The Eurasian Snow—Arctic Oscillation Connection in the Operational Climate Forecast System Model

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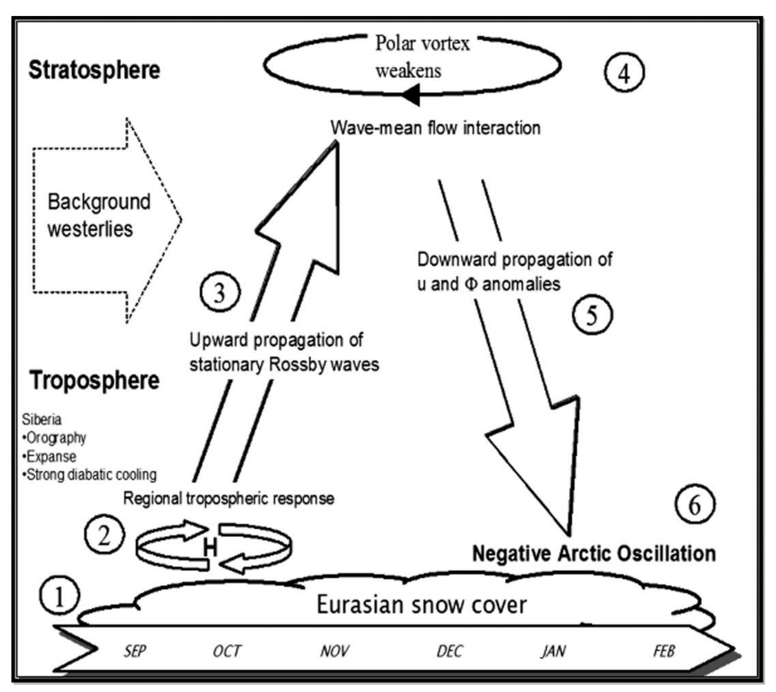
Abstract

Observational studies have established a significant relationship between October snow cover extent over Eurasia and the following wintertime Arctic Oscillation index. We examine how well this relationship is captured in the NCEP Climate Forecast System (CFS) model, comparing hindcasts from CFS version 1 and the newly released CFS version 2. These models are currently used operationally by the NOAA/NCEP Climate Prediction Center to make seasonal forecasts of wintertime climate. The models are able to capture some of the initial tropospheric variability associated with snow cover anomalies, but by winter the models no longer show significant relationships with October snow, suggesting that CPC forecasts could be improved if CFS better represented the Eurasian snow/AO relationship. Towards this goal, we examine details of the model response in the troposphere and stratosphere and diagnose potential areas for model improvement.

Proposed Mechanism



From Cohen et. al. 2007

Figure 1. Cohen et. al. (2007) and others have proposed a stratospheric pathway linking positive snow cover anomalies over Eurasia in the fall with an increased probability of a negative AO in the following winter season. The theoretical mechanism begins with a tropospheric response in October and November to anomalous snowfall covering the landscape over Eurasia. A characteristic upstream ridge and downstream trough pattern develops in response to the snow cover anomaly, amplifying the upward propagation of Rossby waves in November and December. This increased vertical wave activity flux leads to a weakening of the stratospheric polar vortex. The stratospheric signal later propagates back to the surface, increasing the likelihood of a negative AO in the troposphere by January and February.

Datasets and Hindcasts

- Lagged ensembles of CFSv1 and CFSv2 hindcast runs are initialized at different dates in September and run through winter. Each run covers the October—February season, and generates its own October snow and wintertime AO "response".
- Monthly-averaged model output from all common years (1982-2006) are analyzed
- The Rutgers University Snow Extent Climate Data Record is used for snow observations (Robinson et al, 2003).
- The NCEP/NCAR reanalysis is used for upper air "observations" (Kalnay et al, 1996).

