Retrieval of insect parameters from STAR radar data

*Valery Melnikov *, Michael Istok +, and John Westbrook #*

** - NOAA National Severe Storms Laboratory, USA*

+ US National Weather Service

 # US Department of Agriculture

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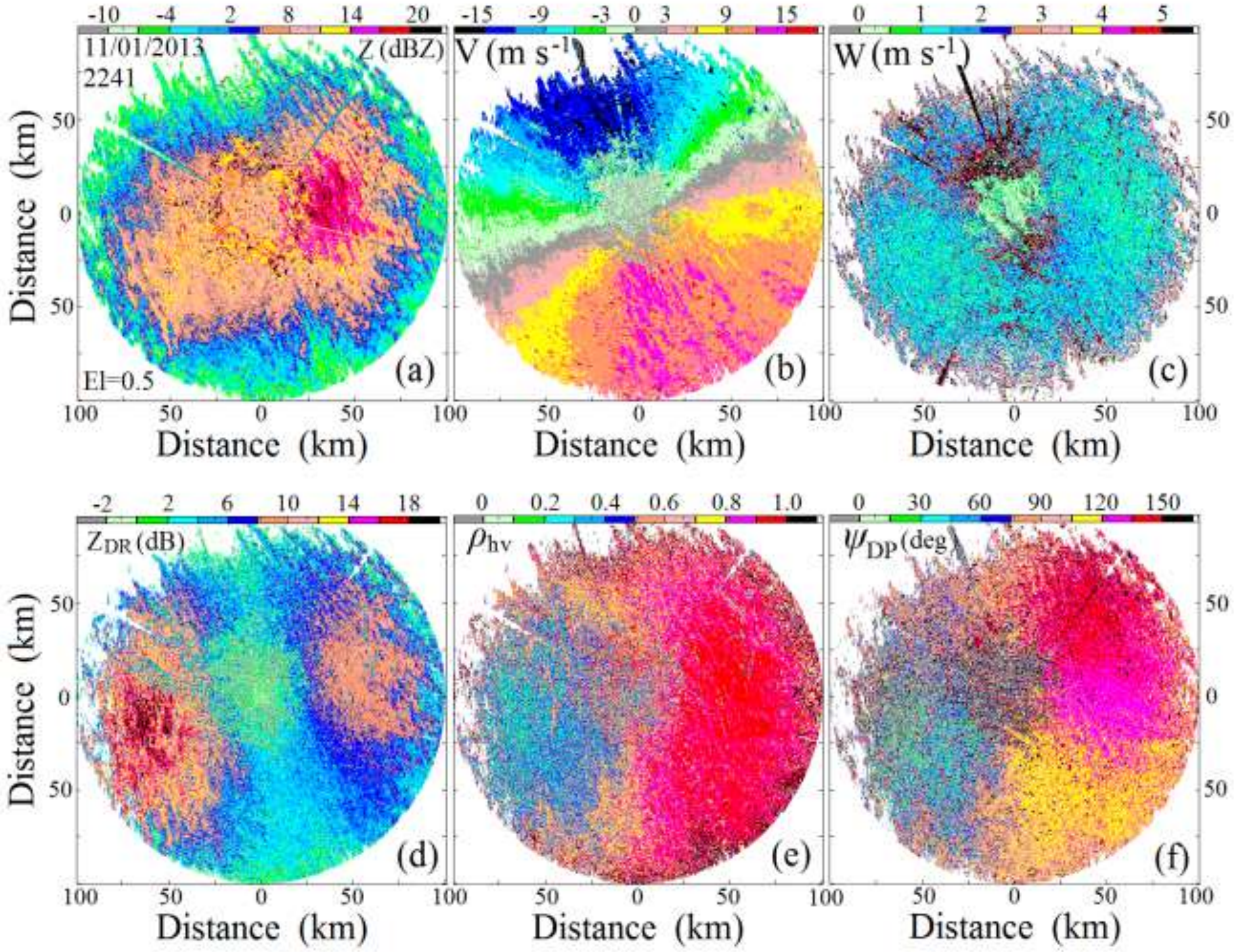
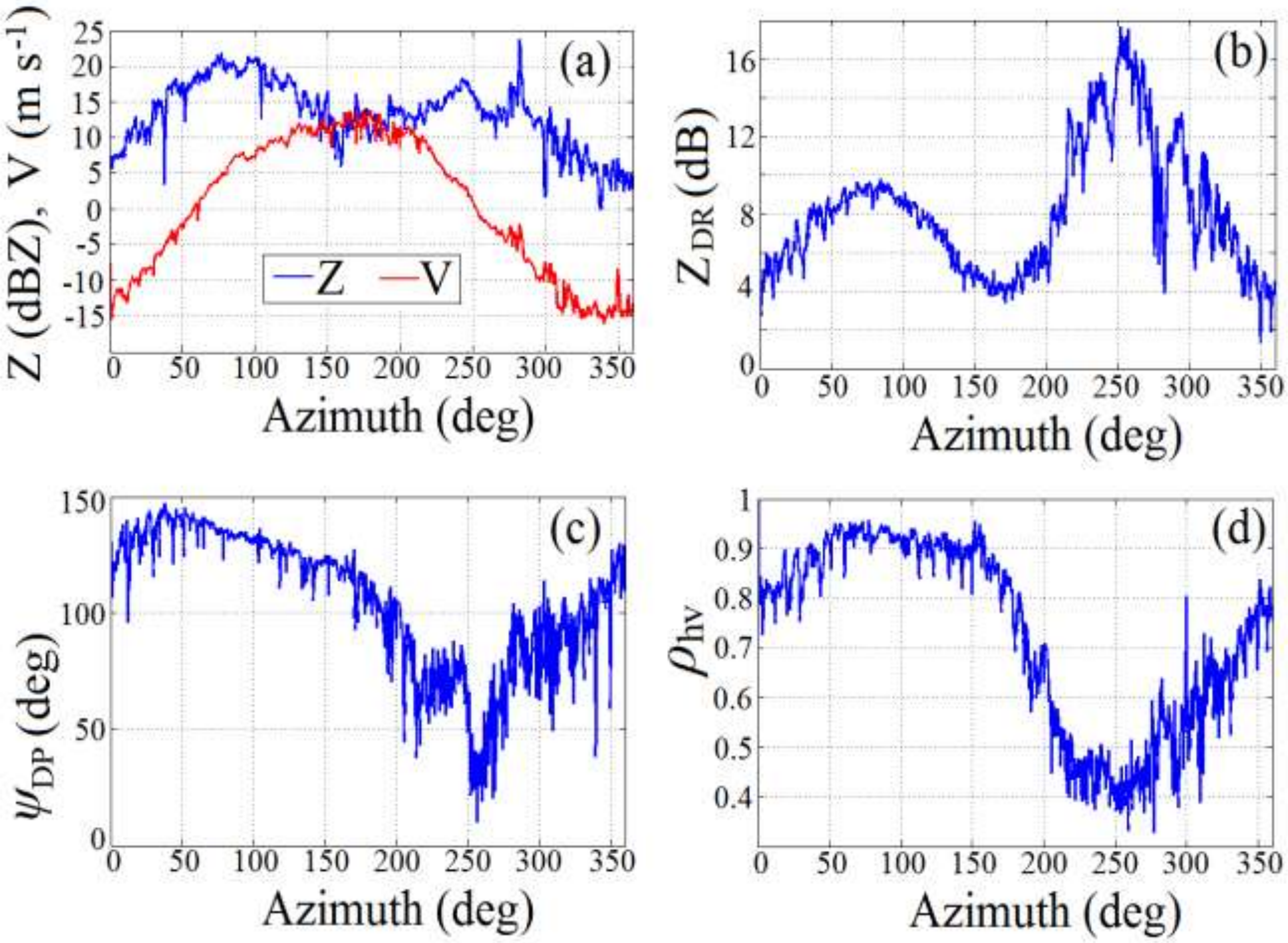
Echo patterns from insects are frequently asymmetrical in STAR radars. Example from WSR-88D KOUN radar (Norman, OK, USA)



