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

Atmospheric:
- NCEP/DOE AMP-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

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.

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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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.

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.

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 2: October mean daily snow water equivalent change, in mm day^-1, for MJO phases 1-8. Colors indicate MJO activity: blue is weak and red is strong. Green indicates medium activity.

Figure 3: October mean daily snow water equivalent change, in mm day^-1, showing daily phase (a) and week phase (b) from December 1980 to April 2013 for MJO phases 1-8. Warm colors indicate MJO activity. Blue is weak and red is strong.

Figure 4: October mean daily snow water equivalent change, in mm day^-1, from December 1980 to April 2013 for MJO phases 1-8. Dark blue areas indicate the slowest intraseasonal changes, with red and yellow areas indicating the fastest changes.

Figure 5: October mean daily snow water equivalent change, in mm day^-1, from December 1980 to April 2013 for MJO phases 1-8. Dark blue areas indicate the slowest intraseasonal changes, with red and yellow areas indicating the fastest changes.

Figure 6: October mean daily snow water equivalent change, in mm day^-1, showing daily phase (a) and week phase (b) from December 1980 to April 2013 for MJO phases 1-8. Warm colors indicate MJO activity. Blue is weak and red is strong.

Figure 7: October mean daily snow water equivalent change, in mm day^-1, for MJO phases 1-8. Colors indicate MJO activity: blue is weak and red is strong. Green indicates medium activity.

Figure 8: October mean daily snow water equivalent change, in mm day^-1, from December 1980 to April 2013 for MJO phases 1-8. Dark blue areas indicate the slowest intraseasonal changes, with red and yellow areas indicating the fastest changes.