



Developments in Ensemble Post-processing at the Met Office

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Ensemble Forecasting Manager

Thanks to Caroline Woolcock, Piers Buchanan, Rob Neal and many others



Contents

- PREVIEW Windstorms verification
- Multi-model Tropical Cyclone tracks
- MOGREPS Performance for Severe Weather
- Requirements for impact prediction



Met Office



PREVIEW Windstorms – performance



Multi-model Ensemble Forecasts



■ Ensemble Forecast inputs:

➤ Medium-Range (3-5 days)

- ECMWF – EPS
- ARPA-SIM – COSMO-LEPS

➤ Short-Range (1-2 days) – multi-model ensemble consisting of contributions from:

- Meteo-France – PEACE
- DWD – SRNWP-PEPS
- Met.no – TEPS/LAM EPS
- Met Office – MOGREPS



Met Office



Deutscher Wetterdienst





Examples of Products - March 10th 2008



Key for wind direction & speed on windrose:

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

VT 0000L

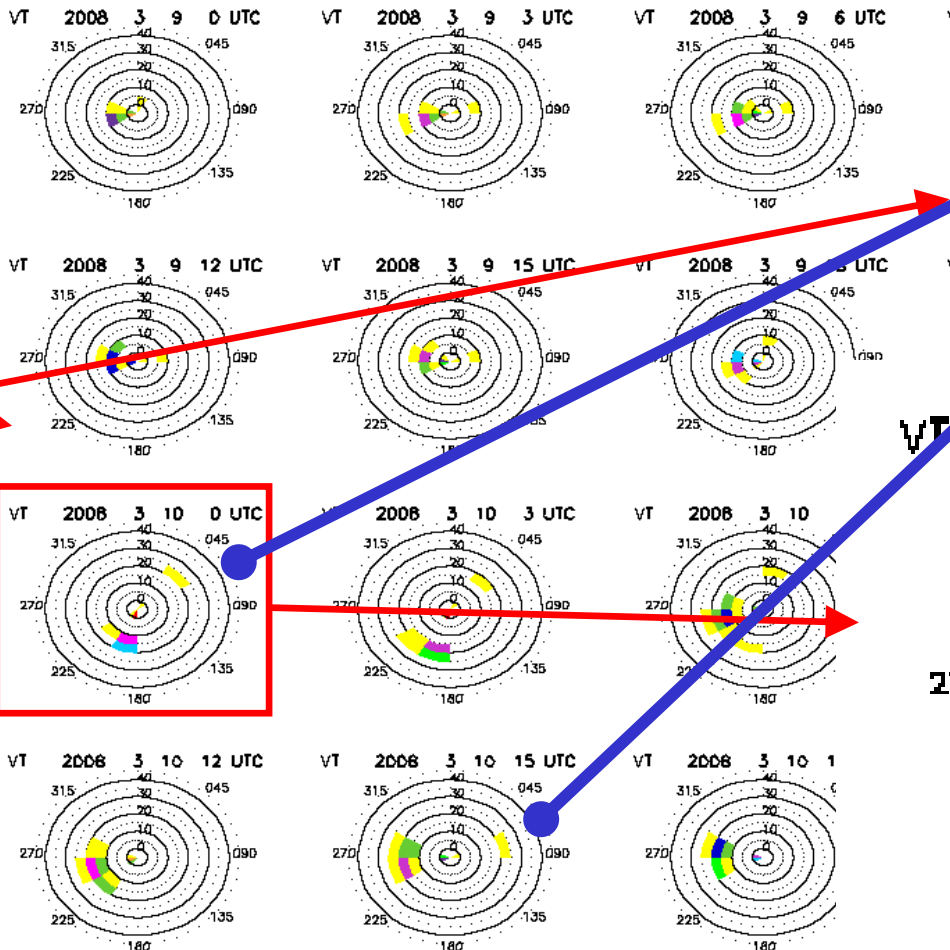
Compass Direction which wind is coming from in 30 degree sectors (000-030, 030-060, ..., 330-360) innermost circle only for wind direction

outer circles are divided into 5 m/s bands, with wind speed increasing outwards

VT=Validity Time

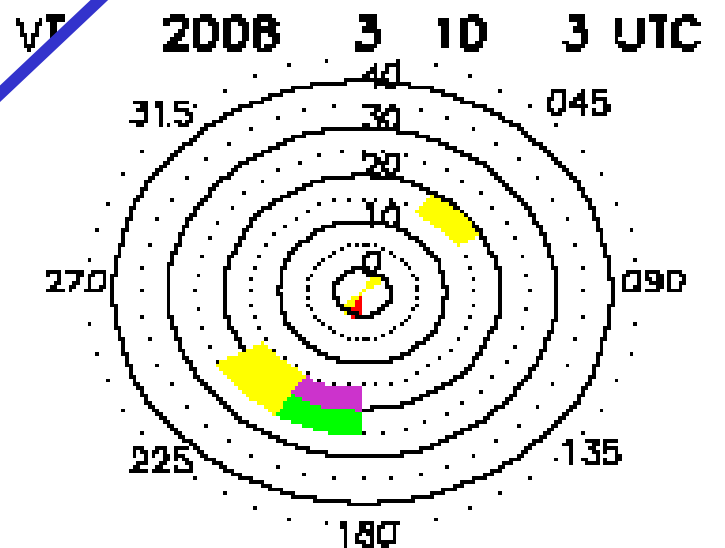
- ▲ SEVERE
- HIGH
- ◆ MEDIUM
- LOW

Model type: EURDRISK Model runtime: 2008 3 9 0 UTC Station: PLYMOUTH, MC



Windstorm combined EPS Meteogram
MOUNT BATTEN (03827) 50.3° N 4.1° W
Forecasts from 9 March 2008 0 UTC

10m Wind Speed [Blue] Wind Gust [Red] (m/s)





Storm in Southern Europe, Sat. 24th January 2009

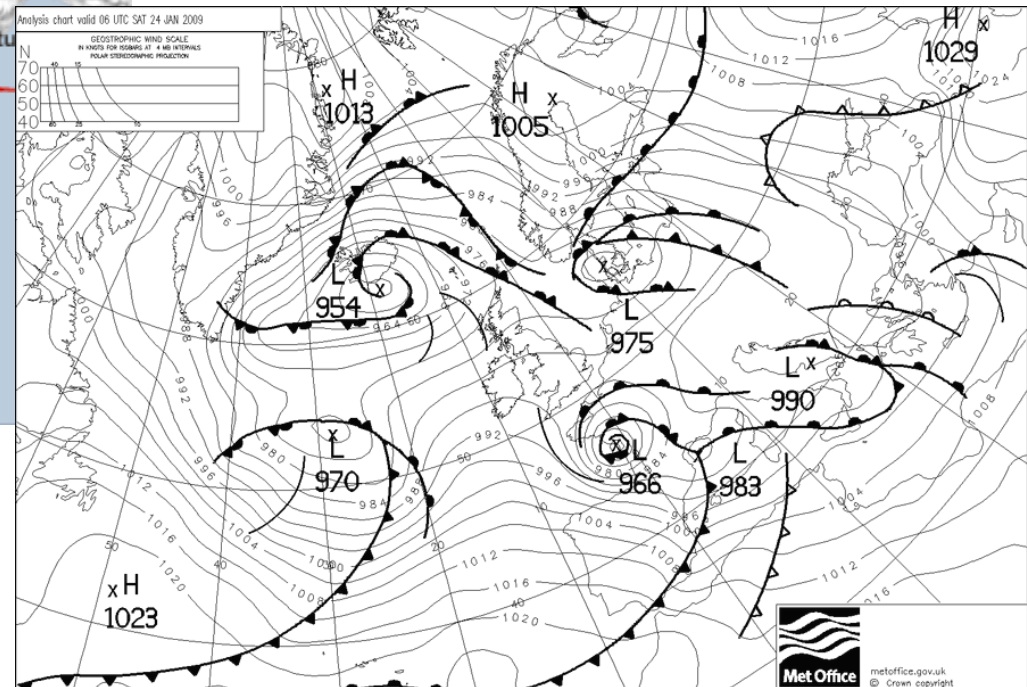


- Torrential rain and winds up to 114 mph.
- At least 20 people died in Spain and SW France.
- Over 1 million in France without power.





06UTC on 24 Jan 2009



Track plot courtesy of BBC

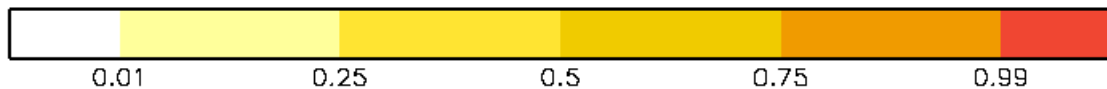
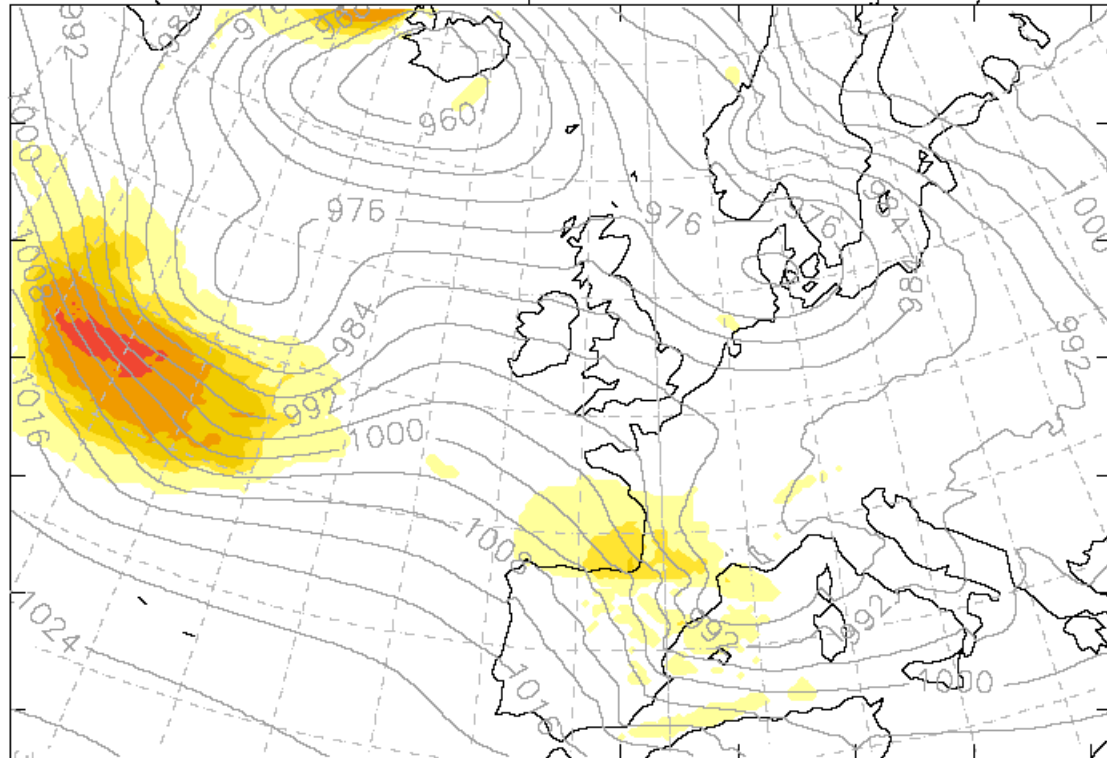


MOGREPS Prob(Gust>60kt)

36h forecast valid 0600 on 24 Jan



MOGREPS (Regional) Probability map for GustSpeed > 60.0knots
DT 18Z on Thu 22/01/2009 VT 06Z on Sat 24/01/2009 lead time 36h
(Ensemble Mean PMSL plotted as faint background)



