Verification value of insect observations made with X-band vertical-beam radars

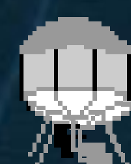
V. Alistair Drake

School of Physical, Environmental and Mathematical Sciences, UNSW Canberra, Australia; and Institute for Applied Ecology, University of Canberra, Canberra, Australia.

Don R. Reynolds

Natural Resources Institute, University of Greenwich, Chatham Maritime, UK.

ENRAM 2014: Helsinki workshop.



Outline

1. Vertical-beam entomological radars
2. Target size
3. Target shape
4. Insect densities
5. Conclusions and inferences

1. Vertical-beam entomological radars

[Photo: VAD.]

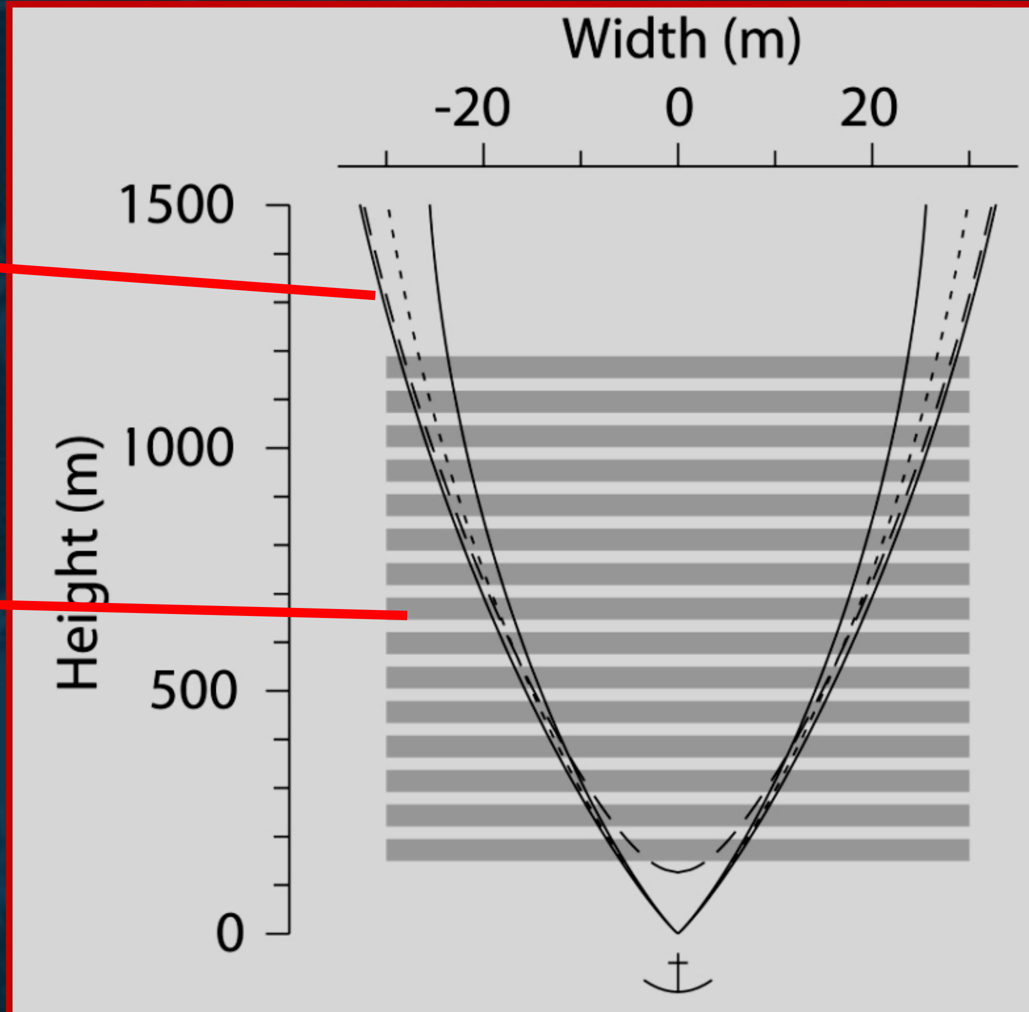
Current IMRs are non-coherent and do not have Doppler capability

UNSW Canberra's Insect Monitoring Radar at Thargomindah in southwest Queensland, Australia.

The radar beam is vertical and stationary. Insects are detected as they fly through it.

Effective beam width (according to 4 different assumptions)

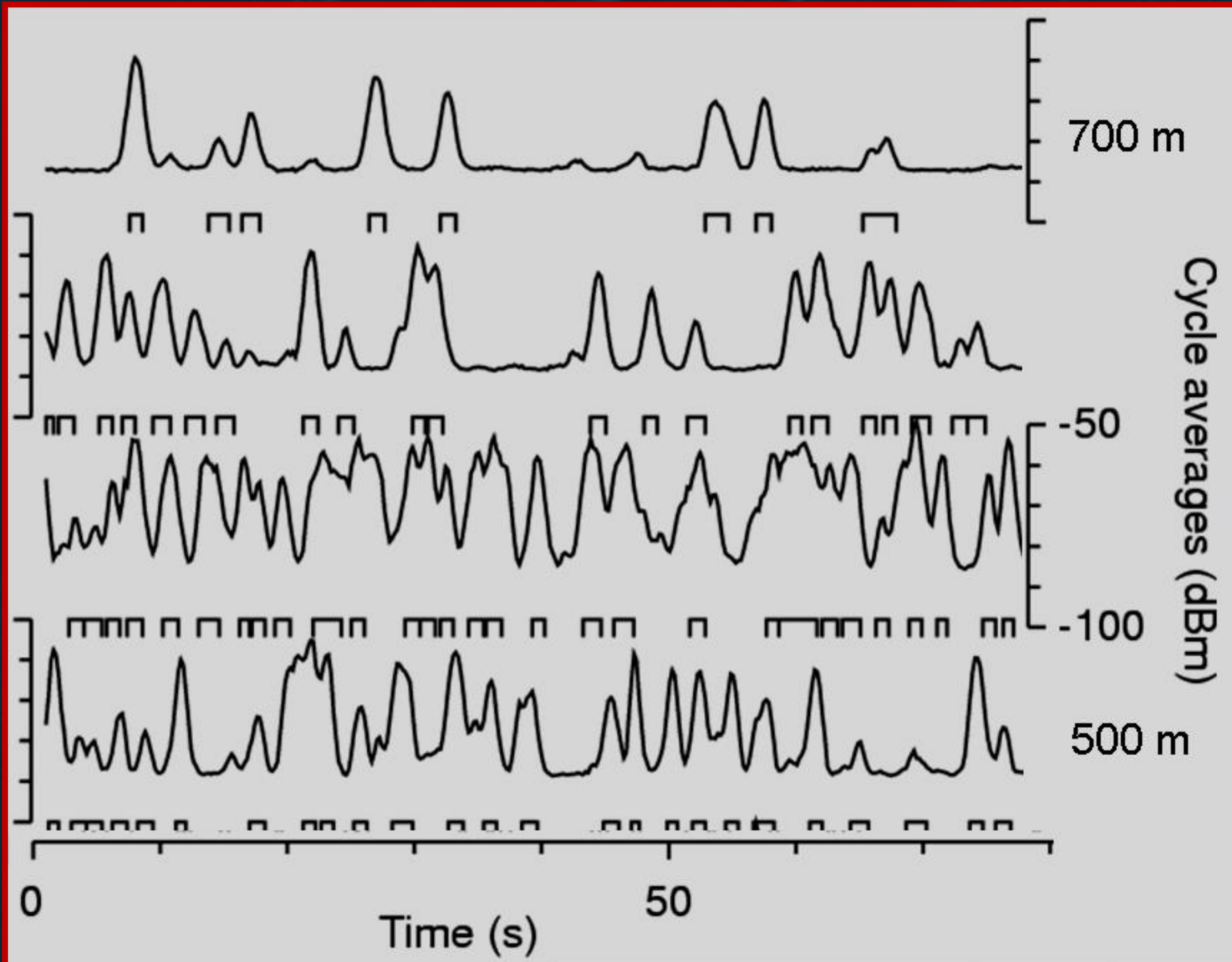
Signal recorded from 15 height intervals



A sampling method

The beam is quite narrow, but the sample is usually adequate because insects are numerous.

Individual insects show as clear electronic signals that can be counted automatically.

