Comment on 'Sea-ice and the antarctic winter circulation: A numerical experiment' by J. F. B. Mitchell and T. S. Hills (October 1986, 112, 953–969)

By IAN SIMMONDS and MARTIN DIX

Department of Meteorology, University of Melbourne, Parkville, 3052, Australia

(Received 3 December 1986)

Mitchell and Hills (MH) present some interesting model results on the effect of sea-ice anomalies in the southern hemisphere (SH). They compared the response of their model with that obtained by one of us in an earlier similar experiment (Simmonds 1981 (S)). Since this latter paper was published we have carried out further experiments to clarify the response shown in that study, particularly with respect to the changes induced in the mean sea level pressure (m.s.l.p.). Some of the results obtained bear on the analysis of MH. The spectral model used in the present experiment (15 wave truncation, 9 level, primitive equations) spans the global domain and has many improvements over the version used in S, the most relevant here being the incorporation of a Monin–Obukhov surface layer parametrization. (The performance of the model in a simulation of January climate may be assessed from the results shown in Simmonds (1985).) For the experiment reported here the control model was run in July mode with the SH sea-ice distribution shown in Fig. 1.

This July integration was initialized with data generated by an earlier version of the model, allowed to settle down for 60 days and then the subsequent 600 days averaged and taken as the estimate of the model climate. This produced a credible simulation of reality, as is exemplified by the m.s.l.p. distribution over the SH, shown in Fig. 2. An anomaly experiment was run after removing all the SH sea-ice and replacing it with open water at 0°C. (Note that the sea-ice anomaly

Figure 1. Southern hemisphere July sea-ice distribution used in the control version of the model.
used here is not the same as those used by S or by MH. However, we feel that the difference in response we observe is not predominantly due to these different specifications.)

This experiment was started from the atmospheric conditions at day 125 of the control run. The first 90 days of the integration were discarded and the next 300 days averaged.

The meridional profile from the equator to the south pole, of the zonal average temperature change induced by this surface anomaly is shown in Fig. 3. Warming of up to 10 degC is observed in the vicinity of and above the region of ice removal, up to the 300 mb level. In the stratosphere a cooling extends to about 30°S. The zonal average of the zonal wind changes (Fig. 4) shows a reduction in the strength of the upper westerlies of more than 4 m s\(^{-1}\), in the vicinity of the northern edge of the sea-ice in the control simulation. Negative anomalies extend through most of the atmosphere between 45 and 70°S, and have a magnitude of about 1 m s\(^{-1}\) at the surface. There is a belt of positive anomalies to the north of this.

All the changes mentioned above are significant at the 95% level. They are similar in structure to, but perhaps greater in magnitude than, the responses displayed in MH and S. A noteworthy difference between the results of MH and the present experiment is that MH found a shallow belt of westerly anomaly winds around 60°S whereas we simulate easterly anomalies at all levels. This is related to the changes in the m.s.l.p.

The changes in m.s.l.p. over the SH caused by the removal of the sea-ice are shown in Fig. 5. The response is not dissimilar to that presented in S, although direct comparison is difficult as a hemispheric model was used in that paper. In common with the earlier experiment, at high latitudes only changes in a few small areas are significant, among which we mention the two anomalously high in the South Atlantic Ocean and the low east of New Zealand. There appears to be no consistent trend to lower pressure where sea-ice had been removed.

By contrast, MH simulated large, and for the most part significant, pressure reductions in regions of ice removal. Hence the apparent disparity between the results of MH and S, to which they draw attention, is still evident in our present results. Our experiment allows us to examine some of the reasons MH suggest for the differing responses.
Figure 3. Difference in the southern hemisphere between the zonal average temperature of the ice anomaly and control simulations. The contour interval is 0.5 degC. Negative contours are dashed and regions of differences significant at the 95% confidence level are stippled.

Firstly, the length of our present integrations precludes the possibility that our lack of consistent response is due to a small sample size. Secondly, it is not clear that our model has lower resolution, as suggested by MH. While it is somewhat difficult to compare the effective resolutions of grid-point and spectral models, practical experience has shown that the latter perform well in climate simulations. For example, Manabe et al. (1979) found, in comparing grid-point and spectral models with nearly identical physics, that "... the overall performance of the ... [15 wave] spectral model

Figure 4. As Fig. 3 but for the zonal wind. The contour interval is 1 m s⁻¹.
in simulating the large-scale sea level pressure distributions is equal to, or slightly better than, that of the . . . [250 km] grid model." We feel that the m.s.l.p. pattern generated by our model (Fig. 2) is superior to that of the 330 km grid model of MH. It is clear (e.g. Palmer 1985) that the response of models to anomalous forcing can depend strongly on their basic climatology. It is of particular importance in the present type of experiment that the high latitude surface climatology be simulated accurately.

