Solutions to Long-standing Problems in Objectively Identifying and Tracking Synoptic-scale Cyclonic Features

Tim Hewson

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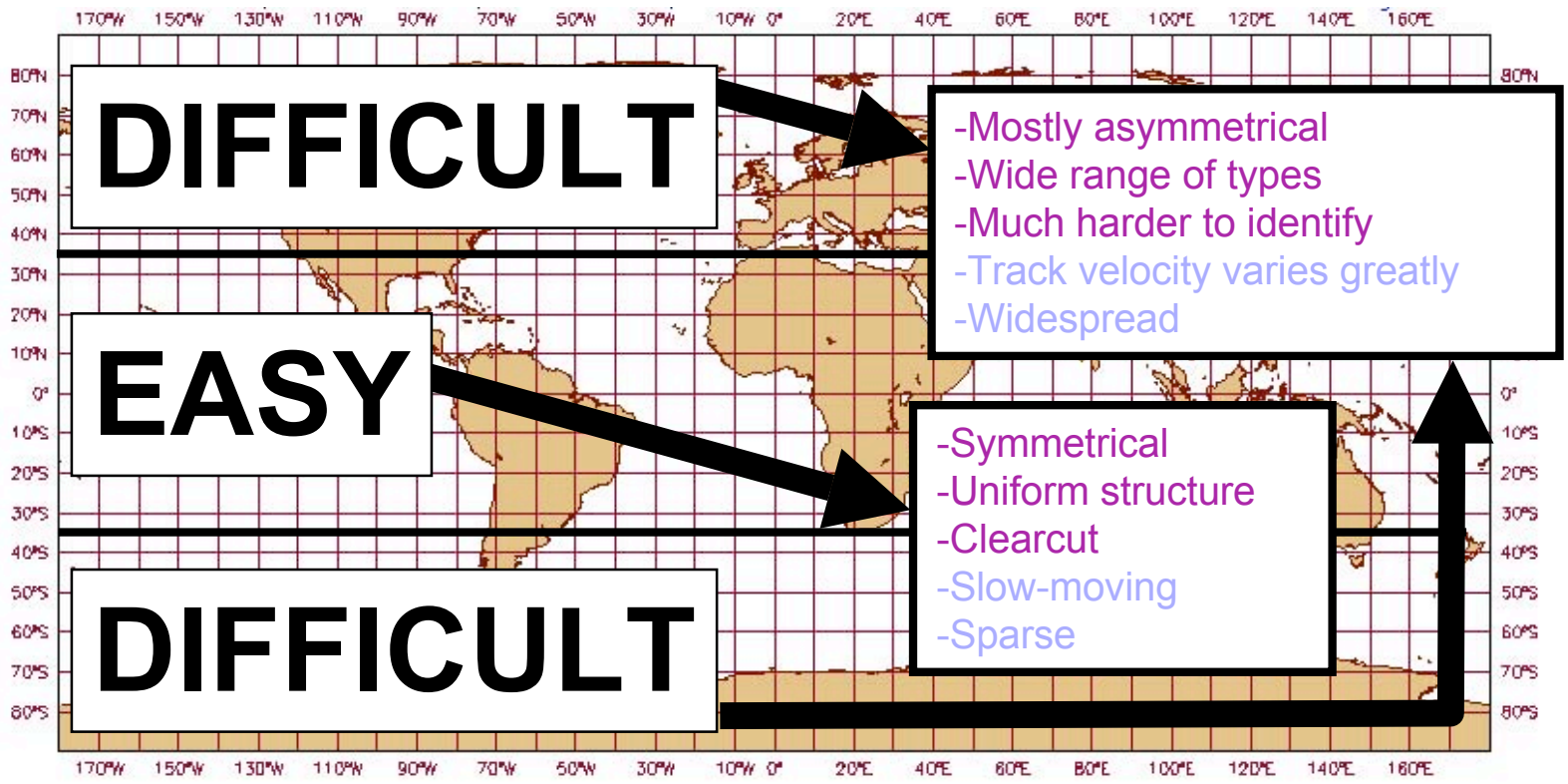
Contents

- Brief description of the identification and tracking algorithms, with examples
- List of ‘long-standing problems’ in feature tracking, and how the new methodology aims to address them
- Summary

1. Description of algorithm

- Two stage process – A. Feature Identification & B. Feature Tracking
- Tropical vs extra-tropical tracking – recognizing some of the issues..



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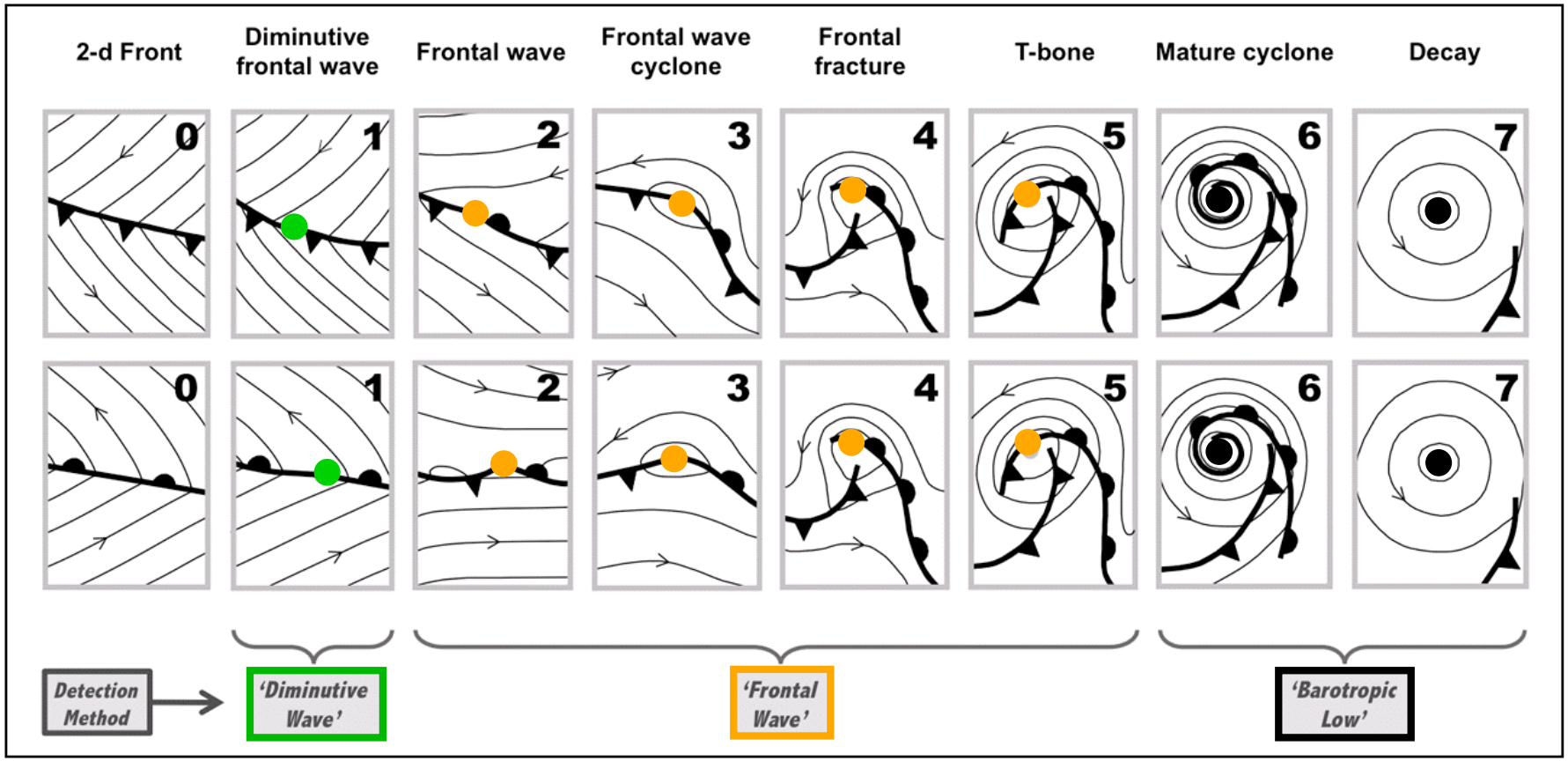
A. Identifying Cyclonic Features

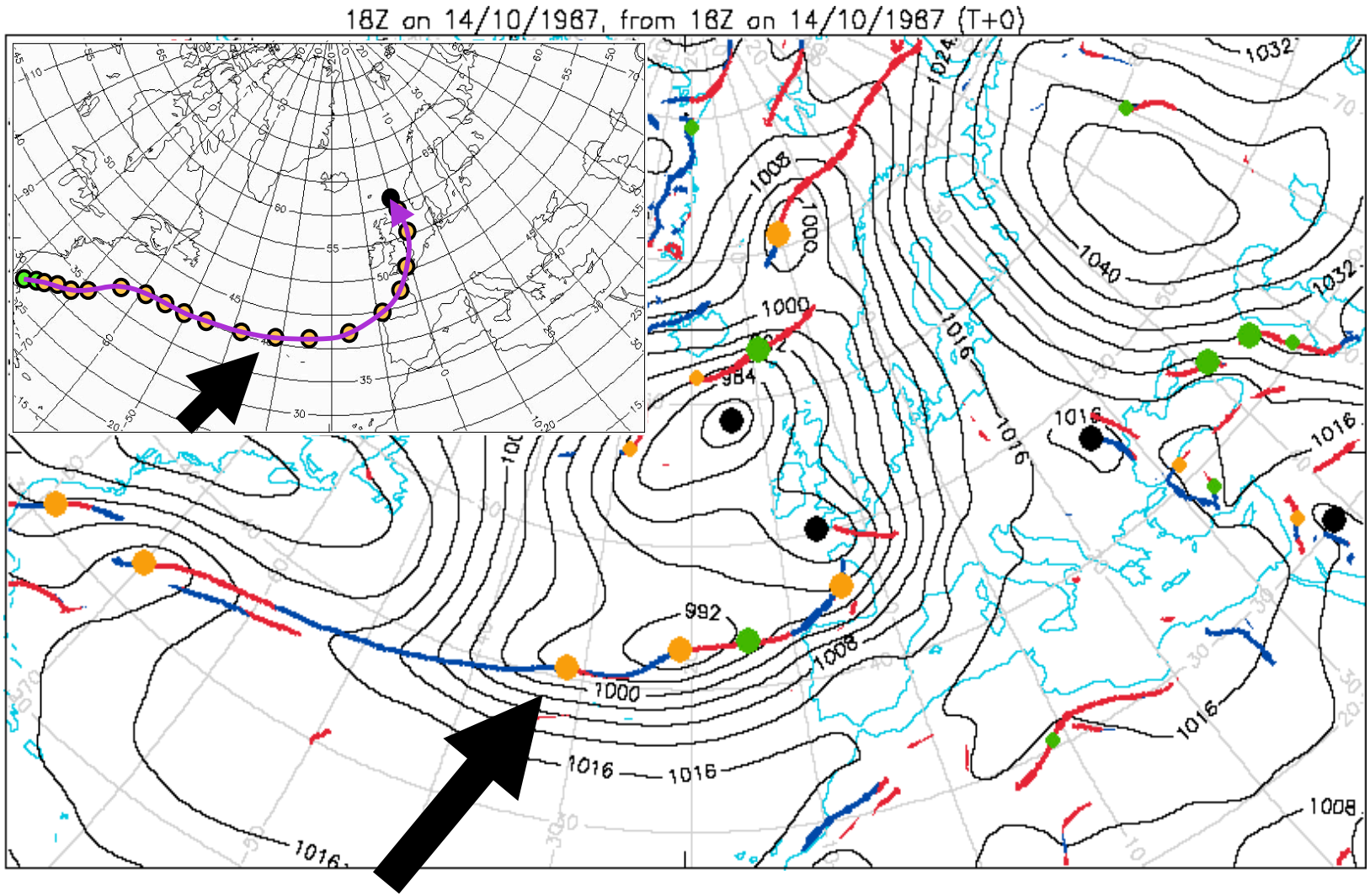
- Work began in 1996.
- Pressure level data provides input

  (T, q, u, v, Z @ 1000,925,850mb,.. @ 12h intervals)
- Range of diagnostics computed from the above (FORTRAN)
- Diagnostics plotted and post-processed using graphical package, currently PV-WAVE (~8000 lines of code)
  - Features essentially lie at the intersection points of two distinct contoured fields
  - Graphical Masking based on other diagnostic fields disallows some intersection points
- Initially output comprises ‘synoptic animations’ and simple ASCII text files showing attributes of each identified feature

- **Identification methodology is based around this conceptual model of extra-tropical cyclone development (but is not constrained by it):**



Example – UK October storm 1987 (in ERA-40)



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Accuracy

- A systematic comparison between cyclonic synoptic features marked on UK Met Office synoptic charts near the UK (low centres and frontal waves) and objective features in model analyses was carried out, for 5 x 6month winter periods.

- For clearcut cases the hit rate was 84%, and the false alarm ratio 17%, implying good agreement.

B. Defining Feature Trajectories (=Tracking)

- Work began in 2005
- Aim is to 'join the dots' between successive time frames, recognising also genesis and lysis of cyclonic features
- Key Input parameters – i.e. in the output of stage A - are:

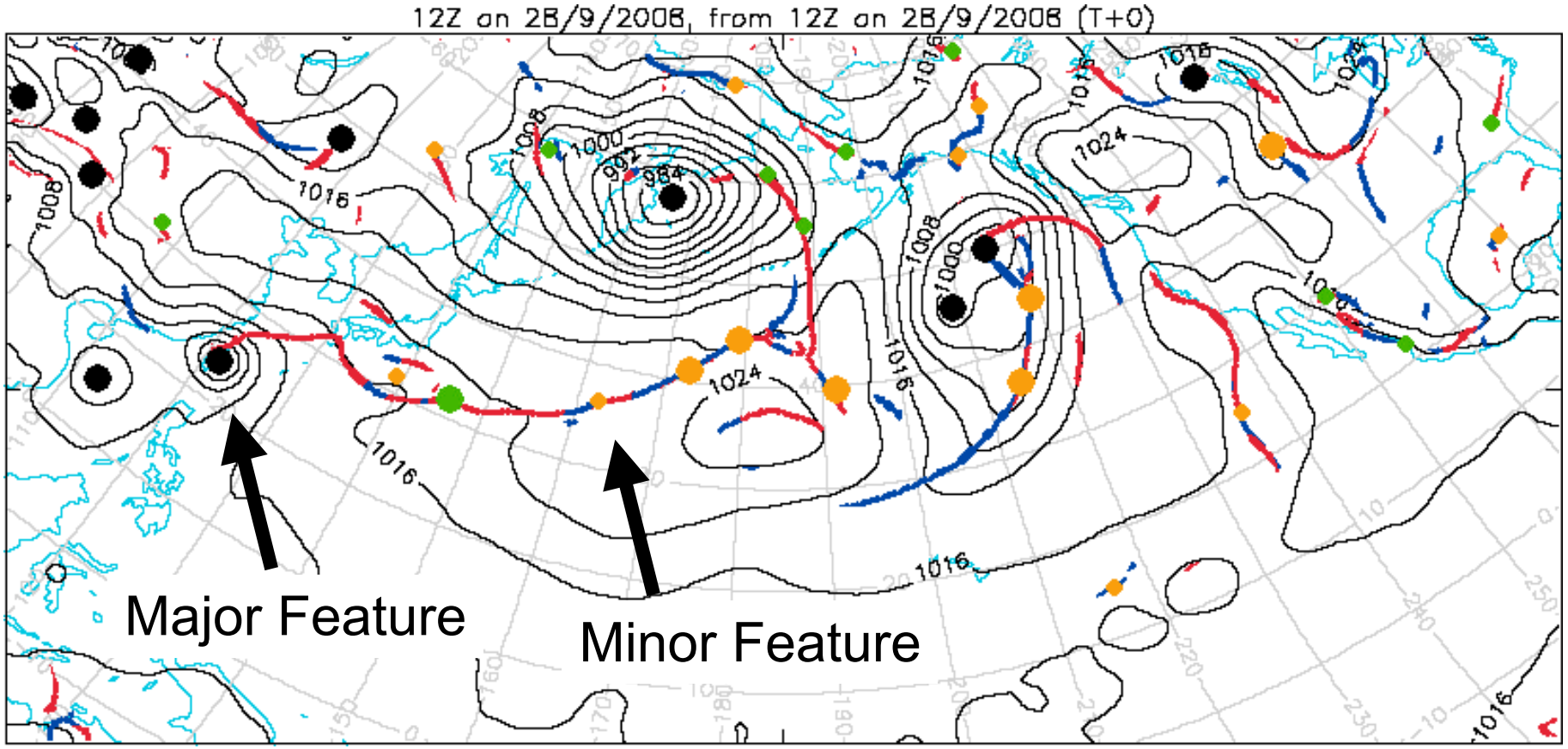
  feature position and type

  500mb wind velocity above feature point (for steering)

  1000-500mb thickness at feature point

  previous movement of feature also used
- Output is a simple ASCII feature-track text file, showing lat/lon, VT and other feature attributes, for each computed track – this is then graphically represented in a number of ways
- Processing performed in FORTRAN

