Effects of a Warming Climate on Daily Snowfall Events in the Northern Hemisphere

James Danco*, Anthony DeAngelis, Bryan Raney, and Anthony Broccoli

* Current affiliation: School of Meteorology, University of Oklahoma, Oklahoma, USA: jdanco@ou.edu

Department of Environmental Sciences, Rutgers University, New Jersey, USA

1. Introduction

Snow is an important aspect of weather and climate with physical, ecological, and societal impacts (Barnett et al. 2005; Eisenberg and Warner 2005; Vavrus 2007). Global temperature has increased during the past half-century, primarily due to the emission of greenhouse gases as a result of human activities, and this trend is likely to continue and perhaps accelerate in the coming decades (IPCC 2013). However, increases in winter precipitation are also likely in middle and high latitudes due to increased water vapor content in a warming climate (Held and Soden 2006). Therefore, the total effect of global warming on snowfall is a delicate balance between increased temperature, reducing the fraction of precipitation that falls as snow, and increased precipitation, which could mean more snowfall in regions that are cold enough. This study uses models from the Coupled Model Intercomparison 5 (CMIP5) project in order to examine how the frequency distribution of daily snowfall events in the Northern Hemisphere (NH) will be affected by increasing temperatures, as well as how these daily snowfall projections may be affected by the temperature biases of the models.

2. Data and Methods

Observations:

- Monthly temperature observations from the Hadley Center-Climatic Research Unit (HadCRU) dataset (1961-1990)

Models:

- 24 models consisting of 37 ensemble members from CMIP5 model suite
- Historical simulation of daily snowfall (1971-2000) and 21st-century climate simulation of daily snowfall using the RCP8.5 forcing scenario (2021-2050 and 2071-2100)
- Historical simulation of monthly temperature (1961-1990)

Methods:

- Model output and temperature observations interpolated to common 1° by 1° grid
- Discarded all grid boxes containing more than 50% water
- Snowfall determined from its water equivalent by assuming uniform 10:1 snow-to-liquid ratio, as in Krasting et al. (2013)

