Eurasian Snow Cover Variability and Wintertime Stratosphere/Troposphere Coupling in the CMIP5 Models

W211B

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INTRODUCTION

- Extratropical Northern Hemisphere (NH) wintertime variability is strongly tied to variations in the **Arctic Oscillation (AO)** [e.g., *Thompson and Wallace,* 1998; 2001; *Baldwin and Dunkerton,* 2001].
- To improve seasonal (or longer-term) forecasts of the AO, studies have looked at autumn Eurasian snow cover to predict its wintertime phase (**Fig. 1**) [e.g., *Cohen et al.,* 2001; 2007; *Fletcher et al.,* 2008; *Allen and Zender,* 2010; 2011].
- Evaluation of this framework (i.e., **Fig. 1**) in the latest coupled general circulation models (GCMs) may improve our understanding of NH climate variability and also enhance confidence in future climate change predictions, particularly for NH winters.
- **OBJECTIVES:**
  (1) ***Assess*** the ability of the models to capture Eurasian snow cover variability;
  (2) ***Diagnose*** the relationships between snow cover variability in the models and the wintertime stratospheric and tropospheric circulation; and
  (3) ***Compare*** results to observations and evaluate model performance.

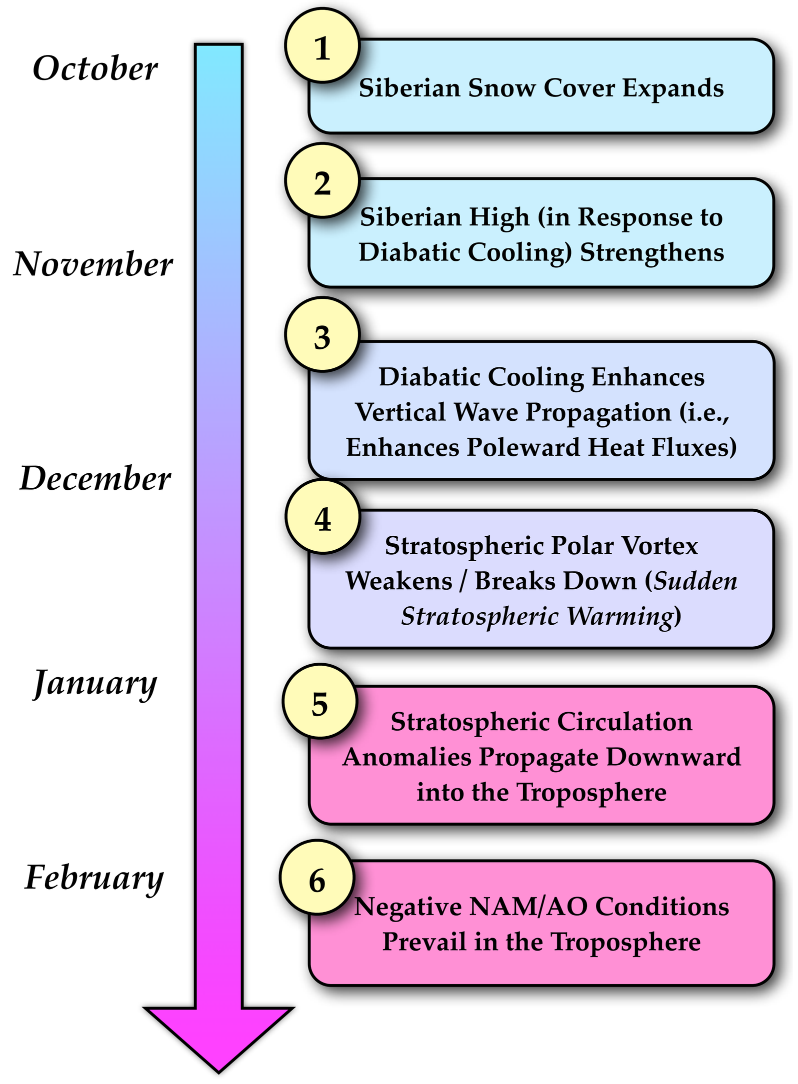


FIG. 1. A six-step process describing how Siberian snow cover in the autumn impacts the NH tropospheric circulation in the following winter. Adapted from *Cohen et al.* [2007].

DATA & METHODS

- *Observations:* Monthly-mean NCEP/NCAR Reanalysis (1970-2011). Eurasian October snow cover data taken from the Rutgers University Global Snow Lab [e.g., *Robinson,* 1993] from 1970-2010.
- *Models*: Eight (8) available models from CMIP5 (**Table 1**). The ***historical scenario*** is examined (1950-2005).

