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Cabauw meteorological data tapes 1973-1984;
description of instrumentation and data processing
for the continuous measurements

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Contents:

1. Introduction

Five tapes have been compiled, each containing half-hourly averages of the continuous measurements at the Cabauw field site, together with supplementary data from surrounding observing stations. These tapes are intended to assist in many meteorological or environmental studies.

The contents of the tapes have been described in concise form in a five-page leaflet (Annex). However, for many studies the user will prefer more background knowledge of the data presented. The present report may then serve as a guide.

Some aspects of the instrumentation and data control have been described elsewhere. For these items duplication is avoided by refering to the other publication. References in the Dutch language, however, will briefly be summarized.

Most symbols as well as the element numbers and the mast positions are defined in the Annex and will therefore not be explained again in the main text.

2. General considerations

2.1 Conversion of moisture parameters

The specific humidity is computed from the measured values of temperature TT and wet-bulb temperature TW as follows

$$SH = 1000\left(\left(\frac{0.622\,\dfrac{2501000 - 2360\ TW}{PP/ES(TW) - 1} - 1005(TT - TW)}{2501000 - 2360\ TW + 1850(TT - TW)}\right)^{-1} + 1\right)^{-1} \text{g/kg} \qquad (1)$$

with

$$PP = PP_o(1 - z/(29.3(TT + 273.15)))\ \text{(mbar)}, \qquad (2)$$

where z is the measuring height, PP_o is the average pressure of the 4 nearest synoptic stations with a default value of 1013 mbar, and the vapour pressure is computed from

$$ES(T) = 6.107 * 10^{\frac{7.63\ T}{241.83 + T}} \quad \text{(mbar)} \qquad (3)$$

with T in °C. The constants in this Magnus-Tetens approximation have been adapted to provide minimum errors between 0 and 25 °C which is the relevant range for wet-bulb measurements.

In the energy-balance method of estimating vertical energy transport the first derivative s of the vapour pressure function is used:

$$s(T) = ES(T)\ \frac{7.63 * 241.83}{(241.83 + T)^2} * 2.30258 \qquad (\text{mbar K}^{-1}). \qquad (4)$$

The psychrometer-constant for an artificially ventilated psychrometer is approximated by

$$\gamma = 0.646 + 0.0006 * TW \qquad (\text{mbar K}^{-1})\ . \qquad (5)$$

Bowens ratio is found from

$$B = \frac{H}{L*E} = ((s(TW)/\gamma(TW)+1)* \frac{\Delta TW}{\Delta TT} - 1)^{-1}\ , \qquad (6)$$

but H = 0 for Δ TT = 0.

2.2 Distinction between day and night [96]

As in the following, numbers between square brackets refer to the element number in Annex A.

The transition from day to night v.v. causes important changes in radiation and stability. During day and night different control criteria will apply in checking e.g. temperature profiles or radiation data. Also the Pasquill class [215 etc] definition is based on this distinction. For these different problems different solutions are used.

Usually half hours with average solar elevation below 10 DEG are considered as part of the night. For the Pasquill class determination and the control procedures a conversion table is applied which approximately matches this 10 DEG criterion. These criteria refer to the sign-change of net radiation. Another problem is the absence of short wave radiation during the night: the presentation is discontinued for solar elevations below -3 DEG. Usually a table is used for this purpose (Nieuwendijk, Van der Vliet, 1978).

2.3 Error checking [1, 64, 88]

The purpose of data control has been to:

a. remove all numbers that are certainly wrong. This certainty is based on physical principles or on the results of instrument checks.

b. provide a warning if measurements are probably wrong. As an example we mention the temperature measurements during rain; they are usually doubtful but may sometimes be correct.

In the latter situation error checking is difficult because comparison measurements are probably also disturbed by the existing unfavorable weather conditions. The indiscriminate removal of all doubtful periods, however, would also destroy a lot of valuable material. Therefore - and this may seem a paradox - the data obtained in disturbed periods pass less severe tests than the data from favourable periods.

The user is advised on the status of the data by means of quality codes, the numbers [1], [64], [88]. The code value indicates whether tests have been performed (cf. a) or a warning is attached to the data (cf. b). Generally the more reliable data have the following codes: [1] = 0, 4 or 8; [64] = 0 - 3; [88] = 0, 2, 4 or 5.

The automatic error checks are described later in this report. On rare occasions data have been removed manually. If part of the half hour (more than 30%) was missing in the original 2 or 10 min. samples , that half hour period was considered absent.

Table 1. <u>Channel numbers of the Cabauw registration system</u>
(modifications with respect to the preceding period are underlined;
a = auxiliary mast P, M or T)

From	1972 Nov. 1			1974 Jan. 1			1977 Mar. 1			1978 Mar. 1			1980 Jan. 3			
			T			T	P	M	T	P	M		P	M		
(m)	N	SE	SW	N	SE	SW	N	SE	SW	N	SE	SW	N	SE	SW	
DD																
200	05	10	00	05	10	00	05	10	00	05	10	00	05	10	00	
160							<u>31</u>	<u>32</u>	<u>33</u>	31	32	33	31		33	
120							<u>34</u>	<u>35</u>	<u>36</u>	34	35	36	34		36	
80	06	11	01	06	11	01	<u>06</u>	<u>11</u>	<u>01</u>	06	11	01	06	11	01	
40							<u>37</u>		<u>38</u>	37		38	37		38	
20							<u>07</u>		<u>02</u>	07		02			07	
20a													<u>02</u>			
15a								<u>12</u>			12			12		
10a	07	12	02	07	12	02										
FF																
200	08	13	03	08	13	03	08		03	08		03	08		03	
160					<u>26</u>		<u>13</u>		<u>26</u>	13		26	13		26	
120					<u>27</u>		<u>14</u>		<u>27</u>	14		27	14		27	
80	09	14	04	09	<u>14</u>	04	<u>09</u>		<u>04</u>	90		04	09		04	
40					<u>28</u>		<u>39</u>		<u>28</u>	39		28	39		28	
20					<u>29</u>		<u>40</u>		<u>41</u>							
20a								<u>29</u>		<u>40</u>	29		40	29		
10a			15			15		<u>42</u>	15	<u>15</u>	42		15	42		
5a								<u>43</u>		<u>41</u>	43					
2a						<u>30</u>			30							
1.5a								<u>44</u>		<u>30</u>	44					
TT	TT	ΔTT		TT	ΔTT		TT	ΔTT		TT	ΔTT		TT	ΔTT	ΔTW	TW
213								<u>45</u>								
200	16			16			16			16			16			<u>47</u>
		17			17			17			17			17	<u>25</u>	
160																
		18			18			18			18			18	<u>30</u>	
120																
		19			19			19			19			19	<u>32</u>	
80	20			20												
		21			21			21			21			21	<u>35</u>	
40																
		22			22			22			22			22	<u>41</u>	
20	23			23												
		24			24			24			24			24	<u>43</u>	
10a		↑			↑			<u>46</u>			<u>46</u>			↑	↑	
5a		25			25									<u>46</u>	<u>44</u>	
		↓			↓			<u>47</u>			47			↓	↓	
2a																
								<u>48</u>			48			<u>20</u>	<u>48</u>	
.6a							<u>20</u>			20			<u>45</u>			<u>23</u>
											<u>45</u>					
.6a																
								<u>23</u>			<u>23</u>					
2a									T ↔	P						
								<u>25</u>			<u>25</u>					
10a																

