Interannual variability of lake ice phenology in southwest Alaska: Integrating remote sensing and climate data

Chuck Lindsay[1], Page Spencer[2], and Beth Hill[2]
[1]National Park Service, Southwest Alaska Network Inventory & Monitoring Program; [2]Lake Clark National Park & Preserve

Introduction

Continued warming in the northern high latitudes is expected to alter freeze and breakup dates of lake ice, affecting lake ecosystems, wildlife migration and habitat, and human subsistence and recreation.


Wolves crossing a frozen lake.


Snowmachine travel on Lake Clark.


Ice fishing for lake trout.


Wheel plane landing on lake ice.

Remotely sensed data can be used to track the timing of ice formation and break-up on large lakes (lake ice phenology). We are using Moderate Resolution Imaging Spectroradiometer (MODIS) imagery from the Aqua and Terra satellites to monitor lake ice dynamics in a network of national parks and wildlife refuges in southwest Alaska. The moderate spatial resolution (250 m) and high temporal frequency (1 day) provided by MODIS allows for frequent observations of a region characterized by frequent cloud cover and little infrastructure to support ground-based measurements. We analyzed the timing of ice formation and break-up on lakes in southwest Alaska during 2001-10 and correlate the interannual variability in lake ice phenology to climate.

Study area

The study area comprises 17 large lakes and small lake systems in southwest Alaska. It includes lakes in Becharof National Wildlife Refuge, Katmai National Park and Preserve, Kenai National Wildlife Refuge, and Lake Clark National Park and Preserve. Lakes and lake systems range in size from 2,300 to 246,200 ha and include Iliamna Lake, the largest freshwater lake in Alaska.

Study area in southwest Alaska. Lake ice cover is monitored at (1) Tustumena Lake, (2) Skilak Lake, (3) northern Kenai lakes, (4) lower Susitna lakes, (5) Beluga Lake, (6) Chakachamna Lake, (7) Telaquana Lake, (8) Twin Lakes, (9) Lake Clark, (10) Iliamna Lake, (11) Kukaklek Lake, (12) Nonvianuk Lake, (13) Lake Coville, (14) Lake Grosvenor, (15) Naknek Lake, (16) Lake Brooks, and (17) Becharof Lake. Other lakes are not shown.

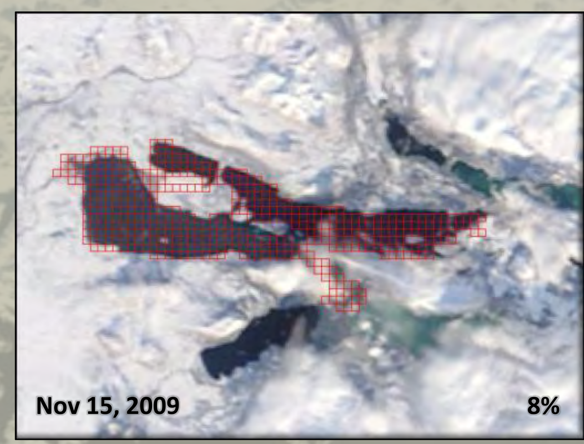
Methods

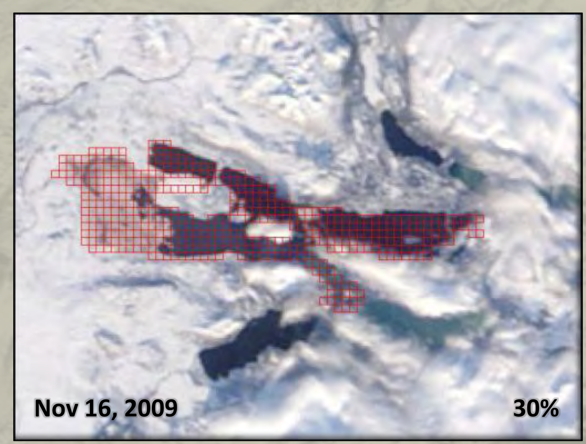
Daily MODIS imagery was manually interpreted to quantify lake ice cover (previous attempts to use automated digital image analysis techniques were problematic and resulted in serious misclassification). Georeferenced, true-color MODIS imagery were obtained through a web map service from the University of Alaska at Fairbanks. Percent ice cover was quantified in a Geographic Information System (GIS) using a 100 ha grid masked to lake margins.