CFSv1 and CFSv2 ensembles of runs started in September

	CFSv1	CFSv2
September start dates: (in days of the month)	1,2,3,9,10, 11,12,13,19,20, 21,22,23,29,30	3,8,13, 18,23,28
# of runs started per day:	1	4
Total # of lagged ensemble members started in September:	15	24

The Eurasian Snow—AO relationship in the hindcasts

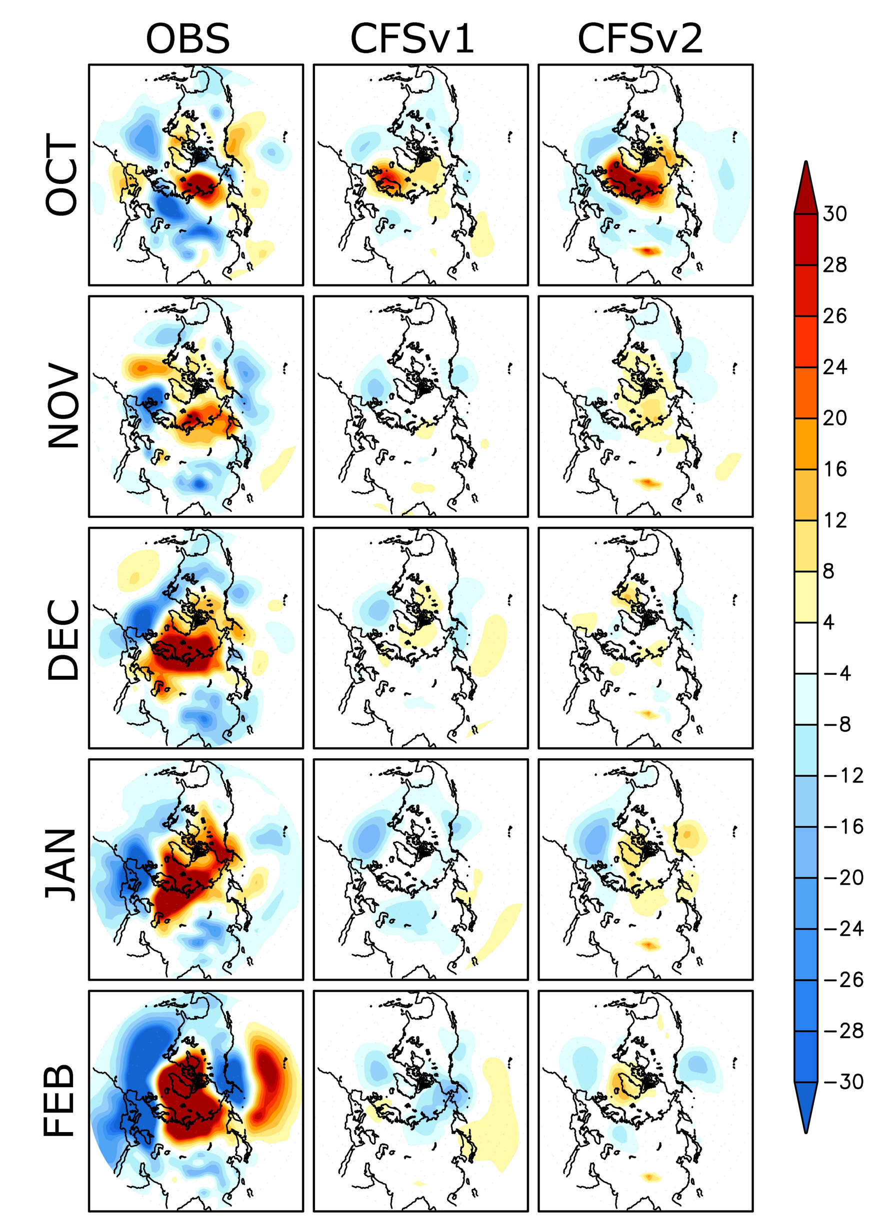


Figure 2. Composites of 1000 hPa geopotential height anomalies (m) for cases of high October Eurasian snow cover minus cases of low October Eurasian snow cover. Composites are formed from the top and bottom 20% of cases. For the hindcasts, the combined pool of all ensemble members and years is considered. A negative AO-like signal is captured in the models in October, but the signal quickly decays in subsequent months.

