ENRAM, and an Unexpected Asymmetry in D-POL Observations of Insect Echo.

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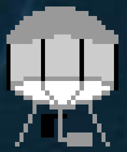
PIRR 2014, Adelaide, 24-25 September 2014.

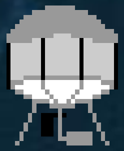


Outline

1. *ENRAM*
2. *Identifying bird and insect echo*
3. *D-POL asymmetries*
4. *Conclusions*
5. *Acknowledgments*

Note

This presentation was prepared for, and given at, *Progress in Radar Research 2014* (Adelaide, Australia, 24-25 September 2014). At the suggestion of the ENRAM coordinator, it is also being made available to ENRAM participants.



1. ENRAM

http://www.enram.eu/

The *European Network for the Radar surveillance of Animal Movement*

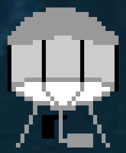
- Europe-wide initiative, funded for 4 years.

- Most European countries represented

- Based on observations from weather radars, available through the OPERA network.

- Bird, bat, and insect flights

- Delegates drawn from radar, radar meteorology, and radar biology communities.



OPERA network

The aim of OPERA is:-

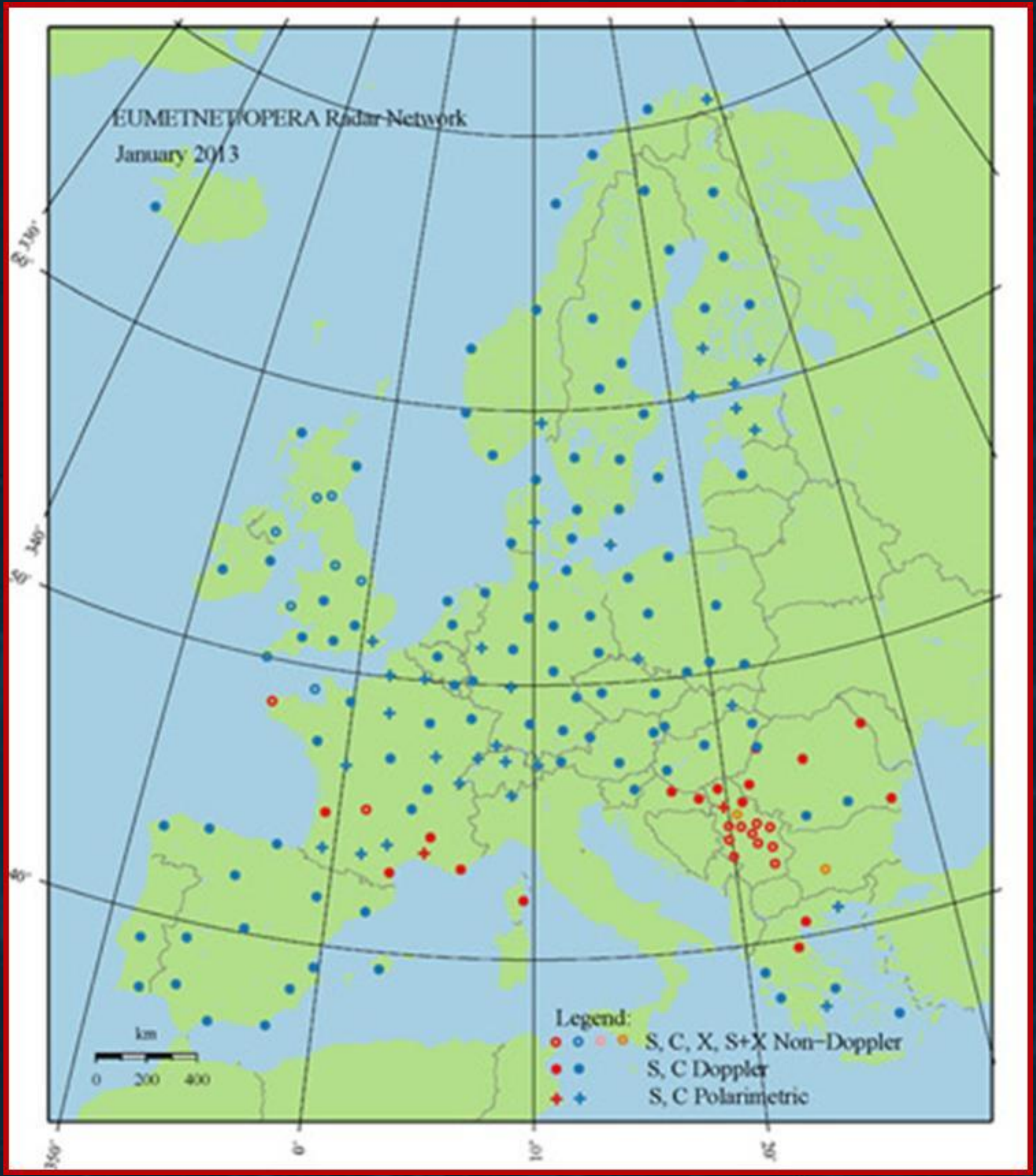
> “to develop, generate and distribute high-quality pan-European weather radar composite products on an operational basis”.

OPERA currently receives and disseminates data from 202 weather radars Europe-wide

-184 Dopplerized, 48 D-POL.

- Radars are of many different types

- Polarization outputs are currently not exchanged



Radars in the OPERA network

Mostly C-band

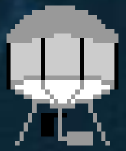
Increasingly being upgraded to D-POL

ENRAM objectives

1) Develop protocol for extracting animal movement data from OPERA weather radars.
2) Promote monitoring of animal movements using existing weather radars
3) Distribute information on spatio-temporal patterns of animal movements across Europe

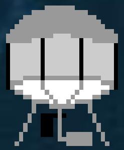
‘Animal movements’ will in practice be restricted to flight well above terrain

- ~100 m or more over land, less over the sea.
- I.e. insects, birds, bats.



ENRAM potential benefits

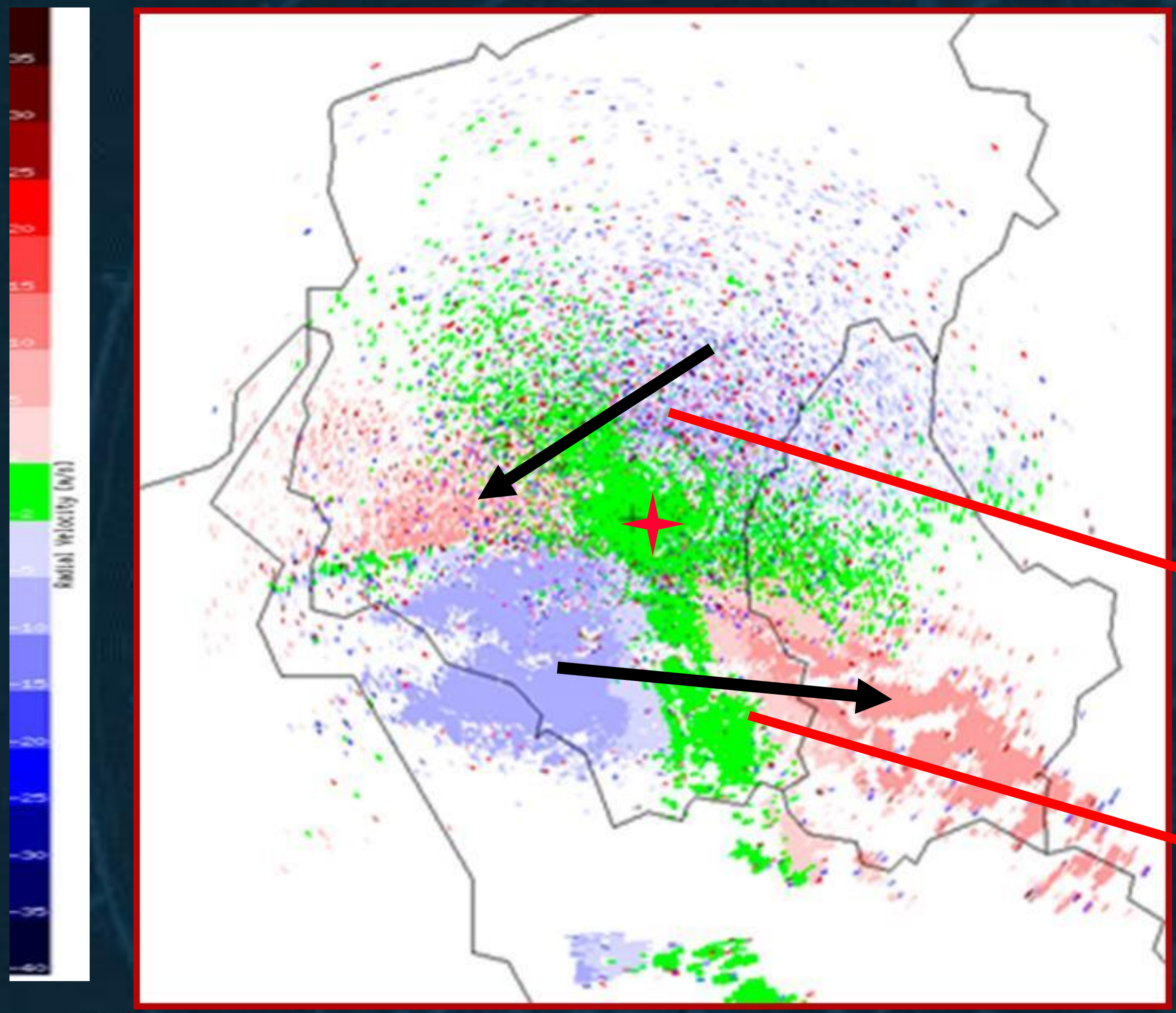
1) Wildlife conservation
    - Recognizing migration routes and timing, reducing hazards, and maintaining stopover habitats.
    - Wind farms a particular hazard for bird migrants
2) Bird hazards to aircraft
    - Especially en route collisions, which are very significant in The Netherlands and Israel.
3) Insect pest management
    - Detect significant invasions, and establish their timing.
4) Weather forecasting
    - Eliminate bird echo from Doppler wind estimates



2. *Identifying bird and insect echo*

2a Non-polarimetric methods

Radial velocity



Birds and precipitation observed with C-band weather radar.

