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No Common Yardstick: An Accuracy Classification for Planetary Control Networks

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Abstract

Geodetic control networks underpin nearly every derived planetary spatial product — image mosaics, digital terrain models, and landing-site hazard maps — yet no accepted classification exists for reporting or comparing their horizontal positional accuracy. Terrestrial geodesy solved an analogous problem decades ago: the U.S. Federal Geographic Data Committee's Geospatial Positioning Accuracy Standards, Part 2 (FGDC-STD-007.2-1998) defines a tiered, radius-of-uncertainty classification for geodetic networks at a stated confidence level, together with a structural distinction between local accuracy (consistency among neighboring points) and network accuracy (consistency with the reference datum). We adapt this classification to define five Planetary Control Network (PCN) accuracy classes spanning sub-meter to multi-kilometer horizontal uncertainty, with a fifth class also capturing networks for which no horizontal accuracy is reported at all. We apply the PCN classes to eight published lunar, Martian, and Galilean-satellite control-network products spanning 1979–2026, drawn from primary USGS, NASA, and peer-reviewed sources. Reported accuracies span roughly three orders of magnitude, products reporting only internal fit default to the fifth class, and no existing framework allows them to be compared. We further show that this gap is acknowledged but not resolved by the planetary community's own foundational-data literature: Laura and Beyer's (2021) fitness-for-use inventory explicitly excludes control networks from its scope, and its own tables report unknown accuracy for several outer-solar-system networks still in active use today. The PCN classification is intended as a lightweight, adoptable reporting convention rather than a new measurement standard.

Keywords: geodetic control network; planetary geodesy; fitness for use; accuracy classification; spatial data infrastructure; photogrammetric control¹

1. Introduction

A geodetic control network — the set of tie points photogrammetrically linking overlapping images to a common reference frame — is the foundation on which every downstream planetary spatial product is built. Image mosaics, digital terrain models (DTMs), orthorectified imagery, and landing-site hazard maps all inherit their positional accuracy from the control network used to produce them (Laura and Beyer, 2021).

¹ Abbreviations: 2DRMS, twice DRMS; CEP, circular error probable; CORS, Continuously Operating Reference Stations; COSPAR, Committee on Space Research; DRMS, distance root mean square; DTM, digital terrain model; FGDC, Federal Geographic Data Committee; IAG/IAU, International Association of Geodesy/International Astronomical Union; ILuRF2026, International Lunar Reference Frame 2026; LEAG, Lunar Exploration Analysis Group; LOLA, Lunar Orbiter Laser Altimeter; LROC NAC, Lunar Reconnaissance Orbiter Camera Narrow Angle Camera; MAPSIT, Mapping and Planetary Spatial Infrastructure Team; MDIM, Mars Digital Image Model; MOLA, Mars Orbiter Laser Altimeter; N/R, not reported; NSRS, National Spatial Reference System; PCN, Planetary Control Network; PDS4, Planetary Data System version 4; STAC, SpatioTemporal Asset Catalog; ULCN2005, Unified Lunar Control Network 2005.

Yet a user comparing two control networks today has no common vocabulary in which to do so. Each network reports its own accuracy, in its own units, against its own reference — when it reports accuracy at all.

The gap is not hypothetical. In a 2026 status report on Europa spatial data infrastructure, the U.S. Geological Survey's own Europa-focused working group states plainly that "Europa does not have a single accepted horizontal datum to which other spatial data sets can be aligned," and that independently produced control products for the body "are not perfectly aligned" as a direct consequence (Bland et al., 2026a). This is not a new observation: a 2020 community white paper prepared for the U.S. planetary science decadal survey noted that foundational planetary spatial products "are rare for many planetary bodies, or were created with outdated standards, coordinate frames, and techniques, or they lack information on accuracy" (Radebaugh et al., 2020). Nor is it merely academic — practitioners have documented real consequences. Wagner et al. (2024), describing best practices for obtaining coordinates from Lunar Reconnaissance Orbiter Camera Narrow Angle Camera (LROC NAC) data, note that the Unified Lunar Control Network 2005 (ULCN2005), still in active use by non-NASA data producers, "can have offsets of several kilometers" from the Lunar Orbiter Laser Altimeter (LOLA) reference frame that now underlies most modern lunar products.