TABLE 1. The models evaluated in this study.

Model Name	# Ensemble Members
BCC-CSM-1-1	3
CNRM-CM5	1
CanESM2	5
GISS-E2-H	5
INMCM4	1
NorESM1-M	3
CSIRO-Mk3-6-0	6
GISS-E2-R	5

Primary Variables Analyzed

- **October Eurasian Snow Cover** (i.e., total snow-covered area from 0°-170°E, 20°-75°N).
- **Meridional and Zonal Wind**
- **Sea Level Pressure (SLP)**
- **Air Temperature**
- **Geopotential Height**
- **Vertical Component of the Wave Activity Flux (F_{sz})** [*Plumb,* 1985]

$$F_{sz} = \frac{\Omega p \sin 2\varphi}{S}\left(v'T' - \frac{1}{2\Omega a \sin 2\varphi}\frac{\partial}{\partial \lambda}(T'\Phi')\right)$$

- All observed data and model output are detrended before computing statistics.
- All model output are interpolated onto the same grid as NCEP/NCAR Reanalysis for direct comparison.
- Ensemble-mean statistics from the models are derived by averaging the individual statistics from each member.

RESULTS

Eurasian Snow Cover Variability

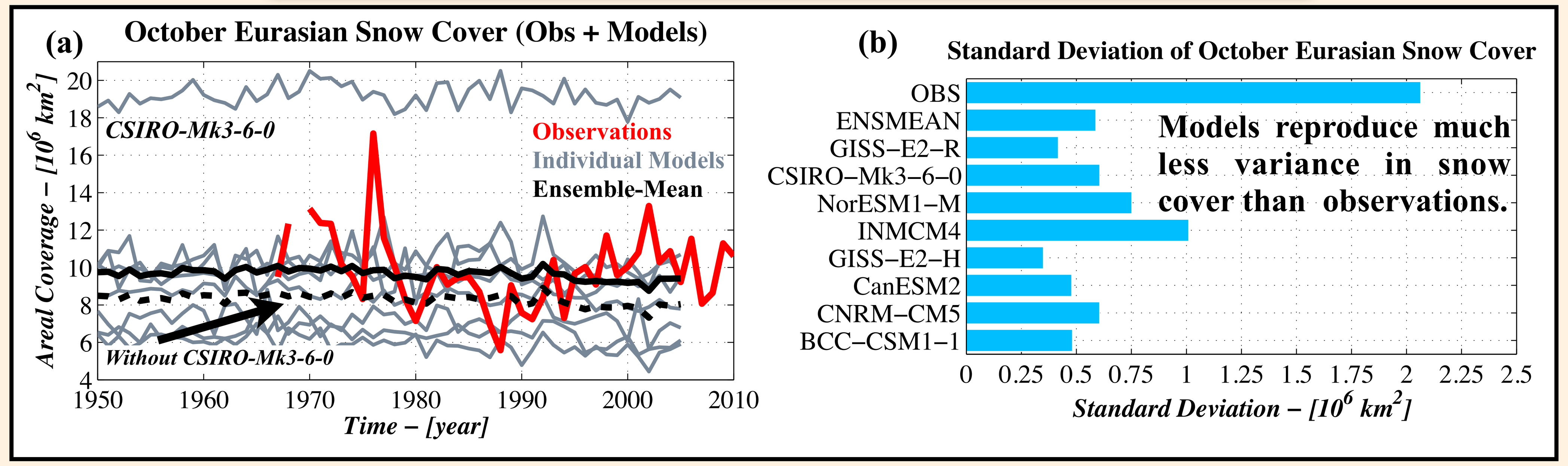


FIG. 2. (a) The October Eurasian snow index (in 10^6 km^2) for observations (**red**), individual models (**gray**), and the ensemble-mean (**solid black**). Ensemble-mean index for all models except the CSIRO-Mk3-6-0 model in **dashed black**. (b) The standard deviation of the October Eurasian snow index (in 10^6 km^2) for each model, the ensemble-mean, and observations.

