New Horizons Encounter with the Pluto System: Mosaics, Topographic Maps, and Bond Albedo Maps for Pluto and Charon – Overview

This data set contains the New Horizons Pluto Encounter geology and geophysics science theme team derived mosaics, topographic and bond albedo maps for Pluto and Charon.

Global Monochrome Mosaics of Pluto and Charon

Detailed, high-quality global mosaics of Pluto and Pluto's largest moon Charon, were assembled from nearly all of the highest-resolution images obtained by the Long-Range Reconnaissance Imager (LORRI) and the Multispectral Visible Imaging Camera (MVIC) on New Horizons.

The mosaics are the most detailed and comprehensive global view yet of the surfaces of Pluto and Charon using New Horizons data. Standing out on Charon is an enormous trough at least 350 kilometers long, and reaching 14 kilometers deep - more than seven times as deep as the Grand Canyon. The mosaics are available in Equirectangular projection at an equatorial pixel scale of 300 meters per pixel.

Mosaic Processing Parameters

The Pluto map was produced using a radius of 1188.3 kilometers, and the Charon map was produced using a radius of 606 kilometers.

Geometric correction was necessary because the reconstructed SPICE kernels still showed a slight mismatch between the SPICE position and the actual location of the object. Correction was performed by bringing images into the ISIS system Keszthelyi, et al. (2014) and associating them with their reconstructed SPICE information. All LORRI images were inspected and image to image control points were assigned with the ISIS 'qnet' program. Then the ISIS bundle adjustment program 'jigsaw' was used on all of the LORRI images to adjust only the instrument pointing parameter (but not the spacecraft position), and letting jigsaw solve for the local radii of the given control points. The process generated a new SPICE C kernel that describes the updated spacecraft pointing at the time of each observation. A controlled LORRI mosaic was then created from this control solution.

A similar approach was used with the MVIC images, but in this case qnet was used while setting the LORRI mosaic as a 'Ground source' such that the locations of features in the LORRI mosaic were treated as known control points. The resultant control network that contained MVIC to MVIC control points, as well as MVIC to LORRI mosaic ground control points was then given two runs through jigsaw. The first run only adjusted the spacecraft position. The second run was allowed to solve for camera angles and their angular velocities as well as update spacecraft position. This produced a pointing (CK) and spacecraft location (SPK) solution for each MVIC image that allowed reprojection of the individual MVIC color bands together to allow for registered color mosaics.

Photometric correction was performed by using the equations in Peterson, et al. (2007) in order to make an approximation from instrument DN to I/F values. The 'photomet' program was also used with a lunar Lambert photometric function to correct for the changing observation angles due to planetary curvature within a scene, normalized to the approach phase angle of fifteen degrees. See Schenk, et al. (2018) for additional details on the photometric correction.

The 8-bit values of the mosaics are in units of relative brightness, which approximate I/F but are not.

More information about mosaic creation can be found in Schenk, et al. (2018) and Schenk, et al. (2017).

Topographic Maps (Digital Terrain Models - DTMs)

New Horizons 2015 flyby of the Pluto system has resulted in high- resolution topographic maps of Pluto Schenk, et al. (2018) and Charon Schenk, et al. (2017), the most distant objects so mapped. A variety of individual DTMs over about 30% of each object were produced at 300-800 m/pixel ground scales and with stereo height accuracies from 100 to 1500 m.

To facilitate geologic investigation of these two bodies (Stern, et al. (2015), Moore, et al. (2016)), imaging strategies were designed to enhance cartographic and topographic mapping products for Pluto and Charon. Cartographic control was complicated by the the high-speed encounter and imaging resolution was variable across both bodies. Selection of tie points between the approach and encounter hemispheres required selection of points at resolutions from 1 to 20 km/pixel. Nonetheless, redundant imaging enhanced bundle adjustments and resulted in stable cartographic solutions and global map products.

Topographic data for Pluto and Charon come from several sources. Bundle adjustments allow for determination of local radii; stereo images allow for direct DTM production; and limb observations reveal local relief along linear traces. Stereo mapping was strictly limited to the encounter hemispheres due to the rapidly decaying resolution around the backside of each sphere. Parallax in the approach images was simply insufficient to resolve topography on these bodies at these distances. Shape-from-shading compliments the stereo with pixel-scale slope measurement over areas of low Sun.