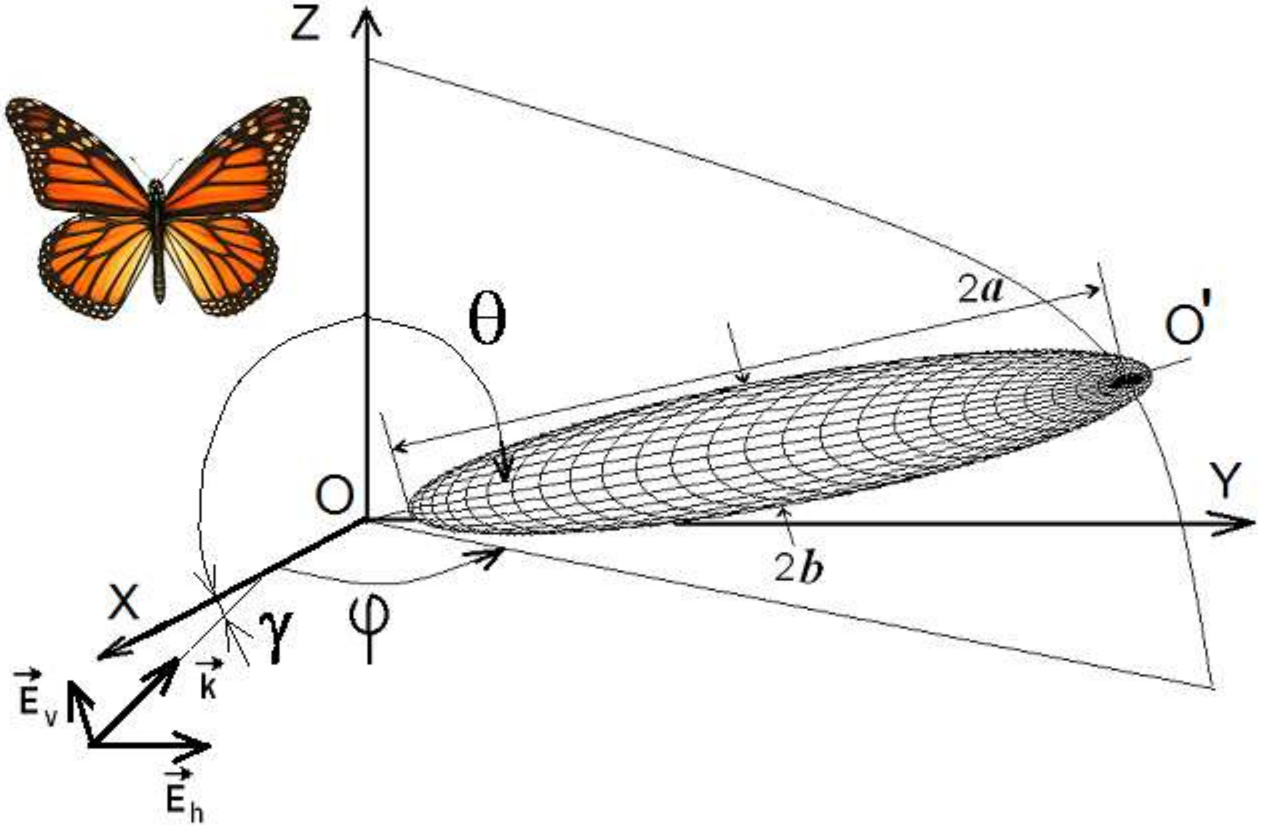
STAR radars: Simultaneous Transmission And Reception of horizontally and vertically polarized waves. The vast majority of polarimetric weather radars have the STAR configuration.

