

**Chapter 4 : Principles of eddy correlation technique and radiation
budget at the surface.**

4.1 : Principle of eddy correlation (EC).

The eddy correlation method was first demonstrated by Swinbank (1951) and is used by workers such as Dyer (1961) and others . The average vertical transfer of water vapor, LE (in latent heat units) and sensible heat, H across a unit area of a horizontal plane was shown by Swinbank (1951) and Priestly (1959) to be :

$$LE = L \overline{(\rho w)'q'} \text{ ----- (4.1)}$$

$$H = C_p \overline{(\rho w)'T'} \text{ ----- (4.2)}$$

Where the primes indicate deviation about the time average and the bar denotes an average over the period of observation. LE can be converted to water vapour flux by dividing it with L and then to a conventional evaporation rate by dividing it with the density of water.

The turbulent fluxes can be measured directly by correlating fluctuations of vertical windspeed, w with fluctuation of the transported scalar. Each component in the equation can be partitioned into a mean value plus the instantaneous deviation from the mean. The deviations of air density, latent heat of vaporization and also the long term mean vertical wind velocity over a flat, uniform surface can be assumed to be zero (Dyer, 1961; Kizer et al, 1988). Applying these assumptions and rules of statistical averaging for period longer than a few seconds equation 4.1 becomes :

$$\overline{LE} = \rho L \overline{w'q'} \text{ ----- (4.3)}$$

where, $\overline{w'q'}$ is the covariance of vertical wind and specific humidity (g.m/g.s). Thus, over a level uniform surface the vertical flux of latent heat is entirely due to eddy transport, with no contribution from mean vertical flow.

The eddy correlation can be applied to the vertical fluxes of other atmospheric entities as well. Following the same procedure as for latent heat flux, the mean sensible heat flux can be calculated as:

$$\overline{H} = \rho C_p \overline{w'T'} \text{ ----- (4.4)}$$

where, H = Mean sensible heat flux (W/m^2)

$\overline{C_p}$ = specific heat of air (J/Kg/K)

$\overline{w'T'}$ = covariance of vertical wind and temperature

Fine wire thermocouples are normally used for fast-response temperature measurement. The upper frequency dictates the response of the sensors and the lower frequency is the averaging time needed to include the longer periods. This atmospheric frequencies is a function of mean horizontal wind speed u , measurement height, z and atmospheric stability. A reasonable averaging periods is between 10 to 20 minutes and 10 Hz response when working within a few meters of the surface (Tanner, 1988).

The instrument used in this study is the CA27 Sonic Anemometer, 127 Fine wire Thermocouple and KH20 Krypton Hygrometer to calculate sensible heat and latent heat flux. The Campbell Scientific Inc., 1992 typically uses a 5 Hz measurement rate, a 10 minute output sub-interval averaging period and a 30 minute output interval. These frequencies is high enough to provide a statistically valid number of samples over the flux averaging period. The performance of the eddy correlation system can be tested by comparing the measured outgoing fluxes of latent heat and sensible heat with the incoming net radiation, as had been done by researchers such as Dyer (1961), Taichi Maki (1991), Tanner (1988), Amiro and Wuschke (1987).

Micrometeorologists have long held that the eddy correlation techniques offer the most promising method for providing accurate measurements of evaporative flux with a sound theoretical basis (Kaimal 1975, Kizer et. al 1988). This method measures the rate of water use by a crop through measurements made in the air above the crop surface. The difference between bare and vegetation covered ground surface is the water content. Plant absorb large volumes of water through their roots and return it again to the atmosphere by transpiration. The transpiration ratio expresses the number of gram(or liters) of water a plant must use in order to produce 1 g(or kg) of dry substance(Geiger, 1966). This quantity depends on the type of plant, radiation and availability of water in the soil.

