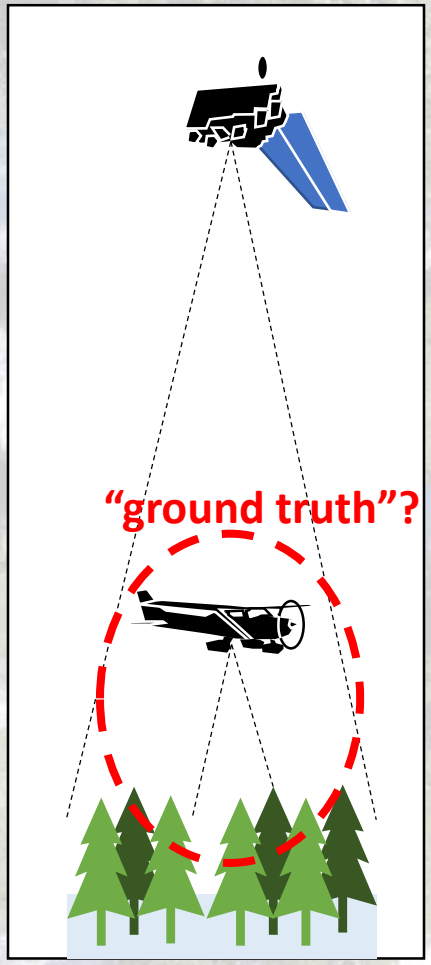
Airborne Remote Sensing Surface Temperatures of Forests and Melting Snow

Steven Pestana[1], C. Chris Chickadel[1], Adrian Harpold[2], Tihomir S. Kostadinov[3], Henry Pai[2], Scott Tyler[2], Clare Webster[4,5], Jessica Lundquist[1]

[1]University of Washington, Seattle, WA, USA; [2]University of Nevada, Reno, NV, USA; [3]Desert Research Institute, Reno, NV, USA; [4]WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland; [5]University of Edinburgh, Edinburgh, UK

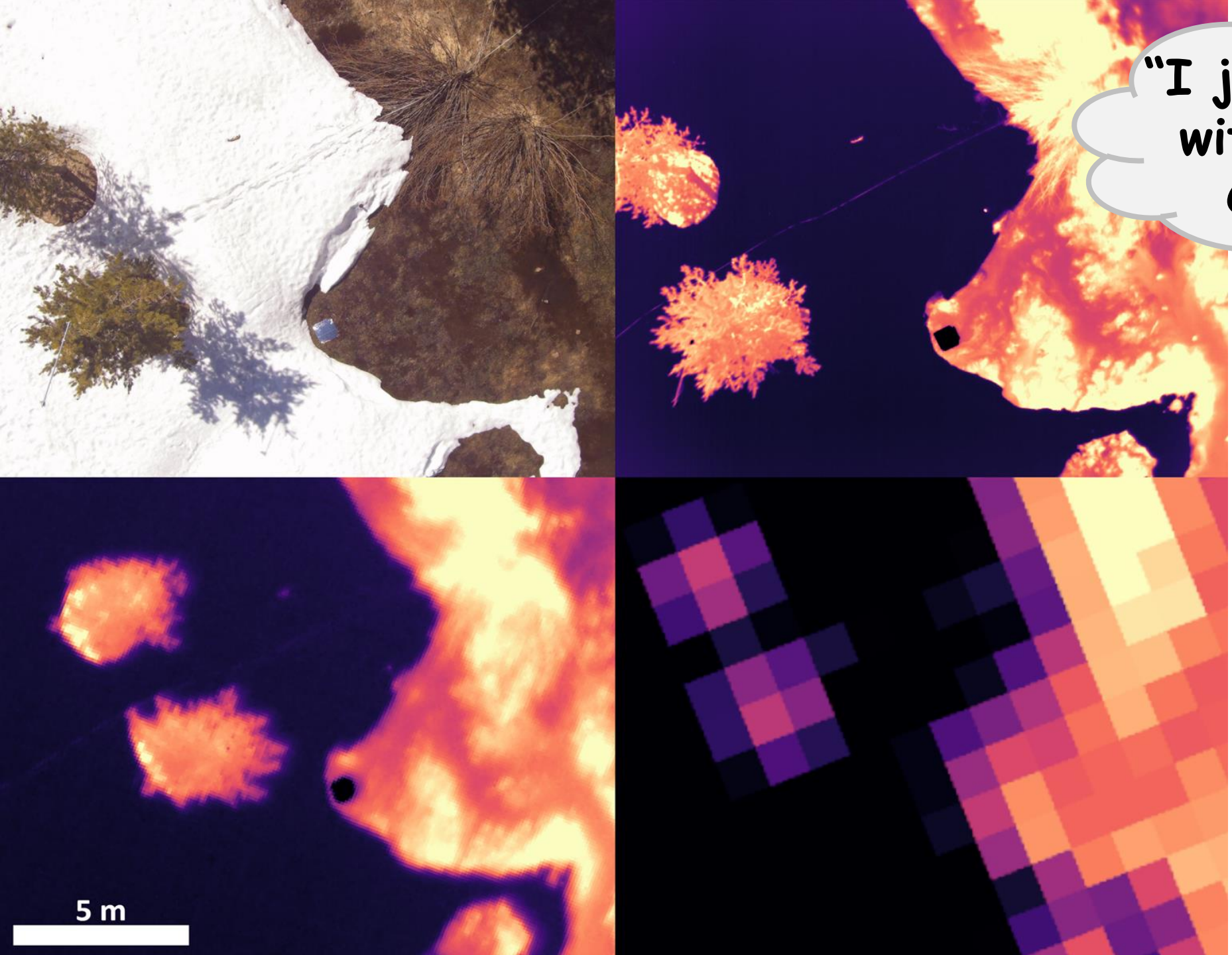
How representative of true surface temperatures are our airborne thermal infrared (TIR) observations over forests and snow?



