Met Office

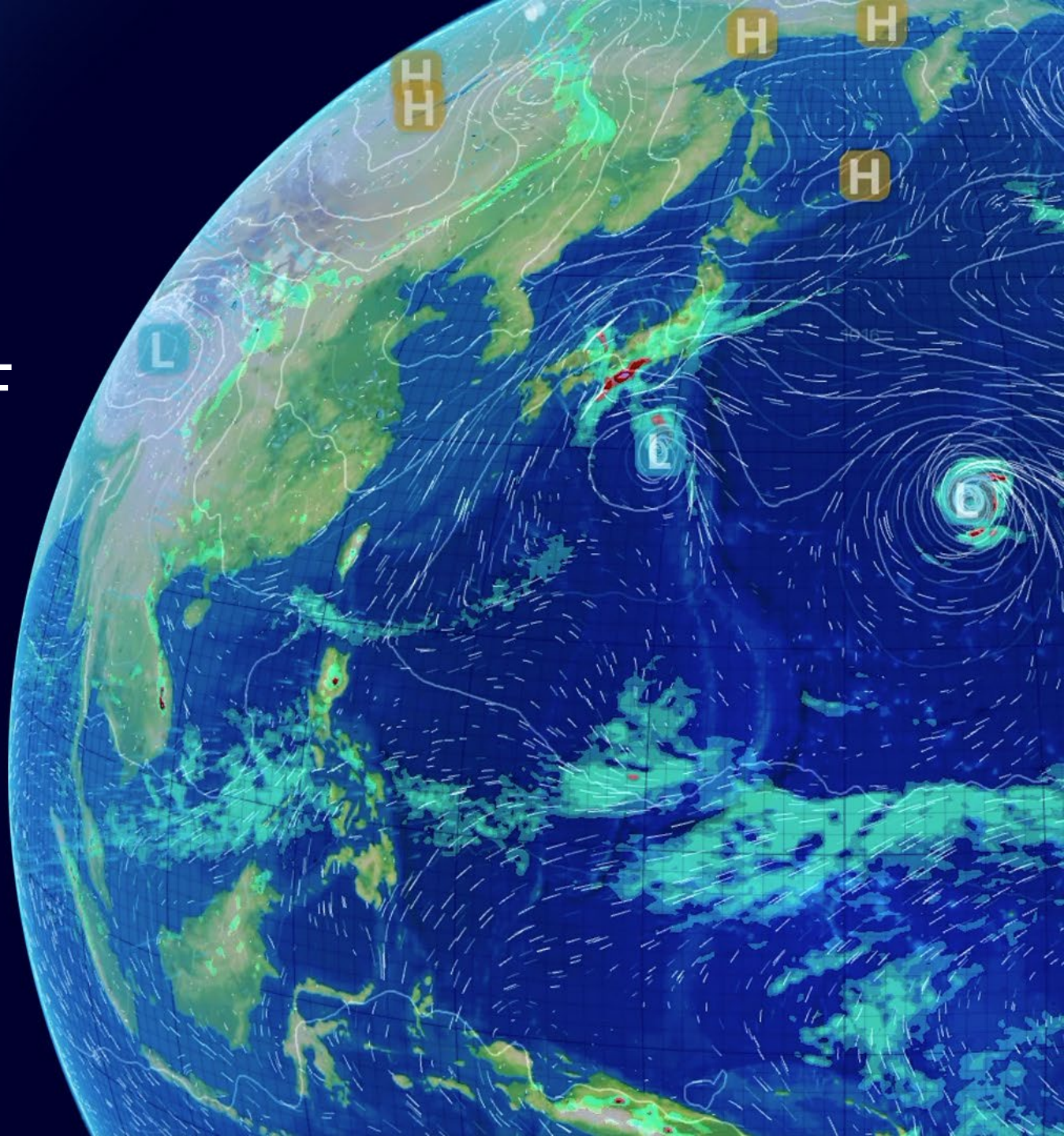
ECMWF

A new curvature diagnostic (CURV) developed at ECMWF and some of its applications

Nigel Roberts

Thanks to Anca Brookshaw, Tim Hewson, Balazs Szintai, Matthieu Chevallier and many others at ECMWF

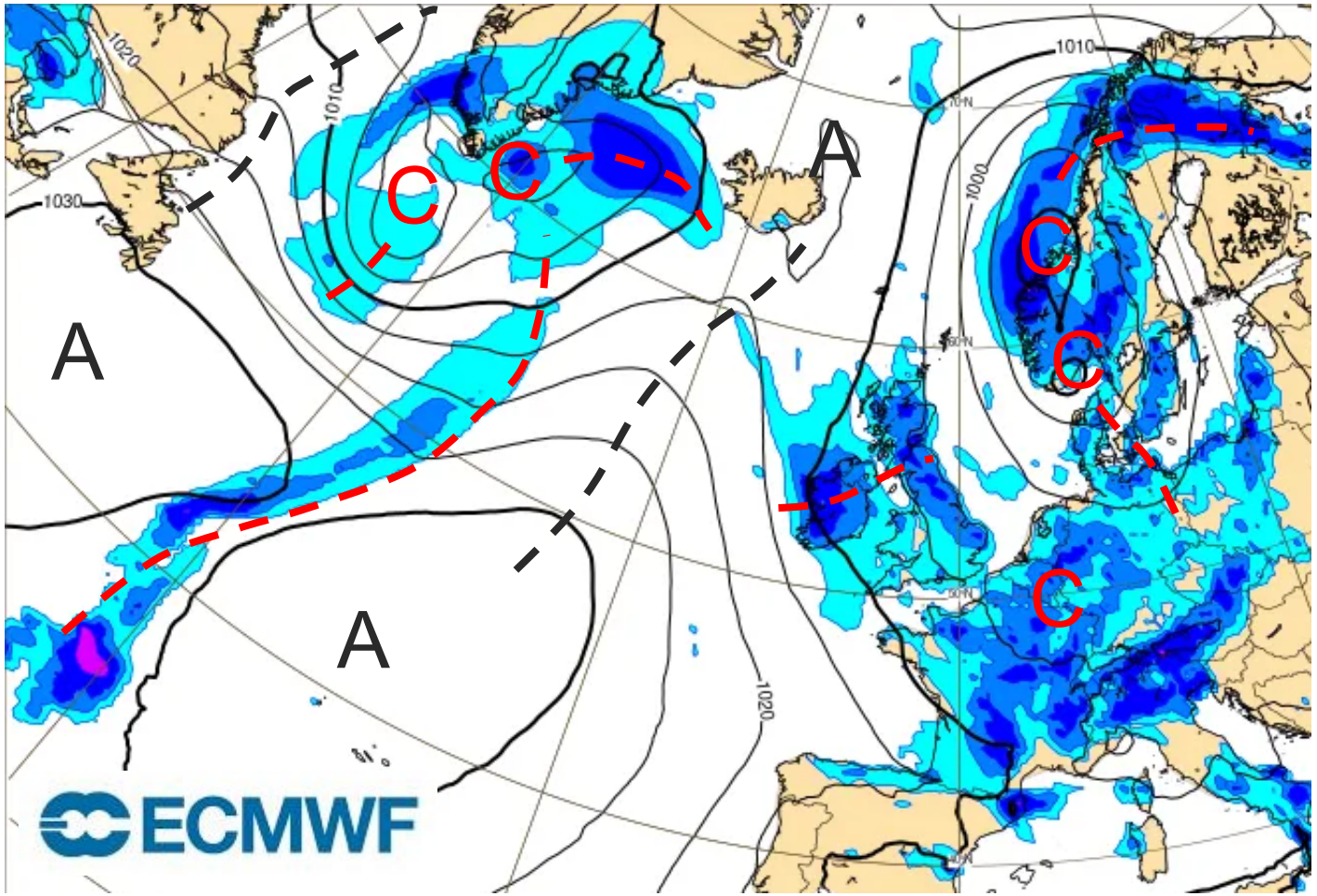
David Flack, Sylvia Bohnenstengel, Huw Lewis at the Met Office



Met Office

Why is a synoptic pressure / geopotential height field useful?

Synoptic curvature and 6h precipitation



Operational guidance taken at random (7th May)

A broadscale change also begins today as **ridge** amplification over Greenland drives downstream **trough** extension across the E Atlantic. Forward of this, a **low** between Scotland and Iceland moves slowly NE'wards to be centred near or over the Faeroes by early Friday.

Another thermal plume is drawn N from France into S England tonight, this on the forward side of a NE'ward moving **short wave**, which will allow release of some instability and development of few moderate showers, before this **short wave** relaxes NE'wards Friday morning.

The period begins with a split in the weather between north and south. The south influenced by a **cyclonic complex** centred west of Iberia, experiencing a mild E'ly flow, and elements of forcing rotating northwestwards close to the south of the UK over a slightly higher WBPT plume. This threatens to generate some medium level cloud and elevated instability at times. The north is influenced by a **trough** over the Norwegian Sea and **high / upper ridge** in the central Atlantic which induce a cool, perhaps better described as chilly flow, from the N'ly quadrant.

Introducing a new diagnostic called ‘Curvature Using Radial Variation’ (CURV)

To quantify the spatially varying curvature of Mean Sea Level Pressure (MSLP) or Geopotential Height (Z) fields at specified spatial scales.

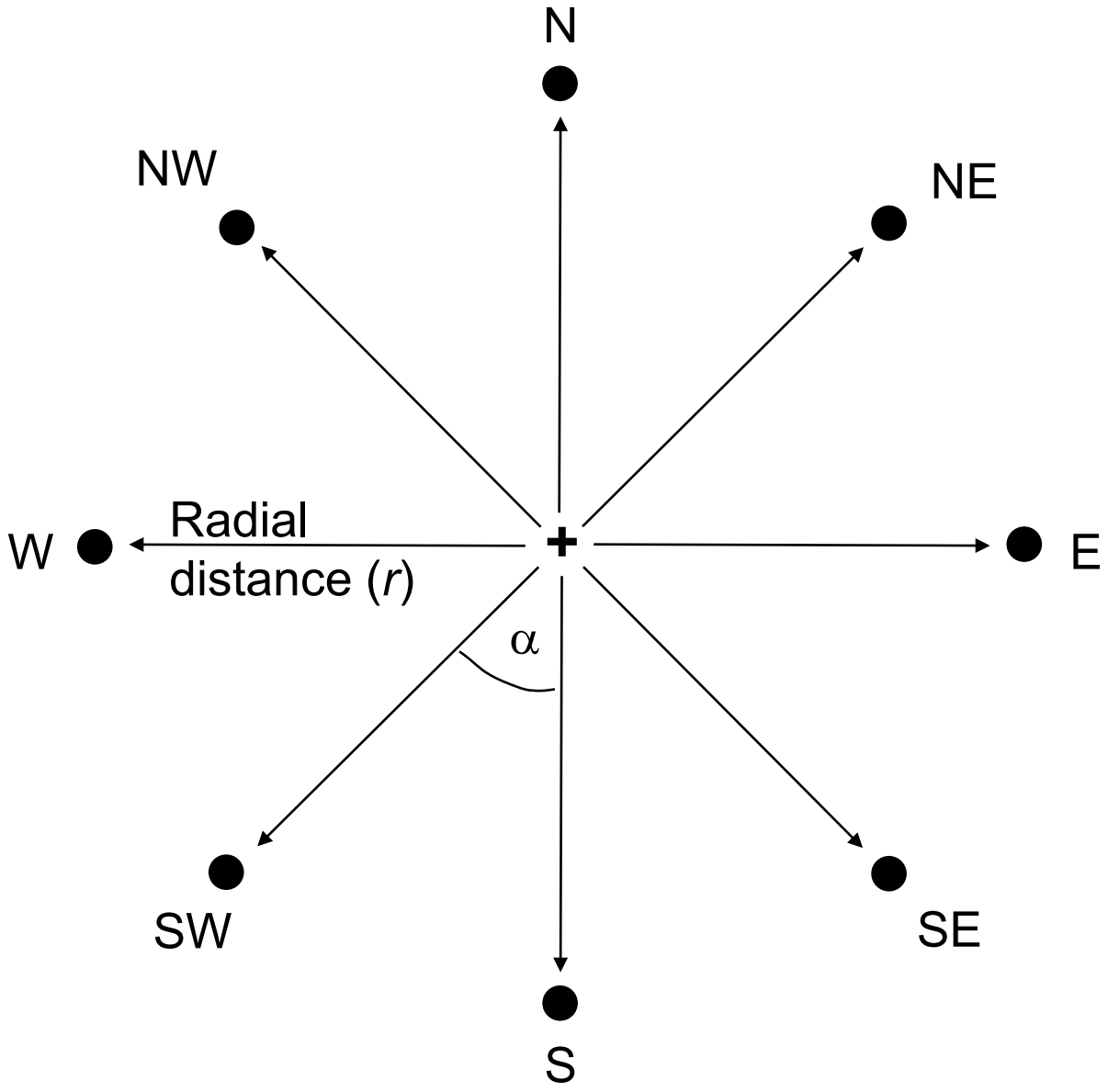
Many existing methods that identify specific features / objects (e.g. cyclone centre, trough/ridge axis …)
Mathematical operators operate locally (small scale) (e.g. vorticity, Laplacian …)

CURV quantifies the curvature at every grid point over weather-system distances -> synoptic weather patterns

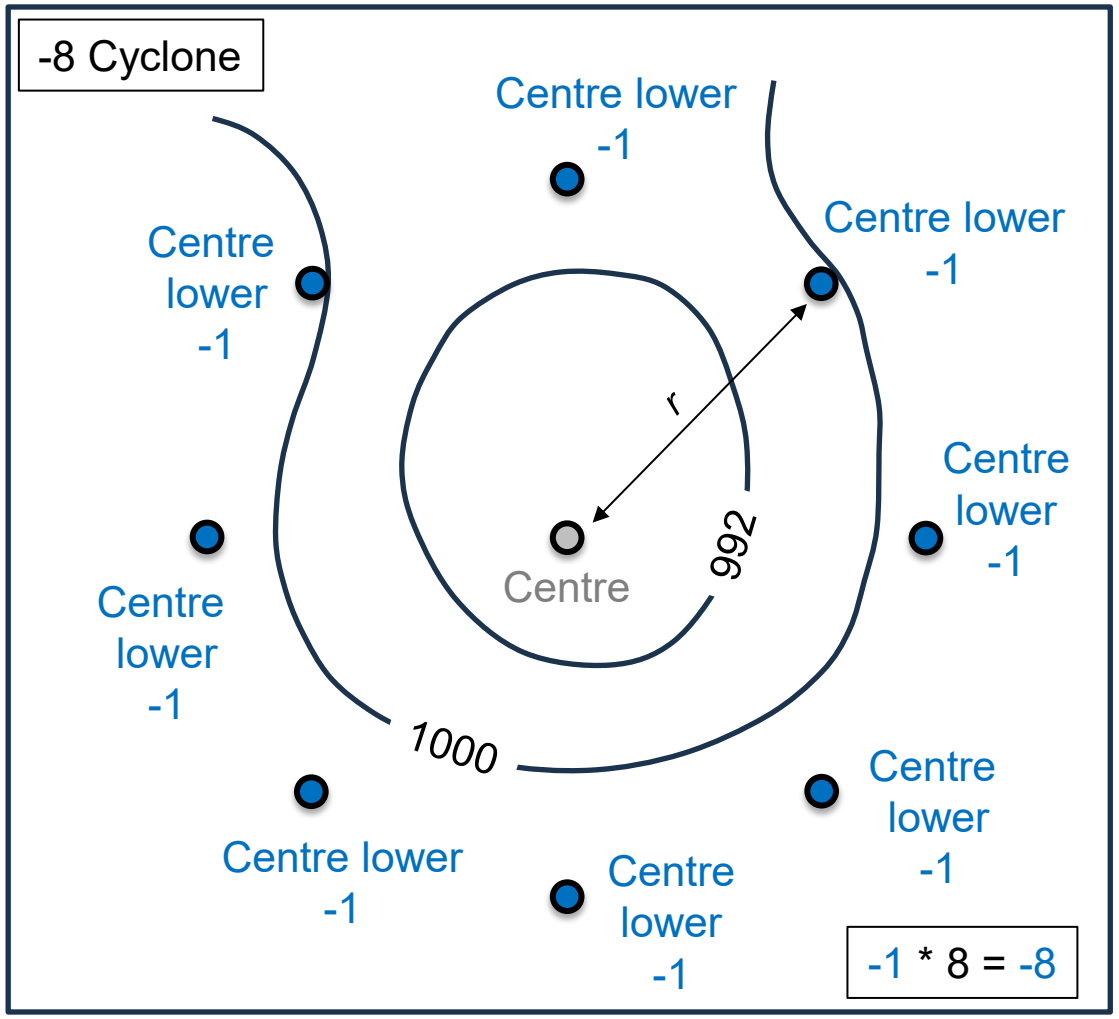
To directly define and evaluate synoptic / mesoscale MSLP / Z patterns because that is what relates to local weather

