The Importance of Terrain-Shading Losses in PV Yield Assessment

The Case of *Oahu*

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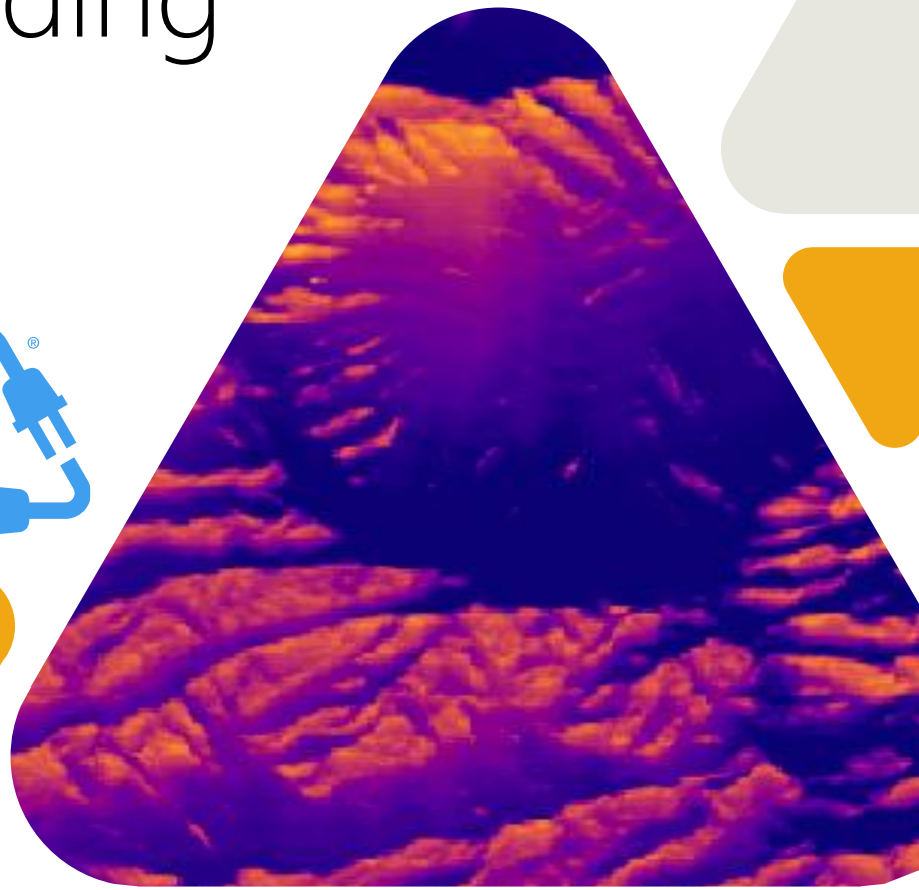

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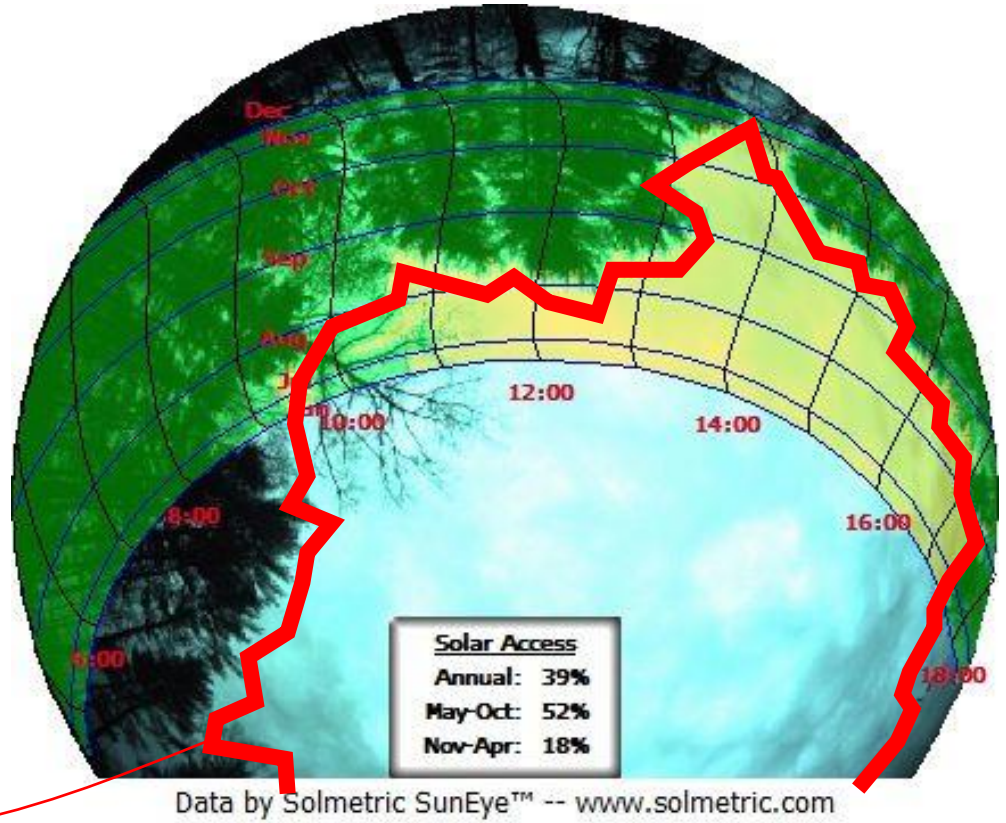
Shadow horizons in PV system design

Horizon information constitutes a series of angles made by the horizon as a function of azimuth

Calculating shadow horizons with a fish-eye lens

How to get it conventionally?

- Fisheye lens takes a photo and horizon is drawn by hand or using image classification techniques
- The information is used pre-construction to assess yield impacts

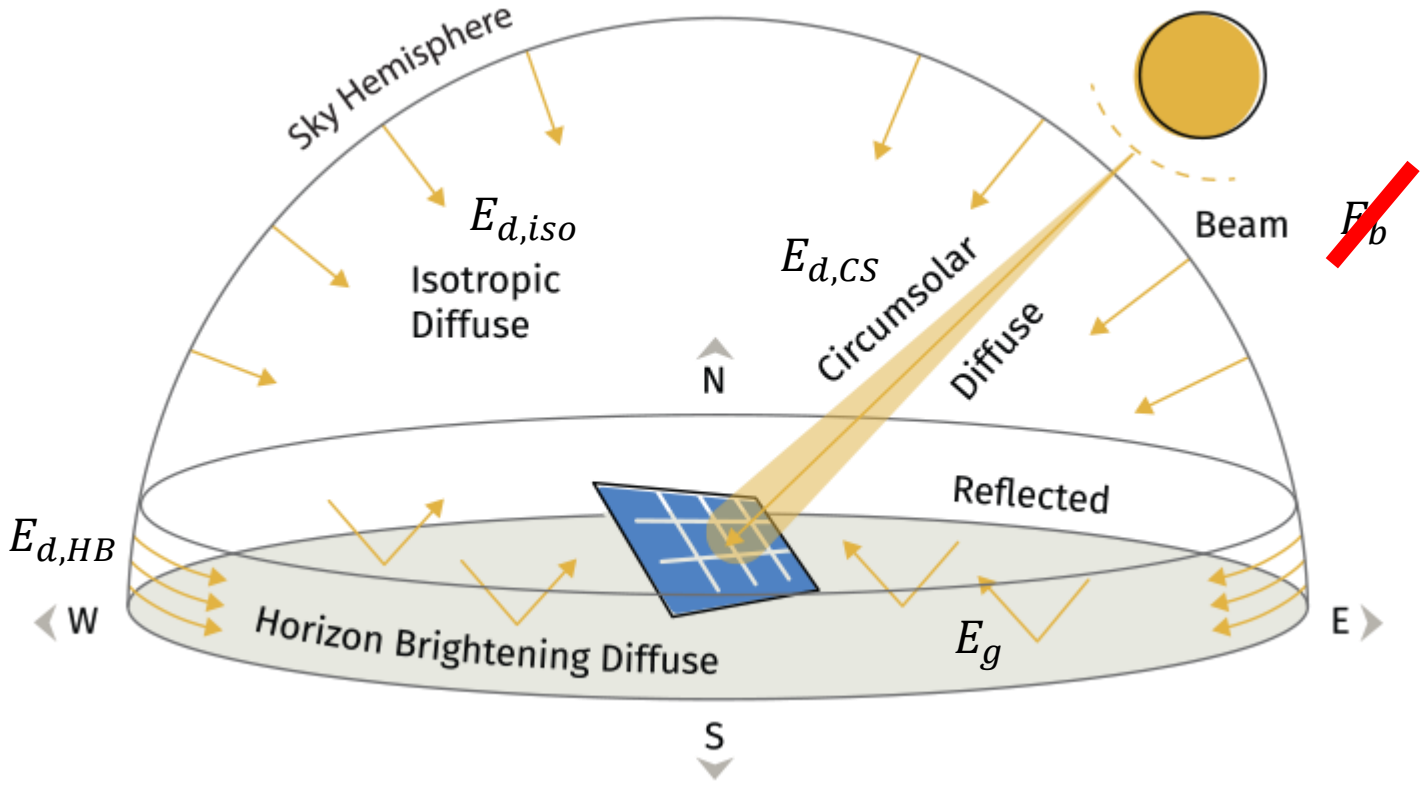


A horizon allows us to identify if we are in shadow or not

How do simulation models use horizon information?

Radiation is anisotropic: $E_{POA} = E_b + E_g + E_d$

If the sun is behind the horizon at time t, E_b is cut entirely, as is $E_{d,CS}$ and sometimes a portion of $E_{d,HB}$ and $E_{d,iso}$: E_g is a function of G & albedo

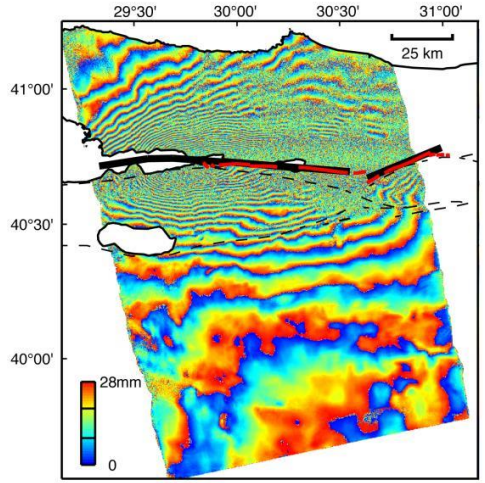


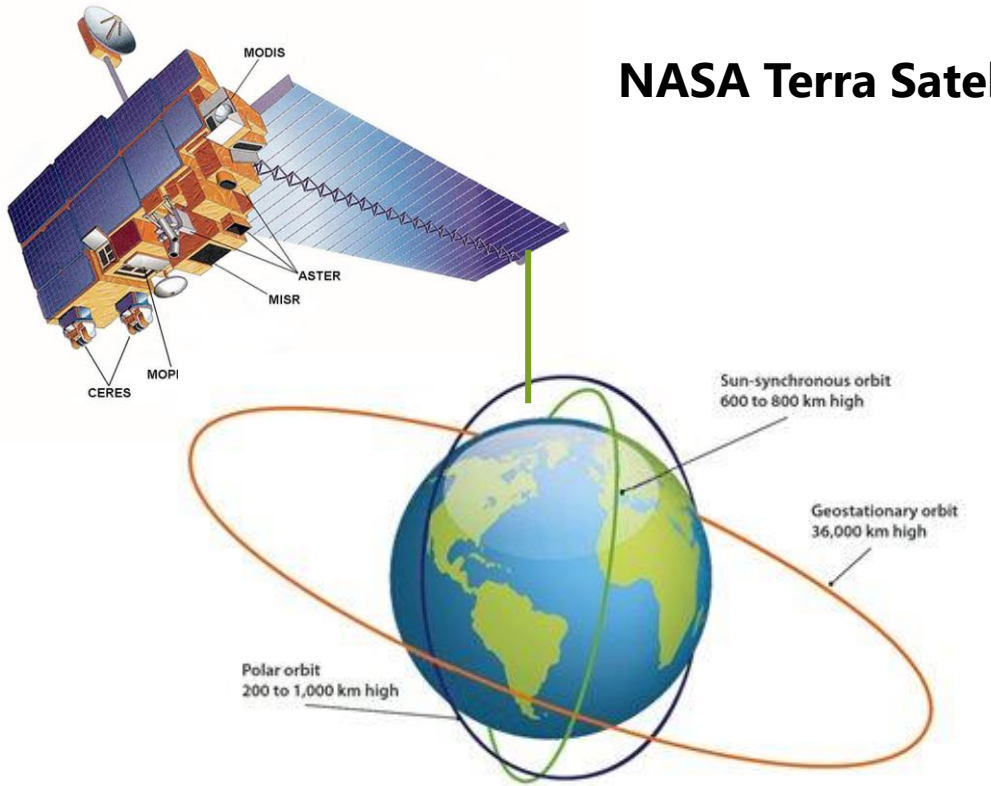
$$E_d = E_{d,iso} + E_{d,HB} + E_{d,CS}$$

NASA SRTM & ASTER: Free high-res DTM data

Stereophotogrammetry: closer to DSM

InSAR: Interferometric synthetic aperture radar





NASA Terra Satellite

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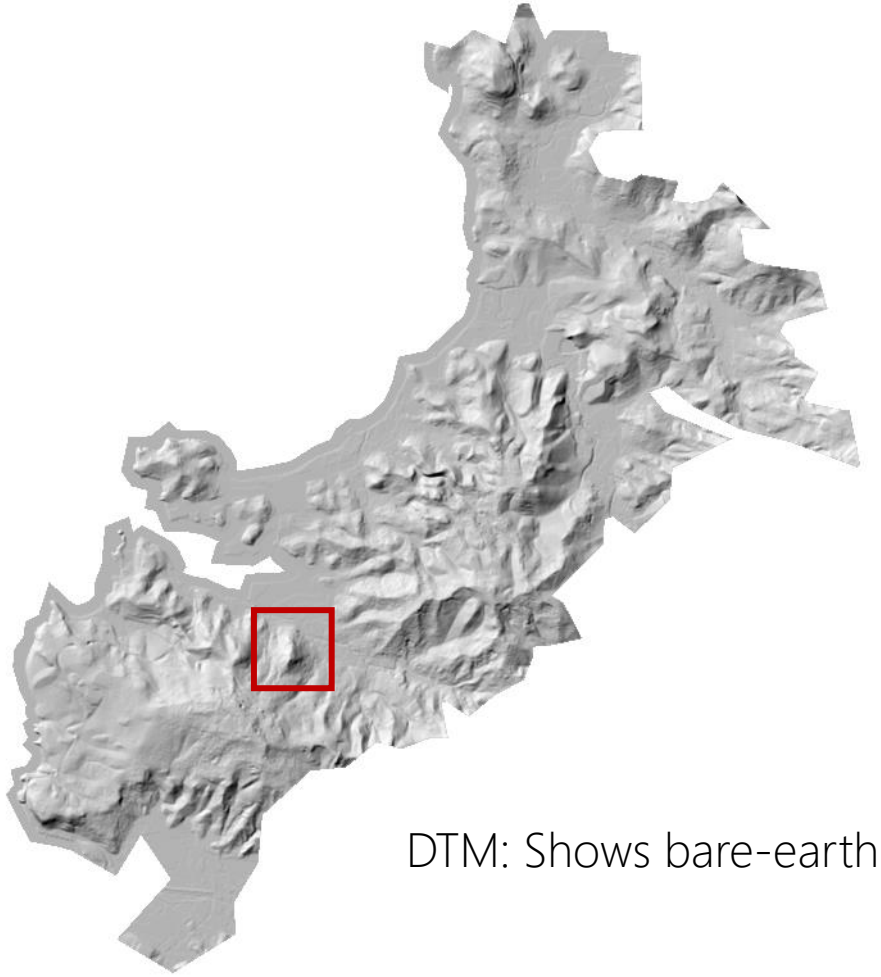
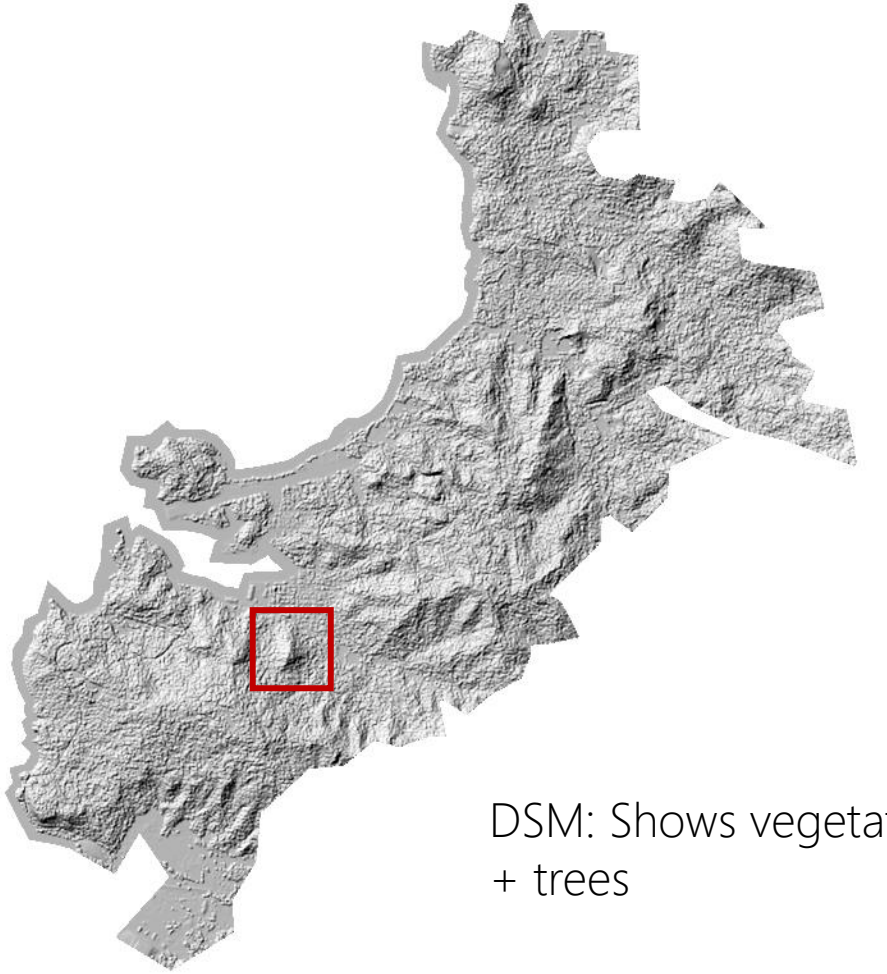
*DTM: Digital Terrain Model, DSM: Digital Surface Model