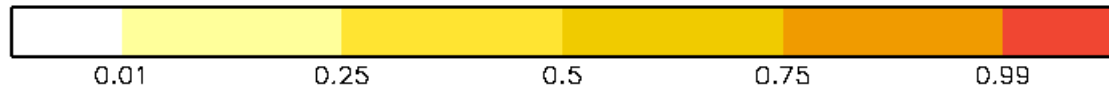
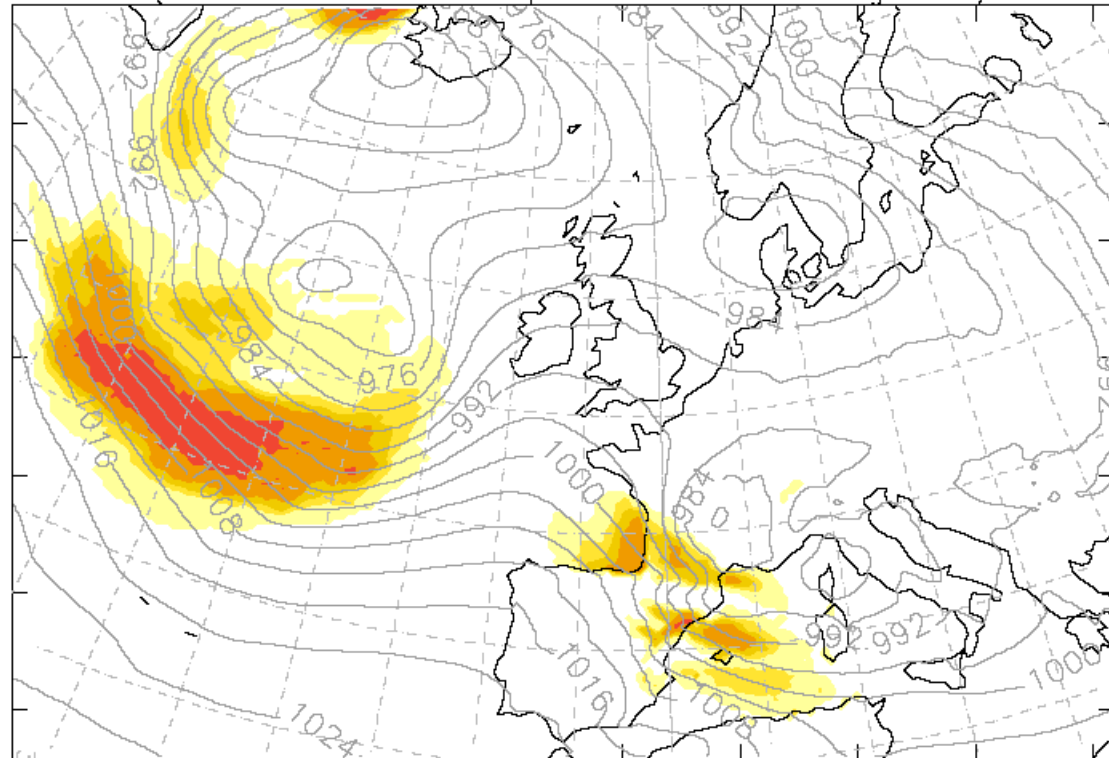


MOGREPS Prob(Gust>60kt)

18h forecast valid 1200 on 24 Jan



MOGREPS (Regional) Probability map for GustSpeed > 60.0knots
DT 18Z on Fri 23/01/2009 VT 12Z on Sat 24/01/2009 lead time 18h
(Ensemble Mean PMSL plotted as faint background)



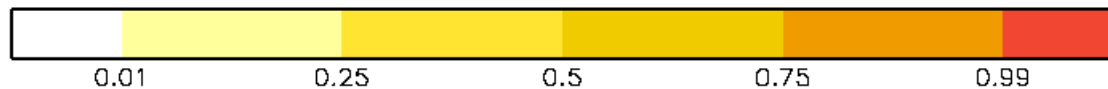
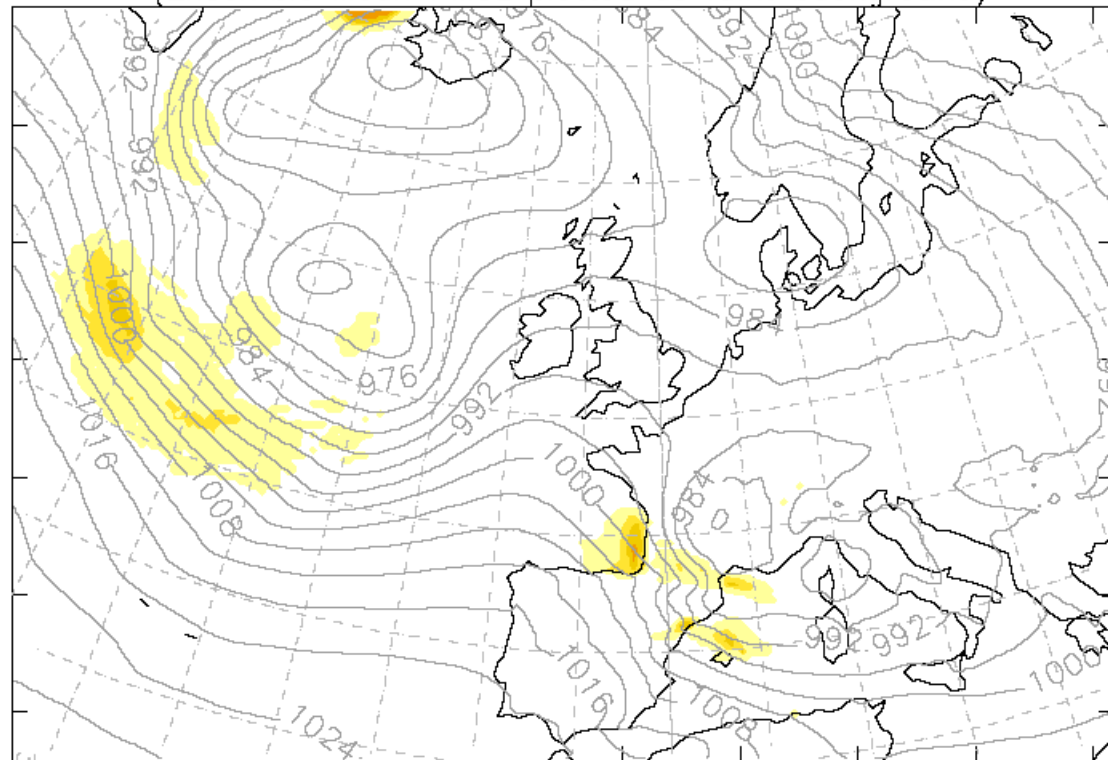


MOGREPS Prob(Gust>70kt)

18h forecast valid 1200 on 24 Jan

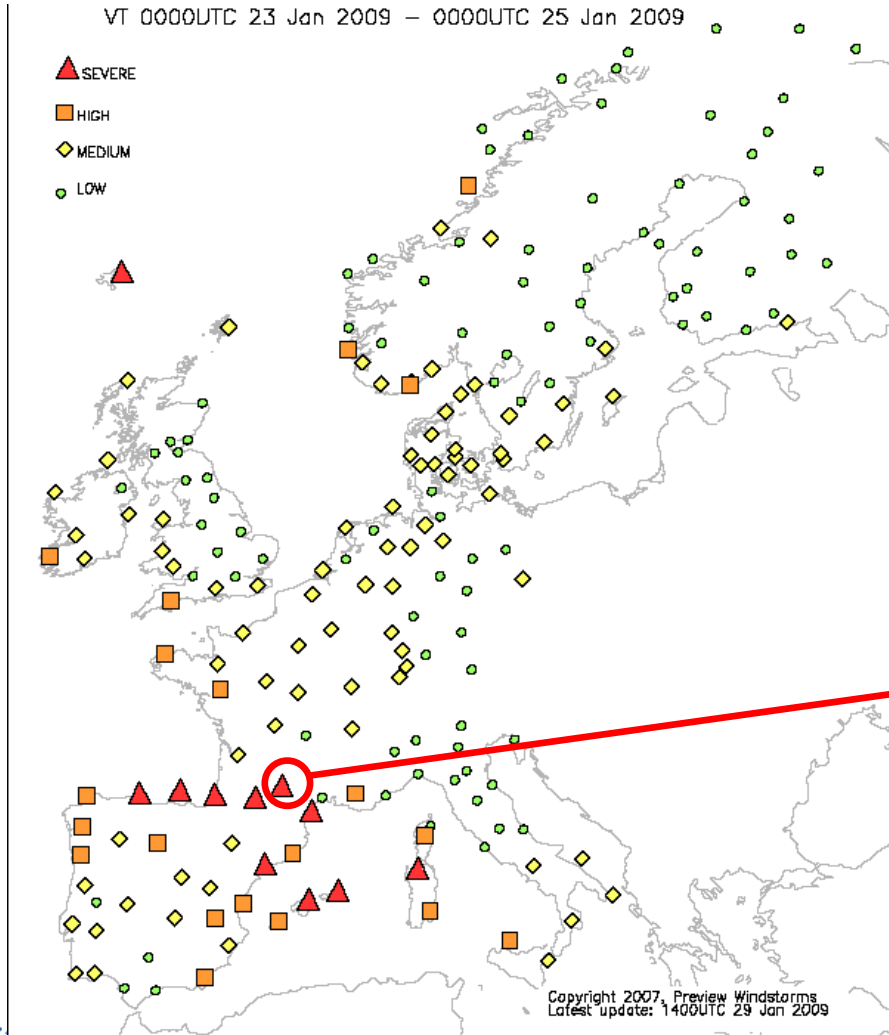


MOGREPS (Regional) Probability map for GustSpeed > 70.0knots
DT 18Z on Fri 23/01/2009 VT 12Z on Sat 24/01/2009 lead time 18h
(Ensemble Mean PMSL plotted as faint background)

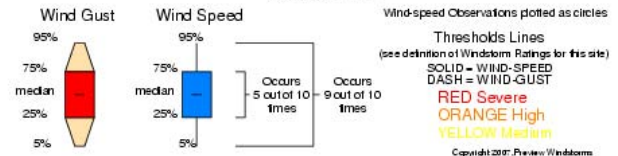
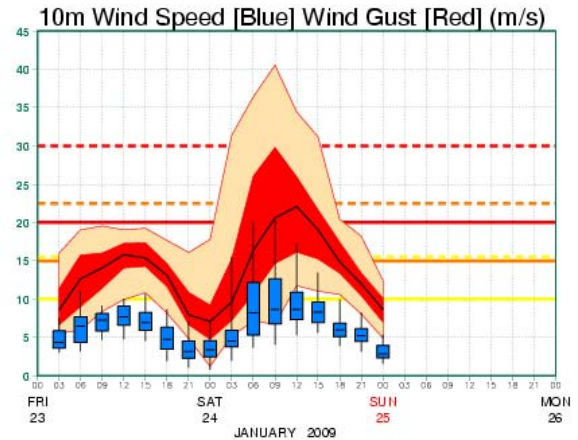