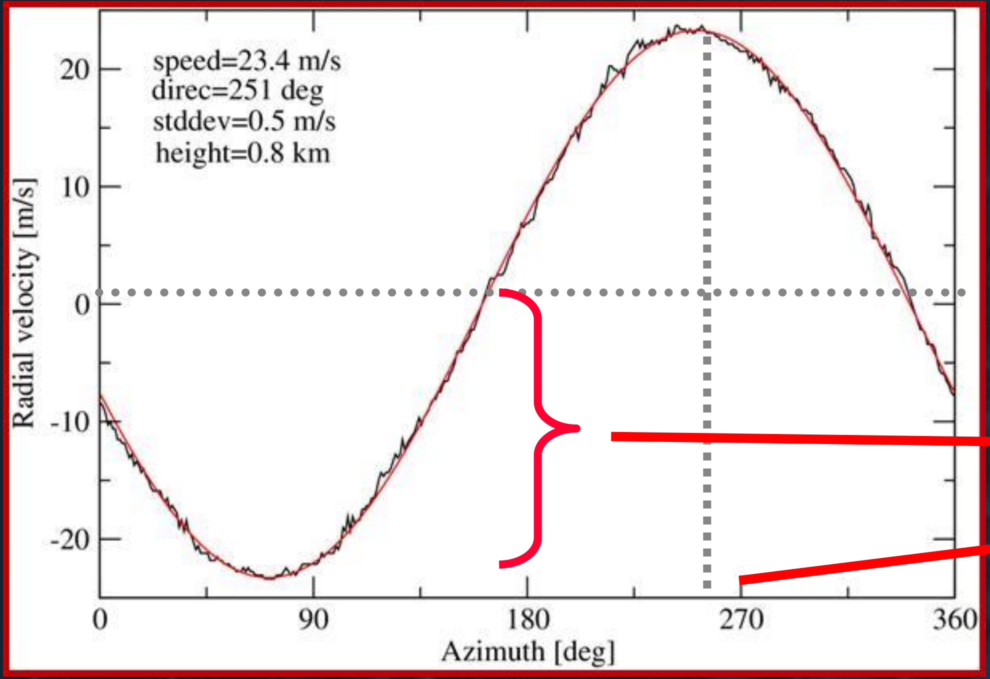
Wideumont, Belgium, 00.47 UTC 29 Sep 2007.

Birds moving to SW, velocity field has granular ‘texture’.

Precipitation moving to E; velocity field is smooth.

From ENRAM presentation by A. Dokter *et al*., July 2014.

Granularity estimated as st. dev. of VAD fit



Precipitation –
st. dev. 0.5 m/s.

14.09 UTC 8 Mar 2003

Ground speed

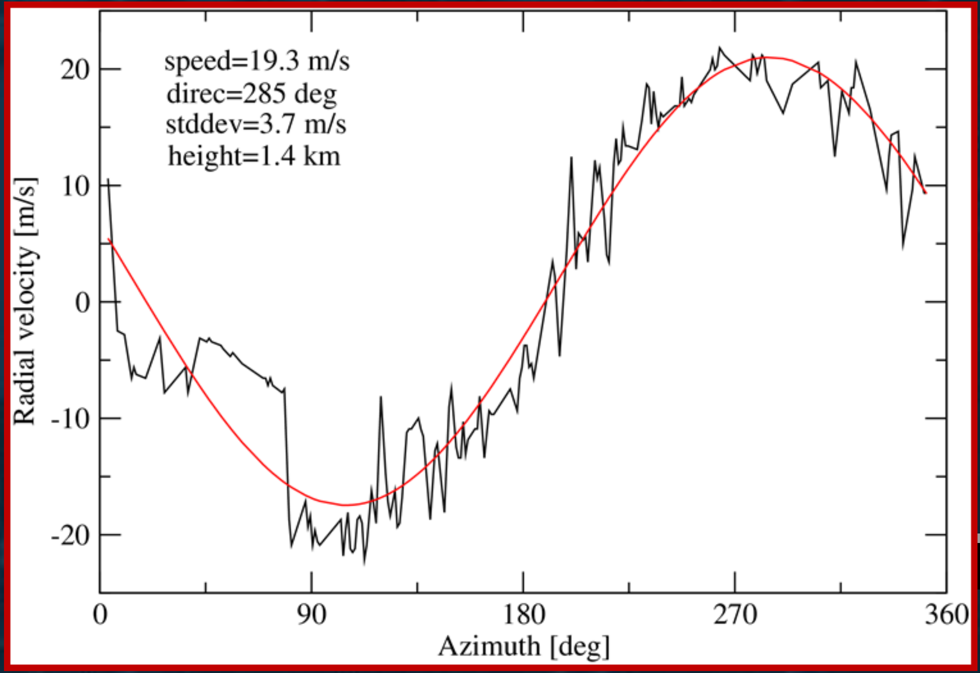
Movement direction

De Bilt, Netherlands.

Birds – st. dev. 3.7 m/s.

00.09 UTC 7 Mar 2003

From ENRAM presentation by A. Dokter *et al*., July 2014. See also Holleman et al. 2007 *J. Atmos. Ocean. Tech.* 25: 2188-2198.

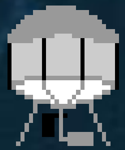


Target classifier (Australia)

Aim is to identify targets that will give reliable wind retrievals

Classes	**Abbrev.**		
Convective precipitation	con	Precip	Use for wind retrievals
Shallow convection	shc		
Stratiform precipitation	str		
Insects	ins	Clear air	Maybe use
Smoke	smk		
Chaff	chf	Clutter	Do not use
Birds/bats	brd		
Permanent ground clutter	pe		
AP ground clutter	gc		
AP sea clutter	ap		
Side-lobe sea clutter	sl		
2nd trip echo	2tp		

From S. J. Rennie *et al*. 2013, American Meterological Society conference presentation.



Quantities used to classify echoes

Field	Description
DBZH	reflectivity
EHGT	echo top height to 4 dB
EHGT2	echo top height to −5 dB, where EHGT does not exist
WAVG	spectrum width from weighted average using adjacent beams
VTDL	vertical gradient of reflectivity
ZTEX[1]	variation of reflectivity in 2D kernel of 11×11
VTEX[1]	variation of velocity in 2D kernel of 15×15
SPIN[2]	change in sign of reflectivity gradient in 2D kernel of 19×19

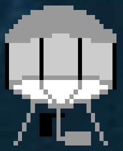
‘Texture’

List is short as only reflectivity and velocity (and spectrum width for a few units) currently available in Australia.

Identify classes using a ‘Naïve Bayesian Classifier’ primed with a training dataset based on expert identifications

~85% of precipitation identified correctly

Little broad-front bird migration in Australia so need to distinguish birds and insects hardly arises

