Analyzing the Impacts of Natural Environments on Launch and Landing Availability for NASA's Exploration Systems Development Programs

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INTRODUCTION

NASA is developing new capabilities for human and scientific exploration beyond Earth orbit. Natural environments information is an important asset for NASA's development of the next generation space transportation system as part of the Exploration Systems Development Program, which includes the Space Launch System (SLS) and Multi-Purpose Crew Vehicle (MPCV) Programs. Natural terrestrial environment conditions – such as wind, lightning and sea states – can affect vehicle safety and performance during multiple mission phases ranging from pre-launch ground processing to landing and recovery operations, including all potential abort scenarios. Space vehicles are particularly sensitive to these environments during the launch/ascent and the entry/landing phases of mission operations.

The Marshall Space Flight Center (MSFC) Natural Environments Branch provides engineering design support for NASA space vehicle projects and programs by providing design engineers and mission planners with natural environments definitions as well as performing custom analyses to help characterize the impacts the natural environment may have on vehicle performance. One such analysis involves assessing the impact of natural environments to operational availability. Climatological time series of operational surface weather observations are used to calculate probabilities of meeting or exceeding various sets of hypothetical vehicle-specific parametric constraint thresholds.

LAUNCH/LANDING CLIMATE ANALYSIS TOOL

The MSFC Natural Environments Branch has a long history of computing mission phase availability with respect to natural environmental conditions. Currently, the branch has developed a tool known as the Probabilities of Atmospheric Conditions and Environmental Risk (PACER). This tool is used to perform climate analyses that feed into launch and landing availabilities for ESD, SLS, and MPCV.

The PACER methodology is straightforward and consists of five steps:

1. Identify environmental parameters and geographical sites of interest.
2. Generate time series datasets for all parameters/sites of interest.
3. Define a specific PACER analysis scenario. A scenario definition consists of a selected set of parameters to be analyzed along with constraint threshold criteria. Each parameter/constraint specification is referred to as a non-exceedance condition (NEC).
4. Submit the scenario definition to the computational engine to calculate resultant probabilities.
5. Computational results are tabulated by hour of day (to show diurnal variability) and by month (to show seasonal variability) (Table 1). PACER also outputs failure mode probabilities (Figure 1) for each individual constraint to show qualitatively which constraints are most strongly influencing the net probabilities.

Table 1. PACER Probabilities. *Example PACER climatological probabilities (%) of satisfying an arbitrary set of NECs.*

Hour (UTC)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	All months
0	77.4	74.7	79.5	88.2	85.0	81.5	86.6	83.3	80.9	82.0	77.4	75.4	81.0
1	78.2	76.4	83.3	86.8	87.5	85.1	89.0	86.6	84.9	81.8	80.5	74.5	82.9
2	76.0	74.8	84.8	88.7	88.8	85.1	92.2	88.4	84.1	83.2	79.3	72.3	83.2
3	75.0	73.3	83.3	88.4	90.4	90.1	94.7	92.7	89.1	84.4	78.6	70.5	84.2
4	74.7	76.5	81.9	89.4	91.9	92.0	95.7	92.1	88.4	85.9	77.4	71.7	84.8
5	71.9	76.1	78.7	89.5	89.8	93.7	96.4	95.4	90.2	83.5	77.2	70.4	84.3
6	68.6	74.2	81.0	89.5	89.7	93.8	96.2	94.8	93.0	84.3	75.2	67.7	84.0
7	69.5	71.5	81.1	86.7	89.1	93.3	95.2	95.6	91.1	83.5	72.8	67.7	83.1
8	67.3	71.9	79.3	86.1	88.4	91.5	95.2	95.6	90.4	83.5	72.7	65.9	82.3
9	65.2	67.2	78.0	84.0	88.2	89.6	93.6	94.9	90.6	81.2	72.1	67.4	81.0
10	63.9	67.5	75.5	80.1	85.0	85.3	92.6	94.4	87.4	79.4	71.4	63.4	78.8
11	59.5	61.2	73.3	75.8	77.3	79.5	86.7	86.8	81.6	74.6	69.3	61.0	73.9
12	58.7	58.4	67.5	78.2	82.3	83.5	88.1	89.1	82.4	70.1	64.3	56.3	73.3
13	57.7	59.4	72.9	80.2	88.3	86.3	91.2	91.7	84.3	75.6	67.4	57.4	76.0
14	66.2	65.8	74.8	80.7	83.9	84.5	90.9	93.4	84.5	79.2	70.5	65.7	78.4
15	70.7	68.0	73.1	81.5	84.5	80.4	90.9	88.7	82.4	78.3	71.0	70.4	78.4
16	72.9	68.1	75.8	79.3	84.2	77.4	85.6	82.8	79.7	80.1	71.9	69.4	77.3
17	71.8	69.0	76.6	78.7	86.0	73.9	79.5	77.3	76.5	77.5	72.4	70.5	75.8
18	72.1	73.5	78.8	80.7	84.8	69.4	73.1	68.7	76.6	77.9	72.2	70.0	74.9
19	73.2	72.6	77.4	82.3	83.8	65.1	68.6	69.3	76.4	76.3	73.2	70.1	74.0
20	72.6	71.7	78.6	84.1	82.8	65.3	68.5	68.9	75.6	77.6	73.6	69.3	74.1
21	73.7	72.2	76.7	84.3	84.3	70.2	71.3	72.8	77.2	77.1	73.7	69.4	75.3
22	75.3	73.7	78.6	85.7	84.6	74.1	74.4	77.9	78.6	77.8	73.8	71.5	77.2
23	74.6	73.4	80.7	84.7	86.7	77.6	80.9	78.3	80.0	79.9	75.1	72.7	78.7
All hours	70.3	70.5	78.0	83.9	86.1	82.0	86.6	85.8	83.6	79.8	73.5	68.4	79.0

