COST Action ES1305

Short Term Scientific Mission:
STSM-35970

Final Report

Real-time visualisation of raw weather radar data over the Netherlands and Belgium

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Executive Summary

A challenge in applying weather radar measurements in ecological applications is characterising and interpreting the typical biological signals that appear in radar observations. Often, this capability is developed subjectively over time by regularly monitoring radar images. This technique systematically builds intuition regarding the timing, intensity, and overall 'look' of animal movements on radar such that the skilled observer can quickly interpret radar images visually.

Currently across Europe, most online radar visualisations show filtered images with only weather signals present, making it difficult for ecologists to have regular exposure to raw radar images. The goal of this Short Term Scientific Mission (STSM) was to develop and deploy a toolbox of radar visualisation resources for the Dutch radar network. Collaborating with Judy Shamoun-Baranes and Liesbeth Verlinden from the University of Amsterdam, the first task was configuring local computer resources to be compatible with a common version of the Python programming language and necessary software packages. The second task was modifying existing code that allows direct download of raw radar data from the Royal Netherlands Meteorological Institute (KNMI) archive server. Once these data links had been established, we wrote additional software to visualise these data and save the resulting images.

Contingent on the success of this product, the remaining time on the STSM was spent on several additional 'wish list' tasks. First, working with Hans van Gasteren we modified the visualisation codes to complement existing weather radar tools for aviation risk monitoring. After successfully making these additions, we attempted to implement the resulting visualisation software online and in real-time, providing a live web portal for monitoring animal movements across the region. Access to the online server was not possible during the STSM, however, efforts to achieve this capability are ongoing. Second, we began planning the expansion of these visualisation tools for radars across Belgium and the United Kingdom. After using a MATLAB toolbox to explore several cases of migration across the English Channel, we have decided to further pursue this expansion of the visualisation software to UK radar sites. Finally, we have established an online git repository for these software source codes so continuing work and upgrades can be efficiently shared.

1 Introduction

Efforts are ongoing for developing a centralised workflow for archiving, accessing, analysing, and visualising weather radar observations of animal movements across the European weather radar network. While these large-scale products will simplify the process of working with radar data, some applications require raw data from single sites, possibly in real- or near real-time. Additional capabilities for visualising other radar products such as Doppler radial velocity or spectrum width are also desirable. In order to achieve these capabilities, countries must provide access to their raw radar data in real-time data streams or archives. Presently, the Dutch and Belgian weather radar networks (Fig. 1, red) provide access to their raw datasets, motivating the initial focus on this region. Additionally, the UK radar archive is accessible with a two-day data lag, allowing near real-time monitoring of seasonal migratory trends over this region (Fig. 1, blue). To our knowledge, no other OPERA member countries provide free, online access to their raw radar data. The overall goal was to develop software to query these archives, download selected files, and visualise the resulting data products.