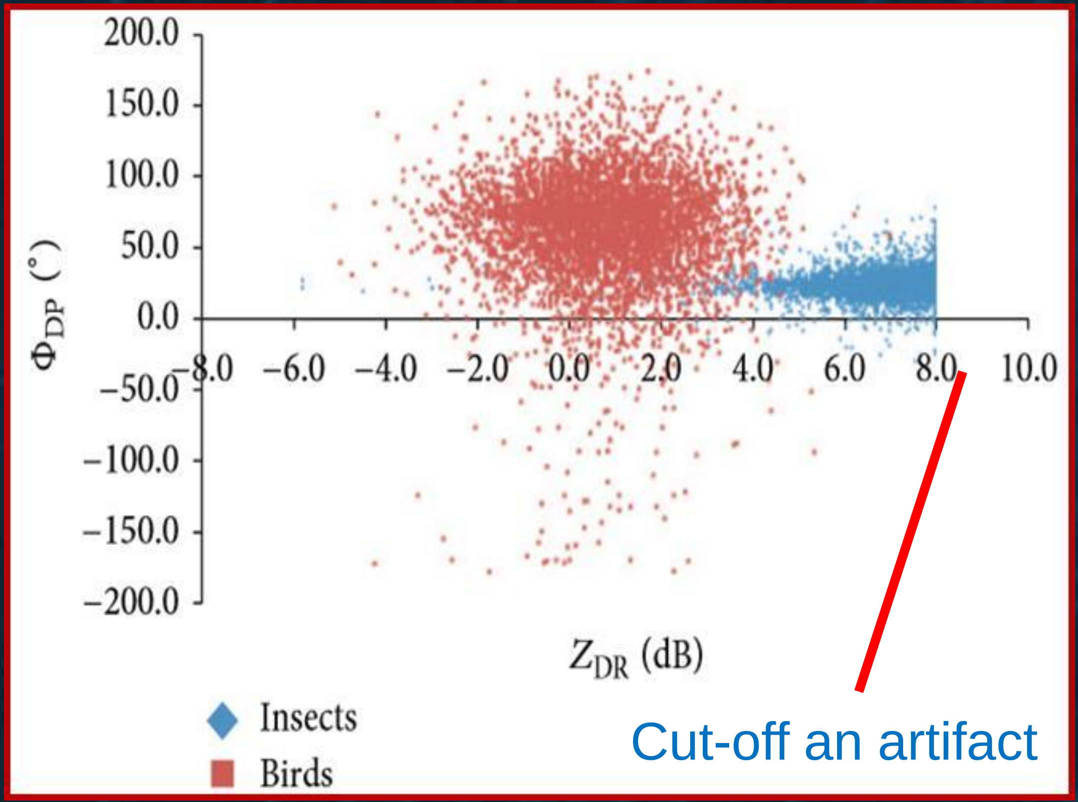


2b. Polarimetric methods

Birds and insects have different polarization properties:-

- Birds are Mie scatterers and only moderately elongated

- Insects (usually) Rayleigh scatterers and (often) highly elongated



Cut-off an artifact

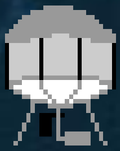
WSR-88D (S-band) at Wichita, KS, USA.

Birds (night-time): higher ϕ_{DP}, lower Z_{DR}.

Insects (daytime): lower ϕ_{DP}, higher Z_{DR}.

<u>However</u>, ϕ_{DP} from WSR-88Ds is shifted to optimize rain estimation, and for birds and insects may vary between radars!

From Jiang *et al*. 2013 *Adv. Meteorol*. 2013:769275 (13 pp.).



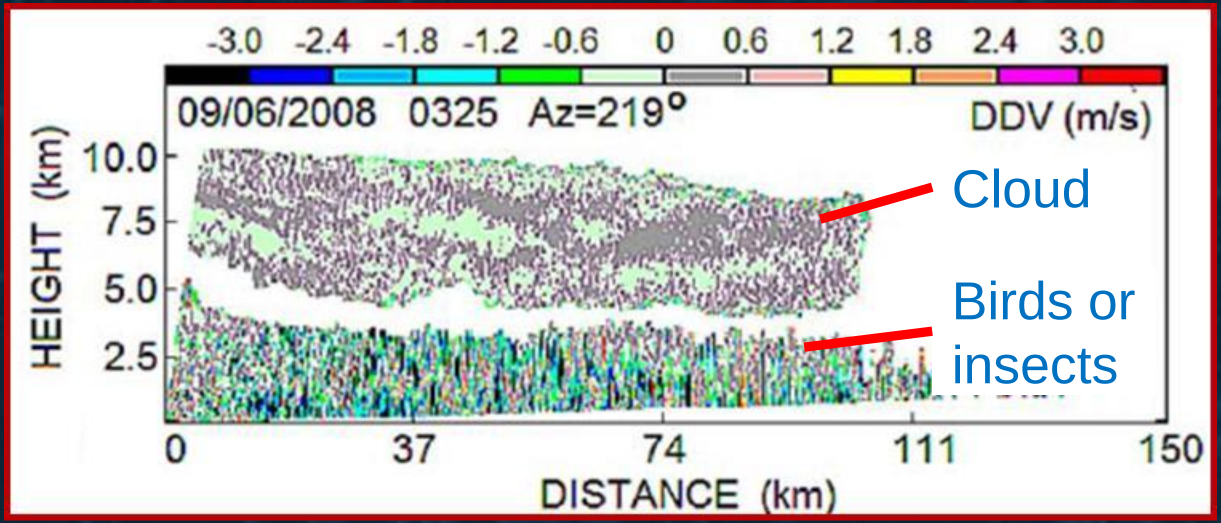
2c. Combined Doppler and polarimetric methods

Differential Doppler velocity (DDV) has recently been proposed as a parameter for distinguishing target types:-

- DDV = $v_{rh} – v_{rv}$ (v_r is radial speed)

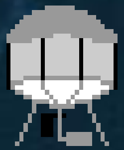
- Raindrops, snowflakes etc. are carried on wind and have similar radial velocities at H- and V-pol. |DDV| <0.5 m/s.

- For birds and insects, |DDV| can reach 5 m/s.

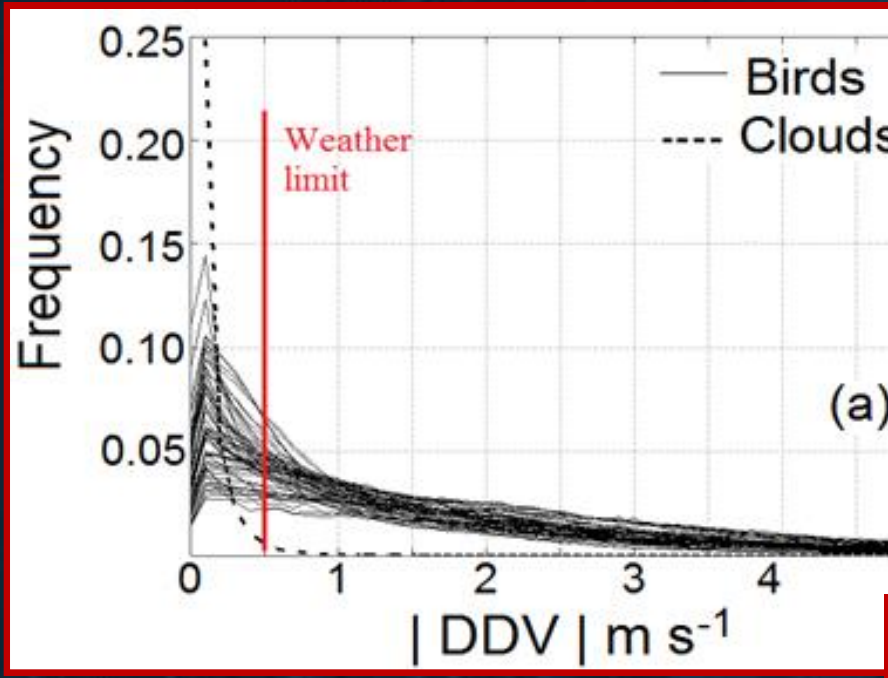


0325 UTC 6 Sep 2008, WSR-88D, Norman, OK, USA.

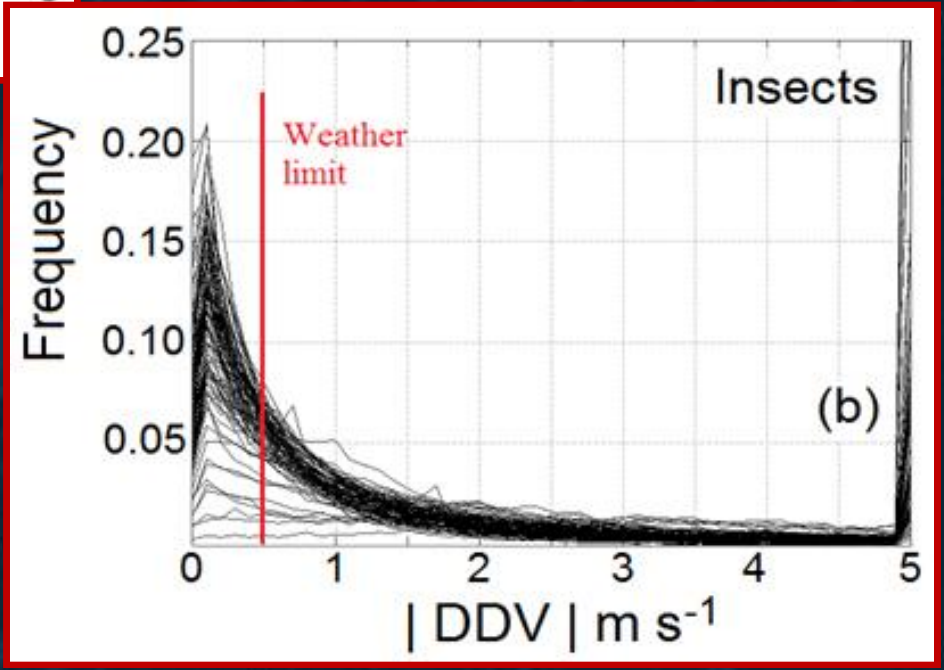
From Melnikov *et al*. 2014 *IEEE Geosc. Rem. Sens. Lett*. **11**(3): 592-596.



Birds show a heavier tail than insects; clouds show no tail.



2006-2008, WSR-88D
Norman, OK, USA.



