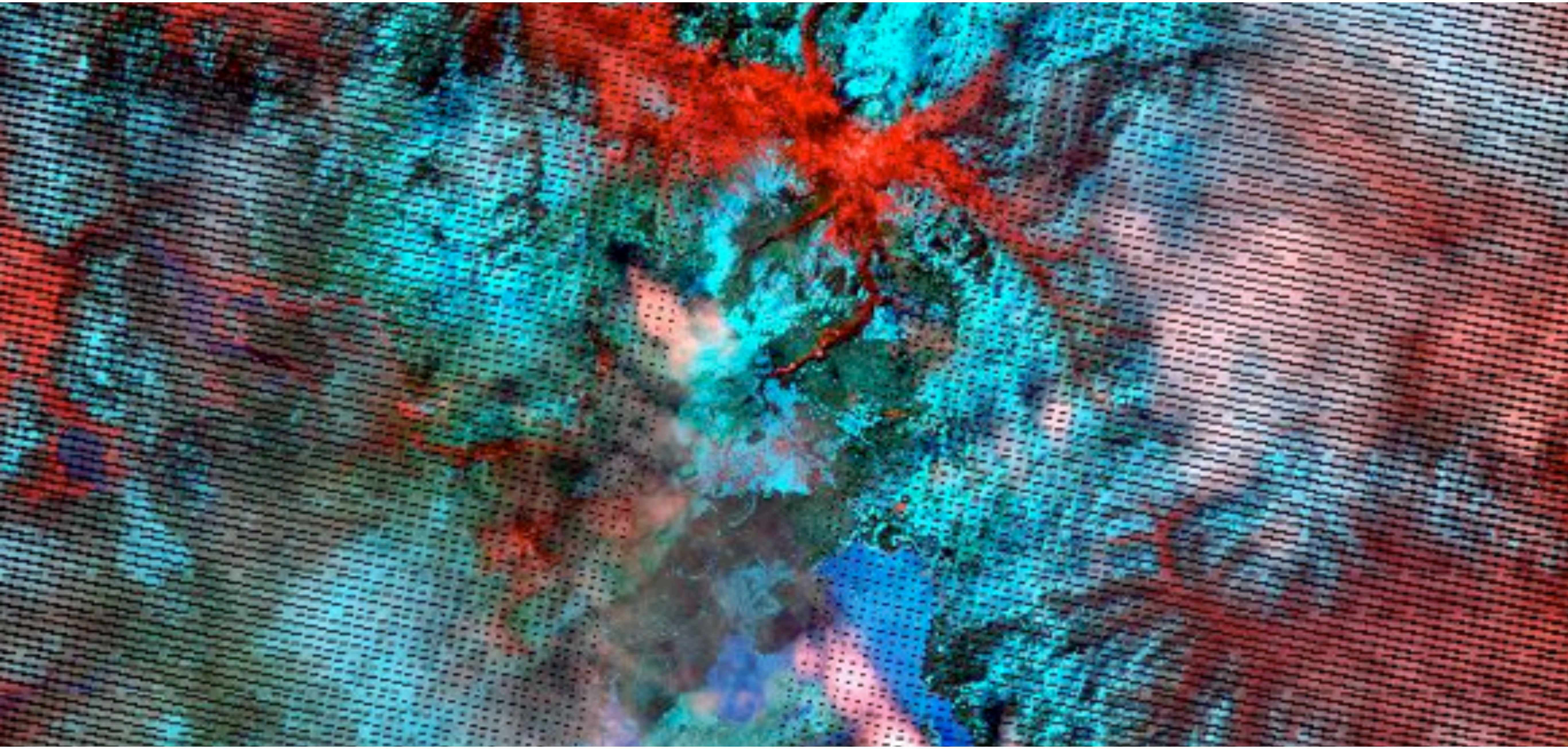
Accuracy Standards for Partially Cloudy Landsat Visible/Infrared Snow Maps



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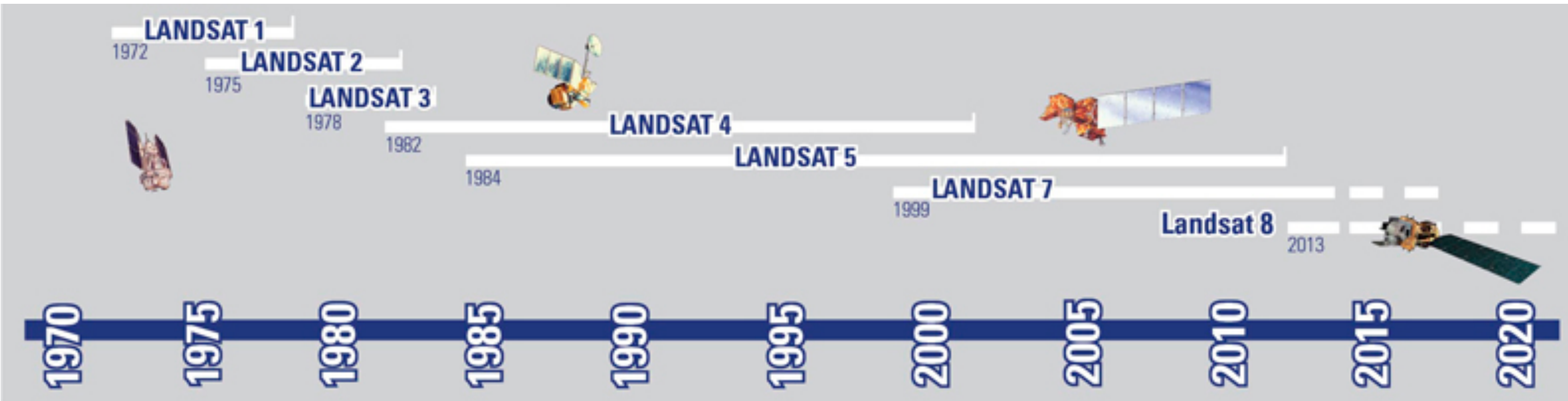
NASA POSTDOCTORAL PROGRAM
Administered by Oak Ridge Associated Universities

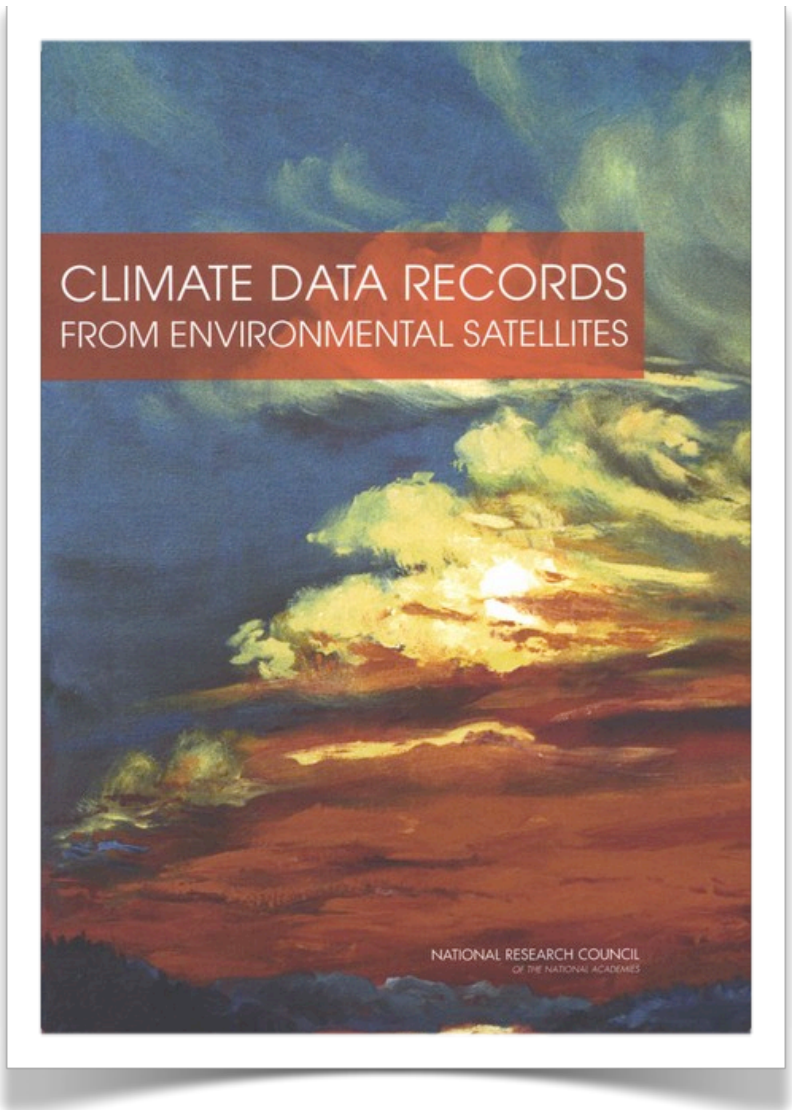
snowpex 1st International Satellite Snow Intercomparsion Workshop (ISSP1), College Park, Maryland

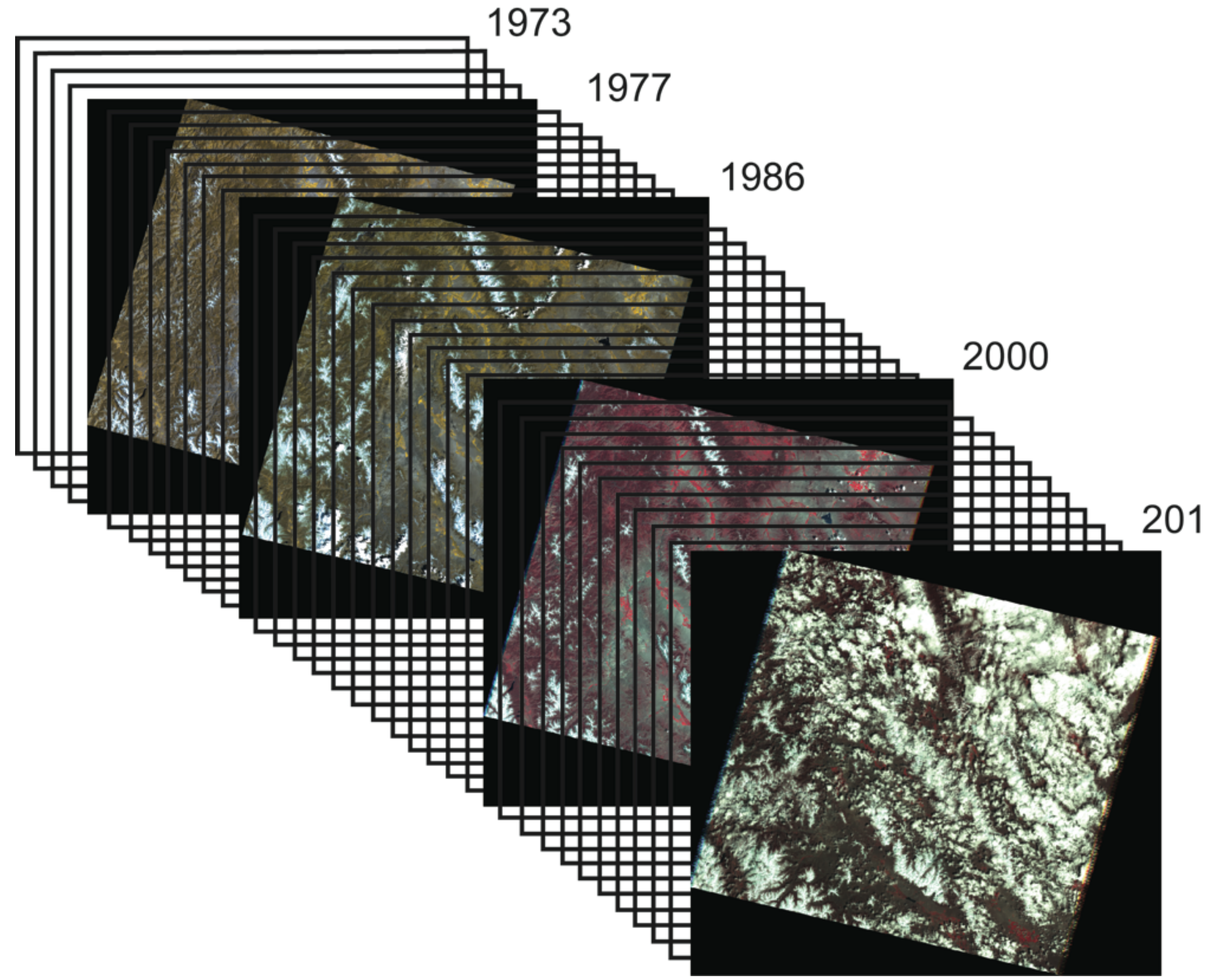
The Landsat Mission Timeline



source: http://landsat.usgs.gov/about_mission_history.php

Motivation for Landsat Snow Work





Crawford, C.J., S.M. Manson, M.E. Bauer, and D.K. Hall (2013). Multitemporal snow cover mapping in mountainous terrain for Landsat climate data record development. *Remote Sensing of Environment* 135:224-235. DOI:10.1016/j.rse.2013.04.004.

Crawford, C.J. (2014). MODIS Terra Collection 6 fractional snow cover validation in mountainous terrain during spring snowmelt using Landsat TM and ETM+. *Hydrological Processes*. DOI:10.1002/hyp.10134

Crawford, C.J. (2013). Evidence for spring mountain snowpack retreat from a Landsat-derived snow cover climate data record *Cryosphere Discussions* 7:2089-2117.DOI:10.5194/tcd-7-2089-2013.

Landsat as Reference Data

Landsat's Relevance to SnowPEx Objectives

1. Review sensor-specific limitations for optical snow mapping

2. Establish *accuracy* standards for Landsat TM, ETM+, and OLI image pre-processing

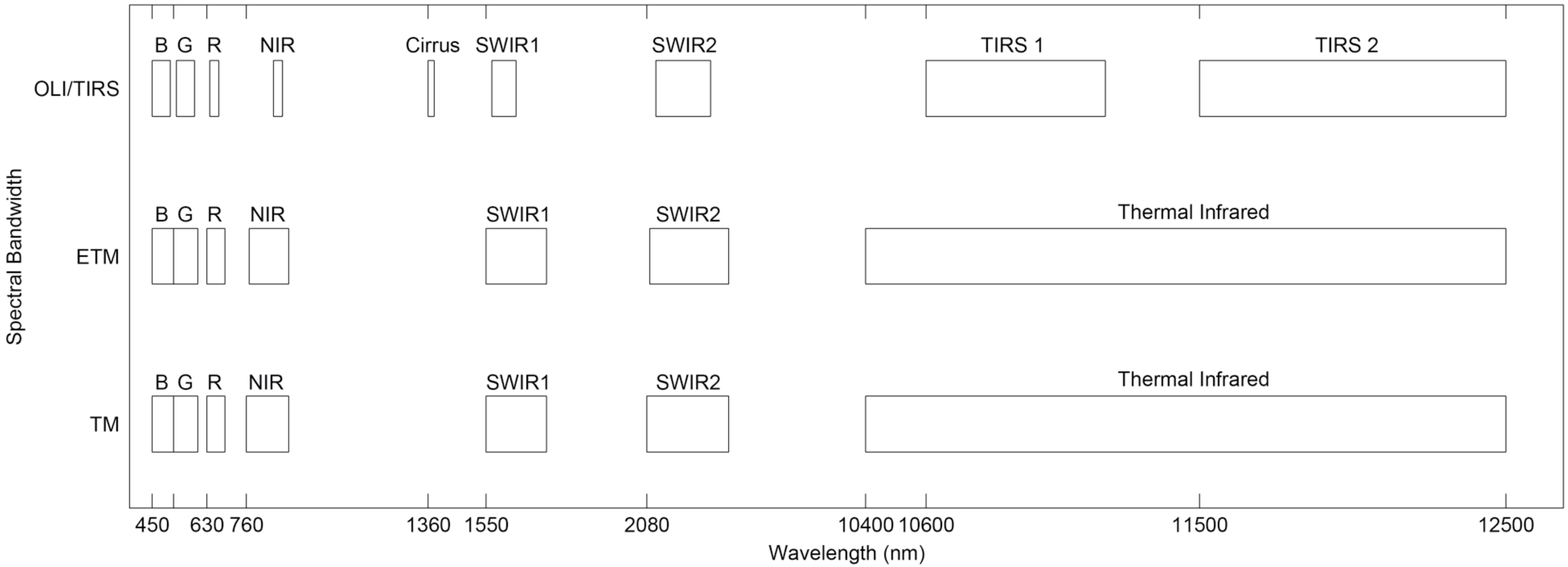
3. Reconcile sensor differences in the context of snow map *comparisons* and *validation*

