Comparison of MODIS Daily Global Fractional Snow Cover Maps at 0.05 and 0.25 Degree Resolutions

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ABSTRACT

The standard NASA Moderate Resolution Imaging Spectroradiometer (MODIS) daily global fractional snow map product is generated at 0.05° spatial resolution. However current climate models often use 0.25° resolution input data sets. In response to modelers' input requirements, a MODIS daily global fractional snow map at 0.25° resolution is created from the standard 0.05° MODIS daily global climate modeling grid (CMG) snow map product. Similarities and differences between the daily fractional snow maps at the two resolutions within a season and between different seasons, as well as effects of the averaging method that includes or excludes no snow (0% snow) data are discussed. Differences were found in the snow maps due to both resolution differences and averaging method differences. Differences were greatest in the lower snow fractions having greatest effect at the snow field edges or in patchy snow regions. Comparative analysis of the MODIS daily global FSC maps at 0.05° and 0.25° resolution reveals that the general synoptic pattern of snow extent is very similar and consistent in different seasons between the maps. However, fractional snow cover amounts especially at high and low fractions can vary considerably within regions with the differences affected by spatial resolution and difference in averaging method.

Keywords: snow cover, MODIS, climate modeling grid.

INTRODUCTION

The standard MODIS daily global fractional snow cover (FSC) climate modeling grid (CMG) map product is generated at 0.05° resolution (about 5 km at the equator). However current climate models typically run at 0.25° to 0.33° spatial resolution, a resolution lower than the MODIS daily global FSC map product. Modelers sometimes use a higher resolution snow map as input though they preprocess it using binning techniques to transform the snow data to the same resolution of their models and apply data screening as a step to controlling the quality of the input. The Global Land Data Assimilation System (GLDAS) which ingests satellite and ground-based observational data products in order to generate fields of land surface states and fluxes, globally at 0.25° resolution producing both retrospective and near–real time output, ingests the standard MODIS daily FSC 0.05° CMG snow product, then applies quality screening and binning to generate a snow map at the 0.25° model resolution (Rodell and Houser, 2004). In response to those modelers' spatial preferences a special daily global FSC map at 0.25° resolution was created from the standard 0.05° MODIS daily global snow map product. Two averaging methods that treat 0% snow observations differently for generating the 0.25° CMG were tested.

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Higher spatial resolution maps yield more accurate representation of snow cover extent than do coarser spatial resolution maps. Studies to support that generalization are not common in the literature. Drush et al., (2004) reported that coarser resolution snow maps result in greater values of snow extent and snow water equivalent (SWE) in models as compared to finer resolutions map and that differences in model outputs were most pronounced at the snowline; higher spatial resolution model output was improved especially in mountainous regions and in patchy snow cover. In general the coarser resolution maps result in overestimates of snow cover systematically over the globe. However, reports of comparative quantitative analysis of snow maps of differing spatial resolution are rare. This work serves to quantify differences in MODIS snow maps that result from generating a reduced resolution snow map from the original resolution snow map

Comparisons between the 0.05° and 0.25° FSC CMG maps at global and regional scale, seasonal differences for the Northern Hemisphere and between different averaging techniques are presented in this paper. Discussion of the effects of resolution and technique on the resulting 0.25° FSC maps especially to mapping at lower FSC ranges is presented.

MODIS SNOW MAPS

The standard MODIS CMG snow product is a daily fractional snow map generated from the daily 500 m resolution snow product MOD10A1 by binning the observations and calculating the fraction of snow observations (pixels) mapped into a cell of the CMG (Hall *et al*., 2002; Riggs *et al*., 2003). The coarser 0.25° resolution CMG is created from the 0.05° CMG by processing a 5 x 5 block of cells from the 0.05° CMG; average FSC is calculated by summing the 0-100% snow values; the 0% fraction snow class is included in the sum, then dividing by the count of observations included in the sum. Observations of other features, e.g. cloud or a lake, are not included in calculating the average. The average snow percentage is then calculated and written to the corresponding 0.25° CMG cell. This technique maximizes snow extent because if snow occupies only a small fraction of the 0.05° CMG cell it is mapped as snow in the larger 0.25° CMG cell. Snow maps were also made with a variation of the averaging method; the 0% snow data observations were excluded from determining the average FSC. A single day of comparison of the averaging techniques is presented.

