Notes and Correspondence

COMMENTS ON THE PAPER "THE STEADY-STATE FORMAT OF GLOBAL CLIMATE"
by G. W. PALTRIDGE (Q.J., 104, 927–946)

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Paltridge (1978) has obtained realistic distributions of surface temperature, fractional cloud cover, together with atmospheric and oceanic heat fluxes from the hypothesis that the preferred steady-state climate is one of maximum entropy production. In his model Paltridge combines the total energy balance and the oceanic energy balance of a zone with the additional assumption that the cloud cover (θ) and surface temperature (T) of the zone are such as to maximize the vertical heat flux (H') from the surface of the zone. This note demonstrates that, as this further assumption cannot be applied in the vicinity of the poles, the model will eventually fail if the latitudinal resolution is increased. The alternative assumptions used in Paltridge (1975) are not affected by the following argument.

In order to simplify the calculation the total energy balance of a zone is written:

$$A + B\theta + (C + D\theta)T^4 + \Delta = 0$$

(1)

where: $$A = R_0(1 - g)/\xi$$, $$B = R_0(g - d)/\xi$$, $$C = -\sigma(e + G)$$, $$D = \sigma(e + G - f\epsilon)$$, and $$\Delta = \Delta X_s + \Delta X_o$$ (in Paltridge's notation). $$R_0$$ is the solar constant, $$g$$ is the planetary albedo of the cloud-free portions of the globe, $$d$$ is the planetary albedo of those portions which are cloud covered, $$\epsilon$$ is the ratio of the actual surface area to the projected area as seen by the sun, $$\sigma$$ is the Stefan-Boltzmann constant, $$e$$ is a fraction related to the width of the window region of the black-body spectrum, $$G$$ is a fraction specifying the long-wave loss of the cloud-free atmosphere to space as a function of surface black-body emission, $$f$$ is the fraction by which the black-body radiation from clouds is reduced below surface black-body emission by reason of their lower temperature, and $$\epsilon'$$ is a constant related to the width of the window region of the infrared spectrum above the bulk of the atmospheric water vapour. $$\Delta X_s$$ and $$\Delta X_o$$ are, respectively, the convergences of atmospheric and oceanic energy flow.

Similarly, the oceanic energy balance of a zone is written:

$$A' + B\theta + (C' + D'\theta)T^4 - H' + \Delta X_o = 0$$

(2)

where: $$A' = R_0(1 - g - m)/\xi$$, $$C' = -ae$$ and $$D' = af\epsilon$$, $$a$$ is the extra short-wave absorption attributable to liquid water in clouds and $$m$$ is the absorption by water vapour in the atmosphere. In Paltridge's paper $$g$$ and $$d$$ assume different values in Eq. (2) from those in Eq. (1). Paltridge's Eqs. (8) and (9) contain errors ("d' + a" in Eq. (8) should be "d'", and "d'" in Eq. (9) should be "d' + a", Paltridge, personal communication) which have been corrected in Eq. (2).

Eliminating $$T^4$$ between Eqs. (1) and (2) produces an equation relating $$H'$$ and $$\theta$$, and imposing the condition of maximum vertical heat flux from the surface by equating $$\partial H'/\partial \theta$$ to zero leads to:

$$B(C + D\theta)^2 - (C + D\theta)(D'(A + B\theta + \Delta) + B(C' + D'\theta)) +$$

$$(C' + D'\theta)(A + B\theta + \Delta)D = 0$$

(3)

Equation (3) shows, as discussed by Paltridge, that $$\theta$$ (and hence $$T$$) depends only on the sum ($$\Delta$$) of $$\Delta X_s$$ and $$\Delta X_o$$, and not on their ratio. If Eq. (1) is now used to eliminate the total heat convergence, $$\Delta$$, from Eq. (3) then, unless $$C + D\theta = 0$$ (implying from Eq. (1) there is no net long-wave flux to space) which for Paltridge's parameter values requires $$\theta > 1$$, the fractional cloud cover $$\theta$$ satisfies the equation:

$$\theta = \{BC - BR\} \cdot \{BD' - BD\}$$

(4)

However, as the poles are approached the ratio $$\xi$$ of the actual area to the projected area seen by the sun diverges and so (from its definition) $$B$$ tends to zero, while $$T$$ (K) and (for Paltridge's
parameter values) $C$, $C'$, $D$ and $D'$ remain non-zero. Therefore, it follows from Eq. (4) that $\theta$ will diverge at the poles and pass outside the physical domain (0 to 1) at polar latitudes, a result that cannot be avoided by increasing the accuracy to which $\xi$ is estimated. Paltridge’s calculations did not extend beyond 64°N and 64°S, and so did not meet this limitation. Hence, the assumption of maximum vertical heat flux cannot be applied in the polar regions, for to retain it would require that $(D'C - C'D) \to 0$ at the poles which would involve additional assumptions about high latitude atmospheric radiation processes. The assumption is also inapplicable if $(g - d)$ is small.

Reference


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Johns and Anwar Ali (JA) have presented a detailed numerical simulation of storm surges generated by tropical cyclones in the Bay of Bengal, an area which history has shown to be particularly sensitive to such events. However, JA’s surge analyses may be to a substantial degree negated by incorrect interpretations of the pressure (and hence wind) distribution in their idealized cyclone.

JA use a pressure distribution given by (their equation 23)

$$p = p_a - \Delta p \exp(-r/R)$$

(1)

where $p$ is pressure at radius $r$, $p_a$ the ambient pressure, $\Delta p$ the difference between the ambient and central pressures and $R$ is a constant. JA describe $R$ as the c-folding radius of the cyclone (strictly of the pressure distribution) which they seem to incorrectly interpret as being 350 km. As shown below, $R$ is better described as the radius to maximum winds (RMW).

Since typical Rossby numbers for tropical cyclones are of order $10^2$, especially in the strongest wind region, we may assume that the tangential winds are in approximate cyclostrophic balance and hence

$$V_c = \left(\frac{2 \Delta p}{\partial p/\partial r}\right)^{\frac{1}{2}}$$

(2)

where $V_c$ is the cyclostrophic tangential wind and $\rho$ the air density. After substituting (1) for $p$ we have:

$$V_c = \left(\frac{r \Delta p \exp(-r/R) \rho R}{\partial p/\partial r}\right)^{\frac{1}{2}}$$

(3)

The characteristic shape of this curve is a rapid increase in winds with radius from the origin to a single maximum followed by a gradual decrease and tangential approach to zero at infinite radius.

We can therefore determine the RMW by differentiating (3) with respect to radius and setting the result equal to zero.

$$\frac{\partial V_c}{\partial r} = \left(\frac{r \Delta p \exp(-r/R) \rho R}{\partial p/\partial r}\right)^{\frac{1}{2}} (1 - r/R) \Delta p \exp(-r/R) \rho R.$$  

(4)

The non-trivial solution is at $r = R$, hence $R$ is the RMW.

A typical RMW is 35 km with variations from 5 to 80 km possible (Shea and Gray 1973). Hence, for a typical cyclone JA’s use of $R = 350$ km is wrong by an order of magnitude. To illust-

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