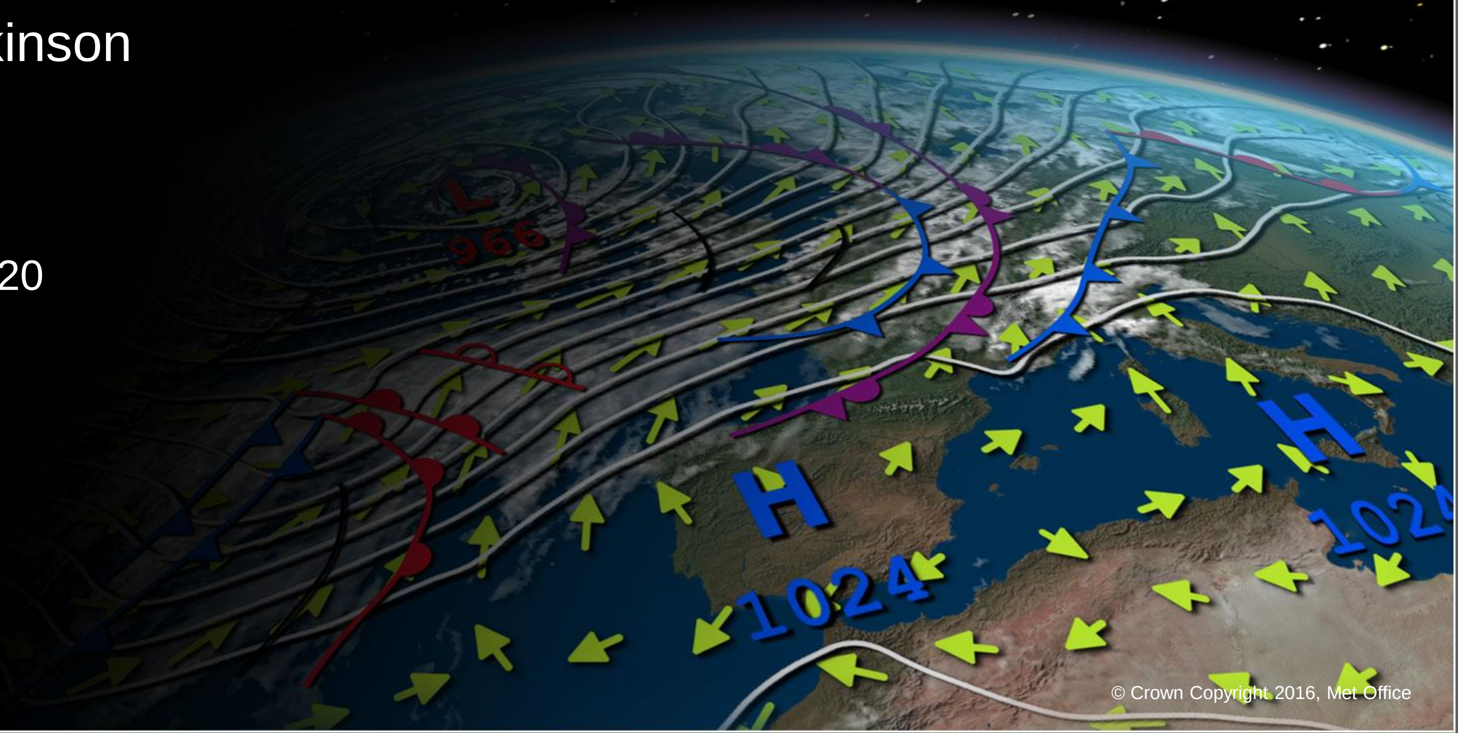
Lightning Parametrization and forecasting developments in Met Office LAMs

Jonathan Wilkinson

EWGLAM

28 September 2020



About me.

- Background: Cloud microphysics modelling.
    - Develop and maintain the Unified Model microphysics:
        - Wilson and Ballard (1999)
        - Cloud-AeroSol Interacting Microphysics (CASIM) : New scheme being developed.
- Lightning Parametrization (& forecasting aspects) – speciality.

UK thunderstorm hazards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Lightning strike death on Highlands mountain was 'freak accident'

9 June 2019

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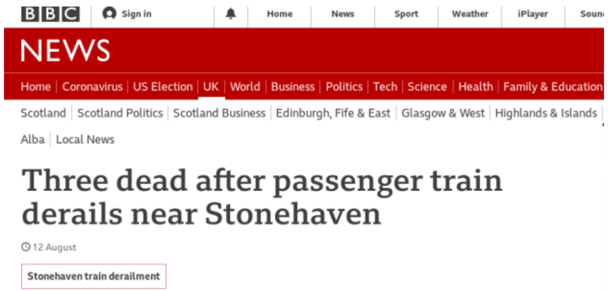
Courtesy BBC Website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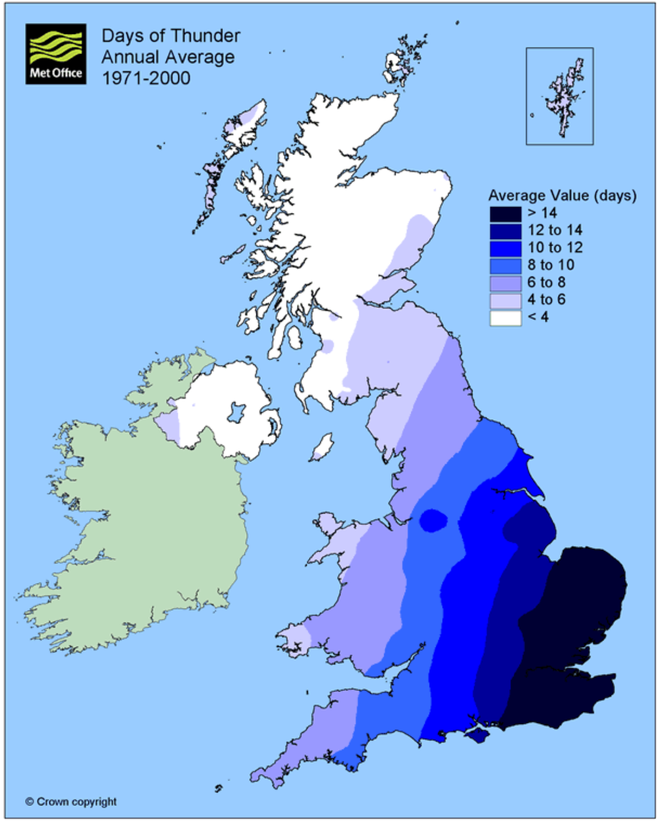
Three dead after passenger train derails near Stonehaven

12 August

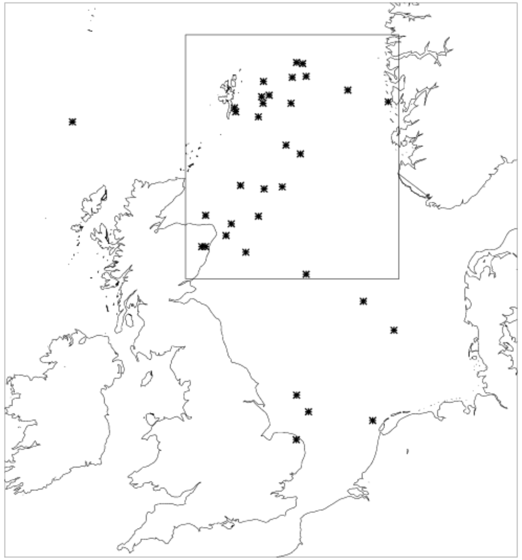
Stonehaven train derailment


The derailment took place on the line west of Stonehaven



Helicopter-Triggered Lightning

Wintertime phenomena:
Transport Helicopters travelling to North Sea Oil/Gas rigs struck by lightning when not expected.



Wilkinson et al (2013, Met. Apps)
Mäkelä et al (2013, BAMS) – fixed wing in Finland.

