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Final Assessment of the Extreme Weather and Climate Change Vulnerability and Risk Assessment Tool

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Executive Summary

Background

Military Departments faced with a changing climate and extreme weather events seek to understand the vulnerability of military assets, both now and in the future. Determining the vulnerability of military assets to the risks associated with these events is complex and requires understanding exposure (How often does it happen or could it happen in the future?), sensitivity (How much does it matter?), and adaptive capacity (Can we do anything about it *right now*?). As a first step in understanding vulnerability, a tool is needed to assist the Military Departments in better understanding and assessing the exposure in a consistent way that informs mitigation planning and infrastructure development.

The National Defense Authorization Act for Fiscal Year 2020 (NDAA), Section 326 authorizes the development of an extreme weather-vulnerability and risk-assessment tool "to quantify the risks associated with extreme weather events and the impact of such events on networks, systems, installations, facilities, and other assets to inform mitigation planning and infrastructure development." In response to this NDAA, the Office of the Under Secretary of Defense for Acquisition and Sustainment funded the U.S. Army Corps of Engineers to update and expand an already-existing climate assessment tool and apply it to a limited set of sites designated by each Military Service. In June 2020, IDA was selected as the FFRDC to certify that the new tool, DoD Climate Assessment Tool (DCAT), relies on the best publicly available science. IDA performed a preliminary assessment of the underlying data and methodologies used in the tool by reviewing references used in the DCAT, but did not review the tool itself because it was in the final stages of development at the time of the evaluation (Bewley et al. 2020).

Now that the first version of DCAT is available, this final assessment includes an evaluation of the tool itself that does not rely solely on reference materials. The goal of this evaluation is to assess how the tool output could best be used to inform high-level mitigation planning and infrastructure development and to identify areas of potential tool enhancement and new investment areas for future research.

DoD Climate Assessment Tool

DCAT is a web-based tool[*] that provides Military Departments and their installation personnel with access to consistent exposure assessments to eight climate change and historical extreme weather hazards (drought, coastal flooding, riverine flooding, heat, energy demand and performance, wildfire, land degradation, and historic weather extremes) based on the best publicly available climate and historical data that can be used to inform high-level mitigation planning and infrastructure development. DCAT utilizes the weighted ordered weighted average (WOWA) data-aggregation methodology to combine indicators (derived from various climate data sources) to calculate WOWA scores, which represent a relative measure of exposure of an installation to a climate-related hazard. DCAT provides two types of WOWA scores: a WOWA score, or the relative measure of exposure for each one of the eight hazard categories, and a total weighted WOWA score, or the weighted sum of all eight of the hazard WOWA scores. The relative exposure of an installation can be assessed using WOWA (when considering a hazard category) and total weighted WOWA (when considering a sum of all hazard categories) scores for the historical baseline and four future climate projections (called "epoch-scenarios"): lower expected greenhouse gas emissions in 2050, higher emissions in 2050, lower emissions in 2085, and higher emissions in 2085. While the DCAT website provides pre-computed exposure assessments, it also allows users to customize exposure-assessment calculations by changing several parameters that go into the WOWA methodology and changing the indicators that are used for each hazard category.

Findings and Recommendations

Through this evaluation we independently replicated the WOWA score calculation performed in DCAT using National Standard View importance weights and ORness = 0.5 for all installations (*N* = 157) and epoch-scenarios (including historical baseline) in DCAT (CONUS/AK/HI) (VA6) as of March 2, 2021. We found that DCAT can be useful in providing consistent relative-exposure measures with a few caveats. DCAT is most powerful for comparing the relative exposure within a specific hazard category or indicator at the installation or regional level, across any future epoch-scenario or historical baseline. For example, an installation with a higher drought WOWA score can be interpreted as having a greater exposure to drought than other installations with smaller drought WOWA scores. DCAT is also useful for comparing WOWA scores for a specific hazard between the four epoch-scenarios and the historical baseline so the trends can be analyzed over time. For example, if the drought WOWA score for a given installation for 2085 is higher than its drought WOWA score for 2050, it can be interpreted as an increase in drought exposure. Note that DCAT only assesses exposure to climate hazards and does not comment on

[*] DCAT for CONUS, AK, HI available at https://corpsmapr.usace.army.mil/cm_apex/f?p=118. DCAT for rest of world available at https://corpsmapr.usace.army.mil/cm_apex/f?p=119.

vulnerability, which considers sensitivity and adaptive capacity in addition to exposure. Any tasks that require an assessment of vulnerability will require additional studies outside the scope of DCAT.

Recommendation 1: Exercise Caution when Comparing certain WOWA Scores

We recommend not comparing WOWA scores between different hazards, even for the same installation, because the normalization method yields WOWA scores sensitive to the indicator values and indicator definitions, which are further compounded by the importance weights assigned by the user. Also, the dependence on the processes (e.g., installation selection, indicator definition, and normalization methods, as well as the subjectivity of the importance weights) makes the output a relative exposure within a hazard category. That is, a drought WOWA score of 80 may not be interpreted as the same exposure as a riverine flooding WOWA score of 80. Comparison of total weighted WOWA scores between installations also has limitations. Our recommendation is that instead of only ranking installations based on the total weighted WOWA scores, users should also assess how the individual hazard categories contribute to the total score and compare the total weighted WOWA to the historical baseline WOWA score to gain a better understanding of the complete picture. Also, because of the nature of the division-by-max normalization method, adding installations could result in the inclusion of a sufficiently high indicator value at a newly introduced installation. This addition would have the effect of lowering the WOWA scores of all other installations, without any change in the relevant climate data, definitions, or mathematical methods. Therefore, we do not recommend comparing any WOWA scores between different versions of the web tool; any analyses should clearly state the DCAT version number used.

Due to the vast differences in the underlying data between different parts of the world, DCAT developers created two web-based tools (DCAT CONUS/AK/HI and DCAT Rest of World, or ROW). While some differences do exist between the underlying data for CONUS and AK+HI regions, it is generally appropriate to compare WOWA scores within the same hazard category for installations within these regions. We do not however, recommend comparing any WOWA scores found in DCAT (CONUS/AK/HI) with those found in DCAT (ROW) because of the differences in the underlying data.

Recommendation 2: DCAT Improvements

Across DCAT, it is often mentioned that the tool should only be used for high-level screening decisions. We recommend clarifying what high-level screening questions *could* be answered with the tool and how those comparisons could be done appropriately. Similarly, the DCAT Quick Guide (2020) mentions that the WOWA score is a “within-group comparative measure.” We recommend clarifying what is meant by “within-group” so that the users will understand when they should not use the WOWA score to compare between groups.

DCAT visualizations should further emphasize that the tool is best used as a relative measure of exposure. Most important, the baseline historical data should be included in all the reports, trend visualizations, and installation-level data so that the future epoch-scenarios can be assessed relative to the baseline scenario. The ability to compare each epoch-scenario with the baseline scenario would allow for stronger analysis of future exposure.

We concluded that WOWA scores for different hazard categories should not be compared with each other. Some of the reports and DCAT visualizations suggest that users make comparisons between hazard categories. For example, the Both First Impact (Hazard) report and the Dominant Impact (Hazard) tab compare hazard categories, but based on the findings in this report, these are not recommended comparisons.

Recommendation 3: Implement Standards for DCAT-Driven Assessments

The preliminary report[†] recommends that standards be implemented for DCAT-driven assessments that require documentation of any changes made in the My Assessment tab to the importance weights or ORness factor and justification be given for doing so. That report also recommends that the outputs from My Assessment tab be compared with the outputs in the National Standard View, which uses the default parameters. We now also recommend that users state which version of DCAT was used to produce the assessment. Because of the use of division by max in the normalization of input indicator values, the addition of new installations or the use of new datasets could in effect change the calculated WOWA scores for an installation. While it is anticipated that the rank order of installations and the percentage change from the base value will remain unchanged, the numerical WOWA scores could change. This may lead to confusion for installations reviewing their metrics. The DCAT version number along with the importance weights and ORness factor used should be clearly documented by the users in any assessments used for mitigation planning and infrastructure development.

Research Road Map

In this evaluation, we included a research road map that identifies multiple areas for future research efforts. These areas of potential future investment to improve the tool's capabilities and robustness include the following:

[†] J. L. Bewley, S. M. Cazares, J. B. Bartel, and S. C. Runkel, "Preliminary Assessment of the Extreme Weather and Climate Change Vulnerability and Risk Assessment Tool," IDA Document D-14353 (Alexandria, VA: Institute for Defense Analyses, 2020).

- Expanding the exposure-sensitivity-adaptive capacity framework to address sensitivity and adaptive capacity.
- Performing sensitivity studies on WOWA parameters and normalization methods by using the Monte Carlo method to systematically vary the ORness and importance weight parameters.
- Investigating potential improvements to the input data to make the input data more consistent between the CONUS and AK+HI regions.
- Investigating improvements to the ROW region.
- Performing DCAT user assessments.
- Identifying other user groups and design tool interfaces specific to their assessments (resist the urge to turning DCAT into a “one size fits all” tool).

Conclusions

During the preliminary assessment of DCAT, the IDA researchers did not have access to DCAT itself because the tool was still under development. Now that a version of DCAT has been released online, we were able to assess the usability of the tool’s output. Therefore, the goal of this final evaluation is to assess how the tool output could best be used to inform high-level mitigation planning and infrastructure development.

Overall, we found that the DCAT web tool does provide a consistent way to produce exposure assessments at the installation or regional level; however, there are a few caveats to the use of DCAT outputs. First, users should understand that WOWA scores are a relative measure of exposure, dependent on not just the data used in the WOWA calculation but also on the procedures used in the overall process itself. We found that the best use for DCAT is (1) assessing—one hazard category at a time—how the exposure changes at one installation over time (i.e., between two epoch-scenarios or simply relative to the historical baseline epoch-scenario) or (2) assessing the relative exposure of *one* hazard category at multiple installations, for the same or different epoch-scenarios and historical baseline, provided the installations are contained within the same DCAT webtool—that is, within DCAT (CONUS/AK/HI) or DCAT (ROW). We found limitations with the interpretation of total weighted WOWA scores and recommend performing additional analysis to gain a better understanding of the complete picture. We determined that comparisons should not be made between WOWA scores for different hazard categories (even within the same installation), any WOWA scores from the two web tools (CONUS/AK/HI and ROW), and any WOWA scores from different versions of the same web tool because the addition of installations could change the WOWA scores. In addition to assessing the usability of the tool output, we also developed a research road map that identifies areas of potential tool enhancement and new investment areas for future research.

Contents

1. Introduction

A. Tasking

One of the biggest challenges facing Military Departments today is understanding the impact of extreme weather events and a changing climate on military assets, both now and in the future. In particular, Military Departments would like to understand how *vulnerable* their installations are to the risks associated with extreme weather events and a changing climate. There are three main dimensions to vulnerability:

1. Exposure (How often does it happen or could it happen in the future?)
2. Sensitivity (How much does it matter?)
3. Adaptive Capacity (Can we do anything about it *right now*?)

Assessing an installation's *exposure* to extreme weather events and a changing climate is the first step toward assessing its overall vulnerability. Currently, there is a need for a tool to assist the Military Departments in better understanding and assessing the exposure in a consistent way that informs mitigation planning and infrastructure development.

The National Defense Authorization Act for Fiscal Year 2020 (NDAA) Section 326 authorizes the development of an extreme weather vulnerability and risk-assessment tool "to quantify the risks associated with extreme weather events and the impact of such events on networks, systems, installations, facilities, and other assets to inform mitigation planning and infrastructure development." However, before releasing a tool, the FY2020 NDAA stated that the Secretary shall obtain from a federally funded research and development center (FFRDC) "a certification in writing that the tool relies on the best publicly available science for the prediction of extreme weather risk and effective mitigation of that risk."

In response to this NDAA, the Office of the Under Secretary of Defense for Acquisition and Sustainment funded the U.S. Army Corps of Engineers (USACE) to update and expand an already-existing climate-assessment tool and apply it to a limited set of sites designated by each Military Service. In June 2020, IDA was selected as the FFRDC to certify that the tool relies on the best publicly available science. IDA performed a preliminary assessment of the underlying data and methodologies used in the tool (herein referred to as the Department of Defense Climate Assessment Tool, or DCAT) to assess if it relies on the best publicly available science. IDA researchers reviewed references for the underlying data and methodologies used in DCAT, but did not review the tool itself because it was in the final stages of development at the time of the evaluation (Bewley et al. 2020).

Overall, the preliminary evaluation performed by Bewley et al. (2020) revealed that DCAT does in fact use underlying data sources and a data-aggregation methodology (i.e., weighted order weighted average method, or WOWA) that are all well established. In general, the wide variety of underlying climate-related data sources are publicly available (with the exception of those that were deemed for official use only by the DoD or planned to be released in the upcoming months). These wide-ranging, authoritative sources have been compiled over several years and are documented in peer-reviewed, scientific literature. The report provided three recommendations:

1. Perform sensitivity studies on WOWA ORness[1] and importance weight[2] parameters to aid in interpreting DCAT results.
2. Implement standards for DCAT-driven assessments to provide a transparent history from which mitigation planning and infrastructure development are based.
3. Reevaluate the rest of world (ROW) (all regions outside the continental U.S., Alaska, and Hawaii) and consider further segmentation of the region to make use of higher resolution datasets that are currently available.

As previously stated, the preliminary assessment did not include an evaluation of DCAT itself, because the tool was still under development. The focus of this final assessment is an independent evaluation of the actual web version of DCAT.

B. Goal/Objective

Now that the first version of DCAT is available on the internet, this final assessment evaluates the tool itself. The goal of this evaluation is to assess how the tool output could best be used to inform high-level mitigation planning and infrastructure development. In addition, this evaluation identifies areas of potential tool enhancement and new investment areas for future research. The next chapter describes the evaluation methodology employed by this assessment.

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[1] User-selected number between 0 and 1 that allows the user to modify the level of optimism or pessimism in a calculation.

[2] User-selected weights chosen based on how important a particular indicator is in contributing to exposure.

2. Evaluation Methodology

As described in the preliminary assessment (Bewley et al. 2020), we find it beneficial to break down the tool into three components as shown in Figure 1. While the preliminary assessment focused on the tool inputs (i.e., the input data sources, or indicators) and mechanisms (i.e., the data-aggregation method of WOWA), this final assessment focuses on the tool output and its ability to inform high-level mitigation planning and infrastructure development. DCAT's primary outputs are WOWA scores that represent the relative exposure of an installation to each of the eight climate change hazard categories (i.e., drought, coastal flooding, riverine flooding, heat, energy demand and performance, land degradation, wildfires, and historic extremes). The WOWA scores for each of these eight hazard categories are also combined to create a total weighted WOWA score for each installation. Chapter 3 gives a summary of DCAT terminology and an overview of the tool.

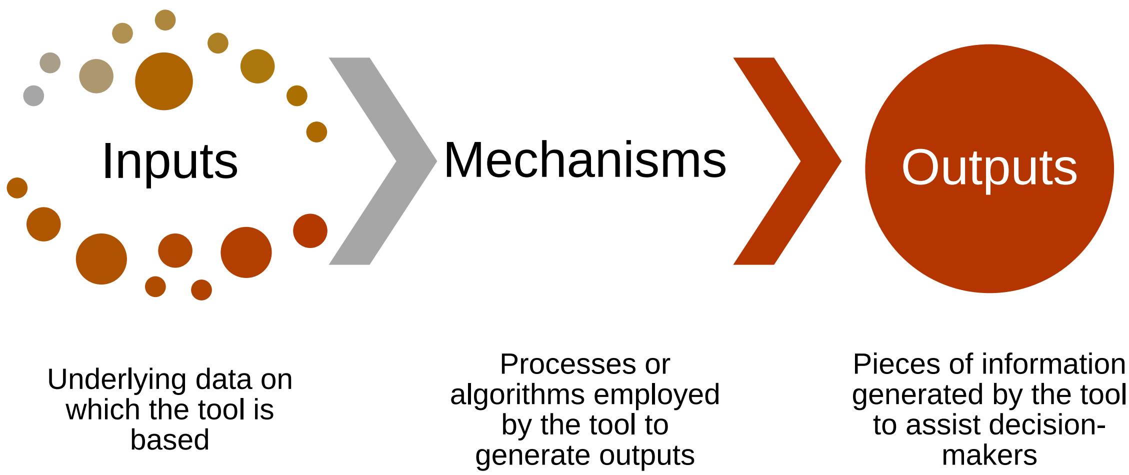

Figure 1. Three Components That Make up the Tool

The first part of this evaluation is an independent verification of the calculation of WOWA scores in DCAT, as discussed in Chapter 1. The distribution of WOWA scores generated for installations in DCAT is further analyzed to identify any systemic biases in the data stemming from indicator definitions, the pre-processing and normalization of the input data to generate normalized indicators, or the installations selected for analysis (site-selection bias). Based on these findings, Chapter 4 discusses recommendations for how installation managers can make use of the WOWA scores output by DCAT.

Chapter 1 presents a framework for performing a user-vignette-driven usability assessment of DCAT. The user vignettes are real-world use cases designed to test the usability of DCAT in performing analyses to support decision-making for each of the intended user groups. This framework provides a way for assessing how well DCAT can aid an installation manager in assessing exposure to historical extreme weather and a changing climate to inform high-level mitigation planning and infrastructure development.

Chapter 7 presents the main findings and recommendations from this assessment, and Chapter 8 presents a future research road map for potential tool enhancements and areas for future investment.

3. DoD Climate Assessment Tool Overview

A. The Purpose of DCAT

DCAT is a Common Access Card (CAC)–enabled, web-based tool[3] that provides Military Departments and their installation personnel with access to exposure assessments to eight climate change and historical extreme weather hazards based on the best publicly available climate and historical data. The intended users of the tool are installation-level planners and engineers, Military Department Headquarters, and DoD leadership (DCAT One Pager 2020).

DCAT is the first step in understanding the vulnerability of military installations to climate change and extreme weather. Vulnerability is assessed by understanding the exposure (How often does it happen or could it happen in the future?), sensitivity (How much does it matter?), and adaptive capacity (Can we do anything about it *right now*?) of an installation. For example, understanding whether an installation is located in a flood hazard area is related to *exposure*, understanding whether there are assets located in the flood hazard area at the installation is the *sensitivity*, and determining whether the assets in the flood hazard areas can be quickly moved to a new location away from the flood hazard area is the *adaptive capacity*.