Storm in Southern Europe, 2009: Windstorms



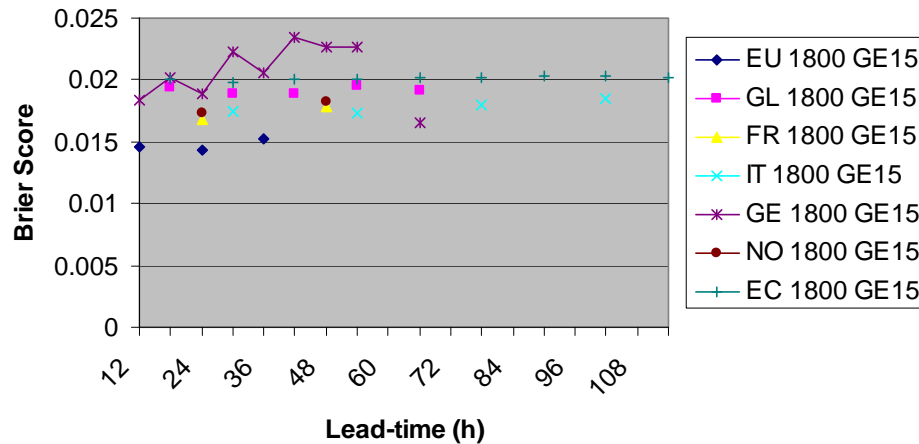
Windstorm combined EPS Meteogram
TOULOUSE / BLAGNAC (07630) 43.6° N 1.4° E
Forecasts from 23 January 2009 0 UTC



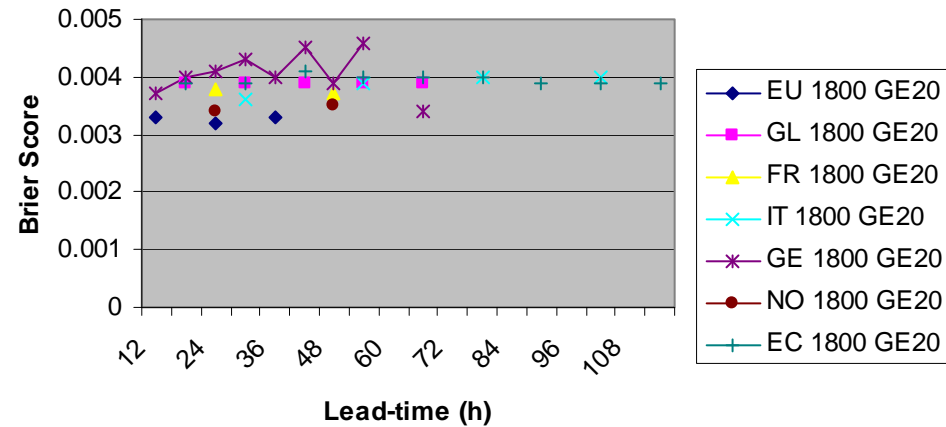
Brier scores of individual ensemble contributions

↓ Lower BS is best

Brier Scores VT18UTC GE15



Brier Scores VT18UTC GE20

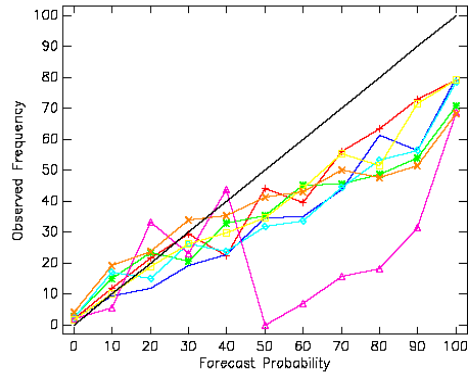




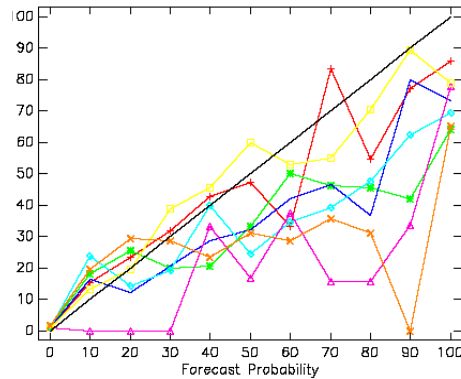
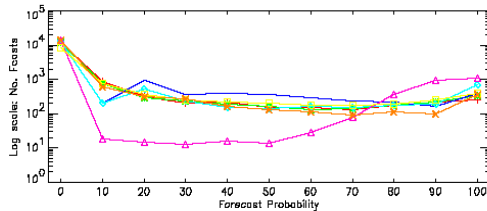
Verification – Reliability Diagrams (2007/08)



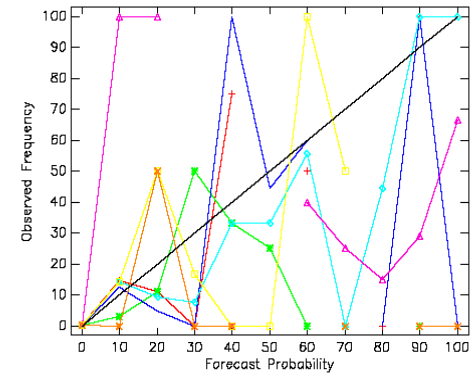
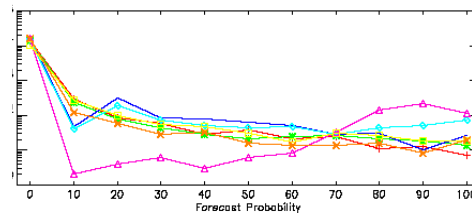
- For individual ensembles (best when nearest to diagonal)
- Forecast Lead time between T+30hrs and T+48. Verifying 18Z



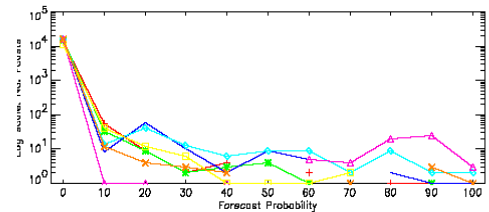
Feast type	Reliability Score
EU T+ 36	0.00305275
GL T+ 30	0.00710127
FR T+ 48	0.00674122
IT T+ 30	0.00673237
GE T+ 30	0.0368281
NO T+ 48	0.00524987
EC T+ 30	0.00594657



Feast type	Reliability Score
EU T+ 36	0.000345026
GL T+ 30	0.00110565
FR T+ 48	0.00111118
IT T+ 30	0.00174850
GE T+ 30	0.00864701
NO T+ 48	0.000355256
EC T+ 30	0.00136191



Feast type	Reliability Score
EU T+ 36	0.000111609
GL T+ 30	0.000129299
FR T+ 48	0.000329130
IT T+ 30	0.000231250
GE T+ 30	0.00121379
NO T+ 48	0.000174291
EC T+ 30	0.000310183



Wind Speed > 10 m/s

> 15 m/s

> 20 m/s



Verification – ROC Area (07/08)



- For individual ensembles (days 1-2)
- Forecast Lead time between T+30hrs and T+48. Verifying 18Z

	ROC Area Score		
	10m/s	15m/s	20m/s
MOGREPS EU	0.84	0.73	0.58
MOGREPS Global	0.80	0.66	0.53
PEACE	0.87	0.74	0.60
PEPS	0.87	0.78	0.63
LAMEPS	0.89	0.78	0.64

ROC Area

Perfect = 1.0

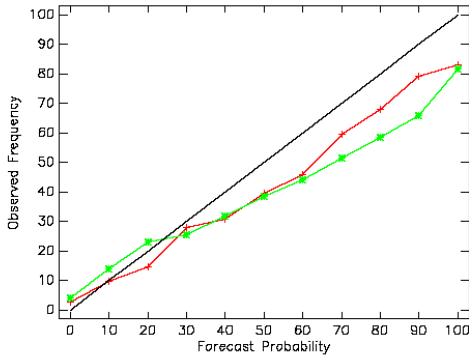
No skill = 0.5



Verification – Reliability + ROC Days 3-5 (07/08)



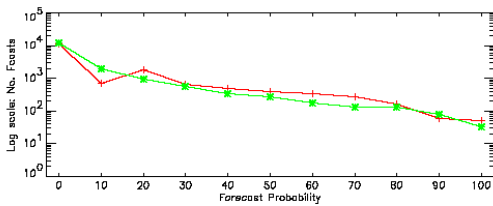
- For individual ensembles (best when nearest to diagonal)
- Forecast Lead time T+120. Verifying 12Z



Forecast type Reliability Score

IT T+ 120 + 0.00227211

EC T+ 120 * 0.00310270



	ROC Area Score		
	10m/s	15m/s	20m/s
ECMWF EPS	0.74	0.57	0.51

ROC Area
Perfect = 1.0
No skill = 0.5

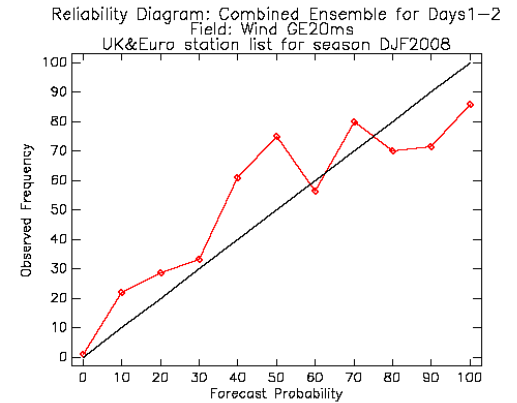
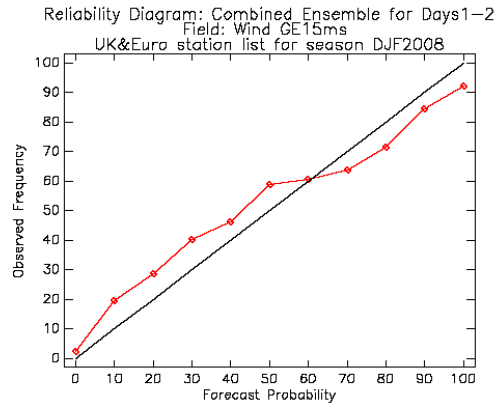
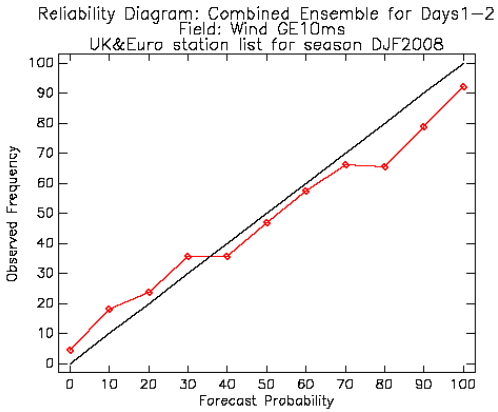
Wind Speed > 10 m/s



Verification of Combined Ensembles



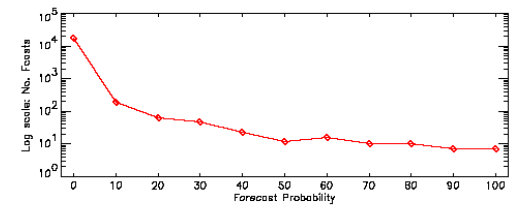
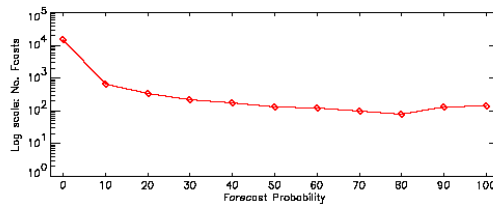
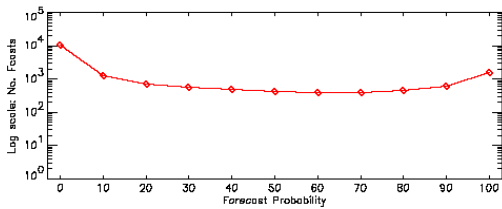
Reliability of combined multi-model ensemble days 1-2



