Clear-Sky Probability for the 2023 Annular Solar Eclipse and the 2024 Total Solar Eclipse Using the NREL National Solar Radiation Database

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Technical Report
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Cover Photos by Dennis Schroeder: (clockwise, left to right) NREL 51934, NREL 45897, NREL 42160, NREL 45891, NREL 48097, NREL 46526.

List of Acronyms

DNI	direct normal irradiance
FARMS	Fast All-Sky Radiation Model for Solar Applications
GOES	Geostationary Operational Environmental Satellite
NREL	National Renewable Energy Laboratory
NSRDB	National Solar Radiation Database

Executive Summary

The National Renewable Energy Laboratory (NREL) and collaborators have created a clear-sky probability analysis to help guide viewers to the 2023 annular solar eclipse and the 2024 total solar eclipse. Using cloud and solar data from the NREL National Solar Radiation Database (NSRDB), the analysis provides cloudless-sky probabilities specific to the date, time, and location of each eclipse with a 4-km resolution. Though not intended to be an eclipse weather forecast, the detailed maps can help guide eclipse enthusiasts to likely optimal viewing locations. Additionally, high-resolution data are presented for the centerline of the path of each eclipse, representing the likelihood for cloudless skies and atmospheric clarity. The NSRDB provides industry, academia, and other stakeholders with high-resolution solar irradiance data to support feasibility analyses for photovoltaic and concentrating solar power generation projects.

Table of Contents

List of Figures

Introduction

Eclipse watchers are enthusiastically awaiting the rare occurrence of two solar eclipses that will be visible in portions of the western hemisphere in 2023 and 2024. An annular eclipse, where the moon is centered on the sun but not completely covering it, will occur on October 14, 2023. A total eclipse, where the moon will completely occlude the sun, plunging the area along its path into an eerie daytime darkness, will occur on April 8, 2024. Two solar eclipses occurring within 6 months of each other is unusual, and to overlap geographically is even more rare.

The two eclipses provide sharply different viewing experiences. The annular eclipse will appear as a bright ring in the sky, and although approximately 90% of the sun will be blocked by the moon, the remaining visible ring and its intense light must be viewed only with special filters or projection methods to avoid eye damage. Conversely, the total eclipse can be viewed without special equipment for the few minutes of totality. It will appear as a black disk surrounded by feathery tendrils of the sun's corona, which are always present but cannot normally be seen.

In each case, viewing the eclipse can be completely spoiled by the presence of a single cloud or other dense, haze-producing atmospheric components. An analysis using the National Solar Radiation Database (NSRDB) (Sengupta et al. 2018) from the National Renewable Energy Laboratory (NREL) provides the opportunity to identify areas along the eclipse path that have the greatest likelihood of cloudless, clear skies. With this information, eclipse watchers can make travel plans—and even alternate travel plans—well in advance of the eclipse events.

Cloudless-Sky Analysis

The central line of the 2023 annular eclipse will pass over the western United States, portions of Central America, and Columbia and Brazil in South America. A view of a partial eclipse, where only a portion of the moon covers the sun's disk, will be visible as far north as central Alaska and as far south as central Argentina.

The path of the 2024 total eclipse passes over central Mexico, the central and northeastern United States, and several eastern Canadian provinces. The partial eclipse view extends to the entirety of Central America, North America (except Alaska), Greenland, and Iceland.

These paths, as well as most of the partial eclipse areas, are within the area covered by the NSRDB. Eclipse watchers always seek to set up under clear skies, but that can be an elusive goal because clouds are among the most difficult weather elements to predict with any certainty more than a few hours in advance. Unfortunately, even a reliable short-term forecast might not suffice because heavy traffic on the day of the eclipse could hinder relocation travel beyond the effects of a weather system.

Considering historical climate data, however, a reliance on the *probability* of clear skies is an informed starting point for selecting a worthwhile location for viewing an eclipse. The analysis presented here takes a focused statistical approach to determine the likelihood of clear skies at any location along the path of each eclipse. The NSRDB coverage area holds 24 years of data at half-hourly intervals for every 0.04° of latitude and longitude. In addition to solar irradiance estimates, the NSRDB provides half-hourly cloud type estimates for much of North America, Central America, and South America. Among the cloud type values designated in the NSRDB are "clear" and "probably clear," which are well suited to the needs of eclipse watchers.

