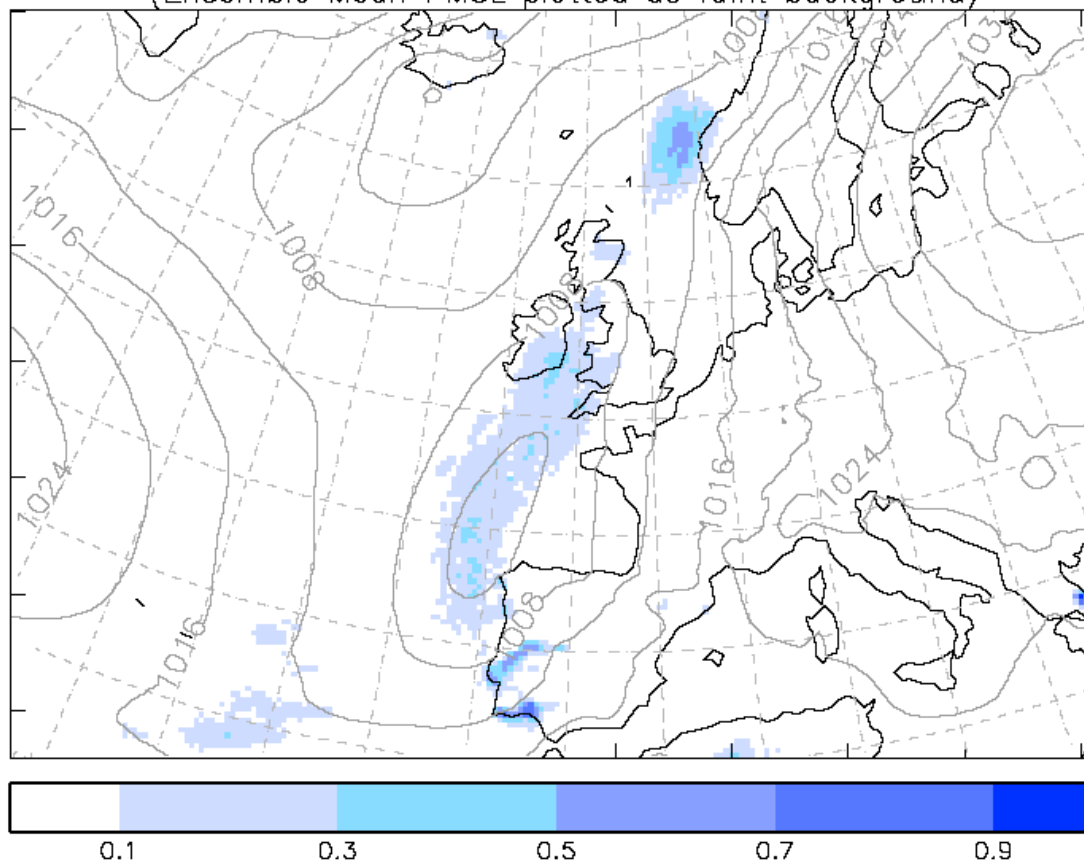


# Probability of $>10\text{mm}/6\text{h}$ T+30



Proportion of ensemble members gives estimate of probability

MOGREPS (Regional) Probability map for 6HourPrecip  $> 10.0\text{mm}$   
DT 06Z on 10/10/2005 VT 12Z on 11/10/2005 lead time 30h  
(Ensemble Mean PMSL plotted as faint background)

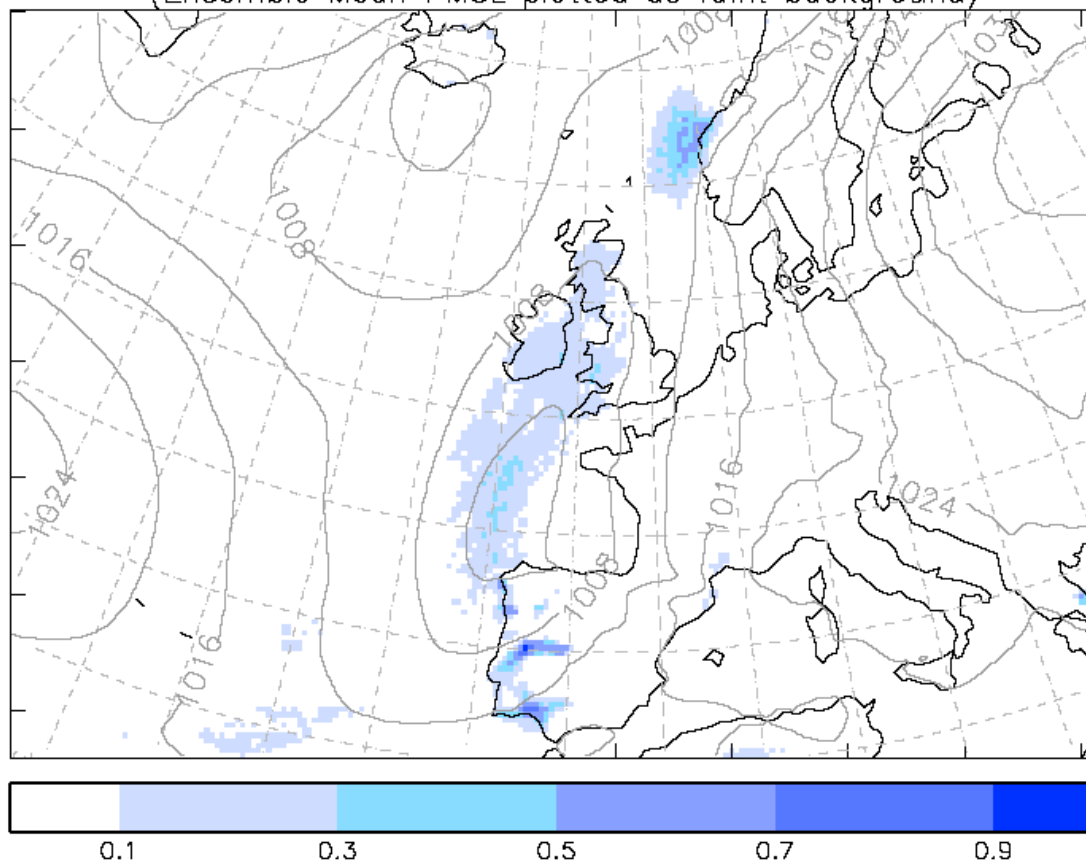


# Probability of $>10\text{mm}/6\text{h}$ T+33



Proportion of ensemble members gives estimate of probability

MOGREPS (Regional) Probability map for 6HourPrecip  $> 10.0\text{mm}$   
DT 06Z on 10/10/2005 VT 15Z on 11/10/2005 lead time 33h  
(Ensemble Mean PMSL plotted as faint background)

