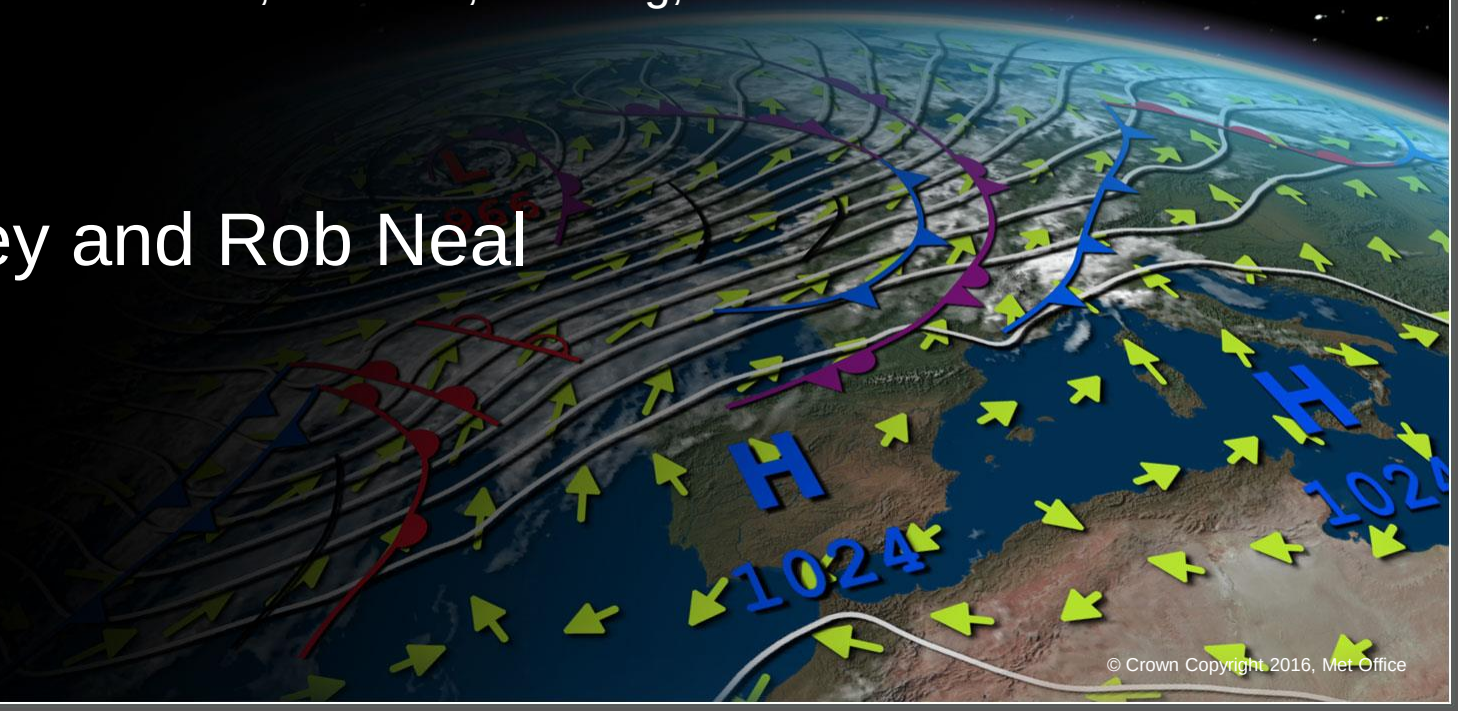
Processing ECMWF ENS and MOGREPS-G ensemble forecasts to highlight the probability of severe extra-tropical cyclones: Storm Doris

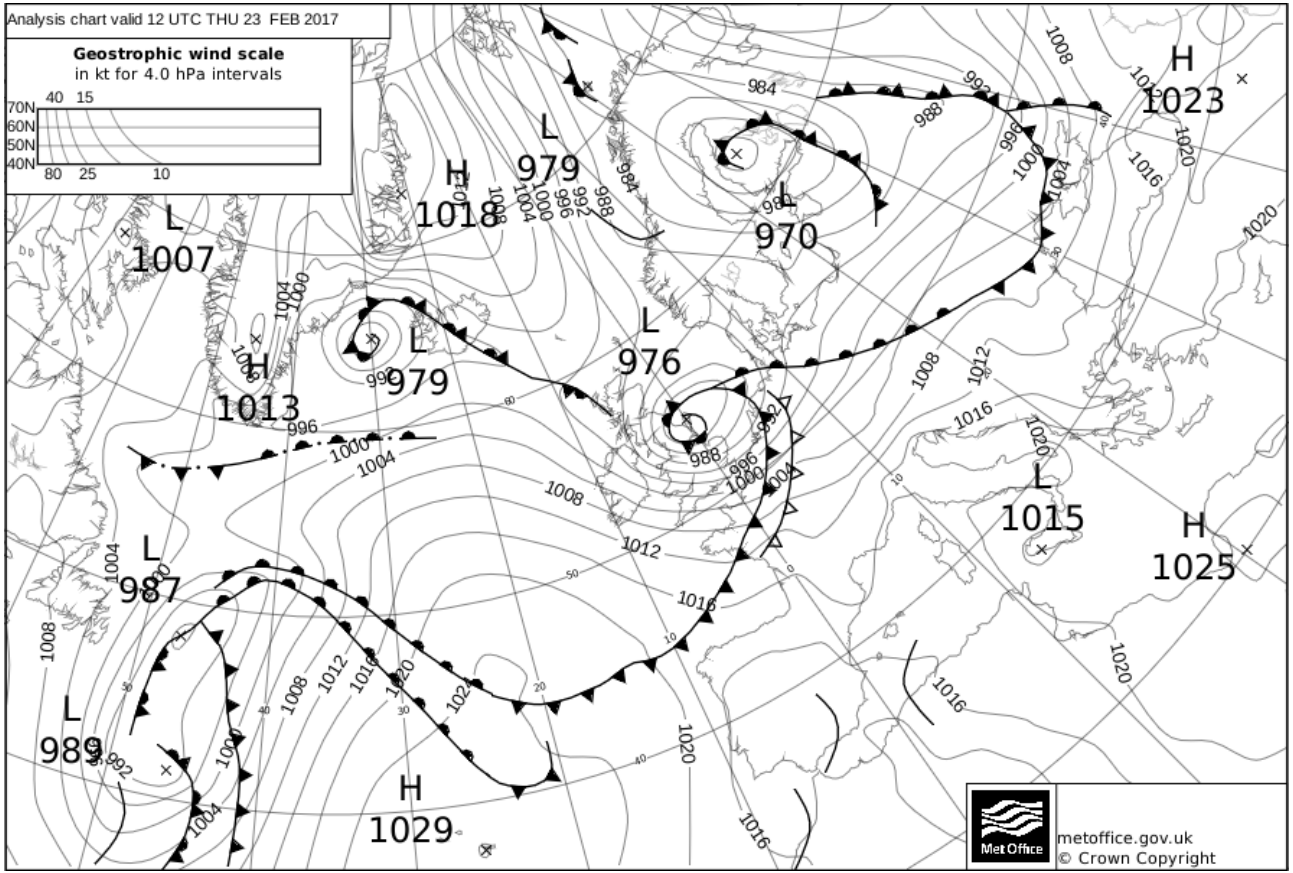
UEF 2017, 12-16 June 2017, ECMWF, Reading, U.K.

Helen Titley and Rob Neal



Storm Doris: Feb 23rd 2017: EUMETSAT Meteosat-9 Rapid Scan Service images and NASA blue marble imagery

Analysis chart for 12Z on 23rd February 2017



Impacts

- 3 deaths (in Shropshire, Wolverhampton, Swindon), and many injuries due to fallen trees, masonry, and traffic accidents
- Severe disruption to road, rail, sea and air travel
- Failures in power supply to around 50,000 homes
- Also caused disruption and damage in the Netherlands and Germany (named as windstorm Thomas)
- Latest combined damage estimates of around €250 million

Our global ensemble-based tools for forecasting severe extra-tropical cyclones

Decider weather regimes

Global Hazard Map

Cyclone Database

Postage stamps

EPS-W first guess warnings

Wind gust, precip and snow probabilities

ECMWF ENS & MOGREPS-G

- Twice a day
- 51 members
- Out to 15 days
- Resolution c.18km

- 4 times a day
- 24 members (time-lagged) (36)
- Out to 7 days
- Resolution c.33km (20km)

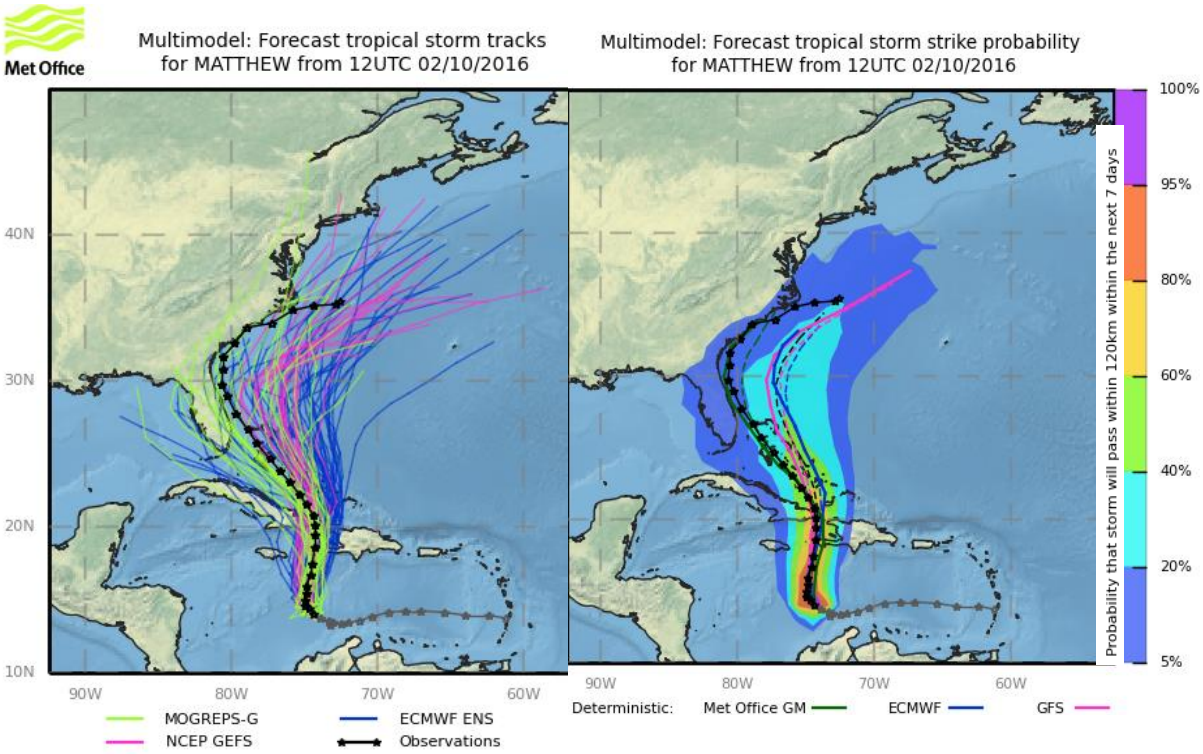
- Matsueda and Tanaka, 2008
- Park et al., 2008
- Johnson and Swinbank, 2009
- Candille, 2009
- Yamaguchi et al., 2012
- Hagedorn et al., 2012
- Hamill, 2012
- Matsueda and Nakazawa, 2015
- Swinbank et al. 2016)

