State-Wide Models of Ambient Heat for Rhode Island

Summary Report

CAPA INSIGHTS

Prepared for American Forests

CAPA
strategies

AMERICAN FORESTS

CRF
CLIMATE RESILIENCE FUND

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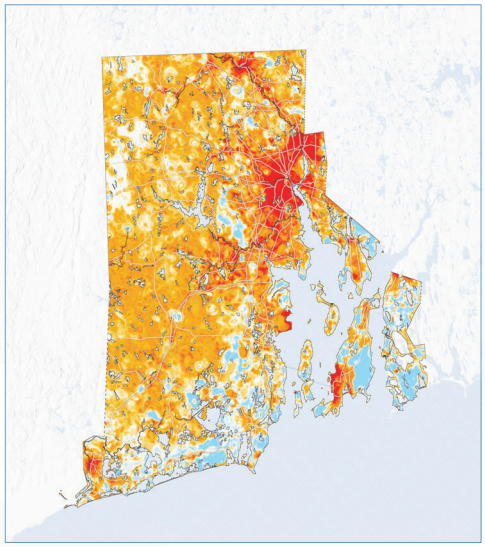
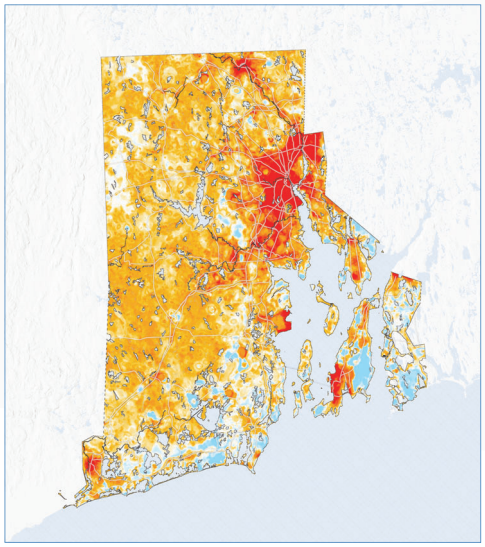
Executive Summary

The purpose of this synopsis is to summarize the technical methods employed, challenges faced and opportunities for deepening future collaborations when generating state-wide ambient heat models. The present project focuses on developing statewide models for Rhode Island through unique collaborative venture between American Forests and CAPA Strategies. The project sought to apply a novel method for describing statewide spatially-explicit air temperatures based on a synoptic capture of measurements in select areas of the State. The intended application of the spatially explicit statewide ambient air temperature outputs is the Tree Equity Score – an American Forests product – which currently uses land surfaces temperatures (not ambient temperatures). The results provide new developments in large-area, high-resolution heat modeling, and also identifies a unique set of challenges related to the sources of data required for such an analysis. The project team exhausted all data sources (e.g. spectral imagery data, ground-based assessments, land surface temperatures, etc.) and created methodological templates to fulfill project goals, producing a set of models for the full State of Rhode Island, and a means for expanding similar applications to other regions of the United States. Below we describe the processes involved in producing the day and night-time models of ambient temperature and heat indices for the State. For additional information about the project, its aims, and outputs, please reference the original proposal, submitted by American Forests to the Climate Resilience Fund.

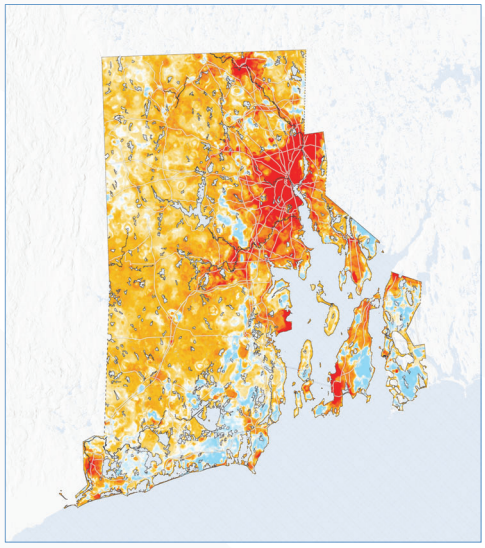
Afternoon (Temperature)



