Landsat-7 Long-Term Acquisition Plan Radiometry - Evolution Over Time

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Abstract

The Landsat-7 Enhanced Thematic Mapper Plus instrument has two selectable gains for each spectral band. In the acquisition plan, the gains were initially set to maximize the entropy in each scene. One unintended consequence of this strategy was that, at times, dense vegetation saturated band 4 and deserts saturated all bands. A revised strategy, based on a land-cover classification and sun angle thresholds, reduced saturation, but resulted in gain changes occurring within the same scene on multiple overpasses. As the gain changes cause some loss of data and difficulties for some ground processing systems, a procedure was devised to shift the gain changes to the nearest predicted cloudy scenes. The results are still not totally satisfactory as gain changes still impact some scenes and saturation still occurs, particularly in ephemerally snow-covered regions. A primary conclusion of our experience with variable gain on Landsat-7 is that such an approach should not be employed on future global monitoring missions.

Introduction

The Landsat-7 Enhanced Thematic Mapper Plus (ETM+) instrument is a derivative of the Thematic Mapper instruments flown on Landsat-4 and Landsat-5 and the Enhanced Thematic Mapper (ETM) instrument built for Landsat-6. The ETM+ has eight bands: three in the visible spectrum (Bands 1, 2, and 3), one near-infrared band (Band 4), two short-wave infrared bands (Bands 5 and 7), one thermal band (Band 6), and one panchromatic band (Band 8). The data are quantized to 8 bits. The ETM+ has three on-board radiometric calibration devices: an Internal Calibrator that uses lamps, a Partial Aperture Solar Calibrator, and a solar diffuser panel-based Full Aperture Solar Calibrator.

One of the changes for ETM, relative to the TM, was to include high-gain and low-gain states for each of the bands. These two gain states differed by a factor of 2 and were implemented by using a 9-bit A/D converter. The 8 most significant bits produced low gain and the 8 least significant bits produced high gain. The intention of this design was to allow trading saturation radiance for signal precision for a given acquisition. The initial ETM+ design also incorporated the capability to switch between two gain states with a ratio of 2 between the states. For ETM+ the implementation was different, as the two “gain” states were achieved by changing the reference voltage applied to the A/D converter. The original plan was for the ETM+ to have one of the two gain ranges set so that its saturation radiance matched the design saturation radiance for TM. The other gain state was selected to either increase the precision or increase the saturation radiance, depending on what was considered more important for the particular band. In general, where it was felt that increased precision would benefit a particular band, precision was selected over increased saturation radiance. Only one of the two gain states is downlinked from the spacecraft, except for the thermal band (Band 6) where both gain states are always available in the downlink. Due to hardware difficulties, the gain ratio was changed to 1.5 partway through the program (for all but the thermal band), resulting in the values in Table 1.

The Landsat-7 Long-Term Acquisition Plan team has worked to effectively use the two gain states available in the ETM+ instrument. This team’s plans were developed and modified based on analyses, feedback from the various International Cooperator stations, and feedback from users of the data. This paper documents the iterations performed on the gain setting strategies, and the successes and problems with each iteration.

Gain Setting Strategies and History

Version 1

Prior to launch, a strategy to set the gain states for each of the ETM+ bands was devised as part of the effort to develop the Long-Term Acquisition Plan (LTAP) (Arvidson *et al.*, 2001). This strategy was based on maximizing the entropy in each band.

The 8-year monthly averages of Advanced Very High Resolution Radiometer (AVHRR) visible and near-infrared planetary reflectances from the AVHRR Global Vegetation Index data set, at the original 15 km spatial resolution, were used to evaluate the gain settings (Goward *et al.*, 1994). Visible (bands 1, 2, and 3), near-infrared (band 4), and shortwave-infrared (bands 5 and 7) gains were considered separately. The at-satellite planetary reflectance was converted to at-satellite radiance, based on the solar zenith angle at the time of satellite overpass. For each Landsat Worldwide Reference System (WRS) scene, the observed spectral radiance was subjected to the two gain states. For each gain state, an entropy statistic was calculated to determine the potential scene contrast in each setting. Where low gain was found to provide substantially greater scene contrast (e.g., glaciers in summer), this setting was selected. For all other cases, the high gain was selected.

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TABLE 1. LANDSAT-7 ETM+ MINIMUM SATURATION RADIANCES (FINAL DESIGN SPECIFICATION) AS COMPARED TO LANDSAT-4 AND LANDSAT-5 TM DESIGN SPECIFICATIONS (NIR = NEAR-INFRARED, SWIR = SHORT-WAVE INFRARED, TIR = THERMAL INFRARED, AND PAN = PANCHROMATIC)

			Saturation Radiances (W m^{-2} sr^{-1} μm^{-1})		
			Landsat-7 ETM+		
Band #	Band Name	Band pass (μm)	Low Gain	High Gain	Landsat -4/5 TM
1	Blue	0.45–0.52	286	191	143
2	Green	0.53–0.61	291	194	291
3	Red	0.63–0.69	225	150	225
4	NIR	0.78–0.90	225	150	214
5	SWIR	1.57–1.78	47.3	31.5	30.0
6	TIR	10.5–12.5 Low	1.13	4.86	1.13
6	TIR	10.5–12.5 High	15.4	12	15.4
7	SWIR	2.10–2.35	16.7	11.1	15.9
8	Pan	0.52–0.9	235	157	N/A

These determinations were performed for the middle of each month of the year, resulting in a gain setting mask for each month. Plate 1 shows June's gain settings. Other months may be found at: **http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_htmls/chapter6/htmls/initial_gain_strategy.html**. Note that band 8, the panchromatic band, was selected to always be in low gain. Two factors drove this choice: (a) the desire to minimize saturation in the band used for sharpening, and (b) the high noise in this band which gave the high gain mode little advantage (see below). The LTAP included a number of "science niche" acquisitions in addition to the regular land mass acquisitions. These included Antarctica (snow and ice), coral reefs, and volcanoes at night. Table 2 provides the gain settings used for these science niche communities.