Shading: DSM vs DTM

Castries, St. Lucia, derived from Digital Globe polar orbiting Satellite



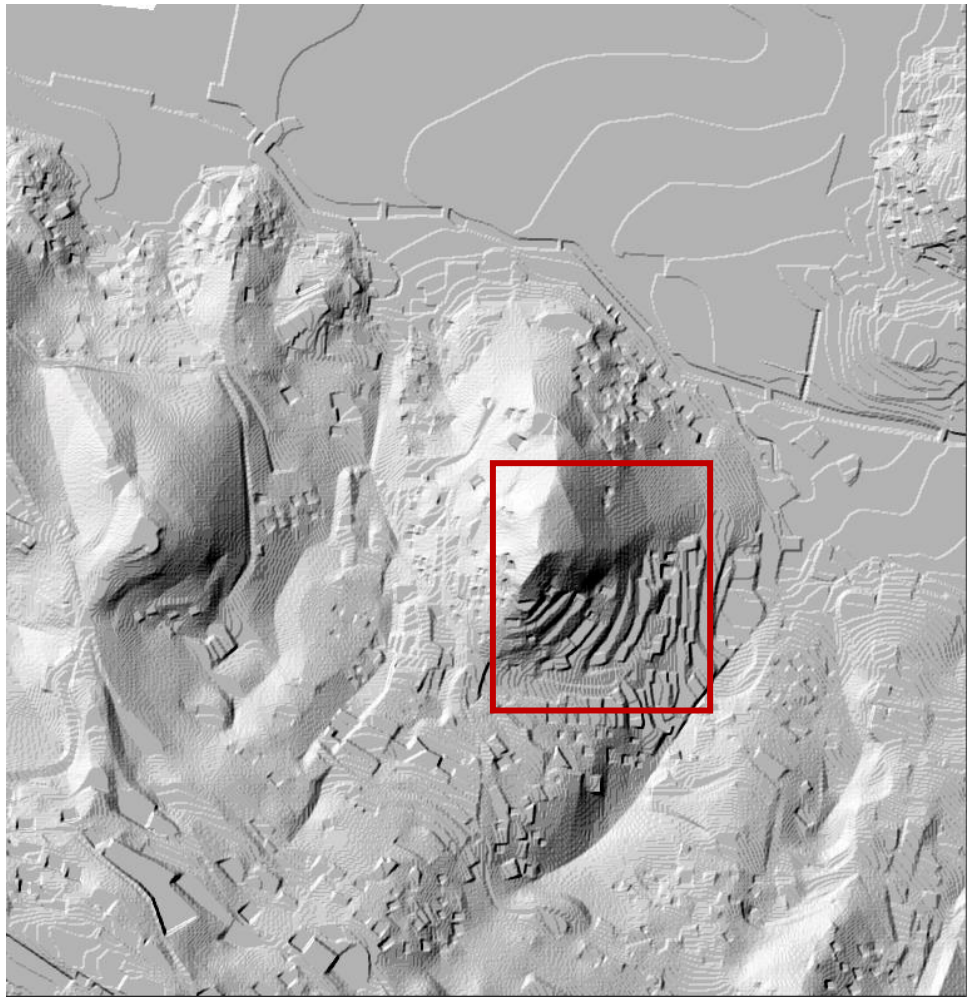
DTM: Shows bare-earth

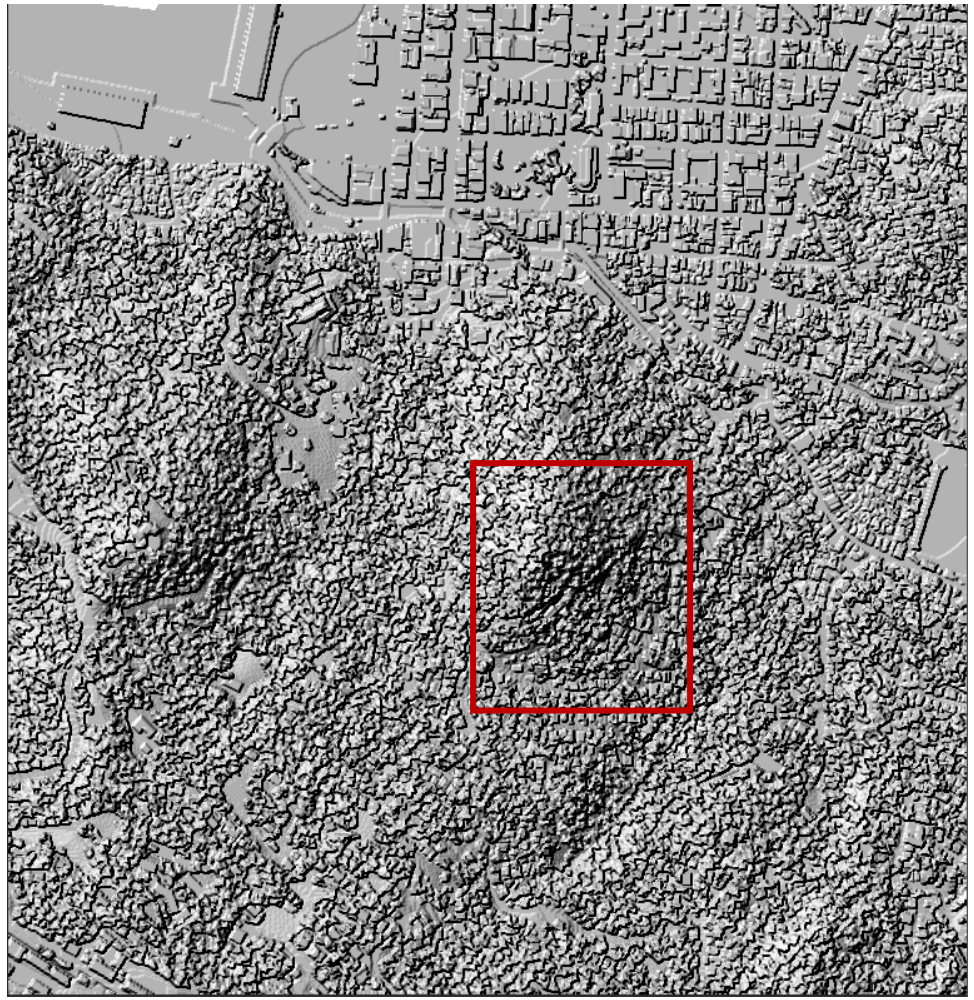


DSM: Shows vegetation + trees

Shading: DSM vs DTM

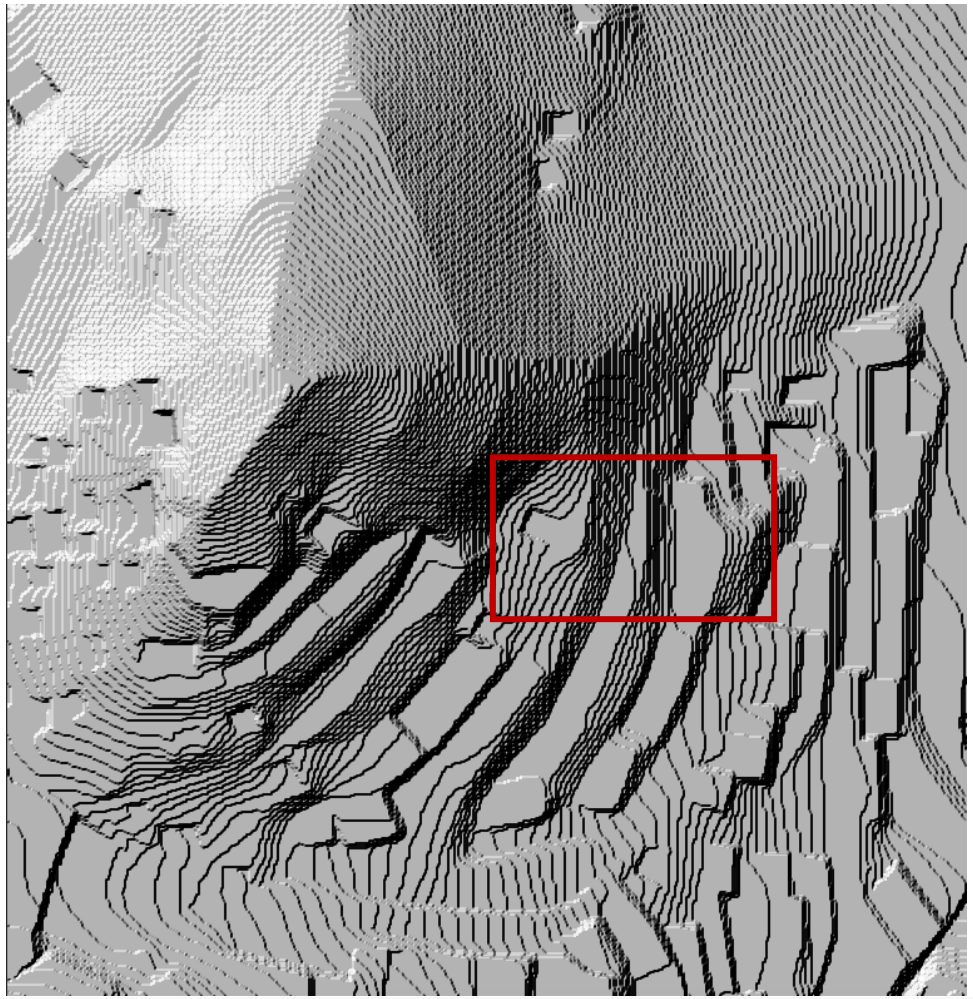
Castries, St. Lucia

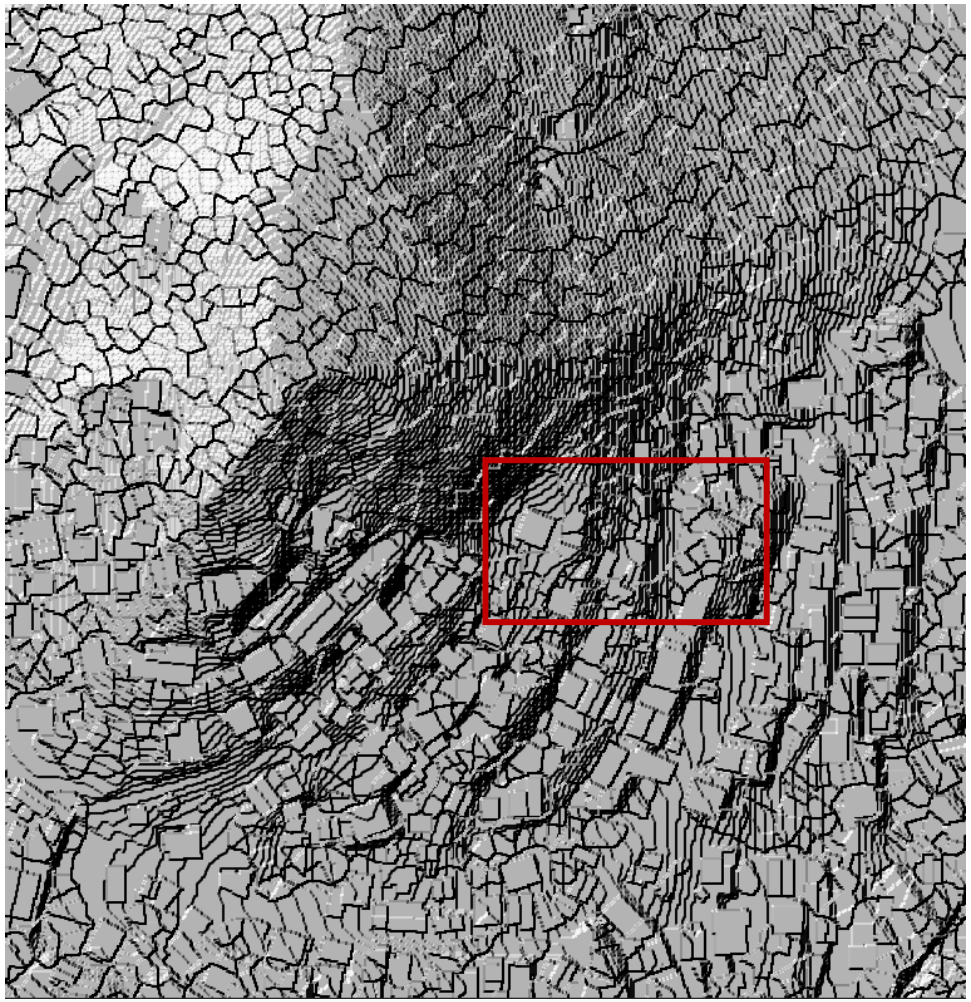




Shading: DSM vs DTM

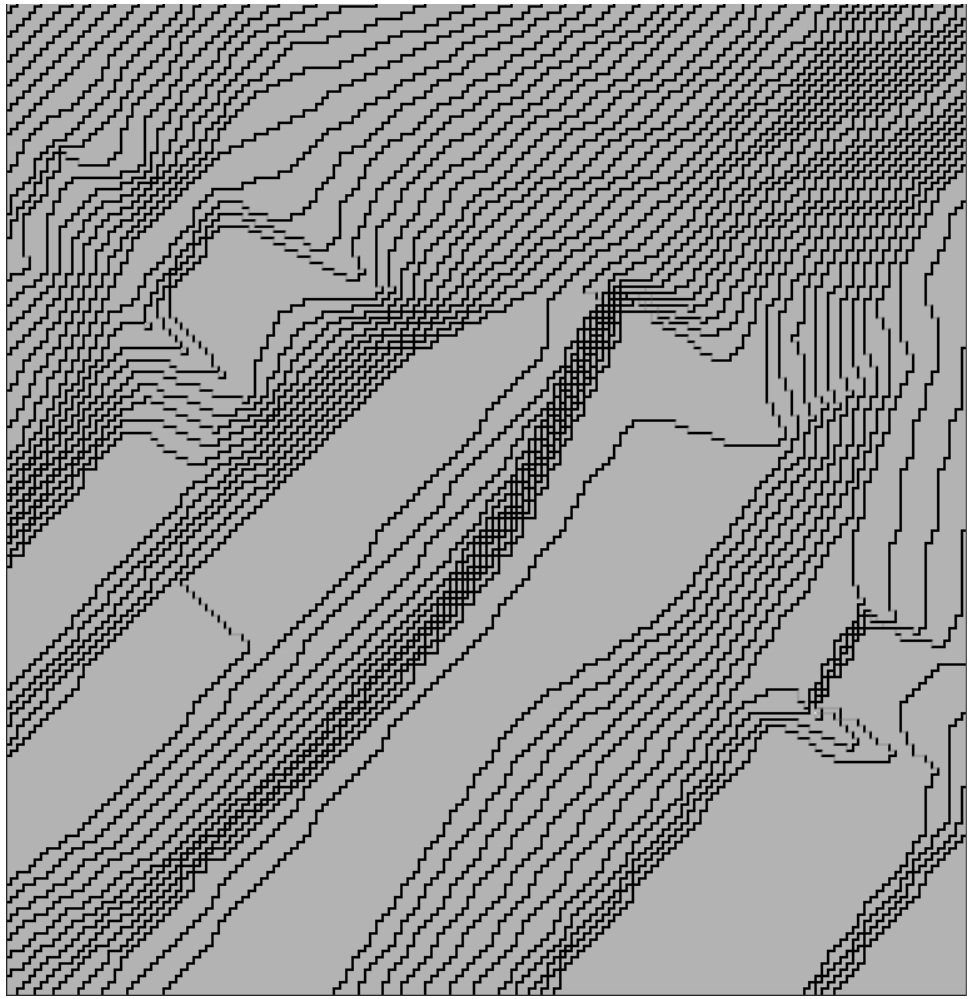
Castries, St. Lucia

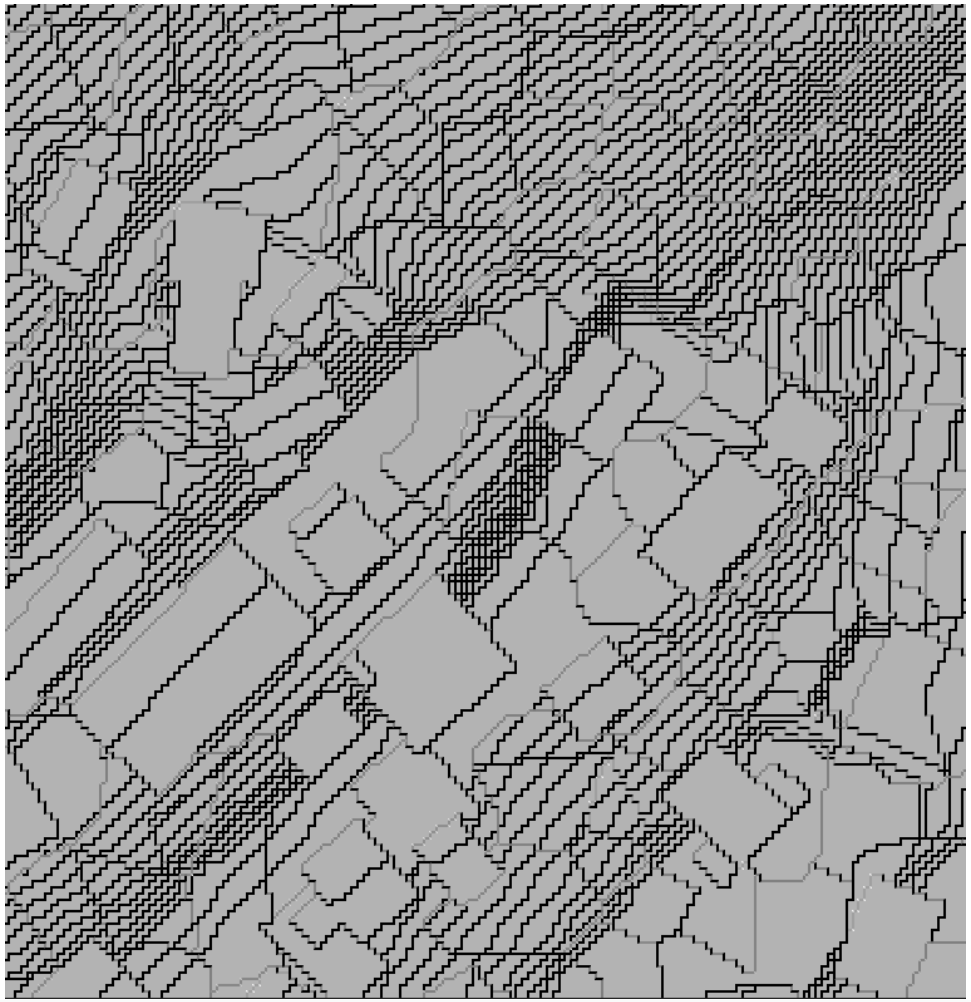




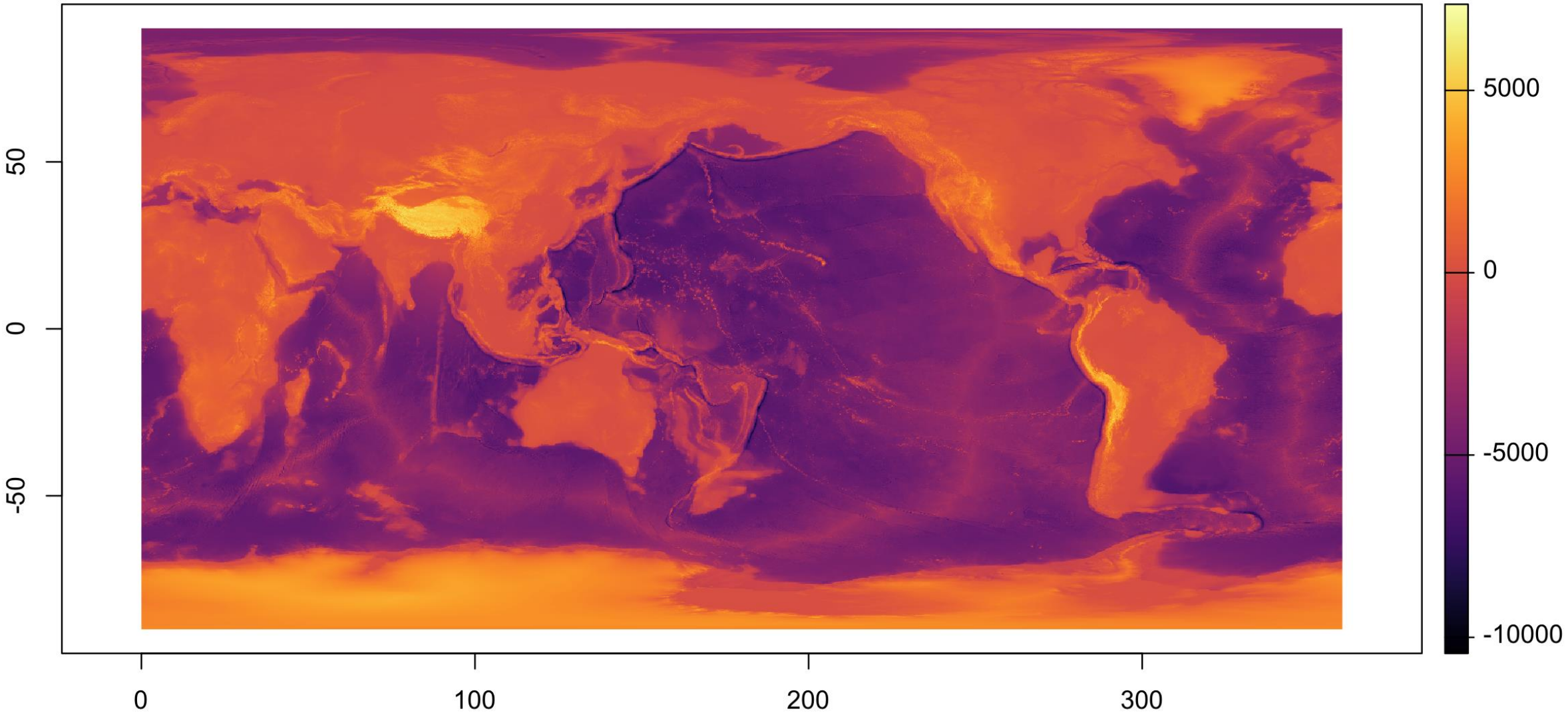
Shading: DSM vs DTM

Castries, St. Lucia



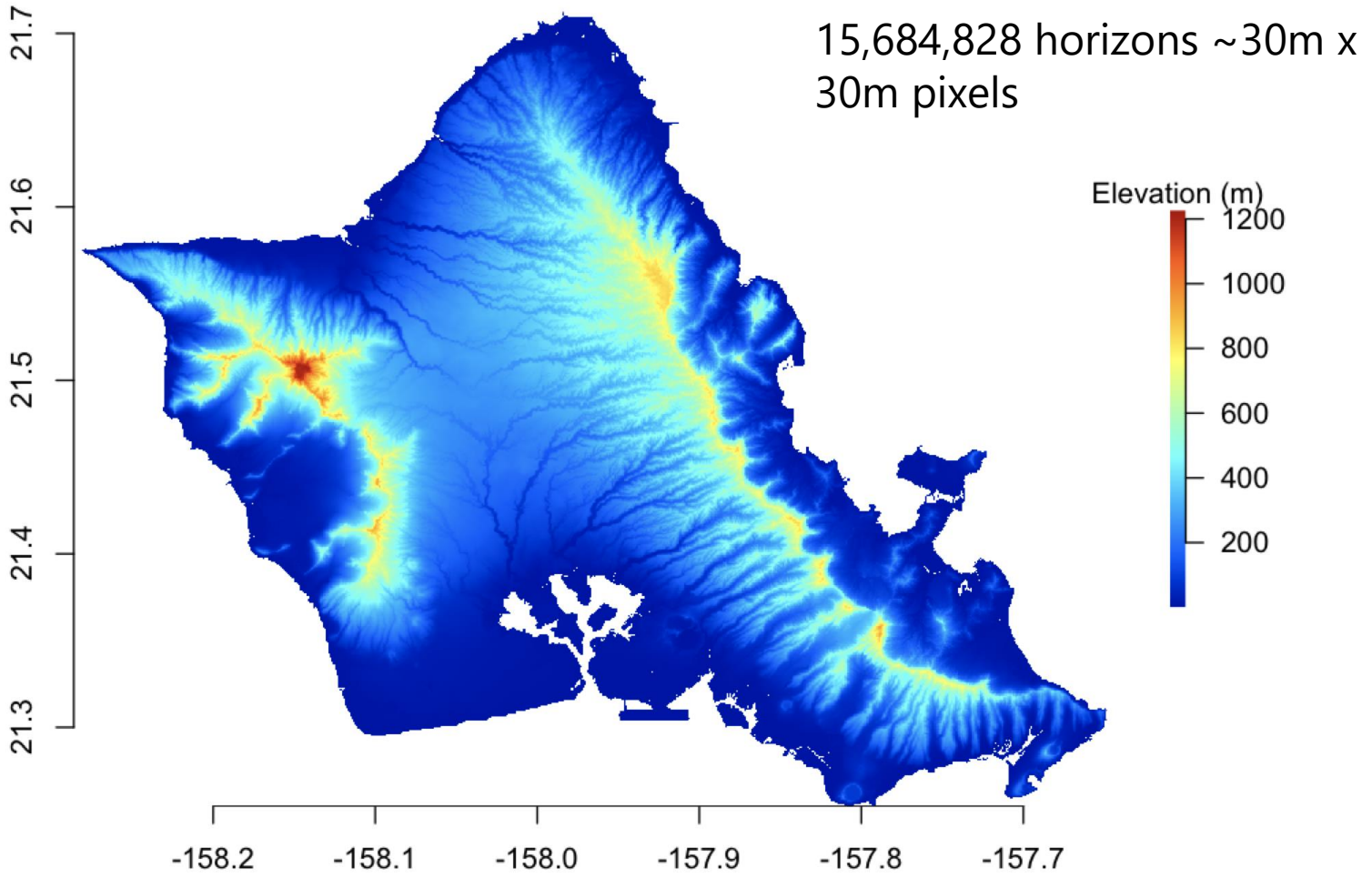


Derivation of Horizons Globally from ASTER at 1 arc second

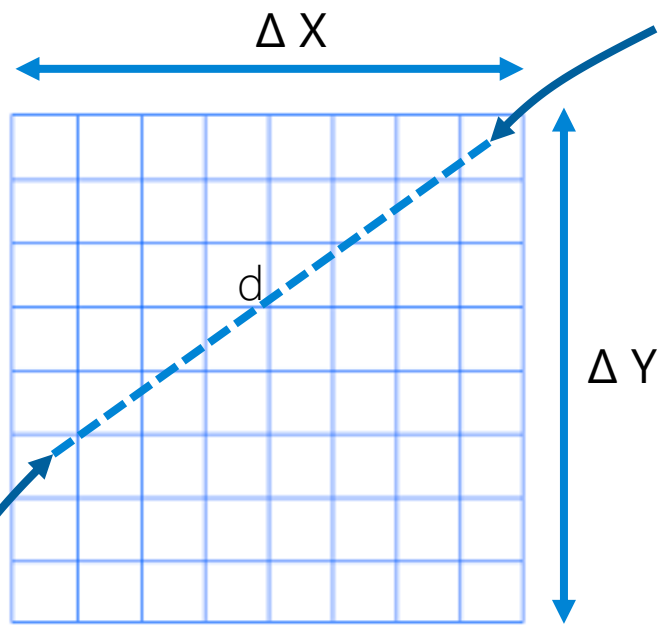


Case Study for calculating such horizons and assessing their impacts

