Mission Operations Cost Estimation Tool (MOCET) 2024 Status Update

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2024 NASA Cost & Schedule Symposium
24 April 2024

Aerospace acknowledges NASA's sponsorship under Contract NNL11AA01B Task Order 80LARC18F0021

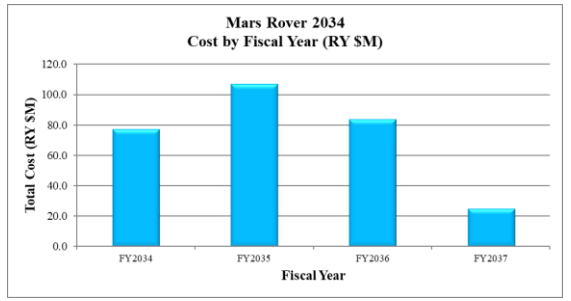
Topics

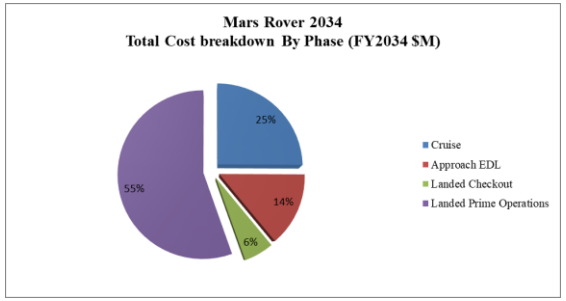
MOCET 2024 Status

- MOCET Overview
- Tool Update Overview
- Example CER Details
- Overall Model Performance
- Extended Mission Overview
- User Community
- Conclusion

MOCET Overview

- The **Mission Operations Cost Estimation Tool (MOCET)**
  - A capability for Phase E estimation jointly developed by The Aerospace Corporation and NASA Science Office for Mission Assessments (SOMA)
  - Based on **actual costs of historical missions** with emphasis on competed missions
  - Constructed by **breaking cost into the various operational phases**
  - Has **few subjective inputs**
  - Estimates total Phase E mission cost
  - Implemented entirely in Excel and requires no additional software or tools
  - Also includes a user manual which provides additional instruction and background





NASA Mission Operations Cost Estimation Tool

About MOCET...

Apply

Mission Type	Planetary
Mission Name	Mars Rover 2034
Mission Class	Large (New Frontiers, Directed Survey)
Science Theme	
Estimate Milestone	CSR

Inflate Costs To: FY2034

Legend:
Input
Calculated/Read-Only
Invalid/Incomplete
N/A

Description	Phase Start	Duration (months)	Estimating Phase	Parameter 1	Value 1	Parameter 2	Value 2	Cost/Mo (FY34 $M)	Total Cost (FY34 $M)	Total Cost (RY $M)	Notes
Cruise	03-16-2034	6.0	Mars EDL Cruise	Rover/Lander Mass (kg)	580			11.79	71.33	71.33	
Approach EDL	09-16-2034	3.0	Approach/EDL	Cruise Avg Cost	Cruise			13.33	39.87	40.30	
Landed Checkout	12-16-2034	1.0	Landed Checkout	Cruise Avg Cost	Cruise			15.39	15.68	16.09	
Landed Prime Operations	01-16-2035	24.0	Prime Landed Ops	Rover/Lander Mass (kg)	580			6.56	157.56	165.86	
End of Mission	01-16-2037							Total	$ 284.44	$ 293.58	
								Reserves	$ 30.91	$ 43.51	
								Total + Reserves	$ 315.36	$ 337.09	

Available to the public:
https://software.nasa.gov/software/LAR-18894-1

NASA internal on the ONCE Model Portal
https://oncedata.hq.nasa.gov

Help desk support:
Email: MOCET@aero.org

Tool Update Overview

MOCET 2024 Status

- MOCET model continues to be updated on an annual basis
  - MOCET v1.4 was released in April of 2023 on ONCE and software.nasa.gov
  - Work on the new version v1.5 has continued through FY23 and FY24
    - Updated CERs are complete and being programmed into the MOCET tool for an imminent release

- Changes and enhancements in v1.5
  - Additional new mission data accumulated
    - IXPE, JWST, EMIT, DART, and Lucy
  - Split out Flagships from Other Helio/Astro missions
    - JWST necessitated creating separate CER
  - Inclusion of extended mission CER suite
    - Extended mission CER development published in IEEE 2024

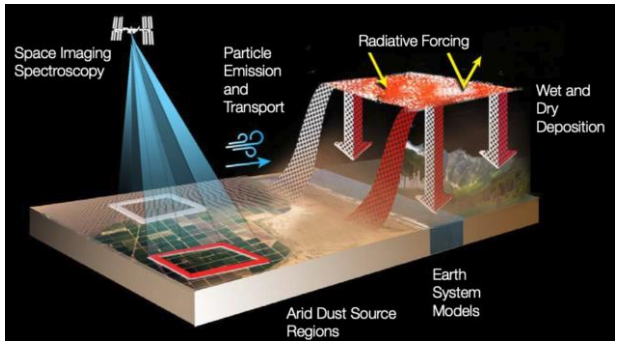
- The performance of the v1.5 is comparable to v1.4b, but statistical error has increased from last presentation of v1.4b
  - Primarily driven by the addition of new mission data; most variables are the same as v1.4b
  - Some continuous variables were added to help improve certain CERs; also adds flexibility to the model
  - The new v1.5 is more robust and capable than v1.4b

