COST ACTION ES1305 (ENRAM) WG1 & WG2

Joint Workshop on Design of Biological Algorithms for Weather Radars
$8^{th}$- $9^{th}$ July 2014
Finnish Meteorological Institute, Helsinki, Finland

Local Organisers: Jarmo Koistinen (FMI), Matti Leskinen (UH)

Attendees: Chris Abela, Johan Backman, Alessio Balleri, Jan Blew, Jason Chapman, Phil Chilson, Adriaan Dokter, Alistair Drake, Natalino Fenech, Günther Haase, Jukka Huhtamäki, Hanna Huitu, Iwan Holleman, Przemyslaw Jacewicz, Reino Keránen, Jarmo Koistinen, Mati Kose, Hidde Leijnse, Felix Liechti, Matti Leskinen, Jason Lim, Valery Melnikov, Boyan Michev, Gonzalo Mũnoz Arroyo, Cecillia Nilsson, Don Reynolds, Laura Rojàs, Curtis Wood, Karl Woodbridge, Pavel Zehtindijiev. (30)

**8th July**

Welcome and introduction to the meeting from Jarmo, round table introductions to start the meeting.

**Session 1: Review and presentations of existing algorithms for diagnosing migrations with weather radars**

**1 - Laura Alku (Vaisala): Hydro Class for separating meteorological and non-meteorological targets in Vaisala radar systems.**
Laura introduced the Hydro Class software for identifying different forms of hydrometers (forms of precipitation) and separating biological and other non-meteorological targets from weather radar returns. The algorithms use ‘fuzzy logic’ to separate radar signals into three classes:-

1 Meteorological/non- meteorological (bio scatter, ground clutter etc.)
Uses horizontal reflectivity (Zh), differential reflectivity (ZDR) and cross-correlation (PHV) coefficient to distinguish bio-scatter from met targets

2 Meteorological Classifier (Hydrometeors)
Uses Zh, Zdr, Phv, altitude (H), specific differential phase (KDP) and melting layer height (MLHGT). It has five classes – rain, wet snow, dry snow, grapel and hail. The algorithm has been verified by in-situ calibration measurements, and optimised for C-band wavelength

3 Weather patterns (Cell classifier)
Uses Zh and H – identifies the weather patterns e.g. evidence of convection, presence of thunderstorms etc.

Optimization/calibration work done in collaboration with the University of Helsinki and Colorado State University (USA)

**2 - Adriaan Dokter (UVA) and Hidde Leijnse (KNMI): Bird migration detection algorithm based on the local Doppler velocity variance and its implementation status in OPERA**

Introduced the bird detection algorithm that they are currently using in the Netherlands. Based on radial velocity, the bio scatterers have patchy (textured) radial velocity, whereas weather (rain) has a very smooth radial velocity. The problem is that insects also have a smooth pattern of radial velocity "if they are travelling with the wind". The reflectivity is related to bird density and bird cross-section – so 1 large bird gives similar value to lots of small birds, there is no way to separate them.

The bird-detection algorithm is working well on the five Dutch & Belgian radars, and is ready for implementation of additional radars.

Prospects for Insect-detection Algorithm – the simple method would be to subtract "birds" from the clear air echoes (in the absence of rain), the remainder *should* be insects

Moving to dual polarization will improve the target classification procedures

A problem using the bird-detection algorithm on WRs is that most bird migration is at relatively low altitudes – this is fine in flat Holland, but a problem in more mountainous countries, where ground clutter will mask the bioscatterers in the lowest altitudes

**3 - Phil Chilson (OU): Algorithms to track the migration of birds along the US east coast**

Working on algorithms to track the migration of birds along the east coast of the US (motivated by plans to put wind farms along the east coast). The study area is offshore around Delaware  Bay and Chesapeake Bay. Not very good coverage in this area, so trying to use NEXRAD operational weather radars (WRs) to study bird migration over a wider area.

Composite Reflectivity (CREF) data goes through Quality Control to remove non-meteorological material. The non-meteorological material (which includes the bio-scatterers) is archived and available. Data is provided for $0.01^0$ x $0.01^0$ squared (~1km$^2$) every 5 minutes.

