GEOG 321 - Reading Package Lecture 9

MEASUREMENT OF RADIATIVE FLUXES

The principal instruments used to measure component fluxes of the radiation budget are listed in Table 1. They represent a range of instrumental configurations, but most modern designs are united by the use of a multi-junction thermopile as the method of transducing the radiation flux into a thermal response, and thence into a voltage signal suitable for electronic monitoring. The receiving surface of the thermopile is often covered by a dome of glass, quartz, polyethylene, etc. which acts as: a protection from weather damage; a spectral filter to distinguish short-from long-wave radiation fluxes; and a means of standardizing convective heat exchange at the thermopile surface so as to reduce the effects of wind speed to the energy balance of the instrument.

Short-wave radiation. Figure 1 shows a typical *pyranometer* used to measure incoming short-wave radiation on a horizontal surface (irradiance, $K_\downarrow$). The thermopile is covered by double glass domes whose radiative properties are such as to only allow radiation in the band from 0.3 to $3.0\,\mu\mathrm{m}$ to pass through to the receiving surface. In this example the receiving surface is painted with a special optical black paint so that it has a very high absorptivity. Half of the thermo-junctions are attached to thin strips whose temperature fluctuates rapidly as $K_\downarrow$ varies, the others are attached to the body of the instrument whose temperature varies slowly.

Figure 1: Pyranometer


Figure 2: Diffusometer

The difference can be related to the short-wave receipt. In another design the junctions are alternately in contact with white- and black-painted surfaces.

An inverted pyranometer senses the short-wave radiation reflected from the underlying surface (reflectance $K_\uparrow$). Therefore the surface albedo (α) can be obtained as $\alpha = K_\uparrow / K_\downarrow$.

A pyranometer can become a *diffusometer* by adding a shade ring set at an angle to obscure the sensing surface from direct-beam radiation at all times (Figure 2). The instrument therefore measures only diffuse short-wave radiation (after correction has been made for the amount of diffuse-radiation cut out by the ring itself). If $K_\downarrow$ from an unshaded pyranometer is available at the same time, then the direct-beam radiation (S) can be obtained by difference from $S = K_\downarrow - D$. Alternatively S can be gained from a *pyrheliometer* which focuses only upon the solar disc and measures S at normal incidence to the beam. To convert this value to that for a horizontal surface resort must be made to the cosine law of illumination.

In vegetation canopies where radiation fluxes vary spatially, a single, fixed pyranometer of the usual pattern is insufficient. Sampling can be improved either by moving the instrument along a trackway, or by constructing an instrument with a long tubular thermopile.

Table 1: Radiometer Terminology

Instrument	Definition
Radiometer	Instrument measuring radiation.
Pyrradiometer	Measures total radiation from the solid angle 2π incident on a plane surface ($Q\downarrow$ or $Q\uparrow$).
Pyranometer (solarimeter)	Measures short-wave radiation from the solid angle 2π incident on a plane surface ($K\downarrow$ or $K\uparrow$).
Net pyranometer	Measures net short-wave radiation (K^*).
Pyrheliometer	Measures direct-beam short-wave radiation at normal incidence (i.e. S_i, see equation 1.9, p. 13).
Diffusometer	Pyranometer and shade device used to measure diffuse short-wave radiation (D).
Pyrgeometer	Measures long-wave radiation on a horizontal blackened surface at the ambient air temperature ($L\downarrow$ or $L\uparrow$).
Net pyrradiometer	Measures net all-wave radiation from above and below (Q^*).