3. Profile measurements

3.1 Organization

The mast and its surroudings have been described elsewhere (Van Ulden et al. 1976, Wieringa 1978, Driedonks et al. 1978, Driedonks 1981). After the 1973 measurements the recording equipment for the main mast measurements has been expanded from 26 to 50 channels. Table 1 lists the channel numbers in consecutive periods and also provides information on the position of wind equipment and the organization of the temperature difference measurements. The latter consist of temperature differences measured between levels and with respect to zero centigrade reference instruments.

The frequent changes regarding the auxiliary masts reflect the problems encountered in obtaining representative near-surface measurements. Although the mast is situated in flat polder country, small scale terrain inhomogeneities remain a problem. A season-dependent factor is the grass length. To normalize the local conditions, an area within 10 m from the masts was cut short regularly, but not as short as the micrometeorology field. In the years before 1981, however, the area around the P-mast received no special treatment.

The primary storage medium has changed gradually from punched paper tape to the microcomputer's hard disk unit, dumping regularly on magnetic tape. Final processing took place on the computer of the KNMI central office at De Bilt. At least one intermediate print out was obtained for manual data control. The controlled 2 min values were finally stored on magnetic tapes together with the selected values of wind speed and direction. Prior to Sep. 1, 1975 these tapes contain hour blocks i.e. 30 measurements of 50 elements following 50 identification words, together 1550 words). After that date (in fact starting a week earlier, but with some errors) the tapes follow the specifications published by Nieuwendijk and Van der Vliet (1978). These 2 min. values have been used to obtain the present tapes with 30 min averages.

3.2 Wind direction and velocity [2-25]

The computer procedure to select the upwind boom considers the three wind directions measured on the different booms at each level. An instrument which differs more than 20 deg from any of the others is assumed to be disturbed. From the remaining two or three booms we select the one which is most upwind. The last part of the procedure can also be applied if a boom is temporarily missing. More details on the selection procedure are given by Nieuwendijk and Van der Vliet (1978).

Especially in later years some levels carried only two vanes instead of three. The selection was then obtained from the adjacent levels. Data from the available SE vanes have been used on tapes B and C although no velocity could be measured at the same boom (see table 1). In these years the velocity was selected according to the wind direction as follows: the south-west anemometer is used between 135 and 315 deg, etc. On tapes A, D and E the anemometer was always chosen from the same boom as the vane.

Between the auxiliary masts no selection is made, but all measurements are made available on the tape. This implies that severe uncorrectable wake-effect errors (up to 25 per cent in velocity) are present in these data, e.g. if the instruments are downwind of the main building.

Two corrections have been applied to the wind measurements. Firstly corrections for upstream flow disturbance have been computed with the formulae of Wessels (1983). For the auxiliary masts these corrections were restricted to a 240 deg upwind sector . To avoid a jump at the edge of the remaining sector the correction diminishes linearly to the center of the wake. Of course the user is advised to use data from the wake with reservation. Secondly - after performing this flow correction - systematic direction errors could be determined by comparing measurements on different booms at the same level and also by considering vertical profiles during strong winds. Sometimes unexplained errors up to 7 deg were detected. A correction table has been applied to improve the accuracy of the resulting data to within 1 or 2 deg.

Special aspects of the instrumentation, calibration and registration of the wind are discussed by Van der Vliet (1981) and also Wessels (1983). In the years 1975-1980 individual calibrations of the anemometers have been used. In other periods the velocity instruments were assumed to have the same calibration.

During the preparation of the data tapes, measurements at very low wind speed (less than 0.7 m/s) were discarded. The 2 m wind [20] was also compared with the 1.5 m wind of the M mast [16]. If the latter indicated more than 2,5 m/s and the difference exceeded 50%, the first was not accepted.

The gust velocities [21-25] were partly obtained manually from strip chart registrations. In the later years the gusts were stored directly in De Bilt and obtained from the continuous data transmission intended for the on-line use of Cabauw data by the Operational Department of KNMI.

3.3 Air temperature [26-39]

Temperature and wet-bulb were measured in ventilated vertical tubes. These housings can be considered as a modification of the well-known Assman-psychrometer. Details of the design are described by Slob (1978). The electrical measurement scheme is indicated in Table 1.

The ventilation air speed was between 5 and 8 m/s. These measuring conditions provide an excellent protection against radiation errors at the cost, however, of increased wetting of the sensors during fog and rain. Especially during drying up, the dry-bulb sensor approaches temporarily the wet-bulb temperature which may be 1 or 2 °C lower. Another problem is the strong accumulation of rime ice during freezing fog conditions. Other causes of error include the failure of ventilation motors and defective amplifiers or zero reference instruments.

The temperature profile is checked on the occurrence of improbable gradients according to the list, published by Van Ulden et al. (1976) and slightly extended for the B and C tapes. The result of this test is included in the quality code [1], so the doubtful values are not eliminated but the profile in question is labeled with a warning.

3.4 Wet-bulb measurements along the main tower [40-48, 55-63]

Some of the errors affecting the dry-bulb measurements do also influence the wet-bulb: ventilation or electrical failure. The most important errors specific for wet-bulbs are the freezing or drying out of the sensors.