From ENRAM presentation by V. Melnikov, M. Leskinen, and J. Koistinen, July 2014. See also Melnikov *et al*. 2014 *IEEE Geosc. Rem. Sens. Lett*. **11**(3): 592-596.

Simple model of how DDV arises

Note that for |DDV| > 0, there *must be* at least two different radial speeds present within a pulse volume.

Suppose the population consists simply of two target classes, A and B, with different radial speeds.

> Targets of class A are the more numerous. However, at H-pol, targets of class B have a (much) larger RCS σ.

With V-pol, class A targets dominate the reflectivity, and $v_{\mathrm{rv}} \approx v_{\mathrm{rA}}$.

With H-pol, class B targets dominate the reflectivity, and $v_{\mathrm{rh}} \approx v_{\mathrm{rB}}$.

> Thus, in this scenario, DDV = $v_{\mathrm{rh}} - v_{rv} \approx v_{\mathrm{rA}} - v_{\mathrm{rB}}$.

Simple model of how DDV arises (cont.)

Suppose classes A and B are Rayleigh-region insects with airspeeds v_a flying in a wind with radial component v_{rw}.

Classes A and B differ only by their orientation: class A is tangential to the beam; class B is flying away from the radar.

Then $v_A = v_{rw}$, as the insects' flight has no radial component; and $v_B = v_{rw} + v_a$.

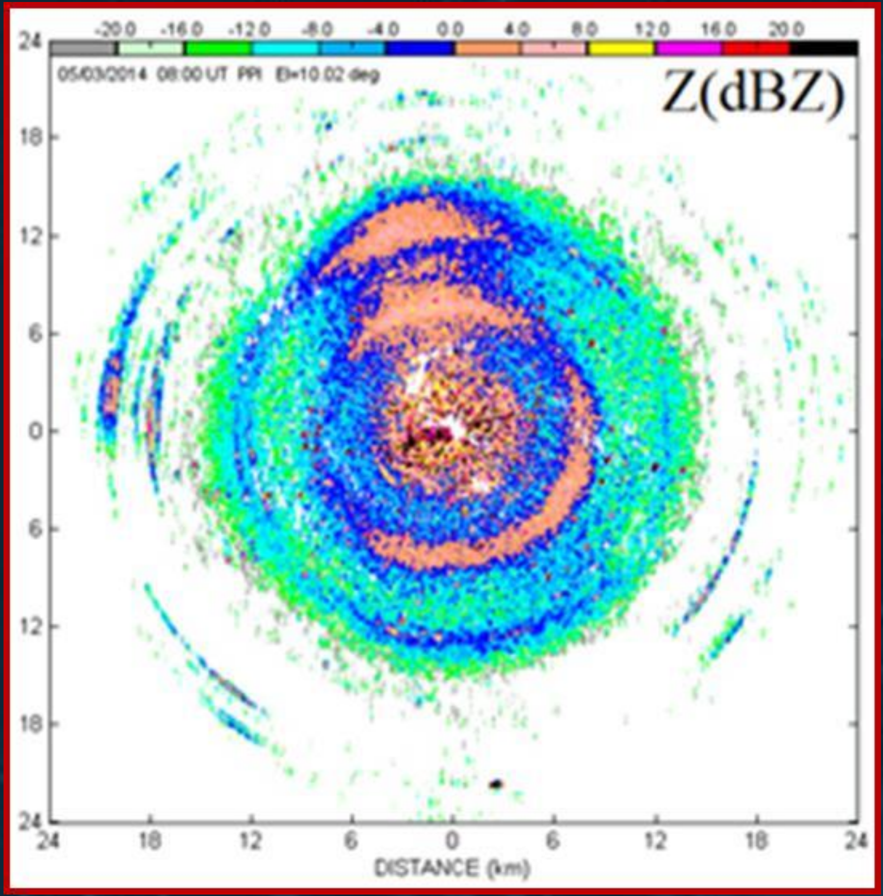
Thus DDV $\approx -v_a$.

Thus DDV can arise from <u>a single target type</u> if this exhibits <u>a range of orientations</u>.

For insects at least, orientations often show a broad spread.

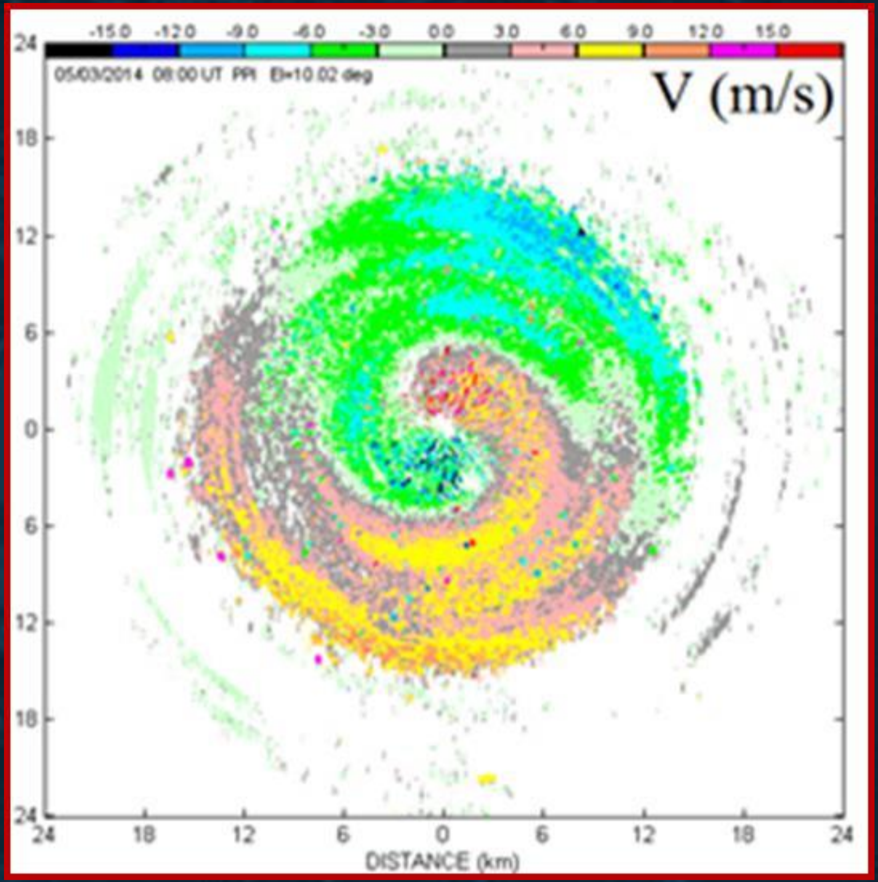
If the orientation distribution is uniform over the scanned area, DDV will vary azimuthally in a systematic way.

DDV example



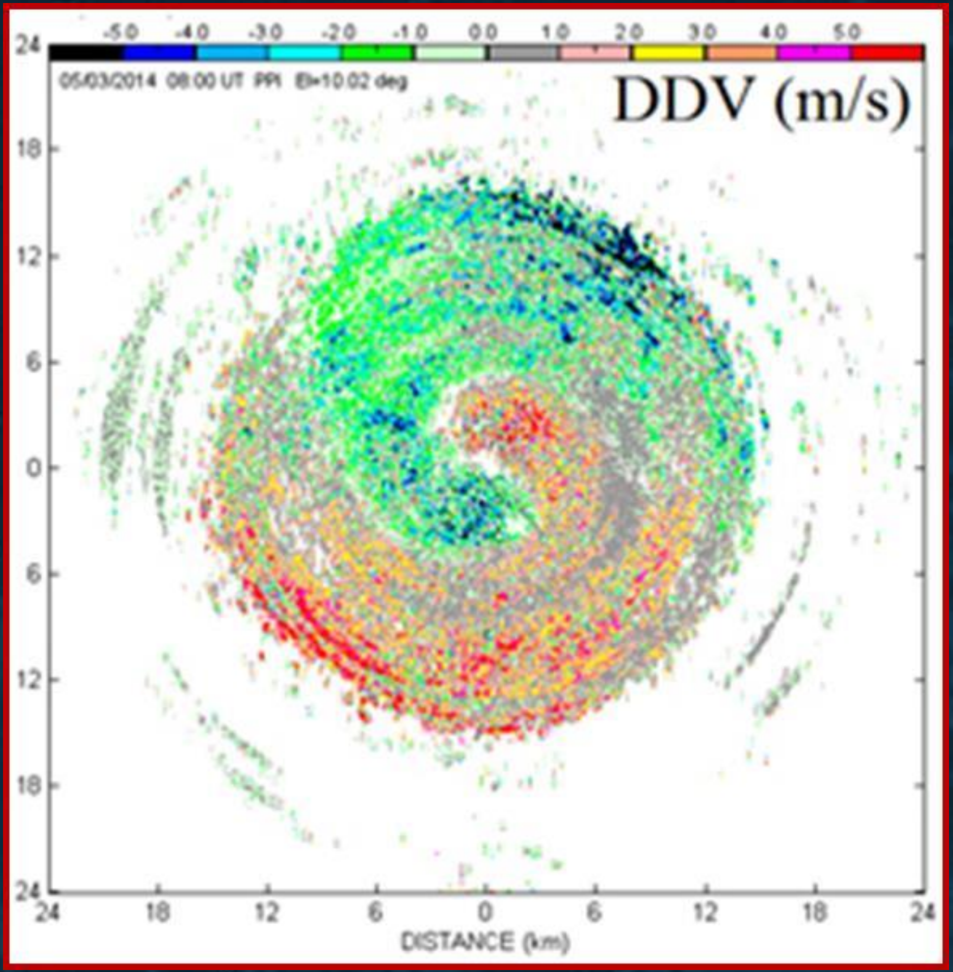
Reflectivity shows strong migration with layering and alignment at higher altitudes.