Terrestrial geodesy confronted an equivalent problem for national geodetic networks and resolved it with a prescriptive, tiered accuracy classification. The Federal Geographic Data Committee (FGDC) Geospatial Positioning Accuracy Standards, Part 2: Standards for Geodetic Networks (FGDC-STD-007.2-1998) defines thirteen accuracy classes, from 1 millimeter to 10 meters, each expressed as a radius of positional uncertainty at 95% confidence, together with a structural distinction between local accuracy (a point's consistency with its immediate neighbors) and network accuracy (a point's consistency with the datum as a whole). This classification has never been adapted for planetary control networks, despite a directly analogous need.

We propose such an adaptation. Section 2 summarizes the FGDC classification and its underlying local/network accuracy distinction, including a limitation of the terrestrial standard, discussed openly. Section 3 defines five Planetary Control Network (PCN) accuracy classes, obtained by extending the FGDC table's own order-of-magnitude progression beyond its 10-meter ceiling. Section 4 applies the PCN classes to eight published lunar, Martian, and Galilean-satellite control networks spanning 1979 to 2026, using only accuracy figures published in the primary sources cited. Section 5 discusses adoption, positions the PCN classes relative to existing planetary spatial-data-infrastructure efforts, and notes the coincident timing of the 46th Scientific Assembly of the Committee on Space Research (COSPAR)'s first dedicated session on planetary geologic mapping and geodesy (COSPAR, 2026), which reflects renewed community attention to exactly this problem.

2. The Terrestrial Precedent: FGDC Geodetic Network Accuracy Standards

Geodetic network surveys are distinguished from general engineering or topographic control surveys by their use of redundant, interconnected, permanently monumented points intended to serve as a long-term reference framework — historically, in the United States, the National Spatial Reference System (NSRS). Because these networks underpin every subordinate survey and mapping product tied to them, the Federal Geodetic Control Subcommittee of the FGDC developed a dedicated accuracy standard for them, published in final form as FGDC-STD-007.2-1998 following a 1996 public-review draft.

The standard's Table 2.1 defines thirteen accuracy classes — 1-millimeter, 2-millimeter, 5-millimeter, 1-centimeter, and so on by decimal steps to 10-meter — each defined as the maximum radius of positional uncertainty at 95% confidence. The standard notes explicitly that "although the largest entry in Table 2.1 is 10 meters, the accuracy standards can be expanded to larger numbers if needed," anticipating exactly the kind of extension undertaken in Section 3 below.

A second, equally important contribution of the standard is a structural distinction between two accuracy measures. Local accuracy describes a point's positional consistency relative to its directly connected neighboring points. Network accuracy describes a point's positional consistency relative to the geodetic datum itself, historically realized through Continuously Operating Reference Stations (CORS). A survey can therefore be internally tight — high local accuracy — while still being poorly tied to the broader reference frame — low network accuracy. This distinction, we argue in Section 3, maps directly onto the central reporting failure identified for planetary control networks: internal (relative) consistency is frequently reported through bundle-adjustment solution statistics, while consistency with a stated absolute reference frame frequently is not.

The terrestrial standard has a documented limitation worth stating directly. The FGDC's own periodic review documentation for this standard records that, at time of review, it was not in active use, that the National Geodetic Survey was "'sheepish' about advancing [the] standard as an American National Standard until it is actively used," and that no mature user community existed among federal or non-federal stakeholders. A rigorously designed classification can therefore go substantially unused without an active application context to sustain it. We consider this precisely the condition planetary control networks satisfy that the terrestrial NSRS did not at the time of that review: planetary reference-frame realizations such as ULCN2005 and the Mars Digital Image Model (MDIM) series are actively and repeatedly revised across mission eras, giving a ported classification logic a use case the original NSRS-specific instrument lacked.