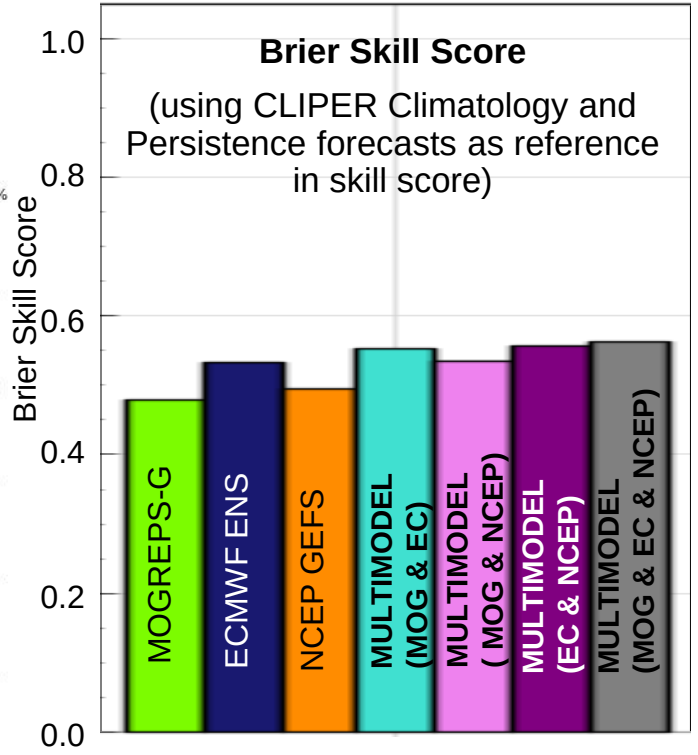
Multi-model ensemble of 96 (108) members

NCEP GEFS

- Twice a day
- 21 members
- Out to 10 days
- Resolution c.33km

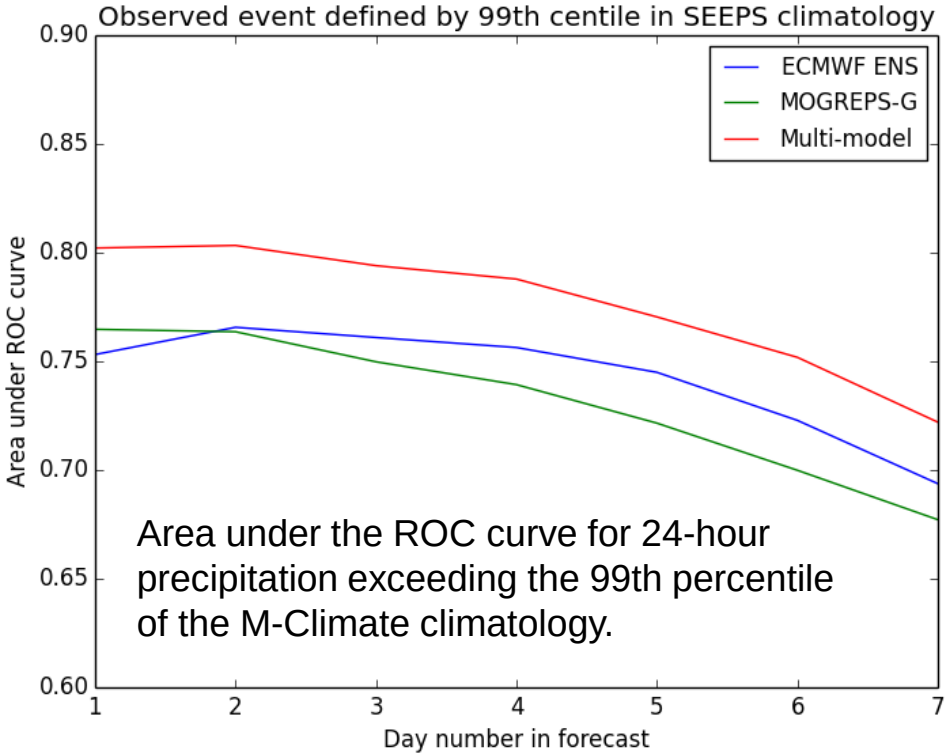
Benefits of multi-model ensemble
Recent verification: TCs





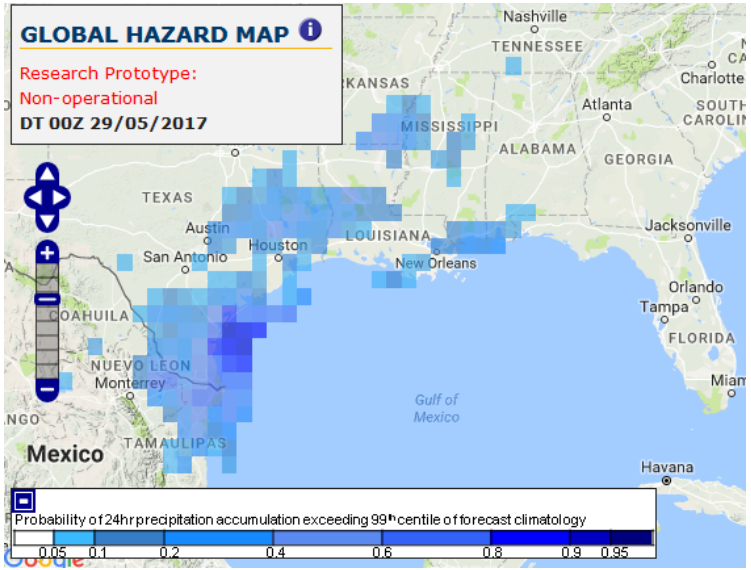
Tropical Cyclone strike probability for named storms during 2016

Benefits of multi-model ensemble: Recent verification: Global Hazard Map precipitation forecasts



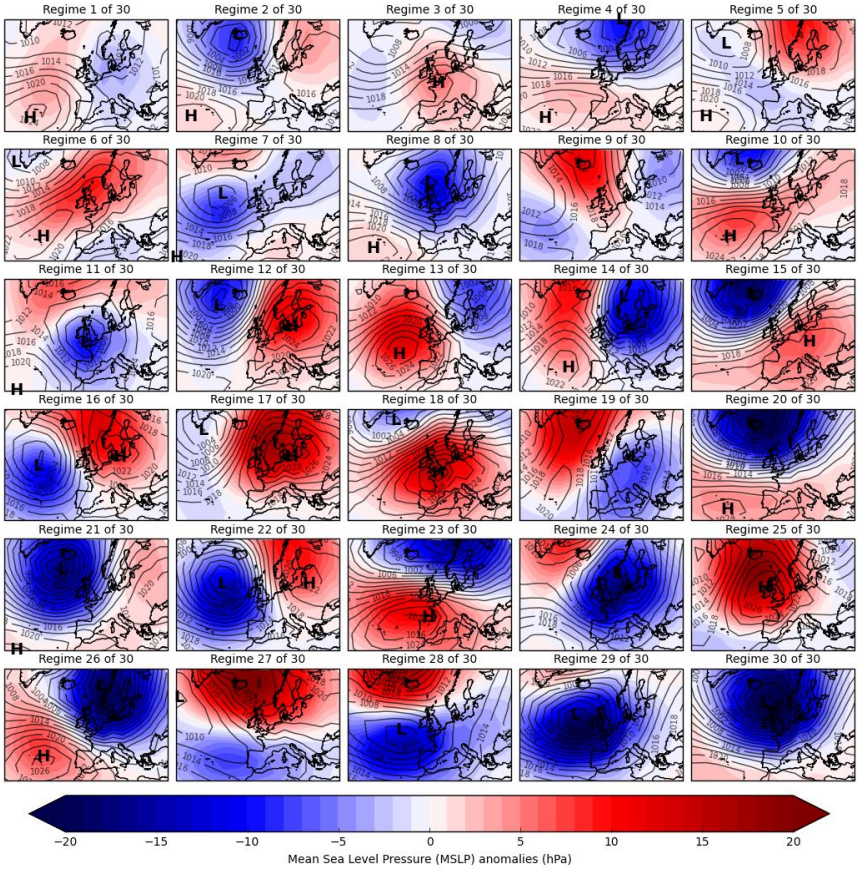
Area under the ROC curve for 24-hour precipitation exceeding the 99th percentile of the M-Climate climatology.

Verification against station-based observations (observed event defined by the 99th percentile in the SEEPS climatology)



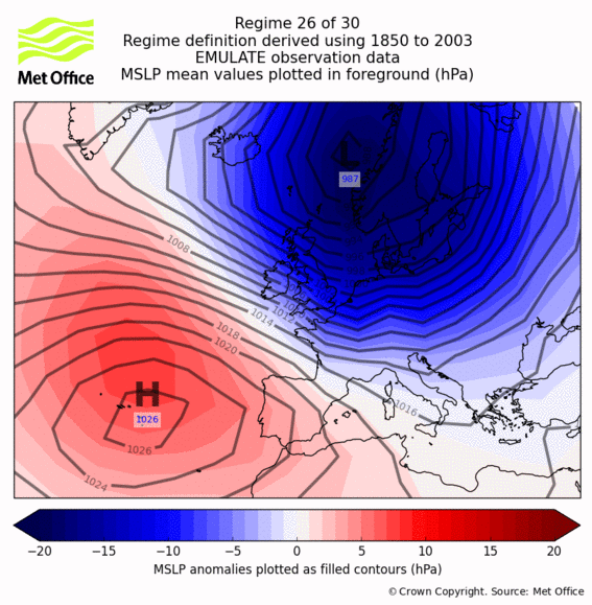
Decider weather regime forecasts

Weather regime definition maps

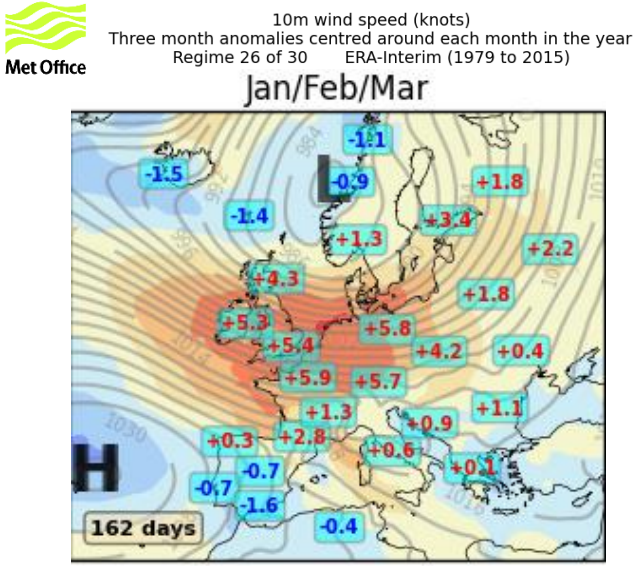


- Objectively derived by clustering 154 years of daily MSLP data
- Defined in terms of their MSLP anomalies (red and blue shading)
- Definitions remain static throughout the year
- Lower numbered regimes have weaker MSLP anomalies and occur more in summer
- Higher numbered regimes have stronger MSLP anomalies and occur more in winter
- Regimes are ordered according to their mean annual occurrence (most common → least common)