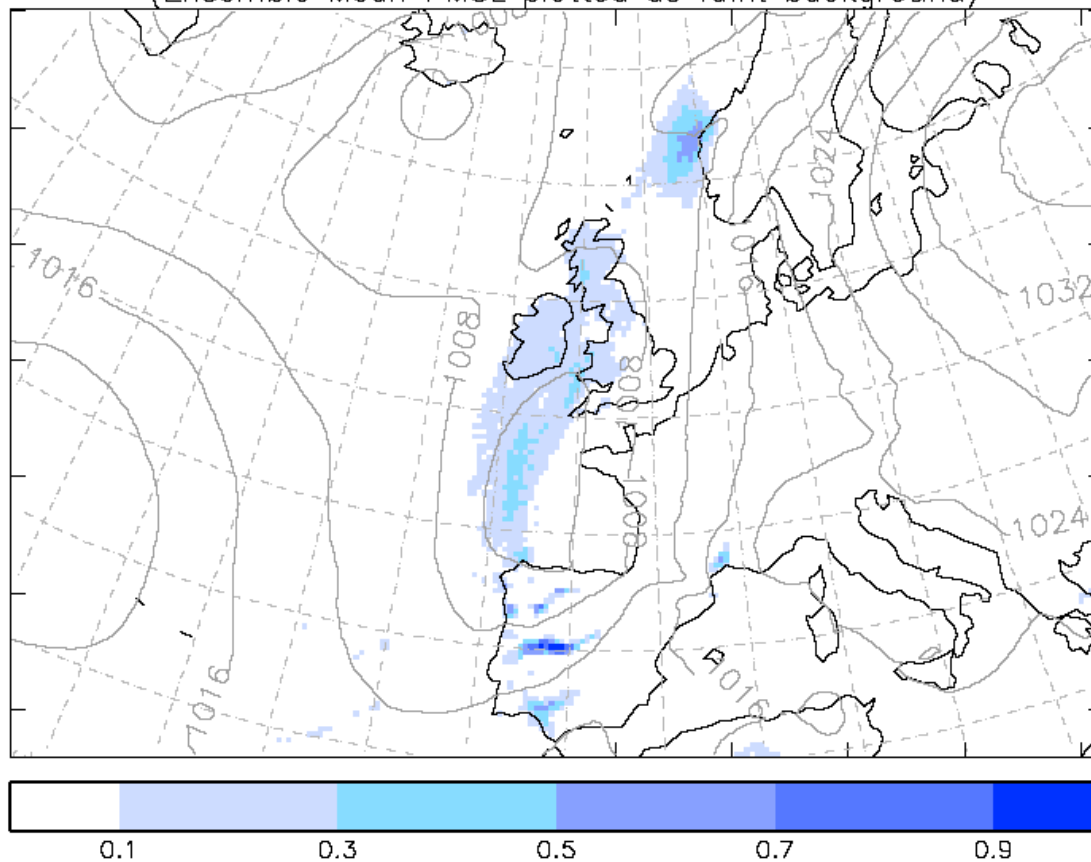


# Probability of $>10\text{mm}/6\text{h}$ T+36



Proportion of ensemble members gives estimate of probability

MOGREPS (Regional) Probability map for 6HourPrecip  $> 10.0\text{mm}$   
DT 06Z on 10/10/2005 VT 18Z on 11/10/2005 lead time 36h  
(Ensemble Mean PMSL plotted as faint background)



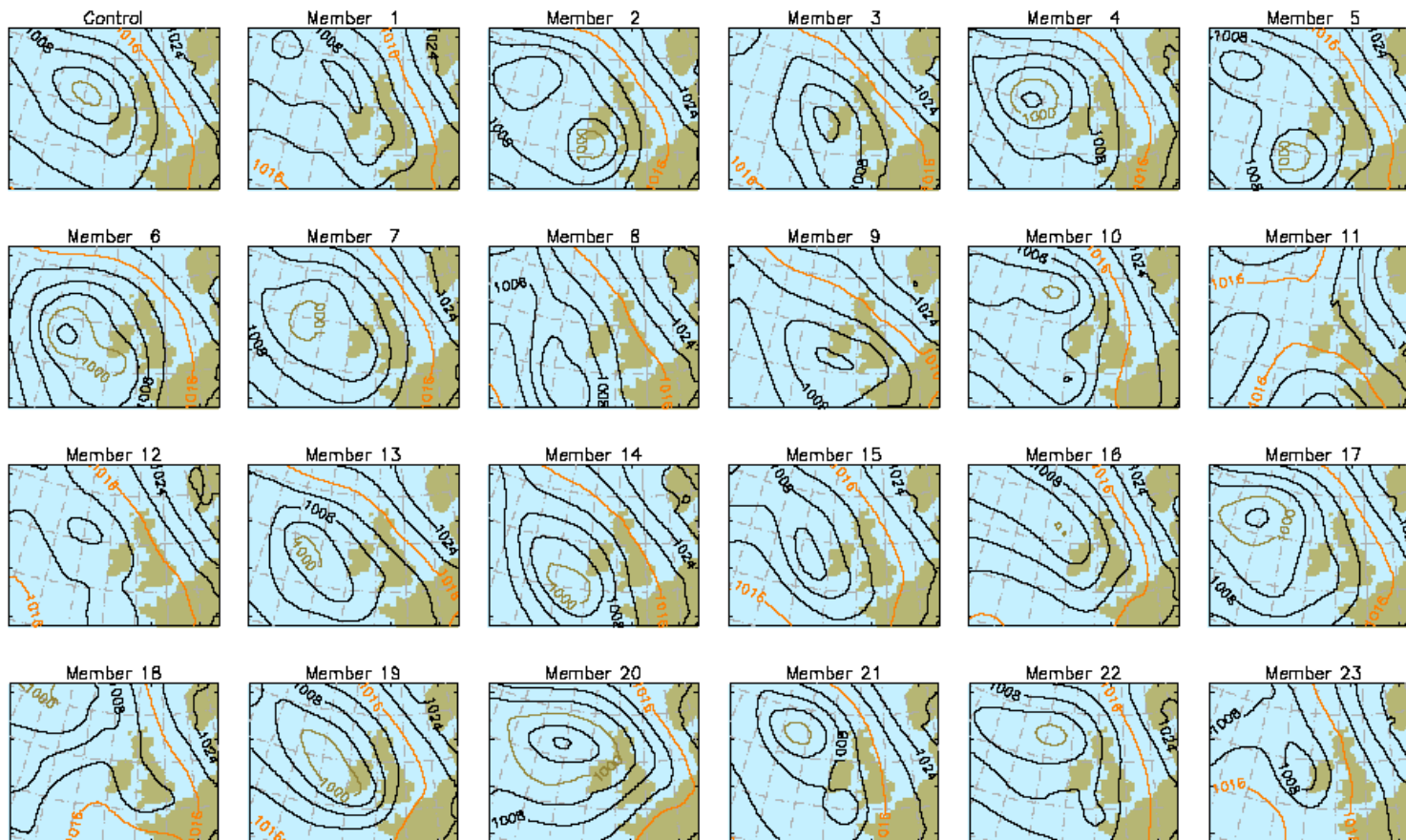
# Global T+42 forecast for 06Z on 19/10/05



MOGREPS (Global) PMSL (hPa)