Cloud obscuration is not a factor in data processing. For the comparison study cloud obscuration is essentially the same in both CMGs and is not explicitly analyzed in the comparisons.

COMPARISONS & DISCUSSION

Synoptic comparison reveals similar snow extent in both the standard product CMG (at 0.05°) and the new 0.25° CMG product on 4 May 2004 (Figs. 1 and 2). Snow appears in the same places and appears to cover about the same area at similar percentages. Closer visual inspection reveals that snow cover in the 0.05° CMG appears in greater detail, with greater range of FSC, notably in mountainous regions and on snow edges where a gradient from high to low snow fraction can be seen. A subset of the Sierra Nevada Mountain region is shown in Figures 3 and 4 as an example. In the 0.05° CMG snow cover ranges from 20-100% whereas snow cover ranges from 20-40% across the mountains. Obviously there is greater detail at the 0.05° resolution than at 0.25° resolution. FSC cover decreases because the FSC are averaged over a larger area, so that high and low FSC is averaged and on snow edges more 0% snow is included in the average.

Comparison of the count of snow cells in each FSC class (Fig. 5) shows that the number of cells in the 0.05° CMG is greater from 1-100% than for the 0.25° CMG. At 100% the 0.05° CMG has 3,053,680 cells of snow whereas the 0.25° CMG has 113,770 cells of snow (not shown in Fig. 5 because the large difference at 100% crushed the scale making the other differences look unrealistically small). Counts do not yield a good comparison because they do not directly convey spatial extent of snow cover. Comparison of areal extent of snow in the two CMG resolutions is more relevant than comparison of cell counts because the climate models that use the data are spatial in nature.

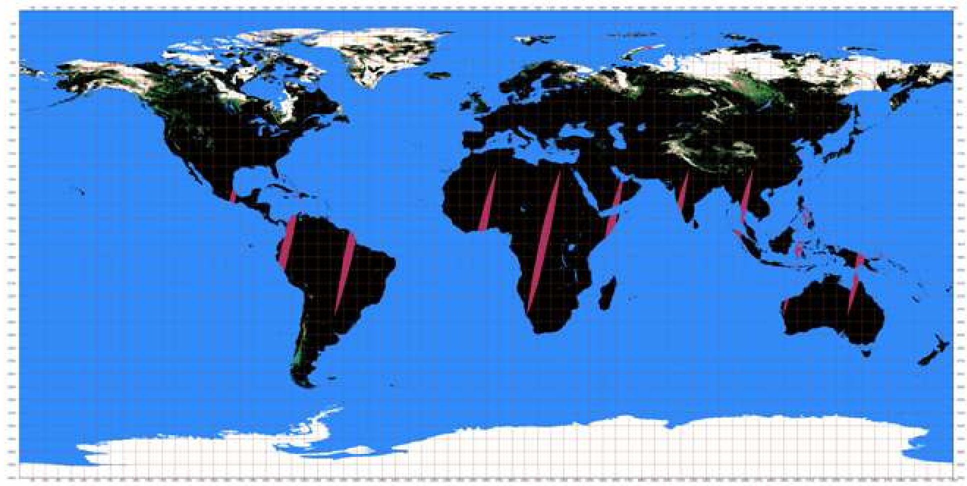
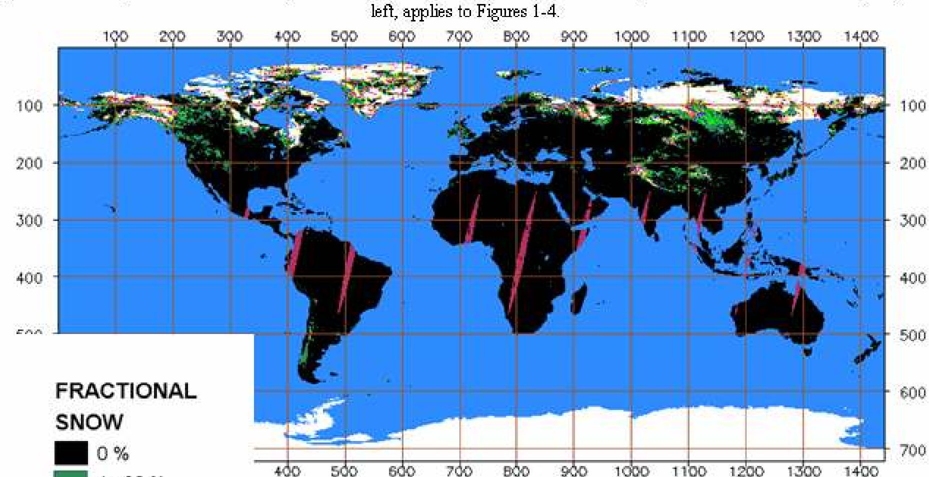


