Using Met3D at ECMWF

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Thanks to:

Marc Rautenhaus (University of Hamburg)
Michael Kern (Technical University of Munich),
Iain Russell, Sandor Kertesz, Luca Romita (all ECMWF)

Structure

- Why use 3D visualisation at ECMWF ?
- What is Met3D ?
- Meteorological Features – 2D and now 3D
- 3D jets in Met3D
  - Uses at ECMWF
  - What have we learnt ?
- 3D frontal surfaces
- Challenges for ECMWF in using Met3D

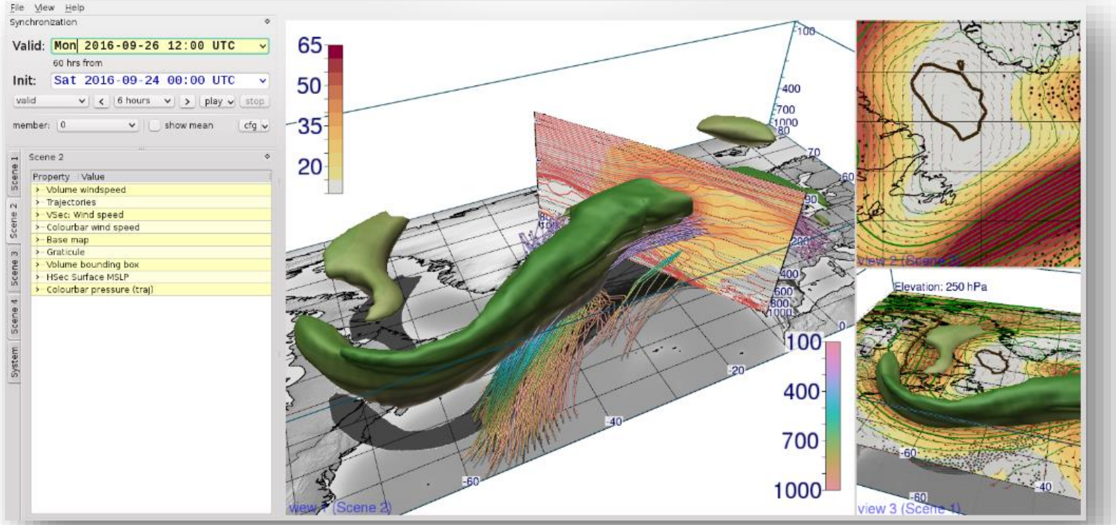
Why use 3D visualization at ECMWF ?

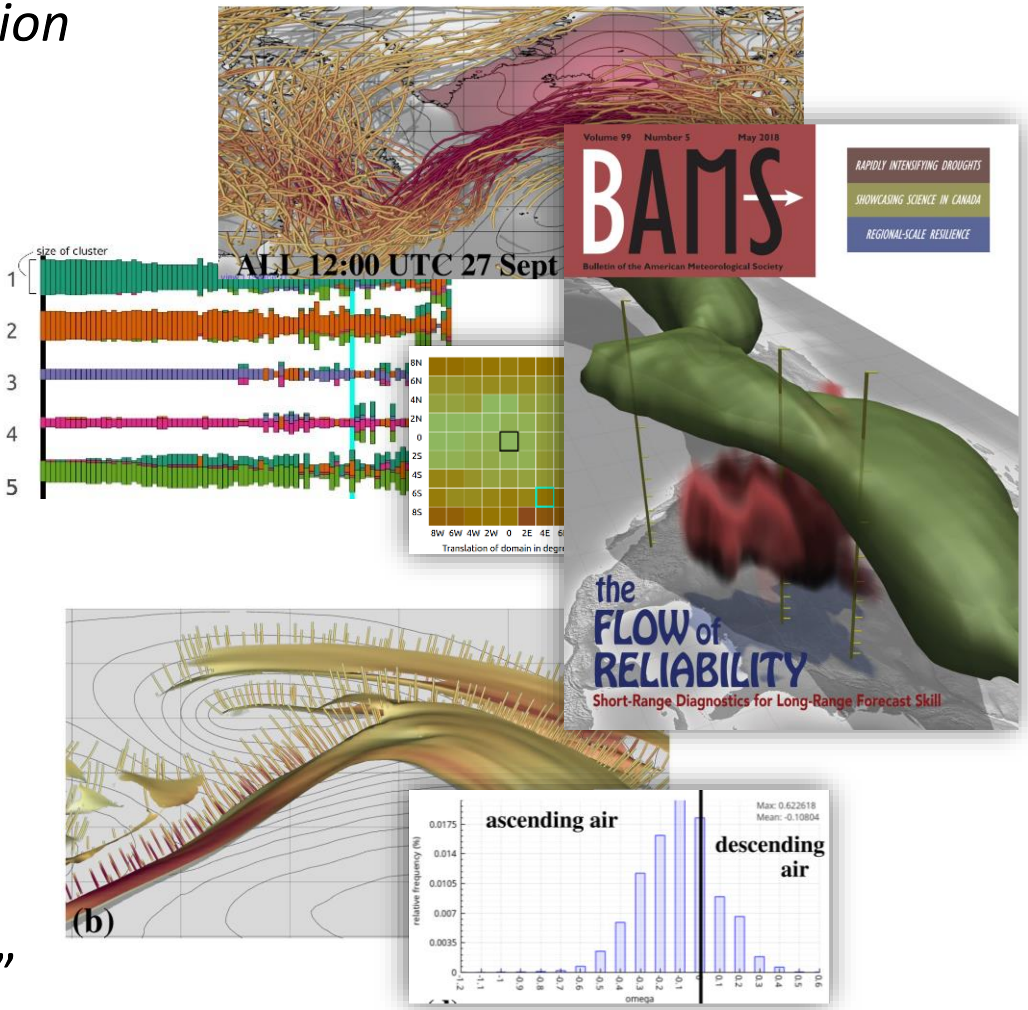
- Atmospheric structures are innately 3-Dimensional
- How does the IFS replicate reality? We need to visualise 3D structures:
  - To better understand atmospheric/model behaviour
  - For improved model evaluation and development
- Historically, the attraction of 3D visualisation has been reduced by:
  - (1) An inability to “see where you are”
  - (2) Lack of computer power. To see 3D on a 2D screen we actually need 4D rendering!
  - (3) Lack of mechanisms for portraying weather features (jet streams, fronts, etc.) in 3D
- But Now:
  - Marc Rautenhaus’ PhD work focused on overcoming (1); his tools were incorporated into Met3D
  - For (2) GPU developments make 4D tractable
  - New algorithms are facilitating (3)
- Forecaster workstations could benefit also – but of course tools need to be easy-to-use, and fast

Met.3D: open-source version and "research code"

Met.3D

Rapidly interpret a large quantity of information to support analysis and decision making.





https://met3d.wavestoweather.de

Open-source version vs. "research code"

Met.3D as an open-source visualization tool

Website:
met3d.wavestoweather.de

Met.3D is open-source (mostly).

It runs under **Linux** and **Windows** (GPU required).

Supported data:
CF-NetCDF and ECMWF-GRIB.
Regular lon/lat in the horizontal (experimental COSMO rotated grids).
Pressure levels, model levels.
Trajectories, pre-computed and on-the-fly.

Easy-to-use binaries for Linux available!