MOCET Mission Types Database Overview

Mission/CER Type	Program	Missions
Earth Science	Earth System Science Pathfinder (ESSP)	CloudSat, OCO-2, CYGNSS, GRACE, CALIPSO, Aquarius
	Earth Systematic Missions (ESM)	Aqua, Aura, Terra, Jason-1, ICESat, GPM, SMAP, SORCE, Jason-2/OSTM, GRACE FO, ICESat-2, Sentinel-6
Planetary	Discovery	MESSENGER, Stardust, Deep Impact, GRAIL, NEAR, Dawn, **Lucy**
	Mars Scout	Phoenix
	Robotic Lunar Exploration	LRO, LADEE
	New Frontiers	New Horizons, Juno, OSIRIS-REx
	Mars Exploration	MRO, Odyssey, MER, MSL, MAVEN, Insight, Mars 2020
	Outer Planets and Ocean Worlds	Cassini
	Living With a Star (LWS)	PSP
	Planetary Defense	**DART**
Explorers	Small Explorers (SMEX)	NuSTAR, IRIS, IBEX, AIM, GALEX, RHESSI, **IXPE**
	Medium Explorers (MIDEX)	THEMIS, Swift, WISE, TESS
	Explorer Missions of Opportunity (MO)	Suzaku (ASTRO-E2), TWINS, CINDI, GOLD
Near Earth Discovery Helio-Astro	Discovery	Genesis, Kepler
	Solar Terrestrial Probes (STP)	STEREO, TIMED, MMS
	Living With a Star (LWS)	RBSP, SDO
	Cosmic Origins	Spitzer, **JWST**
	Physics of the Cosmos	Fermi, Chandra
ISS Hosted	Earth System Science Pathfinder (ESSP)	ECOSTRESS, OCO-3, GEDI, **EMIT**
	Earth Systematic Missions (ESM)	TSIS-1, SAGE-III
	Explorer Missions of Opportunity (MO)	NICER

Bold Blue = New Mission Data in v1.5

Imaging X-ray Polarimetry Explorer (IXPE)
Credit: NASA



Earth surface Mineral dust source InvesTigation (EMIT)
Credit: NASA/JPL

Double Asteroid Redirection Test (DART)
Credit: NASA/Johns Hopkins APL/Joshua Diaz

MOCET CERs Overview

Planetary

CER Name	New Data in v1.5	Comments/Updates in v1.5
Nominal/Quiescent Cruise CER	X	DART and Lucy data incorporated Additional OSIRIS-REx data incorporated
Checkout Cruise CER	X	DART and Lucy data incorporated
Mars EDL Cruise CER		
Orbital Operations CER	X	Additional Parker Solar Probe data incorporated
Flyby/Encounter CER	X	DART data incorporated
Approach/Orbit Insertion/Reduction CER		
Approach EDL CER		
Landed Checkout CER		
Landed Prime Operations	X	Additional Mars 2020 data incorporated
Data/Sample Analysis & Archiving	X	DART data incorporated

Earth/Near-Earth/Other

CER Name	New Data in v1.5	Comments/Updates in v1.5
Earth/Near-Earth Orbiting Checkout CER	X	IXPE and JWST data incorporated
Earth Science Prime Operations CER		
Explorer Prime Operations CER	X	IXPE data incorporated
Near Earth Discovery Helio Astro Prime Operations CER	X	JWST data incorporated
ISS Hosted Instrument	X	EMIT data incorporated

Currently 15 primary CERs used in MOCET, 10 of which are updated with new data in v1.5

MOCET Mission Class

Planetary

Mission Class	NASA Funded Dev Cost*	Planetary Programs	Latest Cost Cap** ($M)	Example Missions
Medium	<$525	Discovery Mars Scout	$500 (FY19 No Ops, No LV) $475 (FY06 w/LV/Ops)	Lucy Phoenix
Large	$525-$1,500	Discovery New Frontiers Directed Survey	$500 (FY19 No Ops, No LV) $850 (FY15 No Ops, No LV)	 OSIRIS-REx MRO
Flagship	>$1,500	Mars Exploration Outer Planets Flagship		Mars 2020 Cassini

*FY23$M excludes contributions, launch vehicle and operations costs

**Sources:

1) Discovery 2019 Announcement of Opportunity, April 1, 2019
2) New Frontiers 4 Announcement of Opportunity, December 9, 2016
3) Mars Scout Announcement of Opportunity, May 1, 2006

