the tropics cool substantially". This is a consequence of the albedo contrast between land and water varying with latitude.

The physical situation is more complicated than Cogley suggests and it is possible that many mechanisms operate which can induce glaciation. Tarling reported an analysis of ice ages which suggested that a continental block is needed in polar areas[2], especially in the Southern Hemisphere. Nevertheless, a near-polar position is insufficient to induce glaciation[3], a point with which Cogley concurs. But his argument depends on variations in albedo contrast. Tarling maintains that adjacent seas are necessary to provide moisture for precipitation. In such conditions the mid-latitudes become sensitive to comparatively small changes in radiation such as those caused by variations in the Earth's orbit and the tilt of its axis[2]. However, contemporary theories of glaciation involve galactic mechanisms[4–6] only insofar as they influence the intensity of solar radiation. In what way can the reduction of solar radiation due to the Solar System passing through a dense galactic cloud (which has been shown to be related to the occurrence of ice epochs[4]) "modulate known tectonic mechanisms" here on Earth?

The distribution of the continents is evidently important. Oceanic current flow, cloud cover and atmospheric circulation, which ultimately determine the amount of heat absorbed, are all affected by continental drift. In the late Cenozoic era, Australia and Antarctica drifted apart, commencing around 55 Myr BP[3]. Circum-Antarctic oceanic circulation increased as the continental barrier was gradually removed with deep water flow occurring after the South Tasman Rise had subsided around 38 Myr BP[3]. After this time an increase in the extent of pack ice occurred with a profound effect on the Southern Ocean[3] and on polar albedo. Kennett also reports that equatorial oceanic circulation diminished during the Cenozoic because of the destruction of the Tethian Seaway and, slightly later, the blocking of the Indonesian Seaway.

On what grounds does Cogley assume that sea level has remained constant between 240 Myr and 0 Myr? Eustatic changes of up to several hundred metres have been proposed[7–9]. A quantitative assessment of changes of land area with latitude and with time cannot be made from maps of palaeocontinents delimited only by the present day shoreline[10]. For example, land areas on the North American continent in the late Cretaceous were at least 50% less than at present[9], a fact that cannot be derived from palaeocontinental maps which do not show any variation of coastline with time. Using Cogley's own formula (equation 1) the change in land area of North America alone would produce an increase in the average global absorbed radiation (about 1 W m^{-2}) which is significantly greater than the variations he proposes through continental drift. Cogley states that the Mesozoic was warm, yet he presents a diagram of average global absorbed radiation over 240 Myr with a minimum (implying coolness) during the Mesozoic. If land area changes are taken into consideration, there should have been an increase in absorbed radiation.

Cogley should have considered the effect of clouds in more detail. Cloud plays a very important part in the global radiation balance[11] and determines the atmospheric transparency term in his equation 1. He has argued a dynamic model of glaciation from static components: from a snow-free world with contemporary cloud cover, from a world without changes of sea level and without pack ice. Albedo contrast may well play a part in initiating glaciation but the evidence cited does not support Cogley's thesis.

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1. Cogley, J. G. *Nature* **279**, 712–713 (1979).
2. Tarling, D. H. in *Climatic Change* (ed. Gribbin, J.) 3–24 (Cambridge University Press, 1978).
3. Kennett, J. P. *J. geophys. Res.* **82**, 3843–3860 (1977).
4. McCrea, W. H. *Nature* **255**, 607–609 (1975).
5. Mason, B. J. *Q. Jl R. met. Soc.* **102**, 473–498 (1976).
6. Hays, J. D., Imbrie, J. & Shackleton, N. J. *Science* **194**, 1121–1132 (1976).
7. Southam, J. R. & Hay, W. W. *J. geophys. Res.* **82**, 3825–3842 (1977).
8. Donovan, D. T. & Jones, E. J. W. *J. Geol. Soc. Lond.* **136**, 187–192 (1979).
9. Hancock, J. M. & Kauffman, E. G. *J. Geol. Soc. Lond.* **136**, 175–186 (1979).
10. Smith, A. G. & Briden, J. C. *Mesozoic and Cenozoic Palaeocontinental Maps* (Cambridge University Press, 1977).
11. Henderson-Sellers, A. *Nature* **279**, 786–788 (1979).

COGLEY REPLIES—I take Reynolds' most important point, that my model is simple while the world is complicated. I do not claim that the model is a comprehensive theory of glaciation; I say merely that physical reasoning leads us to expect a palaeoclimatic signal due to albedo contrast, and that if we could find it this signal would deepen our understanding of glaciation. Reynolds is entitled to reject my interpretation of Fig. 1*c* of my letter. He seems to have no quarrel with the concept of albedo contrast, but to claim instead that the signal is likely to be swamped by other effects. This would not surprise me in the least, and I look forward to accurate estimates of these effects.

Many palaeogeographic effects are consistent with my model. A tropical clustering of landmasses surely suggests reduced tropical, and enhanced higher-latitude, meridional circulation in the oceans[1]. Kennett's evidence for sea ice, found in Southern Ocean sediments after 38 Myr BP, is not in conflict with what I deduced from the concept of albedo contrast. Note that I made no attempt to model the transition to glacial conditions; by design, my radiative calculations were for a snow-free world without pack ice, a state of affairs for which the apparently almost complete absence of glaciogenic rocks in the Mesozoic[2,3] provides circumstantial evidence.

I am unable to comment further on galactic mechanisms; my use of the verb 'modulate' was unthinking.

I assumed constant sea level because I wished to proceed from the simple to the complex. Maps of ancient shorelines carry uncertainties of their own[4], and the only global set[5] is 30 years old; although it was carefully compiled, it needs updating. One should be clear as to how continental flooding bears on my model. To nullify the concept of albedo contrast, flooding would have to be strongly biased towards either high or low latitudes, but such a bias is not seen. I fully agree that flooding may be important in its own right, and will affect my numerical results; I have indeed repeated the procedures of my letter for a series of equal-area maps based on the Termier and Termier set[5], but I am not yet able to discuss these results.

I agree also that clouds deserve thoughtful attention, but I emphasise again that my extremely simple model remains physically sound. I suggest that the time is ripe for modelling Phanerozoic climates at finer scales of resolution, and in increasing detail. However, I would caution that efforts at improving accuracy[6] should keep pace with speculative insight.

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1. Kennett, J. P. *J. geophys. Res.* **82**, 3843–3860 (1977).
2. Dalland, A. *Årbok 1976*, 151–165 (Norsk Polarinstitutt, Oslo, 1977).
3. Mikhaylov, Yu. A. *et al. Dokl. Akad. Nauk S.S.S.R.* **190**, 100–102 (1970).
4. Wise, D. U. in *The Geology of Continental Margins through Time* (eds Burk, C. A. & Drake, C. L.) 45–58 (Springer, New York, 1974).
5. Termier, H. & Termier, G. *Histoire Géologique de la Biosphère* (Masson, Paris, 1952).
6. Cogley, J. G. *Mon. Weath. Rev.* **107**, 775–781 (1979).

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