Example: Pacific – tracking in ECMWF ensemble



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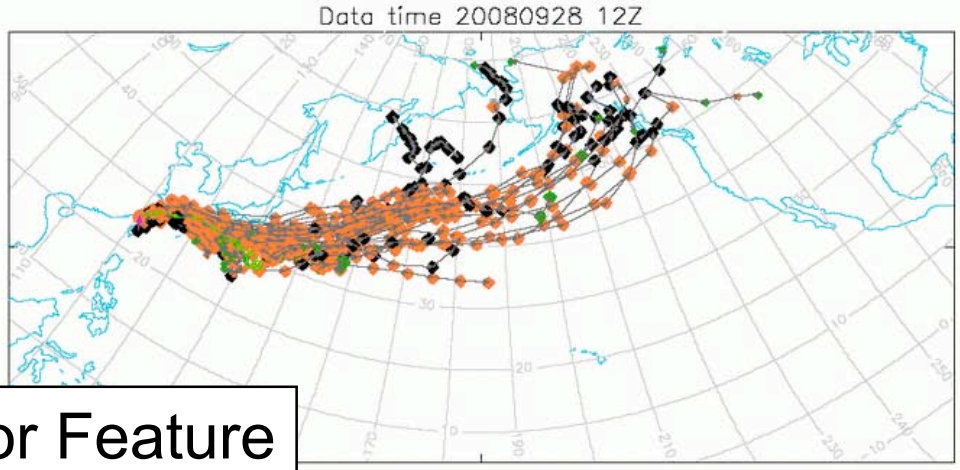
Major Feature



Percentage of members in track, and a list of the member numbers:

T+ 0: 100% 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50

T+ 12: 100% 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50

T+ 24: 100% 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50

T+ 36: 100% 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50

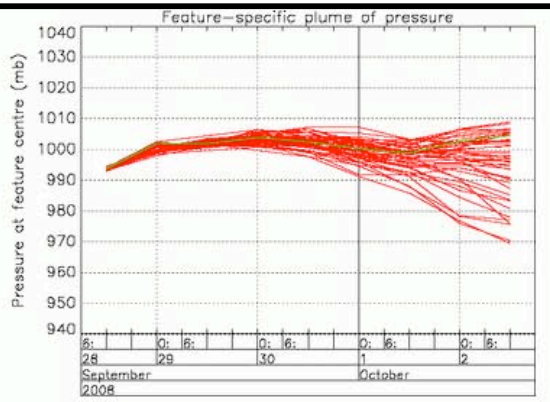
T+ 48: 100% 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50

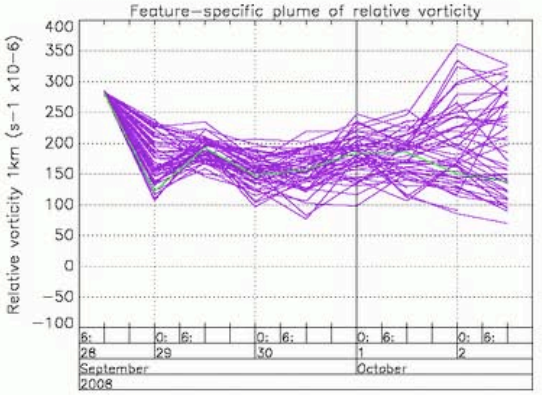
T+ 60: 100% 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50

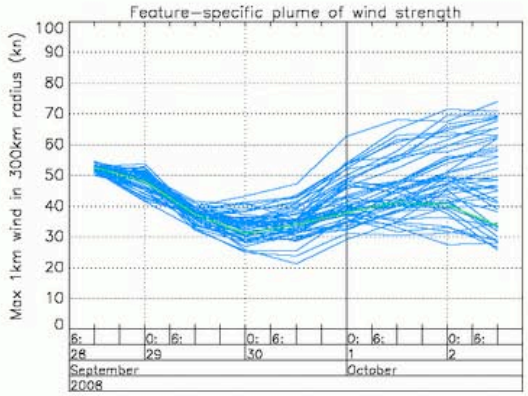
T+ 72: 100% 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50

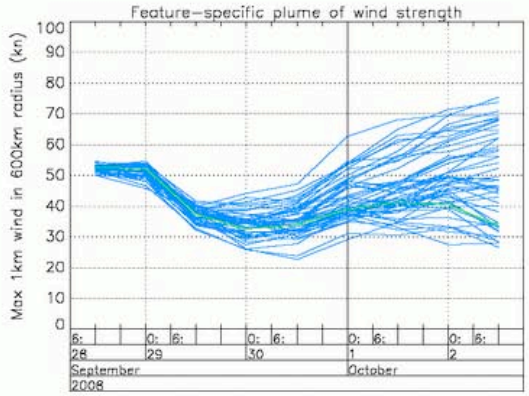
T+ 84: 98% 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,16,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50

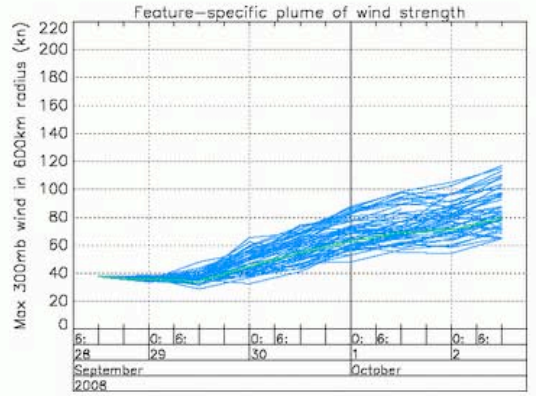
T+ 96: 94% 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,16,19,20,21,22,23,24,25,26,28,29,30,31,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50











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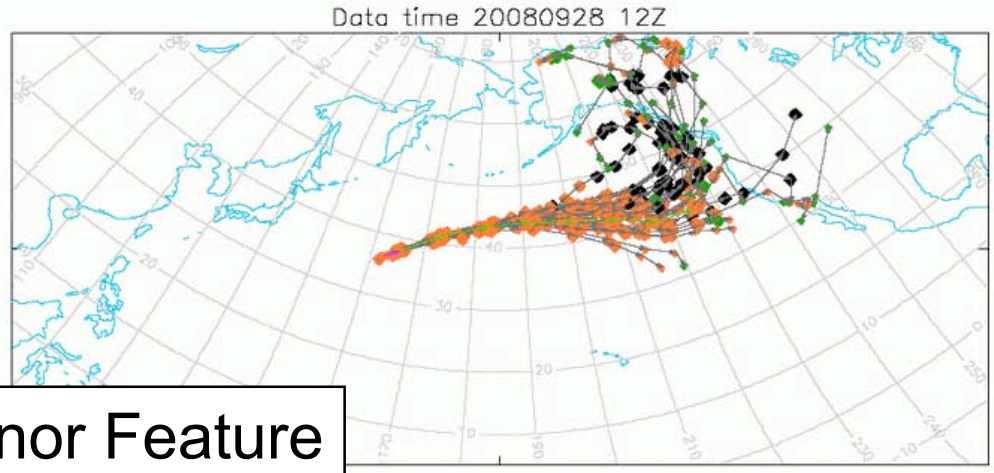
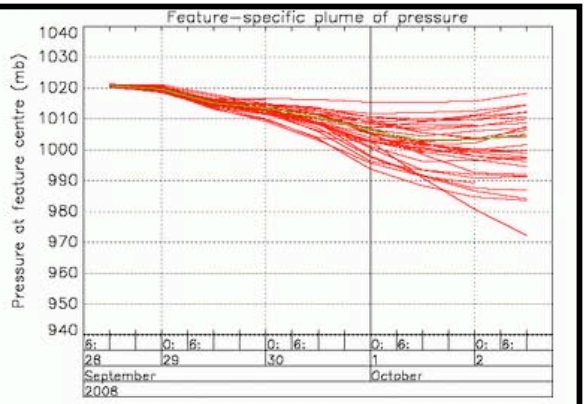
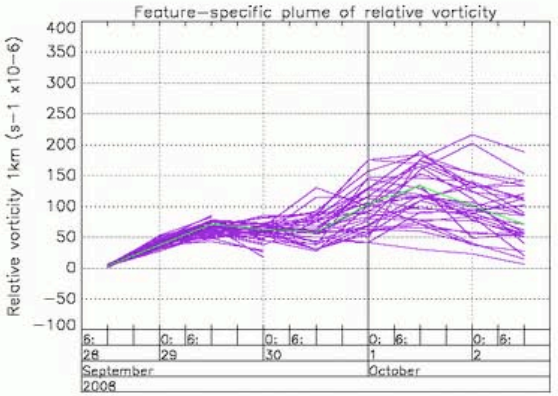
Minor Feature

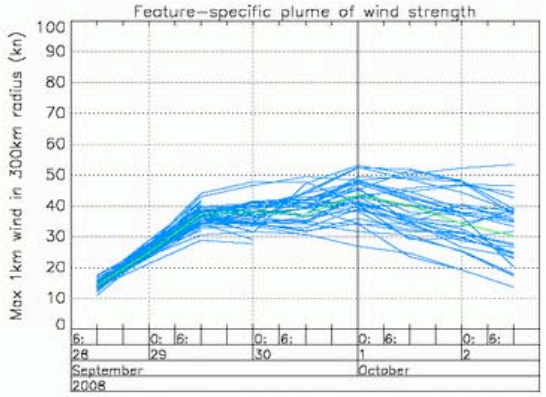


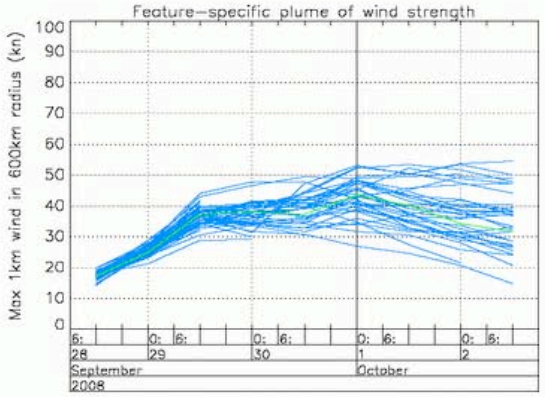
Percentage of members in track, and a list of the member numbers:

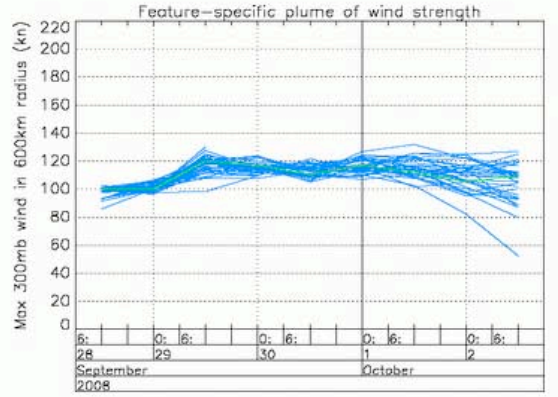
T+ 0:	100%	0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50
T+ 12:	100%	0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50
T+ 24:	100%	0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50
T+ 36:	80%	0,1,2,3,6,7,8,9,10,11,13,14,15,16,17,18,19,20,21,22,23,24,26,27,29,30,32,33,36,37,38,39,40,41,42,43,45,46,47,48,49
T+ 48:	70%	0,1,2,6,7,8,10,11,13,14,15,16,17,18,19,20,21,22,23,24,26,27,29,30,32,36,37,38,39,41,42,43,45,46,47,48
T+ 60:	66%	0,1,2,6,7,10,11,13,14,15,16,17,18,20,21,22,23,24,26,27,29,30,32,36,37,38,39,41,42,43,45,46,47,48
T+ 72:	66%	0,1,2,6,7,10,11,13,14,15,16,17,18,20,21,22,23,24,26,27,29,30,32,36,37,38,39,41,42,43,45,46,47,48
T+ 84:	66%	0,1,2,6,7,10,11,13,14,15,16,17,18,20,21,22,23,24,26,27,29,30,32,36,37,38,39,41,42,43,45,46,47,48
T+ 96:	62%	0,1,2,6,7,10,11,13,14,15,16,17,18,20,21,22,23,24,26,27,30,32,36,37,38,41,42,43,45,46,47,48











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Accuracy

- Feedback from forecasters originally lead to changes to the tracking, with a significant positive impact – ‘half-time tracking’ was one related innovation

- In tests, using 167 N Pacific feature points in one control forecast, the tracking algorithm clearly made the wrong decision (compared to manual tracking) on only 3 occasions (~2%):
  - two cases were weak coastal features over Mexico
  - one case was retained within the domain (over Alaska) when it should have exited

2. Long-Standing Problems, and Solutions

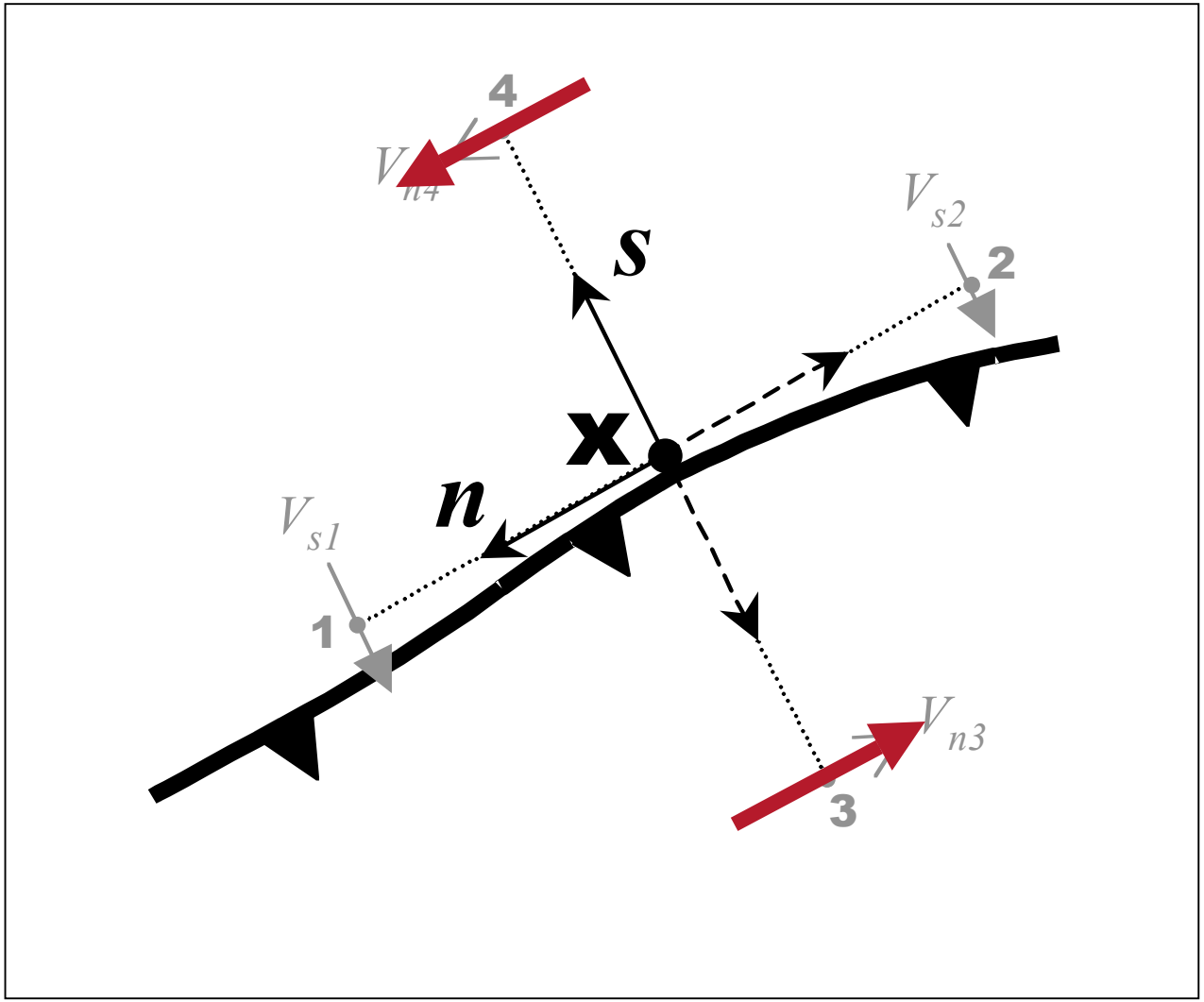
- A. Identification
- B. Tracking

2A. Identification Problems

- (i) *'Low level vorticity patterns are noisy and/or strip-like, and need to be upscaled to lower resolution to be usable'*

  - **By using an objective front methodology, and then decomposing full vorticity into 'frontal' and 'disturbance' vorticities, T399 resolution data (and beyond?) can be successfully used.**

  - **Hence: synoptically significant smaller scale features can be successfully identified and tracked. Very important for cyclonic windstorms, which over Europe are often much smaller scale than their marine counterparts; also for polar lows and frontal waves.**



$$\xi = \xi_{xf} + \xi_{fp}$$

$$where \quad \xi_{xf} = -\frac{\delta V_s}{\delta n}$$

$$and \quad \xi_{fp} = \frac{\delta V_n}{\delta s}$$

'Frontal Vorticity'

and

'Disturbance Vorticity'

