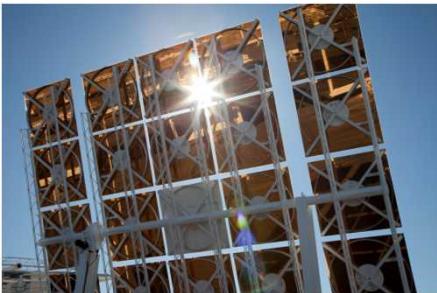


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A Method to Assess Flux Hazards at CSP Plants to Reduce Avian Mortality

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Overview

- Background and Objectives
- Avian Hazard Metrics and Models
- Results
- Conclusions

Background

- Recent reports of birds being singed and killed by solar flux at CSP plants have drawn a significant amount of attention and negative publicity
 - Kagan et al. (2014)
 - Kraemer (2015)
 - Clarke (2015)
- Flux hazards attributed to heliostat standby aiming strategies
 - McCrary et al. 1984, 1986



MacGillivray Warbler with “Grade 3” solar flux injury found at Ivanpah CSP Plant (Kagan et al., 2014)

Objectives

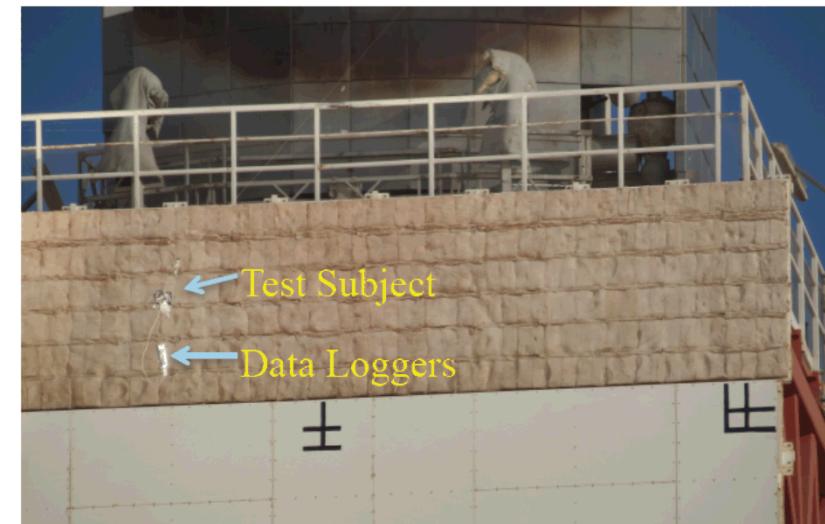
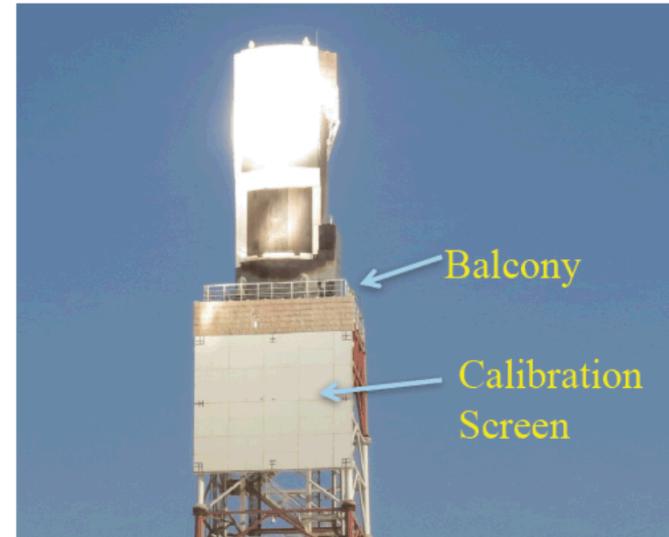
- Develop metrics and model of bird-feather heating with irradiance
 - Assess important model parameters
- Evaluate alternative heliostat standby aiming strategies
- Identify aiming strategies that reduce hazardous avian exposures and minimize impact to operational performance

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Avian Hazard Metrics – Solar Flux

