TOWARDS ONBOARD ORBITAL TRACKING OF SEASONAL POLAR VOLATILES ON MARS. Kiri L. Wagstaff, Rebecca Castaño, Steve Chien, Anton B. Ivanov, *Jet Propulsion Laboratory, Pasadena, CA 91109, USA, (kiri.wagstaff@jpl.nasa.gov)*, Timothy N. Titus, *United States Geological Survey, Astrogeology Team, Flagstaff, AZ.*

Introduction: Current conditions on Mars support both a residual polar cap, composed mainly of water ice, and a seasonal cap, composed of CO_2, which appears and disappears each winter. Kieffer and Titus characterized the recession of the seasonal south polar cap using an arctangent curve fit based on data from the Thermal Emission Spectrometer on Mars Global Surveyor [1]. They also found significant interannual deviations, at the regional scale, in the recession rate [2]. Further observations will enable the refinement of our models of polar cap evolution in both hemispheres.

We have developed the Bimodal Image Temperature (BIT) Histogram Analysis method for the automated detection and tracking of the seasonal polar ice caps on Mars. It is specifically tailored for possible use onboard a spacecraft. We have evaluated BIT on uncalibrated data collected by the Thermal Emission Imaging System (THEMIS) instrument [3] on the Mars Odyssey spacecraft. In this paper, we focus on the northern seasonal cap, but our approach is directly applicable to the future analysis of the southern seasonal ice cap as well.

THEMIS Data: Previous analysis of the polar caps has relied on TES data, which has a per-pixel spatial resolution of 3 km. In this work, we analyze THEMIS IR images, which have a 100-m spatial resolution. The 30-fold increase in spatial resolution over TES data promises to yield much more precise identification of the edge of the polar cap. We focus on data collected in THEMIS band 9 (12.57 μm), which most clearly shows temperature differences in the image. Each THEMIS IR image is 320 pixels (32 km) wide and a variable number (3600 to 14352) of pixels long. To study the seasonal north polar cap recession, we identified images of the northern latitudes that ranged from L_s 350^o (early winter) to 70^o (late spring). Since our goal is to demonstrate the feasibility of onboard analysis, we worked solely with the raw, uncalibrated (EDR) data.

Bimodal Image Temperature (BIT) Histogram Analysis: Images that contain the polar cap edge have an associated temperature histogram that is bimodal, since both "cold" (polar cap) and "warm" (not polar cap) pixels are present. When this is the case, we dynamically identify the cutoff between cap and non-cap pixels, then locate the image line that best matches the transition between the two. We next describe BIT in more detail.

Step 1: Calibration [Optional]. Because we are working with uncalibrated data, we do not know the "true" temperature of each pixel. However, our method does not rely on absolute temperatures and, in fact, can be applied without any calibration. However, we gain a slight improvement in precision by performing a fast approximate calibration to help select the most appropriate cutoff. We pseudo-calibrate each pixel i in the image by converting the raw digital number, DN_i, to a temperature, T_i, as suggested by Josh Bandfield of ASU:

$$T_i = 101.85 \times \log_{10}(DN_i) - 223.3. \qquad (1)$$

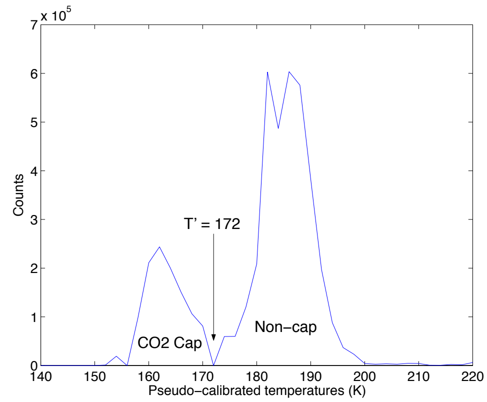

Figure 1: Temperature histogram for pixels in THEMIS image I09640013 (longitude 269.91W, L_s = 360.61^o).

Step 2: Temperature Histogram. We construct a histogram of all of the calibrated temperature values in the image. Each histogram bin is 2K wide, and the histogram ranges from 130 to 270K. For onboard use, we will instead pre-convert the histogram bin temperatures into DNs, and no onboard calibration will be necessary. Figure 1 shows the histogram generated by image I09640013.

Step 3: Dynamic Thresholding. We identify the characteristic "dip" (local minimum) between the two temperature modes, and select the corresponding temperature, T', as the threshold that distinguishes the polar cap from non-cap pixels. In Figure 1, $T' = 172$K. Due to the season, some images include regions that the sun does not illuminate, resulting in a third (extremely cold) mode. In such a case, we select the "dip" closest to 170K.

Step 4: Cap Edge Identification. Returning to the original image, we mark each pixel that is colder than T' as belonging to the polar cap and each pixel that is warmer than T' as "non-cap". We then proceed from north to south and examine each row of the image. As the proportion of CO_2 ice decreases in this direction, we halt when we find a row that is less than 50% "cap". This row is flagged as the edge of the CO_2 polar cap. For image I09640013, BIT finds the cap edge at latitude 59.80 degrees north.

Empirical Results: Although TES has much lower spatial resolution than THEMIS, its temperature observations are much more reliably calibrated. Therefore, we have evaluated BIT's detections against a model derived from contemporary TES observations. This model is a 51-coefficient Fourier fit to cap edge locations identified in 60-km binned TES data, with a 1-sigma error estimate of 1.4 degrees of latitude [4]. For image I09640013, the TES model predicts that the cap edge is at 60.87 degrees north, which is 1.07 degrees farther north than BIT's detection and within the margin of error for the TES model.

