TRACKING RETREAT OF THE NORTH SEASONAL ICE CAP ON MARS: RESULTS FROM THE THEMIS INVESTIGATION. A. B. Ivanov[1], K. L. Wagstaff[1], T. N. Titus[2], [1]*Jet Propulsion Laboratory, MS168-416, Pasadena, CA, 91106; e-mail : anton.ivanov@jpl.nasa.gov*, [2]*United States Geological Survey, Astrogeology Team, Flagstaff, AZ.*

1 Introduction

The CO_2 ice caps on Mars advance and retreat with the seasons. This phenomenon was first observed by Cassini and then confirmed by numerous ground based observations in 19th and 20th centuries [1]. With the advent of the space age observations of the seasonal ice cap were done by all orbiting spacecraft starting with Mariner 7. Viking Orbiters and more recently the Mars Global Surveyor (particularly Mars Orbiter Camera (MOC, [3]) and Thermal Emission Spectrometer (TES, [5]) instruments) have accumulated significant data on the retreat of the CO_2 seasonal cap. During Mars year 2 of THEMIS operations at Mars, we planned an observational campaign in which the THEMIS instrument (onboard the Mars Odyssey spacecraft) repeatedly observed the north seasonal polar cap from mid-winter to late spring. THEMIS allows simultaneous observations in both Thermal IR (12.57μm) and Visible wavelengths (0.65μm).

One of the goals for this work is to initiate an inter-annual program for observations of the seasonal ice caps using the THEMIS instrument. The most efficient way to detect the edge between frost and bare ground is directly onboard of the spacecraft. Prior to onboard software design effort, we have developed two ground-based algorithms for automatically finding the edge of the seasonal polar cap in THEMIS IR data. The first algorithm relies on fully calibrated data and can be used for highly reliable ground-based analyses. The second method was specifically developed for processing raw, uncalibrated data in a highly efficient way [4]. It has the potential to enable automatic, onboard detections of the seasonal cap retreat. We have experimentally confirmed that both methods produce similar results, and we have validated both methods against a model [5] constructed from the MGS TES data from the same season.

2 Available data

In this study, we have used data from the Thermal Emission Imaging System (THEMIS) instrument ([2]) onboard the Mars Odyssey spacecraft. The IR camera has 10 filters from 6 to 15 μm ([2]) and images the surface with 100m/pixel resolution. During the second year of THEMIS operations, a specific campaign was designed to track the edge of the northern seasonal ice cap. Each image was targeted approximately near the cap edge and had to satisfy other requirements such as conflicts with other simultaneous campaigns. All images were then screened for LTP method (see below), based on the fully calibrated data available on the ground, to have a minimum temperature less then 175K (to ensure that ice is present) and a maximum temperature greater than 185K (to ensure that some defrosted terrain is present).

We have identified 113 such images from more than 450 total images collected in the North Polar region during the THEMIS primary mission. Figure 1 illustrates one of the images that we obtained during this campaign. The plot shows

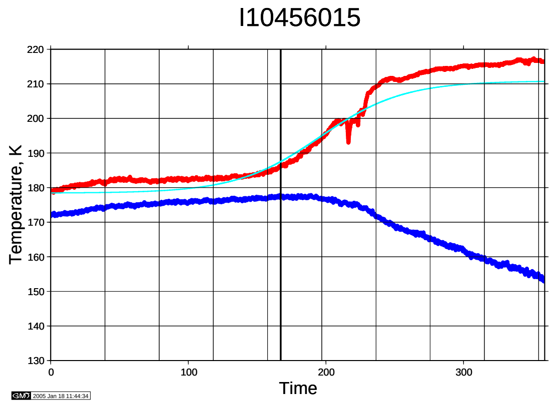

Figure 1: THEMIS IR (image id 10456015) data for images that include the polar cap edge. Band 9 - red, band 10 - blue. The figure shows temperature (averaged in the sample direction) vs. line number, from north to south. The thick line is the fit of the function (Section 3), and the thin vertical line is where the LTP method has identified the cap edge. This particular example is the best for locating the boundary. It covers both a low temperature (ice) and high temperature (regolith free of ice) region.

mean temperature in the sample direction for each line in the image. Moving from left to right on the plot generally corresponds to moving from north to south in an image. We have superimposed the sigmoidal fit (see Section 3.1 for details) to the data, and the cap edge thereby identified is indicated by a vertical line.

3 Data Analysis

3.1 Latitude temperature profile fit

The edge of the seasonal ice cap is not a step function at the THEMIS scale (100m/pixel). This resolution allows us to observe the defrosting region with high precision. In this work, we define the edge of the ice cap where 50% of the surface is covered with frost.

