HLS

Ground Slope Effects on Lander Radiator Performance

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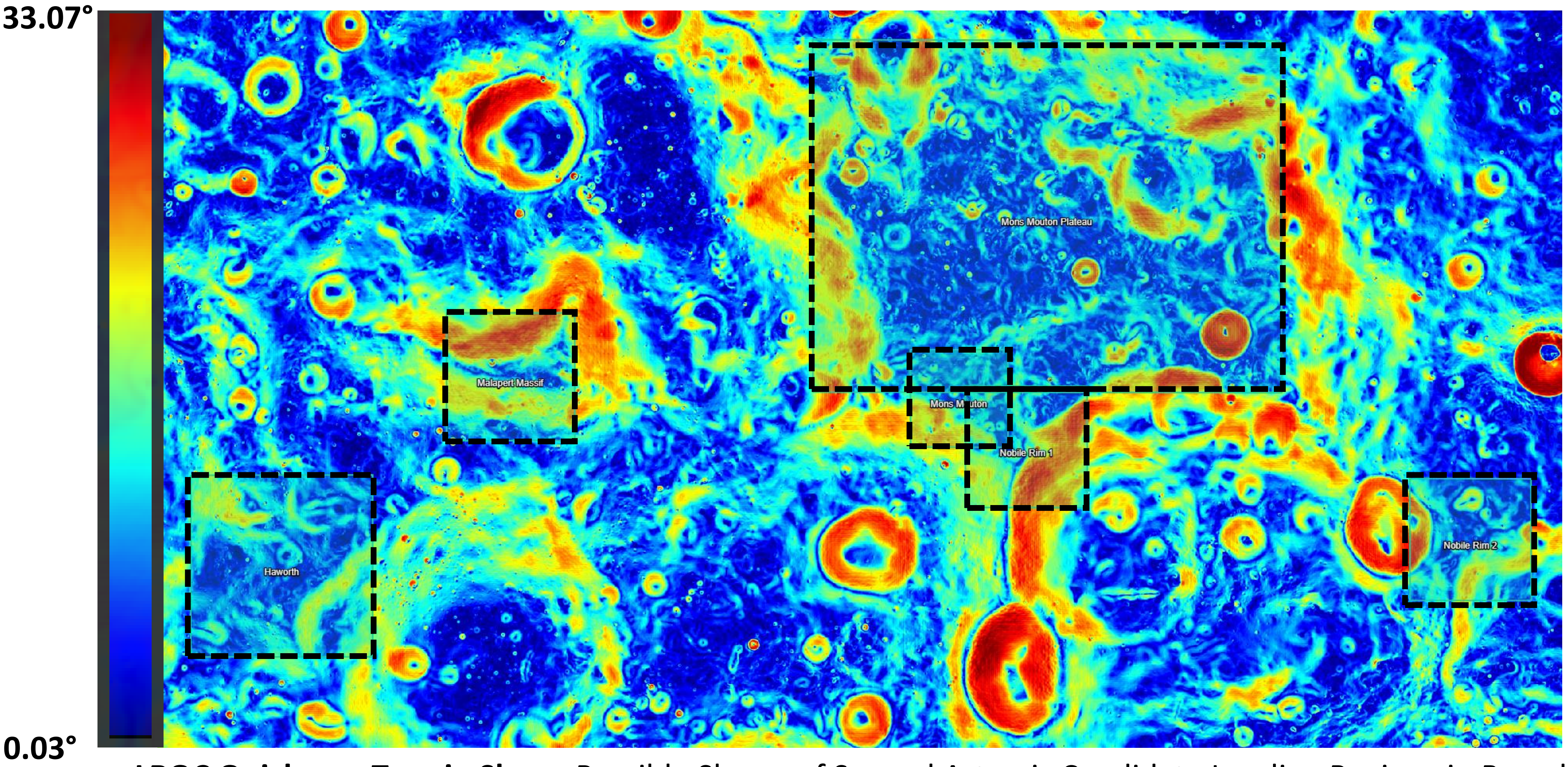
Study Purpose

<u>Problem Statement:</u> A lunar vehicle's heat rejection can be reduced by near and far field slopes[1,2]. We want to provide intuition on how much radiator performance degrades from nearby slopes for rover and lander sized assets near the south pole.

<u>Study Goal:</u> Answer the following questions: (1) What is the worst-case distance for vehicles near local slopes? (2) Can steady state analysis be used to identify the worst case? (3) Are there cases where we can ignore a nearby slope?

<u>Summary:</u> Two sensitivity studies were performed to examine the drop in radiator heat rejection from slopes. Study #1 used a 5.5m tall reduced order asset to represent a small-lander/rover. Study #2 used a 20m asset represent a tall lander. The assets had body mounted horizontal, 45º inward-tilted, and vertical radiator orientations. The impact of slopes on different radiator orientations and on radiators pointing different directions (i.e., slope verses sun) was investigated. The studies were conducted at a polar location of -82.5ºS to capture the incident solar flux at the northmost, and therefore the hottest, range of potential Artemis landing sites (Mons Mouton Plateau).

Lunar Slopes



LROC Quickmap Terrain Slope: Possible Slopes of Several Artemis Candidate Landing Regions in Boxed Areas

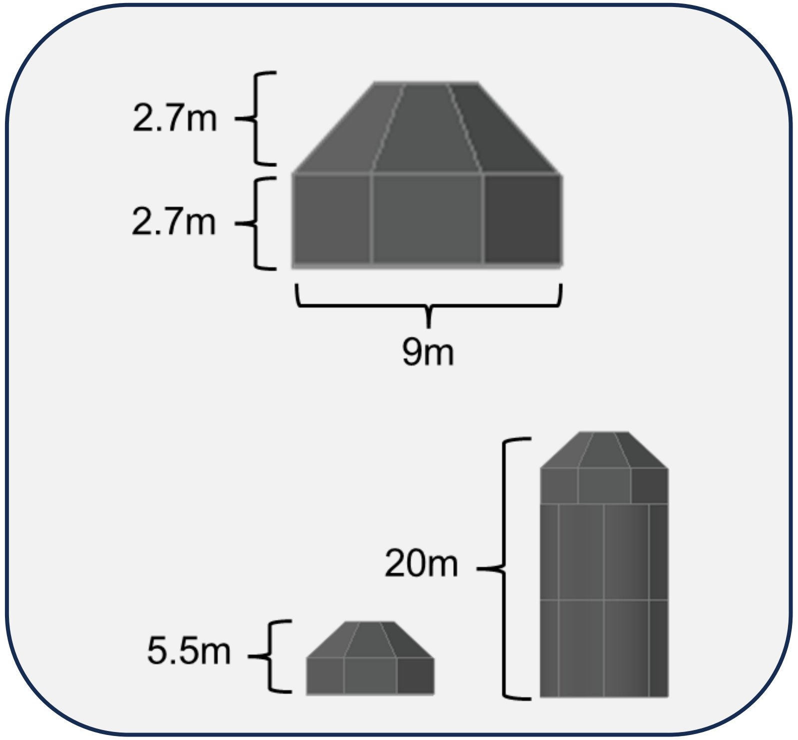
https://quickmap.lroc.im-ldi.com/layers?prjExtent=-102304.3834861%2C47834.4123314%2C218729.8775751%2C209496.2767565&stack=3388%2C3927&selectedFeature=%40%40user-defined%2CvFGiA&proj=17&defs=N4IgzGAckgXKAnAhgOwOYFM4G0AMA6XAJgDYBOaAFgBoJCB2ARjLPrAF1qRl0MAFJABsMAFxFZYIAEaCArhgC0CDABMQXAPYAHJAGMAliICecRgF8uYMkXpxQ2vYZOxzoA

Content

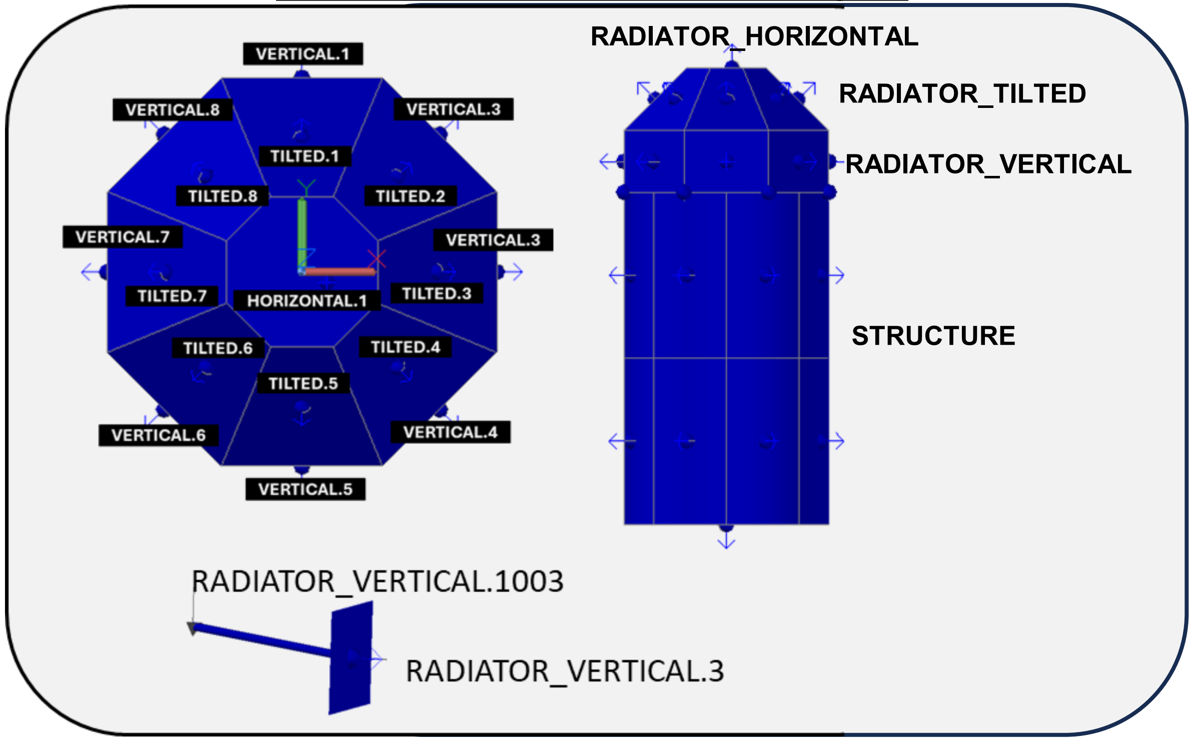
Model Overview: Asset

- A reduced order model representative of existing vehicles in terms of height, radiator placement, optical properties, and external surface temperatures.[3] This model was implemented in Thermal Desktop.
  - **Study #1 used a 5.5m tall asset to represent a rover/small-lander. Study #2 used a 20m tall asset to represent a large lander.**
  - 17 total body mounted radiators at the top of the asset each with a $10m^2$ surface area and horizontal, 45º inward-tilted, or vertical orientation.
  - Material set to Al 6061-T6 with all surfaces covered in clean Z93 (0.16 solar absorptivity, 0.92 IR emissivity).
  - Radiator temperature set at 283K (10ºC) and structure temperature set at 293 K (20ºC).
- Built with diffusion node surfaces connected to boundary nodes via conductors.

Asset Dimensions



Radiator Node Map & Conductor Diagram



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Model Overview: Lunar Environment

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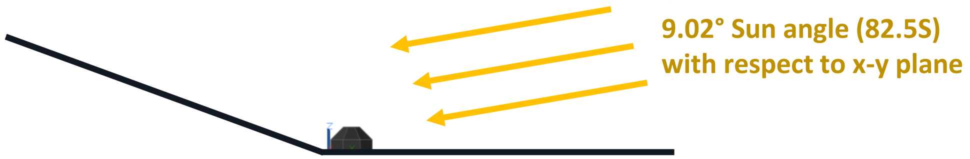
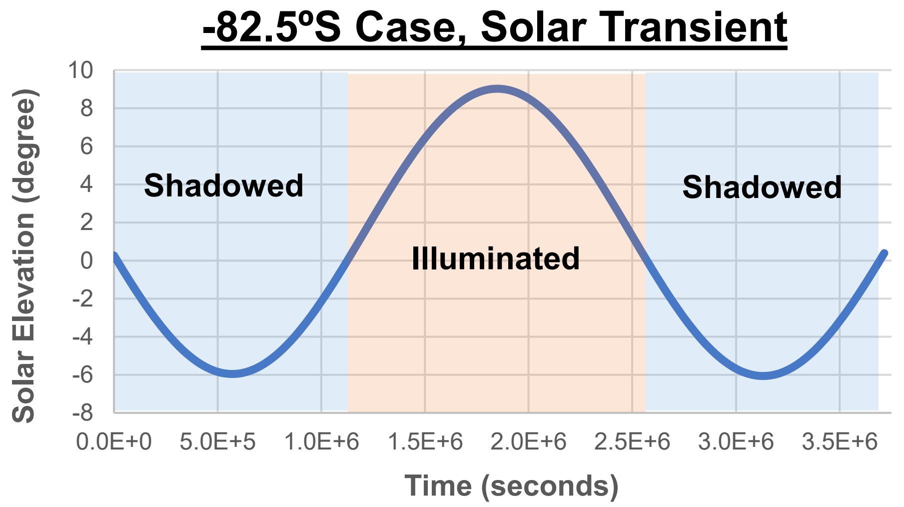
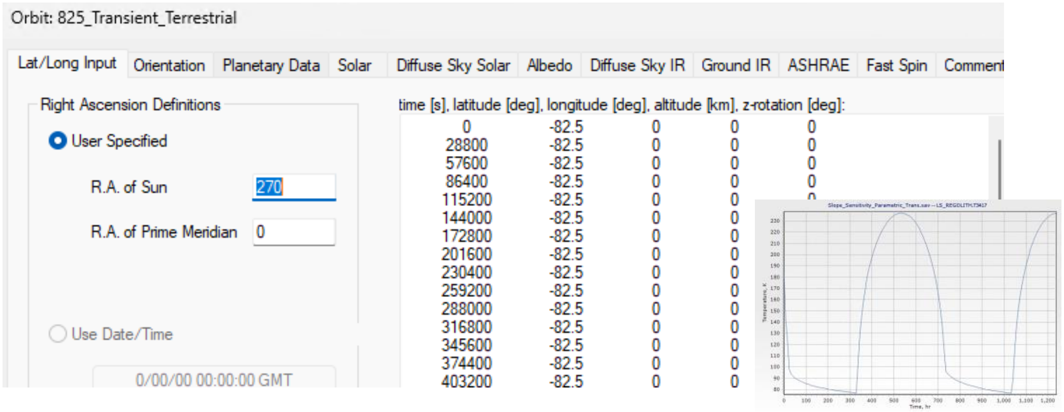
- Selected Latitude: -82.5ºS
  - Steady state: Since the asset is symmetric, performed for one sun angle (elevation = 9.02º, azimuth = directly facing the slope)
  - Transient: For simplicity, performed with a terrestrial orbit configured for summer (R.A. of Sun = 270). Initialized with a steady state case, run for 1240 hours, 8hr timestep
- Lunar environment defined using the Human Landing System (HLS) Lunar Thermal Analysis Guidebook (LTAG), Design Specification for Natural Environments (DSNE), and JPL Horizons data [4,5,6]
  - Constant worst case hot solar flux of 1415 W/m²
  - Solar diameter (subtended) angle (0.53º)[4]
  - Surface IR emissivity[5] ε = 0.95
  - Surface solar absorptivity[2,7]
    - Highland directional α_s (polar)(angle dependent)
  - Surface density[8,9] and specific heat[10] (depth dependent)
  - Surface thermal conductivity (depth & temperature dependent)[9]
  - Subsurface ground heat flow (~0.018 W/m²)[11]



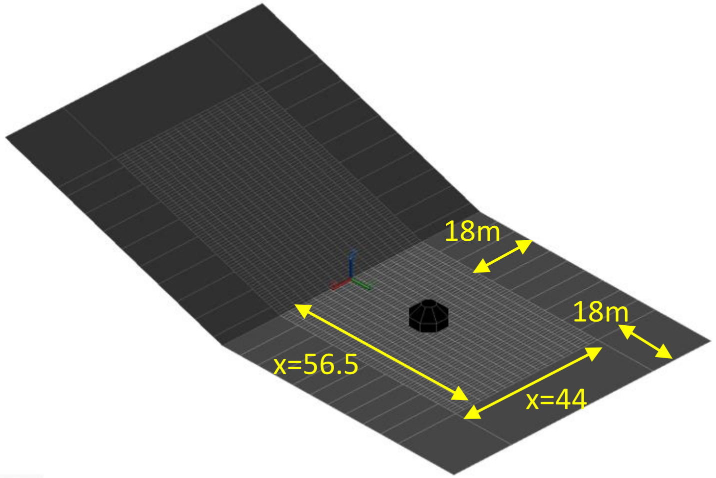




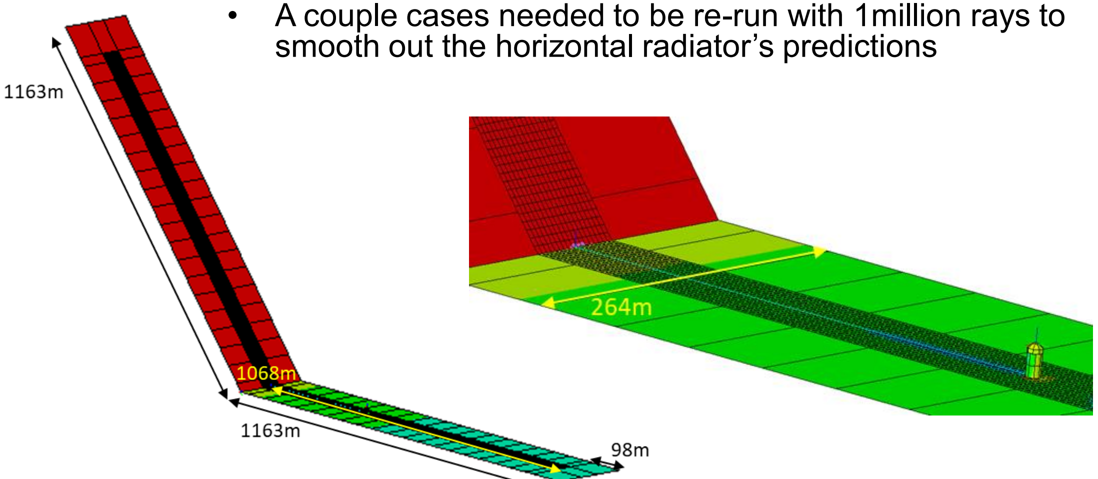
Model Overview: Lunar Surface

- The ground size was large enough to capture 1) the effect of the vehicle on the surface, 2) the effect of the surface on the vehicle, and 3) fill the space between the lander and the slope.
  - The minimum allowed size of the more detailed section's size was calculated using equation 9.3.1.4 in the LTAG[4] to capture #2*: $r_{Ground\ S} \cong r_{asset}(1.77ln(AR) + 5.85))$
  - The minimum allowed size of the entire ground size was selected using equation 9.3.1.4 in the LTAG[4] to capture #1*: $r_{Ground\ L} \cong r_{asset}(12.63(AR) + 0.943)$

- **Study #1: 5.5m tall asset (aspect ratio AR = 0.56)**
  - Total Size:
    - 74.5m long (y direction)
    - 80m wide ground (x direction)
  - Detailed section
    - 44m wide (x direction)
    - 56.5m long (y direction)
  - Required shooting 50k rays per node, 3.35% error target, and 0.0001 bij cutoff* output to SINDA



- **Study #2: 20m tall asset (aspect ratio AR = 2.23)**
  - Total Size:
    - 1163m long (y direction) to model asset 1km from slope
    - 264m wide ground (x direction)
  - Detailed section
    - 68m wide (x direction)
    - 1068m long (y direction) to model asset 1km from slope
  - Required shooting 500k rays per node, a 1% error target, and 1e-7bij cutoff** output to SINDA
    - A couple cases needed to be re-run with 1million rays to smooth out the horizontal radiator's predictions



*The baseline release of [4] gives the ground radius that results in a 5% difference in the overall field of view of the geometry when the ground is a disk as opposed to an infinite plane $|(F_{1-2})_{r_2/r_1\to\infty} - F_{1-2}| = 0.05$ (which is equivalent to $F_{1-2} / (F_{1-2})_{r_2/r_1\to\infty}$ =90%). This may be too small in some cases.

**bij cutoffs were selected with a sensitivity study with 70K rays shot for Study #1 and 500k rays shot for Study #2. The # of rays shot impacted this sensitivity.

Model Overview: Outputs

- Used SINDA subroutine TSINK1 to calculate sink temperatures in Kelvin

SINDA Logic Blocks

Logic implements the following equation to calculate average sink temperature (since each panel has the same area).

$$TSINK_{average} = \left(\sum_{i=1}^{i=\#\ Panels} TSINK^4_{panel\ i} \Big/ \#\ Panels \right)^{0.25}$$

User Code Edit

Enabled for Cond/Cap Calcs...

Comment:

Before/After Submodels | After all thermal submodels | Iteration Dependent (Variables 1)

Declarations (COMMON blocks, INTEGER, REAL):

Code:

```
        call CALC_TSINKS()
        call CALC_QOUTS()
        TFarGround = LS_REGOLITH.T294
        TFarGround_Slope = LS_REGOLITH_SLOPE.T294
```

User Code Edit

Enabled for Cond/Cap Calcs...

Comment:

Operations/Subroutine/Procedure | Subroutine Block

One node per radiator panel

```
SPELLOFF
C-------------------------------------------------------------

C-------------------------------------------------------------
F       subroutine CALC_TSINKS()
          call common

F          integer :: i
F          integer :: n_nodes
F          real :: Ts4
F          real :: Ts4sum
F          real :: Ts
F          real :: Gs
F          real :: Tsink_avg

C         Calculates average TSINK of reach panel - assume units are K
C         Horizontal Radiator -------------------------------------------------------
F         Ts4sum=0.0
F         n_nodes = 1
F         do i=1,n_nodes
            call TSINK1('RADIATOR_HORIZONTAL',i,'none','R',1.0, Gs, Ts)
F           Ts4=Ts**(4.0)              ! Tsink to the 4th power
F           Ts4sum=Ts4sum+Ts4
F          end do
F            Tsink_avg=((Ts4sum/n_nodes)**0.25)
             TSINK_RAD_HORIZ = Tsink_avg
C         Tilted Radiator  ---------------------------------------------------------
F         Ts4sum=0.0
F         n_nodes = 8
F         do i=1,n_nodes
            call TSINK1('RADIATOR_TILTED',i,'none','R',1.0, Gs, Ts)
F           Ts4=Ts**(4.0)              ! Tsink to the 4th power
F           Ts4sum=Ts4sum+Ts4
F          end do
F            Tsink_avg=((Ts4sum/n_nodes)**0.25)
             TSINK_RAD_TILT = Tsink_avg
C         Vertical Radiator ---------------------------------------------------------
F         Ts4sum=0.0
F         n_nodes = 8
F         do i=1,n_nodes
            call TSINK1('RADIATOR_VERTICAL',i,'none','R',1.0, Gs, Ts)
F           Ts4=Ts**(4.0)              ! Tsink to the 4th power
F           Ts4sum=Ts4sum+Ts4
F          end do
F            Tsink_avg=((Ts4sum/n_nodes)**0.25)
           TSINK_RAD_VERT = Tsink_avg

            call TSINK1('RADIATOR_TILTED',1,'none','R',1.0, Gs, TSINK_RAD_TILT_N)
            call TSINK1('RADIATOR_TILTED',2,'none','R',1.0, Gs, TSINK_RAD_TILT_NE)
            call TSINK1('RADIATOR_TILTED',3,'none','R',1.0, Gs, TSINK_RAD_TILT_E)
            call TSINK1('RADIATOR_TILTED',4,'none','R',1.0, Gs, TSINK_RAD_TILT_SE)
            call TSINK1('RADIATOR_TILTED',5,'none','R',1.0, Gs, TSINK_RAD_TILT_S)
            call TSINK1('RADIATOR_VERTICAL',1,'none','R',1.0, Gs, TSINK_RAD_VERT_N)
            call TSINK1('RADIATOR_VERTICAL',2,'none','R',1.0, Gs, TSINK_RAD_VERT_NE)
            call TSINK1('RADIATOR_VERTICAL',3,'none','R',1.0, Gs, TSINK_RAD_VERT_E)
            call TSINK1('RADIATOR_VERTICAL',4,'none','R',1.0, Gs, TSINK_RAD_VERT_SE)
            call TSINK1('RADIATOR_VERTICAL',5,'none','R',1.0, Gs, TSINK_RAD_VERT_S)

F       end subroutine
C
```

Model Overview: Outputs

- Used SINDA subroutines QFLOWSET and QFLOW to get heat rejected by the radiators in Watts
  - Heat rejected by individual horizontal and vertical radiators was calculated using: $Q = \varepsilon\sigma A\left(T_{rad}^4 - T_{sink}^4\right)$

SINDA Logic Blocks

```
User Code Edit
Enabled for Cond/Cap Calcs...
Comment:
Operations/Subroutine/Procedure    Operations Block Post Build (TDPOSTBL)
Declarations (COMMON blocks, INTEGER, REAL):
Code:
C      Call CALL QFLOWSET(setid, 'smn1', list1, 'smn2', list2)

        CALL QFLOWSET(1, 'RADIATOR_HORIZONTAL_BOUNDARY', 0, 'RADIATOR_HORIZONTAL', 0)
        CALL QFLOWSET(2, 'RADIATOR_VERTICAL_BOUNDARY', 0, 'RADIATOR_VERTICAL', 0)
        CALL QFLOWSET(3, 'RADIATOR_TILTED_BOUNDARY', 0, 'RADIATOR_TILTED', 0)
        CALL QFLOWSET(4, 'STRUCTURE_BOUNDARY', 0, 'STRUCTURE', 0)
```

```
User Code Edit
Enabled for Cond/Cap Calcs...
Comment:
Before/After Submodels    After all thermal submodels    Iteration Dependent (Variables 1)
Declarations (COMMON blocks, INTEGER, REAL):
Code:
        call CALC_TSINKS()
        call CALC_QOUTS()
        TFarGround = LS_REGOLITH.T294
        TFarGround_Slope = LS_REGOLITH_SLOPE.T294
```

```
C-----------------------------------------------------------------
F       subroutine CALC_Qouts()
           call common

F           real :: qlin
F           real :: qrad

C         CALL QFLOWSET(1, 'RADIATOR_HORIZONTAL_BOUNDARY', 0, 'RADIATOR_HORIZONTAL', 0)
C         CALL QFLOWSET(2, 'RADIATOR_VERTICAL_BOUNDARY', 0, 'RADIATOR_VERTICAL', 0)
C         CALL QFLOWSET(3, 'RADIATOR_TILTED_BOUNDARY', 0, 'RADIATOR_TILTED', 0)
C         CALL QFLOWSET(4, 'STRUCTURE_BOUNDARY', 0, 'STRUCTURE', 0)

         CALL QFLOW(1, qlin, qrad, QOUT_RAD_HORIZ)
         CALL QFLOW(2, qlin, qrad, QOUT_RAD_VERT)
         CALL QFLOW(3, qlin, qrad, QOUT_RAD_TILT)
         CALL QFLOW(4, qlin, qrad, QOUT_STRUCT)

F       end subroutine
C
```

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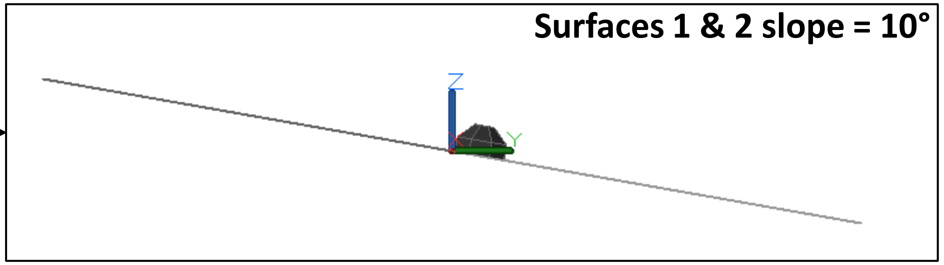
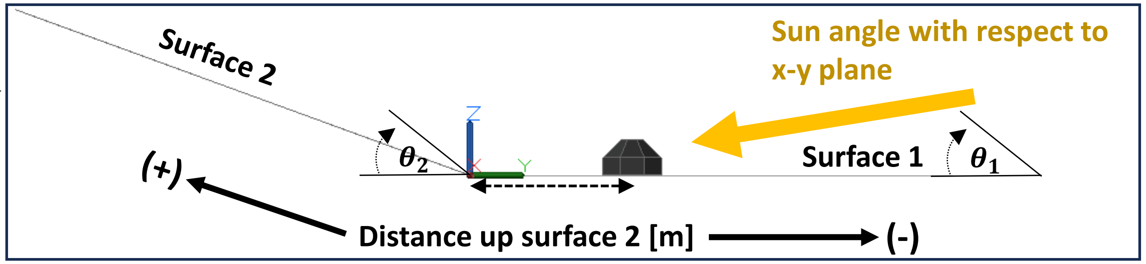
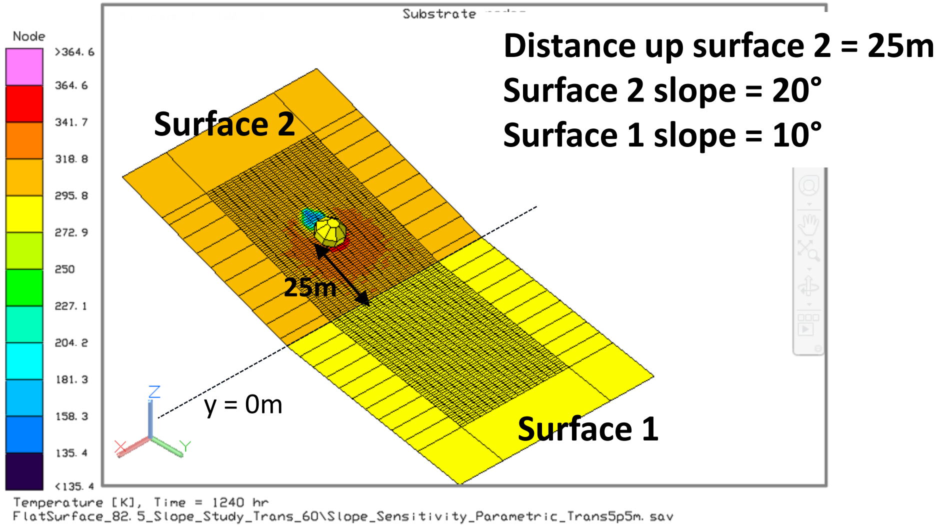
Study #1: Methodology

- Predict radiator sink temperatures (TSINKS) and heat rejection values for the 5.5m asset, varying the asset's location and ground slopes.
- Asset location with respect to its center:
  - ±25m from where Surfaces 1 & 2 intersect (y = 0)
  - Offset distance increments of 5m
- Cases for slopes of Surfaces 1 and 2, measured from x-y plane toward the sun:
  - Both 10°, 15°, 20° (flat surface)
  - Surface 1: 0° / Surface 2: 10°, 20°, 30°
  - Surface 1: 5° / Surface 2: 15°, 20°, 30°
  - Surface 1: 10° / Surface 2: 20°, 30°
  - Surface 1: 20° / Surface 2: 30°
  - Example: a 10° slope increases local solar elevation angle by 10°
  - **Assets are not expected to travel to slopes >20°[17-18]**

- **Cases set reflects desire to see:**
  - What is the worst case – overall, and for each radiator orientation if the asset can approach a max slope of 30°?
  - Can you bound the worst case with a single surface tilted surface?
  - If Surface 2 is sloped, what is the impact if Surface 1 is also sloped?
  - Can steady state analysis be used to capture the worst case?







