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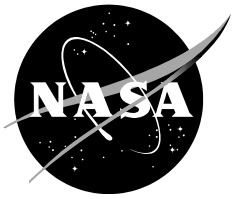

TESS Data Release Notes:
Reprocessing of Sectors 14–19, DR30

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August 5, 2020

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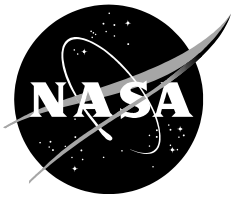

TESS Data Release Notes:
Sector 24, DR30

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Acknowledgements

These Data Release Notes provide information on the processing and export of data from the Transiting Exoplanet Survey Satellite (TESS). The data products included in this data release are full frame images (FFIs), target pixel files, light curve files, collateral pixel files, cotrending basis vectors (CBVs), and Data Validation (DV) reports, time series, and associated xml files.

These data products were generated by the TESS Science Processing Operations Center (SPOC, Jenkins et al., 2016) at NASA Ames Research Center from data collected by the TESS instrument, which is managed by the TESS Payload Operations Center (POC) at Massachusetts Institute of Technology (MIT). The format and content of these data products are documented in the Science Data Products Description Document (SDPDD)[1]. The SPOC science algorithms are based heavily on those of the Kepler Mission science pipeline, and are described in the Kepler Data Processing Handbook (Jenkins, 2019).[2] The Data Validation algorithms are documented in Twicken et al. (2018) and Li et al. (2019). The TESS Instrument Handbook (Vanderspek et al., 2018) contains more information about the TESS instrument design, detector layout, data properties, and mission operations.

The TESS Mission is funded by NASA's Science Mission Directorate.

This report is available in electronic form at
https://archive.stsci.edu/tess/

[1] https://archive.stsci.edu/missions/tess/doc/EXP-TESS-ARC-ICD-TM-0014.pdf
[2] https://archive.stsci.edu/kepler/manuals/KSCI-19081-003-KDPH.pdf

1 Reprocessing and Scope of this Data Release

TESS data release 30 (DR30) provides reprocessed data products of Sector 14 to 19. The updated data products were generated using version 4.0 of the science processing pipeline and conform to the final set of data anomaly flags defined over the last two years of TESS data analysis and pipeline development. A detailed description of the changes in the data products in DR30 is discussed in §2, and a brief list of changes is summarized here:

- The timestamps for 2 minute cadence and FFI data are more accurate. The differences between reprocessed data and previous data releases are less than 2.0 seconds in all cases.
- Photometric apertures were increased in size for targets with Tmag < 11.
- Three new Data Anomaly Flags were added to mitigate the effects of scattered light:
  - Cadences with strong scattered light signals or saturation effects that corrupt the calibration data are flagged and removed from analysis (bit 15, value 16384, "Bad Calibration Exclude").
  - Scattered light data anomaly flags are customized for each target, and flagged automatically based on the local background level (bit 13, value 4096, "Scattered light flag").
  - Cadences with insufficient targets to derive cotrending basis vectors are flagged and the `PDCSAP_FLUX` light curves are set to `NULL` at these times (bit 16, value 32768, "Insufficient Targets for Error Correction Exclude").
- The planet search of the reprocessed light curves produced a different set of TCEs from the original processed data. Although there is a high degree of overlap between the original and reprocessed data (∼83% of targets produced TCEs in common), new TCEs were produced in DR30 and not every TCE from previous data releases was recovered.

2 Detailed Description of Changes

Major changes to the data processing pipeline were detailed in the Data Release Notes[3] for individual sectors. For completeness, these notes have been compiled in this section. As of the time of this writing, Sectors 14–26 have been homogeneously processed using a common code base.

The raw data fed into the SPOC pipeline did not change in reprocessing, and these data are therefore subject to the same jitter patterns and scattered light signals described in the previous data release notes.

[3] https://archive.stsci.edu/tess/tess_drn.html

2.1 Changes to timestamps

The assigned timestamps of both FFIs and 2 minute cadences were modified in the reprocessing. The first complete set of changes was detailed in Sector 20 (DRN27).

The FFI timestamps have been adjusted for the 0.5 second staggered readouts of the four cameras and the 0.02 second staggered readouts for individual CCDs within a camera. In addition, the reported times in previous data releases were too late by 2 seconds. The issue was caused by an off-by-one error in ground system software that identifies the timestamps of individual two-second exposures. In DRN 30, the data product timestamps have been updated and are consistent with the time system of Sector 20 and beyond. Future data releases will include reprocessed data from Sectors 1 to 13 with corrected timestamps.