Summary

The effective use of the two gain states provided by the ETM+ manufacturer has been a challenge for the Landsat team. The limitations of an 8-bit system, the complications of setting the gains to satisfy different users, and the problems that gain changes cause within the scenes where they occur have not led to any totally satisfactory solution. Were the system not being used for global acquisitions, the gains could be set for the particular scene to be acquired and the gain changes themselves would not need to impact users. This is more or less the "solution" being used for gain settings; i.e., the gain changes are being moved to scenes where they cause the least damage, such as cloudy scenes, or before an interval of acquisition. Serious discussions are underway on setting the gains to low for all acquisitions and using high gain on an exception basis only. Feedback received so far from the science community and the International Cooperator station operators has been favorable for such a decision. A basic conclusion from attempting to work with two gain states for Landsat 7 is that variable gain is not a desirable characteristic for satellite sensors systems used to globally and systematically monitor Earth's land areas.

The ultimate solution is to design a sensor system where the full range of earth targets to be sensed can be achieved at the precision required without the need for gain changes. This type of solution is currently in place on the Advanced Land Imager on EO-1, where a 12-bit A/D converter is used and the saturation radiances are set at or above the radiances that would be reflected off a 100 percent diffusely reflecting surface at the appropriate sun angle. Additionally, the Landsat Data Continuity Mission has been specified to meet the necessary dynamic range and precision requirements so that gain changes will become unnecessary.

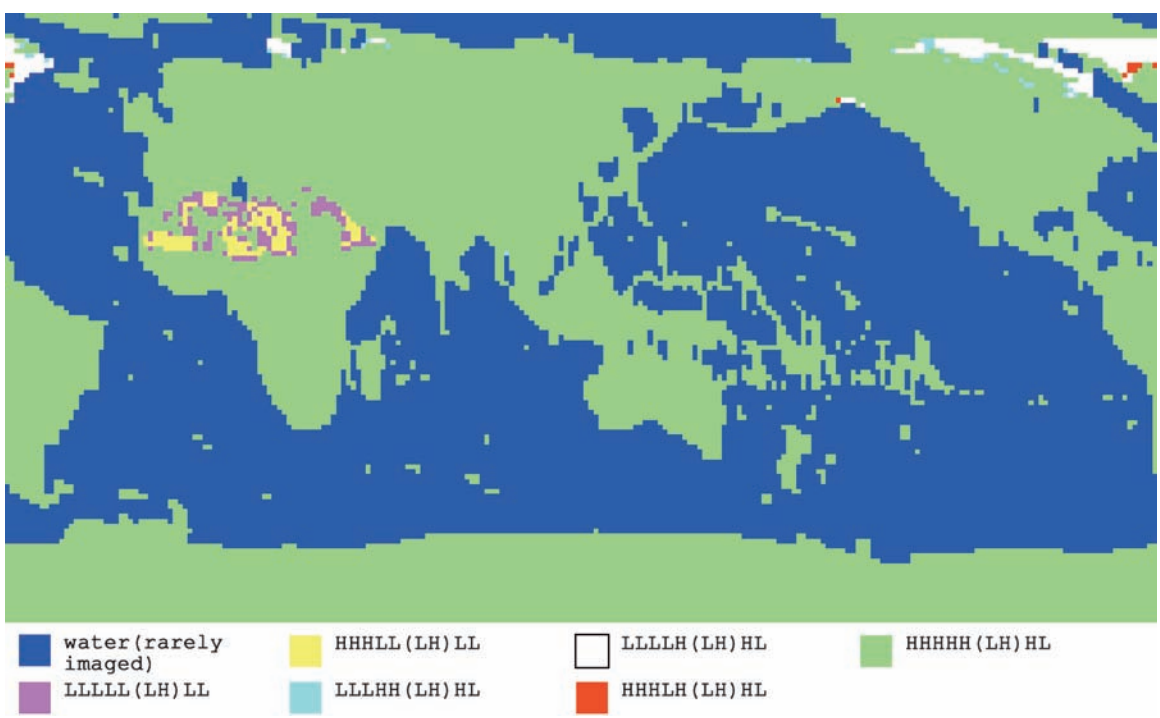

Plate 1. Original LTAP gain settings for June acquisitions. The gain settings in the legend are shown in band order, i.e., 12345 (66) 78, where band 6 is the thermal band, which is always acquired in both gain states, and band 8 is the panchromatic band. If the solar elevation angle is below 0°, a scene is considered night. The default gain settings for night scenes are HHHHL (LH) LL. As the latitude at which the sun angle is 0° varies across the month, night scenes are not shown on the map. For 01 June, the night scenes would be the same as in Plate 2.