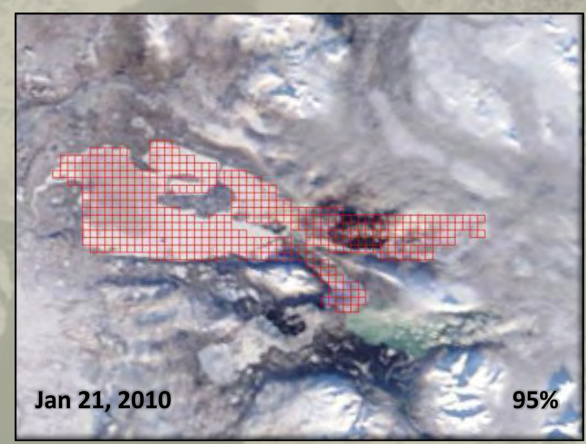
Metrics used for lake ice monitoring. The first date of the first occurrence is reported for freeze-up. The first date of the last occurrence is reported for break-up.

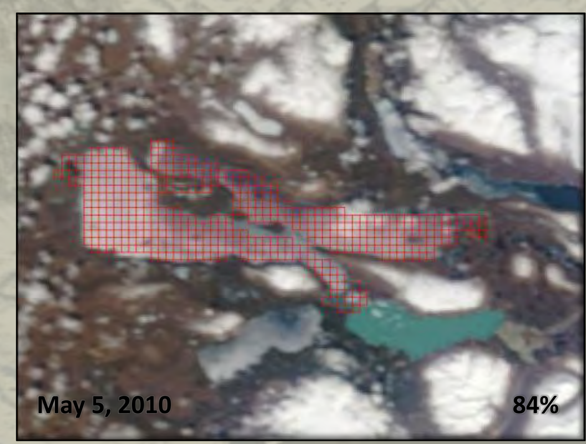
% Ice	Metric
≥10%	Start freeze-up
>90%	Final freeze-up
≤90%	Start break-up
<10%	Final break-up

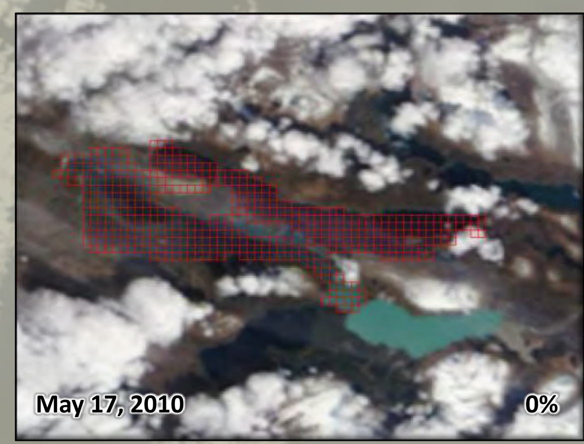
Thick or snow-covered ice appears as white on true-color imagery and is easily interpreted. Open water is black or dark blue, light blue represents water with suspended sediment from glacial or volcanic origin. Wet ice occurs during break-up, overflow, or from mid-winter rain events. Wet ice is often mottled white and black or white and blue. Bare ice is dark colored (blue or black) and occurs before the first snowfall or when frozen lakes are windswept. Pressure cracks are often visible in the imagery and can be used to differentiate ice from open water. Cloud cover frequently obstructs interpretation and sometimes results in misleading (artificially late) dates for freeze-up and break-up.









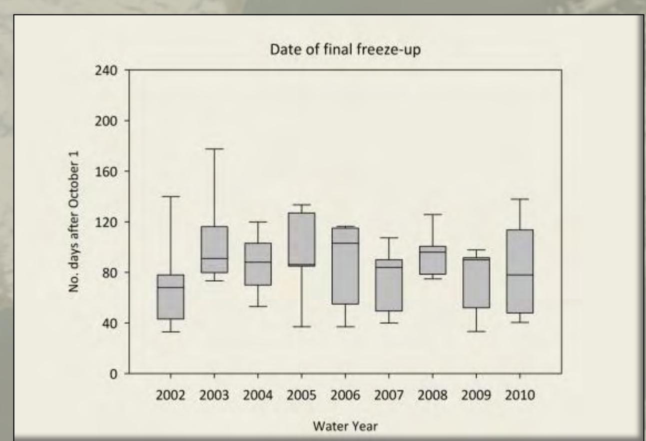


Freeze-up and break-up of Naknek Lake (Katmai National Park & Preserve) during the winter of 2009-10. Ice-free (Nov 15), freeze-up (Nov 16), frozen (Jan 21), break-up (May 5), and ice-free (May 17) conditions are shown above.

