GEOMETRIC CORRECTION AND DATA ARCHIEVES OF THERMAL INFRARED IMAGER ONBOARD HAYABUSA2. T. Arai[1], T. Okada[2], S. Tanaka[2], T. Fukuhara[3], H. Demura[4], K. Suko[4], N. Sakatani[2], T. Kouyama[5], Y. Shimaki[2], H. Senshu[6], T. Sekiguchi[7], and J. Takita[8], [1]Ashikaga University, Tochigi, Japan (arai.takehiko@ashitech.ac.jp), [2]Japan Aerospace Exploration Agency, Sagamihara, Japan, [3]Rikkyo University, Tokyo, Japan, [4]The University of Aizu, Fukushima, Japan, [5]National Institute of Advanced Industrial Science and Technology, Tokyo, Japan, [6]Chiba Institute of Technology, Chiba, Japan, [7]Hokkaido University of Education, Hokkaido, Japan, [8]Hokkaido Kitami Hokuto High School, Hokkaido, Japan.

Introduction: The thermal infrared imager (TIR) onboard the Hayabusa2 spacecraft has observed the surface temperature of the asteroid 162173 Ryugu from June 27, 2018, to late 2019 [1]. To make global maps of the surface thermal properties for the asteroid is the primary goal of the TIR. Thermal inertia is especially the main target, which is written as the thermophysical amount of thermal conductivity, specific heat, and density. Also, a surface roughness [2], caused by surface shadows of light and multiple radiations, apparently changes the local temperature of the surface. Both thermal inertia and surface roughness affects the peak shift of diurnal time at the maximum temperature of the asteroid surface and probably cause orbital changes of the asteroid as studied as the Yarkovsky effect [3]. TIR reveals the evolutional history, such as the physical properties of the coalesced bodies, orbital changes due to the Yarkovsky effect, and the thermal changes.

This study performs a geometric correction of TIR observation for the detailed temperature observation of Ryugu and determines the local temperature of the characteristic body on the surface.

Geometric Correction: After the Earth swing-by of the Hayabusa2 spacecraft, TIR observed the planet and its moon from December 5 to December 22, 2015 [4]. We extracted positions of both the Earth and the Moon from the observed images of TIR and compared the positions and predicted coordinates (J2000) using the SPICE toolkit [5]. We adjusted the Euler angles of TIR for the Hayabusa2 body flame (FK) by the least-squares fitting. The resulting positional accuracy was less than 100 km from 340000~350000 km observation for the Earth and moon positions.

In the rendezvous phase of Ryugu, we performed the detail alignment correction of TIR using a shape model of Ryugu [6]. We adjusted 87 images observed from the mid-altitude of 5 km (2018-08-01) to the shape model for one rotation cycle. These observed images (Fig. 1a) were fitted to the numerical images made from the shape model of Ryugu (Fig 1b). The projection method was ray projection to a focal plane of images [7]. The best-fit Euler angles were,

Z: -1.052 +/- 0.010 (degree)
Y: -180.007 +/- 0.033 (degree)
X: 0.115 +/- 0.017 (degree)

This result implies that the positioning accuracy of the surface resolution achieved to the one sigma error of 2~3 m at an altitude of 5 km observation. Also, the results indicate that the spatial resolution of TIR is within the error of one pixel because the specific resolution of TIR is 0.051 degrees/pixel.

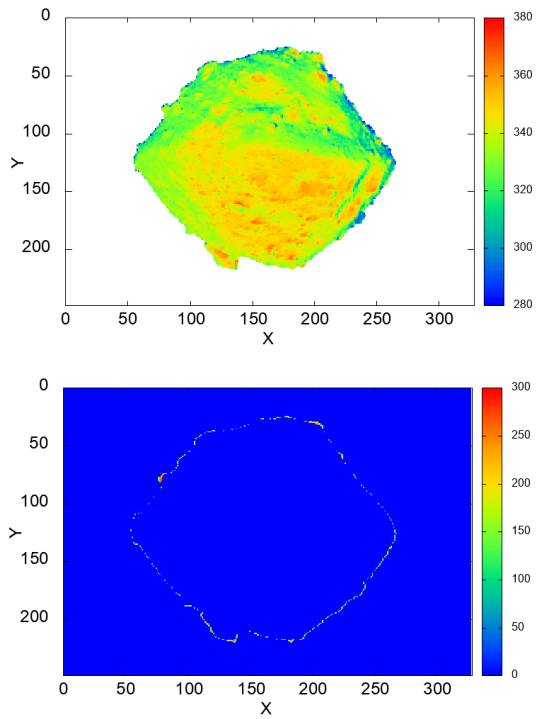

Figure 1. Geometric correction using the shape model of Ryugu (SHAPE_SPC_800k) [6]. (a) upper: example of an observed image (Level-2:2018-08-01T18:22:56). (b) lower: residual of the observed image and the projected temperature onto the TIR image plane from the shape model using SPICE tool kit.

