Comparative Analysis of NOAA and NASA Snow Cover Extent Products

DAVID A. ROBINSON[1], THOMAS W. ESTILOW[1], DOROTHY K. HALL[2], AND GEORGE A. RIGGS[3]

ABSTRACT

Key satellite-derived snow cover extent (SCE) Earth Science Data Records (ESDR) from NOAA and NASA are invaluable in monitoring SCE variability and change. However, questions remain regarding specific SCE values, including confidence limits for these climate ESDRs. Here, we report on a new effort to achieve a better understanding of each product's strengths and weaknesses to ensure the best SCE ESDR at meso-to-macro scale levels is available to the climate community and others in need of such valuable information. Analyses are underway utilizing NOAA/IMS and NASA MODIS and VIIRS products on regional and seasonal levels over the past two decades. In addition to cases studies for individual regions and dates, project analyses include longitudinal evaluations over a wide range of landscapes. Preliminary results for selected regions in all seasons are providing encouraging spatial correlations between products, though fall extents are found to differ between the NOAA and NASA products more than winter and spring extents. This is likely due to a combination of more extensive cloud cover and lower solar illumination during fall. Ultimately, study results will direct users to a particular map product depending upon their needs with regard to spatial resolution or temporal continuity.

INTRODUCTION

While considerable attention has been paid to specific characteristics associated with sea ice, glacial ice, and ice sheets, including variability and trends, less attention has been paid to the distribution of snow cover in the climate system. This is not to say that snow cover has been ignored, however snow on land, the climate variable exhibiting the greatest intra-annual variability, requires additional scrutiny. This includes assessment of the extent of snow cover, where it has long been recognized that spring change is in progress (Robinson and Dewey, 1990). Declining snow cover extent (SCE) has been particularly notable across the Arctic and Sub-Arctic in May and June over the past decade. On the other hand, sizeable increases in SCE have been noted over northern interior lands in mid-late fall. This is apparently associated with enhanced moisture fluxes and persistent circulation regimes, both of which may be influenced by greater open water in the Arctic (Allchin and Déry, 2020).

---

[1] Rutgers University, Piscataway, NJ, USA
[2] Earth System Science Interdisciplinary Center / University of Maryland, College Park, MD, USA
[3] Science Systems and Applications, Inc., Lanham, MD, USA
Corresponding author: david.robinson@rutgers.edu

Key satellite-derived SCE Earth Science Data Records (ESDRs) from NOAA and NASA have been invaluable in monitoring variability and change (Estilow et al., 2015; Woods and Helfrich, 2019; Hall et al., 2019; Riggs and Hall, 2020). These products continue to be the preeminent SCE ESDRs in existence and are likely to remain so for the foreseeable future. However, questions remain regarding specific SCE estimates, including confidence limits for these climate ESDRs. To address these issues and gain a strong understanding of each product's strengths and weaknesses, our team is conducting comparative analyses. Initial results are presented here. Ultimately, this will lead to the best Northern Hemisphere continental SCE ESDR at meso-to-macro scale levels available to the climate community and others in need of such valuable information.

This current study serves as a precursor to a future one that will combine these products into an ESDR with meaningful uncertainty bounds that will extend from the start of the MODerate-resolution Imaging Spectroradiometer (MODIS) era through the present and future Visible Infrared Imaging Radiometer Suite (VIIRS) era, during which time the NOAA IMS analysis/mapping system has been employed to generate the NOAA daily product. Furthermore, combining the NASA MODIS and VIIRS SCE products with the weekly NOAA product that the Rutgers team recently re-digitized at 24 km resolution from 1981–1999, will yield a more confident CDR that can be extended back two decades further. While NOAA weekly maps are available from late 1966, the quality prior to the 1980s is such that re-digitizing to 24 km was not considered useful.

NASA AND NOAA SNOW COVER EXTENT PRODUCTS

We use the NASA MODIS Terra cloud-gap filled (CGF) normalized-difference snow index (NDSI) daily snow-cover product, MOD10A1F, Collection 6.1. A clear view of the surface is provided each day by looking back to the last cloud-free observation of the surface on a per-pixel basis (Hall et al., 2010 & 2019 and Riggs et al., 2018). The MOD10A1F product was developed and produced at Goddard Space Flight Center (Riggs et al., 2017) and is distributed by the National Snow and Ice Data Center (https://nsidc.org/data/mod10a1f/versions/61) as part of a suite of NASA standard snow-cover products [https://modis-snow-ice.gsfc.nasa.gov/]. Daily MOD10A1F data products are available beginning 24 February 2000 (Fig. 1), and extending to the present, except during short-term outage periods caused by spacecraft maneuvers, temporary software or instrument issues or upgrades. The snow cover products have been validated at Stage 2, meaning that product accuracy is estimated over a significant (typically > 30) set of locations and time periods by comparison with reference in situ or other suitable reference data. The greatest uncertainty in SCE mapping is cloud obscuration of the surface.

The Interactive Multisensor Snow and Ice Mapping System (IMS) is a software tool used for daily monitoring of snow and ice extent across the Northern Hemisphere. Qualified analysts at the U.S. National Ice Center assess snow and ice cover using a combination of satellite imagery, derived products, and surface observations. Prior to the charting process, products and imagery from various sources are pre-processed to match the IMS system's geographic parameters (Fig. 2). These data are then retrieved and displayed on IMS workstations, where analysts manually delineate snow covered lands. IMS mapping begins using the previous day's SCE output, which is modified based on interpretation of the most recent data available in the system. According to Helfrich et al. (2007), looping visible satellite imagery in combination with meteorological data comprise 80 to 90% of the inputs used for SCE analysis. IMS output at 24-km nominal resolution has been produced operationally since November 1998, and is considered valid at midnight UTC each day.