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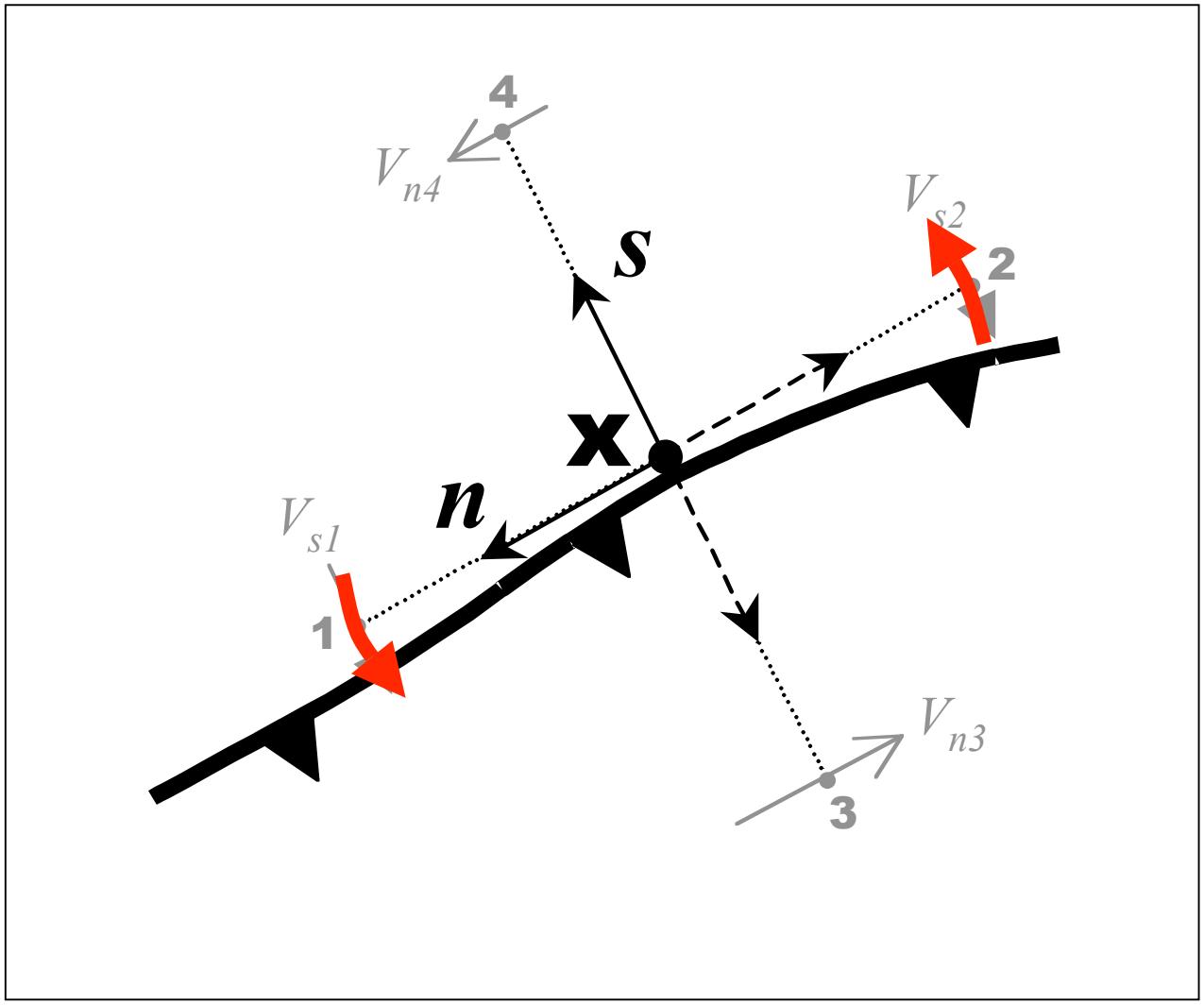

$$\xi = \xi_{xf} + \xi_{fp}$$

$$where \quad \xi_{xf} = -\frac{\delta V_s}{\delta n}$$

$$and \quad \xi_{fp} = \frac{\delta V_n}{\delta s}$$

'Frontal Vorticity'

and

'Disturbance Vorticity'

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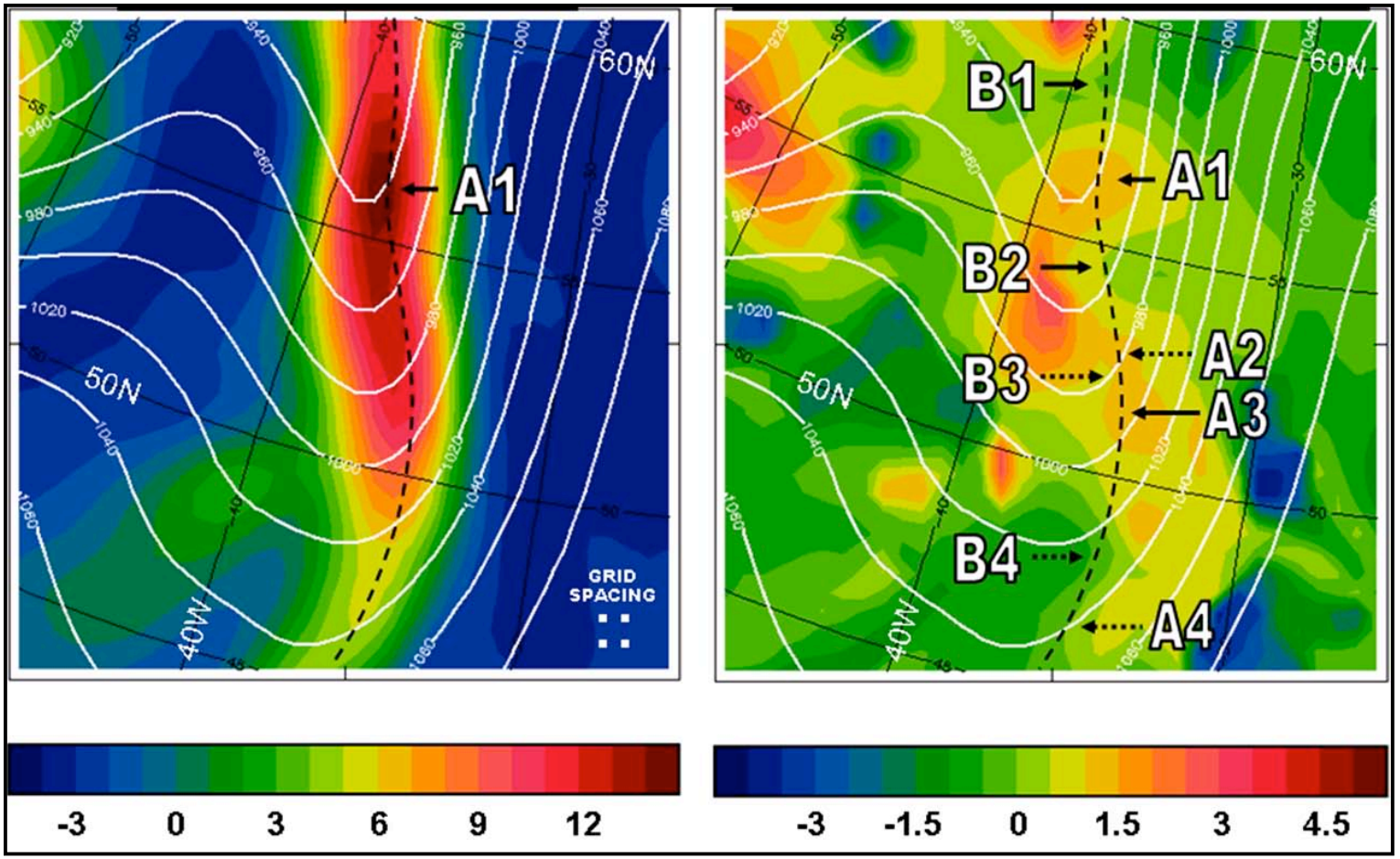
Example

Full Vorticity

Disturbance Vorticity



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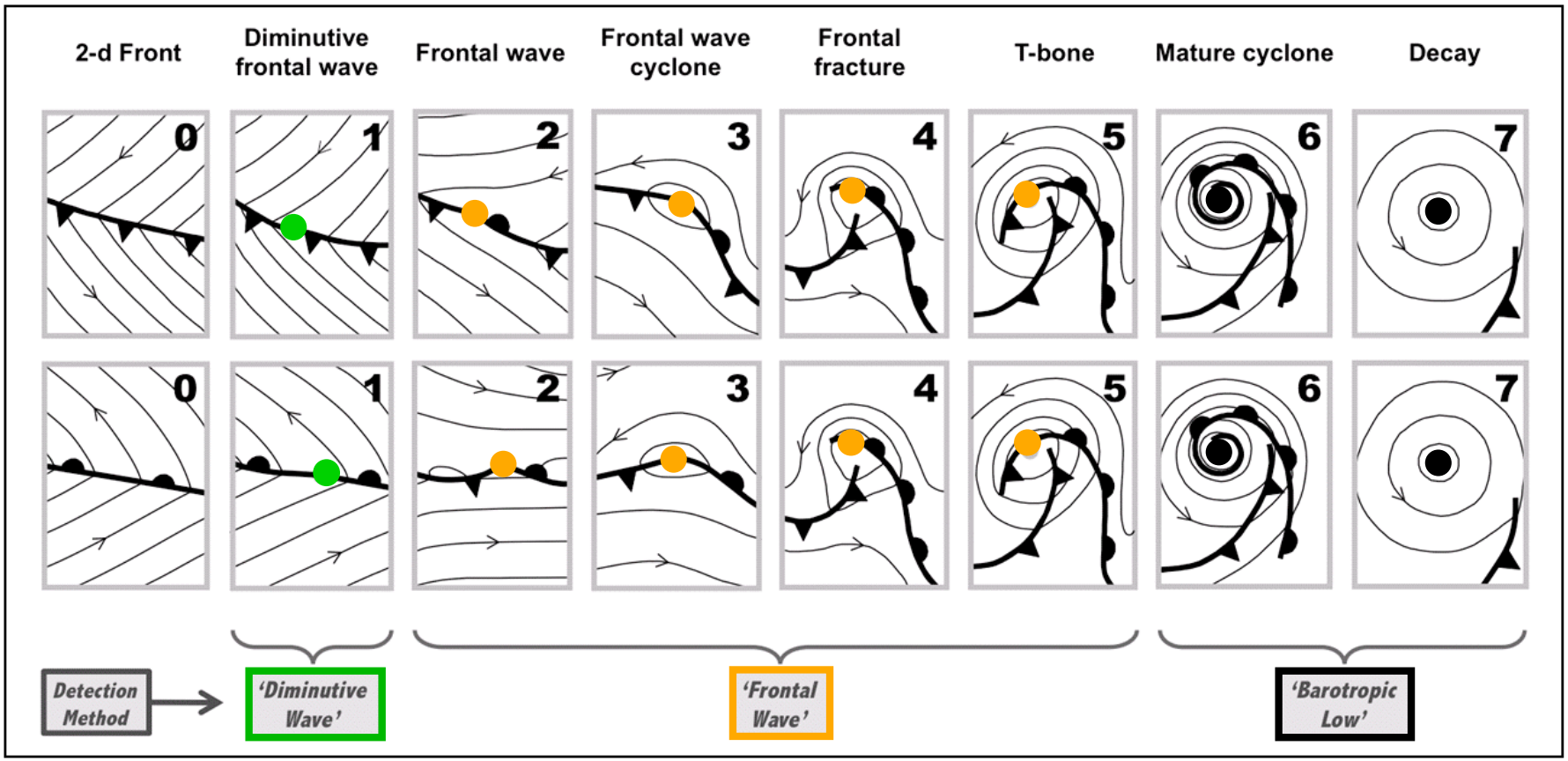
- (ii) ***'Temporal filtering, employed in some studies, removes the connection with synoptic charts and makes feature trajectories less comprehensible to the user'***

  - **By using no such filtering, but instead careful vorticity partitioning, the synoptic chart connection can be retained**

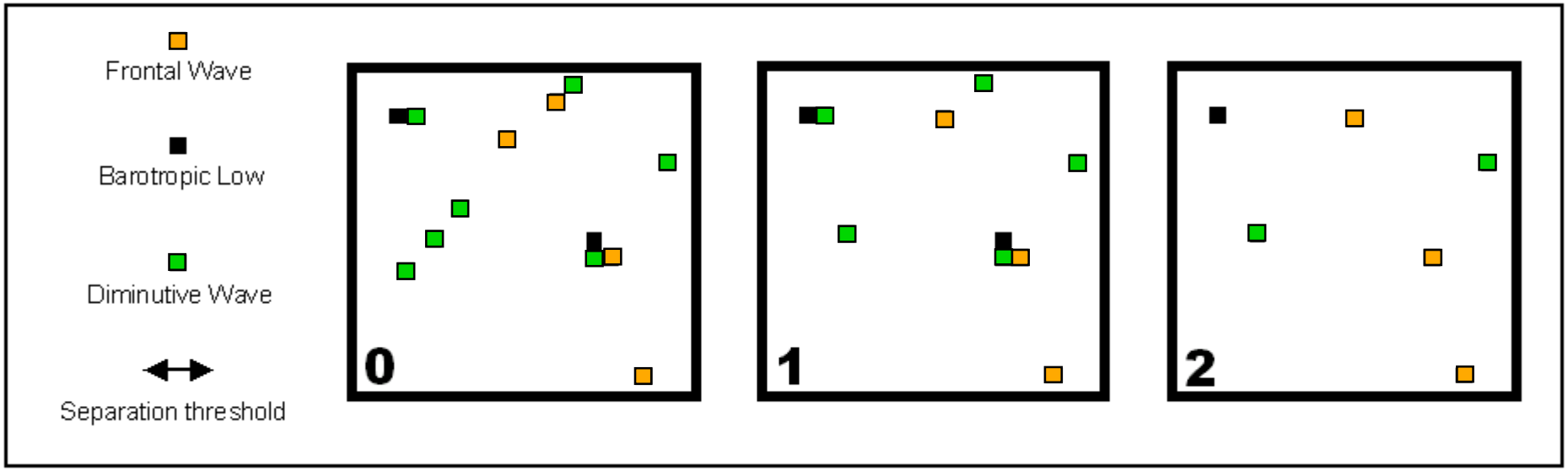
- **(iii) *'MSLP minima and low level vorticity maxima are both used for tracking – each has its own advantages and disadvantages'***

  - **Here we use both, in a multifaceted identification methodology. When feature co-location arises, due to more than one method being used, a hierarchy is employed to remove unwanted duplicates.**

  - **Main benefit is that the advantages of both methods can be realised, preventing features being missed.**


2-d Front
Diminutive frontal wave
Frontal wave
Frontal wave cyclone
Frontal fracture
T-bone
Mature cyclone
Decay
0
1
2
3
4
5
6
7
0
1
2
3
4
5
6
7
Detection Method
'Diminutive Wave'
'Frontal Wave'
'Barotropic Low'

Post-processing stages



- Closely spaced features are reduced to widely spaced, by ‘combination’ (step 1) and then by removal via a hierarchy (step 2).