At ECMWF…

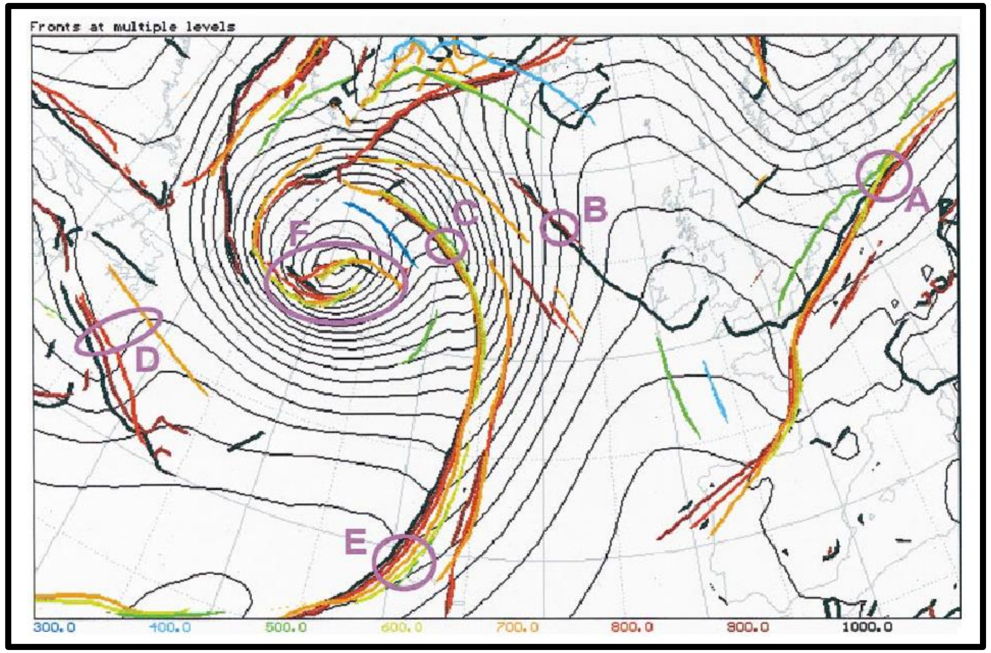
- We are very interested in exploiting the normal functionalities of Met3D
  - Including the ENS-related capabilities (key part of ECMWF strategy)

- We are also very interested in examining “meteorological features”
  - e.g. jet streams, frontal surfaces, sting jets, trough axes, cyclone centres, …
  - part of the language of forecasters
  - involves compression of huge amounts of information into meaningful, focussed entities
  - this also makes 3D ENS visualisation tractable
  - if the features are incorrect, the weather forecasts will be incorrect

- So collaboration with Met3D developers is delivering new feature-related functionality…

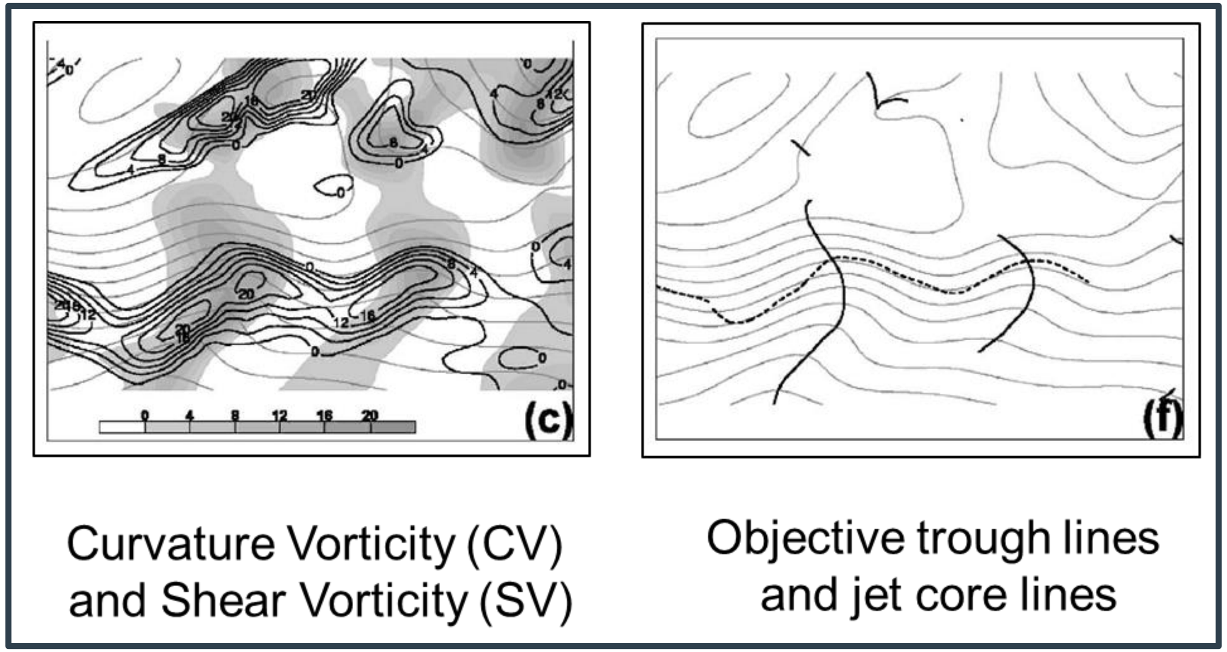
Previous Work – 2D

FRONTS



From: “Objective Fronts” – *Hewson, Meteorological Applications, 1998*

JET STREAMS



From: “African Easterly Waves during 2004 – Analysis Using Objective Techniques” – *Berry, Thorncroft, Hewson, Monthly Weather Review, 2007*

Recent Work…Similar topics in 3D !

FRONTS

2018/19

Interactive 3D Visual Analysis of Atmospheric Fronts

Michael Kern, Tim Hewson, Andreas Schäfler, Rüdiger Westermann, and Marc Rautenhaus

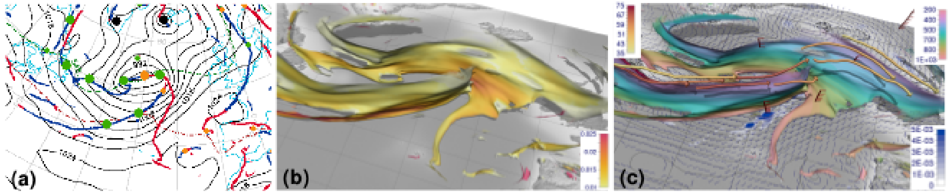


Fig. 1. Cyclone "Vladiana", 00:00 UTC 23 September 2016. **(a)** Objectively identified fronts at 1 km above ground from ECMWF operations, using the algorithm described in [15]. **(b)** 3D fronts identified and visualized with our method, color denotes frontal strength (K km^{-1}). **(c)** 3D fronts combined with further meteorological fields and features. Front color denotes pressure (hPa). Overlain are jet-stream core lines detected and visualized with the approach by Kern et al. [19], colored by wind speed (m s^{-1}). Surface contours show mean sea level pressure. Blue surface color shows precipitation (m h^{-1}). Wind barbs show surface wind.

Abstract— Atmospheric fronts play a central role in meteorology, as the boundaries between different air masses and as fundamental features of extra-tropical cyclones. They appear in numerous conceptual model depictions of extra-tropical weather systems. Conceptually, fronts are three-dimensional surfaces in space possessing an innate structural complexity, yet in meteorology, both manual and objective identification and depiction have historically focused on the structure in two dimensions. In this work, we –a team of visualization scientists and meteorologists– propose a novel visualization approach to analyze the three-dimensional structure of atmospheric fronts and related physical and dynamical processes. We build upon existing approaches to objectively identify fronts as lines in two dimensions and extend these to obtain frontal surfaces in three dimensions, using the magnitude of temperature change along the gradient of a moist potential temperature field as the primary identifying factor. We introduce the use of normal curves in the temperature gradient field to visualize a frontal zone (i.e., the transitional zone between the air masses) and the distribution of atmospheric variables in such zones. To enable for the first time a statistical analysis of frontal zones, we present a new approach to obtain the volume enclosed by a zone, by classifying grid boxes that intersect with normal curves emanating from a selected front. We introduce our method by means of an idealized numerical simulation and demonstrate its use with two real-world cases using numerical weather prediction data.