DCAT is designed to provide screening-level[4] assessments specifically related to *exposure* through the use of the WOWA methodology; however, additional installation-specific information is needed to assess sensitivity, adaptive capacity, and thus vulnerability as a whole. Identifying installations exposed to climate change and extreme weather will help Military Departments determine where additional studies and investments are needed to increase installation climate adaptation and resiliency.

B. DCAT Terminology

Table 1 provides a list of common DCAT terminology provided for the reader's convenience.

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[3] DCAT for CONUS, AK, HI available at https://corpsmapr.usace.army.mil/cm_apex/f?p=118. DCAT for rest of world available at https://corpsmapr.usace.army.mil/cm_apex/f?p=119.

[4] A screening-level tool enables the user to obtain a *preliminary* review of potential vulnerabilities to climate change.

Table 1. Summary of DCAT Terminology

Term	Definition
Hazard Category*	Climate change or historic extreme weather event that could cause damage or disrupt operations at an installation. DCAT considers eight climate change hazards (i.e., drought, coastal flooding, riverine flooding, heat, energy demand and performance, land degradation, wildfires, and historic extremes).
Installation	A site designated by one of the Military Departments. The version of DCAT evaluated by this assessment contained 157 installations in the continental United States (CONUS), Alaska and Hawaii (AK+HI), and 24 international installations.
Region	Geographical area that contains similar input data. DCAT splits installations up into three regions: CONUS, AK+HI, and ROW.
Indicator	A dataset used to define a climate-related hazard. Multiple indicators can be combined to represent a hazard category. DCAT uses 33 indicators.
Epoch-Scenario	Future climate projection for a greenhouse gas concentration and emissions scenario averaged over a certain time period. DCAT considers four future epoch-scenarios: lower expected greenhouse gas emissions in 2050, higher emissions in 2050, lower emissions in 2085, and higher emissions in 2085.**
Historical Baseline	Observed values; record lengths differ for variables.
Importance Weights	User-selected weights chosen based on assessment of how important a particular indicator is in contributing toward exposure, without considering the actual value of the indicator.
Order Weights	Weights given to the rank order of each indicator based on its value, irrespective of what the indicator represents in terms of importance.
ORness Factor	User-selected number between 0 and 1 that allows the user to modify the level of optimism (1) or pessimism (0) in a calculation.
Weighted Ordered Weighted Average (WOWA)	Data-aggregation method to combine multiple data (indicators) into a single number (WOWA score) representing the exposure of an installation to a climate-related hazard.
WOWA Score	Relative measure of exposure for a hazard category.
Total Weighted WOWA Score	Weighted sum of the eight hazard category WOWA scores for a given installation.
DCAT (CONUS/AK/HI)	Web-based tool for CONUS and AK+HI regions.
DCAT (ROW)	Web-based tool for ROW region.
National Standard View	Pre-generated reports and visualizations in DCAT where the WOWA and total weighted WOWA scores are calculated based on a standard set of planning processes, indicators, ORness factor (0.7), and importance weights (see Appendix A for list of standard indicators and their importance weights).

* Formerly referred to as Impact Category.

** See footnotes 7 and 8 for more detailed explanations of the lower greenhouse gas emissions in 2050 and higher greenhouse gas emissions in 2050 scenarios.

DCAT estimates a military installation's exposure to eight different hazards of climate change and historic extreme weather events: drought, coastal flooding, riverine flooding, heat, energy demand and performance, wildfire, land degradation, and historic weather extremes (i.e., tornado frequency; hurricane frequency, winds, maximum precipitation; ice storms; historical drought frequency; wildland-urban interface percentage area; and ice jam occurrence). DCAT calculates eight different WOWA scores for each military installation, one for each of the eight hazards. Each WOWA score is calculated based on two to eight different indicators. There are 33 indicators in total, 5 of the indicators being used for more than one hazard (see Appendix A for a complete list of indicators). Grouping multiple indicators together to represent the exposure to a hazard category enables the user to represent the contribution of multiple factors to the hazard. For example, the coastal flooding hazard category considers not only an indicator for coastal flood extent, or the area of inundation during the most extreme coastal flood events, but also an indicator for coastal erosion, which is a measure of a coastline's susceptibility to erosion, which can further increase an installation's exposure to coastal flooding.

Each of the 33 indicators is calculated from several publicly available, authoritatively sourced datasets. Datasets differing in resolution and richness are available for CONUS, AK+HI, and ROW. The DCAT developers concluded that the datasets available for the CONUS and AK+HI regions were fairly similar to each other but quite different from those for the ROW region. Therefore, the DCAT developers created two separate tools (two separate websites): one for all installations in CONUS+AK+HI, known as DCAT (CONUS/AK/HI), and the other for all installations in ROW, known as DCAT (ROW).

Each military installation is assessed over four different future epoch-scenarios: lower expected greenhouse gas emissions[5] in 2050, higher emissions[6] in 2050, lower emissions in 2085, and higher emissions in 2085. Each military installation was also assessed over a

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[5] The "lower greenhouse gas emissions" scenario uses Representative Concentration Pathway (RCP) 4.5, which is a stabilization scenario that assumes climate policies are invoked to limit emissions. The radiative forcing for RCP 4.5 stabilizes at 4.5 W/m^2 without ever exceeding that value (Thomson et al. 2011). Radiative forcing is the difference between the incoming solar radiation and the outgoing radiation emitted by Earth. This balance can be disrupted by many things, such as emissions of greenhouse (heat-trapping) gases and aerosols or changes in land use that alter the reflectivity of the surface (NOAA n.d.).

[6] The "higher greenhouse gas emissions" scenario uses RCP 8.5, which is a high-population-growth scenario with modest rates of technological change and energy-intensive improvements, making it the scenario with the highest greenhouse gas emissions and the upper bound of the RCPs (Riahi et al. 2011). Void of any specific climate-mitigation target from climate-change policies, greenhouse gas emissions and concentrations increase at a faster rate than those for other RCPs, resulting in a radiation forcing of 8.5 W/m^2 by the year 2100 (Riahi et al. 2011). See Bewley et al. (2020) for more information on the use of RCPs in DCAT.

historical baseline epoch. Although the baseline results are not included in the tool visualizations, they can be downloaded through links in DCAT and used for analysis.

C. DCAT Outputs

From DCAT documentation (DCAT One Pager 2020), the purpose of the tool is to enable "Military Departments and their installation personnel to deliver consistent exposure assessments and identify regions or installations for additional climate-related studies." The DCAT website is divided into three sections: Home, Impact (Hazard) Awareness, and Impact (Hazard) Assessment.[7] Upon entering the DCAT website, the user is directed to the Home section, where a brief introduction outlines the use of the tool (see Figure 2). The Home section also provides a link to WOWA Scores Overview and Indictor Information, where detailed information can be found. The Impact (Hazard) Awareness section increases users' general climate knowledge and provides an overview of the historical and projected climate of the subregions. The Impact (Hazard) Assessment section has three tabs: National Standard View, My Assessment, and My Results (see Figure 2). Users can generate several reports, view installation-level data, and visualize regional trends. The reports and visualizations are pre-generated for the National Standard View, where the WOWA scores are calculated based on a standard set of planning processes, indicators, ORness factor, and importance weights. Users granted additional access[8] can adjust the hazard categories, indicators, ORness factor, and importance weights under the My Assessment tab, and view the reports and visualizations calculated with the user-adjusted inputs in the My Results tab. For more detailed explanations of the subsections, please refer to the DCAT Quick Guide (2020).

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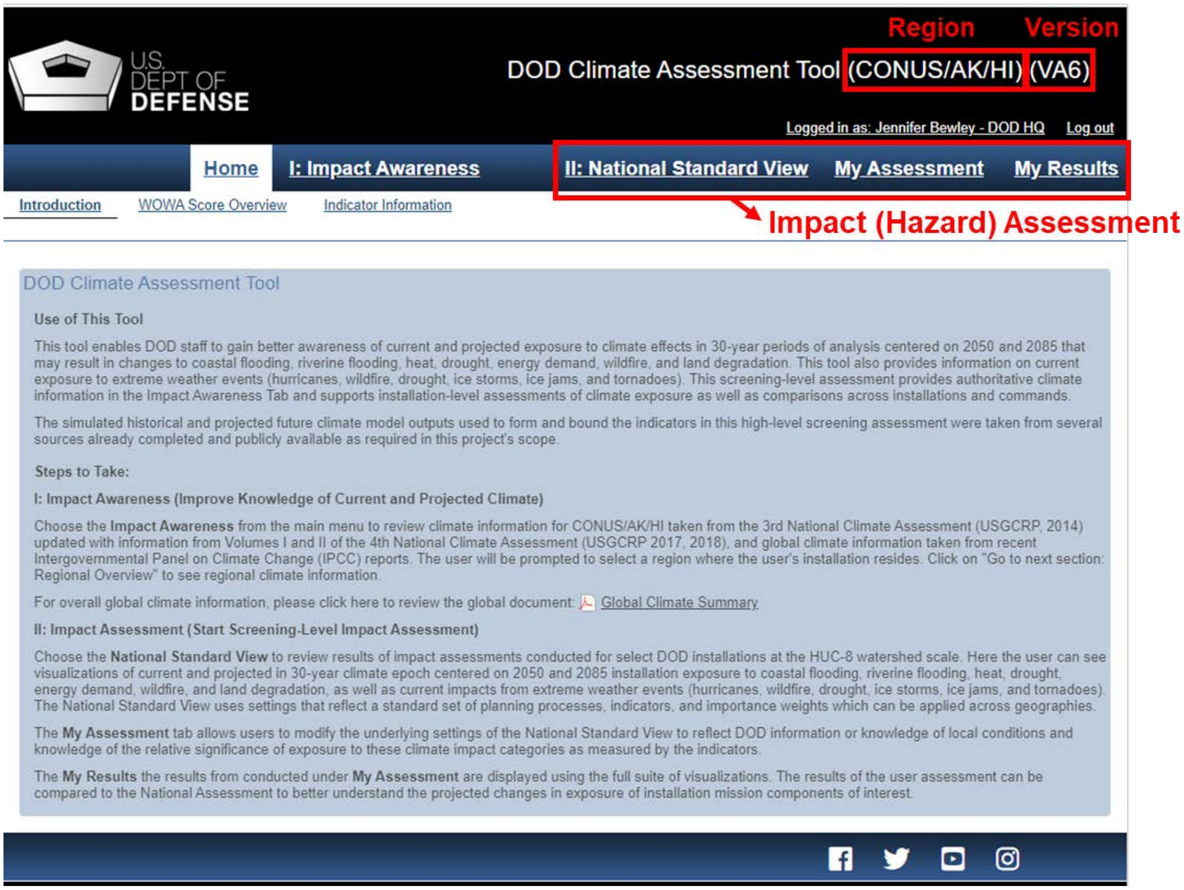
7 In DCAT version VA6 assessed in this report, the hazard categories were referred to as impact categories, and are referenced as Impacts in the screenshots of the tool used in this report. The DCAT developers are in the process of moving away from the use of the word *impact* in favor of the word *hazard*.

8 Users can request full access to DCAT by emailing the DCAT Development Team using the email address provided on the homepage of either DCAT website. By default, all users are given read-only access.



Source: DoD Climate Assessment Tool (CONUS/AK/HI) (VA6). Note: In DCAT version VA6, the hazard categories were referred to as impact categories.

Figure 2. Screen Capture of DCAT Homepage. This screen capture shows the initial page a user sees upon logging into DCAT, annotated to highlight the tabs of the tool that make up the Impact (Hazard) Assessment section. Also highlighted are the regions covered by the tool and the version number.

4. Data-Aggregation Method Assessment

DCAT utilizes the WOWA data-aggregation method to combine multiple data (indicators) into a single number (WOWA score) representing the exposure of an installation to a climate-related hazard (Bewley et al. 2020). WOWA scores are a *relative* measure of exposure, and hence the interpretation of a WOWA score is dependent on a variety of factors, including: which indicators are selected to calculate the WOWA score for a hazard category, how those indicators are defined, how those indicators are normalized or otherwise pre-processed before inputting into the WOWA calculation, and the order weights and importance weights applied during the WOWA calculation. As a result, certain comparisons between scores may lead to misleading or inaccurate assessments of exposure risk. This section discusses selecting and defining indicators, normalizing indicators before inputting them into the WOWA calculation, and calculating the WOWA scores from the normalized indicators. We also present an example of a WOWA calculation using an alternative indicator-normalization method and discuss the implications of different normalization methods on WOWA scores.

A. DCAT Procedure

1. Background

DCAT uses a variety of procedures to convert climatological data into WOWA scores. Figure 3 shows the general process of WOWA score calculation. Climate data are collected and processed before any DCAT calculation. Indicator definitions, which are chosen by expert assessment, attempt to describe a broad array of factors that contribute to a particular climate-related exposure, or hazard, such as drought. For instance, the drought hazard category utilizes five indicators, as seen in Table 2 (DCAT Tool 2020; see Appendix A for a full list of indicators with definitions). Using the pre-determined definitions, “raw” indicator data are constructed.

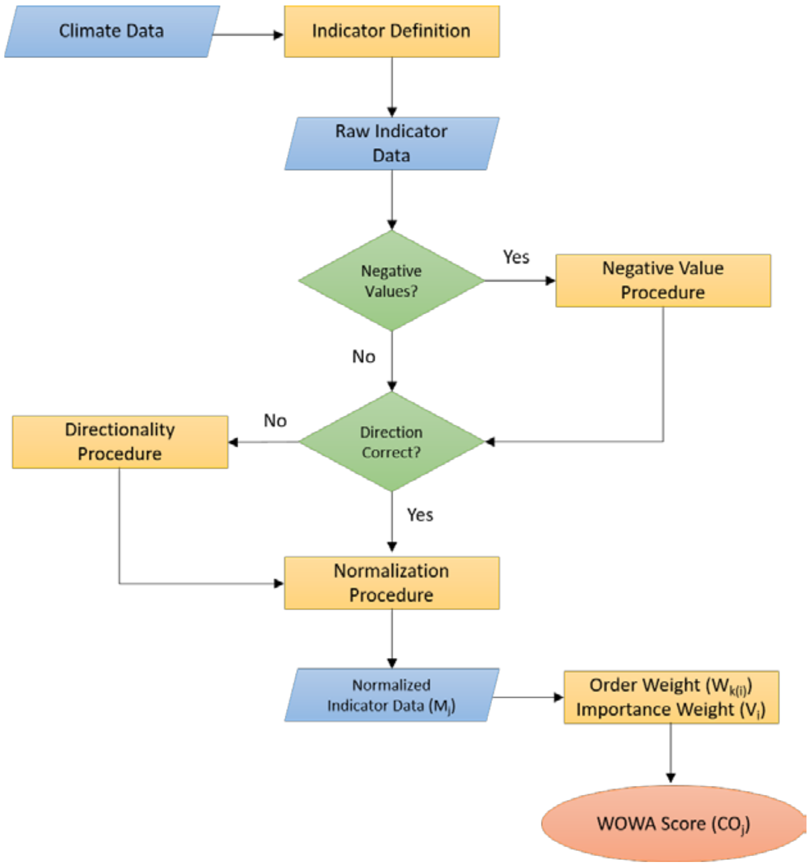


Figure 3. IDA–Generated Flowchart of DCAT General Mathematical Procedure

Table 2. DCAT Indicators Used in the Drought Hazard Category and Their Definitions

Indicator ID	Indicator Name	Description
101	Flash Drought Frequency	The average number of times per year when a flash (rapid onset) drought develops.
102	Drought Year Frequency	The percent of years that are drought years.
105	Aridity	A measure of how dry the climate is overall, as measured by the ratio of precipitation to potential evapotranspiration.
106	Consecutive Dry Days	The average annual maximum number of consecutive days with less than 0.01 inch of precipitation.
108C	Mean Annual Runoff	The average annual discharge (volume of water) from the entire watershed upstream of the downstream-most boundary of the installation for the largest river in this watershed.

Source: Data downloaded from DCAT (CONUS/AK/HI) (VA6) website under My Assessment>Indicators>Indicator Data tab.

Before becoming usable, these indicator data must go through a series of mathematical pre-processing and normalization operations. First, for indicators that contain negative values,[9] a procedure to convert the entire dataset to positive values is performed, using the equation (Runfola et al. 2017)

$$M_j = I_j + \left|\min\left[I_j, j \in \boldsymbol{J}\right]\right| ,$$

where M_j is the modified indicator; I_j is the original indicator value; j is an index for the geographic area of interest, referred to as a hydrologic unit code (HUC) value; and $\boldsymbol{J}$ is the set of all HUCs used in the procedure. Next, for indicators where increasing value implies decreasing exposure (or vice versa), a directionality procedure is applied to enforce a standard "direction" for all indicators in the tool (where higher values always imply a greater exposure). Direction is corrected using the equation (Runfola et al. 2017)

$$D_j = \mathrm{Max}\left[M_j, j \in \boldsymbol{J}\right] - M_j ,$$

where D_j is the modified indicator, M_j is the prior indicator value, j is an index for the HUC value, and $\boldsymbol{J}$ is the set of all HUCs used in the procedure.

After applying these two pre-processing steps, all indicators are now positive and increasing in value with increasing implied exposure. For these indicators to be utilized by DCAT, the next step in the procedure, normalization, must be applied. Section C of this chapter discusses this mathematical operation in depth.

Finally, the order and importance weights chosen by the user are applied to the normalized indicator values to produce a WOWA score. Importance weights can either be set to the National Standard View default weights (listed in Appendix A) or chosen by the user using the My Assessment tab of the tool. Indicators are multiplied by the importance weights in the WOWA calculation process. The effect of importance weights is to raise or lower indicator values relative to each other, within a hazard category grouping.

Next, the tool generates order weights associated with the ORness factor. Similar to the importance weights, the ORness factor can be set to the National Standard View default (0.7) or chosen by the user through the My Assessment tab of DCAT. The indicator values are also multiplied by these order weights. The ORness factor has a direct impact on WOWA scores by either raising or lowering the order weights for indicators within a hazard category. The "weighted" indicator values are then normalized with respect to the total value of these weights and summed to produce an overall WOWA score for that hazard category. For more information on the order and importance weight process, see Bewley et al. (2020).

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9 For example, temperature values (in degrees Fahrenheit) in indicator 503 "5-Day Minimum Temperature" may be negative.

