

The Vera C. Rubin Observatory Data Preview 2

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ABSTRACT

We present an early version of Rubin Data Preview 2 (DP2), the second data preview from the National Science Foundation–Department of Energy Vera C. Rubin Observatory. **Early Data Preview 2 (EDP2)** comprises coadds, detection catalogs, and ancillary data products; eventually, the full DP2 will also include single-epoch images and difference images. DP2 is derived from observations acquired by the LSST Science Camera (LSSTCam) on the Simonyi Survey Telescope at the Summit Facility on Cerro Pachón, Chile, primarily during the on-sky commissioning campaign between 2025-04-16 and 2025-09-21, supplemented by observations taken between 2025-10-25 and 2026-01-06 that overlap the commissioning footprint. The DP2 footprint comprises the Science Validation wide-area survey, five Deep Drilling Fields, and a number of targeted small-field regions, including Trifid and Lagoon, Prawn, M49, and New Horizons, all observed as part of the Rubin First Look campaign. Each field was imaged in up to six broad photometric bands, *ugrizy*, and coadded to produce deep imaging covering an estimated 3,000 deg². The addition of single-visit-only areas expands the total DP2 footprint to an estimated 15,000 deg², with coverage in at least one filter. The median per-visit PSF FWHM across the wide-area survey ranges from 1.17 arcsec in the *z* band to 1.26 arcsec in *g* and *r* bands, with the sharpest fields reaching $\sim 0''.0$. COSMOS, the deepest field, reaches estimated coadded 5σ

depths of $u=26$ mag, $g=26.8$ mag, $r=26.3$ mag, $i=26.1$ mag, $z=25.3$ mag, $y=23.9$ mag. DP2 contains X distinct astrophysical objects, of which X are extended in at least one band in coadds, and X solar system objects, of which X are new discoveries. DP2 is approximately 59.15 TB in size and is available to Vera C. Rubin Observatory data rights holders via the Rubin Science Platform, a cloud-based environment for the analysis of petascale astronomical data. Based on a roughly five-month primary observing baseline and covering only part of the eventual LSST footprint, DP2’s area, depth, and multiband coverage nonetheless support a broad range of early science investigations ahead of LSST Data Release 1.

Keywords: Rubin Observatory - LSST

1. INTRODUCTION

The National Science Foundation (NSF)–Department of Energy (DOE) Vera C. Rubin Observatory is a ground-based, wide-field optical-near-infrared facility on Cerro Pachón in northern Chile, built to carry out the Legacy Survey of Space and Time (LSST) (Ivezić et al. 2019). The observatory is named in honor of Vera C. Rubin, whose observations in the latter half of the 20th century established the first compelling empirical case for dark matter (Rubin & Ford 1970; Rubin et al. 1980). Its 10-yr survey will image the entire visible southern sky every 3–4 nights, reaching a coadded depth of ~ 27 mag in the r -band across an $18,000 \text{ deg}^2$ footprint (Bianco et al. 2022).

At the heart of the facility is the 3.2 gigapixels-gigapixel LSST Science Camera (LSSTCam), mounted on the 8.4 m (6.5 m effective aperture) Simonyi Survey Telescope (Stalder et al. 2024). Together they deliver an instantaneous field of view of 9.6 deg^2 in six broadband filters, *ugrizy* (320–1050 nm), with seeing-limited image quality. The system’s étendue of $319 \text{ deg}^2 \text{ m}^2$ exceeds that of any previous optical facility by over an order of magnitude, enabling the rapid, deep, all-sky cadence that underpins Rubin’s four core science themes: the nature of dark energy and dark matter; a census of the solar system; the transient and variable optical sky; and the structure of the Milky Way (Ivezić et al. 2019). An automated Data Management System processes tens of terabytes of images per night to produce science-ready data products within minutes of each observation for a global community of scientists.

This paper presents Rubin’s third Data Preview, Data Preview 2 (DP2) (NSF-DOE Vera C. Rubin Observatory 2025), and the first to be based entirely on LSSTCam data. It marks the conclusion of the Rubin commissioning program and the transition to full survey operations. DP2 is a reprocessing of all science-grade exposures acquired with LSSTCam during on-sky commissioning and the initial phase of early operations, prior to the formal start of the LSST on 2026-06-29. As such, it represents a

natural boundary and provides a comprehensive dataset that captures the on-sky performance of the as-built system at the end of the Rubin construction project.

