

Meteorology of insect layers observed by weather radars

Matti Leskinen¹, Dmitri Moisseev², Jarmo Koistinen³

¹University of Helsinki, P.O.Box 64, FI-00014 UNIV. OF HELSINKI, Finland, Matti.Leskinen@helsinki.fi

²University of Helsinki, P.O.Box 48, FI-00014 UNIV. OF HELSINKI, Finland, Dmitri.Moisseev@helsinki.fi

³Finnish Meteorological Institute, P.O.Box 503, FI-00101 HELSINKI, Finland, Jarmo.Koistinen@fmi.fi

ABSTRACT

Clear air echo observed by C-band (5 cm wavelength) weather radars, can mostly be related to insects. The insect echoes may be seen as a quite uniform layer in the lower troposphere after normal weather radar processing, e.g. in radar images. Using high resolution measurement close to the radar, the variations caused by significantly large insects is already visible. This has been one of the methods that have been used in Finland to help monitoring aerial migration of insects by weather radars. Dual polarization radar makes it more reliable to separate echoes caused by small insects and precipitation [1]. We have studied insect layers that are frequently observed by the University of Helsinki C-band Doppler weather radars in Finland. Dual polarization radar measurements were used to separate insect related echoes from other sources.

In many cases the echoes from insects have been observed to form horizontal layers. However, turbulent variations in refractive index of the air cause the most distinct echo layers related to sharp inversions. The visible echo layers are produced by the combination of insect sizes and their abundance, and therefore also the biological differences of species may have an effect. In Finland most of the insects are usually below 1.5 km, but the altitude range depends on air temperature. Large insects migrating near freezing temperatures have regularly been observed at levels up to 3 km above the ground.

We compare the properties of these layers to profiles of meteorological parameters. The data provided by the various instruments in the Helsinki Testbed campaign were available for these comparisons. Profiling equipment in the area included radiosondes, ceilometers, Doppler lidar, sodar, wind profiler and RASS. The observations are made near the coastline, which makes it possible to study the situation over the land and sea surface at the same time.

1. INSECTS IN RADAR MEASUREMENTS

A general daily pattern in clear air echoes has been reported by various authors at different geographical locations. The pattern was already found with obvious relation to different insects in 1960's [2][3]. As described with insects the daily cycle of echoes has the following features in Helsinki; peaks of small insect activity at dawn and dusk, after sunset some large nocturnal insects are present and gradually vanish from the air as the night passes, daytime insects begin to fill the convective boundary layer in the morning, and in the afternoon and evening the number of insects in the air is again gradually decreasing. This

general pattern is obviously the result of the different species migrating at different times of the day. Both inter and intra species variability in the flight range covered by individual migrants probably explains the dawn/dusk peaks, and gradual decreases of number density during the night and the day.

Entomological radars have monitored the nocturnal migration of large insects, and the insects have been seen to congregate in the warmest part of the surface inversion layer [4]. But the vertical extent of these radar observations is often much below the observed layers in weather radars.

2. LAYERS OBSERVED IN HELSINKI

2.1 Migration in clear weather

Insects in the air have been studied by trapping, and Johnson [5] found that the vertical profiles of daytime migrating aphids were similar to the profiles of passive particles that were mixed in the convective boundary layer. In Finland, the pest control people are monitoring aphids with ground based traps. The suction traps that they use at 12 m height should give some idea on what kind of migrants are in the upper layers, especially in cases that involve migrants from abroad. In these cases the weather radar has detected obviously small insects in an upper layer, especially over the Gulf of Finland in early summer when the water is cool. This is not in contrast with Johnson's observations, since over the sea the convective boundary layer does not exist at that point. The layer might be caused by low fliers dropping to the sea as the lowest layer is cooling over the water, but usually the altitude is too high for the direct effect of the water surface.

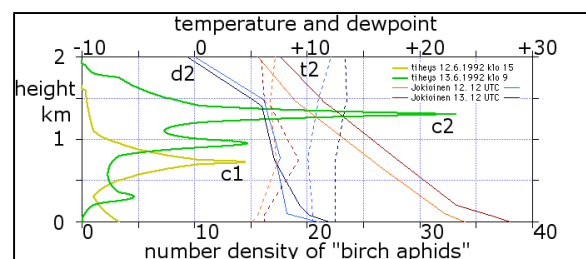


Figure 1 Weather radar echo derived insect number density profiles (thick lines c1 and c2) with radio sounding data (thin lines, t2 = temperature, d2 = dewpoint of the second day).

