Intraseasonal Influences on Terrestrial Snow Cover in the Northern Hemisphere

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Introduction

Climate system variability in the high-latitudes has been extensively studied (Rodney 2013, Lin 2009, Yoo 2012). However, connections between shorter-term, intraseasonal climate system variability and high-latitude snow cover are less understood. The Madden Julian Oscillation (MJO) is the primary mode of intraseasonal variability in the tropics, and it is known to have important teleconnections to the high latitudes, particularly in modulating high-latitude atmospheric circulation (Vecchi 2003, Yoo 2012, L'Heureux 2008).

This study examines variability of high-latitude Northern Hemisphere snow, snow cover extent, the atmosphere, and the Pacific North American Pattern and explores possible connections to the MJO. To accomplish this objective, variability in aforementioned was examined by phase of the Real-time Multivariate MJO (RMM) index. Given the continued increase in predictive skill of the MJO, work such as this that establishes statistical relationships between the MJO and smaller-scale, less predictable phenomena (such as high-latitude snow cover) may lead to increased predictability of the smaller-scale phenomena (Rodney 2013).

Data

- Snow coverage data was obtained from the National Oceanic and Atmospheric Administration's *MEaSUREs Northern Hemisphere Terrestrial Snow Cover Extent Daily 25 km EASE-Grid 2.0* (Robinson, 2014). Data is displayed as either snow cover accumulation, no change, or snow cover ablation.
- MJO data was obtained from the Madden-Julian Real-time Multivariate Index (Wheeler and Hendon, 2004)
- Surface air temperature (SAT), 500 mb heights (z500), and mean sea level pressure (MSLP) data was obtained from the NOAA-NCEP-DOE Reanalysis 2 (Kanamitsu, 2002).
- Only the days within in March from 1999 to 2012 were examined in the study.
- Snow depth data was obtained from ERA-40 dataset from the European Centre for Medium-Range Weather Forecasts (ECMWF, 2009).
- The PNA index was obtained from the NOAA Climate Prediction Center (online at http://www.cpc.ncep.noaa.gov/).

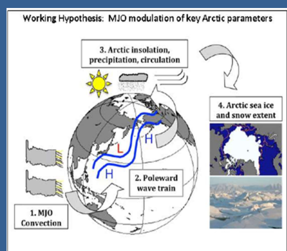

Figure 1. Working hypothesis for MJO modulation of snow.

Methods

MJO & Snow

- Binned atmospheric and snow data by MJO phase. Only days with an MJO amplitude greater than or equal to one were used.
- Averaged snow cover addition, snow cover ablation, snow depth, mean sea level pressure, and surface air temperature in March and for each phase for years 1999 to 2012.
- Calculated anomalies for each variable of each phase by subtracting the monthly mean for each variable from the daily mean of each phase.
- Tested each variable for statistical significance and only showed the anomalies that were statistically significant at the 95% confidence level.
- Repeated for SAT, z500, and MSLP

MJO & PNA

- Binned PNA index by month and then by phase where positive and negative PNA days were separated and neutral days were discarded.
- Bar graphs were generated for positive and negative PNA days for each month showing the number of days of occurrences within each phase.
- The relative frequency of the occurrences of each phase in a month was calculated by dividing the number of days of each phase by the total number of days.
- The anomalous frequency was then calculated by subtracting the relative frequency of an entire month from the individual phase relative frequencies for the month.

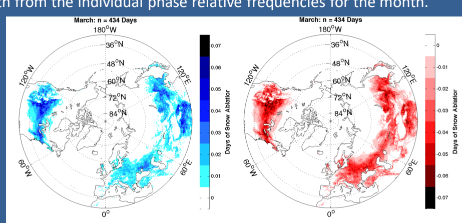

Figure 2. *Mean snow cover accumulation (left) and average snow cover ablation (right) for March from 1999 to 2012.*

Results: Snow Cover, Snow Depth and the MJO

Anomalous Snow Cover Accumulation

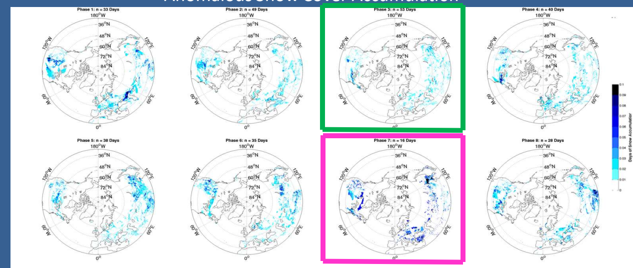
Figure 3. *Snow cover accumulation anomalies for March from 1999 to 2012 for each phase of the MJO. Only anomalies that were statistically significant at the 95% confidence level are shown.*

Anomalous Snow Cover Ablation

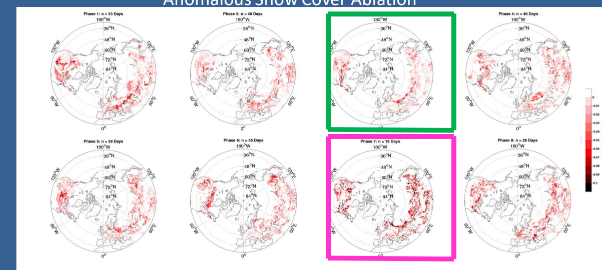
Figure 4. *Snow cover ablation anomalies for March from 1999 to 2012 for each phase of the MJO. Only anomalies that were statistically significant at the 95% confidence level are shown.*

