Use of Forecast Atmosphere for Earth Entry, Descent, and Landing Modeling

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Typical Earth Entry, Descent, and Landing Sequence

Credit: NASA GSFC/LM

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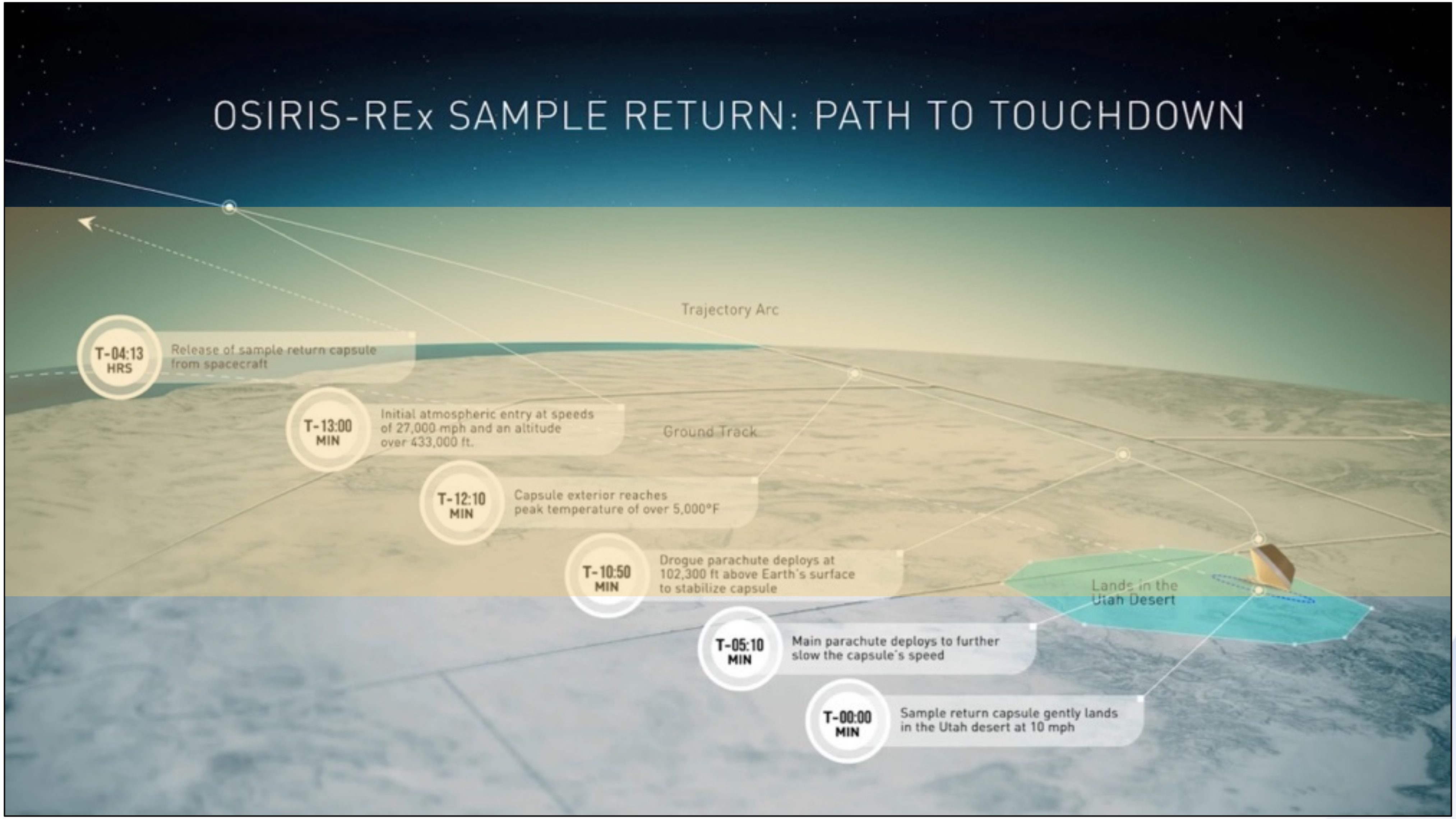

