Controlled Global Ganymede Mosaic from Voyager and Galileo Images

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Abstract

In preparation of the JUICE mission with the primary target Ganymede we generated a new controlled version of the global Ganymede image mosaic using a combination of Voyager 1 and 2 and Galileo images. Baseline for this work was the new 3D control point network from Zubarev et al., 2016, which uses the best available images from both missions and led to new position and pointing of the images. Creating a global mosaic with these corrected images made it reasonable to decide for a higher map scale of the global mosaic as currently existing ones. Therefore, we included very high-resolved Galileo images that cover only a few percent of the surface but can be analyzed directly within their surrounding context. As a consequence, it supports the JUICE operations team during the planning of the Ganymede orbit phase at the end of the mission (Grasset et al., 2013).

Introduction

In 1979 Voyager 1 and 2 arrived at Jupiter to acquire 490 Narrow Angle Camera (NAC) and Wide Angle Camera (WAC) images of Ganymede's surface with pixel scales from 470 m/pxl down to 20 km/pxl. Galileo, with its Solid State Imaging (SSI) camera onboard, entered orbit around Jupiter in 1995 and took 149 images (<20 km/pxl) of Ganymede during 15 flybys. Taken together these images cover almost the entire surface of the Jovian moon. Until today, they build the foundation of our understanding of the formation of Ganymede's surface, the locations of dark regions and bright spots, the crater distribution and much more. Pre-existing global mosaics of Ganymede included images with resolutions up to 400 m/pxl and have a global map scale of 1 km/pxl (Becker et al., 2001; Schenk, 2010). The mosaic from USGS can be found at *The Annex of the PDS Cartography & Imaging Sciences Node* (www[1], in the Weblinks section). The new control point network of Ganymede developed by the use of reconstructed spacecraft ephemerides (Zubarev et al., 2015) led to higher geodetic accuracy in the data and thus created the incentive to generate a new basemap. During the stepwise mosaicking process, we integrated images with resolutions better than 100 m/pxl to worse than 10 km/pxl (Figure 1) and reprocessed all images with a final map scale of about 359 m/pxl. Besides the preparation of the images, the most work-intensive part of the processing chain was the equalization of the image brightness and contrast variations.

Image Data

When combining images from numerous observations of different missions several problems occur. The Voyager and Galileo images were acquired under very differing illumination and viewing conditions and from different observation times, although they have been taken within a short period each. Together with the varying flyby altitudes it strongly influences the images' brightness, contrast, and resolution (Figure 2). Another fact is that images of Ganymede are limited, so there is barely an area covered twice with a proper resolution whereas the poles suffer from a lack of image data. To reach the highest possible coverage in the global mosaic, we selected 118 Voyager 1 and 2 images (Table 1) and 88 Galileo SSI images (Table 2). Due to the different trajectories, Voyager 1 observed the northern hemisphere and Voyager 2 the southern hemisphere of Ganymede, which is also shown in the naming of the images. The names contain the clock count from the time at which an image was shuttered and since Voyager 1 arrived at Ganymede four month earlier the images start with C16 and those of Voyager 2 with C20. Three close Ganymede encounters from Galileo (838, 264, and 808 km altitude) delivered the highest resolved images with resolutions better than 500 m/pxl.

Geodetic Control

A new technique for photogrammetric processing of heterogeneous images obtained at different times under significantly different imaging conditions by different imaging systems was developed and is described in Zubarev et al., 2016. The resulting 3D control point network of Ganymede consists of 3377 control points from 213 Voyager 1 and 2 and Galileo images. The recalculation of pixel coordinates from the initial images to the transformed ones and back was performed with an error of about 0.01-0.1 pixel. The control point accuracy is better than 5.0 km for 78% of the data. This most complete dataset with a high-quality image co-registration set the basis for the generation of a new global Ganymede mosaic with a resolution better than 1 km/pxl.

