



WeatherQuest

The Science of Weather Forecasting

Agri-TechE: Farming in a Warming, Wetter World

Chris Bell

14th May 2025

How does a forecast get made?

It all starts with observations...

How do we observe the weather?

Land based weather stations

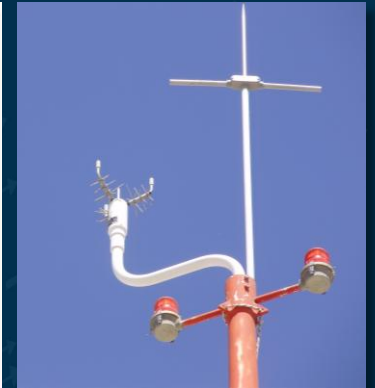


Weybourne, Norfolk, Met Office 03488

How do we observe the weather?

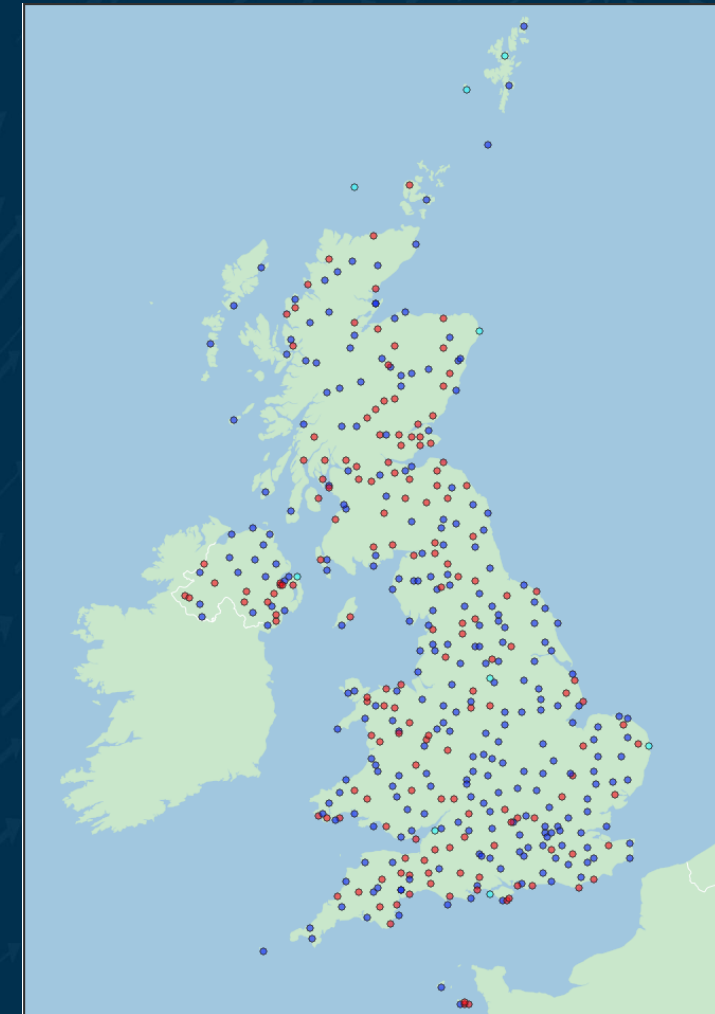
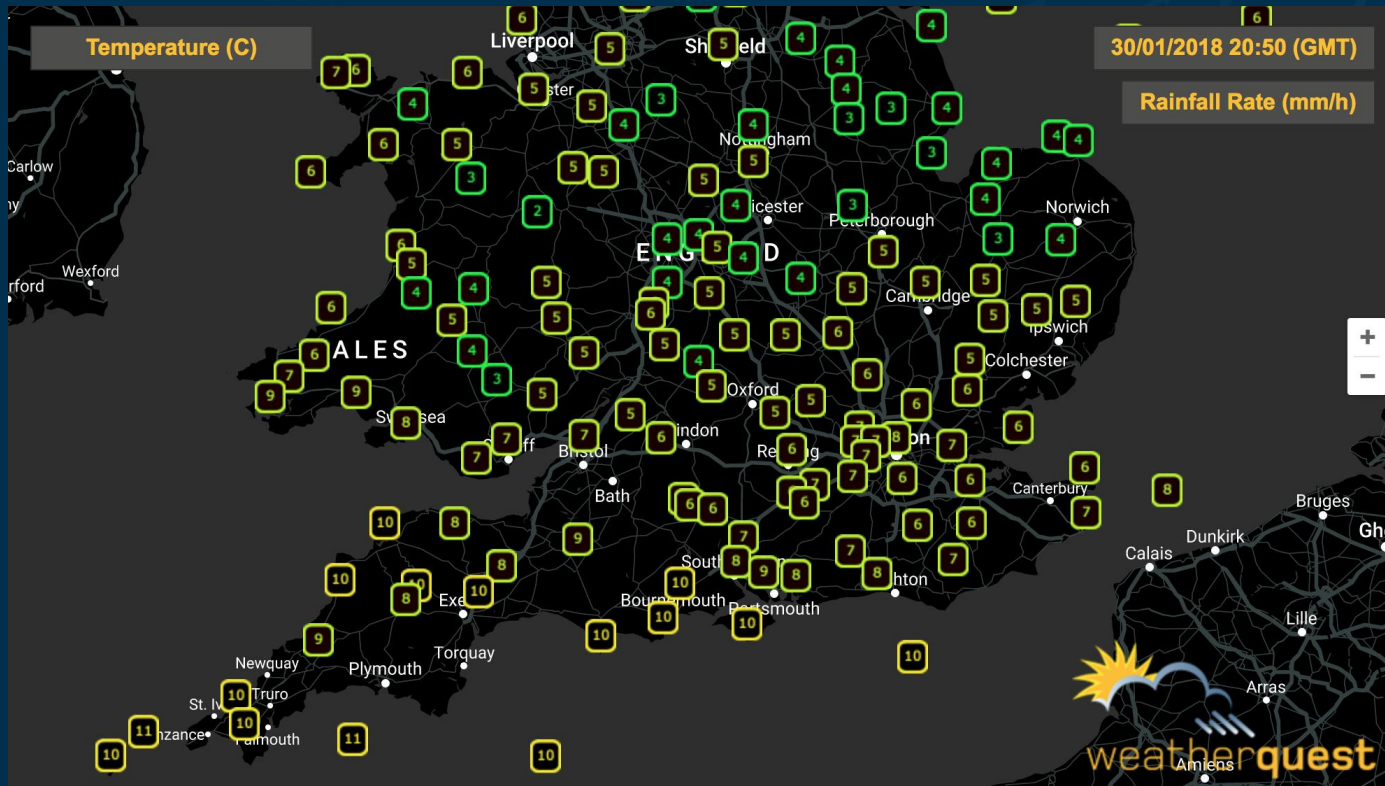
Land based weather stations

- Stevenson screen (temp/humidity)
- Tipping bucket rain gauge
- Ultrasonic snow sensor
- Anemometers (wind)
- Barometers (pressure)
- Sunshine recorder
- Solar radiation pyranometer



How do we observe the weather?

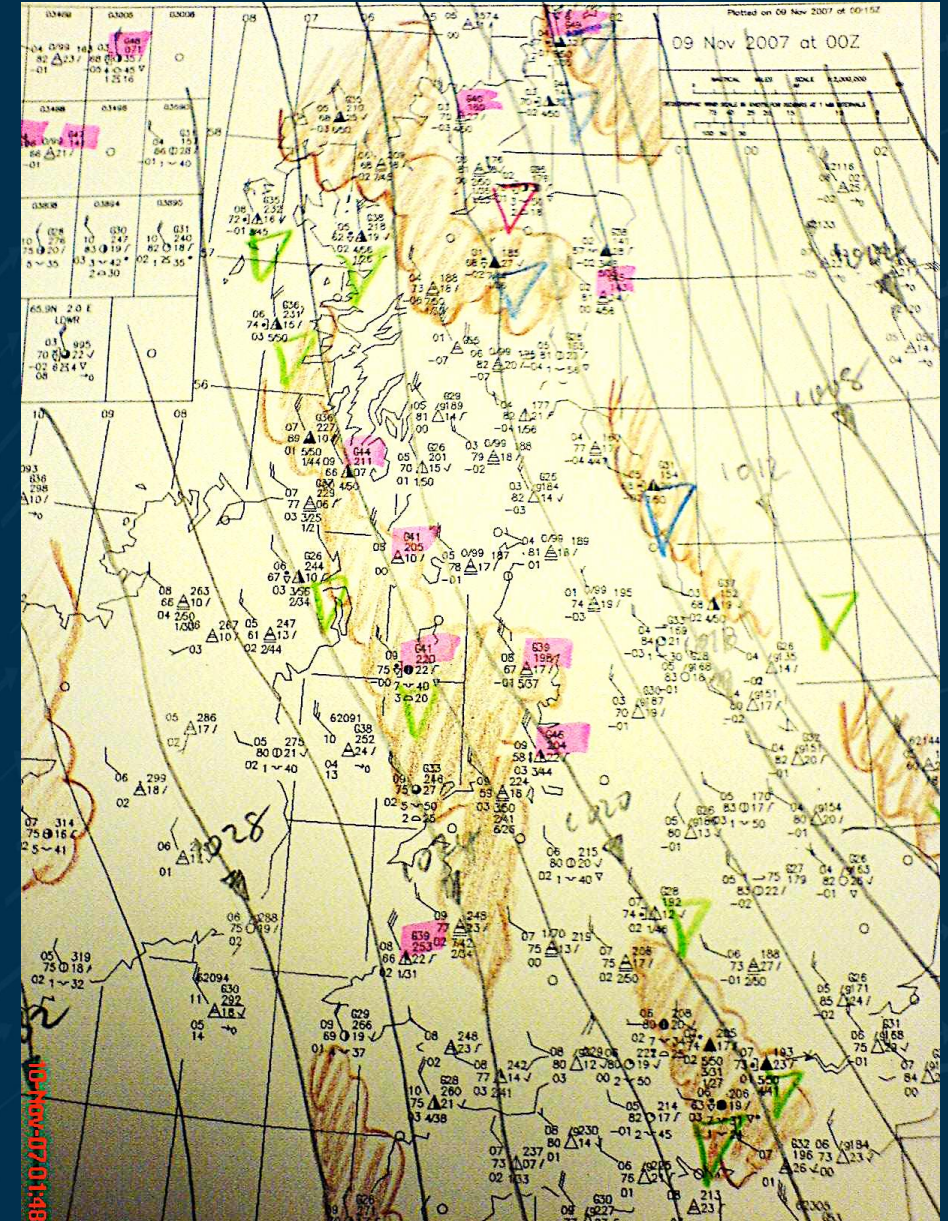
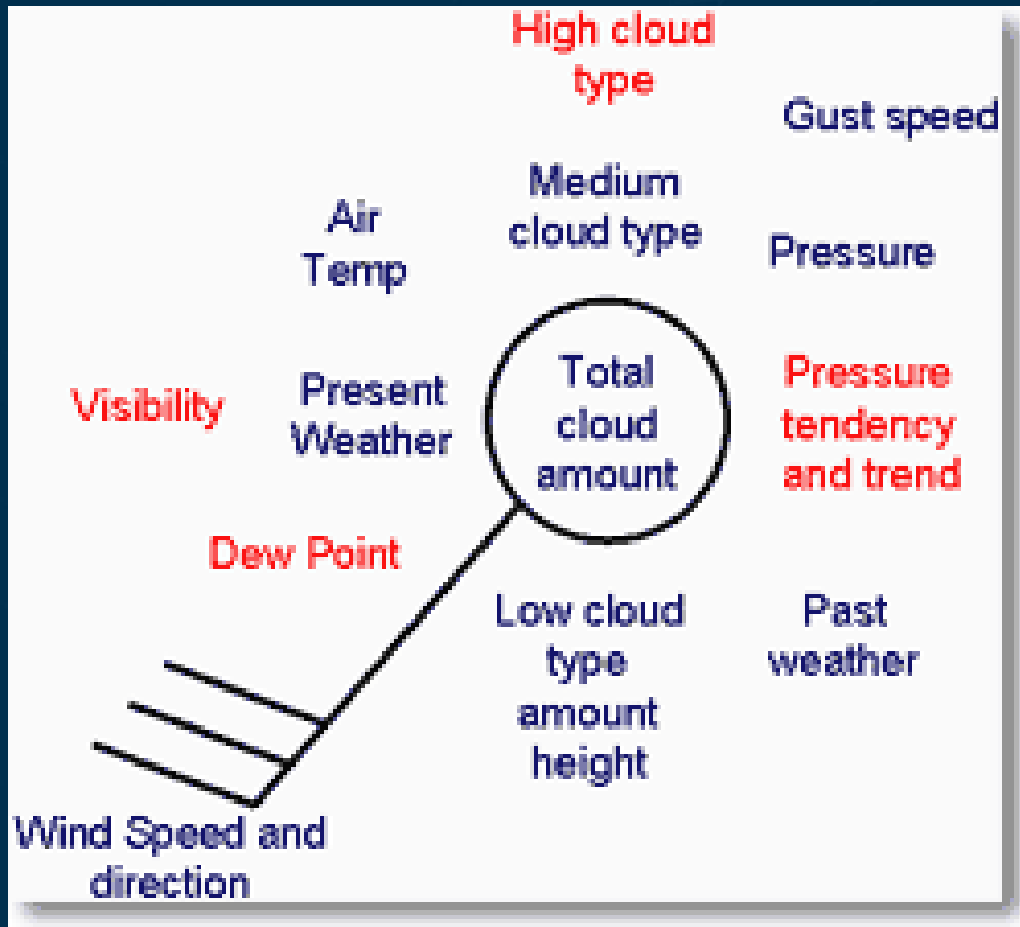
Land based weather stations



Met Office Front Line Weather Stations

How do we observe the weather?