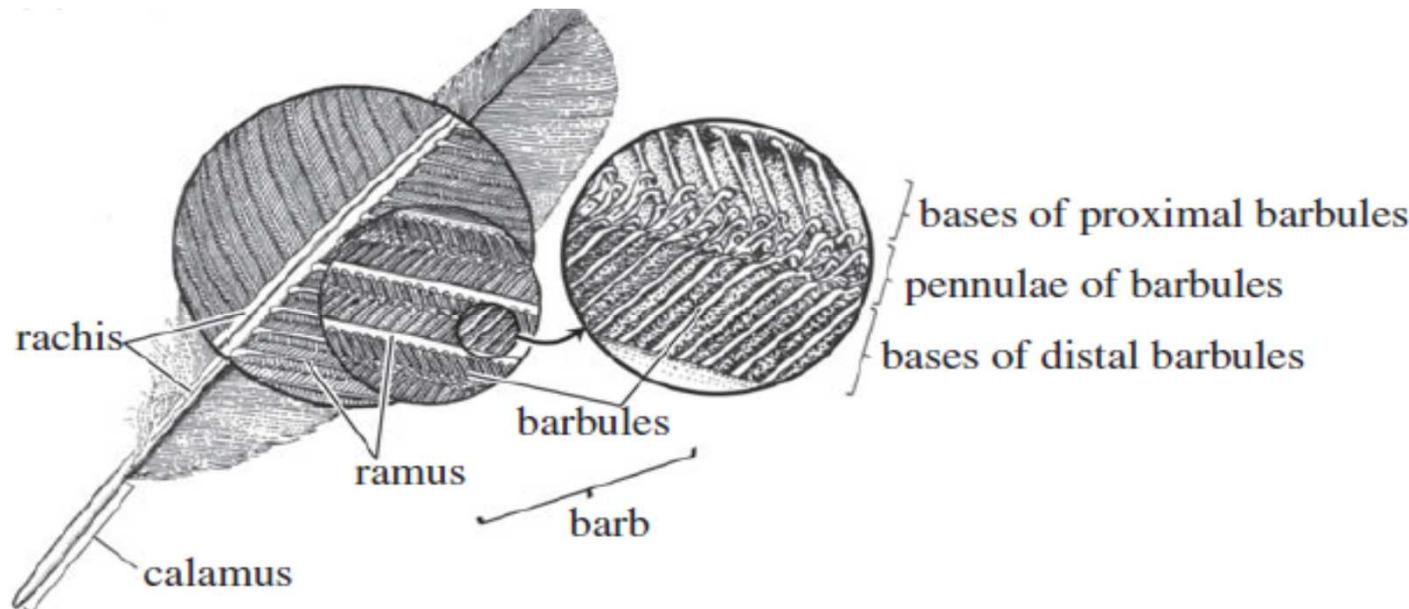
- Tests conducted with bird carcasses exposed to different flux levels (Santolo, 2012)
 - “no observable effects on feathers or tissue were found in test birds where solar flux was below 50 kW/m^2 with exposure times of up to 30 seconds.”
 - California Energy Commission analytical study found that “a threshold of safe exposure does not exist above a solar flux density of 4 kW/m^2 for a one-minute exposure”



Avian Hazard Metrics -

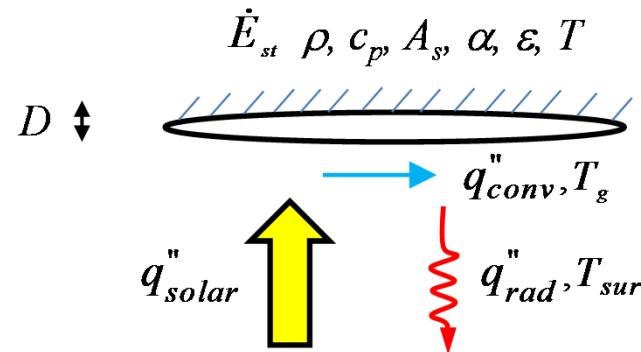
Bird Feather Temperature

- Feather structure can be permanently weakened at $\sim 160^{\circ}\text{C}$
 - Bonds in the keratin structure are broken (Senoz et al., 2012; CEC Tyler et al., 2012)