Data Products: The observed data are automatically converted from raw digital data to temperature images using a Linux computer at ISAS/JAXA and the calibration database HEAT at the University of Aizu [8]. The raw data and part of the Level-1 data are currently available on JAXA's website [9]. Here, the outlines of Level-1~4 products are schematically shown in Figure 2 and described as follows:

Level-1. Raw Image - the raw image includes observed pixel coordinates connect to the planetocentric coordinates in the header - the coordinates generated by the SPICE kernels. The file format is Fits [10]. ***Level-2. Brightness Temperature Image*** - the brightness temperature converted from raw digital number images. The HEAT DB extracts near condition data from the pre-launch experiment DB, concerned with the temperature of the sensor and find best-calibrated data. ***Level-3. Temperature Map on Shape Model*** - the observed brightness temperature is projected onto the shape model of Ryugu. The file format is CSV text tables. ***Level-4. Thermal inertia map*** - the global thermal inertias are projected on a planetocentric map. The effects of surface roughness are corrected by simulation of the heat balance model of the Ryugu surface [11].

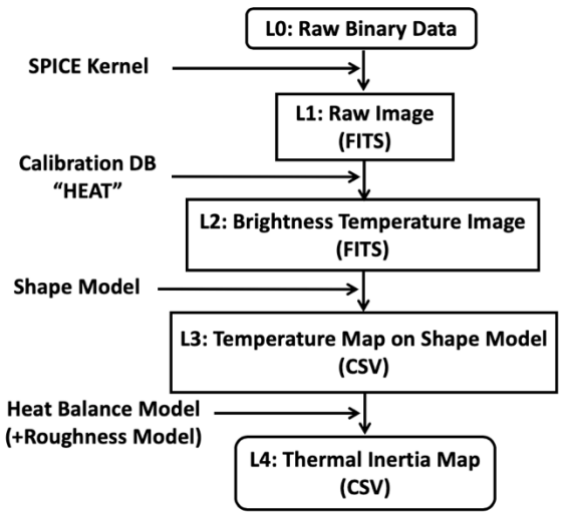

Figure 2. Data Production flow of TIR.

Results and Discussions: The accuracy of the geometric correction is less than 3 m at an altitude of 5 km observation using projection on the shape model. This result satisfies the scientific objective of TIR mentioned in the introduction.

The observed images include distortion in image corners. The distortion correction [7] was performed the same as the geometric correction using a least-squares fitting with a polynomial function. However, the fitting was not converged because the distortion was less than one-pixel. Therefore, we neglected the corner distortion of observed images.

Figure 3a shows the example of map projection data of TIR (Level-3). For comparison, numerical simulation data [12] is shown in Figure 3b. These temperature and thermal inertia (350 $Jm^{-2}s^{-0.5}K^{-1}$) was adjusted to the maximum temperature area (*Ejima Saxum*) of the observed image. The data simulated secondary-radiation and multiple-reflection, but the data did not include a surface roughness. These data imply that the surface geometry affects the surface temperature, such as hot areas. On the other hand, a global flatten-feature concerned with temperature is shown in the observed image, but such features are not shown in the simulated data. Therefore, surface roughness affects the global temperature of the surface.

TIR observed many close-up images with the spatial resolution of centimeters. The MARA radiometer onboard MASCOT lander also observed local surface temperatures [13]. We can compare these data for deriving of the local thermal properties and reveal the amazing characteristic body on the surface of Ryugu.

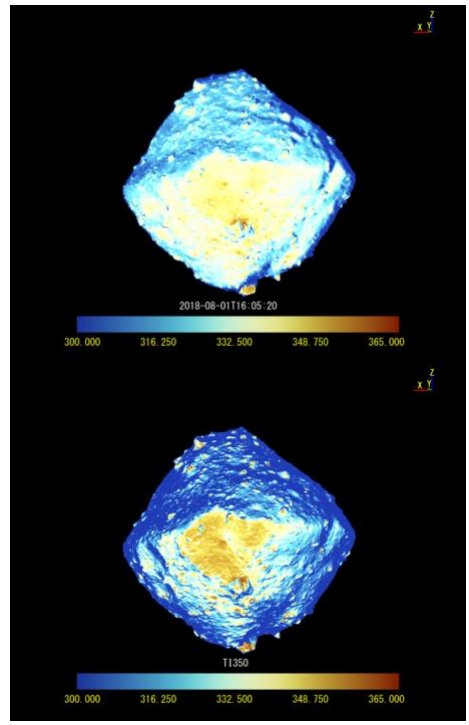

Figure 3. Example data of temperature map on the shape model. (a) upper: observed temperature of TIR projected onto the shape model of Ryugu (Level-3). (b) lower: numerical simulation result projected onto the shape model [12].

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