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The frequency and duration of dew occurrence over a year

Model results compared with measurements

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ABSTRACT

In this paper, a new dew model is presented which is easy to apply and requires only a very limited amount of synoptic data, viz., cloud cover, relative humidity, air temperature and wind velocity. In the dew model, the contribution of the fluxes of infrared radiation, sensible and latent heat to the energy balance of a dew plate are parametarised according to detailed micrometeorological measurements of Holtslag and De Bruin. The model is tested with measurements of dew on the glass surface of an automatic sequential dew sampler. Results of model calculations and measurements of dew occurrence show a fairly close correspondence. The frequency and duration of dew deposition over a year, for 3 places in the Netherlands, have been calculated with the model, using only synoptic data. The numbers of dewy nights and dewy hours were calculated for the year 1987. This resulted in about 220 dewy nights and 1600 dewy hours. Taking the hours of rain into account, it appears that about 75% of the time a surface is wet during the nocturnal hours because of dew or rain. This fact may be important for the quantification of the dry deposition of easily soluble air pollutants and for the effect of air pollutants on vegetation.

1. Introduction

In order to be able to assess the effects of air pollutants upon terrestrial ecosystems, it is important to quantify the various processes that control wet and dry deposition. On many locations, dry deposition of air pollutants is quantitatively more important than wet deposition. Due to a lower atmospheric turbulent resistance and especially a lower surface resistance of vegetation, dry deposition velocities of air pollutants are often higher during the daytime than by night. Deposition velocities of air pollutants on a surface depend not only on atmospheric conditions or the species involved, but also on the properties of the surface, e.g., dry or wet (Römer et al., 1989). Voldner et al. (1986) and Van Aalst et al. (1985) discuss deposition velocities of SO_2 as measured by Davies and Mitchell (1983), in different seasons, at different times of the day and under different conditions of the surface, i.e., wet or dry grass.

From the data in Table 1 it can be concluded that deposition velocities of soluble gases such as SO_2 above wet grass are always higher than above dry grass. Deposition velocities above wet grass at night are comparable to or even higher than corresponding deposition velocities above dry grass by day. Thus, during those periods in the evening and at night when a surface is wet, dry deposition of SO_2 could be greater than in the daytime. Mulawa et al. (1986) found deposition rates on a wet surface to be a factor between 2–20 times higher than on a dry surface. In a model study, Chameides (1987) calculated low deposition velocities of SO_2 onto wetted surfaces (0.03 cm/s), but also concluded that this result depended strongly on the presence of other gases, such as H_2O_2, which are very easily soluble in thin water films. He mentioned that the natural variability of many of the chemical species and atmospheric con-

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Table 1. *Deposition velocities (v_d) of dry deposition of SO_2 on 4–20 cm tall grass in England (Data from van Aalst et al. (1985)*

		v_d (dry grass) ($cm\ s^{-1}$)	v_d (wet grass) ($cm\ s^{-1}$)
summer	day	1.4	12.5
	night	0.6	3.3
winter	day	0.6	1.8
	night	0.8	0.9

ditions involved in dew deposition, preclude an accurate estimate of acid deposition by dew.

There is thus a considerable influence of pH-regulating gases, such as NH_3, and SO_2-oxidizing gases, such as H_2O_2, on the deposition velocity of SO_2.

Because little is known about the contribution of dew to acid deposition, a study was carried out to investigate the chemical composition of dew and the frequency and duration of dew occurrence in the Netherlands.

In the past, several investigations have been carried out into the deposition of dew. Leick (1932) and Duvdevani (1947) measured dew on gypsum and painted wooden surfaces by using respectively a balance and an optical method. In these studies, the meteorological measurements were incomplete to investigate all components of the energy balance of the surface. It is therefore difficult to generalize their results. Micrometeorological measurements of downward fluxes of water vapour associated with dew formation, were carried out by Rider and Robinson (1951) and Frankenberger (1955). However measurements of dew were lacking in their studies. Theorie of dew formation and some experimental measurements of dew were described by Hofmann (1955). Detailed micrometeorological measurements and measurements of dew were carried out by Monteith (1957). He reported results of measurements and calculations of dewfall during some 14 days in 1953 and 1954, which agreed well. But because this kind of detailed micrometeorological measurements are often lacking, these results cannot be used to calculate deposition of dew over a longer period. Garratt and Segal (1988) quote some authors who recently measured dew amounts over a range of vegetated surfaces in a period between 1966 and 1983. Maximum values of the amount of dew which were measured, e.g., on a wheat crop in South Africa, in a forest in the US, on grass and forest in British Columbia, on surfaces in India and on semi-arid grassland in Australia ranged between 0.2 and 0.6 mm per night. But because meteorological measurements and dew models were lacking the frequency and duration of dew deposition over longer periods could not be obtained.

In this paper, a simple model is presented to calculate the frequency and duration of dew over a year. Data on the chemical composition of dew are published elsewhere (Römer et al., 1989).

