Developments in Airborne Entomological Radar

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ABSTRACT

Radar has been used to study insect flight for over 20 years. Radar, especially airborne radar, is unrivaled in its ability to observe the spatial organization of insect migration. This paper reports methods of data collection and analysis used by current airborne entomological radar systems and, in particular, the method used to review the data collected and visualize any large-scale structures detected. Examples of data from recent U.S. Department of Agriculture field experiments are presented to illustrate the analysis techniques. The data review method allows further data collection and analysis to be focused on areas of particular interest and thus significantly enhances the utility of airborne entomological radar.

1. Introduction

Radar has been used to study insect migration for more than 20 years (Reynolds 1988) and is a powerful tool for observing insect behavior. It has revealed remarkable features of organization and structure in insect migration and has shown the heights (often several kilometers, Schaefer 1979) and the distances (up to a few hundred kilometers per night, Wolf et al. 1990) to which migrating insects can fly. The information is used to improve our understanding of pest insect migration and thus to improve crop protection strategies.

Radar entomology is used to support research in agriculture and biology. The focus is thus on providing the information from the radars in a form that is relevant to practicing entomologists and agricultural scientists and not on developing sophisticated hardware. Standard marine radars (X band, 3.2-cm wavelength) are generally used since the equipment is robust, relatively cheap, and widely available, and because the wavelength is suitable for detecting many pest insect species (down to moths of about 1-cm body length), while being insensitive to insects much smaller than these. Signal processors are used to sample the radar signal and to control the system's operation, and data analysis is carried out using standard microcomputers.

Ground-based radars reveal much of the local flight activity of insects (to a range of a few kilometers typically), but for studies of the spatial organization of migration an airborne radar has great advantages and very effectively complements the ground-based systems. Cranfield has operated airborne entomological radars since the 1970s, initially over New Brunswick for the Canadian Forestry Service (Schaefer 1979), and more recently in collaboration with the U.S. Department of Agriculture (USDA) for studies in Texas (Hobbs and Wolf 1989; Wolf et al. 1990), and with whom the current system has been developed.

2. Typical entomological radar systems

A typical airborne entomological radar installation uses a radar antenna mounted to view vertically below the aircraft with a narrow pencil beam (2°–3° beamwidth). The beam is linearly polarized, and the plane of polarization is rotated at 4–10 Hz. This serves two purposes: the signals can be integrated over a complete polarization revolution to remove any bias in signal strength due to correlation between insect alignment and polarization angle, and from the variation in signal with polarization angle it is possible to measure insect orientation (see Vaughn 1985; Riley 1985; Aldhous 1989).

For the recent work with the USDA, a radar of 25-kW peak power, 100-ns pulse length, 2560-Hz pulse repetition frequency, and 10-Hz polarization rotation rate was used. Insects of radar cross section (RCS) 1 cm^2 are detectable to almost 1 km with this radar. For our work, it is important to reduce the large amount of data (150 000 readings per second for flights of up to several hours) to manageable proportions. This is

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achieved by deliberately undersampling the data. (Only 1 reading out of every 16 is recorded at any particular range.) With the aircraft flying at about 1-km altitude, 48 range gates, each 15 m deep, cover most of the range between the aircraft and the ground. Sixteen range gates are multiplexed to each of three data channels. Each data channel (labeled SH0–SH2) is built around a sample-hold device and covers a height band of 240 m. The data channels are either digitized directly or tape-recorded as analog signals and digitized postflight.

3. Experiments and results

The current series of USDA experiments is to study nocturnal insect migration of *Heliothis zea* from maize in northern Mexico to Texas in the spring (Fig. 1) (see Wolf et al. 1990 for details). The insects grow on maize initially but later attack a wide range of crops of economic importance across the southern United States. The team of experimenters includes field entomologists and a meteorologist as well as the radar entomologist, so that information is available on crop state and local meteorology through the migration season. A ground-based radar is sited near the Mexican border in the lower Rio Grande Valley, and the aircraft is used to monitor insect activity to the north (which is downwind during periods of significant migration).

Data collected by the airborne radar are analyzed in two principal ways. The first is to provide a summary of the whole flight, to allow regions of particular interest to be identified. The second stage is a more detailed analysis, able to provide profiles of insect density and orientation at particular points along the aircraft track. Until recently, the first stage was performed in a relatively crude and inflexible manner unable to show detailed vertical structure. The new data summary displays, however, show the full vertical structure of insect density.