3. Spatial Patterns

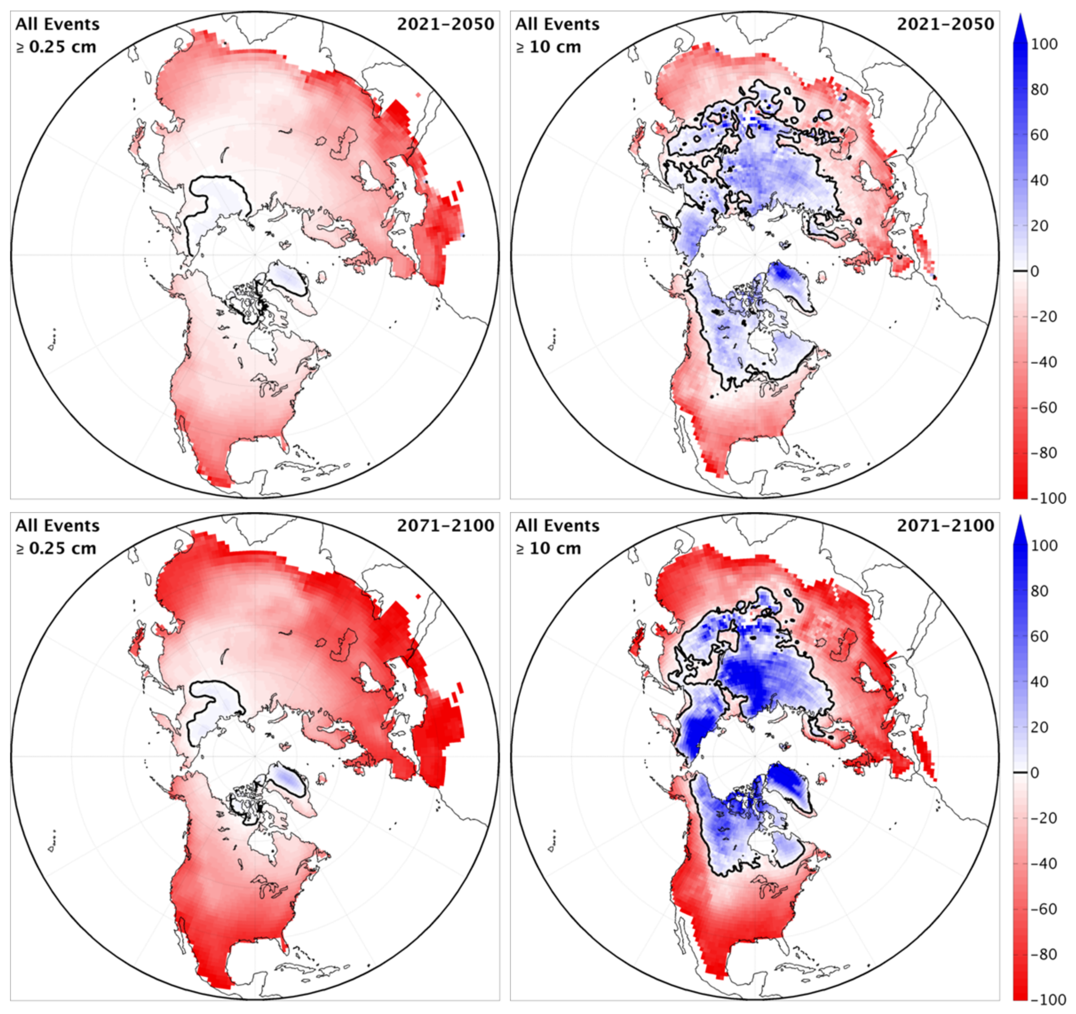

Fig. 1: Percent change in frequency of daily snowfall events ≥ 0.25 cm (left) and ≥ 10 cm (right) in all seasons simulated by the CMIP5 multimodel ensemble for the periods 2021-2050 (top) and 2071-2100 (bottom). The changes are expressed relative to a reference period of 1971-2000. Shading is included only for grid boxes that had at least five events in the reference period.

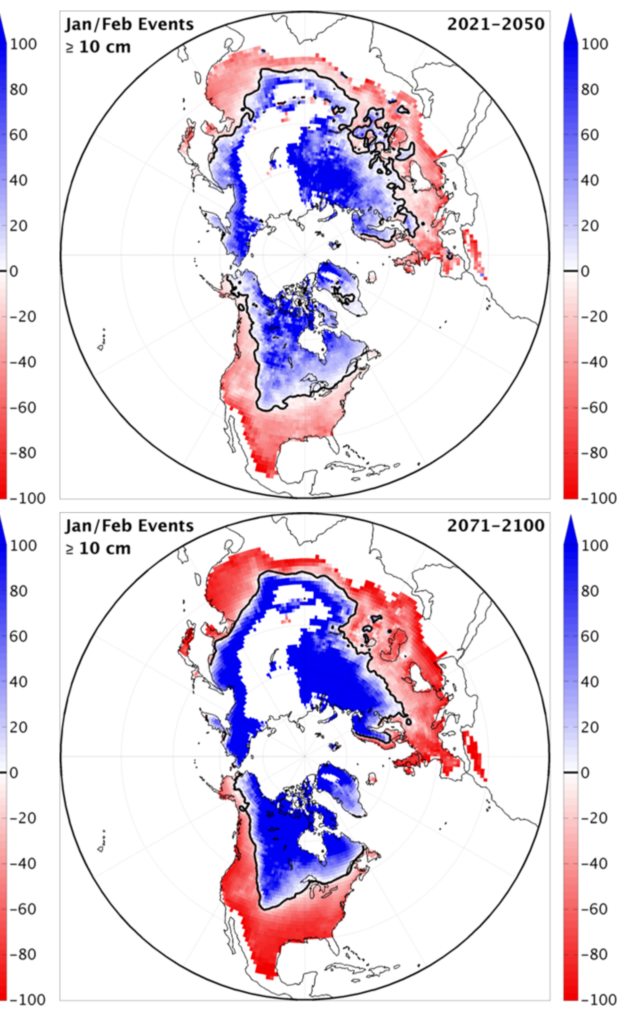

Fig. 2: Same as Fig. 1 (right), except for midwinter (January-February) events only.