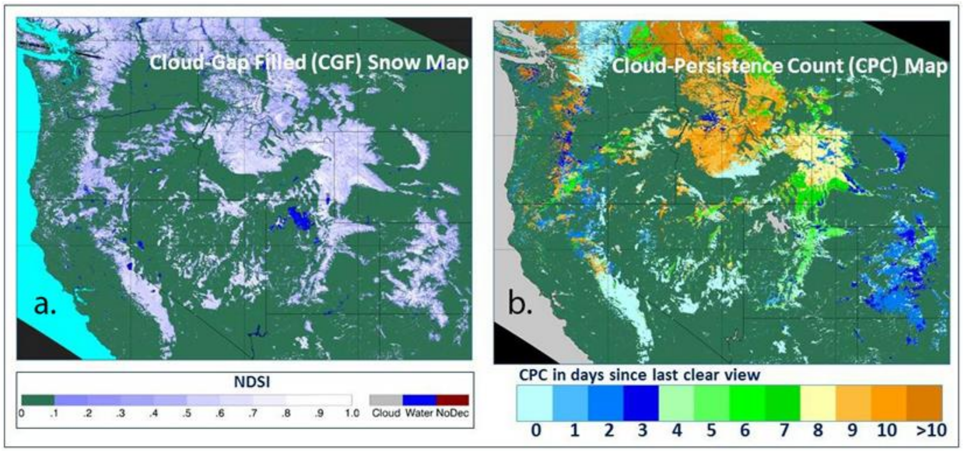

Figure 1. (a) Terra MODIS cloud-gap-filled (CGF) MOD10A1F snow map for 19 March 2012. (b) Cloud-persistence count (CPC) map associated with the MOD10A1F snow map from the quality assurance (QA) data set for the CGF snow map in (a). For 19 March 2012, when a pixel has a CPC of zero, it means that the NDSI value for that pixel was acquired on 19 March 2012. When a pixel has a CPC of one, it means that the NDSI pixel value is 1 day old, and was therefore acquired on 18 March, and so on (from Hall et al., 2019).

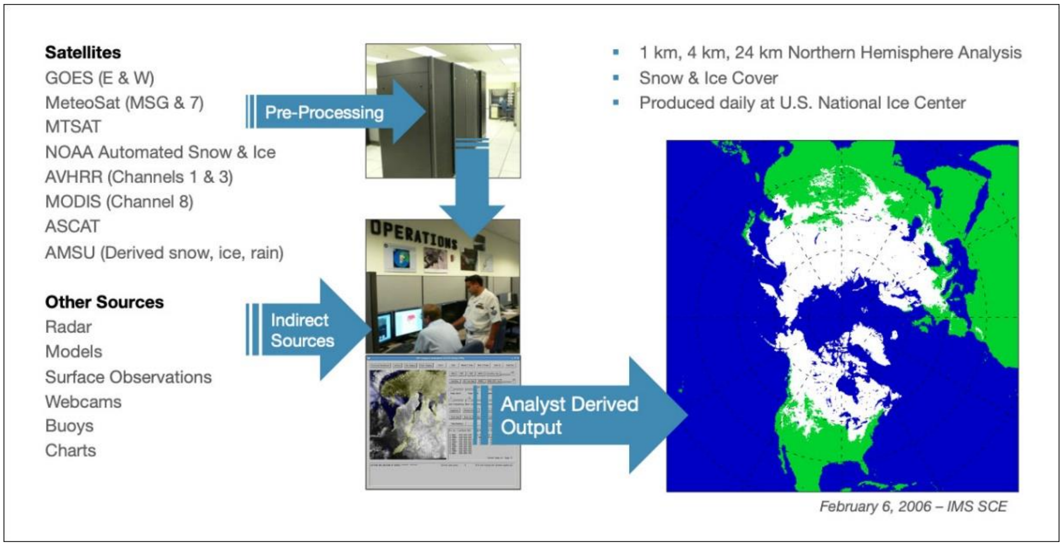

Figure 2. IMS generation process from input sources to processing to daily maps (Helfrich, personal communication.).

STUDY APPROACH

The Rutgers team has assembled a time series of 24-km resolution daily IMS snow cover extent maps for the 2002–2020 study interval. These maps cover the Northern Hemisphere and are quality-controlled for consistency with a standardized land mask applied. Aggregation to monthly maps and SCE area calculations have been performed according to the Rutgers routine (Robinson et al, 1993). The NASA team has developed a time series of MODIS cloud-gap filled snow maps of North America and Eurasia. Comparative studies have been undertaken at continental, regional, and sub-regional scales.

With the focus on product comparisons, particular interest has been paid to times and regions where SCE results differ among the products. This includes employing ancillary data sources such as in situ station observations, Landsat imagery, and the NASA and NOAA imagery that was employed in generating the snow products. This is not an exercise to determine which product is better, as it is known that each has its strengths and weaknesses. Rather, as results illustrate below, it has been possible to identify regions and seasons where differences have occurred.

RESULTS

Initial "blind" comparisons between NOAA IMS and NASA MODIS daily SCE maps find large differences between the two in early and mid-season. Figure 3 exemplifies this for the 2018/2019 and 2019/2020 seasons. Once snow coverage is mapped, it is immediately apparent that the situation results from the MODIS product not mapping snow in high latitude lands deemed to be lacking sufficient solar illumination for the snow detection algorithm to work, thus those regions are shown as dark or missing. Meanwhile, the IMS manual mapping approach can identify snow cover under these conditions or assumes that boreal lands too dark for recognition are snow covered (Fig. 4). As Helfrich et al. (2007) report: "Analysts rely more on snow climatology to estimate snow cover in the high latitudes during the winter than pure microwave data… Even during winter, microwave derived snow data generally only represents 5% of an analysis."

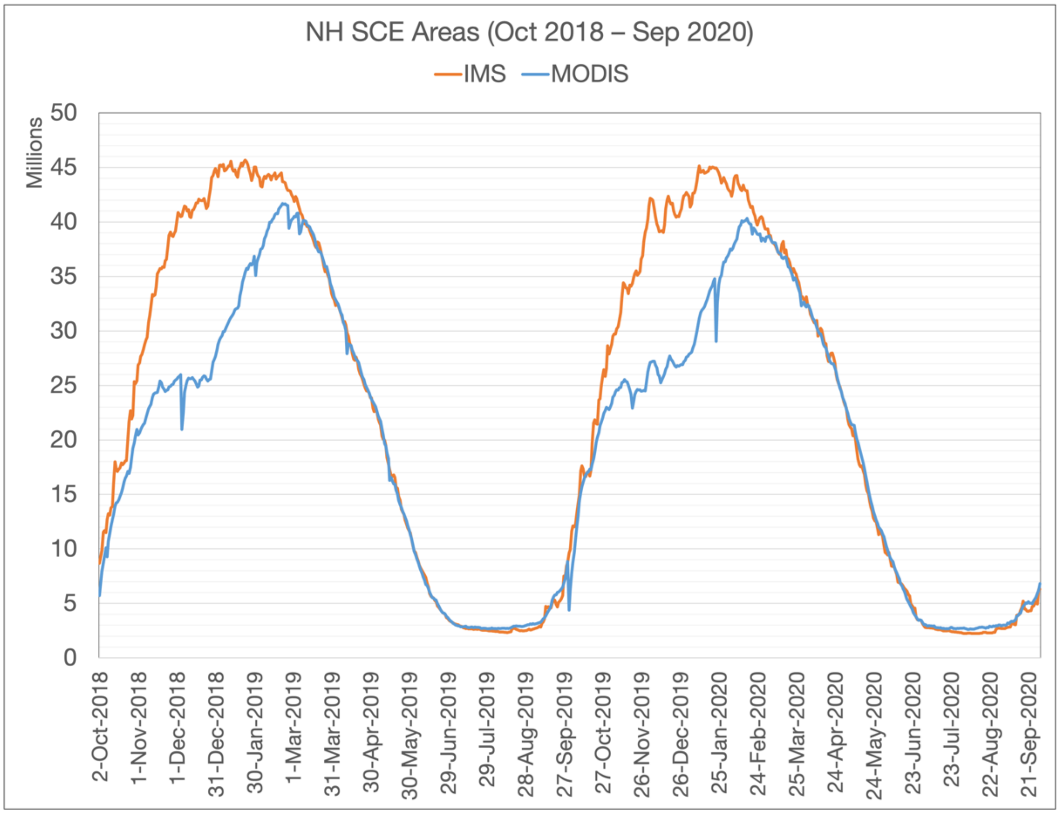

Figure 3. SCE time series for MODIS and IMS products from October 2018 to September 2020.