Weather regime 26 was observed on 23rd February, which is one of the more stormy types

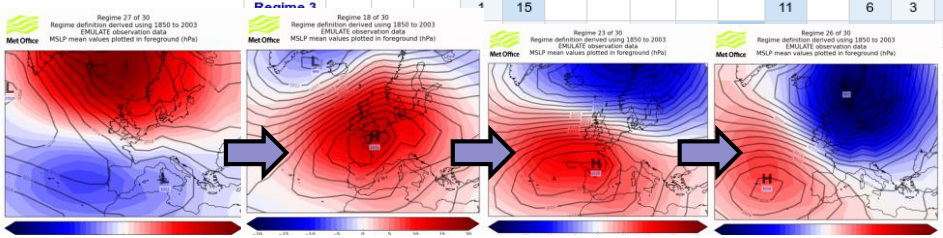


Static regime definition map (MSLP anomalies)



12Z 10m wind gust anomalies (knots) for Jan, Feb and March

Decider forecast summary for Multi-model ensemble (ECMWF, MOGREPS-G and NCEP GEFS): 00Z run 13th February 2017



Anticyclonic Ely, high in Norwegian Sea

Anticyclonic SWly, high over N France

Unbiased Wly, windy in N

Cyclonic NWly, low near Norway, windy

	Mon 13 Feb	Tue 14 Feb	Wed 15 Feb	Thu 16 Feb	Fri 17 Feb	Sat 18 Feb	Sun 19 Feb	Mon 20 Feb	Tue 21 Feb	Wed 22 Feb	Thu 23 Feb	Fri 24 Feb	Sat 25 Feb	Sun 26 Feb	Mon 27 Feb	Regime Descriptions (UK)	Historic Occurrence J/F/M
Regime 1											1		6		1	Unbiased NWly	1.9%
Regime 2												1	1	1	3	Cyclonic SWly, returning Pm airmass	2.5%
Regime 3				1	15						11		6	3	6	Anticyclonic SWly, ridge over N France	1.9%
Regime 4															4	Unbiased Wly	2.4%
Regime 5																Unbiased Sly, high over Scandinavia	2.3%
Regime 6															3	Anticyclonic, Azores high ext.	3.1%
Regime 7															3	Cyclonic SWly, low WNW of Ireland	2.6%
Regime 8															1	Cyclonic Wly, low near Shetland	2.6%
Regime 9															3	Anticyclonic N-NEly, high near Iceland	2.3%
Regime 10																Anticyclonic W-SWly, slight Azores ridge	3.1%
Regime 11																Cyclonic, low centred over southern UK	2.5%
Regime 12																Anticyclonic Sly, high over Poland	3.9%
Regime 13																Anticyclonic NWly, high SW of Ireland	3.8%
Regime 14																Cyclonic N-NWly, low near S Sweden	3.6%
Regime 15					1					3	1	8	3	6	7	Unbiased SWly, very windy NW Britain	4.5%
Regime 16																Anticyclonic S-SEly, high E of Denmark	3.2%
Regime 17		100	63												1	Anticyclonic E-SEly high over Denmark	4.0%
Regime 18			38	99	67	7	5	1	1	3	4	4			1	Anticyclonic SWly, high over N France	5.0%
Regime 19															1	Unbiased Nly, low E of Denmark	3.8%
Regime 20								1	4	8	10	10	13	6	11	Cyclonic Wly, intense low near Iceland	4.4%
Regime 21											1	3	7	4		Cyclonic SWly, deep low S of Iceland	3.5%
Regime 22															1	Cyclonic Sly, low W of Ireland	3.5%
Regime 23					13	66	74	78	53	19	8	7	4		6	Unbiased Wly, windy in N	5.0%
Regime 24											1	1	3	6	8	Cyclonic Nly, low in N Sea	3.3%
Regime 25																Anticyclonic Nly, high centre Irish Sea	3.9%
Regime 26								0	17	19	17	21	13	10	13	Cyclonic NWly, low near Norway, windy	3.4%
Regime 27	100															Anticyclonic Ely, high in Norwegian Sea	3.8%
Regime 28													1			Cyclonic SEly, low SW of UK	3.9%
Regime 29											1	1			1	Cyclonic S-SWly, deep low W of Ireland	3.3%
Regime 30										1	3	8	11	14	11	Cyclonic W-SWly, deep low SE of Iceland	2.9%
Total Members	96	96	96	96	96	96	96	72	72	72	72	72	72	72	72	---	---

Good signal for transition to stormy regime 10 days ahead of Doris

- Ensemble members are assigned to the closest matching regime definition
- Summarises key aspects from the large volumes of data ensembles provide
- Understanding regime characteristics makes it easy to interpret forecast output and describe likely consequences

Decider forecast summary table
ECMWF 00Z run 13th February 2017

	Mon 13 Feb	Tue 14 Feb	Wed 15 Feb	Thu 16 Feb	Fri 17 Feb	Sat 18 Feb	Sun 19 Feb	Mon 20 Feb	Tue 21 Feb	Wed 22 Feb	Thu 23 Feb	Fri 24 Feb	Sat 25 Feb	Sun 26 Feb	Mon 27 Feb	Regime Descriptions (UK)	10mWind anomalies J/F/M
Regime 17		100	33												2	Anticyclonic E-SEly high over Denmark	-4.4 **-1.6** +1.9
Regime 18			67	98	45		2	2	2		4				2	Anticyclonic SWly, high over N France	-4.5 **-1.6** +1.8
Regime 5														2		Unbiased Sly, high over Scandinavia	-4.8 **-1.3** +3.3
Regime 6														2		Anticyclonic, Azores high ext.	-4.8 **-1.2** +2.4
Regime 12												6	2		2	Anticyclonic Sly, high over Poland	-4.1 **-1.2** +2.2
Regime 16																Anticyclonic S-SEly, high E of Denmark	-5.0 **-1.1** +2.6
Regime 25																Anticyclonic Nly, high centre Irish Sea	-4.2 **-1.1** +2.9
Regime 9															4	Anticyclonic N-NEly, high near Iceland	-4.8 **-1.0** +3.4
Regime 10						10	12				2	2		4		Anticyclonic W-SWly, slight Azores ridge	-4.4 **-1.0** +2.9
Regime 3				2	24						6		4		4	Anticyclonic SWly, ridge over N France	-4.6 **-0.9** +3.3
Regime 1											2		8		2	Unbiased NWly	-4.7 **-0.8** +2.7
Regime 2												2	2	2	2	Cyclonic SWly, returning Pm airmass	-4.3 **-0.7** +3.2
Regime 28													2			Cyclonic SEly, low SW of UK	-4.4 **-0.7** +3.2
Regime 7											8	6	6	12	4	Cyclonic SWly, low WNW of Ireland	-4.3 **-0.6** +2.4
Regime 22															2	Cyclonic Sly, low W of Ireland	-4.0 **-0.4** +3.0
Regime 24												2	4	4	8	Cyclonic Nly, low in N Sea	-4.0 **-0.4** +3.7
Regime 11																Cyclonic, low centred over southern UK	-3.9 **-0.3** +3.7
Regime 27	100															Anticyclonic Ely, high in Norwegian Sea	-4.0 **-0.1** +3.8
Regime 8												4	2	2		Cyclonic Wly, low near Shetland	-4.8 **0.0** +4.5
Regime 15										2	2	8		8	6	Unbiased SWly, very windy NW Britain	-3.7 **0.0** +3.5
Regime 19																Unbiased Nly, low E of Denmark	-3.8 **+0.2** +4.4
Regime 13					6	10	12	8	12	14	6	4	2	6	6	Anticyclonic NWly, high SW of Ireland	-3.2 **+0.3** +4.0
Regime 29											2	2			2	Cyclonic S-SWly, deep low W of Ireland	-4.0 **+0.3** +4.7
Regime 4					2	4			8	24	14	4	12	12	4	Unbiased Wly	-3.6 **+0.8** +4.6
Regime 14								2	6	18	18	14	14	14	8	Cyclonic N-NWly, low near S Sweden	-3.1 **+1.0** +5.2
Regime 23					24	76	75	75	51	20	4	2	2		8	Unbiased Wly, windy in N	-3.0 **+1.0** +4.7
Regime 21											2	4	10	6		Cyclonic SWly, deep low S of Iceland	-3.5 **+1.1** +5.3
Regime 30										2	4	8	10	16	12	Cyclonic W-SWly, deep low SE of Iceland	-3.1 **+1.8** +5.8
Regime 20								2	2	4	6	10	10	2	14	Cyclonic Wly, intense low near Iceland	-1.9 **+2.0** +5.8
Regime 26								12	20	18	22	24	12	10	10	Cyclonic NWly, low near Norway, windy	-2.3 **+2.1** +6.3
Total Members	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	---	---

Ordering weather regimes according to their ERA-interim wind speed anomalies shows a transition to windier weather types. Regime 26 is in fact the windiest weather regime over the UK in February.

Decider forecast circulation trends
ECMWF 00Z run 13th February 2017

1) Probabilistic pressure trend over UK (30 regimes)

	Mon 13 Feb	Tue 14 Feb	Wed 15 Feb	Thu 16 Feb	Fri 17 Feb	Sat 18 Feb	Sun 19 Feb	Mon 20 Feb	Tue 21 Feb	Wed 22 Feb	Thu 23 Feb	Fri 24 Feb	Sat 25 Feb	Sun 26 Feb	Mon 27 Feb
00Z Mon 13 Feb 2017	100%	100%	100%	100%	75%	80%	75%	75%	59%	45%	61%	75%	71%	67%	61%
12Z Sun 12 Feb 2017	100%	100%	100%	100%	61%	80%	80%	65%	53%	43%	55%	63%	78%	76%	71%
00Z Sun 12 Feb 2017	100%	100%	100%	100%	65%	80%	63%	59%	51%	43%	39%	49%	69%	71%	
12Z Sat 11 Feb 2017	100%	100%	100%	100%	78%	59%	51%	49%	59%	43%	47%	69%	61%	55%	
00Z Sat 11 Feb 2017	100%	100%	100%	100%	76%	45%	43%	47%	41%	--	45%	67%	67%		
12Z Fri 10 Feb 2017	100%	100%	100%	100%	75%	--	39%	51%	57%	65%	67%	75%	75%		
00Z Fri 10 Feb 2017	100%	100%	100%	100%	75%	39%	45%	--	--	55%	61%	63%			
12Z Thu 9 Feb 2017	100%	100%	100%	100%	69%	47%	53%	65%	57%	63%	61%	73%			
00Z Thu 9 Feb 2017	100%	100%	100%	96%	84%	37%	49%	47%	49%	45%	43%				
12Z Wed 8 Feb 2017	100%	96%	96%	94%	61%	53%	63%	61%	63%	53%	61%				
00Z Wed 8 Feb 2017	100%	100%	100%	98%	78%	53%	45%	39%	43%	63%					

RED	Anticyclonic conditions most likely
GREEN	Unbiased conditions most likely
BLUE	Cyclonic conditions most likely
WHITE	Equal likelihood of two or three of the above tendencies occurring

Left: the probabilistic pressure trend is consistent over several runs at signalling a breakdown in the anticyclonic (blocked) conditions with a return to cyclonic conditions towards the end of the forecast period.