Stereo measurements based on the LORRI framing camera are stable and provide stereo height accuracies as good as 100 m and post-spacings of 1 km. Stereo measurements based on MVIC line-scanner images are equally as good but are complicated by the method of image acquisition, resulting in DTM rumpling in the direction of scan in the highest resolution images. Limb profiles were also possible over narrow restricted parts of the surface, and these extend topographic information to unseen areas.

More information about terrain model creation can be found in Schenk, et al. (2017) and Schenk, et al. (2018).

The values are elevations in kilometers from the reference radius of Pluto: 1188.3 km. So an elevation value in the NH_Pluto_DTM.img of 1 would be a radius of 1,189,300 m.

For Charon, the values are elevations in kilometers from the reference radius of Charon: 606 km. So an elevation value in the NH_Charon_DTM.img of 1 would be a radius of 607,000 m.

Bond Albedo Maps of Pluto and Charon

The exploration of the Pluto-Charon system by the New Horizons spacecraft represents the first opportunity to understand the distribution of albedo and other photometric properties of the surfaces of objects in the Solar System's 'Third Zone' of distant ice-rich bodies. Images of the entire illuminated surface of Pluto and Charon obtained by the Long Range Reconnaissance Imager (LORRI) camera provide a global map of Pluto that reveals surface albedo variegations larger than any other Solar System world except for Saturn's moon Iapetus.

Normal reflectances on Pluto range from 0.12-1.0, and the low-albedo areas of Pluto are darker than any region of Charon. Charon exhibits a much blander surface with normal reflectances ranging from 0.20-0.53.

LORRI Observations used for the Bolometric Bond Albedo Maps

The full list of the LORRI images used in this derivation, along with their integration times and their associated geometric information, can be found in Buratti, et al. (2017). These images represent the best spatial resolution obtained for each geographical location within the week prior to closest approach. For most of the data, Pluto and Charon appear on the same image (It wasn't until three days before closest approach that the binary pair exceeded the LORRI Field-of-View.) Pipeline calibration procedures were employed to flatfield each image, remove blemishes, and transform data numbers (DNs) into radiometric units using the flight calibration current as of late February 2016. These procedures are documented with the LORRI calibrated datasets.

Global Maps of Normal Reflectance

Since geologic analysis of images requires the knowledge of intrinsic values of the albedo, changes due solely to viewing geometry must be modeled and removed from the data. The images used in this study were obtained at small solar phase angles (although still larger than any observed from Earth); thus the corrections for solar phase angle effects are not large. Photometric changes on a surface are due to two primary factors: changes in the viewing geometry as the incident, emission, and solar phase angle change, and the physical character of the surface.

This latter factor includes the anisotropy of scatterings in the surface, which is expressed by the single particle phase function; the compaction state of the surface, which leads to the well-known opposition surge attributed to the rapid disappearance of mutual shadows among regolith particles as the surface becomes fully illuminated to an observer, and to coherent backscatter (Hapke (1981), Irvine (1966)) and to macroscopic roughness, which both alters the local incident and emission angles and removes radiation due to shadowing Hapke (1981) Buratti (1984). Radiative transfer models have been developed that fully describe the specific intensity returned from a planetary surface Hapke (1981) Buratti (1984) Shkuratov, et al. (2005). Empirical photometric models have been developed that are more appropriate for the data set in hand: observations at small solar phase angles (~10-15 degrees) leading up the flyby.

Two widely used models are those of Minneart (1961), which is essentially a first-order Fourier fit that describes the distribution of intensity on a planetary surface, and a lunar-Lambert model that is the superposition of a lunar, or Lommel-Seeliger law, describing singly scattered radiation, and a Lambert law describing multiple scattered photons Squyres, et al. (1981).

Bond Albedo Map Construction

A preliminary map of the Bolometric Bond albedo at LORRI wavelengths can be constructed with a rudimentary phase curve and our normal albedo maps. LORRI Images of Pluto and Charon for which the full disk is included in the image exist for a small range of solar phase angles. The images at large solar phase angles are contaminated by scattered light or atmospheric contributions in the case of Pluto. In future studies, synthetic integral values of Pluto's and Charon's solar phase curves will be constructed from disk-resolved observations.