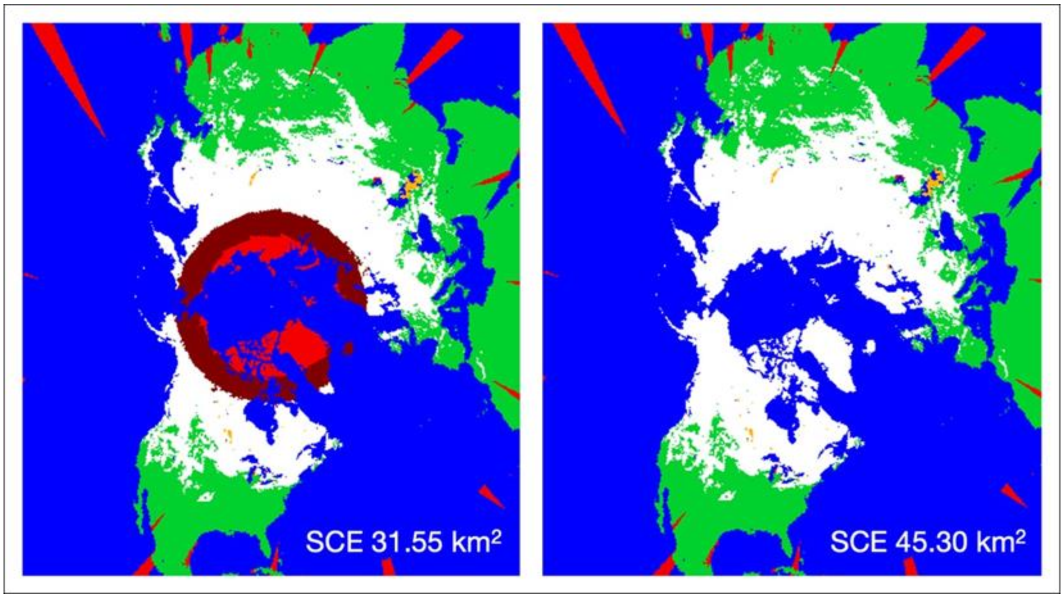

Figure 4. MODIS map of SCE on 10 January 2006 with polar night area in red (left) and with it removed, assuming masked land areas are fully snow covered (right).

Assuming that the dark region on the MODIS map is snow covered results in maps of the two products that are more closely matched (Fig. 5). This is confirmed when comparing the 2018/2019 seasonal SCE mapped by each product (Fig. 6). The close match between MODIS and IMS hemispheric SCE, both in space and over time, provides a strong level of confidence for the overall accuracy of each mapping routine at a macro scale. However, in most years the IMS product shows slightly higher SCE in the early and mid-fall with a closer match in spring. This varies somewhat from year to year, with the 2017/2018 season showing the largest difference between the two over the ten years that were compared (Fig. 7).

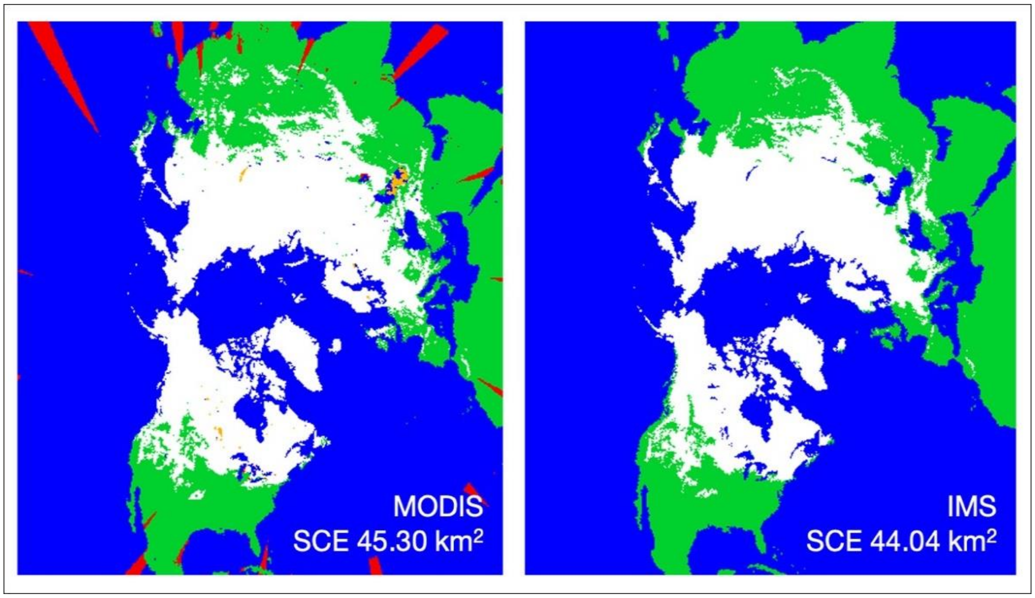

Figure 5. Adjusted MODIS map of SCE on 10 January 2006 from figure 4 (left) and IMS SCE map for that day (right).