- Frequency of measurable daily snowfall events projected to decrease across much of NH except for very high-latitude regions
- Much greater area expected to experience an increase in larger ≥ 10 cm events, including much of Canada, Greenland, northern Asia, and Tibet
- Jan-Feb snowfall events projected to increase in even more regions than events in all months of the year
- Trends become more pronounced by 2071-2100 compared to 2021-2050

4. Daily Snowfall Histograms

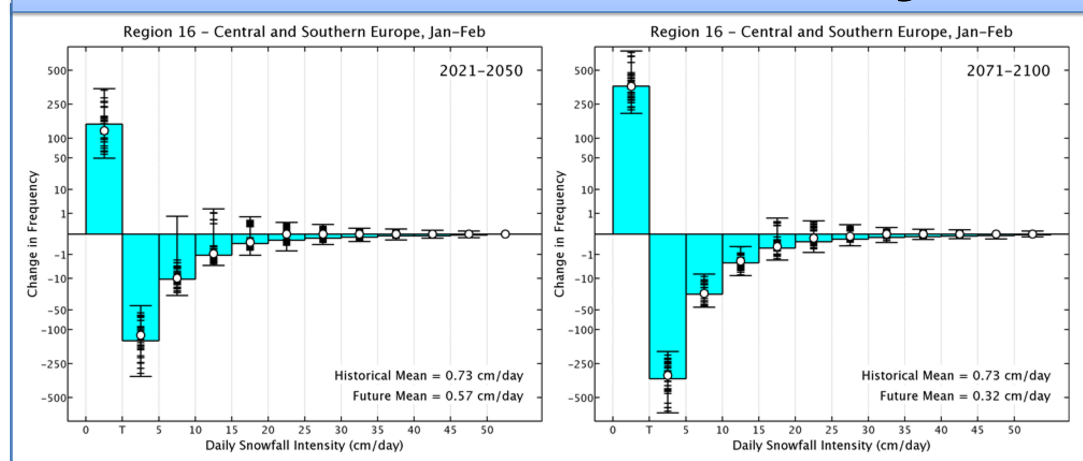

Fig. 3: Histograms depicting the change in frequency of daily snowfall events (January-February) as a function of intensity for the period 2021-2050 (left) and 2071-2100 (right) for central and southern Europe. The ordinate is displayed on a nonlinear scale. The histogram bars represent the mean difference in frequency among the ensemble means of all the models for that particular intensity bin, and each white circle represents the median difference in frequency among the ensemble means. Within a bin, the narrow black tick marks represent the difference in frequency of each multimodel ensemble member for that bin, while the upper and lower whiskers display the maximum and minimum difference, respectively, among all the members. All of the frequency differences are divided by the total number of grid points in the region. Average daily snowfall is displayed on each histogram for the historical and future period.

- Some regions (including southeastern US, US Mid-Atlantic, US West Coast, British Columbia, southern Alaska, and central and southern Europe) warm enough for models to project large decrease in daily snowfall for all bins in all months of the year, due to a lower fraction of precipitation falling as snow

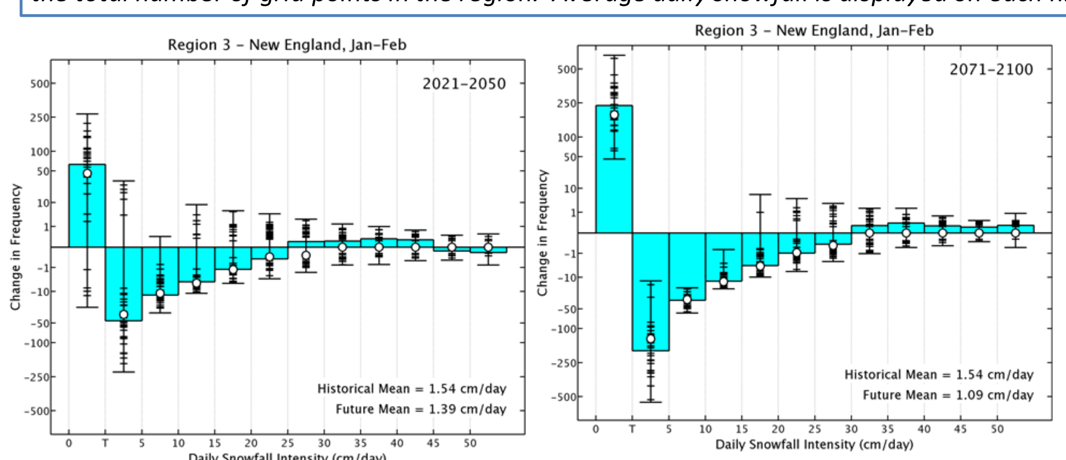

Fig. 4: Same as Fig. 3, except for New England.

