



NASA Langley Research Center

OSIRIS-REx Entry, Descent, and Landing Performance

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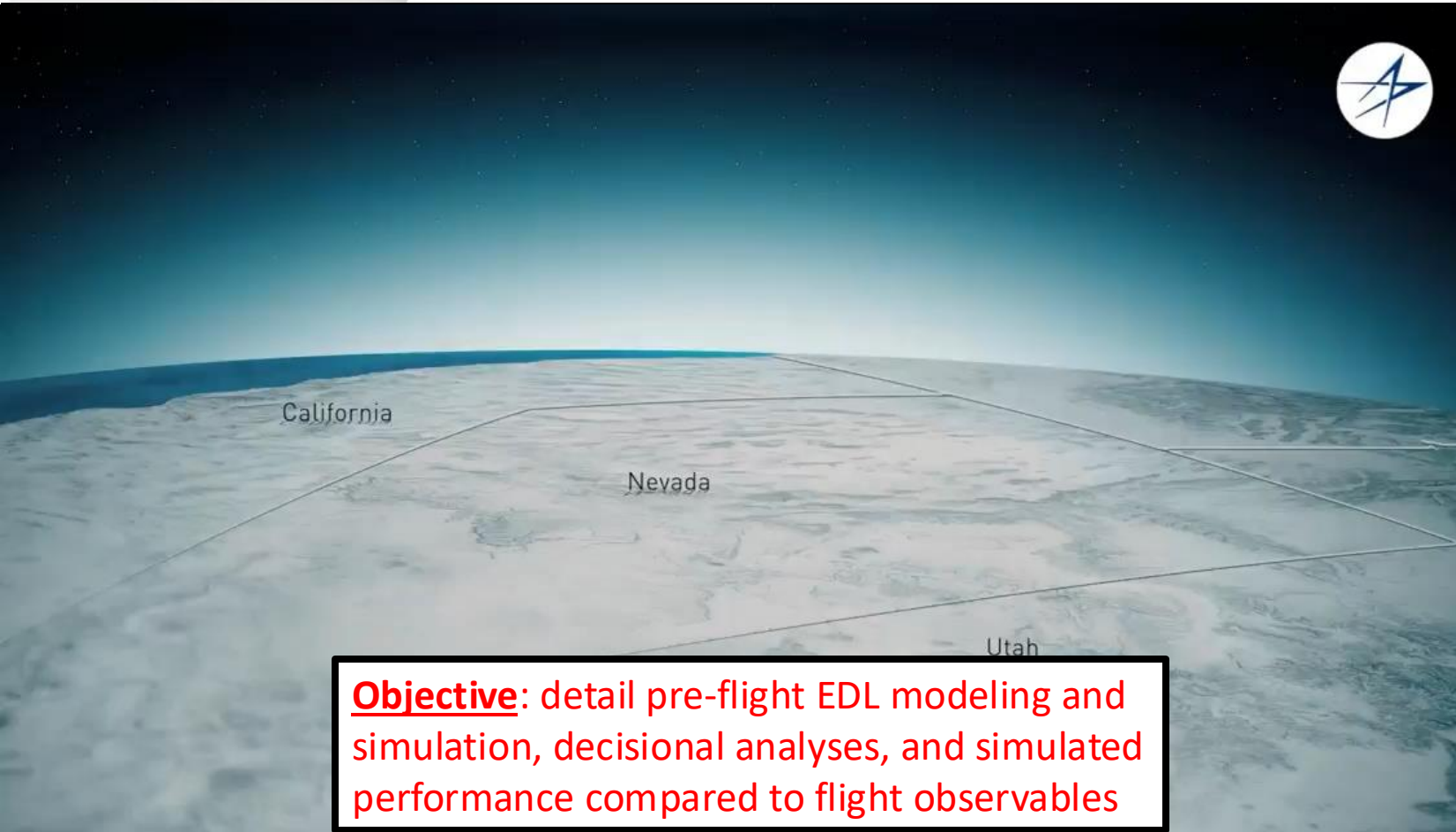
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Entry, Descent, and Landing (EDL) Sequence



Objective: detail pre-flight EDL modeling and simulation, decisional analyses, and simulated performance compared to flight observables