Plotting weather station data



How do we observe the weather?

Traditional Weather Forecasting



How do we observe the weather?

Along came advanced technology and immediately saved lives...

The supercomputer



<https://wxguys.ssec.wisc.edu>

The satellite



<https://www.metoffice.gov.uk>

...and more

How do we observe the weather?

Remote Sensing

- Weather balloons
- Satellites
- Radar
- Aircraft / Ships
- Drones
- Wave buoys
- Lightning detection



How do we observe the weather?

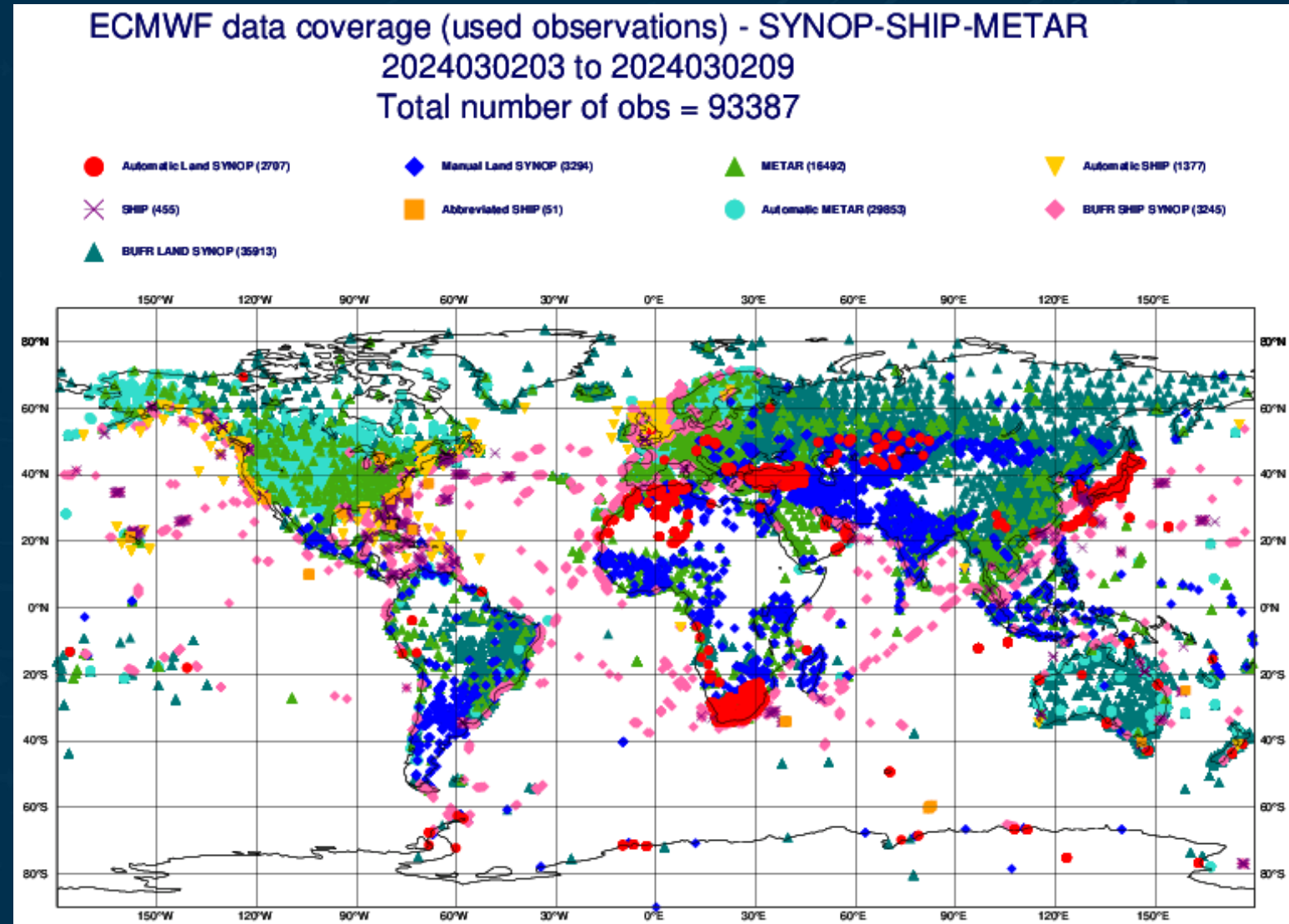
In summary...



<https://www.metoffice.gov.uk/guide/weather/observations-guide>

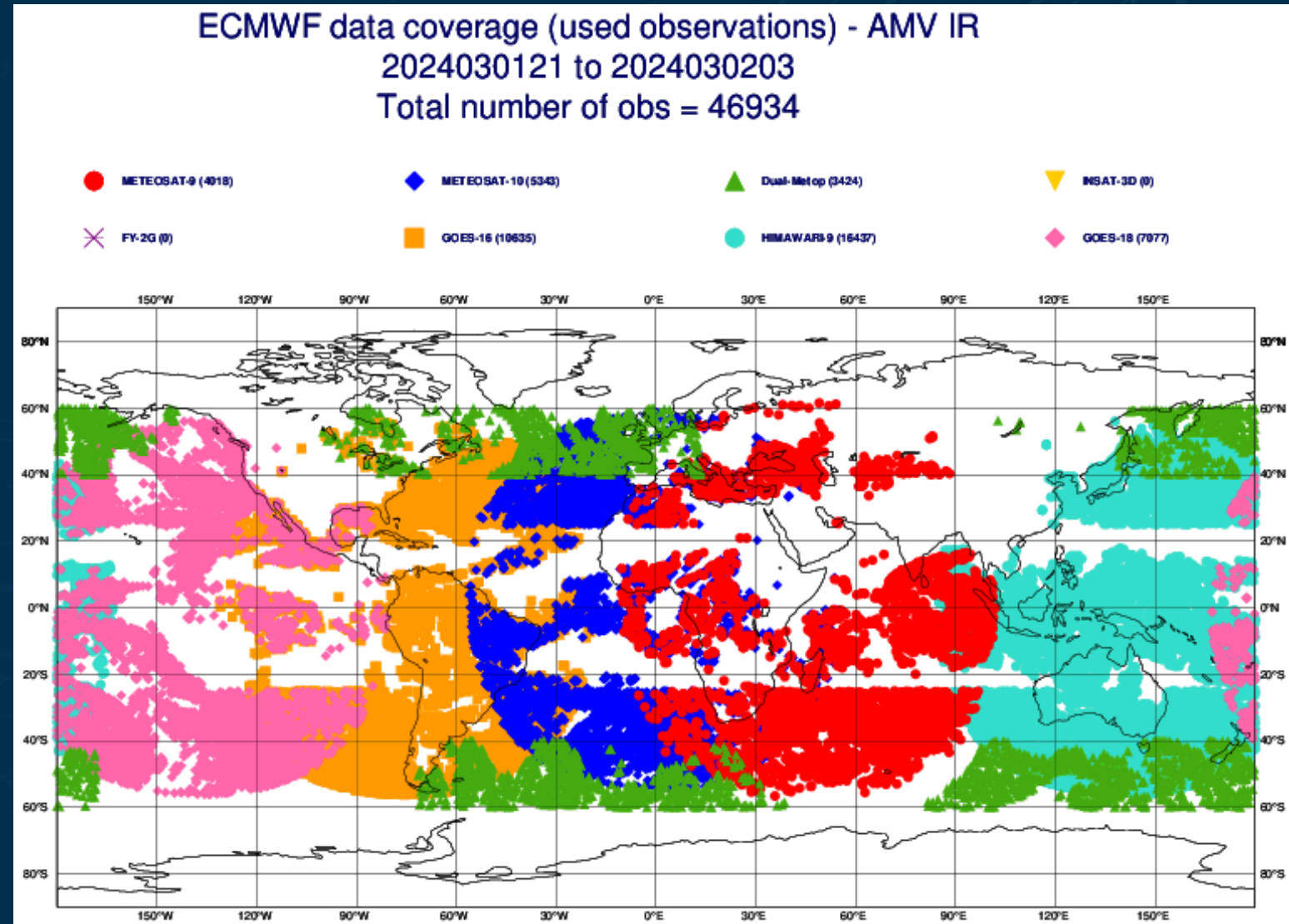
How do we observe the weather?

But there are gaps – in our observations...