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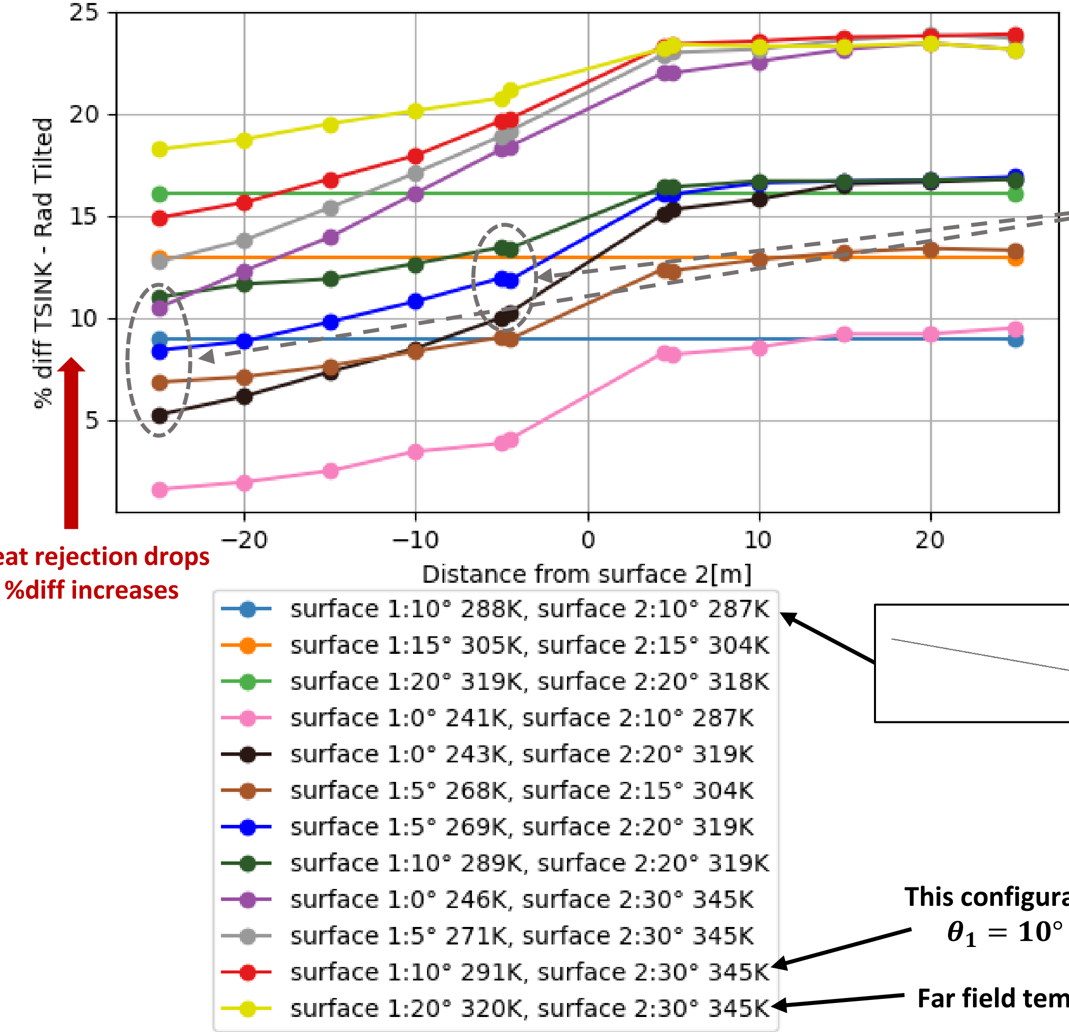
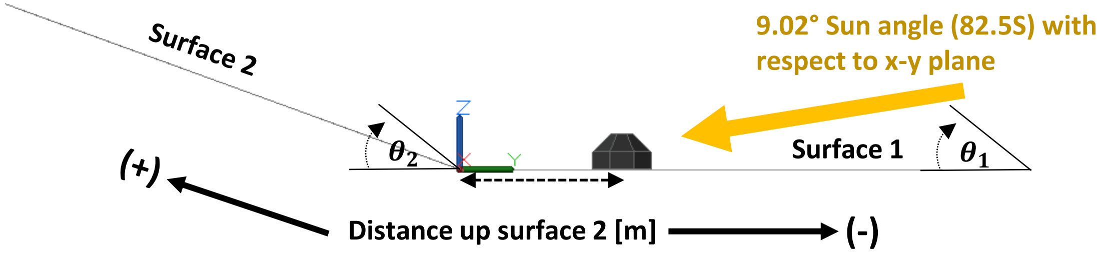
Study #1: Steady State Results: Slope Impact on Average Sink Temperature

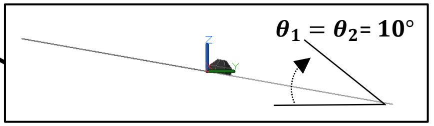
45° Tilted Radiators



Heat rejection drops as %diff increases

- Worst case - where asset cannot be on a slope >20°:
  - Surface 1 = 20°, Surface 2 = 30°, just before the incline
- Excluding all 30° slopes, the worst case would be
  - Surface 2 = 20° far up the incline (~>+25m)
- Surface 2's slope drives worst case TSINKS more then Surface 1's
  - Surface 1's slope significantly drives TSINKS while on Surface 1
- Approaching a given slope, TSINKs increase and level off ~+20-25m up the slope





$$TSINK_{RAD} = \left(\frac{\sum_{i=1}^{i=8} TSINK_{panel\ i}^4}{8}\right)^{0.25}$$

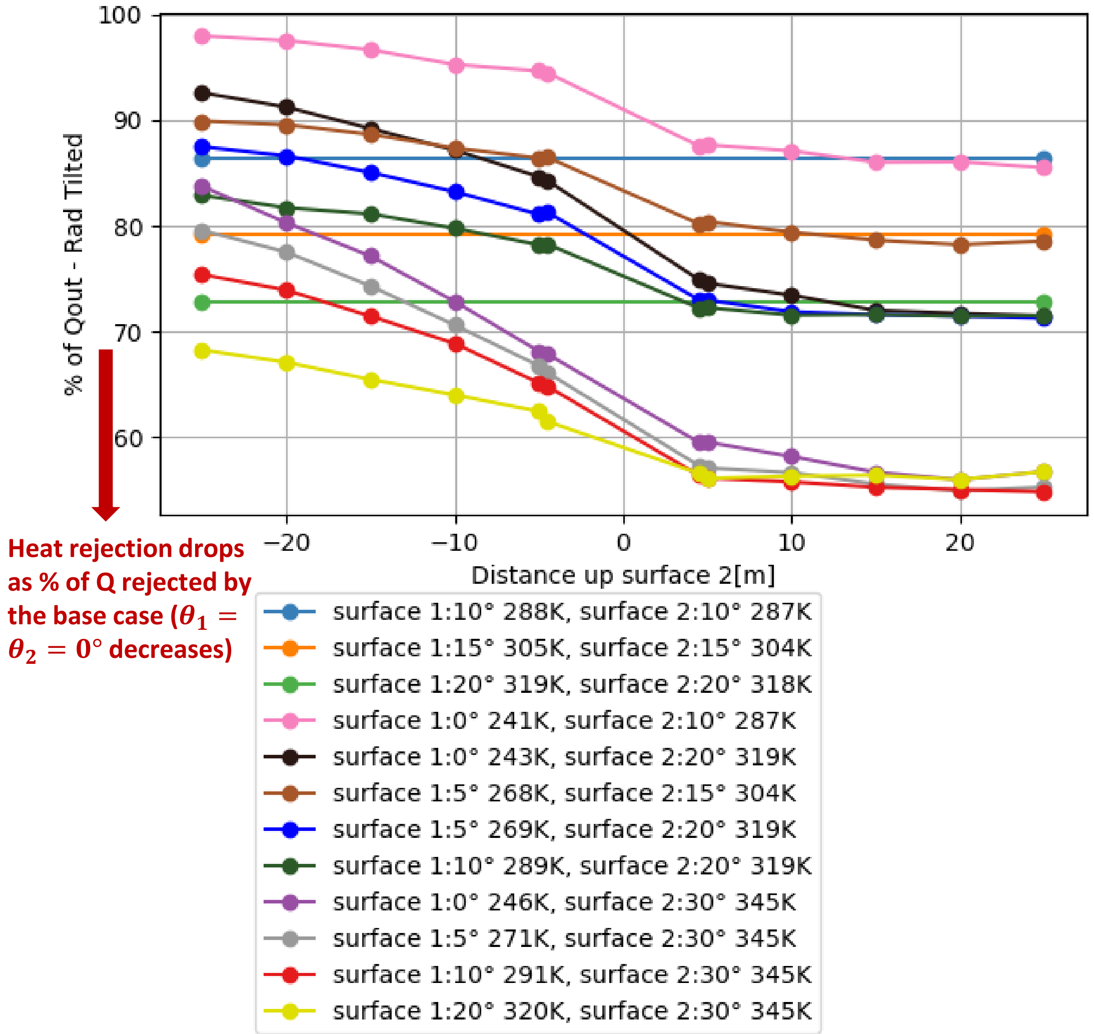
$$\%diff = \frac{TSINK\,[K] - TSINK_{flat\ plane}[K]}{TSINK_{flat\ plane}[K]}$$

This configuration:
$\theta_1 = 10°\ \&\ \theta_2 = 20°$

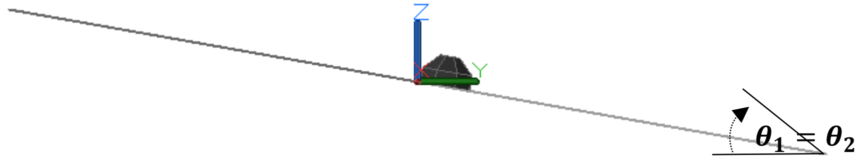
Far field temperatures on each surface not impacted by asset

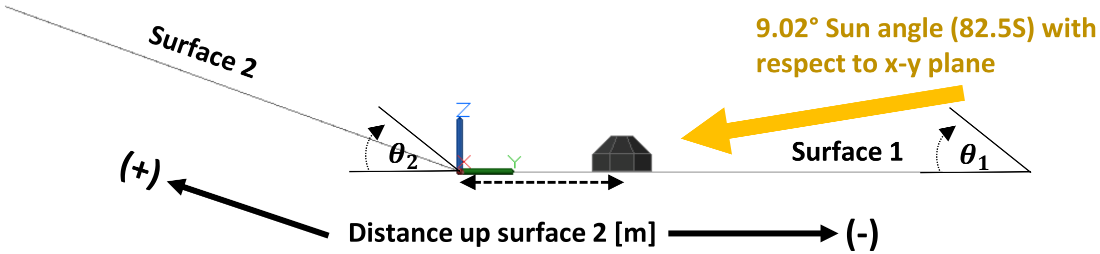
Study #1: Steady State Results: Slope Impact on Heat Rejection

45° Tilted Radiators $\%of = \frac{Qout\ [W]}{Qout_{flat\ plane}\ [W]}$



- The sum of heat rejected by the tilted radiators is less for a **__ shaped** ground than a **\\ shaped ground**
  - +25m up a 10° slope with split terrain (surface 1 slope = 0°) rejects 0.9% less heat (163W) than a flat ground with 10° slope (surface 1 slope = surface 2 slope = 10°)
  - + 25m up a 20° slope with split terrain (surface 1 slope = 10°) rejects 1.9% less heat (271W) rejection than a flat ground with 20° slope (surface 1 slope = surface 2 slope = 20°)
  - On a 20° slope, -4.5m up a 30° slope **(worst case)** rejects **16%** less heat (2271W) than a flat ground with a 20° slope





Study #1: Steady State Results: Slope Impact on Average Sink Temperature

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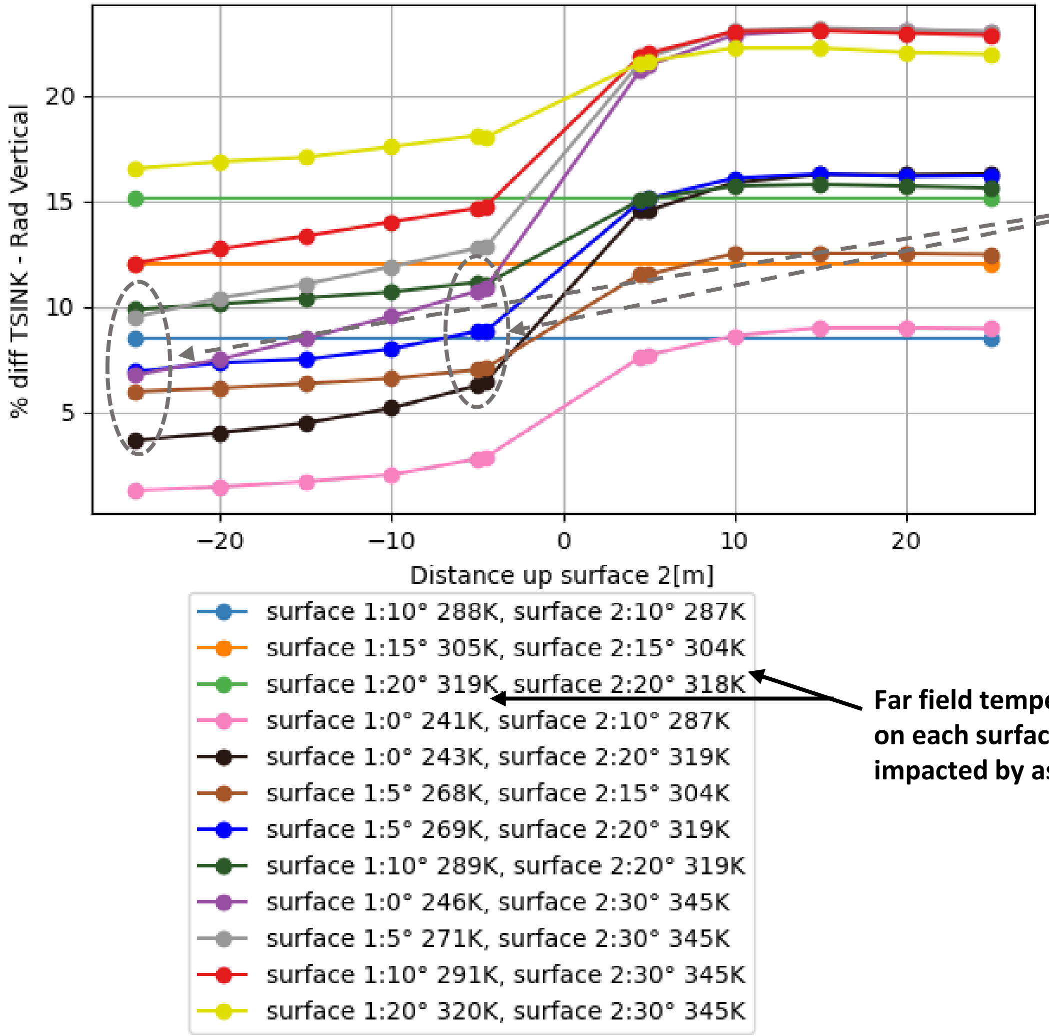
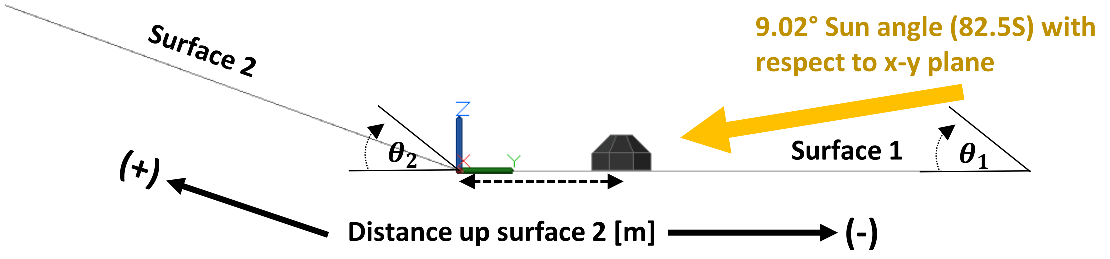
Vertical Radiators



Far field temperatures on each surface not impacted by asset

- Worst case - where asset cannot be on a slope >20°:
  - Surface 1 = 20°, Surface 2 = 30°, just before the incline
- Excluding all 30° slopes, the worst case would be
  - Surface 1 = 5-10°, Surface 2 = 20°, ~>+10m up the incline
- Surface 2's slope drives TSINKS more then Surface 1's slope
  - Surface 1's slope significantly drives TSINKS while on Surface 1
- Approaching a given slope, TSINKs increase and level off at ~+20-25m up the slope



$$TSINK_{RAD} = \left(\frac{\sum_{i=1}^{i=8} TSINK^4_{panel\ i}}{8} \right)^{0.25}$$

$$\%diff = \frac{TSINK\,[K] - TSINK_{flat\ plane}[K]}{TSINK_{flat\ plane}[K]}$$

Study #1: Steady State Results: Slope Impact on Heat Rejection

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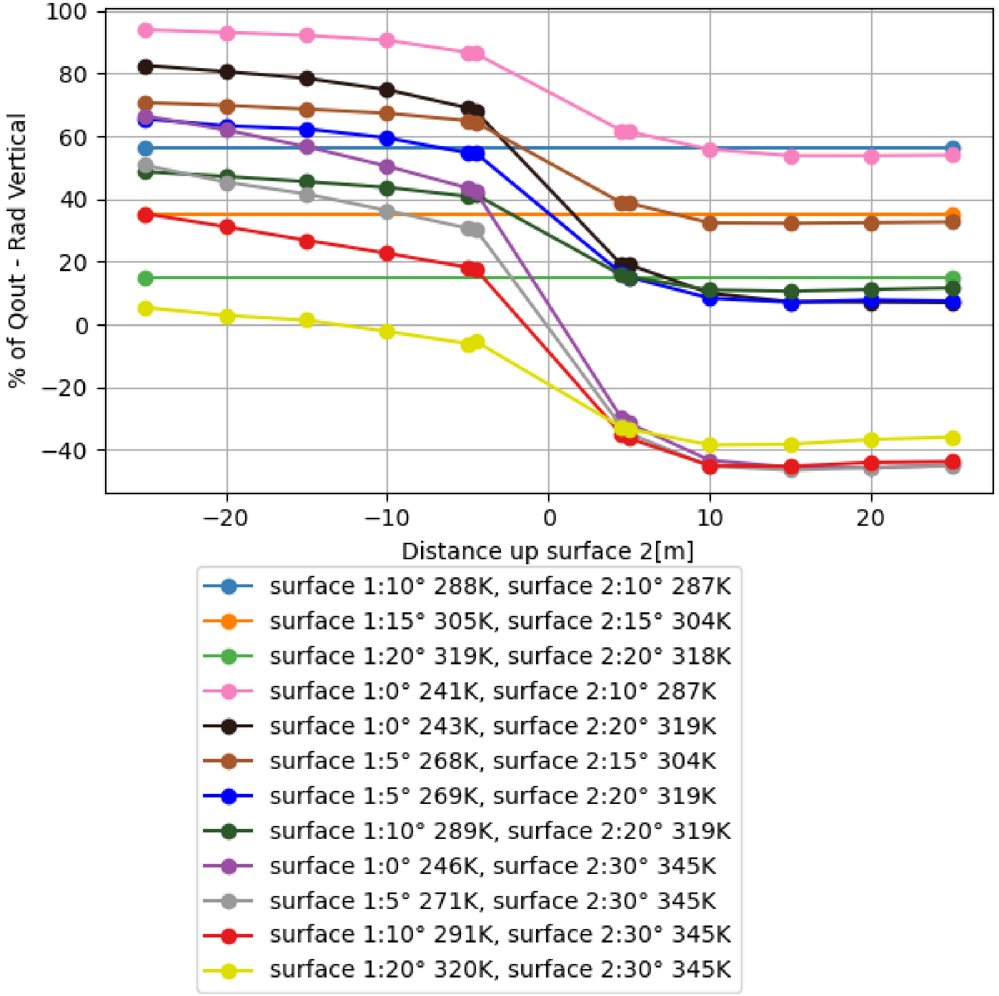
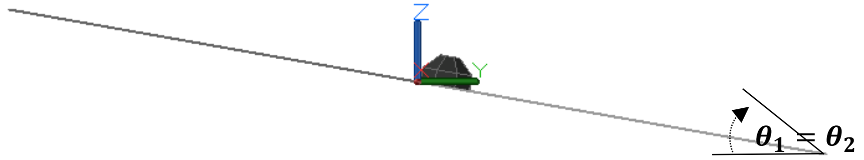
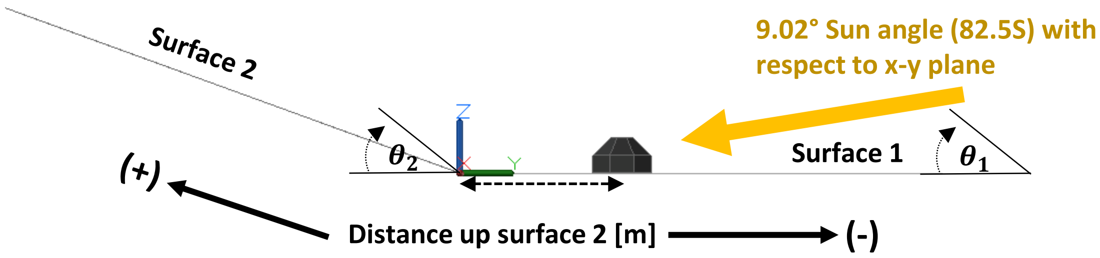
Vertical Radiators

$$\%of = \frac{Qout\ [W]}{Qout_{flat\ plane}\ [W]}$$



- The sum of heat rejected by the vertical radiators is less for a **_ shaped** ground than a **\ shaped ground**
  - +25m up a 10° slope with split terrain (surface 1 slope = 0°) rejects 4.6% less heat (328W) than a flat ground with 10° slope (surface 1 slope = surface 2 slope = 10°)
  - \+ 25m up a 20° slope with split terrain (surface 1 slope = 10°) rejects 54% less heat (1029W) rejection than a flat ground with 20° slope (surface 1 slope = surface 2 slope = 20°)
  - On a 20° slope, -5m up a 30° slope **(worst case)** rejects 140% less heat than a flat ground with a 20° slope
    - -757W verses 1908W





Study #1: Steady State Results: Slope Impact on Average Sink Temperature

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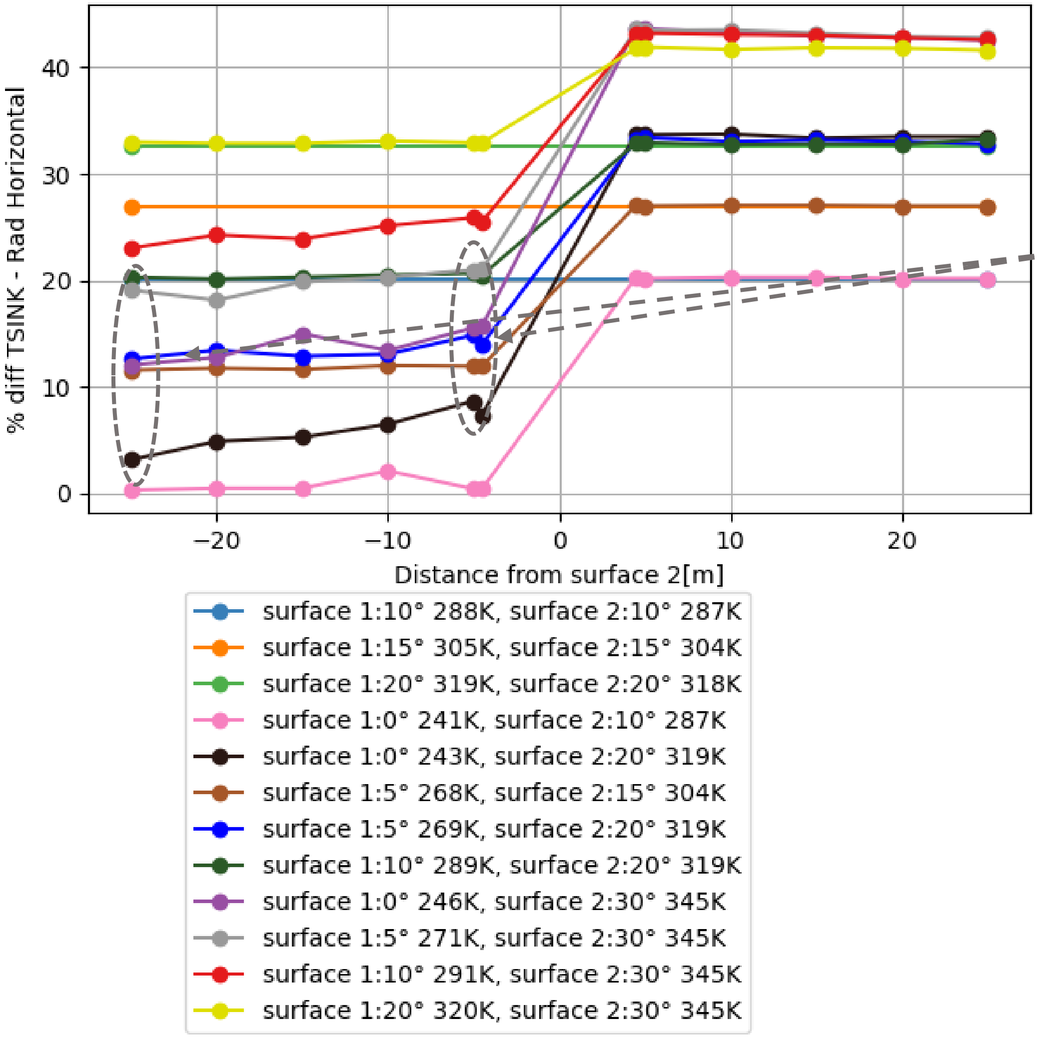
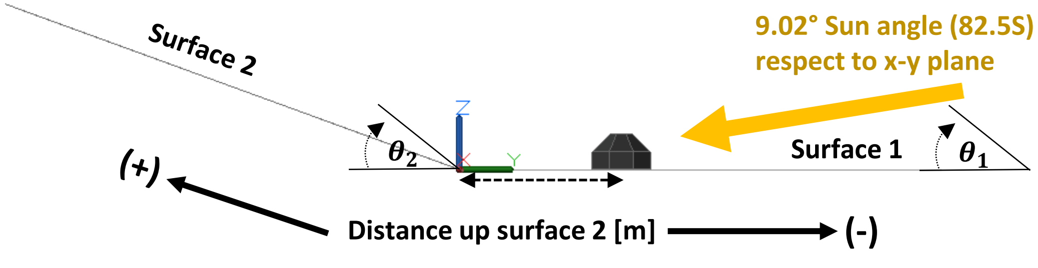
Horizontal Radiator



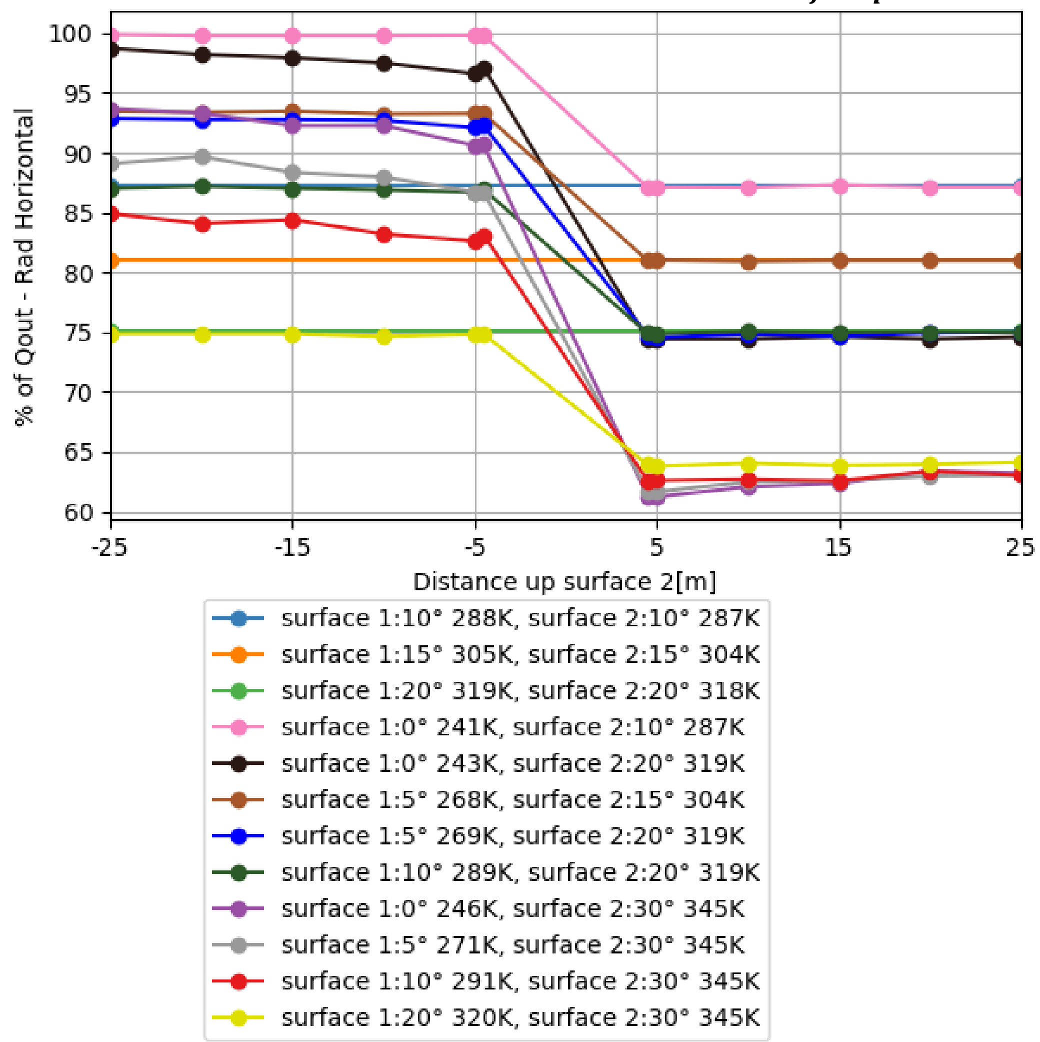
- Worst case - where asset cannot go onto 30° slope:
  - Surface 1 = 0°, Surface 2 = 20°, just before the incline
- Excluding all 30° slopes, the worst case is the same.
  - Heat rejected on 20° slope, -4.5m up a 30° slope ≅ Heat rejected +4.5m up a 20° slope
- As the asset moves >+4.5m up a slope, results barely change.
- Surface 1's slope significantly drives TSINKS while on Surface 1



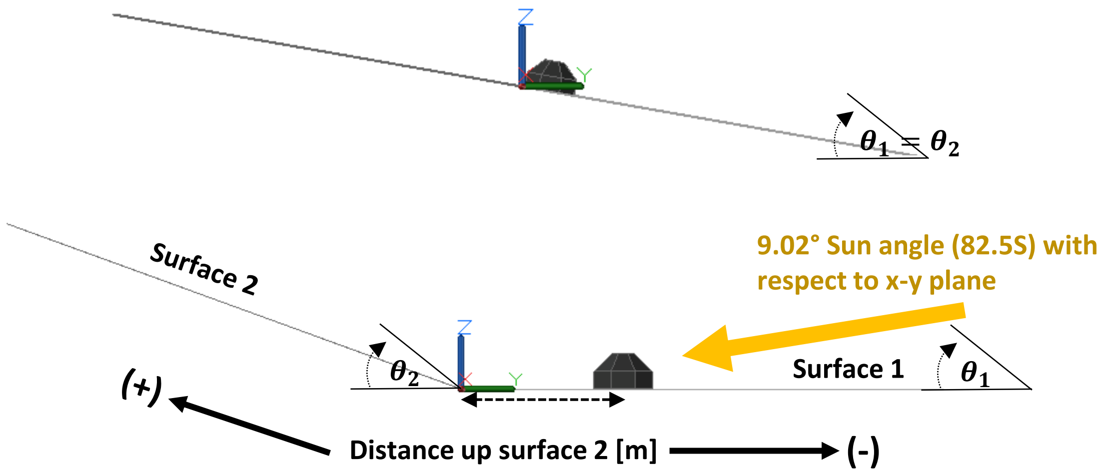
$$\%diff = \frac{TSINK\,[K] - TSINK_{flat\ plane}[K]}{TSINK_{flat\ plane}[K]}$$

Study #1: Steady State Results: Slope Impact on Heat Rejection

Horizontal Radiator $\%of = \frac{Qout\ [W]}{Qout_{flat\ plane}\ [W]}$



- The worst-case heat rejection of the asset's horizontal radiator was closely predicted with the **\ shaped ground**
  - +25m up a 10° slope with split terrain (surface 1 slope = 0°) rejects 0.1% less heat (2W) than a flat ground with 10° slope (surface 1 slope = surface 2 slope = 10°)
  - +25m up a 20° slope with split terrain (surface 1 slope = 10°) rejects 0.7% less heat (16W) rejection than a flat ground with 20° slope (surface 1 slope = surface 2 slope = 20°)
  - +4.5m up a 20° slope near a 0° slope **(worst case)** rejects 1% less heat (23W) than a flat ground with a 20° slope

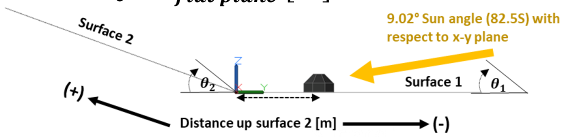


HLS

Study #1: Steady State Results: Slope Impact on Heat Rejection

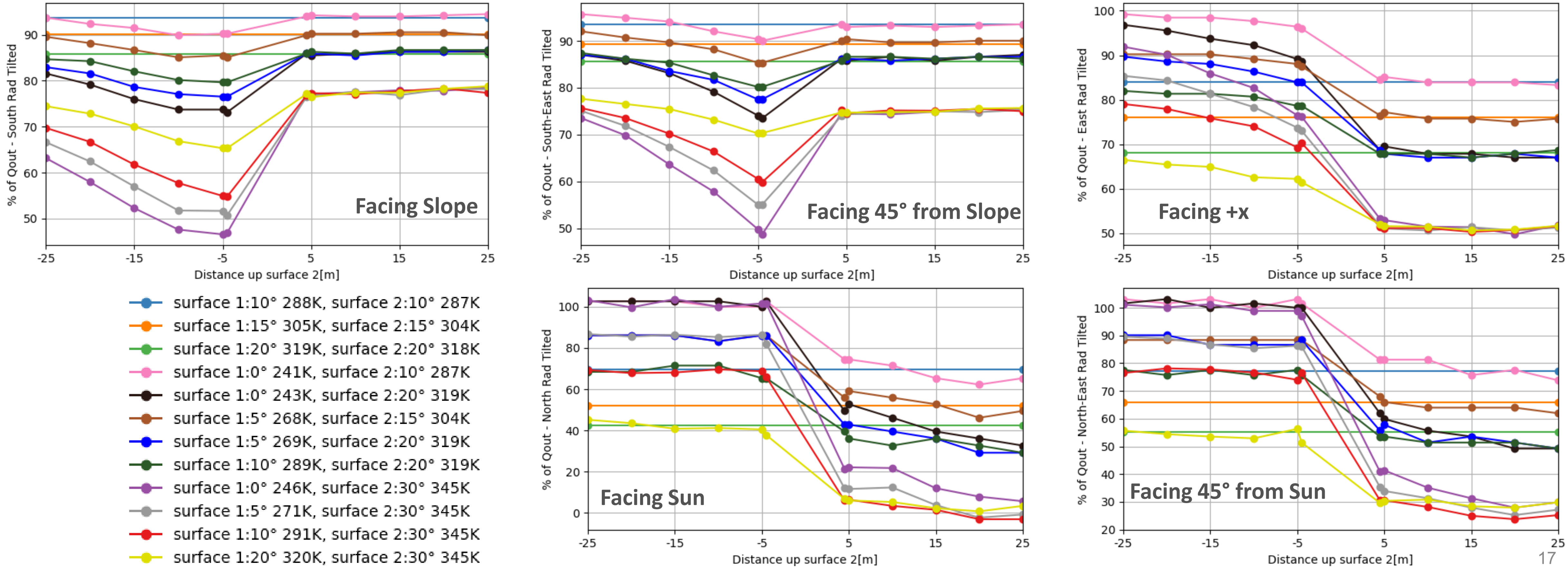
*Asset cannot be on a slope >20°

$$\%of = \frac{Qout\,[W]}{Qout_{flat\ plane}\,[W]}$$



45° Tilted Panel Specific (i.e., Direction-Specific) Worst Cases:*

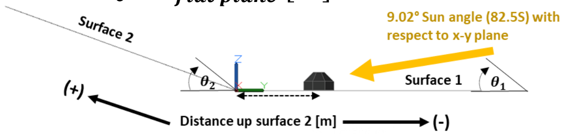
- Panels viewing the slope: on a 0° slope just before a 30° incline
- Panels viewing the sun: 25m up on a 20° sloped surface 2 where surface 1 is ~5-10°
- Panel with no view to slope or sun: on a 0° slope just before a 30° incline



Study #1: Steady State Results: Slope Impact on Heat Rejection

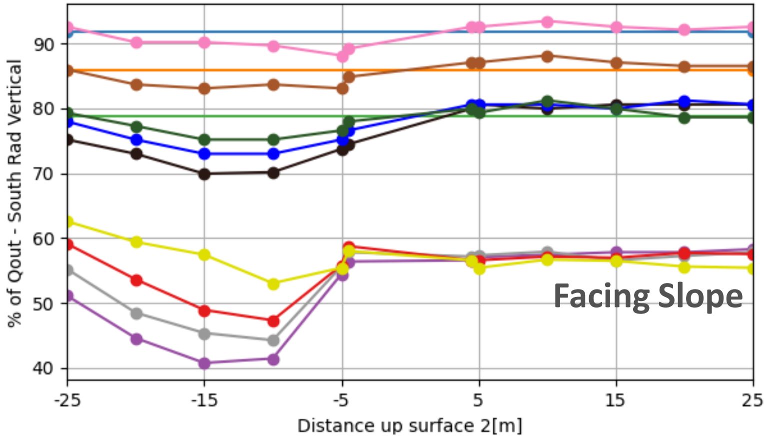
***Asset cannot be on a slope >20°**

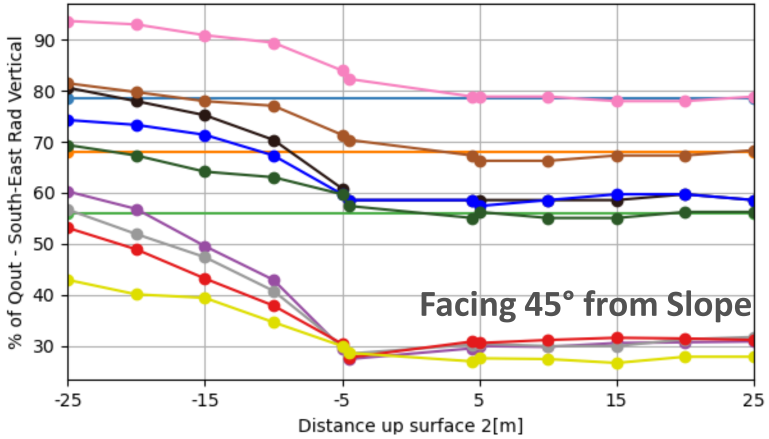
$$\%of = \frac{Qout\,[W]}{Qout_{flat\ plane}\,[W]}$$

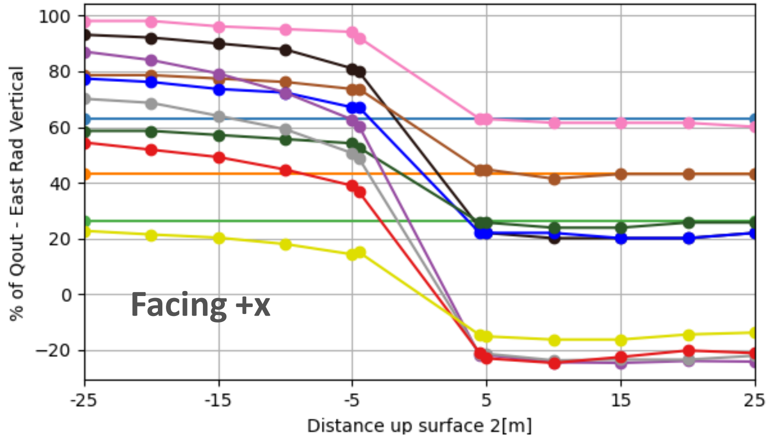


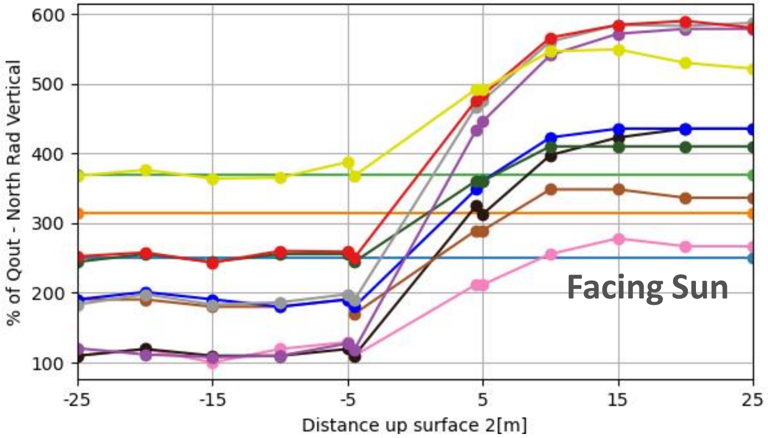
Vertical Panel Specific (i.e., Direction-Specific) Worst Cases:*