Afternoon (Heat Index)



Evening (Temperature)



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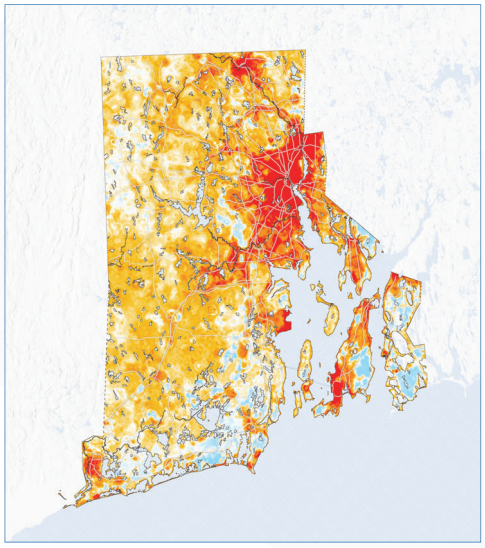

Methods

The approach for generating statewide Near Surface Air Temperature (NSAT, also known as ambient or air temperatures) models across Rhode Island builds on similar techniques deployed in over 50 urban areas across North America, including in 2020 four municipalities in Rhode Island. The techniques rely on data sources and modeling processes developed by CAPA and our partners, and follows a step-by-step protocol that integrates in-situ measurements of air temperatures (Hollingworth[1]), satellite imagery from the Sentinel-2 program, and a string of machine-learning processes, which are well-established through the peer-reviewed literature. Notably, the Rhode Island statewide application of the CAPA technique is the only known attempt to scale the data integration and analysis to an entire state extent, yet other successful applications have occurred in areas of equal geographical size.

The raw temperature and relative humidity data used in this project were collected during a community-based field campaign, which occurred on August 7th, 2020 and consisted of four municipalities including Providence, East Providence, Pawtucket, and Central Falls. At four one-hour time periods throughout the campaign day – 6 to 7am, 3 to 4pm, 7 to 8pm, and 11pm to 12am – local volunteers drove specially-designed sensors along pre-planned routes and effectively sampled heat across the diversity of land covers and land uses present in the study area. The captured temperature and humidity data were then processed using aforementioned techniques to produce 10m models of ambient heat. During the afternoon (3 to 4pm) and evening (7 to 8pm) periods, additional traverses occurred in the southern and western parts of the state, anticipating a broader application to statewide models. The additional traverses sampled the heat across land uses and land covers not abundantly present in the more urbanized regions of the state, and included peri-urban and rural areas. Results from the Heat Watch campaign, including processed traverse datasets and models, interactive web-maps, and in-depth summary report are available through the Open Science Framework, here: https://osf.io/wu9v7/.

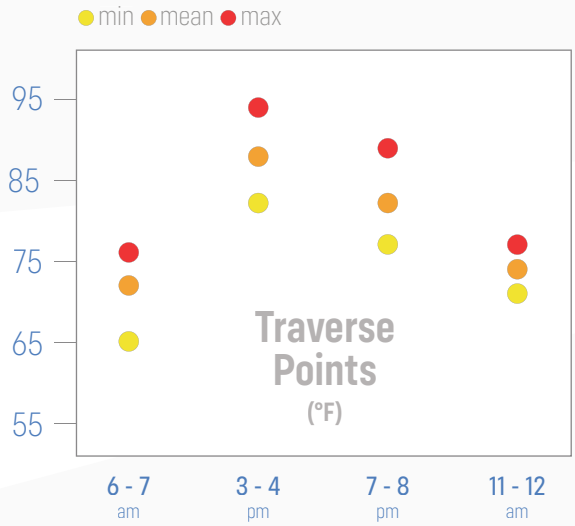

Figure 1: Traverse Point graph from Rhode Island Heat Watch report

The data inputs and modeling protocol for this statewide effort drew on the afternoon and evening Heat Watch traverse datasets and similar Sentinel-2 products. The use of afternoon and evening Heat Watch data occurred for two reasons: (1) these two time periods had the greatest number of points to integrating to statewide modeling, which allows for greater statistical strength; and (2) the Tree Equity Score (TES) contains an option for model outputs and narrowing to the hottest parts of the day (afternoon and evening) fulfills the TES platform requirement.