Modeling Approach

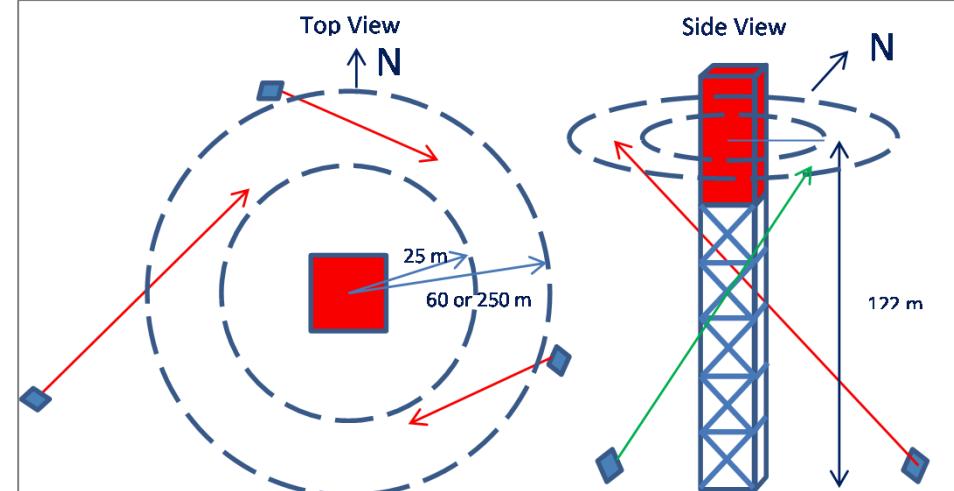
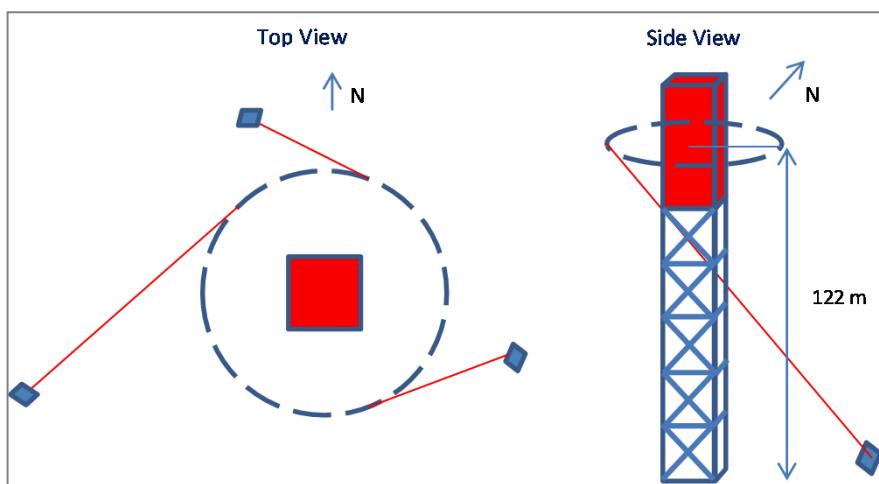
1. Develop heat transfer model of bird feather temperature as a function of irradiance and convective heat loss
2. Develop models of irradiance in airspace above heliostat field for alternative aiming strategies
3. Determine bird feather temperature along flight paths above CSP plant
4. Record total time that bird feather exceeds safe threshold for each aiming strategy