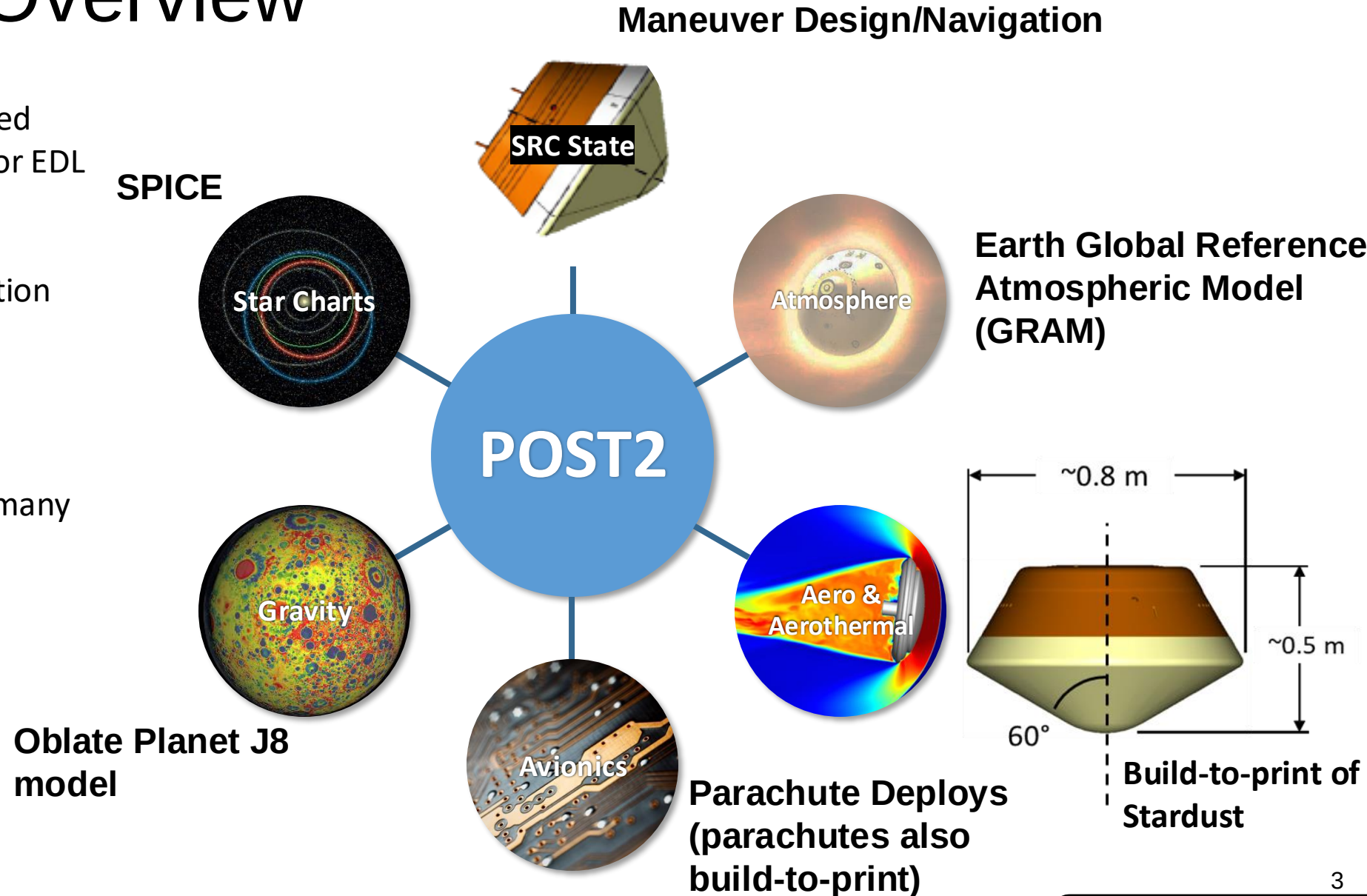
Credit: NASA GSFC/LM

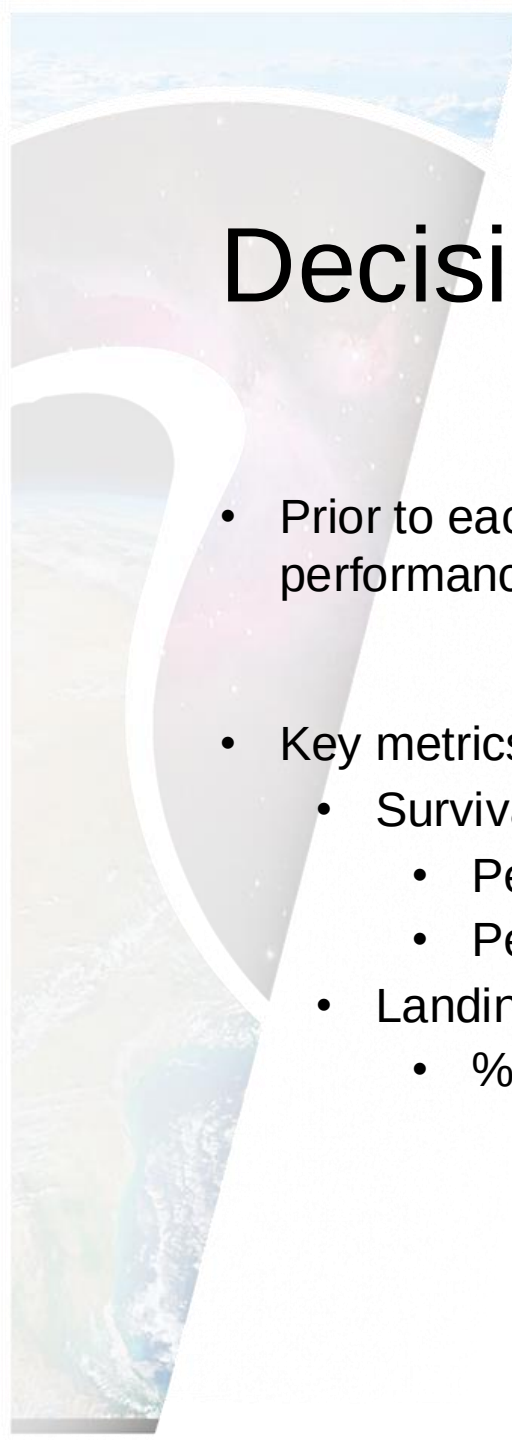
- Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx)
- Third mission in NASA's New Frontiers program
- Launched out of Cape Canaveral, FL on Sept 8, 2016
- Departed surface of Bennu on May 10, 2021
- 2.5 year flight back to Earth
- Sample Return Capsule (SRC) **successfully** completed EDL sequence and touched down at Utah Test and Training Range (UTTR) on September 24, 2023

