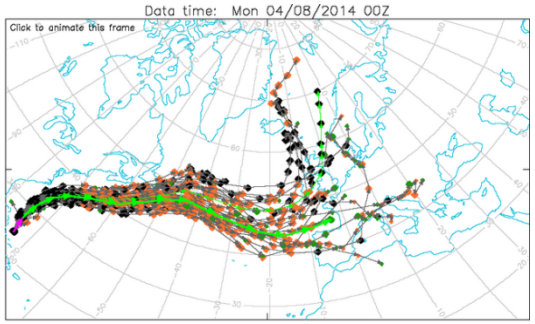
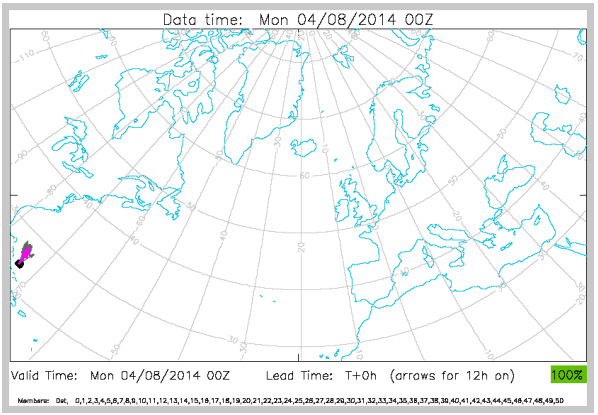
Cyclones and Fronts

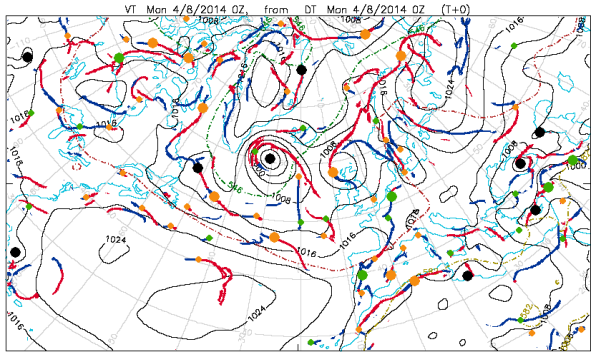
Tim Hewson

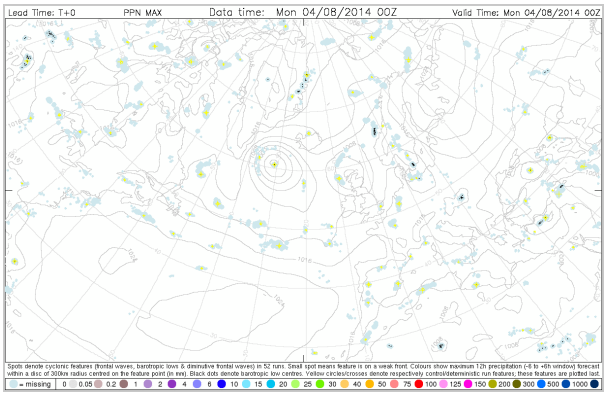
Main Product Links: http://apps.ecmwf.int/r/cdb/ **or**
http://www.ecmwf.int/en/forecasts/charts/extra-tropical-cyclones

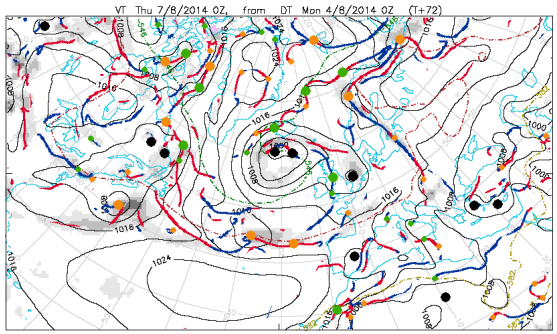
Front and Cyclone-related Products

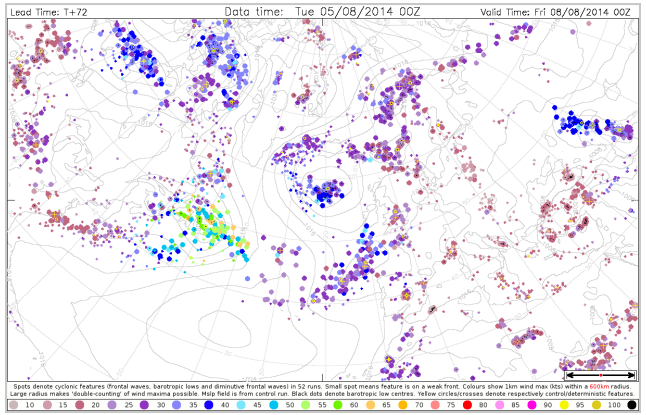


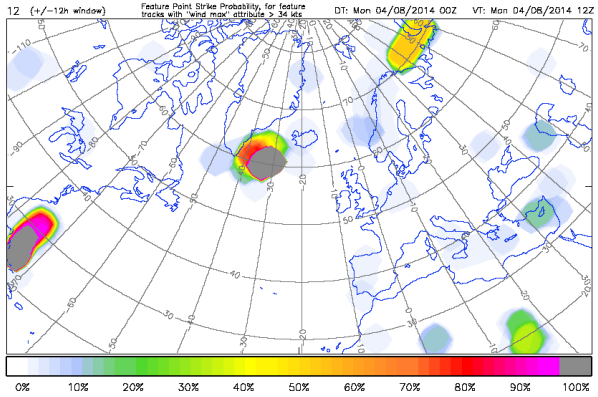


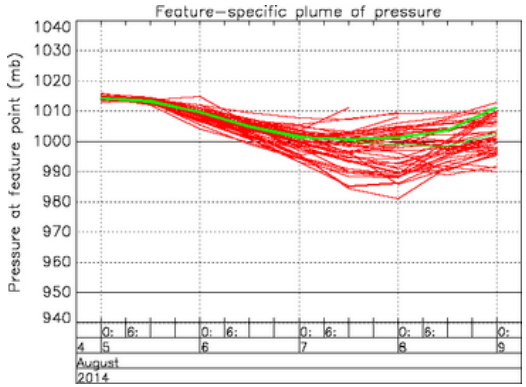


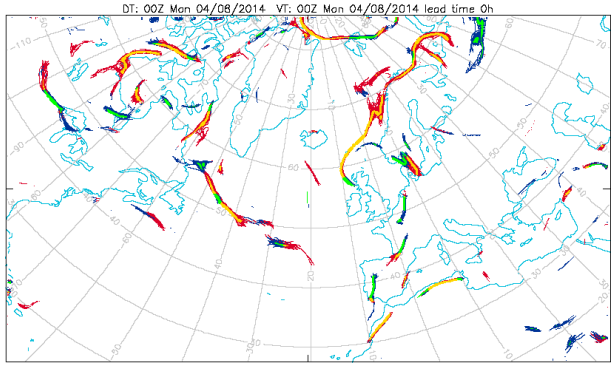












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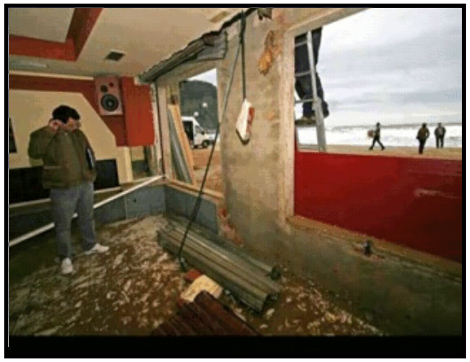
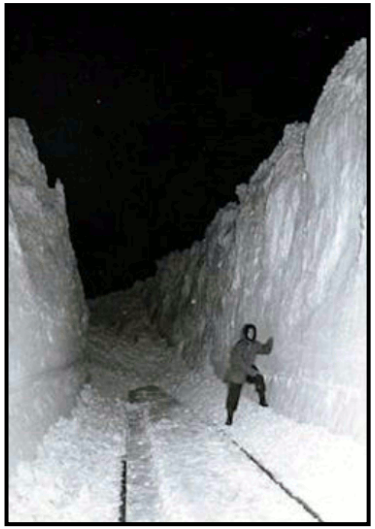
Structure of Talk

- 1. Introduction and Motivation + ‘Klaus’ example…
- 2. Identification of fronts
- 3. Identification of cyclonic features
- 4. Tracking of cyclonic features
- 5. The Web Products – and how to best use them
- 6. Miscellaneous topics
- 7. Summary

- (more extensive guidance on how to use each of the extra-tropical cyclone web products is given at the end of this file)

1. Introduction and Motivation



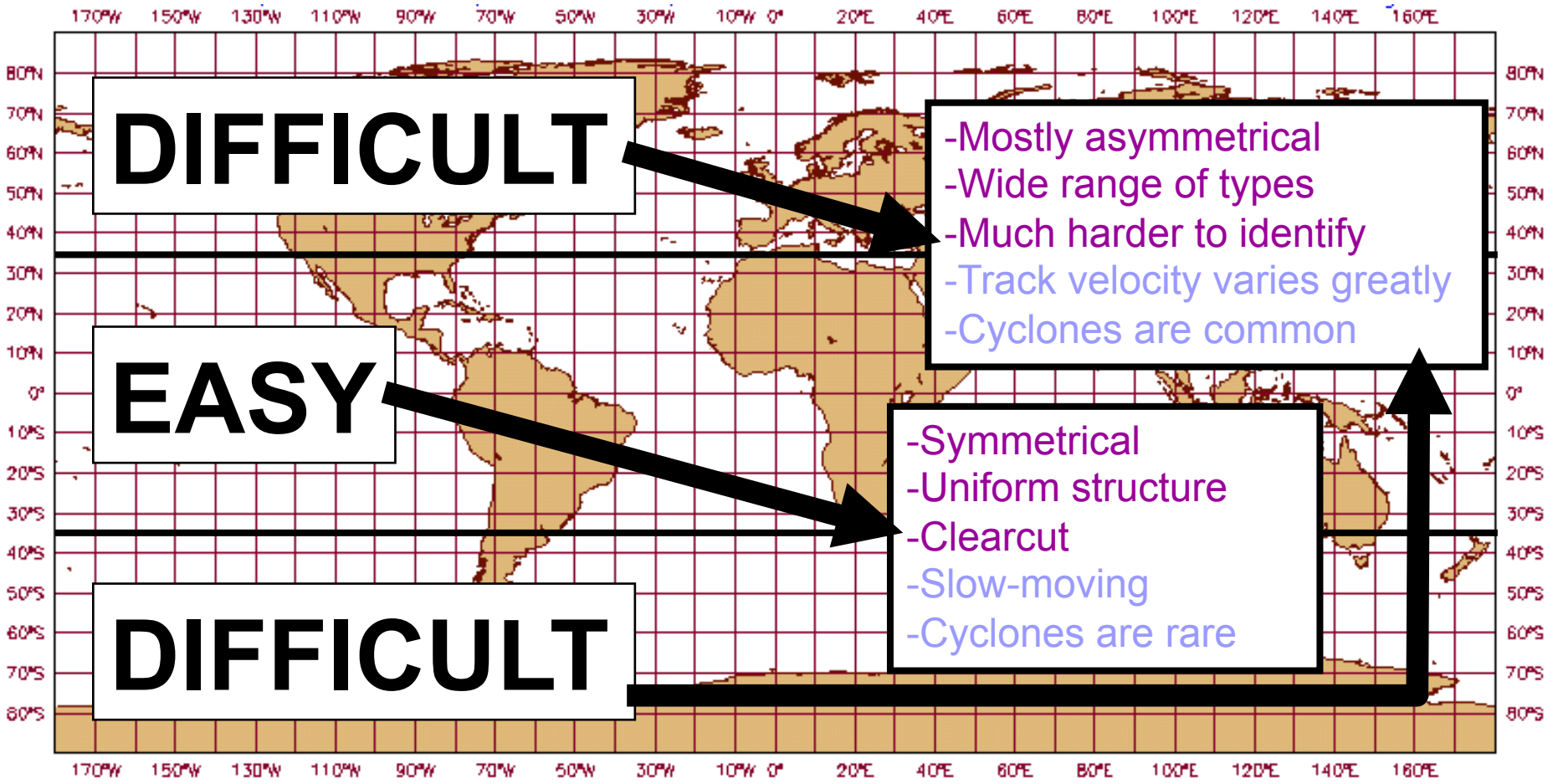
Disruption and destruction due to extra-tropical cyclones

Principles

- Forecasters make daily use of feature identification (e.g. fronts, troughs, frontal waves, easterly waves, lows,…), mainly because those features are responsible for bad (or extreme) weather
- Nowadays manual identification of features is based largely on model data
- So if we can identify cyclones automatically in a manner that is consistent with everyday forecasting, we will have:
  - A range of new IFS-based tools for assisting the forecaster to predict bad weather (Products)
- But, unfortunately, this is not straightforward ☹ ….

Why is it not straightforward?

Tracking Cyclonic Features - Tropics vs Extra-tropics:



Affects Feature Identification ***Affects Feature Trajectory Calculation***

Rationale

- In most cyclone tracking work input data is at low resolution – eg 200-500km
- In reality synoptic scale cyclones, as recognised for many years by forecasters (with good reason!), vary in scale from about 100km to over 1000km
- Here we set out to overcome several problems related to input data resolution, in order to identify the **full range** of cyclones
- Work has been in progress for more than 15 years ☺ Further improvements are possible…

Rationale (continued)

- **Key aspects of our system, which make identifying the full range of features possible, are:**

  - We use a **hybrid** identification system, based on vorticity & mean sea level pressure. With one exception other studies have used these variables in isolation.
  - Many of the features are required to lie **on fronts** (objectively defined). This accords with synoptic practice.
  - A **multi-parameter tracking scheme** is employed to correctly associate features.

- **The tracking system was developed at the Met Office, then ported to and modified/updated at ECMWF**

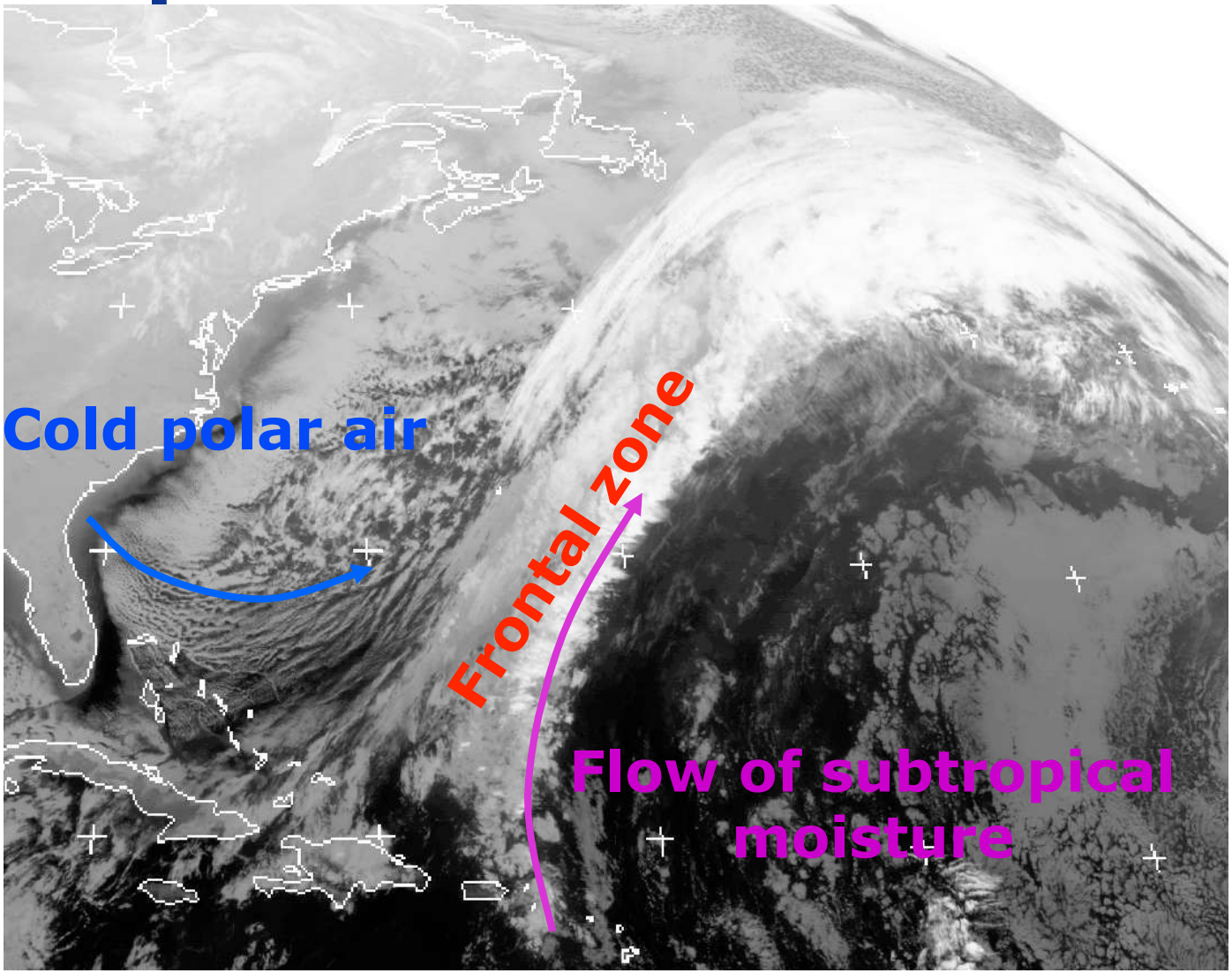
An Example

- Will first illustrate principles with a ‘typical’ example of an intense cyclone..

- Windstorm “Klaus” that hit France and Spain in January 2009

- The objective features we identify in model output consist of:
  - Fronts (warm and cold)
  - Cyclonic features (various types)

Imagery Signatures - Initial Development



22nd 00Z

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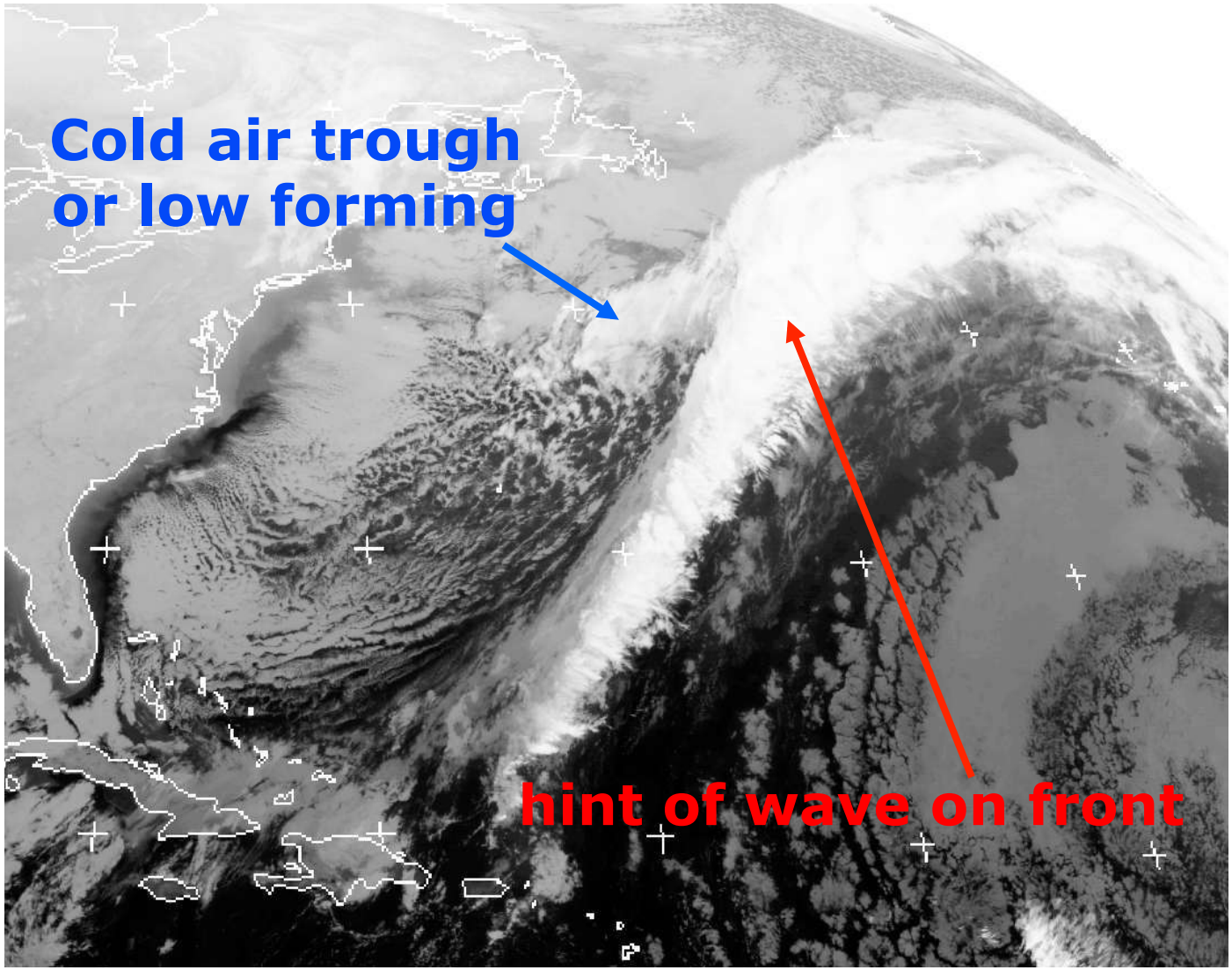
Initial Development



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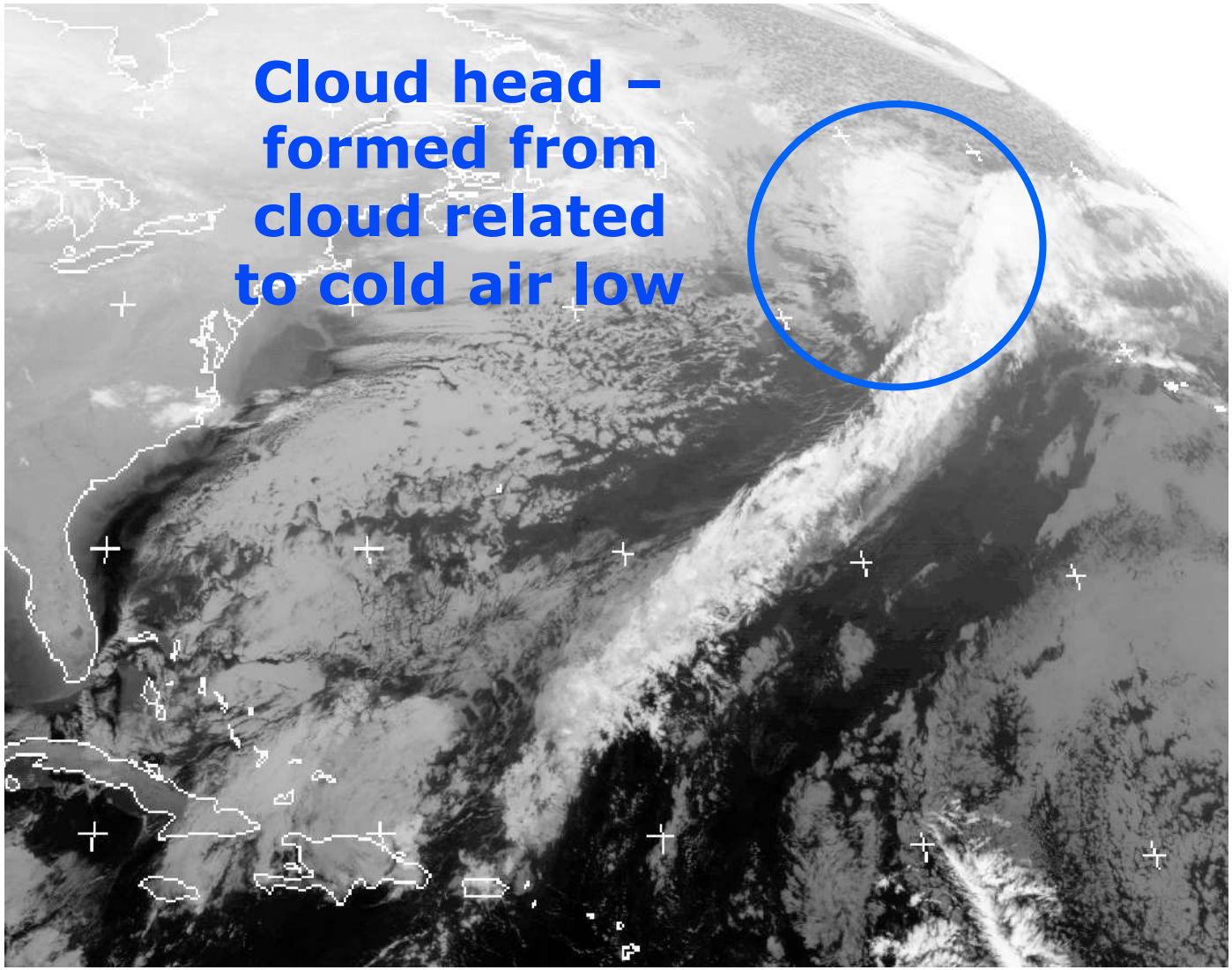
Cloud head development complete



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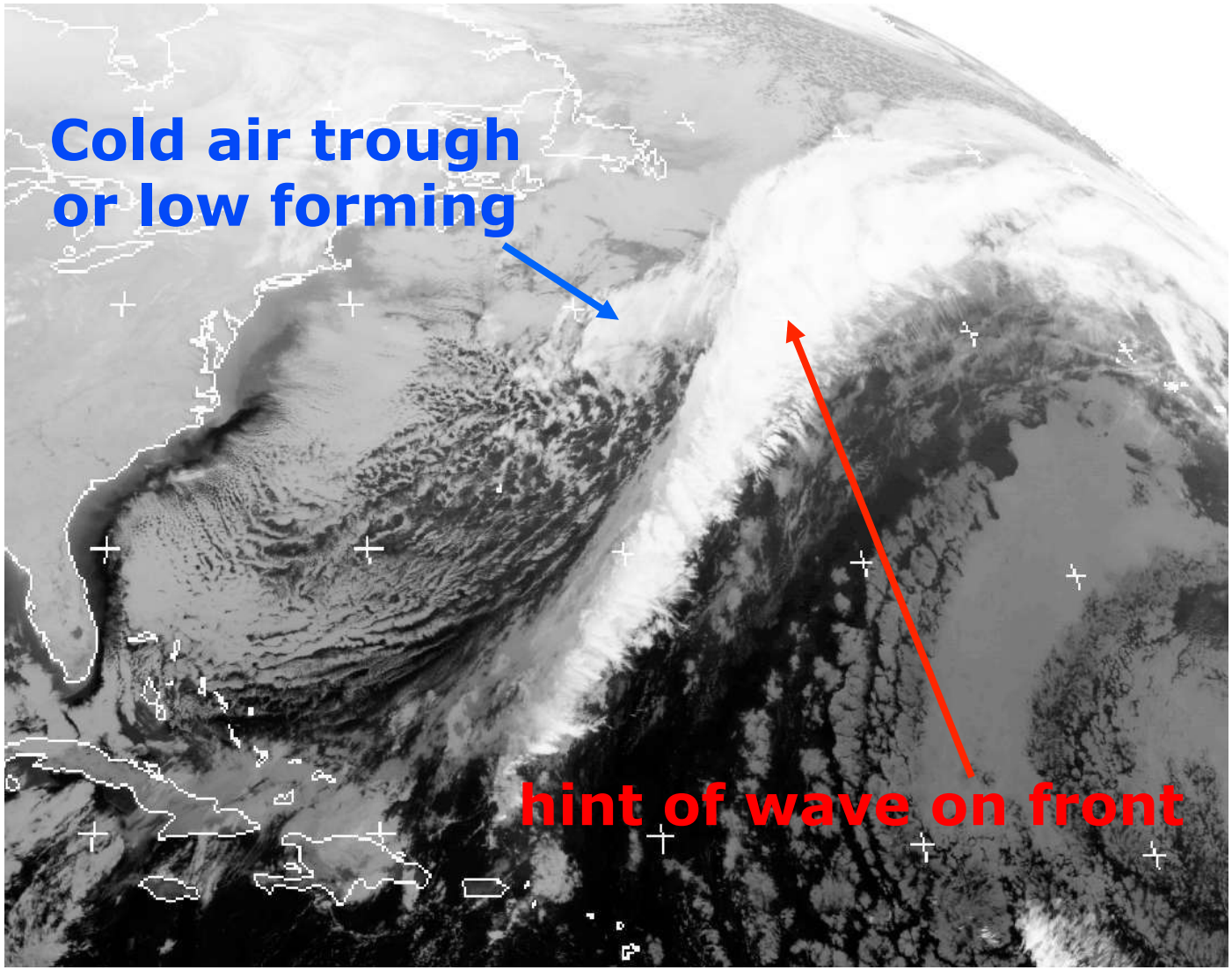
Initial Development



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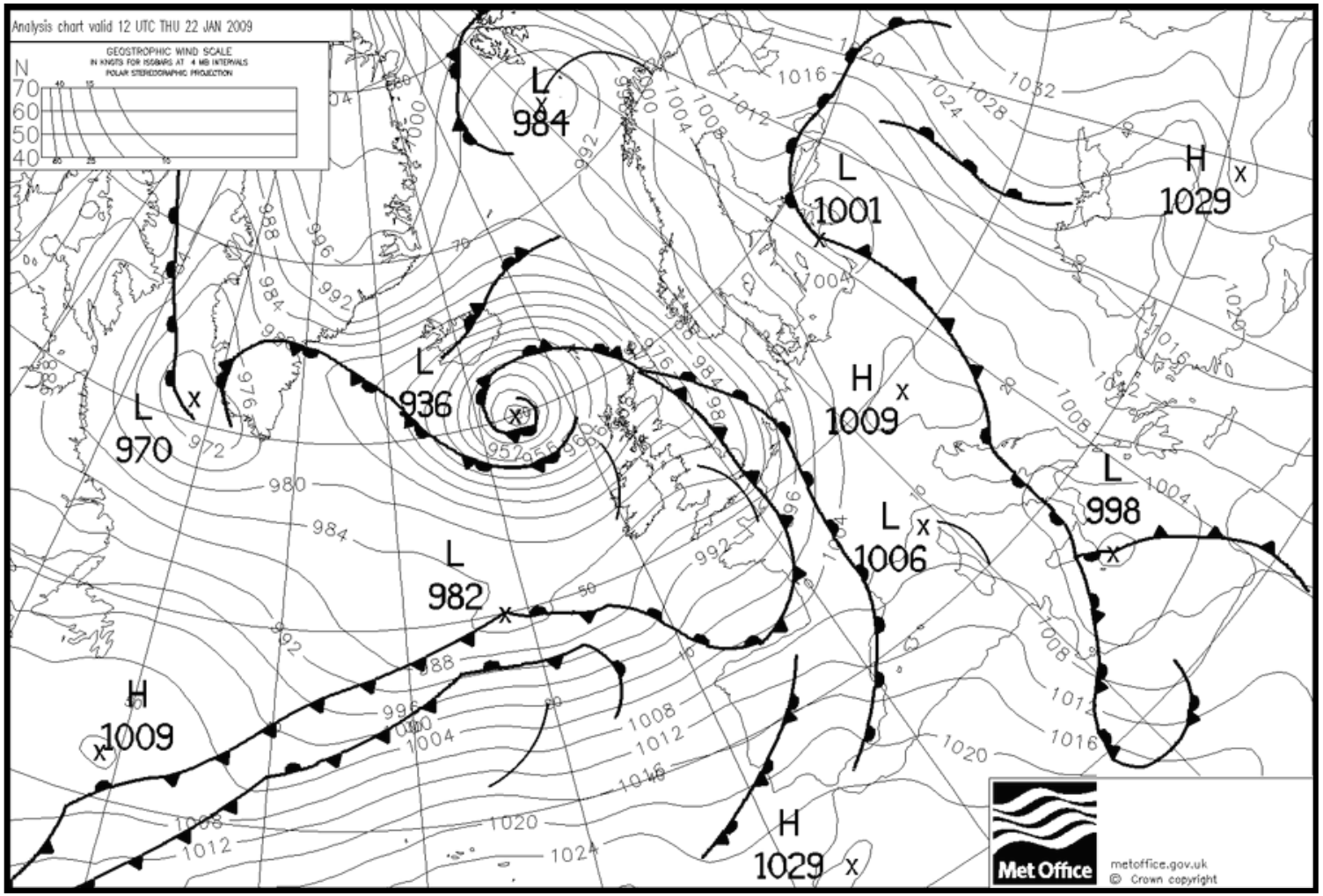
ECMWF