Credit: NASA GSFC/LM

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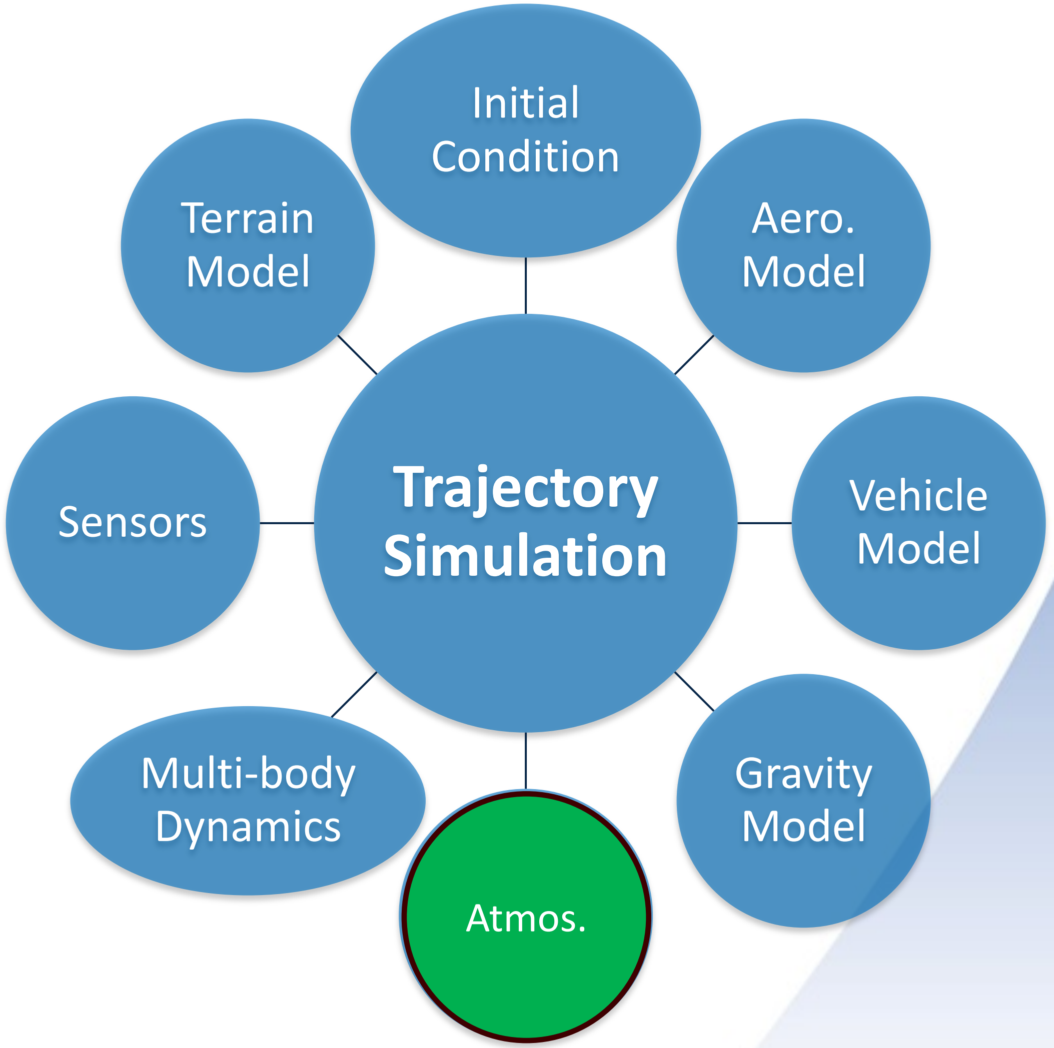
Outline

- Typical Atmospheric Modeling
- Forecast Models
- Motivation Behind Forecast Models
- Recent Results
- Implementation in Modeling and Simulation
- Use for Post-flight Analysis
- Conclusions

