High latitude snow: teleconnections with the tropics

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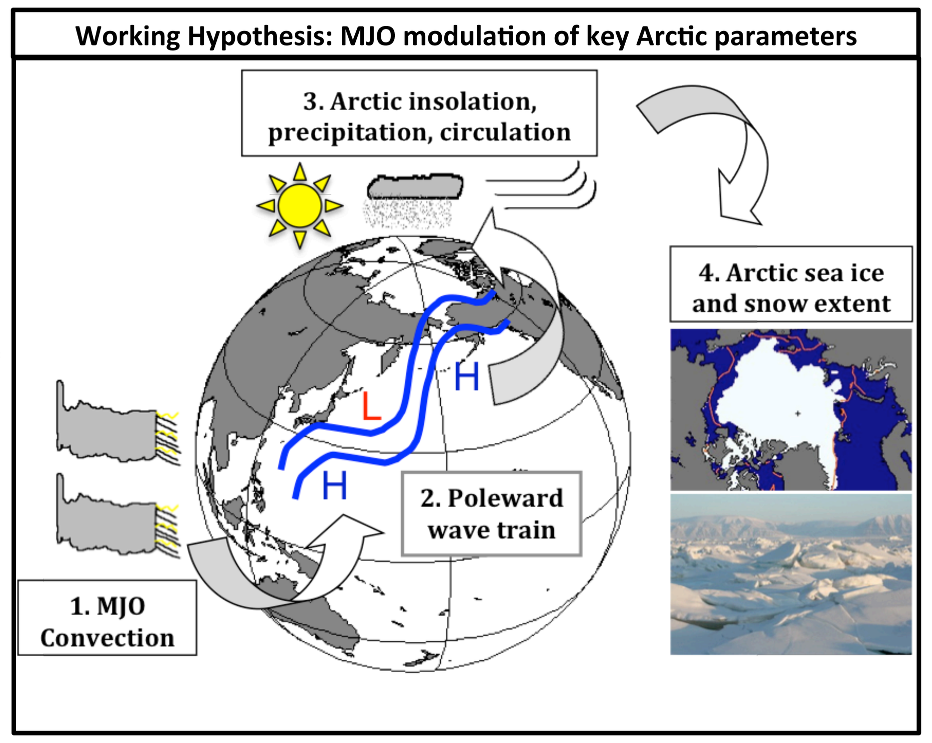
Hypotheses

(1) Spring snow depth across the Northern Hemisphere varies intraseasonally

(2) Eurasian snow water equivalent in October is connected to the Madden-Julian oscillation

(3) Modulations occur by atmospheric Rossby wave teleconnections



Data and data sources

Snow depth and water equivalent:

- NASA MERRA reanalysis: snow depth product (1.0° lat x 0.67° lon horizontal spacing), 1979-2014
- ERA-Interim/Land reanalysis: snow water equivalent (0.75° lat x 0.75° lon horizontal spacing), 1980-2010

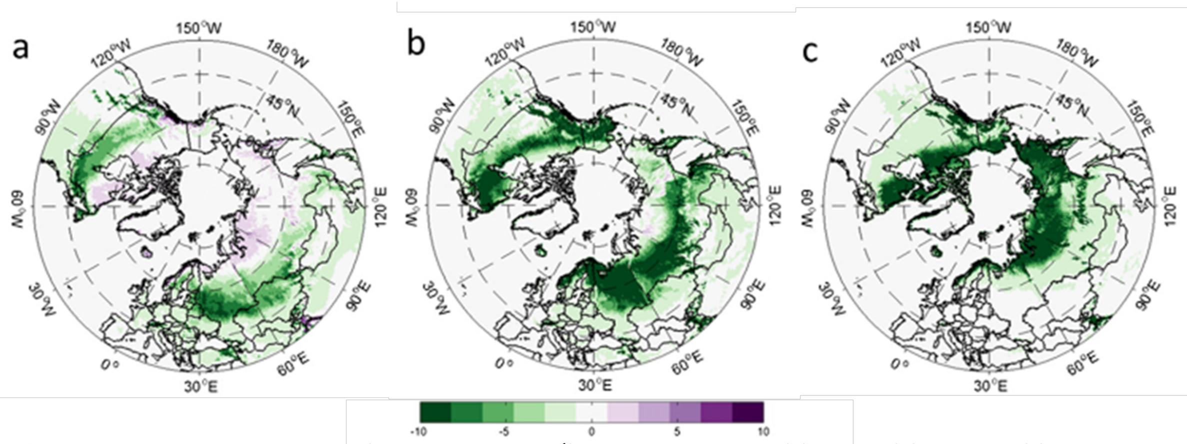


Figure 1: Daily snow depth change (colored; in cm day^{-1}) from 1980-2013 for (a) March, (b) April and (c) May, from NASA MERRA reanalysis (Barrett et al. 2015)