Figure 1. Snow map from the MODIS daily FSC CMG product at 0.05° resolution for 4 May 2004. The fractional snow legend, below left, applies to Figures 1-4.



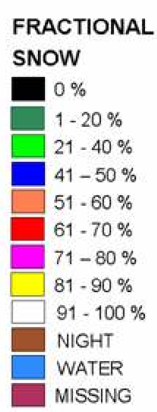


Figure 2. Snow map from the MODIS daily FSC CMG product at 0.25° resolution for 4 May 2004.

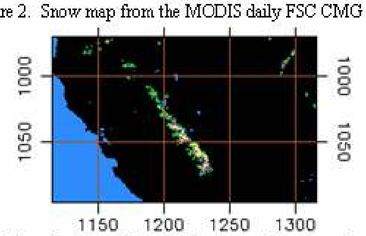


Figure 3. Sierra Nevada Mountain subset from the 0.05°CMG. Grid reference lines shown.

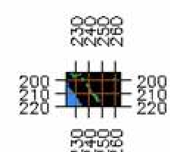


Figure 4. Sierra Nevada Mountain subset from the 0.25° CMG. Grid reference lines shown.

Areal extent of snow cover was greater for all snow fractions except for 100% in the coarser 0.25° CMG snow map (Figs. 6 and 7) compared to the 0.05° CMG snow map. Snow area is calculated as the product of latitude adjusted cell area times the number of cells with that fraction of snow. Across the range of 5-95% FSC the difference in area between CMG resolutions is fairly constant with minimum differences in the 50-70% range with the differences increasing across the low, 1-25% and high 90-100% FSC ranges (Fig. 6). Great differences in snow extent occur at both the low and high snow fractions (Fig. 7). At the low range the great amount of snow cover in the 0.25° CMG is caused by the coarse resolution cell covering a larger area thus a small fraction of snow is calculated for a greater area. At 100% snow fraction the 0.05° CMG has a slightly greater snow area. The 0.25° CMG has a smaller area of 100% snow because there are significantly fewer cells that are mapped as 100% snow at that resolution.

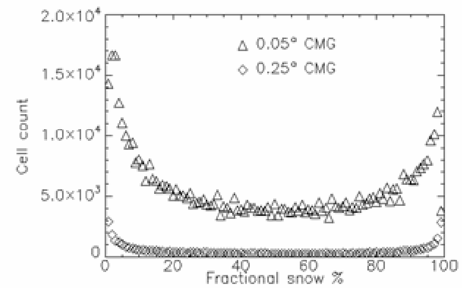


Figure 5. Comparison of snow cell counts between the two CMGs on 4 May 2004. Data for 100% FSC not shown, see text for reason.

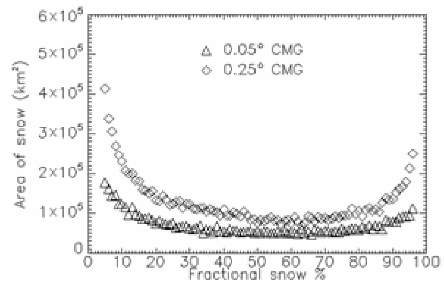


Figure 6. Comparison of snow area between the two CMGs for the 5-95% FSC range on 4 May 2004.