Mosaicking

The selected images were reprocessed with the new pointing and orientation data and then reprojected into the final cylindrical equidistant projection, where the small crater Anat defines the longitude system at 232° East (www[2]). The usage of planetocentric East coordinates was recommended by the JUICE *Task Group for satellites coordinate systems, cartography and nomenclature* (www[3]). Reviewing the single images revealed different artefacts that had to be removed manually by either cutting them off, in particular at the edges, or interpolating values from surrounding pixels using nearest neighbor algorithm. However, there are still artefacts caused by image interpolation and brightness adjustments and one linear shift along the 180° meridian that we could not eliminate from the mosaic. It is a mismatch of heights in the 2D DTM that was divided along the 180° meridian to apply the interpolation method. It has no effect on low resolution images but only on high-resolution images. Since it does not significantly influence the shape, brightness, or position of the features in those areas, the user might get along with it. After artefact correction, images with similar observation times and resolutions i.e., from the same flyby, were set together to regional mosaics, which helps during the last step, the brightness and contrast correction. The regional mosaics can be handled like a single image due to the coherent illumination of the images that comes from the same direction. Putting it all together, the regional mosaics and the remaining single images, required major adjustments using tone-matching methods at the transition zones, where dark shadowed areas are often followed by bright illuminated ones and low contrast regions from nadir incidence angles alternate with high contrast from low solar altitudes. This method does not keep the integrity of the albedo values of the pixels but still allows valuable geomorphologic analyses. Following planetary mapping convention, the map resolution of the final global mosaic was set to 128 pxl/deg, as it is a power of two, and thus results in a map scale of 358.7742 m/pxl assuming that the radius of the reference sphere is 2631.2 km (Archinal et al., 2011). The final global mosaic is shown in Figure 3 and can be downloaded in GeoTIFF format at the public DLR JANUS teamsite: https://janus.dlr.de/ (www[4]). It is available in four versions; in cylindrical equidistant projection centered at 0° and 180° East longitude and in two polar hemispheres in stereographic projection centered at 90°N and 90°S. It is also archived at ESA's PSA Guest Storage Facility: DOI 10.5270/esa-mqhvfjf.

Outlook

In the early 2030s the JUpiter ICy moons Explorer (JUICE) will enter the Jovian system to investigate Jupiter and three of its large moons, Ganymede, Europa, and Callisto, in the context of understanding the habitability of icy worlds. The mission will culminate in a nine months orbital tour around Ganymede during which the onboard JANUS camera will acquire high-resolution images of Ganymede's surface from two different altitudes (5000 and 500 km) reaching spatial resolutions from 400 to 7 m. Until then, the JUICE operations and science teams have to work with available data from Voyager and Galileo to plan the surface observations and determine regions of interest (Stephan et al., 2021) to fulfil the science objectives of the mission. Further activities in the work described here and improved DTMs could delete some of the artefact occurrences that are still visible in the mosaic but are a matter of capacities on different levels. Although, a new Ganymede basemap with a higher global map scale including some high-resolution images from Galileo increases the variety of available data products and should help during pre-JUICE arrival investigations of Ganymede and support the planning process.

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Weblinks

www[1] https://www.usgs.gov/centers/astrogeology-science-center/science/annex-pds-cartography-imaging-sciences-node?qt-science_center_objects=0#qt-science_center_objects

www[2] https://planetarynames.wr.usgs.gov/Feature/251

www[3] https://www.cosmos.esa.int/web/juice/task-group www[4] https://janus.dlr.de/