WSR-88D KOUN, ~02 h LST 3 May 2014; elev. 10º. “Birds.”



Radial speed (H-pol) shows movement to E low down, to S higher up.

DDV example (cont.)



DDV reaches +5 m/s to S at higher altitudes, ~–3 m/s to N.

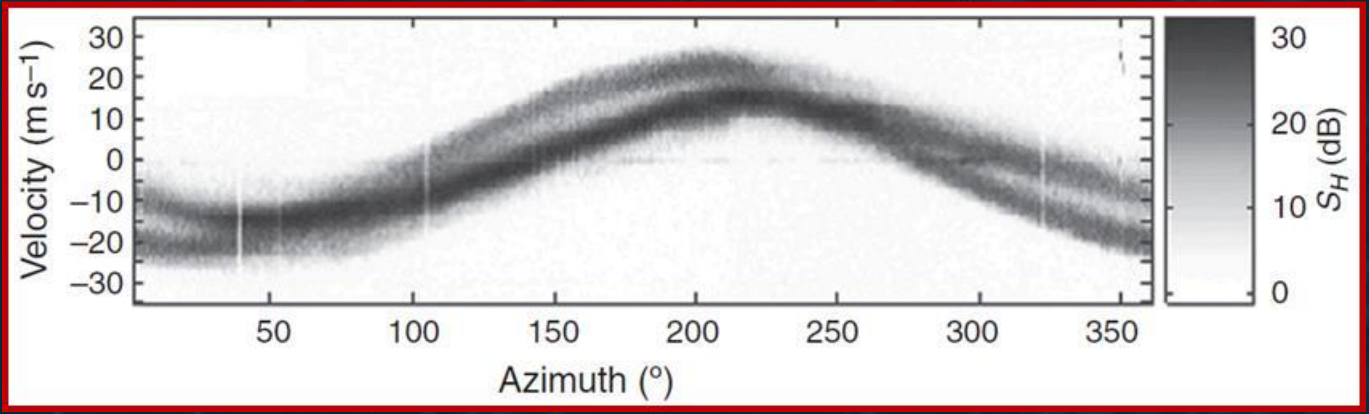
+ve DDV to S suggests receding targets have larger RCS at H-pol than tangential ones.

Possible for birds but not for insects.

From ENRAM presentation by V. Melnikov, M. Leskinen, and J. Koistinen, July 2014.

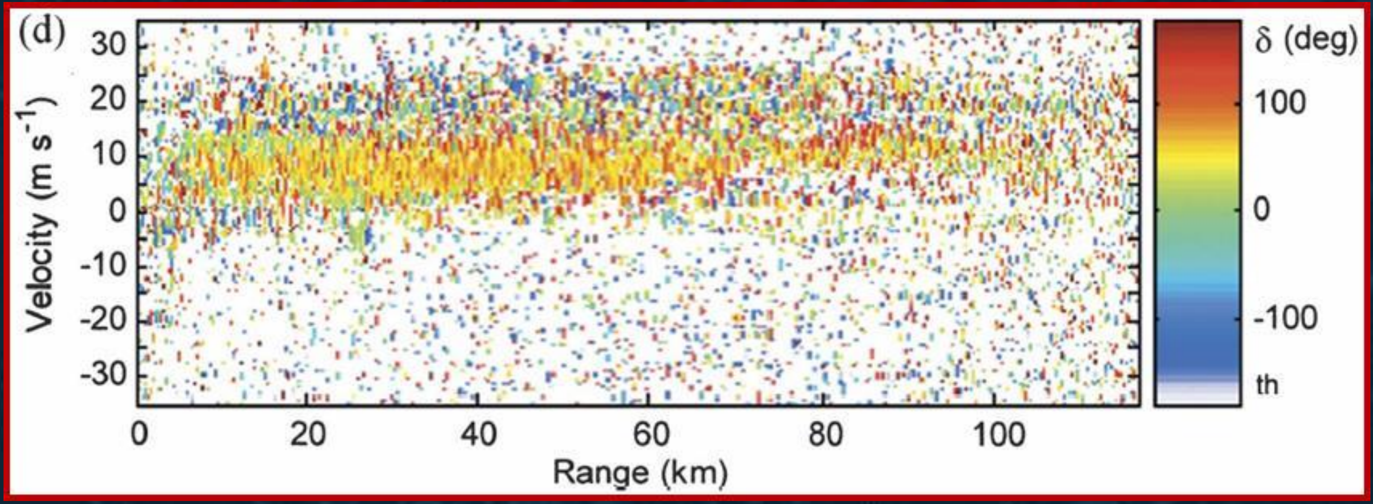
2d. Full Doppler spectrum methods

Generally the full Doppler spectrum is not recorded.
When it is available, additional analyses are possible.



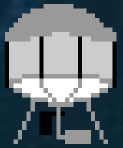
‘Spectral VAD’, showing two speeds – with slightly different directions.

1800-2300 LST 7 Sep 2004, WSR-88D KOUN, Norman, OK, USA.



v_r-δ ($\approx \phi_{DP}$) scatterplot, showing two bands (different speeds) with different δ.

From Bachmann & Zrnić 2007 *J. Atmos. Ocean. Tech*. **24**:1186-1198.



3. D-POL asymmetries

Modern D-POL radars often employ the STAR (simultaneous transmit and receive) polarization basis

- Both H and V polarizations are transmitted simultaneously

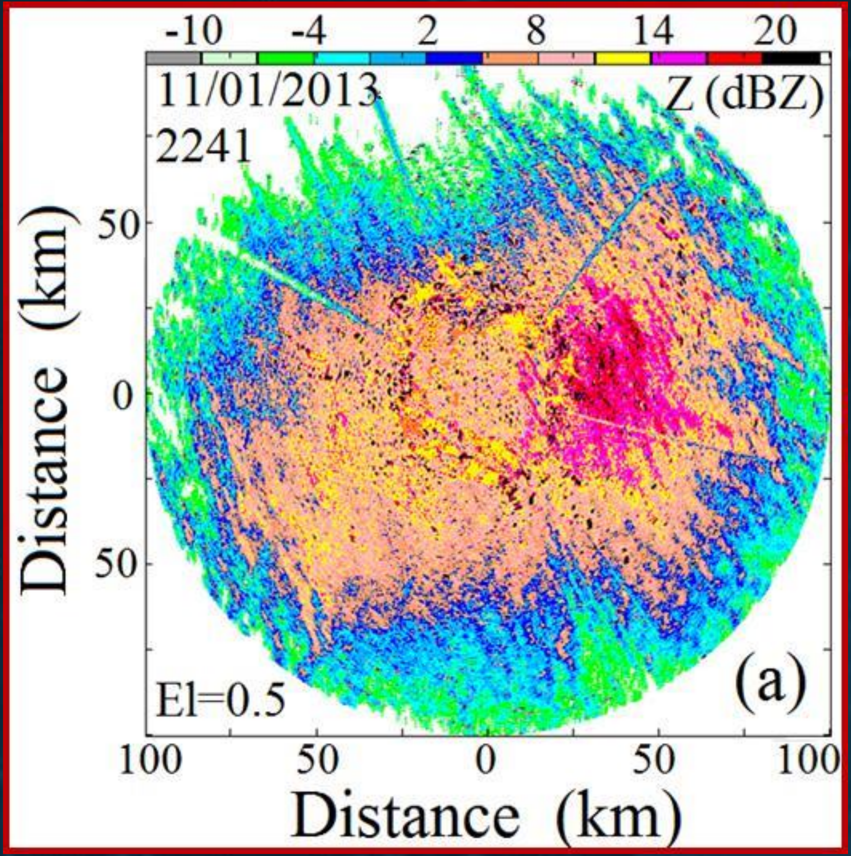
- The phase between the two waves is arbitrary (and sometimes unknown), but constant.

STAR avoids switching and maximizes exploitation of observation time.

It is suitable for precipitation observations as hydrometeors are either spherical or aligned, at least on average, with the vertical.

- Depolarization feeding the H wave into the V receiver etc. therefore will generally not arise.