The algorithm Phil is developing uses the QC CREF to filter out the cases in the UN_QC CREF where "weather" is present – so everything else (including birds) is kept in. Data is sampled from 24 points around the weather radar in a circular pattern, and for six weeks along the east coast which gives 144 data points in total. Looking at several years' worth of data for spring (May) & Autumn (September/October) migrations at sunset (±1hr), midnight (±1hr) and sunrise (±1hr).

Preliminary results show high-intensity bird migration over the land, but in Spring there is no movement over the sea (whether this is genuine, or due to data collection problems needs further work), in Autumn there is movement over the sea.

**4 - Valery Melnikov (NOAA): Doppler velocities at orthogonal polarizations in radar echoes from insects, birds, and precipitation**.

Discussed the velocity data collected by dual-polarization weather radars – where there are two planes of polarization $90^0$ from each other (orthogonal), horizontal and vertical polarization.

DDV = differential Doppler velocity

Precipitation has very similar velocity in horizontal and vertical, so DDV is close to zero. But birds can have DDV values >5m/s; DDV typically <0.5m/s, sometimes up to 1m/s for weather. Insects can have DDV values about 1-3m/s , so potentially separable from weather although the main peak is <1 m/s; also there is much overlap with birds.

Often see peaks in DDV at the fringes of clouds – are birds/insects entering the edge of clouds?
Why is the DDV of birds so high?
Large DDV values arise from multi-peak Doppler velocity spectra – which probably arise from different species or groups of species (large and small birds; birds and insects) migrating together – so DDV gives an indication of diversity
Insect DDV values are sometimes much higher in layer at the top of the boundary layer, than lower down
DDV can be high in thunderstorms/tornados – birds and insects are trapped in inflow areas. This DDV values can be used to identify spatial location and height range of inflow associated with storms
In summary DDV could be a useful additional parameter for separating meteorological and non-meteorological targets. The problem is that the software needed is not routinely used on WRs. It is currently only on one research radar in the UK.
DDV also has an azimuthal dependence - the value depends on the aspect of the target relative to the beam (i.e. whether a bird is head/tail-on to the radar, or side-on to the radar).

## Session 2: Review and presentations of existing algorithms for diagnosing migrations with weather radars (cont.)

### 5 - Jukka Huhtamäki (Eigenor): Birds in triple-PRT measurements

Software developer from private company – signal processing for WRs. Triple PRT refers to the use of three different pulse intervals. The software has been used on a Finnish WR with scans of $10^0$ /s over a 260km range.
Birds and insects are separated by software- “insects” are passive wind-tracers in the day; birds have airspeeds of about 10 m/s. Insects have higher “Differential Reflectivity” than birds, which have higher values than weather.

### 6 - Phil Chilson (OU): Examples of polarimetric and non-polarimetric signatures of bat emergencies

Brazilian Free-tailed Bat 11-14g, wing-span of 30-35cm. Aerial insectivores – moths and other insects. Largest colony – Brazilian Cave, TX ~20m bats
Used X-band radars (storm chasing radars) to study bat emergence from Frio Cave (TX)

Bats emerge from the cave and travel to agricultural lands – rocket up high on emergence to avoid predation, travel high to crop lands, then descend to catch moths. Differential reflectivity values range from +6 to -6 (a very large range). Phil has been modelling X-band reflectivity from bats to try to understand the Zdr value observed by radars.
Bat Radar Cross-section (RCS) modelled, then validated by measuring RCS of a freshly dead bat using Z horns (horizontal and vertical polarization) in the field. Measurement matched the model extremely well.
So models can be developed for any animal (in X-Band), as long as detailed topographical information can be provided on the body shape of the animal. Based on modelling the surface reflectivity but in reality it is the inside which reflects.
Bat emergences travel quickly up to about 2-3km height before dispersing. Polarimetric data can also be used to estimate the densities of flying animals and their orientation.

**7 - Alistair Drake & Susan Rennie (UNSW): Observations of insects with weather radars in Australia**

WR network in Australia is largely along the coast, especially the North coast for watching cyclones. S-Band radar is preferred in the tropics (better rain penetration), but the S and C-Band radars are used in research, not operationally.

Susan Rennie's results from a WR in inland SE Australia were presented – a good area for looking at insects (clear – air echoes). Yarrawonga radar site – flat plain.