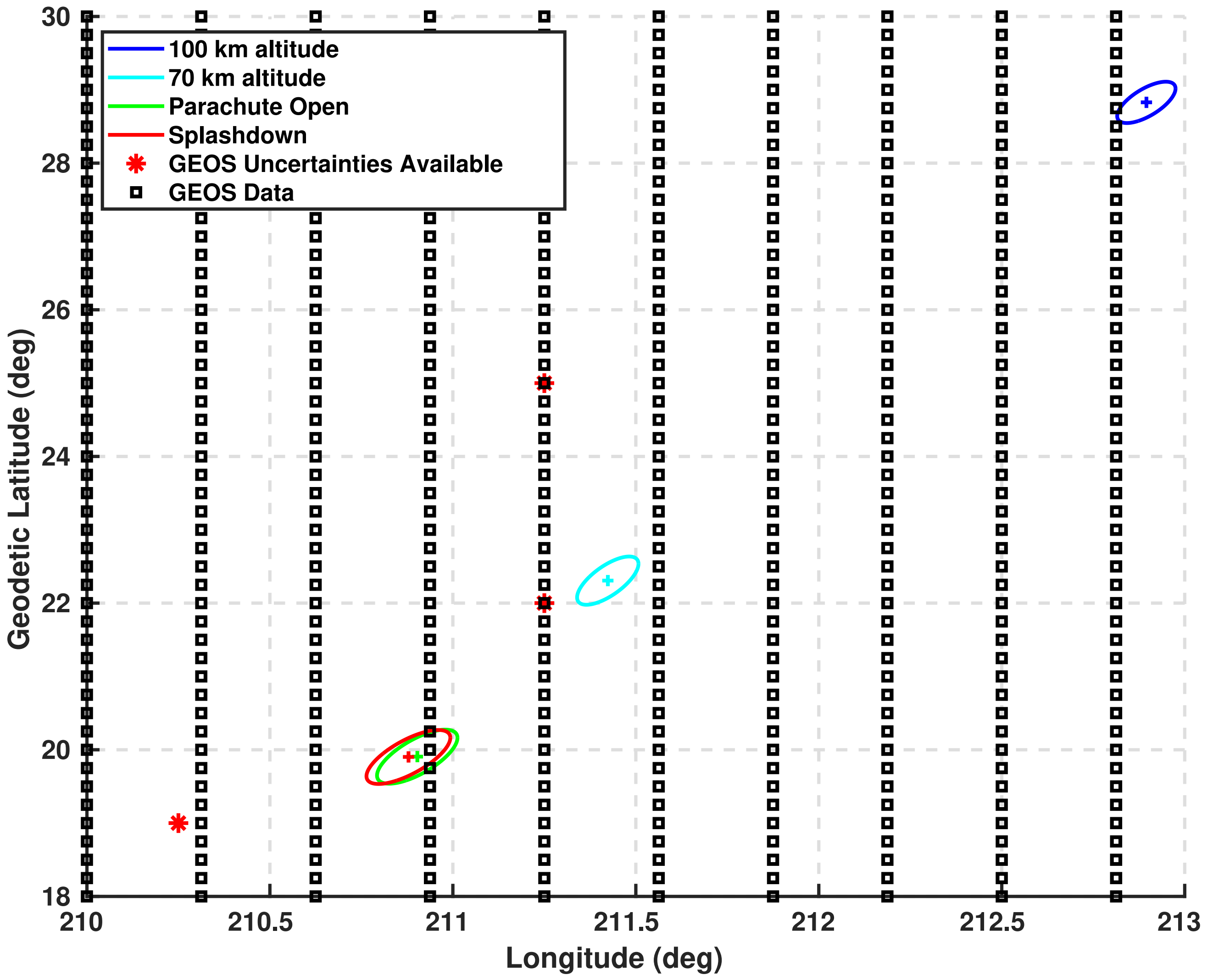
Typical Atmospheric Modeling

- **Flight mechanics simulations incorporate various models to create predictions for flight performance**
- **Atmospheric models frequently used:**
  - 1976 U.S. Standard Atmosphere
  - Tabulated range specific atmosphere
  - Global Reference Atmosphere Model (GRAM)
  - Climate Databases (e.g. those created by Laboratoire de Météorologie Dynamique)
- **Data for typical atmospheric models are based on historical averages**
- **Atmospheric models can be flexible and can give atmospheric estimates for a large number of locations across the globe and at various times far into the future**



Forecast Models

- **Forecast models utilize more recent atmospheric measurements (e.g. balloon data from yesterday, buoy data from ocean) and assimilates the data before running a climate forecast model. Think Computational Fluid Dynamics for atmosphere**
- **Predictions typically made several times a day (at 0000 UTC, 1200 UTC, etc.) for different times of the day (e.g. forecast for 0600 UTC)**
- **Can be several days in advance (24-hr forecast, 48-hr, 5-day forecast etc.)**
- **Examples of forecast models:**
  - Global Forecast System (GFS)
  - European Centre for Medium-Range Weather Forecasts (ECMWF)
  - Goddard Earth Observing System Version 5 (GEOS-5)
- **Predictions for atmospheric properties (temperature, pressure, density, winds, some chemical properties) available for a grid around the world**



UTC = Coordinated Universal Time

Select Recent Results

Credit: NASA

LDSD SFDT1 (2014)

LDSD SFDT2 (2015)

LDSD = Low Density Supersonic Decelerator

SFDT = Supersonic Flight Dynamics Test

ASPIRE = Advanced Supersonic Parachute Inflation Research Experiment

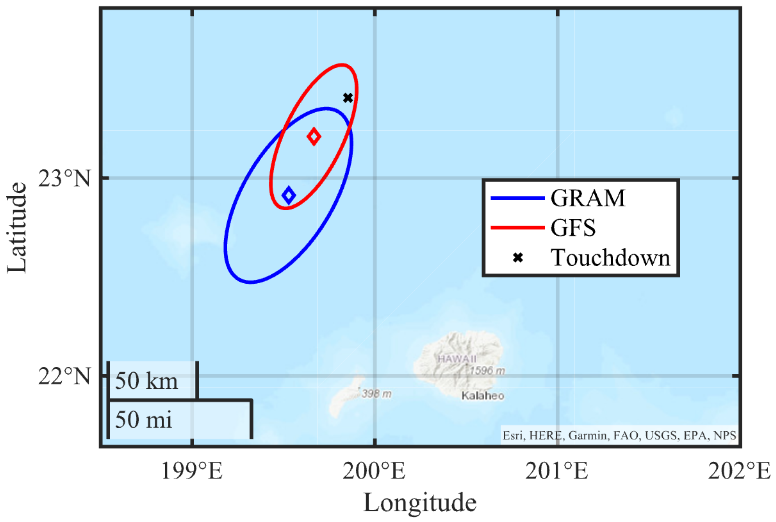
SR = Sounding Rocket

ASPIRE SR01 (2017)

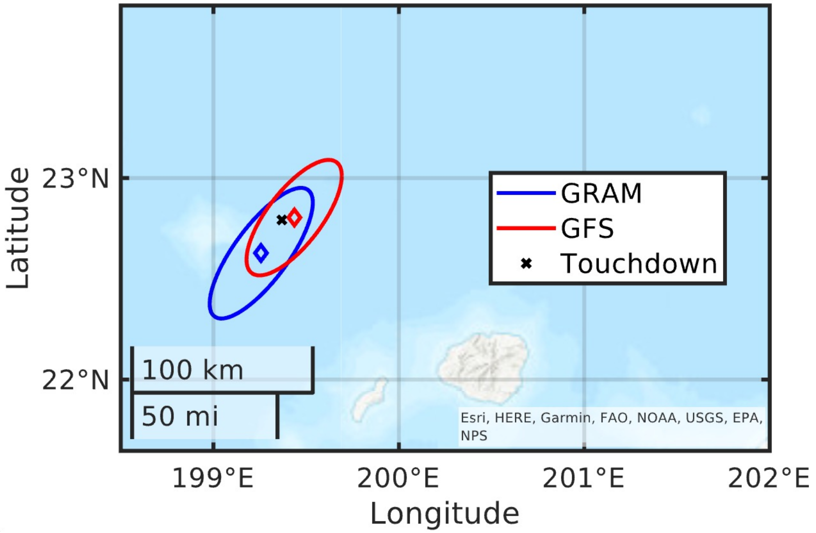
ASPIRE SR02 (2017)