Because it is an extensive job to study both meteorological processes of dew together with its chemical composition, it was decided to develop a model which enabled an estimation of the frequency and the duration of dew occurrence beforehand. In order to test the model, calculated results were compared with results of experimental data of dew occurrence, carried out during selected periods in the course of two years. Sampling of dew was carried out on the glass surface of an automatic dew sampler. During these experiments, the duration, the amount of dew and its chemical composition were established.

Because the intended model should be capable of calculating both the frequency and the duration of dew for a whole year, it should preferably use easily obtainable synoptic meteorological data which are available on a daily basis. The only atmospheric parameters which are used in the model are: cloud cover, temperature, relative humidity and wind velocity. Predictions of the occurrence of dew are in terms of dew (1) or no dew (0). The amount of dew is not calculated. The model is directly derived from results of a more extended model described by Holtslag and de Bruin (1988). Their model is based on a detailed analysis of the surface energy balance and uses a number of atmospheric parameters, such as isothermal and net radiation, surface-sensible heat flux, surface-latent heat flux, soil heat flux and surface radiation temperature which have been measured on the 200 m meteorological tower of the Royal Dutch Meteorological Institute at Cabauw. These data are not usually measured at other meteorological measuring sites in the Netherlands. In spite of the simplifications made in our model, the frequency and duration of dew calculated with our model agreed reasonably well with direct measurements of dew deposition on an artificial surface.

Model calculations of frequency and duration of dew for three different sites in the Netherlands for the year 1987 show that dew occurs frequently, with only small differences in occurrence at different locations.

2. Experimental

2.1. Site

Measurements of frequency of occurrence, duration and chemical composition of dew were performed on a small meadow of 100 × 100 m surrounded by low buildings of KEMA laboratories located on the border of the city of Arnhem in the eastern part of the Netherlands. Measurements were carried out during the months April–October of 1986 and September–October of 1987.

In the period September–October 1987, measurements of dew were also carried out simultaneously on a small meadow of 100 × 100 m in between maize fields, at a rural site near the village of Renkum about 10 km from Arnhem.

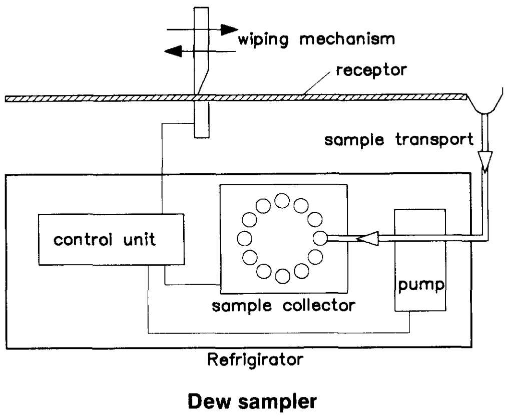

Fig. 1. A diagram of the automatic sequential dew sampler as was used during the experiments.

2.2. Apparatus

Dew was sampled at both measuring sites by two identical automatic sequential dew samplers, see Fig. 1. The dew sampler consists of a glass plate

Table 2. *Results of dew measurements for nights in 1986 and 1987 during operation of the sequential dew sampler*

1	2	3	4	5	6	7
Year	Month	Dew sampler in operation (days)	Dew or rain (days)	No dew (days)	Uncertain, e.g., because of rain (days)	Too little dew for chemical analysis (days)
1986	April	17	2	7	8	—
	May	12	3	6	2	1
	June	22	6	4	12	—
	July	13	3	2	8	—
	August	18	3	6	9	—
	Sept.	15	5	4	4	2
	Oct.	27	12	—	15	—
1987	Sept.	23	15	—	7	1
	Oct.	26	11	10	5	—

Column (4): dew: enough dew sampled for chemical analysis (more than 3 ml). Column (5): no dew or rain: no quantifiable amount ($\ll 3$ ml). Column (6): deposition of dew uncertain. This was caused mainly by rain in one or more sampling periods. It probably occurred more often than is indicated in column (7), that there was too little dew for chemical analysis, but this presumably went unnoticed and is therefore mentioned in column (5): no dew or rain detected.

with a thickness of 3 mm and a surface of 0.35 m^2, on which dew can be deposited. We chose for a thin dew plate to obtain a surface with a small heat capacity. The dew plate is mounted on an ordinary refrigerator and isolated underneath, to prevent a heat flux flowing to the glass plate from below. The refrigerator is used to collect and store the dew samples at about 5°C. After a previously established (adjusted) sampling period of 2 or 3 h, dew which is deposited on the top side of the dew plate, is transported by a wiper to a teflon collection chute. Subsequently, the dew sample is transported by a tubing pump to a fraction collector, which is placed in the refrigerator. The dew plate is rinsed by a sprinkler which is mounted on the wiper holder. Next, the plate is wiped dry as the wiper returns to its starting-point, and the next cycle begins. The minimum amount of dew needed for the chemical analysis was about 3 ml which corresponds with dew deposition over a period of 2 to 3 h of 3 g or about 0.010 mm of dew.