Quantifying asymmetry in radar patterns from insects



Case 1 Nov. 2013, KOUN radar. Azimuthal profiles of reflectivity (Z), Doppler velocity (V), differential reflectivity(Z_{DR}), differential phase (ψ_{DP}), and correlation coefficient (ρ_{hv}) for an annular ring with radii of 50 and 55 km. PPIs of the case are presented on the previous slide.

Geometry of scattering



An insect’s body is approximated with an ellipsoid. The dimensions of the ellipsoid and orientation angles are not known and have to be determined from radar data.

Theoretical approach.

Assumptions:

- the insect's body is approximated with a prolate spheroid,

-dielectric permittivity of the body equals that of water,

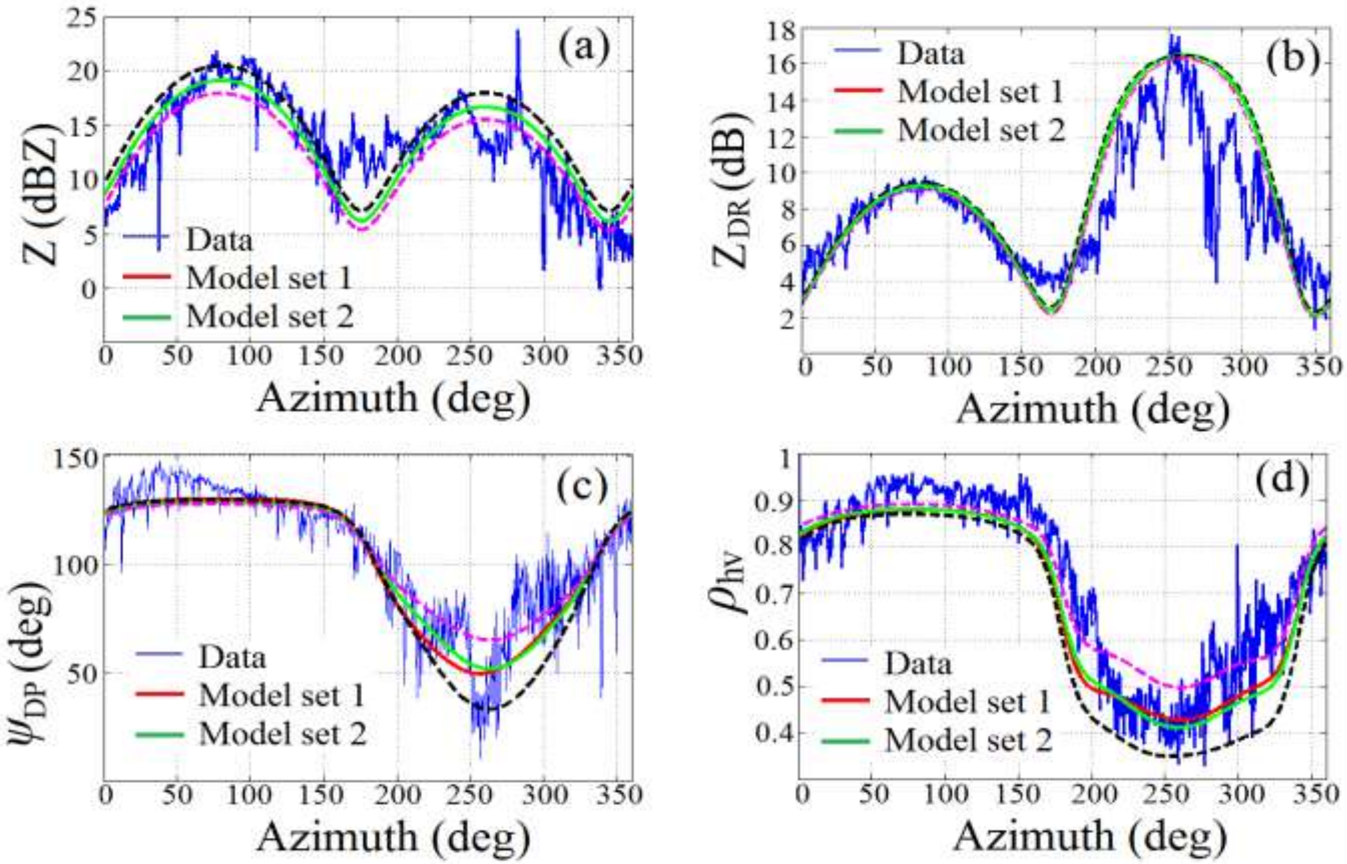
- the insects are the same at a spatial scale of 100 km