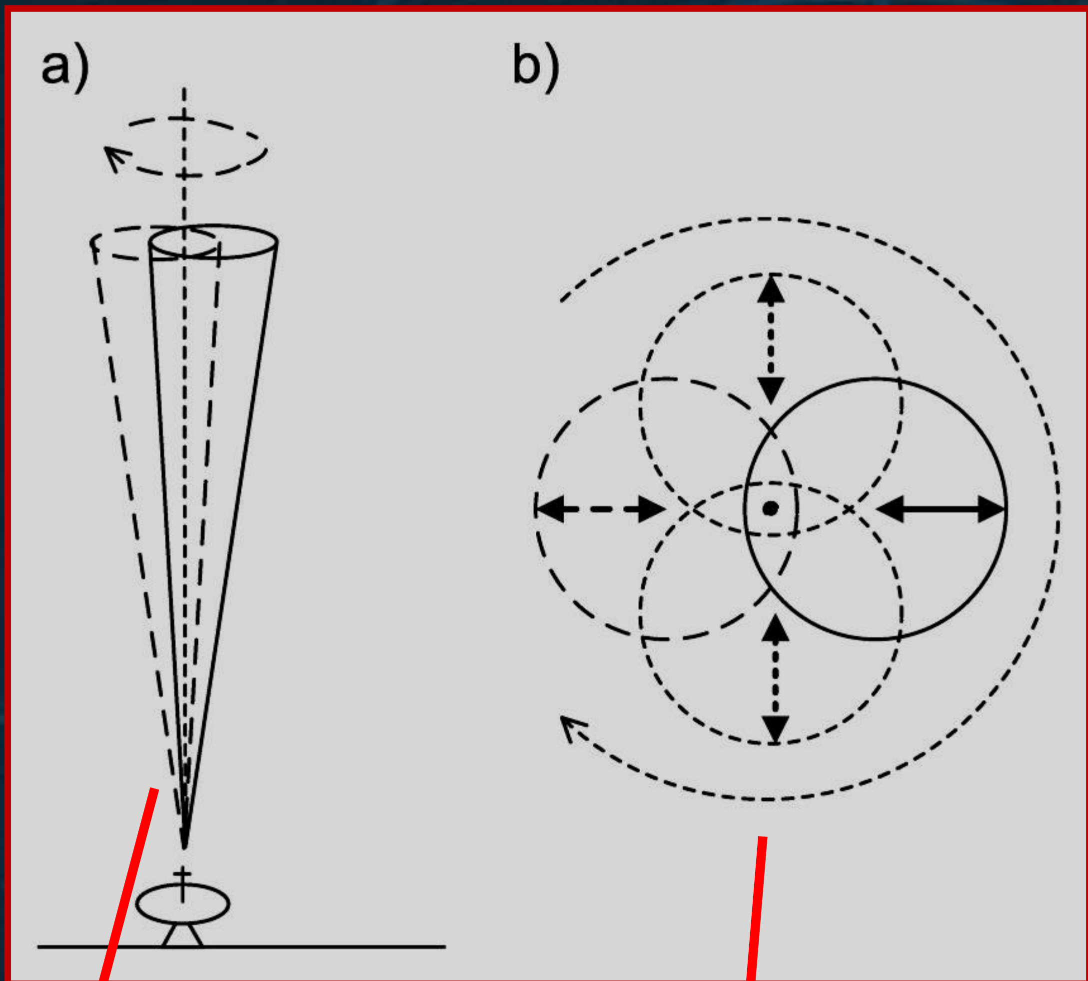


80 s of output from 4 of the 15 sampling heights.

(Plenty of targets, so good statistics.)

Bourke, NSW, 02 h, 25 Dec 2004.

IMRs and similar units incorporate 'target interrogation'



Side view

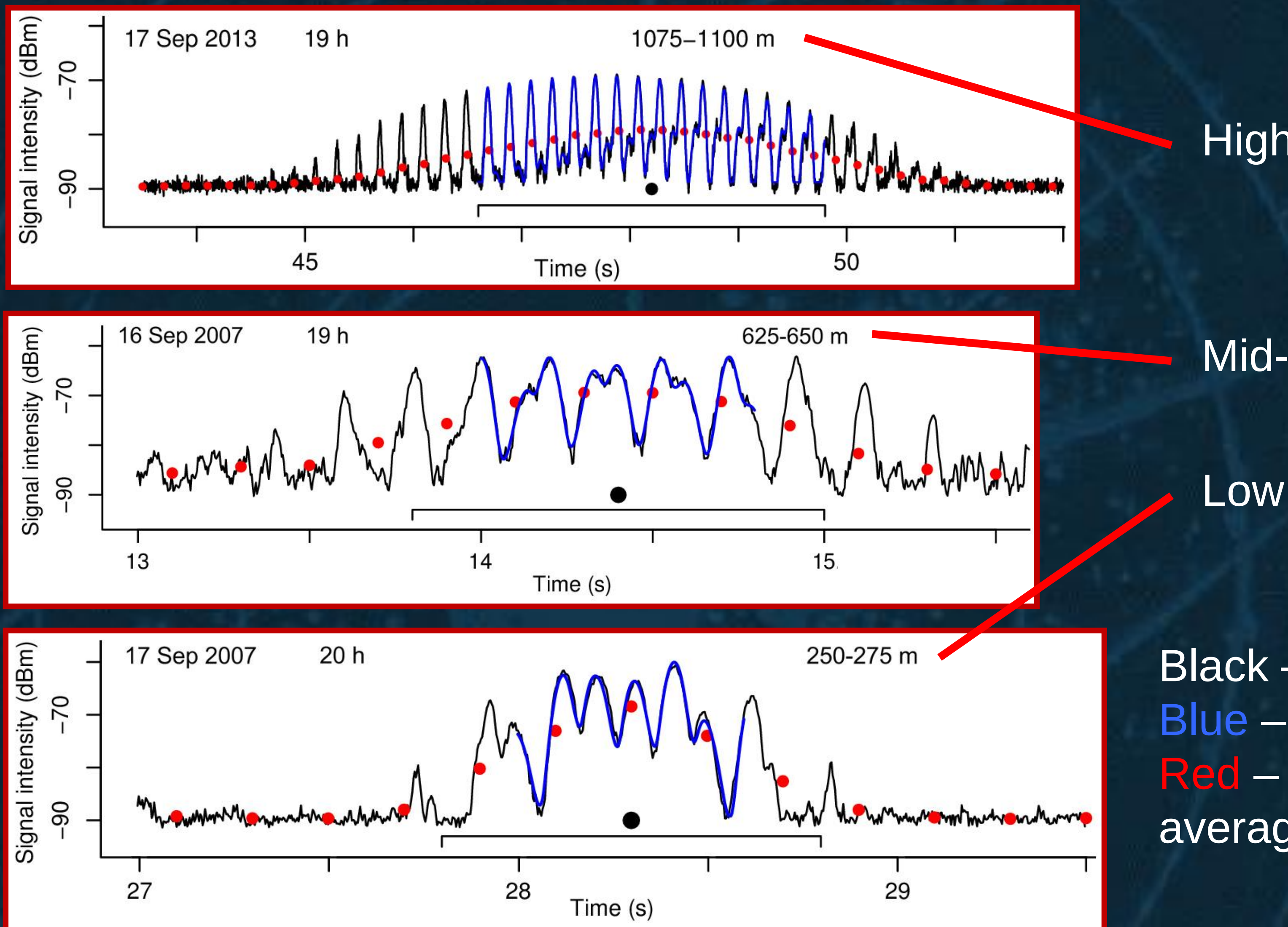
View from above

A small-angle scan produces a complicated echo signal that contains information about the insect's path through the beam.

The scan also incorporates rotating linear polarization, which provides information about target orientation and shape.

[From V.A. Drake & D.R. Reynolds (2012). *Radar Entomology, Observing Insect Flight and Migration*. CAB International, Wallingford, UK.]

Provided there is not interference from other targets, the echo intensity variation can be fitted rather exactly.