ASPIRE SR03 (2018)

Select Recent Results



LDSD SFDT1 (2014)



LDSD SFDT2 (2015)

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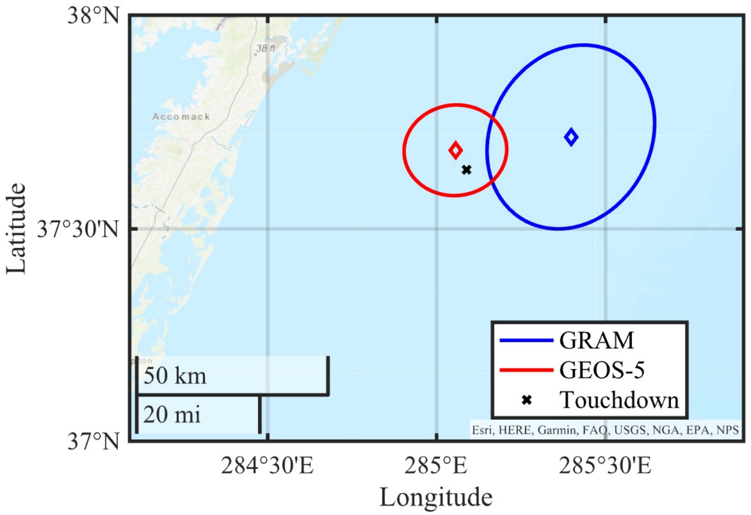
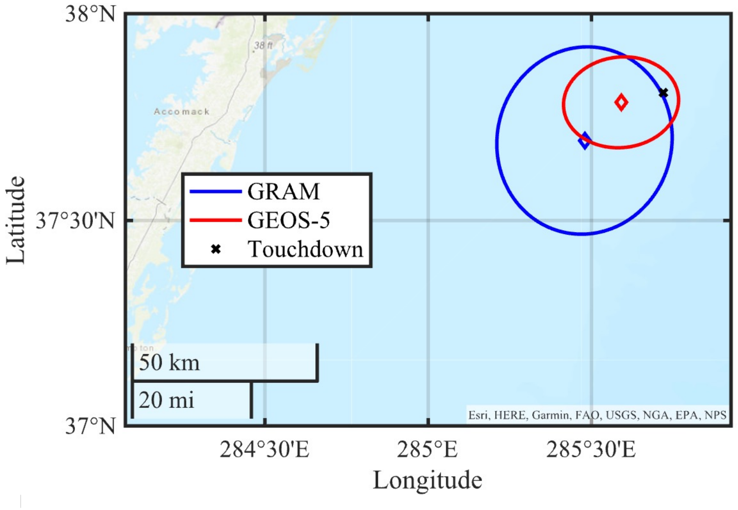
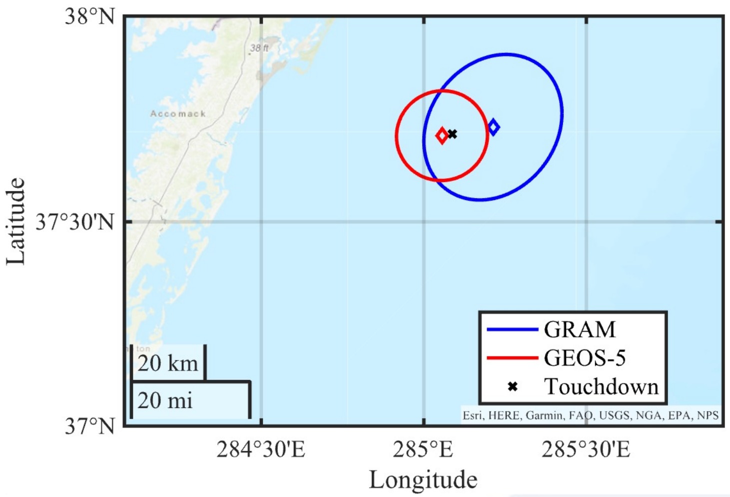


ASPIRE SR01 (2017)

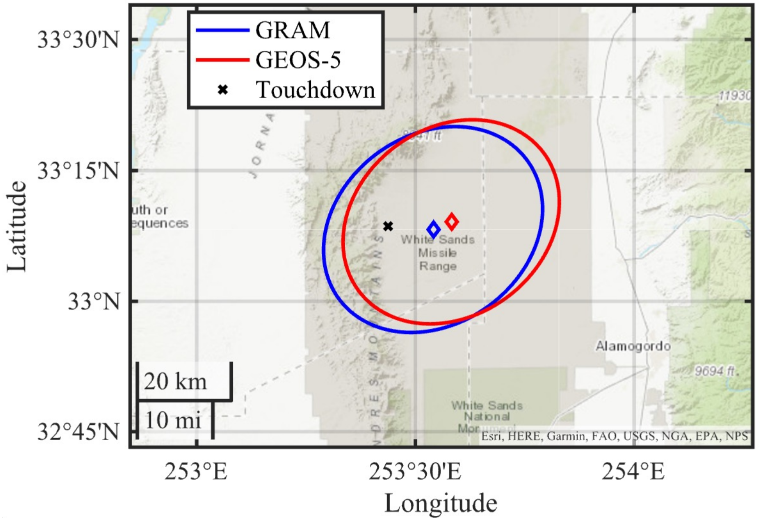


ASPIRE SR02 (2017)