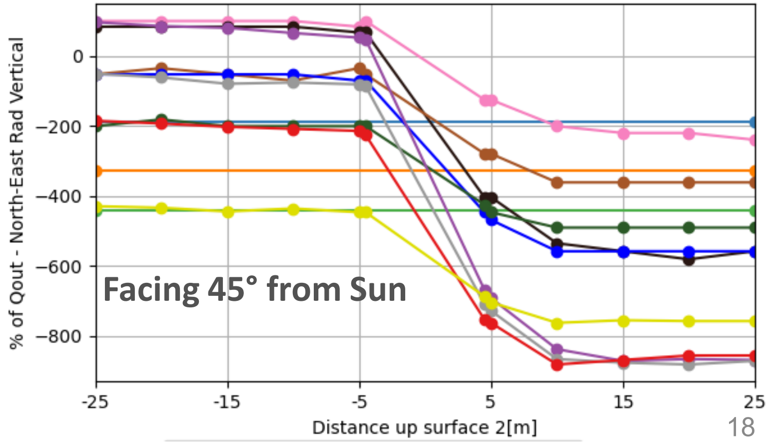
- Panels viewing the slope: on a 0° slope 15 to 4.5 before a 30° incline
- Panels viewing the sun: 20m up on a 20° sloped surface 2 where surface 1 is ~5-10°
- Panel with no view to slope or sun: on a 20° sloped surface about 5m from a 30° slope







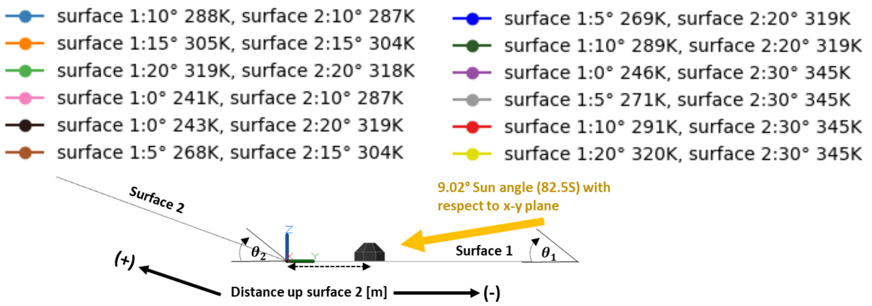




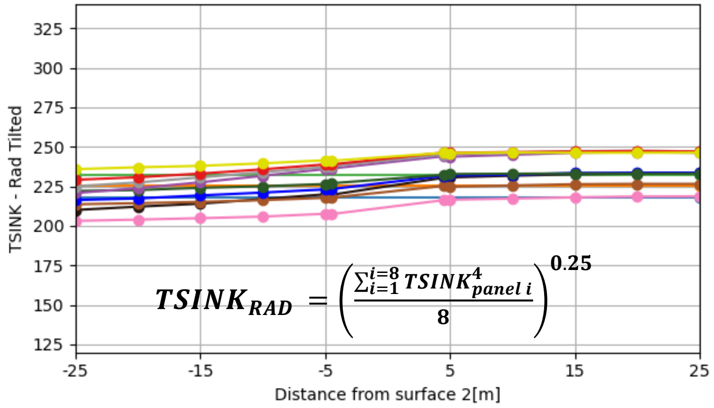
HLS

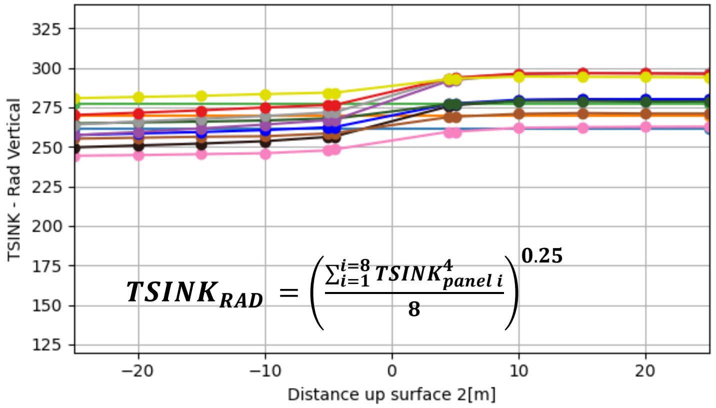
Study #1: Steady State vs Transient: TSINKS of Tilted, Vertical, and Horizontal Radiators

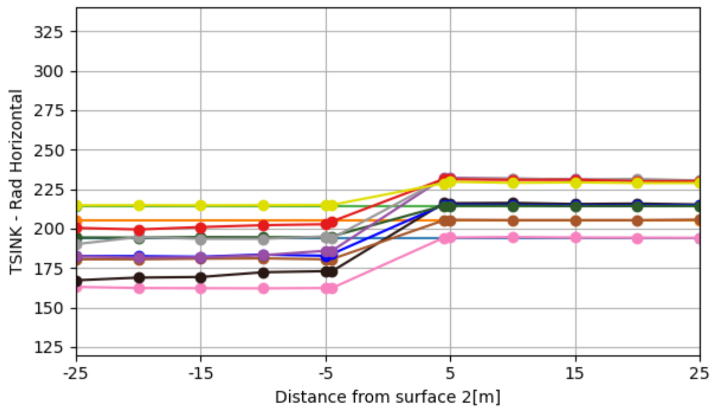
- Transient results follow the same trends
- Difference in Average TSINKS (steady state – transient)
  - Tilted Radiators: -0.2-1.3K → 73 to -289 W
  - Vertical Radiators: -0.2-1.3K → 168 to -327W
  - Horizontal Radiator: -3.8-3.9K →41 to -26W



Transient Results:





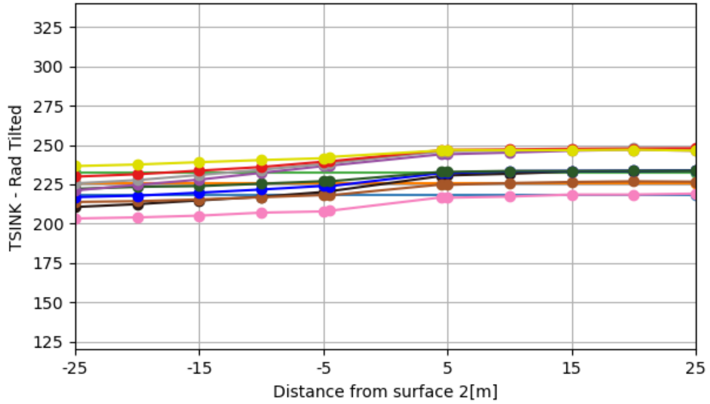


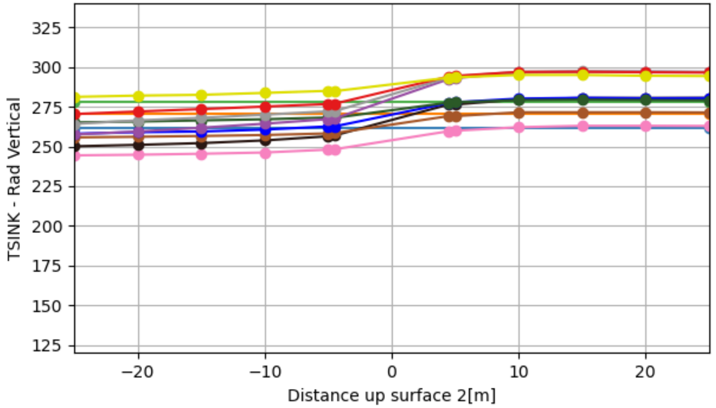
Steady State Results:

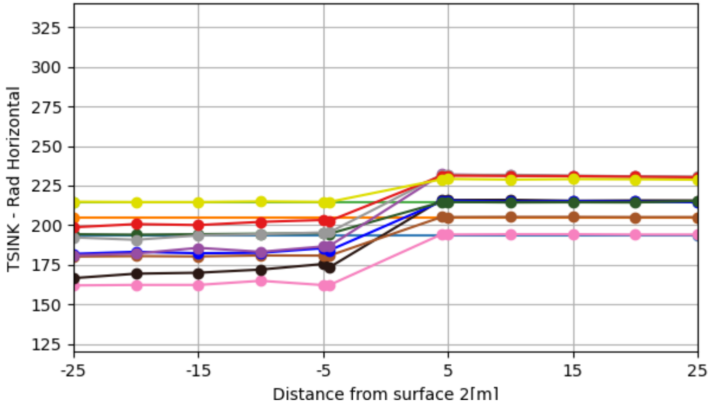
Tilted

Vertical

Horizontal



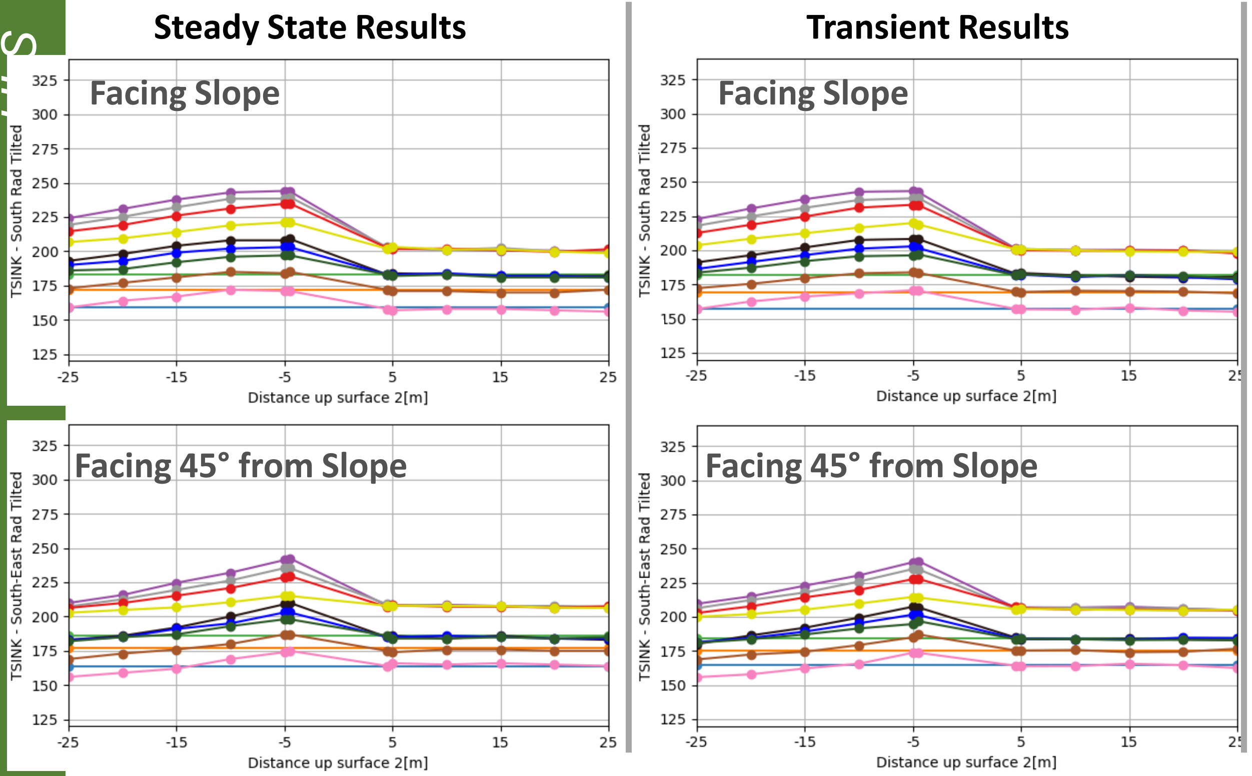


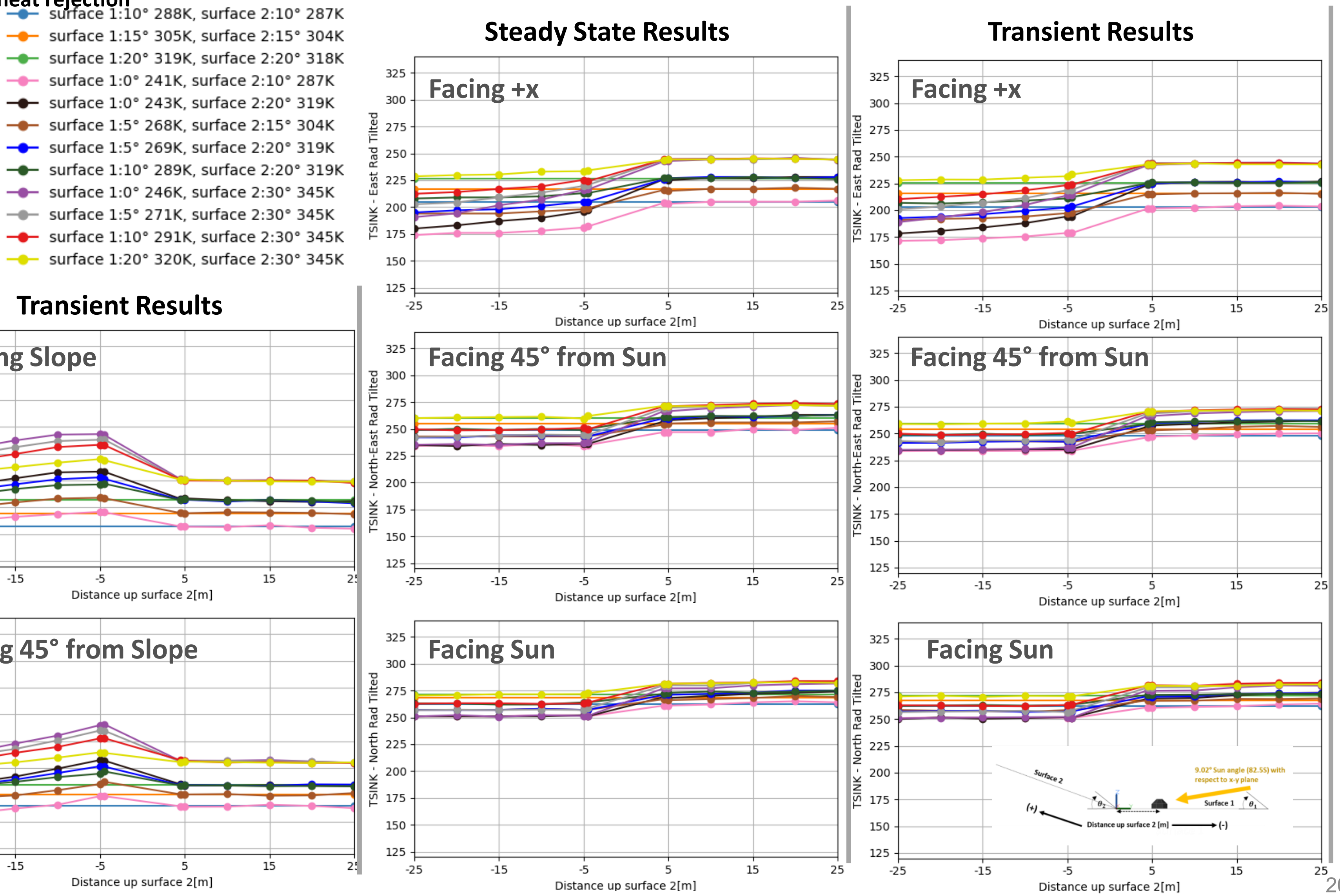


Study #1: Steady State vs Transient: TSINKS of Tilted Radiators

Summary of TSINK deltas and how they map to deltas in heat rejection

	North (Sun)	North-East	East	South-East	South (slope)
Max ΔTSINK	1.8	2.4	4.4	3.6	3.9
Min ΔTSINK	-1.3	-1.4	-0.4	-1.7	-0.4
Min ΔQ	-67	-89	-45	-64	-40
Max ΔQ	45	53	10	19	6

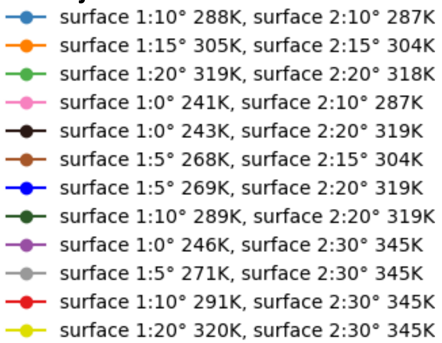


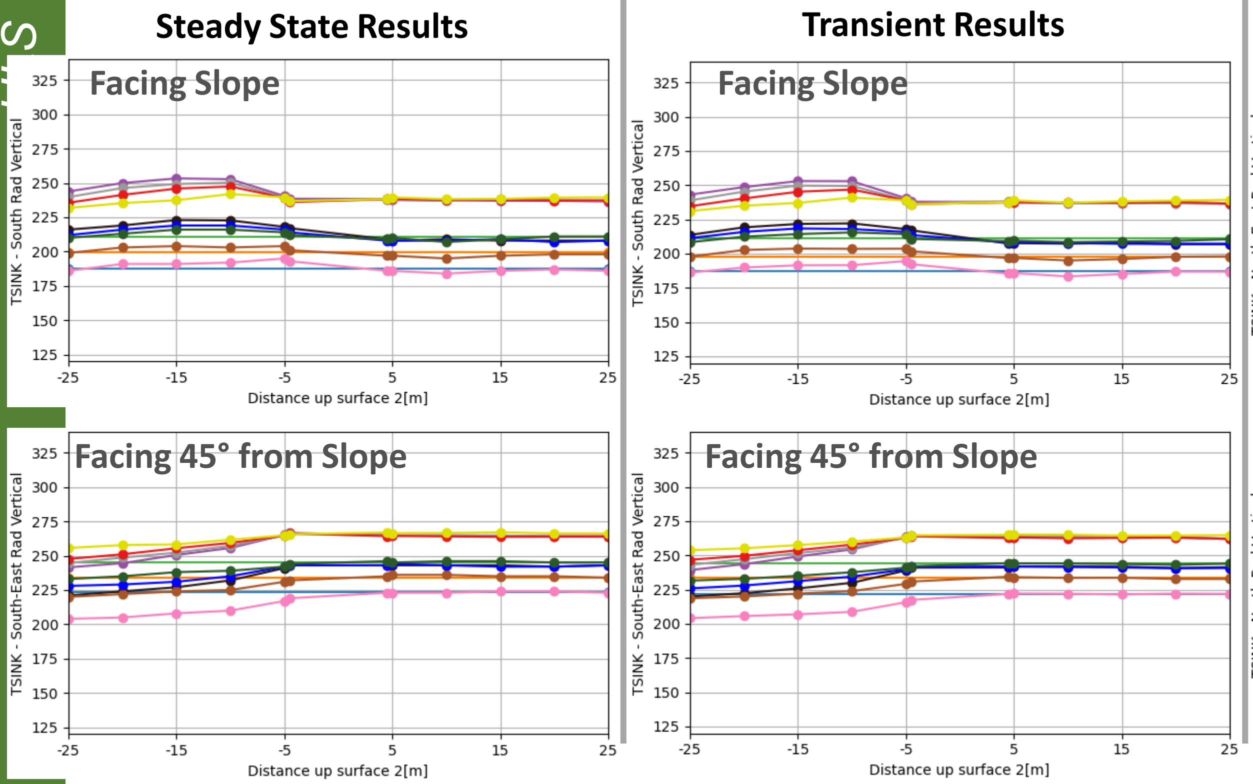


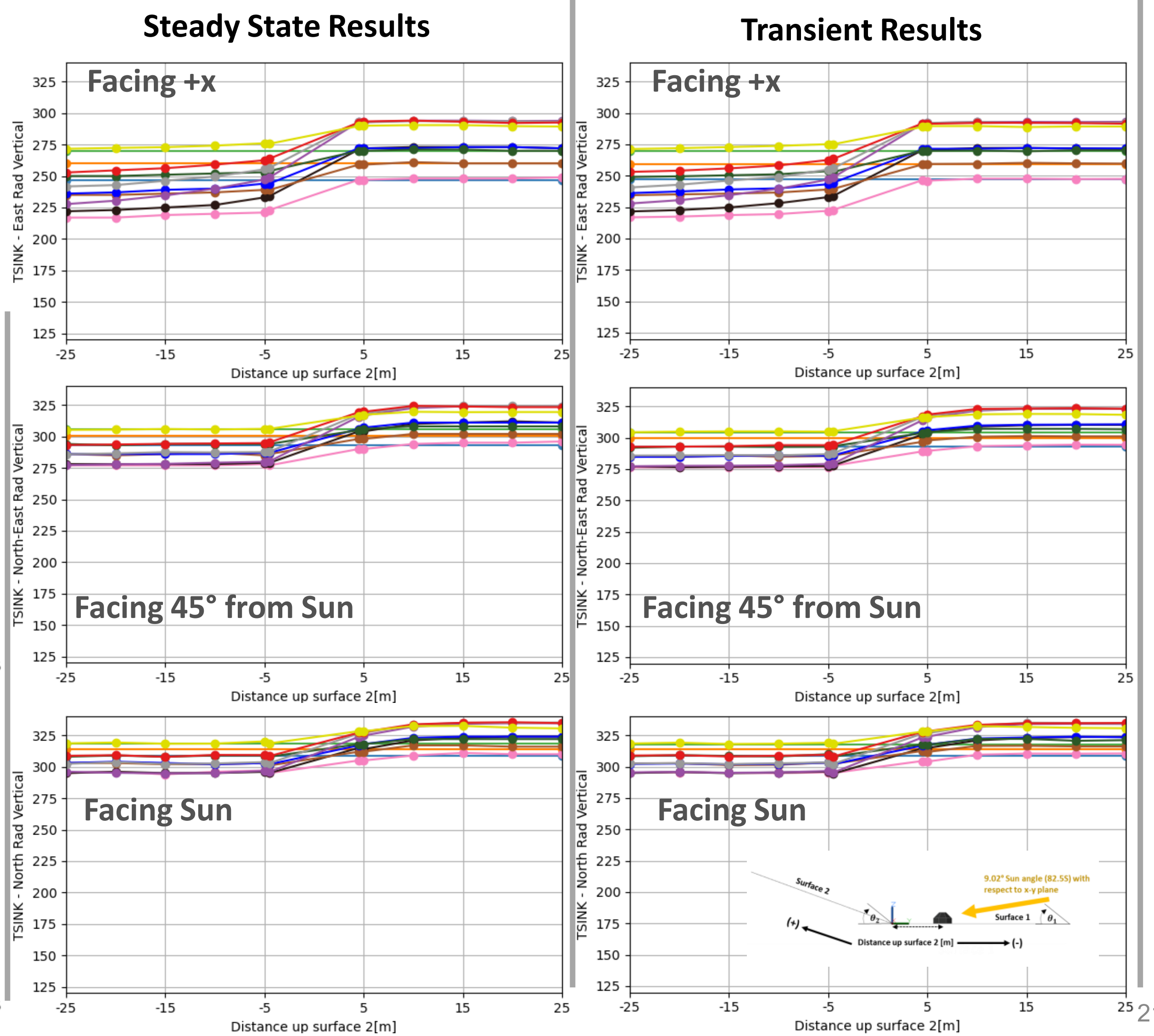
Study #1: Steady State vs Transient: TSINKS of Vertical Radiators

Summary of TSINK deltas and how they map to deltas in heat rejection

	North (Sun)	North-East	East	South-East	South (slope)
Max ΔTSINK	1.4	2.1	2.0	2.7	2.4
Min ΔTSINK	-1.3	-0.3	-1.1	-0.2	-1.0
Min ΔQ	-82	-140	-106	-94	-50
Max ΔQ	75	20	24	4	19







Study #1: Steady vs Transient: Worst Case Location

- The worst cases identified by the steady state and transient parametric sweeps were close but not identical.
- The worst steady state cases bounded the transient worst case.
- However, the transient results at the worst-case steady state locations do not always bound the transient worst cases.

Worst Cases. Heat Rejection in [W]	TILT	VERT	HORIZ	TILT_N	TILT_NE	TILT_E	TILT_SE	TILT_S	VERT_N	VERT_NE	VERT_E	VERT_SE	VERT_S	Total
Steady State Worst Case: N – faces sun, S – faces surface 2 (slope), E – faces +x, SE – faces 45° away from slope, NE – faces 45° away from sun, SS = steady state, Trans = transient. (-) Q indicates a TSINK > T radiator														
Surface 1 slope [°]	20	20	0	10	5	20	0	0	5	0	20	0	0	20
Surface 2 slope [°]	30	30	20	20	20	30	30	30	20	20	30	30	30	30
Distance up surface 2 [m]	-4.5	-5	4.5	25	25	-4.5	-4.5	-5	20	20	-5	-4.5	-15	-4.5
Fraction of base case (with no slope)	0.615	-0.060	0.744	0.295	0.493	0.615	0.487	0.465	4.323	-6.152	0.142	0.274	0.407	0.390
Worst case [W]	12312	-757	2214	369	851	1776	1545	1496	-2413	-1566	317	714	1198	13869
Transient Worst Case														
Surface 1 slope [°]	20	20	0	0	5	20	0	0	5	5	20	20	0	20
Surface 2 slope [°]	30	30	20	20	20	30	30	30	20	20	30	30	30	30
Distance up surface 2 [m]	-5	-4.5	4.5	25	20	-4.5	-4.5	-5	20	25	-5	-4.5	-15	-5
Fraction of base case (with no slope)	0.625	-0.037	0.744	0.296	0.493	0.614	0.503	0.473	4.060	-5.566	0.163	0.302	0.413	0.405
Base case (with no slope) [W]	20078	12396	2977	1291	1780	2934	3173	3216	-590	272	2217	2608	2938	35450
Worst case [W]	12547	-464	2214	382	878	1801	1596	1522	-2397	-1512	360	788	1213	14343
Worst case at steady state worst case location [W]	12601	-430	2214	436	880	1801	1596	1522	-2397	-1487	360	806	1213	14361
ΔQ [Worst Case - Worst case at Worst case SS location (Trans)] [W]	289	327	0	67	28	25	51	26	16	79	43	91	15	493
Are the worst cases the same?	Almost identical	Almost identical	Yes	No - close (Δ10° in surface 1's slope)	Almost identical	Yes	Yes	Yes	Yes	No –(Δ5° in surface 1's slope and 5m on surface 2)	Yes	No –(Δ20° in surface 1's slope)	Yes	Almost Identical
Value if surface 1&2 at 20° slope [W]	14595	2096	2237	492	983	2000	2751	2777	-1974	-1138	594	1483	2310	18929
ΔQ [Worst case - value for both surfaces at 20° slope] [W]	-1994	-2526	-23	-56	-104	-198	-1154	-1254	-423	-349	-234	-677	-1098	-4568

Study #1: Steady State vs Transient: Worst Case Radiator Heat Rejection

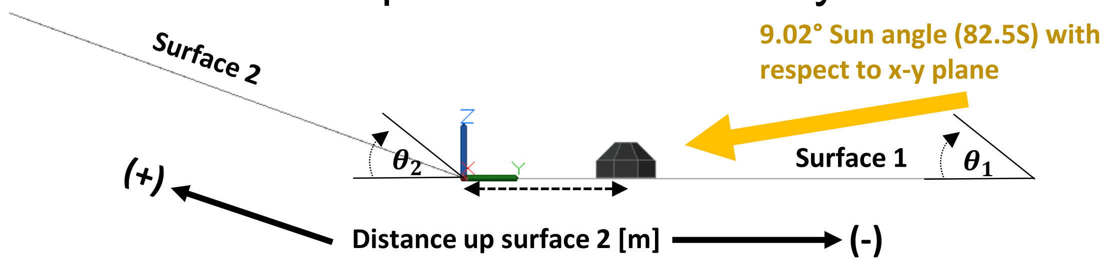
- Worst steady state cases bounded the worst case transient
- For individual panels, steady state cases reject 1% - 12% more heat (ranging 13 to 74W)
    - Largest difference (12%) is for the vertical E radiator
    - 2nd largest is the vertical SE radiator
- Transient results at steady state worst case location are within:
    - 2% except the sun facing tilted panel which predicts 14% more heat rejection

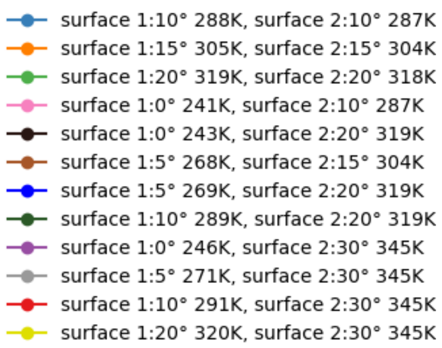
Heat rejection comparison: Red<Orange<Yellow<Green<Blue
N – faces sun, S – faces surface 2 (slope), E – faces +x, SE – faces 45° away from slope, NE – faces 45° away from sun, SS = steady state, Trans = transient.
(-) Q indicates a TSINK > T radiator

$Q = \varepsilon\sigma A\left(T_{rad}^4 - T_{sink}^4\right)$ [W]	TILTED	VERT	HORIZ	TILT_N	TILT_NE	TILT_E	TILT_SE	TILT_S	VERT_N	VERT_NE	VERT_E	VERT_SE	VERT_S	Total
Base value (Trans) Slopes = 0°	20078	12396	2977	1291	1780	2934	3173	3216	-590	272	2217	2608	2938	35450
Worst case value (Trans)	12547	-464	2214	382	878	1801	1596	1522	-2397	-1512	360	788	1213	14343
Worst case value (SS)	12312	-757	2214	369	851	1776	1545	1496	-2413	-1566	317	714	1198	13869
Worst case value (Trans) at SS worst case location	12601	-430	2214	436	880	1801	1596	1522	-2397	-1487	360	806	1213	14361
Value at Surface 1 & Surface 2 at 20° slope (Trans)	14595	2096	2237	492	983	2000	2751	2777	-1974	-1138	594	1483	2310	18929
ΔQ Base - Worst case value (Trans)	7531	12860	763	909	902	1132	1576	1693	1806	1784	1856	1820	1726	21108
ΔQ Base-Worst case value (SS)	7766	13153	762	922	928	1157	1627	1720	1822	1837	1900	1894	1741	21582
ΔQ Base - Worst case value (Trans) at SS worst case location	7477	12826	763	855	900	1132	1576	1693	1806	1758	1856	1803	1726	21089
ΔQ Base - Value at Surface 1& Surface 2 at 20° slope (Trans)	5483	10299	739	799	796	934	422	439	1384	1409	1623	1125	628	16522
ΔQ Worst case Trans - Worst Case SS	235	294	0	13	27	25	51	26	16	54	43	74	15	474
ΔQ Worst Case - Worst case at Worst case SS location (Trans)	-54	-34	0	-54	-2	0	0	0	0	-25	0	-17	0	-19
ΔQ Worst case - value for both surfaces at 20° slope	-2048	-2560	-23	-110	-105	-198	-1154	-1254	-423	-374	-234	-695	-1098	-4586
% |diff Q Worst case Trans - Worst Case SS|	2%	63%	0.0%	3%	3%	1%	3%	2%	1%	4%	12%	9%	1%	3%
% |diff Q Worst Case - Worst case at Worst case SS location (Trans)|	0.4%	7%	0.0%	14%	0%	0.0%	0.0%	0.0%	0.0%	2%	0.0%	2%	0.0%	0.1%
% |diff Q Worst Case - Value at Surface 1& Surface 2 at 20° slope (Trans)|	16%	552%	1%	29%	12%	11%	72%	82%	18%	25%	65%	88%	91%	32%

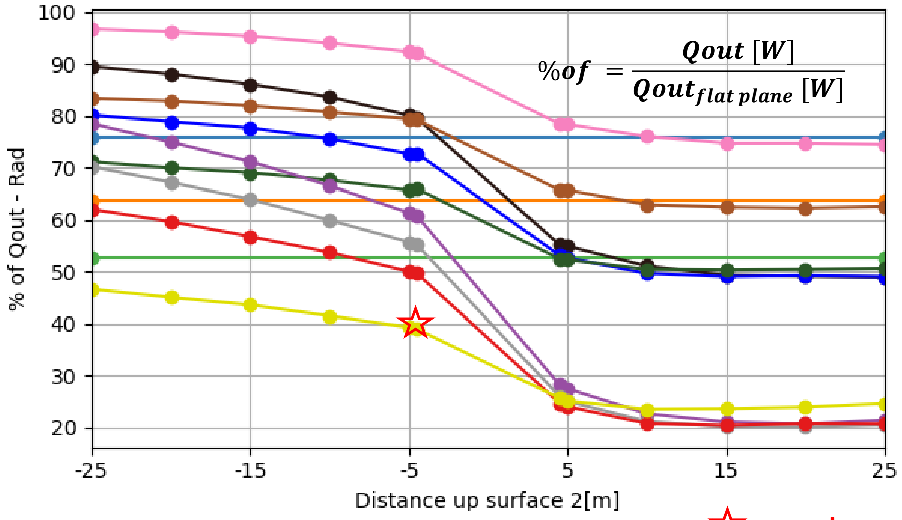
Study #1: Steady vs Trans Worst Cases

- The transient case predicts 3% more total heat rejected by all radiators compared to the steady state case
- Worst case: on a 20° slope 4.5m to 5m away from a 30° slope

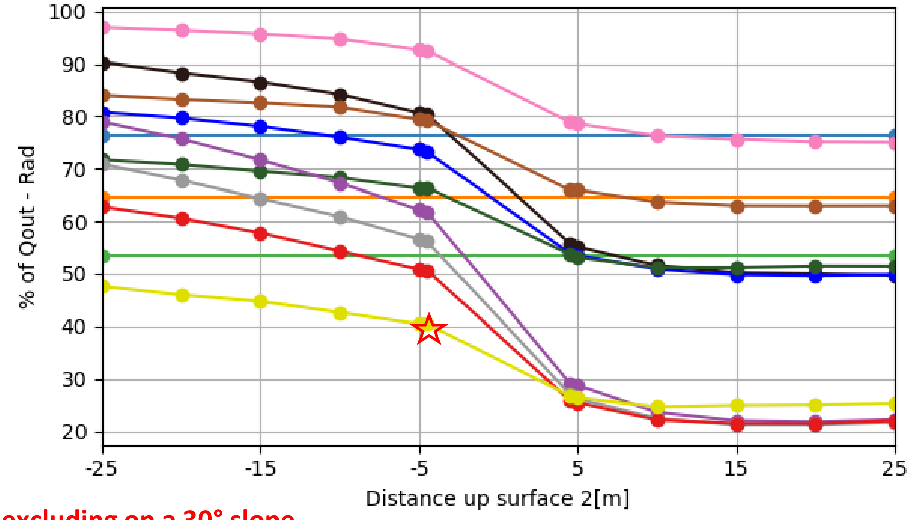




Steady State Results for all radiators:



Transient Results for all radiators:



☆= worst case excluding on a 30° slope

Heat rejection comparison:
Red<Orange<Yellow<Green<Blue
N – faces sun, S – faces surface 2 (slope), E – faces +x, SE – faces 45° away from slope, NE – faces 45° away from sun, SS = steady state, Trans = transient.
(-) Q indicates a TSINK > T radiator

$Q = \varepsilon\sigma A(T_{rad}^4 - T_{sink}^4)$ [W]	**Total**
Base value (Trans) Slopes = 0°	35450
Worst case value (Trans)	14343
Worst case value (SS)	13869
Worst case value (Trans) at SS worst case location	14361
Value at Surface 1 & Surface 2 at 20° slope (Trans)	18929
ΔQ $_{\text{Base - Worst case value (Trans)}}$	21108
ΔQ $_{\text{Base-Worst case value (SS)}}$	21582
ΔQ $_{\text{Base - Worst case value (Trans) at SS worst case location}}$	21089
ΔQ $_{\text{Base - Value at Surface 1\& Surface 2 at 20° slope (Trans)}}$	16522
ΔQ $_{\text{Worst case Trans - Worst Case SS}}$	474
ΔQ $_{\text{Worst Case - Worst case at Worst case SS location (Trans)}}$	-19
ΔQ $_{\text{Worst case - value for both surfaces at 20° slope}}$	-2179
% |diff Q $_{\text{Worst case Trans - Worst Case SS}}$|	**3%**
% |diff Q $_{\text{Worst Case - Worst case at Worst case SS location (Trans)}}$|	0.1%
% |diff Q $_{\text{Base - Value at Surface 1\& Surface 2 at 20° slope (Trans)}}$|	32%

