Investigating the effect of fall Eurasian snow cover on winter climate in general circulation models

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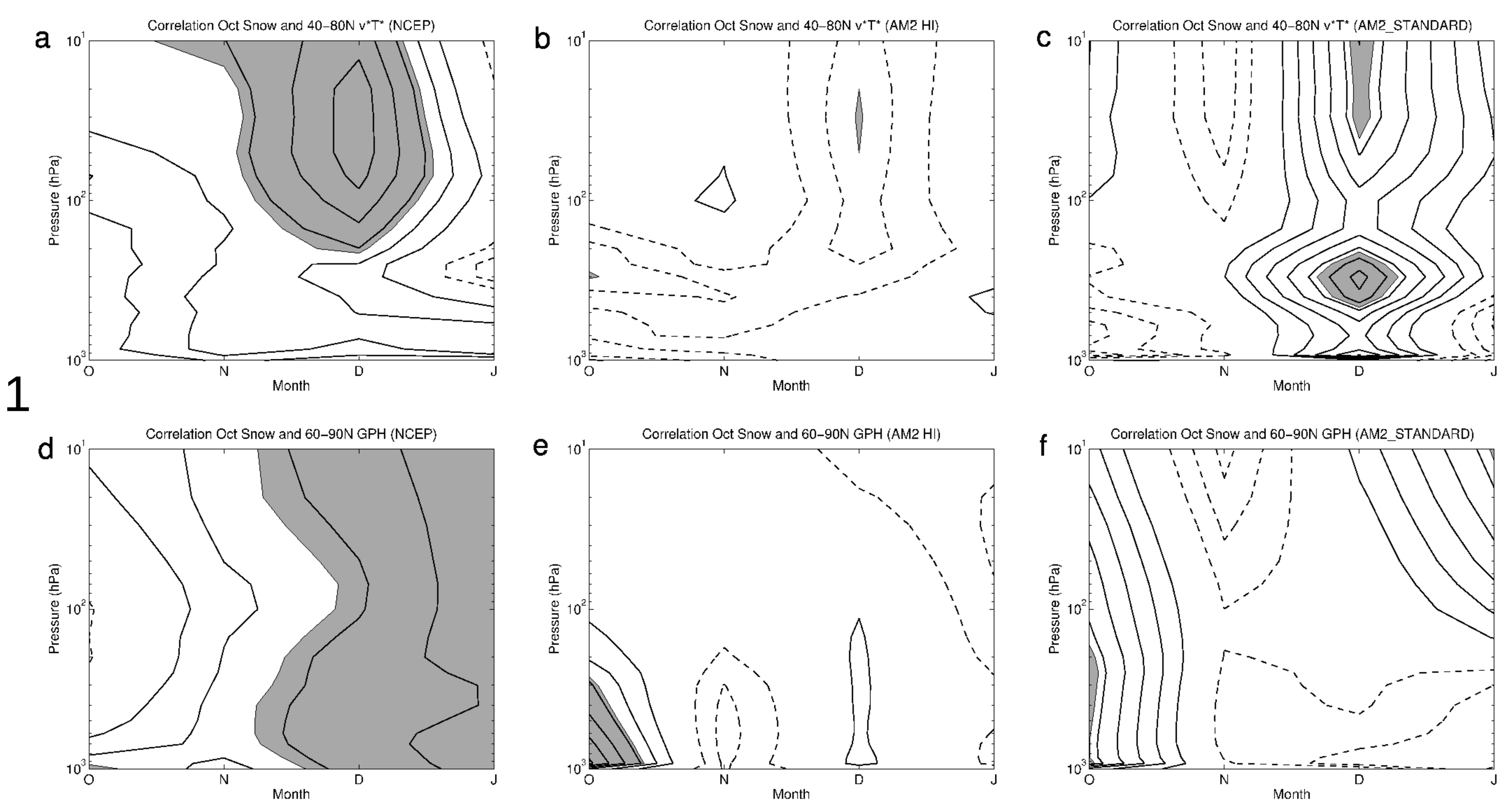
Introduction

The ability of General Circulation Models (GCMs) to reproduce the observed strong correlations of Eurasian snow extent in the fall to wave activity and Northern Annular Mode anomalies in the following winter is studied. The observed correlations have been hypothesised to involve two parts: a Rossby wave pulse generated in the troposphere in response to snow-forced surface cooling, and a coupled zonal-mean stratosphere-troposphere response to this Rossby wave pulse involving eddy mean flow interactions. It is found that all coupled ocean atmosphere GCMs used within the Coupled Model Intercomparison Project 3 (CMIP3) fail to capture the observed correlations. Using the CMIP3 GCMs and two versions of a particular GCM forced by prescribed sea surface temperatures, possible reasons for this are considered.