This case had no observed lightning!

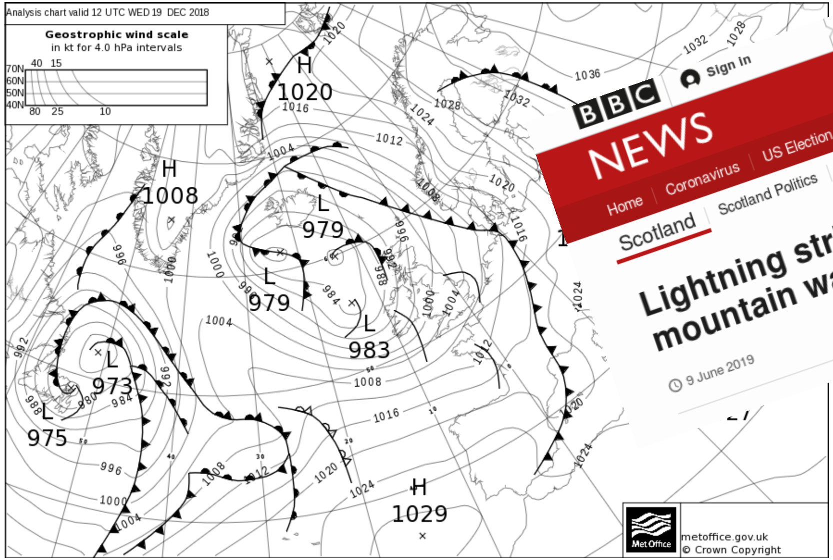


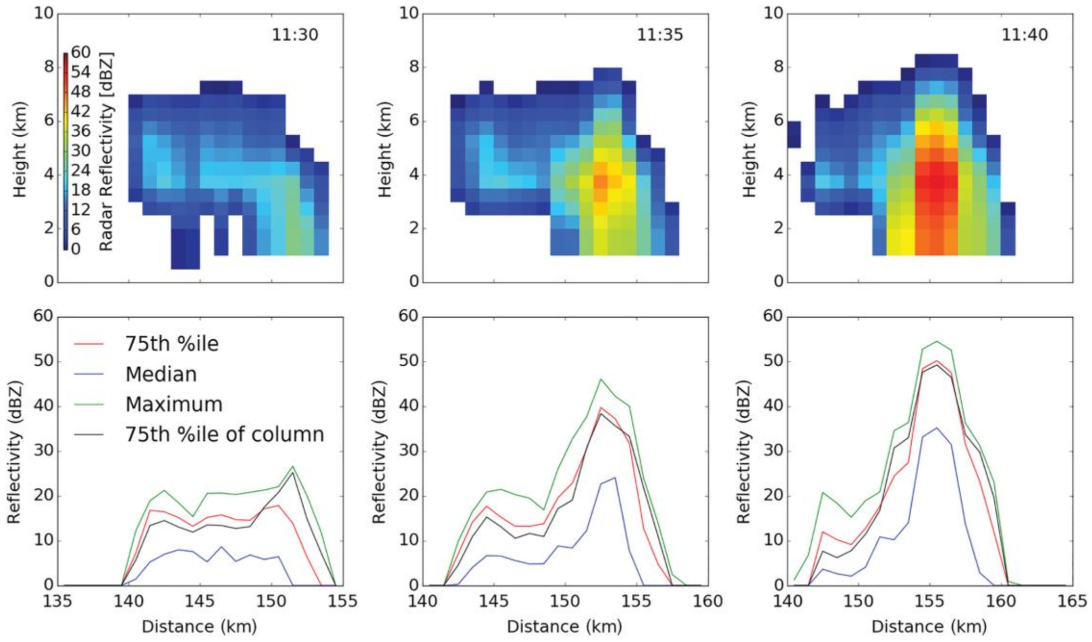
Photo: William Means 0838Z on 19 Dec 2018. Maritime Cb., SW England (near Met Office)

Rapid Storm Intensification Prior to Lightning

UK storms have rapid intensification prior to first lightning.

Radar reflectivity ↑.

Updraught velocity, updraught area & graupel mass also ↑.



Courtier, B. M. et al. (2019, Atmospheric Science Letters). https://doi.org/10.1002/asl.873

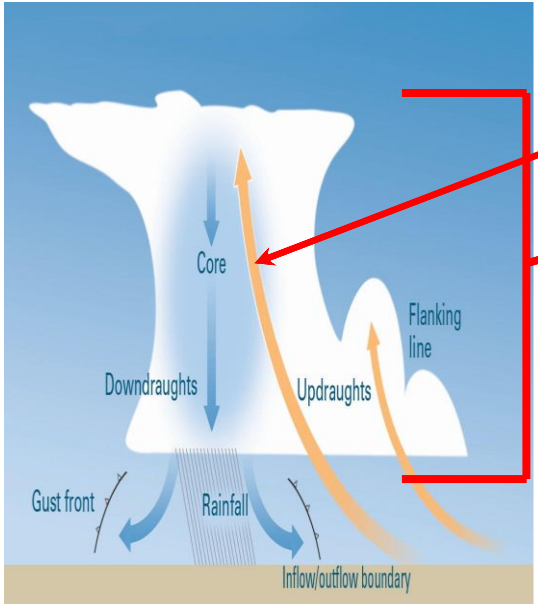
Forecasting Techniques & Methods

- Large-scale stability indices (e.g. CAPE/CIN, Lifted Index).
- High-resolution modelling:
  - Statistical Lightning Parametrizations – such as at Met Office.
  - Lightning Potential Index (after Yoav Yair – function of vertical velocity and hydrometeor water contents).
  - Explicit charging schemes (e.g. Barthe and Pinty, Fierro et al, **Courtier et al**.) – can be expensive.

McCaul et al (2009) Lightning parametrization
(Weather and Forecasting)

$$F = 0.95F_1 + 0.05F_2$$

$$F_1 = 0.042 w q_g(-15°C)$$



$$F_2 = \int \rho(q_i + q_s + q_g)dz$$

In words

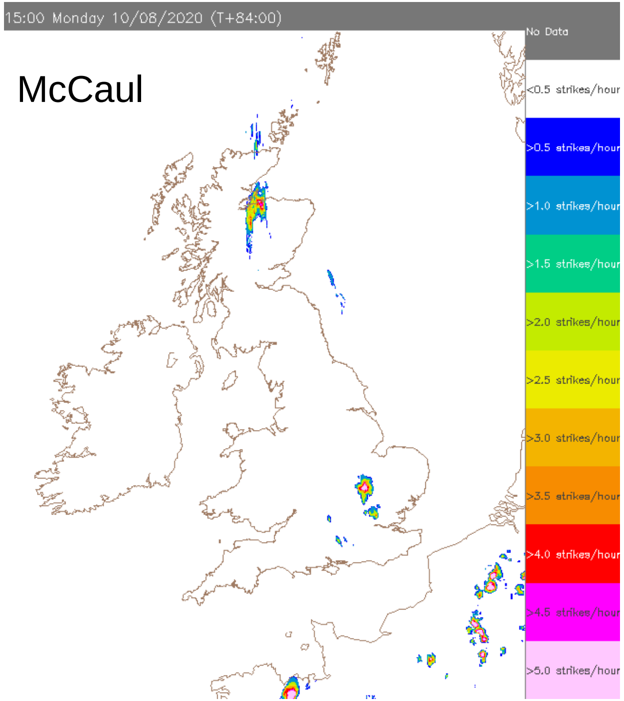
Number of lightning flashes is:

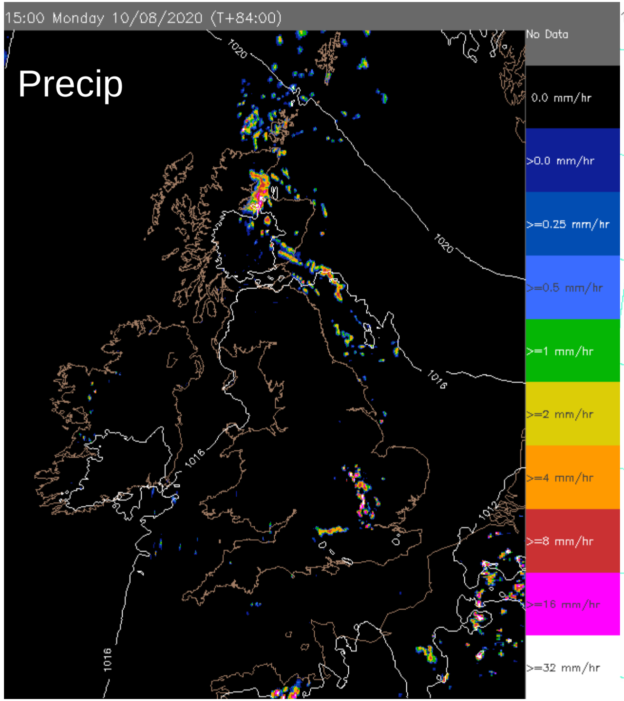
- 95% due to the upward flux of graupel (soft hail) at -15 Celsius level; and

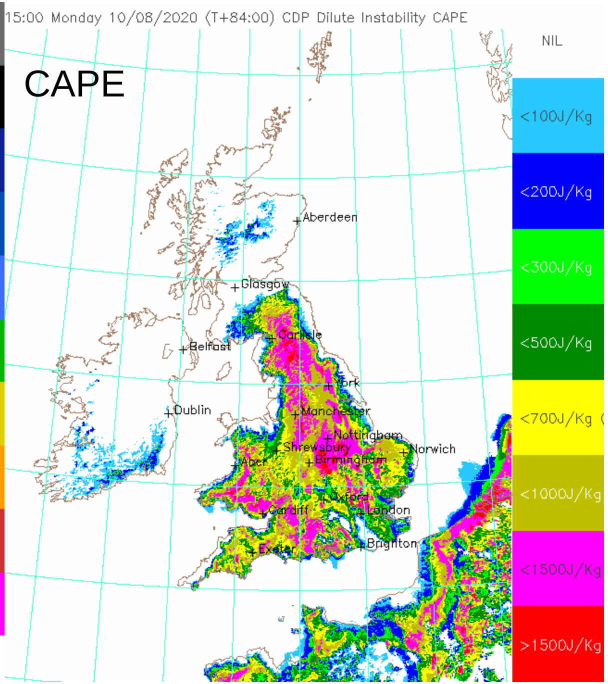
- 5% due to the total ice mass (ice+snow+graupel) in the column.

Sample forecast output

03Z 7 Aug, Valid 15Z
10 Aug (T+84 h)

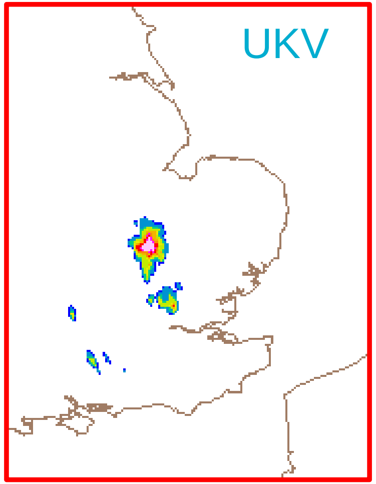


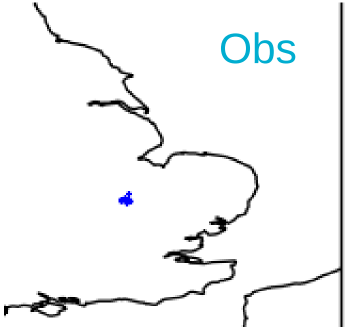


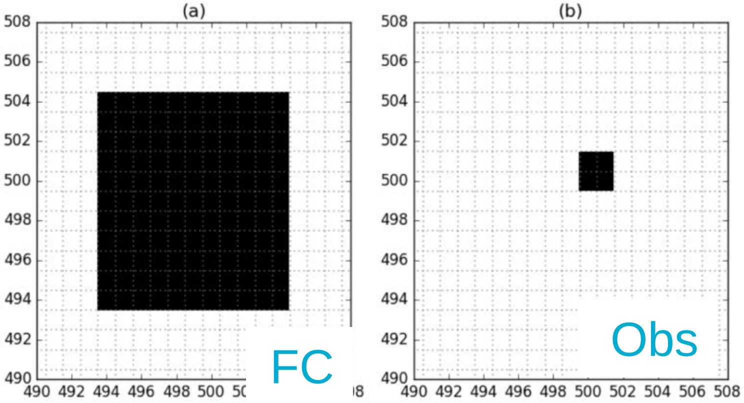


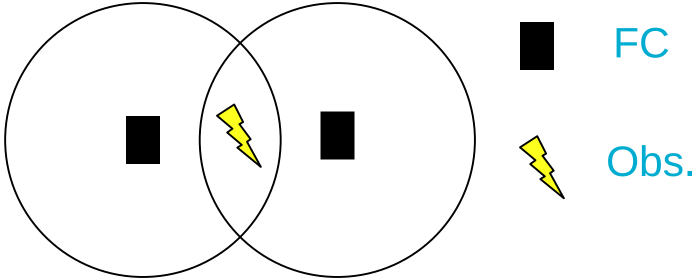
Lightning verification

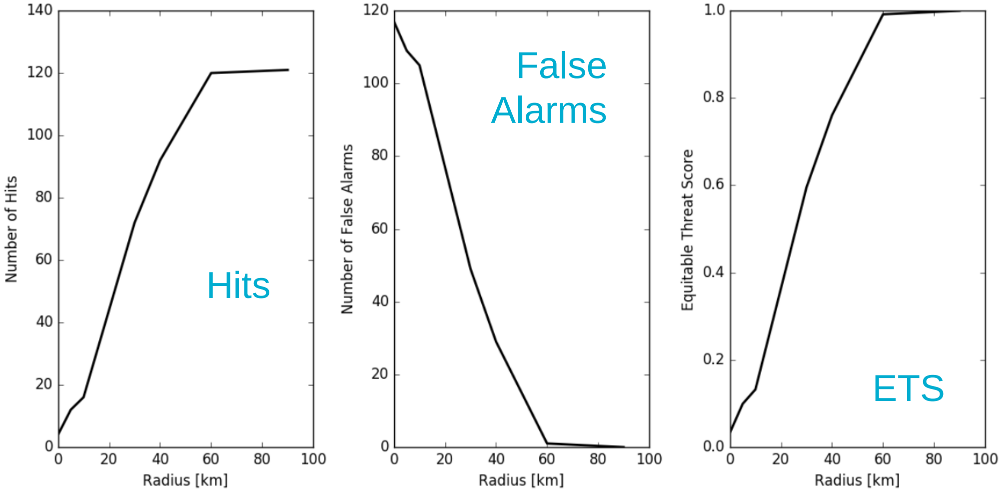
- Parametrization produces direct equivalent to observations (unlike e.g. CAPE).
- High grid resolution of LAMs means suffering from the double-penalty effect at grid scale.
    - Miss by 1 grid box = 1 miss and 1 false alarm.
- CG-Lightning is an instantaneous, point measurement (compared to e.g. precipitation).
- But flashes can also pass over several grid cells.
- Model output is ‘flash origin densities’.
- No lightning sensor is 100% efficient.
    - Met Office ATDnet: ~90% CG; 26% IC.











Forecasts often biased – often quite high bias compared to other parameters.