T+42h

DT 12Z on 17/10/2005  
VT 06Z on 19/10/2005



# NAE T+36 forecast for 06Z on 19/10/05



Note extra detail and deeper lows in NAE

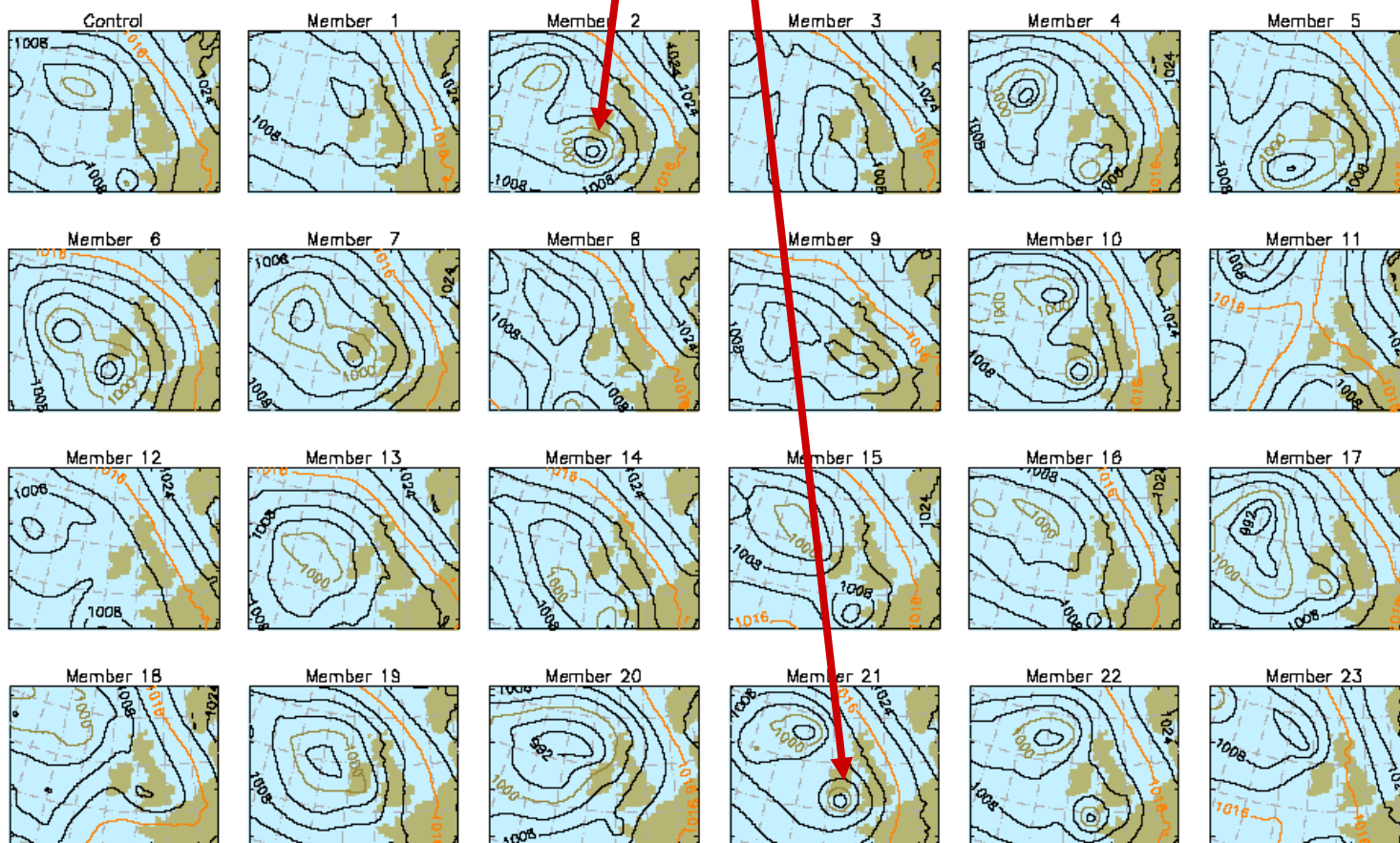
MOGREPS (Regional)

PMSL (hPa)

T+36h

DT 18Z on 17/10/2005

VT 06Z on 19/10/2005



# Global T+42 forecast for 06Z on 19/10/05



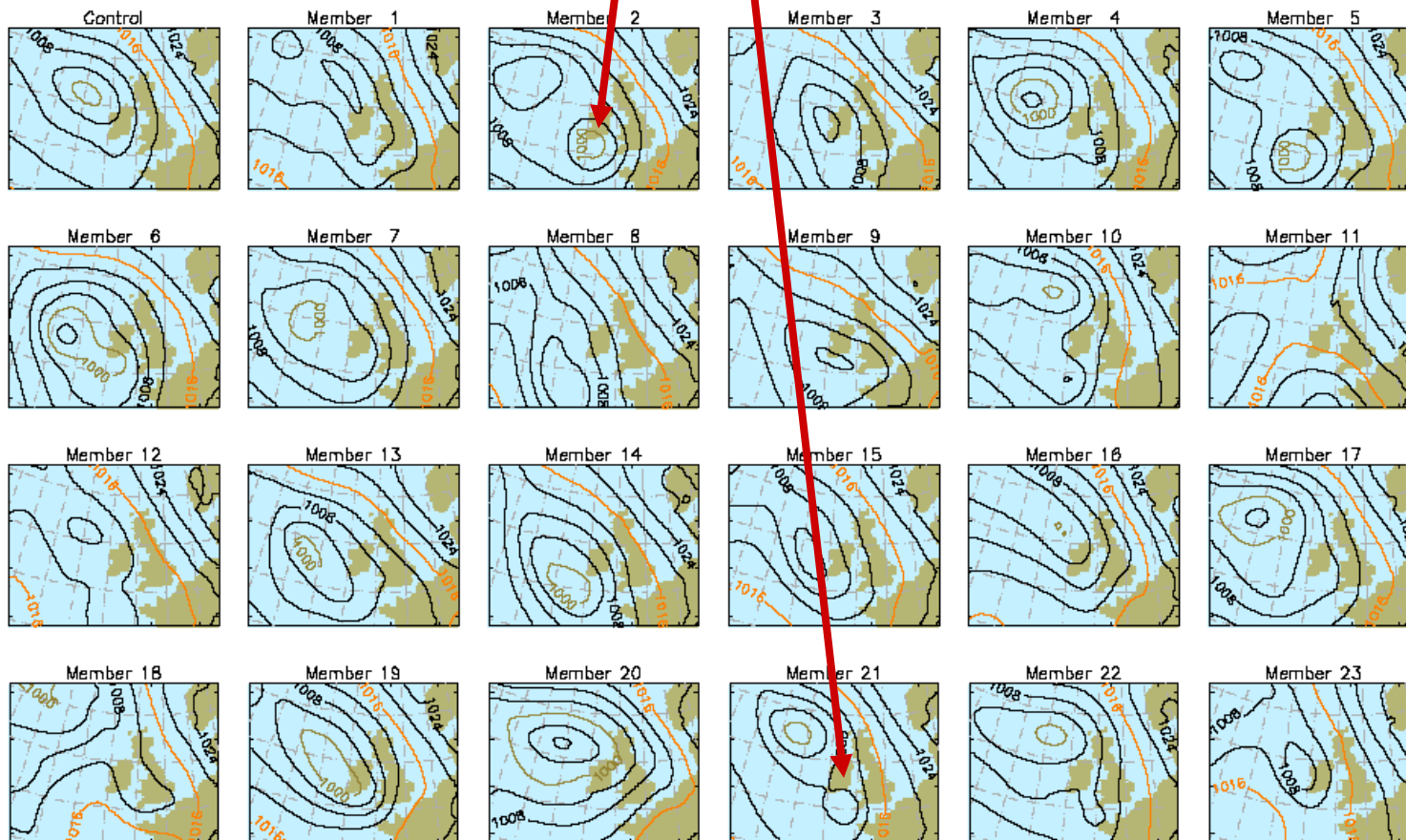
Note extra detail and deeper lows in NAE

MOGREPS (Global)

PMSL (hPa)