12UTC 22nd January 2009, 30-48 hours before windstorm Klaus peaked over land



ECMWF

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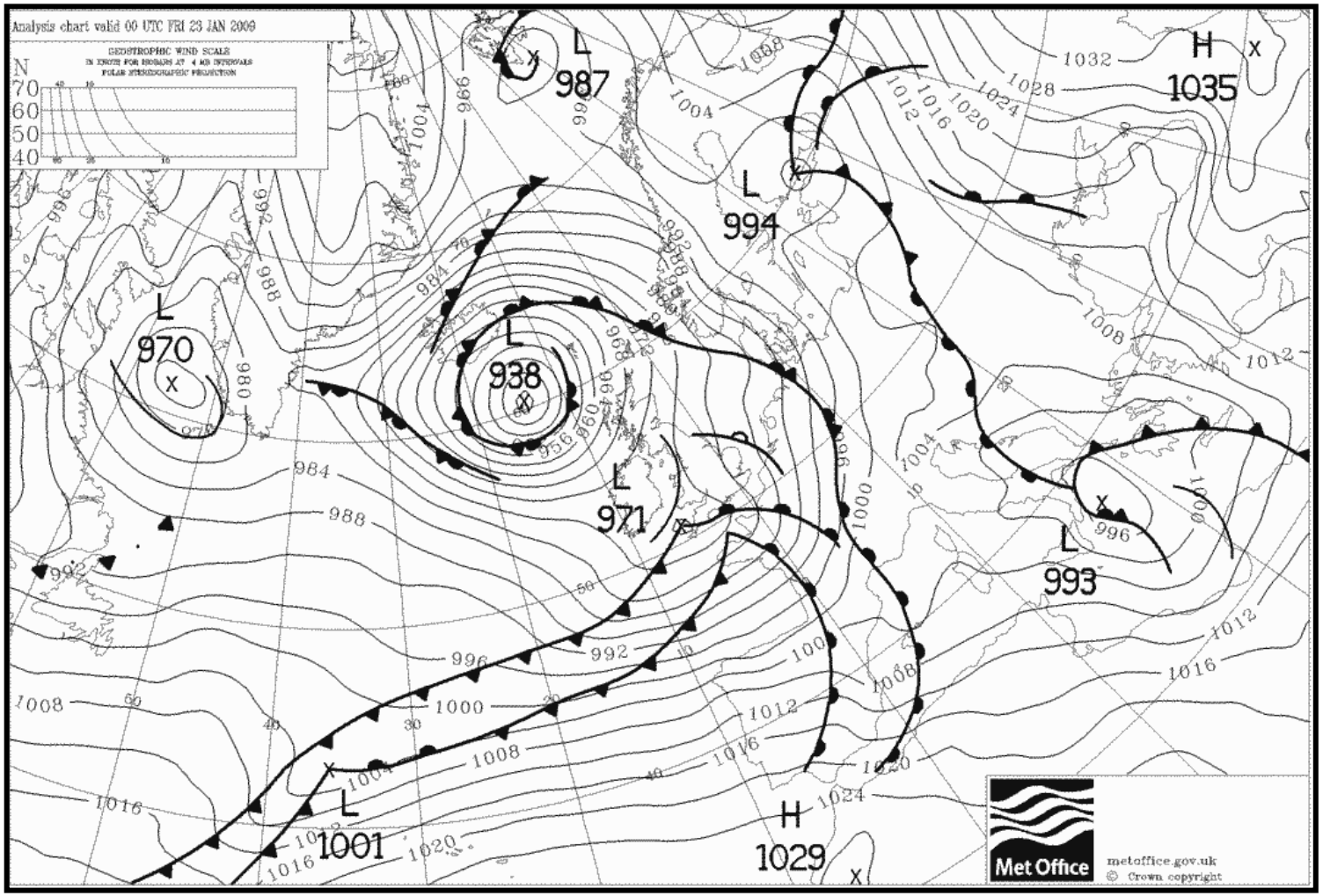

ECMWF

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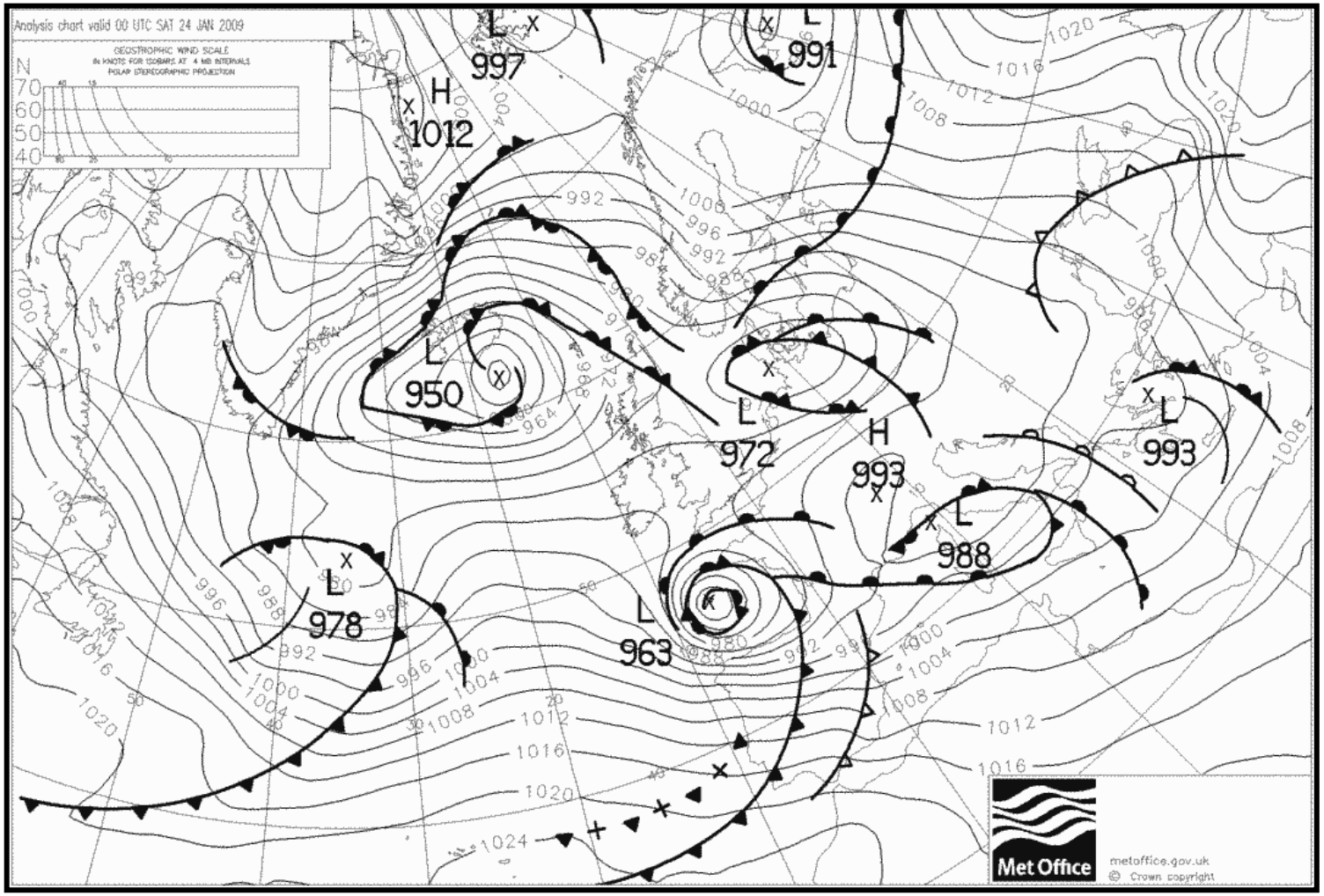
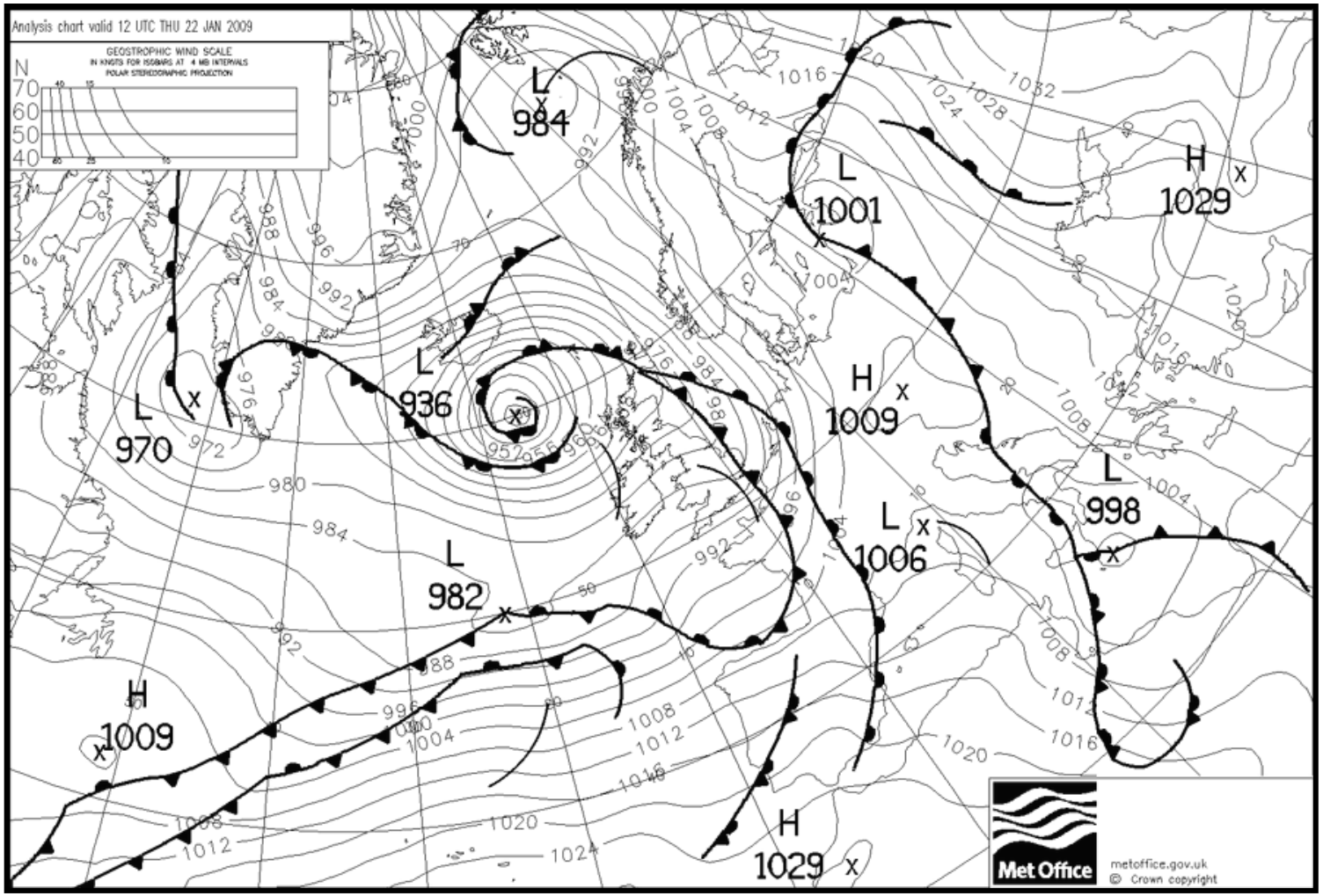
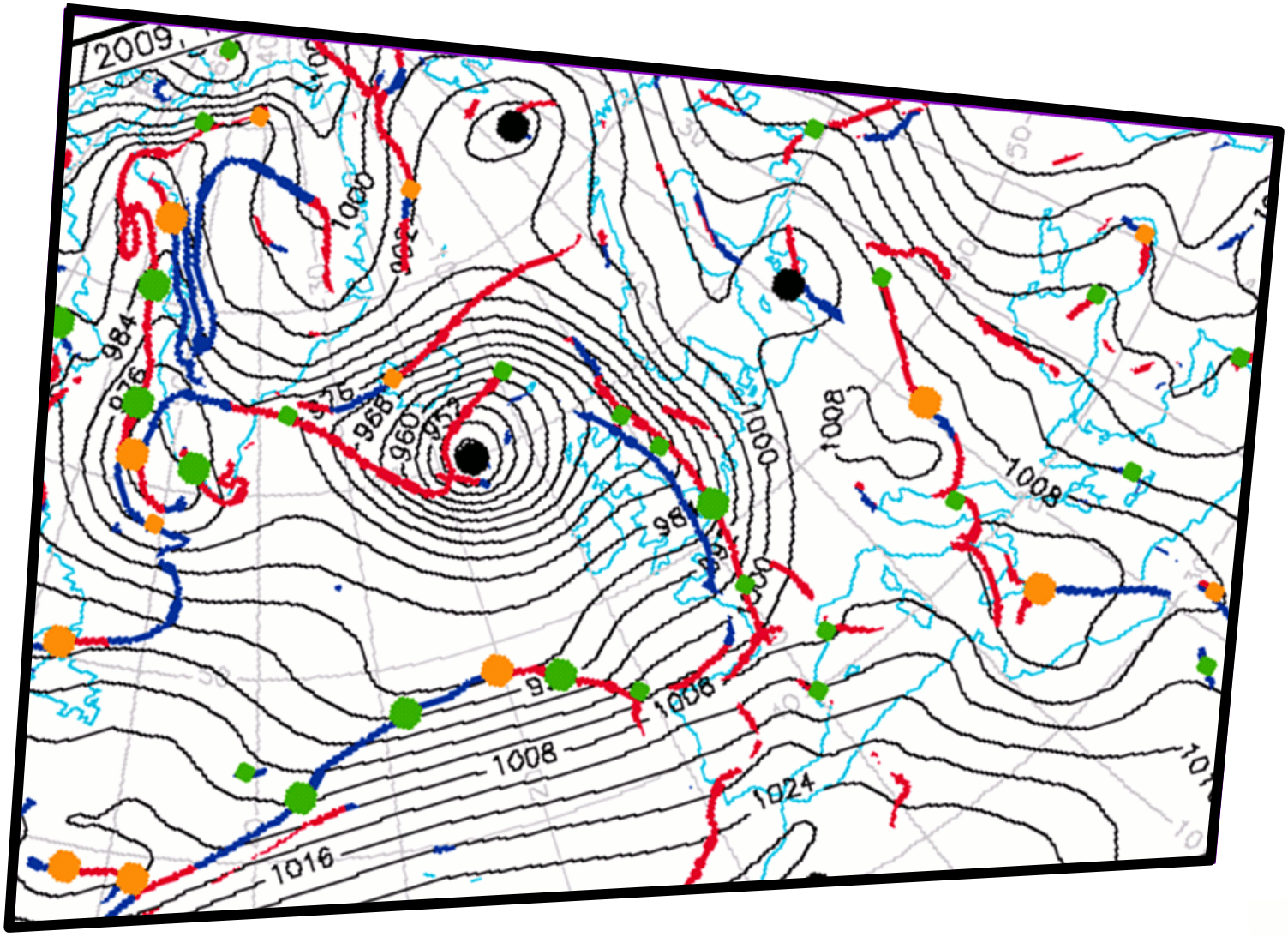


12UTC 22nd January 2009, 30-48 hours before windstorm Klaus peaked over land



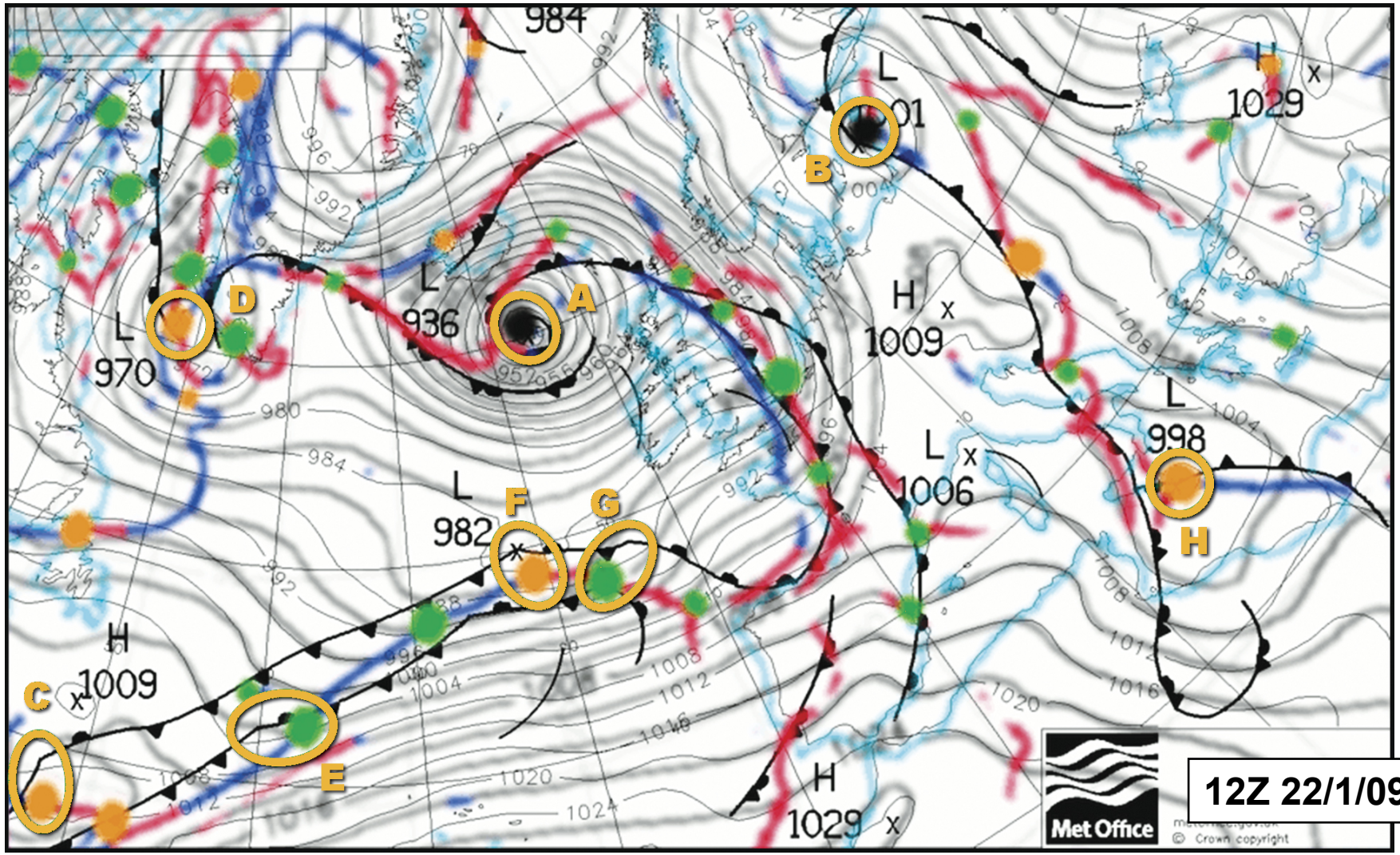
ECMWF

ECMWF Control Run T+0, with objective features



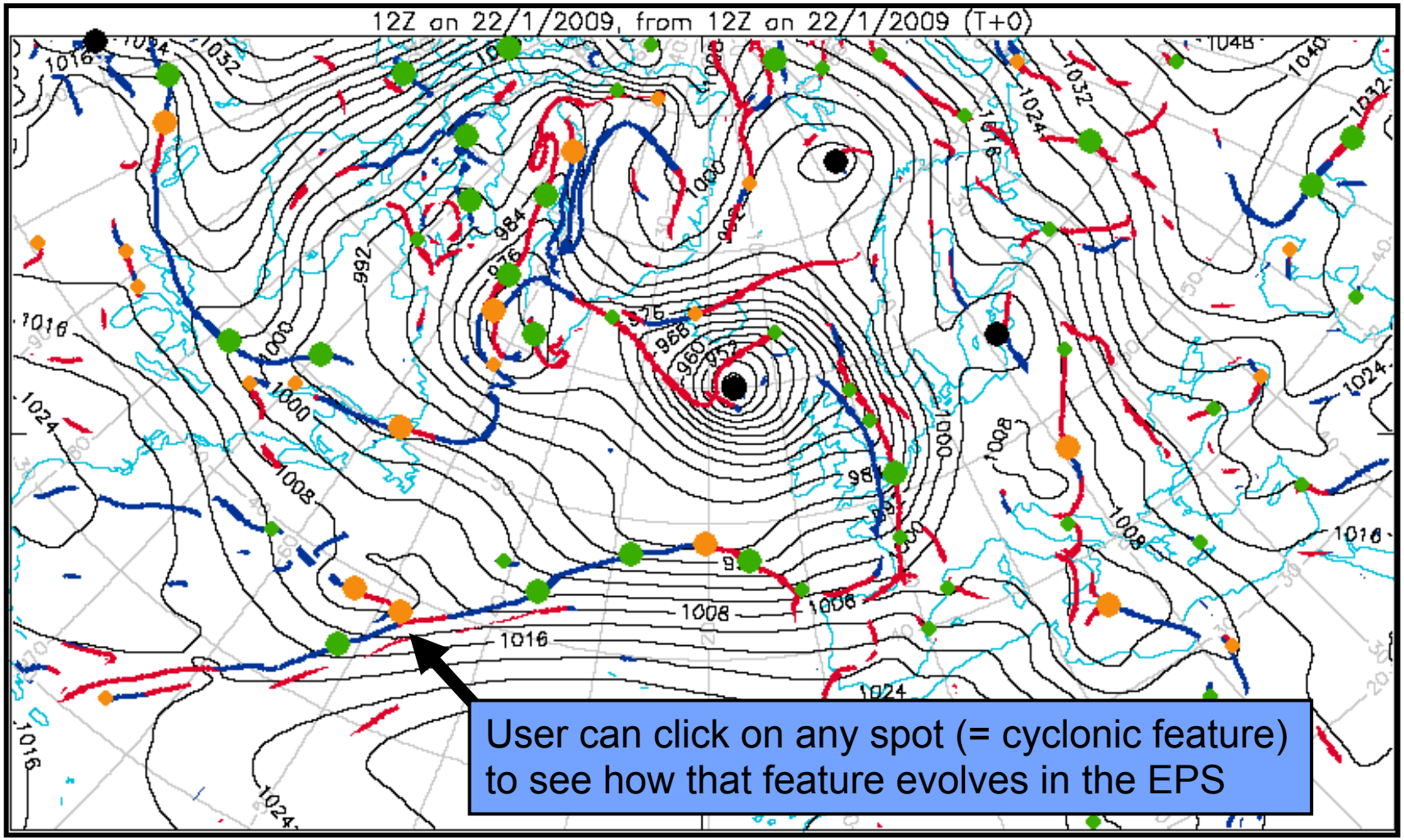
ECMWF

Manual and objective synoptic charts interlaced

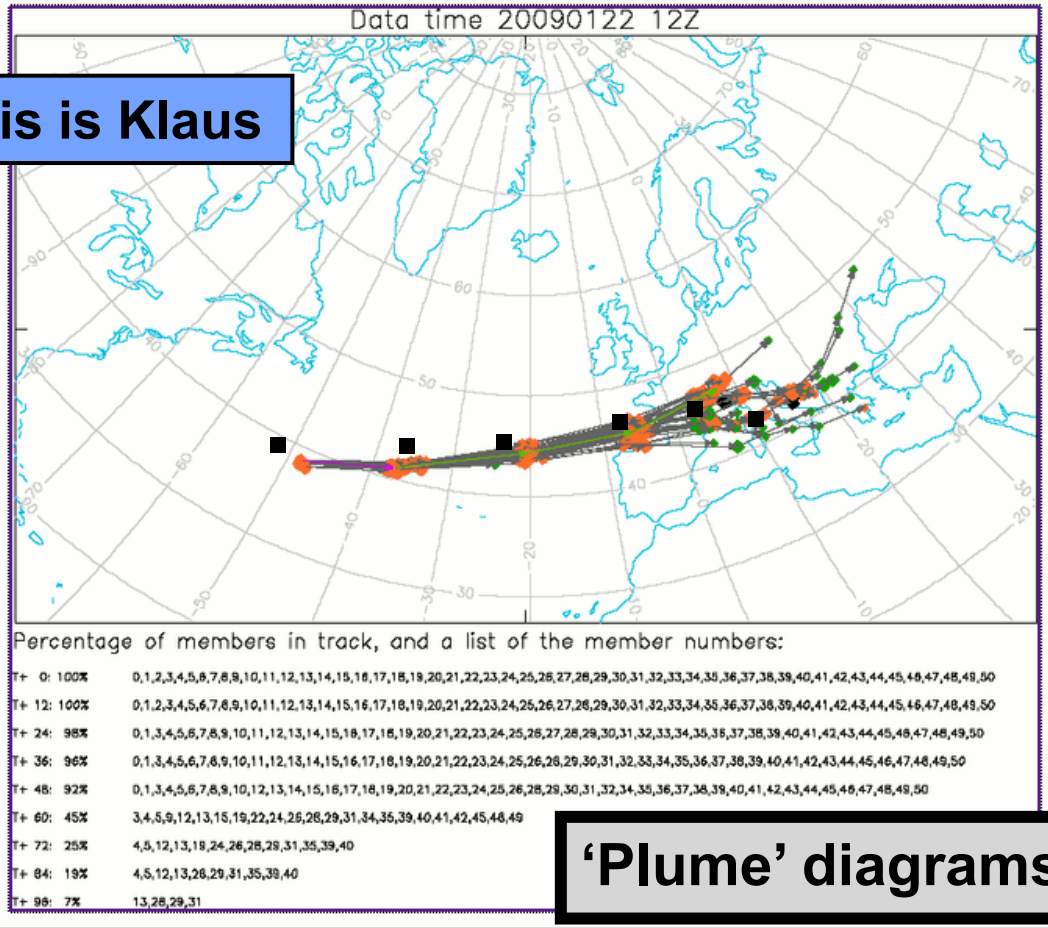


(objective data from ECMWF control run T+0, ~50km resolution)

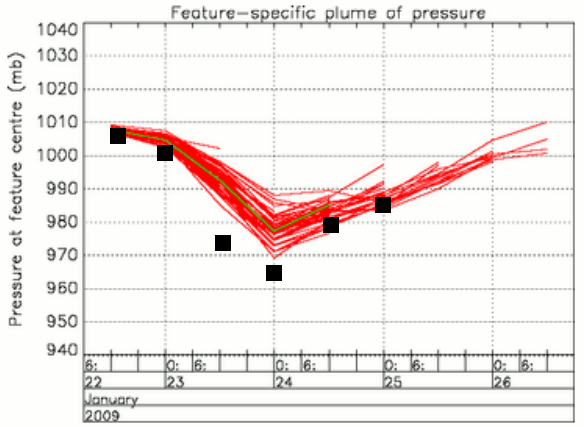
Tracking ‘Klaus’ in ECMWF EPS Forecasts (from T+0)

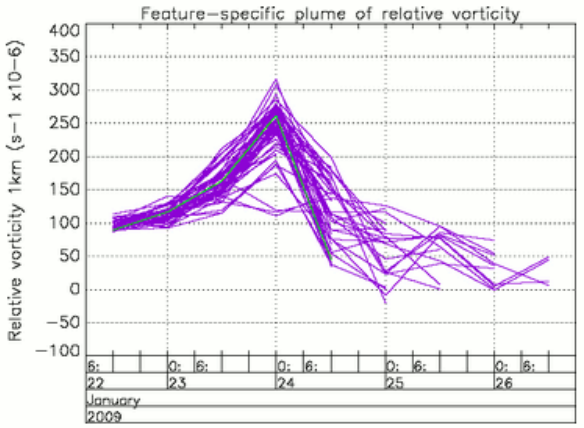


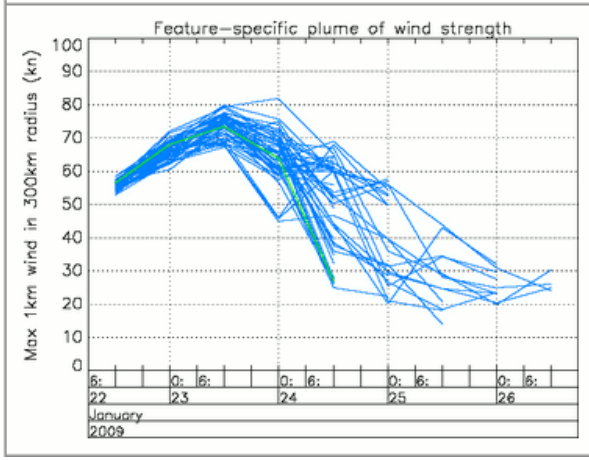
This is Klaus

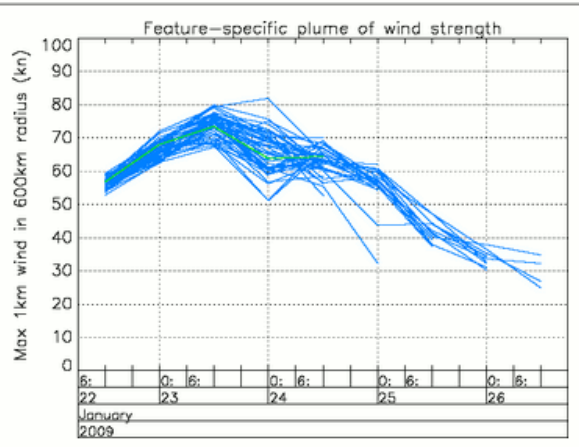


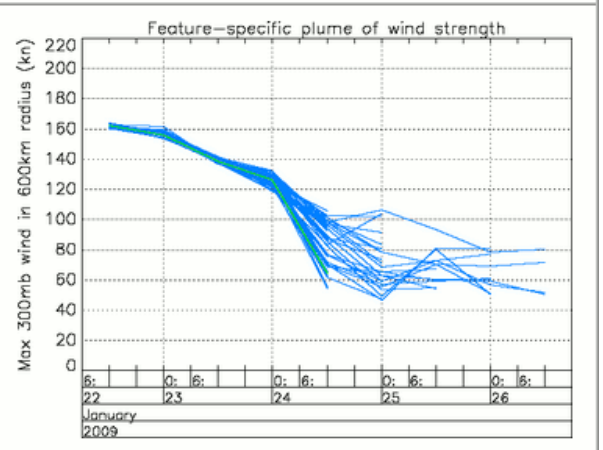
‘Plume’ diagrams











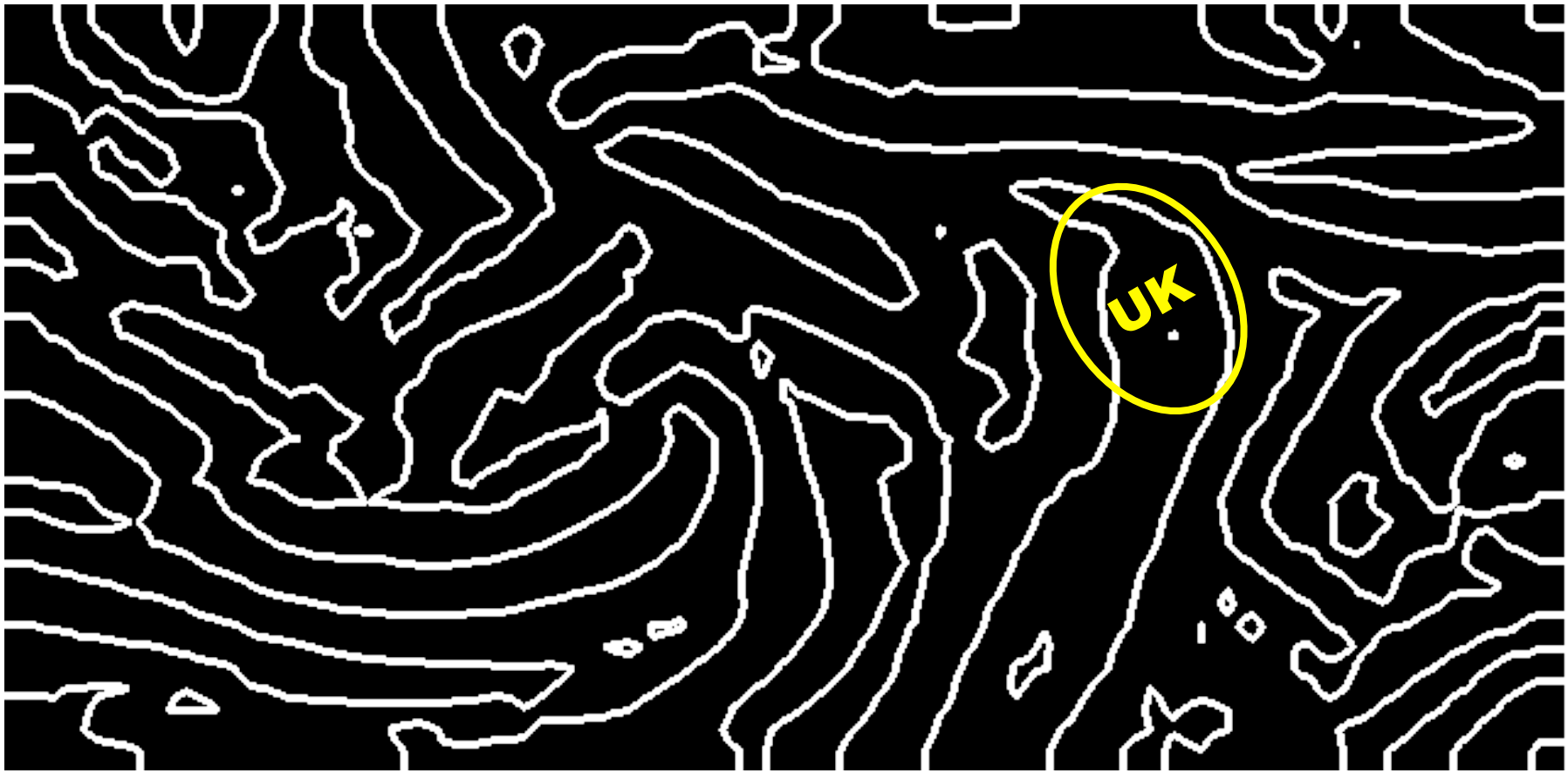
2. Identification of Fronts

A building block for cyclone tracking...

How do we identify the fronts?

- This is done by first computing *appropriate* diagnostic quantities (mathematical derivatives) on a level 1km above the model topography, using model wet bulb potential temperature field (Θ_w) as input. Diagnostics are designed to identify a front along the warm air side of each baroclinic zone.
- The diagnostics are then plotted using contouring and colour filling, with subsequent 'colouring-in' of the remaining line segments based on thermal advection, to denote warm (red) or cold (blue) fronts
- Simple demonstration follows….