Objective #1 Determine the accuracy of cloud/cloud shadow masking for Landsat TM, ETM+, and OLI/TIRS at the pixel scale

Radiometric Calibration

snowpex 1st International Satellite Snow Intercomparsion Workshop (ISSP1)

Spectral Bandwidths, Gain Settings, and Detector Saturation

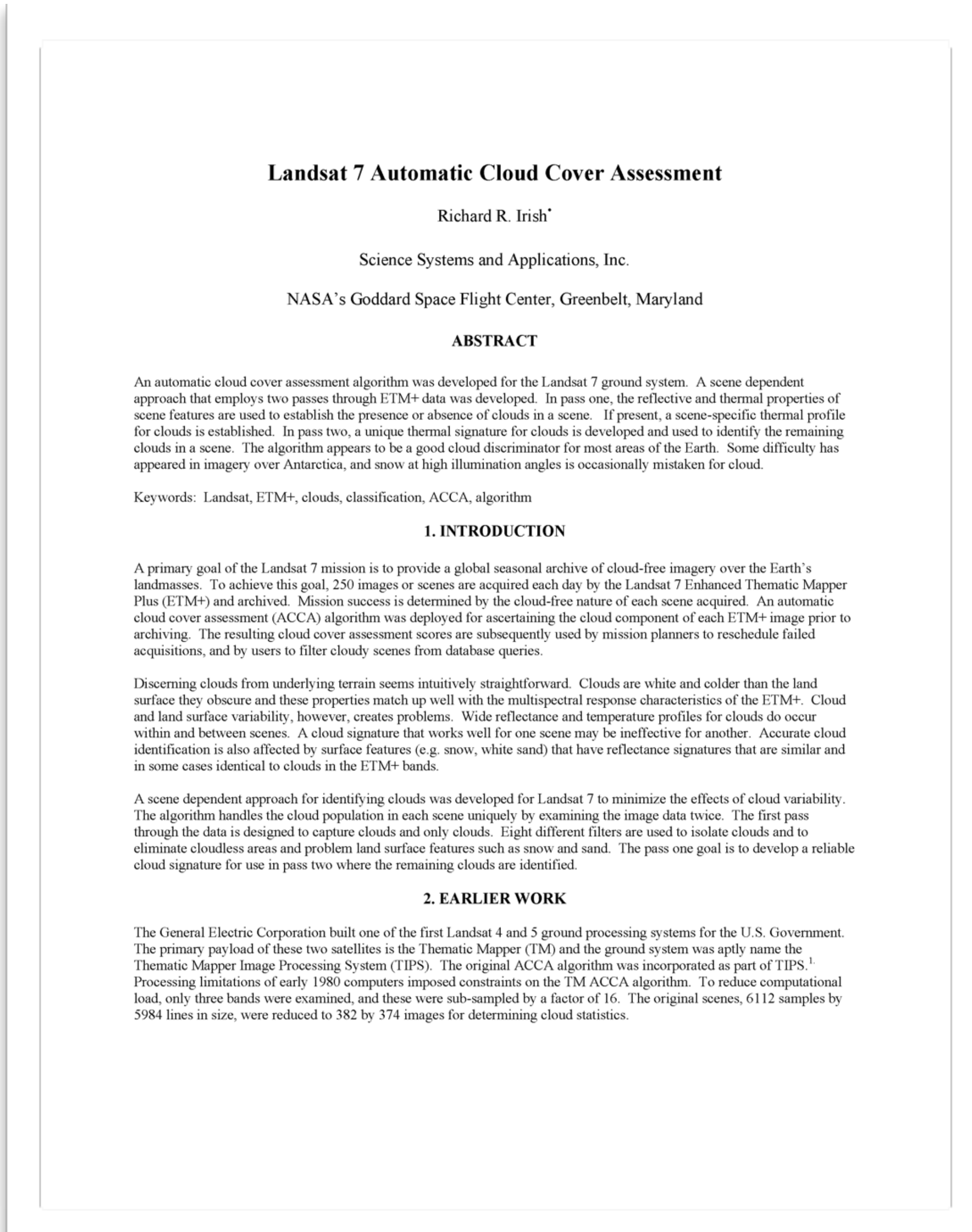


Sun Elevation	35.55225754
Data Type Level 1	ETM+ L1T
Sun Azimuth	159.78796387
Full Aperture Calibration	N
Gain Band 1	H
Gain Band 2	H
Gain Band 3	H
Gain Band 4	L
Gain Band 5	H
Gain Band 6 VCID 1	L
Gain Band 6 VCID 2	H
Gain Band 7	H
Gain Band 8	L
Gain Change Band 1	HH
Gain Change Band 2	HH

Snow and Clouds

255	255	255
237	255	255
208	221	255

Heritage Automated Cloud-Cover Assessment (ACCA) Algorithm



Landsat 7 Automatic Cloud Cover Assessment

Richard R. Irish*

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ABSTRACT

An automatic cloud cover assessment algorithm was developed for the Landsat 7 ground system. A scene dependent approach that employs two passes through ETM+ data was developed. In pass one, the reflective and thermal properties of scene features are used to establish the presence or absence of clouds in a scene. If present, a scene-specific thermal profile for clouds is established. In pass two, a unique thermal signature for clouds is developed and used to identify the remaining clouds in a scene. The algorithm appears to be a good cloud discriminator for most areas of the Earth. Some difficulty has appeared in imagery over Antarctica, and snow at high illumination angles is occasionally mistaken for cloud.

Keywords: Landsat, ETM+, clouds, classification, ACCA, algorithm

1. INTRODUCTION

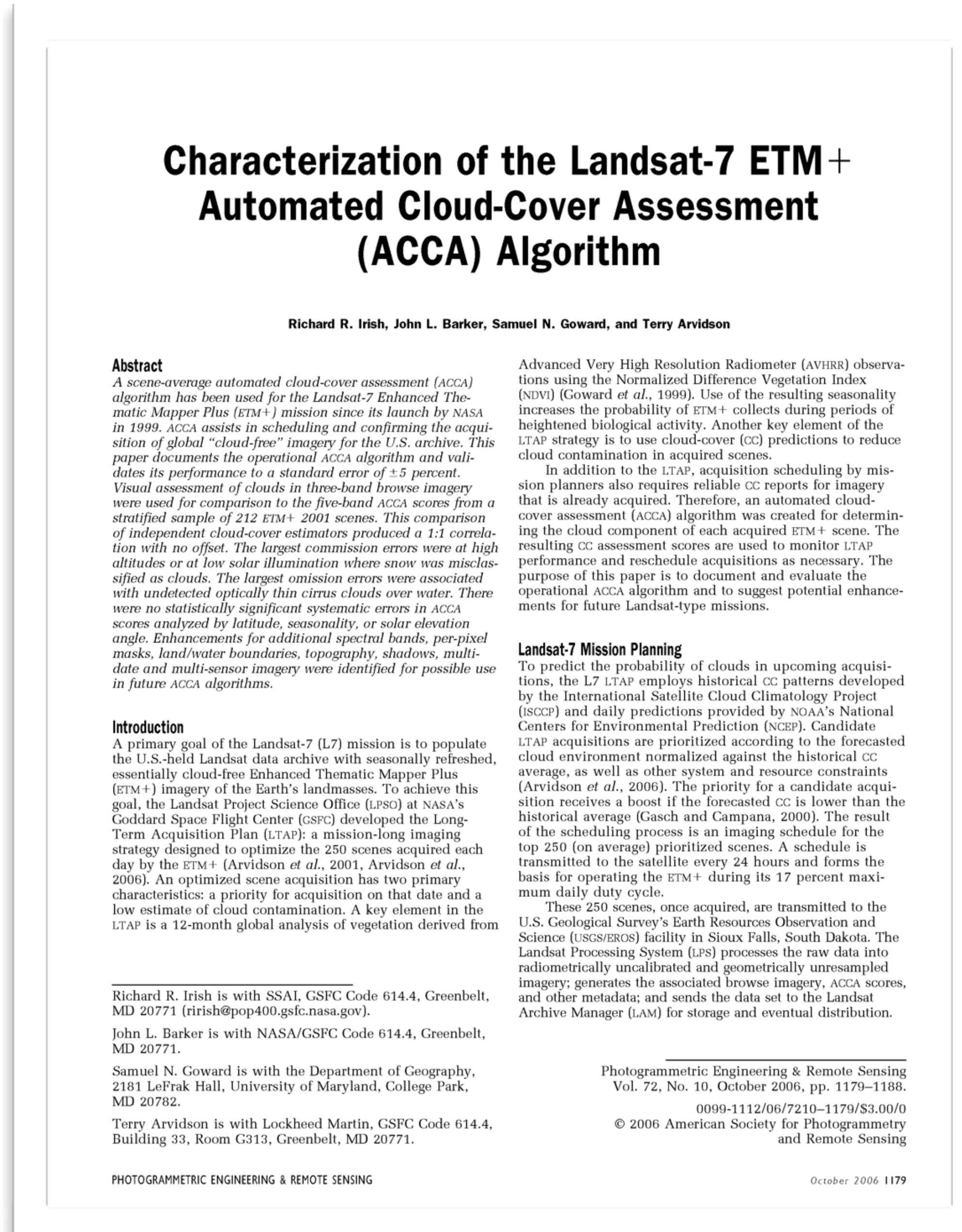
A primary goal of the Landsat 7 mission is to provide a global seasonal archive of cloud-free imagery over the Earth's landmasses. To achieve this goal, 250 images or scenes are acquired each day by the Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and archived. Mission success is determined by the cloud-free nature of each scene acquired. An automatic cloud cover assessment (ACCA) algorithm was deployed for ascertaining the cloud component of each ETM+ image prior to archiving. The resulting cloud cover assessment scores are subsequently used by mission planners to reschedule failed acquisitions, and by users to filter cloudy scenes from database queries.

Discerning clouds from underlying terrain seems intuitively straightforward. Clouds are white and colder than the land surface they obscure and these properties match up well with the multispectral response characteristics of the ETM+. Cloud and land surface variability, however, creates problems. Wide reflectance and temperature profiles for clouds do occur within and between scenes. A cloud signature that works well for one scene may be ineffective for another. Accurate cloud identification is also affected by surface features (e.g. snow, white sand) that have reflectance signatures that are similar and in some cases identical to clouds in the ETM+ bands.

A scene dependent approach for identifying clouds was developed for Landsat 7 to minimize the effects of cloud variability. The algorithm handles the cloud population in each scene uniquely by examining the image data twice. The first pass through the data is designed to capture clouds and only clouds. Eight different filters are used to isolate clouds and to eliminate cloudless areas and problem land surface features such as snow and sand. The pass one goal is to develop a reliable cloud signature for use in pass two where the remaining clouds are identified.

2. EARLIER WORK

The General Electric Corporation built one of the first Landsat 4 and 5 ground processing systems for the U.S. Government. The primary payload of these two satellites is the Thematic Mapper (TM) and the ground system was aptly name the Thematic Mapper Image Processing System (TIPS). The original ACCA algorithm was incorporated as part of TIPS.[1.] Processing limitations of early 1980 computers imposed constraints on the TM ACCA algorithm. To reduce computational load, only three bands were examined, and these were sub-sampled by a factor of 16. The original scenes, 6112 samples by 5984 lines in size, were reduced to 382 by 374 images for determining cloud statistics.



Characterization of the Landsat-7 ETM+ Automated Cloud-Cover Assessment (ACCA) Algorithm

Richard R. Irish, John L. Barker, Samuel N. Goward, and Terry Arvidson

Abstract

A scene-average automated cloud-cover assessment (ACCA) algorithm has been used for the Landsat-7 Enhanced Thematic Mapper Plus (ETM+) mission since its launch by NASA in 1999. ACCA assists in scheduling and confirming the acquisition of global "cloud-free" imagery for the U.S. archive. This paper documents the operational ACCA algorithm and validates its performance to a standard error of ±5 percent. Visual assessment of clouds in three-band browse imagery were used for comparison to the five-band ACCA scores from a stratified sample of 212 ETM+ 2001 scenes. This comparison of independent cloud-cover estimators produced a 1:1 correlation with no offset. The largest commission errors were at high altitudes or at low solar illumination where snow was misclassified as clouds. The largest omission errors were associated with undetected optically thin cirrus clouds over water. There were no statistically significant systematic errors in ACCA scores analyzed by latitude, seasonality, or solar elevation angle. Enhancements for additional spectral bands, per-pixel masks, land/water boundaries, topography, shadows, multi-date and multi-sensor imagery were identified for possible use in future ACCA algorithms.

Introduction

A primary goal of the Landsat-7 (L7) mission is to populate the U.S.-held Landsat data archive with seasonally refreshed, essentially cloud-free Enhanced Thematic Mapper Plus (ETM+) imagery of the Earth's landmasses. To achieve this goal, the Landsat Project Science Office (LPSO) at NASA's Goddard Space Flight Center (GSFC) developed the Long-Term Acquisition Plan (LTAP): a mission-long imaging strategy designed to optimize the 250 scenes acquired each day by the ETM+ (Arvidson *et al.*, 2001, Arvidson *et al.*, 2006). An optimized scene acquisition has two primary characteristics: a priority for acquisition on that date and a low estimate of cloud contamination. A key element in the LTAP is a 12-month global analysis of vegetation derived from Advanced Very High Resolution Radiometer (AVHRR) observations using the Normalized Difference Vegetation Index (NDVI) (Goward *et al.*, 1999). Use of the resulting seasonality increases the probability of ETM+ collects during periods of heightened biological activity. Another key element of the LTAP strategy is to use cloud-cover (CC) predictions to reduce cloud contamination in acquired scenes.

In addition to the LTAP, acquisition scheduling by mission planners also requires reliable CC reports for imagery that is already acquired. Therefore, an automated cloud-cover assessment (ACCA) algorithm was created for determining the cloud component of each acquired ETM+ scene. The resulting CC assessment scores are used to monitor LTAP performance and reschedule acquisitions as necessary. The purpose of this paper is to document and evaluate the operational ACCA algorithm and to suggest potential enhancements for future Landsat-type missions.

Landsat-7 Mission Planning

To predict the probability of clouds in upcoming acquisitions, the L7 LTAP employs historical CC patterns developed by the International Satellite Cloud Climatology Project (ISCCP) and daily predictions provided by NOAA's National Centers for Environmental Prediction (NCEP). Candidate LTAP acquisitions are prioritized according to the forecasted cloud environment normalized against the historical CC average, as well as other system and resource constraints (Arvidson *et al.*, 2006). The priority for a candidate acquisition receives a boost if the forecasted CC is lower than the historical average (Gasch and Campana, 2000). The result of the scheduling process is an imaging schedule for the top 250 (on average) prioritized scenes. A schedule is transmitted to the satellite every 24 hours and forms the basis for operating the ETM+ during its 17 percent maximum daily duty cycle.

These 250 scenes, once acquired, are transmitted to the U.S. Geological Survey's Earth Resources Observation and Science (USGS/EROS) facility in Sioux Falls, South Dakota. The Landsat Processing System (LPS) processes the raw data into radiometrically uncalibrated and geometrically unresampled imagery; generates the associated browse imagery, ACCA scores, and other metadata; and sends the data set to the Landsat Archive Manager (LAM) for storage and eventual distribution.