T+42h

DT 12Z on 17/10/2005  
VT 06Z on 19/10/2005



# NAE T+36 forecast for 06Z on 19/10/05



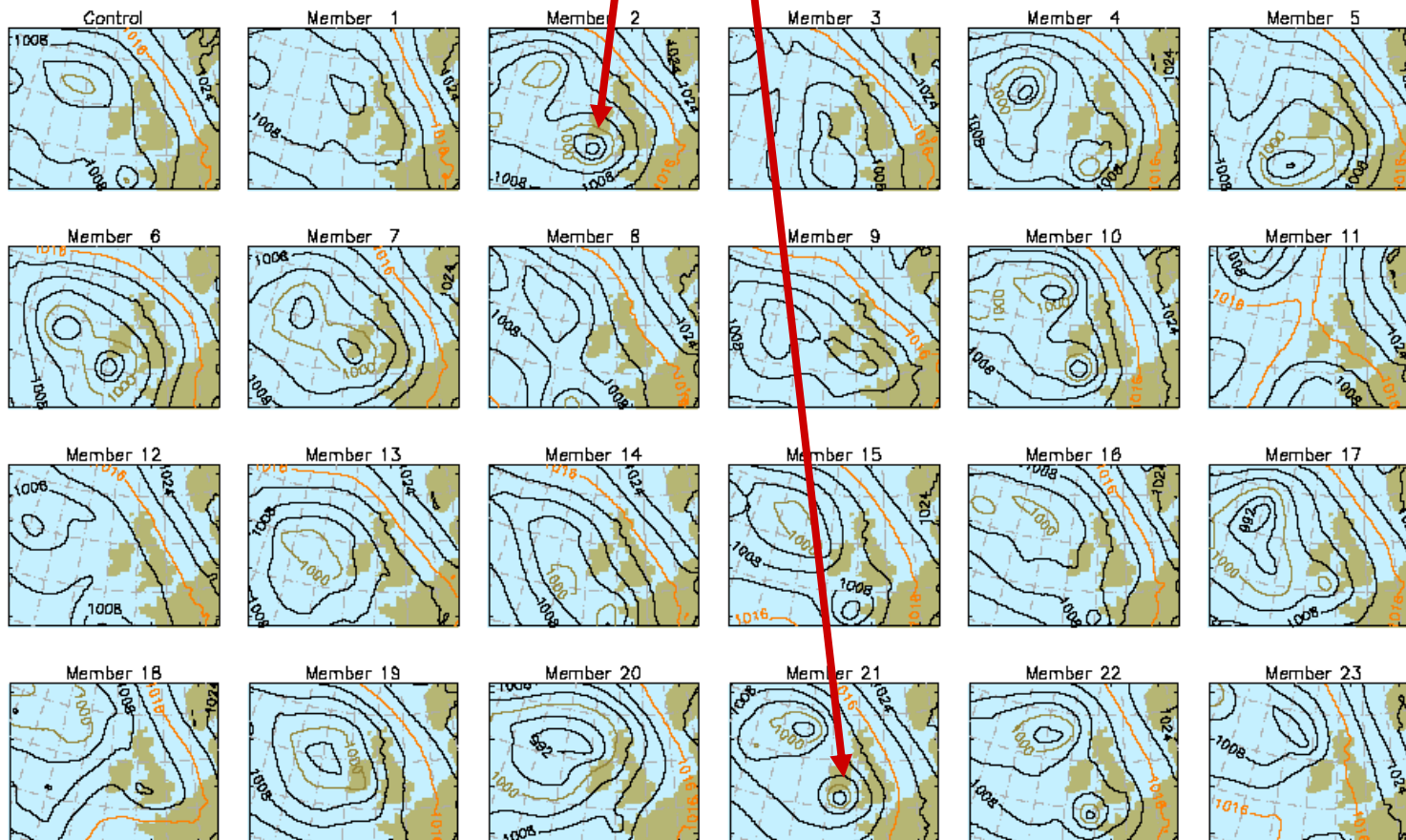
Note extra detail and deeper lows in NAE

MOGREPS (Regional)

PMSL (hPa)

T+36h

DT 18Z on 17/10/2005  
VT 06Z on 19/10/2005

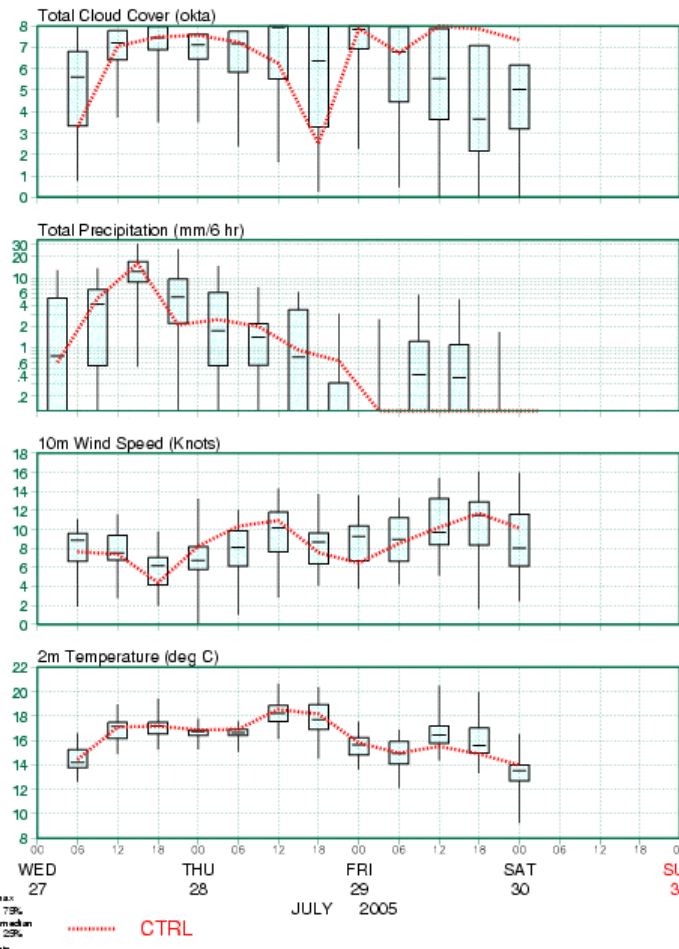


# MOGREPS Site-specific forecasts



## ■ EPS Meteogram

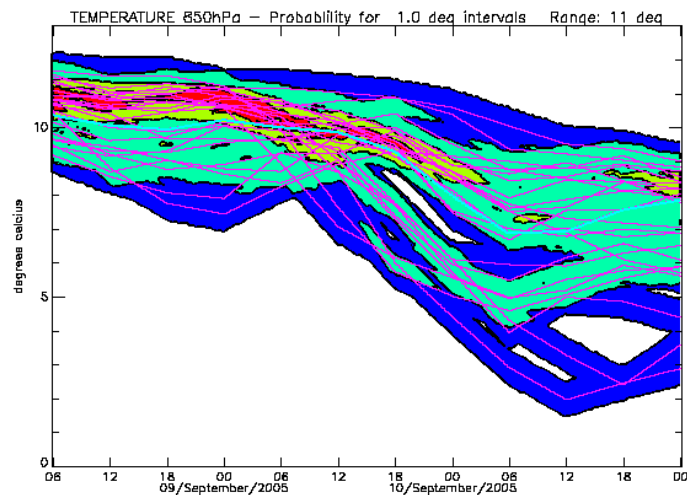
MOGREPS Global EPS Meteogram  
 EXETER HQ SITE (99085) 50.7° N 3.5° W  
 RAW - EPS Forecasts : 27 July 2005 00 UTC



## ■ MOGREPS Plume

MOGREPS Global EPS forecasts  
 EXETER HQ  
 DATE: 20050908 00Z LAT: 50.7 LON: -3.5

Legend for probability intervals:  
 0.5% - 10% (Blue), 10% - 30% (Cyan), 30% - 50% (Green), 50% - 100% (Red)  
 Control (Cyan line), EMem (Pink line)



## ■ Kalman filter MOS is being implemented for MOGREPS forecasts

# Site-specific Probabilistic Wind-rose



Key for wind direction & speed on windrose only:

30 degree sectors (000-030, 030-060,...,330-360)