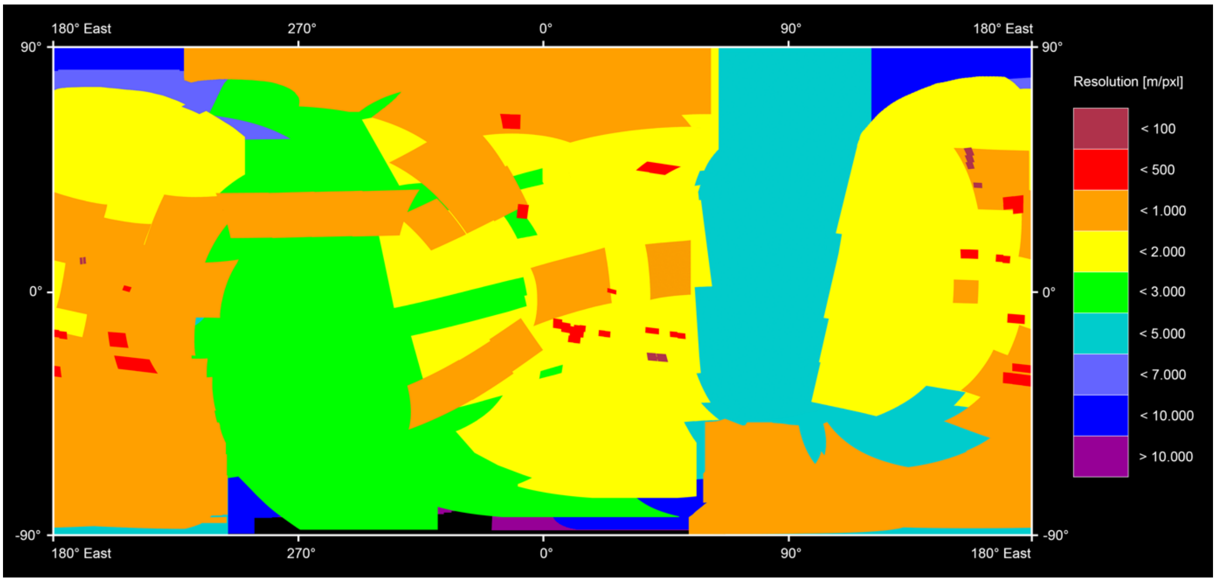

Figure 1: Global resolution map showing the Voyager and Galileo image resolutions used in the mosaic.

Figure 2: Global Ganymede mosaic of the selected images before brightness and contrast corrections. The mosaic is in cylindrical equidistant projection centered at 0° longitude in planetocentric East coordinates.

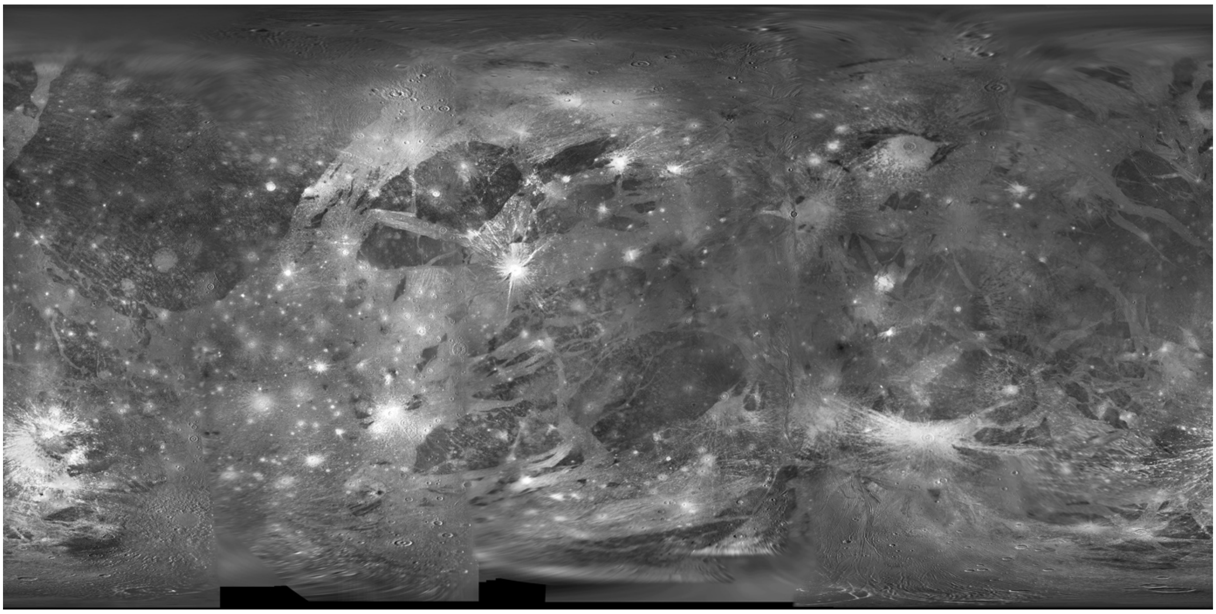

Figure 3: Global Ganymede mosaic of the selected images after brightness and contrast corrections. The mosaic is in cylindrical equidistant projection centered at 0° longitude in planetocentric East coordinates.

Table 1: List of Voyager images used in the global Ganymede mosaic. Image designation after Planetary Data System (https://pds-imaging.jpl.nasa.gov).