[1] *Hollingworth, D. "RI launches "heat watch" team to analyze how extreme heat impacts urban areas." July 30th, 2020, available at: https://www.abc6.com/ri-launches-heat-watch-team-to-analyze-how-extreme-heat-impacts-urban-areas/.*

The NSAT method relies on high-resolution spectral imagery provided by the Sentinel-2 satellite to describe qualities of the existing land and water over an area. The imagery from each pass of the satellite is divided into tiles, or projections of the earth's surface into unique square images. Essential in this process is obtaining cloud-free satellite imagery for the area of interest.

CAPA analysts draw from the R program package named Sen2R, along with proprietary scripts and programming sequences to select suitable tiles according to several criteria, including the clarity of imagery, level of cloud cover, and completeness of spatial extent. Although each tile is eventually mosaiced together, they each represent a unique set of characteristics that are programmatically evaluated and assembled in order to create a coherent image for the whole state.

Rhode Island sits at a unique cross-center of six of these tile locations, making programmatic evaluation and assembly of the tiles a more challenging computational task. Namely, the availability of cloud free images initially proved challenging for generating a consistent, cohesive set of imagery needed for the NSAT models. CAPA analysts were-able to identify cloud-free tiles for the majority of the state, though one portion of the southeaster portion contained no cloud-free satellite images. Those areas were 'clipped' out from the final outputs.

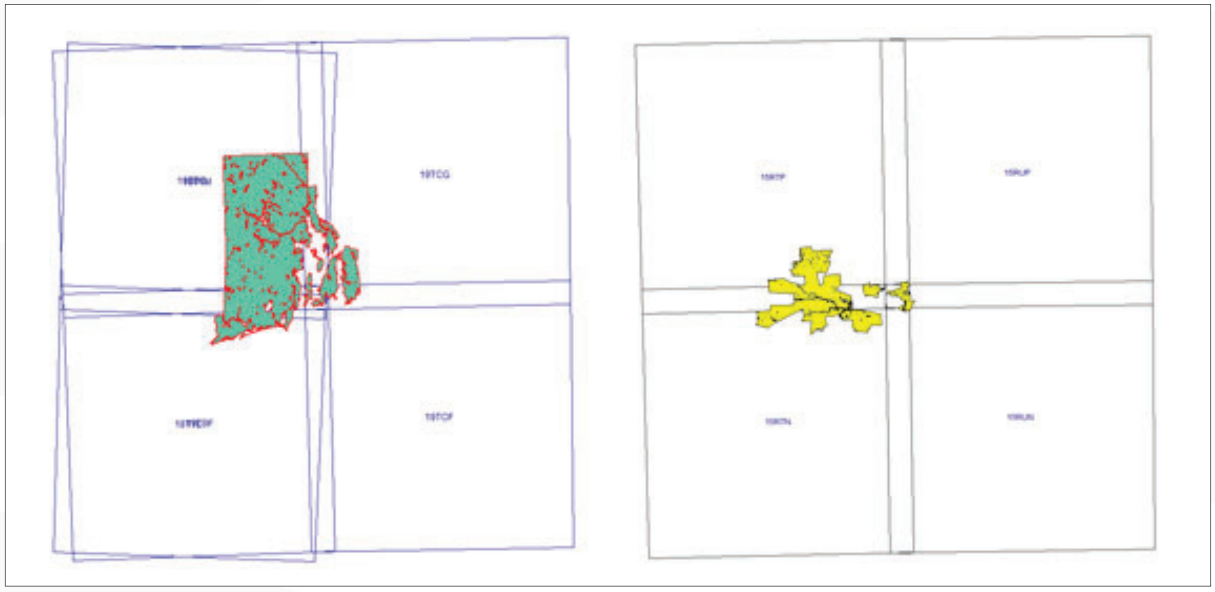

Figure 2a (left): Non-rectilinear Sentinel tiles across Rhode Island study area
Figure 2b (right): Rectilinear Sentinel tiles across Harris County study area.