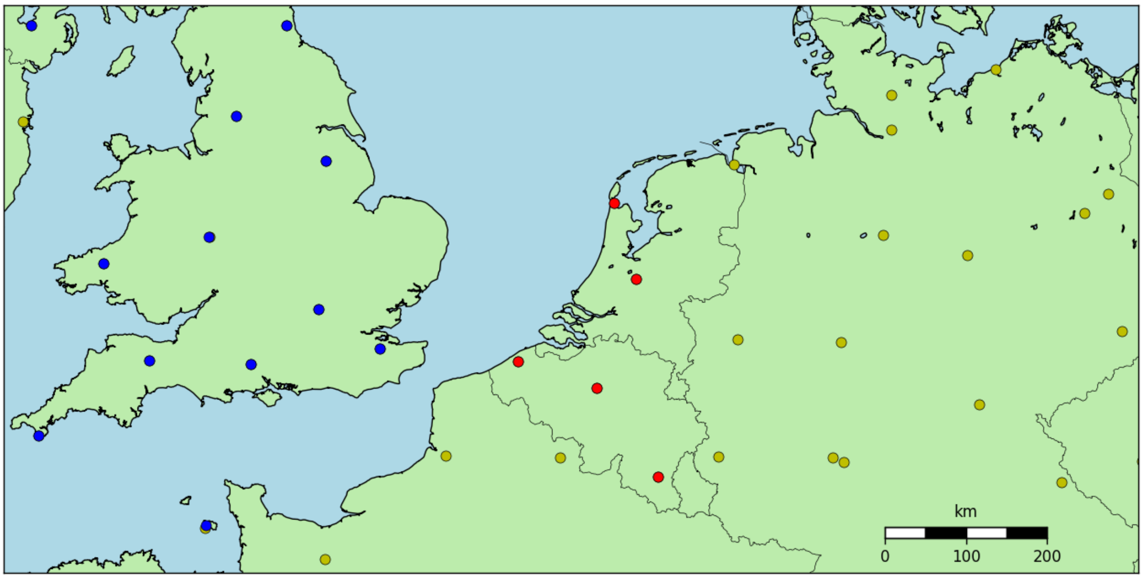

Figure 1: Location of OPERA weather radar sites within the Netherlands and Belgium (red), the United Kingdom (blue), and all other member countries (yellow).

radarPlot.py — Edited

```
##################################  STEP 1: Define function inputs  ##################################

# radar site (60 = de bilt; 61 = den helder)
radarSite = 60

# define start time
yyyy   = 2016    # year
mm     = 11      # month
dd     = 7       # day
HH     = 17      # hour
MM     = 00      # minute (will be rounded down to nearest multiple of 5)
startTime = datetime.datetime.combine(datetime.date(yyyy,mm,dd),datetime.time(HH,int(np.floor(MM/5)*5),0))

# define end time
yyyy   = 2016    # year
mm     = 11      # month
dd     = 7       # day
HH     = 22      # hour
MM     = 00      # minute (will be rounded down to nearest multiple of 5)
endTime = datetime.datetime.combine(datetime.date(yyyy,mm,dd),datetime.time(HH,int(np.floor(MM/5)*5),0))

# interval between images (in minutes)
dt     = 5      # spacing between images in minutes (will be rounded down to nearest multiple of 5 minutes)

# latitude and longitude bounds [min,max] for plotting domain
latSet = [49,56]
lonSet = [0,10]
```

Figure 2: User input in Python visualisation code.

2 Dutch Radar Visualisation Development

The goal of providing online access to the Royal Netherlands Meteorological Institute (KNMI) archive server was achieved using Python 3.5, a freely-available programming language. Direct downloads from the real-time and archive servers (data.knmi.nl) were queried using the PycURL package, returning data files that are temporary stored locally while being opened, read, and visualised. As a simple first step, we used a function within the wradlib package (wradlib.org) to open and read the OPERA HDF5 data format into the Python environment. We then use the marplotlib package (matplotlib.org) to plot the resulting radar data products as desired. The images are saved in the Portable Network Graphics format, and the full data file is then deleted from local memory.

The user selects the desired images by choosing a radar site, start time, end time, and interval between images (Fig. 2). For data on the real-time server (data within one month of present date) each volume scan is stored individually, and download and plotting takes several seconds per image at the native five-minute update resolution. For archival data (beyond one month of present data) each 24-hour period is stored in a one-day tape archive (tar) file, resulting in an approximately two-minute download per file. Once the file has been downloaded, visualisation takes approximately three seconds per scan. Figure 3 shows a single image from the visualisation output on 07 November 2016 at 18:10 UTC at the 0.4° elevation angle from De Bilt. In this case,