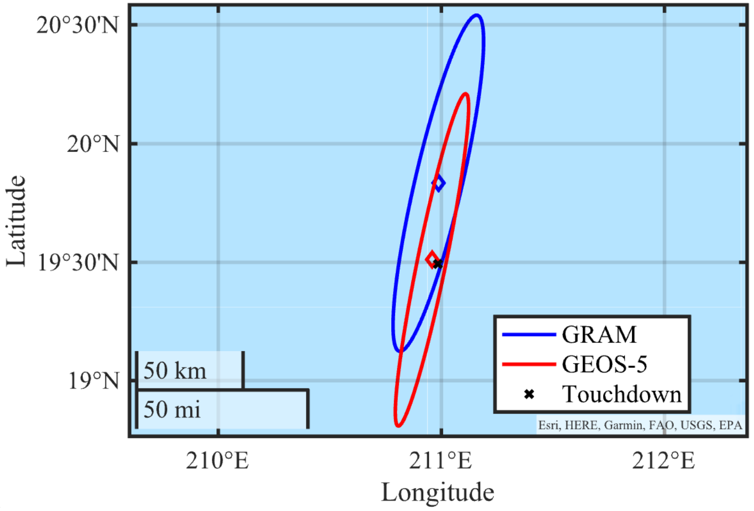


ASPIRE SR03 (2018)

Select Recent Results



ADEPT SR-1 (2018)



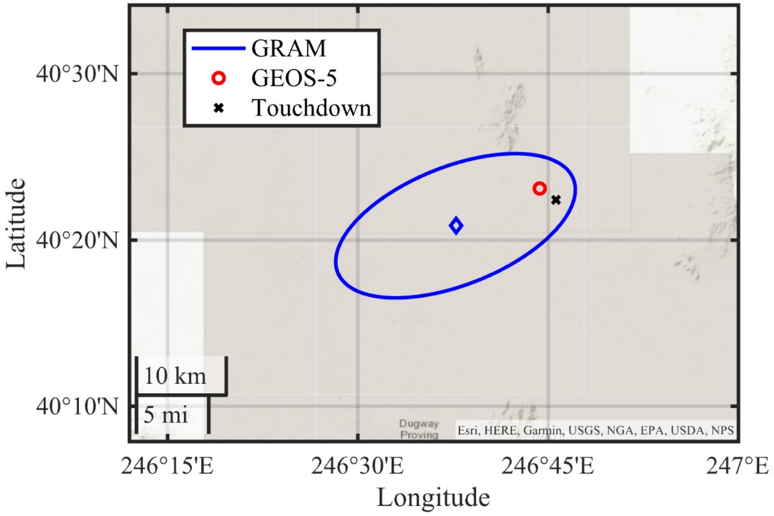
LOFTID (2022)

ADEPT = Adaptable Deployable Entry and Placement Technology

LOFTID = Low-Earth Orbit Flight Test of an Inflatable Decelerator

OSIRIS-REx = Origins, Spectral Interpretation, Resource Identification, and Security – Regolith Explorer

SR = Sounding Rocket



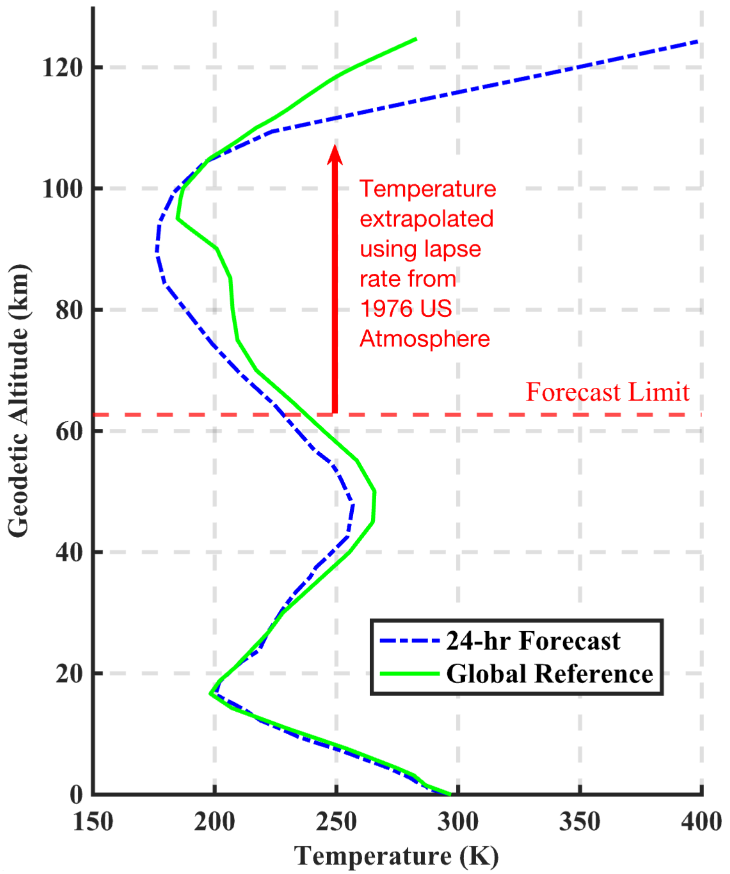
OSIRIS-REx (2023)

