USE OF REMOTELY OBSERVED CLOUD AND SOLAR RADIATION DATA TO ESTIMATE LATENT HEAT FLUX CONDUCIVE TO DEW FORMATION AND DURATION

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ABSTRACT- An energy balance (EB) model to estimate latent heat flux and subsequently predict dew formation (onset and ending) and dew duration was previously developed by the authors, based on on-site ground weather data and off-site cloud data. In the present work, the EB model was validated with hourly data from on-site weather instrumentation data for nights with and without occurrence of dew, and remotely estimated cloud cover (EB/Scl) and incoming solar radiation (EB/Scl+sr) data obtained from SkyBit Inc. at 14 sites in Iowa, Illinois and Nebraska (USA). Also, cloud cover data, estimated by Geographic Information Systems (GIS) from automated observations at airports, located nearby Iowa sites, were integrated in the EB model. The models were then compared with dew predictions from the empirical CART/SLD model. The overall mean absolute error in dew duration estimation was 3.6, 2.9 and 3.4 h for the EB/Scl, EB/Scl+sr and CART/SLD, respectively. The proportion of correctly predicted wet hours during observed dew nights was about 85% for the EB/S models compared with 76% for CART/SLD. Results suggested that both SkyBit and GIS cloud cover data can be used to help estimate the latent heat flux conducive to dew formation and duration.

INTRODUCTION

Three factors must combine for a crop disease to occur: a susceptible host plant, an aggressive pathogen, and persistently favourable environmental conditions. Defining specific environmental factors most critical to disease development can therefore serve as a guide for the development of fungicide spray advisories or disease warning systems. Occurrence of free water on vegetation is a key environmental factor for the development and spread of many diseases. Surface wetness duration (SWD, the period of time during which a particular surface is wet from dew, rainfall or irrigation) is not a conventional atmospheric variable, since is influenced by both the surface and the atmosphere. Hence, wetness is generally not recorded at most weather stations. Due to its recognized importance in the fields of plant pathology, hydrology in semi-arid regions and air pollution, SWD has been measured by electronic sensors or estimated by mathematical models (Weiss, 1990; Huber & Gillespie, 1992; Sentelhas *et al*., 2004).

Energy balance (EB) models are based on the main physical processes in the atmosphere, which control dew formation. A simple EB model to estimate dew duration and quantity, from existing ground on-site data and cloud information (cover and altitude) from airport records, was developed by Madeira *et al.* (2002): the mean accuracy of predicting dew occurrence was 91% and the timing of onset and ending of dew periods was estimated with a mean absolute error of 0.7 h.

However, variables (net radiation or cloud altitude and cover) to estimate the downward long wave radiation in EB models are not commonly measured by weather networks. Weather data provided by off-site weather estimates, e.g., SkyBit Inc. (Boalsburg, PA), which combine simulated observations derived from interpolation algorithms of observed USA Weather Service data with forecasts from mesoscale models, at spatial scales of 1 km^2, are now commercially available. Also, Geographic Information System (GIS) technology (automated observations at airports in the central USA, AWOS system) can be used to assemble and map weather data.

The objective of the present work was to validate the EB model of Madeira *et al.* (2002), using SkyBit cloud cover and solar radiation data and GIS cloud cover data.

MATERIAL AND METHODS

On-site weather data

Electronic wetness sensors (Campbell Scientific Inc., Logan, UT), coated with latex paint, calibrated and deployed (one per field site) facing N at an angle of 45º to horizontal, were installed in open sites on mowed turfgrass (at 0.3 m above the ground). Data loggers were programmed to record the proportion of each hour with sensor readings <1000 kohm as wet periods.

At screen height, solar radiation (Sg), air temperature (T_a), relative humidity (RH) and precipitation were taken at each site; anemometers were installed at 3.0 m and dew point temperature (T_d) measured at 0.3 m. Weather data was gathered (May - September 1999, USA) for 14 sites: Iowa (IA, 5), Illinois (IL, 5), and Nebraska (NE, 4). The number of dew nights ranged between 48 and 108; and dry nights between 3 and 39.

Off-site weather data

SkyBit cloud cover and incoming solar radiation data for IA, IL, NE sites. GIS cloud cover data for IA sites: for IA, the number of dew nights ranged between 23 and 42; and dry nights between 3 and 11.

Model development and validation

Dew forms when surface temperature is below T_d of ambient air, resulting in the condensation of water vapour on the surface. Radiative cooling is the usual cause of surface temperature falling below the ambient T_a. The rate at which the surface cools is controlled by the balance of the following energy fluxes: net radiation (Rn), latent (LE) and sensible (C) heat exchange, heat conduction and storage.

Assuming the heat conduction and storage fluxes are negligible at sensor level, LE (W m^{-2}) from or towards the surface is LE = Rn – C, and by replacing Rn by the sum of two radiative fluxes

$$LE = [(0.76\ Sg + (Ld - Lu)] - C$$

To estimate Rn, incident short wave radiation (Sg) was used in the morning and late afternoon, assuming sensor reflectance similar to that of the grass (about 0.24). Downward long wave radiation (Ld) was calculated based on apparent emissivities (ε): for clear skies (Gates, 1980)

$$\varepsilon_{cl} = 0.674 + 0.007\ T_a$$

and for overcast skies (Monteith and Unsworth, 1990)

$$\varepsilon_{ov} = (1 - c)\ \varepsilon_{cl} + c\ [1 - (1 - \varepsilon_{cl}).\ 4\Delta T / T_a$$

where c is the % cloud cover (clear = 0, few = 25, scattered = 50, broken = 75 and overcast = 100) and ΔT the difference between cloud base temperature and T_a (ΔT = 5º C for all sites). Thus, Ld = $\varepsilon\ \sigma T_a^4$. Upward long wave radiation (Lu)

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was calculated assuming the sensors emit as a blackbody and the sensor temperatures similar to Td. So, $Lu = \sigma T_d^4$.