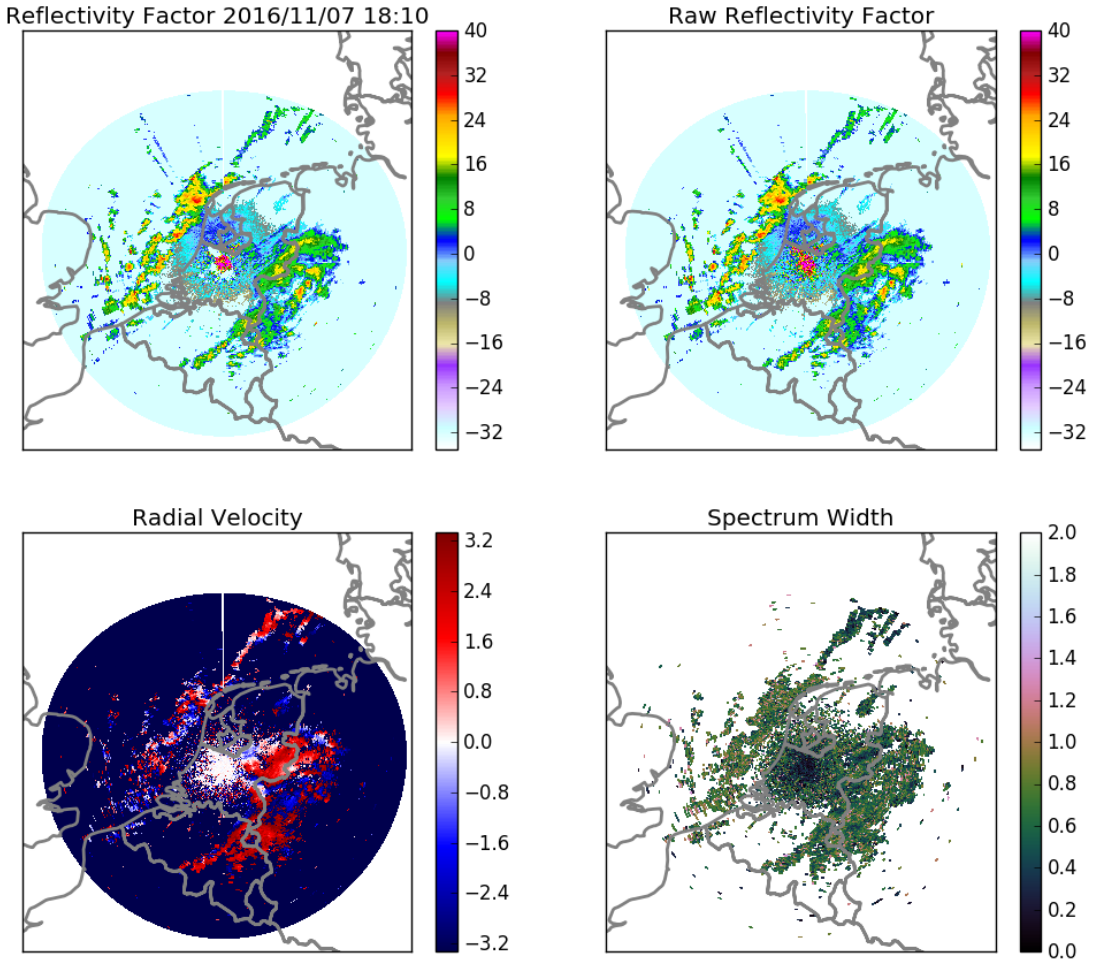

Figure 3: Result of the radar visualisation for the 0.4° elevation angle at the De Bilt site on 07 November 2016 at 18:10 UTC.

two lines of precipitation are oriented southwest to northeast with migration located between the storms. Ground clutter is visible near the radar site, characterised by near-zero radial velocity and spectrum width. Images such as these can be combined to form animated gifs showing the time-evolution of storms and the onset of migration.

While the development of this visualisation was a success, there are still ongoing challenges in ensuring compatibility with Windows operating systems and across computers. Specifically, downloading the correct combination of packages with the correct versions must be done manually, and is especially difficult if other versions of Python (e.g., version 2) must also be installed for other purposes.

3 FlySafe Visualisation Development

Following the success of the visualisation software, we began working with Hans van Gasteren to create a visualisation that is compatible with the FlySafe programme (flysafe-birdtam.eu). Currently, FlySafe uses weather radar to produce vertical profiles of bird density as an aviation risk product, as well as other hazard prediction products (called bird notice to airmen, or BirdTAM). More information on the FlySafe programme and their current and proposed capabilities can be found in their technical document (http://www.flysafe-birdtam.eu/files/FlySafe%20-%20ESA%20 bulletin%20144%20-%20November%202010.pdf). Following this conceptual framework, our goal was to convert the KNMI radar products in to spatially-explicit maps of BirdTAM risk warning levels.