FY bins updated to FY23; dollar values still hold with latest mission data

MOCET Mission Class

Earth Orbiting

Mission Class	NASA Funded Dev Cost*	Programs	Latest Cost Cap** ($M)	Example Missions
Micro	<$80	Explorer Missions of Opportunity (MO) Earth Venture-Instrument (EVI) Earth Systematic Missions (ESM)	$35-70 (FY22 Ops, No LV) $37-42 (FY24 Ops, No LV)	GOLD ACRIMSAT
Small	$80-$150	Earth Venture-Instrument (EVI) Small Explorers (SMEX) Astrophysics Small Explorers (SMEX) Heliophysics Earth Systems Science Pathfinder (ESSP) Earth Systematic Missions (ESM)	$90 for all selected $145 (FY19 Ops, No LV) $165 (FY17 Ops, LV)	TEMPO NuSTAR IBEX GRACE SORCE
Medium	$150-$500	Earth Venture-M Medium Explorers (MIDEX) Astrophysics Medium Explorers (MIDEX) Heliophysics Earth Systems Science Pathfinder (ESSP) Earth Systematic Missions (ESM) Solar Terrestrial Probes (STP)	$190 (FY22 Ops) $300 (FY22 Ops, No LV) $250 (FY19 Ops, No LV)	CYGNSS TESS ICON CloudSat ICESat TIMED
Large	$500-$1,100	Earth Systematic Missions (ESM) Discovery Solar Terrestrial Probes (STP) Living With a Star (LWS) Physics of the Cosmos (PCOS)	$500 (FY19 No Ops, No LV)	LDCM Kepler STEREO SDO Fermi
Flagship	>$1,100	Earth Systematic Missions (ESM) Cosmic Origins (COR) Physics of the Cosmos (PCOS)		Aqua, Aura Spitzer Chandra

*FY23$M excludes contributions, launch vehicle and operations costs

**Sources:

1) 2022 Heliophysics Missions of Opportunity DRAFT Announcement of Opportunity, June 22, 2022
2) Third Stand Alone Missions of Opportunity Notice (SALMON-3), Program Element Appendix (PEA) R, Earth Venture Instrument 6 (EVI-6), October 26, 2021
3) Second Stand Alone Missions of Opportunity Notice (SALMON-2), Program Element Appendix (PEA) J, Earth Venture Instrument 1 (EVI-1),September 29, 2011
4) 2016 Heliophysics Small Explorer Announcement of Opportunity, November 14, 2016
5) 2019 Astrophysics Small Explorer Announcement of Opportunity, April 3, 2019
6) 2020 Earth Venture Mission – 3 Announcement of Opportunity, April 10, 2020
7) 2021 Astrophysics Medium Explorer Announcement of Opportunity, October 25, 2021
8) 2019 Heliophysics Medium Explorer Announcement of Opportunity, July 23, 2019
9) Discovery 2019 Announcement of Opportunity, April 1, 2019

FY bins updated to FY23; dollar values still hold with latest mission data

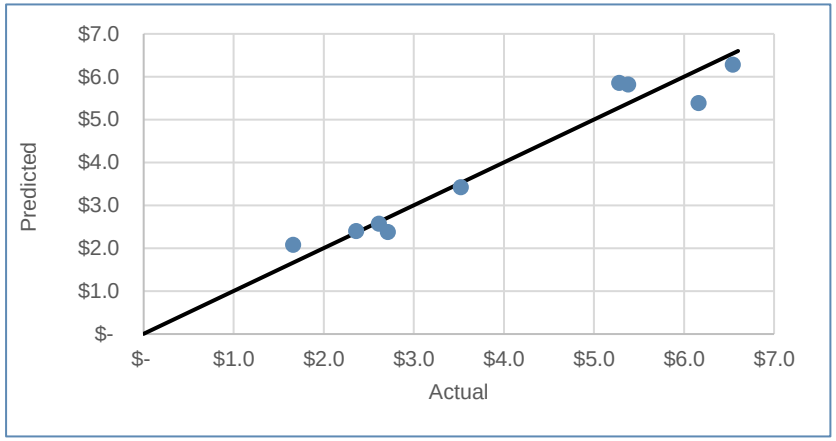
Checkout Cruise Prime Phase CER

- CER Function: $Y = 1.9436 + 3.1695 * EN + 0.0093 * PM$

Variable	Name	Units	Definition
Y	Cost	FY23 $M	Planetary mission average monthly prime nominal or quiescent cruise phase cost
EN	EnhancedNavigation?	0 or 1	Does this cruise require enhanced navigation: • Cruise precedes: aerobraking, or precise targeting operations OR • There are >2 thrust control maneuvers during this cruise with checkout period OR • Total mission cruise phase may be less than 6 months,
PM	Payload Mass*	kg > 0	Mass of payload portion for which NASA will fund operations

- Goodness of Fit

Measure	Value
Regression Method	OLS
Standard Error of the Estimate	0.46
Average Percentage Bias	0.0%
Coefficient of Determination (R^2)	0.94
Adjusted R^2	0.94
Pearson's Correlation Sqd (r^2)	0.93
Number of Observations	9
Number of Input Variables	2



- Database

1. MESSENGER (EN 0, PM 47.2)	4. MAVEN (EN 0, PM 67.7)	7. OSIRIS-REx (EN 1, PM 81.1)
2. Juno (EN 0, PM 159.7)	5. MRO (EN 1, PM 126)	**8. Lucy (EN 0, PM 49.8)**
3. New Horizons (EN 1, PM 30.3)	6. Deep Impact (EN 1, PM 76.5)	**9. DART (EN 0, PM 14.8)**

Bold = New Mission

Additional Notes

- Some missions may have nominal, quiescent, and checkout periods of cruise. Each of these phases should be broken out and estimated separately (e.g. 4 months of cruise with checkout, 12 months of nominal cruise, 36 months of quiescent ops.)
- Mars missions and Deep Impact assumed to use “checkout during cruise” rate until approach phase begins to account for compressed activities in short duration cruises
- For Mars entry, descent, and landing (EDL) missions, use the Mars EDL Cruise CER