Modeling Overview

Program to Optimize Simulated Trajectories II (POST2) used for EDL simulations

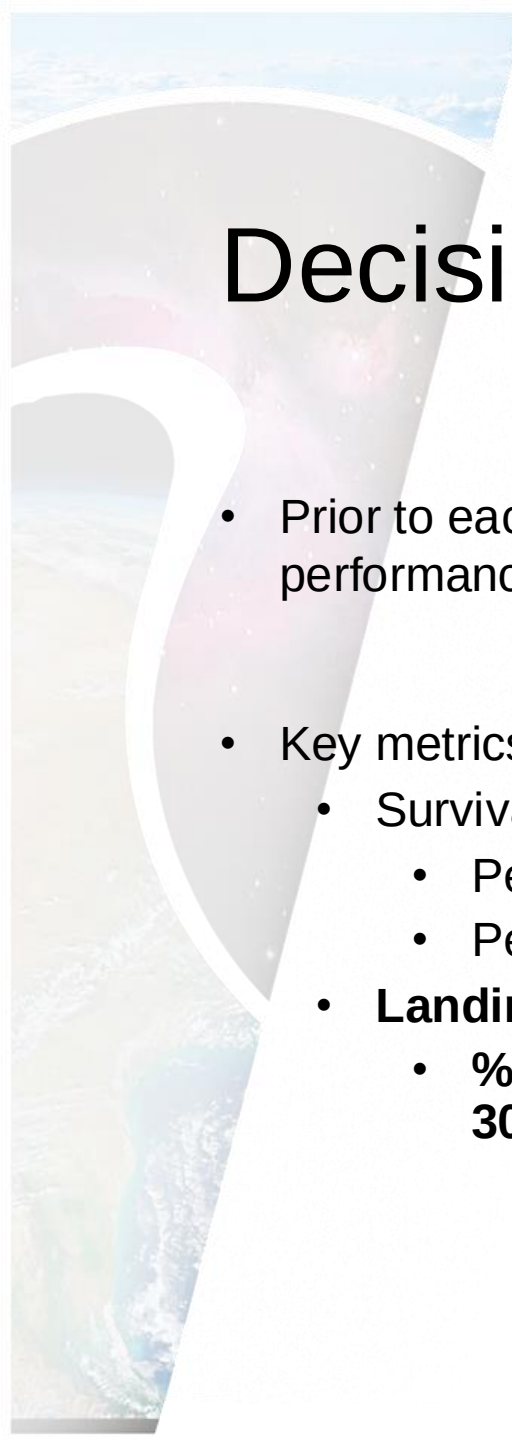
- Propagates six degree-of-freedom equations of motion from 1 minute prior to atmospheric interface (6503.142 km radius) to touchdown at UTTR
- Ingests information from many external sources





