Generating Dynamic Prescription Maps for Winter Road Treatment via Sun-Shadow Simulation

Yaguang Zhang, Sneha Jha, Darcy M. Bullock, James V. Krogmeier

July 30, 2021

PURDUE
UNIVERSITY

BACKGROUND

- Snow and ice can …
  - decrease road transportation efficiency, and
  - cause deadly threats to drivers.

Images courtesy of the Indiana Department of Transportation (INDOT).

Background

- Winter Roadway Treatments
  - Mechanical means such as plowing
  - Pre- and post-treatments for anti- and de-icing

(a) Gang plowing by the Minnesota Department of Transportation (MnDOT).

(b) Anti-icing operation by Kentucky Transportation Cabinet (KYTC).

PURDUE UNIVERSITY

BACKGROUND

- Winter Roadway Treatments
  - Mechanical means such as plowing
  - Pre- and post-treatments for anti- and de-icing

(a) Gang plowing by the Minnesota Department of Transportation (MnDOT).

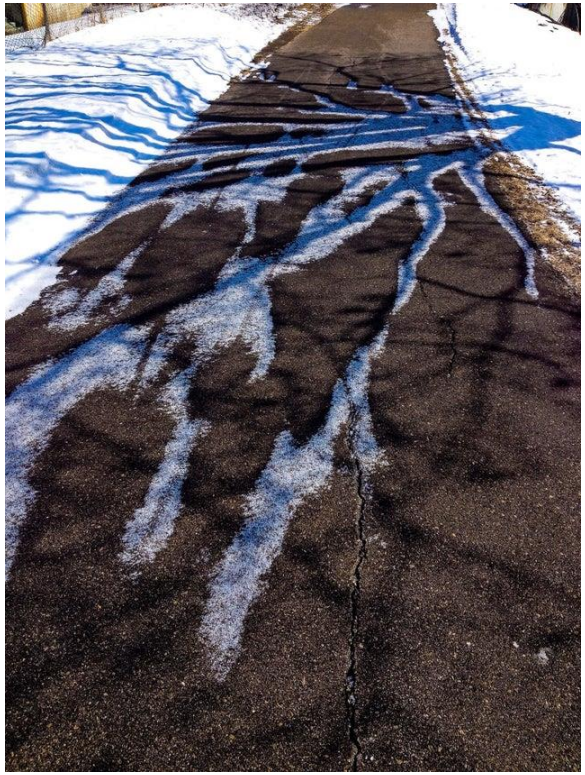
(b) Anti-icing operation by Kentucky Transportation Cabinet (KYTC).

>70% of U.S. roadways are affected.

PURDUE UNIVERSITY

Background

- Dynamic Prescription
  - Sun shadows could worsen the case



Courtesy of banana-nou@reddit.

Courtesy of Roflcopter71@reddit.

Liquid anti-icing is most effective at pavement temperatures > 20°F (-6.7°C). [MnDOT Anti-Icing Guide]

BACKGROUND

- Dynamic Prescription
  - Sun shadows could worsen the case
  - High-risk road segments identification

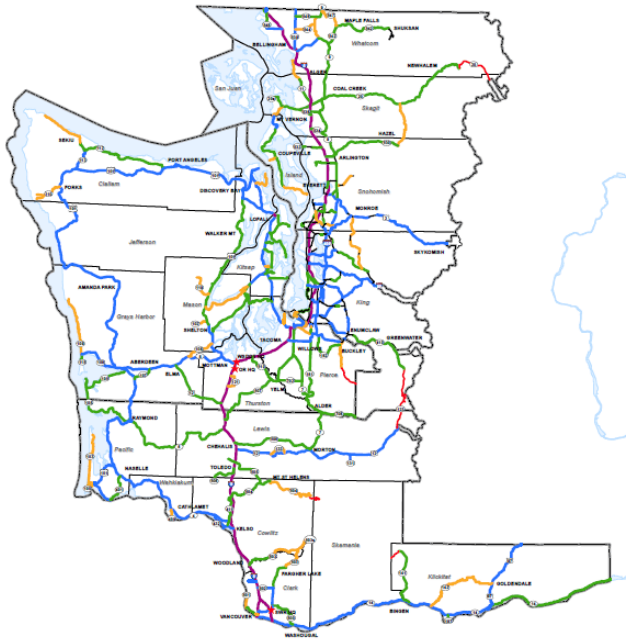


Fig. Western Washington treatment level goals from the Washington State Department of Transportation (WSDOT).

PURDUE UNIVERSITY

Background

- Dynamic Prescription
  - Sun shadows could worsen the case
  - High-risk road segments identification
  - Reducing financial and environmental costs

Highway snow/ice control cost	$2.3 billion/year
Road salt application amount	15 million tons/year
Extra cost to infrastructure	$5 billion/year

Tab. Estimated cost on winter road maintainance in the U.S.

(a) Courtesy of [JoelNolting@UrbanForestDweller]

(b) From [Minnesota Stormwater Manual]

Fig. Plants damaged by road salt.

Source: [How America got addicted to road salt — and why it's become a problem].

