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

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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, multidate 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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During normal operations, the Landsat Mission Operations Center (MOC) located at GSFC receives the previous day's ACCA scores from the LAM. The scheduling software uses the scores to separate successful acquisitions (those with sufficiently low CC) from those that require re-imaging due to high CC. Routine comparisons of ACCA scores to the CC predictions are made to evaluate the reliability of the forecast information; these comparisons treat the ACCA scores as "truth." The accuracy of the ACCA process is essential to the efficient LTAP refreshing of the global archive with cloud-free imagery.

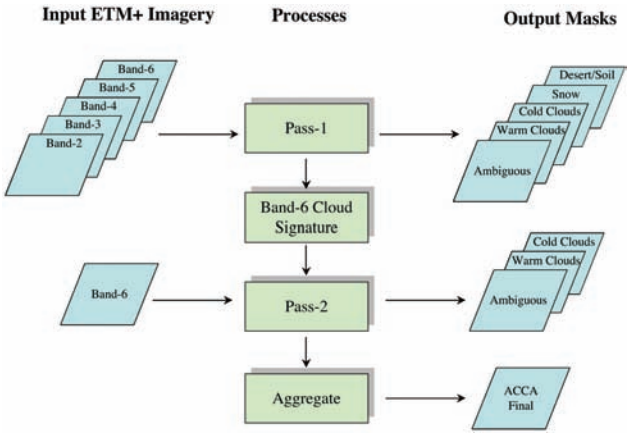

Plate 1. Overview of L7 ETM+ automated cloud-cover assessment (ACCA) algorithm software flow.

Automated Cloud-Cover Assessment (ACCA) Algorithm

Many of the essential elements of the ETM+ ACCA algorithm have been previously described together with the heritage browse-based ACCA algorithm used in processing Thematic Mapper (TM) imagery from the Landsat-4 (L4) and Landsat-5 (L5) satellites and the computer-driven limitations of both (Irish, 2000).

The L7 ACCA algorithm is an unsupervised classifier for clouds, which takes advantage of known spectral properties of clouds, snow, bright soil, vegetation, and water. The primary goal of the algorithm is to quickly produce acceptable scene-average estimates for CC during initial LPS processing. It was not intended to produce a "per-pixel" mask indicating the presence or absence of clouds for every pixel in L7 imagery. L7 "ACCA clouds" are defined as optically thick or nearly opaque because the ETM+ spectral bands do not easily detect semi-transparent clouds such as Cirrus Uncinus (i.e., "mare's tail"), Cirrus Fibratus, and cloud edges. Shadows from clouds are also not assessed. Furthermore, if all cirrus clouds were detected and used as a criterion to "reject" scene acquisitions, then most acquisitions would be "rejected" because of the pervasive character of thin cirrus clouds in the majority of the 183 km by 180 km L7 scenes.

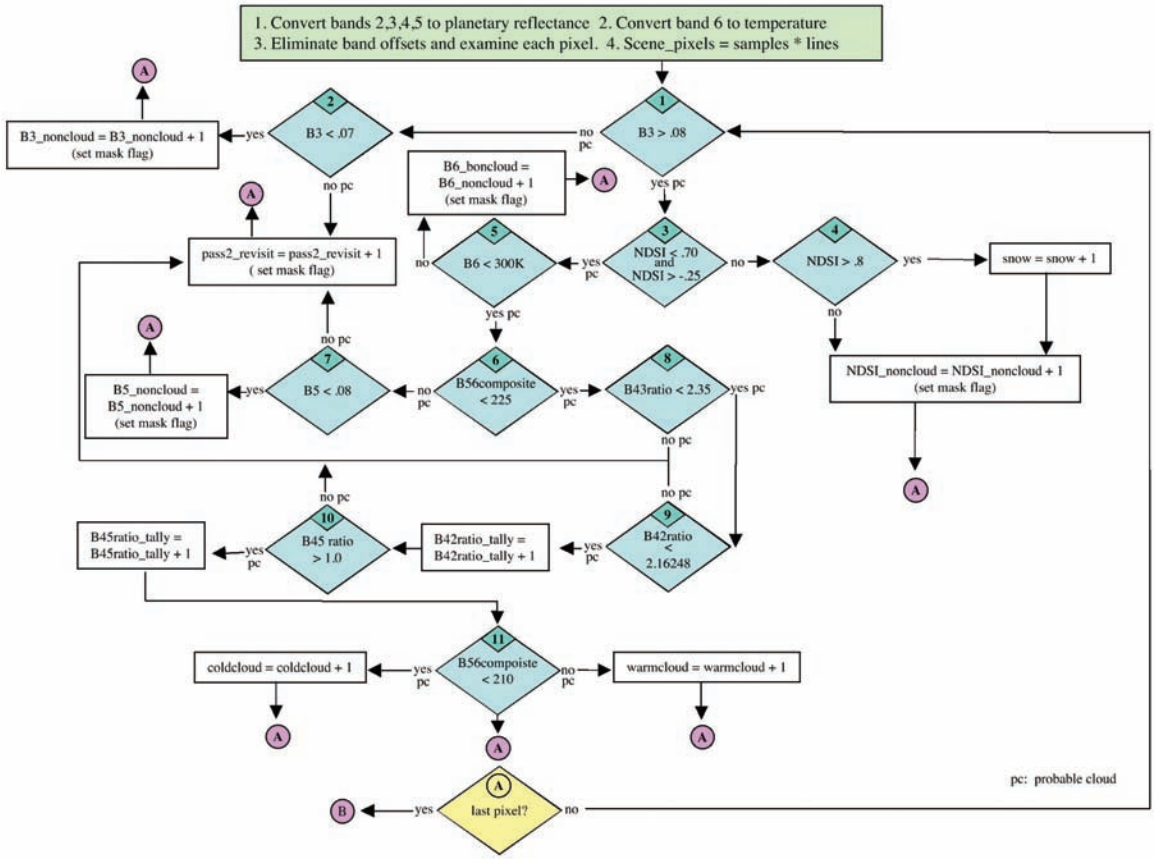

Plate 2. ETM+ ACCA flow chart (1 of 4): spectral cloud identification.