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Regional Trend Analysis of Satellite-Derived Snow Extent and Global Temperature Anomalies

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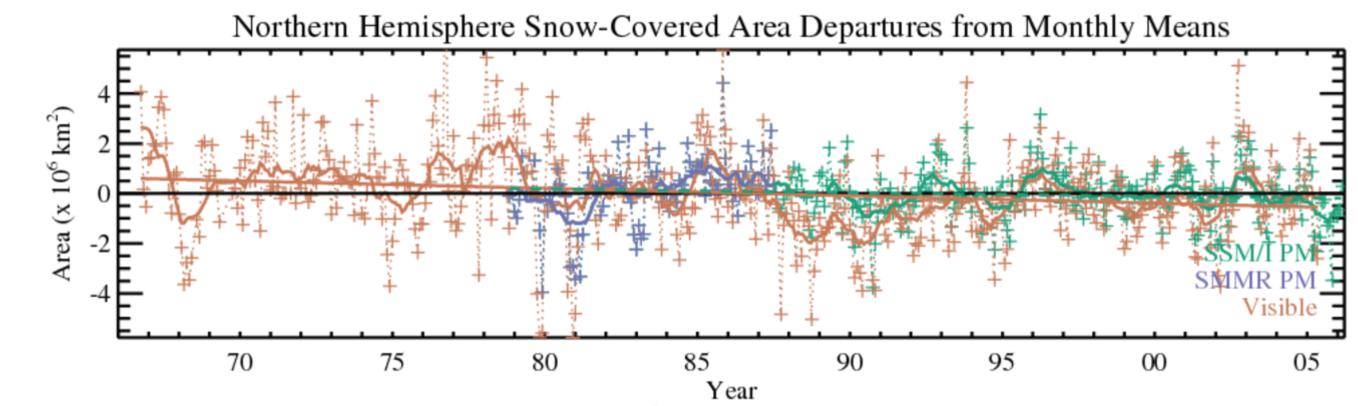
Abstract

The extent and variability of seasonal snow-covered area (SCA) are important parameters in climate and hydrologic systems due to effects on energy and moisture budgets. Northern Hemisphere snow cover extent, comprising about 98 percent of global seasonal snow cover, is the largest single spatial component of the cryosphere, with a mean maximum extent of 47 million square kilometers (nearly 50 percent of the land surface area). During the past four decades, much important information on Northern Hemisphere snow extent has been provided by the NOAA weekly snow extent charts, derived from visible-band polar orbiting and geo-stationay satellite imagery. Since 1978, satellite passive microwave sensors have provided an independent source for snow monitoring, with the ability to penetrate clouds, provide data during darkness, and the potential to provide an index of snow water equivalent. We see both positive and negative trends in SCA derived from these data sets, depending on region and time of year. Efforts are under way to look for attribution of these trends. We present regional trend analysis of both data sets, and comparisons with gridded temperature anomalies from the NASA Goddard Institute for Space Studies (GISS) Surface Temperature Analysis data.

Snow-Covered Area (SCA) Time Series

Our investigation includes a comparison of monthly anomalies in Northern Hemisphere SCA derived from two satellite data sets: the NOAA snow charts revised by D. Robinson that map snow cover from primarily visible-wavelength sensors like AVHRR and GOES, and passive microwave (PM) algorithms using SMMR and SSM/I EASE-Grid brightness temperatures. Since both data sets exhibit significant month-to-month autocorrelation, we have estimated monthly trends with an autoregressive lag-1 model (AR(1)), using the method described by Weatherhead et al. (1998).