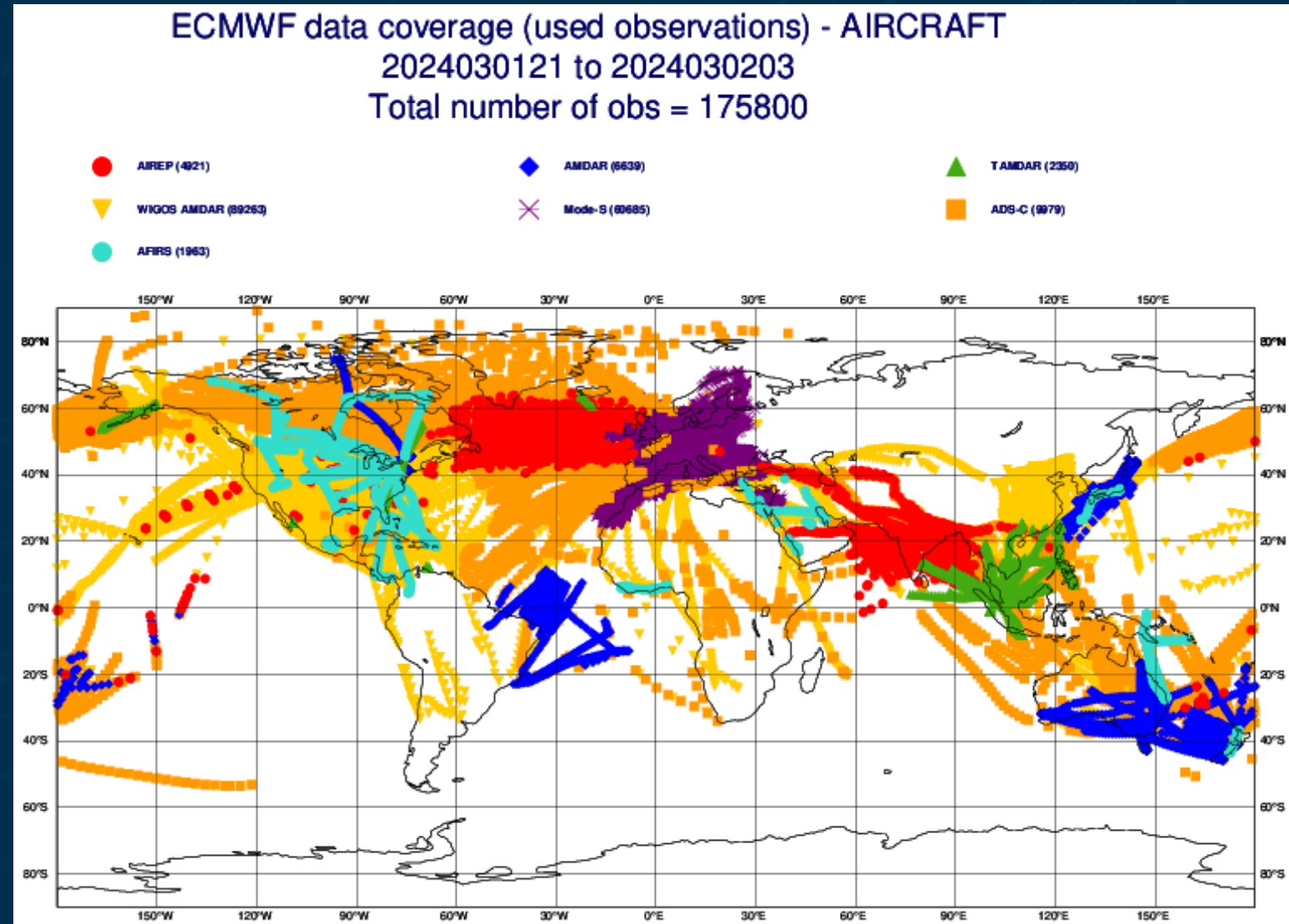
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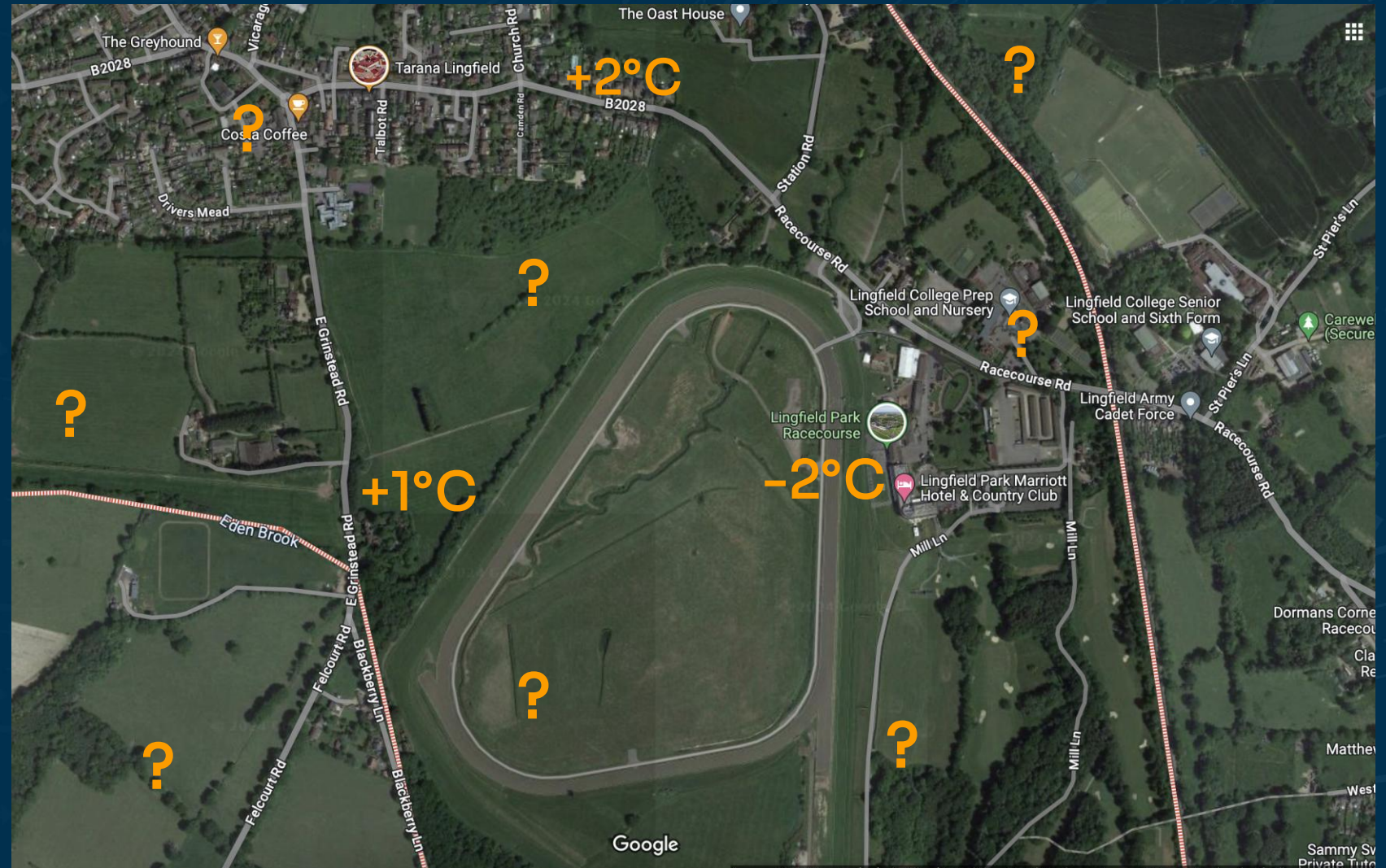
How do we observe the weather?

But there are gaps – in our observations...



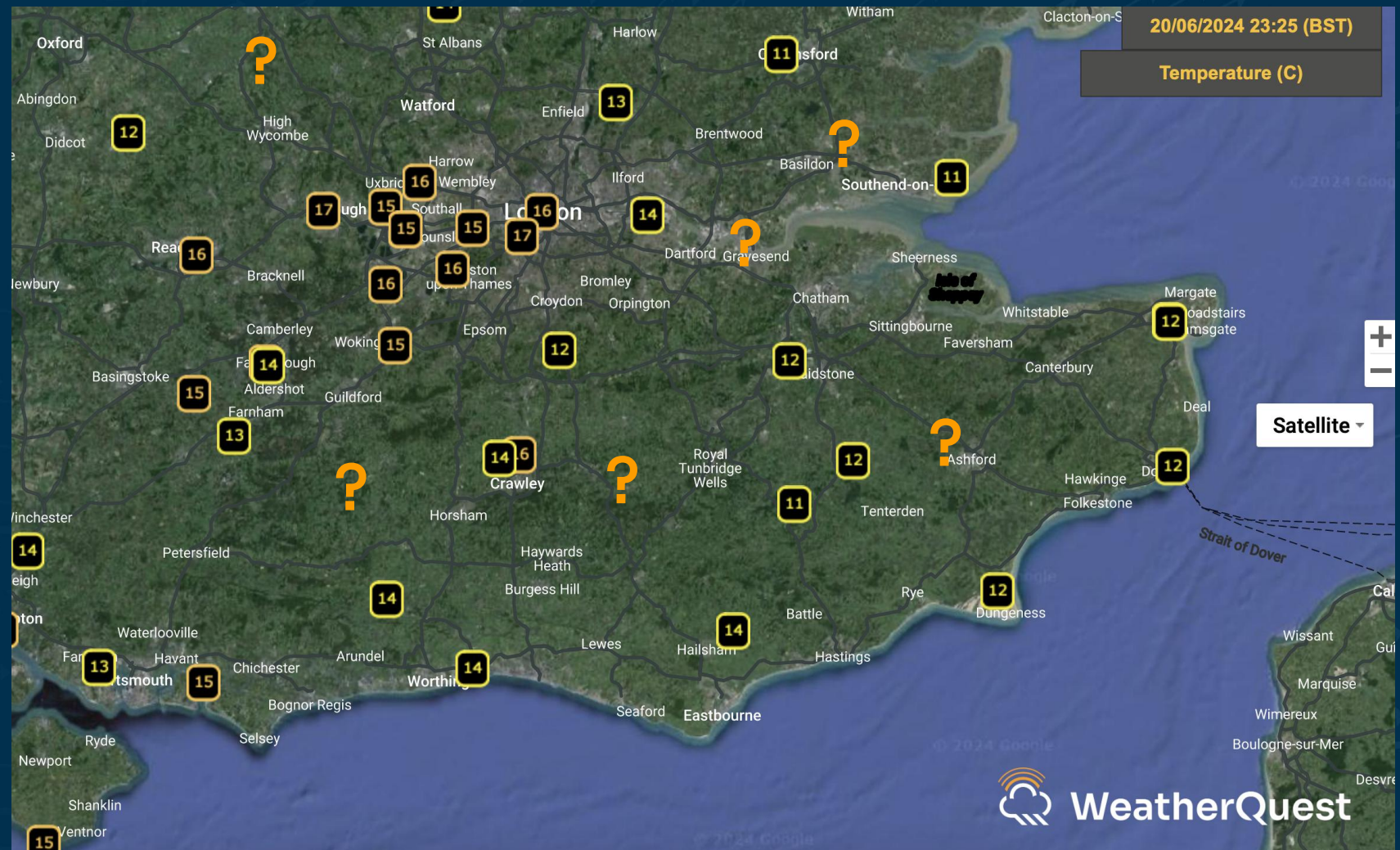
How do we observe the weather?

But there are gaps – in our observations...



How do we observe the weather?

But there are gaps – in our observations...



How does a forecast get made?

Observations to supercomputers...

Observations to supercomputers



Quasigeostrophic Geopotential Tendency Equation

$$\left(\sigma \nabla_{\sigma}^2 + f_0^2 \frac{\partial^2}{\partial p^2} \right) \frac{\partial \Phi}{\partial t} = \underbrace{-f_0 \sigma \bar{\vec{v}}_g \cdot \nabla_{\sigma} (\zeta_g + f)}_{\text{Horizontal advection of absolute geostrophic vorticity by the geostrophic wind}} - \underbrace{f_0^2 \frac{\partial}{\partial p} \left[-\bar{\vec{v}}_g \cdot \nabla_{\sigma} \left(\frac{R_g T_g}{p} \right) \right]}_{\text{Differential horizontal temperature advection by the geostrophic wind}}$$
$$- \underbrace{f_0^2 \omega \frac{\partial \sigma}{\partial p}}_{\text{Vertical advection of static stability}} + \underbrace{f_0 \sigma \bar{\vec{k}} \cdot \nabla \times \bar{\vec{f}}}_{\text{Friction effects}} - \underbrace{f_0^2 R_g \frac{\partial}{\partial p} \left(\frac{\bar{H}}{p c_{p,d}} \right)}_{\text{Diabatic heating effects (latent/insensible heating)}}$$



Observations to supercomputers



UK Met Office Supercomputer Room

Facts and big numbers

Our three Cray XC40 supercomputing systems:

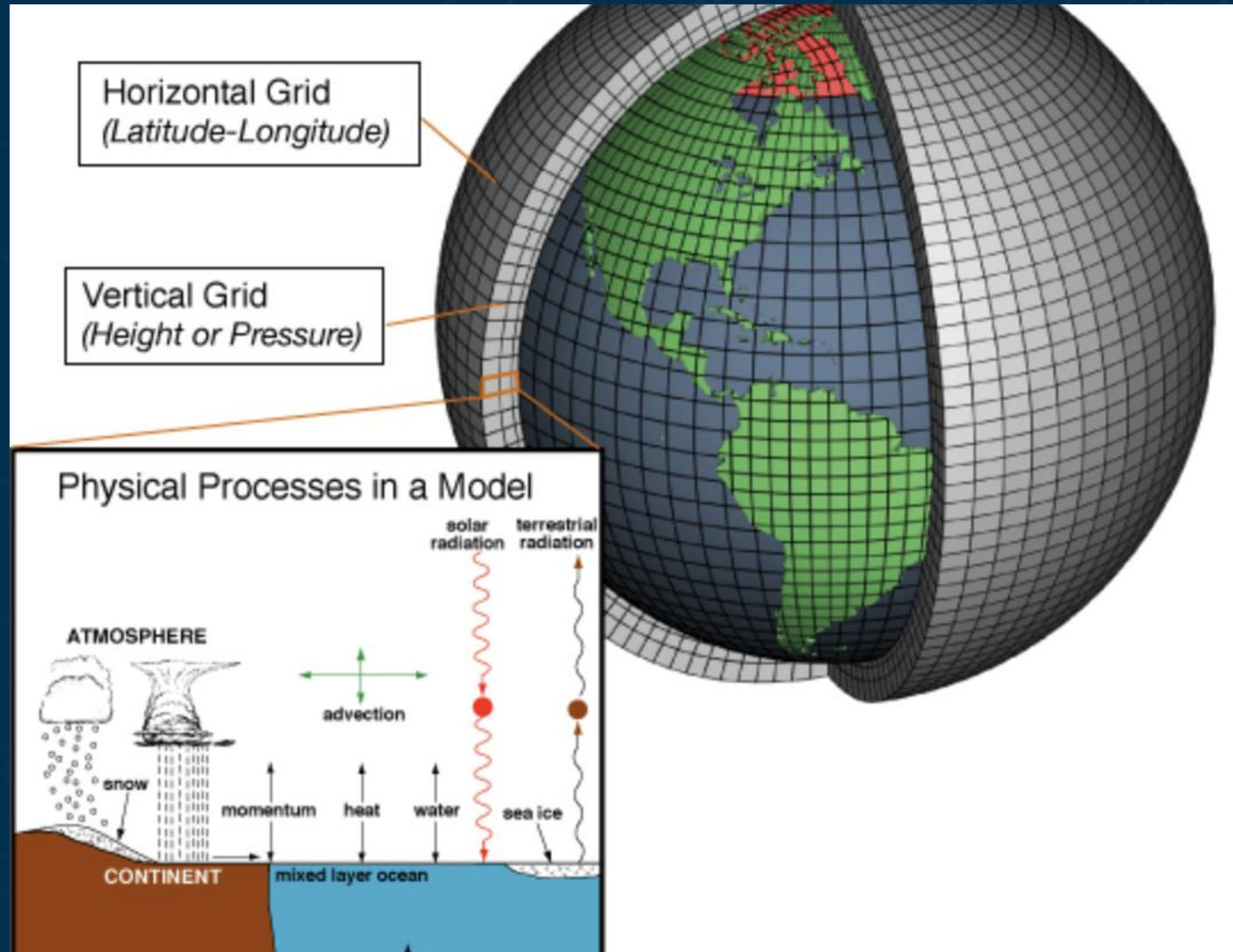
- Are capable of over 14,000 trillion arithmetic operations per second – that's more than 2 million calculation per second for every man, woman and child on the planet.
- Contain 2 petabytes of memory enough to hold 200 trillion numbers.
- Contain a total of 460,000 compute cores. These are faster versions of those found in a typical quad-core laptop.
- Contain 24 petabytes of storage for saving data - enough to store over 100 years worth of HD movies

This power allows the Met Office to take in 215 billion weather observations from all over the world every day, which it then takes as a starting point for running an atmospheric model containing more than a million lines of code.

www.metoffice.gov

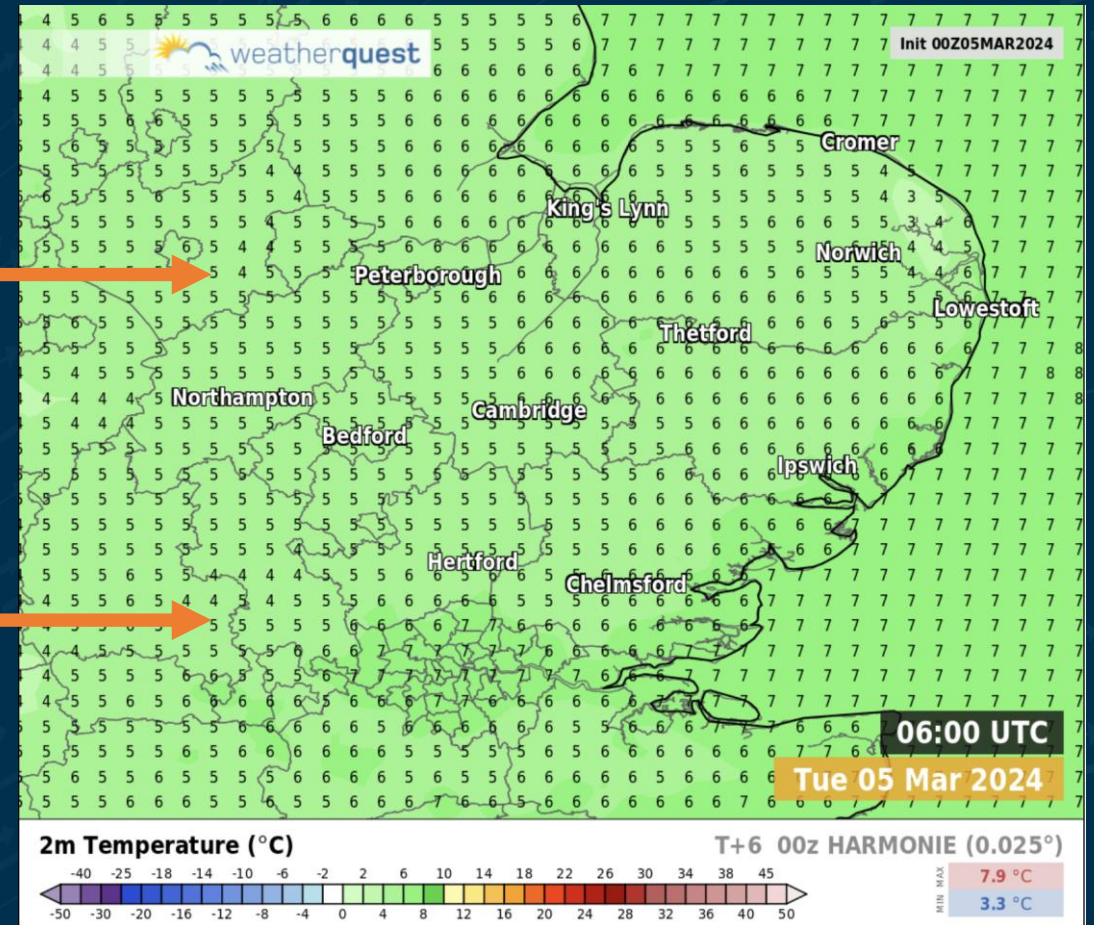
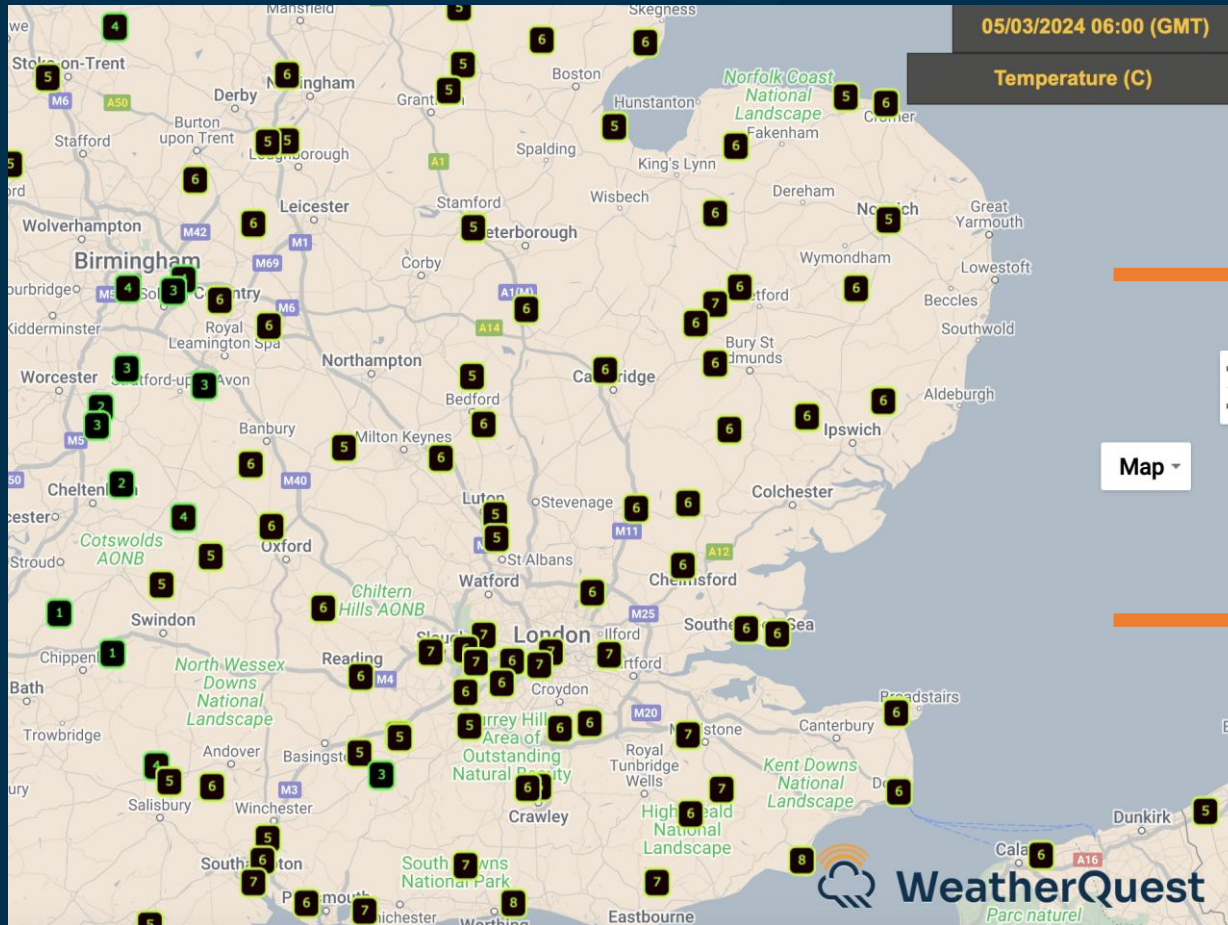
Observations to supercomputers

How the supercomputer sees the world



Observations to supercomputers

From observations to grid points...



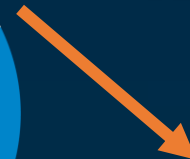
How does a forecast get made?

What should you trust...