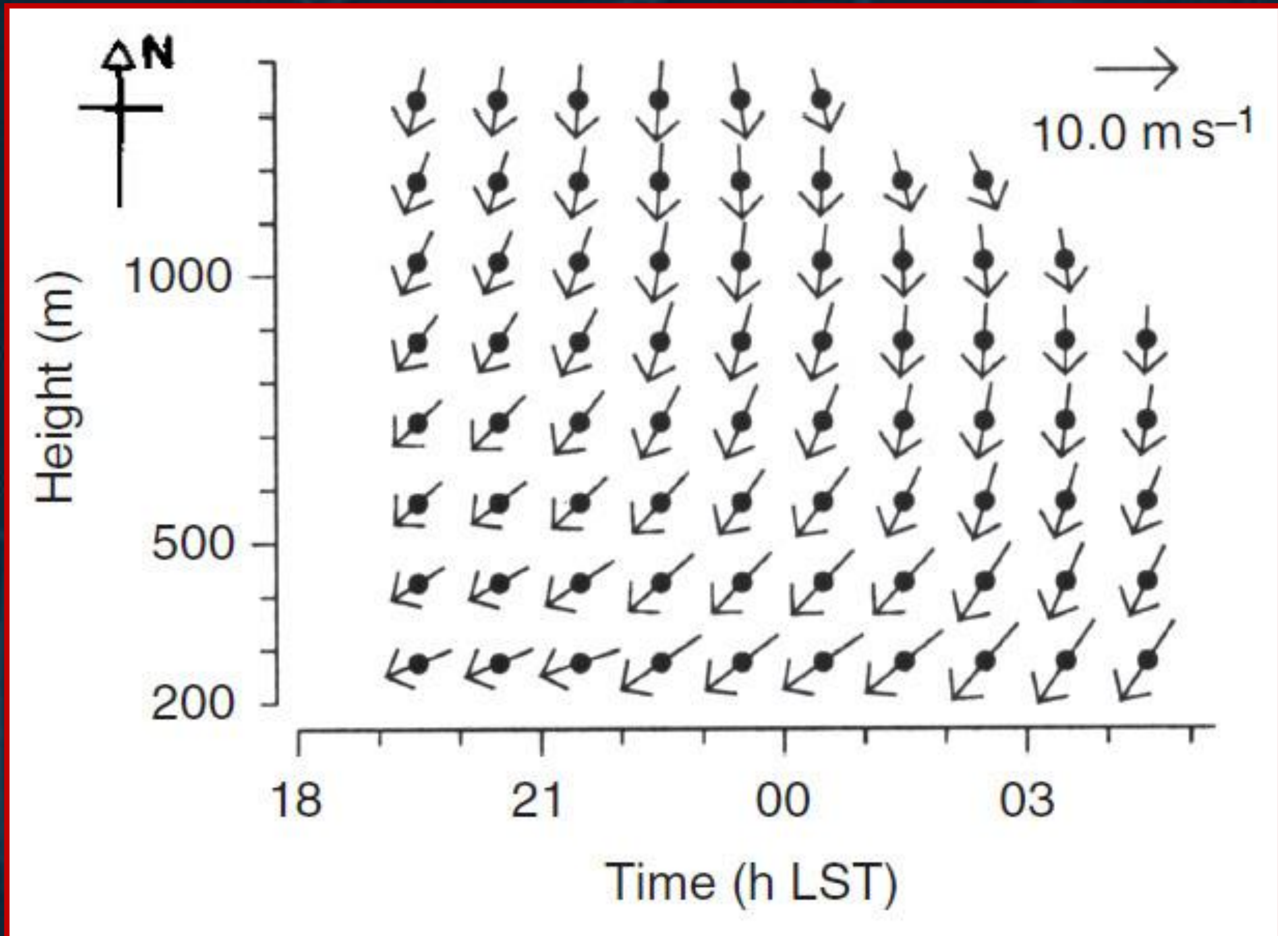


Black – signal
Blue – fit
Red – scan averages.

[From V.A. Drake (2013). 2013 Conference on Radar, Adelaide, 9-12 Sep 2013. IEEE Proceedings.

Bourke, NSW, 16 and 17 Sep 2007.

Changes in speed and direction with both height and time are revealed



Bourke, NSW, September 2007 (single night).

Such detailed speed and direction data would clearly have value for verifying observations of biological targets from weather surveillance radars (WSRs).

Vertical-beam entomological radars with ‘target interrogation’ provide useful identification information

- Size
- Shape
- Wing-beat frequency

} (for individual targets)

Size and shape are potentially of great value for verifying and interpreting biological echo observed with WSRs.

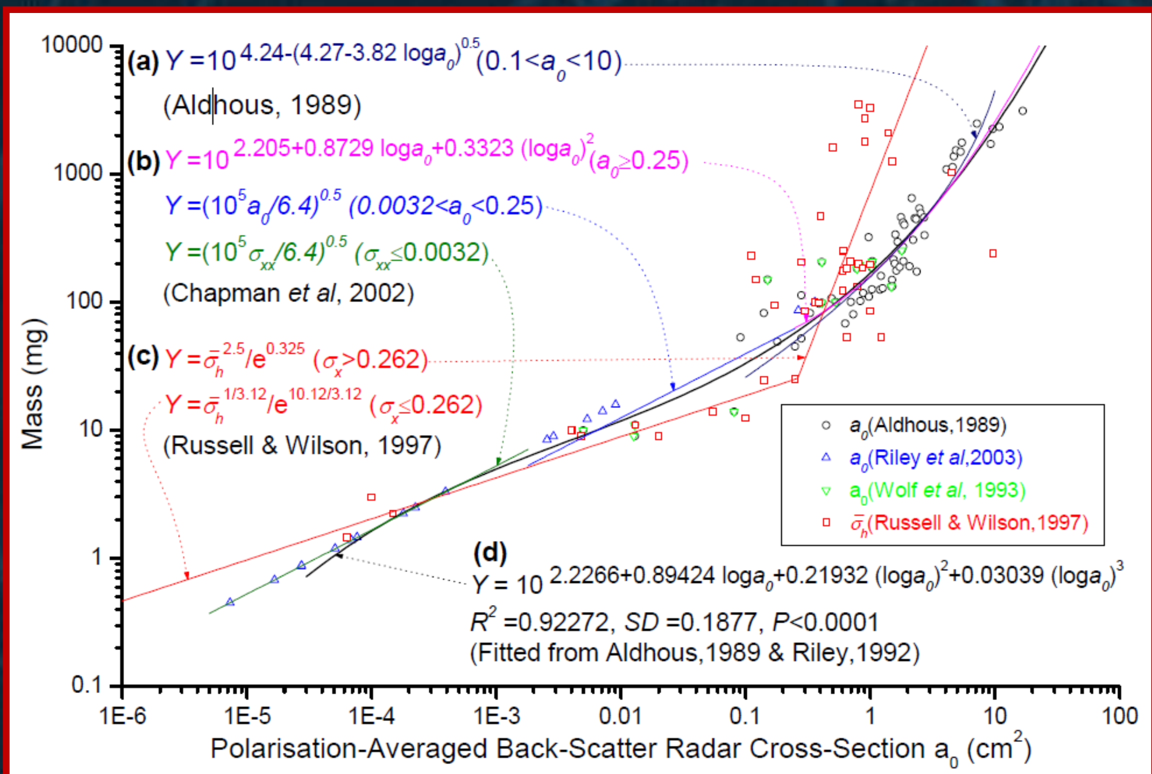
However, results from IMRs are not directly applicable to WSRs, because the configurations are so different.

2. Target size

The usual measure of size in radar work is the Radar Cross Section (RCS).

For insects this is usually measured in cm^2.

As the size range of insects is large, a logarithmic measure is often used: dBsc (dB relative to 1 cm^2).



RCS values have no biological meaning, so mass values are often estimated using an empirical relationship.

However, this shows a lot of scatter so the mass estimates are rather uncertain.

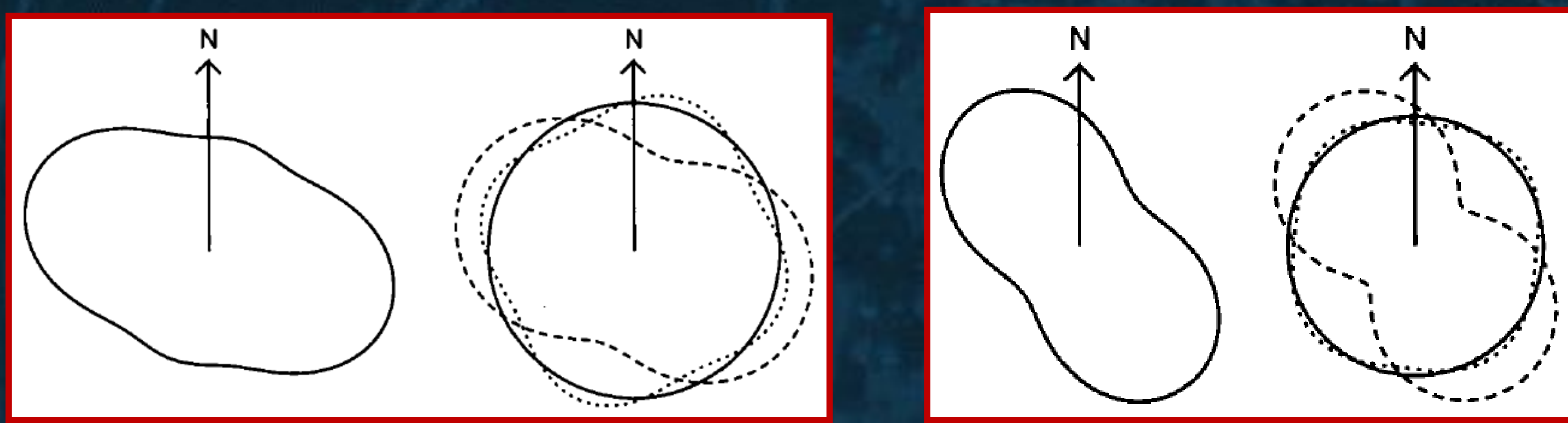
[From H.K. Wang, PhD thesis, 2008, UNSW Canberra.]