For this analysis to account for short-term daily weather patterns as well as the typical 3-day life cycle of large weather systems, we chose to sample the three half-hour values closest to the actual local eclipse time at each location for the 5 days on either side of the eclipse date for each of the 24 years of the NSRDB. The short 1-hour window around the eclipse time is advantageous because of the effects of daily weather patterns that exist in many areas. For example, one time of day might be typically clear yet cloudy 2 or 3 hours later, and this approach helps isolate daily patterns to the local time of the eclipse. The time of the sampling is updated at half-hour intervals as the eclipse progresses along the path. For each pixel (approximately 4 km by 4 km in coverage), up to 759 values form a sample representing the range of weather conditions characteristic to that location and time. From that data set, the frequency of the two clear-sky NSRDB designations determines a cloudless-sky probability for each pixel.

The same procedure provides the clear-sky probability for areas elsewhere in the NSRDB that are not in the path of the eclipse. The sample time for those locations was chosen to be the time for the closest point along the eclipse path.

One captivating feature of a total solar eclipse is the appearance of planets and stars during totality. As with nighttime viewing of stars, the clearer the atmosphere, the greater the number of celestial objects that will be visible during the totality. Because atmospheric components other than clouds, such as water vapor and aerosols, can affect atmospheric clarity, we extracted the coincident direct normal irradiance (DNI) solar values from the NSRDB. DNI signifies sunlight traveling directly from the sun through the atmosphere. The magnitude of the DNI in cloudless skies provides an excellent measure of atmospheric clarity, which serves to characterize atmospheric conditions at the time of the eclipse for each pixel location. Toward this end, we provide the average DNI *specific to cloudless conditions* as an index of atmospheric clarity. This is also valuable information to consider when choosing a viewing location.

Illustrating Analysis Results

The cloudless-sky probabilities for the contiguous United States are mapped in Figure 1 (2023) and Figure 2 (2024).[1] The eclipse paths,[2] which are of greatest interest to serious eclipse watchers, are shown by the dashed lines. The full eclipse occurs only within the bounds of this path, which is roughly 200-km wide (about 125 miles). The longest duration of the eclipse will occur along the centerline of the path, which is shown on the map as a solid line.