Results

Following Cohen et al. (2007), Figure 1 shows the correlation of area averaged October Eurasian snow extent (hereafter snow index) with upward wave activity flux, $v'T'^*$, averaged from 40N-80N and with geopotential height (GPH) averaged from 60N-90N. In the observations there is a correlation of about 0.5 of the snow index with $v'T'^*$ in the stratosphere in December suggesting that anomalously high snow cover increases the production of planetary waves which act on the zonal mean wind until they penetrate the stratosphere in December. There is also a significant correlation of the snow index with GPH in December and January suggesting that these planetary waves break on the polar vortex in December causing Baldwin and Dunkerton like downward migrating signals in the dynamical fields which reach the troposphere by January. Figure 1 shows also that these correlations are missing in General Circulation Models (GCMs). AM2_STANDARD is a low top GCM with observed SSTs, and AM2_HI is a high top GCM with climatological SSTs.

Fig 1



Further, Figure 2 demonstrates that none of the CMIP3 GCMs capture the effect of snow on the dynamics. Figure 2 shows histograms of the correlation of the snow index to October, November and December 100 hPa $v'T'^*$. Only the years within the upper quartile and the lower quartile of snow extent are used, to enhance the anomalies. The CMIP3 GCMs are shown by grey bars, and the observations are shown by black bars.

Fig 2

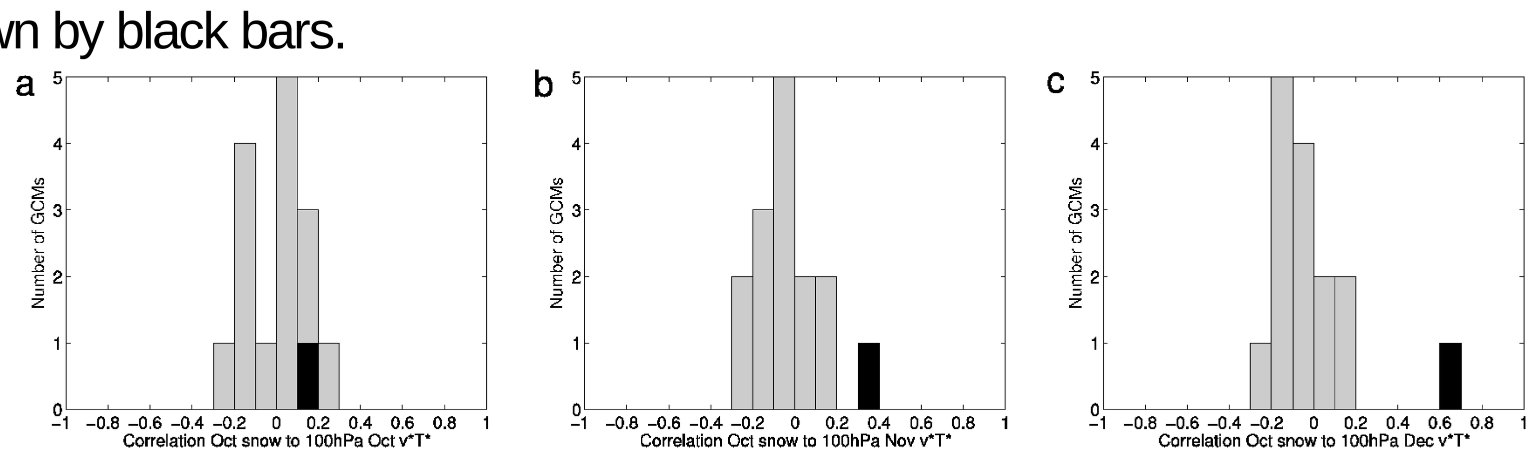
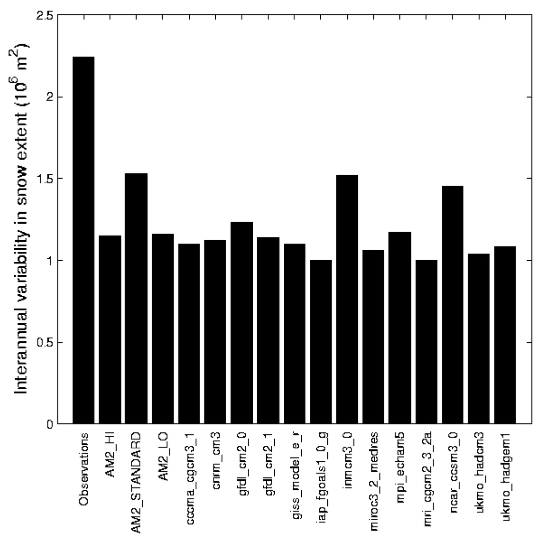