CURV diagnostic
(Curvature Using Radial Variation)

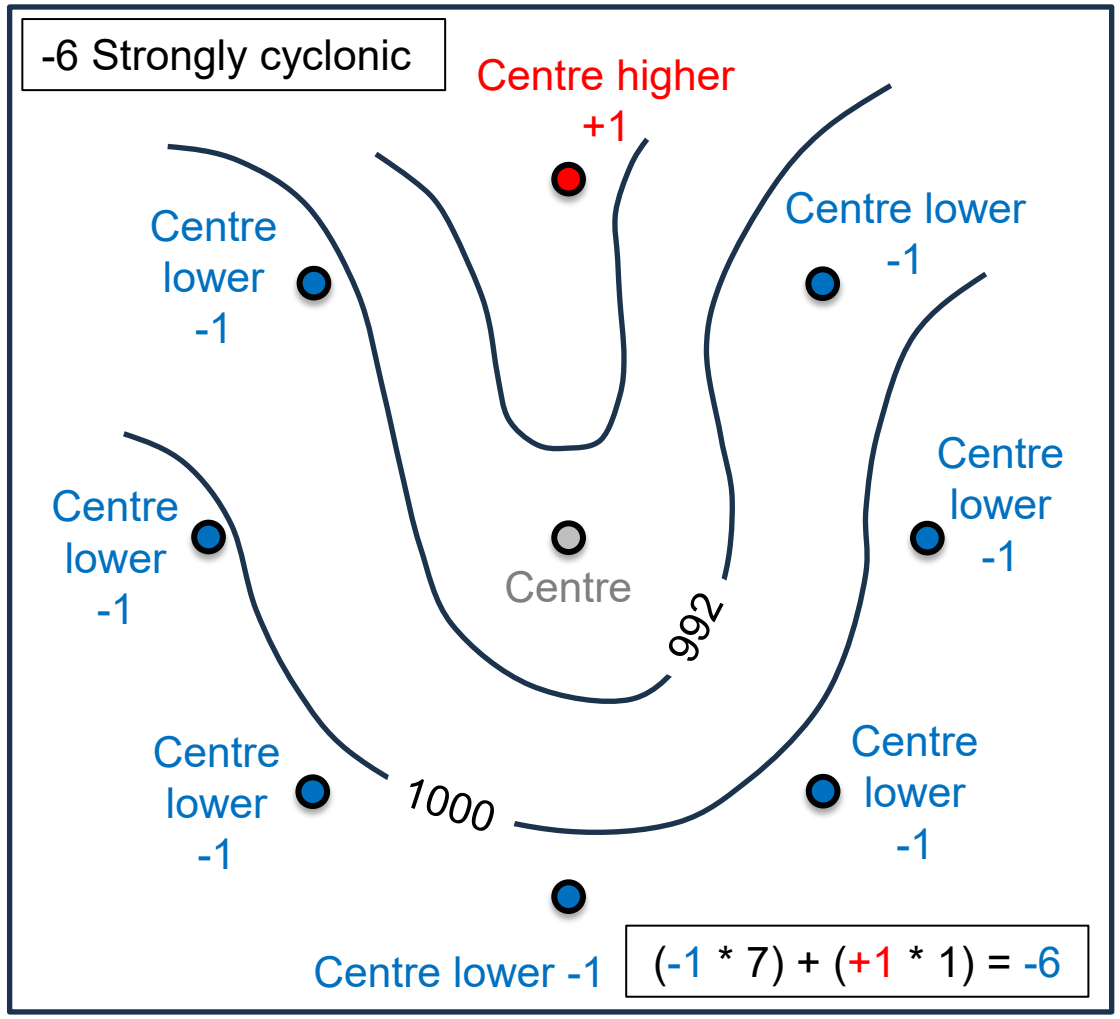
Determine local field curvature from differences between value of MSLP or Z at each grid point and equidistant radial locations