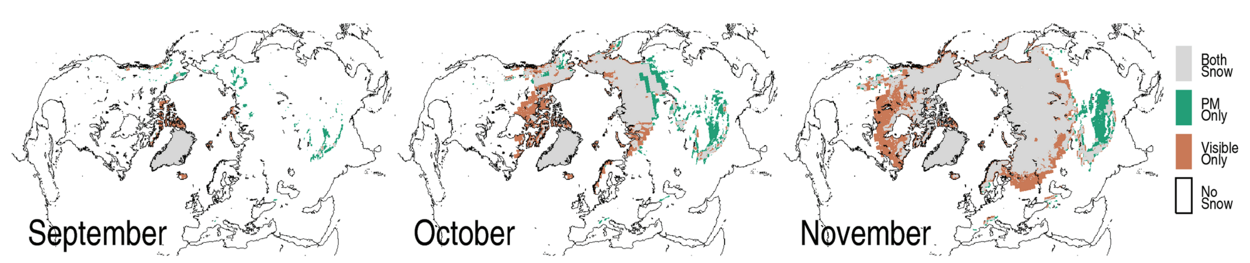


Northern Hemisphere SCA departures from monthly means, from NOAA snow charts (orange, 1966-2005) and microwave satellite (purple/green, 1978-2005) data sets. We find a significant decreasing trend of -1.3% per decade in the NOAA time series. There is a decreasing trend of -0.7% per decade in the microwave snow cover, althouth it is not significant at a 90% level.

Monthly SCA Climatologies

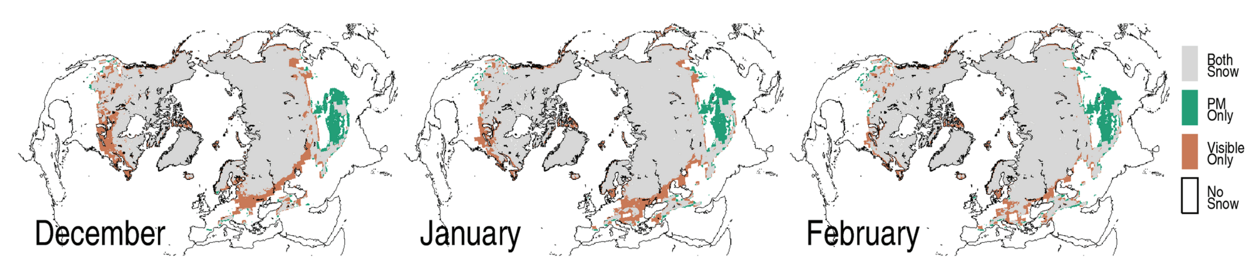
Difference maps of monthly climatologies, 1978-2005.

Autumn



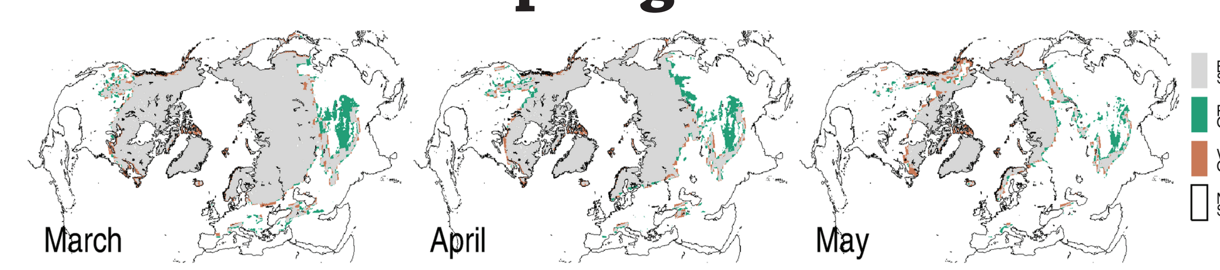
In autumn, passive microwave likely misses shallow, patchy snow, undermeasuring snow extent compared to visible-derived methods.

Winter



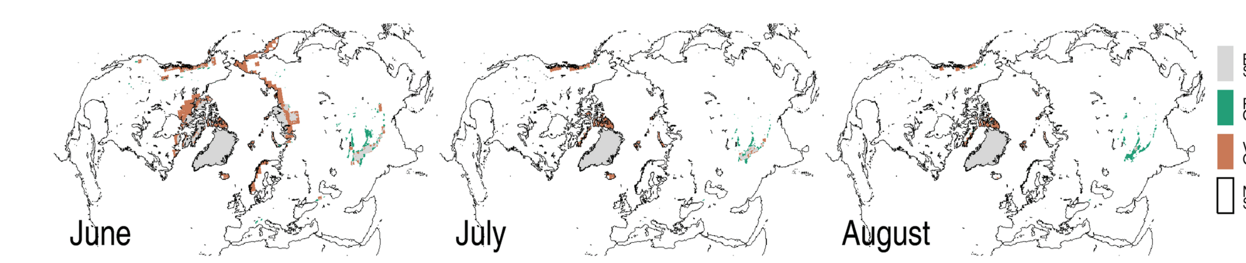
Agreement between microwave and visible-derived snow maps improves steadily during winter months, because microwave algorithms map snow better with increasing snow depth.