Polar Cap Heights and Snow Cover

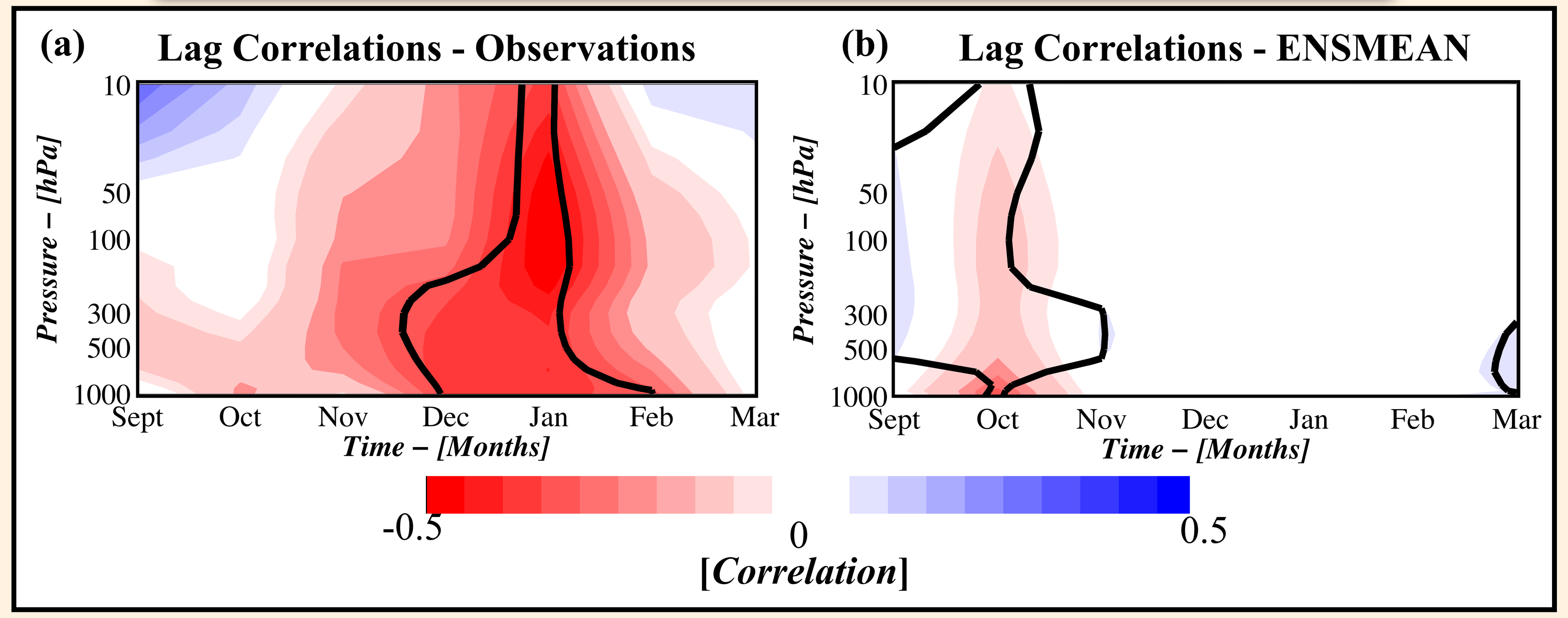


FIG. 3. (a) (shading) Lag correlations of polar-cap geopotential height anomalies (i.e., area-averaged heights poleward of 60°N) with the October Eurasian snow index in observations (i.e., **red** curve in **Fig. 2a**). (b) As in (a) but for the ensemble-mean correlation. Correlation plots for individual models also show no coherent lagged response to October Eurasian snow cover (not shown). Thick **black** line in both plots outline correlations that are significant at the $p < 0.05$ level.