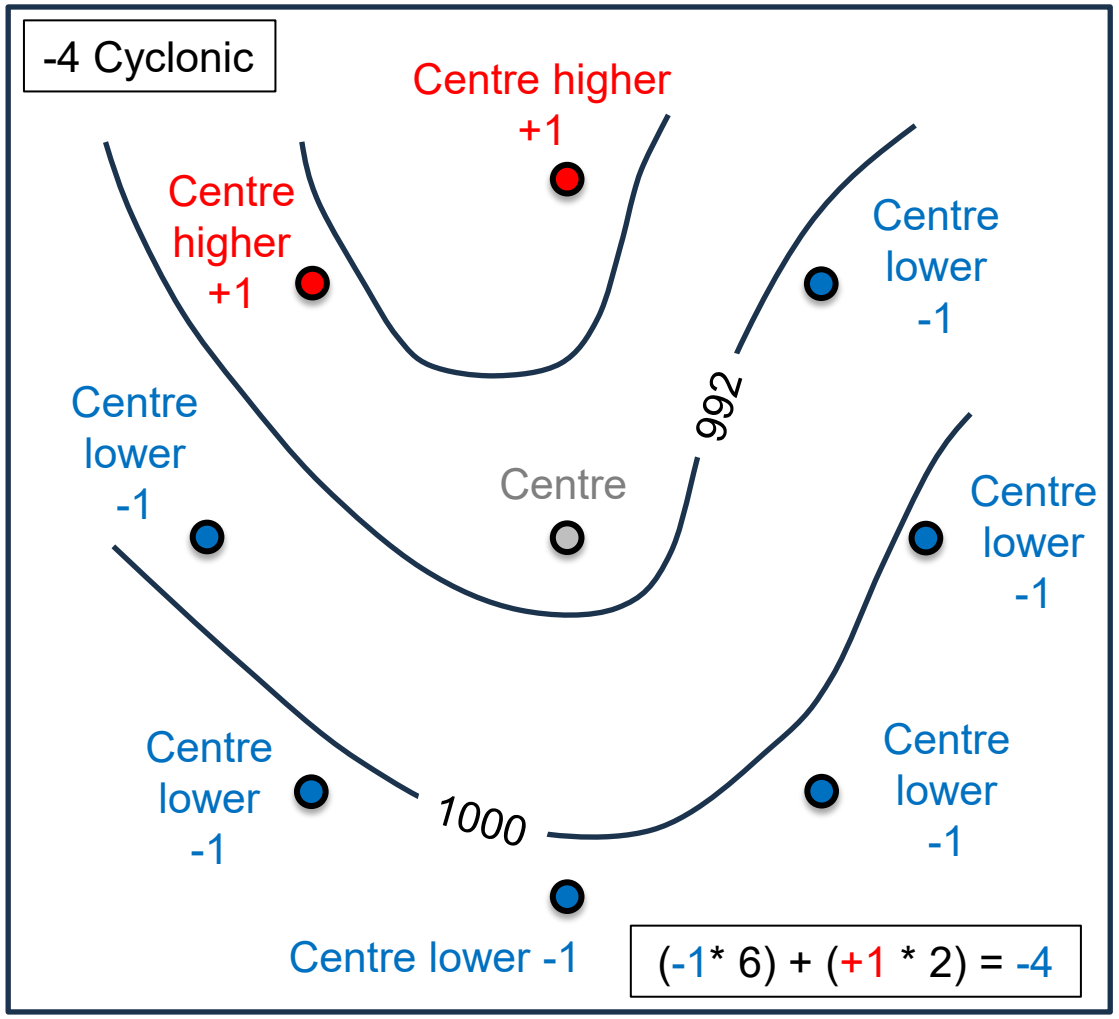
Cyclone CURV = -8



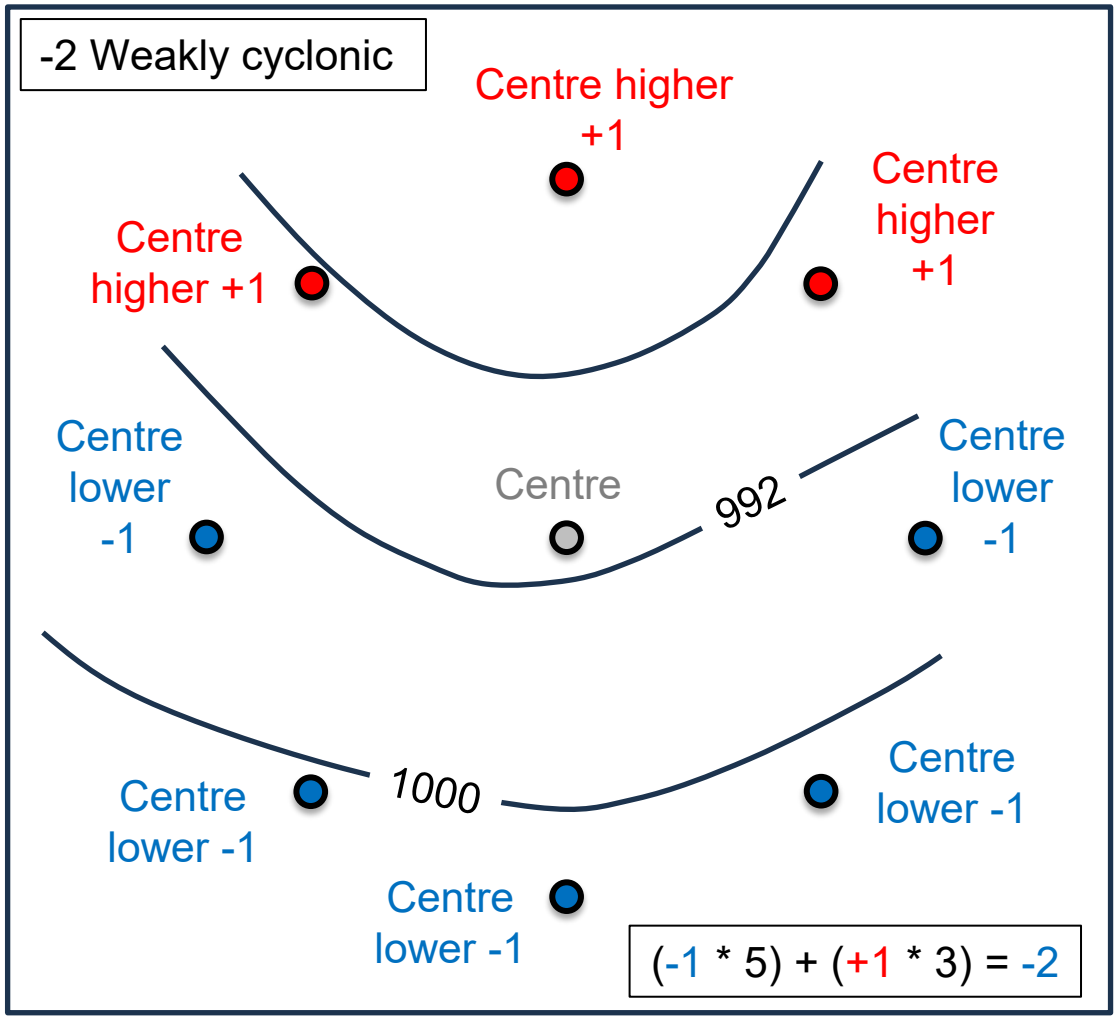
Strongly cyclone CURV = -6



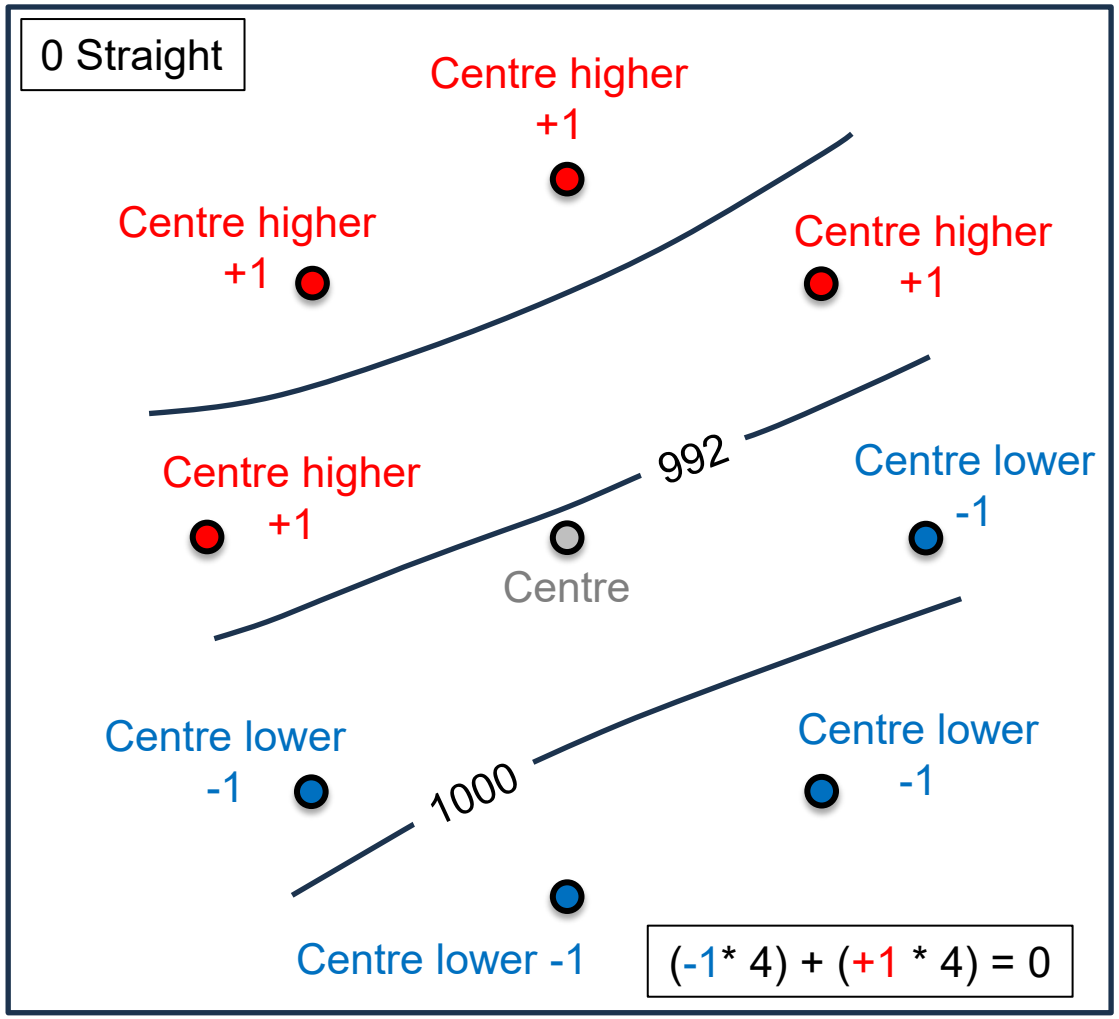
Cyclonic CURV = -4



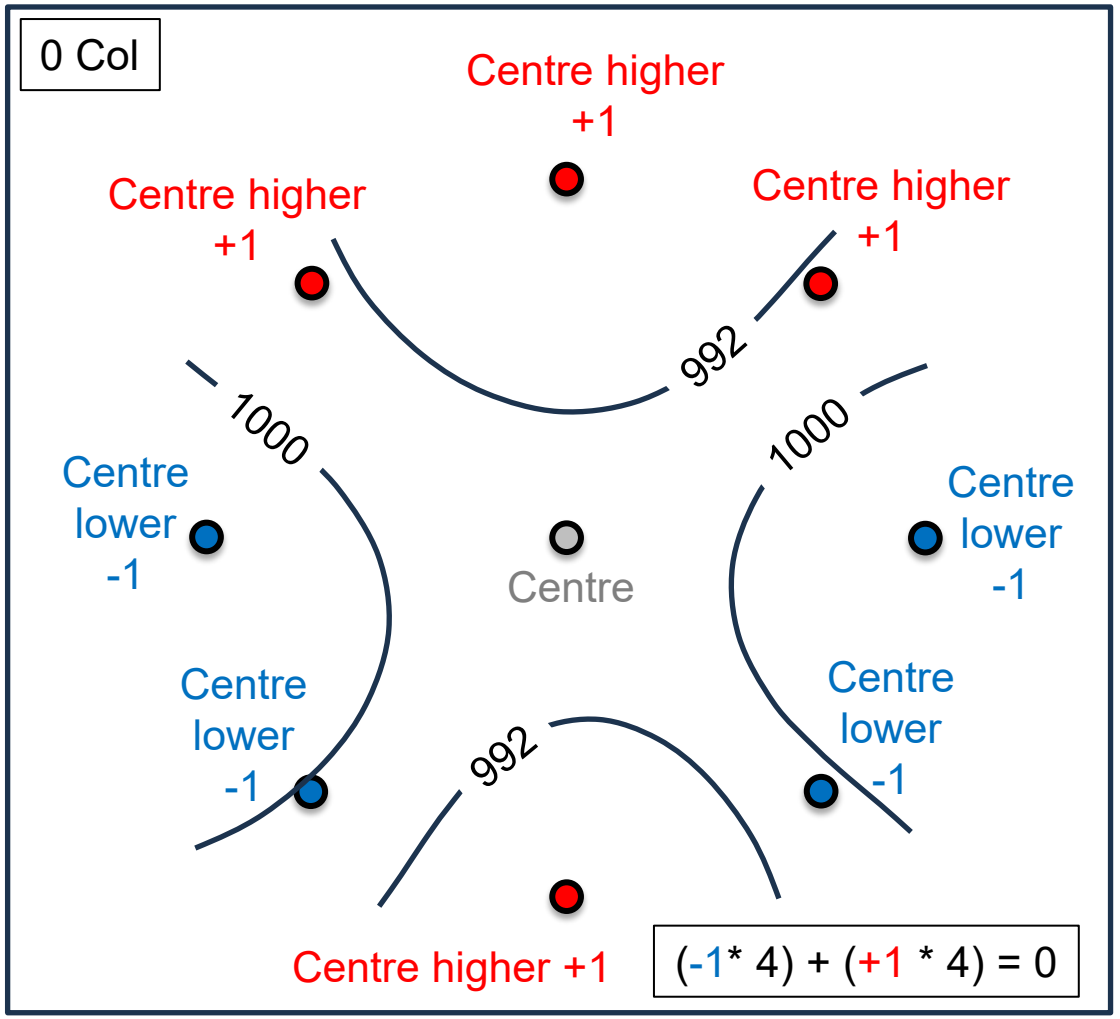
Weakly cyclonic CURV = -2



Straight CURV = 0



Col CURV = 0

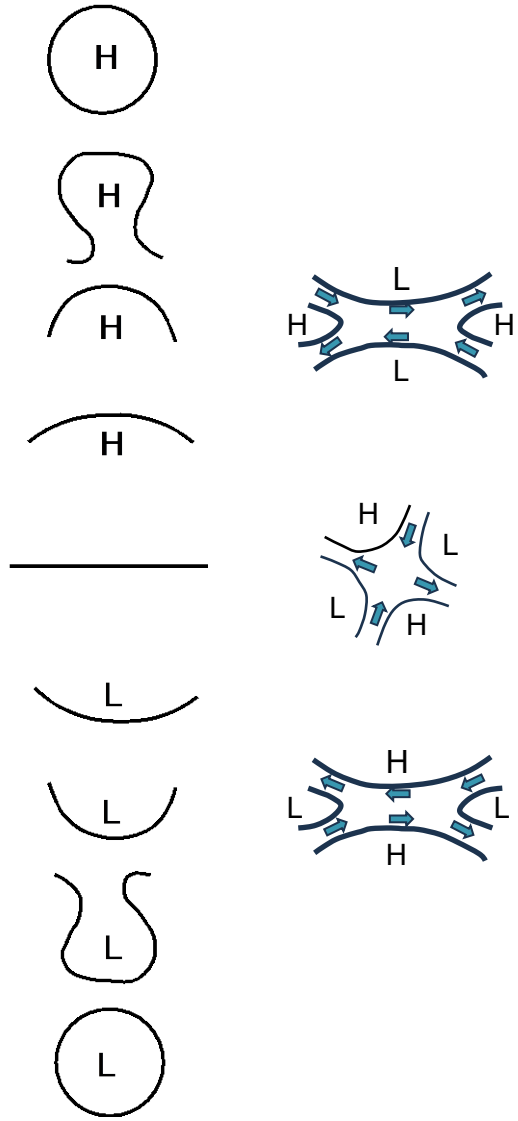


CURV index

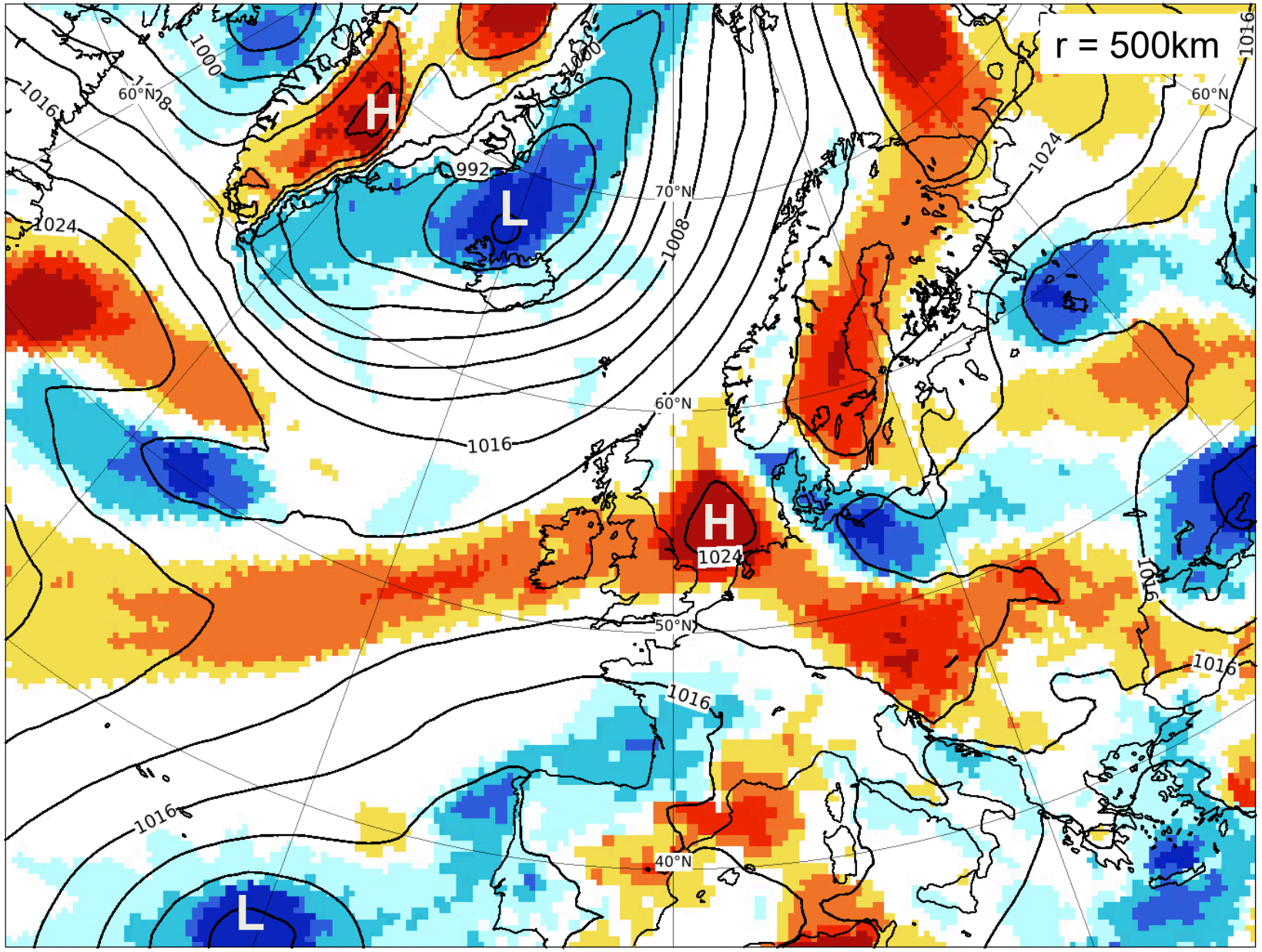
Discrete
Increments of 2

(Can add a tolerance
- Increments of 1)

8 points	16 points	
+8	+16	Anticyclone
	+14	
+6	+12	Strongly anticyclonic
	+10	
+4	+8	Anticyclonic
	+6	
+2	+4	Slightly anticyclonic
	+2	
0	0	Straight / col
	-2	
-2	-4	Slightly cyclonic
	-6	
-4	-8	Cyclonic
	-10	
-6	-12	Strongly Cyclonic
	-14	
-8	-16	Cyclone



CURV example



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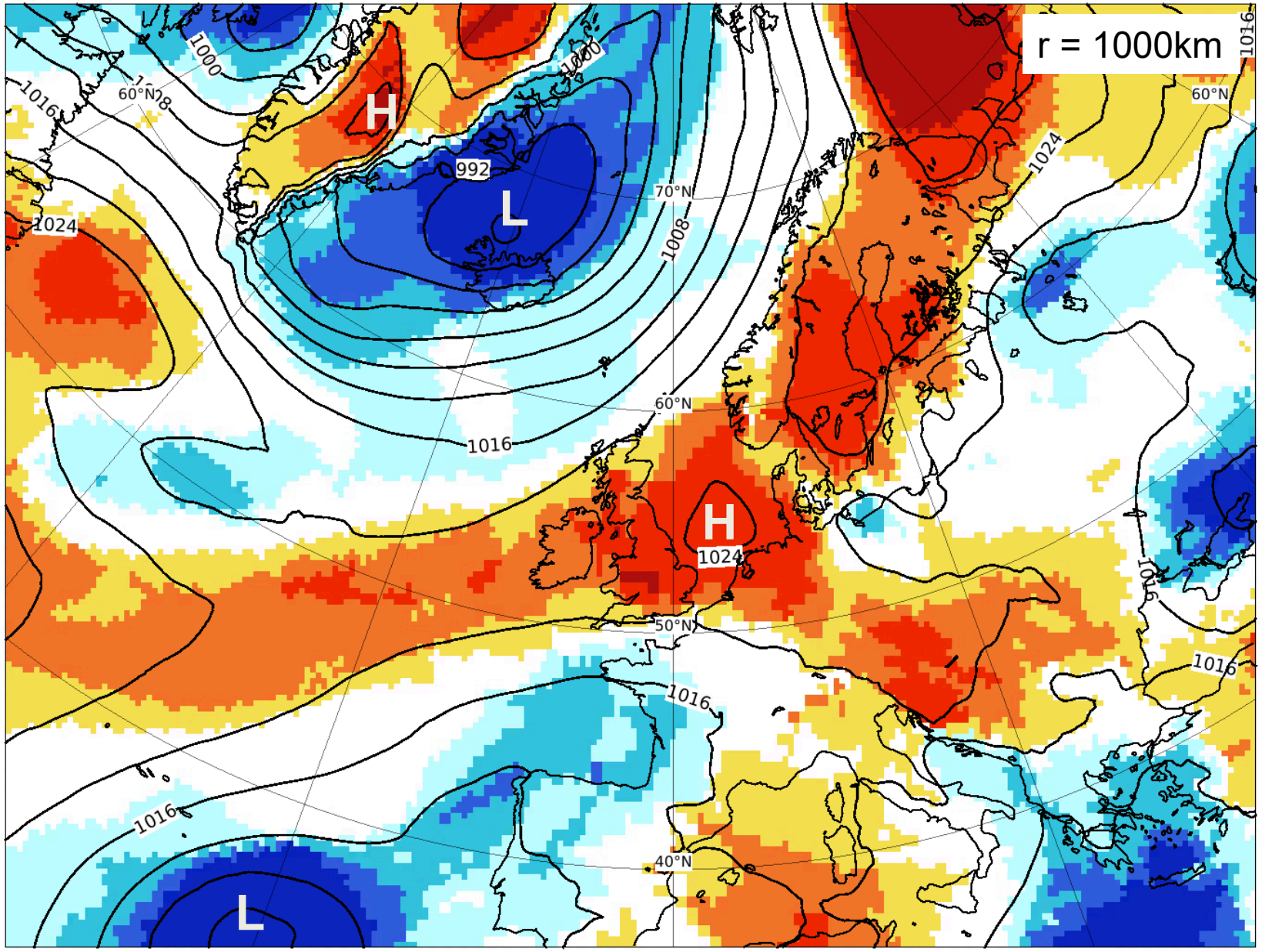