Contrary to the dry thermometer, the wet-bulb measures quite reliably during rain and fog. Physical restrictions for wet-bulb gradients as such, do not exist, but the specific humidity can be used to detect improbable observations. However, the specific humidity can only be derived if the dry temperature is reliable. Therefore a humidity check is performed only if the quality code [1] is an even number. Apart from the lowest meters we may expect the humidity profile to be well mixed during neutral or unstable conditions. In stable stratification large vertical gradients cannot be excluded. Therefore, gradients exceeding 5 per cent (10% below 10 m) are considered impossible if the temperature gradient is unstable. As an example we note that a specific humidity computed with a dry wet-bulb thermometer or with a wet dry-bulb will both be too high. Then no further computation will be carried out with this suspect value and the unreliable value of the specific humidity will not appear in the output [55-63]. The result of the humidity check can therefore be inferred from the presence of the output in combination with the (even) quality code. For odd quality codes the output will not be suppressed.

Because the wet-bulb process ceases operating after freezing of the wet- bulb, the presentation of the results is discontinued if the wet-bulb temperature falls below -0.2°C and resumed if it rises again above +0.2°C.

3.5 Visibility code [49,50]

Right from the start of the measurements in 1972 the Cabauw tower has been equipped with simple transmissometers. These measurements are not only valuable - and probably unique - for studying fog, but also for evaluating the quality of the other profile data. The presence of fog implies the probability of wet thermometers. During freezing fog also wind measurements may be disturbed due to ice accretion. Therefore the visibility is included in the quality code [1].

In the main tower transmissometer lamps are mounted at the tips of some of the SE booms. The lamps have a beam width of 2 x 1.8 deg (PAR 36 floodlight 6 V, 25 or 35 W). The receivers (detectors) are mounted on the balcony handrail on the east side of the tower. A photosensitive resistor is placed at the far end of a 30 cm long 5 cm diameter cylinder. Five equally spaced 1 cm diam. diaphragms restrict the viewing angle of the light detector to 2 x 0.85 deg. As a precaution against daylight the lamps are mounted in black cylinders.

The path between lamp and detector is 10.5 m. Therefore only fogs with a visibility less than about 500 m cause a detectable extinction. Due to the finite opening angles of lamp and receiver we have to correct the transmission T (a number between 0 and 1) with (see Wessels, 1979)

$$+ T \ln T (0.242 - 0.135 T). \qquad (7)$$

Because the visibility V follows from the transmission as

$$V(m) = - 3 \times 10.5/\ln T, \qquad (8)$$

the wide beams cause the visibility to be overestimated.

Actual values of the visibility are only used for case studies. For inclusion in the tapes merely the occurrence or non-occurrence of fog is registered. By inspection of the chart recordings it was usually possible to distinguish low cloud during rain from extinction by rain or snow blowing on the lamps. The latter phenomenon has been codes as "0" apart from a few doubtful cases (code 9).

3.6 Sodar records [197-200]

During most of the measurements a monostatic sodar (AeroVironment Inc.) has been in operation at the Cabauw field site. The signal may e.g. be used to determine mixing height or the heights of low clouds even beyond the top of the tower. The sodar code - as explained in the appendix - has been obtained by visual inspection of the chart records. The interpretation may occasionally be rather subjective. Therefore the coding has been carried out by a small group of people in close cooperation.

The vertical range of the sodar has been 1000 m on tapes B and C, but only 500 m on the later tapes.

4. Micrometeorological data

4.1 General description

The experimental facilities at the micrometeorology field (fig. 1 of the Annex) have been described by De Bruin and Holtslag (1982). The measurements consist of psychrometer data, soil measurements, radiation and 2 m wind speed.

The fluxes in the atmosphere are determined with two psychrometer masts from which the best one is chosen for presentation on these tapes. The high measuring level was at 1.1 m and the low level at 0.45 m (0.40 before 1980) above the grass. Since the start of the measurements the location and orientation of the psychrometers was changed 6 times. The consequences of these changes with regard to flow disturbance and fetch length have been included in the quality code [64].

Data storage was on strip charts in 1977 but on a microcomputer system in the other years. The data stored consisted originally of 10 min. average values. These are combined to half hourly values, if at least 2 of the 3 periods are availabe. During the years 1978 and 1979 sometimes serious timing problems occurred leading to errors up to one hour. These errors have been corrected although they may remain present near start and end of the corrected periods, due to the uncertainty in determining these periods (Table 2). Because of these problems the synchronization with the mast data can sometimes be insufficient.

Table 2 Time correction applied to micrometeorology data on the C-tape.

Period (usually 1978)	correction applied (min).
April 8 , 0130 - April 19, 0000	-60
Sep. 5 , 0830 - Sep, 9 , 0900	-20
Oct. 24 , 0930 - Oct. 31 , 1030	+10
Nov. 7 , 1030 - Nov. 20 , 0700	+10
Nov. 24 , 1400 - Dec. 1 , 0830	+50
Dec. 6 , 1130 - Dec. 7 , 1400	-30
Dec. 9 , 1200 - Dec. 14 , 1800	+10
Dec. 22 , 0930 - Dec. 31 , 0000	+20
Feb. 2 , 0930 - Feb. 6 , 1200 (1979)	+20

4.2 Psychrometer measurements [65-68, 86-87]

The instruments are the modified Assman-psychrometers described in sections 3.3 and 3.4. Each psychrometer set measures one absolute temperature and three temperature differences: ΔT, ΔTW and TT-TW. A series of control procedures is applied to the 10 min. values. The tests run schematically as follows:

a If one of the wet-bulbs sinks below -0.2°C its signal(s) are not accepted until the wet-bulb rises again above +0.2°C.

b If rain is detected or in humid weather (TT-TW < 0.2°C at both levels) the quality code provides a warning and further tests are skipped.

c Dry wet-bulbs or wet dry-bulbs are detected as follows: During daytime test c1 is carried out if the values of TT-TW differ more than 30% between the levels. During the night differences up to 70% are necessary or at least the largest TT-TW must exceed ΔT. Otherwise c2 is applied.

   c1 If the ΔT's differ less than 0.2°C but the ΔTW's differ more, then one of the wet-bulbs may be dry and is discarded accordingly.

   c2 If the values of TT-TW at one mast are not too far apart the values at different masts are compared at least if the dry thermometers differ less than 1.0°C. A wet-bulb being more then 1.5°C warmer than any other is probably dry.

d if during daytime both TT-TW > 0.2°C then absolute values of ΔT or ΔTW exceeding 1.5°C are not accepted.

e A coincidence of negative (stable) ΔT and positive ΔTW (with a tolerance of 0.05°C) is considered improbable.