Starting with the raw products from the KNMI server, the logarithmic radar reflectivity factor (Z) is converted from decibel units of dBZ to its linear form (z) using

$$z = 10^{\frac{Z}{10}}, \tag{1}$$

resulting in units of mm^6 m^{-3}. Next, conversion to reflectivity (η) is achieved using

$$\eta = \frac{z\pi^5 |K_m|^2}{\lambda^4}, \tag{2}$$

in which K_m is the complex refractive index of water, with $|K_m|^2 \approx 0.93$; λ is the radar wavelength and takes a nominal C-band value of 0.06 meters; and the resulting reflectivity has units of m^{-1}. Conversion to aerial bird density (n_{bird}) requires assuming a nominal radar cross-section, here $\sigma_b = 11$ cm^2. Aerial bird density is then defined in units of birds per cubic kilometre as

$$n_{bird} = \frac{\eta}{100000\sigma_b}. \tag{3}$$

Finally, the resulting bird densities are discretised into BirdTAM risk warning levels defined by:

$$
\begin{aligned}
160 <& n_{bird}, & 10 \bullet \\
80 <& n_{bird} \leq 160, & 9 \bullet \\
40 <& n_{bird} \leq 80, & 8 \bullet \\
20 <& n_{bird} \leq 40, & 7 \bullet \\
10 <& n_{bird} \leq 20, & 6 \bullet \\
5 <& n_{bird} \leq 10, & 5 \bullet \\
2.5 <& n_{bird} \leq 5, & 4 \bullet \\
1.25 <& n_{bird} \leq 2.5, & 3 \bullet \\
0.625 <& n_{bird} \leq 1.25, & 2 \bullet \\
0.3125 <& n_{bird} \leq 0.625, & 1 \bullet \\
& n_{bird} \leq 0.3125, & 0 \circ
\end{aligned}
$$

with higher levels indicating greater risk to aviation. Figure 4 shows the resulting BirdTAM visualisation product corresponding with the radar scan shown in Figure 3. In this visualisation, white indicates 'no scatterers detected', while green, yellow, and red indicate successive levels of risk. The signals above a maximum threshold are likely to only occur in precipitation or ground clutter, and therefore are censored black.

Again, successive images can be combined to form animations, an example of which is provided in Figure 5. In this case on 03 October 2016, the dusk ascent of migrating birds is captured at five-minute resolution, and shows the escalation of aviation risk from 'none' to 'high' over a span of 15 minutes. Cases like these illustrate the value of producing spatially-explicit characterisations of flight risk in an operational context. These images are currently produced sufficiently fast to be implemented in real-time and distributed over a web interface. This online capability is an ongoing project extending beyond the duration of the STSM, and will hopefully be running for all Dutch and Belgian radar sites in the future.

Additional improvements are also planned for the BirdTAM visualisation product, one of which is using additional elevation sweeps to account for the inherent range bias in migration intensity. A second task will be developing a radar mosaic product by merging the individual radar sites across the Netherlands and Belgium to create a single continuous map across the region. Finally, some minor changes to the BirdTAM colourscale are planned.