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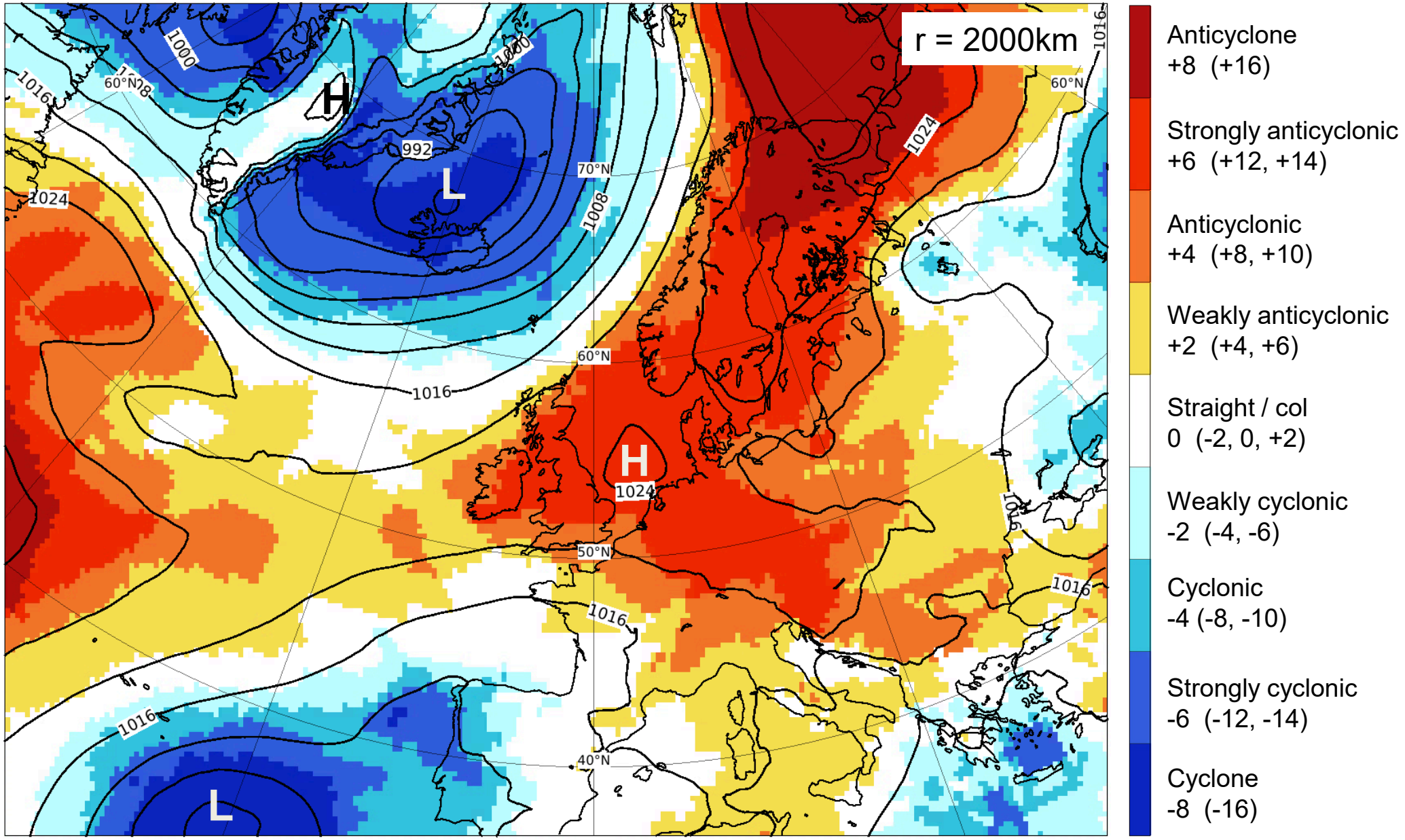

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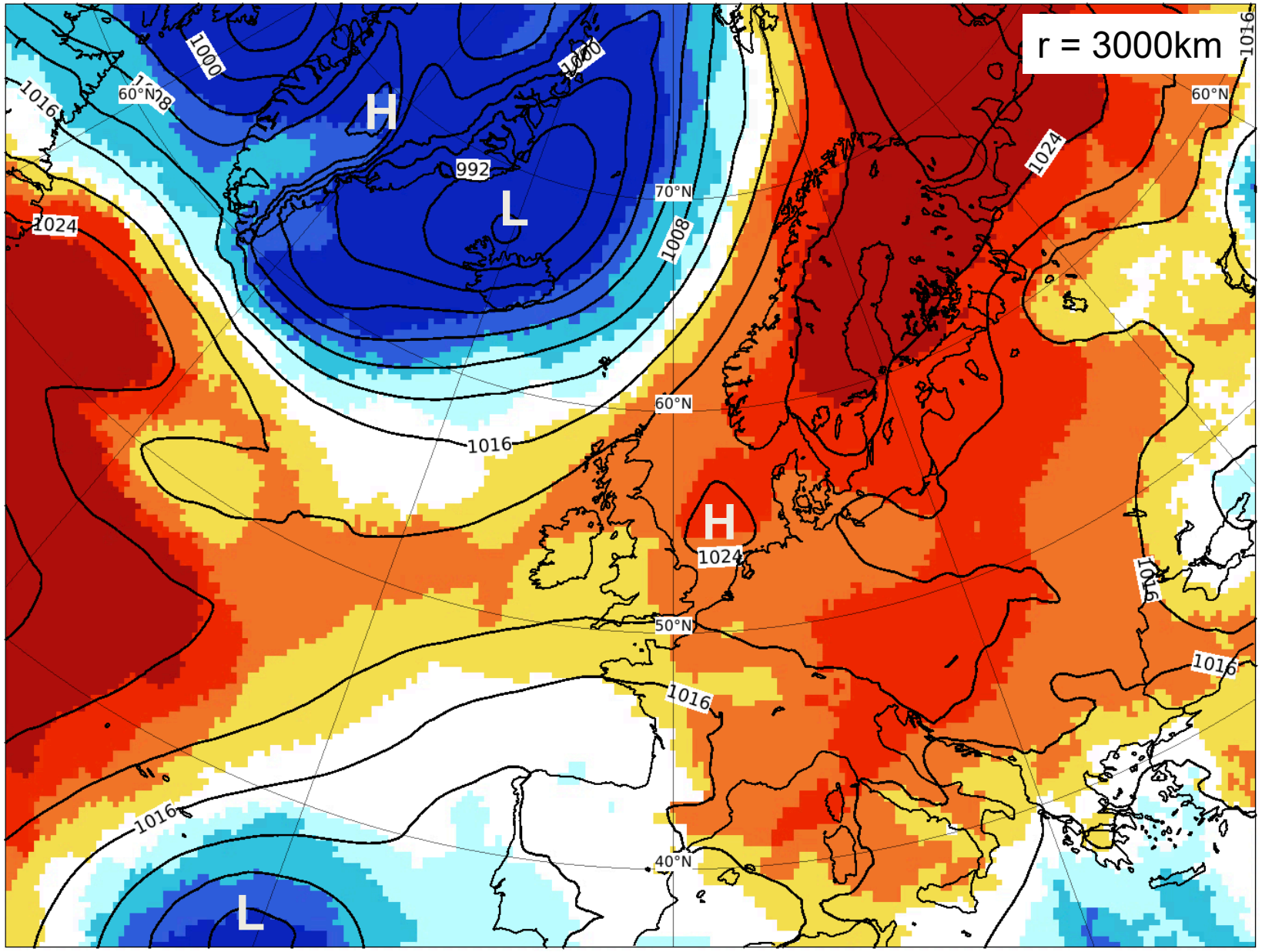

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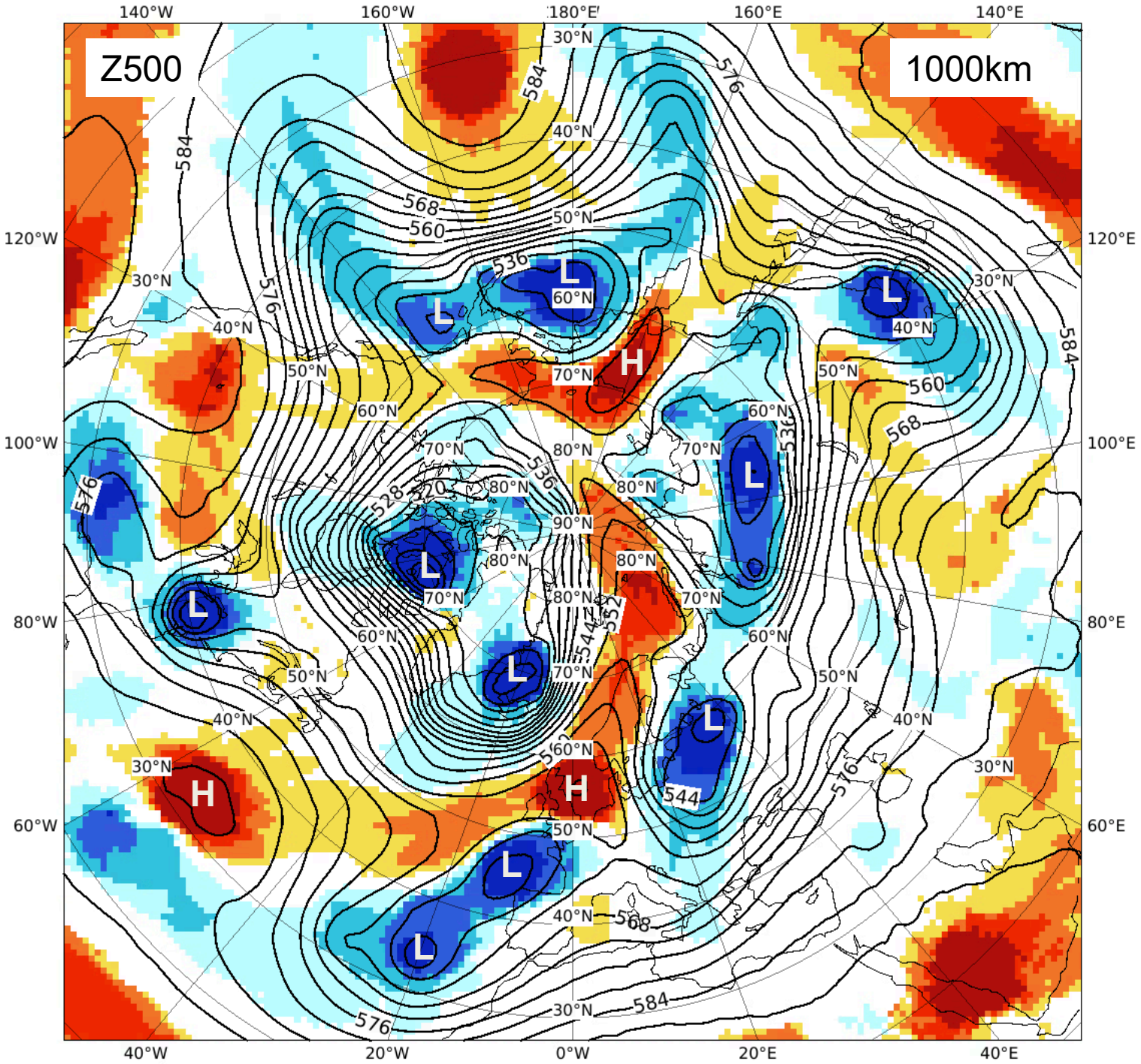


Anticyclone
+8 (+16)

Strongly anticyclonic
+6 (+12, +14)

Anticyclonic
+4 (+8, +10)

Weakly anticyclonic
+2 (+4, +6)

Straight / col
0 (-2, 0, +2)

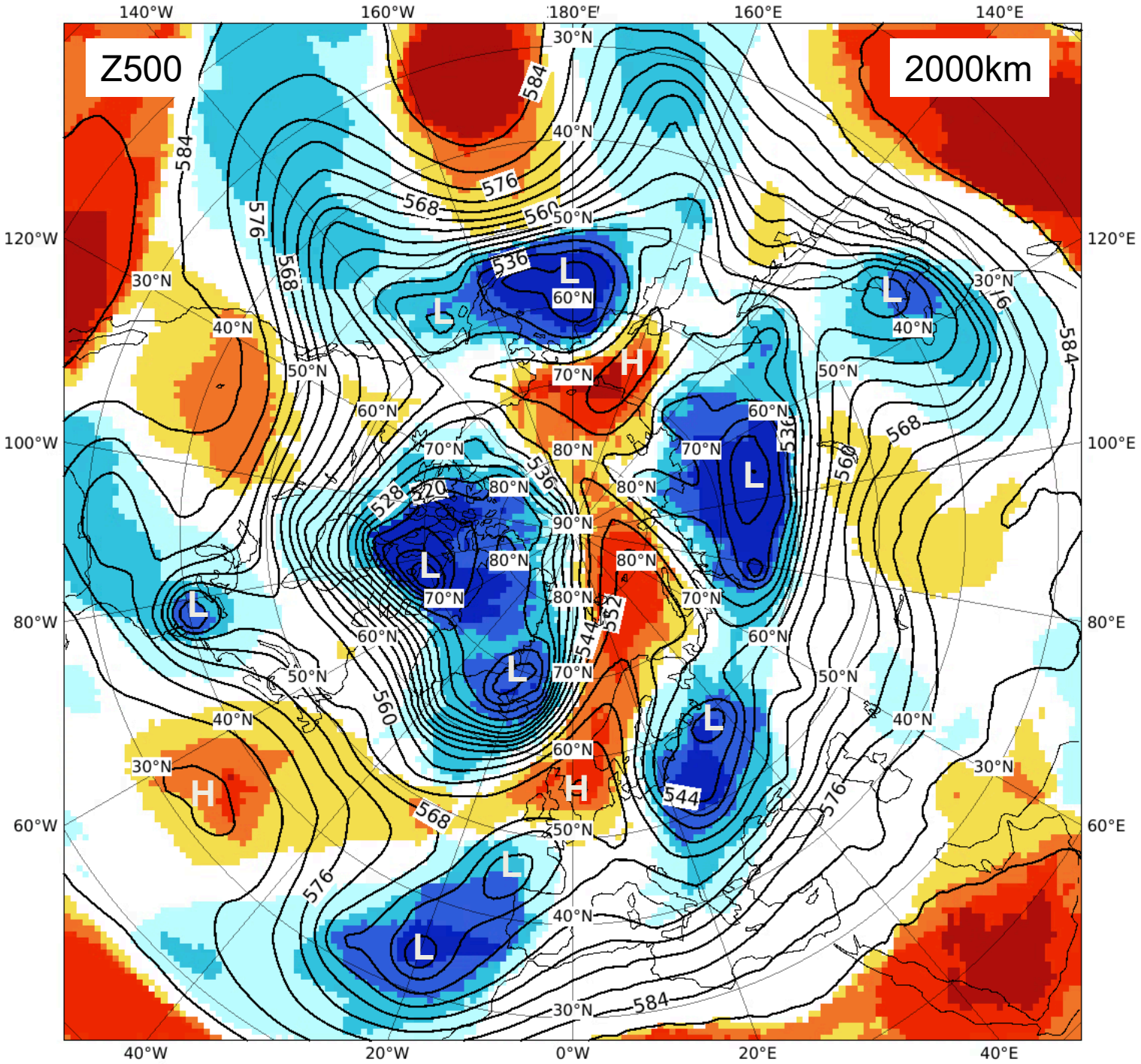
Weakly cyclonic
-2 (-4, -6)

Cyclonic
-4 (-8, -10)

Strongly cyclonic
-6 (-12, -14)

Cyclone
-8 (-16)