It is not clear to us that pressure must inevitably drop over regions where sea-ice removal is associated with anomalous warming in the atmosphere. In both MH and the present experiment the thicknesses increase through the lower and middle troposphere. Thickness increases can be consistent with little or no change in surface pressure, provided they are accompanied by anomalous upper-level highs which are geostrophically balanced by anomalous momentum. Some of this momentum could diffuse downwards and result in increases in surface pressure. We notice that in MH the temperature increase over the Antarctic is similar to that over the ice removal area and yet significant pressure increases are simulated over much of east Antarctica. (Simple reasoning would suggest that the surface pressure changes would be even more significant.)

It is of use to mention some of the other model studies relevant to this topic. Of the handful of studies of the effect of ice removal in GCMs, only a few have considered the statistical significance of their results. Warshaw and Rapp (1973) found that the removal of all arctic sea-ice resulted in a pressure reduction inside the polar cap bounded by 70°N. Herman and Johnson (1978, 1979) compared the results of forcing their model with two sets of prescribed arctic sea-ice extents that differed by about 10° latitude at all oceanic longitudes. They simulated both pressure reductions and increases over the various areas where ice had been 'removed', but in the latitude belt in which most of the removed ice had resided (50–70°N), the average surface pressure significantly increased with its removal.

In many respects, ice removal experiments may be thought of as sea surface temperature anomaly (s.s.t.a.) experiments. Many studies of this latter type have been performed but only a
small number have both placed anomalies at mid to high latitudes and also statistically tested the response. Simpson and Downey (1975) concluded that the effects of s.s.t.a.s on pressure "need not be systematic, particularly in the immediate vicinity of the anomaly". Chervin et al. (1980) failed to find a significant surface pressure response above a large-scale west Pacific warm anomaly (with central value 12 degC) centred at 42.5°N. Palmer and Zhao (1985) have analysed the difference between model responses to warm and cool s.s.t.a.s centred at about 42°N in the west-central Atlantic. Their model simulated a weak, small-scale pressure reduction over a small part of the warm anomaly.

Some studies have examined the link between observed surface conditions and sea level pressure. Ratcliffe and Murray (1970) explored the relationship between monthly mean s.s.t. in a wide area south of Newfoundland and the surface pressure in the following month. In three of the 'warm' or 'cool' months, statistically significant changes in pressure were found in the vicinity of the anomaly, with warm (cool) conditions corresponding to high (low) pressure (their Figs. 5, 8 and 12). Palmer and Zhao (1985) performed a similar analysis for a longer period of data and for a synchronous analysis, and in the 60–40°W 40–50°N area found significantly higher pressures in the years with warm s.s.t.a.s. To assist in interpreting our results, we have examined the relationship between the observed zonal average m.s.l.p. at 65°S (from the Australian Bureau of Meteorology set) and the zonal mean latitude of the antarctic ice edge (from Jacka 1983 and personal communication) for 12 Julys. The results are plotted in Fig. 6 and indicate little relation between these two parameters. To cast some additional light on the observed changes in monthly mean pressure and its gradients, we correlated July monthly averaged zonally average winds at 60°S at 1000 mb with those at 500 mb, over the years 1972–84. The coefficient was 0.97 and assumed a similar value when levels other than 500 mb were used. This indicates that at this latitude (and indeed in a considerable range about it) the July monthly wind anomalies are overwhelmingly of the same sign up to the tropopause. This is the type of response we simulated at this latitude (Fig. 4) as distinct from MH who generated a shallow belt of low-level positive anomalies.