Plan View – Area covers North Atlantic + Europe



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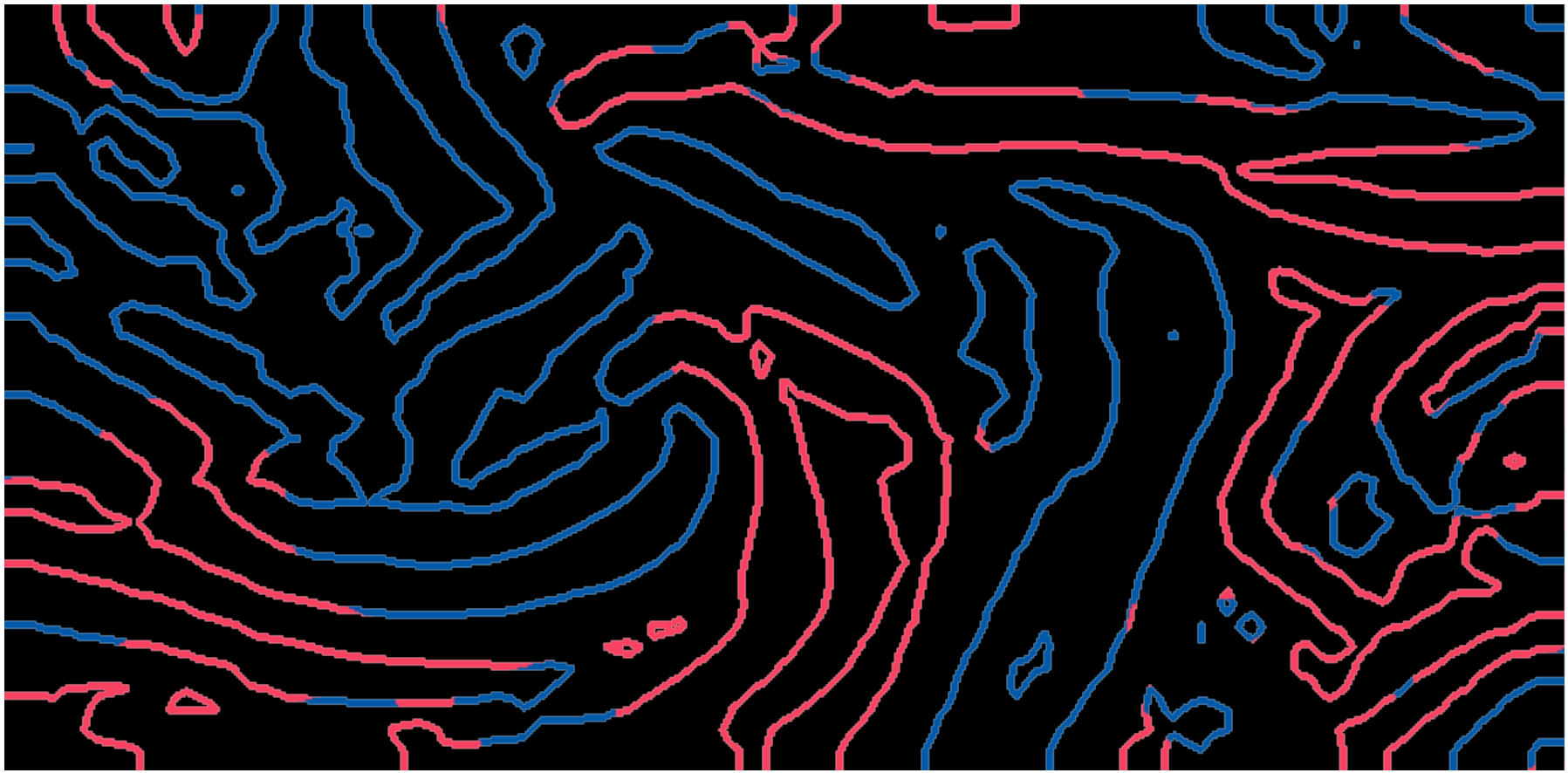
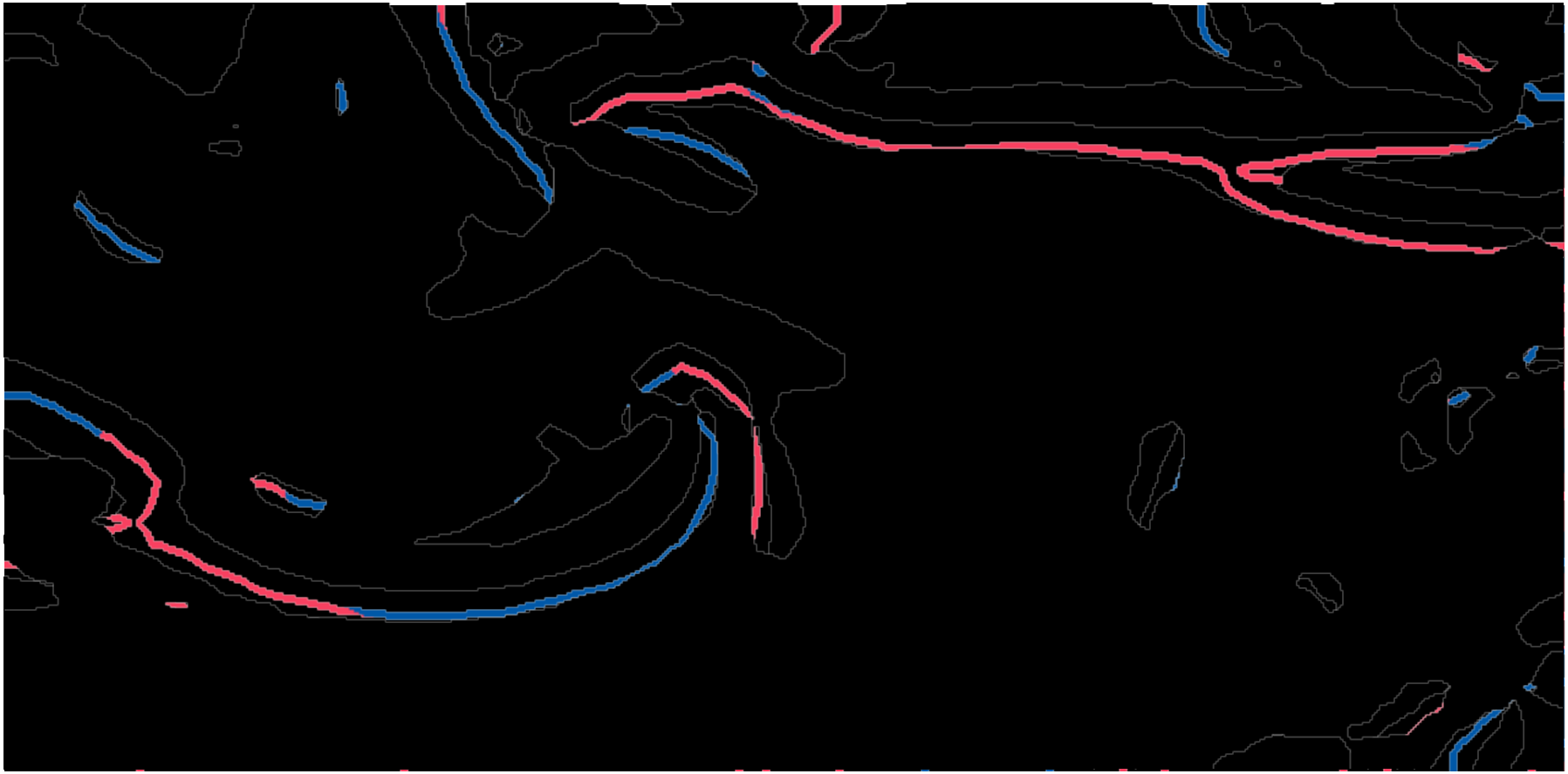
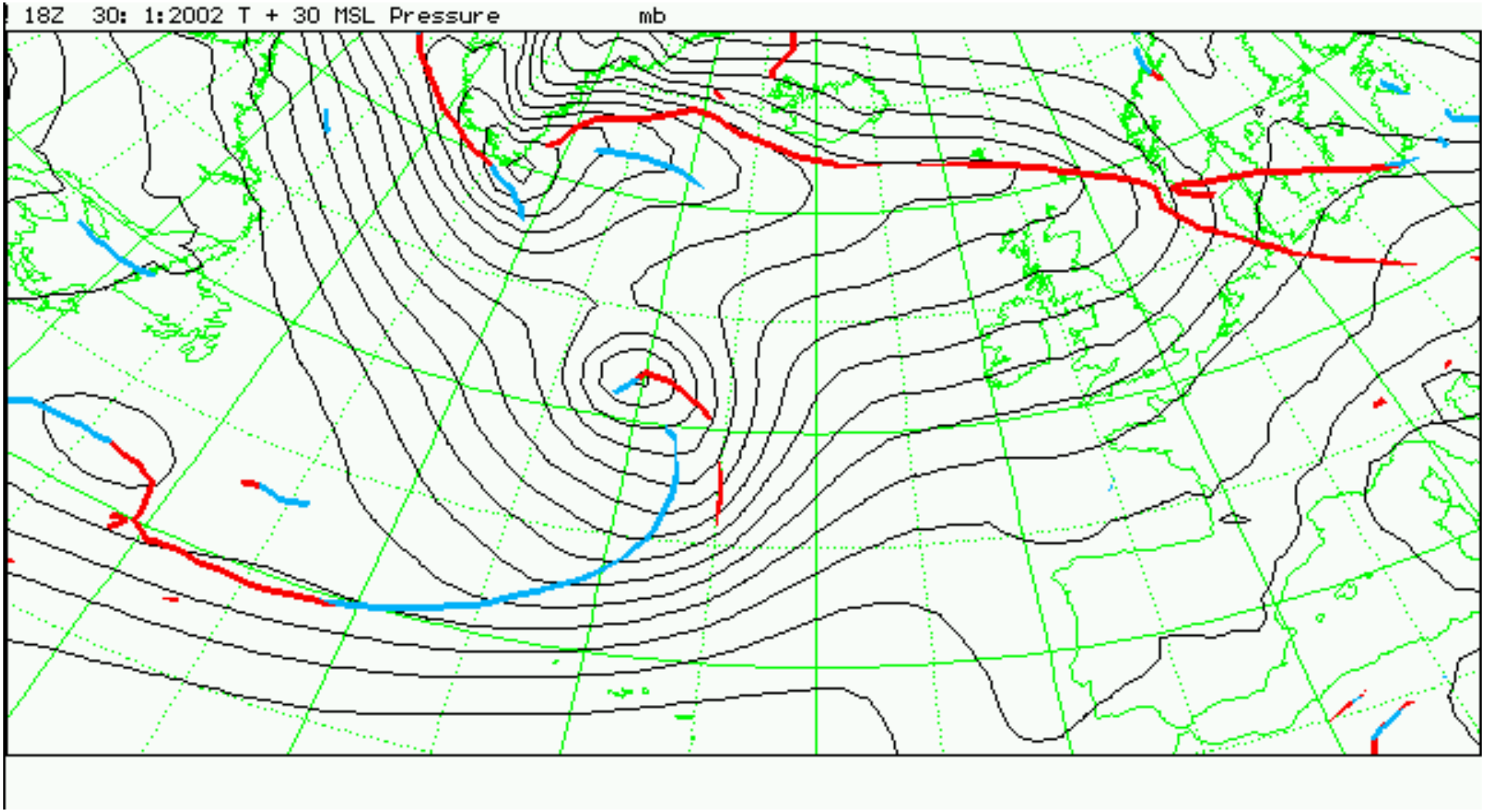
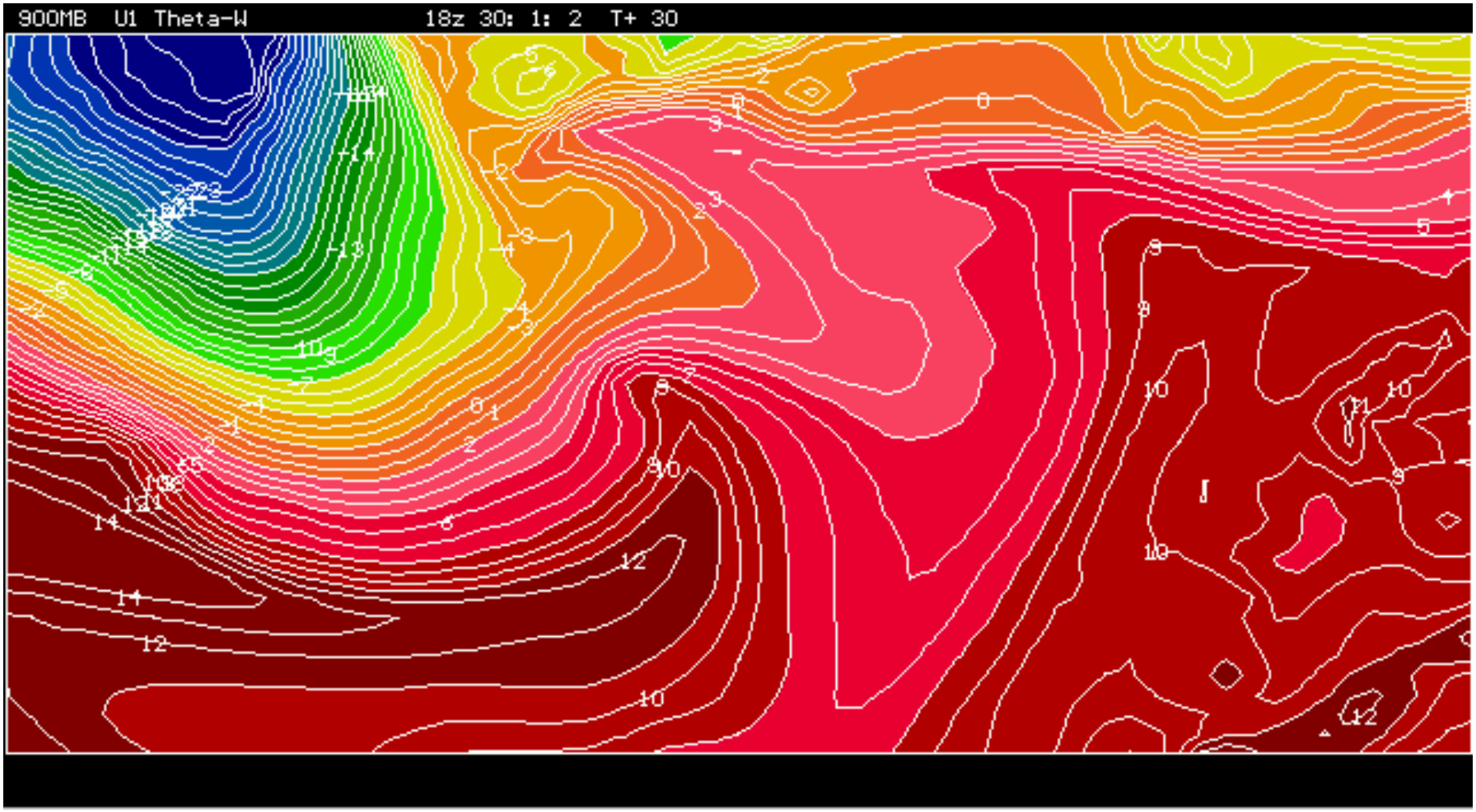





18Z 30: 1:2002 T + 30 MSL Pressure mb


900MB U1 Theta-W
18z 30: 1: 2 T+ 30

3. Identification of Cyclonic Features

ECMWF

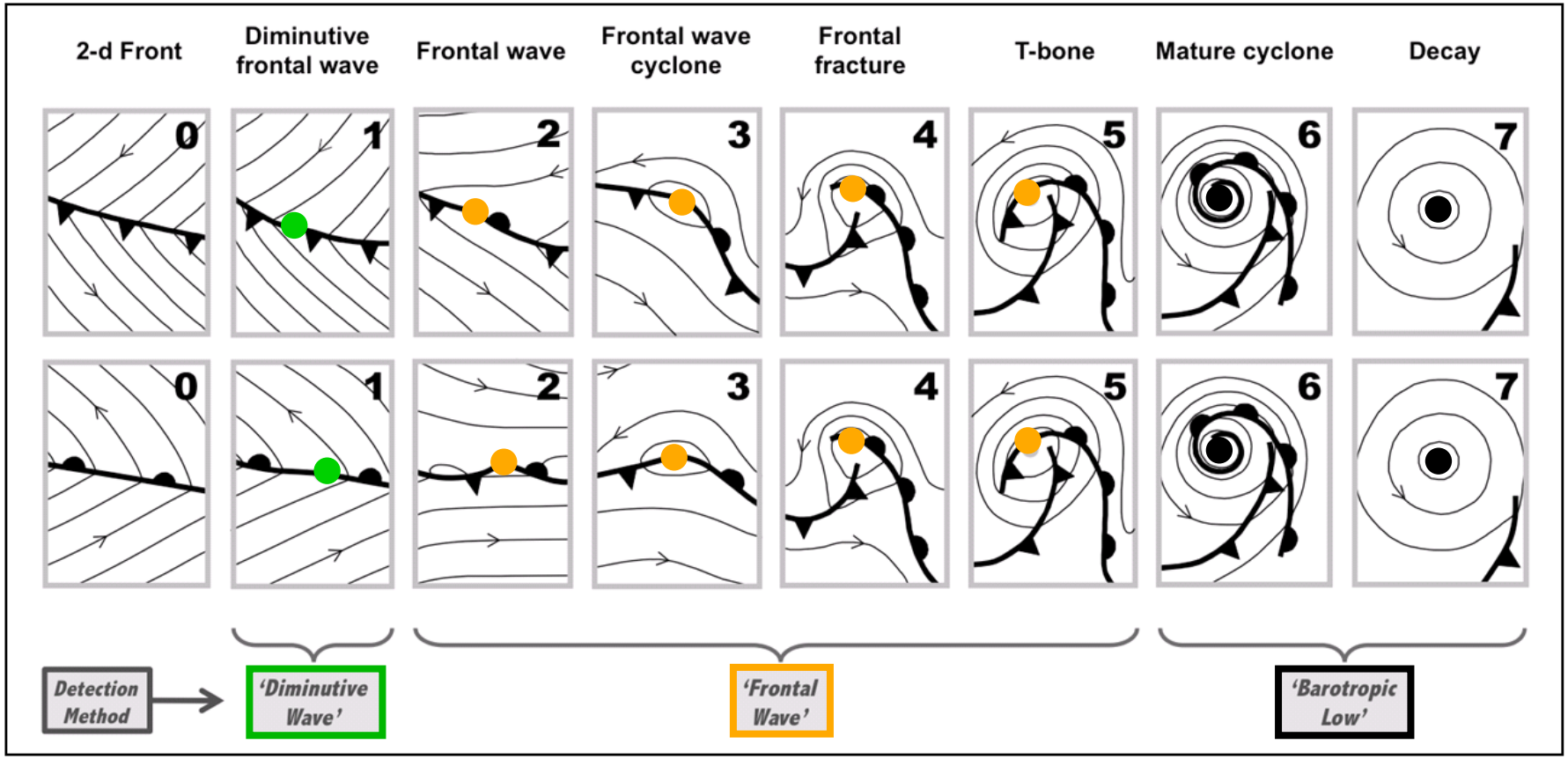
How do we identify the cyclonic features?

- As most such features in the extra-tropics start out on fronts, the first stage is to identify the fronts

- Then various algorithms (more derivatives), pinpoint cyclonic features of different types, mostly on the fronts themselves. The basis is a revised conceptual model of cyclone development.

- Only a brief overview is provided here..

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

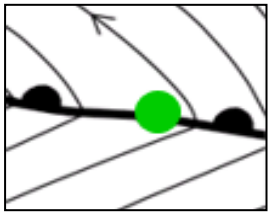


Lows, Frontal Waves and Diminutive Waves

- Barotropic lows are simply low pressure centres

- Frontal waves should be well known – they represent a meeting point of cold and warm fronts (where the vorticity of the cross-front wind is positive)

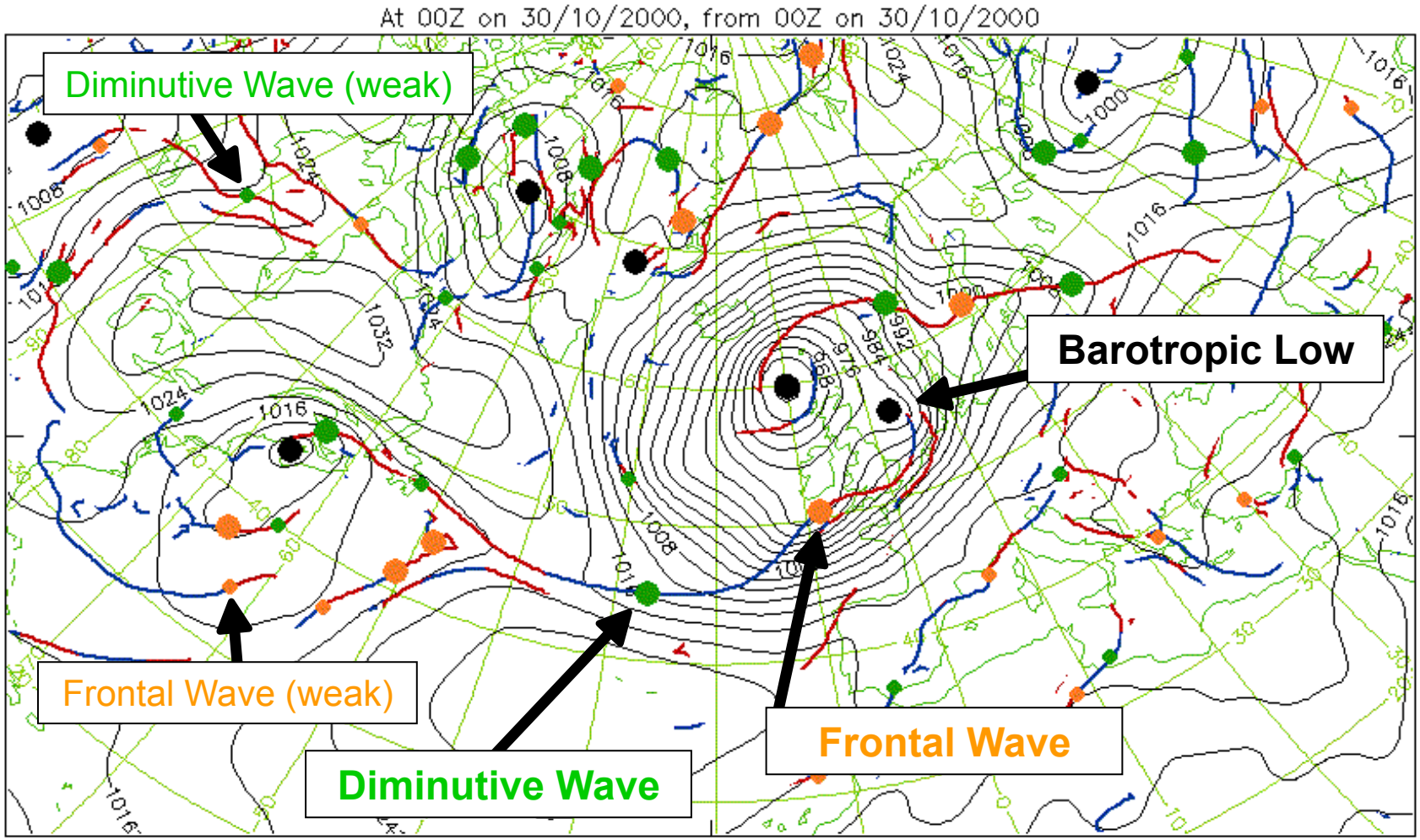
- Diminutive waves are less well known, they represent the first sign on a synoptic chart that a frontal wave may be developing – usually signified by slight opening out of the isobars



- Diagnostic-graphical techniques are used to identify each type of feature

Example Snapshot

Cyclonic Features, Mslp, Objective fronts



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How do we identify these cyclonic features in ECMWF model (IFS) output?

- Pressure level data provides input

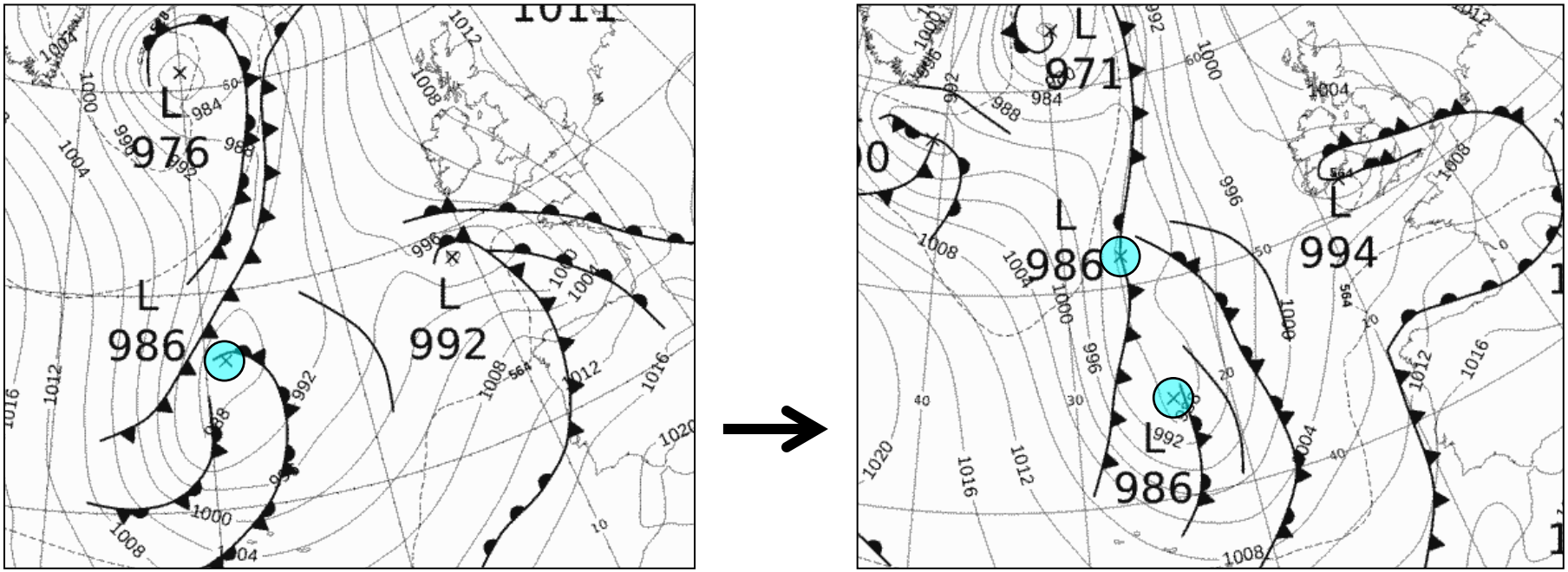
  (T, q, u, v, Z @ 1000,925,850mb,..)
- Data is reprojected at a resolution of about 50km
- 12-h time interval used, so that EPS-based products can be calculated in time to be used by forecasters
- Range of diagnostics computed from input data
- Diagnostics plotted and post-processed using a graphical package
- Output includes ‘synoptic animations’

Accuracy of locating features

- A systematic comparison between cyclonic synoptic features marked on UKMO 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.

4. Tracking and matching of cyclonic features



12h later

ECMWF

Defining Feature Tracks

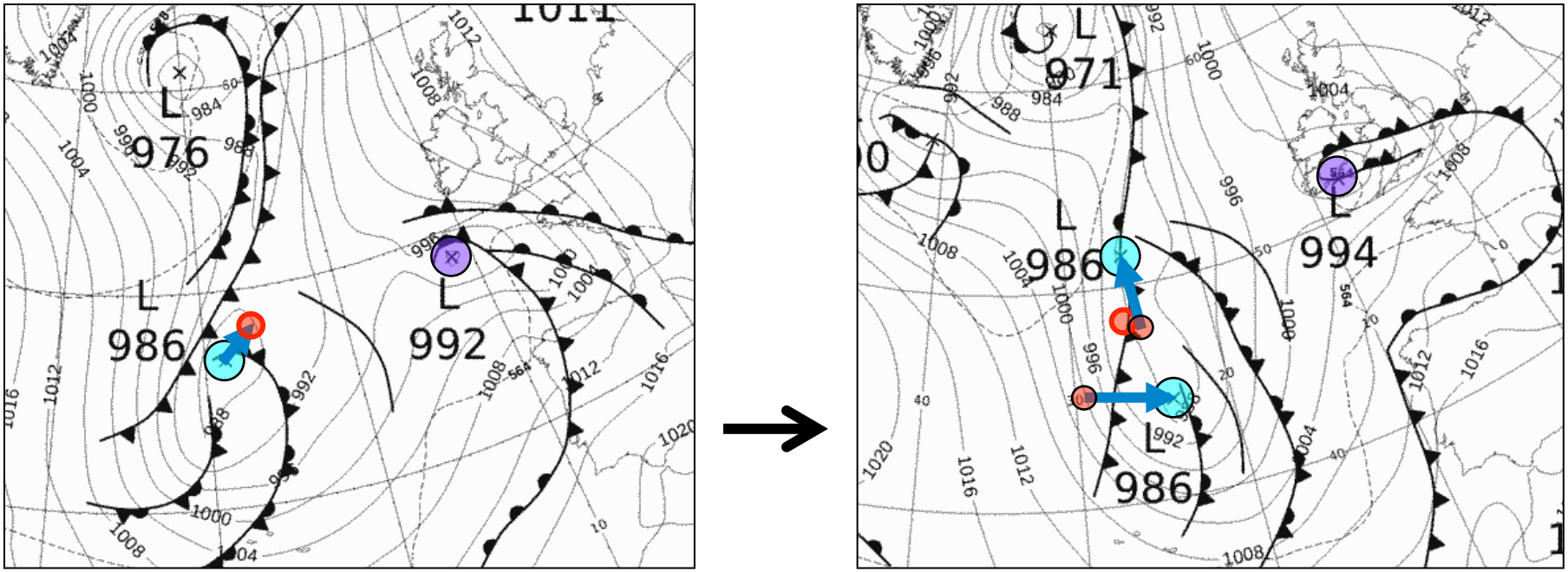
- **Aim is to 'join the dots' between successive time frames, recognising also genesis and lysis (=decay) of cyclonic features**
- **Several input parameters are used in the tracking scheme – to help join the dots by estimating how features are moving - for example:**

  500mb wind velocity above feature point (for steering)

  previous movement of feature also used, if available

  +…

- **An important innovation is the use of 'half-time tracking'…**
  - **Half-time tracking is when we move all the feature points at one time forwards half a time step, and all the features at the next time backwards half a time step, and then see which ones match up *in the middle***
  - **Full-time tracking is when we move all the feature points at one time forwards by a full time step, and then see how those match up at with features *at the next time step***
  - ***Using half-time tracking gives much more accurate tracks for cyclones!***



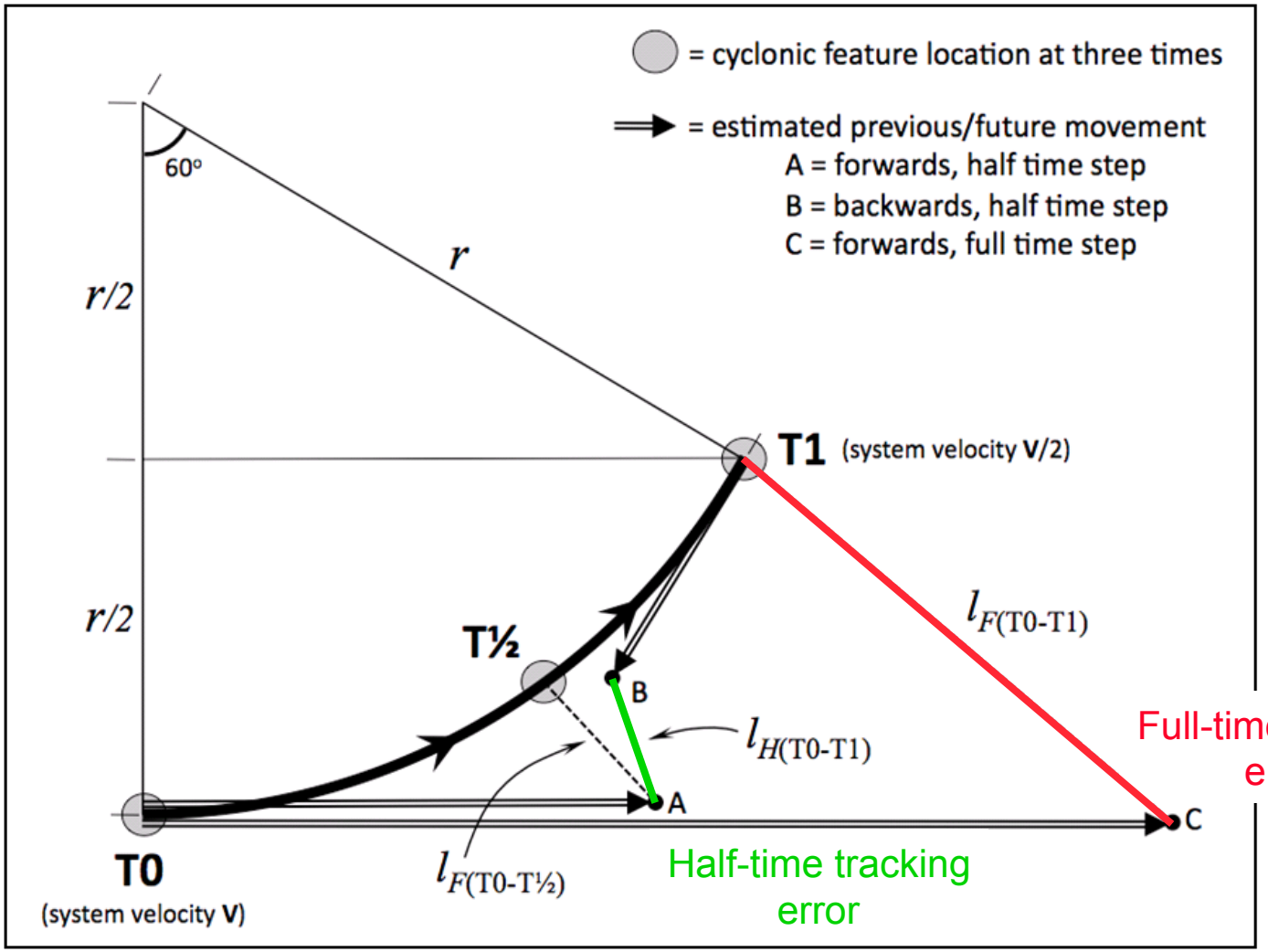
12UTC Sunday **00UTC Monday (yesterday)**

“Half-Time Tracking” helps the code decide which of the two blue cyclones on the second frame corresponds to the blue cyclone on the first frame

Focus on 18UTC Sunday (= “half-time”), estimate approximately where each feature would have been then, and see which gives the closest match

= estimated 6h movement of cyclone

An illustration of 'half-time tracking'



Overall Accuracy of the tracking algorithm

- Feedback from forecasters originally lead to changes to the tracking, with a significant positive impact

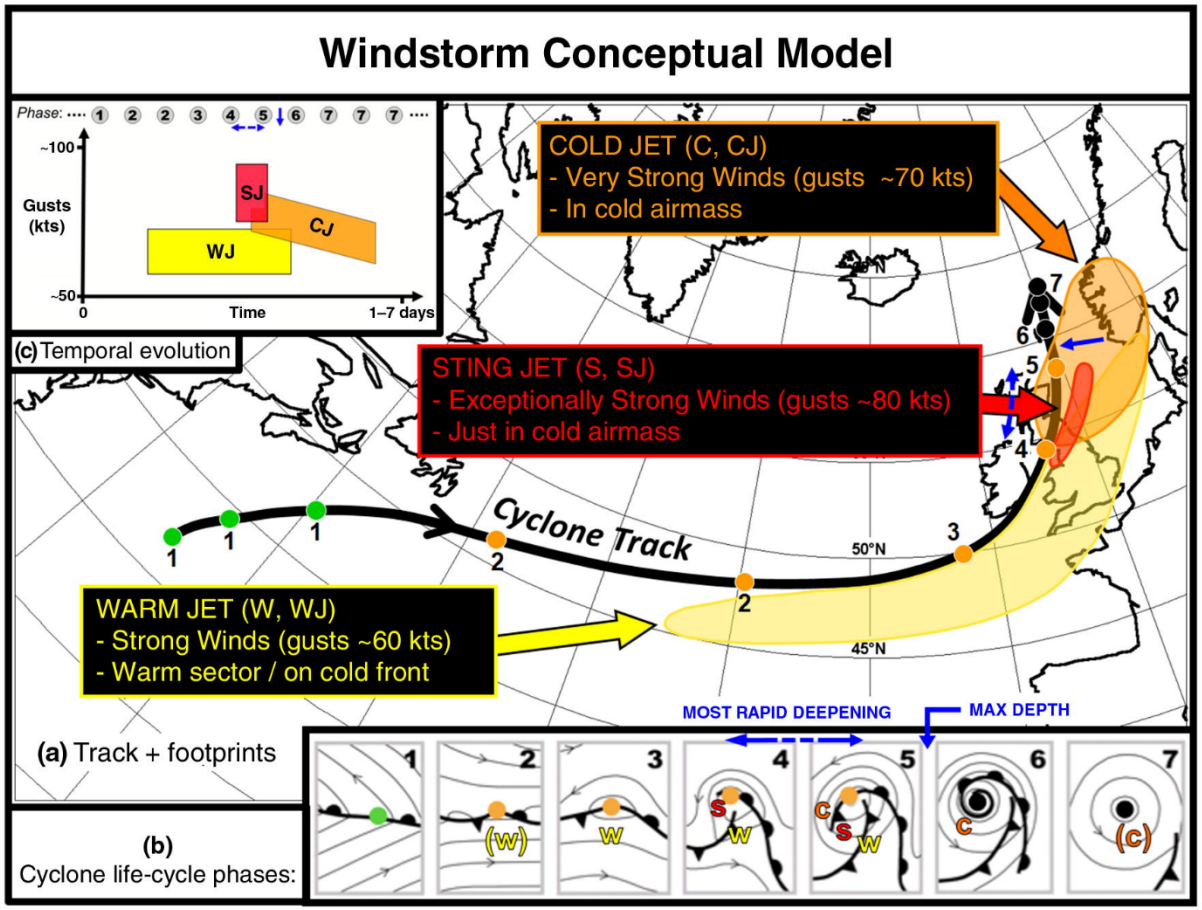
- In one test, using 167 North Pacific feature points in a control forecast, the tracking algorithm clearly made the wrong decision (compared to manual tracking) on only 3 occasions (~2%).