Decisional Analyses

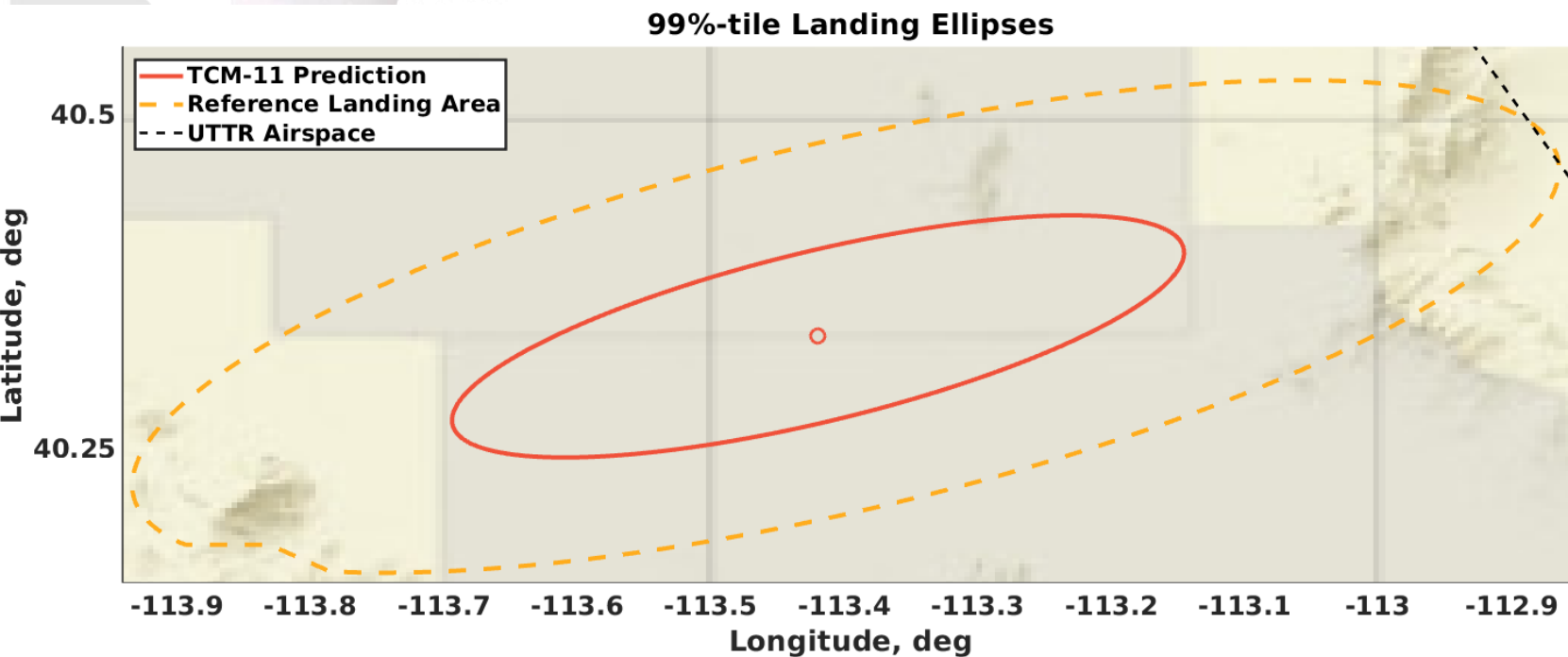
- Prior to each major trajectory event, such as a trajectory correction maneuver (TCM), predicted EDL performance was assessed to determine Go/No-Go
- Key metrics consisted of:
 - Survivability of SRC
 - Peak heat rate, integrated heat load
 - Peak deceleration
 - Landing Accuracy
 - % cases landing within agreed upon reference landing area (RLA) at UTTR (95km x 30km)



