Appendix II

Insolation

Light limitation of new production is parameterized in a similar manner to *Bacastow and Maier-Reimer* [1990], based on a normalized incident light factor, calculated from estimated solar elevation summed over each day [*Holtslag and van Ulden*, 1983]. However, no account is taken of the reduction of radiation incident at the ocean surface with increasing solar elevation due to reflectance at the air-sea interface.

Incoming solar radiation at the ocean surface assuming clear sky conditions, is given by

$$K = a_1 \cdot \sin\phi + a_2 \qquad \text{(II-1)}$$

where ϕ is the solar elevation, and a_1 and a_2 are empirical coefficients, taking values of 1041 and -69 W m^{-2}, respectively [*Holtslag and van Ulden*, 1983]. Solar elevation follows *Holtslag and van Ulden* [1983];

$$\sin\phi = \sin\delta \cdot \sin\psi + \cos\delta \cdot \cos\psi \cdot \cos h \qquad \text{(II-2)}$$

where is ψ the latitude of the location (radians), δ the solar declination

$$\delta = \arcsin(0.398 \cdot \sin(SL)) \qquad \text{(II-3)}$$

where SL is the the solar longitude

$$SL = 4.871 + 0.0175 \cdot d + 0.033 \cdot \sin(0.0175 \cdot d) \qquad \text{(II-4)}$$

with d, is the day number. Finally, h, the hour angle is described by

$$h = -\lambda_w + 0.043 \cdot \sin(2 \cdot SL) - 0.033 \cdot \sin(0.0175 \cdot d) + 0.262 \cdot t - \pi \qquad \text{(II-5)}$$

where λ_w is the western longitude (radians) of the location and t is the universal time (hours).

For each time step in the biological scheme (Δt), the reduction in new production due to sub-optimal insolation is calculated by

$$I_{t,lat} = \sum_{t-\Delta t/2}^{t+\Delta t/2} H(K_{t,lat}) \qquad \text{(II-6)}$$

where the mean hourly insolation is summed over the length of the new production time step at the mean latitude of each grid point, and H is the Heavyside function. I is then normalized to a value of unity at the time and location of maximum calculated insolation on Earth to give $\mu_{(I)}$. No account is taken of past variations in the Earth's orbital parameters.