This checking process may result in a change of a status character describing the quality of the 10 min values on the second tape version:

0 = no check (e.g. during rain)
1 = no action, value OK
2 = correction or removal
3 = suspect value

After this test, which is sometimes repeated with corrected values, a new data set is available from which inaccurate values have been removed and in which suspect values are labelled. Sometimes corrections have been performed which usually concerns a systematic deviation of more than 1°C of the absolute temperatures.

In the next phase one of the masts is selected for further use. With two masts present the one without suspect values is preferred. If no distinction results from the foregoing the quality code [64] decides. In most circumstances the choice is determined by the wind direction.

4.3 Soil heat flux at the earth's surface [73-76]

This imporant contribution to the energy balance cannot be measured directly. The estimation procedure developed by W.H. Slob, employs temperature measurements with resistor needles at and near the surface and also heat flux measurements just under the surface with two heat flux plates. The procedure has been published as an appendix by De Bruin and Holtslag (1982). From the needles available we chose the three registering on channels 8, 10 and 11. On many occasions, however, the signals were incomplete. Then an alternative procedure used the diurnal course of the heat flux at -5 and -10 cm depth after correction for the daily trend. The soil heat flux was reconstructed from the main Fourier components of the two signals, whereby the amplitudes were extrapolated exponentially to the surface and the phase angles were extrapolated linearly.

Both this method and the more complete method using the temperature signals, had to be abandoned if more than one hour of the diurnal curve was missing. Missing heat flux data [76] do therefore always occur over 24 hour periods starting at 03 UT.

4.4 Rainfall intensity and occurrence [77-78]

The amount of rainfall was registered with a pluviograph of the siphoning type. However, in the period before 1982 Feb. 3, 1430 UT only 10 min average positions of the floater were registered in the micro-computer system. Especially if the floater returned to zero it was difficult to estimate the total rainfall between the beginning and end of a 10 min. period. An algorithm has been used to reconstruct the 10 min. totals from the 10 min. averages, thereby avoiding unneccessary smoothing of the signal near the start and end of rainfall periods. After the date mentioned actual positions at the end of 10 min. periods were registered.

Especially during the winter 1978/79 the rainfall totals were less accurate. The main problem was the frequent occurrence of solid precipitation. Also the siphoning level changed sometimes up to 10 per cent, probably becuase of the adverse weather conditions. These errors have been removed or corrected manually.

The rainfall is an important criterium for the quality of the other measurements. As a better means to detect the occurrence of light precipitation a rain alarm signal has been registered [78]. The sensor operated by means of increased conductivity between two electrodes on an exposed plate of insulating material.

4.5 Soil moisture and ground water table [79-80]

The (weekly) measurements on the B and C tapes have been reported by Wessels (1983). From 1981 October the neutron sonde measurements were replaced by a measurement of the capacity between a series of fixed electrodes at a depth of about 15 cm.

Due to technical problems the soil moisture signal is rather incomplete during the last measuring years.

Ground water was measured regularly in a pit near the centre of the micrometeorology field. This location probably underestimates the thickness of the non-saturated layer of most of the surrounding field.

5. Radiation measurements [88-94]

5.1 Instruments near the main tower [89,90,93]

Radiation data have been obtained from two separate sites: near the tower and at the micrometeorology (E-)-field (52). A Moll-Gorczynski pyranometer (Kipp, Delft, CM5 or CM7 instrument) measured the global shortwave radiation at the top of the main mast [89] and also near the auxiliary T-mast. This latter pyranometer was used as a replacement if the data from the micrometeorology field were missing [90]. The substituted data are easily recognised because they are rounded to integer values.

Also near the T-mast net radiation was measured [93], at first with the instrument described by Suomi et al. (1954), later with a "Funk" (Funk 1959). See for details 5.2.

The original registration of these data has been on paper tape using counter-printers. Although some errors were removed, either manually or automatically (e.g. upward fluxes > 130 Wm^{-2} during the night were rejected for the Q2T singal [93]), many doubtful values were retained. Especially suspect were the strongly varying Suomi-measurements during rain. So e.g. upward fluxes > 30 Wm^{-2} were registered during daytime, which can normally occur only above a snow cover. Also strong winds may interfere with the ventilating airstream of the instrument which was blowing to the Northeast in year A and to the Northwest in later years.

5.2 Instruments at the micrometeorology field [72,90-92]

As part of the micrometerology program the minicomputer system stored a variety of radiation data. The instruments were usually located in the northwest corner of the E-field at mutual distances of 4 m.

The instruments included two Funk net radiometers (one of the type CN2 and also a CN1 with external ventilation, Middleton Instruments, Port Melbourne, VIC, Australia) and the Eppley (5.4).

The Heijman infrared thermometer was used during most of the time at a few meters distance from the grass surface.

5.3 Selection of net radiation for use in energy balance computations [88,94]

Depending on the year up to 4 instruments could be used for this quantity. The final choice is documented with the quality code [88] explained in the Appendix.

The Funk with ventilation is preferred, but sometimes its quality may be reduced. If this instrument is missing we use the Funk without ventilation but if dew is supposed to occur (and no rain is measured) one of the Suomi instruments is used as a replacement. Among these the one at the E-field is preferred. If the Funks are both absent and no Suomi is available (missing or disturbed by rain) then we roughly estimate the net radiation as 75 per cent of the global radiation.

The occurrence of dew is not actually measured but simulated by a procedure. The maximum value of TT-TW from the two masts and the 2 m wind speed (m sec^{-1}) are combined in a dew criterium:

$$C = \left(\frac{TT - TW}{0.5}\right)^2 + \left(\frac{FF}{3}\right)^2 \qquad (10)$$

where dew starts forming if C sinks below 1 and any existing dew is evaporated if C rises above 2. We operate this criterium only if the Funk considered measures more than -3 Wm^{-2}, which is usually during nighttime (as stated in the Appendix all upward fluxes are considered positive). The criterium (10) has been developed by comparison of ventilated and unventilated instruments.