Analysis of the Sierra Nevada Mountains subset (Figs. 3 and 4) exhibits the impact of CMG resolution on snow maps in mountainous regions. In the 0.05° CMG subset there are 439 cells of snow for a total area of 10729 km^2, the 0.25° CMG had 37 cells of snow for total area of 22566 km^2. Snow extent is seen in detail including the gradient of snow fractions up then down the slopes of the mountains in the 0.05° CMG. Fractional snow extent is decreased in amount and the gradient in FSC is diminished to about half the range but spread over a wider area in the 0.25° CMG. A transect (single row of CMG cells) of FSC across the Sierra Nevada Mountains (Fig. 8) shows the difference in FSC between the 0.05° and 0.25° CMGs. In the 0.05° CMG FSC ranges from 0-100 %. In the 0.25° CMG FSC ranges from 0-55% and stretches over a longer distance as compared to the distance in the 0.05° CMG. This Sierra Nevada comparison supports the fact that higher resolution maps contain more detail than a comparable coarse resolution map and differences are quantified. Those differences should be considered in relation to the resolution and outputs of a model that may ingest the snow map.

Comparison of the snow extent in the Northern Hemisphere (NH) between the two CMGs was made for four eight-day time periods in 2004. The objective of these comparisons was to determine if the differences in snow extent between the two CMGs change with season. Four eight-day time periods in 2004 covering times of expanding snow extent, maximum snow extent, receding and minimum snow extent in the NH were; 2-9 December, 25 January – 1 February, 8-15 May and 20-27 August. A similar difference relationship was found over all those time periods; the 0.25° CMG had greater amounts of snow across all fractions compared to the 0.05° CMG except at 100% snow where the difference was reversed (Fig. 9). The amount of difference varies with the season and FSC. Differences in snow extent were least across the 60%-95% FSC range and largest across the 1-50% snow fraction range. The largest differences occurred at time of maximum snow cover, January and were least at time of minimum snow cover in August (Fig. 9).

Greater amounts of 100% FSC are mapped in the 0.05° CMG because the higher resolution allows the snow edge to be mapped in greater detail (Figs. 1 and 2). There is increased accuracy or sharpness of snow extent in the 0.05° CMG compared to the coarser 0.25° CMG in which detail of the snow line is lost and blurred at the edges to lower snow fraction by the averaging of lower snow amounts or no snow beyond the snow edge into the larger cell of the CMG. The effect is similar to that seen in comparison of the snow cover in the Sierra Nevada Mountain subset discussed above. At the time of minimum snow extent in the NH, areas of snow are limited and have a distinct snow line. That characteristic is why the differing resolution CMGs exhibit the least difference at yearly minimum snow extent (Fig. 9) because the snow areas are few and distinctly defined. In other seasons the spread and indistinct nature of snow cover contribute to larger differences between the CMGs.

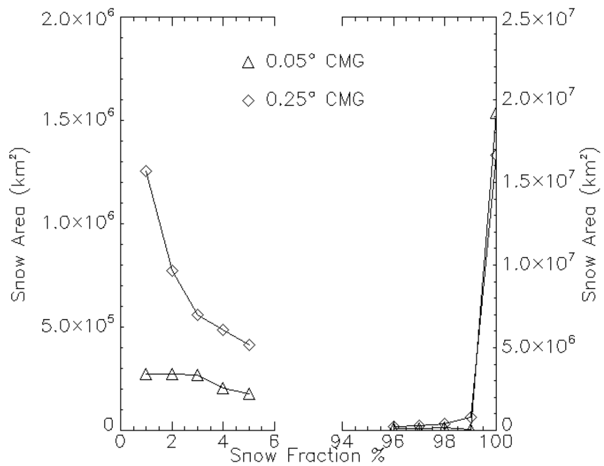


Figure 7. Comparison of snow area between the two CMGs for the 0-5% and 95 -100% FSC ranges on 4 May 2004.

Differences in FSC across the 1-40% range between the two CMG resolutions have two causes- the averaging technique used in this study and the coarser resolution. Increased snow extent of lower snow fractions is caused by averaging snow data into a larger grid cell, thus that FSC is calculated as having a greater area. In large areas of contiguous and near 100% snow cover e.g. the Yukon and Alaska in Figures 1 and 2, the maps show very similar FSC and the extents are least different in the 70-90% fraction range because of the extensive continuity of snow cover in a region. At the edges of snow cover the snow fraction is reduced by averaging because lower snow fractions typically occur at the perimeter of complete snow cover and more snow free land, 0% snow fraction data are included in the average which tends to lower it.