A vertical-beam radar measures the RCS from below ('ventral aspect')

With rotating linear polarization, averaging is necessary.

The *ventral-aspect polarization-averaged RCS*, $<\sigma_{\phi}>$ or a_0.

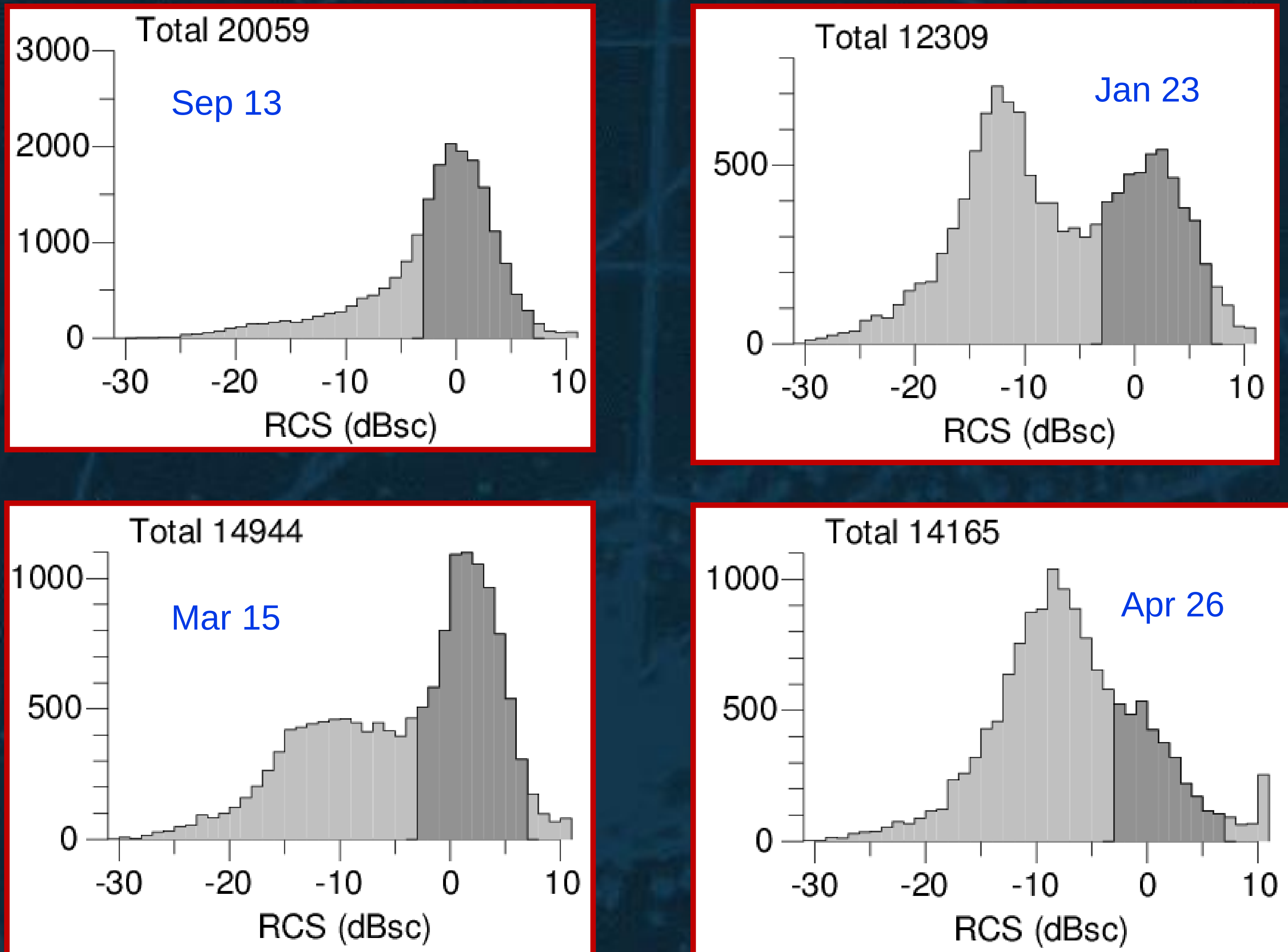
a_0 is a rather good measure as 1) it is not dependent on the insect's orientation, and 2) if the insects are in steady flight they will likely present a consistent (ventral) aspect.



Polarization patterns for two insects. Solid line, a_0; dashed and dotted lines, elongation and cruciform components. Bourke, NSW, 22 Feb 2000, ~1025 m.

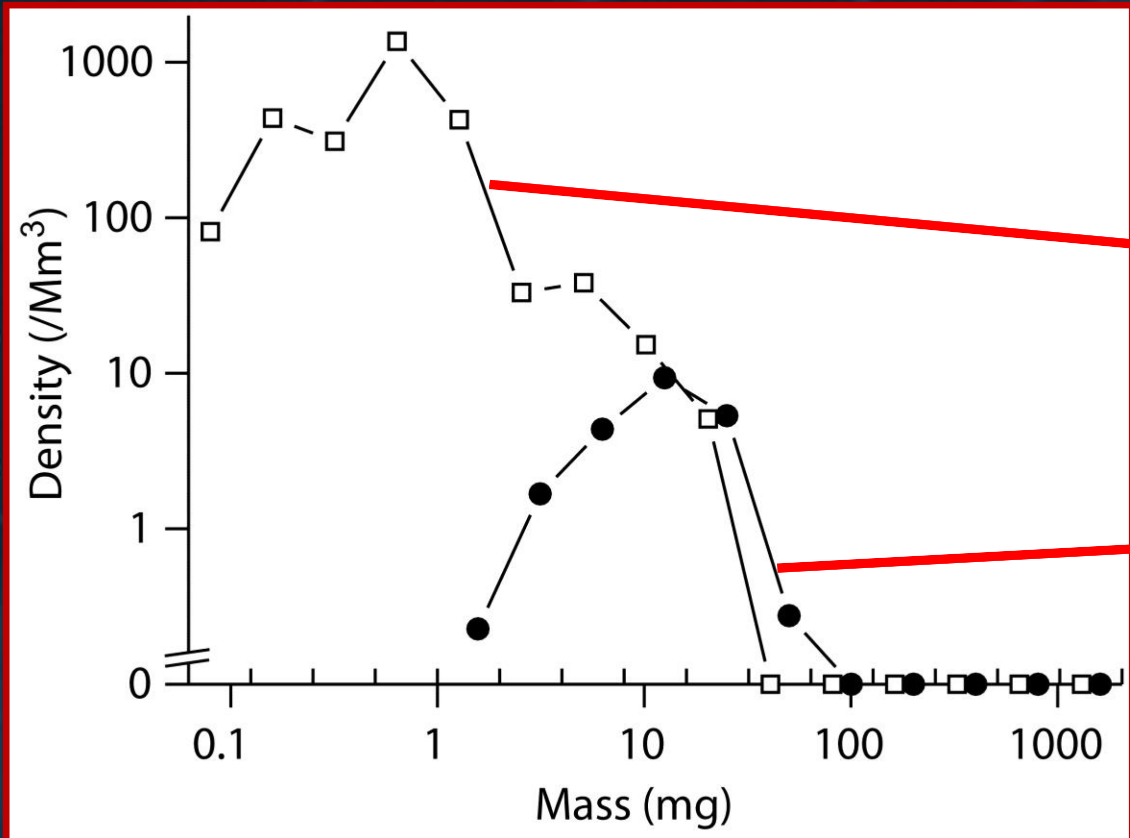
[Figure from V.A. Drake, 2002, *Entomologia Sinica* 9(4):27-39.]

RCS distributions vary from night to night



Bourke, NSW, 2007-08.

Even at X-band and short range, current IMR-type radars do not detect the smallest insects.



From aerial-net catch

From radar (RREU VLR)

July 2002, southern England; ~150 m.

Contribution of small insects, even if numerous, to C-band reflectivity likely to be very small.

[From V.A. Drake & D.R. Reynolds (2012). *Radar Entomology, Observing Insect Flight and Migration*. CAB International, Wallingford, UK.]

Converting X-band RCSs to C-band

Small insects will be Rayleigh scatterers at both frequencies, so their RCS can be scaled by $(\lambda_X/\lambda_C)^4 = (3.2/5.5)^4 = 0.115 = -9.4$ dB.