Two other small adjustments were made to the timestamps. The start times of integrations for every 2 minute and 30 minute cadence were shifted forward by 31 milliseconds, and the end times were shifted forward by 11 milliseconds. These offsets correct for effects in the focal plane electronics that were not accounted for in previous data releases.

2.2 Changes to calibrated data

When scattered light is especially strong, the calibration data can be corrupted and no useful bias and smear correction can be performed. In such cases, the data are flagged and set to `NULL` in the calibrated target pixel files, `SAP_FLUX` light curves, and `PDCSAP_FLUX` light curves (see Sec 2.4). The new flags also cause small changes in the time-averaged row-dependent bias correction (see DRN7), and so the calibrated pixel data in DR30 are different than the calibrated pixel data in previous data release. However, the differences are very small, usually less than 1 electron per second in each pixel.

2.3 Changes to photometric apertures

Different parameters were used to define the photometric apertures of the target stars in DR30. The size of the photometric apertures for targets with Tmag < 11 was increased by a small amount. This change most noticeably affects the light curves of saturated stars, which had higher flux losses during periods of increased pointing jitter. The resulting `SAP_FLUX` light curves are therefore slightly different than previous data releases. The flux fraction in aperture (`FLFRCSAP`) and crowding metric (`CROWDSAP`) have also been updated in DR30.

2.4 Changes to data anomaly flags

2.4.1 New Data Anomaly Flags

New data anomaly flags were introduced in Sector 20 (DRN27) and are used in the reprocessed data, as described below.

Scattered light flags were originally applied to every target on a CCD at a given cadence. However, scattered light caused by the Earth and Moon creates a complicated spatial pattern in the camera, and not every target on a CCD is affected at the same time or to the same degree. In DR30, each individual target now has a unique set of cadences marked with the "Scattered light flag" (bit 13, value 4096). Cadences for a given target are flagged for periods

of time when the measured background rises above the baseline background level by a factor of two and when the measured background exceeds a specified fraction of the target flux (0.25 in this data release).

In DR30, the predicted stray light flag (bit 12, value 2048) is disabled in two minute data products because the scattered light exclude flag (bit 13, value 4096) better identifies cadences affected by scattered light. The predicted stray light flag (bit 12) continues to mark FFIs during times when the Earth/Moon are near the camera FOVs and the image quality may be degraded. We strongly recommend that users inspect the FFI data before removing images marked with bit 12, because this bit is set based on predictions from mission planning and is known to be conservative with respect to the actual image quality.

If the Earth/Moon interference is strong enough to saturate the detector, all targets on a CCD slice will be affected and the data are unusable. Cadences with bad calibrations due to saturation are now explicitly marked with bit 15 (value 16384, "Bad Calibration Exclude"). For some cadences, the majority of targets on a CCD may be flagged for scattered light and not enough valid data remains to derive cotrending basis vectors in PDC. No systematic error correction can be applied at these times. This situation is identified by bit 16 (value 32768, "Insufficient Targets for Error Correction Exclude").

2.4.2 Corrections to Sector 14-16 Manual Exclude Flags

Cadences marked with bit 8 (Manual Exclude) were not marked in Sectors 14, 15, and 16 due to a processing error. All cadences with pointing excursions >7 arcsec ($\sim$0.3 pixel) were flagged for Manual Exclude and are correctly set in the reprocessed data products. For Sectors 17 to 19, there is no difference in the set of Manual Exclude flags. As a reminder, cadences with Manual Exclude flags are ignored by PDC, TPS, and DV for cotrending and transit searches.

2.5 Changes to systematic error corrected light curves

The modifications to the data anomaly flags also changed the cotrended light curves produced by PDC. The reprocessed data have similar quality of cotrended light curves (`PDCSAP_FLUX` light curves) from previous data releases, but make better use of the available data because scattered light flags are marked automatically and are applied target by target. The changes in the data anomaly flags also result in new cotrending basis vectors for each CCD in each sector. The scattered light flags are now only applied to the `PDCSAP_FLUX` light curves. Individual cadences that are lost in the `PDCSAP_FLUX` light curves are available in the `SAP_FLUX` light curves, and astrophysical signals such as transits may still be visible in the `SAP_FLUX` light curve.

2.6 Changes to the transit search and updated TCE lists

Improvements in the cotrended light curves also bolster the ability of TPS to find transits. The new scattered light flags better isolate and remove cadences that are strongly affected by scattered light. Removing cadences affected by scattered light prevents many of the false

positives identified in previous data releases from triggering a TCE in DR30. Figure 1 shows an example of the improvement from Sector 14.