2.3. Sampling period

In 1986, sampling took place during the night for a period of 10 h between 21h00 and 07h00. In that period dew was collected 5 times, always after a sampling period of 2 h. The number of nights in 1986 during which the sequential dew sampler was in operation is shown in Table 2. In 1987, sampling took place during the period of 12 h between 20h00 and 08h00. Dew was collected 4 times, always after a sampling period of 3 h. The number of nights in 1987 during which the sequential dew sampler was in operation is shown in Table 2.

3. The model

3.1. Description of the model

In order to model the deposition of dew, we start with the energy balance of the dew plate (see Fig. 2):

$$H + \lambda E + G + M = Q, \tag{1}$$

in which H and λE are the fluxes of sensible and latent heat respectively (defined positive upwards), G is the heat flux from the underlying material to the dew plate and Q the net radiation (all units Wm^{-2}). The latter two energy densities are defined positive downwards. λ is the heat of condensation

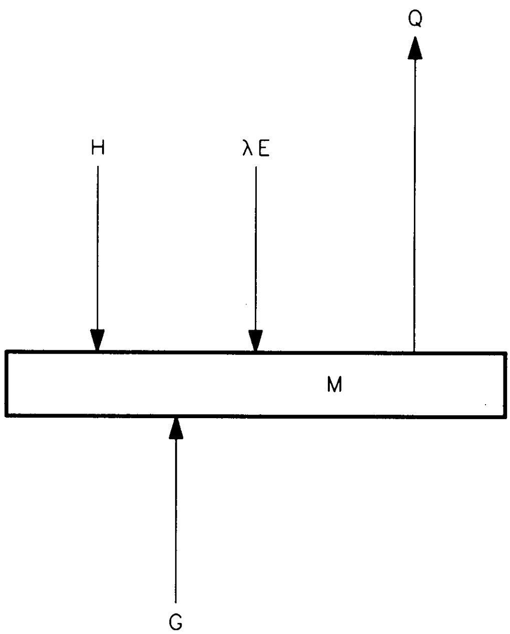

Fig. 2. The different terms of the energy balance of a surface at night ($Q < 0$). H and λE are the fluxes of sensible and latent heat respectively (defined positive upwards), G is the heat flux from the underlaying material to the dew plate and Q the net radiation (all units Wm^{-2}). The latter two energy densities are defined positive downwards. M is the change of the heat content of the dew plate.

of water vapour (Jkg^{-1}) and E the water vapour flux (kg H_2O m^{-2} s^{-1}). M is the rate of change of the heat content of the dew plate. The net radiation Q is the net radiative energy loss during the night that cools the dew plate in relation to the air.

During the night, Q is given by:

$$Q = L_+ - L_-. \tag{2}$$

Here L_+ denotes the incoming long-wave radiation from the atmosphere, which is generally governed by cloud cover and temperature and humidity in the atmosphere. L_- denotes the outgoing long wave radiation flux from the surface, which depends primarily on the surface temperature according to the law of Stefan-Boltzmann.

In our model and our experimental set-up, we were primarily interested in the condensation of water vapour from the air column above the surface, i.e., dew deposition or dew fall, and not in condensation of water vapour coming from the soil, i.e., distillation (Monteith, 1957). The dew surface mounted on the refrigerator is isolated from the ground to prevent a heat flux flowing to the glass plate from below. So in a first approximation, the heat flux G in equation (1) is ignored. Next, because of the small heat capacity of the glass plate, the term M in equation (1) is also ignored. Eq. (1) then becomes:

$$H + \lambda E = Q, \qquad (3)$$

and dew deposition occurs as the condition

$$Q - H < 0 \qquad (4a)$$

or

$$\lambda E < 0 \qquad (4b)$$

is satisfied.

In our dew model, the contributions of the fluxes of net radiation Q, sensible heat H and latent heat λE to the energy balance of a dew plate are parameterized according to detailed micrometeorological measurements and model calculations by Holtslag and de Bruin (1988). They used a large data set of micrometeorological measurements carried out in the night at the 200 m meteorological tower at Cabauw in the central part of the Netherlands.

Based on measurements of net radiation and cloud cover, Holtslag and de Bruin (1988) derived a relation between the values for Q and cloud cover (n) as given in Table 3.

The contribution of the sensible heat flux to the energy balance of the dew plate is parameterized by using the friction velocity u^* and the specific humidity deficit. In our model the friction velocity u^* is estimated from the wind velocity u, using the equation:

$$u^* = u/10, \qquad (5)$$

which applies to a rather flat terrain with only a few small obstacles as in our case. The wind velocity is the velocity measured at a height of 10 m.