Asymmetry example – Z and v_r

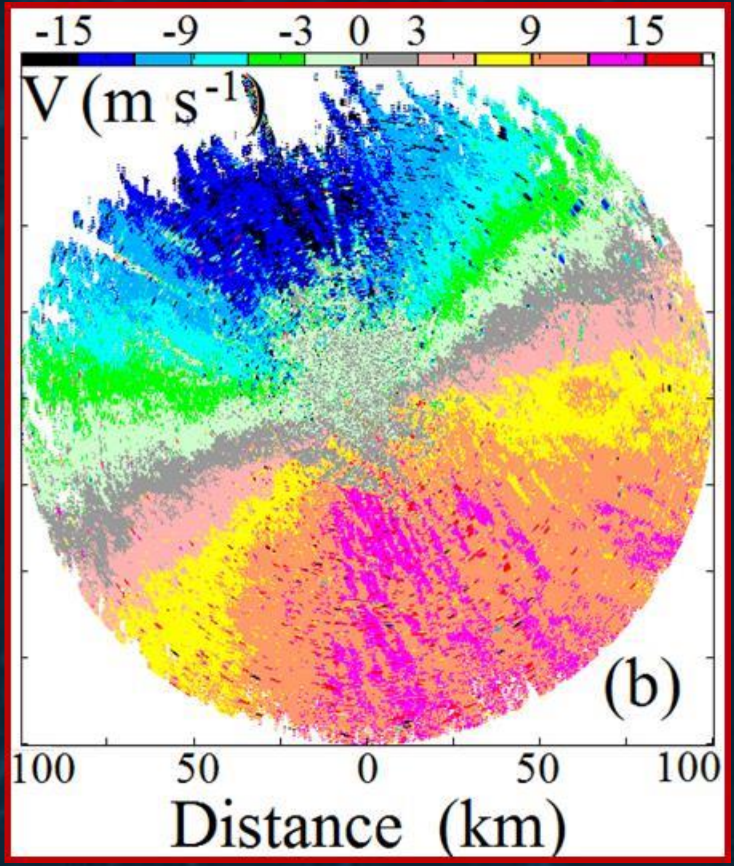


WSR-88D KOUN, Norman OK USA, 22.41 UTC 1 Nov 2013.

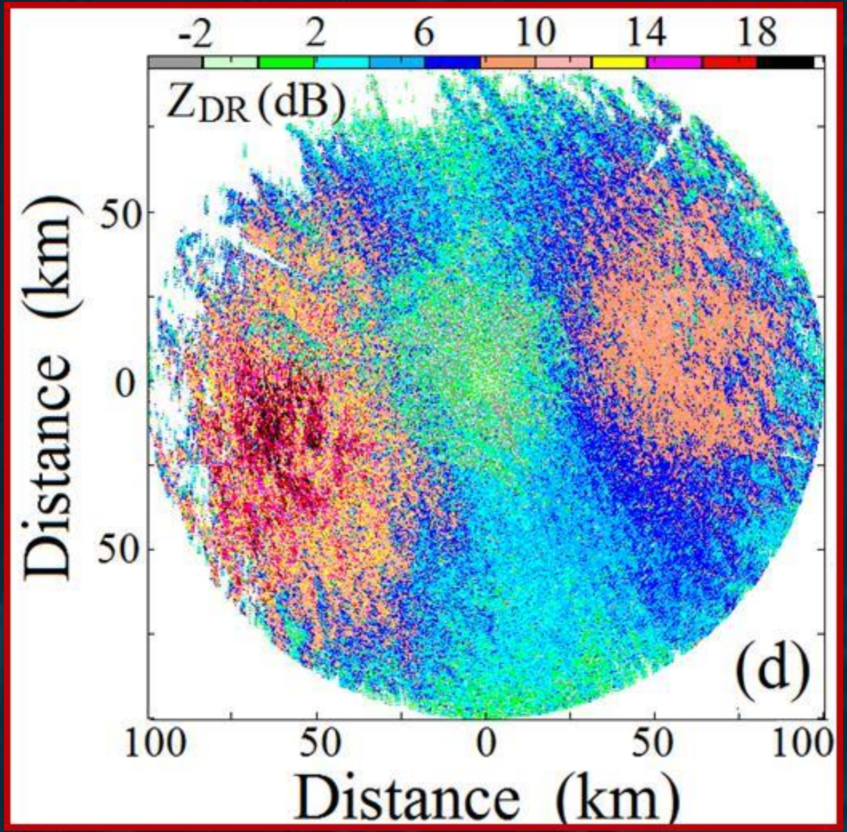
v_r not density dependent. Its field shows good mirror symmetry, indicating broad-front movement to SSE.

Z field shows some mirror symmetry, indicating collective orientation to SSE. Asymmetry may be due to different target densities to E and W.

From ENRAM presentation by V. Melnikov, M. Istok and J. Westbrook, July 2014.

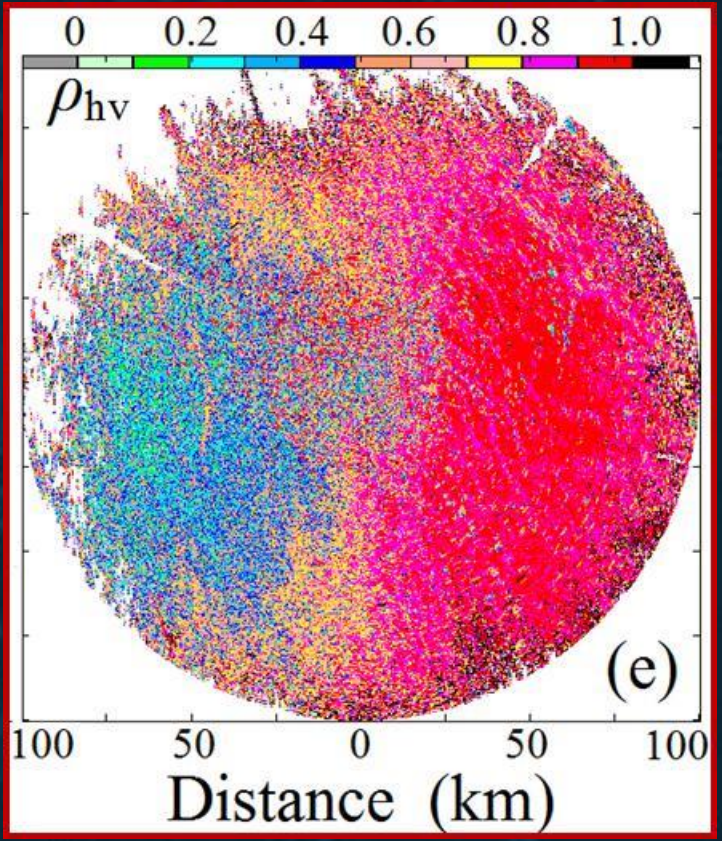


Asymmetry example – Z_{DR} and ρ_{hv}

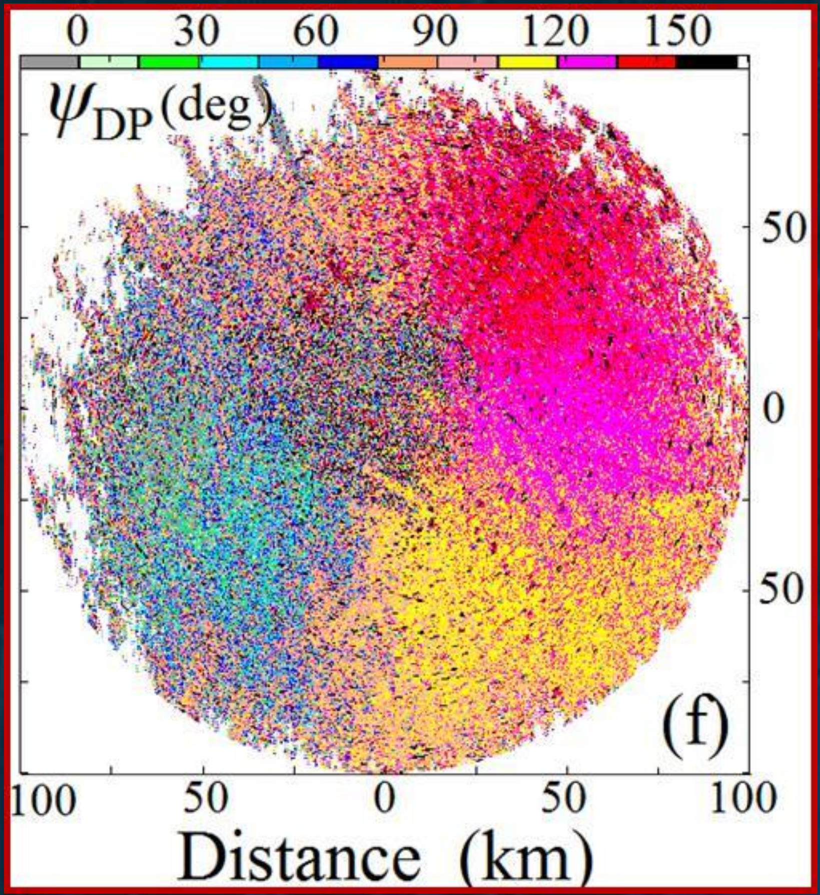


ρ_{hv} is also not density dependent, but its field shows no mirror symmetry in the orientation direction.

Z_{DR} is not density dependent. Its field shows mirror symmetry in the direction of collective orientation, but the symmetry is imperfect.