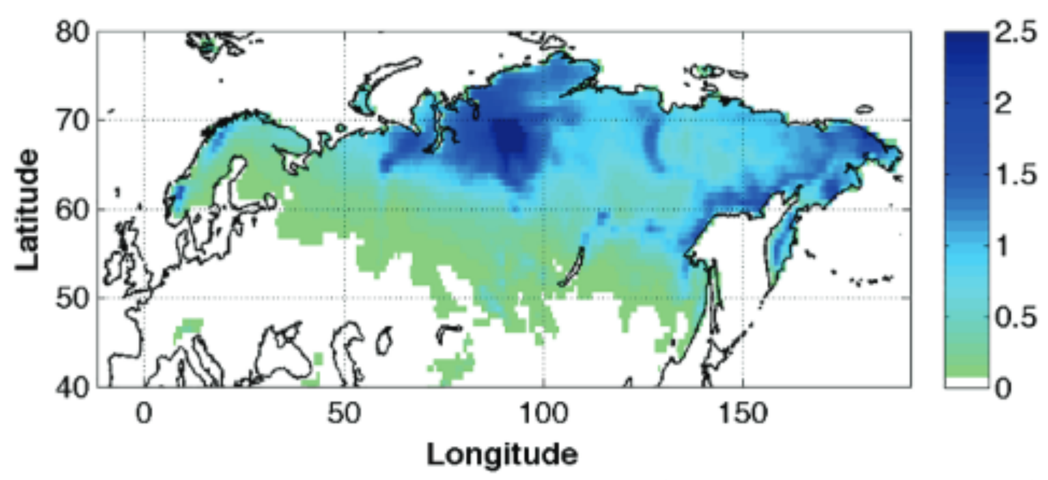


Figure 2: October mean daily snow water equivalent change, in mm day^{-1}, from 1980-2010, from ERA-Interim/Land reanalysis (Henderson et al. 2016)

Atmosphere:

- NCEP/DOE AMIP-II reanalysis: daily 500-hPa height and 2-m surface air temperature from (2.5° lat x 2.5° lon horizontal spacing), 1979-2014
- ERA-Interim reanalysis: 500-hPa height (0.75° lat x 0.75° lon horizontal spacing), 1980-2010

Madden-Julian Oscillation:

- MJO: Real-time multivariate MJO (RMM) first leading principal components (RMM1 and RMM2) from Wheeler and Hendon (2004). Active MJO defined as $(RMM1^2+RMM2^2)^{1/2} > 1.0$

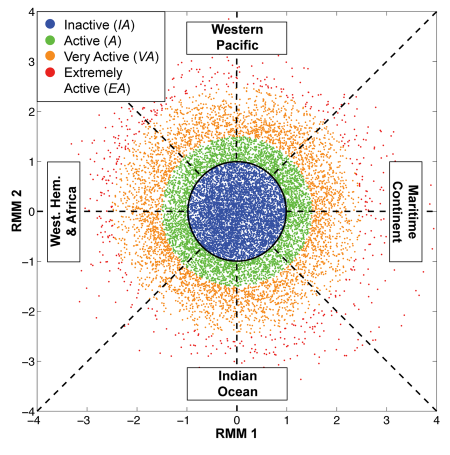


Figure 3: Phase-space diagram of the RMM index showing daily phase (octant) and amplitude (distance from figure center) of the MJO from 01 Jun 1974 to 31 Mar 2014. Colors indicate MJO activity: blue is weak and inactive, green active but not overly so, yellow and red are very and extremely active, respectively (LaFleur et al. 2015).

Methods

Compositing:

- Daily change values of SD and SWE were binned by active MJO phase
- Anomalies of SD and SWE were calculated with respect to monthly means, instead of seasonal means, to avoid seasonal shifts in both variables.