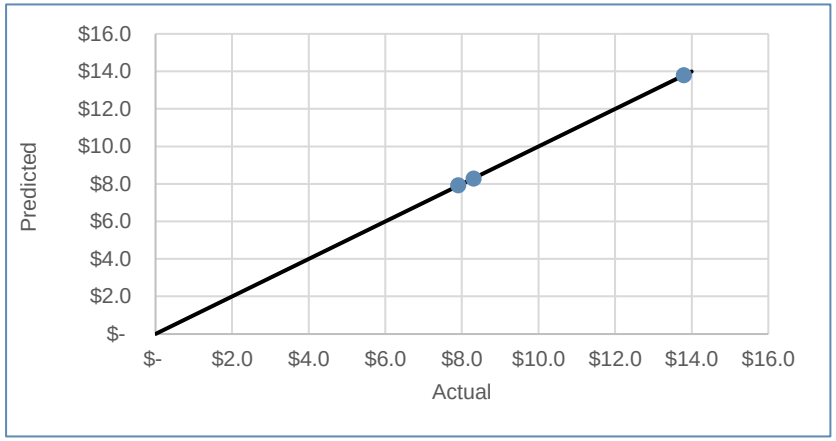
Near Earth Astro Flagship Prime Phase CER

- CER Function: $Y = 7.0345 + 1.0403 * D$

Variable	Name	Units	Definition
Y	Cost	FY23 $M	Near Earth Discovery Helio-Astro mission average monthly prime operations phase cost
D	Diameter of Aperture	meters (m) >= 0	Diameter of the aperture of a flagship optical telescope.

- Goodness of Fit

Measure	Value
Regression Method	OLS
Standard Error of the Estimate	0.02
Average Percentage Bias	0.0%
Coefficient of Determination (R^2)	0.99
Adjusted R^2	0.99
Pearson's Correlation Sqd (r^2)	0.99
Number of Observations	3
Number of Input Variables	1



- Database

1. Spitzer (D 0.85)	3. ~~GP-B (D 0)~~	
2. Chandra (D 1.2)	**4. JWST (D 6.5)**	

Bold = New Mission

Additional Notes

- Although GP-B was assumed to be a flagship mission, the actual Phase BCD development cost was not available.GP-B also operated quite differently than the other multi-instrumented flagship astrophysics missions, as it used sensitive gyroscopes and a guide telescope. For these reasons it has been removed.

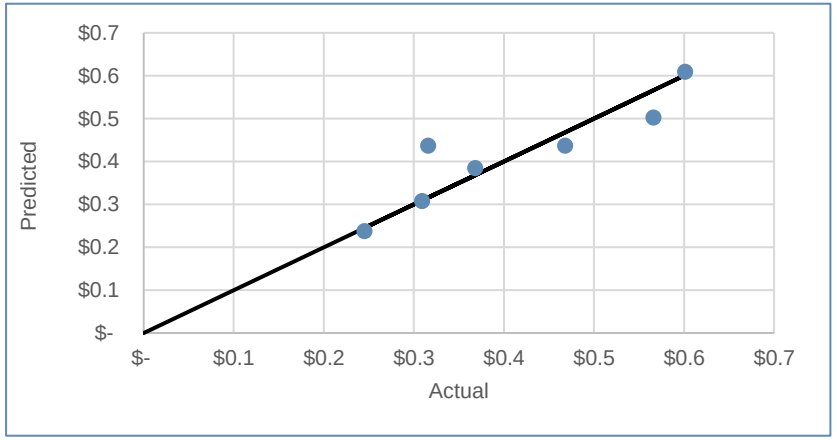
ISS Hosted CER

- CER Function: $Y = 0.1116 * SM^{0.4048}$

Variable	Name	Units	Definition
Y	Cost	FY23 $M	ISS Hosted Instrument average monthly prime operations phase cost
SM	Sensor Mass	kg	CBE mass of ISS instrument sensor portions (see note below)

- Goodness of Fit

Measure	Value
Regression Method	GERM ZMPE
Standard Error of the Estimate	12.9%
Average Percentage Bias	0.0%
Pearson's Correlation Sqd (R^2)	0.82
Number of Observations	7
Number of Input Variables	1



- Database

1. ECOSTRESS (SM 12.3)	4. OCO-3 (SM 66.3)	7. **EMIT (SM 41.2)**
2. TSIS-1 (SM 21.2)	5. GEDI (SM 29.1)	
3. NICER (SM 6.5)	6. SAGE-III (SM 29.1)	