SUN-SHADOW SIMULATOR

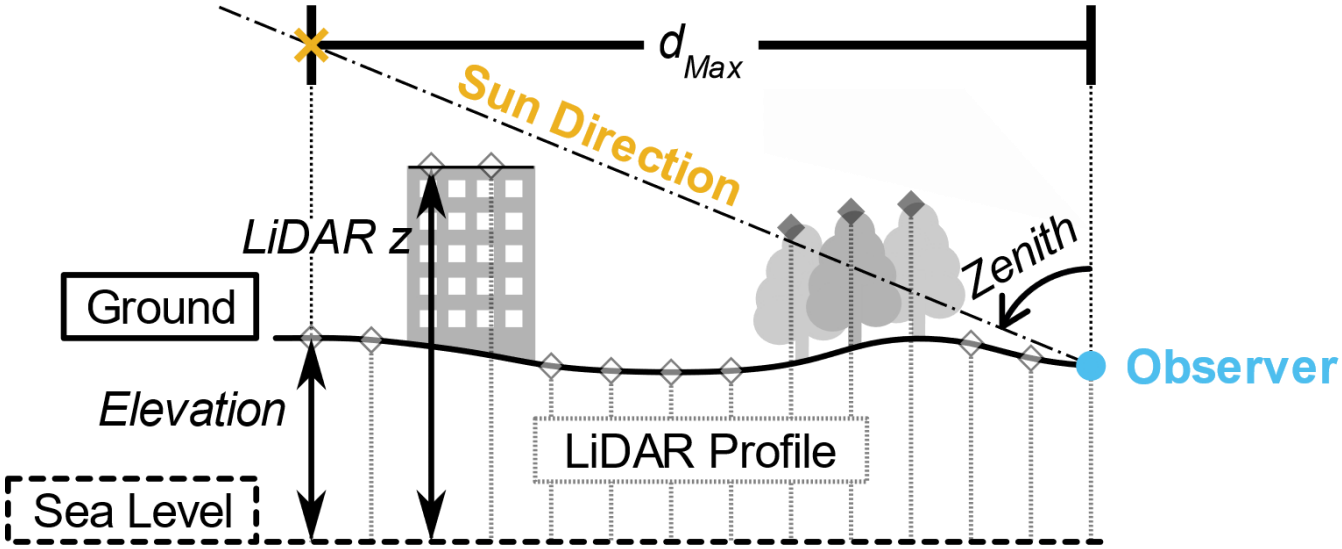
- 2016-2020 Indiana Statewide LiDAR
  - Digital surface model (DSM) provided by Purdue

Fig. Illustration of the LiDAR data for Purdue University.

PURDUE UNIVERSITY

SUN-SHADOW SIMULATOR

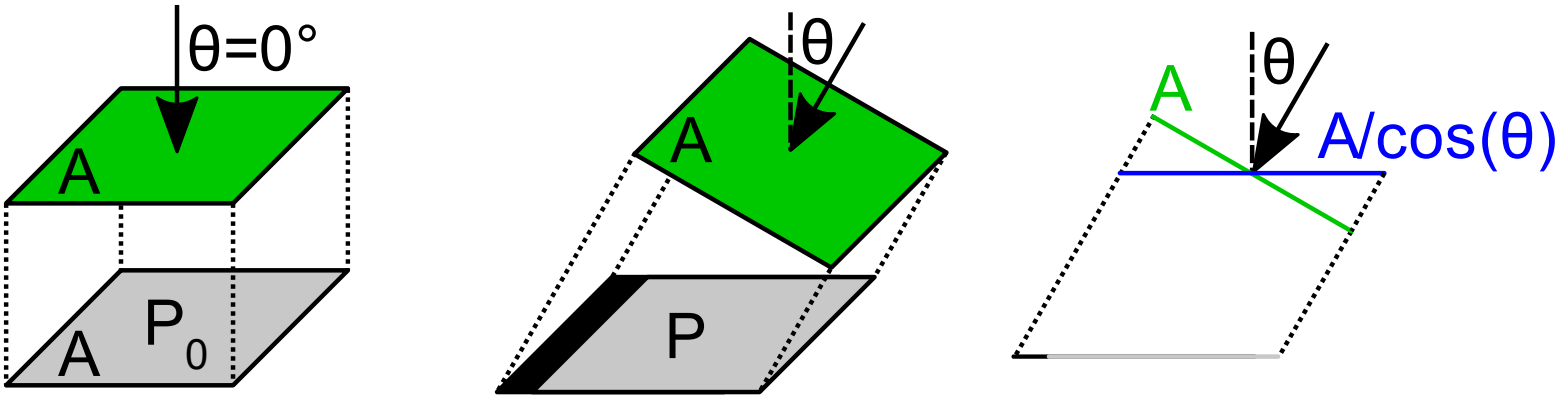
- 2016-2020 Indiana Statewide LiDAR
  - Digital surface model (DSM) provided by Purdue
- Simulation Models
  - Direct-path blockage



PURDUE UNIVERSITY

SUN-SHADOW SIMULATOR

- 2016-2020 Indiana Statewide LiDAR
  - Digital surface model (DSM) provided by Purdue
- Simulation Models
  - Direct-path blockage
  - Normalized sun energy