Multivariate EOF Analysis between December 100 hPa F_{sz} and January SLP

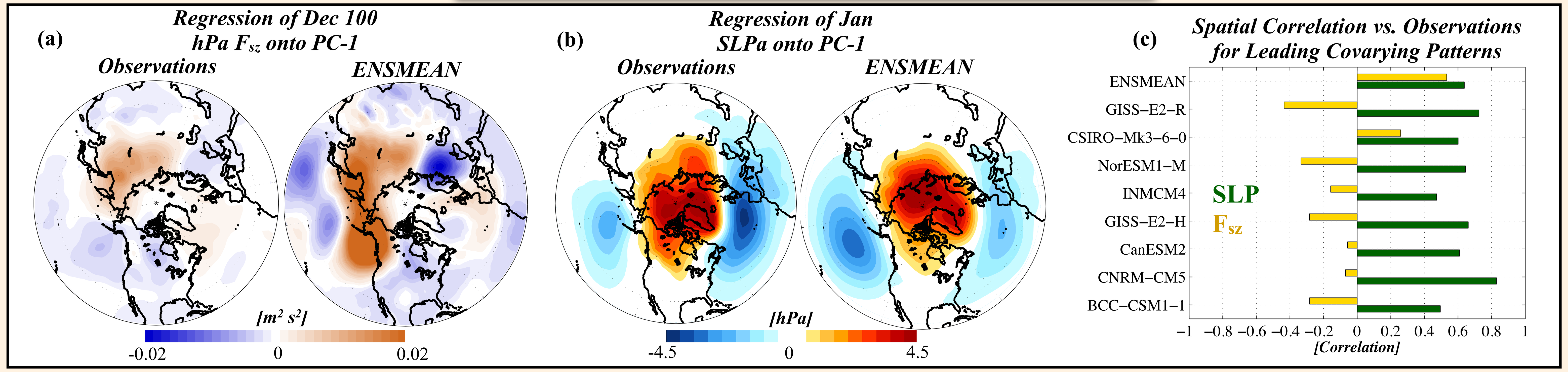


FIG. 4. (a) Regression of December 100 hPa F_{sz} anomalies ($m^2 s^{-2}$) onto the leading principal component of the multivariate empirical orthogonal function (mEOF) of December 100 hPa F_{sz} and January SLP for observations (left) and the ensemble-mean (right). ***Ensemble-mean regression values in (a) multiplied by 10 for comparison.*** (b) Same as (a) except for January SLP anomalies (hPa). (c) Spatial correlation of the SLP (**green**) and F_{sz} (**yellow**) mEOF regression patterns versus the observations.

Zonal-Mean U and Snow Cover

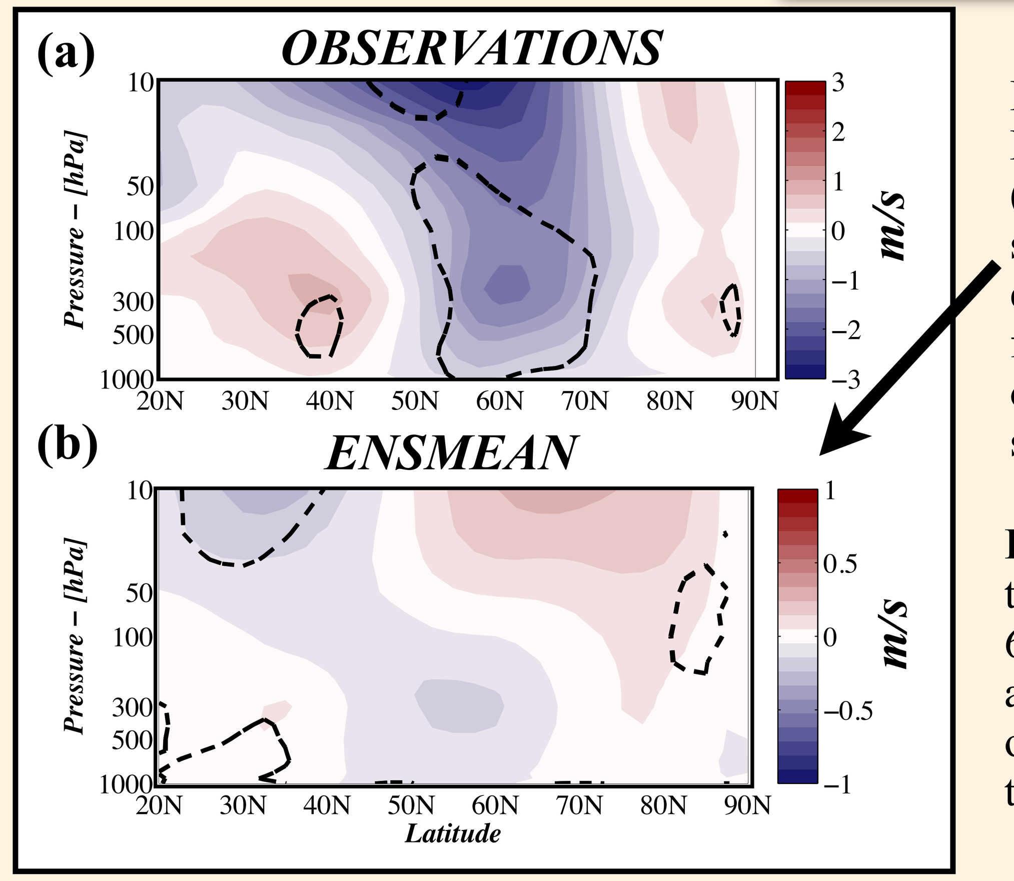
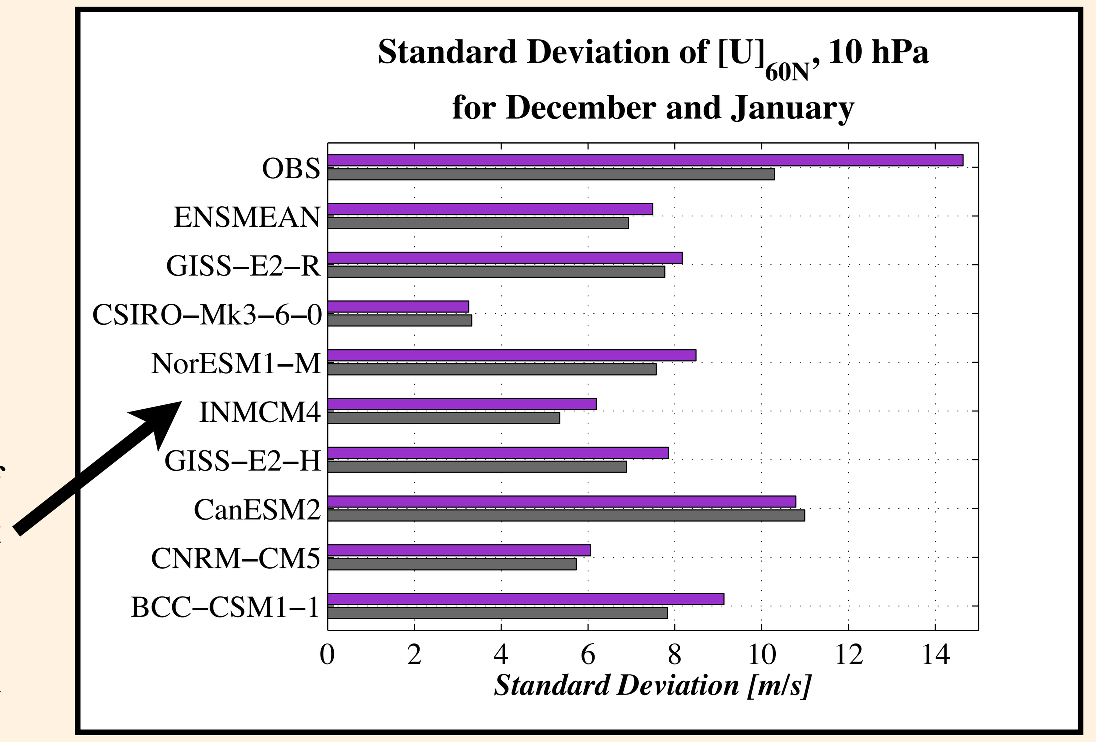