An additional challenge limiting the availability of suitable satellite imagery was the frequent misalignment of relevant tiles. Typically, all Sentinel tiles align rectilinearly, as shown across an equally large area of Harris County, Texas (Figure 2b). For the 1,700+ square miles of Harris County, the four coincident tiles are rectilinearly arranged together allowing for a consistent and precise mosaicking of individual scenes. However, the tiles spanning the State of Rhode Island (Figure 2a) present in a non-rectilinear pattern, creating incompatible errors, or "artifacts", which when stitched together and integrated into the machine learning processes, generate inconsistent and idiosyncratic results. Addressing misaligned tiles in the processing of NSAT is not common, and proved to be a formidable challenge in finding suitable imagery.

The CAPA team took several remedial actions to address and circumvent the non-rectilinear tiling issue. A first step was to establish direct communications with the managers of the Sentinel product at the European Space Agency's Copernicus team, and their supporting developers of the Sen2R package. Initially it was unclear to Sentinel mangers and developers whether the root of the issue was in the raw data itself, or the processing of data, and also whether the issue appeared across the full record of this location's tiles, or just a portion.

With the aim of finding consistent spectral imagery, the CAPA team pored over dozens of historic tiles, manually downloading each, and inspecting the alignment and applying relevant quality control criteria. By circumventing the programmed filter for zero percent cloud cover, the CAPA team was able to determine a set of suitable criteria that drew on rectilinear tiles that featured only minor cloud cover, though one rural, southeastern portion of the state did not conform to the necessary assessment conditions. These few clouds, located over Tiverton and Little Compton, were manually removed by clipping the study area boundary, and present as small spatial gaps in the produced models. Although compromising a small region of the state (<2%), the clipping of clouds allowed for the generation of statewide NSAT for the remainder of the state.