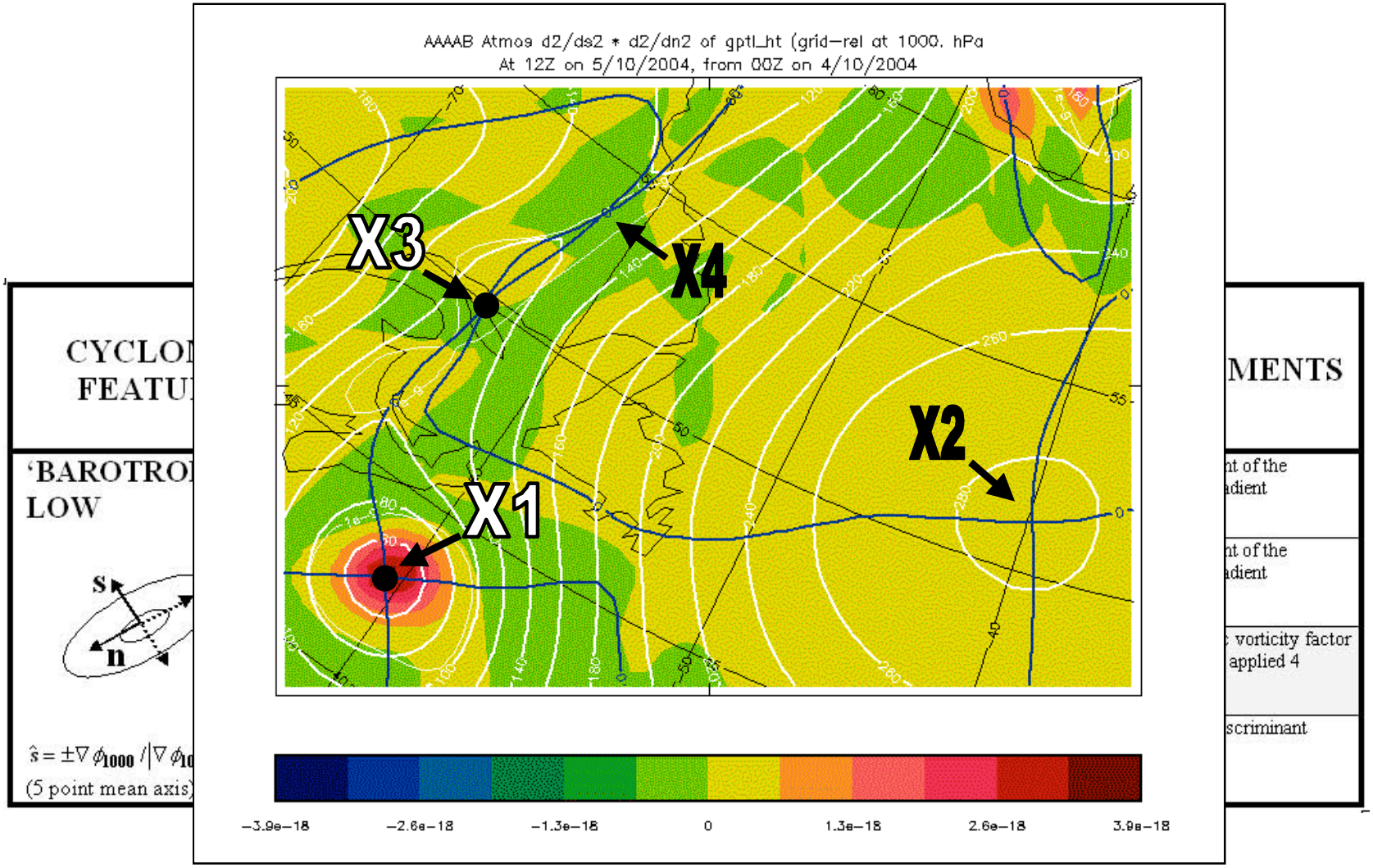
- (iv) *'Jagged, grid-related tracks can result from using searching algorithms to find grid point extrema'*

  - **Utilising the interpolation implicit in contouring algorithms increases the precision in feature location to much less than one grid spacing**

  - **Result is much smoother tracks**

  - **(There are some analogies here with the surface fitting techniques of Simmonds and Murray)**

Example – Barotropic Lows (●)



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2B. Tracking Problems

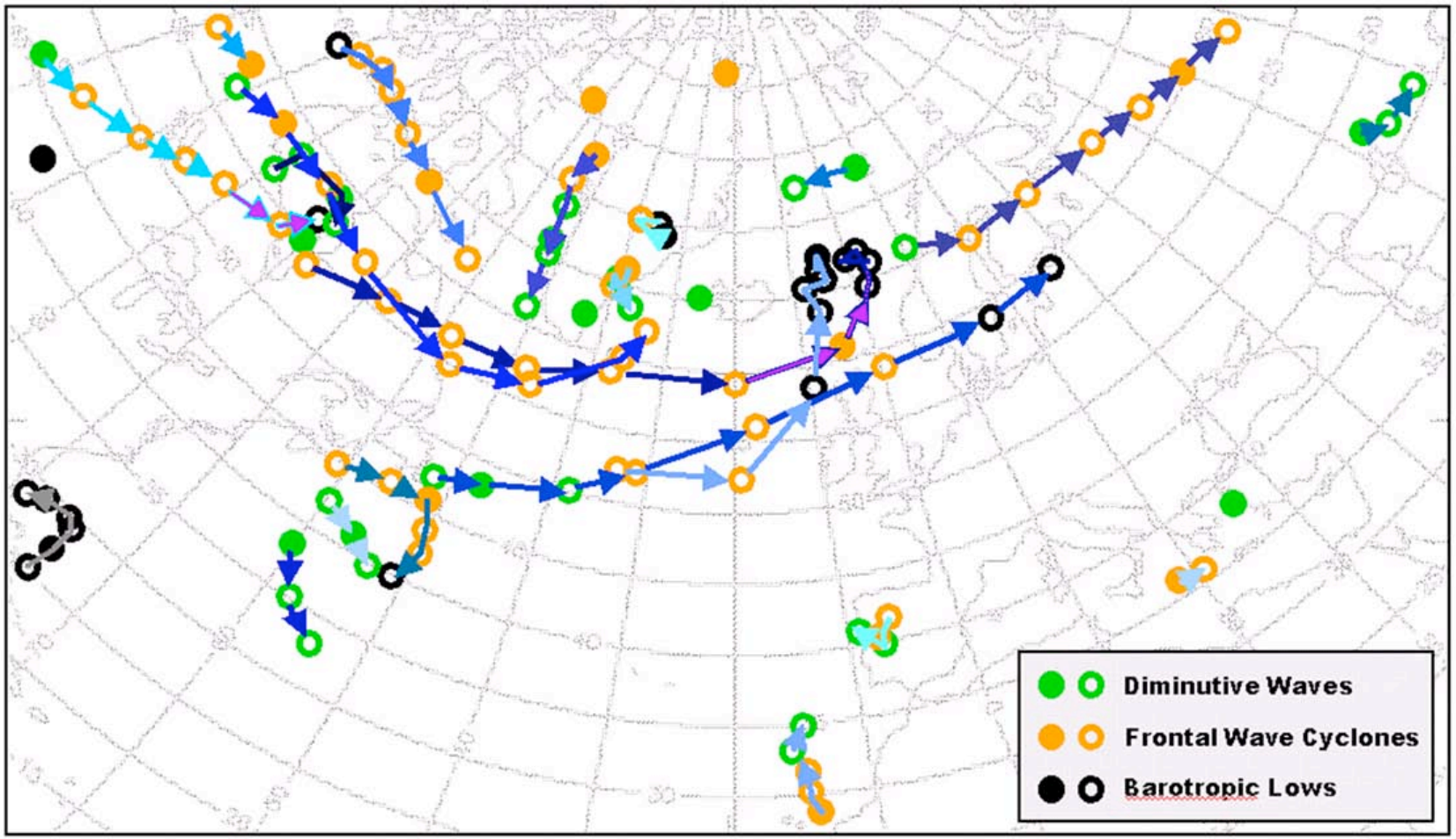
- (i) '*Not using a small temporal resolution in input data (i.e. 3 or 6 hours) increases the probability of false associations when computing feature trajectories*'

  - **Utilising a 'steering wind' reduces false associations. Utilising 'half-time' tracking helps further. Using three parameters in the association process helps further still.**

  - **Most published methods use 'full-time' tracking of one sort or another**

  - ***So what do we mean by 'full-time tracking' and 'half-time tracking' ??***

Example of cyclonic feature tracks in one forecast



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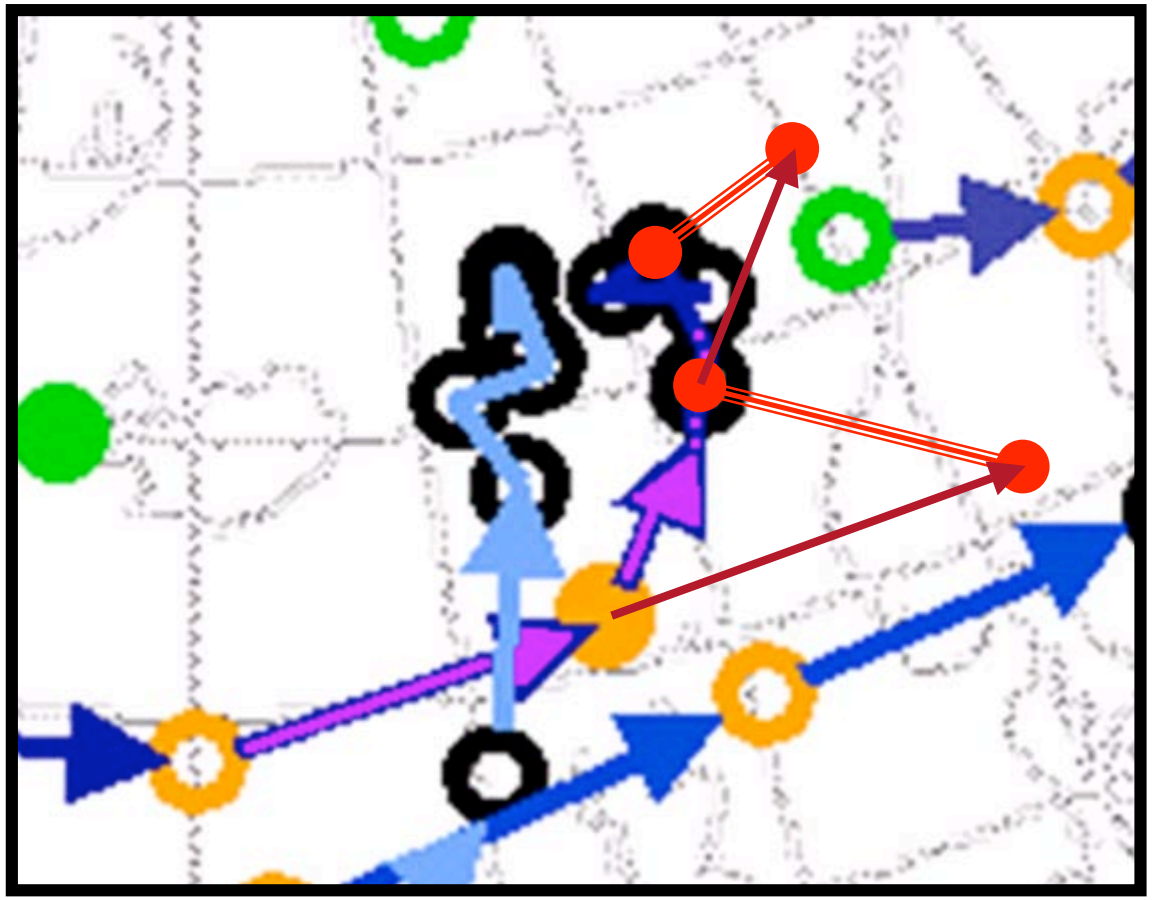
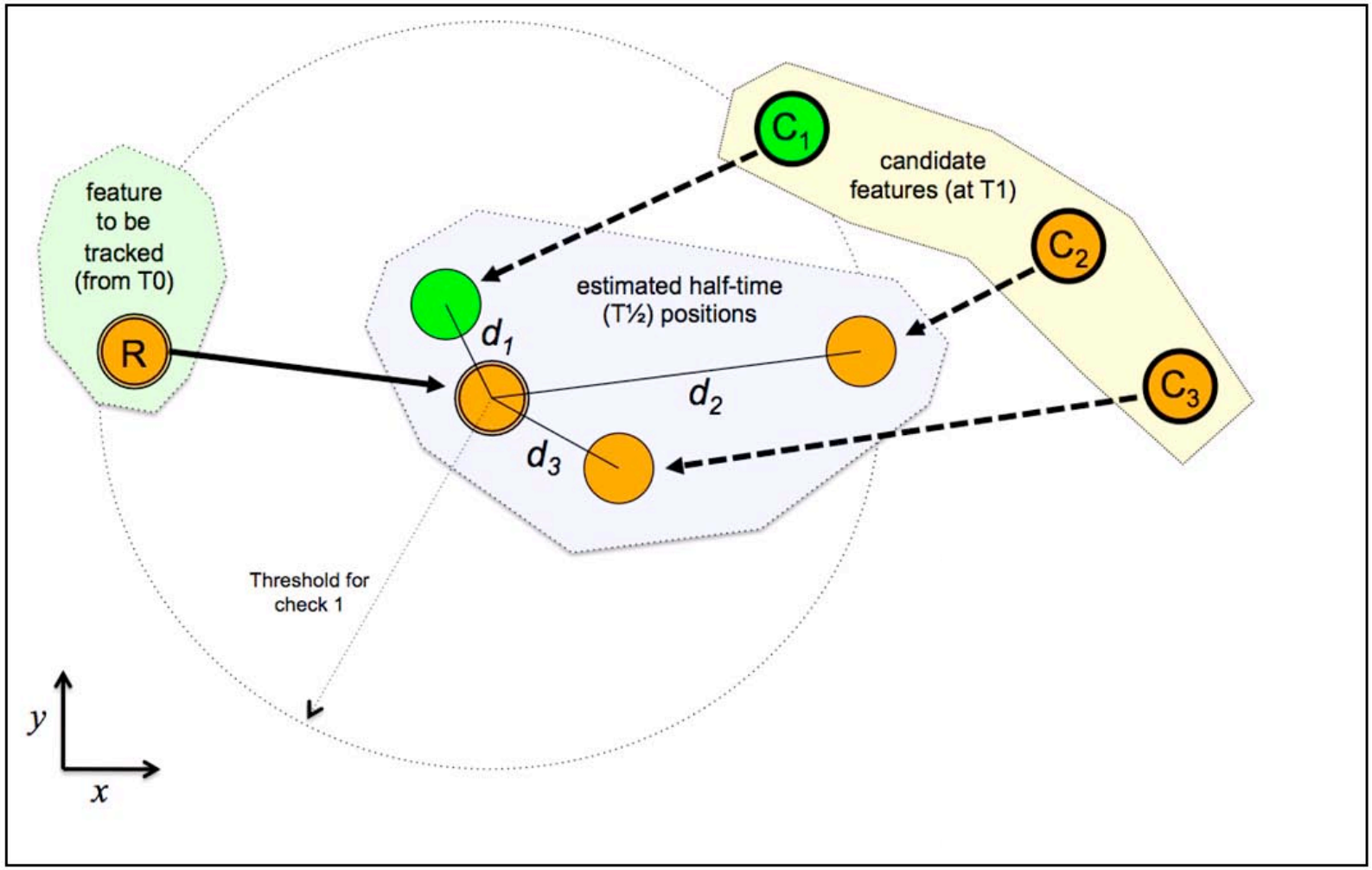
Zoom in to illustrate one form of ‘full-time tracking’



- In both cases there is a large error in estimated future position, which in fact is greater than feature displacement during the time interval
- This is liable to cause association difficulties for a tracking algorithm

How then does ‘half-time tracking’ work ?



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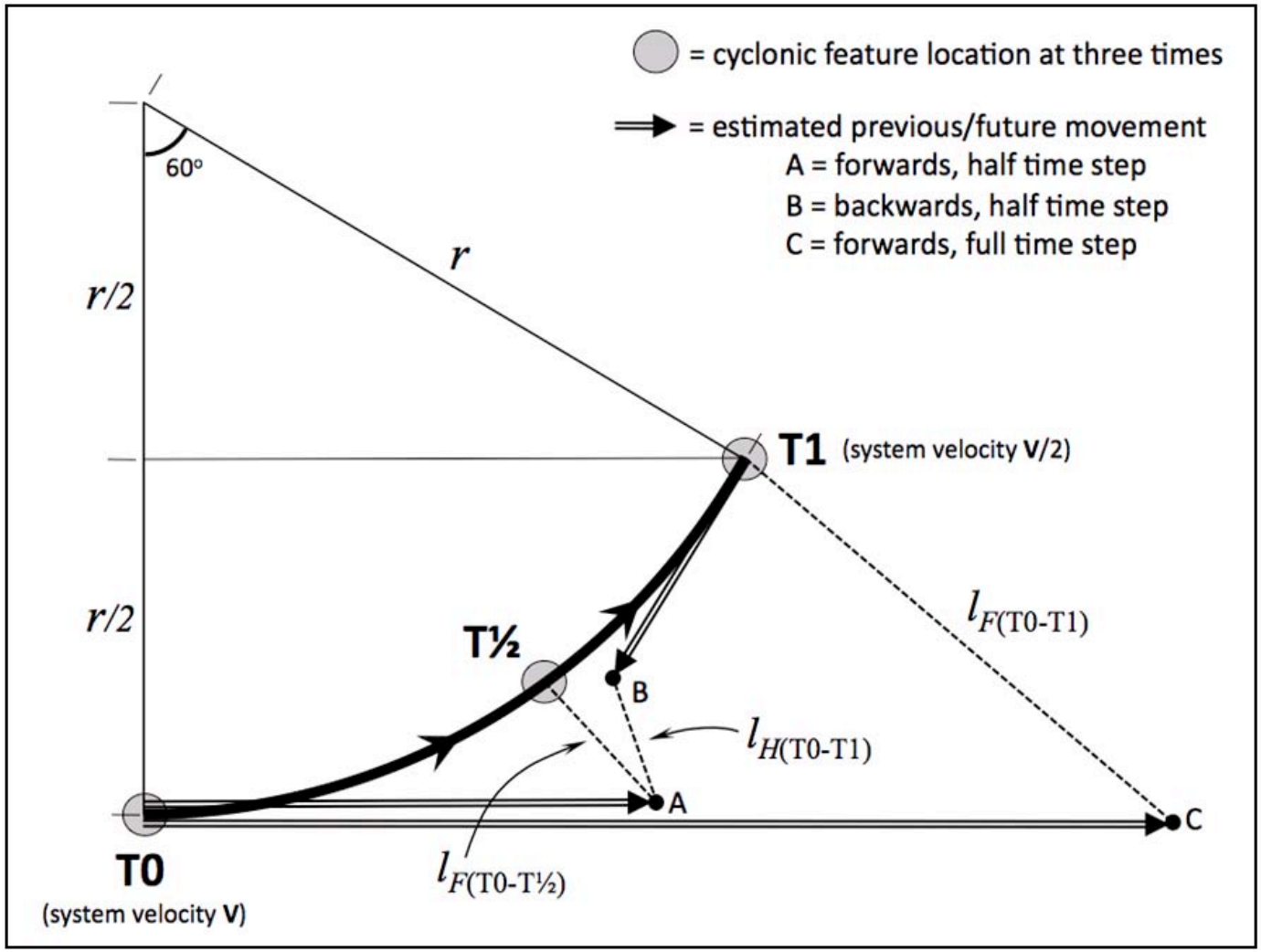
The benefits of 'half-time tracking'..



