Assimitron, A Newly Devised Instrument for Measuring CO_2 Flux in the Surface Air Layer

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Introduction

The measurement of the turbulent flux of carbon dioxide in the surface air layer over crop field is a important problem in agricultural meteorology and production ecology. The aerodynamical method or the gradient method is often used for determining CO_2 flux over a crop field with good results. Inoue (1968) has also indicated the possibility of the turbulent correlation method for measuring CO_2 flux in the surface air layer.

In order to apply the turbulent correlation method to the determination of CO_2 flux, it is planned to design and construct a relatively small, portable instrument based on the correlation and the gradient methods. This instrument has been named Assimitron, referred to the name Evapotron devised by Australian scientists. Test performance of the first model of this instrument has started.

The present paper describes the outline of the principle on which Assimitron is based and of the electronic circuit for measurement of CO_2 flux. A detailed description of the results of measurements and comparison with those by other methods (aerodynamical method and heat balance method) will be published separately in near future.

Principle

At a level in the surface air layer the vertical turbulent flux of carbon dioxide (P_a), corresponding to the assimilation or the respiration of crop plants, is expressed by

$$P_a = -K\frac{dc}{dz}, \qquad (1)$$

$$P_a = D_{c,a}(C_1 - C_2), \qquad (2)$$

where K is the turbulent transfer coefficient for CO_2 (cm^2/sec), dc/dz the vertical gradient of the mean CO_2 concentration ($g\ CO_2/cm^3/cm$) $D_{c,a}$ the exchange velocity for CO_2 in the air layer between z_1 and z_2 (cm/sec), and C_1 and C_2 CO_2 concentrations ($g\ CO_2/cm^3$) at z_1 and z_2. The following relation is between K and $D_{c,a}$

$$D_{c,a} = 1 \Big/ \int_{z_1}^{z_2} \frac{dz}{K(Z)}, \qquad (3)$$

where $K(z)$ denotes the turbulent transfer coefficient as a function of z.

Since it is very difficult to accurately determine K and dc/dz at one given height, Eq. (2) is a practical relation in determining CO_2 flux in the surface air layer over crop field. The following relations are used for the exchange velocity. When the momentum flux (τ) and the sensible heat flux (L) are chosen as measurable fluxes of physical quantity, the exchange velocities are defined respectively by

$$D_u = \tau/\rho\cdot\Delta u, \qquad (4)$$

$$D_T = L/C_p\rho\cdot\Delta T, \qquad (5)$$

where D_u and D_T are exchange velocities for momentum flux τ ($g/cm\ sec^2$) and for sensible heat flux L (ly/sec) respectively, and ρ air density (g/cm^3), C_p the specific heat of air at constant pressure ($cal/g°C$), $\Delta u = u_2 - u_1$ and $\Delta T = T_2 - T_1$.

The vertical turbulent fluxes of momentum and of sensible heat are given respectively by

$$\tau = \overline{\rho u'w'}, \tag{6}$$

$$L = \overline{C_p \rho T'w'}. \tag{7}$$

The primes denote departures from the mean and the overbars time averages. By considering Eqs. (4), (5), (6) and (7), Eq. (2) can be written in

$$P_a = \frac{\overline{u'w'}}{\Delta u}(C_1 - C_2), \tag{2a}$$

$$P_a = \frac{\overline{T'w'}}{\Delta T}(C_1 - C_2). \tag{2b}$$

It is by these equations that the Assimitron computes the vertical turbulent flux of CO_2 in the surface air layer. Eq. (2a) is based on the assumption that the turbulent transfer coefficient for carbon dioxide (K_c) is the same as that for momentum (K_m) and Eq. (2b) assumes that the transfer coefficient for carbon dioxide (K_c) is the same as the coefficient for heat (K_h).

Instrument details

Fig. 1 is the block diagram of the Assimitron. Schematic circuit used for the automatic process of relevant data is given in Fig. 4. Assimitron comprises three units; sonic anemothermometer unit, gas analyzer unit and computing unit. Each unit is housed in a single case (see Fig. 3). Assimitron consumes about 700 w, but most power is used by air pumps in the gas analyzer unit and a ventilation fan in the computing unit. It is because the instrument is completely transistorized. The sensors can be easily set up with roving cables anywhere within a radius of 50 m from the Assimitron. The sonic anemothermometers and air sampling sets can be mounted at various levels on a mast. Fig. 2 schematically shows the experimental layout of the Assimitron in the field.