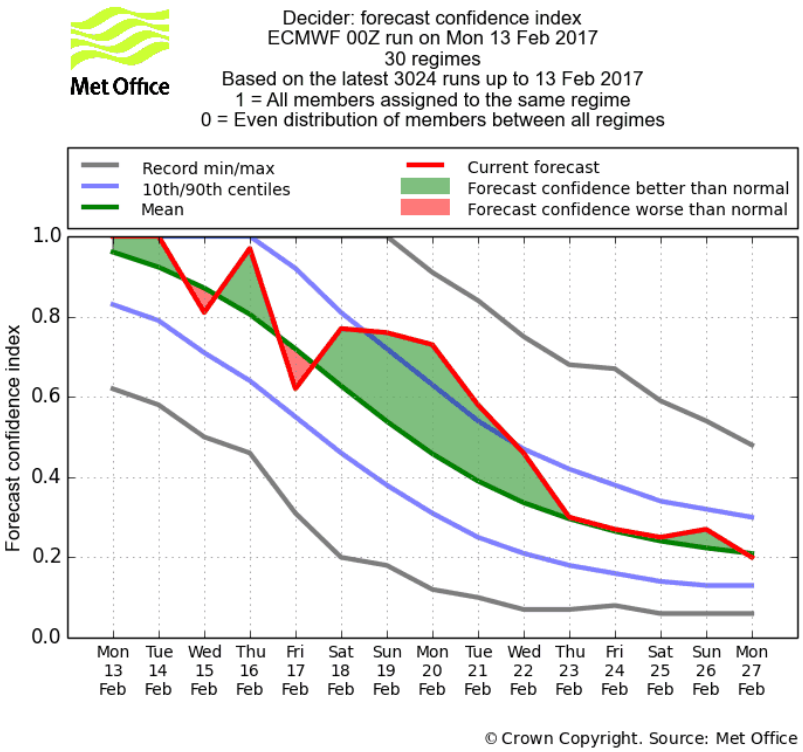
2) Probabilistic zonal trend over UK (30 regimes)

	Mon 13 Feb	Tue 14 Feb	Wed 15 Feb	Thu 16 Feb	Fri 17 Feb	Sat 18 Feb	Sun 19 Feb	Mon 20 Feb	Tue 21 Feb	Wed 22 Feb	Thu 23 Feb	Fri 24 Feb	Sat 25 Feb	Sun 26 Feb	Mon 27 Feb
00Z Mon 13 Feb 2017	100%	100%	67%	100%	100%	100%	100%	100%	100%	100%	100%	92%	92%	92%	82%
12Z Sun 12 Feb 2017	100%	100%	67%	100%	100%	100%	100%	100%	100%	96%	90%	92%	80%	82%	84%
00Z Sun 12 Feb 2017	100%	100%	65%	100%	98%	98%	100%	100%	100%	96%	86%	84%	84%	80%	
12Z Sat 11 Feb 2017	100%	100%	84%	98%	98%	100%	100%	100%	98%	96%	90%	86%	88%	82%	
00Z Sat 11 Feb 2017	100%	100%	86%	100%	98%	98%	98%	100%	98%	96%	94%	86%	92%		
12Z Fri 10 Feb 2017	100%	100%	96%	88%	80%	92%	94%	96%	100%	100%	100%	90%	88%		
00Z Fri 10 Feb 2017	100%	100%	96%	76%	92%	98%	100%	98%	98%	100%	100%	98%			
12Z Thu 9 Feb 2017	100%	100%	92%	45%	73%	90%	92%	88%	92%	96%	100%	94%			
00Z Thu 9 Feb 2017	100%	100%	92%	35%	57%	88%	94%	98%	88%	96%	90%				
12Z Wed 8 Feb 2017	100%	100%	94%	39%	--	63%	73%	78%	76%	80%	78%				
00Z Wed 8 Feb 2017	100%	100%	90%	57%	35%	53%	57%	67%	67%	78%					

RED	Easterly conditions most likely
GREEN	Both westerly and easterly conditions unlikely
BLUE	Westerly conditions most likely
WHITE	Equal likelihood of two or three of the above tendencies occurring

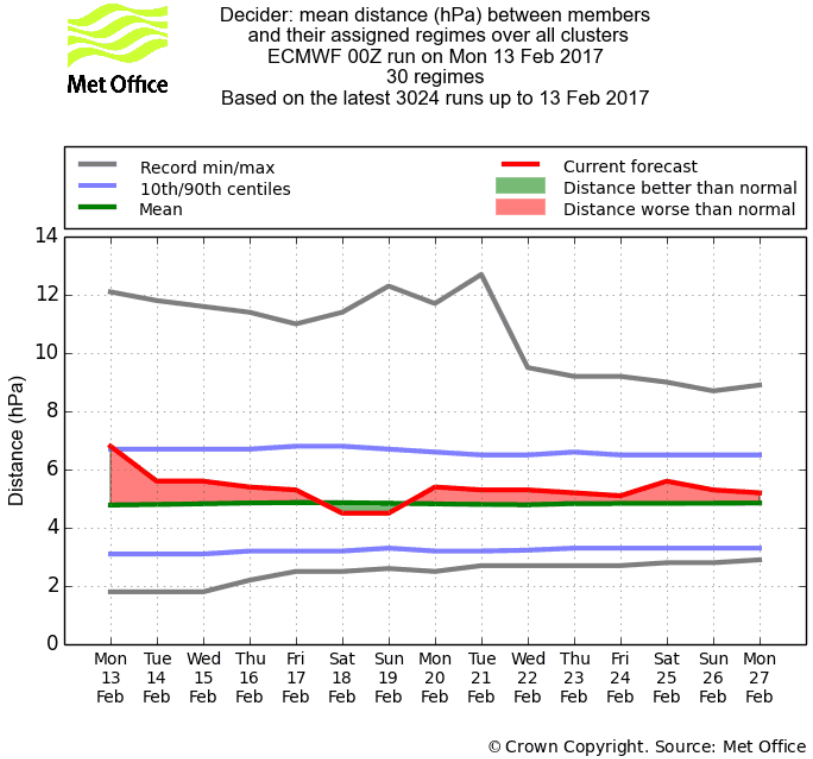
Left: the probabilistic zonal trend is consistent over several runs at signalling a return to westerly conditions around the 16th February.

Decider forecast confidence index
ECMWF 00Z run 13th February 2017



Forecast confidence is normal or better then normal.

Decider forecast distance between members and regimes ECMWF 00Z run 13th February 2017

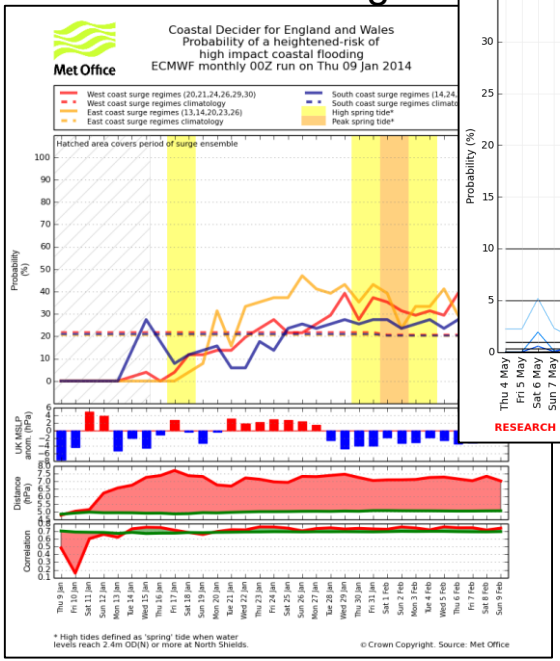


Distance between members and regimes (in terms of their pressure anomalies) is around normal, to slightly worse than normal. But values are within the 10th and 90th percentiles.

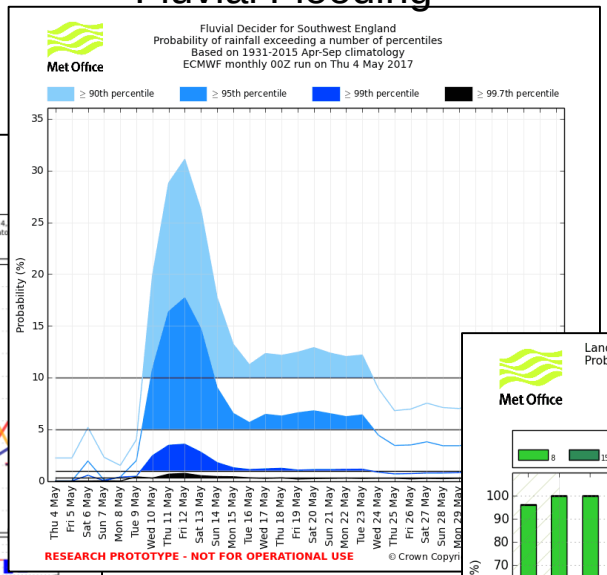
Distances greater than normal can sometimes be a sign of severe weather.

New weather impact forecast applications under development, based on probabilistic weather regime forecast output...