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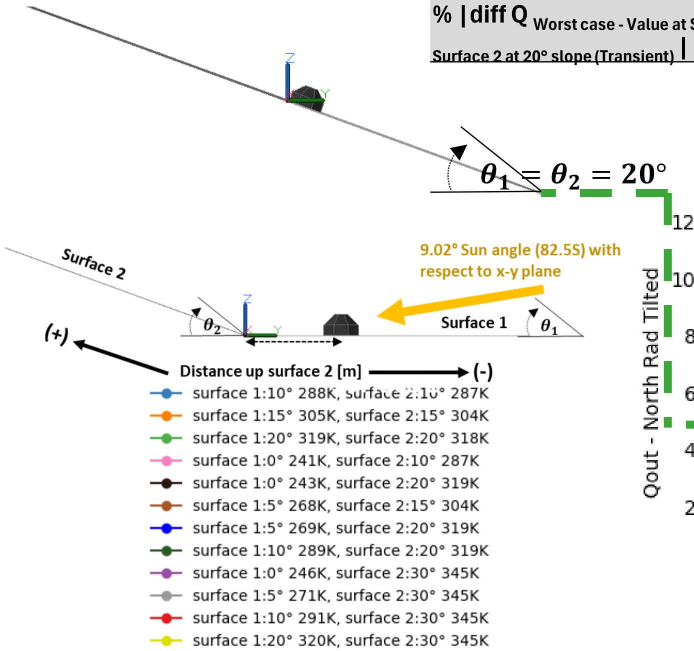
Study #1: Transient Results: Flat vs Split Ground

- **For each radiator panel the _ shaped** ground bounds the worst case (rejecting less heat than the **\ shaped ground)**
- The delta is smallest for the horizontal radiator (1%)
- The delta for the vertical and tilted radiators are significant

Heat Rejection Comparison between Worst Case if $\theta_{2,max} = 30°$ & $\theta_{max\ for\ asset} = 20°$ and case where $\theta_1 = \theta_2 = 20°$
N – faces sun, S – faces surface 2 (slope), E – faces +x, SE – faces 45° away from slope, NE – faces 45° away from sun
(-) Q indicates a TSINK > T radiator Red<Orange<Green

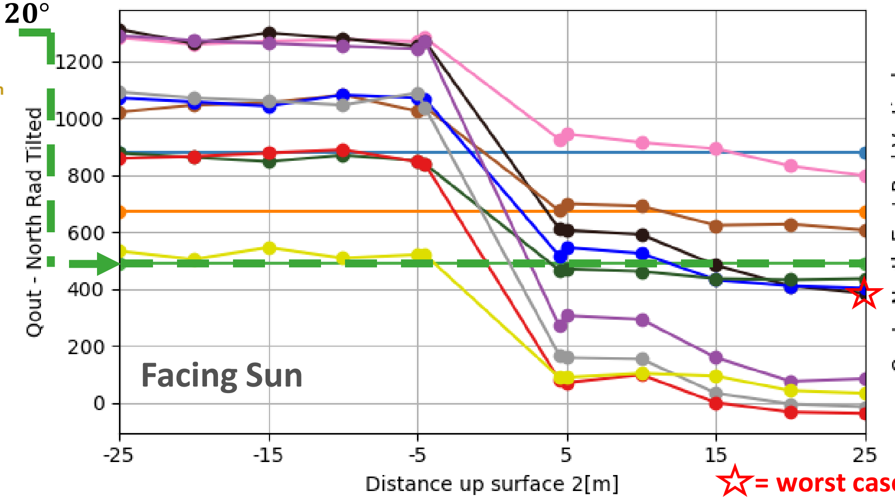
$Q = \varepsilon\sigma A(T_{rad}^4 - T_{sink}^4)$ [W]	TILTED	VERT	HORIZ	TILT_N	TILT_NE	TILT_E	TILT_SE	TILT_S	VERT_N	VERT_NE	VERT_E	VERT_SE	VERT_S	Total
Worst case value (Transient)	12547	-464	2214	382	878	1801	1596	1522	-2397	-1512	360	788	1213	14343
Value at Surface 1 & Surface 2 at 20° slope (Transient)	14595	2096	2237	492	983	2000	2751	2777	-1974	-1138	594	1483	2310	18929
ΔQ Worst case - value for both surfaces at 20° slope	-2048	-2560	-23	-110	-105	-198	-1154	-1254	-423	-374	-234	-695	-1098	-4586
% |diff Q Worst case - Value at Surface 1& Surface 2 at 20° slope (Transient)|	**16%**	**552%**	**1%**	**29%**	**12%**	**11%**	**72%**	**82%**	**18%**	**25%**	**65%**	**88%**	**91%**	**32%**

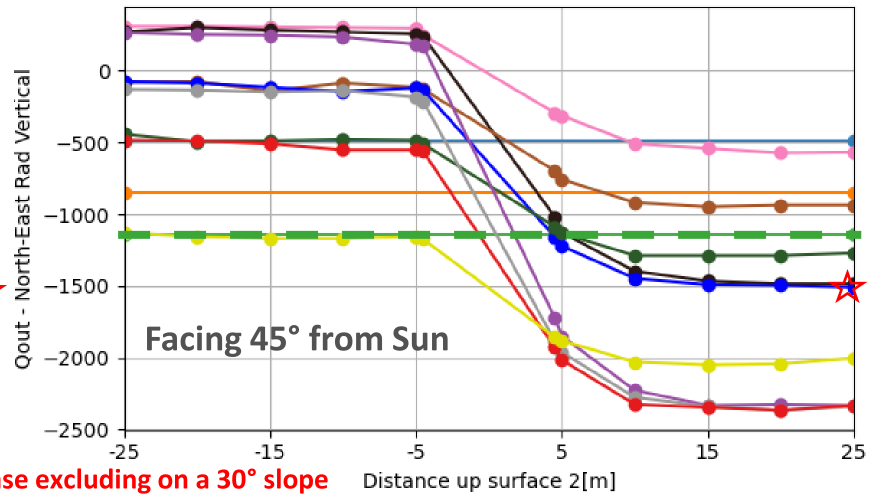


Flat ground has more heat exiting the radiator

Flat ground has less heat entering the radiator

Transient Results





☆= worst case excluding on a 30° slope

Study #1: Transient Results: Flat vs Split Ground: If surface 2’s max slope was 20°

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- **For each radiator panel the _ shaped** ground bounds the worst case (rejecting less heat than the **\ shaped ground)**
- The delta is smallest for the horizontal radiator (1%), The delta for the vertical and tilted radiators

Heat Rejection Comparison between Worst Case if $\theta_{2,max} = 20°$ and case where $\theta_1 = \theta_2 = 20°$

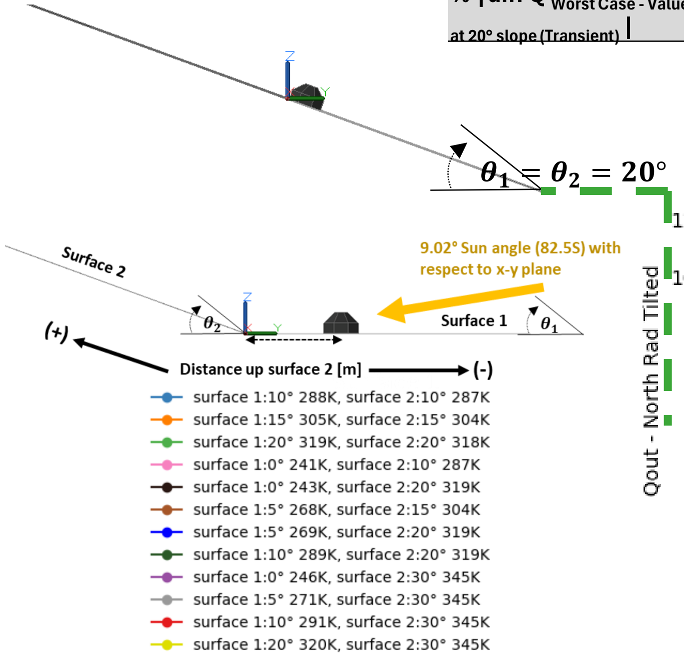
N – faces sun, S – faces surface 2 (slope), E – faces +x, SE – faces 45° away from slope, NE – faces 45° away from sun

(-) Q indicates a TSINK > T radiator

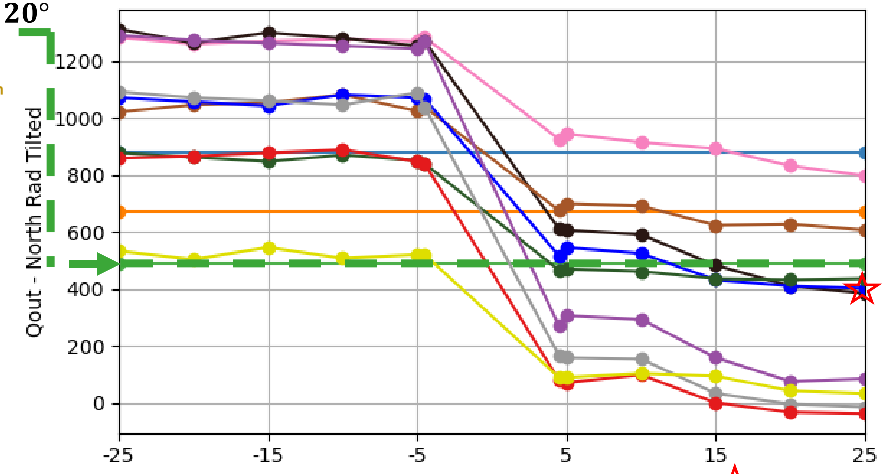
$Q = \varepsilon\sigma A(T_{rad}^4 - T_{sink}^4)$ [W]	TILTED	VERT	HORIZ	TILT_N	TILT_NE	TILT_E	TILT_SE	TILT_S	VERT_N	VERT_NE	VERT_E	VERT_SE	VERT_S	Total
Worst Case Surface 1 slope	0	5	0	0	5	5	0	0	5	5	0	20	0	0
Worst Case Surface 2 slope	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Worst Case Distance up surface 2 [m]	25	20	4.5	25	20	20	-5	-5	20	25	15	0	-10	25
Worst case value (Transient)	14268	1084	2214	382	878	1966	2383	2366	-2397	-1512	484	1483	2078	17600
Value at Surface 1 & Surface 2 at 20° slope (Transient)	14595	2096	2237	492	983	2000	2751	2777	-1974	-1138	594	1483	2310	18929
ΔQ Worst case - value for both surfaces at 20° slope	-327	-1013	-23	-110	-105	-34	-368	-411	-423	-374	-110	0	-232	-1329
% |diff Q Worst Case - Value at Surface 1& Surface 2 at 20° slope (Transient) |	**2%**	**93%**	**1%**	**29%**	**12%**	**2%**	**15%**	**17%**	**18%**	**25%**	**23%**	**0%**	**11%**	**8%**

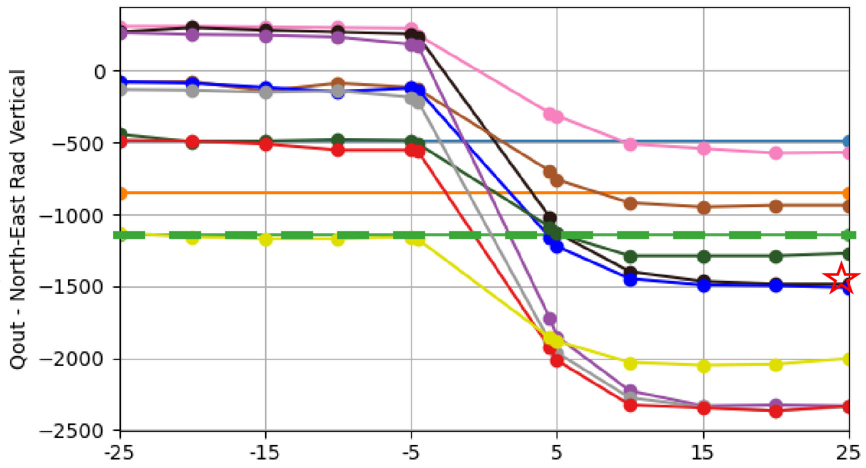
Flat ground has more heat exiting the radiator

Flat ground has less heat entering the radiator



Transient Results





☆= worst case excluding all 30° slopes

Study #1: Conclusions

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1) What is the worst-case location for the 5.5m tall asset?
   - The overall worst case is on a 20° slope 4.5m to 5m away from a 30° slope.
   - The per-panel worst case depends on radiator orientation.
     - For panels that see the slope as well as panels that see neither the slope nor the sun, it tends to be on a flat ground (0° incline) just before a 30° slope.
     - For panels that see the sun, it tends to be 20 to 25m up onto a 20° slope near a surface with a lower incline (~5-10°).
     - For the horizontal panels, it is slightly up 4.5m onto a 20° sloped surface near a flat ground (0° incline). The resulting heat rejection was very close to the 'on a 20° slope just before a 30° slope' case.
2) Can steady state analysis be used to identify the worst case?
   - Yes, in this study the worst-case steady state results always bounded the worst-case transient results.
3) Are there cases where we could ignore a slope?
   - Depends. For example, the worst-case heat rejection of the asset's horizontal radiator, which was on the **_ shaped ground**, was within 1% (23W) of that predicted with the **\ shaped ground.**
   - However, for all over cases ignoring a slope and using a **\ shaped ground** for design purposes would significantly underpredict the heat rejection (32% for asset's total heat rejection and 8% of asset's total heat rejection if 30° slopes were excluded).
4) If Surface 2 is sloped, what is the impact if Surface 1 is also sloped?
   - The impact of Surface 1's incline is small unless the asset is on Surface 1.

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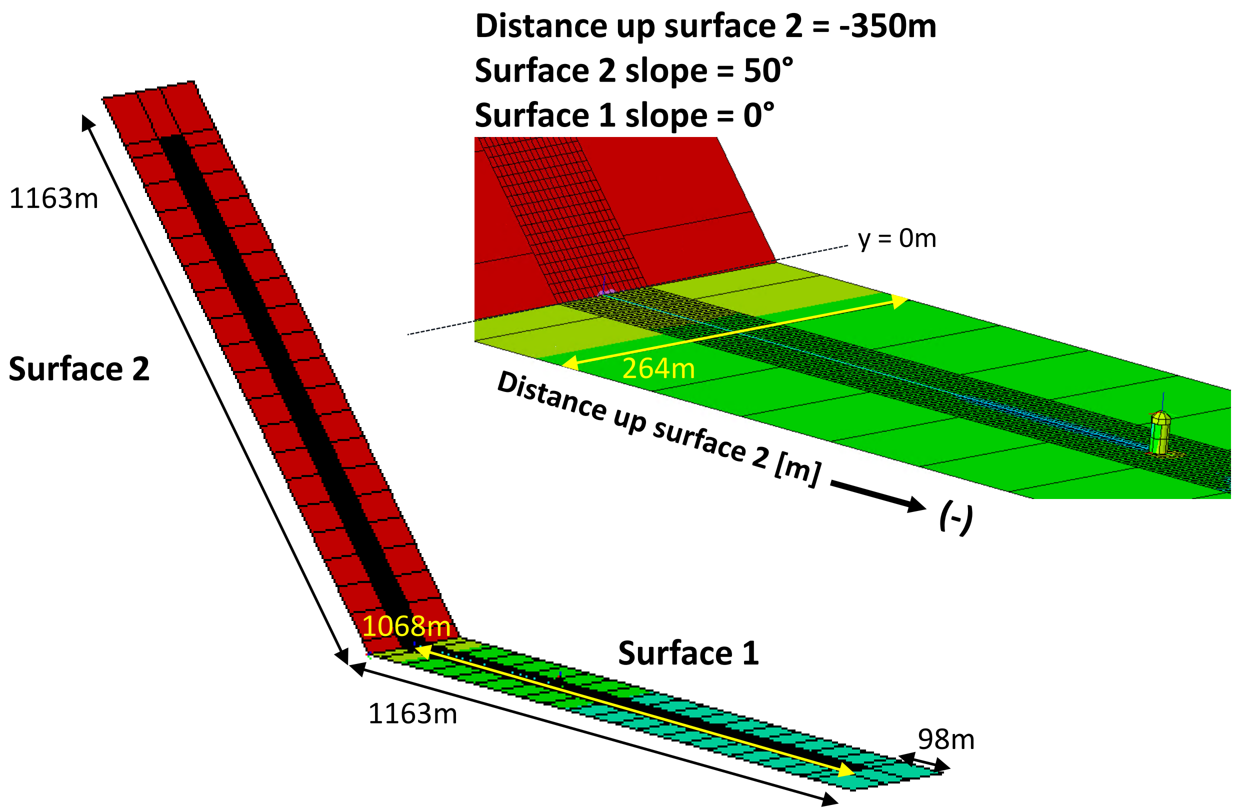
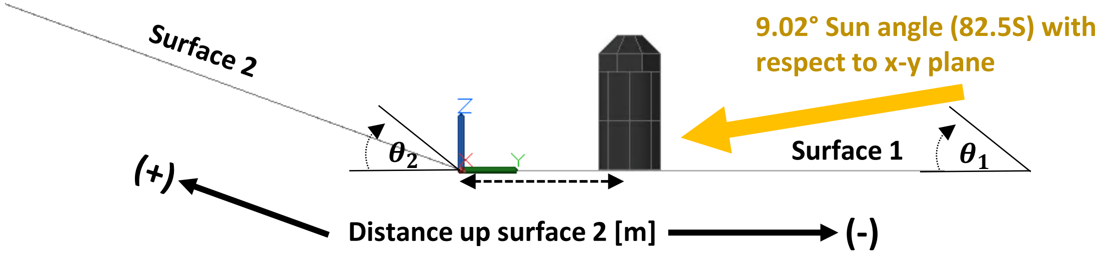
Study #2: Methodology

- Predict radiator sink temperatures (TSINKS) and heat rejections for the 20m asset varying the asset's location and ground slopes.
- Asset location with respect to its center:
  - 10° & 20° slopes: -1km to 100m from y =0
    - i.e.,1km away from the slope up to 100m onto it
  - 30°+ slopes: -1km to -10m
    - Do not expected assets on slopes >20°[20-21]
- Slopes of Surfaces 1 and 2, measured from x-y plane toward the sun:
  - Both 10°, 20° (flat surface)
  - Surface 1: 0° / Surface 2: 10, 20°, 30°, 40°, 50°, 60°, 70°, 80°, 90°
    - "A very small fraction (~0.25%) globally on the Moon have slopes steeper than 32° at 25-m baseline"[5]
    - A 90° slope's impact is intended to be > impact from a nearby asset
  - Surface 1: 10° / Surface 2: 20°, 30°
  - Surface 1: 20° / Surface 2: 30°
  - Example: a 10° slope increases local solar elevation angle by 10°
- **Cases set reflects desire to see:**
  - What is the worst case – overall, and for each radiator orientation if the asset can approach a max slope of 30°?
  - Can you be far enough away from a slope for its impact to be negligible?
  - Can you bound the worst case with a single surface tilted surface?

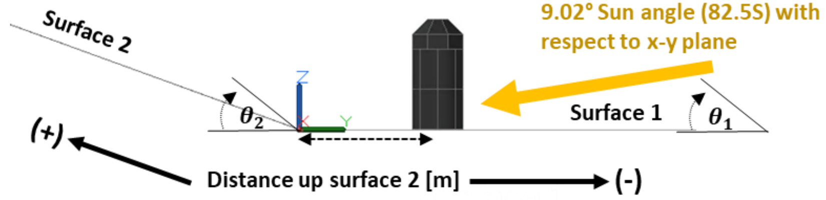
Distance up surface 2 [m]
100
75
50
40
30
20
10
-10
-20
-30
-40
-50
-100
-150
-200
-250
-300
-350
-400
-450
-500
-600
-700
-800
-900
-1000

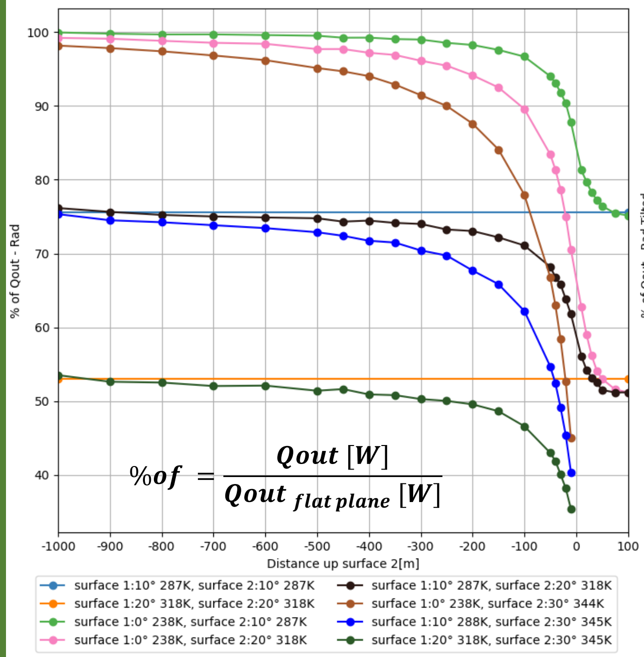




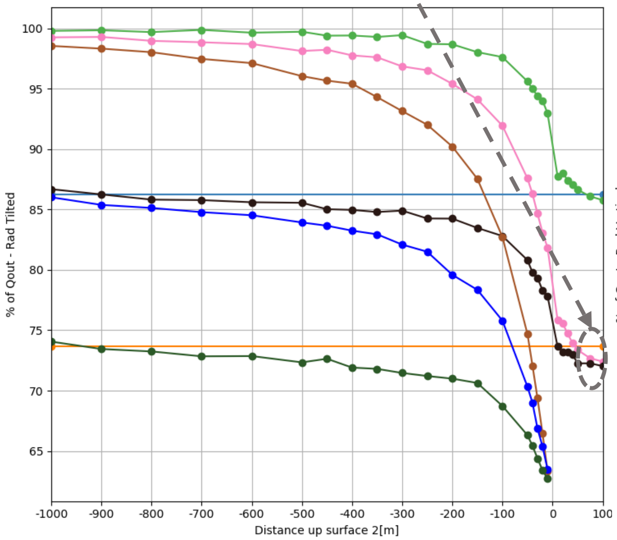
Study #2: Steady State Results: Slope Impact on Heat Rejection for slopes ≤30°

- Worst case:
  - Surface 1 = 20°, Surface 2 = 30°, just before the incline
- Excluding all 30° slopes, the worst case would be:
  - Surface 1 = 0-10°, Surface 2 = 20°, ~+100m up the incline
- The sum of heat rejected by the tilted radiators is less for a **_ shaped** ground than a **\ shaped ground**
  - +100m up a 20° slope with surface 1 slopes = 0° rejects a total of 4% less heat (708W) than a flat ground with 20° slope (slope of surface 1 & surface 2 = 20°)

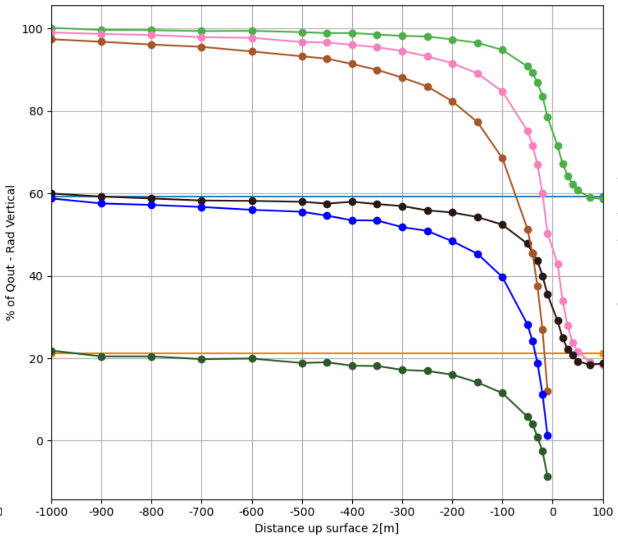




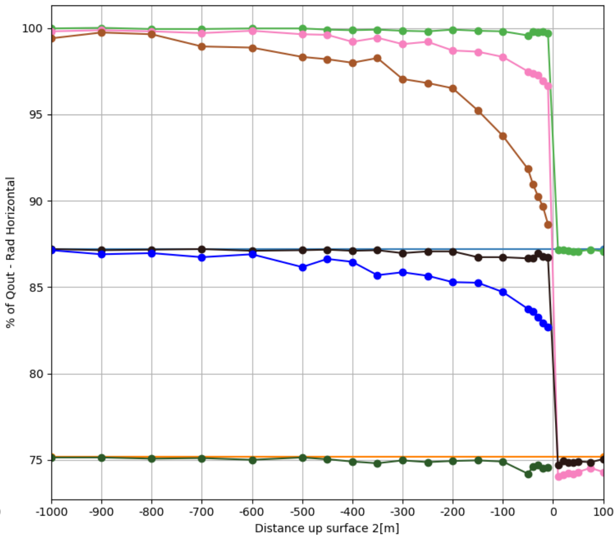
$$\%of = \frac{Qout\ [W]}{Qout_{\ flat\ plane}\ [W]}$$



$$\%of = \frac{Qout\ tilted\ rad\ [W]}{Qout\ tilted\ rad_{flat\ plane}\ [W]}$$



$$\%of = \frac{Qout\ vertical\ rad\ [W]}{Qoutverticalrad_{flat\ plane}\ [W]}$$



$$\%of = \frac{Qout\ horizontal\ rad\ [W]}{Qout\ horizontal\ rad_{flat\ plane}\ [W]}$$

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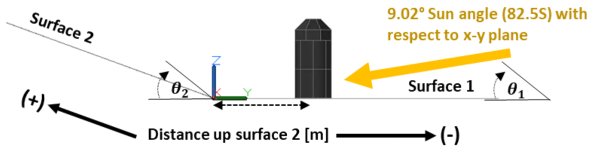
Study #2: Steady State Results: Slope Impact on Heat Rejection for slopes ≤30°

HLS

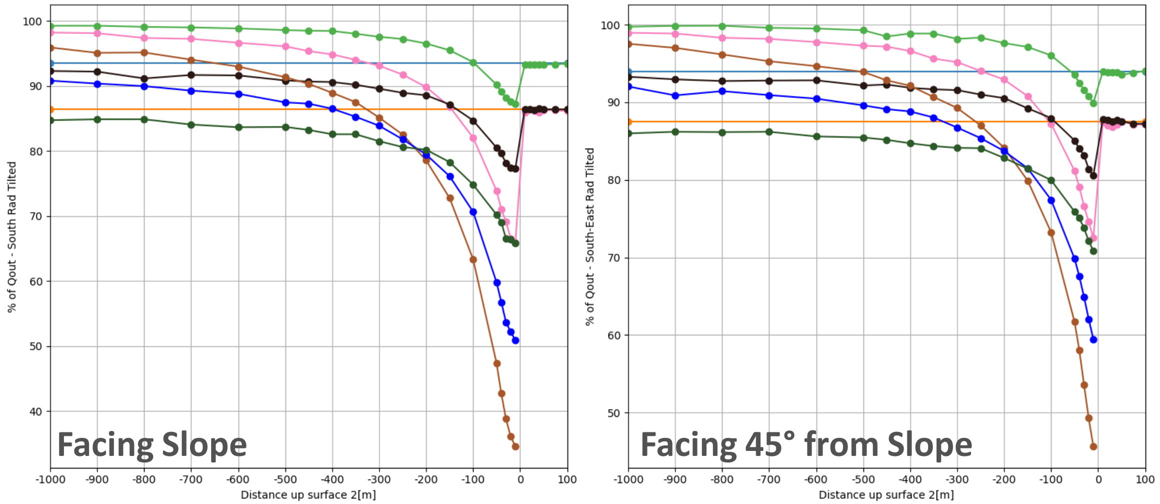
Tilted Panels (i.e., Direction) Specific Worst Cases:*

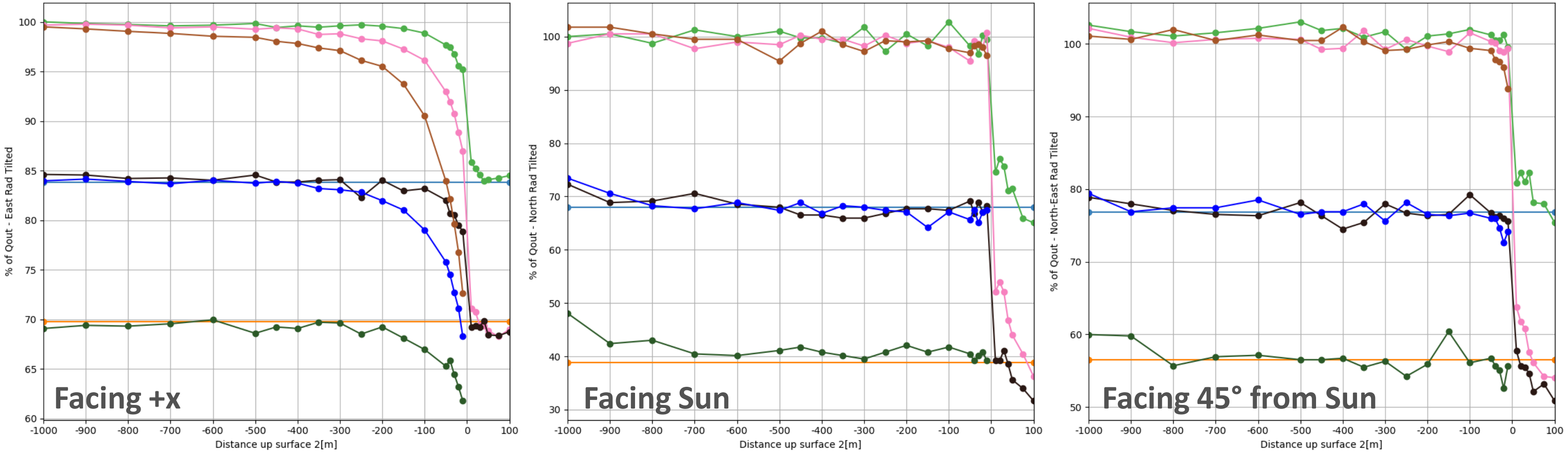
- Panels viewing the slope: on a 0° slope 10m before a 30° slope (closest distance to slope tested)
- Panels viewing the sun: +100m up a 20° sloped surface 2 where surface 1 is 10°
- Panel with no view to slope or sun: on a 20° sloped surface 10m before a 30° slope



$$\%of = \frac{Qout\ [W]}{Qout_{flat\ plane}\ [W]}$$

- surface 1:10° 287K, surface 2:10° 287K
- surface 1:20° 318K, surface 2:20° 318K
- surface 1:0° 238K, surface 2:10° 287K
- surface 1:0° 238K, surface 2:20° 318K
- surface 1:10° 287K, surface 2:20° 318K
- surface 1:0° 238K, surface 2:30° 344K
- surface 1:10° 288K, surface 2:30° 345K
- surface 1:20° 318K, surface 2:30° 345K

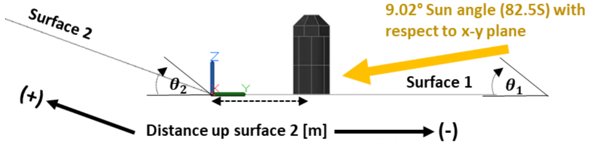




Study #2: Steady State Results: Slope Impact on Heat Rejection for slopes ≤30°

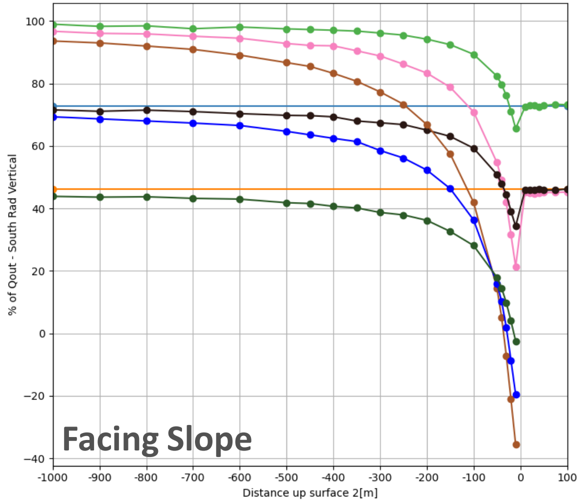
Vertical Panels (i.e., Direction) Specific Worst Cases:*

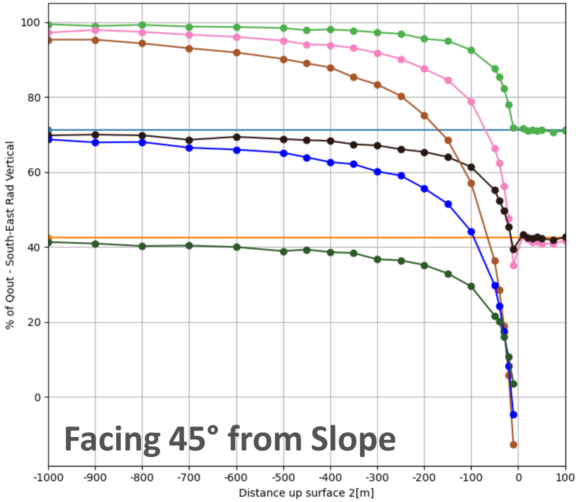
- Panels viewing the slope: on a 0° slope 10m before a 30° slope (closest distance to slope tested)
- Panels viewing the sun: +100m up a 20° sloped surface 2 where surface 1 is 10°
- Panel with no view to slope or sun: on a 20° sloped surface 10m before a 30° slope

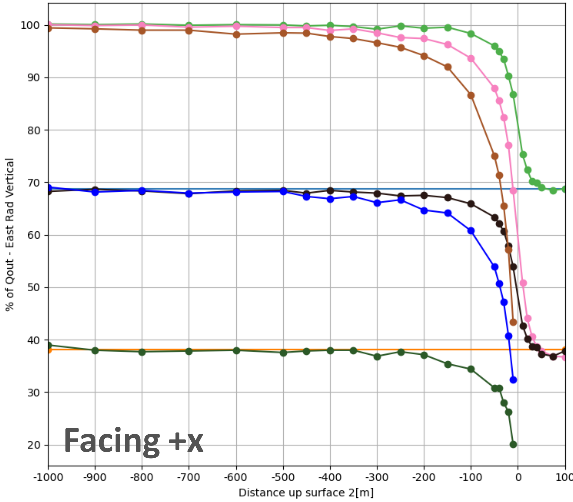


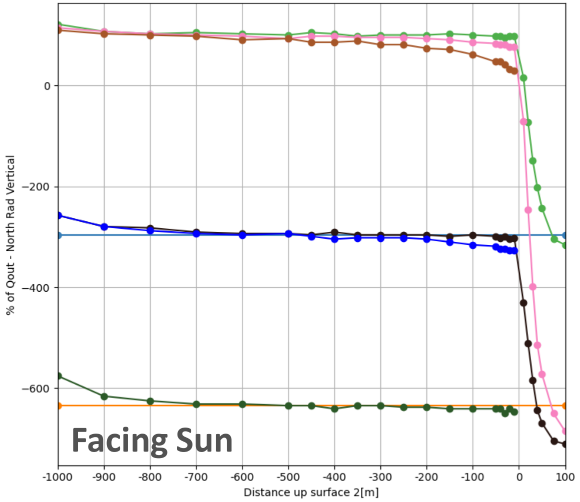
$$\%of = \frac{Qout\,[W]}{Qout_{flat\ plane}\,[W]}$$

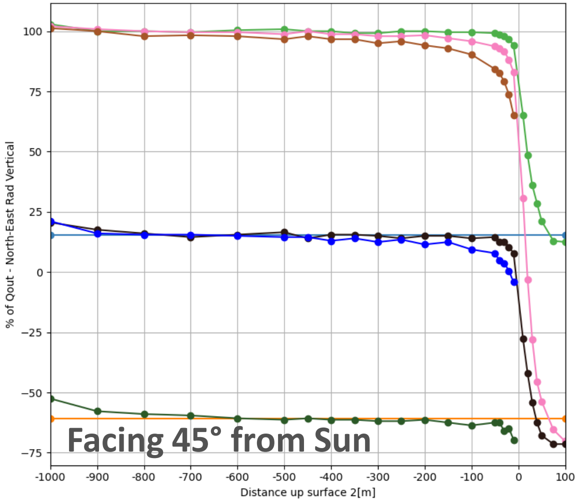
- surface 1:10° 287K, surface 2:10° 287K
- surface 1:20° 318K, surface 2:20° 318K
- surface 1:0° 238K, surface 2:10° 287K
- surface 1:0° 238K, surface 2:20° 318K
- surface 1:10° 287K, surface 2:20° 318K
- surface 1:0° 238K, surface 2:30° 344K
- surface 1:10° 288K, surface 2:30° 345K
- surface 1:20° 318K, surface 2:30° 345K











Study#2 Worst Case Heat Rejection Summary

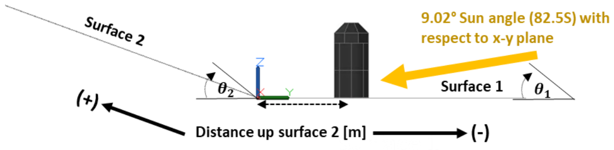
- Per panel worst case depends on direction – e.g., pointing to or away from the sun.
- Radiator tilt 45° verses vertical does not impact worst case configuration.