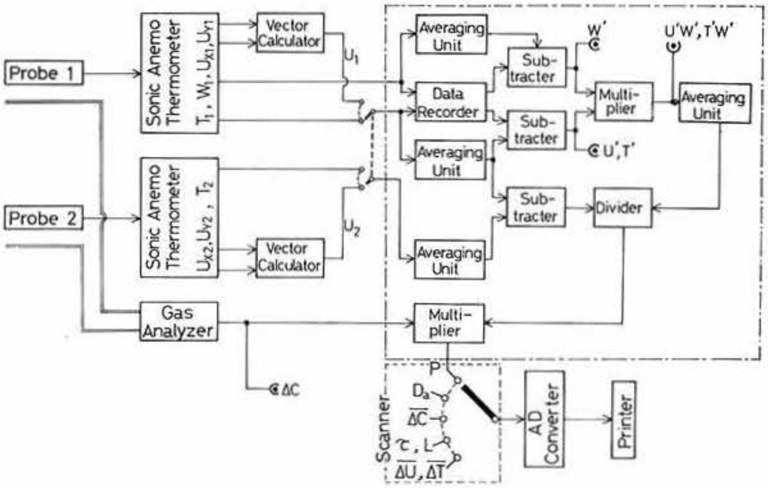


Fig. 1. Block diagram of the Assimitron.

In Eqs. (2a) and (2b), it is necessary to measure instantaneous values of fluctuating horizontal wind velocity and to compute departures from the mean. To determine the exchange velocity, the momentum flux and the difference in the mean horizontal wind velocity

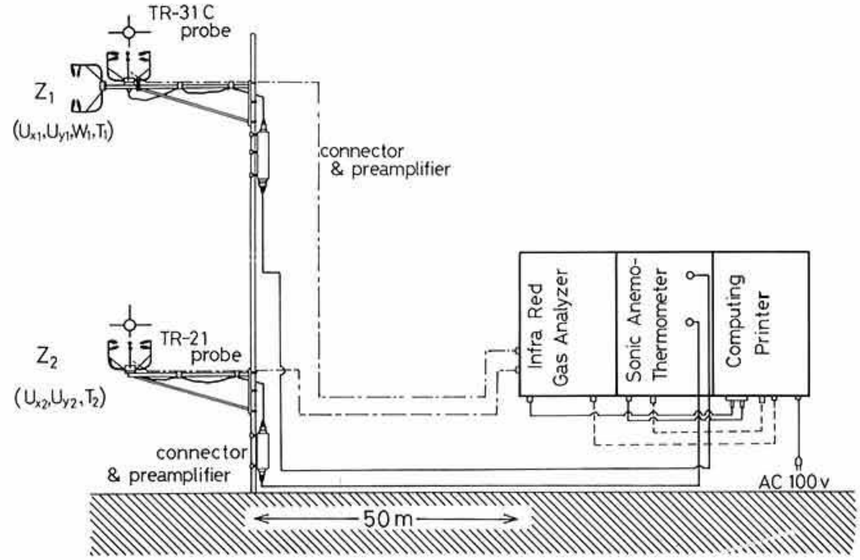


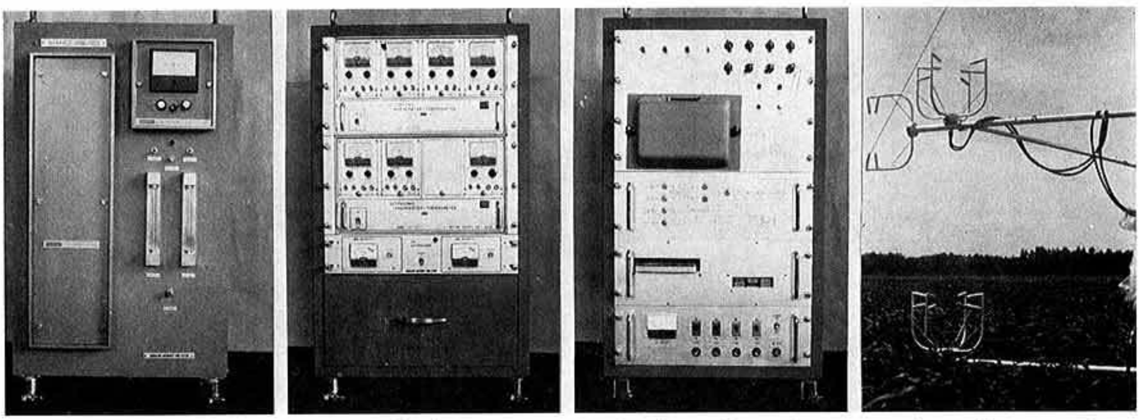
Fig. 2. Schematic layout of the Assimitron in the field.

between two levels are required. The horizontal component of air flow (u) is measured with satisfactory accuracy by a sonic anemothermometer, by employing a ultra-sonic wave of 100 KC.