For these preliminary Bond albedo maps, we make use of the fact that phase integrals of objects that scatter like Pluto and Charon have been derived, and we use these values for this study. For Pluto we adopt the phase integral of Triton of 1.16 derived from Voyager images obtained in the green filter, which at 0.55 um is the closest in wavelength to LORRI Hillier, et al. (1990). For Charon, we use the lunar phase integral at 0.63 um of 0.60 Lane, et al. (1973). For this preliminary study, the assumption of a lunar-like phase curve for Charon is reasonable and supported in Buratti, et al. (2017).

The LORRI images in this study have been scaled to geometric albedos determined from ground based observations. For Pluto, the value is 0.62 +/- 0.02 near the time of the New Horizons encounter for the R-filter Table Mountain Observatory, which is centered at 0.62 um Buie, et al. (2010) near the LORRI pivot wavelength of 0.607, while for Charon, it can be computed from the New Horizons radius of 606 km Stern, et al. (2015) combined with the ground-based opposition magnitude of 17.10 Buie, et al. (2010), transformed to the R-filter using the spectrum of Charon Fink, et al. (1988) Sawyer, et al. (1987). This method yields a geometric albedo at LORRI wavelengths of 0.41 +/- 0.01. These maps were multiplied by the phase integrals for Triton (in the case of Pluto) and the Moon (for the case of Charon).

The preliminary Bond albedo of Pluto is 0.72 +/- 0.07 and that of Charon is 0.25 +/- 0.03. The Bond albedo is the geometric albedo (p) times the phase integral (q). The best determination of the geometric albedo is from the ground, as it is based on observations at small solar phase angles. Buratti, et al. (2015) gives the visible geometric albedo for Pluto as 0.56 +/- 0.03, if an opposition surge is included. From the paper based on New Horizons data Buratti, et al. (2017), we have a phase integral for Pluto of 1.16 (this number has been confirmed by additional unpublished data) for a Bond albedo of 0.65, in the visible.

For these maps, the 8-bit Data Numbers (DN, from LORRI data) can be converted to albedo values using the equation albedo = DN/255. The DNs are the 8-bit integers in the .img file. The data is read in with readPDS with this DN/255 scaling factor already applied so that the data goes from 0 to 1. The accuracy of the data is based on the original 8-bit integers, not the scaled values, and is dimensionless.

Please note that the data along the edges may not be completely accurate due to photometric processing artifacts. In addition, these maps were built based on an early control solution of the spacecraft and the maps may not line up exactly with the other DTM and mosaic maps included in this dataset.

Processing

The data in this data set were created by a software data processing pipeline on the Science Operations Center (SOC) at the Southwest Research Institute (SwRI), Department of Space Operations. This SOC pipeline assembled data as FITS files from raw telemetry packets sent down by the spacecraft and populated the data labels with housekeeping and engineering values, and computed geometry parameters using SPICE kernels. The pipeline did not resample the data. This data was then used by the Science Theme Teams to generate derived data products as provided in this dataset.

References

M.W. Buie, W.M. Grundy, E.F. Young, L.A. Young, S.A. Stern Pluto and Charon with the Hubble Space Telescope. II. Resolving changes on Pluto's surface and a map for Charon Astron. J., 139 (2010), pp. 1128-1143. doi:10.1088/0004-6256/139/3/1128

B.J. Buratti, Voyager disk resolved photometry of the Saturnian satellites Icarus, 59 (1984), pp. 426-435. DOI:10.1016/0019-1035(84)90109-X

B.J. Buratti, M.D. Hicks, P.A. Dalba, D. Chu, A. O'Neill, J.K. Hillier, J. Masiero, S. Banholzer, H. Rhoades. Photometry of Pluto 2008-2014: evidence of ongoing seasonal volatile transport and activity, Astrophys. J. Lett., 804, p. L6, May, 2015. doi.org/10.1088/2041-8205/804/1/L6.