Two earlier Data Previews preceded DP2 as part of the Rubin Early Science Program (Guy et al. 2026), established to provide the community with early access to data products and services needed to produce high-impact science during the period spanning commissioning through the first Data Release. Data Preview 0 (DP0) was based on simulated LSST-like data (LSST Dark Energy Science Collaboration (LSST DESC) et al. 2021) and served primarily to stand up early versions of the Rubin Science Platform (RSP) and prepare the community for data access at scale. Data Preview 1 (DP1) (NSF-DOE Vera C. Rubin Observatory 2025) delivered the first data products derived from on-sky observations using science-grade exposures acquired with Rubin Commissioning Camera (LSSTComCam) (Stalder et al. 2022, 2020; Howard et al. 2018; SLAC National Accelerator Laboratory & NSF-DOE Vera C. Rubin Observatory 2024); a 144-megapixel, single-raft instrument used during early commissioning prior to the installation of LSSTCam on the Simonyi Survey Telescope. DP2 supersedes both in scope, fidelity, and scientific depth.

DP2 contains X science-grade exposures acquired over 158 nights between 2025-04-16 and 2025-09-21, covering a total sky area of $\sim 15 \text{ deg}^2$ across X fields. The data products include raw and calibrated single-epoch images, coadded images, difference images, source detection catalogs, and a range of derived data products. The release totals approximately 59.15 TB and contains around X distinct astronomical objects. Full release documentation is available at <https://dp2.lsst.io>.

Because DP2 is drawn from a commissioning and early-operations data rather than from the more uniform and systematic LSST, its images and derived products reflect a system that was still being commissioned and tuned. LSSTCam’s greater scale and complexity relative to LSSTComCam introduced systematics with no direct counterpart in DP1. For much of the campaign

the [Active Optics System \(AOS\)](#) closed loop converged on a slightly mis-calibrated focus target, imprinting a spatially varying defocus across the focal plane that was only corrected on sky in December 2025 and that remains visible in the point-spread function (PSF) of a large fraction of [DP2](#) exposures. Delivered image quality and PSF ellipticity did not consistently meet [LSST](#) design requirements in wide-area survey-mode observations by the close of commissioning; and stray- and scattered-light artifacts, sky-background systematics in crowded fields, and a chromatic PSF dependence²⁰ were identified and only partially mitigated in [DP2](#) processing. These effects, their diagnosis, and the mitigations applied are described in §2 and §5.

Unlike the systematic, rolling revisit pattern that will characterize the [LSST](#), [DP2](#)’s observing cadence is opportunistic: fields and filters were prioritized to serve [AOS](#) and Science Pipelines commissioning rather than to build a representative time series. The Science Validation survey footprint was repeatedly re-scoped over the course of the science validation campaign due to the competing demands of engineering tests and filter availability, which was constrained by hardware issues for part of the campaign. Visit counts and time sampling therefore vary substantially and idiosyncratically from field to field, and [DP2](#) should not be read as a preview of [LSST](#)’s eventual survey cadence, revisit statistics, or depth-accumulation pattern.

[DP2](#) is being delivered in two phases across the Jul–Dec 2026 window. The first phase, Early [DP2](#) (EDP2), comprises the deep coadd images and all associated catalogs, including new cell-based coadds and the first releases of the Object Shear (§??) shape-measurement catalog and the Isolated Star Stellar Motions catalog (§??). EDP2 is targeted for 2026-07-27. The second phase, [DP2](#), adds the visit-level single-epoch and difference images, completing the full release, and is expected in the Oct–Dec 2026 range. Data products delivered as [EDP2](#) will be incorporated into [DP2](#) unchanged, without additional reprocessing ([Guy et al. 2026](#)). This phased delivery follows directly from Rubin’s hybrid cloud architecture ([O’Mullane et al. 2024](#)), in which science data products are stored at the [United States Data Facility \(USDF\)](#) and served to users via the [US Data Access Center \(DAC\)](#) in Google Cloud. Deep coadd images and catalogs are hosted directly in Google Cloud and are therefore unaffected by hybrid-cloud readiness, allowing them to ship as [EDP2](#). Visit-level images, however, must be streamed from the [USDF](#), and the necessary capacity is