Figure 2 shows examples of the improved data summary output. The diagrams combine many types of information and provide a quick overview of the data collected as well as calibration signals and general data quality. To read the diagram correctly it is helpful to understand the data collection and analysis procedures. The digitized data (either direct from the radar or from tape) are sampled to measure one vertical profile of signal strength each beamwidth along the aircraft track (every 35 m approximately, or 0.5 s). This profile is an average over one whole polarization rotation cycle to remove any bias due to correlation between the polarization angle and the insects' orientations, but preserves the full vertical resolution of the 15-m-deep range gates. The signal profile is not adjusted for the variation of signal strength with range. Each of these profiles is stored as one record of a data summary file. Each record corresponds to about 35 m of aircraft track, so there are about 30 records per kilometer of aircraft track. The 48 range gates currently used are processed as three data channels (SH0–SH2), each channel containing data from 16 contiguous range gates. The data summary display shows signal strength versus height (measured relative to the aircraft) along the aircraft track, with the three channels separated slightly to aid interpretation. The intensity scale is arbitrary and may be adjusted to enhance particular features of interest. SH0 is closest to the aircraft (nominally 120–360-m range) and contiguous with SH1 (360–600-m range). SH2 is usually contiguous with SH1 (and thus covers 600–840-m range) but is occasionally switched by 240 m (to 840–1080 m) to measure the ground return (e.g., records 610–690 and 2520–2600 of Fig. 2a). (The aircraft is usually flown 900–1000 m above the ground.) SH2 includes a voice commentary used to note particular features of the flight such as waypoints passed and changes in equipment settings (e.g., at records 0, 75, 460, 610, etc. of Fig. 2a). The data summary display also shows periods of zero offset check (e.g., records 2450–2510 of Fig. 2a) when the transmitter is switched off to measure any dc bias on the signals. Glitches on the data usually show up as noisy features across all three channels (e.g., the dark line near record 1100 of Fig. 2a).

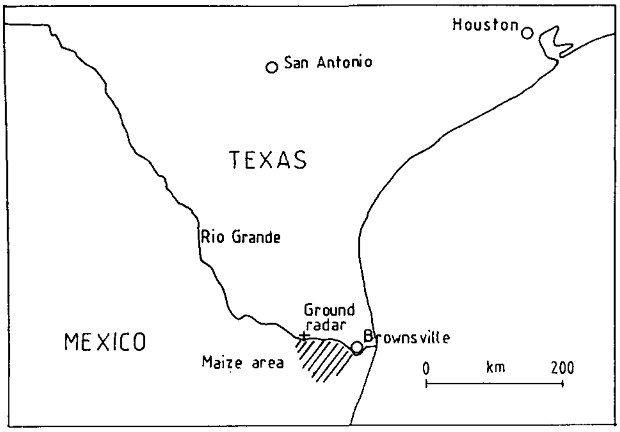

FIG. 1. USDA field experiment site on the United States–Mexico border.

The main feature of entomological interest in Fig. 2a is the area of strong signal at all heights between records 2000 and 3100 (approximately 67–103 km along the aircraft track). This is due to relatively large numbers of insects in the atmosphere (in this case the aircraft itself encountered the cloud of insects), which is often related to ground features such as particular types of vegetation, perhaps some distance upwind. Figure 2b (from the 1987 USDA experiments) by contrast shows thin layers of insects extending over several dozen kilometers. This structure is less common and was probably related to mesoscale flows linked to local thunderstorm activity. Again, the summary display provides a valuable visualization of the data collected, allowing further analysis or experiments to be focused