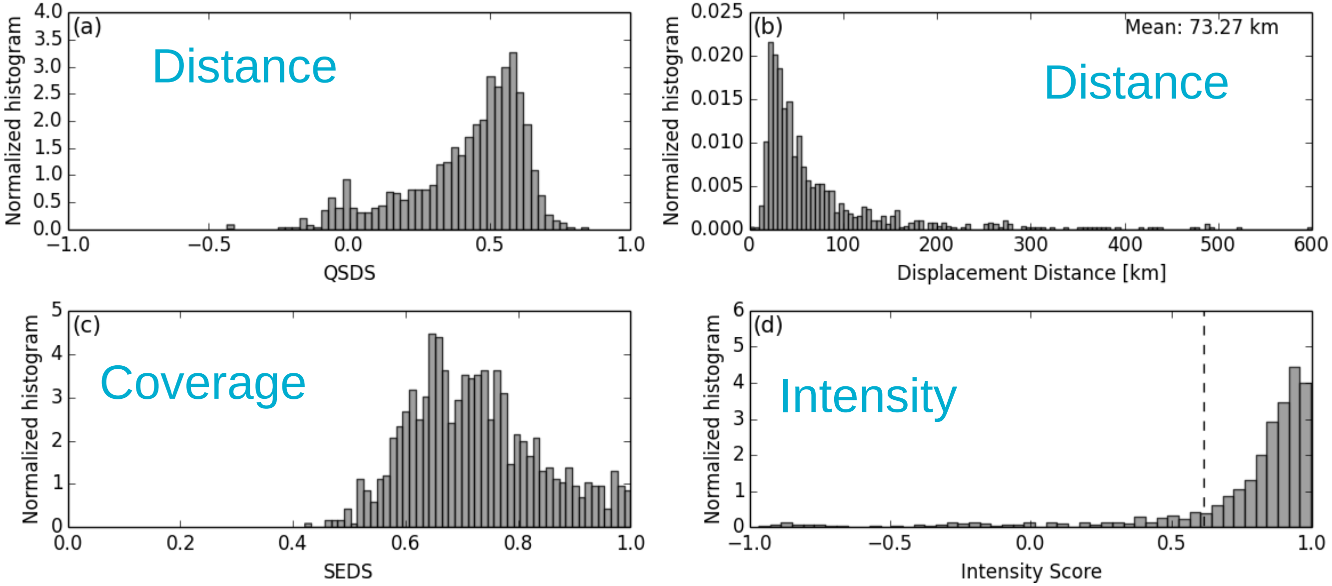
Many studies use the Clark et al (2010) method, developed for precipitation, but applied to lightning.

But potentially flawed if bias ≠ 1

FSS not good in biased case either.

Lightning Verification

- Percentile thresholds?
- My technique: three forecast properties evaluated:
  - Coverage
  - Intensity (num. strikes)
  - Distance to/from forecasts



UKV, June 2016 results from Wilkinson (2017)

- UKV performs well in distance (top row).
- Coverage good.
- Too intense by factor of 5, including accounting for Obs. bias.

Lightning Verification

- Percentile thresholds?
- My technique: three forecast properties evaluated:
  - Coverage
  - Intensity (num. strikes)
  - Distance to/from forecasts

Volume 32, Issue 1
February 2017

RESEARCH ARTICLE | 4 JANUARY 2017

A Technique for Verification of Convection-Permitting NWP Model Deterministic Forecasts of Lightning Activity

Jonathan M. Wilkinson

Wea. Forecasting (2017) **32** (1): 97–115.
https://doi.org/10.1175/WAF-D-16-0106.1 Article history

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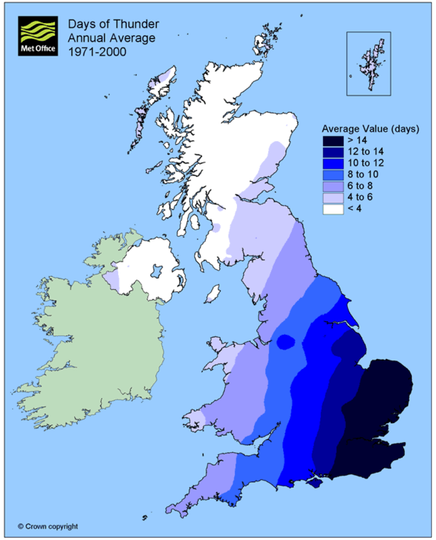
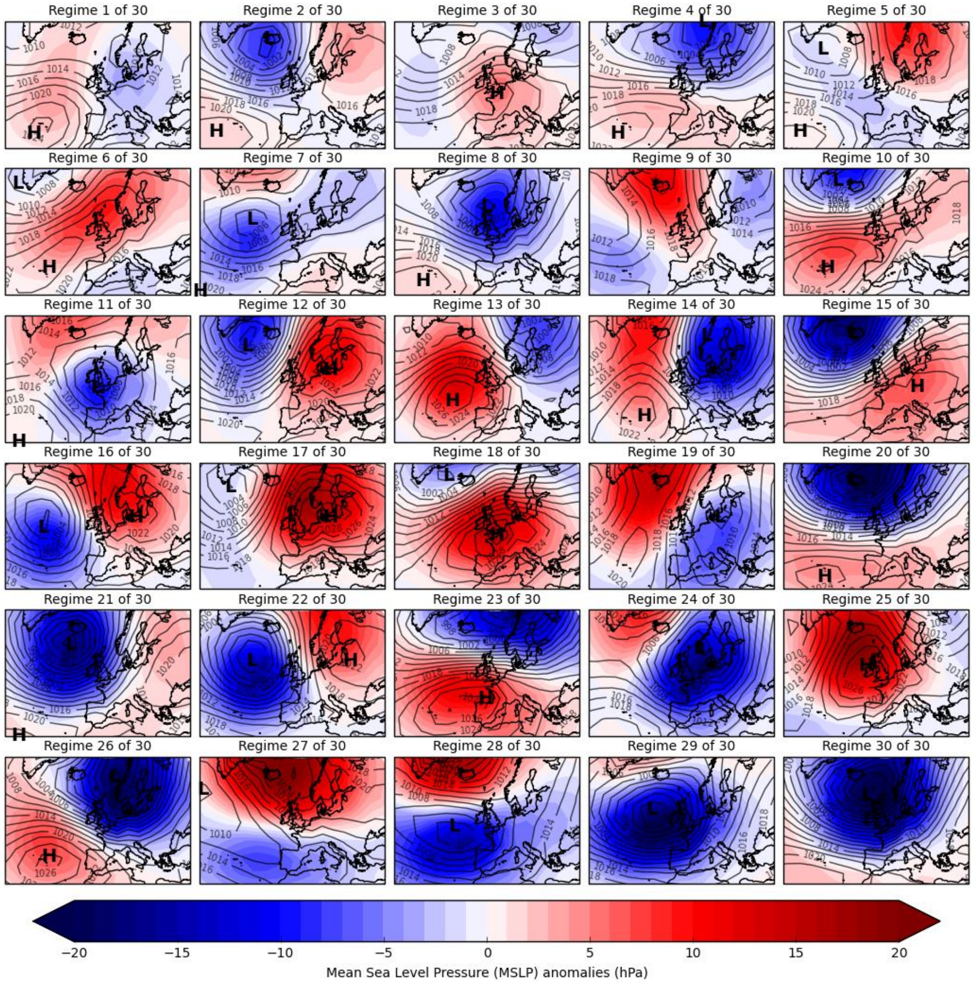
Still a work in progress. If any verification people would like a new challenge…

- Decider has set of 30 weather patterns based solely on mean sea level pressure.
- Forecast tool shows which patterns are predicted based on Global model outputs (e.g. ECMWF).