Specific humidity deficit dq (g kg^{-1}) is derived from the difference between the saturated value of the specific humidity at the prevailing air temperature T_a and the saturated value of the specific humidity of the temperature at dew point T_d:

$$dq = q(T_a) - q(T_d). \qquad (6)$$

In their paper, Holtslag and de Bruin (1988) give relations between the latent heat flux (λE) and friction velocity (u^*) for several values of Q and several values of specific humidity deficit (dq); see Fig. 3. Deposition of dew occurs if there is a downward (negative) flux of latent heat (λE) to the dew plate: $\lambda E < 0$. As is shown in Fig. 3, limit

Table 3. *Relation between cloud cover and net radiation during the night as suggested by Holtslag and de Bruin (1988)*

Cloud cover (n)	Net radiation (Wm^{-2})
$0 \leqslant n < 2$	$Q < -83$
$2 \leqslant n \leqslant 6$	$-38 \leqslant Q \leqslant -83$
$6 < n \leqslant 8$	$-38 < Q$

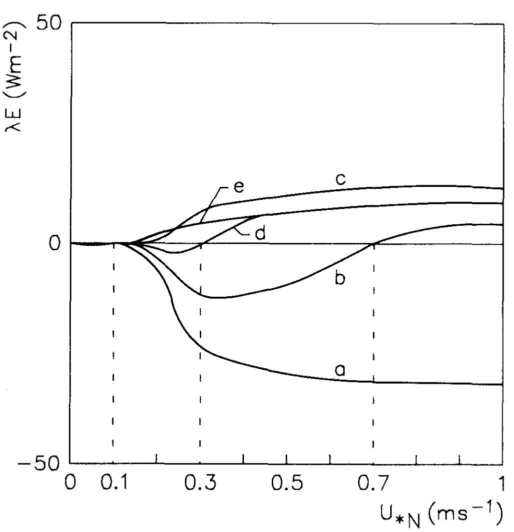

Fig. 3. The relations between λE and friction velocity (u^*) for several values of Q and several values of specific humidity deficit (dq), as calculated by Holtslag and De Bruin (1988). (I) Net radiation $Q = -83\ \text{Wm}^{-2}$ ($n < 2$) and a specific humidity deficit of: (a) $dq = 0\ \text{g kg}^{-1}$; (b) $dq = 0.66\ \text{g kg}^{-1}$; (c) $dq = 2.2\ \text{g kg}^{-1}$; (d) $dq = 1.5\ \text{g kg}^{-1}$. (II) Net radiation $Q = -38\ \text{Wm}^{-2}$ ($n > 6$) and a specific humidity deficit of (e) $dq = 1.5\ \text{g kg}^{-1}$.

values of the friction velocity (u^*) below which the latent heat flux is negative ($\lambda E < 0$), can be derived. They depend on cloud cover (n) and specific humidity deficit (dq). For $n < 2$ and 4 values of specific humidity deficit, the curves (a)–(d) apply. The limit values for u^* for these four cases are: 0, 0.1, 0.3, and 0.7 ms^{-1} for the curves (a)–(d), respectively, see Fig. 3. For $n > 6$ and a value of specific humidity deficit of 1.5 g/kg, the curve (e) in Fig. 3 applies, which yield a limit value for u^* of 0.1 ms^{-1}.

Using the eqs. (7)–(9), the limit values for u^* for dew deposition can be calculated for a range of values of specific humidity deficit and cloud covers. These equations have been derived by interpolating the values of specific humidity deficit and cloud cover between the curves (a) and (e).

From Fig. 3 can be derived that dew deposition, i.e., $\lambda E < 0$, occurs if the friction velocity u^* is lower than the limit value of u^* (u^*_{max}) which for clear skies ($n < 2$) is given by:

$$n < 2: \qquad u^* < (1.5/dq) \times 0.3. \qquad (7)$$

In the eqs. (7)–(9), the factor ($1.5/dq$) is an interpolation factor, which serves to standardize the measured values of specific humidity deficit to the values of specific humidity deficit which belong to the curves in Fig. 3.

The factors 0.3, 0.2 and 0.1 in the eqs. (7)–(9) respectively, serve to incorporate the effect of cloud cover on dew deposition. These factors are also derived by an interpolation of the values given by Holtslag and de Bruin (1988); see also Fig. 3.

Subsequently, to be able to calculate dew deposition for various atmospheric conditions, relations equivalent to eq. (7) which holds for clear skies, also equations for cloudy skies have to be derived.

In their paper, Holtslag and de Bruin (1988) show some model calculations for the relation between friction velocity and dew deposition for cloudy skies ($n > 75\%$; their Fig. 8), however, for only one value of the specific humidity deficit.