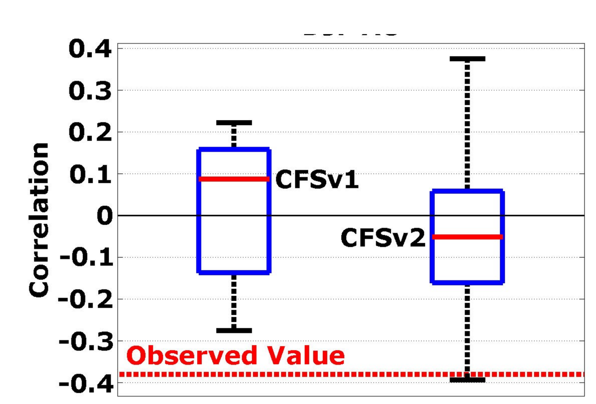


Figure 3 Correlation values between October Eurasian Snow cover and the DJF AO for the years 1982-2006. Box plots show the ensemble means (red horizontal lines), 25%-75% inner quartile range (blue boxes) and total ensemble spread (black bars). The observed correlation value is shown by a horizontal red line.

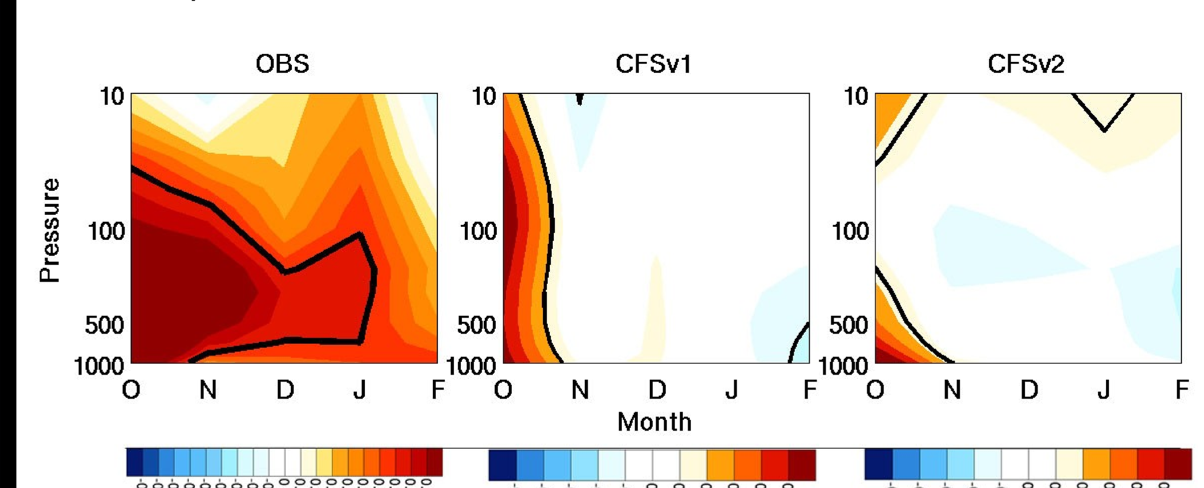


Figure 4 Correlations between polar cap geopotential height (averaged zonally and between 60 N and 90 N) and October Eurasian snow cover for 1982-2006. For the hindcasts, correlations for each ensemble member are calculated separately, then averaged. Significance levels, shown with black solid lines, take into account the ensemble averaging. Significant correlations exist between observed October Eurasian snow cover and wintertime polar cap anomalies. A similar relationship can be observed in the models for October, but the signal is generally lost soon afterward.