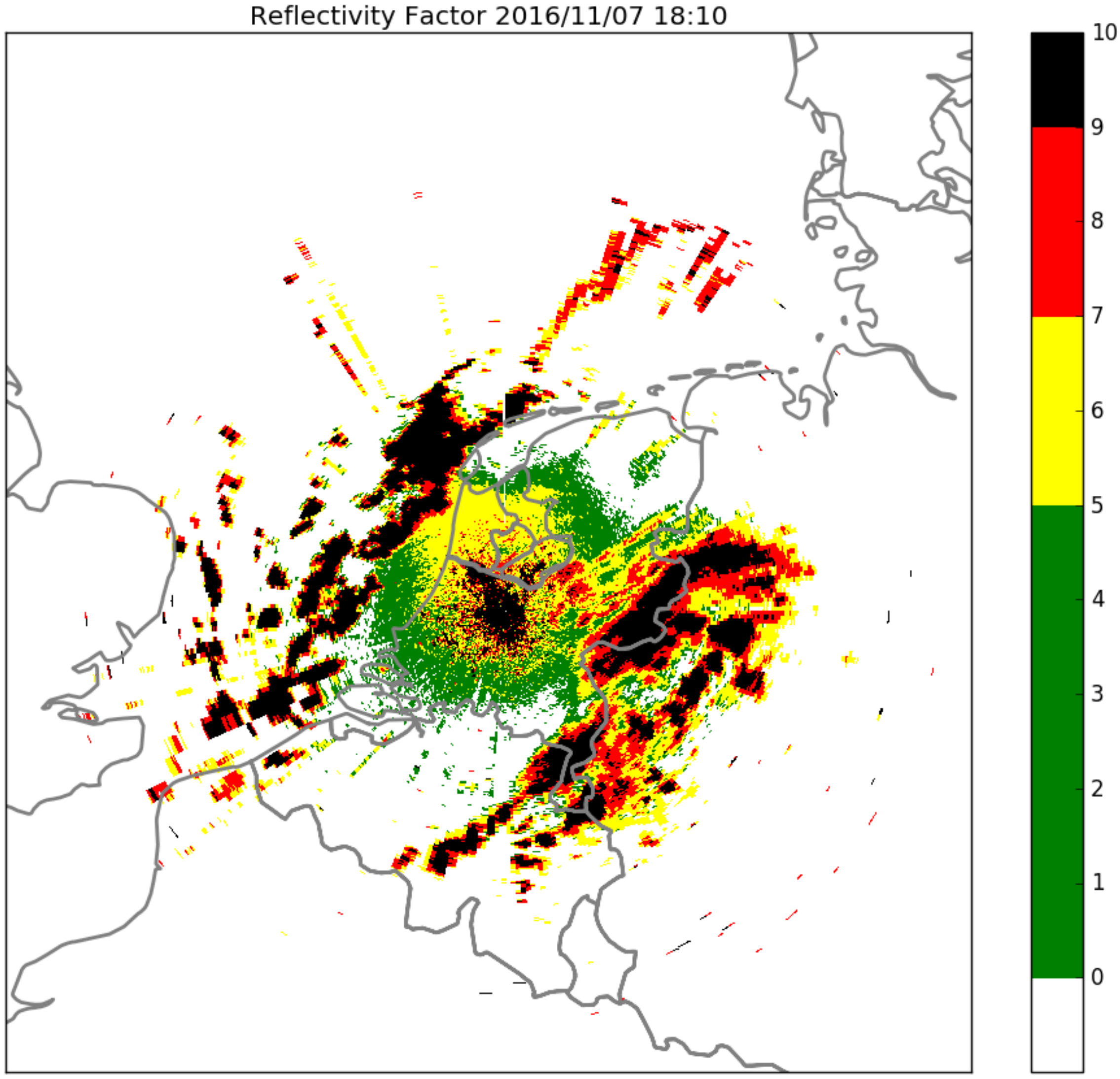

Figure 4: The proposed FlySafe visualisation product corresponding with the radar scan presented in Figure 3 from the De Bilt radar site on 07 November 2016 at 18:10 UTC during a case of migration in the presence of two precipitation bands (northwest and southeast of the radar site). The colourscale and associated BirdTAM risk warning levels are described in the text.