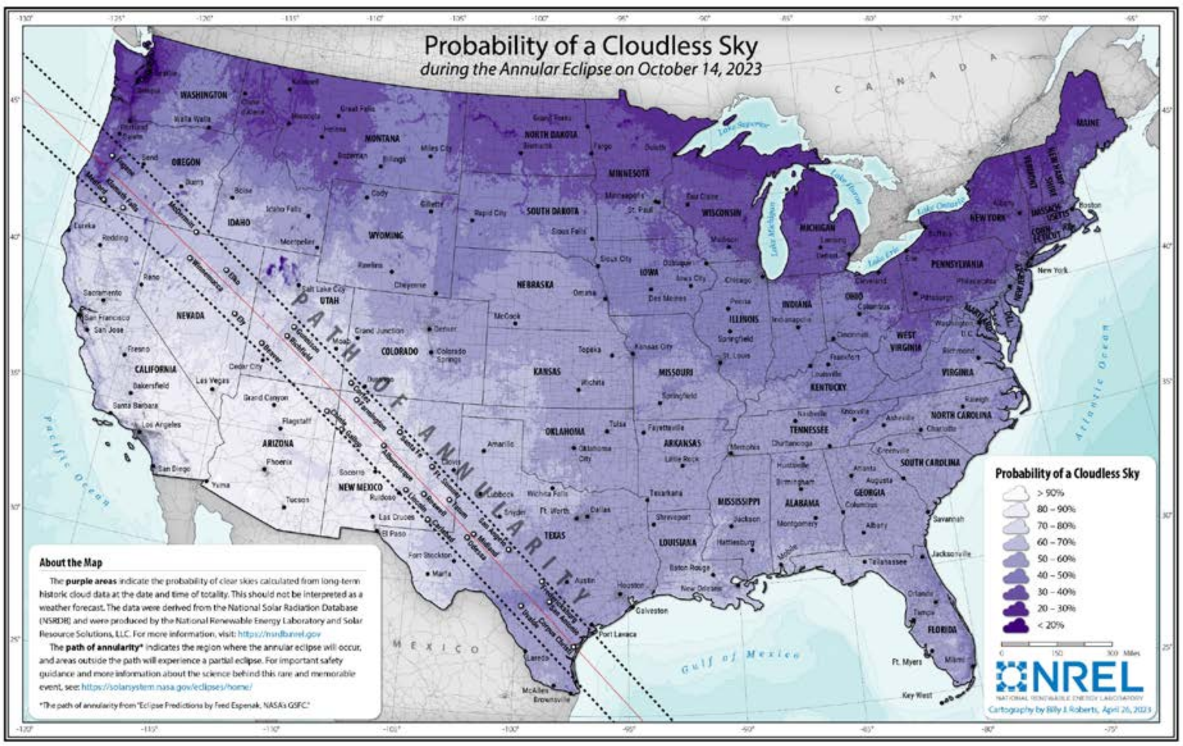

Figure 1. Cloudless-sky probabilities for October 14, 2023

[1] Full-resolution versions of all maps are available at https://www.nrel.gov/gis/solar-resource-maps.html.
[2] The eclipse paths shown are from "Eclipse Predictions by Fred Espenak, NASA/GSFC" (Espenak 2014a; 2014b).

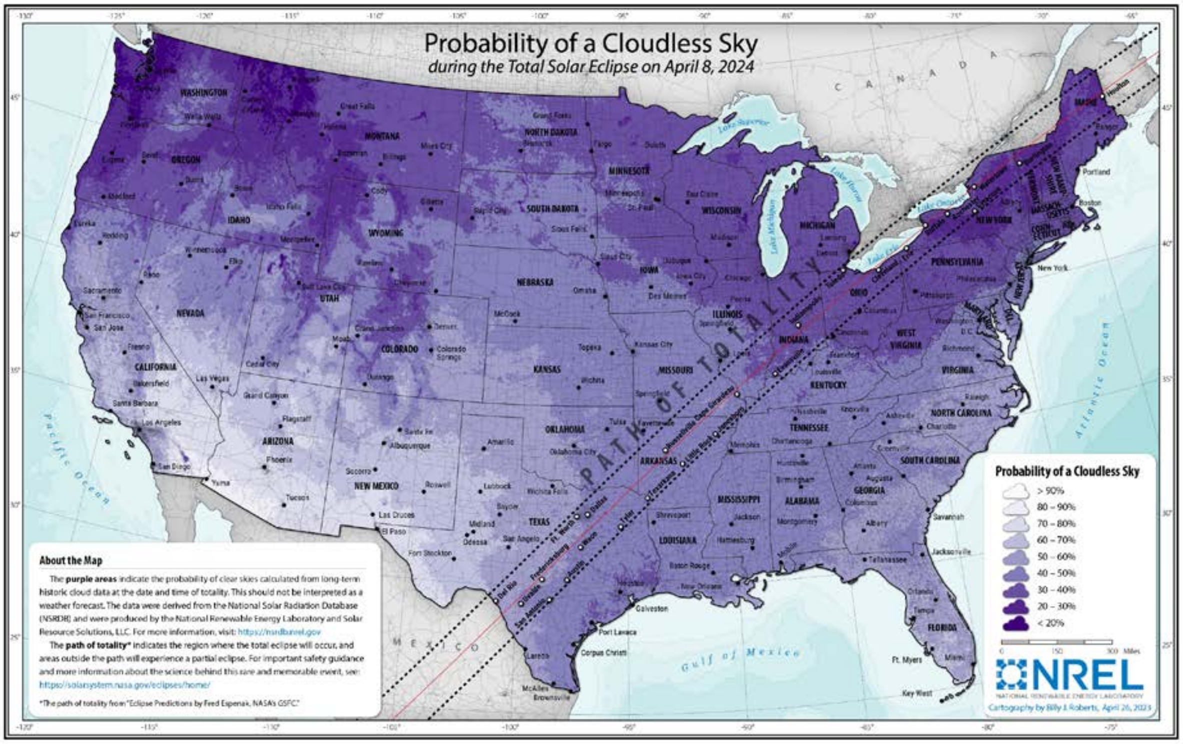

Figure 2. Cloudless-sky probabilities for April 8, 2024

Figure 3 (2023) and Figure 4 (2024) show the eclipse path, but they also include a corresponding graph of cloudless-sky probabilities and average DNI profiles (as an indicator of atmospheric clarity) by longitude along the centerline of each eclipse. Using this information, eclipse watchers can find coincident occurrences by region of high probability for cloudless skies with high DNI to optimize the search for a viewing location. The most important factor by far in this analysis is the probability of cloudless skies, which should be the primary consideration when selecting an eclipse viewing site. High DNI, representing atmospheric clarity, is a secondary but useful factor.