Fig 3



One possible reason for this is that the interannual variability in Eurasian snow extent is somewhat low in most GCMs. As shown in Figure 3, in the CMIP3 models it is on average about half the observed. Another possible reason is given in Figure 4:

Fig 4

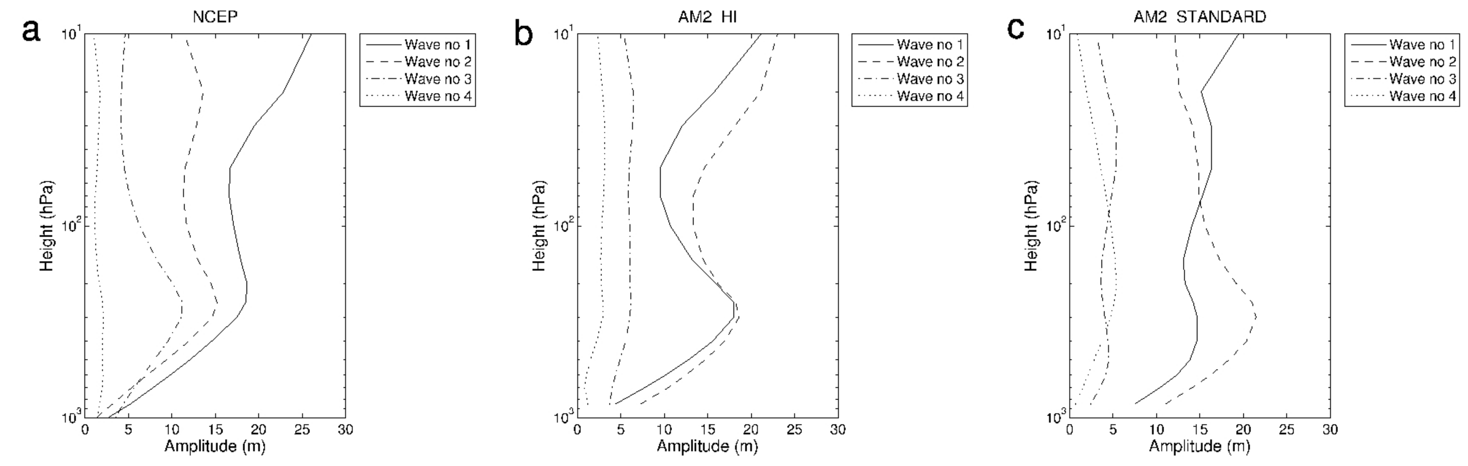


Figure 4 shows the individual zonal wave number components of the regression of October mean eddy GPH (m) at 60N on the normalised snow index. In the observations wave number 1 dominates at all altitudes. In AM2_STANDARD, wave number 1 dominates in the stratosphere and wave number 2 in the troposphere. In AM2_HI wave number 2 dominates at all altitudes. The wavenumber 1 contribution from 50hPa-100hPa (the lower stratosphere) is considerably smaller in AM2_HI than in either observations or AM2_STANDARD. This may be important since, by the Charney-Drazin criterion, lower wavenumber planetary waves can propagate higher into the stratosphere. Further, the wavenumber 1 GPH amplitude is smaller in AM2_HI than in observations and in AM2_STANDARD from 50 hPa to 100 hPa throughout October to December (not shown). Thus it is possible that changes to models that would improve the stationary eddy field would lead to an improved representation of the snow-circulation coupling.