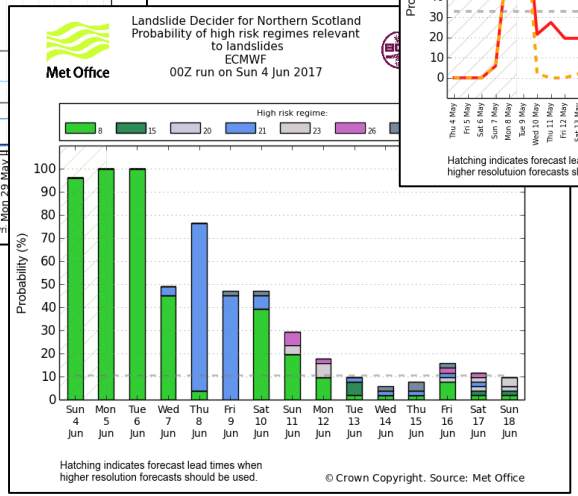
Coastal Flooding



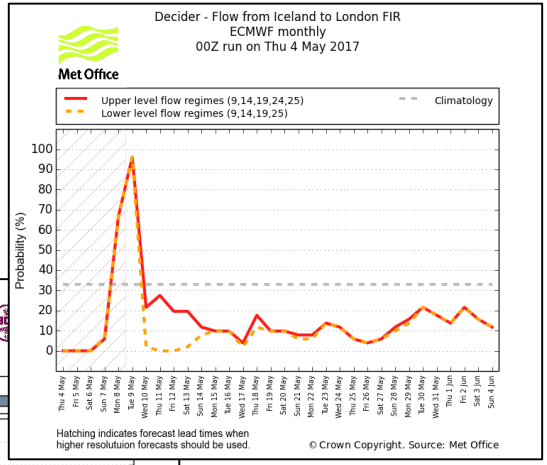
Fluvial Flooding



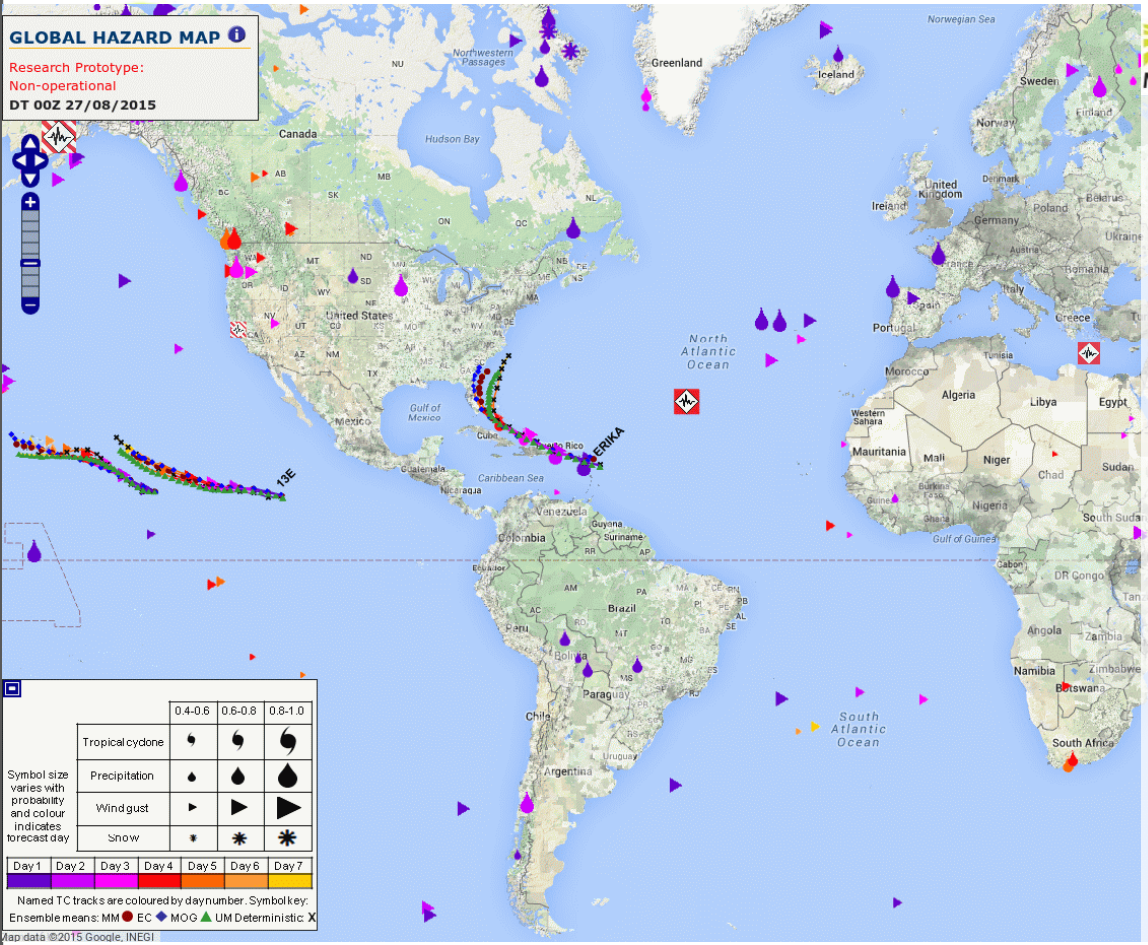
Landslides



Flow from Iceland



Global Hazard Map



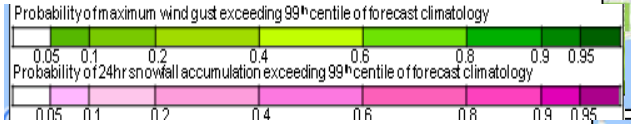
Global Hazard Map

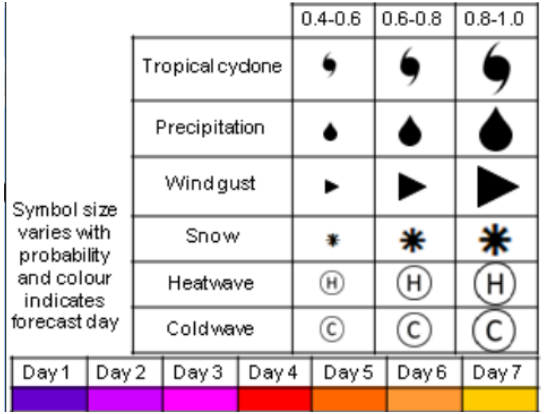
- Aims to summarise the risk of high-impact weather across the globe in the next 7 days using global multi-model ensemble forecasts
  - Precip / Wind / Snow
  - Tropical Cyclones
  - Heatwave and Coldwaves
- Web Map Service – easy to overlay info, zoom/pan, flexible format for data layers
- Symbol-based summary map, coloured by lead time, gives ‘at a glance’ view of all hazards
- Can then drill down to particular variables / days / models / areas of interest
- Can overlay vulnerability and exposure layers to give information on likely impact
  - Population density
  - Fragile State Index
  - Soil moisture
  - Recent earthquakes

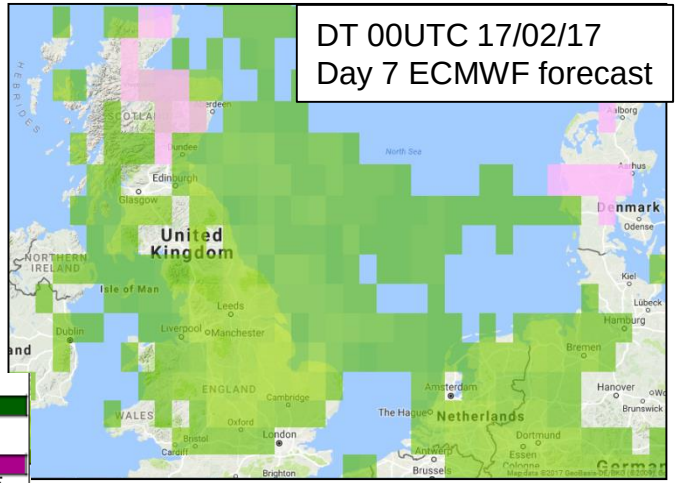
Global Hazard Map wind and snow forecasts

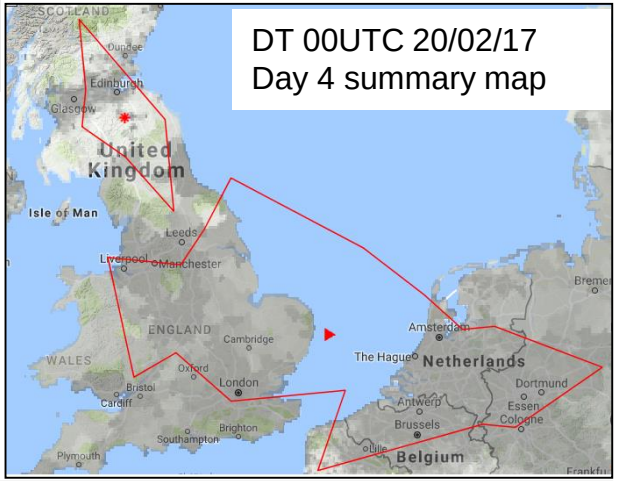
Met Office

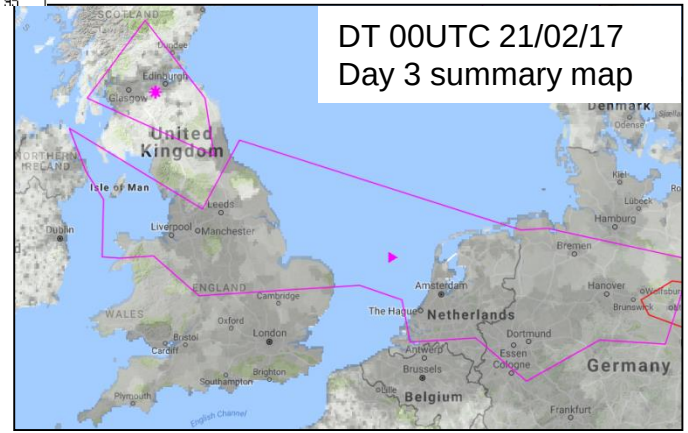
Global Hazard Map forecasts for maximum 24hr wind gust and 24hr snowfall exceeding 99th centile in MClimate