![Figure 6](image_url). Zonal average mean sea level pressure at 65°S in relation to the zonal mean of the antarctic ice edge for Julys, 1973–84.
It should be stated that in reality the surface conditions can affect the atmosphere and vice versa but in the models only the former is true. Hence the enlisting of observational studies to give credence to model results should be treated with caution. Notwithstanding this, it does appear from our result and the circumstantial evidence provided by the above studies that the nature of the local surface pressure response to surface heating at mid to high latitudes is far from obvious. This is consistent with many studies which display large responses up- and down-stream of surface anomalies at mid to high latitudes but often little locally (Egger 1977; Webster 1981). In our and MH's experiments, the ice in an entire latitude belt where the mean surface flow is quite zonal was removed. In this case the meaning of 'down-stream' is not clear.

References


Ratcliffe, R. A. S. and Murray, R. 1970 New lag associations between North Atlantic sea temperature and European pressure applied to long-range weather forecasting. ibid., 96, 226–246


Reply by J. F. B. MITCHELL and T. S. HILLS
Meteorological Office, Bracknell

We welcome the comments by Simmonds and Dix (SD) on our recent paper. It is encouraging that in both their new experiment and that reported by Simmonds (1981, S) the simulated response to the removal of most of the antarctic sea-ice is remarkably consistent with that found in our own experiment (Mitchell and Hills 1986, MH) in all but the lowest levels of the atmosphere. However, both S and SD find a predominance
of increases in sea level pressure where sea-ice is removed, whereas MH find that sea level pressure decreases. It should be noted that S shows decreases near 30°E where the latitudinal extent over which ice was removed was greatest, and SD report decreases over the Ross and Weddell Seas, again where the meridional extent of the sea-ice change is large. Thus the discrepancy in the zonal mean response tends to emphasize the difference between the results of S, SD and MH and underplay the similarities. Furthermore, the equatorward margin of the sea-ice anomalies in S and SD is generally to the south of that in MH so one would expect to see the features in the response displaced to the south relative to those in MH. As noted above, both S and SD do find areas where sea level pressure is reduced, and they are generally to the south of the zone of reduced pressure in MH. (This point is obscured by the smallness of the diagrams in S and SD.) The major discrepancy between SD and MH occurs in the south-east Antarctic near 60°S where SD find significant increases in surface pressure whereas MH find significant decreases. (Note that MH report changes in surface pressure and not mean sea level pressure as implied in SD.)

SD point out that the surface pressure trough in the control simulation of MH is weaker than observed and displaced to the north of the observed position (this is consistent with MH finding reductions in pressure to the north of those in SD). Hills (1982) demonstrated that the simulation in the model used by MH improved in high latitudes when the horizontal resolution was increased. MH’s experiment has been repeated using a 2.5° by 3.75° latitude–longitude version of the Meteorological Office 11-layer model which has a much finer resolution in high latitudes than that used by MH and which reproduces the depth and position of the antarctic circumpolar trough very accurately. (Mitchell et al. (1987) show the simulated distribution of surface pressure from an earlier version of this model.) This model also produces a reduction in zonally averaged surface pressure where the southern hemisphere sea-ice is removed. Thus this response does not appear to be an artifact of how horizontal resolution in high latitudes. (We plan to publish details of the high resolution experiment at a later date.)

SD point out that in MH the surface pressure increases over the pole, even though the lowest model layer warms over the antarctic. This is not surprising. The intense heating in the zone where the ice is removed warms the atmosphere locally and raises constant pressure surfaces at upper levels. It seems likely that as the model moves towards approximate geostrophic balance, some mass at upper levels is displaced down-gradient, both to lower latitudes and towards the pole, reducing surface pressure over the anomaly and increasing it over the antarctic. Although the lowest layer warms over the pole, the depth-averaged warming is only about half that over the sea-ice anomaly. Thus one would not necessarily expect surface pressure to decrease over Antarctica.

In their comment, SD suggest that the simulated response of surface pressure in mid-latitudes to thermal anomalies is highly variable. While we accept this point, the size of the anomalies, their position with respect to major troughs and ridges and the length of the averaging period for the results vary considerably in the experiments they considered, so it is to be expected that the simulated response will vary. The results of each experiment have to be interpreted separately. For example, SD refer to Herman and Johnson (1978) and point out that in the latitude zone where most sea-ice is removed, average surface pressure increases significantly. However, the geographical differences give a different impression. For example in the Atlantic and Pacific, they find a reduction in surface pressure where sea-ice is removed in the west where the air–sea temperature contrast is greatest, and increases where it is removed in the east, where the air–sea temperature contrast is smaller. (There is a further fall in pressure where ice is removed in the Barents sea.) It is the magnitude of the anomalous atmospheric heating and its position relative both to the unperturbed flow and to the underlying pattern of surface temperature and not necessarily the size of the temperature or sea-ice anomaly itself which is relevant to the atmospheric response.