Fig 5

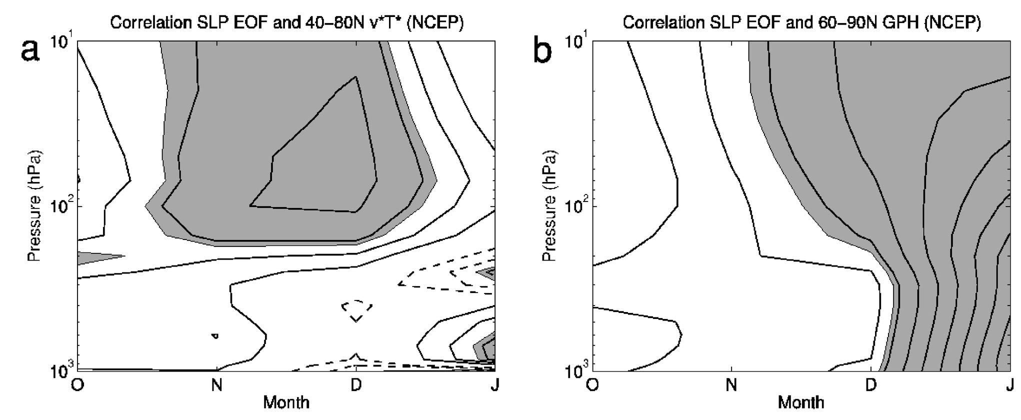
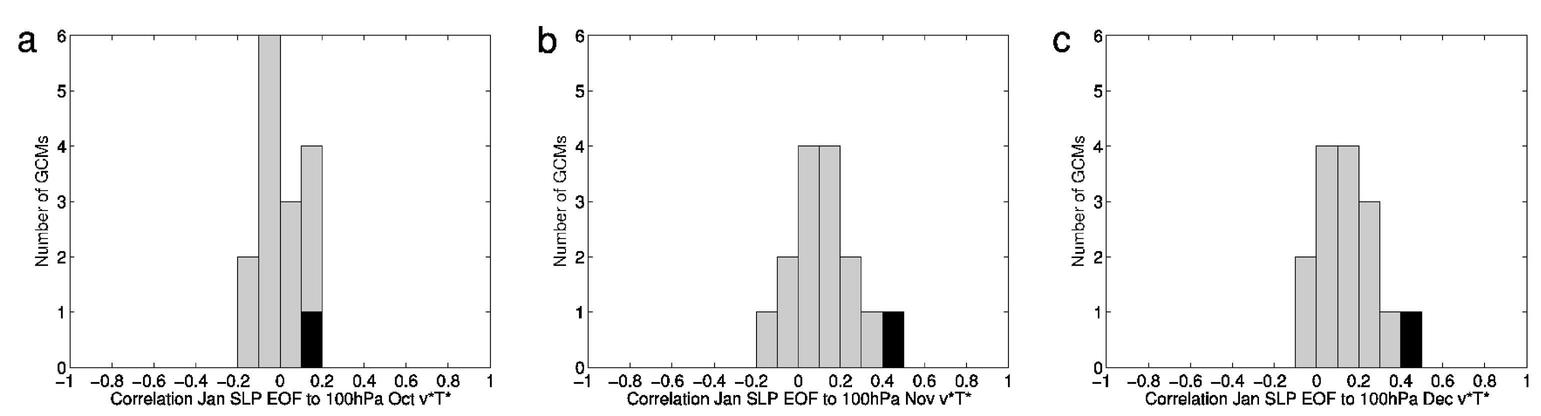


Figure 5 demonstrates, in the observations, the high correlation between wave breaking in the stratosphere in December and dynamical fields in the troposphere in January. This is the second half of the proposed mechanism for October snow cover influencing the winter circulation. Figure 5 is produced as Figure 1 (a) and (d) except that regressions are against the leading EOF of January sea level pressure (SLP) rather than the snow index.

Fig 6



The ability of the CMIP3 GCMs to capture this part of the mechanism is mixed. Figure 6 shows histograms of the correlation of the principal component time series of the January SLP EOF to October, November and December $v'T'^*$ at 100hPa, using all model years. Most models display a correlation of the correct sign throughout November - December. Thus the GCMs, although far from perfect, capture this aspect far better than they capture the influence of snow on planetary waves.

Conclusions

In this study we have investigated the mechanism put forward by Cohen et al. (2007) by which Eurasian snow cover in October may influence winter climate in the Northern Hemisphere. Using the CMIP3 GCMs it is shown that, although the correlation between stratospheric planetary wave flux in December and tropospheric dynamical fields in January is represented in some GCMs, they all fail to capture the effects of October snow cover on these fields. Possible reasons for this are that GCMs capture only about half of the observed interannual variability in snow cover and that the response to snow cover in the models is too horizontally localised implying that planetary waves forced by anomalously high snow cover may not propagate as high into the stratosphere as they do in the observations. That GCMs do not capture the effect of Eurasian snow cover on winter climate means that they might be missing a potentially important aspect of winter climate variability.

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CMIP3 archive: http://www-pcmdi.llnl.gov/projects/cmip/index.php