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Note: a per-pixel version of the heritage ACCA has been developed for TM, ETM+, and OLI/TIRS with some refinements (a paper is in draft)

Projected Cloud Shadows using Solar Geometry

A Geometry-Based Approach to Identifying Cloud Shadows in the VIIRS Cloud Mask Algorithm for NPOESS

KEITH D. HUTCHISON

Center for Space Research, The University of Texas at Austin, Austin, Texas

International Journal of Remote Sensing
Vol. 31, No. 20, 20 October 2010, 5449–5464

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Automated masking of cloud and cloud shadow for forest change analysis using Landsat images

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Accurate masking of cloud and cloud shadow is a prerequisite for reliable mapping of land surface attributes. Cloud contamination is particularly a problem for land cover change analysis, because unflagged clouds may be mapped as false changes, and the level of such false changes can be comparable to or many times more than that of actual changes, even for images with small percentages of cloud cover. Here we develop an algorithm for automatically flagging clouds and their shadows in Landsat images. This algorithm uses clear view forest pixels as a reference to define cloud boundaries for separating cloud from clear view surfaces in a spectral-temperature space. Shadow locations are predicted according to cloud height estimates and sun illumination geometry, and actual shadow pixels are identified by searching the darkest pixels surrounding the predicted shadow locations. This algorithm produced omission errors of around 1% for the cloud class, although the errors were higher for an image that had very low cloud cover and one acquired in a semiarid environment. While higher values were reported for other error measures, most of the errors were found around the edges of detected clouds and shadows, and many were due to difficulties in flagging thin clouds and the shadow cast by them, both by the developed algorithm and by the image analyst in deriving the reference data. We concluded that this algorithm is especially suitable for forest change analysis, because the commission and omission errors of the derived masks are not likely to significantly bias change analysis results.

1. Introduction

The usefulness of optical remote sensing images for land surface studies is often hindered by the presence of cloud and shadow. Little or no information of the surface can be derived from observations contaminated by cloud or shadow. To minimize the impact of such contaminations, cloud-free images are often preferred over cloudy images in land remote sensing applications. For areas that suffer constant cloudy conditions, however, cloud-free images are not always available. This problem is

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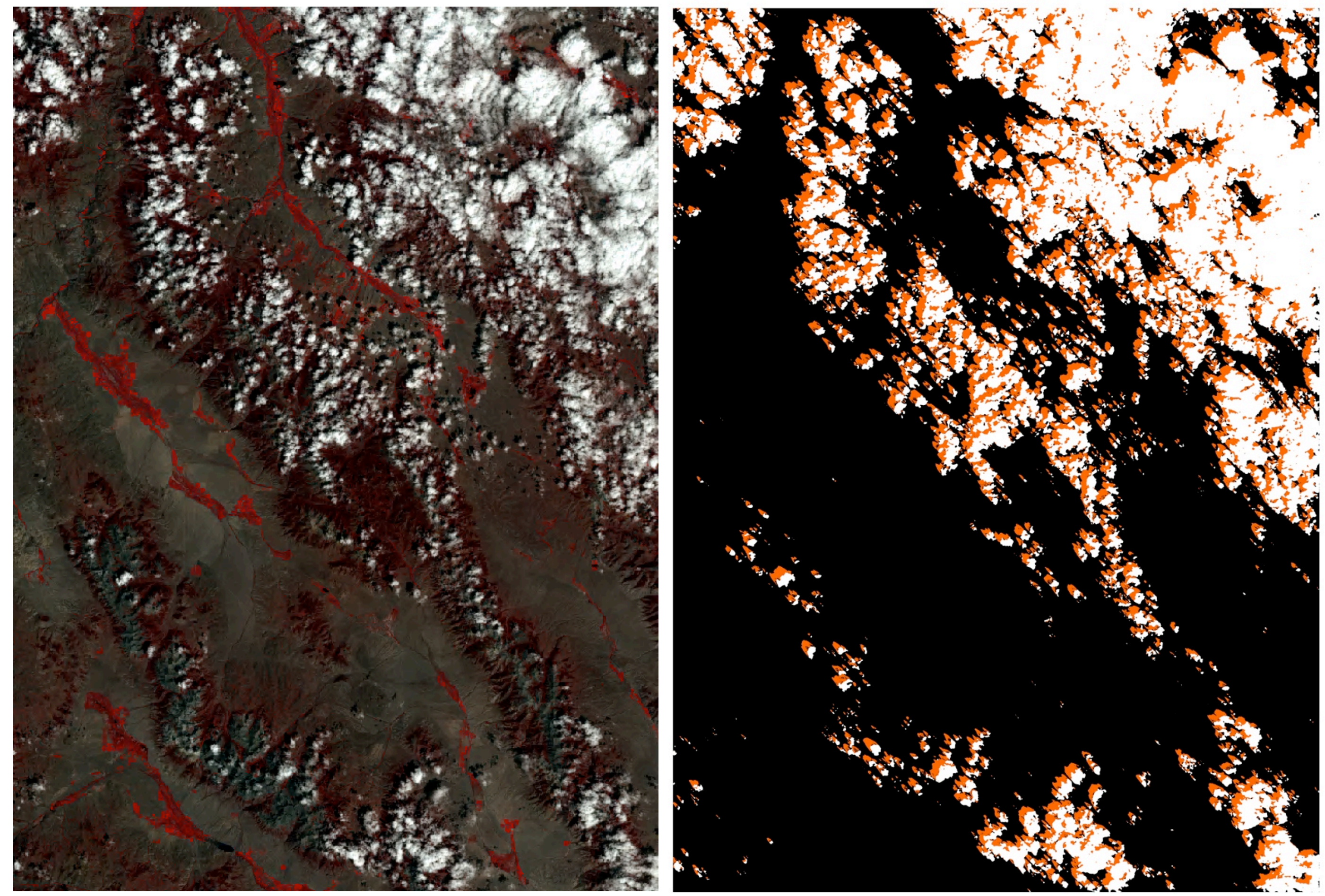
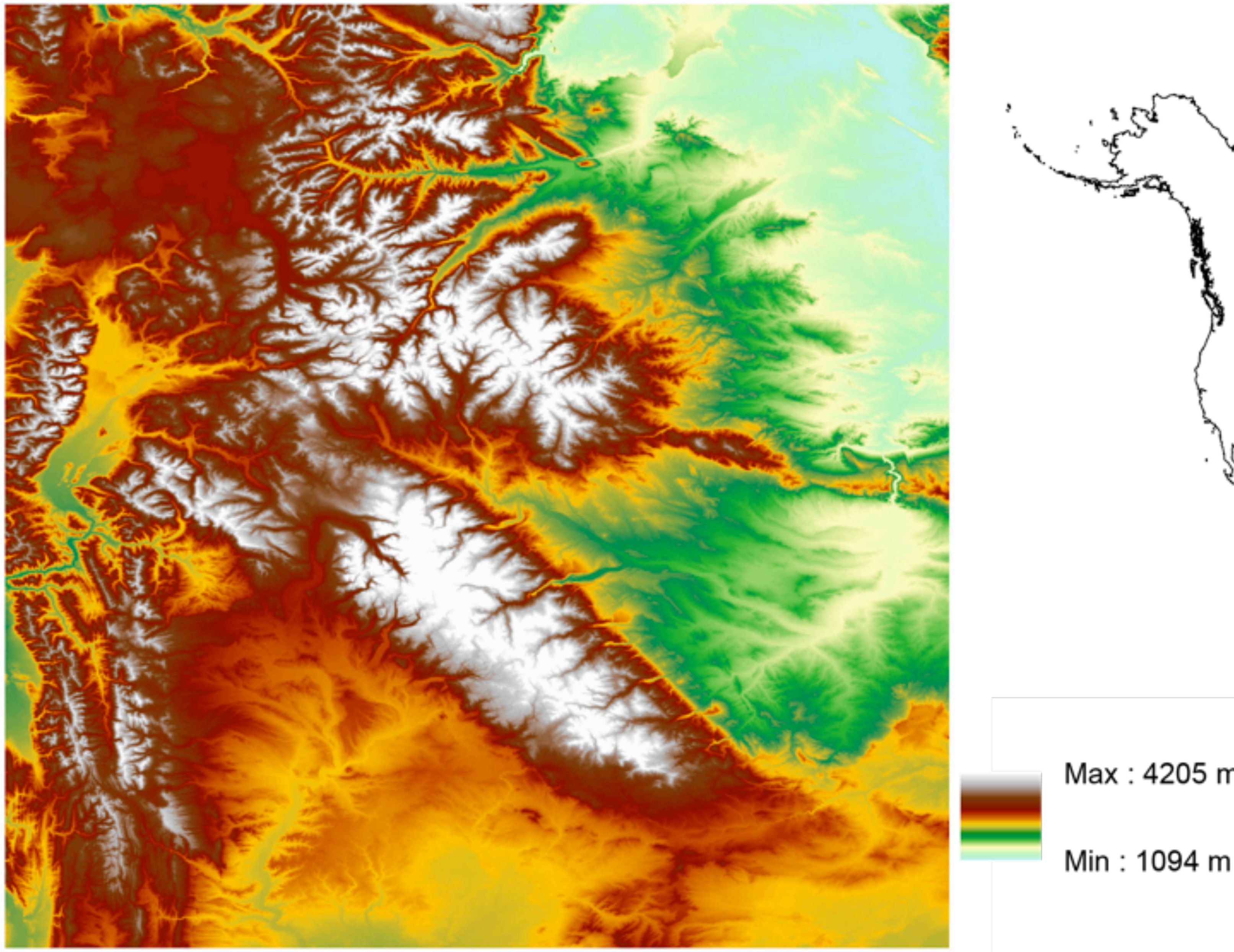
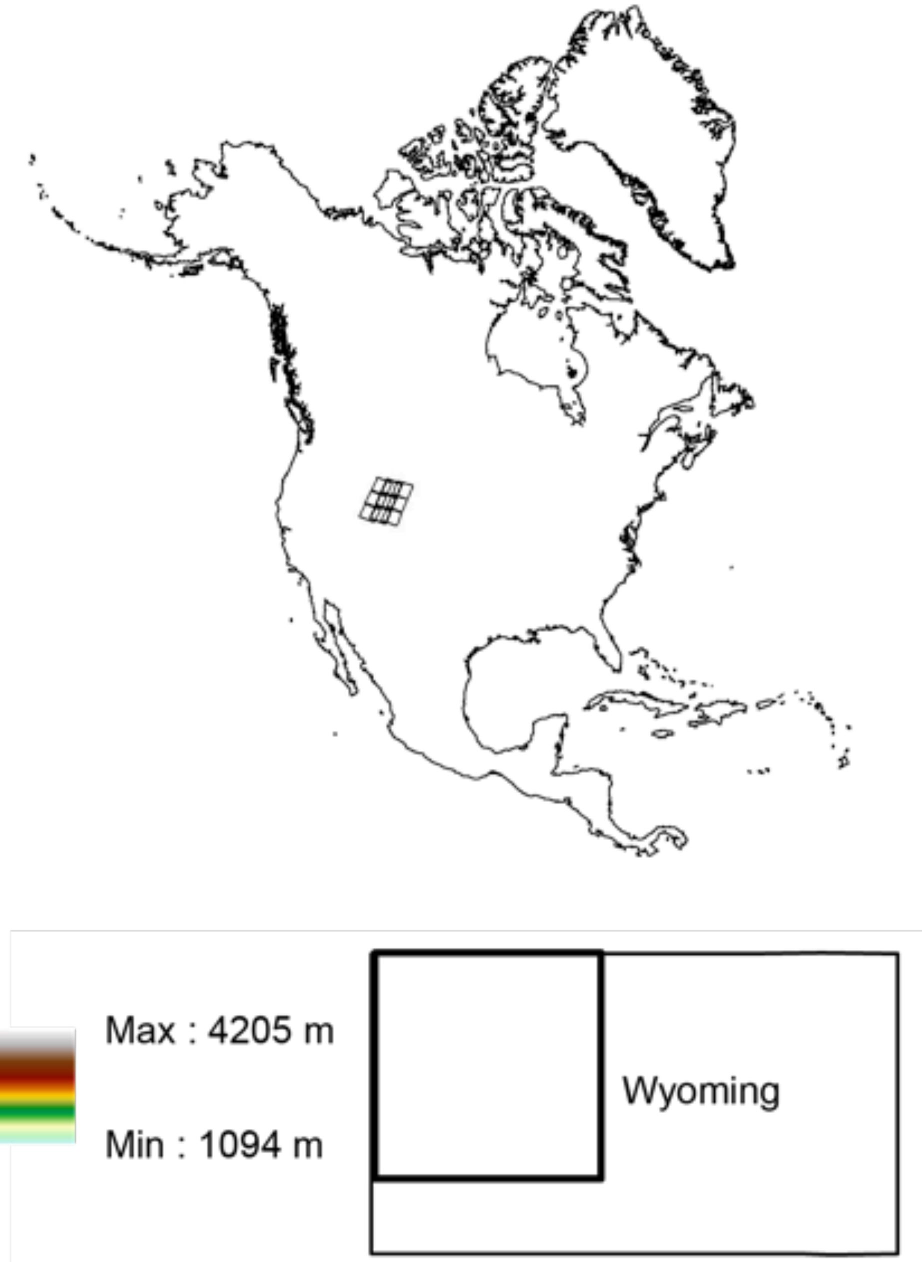