In our model, we suppose, by interpolation between their values, that for cloudy skies, dew deposition occurs, i.e., $\lambda E < 0$, if the friction velocity u^* is lower than the limit value of u^* (u^*_{max}) which is given by:

$$n > 6: \qquad u^* < (1.5/dq) \times 0.1. \qquad (8)$$

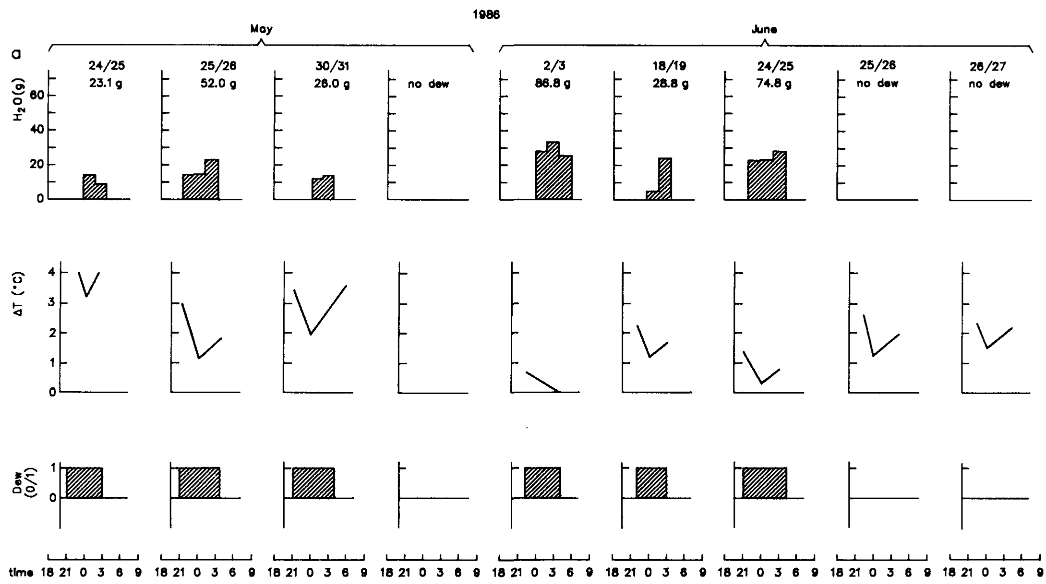

Fig. 4. Results of measurements (gm^{-2}) and model calculations (dew = 1 and no dew = 0) for several months in 1986 and 1987. Dt is the temperature difference between air and dew point (°C). (a) For dew deposition in May and June 1986. (b) For dew deposition in July, August and October 1986. (c) For dew deposition in July and September 1987.