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Decisional Analyses

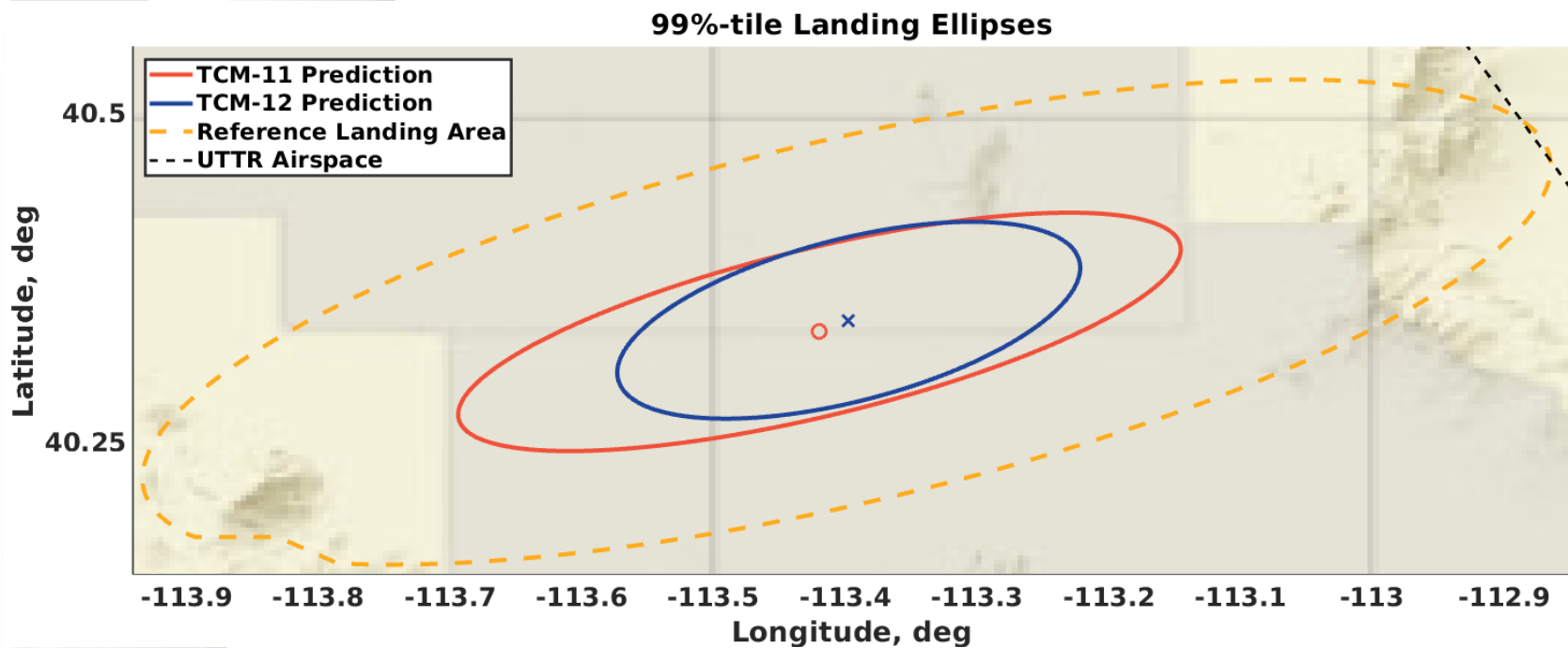


Event	Event Time	Executed	Ellipse Size
TCM-11*	Entry-14 days	Yes	48.7km x 13.9km

* First TCM to target Earth entry trajectory

Reference Landing Area (RLA): 95km x 30km

Decisional Analyses

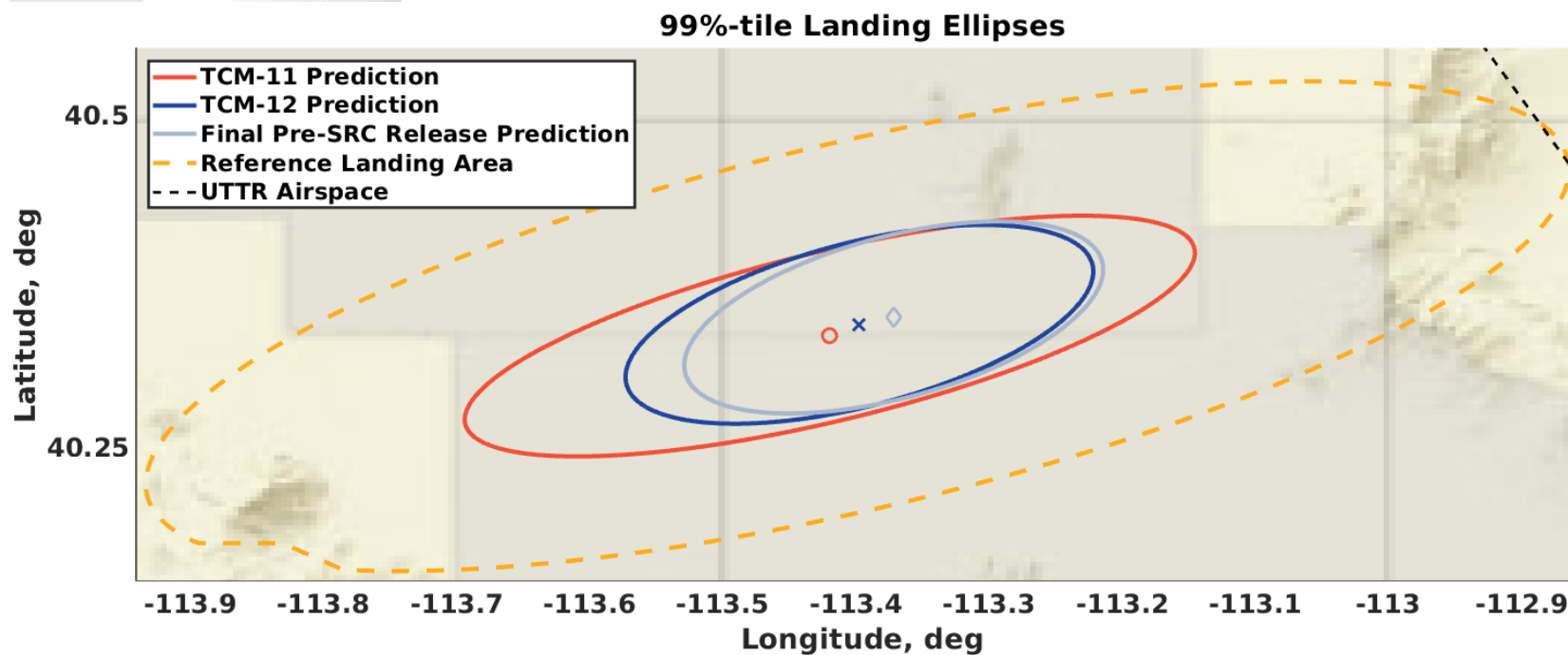


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TCM-12	E-7 days	Yes	32km x 13.6km
TCM-13 **	E-31 hours	No	N/A
SRC Release	E-4 hours	Yes!	28.2km x 13.2 km