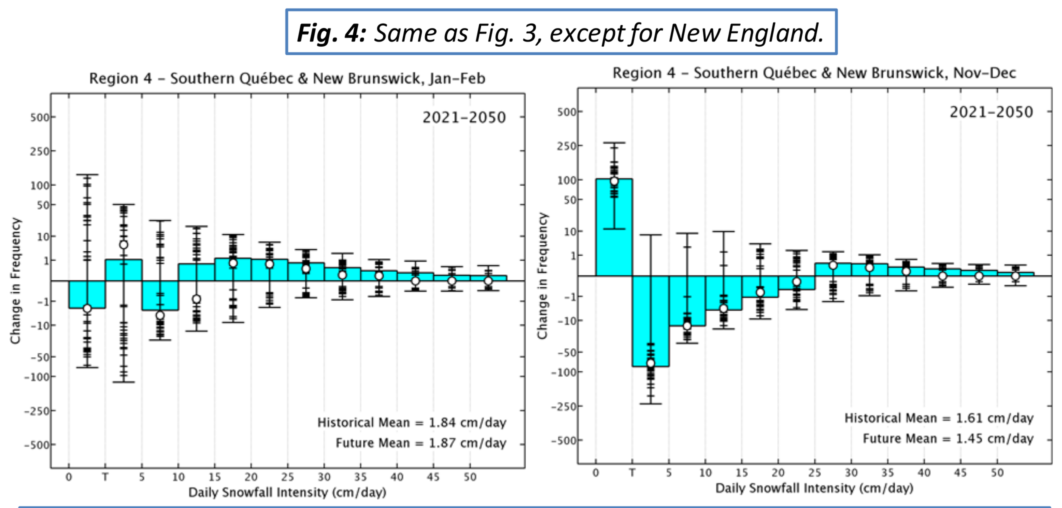

Fig. 5: Same as Fig. 3, except for southern Québec and New Brunswick for January-February (left) and November-December (right) for the period 2021-2050.

- In other regions slightly farther north and colder (New England, Japan, Caucasus Mountains, and Baltic Sea regions), average snowfall still simulated to decrease in all months of year, but in Jan-Feb frequency of intense snowfall events stays about same or slightly increases
- Southern Québec and New Brunswick, Labrador, eastern Hudson Bay, Tibet, and northern Scandinavia: models project overall increase or little change in daily Jan-Feb snowfall by 2021-2050 due to increase in precipitation becoming more dominant factor, with increase in large event frequency still projected for Nov-Dec and Mar-Apr
- NE Québec, NW Siberia, and NE Siberia: frequency of daily snowfall events simulated to rise in Jan-Feb as well as Nov-Dec and Mar-Apr, with increase in large events in Sept-Oct and May-June

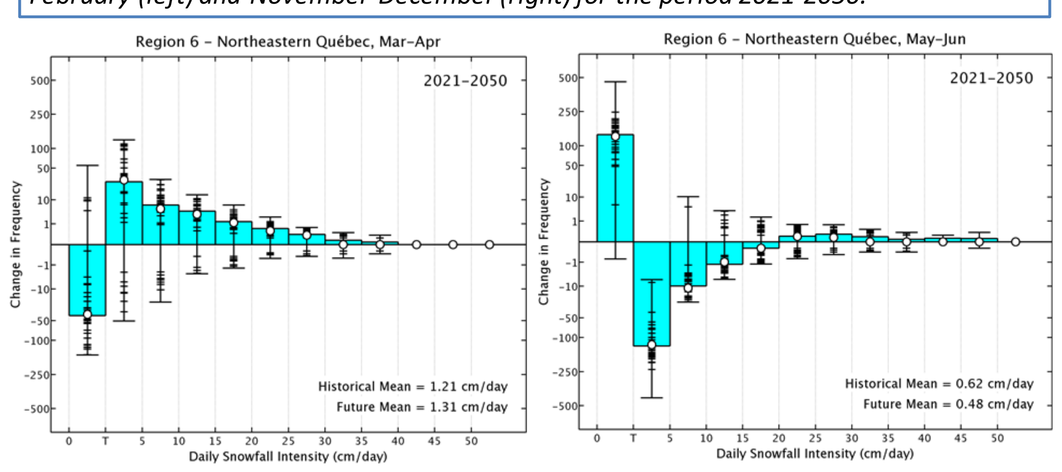

Fig. 6: Same as Fig. 3, except for northeastern Québec for March-April (left) and May-June (right) for the period 2021-2050.