Larger insects will be Mie targets, or Mie at X-band and Rayleigh at C-band.

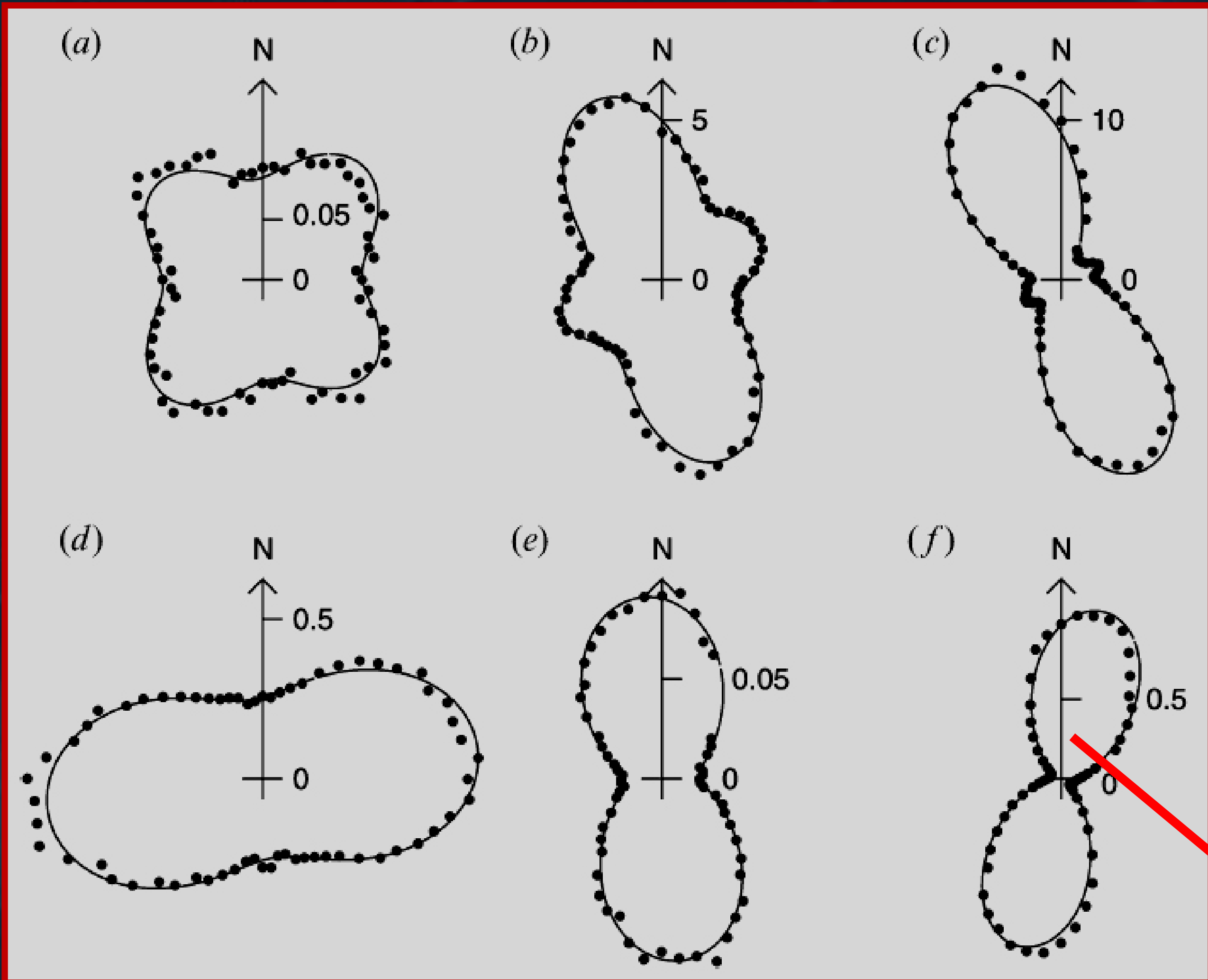
- In most cases the RCS will be smaller at C-band, but by less than the Rayleigh scaling factor.

WSR beams will mostly strike insects horizontally (or nearly so), but at a variety of aspect angles.

- If the insects are orientated, the RCSs (and therefore the observed reflectivity) will vary with beam angle even if the density is uniform.

For many insects, a scaled X-band a_0 should provide a useful estimate of the *mean* lateral-aspect C-band RCS.

3. Target shape



'Shape' is the variation of RCS with the polarization angle of the radio wave

These are 'ventral shapes'

RCS scale (cm^2)

Bourke, NSW, 22-23 h, 15 Nov 1999, 400-700 m.

[From Dean, T.J. & Drake, V.A. (2005) *International Journal of Remote Sensing* 26: 3957-3974.]

Measures of shape

The obvious measure of shape is σ_{xx}/σ_{yy}, the ratio of the RCSs with the linear polarization aligned with the insect's body axis and aligned perpendicular to it.

This measure seems appropriate for WSRs for which the beam is usually nearly horizontal.

For most insects σ_{xx}/σ_{yy} >1 at X-band. The range is quite broad.

At C-band, ratios >1 also seem likely to predominate.

'Shape' is retrieved from an IMR as parameters α_2, α_4.

These determine the strength of the 'elongation' and 'cruciform' components of the polarization pattern.

σ_{xx}/σ_{yy} can be estimated as $(1+ \alpha_2 + \alpha_4)/(1- \alpha_2 + \alpha_4)$.

Converting X-band shapes to C-band

Most insects have approximately cylindrical bodies

For these, σ_{xx}/σ_{yy}, at ventral and sideways-on aspects should be similar.

But many insects viewed by a WSR will be head-on, tail-on, or at some angle between these and sideways-on.

Some insects have flattened bodies. For these σ_{xx}/σ_{yy} will probably be underestimated by the IMR data.

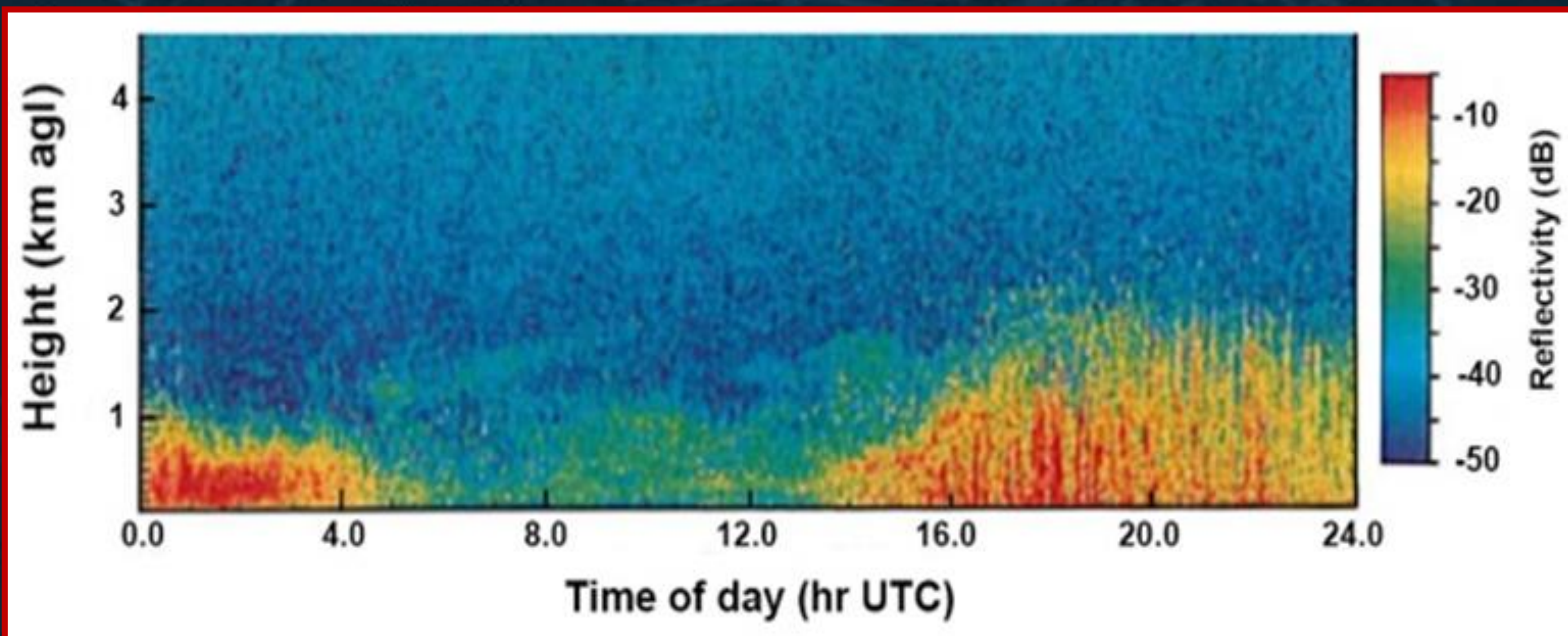
Observing at X-band will probably also underestimate the C-band σ_{xx}/σ_{yy}.