3. Proposed Planetary Control Network (PCN) Accuracy Classes

We retain the FGDC classification's core structure — a radius of positional uncertainty at a stated confidence level, expressed in decimal-scaled classes — and we are explicit that what is adapted here is that structure, the classification table, rather than the FGDC's full four-step assessment procedure described in Section 2 (documentation review, minimally-constrained adjustment, error propagation, comparison against established control). That procedure specifies how a new geodetic survey should be evaluated and assigned a class prospectively; porting it, so that a newly produced planetary control network could be assessed and classified going forward rather than only sorted retrospectively from already-published figures, is a natural extension beyond this paper's scope. We derive the PCN class boundaries independently of the demonstration presented in Section 4, by continuing the same order-of-magnitude progression that separates the base decade markers already present in the FGDC's own table (1 millimeter, 1 centimeter, 1 decimeter, 1 meter, each a factor of ten apart) one further order of magnitude at a time past the FGDC's 10-meter ceiling: 1 meter, 10 meters, 100 meters, 1 kilometer. This progression, extended purely by continuing the FGDC's own logic, happens to span the accuracy range separately observed across the eight demonstration products in Table 2 (from a few meters to several kilometers, with the finest class, PCN-1, populated by no product at present). That overlap is a confirming property of the demonstration, not the basis on which the boundary values were set. We are explicit, however, about what this derivation does and does not settle independently. The four boundary values (1 m, 10 m, 100 m, 1 km) follow mechanically

from continuing the FGDC's progression. But the decision to stop extending after four additional orders of magnitude, and to collapse everything beyond 1 km into a single open-ended PCN-5 rather than adding further classes, are design choices we make knowingly in light of the observed span, not consequences the progression forces on its own. Table 1 defines five Planetary Control Network (PCN) classes on this basis.

PCN Class	Horizontal Network Accuracy (95% confidence, relative to stated reference)	Representative Use
PCN-1	≤ 1 m	Landed/rover-scale operations; sub-meter cross-registration with in-situ ground truth
PCN-2	≤ 10 m	High-resolution controlled mosaics and DTMs; landing-site hazard mapping
PCN-3	≤ 100 m	Regional geologic mapping; cross-instrument coregistration
PCN-4	≤ 1 km	Global reconnaissance mosaics; first-order reference-frame ties
PCN-5	> 1 km, or horizontal accuracy not reported relative to a stated reference frame	Legacy or exploratory networks; unsuitable for quantitative cross-product analysis without independent verification

Table 1. Proposed Planetary Control Network (PCN) fitness-for-use accuracy classes, boundaries derived by extending FGDC-STD-007.2-1998 Table 2.1's own order-of-magnitude progression past its 10-meter ceiling (see Section 3). The Representative Use column reflects illustrative, typical associations drawn from current practice rather than derived operational requirements, offered as a starting point for community refinement rather than a fixed specification.

We recommend network accuracy — a control network's positional consistency with a stated, named planetary reference frame or geodetic proxy (for example, LOLA for the Moon or the Mars Orbiter Laser Altimeter, MOLA, for Mars) — as the primary classification axis, rather than local accuracy or an unqualified solution-RMS statistic. This recommendation follows directly from the evidence Section 4 presents below: internal density and self-consistency are frequently reported (through bundle-adjustment residuals, formal point-position standard errors, or solution RMS), while consistency with a specific, named absolute reference frame frequently is not. Edmundson et al. (2012) document a lunar South Pole control network of 527,756 points, of which only 37 were tied in all three coordinates to an LOLA-derived DTM — an extreme illustration of high internal density paired with minimal absolute reference-frame ties. We further recommend, following the terrestrial standard's practice, that any reported PCN class always be accompanied by the name of the reference frame or proxy against which it was assessed, since a class assigned without a stated reference is not meaningfully comparable across products. Laura and Beyer (2021) illustrate why this matters with a concrete example: LROC NAC DTMs report 1.5 m horizontal accuracy relative to the LOLA reference frame, but LOLA itself carries an estimated reference-frame uncertainty of approximately 20 m, so the total error a data user should consider is closer to 21.5 m than to 1.5 m. Where a product's reported accuracy varies within a single reference frame — for example, across mission phases or observation geometries — we recommend classifying it by its typical reported figure, with the worst-case figure noted alongside; dual classification, as applied to ULCN2005 in Section 4, is reserved for the materially different case where the same product has been assessed against two distinct named reference frames. Formal reference-frame work for the Moon is itself advancing: a 2026 International Association of Geodesy/International Astronomical Union (IAG/IAU) Joint Working Group

report (Fienga, 2026) proposes a first realization of an International Lunar Reference Frame, ILuRF2026. As that or a similar formal frame matures and is adopted, it could serve as an even more rigorous stated reference than the LOLA proxy used throughout Section 4, without requiring any change to the PCN classification structure itself; the requirement is a named reference, not a specific one.

4. Demonstration: Applying the PCN Classes to Published Control Networks

We apply the PCN classes to eight control-network products spanning the Moon, Mars, and the Galilean satellites, drawn entirely from primary sources, to test whether the classification meaningfully discriminates between products currently reported with no common accuracy vocabulary. Table 2 summarizes the results.