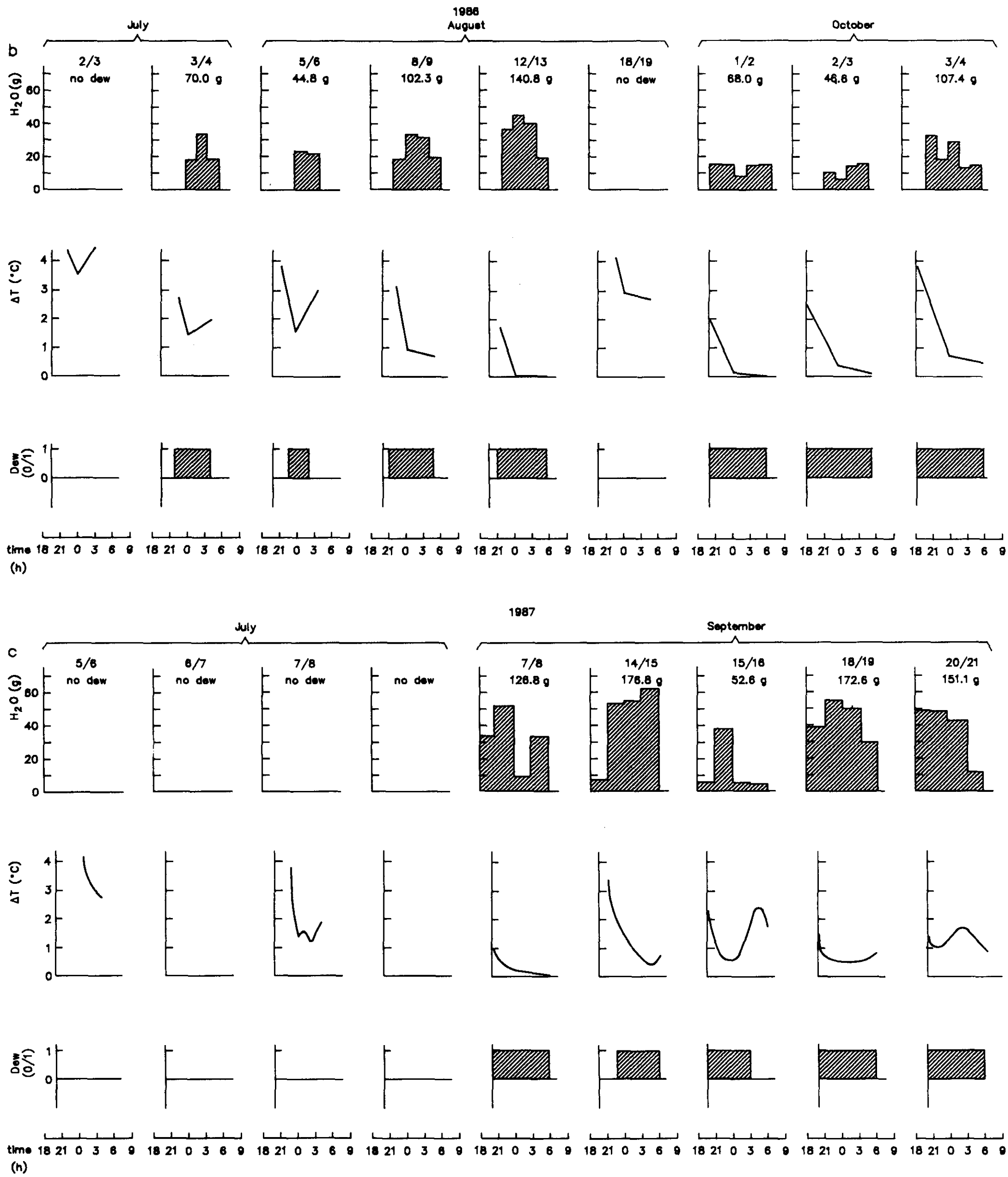

Fig. 4 (continued)

In accordance with equations (7) and (8), we assume that for cloud covers between 2 and 6 octals, dew deposition occurs if the friction velocity u^* is lower than the limit value of u^* (u^*_{max}) which is given by:

$$2 \leqslant n \leqslant 6: \qquad u^* < (1.5/\mathrm{d}q) \times 0.2. \tag{9}$$

3.2. Calculation of dew deposition

Deposition of dew can be calculated with our model using only easily obtainable synoptic data, in the following manner.

First, calculate specific humidity deficit (g kg^{-1}) with eq. (6) using only air temperature and relative humidity measured at one height as input parameters.

Secondly, determine cloud cover. If $n < 2$, use eq. (7); if $2 \leqslant n \leqslant 6$, use eq. (9); if $n > 6$, use eq. (8), to calculate the limit value of the friction velocity: u^*_{max}.

Thirdly, dew deposition occurs if the measured wind velocity (u_{meas}) is smaller than $10 \times u^*_{max}$.

$$u_{meas} < 10 \times u^*_{max}. \tag{10}$$

The wind velocity (u_{meas}) is the velocity measured at a height of 10 m.

Using these results, the contributions of the net radiation, sensible and latent heat flux to the energy balance of the dew plate are parameterized using measurements of cloud cover, wind speed, relative humidity and temperature.

4. Results and analysis

4.1. *Model calculations and measurements*

In our dew model, a limit value of u^* is calculated below which deposition of dew occurs. Therefore, the results of the model calculations are: dew (1) or no dew (0), and the amount of dew is not calculated. The frequency and duration of dew deposition were calculated on the basis of the model and compared with results of dew deposition measurements with the dew samplers (Table 2).

Results of measurements and model calculations for sampling periods in 1986 and 1987 are shown in Fig. 4. In general, the agreement between the dew frequency and duration measured and calculated was rather good. Because of the reasonable agreement between measurements and model calculations, model calculations were extended. Frequency and duration of dew were calculated for the whole year 1987, for which a complete database of synoptic meteorological data, including data of the occurrence of rain, was available.

First the hours during which the radiation balance Q was negative were selected as "nocturnal" hours. Secondly, the nocturnal hours during which there had been rain and hours when the air temperature was below 0°C were excluded from the calculations. For all remaining nights the occurrence and duration of dew deposition were calculated. The results of these model calculations for 1987 are shown in Table 4. Detailed results of the calculations on a hourly basis for the months September and October are given as an example in Tables 5a and 5b.

The results of these calculations show that dew deposition on thin surfaces that are freely exposed

Table 4. *Monthly number of dewy nights, dewy hours, hours of rain and hours without wet deposition (rain or dew)*

Month 1987	Dew nights	Dew hours	Hours with rain	Dry	Total
Jan.	18	151	148	140	439
Feb.	24	193	73	20	286
March	17	122	68	29	219
April	15	101	37	75	213
May	14	86	60	58	204
June	22	93	50	26	169
July	19	89	71	49	209
Aug.	19	125	62	57	244
Sept.	20	154	108	44	306
Oct.	18	170	116	95	381
Nov.	19	173	189	73	435
Dec.	19	170	180	85	435
total	224	1627	1162	751	3540

The last column refers to the total number of hours during which the radiation balance was negative in that particular month.

is a very common phenomenon in the Netherlands and occurs during more than 200 nights. The calculated number of 224 dew nights is somewhat more than the 140 nights measured in Potsdam (Poland) by Antonik (Hofmann, 1955) but it is of the same order of magnitude.

Based on the figures in Table 4, we may conclude that if we also take hours of rain into account, then a surface or vegetation in the Netherlands is wet because of dew or rain for about 75% of the nocturnal hours, i.e., hours during which the radiation balance was negative. Periods with and without dew differ markedly with respect to meteorological conditions. Relative humidity, air temperature, dew point, average wind velocity and the limiting wind velocity for dew and non-dew periods are shown in Table 6.