Asymmetry example - ψ_{DP}



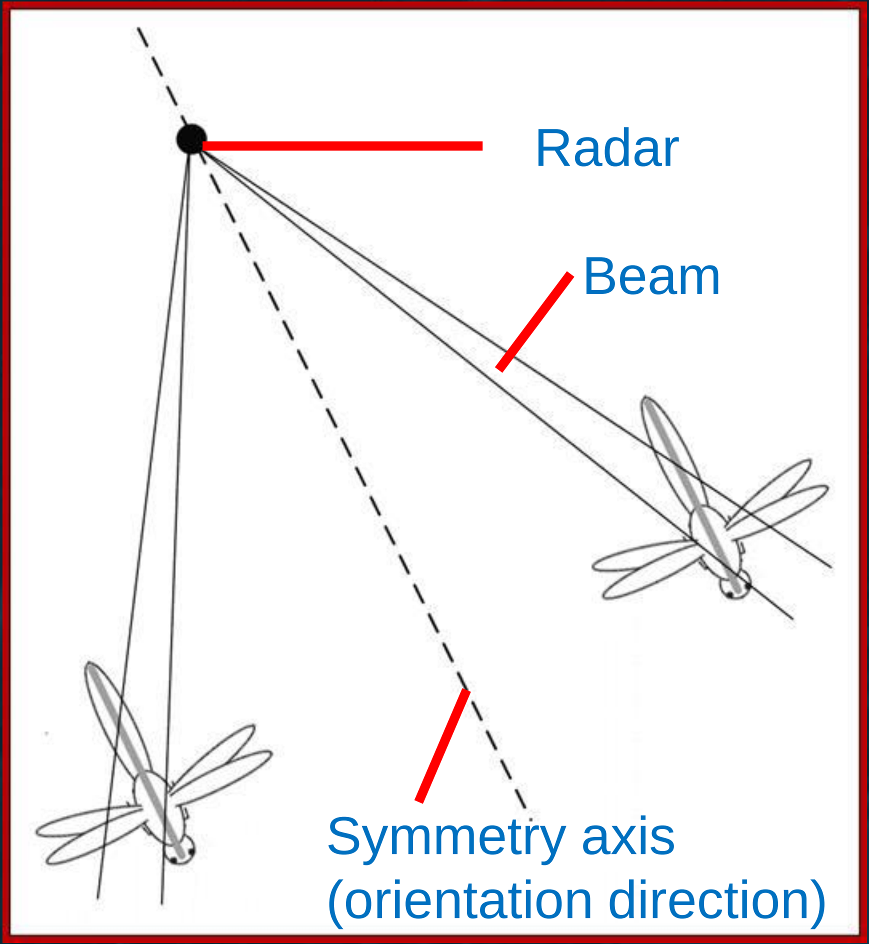
ψ_{DP} ($\approx \phi_{DP}$, δ) is again not density dependent, and its field again shows no mirror symmetry in the orientation direction.

Track direction (from v_r field)

Orientation (from Z and Z_{DR} fields)

These broad-scale asymmetries persist for hours, so cannot be attributed to spatial variations in target types or behaviours.

Asymmetry explanation



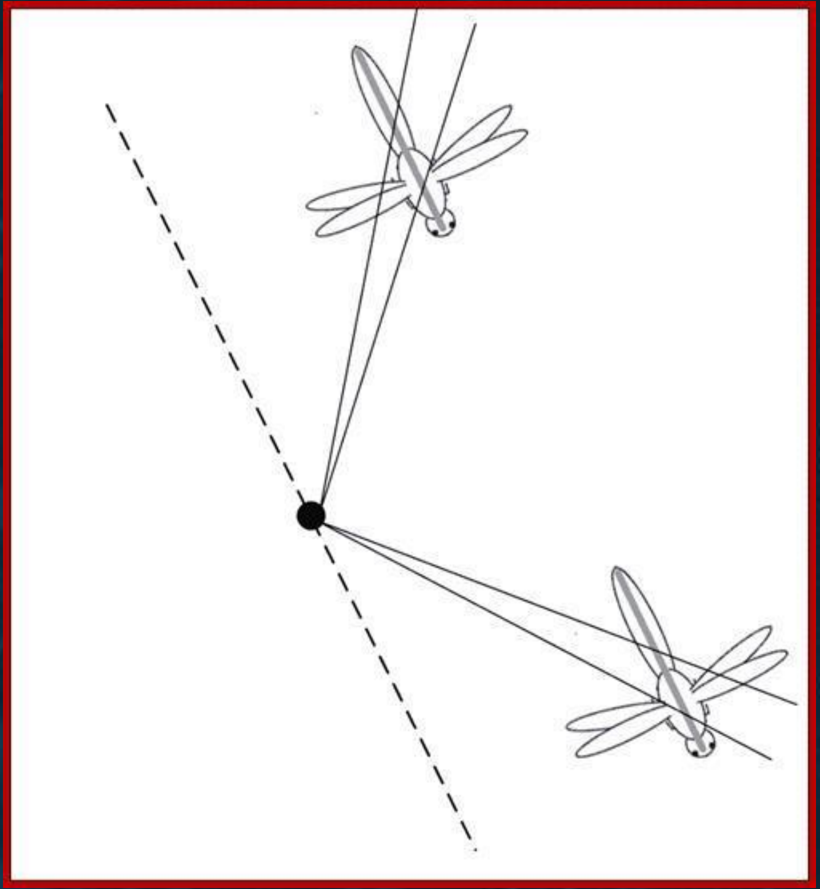
Insects have mirror symmetry. How can collectively oriented insects produce Z_{DR}, ρ_{hv} and ϕ_{DP} fields that are not mirror symmetric along the orientation direction?

Main reflecting element of insect is its body: model it as a long prolate ellipsoid.

Ellipsoids also have forward-backward mirror symmetry. Some of the PPI scans showed asymmetry in the forward-backward as well as the left-right direction.

Forward-back asymmetries

Forward-backward asymmetry could be due to RCS differences between head-on and tail-on aspects



A prolate ellipsoid model will not produce this.

Such differences were reported in early radar-entomology observations

These were made with H-pol non-coherent radars, and simple counts of detected targets in different directions.

Thus, forward-backward asymmetry does not depend on STAR operation.

What if insects fly pitched up?

Aphid in flight, Finland. Body is pitched at ~70°!

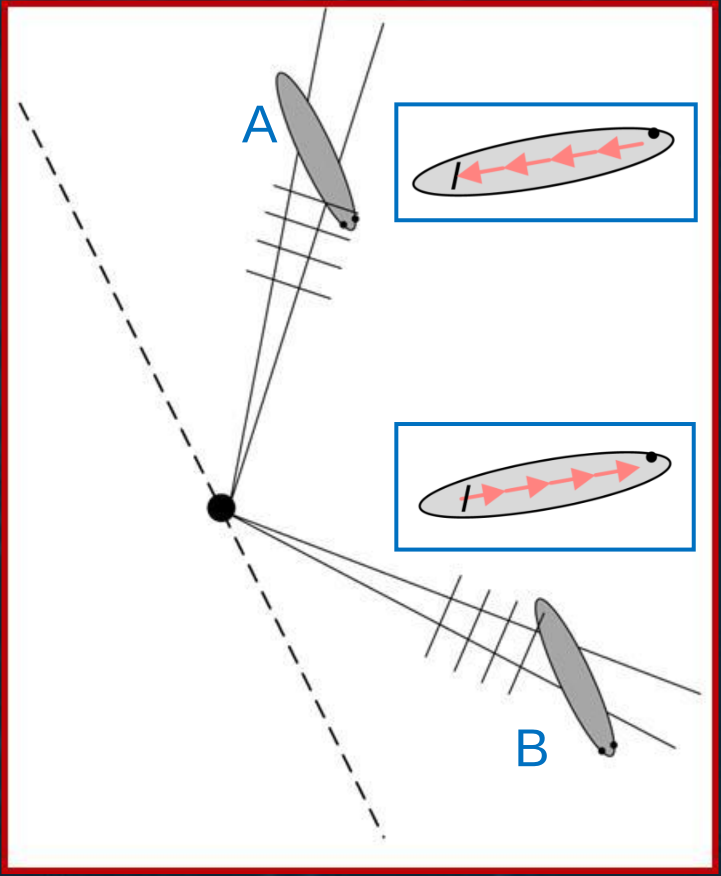
From Leskinen *et al*. 2012 ERAD 2012 conference paper.

Slanting ellipsoids will depolarize both H and V waves!