* First TCM to target Earth entry trajectory

** Not necessary

Most of cross track uncertainty is due to winds

Flight Observations and Comparisons

- While SRC did touchdown safely at UTTR, EDL sequence was not nominal
 - Drogue parachute had anomalous deployment
- No instrumentation on board to provide flight data for comparison
 - Radar data was expected from UTTR, but wasn't captured due to difference from estimated and actual trajectory
- Data that can be used for comparison include
 - EDL sequence timeline as it occurred
 - Atmosphere reconstruction day-of from Goddard Earth Observing System (GEOS)
 - Measured touchdown location



Credit: NASA GSFC

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Credit: NASA GSFC

Parachute Anomaly

Drogue diameter: ~0.8m
Main diameter: ~7.3m

Nominal conops for drogue and main parachutes:

Actual sequence of events:

Drogue Parachute
Deployed, Mortar Fire
~32km altitude

~14 seconds after sensed g's are
decreasing and fall below 3-g's

Drogue released
from SRC, Main

~14 seconds after sensed g's
are decreasing and fall below
3-g's

**Parachute anomaly resulted in the SRC experiencing much higher
angles of attack than estimated, affecting the overall EDL timeline**

drogue deployed

to 10k ft mean
sea level (MSL)

Fire

Deploy

MSL

Main Parachute
Deployed
~3000m altitude

Drogue release deploys Main
parachute

Drogue and Main
Deployment nearly
coincident
~2700m altitude

Drogue release deploys Main
parachute

EDL Timeline

Pre-SRC release predicted timeline compared to observed timeline, time since entry interface

Timeline event	1 %-tile [s]	Mean [s]	99 %-tile [s]	Flight Observed [s]	Delta from Mean [s]
Drogue Mortar Fire	129.13	132.57	136.28	330.358	197.788
Main Parachute Deploy	460.86	476.38	484.91	332.228	-144.152
Touchdown	701.48	811.16	934.31	615.1	-196.06

- Drogue deployed much later than estimated due to parachute anomaly
 - Also affects main parachute deploy time
- Touchdown occurred much earlier than estimated

EDL Timeline

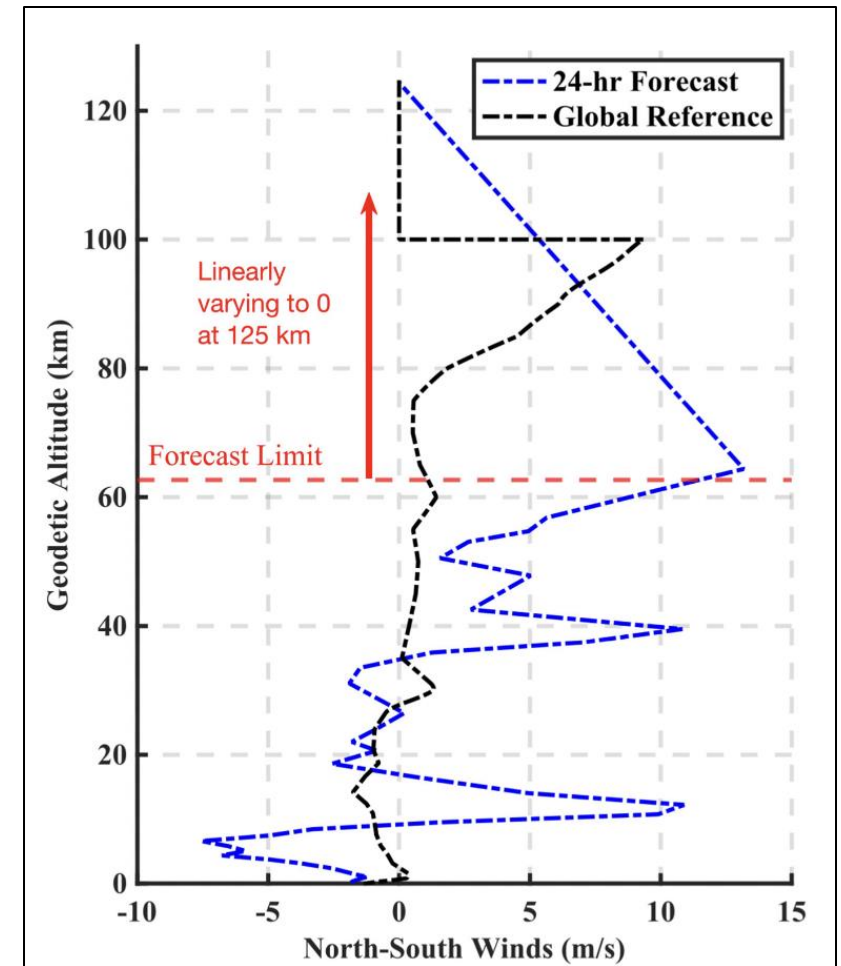
Reconciled SRC release with corrected parachute sequence timeline compared to observed timeline, time since entry interface

Timeline event	1 %-tile [s]	Mean [s]	99 %-tile [s]	Flight Observed [s]	Delta from Mean [s]
Drogue Mortar Fire	380.96	391.56	398.76	330.358	-61.206
Main Parachute Deploy	381.09	391.69	398.89	332.228	-59.466
Touchdown	714.79	788.42	875.94	615.1	-173.32