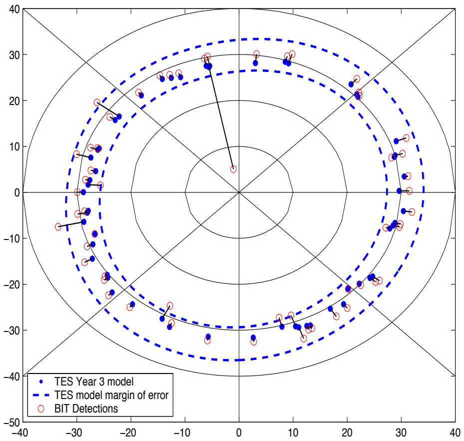

Figure 2: Comparison of BIT CO_2 ice cap detections (open circles) against the TES model (closed circles), in polar projection, for $L_s = 340^o$ to 360^o. Dashed lines show the TES model's range of predictions, including the margin of error.

The BIT method has very good agreement with the TES model. We used BIT to analyze 105 images known to contain the cap edge. The mean deviation between BIT and the TES model was just 0.18 degrees (about 9 km), with a standard deviation of 2.95 degrees. Figure 2 shows a polar projection that incorporates all detections from L_s 340^o to 360^o (late winter to early spring). The dashed lines indicate the minimum and maximum extent of the polar cap according to the TES model, including the 1.4 degree margin of error. Each BIT detection is connected to the corresponding TES model prediction. Note that there is one significant outlier, where the BIT method detected the cap edge to be at a latitude in excess of 85 degrees. However, the remaining detections almost entirely fall within the TES model margin of error, visually displaying the high agreement between BIT and the TES model.

We also assessed BIT's ability on the more difficult task of determining whether or not the cap edge is present at all. We created a separate test set of 476 images: 166 images that contain the edge of the polar cap (according to the TES model) and 310 images that do not contain the edge of the cap. As shown in Table 1, the BIT method agreed with the TES model for 455 of the 476 images (96%). For the 160 images that BIT and the TES model both identified as containing the polar cap edge, the BIT mean detection was 1.68 degrees north of the TES model, and the median offset was 0.66 degrees (standard deviation of 4.41 degrees).

Scenario 1: Targeted Imaging. This algorithm was designed to be efficient, with low memory requirements, so as to meet the processing and memory constraints onboard a spacecraft. We have identified two operational scenarios in which BIT can be used to identify and track the polar cap edge. In the first scenario, THEMIS operates in its current targeted mode. BIT is used to quickly analyze each image of the polar region as it is collected, determine whether the cap edge is present, and if so, downlink the cap edge location. Initially, this will manifest simply as an additional number transmitted along with the full image (for validation). Once sufficient reliability has been demonstrated, THEMIS can take multiple additional images of the polar region—more than it is possible to downlink given bandwidth constraints—and BIT can analyze them onboard and send only the detection results back to Earth. This mode can greatly increase effective surface coverage; THEMIS is currently restricted to a 5% duty cycle due to bandwidth constraints. Given the encouraging results from our empirical testing, we have discussed the possibility of running BIT onboard THEMIS with the THEMIS science team.

Table 1: Comparison of the BIT seasonal ice cap detection technique to the TES data model on 476 THEMIS images.

	Agreement with TES Model	
BIT Detections	Yes	No
Cap edge present	**160**	15 (false alarms)
No cap edge	**295**	6 (missed)
Totals	**455** (96%)	21

Scenario 2: Continuous Monitoring. In the second scenario, THEMIS operates in a continuous monitoring mode. Instead of identifying targets for imaging, it collects data throughout its orbit around Mars. In this mode, BIT can analyze "windows" of data as they are collected. If the characteristic bimodal warm-cold histogram shape appears within a given window, BIT will flag the location of the cap edge and store the detection for later transmission. We can reduce processing demands by only running BIT when the spacecraft is between 50 and 90 degrees of latitude. We are currently evaluating this scenario on archived THEMIS data to identify the optimum window size (number of lines) required for high precision detection of the polar cap edge.

Conclusions: The main goal of this work was to develop and validate an automated algorithm for tracking the seasonal ice caps on Mars. The BIT Histogram Analysis method operates on uncalibrated data and automatically identifies the temperature that separates two modes, warm and cold, and then uses this temperature to identify the edge of the cap. In evaluation on 476 THEMIS images, we find that BIT produces results that are highly consistent with a model of seasonal cap retreat derived from contemporary TES data.

We have proposed two scenarios in which BIT could be used onboard THEMIS to continuously monitor and track the seasonal polar ice caps on Mars. BIT can transmit cap edge detections even when bandwidth constraints would prevent the entire THEMIS image from being transmitted, or it can operate in a continuous monitoring mode without any ground intervention. In this way, we can greatly increase our temporal and spatial coverage of the Mars polar regions and add to our understanding of long-term climate changes on Mars.

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References: [1] Kieffer, H. H. et al. (2000) *JGR, 105*, 9653-9699. [2] Titus, T. N. and Kieffer, H. H. (2002) *LPS XXXIII*, Abstract #2071. [3] Christensen, P. R. et al. (2003) *LPS XXXIV*, Abstract #1519. [4] Titus, T. N. (2005) *LPS XXXVI*.