2. Example Using DCAT Data

Figure 4 shows the distributions and hazard category memberships of each of the 33 indicators used by the current version (VA6) of the DCAT (CONUS/AK/HI) webtool, for all installations (*N* = 157), for all epochs (historical baseline, 2050, 2085), and for all future scenarios (lower and higher greenhouse gas emissions). Each of the 33 columns along the horizontal axis corresponds to one of the 33 indicators. The vertical axis corresponds to the indicator values, after they have been pre-processed (to ensure positive indicator values with proper directionality) and normalized so that they range from 0 to 1. The individual normalized indicator values for every installation and epoch-scenario (including historical baseline) in the tool are displayed as red or black dots in each column. For any given installation in the tool, one indicator value in each column (red or black dot) is used in the WOWA score calculation for the historical baseline or a future epoch-scenario.

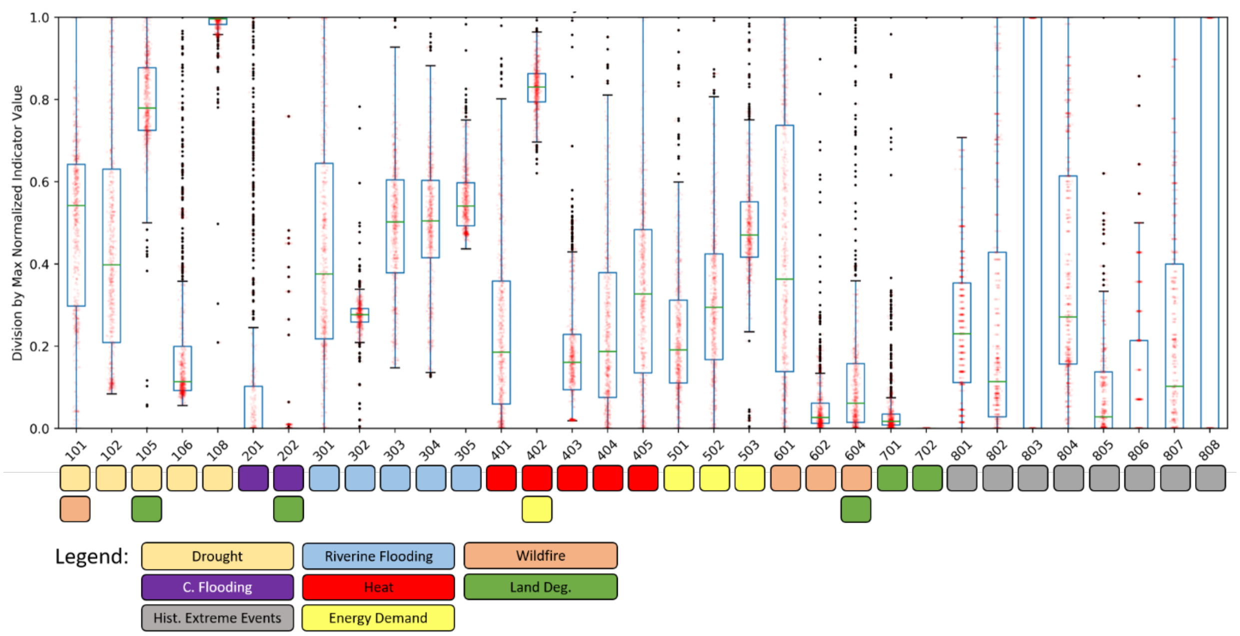


Figure 4. Independently Pre-processed and Normalized Indicator Distributions and Their Corresponding Hazard Category Membership(s), for All Installations (*N* = 157) and Epoch-Scenarios (including historical baseline) in DCAT (CONUS/AK/HI) (VA6) as of March 2, 2021

The box-and-whisker plot in each column describes the distribution of these values from a top-down view. That is, the green bar in the middle of the box represents the median value of the distribution, and the top and bottom of the box represents the 75th and 25th percentiles, respectfully. Whiskers extend from the minimum value to the maximum value, ignoring outliers (this means that if the minimum or maximum value of the distribution is not an outlier, the whiskers will only extend to that point). Above or below the box-and-whisker plots, black dots denote statistical outlier data points for each indicator, defined by the equations

$$x < Q_1 - 1.5 * IQR$$

$$x > Q_3 + 1.5 * IQR\ ,$$

where x is an individual, pre-processed, normalized indicator value, Q_1 is the 25th percentile of all x values, Q_3 is the 75th percentile, and IQR is the interquartile range of the x values ($Q_3 - Q_1$). If an individual indicator value x falls outside this range, it is considered an outlier and circled with a black dot rather than a red dot. Note that these box plots are meant for visualization only, and DCAT does not use the median or percentile values displayed in these plots.

Some normalization techniques, such as the division by max method, are sensitive to outliers because the normalization is dependent on an extreme value (like the maximum of a dataset), which is why we chose to differentiate them by using black dots in Figure 4. These outlier effects are exacerbated if an indicator is defined in such a way that produces a highly skewed distribution, where the median indicator value is small compared with the maximum indicator value. For instance, indicator 108C (Mean Annual Runoff) has a maximum value roughly 280 times its median value (see Table 3). This large difference naturally produces a skewed distribution when the division by max method is used. Section 4.B gives an overview of how indicator definitions affect indicator distributions, and Section 4.C shows an analysis of normalization techniques.

The horizontal axis of the plot denotes the unique indicator identification number (indicator ID) belonging to each indicator. Below the horizontal axis there is a colored box identifying each indicator's hazard category membership (i.e., which of the eight hazards the indicator contributes to). For example, indicators 101–108C are used to calculate the WOWA score for the Drought hazard category, while indicators 201 and 202 are used to calculate the WOWA score for the C. [Coastal] Flooding hazard category. Some indicators are used in multiple categories, while others are solely used in a single hazard category. For example, indicators 301–305 are only used to calculate the WOWA score for the Riverine Flooding hazard category, but indicator 202 is used to calculate the WOWA scores for two hazard categories: C. Flooding and Land Deg. [Degradation].

DCAT takes the individual normalized indicator data from Figure 4 and applies a series of weights (importance and order weights) through a scheme described briefly in the section above and shown in the Figure 5 flowchart. A more detailed explanation of this scheme can be found in Bewley et al. (2020). For some indicators, this weighting scheme serves to raise already high indicator values (such as indicator 108C) by applying additional weight, exacerbating issues created by outlier effects. That is, because of the way indicator 108C is defined (see Table 2) its median value ends up being 280 times smaller than its maximum value (see Table 3). This large difference naturally produces a skewed distribution when the division by max method is used. As shown in Figure 4, most of the normalized indicator values for 108C are clustered near 1. This already high normalized value is magnified when the importance weight (1.5, which happens to be the highest importance weight for the drought hazard category as seen in Appendix A) and order weights are applied.

After applying the order and importance weights, WOWA scores are calculated by summing over relevant indicators in each hazard category (identified in Figure 4 by the colored boxes along the horizontal axis). Figure 6 shows the final result of this process for a DCAT run with an ORness of 0.5 and specifying the 2050-Higher epoch-scenario. Higher normalized indicator values lead directly to larger WOWA scores within their respective hazard category. As shown in Figure 6, the drought hazard category has the highest median WOWA score because of the relatively high normalized values for indicators 105 and 108C. An installation with a higher drought hazard WOWA score can be interpreted as having a greater exposure to drought than other installations with lower drought hazard WOWA scores. Due to the relative nature of WOWA scores, one must be careful not to make any "apples-to-oranges" WOWA comparisons. Two WOWA scores, calculated based on the *same* underlying datasets and indicators and applying the *same* mathematical processes to those indicators, may be directly compared. In contrast, for two WOWA scores based on *different* underlying datasets and indicators, or applying *different* mathematical processes on those indicators, the comparison may not be meaningful (see Chapter 4 for more information).

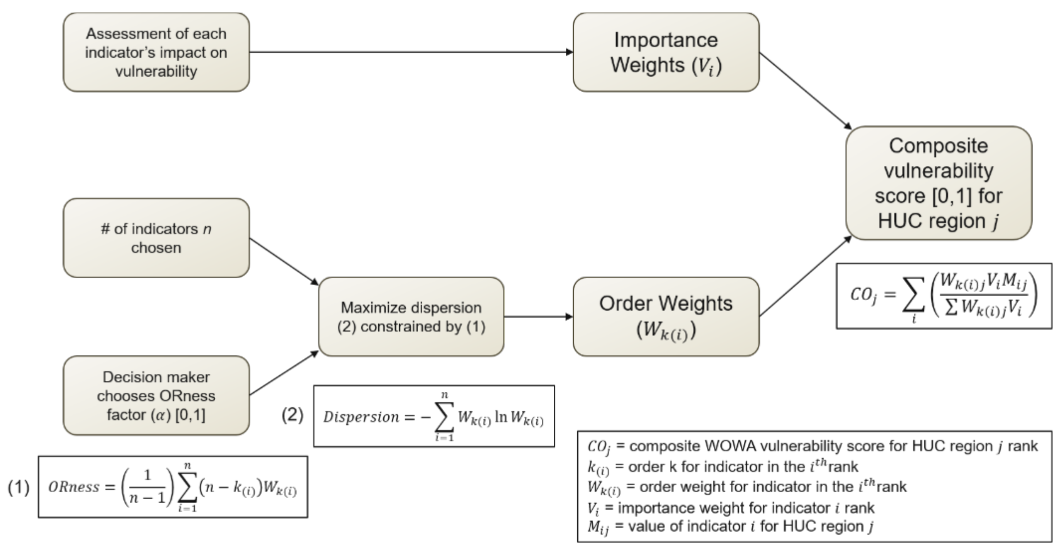


Figure 5. IDA Flowchart of DCAT WOWA Importance and Order-Weighting Scheme

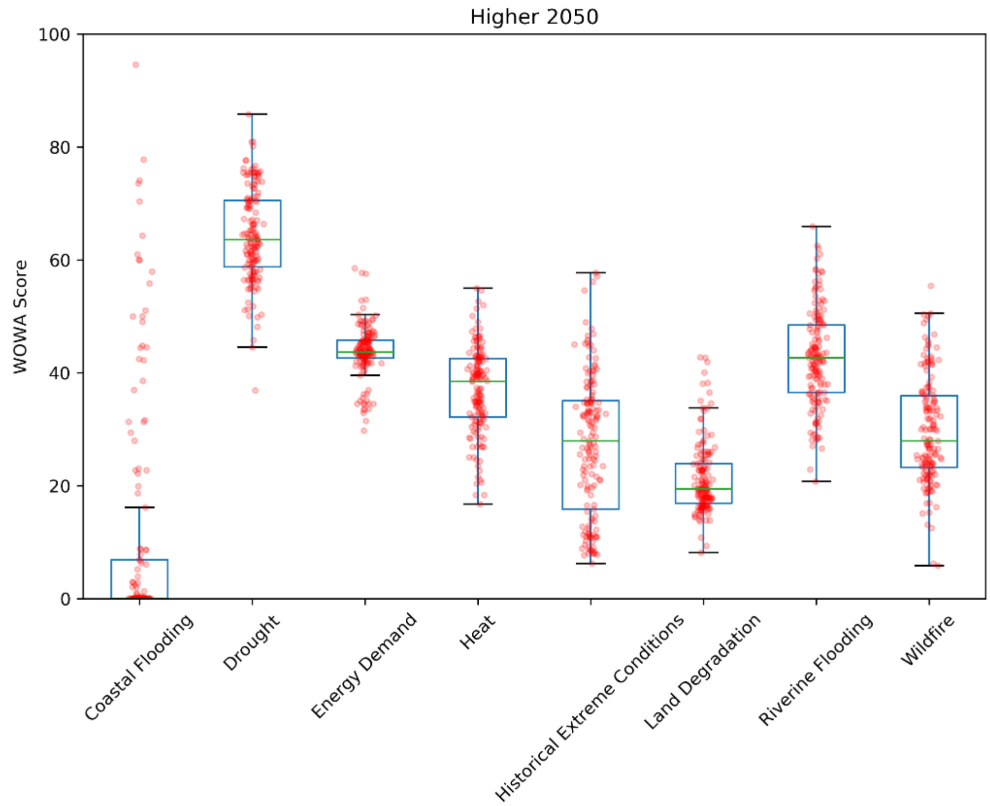


Figure 6. Independently Calculated WOWA Scores for All Installations (*N* = 157), in DCAT (CONUS/AK/HI) (VA6) as of March 2, 2020, for the Higher 2050 Epoch-Scenario, with ORness factor of 0.5 and National Standard Importance Weights (which can be found in Appendix A)

B. DCAT Indicator Definition

Indicator selection has a significant impact on the final WOWA value. Indicators are chosen based on their ability to describe phenomena that contribute to climate-related exposure, based on expert assessment. One can see a wide variety of indicator distributions in Figure 4 due to the definitions chosen by the DCAT team. The maximum and median values of these distributions are listed in Table 3 to describe these distributions in terms most relevant to the division by max method. Appendix A has a full list of indicators and their definitions.

Some indicators, such as indicator 106 "Consecutive Dry Days" (i.e., the mean annual number of consecutive days with less than 0.01 inch of precipitation) are defined such that most installations will exhibit values that are usually much lower relative to the maximal value over all installations. In this case, the maximum value is 141.1 days/year, while the median value is only 16.2 days/year. Other indicators are defined such that most installations will exhibit values that are usually much closer to the maximum value—indicator 402 "5-Day Maximum Temperature" has a maximum value of 120.7 °F and a median of 100.3 °F.

Table 3. List of DCAT Indicators and Their Maximum and Median Values across All Epoch-Scenarios (including historical baseline), before Pre-processing and Normalization, for All Installations (*N* = 157) in DCAT (CONUS/AK/HI) (VA6) as of March 2, 2021

Indicator ID	Maximum Indicator Value	Median Indicator Value
101	0.404	0.219
102	103.333	41.146
105	4.695	1.067
106	141.464	16.150
108C	8961.704	31.944
201	100.000	0.000
202	1.000	0.000
301	100.000	37.600
302	3.608	1.000
303	3.880	1.952
304	8.323	4.204
305	7.680	4.156
401	192.732	35.870
402	120.749	100.292
403	150.910	24.322
404	236.750	44.388
405	264.000	86.361
501	13858.482	2648.385
502	7502.162	2212.523
503	77.741	21.450
601	96.107	34.926
602	8713.819	233.776
604	340.823	20.909
701	12.182	0.211
702	0.028	0.000
801	2.600	0.600
802	3.723	0.426
803	1.000	1.000
804	45.005	12.210
805	42.422	1.220
806	0.467	0.000
807	3.491	0.359
808	1.000	0.000

These indicator values end up shaping the WOWA score produced by DCAT. For instance, if a WOWA score is calculated from indicators defined in such a way as to produce consistently high indicator values, close to the maximum values, then the resultant WOWA score will be commensurately high. On the other hand, if a WOWA score is calculated from indicators that are defined in such a way as to produce indicator values that are consistently much lower than the maximal value, the resultant WOWA score will indicate low exposure. For this reason, *users must be careful to take into account the definitions of the underlying indicators when comparing and interpreting WOWA scores.*

C. DCAT Indicator Normalization Methodology

1. Background

Normalization methods are techniques used to create a common scaling between different datasets. In this case, DCAT re-scales indicator values to a range between zero and one. DCAT utilizes the division-by-max normalization method (Yoon 2012, Runfola et al. 2017, Bewley et al. 2020). This method uses the maximum value of an indicator across all installations, historical baselines, and epoch-scenarios to normalize the indicator value, using the equation

$$M_j = \frac{I_j}{\mathrm{Max}\left[I_j, j \in \boldsymbol{J}\right]},$$

where M_j is the modified indicator value for HUC j, I_j is the original indicator value for HUC j, and $\boldsymbol{J}$ is the set of all HUCs.

This normalization method is widely used, in part due to the simplicity of its implementation and wide applicability. As with any normalization method, however, it carries with it some limitations, including unit dependence and outlier effects (Bewley et al. 2020).

2. Comparison with an Alternative Method

To show the effect that a normalization technique can have on the WOWA scores, we will perform two example calculations: one using the division by max method (like DCAT) and the other using the widely used min-max normalization method (Yoon 2012). The min-max normalization method uses the equation:

$$M_j = \frac{I_j - \mathrm{Min}\left[I_j, j \in \boldsymbol{J}\right]}{\mathrm{Max}\left[I_j, j \in \boldsymbol{J}\right] - \mathrm{Min}\left[I_j, j \in \boldsymbol{J}\right]},$$

where M_j is the modified indicator value for HUC j, I_j is the original indicator value for HUC j, and $\boldsymbol{J}$ is the set of all HUCs. The key difference between min-max rescaling and the division by max rescaling is the that the min-max method shifts the data to lie within the original range of the data, rather than scaling the data between an arbitrary number and one. Table 4, adapted from Bewley et al. (2020), shows a simple example comparing the two methods for different temperature scales. In this example, the min-max method retains the same scaling between data points despite changing units, unlike the division by max method. In other words, the spacing between normalized temperature values remains constant using the min-max method, and the result remains unchanged in all three cases of unit transformation. In the division by max method, three different temperature units give three different results, even though all the temperatures are physically equivalent. However, the min-max method has limitations as well, such as outlier effects—where an outlier data point can significantly shift the normalized values of a dataset.

Table 4. Equivalent Temperatures in Celsius, Fahrenheit, and Kelvin Normalized by the Division by Max Method and the Min-Max Method

°C	°F	Kelvin	Celsius Division by Max	Fahrenheit Division by Max	Kelvin Division by Max	Celsius Min-Max	Fahrenheit Min-Max	Kelvin Min-Max
0	32	273.15	0	0.31	0.87	0	0	0
10	50	283.15	0.25	0.48	0.90	0.25	0.25	0.25
20	68	293.15	0.5	0.65	0.94	0.5	0.5	0.5
30	86	303.15	0.75	0.83	0.97	0.75	0.75	0.75
40	104	313.15	1.0	1.0	1.0	1	1	1

To compare the two different methods, IDA independently replicated DCAT's WOWA score calculation starting from the indicator level, using the indicator values downloaded from DCAT (CONUS/AK/HI) (VA6), for all available installations (N = 157) as of March 2, 2021. Figure 7 and Figure 8 show DCAT indicators after normalization using the two different methods. In these figures, indicator values at each installation are represented as red dots in each column, and the box-and-whisker plots in each column represent the collective distribution of the indicator's values across all epoch-scenarios and historical baselines. Statistical outliers, calculated using the equations in Section A.2, appear as black circles.