OAHU @ 1 arc-second resolution



We use simple trig to calculate horizons in 1° azimuthal angle increments



P_1: X_1 = 8 , Y_1=8 , H_1=10

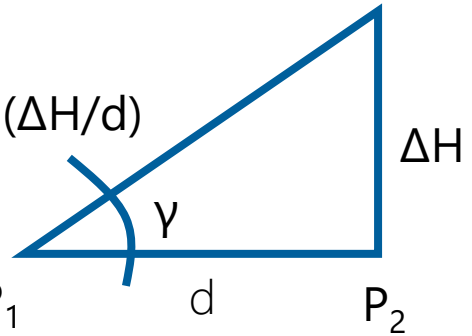
P_2: X_2 = 1 , Y_1=3 , H_1=1

DSM

UTM : Universe Transverse Mercator projection

Δ X = Δ Y

Cell size is uniform in m



$$a = \sin^2(\Delta\varphi/2) + \cos\varphi_1 \cdot \cos\varphi_2 \cdot \sin^2(\Delta\lambda/2)$$

$$c = 2 \cdot \operatorname{atan2}(\sqrt{a}, \sqrt{(1-a)})$$

$$d = R \cdot c$$

d = haversine(P_1, P_2)

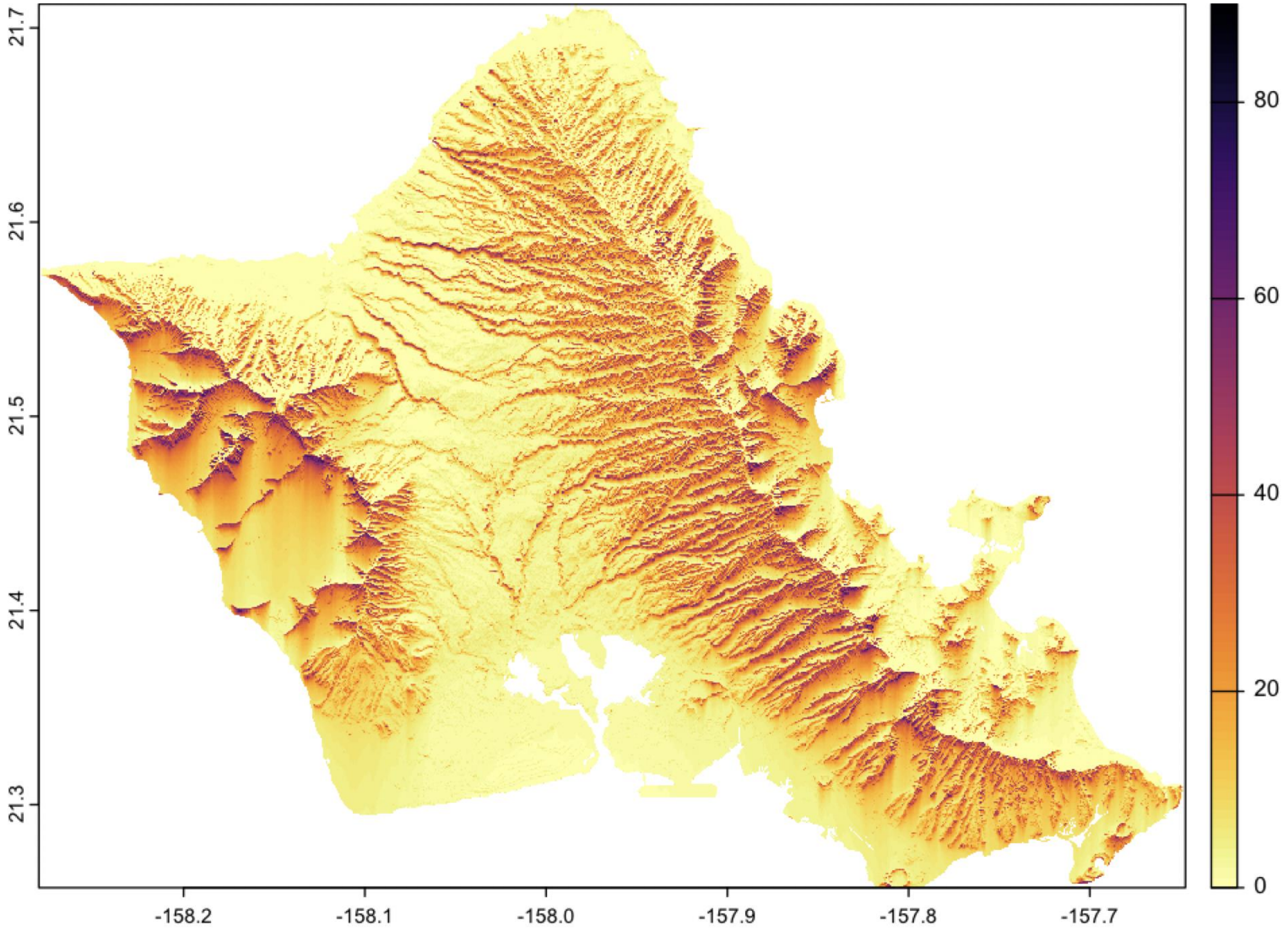
نصیرالدین طوسی

Nasīr al-Dīn Tūsī

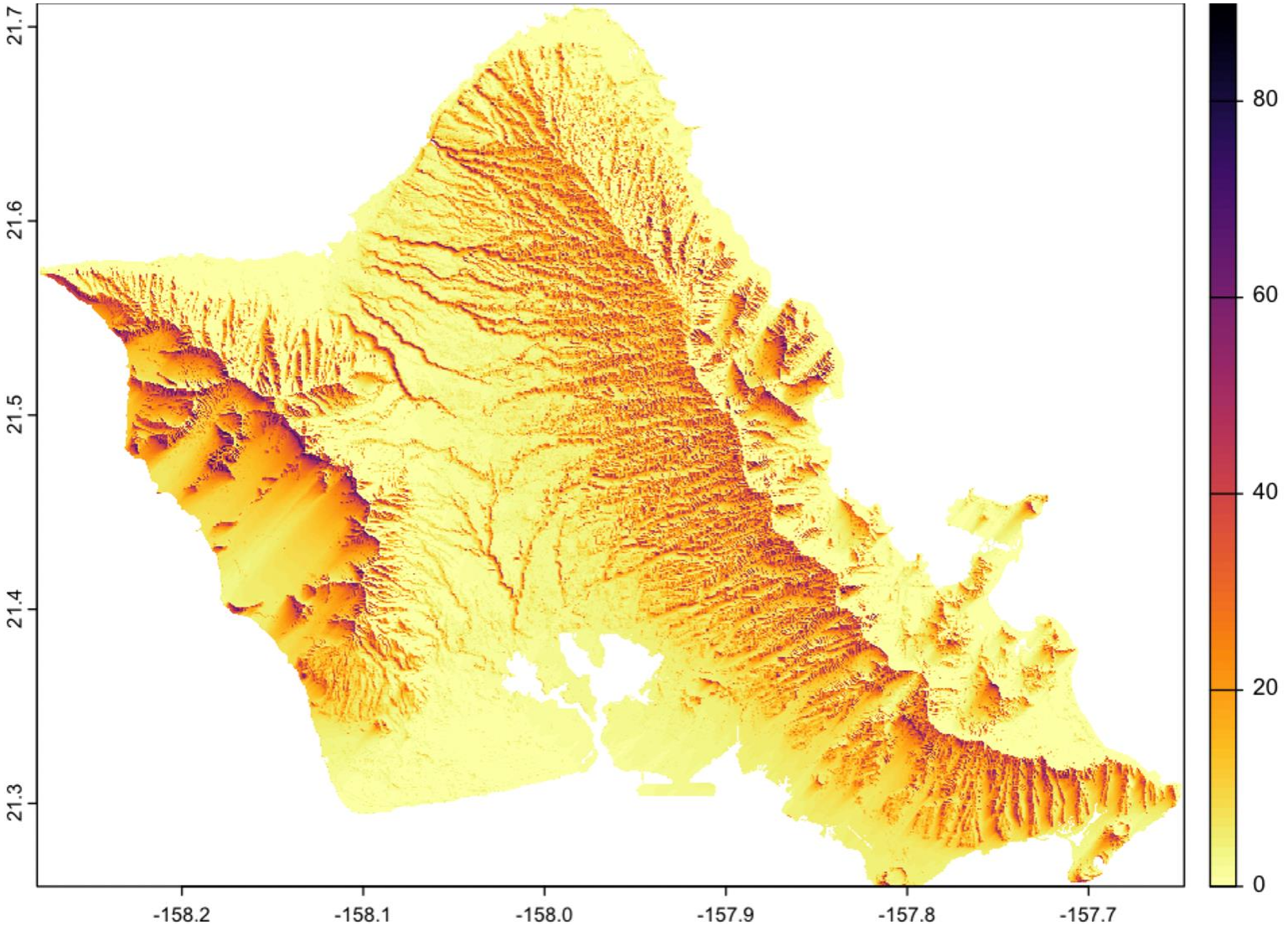
Discoverer of the law of tangents

c. ~1230, Persia

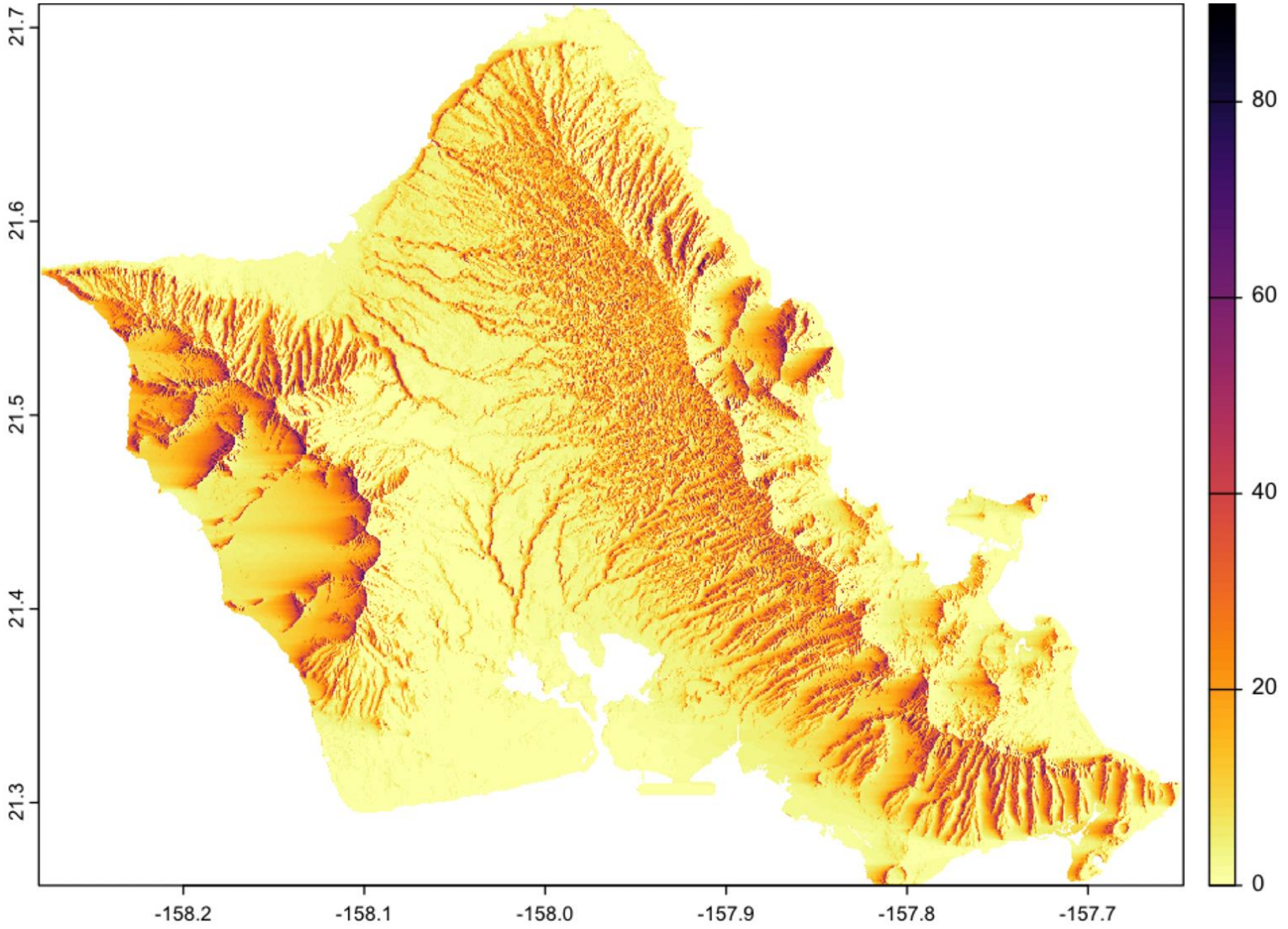
16M horizon angles when looking due North