not yet fully in place, introducing timing uncertainty for the second phase. Delivery of the Prompt Data Products follows the same logic. The [Prompt Products DataBase \(PPDB\)](#), Rubin’s real-time catalog of transient, variable, and moving-object detections, does not depend on [USDF](#)–Google Cloud bandwidth and is therefore prioritized as the second Early-Operations delivery milestone, following EDP2 and preceding the full [DP2](#) release, expected in the Sep–Oct 2026 range. Prompt images (raw images, Processed Visit Images, and difference images), which do require that bandwidth, have been deprioritized relative to EDP2 and the [PPDB](#) and are expected to become available only in the Oct–Dec 2026 range, following both.

[DP2](#), like all Rubin Data Previews and Data Releases, is subject to a 2 yr proprietary period; during this time access is restricted to [LSST](#) data rights holders ([Blum & the Rubin Operations Team 2020](#)) via the [RSP](#) ([Jurić et al. 2019](#)), Rubin’s cloud-based data science platform ([Jurić et al. 2019](#)). After the proprietary period, [DP2](#) will be made public, though access through Rubin [DACs](#) in the US and Chile will remain limited to data rights holders ([Blum & the Rubin Operations Team 2020](#)). Alternative public access mechanisms have not yet been finalized.

The structure of this paper is as follows. Section 2 describes the observatory system and its status at the close of commissioning, the fields included in [DP2](#), and the observing strategy employed. Section 3 summarizes the data products in the release. The processing pipelines are described in Section 4, followed by data validation and performance characterization in Section 5. Section 6 describes the [RSP](#). Section 7 outlines Rubin’s community support model. A summary and outlook toward the start of formal [LSST](#) Data Releases is given in Section 8.

All magnitudes are quoted in the AB system ([Oke & Gunn 1983](#)) unless otherwise specified.

2. COMMISSIONING WITH LSSTCAM

3. OVERVIEW OF THE CONTENTS OF RUBIN [DP2](#)

4. DATA RELEASE PROCESSING

Data Release Processing (DRP) is the data pipeline that produces the calibrated images, detection catalogs, and derived data products defined in section §TBD, using the [LSST](#) Science Pipelines (citation). [DP2](#) was processed at the [United States Data Facility \(USDF\)](#) at SLAC, with pilot runs at the National Institute of Nuclear and Particle Physics (IN2P3) computing center.

The processing campaign consists of four major stages: (1) single-frame processing, (2) calibration, (3) multi-visit processing, (4) variable and transient source pro-

²⁰ [LSSTCam](#) has no atmospheric dispersion corrector

cessing. Data quality and key metrics for verification and validation are actively monitored during each stage, and comprehensive verification and validation assessments are completed before processing the next stage.

This section describes the high-level algorithms, configurations, and verification metrics for each stage, including changes and improvements from DP1 (citation).

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4.1. *Single-Visit Processing*

4.1.1. *Calibration & Instrument Signature Removal (ISR)*

4.1.2. *Background Subtraction*

Background subtraction in `CalibrateImageTask` estimates and removes large-scale background signals from science imaging prior to source detection and measurement. Such signals include sky brightness from airglow, moonlight, scattered light, zodiacal light, and diffuse astrophysical emission. The background is estimated twice: an initial model (`psf_subtract_background`) is subtracted before PSF characterization, and a second model (`star_background`) is fit on the updated source-masked image before the final detection pass. Each post-ISR image is divided into 128×128 pixel superpixels, and the iterative 3σ -clipped mean of unmasked pixels in each bin is fit with a sixth-order two-dimensional Chebyshev polynomial, evaluated at native pixel resolution via Akima spline interpolation. Before fitting `star_background`, the DETECTED mask plane is dilated by up to 10 pixels to suppress source-wing flux from leaking into background bins. After `star_background` subtraction, a zeroth-order pedestal correction is estimated iteratively over bin sizes starting at 32×32 pixels, doubling each step until the cumulative pedestal level changes by less than 5% or 0.5 counts between steps. The `star_background` model and pedestal corrections together constitute the output

background model (`preliminary_visit_image_background`; see Figure 1).