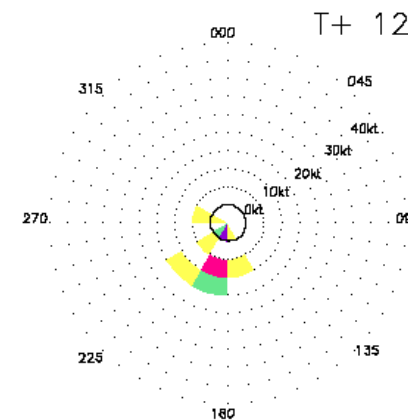
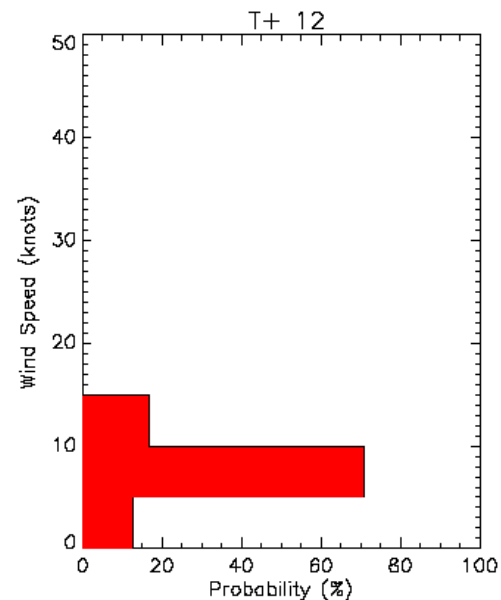
innermost circle only for wind direction

outer circles are divided into 5 knot bands, with wind speed increasing outwards (eg. 0-5kt,5-10kt,10-15kt,15-20kt)

1% to 10% probability =		50% to 60% probability =	
10% to 20% probability =		60% to 70% probability =	
20% to 30% probability =		70% to 80% probability =	
30% to 40% probability =		80% to 90% probability =	
40% to 50% probability =		90% to 100% probability =	

NO COLOUR KEY FOR BAR CHART

GLENS 2005090800 Station: 99085

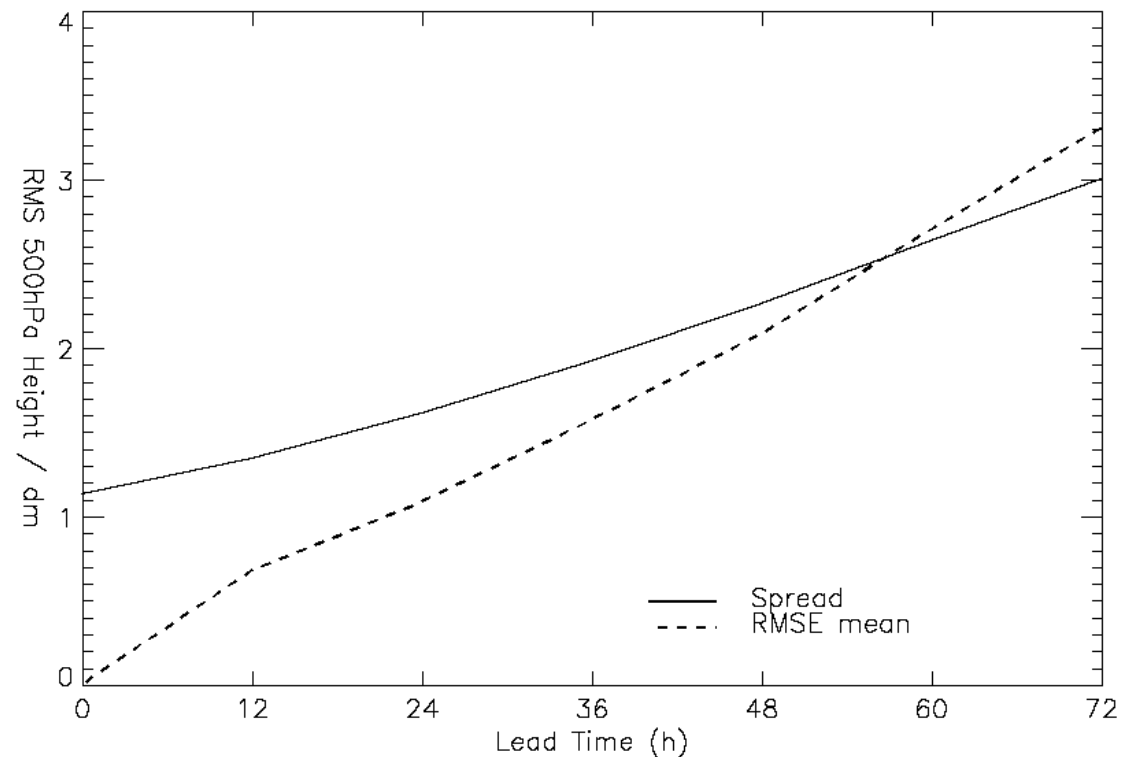


# Global MOGREPS Performance



- Spread growth is slower than error growth
  - SKEB should improve this
- Spread optimised by variable inflation factor against observations in  $u$ ,  $v$ ,  $T$  and  $RH$  at  $T+12$ 
  - Appears too large because verified against analysis