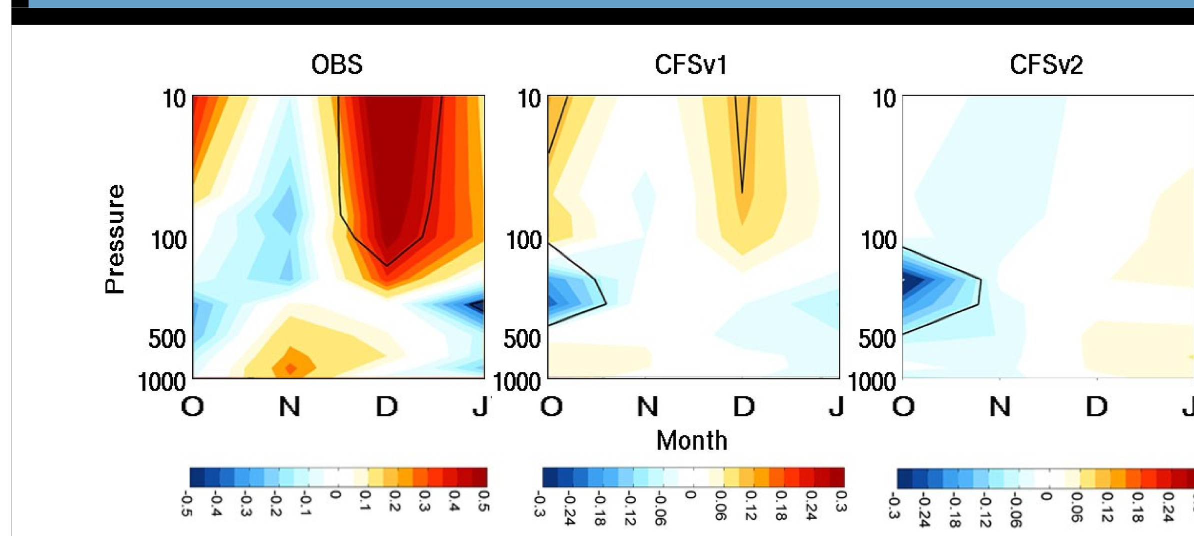


Figure 5 Correlations between vertical wave activity flux (averaged zonally and between 40 N and 80 N) and October Eurasian snow cover for 1982-2006. In the theory proposed by Cohen et. al. (2007), the December pulse in wave activity flux is responsible for translating the tropospheric response to snow into the stratosphere. More work is needed to understand why version 1 captures this signal more strongly than version 2.