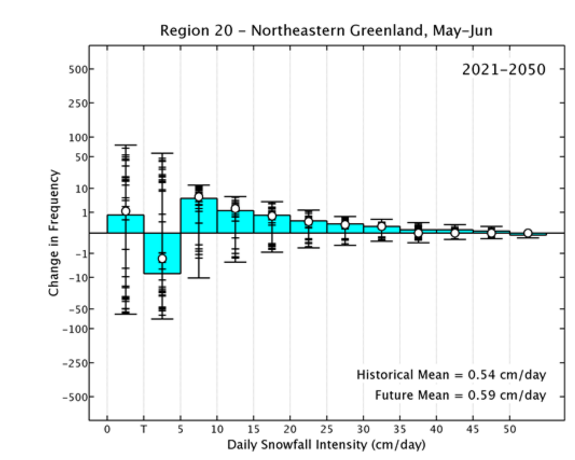

Fig. 7: Same as Fig. 3, except for northeastern Greenland for May-June for the period 2021-2050.

- Greenland: only region examined where daily snowfall projected to increase by 2021-2050 for all two-month intervals and nearly all bins, with the exception of July-August

5. Model Temperature Biases

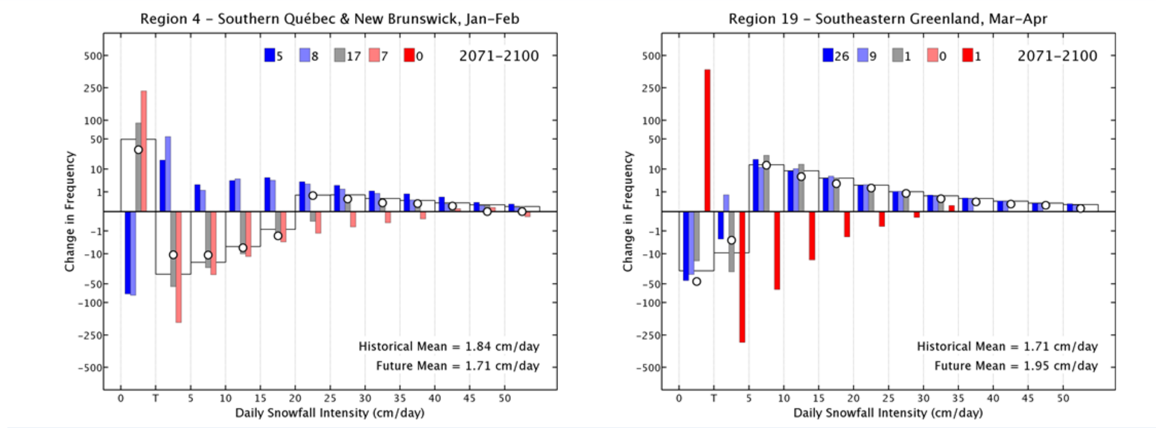

Fig. 8: Similar to Fig. 3, except modified to show relationships between changes in snowfall events and temperature biases for southern Québec and New Brunswick for January-February (left) and southeastern Greenland for March-April (right) for the period 2071-2100. Within each intensity bin, the individual ensemble members are divided into five groups based on their bias in simulated temperature over the period 1961-1990 for the specified region. The five colored bars in a bin represent the mean difference in frequency of daily snowfall events computed over each of the temperature bias groups: Darker and lighter blue bars average over members with cold biases of >5 °C and 2-5 °C, respectively; darker and lighter red bars average over members with warm biases of >5 °C and 2-5 °C, respectively; and gray bars average over members with biases smaller than 2 °C. The numbers next to the colored boxes at the top of each graph display the total count of members belonging to the corresponding temperature bias group. For reference, the wider white bars and white circles represent the same as the cyan bars and white circles in Figs. 3-7.