The basic equation for a radar with simultaneous transmission and reception of polarized waves :

$$\underbrace{\begin{pmatrix} E_{hr} \\ E_{vr} \end{pmatrix}}_{\text{Received waves}} = \underbrace{\mathrm{C_r}}_{\text{Radar constant and the range factor}} \underbrace{\begin{pmatrix} 1 & 0 \\ 0 & \exp[i(\psi_r + \frac{1}{2}\Phi_{DP})] \end{pmatrix}}_{\text{Propagation matrix (from insects to radar)}} \underbrace{\begin{pmatrix} S_{hh} & S_{hv} \\ S_{hv} & S_{vv} \end{pmatrix}}_{\text{Scattering matrix}} \underbrace{\begin{pmatrix} 1 & 0 \\ 0 & \exp[i(\psi_t + \frac{1}{2}\Phi_{DP})] \end{pmatrix}}_{\text{Propagation matrix (from radar to insects)}} \underbrace{\begin{pmatrix} E_h \\ E_v \end{pmatrix}}_{\text{Transmitted radar waves}}$$

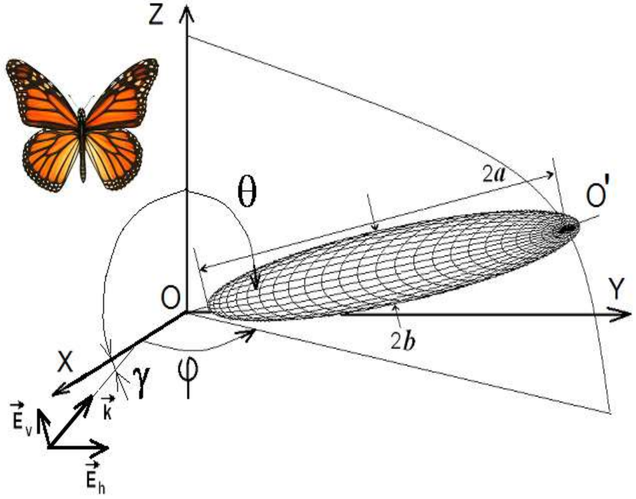
ψ_t	System differential phase on transmit
ψ_r	System differential phase on receive
Φ_{DP}	Propagation differential phase

We obtain the insect parameters by matching all radar profiles (the blue lines) with the model output (the solid green and red lines).



The black dashed and magenta dashed lines are the model azimuthal profiles for width-to-length ratio *b/a* = 0.15 + 0.02 and b/a = 0.15 – 0.02, correspondingly. This shows sensitivity of the model to the b/a retrieval.

Sets of model parameters used to generate the model curves for case 1 (slide 3 above).