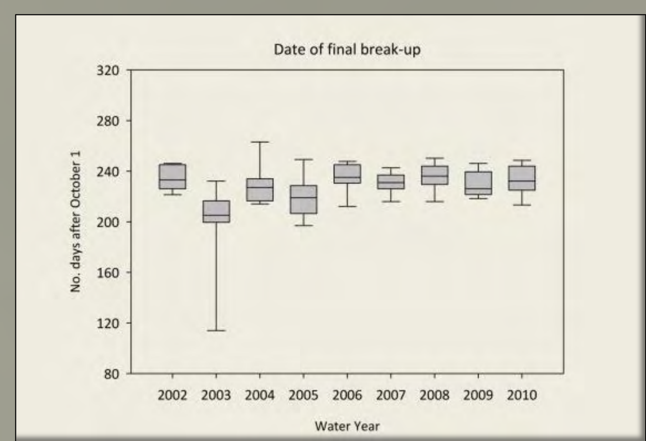
Climate data (daily maximum and minimum temperature and precipitation) for Kenai, King Salmon, and Port Alsworth were obtained from the National Climatic Data Center Global Historical Climatology Network database. El Niño-Southern Oscillation (ENSO) conditions are represented by the Multivariate ENSO Index (MEI), which is based on six atmospheric and oceanic variables observed over the tropical Pacific. Cold-ENSO phase La Niña conditions are represented by negative MEI values, while warm-ENSO phase El Niño conditions are represented by positive values.

Results

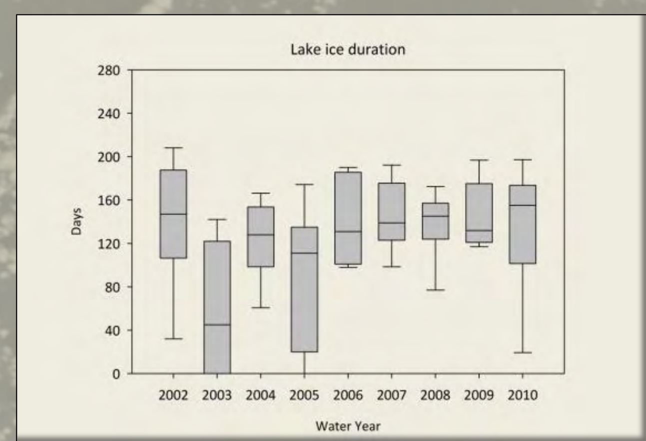
Lake ice showed significant interannual variability in freeze-up dates over 2001-10. Initial ice cover was more dynamic than mid-winter ice cover. Lake ice responded to mid-winter thaw (Chinook and warm air advection) events with reduced ice cover and to prolonged cold snaps with increased ice cover. Break-up was more rapid than freeze-up and the timing of break-up was relatively consistent from year-to-year. The average lake ice duration (period between final freeze-up and final break-up) was four months (124 days). Seven large lakes did not completely freeze (>90% ice cover) during the 2002-03 winter. Duration of lake ice cover was negatively correlated with average winter air temperature. Lake ice phenology is a simple measurement that is a useful indicator of climatic conditions in the hydrologic system.



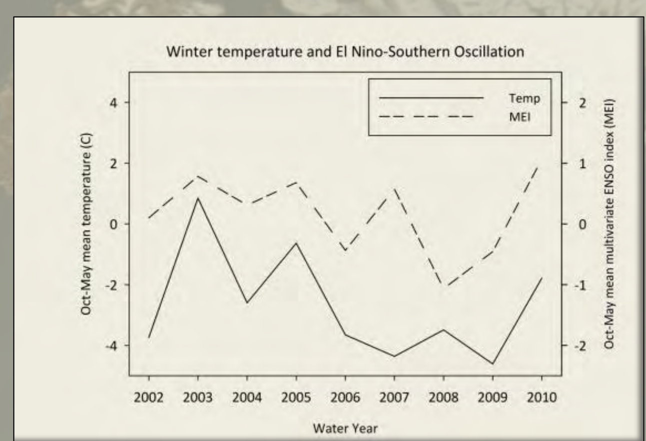
Final freeze-up (>90% ice cover) dates for all study lakes. The range of dates for each water year are shown by percentile (10, 25, 75, and 90%) and median value.