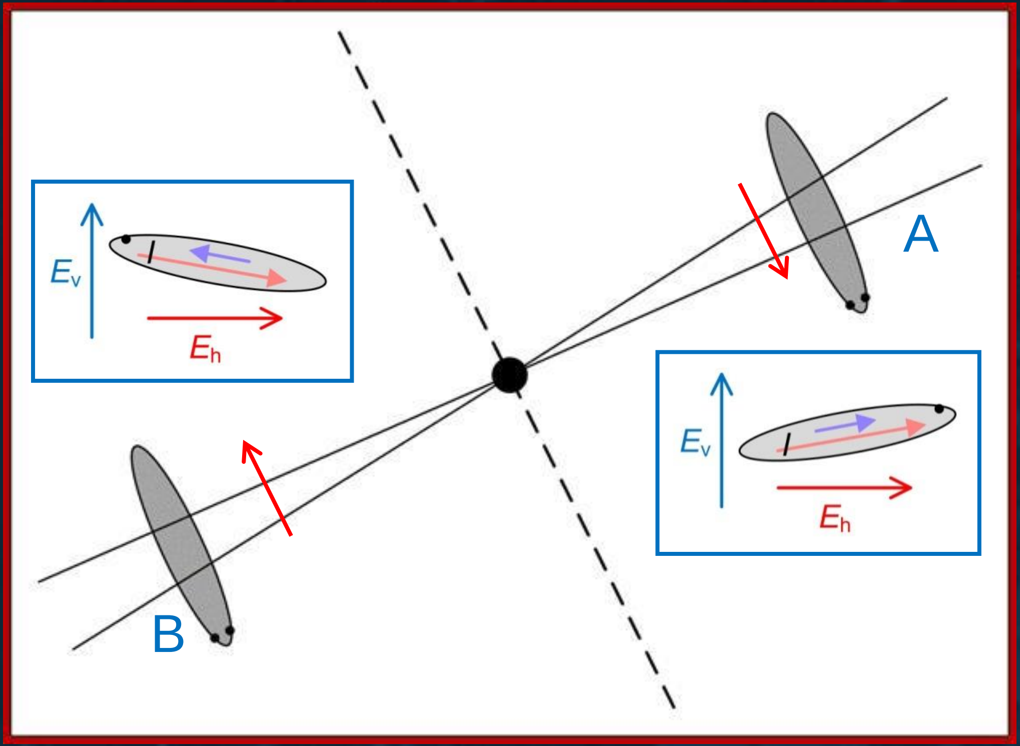
At A, wave hits head first. Propagation of wave along body induces a current with a downwards component.

At B, wave hits tail first. An upwards current component will be induced.

Resulting E_v fields of echoes will have opposite phases. Forward-backward symmetry is broken!



How about left-right symmetry?



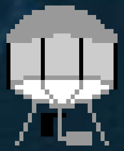
At A, H wave at phase when E is to right will induce a tail-to-head current.

At B, current will be head-to-tail and have a downwards component.

Current induced by an (in-phase) V wave will have an upwards component at both A and B.

Vertical components of currents will add at A and subtract at B, so A will have a stronger V echo than B.

Thus left-right symmetry is also broken (only with STAR).



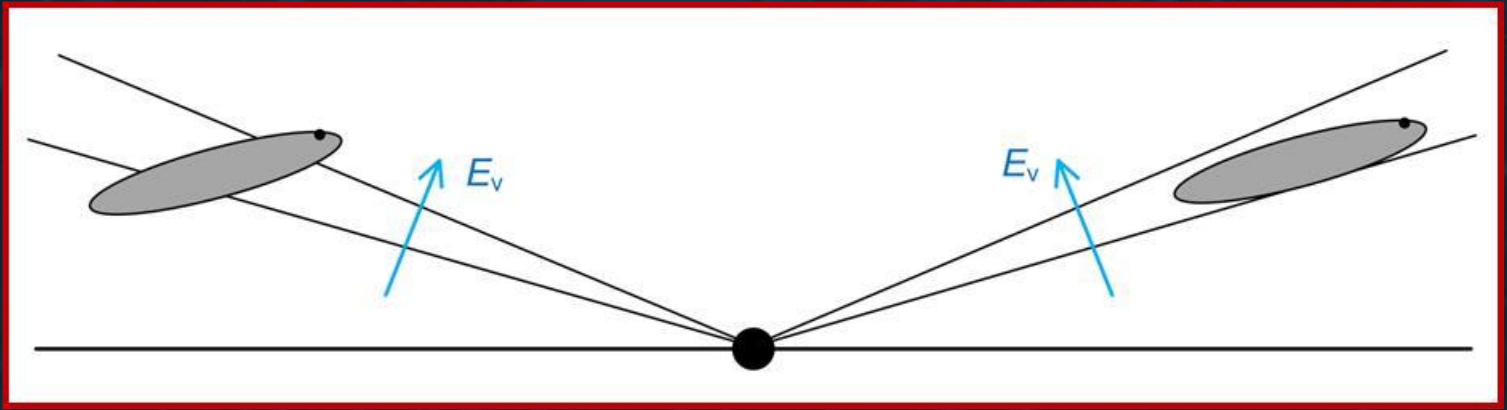
Pitching-up and a slanting beam

Pitching-up will produce additional effects if the beam is not horizontal.

An approaching insect will present a larger optical cross-section, and therefore quite probably a larger RCS, than a receding one.

Effect on RCS more obvious at V- than H-pol?

Could this account for the forward-backward asymmetry seen with entomological radars?



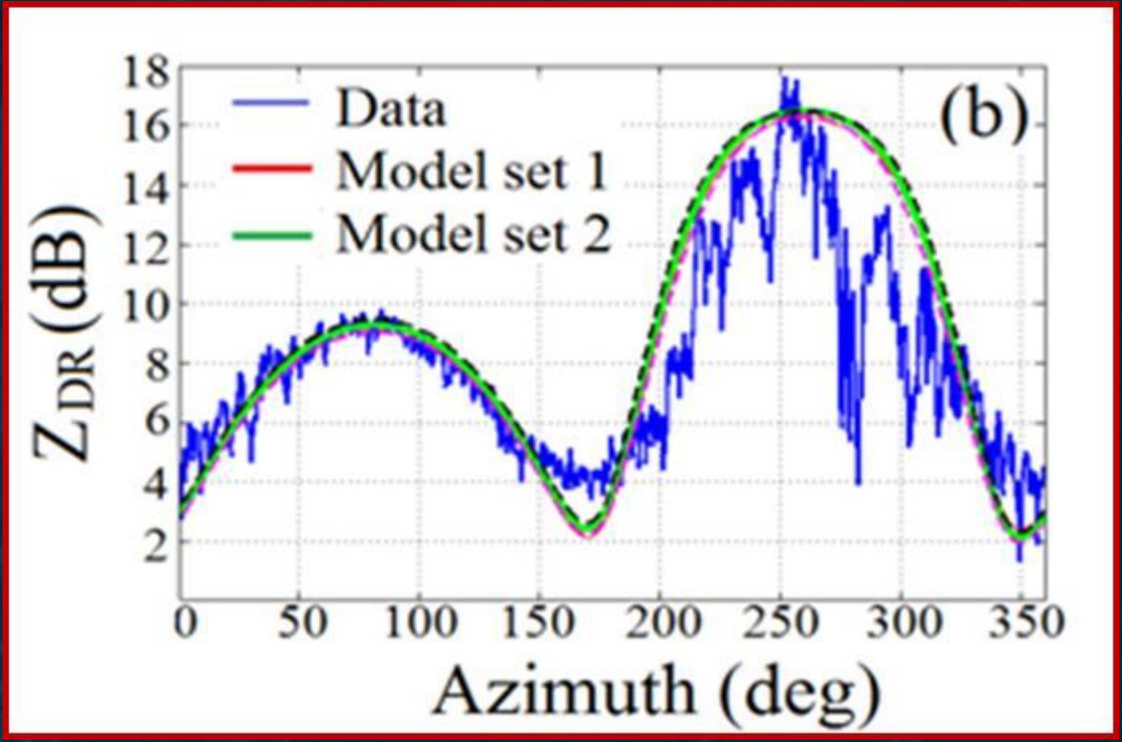
Asymmetry theory

A full S-matrix theory of these effects, assuming Rayleigh targets, has been developed by V. Melnikov.

It reproduces observed azimuthal variations of the polarimetric parameters quite well

For ρ_{hv}, it is necessary to take account of the distribution of orientations, not just the mean value.

A sloping beam produces an additional asymmetry



From ENRAM presentation by V. Melnikov, M. Istok and J. Westbrook, July 2014.

Implications of the theory

The theory indicates that, for aligned elongated targets:-

All polarimetric parameters measured with an STAR radar are dependent on the phase difference of the transmitted H and V waves.

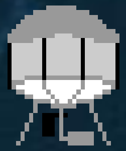
This is usually unknown, and is likely to vary from radar to radar.

Z_{DR} measured in STAR and ‘alternating’ (hh vv hh vv…) modes will differ.

The slant angle of the targets, and the ellipsoid ratio *b*/*a,* can be retrieved from the STAR azimuthal variations.

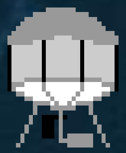
b/*a* is potentially a useful target-identification parameter for entomologists.

Slant angle may have value both for identification and as an indication of the type of flight being undertaken.



4. Conclusions

- Radar biology continues to be fascinating!
- Interest in biological targets is becoming widespread and mainstream within the radar-meteorological community
- Networks of modern D-POL Doppler weather surveillance radars (WSRs) are providing an unexpected source of information on bird, bat, and insect movements.
- WSRs are now competing with/complementing special-purpose entomological and ornithological radars as effective biological research tools.
- Radar-based research on bird, bat, and insect movement is unifying into a single field.



5. Acknowledgments

- Participants in the ENRAM workshop, Helsinki, 8-9 July 2014.
- Susan Rennie (Bureau of Meteorology, Australia).
- Valery Melnikov (University of Oklahoma and NOAA-NSSL, USA).
- ENRAM/COST and UNSW, for travel support.