CURV example



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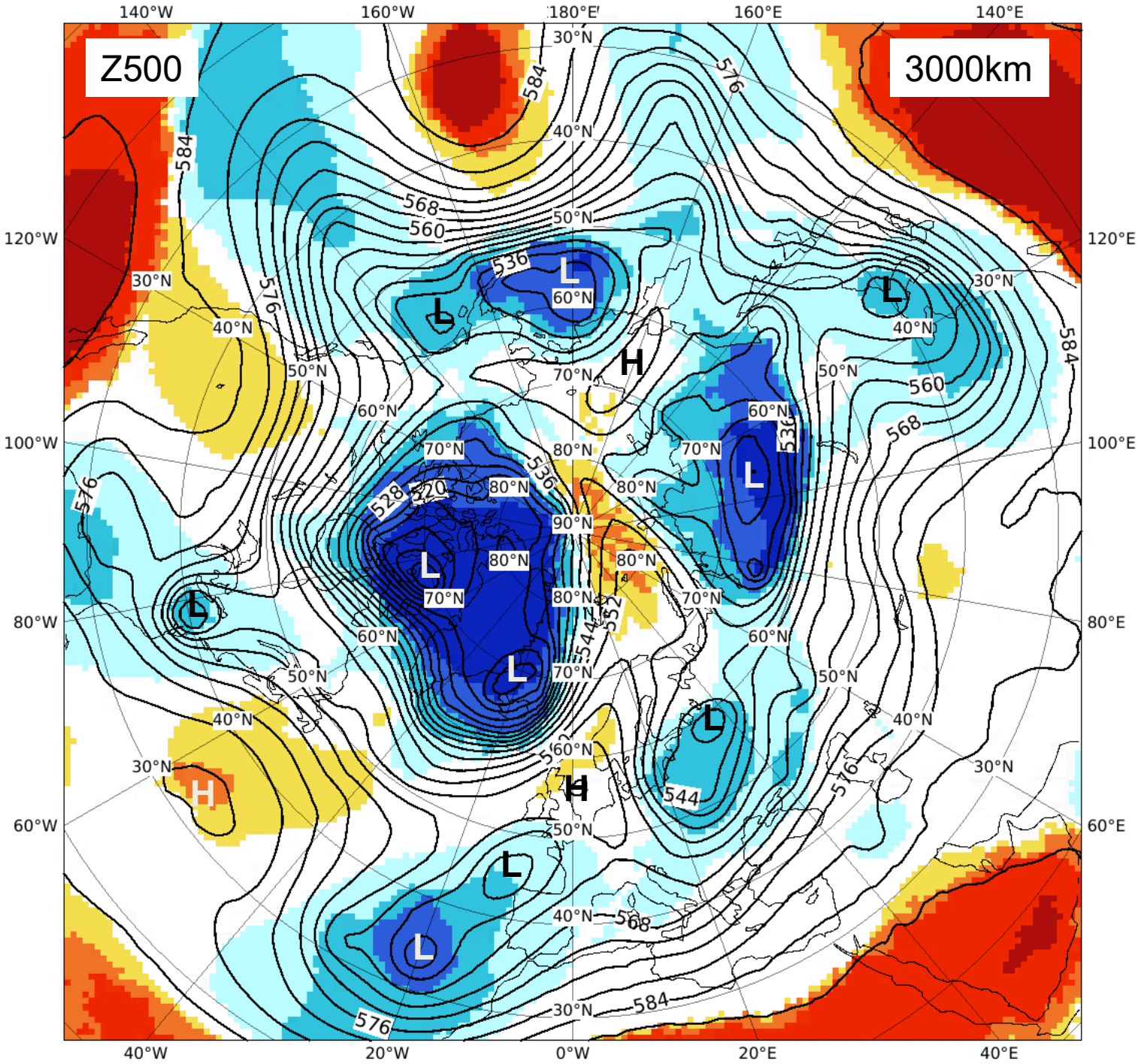

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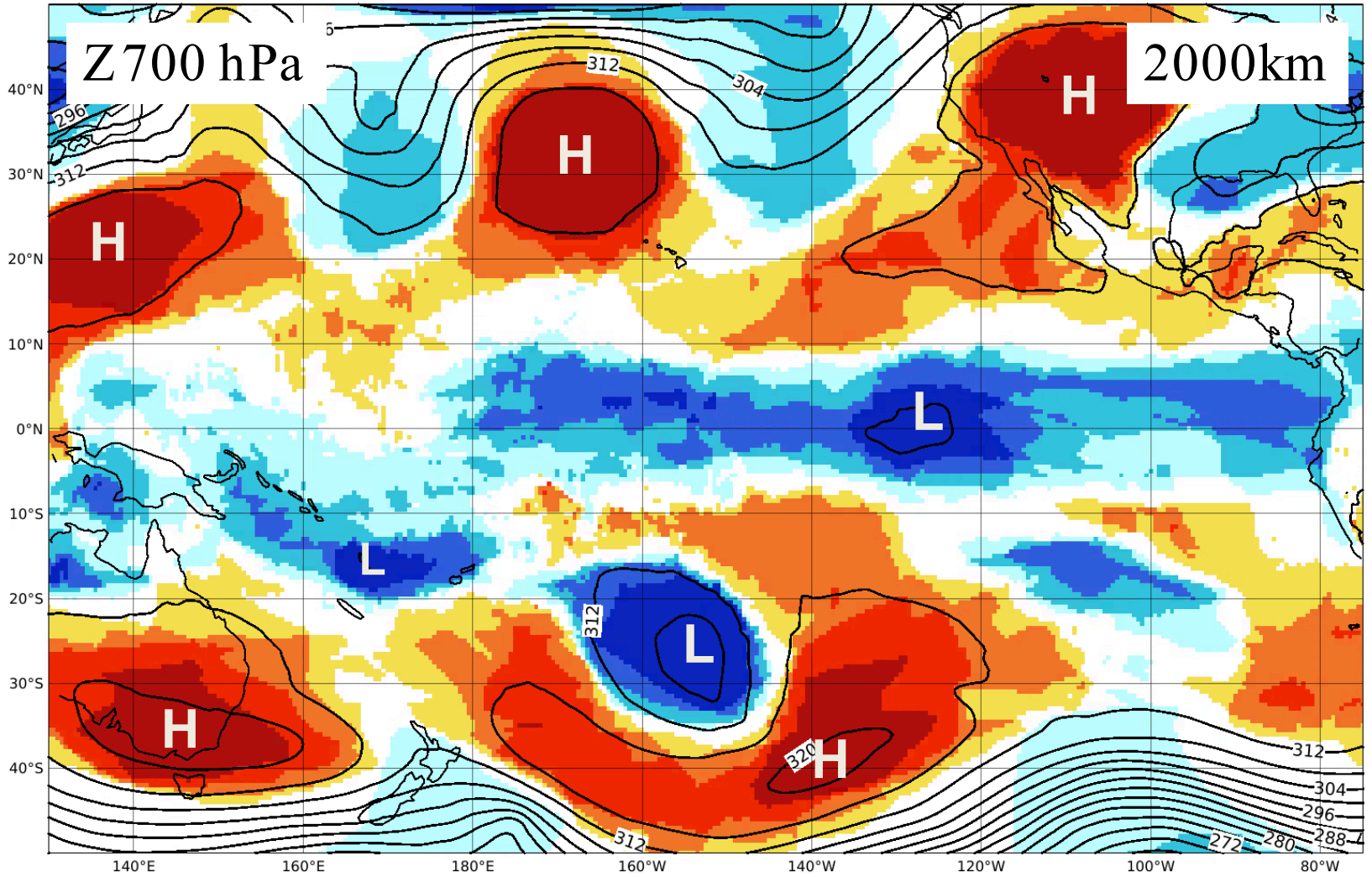
Tropical Pacific

CURV example



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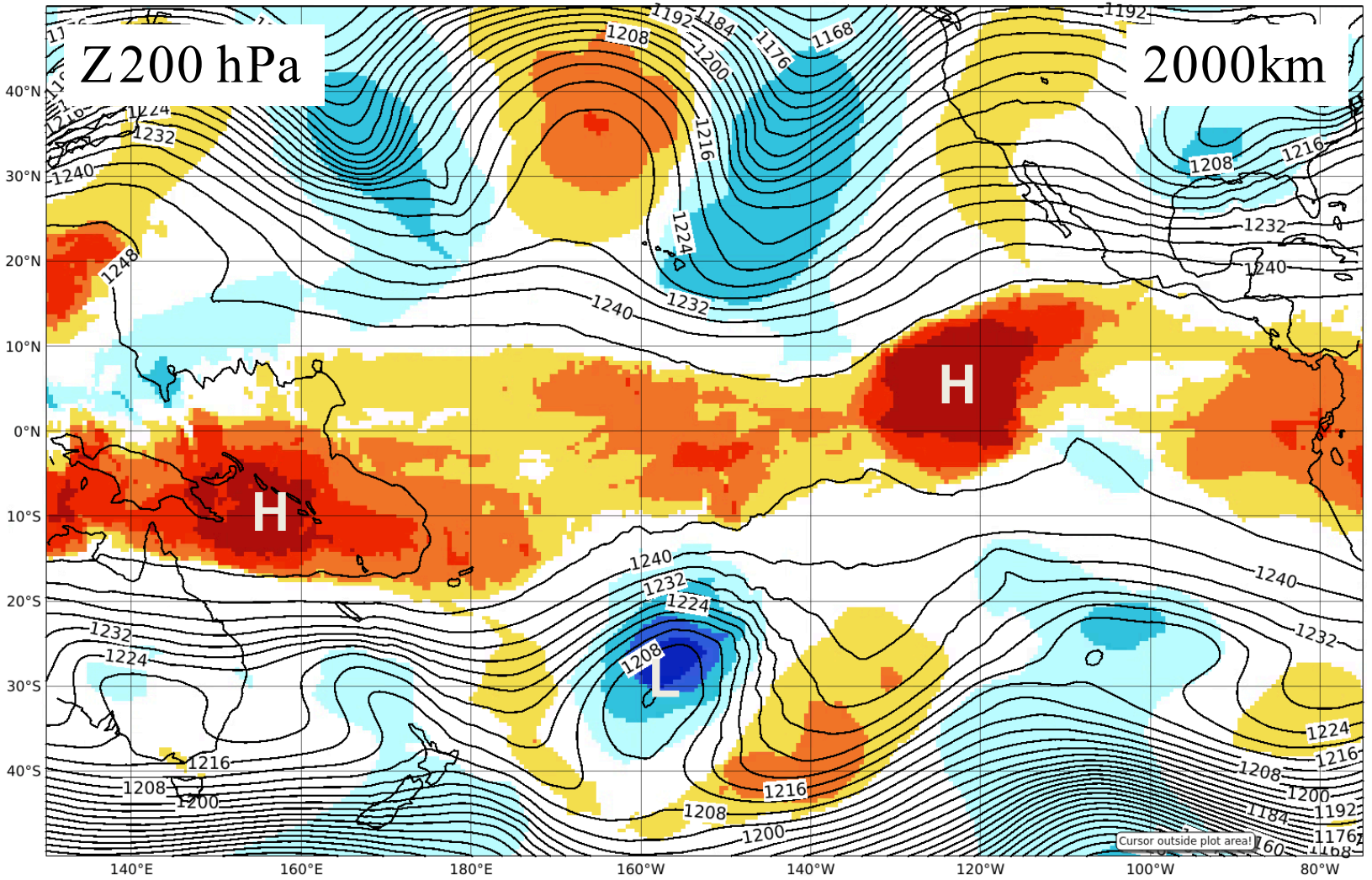

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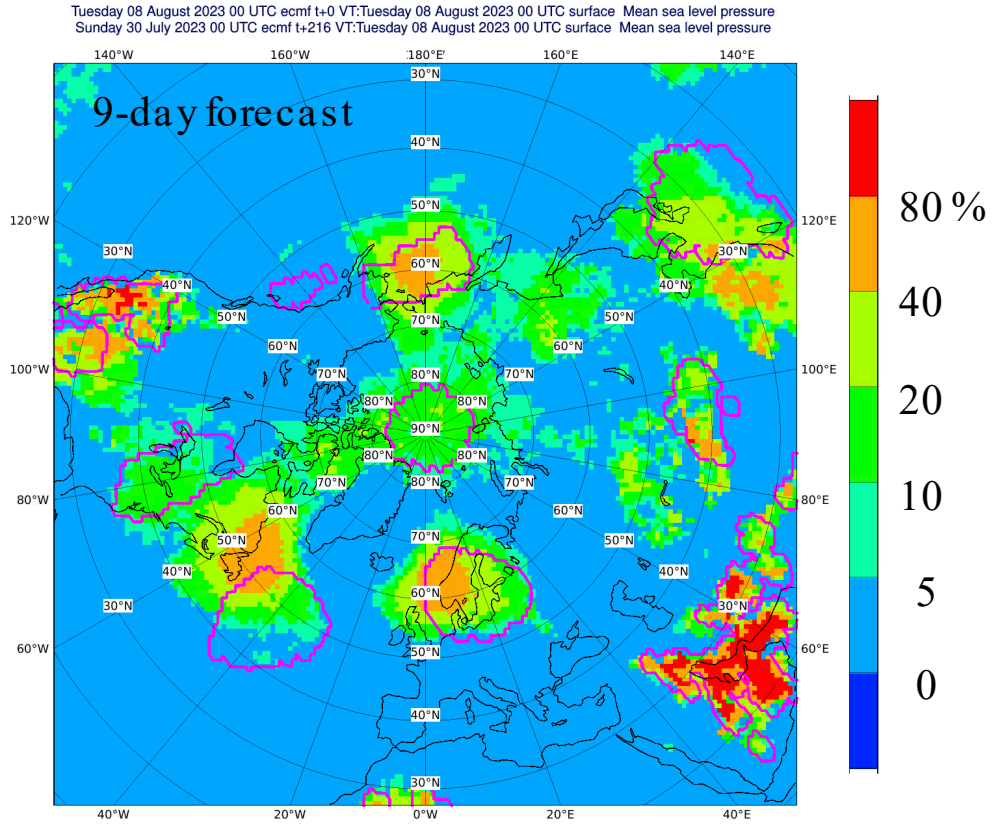
Verification of ensemble probabilities of curvature

Probability above/below MSLP CURV value (e.g. probability of at least cyclonic)

Aggregated Brier Skill Score (relative to area-averaged observed frequency)

12-month period May 2023 to April 2024 (366 forecasts starting at 00 UTC)