Reliable sources

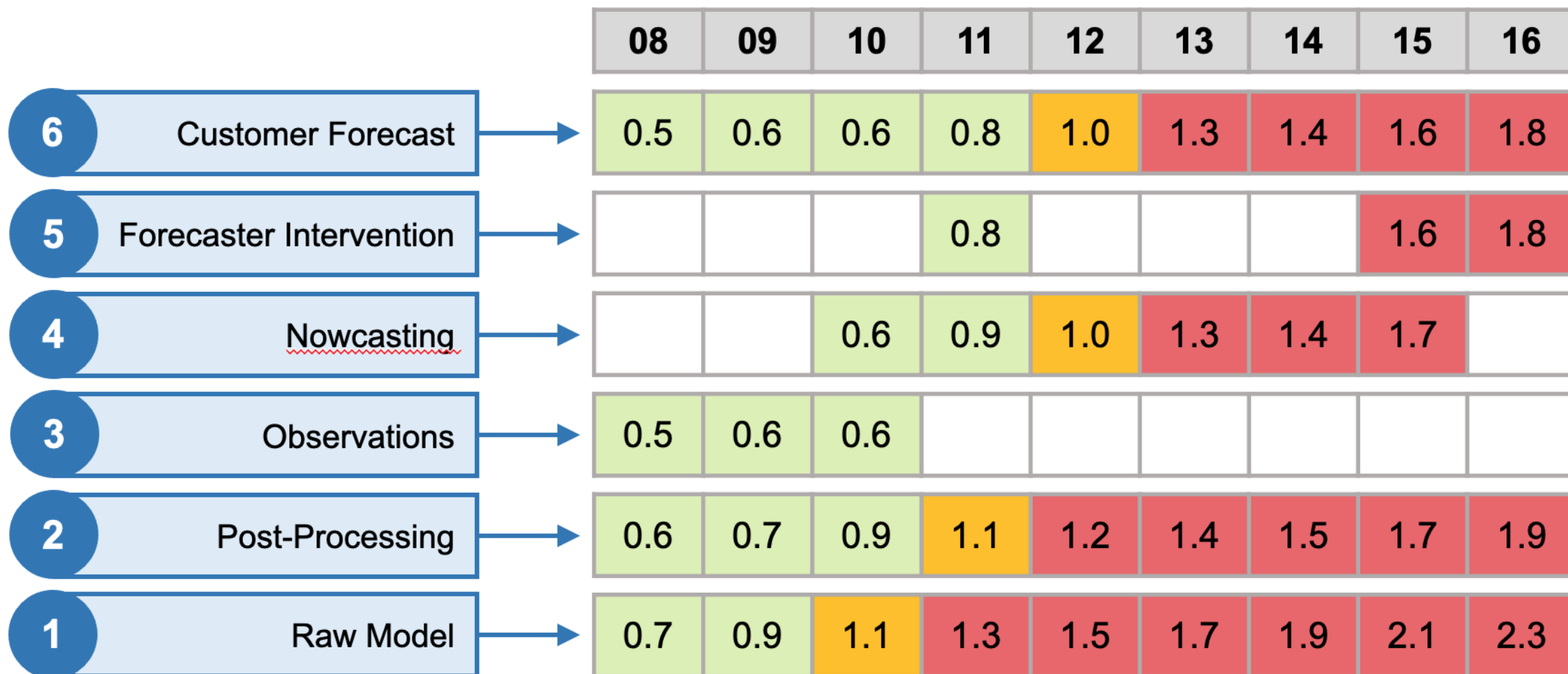
Weather patterns

Quality data sources



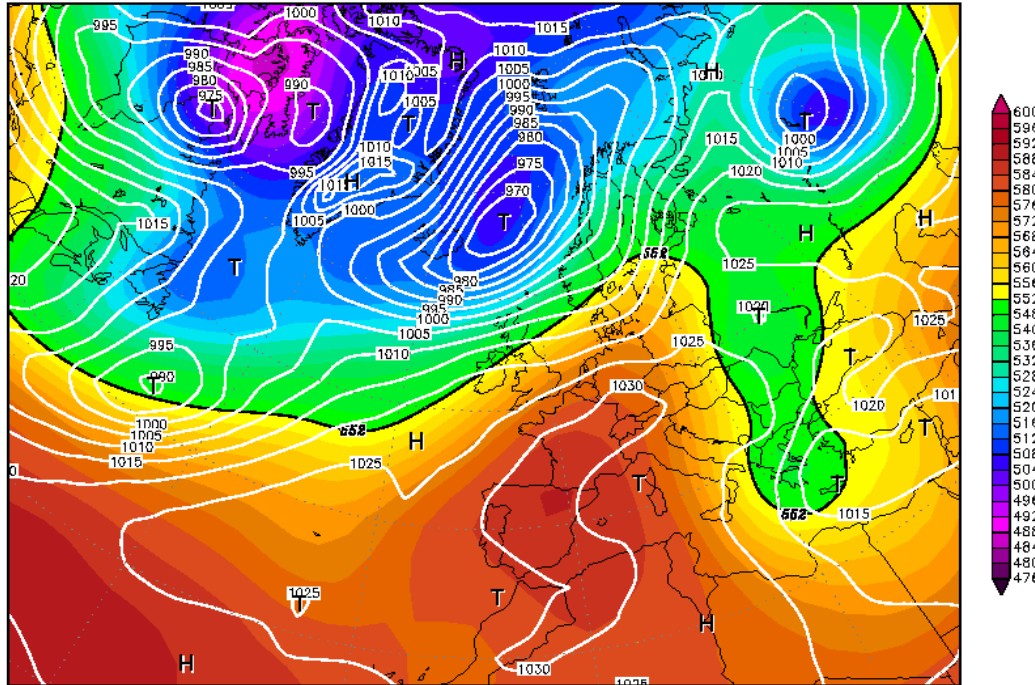
WeatherQuest

Site-specific forecasting: a multi-layer approach



Weather Patterns

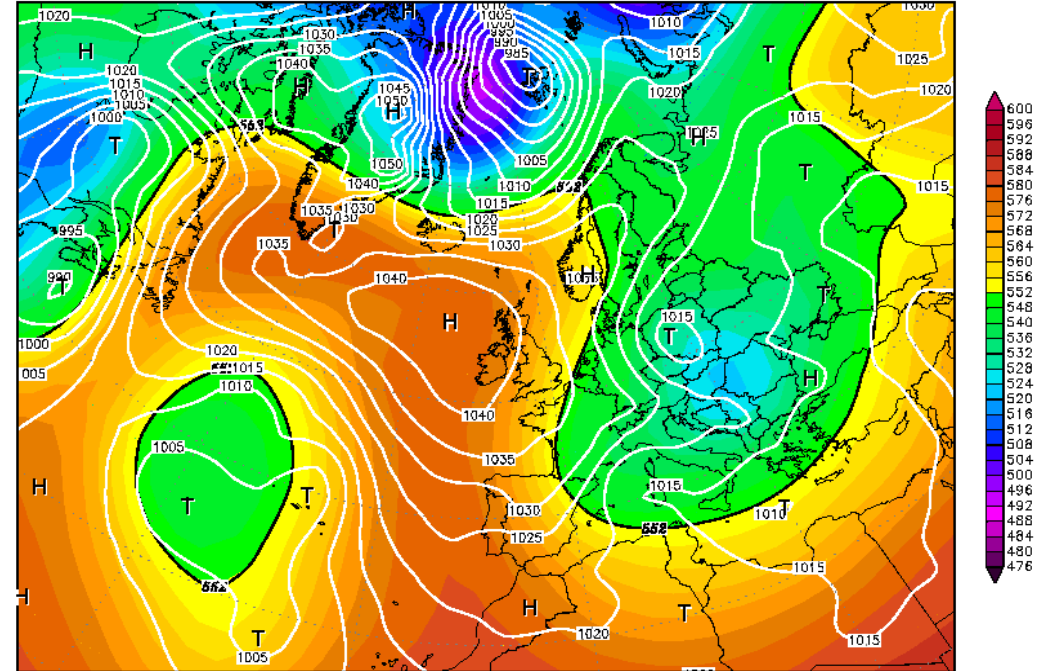
15DEC1998 00Z
500 hPa Geopotential (gpm) und Bodendruck (hPa)



Daten: Reanalysis des NCEP
(C) Wetterzentrale
www.wetterzentrale.de

Mobile westerly patterns bring unsettled conditions, but specific detail is very tricky

15DEC2010 00Z
500 hPa Geopotential (gpm) und Bodendruck (hPa)

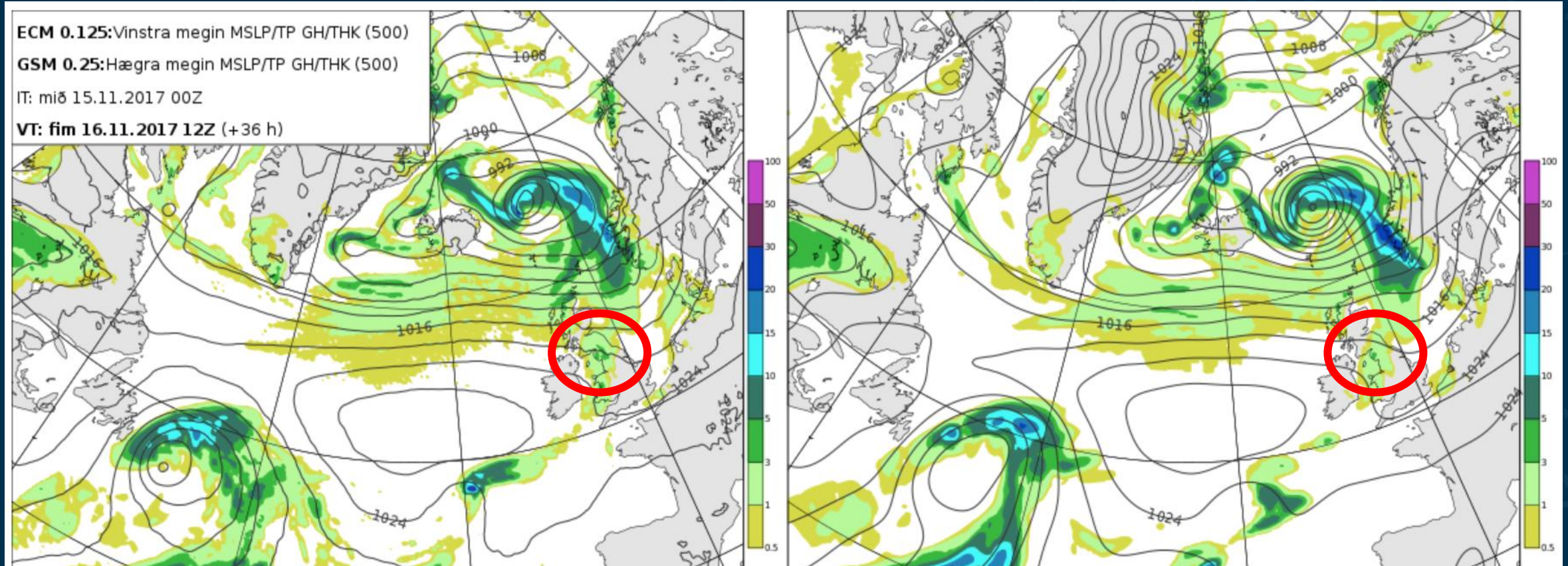


Daten: Reanalysis des NCEP
(C) Wetterzentrale
www.wetterzentrale.de

Blocked patterns are more predictable once they are established

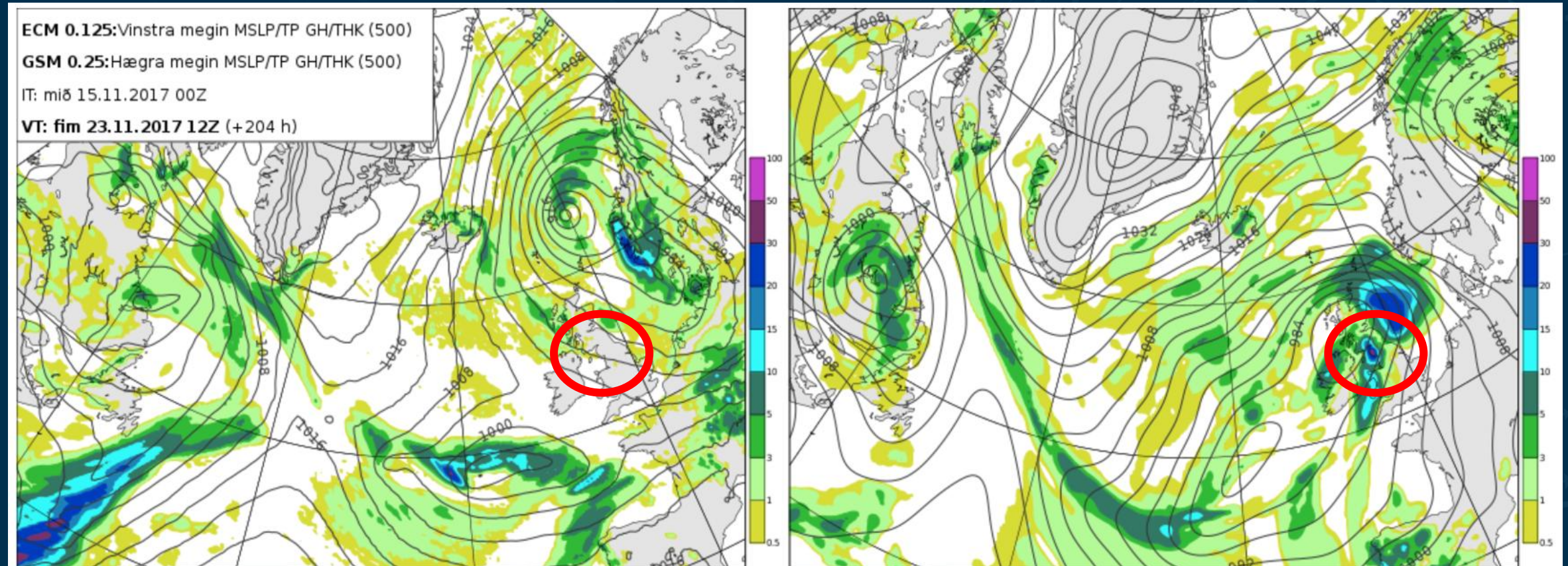
Weather Patterns

Mostly similar short-term forecasts - forecast for 1.5 days ahead...