Spread and RMSE for 500hPa GPH

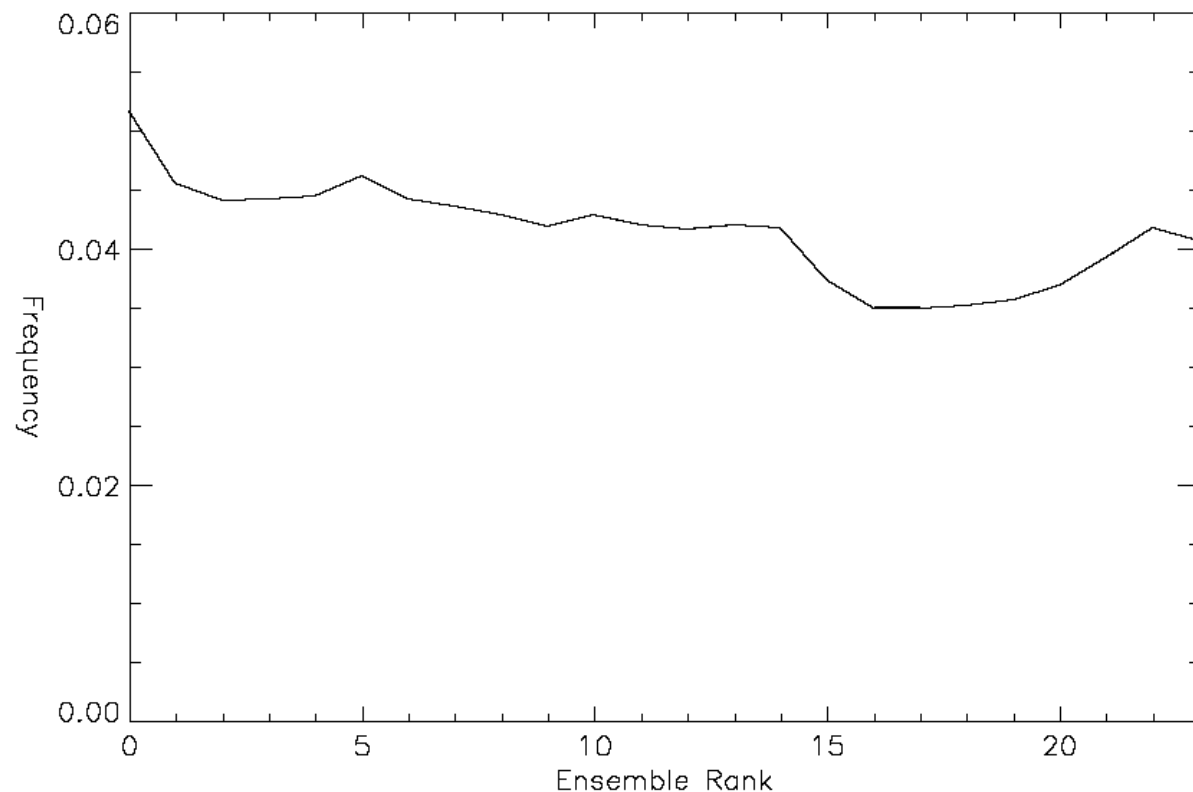


# Global MOGREPS Performance

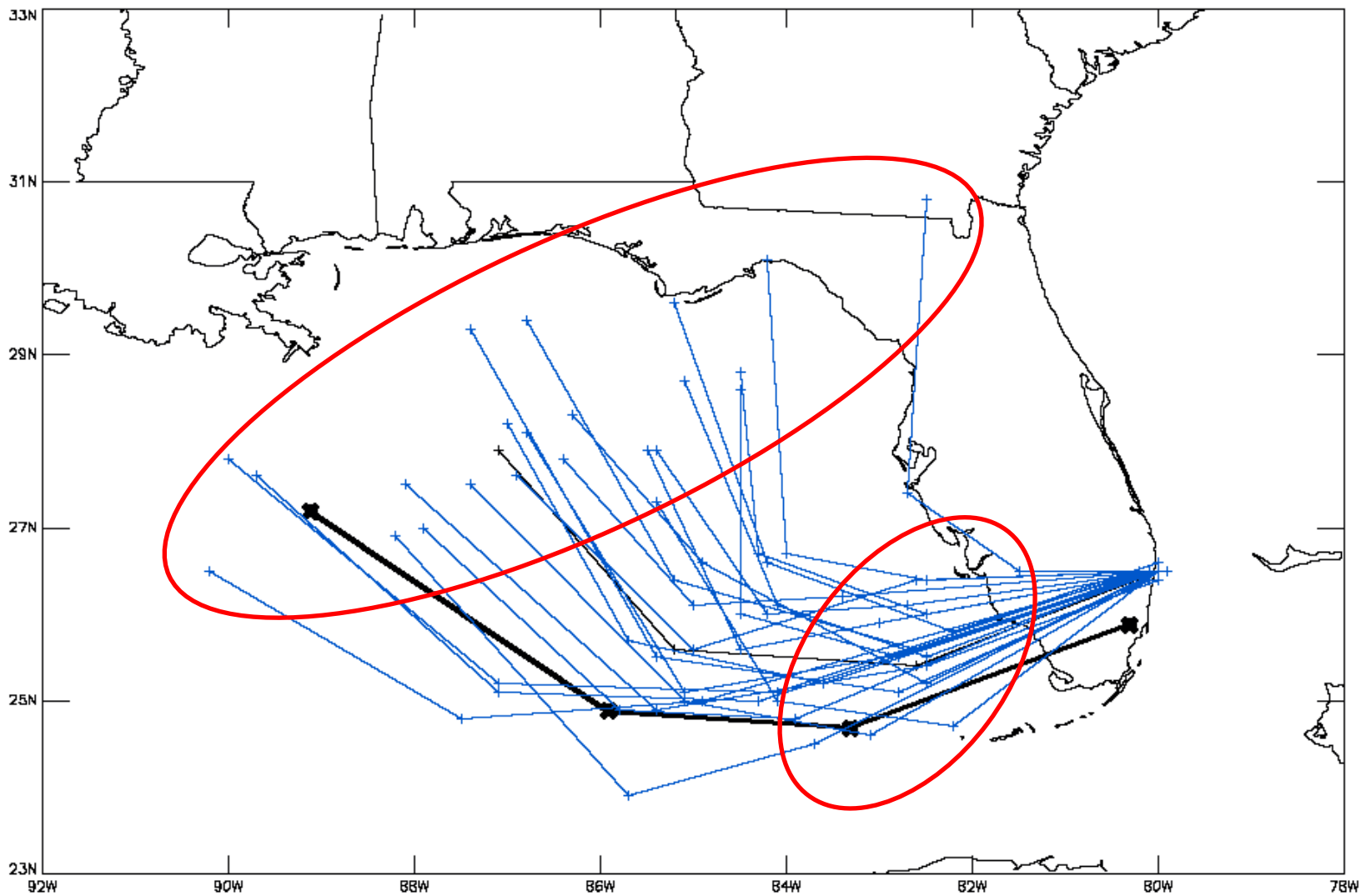


- Rank histogram is encouragingly flat
  - Close to ideal
- Suggests that ETKF perturbations are representative of genuine analysis errors
- RH for shorter lead-times is peaked in middle
  - Suggests overspread, but...
  - Probably due to verifying against analyses