FIG. 5. (a) Regression of observed December zonal-mean zonal wind (m/s) onto the October Eurasian snow index. (b) As in (a) but the ensemble-mean regression pattern from the models. Dashed black line outlines where coefficients are significant at the $p < 0.05$ level.

FIG. 6. The standard deviation of the zonal-mean zonal wind (m/s) at 60°N, 10 hPa in December (gray) and January (**purple**) for the observations, the eight models, and the ensemble mean.



Projections onto the High-Latitude Planetary Wave Pattern

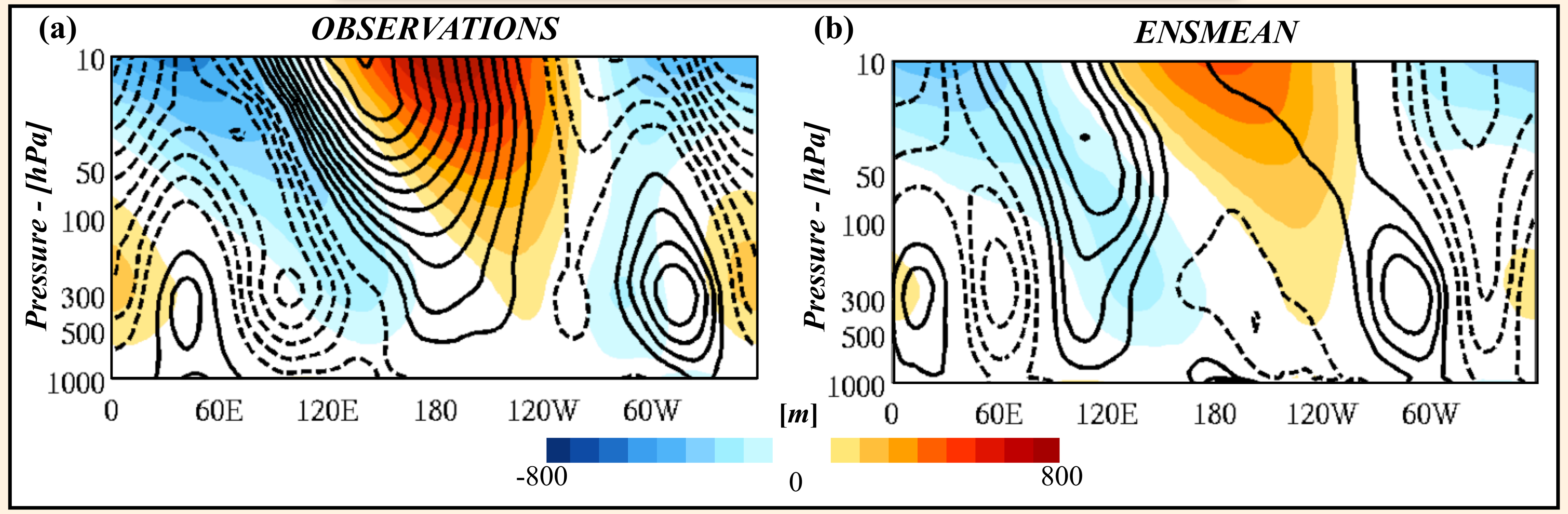


FIG. 7. (a) (Contours) Regression of observed December-January (DJ) eddy geopotential height (Z^*; m) at 60°N onto the October Eurasian snow index. (Shading) The climatological DJ Z^* field (m) at 60°N. (b) As in (a) but the ensemble-mean pattern. Line contour interval every 5 m for (a) and 1 m for (b). Positive (negative) regression coefficients in solid (dashed) line contours.

Smith et al. [2011, in press] illustrate that the covariance of December-January (DJ) high-latitude eddy height field (Z^*) and October Eurasian snow cover ***constructively*** interferes with the climatological planetary wave pattern, thus enhancing wave driving in the polar stratosphere. Models, however, generally illustrate either a ***weak*** and/or ***destructive*** projection (**Fig. 7** and **Table 2**).

Models / Observations	Pattern Correlation
BCC-CSM-1-1	0.01
CNRM-CM5	-0.28
CanESM2	-0.82**
GISS-E2-H	0.09
INMCM4	0.29
NorESM1-M	**0.67****
CSIRO-Mk3-6-0	-0.13
GISS-E2-R	**0.49***
ENSMEAN	-0.01
Observations	**0.52***

TABLE 2. The pattern correlation, representing the projection of the DJ Z^*-snow regression pattern onto the climatological DJ Z^* pattern. Single (double) asterisk denotes correlations significant at the $p < 0.05$ ($p < 0.01$) level.

SUMMARY & CONCLUSIONS

- Boreal winter weather and climate have significant ties to autumn Eurasian snow cover variability, but the latest coupled GCMs fail to capture this relationship.
- The CMIP5 coupled climate models underestimate Eurasian snow cover variability (**Fig. 2**) and lack a significant lagged response between October Eurasian snow cover and wintertime geopotential heights (**Figs. 3 and 7**) and the jet stream (**Fig. 5**).
- Models exhibit weak covariance between stratospheric wave driving and subsequent tropospheric weather (**Fig. 4**). Weaker wave driving likely impacts stratospheric polar vortex variability in the models (**Fig. 6**).
- Based on these preliminary results, we see *little if any* improvement in the snow-AO relationship between the CMIP3 and CMIP5 models [*Hardiman et al.,* 2008]. Hence, forecasts of boreal winter NH climate variability, especially under future scenarios, should be examined and interpreted cautiously.
- **NEXT STEPS: (1)** Examine model-by-model comparisons of the snow-AO relationship to other model parameters (e.g., stratospheric resolution, polar vortex strength, AO variability). **(2)** Investigate further the simulated wave driving in the models through wavenumber decomposition, particularly wave-1 forcing. **(3)** Analyze other snow-cover related variables in the model (e.g., surface albedo, precipitation as snow) and calculate similar statistics and relationships.
- **ACKNOWLEDGEMENT:** This work was funded by the National Oceanic and Atmospheric Administration (NOAA) Grant # NA10OAR4310163.