Self-organizing maps (SOM):

- Fields of daily change in SWE (961 total days) were organized into 15 nodes by a SOM technique.
- Different numbers of nodes, as well as different numbers of iterations (10,000 to 20,000) were explored, with the results shown for 15 nodes and 20 000 iterations.

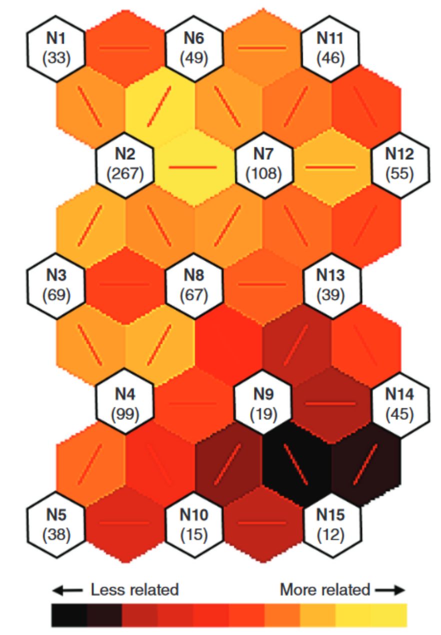


Figure 4: SOM neural network and number of members (in parentheses) for daily SWE over Eurasia for October days, 1980-2010, (Henderson et al. 2016).

Result: snow depth variability

Snow depth and the MJO:

- For the first time, variability in springtime Northern Hemisphere snow depth was explored by phase of the MJO.
- Statistically significant regions of daily snow depth change anomalies were found in March, April and May in both North America and Eurasia, sometimes exceeding 100% of the monthly normal for MJO phase.

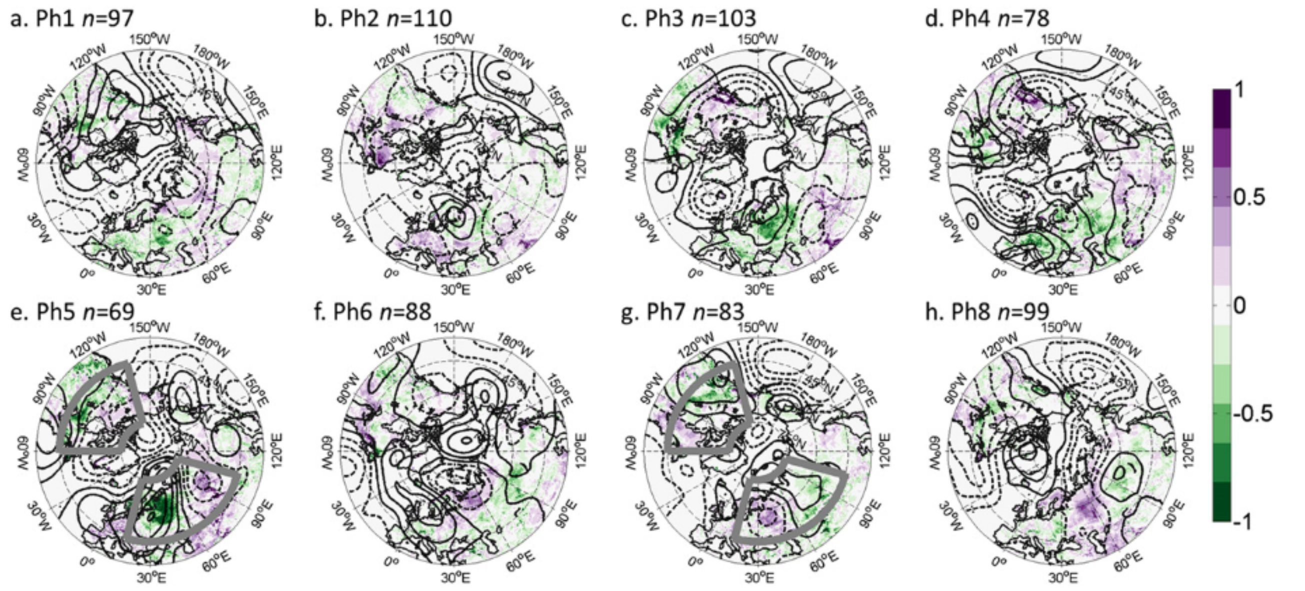


Figure 5: March daily anomalies of snow depth change (shaded; cm day-1) and 500-hPa height (black contours every 20 m, positive solid and negative dashed), for MJO phases 1-8. Gray sectors in phases 5 and 7 indicate strongest variability in those two phases (Barrett et al. 2015)

March

- In March, seven days after active MJO phase 5, wavy 500-hPa and 2-m surface temperature anomaly fields were noted over the entire Northern Hemisphere.
- Correlation coefficients (r^2) between anomalies of snow depth change and both surface air temperature and 500-hPa height approached -0.6, indicating moderate to strong physical relationship between both.
- Similar patterns were found for April and May, but with weaker statistical relationships, indicating the strongest intraseasonal variability of snow depth in March.