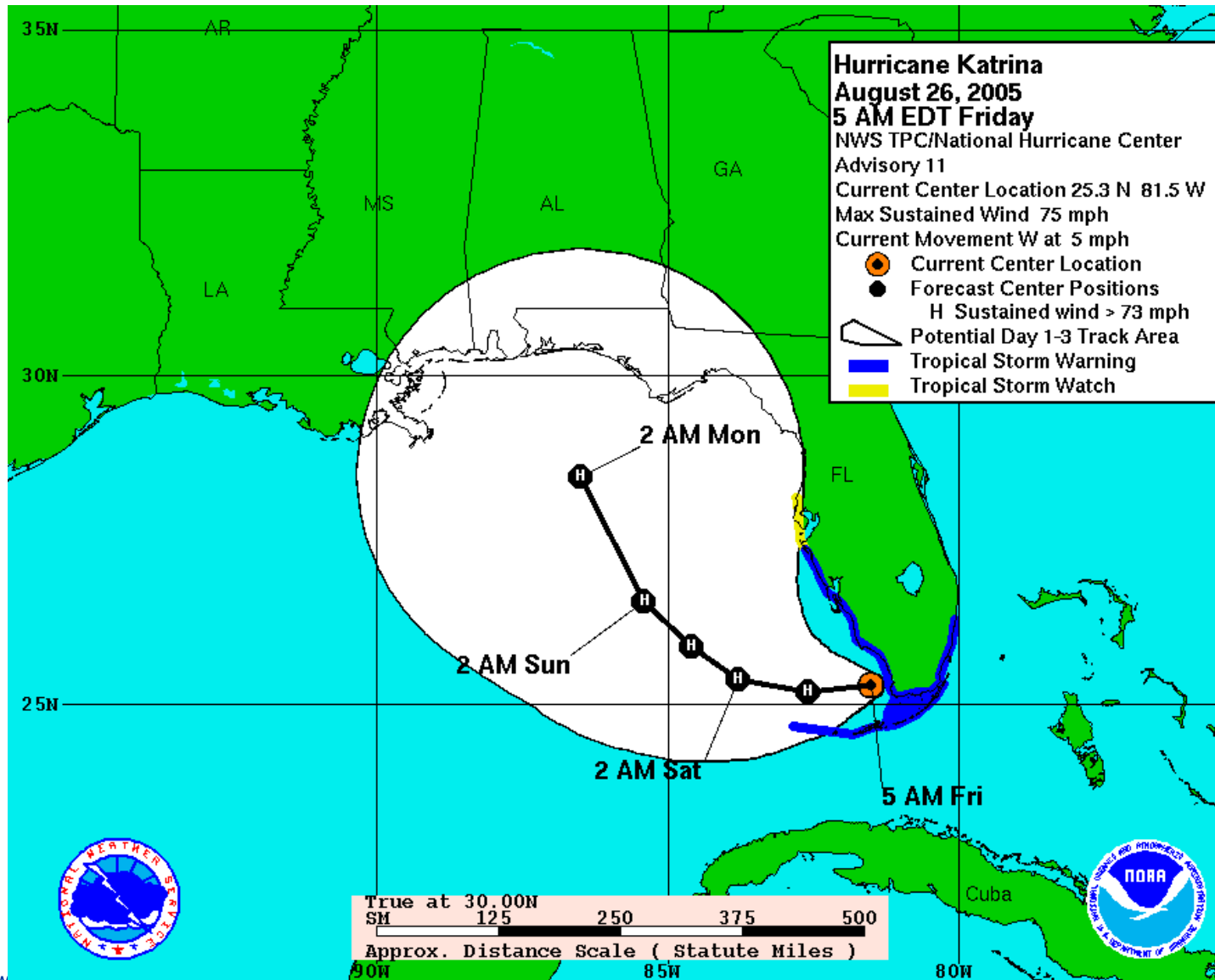
Rank Histogram at T+72 for 500hPa GPH



# Katrina – from “operational” system



# Katrina – NHC warning



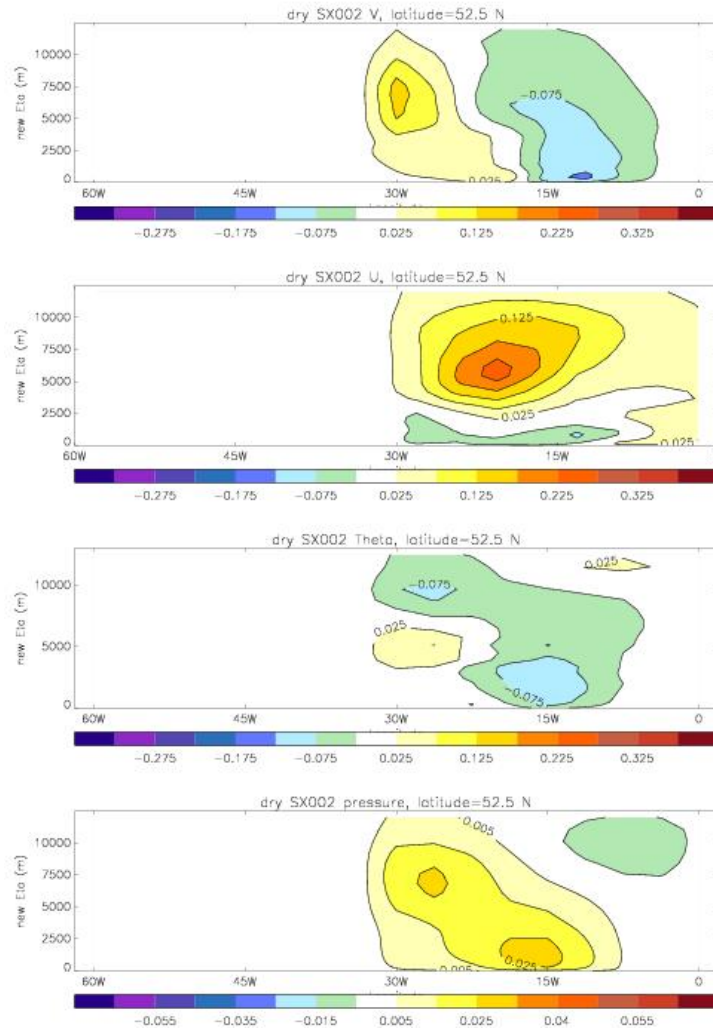
- Verification to date is very basic
- Verification is being implemented within the Area-based Verification system (ABV) and Site-specific Verification system (SBV)
  
- Daily assessment is being carried out by Ops Centre forecasters and research staff
  - Fixed sets of questions
  - Initial forecaster response is enthusiastic and very positive

- ETKF is believed to be well-suited to short-range ensemble, but...
  - Singular vectors perform very well at ECMWF
  - Coutinho and Hoskins showed benefit of moist SVs with shorter optimisation time
- Following idea of Hoskins to use a very small SV-perturbed ensemble to assess possible extreme deviations from ensemble mean
  - Capability to calculate dry or moist SVs from DA team
  - Future possibility that forecasters could choose a target area around a feature of concern

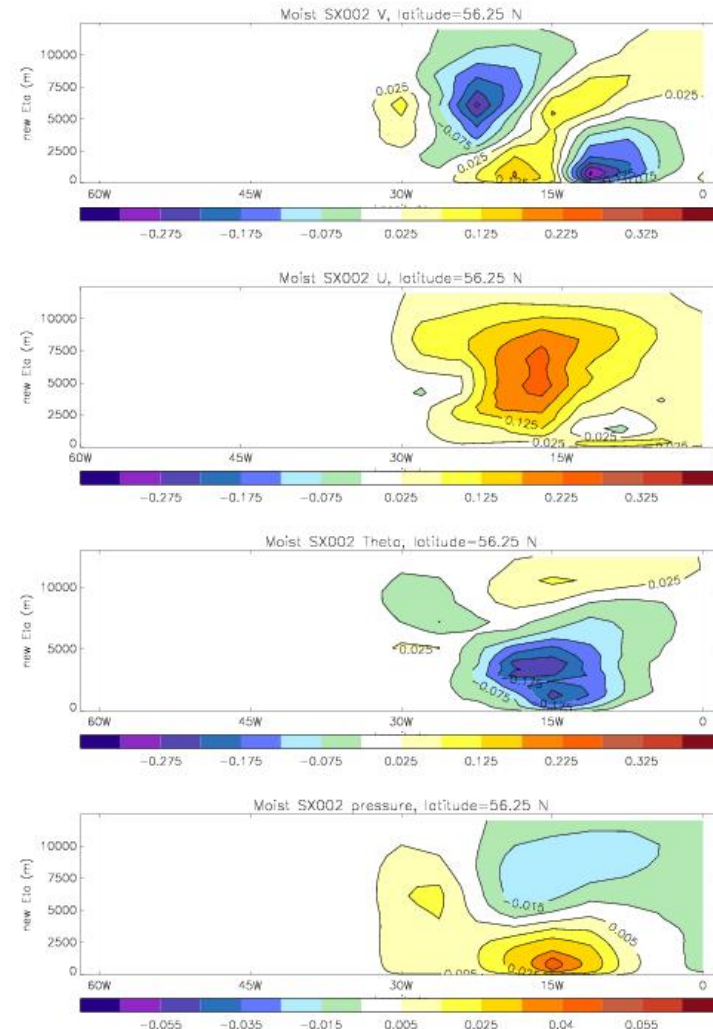
# Singular Vector at final time (T+24)