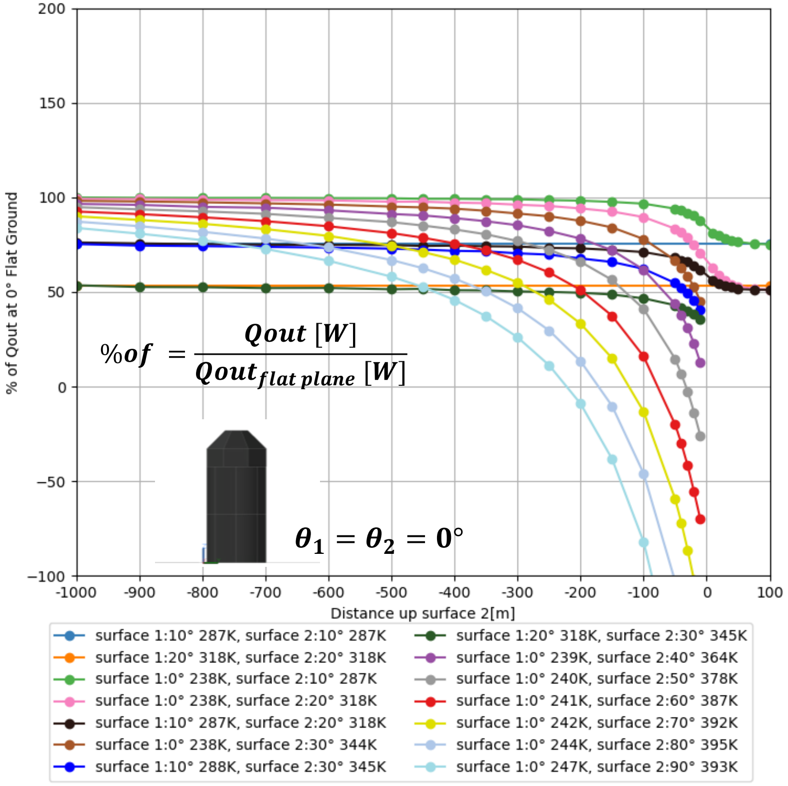
Steady State Heat Rejection Comparisons:
N – faces sun, S – faces surface 2 (slope), E – faces +x, SE – faces 45° away from slope, NE – faces 45° away from sun
(-) Q indicates a TSINK > T radiator

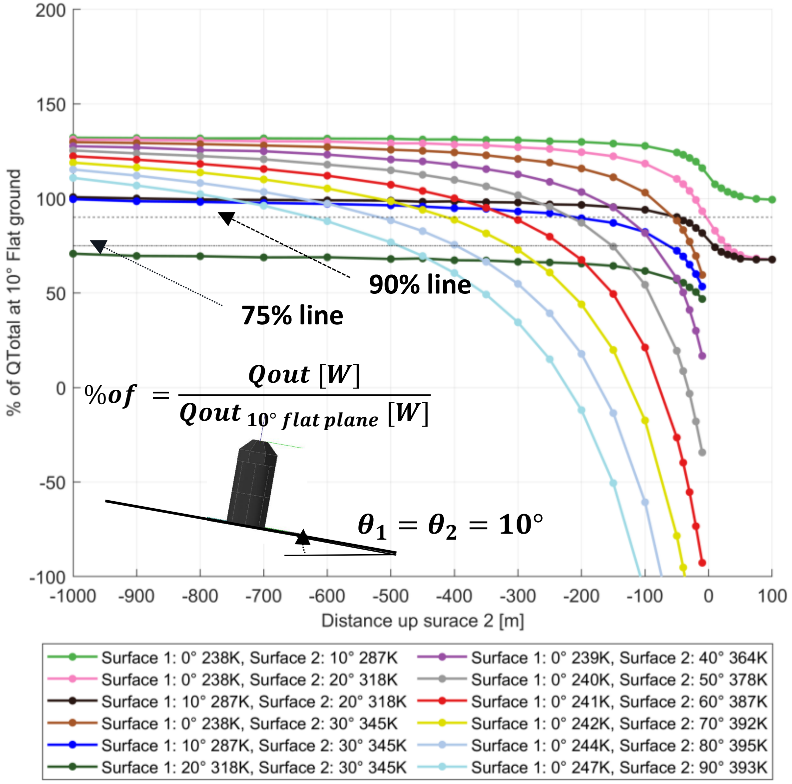
$Q = \varepsilon\sigma A\left(T_{rad}^4 - T_{sink}^4\right)$ [W]		TILTED	VERT	HORIZ	TILT_N	TILT_NE	TILT_E	TILT_SE	TILT_S	VERT_N	VERT_NE	VERT_E	VERT_SE	VERT_S	Total
Base value Slopes = 0°		20165	15121	2977	1297	1761	2936	3159	3166	188	898	2572	2653	2710	38263
$\Delta Q_{\text{Base case - Worst case}}$		7518	16439	772	887	865	1121	1716	2071	1539	1541	2058	2990	3676	24715
% $\lvert$diff $Q_{\text{Base case - Worst case}}\rvert$		37%	109%	26%	68%	49%	38%	54%	65%	820%	172%	80%	113%	136%	65%
Worst case – with restrictions: no slopes >30°, asset cannot be on slopes >20°	**Surface 1 slope**	20	20	0	10	10	20	0	0	10	10	20	0	0	20
	Surface 2 slope	30	30	20	20	20	30	30	30	20	20	30	30	30	30
	Distance up surface 2 [m]	-10	-10	10	100	100	-10	-10	-10	100	100	-10	-10	-10	-10
	Worst case value [W]	12647	-1318	2204	409	896	1814	1443	1096	-1351	-643	514	-337	-967	13548
Value at Surface 1 & Surface 2 at 20° slope		14854	3201	2238	504	994	2050	2767	2736	-1205	-545	979	1128	1251	20293
$\Delta Q_{\text{Worst case - value for both surfaces at 20° slope}}$		-2207	-4519	-33	-95	-98	-235	-1324	-1640	-146	-98	-465	-1465	-2218	-6745
% $\lvert$diff $Q_{\text{Worst case - Value at Surface 1\& Surface 2 at 20° slope}}\rvert$		17%	343%	2%	23%	11%	13%	92%	150%	11%	15%	91%	435%	229%	50%
Value at Surface 1 at 20° slope & Surface 2 at 30° =10m from surface 2		12647	-1318	2220	507	979	1814	2238	2086	-1228	-626	514	93	-65	13548
$\Delta Q_{\text{Worst case - Value at Surface 1 at 20° slope \& Surface 2 at 30° =10m from surface 2}}$		0	0	-15	-98	-83	0	-795	-990	-123	-17	0	-430	-902	0
% $\lvert$diff $Q_{\text{Worst case - Value at Surface 1 at 20° slope \& Surface 2 at 30° =10m from surface 2}}\rvert$		0%	0%	1%	24%	9%	0%	55%	90%	9%	3%	0%	128%	93%	0%
Worst case – with restrictions: no slopes >20°, asset cannot be on slopes >20°	**Surface 1 slope**	10	0	0	10	10	0	0	0	10	10	0	0	0	0
	Surface 2 slope	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	Distance up surface 2 [m]	100	100	10	100	100	75	-10	-10	100	100	100	-10	-10	100
	Worst case [W]	14526	2771	2204	409	896	2004	2290	2088	-1351	-643	945	934	576	19584
$\Delta Q_{\text{Worst case - value for both surfaces at 20° slope}}$		-327	-430	-33	-95	-98	-46	-477	-648	-146	-98	-34	-194	-675	-708
% $\lvert$diff $Q_{\text{Worst case- value at Surface 1\& Surface 2 at 20° slope}}\rvert$		2%	16%	2%	23%	11%	2%	21%	31%	11%	15%	4%	21%	117%	4%

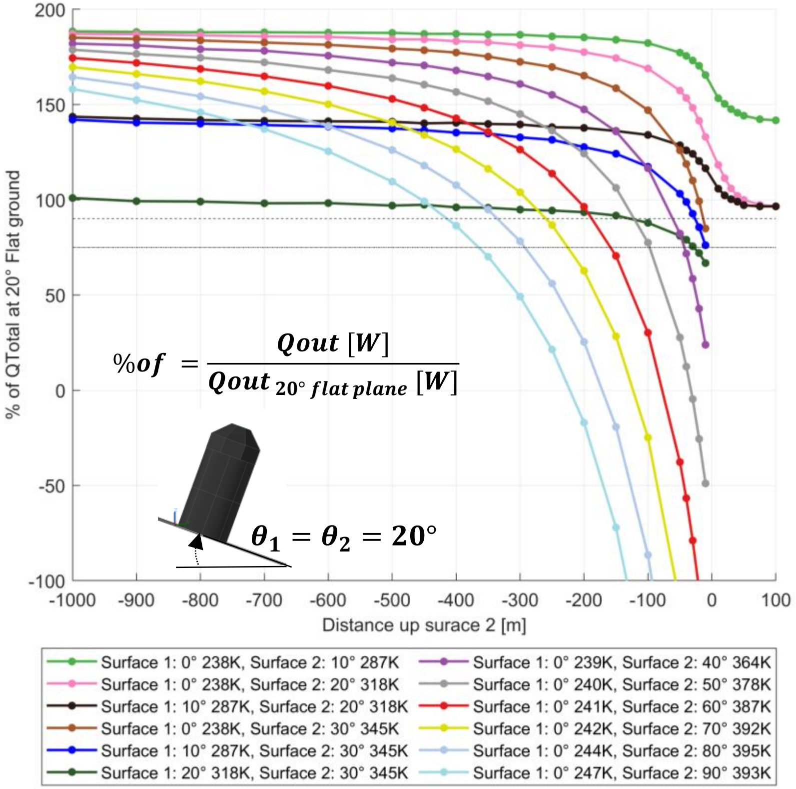
Study #2: Steady State Results: Slope Impact on Heat Rejection vs a 0°, 10°, or 20° Flat Ground

- **Slope impacts on total overall heat rejection:**
  - If the asset, with horizontal, tilted, and vertical radiators, was designed assuming 0° slope, existing on a 10° or 20° slope would exceed a 10% Q margin*.
  - If the asset was designed for a 10° slope, landing on a 10° <209m from a 30° slope would exceed a 10% Q margin , landing on a 10° <49m from a 20° slope would exceed a 10% Q margin.
  - If the asset was designed for a 20° slope, landing on a 20° <127m from a 30° slope would exceed a 10% Q margin.
  - Note: the impacts to radiators with different orientations are different.
  - Note: % of Q values with respect to a 10° or 20° flat plane can be >100.









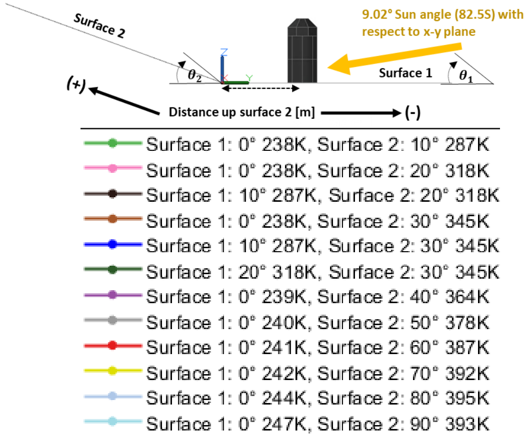
*Use 10% margin as an example since it maps to the typical 10% radiator area margin recommended in SMC-S-016[19]

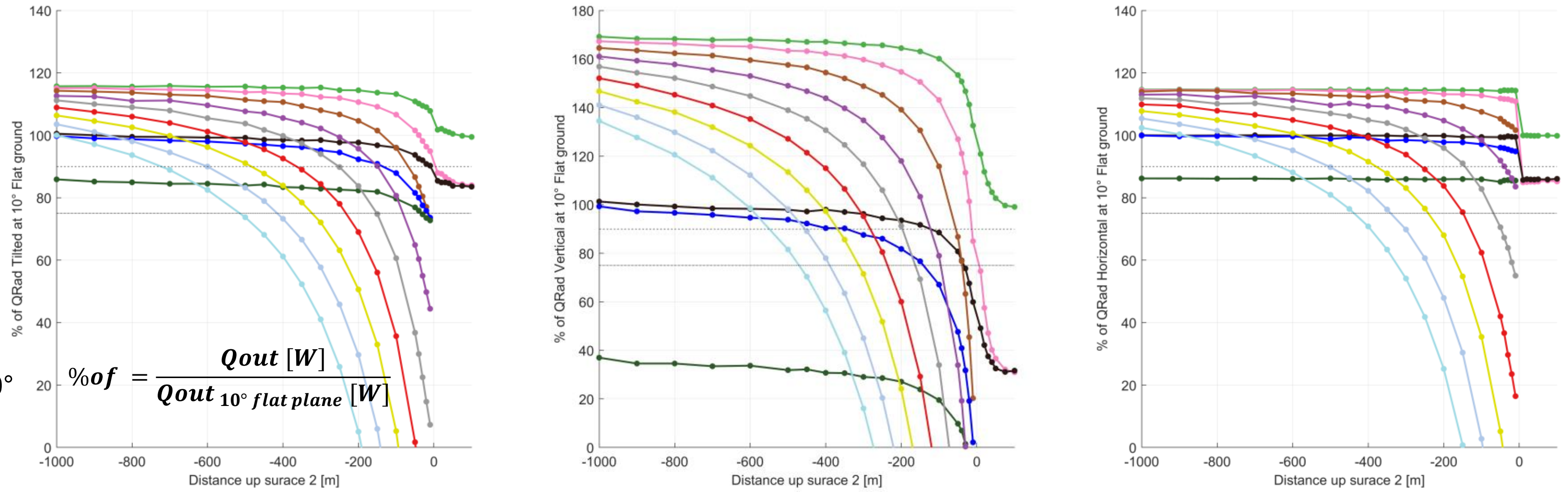
Study #2: Steady State Results: Slope Impact on Heat Rejection vs a 0°, 10°, or 20° Flat Ground

Tilted Panels
- _ **shaped ground** cases where surface 2's slope equals the slope \ **shaped ground** predicts similar results (≤2% different).
- Being near a 20° slope will not cause $Qout < 90\% Qout_{\ 10°\ flat\ plane}$.
- Being on a 20° slope near a 30° will cause $Qout < 90\% Qout_{\ 20°\ flat\ plane}$

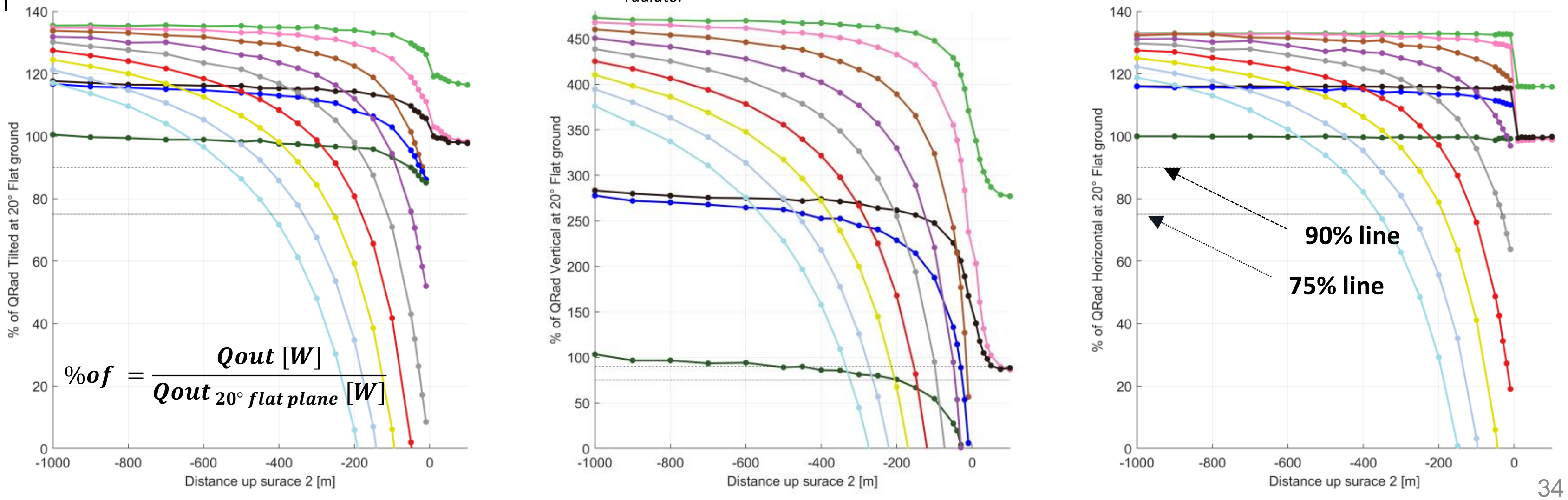
Vertical Panels
- Being on a 10° near a 20° slope will cause $Qout < 90\% Qout_{\ 10°\ flat\ plane}$.
- Being on a 20° slope on a 20° slope near a 30° will cause $Qout < 90\% Qout_{\ 20°\ flat\ plane}$

Horizontal Panels
- Nearby slopes need to be ~30° steeper than the 10° or 20° flat ground to drop heat rejection by >10%

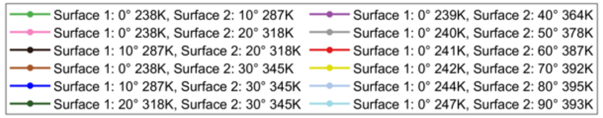




Not showing - % of Qs , where slope causes TSINK > T $_{radiator}$

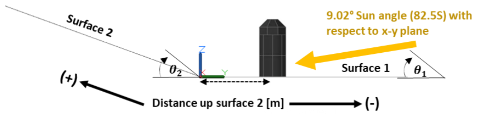


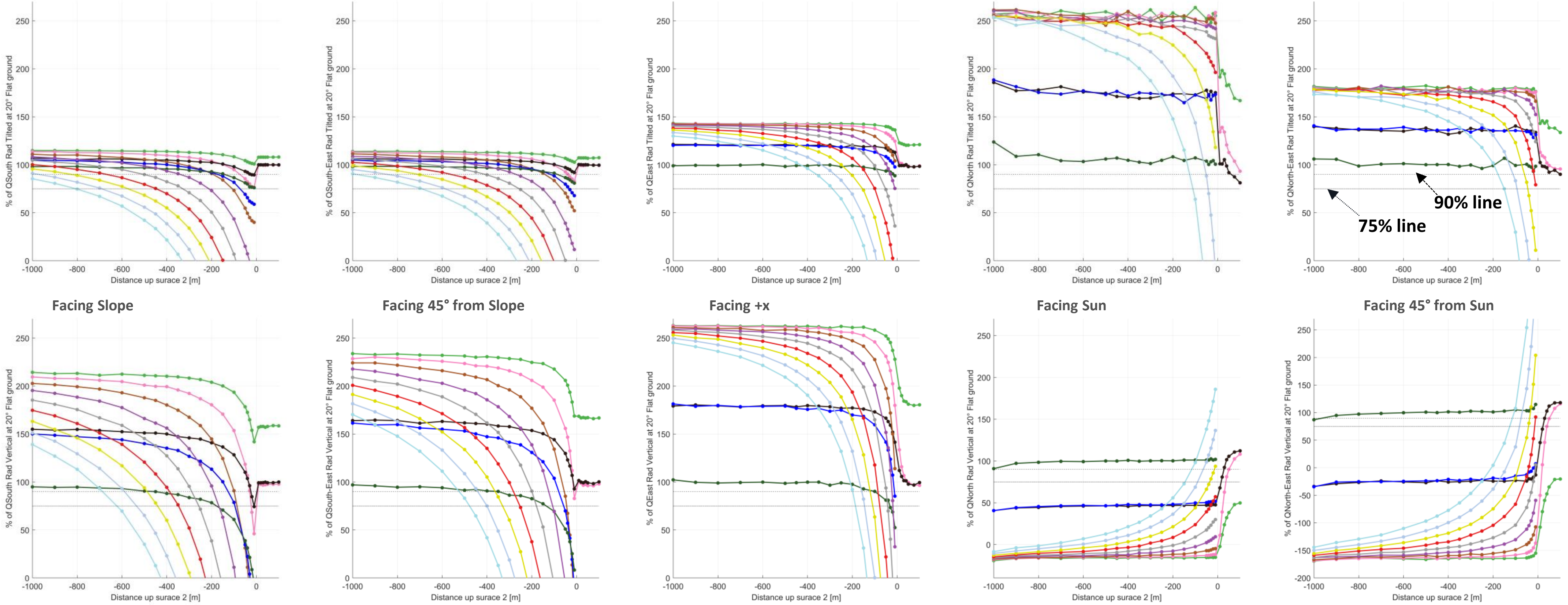
Study #2: Steady State Results: Slope Impact on Heat Rejection vs a 20° Flat Ground



$$\%of\ Q = \frac{Qout\ [W]}{Qout_{20°\ flat\ plane}\ [W]}$$

Not showing - % of Qs , where slope causes TSINK > T $_{radiator}$, except sun and 45° from sun facing vertical panels which do not reject heat in the $Qout_{20°\ flat\ plane}$ case





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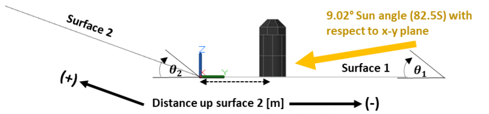
Study #2: Steady State Results: Slope Impact on Heat Rejection vs a 10° Flat Ground

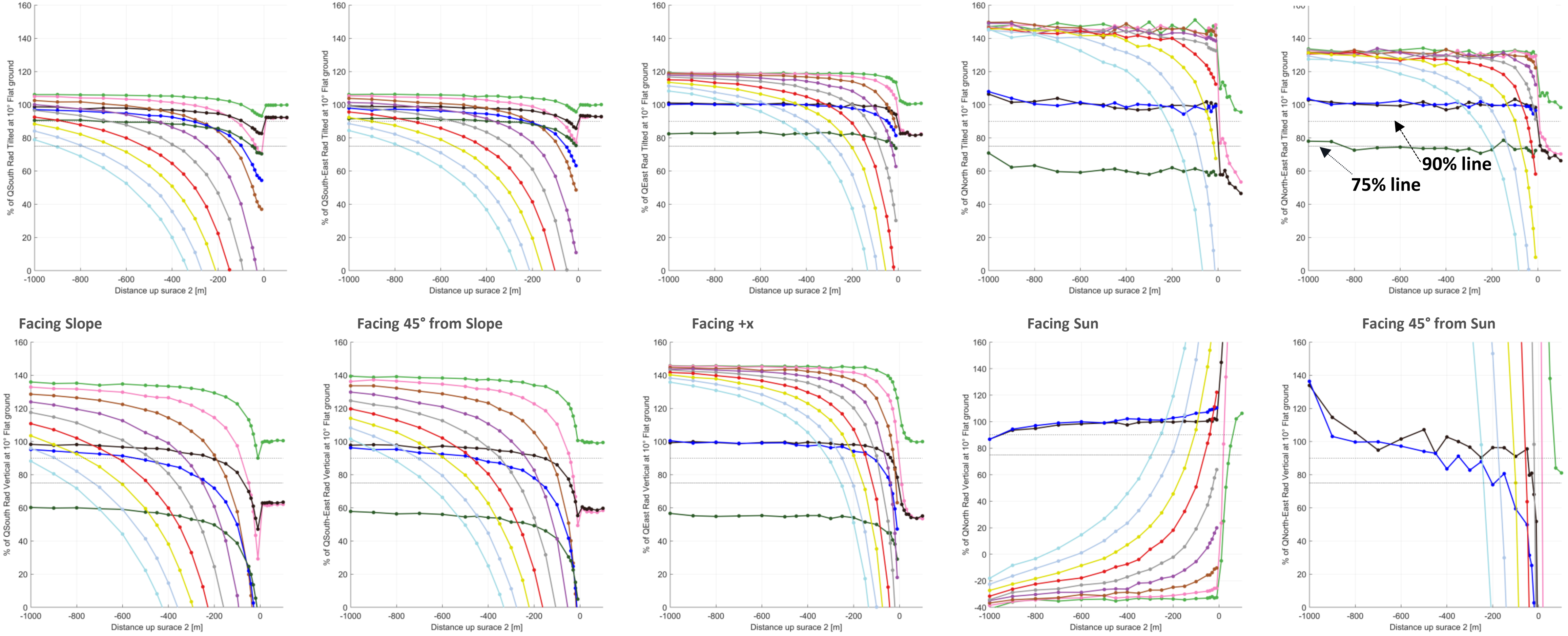
HLS

- Surface 1: 0° 238K, Surface 2: 10° 287K
- Surface 1: 0° 238K, Surface 2: 20° 318K
- Surface 1: 10° 287K, Surface 2: 20° 318K
- Surface 1: 0° 238K, Surface 2: 30° 345K
- Surface 1: 10° 287K, Surface 2: 30° 345K
- Surface 1: 20° 318K, Surface 2: 30° 345K
- Surface 1: 0° 239K, Surface 2: 40° 364K
- Surface 1: 0° 240K, Surface 2: 50° 378K
- Surface 1: 0° 241K, Surface 2: 60° 387K
- Surface 1: 0° 242K, Surface 2: 70° 392K
- Surface 1: 0° 244K, Surface 2: 80° 395K
- Surface 1: 0° 247K, Surface 2: 90° 393K

$$\%of\ Q = \frac{Qout\ [W]}{Qout_{\ 10°\ flat\ plane}\ [W]}$$

Not showing - % of Qs , where slope causes TSINK > T $_{radiator}$, except sun facing vertical panels which does not reject heat in the Qout $_{10°\ flat\ plane}$ case





Study #2: Distances where Slope Impact on Heat Rejection is Negligible

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Can you be far enough away from a slope for its impact to be negligible?

- Yes – the tables show tested points where slops degrade rejection by ≤99% and ≤90%.

- The 99% criteria is not met for the totals of the tilted, vertical, or horizontal radiators when
  - surface 1=0º & surface 2>30º
  - surface 1≥10º & surface 2≥30º
- A single surface sloped by 10º and 20º always exceed these criteria.

However, it's common to design to a 10º - 20º sloped surface.

Test point distance up Surface 2 where Qout ≤ 90% of Q out for a flat plane.

surface 1 [°]	surface 2 [°]	Total TILTED [m]	Total VERTICAL [m]	HORIZ [m]	TILT_N [m]	TILT_NE [m]	TILT_E [m]	TILT_SE [m]	TILT_S [m]	VERT_N [m]	VERT_NE [m]	VERT_E [m]	VERT_SE [m]	VERT_S [m]
10	10	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$
20	20	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$
0	10	-10	-50	-10	-10	-10	-10	100	100	-10	-10	-20	-100	-150
0	20	-100	-200	-10	-10	-10	-30	-150	-250	-150	-30	-100	-250	-350
10	20	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	-200	-350	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$
0	30	-200	-400	-30	-10	-10	-100	-350	-450	-500	-100	-150	-500	-700
10	30	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	-600	-900	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$
20	30	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$
0	40	-400	-600	-200	-10	-30	-200	-600	-700	-800	-300	-250	-900	-1000
0	50	-600	-800	-350	-10	-100	-350	-800	-1000	-1000	-500	-350	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$
0	60	-800	-1000	-600	-150	-150	-500	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	-1000	-800	-450	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$
0	70	-900	N/A	-800	-250	-300	-700	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	-900	-600	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$
0	80	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	-900	-450	-450	-800	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	-1000	-700	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$
0	90	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	-600	-600	-1000	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$	-900	All<0.9Q$_{@0°}$	All<0.9Q$_{@0°}$

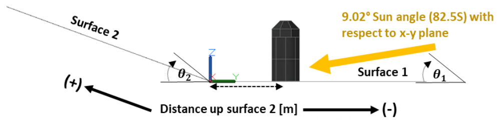
Test point distance up Surface 2 where Qout ≤ 99% of Q out for a flat plane.

surface 1 [°]	surface 2 [°]	Total TILTED [m]	Total VERTICAL [m]	HORIZ [m]	TILT_N [m]	TILT_NE [m]	TILT_E [m]	TILT_SE [m]	TILT_S [m]	VERT_N [m]	VERT_NE [m]	VERT_E [m]	VERT_SE [m]	VERT_S [m]
10	10	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$
20	20	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$
0	10	-300	-500	-10	-10	-10	-150	-500	-700	-100	-50	-150	-800	All<0.99Q$_{@0°}$
0	20	-900	-1000	-250	-10	-10	-400	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	-700	-450	-350	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$
10	20	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$
0	30	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	-800	-150	-50	-800	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	-800	-900	-700	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$
10	30	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$
20	30	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$
0	40	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	-450	-150	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	-1000	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$
0	50	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	-1000	-350	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	-1000	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$
0	60	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	-1000	-800	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$
0	70	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	-800	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$
0	80	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	-1000	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$
0	90	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$	All<0.99Q$_{@0°}$

N – faces sun, S – faces surface 2 (slope), E – faces +x, SE – faces 45° away from slope, NE – faces 45° away from sun
TILT = 45° - Tilted towards center of asset, HORIZ = horizontal, VERT = vertical
Impact of steeper slopes are seen further away.

Study #2: Distances where Slope Impact on Heat Rejection Exceeds a Typical Margin

- **Are there cases where a slope would cause the asset to not meet heat rejection needs if it were designed for a 10º or 20º slope?**
  - Find the 'distances up Surface 2' where Qout = 90% $Q_{10^\circ \text{ or } 20^\circ}$



An asset ≤ 193m from surface 2 at 30º while surface 1 =0º exhibits Qout < 90%Q_{20° for the slope facing tilted radiator.

An asset ≤ 143m from surface 2 at 30º while surface 1 =20º exhibits Qout < 90%Q_{20° for the slope facing tilted radiator.

100m is a typical landing accuracy requirement[17]

- Qout < 90%Q_{20° for distances a >100m approaching slopes as low as 30º
- Qout < 90%Q_{10° for distances a >100m approaching slopes as low as 20º

Qout < 90%Q_{10° at distances greater than for Qout < 90%Q_{20°

Linear Interpolated Distance where Qout = 90% of Qout for a 20° sloped plane
(-) values = distance away from slope. Further from the slope Qout > 90% of Qout sloped plane.

surface 1 [°]	surface 2 [°]	Total [m]	Total TILTED [m]	Total VERTICAL [m]	HORIZ [m]	TILT_N [m]	TILT_NE [m]	TILT_E [m]	TILT_SE [m]	TILT_S [m]	VERT_N* [m]	VERT_NE* [m]	VERT_E [m]	VERT_SE [m]	VERT_S [m]
0	10	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$
0	20	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	75	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	On Slope | -39	On Slope | -74	50	51	All >0.9$Q_{@10^\circ}$	On Slope | -12	On Slope | -30
10	20	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	56	All >0.9$Q_{@10^\circ}$	61	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	On Slope | -25	28	30	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	On Slope | -25
0	30	-14	-19	-15	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	-142	-193	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	-55	-99
10	30	-26	-26	-30	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	-117	-174	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	-12	-80	-126
20	30	-127	-50	-519	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	-17	-86	-143	All <0.9$Q_{@10^\circ}$	-962	-99	-347	-451
0	40	-61	-88	-49	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	-29	-271	-340	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	-23	-124	-191
0	50	-122	-162	-99	-79	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	-82	-408	-503	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	-48	-199	-289
0	60	-188	-244	-155	-163	All >0.9$Q_{@10^\circ}$	-17	-137	-561	-669	All >0.9$Q_{@10^\circ}$	-11	-86	-282	-388
0	70	-259	-337	-215	-258	All >0.9$Q_{@10^\circ}$	-60	-205	-707	-826	-15	-37	-120	-363	-488
0	80	-335	-432	-274	-361	-51	-111	-280	-845	-973	-65	-75	-158	-441	-589
0	90	-414	-536	-335	-463	-125	-178	-360	-984	All <0.9$Q_{@10^\circ}$	-116	-114	-198	-524	-687

Linear Interpolated Distance where Qout = 90% of Qout 10° sloped plane.

surface 1 [°]	surface 2 [°]	Total [m]	Total TILTED [m]	Total VERTICAL [m]	HORIZ [m]	TILT_N [m]	TILT_NE [m]	TILT_E [m]	TILT_SE [m]	TILT_S [m]	VERT_N* [m]	VERT_NE [m]	VERT_E [m]	VERT_SE [m]	VERT_S [m]
0	10	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	60	72	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$
0	20	-4	4	-13	6	6	7	5	On Slope | -78	On Slope | -122	21	15	-2	-45	-83
10	20	-49	-9	-123	4	-5	-3	-3	On Slope | -45	On Slope | -94	-952	-46	-39	-159	-214
0	30	-56	-68	-56	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	-17	-208	-282	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	-26	-131	-193
10	30	-209	-136	-345	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	-47	-226	-312	-957	-434	-116	-463	-547
20	30	All <0.9$Q_{@10^\circ}$	All <0.9$Q_{@10^\circ}$	All <0.9$Q_{@10^\circ}$	All <0.9$Q_{@10^\circ}$	All <0.9$Q_{@10^\circ}$	All <0.9$Q_{@10^\circ}$	All <0.9$Q_{@10^\circ}$	-382	-717	All <0.9$Q_{@10^\circ}$	All <0.9$Q_{@10^\circ}$	All <0.9$Q_{@10^\circ}$	All <0.9$Q_{@10^\circ}$	All <0.9$Q_{@10^\circ}$
0	40	-130	-149	-123	-40	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	-71	-368	-469	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	-61	-235	-330
0	50	-217	-252	-197	-144	All >0.9$Q_{@10^\circ}$	All >0.9$Q_{@10^\circ}$	-134	-546	-675	All >0.9$Q_{@10^\circ}$	-19	-98	-348	-477
0	60	-311	-364	-282	-260	All >0.9$Q_{@10^\circ}$	-47	-209	-727	-877	-41	-57	-146	-473	-623
0	70	-412	-484	-369	-379	-38	-99	-300	-903	All <0.9$Q_{@10^\circ}$	-107	-106	-196	-593	-767
0	80	-518	-600	-455	-504	-122	-175	-401	All <0.9$Q_{@10^\circ}$	All <0.9$Q_{@10^\circ}$	-177	-174	-250	-706	-895
0	90	-625	-723	-550	-635	-220	-269	-510	All <0.9$Q_{@10^\circ}$	All <0.9$Q_{@10^\circ}$	-254	-247	-312	-827	All <0.9$Q_{@10^\circ}$

N – faces sun, S – faces surface 2 (slope), E – faces +x, SE – faces 45° away from slope, NE – faces 45° away from sun
TILT = 45° - Tilted towards center of asset, HORIZ = horizontal, VERT = vertical
***= Qout for uniform slope case was negative and given distance does not imply a + Qout. Impact of steeper slopes is seen further away.**