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Afternoon

Temperature

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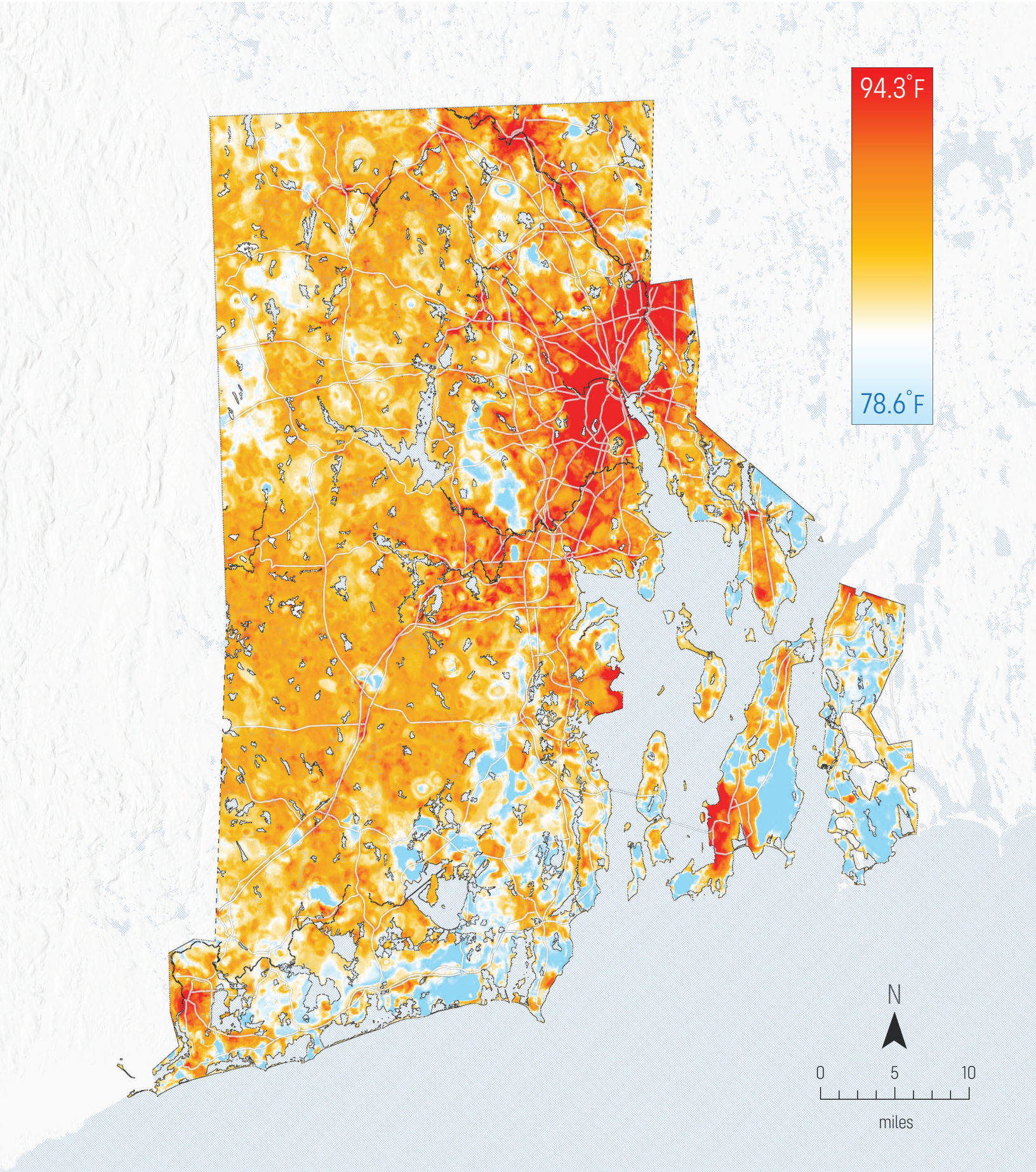