Forecast type: RAW
Reliability Score: 0.00360582

Forecast type: RAW
Reliability Score: 0.00132981

Forecast type: RAW
Reliability Score: 0.000403316



Wind Speed > 10 m/s

> 15 m/s

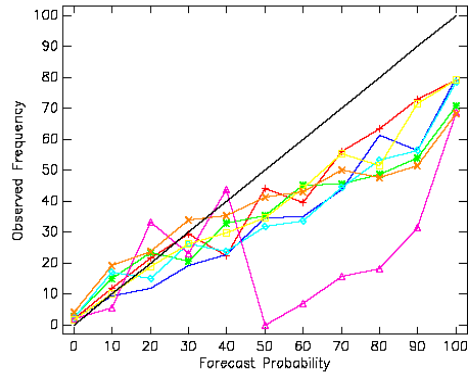
> 20 m/s



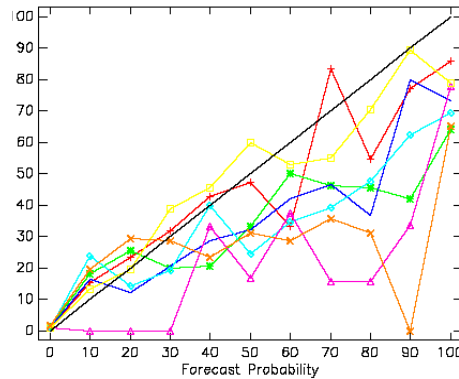
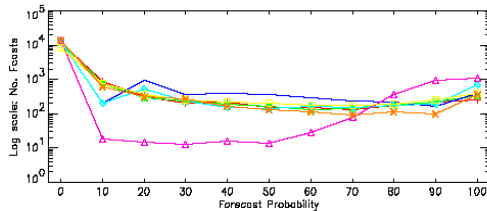
Verification – Reliability Diagrams (2007/08)



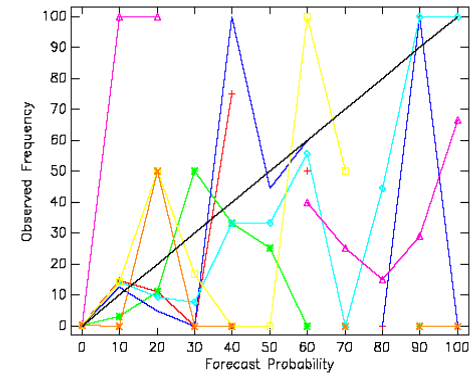
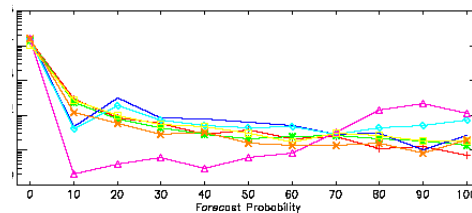
- For individual ensembles (best when nearest to diagonal)
- Forecast Lead time between T+30hrs and T+48. Verifying 18Z



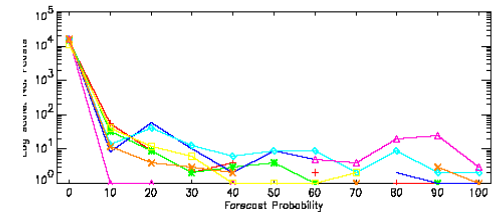
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Feast type	Reliability Score
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IT T+ 30	0.000231250
GE T+ 30	0.00121379
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EC T+ 30	0.000310183



Wind Speed > 10 m/s

> 15 m/s

> 20 m/s



Removing Poorest Individual Ensemble



- **Multi-model ensemble appears to provide better Reliability diagrams than individual ensembles**
 - Uses all ensemble contributions with equal weightings
- **A simple test of this strategy is to remove the least good individual ensemble from the mix**
 - The PEPS ensemble from DWD (GE) has very poor reliability and Brier Score (although good resolution)
- **Verification was re-run excluding GE from the combined ensemble:**

Combined Ensemble	Reliability Scores			ROC Area Scores		
	10 ms ⁻¹	15 ms ⁻¹	20 ms ⁻¹	10 ms ⁻¹	15 ms ⁻¹	20 ms ⁻¹
Including GE	0.00361	0.00133	0.00040	0.881	0.811	0.684
Excluding GE	0.00484	0.00159	0.00044	0.869	0.797	0.662

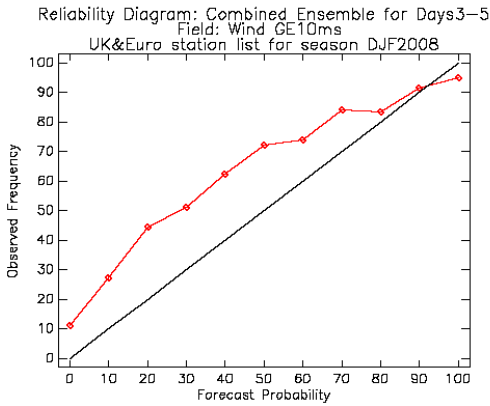
- **Combined scores were better including GE than excluding for both reliability and resolution**
 - Suggests that including all ensembles is beneficial



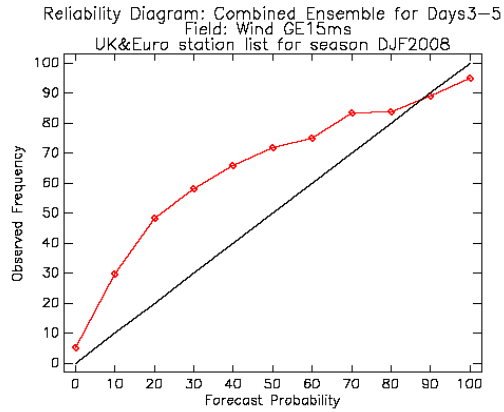
Verification of Combined Ensembles



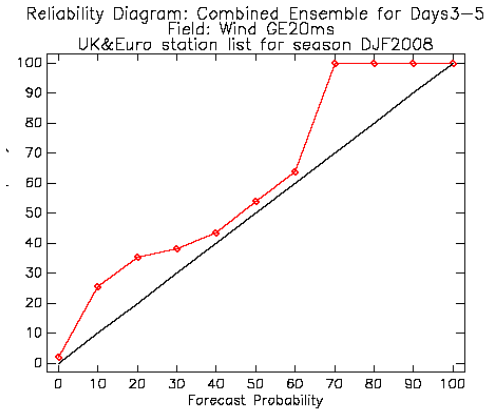
Reliability of combined multi-model ensemble days 3-5



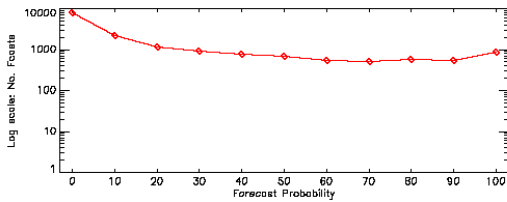
Cast type: RAW
Reliability Score: 0.0220484



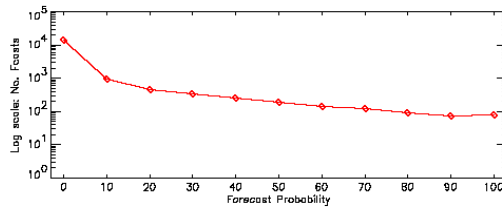
Cast type: RAW
Reliability Score: 0.0101862



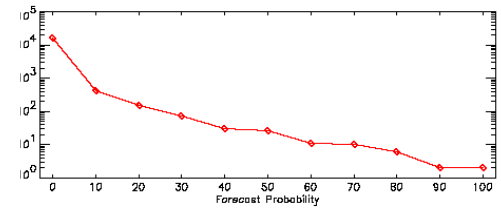
Cast type: RAW
Reliability Score: 0.00133613



Wind Speed > 10 m/s



> 15 m/s



> 20 m/s



Multi-model Tropical Cyclone Track products

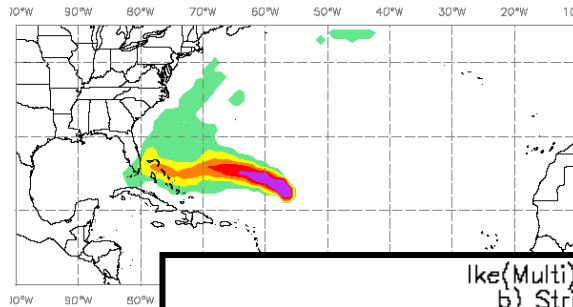


Ike - Sep 4th 2008 at 12Z

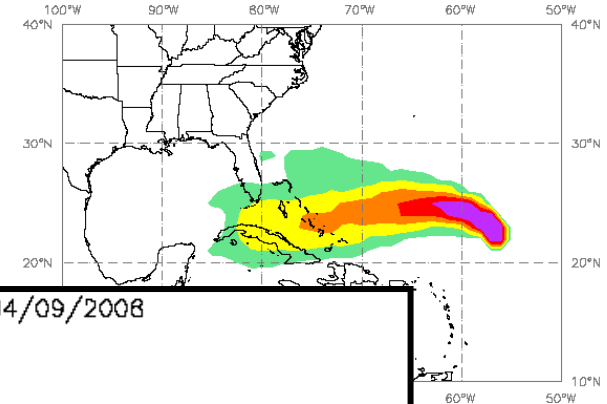
Met Office

- Multi-model EPS TC tracks developed for THORPEX T-PARC
- May be used for WMO SWFDP (Severe weather f/c demo project)
- Verification shows small benefit over ECMWF EPS

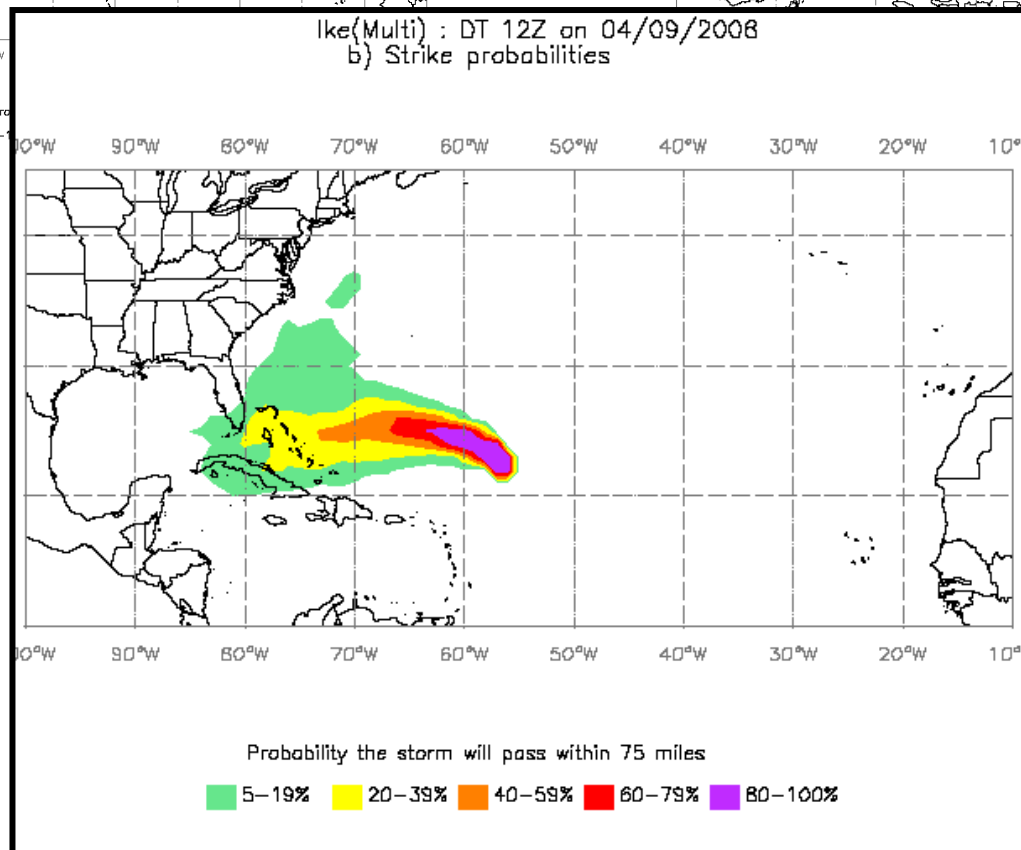
IKE(ukmo) : DT 12Z on 04/09/2008
b) Strike probabilities