Inclusion or exclusion of 0% FSC in averaging the snow data has an observable effect on the 0.25° CMG snow maps. In the original 0.25° CMG snow maps it was observed that the FSC at the edges of snow cover and the amounts of erroneous snow cover in grid cells were lower than expected. The inclusion of the 0% snow fraction in calculation of the average FSC of the 0.25° CMG lowered the expected FSC. At snow edges including 0% snow as a data value lowers the average snow fraction below what the average would be if only observed snow i.e. snow data from 1-100% were used in the average. For example, a 5x5 block of cells from the 0.05° CMG has snow values of ; 24, 7, 1, 0, 0…, only three observed snow values, the other 22 observations are 0 values, the technique used gives an average snow fraction of 1% in the corresponding 0.25° CMG cell. If the 0, i.e. no snow, values are excluded from the average then the average snow fraction is 11%. That can be a significant difference in snow around perimeters of snow covered areas or in areas of patchy snow cover. To investigate further, a version of the 0.25° CMG algorithm that excludes 0% snow data from the average was written and tested.

Two 0.25° CMGs were made for 4 May 2004, one using the original algorithm and one using the revised algorithm that excludes 0% FSC snow data from the average. Comparison of those CMGs found that the revised 0.25° CMG excluding 0% FSC had increased FSC over the 1-70% FSC range than the original 0.25° CMG (Figs. 10 and 11). In the Sierra Nevada transect (Fig. 8) FSC increased but the distance from 0% to 0% FSC remained the same. Excluding 0% FSC data from the average increased the calculated average FSC. The revised 0.25° CMG also had increased amount of FSC relative to extent of FSC in the 0.05° CMG (Figs. 10 and 11). At higher snow cover, FSC >70% the difference between the two 0.25° CMGs decreases and at about 90% and greater FSC the difference becomes zero (Fig. 10). In areas of contiguous FSC greater than about 85% there is negligible difference in snow area between the two averaging techniques because there are few if any 0% snow data values in those areas.

Across the lower FSC range, 5-25%, excluding 0% snow data from the average resulted in larger increases the FSC than at higher FSC range (Fig. 11). Across the 1-5% FSC range the difference between averaging methods became small and reversed with the revised FSC having lesser extent of 1-2% FSC. Including only non-zero FSC data in the average resulted in a snow map that had increased average FSC. It is thought that the FSC map made by excluding 0% FSC data yields a better representation of snow cover along edges of snow covered areas. Differences in FSC maps were not quantitatively evaluated in this study. It is uncertain how the differences would affect outputs of models that use the FSC data as input.

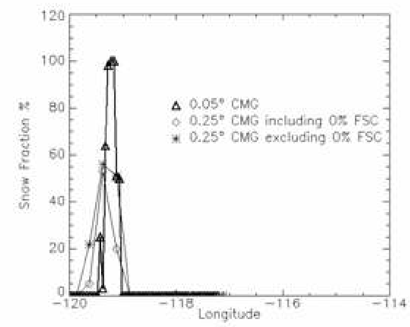


Figure 8. Comparison of FSC along transect of the Sierra Nevada Mountains between the two CMGs. Also plotted is the comparison of FSC between the two methods used to generate the 0.25° CMG.

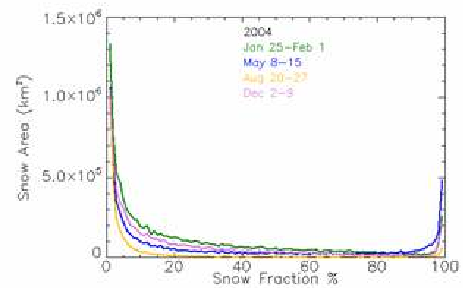


Figure 9. Eight-day FSC area average differences for the Northern Hemisphere for 2004, 25 Jan – 1 Feb, 8-15 May, 20-27 Aug and 2-9 Dec.

