Thoughts on latitude bands
William Boynton
2015-08-18

Summary

Collecting PolyCam images via latitude bands in Orbital-A appears to be a viable approach to reducing the amount of data that are needed later in Orbital-B. It is likely that we will be able to collect data with sufficient resolution to satisfy the 5-cm resolution requirement of MRD-2.4.2, or at a minimum, reduce the number of sites for which the complex site-specific imaging is required. Another advantage of collecting these images is that they can be used more than three months earlier than the site-specific images from Orbital-B. Using latitude bands in Orbital-B to replace the site-specific imaging, however, does not look viable, as the slew times are such that only very narrow bands can be collected.

How are data collected in latitude bands?

In order to collect high-resolution images over a large area, we are considering using latitude bands. With latitude bands we image from a terminator orbit, generally by pointing toward the sunlit side of Bennu and then slewing the spacecraft back and forth in roughly the along-track direction. For example, if the spacecraft is over the terminator at 15° latitude with an orbit radius of 1500 meters, we can point approximately 5.5 deg sunward placing the PolyCam axis on the surface at a solar incidence angle of 60°. We can then slew the spacecraft along a line of constant longitude on the surface between the equator and 30° latitude taking images (and other data) during the slew (fig 1). At the end of the slew, we make a second slew to transfer to a nearby longitude to compensate for the Bennu rotation, but no images are taken on this transfer slew. At this point we then slew back to the equator with another image-taking slew followed by another transfer slew to the next longitude line. At the end of this four-slew pattern, the axis of PolyCam is pointed in solar coordinates at the same location where it started, and Bennu has rotated by the equivalent of two PolyCam field of views (FOV). This pattern is repeated for 4.3 hours, the rotation period of Bennu, after which we will have collected data over the entire latitude band from 0° to 30°.

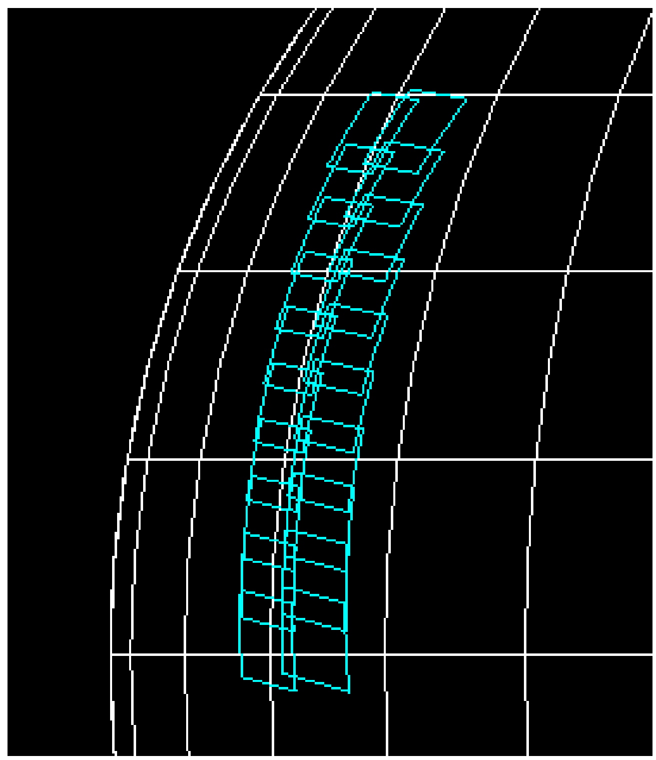

Fig. 1. The first two slews of a latitude band from the equator to 30° latitude. The footprints are those of the PolyCam FOV.

Trades in collecting latitude-band data

The width of the latitude band is determined by the amount Bennu rotates during the time it takes the spacecraft to complete the four-slew cycle. The slew rate, however, is determined by the amount of image-motion blur that is acceptable and the image exposure time. The width of the band can be increased by using a faster slew rate, but this increased width comes at the expense of more image-motion blur or a lower signal-to-noise ratio (SNR) due to a shorter exposure time.

Additional trades can be made in terms of optimizing the angles to get the best images for stereo photoclinometry (SPC) or geometric stereo. For example, we can point to a greater or lesser extent toward the sunlit hemisphere to change the solar incidence angle, and we can image slightly fore or aft of the spacecraft to change the look angles for stereo.

Results of latitude-band studies

I have carried out a simplified analysis of the capabilities of the latitude bands to either satisfy some of our observational requirements or reduce risk by getting data earlier than otherwise planned. The study assumed a 10% overlap between image scan lines, and it set a one-pixel blur limit. Two different exposure times and three different orbit radii were considered. The results are shown in Table 1.

Table 1. Results with different orbits and exposure times; longer exposure times => slower slew rates

Exposure time (ms)	20	30	20	30	20	30
Orbit radius (m)	1500	1500	1250	1250	1000	1000
Number of latitude bands	4	6	6	8	10	14
Latitude limit (deg)	59	61	61	53	53	56
Average width of band (deg)	14.8	10.2	10.2	6.6	5.3	4.0
Number of images for all bands	1762	1788	2316	2520	3740	4964
PolyCam pixel size (cm)	1.75	1.75	1.4	1.4	1.1	1.1

In the first column we see that with a 20-msec exposure time and the 1500-m orbit radius expected for Orbital-A, we can cover Bennu up to 59° latitude with only 4 bands. With the current constraints on operations, we are limited to one 5-hr data collection per day, so it will take 12 days to cover the surface with three sets of images. In reality it will take more than 12 bands to cover the surface since the analysis did not allow for navigational uncertainties in the location of the spacecraft. Because we are taking data in a wide swath, however, a latitude-band imaging sequence taken from an orbit position somewhat different from that expected, will still cover a similarly wide swath of the surface, but there may be extensive overlap between some bands and gaps between others. The gaps can be filled at the expense of a few additional days of data collection. Alternatively, we can plan on covering less of the surface and plan on more overlap between adjacent bands to allow for navigational uncertainties.