A sonic sensor combined vertically with the horizontal sonic sensors measures the vertical component (w) of air flow and is mounted at a high level (see Fig. 2). Another sonic anemothermometer consists of the two-wind sensors for determination of the mean wind speed at a low level in the mean wind direction.

The anemothermometer for determination of the momentum flux or sensible heat flux is normally mounted at a height of about 2 m from the top of crop canopy, while the lower one is normally set near the top.

Feeding the electrical output from the two anemothermometers into a subtracting set in the computing unit gives automatically the



Infra-red Analyzer — Sonic Anemothermometer — Analogue Computer and Printer — Anemothermometers Three and two components sensors

Fig. 3. Photographical view of Assimitron.

difference in the mean horizontal wind velocity or in the mean air temperature between levels z_1 and z_2.

When the thermal stability in the surface air layer quite deviates from the neutral, Eq. (2b) should be used in place of Eq. (2a) in determining the exchange velocity because the equality between K_c and K_m is lost under such conditions.

Toshiba-Beckman model 315 A(S) is used as an infra-red gas analyzer in the Assimitron. The sensitivity of this analyzer is 0.25 PPM CO_2 with a practically linear full scale difference of 50 PPM of CO_2 concentration within a range 250~350 PPM. The analyzer has sample and reference cells with length of 34.3 cm and diameter of 1.9 cm.

A carbon blade oilless rotary air pump is used for sucking air samples from the sampling sites. Air intake nozzles sheltered from radiation are mounted at the same levels as those of the two sonic anemothermometers. Each intake nozzle is connected with the air pump by a polyethylene tube of 13 mm in diameter and 30 m in length. The pumping rate for the each intake nozzle is about 20 *l/min*. The high rate provides a proper ventilation for the thermometers (dry and wet bulbs) located in the nozzles and quick delivery of the sample air to the analyzer.

The air speed in the polyethylene tubes is about 300 cm/sec, which is considered enough for proper ventilation. The sucked air is divided and one part is fed into the analyzer at a rate of about 1 *l*/min.

The detailed circuits used for the computing unit are presented in Fig. 4. The computing unit comprises six parts such as a computing part, a memory part, an A-D converter, a digital printer, a self-timer and a power supply unit. A small endless-tape recorder of cassette type is used as a memory element to continuously record fluctuating windspeed and temperature during a period of 15 minutes. It is available to overcome the difficulty in the immediate determination of turbulent fluctu-