TABLE 1. Spearman rank correlations between 500-hPa height and daily snow depth change as well as surface temperature and daily snow depth change for March 1980–2013. The Eurasian sector includes 45°–75°N, 15°–105°E, while the North American sector includes 45°–75°N, 135°–60°W. Bold values indicate the phase with the largest correlation coefficient.

March	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	Phase 7	Phase 8
Eurasia Z500	−0.21	−0.20	−0.37	−0.09	**−0.62**	−0.31	−0.56	−0.53
Eurasia SAT	0.01	0.27	0.22	−0.21	−0.37	0.32	**−0.55**	−0.43
North America Z500	−0.03	−0.01	−0.49	−0.28	−0.51	0.20	**−0.55**	−0.01
North America SAT	0.09	−0.05	−0.03	−0.15	**−0.45**	0.21	0.12	0.08

(Barrett et al. 2015)

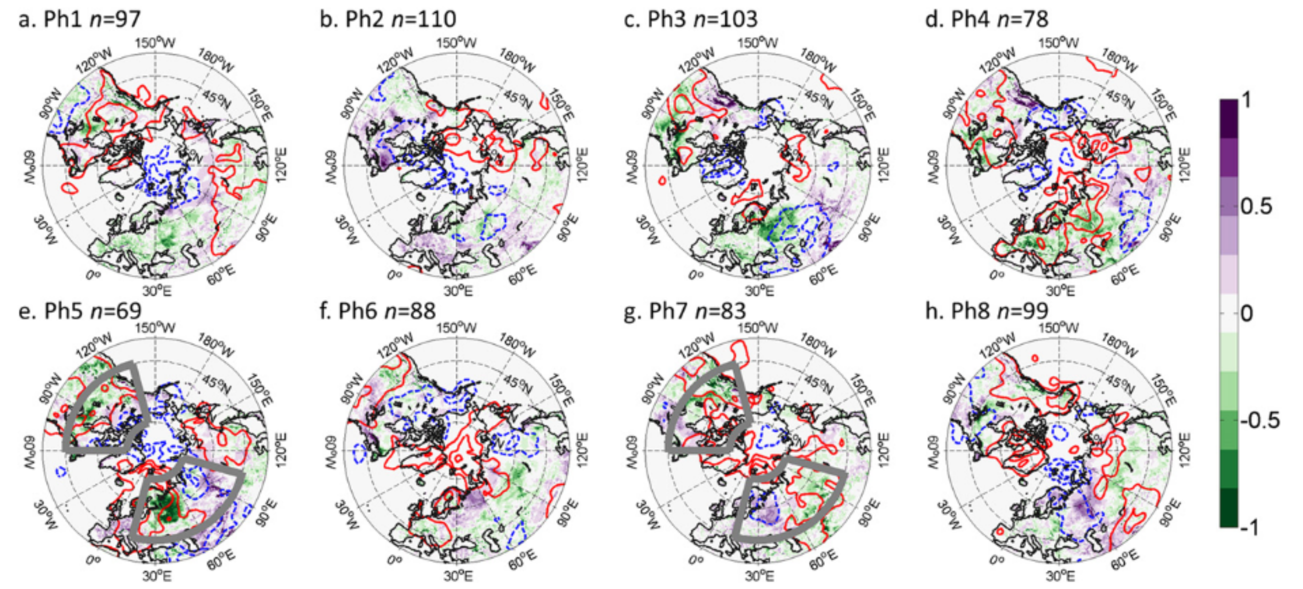


Figure 6: March daily anomalies of snow depth change (shaded, in cm day-1), as in Fig. 5, and anomalies of 2-m air temperature (every 1 K, red contours positive, blue negative). Gray bounded regions indicate Eurasian and North American sectors reported in Table 1 (Barrett et al. 2015).

