Appendix 2.2

Net radiation model implementations

Background and methods

In general, net radiation is calculated as:

$$R_n = (1-\alpha) * S_i + L_i - L_o \tag{1.1}$$

Where

α = albedo, for reference grass conditions, α = 0.23.

S_i= Global shortwave radiation [W m^{-2}]

L_i= Incoming longwave radiation [W m^{-2}]

L_o = outgoing longwave radiation [W m^{-2}]

Outgoing longwave radiation is calculated as

$$L_o = \varepsilon_v \sigma T_a^4 \tag{1.2}$$

where

ε_v = the surface emissivity, in Daisy generally assumed to be 0.98. The value is hard coded except in the SSOC-module where the default values for leaves and soil are 0.98 and 0.95, respectively.

σ = Stefan-Boltzmann Constant 5.67 * 10^{-8} [W m^{-2}K^{-4}]

T_a = air temperature [K]

Incoming longwave radiation is outgoing longwave radiation, reflected back by the atmosphere, in particular clouds and vapour. For this reason, net longwave radiation is often calculated directly, as a function of the fraction of the sky which is clear.

The net outgoing longwave radiation L_n equals L_o - L_i.

The code combines six methods to estimate Long-wave clear sky irradiance (L_{io}). The implementation builds on Kjaersgaard et al. (2007b) and Allen et al. (1998).

Net Longwave radiation is calculated as:

$$L_n = f_c(\varepsilon_v - \varepsilon_a)\sigma T_a^4 \tag{1.3}$$

f_c = adjustment for cloud cover (Cloudiness factor),

ε_a = the effective emissivity of the atmosphere. See options for calculation below.

ε_v = the emissivity of vegetation (0.99 - 0.94) and soil (range 0.98 - 0.80), a fixed value of 0.98 is used by Daisy.

σ = the Stefan-Boltzmann constant (5.67 10^{-8} [W m^{-2} K^{-4}]),

T_a = mean air temperature [K].

ε_a may be calculated according to

(Brunt, 1932) with FAO-parameterisation (Allen et al., 1998):

$$\varepsilon_a = A + B\sqrt{e_a} \tag{1.4}$$

Where e_a is vapour pressure in hPa, and A and B are 0.64 [] and 0.044 $hPa^{-1/2}$ (or 0.14 if e_a is specified in kPa), respectively. Introduction in eq. (1.3) results in the well-known Brunt expression used in (Allen et al., 1998).

$$L_n = f_c\left(0.98 - (0.64 - 0.14\sqrt{e_a})\right)\sigma T_a^4 = f_c\left(0.34 - 0.14\sqrt{e_a}\right)\sigma T_a^4 \tag{1.5}$$

(Swinbank, 1963)

$$\varepsilon_a = 9.2 \cdot 10^{-6} T_a^2 \tag{1.6}$$

(Idso and Jackson, 1969)

$$\varepsilon_a = \left(1 - 0.261 \cdot \exp\left(7.77 \cdot 10^{-4}\left(273 - T_a\right)^2\right)\right) \tag{1.7}$$

(Brutsaert, 1975)

$$\varepsilon_a = 1.24\left(\frac{e_a}{T_a}\right)^{1/7} \tag{1.8}$$

Where e_a is in hPa.

(Satterlund, 1979)

$$\varepsilon_0 = 1.08\left(1 - \exp\left(-e_a^{T_a/2016}\right)\right) \tag{1.9}$$

(Prata, 1996)

$$\varepsilon_a = 1 - (1 + w)\exp\left(-(1.2 + 3.0w)^{0.5}\right)$$
$$w = 46.5\left(\frac{e_a}{T_a}\right) \tag{1.10}$$

Where e_a is in hPa.

It should be noted that the expression of cloudiness appears different in the two publications. Kjaersgaard et al. (2007b) calculates total outgoing longwave blackbody radiation and incoming radiation is then 100% reflection from cloudy sky-fraction and long-wave clear sky irradiance from the clear sky fraction. Allen et al.(1998) considers net radiation, and as the net radiation in the cloudy sky-fraction is 0, the calculation only concerns the clear sky fraction.

Options for calculating the cloudiness factor, f_c, is described in Chapter 2 (2.4.1)

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