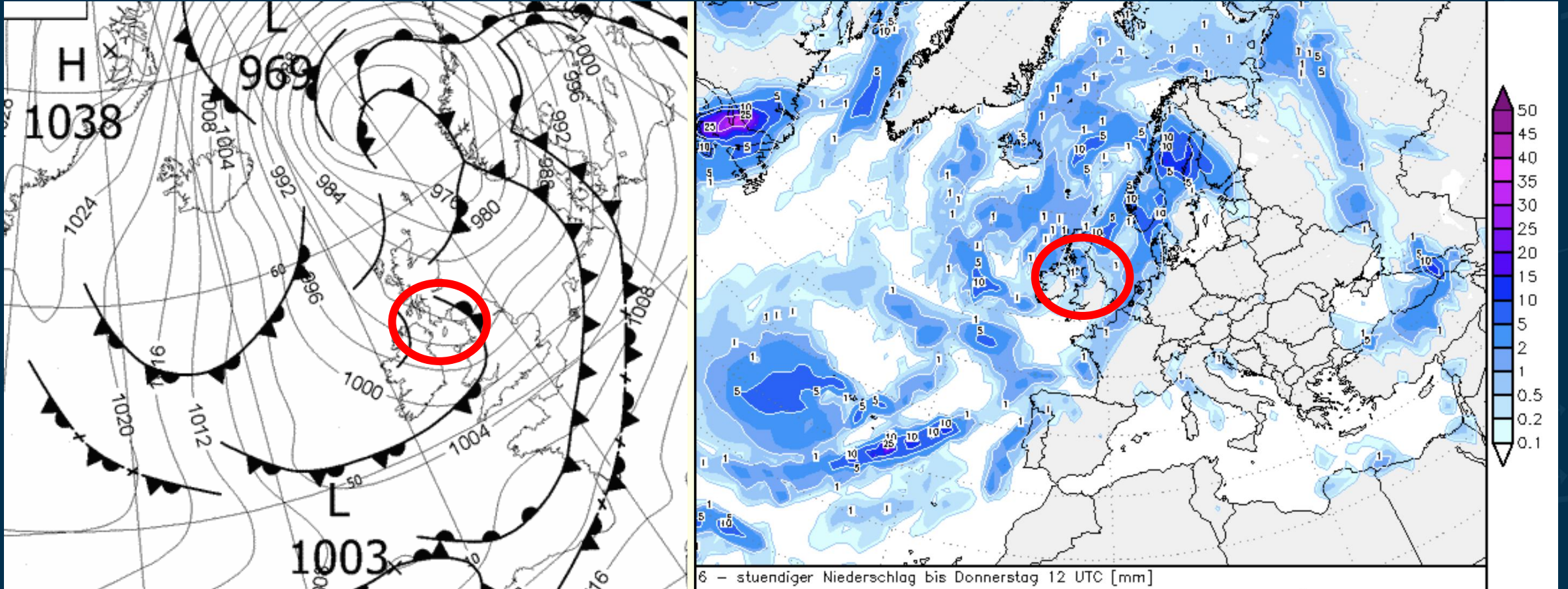
Weather Patterns

Uncertainty grows with time - forecast for 7.5 days ahead...

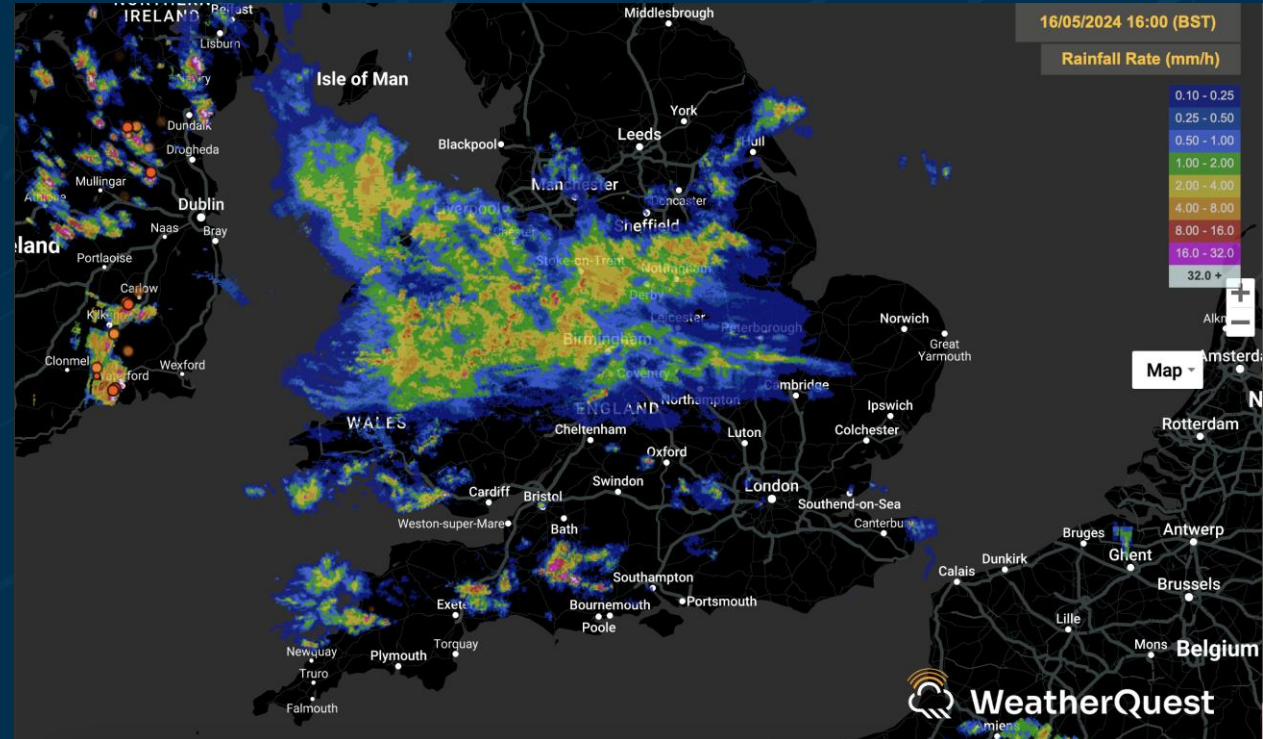
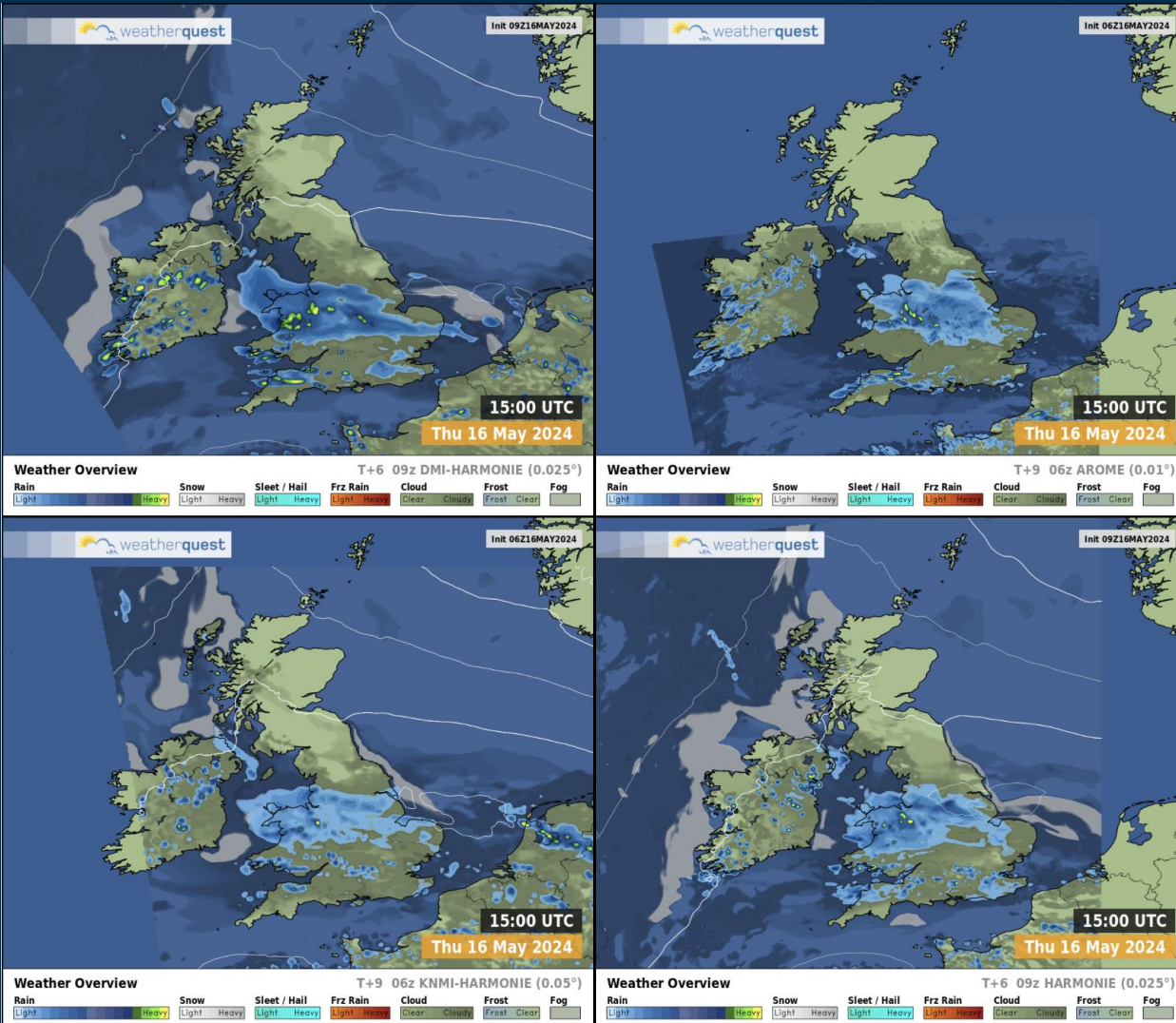


Weather Patterns

What actually happened...



The challenge of rain and showers












































Deterministic vs Ensemble forecasts

The advance of weather forecasting is progressing along two fronts: on one hand improving the observational network, the data assimilation system and the NWP models; on the other hand, accepting that the forecasts will always be imperfect, trying to provide a measure of the degree of uncertainty.

