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DIS 142305: Using Remote Sensing and GIS Techniques to Monitor the State of the Greenland Ice Sheet

PAYNE, Meredith C., College of Oceanic and Atmospheric Sciences, Oregon State University, 104 COAS Administration Building, Corvallis, OR 97331, mpayne@coas.oregonstate.edu and NOLIN, Anne W., Department of Geosciences, Oregon State University, 104 Wilkinson Hall, Corvallis, OR 97331

As we strive to tailor hypotheses related to global climate change while assessing the possibility of an anthropogenic driver, it becomes crucial to constantly monitor the world's most climatically sensitive areas. Examples of such areas include glaciers and ice sheets whose record melt is impacting communities on a global scale. In some cases, regions that rely upon glacier water as a principle source of fresh water are witnessing the rapid dwindling of resources. In other cases, rising sea level, to which the melting of glacier ice contributes, is threatening low-lying communities. Unfortunately, as is the case with the Greenland ice sheet, many such areas are remote and dangerous, making spatially and temporally comprehensive field measurements cost prohibitive. Hence, we must rely on remotely sensed measurements from aircraft and satellites in order to fill in our knowledge gaps left by sparse field measurements.

The Multi-angle Imaging SpectroRadiometer (MISR) instrument, operational since 2000, is onboard the Earth Observing System (EOS) satellite, Terra, in sun-synchronous polar orbit. MISR is uniquely suited for studying the poles due to the continuous, overlapping coverage of data taken by its nine, pushbroom cameras arrayed at fixed angles ranging from 0° to 70.5° (from nadir) and symmetric about the nadir camera. Each camera has four filters: red, green, and blue (in the visible), and a near-infrared (NIR) at 866 μm wavelength. The multi-angle views in conjunction with the 275-meter resolution available at the visible red wavelength on all nine cameras can be used to compute a proxy of surface roughness of the observed target on comparable scale to Moderate Resolution Imaging Spectroradiometer (MODIS) 250-meter data (Nolin et al., 2002). We have elected to use MISR's red-filtered C-cameras (60.0° fore and aft) in order to define and investigate a proxy for ice surface roughness based on forward and backward scattered radiation, which we call the Normalized Difference Angular Index (NDAI). We define NDAI for Greenland to be fore C-camera red-channel values subtracted from the aft C-camera red-channel values divided by their sum. Since the forward –viewing camera is seeing forward-scattering radiation while the aft camera sees backscattered radiation (the sun is to the south), forward scattering as associated with generally smooth surfaces and backward scattering dominates when an observed surface is rough (Nolin and Payne, 2007). Therefore, in an NDAI image, values range from -1 to 1 and rougher surfaces appear brighter.

As a case study of the NDAI proxy measurement, we chose to study a region in Western Greenland, encompassing Jakobshavn Glacier (69.2° N, 50.2° W, 40 m elevation), one of the fastest moving glaciers in the world and one that drains a significant percentage of the Greenland Ice Sheet (> 90 x 103 km2, (Rignot and Kanagaratnam, 2006). Our study site extends upglacier in the inland ice to Summit (72.6°N, 38.5° W, 3200 m elevation) the highest point on the Greenland Ice Sheet. We reviewed MISR browse images of the Greenland ice sheet for blocks 30-35, paths 8-10 during the 2000-2007 sunlit seasons across this transect and determined 2004 to be the year when our study site was least obscured by clouds. Nevertheless, completely cloud-free images over the entire region of study were impossible to come by. We investigated application of the Radiometric Camera-by-camera Cloud Mask (RCCM) products provided by the National Aeronautics and Space Administration (NASA) Langley Atmospheric Science Data Center (ASDC) to the radiance images, but found the mask to be overly strict when distinguishing cloud pixels from ice pixels. Hence, using digital image processing along with Geographical Information Systems (GIS) techniques, we devised a method of creating composite images of NDAI and of top of the atmosphere (TOA) bidirectional reflectance factor (BRF) encompassing the early- (April + May), mid- (June + July), and late- (August + September) ablation season (Figure 1). These composite NDAI and reflectance images, along with their corresponding gradient images (mid-season composite minus early-season composite, and late-season composite minus mid-season composite) in order to establish a pattern whereby the coastal regions are observed to grow progressively rougher as 1) seasonal snow and ice in the ablation zone melts back to reveal underlying bedrock, 2) melt ponds form upglacier in the wet-snow (slush) and percolation zones (as defined by Benson, 1962; Long and Drinkwater, 1994), 3) sastrugi relief is intensified, and 4) snow/ice-bridges melt and collapse, revealing the highly irregular crevasse topography beneath. Although changes are not as dramatic upglacier towards Summit (melt ponds do not appear in the dry-snow zones), changes towards a rougher surface are observed mid-season in the percolation-zone, as NDAI pixels have greater values and become brighter compared with the early-season. As expected there is little observed change in the near proximity of Summit over the sunlit season, as it lies in the conjectured dry-snow zone (as defined by Benson, (1962) and Long and Drinkwater, (1994). In the late-season images (August + September), after snowfall has resumed (especially over the wet-snow and percolation zones), NDAI values are observed to drop, but not fall as low as the early-season (April + May) values. Study of TOA reflectance images reveals the exact opposite relationship of pixel values throughout the time series, becoming darker (lower values) mid-season and brightening again after fresh snowfall towards the end of the sunlit season.