- In many colder NH regions examined in Jan-Feb (and occasionally warmer months as well), temperature biases appear to influence model snowfall projections, with warm-biased ensemble members more likely to show snowfall decreases, or smaller increases, than cold-biased members

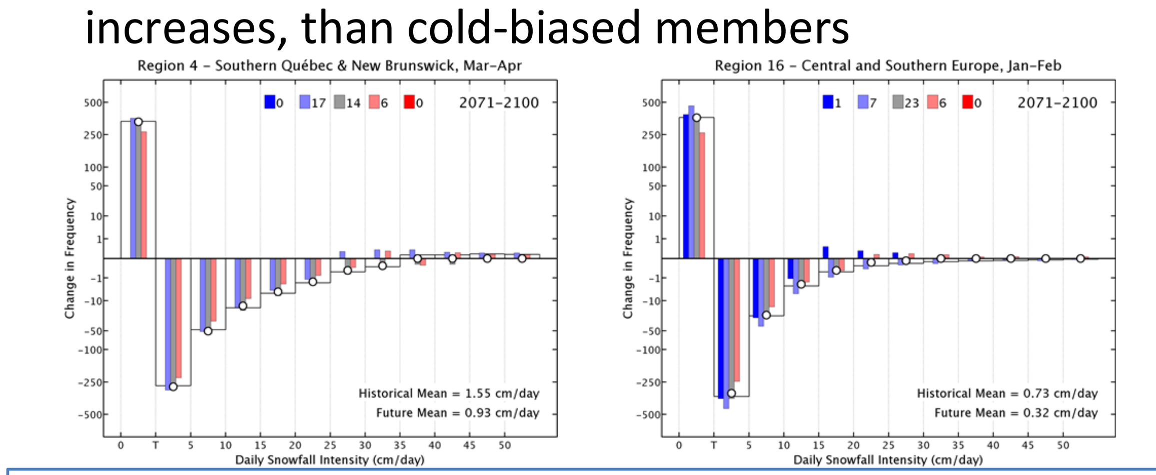

Fig. 9: Same as Fig. 8, except for southern Québec and New Brunswick for March-April (left) and central and southern Europe for January-February (right).

- Influence of biases during warmer months and regions can be much less conclusive

6. Conclusions

- CMIP5 models simulate decrease in daily snowfall events across much of NH during 21st century due to warming temperatures, except at highest latitudes such as NE Canada, northern Siberia, and Greenland where increase in precipitation is expected, but temperatures are cold enough that some warming will not result in more precipitation falling as rain
- Much larger region of NH projected to have increase in daily snowfall in Jan-Feb than in warmer months of year because temperatures in warmer months more likely to be marginal for snowfall
- Frequency of large snowfall events simulated to increase in many regions/months (even while overall snowfall decreases) due to higher sea surface temperatures and more abundant atmospheric moisture in a warmer climate (Held and Soden 2006)
- Projected changes in daily snowfall exhibit some dependence on temperature biases of models, mainly in colder regions and months

References

Barnett, T. P., J. C. Adam, and D. P. Lettenmaier, 2005: Potential impacts of a warming climate on water availability in snow-dominated regions. *Nature*, **438**, 303-309, doi:10.1038/nature04141.

Eisenberg, D., and K. E. Warner, 2005: Effects of snowfalls on motor vehicle collisions, injuries, and fatalities. *Amer. J. Public Health,* **95,** 120–124, doi:10.2105/AJPH.2004.048926.

Held, I. M., and B. J. Soden, 2006: Robust responses of the hydrological cycle to global warming. *J. Climate,* **19,** 5686–5699, doi:10.1175/JCLI3990.1.

IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Krasting, J.P., A.J. Broccoli, K.W. Dixon, and J.R. Lanzante, 2013: Future changes in Northern Hemisphere snowfall. *J. Climate,* **26**, 7813-7828, doi:10.1175/JCLI-D-12-00832.1.

Vavrus, S., 2007: The role of terrestrial snow cover in the climate system. *Climate Dyn.*, **29**, 73–88, doi:10.1007/s00382-007-0226-0.