Control network	Era	Reported horizontal accuracy	Reference basis	PCN class
RAND Galilean-satellite networks (Davies et al., 1979)	1979	Not reported; only internal image-plane residuals (0.021–0.032 mm) and radial (vertical) uncertainties (± 5 –10 km) were published	Internal (photogrammetric) only	PCN-5u
Galileo-updated Io network (Davies et al., 1998)	1998	≈ 4.4 km mean; individual point range 2.97–16.9 km	Internal solution (Voyager + Galileo)	PCN-5r
Unified Lunar Control Network 2005 (Archinal et al., 2006)	2006	Few hundred m typical; ≤ 5.1 km worst-case (3σ); later found several km from LOLA (Wagner et al., 2024)	Internal solution; absolute tie later superseded	PCN-4 (nominal); PCN-5r (vs. current LOLA frame)
Mars Digital Image Model 2.1 (Archinal et al., 2004)	2004	≈ 250 m horizontal (authors' estimate)	Tied to MOLA	PCN-4
Lunar South Pole network (Edmundson et al., 2012)	2012	Not independently reported; only 37 of 527,756 points tied in all coordinates to an LOLA-derived DTM	Internal (bulk); minimal absolute tie	PCN-5u (network); dense internally
Uncontrolled LROC NAC images (Wagner et al., 2024)	2024	≈ 35 m typical; up to 200 m without corrected pointing kernels	Spacecraft position/pointing only	PCN-3
Regional absolutely-controlled LRO NAC (Bland et al., 2026b)	2026	No accuracy against a reference frame reported; only bundle-adjustment point residuals < 0.6 px (99th percentile, $\approx < 0.3$ m at 0.5 m/pixel) and $\sigma_0 < 0.18$	Tied to LOLA ($\approx 4,000$ ties); fit residuals only	PCN-5u (internal fit ≈ 0.3 m)
Controlled LROC NAC DTMs (Wagner et al., 2024)	2024	< 10 m horizontal; 90th-percentile offsets 5.1–5.6 m	Tied to LOLA (+ ≈ 20 m LOLA frame uncertainty; Laura & Beyer 2021)	PCN-2

Table 2. Application of the proposed PCN classes to eight published planetary control-network products, 1979–2026, using only horizontal accuracy figures reported in the cited primary sources, exactly as reported. Table 3 normalizes the subset of these figures for which a 95%-equivalent bound can be derived. PCN-5r and PCN-5u denote the reported (> 1 km) and unreported sub-designations proposed in Section 5.

The underlying figures in Table 2 are not originally reported at a uniform confidence level, while Table 1's boundaries, following the FGDC convention, are defined at 95%. Where the source data permit, we

normalize each figure to a 95%-equivalent bound under an isotropic circular Gaussian (Rayleigh) error model — the same model conventionally used to convert between circular error probable (CEP), distance root mean square (DRMS), and twice-DRMS (2DRMS) measures in positioning accuracy reporting. For an isotropic 2D Gaussian error with per-axis standard deviation σ , the radial positional error R follows a Rayleigh distribution. Writing $p \in (0,1)$ for a confidence level (for example $p = 0.95$ for 95% confidence) and r_p for the radius satisfying $P(R \leq r_p) = p$, this radius is given by

$$r_p = \sigma \sqrt{-2 \ln(1 - p)} \quad (1)$$

so that a standard deviation can be recovered from a stated percentile bound,

$$\sigma = r_p / \sqrt{-2 \ln(1 - p)} \quad (2)$$

or, for a bound stated as an n -sigma radial distance — as for ULCN2005's three-sigma figure, where the reported bound equals $n\sigma$ —

$$\sigma = r_{n\sigma} / n \quad (3)$$

and the 95%-equivalent bound follows by substituting σ back into Equation (1) at $p = 0.95$. We write this bound as r_{95} , shorthand for r_p at $p = 0.95$:

$$r_{95} = \sigma \sqrt{-2 \ln(0.05)} = 2.448\sigma \quad (4)$$

Table 3 applies Equations (1)–(4) to the three Table 2 products whose reported figures carry sufficient distributional information to convert.