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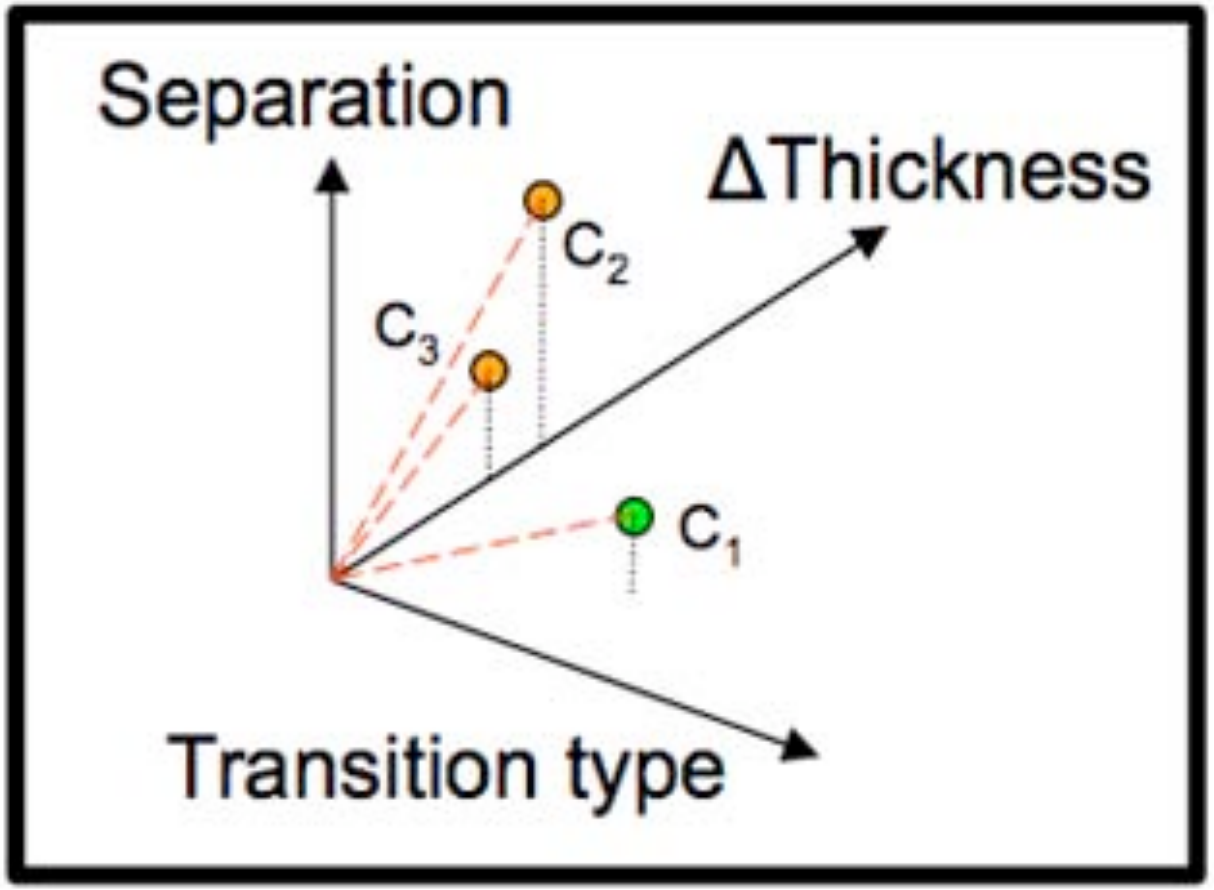
Further refinements in feature association…



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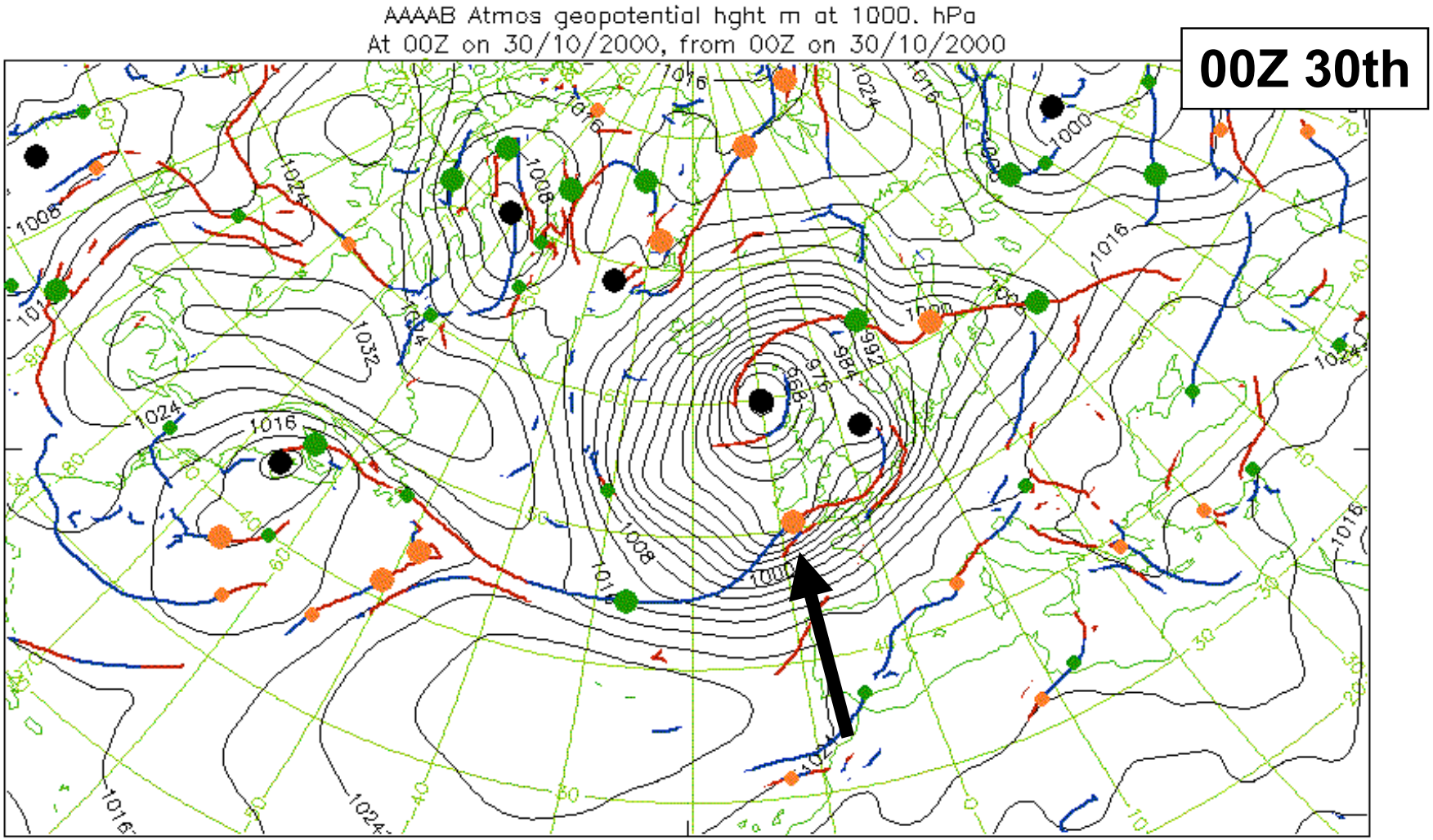
- (ii) *'Applying a short lifetime cut-off can mean that synoptically-important cyclonic features are unfortunately discarded'*

  - Tests suggest ~ 50% have a lifetime of less than 2 days

  - Applying no such cut-off and identifying features from the earliest point imaginable in their life-cycle (diminutive waves) ensures that such features are retained

  - Again highly relevant for small cyclonic windstorms, and indeed some other features.

North Sea Storm of 30 October 2000



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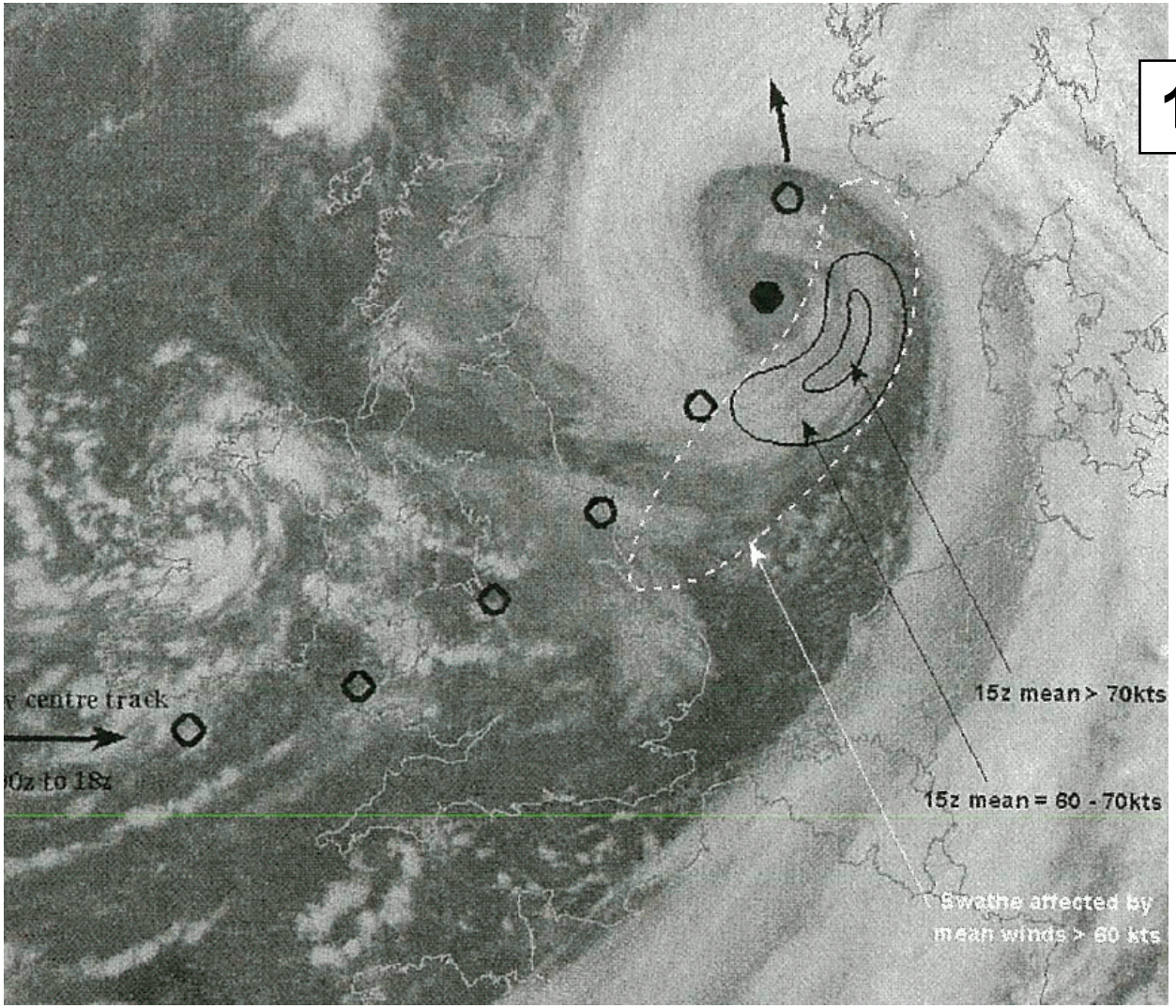
9-15 hours later – sub 950mb low – F12 winds



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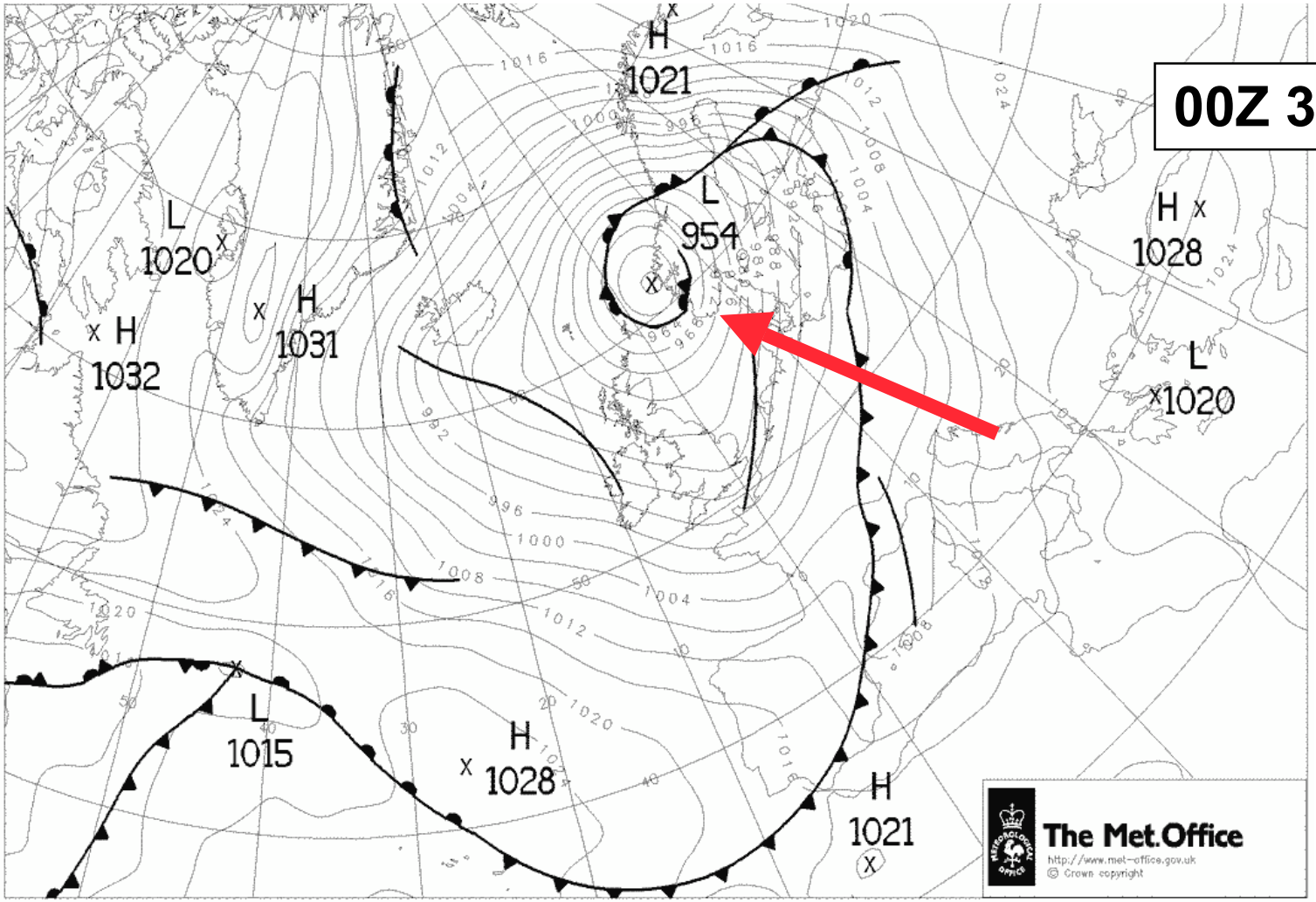
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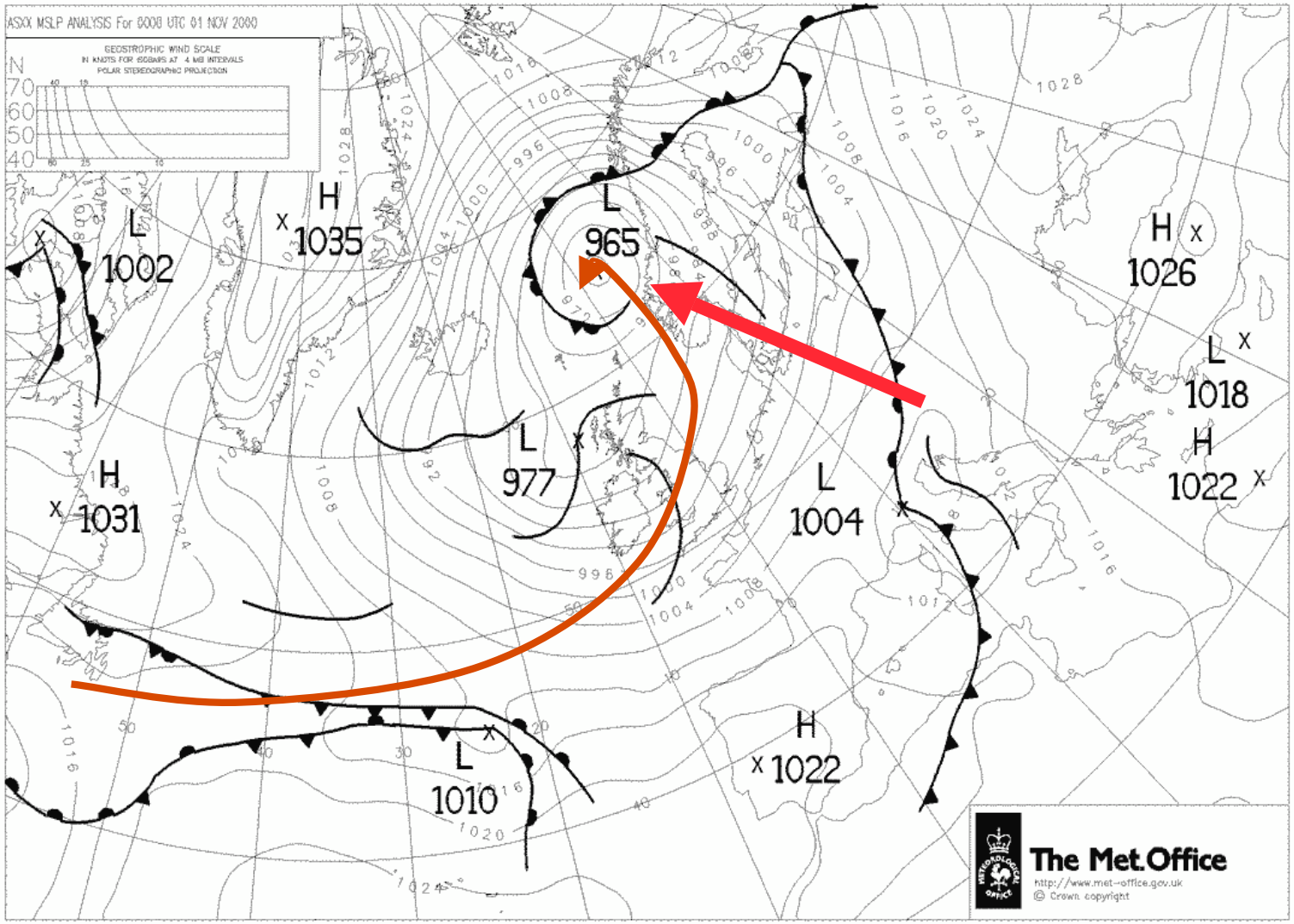
ASXX MSLP ANALYSIS For 0000 UTC 01 NOV 2080
GEOSTROPHIC WIND SCALE
IN KNOTS FOR ISOBARS AT 4 MB INTERVALS
POLAR STEREOGRAPHIC PROJECTION
L 1002
H 1035
L 965
H 1026
L 1018
H 1022
H 1031
L 977
L 1004
L 1010
H 1022
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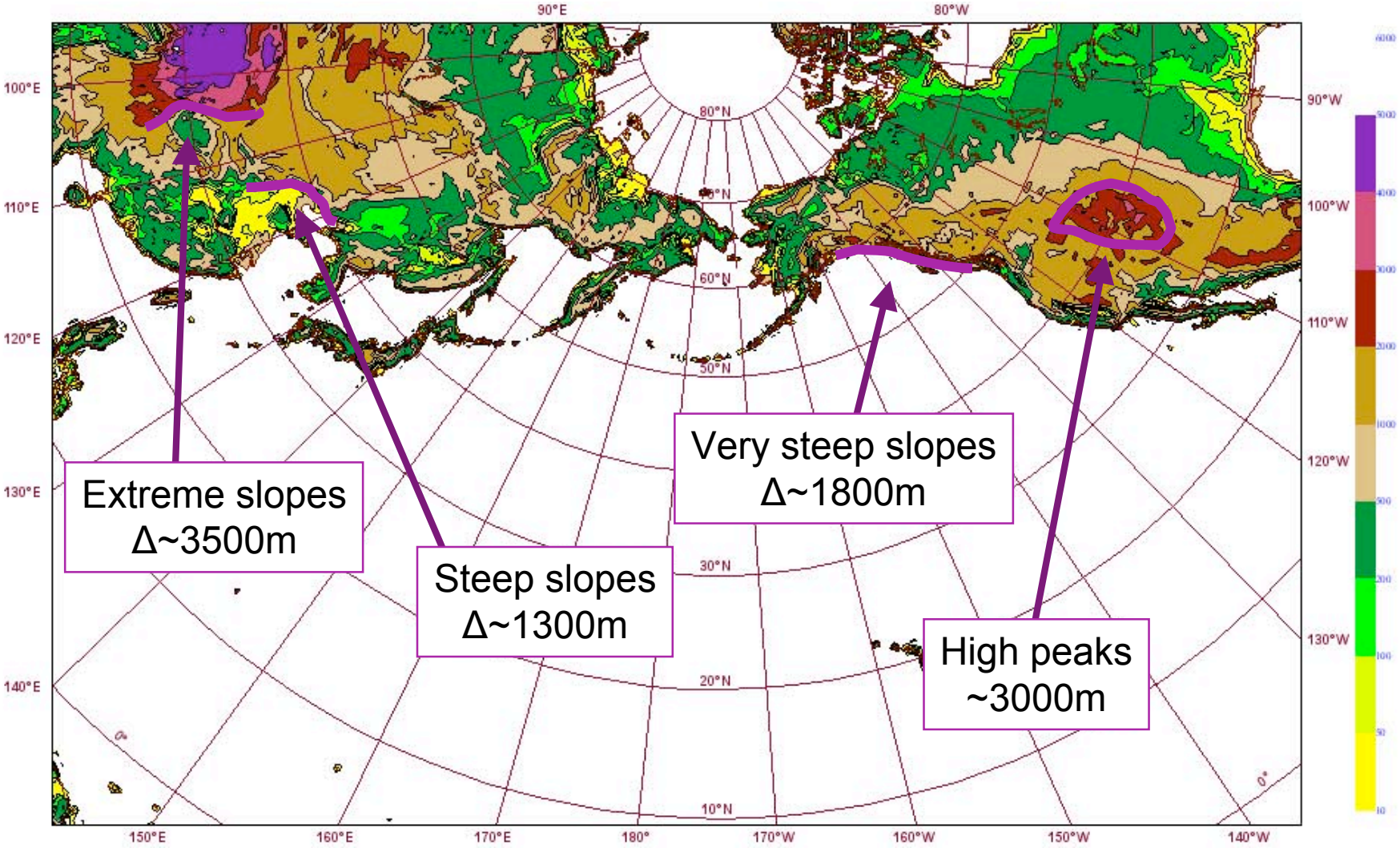
- **(iii) '*Cyclonic feature tracking can be very unreliable near to and over significant topography*'**