Tracking windstorm-generating cyclones

- ‘Klaus’ was successfully tracked, in all the EPS members, from a very early stage when it was a relatively minor frontal wave
- Without the high resolution input data, and without developing identification and tracking algorithms to deal with this, this would not have been possible.

- In tailoring the algorithms special attention was paid to coping with typical windstorm-generating cyclones, which can (i) move very rapidly, (ii) change speed and direction quickly, and (iii) vary in size

Windstorm Conceptual Model / Reference



See:

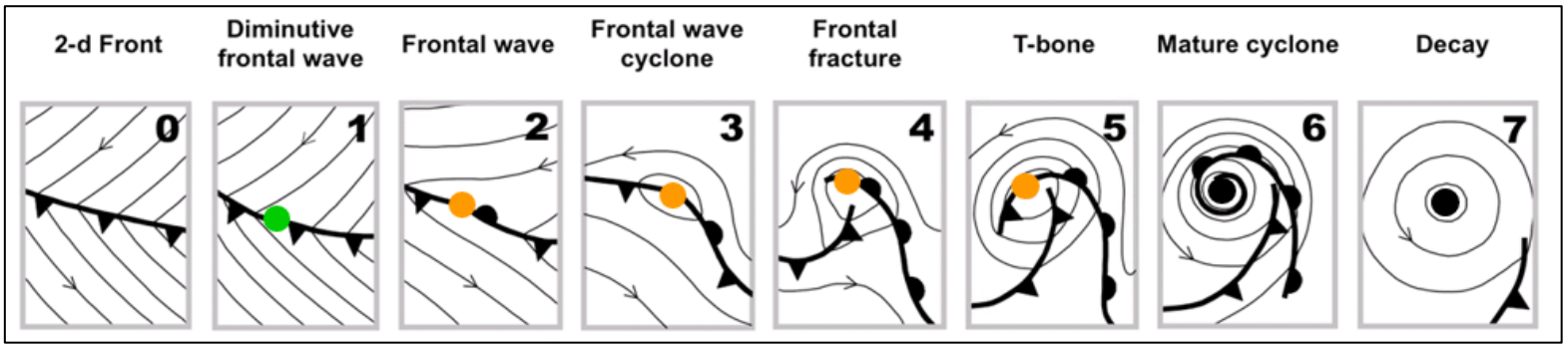
"Cyclones, windstorms and the IMILAST project"

Hewson and Neu, Tellus A, Sep 2015.

Paper is free to download!: **http://www.tellusa.net/index.php/tellusa/article/view/27128**

5. The Web Products – and how to use them

WEB DEMO



Extra-Tropical Cyclones - Product Options from drop down menu

most appropriate lead times to assess

- Clickable Control T+0 image ← Gives feature plumes / tracks (0-5 days)
- Fronts Animation ← Fronts (2-8 days)

- Features Animation
- Feature Anim (mslp)
- Feature Anim (300km 1km wind max)
- Feature Anim (600km 1km wind max)
- Feature Anim (Disc Ppn mean)
- Feature Anim (Disc Ppn max)
- Feature Anim (Disc Snow mean)
- Feature Anim (Disc Snow max)
- Feature Anim (thickness)
- Features - ALL PARAMETERS ← **ALL** dalmatian charts in one place

← Dalmatian charts (1-10 days)

- Postage stamps Animation
- Postage stamps (ALL)
- Postage stamps (by time)

← Postage stamps, various formats (All times)

- Strike prob (1km wind >60kt)
- Strike prob (1km wind >34kt)
- Strike prob (all features)
- Strike prob Postage stamps ← **ALL** strike prob charts in one place

← Storm track strike probs (5-15 days)

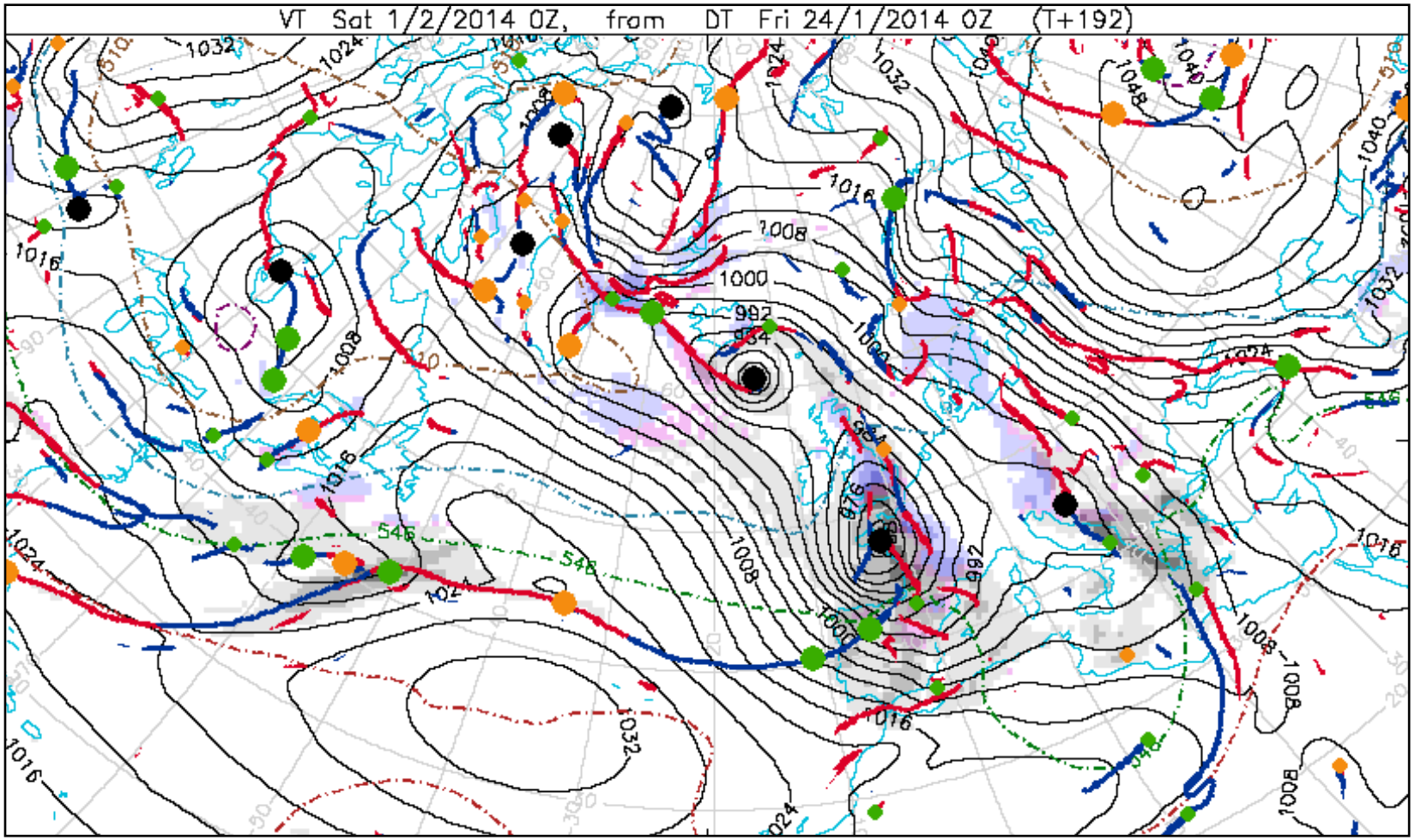
- Animation of Deterministic
- Animation of control
- Animation of member 1
- :

← Synoptic animations, single runs (0-6 days)

- T+0 'animation'
- T+12 'animation'
- :

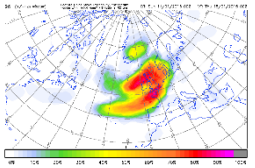
← Fixed time animations, for all runs (All times)

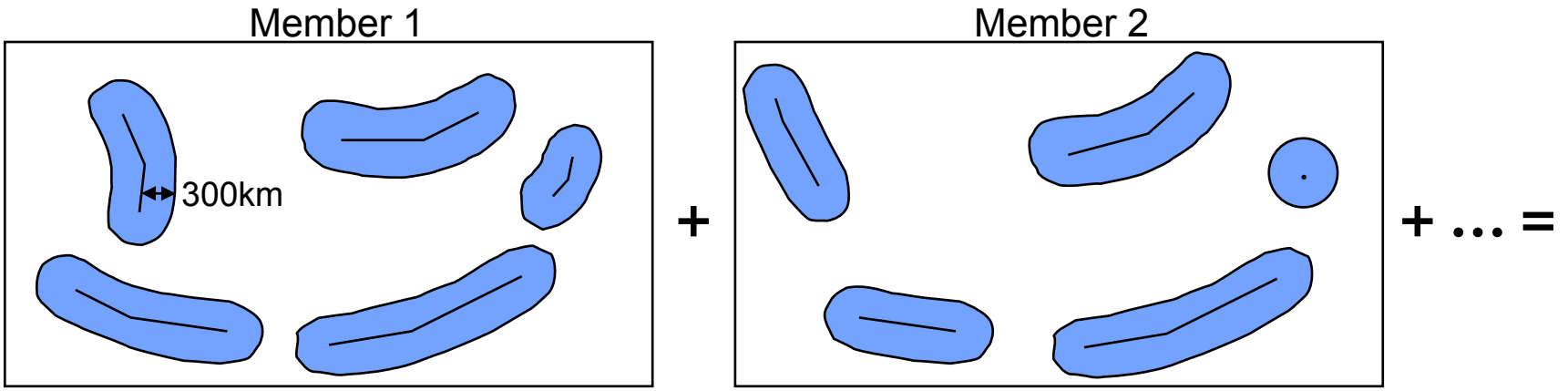
Snapshot of Synoptic Feature Chart



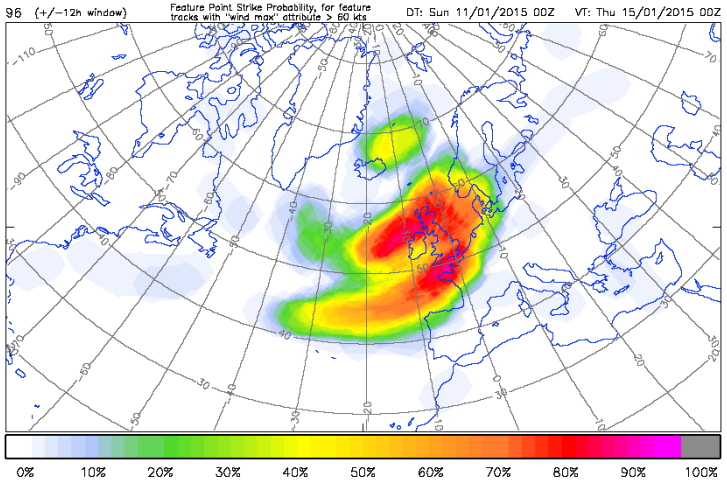
12h precipitation shown by shading – greys for mainly rain, pinks for rain-snow mix, blues for mainly snow
Ranges, in mm water equivalent: 2-8mm, 8-20mm, 20-50mm, >50mm

Construction of Strike Probability Charts



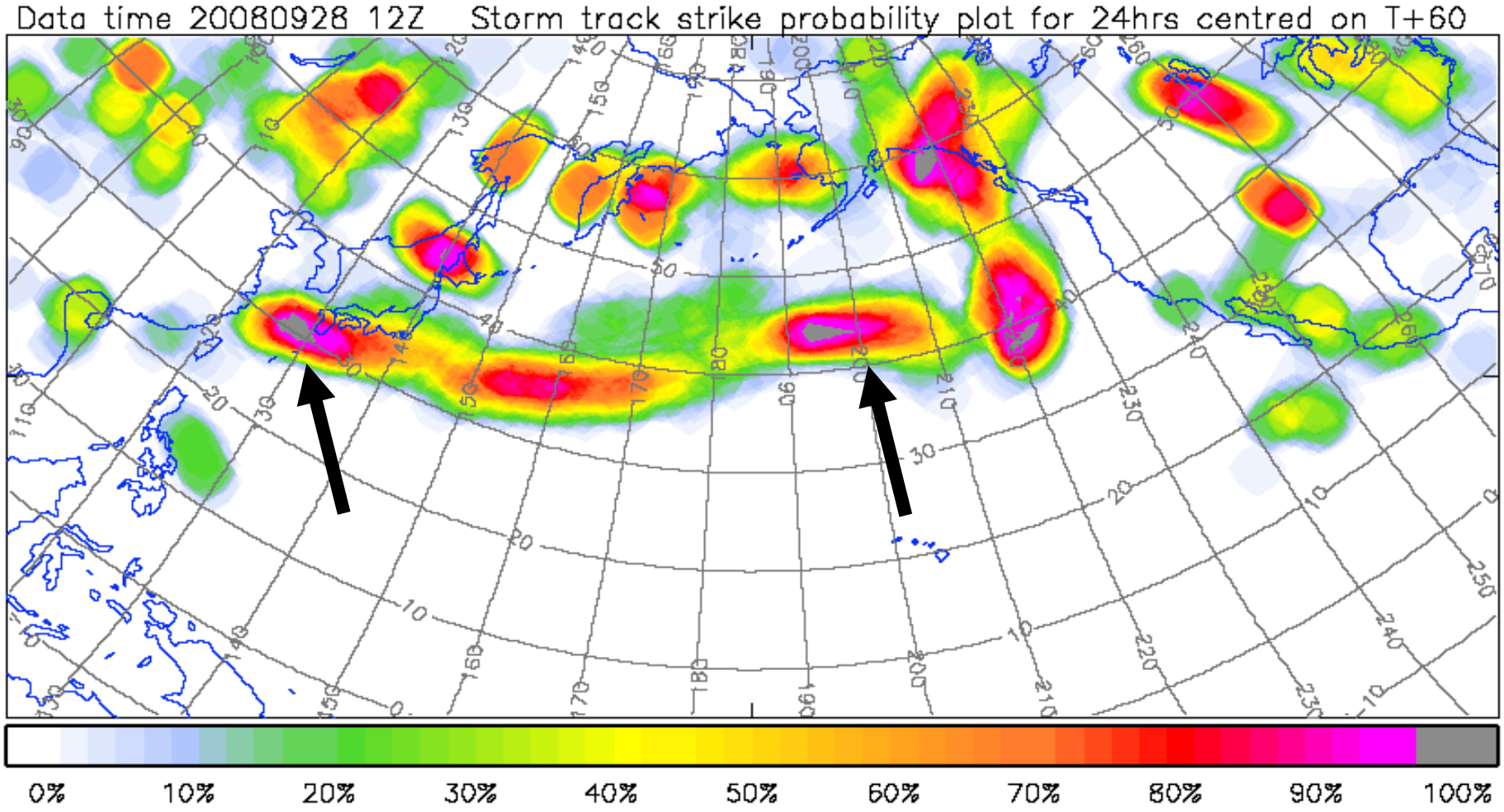


tracks in +/-12h window



- **Strike Prob charts are based on tracking feature points, not wind maxima**
- **‘Spots’ on strike prob charts are generally due to slow-moving or short-lived features**
- **Thresholding (‘>34kts’, ‘>60kts’) is based on wind maxima, at 1km, within a 300km radius of the feature point, being achieved *somewhere along the track segment for -12h to +12h.* Tracks of features that match the criteria are retained in computation of the strike prob chart, the rest are not….**

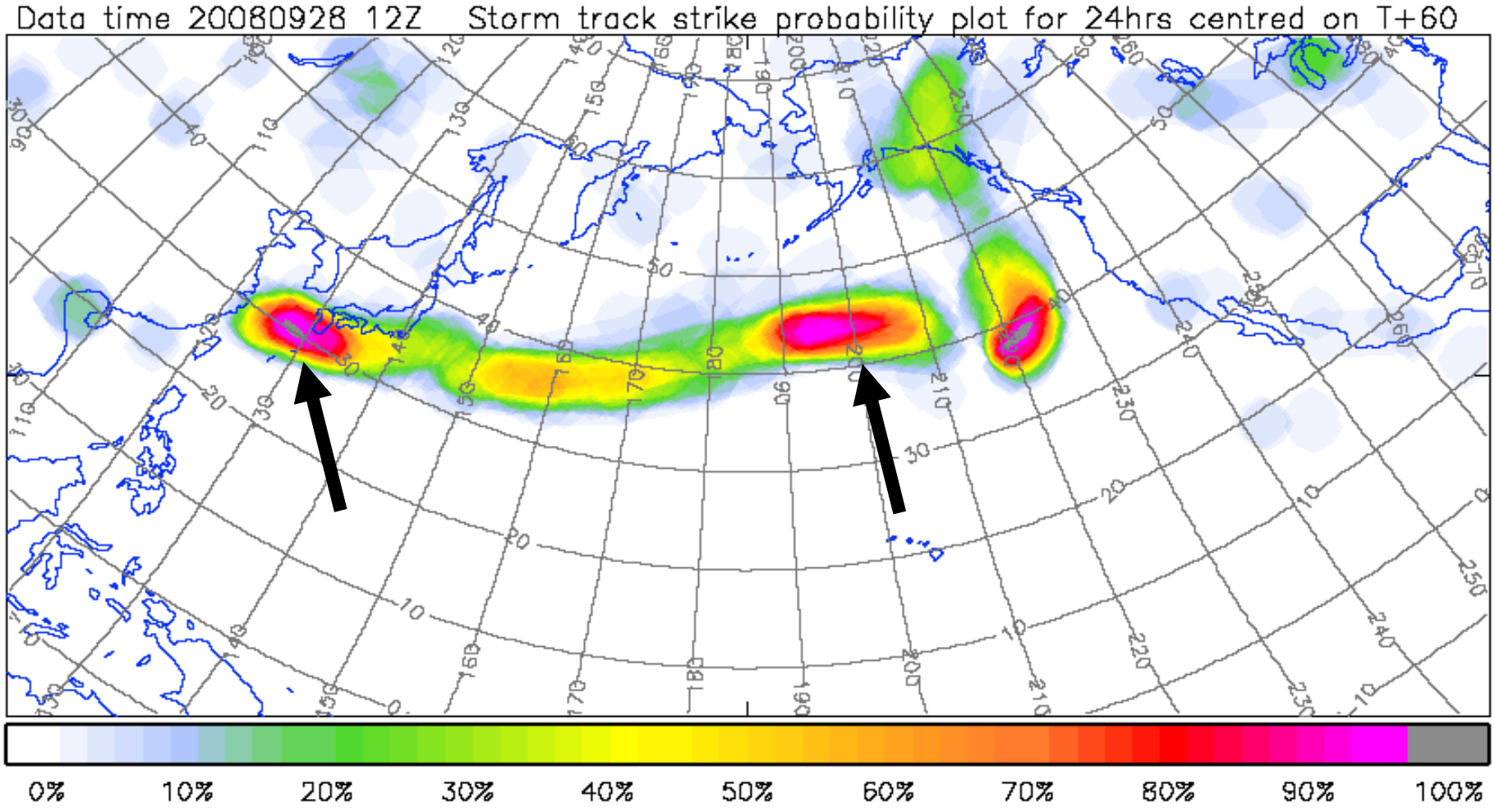
Strike Probs – All features



Also animates

ECMWF

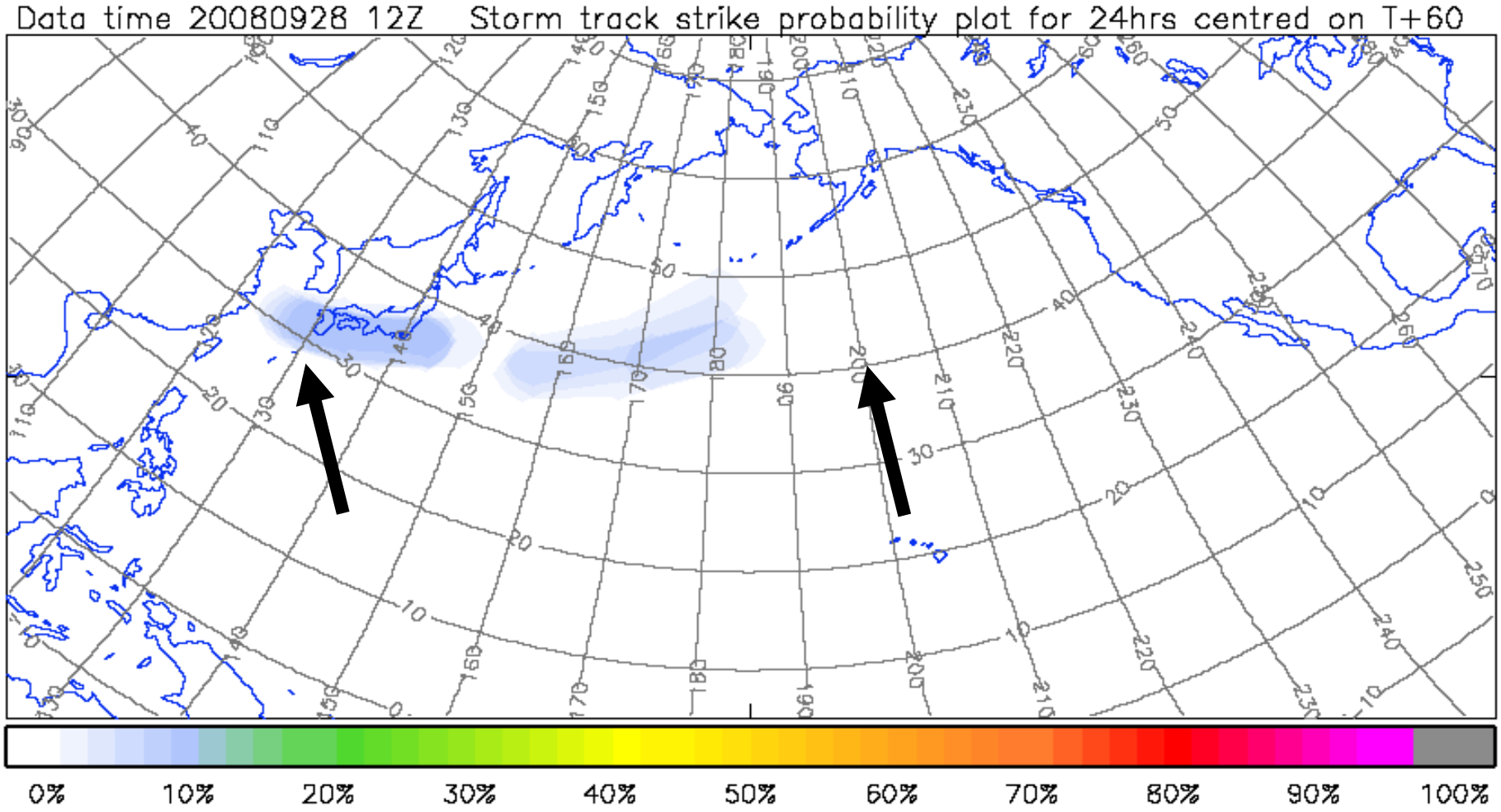
Strike Probs – Stronger Features (‘>34kts’)



Also animates

ECMWF

Strike Probs – Storms (‘>60kts’)

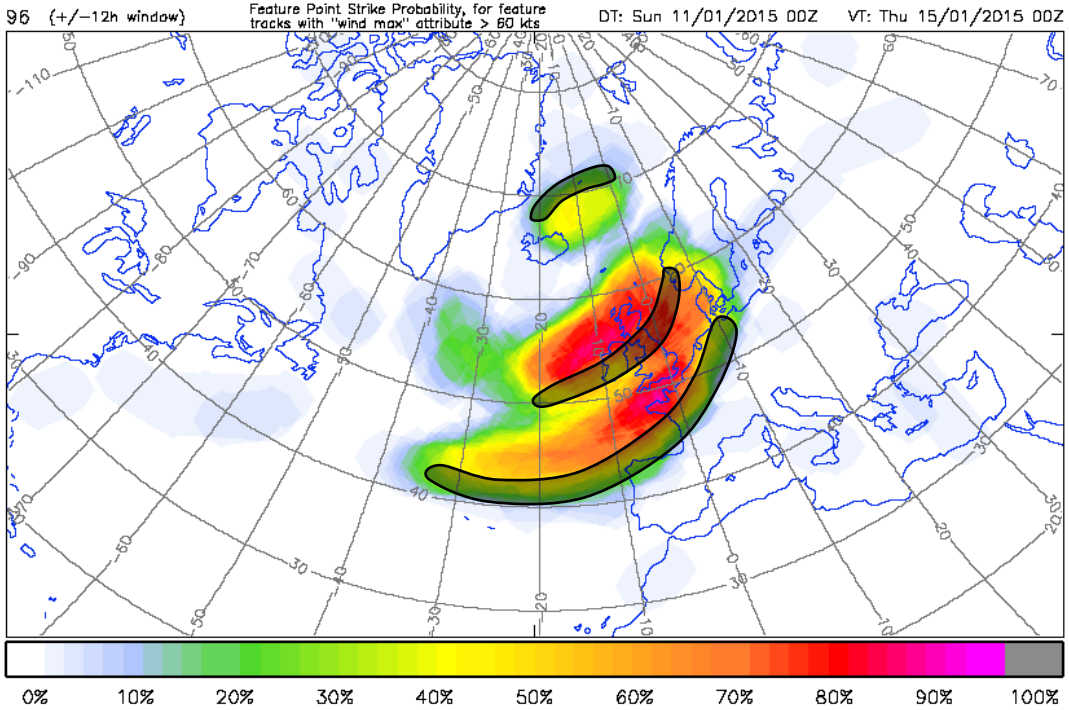


Also animates

ECMWF

Question:

- **Where would you expect the strongest surface winds to be, relative to the where the Strike Prob chart shows a maximum?**

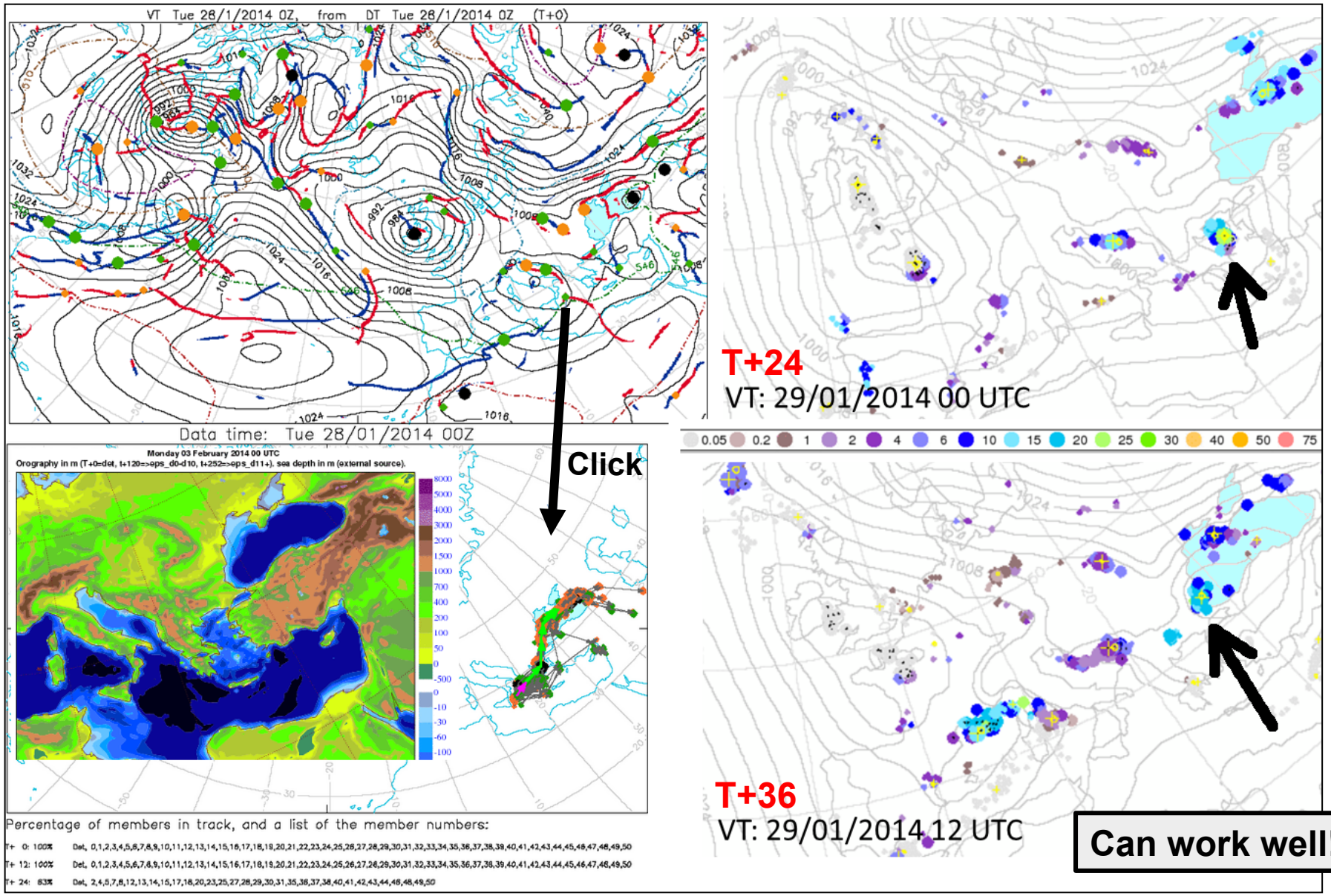


- **Answer: To the right of the Cyclone Track (other tracking products can be used to infer track direction)**