Fig. 1 shows insect number density estimates by the radar, and radio soundings from two successive days, the 12th and 13th of June, 1992. An insect layer below 1 km was found to be higher on the second day, but

roughly at the same temperature, +15 to +17 degrees C. This may be a result from the ability of insects to find the optimal temperature for migration.

Large insects have been seen to gather in a separate layer of 0.5 to 1 km thick at altitudes that have close to freezing temperatures, and above the daytime convective boundary layer. Noctuid moths are known to have high body temperature during flight because of the heat produced by their working muscles, and the low environmental temperature is not a problem for them. Some of these cases have had medium level clouds, *Altostratus*, and moths may rather continue their migration above the clouds than cross the layer that may be colder and significantly moist. On the other hand, during the day solar radiation is warming the migrants, especially above a cloud layer. In a case involving mass immigration of underwing moths, *Catocala spp.*, large insects were spotted by the weather radar in huge numbers at altitudes from 2 to 4 km, and the layer was much higher at noon than in the morning or evening. This may have been caused by the need of insects to rise to cooler air during the brightest sunlight. Migrants at these heights have to rise there by their own force. Migrant moths have been studied by entomological radars, but at much lower altitudes [6].

Example of insect mass migration in warm air mass is shown by radar images 28th of May, 2007 in Figures 2,3 and 4. Kumpula radar is our dual-polarization radar, and it is situated near the coast of the Gulf of Finland. The figures 2 and 3 show vertical cross-sections from the radar towards north over the land and towards south over the sea. Our vertical-looking Doppler weather radar was recording at the same time 32 km landwards from Kumpula radar, and it produced time-height cross-section of vertical speed in Fig. 4. The insects are seen as dots, traversing the radar beam in a few seconds. The radar half-power pulse length is about 90 m, and the echo layer is seen mostly in only one bin that has a 50 m separation. The relatively large insects can cause echoes that can be tracked in 2 or 3 consecutive range bins due to the oversampling in range. Lowest range bins are attenuated by the heavy protection of the receiver by RF limiter.

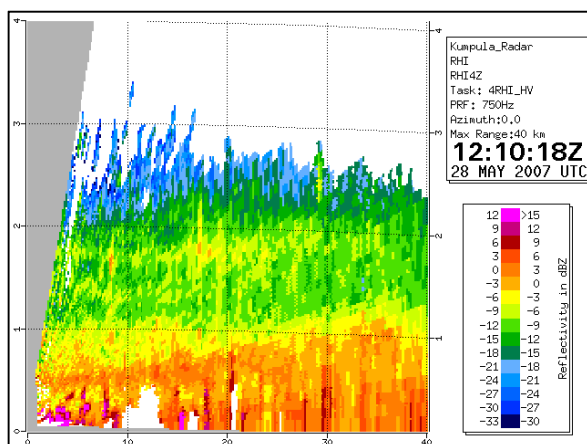


Figure 2. Kumpula radar vertical cross-section of equivalent radar reflectivity factor over the land; height range from 0 to 4 km, and distance from 0 to 40 km.

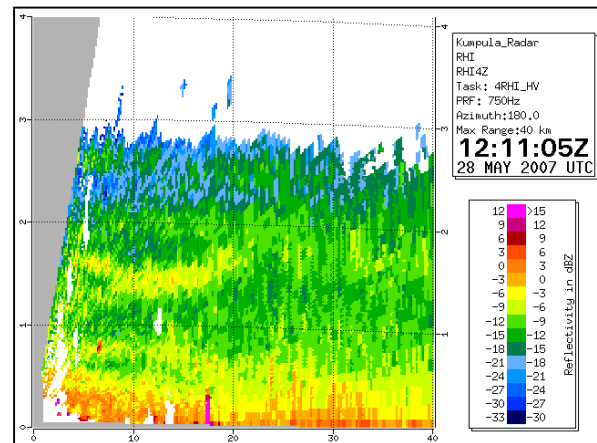


Figure 3. Kumpula radar vertical cross-section of equivalent radar reflectivity factor over the sea.