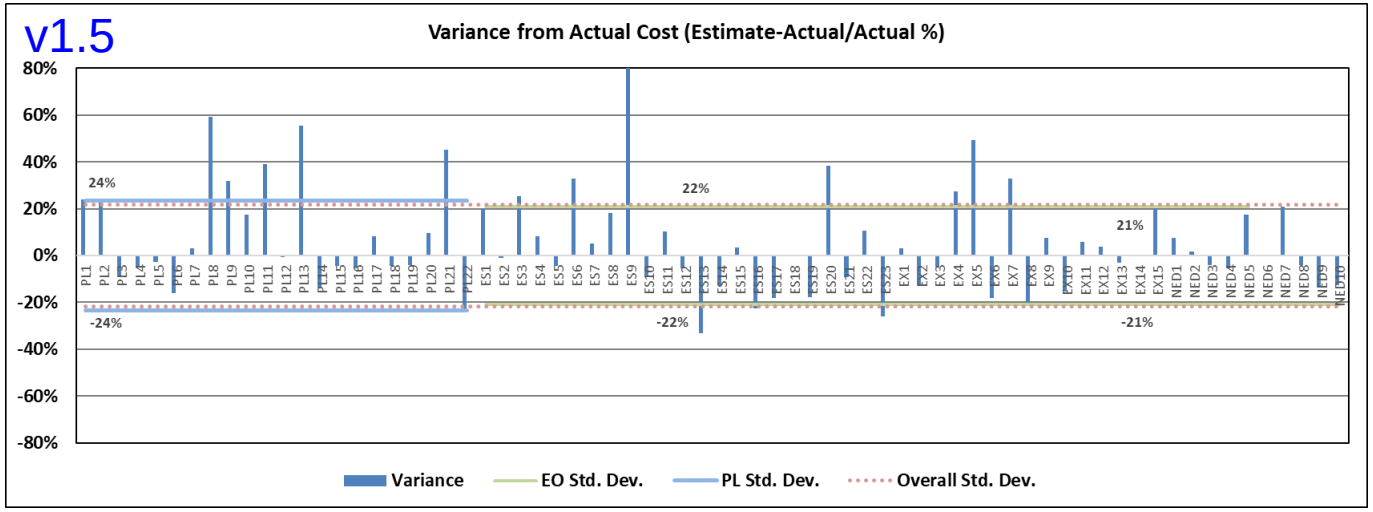
Bold = New Mission

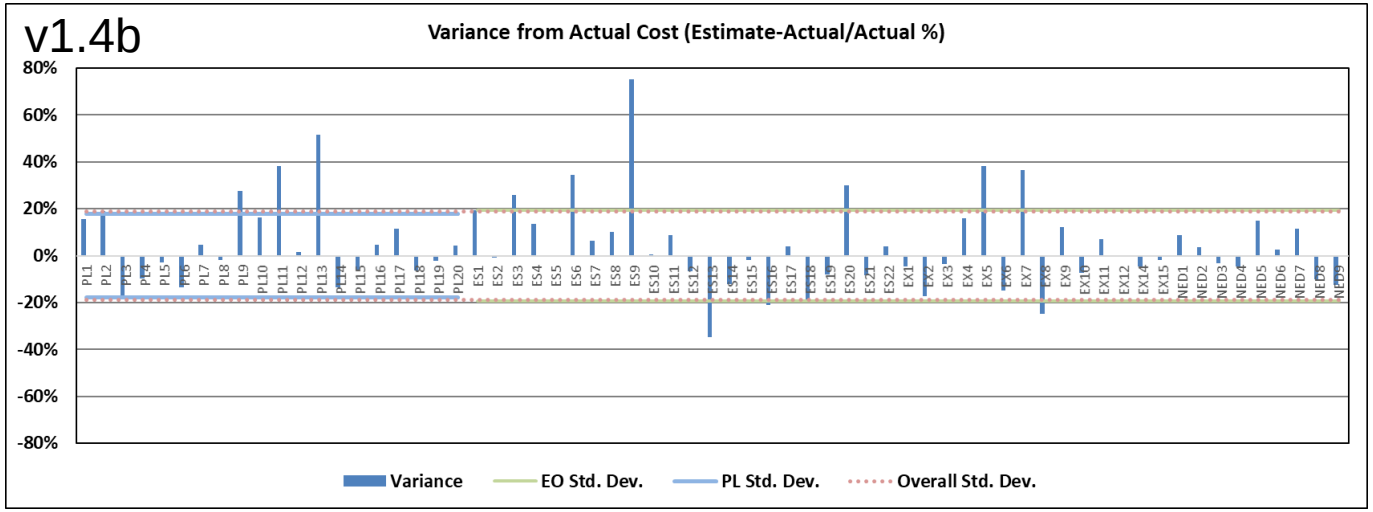
Additional Notes

- Sensor mass: include all optical components, detectors, and items labeled as sensor or telescope. Exclude all items required for ISS accommodation: pointing systems, data processing units, power supplies, and thermal systems. Exclude any large structural or thermal instrument portions. For multiple identical complex sensor instruments (multiple different optical components working together) consider only the mass of the single sensor unit. Sensor mass may include some housing and other components for smaller instruments delivered as a single integrated sensor.

Overall Model Performance

- The model was compared against actual mission costs to gauge performance
  - *Standard Deviation for all missions is 22% (v1.4b:19%, v1.3*: 18%, v1.2*: 18%, v1.1*: 18%, v1.0*: 26%)*
    - Planetary: 24% (v1.4b: 18%, v1.3*: 18%, v1.2*: 17%, v1.1*: 17%, v1.0*: 30%)
    - Earth/Near Earth Orbiting: 21% (v1.4b: 19%, v1.3: 19%, v1.2: 19%, v1.1: 19%, v1.0: 25%)





v1.5	Delta	Act. Var.	Est. Var.
Avg.	$ 1.38	6%	2%
Avg. Absol	$ 10.32	16%	15%
STDEV	$ 19.40	22%	19%
PL STDEV	$ 31.21	24%	19%
EO STDEV	$ 10.40	21%	18%
Median	$ 0.13	0%	0%
Maximum	$ 119.07	81%	45%
Minimum	$ (40.90)	-33%	-50%

