Orion versus Poseidon: Understanding How NASA¹s Crewed Capsule Survives Nature's Fury

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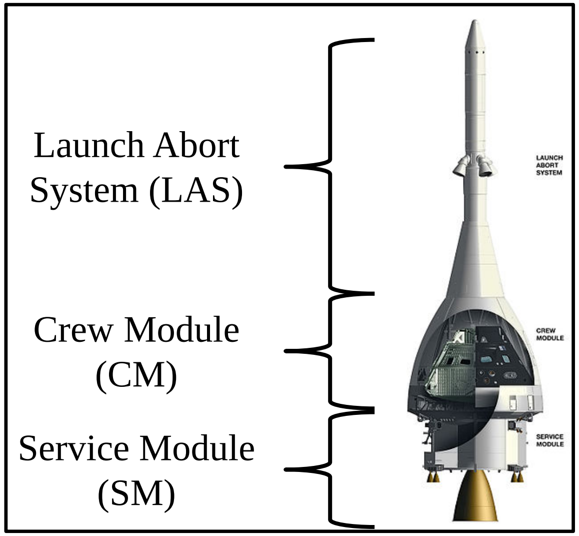
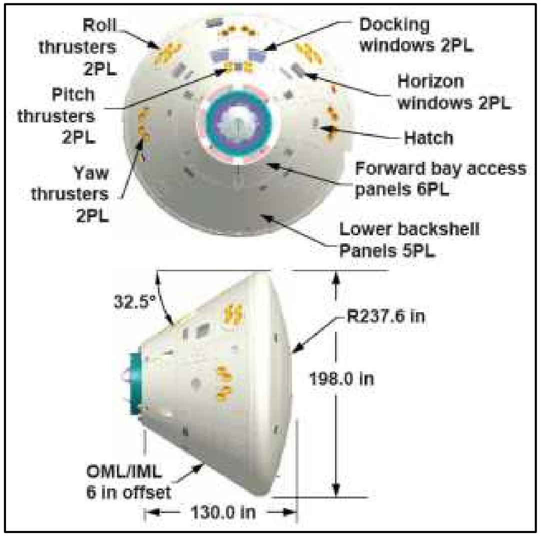
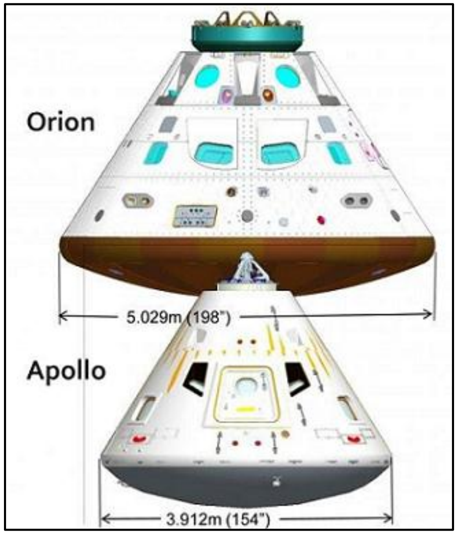
Outline

- Description of the Multi-Purpose Crew Vehicle Program’s (MPCV’s) Orion Vehicle
- Introduction to Natural Environments
- Examples of Terrestrial Environments Support
  - Design
  - Test
  - Mission
- Summary

Orion Description







- Designed to carry astronauts beyond low-Earth orbit.
- Originated during NASA's Constellation Program.
- Undergoing various tests.
  - Underway Recovery Test (URT)
  - Capsule Parachute Assembly System (CPAS) drop tests
  - Exploration Flight Test (EFT) – 1
  - Ascent Abort 2 (AA2)
  - Exploration Mission (EM) – 1 and EM – 2

http://www.nasaspaceflight.com/2012/07/nasa-esd-key-orion-requirement-lunar-missions/

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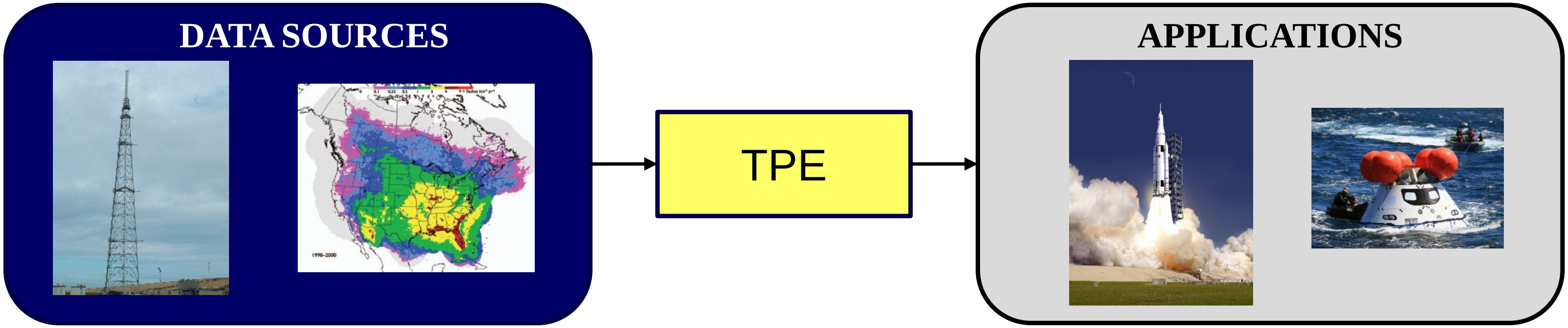
Introduction to Natural Environments

Natural Environment Concerns

- The “Natural Environment” is a phenomena that occur regardless of human constructed objects.
- Vehicles are exposed to the natural environment throughout any mission.
- Mission phase and potential environmental considerations.
  - Pre-launch (ground winds, temperature, moisture, lightning, ionizing radiation)
  - Launch (ground and near-surface winds, visibility, lightning)
  - In-flight (winds aloft, atmospheric density, space environments, ionizing radiation, plasma, spacecraft charging)
  - Entry and descent (winds aloft, atmospheric density)
  - Landing and recovery (ground winds, visibility, sea conditions)
- Lifecycle consists of vehicle design and operation.
  - Robust design implies fewer operational constraints, but higher upfront cost.
  - Operational constraints are implemented when design is insufficient.
  - Design process must predict how the vehicle will be operated.
- Meteorological climatologies provide data to use in design phase, and one must address the same data during operations (e.g., wind constraint).