The lack of statistical significance in some of the studies cited by SD does not necessarily imply that a systematic response does not exist: it could be that the averaging period is too short or the statistical test is weak. For example, although the decrease in surface pressure over a warm mid-latitude sea surface temperature anomaly reported by Chervin et al. (1980) is not statistically significant, the averaging period (30 days) is short. Even so, they also report a statistically significant rise in surface pressure over a cold sea temperature anomaly. Simmonds and Dix (1986) themselves report a statistically significant decrease in surface pressure when they remove sea-ice from the Weddell Sea only. Thus the model results may not be as mutually inconsistent as they might first appear.

SD show that there is little relationship between analyses of zonally averaged surface pressure at 65°S and the zonal mean latitude of the antarctic ice edge. We have already pointed out that the zonally averaged pressure response may be misleading where the sea-ice anomalies are azonal. Furthermore, the observed ice edge may enclose thin ice with a large fractional area of leads, whereas ‘model’ ice is 2 m thick everywhere. Thus the observed ice edge does not necessarily mark a region of sharp transition in the surface heat flux (see the introductory discussion in MH), whereas the model ice edge does. Hence these observationally based data do not necessarily indicate that the models’ responses are incorrect, except insofar as the model sea-ice is too thick. SD also correlate July monthly zonally averaged winds at 60°S at 1000 mb with those at 500 mb. It is unlikely that all the variability in observed winds is related to changes in sea-ice. Once again, zonal averages may obscure the response to azonal anomalies. We are not aware of many radiosonde stations near 60°S, so we assume that a considerable amount of interpolation was used to obtain the analyses. This may produce biases in the data. If operational analyses have been used, then the analysis fields will tend towards the background field produced by the forecast model in regions of sparse data such as this. If the forecast model has the same characteristics as that used by SD, then it is not surprising that the 1000 mb and 500 mb winds
are strongly correlated. The climatological value of sea level pressure at 60°S in July is 990 mb so some inventive vertical interpolation is also involved in deriving winds at 1000 mb! To be fair, SD warn that the use of "observational studies to give credence to model results should be treated with caution".

It may be possible to determine why the models used by SD and MH produce different results. The differences between the results from SD and MH are largely confined to the boundary layer, so it may be here that the source of the discrepancy lies. If the model formulation is such that changing from sea-ice to sea leads to a reduction in surface drag coefficient, then it seems likely that this alone will cause surface pressure to decrease in regions of cyclonic activity where sea-ice is replaced by sea.

If it transpires that the simulated response near the surface is very sensitive to the details of the treatment of the boundary layer, then there are serious consequences for other sensitivity studies. It would then be desirable to determine which models give the correct response. This might be achieved by a carefully designed set of experiments using a series of observed anomalies and verifying against the observed response, as has been done for the 1982-83 El Niño (various authors, reported in Nihoul 1985).

REFERENCES


REVIEWS


In this book of 293 pages and 17 chapters the many references are grouped at the end of each chapter but lack of an index of names will be a handicap for some readers.

The first chapter deals with the physics and mechanics of aerosols. The description of the Brownian motion of airborne particles as a "rapid vibration about a point which drifts randomly" is inaccurate and disregards the essential fact that the particles and gas molecules soon come to equilibrium. There is confusion about transport by diffusion which results from Brownian motion only in the presence of a gradient of concentration. It is doubtful if the calculation of terminal velocity by equation (1.8) will always be as accurate as suggested.

Chapter 2 is concerned with the generation of aerosols, mainly by atomizing liquid suspensions and, briefly, with their sampling. Failure of organisms to survive and retain infectivity are frequent problems in experimental work which are difficult to predict but can be dealt with to some extent by additives to the suspension, such as raffinose.

Sampling with impingers is still popular, after 40 years, which leaves open the choice of collecting fluid for which micro-organisms have specific preferences and react differently upon rehydration.

Alternatively, particles are sampled on spider threads to yield a 'captive' aerosol. It was this method which first revealed the existence of the 'open air factor', which causes outdoor air to be more toxic to micro-organisms than indoor air.