Monarch butterfly

Model parameter	**KOUN, 1 Nov., 2013, 2241 UTC, 1741 LT. (case 1)**	
	1st set (red curves)	2nd set (green curves)
b/a	0.15	0.15
Θ_m (deg)	79	101
ϕ_m (deg)	350	350
ψ_t (deg)	27	205
σ_ϕ (deg)	20	20
σ_θ (deg)	10	10

b/a is the axis ratio of the insect’s body, i.e. width/length,

Θ_m is the mean pitch angle of an insect,

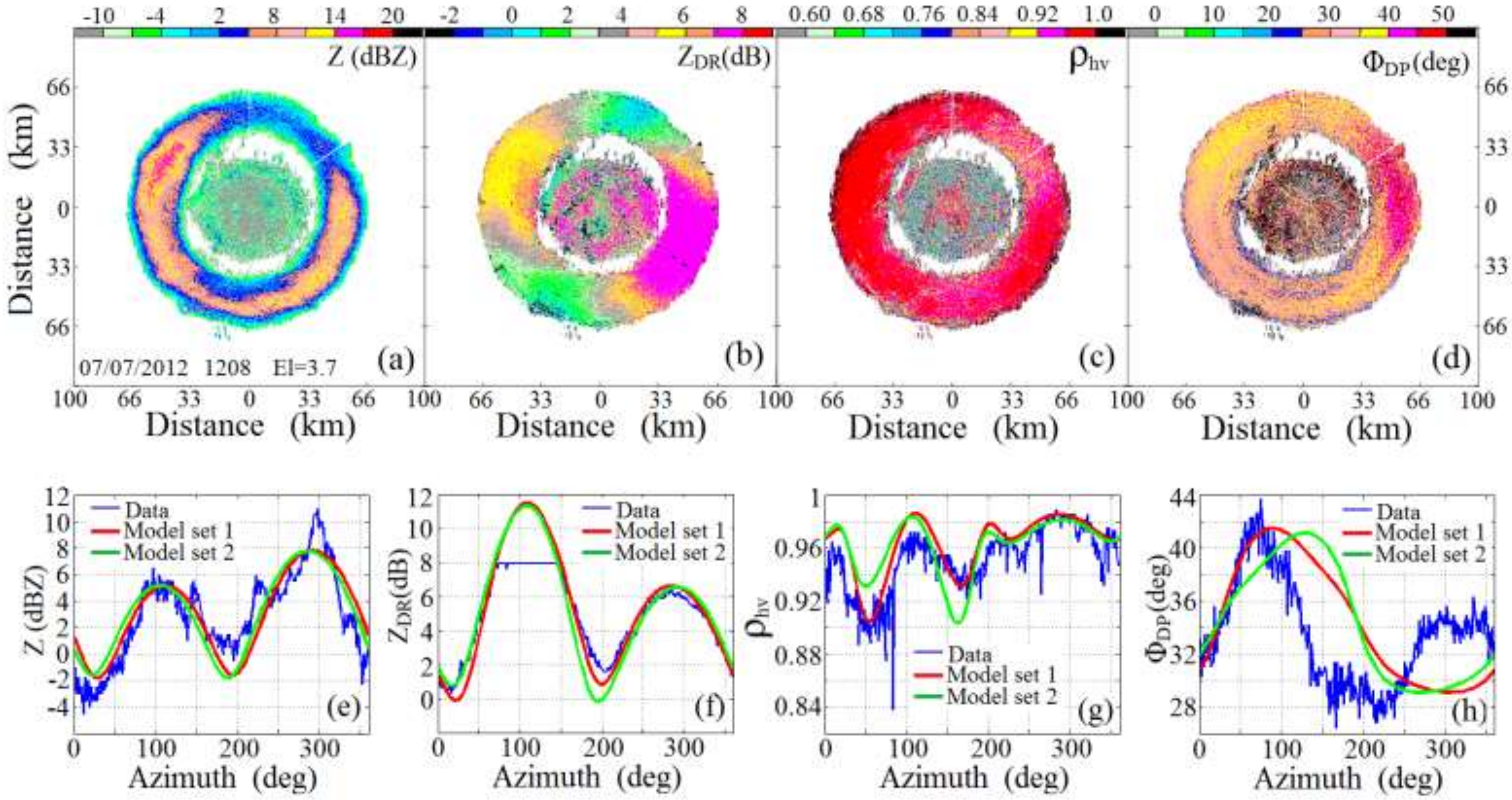
σ_θ is the standard deviation in the pitch angles,

ϕ_m is the mean orientation angle of insects on the horizontal plane,

σ_ϕ is the standard deviation in ϕ angle,

ψ_t is a radar parameter (differential phase on transmit).