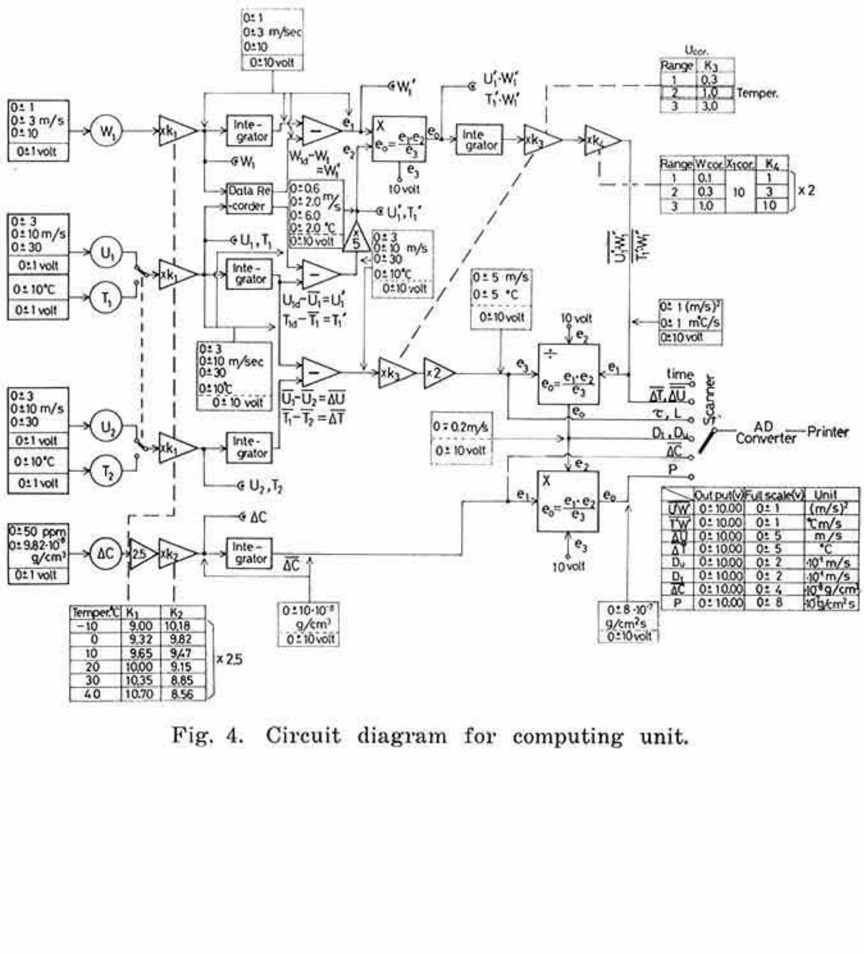


Fig. 4. Circuit diagram for computing unit.

ations about the mean of each quantity.

Calculations necessary to determine the CO_2 flux are made by transmitting analogue signals from CO_2 analyzer, vertical wind sensor, horizontal wind sensors and air temperature additional potentio-type chart recorders:

(1) Air temperature and horizontal windspeed; (2) Turbulent fluctuation about the mean of air temperature, horizontal windspeed and vertical windspeed; (3) Instantaneous

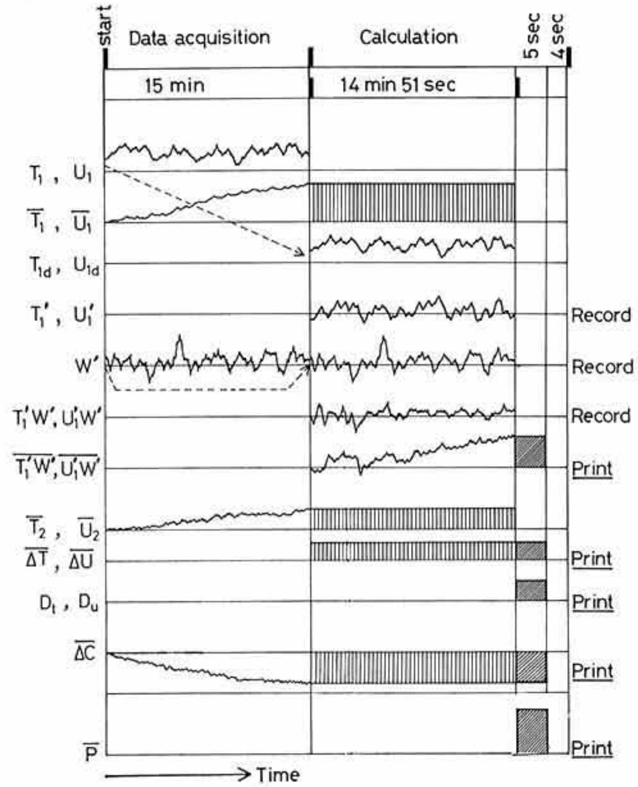


Fig. 5. Schematic example of data acquisition and calculations in the Assimitron.

sensors to an analogue computer specially designed for this purpose. Computed results are digitally typed out through the A-D converter. First 15 minutes of each period of 30 min. are for the data acquisition and the remainder is for data reduction and typewriter output. The following quantities are typed out:

(1) Start time of data acquisition; (2) Momentum flux or sensible heat flux; (3) Windspeed difference or temperature difference; (4) Exchange velocity; (5) CO_2 concentration difference and (6) CO_2 flux.

In addition, instantaneous values of the following quantities can be recorded with values of momentum or sensible heat flux and (4) Instantaneous values of the difference in CO_2 concentration between two levels.

Since the exchange velocity is determined with the Assimitron, the water vapor flux can be easily determined by simultaneous measurement of the humidity difference with an appropriate humidity sensor. Fig. 5 schematically shows the time processes of the data acquisition and calculations in the Assimitron.

Conclusion

To avoid laborious work of the data analysis and to improve the accuracy of the results, the Assimitron is designed and constructed on the basis of the correlation and the gradient methods. This instrument gives on-line the 15-min. mean CO_2 flux, approximately corresponding to the assimilation or respiration of crop plants.

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