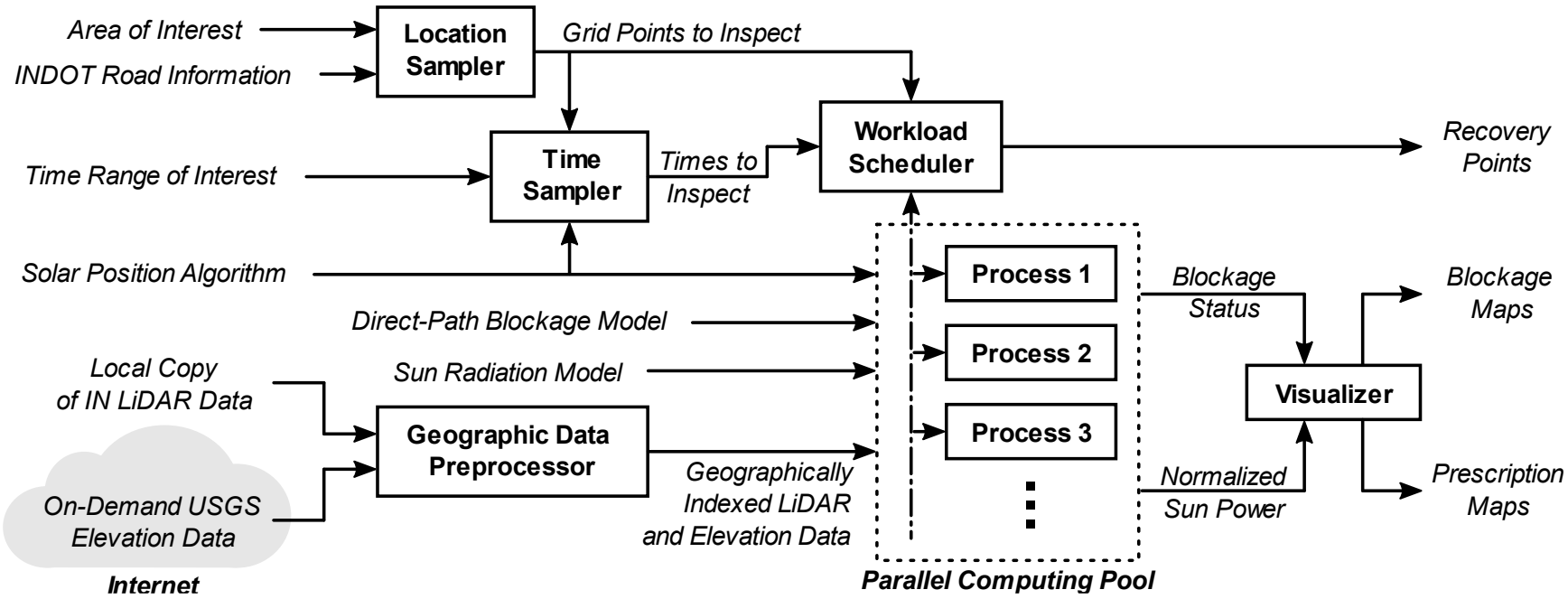


(a) Zenith angle is zero. (b) Zenith angle is non-zero. (c) Front view of (b).

PURDUE UNIVERSITY

SUN-SHADOW SIMULATOR

- Simulator

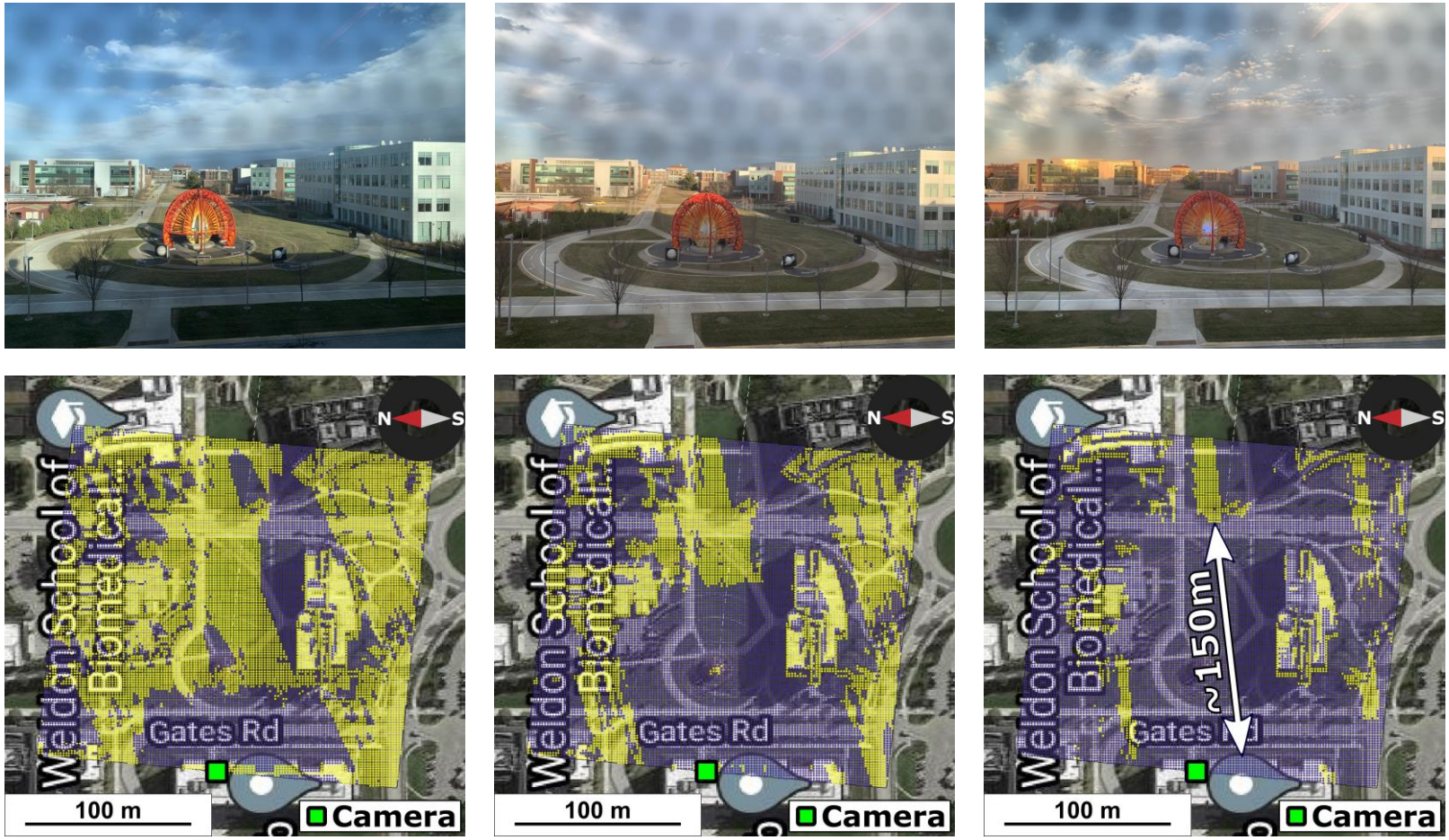


The Solar Position Algorithm (SPA) was developed by the National Renewable Energy Laboratory (NREL). We used a Matlab implementation.