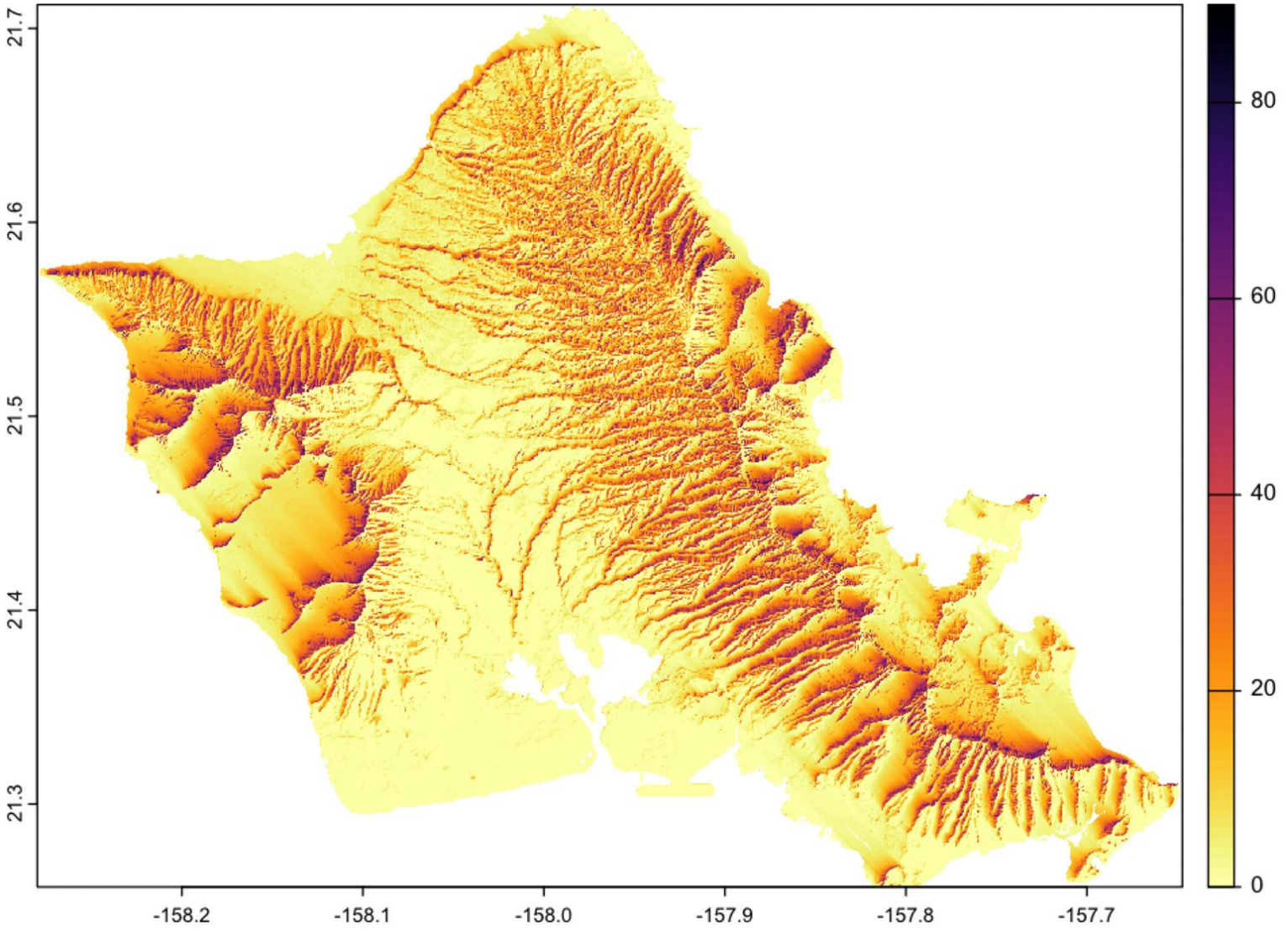
Northeast



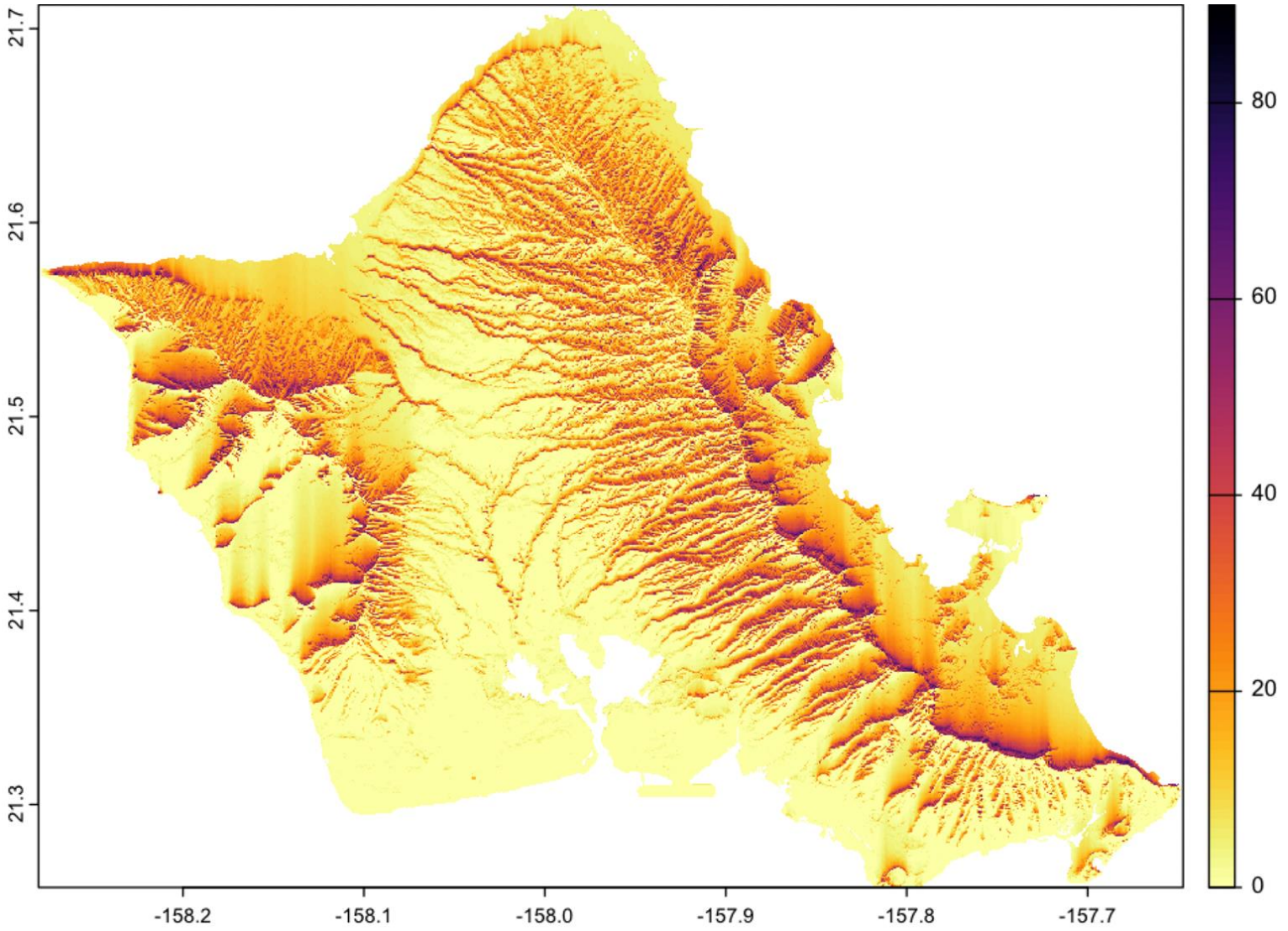
East



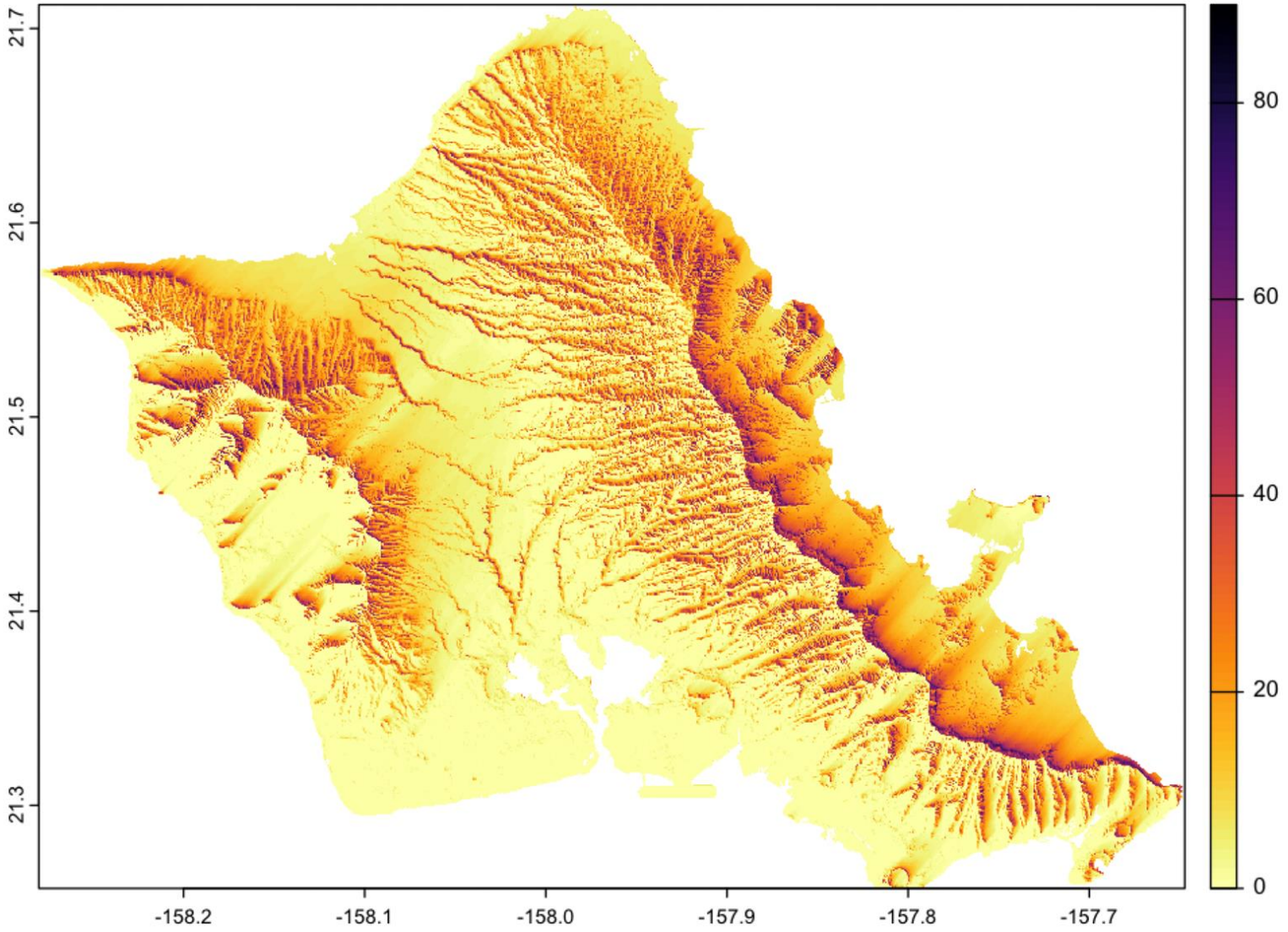
Southeast



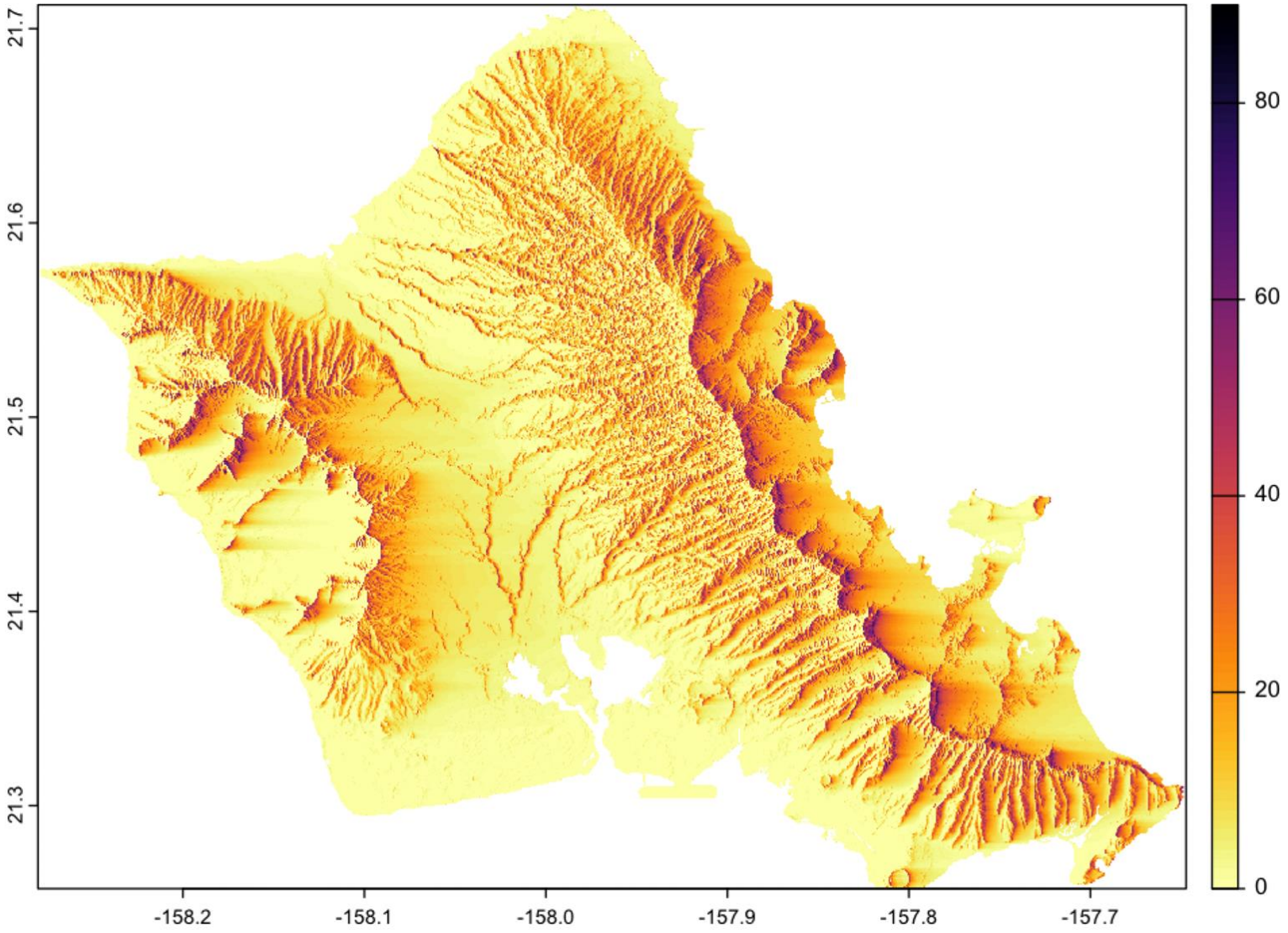
South



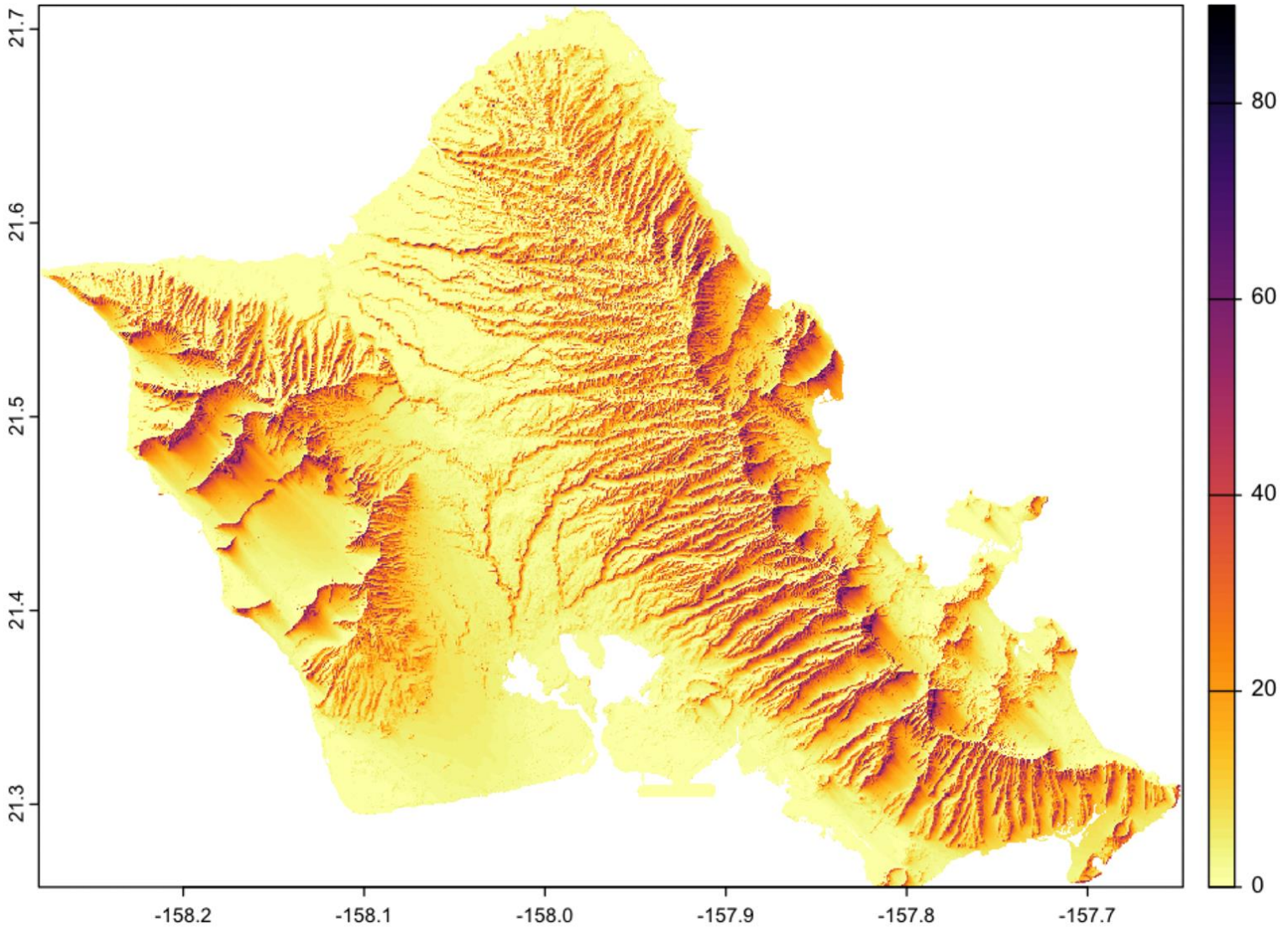