All-wave radiation. The receiving surface of a *net pyrradiometer* is a blackened plate across which there is a thermopile with one set of junctions in contact with the upper face and the other set attached to the lower face. With the plate aligned parallel to the surface the thermopile output is related to the temperature difference across the plate, and this is proportional to the difference between the total incoming ($Q_\downarrow = K_\downarrow + L_\downarrow$), and outgoing ($Q_\uparrow = K_\uparrow + L_\uparrow$) radiation fluxes at all wavelengths ($Q^* = Q_\downarrow - Q_\uparrow$). However, the temperature difference is really an expression of the difference in the energy balances of the two faces and these are affected by convective as well as radiative exchanges. To overcome the effects of wind differences on the two faces the plate is either forcefully ventilated at a constant rate, and/or protected by a hemispheric dome of polyethylene. This material is chosen because it is virtually transparent to radiation with wavelengths in the range of 0.3 to $100\,\mu$m. There are a few absorption bands in the infra-red but these can be allowed for in calibration.

Long-wave radiation. A net pyrradiometer can be used to estimate the net long-wave radiation. At night a net pyrradiometer becomes a *net pyrgeometer*, i.e. it measures L^*. By day, if K^* is measured separately by pyranometers, it can also be used to obtain L^* by difference. In a *pyrgeometer*, the glass dome of a pyranometer is replaced by a hemisphere of KRS-5 (silicon). It is coated with an interference filter which only allows transmission of radiation at wavelengths greater than 3μm. The key problem is to separate the required flux of incoming infra-red radiation from that emitted by the detector iteself. The design attempts to do this by an electronic compensation circuit involving a thermistor-battery-resistor network.

Another approach towards measuring $L_\downarrow$ or $L_\uparrow$ is to modify a net pyrradiometer by removing the polythene dome from one face and replacing it with a black body cavity. The cavity consists of an aluminium dome whose interior is coated with optical black paint, and whose interior temperature (T_{cav}) is sensed by means of a thermocouple. Thus with a cavity on the lower surface, by day the instrument output is due to the difference between $Q_\downarrow$ on the upper face, and the black body output of the cavity interior (σT_{cav}^4) on the lower face, i.e.:

$$\text{Instrument output} = Q_\downarrow - \sigma T_{\text{cav}}^4 \qquad (2.1)$$

which allows to solve for $Q_\downarrow$.

If $K_\downarrow$ is available at the same time from a pyranometer then the incoming long-wave radiation from the atmosphere ($L_\downarrow$) can be obtained by difference (i.e. $L_\downarrow = Q_\downarrow - K_\downarrow$). Further, if $K_\uparrow$ from an inverted pyranometer and Q^* from a net pyrradiometer are also available, the radiation budget can be solved for the outgoing long-wave radiation from the surface ($L_\uparrow$), i.e.:

$$L_\uparrow = K_\downarrow - L_\uparrow + L_\downarrow - Q^* \qquad (2.2)$$

At night when $Q_\downarrow$=$L_\downarrow$ all of the long-wave terms can be obtained using two net pyrradiometers, one of which is equipped with a cavity.

Surface temperatures. The surface temperatures of leaves or the ground are difficult to measure. Very fine-wire electrical thermometers can be attached to leaves or appressed to the ground, but even using a large number may not give an adequate spatial sample. Probably the best approach is to sense the surface temperature remotely using the Stefan Boltzmann law. An *infrared thermometer* (IRT) measures longwave radiation limited to the $8 - 14\,\mu\mathrm{m}$ waveband (i.e. in the atmospheric window) emitted by surfaces placed in its field-of-view. The radiation 'seen' by the instrument is that emitted by the surface ($L_{\uparrow} = \varepsilon_0 \sigma T_0^4$) plus any radiation in the same waveband from the sky which is reflected ($L_{\downarrow}(1-\varepsilon)$). Since most natural surfaces are close to full radiators in this waveband ($\varepsilon \approx 1.0$) the reflected term can often be ignored, and the apparent surface radiative temperature (T_k) can be equated with the true surface temperature (T_0) so that:

$$T_0 \approx T_k = (L_{\uparrow}/\sigma)^{1/4} \tag{2.3}$$

The approach is very helpful because no contact with the surface is involved, and the radiation 'seen' is an integration of that emitted from an area. The effect of neglecting the variation of emissivities is of the order of 1-3K for most natural surfaces.