- Parachute sequence corrected to deploy drogue by pressure transducer
 - **Simulated drogue deploy occurs much closer to observed time**
- Touchdown still occurred much earlier than estimated

Atmosphere Reconstruction from GEOS

- Pre-flight modeling used Earth Global Reference Atmosphere Model (Earth GRAM) 2021 as the baseline for atmospheric quantities
 - GRAM uses historical data aggregated for landing sites of interest (such as UTTR) for atmospheric predictions
 - GRAM is not a forecast model. Thus, GRAM data has large uncertainties and is primarily driven by large-scale historical data
 - OREX used GRAM as that was the mission posture for Stardust too
- Global Modeling and Assimilation Office (GMAO) provides weather forecast models leading up to day of entry utilizing GEOS
- Post-flight reanalysis completed by GMAO to provide reconstruction of atmosphere
- Both pre-flight and post-flight atmosphere data from GEOS showed a lower density than was estimated by Earth GRAM 2021 (EG21)



Comparison of GEOS (24-hr forecast) and GRAM (Global Reference)

Credit: Dutta 2024

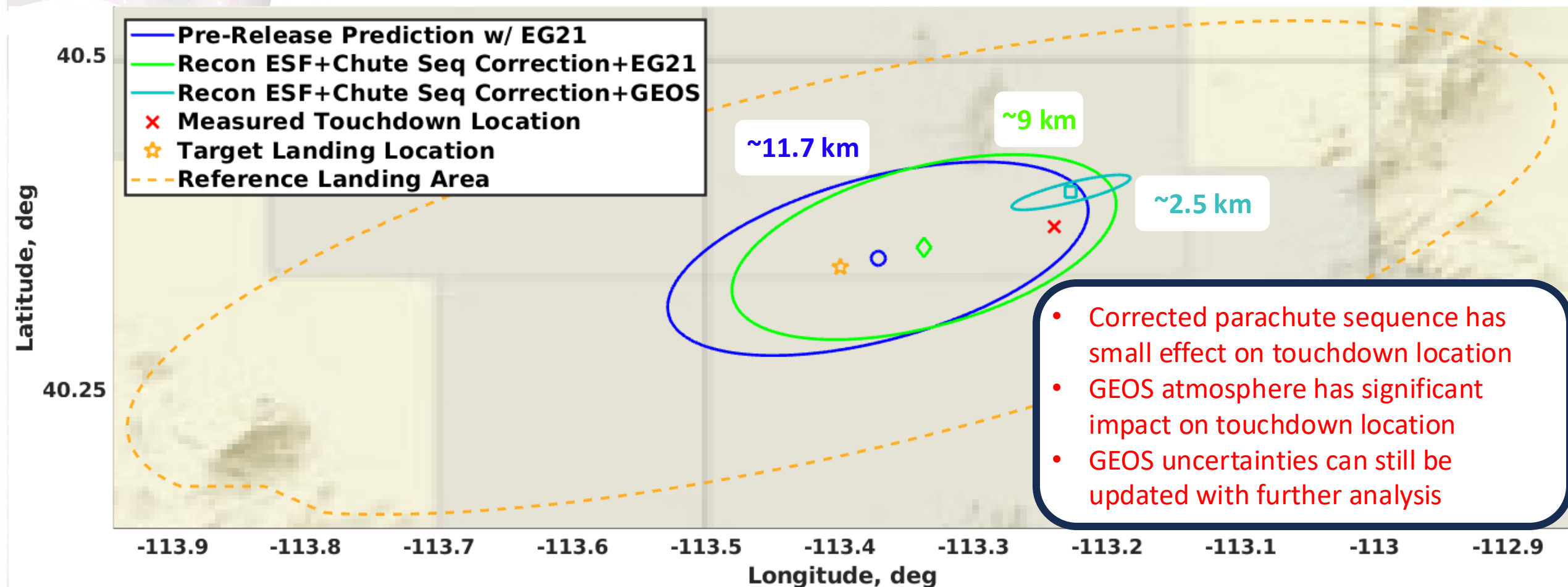
EDL Timeline

Reconciled SRC release with corrected parachute sequence and GEOS atmosphere timeline compared to observed timeline, time since entry interface

Timeline event	1 %-tile [s]	Mean [s]	99 %-tile [s]	Flight Observed [s]	Delta from Mean [s]
Drogue Mortar Fire	380.29	390.92	399.28	330.358	-60.56
Main Parachute Deploy	380.43	391.05	399.41	332.228	-58.82
Touchdown	750.34	782.87	814.55	615.1	-167.77

- Atmosphere has very little affect on EDL timeline
- Touchdown still occurred much earlier than estimated