5.4 Measurement of long wave radiation [92]

This quantity was measured with an Eppley infrared radiometer (Eppley Lab. Inc., Sci. Instr., Newport, RI). The signals from the reference (a NTC resistor) and the thermocouple measurement of the temperature difference between reference and sensor surface were registered independently on the microcomputer. Although the registration was available since March 1978 the instrument proved defective from June 23, 13 UT through the remaining measuring year.

Until 1979 Feb. 28 and also before 1978 April 4, 13 UT an Eppley without ventilation has been used as a replacement. An unventilated instrument, however, is sometimes unreliable because of the presence of dew. The suspected data were removed with the procedure described in 5.3, with the exception that the start of dew was delayed until the simultaneous occurrence of the conditions:

- selected net radiation > 25 Wm^{-2}, i.e. during the night
- thermocouple signal < 1,35 * the selected net radiation.

This procedure was tested during a period that both the ventilated and unventilated instruments were available.

6. Derived quantities

6.1 Fluxes computed from profile data [52-54, 81-85)

The following procedure was applied to estimate u_*, H and L * E from the differences of potential temperature θ and the specific humidity between the levels z_2 and z_1 ($z_2 > z_1$), from the wind velocity measured at level z_o, together with the surface roughness specified by Van Ulden et al. (1976) as a function of wind direction, season and (temporary) presence of trees.

- neutral case:

$$H = 0 \;;\; L * E = \text{missing} \;:\; u_* = \frac{0.41\,u}{\ln(z_u - z_o)} \qquad (11a,b,c)$$

- unstable case (θ2 < θ1), according to Benoit (1977):

$$u_* = 0.41\,u\left(\ln\frac{z_u}{z_o} + \ln\frac{(1+\xi_o)^2(1+\xi_o^2)}{(1+\xi_u)^2(1+\xi_u^2)} + 2(\tan^{-1}\xi_u - \tan^{-1}\xi_o)\right)^{-1}$$

(12a)

and

$$T_* = 0.41\,(\theta_2 - \theta_1)\left(\ln\frac{z_2}{z_1} - 2\ln\frac{1+\xi_2^2}{1+\xi_1^2}\right)^{-1} \qquad (12b)$$

where ξ depends on z as follows:

$\xi = (1-16\,\frac{z}{L})^{\frac{1}{4}}$ with L from Eq. (14).

To obtain ξ_o, ξ_u, ξ_1, ξ_2 we must insert z_o, z_u, z_1 and z_2.

- stable case, along the same lines:

$$u_* = 0.41\quad u\left(\ln\frac{z_u}{z_o} + 5{,}2\,\frac{z_u - z_o}{L}\right)^{-1} \qquad (13a)$$

$$T_* = 0.41\,(\theta_2 - \theta_1)\left(\ln\frac{z_2}{z_1} + 5{,}2\,\frac{z_2 - z_1}{L}\right)^{-1} \qquad (13b)$$

As a first guess we use L = -36 and +36 respectively and from the computed u_* and T_* a new value of L is found:

$$L = u_*^2 \ (T + 237.15)/(3.43\ T_*) + 10^{-6} \tag{14}$$

If during the fifth iteration the change of L is less than 1 per cent, the results are accepted and we finally compute:

$$H = -1220\ u_*\ T_* \tag{15a}$$

$$L * E = 2.488\ \frac{\Delta(SH)}{\Delta\theta}\ H \tag{15b}$$

Under some conditions these values of H can be presented in elements [53,83]. Also L * E in [54,84] and u_* in [52,85].
The conditions for accepting these results have been as follows:
- the iteration procedure converges sufficiently
- the resulting u_* is at least 0.05 ms^{-1}
- for the psychrometer mast the quality [64] must be less than 4, but Bowen ratios near -1 are accepted
- for the main mast the temperature must be accurate and no rain should occur (both according to quality code [1]).

An alternative method computes fluxes from the energy balance components by using Bowen's ratio from Eq. (6):

$$H = - Q^* - G - L * E. \tag{16a}$$

$$L * E = -(Q^* + G)/(1 + B) \tag{16b}$$

These results are accepted if the quality code [64] is less than 4. Especially during the night this method may be unreliable, so the results are not accepted if the heat flux is too much different and of opposite sign compared to the profile result (15a). The fluxes computed with (16) are presented in elements [82] resp. [81].

During 1973 the lowest thermometer was at 2 m in stead of 0.5 m. A comparison suggests that this height difference causes the heat flux H to be some 11 per cent too low with regard to the procedure followed in the other years.

On some occasions with missing data the south-east mast was replaced by the north-west, but only for wind directions between west and north.

6.2 Geostrophic wind and thermal wind [362-365]

In contrast to other wind data on the tapes the geostrophic and thermal wind are valid for short periods at the end of hourly periods. The reason for this is their dependence on synoptic pressure and temperature readings.

The geostrophic wind has been computed as the pressure gradient between 10 stations by optimum interpolation (Cats 1978, 1979). Although in the original method stations with large deviations from the expected pressure pattern are deleted, we want to avoid the averaging over a varying collection of stations, including some with systematic errors. The interpolation scheme was applied without the error control procedure.

The thermal wind can be considered as a more local quantity than the pressure gradient. The reason for this is that the thermal wind reflects boundary layer temperature gradients while the geostrophic wind depends on the pressure distribution through the whole depth of the atmosphere. We have computed the temperature gradient vector by two dimensional least squares fitting to the screen temperature measurements of the 4 nearest synoptic stations. The thermal wind defined in this fashion can e.g. be useful to discern sea-land-breezes in the diurnal hodograph.

6.3 Mixing height and Pasquill class [201,215]

Mixing height is estimated for Cabauw from the sodar echo. We chose - rather arbitrarily - the center of the highest echo. This will occasionally overestimate the true mixing conditions (if a lower inversion is present) and sometimes underestimate them (if the center of thermal plumes is chosen as mixed layer top).

Pasquill classes are included for the synoptic stations (not Cabauw) to provide a rough estimate of mixing conditions. They are based on season, wind speed, cloud amount, and the day/night difference. The criteria we used are the same as published by Nieuwstadt et al. (1976).