Index Terms—Meteorology, Atmospheric Fronts, Feature Detection

1 Introduction

In meteorology, fronts separate atmospheric air masses of different characteristics (e.g., warm and humid versus cold and dry; see, e.g., analysts currently lack the tools and the time to investigate this in detail. Frontal structures have also been extensively studied in atmospheric

JET STREAMS

2017/18

Robust Detection and Visualization of Jet-stream Core Lines in Atmospheric Flow

Michael Kern, Tim Hewson, Filip Sadlo, Rüdiger Westermann, and Marc Rautenhaus

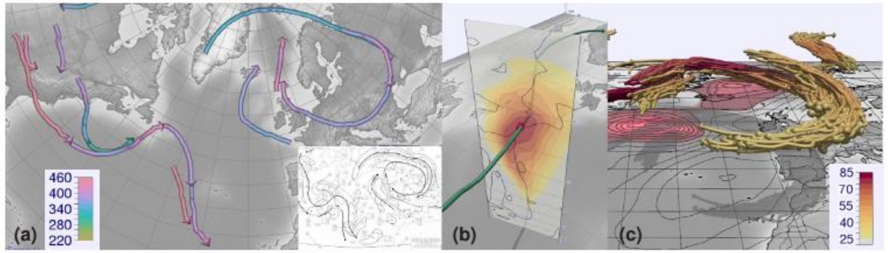


Fig. 1. **(a)** Jet-stream core lines extracted from a 3D wind field with our method, colored by flight level (hft). To the best of our knowledge, these features are still created manually by domain experts in operational weather forecasting and provided via 2D maps, as shown in the inset. **(b)** Normal plane perpendicular to the wind vector, used by our method as a local coordinate frame to extract jet cores. Color shows wind speed (ms^{-1}). **(c)** 3D "spaghetti plot" visualization of an ensemble of jet-stream cores (color shows wind speed as in (b)) enables an improved analysis of their spatial structure, forecast uncertainty, and relation to further atmospheric features including, e.g., mean-sea level pressure (MSLP; black contour lines, red regions indicate where pressure is below 1000 hPa).

Abstract— Jet-streams, their core lines and their role in atmospheric dynamics have been subject to considerable meteorological research since the first half of the twentieth century. Yet, until today no consistent automated feature detection approach has been proposed to identify jet-stream core lines from 3D wind fields. Such 3D core lines can facilitate meteorological analyses previously not possible. Although jet-stream cores can be manually analyzed by meteorologists in 2D as height ridges in the wind speed field, to the best of our knowledge no automated ridge detection approach has been applied to jet-stream core detection. In this work, we –a team of visualization scientists and meteorologists– propose a method that exploits directional information in the wind field to extract core lines in a robust and numerically less involved manner than traditional 3D ridge detection. For the first time, we apply the extracted 3D core lines to meteorological analysis, considering real-world case studies and demonstrating our method's benefits for weather forecasting and meteorological research.

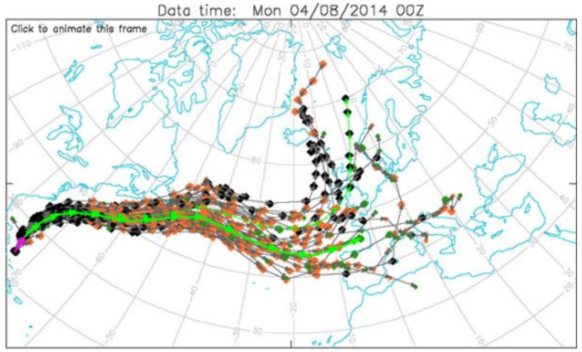
Index Terms—Meteorology, weather forecast, jet-stream, feature detection

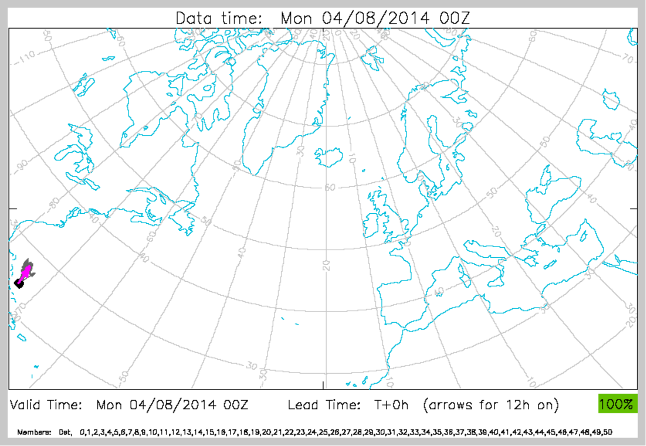
1 Introduction

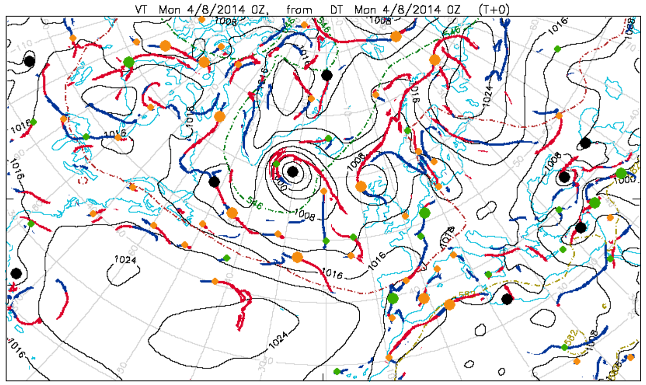
The improvement of weather forecasts and climate change projections depends heavily on documenting and understanding complex three- depicted as fundamental atmospheric structures on significant weather (SIGWX) charts used by pilots [53]. Even though a concise definition

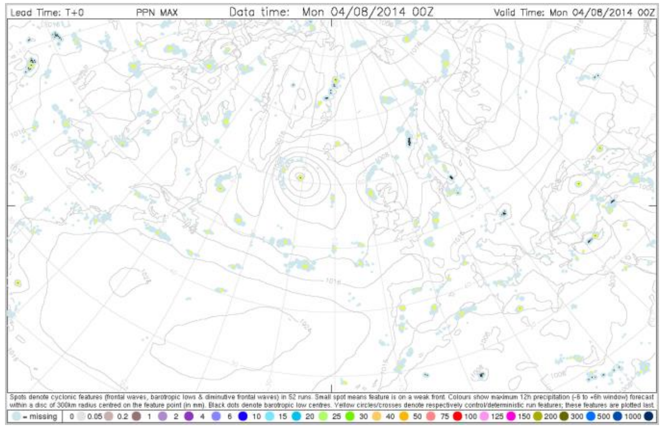
In: "IEEE Transactions on Visualisation and Computer Graphics"