Met Office

Today's 00Z ECMWF

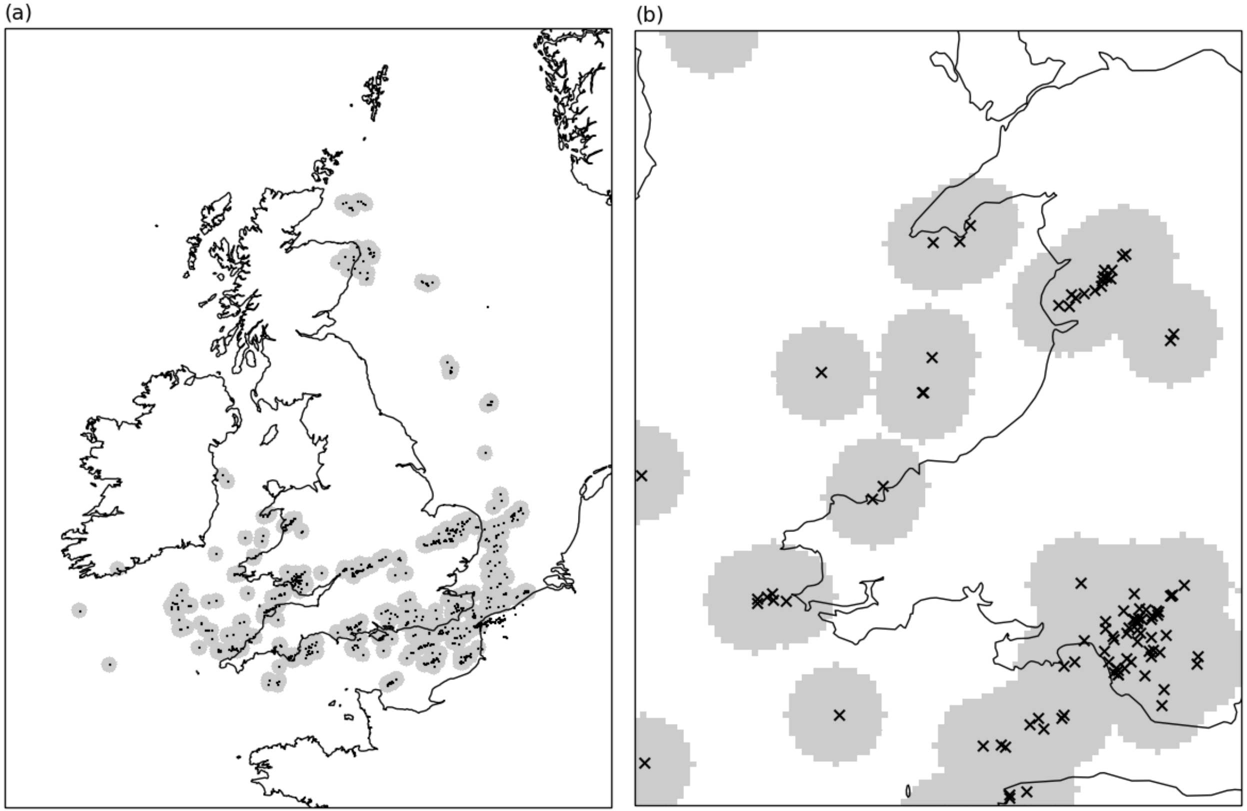
	Mon 28 Sep	Tue 29 Sep	Wed 30 Sep	Thu 1 Oct	Fri 2 Oct	Sat 3 Oct	Sun 4 Oct	Mon 5 Oct	Tue 6 Oct	Wed 7 Oct	Thu 8 Oct	Fri 9 Oct	Sat 10 Oct	Sun 11 Oct	Mon 12 Oct	Regime Descriptions (UK)
Regime 1								2	12	12	2	2	4	6	4	Unbiased NWly
Regime 2		100	94		2			2	4	6	18	2	4	2		Cyclonic SWly, returning Pm airmass
Regime 3											2	10	2			Anticyclonic SWly, ridge over N France
Regime 4									2	6	6	6	2	4	4	Unbiased Wly
Regime 5										4	8	8	6	8	6	Unbiased Sly, high over Scandinavia
Regime 6												4	6	8	10	Anticyclonic, Azores high ext.
Regime 7										8	6	10	4	4		Cyclonic SWly, low WNW of Ireland
Regime 8			6	75		4	16	39	43	31	22	2	2	4	6	Cyclonic Wly, low near Shetland
Regime 9												4	8	4	4	Anticyclonic N-NEly, high near Iceland
Regime 10	100											2			4	Anticyclonic W-SWly, slight Azores ridge
Regime 11				14	18	8	2	2	2	4	10	12	10	4	4	Cyclonic, low centred over southern UK
Regime 12												8	2			Anticyclonic Sly, high over Poland
Regime 13												4	12	14	14	Anticyclonic NWly, high SW of Ireland
Regime 14											2	2		4	6	Cyclonic N-NWly, low near S Sweden
Regime 15													2	4		Unbiased SWly, very windy NW Britain
Regime 16													2			Anticyclonic S-SEly, high E of Denmark
Regime 17												2	4	6	4	Anticyclonic E-SEly high over Denmark
Regime 18											4	4	6	4	6	Anticyclonic SWly, high over N France
Regime 19										2	6	2	2	8	10	Unbiased Nly, low E of Denmark
Regime 20								2	2		2					Cyclonic Wly, intense low near Iceland
Regime 21							2	8	4	2	6	6	2	2	2	Cyclonic SWly, deep low S of Iceland
Regime 22											4	6	6	2		Cyclonic Sly, low W of Ireland
Regime 23													4		4	Unbiased Wly, windy in N
Regime 24				12	75	86	67	35	18	16	2	2	2			Cyclonic Nly, low in N Sea
Regime 25												2	6	10	8	Anticyclonic Nly, high centre Irish Sea
Regime 26														2	4	Cyclonic NWly, low near Norway, windy
Regime 27												2	4	2	2	Anticyclonic Ely, high in Norwegian Sea
Regime 28																Cyclonic SEly, low SW of UK
Regime 29					4	2	4	2	2	4	2					Cyclonic S-SWly, deep low W of Ireland
Regime 30					2		10	8	12	6						Cyclonic W-SWly, deep low SE of Iceland
Total Members	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	---