Spring



Microwave and visible-derived snow maps are in general agreement during spring months.

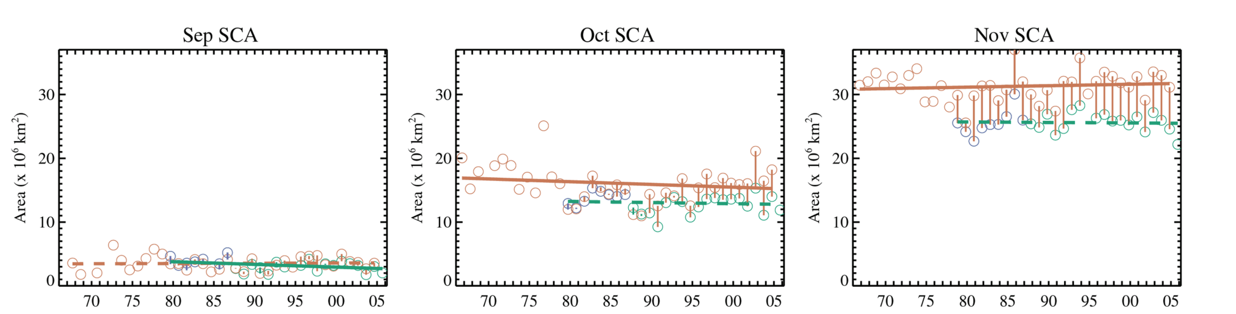
Summer



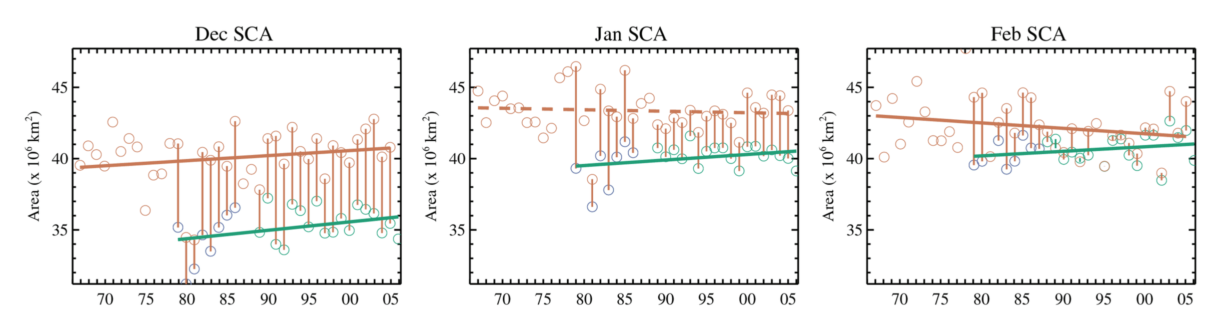
Microwave snow cover disappears sooner than visible-derived snow in June, possibly because the snow remaining at these high latitude locations is melting throughout the diurnal cycle and microwave retrievals cannot accurately distinguish between melting snow and bare ground..