Specifically, what are the impacts of …

1. **TIR camera bias**
2. **Image resolution**
3. **View angle**

…on retrieving accurate surface temperature measurements over forests and snow?


5 m

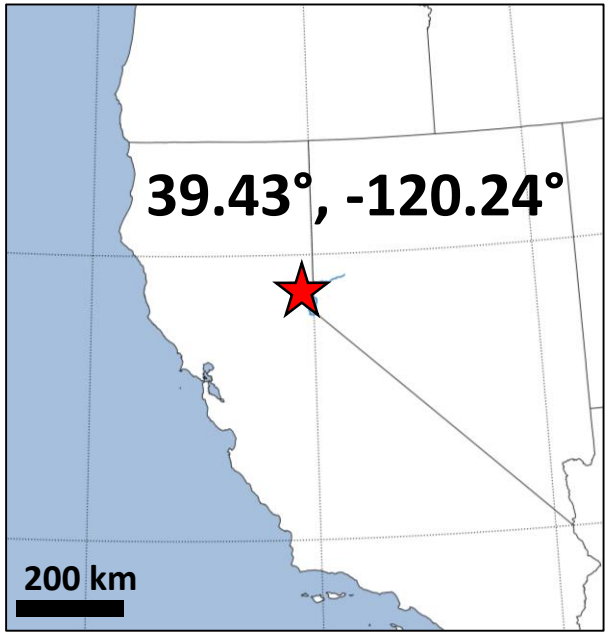

"I just bought a drone with a TIR camera. Can I trust it?"
?

Study Sites

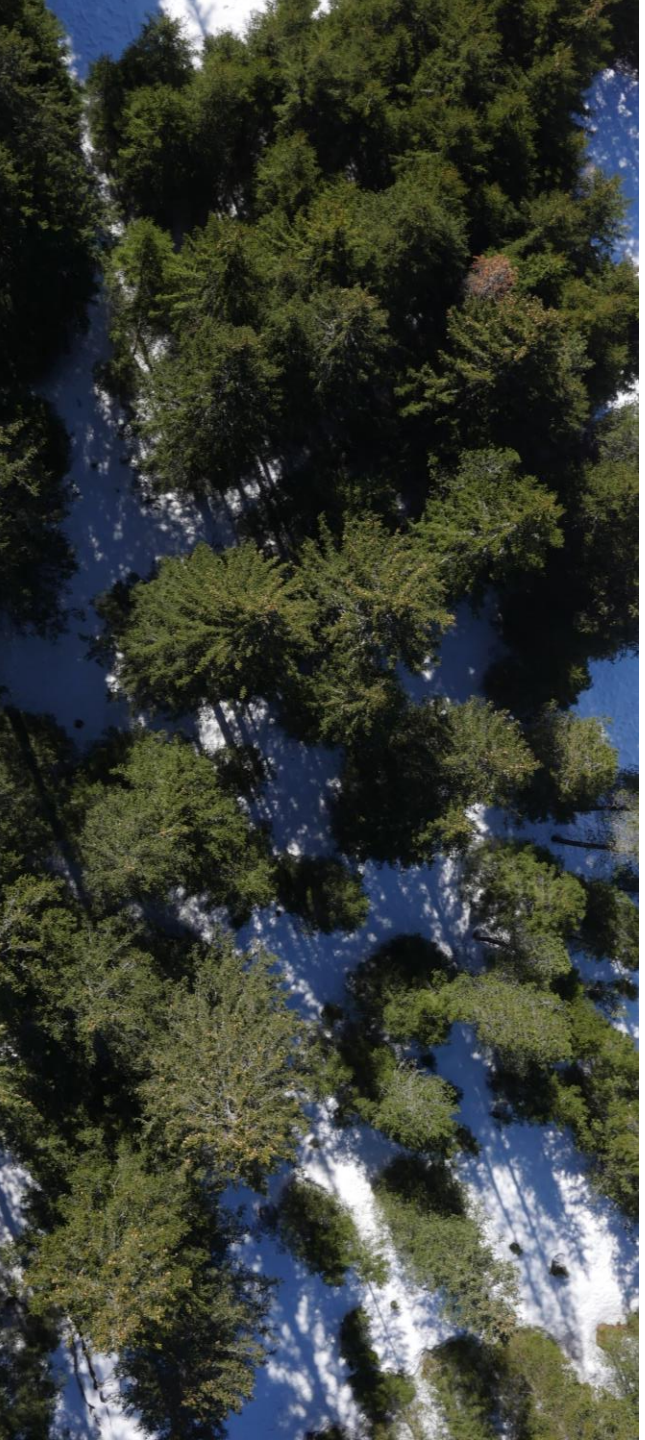
Davos Laret
Switzerland
(Alps)

27 March 2017

Sagehen Creek
California, USA
(Sierra Nevada)