$$T_{i+1} = T_i + \frac{1}{\rho D c_p} \left(\alpha q''_{solar} - h(T_i - T_g) - \varepsilon \sigma (T_i^4 - T_{sur}^4) \right) \Delta t$$

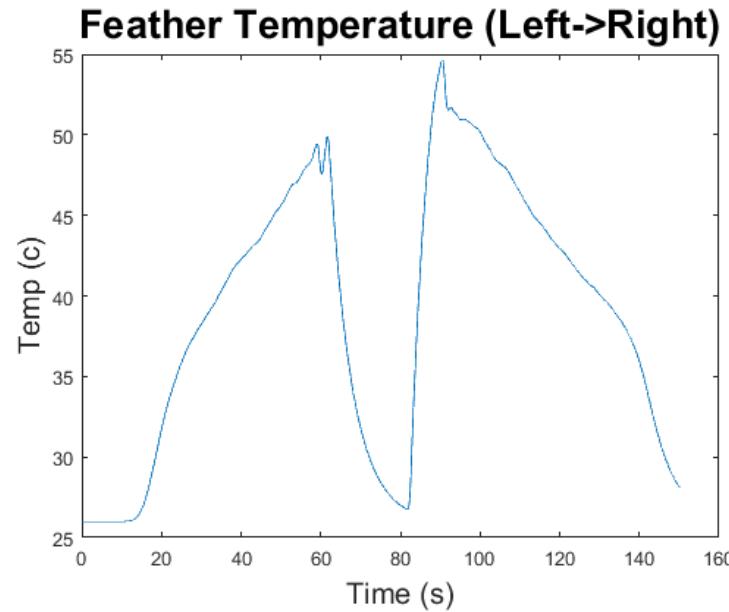
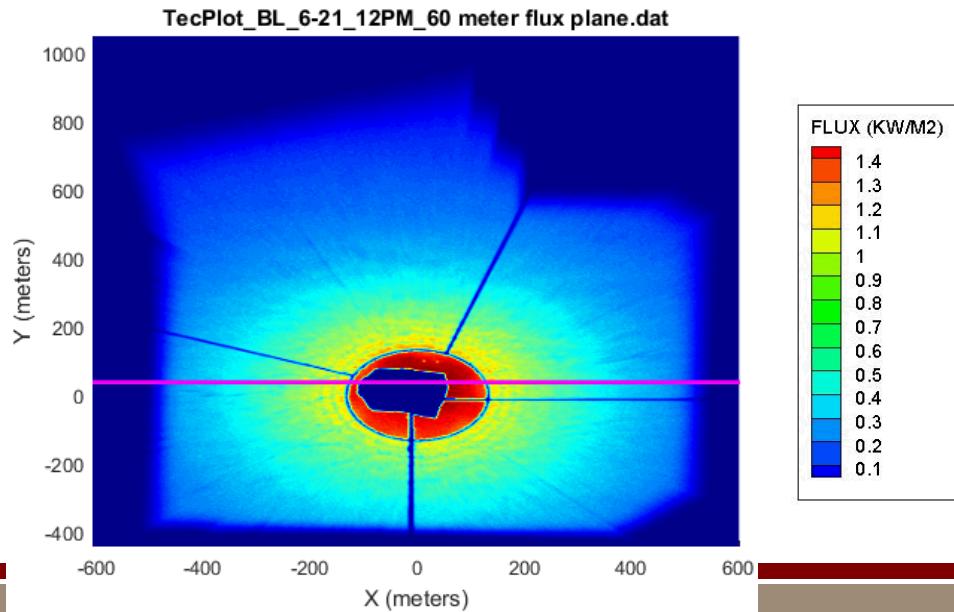
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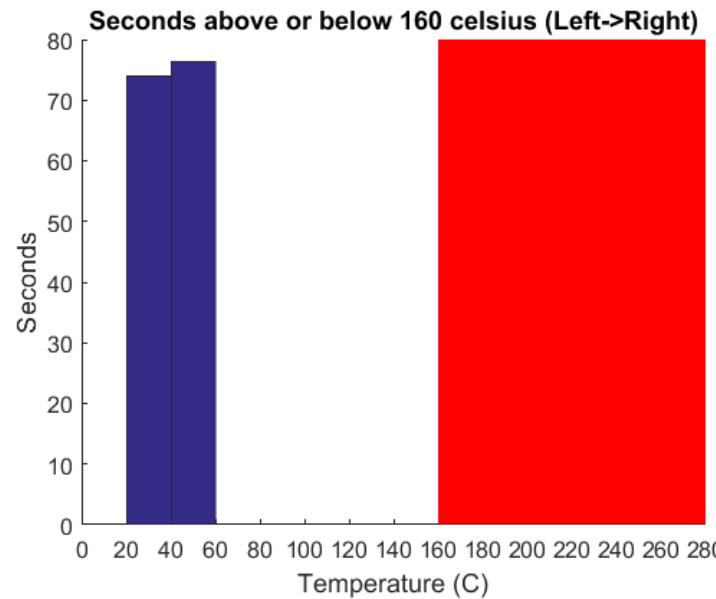
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Modeling Approach