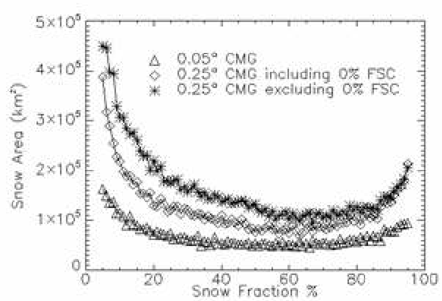


Figure 10. Comparison of snow areas between the ¼ deg CMGs and the 0.05 deg CMG.

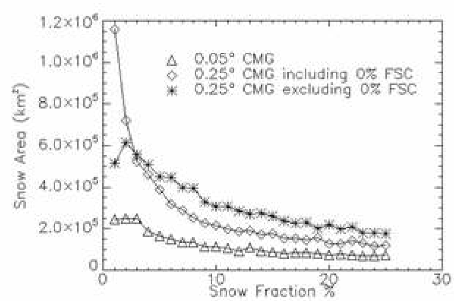


Figure 11. Comparison of FSC areas between the CMGs.

The averaging method used to make the FSC map has an influence on erroneous snow in the product. The primary source of erroneous snow, i.e. mapped snow that is not actually snow, originates from snow and cloud discrimination errors made in the Level-2, MOD10_L2 algorithm/product that are carried through to these higher level products. Erroneous snow caused by those errors is most obvious in the summer season in locations that snow is impossible, e.g. southern Alabama where cells may occasionally have 1-20% or higher erroneous snow in the MOD10_L2 product and occur in small groups of pixels scattered around the map or widely scattered individual pixels. Erroneous snow occurs across the range of 1-30% FSC in the 0.05° CMG That erroneous snow is reduced to a range of 1-3% in the original averaging to 0.25° CMG cells, but can be in the 1-20% FSC range in the revised averaging that excludes 0% FSC data values 0.25° CMG cells. Investigation of how to screen erroneous snow from any of the CMGs was not pursued. In some circumstances it may be possible for a user to either create an algorithm to screen out the obvious erroneous snow or manually screen it from either CMG. The ultimate solution is to greatly reduce the erroneous snow resulting from snow/cloud confusion in the Level-2 snow mapping algorithm.

CONCLUSIONS

From a synoptic perspective the 0.05° and 0.25° resolution CMGs are similar in mapping FSC extent with the coarser resolution tending to map snow over a broader area at all FSC fractions except at 100% FSC. In effect, the coarser resolution snow map appears to spread snow over more area and have greater area of lower FSC compared to the higher resolution CMG. Observed difference characteristics between the high and low resolution CMGs were consistent between four seasons at times of snow covered area expansion, maximum, contraction and minimum for the Northern Hemisphere. When scrutinized at local or regional scales there are significant differences in FSC amounts and extent between the CMGs. The higher spatial resolution CMG snow map yields a more detailed picture of snow extent conditions that does the coarser resolution CMG

Comparison of the 0.25° FSC CMGs made by two averaging techniques, including or excluding 0% FSC data in the averaging, revealed that the technique has an effect on the resulting FSC map when the FSC less than about 80%. Either technique is valid but the resulting FSC maps can be interpreted or screened for usage in different ways. The two most observable differences were delineation of snow edges and extent of FSC between the CMGs. Recommendation of which technique is preferred for making the 0.25° FSC CMGs cannot be made based on this study because quantitative evaluation was not done nor was validation done for the FSC maps.

REFERENCES

Drush M, Vasiljevic D, Viterbo P. 2004. ECMWF's Global Snow Analysis: Assessment and Revision Based on Satellite Observations. Journal of Applied Meteorology 43 (9): 1282–1294.

Hall DK, Riggs GA, Salomonson VV, DiGirolamo N, Bayr KJ. 2002. MODIS Snow-Cover Products. Remote Sensing of Environment 83:181-194.

Riggs, G.A., Hall, D.K., and Salomonson, V.V. 2003. MODIS Snow Products User Guide. http://modis-snow-ice.gsfc.nasa.gov/

Rodell M, Houser PR. 2004. Updating a Land Surface Model with MODIS-Derived Snow Cover. Journal Hydrometerology 5(6): 1064-1075.

Relevant Websites

MODIS snow and sea ice global mapping project http://modis-snow-ice.gsfc.nasa.gov/