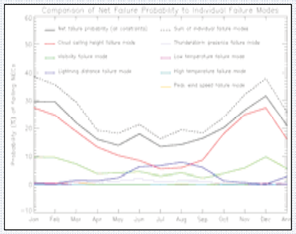

Figure 1. Failure Probabilities. *Example PACER results showing probabilities (%) of failing an arbitrary set of NECs. Net results are shown for the full scenario as well as failure modes for the individual constraints.*

NATURAL ENVIRONMENTS DATASETS

Three types of environmental parameters are assessed within PACER – surface conditions, lightning, and sea states.

1. <u>Surface Meteorological Environments</u>

Archived data from the Kennedy Space Center (KSC) Shuttle Landing Facility (SLF) define the surface meteorological environment for the launch site and consists of hourly data records for mean wind speed and wind direction, peak wind speed, ceiling height, visibility, temperature, dewpoint temperature, atmospheric pressure, precipitation, thunderstorms, visibility, and sky cover (Figure 2).

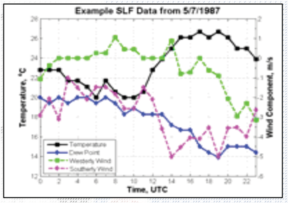

Figure 2. Surface Data. *Example time series plot of SLF mean wind component velocities, air temperature, and dewpoint temperature.*

2. <u>Lightning Observations</u>

The National Lightning Detection Network (NLDN) measures electromagnetic discharges from cloud-to-ground lightning strikes. The NLDN archive within PACER contains the timestamp and location of every cloud-to-ground lightning occurrence within 50 km of the KSC launch pads (Figure 3).

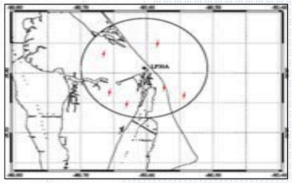

Figure 3. Lightning Data. *Plot of lightning strikes recorded by the NLDN around the KSC launch pads for an arbitrary day.*

3. <u>Sea States</u>

Output from the European Centre for Medium Range Weather Forecasts Re-Analysis (ERA) dataset is used to quantify PACER's sea state assessment. The ERA dataset contains records of numerous parameters including significant wave height (Figure 4), average wave period, and 10-m wind speed on a global 1.5° longitude by 1.5° latitude grid.