To estimate the sensible heat

$$C = \rho c_p (T_d - T_a) / r_a$$

Wind speed (at 3 m above ground) was converted to represent air movement at sensor height (u(z)) using the log profile equation, and aerodynamic resistance (r_a) then given by

$$r_a = \ln [(z - d)/ z_o]^2 / 0.17 u(z)$$

where d is the zero plane displacement (0.64 z, or 0.192 m) and z_o the roughness parameter (0.13 z, or 0.039 m).

EB models were validated with hourly data from on-site weather station instrumentation and off-site SkyBit cloud cover (Scl) and incoming solar radiation (Scl+sr), and GIS cloud cover (Gcl). Timing and duration of dew periods (18:00pm-10:00am) were compared with measurements by wetness sensors. Threshold for dew onset and ending on the wetness sensor was 0.1 h, i.e., six minutes of recorded wetness was the minimum time required for a specific hour being considered wet. Duration of dew deposition: 1st hour of dew occurred when LE<0; last hour occurred when condensation accumulated by the model during the night was consumed by an equivalent amount of evaporation in the morning, i.e., LE>0 $\approx$ LE<0. Nights with measured rainfall were excluded from the analysis of wetness duration. Dew onset, ending and duration estimated by the EB models were compared with those by the CART/SLD model based on ground data. CART/SLD, an empirical model, combines the non-parametric CART data classification procedure, based on physical criteria, with a stepwise linear discriminant function which is used to identify thresholds of Td, u and RH beyond which dew deposition is unlikely. Thresholds: $T_d < 3.7^o$ C, $u < 2.5$ m s^{-1}, RH >87.8% (Gleason *et al*., 1994).

RESULTS AND DISCUSSION

EB/Scl, EB/Scl+sr and CART/SLD: IA, IL and NE sites

EB/S models predicted onset, ending and duration of dew within 1 hour. The overall mean duration difference between measured and estimated wetness for all sites was +0.9, +0.1 and -1.0 h, being the overall mean absolute error (MAE) of 3.6, 2.9 and 3.4 h, respectively, for the EB/Scl, EB/Scl+sr and CART/SLD models. All models estimated the timing of dew onset earlier than the sensors (MAE of 2.0, 1.9 and 2.3 h, respectively), while EB/S predicted the ending of dew later in the morning (MAE of 1.5, 1.0 and 1.1 h, respectively). On the other hand, the EB/S models gave substantially higher % of correct prediction of dew hours and hence dew duration estimates than CART/SLD (Table 1).

For Ames (IA), the EB/S and CART/SLD models predicted wet hours during dew nights with an accuracy of about 81 and 66%, respectively. These accuracy levels were less than those obtained using sky apparent emissivity based on Des Moines (IA) airport cloud records in 1999: 89% (EB) and 75% (CART/SLD) (Madeira *et al*., 2002).

CART/SLD is a better predictor of dry nights (or of dry hours in wet nights, Table 1) than of wet hours. However, EB/S predicted dew or dry nights with similar accuracy. Thus, the overall accuracy (corrected predicted occurrence and absence of dew either in wet or dry nights) was similar: 80 (EB/Scl), 84 (EB/Scl+sr) and 82% (CART/SLD). CART/SLD performance in this study was similar to that obtained by Gleason *et al*. (1994) for the same locations.

Table 1. Accuracy (%, mean of correctly classified wet or dry hours) for EB and CART/SLD models

	EB/Scl	EB/Scl+sr	CART	EB/Gcl
		Wet		
IA mean	86.9	86.8	78.4	85.2
IL mean	89.3	87.2	80.7	-
NE mean	76.9	76.9	65.4	-
Mean	84.9	84.1	75.5	
		Dry		
IA mean	79.1	79.9	87.9	89.8
IL mean	81.2	84.9	92.2	-
NE mean	89.3	91.0	92.6	-
Mean	82.9	84.9	90.8	

EB/Gcl and CART/SLD: IA sites

The values for the onset, ending and duration from EB/Gcl were relatively similar to those from EB/Scl. Again, % of wet hours correctly classified during dew nights was greater for the EB/Gcl (Table 1) than for CART/SLD (79%, data not shown).

CONCLUSIONS

Overall accuracy of predicting dew and dry hours was similar. However, accuracy for estimating dew occurrence was greater for the EB/S than for CART/SLD.

The smaller magnitude of errors in estimating both ending and duration of dew and greater overall accuracy in predicting dew, from the EB/Scl+sr, seemed to be related to replacing radiometer data by satellite-measured incoming solar radiation. So, the use of satellite-measured solar radiation should be considered in the future whenever off-site weather data is included in physical models for dew estimation.

The prediction of dew hours when either GIS or SkyBit cloud cover data were integrated in the EB model was similar, suggesting that either SkyBit or GIS cloud cover can be used to estimate the latent heat flux conducive to dew formation. However, use of GIS cloud cover improved the accuracy to predict dry nights when compared with the SkyBit cloud cover. The use of cloud altitude, either from GIS or SkyBit, may improve the energy balance model.

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