Monthly SCA Trends

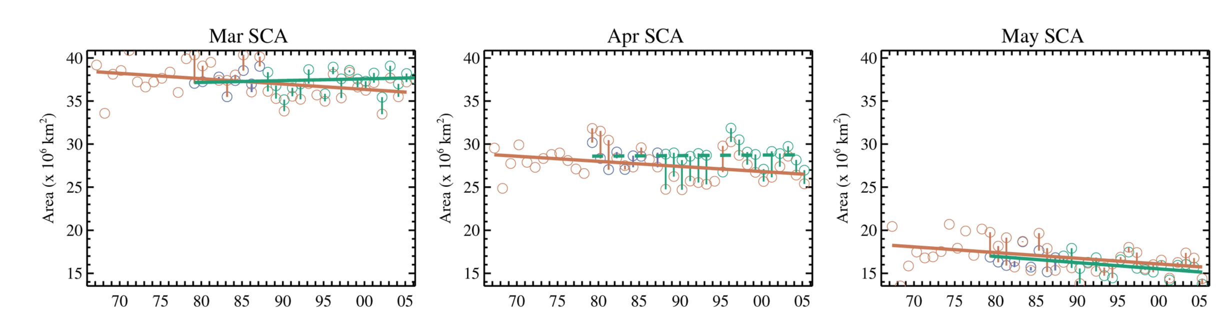
Monthly time series SCA, 1966-2005. Significant (90% level) trends are solid lines.



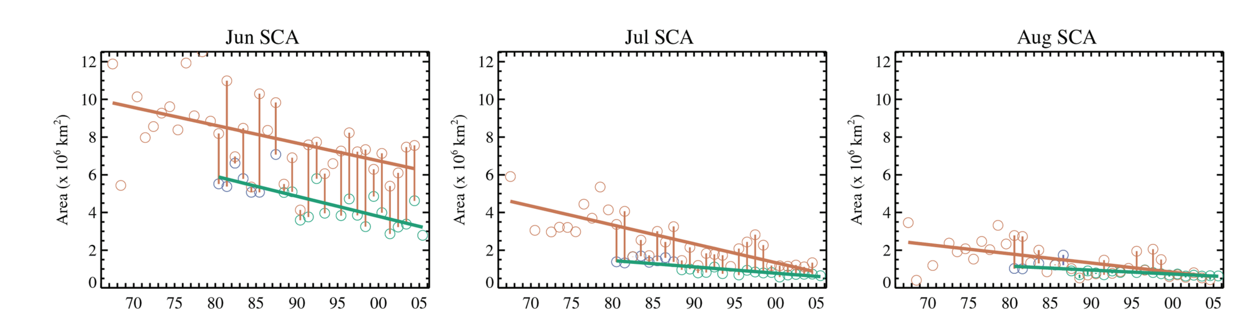
There are significant trends in visible SCA during October (decreasing) and November (increasing). In the microwave, decreasing SCA in September is the only significant trend.



Microwave shows significant increasing trends in SCA throughout the winter months, in contrast with significant increasing visible-derived SCA in December and significant decreasing visible-derived SCA in February.



All spring months show significant decreasing visible-derived SCA. Microwave still shows a significant increasing trend in March, but reverses in May to agree with the decreasing SCA from visible data.

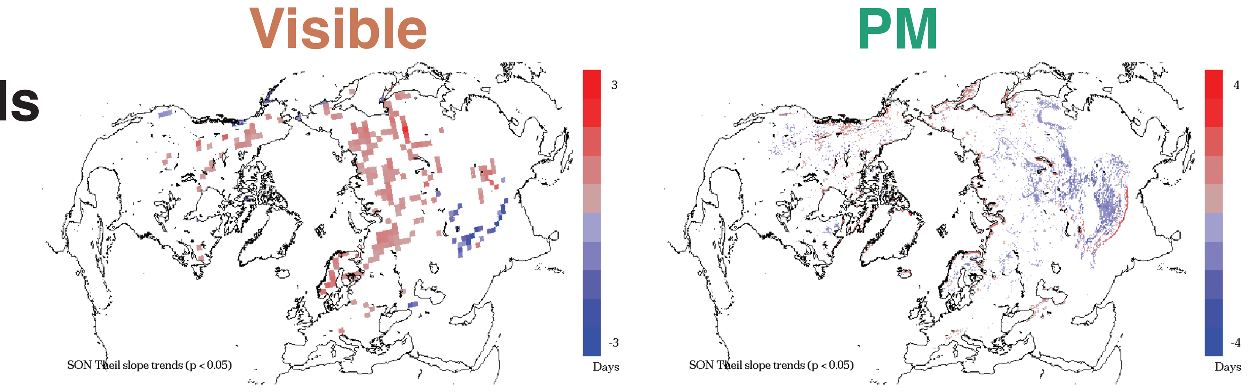


Both data sets agree on significant decreasing snow-cover trends during summer months.