6. Miscellaneous

- Mountainous areas…
- Verification…
- Research mode (re-analyses)…
- Resolution upgrade

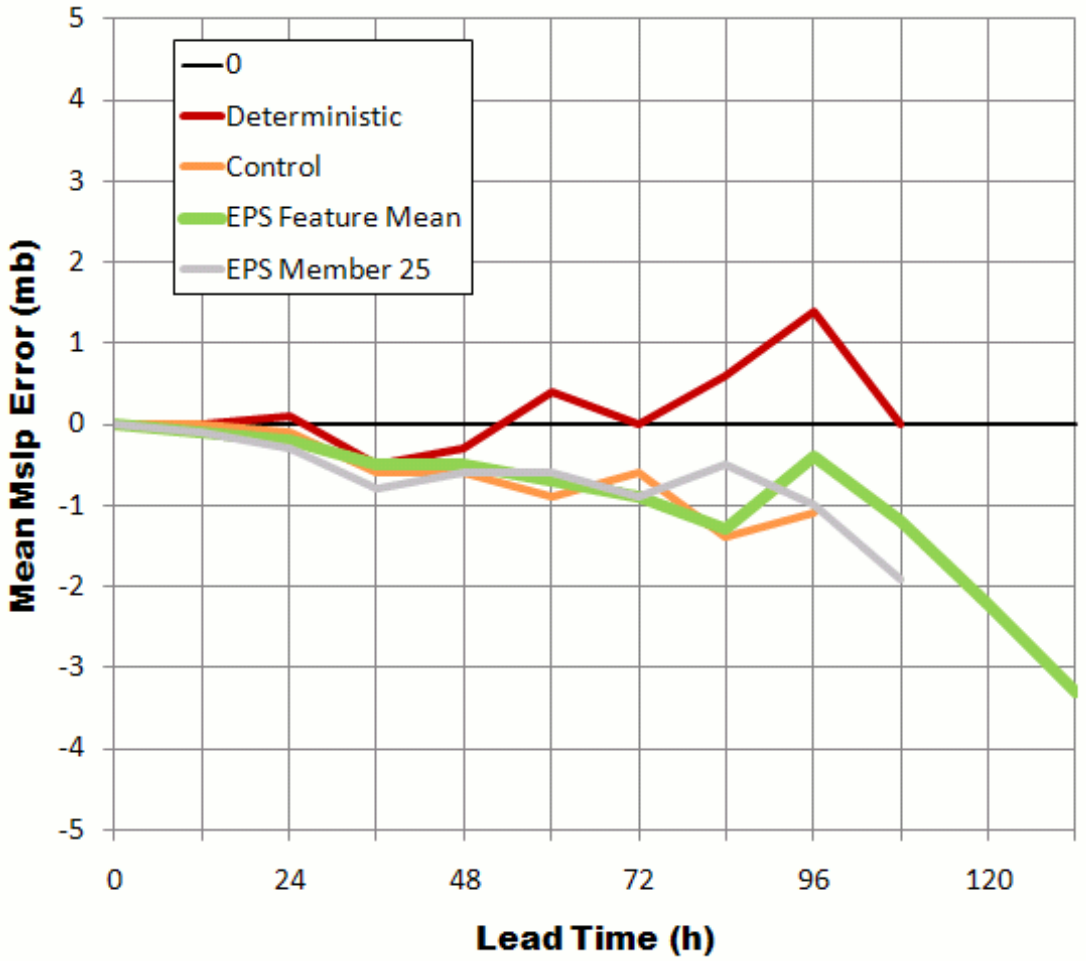
Front and cyclone tracking in mountainous areas…



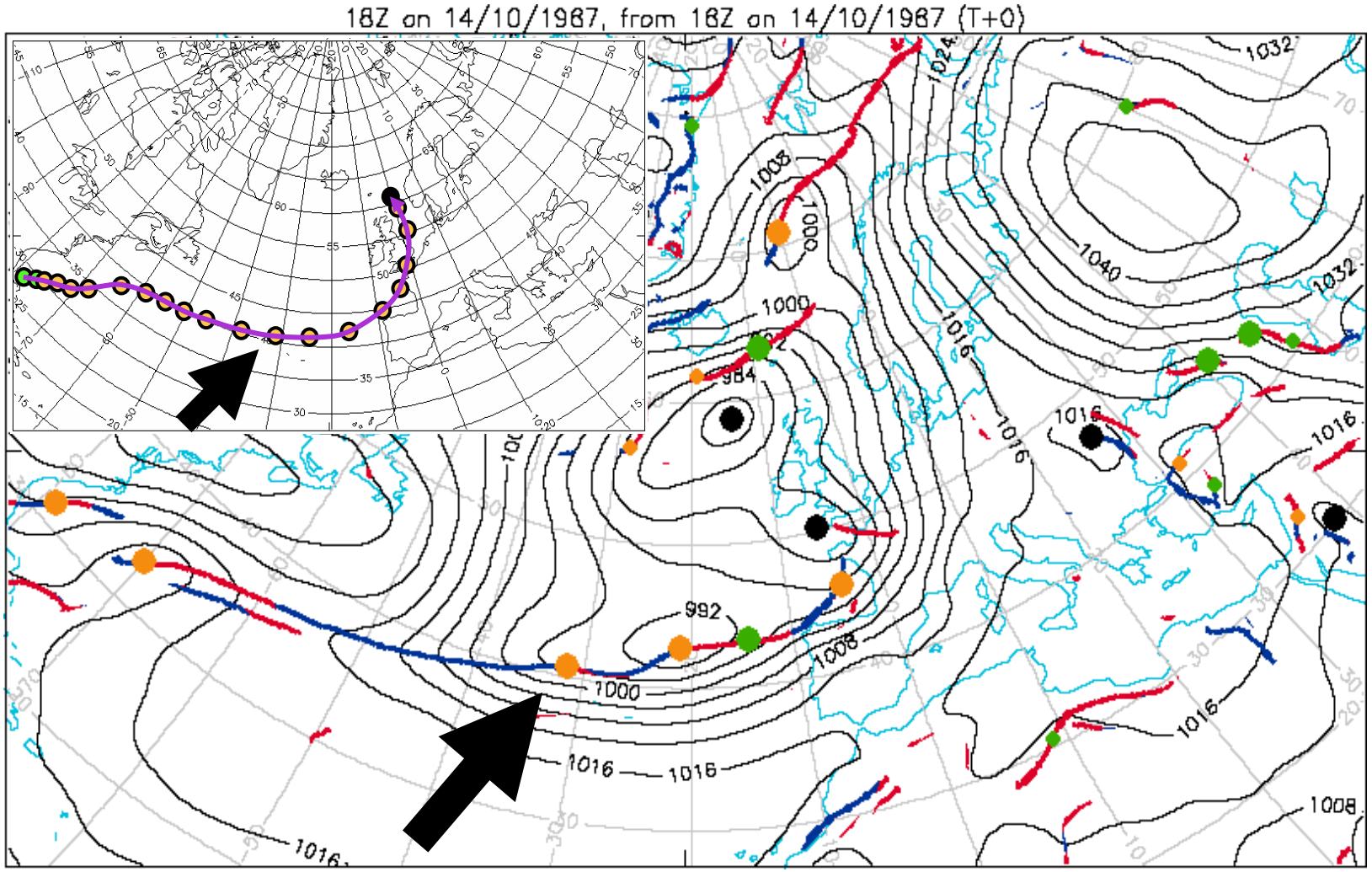
ECMWF

VERIFICATION - Biases in cyclone handling?

…very small



Cyclone tracking algorithms work on re-analyses too (research mode) – e.g. UK October storm 1987:



ECMWF

2016 Resolution Upgrade

- In March 2016 ECMWF increased the gridpoint resolution of both HRES and ENS, to about 9 and 18km respectively
- AND: ENS now continues on at 18km resolution from day 10 to day 15 (resolution used to reduce at day 10)
- For the front and cyclone products we continue to work on a (degraded) grid of about 50km resolution (using interpolation)
- For identifying fronts and cyclones this is consistent with synoptic practice, although “attributes” (e.g. Dalmatian charts for “Ppn maximum”) may slightly under-represent the extremes seen in raw model output
  - In due course we hope to address this..

Tropical Cyclones (just some brief notes)

- ECMWF has tropical cyclone tracking products at various time ranges
  - Short -> medium range (click for specific TC)
  - Medium range (genesis products) deals with TC's that develop during the forecast (48h strike prob windows)
  - Monthly forecast (TC probability)
- Handling of TCs by ECMWF is very good
  - Track accuracy is world leading, though performance can vary
  - Intensity accuracy is much more problematic (as with other centres)
  - Occasionally the analysis is noisy (under investigation in research department), though this seems to not affect forecast skill
  - Sometimes we get good guidance of an elevated risk of TC activity as much as 3 or 4 weeks in advance (partly an MJO link?)

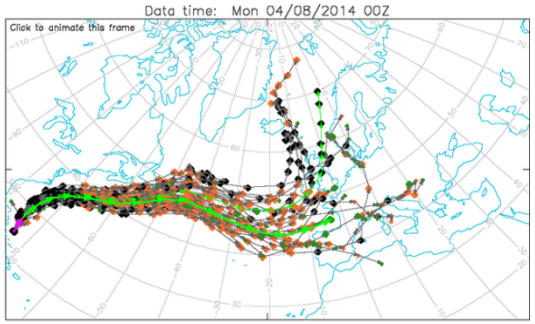
7. Summary

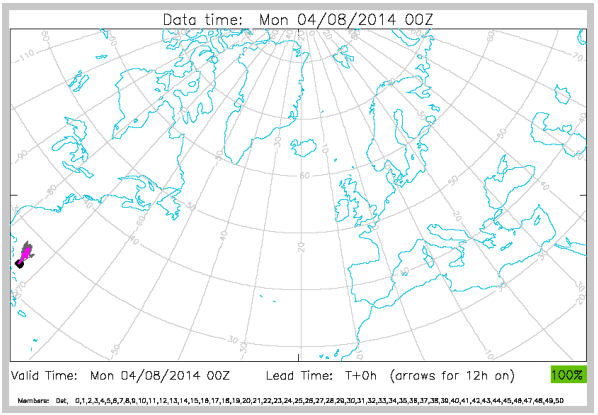
Summary

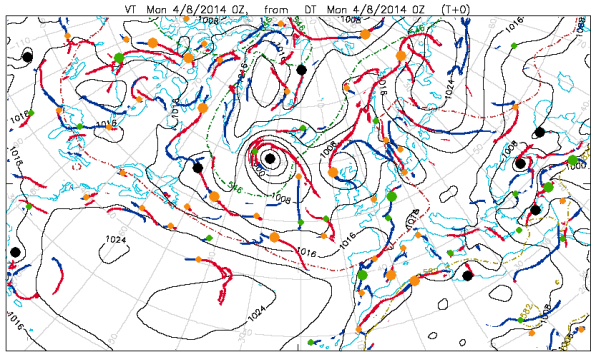
- Objective techniques for identifying mid-latitude synoptic scale features, originally constructed and tuned at the Met Office, have been applied to the ECMWF IFS system, and further developed. A very wide range of useful products has resulted, related to severe and everyday weather.
- Products are available on the web in real-time.
- Further feedback from users, and suggestions, are encouraged. Some user proposals have already been incorporated, others are planned… (e.g. clickable Dalmatian charts)
- We now also have a mechanism for importing front and cyclone objects into ecCharts, but implementing this will take some time..
- *Further reading: "Tracking fronts and extra-tropical cyclones" – ECMWF Newsletter, Autumn 2009, and the references at the end.* **Free to download from the ECMWF website!**

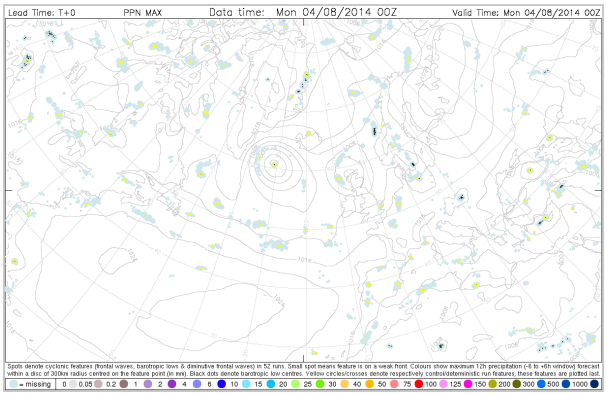

All questions
welcome !

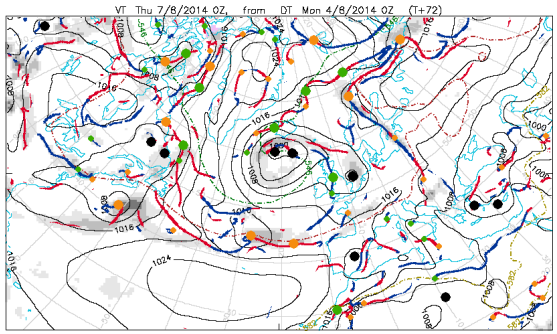
Front and Cyclone-related Products

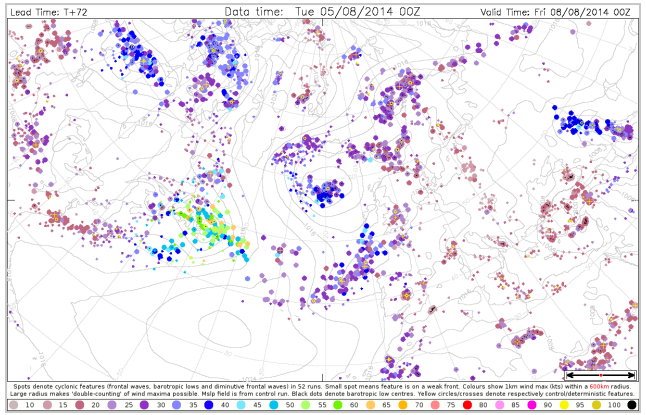


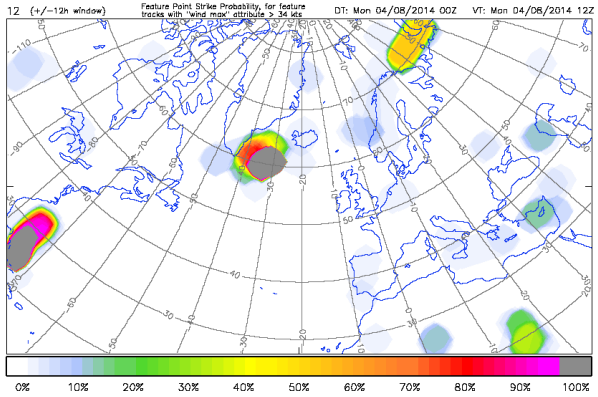


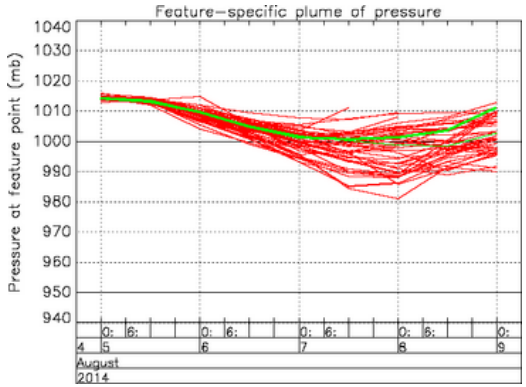


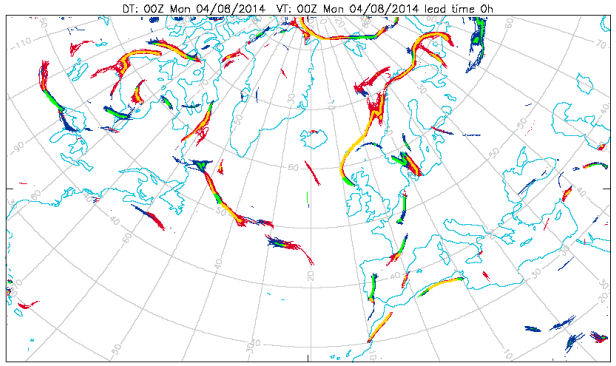












ECMWF

ECMWF

http://apps.ecmwf.int/r/cdb/

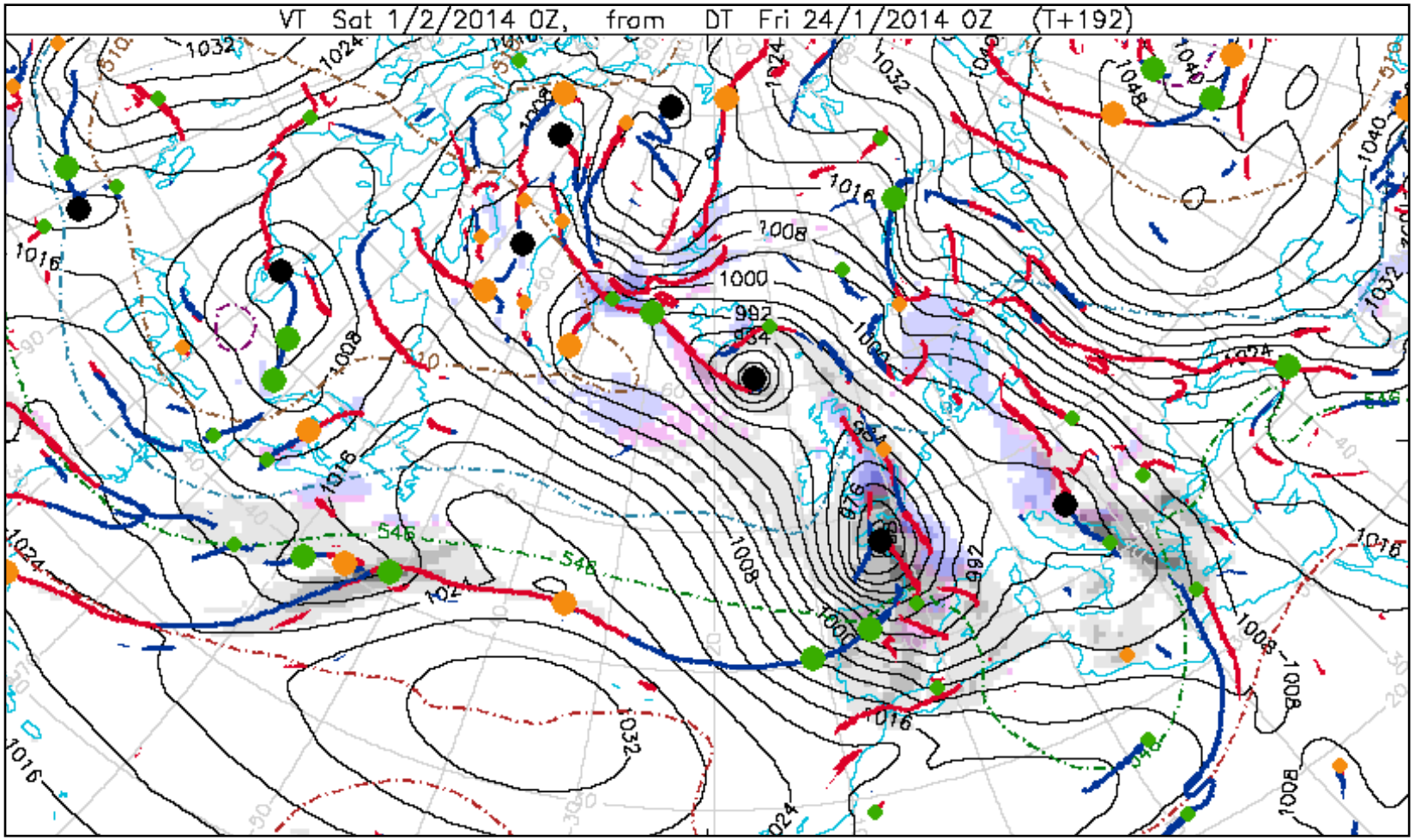
tim.hewson@ecmwf.int

Extra-Tropical Cyclones - Product Options from drop down menu

most appropriate lead times to use

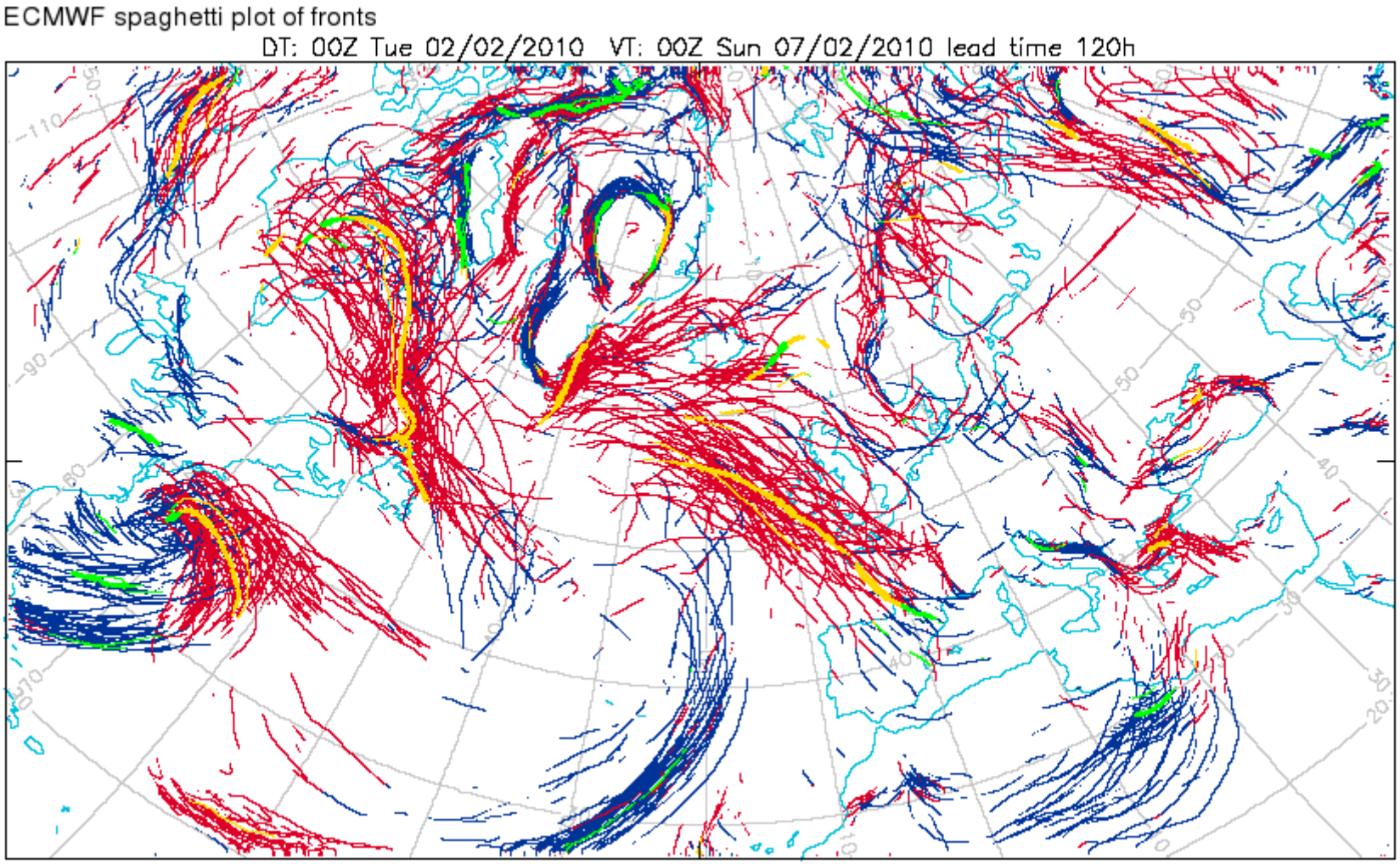
- Clickable Control T+0 image ← Gives feature plumes / tracks (0-5 days)
- Fronts Animation ← Fronts (2-8 days)
- Features Animation
- Feature Anim (mslp)
- Feature Anim (300km 1km wind max)
- Feature Anim (600km 1km wind max)
- Feature Anim (Disc Ppn mean)
- Feature Anim (Disc Ppn max)
- Feature Anim (Disc Snow mean)
- Feature Anim (Disc Snow max)
- Feature Anim (thickness)
- Features - ALL PARAMETERS ← Dalmatian charts (1-10 days); **ALL** dalmatian charts in one place
- Postage stamps Animation
- Postage stamps (ALL)
- Postage stamps (by time) ← Postage stamps, various formats (All times)
- Strike prob (1km wind >60kt)
- Strike prob (1km wind >34kt)
- Strike prob (all features)
- Strike prob Postage stamps ← Storm track strike probs (5-15 days); **ALL** strike prob charts in one place
- Animation of Deterministic
- Animation of control
- Animation of member 1
- :
- T+0 'animation'
- T+12 'animation'
- : ← Synoptic animations, single runs (0-6 days); Fixed time animations, for all runs (All times)

Snapshot of Synoptic Feature Chart



12h precipitation shown by shading – greys for mainly rain, pinks for rain-snow mix, blues for mainly snow
Ranges, in mm water equivalent: 2-8mm, 8-20mm, 20-50mm, >50mm

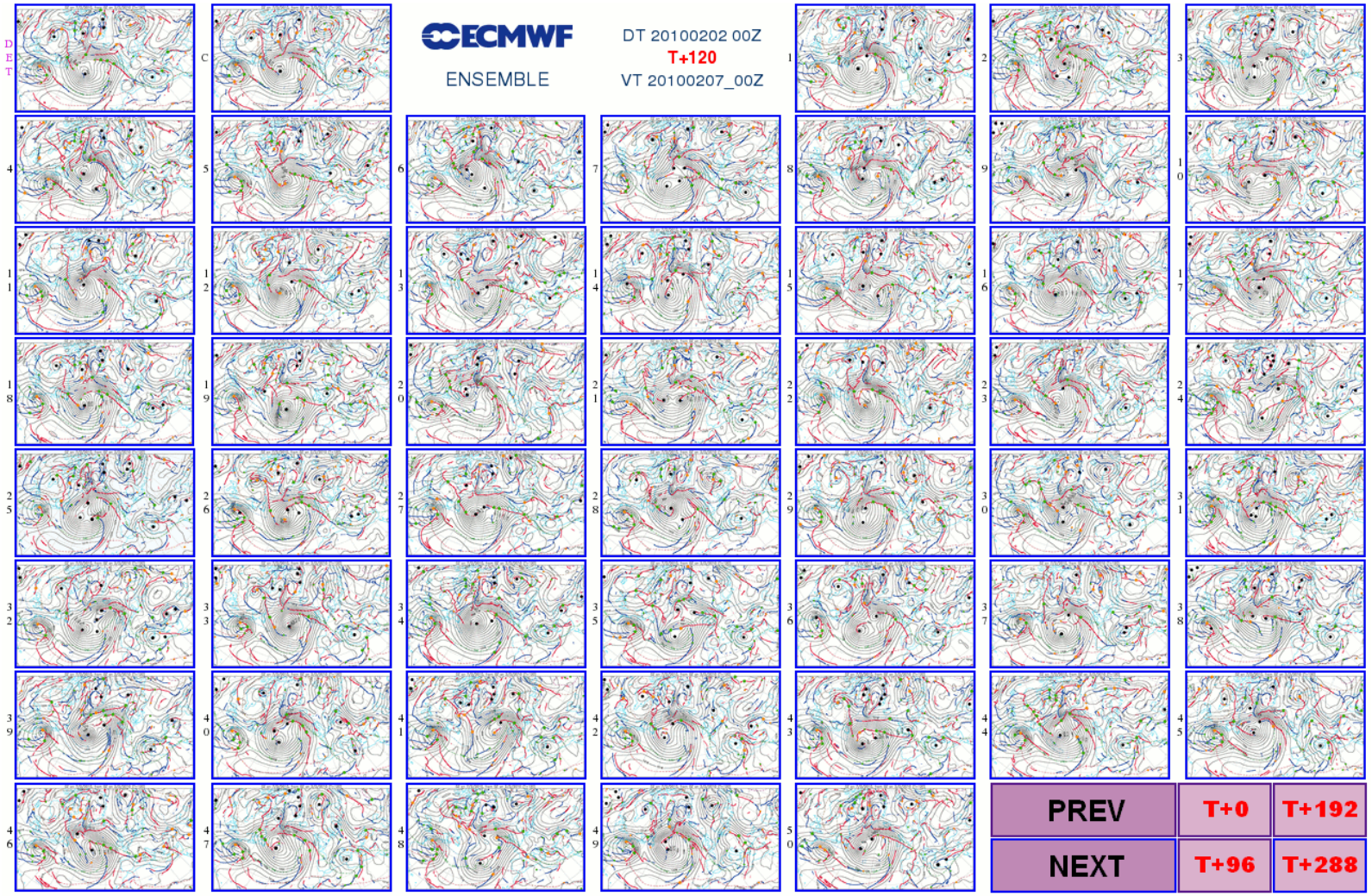
Fronts Spaghetti Plot



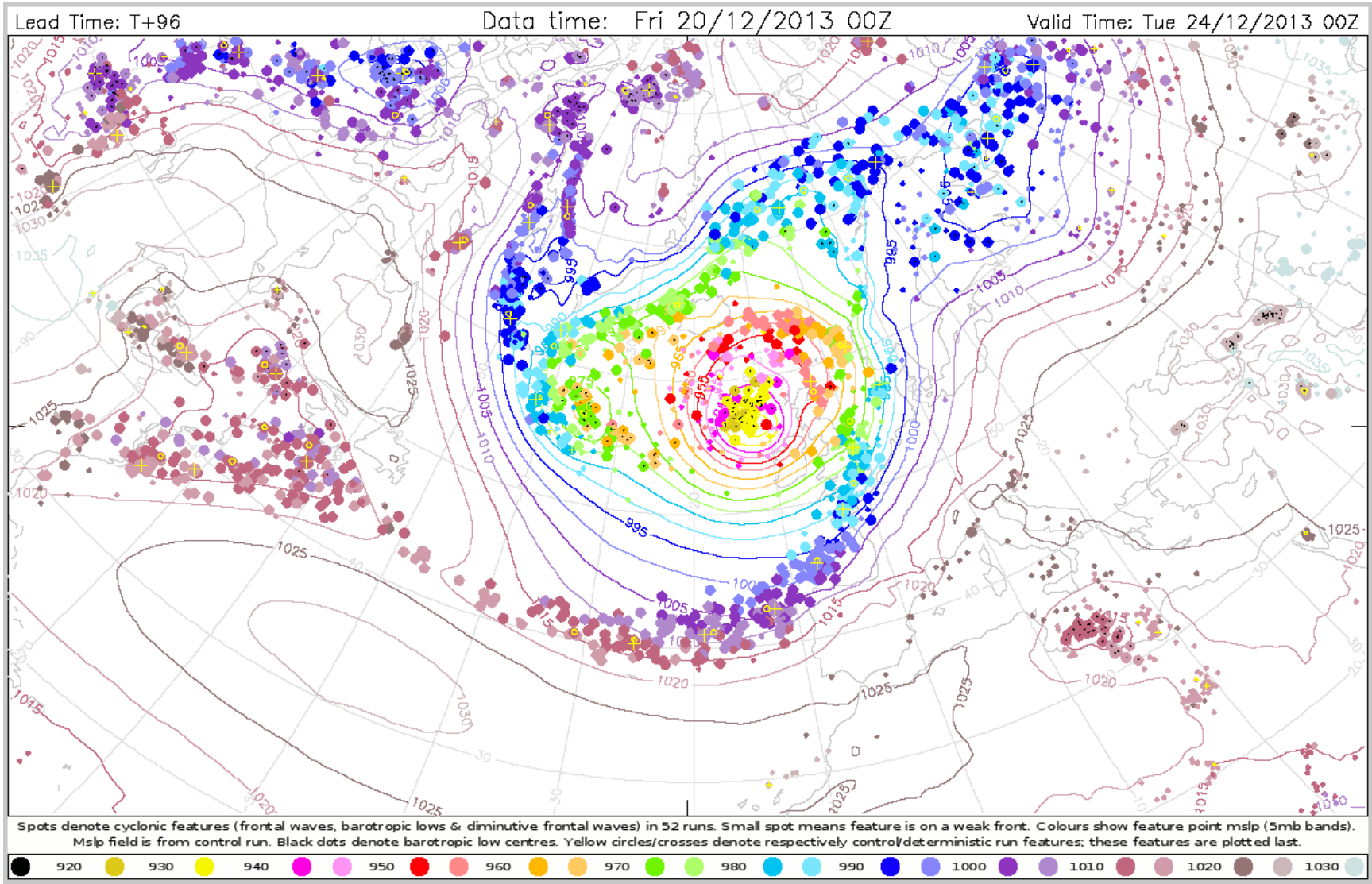
Front Spaghetti Charts - Recommended Usage

- For assessing airmass movement, and changes of type
- Most useful T+36 to T+192, but also on occasion at other times
- Note also regions where fronts are absent
  - recognising that this could be due to either slow moving cyclones, or anticyclones

Postage stamps (various options)



Dalmatian Chart (mslp attribute shown)