Southwest



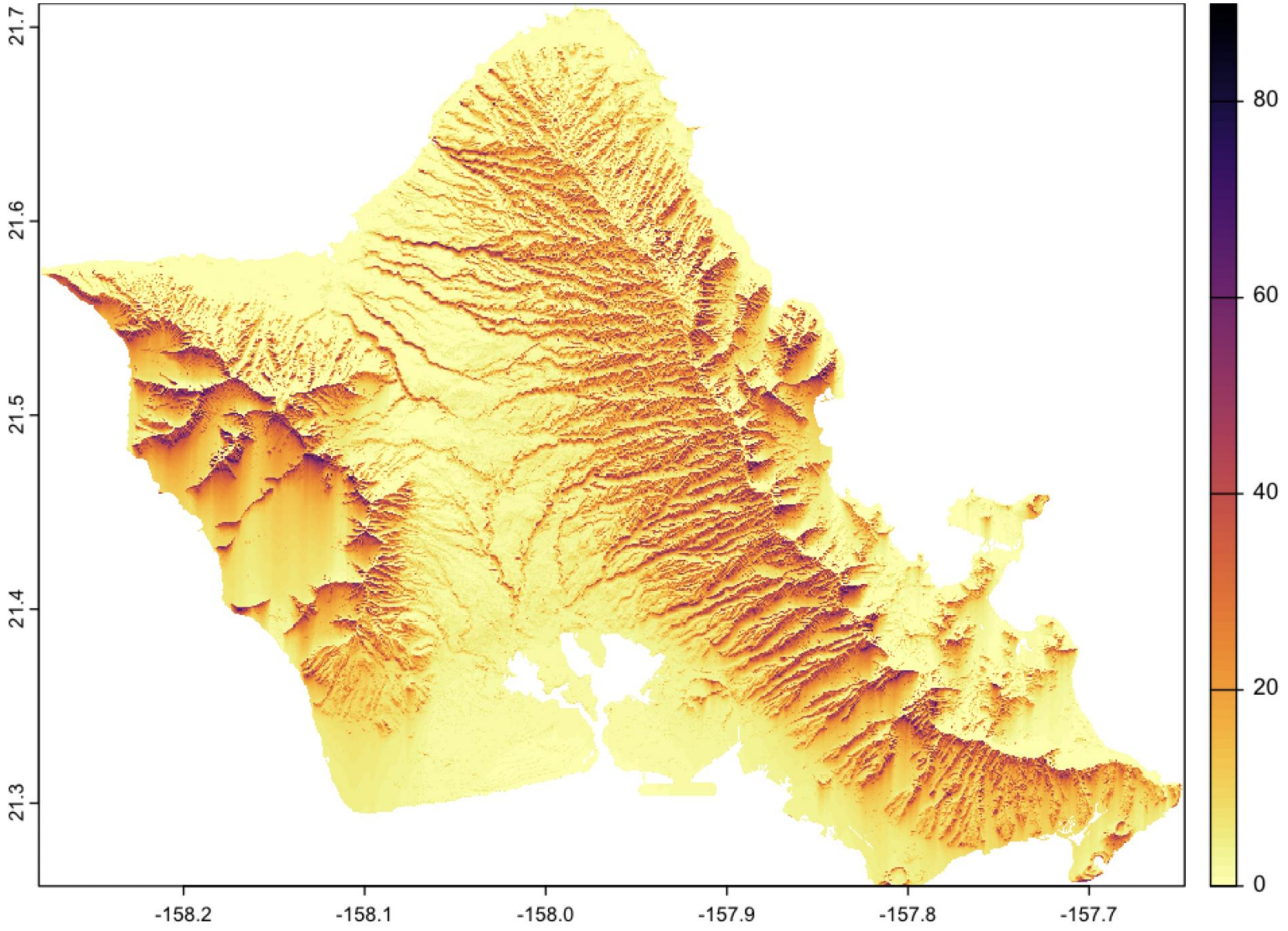
West



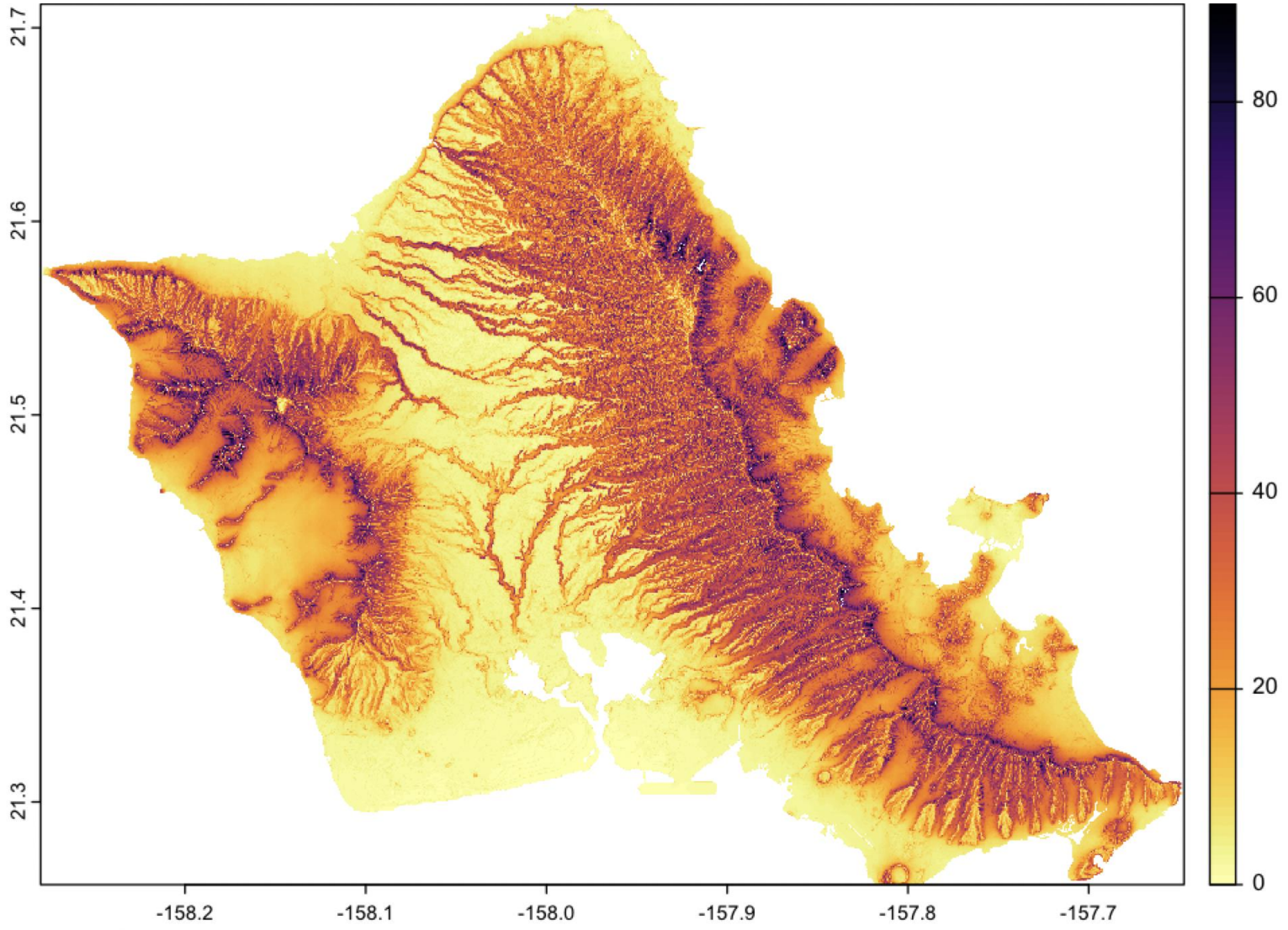
Northwest



North

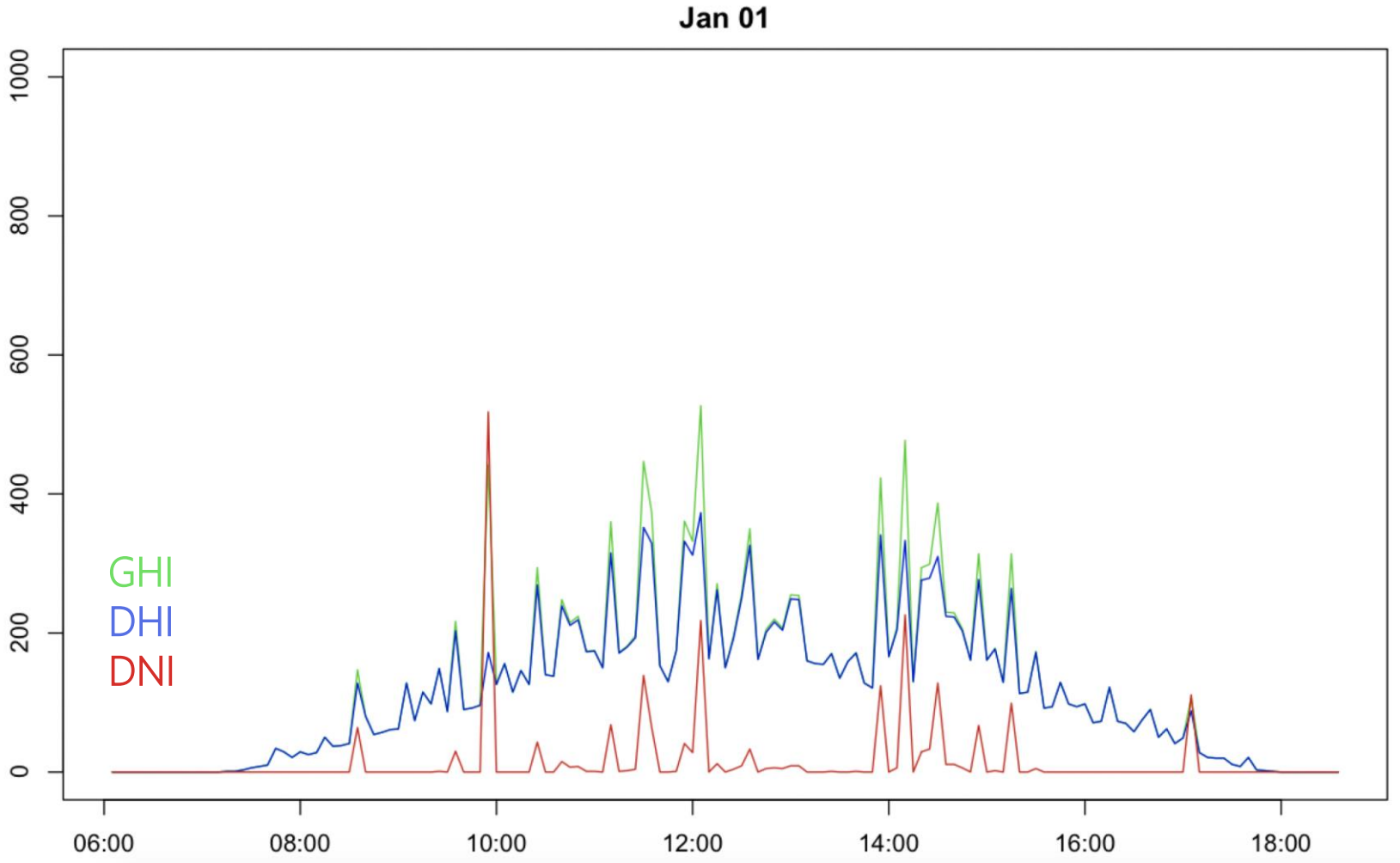


Average Horizon Angle in all directions



How do horizons impact irradiance TS?