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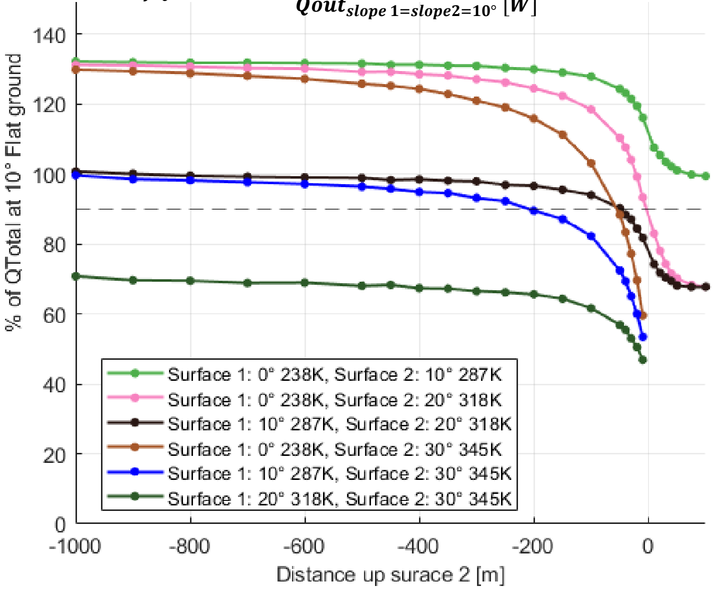
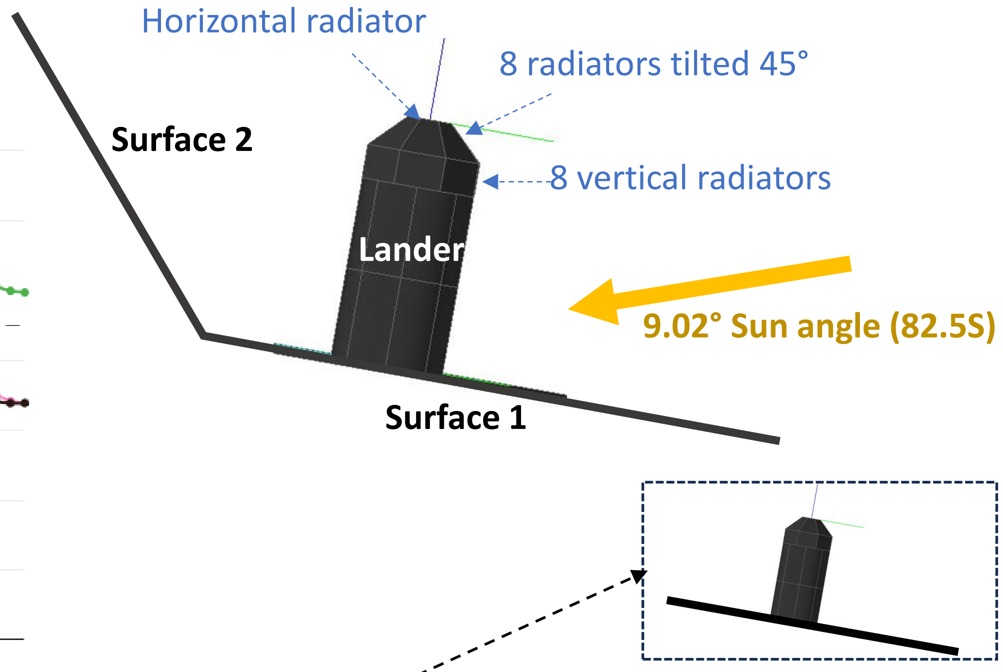
Study #2: Distances where Slope Impact on Heat Rejection is Exceeds a Typical Margin

Unexpected slopes >100m from a lander designed to land on a 10° sloped ground could cause it to not meet its heat rejection needs

- 20m lander designed for a 10° slope with a 10% radiator heat rejection margin[19]
  - 16 radiators each 10m^2 with white paint α=0.16 and ε=0.92 and a panel temperature of 10C.
- Margin is exceeded when:
  - Landing on a 10° slope <49m from a 20° slope
  - Landing on a 10° slope <209m from a 30° slope
- If the lander only had 45° tilted panels that face away from the sun (and see the slope), margins exceeded when:
  - Landing on a 10° slope ~<45-94m from a 20° slope
  - Landing on a 10° slope ~<226-312m from a 30° slope
- If the lander only had vertical panels that face away from the sun (and see the slope), margins exceeded when:
  - Landing on a 10° slope ~<159-214m from a 20° slope
  - Landing on a 10° slope ~<463-547m from a 30° slope

$$\%of\,Q\,out\,total = \frac{Qout\,[W]}{Qout_{slope\,1=slope2=10^\circ}\,[W]}$$





Distance up a slope where radiator heat rejection drops to ≤90% of heat rejection by a lander on a 10° sloped plane.

surface 1 [°]	surface 2 [°]	Total [m]	Total of Tilted Radiators [m]	Total of Vertical Radiators [m]	Horizontal Radiator [m]	Sun facing Tilted Radiator [m]	45° from Sun facing Tilted Radiator [m]	East (Not sun or slope) facing Tilted Radiator [m]	45° from Slope facing Tilted Radiator [m]	Slope facing Tilted Radiator [m]	Sun facing Vertical Radiator* [m]	45° from Sun facing Vertical Radiator [m]	East (Not sun or slope) facing Radiator [m]	45° from Slope facing Vertical Radiator [m]	Slope facing Vertical Radiator [m]
0	10	All >$0.9Q_{@10°}$	All >$0.9Q_{@10°}$	All >$0.9Q_{@10°}$	All >$0.9Q_{@10°}$	All >$0.9Q_{@10°}$	All >$0.9Q_{@10°}$	All >$0.9Q_{@10°}$	All >$0.9Q_{@10°}$	All >$0.9Q_{@10°}$	60	72	All >$0.9Q_{@10°}$	All >$0.9Q_{@10°}$	All >$0.9Q_{@10°}$
0	20	-4	4	-13	6	6	7	5	On Slope | -78	On Slope | -122	21	15	-2	-45	-83
10	20	-49	-9	-123	4	-5	-3	-3	On Slope | -45	On Slope | -94	-952	-46	-39	-159	-214
0	30	-56	-68	-56	All >$0.9Q_{@10°}$	All >$0.9Q_{@10°}$	All >$0.9Q_{@10°}$	-17	-208	-282	All >$0.9Q_{@10°}$	All >$0.9Q_{@10°}$	-26	-131	-193
10	30	-209	-136	-345	All >$0.9Q_{@10°}$	All >$0.9Q_{@10°}$	All >$0.9Q_{@10°}$	-47	-226	-312	-957	-434	-116	-463	-547
20	30	All <$0.9Q_{@10°}$	All <$0.9Q_{@10°}$	All <$0.9Q_{@10°}$	All <$0.9Q_{@10°}$	All <$0.9Q_{@10°}$	All <$0.9Q_{@10°}$	All <$0.9Q_{@10°}$	-382	-717	All <$0.9Q_{@10°}$	All <$0.9Q_{@10°}$	All <$0.9Q_{@10°}$	All <$0.9Q_{@10°}$	All <$0.9Q_{@10°}$

Sun facing vertical radiators only absorb heat when on a 10° sloped plane. NaN = never happens. Distances > than 100m, a typical margin of error for landing[17] are shown in red.
On Slope = all tested locations on the slope had Q>$Q_{@10°}$.

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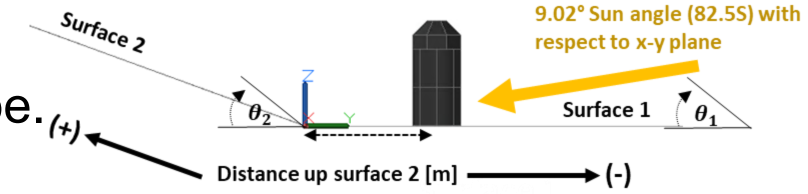
Study #2: Conclusions

1) What is the worst-case location for the 20m tall asset?
   - The overall worst case is on a 20° slope just before a 30° slope.
   - The per-panel worst case depends on radiator orientation.
     - For panels that see the slope, it was on a flat ground (surface 1 = 0°) just before a 30° slope.
     - For panels that see the sun, it was 100m up onto a 20° sloped surface 2 where surface 1's slope is 10°.
     - For panels that see neither the slope nor the sun, it was to be on a 20° slope just before a 30° slope.
     - For the horizontal panels, it was slightly up onto a 20° sloped surface where surface 1's slope is 10°.
     - Often other configurations produce results very close to the worst case.



2) Can you be far enough away from a slope for its impact to be negligible?
   - It is possible for a slope to be far enough away that its impact on radiator heat rejection is negligible or is accounted for in design margin.
     - E.g., if the asset is on a surface with no incline 800m from a 30°, the reduction in heat rejection from the slope for the horizontal radiator ≤1% (an increase in average TSINK of ≤1.35K).
     - E.g., if the asset is on a 10° slope, and >214m away from a 20° slope or >547m from a 30° slope the degradation in heat rejection from slope facing radiators is <10% (an increase in average TSINK of 8K)

3) Can you bound the worst case with a single surface tilted surface?
   - No, a _ **shaped ground** results in lower heat rejection than a \ **shaped ground**.
   - Moreover, depending on the landing site, even a _ **shaped ground** may not bound the hot case.

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Summary of Conclusions

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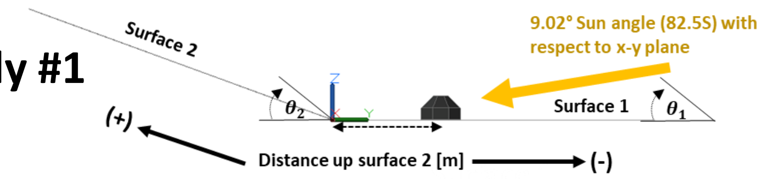
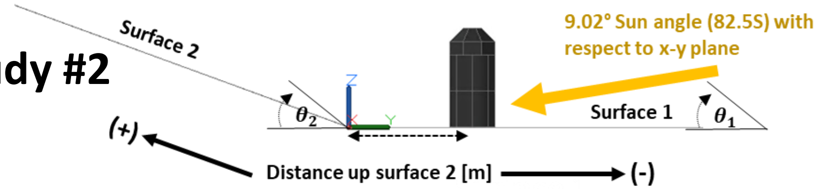
- Both Study #1 and #2 demonstrated that the presence of slopes, represented by a **_ shaped ground** should be considered when attempting to predict worst hot cases.
  - The overall worst case (i.e., minimum total heat rejection of all radiators) occurs just before the maximum slope the asset can encounter.
  - The per panel worst case depended on the panel's view of the slope or sun.
    - The horizontal panel's worst case was shortly up that max allowed slope of that the asset could be on (surface 2 = 20°) where surface 1 has a lower slope (0° for the 5.5m and 10°for the 20m tall lander)
    - Panels that saw the sun tended to have a worst case that was on the max slope the asset could be on (surface 2 = 20°), far enough on the slope that the heat rejection leveled off (25m for the 5.5m tall asset and 100m for the 20m tall asset). Surface 1 in these cases ranged from 5 to 10°.
    - Panels that saw the slope had a worst case on a flat ground (surface 1=0°) just before the max expected nearby slope (surface 2 = 30°).
    - Panels that saw neither the slope nor the sun (i.e., faced east) had worst cases just before the max expected nearby slope (surface 2 = 30°). Surface 1 in these cases ranged from 0° for the 5.5m tall asset to 20° for the 20m tall asset.
  - Study #1 and #2 showed that using a **\ shaped ground at** 20° for design purposes would significantly underpredict the total worst-case heat rejection if the max possible expected slope was 30° (32% for the 5.5m tall asset and 50% for the 20m tall asset).
- Study #1 showed that steady state cases can be used to predict worst case radiator heat rejections.
- Study #2 presented for each possible surface 1 and surface 2 configurations, distances where if an asset lands further away the degradation in heat rejection is ≤10% the heat rejected by a vehicle on a flat 0°, 10°, or 20° slope. (Backup slides include distances where ΔTSINKS are ≤1K and ≤5K.)

Study #1



Study #2



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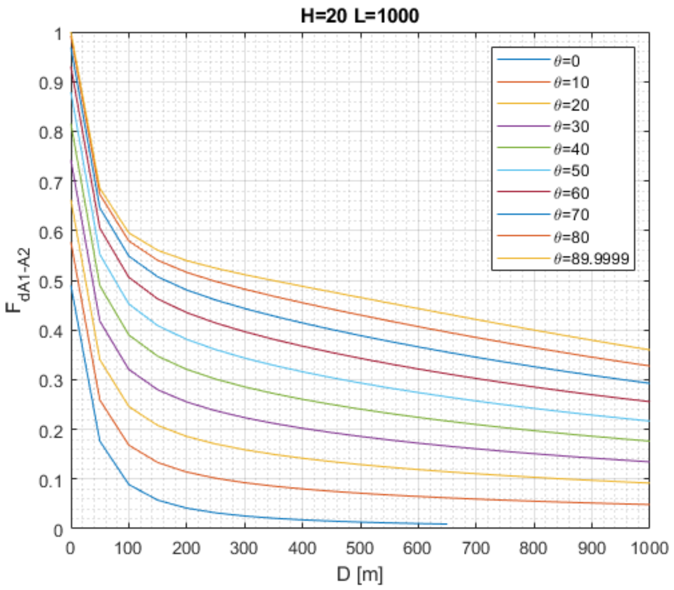
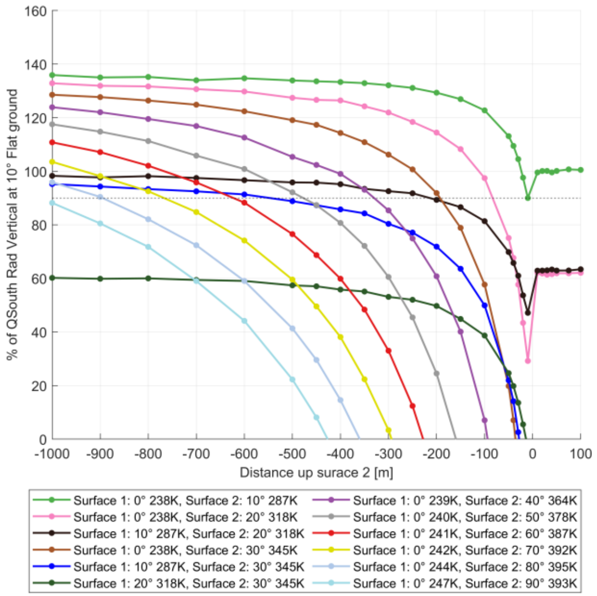
“We acknowledge the use of imagery from Lunar QuickMap (https://lunar.quickmap.io), a collaboration between NASA, Arizona State University & Applied Coherent Technology Corp."

Backup

HLS

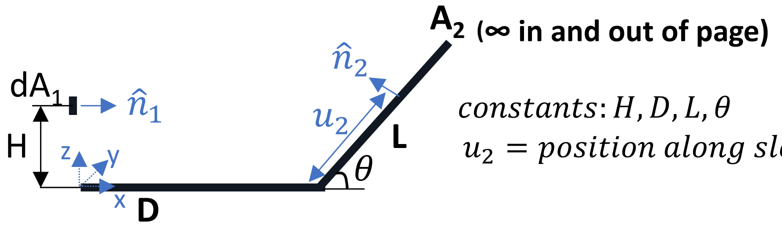
View factor from a differential element to a slope compared to distance where radiator degradation is <10%





For the 20m tall asset, view factors between a differential element and the slope ranging from 0.13 to 0.17 mapped to a drop in heat rejection from the slope that is <10%.

Slope [°]	Distance from slope where Q=90%Qflat plane for slope facing panel [m]	VF	VF at 1km from slope
10	150	0.1332	0.0486
20	350	0.1496	0.0919
30	700	0.1608	0.1346
40	1000	0.1763	0.1763
50	>1000		0.2167
60	>1000		0.2556
70	>1000		0.2926
80	>1000		0.3275
90	>1000		0.3600



$constants: H, D, L, \theta$

$u_2 = position\ along\ slope$

View Factor dA_1A_2 MATLAB:

```
c1 = (D*sin(theta)+H*cos(theta));
c2 = (D*cos(theta)-H*sin(theta));
c3 = D^2+H^2;
fun2 = @(u2,y2) (1/pi)*(D+u2.*cos(theta)).*((c3+2*u2.*c2+u2.^2+y2.^2).^(-2)).*c1;
VF_dA1_A2(j,i) = integral2(fun2,0,L,-Inf,Inf,'Method','iterated');
```

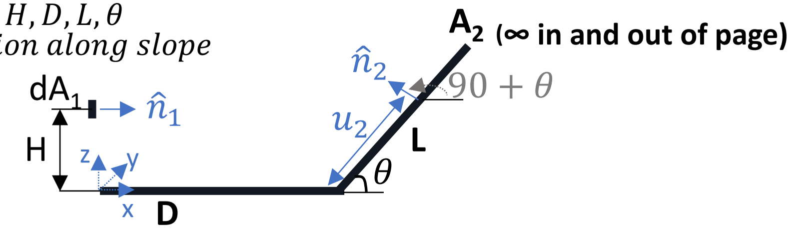
Derivation: view factor from a differential element to a slope

(1) Find position vectors that go from origin to point on surface

$\vec{r_1} = x_1\hat{\imath} + y_1\hat{\jmath} + z_1\hat{k} = H\hat{k}$ (always on the $x - z$ plane)

$\vec{r_2} = x_2\hat{\imath} + y_2\hat{\jmath} + z_2\hat{k} = (D + u_2\cos(\theta))\hat{\imath} + y_2\,\hat{\jmath} + u_2\sin(\theta)\hat{k}$

$constants: H, D, L, \theta$
$u_2 = position\ along\ slope$



(2) Find $\overrightarrow{s_{12}}$, $\overrightarrow{s_{21}}$, and S^2 (i.e. the distance² between dA_1 and dA_2)

$\overrightarrow{s_{12}} = (x_2 - x_1)\hat{\imath} + (y_2 - y_1)\hat{\jmath} + (z_2 - z_1)\hat{k} = (D + u_2\cos(\theta))\hat{\imath} + y_2\hat{\jmath} + (u_2\sin(\theta) - H)\hat{k}$

$\overrightarrow{s_{21}} = -(D + u_2\cos(\theta))\hat{\imath} + -y_2\hat{\jmath} + (H - u_2\sin(\theta))\hat{k}$

$S^2 = \left|\left|S_{12}\right|\right|^2 = (D + u_2\cos(\theta))^2 + y_2^2 + (u_2\sin(\theta) - H)^2$

(3) Find normal vectors for dA_1 and dA_2

$\hat{n} = l\hat{\imath} + m\hat{\jmath} + n\hat{k} = \cos(\theta_x)\hat{\imath} + \cos(\theta_y)\hat{\jmath} + \cos(\theta_z)\hat{k}$

Angle between $\hat{n}$ & axis

$\hat{n}_1 = \cos(0)\,\hat{\imath} + \cos\left(\frac{\pi}{2}\right)\hat{\jmath} + \cos\left(\frac{\pi}{2}\right)\hat{k} = \hat{\imath}$ $\quad$ $\hat{n}_1$ is parallel to x-axis and perpendicular to y and z axis

$\hat{n}_2 = \cos(90 + \theta)\,\hat{\imath} + \cos\left(\frac{\pi}{2}\right)\hat{\jmath} + \cos(-\theta)\,\hat{k} = \sin(\theta)\,\hat{\imath} + \cos(\theta)\,\hat{k}$

(4) Sub into view factor equation (integrates over y_2 and u_2 to get view factor from dA_1 to A_2)

$$F_{dA_1\rightarrow A_2} = \int_{A_2} \frac{\cos(\theta_1)\cos(\theta_2)}{\pi S^2} dA_2 = \int_0^L \int_{-\infty}^{\infty} \frac{1}{\pi S^2}\left(\frac{\hat{n}_1 \cdot \overrightarrow{s_{12}}}{S}\right)\left(\frac{\hat{n}_2 \cdot \overrightarrow{s_{21}}}{S}\right) dy_2 du_2$$

$$\hat{n}_1 \cdot \overrightarrow{s_{12}} = D + u_2\cos(\theta)$$

$$\hat{n}_2 \cdot \overrightarrow{s_{21}} = H\sin(\theta) + D\cos(\theta)$$

$$F_{dA_1\rightarrow A_2} = \int_0^L \int_{-\infty}^{\infty} \frac{(D + u_2\cos(\theta))(H\sin(\theta) + D\cos(\theta))}{D^2 + 2u_2(D\cos(\theta) - H\sin(\theta)) + u_2^2 + H^2 + y_2^2} dy_2 du_2$$

$$F_{dA_1\rightarrow A_2} = \int_0^L \int_{-\infty}^{\infty} \frac{(D + u_2\cos(\theta))}{c_3 + 2u_2c_2 + u_2^2 + y_2^2} dy_2 du_2$$

$$c_1 = H\sin(\theta) + D\cos(\theta)$$
$$c_2 = D\cos(\theta) - H\sin(\theta)$$
$$c_3 = D^2 + H^2$$

(5)Numerically integrate in MATLAB

View Factor dA_1A_2 MATLAB:

```
c1 = (D*sin(theta)+H*cos(theta));
c2 = (D*cos(theta)-H*sin(theta));
c3 = D^2+H^2;
fun2 = @(u2,y2) (1/pi)*(D+u2.*cos(theta)).*((c3+2*u2.*c2+u2.^2+y2.^2).^(-2)).*c1;
VF_dA1_A2(j,i) = integral2(fun2,0,L,-Inf,Inf,'Method','iterated');
```

HLS

HLS

Study #2: Steady State Results

At what distance are the slope impacts negligible?

Test point distance up Surface 2 where Qout ≤ 90% of Q out for a flat plane.

surface 1 [°]	surface 2 [°]	Total TILTED [m]	Total VERTICAL [m]	HORIZ [m]	TILT_N [m]	TILT_NE [m]	TILT_E [m]	TILT_SE [m]	TILT_S [m]	VERT_N [m]	VERT_NE [m]	VERT_E [m]	VERT_SE [m]	VERT_S [m]
10	10	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$
20	20	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$
0	10	-10	-50	-10	-10	-10	-10	100	100	-10	-10	-20	-100	-150
0	20	-100	-200	-10	-10	-10	-30	-150	-250	-150	-30	-100	-250	-350
10	20	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	-200	-350	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$
0	30	-200	-400	-30	-10	-10	-100	-350	-450	-500	-100	-150	-500	-700
10	30	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	-600	-900	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$
20	30	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$
0	40	-400	-600	-200	-10	-30	-200	-600	-700	-800	-300	-250	-900	-1000
0	50	-600	-800	-350	-10	-100	-350	-800	-1000	-1000	-500	-350	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$
0	60	-800	-1000	-600	-150	-150	-500	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	-1000	-800	-450	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$
0	70	-900	N/A	-800	-250	-300	-700	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	-900	-600	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$
0	80	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	-900	-450	-450	-800	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	-1000	-700	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$
0	90	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	-600	-600	-1000	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$	-900	All<0.9Q$_{@0^{\circ}}$	All<0.9Q$_{@0^{\circ}}$

Test point distance up Surface 2 where Qout ≤ 99% of Q out for a flat plane.

surface 1 [°]	surface 2 [°]	Total TILTED [m]	Total VERTICAL [m]	HORIZ [m]	TILT_N [m]	TILT_NE [m]	TILT_E [m]	TILT_SE [m]	TILT_S [m]	VERT_N [m]	VERT_NE [m]	VERT_E [m]	VERT_SE [m]	VERT_S [m]
10	10	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$
20	20	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$
0	10	-300	-500	-10	-10	-10	-150	-500	-700	-100	-50	-150	-800	All<0.99Q$_{@0^{\circ}}$
0	20	-900	-1000	-250	-10	-10	-400	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	-700	-450	-350	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$
10	20	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$
0	30	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	-800	-150	-50	-800	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	-800	-900	-700	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$
10	30	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$
20	30	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$
0	40	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	-450	-150	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	-1000	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$
0	50	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	-1000	-350	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	-1000	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$
0	60	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	-1000	-800	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$
0	70	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	-800	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$
0	80	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	-1000	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$
0	90	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$	All<0.99Q$_{@0^{\circ}}$

HLS

Study #2: Steady State Results

TILT = 45° - Tilted towards asset's center
HORIZ = horizontal
VERT = vertical
N – faces sun, S – faces surface 2 (slope),
E – faces +x, SE – faces 45° away from slope,
NE – faces 45° away from sun
= Qout for uniform slope case was negative
On Slope = all values on the slope had Q>0.9$Q_{@\#°}$

Linear Interpolated Distance where Qout = 90% of Qout for a 20° sloped plane

(-) values = distance away from slope. Further from the slope Qout > 90% of Qout sloped plane.

surface 1 [°]	surface 2 [°]	Total [m]	Total TILTED [m]	Total VERTICAL [m]	HORIZ [m]	TILT_N [m]	TILT_NE [m]	TILT_E [m]	TILT_SE [m]	TILT_S [m]	VERT_N* [m]	VERT_NE* [m]	VERT_E [m]	VERT_SE [m]	VERT_S [m]
0	10	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$
0	20	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	75	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	On Slope | -39	On Slope | -74	50	51	All >0.9$Q_{@10°}$	On Slope | -12	On Slope | -30
10	20	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	56	All >0.9$Q_{@10°}$	61	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	On Slope | -25	28	30	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	On Slope | -25
0	30	-14	-19	-15	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	-142	-193	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	-55	-99
10	30	-26	-26	-30	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	-117	-174	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	-12	-80	-126
20	30	-127	-50	-519	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	-17	-86	-143	All <0.9$Q_{@10°}$	-962	-99	-347	-451
0	40	-61	-88	-49	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	-29	-271	-340	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	-23	-124	-191
0	50	-122	-162	-99	-79	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	-82	-408	-503	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	-48	-199	-289
0	60	-188	-244	-155	-163	All >0.9$Q_{@10°}$	-17	-137	-561	-669	All >0.9$Q_{@10°}$	-11	-86	-282	-388
0	70	-259	-337	-215	-258	All >0.9$Q_{@10°}$	-60	-205	-707	-826	-15	-37	-120	-363	-488
0	80	-335	-432	-274	-361	-51	-111	-280	-845	-973	-65	-75	-158	-441	-589
0	90	-414	-536	-335	-463	-125	-178	-360	-984	All <0.9$Q_{@10°}$	-116	-114	-198	-524	-687

Linear Interpolated Distance where Qout = 90% of Qout 10° sloped plane.

surface 1 [°]	surface 2 [°]	Total [m]	Total TILTED [m]	Total VERTICAL [m]	HORIZ [m]	TILT_N [m]	TILT_NE [m]	TILT_E [m]	TILT_SE [m]	TILT_S [m]	VERT_N* [m]	VERT_NE [m]	VERT_E [m]	VERT_SE [m]	VERT_S [m]
0	10	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	60	72	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$
0	20	-4	4	-13	6	6	7	5	On Slope | -78	On Slope | -122	21	15	-2	-45	-83
10	20	-49	-9	-123	4	-5	-3	-3	On Slope | -45	On Slope | -94	-952	-46	-39	-159	-214
0	30	-56	-68	-56	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	-17	-208	-282	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	-26	-131	-193
10	30	-209	-136	-345	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	-47	-226	-312	-957	-434	-116	-463	-547
20	30	All <0.9$Q_{@10°}$	All <0.9$Q_{@10°}$	All <0.9$Q_{@10°}$	All <0.9$Q_{@10°}$	All <0.9$Q_{@10°}$	All <0.9$Q_{@10°}$	All <0.9$Q_{@10°}$	-382	-717	All <0.9$Q_{@10°}$	All <0.9$Q_{@10°}$	All <0.9$Q_{@10°}$	All <0.9$Q_{@10°}$	All <0.9$Q_{@10°}$
0	40	-130	-149	-123	-40	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	-71	-368	-469	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	-61	-235	-330
0	50	-217	-252	-197	-144	All >0.9$Q_{@10°}$	All >0.9$Q_{@10°}$	-134	-546	-675	All >0.9$Q_{@10°}$	-19	-98	-348	-477
0	60	-311	-364	-282	-260	All >0.9$Q_{@10°}$	-47	-209	-727	-877	-41	-57	-146	-473	-623
0	70	-412	-484	-369	-379	-38	-99	-300	-903	All <0.9$Q_{@10°}$	-107	-106	-196	-593	-767
0	80	-518	-600	-455	-504	-122	-175	-401	All <0.9$Q_{@10°}$	All <0.9$Q_{@10°}$	-177	-174	-250	-706	-895
0	90	-625	-723	-550	-635	-220	-269	-510	All <0.9$Q_{@10°}$	All <0.9$Q_{@10°}$	-254	-247	-312	-827	All <0.9$Q_{@10°}$

TILT = 45° - Tilted towards asset's center
HORIZ = horizontal
VERT = vertical
N – faces sun, S – faces surface 2 (slope),
E – faces +x, SE – faces 45° away from slope,
NE – faces 45° away from sun
= Qout for uniform slope case was negative
On Slope = all values on the slope had $Q>0.75Q_{@\#^\circ}$

Study #2: Steady State Results

HLS

Linear Interpolated Distance where Qout = 75% of Qout for a 20° sloped plane

(-) values = distance away from slope. Further from the slope Qout > 90% of Qout sloped plane.

surface 1 [°]	surface 2 [°]	Total [m]	Total TILTED [m]	Total VERTICAL [m]	HORIZ [m]	TILT_N [m]	TILT_NE [m]	TILT_E [m]	TILT_SE [m]	TILT_S [m]	VERT_N* [m]	VERT_NE* [m]	VERT_E [m]	VERT_SE [m]	VERT_S [m]
0	10	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$
0	20	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	37	40	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	On Slope | -23
10	20	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	16	23	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	On Slope | -11
0	30	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	-13	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	-67	-108	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	-44	-87
10	30	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	-26	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	-33	-73	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	-58	-96
20	30	-28	All $>0.75Q_{@10^\circ}$	-196	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $<0.75Q_{@10^\circ}$	All $<0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	-32	-135	-178
0	40	-43	-48	-45	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	-153	-212	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	-19	-107	-168
0	50	-97	-112	-94	-32	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	-256	-329	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	-42	-179	-257
0	60	-159	-181	-148	-109	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	-363	-447	All $>0.75Q_{@10^\circ}$	-14	-78	-253	-347
0	70	-226	-255	-205	-187	All $>0.75Q_{@10^\circ}$	-45	-155	-474	-573	-35	-42	-109	-330	-441
0	80	-293	-336	-263	-272	-43	-93	-219	-586	-691	-90	-82	-146	-400	-535
0	90	-365	-421	-323	-359	-111	-150	-288	-692	-805	-146	-126	-186	-478	-623

Linear Interpolated Distance where Qout = 75% of Qout 10° sloped plane.

surface 1 [°]	surface 2 [°]	Total [m]	Total TILTED [m]	Total VERTICAL [m]	HORIZ [m]	TILT_N [m]	TILT_NE [m]	TILT_E [m]	TILT_SE [m]	TILT_S [m]	VERT_N* [m]	VERT_NE* [m]	VERT_E [m]	VERT_SE [m]	VERT_S [m]
0	10	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$
0	20	28	All $>0.75Q_{@10^\circ}$	6	All $>0.75Q_{@10^\circ}$	32	40	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	On Slope | -35	19	16	9	-27	-50
10	20	8	All $>0.75Q_{@10^\circ}$	-34	All $>0.75Q_{@10^\circ}$	2	11	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $<0.75Q_{@10^\circ}$	-25	-6	-44	-72
0	30	-27	-14	-39	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	-88	-136	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	-16	-91	-141
10	30	-63	-16	-141	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	-54	-98	All $<0.75Q_{@10^\circ}$	-204	-43	-174	-230
20	30	All $<0.75Q_{@10^\circ}$	-33	All $<0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	-847	-17	All $>0.75Q_{@10^\circ}$	-50	All $<0.75Q_{@10^\circ}$	All $<0.75Q_{@10^\circ}$	All $<0.75Q_{@10^\circ}$	All $<0.75Q_{@10^\circ}$	All $<0.75Q_{@10^\circ}$
0	40	-86	-82	-96	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	-29	-186	-253	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	-40	-176	-250
0	50	-152	-151	-163	-68	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	-82	-297	-387	All $>0.75Q_{@10^\circ}$	-18	-79	-271	-367
0	60	-230	-233	-237	-149	All $>0.75Q_{@10^\circ}$	All $>0.75Q_{@10^\circ}$	-137	-420	-523	-63	-53	-118	-371	-490
0	70	-312	-323	-312	-241	-18	-74	-205	-542	-658	-133	-100	-160	-469	-608
0	80	-397	-415	-390	-340	-88	-131	-280	-662	-790	-207	-168	-206	-570	-727
0	90	-488	-514	-471	-437	-174	-201	-360	-777	-911	-295	-240	-256	-670	-837

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Study #2: Steady State Results

TILT = 45° - Tilted towards asset's center
HORIZ = horizontal
VERT = vertical
N – faces sun, S – faces surface 2 (slope),
E – faces +x, SE – faces 45° away from slope,
NE – faces 45° away from sun

Linear Interpolated Distance where TSINK – TSINK for a 0° sloped plane = 1K

(-) values = distance away from slope. Further from the slope TSINK < TSINK for the plane + (1 or 5)K.

surface 1 [°]	surface 2 [°]	Total TILTED [m]	Total VERTICAL [m]	HORIZ [m]	TILT_N [m]	TILT_NE [m]	TILT_E [m]	TILT_SE [m]	TILT_S [m]	VERT_N [m]	VERT_NE [m]	VERT_E [m]	VERT_SE [m]	VERT_S [m]
0	10	-435	-434	-26	-176	-237	-490	-910	All >TSINK+1K	-20	-16	-210	All >TSINK+1K	All >TSINK+1K
0	20	All >TSINK+1K	-936	-676	-631	-20	-789	All >TSINK+1K	All >TSINK+1K	-10	-92	-433	All >TSINK+1K	All >TSINK+1K
10	20	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K
0	30	All >TSINK+1K	All >TSINK+1K	-888	-137	-170	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	-214	-254	-974	All >TSINK+1K	All >TSINK+1K
10	30	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K
20	30	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K
0	40	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	-417	-237	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	-428	-626	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K
0	50	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	-442	-263	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	-669	-861	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K
0	60	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	-711	-556	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	-870	-973	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K
0	70	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	-697	-652	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	-956	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K
0	80	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	-865	-953	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K
0	90	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	-884	NaN	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K

Linear Interpolated Distance where TSINK – TSINK for a 0° sloped plane = 5K.

surface 1 [°]	surface 2 [°]	Total TILTED [m]	Total VERTICAL [m]	HORIZ [m]	TILT_N [m]	TILT_NE [m]	TILT_E [m]	TILT_SE [m]	TILT_S [m]	VERT_N [m]	VERT_NE [m]	VERT_E [m]	VERT_SE [m]	VERT_S [m]
0	10	-75	-79	-8	0.2	-2	-74	-488	-814	14	1	-66	-292	-477
0	20	-272	-249	-158	-4	-6	-238	All >TSINK+5K	All >TSINK+5K	4	-8	-174	-774	All >TSINK+5K
10	20	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K
0	30	-565	-501	-544	All <TSINK+5K	All <TSINK+5K	-473	All >TSINK+5K	All >TSINK+5K	All <TSINK+5K	-29	-314	All >TSINK+5K	All >TSINK+5K
10	30	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K
20	30	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K
0	40	-880	-791	-883	All <TSINK+5K	-30	-805	All >TSINK+5K	All >TSINK+5K	-41	-97	-485	All >TSINK+5K	All >TSINK+5K
0	50	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All <TSINK+5K	-87	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	-141	-220	-702	All >TSINK+5K	All >TSINK+5K
0	60	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	-83	-174	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	-264	-348	-878	All >TSINK+5K	All >TSINK+5K
0	70	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	-195	-326	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	-393	-511	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K
0	80	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	-343	-475	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	-525	-650	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K
0	90	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	-537	-633	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	-666	-800	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K

HLS

Study #2: Steady State Results

TILT = 45° - Tilted towards asset's center
HORIZ = horizontal, VERT = vertical
N – faces sun, S – faces surface 2 (slope),
E – faces +x, SE – faces 45° away from slope,
NE – faces 45° away from sun
If two values are given, between them the increase in sink temperature rose above the criteria.