We reran TPS on the reprocessed data, which resulted in a different set of TCEs than was found in previous data releases. Table 1 summarizes the number of targets with TCEs found in the rerun of TPS for each sector, as well as the number of targets with TCEs found in the previous data releases and the number of targets with TCEs in common between the two transit searches.

Table 1: Comparison of numbers of targets with TCEs in DR30 and initial processing

Sector	Initial DR Number	N Targets with TCEs (DR30)	N Targets with TCEs (initial release)	N Targets with TCEs in Common
14	DR19	952	946	840
15	DR21	870	858	759
16	DR22	731	694	609
17	DR24	744	702	626
18	DR25	697	630	566
19	DR26	757	792	663
14–19	DR28	2129	2031	1766

In order to differentiate Data Validation products from DR30 and the initial data releases, "pipeline instance number" (`pin`) is included in the filenames of the dv-timeseries, dv-reports, and dv-result xml files. A larger number for the `pin` always indicates more recently processed data. The DR number is also included as a keyword in the export product headers (`DATA_REL`). The SDPDD contains additional information about file names and the associated fields for DV products.

2.7 Changes to DV products

With the introduction of TIC-8 in Sector 14, we observed that DV difference images can become so crowded that they fail to support the diagnostic purpose of establishing whether the source of a given TCE is on target or off. In Sector 15, we made a simple code change to limit the number of stars displayed on the difference images to the brightest 75 within 8 magnitudes of the target. The same stars were displayed on the centroid offset diagnostic figures where applicable. However, a number of situations arose where a star that was very likely the (background) source of a TCE was no longer displayed on either the difference image or the associated centroid offsets figure because it was trimmed for the sake of legibility.

Beginning in Sector 16, the DV reports display and label the brightest 120 TIC objects (within 9 magnitudes of the target) in the difference images postage stamps, while all TIC objects are now displayed on the associated centroid offset figures. The dim TIC objects that are not labeled in the difference images are marked by (-) on the centroid offsets figures along with their respective TIC IDs and magnitudes. These stars do not appear in the tables of bright stars in the full and mini DV reports; they are generally identifiable, however. This trade-off was made so that the difference images and centroid offset figures may still provide useful diagnostic information in highly crowded fields.

Data were processed uniformly in the DR30 run so that the DV products for TCEs in Sectors 14–15 are now consistent with those produced in pipeline runs beginning with Sector 16.

