Using Met3D at ECMWF

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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”

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.wavestoweweather.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

Curvature Vorticity (CV) and Shear Vorticity (SV)

Objective trough lines and jet core lines

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

**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

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**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

• Will illustrate ECMWF applications using “jet core identification”

• 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…

\[
\frac{\partial V_s}{\partial n} = 0, \quad \frac{\partial V_s}{\partial z} = 0
\]

\[
H_N = \begin{bmatrix}
\frac{\partial^2 V_s}{\partial n^2} & \frac{\partial^2 V_s}{\partial n \partial z} \\
\frac{\partial^2 V_s}{\partial z \partial n} & \frac{\partial^2 V_s}{\partial z^2}
\end{bmatrix}
\]

\[\lambda_0 < 0, \lambda_1 < 0\]

Equations apply to 3D volumes, not 2D planes

From Hewson and Titley, 2010
Tropical cyclone KARL, September 2016

ECMWF HRES forecast from 00:00 UTC 24 September 2016

view 1 (Scene 1)
Blue = Cloud
Green = Cloud Shadows
Colours = jet cores
(width denotes speed)
(colour denotes height)
Grey = jet shadows
Pink = unstable volume
Purple = isobars
Blue = Cloud
Green = Cloud Shadows
Colours = jet cores (width denotes speed) (colour denotes height)
Grey = jet shadows
Pink = unstable volume
Purple = isobars
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…
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

- 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…

Colour shows height (as pressure)
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:
  – First target is for Daily Report Analysts to actively use the software