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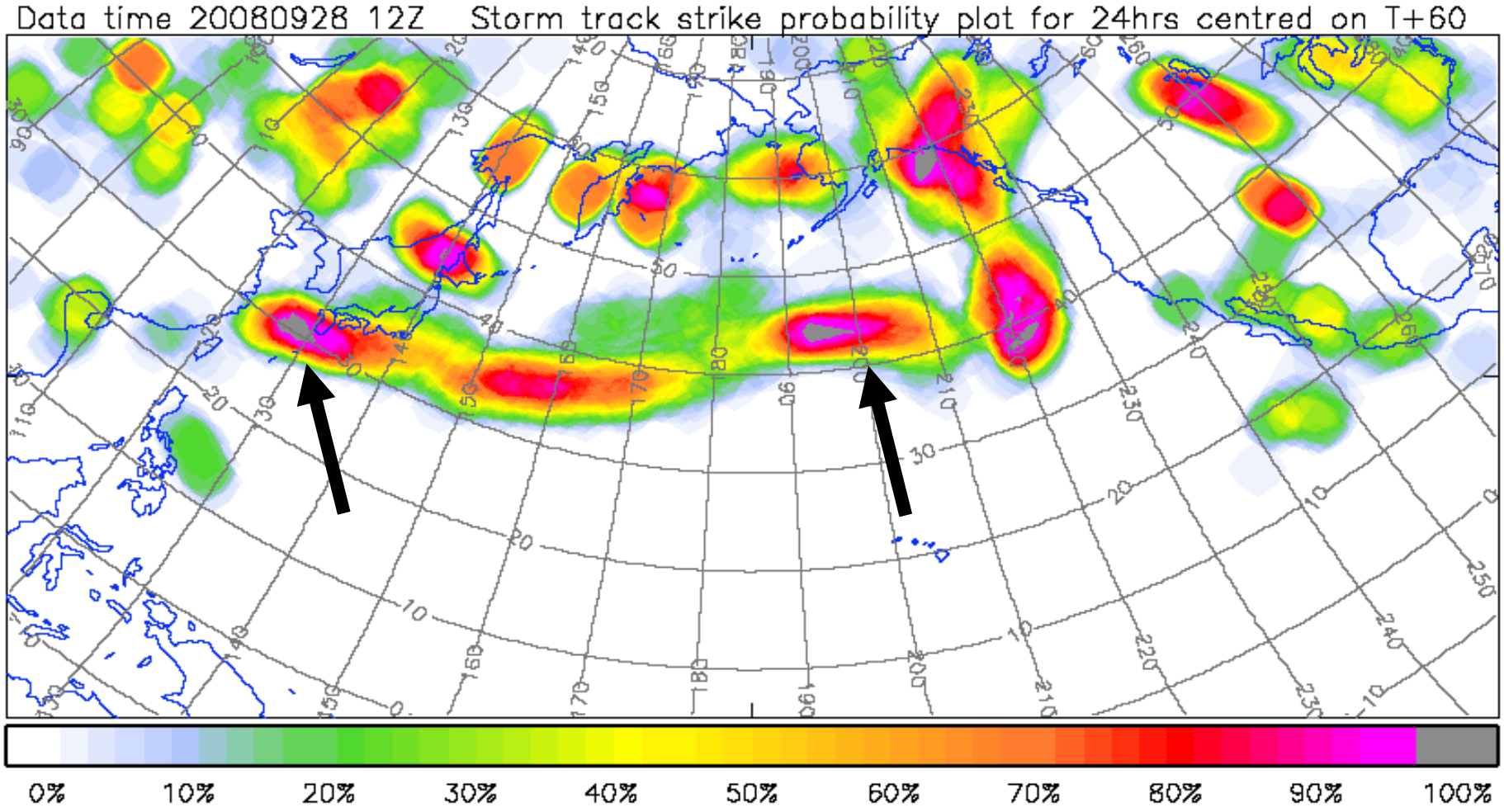
Dalmatian Charts - Recommended Usage

- **Most useful between T+24 and T+240**
  - **Can sometimes be helpful at other times, e.g.:**
    - **At longer ranges when a persistent block is present**
    - **At shorter ranges when there is large dynamical uncertainty surrounding developments (=unusually large spread)**

- **Remember to contrast the features positions (and attributes) in the control and deterministic runs (yellow cross and circle highlighting), with those found in the EPS, to see how representative these single runs are**

- **Do not neglect the 'feature type' charts, which contain valuable information regarding the synoptic pattern**

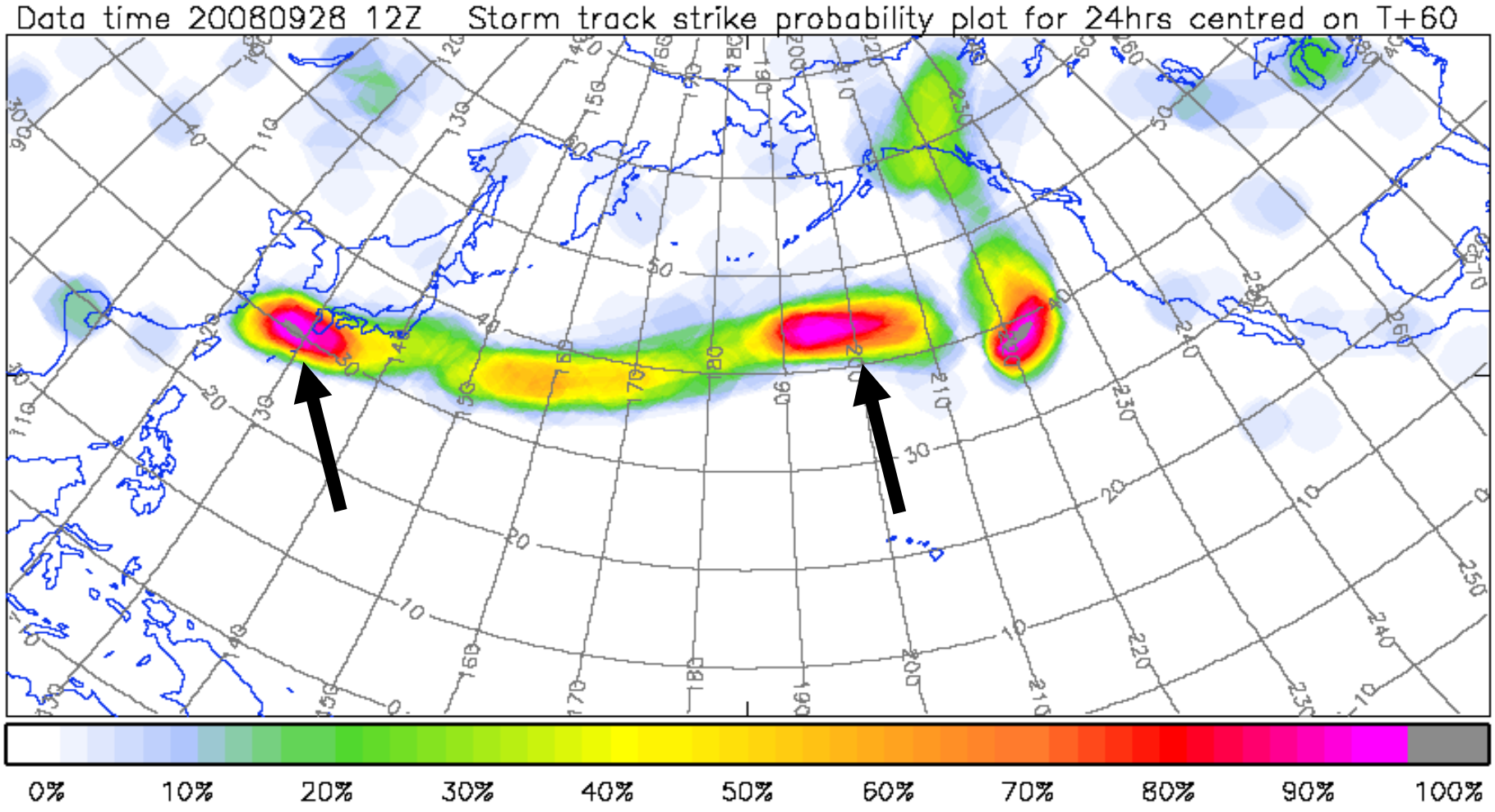
Strike Probs – All features



Also animates

ECMWF

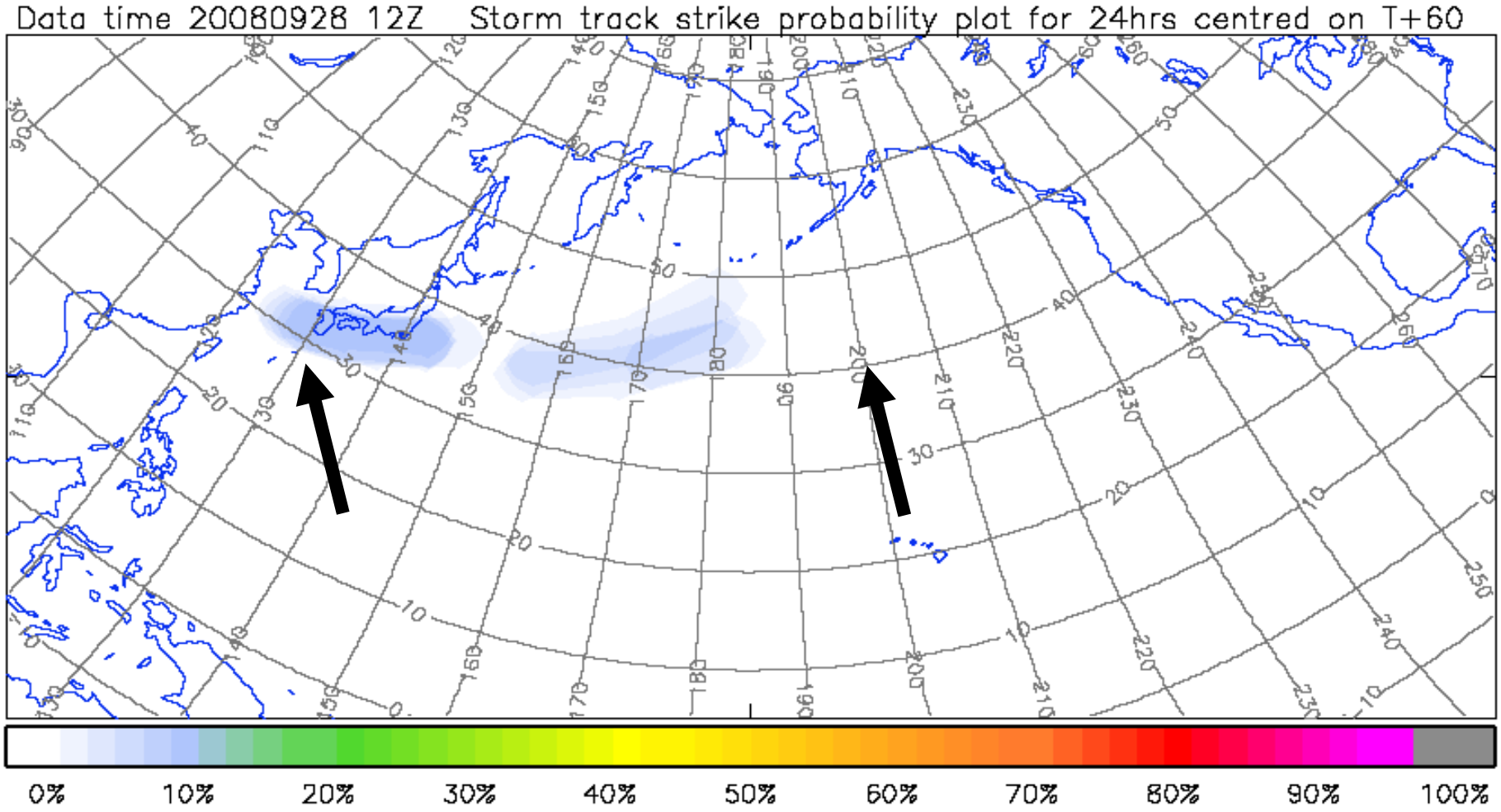
Strike Probs – Stronger Features (‘>34kts’)



Also animates

ECMWF

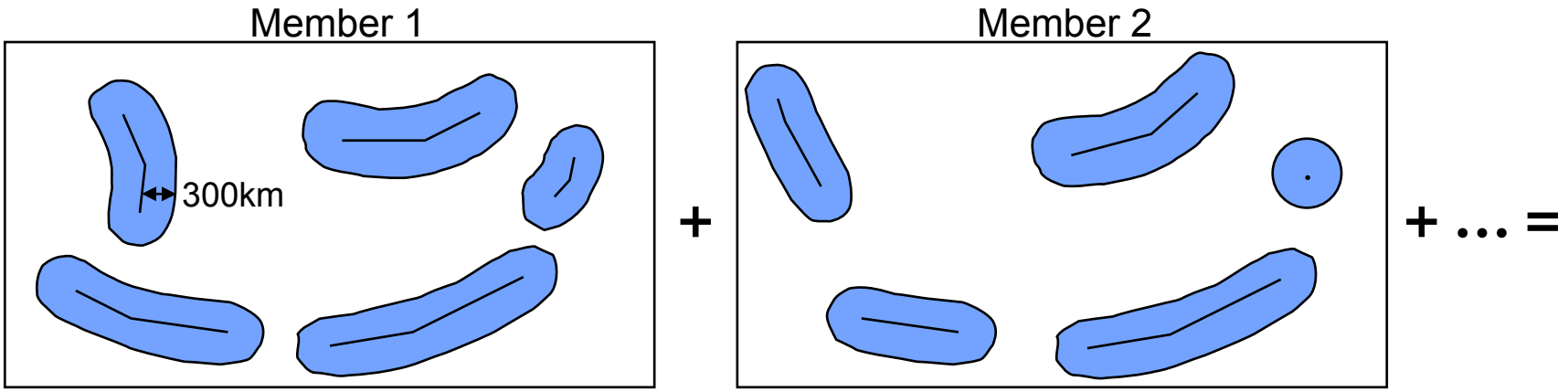
Strike Probs – Storms (‘>60kts’)



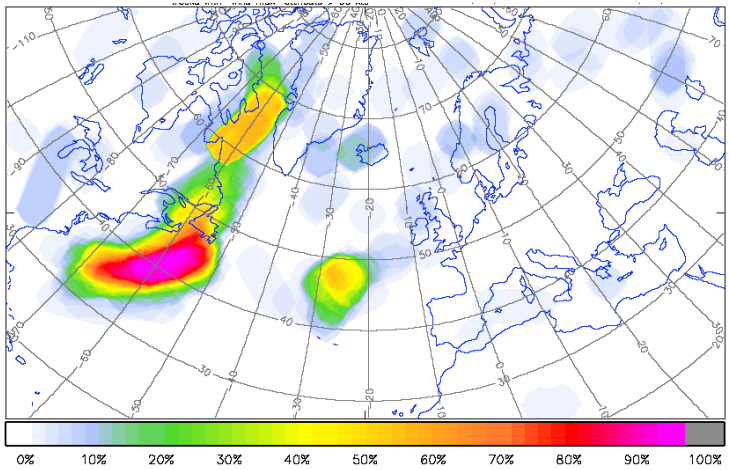
Also animates

ECMWF

Construction of Strike Probability Charts



tracks in +/-12h window

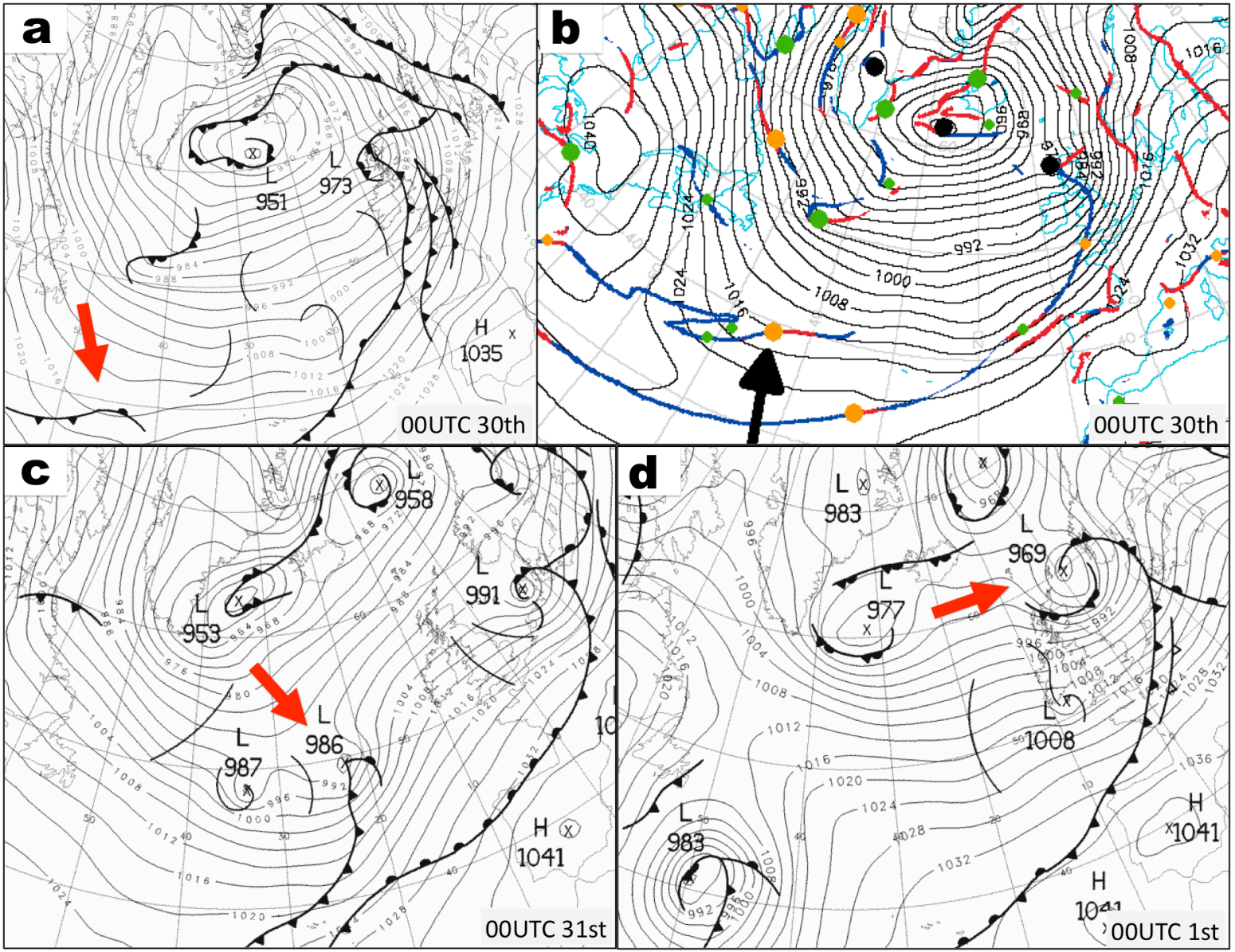


- **Strike Prob charts are based on tracking feature points, not wind maxima**
- **'Spots' on strike prob charts tend to be due to slow-moving or short-lived features**
- **Thresholding ('>34kts', '>60kts') is based on wind maxima, at 1km, within a 300km radius of the feature point, being achieved *somewhere along the track segment for -12h to +12h.* Tracks of features that match the criteria are retained in computation of the strike prob chart, the rest are not….**

Strike Prob Charts - Recommended Usage

- **Strike probability charts should be used:**
  - **1. At longer leads (signalling cyclonically active or inactive, etc.)**
  - **2. Also at short leads, together with plume diagrams, whenever there is some uncertainty regarding:**
    - **A) whether a cyclonic feature is splitting into two, or**
    - **B) which of two closely spaced pre-existing features will develop**
- **Note that there is evidence of a small degree of skill, for the more extreme storm class, beyond 10 days**

Example - Windstorm crossing N of UK



ECMWF

Forecast - Strike Probability – severe storm class

- **Showing forecasts for fixed VT - 12Z 31st, when windstorm was approaching the N of the UK. Hints of skill in week 2.**

Verifying track segment has been added (black line)

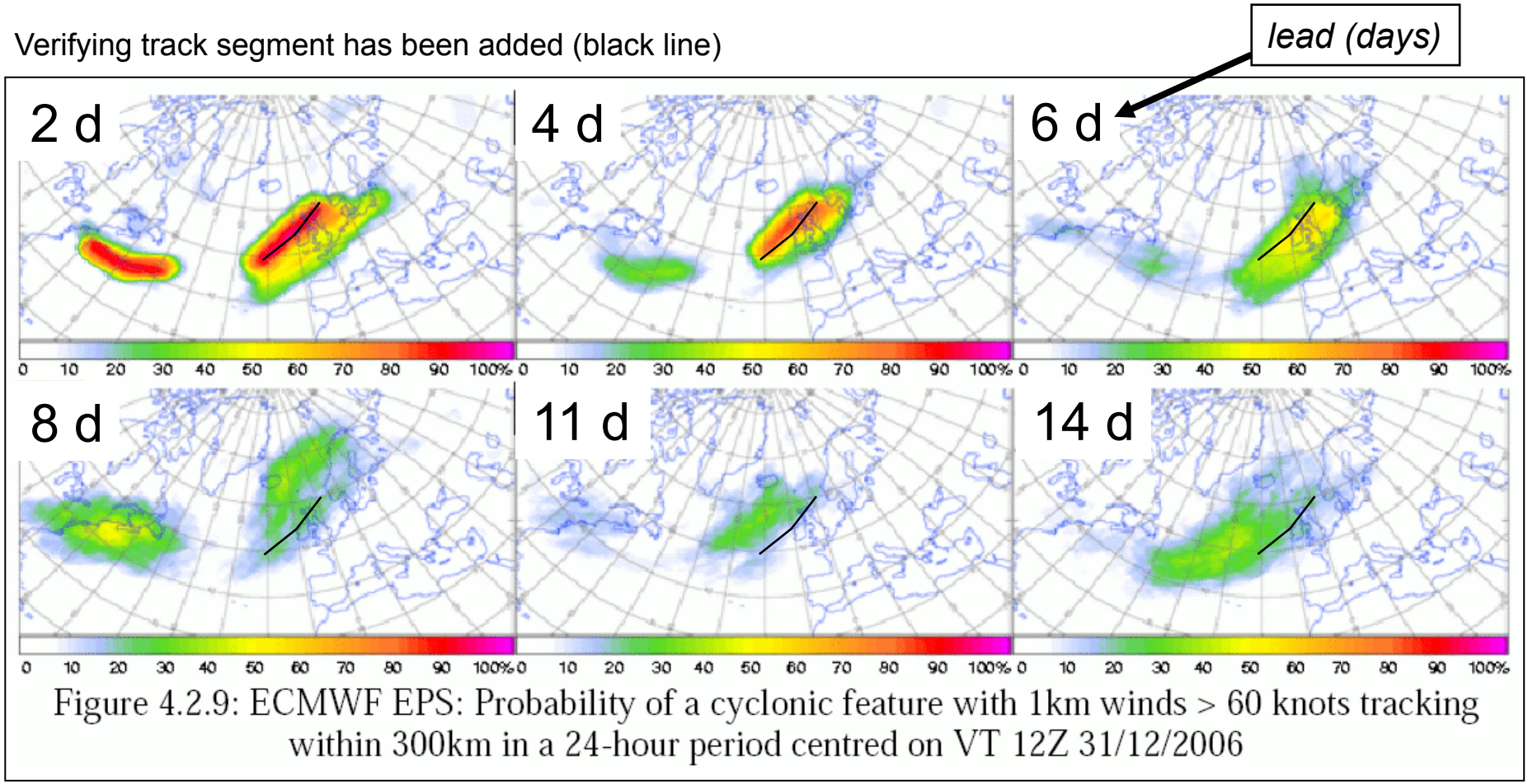
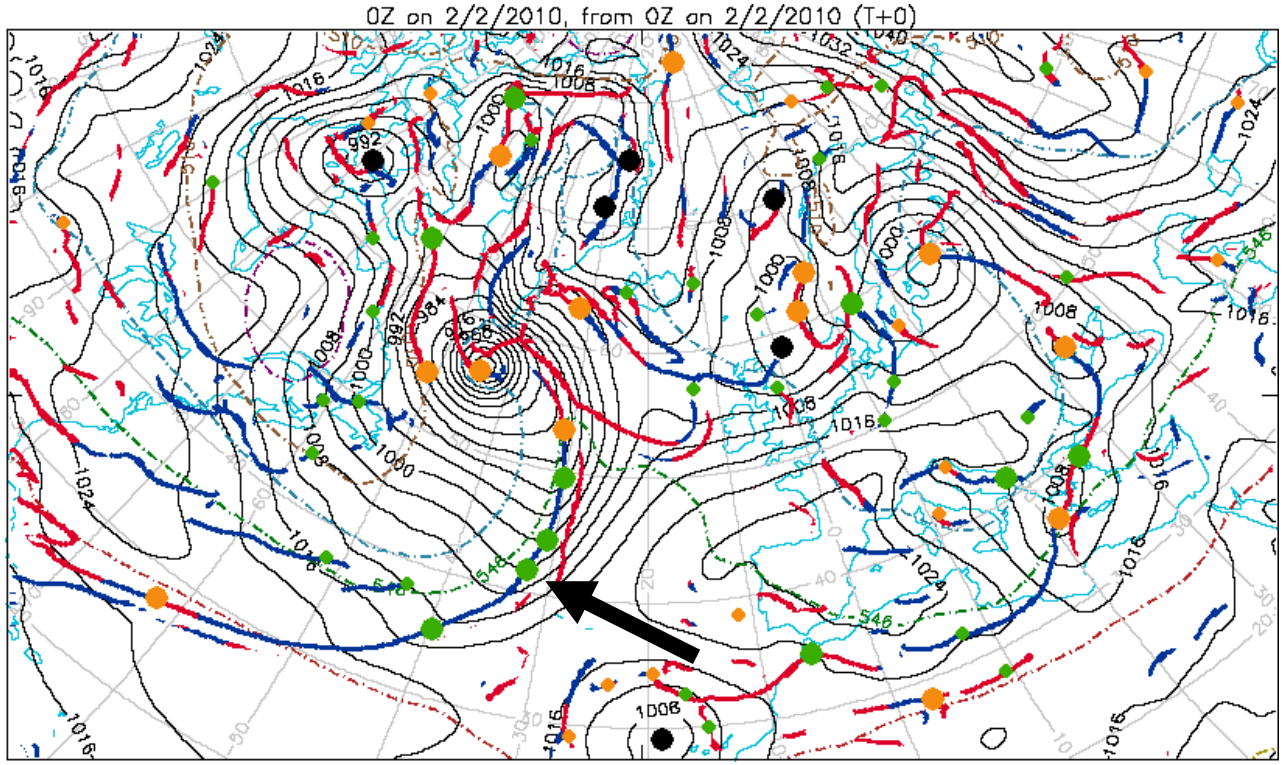
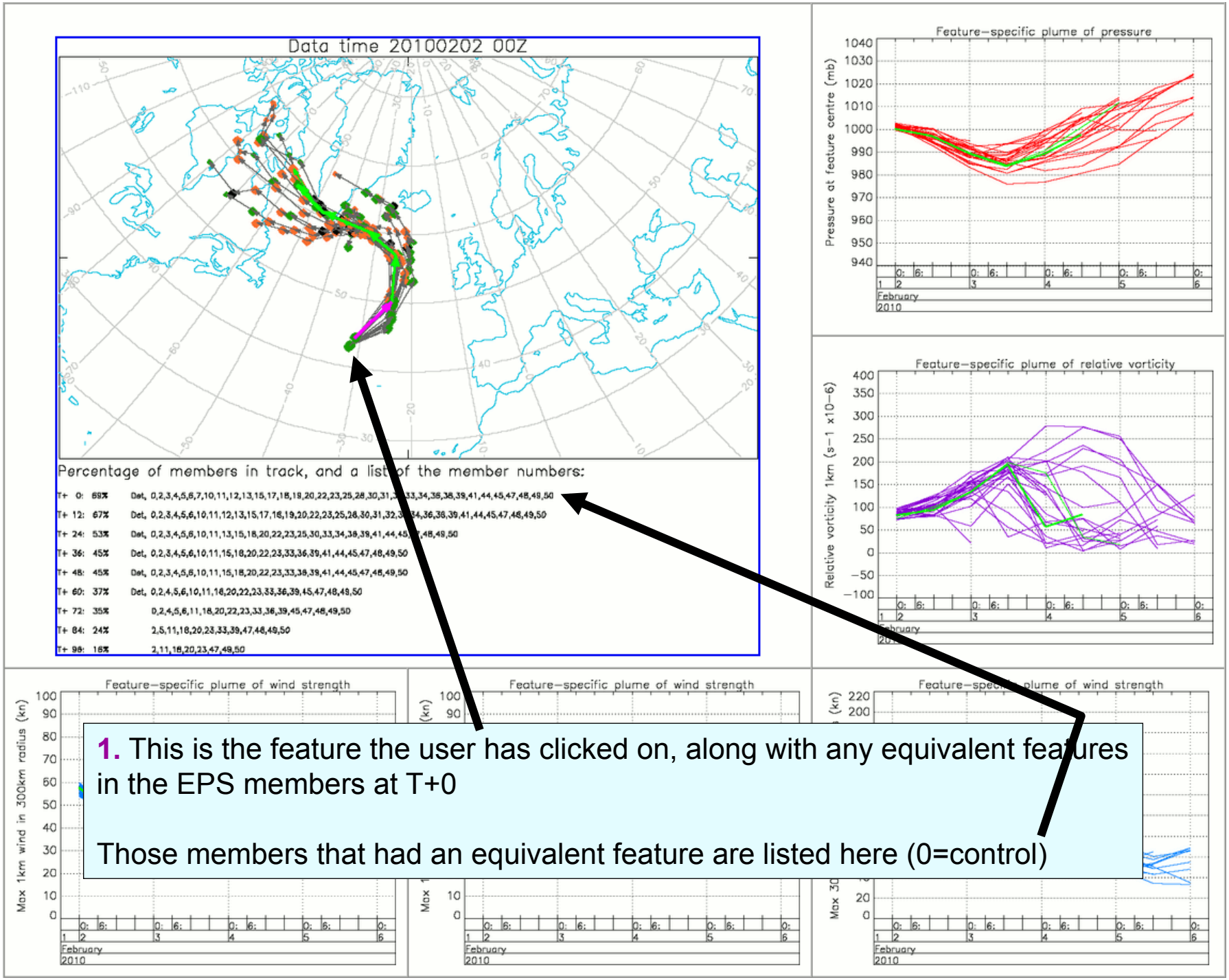


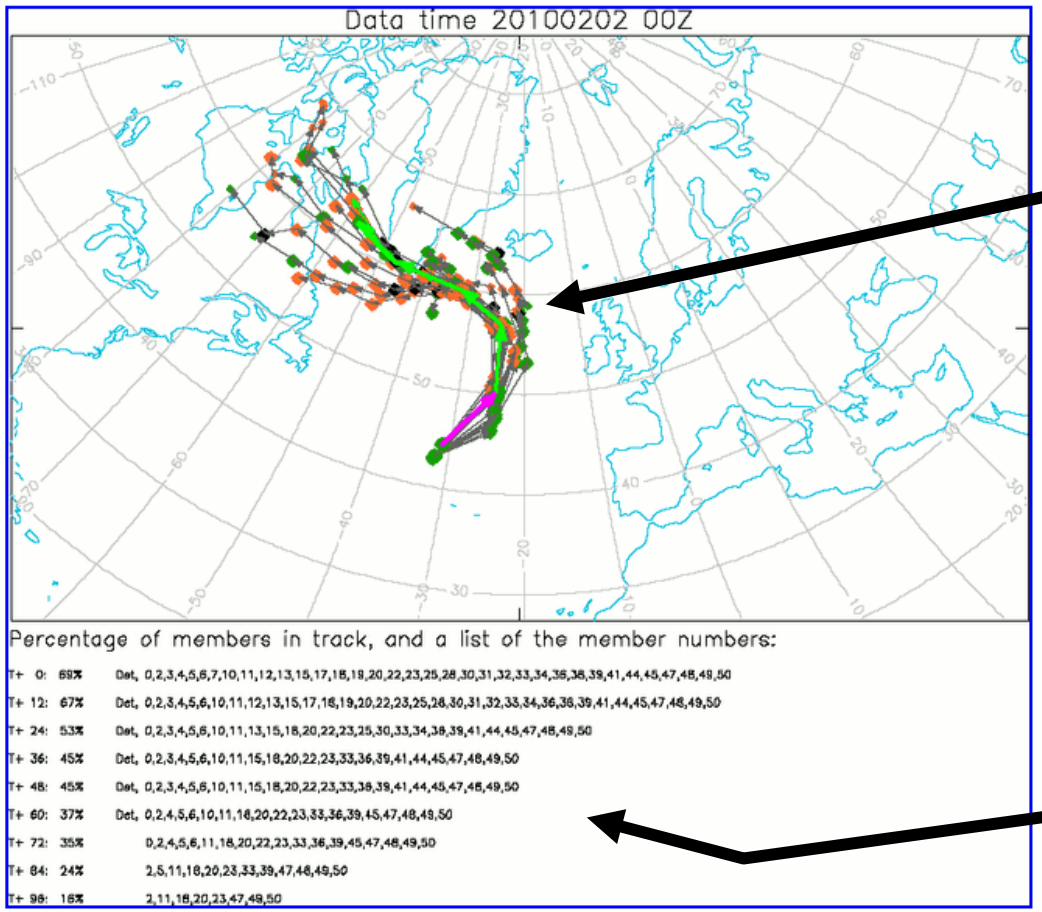
Figure 4.2.9: ECMWF EPS: Probability of a cyclonic feature with 1km winds > 60 knots tracking within 300km in a 24-hour period centred on VT 12Z 31/12/2006