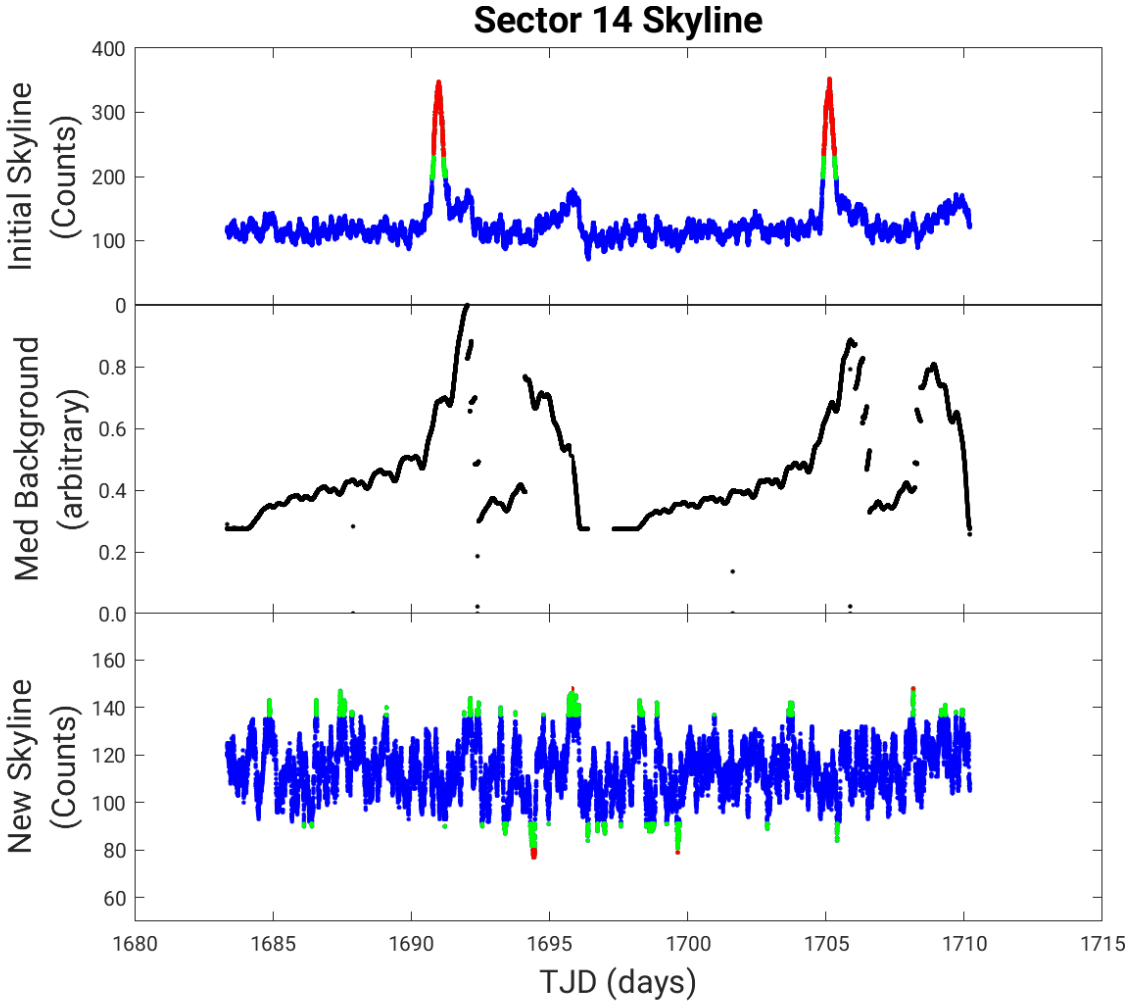

Figure 1: Comparison of TPS results before and after reprocessing, using Sector 14 as an example. Top panel: Number of TCEs in transit for each cadence in Sector 14, the so-called "skyline figure," from the initial data release. These data are from the first iteration of TPS, before any deemphasis weights are applied (see §4.2 of DRN19). The blue, green, and red points show the 1, 2, and 3σ outliers, respectively. The large spikes indicate times when many TCEs show a transit signal, marking cadences affected by systematic errors. Middle panel: Median background flux across all targets as a function of time. The increase in the background level towards the end of each orbit is caused by the proximity of the Earth to the camera fields-of-view. In the initial data release, scattered light flags were set for all targets on a given CCD during the times with the largest background levels. These flags cause a deep drop in the median background from approximately TJD 1692 to 1694 and from TJD 1707 to 1709. The excess of TCEs in the top panel is correlated with the initial increase in the background level, and then falls off when the scattered light flags are applied. Bottom panel: Same as top panel but for DR30, using target-by-target automated scattered light flags (see §2.4). No correlation with the median background exists, showing how the improved scattered light flags suppress the systematic errors in the transit search.

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Acronyms and Abbreviation List

BTJD Barycentric-corrected TESS Julian Date

CAL Calibration Pipeline Module

CBV Cotrending Basis Vector

CCD Charge Coupled Device

CDPP Combined Differential Photometric Precision

COA Compute Optimal Aperture Pipeline Module

CSCI Computer Software Configuration Item

CTE Charge Transfer Efficiency

Dec Declination

DR Data Release

DV Data Validation Pipeline Module

DVA Differential Velocity Aberration

FFI Full Frame Image

FIN FFI Index Number

FITS Flexible Image Transport System

FOV Field of View

FPG Focal Plane Geometry model

KDPH Kepler Data Processing Handbook

KIH Kepler Instrument Handbook

KOI Kepler Object of Interest

MAD Median Absolute Deviation

MAP Maximum A Posteriori

MAST Mikulski Archive for Space Telescopes

MES Multiple Event Statistic

NAS NASA Advanced Supercomputing Division

PA Photometric Analysis Pipeline Module

PDC Pre-Search Data Conditioning Pipeline Module

PDC-MAP Pre-Search Data Conditioning Maximum A Posteriori algorithm

PDC-msMAP Pre-Search Data Conditioning Multiscale Maximum A Posteriori algorithm

PDF Portable Document Format

POC Payload Operations Center

POU Propagation of Uncertainties

ppm Parts-per-million

PRF Pixel Response Function

RA Right Ascension

RMS Root Mean Square

SAP Simple Aperture Photometry

SDPDD Science Data Products Description Document

SNR Signal-to-Noise Ratio

SPOC Science Processing Operations Center

SVD Singular Value Decomposition

TCE Threshold Crossing Event

TESS Transiting Exoplanet Survey Satellite

TIC TESS Input Catalog

TIH TESS Instrument Handbook

TJD TESS Julian Date

TOI TESS Object of Interest

TPS Transiting Planet Search Pipeline Module

UTC Coordinated Universal Time

WCS World Coordinate System

XML Extensible Markup Language