7. Supplementary data

These include radiosoundings and synoptic surface observations. The data were obtained from the climatological data base of KNMI. Various control procedures on these data have been carried out by the Operational Division.

The coding on these tapes has been the old WMO-format used before the major code change of 1982 Jan 1. Therefore the later observations have been translated to the old code. Apart from the codes for weather (W) and surface condidtions (E) this was a straightforward process. On the present tapes W1 was chosen to replace W. The old value of E could be estimated from the new values of E and E' with the help of Table 3.

Table 3. Conversion of new to old WMO code for surface conditions.

new code	E	0,9	1	2,3	4	5				6	7,8
new code	E'					0	1,5	2	3,4,9	6	7,8
old	E	0	1	2	3	4	5	6	7	8	9

All other quantities have been coded according to the WMO code with the exception of wind speed. Contrary to synoptic usage we used SI units to comply with the presentation of the tower data.

The wind measurements at TV-towers have been made available by the National Institute for Public Health (RIVM). No correction has been applied to these measurements although flow distorion will frequently cause errors (Mellink, Velds, 1979).

8. Acknowledgements

The data collection obtained at the Cabauw field site was the result of many years of dedicated work by numereous colleagues from the Instruments Department and the Computer and Research Divisions of KNMI.

During the final stage a major part of the data processing and data control - the checking of more than 10 million numbers - was organized and carried out by J.J.M. den Braber and C. Hofman.

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ROYAL NETH. METEOR. INST.

ANNEX

(DEPT. OF PHYS. MET., 1984, Sep.)

Description of CABAUW magnetic tapes

Titles	Nrs.:	Measuring periods:
CABAUW7373A	1852	A 1973 Jan. 1, 01 UT - 1973 Dec. 31, 24 UT
CABAUW7778B	1853	B 1977 Mar. 1, 01 UT - 1978 Feb. 28, 24 UT
CABAUW7879C	1854	C 1978 Mar. 1, 01 UT - 1979 Feb. 28, 24 UT
CABAUW8182D	1855	D 1981 Oct. 1, 01 UT - 1982 Sep. 30, 24 UT
CABAUW8384E	1856	E 1983 Feb. 1, 01 UT - 1984 Jan. 31, 24 UT

Tape specification:

words tape:	character tape:
9 track: 1600 bpi	9 track: 1600 bpi
labelled: title = "CABAUW7373A" etc.	optional
blocksize: 11200	1674
maxrecsize = 400	1674
number of blocks = 365	10220
units = words	characters
parity = odd	-------

For missing data the value -9999 is read (except for visibility V).
Missing values on the character tape are filled with "9"'s.

Tape contents

Half hourly observations from the Cabauw mast;
Energy budget data from the nearby micrometeorology field site;
(not available on tape A and on tape B before April 27 and after Oct. 1)
Selected synoptic data from nearby weather stations;
Aerological data from De Bilt (06260).
Wind measured at TV-towers (measured by the National Inst. of Public Health (RIV)).
For every day 28 records are presented. The first 4 records contain aerological data for 00, 06, 12 and 18 UT respectively. They are followed by 24 records with the observations for 01-24 UT.

Symbols used in the following tables;

Units used on 'words' tapes. Every asterisk indicates multiplication by 10 on character tapes (e.g. temperatures are then in 0.01°C).

k = number indicating level with aerological data.
p = number indicating first half hour (p = 0) or second half hour (p = 1).
m = number indicating synoptic weather station.

m	Station	Nr.	Lat.	Lon.
m = 0	Schiphol Airport	(06240)	52°18'N	4°46'E
m = 1	Rotterdam Airport	(06344)	51°57'N	4°26'E
m = 2	Gilze Rijen	(06350)	51°34'N	4°56'E
m = 3	De Bilt	(06260)	52°06'N	5°11'E
m = 4	De Kooy	(06235)	52°55'N	4°47'E
m = 5	Vlissingen	(06310)	51°27'N	3°36'E
m = 6	Zuid Limburg	(06480)	50°55'N	5°46'E
m = 7	Eindhoven	(06370)	51°27'N	5°25'E
m = 8	Twenthe	(06290)	52°17'N	6°54'E
m = 9	Eelde	(06280)	53°08'N	6°35'E

z = height above ground (m) (** for roughness length and groundwater table)
JJ = year-1900, MM = month (1-12), YY = day of month (1-31)
DD = wind direction (deg. clockwise from north: 00 = calm or variable)
FF = wind speed (ms^{-1}) *(** for surface friction velocity)
PP = pressure reduced to sea-level (mbar) *
TT = temperature (°C) ** (also for temperature differences)
TW = wet-bulb temperature (°C) **
RH = relative humidity (per cent) *
SH = specific humidity ($g.kg^{-1}$) **

H = sensible heat flux density (Wm^{-2})
L * E = latent heat flux density (Wm^{-2})
G = soil heat flux density (Wm^{-2})* all fluxes upward
K↓ = incoming (global) shortwave radiation (Wm^{-2}) e.g. K↓ is
K↑ = reflected shortwave radiation (Wm^{-2}) always negative
L↓ = incoming longwave radiation (Wm^{-2})
Q_* = net radiation (Wm^{-2})
S = relative sunshine duration (per cent; < 10% coded as 5)
V = visibility code (V = 0, visibility good; V = 1, visibility has been < 500 m during observing period; V = 9, missing or disturbed by precipitation).
R = rain indicator (R = 1 resp. 0: precipitation detected resp. not detected during observing period).
RR = precipitation ($mm\ hr^{-1}$) **

Format specification of the character version
(modified units are given above; in addition the radiosonde start time is multiplied by 100 and the synoptic cloud code by 10).
Radiosonde record:
I8,I4,I4,23(I4,I5,I5,I4,I3,I3),245I4,14I9
Hourly record:
I8,2(I4,6I3,18I3,23I5,I5,I6,I3,I3,2I4,9I4,I2,8I5,I1,3I5,I5,I1,I3,I4,4I4,I3,2I4,
I1,6I4,I4,I3,2I6),4I7,I5,
10(I4,I2,2I5,I4,I5,2I3,I3,I5,I5,I2,I7,I1,I6),
7(I3,I3),I5,33I6

Sodar code used on Cabauw magnetic tapes
The observed acoustic echoes are described with four 7-digit numbers. Subsequent code numbers are used to code echoes in order of elevation.