5. Conclusions

In this paper, a simple dew model is presented, which is easy to apply and uses only a limited number of synoptic data, viz., cloud cover, relative humidity, air temperature and wind velocity. Calculated frequency and duration of dew deposition proved to be in fairly good agreement with measurements of dew on a surface of an automatic sequential dew sampler.

The model has the advantage that only

Table 5a. *Dew calculated (d), rain measured (r) and dry hours calculated (n) for each hour in September 1987*

		Hour														
Sept.	Night	17	18	19	20	21	22	23	24	01	02	03	04	05	06	07
	01/02				d	d	d	d	d	d	d	d	d			
	02/03				r	r	d	d	d	d	d	d	d			
	03/04				d	d	d	d	r	r	d	r	r			
	04/05				n	n	r	r	r	r	r	r	r			
	05/06				r	r	r	d	d	d	d	d	r			
	06/07				r	r	r	r	r	r	r	r	r			
	07/08				d	d	d	d	d	d	d	d	d			
	08/09				d	d	d	d	d	r	r	r	d	d		
	09/10				n	r	n	n	n	n	n	n	n	n		
	10/11				n	n	n	n	n	n	n	n	n	r		
	11/12				r	r	r	n	r	r	r	n	n	n		
	12/13				r	r	r	r	r	r	r	r	r	r		
	13/14				r	r	r	r	r	r	r	r	r	r		
	14/15				n	n	n	d	d	r	d	d	d	d		
	15/16			d	d	d	d	d	d	d	d	d	d	d		
	16/17			r	d	r	r	d	d	d	d	d	d	d		
	17/18			n	n	r	r	n	n	n	r	r	r	r		
	18/19			r	d	d	d	d	d	d	d	d	d	d		
	19/20			r	r	r	r	r	r	r	r	r	r	r		
	20/21			d	d	d	d	d	d	d	d	d	r	r		
	21/22			r	n	r	n	n	n	r	n	n	n	n		
	22/23			d	d	d	d	d	d	d	d	d	d	d		
	23/24			d	d	d	d	d	r	r	r	r	r	d		
	24/25			r	r	d	d	r	r	r	d	d	d	d		
	25/26			d	d	d	d	d	d	d	r	r	d	d		
	26/27			d	r	d	d	r	n	r	n	n	n	r		
	27/28			d	d	r	r	d	d	r	r	d	d	r		
	28/29			d	d	d	d	d	d	d	d	d	d	d		
	29/30			r	d	d	d	d	r	d	d	d	d	d		
	30/01			r	r	r	d	d	d	d	d	d	d	d		

Table 5b. *Dew calculated (d), rain measured (r) and dry hours calculated (n) for each hour in October 1987*

Oct. Night	17	18	19	20	21	22	23	24	01	02	03	04	05	06	07
01/02			n	n	n	d	d	d	d	d	d	d	d		
02/03			n	r	n	n	n	n	n	n	n	n	n		
03/04			n	n	n	d	d	d	d	d	d	d	d		
04/05			d	d	r	d	d	d	d	d	d	d	d		
05/06			r	r	n	n	r	r	r	r	r	r	r		
06/07			r	r	r	r	r	r	r	r	r	r	r		
07/08			r	r	r	r	r	r	r	r	r	r	r		
08/09			r	r	r	r	r	r	r	r	r	r	r		
09/10			n	n	n	n	n	n	n	n	n	n	n		
10/11			r	r	n	n	n	n	n	n	n	n	n		
11/12		d	d	d	d	d	d	d	d	d	d	d	d		
12/13		r	d	d	r	r	r	d	d	d	d	d	d		
13/14		d	d	d	d	d	d	d	d	d	d	d	d		
14/15		n	n	n	r	r	r	r	r	r	r	n	n	n	
15/16		r	r	r	r	r	r	r	r	n	r	n	n	n	
16/17		n	n	n	r	r	n	n	n	d	d	d	d	d	
17/18		n	d	d	d	d	d	d	d	d	d	d	d	d	
18/19		r	r	r	r	r	r	r	r	d	d	d	d	d	
19/20		n	n	n	n	n	n	n	n	n	n	n	n	n	
20/21		n	n	n	n	n	n	n	n	n	n	n	n	n	
21/22		d	d	d	n	d	d	n	n	r	r	r	r	d	
22/23		d	d	d	d	d	d	d	d	d	d	d	d	d	
23/24		r	r	r	r	d	d	d	d	d	d	d	d	d	
24/25		d	d	d	d	d	d	d	d	d	d	d	d	d	
25/26		d	d	d	d	d	d	d	d	d	d	d	d	d	
26/27		r	r	r	d	d	d	d	d	d	d	d	d	d	
27/28		n	n	n	n	n	n	n	n	n	r	n	n	n	
28/29		r	r	r	r	r	r	r	r	r	r	r	r	r	
29/30		r	r	d	d	d	d	d	d	d	d	d	d	d	
30/31		d	d	d	d	d	d	d	d	d	d	d	d	d	
31/01		r	r	r	d	r	r	r	r	r	d	r	r	r	