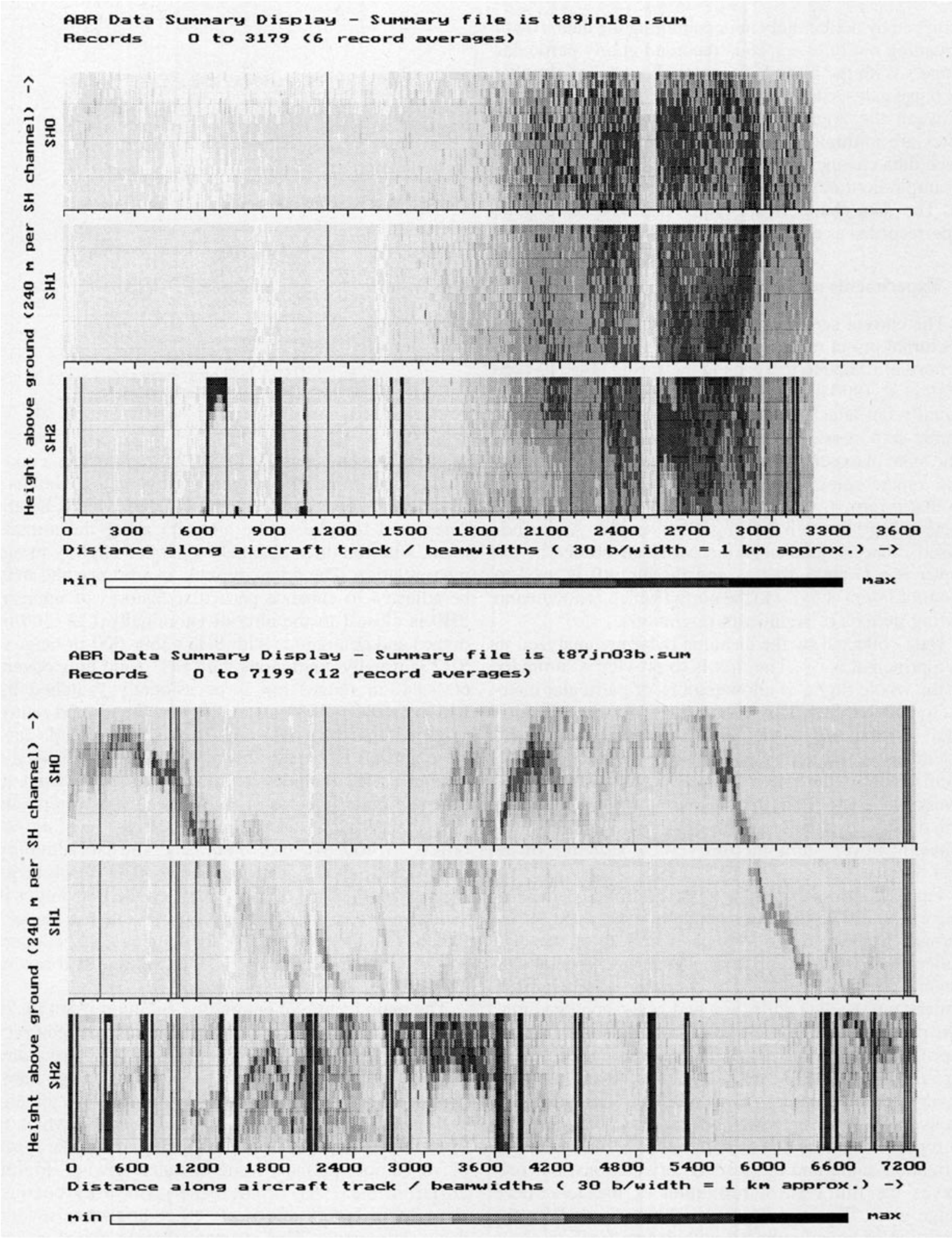

FIG. 2. Examples of the airborne radar data summary display: (a) for the first flight on 18 June 1989 (note the high insect concentration at all heights between records 2000 and 3100), and (b) from the second flight on 3 June 1987 (showing narrow layers of insects at altitude extending of several dozen kilometers). Dark bars limited to SH2 are the voice commentary; dark bars across all three channels indicate signal glitches; and bands of quiet low-level signal across all three chennels (delimited by voice commentary) are dc offset checks. The rest is signal from (predominantly) insects.

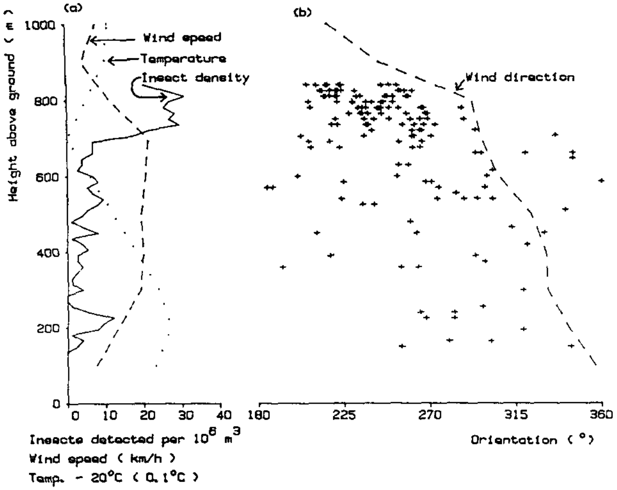

FIG. 3. Measured insect density and orientation profiles on 3 June 1987: (a) density, wind speed and air temperature, and (b) orientation and wind direction profiles measured at 2350 LT. The air temperature is plotted in units of 0.1°C above 20°C; the range measured is thus 20.0°–22.7°C.

on regions of interest. These diagrams can now be produced quickly enough for them to be used to plan subsequent flights to examine particular features in more detail.

Figure 3 shows results from a detailed examination of the insect layer near record 5500 of Fig. 2b and is an example of the more detailed analysis available (Hobbs and Wolf 1989). In this case a radiosonde profile was available (about 5 km away and 7 min earlier) and helps explain the layer of insects observed around 800 m. There is an inversion close to the layer, associated with a fall in wind speed above the inversion and a change in wind direction. The insect orientations are clustered about 240°, although the cue used by the insects to orientate is not understood. (The radar measurement of orientation is actually ambiguous by 180°, so the orientations may actually be clustered about 60°.) Further analysis showed the mean insect orientation to be almost constant along the whole length of the layer.

4. Discussion

Figures 2 and 3 illustrate the results available with current airborne entomological radars. The ability to visualize the atmospheric structure of insect migration is a powerful aid to understanding, and to be able to do this quickly and easily is a significant enhancement of our airborne entomological radar system. Qualitative descriptions of insect migration are valuable for studies of pest insect behavior. In cases where one species predominates, it is possible to provide quantitative estimates of insect densities, but mixed species distributions are much more difficult to measure. For ground-based radars we are developing methods of making quantitative insect RCS measurements that may allow some degree of target classification and that could in the future be applied to airborne entomological radar systems.

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