Night time insect echoes (locusts) show common alignment (visible as asymmetry in the reflectivity patterns, due to insects being head on or side on to the beam); and crab angles from wind up to $\pm 50^0$

Daytime insects appear in convective updrafts, don't show any alignment patterns

Layers appear as rings; sometimes narrow line echoes travel in front of morning weather (precipitation) front – may be lifted by a passing solitary wave

Bird echoes are not observed very frequently – and when they are, they tend to be tight patches associated with pre or post-roost flights of communal birds; or then linear e.g. gulls crossing a bay

Australian Bureau of Meteorology (Rennie) is investigating whether insect echoes (Doppler speeds) can be assimilated into weather data. This depends on insect airspeed and orientation. They are developing a classification scheme for separating weather, insects, chaff, birds, bats etc. Classification depends on strength and 'texture' of the reflectivity, and the 'texture' of the velocity.

**Session 3: Review and presentations of existing algorithms for diagnosing migrations with weather radars (cont.)**

**8 - Matti Leskinen (UH): Recognition of insect migrations in polarimetric C-band weather radar measurements**

Matti presented images of insects detected by polarimetric C-band radar. He was able to see huge invasions of insects from Baltic countries, across the Baltic Sea into Finland. One intriguing result is a right-left asymmetry in differential phase measurements – not sure if this is a local effect, or more widely seen.

**9 - Valery Melnikov (NOAA): Orientation of insect's bodies retrieved from radar data**

Most polarimetric weather radars are "STAR" radars (Simultaneous Transmission and Reception of horizontally and vertically polarized waves). In STAR radars, echo patterns are frequently **asymmetrical**, especially in differential reflectivity (ZDR). This needs to be explained:

Insect body is ellipsoid (approximated as a prolate spheroid), and assumed to have the dielectric permittivity of water.

WSR-88D radars are capable of estimating various parameters of flying insects, including shape. If information on insect species is available, density can be estimated.

It was thought that the asymmetry in the reflections is due to insects flying with their body tilted, so that there head is up but their tail down – so even when they flying along a horizontal plane, it is thought that their longitudinal body axis is not horizontal, but tilted upwards, giving rise to the asymmetry that is recorded.

**10- Jarmo Koistinen (FMI): Classification of non-meteorological echoes with C-band polarimetric radars applying new statistical methods**
Dual-pol (H+V) provide additional quantities compared to single-pol (Doppler – H only)
He is developing statistical models, using 1000 training cases – separated into 4 types of insects, 4-5 types of birds, 1 mixed insects and birds (the insects are separated on basis of: day-land, day-sea, night–land, night-sea)
Human expert trains a fuzzy-logic statistical classification scheme – but this is a very slow process.

## 9th July

Attendees: Chris Abela, Johan Backman, Alessio Balleri, Jan Blew, Jason Chapman, Phil Chilson, Adriaan Dokter, Alistair Drake, Natalino Fenech, Günther Haase, Jukka Huhtamäki, Hanna Huitu, Iwan Holleman, Przemyslaw Jacewicz, Reino Keránen, Jarmo Koistinen, Mati Kose, Hidde Leijnse, Felix Liechti, Matti Leskinen, Jason Lim, Valery Melnikov, Boyan Michev, Gonzalo Mũnoz Arroyo, Cecillia Nilsson, Don Reynolds, Curtis Wood, Karl Woodbridge, Pavel Zehtindijiev. (29)

**Session 4: Validation methodologies of migration algorithms and Work plan for day 2**

**Felix Liechti (Swiss Ornithological Institute): Reference methodologies in bird migration**
Felix indicated that WG2 would like to turn the 'blips on the screen' of WR's into information on the movement of bird and bat populations
An important differentiation between WRs and Bird radars
WR – reflectivity per volume
BR – targets per volume

But the volume sensed depends upon the size (RCS) and aspect of the target, so densities have to take this into account

Scanning and static beam BR's have pros and cons
Target identification is difficult, but BR's can provide the following parameters:-
Ground speed
Air speed
Total echo size (reflectivity)
Variation of echo (polarization dependence, wing beat frequency)

Insects and birds can be separated on the basis of air speed, echo size (reflectivity) and echo variation (e.g. WBF)