PURDUE UNIVERSITY

SUN-SHADOW SIMULATOR

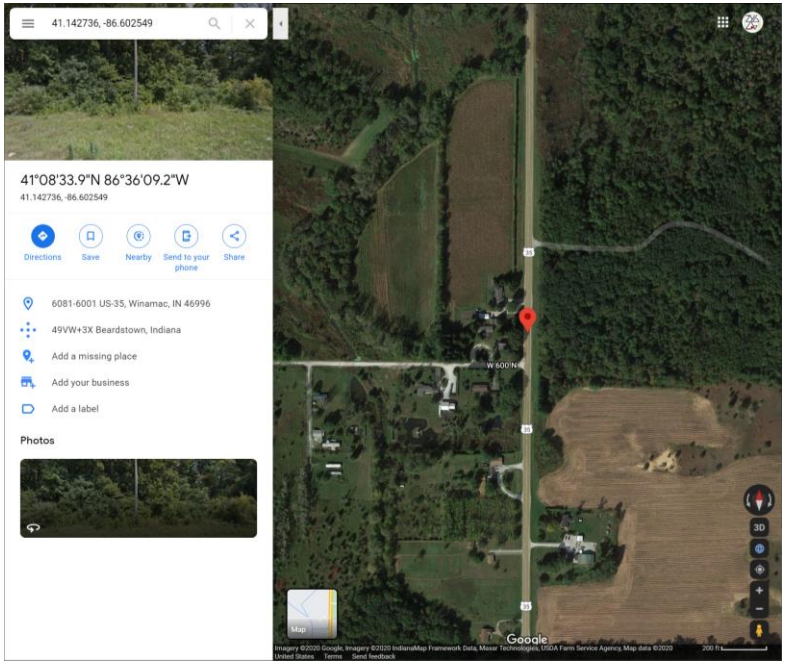
- Simulation Result Verification for Buildings



(a) 4:08 p.m. (b) 5:01 p.m. (c) 5:33 p.m.

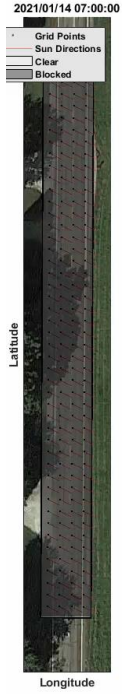
SUN-SHADOW SIMULATOR

- Simulation Result Verification for Trees



(a) Map view*

(b) Street view



(c) Simulation

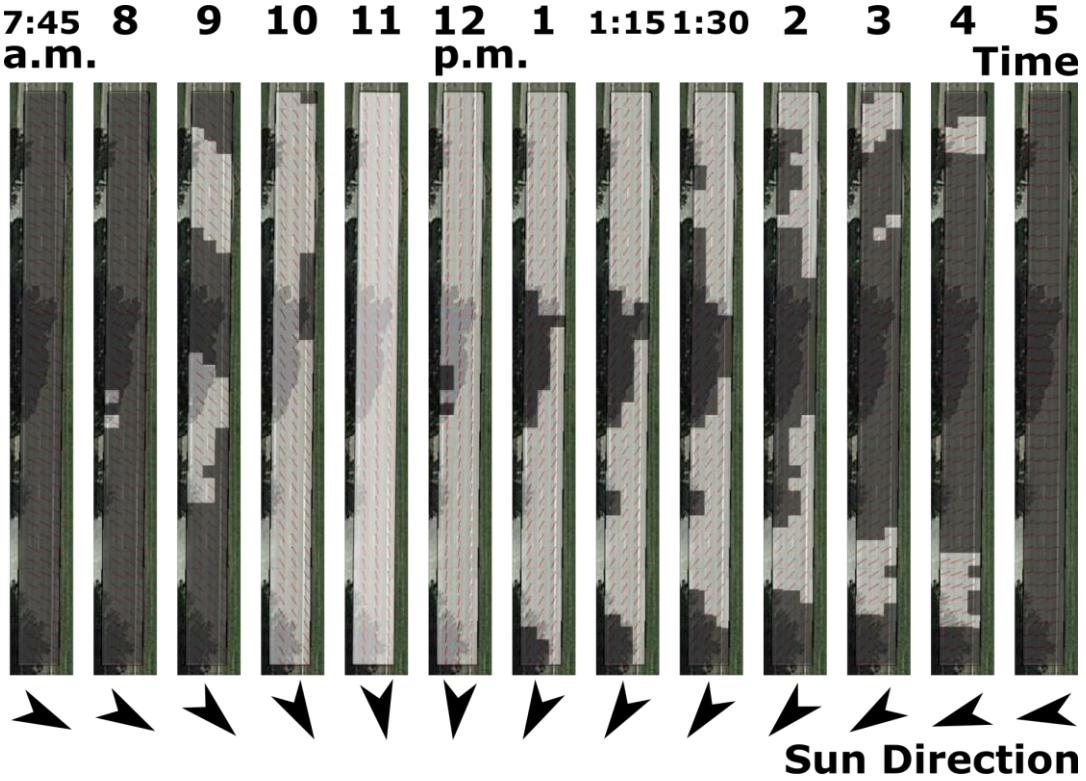
* Satellite images in this presentation are from Google Maps.