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Afternoon

Heat Index

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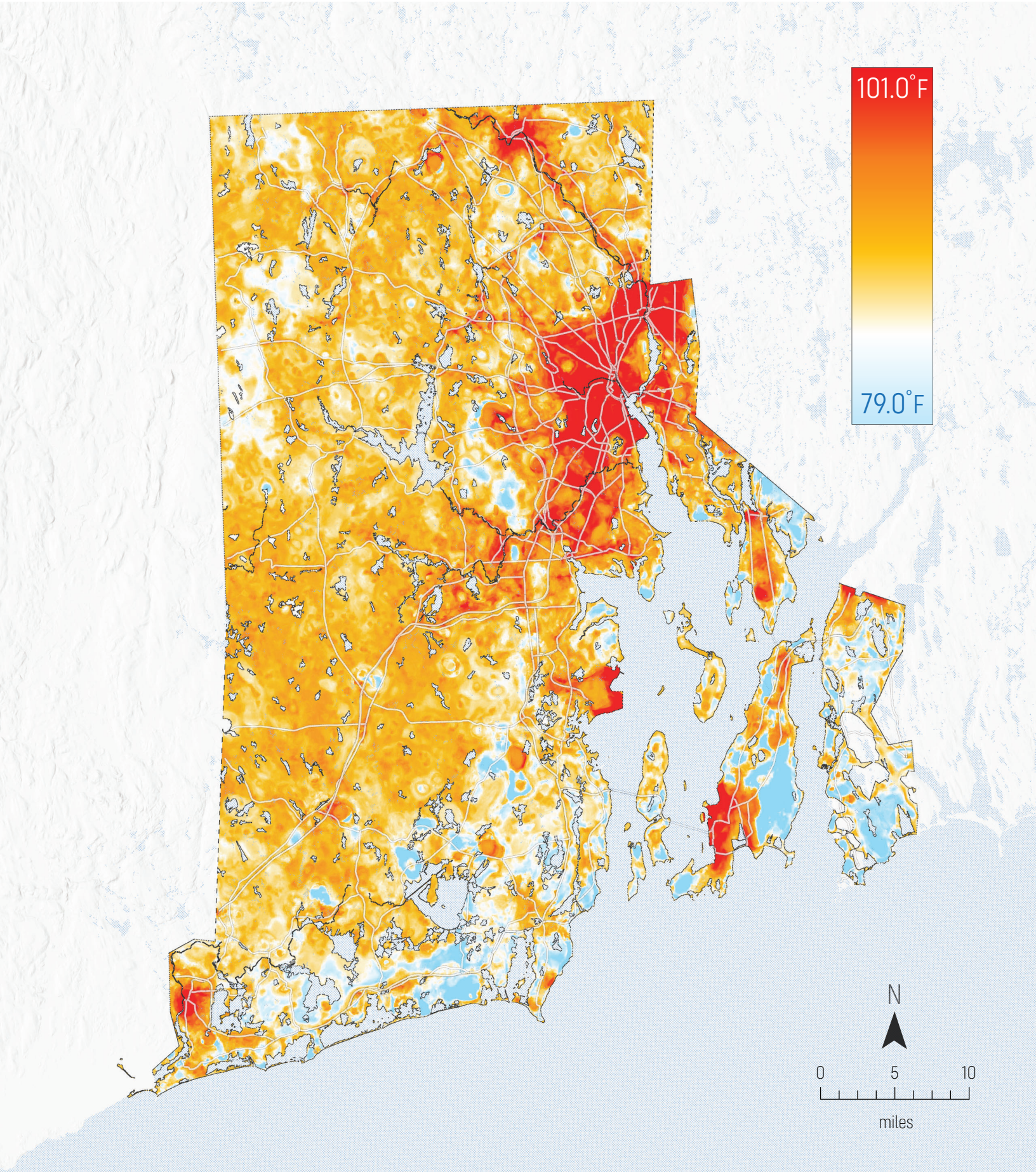
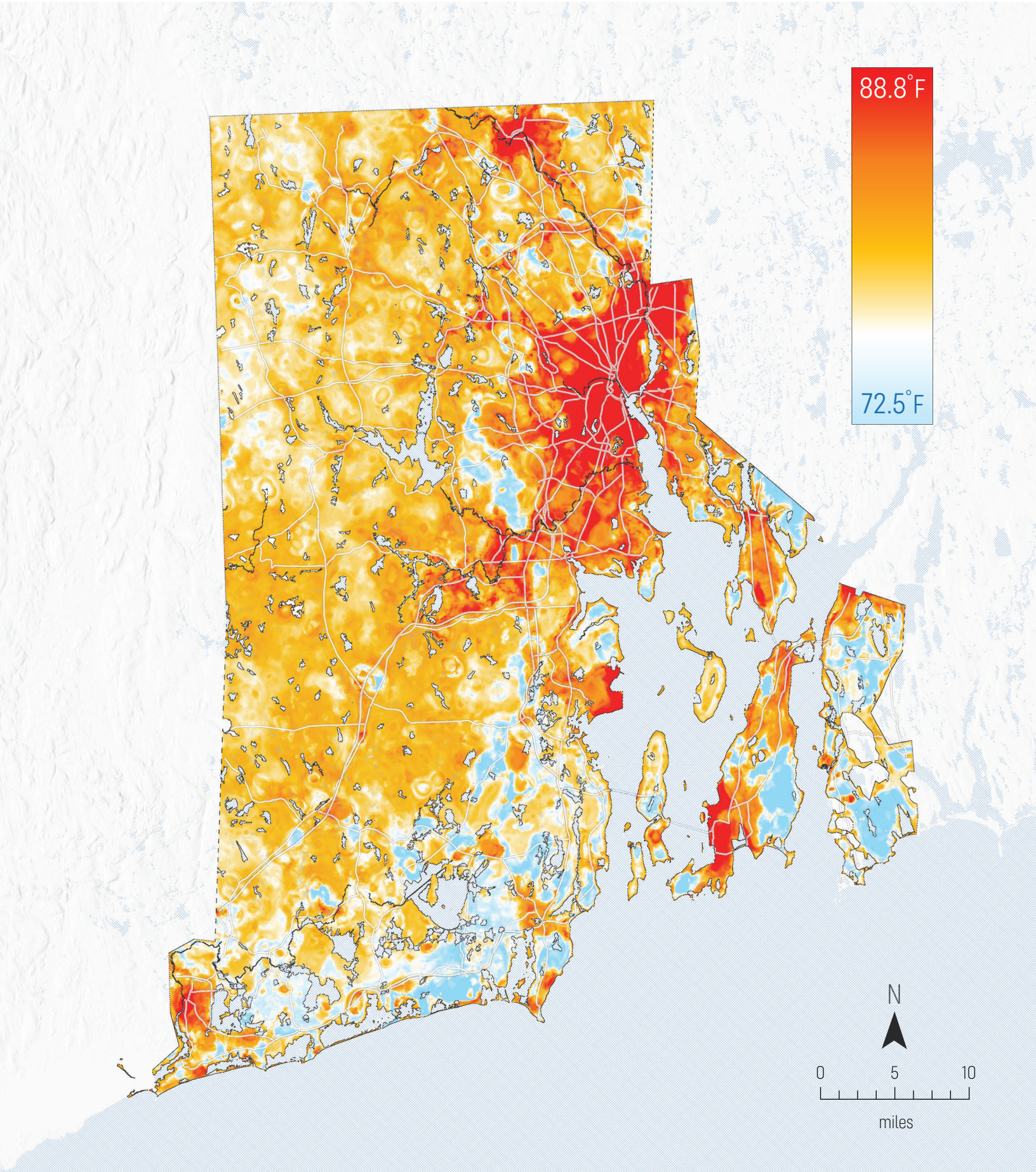