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Modeling Approach

- Identify aiming strategies that minimize hazardous exposure time and impact on operational performance
 - Identify slew time for each heliostat aiming strategy
 - Correlate slew time to energy production using SAM
 - Greater slew times → reduced energy production

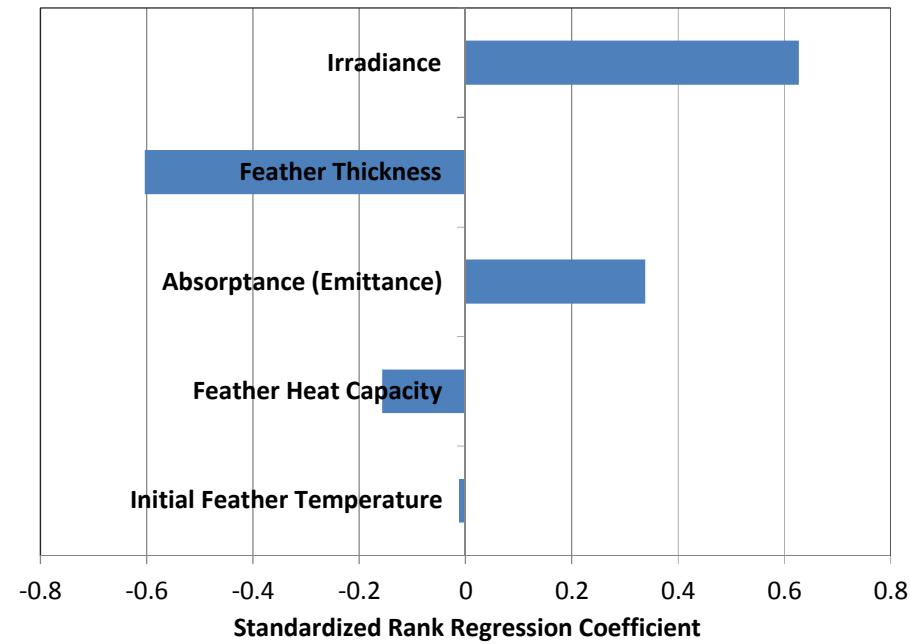
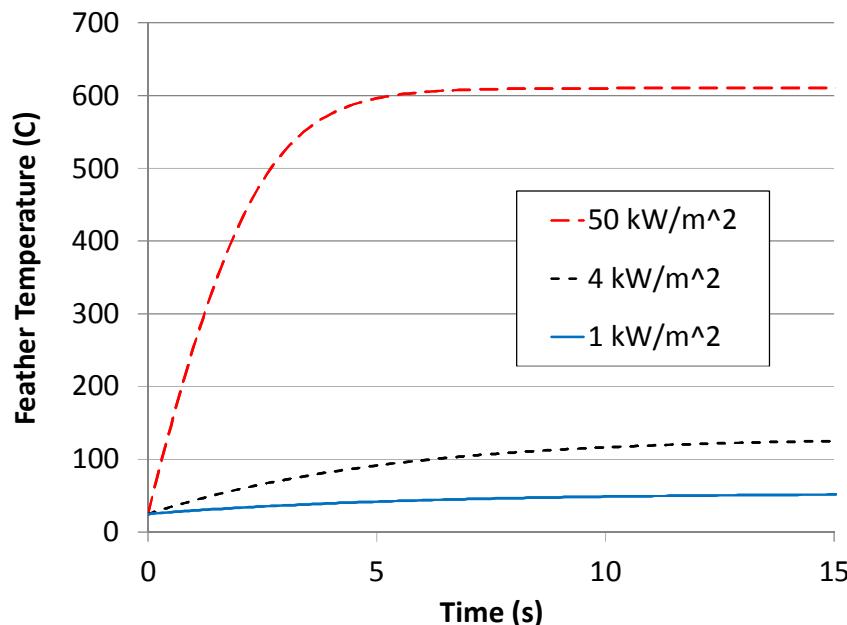
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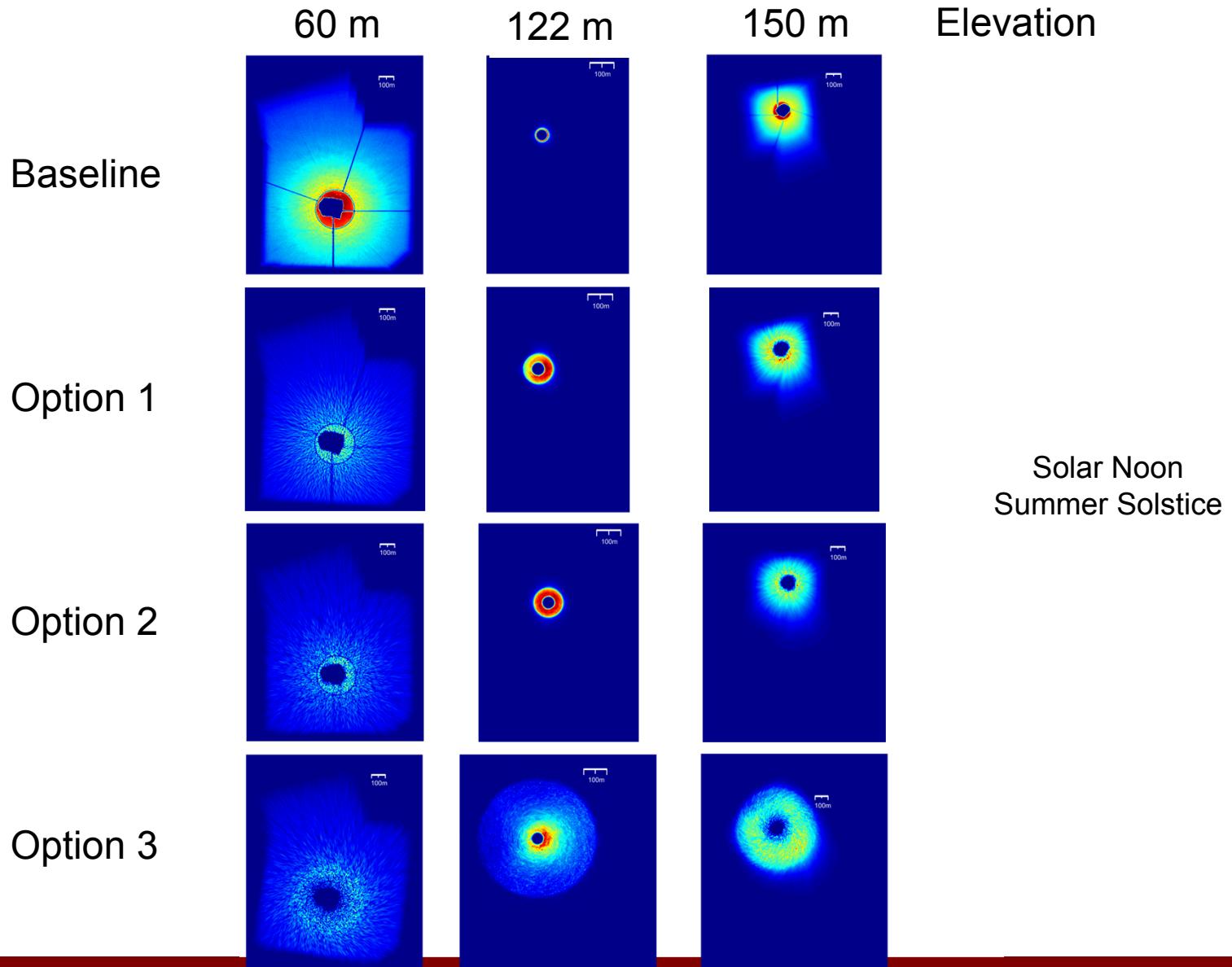
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Bird Feather Temperature