Potential Areas for Model Improvement

I. Low Model Snow Cover Variability

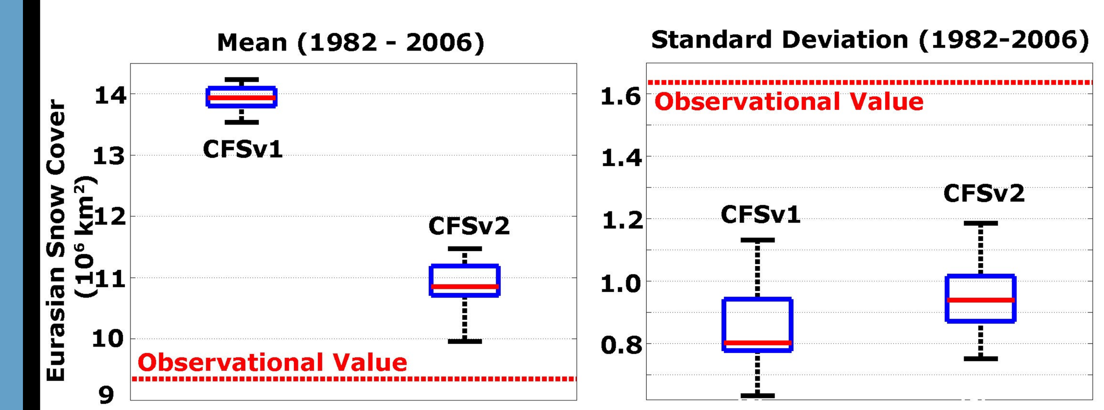


Figure 6. Mean and standard deviation of October Eurasian snow cover mean for the years 1982-2006. Box plots show the mean (red horizontal lines), 25%-75% inner quartile range (blue boxes) and total spread (black bars) for CFSv1 and CFSv2 ensembles of September start dates. Observed values over the same period (1982 -2006) are shown with long red horizontal lines. In both models, the climatological October Eurasian snow cover extent is too large in the model, but the year-to-year variability is significantly too small. Values in CFSv2 are somewhat more realistic than in CFSv1. Recent modeling studies (e.g., Allen and Zender, 2011) have suggested that using more realistic snow variability in global climate models can improve the wintertime AO simulation. Experiments are underway to test if this is true for the CFSv2 model.

II. Unrealistic spatial structure in tropospheric response

Hardiman et. al. (2008) suggested that the tropospheric response to October snow anomalies may be too spatially compressed in some models, inhibiting propagation into the stratosphere. Others (e.g., Garfinkel et. al., 2010) have suggested that the *phase* of the tropospheric response must be correct in the models in order to positively interfere with the climatological wave pattern. Like Hardiman et. al. (2008), we found that the CFSv2 tropospheric response to snow anomalies is generally composed of higher wave numbers in than in the observations (not shown). Further work is needed to see if correct representation of the scale and phase of the response could improve the forecasts.