PURDUE UNIVERSITY

SUN-SHADOW SIMULATOR

- Simulation Result Verification for Trees

(a) Grid points for the are of interest



(b) Selected blockage maps

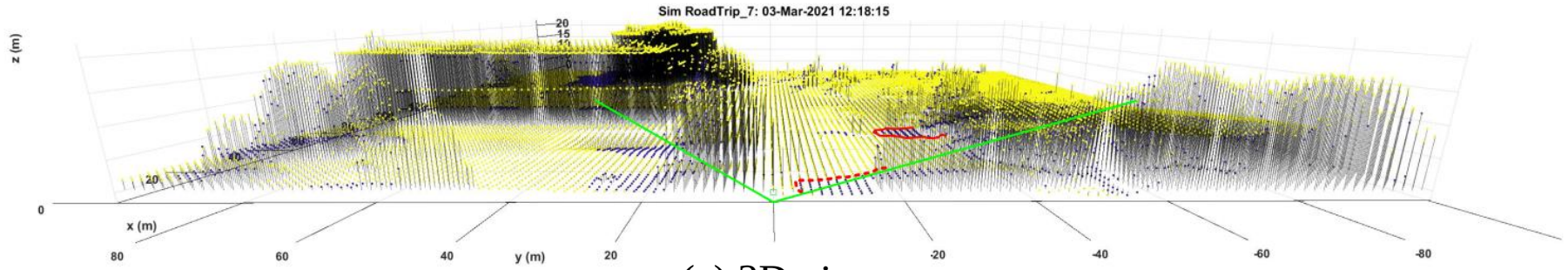
PURDUE UNIVERSITY

SUN-SHADOW SIMULATOR

- Simulation Result Verification – Road Tests

(a) Photo

(b) Map view



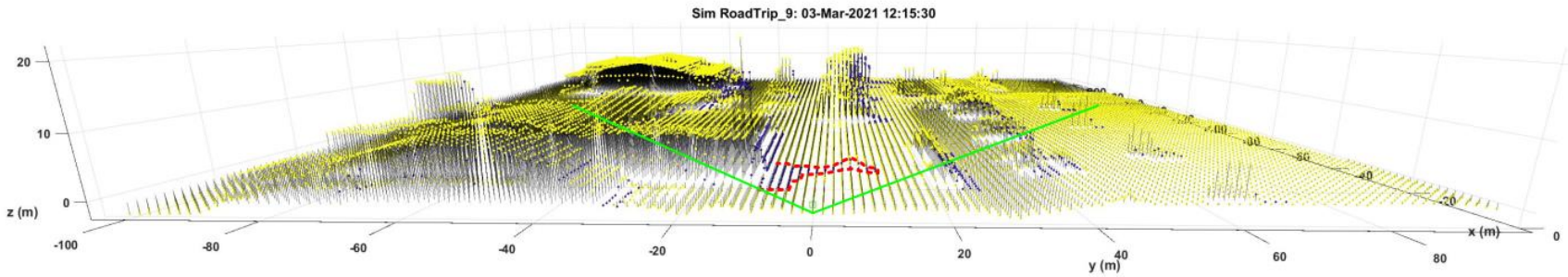
(c) 3D view

PURDUE UNIVERSITY

SUN-SHADOW SIMULATOR

- Simulation Result Verification – Road Tests

(a) Photo



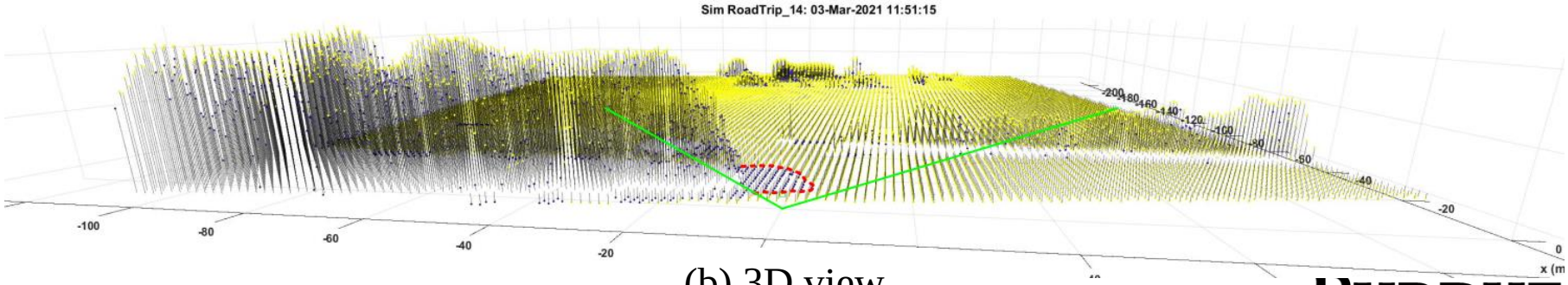
(b) 3D view

PURDUE UNIVERSITY

SUN-SHADOW SIMULATOR

- Simulation Result Verification – Road Tests

(a) Photo

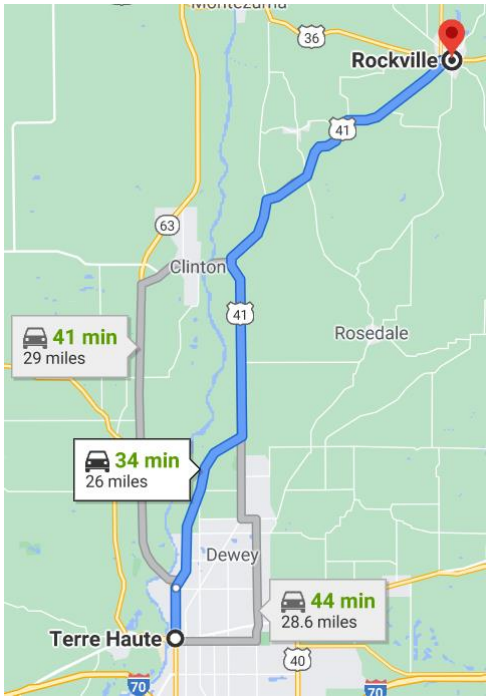


(b) 3D view

PURDUE UNIVERSITY

LARGE-SCALE SIMULATIONS

- Case Study for U.S. 41
  - Scene reconstruction (38 km or 26 miles)