Anomalous Snow Depth Change (SDC)

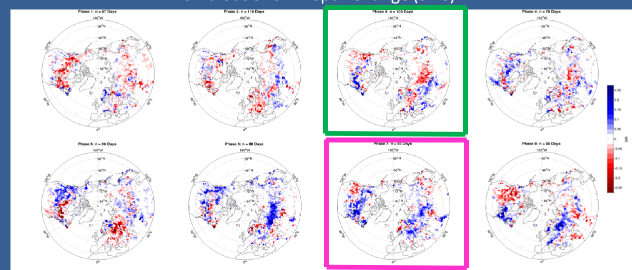
Figure 5. *Anomalies of Daily Snow depth change for March for 1980 to 2013 for each phase of the MJO. Only anomalies that were statistically significant at the 95% confidence level are shown.*

Snow Cover & MJO

- Both snow cover accumulation and ablation was expected in March and changes in snow cover extent occurred near the ephemeral snow line (Figure 3 and 4).
- Phase-to-phase variability in snow cover accumulation, ablation, and snow depth was observed (Figure 3, 4, and 5).

Snow Depth & MJO

- Snow depth changed significantly in each phase and variability between phases was evident (Figure 5).
- Phases 5 and 8 featured dipole patterns in snow depth over both North America and Eurasia. Patterns in phase 5 were of opposite sign from phase 8 (Figure 5).
- Phase 7 displayed the greatest accumulation and ablation, while phase 3 displayed the least accumulation and ablation (Table 1).

Phase	Accumulation	Ablation
1	367.07	496.17
2	252.30	329.75
3	210.34	269.98
4	256.43	404.87
5	314.69	423.61
6	294.62	424.27
7	400.52	777.21
8	319.05	487.07

Table 1. *Sum of the magnitude of the anomalies for snow cover accumulation and ablation for each phase.*

Atmospheric Variables & MJO

- To explain observed snow anomalies, phases 3 and 7 were compared to surface air temperature, mean sea level pressure, and 500 mb geopotential heights (Figure 6).
- During phase 3 in North America, MSLP anomalies seen may support the observed dipole in SDC anomalies, with low pressure off the east coast possibly supporting pos. SDC, and high pressure in GOA possibly supporting neg. SDC (Figure 6).
- During phase 3 in Eurasia, pos. SDC is collocated with positive SAT, given normally cold conditions, warmer conditions could support snowier conditions, also 500 mb troughs and ridges could support SD accumulation and ablation in given area (Figure 6).
- During phase 7 in North America, SDC is supported by SAT anomalies in western and eastern sides of the continent. Trough and ridge patterns associated with 500 mb heights possibly supports pos. and neg. SDC (Figure 6).
- During phase 7 in Eurasia, large pos. SDC was observed, but with the exception of certain SAT anomalies, circulation patterns do not appear related to SDC anomalies (Figure 6).

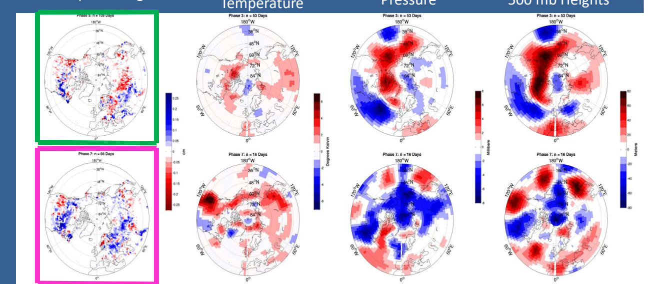

Figure 6. *Anomalies of Surface Air Temperature (degrees kelvin), Mean Sea Level Pressure (millibars), and 500 mb Heights (meters) for Phase 3 (top) and Phase 7 (bottom). Only anomalies that were statistically significant at the 95% confidence level are shown.*

Results: the Pacific North American Pattern and the MJO

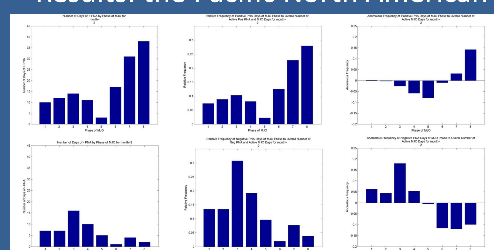
Figure 7. *From left to right, number of occurrences per phase, relative frequency and anomalous frequency for positive (top) and negative (bottom) PNA days for in March.*

- A positive anomaly occurred for phases 7 and 8 and a negative anomaly for 3 through 6 for (+) PNA days (Figure 7).
- A positive anomaly occurred for phases 1 through 4 and a negative anomaly for 5 through 8 for (-) PNA days (Figure 7).
- Dipole behavior is observed between pos. and neg. PNA days (Figure 7).

Summary

1. General variability of snow and PNA by phase of MJO was observed.
2. Positive and negative SDC movement in a dipole pattern suggest a connection with MJO as it progresses through phases.
3. Several connections between snow, atmospheric variables, and the MJO are seen as distinct possibilities
4. Some variables have little connection with snow depth during certain phases of the MJO.
5. Suggestion of a dipole relationship between positive and negative PNA according to phase of the MJO.

Acknowledgments & References

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