III. Weak Polar Vortex in the Models

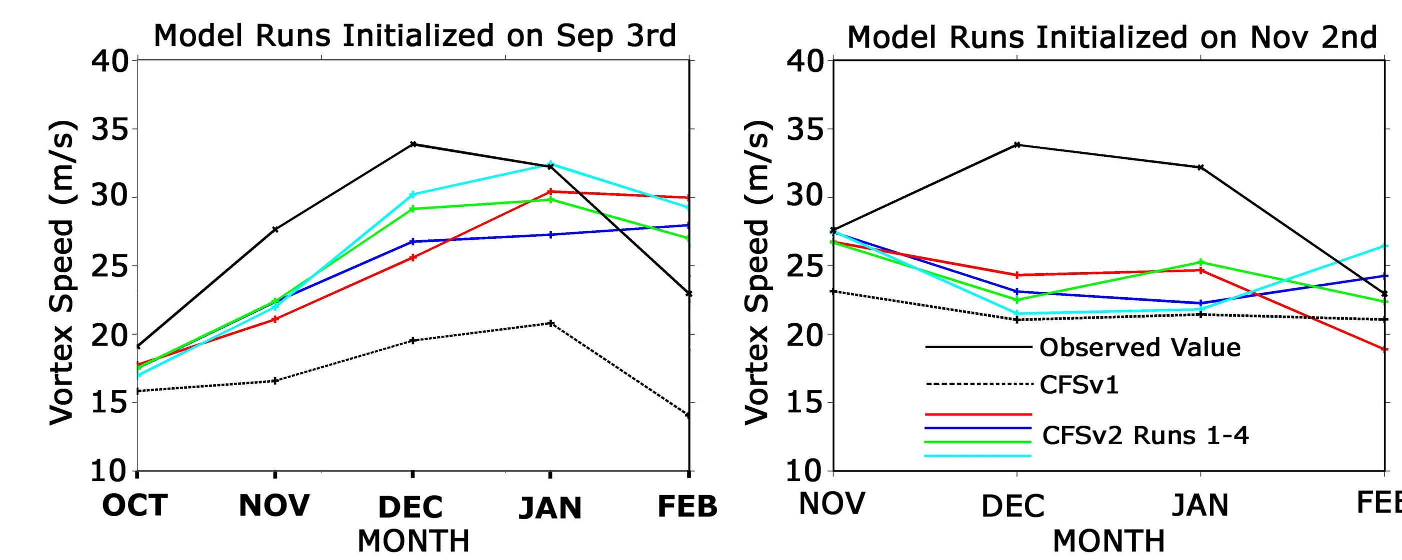


Figure 7. The 1982-2006 climatological cycle of the NH polar vortex (10 hPa zonal mean zonal wind at 60 N) for hindcast runs starting on September 3rd (left), and runs starting on November 2nd (right). The CFSv2 runs in the September initialization example (left) are more accurately capturing the seasonality and strength of the vortex than CFSv1. However, given that the wave activity flux into the stratosphere is stronger in version 1 (Figure 4), the weaker vortex does not appear to be the main factor inhibiting wave propagation. While not part of our ensemble of September start dates, the November 2nd example (right) highlights an additional short coming of the forecast models: a spin-up problem in the stratosphere. The seasonal cycle is completely missed in the runs initialized on November 2nd. Figure 8 illustrates this problem in CFSv2 using a larger number of initialization times.

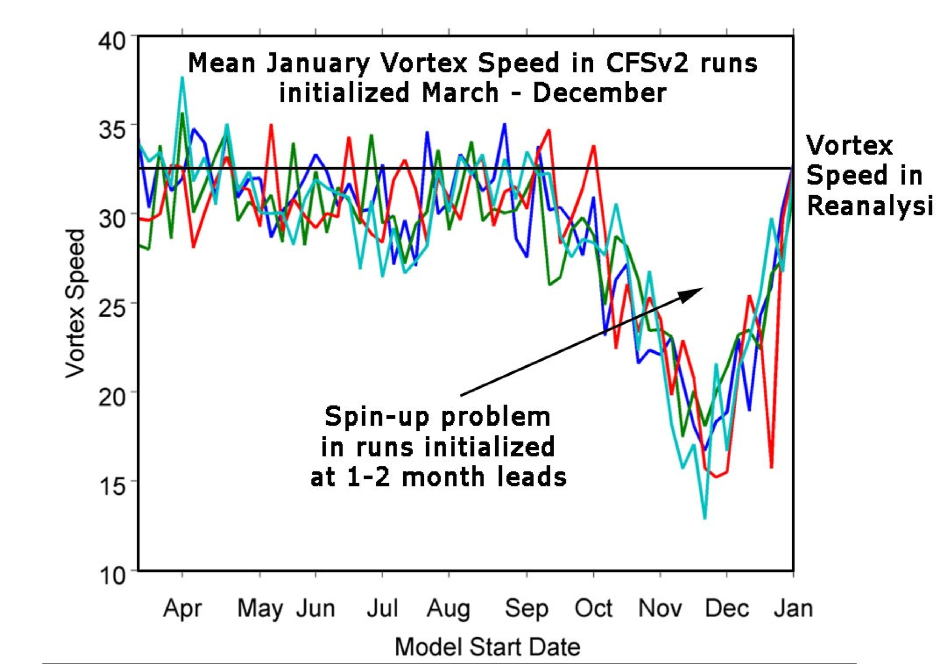


Figure 8. Mean January vortex speed (10 mb zonal mean zonal wind at 60 N) from all CFSv2 hindcast runs initialized March through December (10 months—0 months lead). Colored lines show results from the 4 -ensemble members initialized at each start date.

Conclusions

- Neither CFSv1 nor CFSv2 are able to capture the observed correlations between October Eurasian snow cover and the wintertime AO.
- Several shortcomings in CFS are identified. Model upgrades might focus on 1) improving the representation of snow variability in the model, 2) Improving the representation of the polar vortex in the model, and 3) Improving the spatial structure of the tropospheric response.
- CFSv2 performed better than CFSv1 in many aspects. These include a better representation mean Eurasian snow cover, a better representation of the polar vortex speed (at sufficiently long leads), and stronger contemporaneous correlations in the troposphere between Eurasian snow and the AO. On the other hand, CFSv1 captured the December pulse of enhanced wave activity flux more accurately than CFSv2. More work is needed to better understand these model differences.
- Future work will focus on forced CFS experiments with prescribed snow and on examining hindcast runs initialized in November and December when the real-world atmospheric response to snow cover anomalies is already underway.