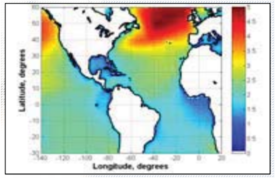

Figure 4. Sea State Data. *Map of ERA mean significant wave height at each gridpoint during January over the 1979-2012 period of record.*

CONCLUSION

The capability of the MSFC Natural Environments Branch to perform climate analyses for varying locations and scenarios allows the ESD Program to assess the risks and form mitigation strategies early on. The MSFC Natural Environments Branch maintains a large inventory of statistical analysis tools, environment definition models, and observational data archives. These assets provide the capability to support many different hardware design and operational planning analyses. Expertise is available for both the application of current models and datasets and in the development of new models and datasets. Delivered products can support a wide variety of engineering analyses and provide decision tools for design engineers and mission planners throughout the lifecycle from concept to design and throughout operations.

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ESD PROGRAM CLIMATE ANALYSIS NEEDS

With the new launch system SLS and crew vehicle Orion, NASA is looking to send human and scientific missions beyond low Earth orbit. Specific Design Reference Missions (DRMs) are still being defined, but NASA's goal is to have the capability to support a number of DRMs, including lunar fly-by and multi-launch Mars missions. To be able to perform these missions, the integrated vehicle must be able to launch on schedule. Having a system that is robust enough to have high launch availability regardless of weather conditions is highly desirable, and understanding which environments most affect that capability is critical. However, the SLS/Orion launch trajectories and Orion target launch and landing zones (Figure 5) are already being discussed and the environments (Table 2) in those regions are being assessed for potential launch and landing availabilities.

Table 2. Launch Environments. *List of environmental launch parameters within PACER for ESD Program.*

SURFACE ENVIRONMENT PARAMETERS
Air Temperature
Land-based Peak Wind Speed
Presence of Precipitation
Presence of Thunderstorms
SEA STATE PARAMETERS
Oceanic Mean Wind Speed
Significant Wave Height
Average Wave Period
RANGE SAFETY LAUNCH PARAMETERS
Cloud Ceiling Height
Visibility
Distance to Nearest Lightning Strike

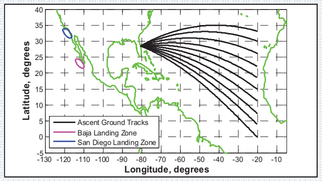

Figure 5. Launch and Landing Zones. *Preliminary ascent tracks and landing zones for surface and sea state environment being assessed for the ESD Program.*

CONFIGURING PACER FOR DIFFERENT PROGRAM NEEDS

<u>SLS Launch Climate Analysis Support</u>

The SLS launch vehicle is responsible for delivering NASA crew vehicles and payloads to orbit. The SLS Program manages launch availability due to natural environments through a Technical Performance Measure (TPM). The surface environments assessed by PACER in the TPM include the surface environment parameters listed in Table 2.

<u>Orion Launch Climate Analysis Support</u>

The Orion crew vehicle is responsible for transporting astronauts on exploration and scientific missions and returning them to Earth. Orion must be able to perform successful abort separations and landings during all launch mission phases. On-pad and near-pad aborts would place the vehicle just offshore from KSC. Ascent aborts would place the Orion vehicle in the Atlantic Ocean along the ascent ground track. Pre-orbital in-space aborts would place the vehicle in the Abort-Once-Around (AOA) landing zone offshore from the Baja Peninsula. Orion must also be able to perform nominal end-of-mission landings within a pre-determined water landing zone. To perform an Orion-only launch climate analysis for the MPCV Program, the sea state parameters listed in Table 2 are assessed in PACER using off-nominal sea state criteria for the abort zones. For an Orion nominal landing climate analysis, these same parameters are assessed using nominal sea state criteria for the nominal landing zone only.

<u>ESD Launch Climate Analysis Support</u>

The ESD Program is assessing overall launch availability through an ESD Launch Availability TPM. PACER is used to provide launch climate analyses for both the SLS-only and SLS-Orion configurations, including the range safety parameters shown in Table 2 (Figure 6).

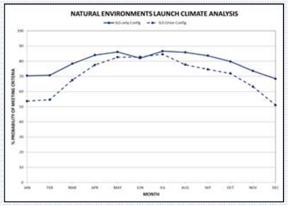

Figure 6. Sample Launch Climate Analysis Results. *Plots show sample PACER launch climate analysis results for the SLS-only and the SLS-Orion configurations. The Orion availability is lower due to the impact of sea states in the ascent abort and AOA abort zones.*