Sodar code specification: K t t h h d b

where K = classification

0 no echo (code number = 0)
1 surface based inversion
2 surface- and elevated-inversion
3 elevated inversion only
4 thermal plumes
5 combination of structures 1-4
6 wind noise
7 precipitation noise
8 equipment out of order

tt = width of echo
hh = height of upper edge

both in 10's of meters

d = echo rise and echo intensity

0 not coded
1 stationary — echo with
2 rising — normal
3 lowering — intensity
4 stationary — echo with
5 rising — large
6 lowering — intensity

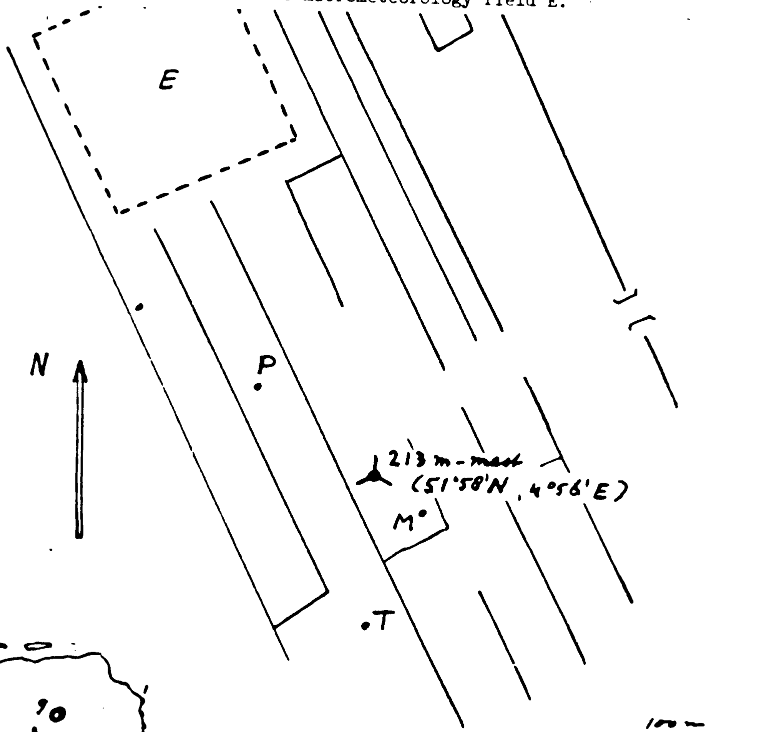
b = further specifications

0 no special remarks
1 sharp discontinuity
2 way pattern
3 echo appeared during last hour
4 echo disappeared during last hour
5 interrupted echo

Tabular description of aerological record

number of the element	code and measuring height	period of absence	specification or note (→)
0	JJMMYYUU		UU = standard observing hour (UT) (00,06 etc).
1	quality code		1000 to identify aerological record.
2	start time		hours (UT) + minutes/100 of balloon release.
3+k*6	Z		(m. or geop. m.). } for 23 levels, i.e.
4+k*6	pressure		(mbar).
5+k*6	TT		levels for the minutes 1-11(k=0-10),
6+k*6	RH		7 standard pressure levels ⩾ 500 mbar,
7+k*6	FF		5 levels with characteristic tempe-
8+k*6	DD		rature : k=18(surface) -22
141-399			reserved

Fig. 1. Sketch of observing field with auxiliary masts M, P and T and the micrometeorology field E.



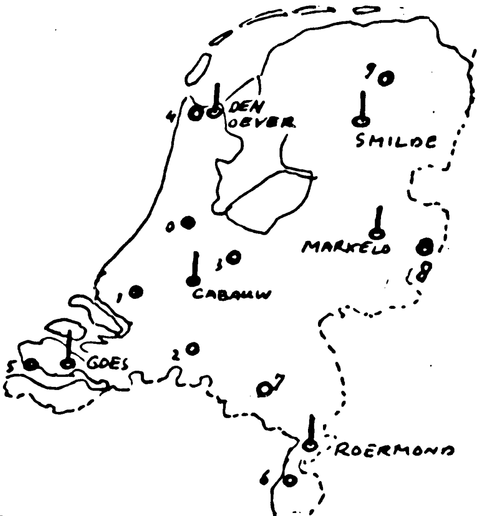


Fig. 2. Location of Cabauw, the instrumented TV-towers and synoptic stations (m=0-9).

Description of hourly observation records

number of the element	code and measuring height	period of absence	specification or note (→)
0	JJMMYYUU		UU = hour (01-24 UT) ending observing period
1+98*p	quality code for mast data (number 0-63)		0 for optimum quality of the profiles + 32 if V = 1 at any level + 16 if R = 1 or missing + 8 if K is incomplete + 4 if DD, FF or TT is incomplete + 2 resp. 1 if Q resp TT is inaccurate.
2+98*p	DD200		wind direction
3+ "	DD160	A	
4+ "	DD120	A	
5+ "	DD80		
6+ "	DD40	A	
7+ "	DD20	→	→on tape A: 10T (see fig. 1)
8+98*p	FF200		wind speed
9+ "	FF160	A	
10+98*p	FF120	A	
11+ "	FF80		
12+ "	FF40	A	
13+ "	FF20M	A	
14+ "	FF10T/M	→	→on tape A: 10T
15+ "	FF5M	A,D,E	
16+ "	FF1.5M	A,D,E	
17+ "	FF20P	A→	→on tape B from north boom of main mast
18+ "	FF10P	A,B	
19+ "	FF5P	A,B,D,E	
20+ "	FF1.5P/E	A→	→on tapes B, D and E: 2E
21+ "	maxFF200	B,C	maximum gust velocity in half hour
22+ "	maxFF80	B,C	(measured with a time constant of 5 sec)
23+ "	maxFF40	A,B,C,D,E	(on tape A only in periods with
24+ "	maxFF20	A,B,C,D,E	large average wind speed)
25+ "	maxFF10T	B,C	
26+98*p	TT213	A,C,D,E	temperature
27+ "	TT200		
28+ "	TT160		
29+ "	TT120		
30+ "	TT80		
31+ "	TT40		
32+ "	TT20M	→	→on tape A from main mast.
33+ "	TT10T/M	→	→on tape A: 9T.
34+ "	TT5M	A,D,E	
35+ "	TT2T/M	→	→on tape A: 2T
36+98*p	TT0.5M	A	
37 "	TT10P	A,B	
38+ "	TT2P	A,B	
39+ "	TT0.5P	A,B,D,E	
40+98*p	TW200	A,B,C	Wet bulb temperature
41+ "	TW160	A,B,C	
42+ "	TW120	A,B,C	
43+ "	TW80	A,B,C	
44+ "	TW40	A,B,C	
45+ "	TW20	A,B,C	
46+ "	TW10	A,B,C	
47+ "	TW2	A,B,C	
48+ "	TW0.5	A,B,C	
49+ "	visibility code (5 digit number)	→	(((V180*10+V140)*10+V100)*10+V60)*10+V40 →M absent on A
50+ "	vis. code (6 dig)		((((V20*10+V10M)*10+V5M)*10+V1M)*10+V5T)*10+V1T
51	z_o		roughness height for upwind sector (Wieringa, Q.J. of RMS, 102, 1976, 241).
52+ "	u_*		surface friction velocity (ms^{-1}) } computed from surface layer profiles (Dyer formulae)
53+ "	H		sensible heat flux density
54+ "	L*E	A,B,C	latent heat flux density
55+98*p	SH200	A,B,C	specific humidity computed from TT and TW if TW> -2°C
56+ "	SH160	A,B,C	
57+ "	SH120	A,B,C	
58+ "	SH80	A,B,C	
59+ "	SH40	A,B,C	
60+ "	SH20	A,B,C	
61+ "	SH10	A,B,C	
62+ "	SH2	A,B,C	
63+ "	SH0.5	A,B,C	