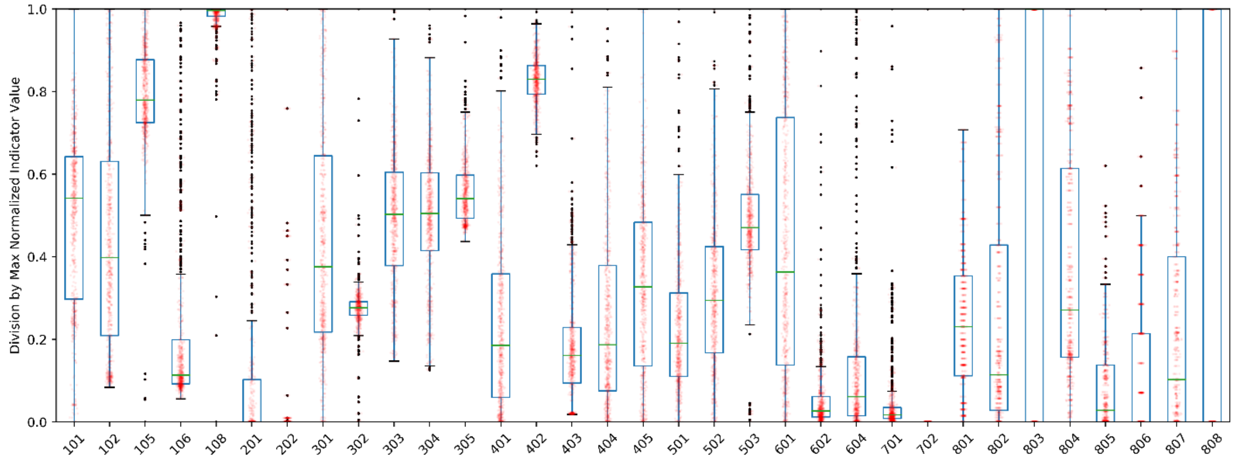


Figure 7. DCAT Indicators Normalized Using the Division by Max Method (same data as Figure 4) for All Installations (*N* = 157) and Epoch-Scenarios (including historical baseline) in DCAT (CONUS/AK/HI) (VA6) as of March 2, 2020

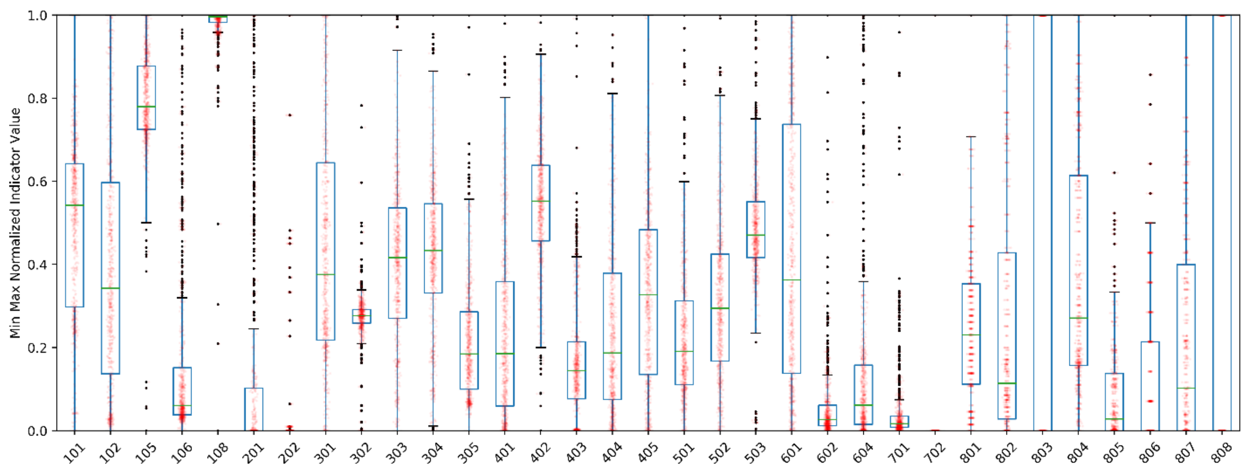


Figure 8. DCAT Indicators Normalized Using the Min-Max Method, for All Installations (*N* = 157) and Epoch-Scenarios (including historical baseline) in DCAT (CONUS/AK/HI) (VA6) as of March 2, 2020

Indicators 102, 106, 303, 304, 305, 402, 403, 502, 602, and 701 show differences between the two normalization methodologies. These indicators are used to calculate WOWA scores for the drought, riverine flooding, heat, energy demand, wildfire, and land degradation hazard categories. Table 5 shows these differences in numerical form, as percentage differences in median values. Outliers affect the result of both normalization methods (due to outlier effects)—and as the black circled values in Figure 8 show, a large portion of indicator datasets contain outliers.

Table 5. Numerical Differences between Division by Max and Min-Max Normalized Indicator Values

Indicator ID	Div. By Max Indicator Value	Min-Max Indicator Value	Difference (%)
305	0.5412	0.1852	-65.78
106	0.1142	0.0612	-46.37
402	0.8306	0.5527	-33.45
303	0.5030	0.4168	-17.14
304	0.5050	0.4338	-14.10
102	0.3982	0.3430	-13.86
403	0.1612	0.1451	-9.95
701	0.0173	0.0171	-1.06
602	0.0268	0.0267	-0.58
502	0.2949	0.2949	-0.01
101	0.5422	0.5422	0.00
105	0.7795	0.7795	0.00
108C	0.9964	0.9964	0.00
301	0.3760	0.3760	0.00
302	0.2771	0.2771	0.00
401	0.1861	0.1861	0.00
404	0.1875	0.1875	0.00
405	0.3271	0.3271	0.00
501	0.1911	0.1911	0.00
503	0.4708	0.4708	0.00
601	0.3634	0.3634	0.00
604	0.0613	0.0613	0.00
801	0.2308	0.2308	0.00
802	0.1143	0.1143	0.00
803	1.0000	1.0000	0.00
804	0.2713	0.2713	0.00
805	0.0288	0.0288	0.00
807	0.1027	0.1027	0.00
201	0.0000	0.0000	0.00
202	0.0000	0.0000	0.00
702	0.0000	0.0000	0.00
806	0.0000	0.0000	0.00
808	0.0000	0.0000	0.00

Six indicators show median differences of greater than 10%; the largest differences are seen in indicator 305 at over 65% difference. The min-max method, by scaling indicators with both the minimum and maximum value of the dataset, rather than having no defined lower limit to scale the data, tends to create lower normalized indicator values.

Next, IDA independently used these normalized indicators to recalculate WOWA scores using a process similar to that used in DCAT.[10] Figure 9 shows the results of this calculation process for the Lower-2050 (top) and Higher-2085 (bottom) epoch-scenarios, for all installations (*N* = 157) included in DCAT (CONUS/AK/HI) (VA6) as of March 2, 2021. These two epoch-scenarios were chosen to represent the full range of possible DCAT results for future climate scenarios. Note that the WOWA scores shown here were not generated by DCAT, but rather with an algorithm utilizing the same methodologies as DCAT.

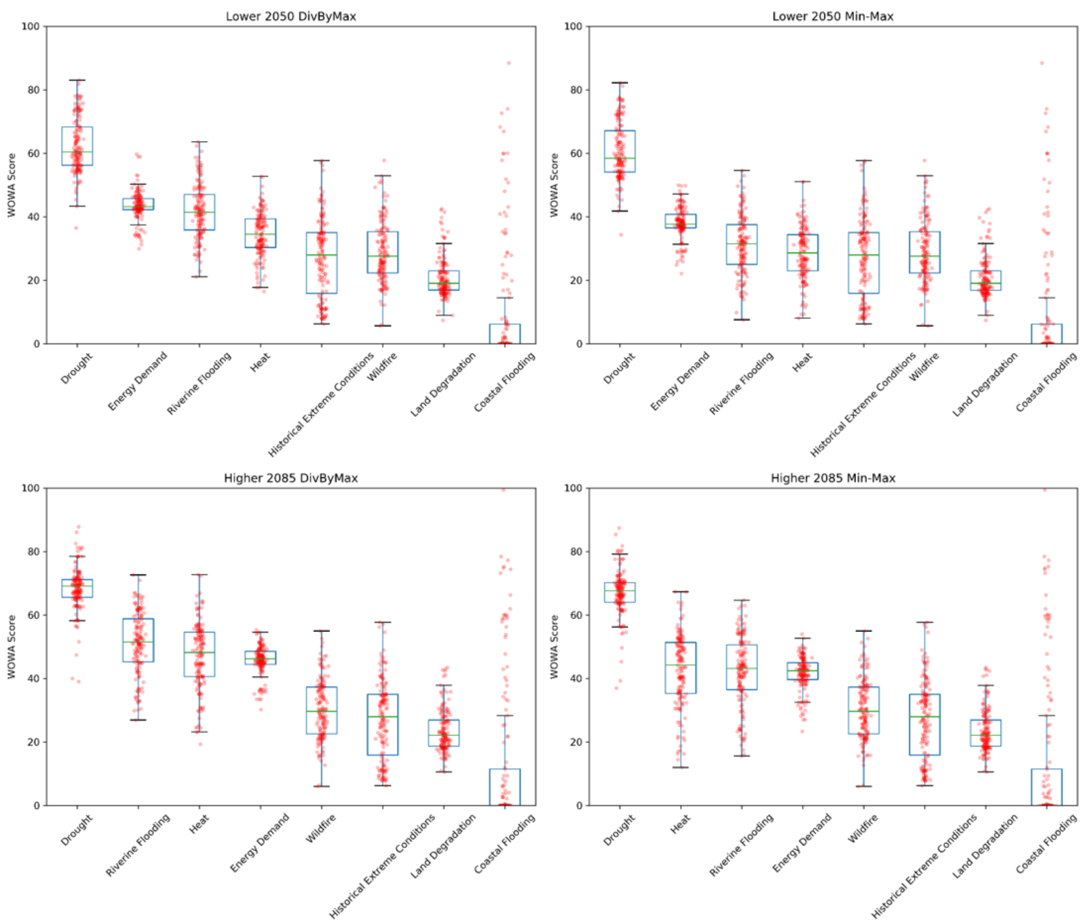


Figure 9. Independent Recalculation of WOWA Scores Using the Division by Max (left) and Min-Max (right) Normalization Methods for the Lower-2050 (top) and Higher-2085 (bottom) Epoch-Scenarios, for All Installations (*N* = 157) in DCAT (CONUS/AK/HI) (VA6) as of March 2, 2020

[10] Since we did not have access to the order weights used by DCAT, our analysis assumes all order weights are equivalent, which would be mathematically equivalent to setting the ORness factor to 0.5.

Table 6 shows the differences in median WOWA scores for each hazard category. These two test scenarios show clear differences of up to 24% in median WOWA score when applying two different normalization techniques to the indicator data. The largest differences are seen in the riverine flooding, heat, and energy demand hazard categories.

Table 6. Numerical Differences between Median WOWA Scores Independently Calculated for Each Hazard Category Using the Division by Max and Min-Max Normalization Methods for the Lower-2050 and Higher-2085 Epoch-Scenarios, for All Installations (*N* = 157) in DCAT (CONUS/AK/HI) (VA6) as of March 2, 2020

	Lower 2050			Higher 2085		
Hazard	Div. By Max Median WOWA Score	Min-Max Median WOWA Score	Difference (%)	Div. By Max Median WOWA Score	Min-Max Median WOWA Score	Difference (%)
Coastal Flooding	0	0	0	0	0	0
Drought	60.42	58.41	–3.33	69.07	67.57	–2.17
Energy Demand	43.20	37.64	–12.87	46.21	42.42	–8.20
Heat	34.50	28.63	–17.02	48.19	44.21	–8.25
Historical Extreme Conditions	27.95	27.95	0.00	27.95	27.95	0.00
Land Degradation	19.01	19.01	–0.02	22.16	22.16	–0.02
Riverine Flooding	41.40	31.47	–23.98	51.51	43.14	–16.25
Wildfire	27.56	27.55	–0.01	29.63	29.63	–0.01

Table 7 ranks the eight hazards by their median WOWA scores from Table 6. In the Lower-2050 epoch-scenario, both normalization methods produced the same rankings. In the Higher-2085 scenario, however, the two normalization methods had different rankings in the second and third highest valued categories, with heat and riverine flooding switching places.

Table 7. Median WOWA Score Rankings by Hazard Category Calculated Using the Division by Max and Min-Max Normalization Methods for the Lower-2050 and Higher-2085 Epoch-Scenarios

	Lower 2050		Higher 2085	
Ranking by Median Value	Div. By Max	Min-Max	Div. By Max	Min-Max
1	Drought	Drought	Drought	Drought
2	Energy Demand	Energy Demand	Riverine Flooding	Heat
3	Riverine Flooding	Riverine Flooding	Heat	Riverine Flooding
4	Heat	Heat	Energy Demand	Energy Demand
5	Historical Extreme Conditions	Historical Extreme Conditions	Wildfire	Wildfire
6	Wildfire	Wildfire	Historical Extreme Conditions	Historical Extreme Conditions
7	Land Degradation	Land Degradation	Land Degradation	Land Degradation
8	Coastal Flooding	Coastal Flooding	Coastal Flooding	Coastal Flooding

These data show that differences in the normalization method used in a WOWA score calculation can influence the result of an analysis performed using DCAT indicators. The min-max method tended to reduce indicator values relative to the division by max method by rescaling the indicators over the range of possible values in each dataset. Further studies into the effects of alternative normalization methods, such as *z*-score normalization, should be performed to adequately characterize the full effect of this normalization method on the outputs of DCAT.

Note that comparisons between hazard categories may not be "apples-to-apples," for reasons explained in Chapter 5. If WOWA scores across hazard categories are not to be compared, then any changes in relative ranking across hazard categories are unimportant to any analysis. The change in WOWA scores due to a change in normalization method therefore would have no consequence. For instance—though the riverine flooding WOWA scores may change when using the min-max method instead of division by max, each installation's WOWA score will be affected similarly within a hazard category. WOWA score comparisons between installations or between epoch-scenarios at a single installation, within a hazard category, would still be valid regardless of normalization technique. *But if the goal is to enable comparisons of WOWA scores between hazard categories, then more work needs to be done to find a normalization procedure that can remove the issue with indicator definitions that is not solved by division by max.* The current normalization procedure has not equalized indicator definitions because of the outlier effects.

D. Effect of Installation Selection

The effect of installation selection was not analyzed in this chapter, but this aspect of DCAT has an effect on the result of WOWA calculations as well. For instance, as a result of using the division by max normalization method, including a sufficiently high indicator value at a newly introduced installation would have the effect of lowering the WOWA scores of all other installations, if all other factors and indicators are held constant. The addition of a large number of new installations into DCAT would likely introduce these effects. The dataset for the analysis in Section C.2 contained 157 installations, those included in DCAT (CONUS/AK/HI) (VA6) as of March 2, 2021.

For example, consider a random dataset with the division by max normalization technique applied to it in Table 8. In Table 9 we will add a single large data point to the dataset, and recalculate the division by max normalized values.

The effect of the outlier is readily seen—it shifts all other normalized values in the dataset down by a significant margin, simply by being included in the dataset. *As DCAT continues to expand its portfolio of installations, adding new installations could result in different WOWA scores for all installations in the tool, without any change in the relevant climate data, definitions, or mathematical methods.* While the rank-ordering of the original installations would remain unchanged if new installations are added (relative to other original installations), the rank-order of the new dataset (inclusive of new installations) would naturally be different. Therefore, DCAT results must also be seen as version dependent; otherwise, comparisons between versions could give the perception of an increased or decreased exposure to some climate-related hazards, without any change in the underlying data.

Table 8. Example Dataset and the Division by Max Normalization Method

Value	Division by Max Normalized Value
5	0.455
8	0.727
2	0.182
11	1.000
6	0.545

Table 9. Example Dataset with an Outlier Added to It and Division by Max Normalization Method Applied

Value	Division by Max Normalized Value
5	0.217
8	0.348
2	0.087
11	0.478
6	0.261
23	1.000

E. Discussion

The analyses in this chapter show that selection and definition of indicators, the method employed to normalize indicator data, and the selection of installations can all have a measurable effect on the final result of a WOWA calculation. Indicators rely on definitions that contain thresholds and criteria that influence indicator value, which ultimately influence WOWA scores. When normalizing indicators using the min-max method instead of the division by max method, six indicators had their median value changed by more than 10%; one indicator's median value was reduced by over 60%. WOWA scores showed a median discrepancy of up to 24% between the two normalization methods, as multiple categories across two test epoch-scenarios saw a change. When ranked, these two normalization methods produced a slightly different ranking list for the Higher-2085 epoch-scenario, the second and third rank switching places. However, due to the "apples-to-oranges" nature of WOWA score comparisons across hazard categories, this type of ranking may not be advised at all; the WOWA score differences due to the normalization method used may be inconsequential. In addition, the introduction of new installations can influence WOWA scores for all installations in the tool, if those new installations had sufficiently high indicator values, due to the normalization method used by DCAT.

It is easy to see how climate data, importance weights, and ORness factors may change DCAT results by directly modifying the inputs or outputs of the code, as discussed in Bewley et al. (2020). *However, other factors, such as indicator definitions, indicator-normalization methods, and installation selections also play a role in determining the final result of a WOWA calculation, and hence the analysis performed by DCAT.* The analysis in this chapter focused primarily on the indicator-normalization technique, but similar analyses could be performed to investigate whether the threshold selection in indicator definitions leads to higher or lower WOWA scores. Ultimately, WOWA scores are a relative measure of exposure, dependent not only on not just the data used in the WOWA calculation but also on the procedures used in the overall process itself. Therefore, to prevent a misleading hazard ranking, any comparison or analysis of WOWA scores must be made with the full knowledge and understanding of the indicator definitions, normalization techniques, and installation selections—as well as the climate datasets, importance weights, and ORness factor—used to generate the WOWA scores.

In light of the sensitivity of the WOWA scores to the definition of input indicators, normalization procedures, and installation selections, the next chapter of this evaluation further discusses the WOWA comparisons enabled in DCAT and when users should exercise caution.

5. WOWA Score Comparisons in DCAT

WOWA score comparisons made within DCAT can be used only to inform high-level screening assessments. From our understanding, a screening-level tool enables the user to obtain a *preliminary* review of potential vulnerabilities to climate change hazards. The tool indicates potential *exposure* risk only; in other words, it indicates where additional assessment of exposure is advisable. DCAT does not purport to provide any information about an installation's sensitivity or adaptive capacity to a changing climate and historical extreme weather events.