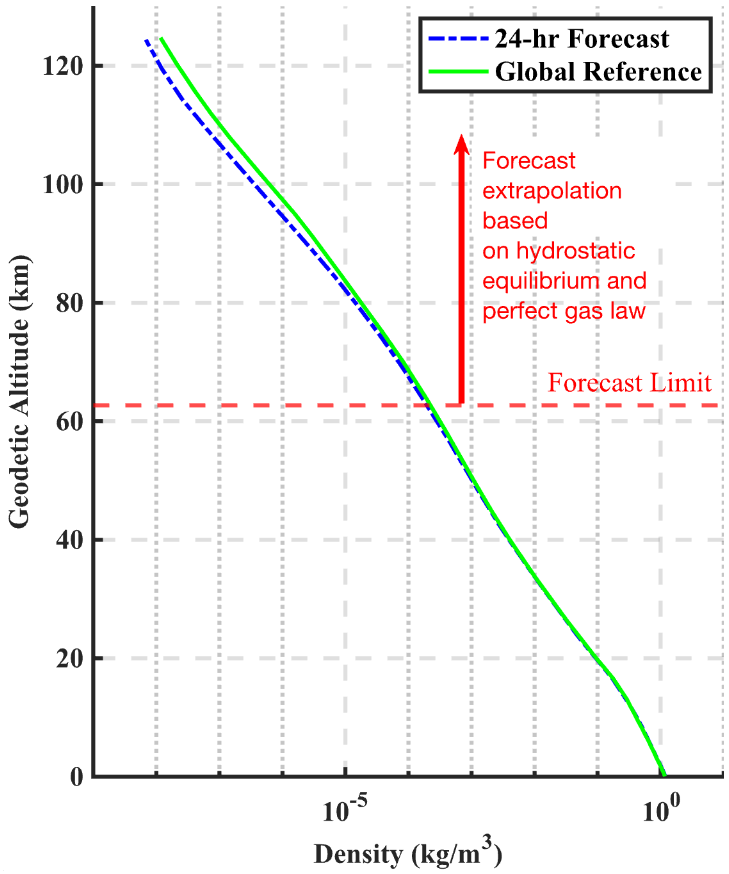
Select Recent Results

Mission	Year	Landing to prediction distance (km)		Location	Comments
		Global Reference	Forecast		
LDSD SFDT1	2014	63.821	28.778	Hawaii, PMRF	Vehicle had a parachute failure and performed off-nominally. Both predictions are no parachute
LDSD SFDT2	2015	21.623	7.045	Hawaii, PMRF	Vehicle had a parachute failure and performed off-nominally. Both predictions are no parachute
ASPIRE SR01	2017	28.585	5.785	Virginia, Wallops	
ASPIRE SR02	2018	24.755	11.607	Virginia, Wallops	Flight was launched 4 later hours than the original plan due to concerns about sea states.
ASPIRE SR03	2018	11.218	2.774	Virginia, Wallops	
ADEPT SR-1	2018	9.692	13.57	New Mexico, White Sands	Vehicle tumbled after Mach 0.2.
LOFTID	2022	38.043	3.411	Pacific Ocean off-coast Hawaii	
OSIRIS-REx	2023	11.48	2.214	Utah, UTTR	Drogue parachute timing was off-nominal, but the vehicle did land successfully on the main parachute.

PMRF = Pacific Missile Range Facility
UTTR = Utah Test and Training Range

Implementation in Modeling and Simulation Tools





- **Forecast data are often based on pressure level grid (e.g. 0.001 Pa is the highest level) and will have a top altitude that can vary day-to-day, e.g. a cold-day vs. a hot-day**
- **Top altitudes are in the range of 60 km – 80 km depending on the model**
- **Atmospheric interface for most Earth projects is 125 km**
- **Solutions:**
  - Use auxiliary profiles within global reference models, like GRAM, and let the model blend the data
  - Use 1976 Standard atmosphere’s lapse rate (change in rate of temperature with altitude) to extend the temperature up to atmospheric interface and then use hydrostatic equilibrium and perfect gas law
- **Winds also extended to the atmospheric interface using heuristics (could assume 0 winds when no forecast, allow global model to blend, or linearly blend to 0 winds at the interface point)**