Compared to DP1 (?), several changes were made to background subtraction for DP2. The inline re-estimation performed after each detection pass in DP1 (`reEstimateBackground = True`) has been replaced by the dedicated `star_background` subtask. In addition to source mask dilation and a pedestal correction, other new features for DP2 include adaptive threshold determination and diffraction spike masking. The per-step illumination correction used in DP1 has been disabled for DP2. Following background subtraction, the median and standard deviation of all unmasked pixels and of *sky source* fluxes are recorded in the task metadata as diagnostics of background subtraction quality.

4.2. *Calibration*

4.2.1. *PSF Modeling*

PSF modeling in DP2 uses two distinct approaches, as described in the (Rubin Observatory Science Pipelines Developers 2025) and it is similar to what was originally described in DP1. The first model—faster but less precise—is fit with PSFEx (Bertin 2011), while the final model—slower yet more accurate—is fit with Piff (Jarvis et al. 2021). Broadly speaking, PSFEx and Piff both represent the PSF on a pixel basis and interpolate its parameters across a single CCD using two-dimensional polynomials. However, their technical implementations differ (see Bertin et al. and Jarvis et al. 2021 for more details). Previous comparisons have shown that Piff outperforms PSFEx by delivering an unbiased reconstruction of the PSF size (see Zuntz et al. 2018 and Jarvis et al. 2021), can work in sky coordinates like in Schutt et al. 2025, can include a color dependency like in Schutt et al. 2025, and is supporting alternative models and interpolation schemes (see Schutt et al. 2025 for more details).

In the initial PSF modeling pass, PSFEx is run with a pixel basis and a second-order polynomial interpolation on each CCD. For the final modeling, Piff uses its PixelGrid with a fourth-order polynomial interpolation per CCD—except in the u-band, where star counts are too low to constrain a fourth-order fit, so a second-order polynomial is used instead. Both are working in pixel coordinates. Choices of polynomial order, overall PSF-modeling performance, and known issues are discussed in Section “Performance and Known Issues for PSF.”

4.2.2. *Astrometric Calibration*

The final astrometric calibration of the data follows the method in DP1, but with some key additions. As described in DP1, a joint calibration is performed on all

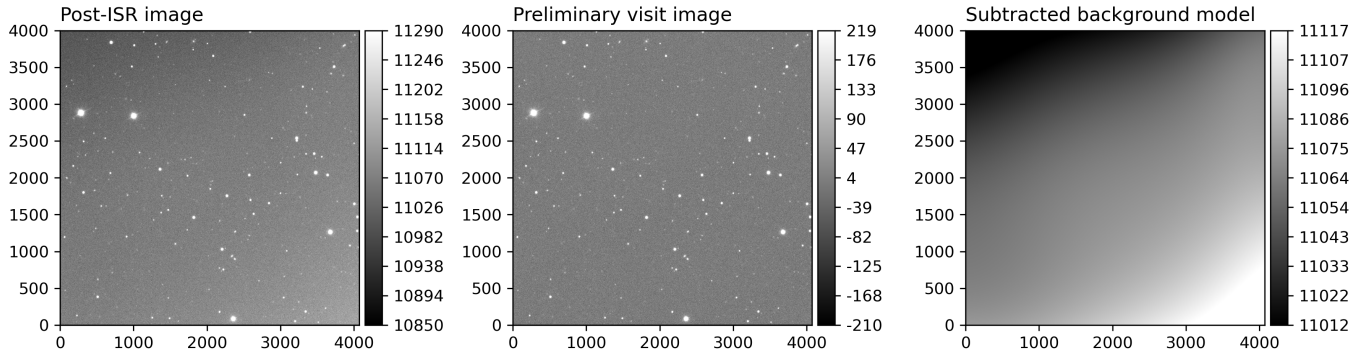


Figure 1. Background subtraction for LSSTCam visit 2025110500300, detector 25. *Left:* Post-ISR image (`post_isr_image`), before any background removal. *Center:* Preliminary visit image (`preliminary_visit_image`), after background subtraction by `CalibrateImageTask`. *Right:* The subtracted background model (`preliminary_visit_image_background`), illustrating the large-scale structure removed. All three panels use a linear stretch clipped to the central 95th percentile of pixel values.

visits in a given band overlapping a given area. By associating all the isolated point sources shared among the overlapping visits, we can refine the astrometric solution beyond the level achieved in single-frame processing using only a reference catalog.