B.J. Buratti, J.D. Hofgartner, M.D. Hicks, H.A. Weaver, S.A. Stern, T. Momary, J.A. Mosher, R.A. Beyer, A.J. Verbiscer, A.M. Zangari, L.A. Young, C.M. Lisse, K. Singer, A. Cheng, W. Grundy, K. Ennico, C.B. Olkin, Global albedos of Pluto and Charon from LORRI New Horizons observations, Icarus, Volume 287, Pages 207-217, ISSN 0019-1035, 2017. https://doi.org/10.1016/j.icarus.2016.11.012.

U. Fink, M.A. Disanti The separate spectra of Pluto and its satellite Charon Astron. J., 95 (1988), pp. 229-236. DOI:10.1086/114632

B. Hapke, Bidirectional reflectance spectroscopy. 1 Theory, J. Geophys. Res., 86 (1981), pp. 3039-3054. https://doi.org/10.1029/JB086iB04p03039

J. Hillier, P. Helfenstein, A. Verbiscer, J. Veverka, R.H. Brown, J. Goguen, T.V. Johnson Voyager disk-integrated photometry of Triton Science, 250 (1990), pp. 419-421.DOI: 10.1126/science.250.4979.419

W.M. Irvine, The shadowing effect in diffuse radiation J. Geophys. Res., 71 (1966), pp. 2931-2937 DOI:10.1109/IGARSS.2008.4779468

Keszthelyi, L.; Becker, T.; Titus, T.; Sides, S.; Gaddis, L.; Hare, T.; Kirk, R.; Edmundson, K.; Anderson, J. 2014. Utilizing the Integrated Software for Imagers and Spectrometers (ISIS) to support future missions. 45th Lunar and Planetary Science Conference, LPI Contribution No. 1777, #1686.

A.P. Lane, W.M. Irvine Monochromatic phase curves and albedos for the lunar disk Astron. J., 78 (1973), pp. 267-277. DOI:10.1086/111414

M. Minnaert, Photometry of the moon G.P. Kuiper, B.M. Middlehurst (Eds.), The solar system III. Planets and Satellites, University of Chicago Press, Chicago (1961)

Moore, J. M., et al., The geology of Pluto and Charon through the eyes of New Horizons. Science 351, 1284-1293, 2016. doi:10.1126/science.aad7055.

Peterson, J. et al., 2007. New Horizons SOC to instrument pipeline ICD. In A. F. Cheng, editor, LORRI Jupiter Encounter V1.1, NH-J-LORRI-3-JUPITER-V1.1, Planetary Data System.

S.R. Sawyer, E.S. Barker, A.L. Cochran, W.D. Cochran Spectrophotometry of Pluto-Charon mutual events - Individual spectra of Pluto and Charon Science, 238 (1987), pp. 1560-1563 https://doi.org/10.1126/science.238.4833.1560

Schenk, P. M., et al., Canyons, Craters, and Volcanism: Global Cartography and Topography of Pluto's Moon Charon from New Horizons. Submitted to Icarus. 2017.

Schenk, P., Beyer, R., McKinnon, W., Moore, J., Spencer, J., White, O., Singer, K., Nimmo, F., Thomason, C., Lauer, T., Robbins, S., Umurhan, O., Grundy, W., Stern, S., Weaver, H., Young, L., Smith, K., Olkin, C., and the New Horizons Geology and Geophysics Investigation Team, Basins, Fractures and Volcanoes: Global Cartography and Topography of Pluto from New Horizons, Icarus, ISSN 0019-1035, 11 June 2018, doi.org/10.1016/j.icarus.2018.06.008.

Y.G. Shkuratov, Y.S. Grynko, Light scattering by media composed of semitransparent particles of different shapes in ray optics approximation: consequences for spectroscopy, photometry, and polarimetry of planetary regoliths Icarus, 173 (2005), pp. 16-28. https://doi.org/10.1016/j.icarus.2003.12.022

S. Squyres, J. Veverka, Voyager photometry of surface features on Ganymede and Callisto Icarus, 46 (1981), pp. 137-155. DOI:10.1016/0019-1035(81)90203-7

Stern, S. A., et al., The Pluto system: Initial results from its exploration by New Horizons, Science 350, id.aad1815. doi:10.1126/science.aad1815, 2015.