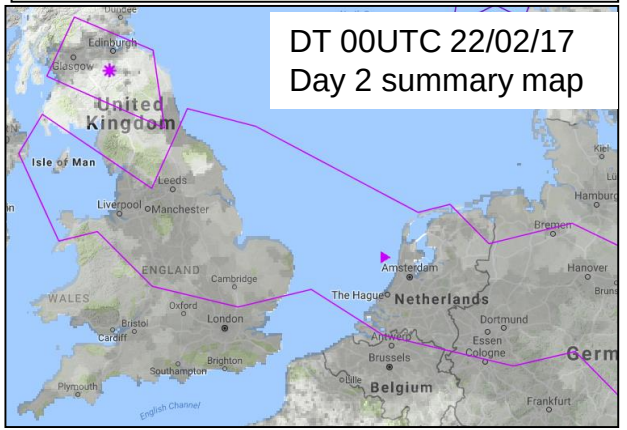






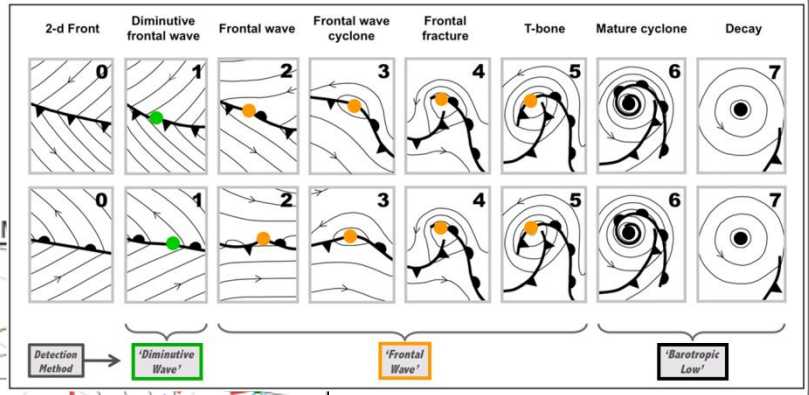


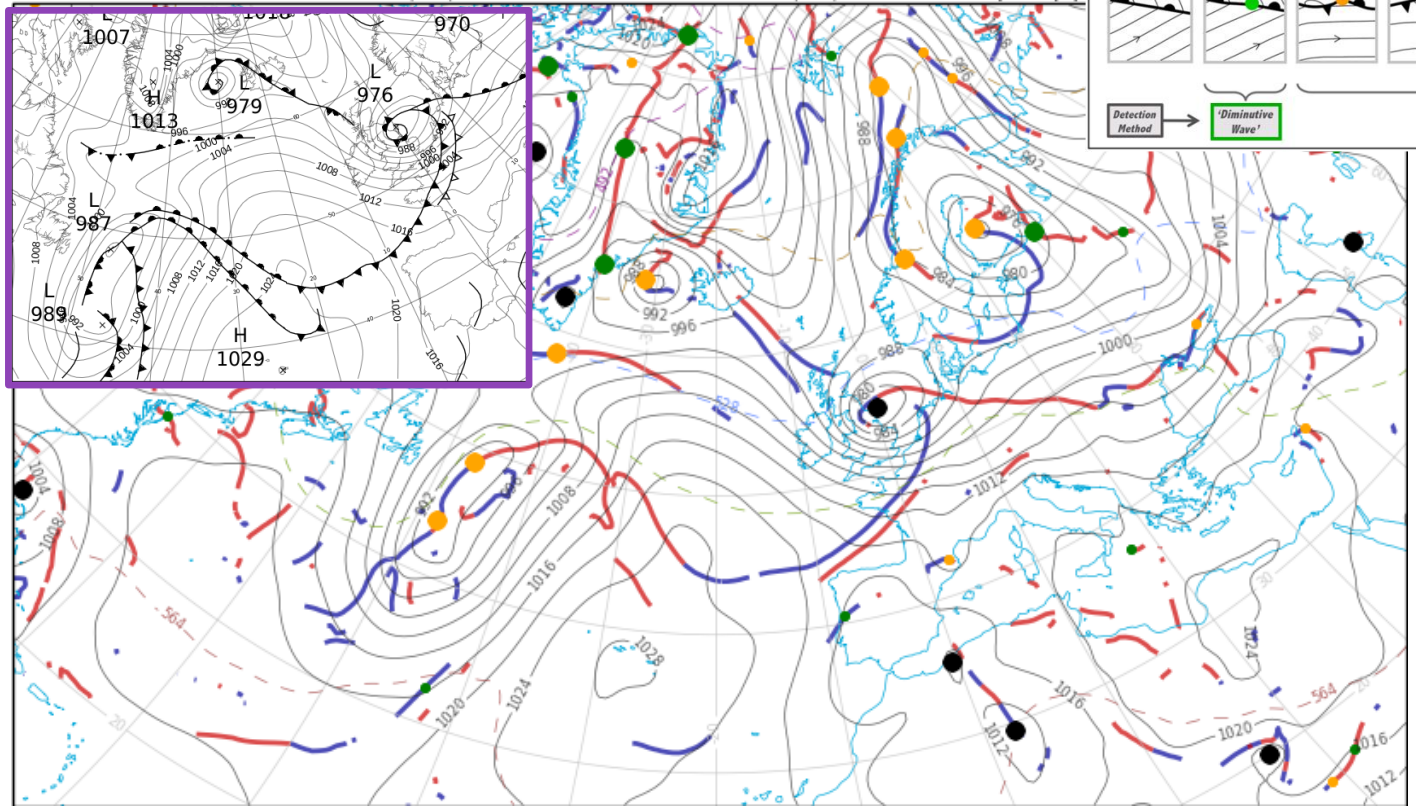




Cyclone Database

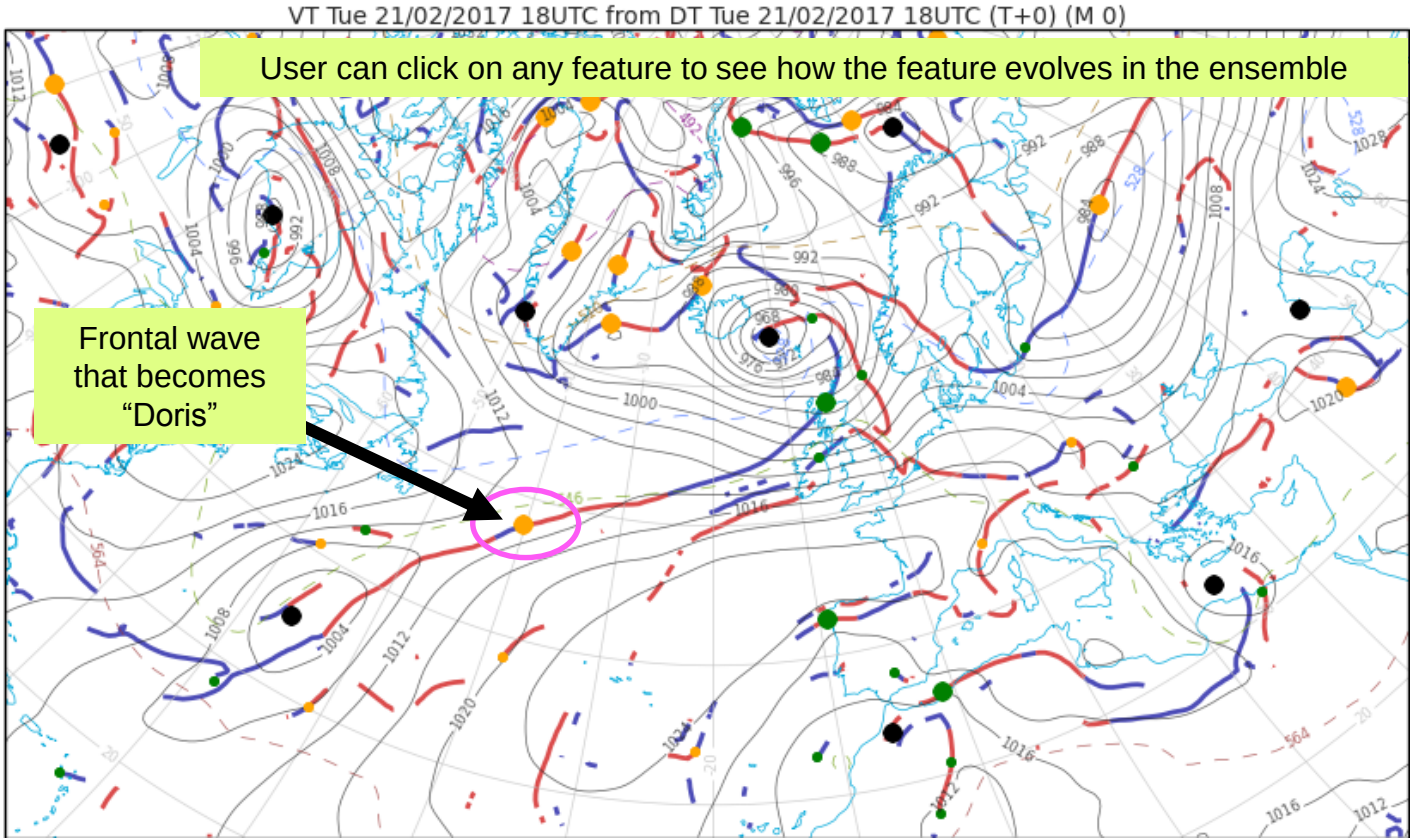
Cyclone Database





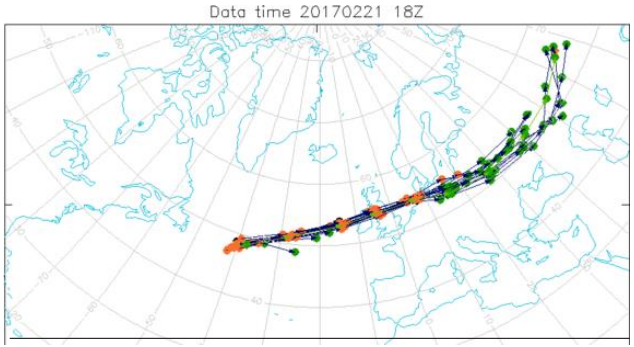
- Hewson and Titley (2010)
- Objectively identifies **warm** and **cold** fronts and cyclonic features: **diminutive waves**, **frontal waves**, and **barotropic lows**
- Available for ECMWF ENS and MOGREPS-G

Cyclone database: Feature tracking



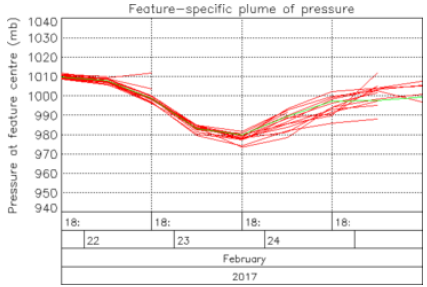
MOGREPS-G

Cyclone database: Feature tracking

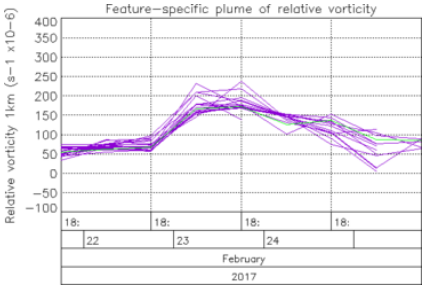


Shows the forecast for the control feature that was clicked on, along with matched features from the other ensemble members

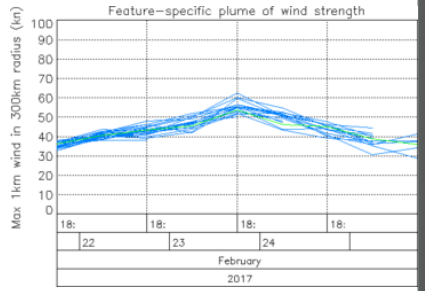
The tracks and future positions (coloured spots) are plotted for ensemble members at 12 h intervals



Estimated mean sea level pressure at the feature point



1km relative vorticity at the feature point

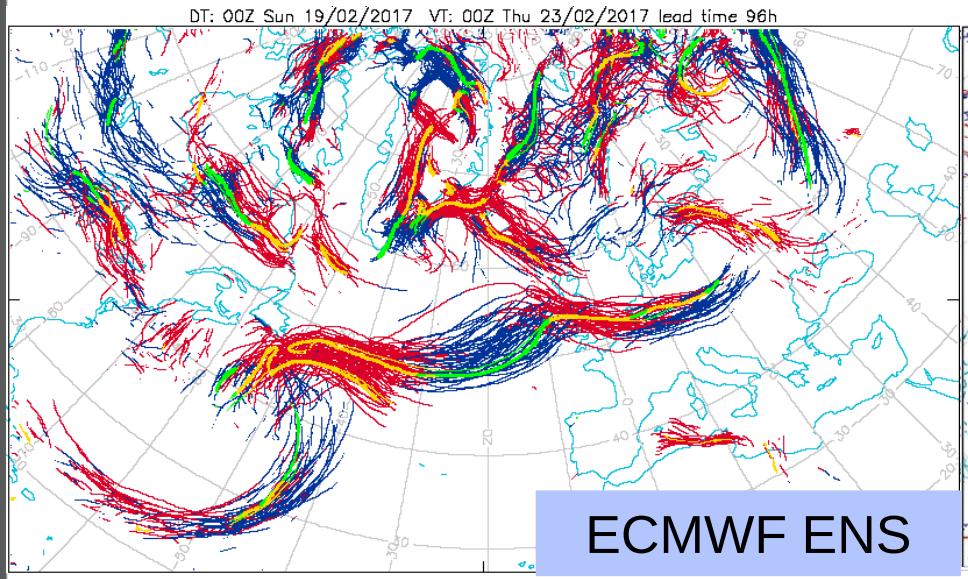


Maximum 1km wind strength in a 300 km radius

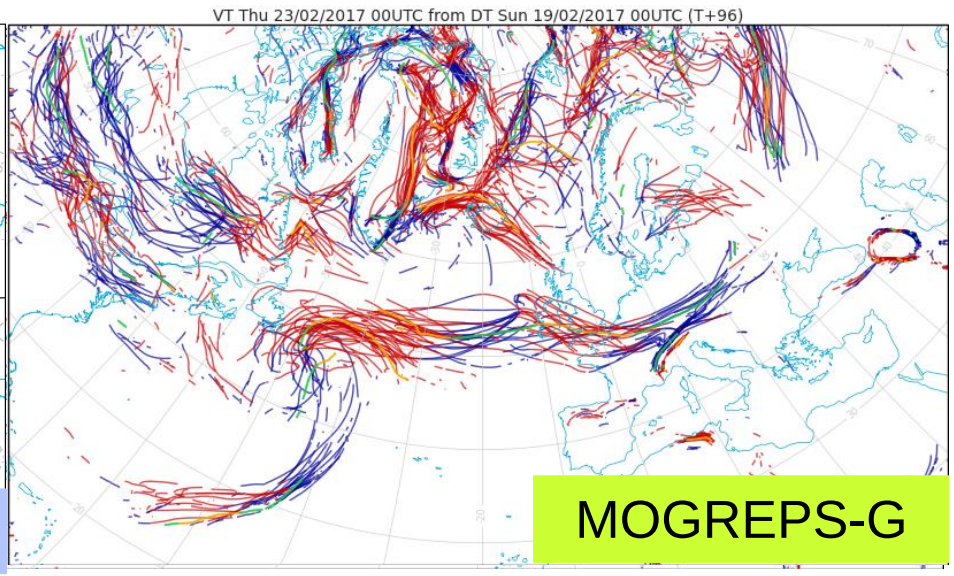
- Generally used at short leads only as feature of interest needs to be present
- Useful for Doris as shows good confidence in track and signal for rapid cyclogenesis