MSFC NE Terrestrial and Planetary Environments Team

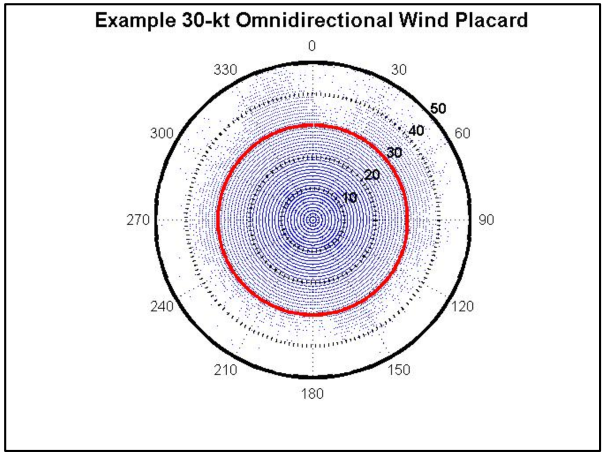
- Terrestrial and Planetary Environments (TPE) Team is part of the Marshall Space Flight Center Natural Environments (MSFC NE) Branch.
- Serve as a bridge between meteorological data collection sources and engineering analyses.
- Obtain and maintain meteorological archives.
  - Instrumentation at flight ranges and other sites of interest.
  - Global climatologies.
  - Implements quality control procedures and processes data for interrogation.
  - Develop in-house datasets and models.
- Define environment criteria for vehicle design.
- Provide tailored assessments to the engineering community for specific applications.

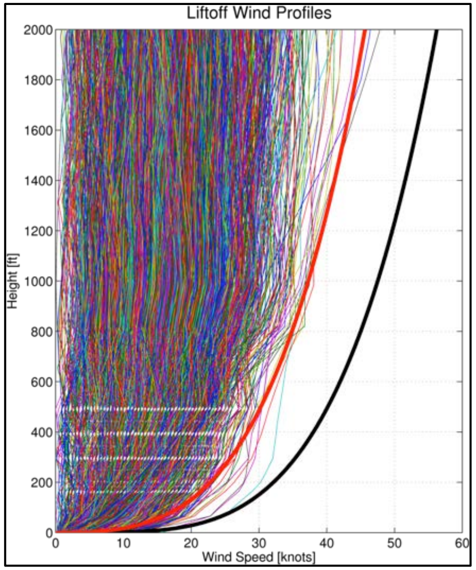


Examples of Support during Vehicle Design

Launch Wind Constraint

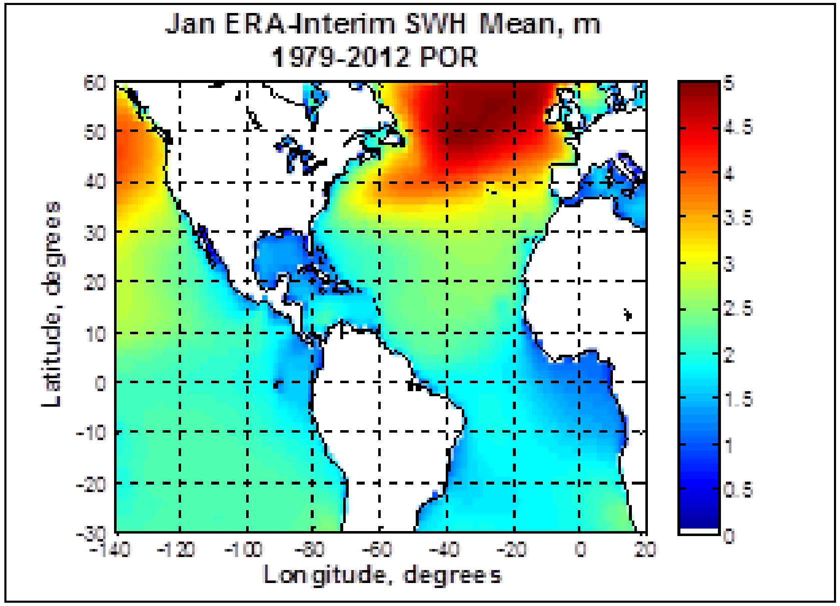
- Wind constraint is defined at 18.3 m, and depends on wind direction.
  - Adjust constraint based on vehicle sensitivities.
  - Process generates a constraint versus wind direction.
- Space Launch System (SLS) is designed to a peak wind profile based on a measurement at 18.3 m.
  - Log profile that envelopes winds given an 18.3 m wind.
  - Compare to measurements.
- Threshold determined during design evaluated on day-of-launch (several exist).
- SLS constraints apply to Orion for launch commit.