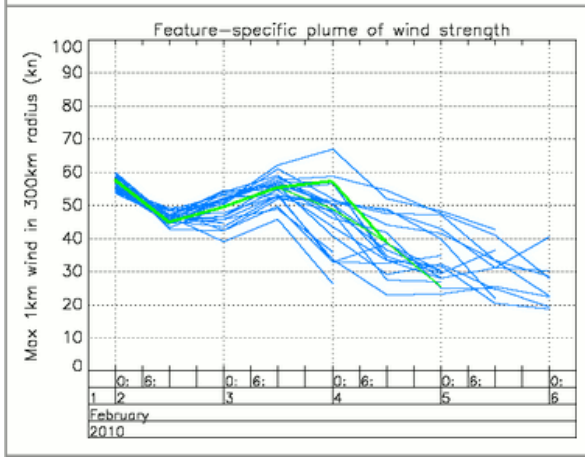
Feature Plume Diagrams

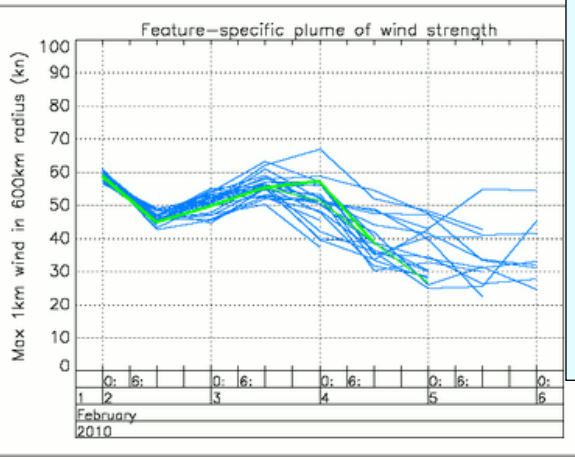
- These are activated by clicking on a feature on the control T+0 ‘synoptic chart’ frame
- Plume then displays the behaviour of that feature as tracked in the ensemble (and control and deterministic runs)…

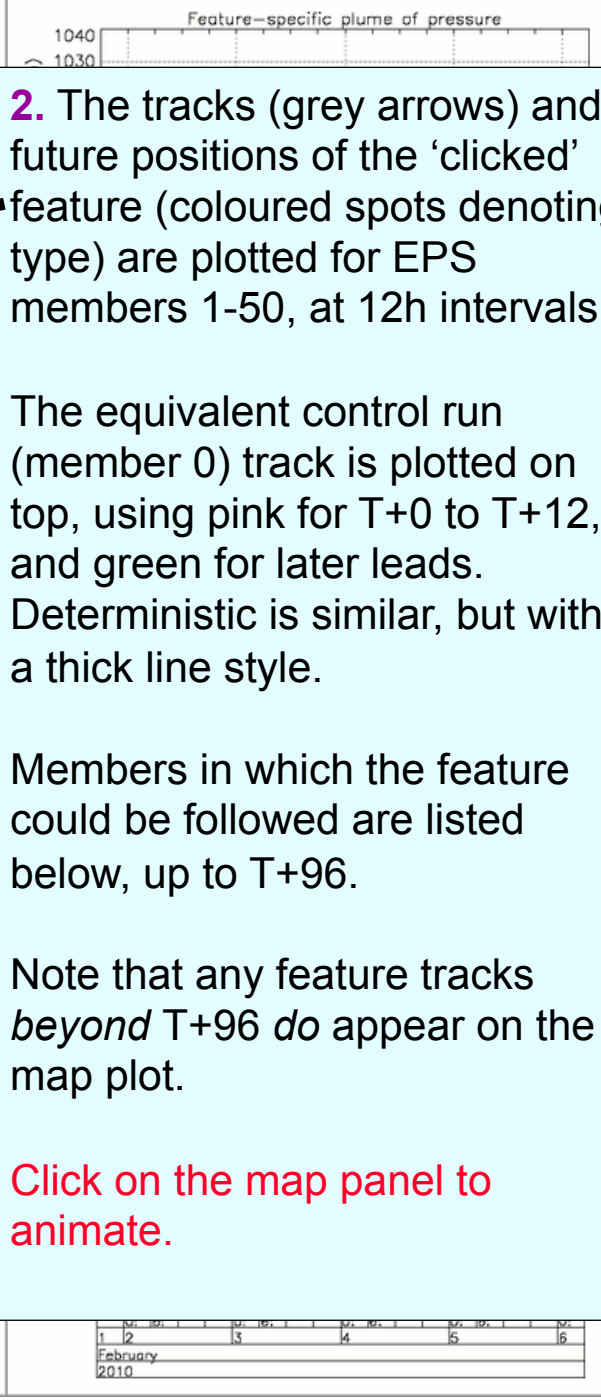



Data time 20100202 00Z
Percentage of members in track, and a list of the member numbers:
T+ 0: 69% Det, 0,2,3,4,5,6,7,10,11,12,13,15,17,18,19,20,22,23,25,28,30,31,
T+ 12: 67% Det, 0,2,3,4,5,6,10,11,12,13,15,17,18,19,20,22,23,25,28,30,31,32,
T+ 24: 53% Det, 0,2,3,4,5,6,10,11,13,15,18,20,22,23,25,30,33,34,38,39,41,44,45,
T+ 36: 45% Det, 0,2,3,4,5,6,10,11,15,18,20,22,23,33,36,39,41,44,45,47,48,49,50
T+ 48: 45% Det, 0,2,3,4,5,6,10,11,15,18,20,22,23,33,38,39,41,44,45,47,48,49,50
T+ 60: 37% Det, 0,2,4,5,6,10,11,16,20,22,23,33,36,39,45,47,48,49,50
T+ 72: 35% 0,2,4,5,6,11,18,20,22,23,33,36,39,45,47,48,49,50
T+ 84: 24% 2,5,11,18,20,23,33,39,47,48,49,50
T+ 96: 16% 2,11,18,20,23,47,49,50
Feature-specific plume of pressure
Pressure at feature centre (mb)
Feature-specific plume of relative vorticity
Relative vorticity 1km (s-1 x10-6)
Feature-specific plume of wind strength
Max 1km wind in 300km radius (kn)
February
2010
1. This is the feature the user has clicked on, along with any equivalent features in the EPS members at T+0
Those members that had an equivalent feature are listed here (0=control)









2. The tracks (grey arrows) and future positions of the 'clicked' feature (coloured spots denoting type) are plotted for EPS members 1-50, at 12h intervals.

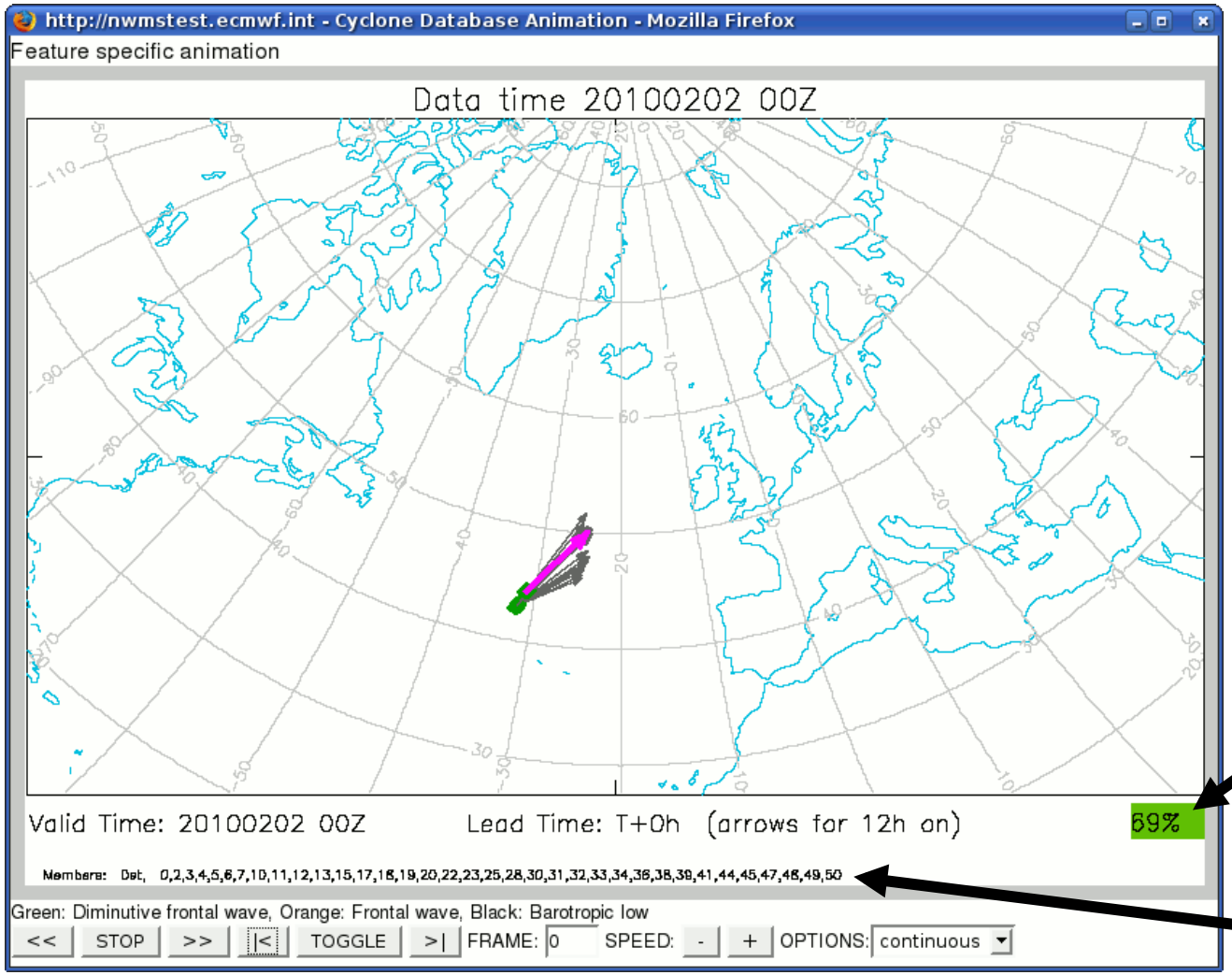
The equivalent control run (member 0) track is plotted on top, using pink for T+0 to T+12, and green for later leads. Deterministic is similar, but with a thick line style.

Members in which the feature could be followed are listed below, up to T+96.

Note that any feature tracks *beyond* T+96 *do* appear on the map plot.

Click on the map panel to animate.

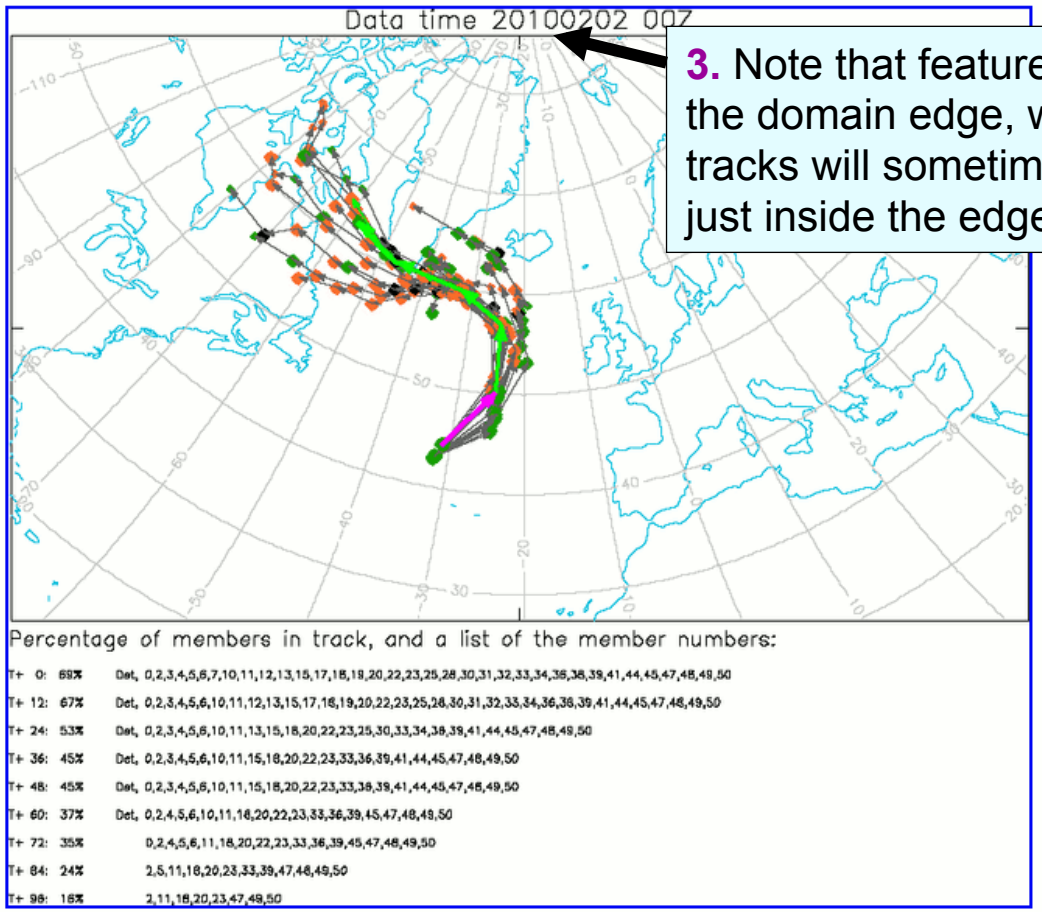
Frame from an animated feature track



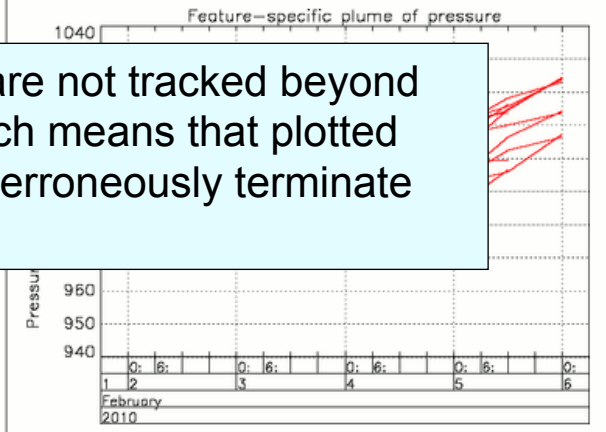
Percentage of members in which feature is tracked to this time (colour coded)

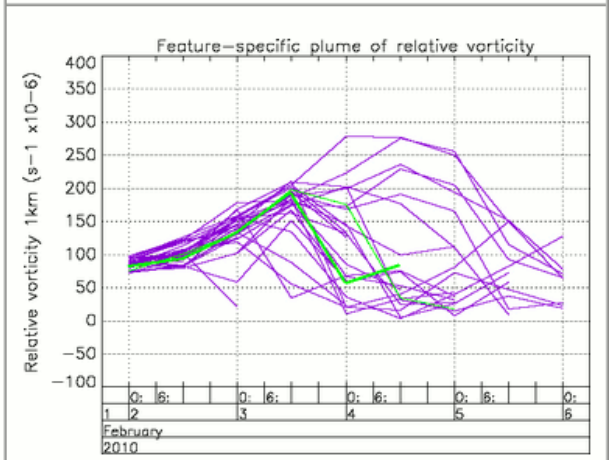
List of the members

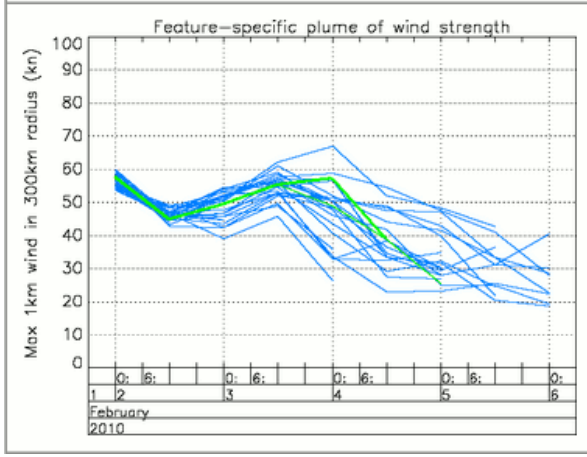
ECMWF

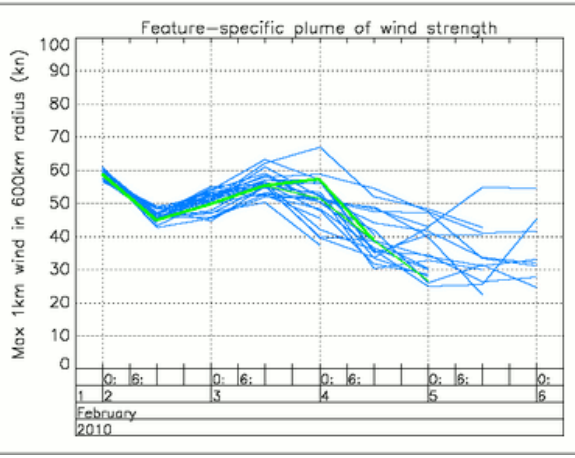


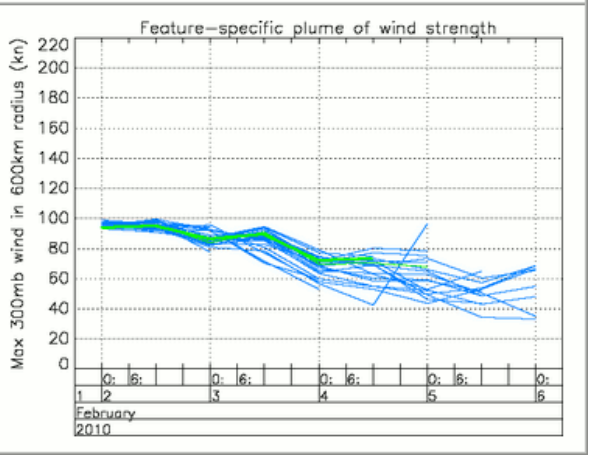
3. Note that features are not tracked beyond the domain edge, which means that plotted tracks will sometimes erroneously terminate just inside the edge

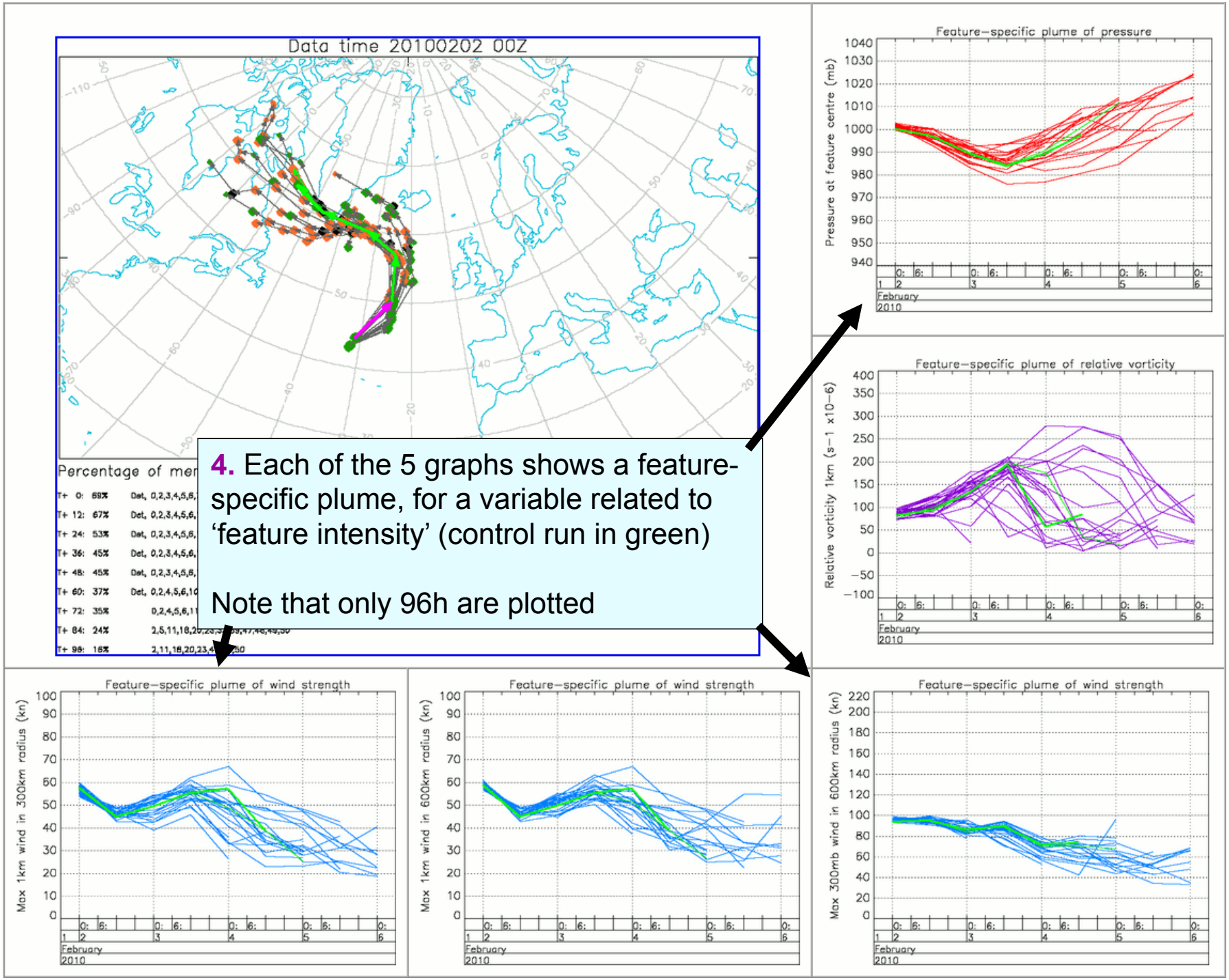


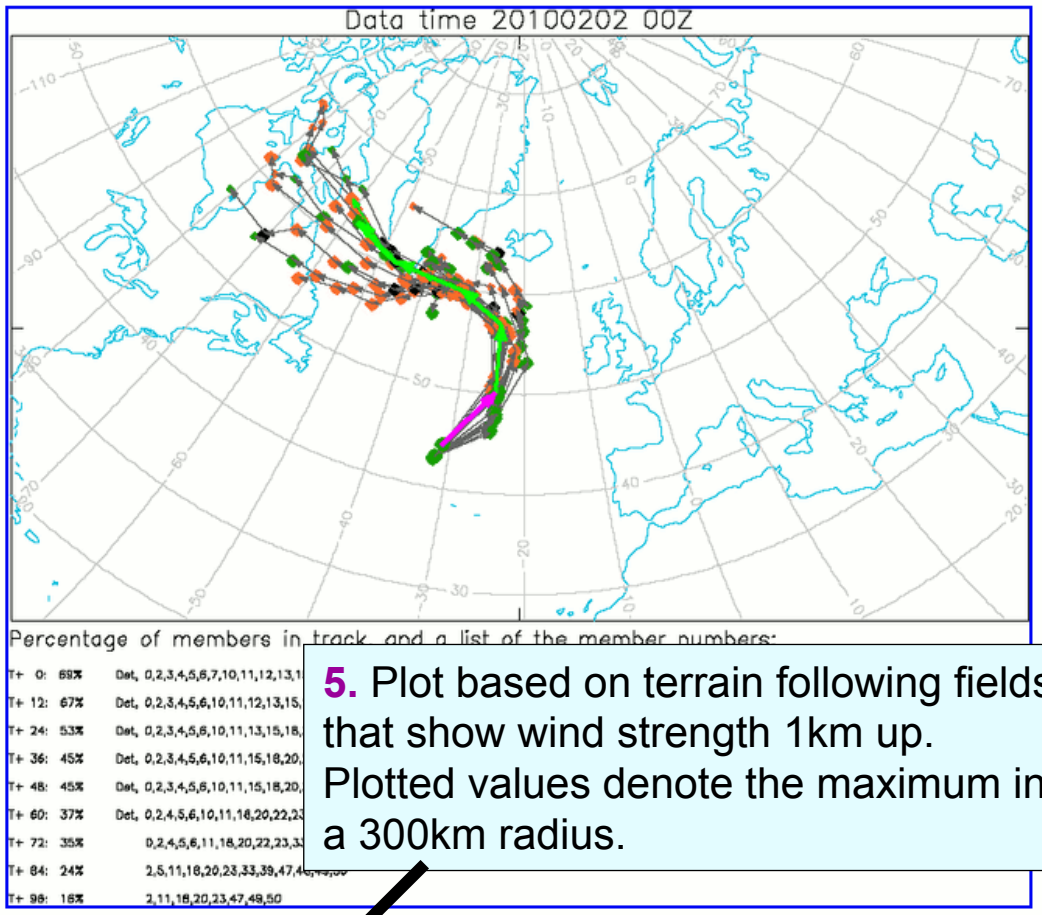




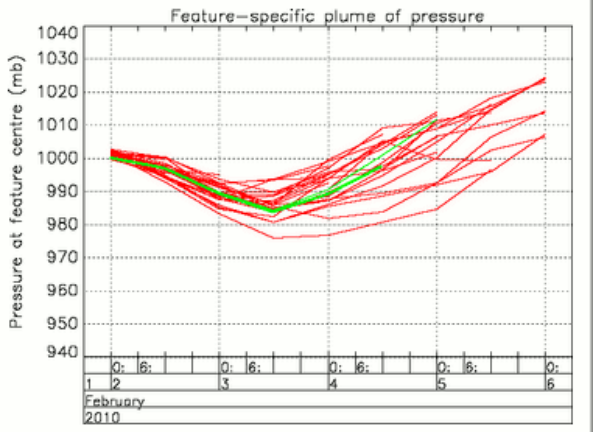


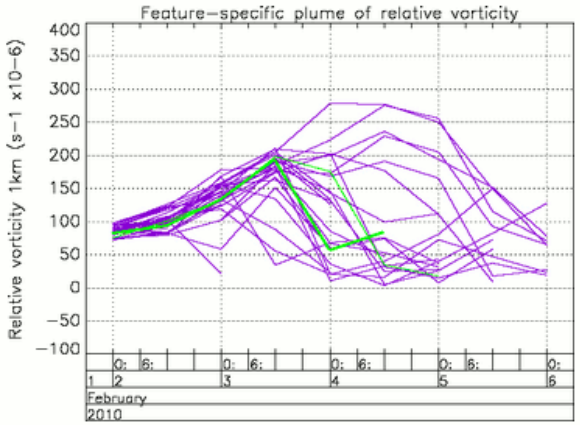


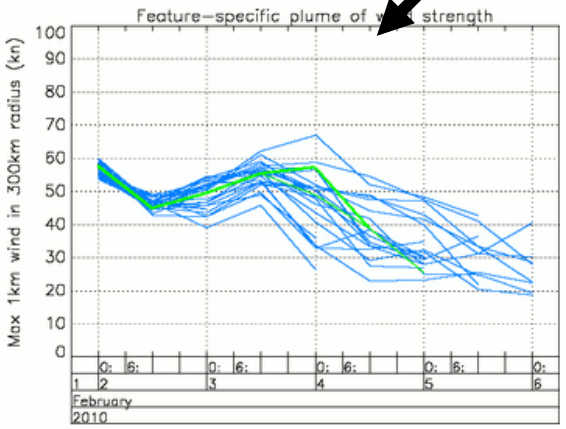

Data time 20100202 00Z
Percentage of mer
T+ 0: 69%
T+ 12: 67%
T+ 24: 53%
T+ 36: 45%
T+ 48: 45%
T+ 60: 37%
T+ 72: 35%
T+ 84: 24%
T+ 96: 16%
4. Each of the 5 graphs shows a feature-specific plume, for a variable related to 'feature intensity' (control run in green)
Note that only 96h are plotted
Feature-specific plume of pressure
Pressure at feature centre (mb)
Feature-specific plume of relative vorticity
Relative vorticity 1km (s-1 x10-6)
Feature-specific plume of wind strength
Max 1km wind in 300km radius (kn)
Feature-specific plume of wind strength
Max 1km wind in 600km radius (kn)
Feature-specific plume of wind strength
Max 300mb wind in 600km radius (kn)
February
2010

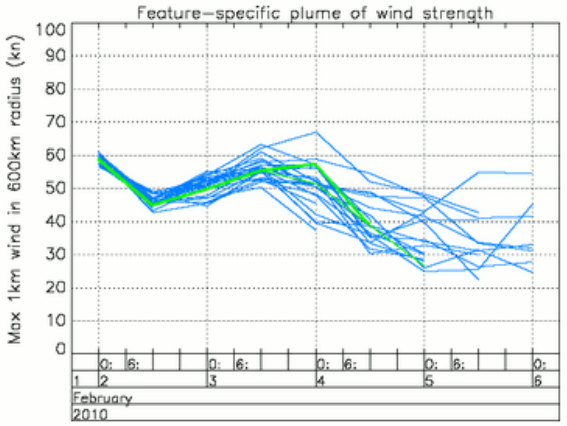


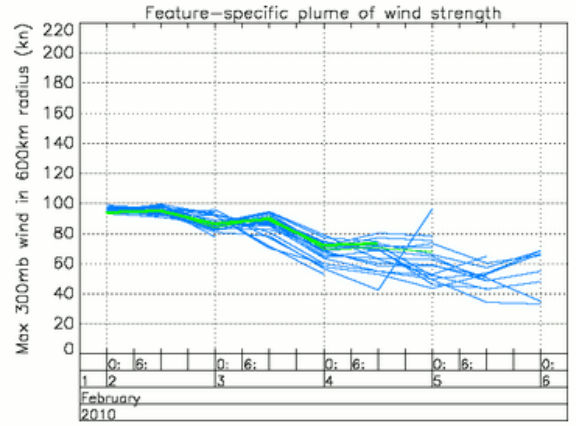
5. Plot based on terrain following fields that show wind strength 1km up. Plotted values denote the maximum in a 300km radius.