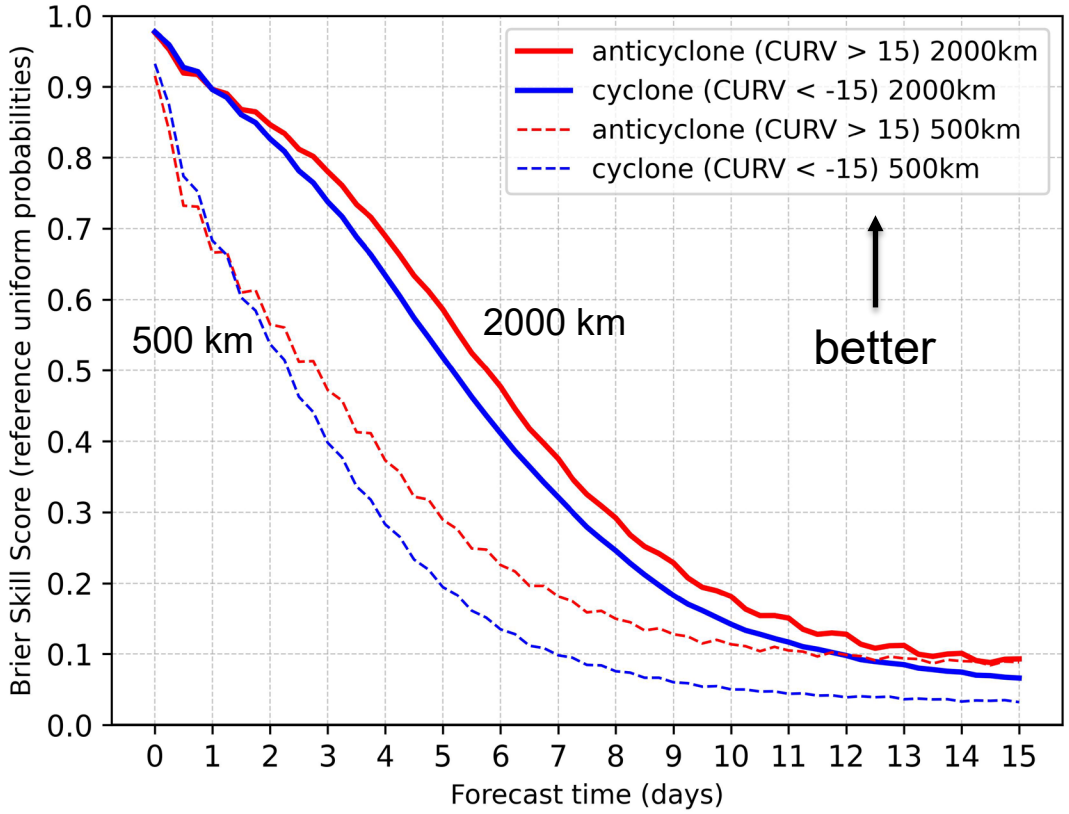
Example

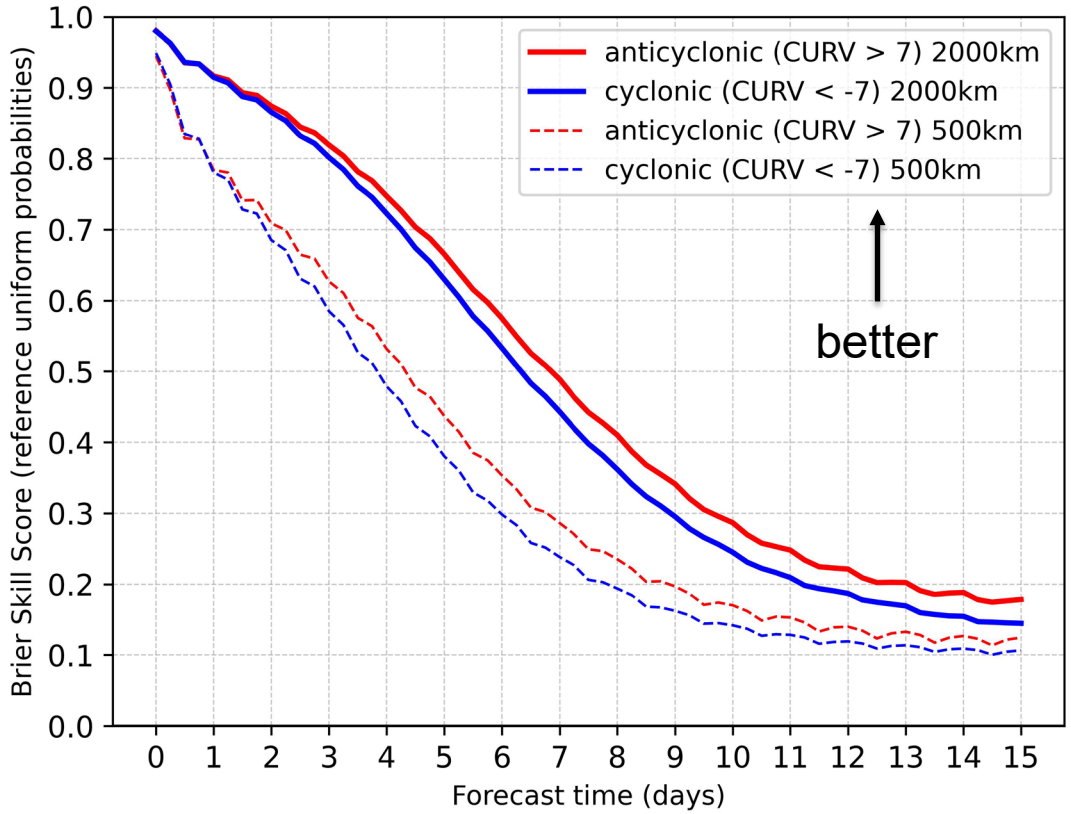


Probability MSLP CURV < -15 (cyclone)

Purple contours enclose binary analysis occurrences (Probability = 1)

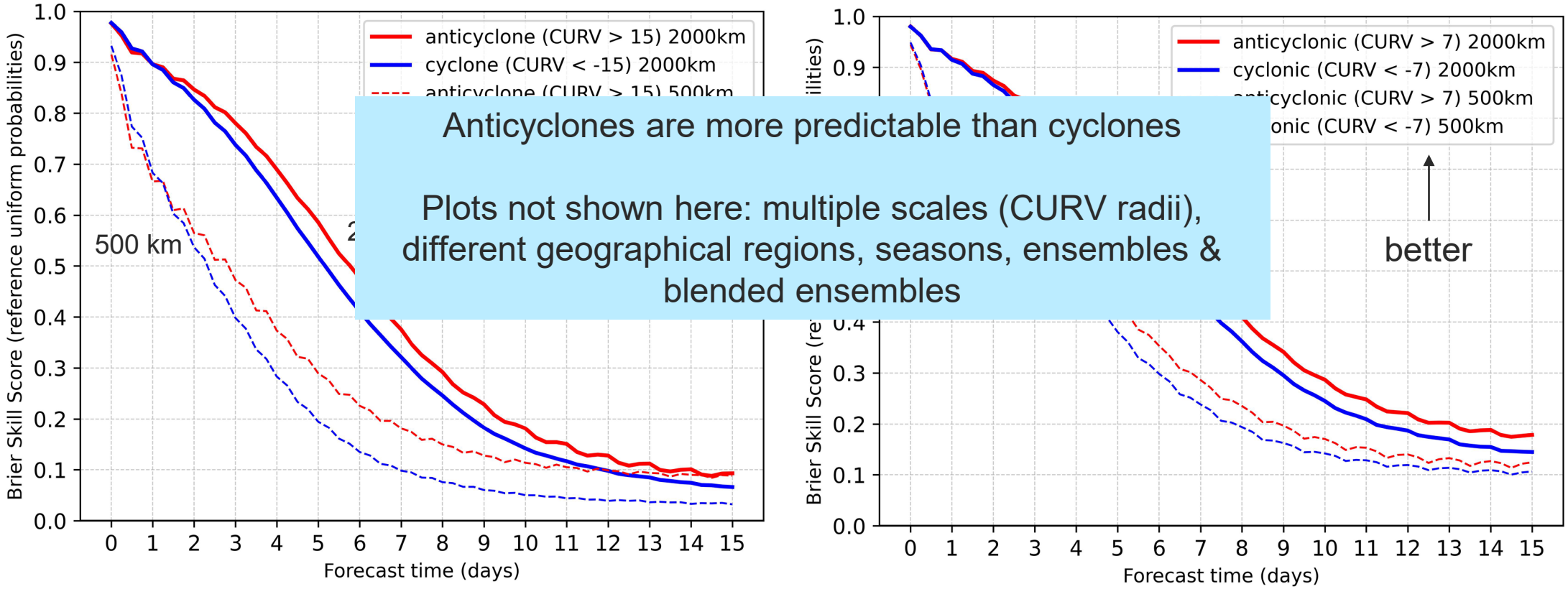
Cyclonic versus anticyclonic





Medium-range ensemble (9 km, 51 members)

Cyclonic versus anticyclonic



Anticyclones are more predictable than cyclones

Plots not shown here: multiple scales (CURV radii), different geographical regions, seasons, ensembles & blended ensembles

Medium-range ensemble (9 km, 51 members)

Conditional verification

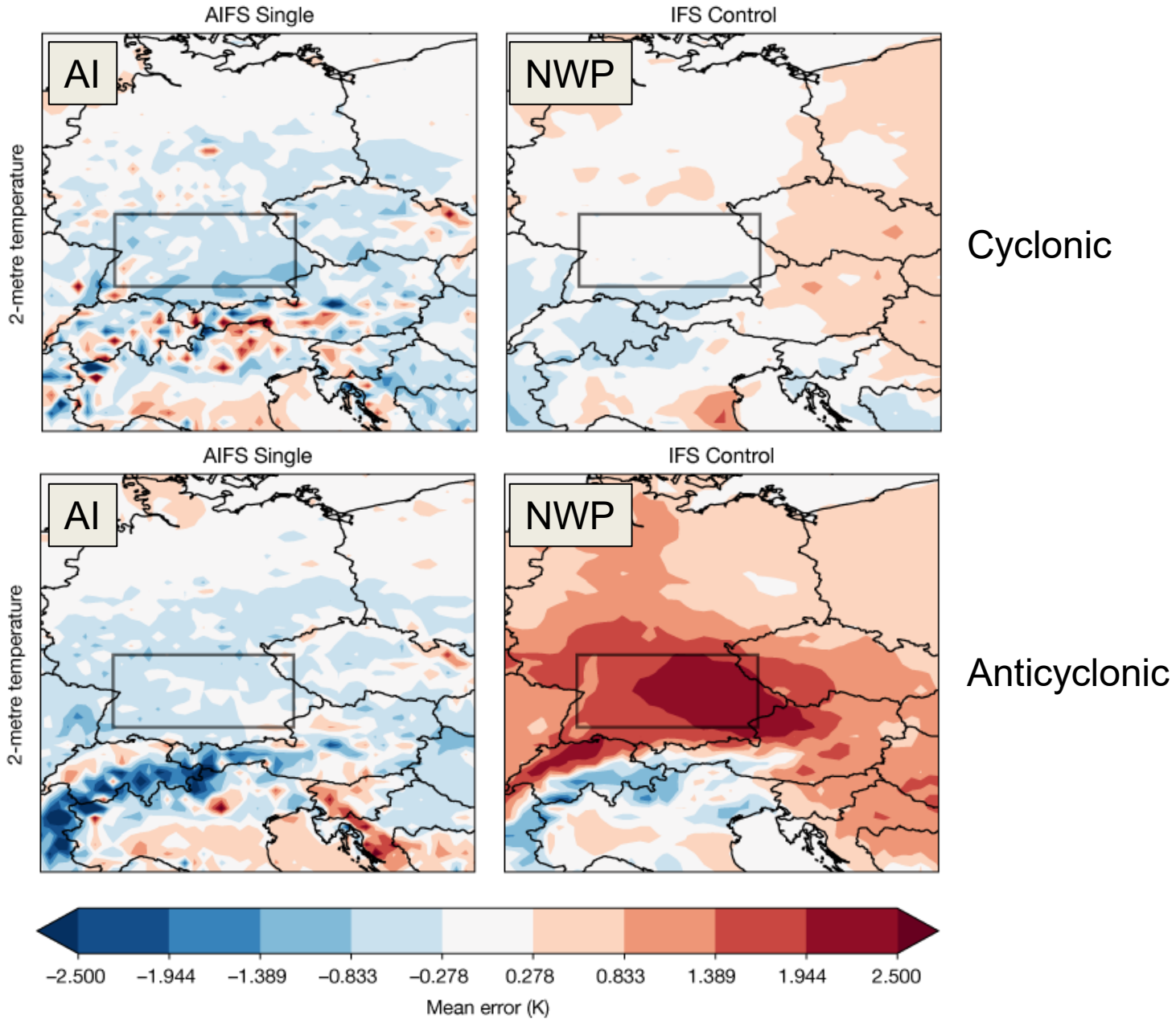
Relationship between synoptic pattern using CURV and forecast temperature errors

Conditional verification of temperature errors

Dec-Jan-Feb 2024-2025
36h forecasts
Mean 2m temperature error

Soufiane Karmouche and co-authors
22 May 2025
Verifying 2 m temperature forecasts in wintertime anticyclonic conditions

ECMWF AIFS blog
[Verifying 2 m temperature forecasts in wintertime anticyclonic conditions | ECMWF]