Climatology

	D/J/F	J/F/M	F/M/A	M/A/M	A/M/J	M/J/J	J/J/A	J/A/S	A/S/O	S/O/N	O/N/D	N/D/J	Mean occurrence
Regime 1	1.8%	1.9%	3.1%	5.1%	8.3%	12.0%	14.4%	12.7%	8.4%	4.1%	2.6%	2.0%	6.4%
Regime 2	2.3%	2.6%	3.4%	5.0%	7.0%	8.9%	9.7%	9.2%	7.5%	5.4%	3.8%	2.8%	5.6%
Regime 3	1.9%	1.9%	2.7%	4.3%	6.4%	8.8%	9.9%	9.3%	7.1%	4.7%	3.3%	2.3%	5.2%
Regime 4	2.2%	2.3%	3.1%	4.4%	5.7%	6.9%	7.5%	7.8%	6.7%	5.2%	3.5%	2.6%	4.8%
Regime 5	2.4%	2.3%	3.0%	4.3%	5.8%	7.3%	8.0%	7.9%	6.3%	4.6%	3.3%	2.6%	4.8%
Regime 6	2.7%	3.1%	4.1%	5.3%	6.5%	6.8%	7.0%	6.6%	5.8%	4.4%	3.4%	2.8%	4.9%
Regime 7	2.1%	2.6%	3.5%	5.4%	7.3%	8.4%	8.5%	6.9%	5.4%	3.6%	2.8%	2.2%	4.9%
Regime 8	2.7%	2.6%	3.3%	4.3%	5.3%	6.0%	6.7%	6.7%	6.0%	4.6%	3.8%	3.1%	4.6%
Regime 9	1.9%	2.3%	3.5%	5.6%	6.5%	6.3%	5.4%	5.5%	5.4%	4.9%	3.5%	2.6%	4.5%
Regime 10	2.9%	3.2%	4.1%	4.8%	5.5%	5.1%	4.9%	4.7%	4.5%	4.4%	3.7%	3.4%	4.3%
Regime 11	2.0%	2.4%	3.5%	4.8%	5.1%	4.6%	4.0%	3.8%	4.0%	3.6%	3.1%	2.4%	3.6%
Regime 12	4.1%	3.9%	3.7%	3.4%	3.0%	2.3%	2.2%	3.0%	4.1%	4.7%	4.5%	4.2%	3.6%
Regime 13	3.9%	3.8%	4.2%	4.1%	3.8%	2.8%	2.2%	2.2%	2.7%	3.9%	4.3%	4.4%	3.5%
Regime 14	3.8%	3.6%	3.6%	3.1%	2.4%	1.7%	1.6%	2.1%	2.9%	3.8%	4.1%	4.1%	3.1%
Regime 15	4.9%	4.4%	3.8%	3.0%	2.1%	1.4%	1.2%	1.2%	2.3%	3.1%	4.3%	4.6%	3.0%
Regime 16	2.6%	3.2%	3.5%	3.4%	2.7%	1.9%	1.5%	1.8%	2.7%	3.4%	3.1%	2.7%	2.7%
Regime 17	4.4%	4.0%	3.1%	2.3%	1.3%	0.8%	0.4%	1.0%	2.2%	3.2%	3.9%	4.2%	2.6%
Regime 18	5.4%	5.1%	4.1%	2.6%	1.2%	0.6%	0.3%	0.4%	1.1%	2.3%	3.9%	4.8%	2.6%
Regime 19	3.8%	3.8%	3.5%	2.7%	1.8%	0.9%	0.6%	0.8%	1.8%	3.1%	3.8%	4.1%	2.6%
Regime 20	4.5%	4.5%	3.7%	2.6%	1.5%	0.8%	0.4%	0.9%	1.8%	2.8%	3.5%	4.1%	2.6%
Regime 21	3.8%	3.4%	2.9%	2.3%	1.7%	1.3%	0.9%	1.4%	2.2%	3.2%	3.6%	3.8%	2.5%
Regime 22	3.4%	3.5%	3.3%	2.8%	2.0%	1.2%	0.8%	1.0%	1.6%	2.4%	2.9%	3.2%	2.3%
Regime 23	4.8%	5.0%	4.0%	2.7%	1.3%	0.6%	0.2%	0.4%	0.9%	1.8%	2.8%	4.1%	2.4%
Regime 24	3.3%	3.3%	2.8%	2.0%	1.1%	0.5%	0.5%	0.7%	1.4%	2.3%	2.9%	3.2%	2.0%
Regime 25	4.2%	3.9%	3.1%	1.8%	1.1%	0.5%	0.3%	0.5%	1.1%	2.2%	2.9%	3.7%	2.1%
Regime 26	3.6%	3.5%	2.8%	1.9%	0.9%	0.4%	0.2%	0.6%	1.3%	2.3%	3.0%	3.5%	2.0%
Regime 27	4.0%	3.8%	2.6%	1.4%	0.5%	0.3%	0.1%	0.2%	0.8%	1.9%	2.8%	3.7%	1.8%
Regime 28	3.6%	3.8%	3.2%	2.0%	0.8%	0.3%	0.1%	0.2%	0.7%	1.3%	2.1%	2.8%	1.7%
Regime 29	3.7%	3.3%	2.8%	1.6%	0.9%	0.3%	0.2%	0.2%	0.6%	1.2%	2.2%	2.9%	1.7%
Regime 30	3.2%	2.9%	2.0%	1.1%	0.5%	0.2%	0.2%	0.4%	0.9%	1.7%	2.4%	3.0%	1.5%

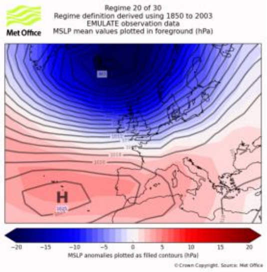
Thunder Area

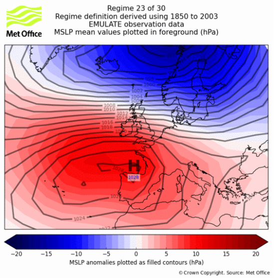
- Ignore observations outside the radar domain and any in continental Europe.
- Draw a 10-mile (16 km) radius around each to be the 'thunder area'.
- Example: 18 Oct 2019 118144 km^2(11.09% of the domain).



Wilkinson and Neal (2020, in review)

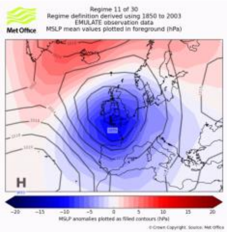
Met

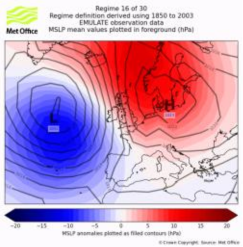


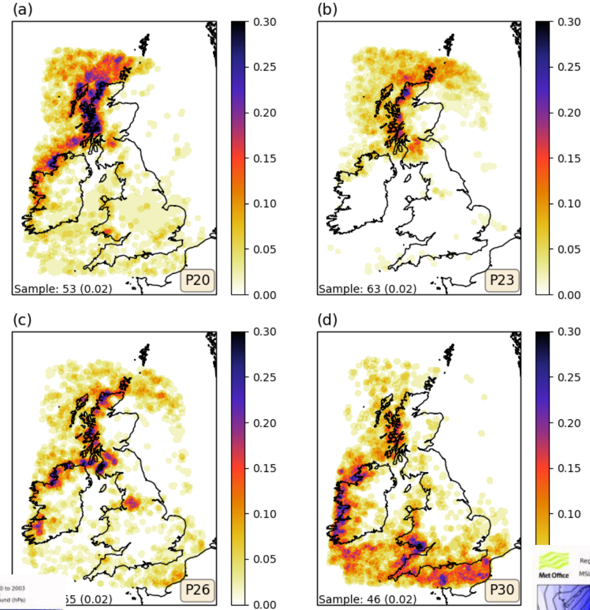


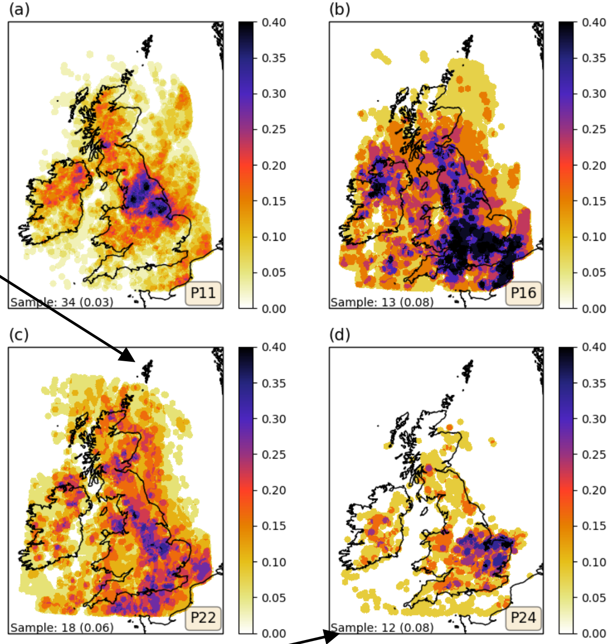
Summer

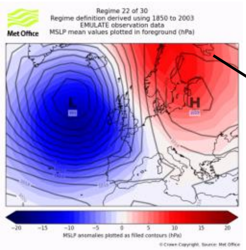
Wilkinson and Neal (2020, QJRMS, Submitted).