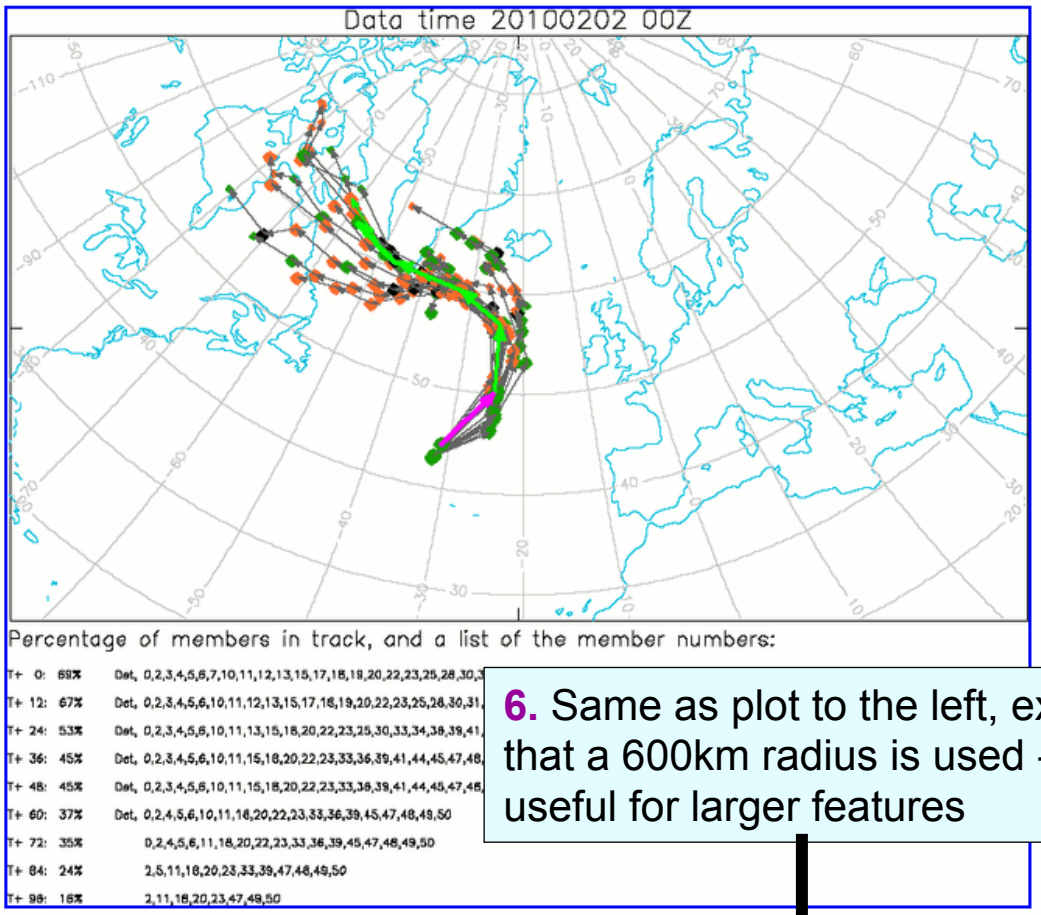


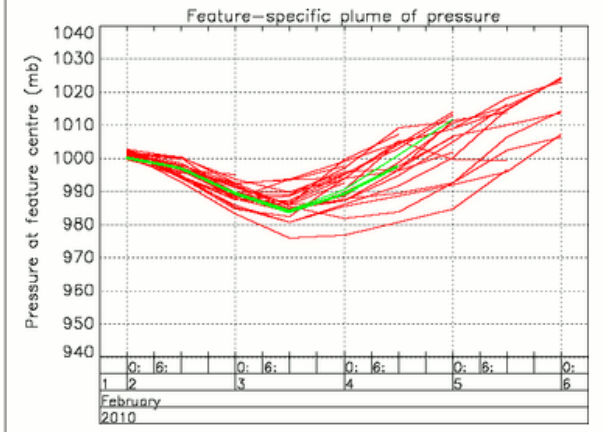


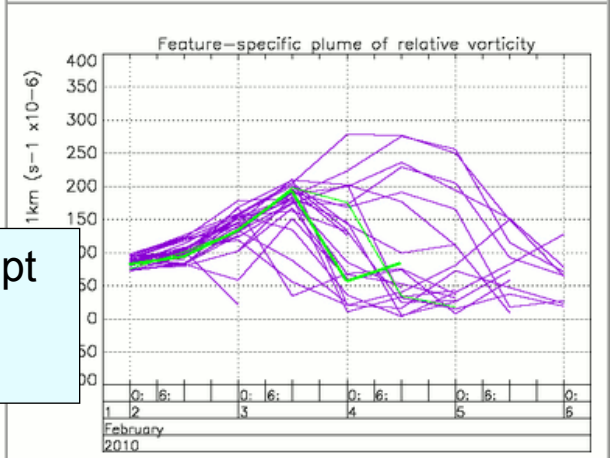




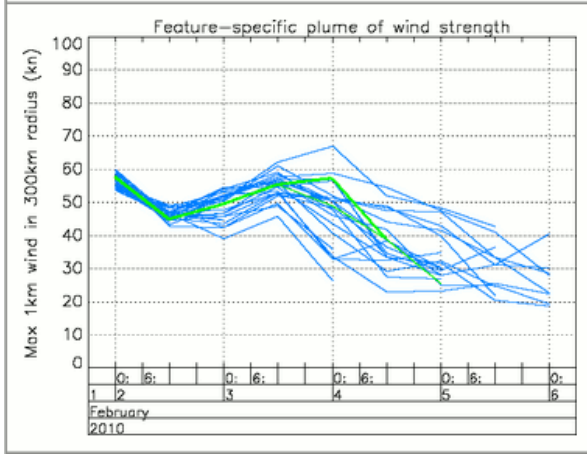


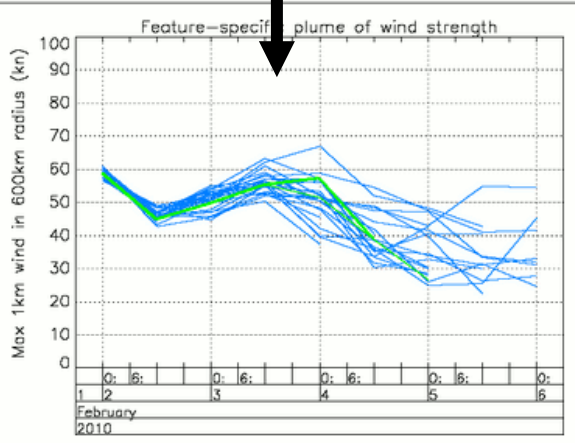


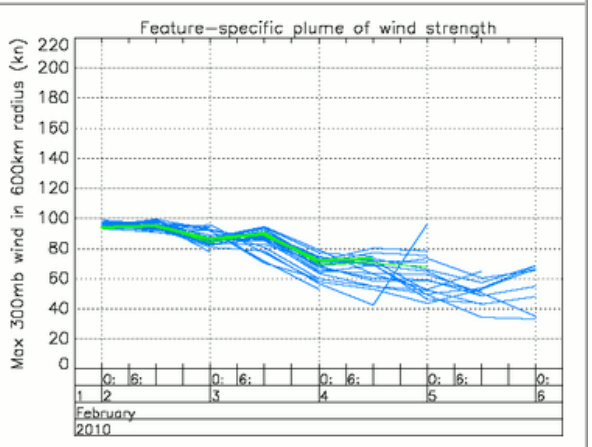


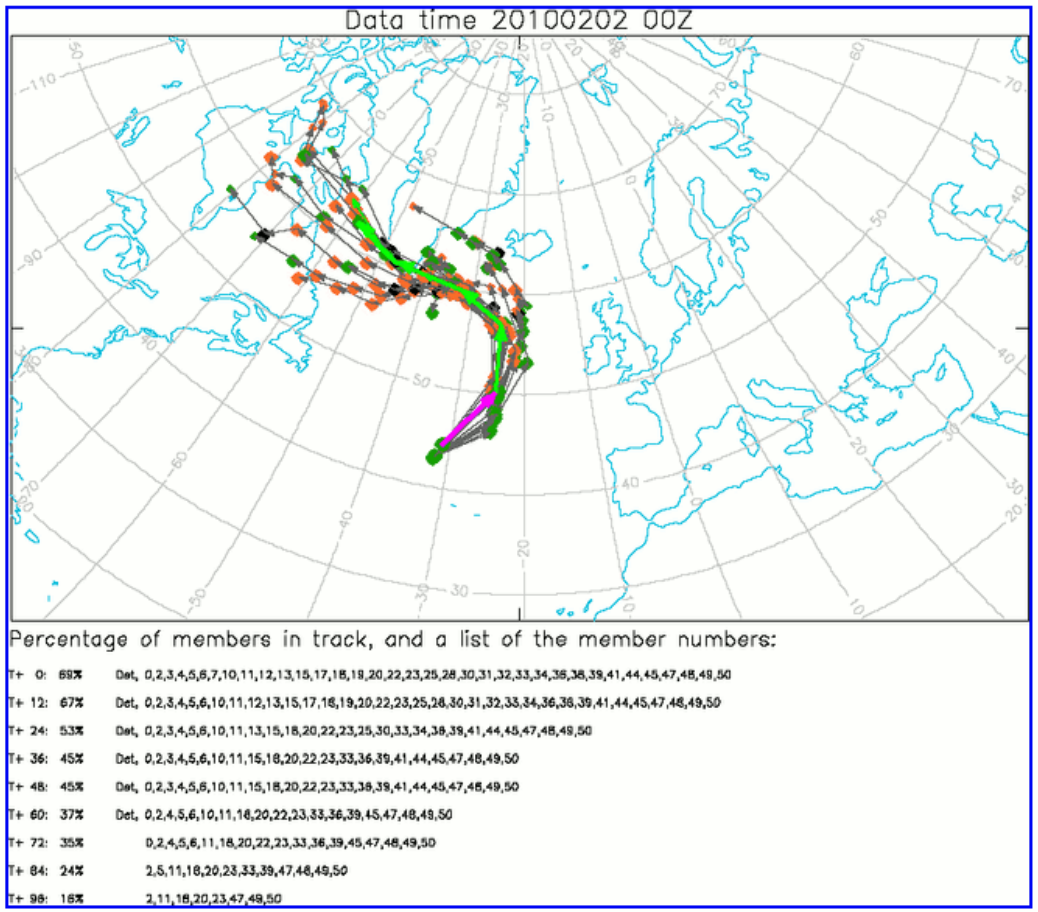


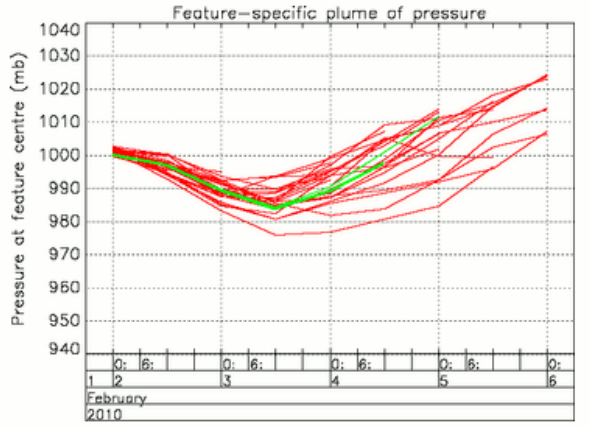
6. Same as plot to the left, except that a 600km radius is used - useful for larger features

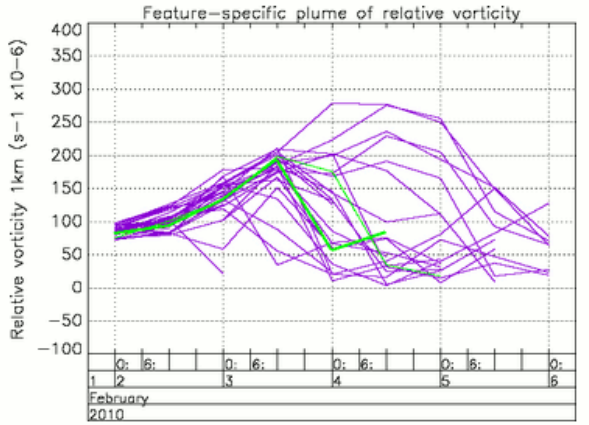


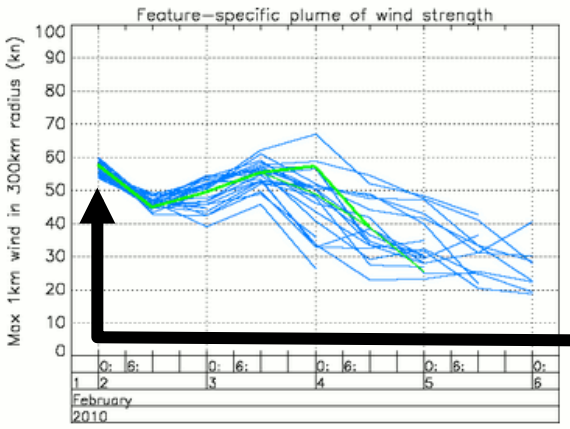


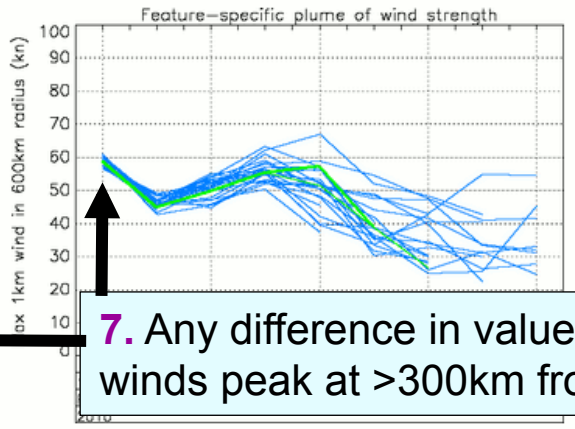


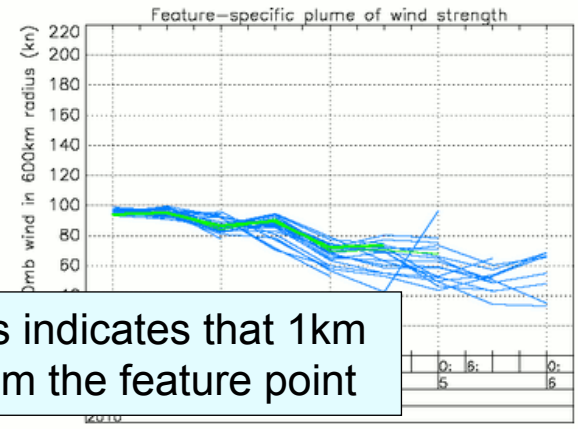




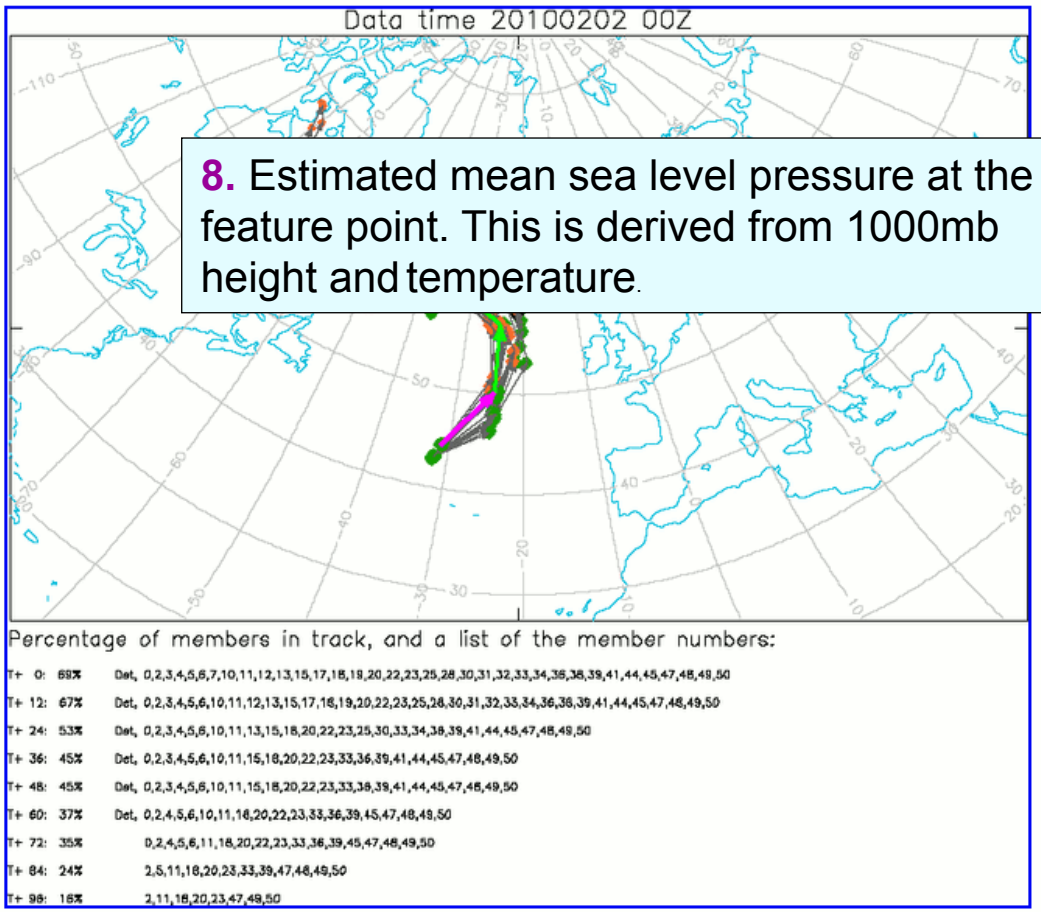




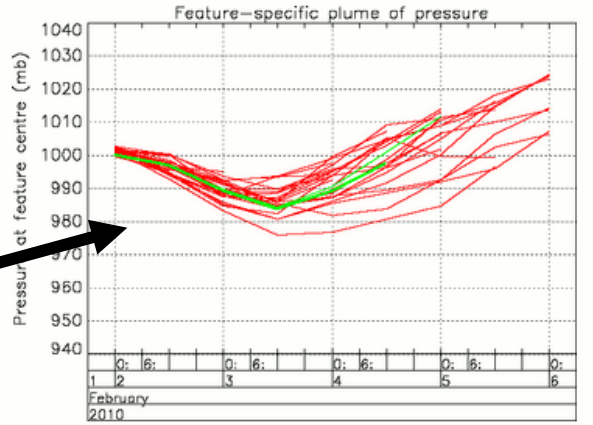


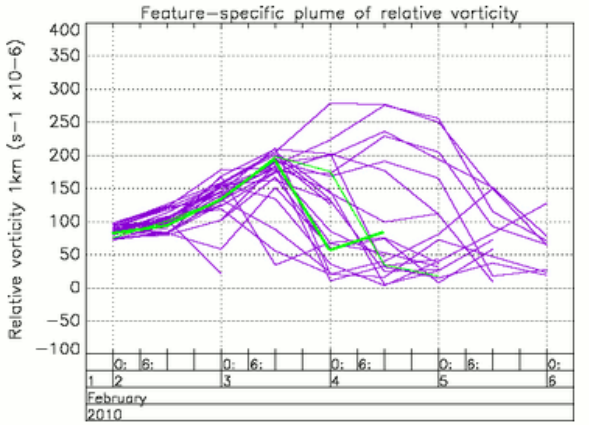


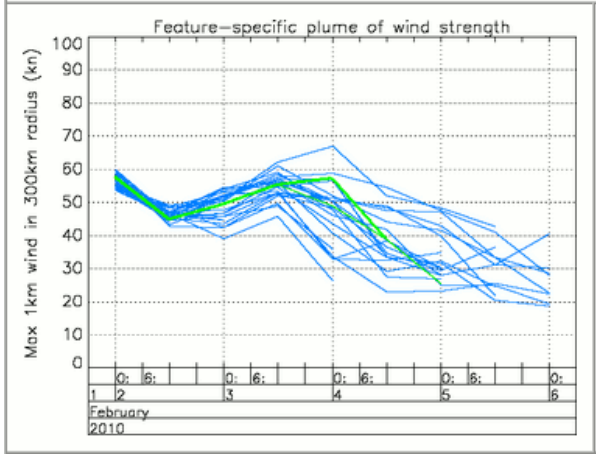
7. Any difference in values indicates that 1km winds peak at >300km from the feature point

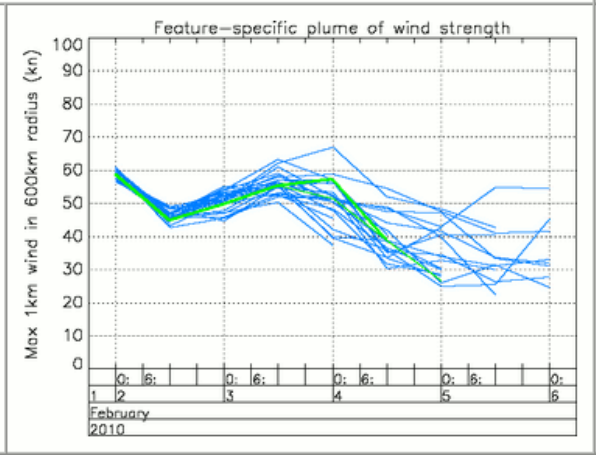


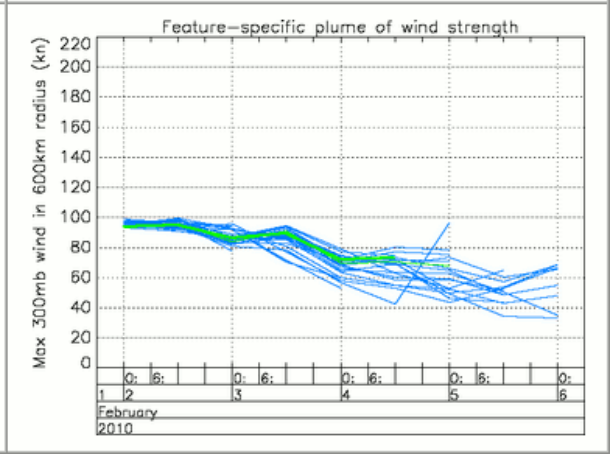
8. Estimated mean sea level pressure at the feature point. This is derived from 1000mb height and temperature.

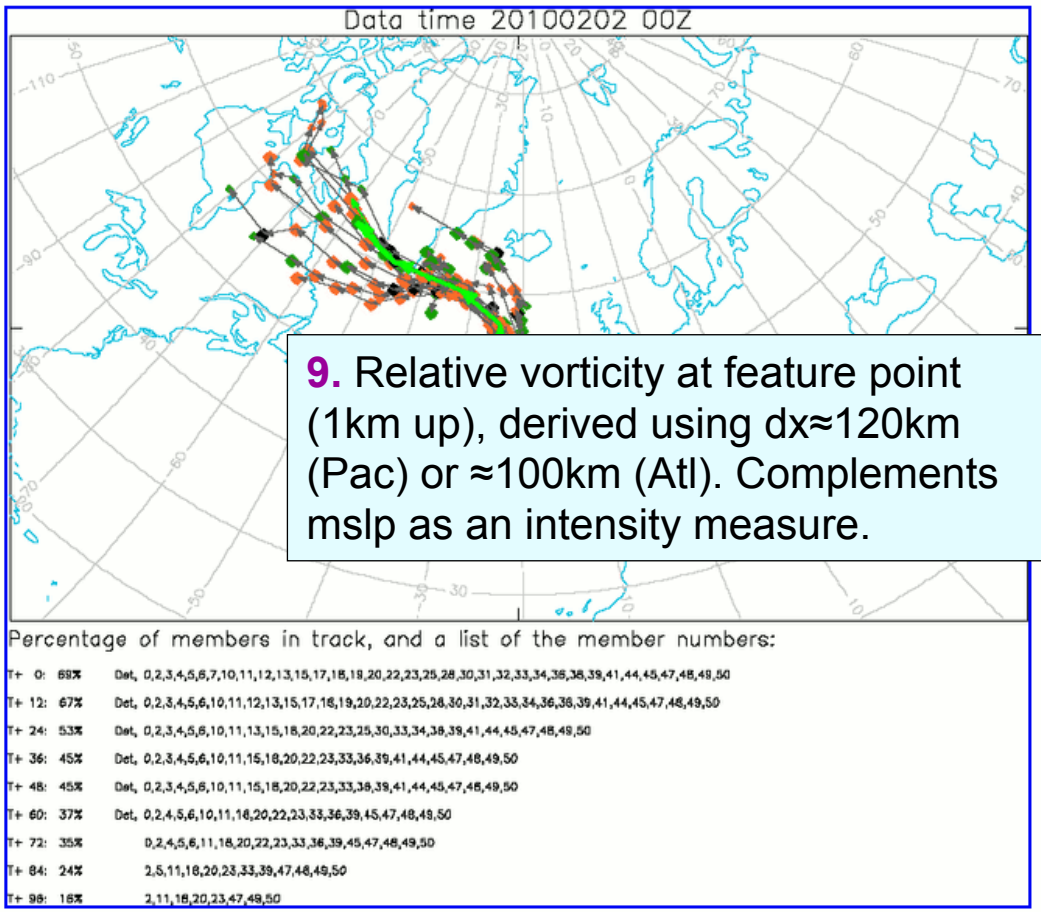




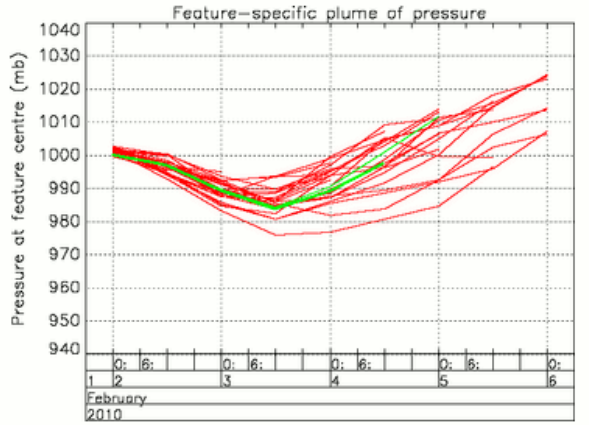


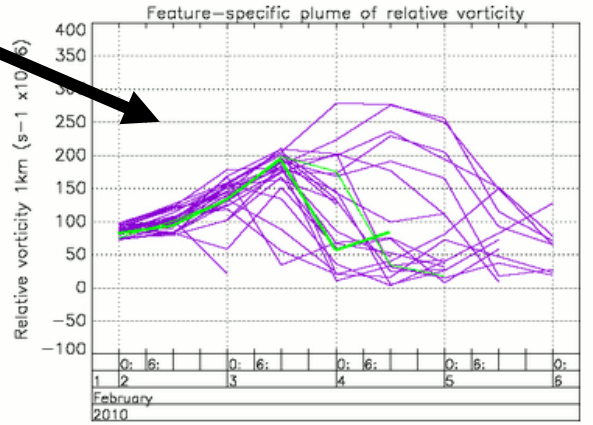


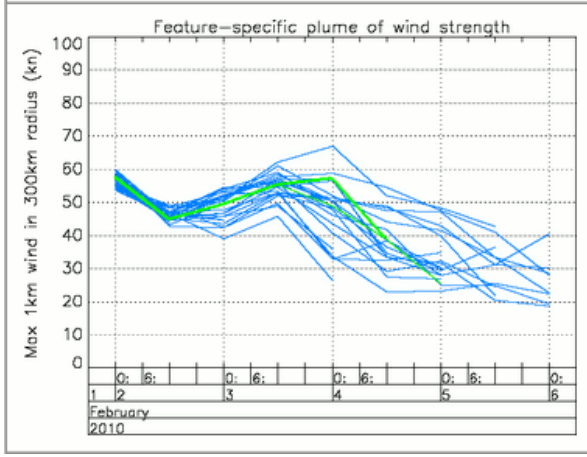


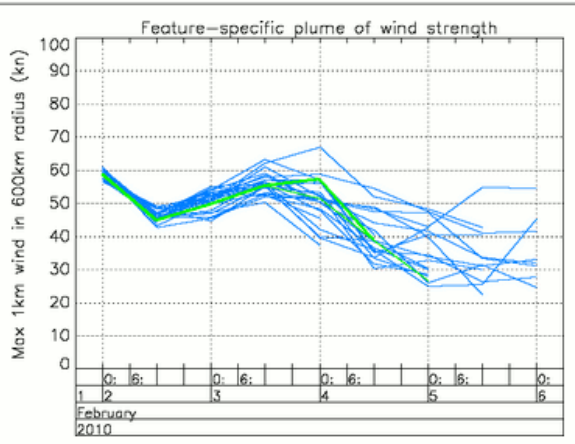


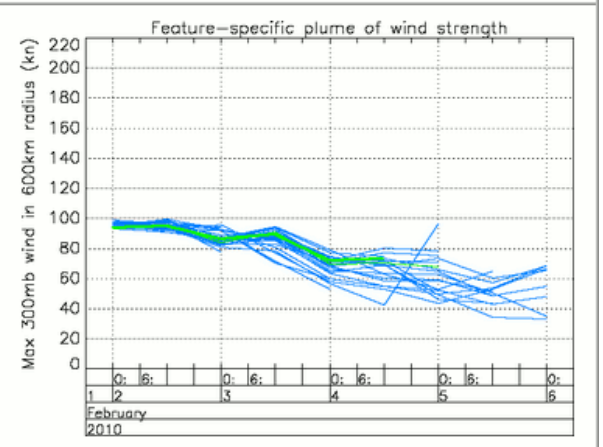
9. Relative vorticity at feature point (1km up), derived using dx≈120km (Pac) or ≈100km (Atl). Complements mslp as an intensity measure.

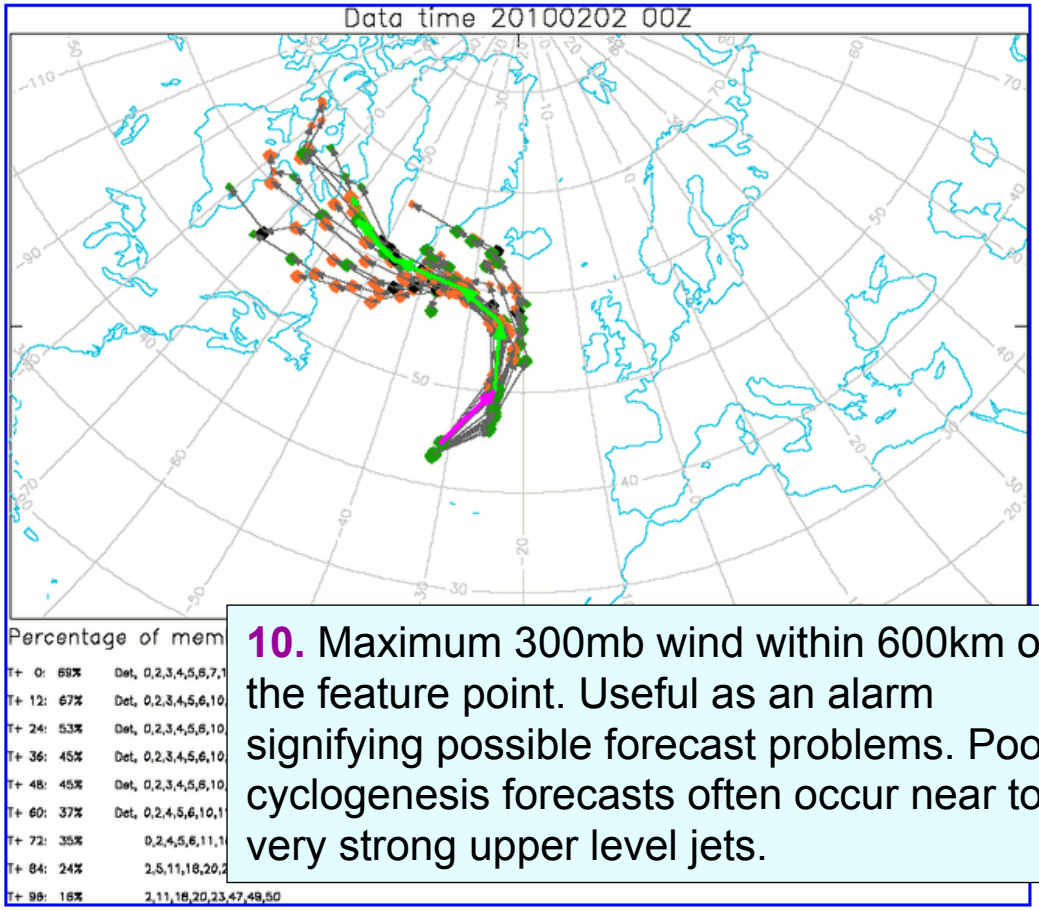




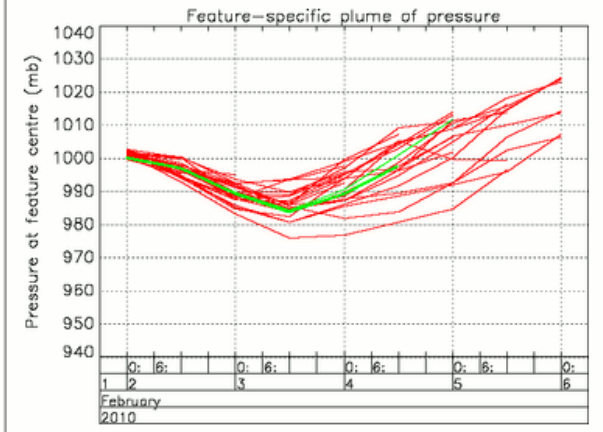


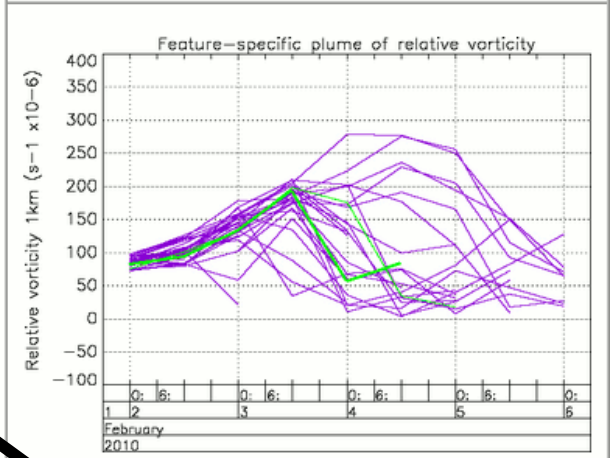


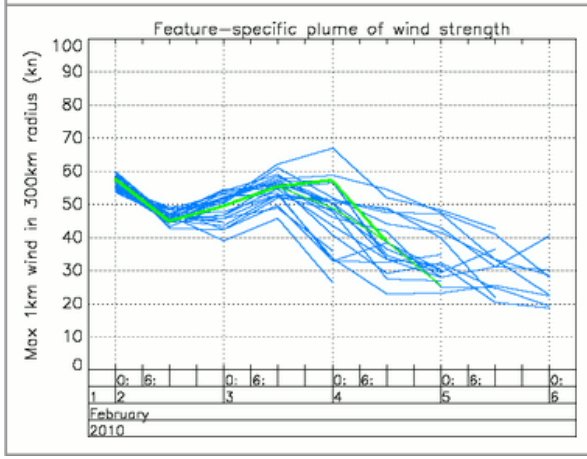


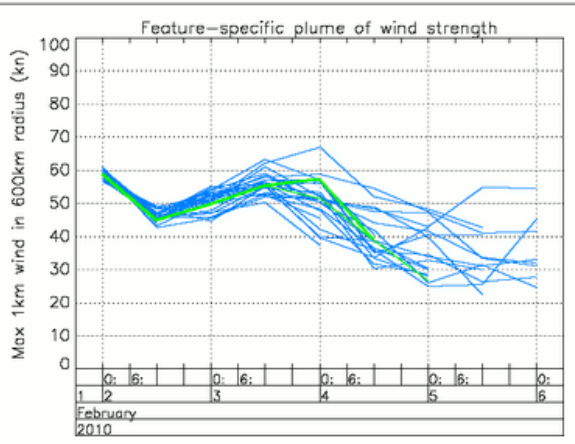


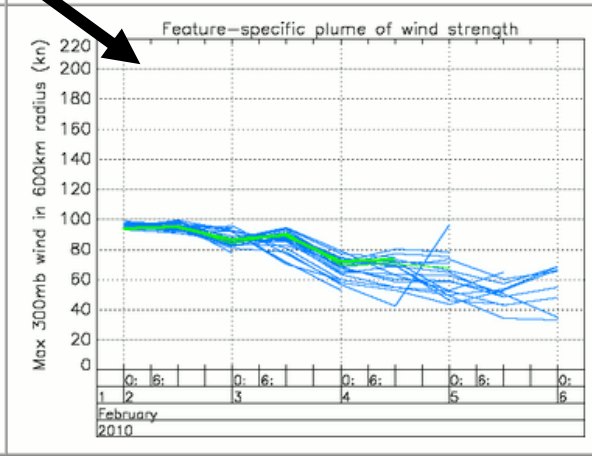
10. Maximum 300mb wind within 600km of the feature point. Useful as an alarm signifying possible forecast problems. Poor cyclogenesis forecasts often occur near to very strong upper level jets.











Plume Diagrams - Recommended Usage

- Generally use at short leads only (typically up to about T+120)
  - Because a feature needs to be present at T+0
- Beware of interpreting the ‘percentage of members tracked’ too literally
  - Reductions in number could be due to feature splitting during the forecast
  - Or, very occasionally, to tracking errors
- Note that high vorticity can sometimes be more indicative of the ‘intensity’ of a system than low mslp
- Be aware of the potential for large forecast errors when the 300mb jet is strong (say >~150kts)