Tracking radars provide WBF and wing-beating patterns (e.g. flap-glide-flap)
Tracking is widely used; this data should be used to help interpret radar data; also ground truthing data on bird observations (e.g. Euro bird Portal)
WG2 need to establish what techniques are available to the group, what parameters can be collected, and what overlap with WRs at the chosen field sites
Possibility: generate a central database of bird target characteristics

**Alistair Drake (UNSW) and Don Reynolds (University of Greenwich): Verification value of insect observations made with X-band vertical-beam radars**

Introduced the modern vertical-beam X-band insect radars – these are non-coherent, pulsed (not continuum), and don't have Doppler; but do have rotating polarisation and nutation (slight wobble)
Size (RCS), shape, (WBF – sometimes), height, displacement speed and direction, and body alignment information are available for good quality signals. WBF (insects: 1-3dB; birds 10dB) produces a small modulation ("ripple") on the signal (cf. birds, which have heavily modulated signals due to WBF); an advantage, because the WBF modulation does not mask the other information (the modulation caused by polarisation and nutation)

The rotating linear polarisation measures the RCS of the vertical aspect of overflying insects ($a_0$).

Insect monitoring radars detect only the larger insects (>2mg); micro-insects are much more abundant (x 100 at least), but it's not clear if they contribute much to the total WR reflectivity, as individual RCS are very small.
Densities of insects typically in the region of about 1 per million sq. metres, sometimes 2 or 3 orders of magnitude higher
Activity patterns (e.g. dawn and dusk peaks) and vertical distributions (e.g. nocturnal layers) can be measured and are well known
Patterns of common alignment are also frequent, which has implications for the output expected on WRs

*Minutes taken by Jason Chapman*

**The participants then broke into 2 groups for separate WG discussions:**

**Minutes of the WG1 meeting during the ENRAM workshop in Helsinki**

**Discussion: Fuzzy logic approach vs more physical approach.**
There are several ways to separate biological from meteorological scatterers in weather radar data. The first distinction is between a fuzzy logic approach (where as many data as possible are used in an algorithm that is trained based on independent observations) and a physics-based approach (where a limited number of variables are used in an algorithm that is based on what we know of the behaviour and the scattering cross-sections of the birds/insects). The second distinction is between determining the type of scatterer (bird/insect/meteorological/etc.) per pixel or per radar (in which many pixels around the radar are used). There was a discussion on what approach to focus on within ENRAM.

The outcome of the discussion is that we should focus on the development of physics-based algorithms that provide information per radar. The main reason for opting for physics-based algorithms is that these types of algorithm are more generally applicable and don't require training. The ENRAM aim of implementing them across Europe calls for such generally applicable algorithms. We will use ingredients of fuzzy logic algorithms to determine which members will be interesting to use in physics-based algorithms. Specifically the algorithm presented by Alistair Drake (on behalf of Susan Rennie from the Australian Bureau of Meteorology) will be beneficial in this respect. This algorithm uses reflectivity, echo top height, spectrum width, vertical gradient of Z and V, texture of Z, and spin change (change in sign of reflectivity gradient in 2D kernel). The reason to opt for an algorithm that yields just one profile per weather radar is because such algorithms are generally more robust. The data will also be easier to use for studying large-scale migration across Europe.

One of the boundary conditions we took was that it should be possible to implement the resulting algorithms in OPERA. This means that the algorithm should be generally applicable. Moreover, it means that the algorithms shouldn't depend on the availability of polarimetric variables, as OPERA won't provide these variables for several years to come. The implication of this is that it will be difficult to distinguish between small and large insects. One thing that could aid us here is to look at azimuthal patterns of reflectivity. However, these may very well be influenced by horizontal density gradients. Unfortunately the Rothamsted entomological radar cannot measure small insects, so it is difficult to find out how many of these are in the air, and whether their signal would dominate that of larger insects. Looking at daytime returns on warm days may help.

Adriaan has volunteered to study the Australian Bureau of Meteorology algorithm, and to see which of the variables used in this algorithm would be suitable for use in a physics-based algorithm. In developing an algorithm that can detect insects, it is of course vital to be able to validate the algorithm. This requires ground truth. Apart from using the Rothamsted entomological radar, it is suggested to use expert judgement based on polarimetric radar data. Matti Leskinen has volunteered to provide this judgement.

*Minutes taken by Hidde Leijnse*

**Minutes of the WG2 meeting during the ENRAM workshop in Helsinki**

Goal: To get as much info as possible from other sources than weather radar to transfer info to the weather radar data analyses.