To find the cap edge boundary, we fit a sigmoidal function to a temperature profile (see Fig. 1). Sigmoidal function is very similar to the arctangent function, but easier to work with. Whenever this function crosses a predetermined value of 0.29 (corresponding to approximately 50% ice content on surface), we store the x-value of the corresponding image line. This value is then converted to latitude, longitude and L_s. Method, described above, is referred to as Latitude Temperature Profile (LTP).

3.2 Bimodal Image Temperature (BIT) Histogram Analysis

The second method that we have developed is specifically tailored for possible use onboard a spacecraft or instrument, such as THEMIS. It is described in significant detail in [4]. Our primary goal for this method was to match the accuracy of LTP while processing the raw, uncalibrated data (EDRs).

First, we perform a fast approximate calibration of each pixel i in the image by converting the raw digital number (DN) value, DN_i, to a temperature, T_i:
$T_i = 101.85 \times \log_{10}(DN_i) - 223.3$

Next, we construct a histogram of all of the calibrated temperature values in the image. We then identify the characteristic "dip" between the two temperature modes, which separates the warm (non-ice) pixels from the cold (ice) pixels. The corresponding temperature, T', is selected as the threshold that will distinguish ice from non-ice in the image. Returning to the original image, we mark each pixel that is colder than T' as "ice" . We then proceed from north to south and examine each row of the image. We halt when we find a row that is less than 50% ice. This row is flagged as the edge of the CO_2 polar cap.

3.3 Results

We processed more than 450 images using BIT method and 113 images using LTP method to detect the CO_2 cap edge, thereby producing a catalog of detections specified by latitude, longitude, and L_s. 64 images have satisfied strict temperature and fit quality requirements in both methods. This set of images was used to calculate statistics shown in Table 1. Number of images processed by BIT method is much higher, since input images were *all* IR images taken in North Polar Region. We have done this on purpose in order to verify method's stability in onboard situation.

Methods and Models	Mean offset	σ	N
LTP vs. TES Model	0.08	1.02	64
BIT vs. TES Model	0.56	0.79	64

Table 1: Comparison of the LTP and BIT seasonal ice cap detection techniques to the TES data model (TES year 3).

In Table 1, we report on the results obtained by each method by comparing them with a model developed from TES observations over the same time period. TES model [5] is based on observations made during the same year of observations (THEMIS year 2 is the same as TES year 3 of observations). We find that both methods exhibit remarkable consistency with the TES-based model.

4 Discussion

The next step, after algorithm validation, is to put observations made by THEMIS IR into the context of observations made in previous years. All authors use slightly different approaches. Here we propose to use a simple method where the ice cap regression is approximated by a simple linear relation $L = a \times L_s + b$, where L is latitude of the edge of the ice at time L_s. Consequently, a is the rate of recession and b is an offset or position of the cap at $L_s = 0$. In table 2 we compare observations made by MGS TES instrument and THEMIS year 2 observations. To compile this table we have evaluated the TES model at L_s and longitude locations where THEMIS data was available. MOC Visible observations exist [3], but are not yet presented here due differences in definitions of the ice cap boundary.

Platform	Offset (b)	Slope (a)	Comment
TES year 1	62.65	0.24	Cal change
TES year 2	61.58	0.23	
TES year 3	61.33	0.24	Same
THEMIS year 2	62.01	0.22	year

Table 2: Interannual comparison of general parameters of the North Polar ice cap retreat.

Note that there was a calibration change between TES years 1 and 2, which possibly accounts for the difference in offset between the two years. TES model has an error of approximately 1 degree, hence offsets are within error bounds. The rate of recession between TES and THEMIS data are slightly different. One possible explanation lies in the fact that TES model was used for this fit, while for THEMIS we have used actual data points. Table 2 is the beginning of trying to bring together observations from different platforms and initiate long-term monitoring of the seasonal caps. Note that Table 2 only describes data taken in Northern Hemisphere. It is very important to make sure that data used for interannual comparisons are similar in nature.

5 Conclusions

The major goal of this work was to develop and validate automated algorithms for tracking the retreat of the seasonal ice cap on Mars using THEMIS IR data. Methods, described above, produce results that are highly consistent with a model of seasonal cap retreat derived from contemporary MGS TES data; mean offsets are at or within the TES model's margin of error.

The BIT method can be implemented for onboard use on the Mars Odyssey spacecraft, to send down the time-on-orbit when the seasonal cap edge is detected. The Mars Odyssey spacecraft has the potential for a long mission life in orbit around Mars. We are now making progress towards tracking of the seasonal cap retreat in coherent way with previous observations to initiate long-term climate observations using the THEMIS instrument.

References

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