T-matrix RCS calculations may be needed to supplement and aid interpretation of the X-band ventral-aspect data.

4. Insect densities

Diurnal variability in intensity and vertical extent of a layer of small insect targets

Reflectivity from a 35-GHz cloud radar on a cloud-free day in Oklahoma, USA.



Depth of the layer follows the diurnal variation of the CBL, increasing during the morning and with a maximum in the afternoon.

From Luke et al. 2008, *J. Atmospheric & Oceanic Technology* 25, 1498-1513.

Insect Biomass and Periodicity

Biomass

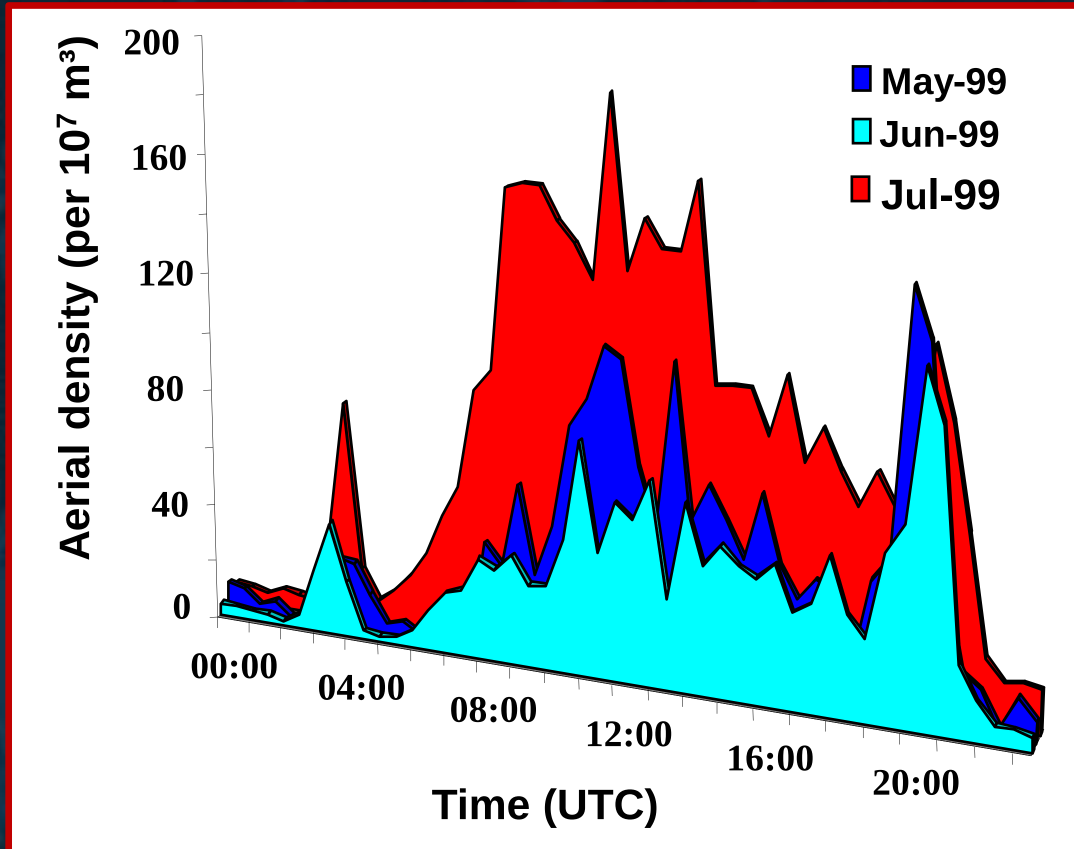
VLR, summer day:

- 10,000 large insects

1 km² 'window', 1 month:

- 35 Million large insects
- 3.5 Billion micro-insects
- 1 Metric Tonne

Diel periodicity



Mean monthly patterns of daily flight activity, at 150-195 m above ground, Harpenden, UK.

Chapman *et al* 2003, *Bioscience*

Volume densities during the dusk emigration peak

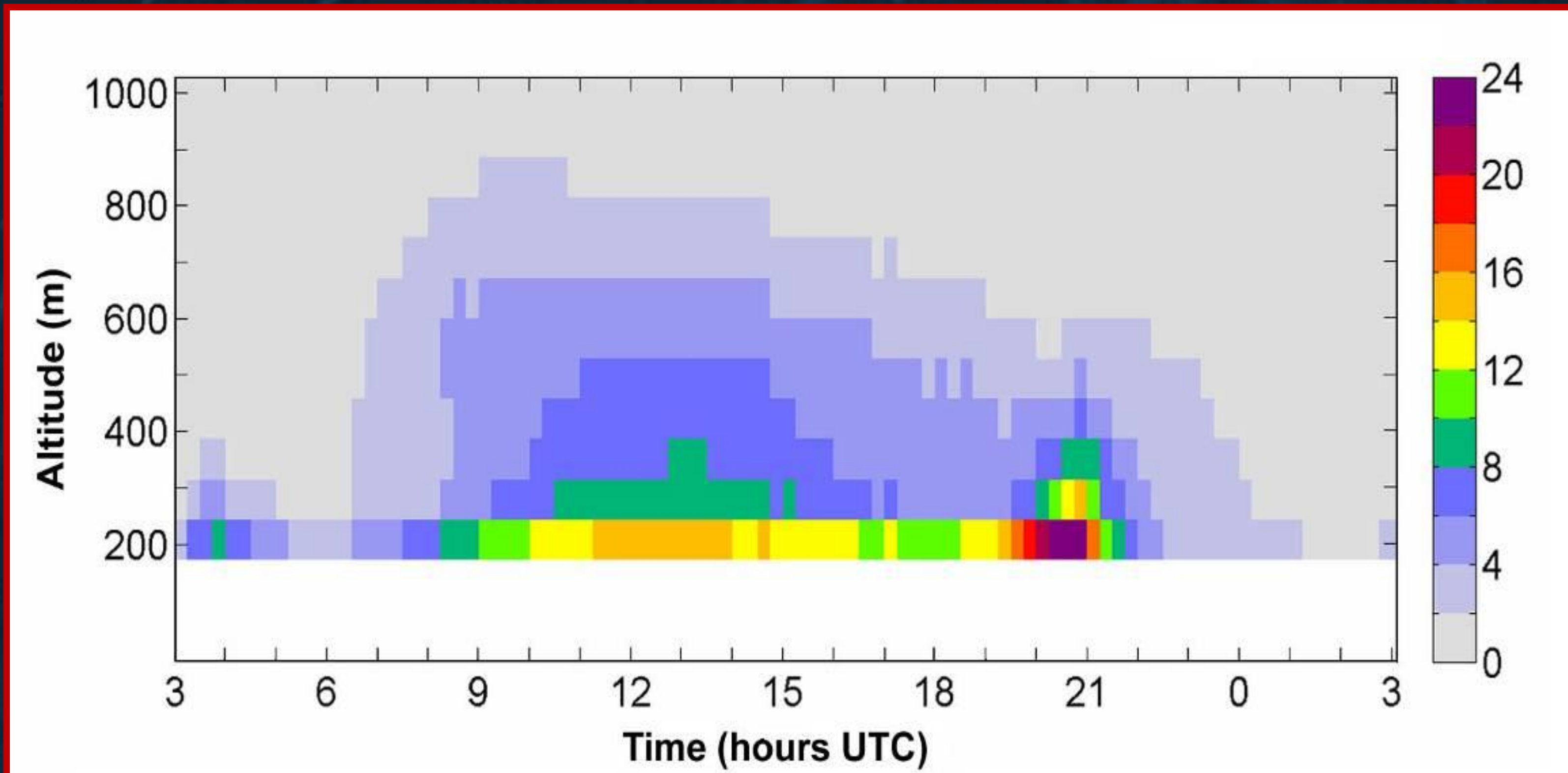
(as recorded by entomological radars)

Species	Location	Volume density (insects per m^3)	References
Moths, mainly noctuids	United Kingdom	$1\times10^{-6} – 1\times10^{-5}$	Reynolds *et al.*, 2005; Wood *et al.*, 2006
Noctuids, mainly corn earworm moth	Texas, USA	~5×10^{-6}	Beerwinkle *et al.*, 1988; Wolf *et al.*, 1994
Noctuid and pyralid moths (several species)	N.S.W., Australia	$1\times10^{-6} – 1\times10^{-5}$	Drake & Farrow, 1985
Australian plague locusts	N.S.W., Australia	$2\times10^{-7} – 5\times10^{-3}$ (variation with height)	Drake, 1982; Drake & Farrow, 1983
Brown planthoppers	Eastern China	$9\times10^{-4} – 2\times10^{-2}$ (from aerial netting)	Riley *et al.*, 1991

Time-height plot of insect numbers

Number of resolvable insect targets at each sampling height during each 5-min sampling period.