<u>Plans for the validation measurements</u>
Because it is not possible to bring many radars to a single site, several validation measurements will take place at different sites. At all sites we need to get data not only from specific bird/insect radar systems but also from the closest weather radar systems.

Günther Haase: able to provide weather radar data for most countries, not for UK (reflectivity, wind and wind velocity, spectral width)

Planned observation period: continuous or selected nights during August – October 2014.

**Rothamsted (Jason, Felix, Giacomo):** continuous parallel measurements will be performed during August-September with the Swiss "Birdscan" (fixbeam-radar) and the Rothamstad vertical looking insect radar. Within an STSM Giacomo will bring his fan-beam marine radar during October?
From a nearby dual-pol C-band weather radar in some 18 km distance, data should be available for the whole period.
To compare: RCS, migration intensity, height distribution

**Lund (Cecilia, Johan):** During selected nights (September – October) tracking and semi-quantitative data (will try countings within a fixbeam) will be collected by Cecilia and Johan. Dual-pol weather radar should be available for the selected nights from southern Sweden (~ 60 km) and Denmark (~30-40 km).
To compare: (qualitatively) RCS, height distribution
Maybe collect Ornitho.se and Falsterbo data for additional information; maybe get moth (insect) data from Lars Petterson; consider PhD Student project for 2015

**Bulgaria (Pavel, Boyan):** Data from an automatically running fixbeam radar within a windfarm at the Black seas coast (Kaliakra) will be available for this period; there is also a RobinRadar plus field ornithologist to verify / provide info. It is unclear what data are from those five weather radar data are available (not part of OPERA). 2 Radars (air traffic) deliver velocity, reflectivity (uncorrected); 3 radars are from Vaisala, should be able to deliver compatible data. However, the data format has been checked and seems to be fine for the analysis.
(some discussion how to proceed with Bulgaria: available are archived data from 2010 up to now, plus 2010 data for 50 locations in Bulgaria; STSM plan to send Boyan Michev to Hidde Lijnse to learn to analyse weather radar data; Pavel would like to have assistance to decide which weather radar to use…..
To compare: undecided…

**Spain (Gonzalo, Antonio-Roman):** A Merlin-System (DeTect) might be available nearby Tarifa for tracking, 1.August to 1. October (autumn migration). Unfortunately the weather radar at Malaga is 100km away (still a correlation of density data might be useful), however data from Gibraltar weather radar might be used better, if available. Ground-truthing of diurnal migration takes place by a standardized observation program at the Strait.
Hidde will contact the weather radar in Sevilla (NW of Tarifa) to find out whether this can provide data.
Jason will contact the Gibraltar weather radar.
To compare: ….

**Malta (Natalino):** A potential comparison between weather radar and visual diurnal observations is the only option for this season ➔ raptor migration?
unclear which weather radar type; airport radar.

**Germany (Jan):** Pencil beam and surveillance radar data from the Fehmarnbelt project are available; Danish side – 2009 (March to November), German side – 2010 (March to November). Weather radar data have been compiled from the Stevns Radar (DK) 2009 and 2010 and analysed manually (M. Desholm, T. Bøvith). This yielded a report with correlations

of migration intensity. Further analyses are possible; further extracted data from the weather radar (2009 and 2010 – to be extracted with the assistance of G. Haase / T. Bøvith); further comparisons between selected parameters.
Additional ornithological data are available: night acoustics (flight call intensity), visual observations (migration intensity).
Permission for data usage will be needed from the client (probably not a problem)..
To compare: ….

**Finland (Matti):** There is the possibility to compare a vertical looking weather radar with a operational weather radar. Ground trothing might be possible. Bat migration data?

**Estonia (Mati):** data are available from a robin system 2013, but only indirect comparison with weather radar on the mainland (Tallin and/or Riga). Parnu – 100 km away; Riga data are not good (bad quality). Mati can provide some 20.000 RCS data; nights with high migration intensity; -

Generally, weather radar data can only be derived through OPERA (Hidde) or BALTRAD (Gunther). Each group will have to contact Hidde or Gunther to ask for bird movements recorded by weather radar data within their area. Details will have to be discussed during the meeting in Tarifa.

*Minutes taken by Felix Liechti & Jan Blew*