Western Wyoming Study Region

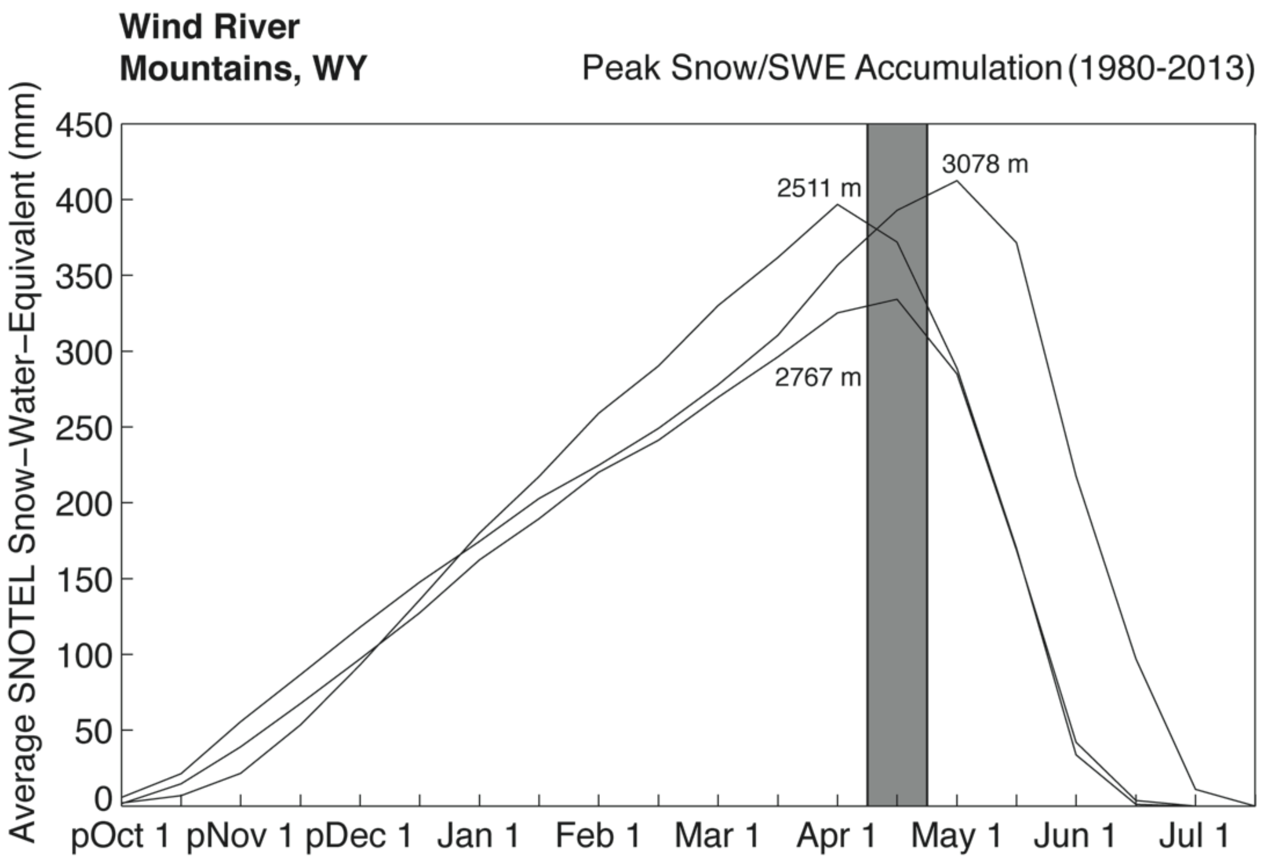


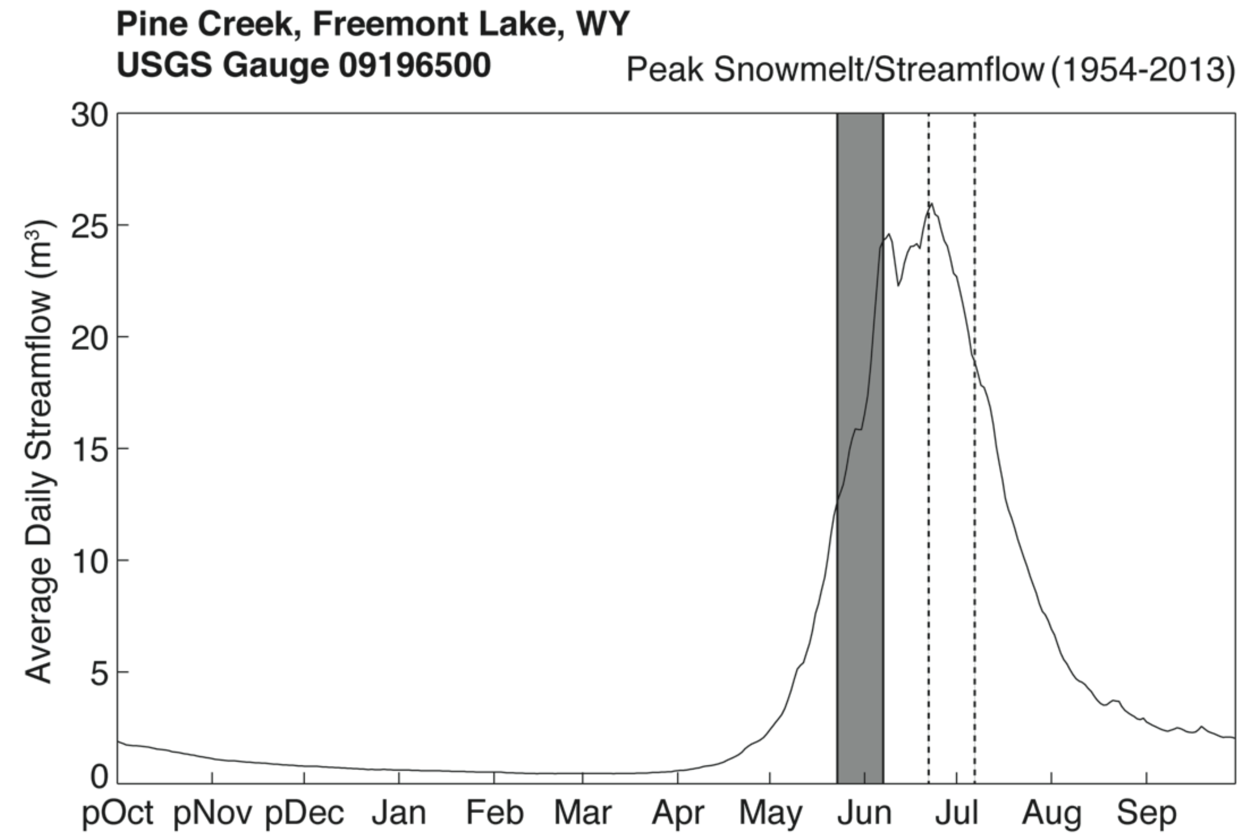


Temporal Scale: Julian peak snow accumulation (98-112) and melt (143-158) intervals from 2000-2014

365 image samples from TM, ETM+ and OLI/TIRS

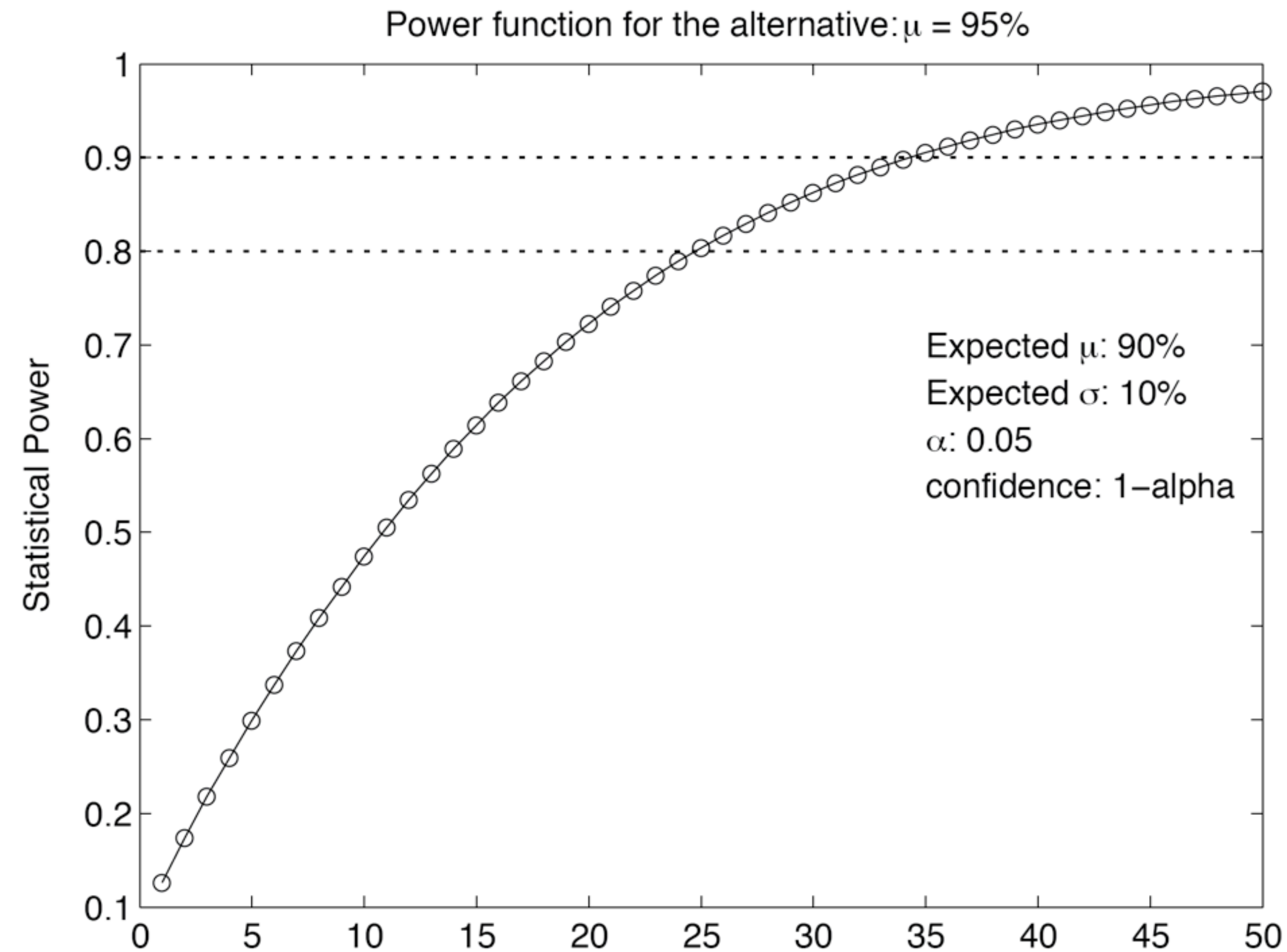
Peak Snow Accumulation and Melt Intervals for Western Wyoming, USA





Method: Cloud/Shadow Accuracy Assessment

Heritage ACCA Population Sample

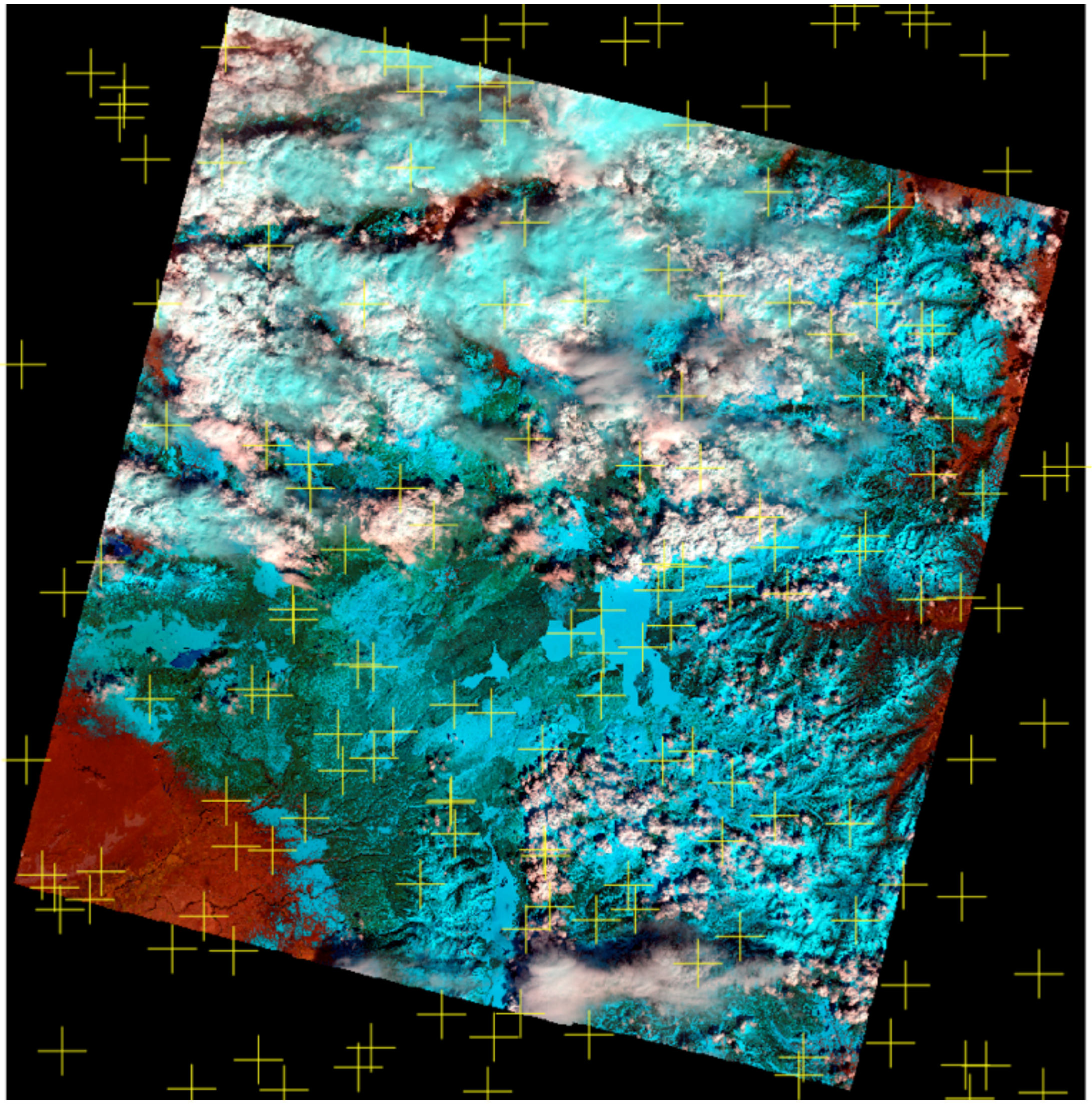


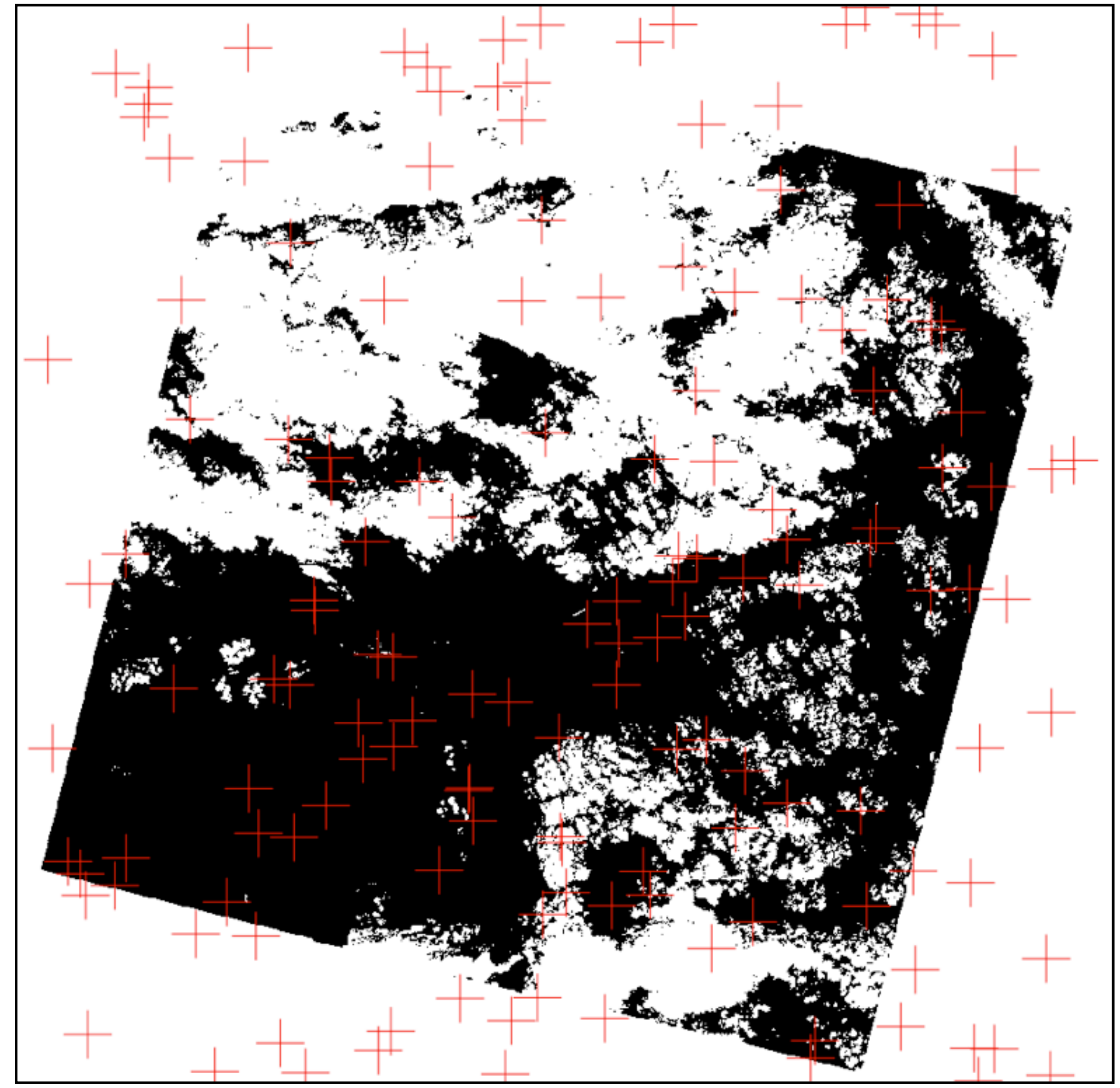
Thematic Sample Size: Binomial Probability Theory

$$N = \frac{Z^2(p)(q)}{E^2} \qquad \frac{1.96^2(90)(10)}{10^2} = 35 \text{ samples}$$