Product	Reported basis	Reported value	95%-equivalent
Unified Lunar Control Network 2005 (Archinal et al., 2006)	3σ radial bound (Eq. 3)	5.1 km	≈ 4.16 km
Controlled LROC NAC DTMs (Wagner et al., 2024)	90th percentile (Eq. 2)	5.1–5.6 m	≈ 5.8 – 6.4 m
Uncontrolled LROC NAC, pointing-corrected (Wagner et al., 2024)	95th percentile (reported directly; no conversion needed)	—	12.5 / 26.9 / 50.6 m by mission phase

Table 3. 95%-equivalent horizontal accuracy for the three Table 2 products whose reported figures carry sufficient distributional information, computed via Equations (1)–(4) under an isotropic circular Gaussian error model. The pointing-corrected uncontrolled-LROC-NAC figures here are Wagner et al.'s (2024) mission-phase 95th-percentile values with corrected pointing kernels; Table 2's separate 200 m worst-case figure covers uncorrected pointing and is not part of this comparison. The remaining five Table 2 products — the RAND-era networks, the Galileo-updated Io solution, MDIM 2.1, the Lunar South Pole network, and the regional controlled LRO NAC product — report no percentile of positional accuracy or an ambiguous statistic (Davies et al.'s 1998 "standard deviation" does not specify whether it is a per-axis or radial quantity) and are not converted; assuming a distribution for figures that do not state one would substitute an unstated assumption for the reporting gap this paper diagnoses, not resolve it. The regional controlled LRO NAC product (Bland et al., 2026b) reports only fit residuals at a 99th percentile; a residual is not an accuracy against a reference frame and is therefore not converted.

Applying Equation (3) to ULCN2005's three-sigma radial bound of 5.1 km gives $\sigma \approx 1.70$ km and a 95%-equivalent bound of approximately 4.16 km — smaller than the reported worst case, but the more directly comparable figure against Table 1's own 95% convention, and still roughly four times the 1 km PCN-

4/PCN-5 boundary. We note in passing that a three-sigma radial bound corresponds to approximately 98.9% coverage under this model, not the 99.7% sometimes assumed from one-dimensional normal-distribution convention; the two are frequently conflated but are not the same quantity. None of the three conversions in Table 3 change which PCN class its product occupies, which is expected since the underlying reported figures were already unambiguous with respect to Table 1's order-of-magnitude boundaries; the value of the normalization is comparability at the stated confidence level, not a different classification outcome.