A. Comparison Tables

DCAT is designed to compare WOWA scores at a variety of different levels. Understanding that this tool was created as a high-level screening tool, comparisons made should be suitable to inform high-level decisions about exposure to climate hazards. For comparisons between WOWA scores, we must first define which scores can be accessed in the tool and in what ways they vary. There is a WOWA score for each hazard category, and a weighted sum of all the WOWA scores for each installation, called the total weighted WOWA score. These WOWA scores are available for the historical baseline and four future epoch-scenarios that represent different emission scenarios at different time periods: lower-2050, higher-2050, lower-2085, higher-2085 (see Chapter 3 for more details). The WOWA scores can either be from the same installation or from different installations, but both must be from the same DCAT web tool (CONUS/AK/HI or ROW). Additional caveats for comparing variables between the CONUS and AK+HI regions within the DCAT(CONUS/AK/HI) web tool and for comparing variables between the DCAT(CONUS/AK/HI) and the DCAT(ROW) web tools will be discussed later in this chapter.

Table 10 assesses the comparisons between the WOWA scores of different data variables. A green box indicates that it is an appropriate comparison, yellow indicates that there are caveats while comparing and additional steps should be taken, and red means it is not a recommended comparison; gray indicates that the variables are the same and there is no comparison to be made. The third and fourth column show comparisons between the WOWA score of the variables at installations in different epoch-scenarios, and the fourth and fifth column shows the comparisons between the WOWA score of the variables at installations in the same epoch-scenarios. For example, the green box in the last row, second column of Table 10 shows that it is appropriate to compare total weighted WOWA scores across two different epoch-scenarios, for the same installation. However, the yellow box just to the left of that, in the last row, first column, shows that there are some caveats when comparing total weighted WOWA scores across different installations, even if they are in the same region, and even if the epoch-scenario is held constant.

As shown in Table 10, we have determined that DCAT is most powerful in assessing *relative* exposure, or in other words, it's best at assessing how the exposure changes at one installation over time (i.e., between two epoch-scenarios, or simply relative to the historical baseline epoch-scenario). Alternatively, this comparison can be done by comparing the relative exposure of one hazard at multiple installations, for the same or different epoch-scenarios. In the next section, we explain the reasoning behind these recommendations.

B. Explanations and Caveats

Although all the input data have been normalized, averaged, and weighted, the outcome still does not lead to a perfect comparison. While all WOWA scores range between 0 and 100, they do not represent the *probability* that a hazard will happen, but a *relative scale of exposure* to a hazard. It is important to remember the limitations of the tool when making comparisons.

1. WOWA Score Caveats for Hazard Categories

WOWA scores should not be compared between two hazard categories, even for the same installation. We conclude that these WOWA scores cannot be compared because (1) the normalization method makes the WOWA score sensitive to the indicator values and indicator definitions, (2) the importance weights further compound the sensitivity of the normalization methods, and (3) the dependence on processes like installation selection, indicator definition, and normalization methods, as well as the subjectivity of the importance weights, makes the output a relative measure of exposure within a hazard category. The result of comparing between hazard categories is therefore not meaningful.

Table 10. Comparisons of Variable WOWA Scores where Variable 1 and Variable 2 Are in the Same Region

		Different Epoch-Scenario		Same Epoch-Scenario	
Variable 1	**Variable 2**	**Different Installation**	**Same Installation**	**Different Installation**	**Same Installation**
Hazard A	Hazard A				
Hazard A	Hazard B				
Hazard A + Hazard B	Hazard A + Hazard B				
Total Weighted WOWA	Total Weighted WOWA				

The division-by-max normalization method is sensitive to the indicator values and indicator definitions. Each WOWA score is dependent on the value of the indicator at other installations; Table 8 and Table 9 show the sensitivity of the WOWA score to outlier effects. In the current version of DCAT, V06, the effect of an outlier can be seen on the distribution of indicator 108C (Mean Annual Runoff). The maximum value of indicator 108C is approximately 8,962 cubic feet per second, while the median value is only 32 cubic feet per second. In other words, over half the installations will be normalized with a maximum value over 280 times their value, resulting in low normalized values. This indicator is inverted, meaning that a lower value results in a higher WOWA score contribution. In the indicator-distribution plot shown in Figure 7, we can see that this outlier effect caused the normalized values for indicator 108C to be clustered around 1. Approximately 95% of the installations have a normalized indicator value above 0.8. Future analysis could be done to assess how choosing a different normalization procedure that is not as affected by outliers would affect the distribution of indicator 108C.

If the indicators had no outliers and a normal distribution, the range of values would not affect the normalization. As shown in Figure 7, however, the normalized indicators do not have normal distributions, and they vary from one indicator to the next. The definition of the indicators affects the range of possible values. For indicator 108C, the range of possible values was from almost 0 to thousands of cubic feet per second. Other indicators, however, have a smaller range of values by definition. For example, an indicator like Consecutive Dry Days (106) is defined as the mean-annual maximum number of consecutive days with less than 0.1 inches of rainfall. In other words, the maximum value of this indicator could be 365 days *if* a location never experienced any rainfall, and the minimum possible value is 0 days *if* a location experienced rain every day. Even if these extremes occurred, the range of values would be substantially limited by the range of values possible for indicator 108C. In practice, the maximum value of 106 is approximately 141 days. Further analysis would be needed to conclude how the range in values contribute to the different distributions of 108C, 106, and other indicators included in DCAT.

After an indicator is normalized, the normalized values are compiled into the WOWA score. Each indicator is assigned an importance weight based on logic that is discussed in "Hazard Category and Indicator Overview" (USACE 2020), available on the DCAT website (see Appendix A for a full list of indicators and importance weights). A higher importance weight means that the indicator has a greater potential contribution to the WOWA score. For example, indicator 108C and indicator 106, the indicators discussed above, both contribute to the drought hazard WOWA score. Indicator 108C primarily has a normalized value greater than 0.8, while indicator 106 primarily has a normalized value less than 0.2 (see Figure 7 for indicator distribution plot). Indicator 108C has an importance weight of 1.5, the highest importance weight assigned to a drought indicator, and indicator 106 has an importance weight of 1, the lowest weight assigned to a drought indicator. These importance weights meant that the biases due to installation selection and outliers are compounded in the drought hazard WOWA score because the importance weight selection gives more weight to indicator 108C, with a higher value distribution, and less weight to indicator 106, with the lower value distribution.

While the importance weights were selected logically to represent the interaction of indicators and how those contribute to the hazard, the indicator values are sensitive to outliers. As a result, if an indicator is skewed high or low by an outlier, the corresponding importance weight only exacerbates that bias. Interestingly, the drought hazard category, which includes indicator 108C and 106, has the highest WOWA values of any hazard category. While we cannot definitively conclude from this analysis that the normalization and importance weights of these two indicators were the primary cause of the high drought WOWA scores, we recommend that these factors be considered before concluding that an installation is most exposed to the drought hazard category because the drought hazard WOWA score is the highest WOWA score.

Although the indicator values have been normalized throughout, the possible values of each hazard category's WOWA score is highly dependent on the processes used to define and calculate the indicators and the subsequent choices of normalization procedure and importance and order weights. The WOWA score does not represent the probability that an installation will be affected by a hazard; rather it represents the exposure an installation has to a hazard category relative to the exposure other installations have to that same hazard. In other words, comparing WOWA scores between hazard categories is an "apples-to-oranges" comparison. That is, due to the sensitivities described above, it should not be concluded that a higher WOWA score for one hazard category means that an installation has a higher exposure than it has for another hazard category with a lower WOWA score.

As an example, consider the case in which an installation has a drought hazard WOWA score of 80 and a coastal flooding WOWA score of 40, for the same epoch-scenario. These numbers should not be interpreted to mean that the installation is twice as likely to experience drought than coastal flooding in that epoch-scenario. Because of potential outlier effects resulting from indicator definitions, it does not necessarily even mean that the installation is more likely to experience drought than coastal flooding.

The visualizations presented in DCAT might tempt the user to compare the WOWA scores between hazard categories. For example, Figure 10 shows the Installation Details tab of DCAT. The user selects an installation, and DCAT generates a combination of donut charts and pie charts. The rows represent the different epoch-scenarios; the top two rows display WOWA scores from the lower emission scenario, and the bottom two rows display WOWA scores from the higher emission scenario. The left-most column represents the total weighted WOWA score as donuts, where the eight slivers of the donut represent the eight hazard categories. The size of the sliver is the percentage contribution of a given hazard category to the total weighted WOWA score; the number in the center is the value of the score. The eight columns to the right of the donut charts display a pie chart for each hazard; the pieces of the pie indicate the relative contribution of the indicator to the WOWA score. For example, the first pie chart in the wildfire column represents the wildfire WOWA score in the Lower-2050 Scenario. Each color of the pie represents the percentage of the WOWA score that the respective indicator contributes to that hazard category.

Source: DCAT (CONUS/AK/HI) (VA6).

Figure 10. Screen Capture Taken from the Installation Details Tab of DCAT (CONUS/AK/HI). The red-circle shows the link clicked to access this page within DCAT.

The user might be tempted to use the donut charts shown in Figure 10, column 1 to compare the WOWA scores with each other. For example, in the first donut representing the total weighted WOWA score in the Lower-2050 Scenario, the drought sliver of the donut is much larger than the wildfire sliver of the donut. The user might be tempted to conclude that this installation is more exposed to drought. The user might be similarly tempted to compare the individual WOWA scores that are displayed in a horizontal row. In both cases, we do not recommend comparing between different WOWA scores even in the same epoch-scenario. Instead, we recommend that the user focus on the change in the WOWA scores for each hazard category separately and analyze how these scores change between each epoch-scenario. Similarly, for the pie charts on the right, we recommend the user focus on how each indicator's contribution to the WOWA score (i.e., the size of wedge) changes over time between each epoch-scenario.

2. Total Weighted WOWA Caveats

DCAT was designed to use the total weighted WOWA score to rank installations by their relative exposure to select climate extremes. This is not a perfect comparison because, as discussed above, we do not recommend comparing WOWA scores from different hazard categories with each other. Installations that are more exposed to hazards with higher WOWA score distributions will have the potential to have a higher total weighted WOWA score than those that are more exposed to hazards with lower WOWA score distributions. Some installations may not be exposed to all the hazard categories covered in this tool and will have a WOWA score of zero for some hazard categories (e.g., inland installation with zero coastal flooding exposure because it is not located on the coast). To help combat the limitations of comparing total weighted WOWA scores, we recommend that the user also (1) assess how the individual hazard categories contribute to the total score and (2) compare the total weighted WOWA score for future epoch-scenarios to the total weighted WOWA score for the historical baseline.

Assessing how the individual hazards contribute to the total score gives a detailed view of an installation's exposure. The total weighted WOWA score could be high because the installation is exposed moderately to all hazards, or it could be high because it is extremely exposed to a smaller number of hazards. Both of those conditions result in high total exposure, but without looking at how individual hazards contribute to the score, an incomplete picture of exposure is drawn. In addition, the total weighted WOWA score can be understood better when it is compared with the historical baseline to observe the relative change in exposure over time. Moreover, the total weighted WOWA score for the historical baseline can be put into context by speaking with installation managers to understand the current exposure. If an installation has a total weighted WOWA score of 380 in the historical baseline scenario, and the installation manager says that the installation has already been affected by flooding and wildfires, an increase in the total weighted WOWA in the future, especially if it is from an increase in the WOWA scores in the flooding and wildfire hazard categories, could be interpreted that the installation will likely face even greater exposure in future scenarios.

One of the DCAT-generated reports compares the sum of the WOWA scores for two hazard categories at one installation with the sum of the WOWA scores for two hazard categories at another installation. The same limitations described above apply to the output of that report, and the same additional steps should be taken when making that comparison.

3. CONUS and AK+HI Comparison within DCAT (CONUS/AK/HI)

While it is generally appropriate to compare the WOWA scores of the variables noted in Table 10 within the DCAT (CONUS/AK/HI) web-based tool when one variable is from an AK+HI installation and the other is from a CONUS installation, a couple caveats should be noted.

a. Different downscaling techniques

In our initial assessment (Bewley et al. 2020) of the data sources used to calculate indicators for CONUS and AK+HI, we concluded that it was not a fully appropriate comparison between these two regions because of the different climate model downscaling techniques used:

> A recently published comparison study…found some differences between BCSD- and LOCA-processed projections for CONUS, particularly in mountain areas. However, differences between the two methods were generally smaller than differences between RCP 4.5 and RCP 8.5 climate scenarios. Regardless, the study authors urge their readers to avoid direct comparisons between BCSD-processed and LOCA processed data. (Bewley et al., 2020).

The user needs to keep in mind that the comparison between AK+HI and CONUS is based on different climate inputs anywhere a downscaled climate projection is used as an input to an indicator.

b. Different Data Sources

Another concern of comparing CONUS with AK+HI installations was that some of the AK+HI installations had indicators held constant in time, while the same indicators for CONUS varied in time. The two indicators that are stationary for AK+HI are Ignition Rate (602), which is defined as the population density around an installation, and Fuel Abundance (601), which is defined as the land use/land cover around an installation. Note that although comparing wildfire between AK+HI and CONUS is comparing static and non-static variables, these two specific indicators are not likely to change drastically over time for AK+HI. Therefore, since there are other, more comparable indicators that contribute to the wildfire hazard, it likely will not make a large difference in understanding the total exposure.

Similarly, because the river-routing methodology (mizuRoute) used for CONUS to provide the data for indicator 108C (Mean Annual Runoff) was not available for AK+HI, that indicator was calculated without river-routing capabilities. The uncertainty that results from using different methodologies is unknown.

4. Comparison between DCAT (ROW) and DCAT (CONUS/AK/HI)

Although CONUS and ROW are in two separate tools—DCAT (CONUS/AK/HI) and DCAT (ROW)—on the DCAT website, the website notes that comparisons between ROW and CONUS "can be legitimate for high-level screening questions" but are not legitimate for "closely resolved questions about either historical climate or projected future possible climate." Since the indicators and data sources vary greatly between CONUS and ROW, little can be concluded from comparing any WOWA scores between the two regions, and we do not recommend any comparison between the two tools. We recommend clarifying what high-level screening questions *could* be answered with the tool by comparing CONUS and ROW and how those comparisons could be appropriately done. But we do not recommend that users compare WOWA scores found in DCAT (CONUS/AK/HI) with those found in DCAT (ROW).

With the explanations and caveats above in mind, the next chapter of this report leverages a vignette-based assessment of the usability of DCAT outputs for the intended user groups.

6. Framework for Usability Assessment

DCAT is a tool intended for three major user groups to make decisions at different levels of the DoD:

- *Installation-level planners and engineers* can analyze an installation's exposure and use this information to help inform installation planning and support resilient design.
- *Military Department headquarters* can identify regions or installations requiring focused attention like further studies on mission-specific hazards or exposure mitigation.
- *DoD leadership* can compare exposure across the Department to inform investment and policy decisions (DCAT One Pager 2020).

Below, we explore user vignettes on how different users could appropriately apply DCAT to real-world situations. For a complete assessment, we would have to determine (1) if the tool's input data and methodology are appropriate for the task, (2) if the tool outputs the correct data for the user group's analysis, and (3) if this analysis is sufficient for the user to create sound recommendations. This type of complete assessment was beyond the scope of our analysis; however, we did a simple assessment of possible user vignettes and looked at ways DCAT could help the user in each scenario. Note that we are only assessing how DCAT can be used to judge exposure. We will not be assessing how an installation's exposure informs planning or how one might use the exposure tool to assess sensitivity or adaptive capacity, but because such information will likely be important in informing how the tool can be used properly, we recommend that it be assessed in future work.

A. Installation Manager

Tasks:

1. Analyze exposure and/or susceptibility to climate extremes.
    a. Add separate geographic information system (GIS) layers available from military-installed GIS systems at specific installations (*optional step*).
2. Use this information to inform planning, land use recommendations, and resilient infrastructure.

Vignette:

> Your installation has suffered damages over the past decade due to inclement weather conditions and extreme events. HQ wants you to try to understand what hazards you will be most vulnerable to so that you can take preventive measures against future costly repairs. You are asked to provide a report that analyzes your vulnerability to future events and provides a funding estimate for further research.

In this case, the installation has already experienced the effects of extreme weather events, and the manager needs to know if and how this will change in the future. The user can use DCAT to answer which installations have been highly exposed to climate in the past using the historical baseline and historical weather extremes WOWA scores. The installation manager should look at the relative *change* in exposure over time by comparing each WOWA score in future epoch-scenarios, with respect to the historical baseline epoch. Any WOWA score that markedly increases over time indicates an increasing exposure to that hazard category over time. DCAT alone cannot answer any questions about *vulnerability* to events, so the following analysis only will describe *exposure*.

For example,

Table 11 shows the WOWA scores for drought, riverine flooding, and coastal flooding at the Norfolk Virginia Naval Station. For the Lower-2050 scenario, drought has an WOWA score of 71, and coastal flooding and riverine flooding have WOWA scores of 35 and 53, respectively. For the Higher-2085 scenario, coastal flooding and riverine flooding now have scores of 76 and 77, respectively, and the drought score is 81. Although the drought score is still higher, it experienced the smallest relative increase out of these three hazards.

Table 11. Drought, Coastal Flooding, and Riverine Flooding WOWA Scores at the Norfolk, VA, Naval Station

Epoch-Scenario	Drought	Coastal Flooding	Riverine Flooding
Historical Baseline	65	27	46
Lower-2050	71	35	53
Higher-2085	81	76	77
Percentage increase from Baseline to Higher-2085	*24%*	*181%*	*67%*

Source: WOWA Scores downloaded from DCAT (CONUS/AK/HI) (VA6).

Comparing the relative increase of the WOWA scores from the historical baseline to the Higher-2085 scenario informs how exposure will change with time. At the Norfolk Naval Station, drought increased 24% from its historical baseline WOWA score, whereas the coastal flooding score increased 181% and the riverine flooding increased 67%, respectively. Although in the base scenario those WOWA scores are lower, in the future scenarios they rose to significantly higher levels. These changes emphasize that higher WOWA scores from one hazard category do not tell the full story of exposure. It is important to assess both the WOWA score and the relative change in that score from the baseline historical scenario.

To increase the depth of analysis at the Norfolk Virginia Naval Station, additional steps outside the current scope of the tool can be taken. For example, an installation manager could add installation specific GIS layers to see if more information will affect the installation's exposure to climate hazards. An installation manager could also use outside historical climate data or outside data on past extreme flooding or drought events to give more context to the current exposure to these climate hazards.

B. Service Department Headquarters

Tasks:

1. Identify regions or installations that require focused attention.
2. Perform further studies on mission-specific hazards or climate-mitigation techniques.