MOGREPS-G

Cyclone database: Spaghetti fronts



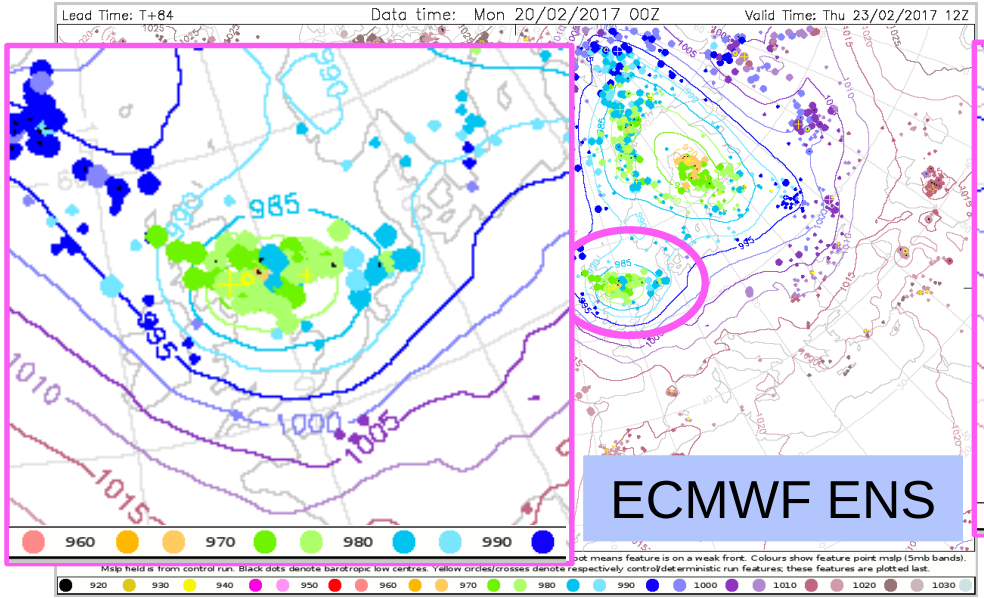
ECMWF ENS

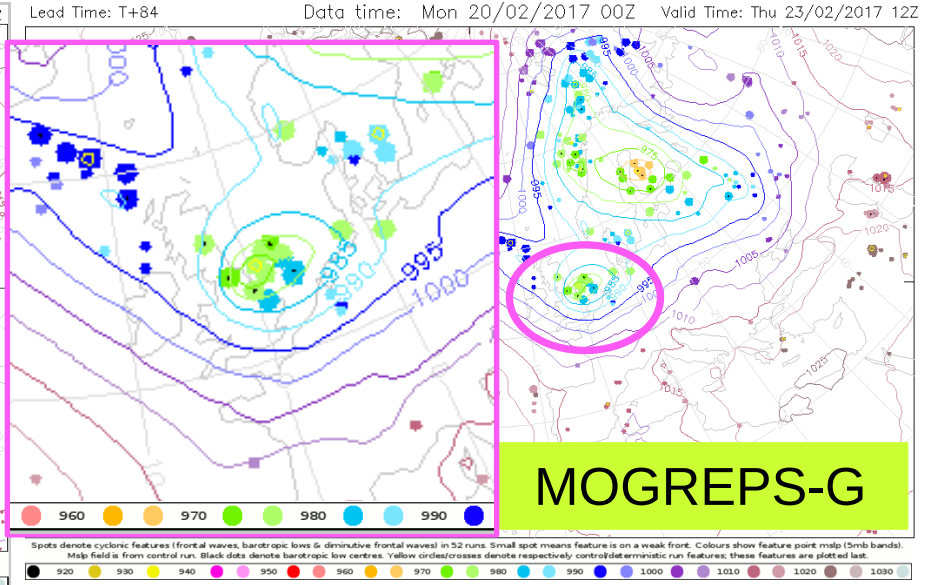


MOGREPS-G

- DT 00Z 19th Feb – 4 days ahead of Storm Doris

Cyclone database: Dalmatian plots





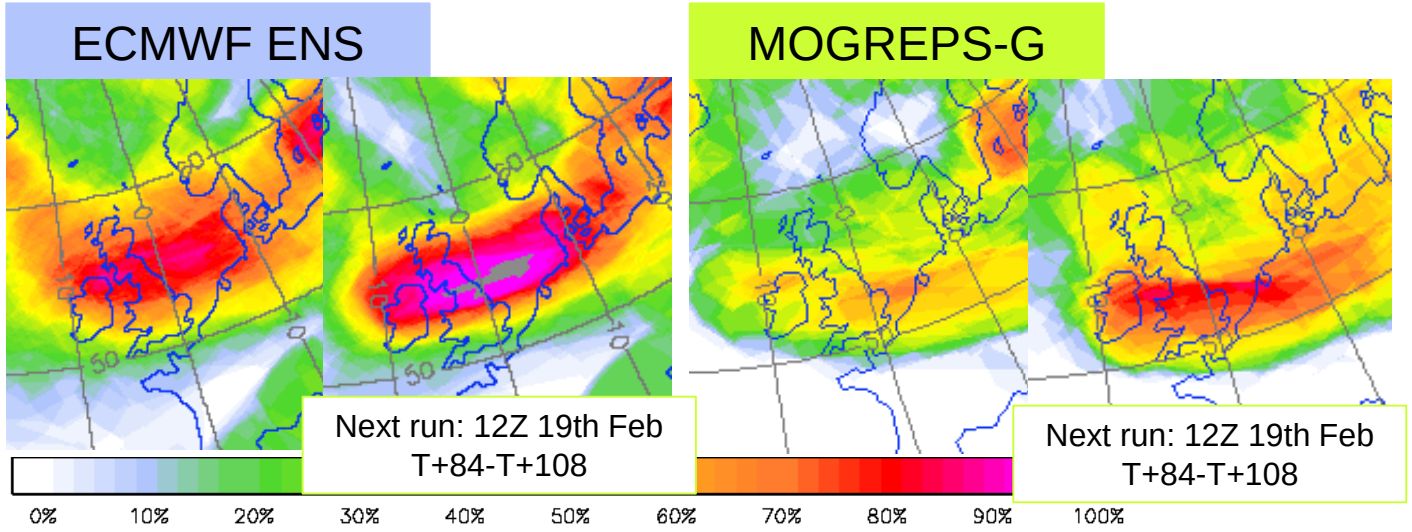
- Spots show the location of cyclonic features in each member in the ensemble
- Size denotes the strength of the feature, while colours indicate the MSLP depth of the feature
- Background is the MSLP fields from the control run.

Cyclone database: Strike probability maps

DT 00Z 19th Feb

T+96-T+120

Probability of a cyclonic feature with 1km wind speed maxima > 34kn tracking within 300km radius from *–12h to +12h*



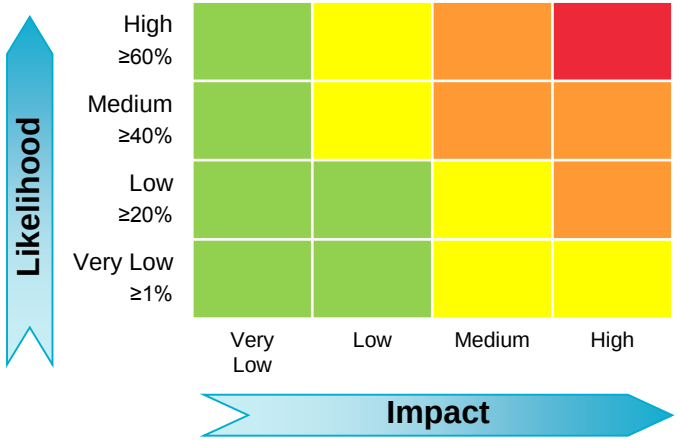
- Strike probability charts are based on tracking **feature points**, not wind maxima. Only cyclonic features reaching a certain intensity threshold at some point in the 24h period are included. Here the threshold is that the max 1km wind speed within 300km must exceed 34kts.
- Strongest winds are likely to be to the right of the cyclone track
- Gives higher probabilities than “at a point” wind speed probabilities, extending the predictability

Ensemble Prediction System first guess warnings (EPS-W)

Ensemble Prediction System First Guess Warnings (EPS-W)

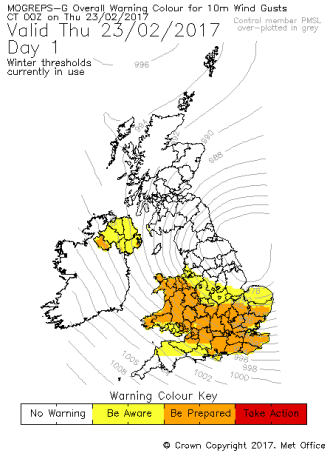
- EPS-W post-processes ensemble data into a format which mimics the **risk-based** National Severe Weather Warning Service (NSWWS) colour states
- Mapped first guess warnings aid forecasters in deciding warning areas
- First-guess warnings are based on a combination of **likelihood** and **impact** as illustrated in the NSWWS weather impact matrix
- Regionally varying thresholds are used to define the impact levels
- Uses **MOGREPS** and **ECMWF ENS**

NSWWS weather impact matrix including likelihood probabilities, which are used in EPS-W only.