CAPA

Evening

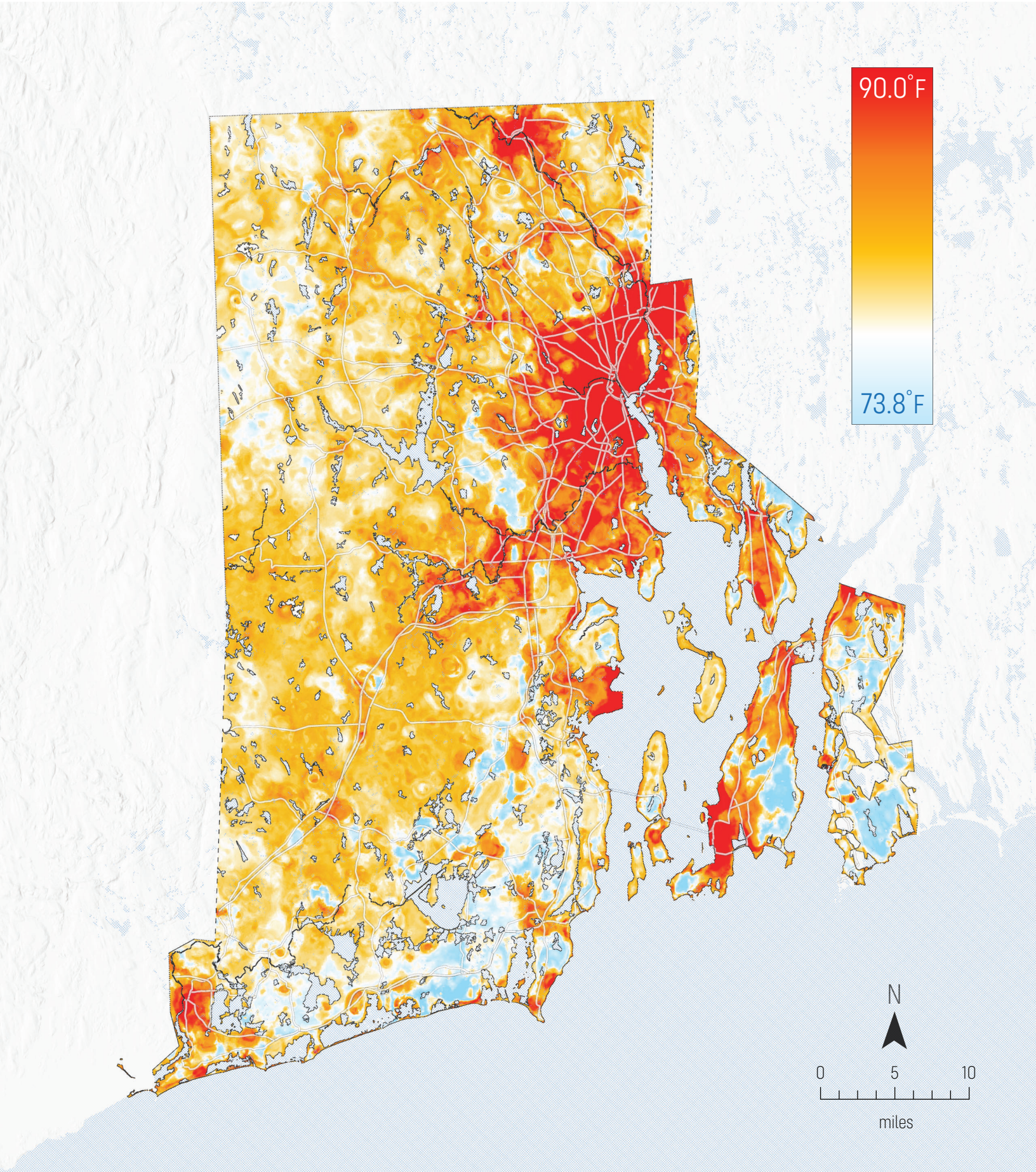
Temperature

INSIGHTS



Evening

Heat Index



Findings

The final models include a 10-meter temperature and heat index models at afternoon and evening hours, and are available for download as geo-raster TIFs on the Open Science Framework: https://osf.io/a53uk/.

To assess the strength of our predictive temperature models, we used a 70:30 "holdout cross-validation method," which consists of predicting 30% of the data with the remaining 70%, selected randomly. The 70:30 approach is an internal approach to validating the outputs of the NSAT models, and is a standard technique for accuracy assessments of spatial-explicit data. As shown in Table 1, along with brief summary statistics, the generated models showed high accuracy with the collected traverse data.

Table 1: Raster Summary Statistics

	Min	Max	Mean	Adjusted R-Squared
Afternoon Temperature	78.6°F	94.3°F	85.2°F	0.99
Afternoon Heat Index	79.0°F	101.0°F	86.2°F	0.99
Afternoon Temperature	72.5°F	88.8°F	78.0°F	0.99
Afternoon Heat Index	73.8°F	90.0°F	78.7°F	0.99

Based on the results of the accuracy assessment, although not including a small portion of the southeaster portion of the state, CAPA analysts recognized several notable improvements for future applications for generating statewide applications using Heat Watch data. The first is the evaluating the extent to which cloud-free tiles are available for the area of interest. Second, an initial evaluation of the extent to which each of the satellite tiles are rectilinear. While both the amount of cloud cover, and level of alignment are outside the control of CAPA's analytical abilities, the third factor will be instrumental in future statewide applications: assembly of all relevant data prior to commencing the project. While the CAPA team had applied similar machine learning processes to areas of equivalent geographic extent, the present project was a notable example of characterizing the locations prior to applying analytical techniques. Such an oversight required an additional one month of assessment, evaluation, and revisioning of processes, which was unaccounted for in the original proposal. In future applications, CAPA will expect to conduct a full review of available and suitable data prior to proposing outputs.

Despite the additional effort required to complete the project, the outputs are highly consistent with the 2020 field campaign. CAPA analysts compared independent outputs from the statewide model to those of the regional model and the outputs are near identical, which suggests a consistency of the application. The analytical team will continue scrutinizing the outputs in the coming months, and offer these results as the final deliverables.

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