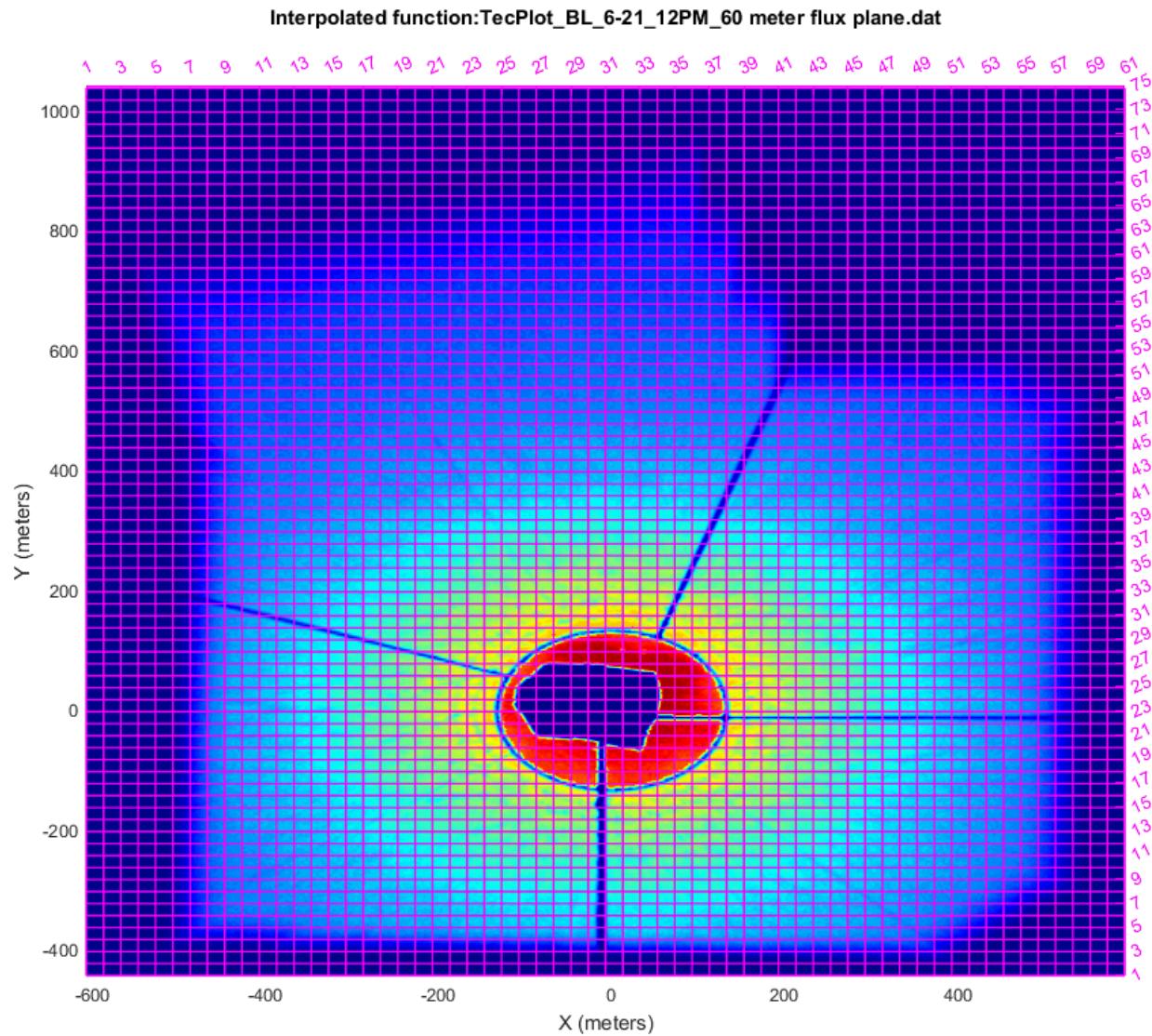
→ Bird feather temperature strongly dependent on irradiance, which varies in the airspace depending on heliostat aiming strategy

