Polar Cloud Detection using MISR and MODIS Data

Tao Shi[*], Bin Yu [†], Eugene E. Clothiaux [‡], and Amy J. Braverman [§]

1 Introduction

Global climate models predict that the strongest dependences of surface temperatures on increasing atmospheric carbon dioxide levels will occur in the Arctic and this region temperature increment can lead to global temperature increase (Charlock and Ramanathan 1985). A systematical study of this relationship requires accurate global scale measurements, especially the cloud coverage, in polar regions. Thus arctic cloud detection is extremely important for climate modeling. It has been proven, however, very challenging because of the similar remote sensing characteristics of clouds and ice-snow surfaces. As the first of a long line of research that must be pursued to characterize accurately the properties of clouds over the polar regions, this paper proposes two new Arctic cloud detection algorithms using data collected by NASA's satellite sensors: the Multi-angle Imaging SpectroRadiometer (MISR) and the Moderate Resolution Imaging Spectrometer (MODIS).

We first developed a polar cloud detection algorithm, the Enhanced Linear Correlations Matching algorithm (ELCM), using only MISR angular radiances. Specifically, our algorithms are based on three physically meaningful MISR features, correlation, standard deviation, and Normalized Differential Angular Index (NDAI) that are aimed to capture the difference between the properties of the ice/snow covered surfaces and those of clouds. And they are arrived at with ample exploratory data analysis and interactions of statisticians and atmospheric scientists over the course of more than three years. The ELCM algorithm provides a 91.80% agreement rate when compared to around 4 million pixels of expert labels.

Then we fuse the cloud mask produced from the MISR ELCM algorithm and that from the MODIS operational algorithm (91.97% agreement rate with expert labels). In the data fusion process, the consensus pixels of two masks agree amazingly with the expert labels (97.75%), but the these pixels only have a 76% coverage. Therefore, those accurate consensus

[*]Department of Statistics, The Ohio State University, Columbus, OH 43210-1247. Email: taoshi@stat.ohio-state.edu

[†]Department of Statistics, University of California, Berkeley, CA 94720-3860. Email: binyu@stat.berkeley.edu

[‡]Department of Meteorology, Pennsylvania State University, University Park, PA 16802. Email: cloth@essc.psu.edu

[§]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109-8099. Email: Amy.Braverman@jpl.nasa.gov

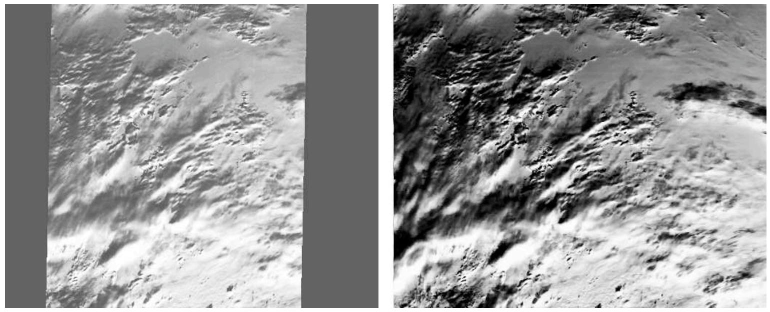

Figure 1: Left: MISR An red image; Right: MODIS band 1 image mapped to MISR grid. MISR orbit 12558, blocks 25-27.

pixels may serve as training data to obtain a classifier, which is applied back to classify the combined MISR/MODIS data with a better accuracy (94.51%) and a better coverage (100%) than masks from each sensor alone. This paper is organized as follows: Section 2 describes the MISR ELCM algorithm; The data fusion between MISR and MODIS is explained in Section 3; We conclude in Section 4 with discussions.

2 MISR ELCM algorithm

Viewing the atmosphere from multiple angles, MISR has stereo capabilities that can be used to retrieve the elevation of objects on and above the surface of the Earth. Besides the stereo information, MISR off-nadir angle cameras provide three dimensional scattering patterns of different objects. Those two type of novel information leads to two MISR operational cloud masks for detecting polar clouds (Diner et al 1999b, Diner et al 2001, Di Girolamo et al 2000): the Stereoscopically Derived Cloud Mask (SDCM) and the Angular Signature Cloud Mask (ASCM). However, both algorithms do not reach the full potential of the information existed in MISR angular radiances. Compared to around 4.4 million expert labelled pixels over Greenland collected in 2002, the SDCM has an 80% accuracy and a 27%coverage, and the ASCM has a 76% accuracy and an 80% coverage.