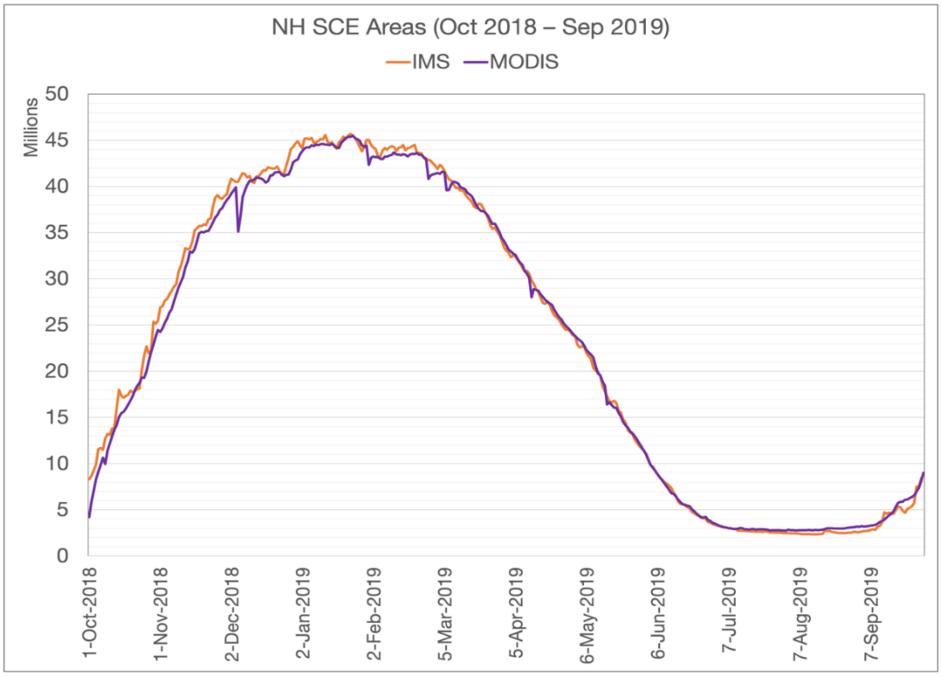

Figure 6. MODIS and IMS Northern Hemisphere SCE from October 2018 to September 2019 after polar night adjustment.

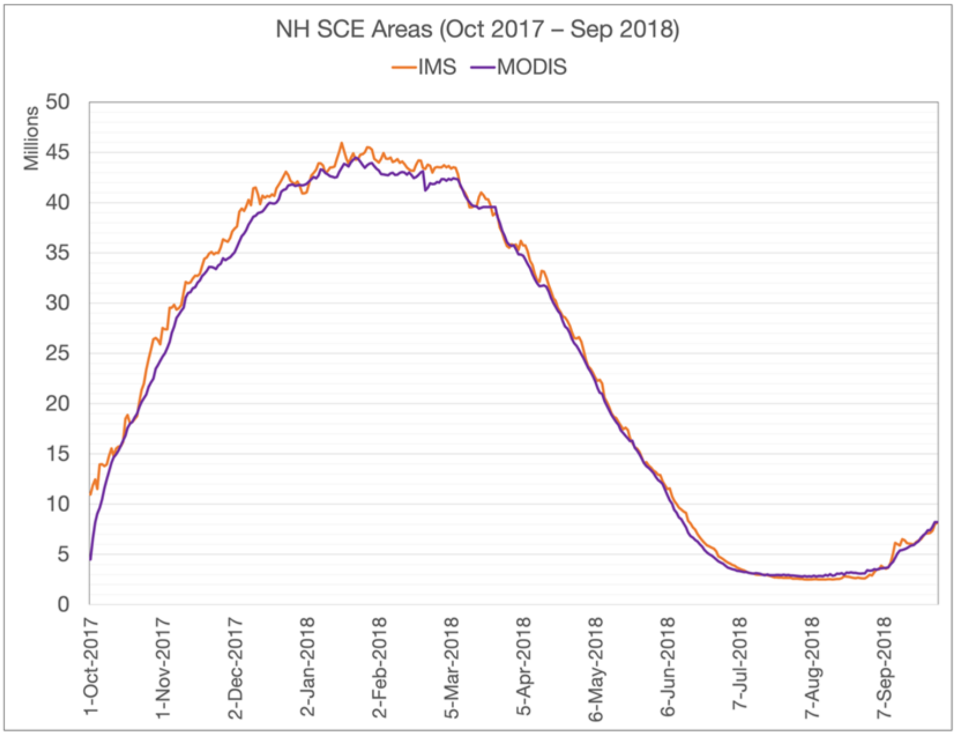

Figure 7. Same as figure 6 except for October 2017 to September 2018.

With, by far, the most apparent impediment to comparisons removed, we next delve into more detailed comparisons. This includes comparing monthly SCE areas for each product from the 2010-/2011 to 2019/2020 seasons. Such an evaluation for Octobers finds the IMS product depicting more cover in most years (Fig. 8). Differences range from the areas being within a few percent in four years and up to 12% different in six years. November differences (not shown) lean the same way but do not exceed 7%.

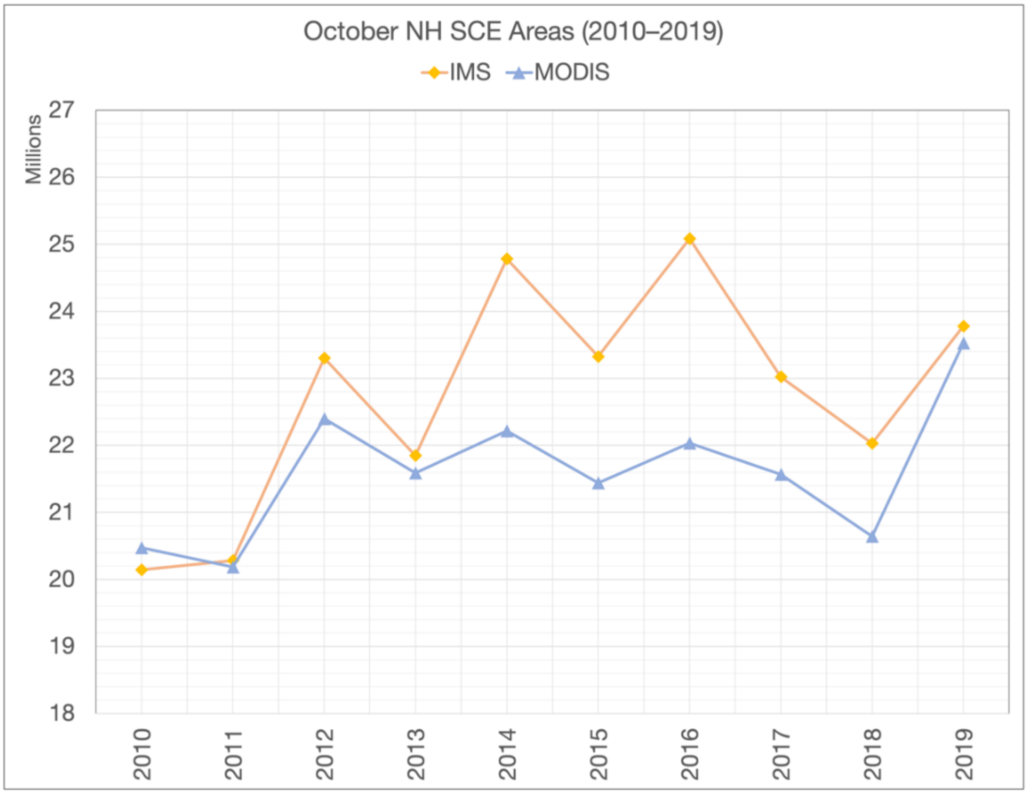

Figure 8. MODIS and IMS October Northern Hemisphere SCE from 2010 to 2019.