It can also be seen in Table 1 that as one goes to the right in the table with longer exposure times and smaller orbits, the number of bands it takes to cover Bennu greatly increases. The reason is that at a closer range, the spacecraft must slew through a larger angle to cover the same latitude range on the surface, and the FOV of the camera is smaller so it takes more slew cycles per Bennu rotation. At one point we were thinking that latitude bands taken in Orbital-B could eliminate the need for the site-specific imaging, but coverage for any reasonable exposure time is rather poor from the 1000-m radius orbit.

Requirements

The main reason for collecting site-specific imaging during Orbital-B is to get 5-cm resolution on up to 12 candidate sampling sites. Mission requirement MRD-2.4.2 states, "For a 3-sigma TAG delivery error ellipse around each of up to 12 candidate sampling sites, produce a topographic map at < 5cm spatial resolution and < 5cm (1-sigma) vertical precision." It can be seen from Table 1 that even from the 1500-m orbit the pixel size is 1.75 cm, which is likely to be good enough to satisfy the 5-cm resolution requirement.

A possible CONOPS for Orbital-A

It appears that collecting latitude band data in Orbital-A can eliminate at least some of the need for site-specific imaging, so it may be worth taking extra time to take latitude-band data in Orbital-A. I suggest we consider the following approach to imaging in Orbital-A. We begin by taking both MapCam and PolyCam images in nadir-point mode for the first two weeks. I suggest we begin the imaging with MapCam even as we are entering into the 1500-m orbit. These images can be taken in conjunction with the NavCam images and could conceivably be a valuable supplement to the NavCam images due to their better spatial resolution. Once we achieve the 1500-m orbit, we intermix PolyCam images with MapCam images still maintaining pointing in nadir mode with some offset toward the sunlit hemisphere. During the first two weeks, it is important that we not do any slewing for image taking since the Flight Dynamics team will want the spacecraft attitude to be steady to help them estimate non-gravitational forces.

After about 2 weeks I suggest we plan on collecting two sets of data on a single latitude band. We can collect one set of images on the morning hemisphere, and then approximately a day later, when the spacecraft is on the other side of Bennu, we can collect afternoon data. At this two-week point we will have full global coverage from a variety of incidence and emission angles at MapCam resolution, and we will have a good random sampling of images at PolyCam resolution. Having the global coverage will provide good context images onto which the higher resolution latitude band images can be placed. It is possible, perhaps even likely, that we will have a first cut at a shape model based on the Orbital-A MapCam data, which have a 9-cm pixel size.

The purpose of the exercise would be to both test our ability to collect the data as planned and to see to what extent this operation changes the ability of the FD team to predict the orbit evolution into the future. We would not do additional latitude-band imaging until the effect of this first one was fully evaluated both in terms of the value of the images as well as the disruption of the Nav effort.

After evaluating the data, we can make a decision to collect more images via the latitude-band approach or we can decide to move on to the Detailed Survey Phase. If we decide to collect more images from Orbital-A, another option to consider is lowering the orbit somewhat if it is felt that slightly better spatial resolution would be worth the added time. Obviously these decisions would depend in large part on the nature of the surface and what the rock distribution looks like. In addition, where we are in our time line may influence the decision. For example if we have already had a safe-mode excursion that has cost us a lot of time, we may accept that the latitude band imaging will be good enough and we can do the site selection without the need for site-specific imaging in Orbital-B. On the other hand, if there are many rocks near the 5-cm size at some locations of interest, we may feel we will need the Orbital-B resolution to be sure of our sample-site evaluations.

Benefits

We obviously cannot be certain that collecting these images will forego the need to collect site specific images in Orbital-B, but what is almost certainly going to be the case, however, is that the latitude bands in Orbital-A will significantly cut the number of candidate sites that need site-specific imaging. In addition, these data will be collected over three months earlier than currently planned in Orbital-B. Having these data so much earlier will provide immeasurable help in planning later stages of the mission. They may permit us to eliminate some areas from further consideration, or they may point us in the direction of some areas that need particular attention in the future.

Pre-launch preparations

Several things can be done to help prepare for the possibility of collecting latitude-band images. We could generate test data, as we are for SPC testing, where the starting point is wherever we expect to be with the shape model at the time we enter into Orbital-A. I can work with John Kidd to suggest a few data collection plans geared toward just one latitude band but with a variety of different incident and emission angles. John can then generate the location of the images with the appropriate angles, and Eric Palmer can generate synthetic images under those conditions and process them using SPC. He will assume some uncertainty in the spacecraft location in placing the images on the surface but will assume an uncertainty typical of that expected for the post orbit determination reconstruction. In addition, John and I can work with the much larger expected uncertainties associated with the orbit predictions to determine how far off nominal we need to be before it no longer makes sense to take the data. Modest uncertainties should be no problem, but at some point the spacecraft location may be off by so much that the look angles are too oblique for the images to be useful. In any event, it seems clear that we have to plan on being able to do the site-specific imaging in Orbital-B as currently envisioned even if it is not clear it will be needed.