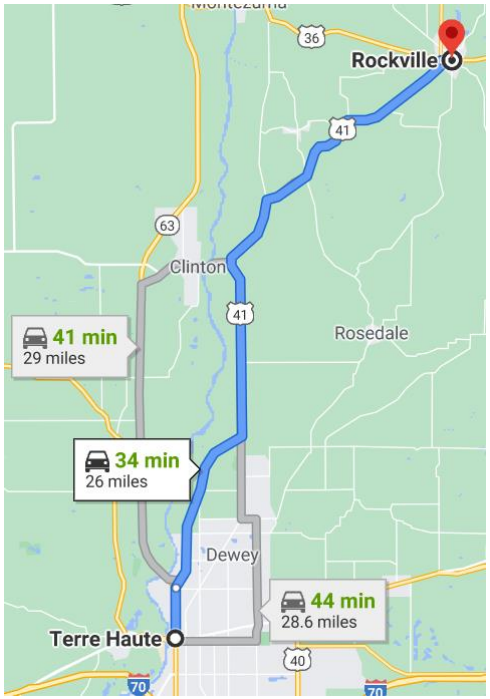


(a) Overview

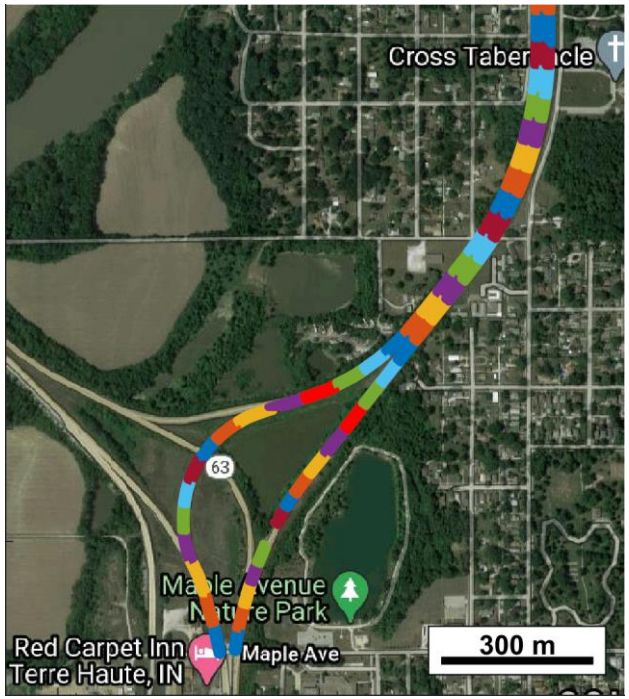
PURDUE UNIVERSITY

LARGE-SCALE SIMULATIONS

- Case Study for U.S. 41
  - Scene reconstruction (38 km or 26 miles)



(a) Overview

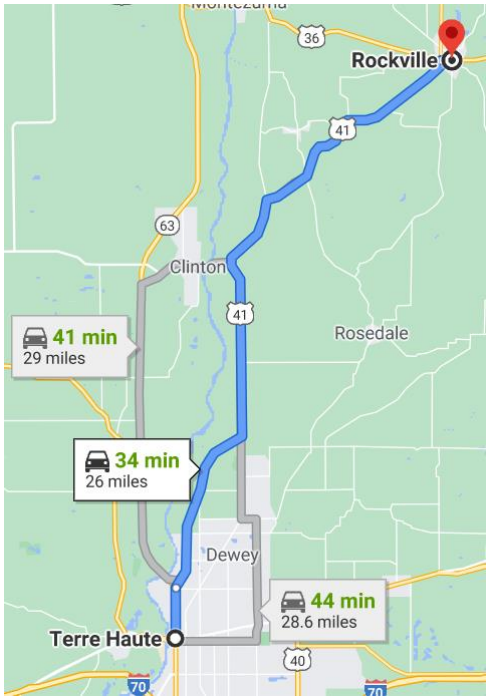


(b) Segmentation

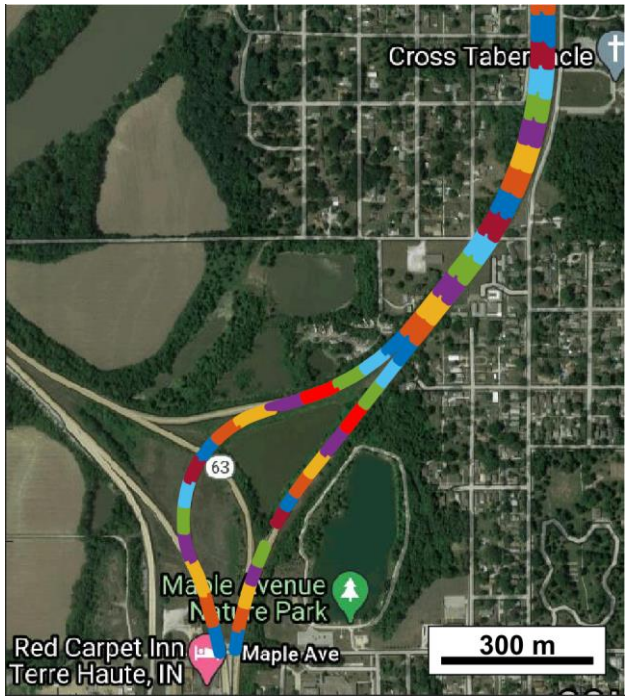
PURDUE UNIVERSITY

LARGE-SCALE SIMULATIONS

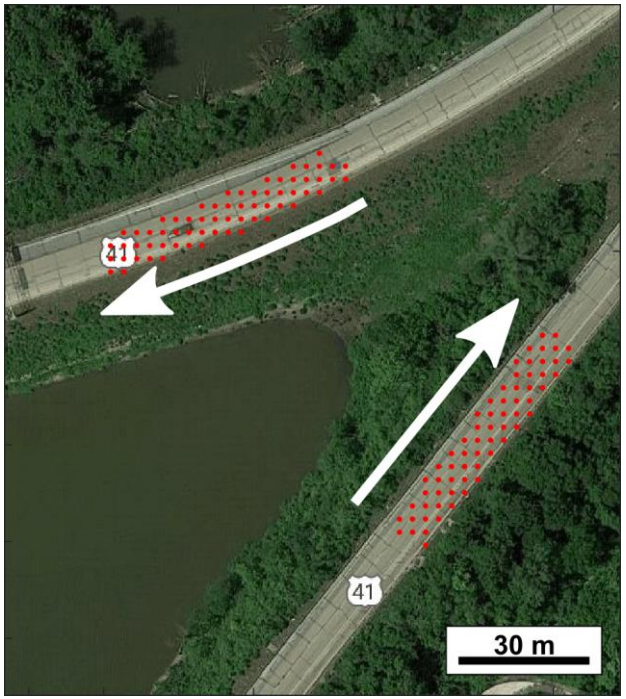
- Case Study for U.S. 41
  - Scene reconstruction (38 km or 26 miles)