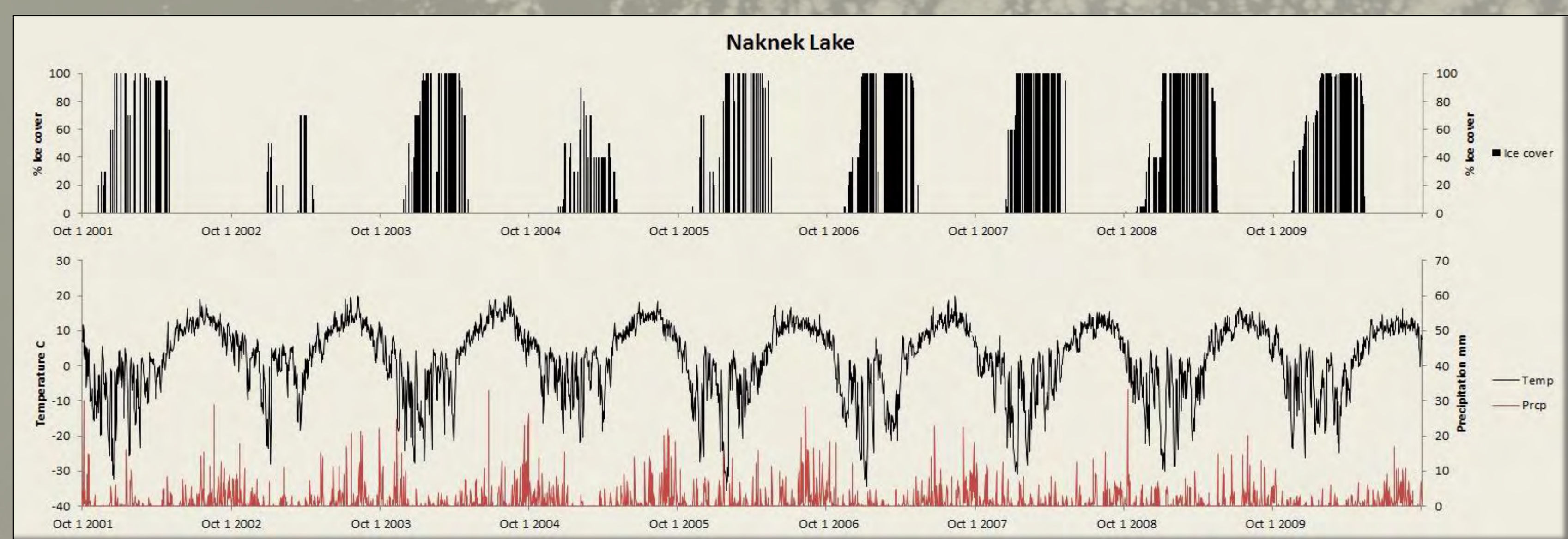
Final break-up (<10% ice cover) dates for all study lakes. The water year encompasses Oct. 1 to Sep. 30 and is titled by the year in which it ends.



Lake ice duration (number of days between final freeze-up and final break-up) for all study lakes.



Average winter (Oct-May) temperatures for SW Alaska and ENSO conditions. El Niño conditions occurred during the 2002-03, 2004-05, 2006-07, and 2009-10 winters. These winters were warm, with the exception of 2006-07. Large lakes (n=7) did not completely freeze (<90% ice cover) in 2002-03 and 2004-5 (n=2).



Lake ice cover for Naknek Lake and corresponding daily temperature and precipitation for King Salmon. The ice-season (lake ice duration) occurs between final freeze-up (>90%) and final break-up (<10%). Missing data during the ice-season represent partial or complete cloud cover.

Background: MODIS Terra satellite image of SW Alaska on February 27, 2011 (MODIS Rapid Response, NASA GSFC)