21 April 2017



In Situ and **Airborne** Data Collection

Davos: 27 March 2017

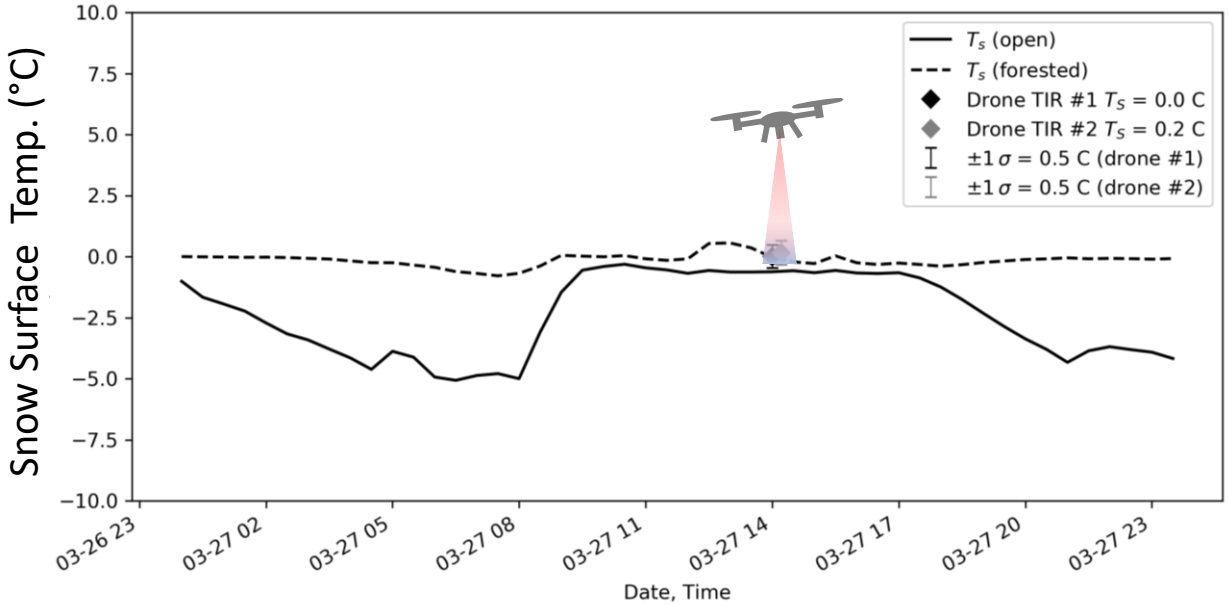
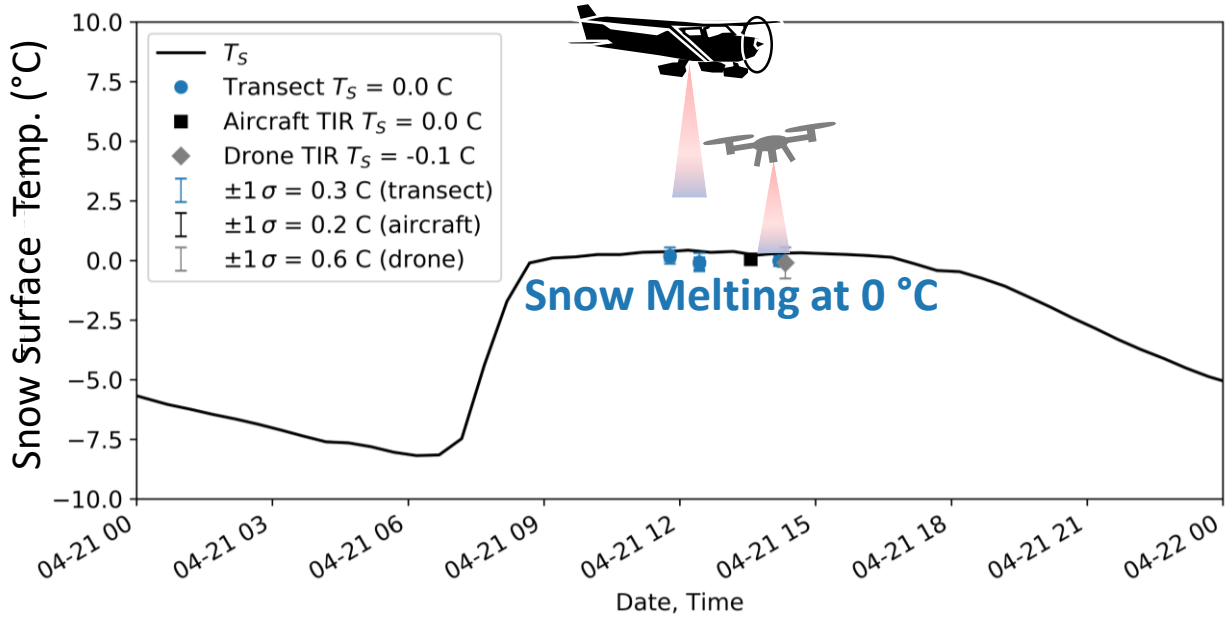