Z: standard normal deviate
p: expected map accuracy
q: 100-p
E: allowable error

Error Matrix: Visual Interpretation vs. ACCA



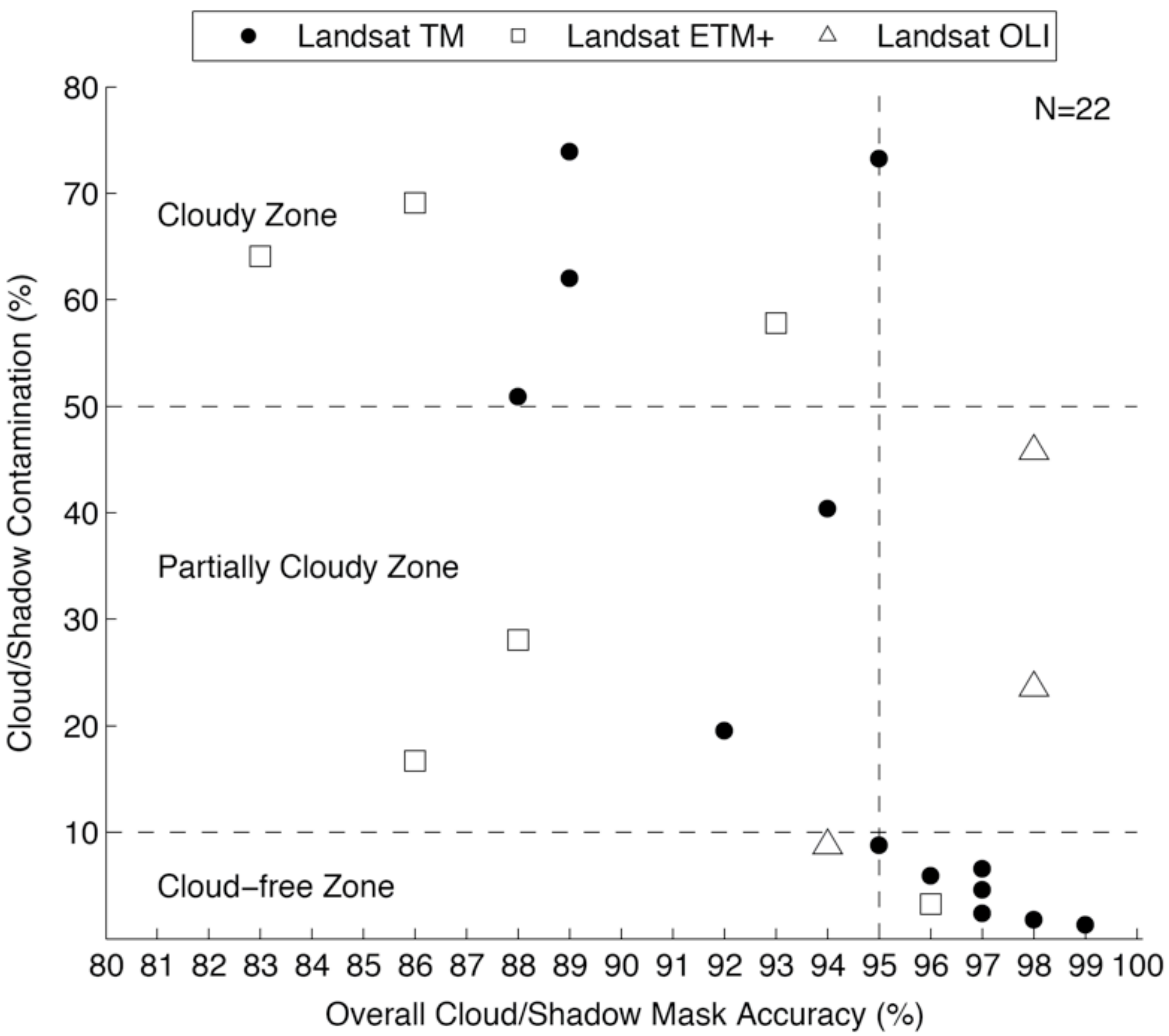


Class Assignments

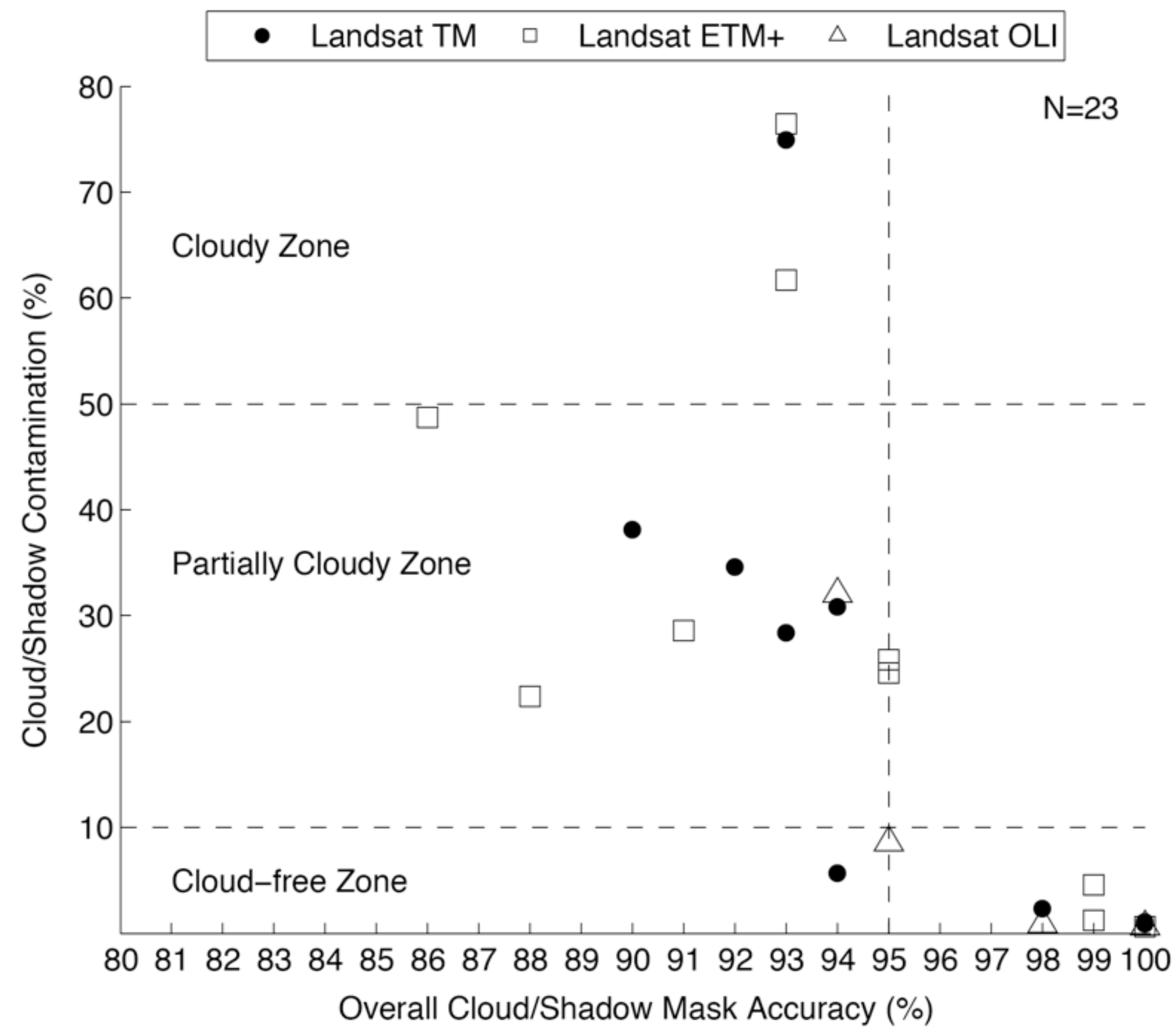
Cloud/Shadow-Free Pixels: Snow Surface (**SS**) or Snow-Free Land (**SFL**)

Cloud/Shadow Pixels: Cloud over Snow-Free Land (**CSFL**), Cloud Edge over Snow-Free Land (**CESFL**), Cloud over Snow Surface (**CSS**), Cloud Edge over Snow Surface (**CESS**), Shadow over Snow-Free Land (**SSFL**), and Shadow Edge over Snow-Free Land (**SESFL**)

Peak Snow Accumulation



Peak Snowmelt



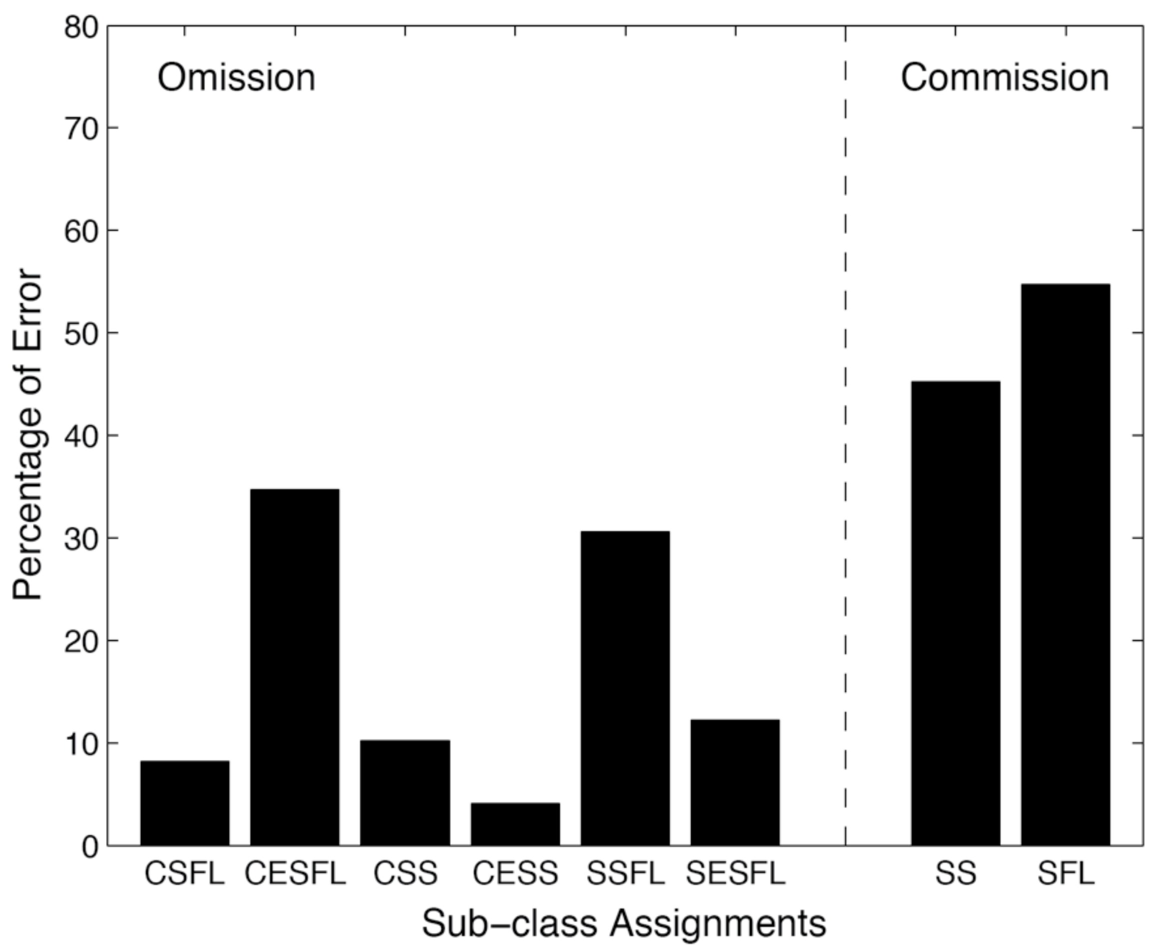
Peak Snow Accumulation

Heritage ACCA	Visual Reference Images (N=22)			
	Cloud/Shadow-free	Cloud/Shadow		User Accuracy
Cloud/Shadow-free	1436	49	1485	**0.97**
Cloud/Shadow	95	563	658	**0.86**
	1531	612	1999	
Producer Accuracy	**0.94**	**0.92**		**0.93**

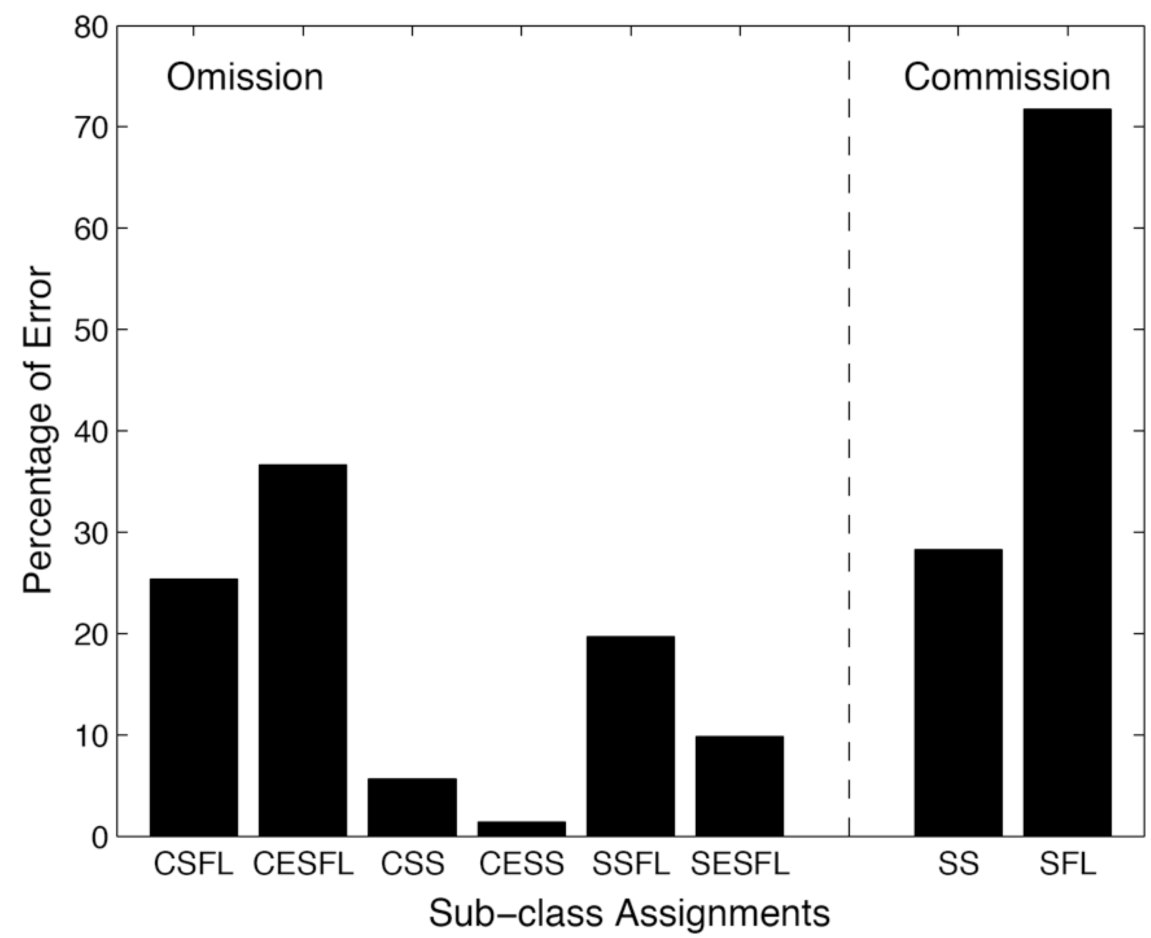
Peak Snowmelt

Heritage ACCA	Visual Reference Images (N=23)			
	Cloud/Shadow-free	Cloud/Shadow		User Accuracy
Cloud/Shadow-free	1708	71	1779	**0.96**
Cloud/Shadow	46	506	552	**0.92**
	1754	577	2214	
Producer Accuracy	**0.97**	**0.88**		**0.95**

Error Distribution



Error Distribution



Objective #2 Determine the importance of topographic normalization for Landsat TM, ETM+, and OLI/TIRS images during snowmelt

Topographic Normalization for Local Solar Illumination

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The Lambertian Assumption and Landsat Data

ON THE SLOPE-ASPECT CORRECTION OF MULTISPECTRAL SCANNER DATA

by P.M. Teillet, B. Guindon and D.G. Goodenough

Canada Centre for Remote Sensing

IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 28, NO. 5, SEPTEMBER 1990 963

Rapid Calculation of Terrain Parameters For Radiation Modeling From Digital Elevation Data

JEFF DOZIER, ASSOCIATE, IEEE, AND JAMES FREW, MEMBER, IEEE

Volume 48, number 4, 1993 17

Peter Meyer [1,*], Klaus I. Itten [1], Tobias Kellenberger [1], Stefan Sandmeier [1] and Ruth Sandmeier [1]

Radiometric corrections of topographically induced effects on Landsat TM data in an alpine environment

Four radiometric correction methods for the reduction of slope-aspect effects in a Landsat TM data set are tested in a mountainous test site with regard to their physical soundness and their influence on forest classification, as well as on the visual appearance of the scene. Excellent ground reference information and a fine-resolution DEM allowed precise assessment of the applicability of the methods under investigation. The results of the study presented here demonstrate the weakness of the classical cosine correction method for radiometric correction in rugged terrain. The statistical, Minnaert and C-correction approaches, however, yielded an improvement of the forest classification and an impressive reduction of the visual topography effect.