We are encouraged enough by these results to proceed with production of similar NDAI composite images for the entire Greenland ice sheet for all years where enough low-cloud percentage images are available. We hope to use these products to expand our work analyzing the evolution of glacier zones during the operational lifetime of the MISR instrument, including possible identification of glacier zones (i.e. the superimposed-ice zone) invisible to radar (Nolin and Payne, 2007). Furthermore, we believe that these products will enrich the already plentiful MISR dataset publically available for use in analyses.

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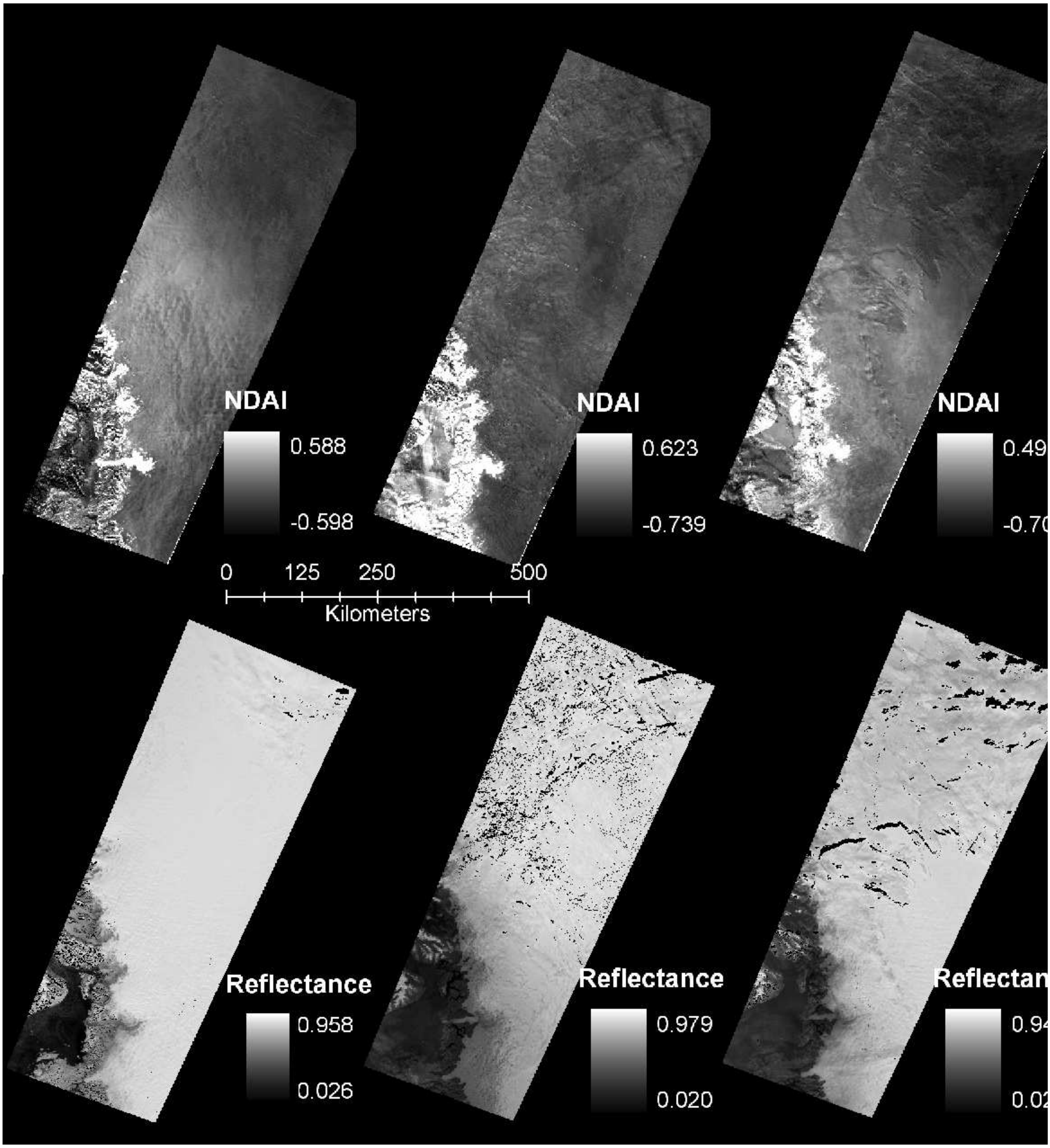

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