4.2 Radiation budget method.

Generally in the treatment of energy balance the thickness of the atmosphere is considered as a plane rather than a layer and hence, storage is neglected. The surface heat budget in this case is given as;

$$- Q_N = Q_H + Q_E - Q_G \text{ ----- (4.5)}$$

where ,

Q_N represent net upward radiation at the surface

Q_H represents the upward sensible heat out of the top

Q_E represents the latent heat flux out of the top

Q_G represents the upward molecular heat flux into the bottom

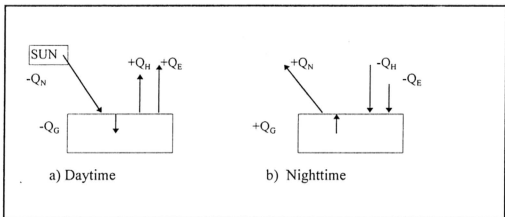


Figure 4.2(a) : The surface energy balance overland
(after Stull, 1991)

According to figure 4.2(a), assuming no storage of energy, there is more downward radiation entering the layer than that leaving upward during sunny days overland, resulting in positive values of $-Q_N$. In the case of Q_H and Q_E , these are also positive because of heat and moisture transport upward away from the surface. $-Q_G$ is positive when heat is conducted downward into the ground from the warm surface.

At night overland, $-Q_N$ is often negative because of the net upward longwave radiative cooling to space. Q_H and Q_E are also negative through the conduction of heat from the warm ground up to the cooler surface. While $-Q_G$ is negative due to the net upward transport of the ground heat flux to the surface.

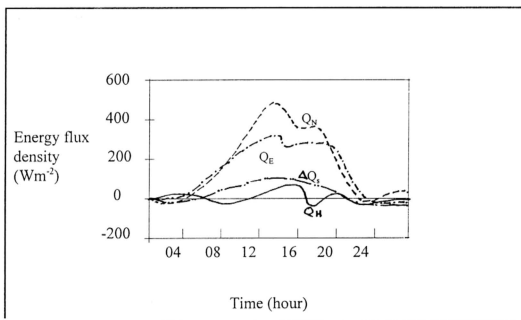


Figure 4.2(b) : Energy balance components over a barley field at Rothamsted, England (after Long et.al., 1964, Monteith et al,1965 and Oke,1978)

The general equation for energy balance which is applicable at any instant in time is given as (Munn,1966);

$$Q_T - Q_R + Q_L = \pm Q_N = Q_G + Q_H + Q_E \text{ ----- (4.6)}$$

where,

Q_T = Short-wave radiation from sun and sky(global radiation),

a downward flux is positive(It is absent at night)

Q_R = Short-wave radiation reflected from the earth also absent at night

Q_L = Longwave radiation emitted by the surface

In general the radiation terms can be measured directly with a particular radiation sensors and with greater accuracy than any component on the right hand side of the equation. Q_G too over land surface can be measure with less accuracy. However in the case of Q_H and Q_E , there are many experimental and theoretical difficulties in calculating their values.

Q_N is positive in the daytime since Q_T is the largest due to the reception of solar energy from the sun. At nighttime Q_N is negative due to terrestrial radiation(Q_L) emitted from the earth surface.

The expression "energy balance" does not imply that individual components in above equation are necessarily constant with time in a steady state condition where there is no appreciable change in the mean temperature at the surface.

Examination of the components of the energy balance equation during the daytime,

$$Q_N = Q_G + Q_H + Q_E \text{ ----- (4.7)}$$

where Q_E is related to the water loss by the equation;

$$Q_E = LE \text{ ----- (4.8)}$$

One can see the partitioning of the energy with Q_G downward flux of heat into the soil, Q_H upward heat flux into the atmosphere with the remainder going into Q_E i.e cooling. The term Q_G and Q_H are real flows of heat while the Q_E takes place only at the surface.

Even though there is a resultant upward flow of water vapor, the heat exchange is felt through a compensating reduction in the magnitude of Q_G and Q_H . At night there is a net loss of radiation by the surface (negative Q_N). This is balanced by heat flows upward through the ground.

Conclusion

As can be seen, both eddy correlation method and energy balance equation are convenient ways of measuring a land surface evaporation and fulfill a basic need of parameterisation the vertical transport of heat and moisture to the atmosphere. In the case of the energy balance equation however the effects of surface roughness is not explicitly represented as in the EC case.

According to the two methods above, evaporation, LE which can be measured directly with the EC technique should be nearly equal to that obtained from the energy balance equation estimate ie; $LE = R_n - H - G$.