Unlike in DP1, the area we use for individual fits of the astrometric solution is an order-3 healpix, instead of a tract. This is done to reduce repetitive calculations, since the small size of tracts compared to the LSSTCam field of view means that neighboring tracts often share identical overlapping visits, which would lead to doing many identical fits of the astrometric calibration.

As in DP1, the astrometric model consists of a static map from pixel space to an intermediate frame, which is followed by a per-visit map from the intermediate frame to the plane tangent to the telescope boresight, and finally a deterministic mapping from the tangent plane to the sky. This is done by the `gbdes` package (Bernstein et al. 2017), as described in Saunders (2024). The proper motion and parallax of the objects used in the calibration are fit as part of the solution, but we do not yet include differential chromatic refraction or lateral color. These will be included in future data releases during Rubin Operations.

The main difference from the DP1 astrometric calibration is an additional step that models the effect of atmospheric turbulence on the astrometry. The per-visit part of the astrometric model already described captures large-scale variation between visits, which includes some atmospheric effects. However, higher order oscillations are visible in the astrometric residuals, and these can be attributed to atmospheric turbulence (Saunders 2025). As described in Fortino et al. (2021) and Léget et al. (2021), the wave-like astrometric effects caused by turbulence can be modeled by a Gaussian process. In DP2, we do this by taking the astrometric residuals remaining after the `gbdes` fit, grouping them by visit, then mod-

eling them with the Gaussian Process package `treegp`. We then use this Gaussian Processes model to predict the effects of turbulence on a grid. Finally, this grid is turned into a two-dimensional spline that can use the AST component `SplineMap` so that it can be concatenated with the `gbdes` model. By including this model for the higher-order atmospheric turbulence, we achieve a significant improvement in the astrometric calculation, as demonstrated in Section 5.

A corollary product of the `gbdes` astrometric calibration is the catalog of proper motions and parallaxes of the sources used in the calibration. Since the `gbdes` fit is done per-band, and then improved by the turbulence fit, we perform an additional final fit of the proper motion and parallax, using the final astrometric model and all available bands. The resulting catalogs are included in the DP2 data release. These catalogs only include isolated point sources, but future data releases will be extended to include proper motion and parallax for all objects.

4.2.3. Photometric Calibration

Photometric calibration of the DP2 dataset is based on the Forward Global Calibration Method (FGCM Burke et al. 2018) adapted for the LSST Science Pipelines (Aihara et al. 2022; Fagrelus & Rykoff 2025). We used the FGCM to calibrate the full DP2 dataset with a forward model that uses a parameterized model of the atmosphere as a function of airmass along with a model of the instrument throughput as a function of wavelength. The FGCM process typically begins with measurements of the instrumental throughput, including the mirrors, filters, and detectors. For the LSST-Cam filter throughputs, we start with the filter scans provided by the manufacturer, Matecon. These were taken in a grid with 159 positions, at 5 incidence angles from 13.8 to 23 degrees, at a wavelength resolution of 1

nm. We performed an averaging procedure to get the approximate appropriate throughput for the LSSTCam beam as it intersects the filter at the central location of each detector. For the LSSTCam detector quantum efficiency (QE) curves, we start with per-raft measurements of the QE performed at Brookhaven National Laboratory (BNL) and SLAC National Accelerator Laboratory (SLAC) at 10 to 25 wavelength steps. These preliminary scans were then normalized relative to each other at 750 nm. However, there are still some per-raft systematic differences seen, particularly in the u and y bands. In the future we will use the in-dome tunable laser system and the Collimated Beam Projector (CBP) for improved filter and detector throughputs.

The FGCM atmosphere model, provided by MODTRAN (Berk et al. 1999), was used to generate a look-up table for atmospheric throughput as a function of zenith distance at Cerro Pachón. This model accounts for absorption and scattering by molecular constituents of the atmosphere, including O₂ and O₃; absorption by water vapor; and Mie scattering by airborne aerosol particulates. Nightly variations in the atmosphere are modeled by minimizing the variance in repeated observations of stars with an SNR greater than 10, measured using “compensated aperture fluxes.” These fluxes include a local background subtraction to mitigate the impact of background offsets. The model fitting process incorporates all six bands (*ugrizy*) but does not include any gray (achromatic) terms, except for a linear assumption of mirror reflectance degradation and dust accumulation on lenses. Fortunately, there is no evidence of any significant loss of throughput over the 250 days of the DP2 dataset. As an additional constraint on the fit, we use a subset of stars from the Monster reference catalog (Ferguson et al. 2025), primarily to constrain the system’s overall throughput and establish the “absolute” calibration.

