OPERATIONAL AND SCIENTIFIC NOTES

APPLICATION OF RADAR RAINFALL ESTIMATES FOR SURVEILLANCE OF *AEDES TAENIORHYNCHUS* LARVAE

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ABSTRACT. A preliminary investigation of land-based radar rainfall estimates for surveillance of *Aedes taeniorhynchus* larvae was conducted from January 1 to May 21, 1991 in Collier County, FL. Rainfall estimates from the National Weather Service RADAP II radar system, supplemented with tide gauge data, served as criteria for larval inspection. Rain, rain + tide and tide, respectively, triggered 48, 26 and 26% of the 14 proposed inspection trips. This system detected 7/8 larval broods found by Collier Mosquito Control District surveillance; the only brood not detected consisted of stragglers from an earlier brood exposed to cool weather and methoprene. A QUICKBASIC® program that extracts Cartesian coordinates and rainfall estimates from RADAP II B-SCAN data was developed.

Remote sensing offers great potential in the surveillance of medically important arthropods (Hugh-Jones 1989). Radar (Downing and Frost 1972, Pedgley 1982, Linthicum et al. 1991), aerial photography (Hugh-Jones 1989, Welch et al. 1989), tide gauges (Balling and Resh 1983) and satellite images (Hugh-Jones 1991, Linthicum et al. 1987) have been employed to identify insect outbreaks or habitat and conditions conducive to insect and disease outbreaks.

Because mosquito population dynamics are affected greatly by rainfall, remotely sensed rainfall is a potentially powerful mosquito surveillance tool. Lightning frequency (Shih 1988), cloud top heights (Woodley et al. 1980) and radar (Saffle 1976) have been used successfully to estimate rainfall. Linthicum et al. (1991) were the first to apply radar for larval surveillance, using airborne radar to locate flooded dambos that breed Rift Valley fever vectors. Ground-based radar is commonly used to map rainfall (Saffle 1976) and could be employed to locate hatches of mosquitoes.

Southwest Florida offered an ideal situation to develop and test such a system. The black salt marsh mosquito, *Aedes taeniorhynchus* (Wied.), the primary pest mosquito in coastal Florida, hatches in huge numbers when salt marshes and mangrove forests are flooded by rain or tide (Provost 1977). Unfortunately, much of this habitat is remote and expensive to access. Tidal flooding is anticipated using tide gauges and tide tables (e.g., National Oceanic and Atmospheric Administration 1990) (Beidler and Dodd 1985). By coupling tide data with remotely sensed rainfall, *Ae. taeniorhynchus* hatches could be predicted in remote areas. The National Weather Service (NWS) in Ruskin, FL provides radar-estimated rainfall using the Radar Data Processing (RADAP II) system [see Saffle and Elvander (1981), McGovern and Saffle (1984), Davis and Rossi (1985) and McDaniel (1991) for validation and applications]. The objectives of this paper are to describe a surveillance system for *Ae. taeniorhyhnchus* larvae based on tide data and RADAP II rainfall estimates and provide preliminary evidence of its effectiveness.

RADAP II estimates of 24-h rainfall were accessed from the NWS in Ruskin, FL (160 k NNW of Naples, FL) whenever rainfall was suspected or observed in Collier County, FL from January through May, 1991. RADAP II provides alphanumerically coded data in 2 formats (Saffle 1976). GRID plots rainfall for each 3 × 5 nm cell within 125 nm of the radar and B-SCAN (Fig. 1) provide data by range (10–125 nm at 1 nm increments) and azimuth (2° beam width). B-SCAN provides higher resolution than GRID (respective size of a B-SCAN and GRID cell at 100 nm is 1 × 3.5 nm and 3 × 5 nm) and was used preferentially. RADAP II was accessed via computer modem with PROCOMM PLUS® set at 1,200 baud; daily data were stored in an ASCII file. Nominal settings were as follows: rainfall increment (0.10 in), range (75–125 nm) and azimuth (150–170°). Because each row of a RADAP II data file is a string variable, a program was written in QUICKBASIC® 4.5 to provide Cartesian coordinate and rainfall (i.e., X-Y-Z data) for each cell.