1. Introduction

The overutilization of tropical forests as well as the problems of deterioration of the health of forests in mid latitudes, have warned mankind that an important ecological factor, i.e., an important natural resource is endangered and may not be so renewable as was anticipated. In recent years, much emphasis was laid on the mapping and inventorying of forests and forest damage. On a local level, colour-infrared air photographs have been used with great success, and on larger scales, be they regional, continental or even global, satellite studies show quite encouraging results.

In this study the feasibility of Landsat TM forest classifications in an alpine environment is tested versus excellent ground reference data. It has been shown in the past that terrain-induced illumination variations have hindered an easy and straightforward solution of the distinction of forests versus non-forest backgrounds, and also to separate a forest into its major classes. Four methods to correct the impact of illumination have been tested in order to improve the accuracy of forest classifications. Since a correction of the atmospheric effects based on 5S (Tanré et al., 1986) did not result in a significant improvement of the forest classification (Leu, 1991), no atmospheric correction was applied in this study.

2. Basis of the study

2.1. Selection of test sites and associated ground reference data

The base dataset consists of a 7-band TM scene (194-27) of 3 July, 1985. Fall, winter or spring imagery is not suited for forest classification due to the lower sun angles which cast shadows, and the fact that the foliage of the various forest types is not fully developed. Within the selected cloud-free scene, the "Beckenried" site was selected, situated in the mountainous pre-Alps of the Canton of Nidwalden in Central Switzerland. The terrain elevation in the 12.0 km by 17.5 km test site varies from 434 to 2404 m with pronounced steep slopes.

For this test site the green plates, containing the class forest, of the 1:50,000 Swiss Federal Office topographic maps were scanned. Additionally, maps of forest stands were digitized which had been generated by the Swiss Sanasilva Project using colour-infrared air photographs at a scale of 1:10,000 and flown on 25 July, 1985 (353 ha) and 13 August, 1987 (572 ha). Thus, well timed ground reference information was available, which in part

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photo: christopher j. crawford

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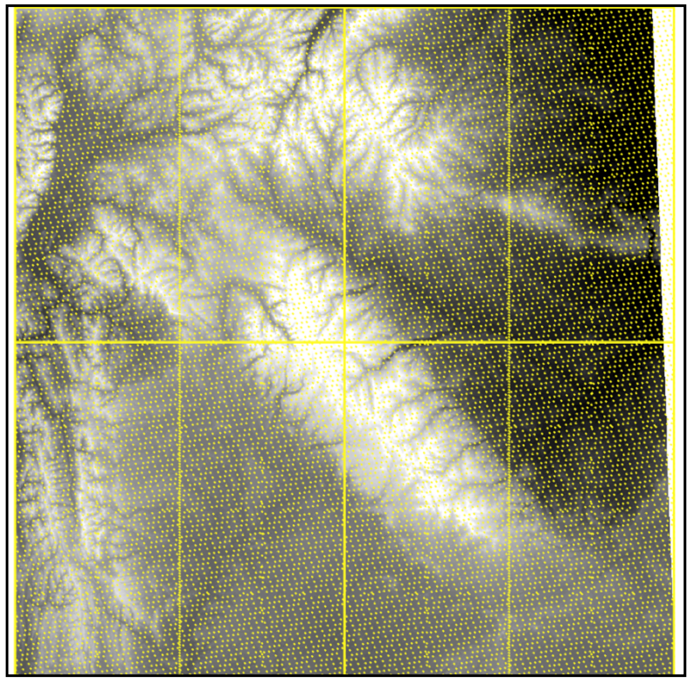
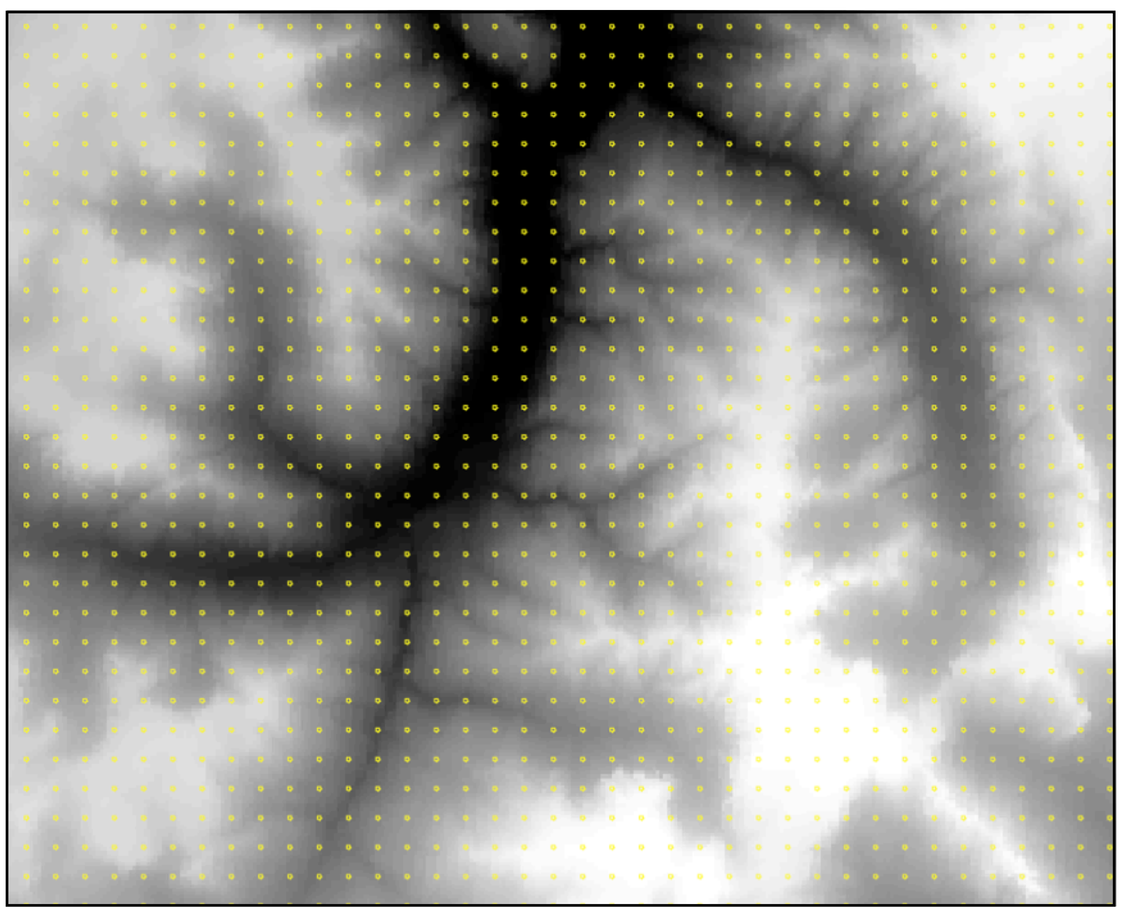
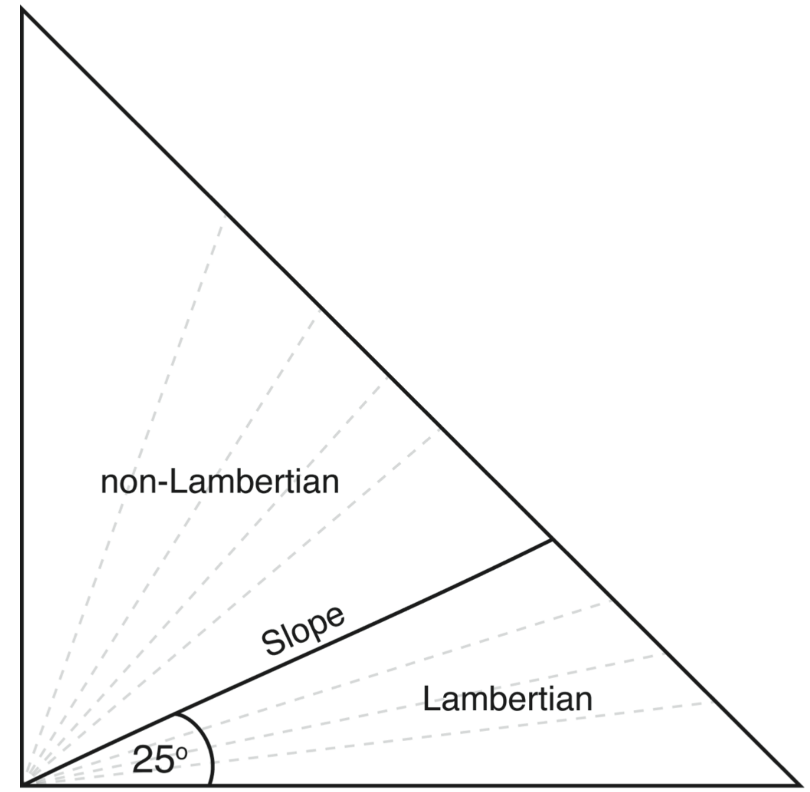
Method: Sample Size / Minnaerts Correction







$$L_H = L_T * \frac{\cos(sz)}{\cos(i)}^k$$

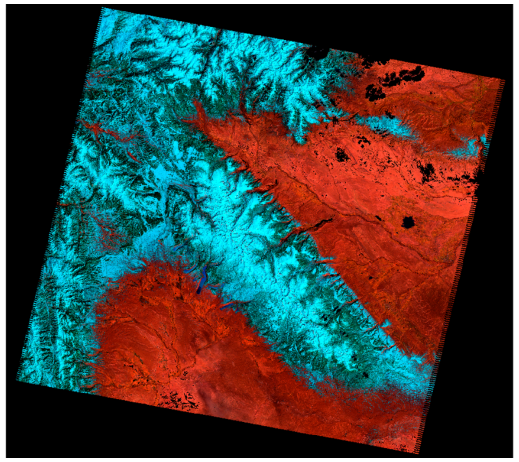
L_H: path radiance for horizontal surface

L_T: path radiance over sloped terrain

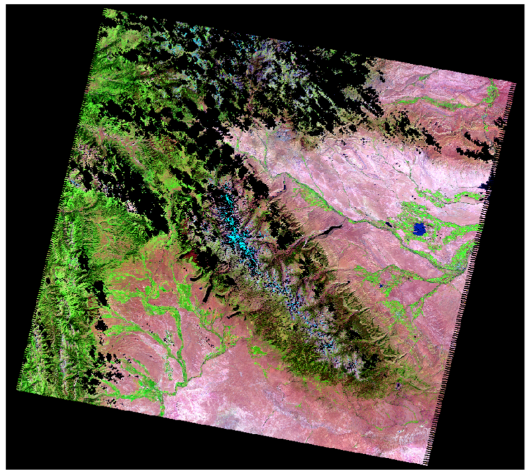
cos (sz): sun's zenith angle

cos (i): sun's incidence angle

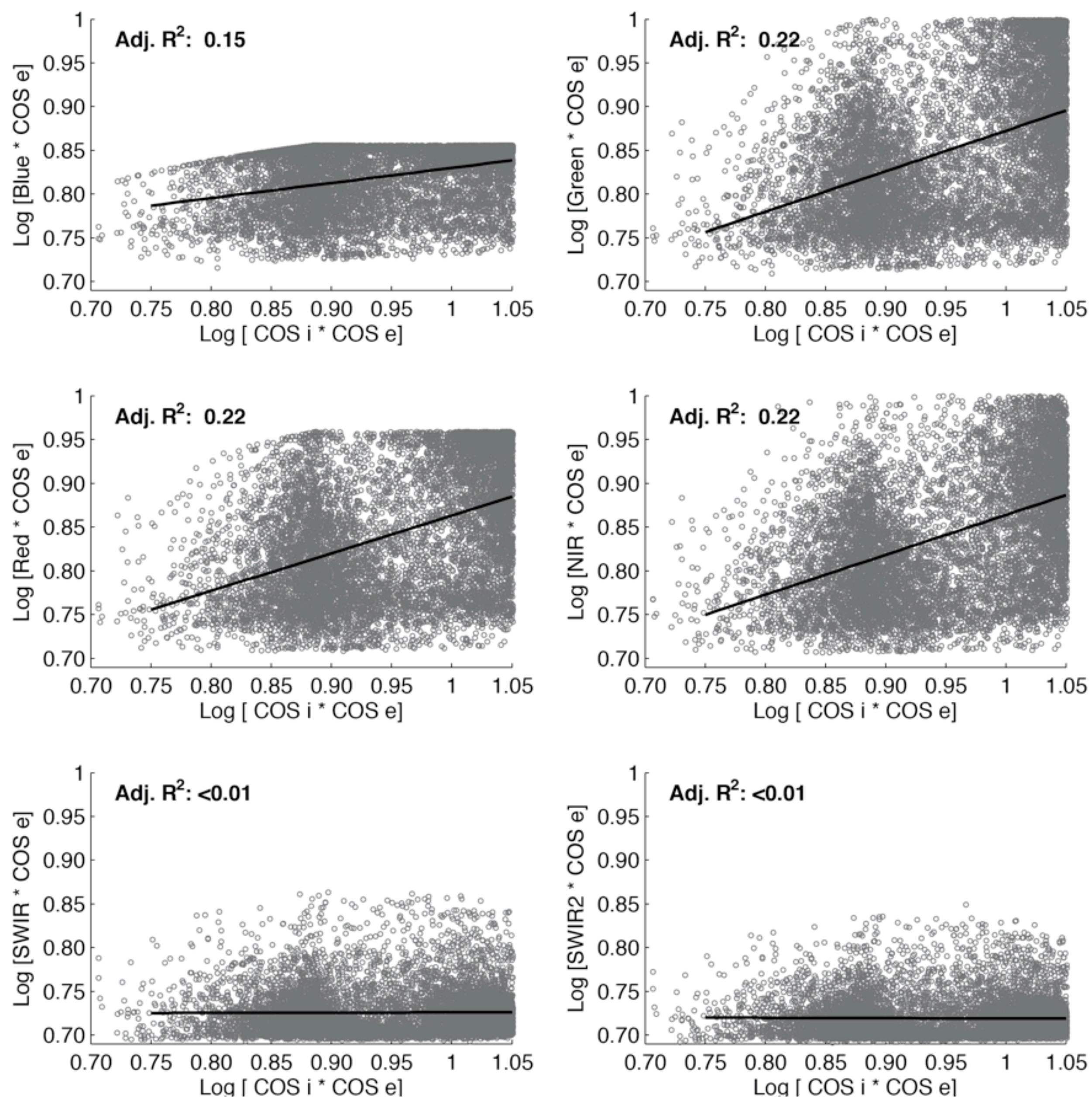
Landsat TM and the Lambertian Assumption