Seasonal SCA Duration Trends

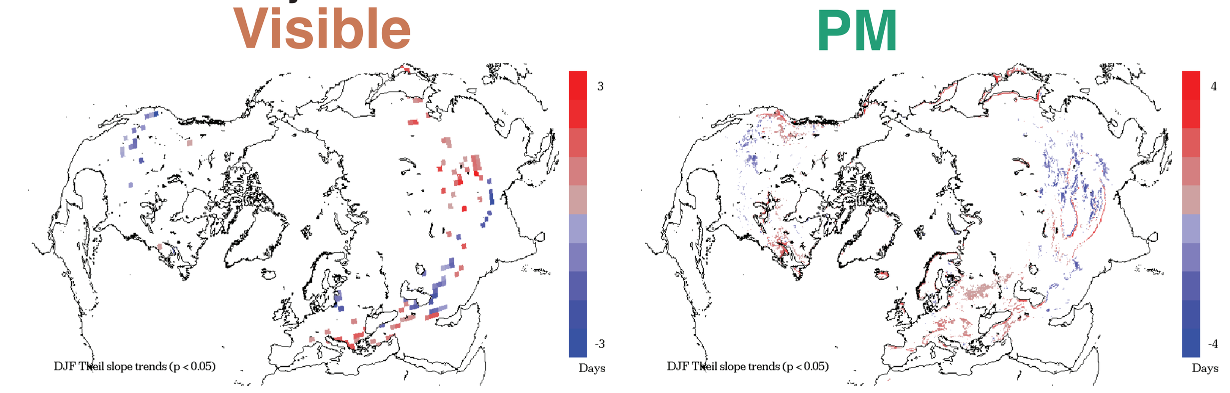
Significant (95% level) trends in seasonal SCA duration, 1978-2005, calculated from pixel-by-pixel Theil slopes.

Visible / **PM**



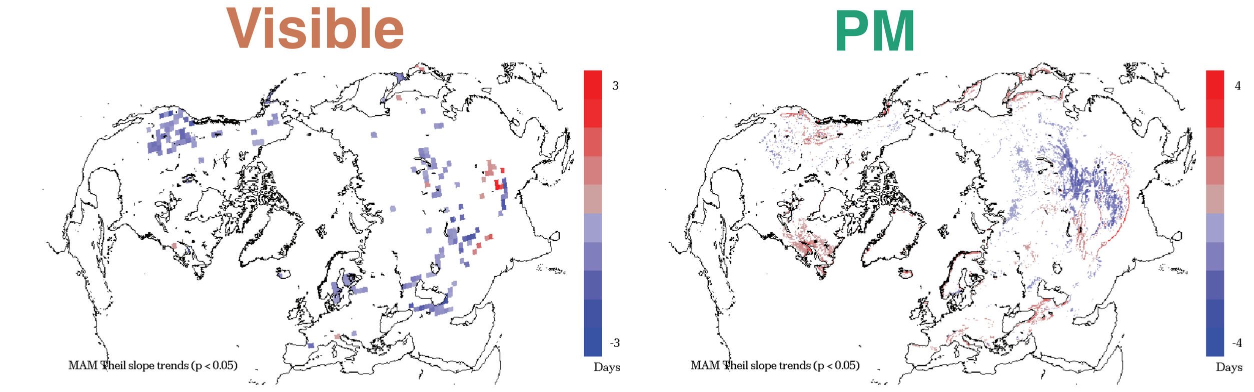
There are large areas of increasing SCA duration (reds) in the visible-derived seasonal trend maps, while microwave SCA duration is decreasing. (At this time, we are not analysing trends in the Tibetan Plateau region, due to known technical problems in both of the source data sets. Corrections for each are currently being researched at NSIDC and Rutgers.)