Sample Flux Maps



Simulated Bird Flight Paths

- 3 elevations
 - 60 m
 - 122 m (receiver)
 - 150 m
- 4 dates
 - Winter solstice
 - Summer solstice
 - Spring equinox
 - Fall equinox
- 2 Times
 - Solar noon
 - 3 hours before solar noon



Results

Cumulative Exceedance Times (>160 °C) and Normalized Annual Energy Output

Heliosstat Aiming Strategy	Exceedance Time (s) >160 °C	Exceedance Time Normalized to Baseline	Annual Energy Output Normalized to Baseline
Baseline	1170	-	-
Option 1	1806	1.54	1
Option 2	1809	1.55	1
Option 3	751	0.64	0.85

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Conclusions

- Models and methods developed to evaluate avian flux hazards from heliostat standby aiming strategies
 - Bird feather temperature used as metric
 - Cumulative exceedance time $> 160 \text{ }^{\circ}\text{C}$
 - Energy balance model of feather to determine temperature as a function of irradiance, wind, and other parameters
 - Irradiance determined by ray-tracing models of alternative heliostat aiming strategies
- Results show spreading aiming points may increase hazardous exposure times (time exceeding 160 °)
 - Also reduces performance
- Need to find aiming strategy that reduces hazardous exposure time and slew times to target

Team / Collaborators

- **Sandia**
 - Cliff Ho (PI), Luke Horstman (avian hazard modeling), Julius Yellowhair (optical modeling)
- **NREL**
 - Tim Wendelin (flux modeling, avian hazards)
- **Sims Industries**
 - Cianan Sims (SGHAT, TIM)
- **CSP Industry**
 - Doug Davis (NRG/Ivanpah); Gary Raczka/Adam Green (SolarReserve), Hank Price (Abengoa)
- **DoD**
 - Michael Aimone, Ron Tickle (DoD Siting Clearinghouse)
- **Navy**
 - Steve Chung



SunShot

U.S. Department of Energy

Clifford K. Ho

Distinguished Member of the Technical Staff

Sandia National Laboratories

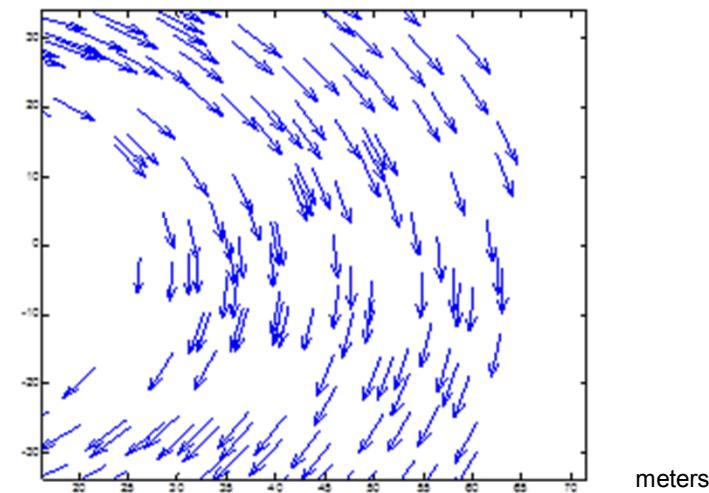
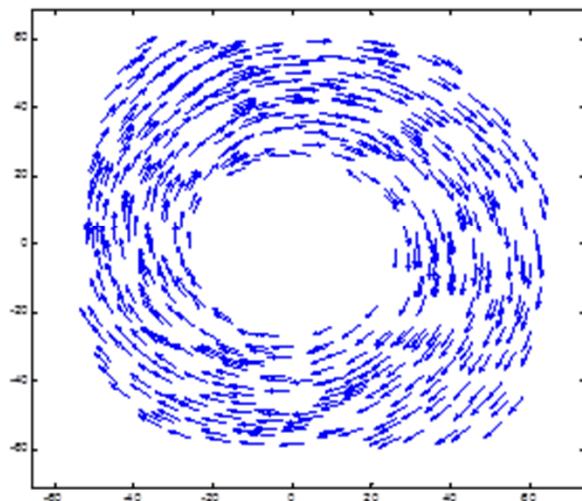
ckho@sandia.gov

Heliostat Standby Aiming Strategies

(Personal communication – Nitzan Goldberg, Brightsource Energy, 7/22/14)

- Option 1 (original)

- Standby points are as close to the receiver as possible
- Each heliostat as its own aim point depending on azimuth and distance
- Each heliostat aims to the left side of the receiver