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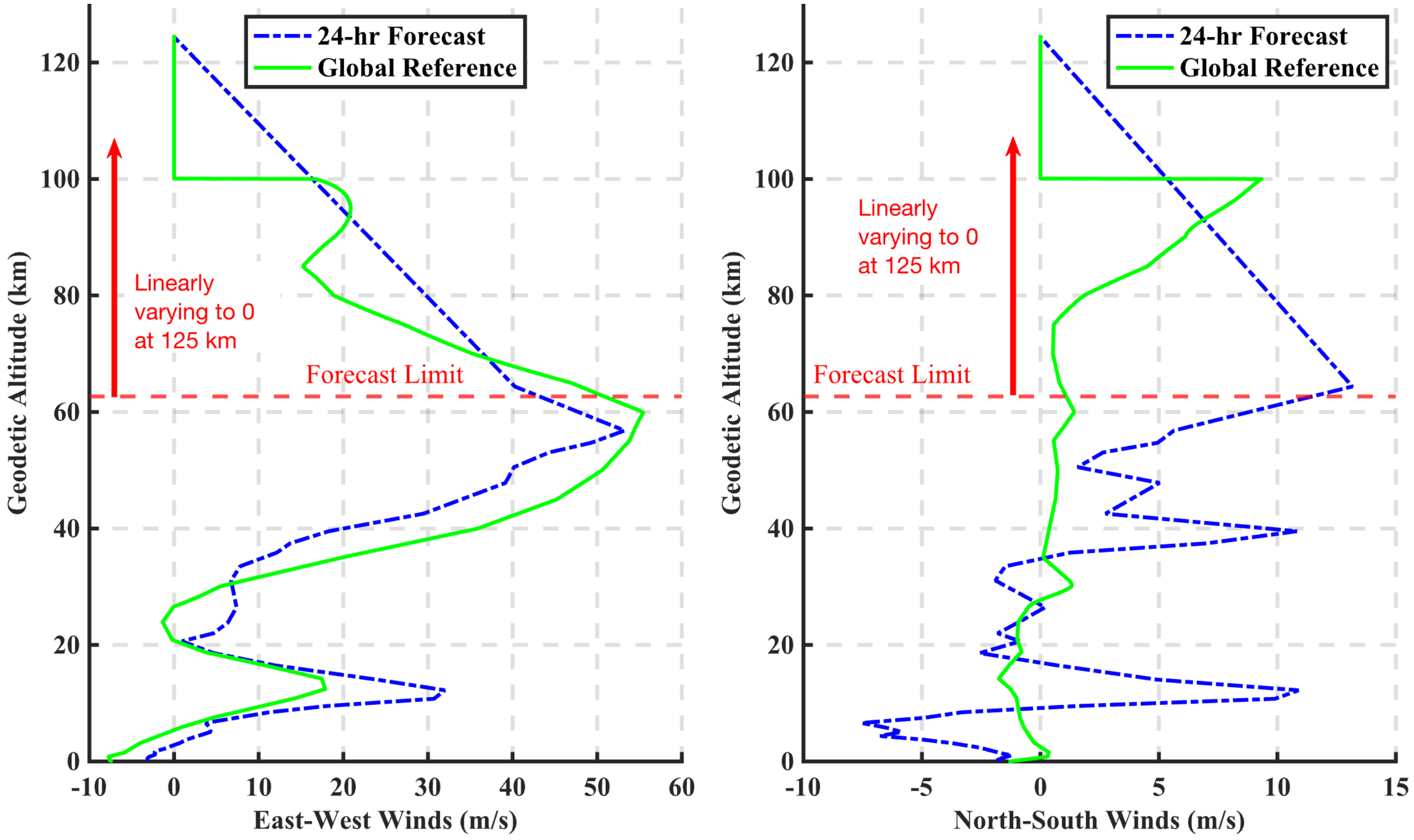

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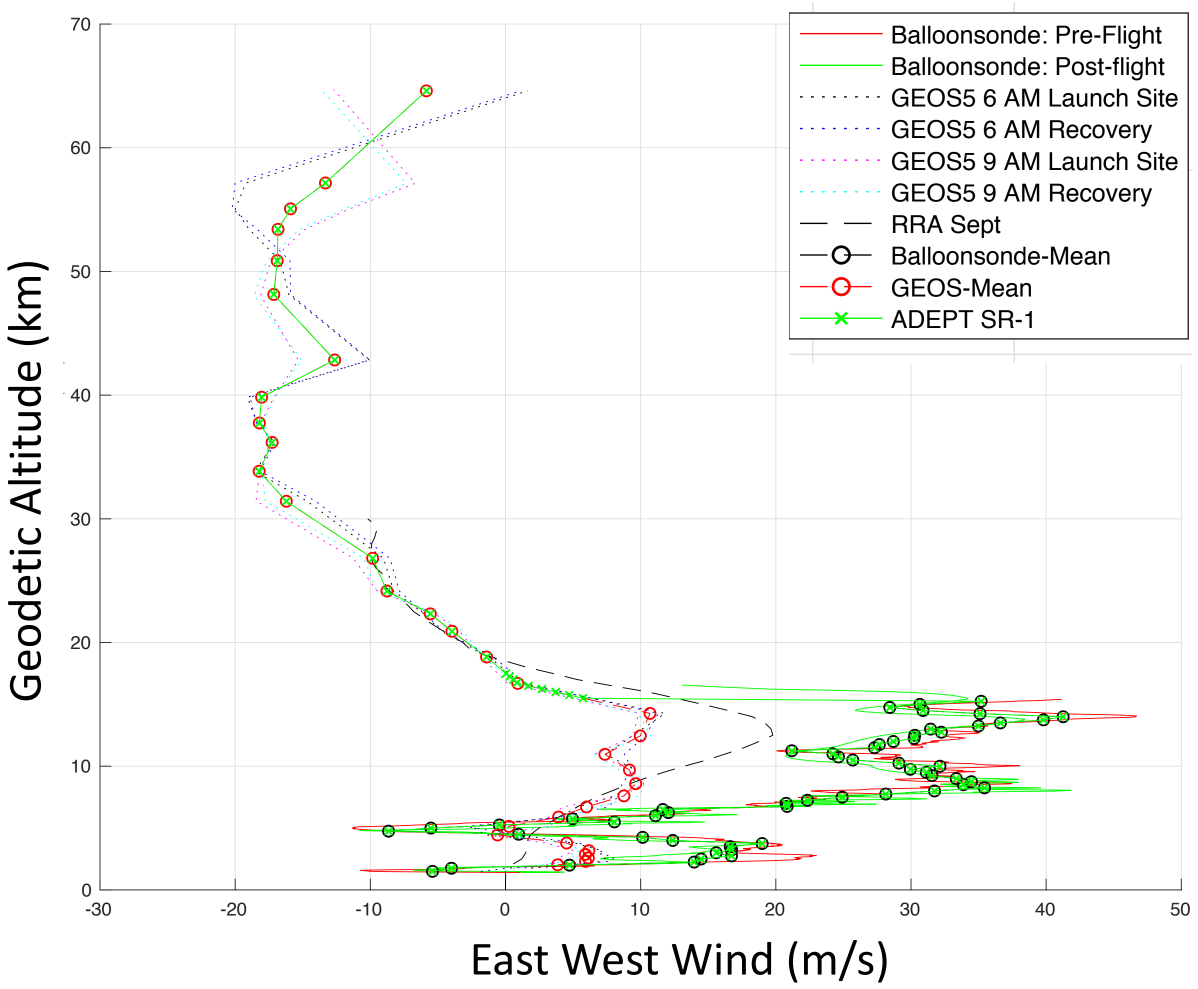
Note: Future GRAM updates will have a method to read forecast model outputs