Ike(ecmwf) : DT 12Z on 04/09/2008
b) Strike probabilities



Ike(Multi) : DT 12Z on 04/09/2008
b) Strike probabilities

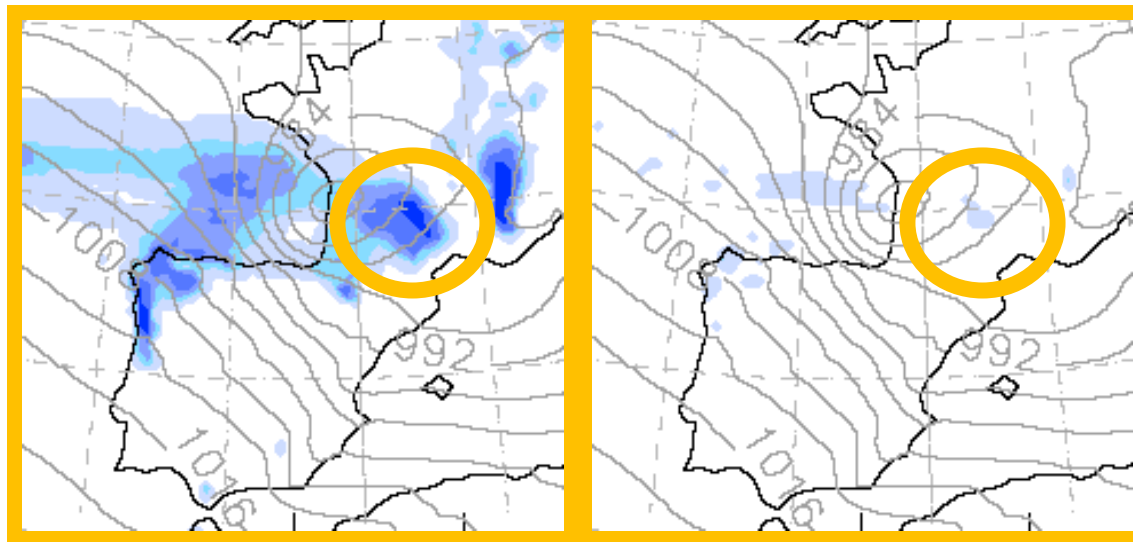




MOGREPS severe weather performance

Sat 24th Jan 2009 Probability Maps

Heavy rain was also a hazard in parts of SW France...



Heavy rain near Bergerac forecast at T+24h – flooding of River Dropt

NAE probability of 24-hour accumulated precipitation exceeding 25mm (left) and 50mm (right).

DT 06Z 23/01/2009, VT 06Z 24/01/2009, T+24h.

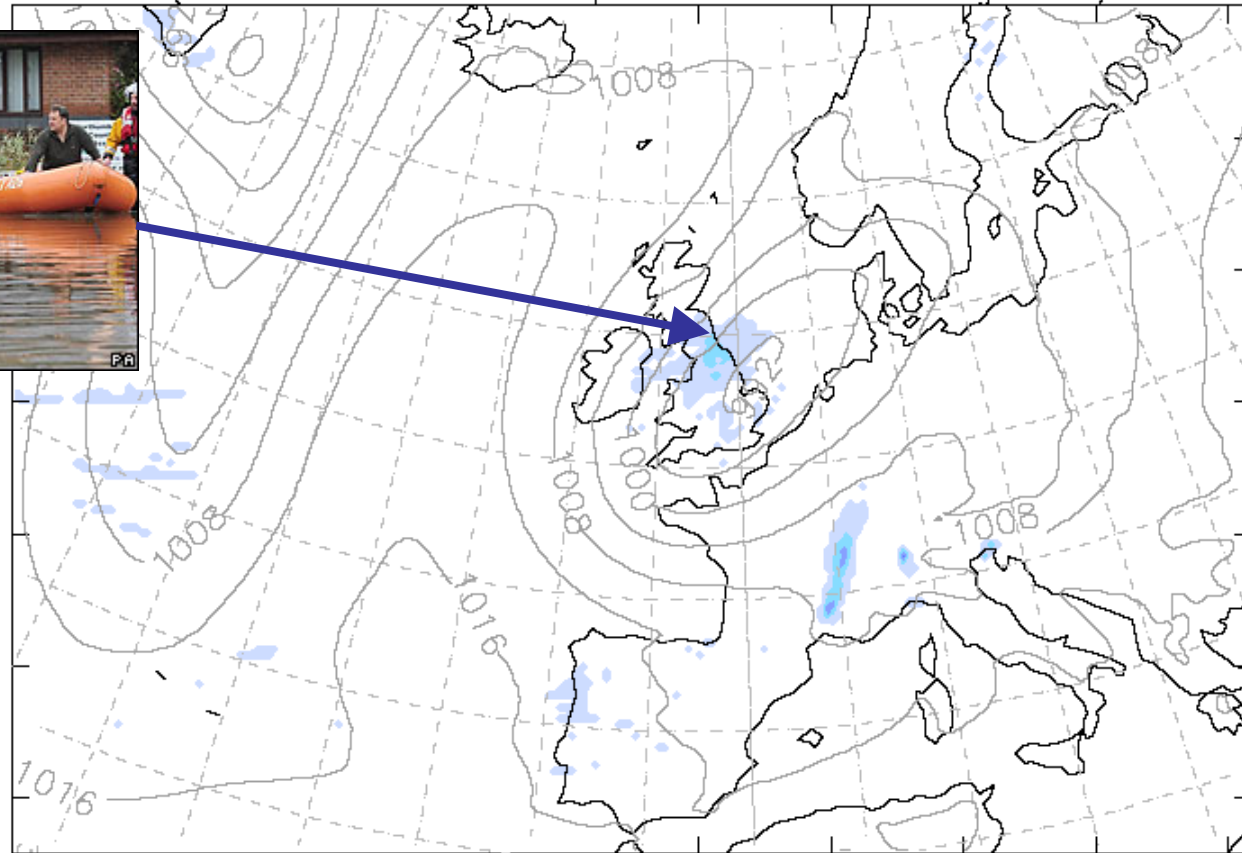


Prob >50mm in 24h 2-day forecast

MOGREPS (Regional) Probability map for 24HourPrecip > 50.0mm
DT 06Z on Thu 04/09/2008 VT 12Z on Sat 06/09/2008 lead time 54h
(Ensemble Mean PMSL plotted as faint background)



Morpeth



0.01

0.25

0.5

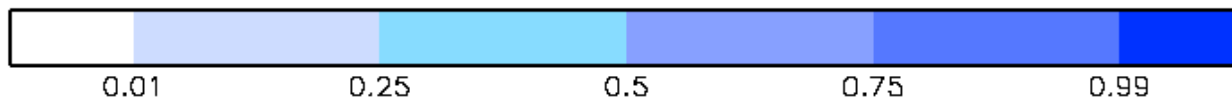
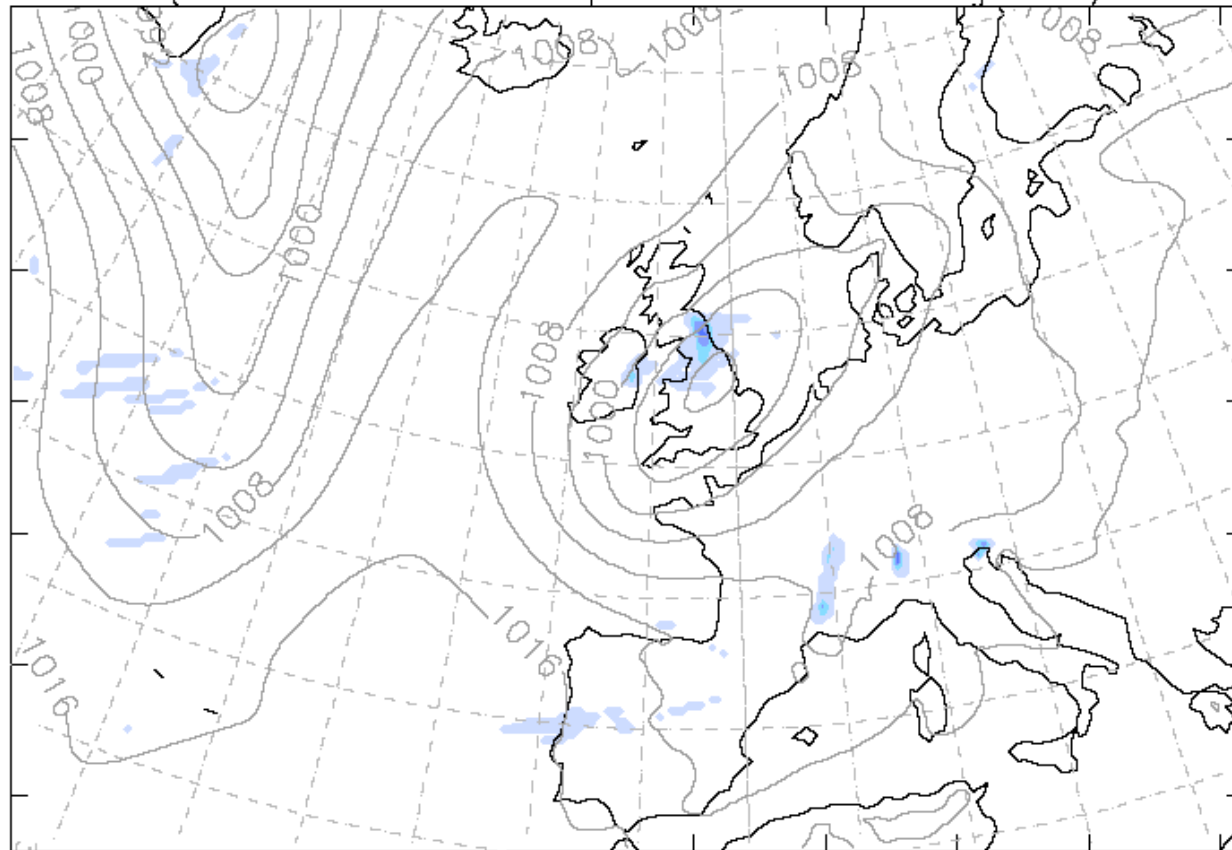
0.75

0.99



Prob >50mm in 24h 1-day forecast

MOGREPS (Regional) Probability map for 24HourPrecip > 50.0mm
DT 06Z on Fri 05/09/2008 VT 12Z on Sat 06/09/2008 lead time 30h
(Ensemble Mean PMSL plotted as faint background)