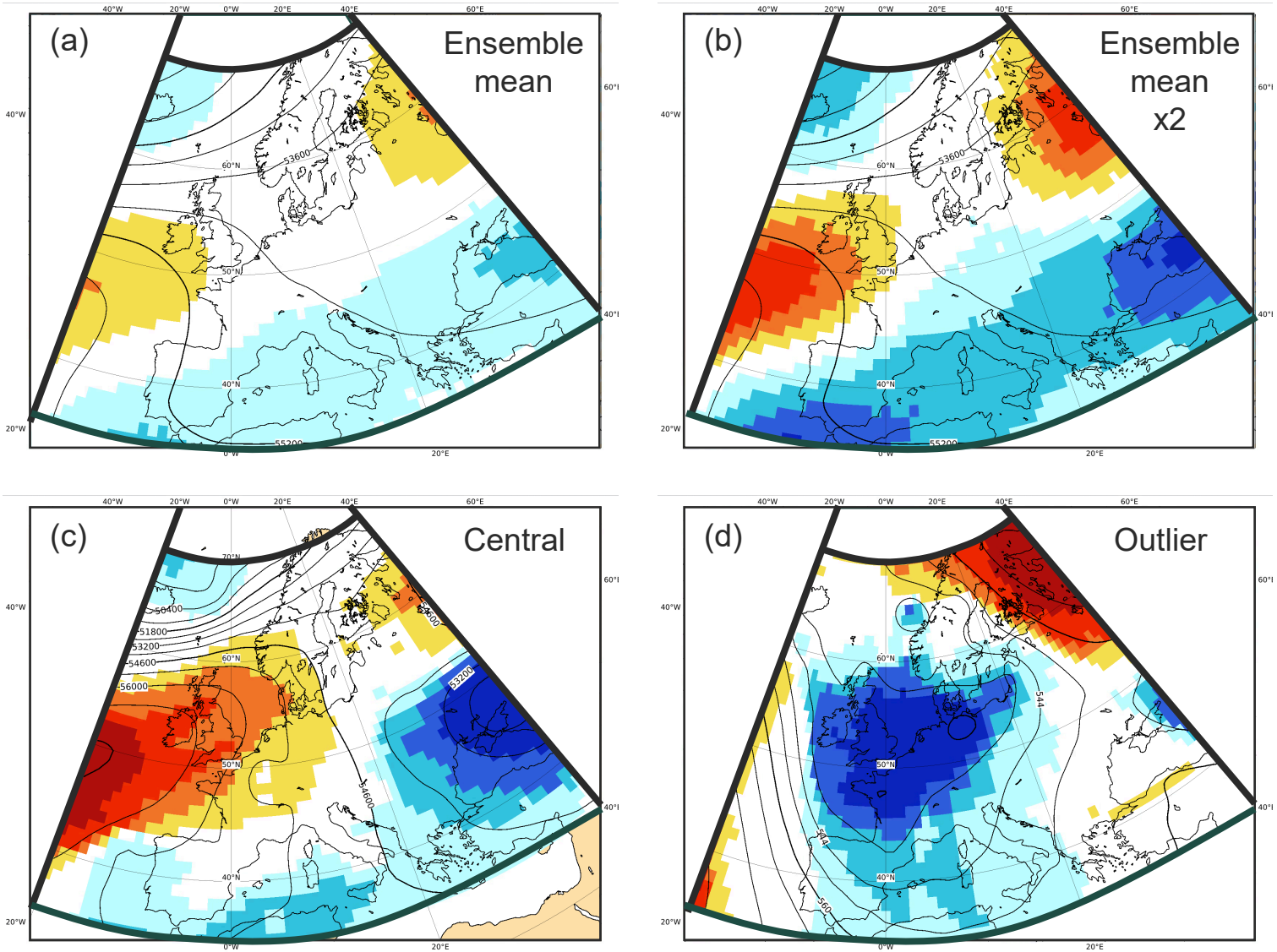
Representative (central) forecast

The ensemble member with CURV pattern closest to the ensemble mean CURV pattern

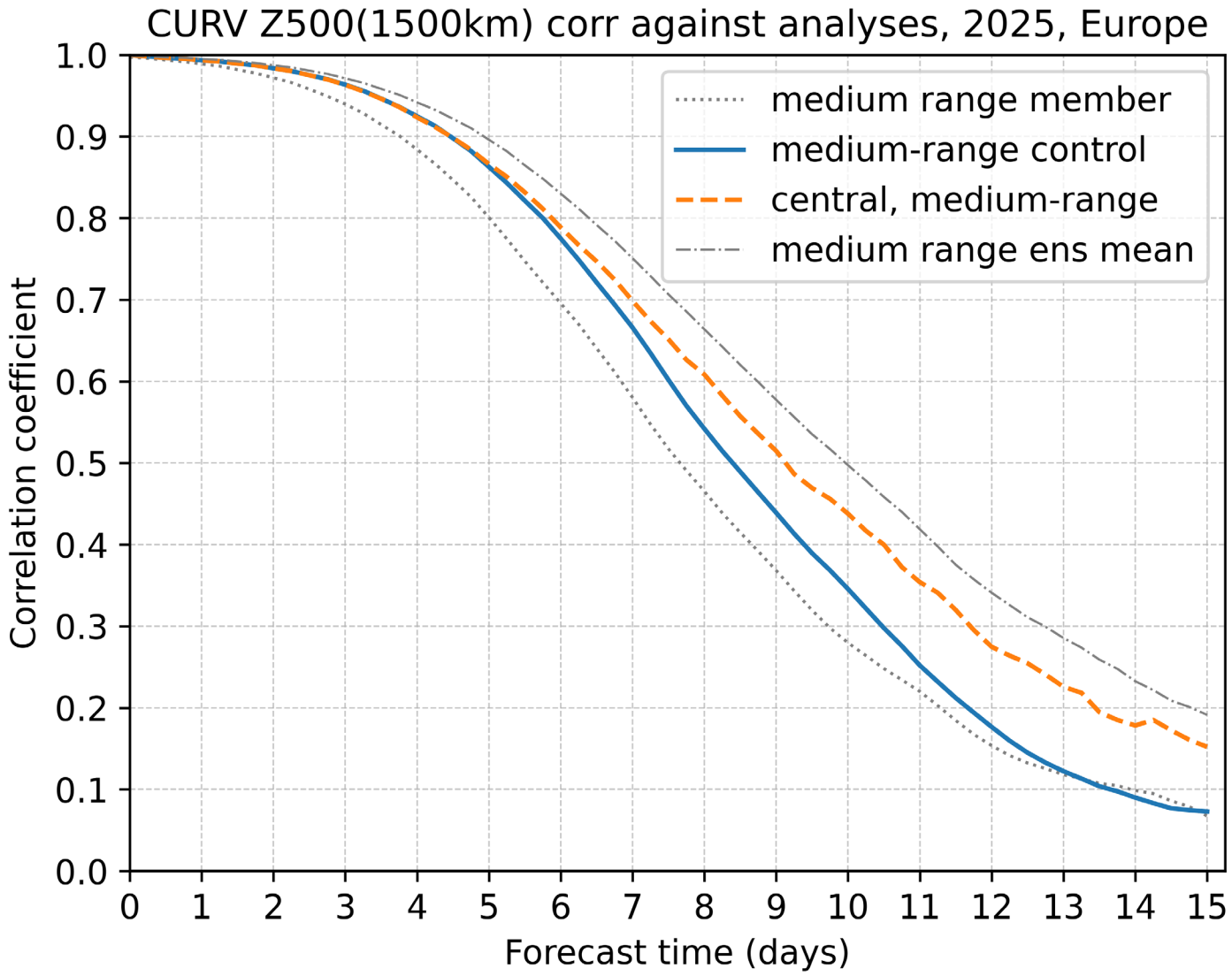
A ‘real’ plausible forecast that gives the ensemble consensus synoptic pattern
(the ensemble mean is not a possible evolution)

Such a forecast should be the most skilful member on average
(given an appropriately spread and unbiased ensemble)

Use spatial correlation with ensemble mean to find representative (central) member



Comparison of the central member and control forecast



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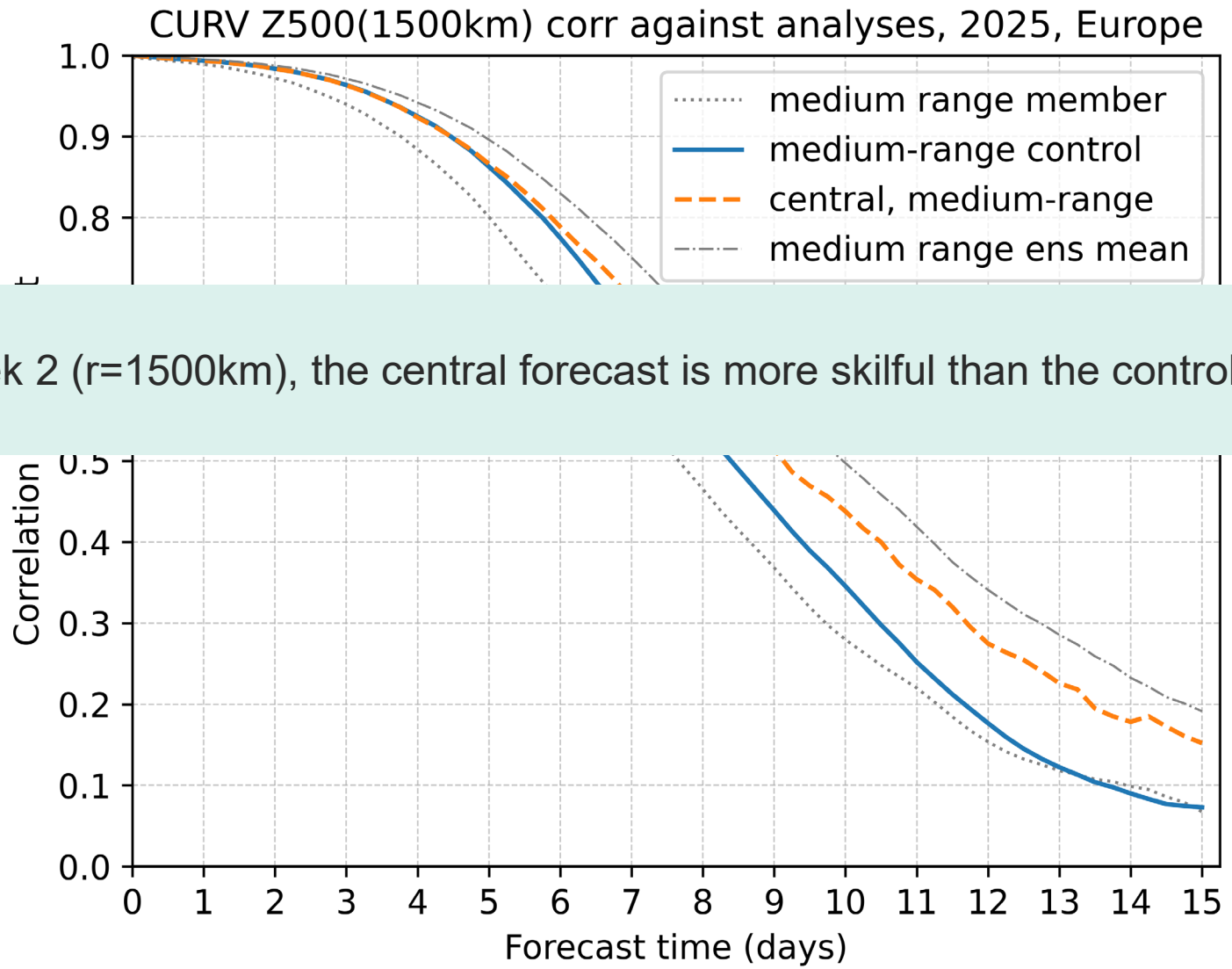


For week 2 (r=1500km), the central forecast is more skilful than the control by around a day

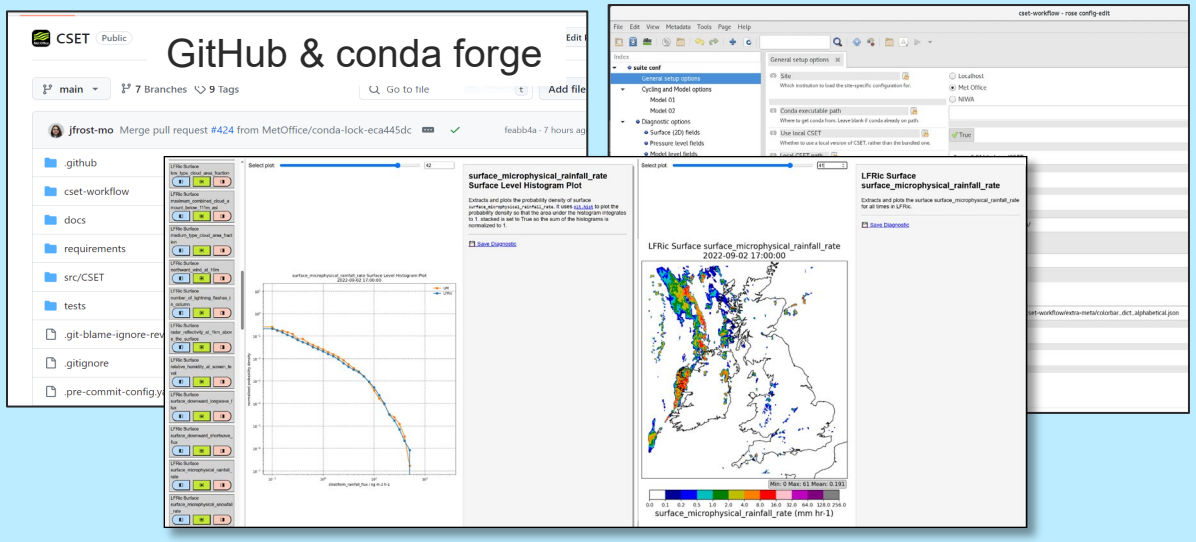
Use in the Met Office

David Flack in the Regional System Evaluation Group (Sylvia Bohnenstengel) has started to code CURV into CSET.

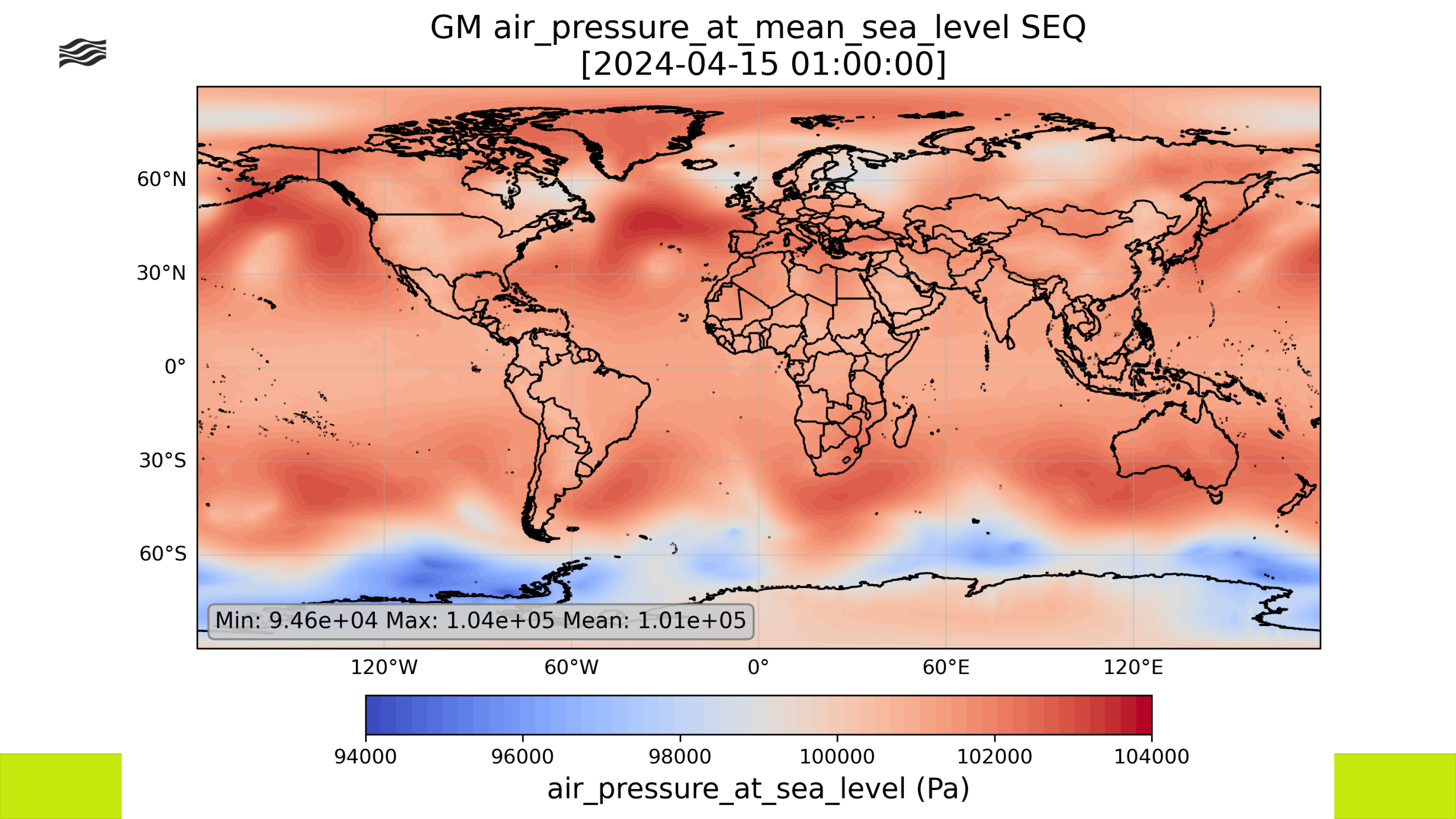
Regional Model Evaluation & Diagnostics (RMED) (Huw Lewis)