Image Resolutions: **< 20 cm/px**

In Situ and **Airborne** Data Collection
Sagehen: 21 April 2017



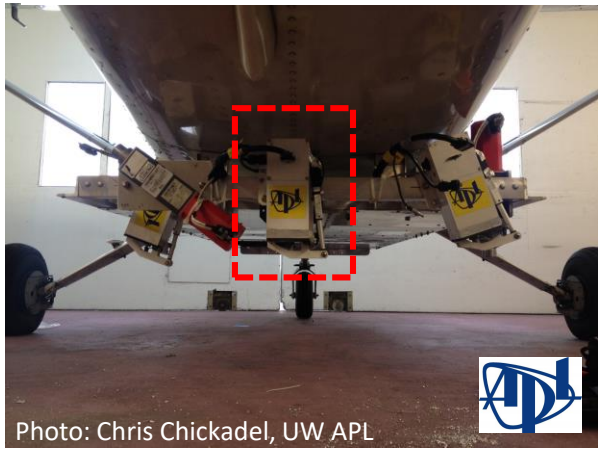
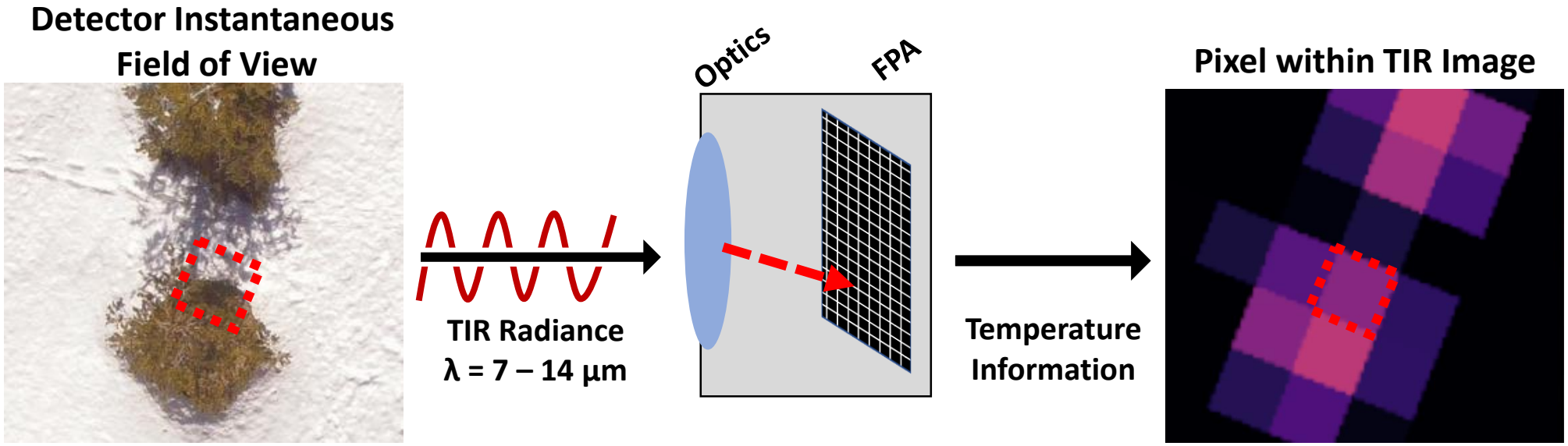


Image Resolutions: **1.5 m/px** **< 10 cm/px**

Uncooled microbolometer TIR cameras **sense radiance as changes in detector temperature**, relative to their **focal plane array (FPA) temperature**.

Differences in ambient air temperature, solar illumination, or self-heating from electronics can change the FPA temperature over time and introduce **bias in surface temperature observations**.



How representative of true surface temperatures are our airborne TIR observations over forests and snow?

1. **TIR camera bias** & how to correct
2. Image resolution
3. View angle

Methods for correcting TIR camera bias

Internal Shutter

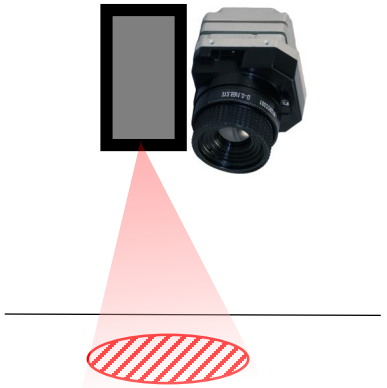
- Periodic recalibrations

Instrumented Field Targets

- Requires additional fieldwork, equipment
- Limited to smaller, accessible survey areas

[Torres-Rua, 2017; Jensen et al., 2014]

Paired Radiometer



- Requires additional instrument

[Lundquist et al., 2018]

Melting Snow Field Target

- Requires melting snow

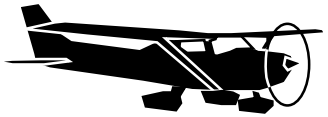
Methods for correcting TIR camera bias

Internal Shutter

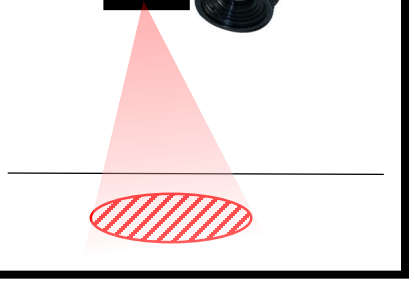
- Periodic recalibrations

Instrumented Field Targets

- Requires additional fieldwork, equipment
- Limiting to smaller survey areas



Paired Radiometer

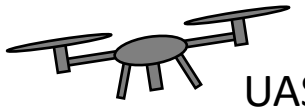


- Continuous calibration
- Requires additional instrument

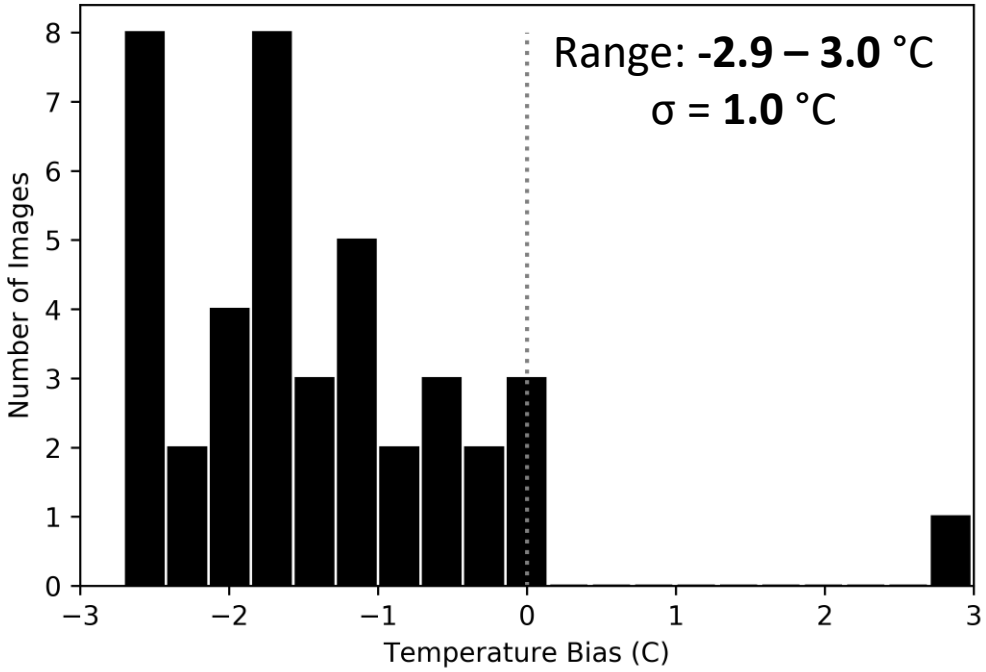
Melting Snow Field Target

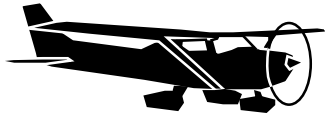
- Continuous
- Requires melting snow

Vicarious calibration of a TIR camera with a paired radiometer performed better than that with an internal shutter