(pooled mean data for summers 2000 - 2003 for two VLRs)

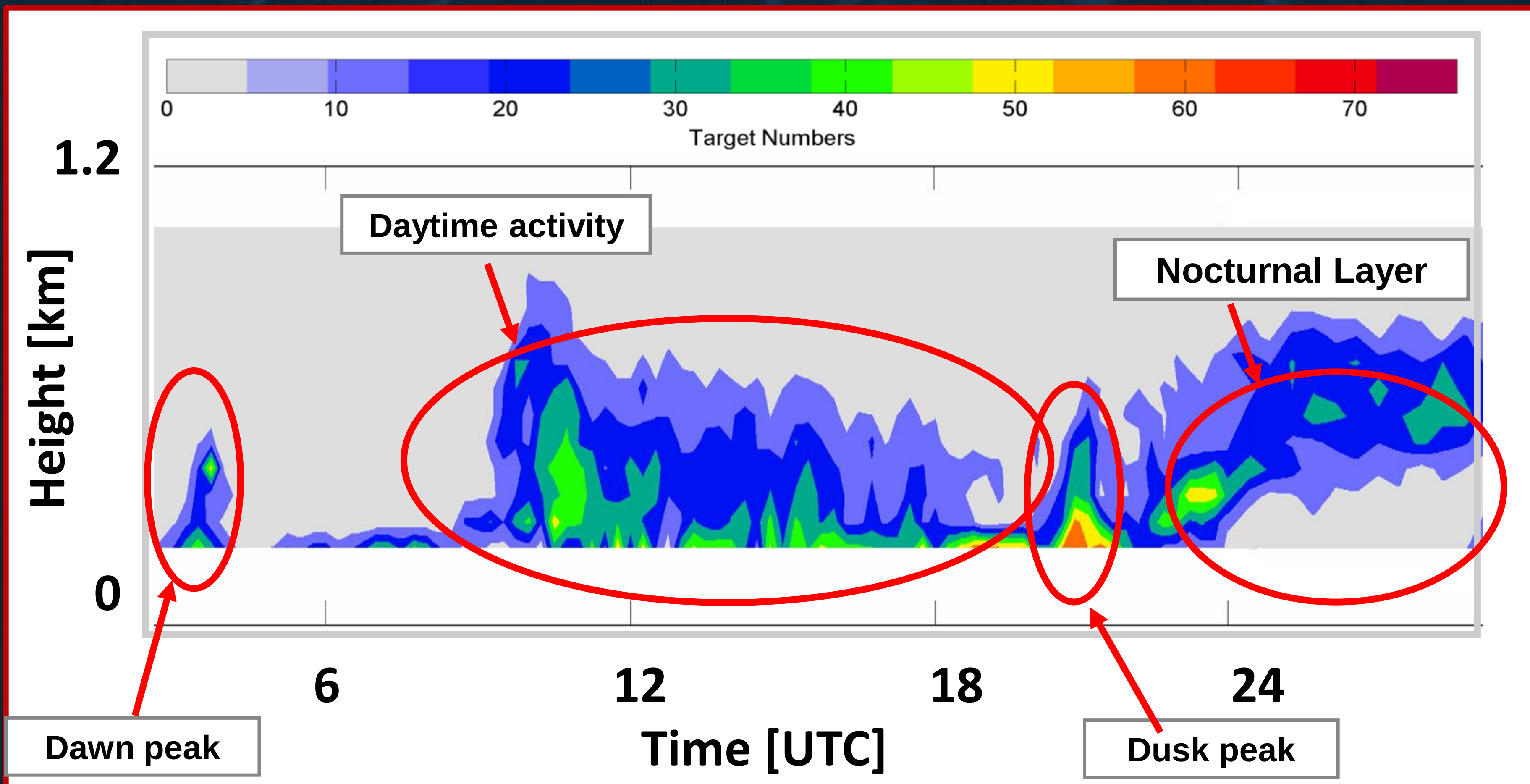


Shows main periods of flight activity.

A general *decrease* of numbers with height is also apparent in pooled data

Diurnal periodicity & layers

Some important features are not shown in pooled data – e.g. nocturnal layering, so look at individual nights

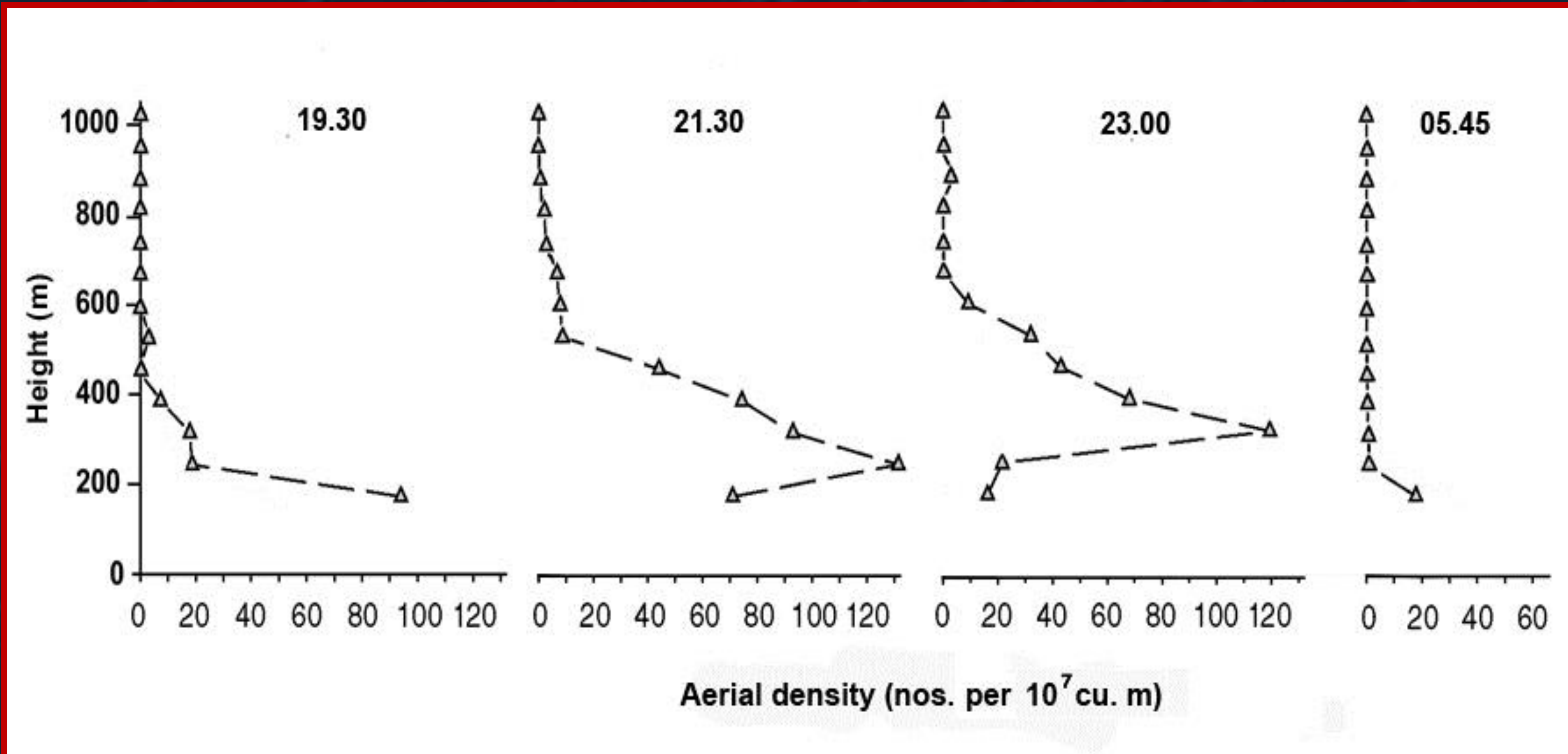


Malvern, UK, 16 June 2000.

Courtesy of Curtis Wood, University of Reading.

Typical evolution of vertical distribution of largish insects through night

VLR observations; insects of mass > 12 mg only.