Measured Touchdown Location



EG21: Earth GRAM 2021

ESF: Entry State File

Summary

- OSIRIS-REx returned a sample from surface near-Earth asteroid Bennu, touching down safely at UTTR on September 24, 2023
- Measured touchdown location was within the preflight predicted 99% landing ellipse
 - Due to less-dense atmosphere and drogue parachute deployment anomaly, touchdown location was ~11.7km from preflight predicted mean landing location
- Reconciliation efforts show parachute anomaly has biggest impact on EDL timeline, while atmosphere differences impact landing location
 - Comparisons to flight observables show parachute anomaly and atmosphere do not account for all differences seen
 - Larger than expected angles of attack experienced resulted in a condensed timeline
 - Current aerodynamic modeling does not show this – more testing data is needed



Credit: NASA GSFC

Acknowledgements

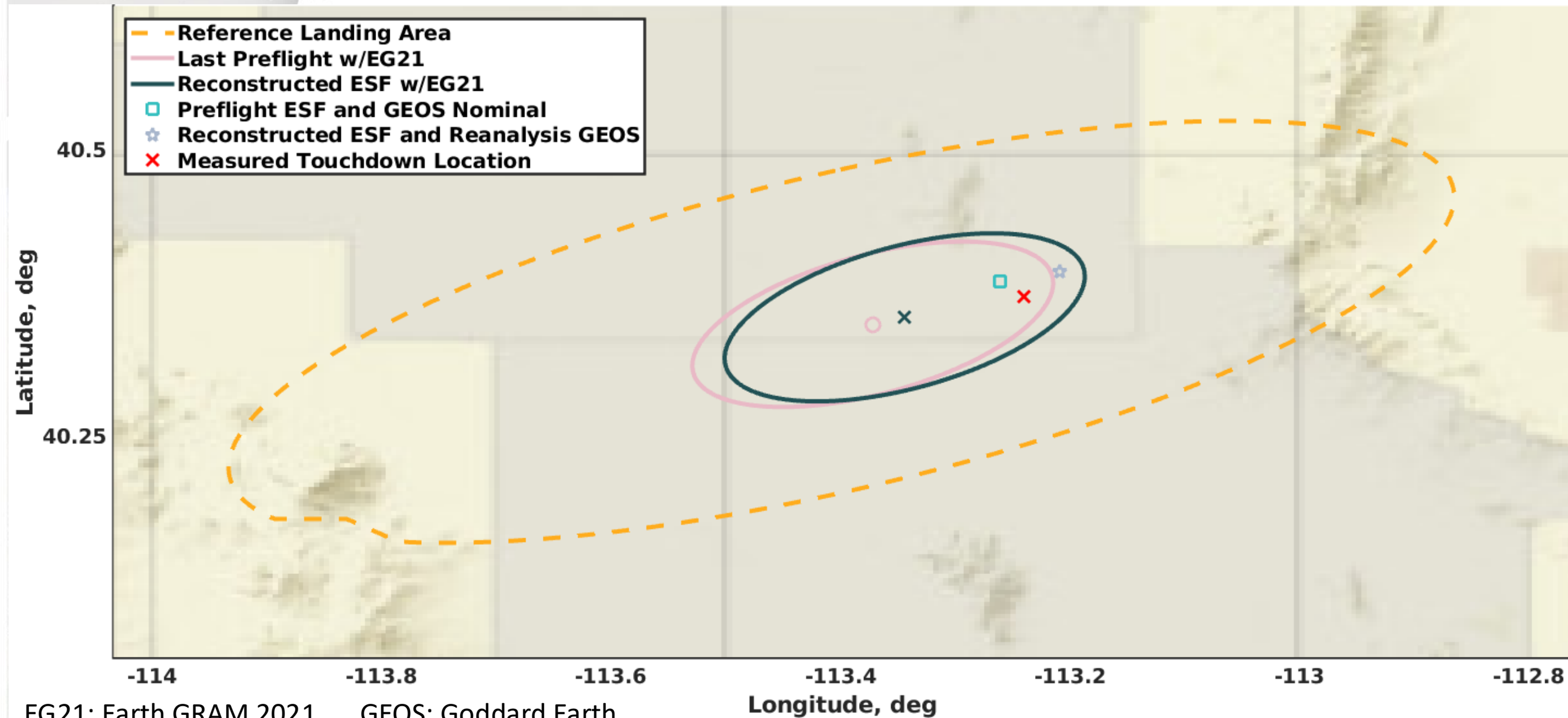
- Authors thank the OREX EDL team from Goddard, Lockheed Martin, KinetX, and NASA Langley
- Special acknowledgements to Mark Johnson and Scott Francis from Lockheed Martin who did independent verification and validation of the EDL performance

Questions



Backup

Pre- and Post-Flight Comparisons



EG21: Earth GRAM 2021
ESF: Entry State File

GEOS: Goddard Earth
Observing System

Latitude, deg

- Last Preflight w/EG21
- Reconstructed ESF w/EG21
- Preflight ESF and GEOS Nominal
- ☆ Reconstructed ESF and Reanalysis GEOS
- ✗ Measured Touchdown Location

40.25

-113.5

-113.45

-113.4

-113.35

-113.3

-113.25

-113.2

-113.15

Longitude, deg

11.7km

9.3km

2.3km

3.6km

GEOS regularly showed a less dense atmosphere at higher altitudes, resulting in landing further East