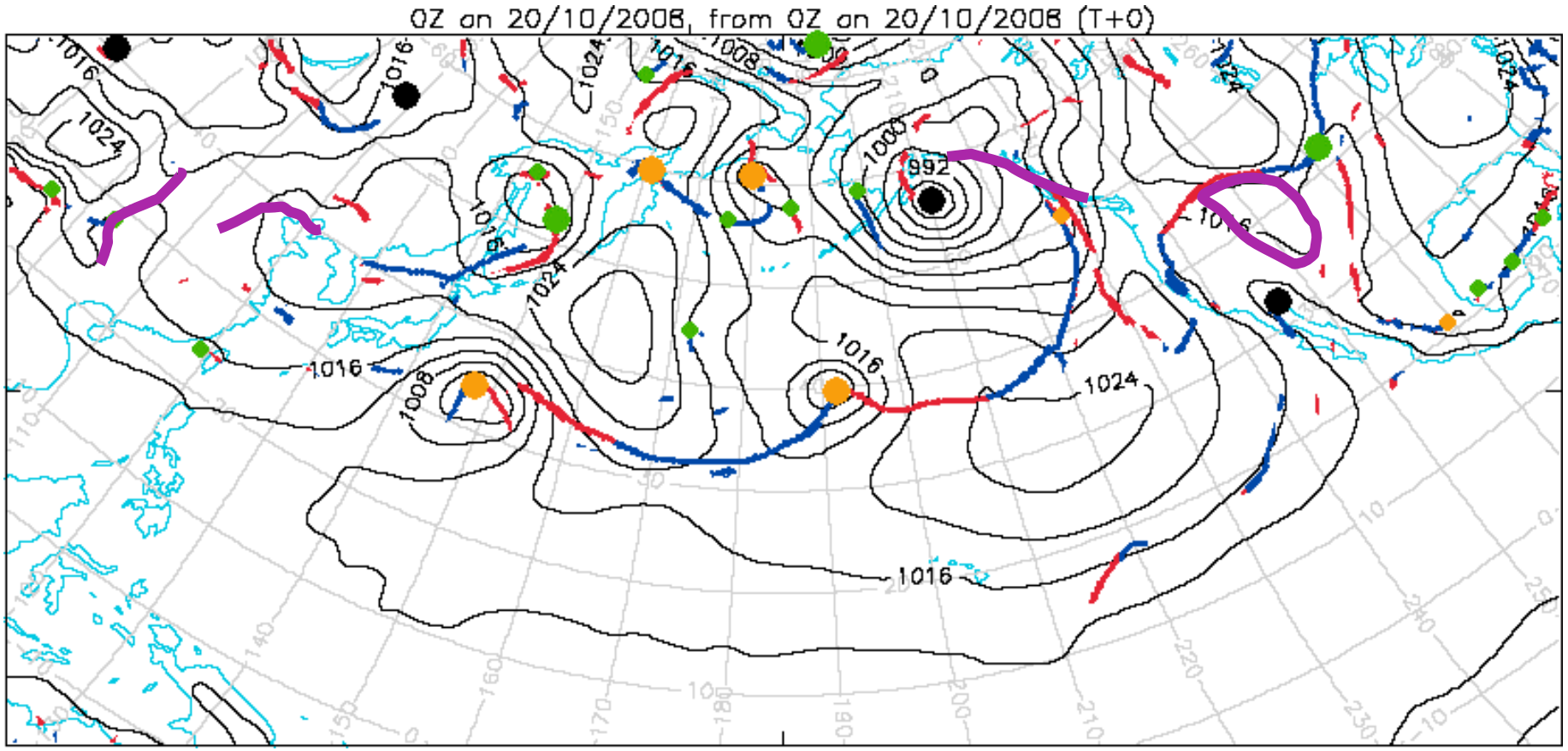
  - **Utilising a terrain following co-ordinate (1km up) for frontal feature identification has improved the identification of those fronts, and cyclonic features that form on them**

  - **Where steep topography exists across a significant depth there are still problems**

ECMWF model orography



ECMWF



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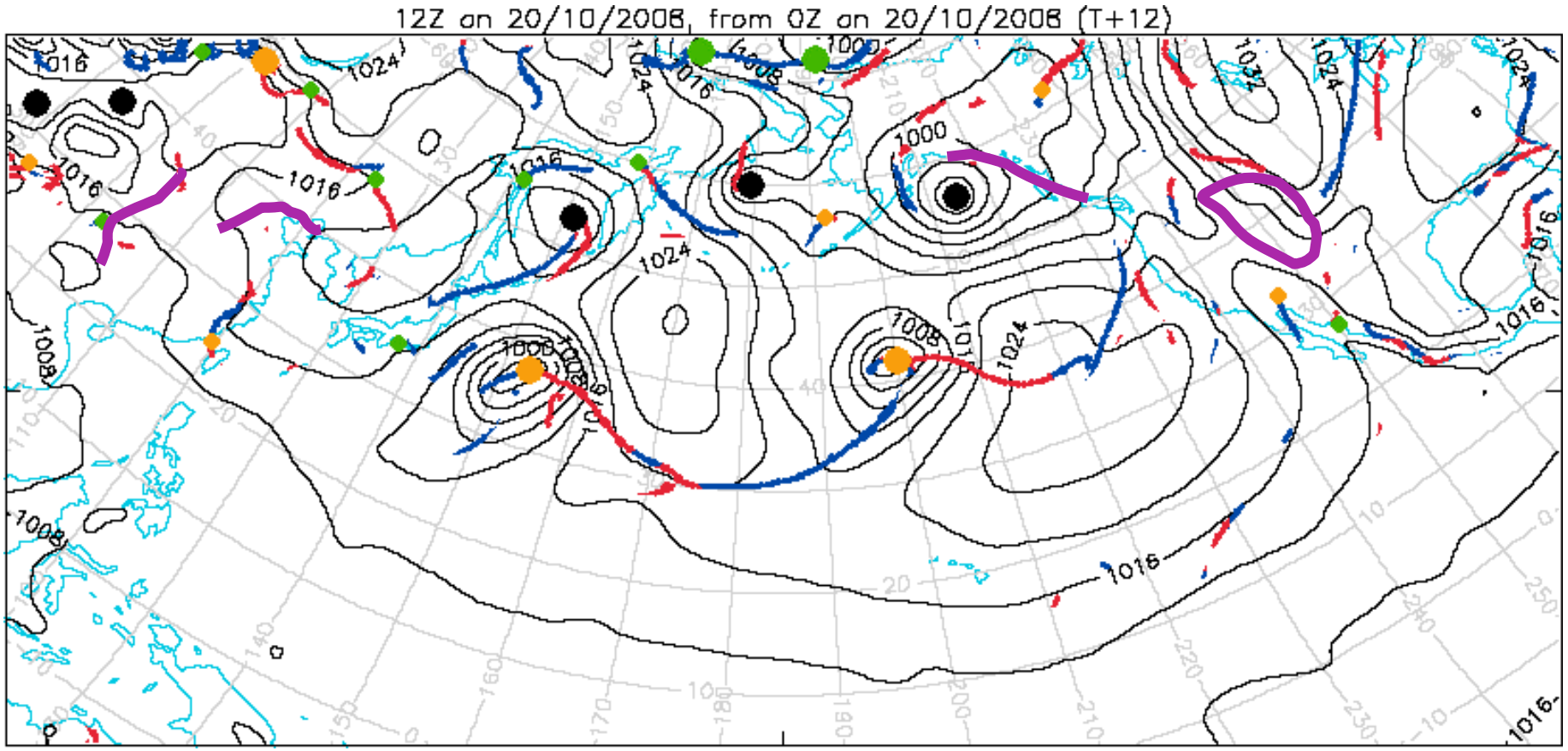