Linear Interpolated Distance where TSINK – TSINK for a 10° sloped plane = 1K

(-) values = distance away from slope. Further from the slope TSINK < TSINK for the plane + (1 or 5)K.

surface 1 [°]	surface 2 [°]	Total TILTED [m]	Total VERTICAL [m]	HORIZ [m]	TILT_N [m]	TILT_NE [m]	TILT_E [m]	TILT_SE [m]	TILT_S [m]	VERT_N [m]	VERT_NE [m]	VERT_E [m]	VERT_SE [m]	VERT_S [m]
0	10	All <TSINK+1K	All <TSINK+1K	All <TSINK+1K	All <TSINK+1K	All <TSINK+1K	All <TSINK+1K	64 | -52	42 | -94	All <TSINK+1K	All <TSINK+1K	All <TSINK+1K	All <TSINK+1K	-22
0	20	-35	-17	0	5	4	-5	-234	-309	25	16	-9	-65	-106
10	20	-496	-360	-86	-8	-414	-276	All >TSINK+1K	All >TSINK+1K	-6	-19	-278	All >TSINK+1K	All >TSINK+1K
0	30	-128	-67	All <TSINK+1K	All <TSINK+1K	All <TSINK+1K	-46	-490	-627	All <TSINK+1K	All <TSINK+1K	-34	-163	-239
10	30	-919	-878	-573	-166	-32	-352	All >TSINK+1K	All >TSINK+1K	-25	-117	-471	All >TSINK+1K	All >TSINK+1K
20	30	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K	All >TSINK+1K
0	40	-246	-137	-116	All <TSINK+1K	All <TSINK+1K	-112	-781	-969	All <TSINK+1K	All <TSINK+1K	-75	-288	-398
0	50	-386	-219	-261	All <TSINK+1K	-18	-194	All >TSINK+1K	All >TSINK+1K	All <TSINK+1K	-17	-118	-421	-575
0	60	-540	-308	-408	All <TSINK+1K	-64	-301	All >TSINK+1K	All >TSINK+1K	-22	-51	-170	-559	-746
0	70	-680	-399	-572	-49	-124	-422	All >TSINK+1K	All >TSINK+1K	-83	-98	-226	-695	-911
0	80	-834	-493	-734	-138	-209	-550	All >TSINK+1K	All >TSINK+1K	-144	-165	-287	-823	All >TSINK+1K
0	90	-968	-590	-875	-242	-317	-673	All >TSINK+1K	All >TSINK+1K	-217	-236	-355	-954	All >TSINK+1K

Linear Interpolated Distance where TSINK – TSINK for a 10° sloped plane = 5K.

surface 1 [°]	surface 2 [°]	Total TILTED [m]	Total VERTICAL [m]	HORIZ [m]	TILT_N [m]	TILT_NE [m]	TILT_E [m]	TILT_SE [m]	TILT_S [m]	VERT_N [m]	VERT_NE [m]	VERT_E [m]	VERT_SE [m]	VERT_S [m]
0	10	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	On Slope | -40	On Slope | -75	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	-15
0	20	-10	-9	2	10	8	-1	-188	-260	34	23	-4	-50	-91
10	20	-77	-71	-6	1	-1	-41	-544	-882	11	1	-49	-267	-356
0	30	-94	-47	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	-34	-424	-540	All <TSINK+5K	All <TSINK+5K	-27	-140	-210
10	30	-290	-228	-100	All <TSINK+5K	All <TSINK+5K	-142	All >TSINK+5K	All >TSINK+5K	All <TSINK+5K	All <TSINK+5K	-138	-685	-831
20	30	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K	All >TSINK+5K
0	40	-193	-110	-89	All <TSINK+5K	All <TSINK+5K	-94	-687	-865	All <TSINK+5K	All <TSINK+5K	-64	-250	-355
0	50	-315	-183	-220	All <TSINK+5K	All <TSINK+5K	-171	-942	All >TSINK+5K	All <TSINK+5K	All <TSINK+5K	-102	-372	-517
0	60	-442	-262	-360	All <TSINK+5K	-43	-265	All >TSINK+5K	All >TSINK+5K	All <TSINK+5K	-33	-150	-497	-670
0	70	-576	-344	-502	-21	-95	-377	All >TSINK+5K	All >TSINK+5K	-44	-74	-202	-628	-819
0	80	-714	-427	-656	-93	-166	-494	All >TSINK+5K	All >TSINK+5K	-99	-122	-259	-745	-958
0	90	-838	-515	-793	-182	-256	-609	All >TSINK+5K	All >TSINK+5K	-159	-183	-322	-869	All >TSINK+5K

HLS

Study #2: Steady State Results

TILT = 45° - Tilted towards asset's center
HORIZ = horizontal, VERT = vertical
N – faces sun, S – faces surface 2 (slope),
E – faces +x, SE – faces 45° away from slope,
NE – faces 45° away from sun
If two values are given, between them the increase in sink temperature rose above the criteria.

Linear Interpolated Distance where TSINK – TSINK for a 20° sloped plane = 1K

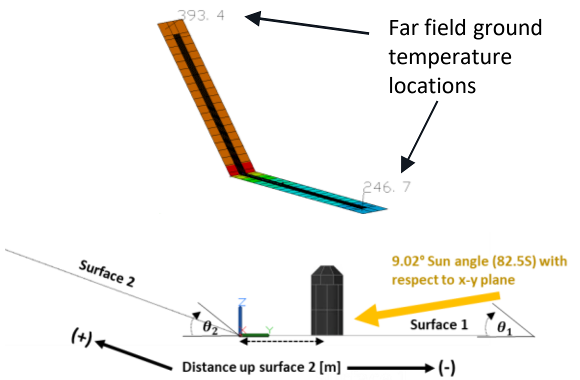
(-) values = distance away from slope. Further from the slope TSINK < TSINK for the plane + (1 or 5)K.

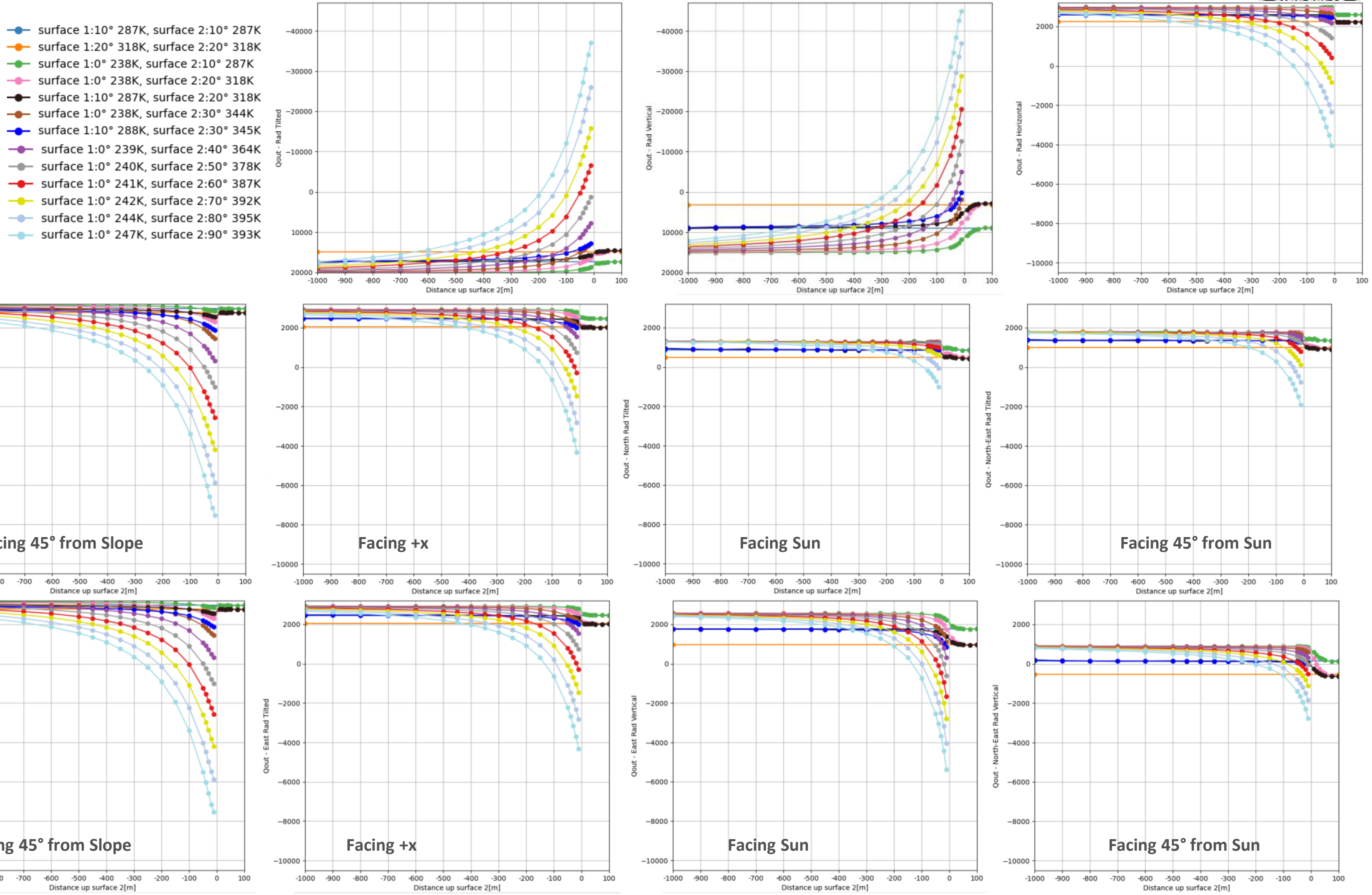
surface 1 [°]	surface 2 [°]	Total TILTED [m]	Total VERTICAL [m]	HORIZ [m]	TILT_N [m]	TILT_NE [m]	TILT_E [m]	TILT_SE [m]	TILT_S [m]	VERT_N [m]	VERT_NE [m]	VERT_E [m]	VERT_SE [m]	VERT_S [m]
0	10	All <TSINK+1K	All <TSINK+1K	All <TSINK+1K	All <TSINK+1K	All <TSINK+1K	All <TSINK+1K	All <TSINK+1K	All <TSINK+1K	All <TSINK+1K	All <TSINK+1K	All <TSINK+1K	All <TSINK+1K	All <TSINK+1K
0	20	78	79	10	NaN	72	46	75|-99	41|-140	86	81	NaN	85|-15	43|-34
10	20	45	61	All <TSINK+1K	51	41	46	On Slope|-86	On Slope|-126	49	48	All <TSINK+1K	On Slope|-13	On Slope|-31
0	30	-42	-15	All <TSINK+1K	All <TSINK+1K	All <TSINK+1K	All <TSINK+1K	-253	-317	All <TSINK+1K	All <TSINK+1K	All <TSINK+1K	-61	-109
10	30	-71	-30	All <TSINK+1K	All <TSINK+1K	All <TSINK+1K	-13	-316	-378	All <TSINK+1K	All <TSINK+1K	-15	-89	-143
20	30	-582	-512	-74	All <TSINK+1K	-252	-530	All >TSINK+1K	All >TSINK+1K	All <TSINK+1K	-17	-186	-989	All >TSINK+1K
0	40	-118	-49	-18	All <TSINK+1K	All <TSINK+1K	-45	-435	-528	All <TSINK+1K	All <TSINK+1K	-25	-132	-203
0	50	-204	-98	-117	All <TSINK+1K	All <TSINK+1K	-99	-634	-742	All <TSINK+1K	All <TSINK+1K	-52	-211	-305
0	60	-299	-154	-217	All <TSINK+1K	-22	-166	-833	-966	All <TSINK+1K	All <TSINK+1K	-88	-295	-410
0	70	-406	-214	-326	All <TSINK+1K	-67	-244	All >TSINK+1K	All >TSINK+1K	All <TSINK+1K	-30	-124	-380	-514
0	80	-516	-273	-441	-53	-121	-331	All >TSINK+1K	All >TSINK+1K	-43	-65	-163	-462	-619
0	90	-628	-334	-563	-126	-190	-422	All >TSINK+1K	All >TSINK+1K	-91	-99	-205	-548	-720

Linear Interpolated Distance where TSINK – TSINK for a 20° sloped plane = 5K.

surface 1 [°]	surface 2 [°]	Total TILTED [m]	Total VERTICAL [m]	HORIZ [m]	TILT_N [m]	TILT_NE [m]	TILT_E [m]	TILT_SE [m]	TILT_S [m]	VERT_N [m]	VERT_NE [m]	VERT_E [m]	VERT_SE [m]	VERT_S [m]
0	10	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K
0	20	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	On Slope|-84	On Slope|-122	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	On Slope|-10	On Slope|-28
10	20	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	On Slope|-57	On Slope|-94	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	On Slope|-21
0	30	-27	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	-223	-282	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	-49	-96
10	30	-37	-18	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	-254	-313	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	-70	-117
20	30	-93	-82	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	-63	-502	-721	All <TSINK+5K	All <TSINK+5K	-40	-224	-340
0	40	-96	-38	All <TSINK+5K	All <TSINK+5K	All <TSINK+5K	-36	-386	-470	All <TSINK+5K	All <TSINK+5K	-20	-117	-185
0	50	-175	-85	-98	All <TSINK+5K	All <TSINK+5K	-89	-572	-676	All <TSINK+5K	All <TSINK+5K	-45	-191	-280
0	60	-260	-136	-191	All <TSINK+5K	-11	-147	-760	-877	All <TSINK+5K	All <TSINK+5K	-79	-270	-377
0	70	-358	-189	-294	All <TSINK+5K	-50	-222	-942	All >TSINK+5K	All <TSINK+5K	-20	-112	-349	-475
0	80	-455	-244	-402	-34	-98	-300	All >TSINK+5K	All >TSINK+5K	-20	-48	-149	-425	-574
0	90	-564	-300	-518	-96	-161	-387	All >TSINK+5K	All >TSINK+5K	-66	-85	-190	-503	-670

Study #2: Steady State Results: Heat Rejection

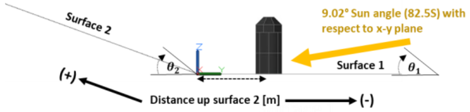




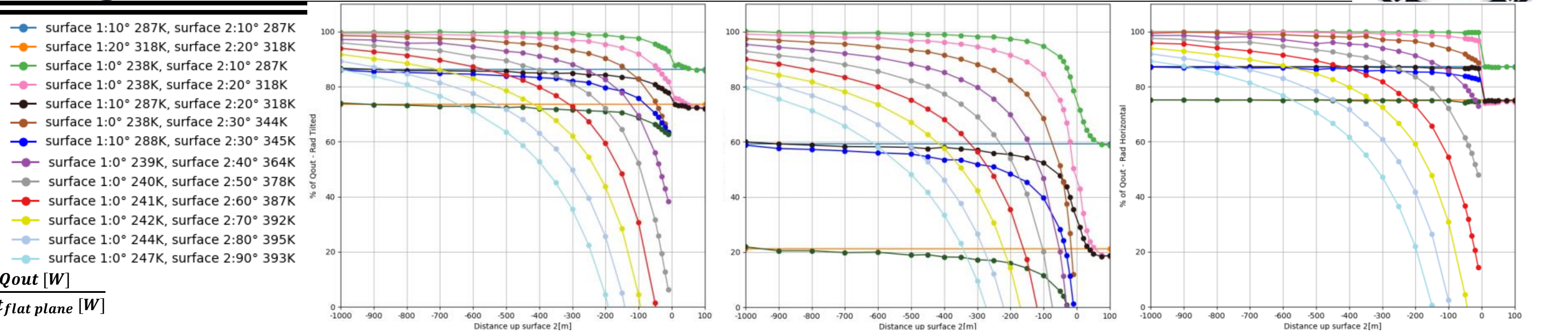
Study #2: Steady State Results: Slope Impact on Heat Rejection vs a 0° Flat Ground

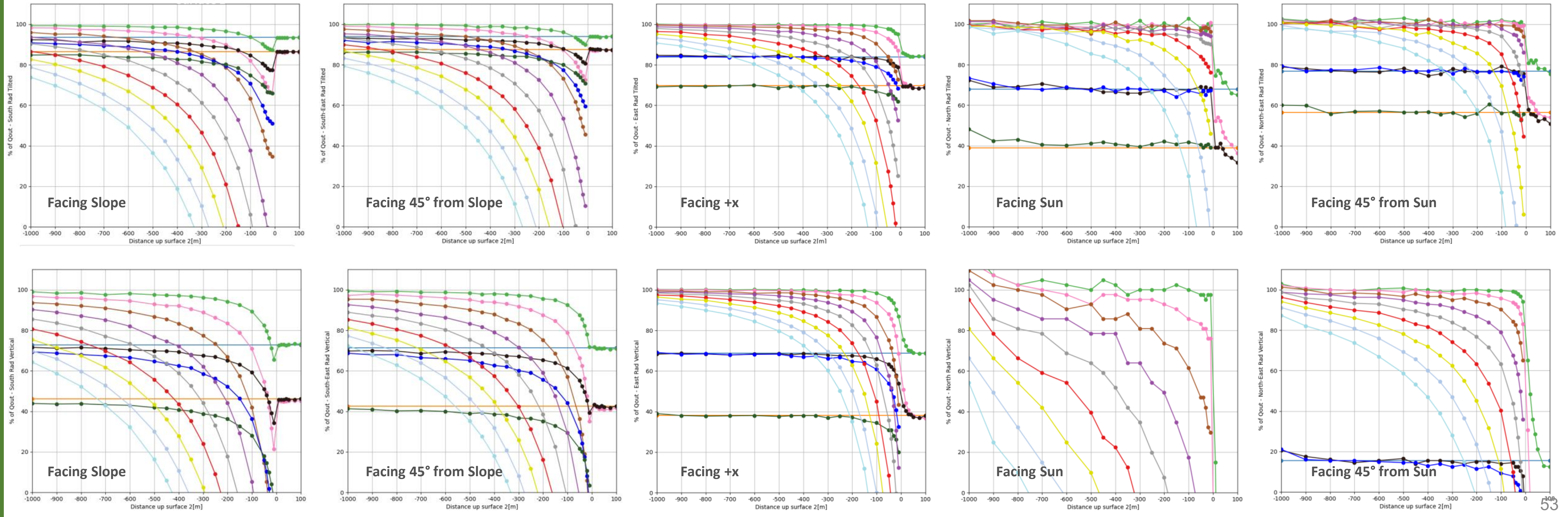
In general, the slope impacts:

- Qout tilted radiators < Qout horizontal radiators < Qout vertical radiators
- Are lowest for titled radiators that view sun
- Are highest for vertical radiators viewing the slope

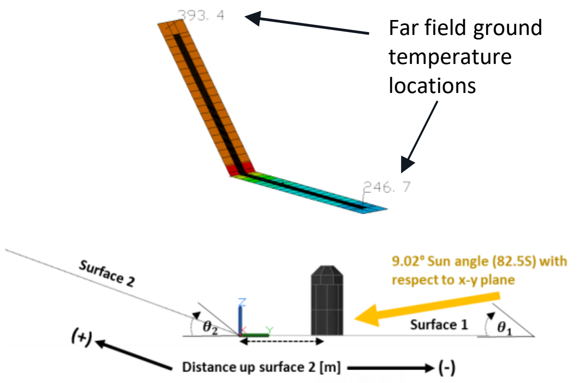


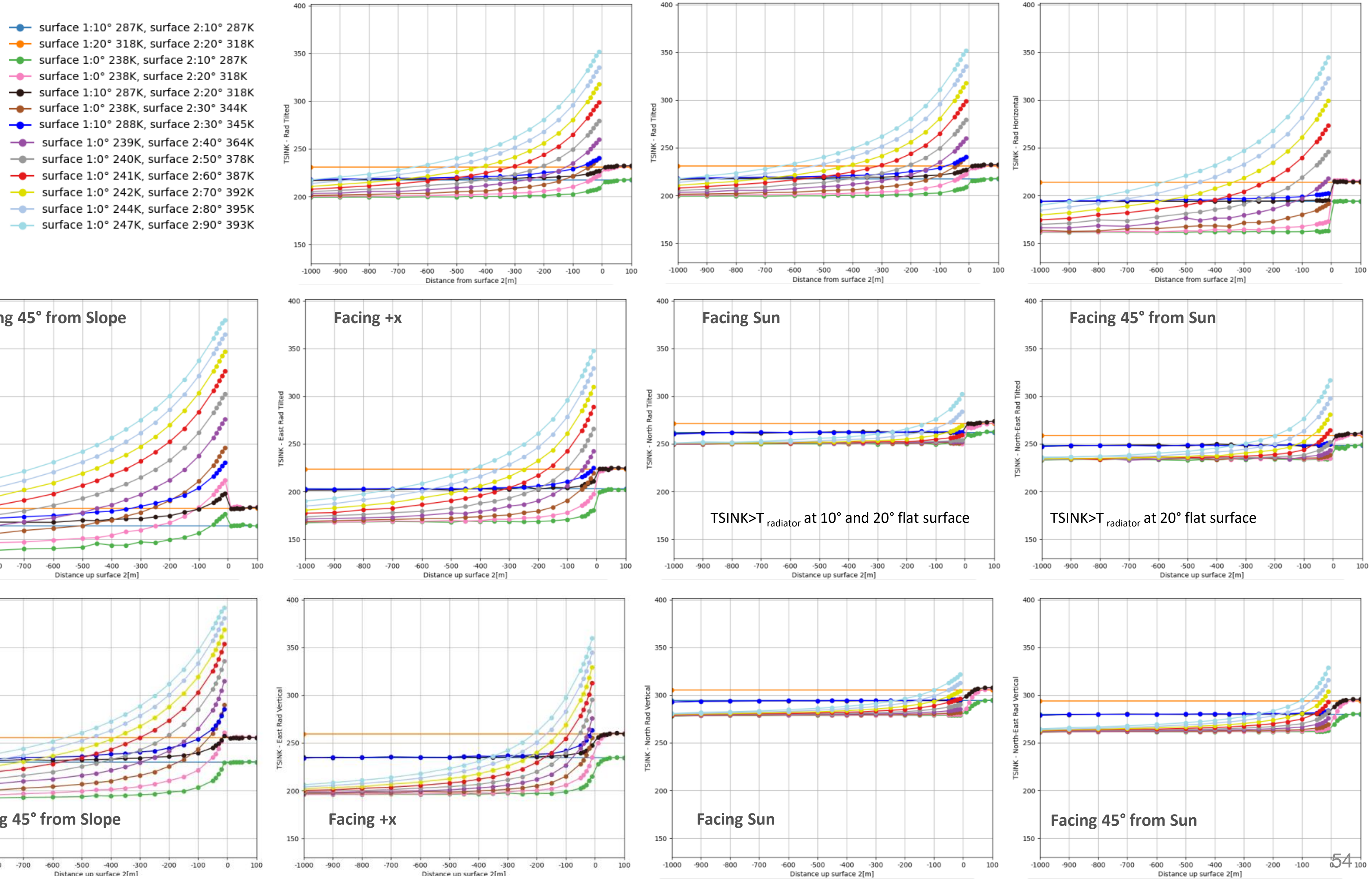
$$\%of = \frac{Qout\,[W]}{Qout_{flat\ plane}\,[W]}$$





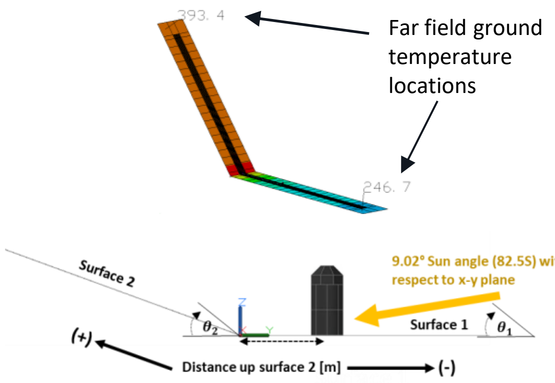
Study #2: Steady State TSINKS



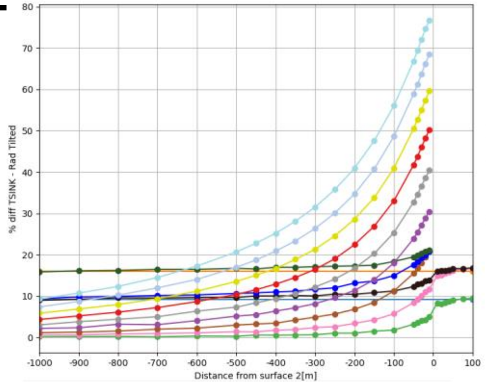


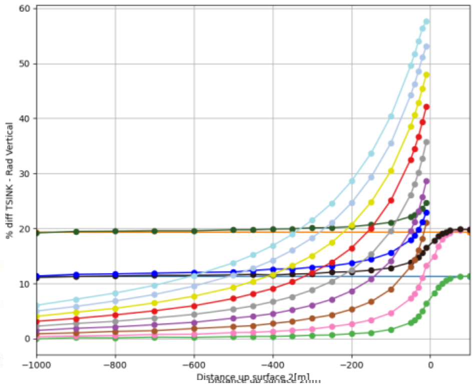
Study #2: Steady State Results: Slope Impact on TSINK vs a 0° Flat Ground

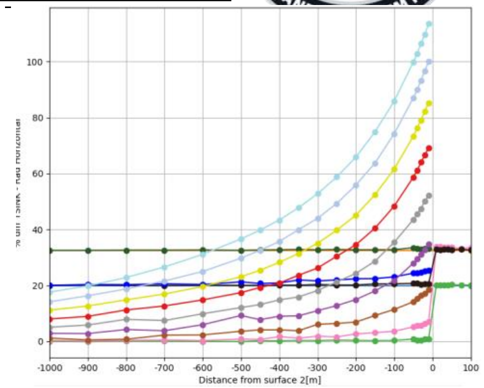
HLS

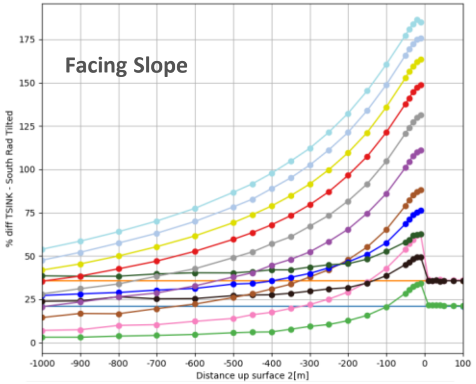


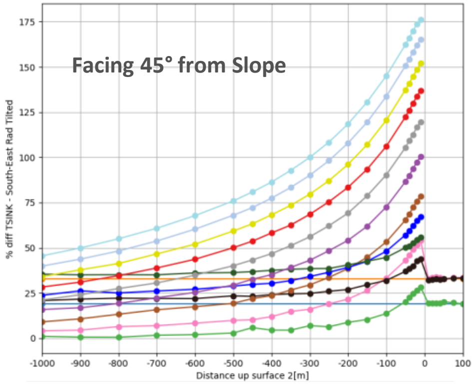
- surface 1:10° 287K, surface 2:10° 287K
- surface 1:20° 318K, surface 2:20° 318K
- surface 1:0° 238K, surface 2:10° 287K
- surface 1:0° 238K, surface 2:20° 318K
- surface 1:10° 287K, surface 2:20° 318K
- surface 1:0° 238K, surface 2:30° 344K
- surface 1:10° 288K, surface 2:30° 345K
- surface 1:0° 239K, surface 2:40° 364K
- surface 1:0° 240K, surface 2:50° 378K
- surface 1:0° 241K, surface 2:60° 387K
- surface 1:0° 242K, surface 2:70° 392K
- surface 1:0° 244K, surface 2:80° 395K
- surface 1:0° 247K, surface 2:90° 393K

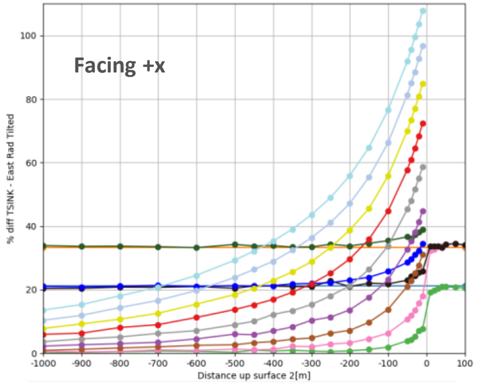


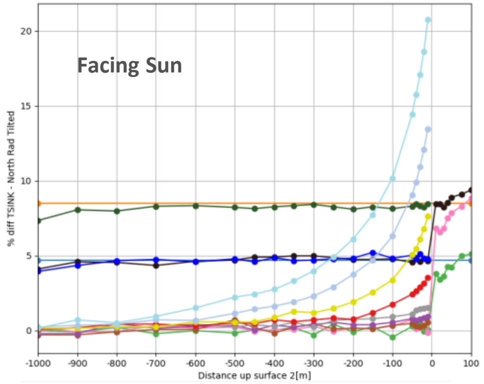


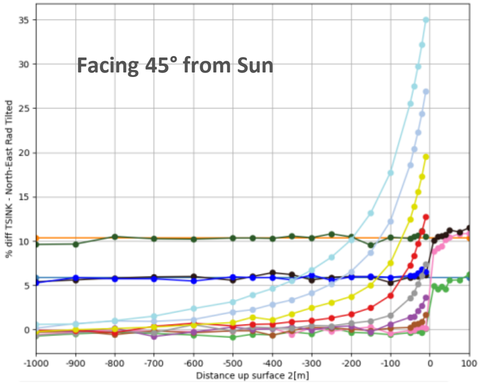


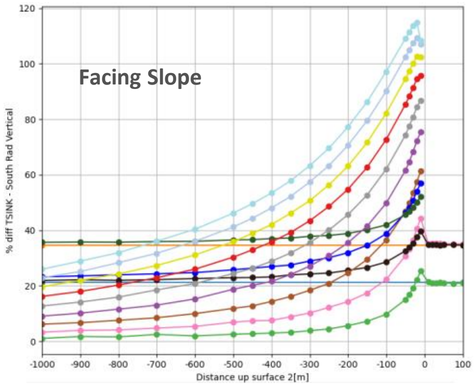


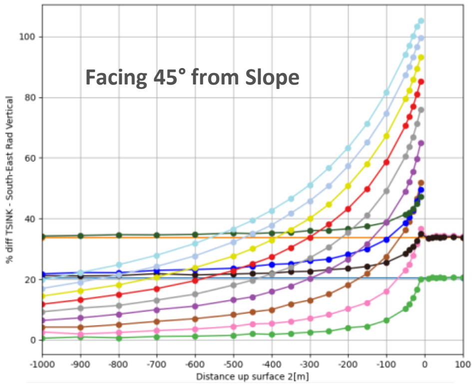


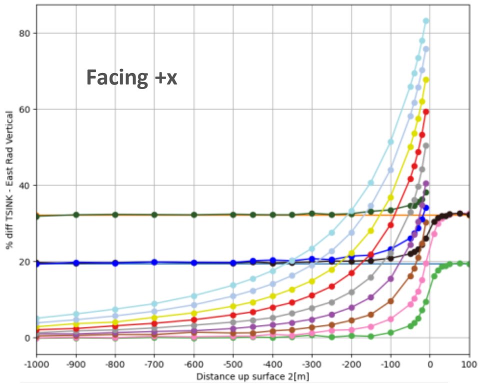


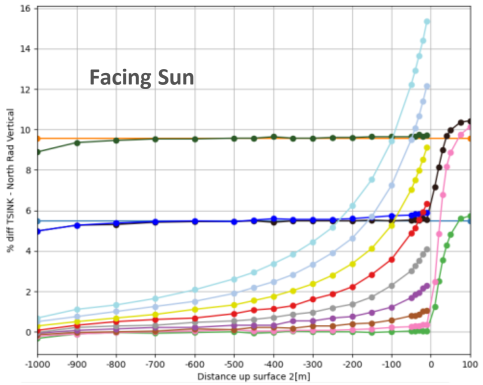


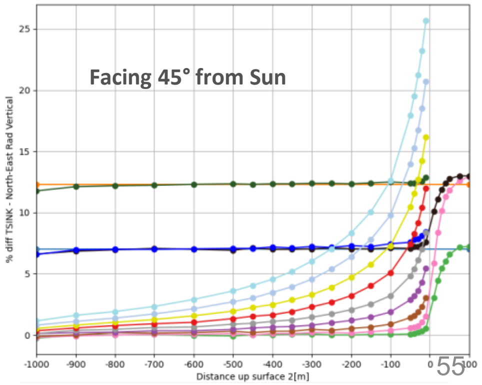




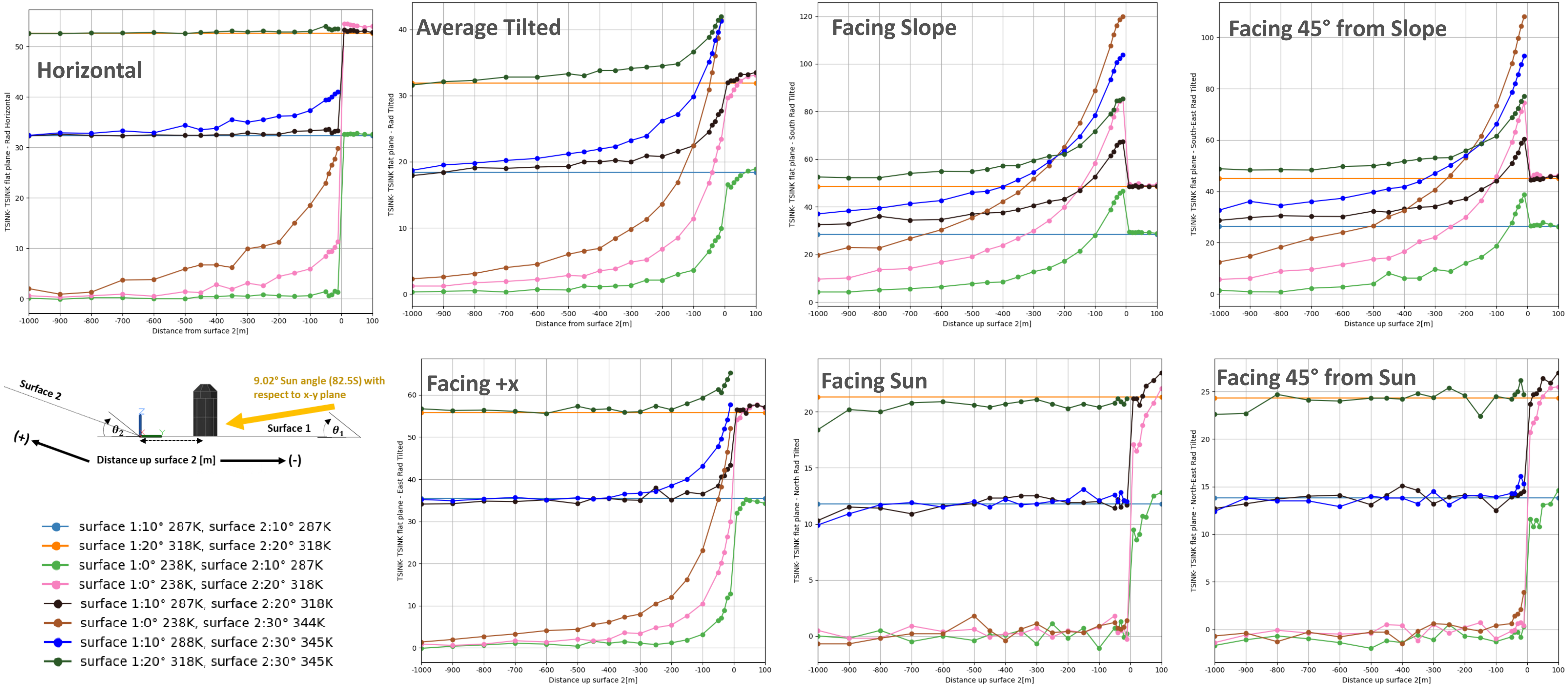




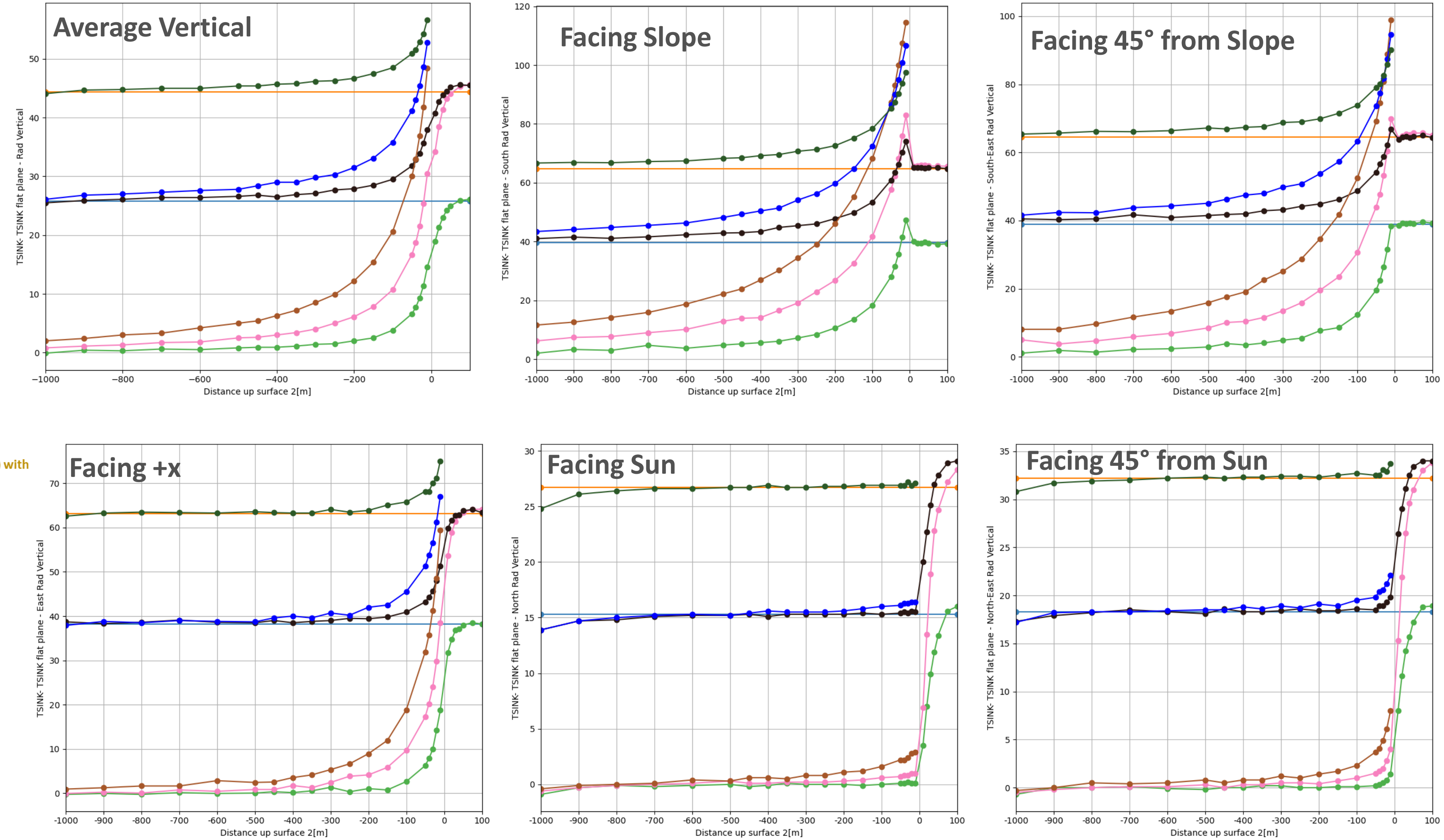


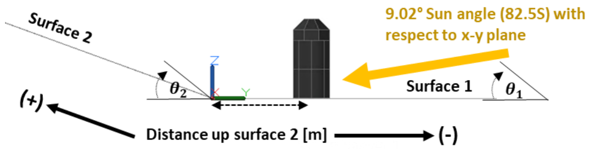


Study #2: Steady State Results: Slope Impact on TSINK vs a 0° Flat Ground



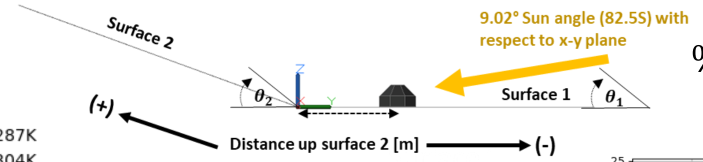
Study #2: Steady State Results: Slope Impact on TSINK vs a 0° Flat Ground