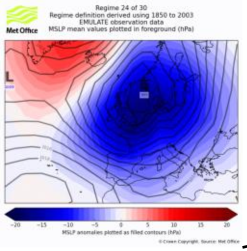


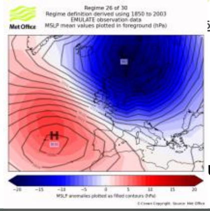


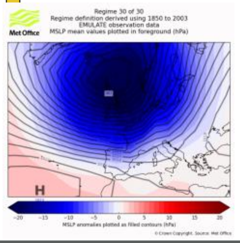








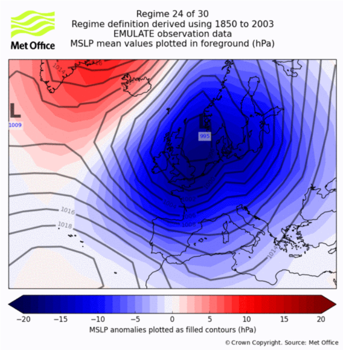


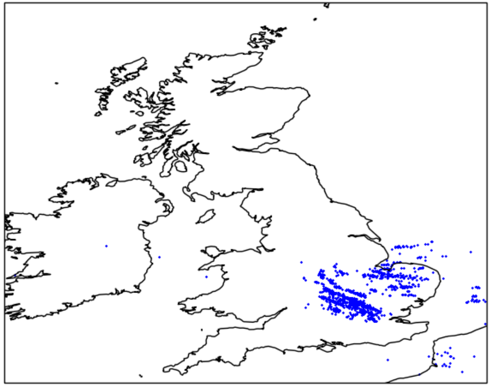


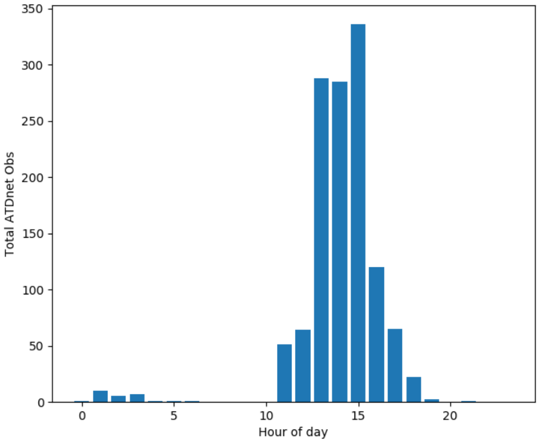
Winter

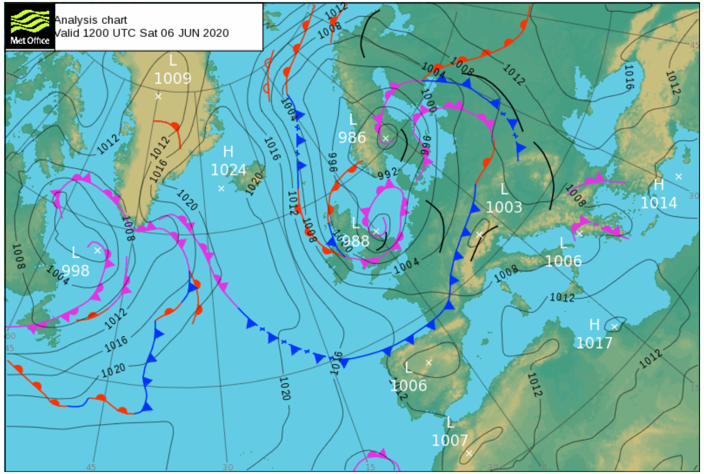
uk

6 June Obs./forecasts
(Pattern 24 event)

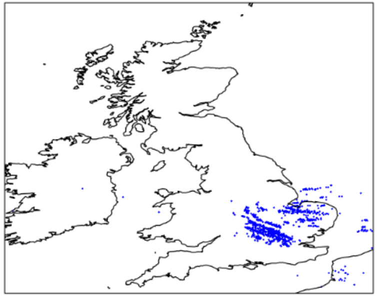


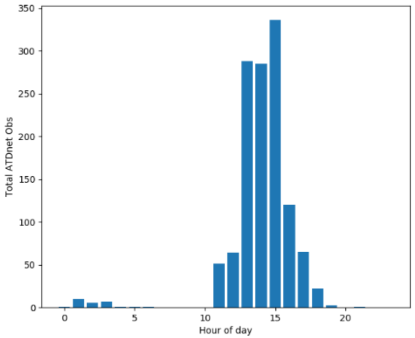


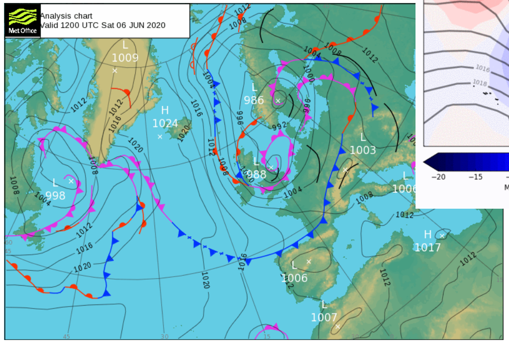


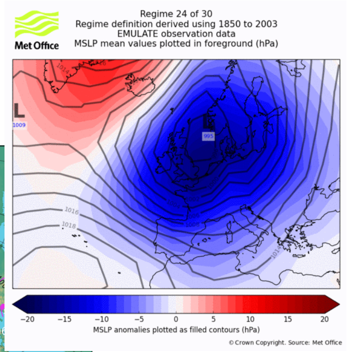


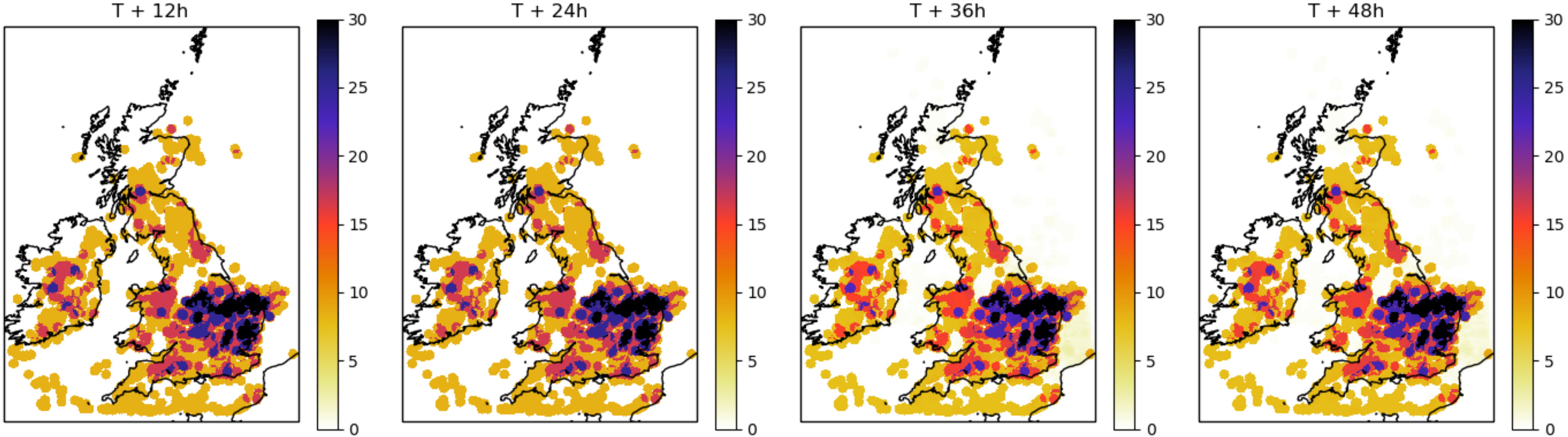
6 June Obs./forecasts











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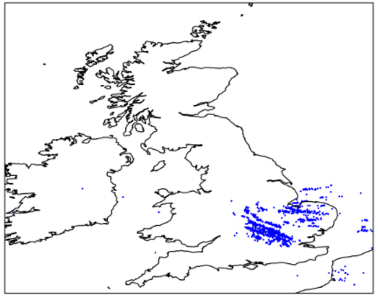