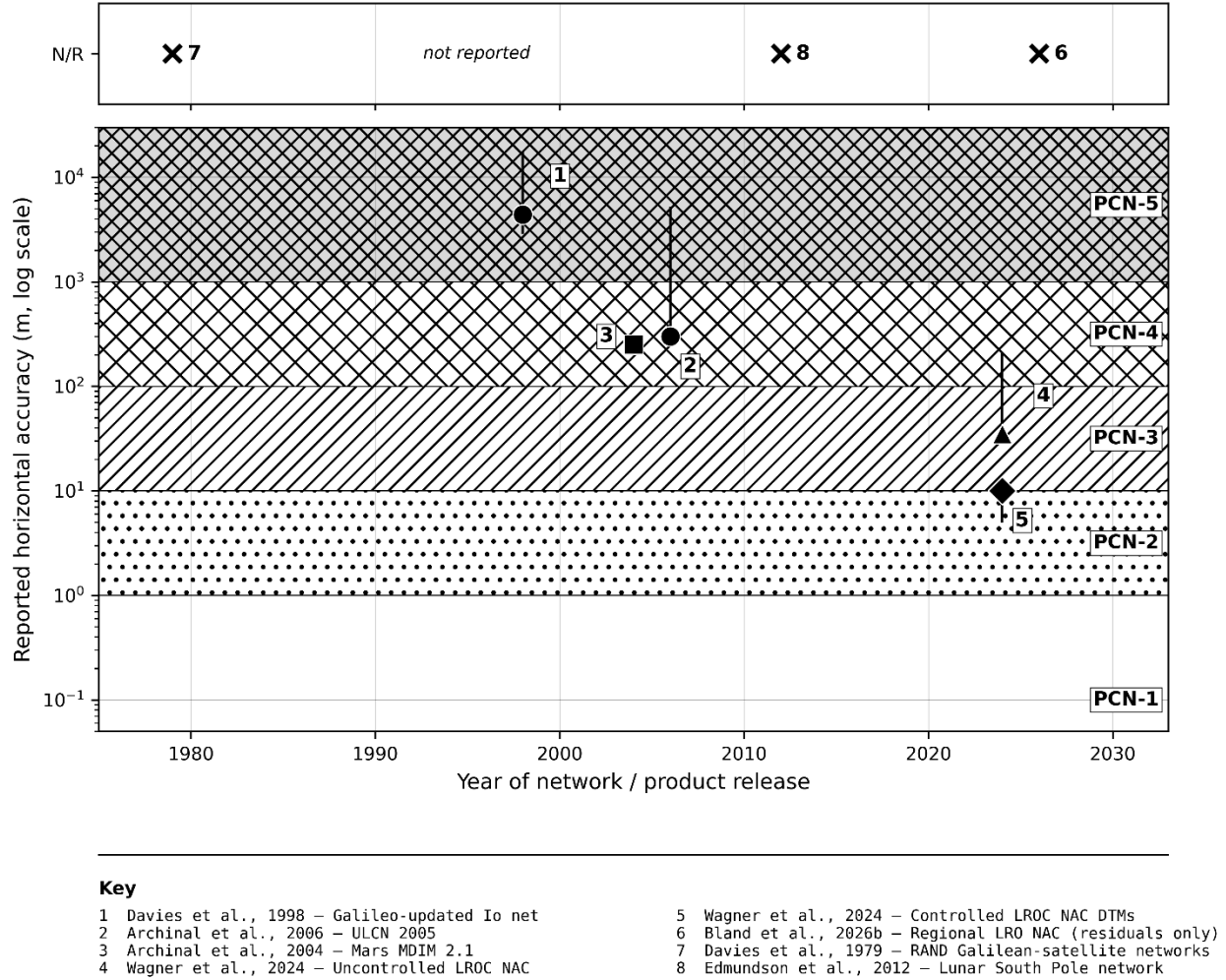


Fig. 1. Reported horizontal accuracy of the eight control-network products in Table 2, plotted by year of release against the proposed PCN classes (shaded bands use a grayscale, ASCII hatch-pattern key rather than color, with density increasing from PCN-1, plain, to PCN-5, densest crosshatch, so the ordering survives black-and-white reproduction). Numbered markers: 1 Davies et al. (1998); 2 Archinal et al. (2006); 3 Archinal et al. (2004); 4 Wagner et al. (2024), uncontrolled LROC NAC; 5 Wagner et al. (2024), controlled LROC NAC DTMs. Vertical bars span each product's reported typical-to-worst-case range. Networks 6 (Bland et al., 2026b; fit residuals only), 7 (Davies et al., 1979) and 8 (Edmundson et al., 2012) report no horizontal accuracy against a stated reference frame and are shown separately in the upper (N/R, not reported) panel, positioned at their release year but with no accuracy value assigned, rather than plotted with an invented one. The PCN-1 band is unpopulated.

Figure 1 makes the resulting span visible at a glance. The 1979 RAND control networks for the Galilean satellites (Davies et al., 1979) published internal image-plane measurement precision (0.021–0.032 mm)

and radial (vertical) uncertainties ($\pm 5\text{--}10$ km) but no horizontal ground-position accuracy at all, placing them in PCN-5 by definition — not because the network is poor, but because the reported quantities do not permit a horizontal-accuracy classification to be assigned. The subsequent Galileo-updated solution for Io (Davies et al., 1998) does publish individual point-position standard deviations, averaging approximately 4.4 km, which places it in PCN-5 on reported evidence — a genuine multi-kilometer horizontal uncertainty, not merely an unreported one.

The Unified Lunar Control Network 2005 (Archinal et al., 2006), at the time described by its authors as the largest planetary control network yet completed, illustrates the necessity of naming a reference frame explicitly. Its own solution statistics imply a horizontal accuracy in the low hundreds of meters, with a worst-case three-sigma bound of 5.1 km — equivalently, per Table 3, approximately 4.16 km at 95% confidence — nominally PCN-4 on its typical figure, following the convention of Section 3, although that worst-case bound alone would fall in PCN-5. But Wagner et al. (2024), citing subsequent comparison work, report that ULCN2005 can diverge from the modern LOLA reference frame by several kilometers. The same network is therefore PCN-4 relative to its own internal solution and effectively PCN-5 relative to the reference frame in common use today — precisely the ambiguity a stated-reference requirement is intended to prevent. Applying that rule resolves the apparent contradiction rather than leaving it open: because LOLA, not ULCN2005's own internal solution, is the reference frame in current community use, ULCN2005 should be catalogued as PCN-5 relative to LOLA, with its PCN-4 internal figure reported only alongside that name, not in place of it.