Spatial comparisons of the two products are next investigated. Figure 9 shows maps for four consecutive October days in 2016, the October with the largest difference between the MODIS and IMS products over the ten-year study period. The IMS maps show more snow on day one of each comparison but on subsequent days the IMS and MODIS maps begin to compare more closely. This was also noted in November, as seen in Figure 10 from 2010. Further comparisons are needed using ancillary data, but it is apparent that the IMS analysts are able to identify snow cover more quickly than in the automated MODIS approach, with the latter quickly “catching up” to the IMS coverage, though complete depiction of cover due to persistent cloudiness remains a mapping challenge. While having an impact on daily comparisons, differences are minimized when considering monthly values.

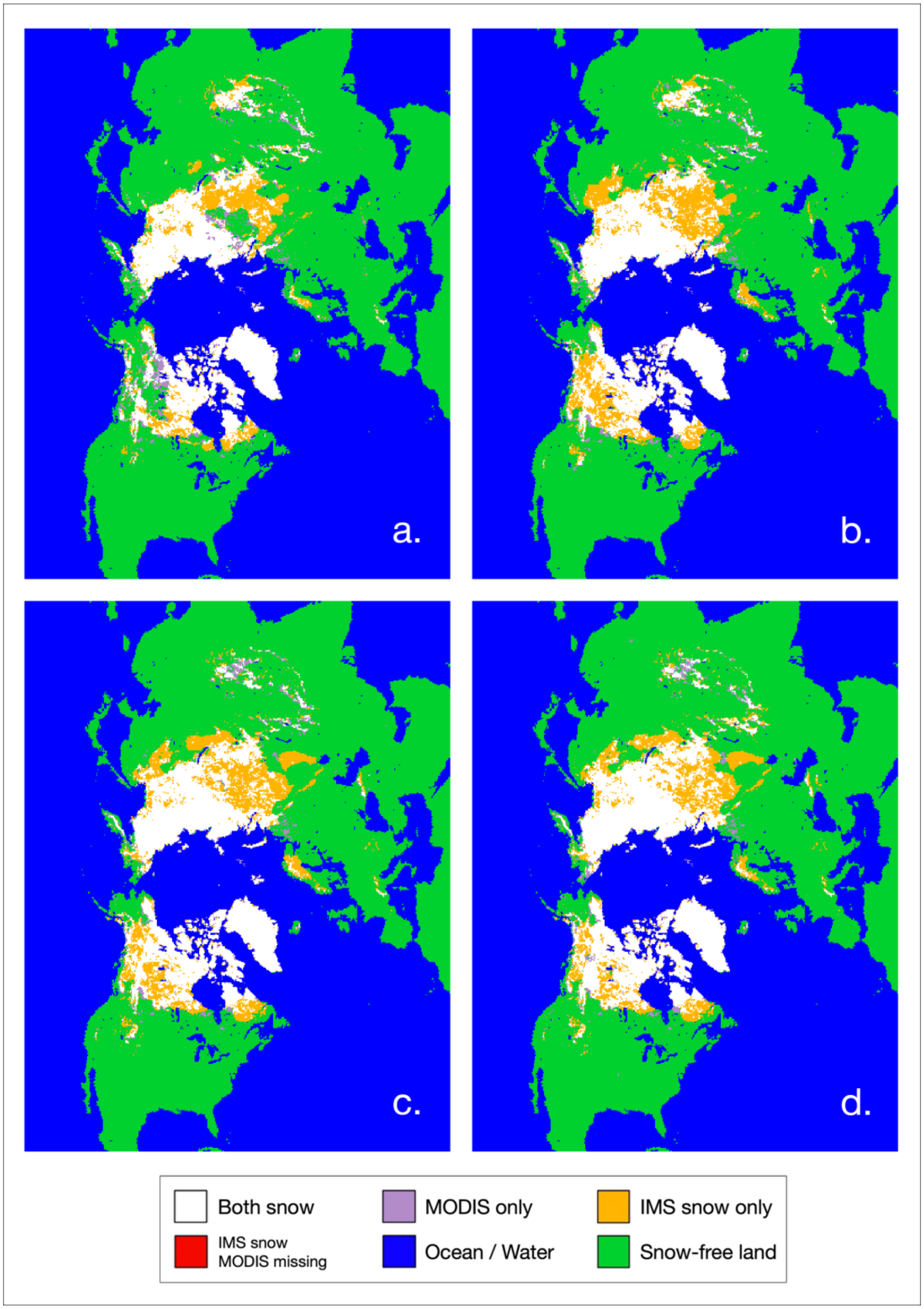

Figure 9. Example of maps comparing the two snow products on consecutive days: (a) 16 October 2016, (b) 17 October 2016, (c) 18 October 2016, and (d) 19 October 2016.