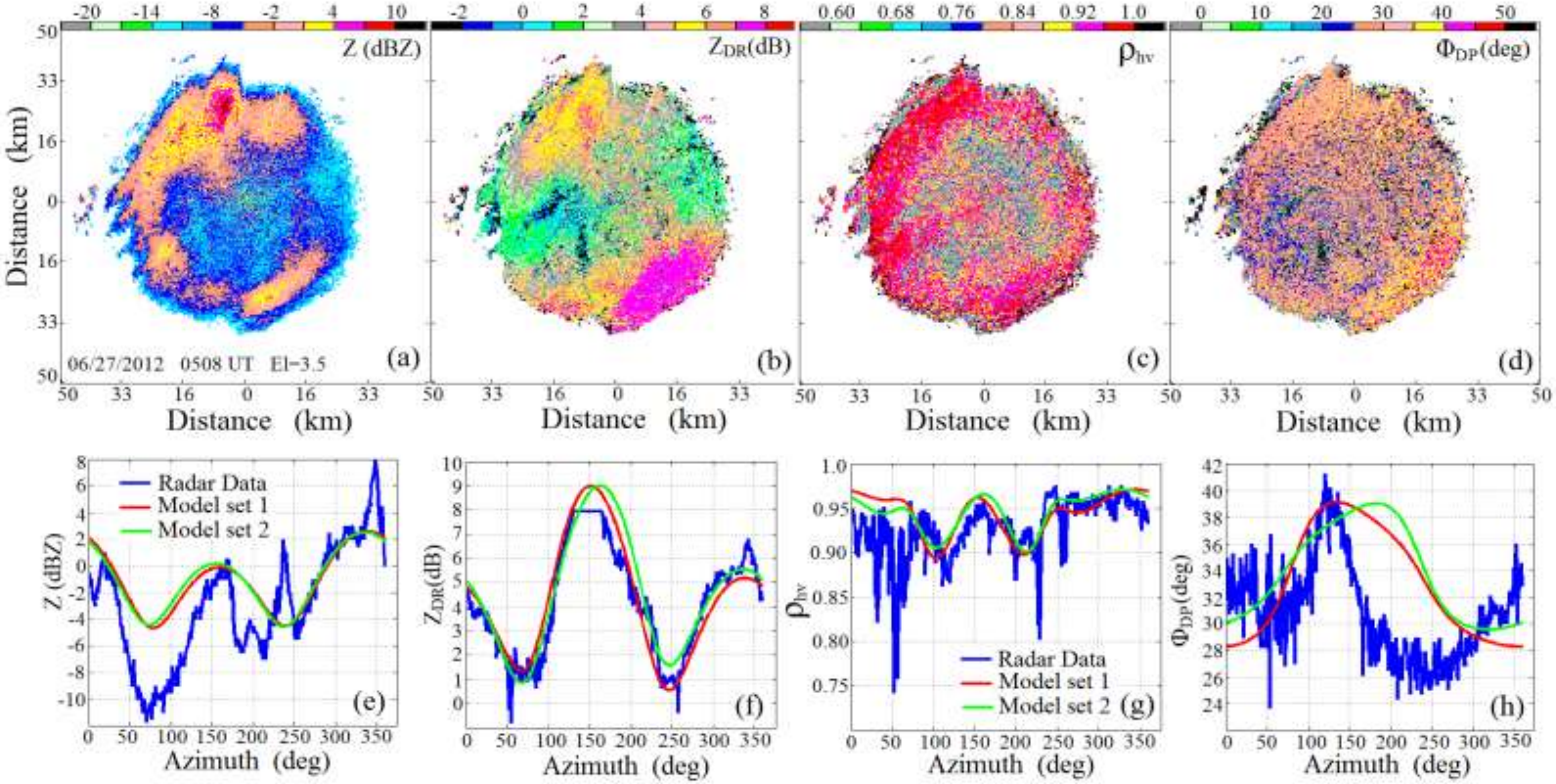
Case 2. Sterling, VA, KLWX radar. July 7, 2012.