- surface 1:10° 287K, surface 2:10° 287K
- surface 1:20° 318K, surface 2:20° 318K
- surface 1:0° 238K, surface 2:10° 287K
- surface 1:0° 238K, surface 2:20° 318K
- surface 1:10° 287K, surface 2:20° 318K
- surface 1:0° 238K, surface 2:30° 344K
- surface 1:10° 288K, surface 2:30° 345K
- surface 1:20° 318K, surface 2:30° 345K

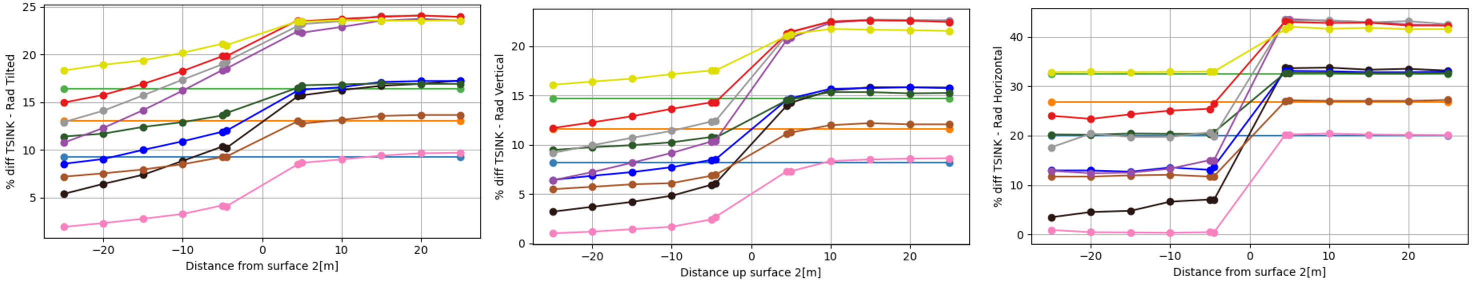
Study #1: Transient Results: Slope Impact on TSINK vs a 0° Flat Ground



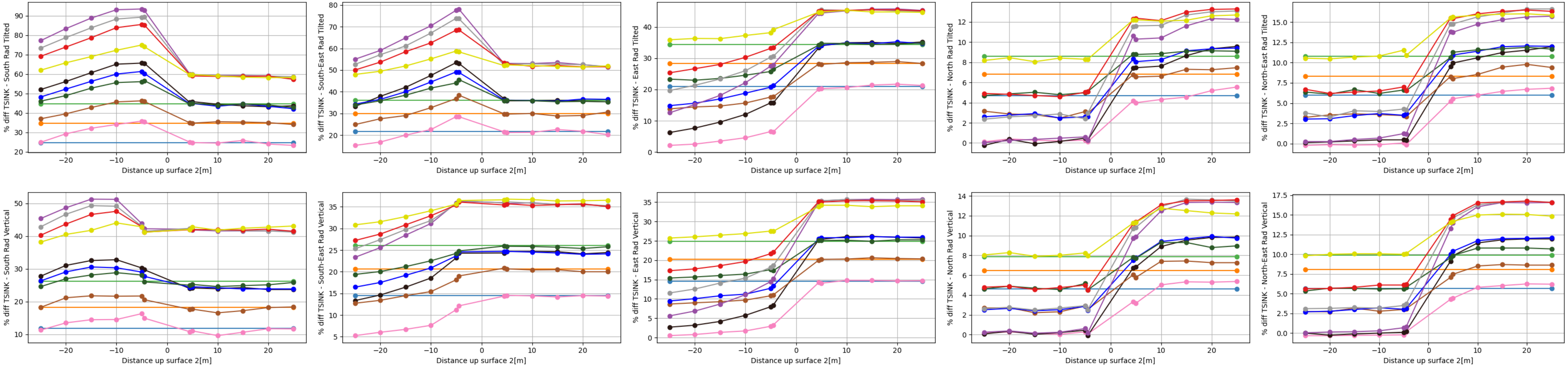
$$\%diff = \frac{TSINK\,[K] - TSINK_{flat\ plane}[K]}{TSINK_{flat\ plane}[K]}$$

$$TSINK_{RAD} = \left(\frac{\sum_{i=1}^{i=\#\ panels} TSINK_{panel\ i}^{4}}{\#\ Panels}\right)^{0.25}$$

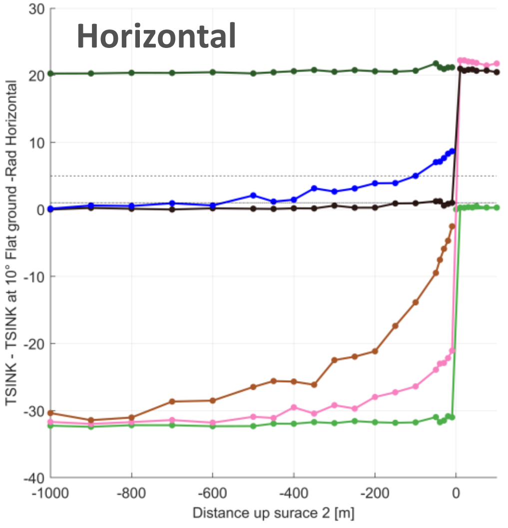
- surface 1:10° 288K, surface 2:10° 287K
- surface 1:15° 305K, surface 2:15° 304K
- surface 1:20° 319K, surface 2:20° 318K
- surface 1:0° 241K, surface 2:10° 287K
- surface 1:0° 243K, surface 2:20° 319K
- surface 1:5° 268K, surface 2:15° 304K
- surface 1:5° 269K, surface 2:20° 319K
- surface 1:10° 289K, surface 2:20° 319K
- surface 1:0° 246K, surface 2:30° 345K
- surface 1:5° 271K, surface 2:30° 345K
- surface 1:10° 291K, surface 2:30° 345K
- surface 1:20° 320K, surface 2:30° 345K

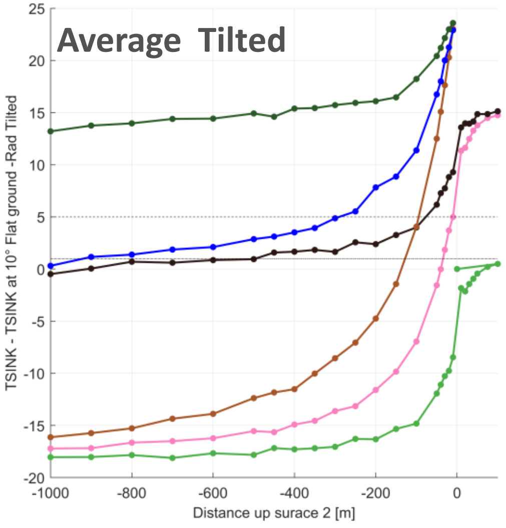


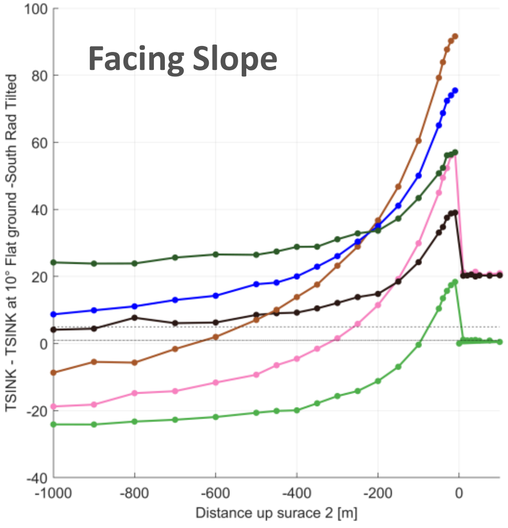
Facing Slope | Facing 45° from Slope | Facing +x | Facing Sun | Facing 45° from Sun

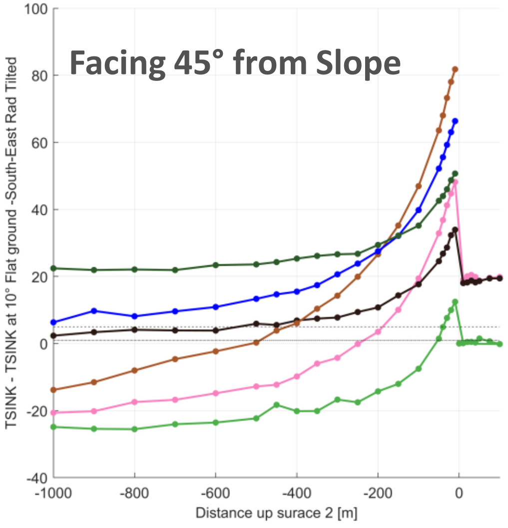


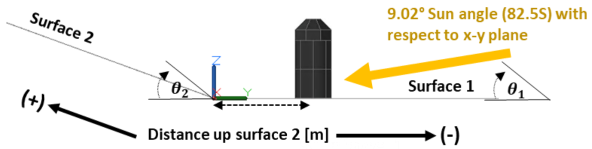
Study #2: Steady State Results: Slope Impact on TSINK vs a 10° Flat Ground



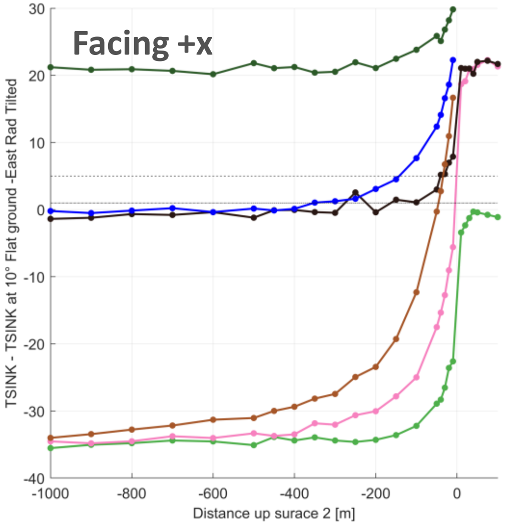


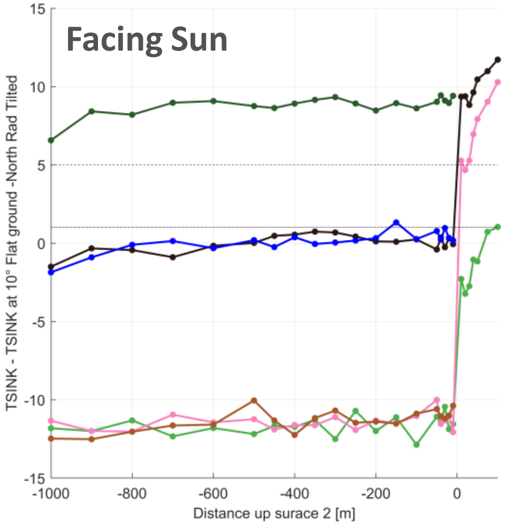


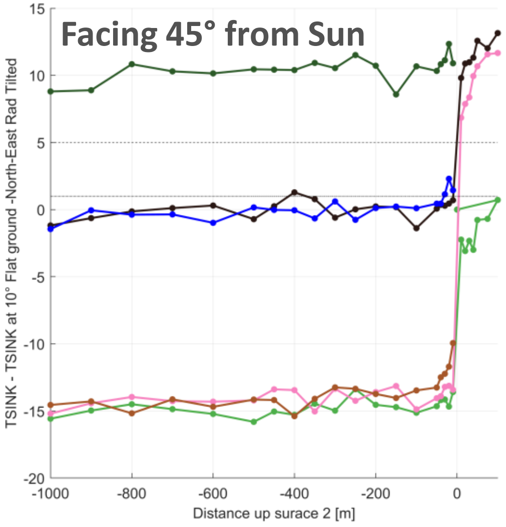




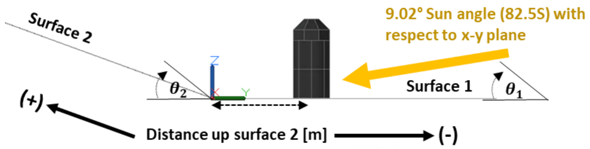
- surface 1:10° 287K, surface 2:10° 287K
- surface 1:20° 318K, surface 2:20° 318K
- surface 1:0° 238K, surface 2:10° 287K
- surface 1:0° 238K, surface 2:20° 318K
- surface 1:10° 287K, surface 2:20° 318K
- surface 1:0° 238K, surface 2:30° 344K
- surface 1:10° 288K, surface 2:30° 345K
- surface 1:20° 318K, surface 2:30° 345K



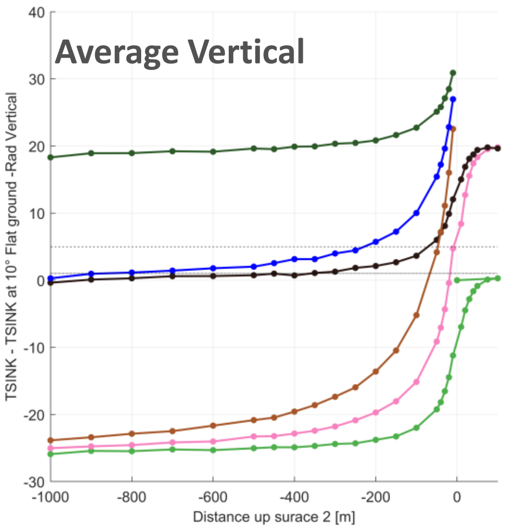


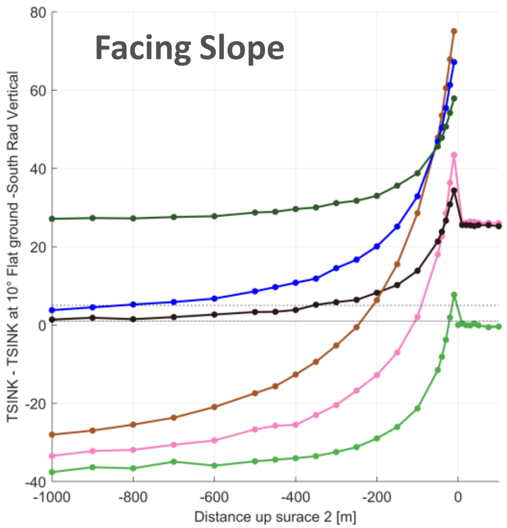


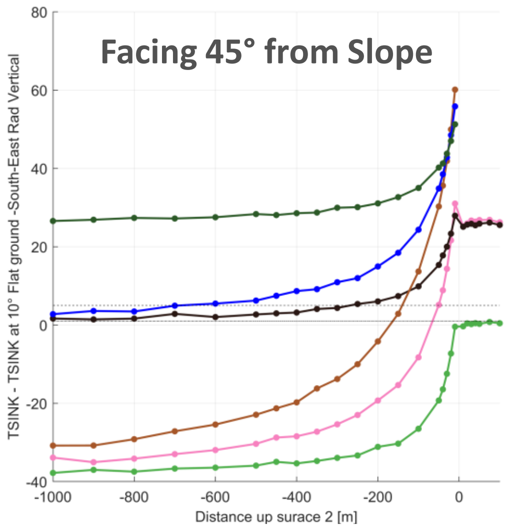
Study #2: Steady State Results: Slope Impact on TSINK vs a 10° Flat Ground

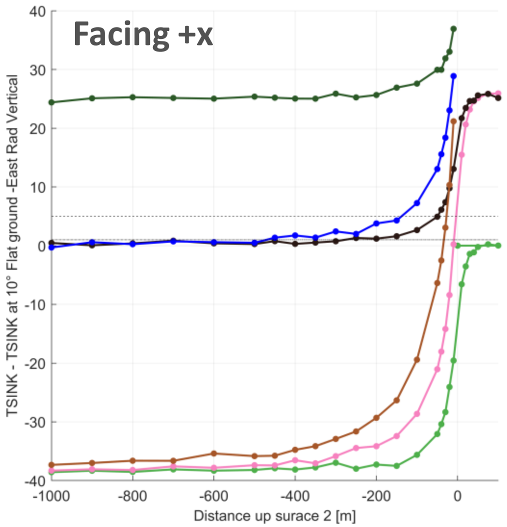


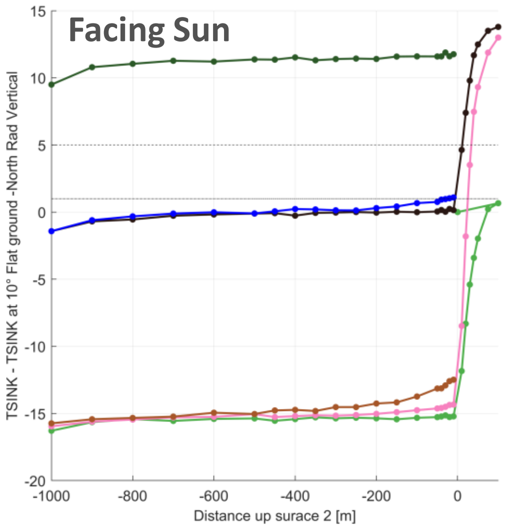
- surface 1:10° 287K, surface 2:10° 287K
- surface 1:20° 318K, surface 2:20° 318K
- surface 1:0° 238K, surface 2:10° 287K
- surface 1:0° 238K, surface 2:20° 318K
- surface 1:10° 287K, surface 2:20° 318K
- surface 1:0° 238K, surface 2:30° 344K
- surface 1:10° 288K, surface 2:30° 345K
- surface 1:20° 318K, surface 2:30° 345K

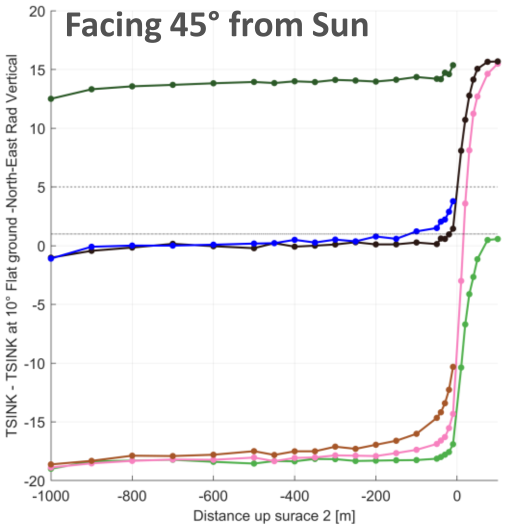






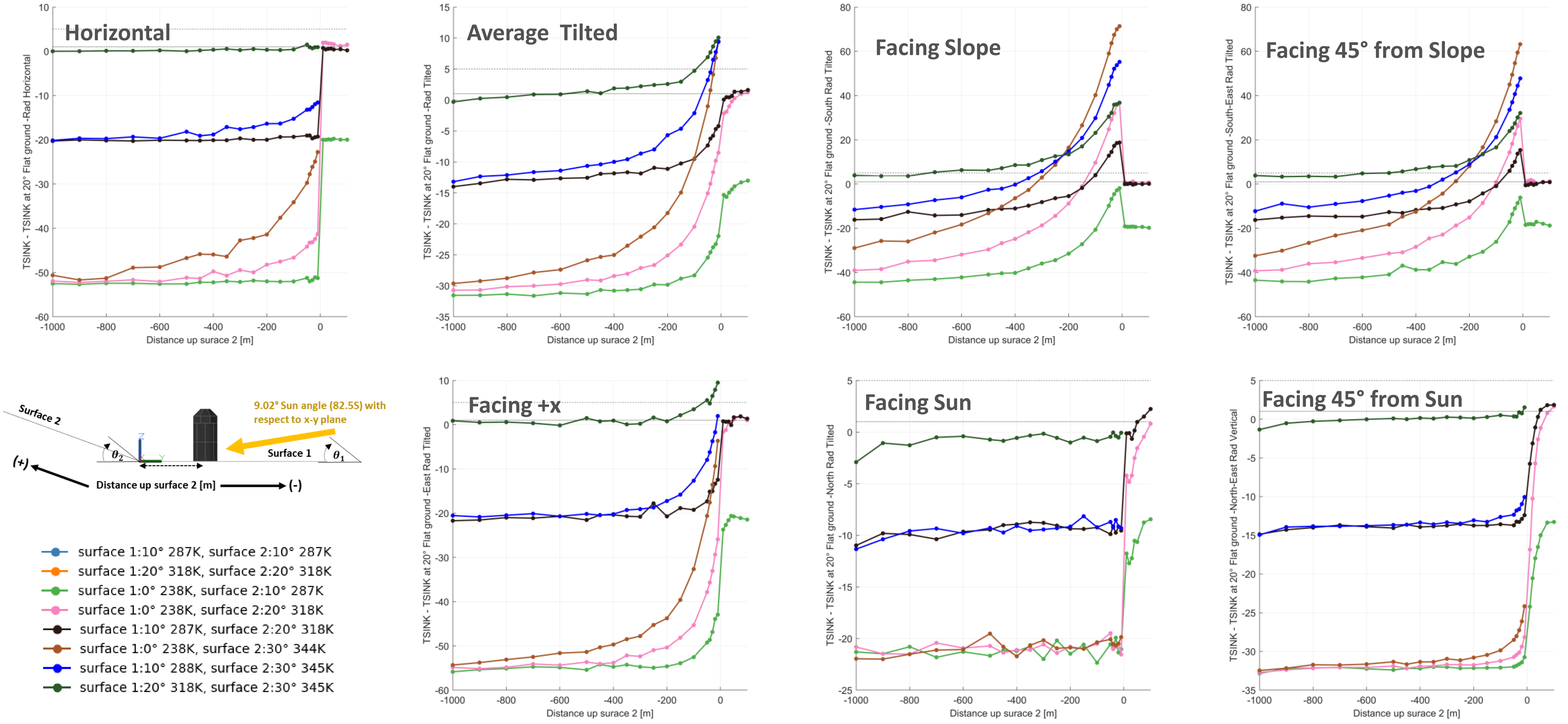




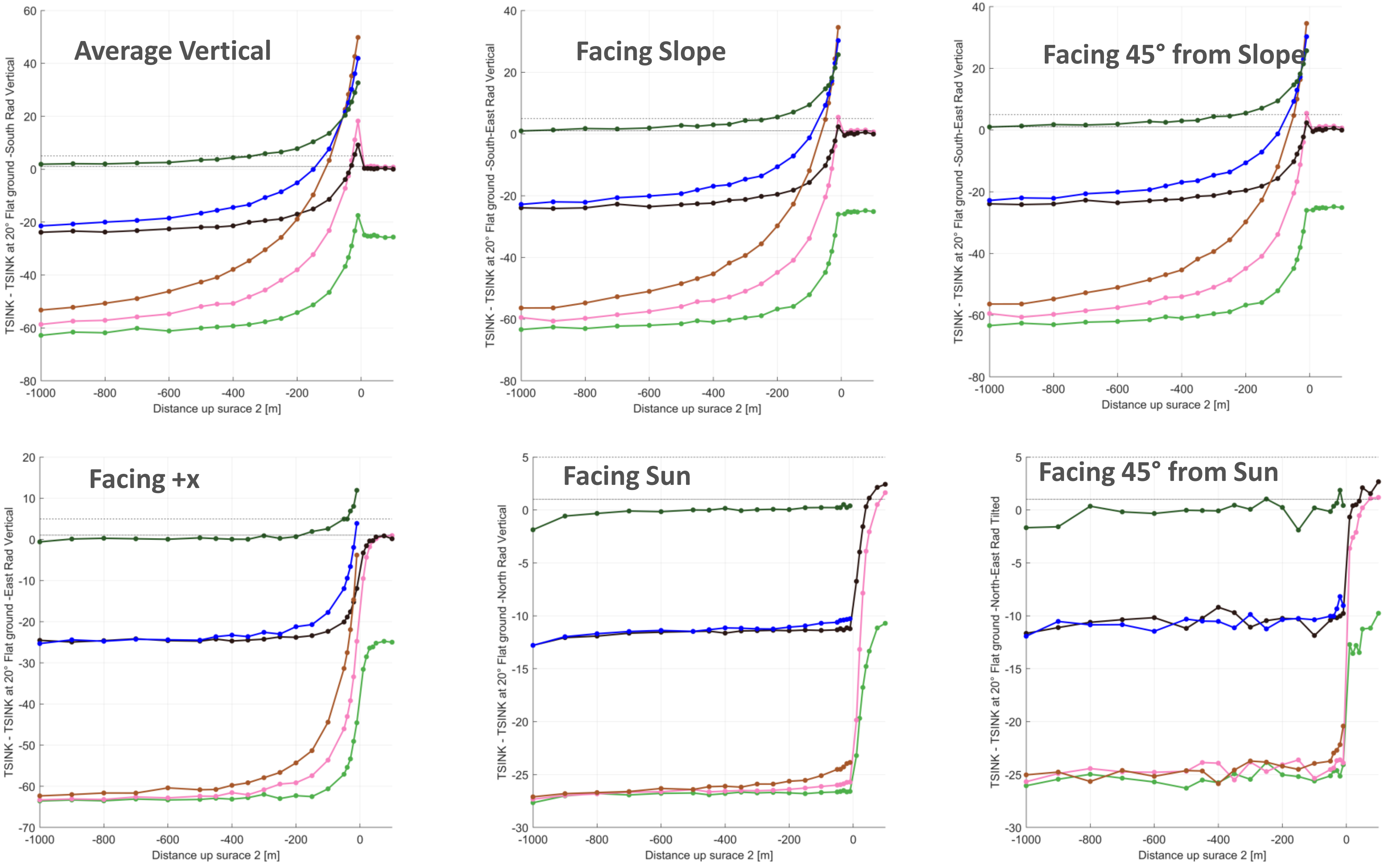


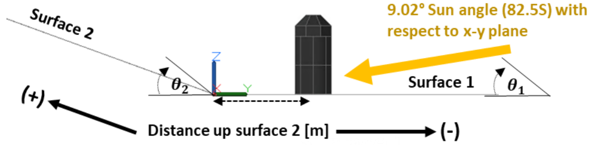
HLS

Study #2: Steady State Results: Slope Impact on TSINK vs a 20° Flat Ground



Study #2: Steady State Results: Slope Impact on TSINK vs a 20° Flat Ground

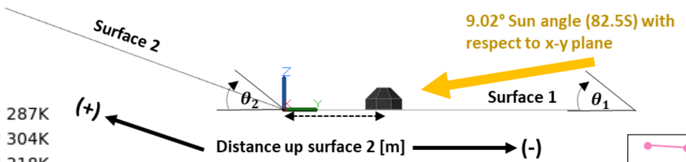




- surface 1:10° 287K, surface 2:10° 287K
- surface 1:20° 318K, surface 2:20° 318K
- surface 1:0° 238K, surface 2:10° 287K
- surface 1:0° 238K, surface 2:20° 318K
- surface 1:10° 287K, surface 2:20° 318K
- surface 1:0° 238K, surface 2:30° 344K
- surface 1:10° 288K, surface 2:30° 345K
- surface 1:20° 318K, surface 2:30° 345K

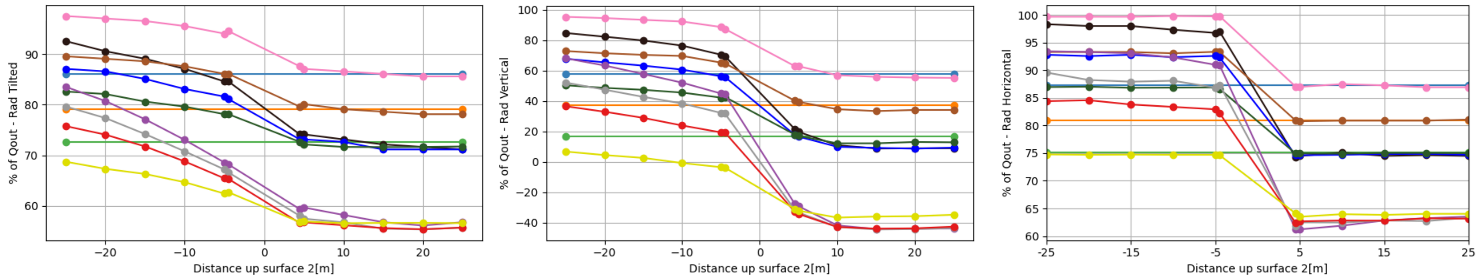
Study #1: Transient Results: Slope Impact on Heat Rejection vs a 0° Flat Ground

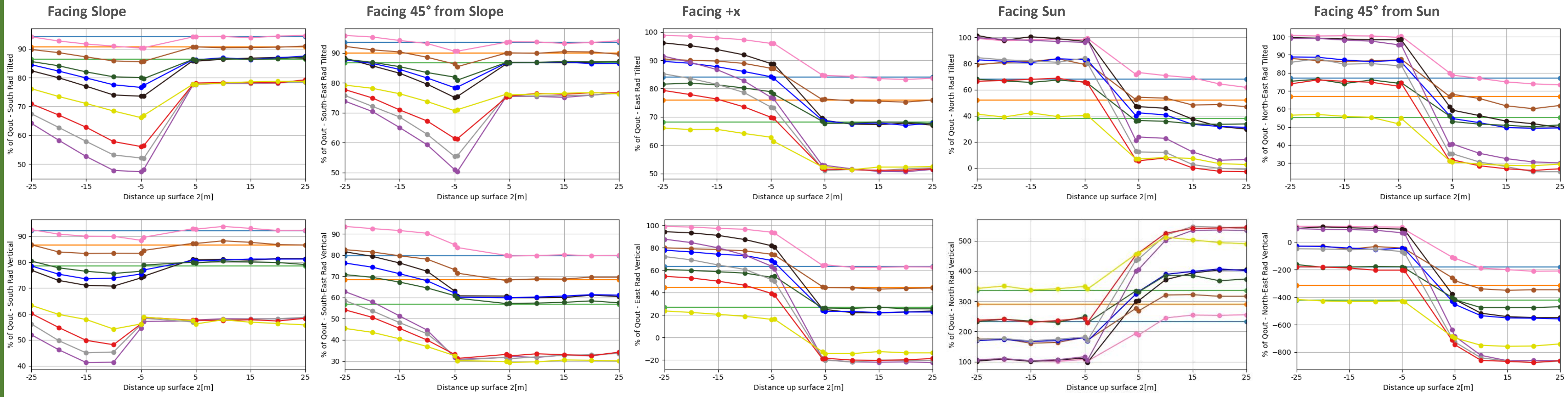
HLS



- surface 1:10° 288K, surface 2:10° 287K
- surface 1:15° 305K, surface 2:15° 304K
- surface 1:20° 319K, surface 2:20° 318K
- surface 1:0° 241K, surface 2:10° 287K
- surface 1:0° 243K, surface 2:20° 319K
- surface 1:5° 268K, surface 2:15° 304K
- surface 1:5° 269K, surface 2:20° 319K
- surface 1:10° 289K, surface 2:20° 319K
- surface 1:0° 246K, surface 2:30° 345K
- surface 1:5° 271K, surface 2:30° 345K
- surface 1:10° 291K, surface 2:30° 345K
- surface 1:20° 320K, surface 2:30° 345K

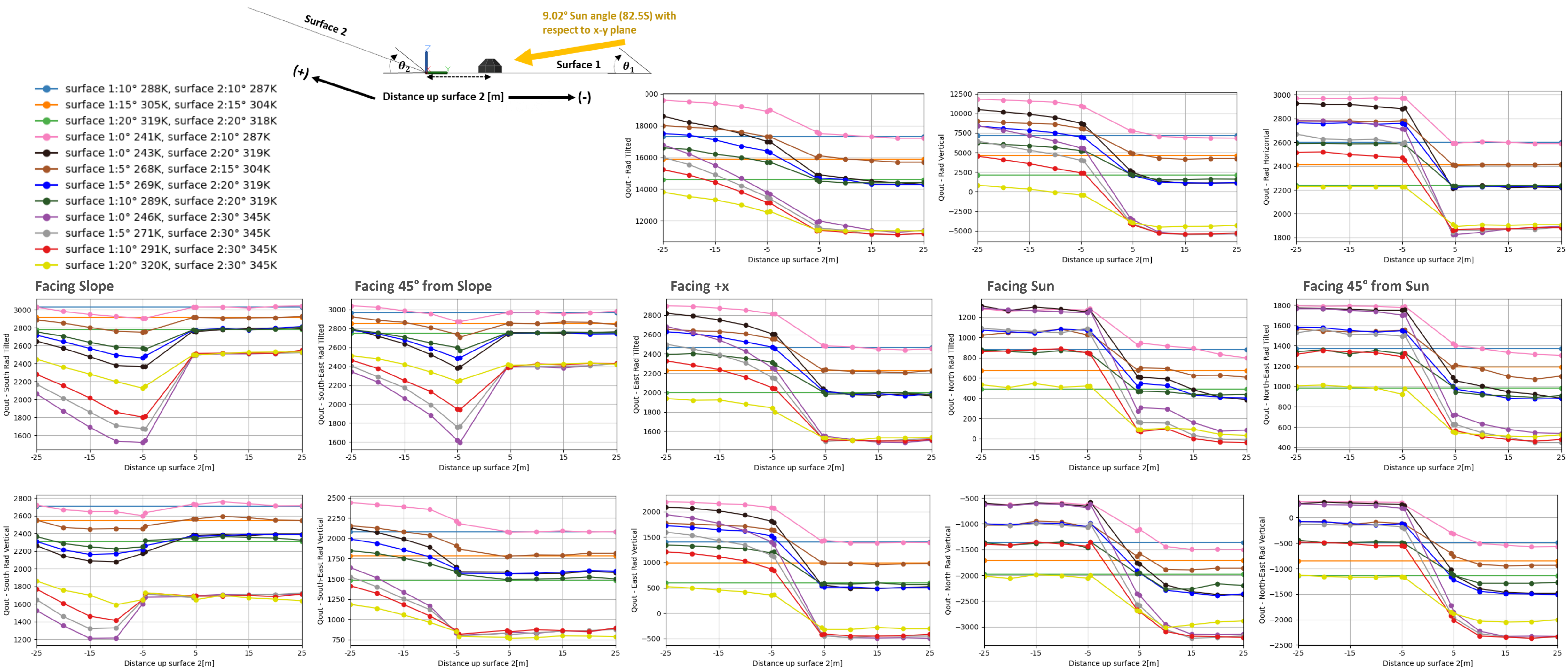
$$\%of = \frac{Qout\ [W]}{Qout_{flat\ plane}\ [W]}$$





Study #1: Transient Results: Slope Impact on Heat Rejection vs a 0° Flat Ground

HLS



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