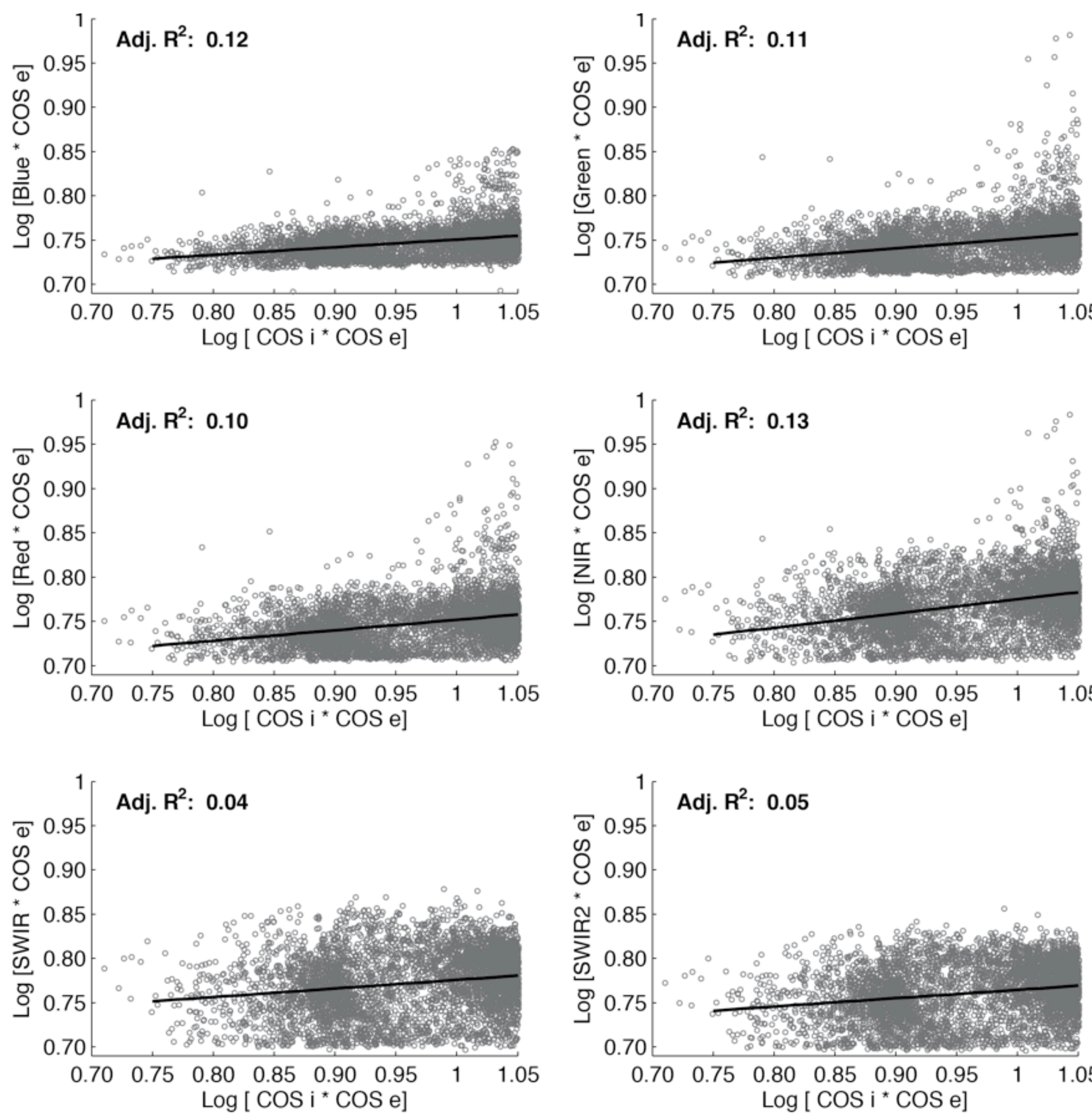


April 20, 2009
snow-on

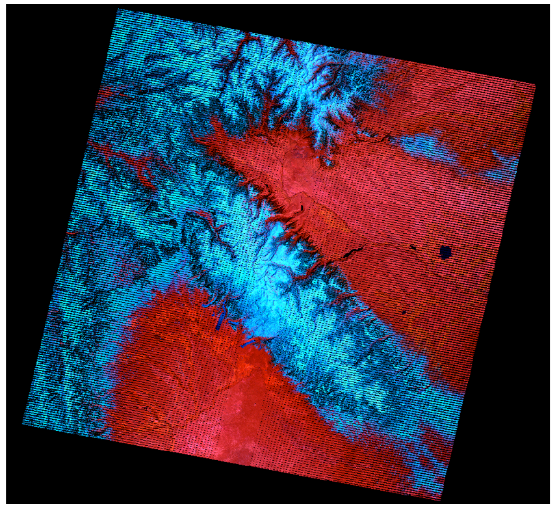


August 10, 2009
snow-off

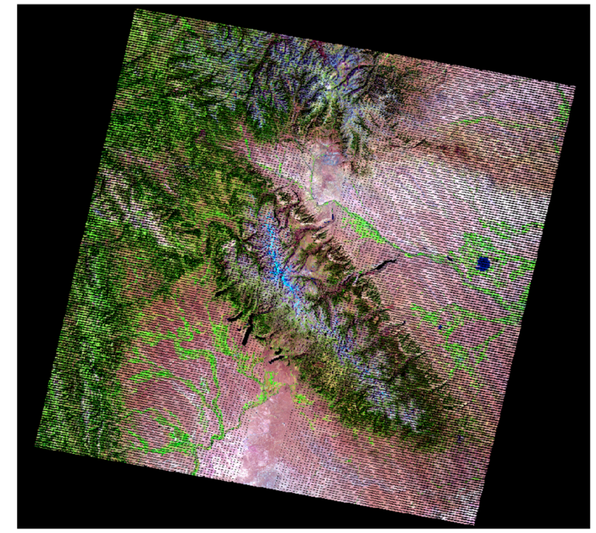




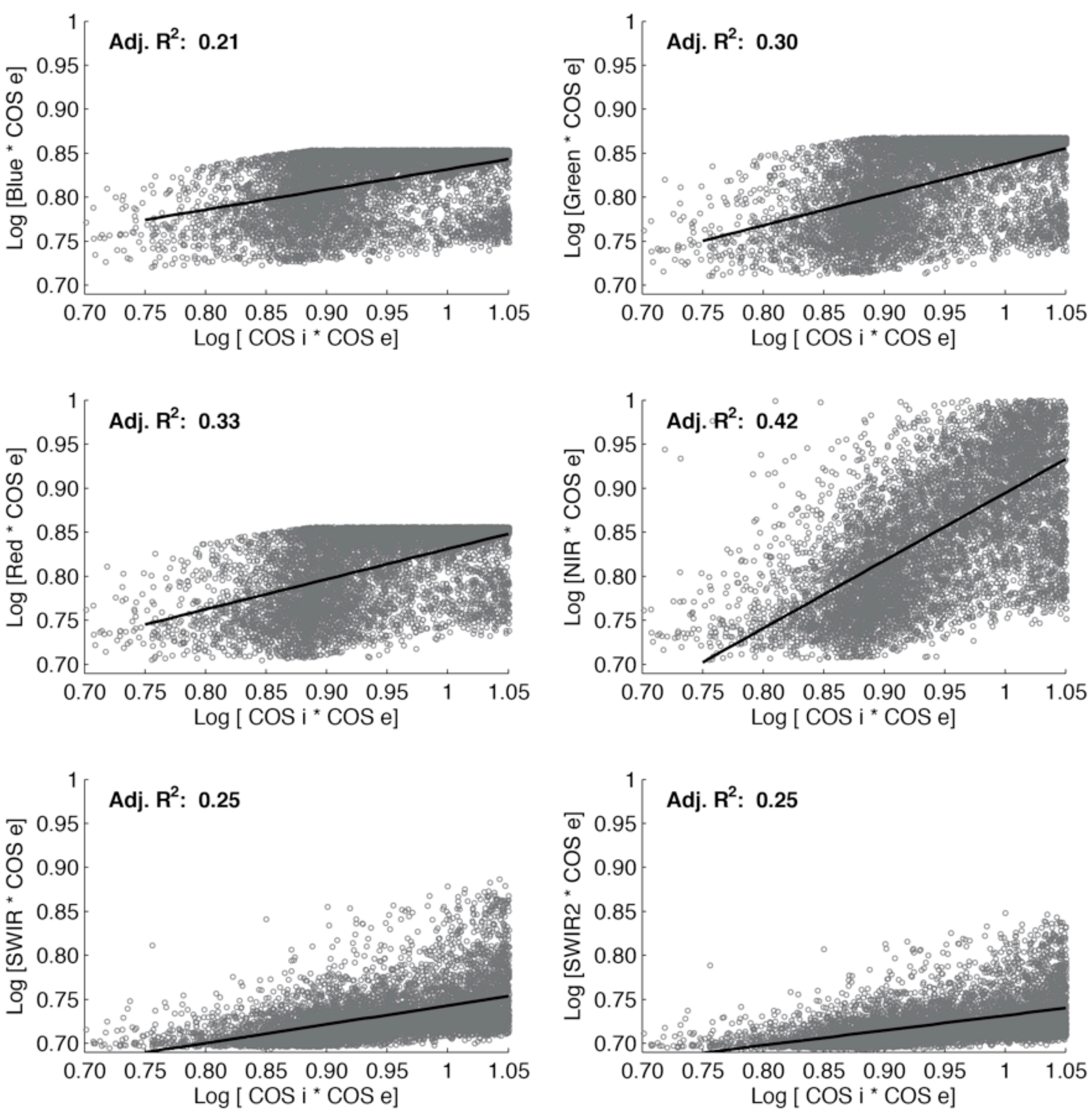
Landsat ETM+ and the Lambertian Assumption