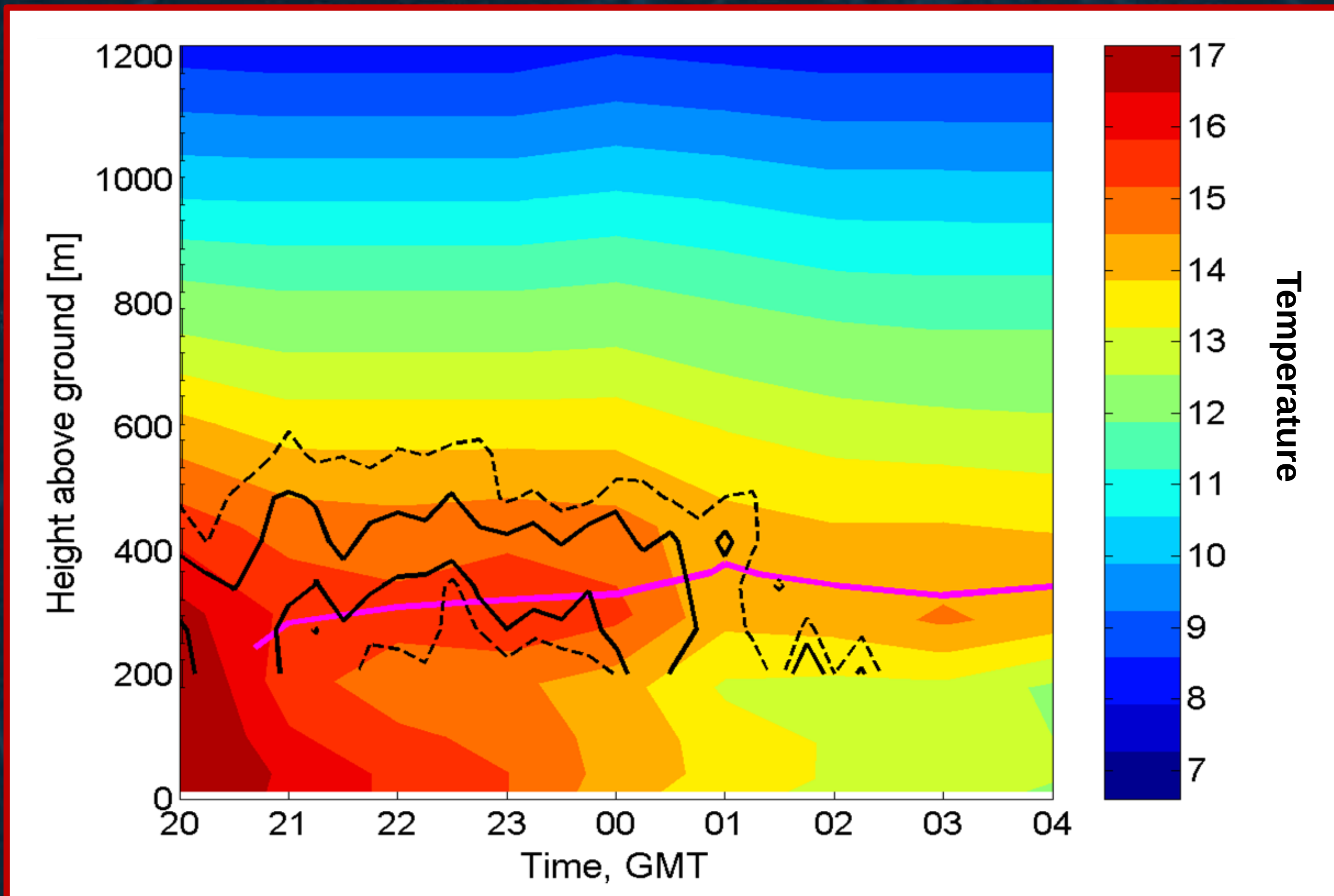
Malvern, UK, 24=25 August 2000.

From Reynolds *et al*. 2005, *Bull. Entomol. Res.*

Layering and nocturnal temperature inversion

Black lines show the aerial density contours for 25 (---) and 50 (—) insects / 10^7 m^3.

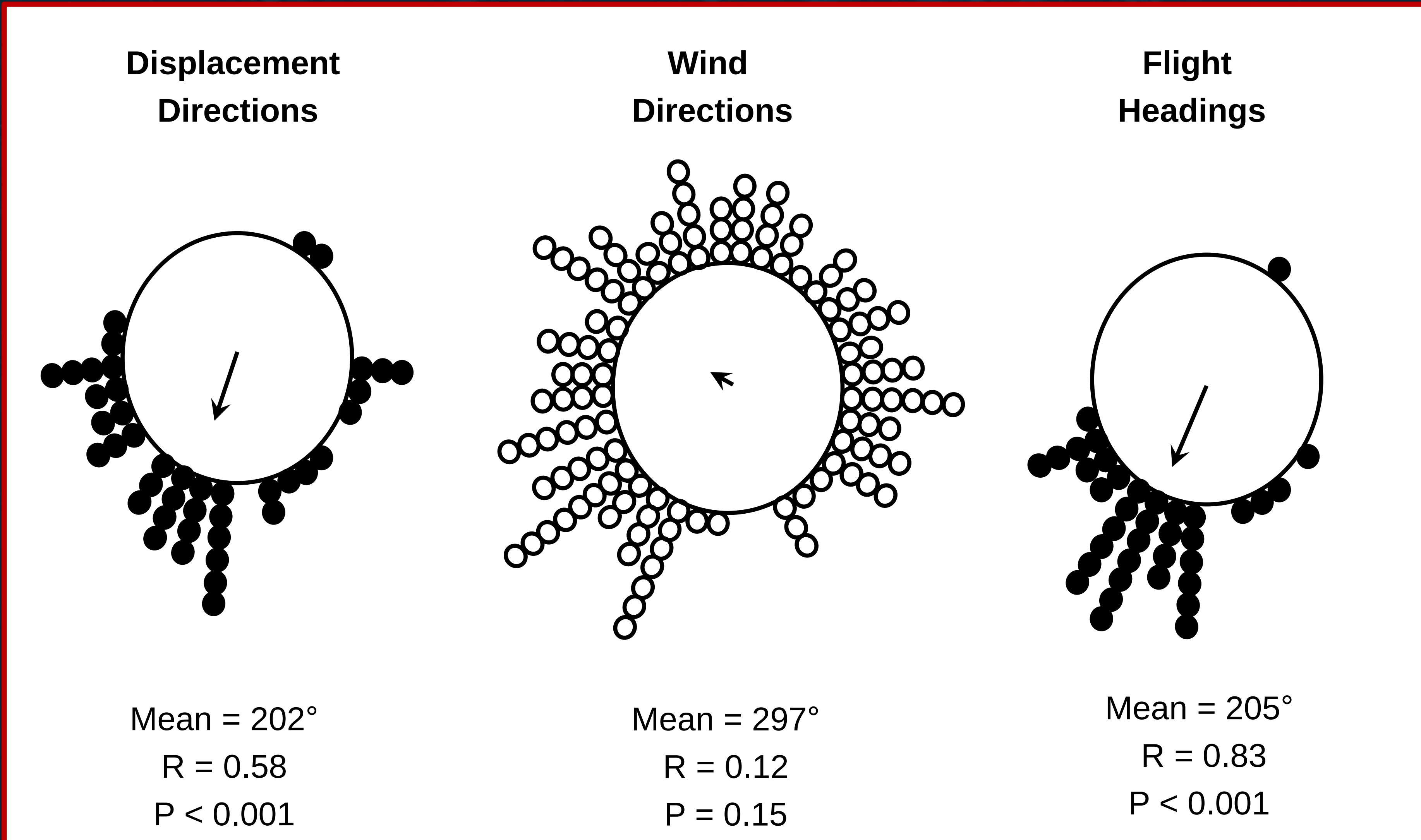
The magenta line marks the top of the temperature inversion



Wood *et al* 2006, *Int. J. Biometeorology*

Selection of Favourable Winds

Distributions of directional data obtained during return migration 'events' of the Silver-Y moth.



Chapman *et al* 2008, *Current Biology.*

5. Conclusions and inferences

Vertical-beam radars with target interrogation have considerable potential for verification of biological data products from WSRs.

> However, X-band ventral-aspect data are only indirectly applicable to near-horizontal C-band scans.
>
> Vertical-beam IMR-type radars operating at C-band could be optimal for the verification task, especially if bird targets are numerous.

Vertical-beam radars obtain information that scanning radars with large pulse volumes can never provide.

> E.g. distributions of target sizes, and target-identification characters (shape, wing-beat frequency).

A role can be envisaged for such radars, operating alongside WSRs to provide complementary data to assist interpretation of biological echo.

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