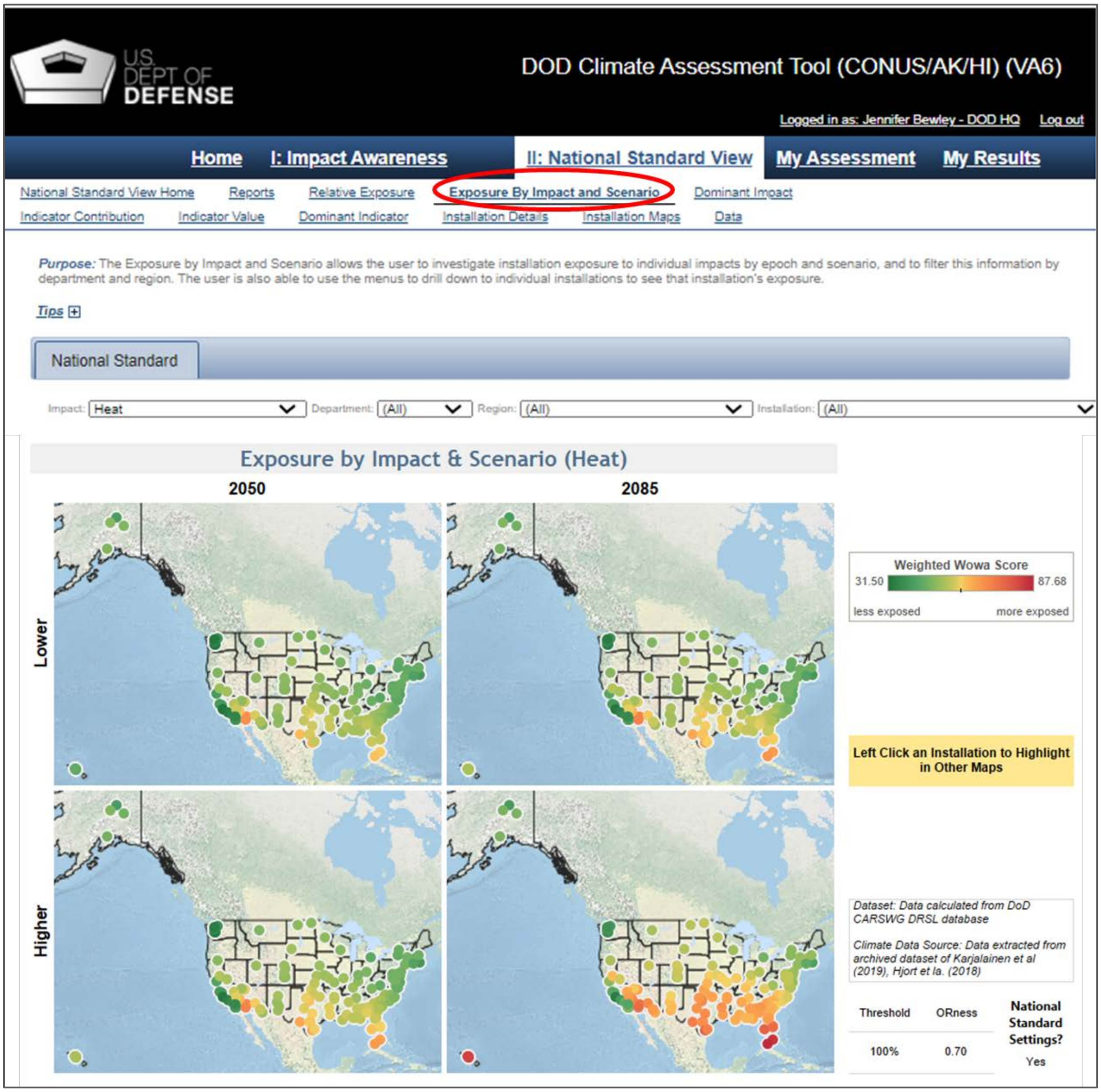
Vignette:

> You have noticed a rise in heat-related injuries during training and want to figure out which installations or regions could be susceptible to increasing occurrences of heat-related training injuries. You are asked to identify all the regions that will be increasingly vulnerable to rising temperatures. You are also asked to create a report of the top installations with the greatest likelihood of heat-related injuries.

In this scenario, department headquarters identifies the installations that are the most exposed to the heat hazard category. The user can first rank installations based on the heat WOWA score using the Reports section of the DCAT web tool. DCAT's Exposure by Impact (Hazard) and Scenario tab can also provide a heatmap to help identify which installations are most exposed to the heat hazard category, as shown in Figure 11. For a regional analysis, CONUS could be split into predefined subregions to identify those subregions with the highest exposure to the heat hazard category in any given epoch-scenario. Furthermore, for those subregions with a *low* exposure to the heat hazard category, additional analysis could investigate if they may still exhibit a large change (increase) in exposure over time.

Once the most exposed installations overall have been selected, or the most exposed installations in each subregion have been selected, department headquarters can take a deeper look at how the indicators contribute to the heat hazard category at each installation.

This gives the user information on the specific indicators that contribute to the increase in exposure and how those indicators change in the different epoch-scenarios.

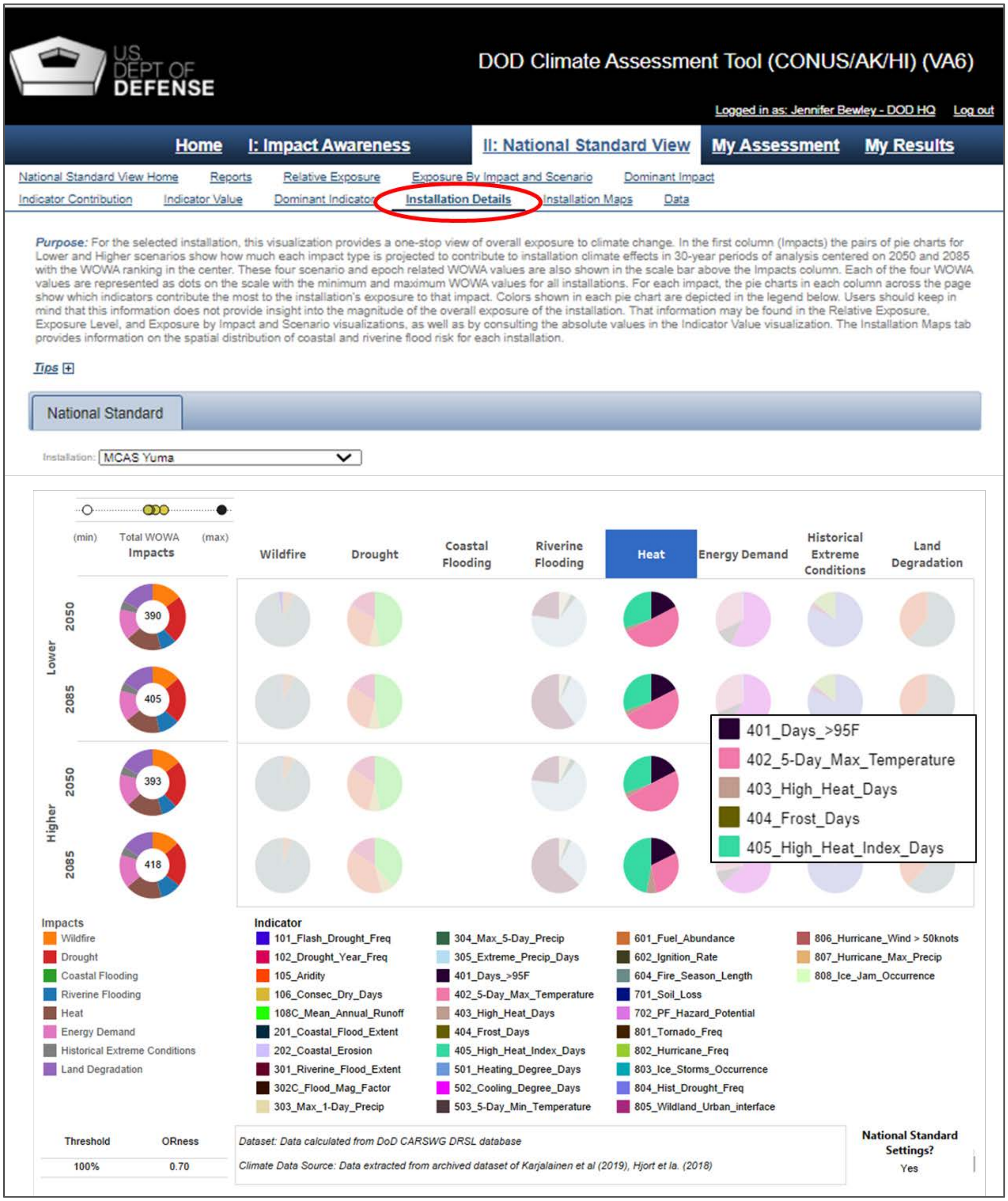


Source: DCAT (CONUS/AK/HI) (VA6) Exposure by Impact and Scenario page. Note: In DCAT version VA6, the hazard categories were referred to as impact categories.

Figure 11. A Map of the Heat WOWA Scores with the Red-Circle Annotation Indicating where to Access This Page within DCAT

For example, the MCAS Yuma installation has the highest WOWA score for the heat hazard category for all installations. In the Installation Details view shown in Figure 12, all the indicators contribute the same relative amount to the heat WOWA score until the Higher 2085 scenario, when the high heat index days indicator suddenly dominates. While

Yuma historically has a high heat WOWA score, the change in the high heat index days indicator could cause concern for how that will affect training days in the future.



Source: DCAT (CONUS/AK/HI) (VA6) Installation Details page. Note: In DCAT version VA6, the hazard categories were referred to as impact categories.

Figure 12. MCAS Yuma Indicator Contributions to the Heat Hazard at Different Epoch-Scenarios with the Red-Circle Annotation Indicating where to Access This Page within DCAT. A larger legend for the heat indicators is added for clarity.

Ranking installations by WOWA score is a good first step to assessing exposure, but the tool becomes much more powerful when the WOWA score is further broken in down into indicators. In addition, the WOWA scores should be compared with the historical baseline to assess the relative change in exposure at each installation. Note, however, that the web tool does not currently display the historical baseline values for hazard categories; including those would allow for better analysis.

C. DoD Leadership

Tasks:

1. Compare exposure risks at different installations across the Department.
2. Use this comparison to answer questions from Congress and inform investment and policy decisions.

Vignette:

Congress has told you that you are spending too much money on infrastructure repairs and that mitigating efforts need to be taken.

1. You must look at installations that have *current* high exposure to climate change (have already experienced damages due to climate extremes) and assess what their future exposure will be.
2. You must decide which installations overall will be most exposed to *future* climate change and how much money they need to do sensitivity and adaptive capacity research.

This scenario has two parts: determining the past exposure to climate hazards and determining the future exposure to climate hazards. The tool can be used to determine past exposure using the total weighted WOWA scores from the historical baseline epoch and with the WOWA scores from the historical weather extremes hazard category. This information could be supplemented with information outside the tool by identifying installations that have experienced a lot of infrastructure damage or disruption to routine operations due to weather extremes. Understanding which installations are currently exposed will provide a frame of reference for determining future exposure.

To determine future exposure, DoD leadership could look at the ranking of total weighted WOWA scores. Unfortunately, the tool currently does not offer a ranking of total weighted WOWA scores during the historical baseline epoch. *Future versions of DCAT should therefore present results for the historical baseline as well as the four future epoch-scenarios.* Table 12 displays the three installations with the highest total weighted WOWA scores in the lower emission scenarios using data from the DCAT reports. However, as noted in Chapter 5, we recommend assessing the WOWA scores for each hazard category alongside the total weighted WOWA scores. Further, before a definitive ranking of installations with the highest exposure is given to Congress, both the individual contributions of each hazard category to the total weighted WOWA score and the relative change in exposure from the historical baseline epoch should be assessed as discussed in Chapter 5.

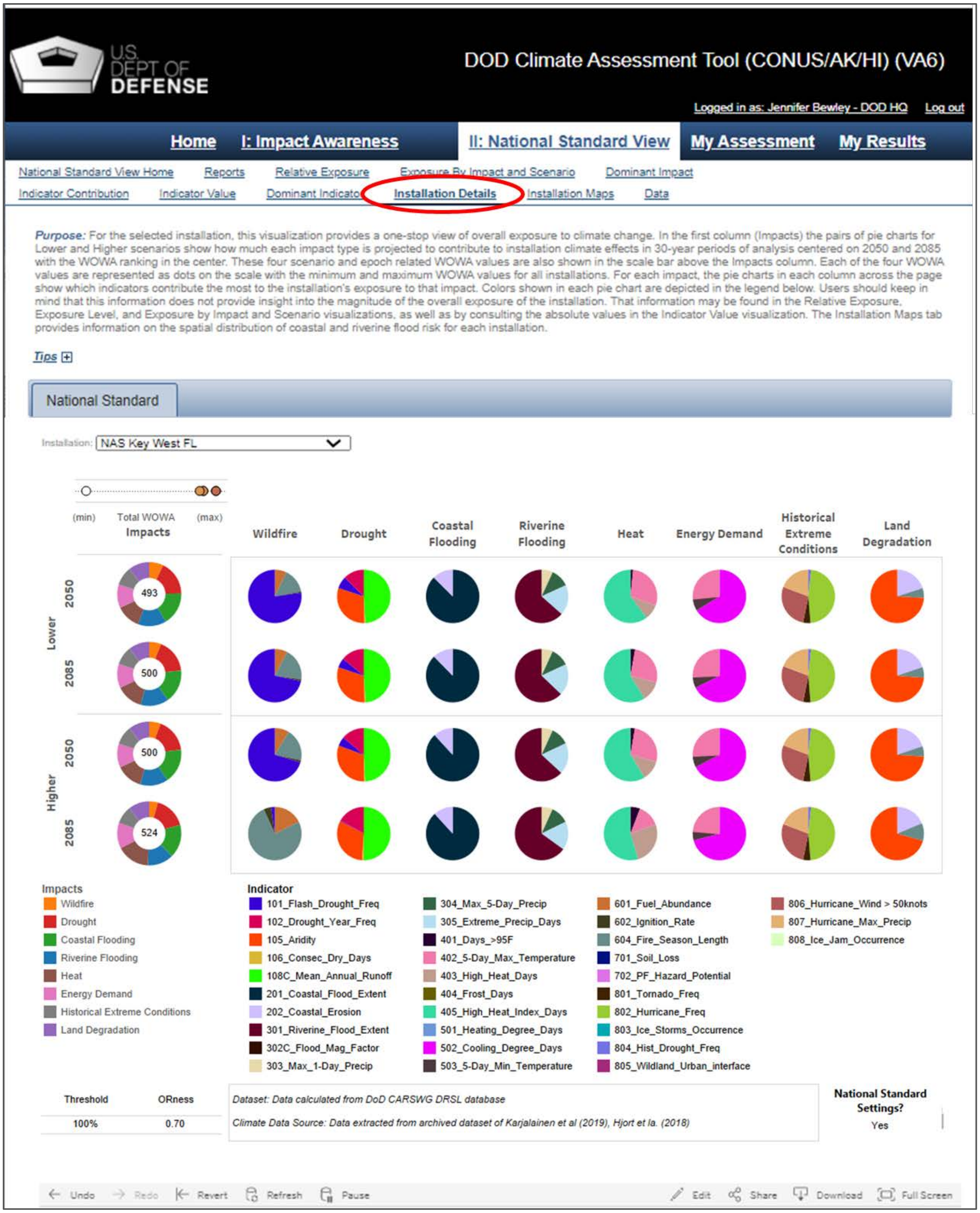
Table 12. Installations with the Highest Total Weighted WOWA Score in the Lower Emission Scenario

Lower 2050	Total Weighted WOWA Score	Lower 2085	Total Weighted WOWA Score
NAS Key West, FL	493.02	NAS Key West, FL	500.00
Homestead ARB	459.20	Langley AFB	477.51
Aberdeen Proving Ground	458.78	Homestead ARB	470.71

Source: Data downloaded from DCAT (CONUS/AK/HI) (VA6).

To look at how the exposure changes over time at one installation, the Installation Details tab of DCAT can be used, but as noted previously, it currently does not show any historical baseline WOWA scores for comparison. Figure 13 shows the Installation Detail tab of DCAT for the installation with the highest total weighted WOWA score in the lower emission scenario: NAS Key West FL. This breakdown gives more insight into how individual indicators and hazard categories contribute to the total weighted WOWA score over time. The NAS Key West FL installation's exposure to the eight different hazard categories does not change significantly between epoch-scenarios until the Higher-2085 scenario.

As discussed in Chapter 5, the pie charts in Figure 13 can be used to assess the change in relative contribution of indicators to the eight WOWA scores. For example, the wildfire hazard category has the same composition of indicators until the Higher-2085 epoch-scenario, when the fire season length indicator (604, gray) increases significantly. Similarly, the high heat days indicator (403, tan) becomes a greater concern in the heat hazard category in the Higher-2085 epoch-scenario. With access to the historical baseline WOWA scores, headquarters could assess how these findings compare with the historical baseline epoch to understand the total relative change in exposure.



Source: DCAT (CONUS/AK/HI) (VA6) Installation Details page. Note: In DCAT version VA6, the hazard categories were referred to as impact categories.

Figure 13. NAS Key West FL Indicator Contributions to Hazards in Different Epoch-Scenarios with the Red-Circle Annotation Indicating where to Access This Page within DCAT

We also recommend that DoD leadership assess the relative change in total weighted WOWA score. For example, in the Lower-2050 epoch-scenario, the total weighted WOWA score of 452 is not high enough to rank Langley AFB as having one of the three highest total weighted WOWA scores, but the scores of 478, 476, and 520 are high enough to rank it as having the second highest total weighted WOWA score in the other three future epoch-scenarios. Further, the Langley AFB total weighted WOWA score increases approximately 15% from the Lower-2050 to the Higher-2085 epoch-scenario, while the higher valued NAS Key West total weighted WOWA score increases approximately 6%. Even though Langley is not one of the three most exposed installations based on highest total weighted WOWA scores for the Lower-2050 epoch-scenario, it becomes more exposed over time; therefore, the installation managers should be prepared for increased exposure longer term. In contrast, although NAS Key West has the highest total weighted WOWA score over epoch-scenarios, it does not increase significantly in exposure over time.