(a) Overview



(b) Segmentation

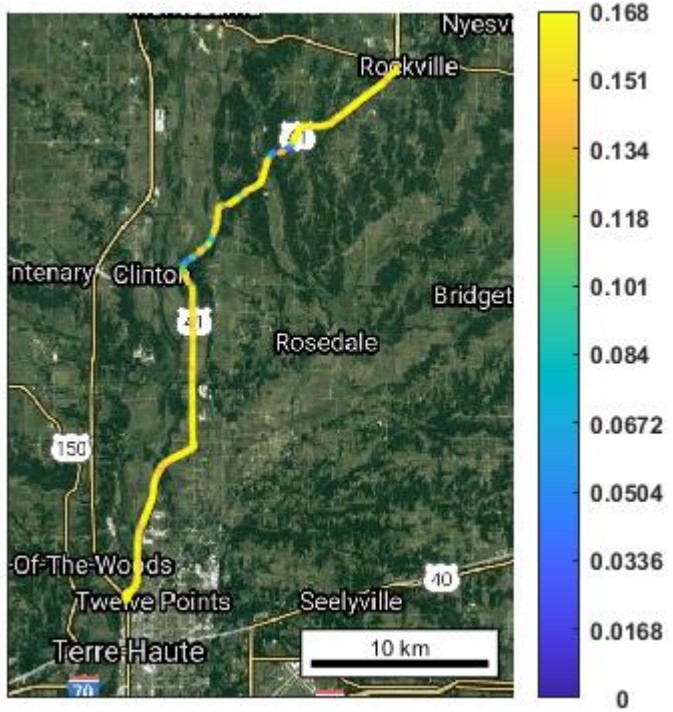


(c) Simulation grid

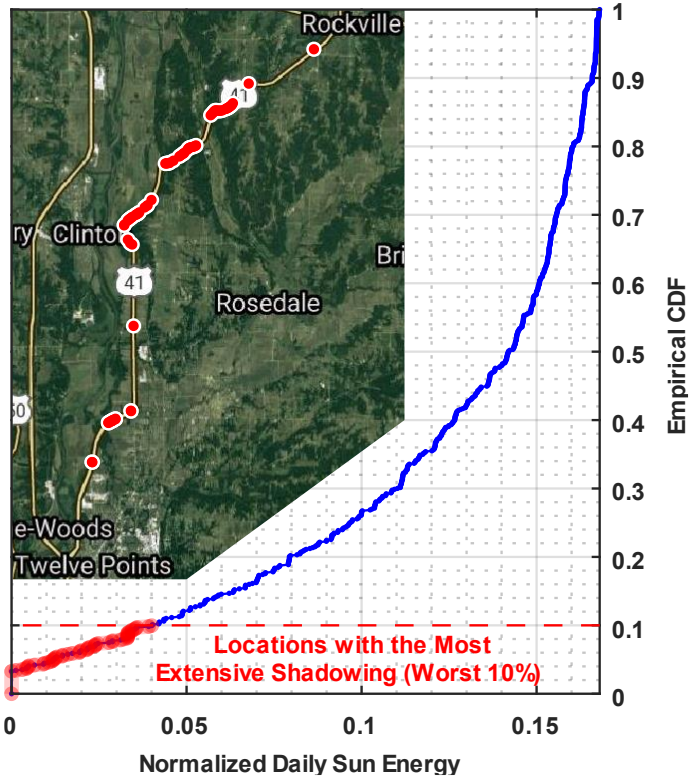
PURDUE UNIVERSITY

LARGE-SCALE SIMULATIONS

- Case Study for U.S. 41
  - Scene reconstruction (38 km or 26 miles)
  - Simulation result aggregation