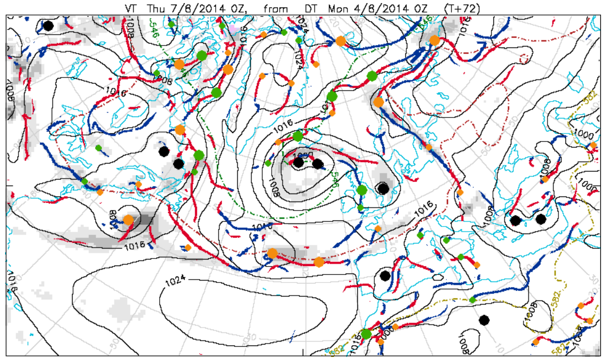
Some 2D ECMWF Products

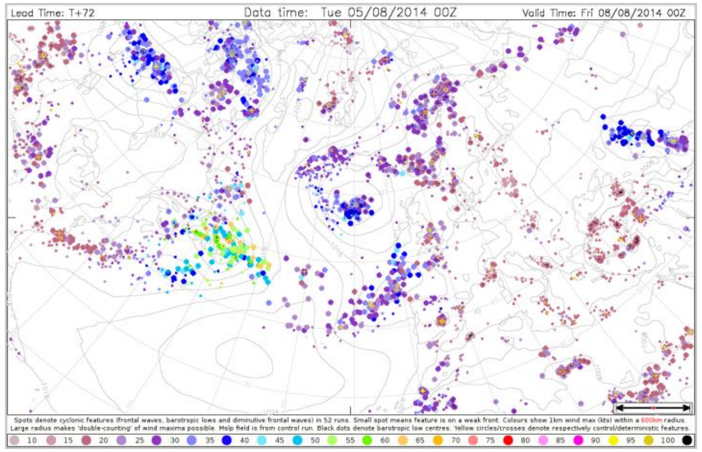


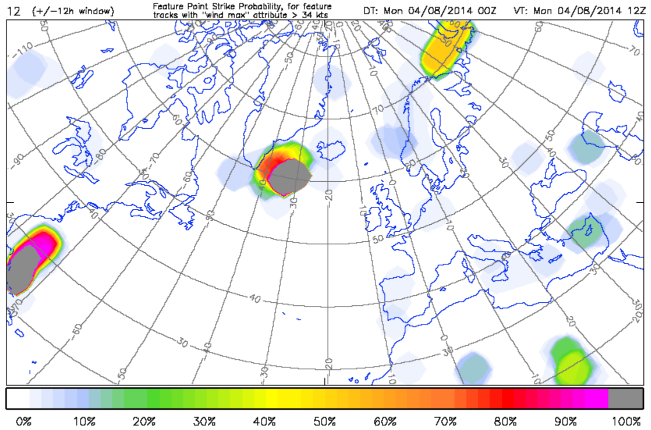


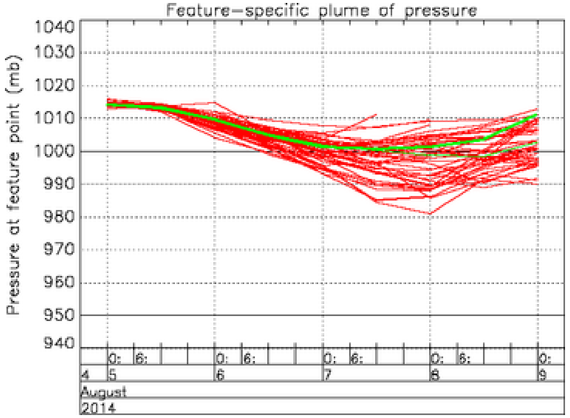


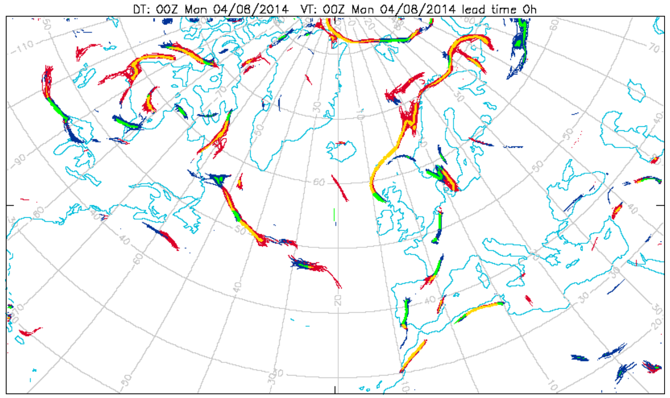






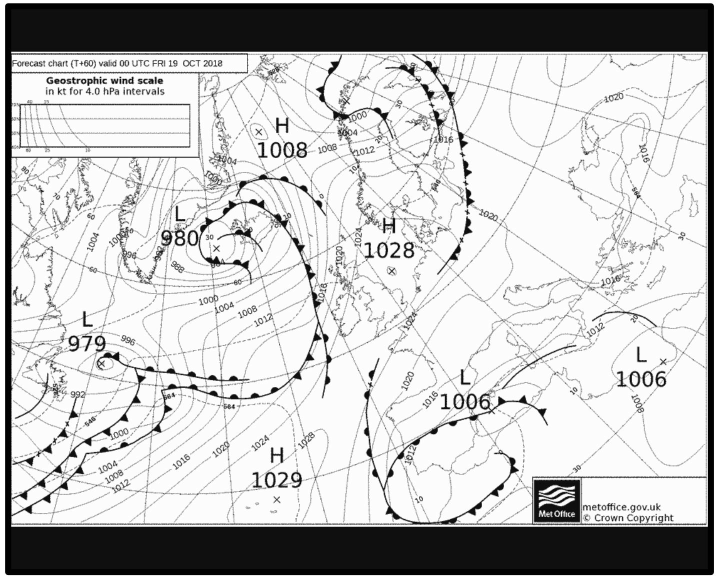


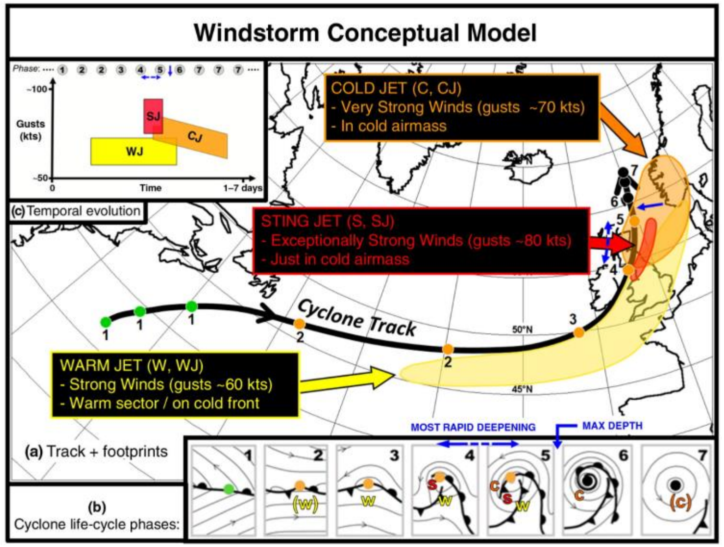




Using Feature Identification

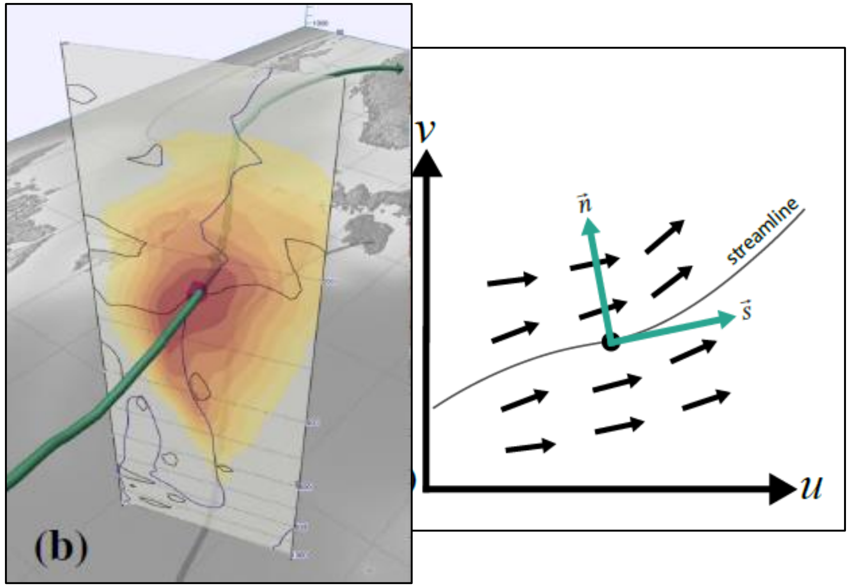
- 2D feature-related charts
  - Are widely used and appreciated within forecasting
  - Provide tools for ECMWF’s meteorological analysts
- What about 3D equivalents ?
  - Starting to attract the interest of forecasters…
  - More immediate applications in R&D
- <u>Will illustrate ECMWF applications using “jet core identification”</u>
- Jets play a fundamental role in meteorology:
  - Upper level jets drive development and movement of surface cyclones
  - Jet core existence implies a thermal gradient exists in the atmosphere
  - Low level strong-wind phenomena can be denoted by jets:
    - Warm Jet, Cold Jet, Sting Jet