RADAP II rainfall estimates were correlated to rain gauge data from 4 sites in western Collier County. The Cartesian coordinate of each rain

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TBW RAINFALL ACCUMULATIONS BY AZIMUTH AND RANGE
1200Z,  MAY 06, 1991  TO 1110Z,  MAY 07, 1991

CODE VALUE        1   2   3   4   5   6   7   8   9   A   B   C
D   E   F
RAIN(100TH IN)  10  20  30  40  50  60  70  80  90 100 110 120
130 140 150

        80        90       100       110       120
    .....*.........*.........*.........*.........*.....
150-CCDGINMLKHGC9878EED96433222222358AA75223322221234322
152-EBGFBFIIIHEAAEC9EFGFC65543332369DCA5433356654567644
154-DGIFA7AACADFIJJHNQRONKGFC9754568AA98664333336799764
156-ACLKD446869BGMRSXWUTUUNOONGA6555688655322224 68A8753
158-6DJH84234337AEKPTTUWUTQQLJKE98767763232223325898756
160-39BA8321211246CJNPWYWWSSQMJJJOJFD98543222222249ABB99
162-3354521100112 36BLOUWUXSWXXVUMQPQOKF75333432 24668A88
164-1220111    012335CIWXVWSX??TKGIIJIHEA886543444345755
166-1100 *     0112349FRW??YY?XLECDDECACCBB9765643222323
168-  00 *      0122248MW??YXXURMDDEFDAFIHHD875431222222
170-     *       001135ETZZYTSSPJGECDBFJMKIIGC9853322221
    .....*.........*.........*.........*.........*.....
        80        90       100       110       120

READY FOR COMMAND (HIT "A" FOR MENU DISPLAY)
$
OK
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Fig. 1. RADAP II B-SCAN plot for May 7, 1991 showing rainfall by range and azimuth. Collier County coastline runs along the 160° azimuth from 89 to 115 nm range before cutting east. Rainfall estimates beyond the alphanumeric code are depicted by "?". Heavy rainfall (from 90 to 110 nm at 160° and 162°) hatched large numbers of *Aedes taeniorhynchus* larvae.

gauge station was calculated by first locating the range and azimuth of a nearby reference site (relative to the radar site) on a map using a ruler and protractor. The Cartesian coordinate of the reference site was calculated in LOTUS 123® using the following formulas: X = range * @sin (@pi * (azimuth/180)); Y = range * @cos (@pi * (azimuth/180)). These values were then added to the Cartesian coordinate of each gauge station (determined from a U.S. Geological Survey quadrangle map) to calculate the gauge station Cartesian coordinate relative to the radar site. Two B-SCAN rainfall estimates were obtained: 1) the value of the B-SCAN cell containing the gauge station (cell estimate), and 2) an estimated value for the gauge station (point estimate). The latter was calculated using an inverse distance^2 algorithm used in Surfer® (Golden Graphics Software 1987) incorporating rainfall at the station cell and the 8 adjacent cells. The accuracy of both rainfall estimates was examined by correlating each with rain gauge data and calculating the mean percent deviation from rain gauge data.

The RADAP II cell estimates were coupled with tide gauge data to estimate the occurrence of *Ae. taeniorhynchus* larvae within 3 zones in western Collier County. A staff crest gauge (Ritchie and Addison 1992) measured daily high tide in each zone. Larval inspection of a zone was proposed within 3 days of a potentially flooding rain or tide. The rain threshold (2 cm) was chosen based on the minimal rainfall necessary to raise the water level 3 cm in a mangrove basin forest (Ritchie 1990), a level sufficient to hatch some eggs (Ritchie 1988).[2] The tide threshold (75 cm National Geodetic Vertical Datum) was the minimum tidal height required to flood *Ae. taeniorhynchus*-producing mangrove forests (Ritchie and Addison 1992). Inspection was delayed one day if potentially flooding tides, based on a tide table (National Oceanic and Atmospheric Association 1990), were due that day. The effectiveness of the surveillance system was based on the number of proposed surveillance trips that corresponded to surveillance trips by Collier Mosquito Control District (CMCD) personnel that detected *Ae. taeniorhynchus* larvae. Collier Mosquito Control District inspected (minimum of 10 300-ml dips/site) known breeding sites in all zones based on tide and rain gauge data only, with a maximum of 1–2 wk between inspections.