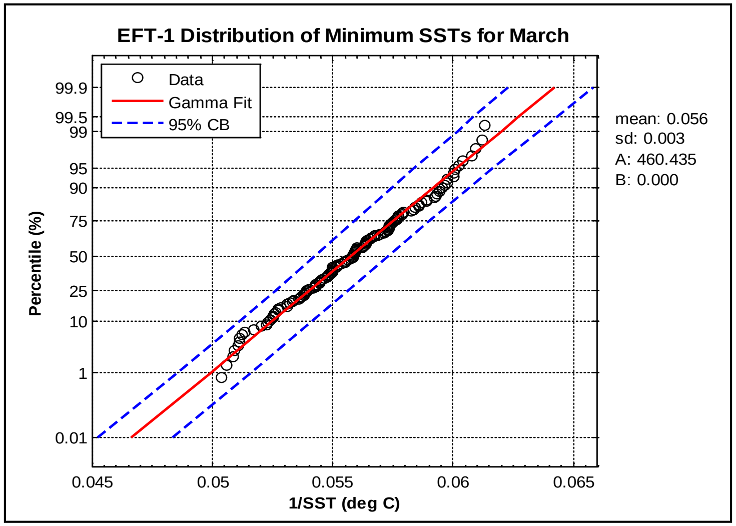
Defining Sea Conditions

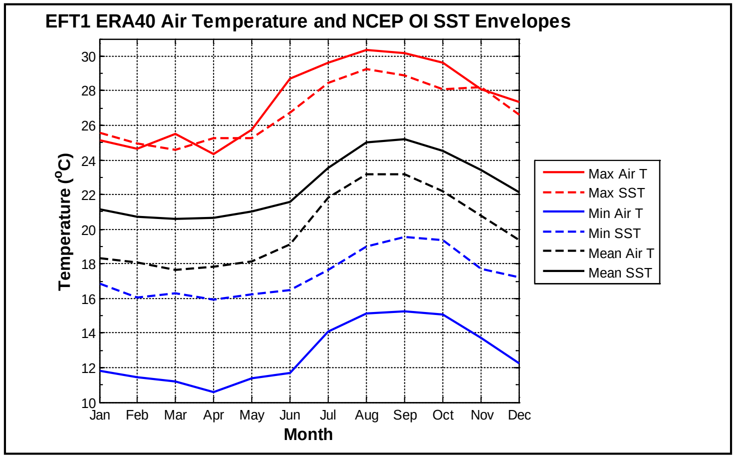
- Sea conditions influence the CM's landing and recovery limits.
- Usually do not apply to launch vehicles.
- Parameters of interest.
  - Significant wave height (SWH)
  - Wave period
  - Wind speed
- Use global climatologies to derive the probability of not exceeding specified constraints.
- Define constraints based on practical thresholds and probability of occurrence.



Temperature for CMUS Helium Tanks

- Composite Overwrapped Pressure Vessels (COPVs) store helium to inflate CMUS bags.
  - Amount of helium needed to inflate the CMUS bags increases as temperature decreases.
  - Excessive helium exerts too much pressure on the COPV.
- Initial requirement was to fill bags at -2°C.
- Performed analysis using multiple global climatologies to support increasing the ambient temperature threshold to 10°C for EFT-1.





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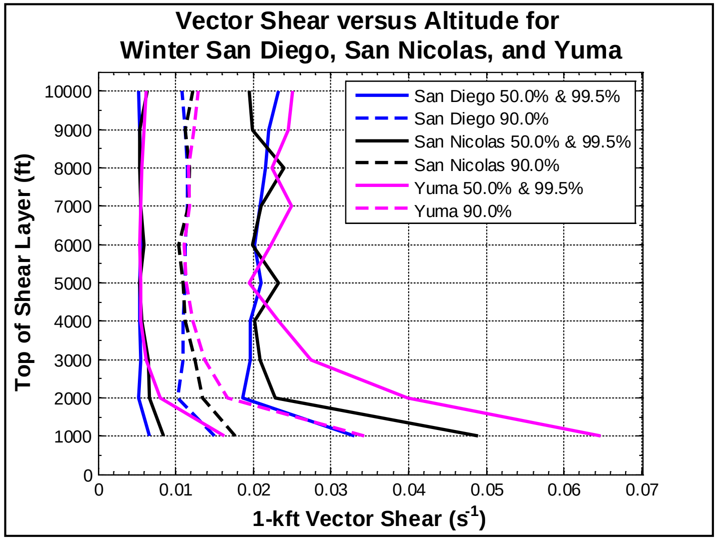
Examples of Orion Test Support

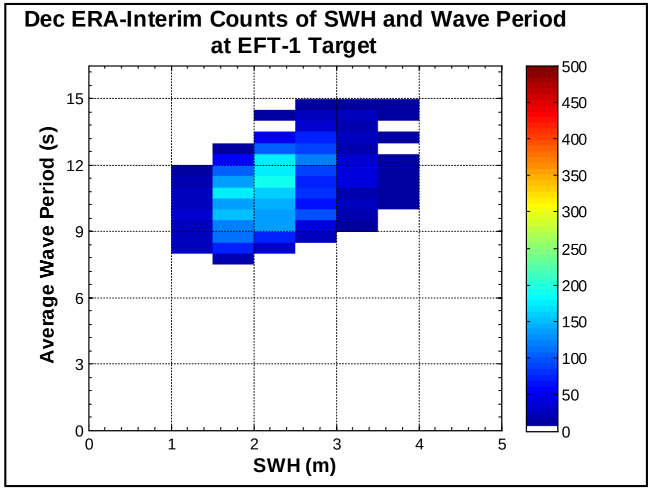
Wind shear analysis for CM Descent

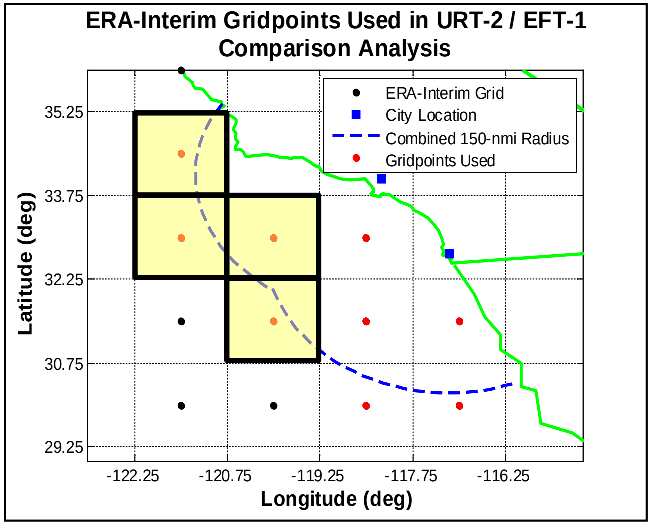
- CM can swing in various oscillatory modes late in descent.
- Compared wind shears from CPAS test site (Yuma, AZ) to near-shore locations.
  - Could shears generated near mountains exist at landing site?
  - Used balloon archives.
  - Found some differences below 5,000 ft.
  - Little differences where modes would start (as high as 10,000 ft).
- Verified balloon measurement accuracy.