^ from the European Centre for Medium Range Weather Forecasting


Deterministic forecasts

Goodwood Racecourse																				PDF version
	5th Tue 0700	5th Tue 0800	5th Tue 0900	5th Tue 1000	5th Tue 1100	5th Tue 1200	5th Tue 1300	5th Tue 1400	5th Tue 1500	5th Tue 1600	5th Tue 1700	5th Tue 1800	5th Tue 1900	5th Tue 2000	5th Tue 2100	5th Tue 2200	5th Tue 2300	6th Wed 0000	6th Wed 0100	6th Wed 0200
	 Sunrise 06:37  Sunset 17:51																	 Sunrise 06:35		
Weather																				
Air Temp (°C)	5	5	6	7	8	9	9	9	9	9	8	7	5	5	4	4	4	4	4	
Ground Temp (°C)	5	5	6	10	11	11	11	11	11	10	10	7	5	4	4	4	4	3	3	
Grass Temp (°C)	4	5	6	8	9	9	9	10	10	9	9	7	5	4	3	3	3	3	2	
Dewpoint (°C)	5	5	6	6	6	6	6	5	6	6	6	5	4	4	3	3	3	3	3	
Humidity (%)	98	98	97	92	87	84	83	77	79	79	83	88	94	95	94	93	92	92	93	
Wind Speed (mph)	 3	 3	 3	 3	 4	 6	 8	 8	 8	 9	 8	 6	 4	 4	 5	 5	 6	 5	 6	
Gust Speed (mph)	7	7	8	9	11	13	15	15	15	17	16	16	9	8	8	10	10	9	9	
Maximum and Mean Rainfall (mm)						2.7														
	0.0	0.0	0.4	0.0	0.4		0.5	0.3	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	0.0	0.0	0.1	0.0	0.2	1.1	0.2	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Precip chance %	10%	20%	10%	20%	60%	50%	40%	40%	20%	10%	20%	10%	0%	0%	0%	0%	0%	0%	0%	
Maximum and Mean Snowfall (cm)																				
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Evaporation (mm)	0.00	0.03	0.06	0.11	0.10	0.11	0.19	0.12	0.12	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Solar Radiation (kJ/m2)	1	25	44	83	82	86	147	96	91	36	3	0	0	0	0	0	0	0	0	
Sunshine Hrs	0.0	0.1	0.0	0.1	0.0	0.0	0.2	0.1	0.2	0.2	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Total Cloud Cover (%)	100	93	100	95	100	100	82	90	77	79	18	34	54	7	14	54	50	40	44	

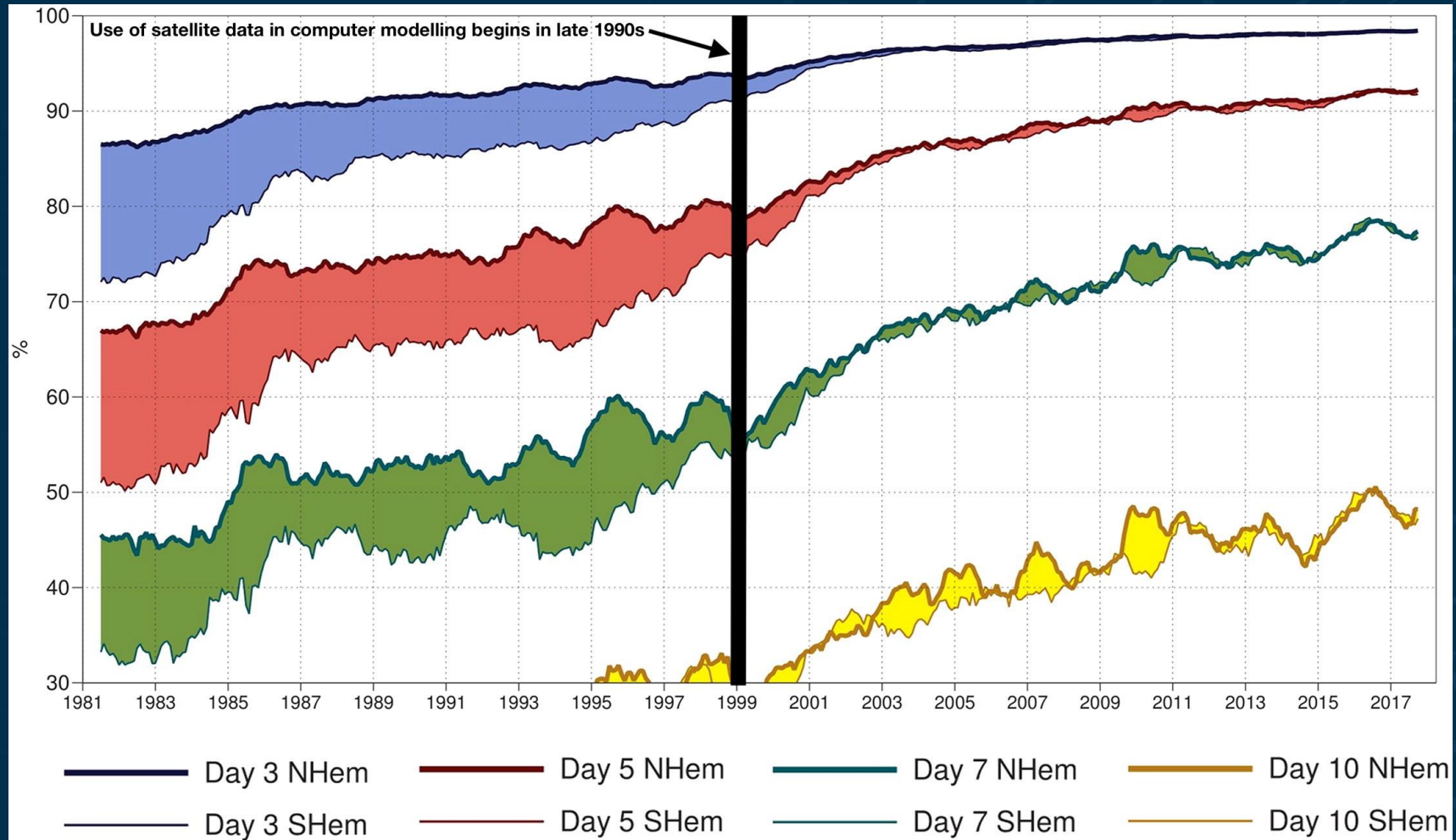
Ensemble (probability) forecasts

Goodwood Racecourse																																					
	Tue 05 Mar				Wed 06 Mar				Thu 07 Mar				Fri 08 Mar				Sat 09 Mar				Sun 10 Mar				Mon 11 Mar				Tue 12 Mar				Wed 13 Mar				
	00	06	12	18	00	06	12	18	00	06	12	18	00	06	12	18	00	06	12	18	00	06	12	18	00	06	12	18	00	06	12	18	00	06	12	18	
Precipitation minus Evaporation probability (%)																																					
≥ 80 mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
≥ 60 mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	6	6		
≥ 40 mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	4	4	6	8	10	12	18	18	16	16	14
≥ 25 mm	0	0	0	0	0	0	0	1	2	2	2	2	2	2	3	4	6	6	10	15	18	26	34	32	36	38	38	38	36	36	42	40	46	50	50	50	
≥ 10 mm	30	38	59	64	63	67	85	87	86	86	93	94	94	94	95	94	92	92	88	83	80	74	66	66	62	58	58	56	56	54	46	42	36	32	30	30	
≥ 5 mm	68	60	39	34	35	31	15	12	12	12	12	5	4	4	4	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
≥ 0 mm	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
≥ -5 mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
≥ -10 mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
≥ -25 mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
≥ -40 mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
≥ -60 mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
≥ -80 mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Air Temperature probability (%)																																					
35°C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
30°C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
25°C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
20°C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
15°C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
10°C	0	5	30	0	0	13	30	0	0	12	57	0	0	42	46	3	0	41	47	1	0	64	6	0	0	26	2	0	0	18	4	4	2	24	10	4	
5°C	12	68	69	23	4	54	66	23	18	62	43	64	19	58	54	70	63	59	53	85	62	36	94	56	38	72	82	34	20	70	66	24	28	64	62	34	
0°C	88	27	1	77	85	29	4	77	78	26	0	36	81	0	0	27	36	0	0	14	38	0	0	44	60	2	16	64	68	12	30	64	58	12	28	56	
-5°C	0	0	0	0	11	4	0	0	3	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	2	12	0	0	8	12	0	0	6		
-10°C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
-15°C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
-20°C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		

Ensemble (probability) forecasts

	Goodwood Racecourse																VL	L	M	H	VH						
	Subseasonal Outlook		50.89°N, -0.74°E				Issued 07:24 Tue 05 Mar 2024						Very Low	Low	Medium	High	Very High										
Likelihood of...all variables cover the period midnight to midnight																											
	Tue 05 Mar	Wed 06 Mar	Thu 07 Mar	Fri 08 Mar	Sat 09 Mar	Sun 10 Mar	Mon 11 Mar	Tue 12 Mar	Wed 13 Mar	Thu 14 Mar	Fri 15 Mar	Sat 16 Mar	Sun 17 Mar	Mon 18 Mar	Tue 19 Mar	Wed 20 Mar	Thu 21 Mar	Fri 22 Mar	Sat 23 Mar	Sun 24 Mar	Mon 25 Mar	Tue 26 Mar	Wed 27 Mar	Thu 28 Mar	Fri 29 Mar	Sat 30 Mar	Sun 31 Mar
MAX Temp: Above-Avg	M	M	M	M	M	M	VL	VL	VL	VL	VL	L	L	L	L	L	L	L	L	L	VL	VL	VL	VL	L	L	L
MAX Temp: Below-Avg	VL	VL	VL	VL	VL	VL	L	M	L	L	L	VL	L	VL	L	VL	VL	VL	L	L	L	L	L	M	L	L	L
MIN Temp: Above-Avg	L	VL	VL	VL	M	L	VL	VL	VL	L	L	M	M	L	L	L	L	L	L	L	L	L	L	L	L	L	L
MIN Temp: Below-Avg	VL	M	M	VL	VL	VL	L	M	L	L	L	L	VL	VL	L	VL	VL	VL	L	L	L	L	L	L	VL	VL	L
Frost	M	M	M	VL	VL	VL	L	M	L	L	L	L	VL	VL	L	VL	VL	VL	VL	L	L	L	L	L	VL	VL	VL
Significant Rain	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	L	VL	VL	VL	VL	VL	VL	VL
Dry Day	M	VH	VH	VH	M	L	H	H	M	H	M	M	M	M	M	M	L	M	M	M	M	M	M	L	M	M	M
Solar Radiation: Above-Avg	M	M	H	VH	M	L	L	VL	VL	L	L	VL	VL	VL	L	L	L	L	L	L	L	L	VL	VL	L	L	L
Solar Radiation: Below-Avg	VL	VL	VL	VL	VL	L	L	M	L	L	L	L	M	L	L	VL	L	L	L	L	L	L	M	L	L	L	L
Light Winds	VH	VH	M	M	M	H	M	H	M	L	M	L	M	M	M	M	M	M	L	M	M	M	M	M	M	M	M
Strong Winds	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
Significant Snow	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL

Improving forecast accuracy with time



ECMWF weather model forecast accuracy over time correlated to satellite data integration. Forecasts for 3, 5, 7, and 10 days (shown as D+3, D+5, etc.) all experienced vast improvements starting in the late 1990s. (figure adapted from Schmetz and Menzel (2015)).

Managing expectations

What can modern weather forecasting do?

- Generally very solid guidance in the Day 1-3 period, sometimes out to Day 4-7.
- Pattern recognition in the 2-4 week period
- Better than flipping a coin on seasonal forecasts
- Post-processing / AI advancements are also improving forecasts (comparing model forecast to observations to correct biases after the model runs)

What can't modern weather forecasting do?

- Tell you exactly where a shower or thunderstorm will develop (or exactly to the minute what time it will start or stop raining)
- Give you specific detail in a forecast beyond Day 4-7 (usually)
- Tell you if the upcoming summer will have an extreme heat wave / drought or if there will be widespread flooding (or if the winter is going to have a significant cold snap, etc) – high impact events are difficult to forecast well in advance

Forecasts will still occasionally be wrong (but much less so than in the past)!

Don't believe everything you read



EXPRESS

Coldest winter for 50 YEARS set to bring MONTHS of heavy snow to UK

BRITAIN is facing the most savage winter in more than 50 years with months of heavy snowfall and bitter Arctic winds set to bring the country to a total standstill.

By **NATHAN RAO**
03:10, Thu, Sep 17, 2015 | UPDATED: 11:47, Thu, Feb 11, 2016

EXPRESS

100 DAYS OF HEAVY SNOW: Britain now facing worst winter in SIXTY YEARS warn forecasters

LONG-RANGE weather forecasters have warned that Britain should prepare for heavy and persistent snow for up to THREE MONTHS with winter 2013 set to be the worst in more than 60 years.