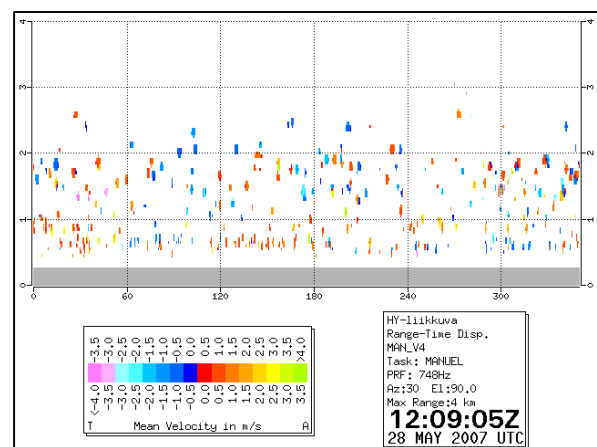


Figure 4. Vertical-looking radar time-height cross-section of vertical speed; negative numbers indicate downward speed (towards the radar); height range from 0 to 4 km, and time span is 6 minutes.

Organized convection during the day lifts or helps insects to gain height, and also short range migrants are seen over the land, which increases the reflectivity in the lower planetary boundary layer. The vertical speed has some kind of cyclic variation in time, which is consistent with organized convection cells, but includes obviously reactions of insects as well. In these convective cells it is quite common that a thin echo layer forms on top of the uplift cell.

Fig. 5 to 9 are from a case where strong cells of convection were observed over the land, and sea-breeze front advanced during the afternoon many tens of kilometres from the coastline. Insects were observed up to about 2 km altitude during the day in both the strongest cells of organized convection over the land, and at the sea-breeze front. The front passed the vertical-looking radar after 16:30 UTC, i.e. after 18 local solar time, and at that point the number of daytime insects was already somewhat reduced. The sea-breeze front convergence causes insects to congregate, and long echo bands connected to these fronts are frequent features near the Finnish coastlines during the summer. In some cases the echoes in the band are mainly caused by birds and not insects, especially in spring when the number of insects is still quite low after the winter.

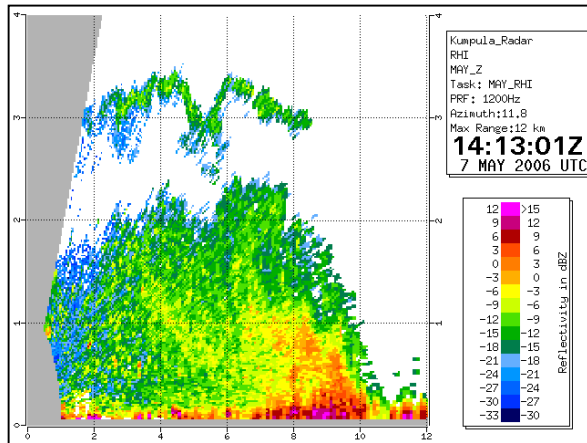


Figure 5. Kumpula radar vertical cross-section of equivalent radar reflectivity factor at the sea-breeze front zone.

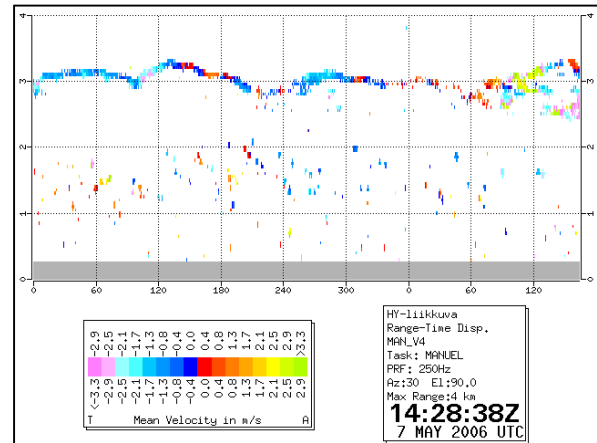


Figure 8. Vertical-looking radar time-height cross-section of vertical speed during cellular convection; height range from 0 to 4 km, and time span 9 minutes.