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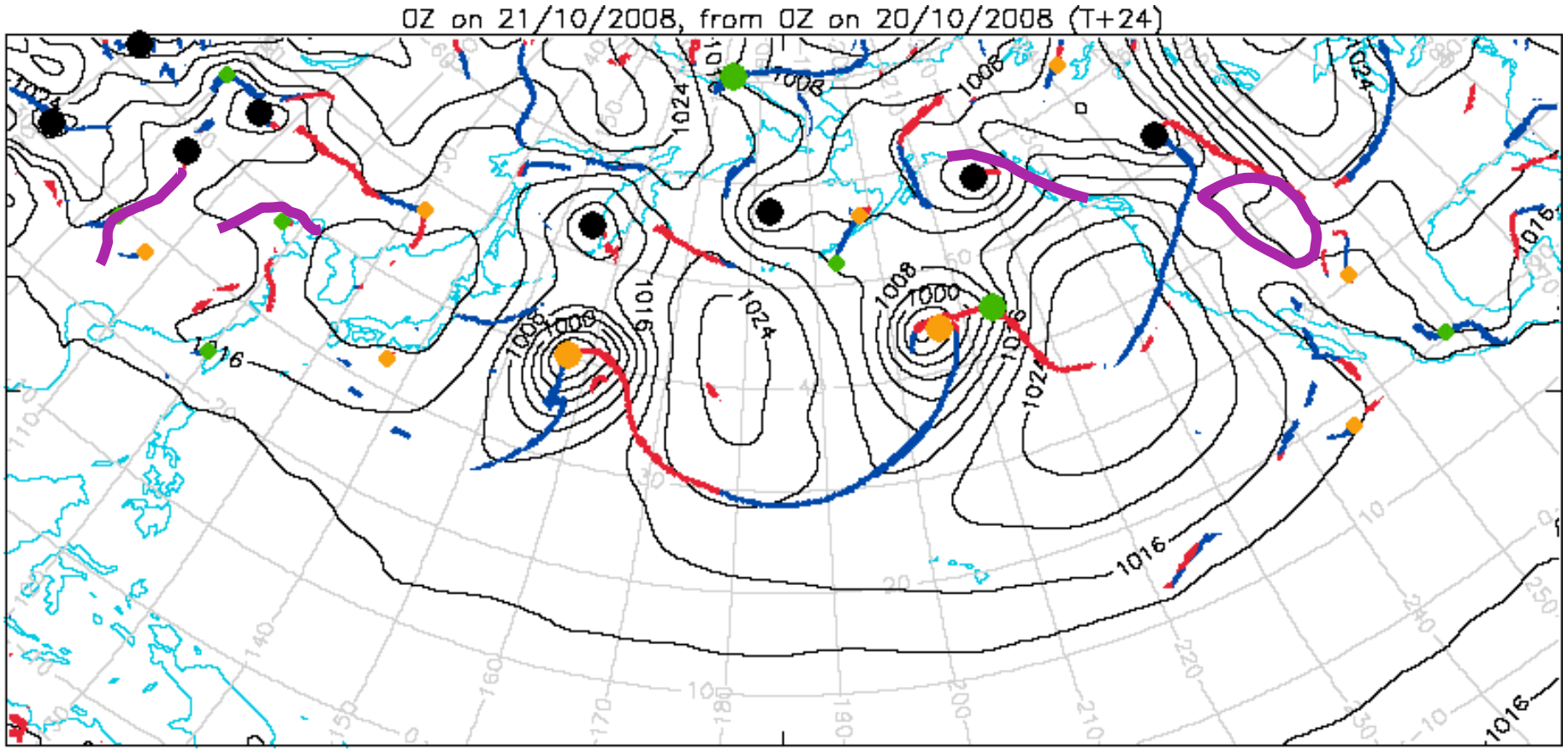
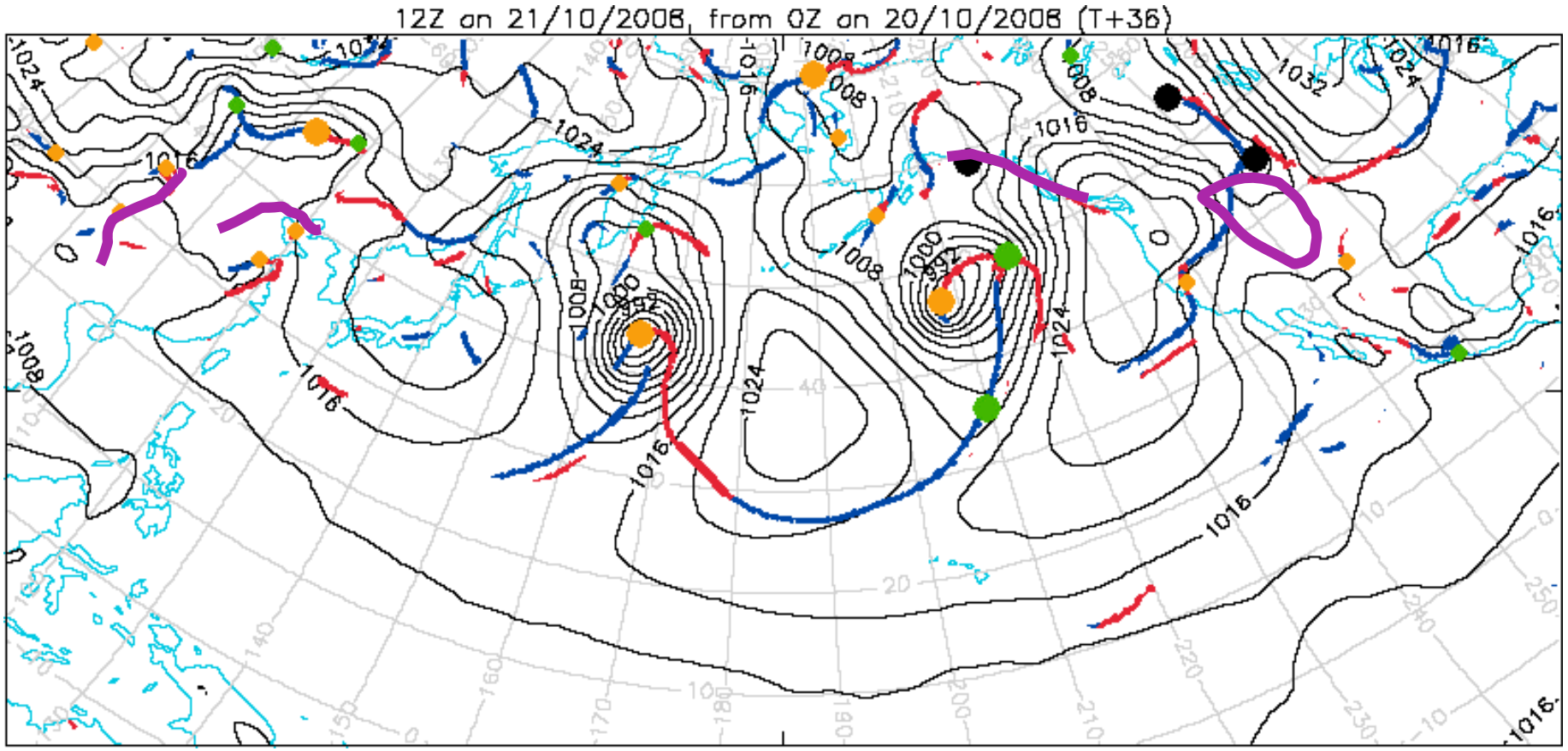
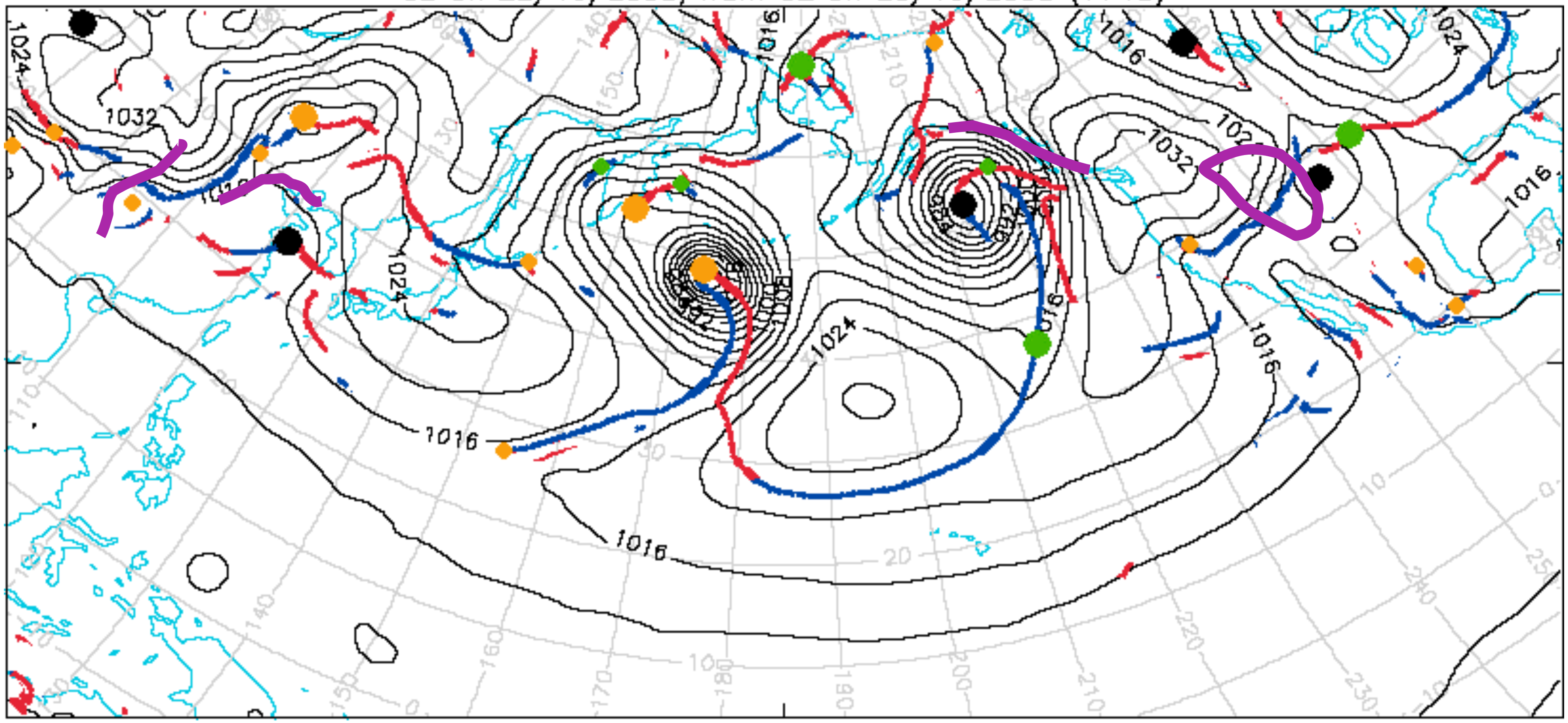

0Z on 21/10/2008, from 0Z on 20/10/2008 (T+24)
1024
1008
1016
1000
1024
1008
1016
1024
1008
1000
1016
1024
1016
1016

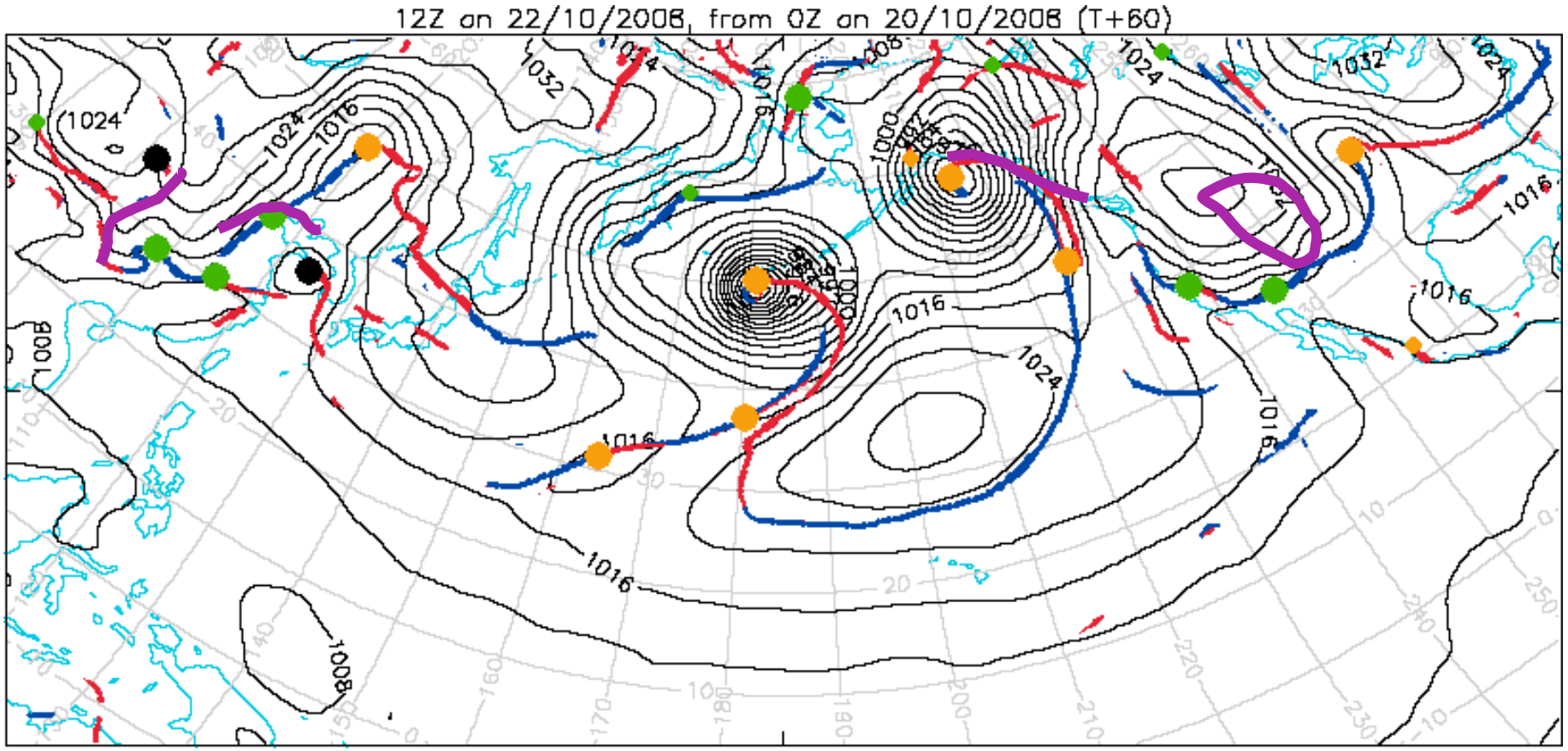
ECMWF



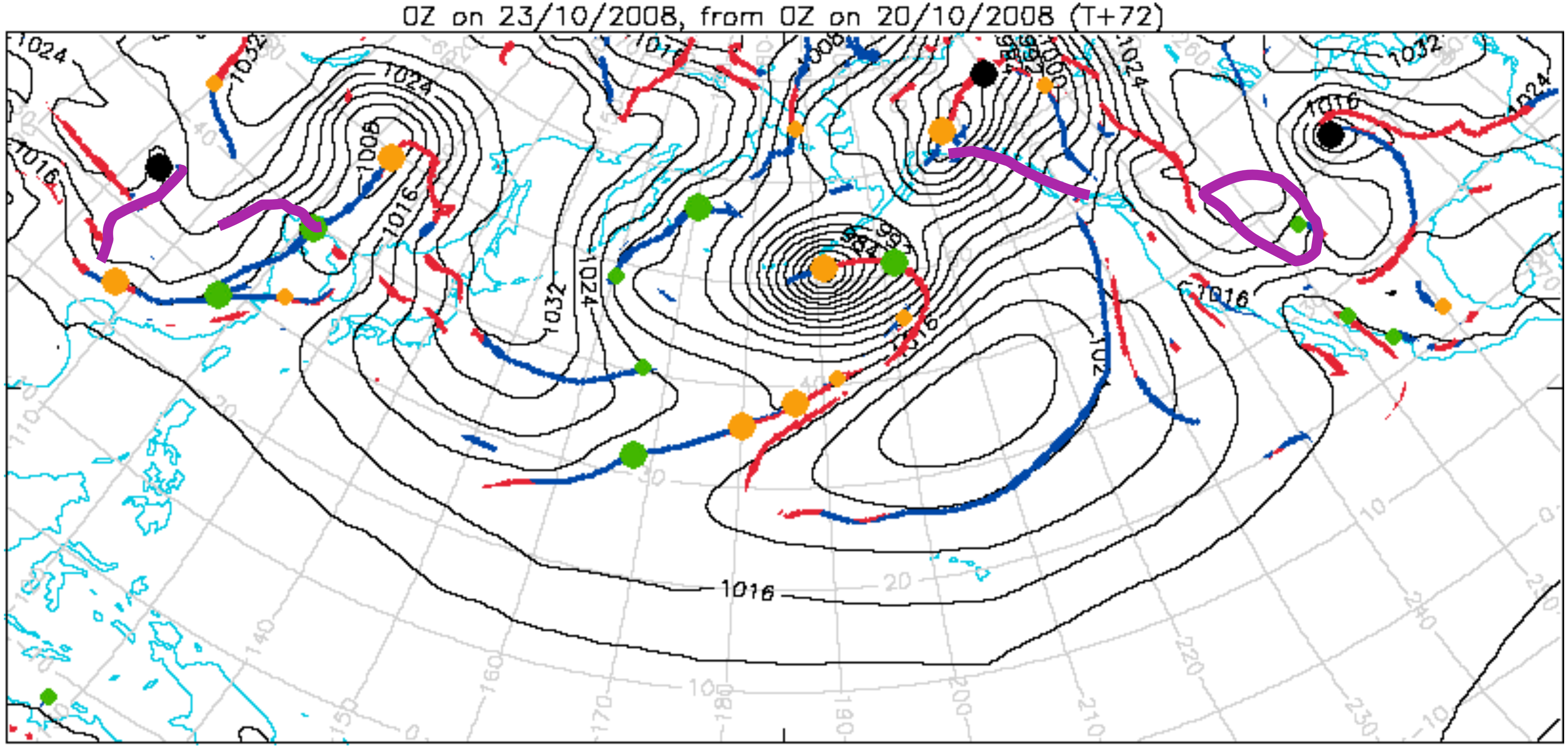
ECMWF

0Z on 22/10/2008, from 0Z on 20/10/2008 (T+48)




12Z on 22/10/2008, from 0Z on 20/10/2008 (T+60)
1024
1016
1032
1008
1000
992
984

ECMWF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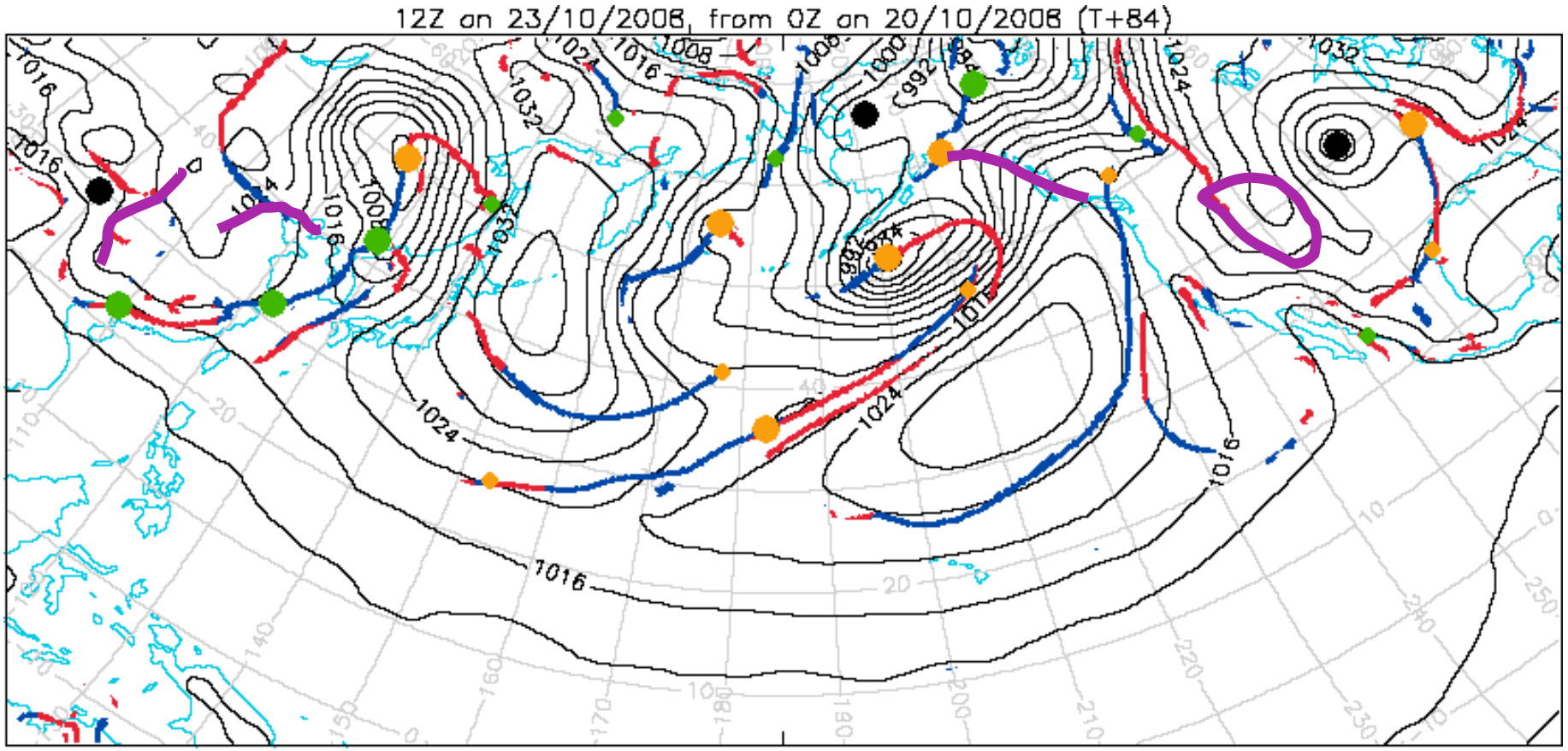
1016
1024
1032