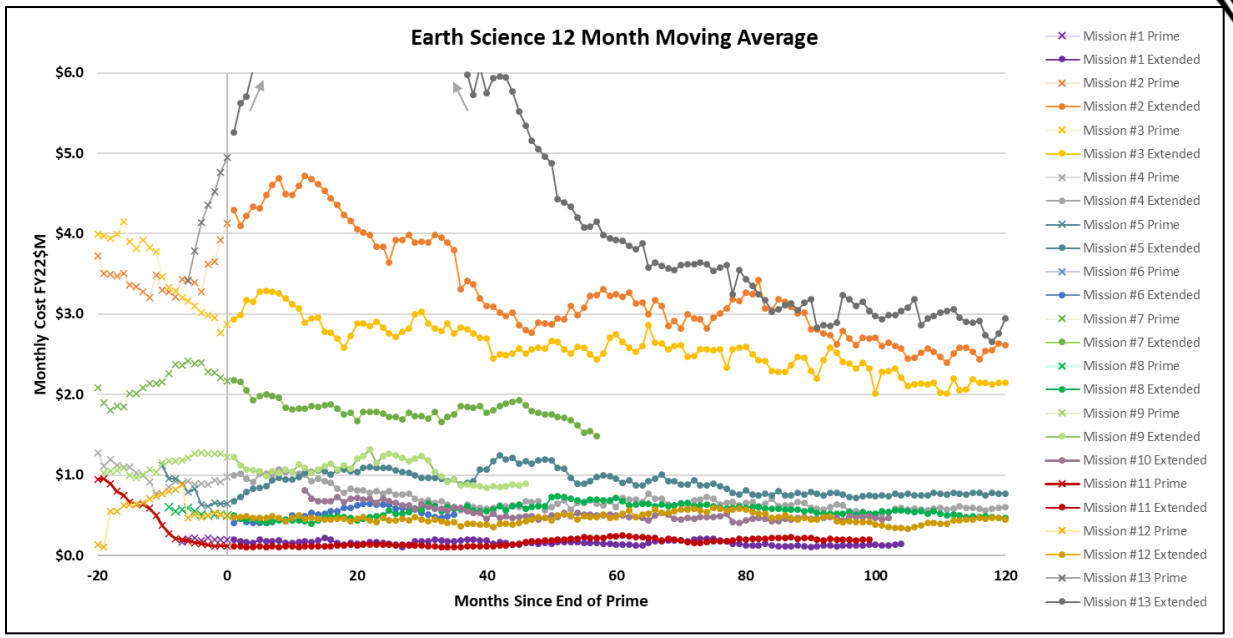
* No longer using NEAR and Pathfinder in the benchmarking of any MOCET versions. NEAR and Pathfinder were originally introduced to benchmark MOCET with missions that the models were not fit on. They have been removed as their age makes them non-analogous to current missions.

v1.4b	Delta	Act. Var.	Est. Var.
Avg.	$ 1.19	4%	1%
Avg. Absolute	$ 8.09	13%	12%
STDEV	$ 15.81	19%	16%
PL STDEV	$ 26.89	18%	15%
EO STDEV	$ 7.09	19%	17%
Median	$ 0.20	1%	1%
Maximum	$ 94.51	75%	43%
Minimum	$ (29.99)	-35%	-54%

Extended Mission Overview

MOCET 2024 Status

- Extended mission cost modeling completed in FY23 and included in v1.5
  - Data collected and evaluated for 46 NASA missions
  - CERs were developed using 41 of the 46 missions
  - Utilizes 12-month moving averages for CER fitting
  - Months since end of prime mission main variable
  - Prime mission average cost variable newly introduced
    - Can be estimated using MOCET tying the existing model with new CERs
  - Multiple equations forms tested
    - Scaled logarithmic for gave the best performance
      - Scaled Logarithmic: Y = [A + B*ln(m)] * p
- Can be used to support
  - NASA Senior Reviews of operating missions
  - Overall portfolio planning within NASA
- Full methodology and details published in IEEE 2024 publication