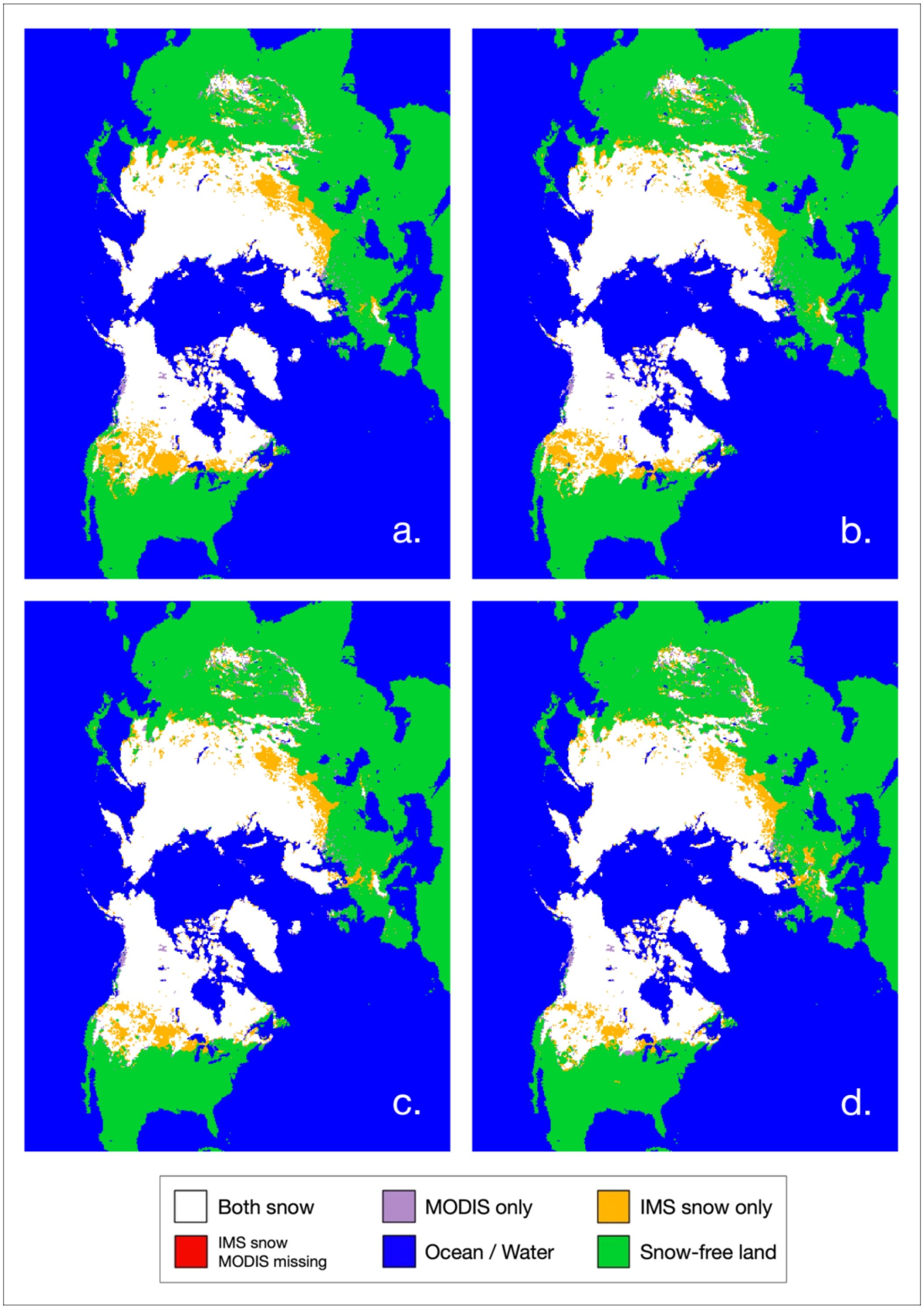

Figure 10. Example of maps comparing the two snow products on consecutive days: (a) 22 November 2010, (b) 23 November 2010, (c) 24 November 2010, (d) 25 November 2010.

DATA

Continuing with a fall focus, a comparison is made between the two products by mapping the monthly mean number of days over the 18-year study period where each showed the ground to be snow covered. An example is shown for November from 2002 to 2019 (Fig. 11). A large level of agreement is evident by the reasonable depiction of SCE for this early-season month. This approach also provides information on areas where there were disagreements between the products and the frequency of such differences. This is shown with two maps in Figure 12, one depicting where and how often snow is mapped in the MODIS product and not IMS and the other where IMS reports snow cover and MODIS does not. In both situations the average disagreement is generally no more than several days. Only in portions of Scandinavia do the MODIS maps show upwards of a week or more greater frequency of snow cover than IMS. Elsewhere, this tendency is mostly seen in mountainous areas of south-central Asia and western North America.

A different picture emerges where IMS reports cover and MODIS does not. The spatial coverage of this tendency is greater, covering the southern border of the snow boundary on both continents but with a lower frequency of days than found more locally in the greater MODIS snow cover locations. Further investigation into these patterns is needed using ancillary data. In the Scandinavian region it could be due to snow cover coming and going in November, with cloud persistence and product resolution differences impacting both products. The zonal difference might be more a result of the previously described multi-day MODIS "catch up" situation.

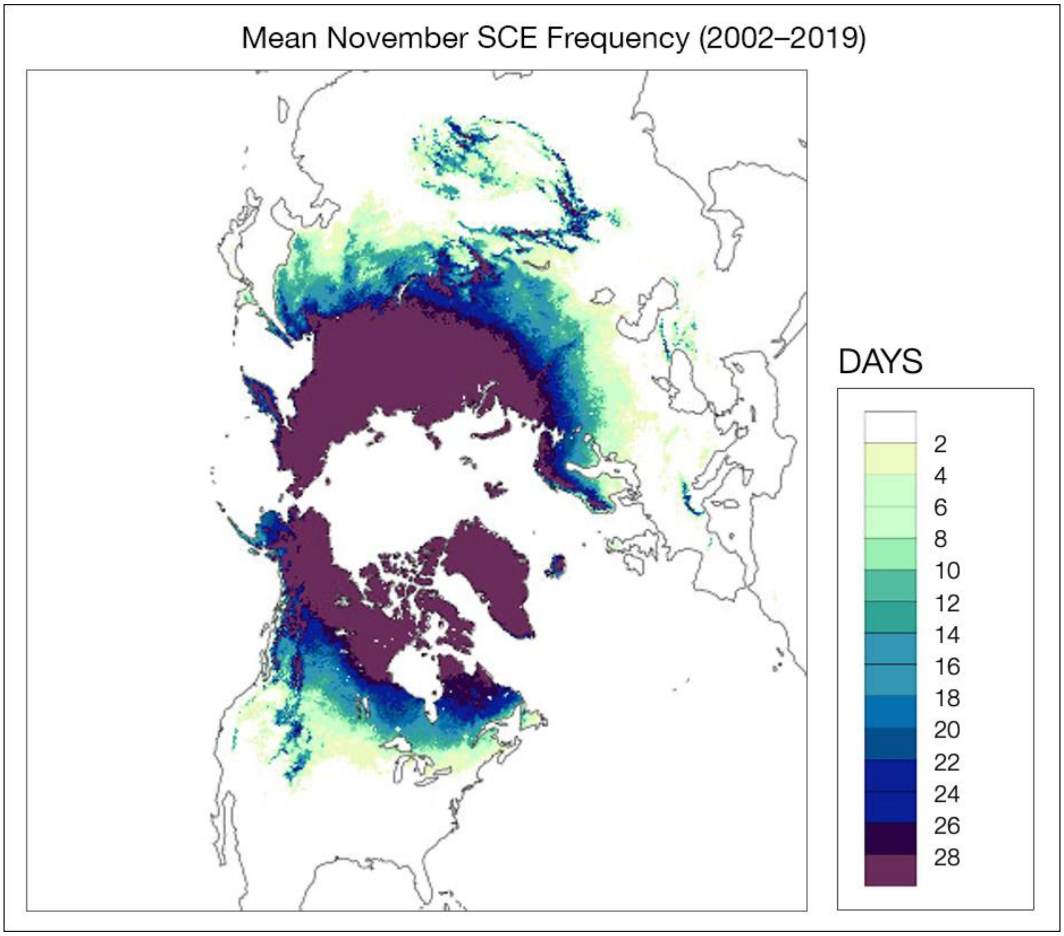

Figure 11. Mean November SCE frequency (2002–2019) where both MODIS and IMS show snow cover.