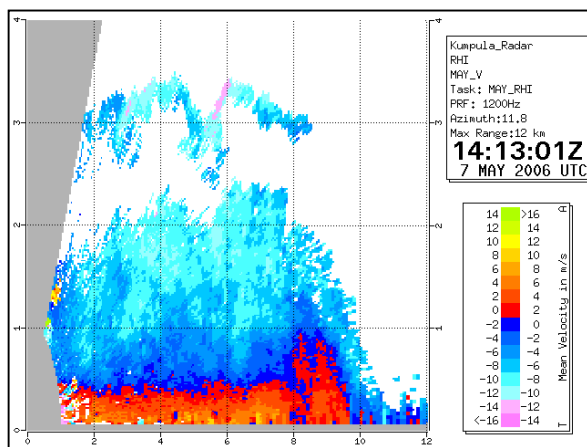


Figure 6. Kumpula radar vertical cross-section of radial velocity at the sea-breeze front zone; negative values (blue) indicate towards the radar component, sea-breeze causes the positive velocities (red) away from the radar.

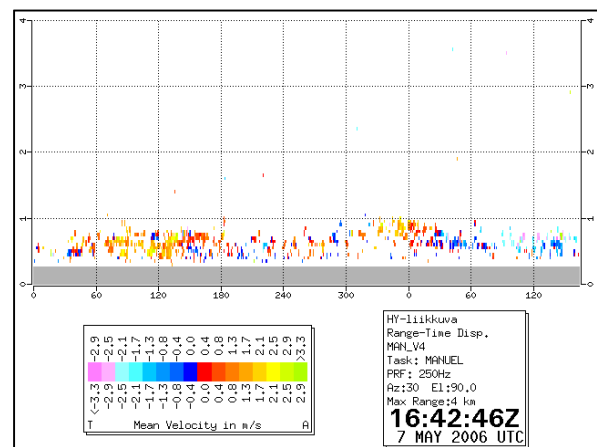


Figure 9. Vertical-looking radar time-height cross-section of vertical speed during sea-breeze front passage.

Above the insects both radars show a thin echo layer that is probably related to turbulence occurring at the boundary layer top inversion layer, and triggered by the upward airstream from below. The resolution of the vertical-looking pulsed Doppler weather radar seems to be quite good in these cases to separate echo mechanisms. Already decades ago, high resolution FM-CW atmospheric radar recordings were very spectacular in this sense [7].

2.2 Insects and precipitation

Insect migration is probably blocked by rain, at least if it is dense enough. The insects are carried by the wind. They can avoid to be overrun by the precipitation cells if the clouds are moving with about the same wind as the migrants. Vertical wind shear is usually present, and rain clouds have tracks that cross the wind blown flight paths of insects below them. We have observed by radar how migrants have been reduced in number downwind of a rain shower cell crossing the migration flight path. Upper migrants whose route follows more closely the direction of movement of the rain cells may not be so easily washed down by rain. This may explain some part of the upper layer seen in figures 10 to 12 showing insects migrating near the edge of rain. Insect can be

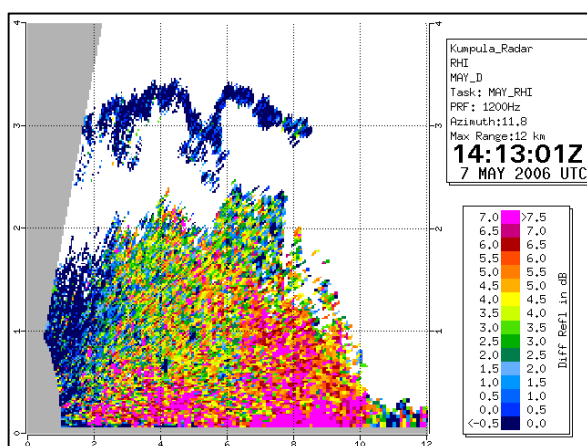


Figure 7. Kumpula radar vertical cross-section of differential reflectivity at the sea-breeze front zone.

detected by the dual-polarization radar even a bit inside of the weak rain.

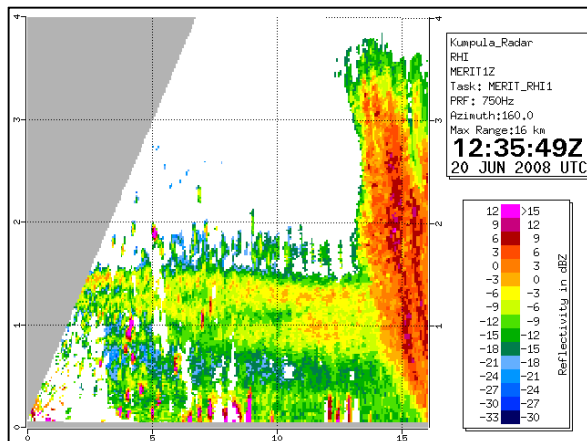


Figure 10. Kumpula radar vertical cross-section of equivalent radar reflectivity factor; height range from 0 to 4 km, and distance from 0 to 16 km.