Determining Optimal URT Locations

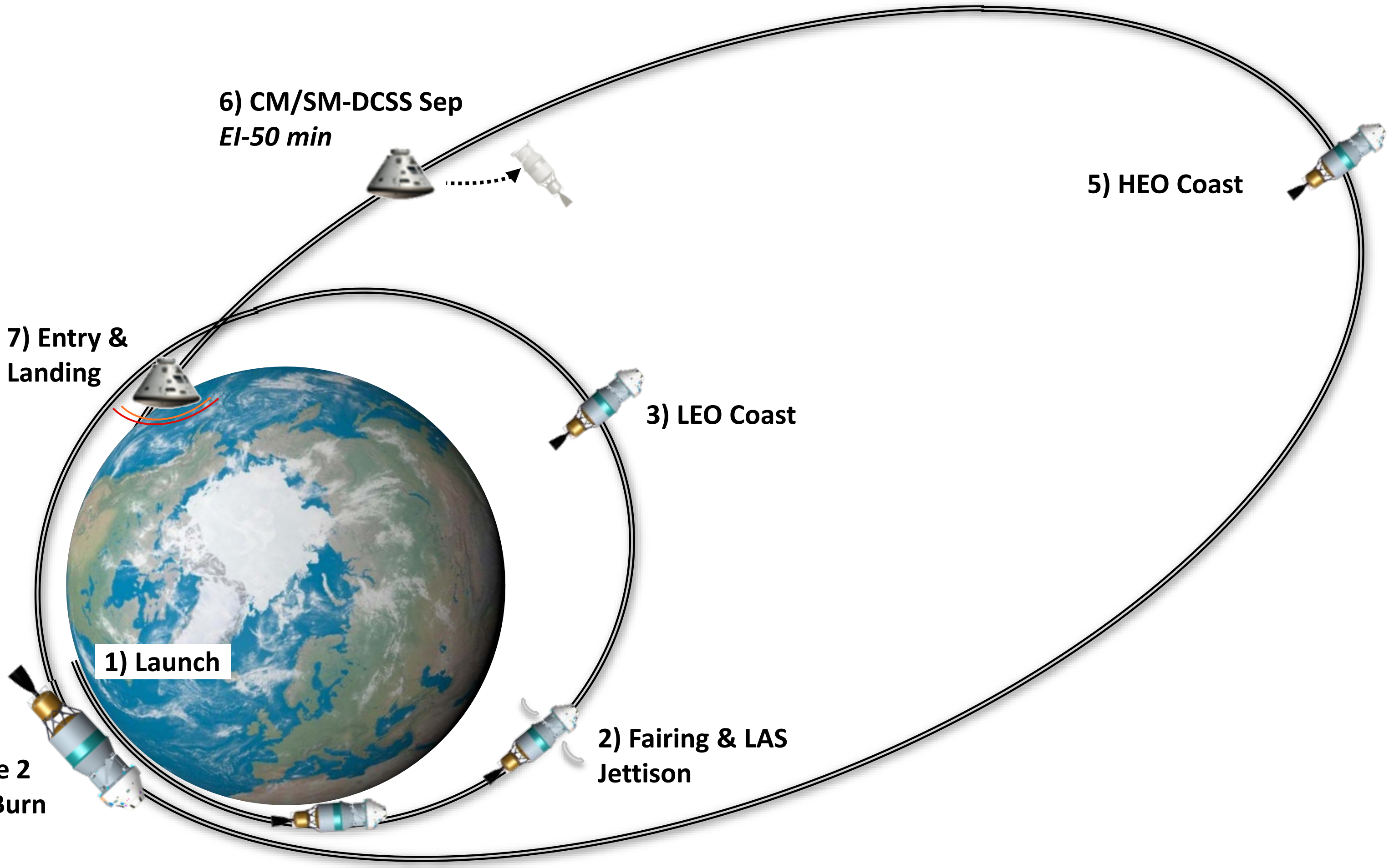
- Orion recovery personnel performed URTs leading up to EFT-1 off the CA coast.
  - EFT-1.
  - Off-nominal conditions.
- MSFC NE received request to quantify locations within the URT zone that climatologically best represent conditions at the EFT-1 site.
- Generated difference maps of concurrent SWH and average wave period counts between each gridpoint within the URT zone and the EFT-1 site.
  - Computed root mean square (RMS) difference from EFT-1 at each gridpoint.
  - Determined which gridpoints had lowest RMS differences.
- Concluded that testing in the west-northwest regions of the URT zone would likely best replicate EFT-1 conditions.
- Included caveat that this analysis is only based on climatology, and not any forecast.





Examples of Orion Mission Support

EFT-1 Mission Overview:

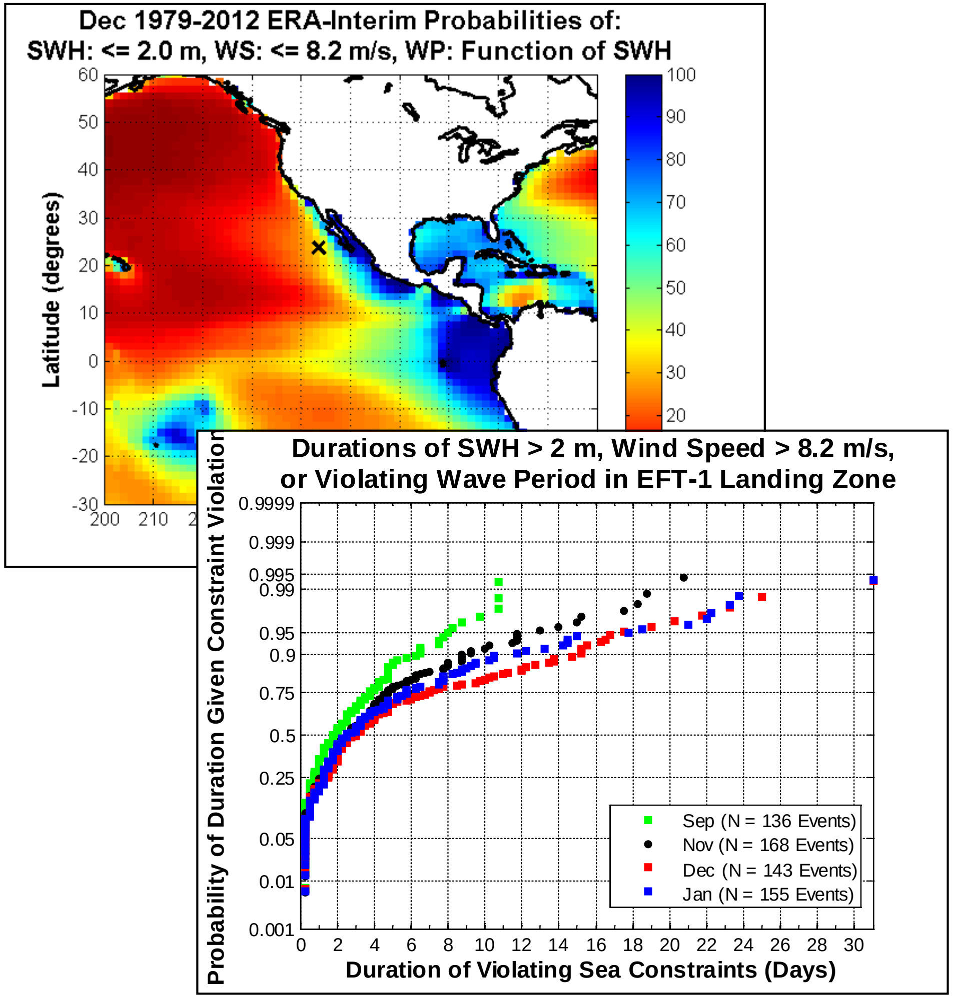


Delta IV Heavy
- 3 Common Booster Core
- DCSS Upper Stage

Objectives
- Demonstrate core CM systems performance
- Demonstrate high energy entry (~9 km/s) and TPS performance
- Demonstrate integrated entry, descent, and landing operations

EFT-1 Landing Availability

- For EFT-1, nominal landing conditions had to be met at launch.
- EFT-1 site exists within gradient of good and poor sea conditions.
- Questions arose relating to launching if landing conditions were marginally "no-go" at launch time.
  - "If we are no-go now, will we be no-go at landing?"
  - Requires climatological and forecast input.
- MSFC NE assessed the probability of violating sea condition constraints for specified durations.
  - Provides likelihood for staying no-go for a certain time.
  - Violating conditions persist longest during December.



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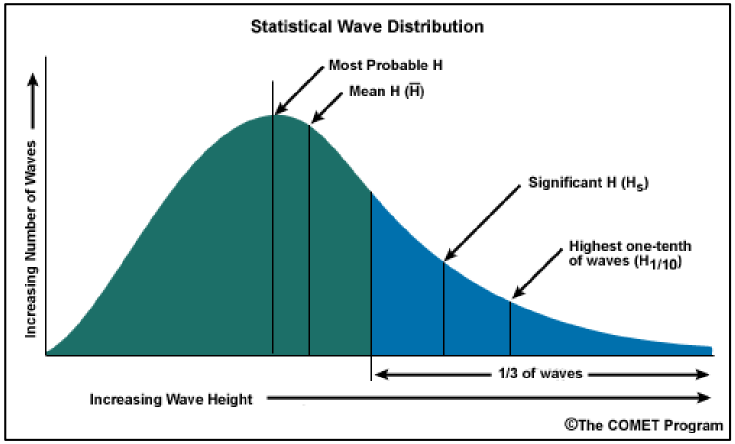
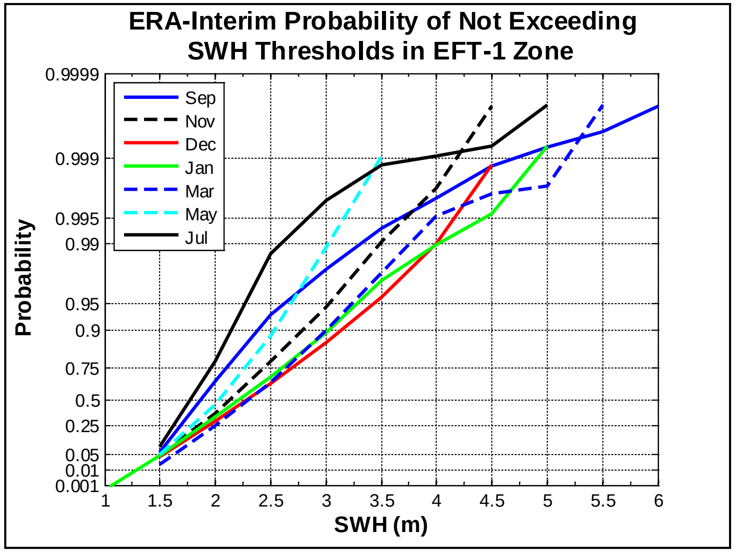
EFT-1 and Significant Wave Height

- SWH description
  - Represents average of the highest 1/3 of waves.
  - Computed directly from wave spectrum.
- SWH does not apply to Orion landing design, but is important for recovery operations.
- Recovery threshold is typically near 2 m SWH, but captain makes decision.
- EFT-1 originally scheduled for September, but moved to December, which led to accounting for higher seas.
- MSFC NE provided the probability of not exceeding different SWH for different months to MPCV.
  - Produces consequence of adjusting SWH limit.
  - Shows distribution of SWH for different months to support possibility of moving mission.