Image Number	Center Latitude [°]	Center Longitude [° East]	Pixel Resolution [km]
c1640152	4.00	18.53	2.28
c1640202	4.27	18.90	2.21
c1640212	4.56	19.31	2.14
c1640222	4.86	19.75	2.08
c1640232	5.18	20.24	2.03
c1640242	5.51	20.77	1.97
c1640256	6.01	21.60	1.87
c1640302	6.24	21.99	1.83
c1640312	6.64	22.68	1.78
c1640322	7.06	23.43	1.72
c1640342	7.98	25.16	1.61
c1640352	8.49	26.15	1.55
c1640356	8.70	26.57	1.53
c1640400	8.91	27.00	1.51
c1640414	9.71	28.66	1.44
c1640420	10.07	29.43	1.41
c1640422	10.19	29.70	1.43
c1640444	11.64	32.98	1.32
c1640446	11.78	33.31	1.28
c1640448	11.92	33.65	1.27
c1640454	12.36	34.70	1.26
c1640456	12.51	35.06	1.24
c1640502	12.96	36.19	1.21
c1640504	13.12	36.58	1.20
c1640520	14.40	39.97	1.13
c1640522	14.57	40.42	1.12
c1640528	15.08	41.84	1.10
c1640530	15.25	42.33	1.09
c1640542	16.29	45.44	1.04

c1640546	16.64	46.55	1.06
c1640548	16.82	47.12	1.03
c1640550	17.00	47.69	1.02
c1640606	18.42	52.64	0.98
c1640608	16.60	53.30	0.96
c1640723	23.21	82.87	0.91
c1640725	78.50	80.00	0.91
c2056847	4.77	273.14	25.95
c2060811	4.89	221.46	9.65
c2063525	-6.97	190.77	1.39
c2063533	-7.35	190.91	1.37
c2063537	-7.55	190.98	1.32
c2063541	-7.75	191.06	1.37
c2063545	-7.96	191.15	1.30
c2063549	-8.17	191.24	1.27
c2063551	-5.08	184.60	9.33
c2063553	-8.38	191.34	1.29
c2063556	-8.55	191.41	1.26
c2063559	-8.72	191.49	1.23
c2063602	-8.89	191.57	1.22
c2063608	-9.24	191.75	1.22
c2063611	-9.42	191.84	1.19
c2063614	-9.61	191.94	1.17
c2063620	-9.99	192.14	1.21
c2063641	-11.45	192.99	1.08
c2063644	-11.68	193.13	1.06
c2063647	-11.91	193.28	1.06
c2063653	-12.39	193.58	1.03
c2063656	-12.63	193.74	1.01
c2063659	-12.88	193.91	1.00
c2063702	-13.14	194.08	0.99
c2063705	-13.40	194.27	0.97
c2063708	-13.67	194.45	0.96
c2063711	-13.94	194.65	0.95
c2063714	-14.22	194.85	0.95
c2063717	-14.51	195.05	0.93
c2063720	-14.80	195.27	0.91
c2063723	-15.10	195.50	0.91
c2063729	-15.72	195.97	0.88
c2063732	-16.04	196.22	0.87
c2063735	-16.37	196.48	0.86
c2063738	-16.70	196.75	0.85
c2063741	-17.04	197.03	0.84
c2063744	-17.39	197.32	0.83
c2063747	-17.75	197.62	0.82
c2063750	-18.12	197.93	0.81
c2063753	-18.49	198.25	0.80
c2063756	-18.87	198.59	0.79
c2063759	-19.27	198.93	0.78
c2063802	-19.67	199.30	0.77
c2063805	-20.08	199.67	0.76
c2063808	-20.50	200.06	0.75
c2063811	-20.93	200.47	0.74
c2063817	-21.82	201.32	0.72
c2063829	-23.72	203.25	0.69
c2063833	-24.39	203.97	0.67
c2063837	-25.08	204.72	0.66
c2063851	-27.65	207.69	0.62
c2063855	-28.43	208.65	0.60
c2063857	-28.83	209.15	0.60
c2063859	-29.23	209.66	0.59
c2063901	-29.63	210.19	0.59
c2063903	-30.04	210.73	0.58
c2063905	-30.45	211.28	0.58
c2063907	-30.87	211.86	0.57
c2063909	-31.29	212.44	0.57
c2063911	-31.71	213.05	0.57
c2063913	-32.13	213.67	0.56
c2063915	-32.56	214.31	0.56
c2063917	-33.00	214.96	0.56

c2063919	-33.43	215.64	0.55
c2063921	-33.87	216.33	0.55
c2063951	-40.41	229.26	0.50
c2063952	-30.16	204.00	3.61
c2064024	-70.93	213.01	3.48
c2064025	-45.92	249.98	0.47
c2064027	-46.12	251.34	0.48
c2064029	-46.29	252.72	0.49
c2064031	-46.45	254.11	0.48
c2064033	-46.59	255.50	0.48
c2064037	-46.81	258.29	0.48
c2064039	-46.89	259.69	0.48
c2064041	-46.95	261.08	0.48
c2064043	-47.00	262.47	0.48
c2064045	-47.03	263.85	0.49
c2064047	-47.04	265.23	0.49
c2064051	-47.00	267.95	0.50
c2064053	-46.96	269.29	0.50
c2064055	-46.90	270.62	0.50