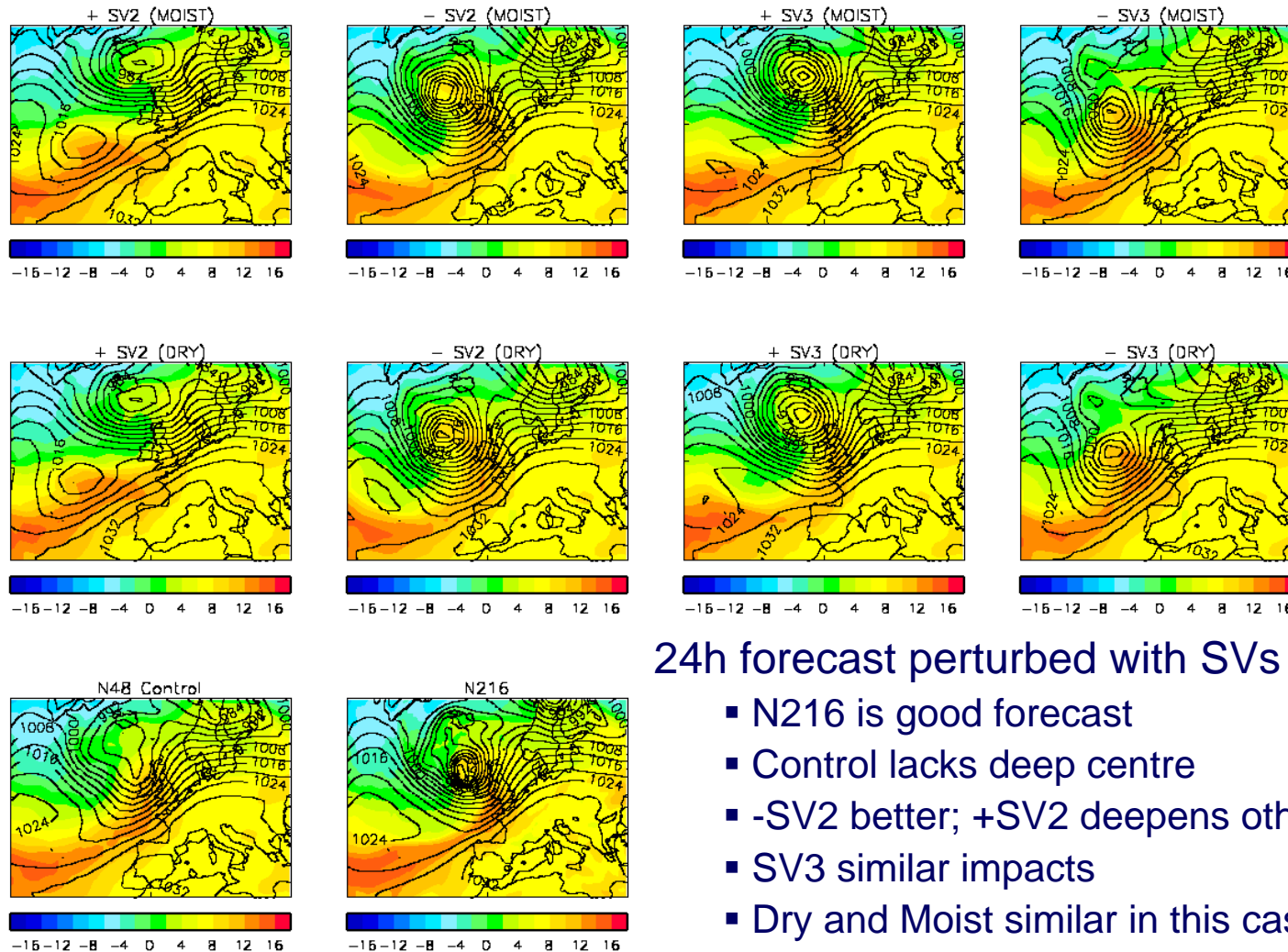
## Dry



## Moist



# First SV perturbed forecast (N48 resolution)



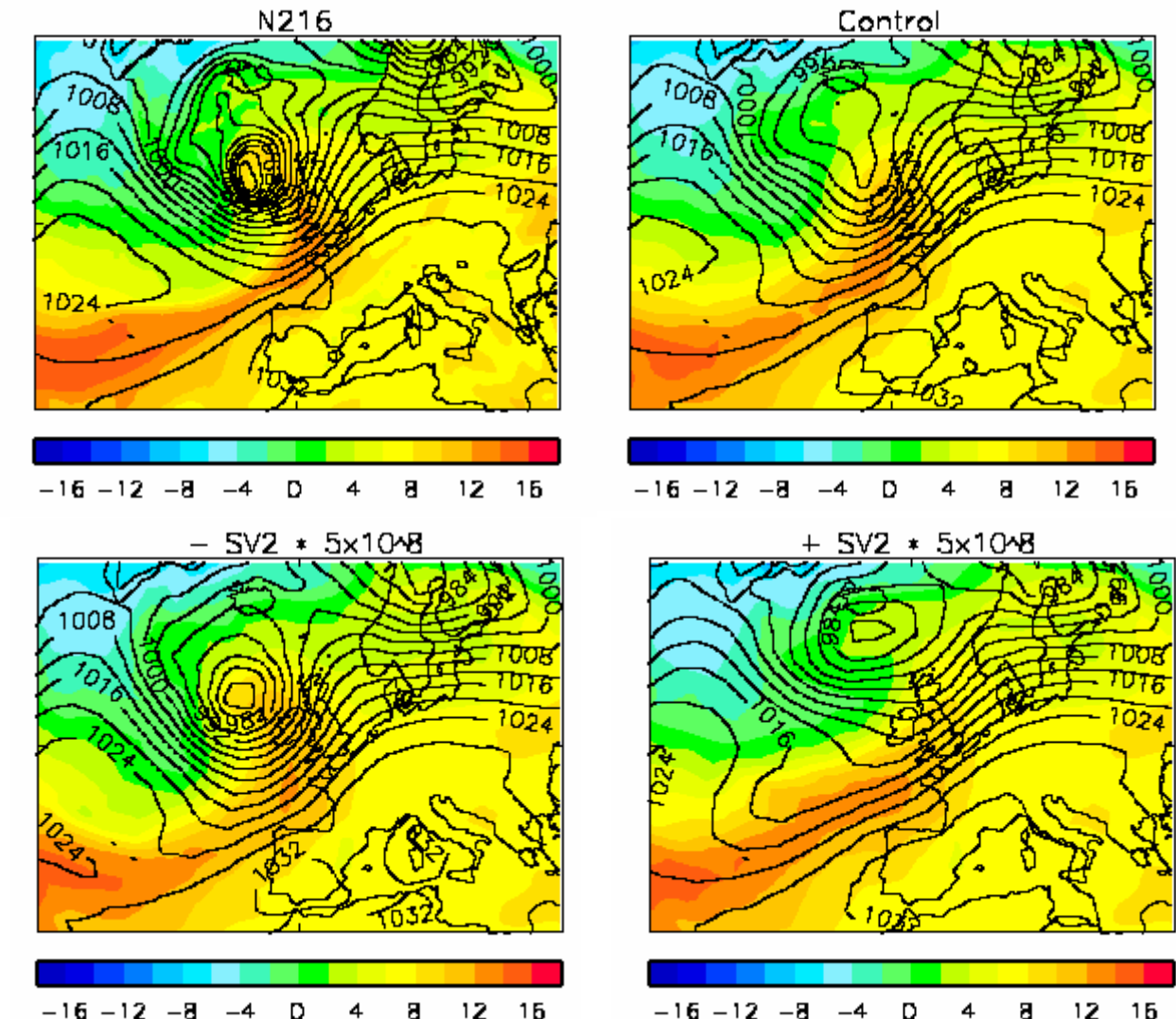
## 24h forecast perturbed with SVs at N48

- N216 is good forecast
- Control lacks deep centre
- -SV2 better; +SV2 deepens other centre
- SV3 similar impacts
- Dry and Moist similar in this case

# First SV perturbed forecast (N48 resolution)



- Early 24h forecast perturbed with dry SV at N48
  - N216 is good forecast
  - Control lacks deep centre
  - -SV2 much better
  - +SV2 deepens other low centre



- MOGREPS started operational trials in September
  - Trials scheduled to run for 12 months
  - Objective verification and forecaster assessment
  
- Further science upgrades planned
  - SKEB
  - Local ETKF and Regional perturbations for NAE
  
- Global MOGREPS being implemented at ECMWF to run to 15 days for THORPEX/TIGGE
  - Initial conditions supplied from Exeter
  
- MOGREPS cannot yet be used operationally
  - Could be operational later in 2006/07 subject to satisfactory performance in trial



**Any questions?**