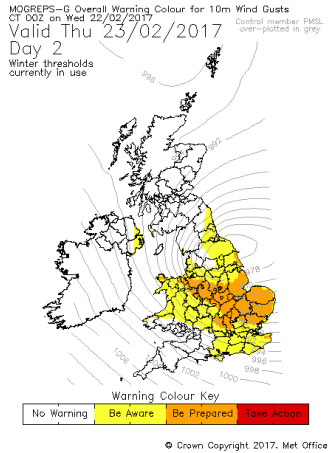


Overall warning colour key

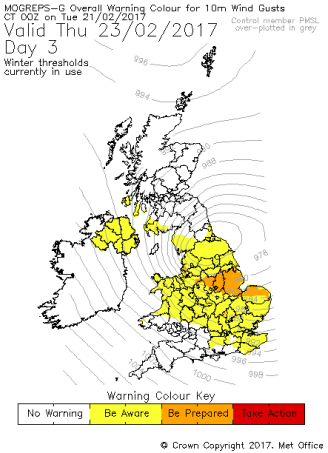
MOGREPS-G version of EPS-W (Overall warning colour for 10m wind gusts)



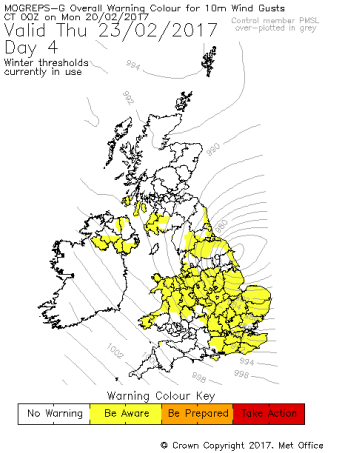
1 day forecast



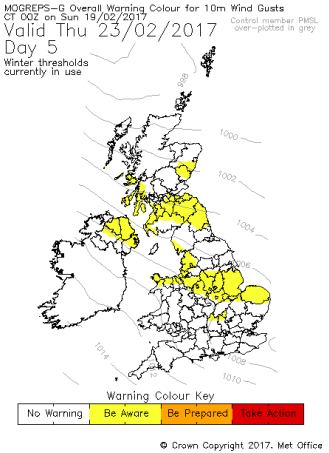
2 day forecast



3 day forecast



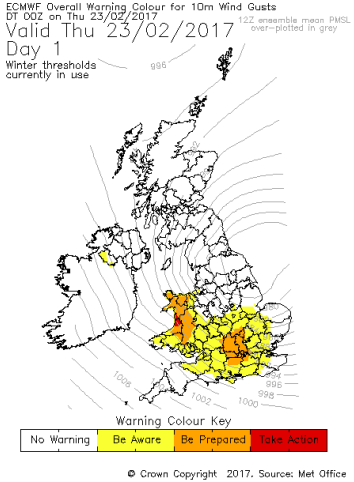
4 day forecast



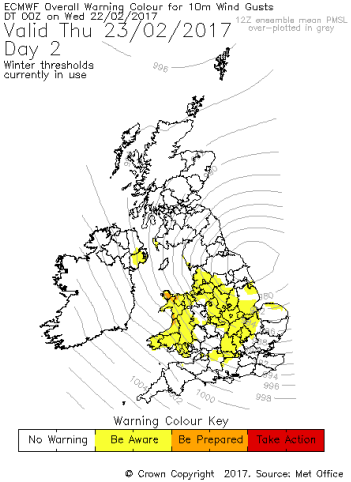
5 day forecast

The 5 day warning highlights broad areas at risk across the UK. The area at risk reduces as the event draws closer. The main risk area also moves further south.

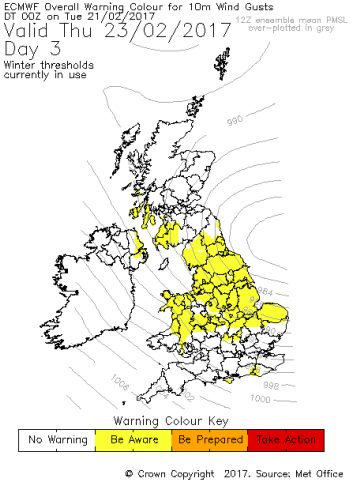
ECMWF version of EPS-W (Overall warning colour for 10m wind gusts)



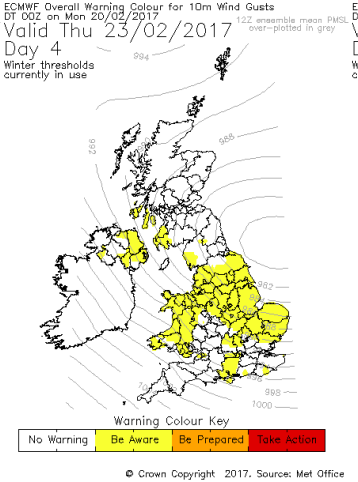
1 day forecast



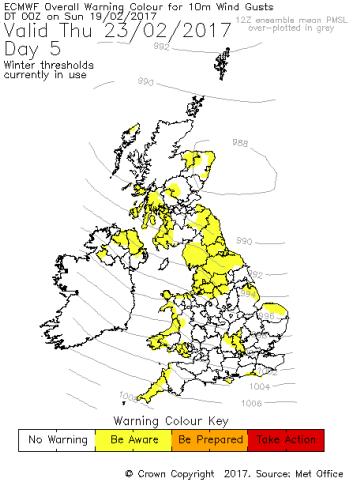
2 day forecast



3 day forecast



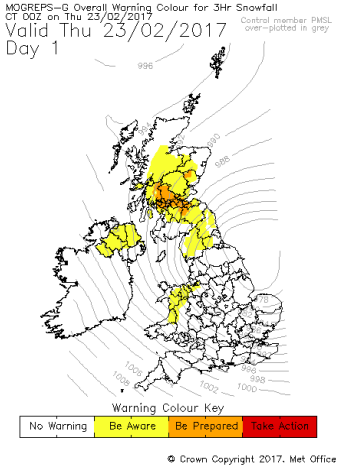
4 day forecast



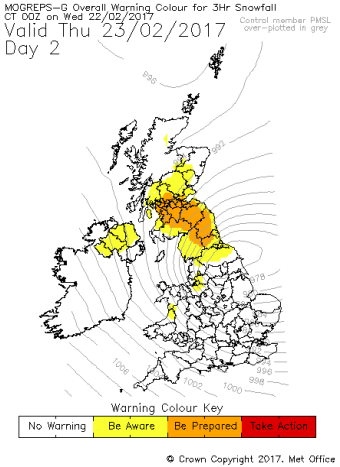
5 day forecast

The 5 day warning highlights broad areas at risk across the UK. The area at risk reduces as the event draws closer. The main risk area also moves further south. MOGREPS-G picks out amber areas 2 days earlier than ECMWF.

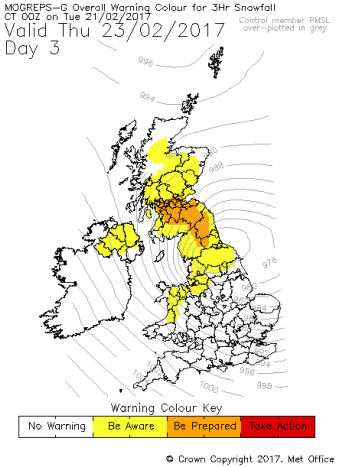
MOGREPS-G version of EPS-W (Overall warning colour for 3 hour snowfall)



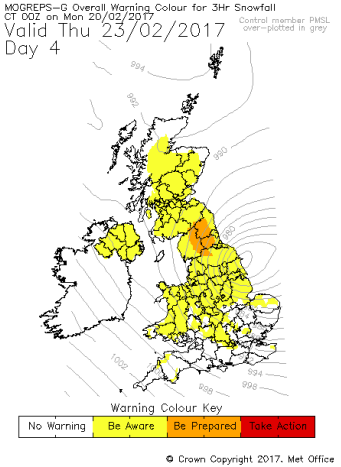
1 day forecast



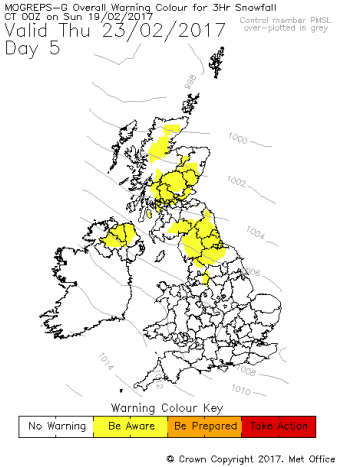
2 day forecast



3 day forecast



4 day forecast

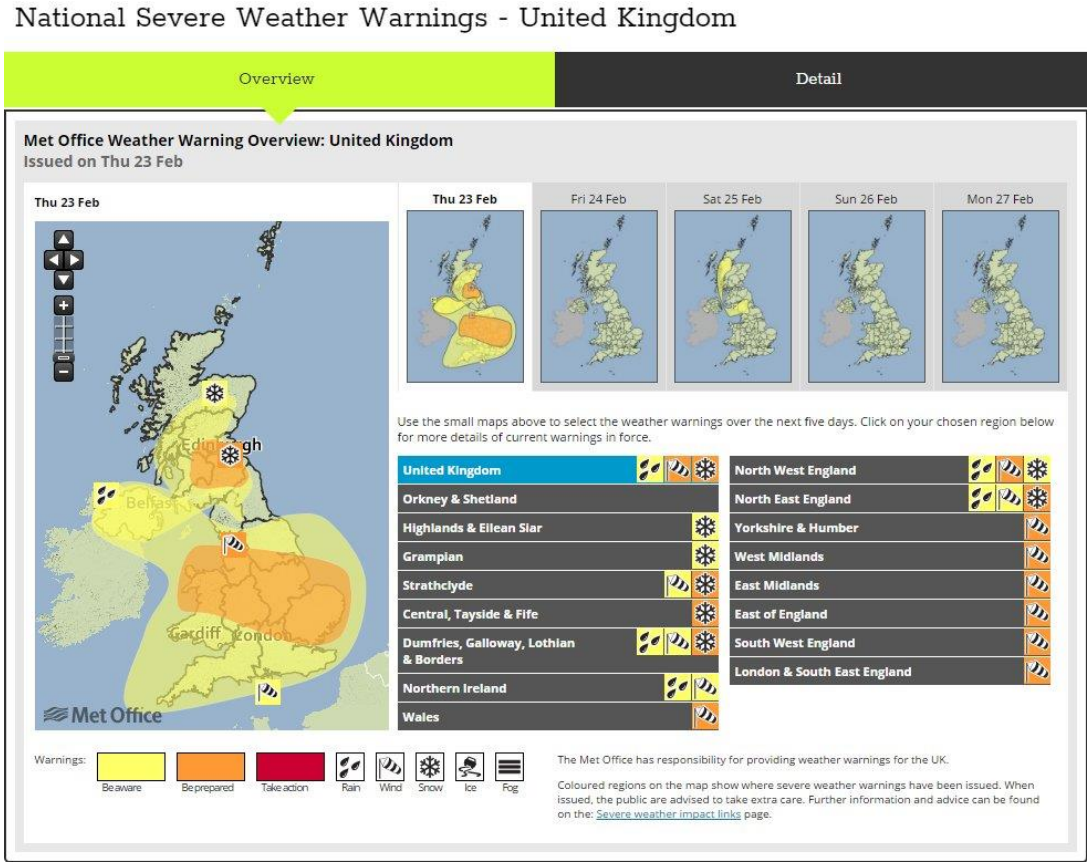


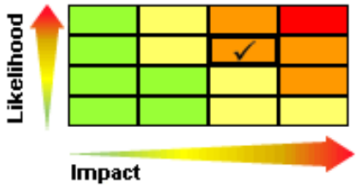
5 day forecast

The 5 day warning highlights broad areas at risk across the north of the UK, with warnings refined as lead time reduces.

PWS warnings

Final forecaster issued weather warnings





Matrix location for snow and wind warnings

www.metoffice.gov.uk