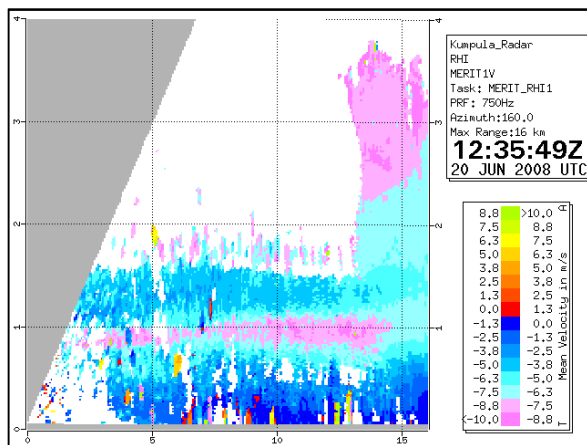


Figure 11. Kumpula radar vertical cross-section of radial velocity.

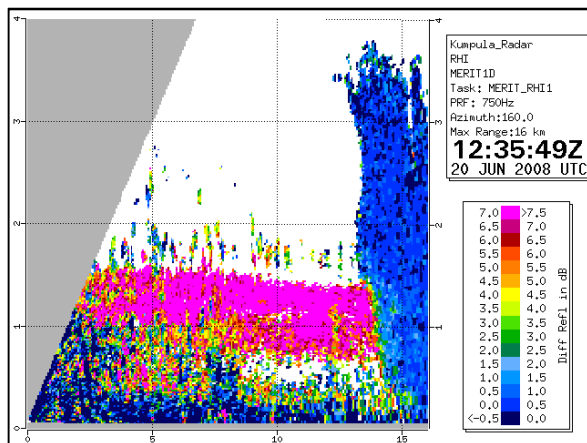


Figure 12. Kumpula radar vertical cross-section of differential reflectivity.

3. DISCUSSION

The echo power in normal weather radars with huge pulse volumes may show layer structures caused by insects that can be related to different number densities or differences in the preferred flight altitudes of

different size insects. Orientation of the elongated bodies of insects affects not only polarimetric variables but also reflectivity. To exactly know what is actually up there is practically impossible. Meteorological reasons for the layers can be sought even if the identity of the insects remains unclear. Layers of insects may sometimes be misinterpreted as something more meteorological, such as clouds or inversion layers.

Can the radar be used to determine which insects might be causing the echoes observed? Something can be deduced from the signals, and dual-polarization radar can get information that is closely connected to the shapes and orientation of the scattering insects. However, there may always be lack of reliable information on the behaviour of the insects in the high air layers that weather radars are probing. Combining the radar information of migrants with the entomological observations on the ground may be quite a reliable way to find out afterwards what the insects were.

REFERENCES

- [1] Zrnica D., A. Rhyskov, 1998: Observation of insects and birds with a polarimetric radar. *IEEE Trans. Geoscience Remote Sens.*, **36**, pp. 661-668.
- [2] Lhermitte R. M., 1966: Probing air motion by Doppler analysis of radar clear air returns. *J. Atmos. Sci.* **23**, pp. 575-591.
- [3] Browning, K. A., D. Atlas, 1966: Velocity characteristics of some clear-air dot angles. *J. Atmos. Sci.* **23**, pp. 592-604.
- [4] Drake V. A., 1984: The vertical distribution of macro-insects migrating in the nocturnal boundary layer: a radar study, *Boundary-layer meteorology*, **28**, pp. 353-374.
- [5] Johnson C. G., 1957: The vertical distribution of aphids in the air and the temperature lapse rate, *Quart. J. Royal Met. Soc.*, **83**, pp. 194-201.
- [6] Chapman J., D. Reynolds, H. Mouritsen, J. Hill, J. Riley, D. Sivell, A. Smith, I. Woivod, 2008: Wind selection and drift compensation optimize migratory pathways in a high-flying moth. *Current Biology*, **18**, pp. 514-518.
- [7] Richter J. H., D. R. Jensen, V. R. Noonkester, J. B. Kreasky, M. W. Stimmann, W. W. Wolf 1973: Remote radar sensing: atmospheric structure and insects. *Science*, **180**, pp. 1176-1178.