http://www.meted.ucar.edu/marine/mod1_wv_type_char/frameset.htm

Videos

- EFT-1 End-of-Mission recovery (1:00-2:30, 4:30-5:30)

https://www.youtube.com/watch?v=PbRgTRSdBLg

- What could happen if we're not careful…

https://www.youtube.com/watch?v=A1lqHRufgI8

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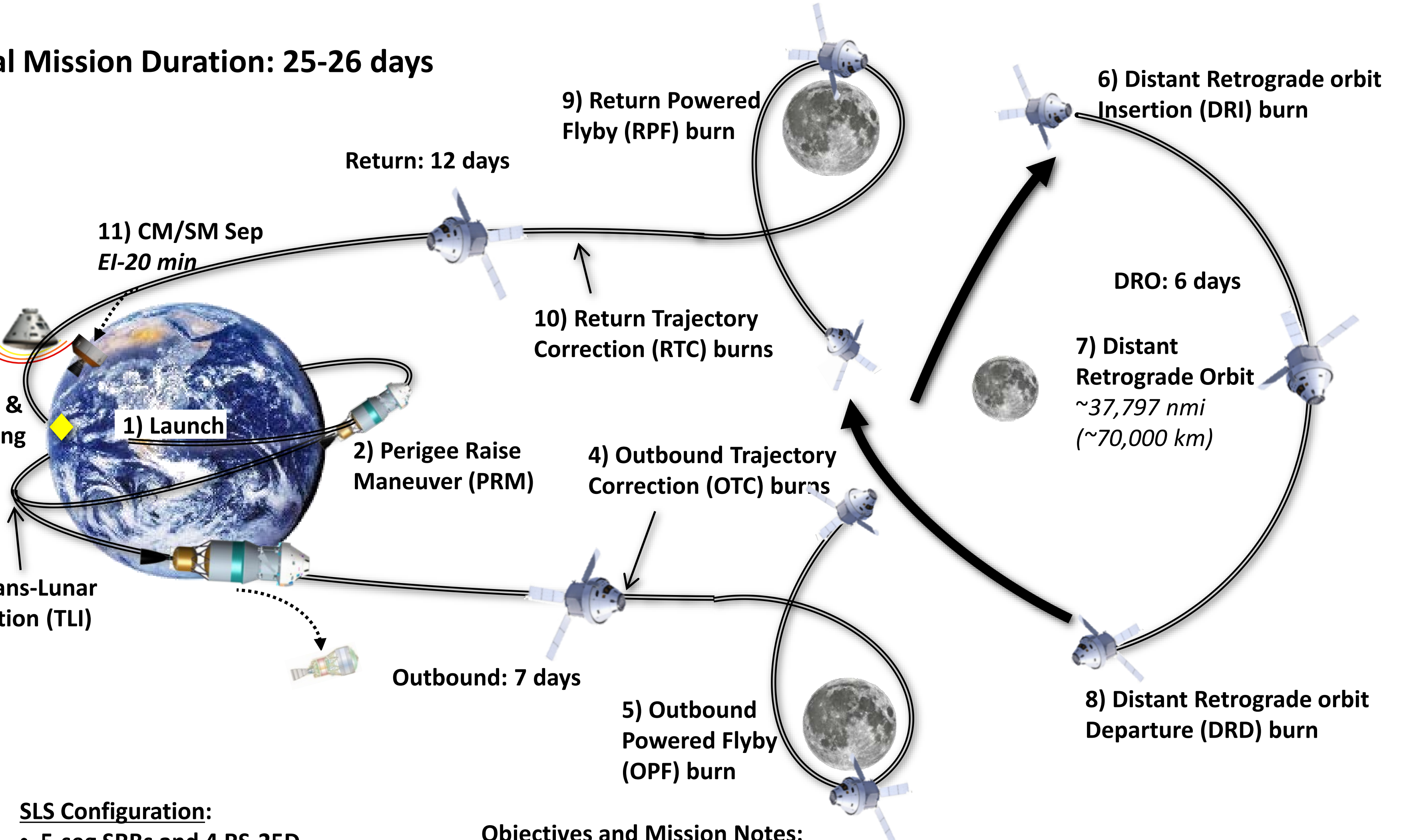
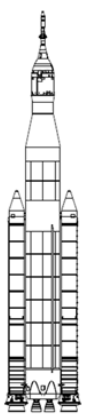
EM-1: Uncrewed Distant Retrograde Orbit

Total Mission Duration: 25-26 days





<u>SLS Configuration</u>:

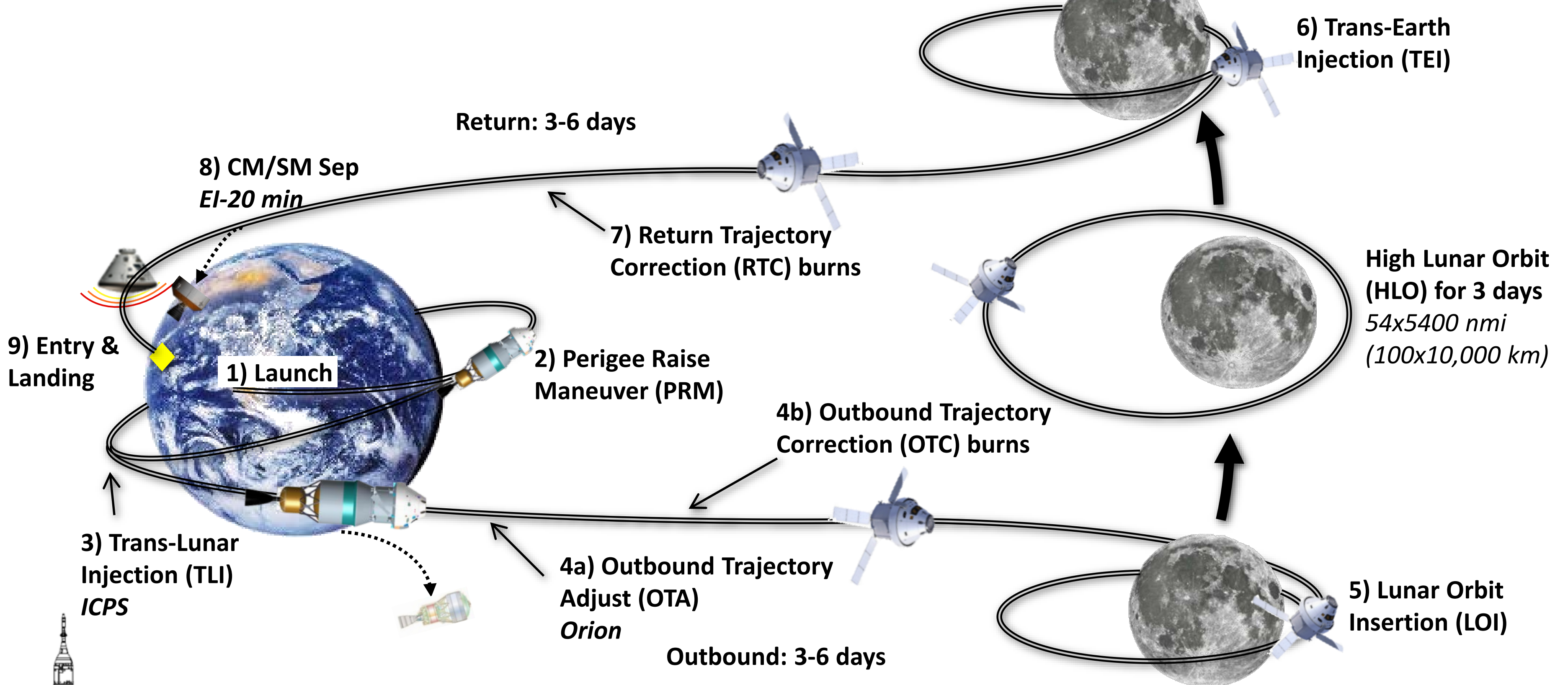
- 5-seg SRBs and 4 RS-25D
- Interim Cryogenic Propulsion Stage
- 28.5 – 35 deg inclination parking orbit

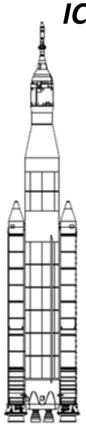
<u>Objectives and Mission Notes:</u>

- Demonstrate spacecraft systems performance prior to crewed flight
- Demonstrate high speed entry (~11 km/s) and TPS performance prior to crewed flight
- Landing off the coast of California

EM-2: Crewed (High) Lunar Orbit

Total Mission Duration: 10-14 days





<u>SLS Configuration</u>:
- 5-seg SRBs and 4 RS-25D
- 28.5 – 35 deg inclination parking orbit

<u>Objective and Mission Notes:</u>
- Demonstrate crewed (up to 4) flight beyond LEO
- Demonstrate baseline Orion vehicle
- TLI places Orion on a lunar flyby free-return trajectory

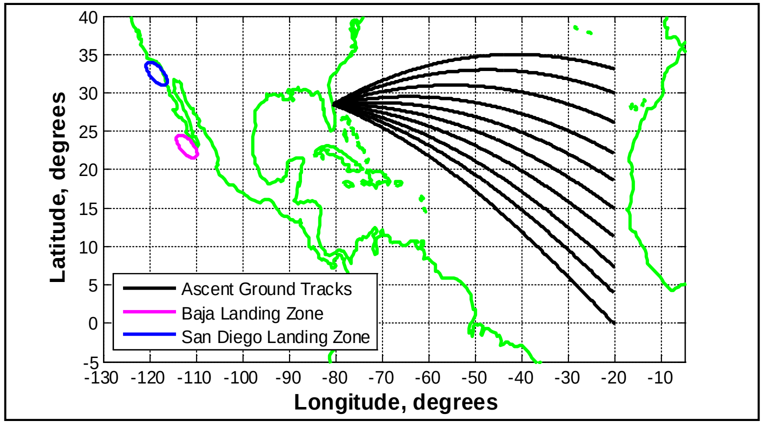
Launch Availability

- MSFC NE has an in-house tool to compute the probability of meeting specified constraints for launch.
- Sea conditions are incorporated to overall launch availability assessment for Orion.
  - Segregate global climatology to represent landing areas.
  - Conditions usually worse from Dec-Mar.
- Analysis is tailored to individual launch and landing vehicle constraints.
  - EFT-1 flew on a Delta IV.
  - EM-1 and EM-2 will fly on the SLS.
  - Cargo and uncrewed missions do not require sea condition constraints.
- SLS can fly on different azimuths, which lead to accounting for sea conditions across different ground tracks for EM missions.