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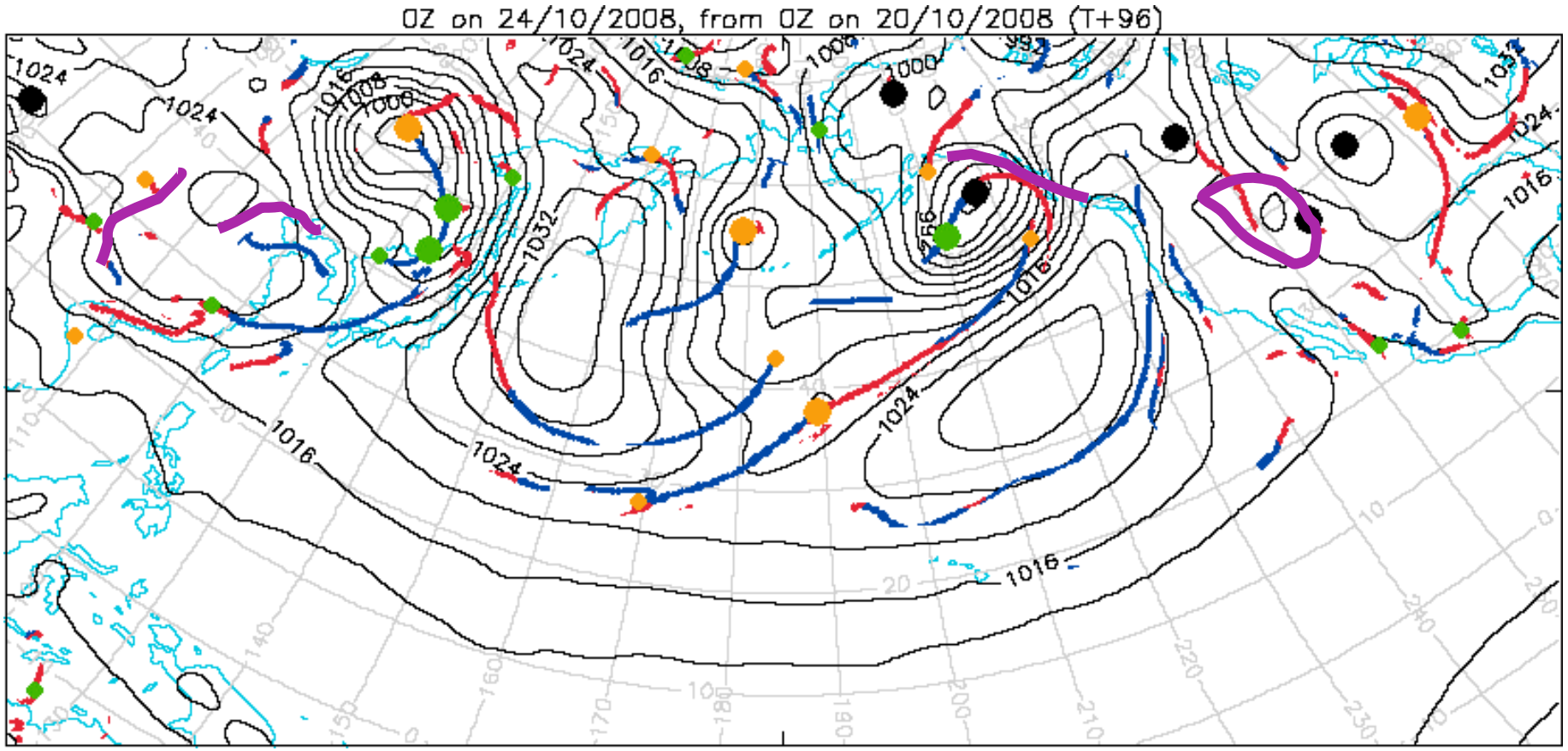
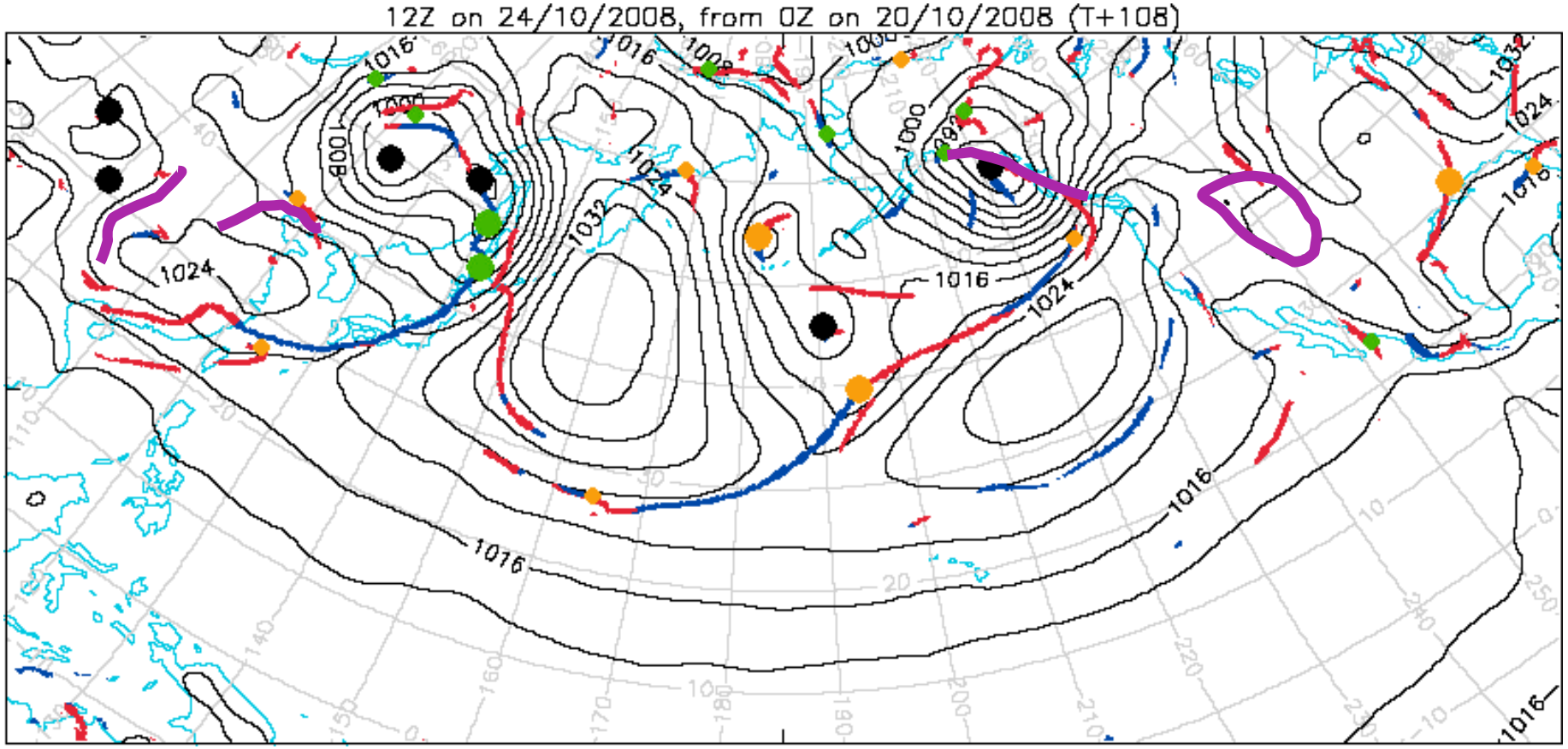
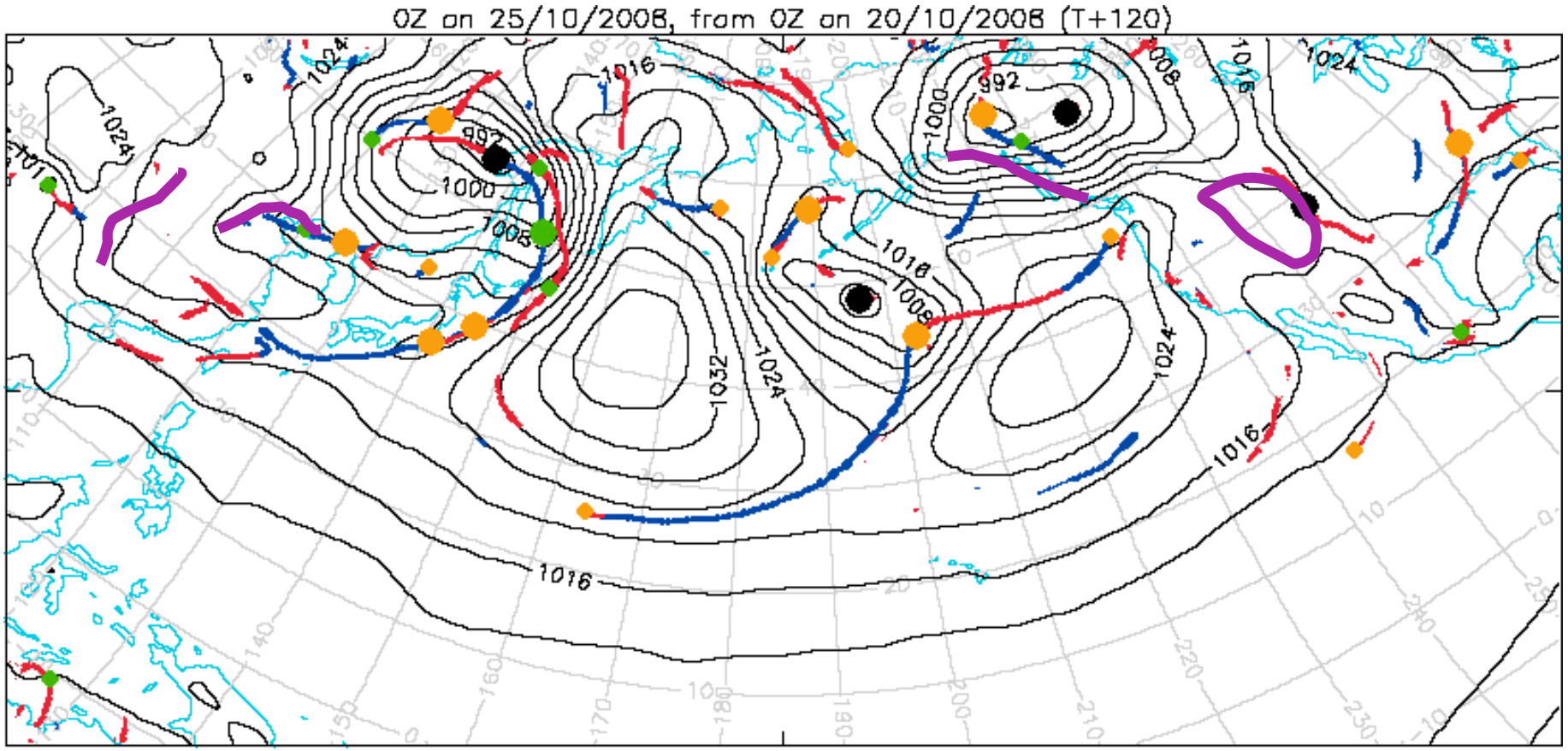

0Z on 24/10/2008, from 0Z on 20/10/2008 (T+96)
1024
1016
1008
1000
992
1032
1024
1016
1024
1016
1016
1024
1016

ECMWF

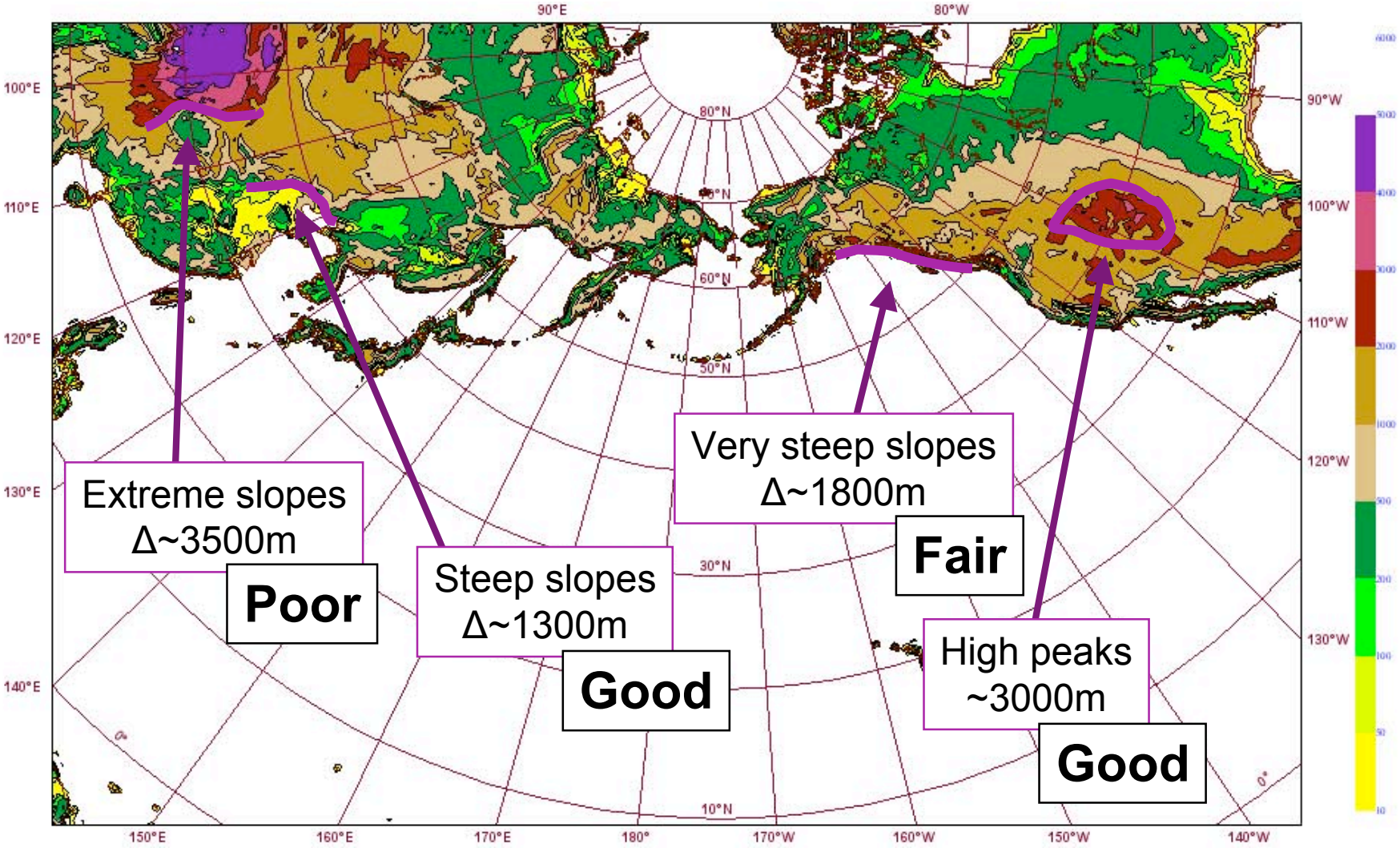

12Z on 24/10/2008, from 0Z on 20/10/2008 (T+108)
1016
1000
1024
1032
1008

ECMWF


0Z on 25/10/2008, from 0Z on 20/10/2008 (T+120)
1024
1016
992
1000
1008
1032
1024
1016
1024
1016
1008
992
1000
1008
1016
1024
1016

ECMWF

Verdict regarding feature handling



3. Summary

- Work over the last 12 years has lead to the development of a sophisticated software suite for identifying and tracking synoptic-scale (~50km+) cyclonic features
- The features identified are closely allied to those commonly recognised by forecasters (e.g. frontal waves)
- Significant effort has gone into ensuring that the full life-cycles of cyclonic windstorms are correctly replicated
- Another key objective has been to overcome some of the limitations of previous algorithms
- A few problems remain, mainly near steep topography
- Products have been used operationally by Met Office forecasters for about 3 years (and also by the T-PARC project) – these have been very well received
- In this time the tracking algorithm has had to deal with ~11 million feature associations !
- Until now processing has been done for just limited domains. Future plans include using ERA-40 / ERA-interim for hemispheric / global tracking