The aim is to use CURV for conditional evaluation to start with

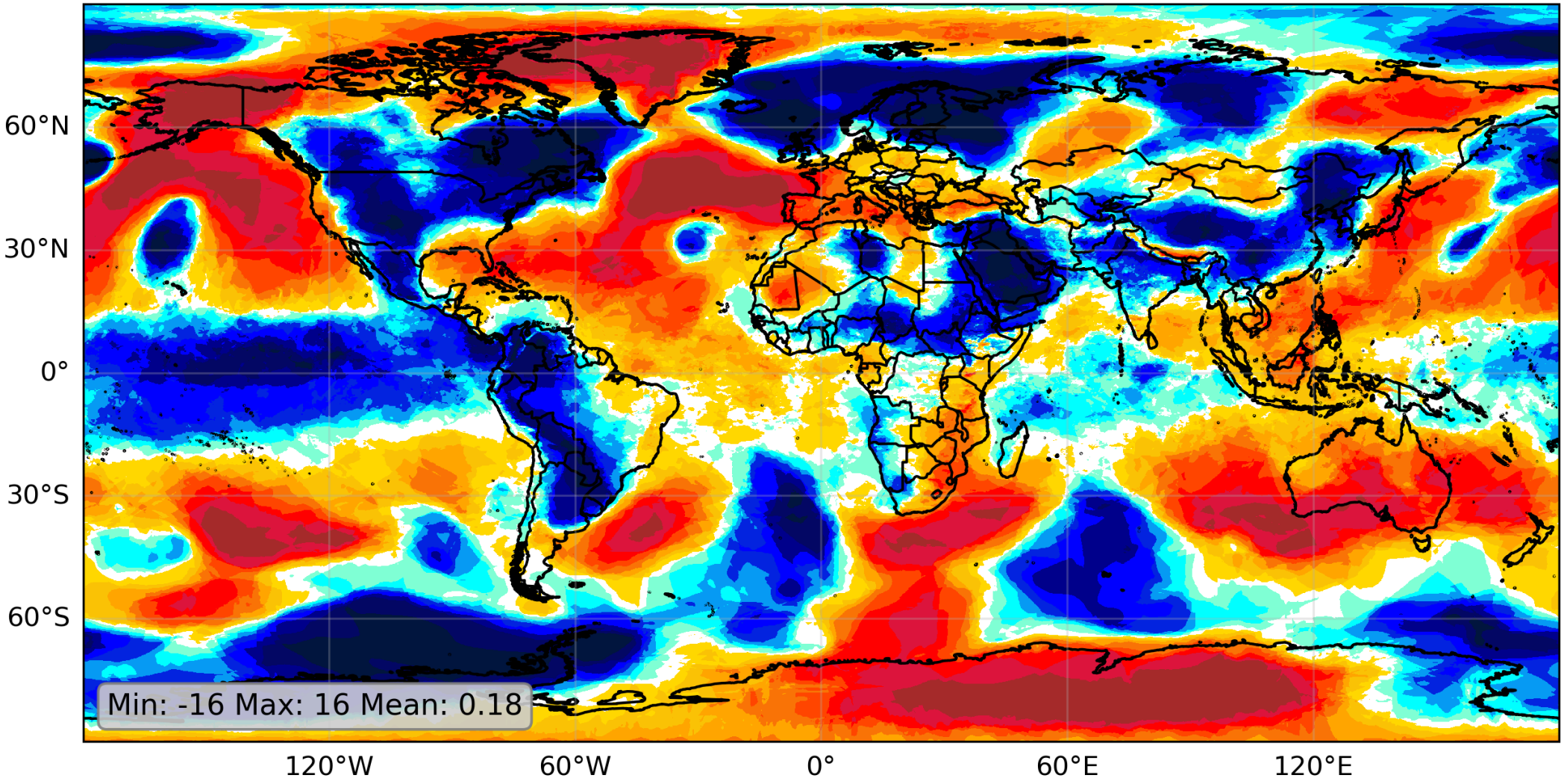
Community **S**eamless **E**valuation **T**oolkit: CSET



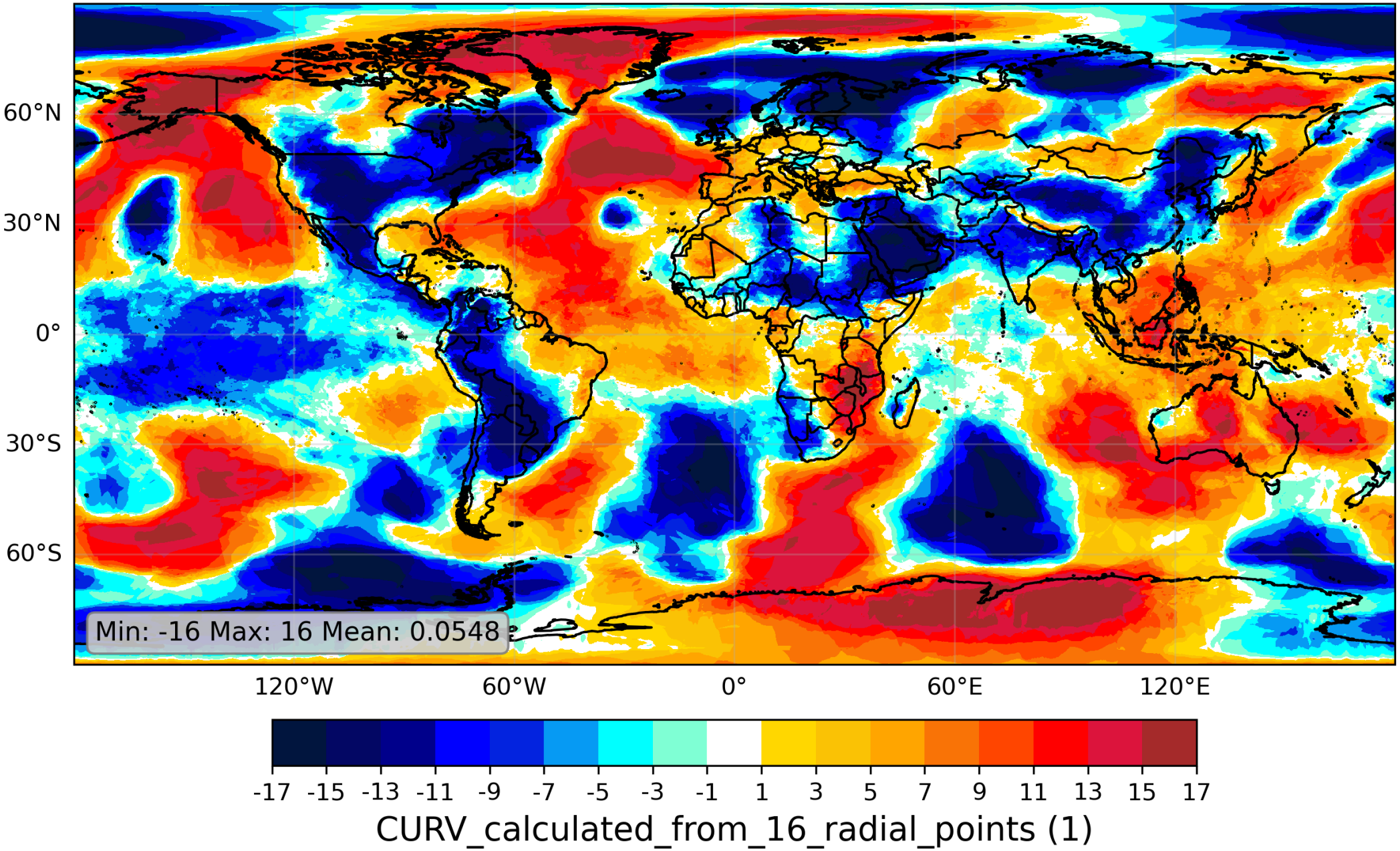
James Frost, David Flack, James Warner, Carol Halliwell, Bernard Claxton, John Edwards, Jorge Bornemann, Stephen Gallagher, Sylvia Bohnenstengel, Huw Lewis, + other CSET developers


GM air_pressure_at_mean_sea_level SEQ
[2024-04-15 01:00:00]
60°N
30°N
0°
30°S
60°S
Min: 9.46e+04 Max: 1.04e+05 Mean: 1.01e+05
120°W
60°W
0°
60°E
120°E
94000
96000
98000
100000
102000
104000
air_pressure_at_sea_level (Pa)

GM CURV spatial plot from 16 points and radius of 1500 km
[2024-04-15 01:00:00]



GM CURV spatial plot from 16 points and radius of 500 km
[2024-04-15 01:00:00]



Some potential uses

- Verification (including ML models) and conditional verification / evaluation
- Local regime classification – zonal, blocked …
- Ensemble applications – central member, clustering, partitioning, selection for LAMs, simplification
- Forecast applications – synoptic narrative, model/ensemble differences, storm footprints
- Seasonal and climate timescales

Example of some potential CURV applications

Plume forecast and verification

Hurricane Milton footprint
CURV < -15
CURV < 15 & > 30hPa in 700km

ERA5 Climatology

In line with Potential Vorticity expectations

Probability of anticyclonic curvature (blocking)

Summary

The CURV diagnostic, developed at ECMWF, for quantifying curvature has been introduced

Shown its use for ensemble verification, conditional verification and representative member selection

Paper ‘A new scale-selective measure of curvature for meteorological fields’
Nigel Roberts, Tim Hewson, Anca Brookshaw & Matthieu Chevallier
Submitted to QJRMS (in second revision)

Paper to be submitted about member selection

Contact:
Balazs Szintai balazs.szintai@ecmwf.int if interested in CURV at **ECMWF** (experimental)

nigel.roberts@metoffice.gov.uk

ECMWF

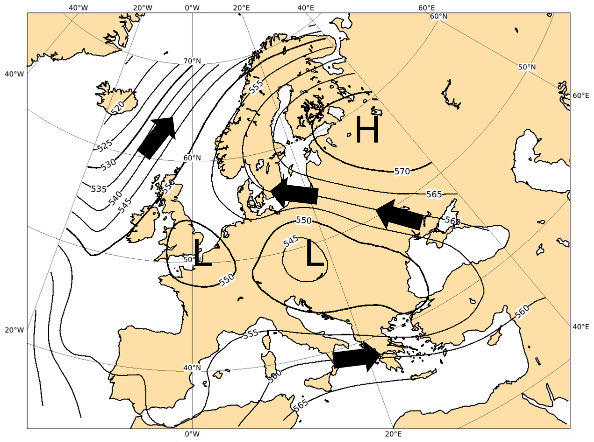
Thanks for listening

ECMWF

8-member ensemble constructed from 203 members using CURV correlation percentiles, T+288

Quite blocked

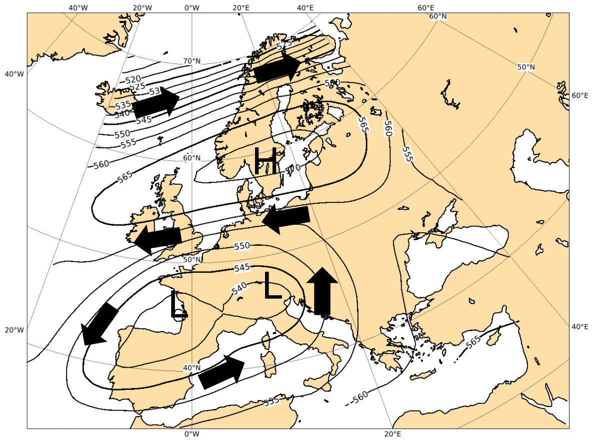
Thursday 30 January 2025 00 UTC ecmf t+288 VT:Tuesday 11 February 2025 00 UTC 500 hPa Geopotential



Closest to mean

Most like outcome

Thursday 30 January 2025 00 UTC ecmf t+288 VT:Tuesday 11 February 2025 00 UTC 500 hPa Geopotential



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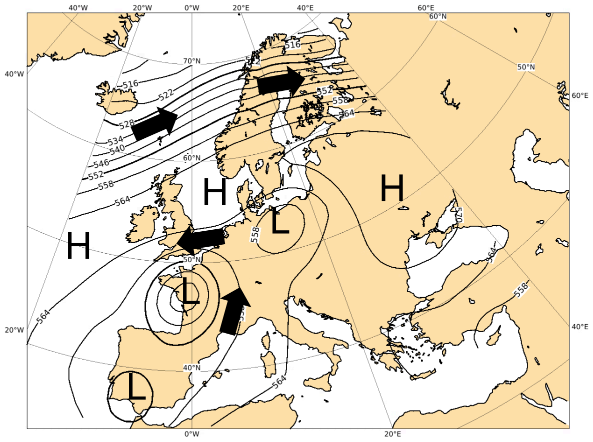

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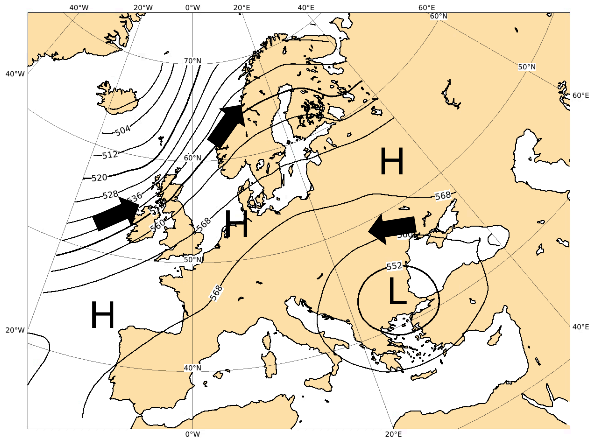
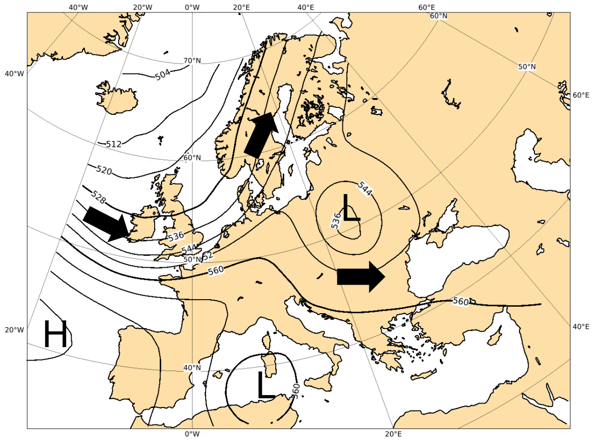


More zonal

Thursday 30 January 2025 00 UTC ecmf t+288 VT:Tuesday 11 February 2025 00 UTC 500 hPa Geopotential



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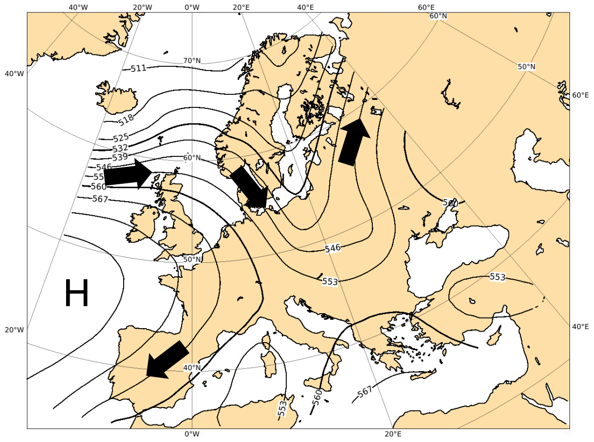

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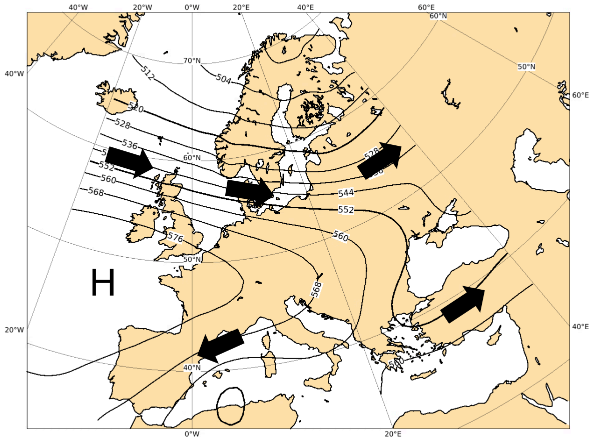

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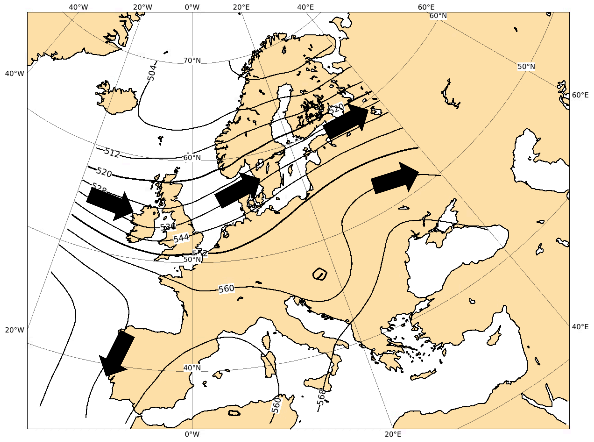

Furthest from mean