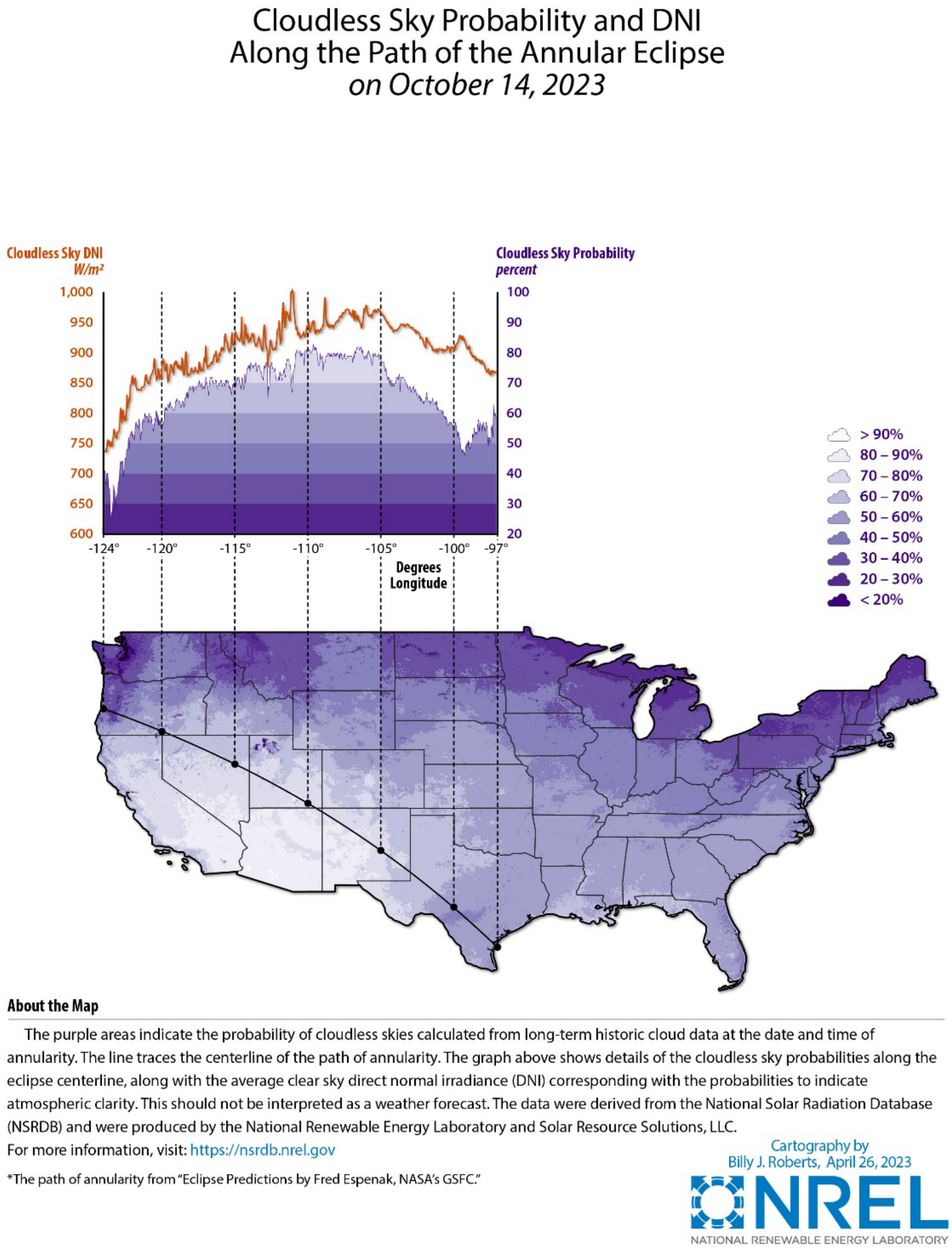

Figure 3. October 14, 2023, annular eclipse centerline profile

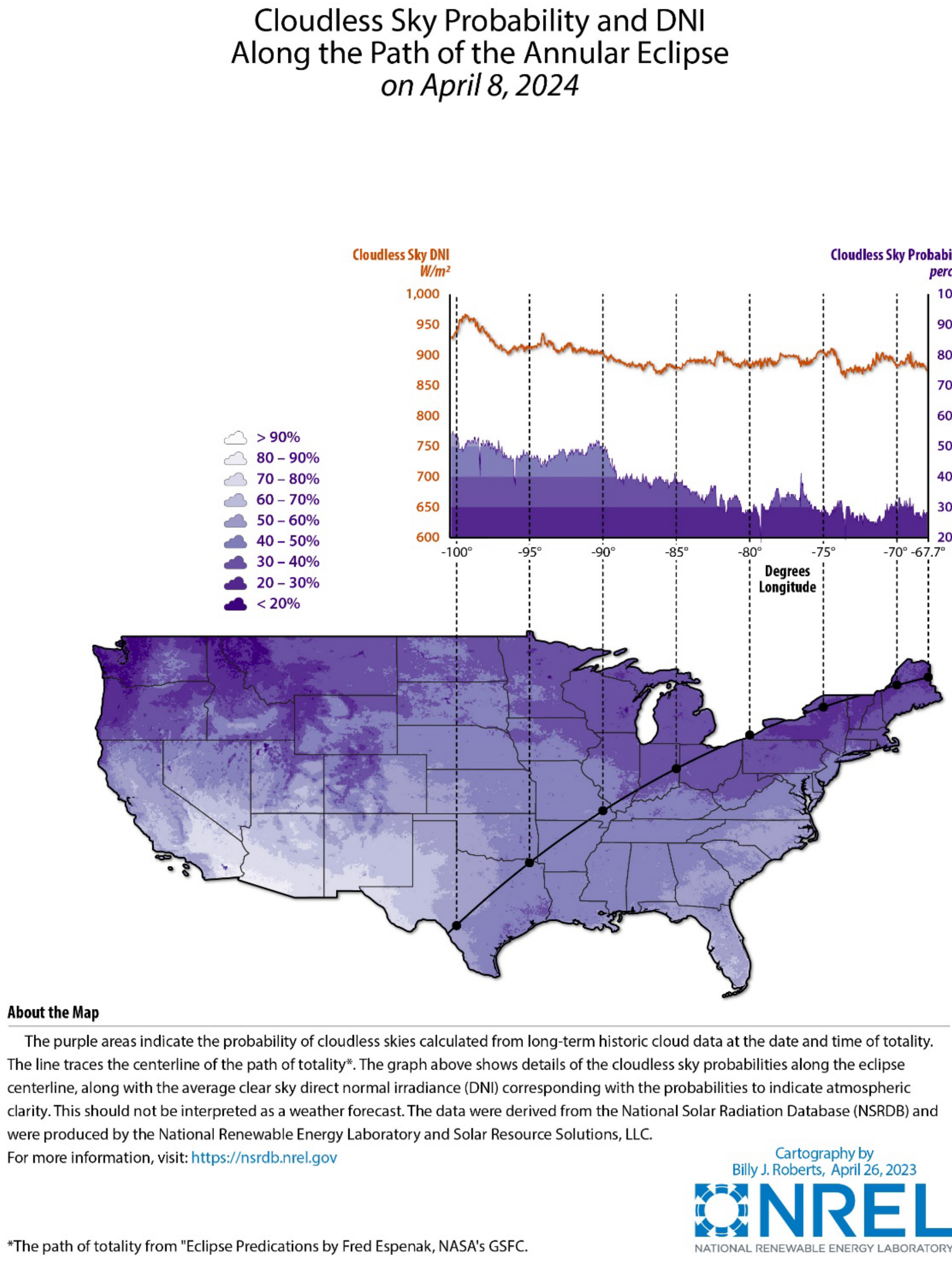

Figure 4. April 8, 2024, total eclipse centerline profile

Both eclipses will be visible well beyond the boundaries of the United States shown in Figure 3 and Figure 4. The NSRDB covers the entirety of the eclipse paths over land as well as most of the geographic area of partial eclipse viewing. Figure 5 (2023) and Figure 6 (2024) show the clear-sky probability maps for the larger extent of the NSRDB.