At the accurate end of the span, LROC NAC DTMs (Wagner et al., 2024), with horizontal offsets against LOLA below 10 m (90th-percentile offsets of 5.1–5.6 m, or $\approx 5.8\text{--}6.4$ m at 95% confidence, Table 3), meet PCN-2; they are the most accurate products in Table 2 for which an accuracy against a named reference frame is actually reported. Bland et al.'s (2026b) regional, absolutely controlled LRO NAC image sets, tied to LOLA across single regions exceeding one million square kilometers at 0.5 m/pixel, report point residuals below 0.6 pixels at the 99th percentile. This describes how well the adjusted network fits its own control, a local-accuracy statistic, not an accuracy against LOLA, so under the network-accuracy criterion of Section 3 the product is classed PCN-5u until an independent check-point comparison is published. The distinction matters: independent assessments of controlled NAC mosaics produced by the LROC team, made against overlapping NAC images rather than against the fitted control, find median positional errors of <12 m in latitude and <5 m in longitude and 95th-percentile errors of up to 42 m in latitude (Collins et al., 2026a), and LOLA itself carries a reference-frame uncertainty of the order of 20 m (Laura and Beyer, 2021). Between these extremes, Mars MDIM 2.1 (Archinal et al., 2004), tied to MOLA data with an authors'-estimated horizontal accuracy near 250 m, meets PCN-4, and uncontrolled LROC NAC images, with typical accuracies near 35 m (Wagner et al., 2024), meet PCN-3.

Across eight products and forty-seven years, reported horizontal accuracies span roughly three orders of magnitude, from about 6 m to about 4 km at 95% confidence, and three of the eight products report no horizontal accuracy against a stated reference frame at all. No existing framework is available to state where any one product sits relative to another without consulting each primary source individually. No product in Table 2 currently reports a network accuracy in PCN-1; the class is retained because landed and rover-scale operations require it (Table 1) and because only five lunar ground control points are known at meter level (Wagner et al., 2024), which limits how such accuracy can currently be demonstrated. This gap persists even as methodological tooling advances: automated frameworks for constructing and thinning large-scale planetary control networks (Ma et al., 2024) improve processing efficiency for exactly the kind of massive,

modern networks summarized in Table 2, but do not themselves propose an accuracy classification — reinforcing that the absence of a fitness-for-use standard is a reporting gap, not a tooling limitation. Quality-control workflows for large-scale planetary bundle adjustment (Geng et al., 2026) likewise address how a network is built and checked rather than how the accuracy of the resulting network is classified for comparison across products.

5. Discussion

The gap the PCN classes address is not merely unnoticed; it is explicitly out of scope for the planetary community's most directly relevant existing framework. Laura and Beyer (2021), whose "spatial efficacy" concept for foundational planetary data products is the closest existing analogue to a fitness-for-use classification in this domain, state directly that control networks "are not foundational data products" under their scheme, classifying them instead as a by-product of foundational products. An earlier framework had listed geodetic control among the foundational products (Laura et al., 2018); Laura and Beyer (2021) refined this to geodetic coordinate reference frames and treated control networks as by-products. Consistent with this scope decision, their own knowledge-inventory tables report unknown ("?") accuracy for control networks covering Ariel, Umbriel, Titania, Oberon, and Miranda, and partially unknown accuracy for Triton and Phobos. The PCN classification is intended to fill precisely this explicitly acknowledged, currently unaddressed scope.

A related, narrower precedent exists for a different product type: Collins et al. (2026b) developed a numbered accuracy-categorization scheme for USGS-produced Kaguya Terrain Camera digital terrain models, ranking each product 1–5 across several internal quality metrics. That scheme addresses a single DTM product line rather than control networks, and its thresholds were set from internal tolerances specific to that product rather than derived to be portable across missions or bodies; we note it here as the closest existing precedent for numbered accuracy categorization of a planetary geodetic data product, distinct in both scope and portability from the cross-network, reference-frame-anchored classification proposed here. Qualitative control-status labels (controlled, semi-controlled, uncontrolled) are also in use (Laura and Beyer, 2021; Stickle et al., 2021), and the joint Lunar Exploration Analysis Group (LEAG) and MAPSIT Lunar Critical Data Products report calls for accuracy, precision, fitness for use and level of control to be "clearly and consistently defined" (Stickle et al., 2021). The PCN classes are a numeric complement to that vocabulary, not a replacement: control status records how a product was made, whereas the PCN class states how accurate it is against a named reference frame. The same report notes that the absolute uncertainty of a controlled product is tied to that of the dataset used as control (Stickle et al., 2021), which is the principle behind the stated-reference requirement of Section 3.