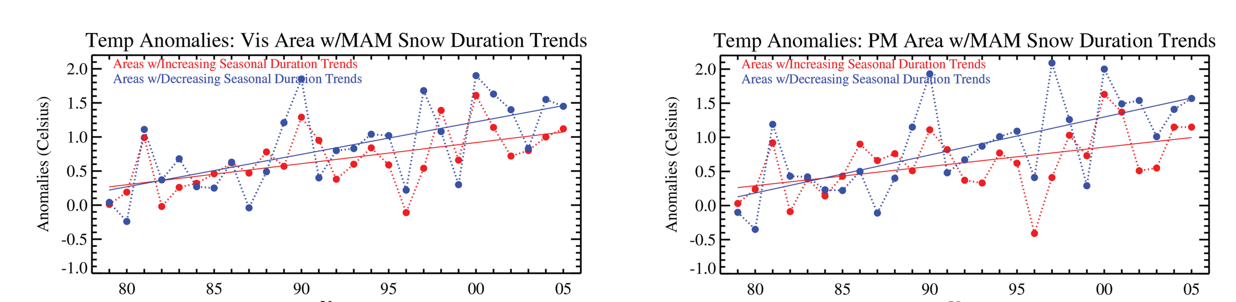
Visible / **PM**



Both data sets indicate areas of significant decreasing seasonal SCA duration (blues) in the western USA, and significant increasing duration (reds) in southeastern Europe.

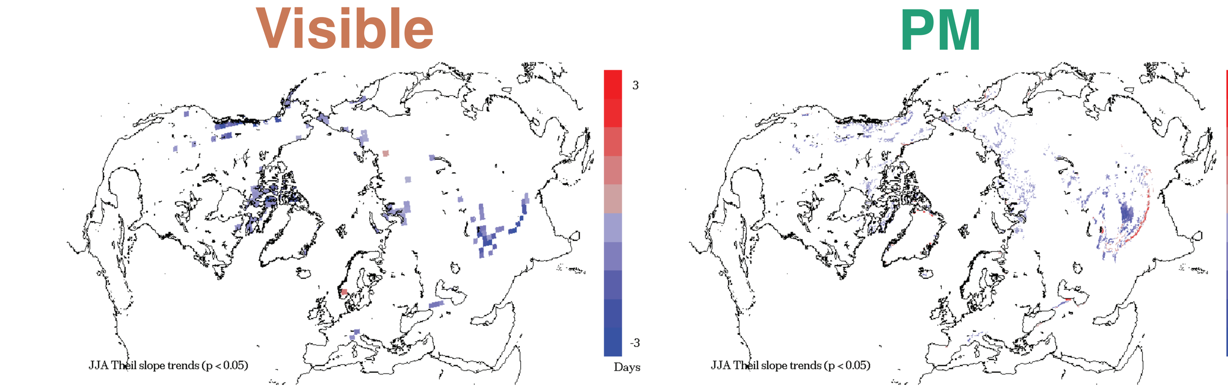
Visible / **PM**





In North America, visible data indicate large areas of decreasing seasonal SCA duration in the western USA, while microwave duration trends are mostly increasing. We also calculated trends in surface temperature (NASA GISTEMP data), in regions of increasing (red) and decreasing (blue) trends in seasonal duration. While trends in temperature significantly increase in both regions, the trend magnitudes are larger in areas with decreasing snow duration.

Visible / **PM**



Although snow extent is minimal during summer months, most of the high-latitude seasonal duration trends are decreasing (blues) in both data sets.

Conclusions

We find decreasing trends in Northern Hemisphere SCA derived from both visible and microwave-based methods. Eight months in the visible-derived SCA exhibit significant decreasing trends, while two exhibit significant increasing trends. For the microwave-derived snow extent, the situation is more ambiguous. Five months exhibit significant decreasing SCA trends, with four months exhibiting significant increasing SCA trends. The strongest seasonal signal occurs during May to August, when both data sets indicate significant decreasing trends. This pattern makes physical sense in the context of increasing air temperatures during the period of maximum seasonal snow melt over much of the Northern Hemisphere.

References and Data Sets Used

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