PROBABILITY (%) OF SATISFYING ALL CONSTRAINTS

Hour (UTC)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
0	77.1	73.6	70.6	81.3	84.8	76.4	85.6	80.4	77.3	75.3	77.5	76.1	78.1
1	77.7	76.6	76.8	81.7	86.3	80.3	87.6	85.5	78.7	79.5	77.9	76.2	80.6
2	76.8	73.3	76.7	86.0	87.9	81.0	91.0	86.2	79.1	78.2	76.9	71.6	80.8
3	74.2	72.1	75.8	85.8	89.1	86.6	94.3	91.1	86.3	77.1	76.6	70.9	82.0
4	77.0	75.2	76.4	86.3	92.0	90.9	94.2	90.1	87.8	80.3	75.1	73.2	83.7
5	70.8	74.8	72.8	87.0	92.4	93.7	96.3	91.9	90.2	79.4	74.3	75.3	83.7
6	70.9	72.6	77.0	85.3	91.2	93.1	95.6	92.6	92.5	81.5	71.8	73.8	83.7
7	72.1	71.6	78.7	82.6	91.3	92.5	94.8	94.4	87.7	81.4	71.0	71.3	83.0
8	68.8	71.1	75.7	84.6	90.9	90.8	95.4	93.7	87.7	79.3	71.0	65.9	81.9
9	65.5	67.0	75.4	79.3	89.1	88.9	92.8	92.1	87.2	78.5	72.4	69.1	80.2
10	64.4	66.2	73.5	77.7	85.2	83.4	91.0	91.6	86.1	78.5	73.5	67.4	78.6
11	59.9	59.1	72.0	74.0	78.6	77.9	82.1	84.3	79.8	72.7	72.8	63.3	73.4
12	59.6	56.1	66.7	74.2	80.6	81.6	86.0	86.7	77.8	67.8	67.0	59.8	72.5
13	59.2	57.8	67.5	75.4	87.8	84.0	88.3	89.6	80.3	73.0	70.7	56.9	74.8
14	69.8	61.3	69.4	76.8	83.8	81.4	90.0	90.6	81.4	74.5	73.1	67.3	76.8
15	72.6	59.9	66.7	76.1	83.4	77.6	88.3	87.5	78.5	73.9	69.3	68.4	75.4
16	71.7	61.3	65.4	74.6	83.5	75.6	83.9	81.7	75.1	73.7	71.7	62.1	73.6
17	68.1	61.1	64.7	74.1	84.1	70.5	77.0	76.2	71.5	71.7	71.0	61.2	71.2
18	68.4	64.4	67.3	74.9	83.6	67.3	74.2	67.0	72.6	72.2	68.6	59.0	70.2
19	68.4	62.9	64.7	75.2	80.4	64.5	72.5	65.4	71.0	69.3	70.2	62.5	69.0
20	68.7	61.9	65.6	77.2	81.1	61.4	70.5	67.5	72.7	74.2	72.3	63.2	69.7
21	71.5	63.1	63.3	77.4	82.7	69.2	69.9	71.8	70.0	70.7	73.8	66.3	70.9
22	71.9	66.6	67.8	76.6	83.1	72.5	72.8	75.5	69.9	74.3	75.1	69.1	73.0
23	74.4	68.4	69.1	77.5	82.8	72.3	77.8	77.7	76.9	75.6	75.3	69.6	74.8
All	70.0	66.5	70.8	79.2	85.7	79.7	85.6	83.7	80.0	75.5	72.9	67.5	76.7

P < 60% | 60% <= P < 70% | 70% <= P < 80% | 80% <= P < 90% | P >= 90%



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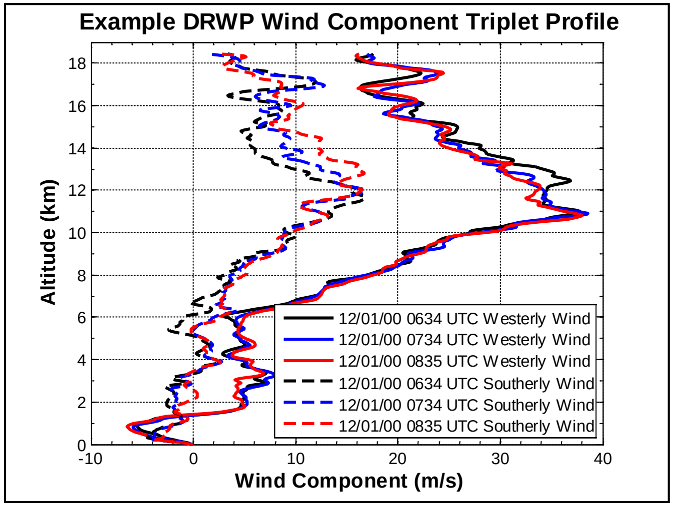
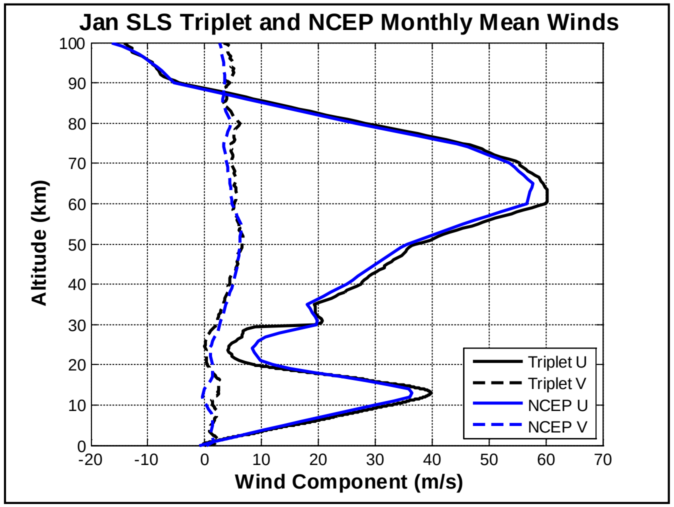
Wind Profiles for Ascent

- Generated a database of DRWP wind profile triplets.
  - SLS loads and trajectory design (design trajectory, check, fly).
  - Earth-Global Reference Atmospheric Model (Earth-GRAM) characterizes upper atmosphere.
- MPCV program incorporates SLS wind profiles.
  - Goal: Use same winds as SLS.
  - Includes pad and ascent aborts.
  - Ensured that database represents winds for early aborts.
- Determine locations of insufficient water depth for MPCV pad abort landings.





Summary

- Accounting for environmental dispersions during vehicle design is paramount to success of a space vehicle program.
- Understanding and properly designing for natural environments early in a program mitigate adverse cost, schedule, and risk impacts.
- MSFC NE’s TPE has provided terrestrial environments support to MPCV and SLS to ensure robust design, detailed operational planning, and understanding of accepted risks.
  - Define environments across different mission phases.
  - Analyses utilize archives of measured and modeled meteorological data.
  - Iterate with end users to tailor environment for specific applications.
  - Also provided space environment definition.