Raw Data @ 500m / 5min from SolarAnywhere



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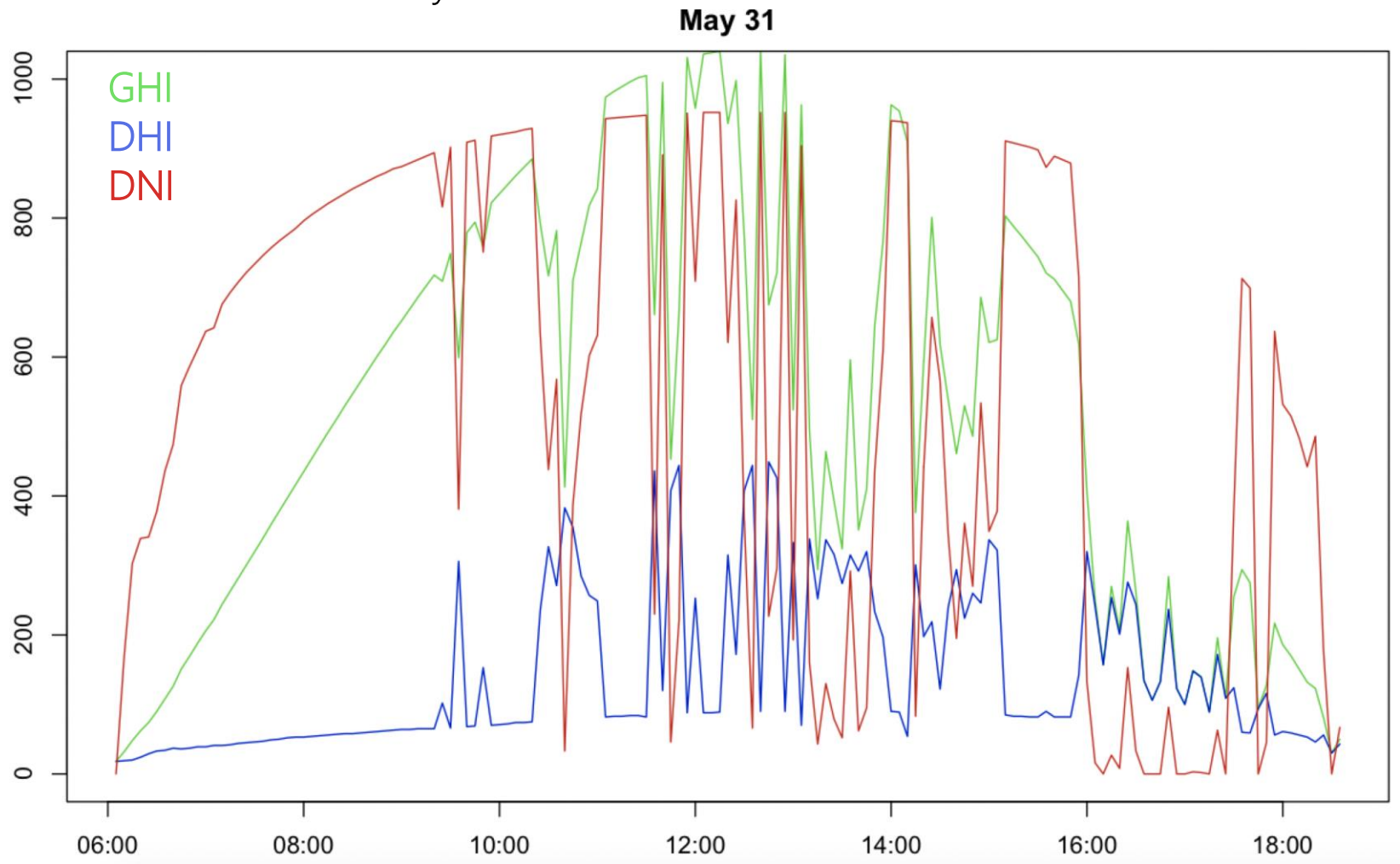
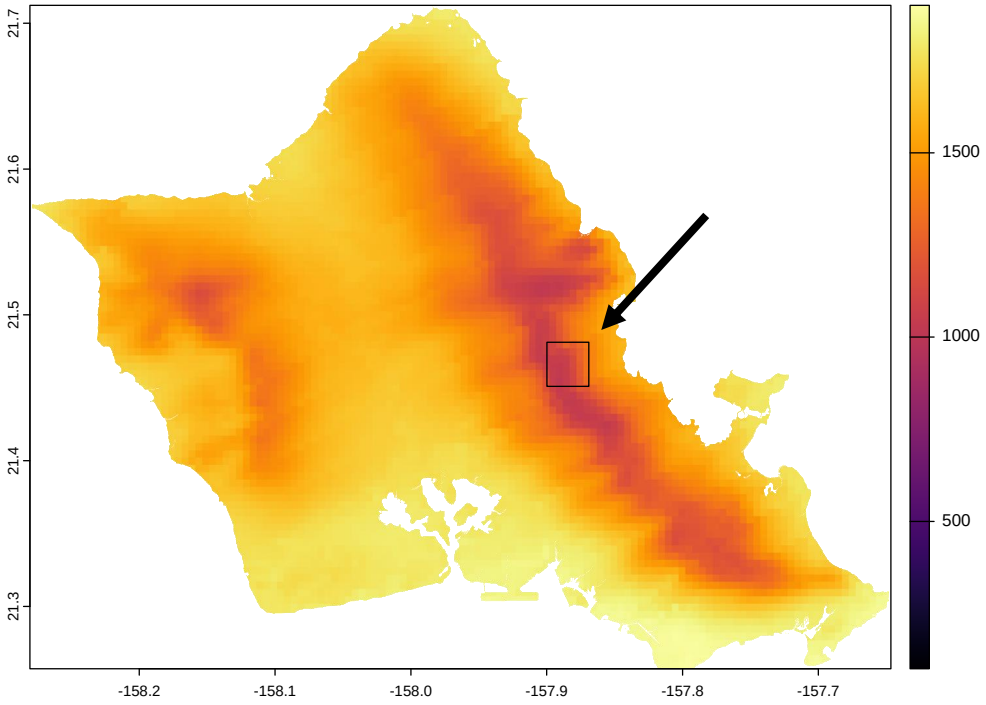
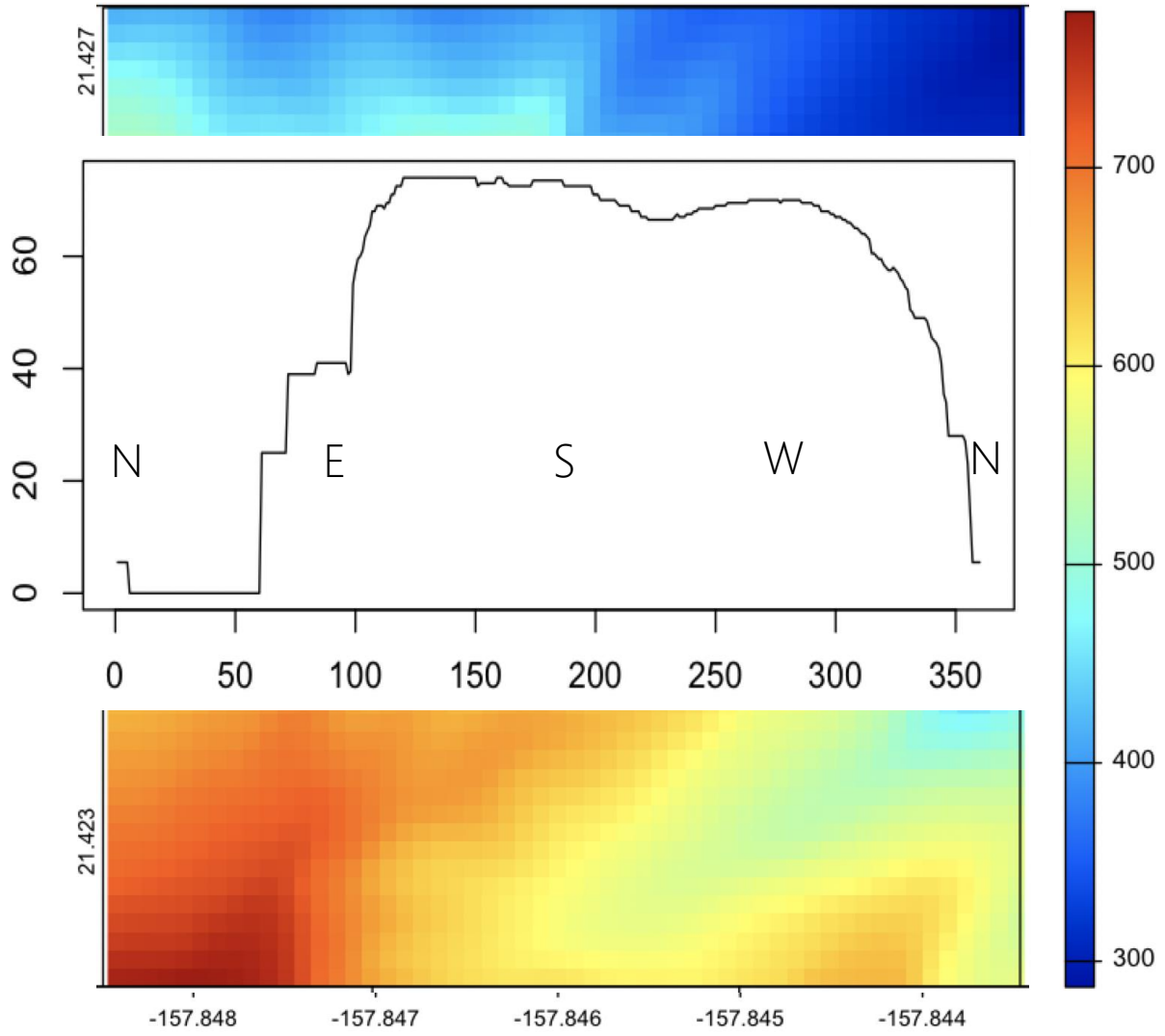
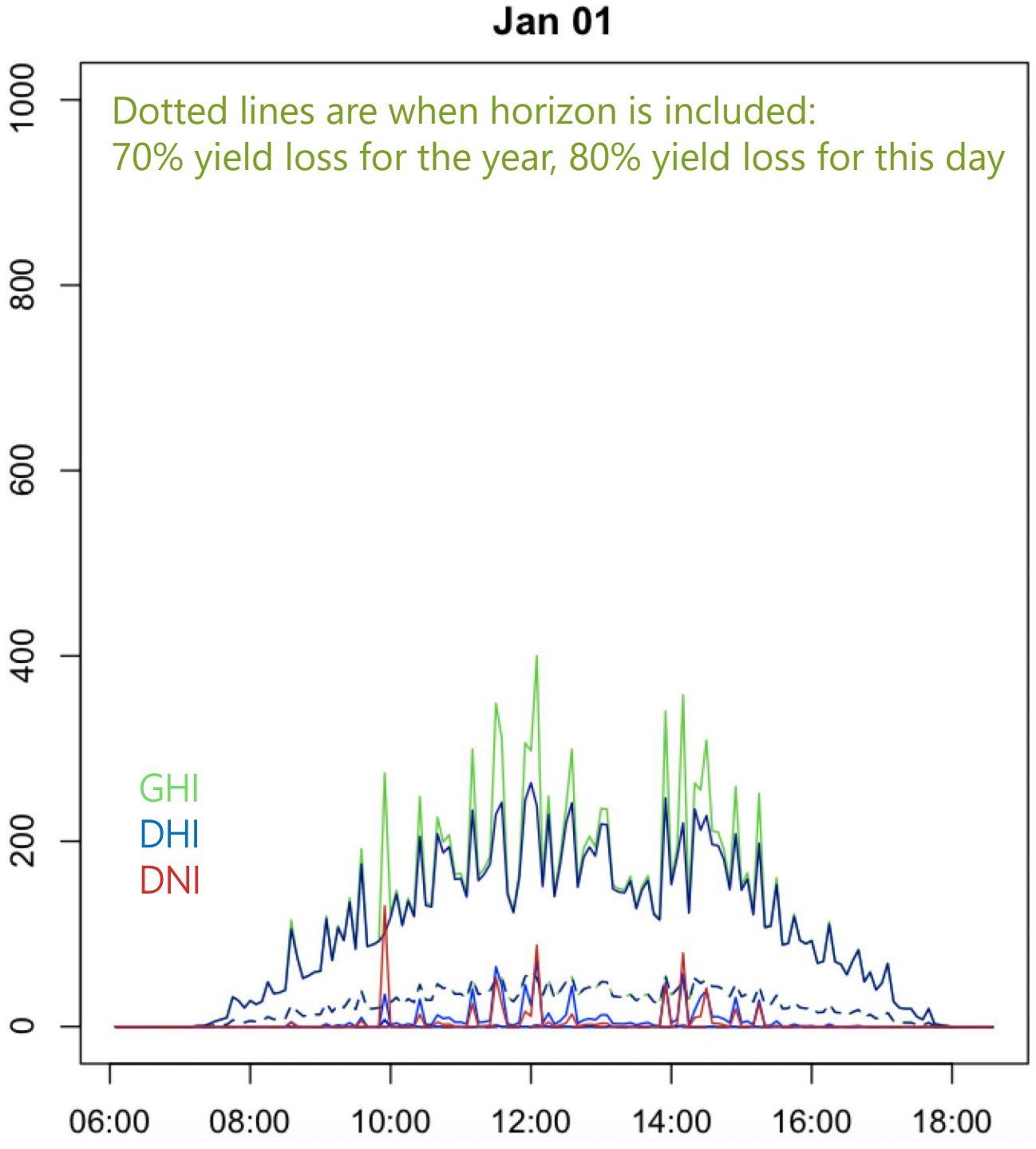
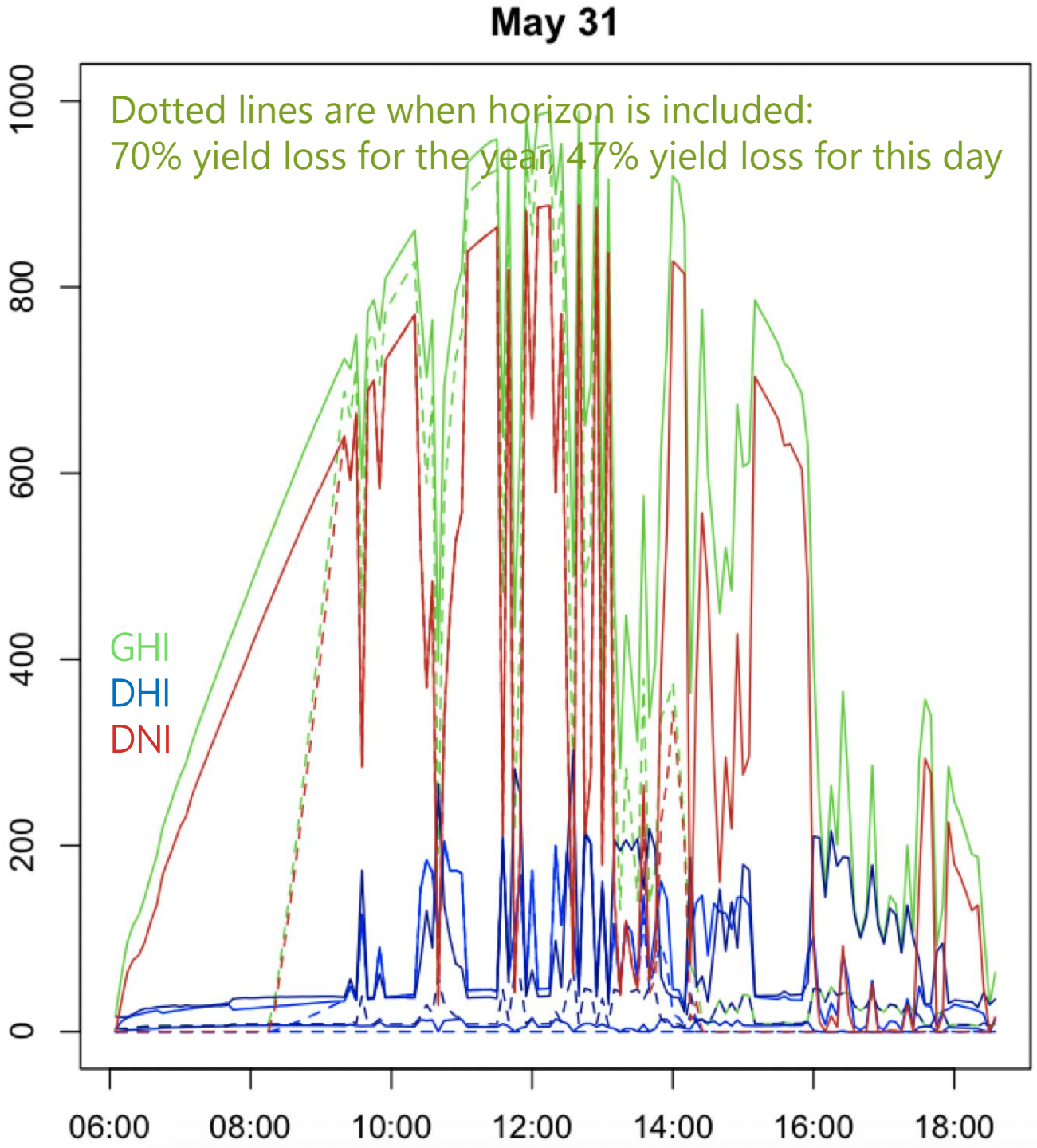


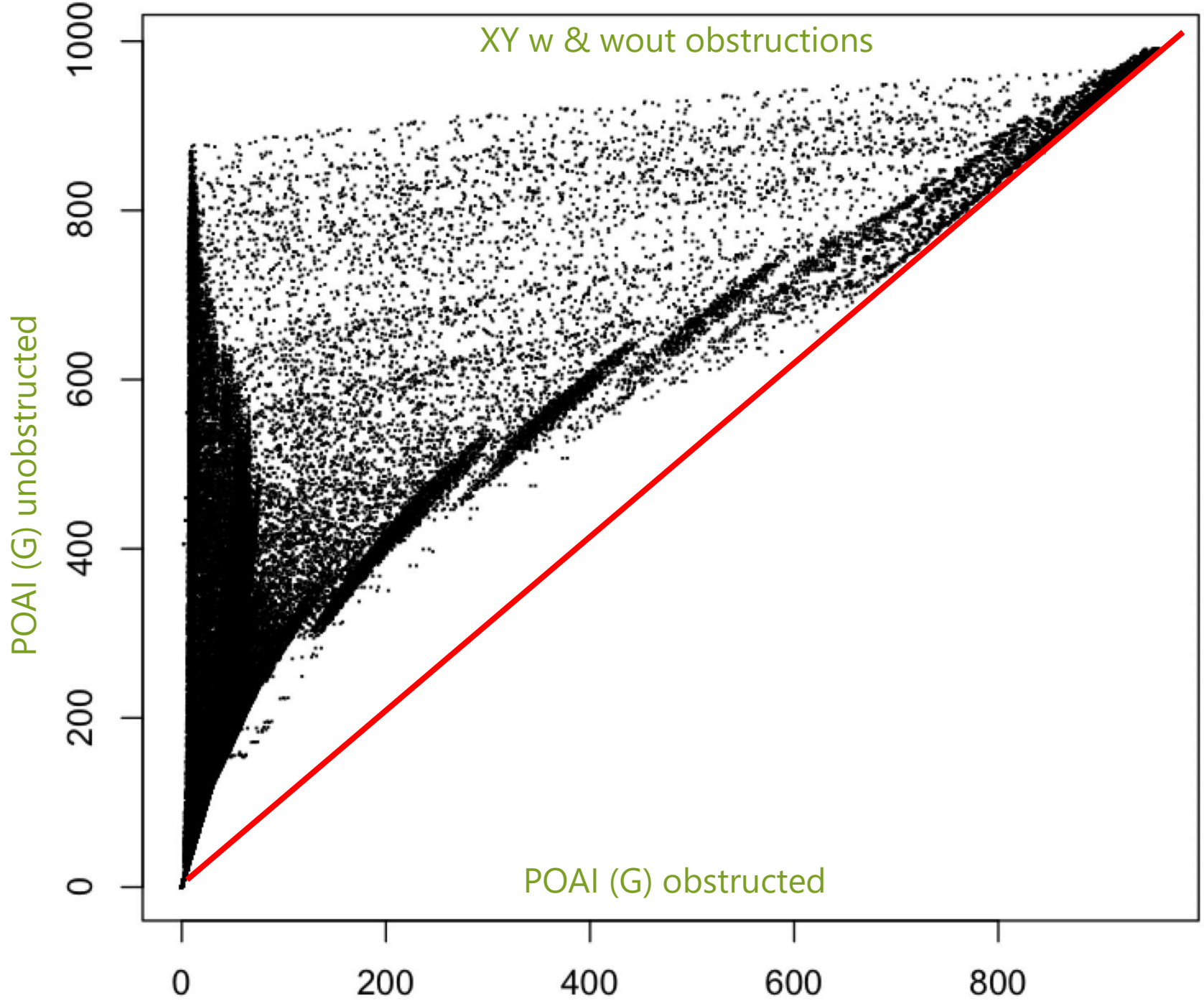
Take an extreme horizon just beneath a cliff on the eastern side of Hawaii

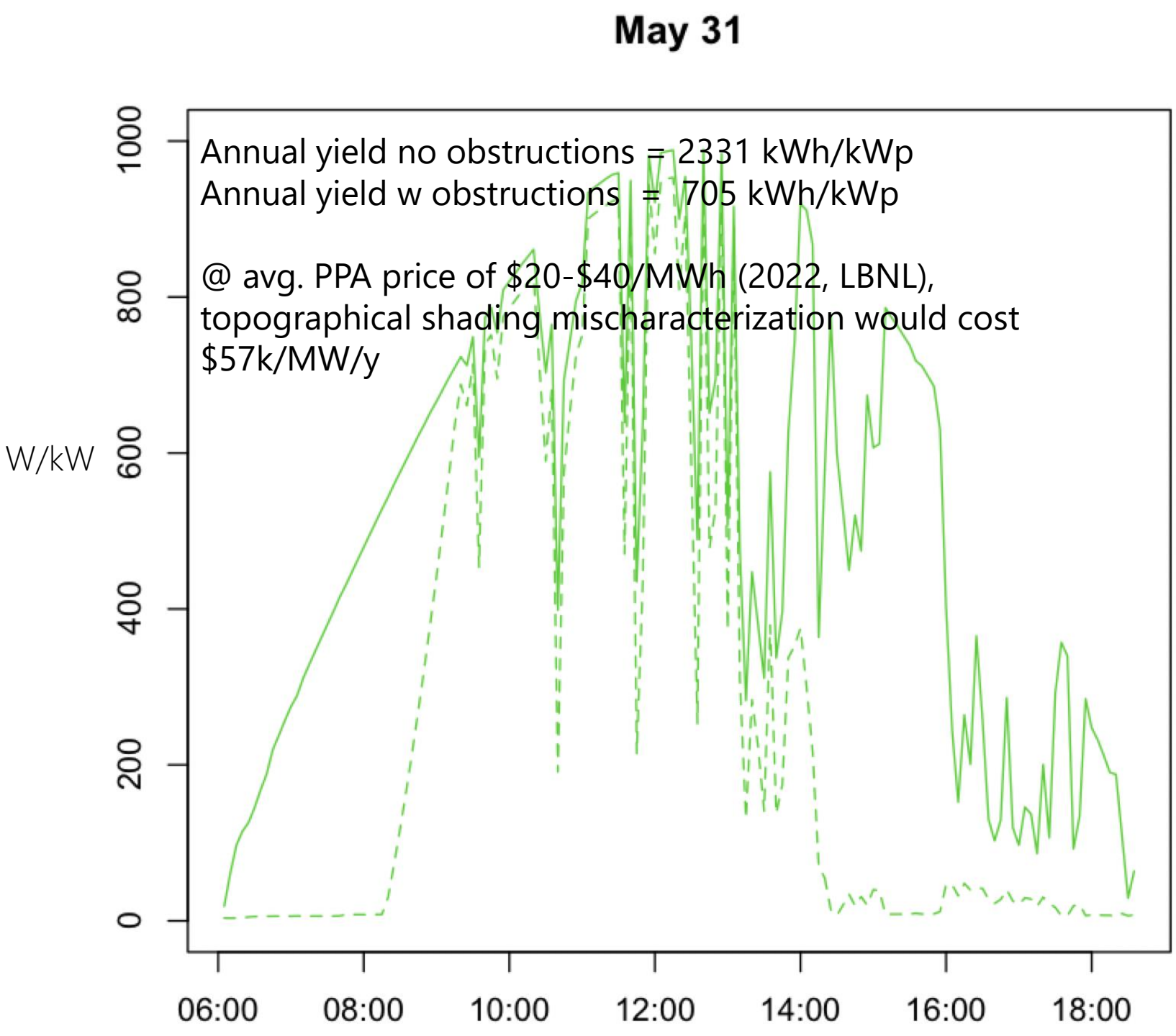





Jan 01
Dotted lines are when horizon is included:
70% yield loss for the year, 80% yield loss for this day
GHI
DHI
DNI
0
200
400
600
800
1000
06:00
08:00
10:00
12:00
14:00
16:00
18:00