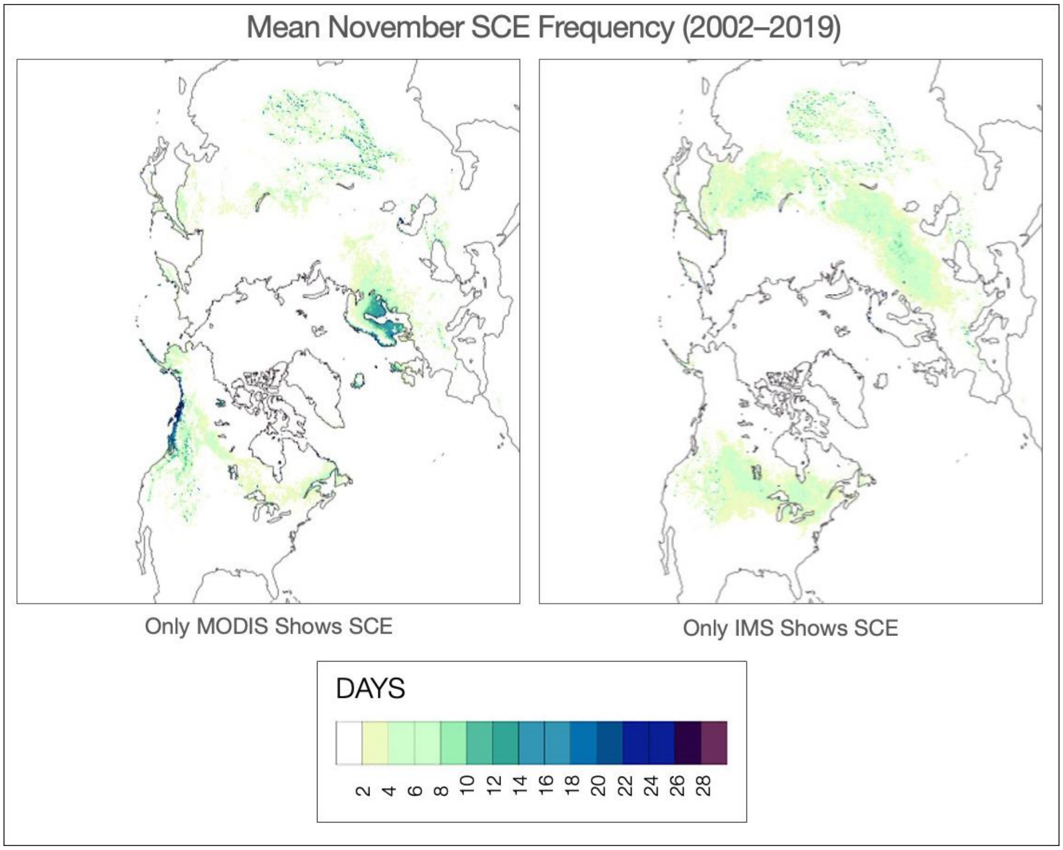

Figure 12. Mean November SCE frequency (2002-2019) where only MODIS shows snow cover (left) and only IMS shows snow cover (right).

Attention is next given to the spring melt season. As discussed earlier, the two products agree better during the melt season than in fall and winter. An examination of May SCE over the continents shows that all but one year of the ten show differences of less than approximately 0.5 million sq. km or several percent (Fig. 13). Four springs are essentially identical, two have MODIS showing more snow, and four with IMS mapping more. Examples of spatial differences between the products are shown for selected May days in 2017, the year with the largest difference between the two and 2019 where the monthly areas are equivalent (Fig. 14). In 2017, IMS SCE exceeds MODIS SCE at several locations along the southern periphery of the snow cover, in central Alaska, and some mountainous areas of south-central Asia. There are some quite localized areas where MODIS shows snow where IMS does not. The 2019 map shows very little spatial differences in cover between the two products. One small area along the snowline at lower elevations on each continent shows more snow mapped by IMS than MODIS, while locations where only MODIS mapped snow are more common in mountainous areas.

CONCLUSION

Temporal and spatial comparisons of 18 seasons of snow cover extent across Northern Hemisphere lands mapped by NASA MODIS and NOAA IMS snow cover extent products show an overall strong agreement on a macroscale across Northern Hemisphere continents. These results are achieved once masking of areas of low solar illumination in the MODIS product are removed, assuming snow cover in those high-latitude regions. A better agreement is noted in spring than fall perhaps because at the end of the winter season both have a common base level to start the melt season, while in fall there may be multiple episodes of snowfall and snowmelt accompanied by extensive cloudiness. The latter, in particular, appears to result in the manually generated IMS product recognizing snow cover a day or so before the automated MODIS product being more sensitive to cloud cover, catching up. Resolution issues with the IMS product in local areas, particularly with ephemeral snow cover and extensive fall cloudiness may impact accurate snow mapping.

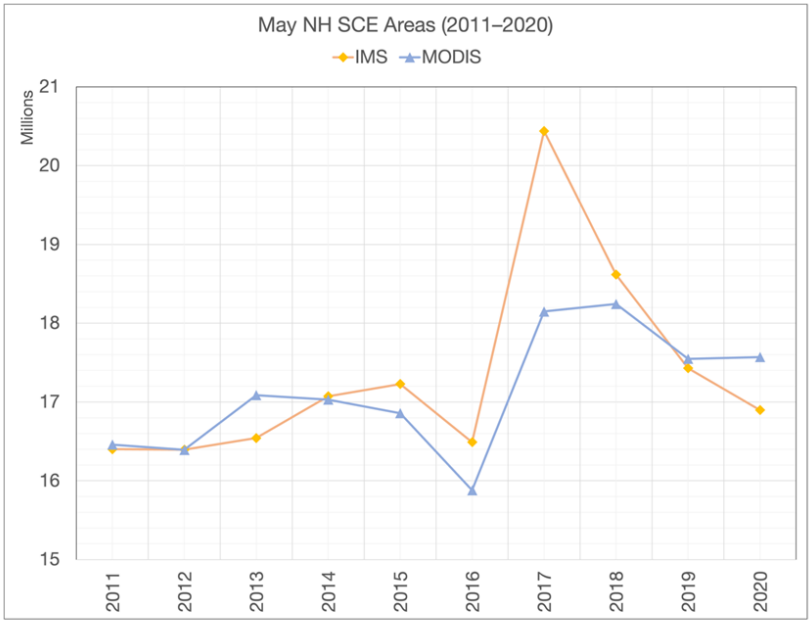

Figure 13. MODIS and IMS May Northern Hemisphere SCE from 2011 to 2020.