(Upper row):PPIs of the polarization parameters.
(Lower row): Azimuthal profiles in the annular rings with radii 40 and 50 km (the blue lines) and the model results (the red and green lines).

Picture of the sky at Sterling, VA, KLWX radar. July 7, 2012, 7:30 local time (12:30 UTC)

Case 3. Sterling, VA, KLWX radar. June 27, 2012.



(Upper row):PPIs of the polarization parameters.
(Lower row): Azimuthal profiles in the annular rings with radii 22 and 28 km (the blue lines) and the model results (the red and green lines).

Sets of model parameters used to generate the model curves for cases 2 and 3 (in red).

Kudzu bug

Model parameter	KOUN, 1 Nov., 2013, 2241 UTC, 1741 LT. -(case 1)		KLWX, 7 July, 2012 1208 UTC, 0708 LT. (case 2)		KLWX, 27 June, 2012 0508 UTC, 0008 LT. (case 3)	
	1st set (red curves)	2nd set (green curves)	1st set (red curves)	2nd set (green curves)	1st set (red curves)	2nd set (green curves)
b/a	0.15	0.15	0.37	0.37	0.40	0.40
θ_m (deg)	79	101	103	77	105	75
ϕ_m (deg)	350	350	20	17	67	67
ψ_t (deg)	27	205	10	190	10	190
σ_ϕ (deg)	20	20	17	17	25	25
σ_θ (deg)	10	10	6	7	10	10

b/a is the axis ratio of the insect's body, i.e. width/length,

θ_m is the mean pitch angle of an insect,

σ_θ is the standard deviation in the pitch angles,

ϕ_m is the mean orientation angle of insects on the horizontal plane,

σ_ϕ is the standard deviation in ϕ angle,

ψ_t is a radar parameter (differential phase on transmit).

Table 2. Physical parameters associated with cases 1,2,and 3 (LT is local time in 24-hour format).

	KOUN, 1 November, 2013 **2241 UTC (1741 LT)** **Sunset at 1835 LT** ~~Fig. 5~~ **(case 1)**	**KLWX, 7 July, 2012** **1208 UTC (0708 LT)** **Sunrise at 0552 LT** ~~Fig. 6~~ **(case 2)**	**KLWX, 27 June, 2012** **0508 UTC (0008 LT)** **Sunset at 2027 LT** ~~Fig. 7~~ **(case 3)**
Heights (m AGL)	436 – 480	2442 -- 3052	1343 – 1709
Track direction (deg)	155	227	193
Deviation from the track direction (deg)	15/right	27/left	54/right
Temperature at the heights of radar data, °C	17	16	11

Conclusions

- WSR-88D radar is capable of estimating several parameters of flying insects (the mean axis ratio, pitch angle, track direction, orientation relative to the track direction).

- The number of insects could be estimated if the species is known.

- To identify insect species using radar data, laboratory measurements of radar parameters are needed.

Possible future work

- collect radar data at various elevation angles and apply the retrieval procedure to obtain insect’s parameters with better accuracy,

- compare data from the vertically looking entomological radar and weather radar,

- continue theoretical studies of scattering properties of insects for weather STAR radars (non-symmetrical bodies, impacts of propagation effects, changing radar phase on transmit, etc.)

We thank the members of ENRAM working groups 1&2 for the opportunity to present and discuss our results.