DoD leadership should also consider the possibility that some locations could be extremely exposed to one hazard, but not exposed to others. These installations may not have very high total weighted WOWA scores and as a result may not be ranked high overall. However, they have the potential to be extremely exposed to some particular hazard categories. We advise looking at which installations have the highest WOWA scores for each individual hazard category, as well as the total weighted WOWA score, before compiling a list of the most exposed installations. For example, the top-three installations with the highest WOWA scores for energy demand in the Lower-2050 epoch-scenario are all located in Alaska and do not appear in the top-three list for highest ranked total weighted WOWA scores shown in Table 12. Similarly, none of the top-3 installations for riverine flooding in the Lower-2050 epoch-scenario make the top-10 highest ranked total weighted WOWA scores. While the overall exposure at these installations may be less, high exposure to one hazard category may still result in high vulnerability depending on the installations' sensitivity and adaptive capacity.

The next step in interpreting these findings would be to look at the historical baseline total weighted WOWA score of the top installations to assess the relative change in exposure from the historical baseline epoch. Assessing the relative change in exposure helps identify the installations that do not have a high exposure to climate hazards currently, but are predicted to in future scenario; these installations might be less prepared for extreme changes in climate than those with high exposure at the historical baseline. DoD leadership could speak to the installation managers at these locations to better understand the current conditions and affirm that the historical baseline WOWA scores from DCAT align with the exposure that an installation manager has witnessed at the installation.

D. Conclusions

DCAT can be a powerful aid in decision-making at different levels in the DoD. Installation managers can perform preliminary assessments on relative trends in exposure to different hazard categories and indicators at their installation to inform future planning decisions. Department headquarters can identify regional trends using the heatmap visualizations and DCAT-generated reports to target areas of future research and mitigation. DoD leadership can assess a broad overview of total exposure at a high level. Note, however, that even though DCAT is powerful, it is a screening-level tool. Users should keep in mind the scope of the tool when performing analysis:

1. The tool only assesses *exposure* to climate hazards and does not comment on sensitivity or adaptive capacity; any use-case that asks to determine vulnerability will require additional studies outside the scope of DCAT.
2. The WOWA scores in DCAT are a *relative* measure of exposure, so comparing future epoch-scenario WOWA scores with the historical baseline scores will strengthen analysis. Future versions of DCAT should provide results for the historical baseline epoch and include them in visualizations.
3. Many of the potential uses of DCAT involve ranking installations by exposure based on the value of the total weighted WOWA score. As discussed in Chapter 5, analysis involving ranking installations will be strengthened if multiple methods are employed to determine the relative exposure.
4. For any analysis performed by DCAT, adding supplemental information directly from installation managers will provide more data to draw stronger conclusions.

Additional examples of user vignettes can be found in Appendix A.

7. Findings and Recommendations

The goal of this evaluation was to assess how the DCAT output could best be used to inform high-level mitigation planning and infrastructure development. Overall, we found that higher indicator values led directly to larger WOWA scores such that the WOWA scores in DCAT provided a relative measure of an installation's *exposure* to climate hazards for four epoch-scenarios with the ability to download WOWA scores for the historical baseline. Although DCAT is a powerful tool, we found that when assessing exposure there are some limitations to the comparisons that can be made in the tool. Also note that DCAT only assesses exposure to the eight climate hazard categories, but does not comment on vulnerability, which considers sensitivity and adaptive capacity in addition to exposure. Any tasks that require an assessment of vulnerability will require additional studies outside the scope of DCAT. The sections below summarize our findings and recommendations.

A. Summary of Findings

1. Data-Aggregation Method Assessment

- In this assessment we reproduced the WOWA calculation performed in DCAT using National Standard View importance weights and ORness = 0.5 for all installations (*N* = 157) and epoch-scenarios (including historical baseline) in DCAT (CONUS/AK/HI) (VA6) as of March 2, 2021. This process included independently pre-processing and normalizing indicator values.
- DCAT utilizes the division-by-max (Yoon 2012, Runfola et al. 2017, Bewley et al. 2020) normalization method, which uses the maximum value of an indicator across all installations, historical baselines, and epoch-scenarios to normalize the indicator values.
  - Limitations of the division-by-max method include unit dependence and outlier effects.
  - We found that higher normalized indicator values lead directly to larger WOWA scores within their respective hazard categories.
  - Users must be careful to consider the definitions of the underlying indicators, the normalization technique, and the importance and order weights when comparing and interpreting WOWA scores.

- Indicator selection has a significant impact on the final WOWA value. Indicators rely on definitions that contain thresholds and criteria that influence indicator value, which ultimately influence WOWA scores.
  - If a WOWA score is calculated from indicators defined in such a way as to produce consistently high indicator values, close to the maximal values, then the resultant WOWA score will be commensurately high because of the dependence on the division-by-max method. On the other hand, if a WOWA score is calculated from indicators that are defined in such a way as to produce indicator values that are consistently much lower than the maximal value, the resultant WOWA score will indicate low exposure.
  - Order and importance weights assigned by the user act to raise or lower indicator values relative to each other, within a hazard category. For some indicators, this weighting scheme serves to raise already high indicator values, resulting from outlier effects in the division-by-max method (such as seen with indicator 108C), by applying additional weight, exacerbating issues created by outlier effects.
  - Because of the dependence of the final WOWA scores on the entire process, from indicator definitions, to normalization technique and weighting procedures, *we do not recommend comparing WOWA scores between hazard categories*. If the goal of DCAT is to enable comparisons of WOWA scores between hazard categories then more work should be done to investigate a new normalization method that is not sensitive to outlier effects stemming from indicator definitions. If, however, the goal of DCAT is to limit WOWA comparisons to within a hazard category only, then the selection of normalization method does not matter.
- We independently replicated DCAT's WOWA score calculation starting from the indicator level for the division-by-max method and an alternate normalization method (min-max method) and found that differences in the normalization method used in a WOWA score calculation can influence the result of an analysis performed using DCAT indicators.
  - Some indicators (i.e., 102, 106, 303, 304, 305, 402, 403, 502, 602, and 701) show differences between the two normalization methodologies. These indicators are used to calculate WOWA scores for the drought, riverine flooding, heat, energy demand, wildfire, and land degradation hazard categories, resulting in a difference in median WOWA score of up to 24%.
- Because DCAT uses the division-by-max normalization method, adding a large number of new installations into DCAT could result in including a sufficiently high indicator value from a newly introduced installation. This addition would

have the effect of lowering the WOWA scores of all other installations, without any change in the relevant climate data, definitions, or mathematical methods. *Therefore, we do not recommend comparing WOWA scores between different versions of the web tool; any analyses should clearly state the DCAT version number used.*

2. WOWA Score Comparisons in DCAT

- WOWA score comparisons made within DCAT can be used only to inform high-level screening assessments.
- While all WOWA scores range between 0 and 100, they do not represent the *probability* that a hazard will happen, but a *relative scale of exposure* to a hazard.
- DCAT is most powerful in assessing *relative* exposure. In other words, it is best at assessing how the exposure (assessing one hazard category at a time) changes at one installation over time (i.e., between two epoch-scenarios or simply relative to the historical baseline epoch-scenario) or assessing the relative exposure of *one* hazard category at multiple installations, for the same or different epoch-scenarios and historical baseline, provided the installations are contained in the same DCAT webtool.
- WOWA scores should not be compared between two hazard categories, even for the same installation, as noted above.
- DCAT was designed to use the total weighted WOWA score to rank installations by their relative exposure to select climate extremes. This is not a perfect comparison because:
  - Some installations may be moderately exposed to a large number of hazard categories,
  - Some installations may be highly exposed to a limited number of hazard categories, or
  - Some installations may not be exposed at all to some of the hazard categories covered in this tool and will have a WOWA score of zero (e.g., inland installation with zero coastal flooding exposure because it is not located on the coast) for those categories.
- To help combat the limitations of comparing Total Weighted WOWA scores, we recommend that the user also (1) assess how the individual hazard categories contribute to the total score and (2) compare the total weighted WOWA score for future epoch-scenarios to the total weighted WOWA score for the historical baseline.

- We do not recommend that users compare WOWA scores found in DCAT (CONUS/AK/HI) with those found in DCAT (ROW) because of significant differences in underlying datasets.

3. Framework for Usability Assessment

- DCAT was intended for three major user groups (installation-level planners and engineers, Military Department headquarters, and DoD leadership) to make decisions at different levels of the DoD.
- User vignettes were designed for each of the three user groups to assess ways in which DCAT could or could not help the user in each scenario. We found the following:
  - The tool only assesses *exposure* to climate hazards and does not comment on sensitivity or adaptive capacity; any use-case that asks to determine vulnerability will require additional studies outside the scope of DCAT.
  - The WOWA scores in DCAT are a *relative* measure of exposure, so comparing future epoch-scenario WOWA scores to the historical baseline scores will strengthen analysis. *Future versions of DCAT should provide results for the historical baseline epoch and include them in visualizations.*
  - Many of the potential uses of DCAT involve ranking installations by exposure based on the value of the total weighted WOWA score. Analysis involving ranking installations will be strengthened if multiple methods are employed to determine the relative exposure.
  - For any analysis performed by DCAT, adding supplemental information directly from installation managers will provide more data to draw stronger conclusions.

B. Recommendations

1. Exercise Caution when Comparing Certain WOWA Scores

DCAT is most powerful for comparing the relative exposure within a specific hazard category or indicator at the installation or regional level. For example, an installation with a higher drought WOWA score can be interpreted as having a greater exposure to drought than other installations with smaller drought WOWA scores. DCAT is also useful for comparing WOWA scores for a specific hazard category between the four epoch-scenarios and the historical baseline so the trends can be analyzed over time. For example, if a given installation has a higher drought WOWA score for 2085 than for 2050, the installation can be interpreted as having an increase in drought exposure.

Two WOWA scores based on different underlying datasets and indicators, or applying different mathematical processes on those indicators, yield comparisons that may not be meaningful. We do not recommend comparing WOWA scores between different hazard categories, even for the same installation, because (1) the normalization method makes the WOWA score sensitive to the indicator values and indicator definitions, (2) the importance weights further compound the sensitivity of the normalization methods, and (3) the dependence on the processes (like installation selection, indicator definition, and normalization methods, as well as the subjectivity of the importance weights) makes the output a relative measure of exposure within an hazard category. That is to say, a drought WOWA score of 80 cannot be interpreted as being the same exposure as a riverine flooding WOWA score of 80. Also note that while all WOWA scores range between 0 and 100, they do not represent the *probability* that a hazard will happen, but a *relative scale of exposure* to a hazard. Comparisons of total weighted WOWA scores between installations also have limitations. Instead of solely ranking installations based on the total weighted WOWA scores, we recommend that users also assess how the individual hazard categories contribute to the total score, comparing the total weighted WOWA with the historical baseline WOWA score to gain a better understanding of the complete picture.

Because DCAT uses the division-by-max normalization method, adding a large number of new installations into DCAT could result in a high indicator value at a newly introduced installation, which would have the effect of lowering the WOWA scores of all other installations, without any change in the relevant climate data, definitions, or mathematical methods. As a result, we do not recommend comparing any WOWA scores between different versions of the web tool; any analyses should clearly state the DCAT version number used.

Because of the vast differences in the underlying data between the CONUS+AK+HI and ROW regions, DCAT developers created two web-based tools—DCAT (CONUS/AK/HI) and DCAT (ROW). Although some differences do exist between the underlying data for the CONUS and AK+HI regions, it is generally appropriate to compare WOWA scores within the same hazard category for installations within these regions. We do not however, recommend comparing any WOWA scores found in DCAT (CONUS/AK/HI) with those found in DCAT (ROW).

2. DCAT Improvements

DCAT is most powerful when used as a relative measure of exposure; DCAT's visualizations and reports should reflect this. To reduce misuse, DCAT should provide more easily identifiable definitions for some of the terminology used throughout the tool and supporting documentation that describes the limitations of the tool. DCAT documentation often mentions that the tool should only be used for high-level screening decisions. We suggest to clarify what high-level screening questions *could* be answered with the tool and how those comparisons could be done appropriately. Similarly, the DCAT Quick Guide (2020) says that the WOWA score is a “within-group comparative measure.” We suggest clarifying what is meant by “within-group,” so that the users will understand when they should not use the WOWA score to compare between groups.

The visualizations should further emphasize that the tool is best used as a relative measure of exposure. Most important, the base data should be included in all the reports, trend visualizations, and installation-level data, so that the future epoch-scenarios can be assessed relative to the baseline scenario. The ability to compare each epoch-scenario to the base scenario would allow for stronger analysis of future exposure.

Another aspect of data visualization that can be improved is the data visualizations on the Installation Detail tab. This tab is one of the most informative; however, because all the pie charts for hazards display the relative contribution of an indicator to a hazard, it is difficult to see how the hazards or indicators change with time. For example, if all indicators of coastal flooding increase in every scenario, but their relative contribution remains the same, the pie charts do not change. It would be useful to have the values of these indicators or hazards available in text. In addition, we can envision changing the overall size of the pie chart relative to the WOWA score, so that even if the relative slices did not change, the pie chart increases in size as the WOWA score grows.

We concluded that different WOWA scores should not be compared with each other, even though some of the available reports and tabs, such as the Both First Impact (Hazard) report and the Dominant Impact (Hazard) tab, compare between hazard categories.

3. Implement Standards for DCAT-Driven Assessments

The preliminary report (Bewley et al. 2020) recommended that standards be implemented for DCAT-driven assessments that require documentation of any changes made in the My Assessment tab to the importance weights or ORness factor and justification for doing so. The report also recommended that the outputs from My Assessment be compared with the outputs in the National Standard View, which uses the default parameters. In addition, *we now also recommended that the user state which version of DCAT was used to produce the assessment.* Because of the use of division by max in the normalization of input indicator values, adding new installations or using new datasets could in effect change the calculated WOWA scores for an installation. While we expect that the rank order of installations and the percentage change from the base value will remain unchanged, the numerical WOWA scores could change, which may lead to confusion for installations reviewing their metrics. Users should clearly document the DCAT version number along with the importance weights and ORness factor used in any assessments designed for mitigation planning and infrastructure development.

8. Research Road Map

Through this assessment, multiple areas for future research efforts have been identified. These are areas of potential future investment to improve the tool's capabilities and robustness.

A. Expand Exposure-Sensitivity-Adaptive Capacity Framework

As detailed in this report, DCAT only provides information about the relative *exposure* of an installation to the eight climate change hazards and historical extreme weather events covered in this tool. Future work is still needed to fully develop the exposure-sensitivity-adaptive capacity framework. That is, once a high-level assessment of exposure is completed using DCAT, how can sensitivity and adaptive capacity be assessed to develop a clear picture of an installation's vulnerability to a changing climate and extreme-weather events? Furthermore, how can the information leveraged through this framework be used to guide infrastructure investments across the DoD enterprise? More investigation should be done to understand the best uses of DCAT for the three intended user groups of DCAT and how DCAT can be incorporated into current infrastructure planning processes.

B. Perform Sensitivity Studies on WOWA Parameters and Normalization Methods

As noted in Bewley et al. (2020), users of DCAT are able to adjust the ORness factor and importance weights under the My Assessment tab as a way to leverage their expert judgment in refining the results for their installation. While it is likely that most DCAT users will not attempt to perform their own analyses and will stick with the National Standards View, the sensitivity of the results to the ORness factor and importance weights should be investigated. One way to perform a sensitivity study is to use the Monte Carlo method to systematically vary the ORness and importance weight parameters. The output from these tests can then be used to determine how much those parameters affect the output of DCAT.

In addition, this assessment has shown that the WOWA score calculations are sensitive to the normalization procedure selected by the developers. Any normalization method will have positive benefits and drawbacks. As shown in Figure 7 and Figure 8, the min-max method tended to reduce indicator values relative to the division-by-max method by rescaling the indicators over the range of possible values in each dataset. Neither normalization procedure, however, was able to completely mitigate outlier effects that can result from the way in which indicators are defined. As a result, we recommended only comparing WOWA scores within a specific hazard category. If, however, the goal of DCAT is to be able to compare WOWA scores between hazard categories, more work is needed to identify a normalization procedure that is not sensitive to the outlier effects generated from indicator definitions. Additional methods (e.g., Z-score normalization, etc.) should be tested and evaluated.

For any sensitivity tests performed on DCAT, it is important not only to understand if a change in parameters affects the final WOWA scores in the tool but also by how much the WOWA scores are affected. Small differences in WOWA scores may be deemed tolerable for a screening-level assessment tool. In that case, we would recommend that the DoD leave DCAT as is and focus resources on higher priority improvements.

C. Identify Other User Groups and Design Tool Interfaces Specific to their Assessments

The intended user group for which DCAT was developed is installation-level planners and engineers, Military Department headquarters, and DoD leadership (DCAT One Pager 2020). The purpose of the tool is to inform mitigation planning and infrastructure development. Because DCAT is the first tool developed by the DoD that provides consistent data on historical extreme-weather events and the potential range of plausible future climate conditions, it is anticipated that DoD personnel outside the intended user group will attempt to use DCAT for their own assessments. We therefore recommend that the DoD identify these other user groups, define their requirements, and determine how DCAT could be used to support their missions. The behind-the-scenes databases that feed into DCAT could be leveraged to support additional tools. This would require adapting the current DCAT user interface to meet the needs of the other identified user groups. On the other hand, DCAT may not be able to meet the needs of some users. In that case, the DoD should resist the urge to turning DCAT into a one-size-fits-all tool. Instead, the DoD should consider developing a new tool that better suits a particular user group's needs.

D. Investigate Potential Improvements to the Input Data

Although the underlying data sources in DCAT were found to be from publicly available authoritative sources and documented in peer-reviewed scientific literature, some input data could be improved in the future. For example, the data between CONUS and AK+HI regions could be made more similar by improving the input data for AK+HI. Currently, the data between the two regions varies in three ways: (1) CONUS leverages higher resolution downscaled climate (Coupled Model Intercomparison Project Phase 5) data, (2) CONUS uses different hydrologic inputs for watershed calculations/indicators, and (3) some variables are held constant in AK+HI due to limited data availability. One possible improvement is to pursue climate projections for AK+HI that are downscaled to the same resolution as those for CONUS. This could potentially be done using the Coupled Model Intercomparison Project Phase 6 climate data for CONUS, AK, and HI. Also, running consistent river-routing simulations (like mizuRoute) for each region would provide consistent watershed calculations and improve the consistency of hydroclimate indicators.