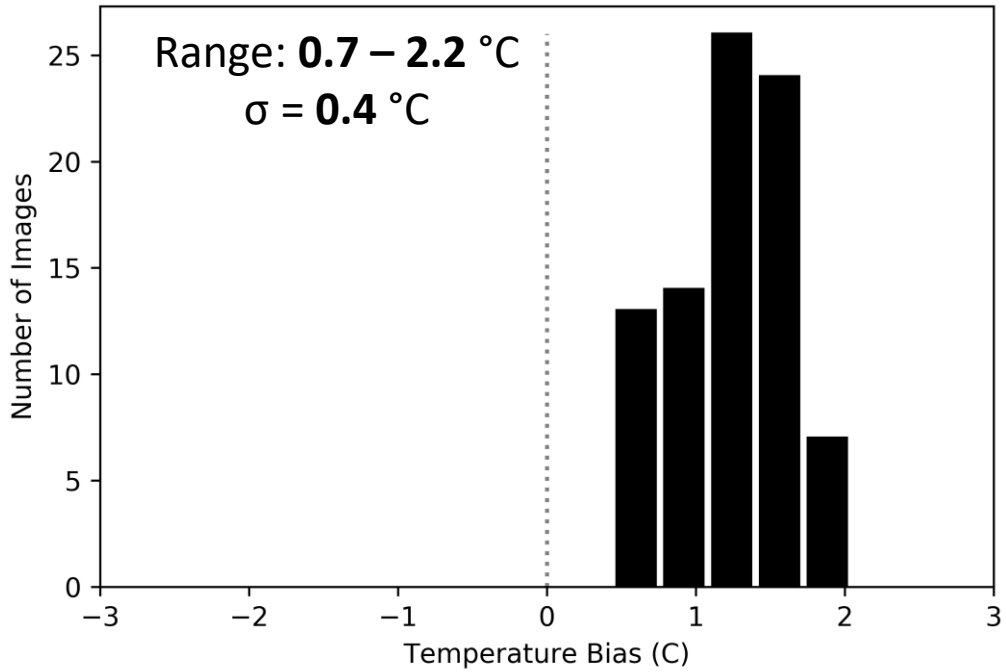


Bias Histogram
UAS TIR with **internal shutter**



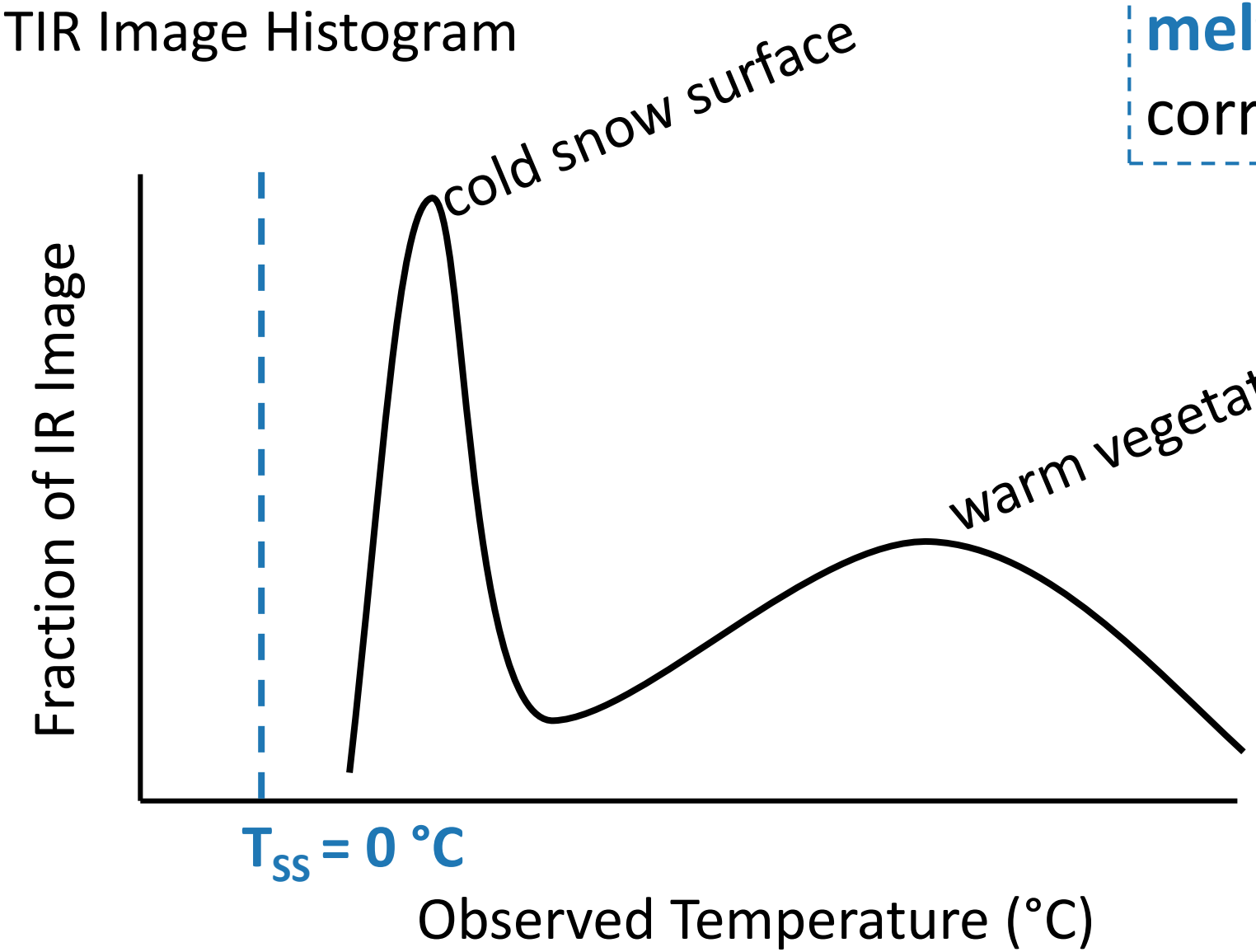


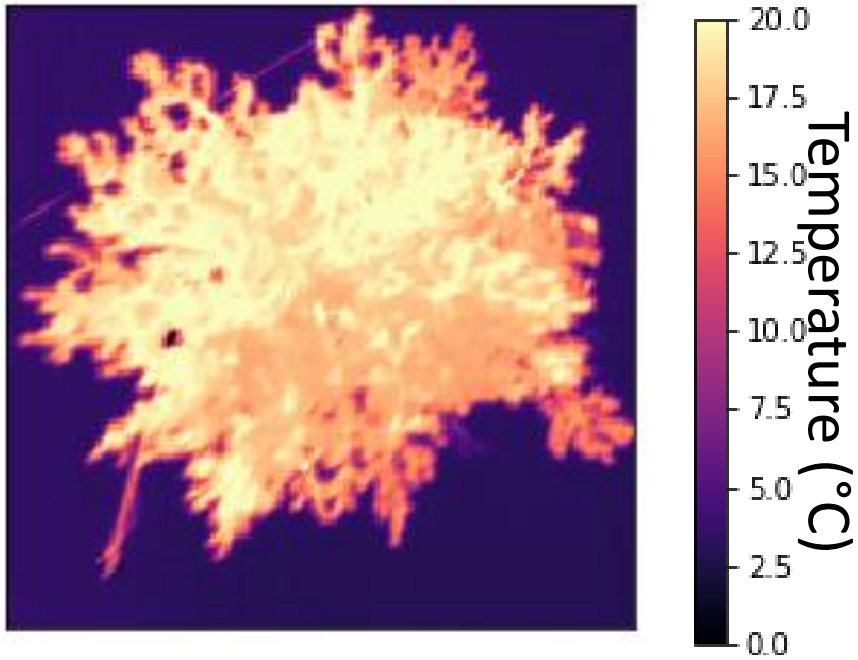
Bias Histogram
Aircraft TIR with **paired radiometer**



The uniform **temperature of melting snow** is used to bias correct individual TIR images