By **NATHAN RAO**
00:10, Sun, Nov 17, 2013

- 2013 Headline
- Conflicting headlines written about the same summer!
- (top 14% driest summer on record)
- 2015 Headline
- The Winter of 2015/16 ended up being the 3rd warmest winter on record for the UK!
- 2013 Headline
- The Winter of 2013/14 ended up being the 7th warmest winter on record for the UK

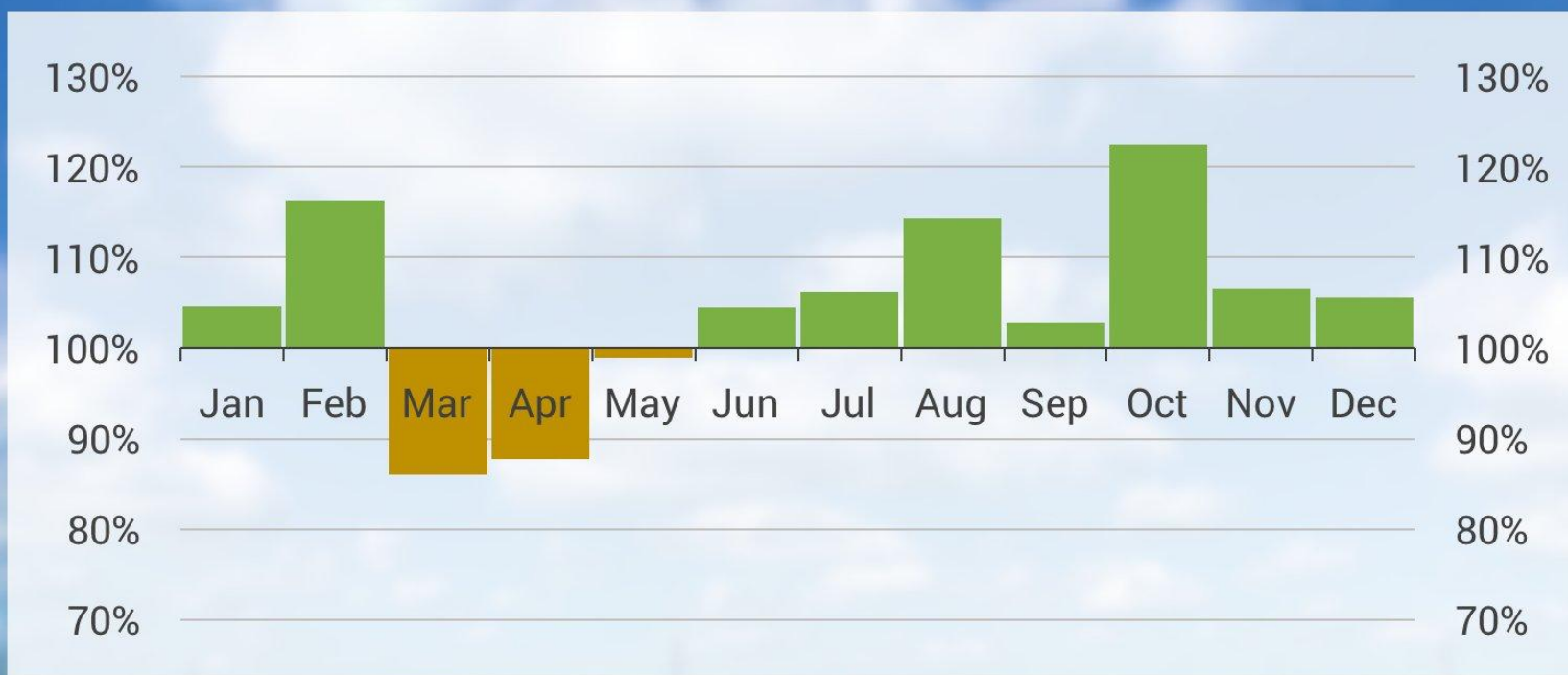
- Tabloids often publish misleading weather headlines
- Extreme weather headlines sell more copies
- These headlines get picked up in everyday conversation and become the story. ie, “*they say* it’s going to be...”
- Check the sources...reputable organisations are usually not quoted (and when they are, it’s a more reasonable quote)
- Images from long range forecast models which very rarely verify are sometimes used

Climate Change Impacts on the British Isles

- Summer **Heat Waves** will become more frequent
- Generally **wetter** – especially during Autumn and winter
 - Some evidence that springs could be drier
- Heavy downpours / **flash flooding** up to 4x more likely
- No strong signal on drought, although reduced soil moisture due to increase evaporation in summer
- Cold spells / snow / hard frost less common
- Growing season lengthening (although risk of frost damage and disease perhaps increasing?)

EAST ANGLIA

Change in average rainfall, 1991-2020 vs 1961-1990

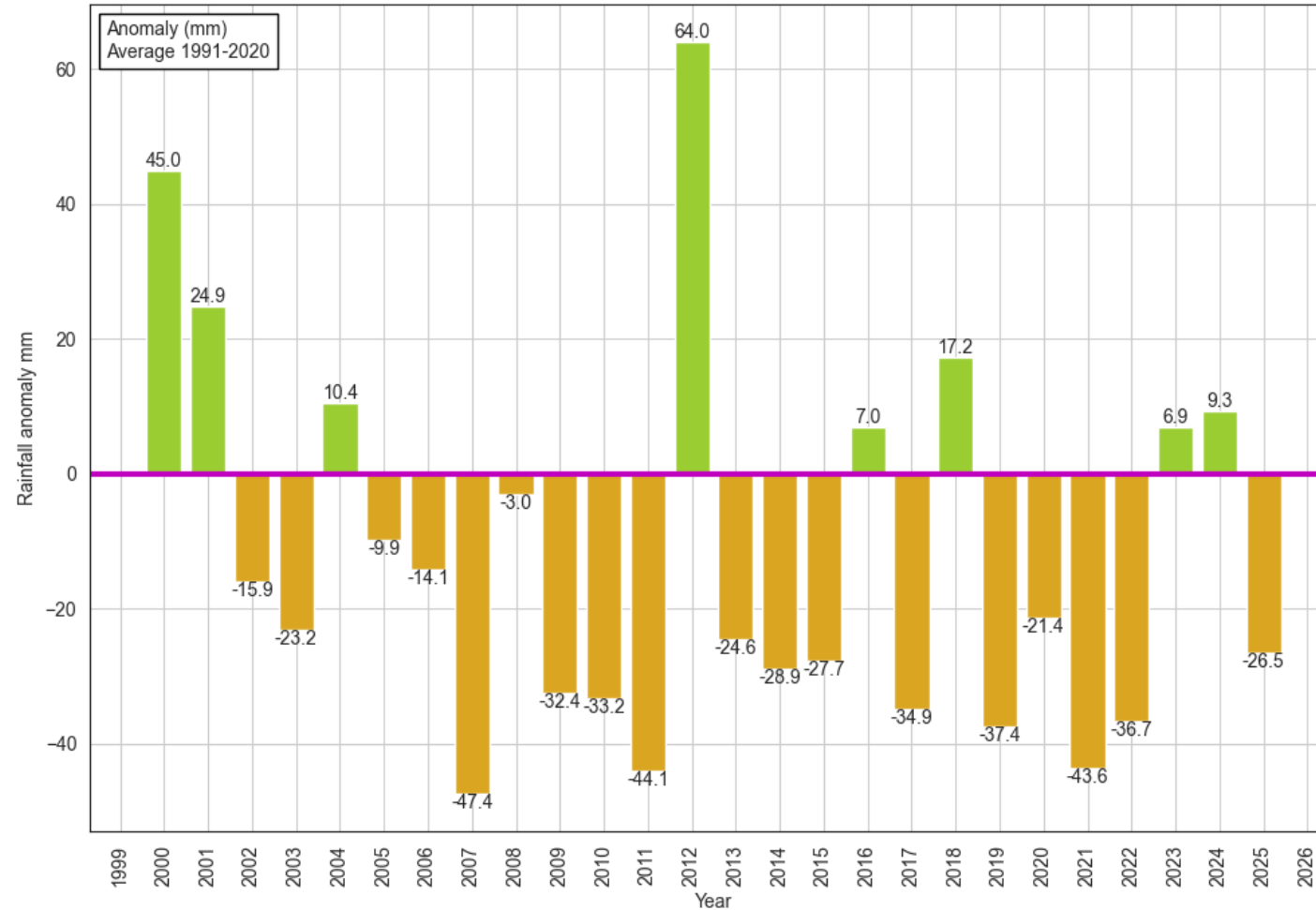


Data: Met Office HadUK-Grid

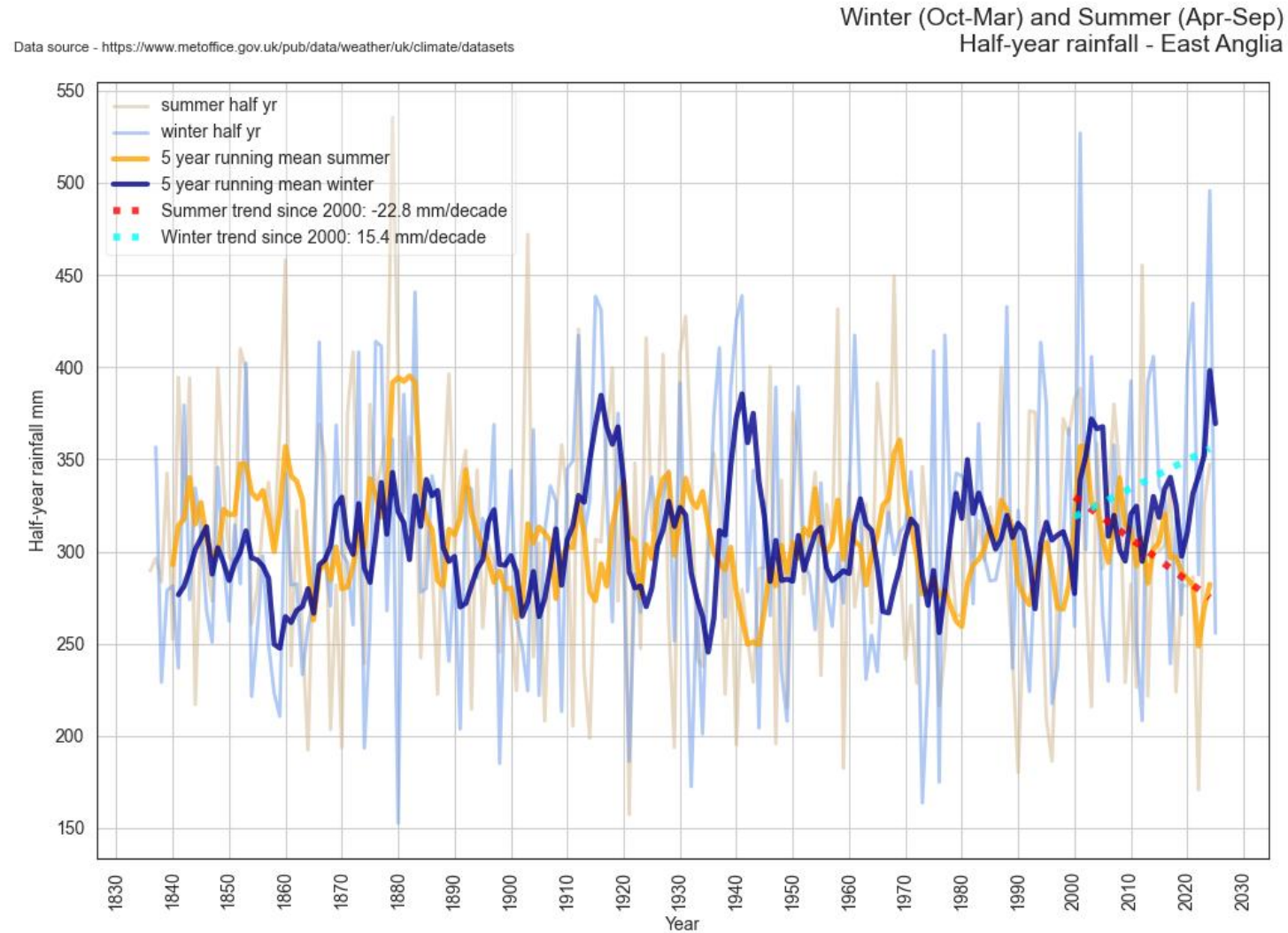
Rainfall trends in April – East Anglia

Data source - <https://www.metoffice.gov.uk/pub/data/weather/uk/climate/datasets>

April total rainfall - East Anglia



Rainfall trends in Summer vs Winter – East Anglia



Questions? and thank you.

chris.bell@weatherquest.co.uk

[+44 \(0\) 1603 507605](tel:+441603507605)

info@weatherquest.co.uk

The Enterprise Centre,
University of East Anglia,
Norwich Research Park,
Norwich, NR4 7TJ