To improve the polar cloud detection for MISR, we develope the ELCM algorithm based on three physically meaningful features, correlation, standard deviation, and Normalized Diffe rential Angular Index (NDAI) that are aimed to capture randiance properties of the ice/snow covered surface. The correlation feature is designed to capture the high correlation between MISR angles when no clouds present in the view angles. The standard deviation of An red radiance is used to characterize the smoothness of the reflecting surface. The NDAI feature measures the forward scattering of radiance in the off-nadir angles.

Thresholding on these three features together, the ELCM algorithm is proposed. The ELCM algorithm is applied to the data collected over Greenland during daylight season of 2002. The left panel of Figure 1 shows an example of three blocks of MISR nadir angle red band image. Expert labels and ELCM algorithm results are shown at the upper left and

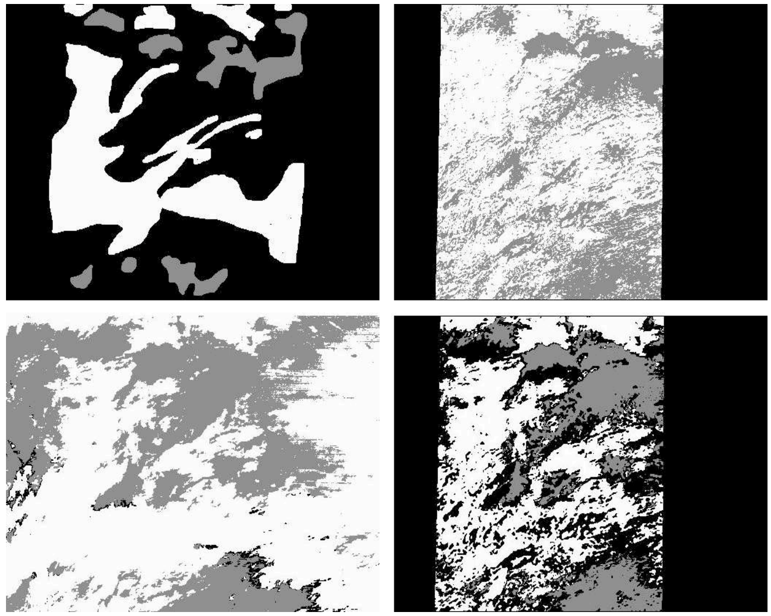

Figure 2: MISR orbit 12558, blocks 25-27. Upper left: expert labels Upper right (white for “cloudy”, gray for “clear” and black for “not sure”): MISR ELCMC result; Lower left: MODIS results; Lower right: Consensus pixels. Coding scheme: white for “cloudy”, gray for “clear”, and black for “no retrieval” or “dis-agree”.

upper right panels of Figure 2 respectively. The agreement rate with the 4.4 million (171 MISR blocks) of expert labels is 91.80%, much higher than both SDCM and ASCM. The coverage of the ELCM algorithm is over all pixels with valid radiance observations. Detailed algorithm description is in Shi et al (2004a).

3 Fusing MISR and MODIS

Since MISR and MODIS covers the same location simultaneously, it is nature to directly combine the cloud detection results from two sensors. We fuse the MISR ELMC mask and the MODIS operational algorithm mask (Ackerman et al 2002) together to achieve better results. Because MISR masks are reported at a 1.1km by 1.1km resolution and MODIS masks are reported at a 1km by 1km resolution, we project the MODIS results onto the MISR SOM grid by a nearest neighbor method. The right panel of Figure 1 shows the MODIS image mapped to the MISR grid and the lower left panel of Figure 2 gives the MODIS cloud mask mapped on MISR grid.

With the MODIS cloud masks on the MISR grid, a straightforward way to fuse two masks is reporting the consensus pixels of them. The dis-agreed pixels are reported as “non-retrieval”. Overall, the consensus pixels agree with the expert labels at an amazing rate 97.75%, but the consensus pixels only cover 76% of the valid pixels. As an example shown in Figure 2, the lower right panel shows the consensus pixels in white ("cloudy") and gray ("clear") pixels, while the black pixels represent the dis-agreed pixels.