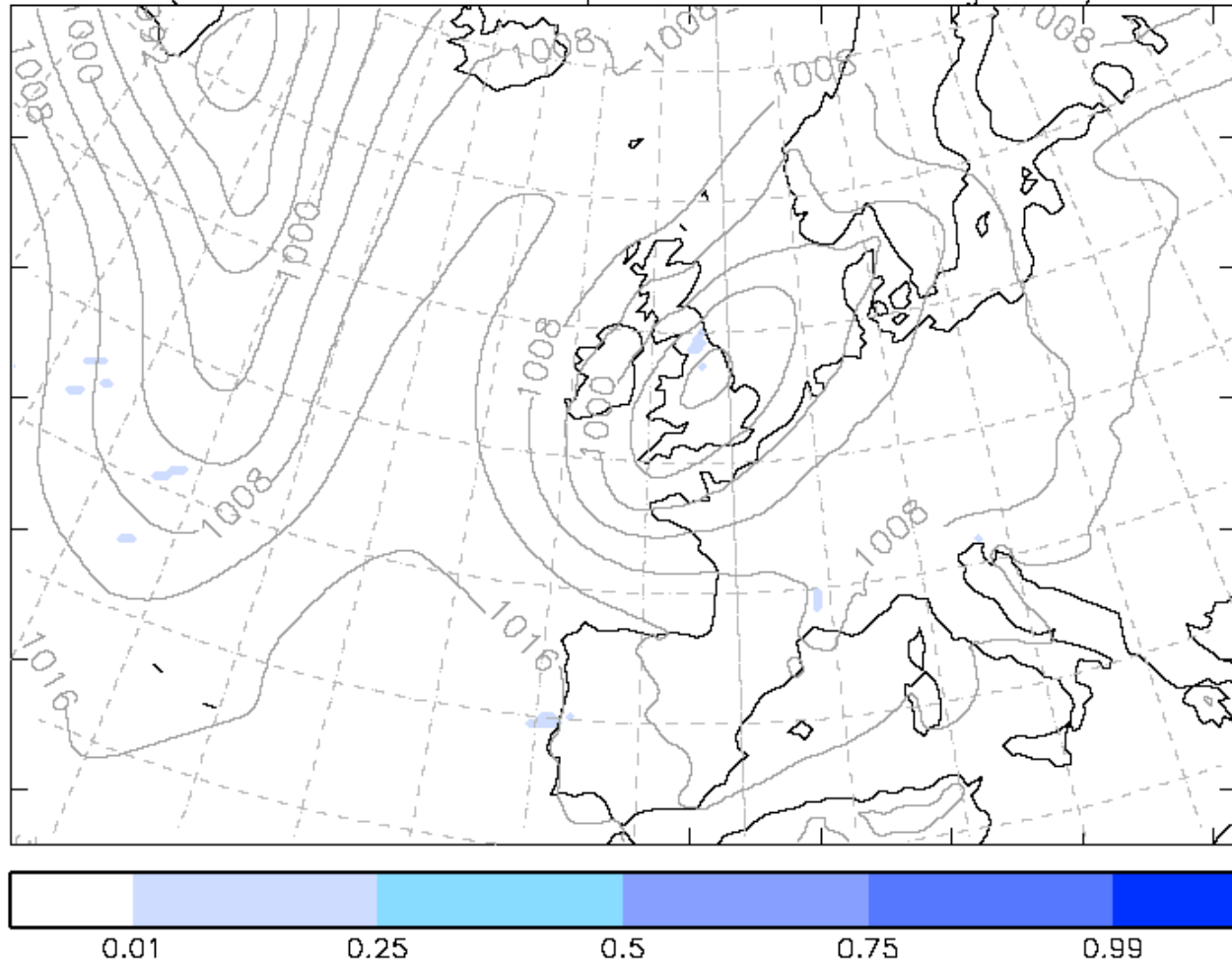


And even >100mm in 24h 1-day forecast

MOGREPS (Regional) Probability map for 24HourPrecip >100.0mm
DT 06Z on Fri 05/09/2008 VT 12Z on Sat 06/09/2008 lead time 30h
(Ensemble Mean PMSL plotted as faint background)

Product was not available operationally but has now been added

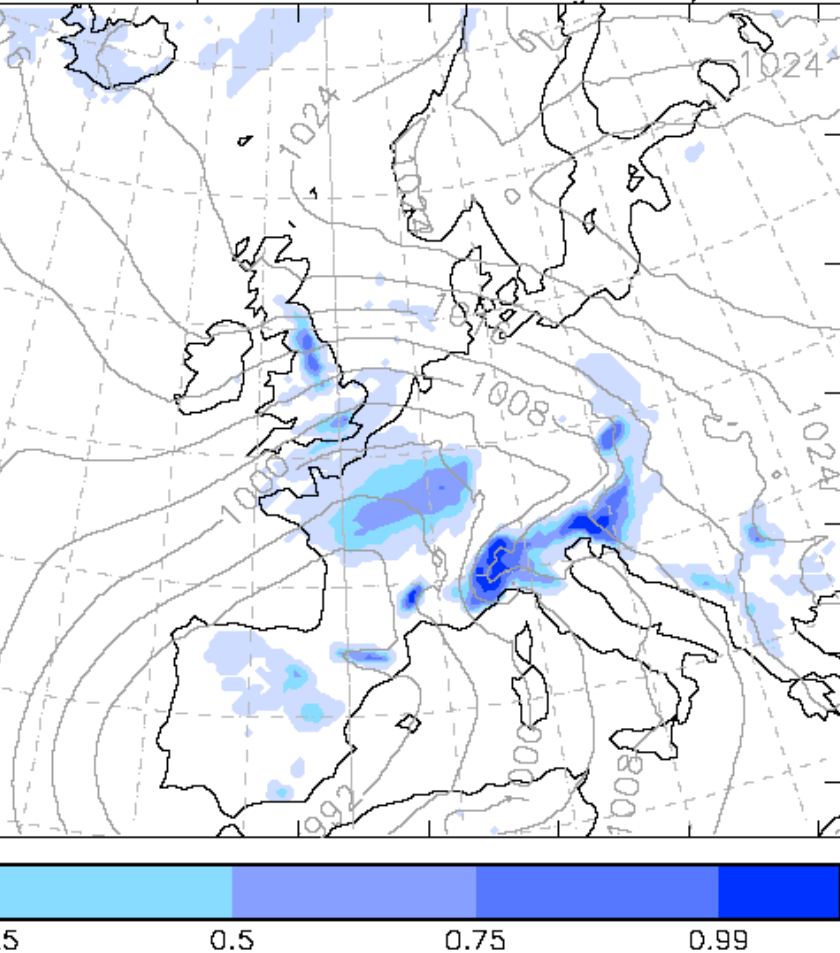
Forecast office reviewing warning process to use it





Snow on 2nd Feb 2009

Probability map for Snowfall6hr > 1.0(mm rain equiv.)
09 VT 06Z on Mon 02/02/2009 lead time 48h
(mean PMSL plotted as faint background)

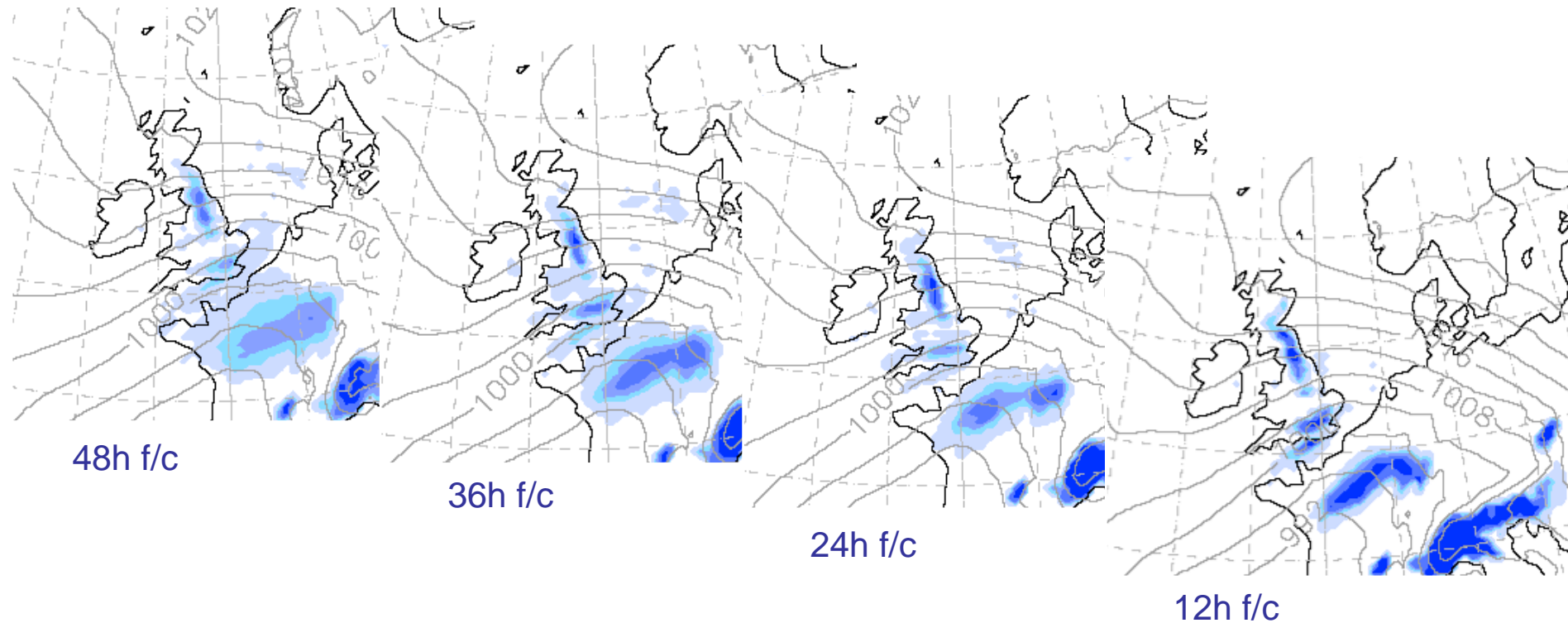


Heavy snow on Sun 1st and Mon 2nd Feb 2009, SE England. Reported to have been the most snow to affect this region for 18 years.

48h forecast valid 0600 on 2nd Feb gave good indication of areas at risk, but underestimated the quantity of snow.
This is Prob(>1cm/6h).
Prob(>5cm/6h) was less than 25%.

Probabilities for climatological extremes are often low.

Snow on 2nd Feb 2009



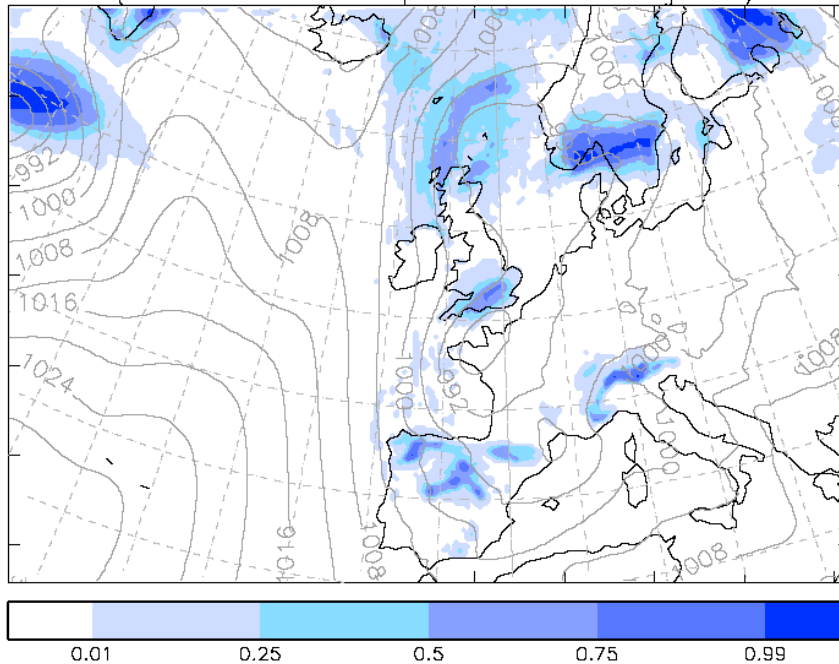
Managing risk – ensemble forecasts reduce the jumpiness of the forecast from run to run.