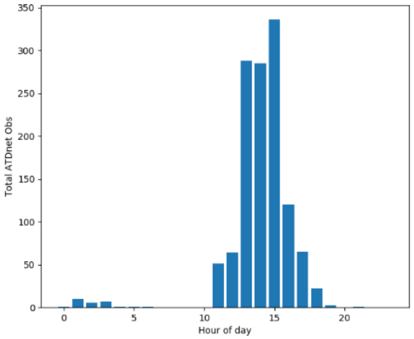

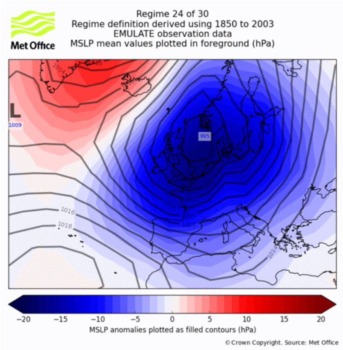

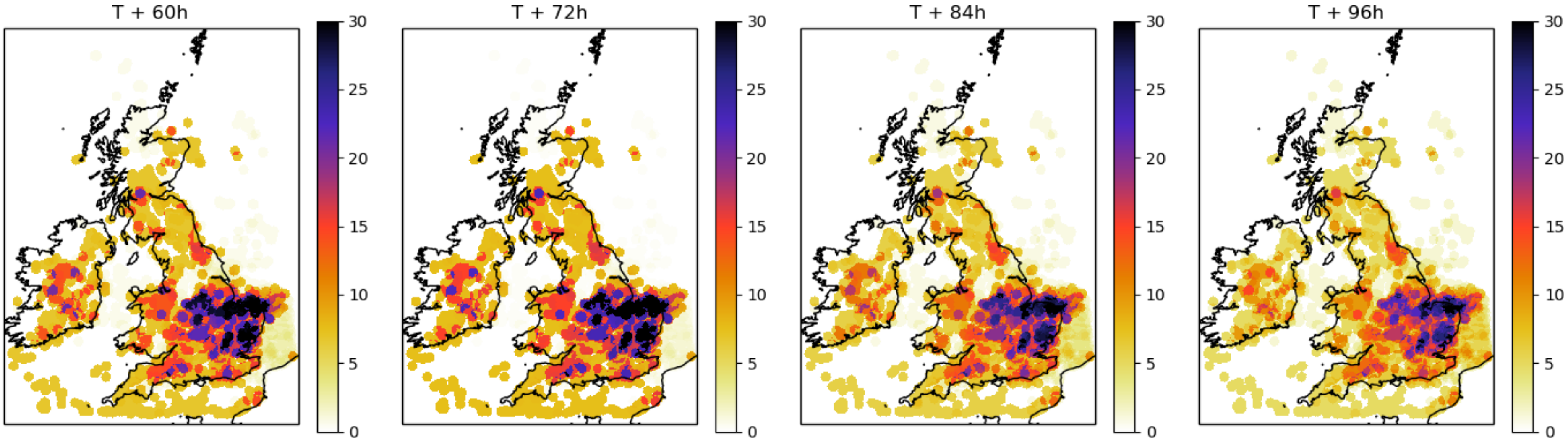

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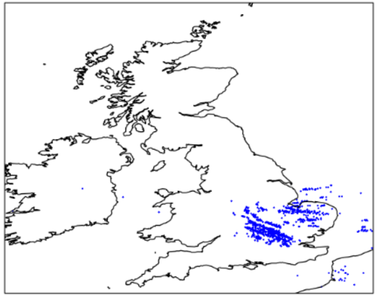

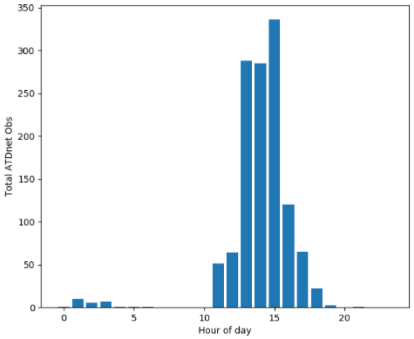

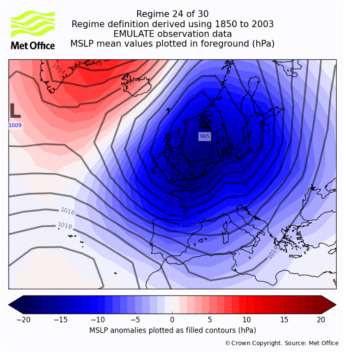

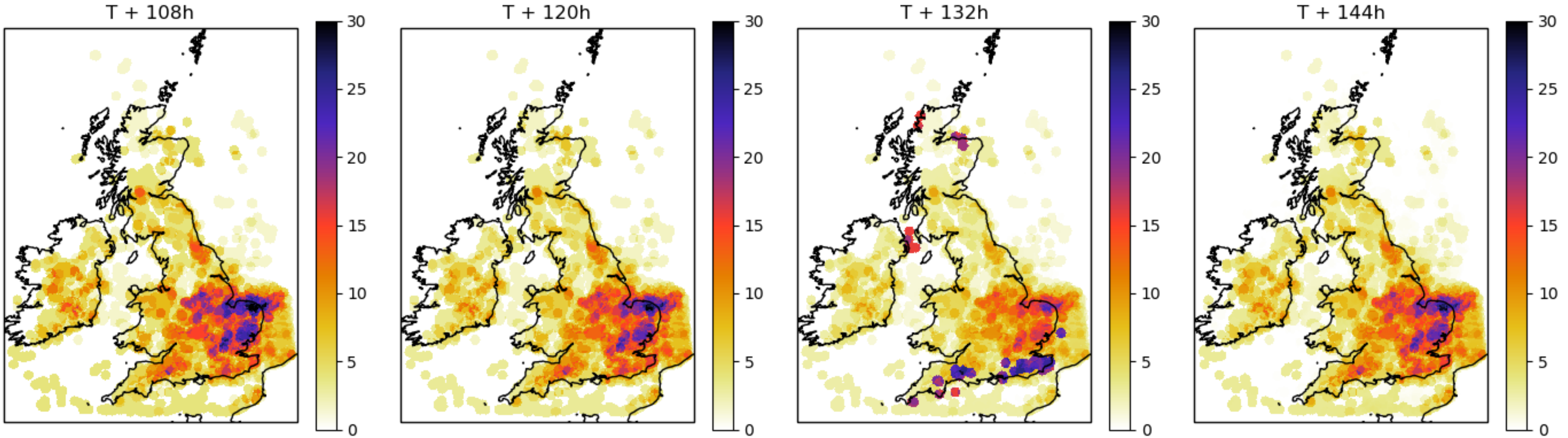

Future Steps: Machine Learning?

Envisage two strands of work:

1. Reduce the cost of computationally expensive explicit charging lightning parametrizations.

2. Try and predict lightning events using observations in the short-range and the medium range by exploring variable space.

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Nowcasting lightning occurrence from commonly available meteorological parameters using machine learning techniques

Amirhossein Mostajabi, Declan L. Finney, Marcos Rubinstein & Farhad Rachidi

npj Climate and Atmospheric Science 2, Article number: 41 (2019) | Cite this article

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Abstract

Lightning discharges in the atmosphere owe their existence to the

Summary

- High-resolution NWP allows more realistic prediction of thunderstorm-like systems.
- Can therefore forecast lightning (+ hail, turbulence) with more realism.
- A lot of work still to be done to fully get the maximum value from these forecasts:
  - Ensembles, Verification, Post-Processing, Machine Learning?

Collaborations?

- Always happy to work with other centres to pool scientific knowledge.
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- Publons: https://publons.com/researcher/1542754/jonathan-wilkinson/
- Email: jonathan.wilkinson@metoffice.gov.uk

Thank You!
Any questions?