B-SCAN plots were obtained for 29 (87.9%) of 33 rainfall events accessed with RADAP II. The project was terminated on May 21, 1991 due to mechanical problems with RADAP II. The QUICKBASIC® program (available from the author upon request) efficiently extracted X-Y-Z data from B-SCAN plots and can be modified to provide data for specific locations (e.g., oviposition sites). B-SCAN rainfall estimates were comparably correlated to data from the 4 rain gauge stations (mean $r \pm$ SD = 0.929 ± 0.025 and 0.924 ± 0.028 for cell and point estimates, respectively). For gauge rainfall > 1.3 cm (0.5 in), B-SCAN cell and point estimates deviated from gauge rainfall by a mean (±SD) of 47.7 ± 50.4% and 50.3 ± 49.4%, respectively. Percent deviation was negatively correlated with gauge rainfall ($r = -0.224$, $P = 0.14$ for cell estimates), indicating that the percent deviation decreased as rainfall increased (Barnston and Thomas 1983). These data indicate that while rainfall estimates often varied considerably from rain gauge data, RADAP II did locate relative rainfall with increasing accuracy as rainfall increased. For example, on January 16, 1991, four CMCD rain gauges overflowed (>15 cm of rain) in an area RADAP II estimated 13–20 cm of rain fell.

RADAP II B-SCAN date, when coupled with tide data, detected all but one brood found by CMCD surveillance. This brood (located on March 18) were stragglers (due to cool weather and methoprene larvicide; both of which retard development) from a brood hatched March 4 during a flooding tide. Rain (48%) was the most

[2] Ritchie, S. A. 1988. A simulation model of the population dynamics of the black salt marsh mosquito (*Aedes taeniorhynchus*) in a Florida mangrove forest. Ph.D. dissertation, University of Florida, Gainesville.

common flooding mechanism triggering inspection (14 proposed trips), followed by tide (26%) and tide + rain (26%).

While radar has been used to locate mosquito swarms (Downing and Frost 1972) and flooded breeding sites (Linthicum et al. 1991), this is the first instance where ground-based radar has been employed for mosquito larvae surveillance. Rainfall estimates must be used with caution, however. Anomalous propagation (false echoes) due to temperature inversions can create erroneously high rainfall estimates (Joss and Waldvogel 1990). This was minimized by accessing RADAP II soon after a rain event. In Florida, summer convective rainfall is concentrated in the afternoon and RADAP II was accessed that evening. I also viewed televised satellite images (The Weather Channel® and local news), as suggested by Bellon et al. (1980), to verify if rain-producing clouds were present. Often RADAP II processing was interrupted, resulting in loss of data and underestimation of rainfall. Beam attenuation along a line of storms can also lead to low rainfall estimates, especially at long distances (Joss and Waldvogel 1990). Because cell estimates may differ substantially from local rainfall, a small network of conveniently placed rain gauges should be used to calibrate radar estimates (Barnston and Thomas 1983) and serve as a backup. Finally, tide data must be incorporated. Tide gauges must supplement tide tables to detect unexpectedly high tides (e.g., wind tides).

The system could be improved. Many flooding events do not hatch a significant brood. Coupling of the system with models of oviposition site hydrology (Ritchie 1990) and mosquito population dynamics (Ritchie 1988)[2] could improve performance. Even the use of a simple algorithm (e.g., inspect only if time since previous flooding event > 1 wk) could eliminate revisiting sites following each heavy rainfall. Extracted X, Y, Z data from B-SCAN files could be used with mapping software (e.g., Golden Graphics Software 1987) to produce rainfall maps.

Radar has additional applications to mosquito control. Rainfall estimates could be used direct adulticiding during outbreaks of St. Louis encephalitis (SLE). Day et al. (1990) found that widespread heavy rain triggers oviposition by gravid and potentially viremic *Culex nigripalpus* Theobald. "Nowtime" radar rainfall maps could direct adulticiding to areas of significant rainfall. Finally, radar echoes can be used to warn of severe weather (Saffle and Elvander 1981) and by pilots to avoid rainstorms during night flights. In areas without a RADAP II system [McDaniel (1991) indicates 11 RADAP II sites], NWS radar can be downloaded and processed in a personal computer to produce rain fall maps (Engdahl and McKim 1990). I have also used WSI[3]'s PRECIP® radar rainfall maps to successfully locate 4 broods of *Ae. taeniorhynchus* during 1992. This system, employing multiple radars, claims increased accuracy and was more reliable than RADAP II. Future employment of doppler radar (next generation radar, NEXRAD) should improve the quality and accessibility of radar products (McDaniel 1991). The positive results of this study suggest that further testing of radar-based mosquito surveillance systems is warranted.

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