Table 6. *Average meteorological parameters for dew and dry periods in the months September and October of 1987*

	September		October	
	dew period	dry period	dew period	dry period
relative humidity (%)	95	85	94	80
air temp. (°C)	11	15	7.5	11
dew point (°C)	10.5	13	6.5	8
wind velocity (ms^{-1})	1	2.5	1.6	4.2
limiting wind velocity for dew fall (ms^{-1})	1.5	0.2	1.5	0.2

meteorological parameters are used and properties of the dew plate do not have to be taken into account. In this model, the heat flux (G) to the dew surface from below and the change of the heat content of the dew plate (M) are ignored. The model is therefore applicable to thin surfaces (with a small heat capacity and therefore small value of M) which are badly connected (low conductance for heat transport, i.e., a small value for G) to a larger body with a greater heat capacity. This is for instance the case for grass or leaves of vegetation. Because our dew sampler does not meet these requirements perfectly, small values of M and G will result in a small extra contribution to the energy balance of the surface. Frequency and duration of dew will then be somewhat overestimated. Based on our measurements and model calculations, we conclude that this amounts to about 10–20% at most. Another aspect is the fact that the minimum observable quantity of dew which has to be deposited on the dew plate in a period of 2 or 3 h is about 3 ml or 3 g. The amount of water deposited by dew on a surface is always very small. If it is below the detection limit or is already evaporated in the measuring period, no dew is registrated, although it did occur and will correctly be calculated by the model. This improves the performance of the model.

From the number of calculated dew nights, which is over 200, it is concluded that a surface is wet for most of the time during the nocturnal hours. This result is important in quantifying the dry deposition in particular of easily soluble air pollutants and may influence the effect of air pollutants on vegetation.

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REFERENCES

Chameides, W. L. 1987. Acid dew and the role of chemistry in the dry deposition of reactive gases to wetted surfaces. *Journal of Geophysical Research 92, D 10*, 11895–11998.

Davies, T. D. and Mitchell, J. R. 1983. Dry deposition of sulphur dioxide onto grass in rural Eastern England. In: *Precipitation scavenging, dry deposition and resuspension* (eds. H. R. Pruppacher et al.), vol. 2, Elsevier New York, pp. 795.

Duvdevani, S. 1947. An optical method of dew estimation. *Quart. J. Royal Meteorol. Soc. 73*, 282–296.

Frankenberger, E. 1955. Über vertikale Temperatur-Feuchte- und Windatmosphäre, den Vertikalaustausch and den Wasserhaushalt an Wissenboden bei Quickbron/Holstein, 1953–1954 (in German). Berichte der Deutschen Wetterdienstes, 3, nr. 20, Bad Kissingen, 1955, Bundesrepublik Deutschland (BRD).

Garratt, J. R. and Segal, M. 1988. On the contribution of atmospheric moisture to dew formation. *Bound. Layer Met. 45*, 209–236.

Hofmann, G. 1955. Die Thermodynamik der Taubildung (in German). Berichte der Deutschen Wetterdienstes, 3, nr. 18, Bad Kissingen, 1955, Bundesrepublik Deutschland (BRD).

Holtslag, A. A. M. and De Bruin, H. A. R. 1988. Applied modeling of the nighttime surface energy balance over land. *Journal of Applied Meteorology 27*, 689–704.

Leick, E. 1932. Zur Methodik der relativen Taumessung (in German). *Beih. zur Botanisches Zentralblad 49*, 160–189.

Monteith, J. L. 1957. Dew. *Quart. J. Royal Meteorol. Soc. 83*, 322–341.

Mulawa, P. A., Cadle, S. H., Lipari, F., Ang, C. C. and Vandervenmet, R. T. 1986. Urban dew, its composition and influence on dry deposition rates. *Atmospheric Environment 20*, 1389–1396.

Rider, N. E. and Robinson, G. D. 1951. A study of the transfer of heat and water vapour above a surface of short grass. *Quart. J. Royal Meteorol. Soc. 77*, 375–401.

Römer, F. G., Te Winkel, B. H. and Janssen, L. H. J. M.

1989. The deposition of acidifying components on wet surfaces. Occurrence and chemical composition of dew. *Proceedings of the 5th European Symposium on Physico-Chemical Behaviour of Atmospheric Pollutants*, Italy, Varese, Sept. 1989, (eds. G. Angeletti and G. Restelli) Reidel Publ. Comp., Dordrecht/Boston/Lancaster/Tokyo.

Van Aalst, R. M., Duyzer, J. H. and Meijer, G. M. 1985. Dry deposition from plumes of coal-fired installations. TNO-report R85/353, P.O. Box 217, Delft, The Netherlands.

Voldner, E. C., Barrie, L. A. and Sirois, A. 1986. A literature review of dry deposition of oxides of sulphur and nitrogen with emphasis on long range transport modeling in North America. *Atmospheric Environment 20*, 2101–2123.