number of the element	code and measuring height	period of absence	specification or note (+)
64+98*p	quality code for surface flux data from field E (number 0-32)		0 for optimum quality of the chosen psychrometer data +32 if the Bowen ratio between 0.7 and -1.3 +16 during rain +8 if temperatures inaccurate +4 if T-TW < 0.2 at either level +2 for flow not adapted to field E +1 for DD within 20DEG from psychrometer mast.
65+98*p	TT1.1	A	from psychrometer set with
66+ "	TT1.1-TW1.1	A	1) the smallest errors
67+ "	TT1.1-TT0.45	A	2) undisturbed flow
68+ "	TW1.1-TW0.45	A	
69+ "	TT(+0.03)	A,B	ground temperature for surface
70+ "	TT(-0.0)	A	with short (5-8 cm) grass.
71+ "	TT(-0.02)	A	
72+ "	TT rad.	A,B	radiative temperature of surface ("Heiman")
73+ "	quality code for soil heat flux (0-2)	A	0 estimated from soil temperature and flux plates 1 estimated from flux plates only 2 not available
74+ "	G(-0.05)	A	
75+ "	G(-0.10)	A	average of three heat flux plates
76+ "	G(0)	A	computed surface flux
77+ "	RR	A,B	from pluviograph
78+ "	R	→	on tapes A-B estimated from RR
79+ "	soil moisture	A	vol. percent, weekly measured at -0.2 m; on tapes B, C neutron sonde, later capacity method
80+ "	ground water table	A	from the last weekly observation
81+ "	H	A	computed from energy balance measurements
82+ "	L*E	A	(Bowen's ratio)
83+ "	H	A	computed from profiles in the
84+ "	L*E	A	lowest 2 m with z_o = 0.02 m.
85+ "	u*	A	
86+ "	SH1.1-SH0.45	A	
87+ "	SH1.1	A	computed from TT and TW if TW > -2°C
88+ "	quality code for Q*2(E) (number 0-7)		0 for optimum quality ("Funk" with ventilation) 7 not available 6 for Q estimated from K↓ 5 "Suomi T" used; no rain and/or crosswind 4 "Suomi E" used; no rain etc. 3 "Funk" without ventilation; dew or rain 2 "Funk" without ventilation; no dew 1 "Funk" with ventilation but registration doubtful
89+ "	K↓214		pyranometer at top of Cabauw mast
90+ "	K↓2E	→	replaced by K↓2T if missing
91+ "	K↑2E	A	
92+ "	L↓2E	A,B	
93+ "	Q*2T	→	Suomi on A,B,C, Funk on D,E
94+ "	Q*2E	A	
95+ "	solar elevation		DEG, at (UU-45 min) and (UU-15 min) resp.
96+ "	progression of day or night		sequential number +1, +2, ... of daylight half hours and -1, -2, ... for twilight and night half hours, starting for solar elevation near 10DEG
97+ "			reserved
98+98*p			reserved
197-200	sodar code	A	see page 2.
201	Z_M	A	mixing height estimated from sodar
202+15*m	K↓2		hourly average; m = 3-6 and 9 only
203+ "	S		sunshine of last hour
204+ "	TT2		
205+ "	TW2		
206+ "	RH2		
207+ "	PP		
208+ "	FF10		hourly average
209+ "	FF10		10 min. average
210+ "	DD10		"
211+ "	VVwwW		visibility and weather (WMO code)
212+ "	TT0.1		minimum of last night (08 UT only)
213+ "	Es		surface conditions and snow depth (WMO code) reported at 06 UT or 08 UT
214+ "	$NN_hC_LhC_MC_H$,i		clouds (WMO code); i = number of "/" here coded as "ø" (starting from right); e.g. 77853/+778530,1
215+ "	Pasquill class		A-F is coded 0-5
216+15*m			reserved
352	DD200	A,B,C	Den Oever 52°55'N, 5°02'E
353	FF200	A,B,C	
354	DD147	A,B,C	Goes 51°31'N, 3°53'E
355	FF147	A,B,C	
356	DD192	A,B,C	Roermond 51°11'N, 5°58'E — Wind (hourly average) measured at TV-towers
357	FF192	A,B,C	
358	DD179	A	Markelo 52°14'N, 6°27'E
359	FF179	A	
360	DD312	A,B,C	Hoogersmilde 52°54'E, 6°24'E
361	FF312	A,B,C	
362	DD		- geostrophic wind for Cabauw; optimum interpolation with pressure readings of stations m = 0 to 9
363	FF		
364	DD		- thermal wind at Cabauw for 1000m layer; estimated from temperatures of stations m = 0 to 3
365	FF		
366	TT of sea surface		- from the last 3-hourly observations at 06300
367-399			reserved