Not every case is as consistent as this but generally as an event gets nearer:

- Peak probabilities increase
- Area at risk converges on highest risk

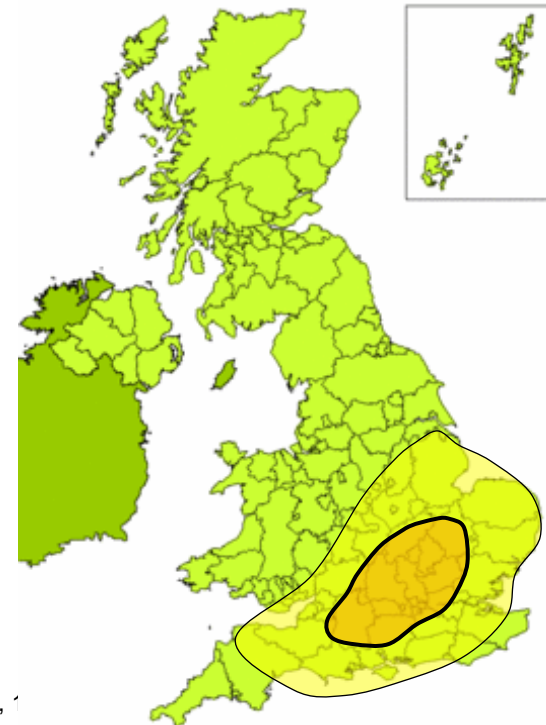
Risk of disruption due to snow on Friday Feb 6th 2009

MOGREPS (Regional) Probability map for Snowfall6hr > 1.0(mm rain equiv.)
 DT 06Z on Thu 05/02/2009 VT 09Z on Fri 06/02/2009 lead time 27h
 (Ensemble Mean PMSL plotted as faint background)



Outer bounded area (yellow)
 –mod risk of disruption
 2-5cm of snow, locally 5-10cm on high ground

Inner bounded area (orange)
 – high risk of disruption
 5-10cm of snow, locally 15-20cm on high ground



MOGREPS Prob(>1cm snow/6h)

Risk area on Met Office website



First-Guess Early Warnings

Severe weather warnings based on EPS

Recalibration 2008



First Guess Early Warnings

1st Feb 2009 at 12Z

Automatic severe weather probabilities based on ECMWF EPS help forecasters issue Early Warnings

RECOMMEND ISSUE OF A WARNING:

Probability % of event by region between 1200 02 FEB 2009 and 1800 03 FEB 2009 (T+ 24 to T+ 54)

Prob. of event occurring anywhere in the UK is 100%

Highland	20%
Grampian	20%
Cent/Tays/Fife	51%
Strathclyde	20%
Southern Scot	63%
NorthernIreland	33%
N.W. England	82%
N.E. England	61%
YorkshireHumber	94%
E.Midlands	94%
W.Midlands	94%
Wales	80%
S.W. England	82%
S.E. England	90%
EasternCounties	90%

One remaining area has a probability below 10%

Weather warnings

Severe weather warnings have been issued for the UK



Click on a map to see all warnings issued for the UK.



Met Office

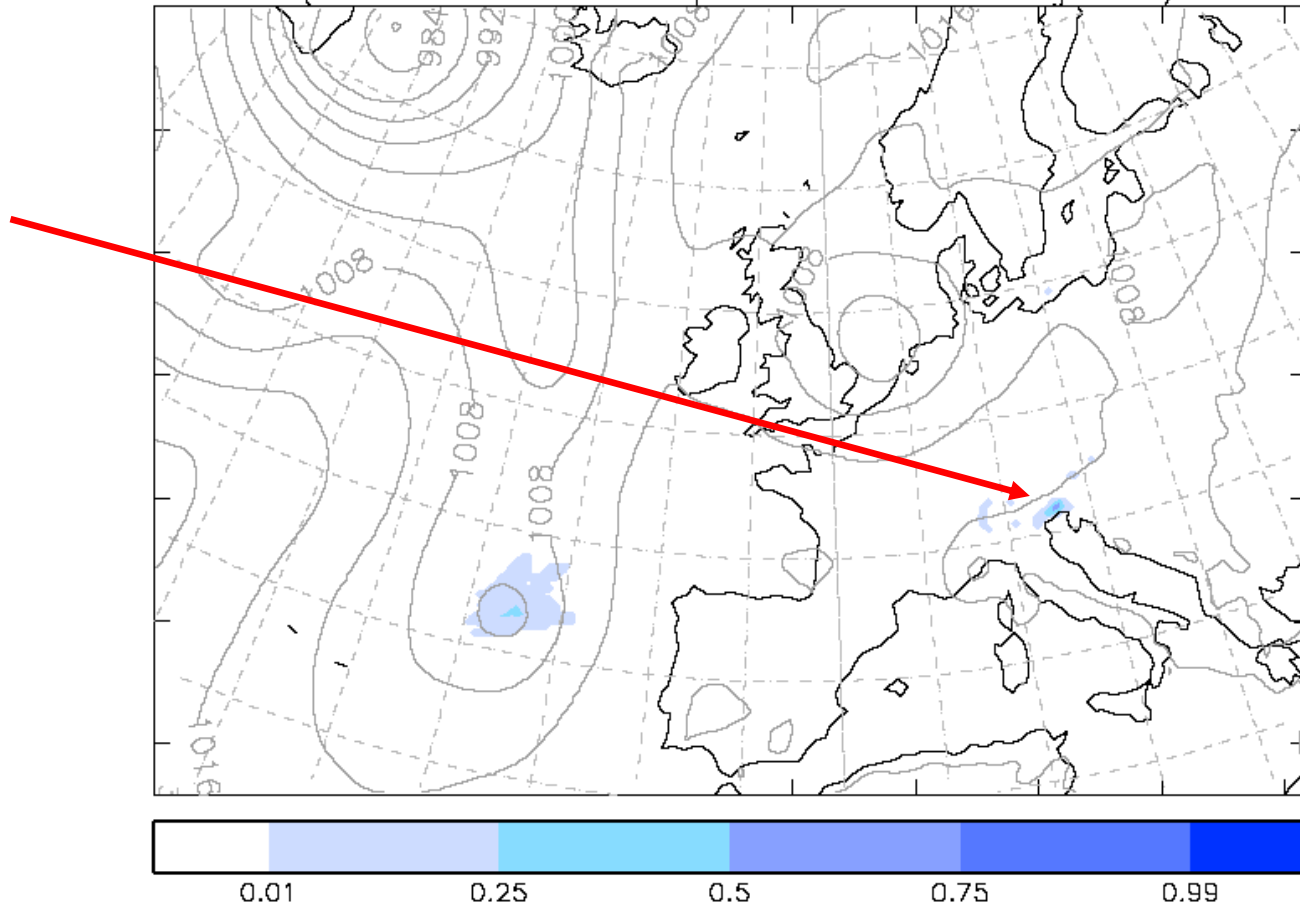
Microburst at USAF Aviano

- Sunday, 7th Sep, microburst at Aviano
- Reported wind speeds up to 200KM/h
 - windows blown out
 - numerous trees uprooted
 - Damage to homes



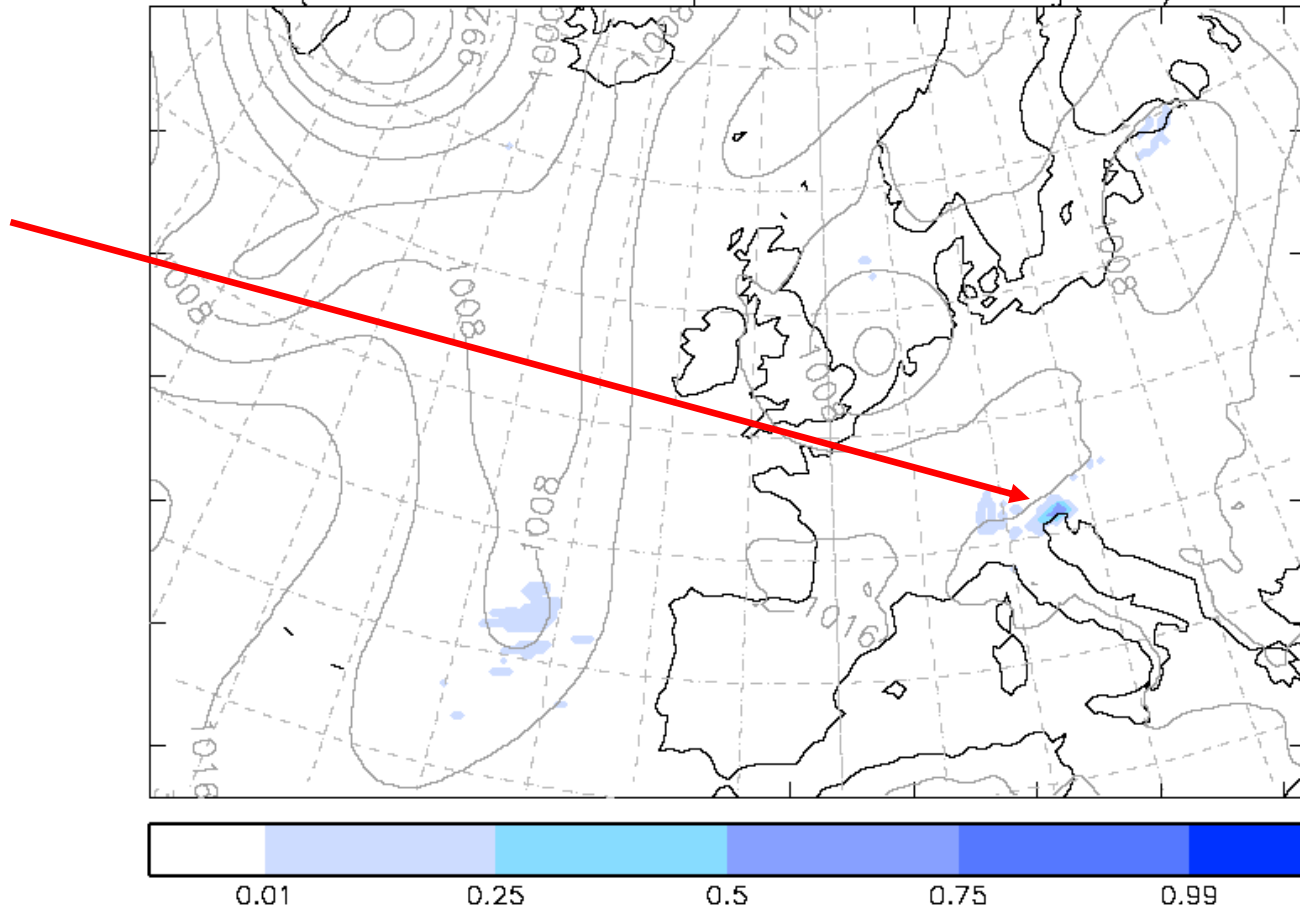
Prob 6h precip >30mm T+24

MOGREPS (Regional) Probability map for 6HourPrecip > 30.0mm
DT 18Z on Sat 06/09/2008 VT 18Z on Sun 07/09/2008 lead time 24h
(Ensemble Mean PMSL plotted as faint background)