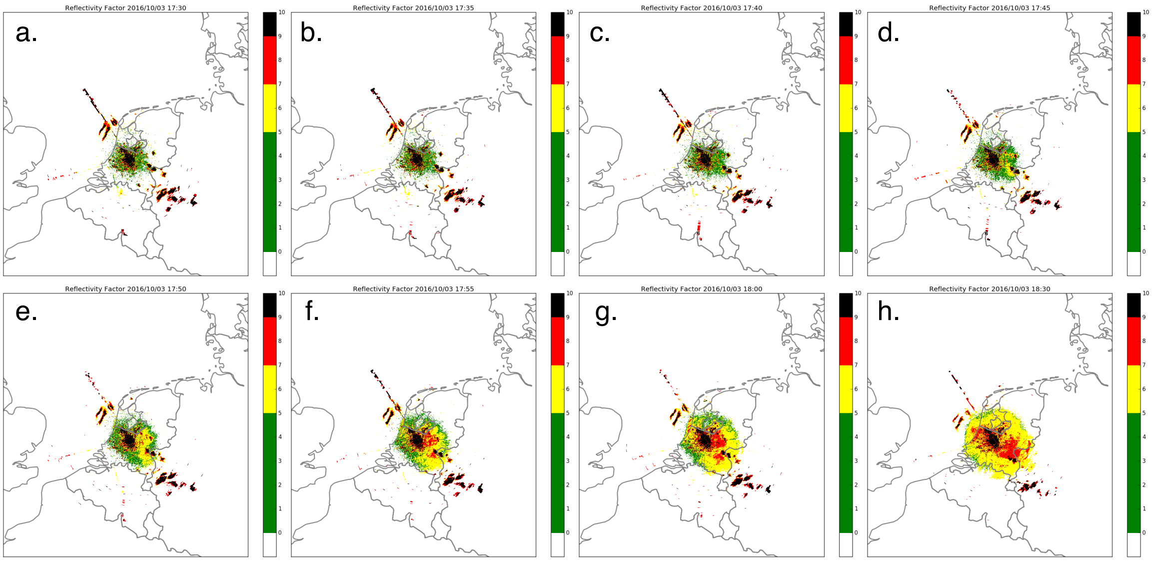

Figure 5: Sequence of successive frames from the FlySafe visualisation animation, showing the dusk ascent of migrating birds on 03 October 2016 at (a) 17:30 UTC, (b) 17:35 UTC, (c) 17:40 UTC, (d) 17:45 UTC, (e) 17:50 UTC, (f) 17:55 UTC, (g) 18:00 UTC, and (h)18:30 UTC.

4 British Radar Data Exploration

As a final task, we needed to decide whether to generalise these plotting algorithms to run on data from the UK weather radar archive. It has been unclear how capable the UK weather radar systems are at detecting biological scatterers, so inspection of known cases of migration was used to address this uncertainty. Using existing MATLAB software, we looked at several cases characterised by favourable tailwind assistance and strong migration over the Netherlands. An example of such a case is shown in Figure 6. In these cases, migration is visually apparent but often lacks the clear definition seen in other countries. Additionally, ground clutter contamination is apparent at farther ranges in the UK, obscuring typical regions of widespread migration. Nonetheless, the visible patches of migration—especially coordinated Channel crossings as in Figure 6—have motivated the development of functionality of the Dutch visualisation tools for plotting British data. Currently, the Python code has been generalised for downloading UK weather radar data from the MetOffice archive server, but the additional code for reading the files—which use a non-standard storage format—is still in development. Unlike most OPERA countries, the UK does not use the HDF5 format, but rather a custom binary file format specifically designed for their weather observations. The description of this Met Office digital file

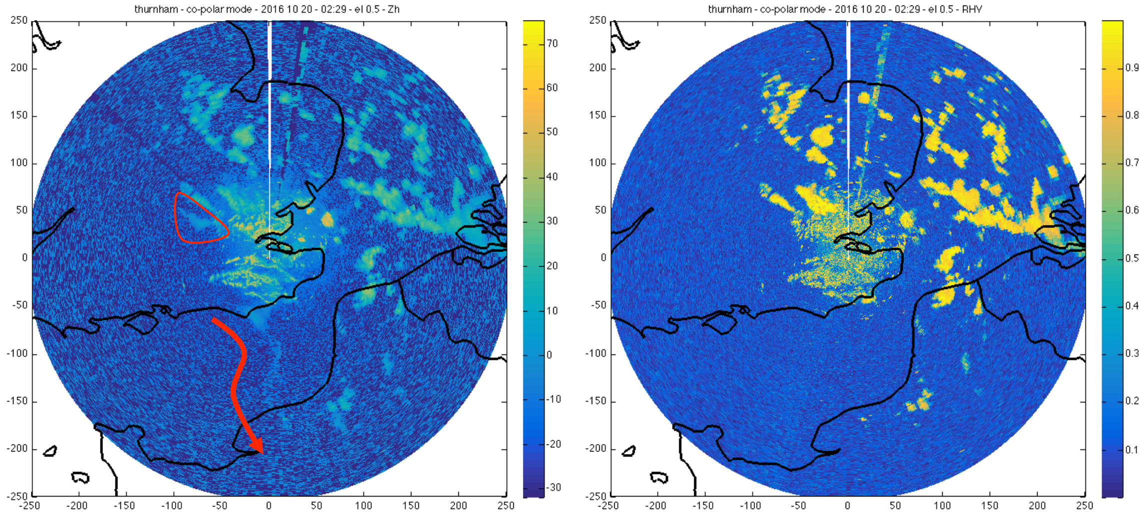

Figure 6: A case of migration from the Thurnham radar site on 20 October 2016 at 02:20 UTC. (left) Radar reflectivity factor and (right) correlation coefficient products for the 0.5° elevation angle. Areas of localised strong movements are annotated in red.

format (named 'NIMROD') can be found in the technical document located at the following web address: http://cedadocs.badc.rl.ac.uk/1256/.