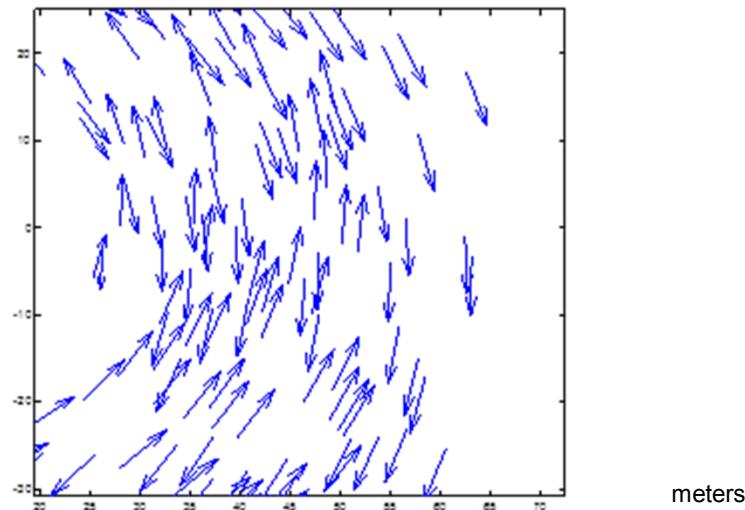
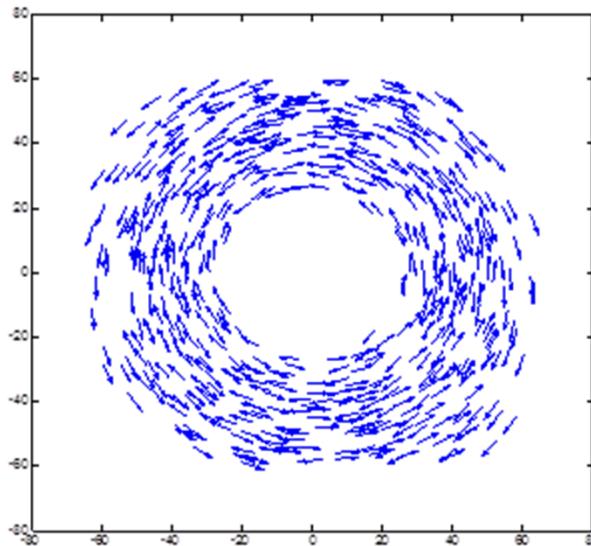


Quiver plots showing flux vectors near the receiver from a sample of heliostats for Option 1

Heliostat Standby Aiming Strategies

(Personal communication – Nitzan Goldberg, Brightsource Energy, 7/22/14)

- Option 2 (Unit 1 during April 24 flyover?)
 - Standby points are as close to the receiver as possible
 - Each heliostat as its own aim point depending on azimuth and distance
 - Aiming is to both sides of the receiver

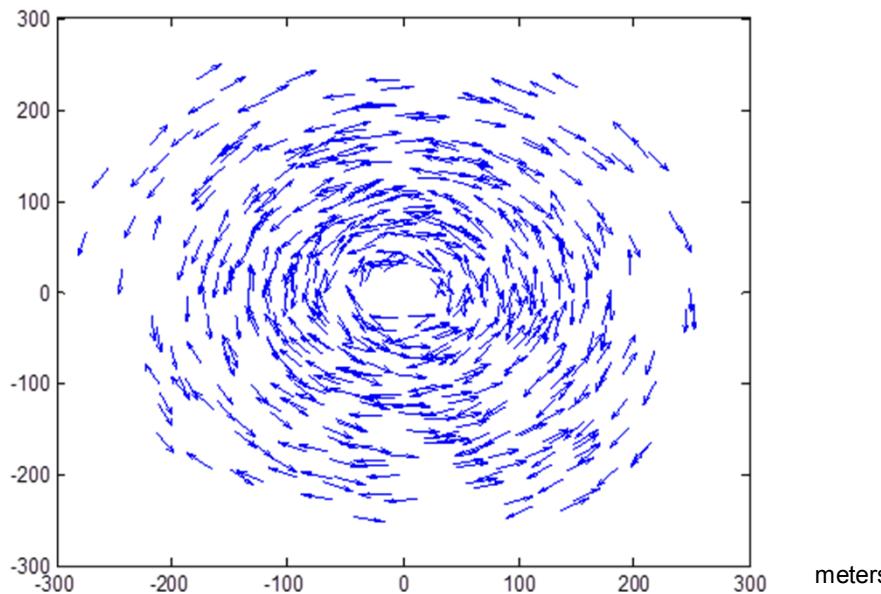


Quiver plots showing flux vectors near the receiver from a sample of heliostats for Option 2

Heliostat Standby Aiming Strategies

(Personal communication – Nitzan Goldberg, Brightsource Energy, 7/22/14)

- Option 3 (Units 1 and 2 during July 22 flyover)
 - Spread standby points to reduce flux density in air around receiver and to disperse the observable glare
 - Aiming is to both sides of the receiver



Quiver plots showing flux vectors near the receiver from a sample of heliostats for Option 3