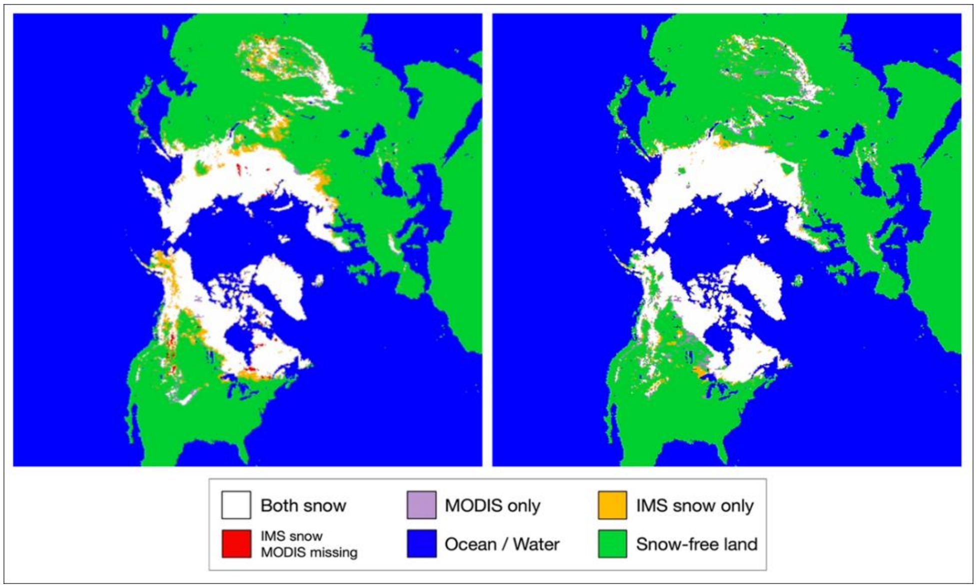

Figure 14. May 2, 2017 map comparing MODIS and IMS SCE (left) and May 2, 2019 map comparing the two products (right).

Ongoing comparisons include longitudinal evaluations over a wide range of landscapes and case studies for individual regions and specific dates. These will assist in confirming or refuting the assumption that snow cover indeed can most always be found in areas deemed in darkness by the MODIS methodology, provide a better understanding of intra- and inter-annual differences in SCE results between each product, and look specifically at potential local/regional differences in coastal and mountainous locations. This will involve using Landsat imagery and ground truth where station data are available. More robust statistical analyses will accompany these efforts.

Both CDR/ESDR products are currently archived at the National Snow and Ice Data Center (MODIS: *https://doi.org/10.5067/MODIS/MOD10A1F.061*, IMS: *https://doi.org/10.7265/N52R3PMC*). This will continue, with our team augmenting the documentation of each product with the knowledge gained through this study. Results of this project will provide user communities with the best understanding to date of the areal distribution of snow cover on regional to hemispheric scales for each product. Eventually, unifying these products will improve and extend the MEaSUREs snow product that currently extends only through 2012 (Robinson et al., 2014).

Acknowledgements. This study is supported by NASA funds to Rutgers University. The authors would also like to acknowledge support from NASA grant number 80NSSC21K1927.

REFERENCES

Allchin MI, Déry SJ. 2020. The climatological context of trends in the onset of Northern Hemisphere seasonal snow cover, 1972–2017. *Journal of Geophysical Research: Atmospheres*, **125:** e2019JD032367. doi: 10.1029/2019JD032367.

Estilow TW, Young AH, Robinson DA. 2015. A long-term Northern Hemisphere snow cover extent data record for climate studies and monitoring. *Earth System Science Data*, **7**(1):137-142. doi: 10.5194/essd-7-137-2015.

Hall DK, Riggs GA, Foster JL, Kumar SV. 2010. Development and evaluation of a cloud-gap-filled MODIS daily snow-cover product. *Remote Sensing of Environment*, **114**(3): 496-503. doi: 10.1016/j.rse.2009.10.007.

Hall DK, Riggs GA, DiGirolamo NE, Román MO. 2019. Evaluation of MODIS and VIIRS cloud-gap-filled snow-cover products for production of an earth science data record. *Hydrology and Earth System Sciences*, **23:** 5227–5241. doi: 10.5194/hess-23-5227-2019.

Hall DK, Riggs GA. 2020. MODIS/Terra CGF Snow Cover Daily L3 Global 500m SIN Grid, Version 61. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: 10.5067/MODIS/MOD10A1F.061.

Helfrich SR, McNamara D, Ramsay BH, Baldwin T, Kasheta T. 2007. Enhancements to and forthcoming developments in the Interactive Multisensor Snow and Ice Mapping System (IMS). *Hydrological Processes*, **21**: 1576–1586. doi: 10.1002/hyp.6720.

Riggs GA, Hall DK, Román MO. 2017. Overview of NASA's MODIS and Visible Infrared Imaging Radiometer Suite (VIIRS) snow-cover earth system data records. *Earth System Science Data*, **9**(2): 765-777. doi: 10.5194/essd-9-765-2017.

Riggs GA, Hall DK, Román MO. 2018. MODIS snow products user guide for Collection 6.1 (C6.1). Available at: *https://modis-snow-ice.gsfc.nasa.gov/?c=userguides*, last accessed 3/17/2019.

Riggs GA, Hall DK. 2020. Continuity of MODIS and VIIRS snow cover extent data products for development of an Earth Science Data Record. *Remote Sensing*, **12**, 3781. doi: 10.3390/rs12223781.

Robinson DA, Hall DK, Mote TL. 2014. MEaSUREs Northern Hemisphere Terrestrial Snow Cover Extent Daily 25km EASE-Grid 2.0, Version 1. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: 10.5067/MEASURES/CRYOSPHERE/nsidc-0530.001.

Robinson DA, Dewey KF, Heim Jr R. 1993. Global snow cover monitoring: an update. *Bulletin of the American Meteorological Society*, **74**: 1689–1696. doi: 10.1175/1520-0477(1993)074<1689:GSCMAU>2.0.CO;2.

Robinson DA, Dewey KF. 1990. Recent secular variations in the extent of Northern Hemisphere snow cover. *Geophysical Research Letters*, **17**: 1557–1560. doi: 10.1029/GL017i010p01557.

U.S. National Ice Center. 2008. IMS Daily Northern Hemisphere Snow and Ice Analysis at 1 km, 4 km, and 24 km Resolutions, Version 1. National Snow and Ice Data Center (NSIDC), Boulder, CO. doi: 10.7265/N52R3PMC.

Woods J, Helfrich S. 2019. Interactive Multisensor Snow and Ice Mapping System (IMS) upgrades and improvements. *Proceedings of the 76th Eastern Snow Conference, Fairlee, VT*.