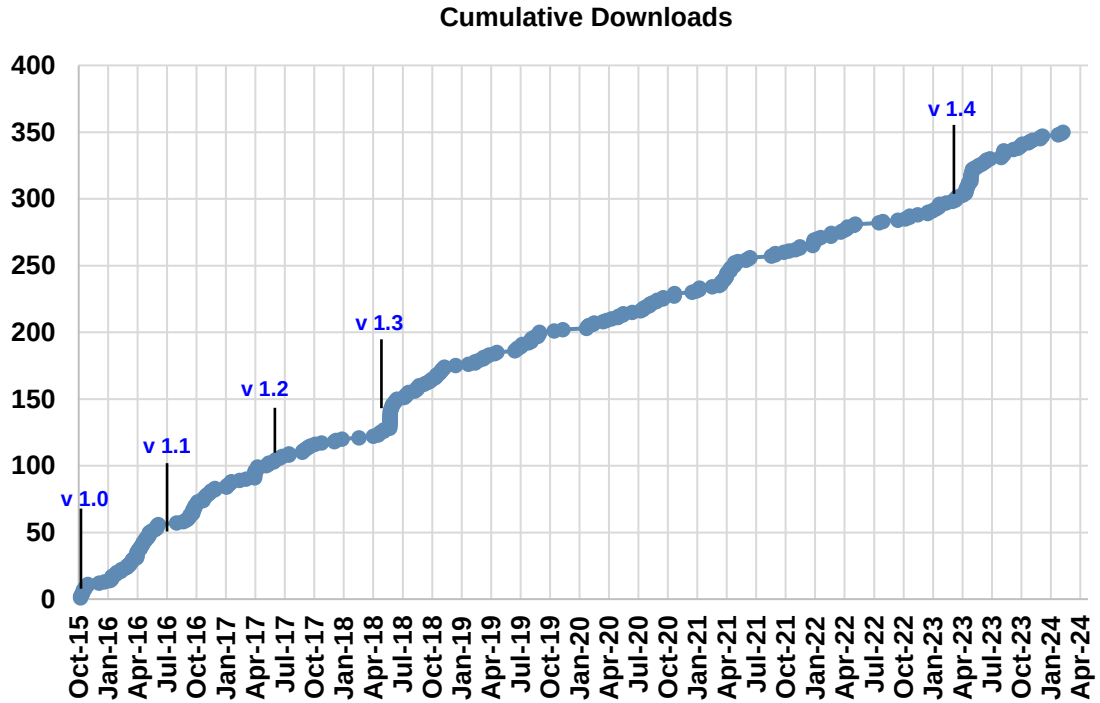
CER Group	Missions	Equation	No. Data Points	No. Missions	r2	SEE (%)
Explorers	AIM, IBEX, RHESSI, THEMIS, IRIS, Swift, NuSTAR, GALEX, Suzaku, TWINS, CINDI	$Y = [1.3765 - 0.192 * ln(m)] * p$	1297	11	0.69	0.35
Earth Science	SORCE, GRACE, CYGNSS, OSTM, Jason-1, AcrimSat, CloudSat, CALIPSO, ICESat, Aqua, Aura, Terra*, GPM	$Y = [1.0225 - 0.0625 * ln(m)] * p$	1528	13	0.91	0.29
Other Helio/Astro	Kepler, Fermi, MMS, SDO, VAP, STEREO, TIMED	$Y = [1.6355 - 0.2714 * ln(m)] * p$	731	7	0.76	0.25
Planetary – Orbital Ops	MRO, MESSENGER, MAVEN, Mars Odyssey, Dawn, Cassini, LRO	$Y = [1.3001 - 0.1572 * ln(m)] * p$	632	7	0.97	0.13
Planetary - Landed	MSL, MER, InSight	$Y = [1.4207 - 0.2551 * ln(m)] * p$	256	3	0.54	0.38

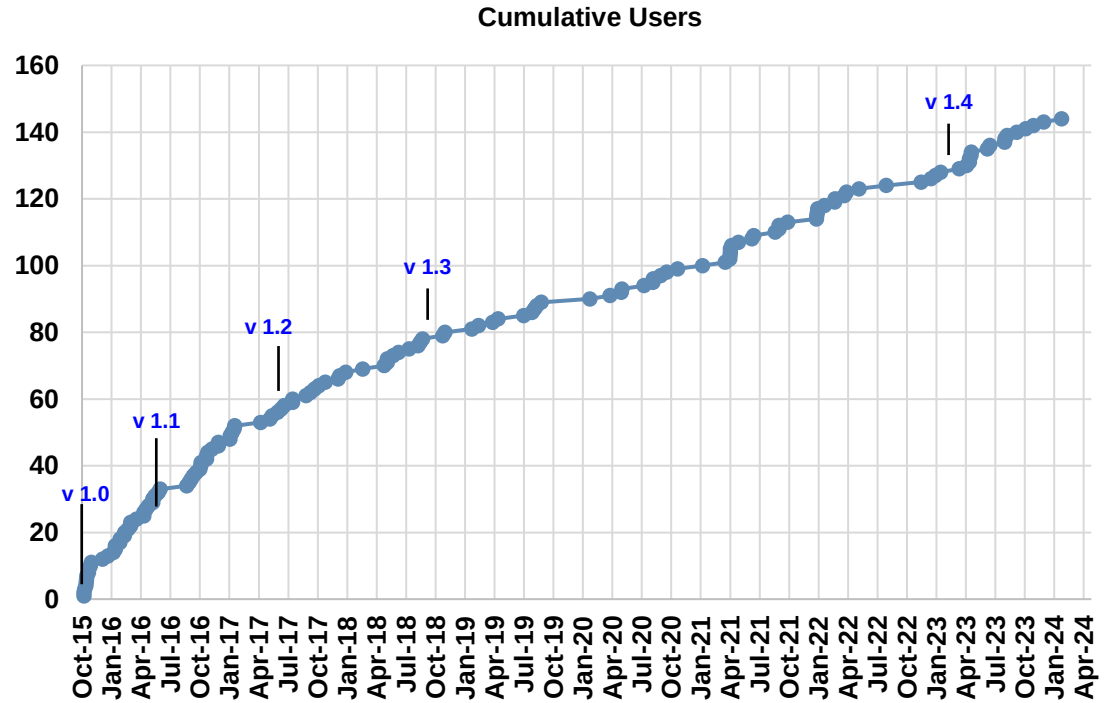
m = months since end of prime mission, *p* = prime monthly average cost

ONCE Download & Users

MOCET 2024 Status

- As of March 2024, MOCET has been downloaded from ONCE 350* times since the initial release
  - *Downloads include those from inactive users and duplicate downloads
    - ONCE output generally only shows active users and unique downloads
  - v1.0 - 30, v1.1 - 60, v1.2 – 37, and v1.3 – 176, v1.4 - 47
- Also, 144 unique users have downloaded MOCET from ONCE
  - Since the release of v1.0 the number of users has increased steadily