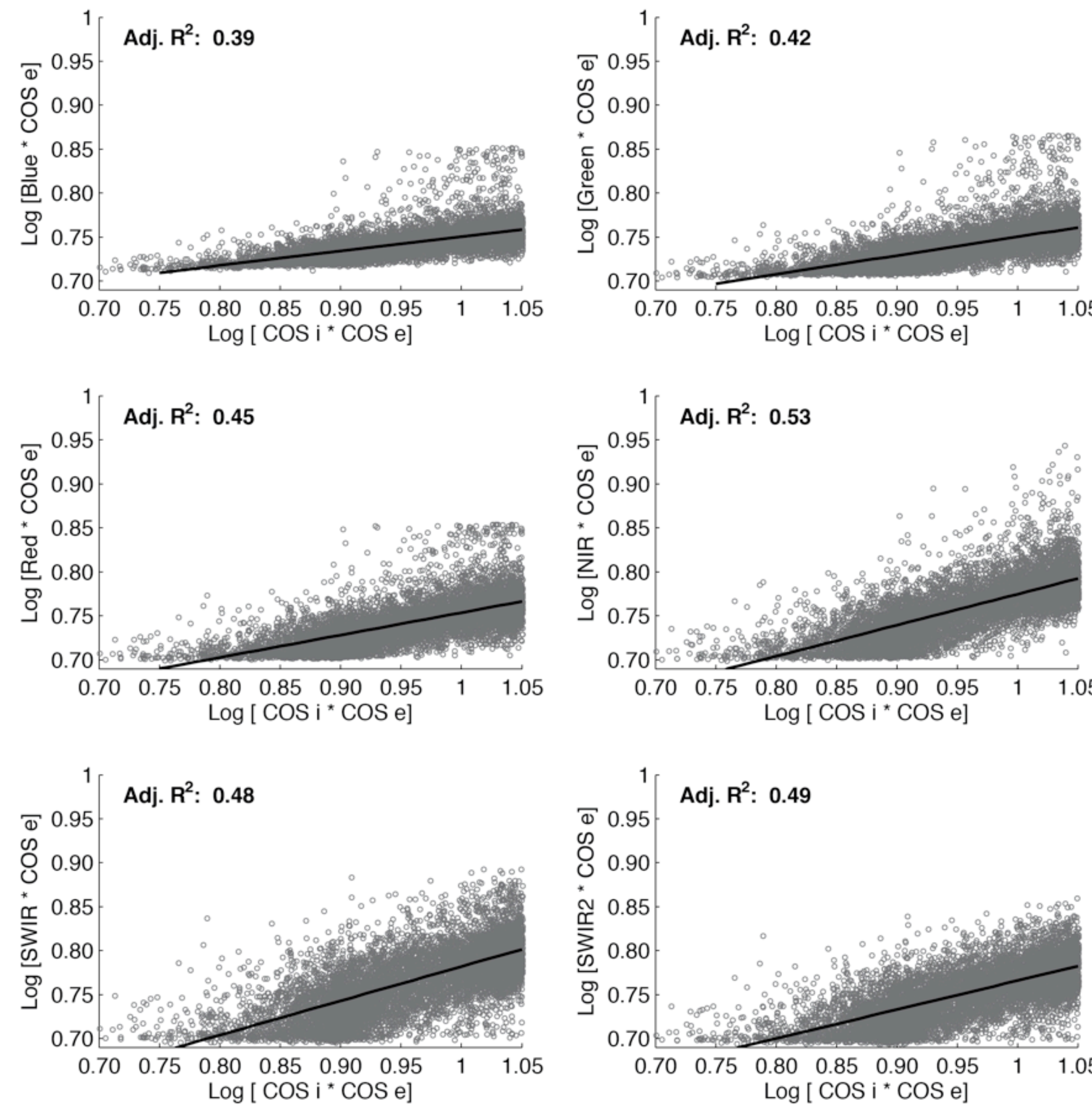


April 10, 2009
snow-on

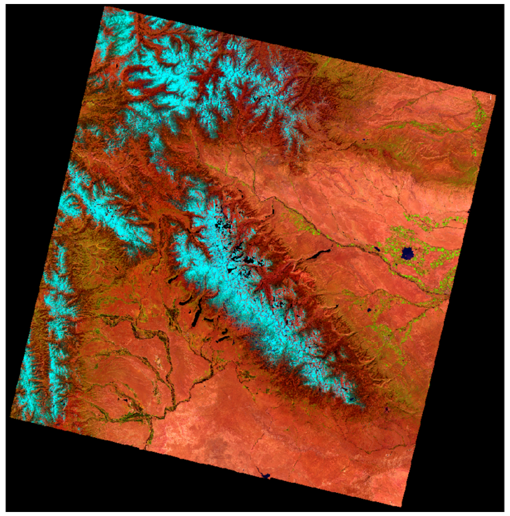


August 10, 2009
snow-off

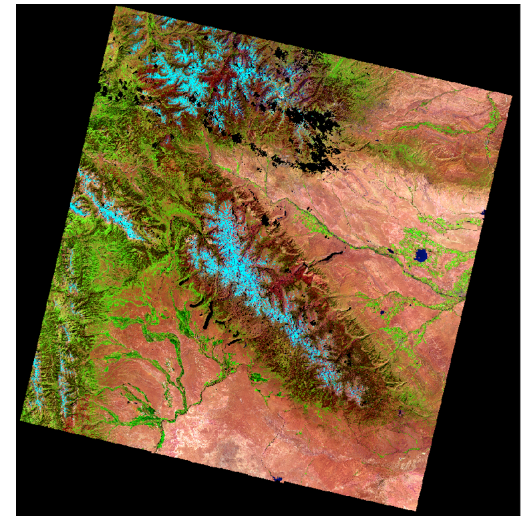




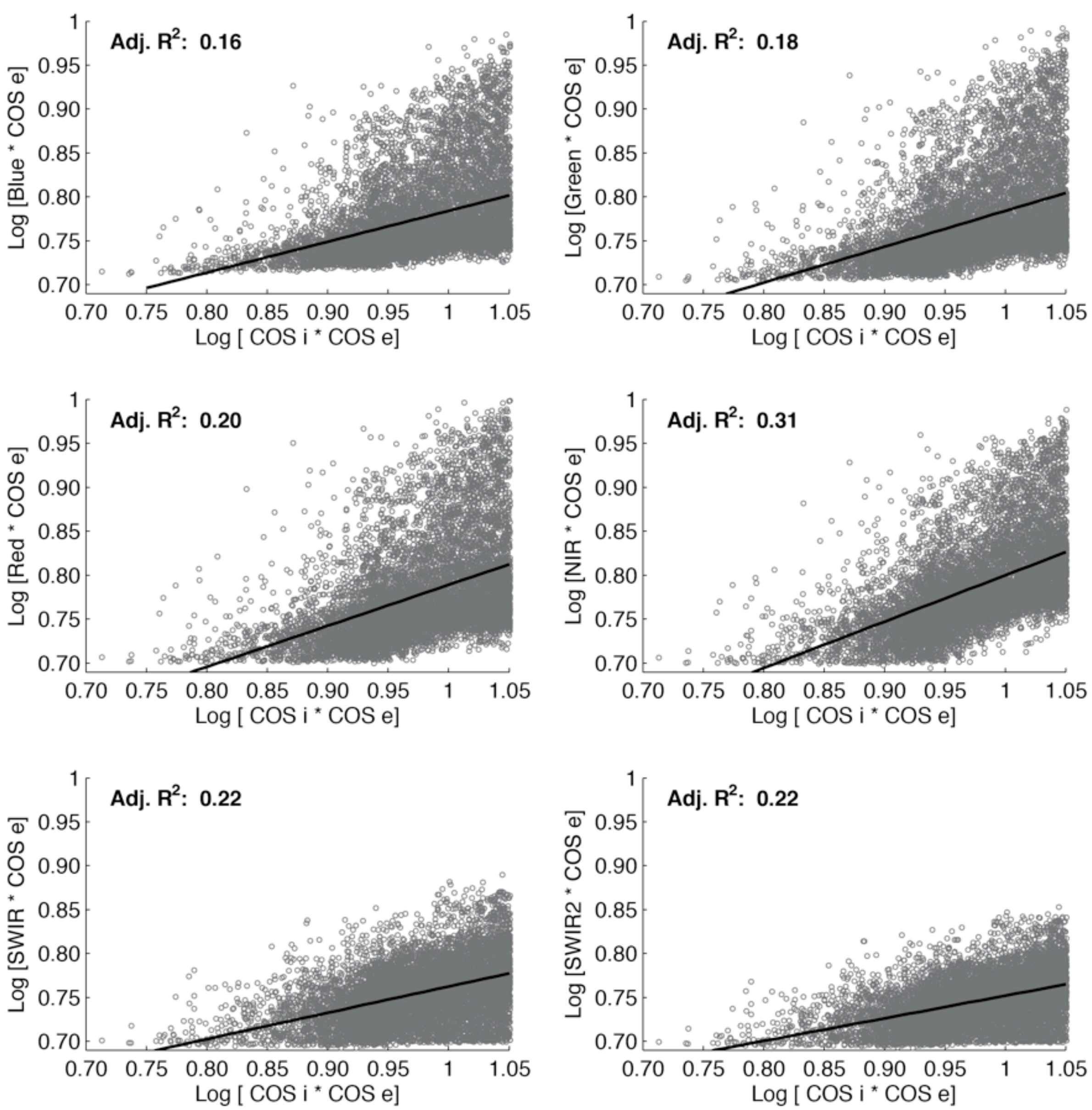
Landsat OLI and the Lambertian Assumption

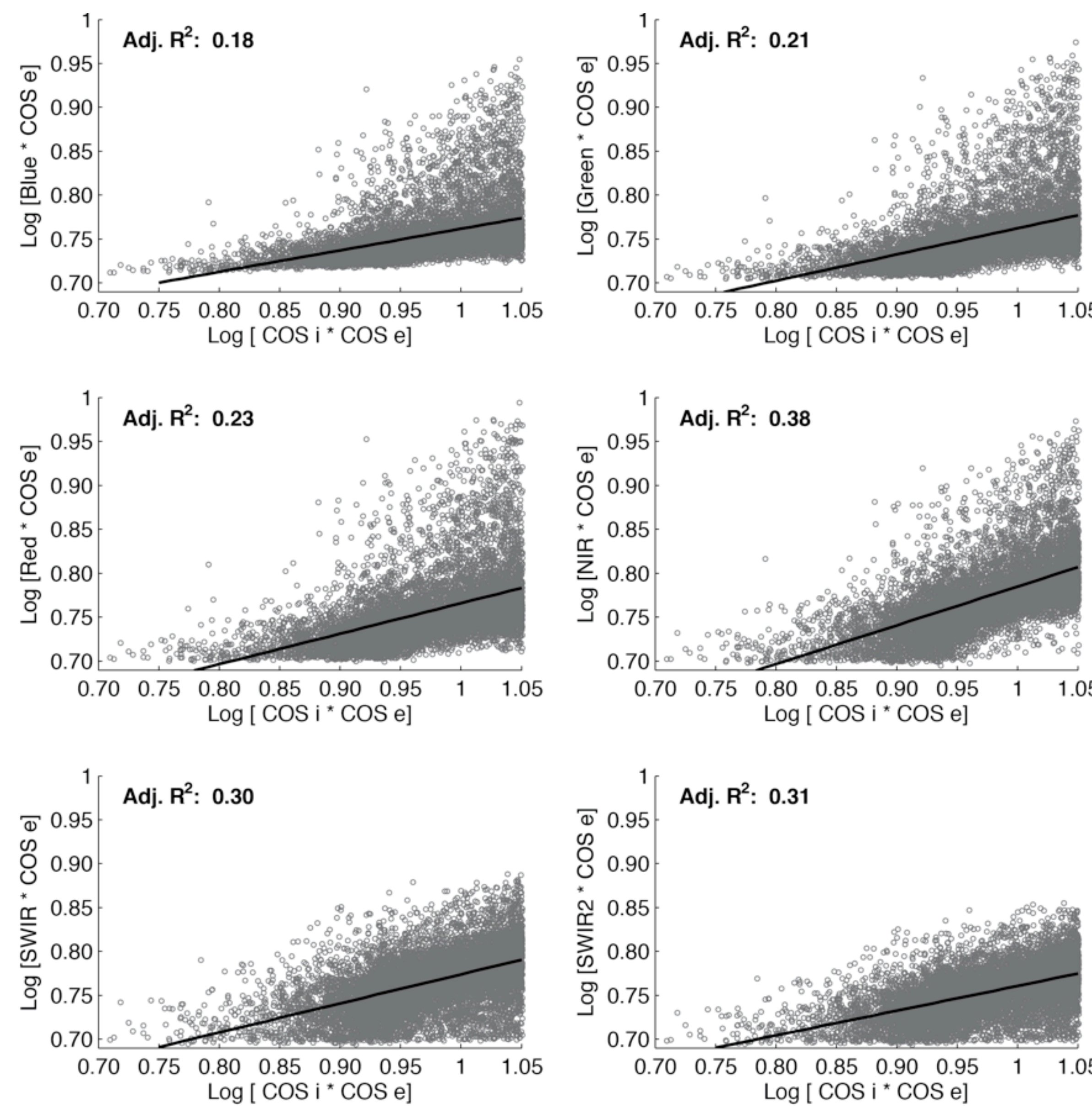


June 4, 2014
snowmelt



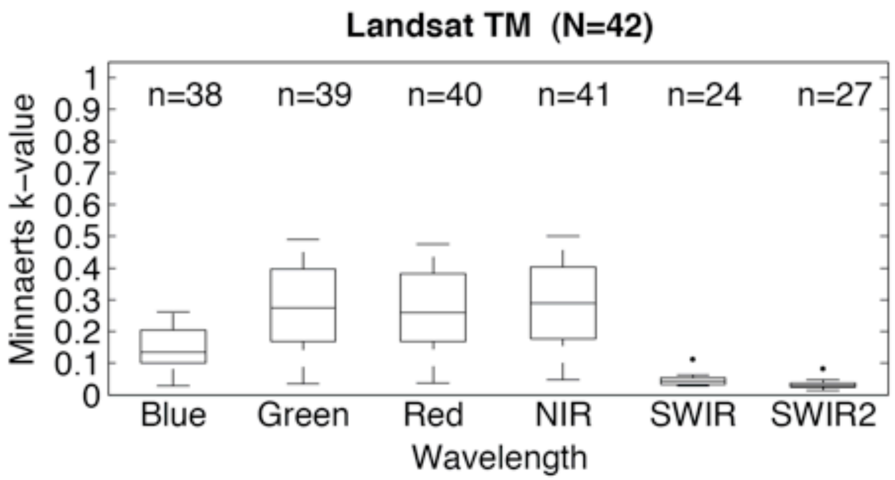
July 7, 2014
snowmelt

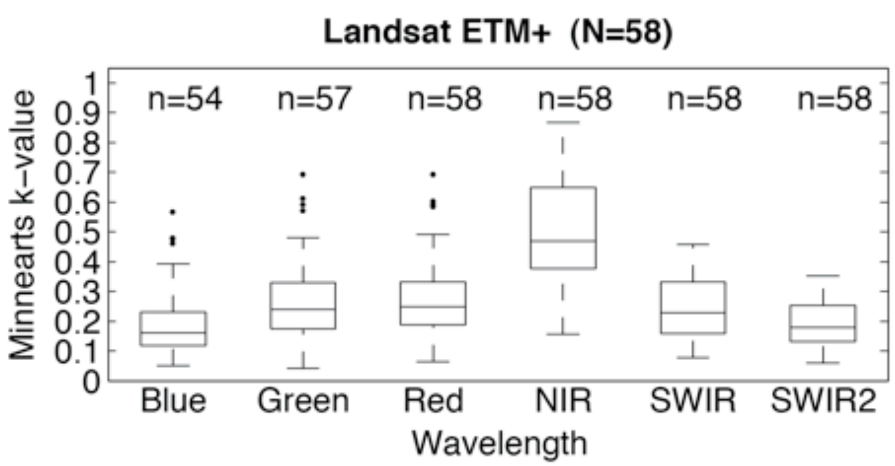


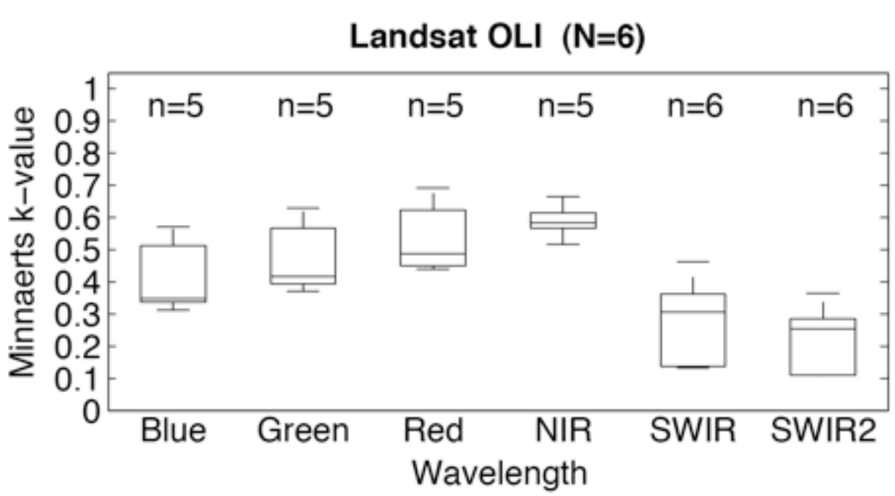


Wavelength-Dependent Response by Sensor

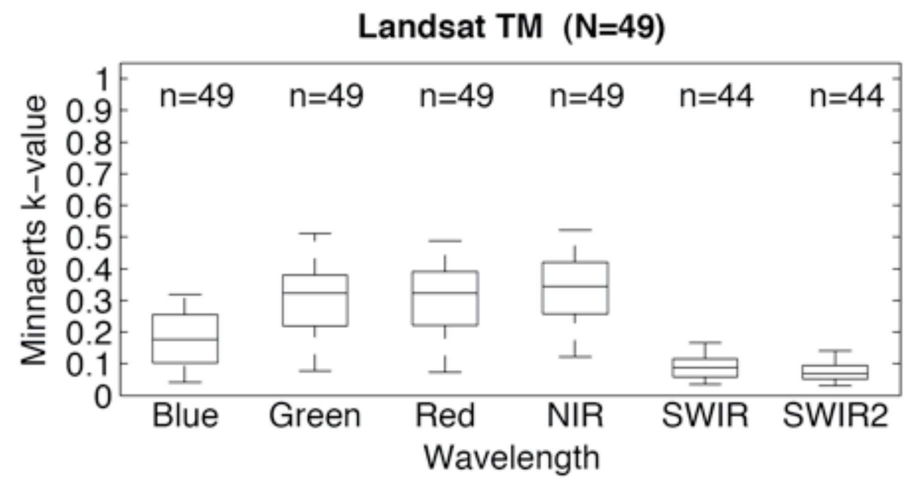
Peak Snow Accumulation

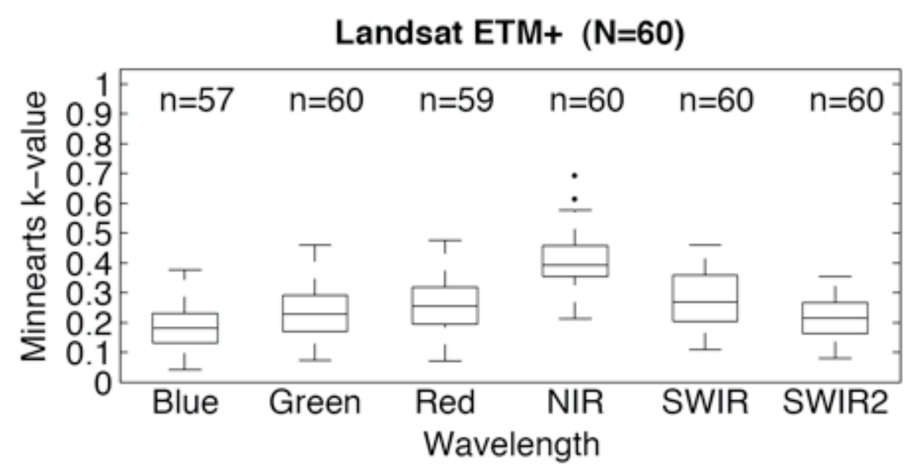


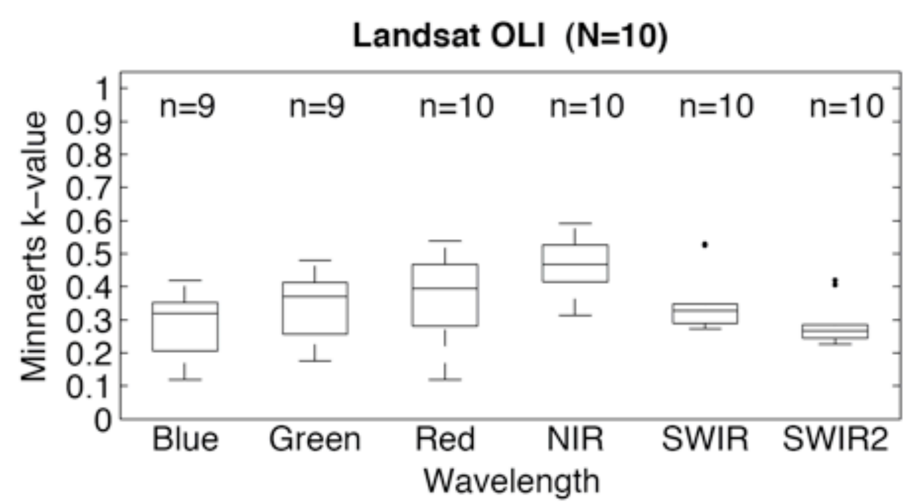




Peak Snowmelt







Summary and Way Forward

* Cloud/cloud shadow omission and commission errors are seasonally dependent and reflect the limits of observation over changing heterogenous surfaces

* Topographic-induced effects on local solar illumination cannot be ignored for higher resolution sensors that exhibit wavelength-dependent responses

* Evaluate pixel and sub-pixel snow algorithm performance under partially cloudy conditions

photo: christopher j. crawford