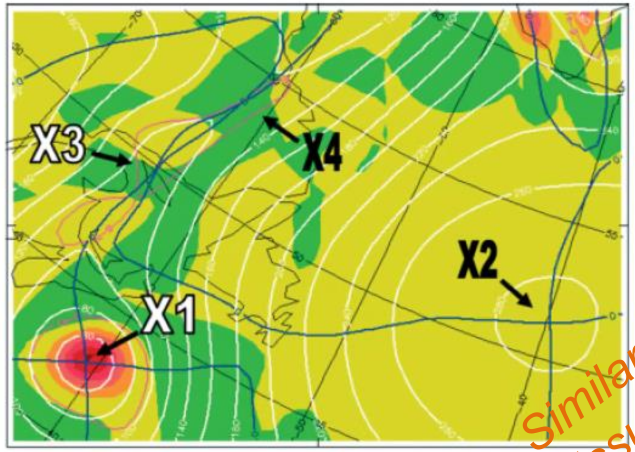


New Algorithms for 3-D Jet Identification

- Based on the concept of shear vorticity…



Low Identification



From *Hewson and Titley, 2010*

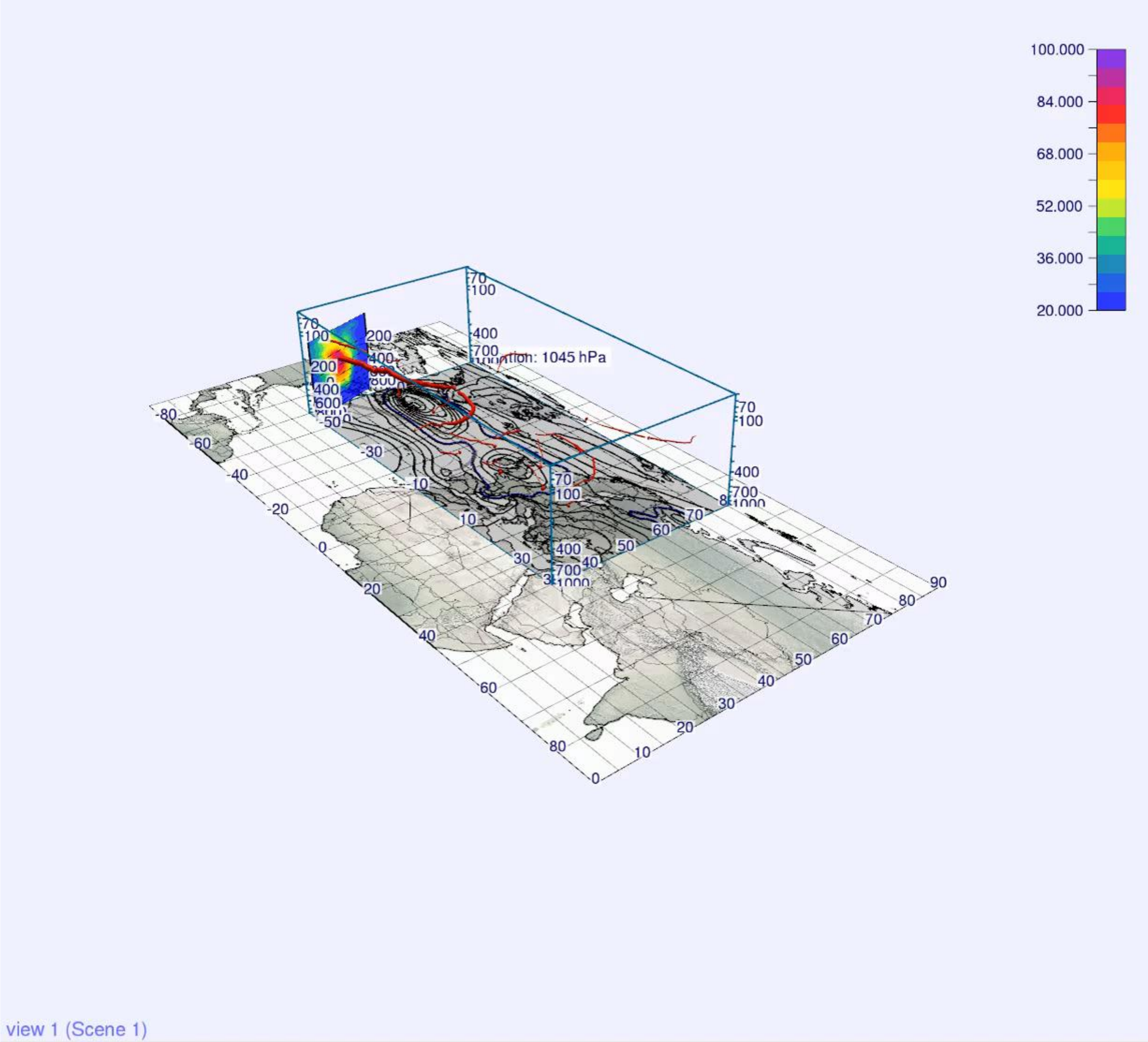
Similar issue

$$\frac{\partial V_s}{\partial n} = 0 \qquad \frac{\partial V_s}{\partial z} = 0$$

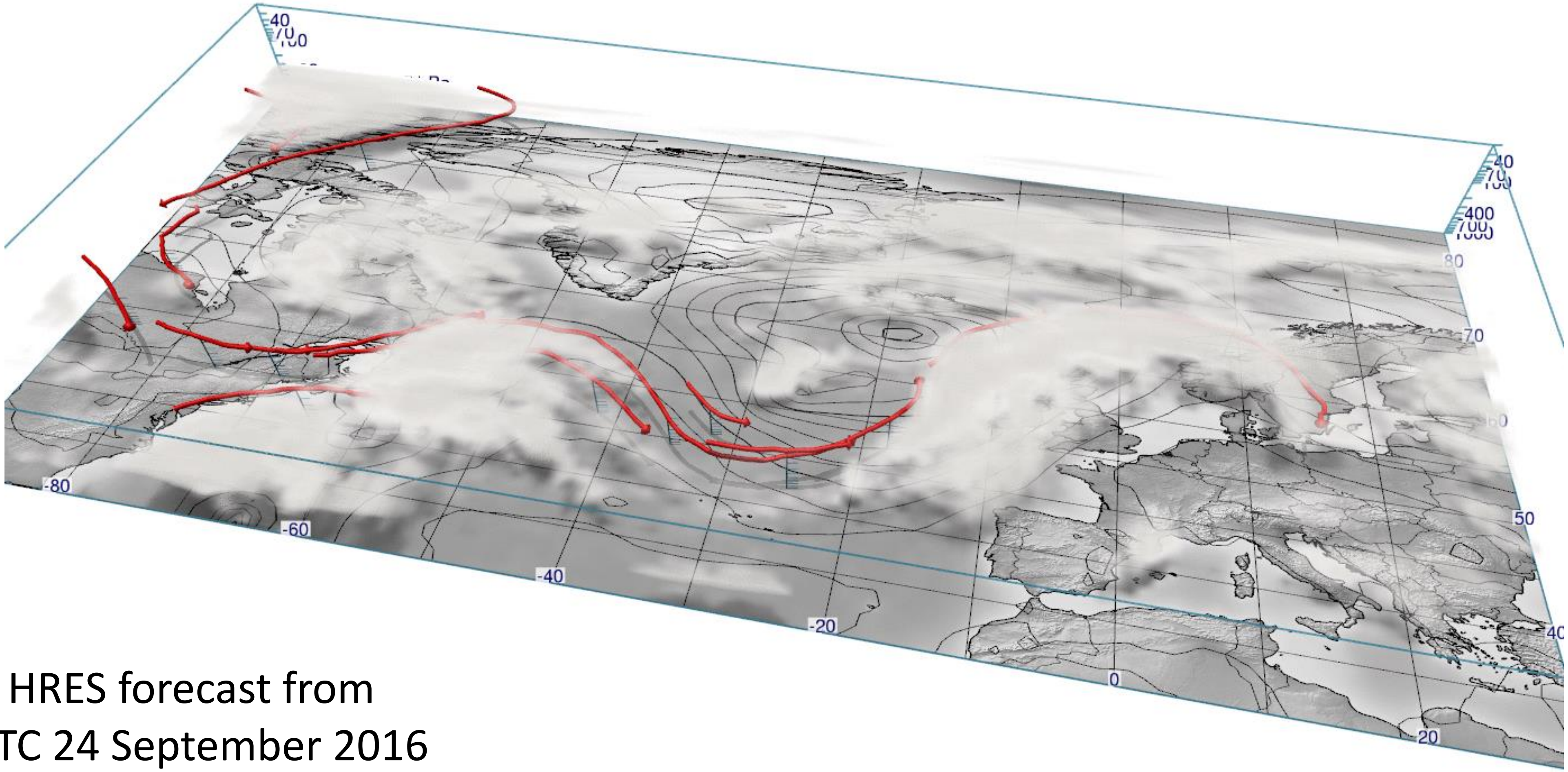
$$H_N = \begin{bmatrix} \frac{\partial^2 V_s}{\partial n^2} & \frac{\partial^2 V_s}{\partial n \partial z} \\ \frac{\partial^2 V_s}{\partial z \partial n} & \frac{\partial^2 V_s}{\partial z^2} \end{bmatrix} \qquad \lambda_0 < 0, \lambda_1 < 0$$