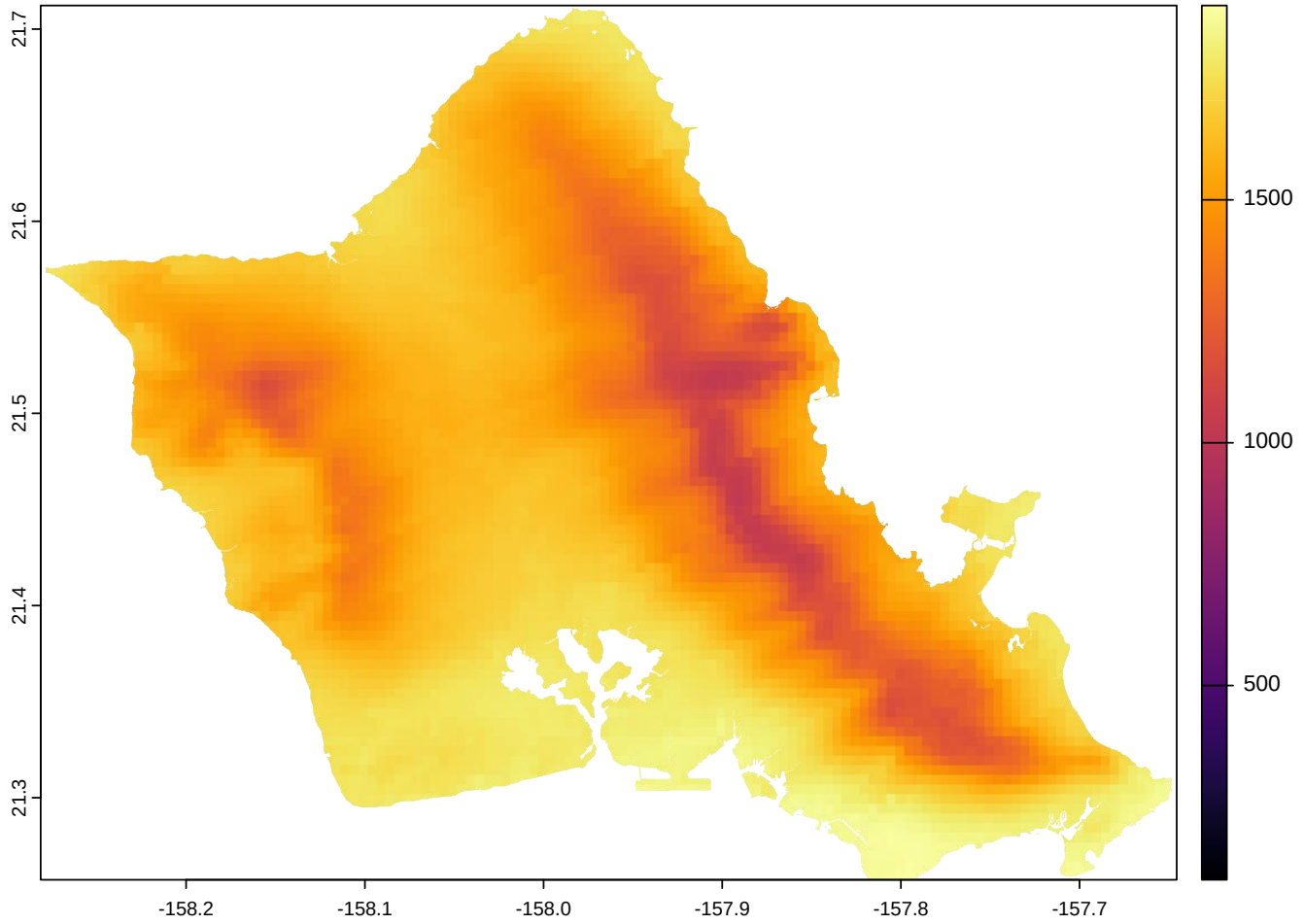

May 31
Dotted lines are when horizon is included:
70% yield loss for the year, 47% yield loss for this day
GHI
DHI
DNI
0
200
400
600
800
1000
06:00
08:00
10:00
12:00
14:00
16:00
18:00


XY w & wout obstructions
POAI (G) unobstructed
POAI (G) obstructed
0
200
400
600
800
1000
0
200
400
600
800

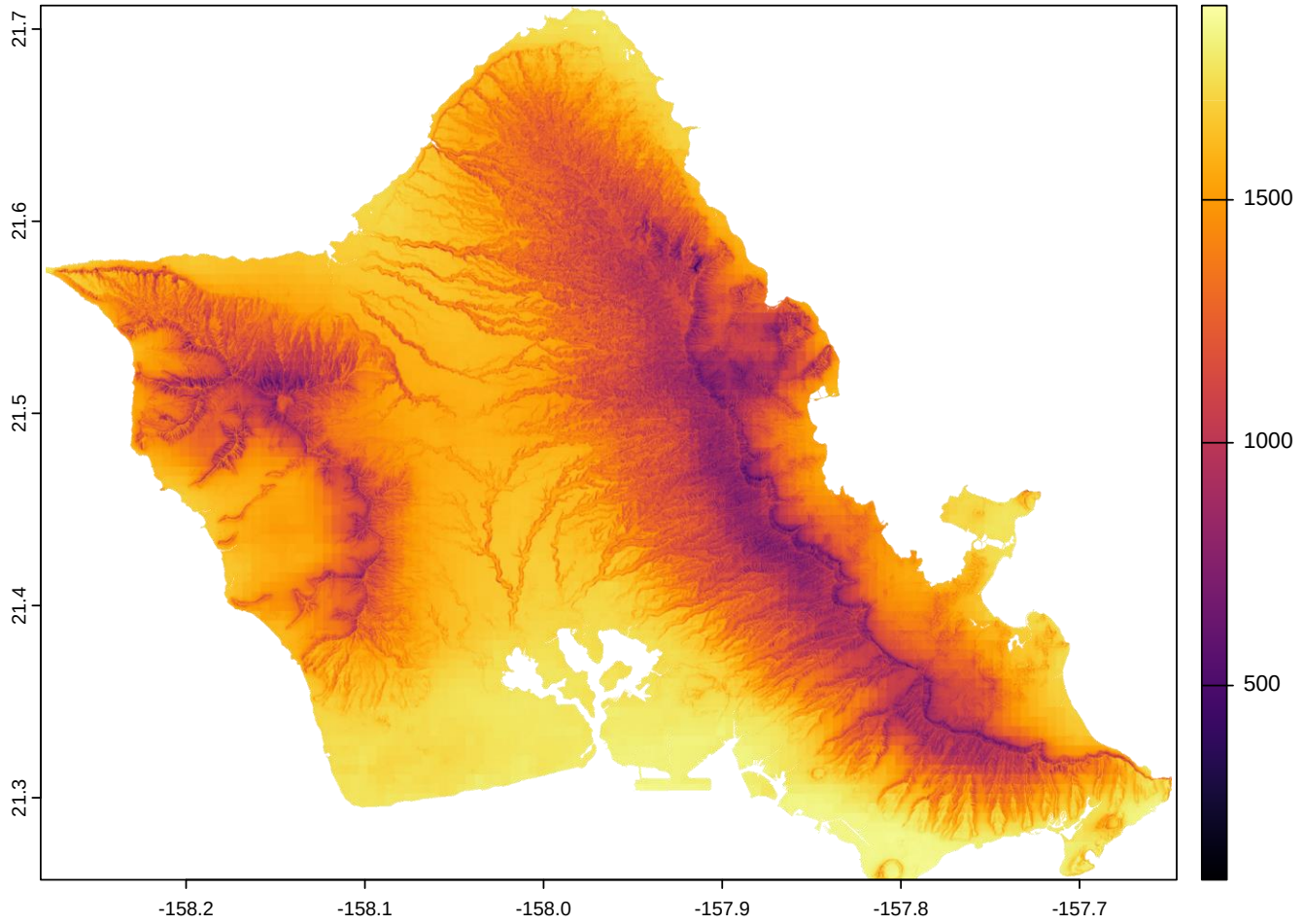

May 31
Annual yield no obstructions = 2331 kWh/kWp
Annual yield w obstructions = 705 kWh/kWp
@ avg. PPA price of $20-$40/MWh (2022, LBNL), topographical shading mischaracterization would cost $57k/MW/y
W/kW
0
200
400
600
800
1000
06:00
08:00
10:00
12:00
14:00
16:00
18:00

POAI Latitude Tilt from SolarAnywhere

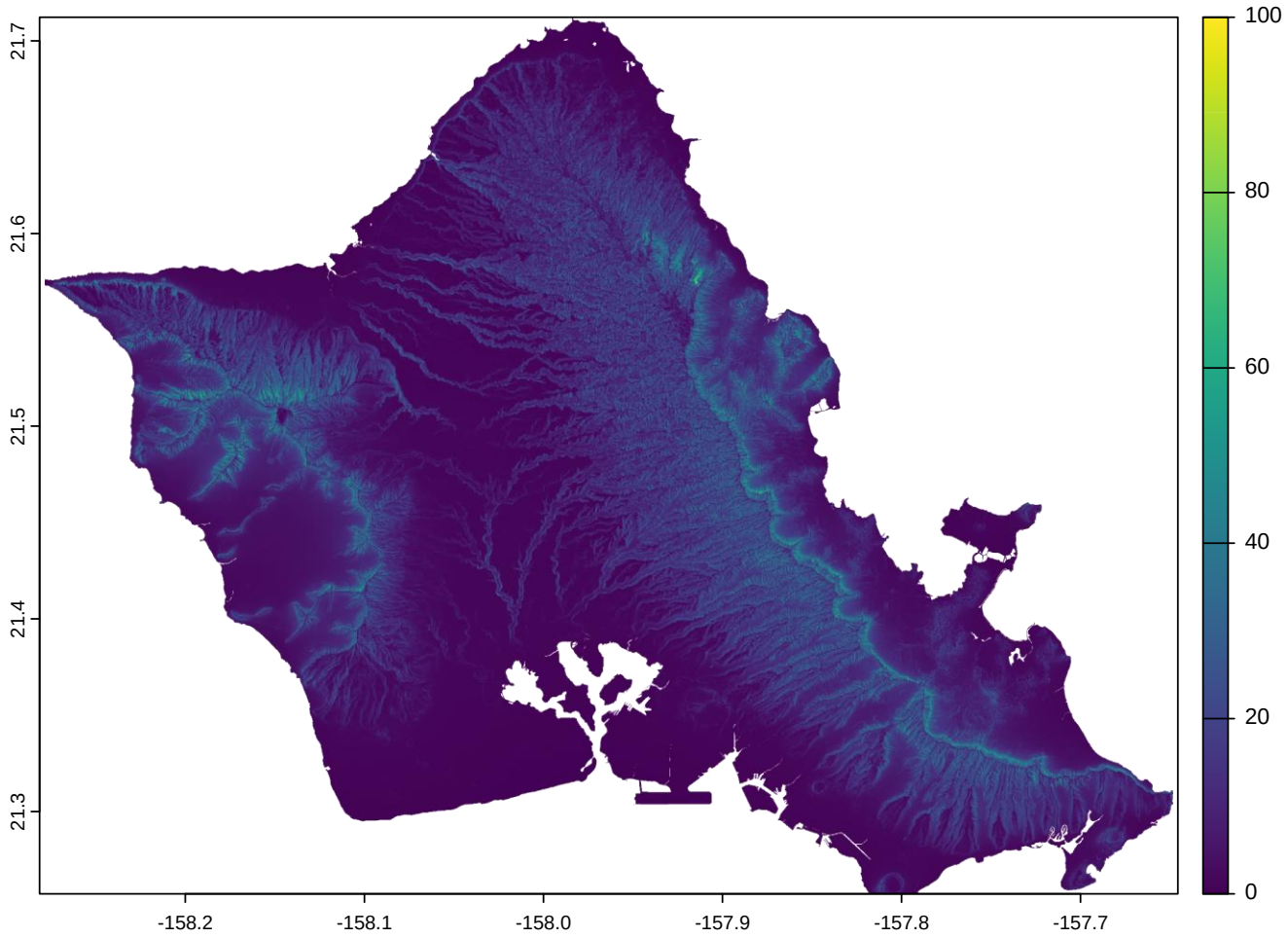
Zoom out to the whole island



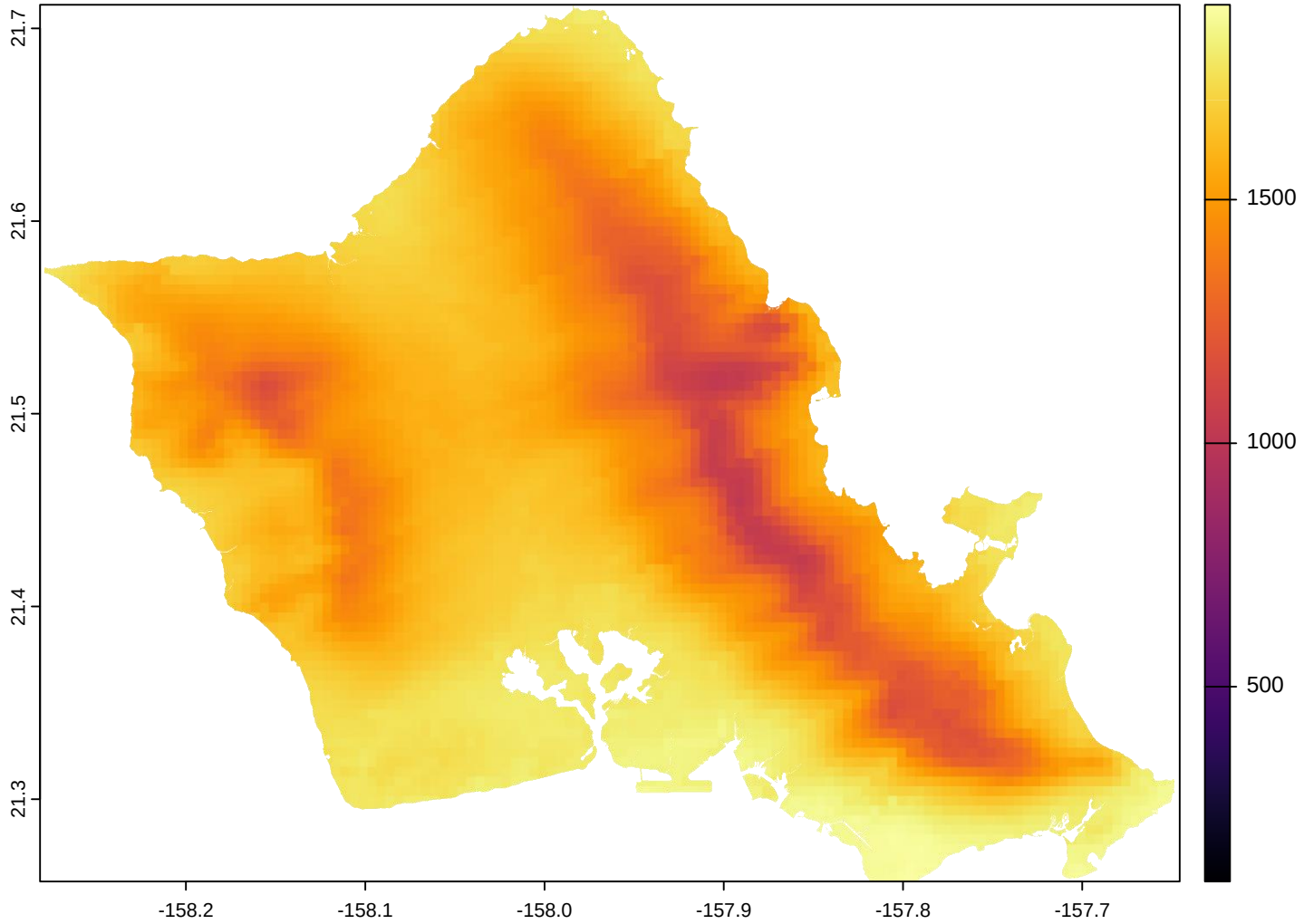
POAI Latitude Tilt from SolarAnywhere + shading



Shading-introduced Bias (SA - SAshadow)/SA



Let's zoom in to a particularly topographical section



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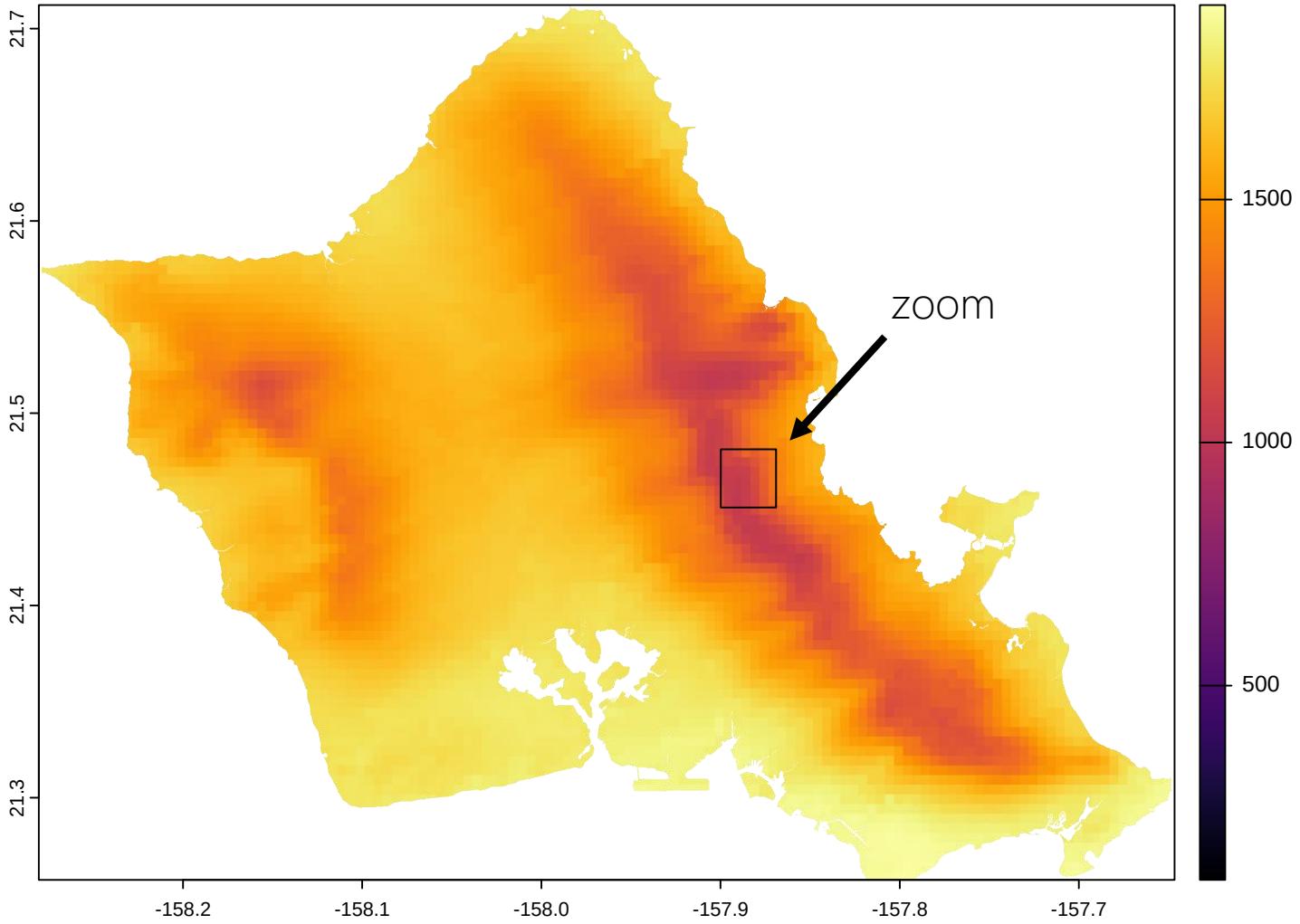
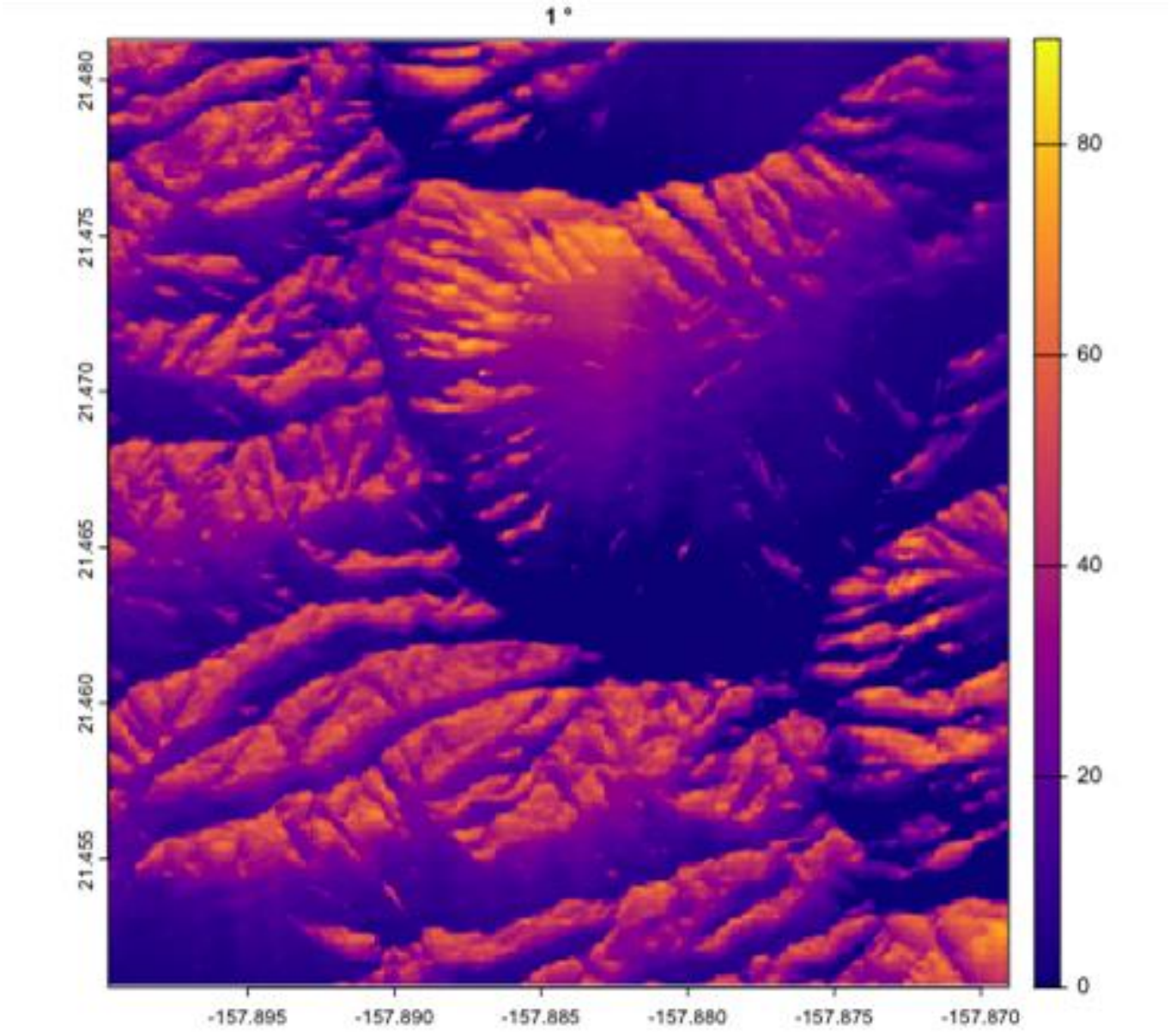