4.3. Multi-Visit Processing

4.3.1. Input Data Selection

4.3.2. Coaddition

4.3.3. Detection, Deblending, & Measurement

4.3.4. First Look

4.4. Variable & Transient Source Processing

4.4.1. Difference Image Analysis (DIA)

DP2 difference imaging analysis did not change significantly relative to DP1. DP2 **Difference Image Analysis (DIA)** uses the decorrelated Alard and Lupton image differencing algorithm (Alard & Lupton 1998; Reiss & Lupton 2016). Both positive and negative **DIASources** are detected in the difference image at 5σ . We fit a

dipole model to sources containing both positive and negative peaks, and infer trail parameters from the second moments of the PSF. After rejecting likely artifacts (§4.4.2), we associate **DIASources** into **DIAObjects** with a 1'' matching radius.

4.4.2. Artifact Rejection

DIA analysis is prone to false positives. We employ several layers of artifact rejection, although we err on the side of completeness rather than purity in Data Release Processing.

As in DP1, prior to writing the **DIASource** catalog, we remove sources with pixel flags artifacts, non-astrophysical trail lengths, and unphysically negative direct fluxes. In DP2 we also reject sources that land on the modeled positions of diffraction spikes and apply morphological cosmic ray rejection on both the direct and difference images. Further, we flag but do not remove multiple **DIASources** that occur in a straight line with **glint_trail**, indicating that they may be due to rotating orbital debris (Karpov & Peloton 2022).

We developed a machine-learned reliability score to assess whether **DIASources** were astrophysical. (Acero-Cuellar et al. 2026) provides an overview of the model architecture, training, and performance of the real-bogus model. The v0.1 model used in DP1 was again used during DP2 processing. No cuts were applied on reliability for the DP2 **DIASource** catalogs, so users interested in higher purity should apply a minimum reliability threshold.

4.4.3. Light Curves

4.4.4. Solar System Processing

5. PERFORMANCE CHARACTERIZATION AND KNOWN ISSUES

6. RUBIN SCIENCE PLATFORM

7. SUPPORT FOR COMMUNITY SCIENCE

8. SUMMARY AND FUTURE RELEASES

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Facilities: Rubin:Simonyi (LSSTComCam), Rubin:USDAC

Software: Rubin Data Butler (Jenness et al. 2022), LSST Science Pipelines (Rubin Observatory Science Pipelines Developers 2025), LSST Feature Based Scheduler v3.0 (Jones 2026) Astropy (Astropy Collaboration et al. 2013, 2018, 2022) PIFF (Jarvis et al. 2021), GBDES (Bernstein 2022), Qserv (Wang et al. 2011; Mueller et al. 2025), Slurm, HTCondor, CVMFS, FTS3, ESNet

APPENDIX

Glossary

AOS: Active Optics System.

AURA: Association of Universities for Research in Astronomy.

DAC: Data Access Center.

Data Management System: The computing infrastructure, middleware, and applications that process, store, and enable information extraction from the LSST dataset; the DMS will process petascale data volume, convert raw images into a faithful representation of the universe, and archive the results in a useful form. The infrastructure layer consists of the computing, storage, networking hardware, and system software. The middleware layer handles distributed processing, data access, user interface, and system operations services. The applications layer includes the data pipelines and the science data archives’ products and services.

DIA: Difference Image Analysis.

DOE: Department of Energy.

DP0: Data Preview 0.

DP1: Data Preview 1.

DP2: Data Preview 2.

EDP2: Early Data Preview 2.

LSST: Legacy Survey of Space and Time.

LSSTCam: LSST Science Camera.

LSSTComCam: Rubin Commissioning Camera.

NSF: National Science Foundation.

PPDB: Prompt Products DataBase.

RSP: Rubin Science Platform.

USDF: United States Data Facility.

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