The PCN classes are complementary to, not competing with, contemporaneous description-standard efforts. Bland et al. (2026a) recommend that Europa spatial data accuracy be described using the ISO 19157:2013 geographic-information data-quality framework — a metadata and reporting standard specifying how accuracy should be documented. The PCN classes address a different, prior question: what numeric class a given accuracy value falls into, so that two independently documented products can be compared without a domain expert re-deriving the comparison each time. A control network's ISO 19157 accuracy description and its PCN class are both necessary and serve different purposes. Realizing the PCN classes' stated goal, however, requires more than defining the taxonomy conceptually; it requires somewhere consistent to record it. We recommend PCN class be encoded as a discrete metadata field alongside existing description

standards — for example within an ISO 19115/19157 data-quality element, a SpatioTemporal Asset Catalog (STAC) property, or a Planetary Data System (PDS4) label attribute — so that the classification travels with a product's existing metadata rather than depending on authors remembering to state it in prose.

We acknowledge four limitations. First, five classes are coarse relative to the FGDC's original thirteen; we consider this an intentional simplification appropriate to the planetary domain's presently sparse and heterogeneous accuracy reporting, not a claim that five classes are optimal in the long term. Second, the PCN-5 class conflates "greater than 1 km" with "not reported" — two materially different situations, as the RAND-era and Galileo-updated Io examples in Table 2 illustrate. We retain this conflation deliberately: a network with no reported horizontal accuracy and a network with a documented multi-kilometer uncertainty present the same practical hazard to a downstream user attempting quantitative cross-product analysis, even though the underlying cause differs. This is not a distant concern: four of the eight products in Table 2, half, fall into PCN-5 on their own reported figures, and three of those four are there solely because no horizontal accuracy against a reference frame was published, not because the underlying network is necessarily poor. Pending formal community revision, we suggest an immediate, low-cost interim fix any user of the classification can adopt now: appending a lower-case "r" (reported, greater than 1 km) or "u" (unreported) suffix to a PCN-5 assignment. Formal splitting into separate classes, ideally through a community process analogous to the Mapping and Planetary Spatial Infrastructure Team's (MAPSIT) existing coordination role, remains the long-term goal; the 2026 COSPAR Scientific Assembly's inaugural session on planetary geologic mapping and geodesy (COSPAR, 2026) suggests the community context for such a process now exists.

Third, one of the eight demonstration products in Table 2 (Bland et al., 2026b) is a current conference abstract rather than a peer-reviewed journal article; we include it because it is the most recent and most directly relevant regional product available at the time of writing, but its classification here should be treated as provisional pending peer-reviewed publication. Fourth, the demonstration set concentrates heavily on the Moon and Mars, with the Galilean satellites as the only outer-solar-system representation; Venus, Mercury, small bodies, and the outer planets beyond Io currently have no entry in Table 2. This reflects which control networks presently report enough information to classify, not a judgment that the PCN framework applies only to these bodies; extending the demonstration as more small-body and outer-planet control networks report horizontal accuracy is a direct and necessary next step before the classification's generality to "planetary" control networks, rather than specifically lunar and Martian ones, can be considered demonstrated rather than proposed.

6. Conclusion

Planetary control networks currently report accuracy, when they report it at all, in incompatible units against unstated or inconsistent reference frames. We have adapted the FGDC's terrestrial geodetic network accuracy classification into a five-class Planetary Control Network (PCN) scheme and applied it to eight published lunar, Martian, and Galilean-satellite control networks spanning forty-seven years, drawn entirely from primary sources. The exercise both demonstrates that the classification discriminates meaningfully between real products and confirms, independently of our own literature search, that the gap is one the planetary spatial-data community has already identified but explicitly left unaddressed. We offer the PCN classes as a lightweight, adoptable reporting convention — not a new measurement standard — intended to let two independently produced control networks be compared at a glance.

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