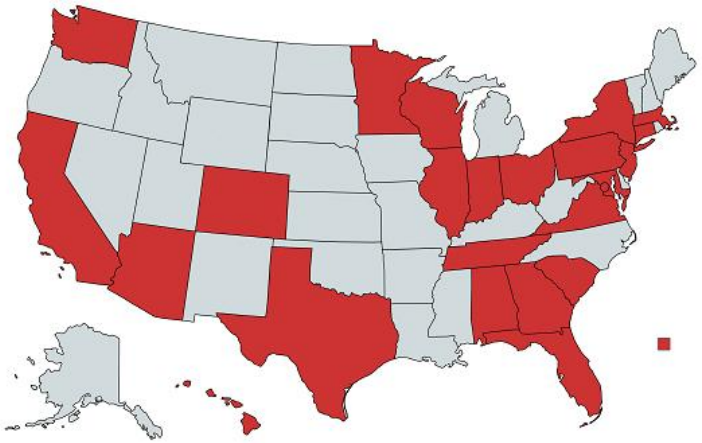


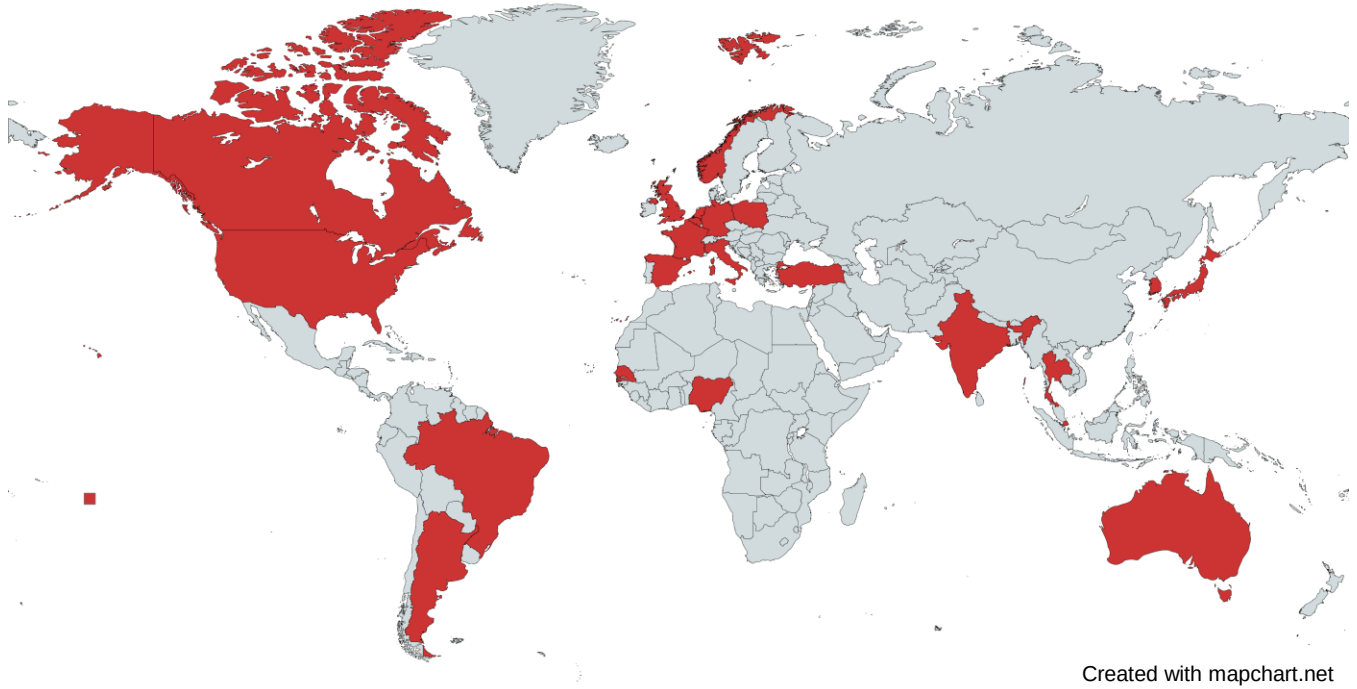


software.nasa.gov Downloads and Users

MOCET 2024 Status

- There are MOCET 223 users on software.nasa.gov since its release there in April of 2017
  - Most users are from Industry (80), Representing Self (63), Academic (45), and from NASA (25)
  - There are also 9 Other Civil/Government
  - Of the 223 users, 63 are also international and an additional 14 are unknown





Created with mapchart.net

Conclusion

MOCET 2024 Status

- The 2024 status of MOCET updates and research has been presented
- MOCET will continue to be periodically updated with new mission data
- New implementation methods being considered for future release
- Model is currently being used by both evaluators and proposers
- We will continue to engage and grow the user community

James Webb Space Telescope
Credit: NASA

Selected Publications

- Extended Missions Operations Costing Capability for NASA Science Missions, 2024 IEEE Aerospace Conference, Big Sky, MT
- Mission Operations Cost Estimation Tool (MOCET) 2023 Status Update, 2023 NASA Cost and Schedule Symposium, April 2023, Pasadena CA
- Mission Operations Cost Estimation Tool (MOCET), 2017 IEEE Aerospace Conference, Big Sky, MT

MOCET Contact

Available to the public:
https://software.nasa.gov/software/LAR-18894-1

NASA internal on the ONCE Model Portal
https://oncedata.hq.nasa.gov

Help desk support:
Email: MOCET@aero.org


Questions?


Thank you