Equations apply to 3D volumes, not 2D planes

ECMWF


100.000
84.000
68.000
52.000
36.000
20.000
1045 hPa
view 1 (Scene 1)

Tropical cyclone KARL, September 2016



ECMWF HRES forecast from
00:00 UTC 24 September 2016

view 1 (Scene 1)

Windstorm Xavier – 5 Oct 2017

Blue = Cloud

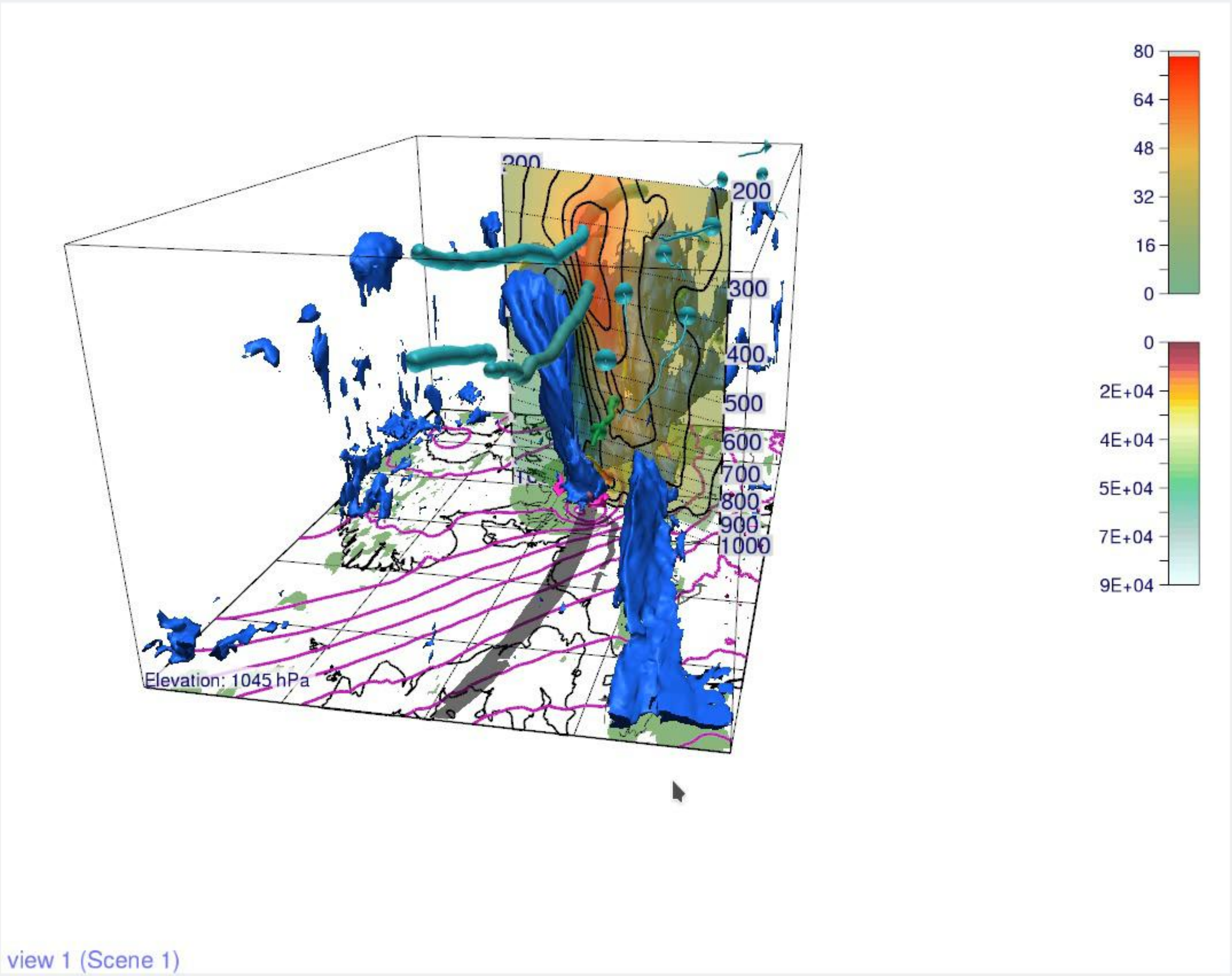
Green = Cloud Shadows

Colours = jet cores
(width denotes speed)
(colour denotes height)