The high "non-retrieval" rate stand as a major drawback of the simple MISR and MODIS fusion scheme discussed above. However, the consensus pixels are highly accurate, so they can serve as training data for other statistical methods, such as Quadratic Discriminate Analysis (QDA, see Mardia et al 1979 for details). It is pointed out in Shi et al (2004b) that QDA with accurate labels has the potential to provide very good accuracy on MISR data. For online processing of the data, accurate training labels are unavailable in each single sensor. By fusing the labels provided by MISR and MODIS based on different physics properties of clouds and snow/ice, we get high confidence labels for other statistical methods based on training labels.

Since we process data three block by three block, a QDA classifier is trained if the data set contains both "cloudy" and "clear" areas. In the data we investigated, there are 32 partly cloudy data sets. The QDA classifier uses the consensus pixels as training data and takes three MISR ELCM features and five MODIS features. Then its results are compared with the expert labels to evaluate the accuracy. Over all partly cloudy data set, MISR ELCM agrees with expert 88.6%, MODIS agrees 90.7%, and the QDA classifier agrees 93.4%. So the accuracy over those data sets is greatly increased. Besides better accuracy, the coverage is also extend to all pixels with valid radiance measurements.

4 Conclusions and Discussions

In this paper, a new MISR polar cloud detection algorithm is discussed and a MISR and MODIS data fusion algorithm is proposed. The MISR ELCM algorithm shows good classification accuracy and its computation is simple and fast enough for online data process. By fusing the MISR and MODIS data together, the cloud detection accuracy is improved over the partly cloudy data sets.

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References

[1] Charlock, T.P., and Ramanathan, V. (1985). The albedo file and cloud radiative forcing produced by a general circulation model with internally generated cloud optics. *J. Atmos. Sci.*, **42**, 1408–1429.

[2] Di Girolamo, L., Clothiaux, E.E., Davies, R., Diner, D.J., Moroney, C., Mullers, J.-P., et al. (2000). MISR: a new way to look at clouds. IGARSS 2000. IEEE 2000 International Geoscience and Remote Sensing Symposium. Taking the Pulse of the Planet: The Role of Remote Sensing in Managing the Environment. Proceedings (Cat. No.00CH37120). **3**, 947-8.

[3] Diner, D.J., Asner, G.P., Davies, R., Knyazikhin, Y., Muller, J. Nolin, A.W., et al. (2001) New directions in earth observing scientific applications of mulitangle remote sensing. *Bulletin of American Meteorological Society.* **80**, 2209–2228.

[4] Diner, D.J., Davies, R., Di Girolamo, L., Horvath, A. Moroney, C., Muller, J.-P., et al. (1999b). MISR level 2 cloud detection and classification algorithm theoretical basis. Jet Propulsion Lab., Pasadena, CA, JPL Tech. Doc. D-11399, Rev. D, 1999.

[5] Clothiaux, E.E., and MISR Science Team Members, (2002): Using MISR data to identify clouds in the Arctic, IEEE 2002 International Geoscience and Remote Sensing Symposium, Westin Harbour Castle Hotel, Toronto, Ontario, Canada, 23-28 June 2002. Talk.

[6] Mardia, K. V., Kent, J.T., and Bibby, S. M. (1979) *Multivariate Analysis.* Academic Press.

[7] Shi, T., Yu, B., Clothiaux, E.E., Braverman, A. (2004a) Cloud Detection over Snow and Ice based on MISR Data. *Technical Report, Department of Statistics, University of California.*

[8] Shi, T., Yu, B., Clothiaux, E.E., Braverman, A. (2004b) Fusing information from MISR and MODIS for Polar Cloud Detection *The 38th Asilomar Conference on Signals, Systems and Computers.* Montery, California, November 2004.

[9] Ackerman, S., Strabala, K., Menzel, P., Frey, R., Moeller, C., Gumley, L., et al. (2002) Discriminating Clear-Sky From Cloud With MODIS, Algorithm Theoritical Basis Document (MOD35), NASA Goddard Space Flight Center.