Use for Post-Flight Analysis



- Forecast modelers often create <u>reanalysis</u> products. Think of what is the updated value from the model after data at the current time has been assimilated
- Reanalysis products can be combined with atmospheric data from flight (e.g. balloon data for the lower atmosphere) to create a reconstruction of the atmosphere
- Using post-flight atmospheric estimates in modeling and simulation results have been shown to reconcile models with flight observables

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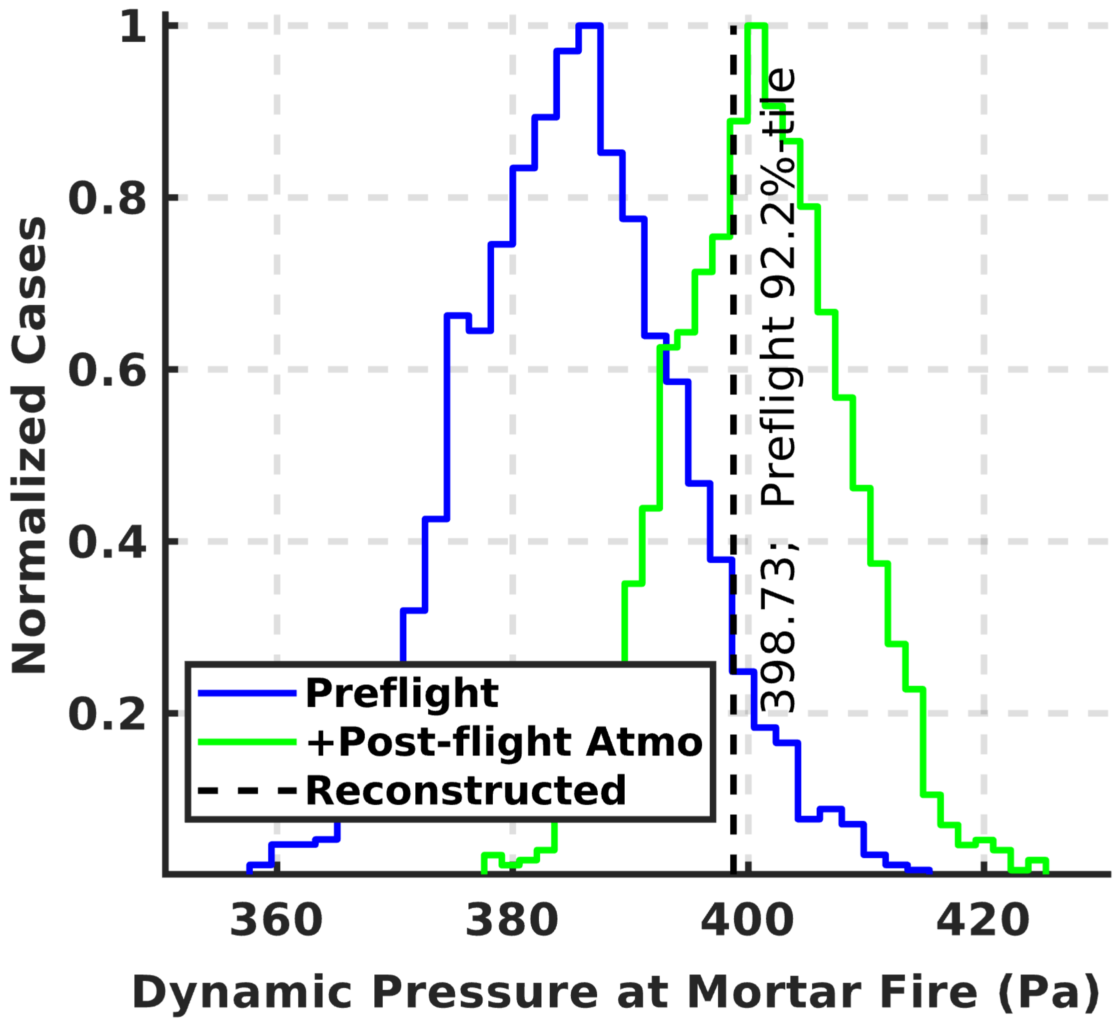

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Conclusions

- **Typical Earth Entry, Descent, and Landing modeling involves atmospheric models, like Global Reference Atmosphere Model, 1976 U.S. Standard atmosphere etc., which are useful for initial phases of flight planning**
- **For operations, forecast atmosphere models can capture late-breaking atmosphere and improve performance and landing predictions**
- **Recent flight examples since 2014 have shown forecast atmospheres, such as GFS and GEOS-5, have provided very accurate landing predictions compared to global reference models like GRAM**
- **Reanalysis products created by forecast atmosphere modelers can be helpful for post-flight analysis**

Questions