Result: snow water equivalent variability

Snow water equivalent (SWE) and the MJO:

- Motivated by a well-established link between autumn snow and subsequent winter NH circulation, October Eurasian snow variability was connected to the MJO.
- Circulation and SWE anomalies were most strongly correlated during MJO phases 4-7.
- Snow patterns represented by Nodes 1, 3, and 12 (Fig. 7) were best connected to MJO phases, indicating the MJO may project preferentially onto those patterns.

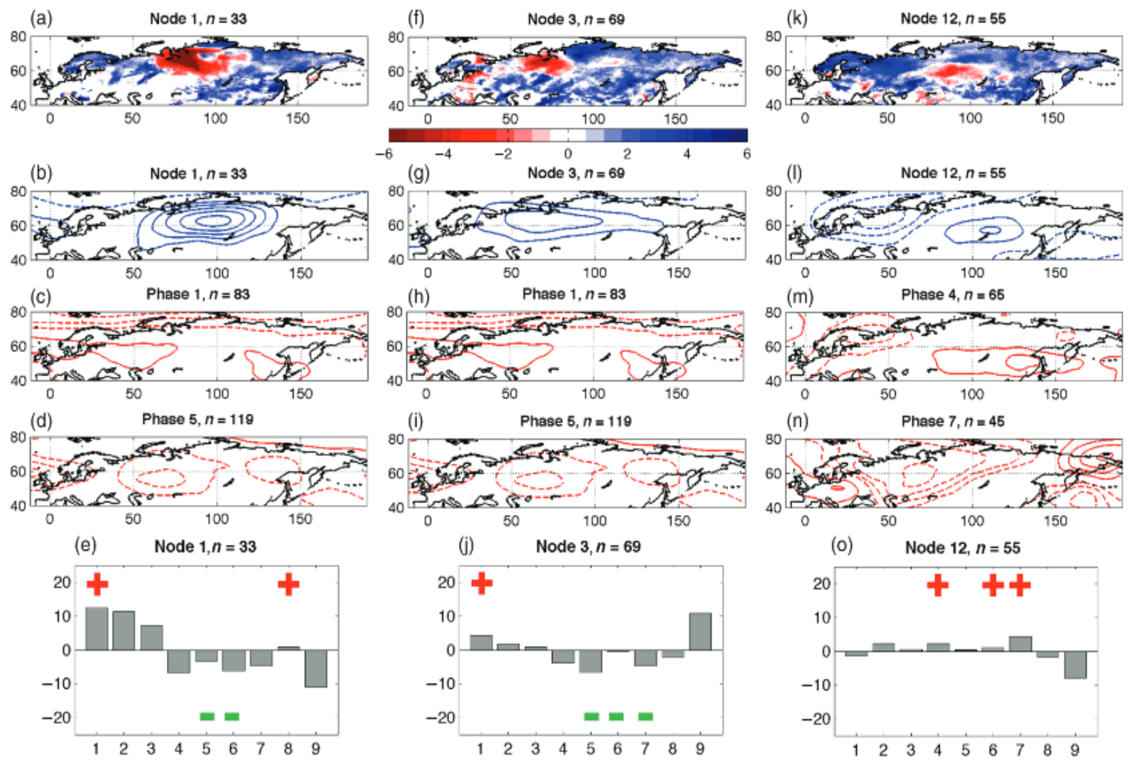


Figure 7: (a, f, k) Anomalies of mean daily change in SWE (mm day-1) and (b, g, l) 500-hPa height anomalies (in m, contour interval 40 m) for three SOM nodes having strongest correlations between change in SWE anomalies and 500-hPa height anomalies. (c, d, h, i, m, and n) Mean daily 500-hPa height anomalies for MJO phases 1, 5, 4, and 7, respectively, selected for having strongest correlations to height anomalies in those nodes. (e, j, and o) Anomalies of relative frequency, with + and – symbols indicating phases with strongest positive and negative correlations between MJO and node heights (Henderson et al. 2016).

Conclusions and acknowledgements

- ✓ The Madden-Julian Oscillation modulates spring-season snow depth changes
  - Modulation depends on MJO phase and month
- ✓ The MJO also modulates autumn-season changes in Eurasian snow water equivalent
  - Some patterns of 500-hPa height and SWE change showed preference for certain MJO phases

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