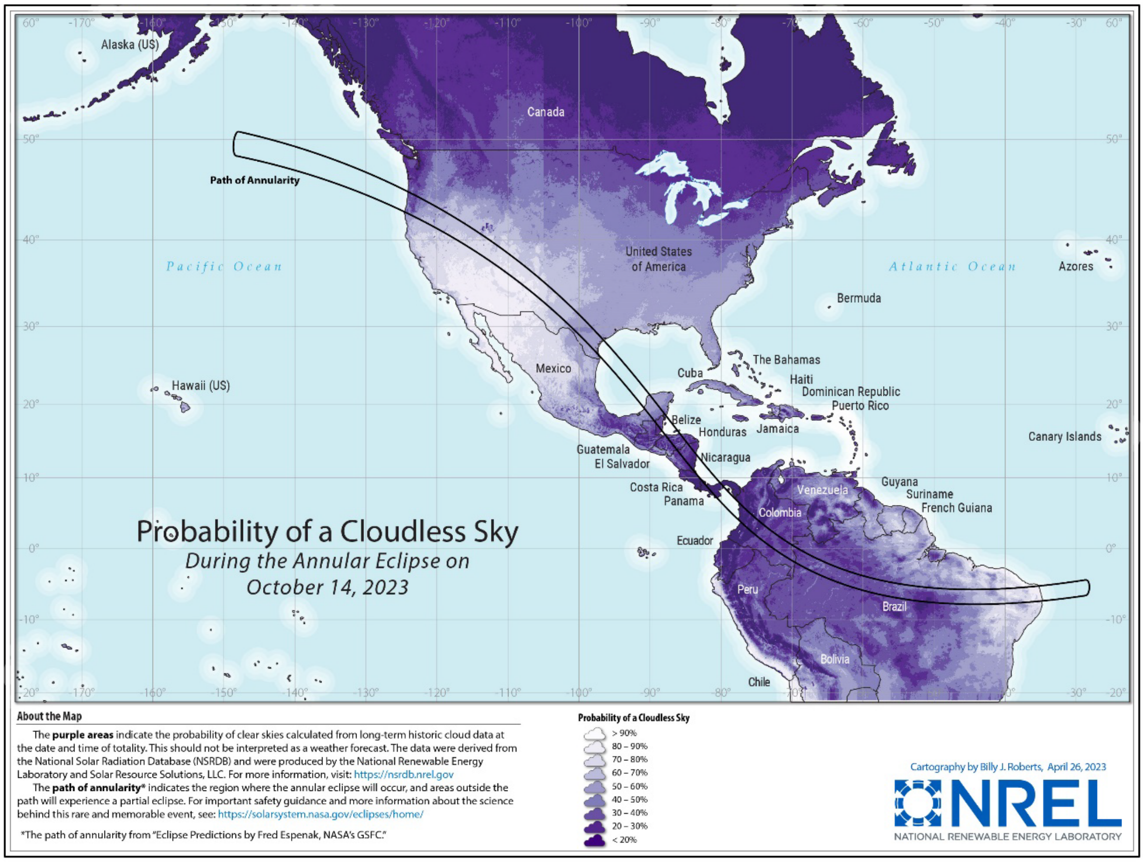

Figure 5. Cloudless-sky probabilities for October 14, 2023, full NSRDB region

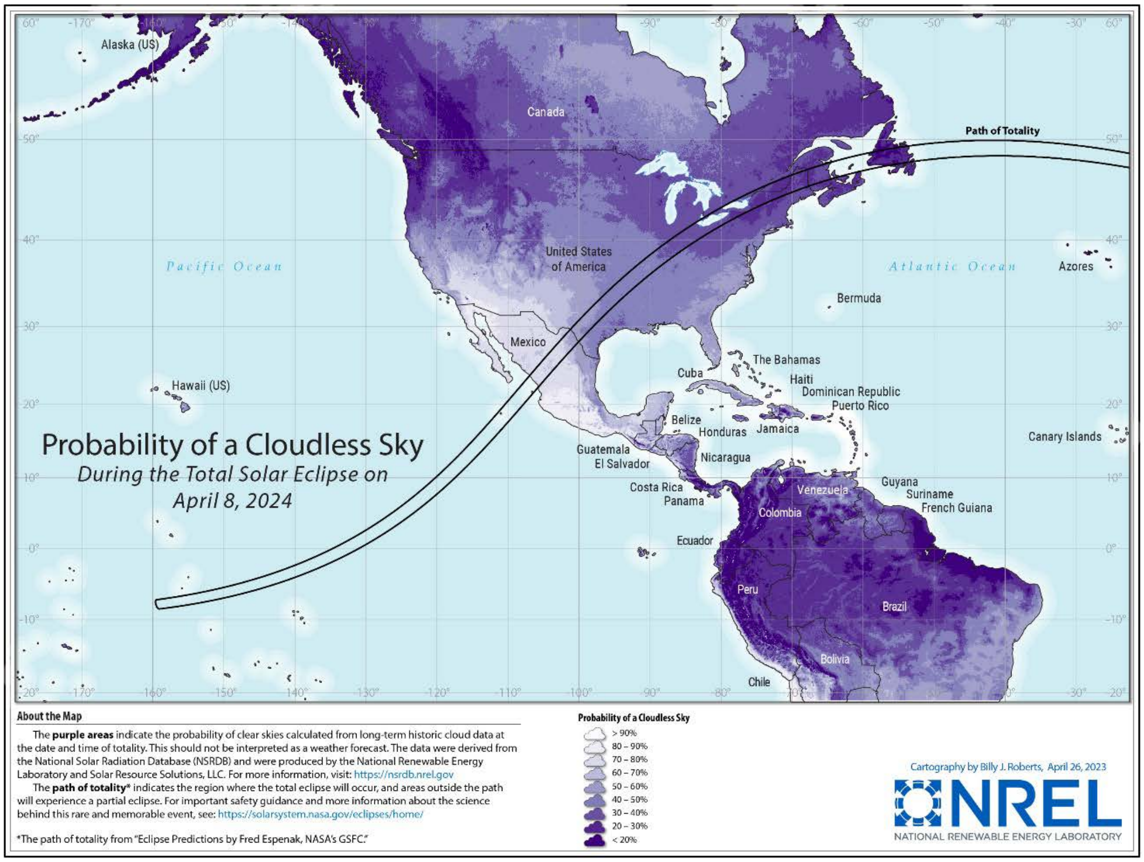

Figure 6. Cloudless-sky probabilities for April 8, 2024, full NSRDB region

Understanding the Results

Although interpreting the eclipse maps is straightforward, applying the information to find the best viewing location must be accompanied by strong caveats. Not the least of these caveats is that the clear-sky probability for any location is rendered irrelevant by actual conditions as the moment of the eclipse approaches. For most pixels, the sample cloud values in this analysis range from completely overcast to completely clear; hence, *any* sky condition is possible at any location. Thus, these probabilities are not a guarantee or a forecast, and in the final analysis, there is no arguing with the weather! If an eclipse watcher has the flexibility to travel on or before the eclipse day, however, these maps could help select a primary viewing location and several alternatives. As the day of the eclipse approaches, these maps, coupled with short-range weather forecasts, can provide useful location information to maximize the likelihood of viewing the solar eclipse in clear skies.

The NSRDB

The source data for this analysis, the 1998–2021 NREL NSRDB, provides industry, academia, and other stakeholders with high-resolution solar irradiance data to support feasibility analyses for photovoltaic and concentrating solar power generation projects. Improved satellite-based solar irradiance models are essential to increasing the deployment of solar energy conversion systems and to understanding system efficiencies of existing installations. In particular, the improved solar resource data will reduce the financial risks presently associated with the design, deployment, and routine operations of utility-scale solar energy conversion systems. NREL, the University of Wisconsin, and the National Oceanic and Atmospheric Administration collaborated to develop a 4-km by 4-km product for the Geostationary Operational Environmental Satellite (GOES) coverage region using the Fast All-Sky Radiation Model for Solar Applications (FARMS) as the underlying radiative transfer model. The NSRDB uses a two-stage scheme to first retrieve cloud properties and then use those properties in FARMS to calculate surface radiation. The project creates a half-hourly, 4-km gridded solar irradiance product of known quality and accuracy for use in the database.

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