Another area for improvement is within the wildfire hazard category. This hazard category considers indicators that represent fuel abundance, ignition rate, fire season length, and flash drought frequency. It does not have an indicator to represent the hazards of lightning on wildfire ignitions. Given the number of convective storms is projected to increase in places like Alaska (Poujol, Prein, and Newman 2020 and Poujol, Prein, and Molina 2021), research should be performed to determine if such an indicator can be created from available authoritative data. If no authoritative data are currently available, data requirements for creating such an indicator should be identified.

E. Investigate Improvements to ROW

The ROW section of the tool could be strengthened and expanded. Our suggestions to achieve this are to (1) split ROW into subregions; (2) add additional, subregion-specific datasets; (3) expand the tool into other regions of the world.

Splitting ROW into subregions and adding more regional information to DCAT would allow DoD leadership to have a better understanding of the varied regions as a whole. In the DCAT (CONUS/AK/HI) tool, pages describe current climate concerns in CONUS+AK+HI subregions and provide helpful context for the data presented in the tool. Splitting the ROW regions into subregions would allow the use of higher resolution datasets where available and would allow for the addition of more subregional-focused climate information.

Currently, the data used in the ROW tool are limited by the availability of datasets at all the locations. For example, more climate datasets are in Europe or Japan than in Djibouti, so splitting ROW up into subregions would allow for a more skilled tool. For example, Europe and Japan have their own geolocated tornado databases (ESWD, Japan Meteorological Agency). If some subregions of the ROW tool became more sophisticated, more comparisons between ROW locations and CONUS may be possible. Moreover, this would aid in expanding the tool into other regions of the world because dataset usage would not be limited to accessibility at all ROW installations.

As more data becomes available globally, the tool could be updated to include additional global datasets. For example, indicators reliant on relative humidity data, like high heat index days, are currently absent from ROW. Different regional downscaling techniques, like the Coordinated Regional Climate Downscaling Experiment (CORDEX), could potentially be used to expand this indicator to ROW. Population projections from the Wittgenstein Center used in CONUS for the ignition rate indicator could be assessed to potentially expand that indicator into ROW as well.

F. Perform DCAT User Assessments

While this evaluation made use of a vignette-derived user assessment performed by IDA researchers, plans should be made to test DCAT in the field with participants from the three intended user groups. User assessments could involve giving participants a task such as the vignettes designed for this evaluation. The participants could then be asked to use DCAT to complete the task. Once the participants complete the task, they could then be asked to complete a system usability scale (SUS) questionnaire (Figure 14). The SUS is a 10-question survey for users that provides a measure of a tool's usability. The questionnaire is easy to administered and score. Results of the questionnaire could be compiled and compared across different user groups. It may be that some user groups find DCAT to be more usable than others. Such information would help the DoD plan and prioritize improvements to the tool that increase the usability of DCAT.

System Usability Scale

For each of the following statements, please mark one box that best describes your reactions to DCAT today.

		Strongly disagree				Strongly agree
1.	I think that I would like to use DCAT frequently.	1	2	3	4	5
2.	I found DCAT unnecessarily complex.	1	2	3	4	5
3.	I thought DCAT was easy to use.	1	2	3	4	5
4.	I think that I would need the support of a technical person to be able to use DCAT.	1	2	3	4	5
5.	I found the various functions in DCAT were well integrated.	1	2	3	4	5
6.	I thought there was too much inconsistency in DCAT.	1	2	3	4	5
7.	I would imagine that most people would learn to use DCAT very quickly.	1	2	3	4	5
8.	I found DCAT very cumbersome (awkward) to use.	1	2	3	4	5
9.	I felt very confident using DCAT.	1	2	3	4	5
10.	I needed to learn a lot of things before I could get going with DCAT.	1	2	3	4	5

Comments (optional):

Source: Questions generated using www.usability.gov.

Figure 14. Ten-Question System Usability Scale Assessment for DCAT Users

Appendix A.
DCAT Input Indicators

Table A-1 lists the 33 indicators that are used in DCAT. This table provides the indicator ID number, hazard category, indicator name, description, units, and importance weight for the National Standard View. Note that five indicators are used in more than one hazard category and therefore are listed more than once.

Table A-1. DCAT Indicators by Indicator Number, Category, Indicator Name, Description, Units, and Importance Weight

Indicator Number	Category	Indicator Name	Description	Units	Importance Weight
Hazard Category: Drought					
101	Drought	Flash Drought Frequency	The average number of times per year when a flash (rapid onset) drought develops.	Frequency (occurrence/ year)	1.4
102	Drought	Drought Year Frequency	The percent of years that are drought years.	Percentage	1.2
105	Drought	Aridity	This is a measure of how dry the climate is overall, as measured by the ratio of precipitation to potential evapotranspiration.	Unitless	1.5
106	Drought	Consecutive Dry Days	The average annual maximum number of consecutive days with less than 0.01″ of precipitation.	Days/year	1

Indicator Number	Category	Indicator Name	Description	Units	Importance Weight
108C	Drought	Mean Annual Runoff	The average annual discharge (volume of water) from the entire watershed upstream of the downstream-most boundary of the installation for the largest river in this watershed.	Cubic feet per second (cfs)	1.5
Hazard Category: Coastal Flooding					
201	Coastal Flooding	Coastal Flood Extent	The area of inundation during the most extreme coastal flood events.	Percent of area	1.5
202	Coastal Flooding	Coastal Erosion	A measure of a coastline's susceptibility to erosion due to wave action.	Probability	1
Hazard Category: Riverine Flooding					
301	Riverine Flooding	Riverine Flood Extent	The percent of an installation that may be flooded during a major flood event (the 1% annual chance riverine flood event).	Percent of area Baseline: 1% AEP	1.5
	Riverine Flooding			2050: +2'	
	Riverine Flooding			2080: +3'	
302C	Riverine Flooding	Flood Magnification Factor	The ratio of future flood discharge to current flood discharge. This indicator measures how much larger (or smaller) future floods are likely to be.	Unitless ratio	1.3
303	Riverine Flooding	Maximum 1-Day Precipitation	The average annual maximum 1-day precipitation amount (inches).	Inches	1
304	Riverine Flooding	Maximum 5-Day Precipitation	The average annual maximum 5-day precipitation total (inches).	Inches	1

Indicator Number	Category	Indicator Name	Description	Units	Importance Weight
305	Riverine Flooding	Extreme Precipitation Days	The average annual number of days that precipitation in a future epoch-scenario is greater than what would have been considered an extreme precipitation day historically (the historic period 1% annual chance event storm).	Days/year	1.4
Hazard Category: Heat					
401	Heat	Days Above 95F	The average annual number of days in which the high temperature exceeds 95 °F.	Days/year	1.1
402	Heat	5-Day Maximum Temperature	The average annual highest 5-day average temperature.	Degrees Fahrenheit	1.2
403	Heat	High Heat Days	The average number of days in which temperatures exceed the 99th percentile temperature in the historic baseline period.	Days/year	1.3
404	Heat	Frost Days	The average annual number of days in which the minimum temperature is below freezing (32 °F).	Days/year	1
405	Heat	High Heat Index Days	The average annual number of days where heat index values are ≥90 °F for a portion of the day (extreme caution or higher).	Days/year	1.7
Hazard Category: Energy Demand					
501	Energy Demand	Heating Degree Days	The average annual sum of the number of degrees that every day's average temperature is below 65 °F, and buildings must therefore be heated.	Degree days	1.2

Indicator Number	Category	Indicator Name	Description	Units	Importance Weight
502	Energy Demand	Cooling Degree Days	The average annual sum of the number of degrees that every day's average temperature is above 65 °F and buildings must therefore be cooled.	Degree days	1.7
503	Energy Demand	5-Day Minimum Temperature	The average annual lowest 5-day minimum temperature.	Degrees Fahrenheit	1
402	Energy Demand	5-Day Maximum Temperature	The average annual highest 5-day average temperature.	Degrees Fahrenheit	1.5
Hazard Category: Wildfire					
601	Wildfire	Fuel Abundance	The percentage of an installation and a 1-mile buffer around the installation that is in wildland vegetation. *This indicator is Static for Alaska and Hawaii*.	Percent area	1.3
602	Wildfire	Ignition Rate	The population density in proximity to an installation, since human activity is a major source of ignitions. *This indicator is Static for Alaska and Hawaii*.	People/square mile	1.1
604	Wildfire	Fire Season Length	The average annual number of days in which the Keetch-Byram Drought Index (KBDI) is >600, indicating long-term arid conditions and dry coarse fuels.	Days/year	1.7
101	Wildfire	Flash Drought Frequency	The average number of times per year when a flash (rapid onset) drought develops.	Frequency (Occurrence/ year)	1.5

Indicator Number	Category	Indicator Name	Description	Units	Importance Weight
Hazard Category: Land Degradation					
604	Land Degradation	Fire Season Length	The average annual number of days in which the Keetch-Byram Drought Index (KBDI) is >600, indicating long-term arid conditions and dry coarse fuels.	Days/year	1.5
105	Land Degradation	Aridity	This is a measure of how dry the climate is overall, as measured by the ratio of precipitation to potential evapotranspiration.	Unitless	1.4
701	Land Degradation	Soil Loss	Average annual rate of land surface erosion, computed using the revised universal soil loss equation (RUSLE).	Tons/acre/year	1.7
202	Land Degradation	Coastal Erosion	This is a measure of a coastline's susceptibility to erosion due to wave action.	Probability	1.2
702	Land Degradation	Permafrost Hazard	The percent of the installation rated as low (1) or higher on the consensus geohazard index indicating significant risk for damage to infrastructure for a given location.	Percent of area	1
Hazard Category: Historic Extremes Events					
801	Historic Extreme Events	Tornado Frequency	The average annual probability of a tornado occurring on or in the HUC8 watershed(s) of an installation.	Probability	1.4

Indicator Number	Category	Indicator Name	Description	Units	Importance Weight
802	Historic Extreme Events	Hurricane Frequency	The mean annual probability of being impacted by a hurricane, defined as being within 200 km buffer around the hurricane track.	Probability	1.7
803	Historic Extreme Events	Ice Storm Occurrence	A presence-absence indicator identifying places in the United States where freezing-rain storms have occurred that have significantly affected above-ground infrastructure.	Occurrence (presence, absence)	1.2
804	Historic Extreme Events	Historical Drought Frequency	The percentage of weeks in the historic period when any part of an installation was categorized as in severe (D2), extreme (D3) or exceptional (D4) drought as determined by the National Integrated Drought Information System (NIDIS) historical records.	Percent of weeks	1.1
805	Historic Extreme Events	Wildland Urban Interface	The percentage of an installation classified as wildland-urban interface or intermix.	Percent of area	1.3
806	Historic Extreme Events	Hurricane Wind > 50 knots	The maximum frequency with which any portion of an installation's watershed was impacted by hurricane winds greater than 50 knots.	Count/year	1.4
807	Historic Extreme Events	Hurricane Maximum Average Precipitation	The maximum average annual precipitation from hurricane events experienced in any portion of an installation's watershed across all storms.	Inches	1.5

Indicator Number	Category	Indicator Name	Description	Units	Importance Weight
808	Historic Extreme Events	Ice Jam Occurrence	A presence-absence indicator identifying places in the United States where ice jams have occurred in an installation's HUC8 watershed(s).	Occurrence (presence, absence)	1.2

Source: Data downloaded from DCAT (CONUS/AK/HI) website under My Assessment>Indicators>Indicator Data tab. Importance weights from “Hazard Category and Indicator Overview” (USACE 2020).

Appendix B.
Additional User Vignettes

Installation Manager

- Your installation has suffered damages over the past decade due to inclement weather conditions and extreme events. HQ wants you to try to understand what hazards you will be most vulnerable to so that you can take preventive measures against future costly repairs. You are asked to provide a report that analyzes your vulnerability to future events and provides a funding estimate for further research.
- Your installation has not directly experienced the effects of climate change, such as infrastructure damages resulting in expensive repairs, and does not see any direct need to start looking at climate change.
  - You are required to make a report that identifies potential climate vulnerabilities in the future so that you can request funding for areas that you believe require further research and resilience planning.
  - You are required to identify the dominant hazard using DCAT and, using data specific to your installation, assess your vulnerability to that hazard and your need for increased funding for research and mitigation.
  - You are asked to identify hazards or indicators that will affect "mission readiness," like your ability to train, deploy, or conduct mission-specific tests (e.g., rocket launches)
- You are asked to create a report of your installation's vulnerability to climate change. You are asked to first analyze vulnerability using DCAT and then to include other data sources and research specific to your installation.
- After the 2020 fire season, you are asked to create a report of your installation's vulnerability to wildfires. You are asked to analyze your future vulnerability using DCAT and also asked to include data specific to this fire season and hazards on installations.
- Your coastal installation has experienced increased flooding over the years, and you are trying to figure out how to rebuild your destroyed infrastructure. You are asked to create a report that assesses your vulnerability to future floods and

other climate extremes in all epoch-scenarios and propose mitigation techniques based on these findings.

Department Headquarters

- You know flooding is a problem at coastal installations, but you don't know to what extent, or whether, it will get worse. You are asked to assess the vulnerability of installations to flooding within one region. You are asked to identify all the installations that are vulnerable and identify those installations that require the most emergent funding.
- You have noticed a rise in heat-related injuries during training and want to figure out which installations or regions could be susceptible to increasing occurrences of heat-related training injuries. You are asked to identify all the regions which will be increasingly vulnerable to rising temperatures. You are also asked to create a report of the top installations with the greatest likelihood of heat-related injuries.
- You are trying to evaluate installations that could experience interruptions in operations due to wildfire conditions. Using DCAT, you determine the installations that are most vulnerable to wildfires and ask those installations to perform further studies.
- You are concerned that food production in the Southwest will be affected by water shortages and heat waves. You worry that this will drive up food costs or even lead to food shortages in the Southwestern installations. You decide that you need more information from your installations and use DCAT's two dominant hazard-comparison reports to find the top-three installations in the Southwest vulnerable to the heat and drought indicators. The three installations identified will be asked to do further research on how food production will affect them.

DoD Leadership

- Congress has told you that you are spending too much money on infrastructure repairs and that mitigating efforts need to be taken.
  - You must decide which installations are most vulnerable to climate change and how much money they need to do sensitivity and adaptive-capacity research.
  - You must look at installations that have already experienced damages due to climate extremes and report what their future exposure will be to decide the best approach in moving forward.

- You see that drought is the largest hazard in many installations and you are asked to address this issue. You decide the best way is to identify the installation most vulnerable to drought in each region of CONUS and allocate funding for the installation managers to perform a regional study of drought vulnerability.
- After a heavy year of wildfires in 2020, you are concerned about the potential vulnerability to wildfires and their effect on infrastructure and operations. You first determine how many installations DCAT says are vulnerable to wildfires to decide how much money to allocate to further research. Then, you identify the installations with the highest vulnerability to fund installation-specific research.
- An installation manager in Alaska submits a report noting that permafrost melting is reducing training capacity, and the manager expresses concerns that the melting could start to affect the infrastructure integrity. The manager requests additional funding to research the problem and mitigation techniques. You look at the installation on DCAT and see that despite the manager’s concern, DCAT doesn’t show permafrost as a one of the dominant indicators. How do you proceed with the installation manager’s request?
- Multiple coastal installations recently suffered millions of dollars in damages from a hurricane and the subsequent flooding associated with the hurricane. Before you receive the funding to rebuild, you must create a report using DCAT of the future vulnerabilities to these extremes in all future epoch-scenarios.
- You are deciding how to allocate your funding between CONUS and ROW.
    - Using DCAT, you want to compare the vulnerability between CONUS and ROW to decide how much funding should go to each.
    - You decide to identify the top-five most vulnerable installations in ROW and CONUS separately using the aggregate WOWA score. These 10 installations will receive the largest amount of funding.

Appendix C.
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Appendix D.
Abbreviations

CAC	Common Access Card
CONUS	continental United States
CORDEX	Coordinated Regional Climate Downscaling Experiment
DCAT	DoD Climate Assessment Tool
FFRDC	federally funded research and development center
GIS	geographic information system
HUC	hydrologic unit code
NDAA	National Defense Authorization Act
RCP	Representative Concentration Pathway
ROW	Rest of World
SUS	system usability scale
USACE	U.S. Army Corps of Engineers
WOWA	weighted ordered weighted average

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14. ABSTRACT

Section 326 of the FY20 National Defense Authorization Act (NDAA) authorizes the development of an extreme weather vulnerability and risk assessment tool "to quantify the risks associated with extreme weather events and the impact of such events on networks, systems, installations, facilities, and other assets to inform mitigation planning and infrastructure development". In response to this NDAA, The Office of the Under Secretary of Defense for Acquisition and Sustainment funded the U.S. Army Corps of Engineers (USACE) to update and expand an already-existing climate assessment tool and apply it to a limited set of sites designated by each Military Service. This new tool is called the DoD Climate Assessment Tool, or DCAT. The preliminary evaluation (Bewley et al. 2020) reported on the results of a scientifically rigorous, independent, third-party analysis of the underlying data and methodologies used in DCAT to assess if the tool relies on the best publicly available science for the prediction of extreme weather and climate change risk and effective mitigation of that risk. The goal of this current, and final, evaluation is to assess how the tool output could best be used to inform high-level mitigation planning and infrastructure development and identifies areas of potential tool enhancement and new investment areas for future research. Overall, it was found that the DCAT webtool does provide a consistent way to produce exposure assessments at the installation or regional level, however, there are a few caveats to the use of DCAT outputs. First, users should understand that Hazard WOWA scores are a relative measure of exposure, and are dependent on not just the data used in the WOWA calculation, but also on the procedures used in the overall process itself. This evaluation found that the best use for DCAT is assessing how the exposure (assessing one hazard category at a time) changes at one installation over time (i.e., between two epoch-scenarios, or simply relative to the historical baseline epoch-scenario), or assessing the relative exposure of one hazard category at multiple installations, for the same or different epoch-scenarios and historical baseline, provided the installations are contained within the same DCAT webtool [i.e., within DCAT (CONUS/AK/HI) or DCAT (ROW)]. This evaluation found limitations with the interpretation of Total Weighted WOWA scores and recommends performing additional analysis to gain a better understanding of the complete picture. This evaluation determined that the following comparisons should not be made: Hazard WOWA scores for different hazard categories or indicators (even within the same installation), any WOWA scores between the two webtools (CONUS/AK/HI and ROW), and any WOWA scores from different versions of the same webtool as the addition of installations could change the WOWA scores.

15. SUBJECT TERMS

base resilience; changing climate; Climate Change; climate change adaptation; DoD Climate Assessment Tool (DCAT); FY20 NDAA Sec 326; Infrastructure Resilience; resiliency

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