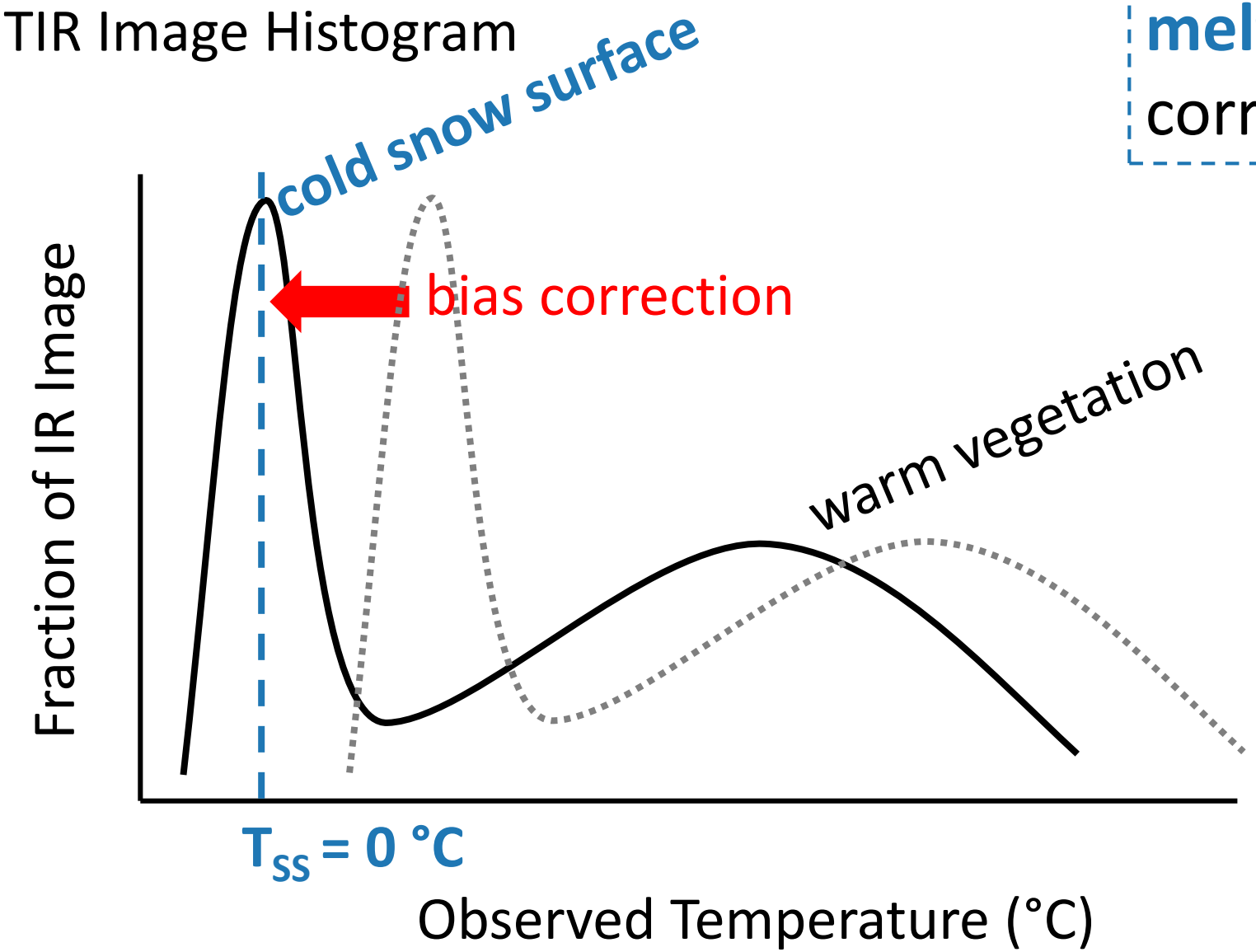
TIR Image Histogram

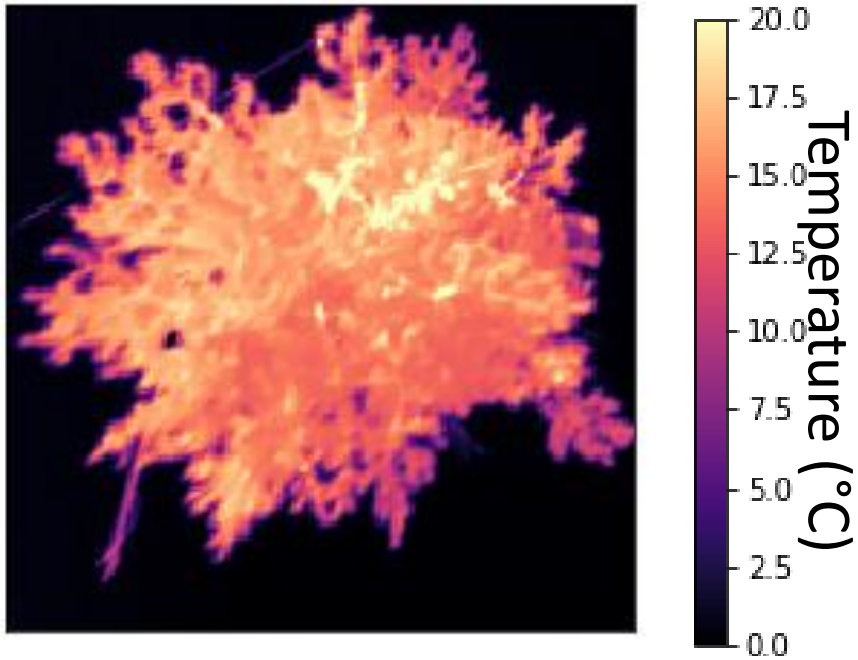




The uniform **temperature of melting snow** is used to bias correct individual TIR images