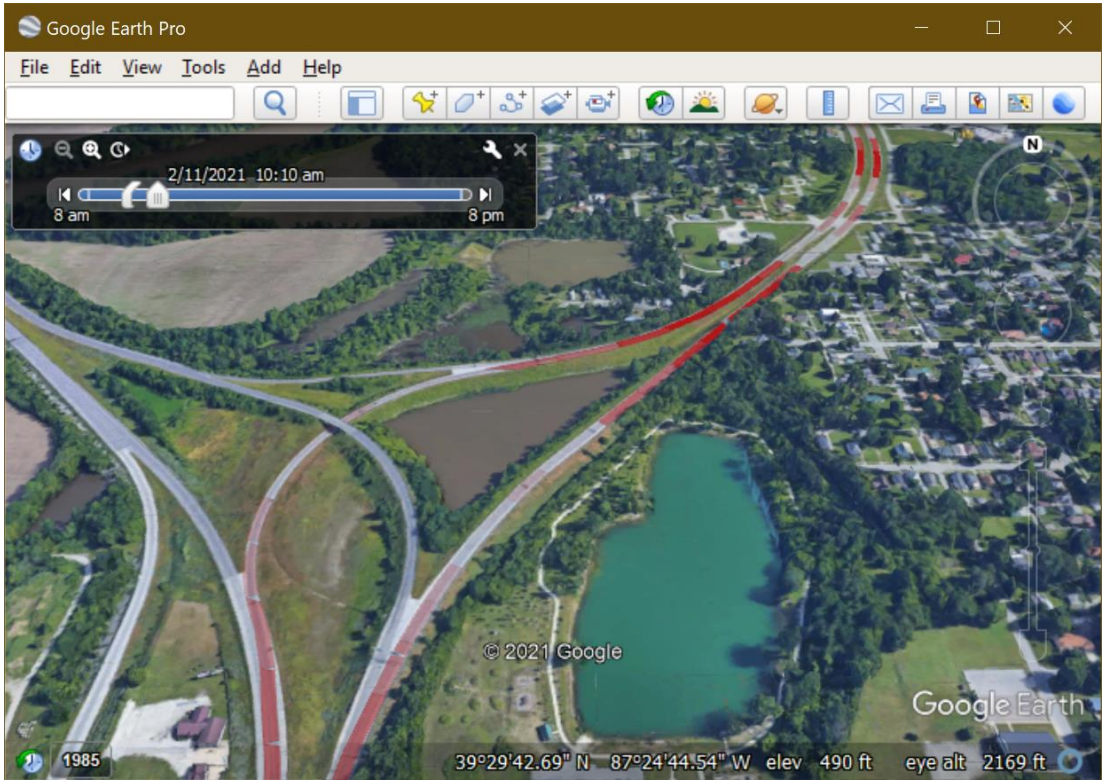
(a) Normalized daily sun energy for Feb. 11, 2021



(b) The worst 10% locations

LARGE-SCALE SIMULATIONS

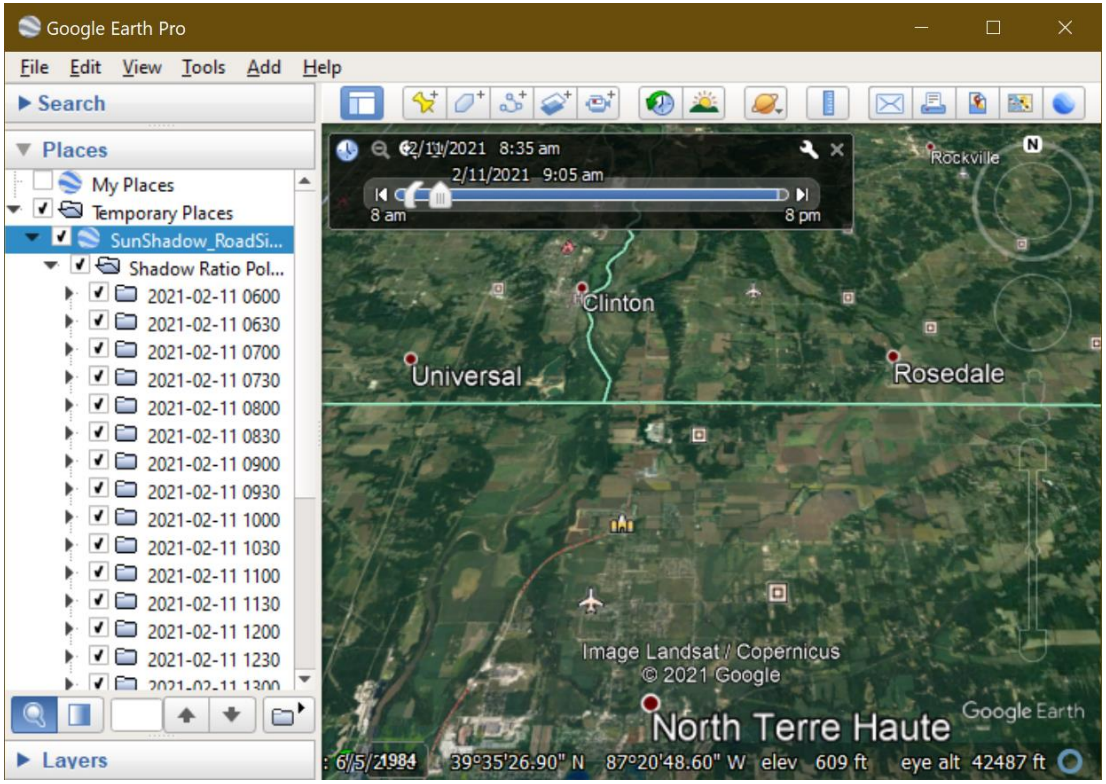
- Case Study for U.S. 41
  - Scene reconstruction (38 km or 26 miles)
  - Simulation result aggregation



PURDUE UNIVERSITY

LARGE-SCALE SIMULATIONS

- Case Study for U.S. 41
  - Scene reconstruction (38 km or 26 miles)
  - Simulation result aggregation



PURDUE UNIVERSITY

SUMMARY

- Anti-Icing Treatments
  - High cost
  - Negative environmental effects
- Sun-Shadow Simulator
  - Shading slows down the melting process.
  - Identification of the Sun's shadows for large areas at a low cost via LiDAR.
  - Fully-automated with high accuracy.
- User-Friendly Prescription Maps
  - Normalized daily sun energy map
  - Blockage percentage map

Thank you!

Sponsorship for this work was provided by the Joint Transportation Research Program (JTRP) administered by INDOT and Purdue University under Project SPR-4322, and the Foundation for Food and Agriculture Research (FFAR) under Award 534662.

Thanks to Professor Jinha Jung at Purdue University for assisting with the Indiana statewide LiDAR data set.

Yaguang Zhang
ygzhang@purdue.edu

PURDUE UNIVERSITY

IEEE

INTELLIGENT TRANSPORTATION SYSTEMS SOCIETY ITSS IEEE

IEEE ITSC 2021 INDIANAPOLIS, USA

JOINT TRANSPORTATION RESEARCH PROGRAM Discovery with Delivery Since 1937 JTRP

FFAR Foundation for Food and Agriculture Research