Using daily MODIS 250m data to monitor lake ice-out

Naven Kathuroju, Michael A. White, Chris Luecke

Department of Watershed Sciences
Utah State University

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Introduction

Late 20th and early 21st century climate change has occurred asymmetrically such that high northern latitudes have experienced larger temperature increases than other areas. The potential for ecosystem alteration, including changes in permafrost dynamics, soil carbon, ecosystem carbon exchange, phenology, species diversity is thus considerable. In particular, seasonal ice dynamics of the numerous small freshwater lakes in Alaska are likely to be both diagnostic of climate change and important components of ecosystem function. Due to the remote location of most lakes and logistical sampling difficulties, it is impractical to conduct field monitoring of lake resources. Remote sensing is a potentially attractive alternate method. It is therefore our purpose in this pilot study to investigate the possibility of using information from the Moderate Resolution Imaging Spectroradiometer (MODIS) 250m products to monitor seasonal ice dynamics in the north slope of the Brooks Mountain Range. In the following sections we presents three areas: (1) methods and data we have used to address this topic; (2) results; and (3) suggestions for future approaches.

Methods

Obtaining MODIS images

Using the Earth Observing System Data Gateway (http://edcimswww.cr.usgs.gov/pub/imswelcome/), we obtained DLT-format daily 2000 to 2004 MODIS collection 4 MOD09GQK data from the Terra satellite for tile number horizontal 12 and vertical 2, corresponding to the North Slope of Alaska. MOD09GQK is a daily resolution, Level-2g MODIS land product including 250m atmospherically corrected red and near-infrared (NIR) reflectances. MODIS land data are tiled into a sinusoidal projection that produces visually unacceptable distortion for Alaska; consequently we reprojected all data to UTM with the MODIS reprojection tool (MRT). We used daily data on the rationale that given the extensive cloud cover on the North Slope, the maximum number of opportunities to obtain cloud-free data was desirable.

Quality check of the images

We used the standard quality control (QC) bits included with the MOD09GQK product and retained only those pixels with bit sums of 0 or 1 for QC bits 0-7 (indicating no cloud cover and ideal or less than ideal quality). Unfortunately, this quality control process was helpful but did not remove all clouds. Manual pixel-by-pixel screening was not possible and significant cloud cover was still present in the following processing scheme.

Generating lake masks

As our goal was to process the MOD09GQK for individual lakes, a critical process was the creation of a lake mask, indicating for each 250m pixel whether or not it was a water body (indicated by a 1) or land (indicated by a 0). The standard MODIS land/sea mask is not useful for this task. Further, it was impossible to identify this condition solely by analysis of MODIS imagery. The process was extremely labor intensive but may be summarized by the following four steps. First, in preliminary analysis we observed that persistent shadowing caused extensive image processing difficulties in the Brooks Range. Using Erdas IMAGINE, we created a region of interest polygon and eliminated the central mountain region. Second, we used TM imagery to identify, at a 30m resolution, water/non-water pixels. During this process, we experimented with numerous techniques and ultimately settled on use of NIR channel data alone. We verified the technique against known area for Toolik Lake and visually compared the mask with atlas and TM images. Third, we resampled the 30m TM data to the 250m MODIS resolution and set the MODIS pixel to water if more than 50% of the pixel was water. Fourth, we executed the same lake identification technique with the MODIS data and selected only those pixels identified as water in both the TM and MODIS approach. Identification as water was consequently highly conservative.

Spatial compositing

After producing the pixel-specific water/non-water mask, we created an algorithm to group contiguous water pixels into uniquely identified water bodies. With this approach, pixels in individual lakes would have a unique numerical identifier. This allowed us to use a spatial compositing process for remote sensing analysis, i.e. we created an average lake-wide value for each day.

Ice out detection

After generating lake mask, we conducted an extensive analysis of temporal patterns of various vegetation indices and individual channel data. We found that use of the simple normalized difference vegetation index (NDVI) was useful, on an exploratory basis, for detecting ice-covered and ice-free lake conditions. For each unique water body, we generated NDVI time series and estimated ice-out as the date at which NDVI exceeded 0.

Results and Discussion

Using this method in 2000, we found a total of 214 unique water bodies. The average lake thaw date from all the lakes in this region was day of year (DOY) 153 (June 2) with a standard deviation of 14.6 days. Although the dates appear to be in agreement with the field observations, general questions about the method's validity still prevail. Specifically, we concluded that it was not possible to estimate with any confidence the ice-out date. In reality, the estimates we obtained are only the earliest date on which we can say ice-out occurred. Essentially, it is possible and in fact very likely that ice-out occurred earlier during cloud-covered conditions. Improvements to the detection approach we used, which is based on a fairly crude remote sensing analysis, are unlikely to overcome the fundamental cloud cover problems limiting the use of optical remote sensing approaches. We therefore recommend that optical remote sensing not be used for ice-out monitoring.

Suggestions for future work

An improved approach would be to use synthetic aperture radar, which can provide high temporal and spatial coverage of small lakes. Perhaps most critically, radar data does not experience cloud cover limitations. We have pursued this approach for this project for over a year and on August 22, 2006, we received notification that the Alaska Satellite Facility has granted us free data access to several years of ERS-1/2 and RADARSAT data. Our top priority will be to obtain these data for the Toolik region and to investigate radar-based ice-out detection approaches.