Derived Horizon Angles



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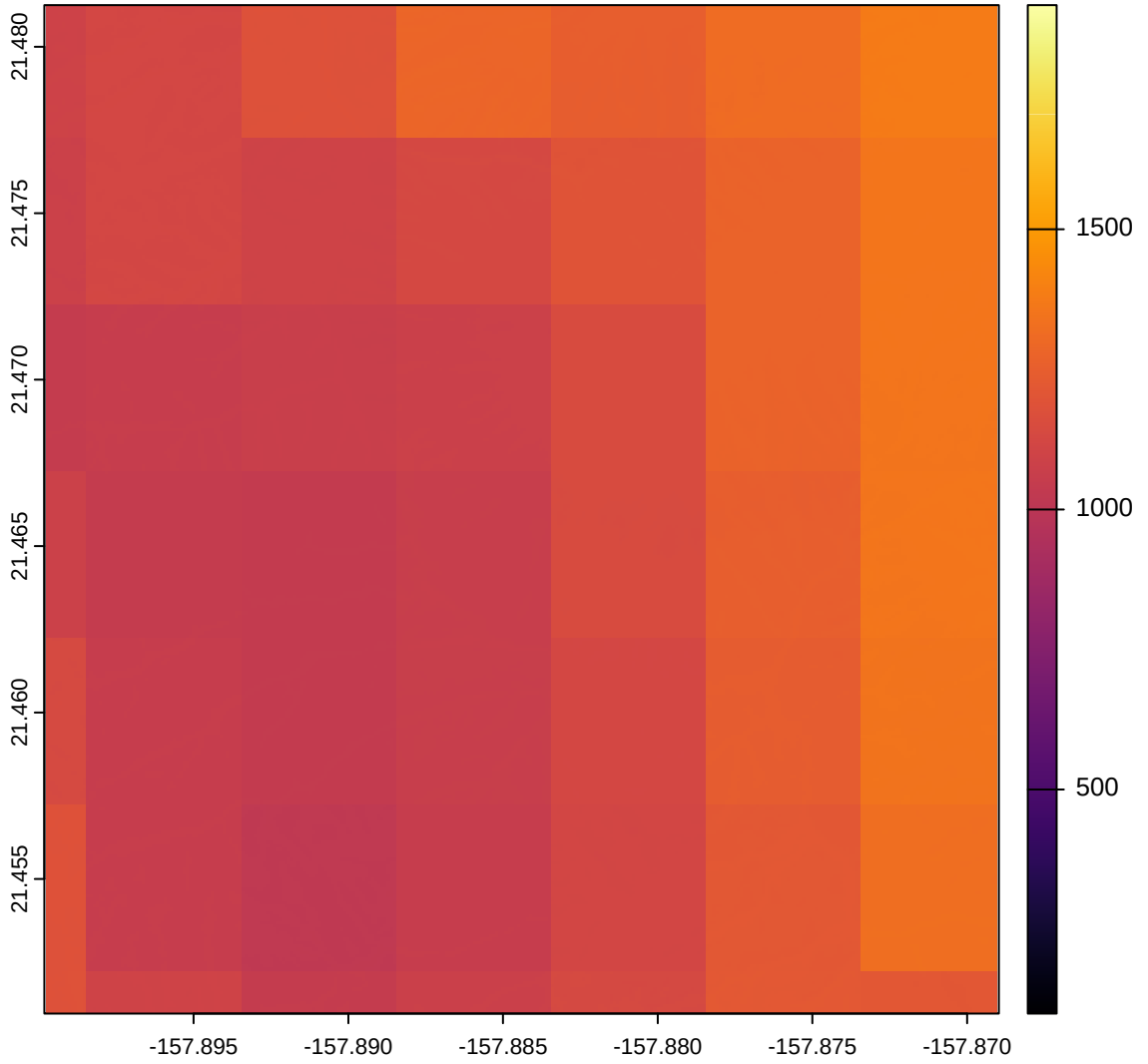
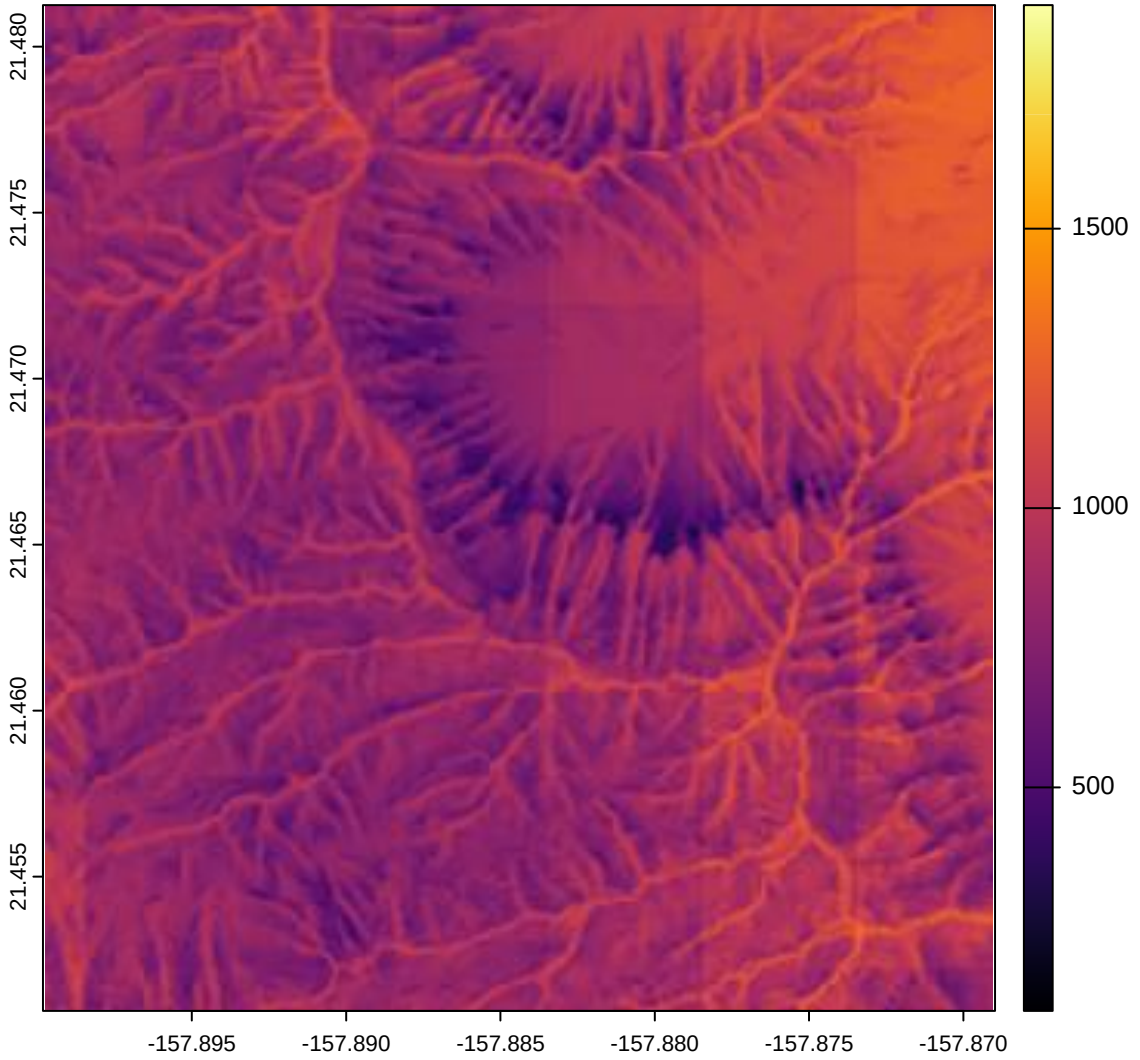


POAI Latitude Tilt from SolarAnywhere + shading



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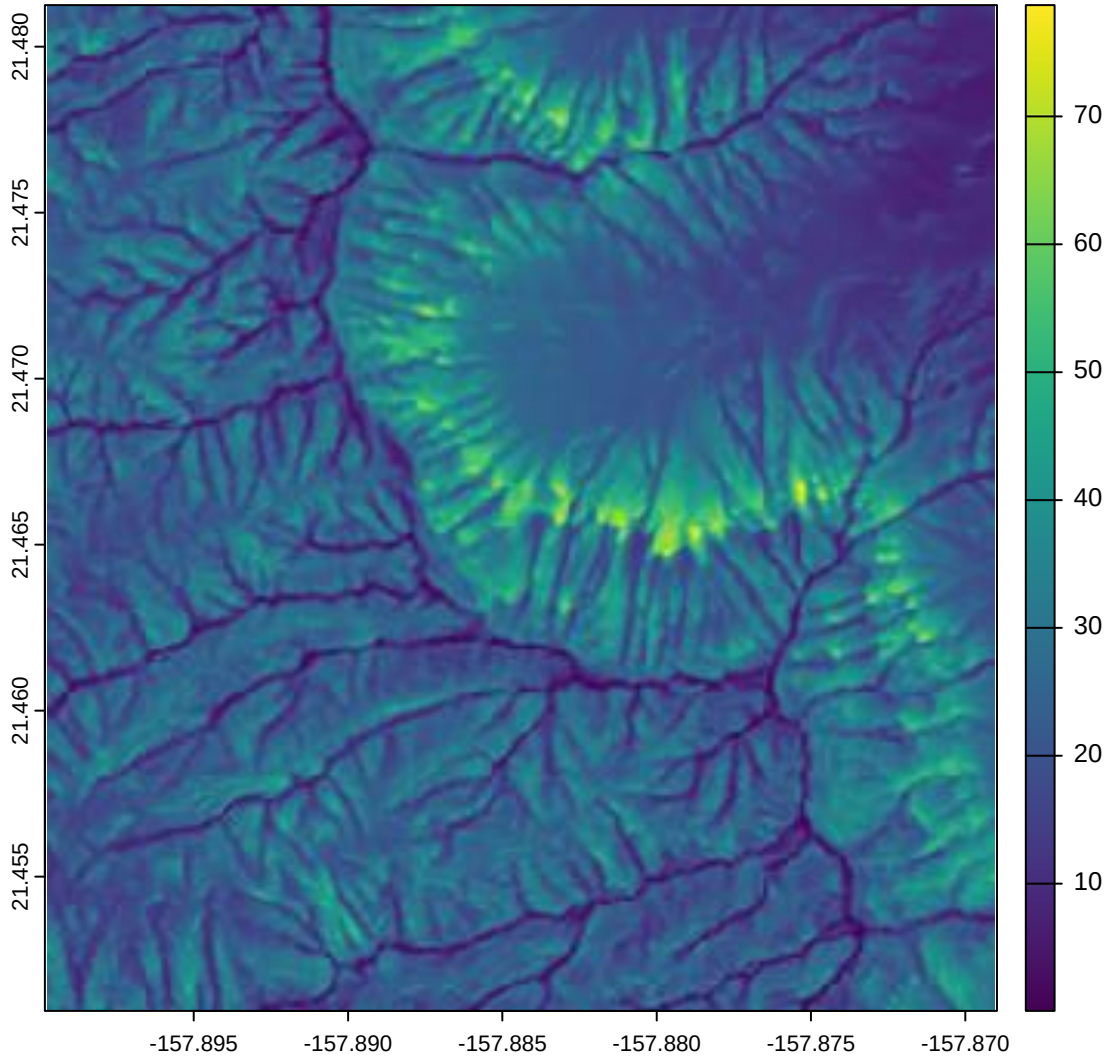
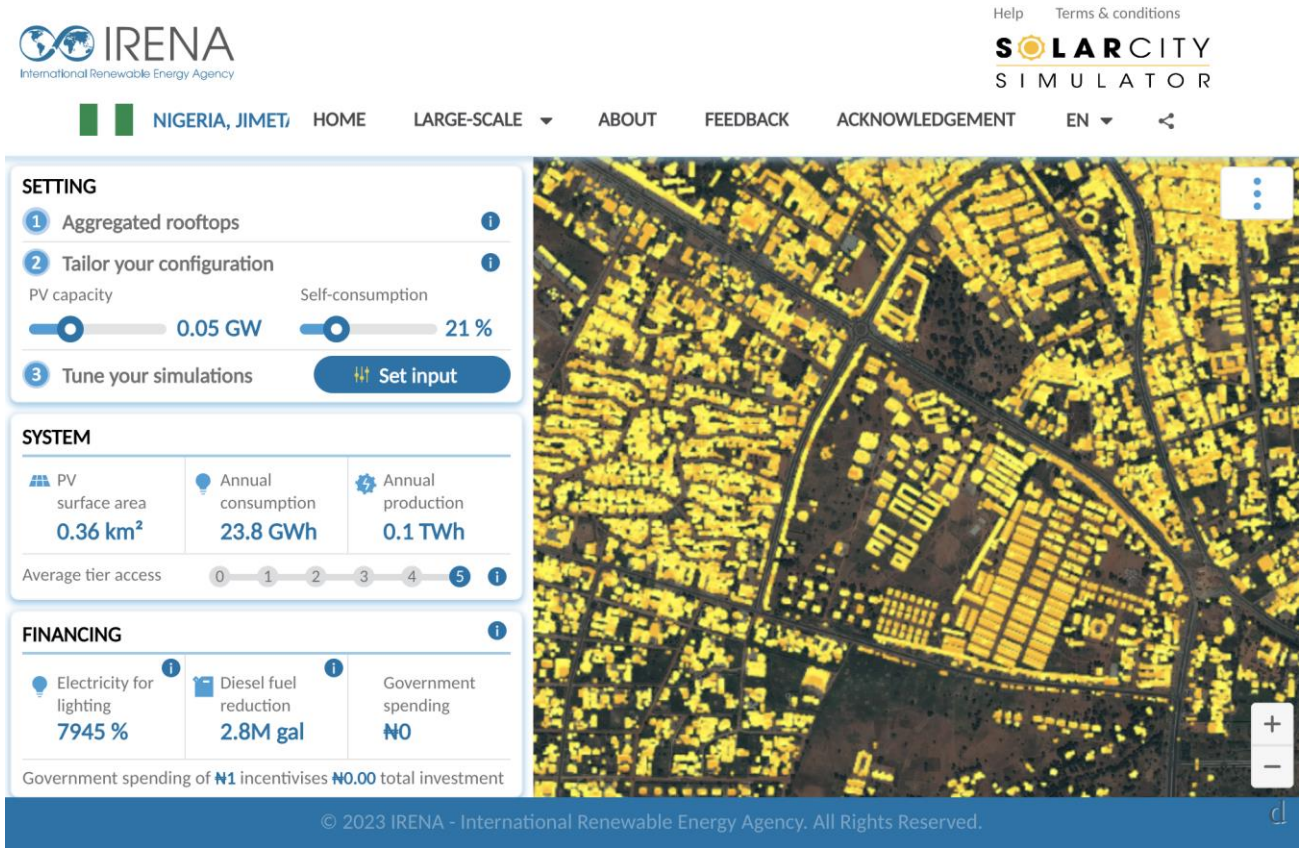


Conclusions

- Yield losses from terrain obstructions average 3% across Oahu
  - Significant spatial variations where yield loss can exceed 70%
- Shading should be properly accounted for in diffuse irradiance to account for its anisotropic nature



Far-horizon Shading Now Available in SolarAnywhere®

- New hi-res terrain observation capability derived from ASTER is available in SolarAnywhere, globally
  - New algorithms yield 1-degree az-resolution horizons with a 20km max view distance in 1.5s: calculation on the fly based on API request
- Easily integrable with, and complementary to, roof potential assessment tools with SolarAnywhere

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Thank You

Kyle Seymour | Data Scientist

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