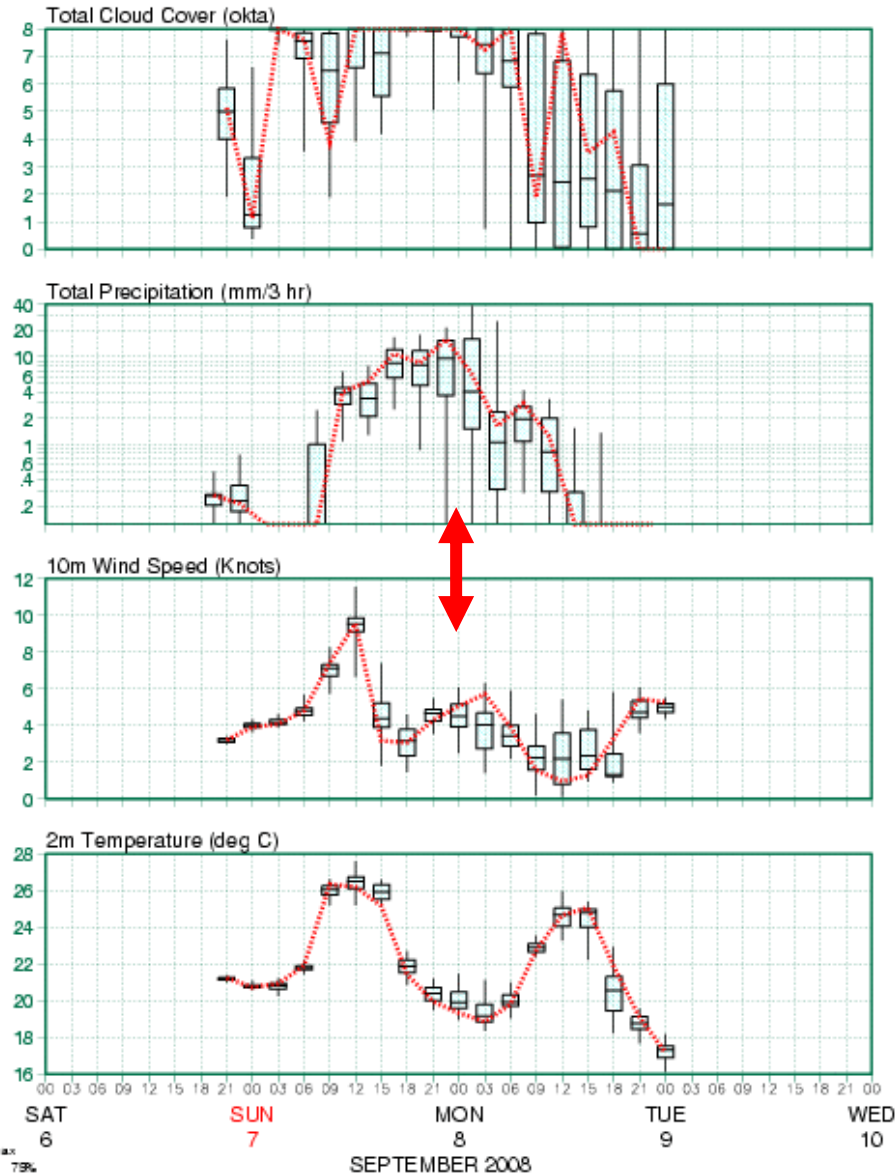


Prob 6h precip >30mm T+51

MOGREPS (Regional) Probability map for 6HourPrecip > 30.0mm
DT 18Z on Fri 05/09/2008 VT 21Z on Sun 07/09/2008 lead time 51h
(Ensemble Mean PMSL plotted as faint background)



- Meteogram for Trieste a short distance SE of Aviano
- Good signal for heavy rain
- No signal for wind
 - No convective gust algorithm

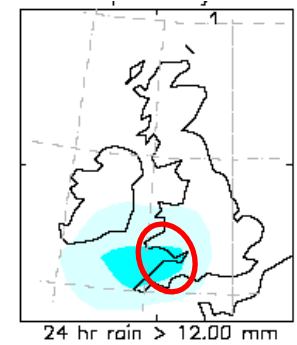
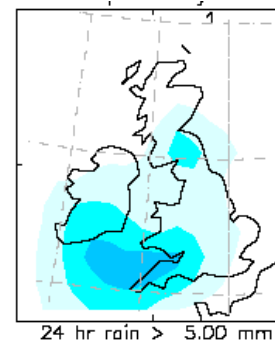
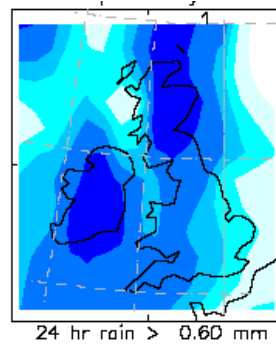
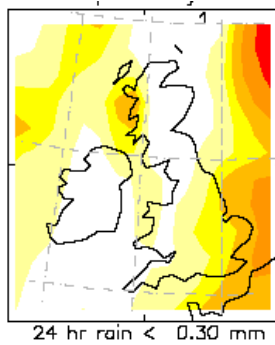


..... CTRL

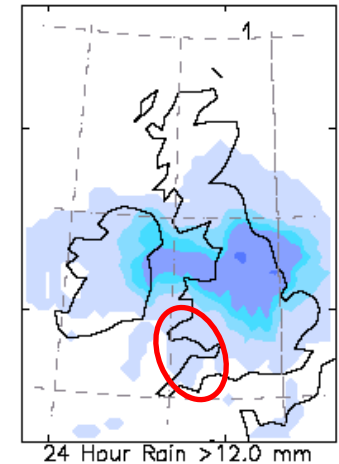
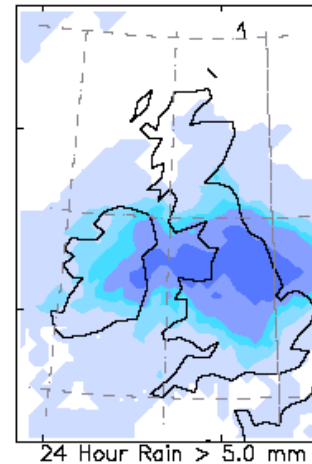
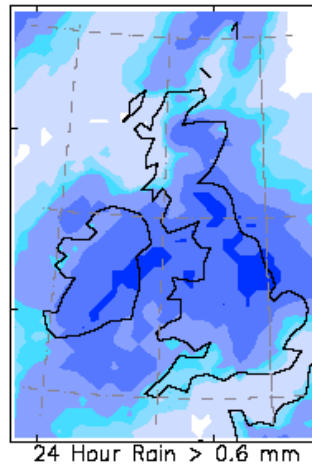
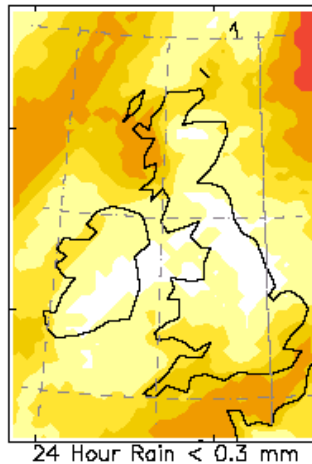


Heavy rain Devon & S. Wales Sat 6th June

ECMWF
1200 4th June



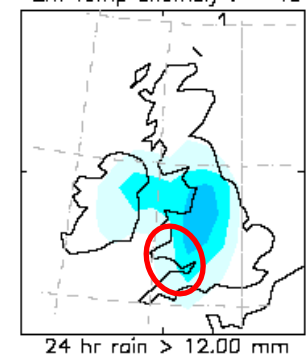
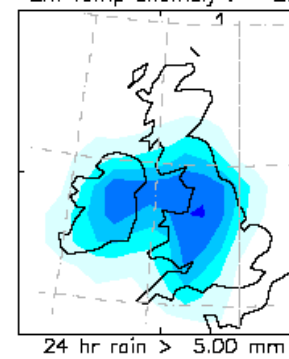
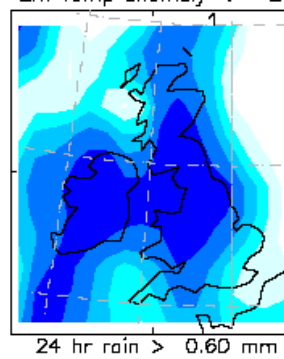
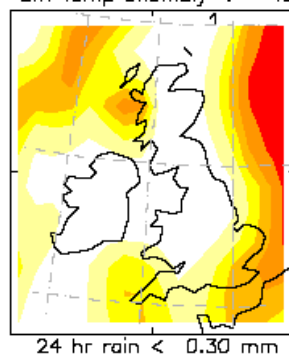
MOGREPS
1800 4th June



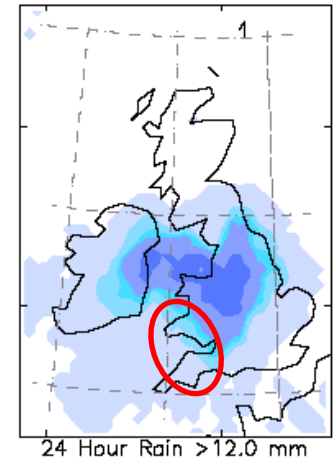
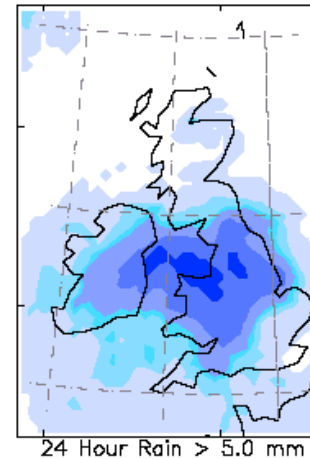
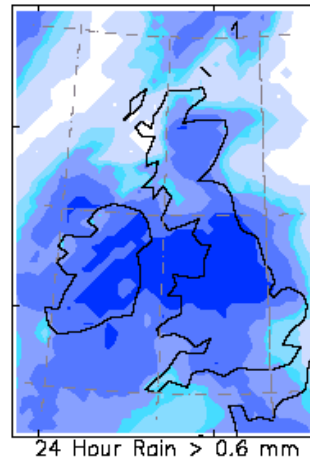
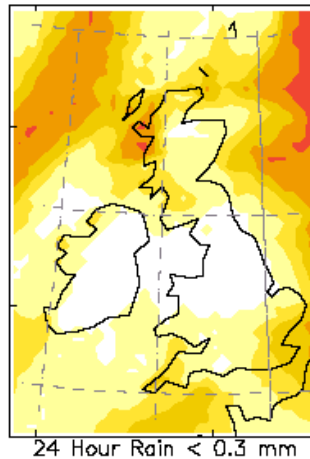


Heavy rain Devon & S. Wales Sat 6th June

ECMWF
0000 5th June



MOGREPS
0600 5th June

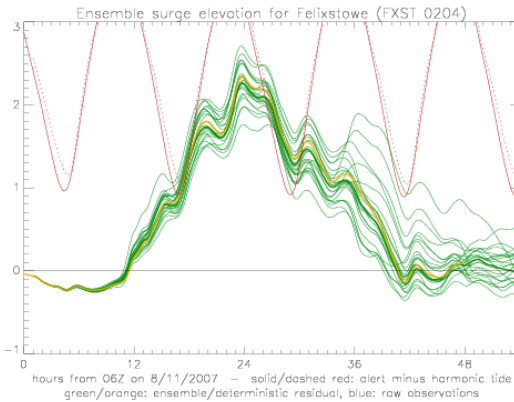




User requirements for ECMWF



Where are we going? Probabilities of impacts



- Storm surge ensemble – becoming operational
- Wave ensemble – feasibility demonstrated
- River flow ensembles – under development
- Strong wind impacts – demonstrated
 - Road vehicles
 - Power transmission lines
- Wind power output prediction – under development
- Convection-resolving models – in research
- Road icing – planned



Additional requirements from ECMWF EPS

- More parameters to allow generation of user products:
 - More detail on cloud including low cloud amount and height
 - Visibility diagnostic
 - Winds at heights above surface in PBL:
 - Model levels up to ~925hPa
 - Allows estimation of hub-height winds for wind power
 - Gust estimation parameters for forecasters
- Website products for CAPE and gusts (925hPa winds)



Summary

- PREVIEW Windstorms has demonstrated the value of multi-model ensembles
- Multi-model ensembles also beneficial for Tropical cyclones
- MOGREPS forecasts give forecasters confidence in severe weather forecasting
 - Run-to-run consistency build confidence
 - But ... longer-lead forecasts can still sometime be better for both MOGREPS and ECMWF EPS
- Increasing requirement for more weather variables to meet customer impact requirements