Table 2: List of Galileo images used in the global Ganymede mosaic. Image designation after Planetary Data System (https://pds-imaging.jpl.nasa.gov).

Image Number	Center Latitude [°]	Center Longitude [° East]	Pixel Resolution [km]
0265r	-17.66	204.03	0.289
0500r	-6.8	29.94	0.551
0800r	-8.71	17.76	0.568
1000r	38.24	258.23	2.023
1013r	-0.77	258.79	2.023
1026r	-39.92	258.41	2.024
1039r	61.01	180.00	2.026
1052r	17.37	303.31	2.022
1065r	-18.46	305.28	2.023
1078r	-61.35	180.00	2.028
1100r	-11.50	29.95	0.589
1266r	-27.18	213.80	0.243
1278r	-26.36	206.95	0.240
1400r	-13.89	17.22	0.606
1500r	45.07	180.00	3.603
1513r	-33.99	93.68	3.604
1700r	16.39	4.82	0.625
2000r	-4.69	180.00	6.741
2000r	-58.42	60.82	0.660
2101r	-67.81	58.25	0.667
2139r	13.63	158.12	0.189
2152r	13.76	154.86	0.189
2201r	-75.93	57.65	0.678
2265r	-10.17	175.27	0.183
2278r	-9.89	172.18	0.182
2400r	30.91	174.07	0.188
2413r	30.53	170.63	0.187
2413r	-29.36	181.33	0.180
2426r	34.49	173.98	0.187
2427r	-28.92	177.73	0.179
2439r	34.11	170.42	0.187
2440r	-28.50	174.26	0.178
2452r	-32.74	178.00	0.178
2465r	-32.30	174.40	0.177
2478r	-31.89	170.85	0.177
2865r	11.82	169.98	0.152
2878r	12.27	167.44	0.152
3000r	-11.82	5.46	0.181
3013r	-13.24	8.51	0.181
3026r	-14.74	11.69	0.181
3066r	-16.03	183.84	0.145
3078r	-15.37	181.12	0.144
3200r	62.51	350.44	0.177

3213r	62.77	343.77	0.177
3400r	45.01	44.73	0.169
3413r	45.86	39.16	0.167
3600r	28.17	353.81	0.149
3613r	28.37	351.10	0.148
3626r	30.86	351.30	0.148
3639r	30.65	354.07	0.147
3800r	0.62	25.28	0.144
4000r	18.53	49.61	0.040
4013r	18.50	48.85	0.041
4026r	18.46	48.08	0.041
4039r	18.41	47.28	0.042
4145r	1.24	207.32	0.221
4426r	46.46	156.21	0.098
4439r	48.88	156.01	0.099
4452r	51.46	155.70	0.099
4639r	39.15	159.88	0.086
4652r	39.25	158.07	0.086
5100r	11.25	57.04	0.114
5113r	11.01	54.28	0.114
5200r	9.79	47.12	0.118
5213r	9.54	44.75	0.118
5300r	10.84	29.18	0.121
5313r	10.61	27.15	0.122
5400r	-9.01	20.22	0.126
5413r	-8.76	18.42	0.128
5426r	-10.93	19.26	0.129
5439r	-10.69	17.42	0.130
5452r	-12.92	18.26	0.131
5465r	-12.68	16.36	0.132
5600r	11.41	191.53	0.042
5613r	11.97	190.94	0.042
6200r	0.06	154.80	0.496
6900r	0.75	180.00	9.185
7800r	41.69	163.28	0.935
8200r	1.17	180.00	8.211
8900r	0.09	36.34	14.42
8900r	29.27	250.40	0.833
8913r	29.52	267.28	0.832
8926r	29.76	285.07	0.832
8939r	10.46	192.11	0.076
8939r	30.25	303.37	0.834
8952r	10.77	190.90	0.075
8965r	11.92	190.81	0.074
8978r	12.01	192.01	0.074