Grey = jet shadows

Pink = unstable volume

Purple = isobars



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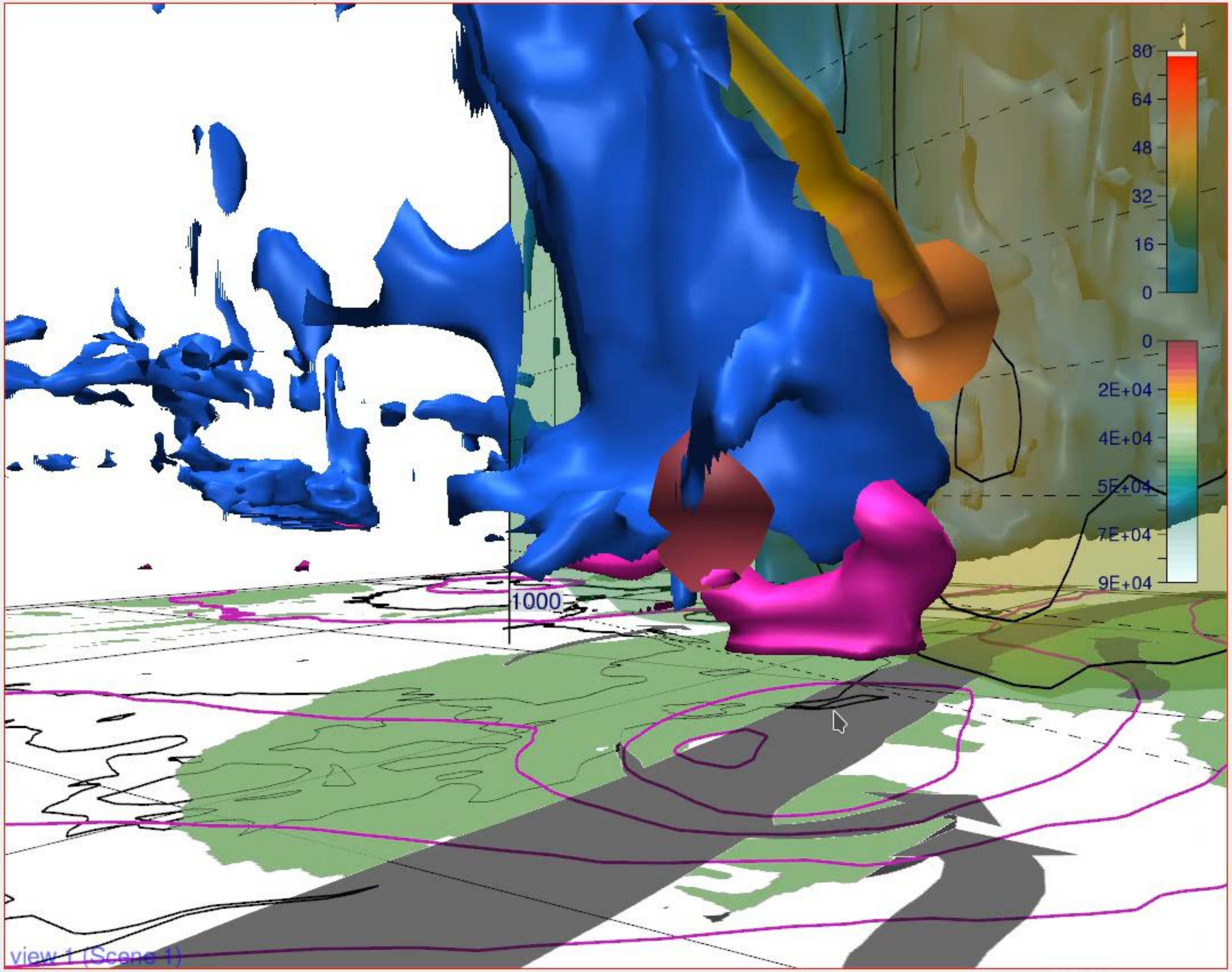
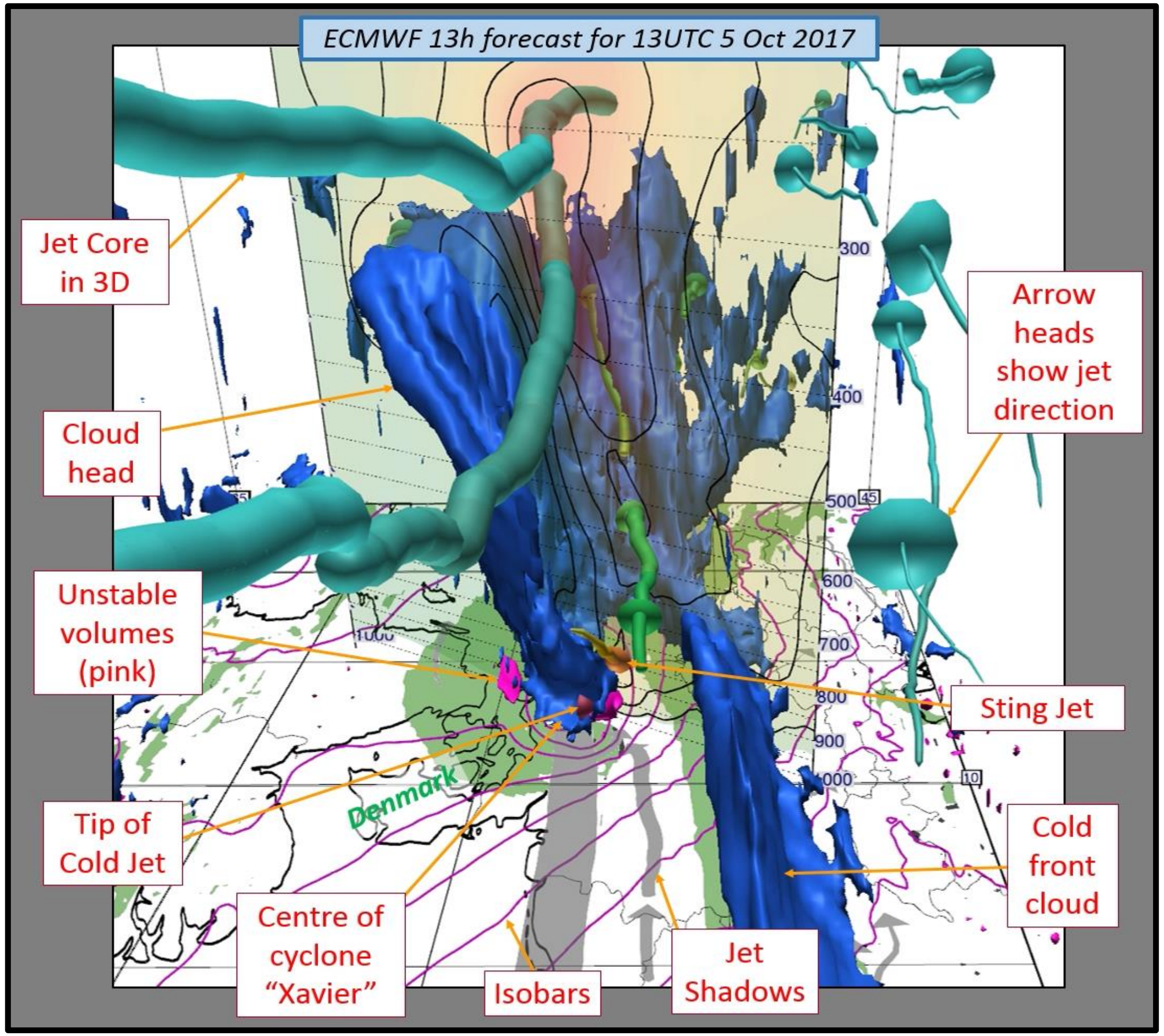
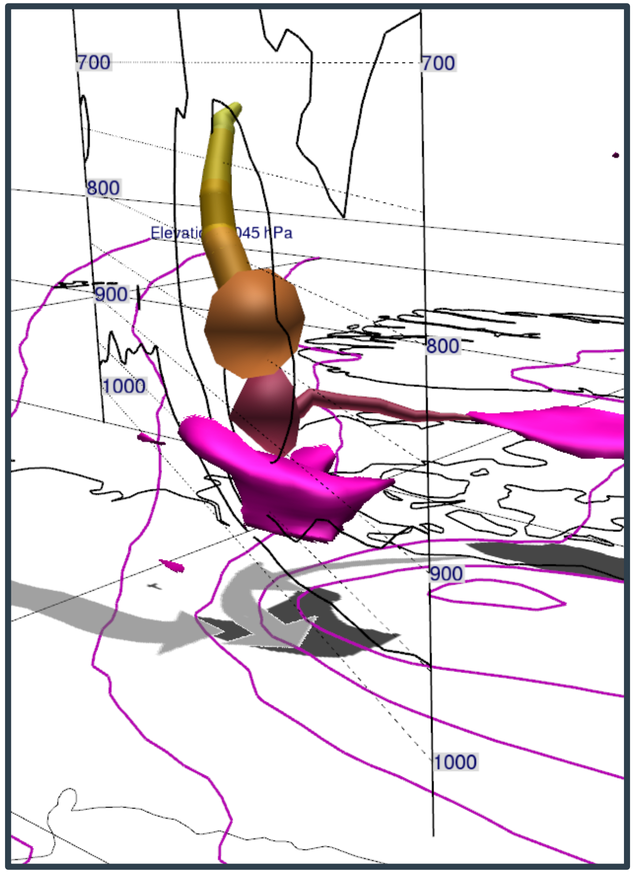


What have we learnt ?

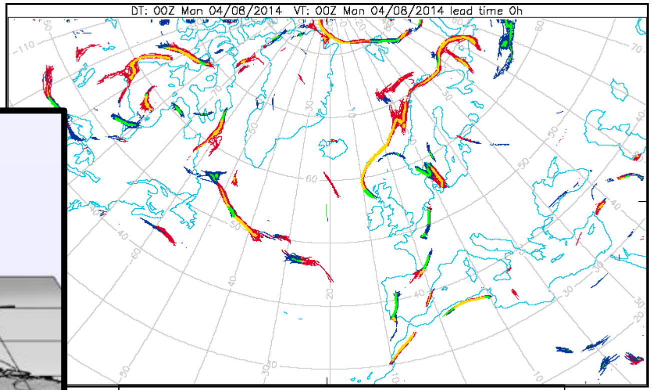




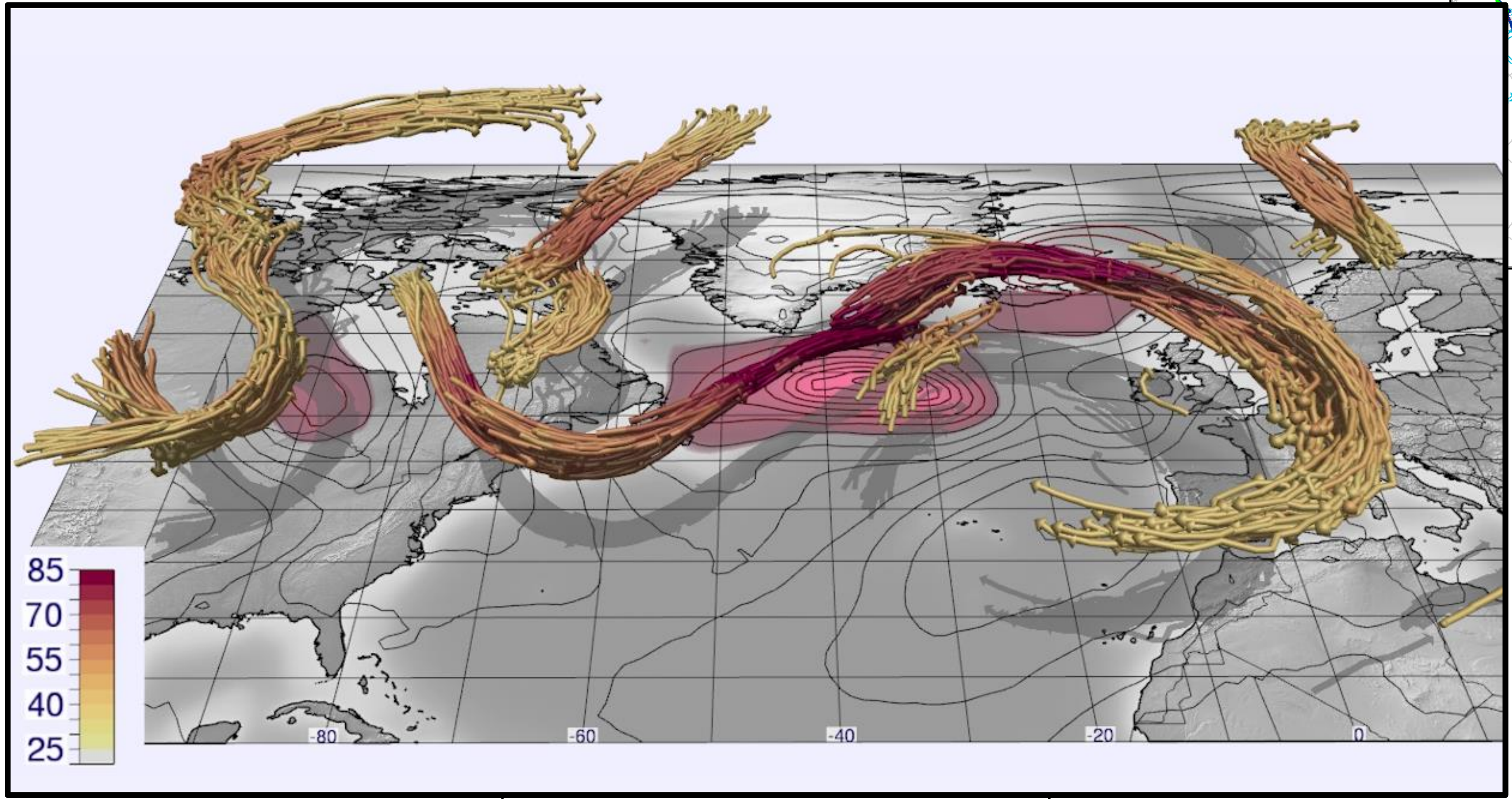
In the IFS at least, the "unstable volume" beneath a sting jet is key for allowing high momentum air (and very strong gusts) to propagate down to the surface

Such volumes can be a focal point for future work…

Visualisation of Jet cores within the Ensemble



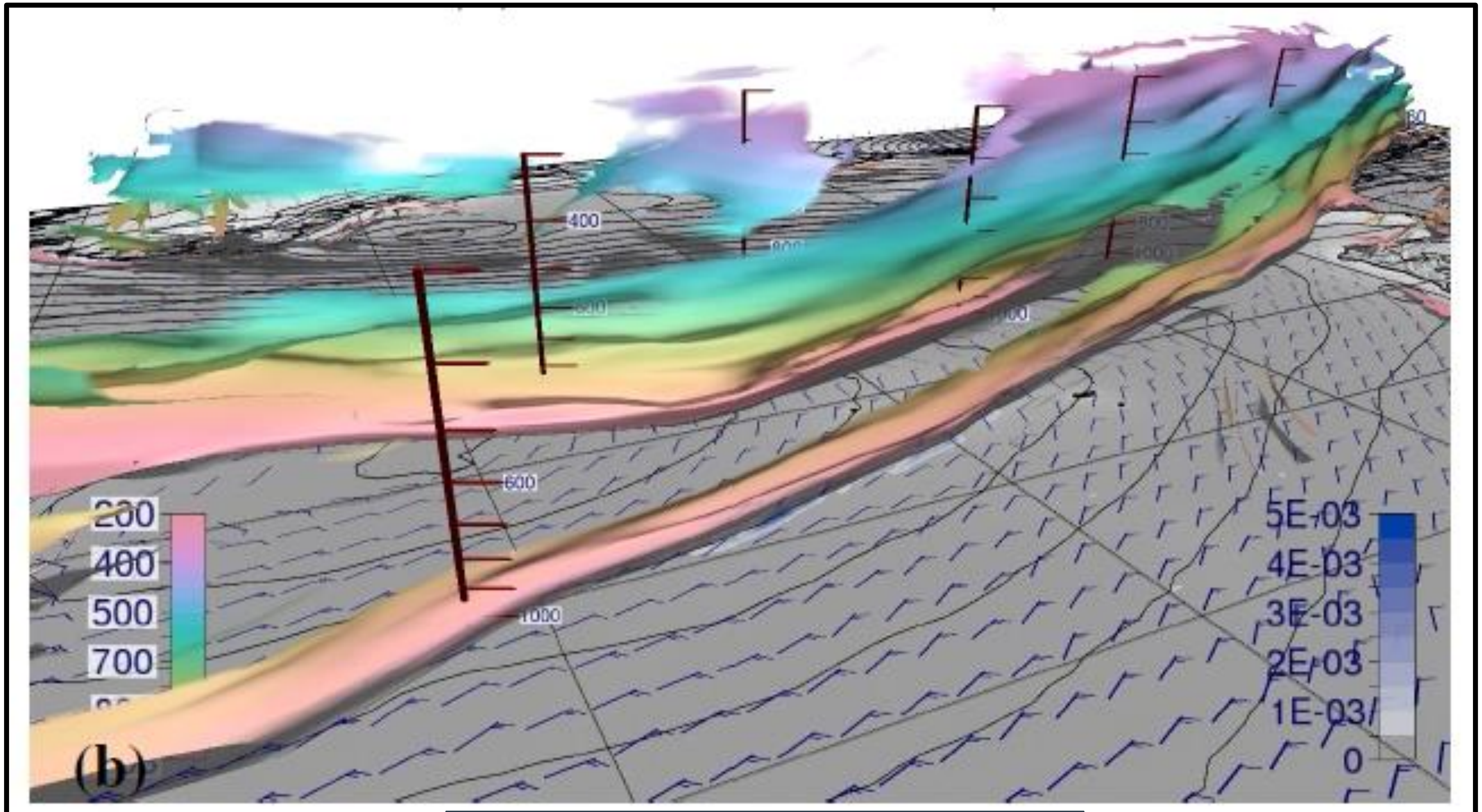
2D spaghetti fronts (old)



3D spaghetti jet cores (new)

- The string-like nature of jet cores facilitates representation of massive volumes of data – i.e. all ENS members
- Jet clustering algorithms are now under consideration

More Recent Work – 3D frontal surfaces



Colour shows height (as pressure)

- Frontal surfaces have coherence in the vertical
- Frontal slope changes and folding are quite clear – probably relate to rainfall patterns
- Previously unknown structures can be documented (e.g. “frontal tear”)
- As with the jets colouring can be based on any other variable
- Huge scope for further work…

Where are we now ?   Some Challenges for ECMWF…

- GPUs are critical
  - Related Problem with design of standard ECMWF desktops!
  - Exploring the use of remote GPUs
    - Create images remotely, transmit back to user
    - Hopefully no latency issues…
    - Strategy already in use, with Met3D, in other parts of Europe (e.g. Karlsruhe)
- University research department aims and ECMWF aims are somewhat different
  - “Publication record” versus “Easy-to-use, reliable, software”
  - Creative ways to address this disconnect are needed…
- Different to the Metview framework, but we are co-ordinating. Python links also planned.
- Training and code/configuration sharing are needed:
  - <u>First target is for Daily Report Analysts to actively use the software</u>

Met3D