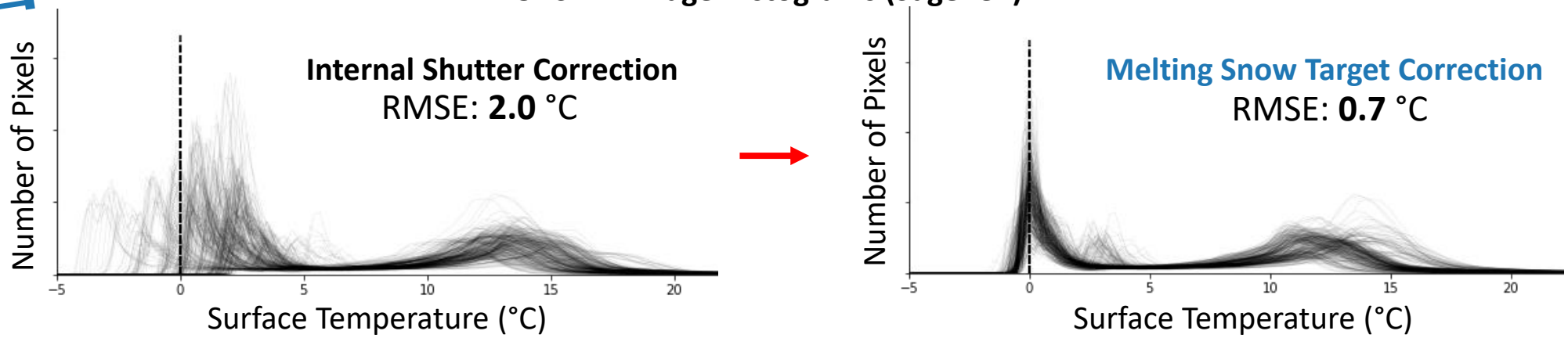
TIR Image Histogram



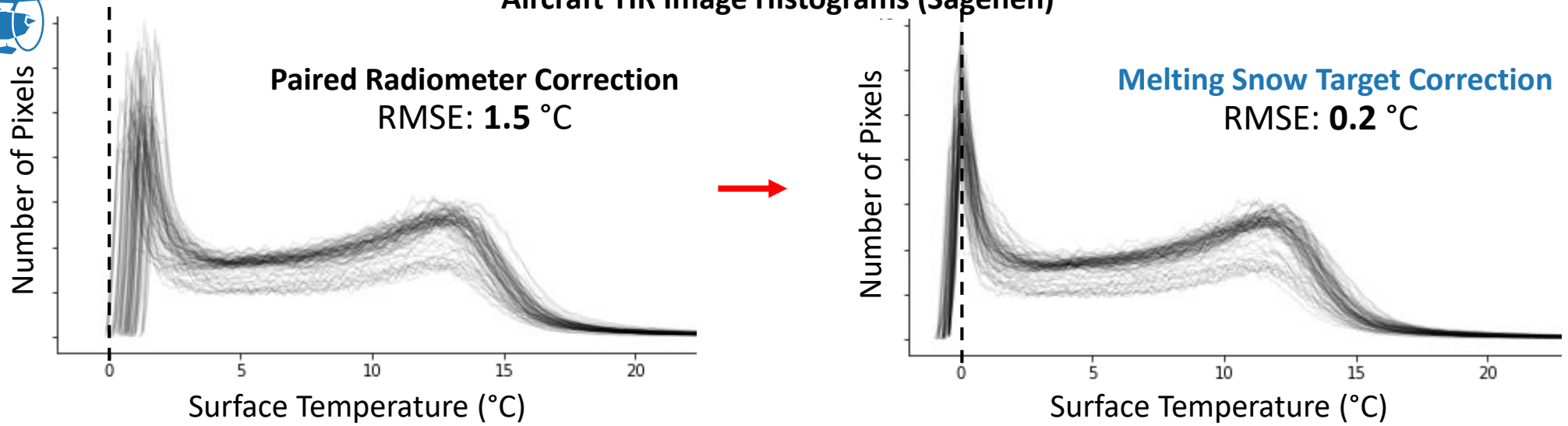


Using melting snow as a calibration target reduced surface temperature RMS errors by ≈1.0 °C

UAS TIR Image Histograms (Sagehen)



Aircraft TIR Image Histograms (Sagehen)



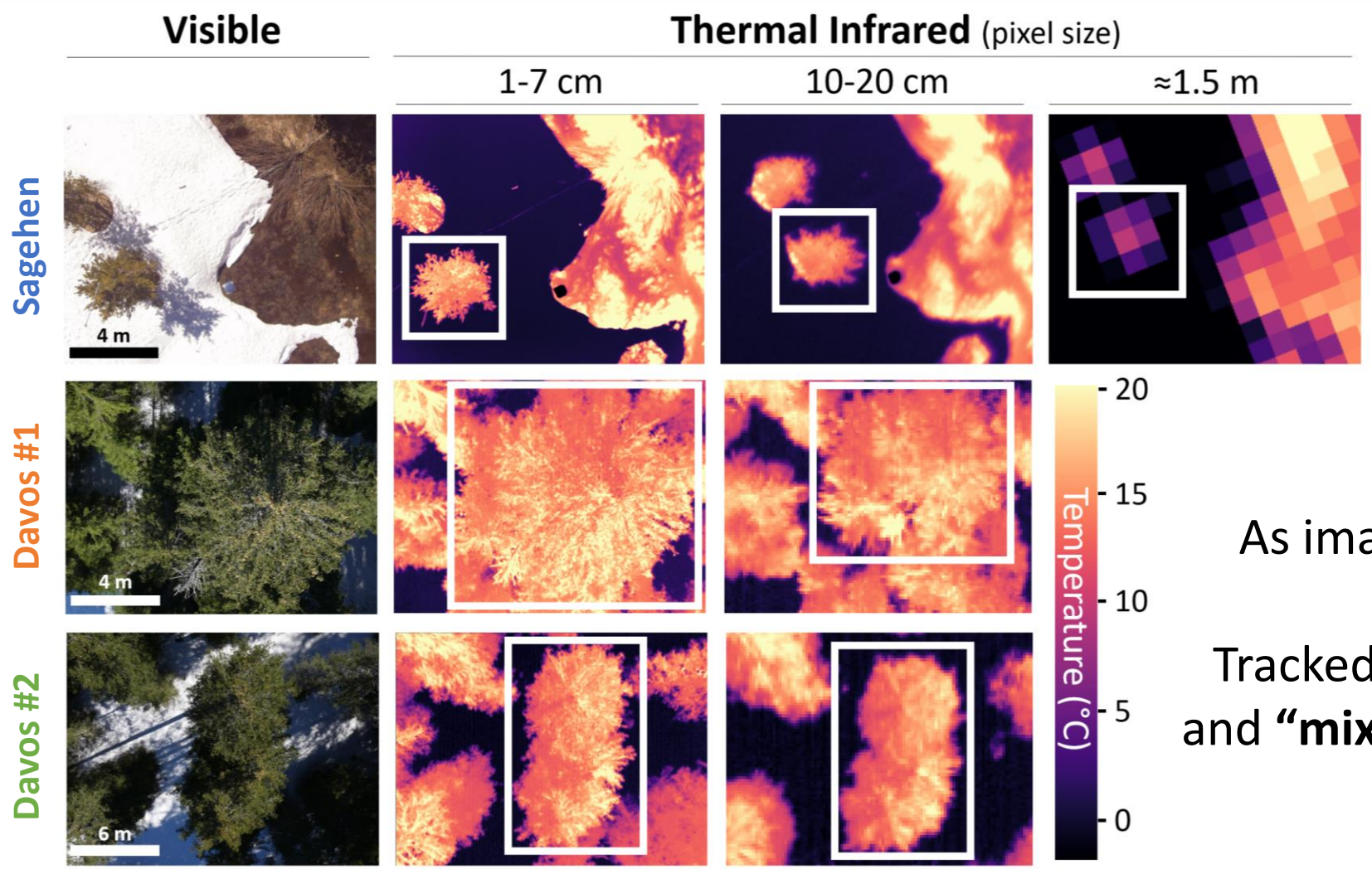
TIR Camera Bias Summary

- **Melting snow provides a natural calibration target** for bias correction of TIR cameras
- This can enable more accurate **TIR surveys of large or inaccessible areas** without the need for installing numerous ground targets

How representative of true surface temperatures are our airborne TIR observations over forests and snow?

1. TIR camera bias
2. **Image resolution**
3. View angle

Vertical flights to decrease TIR image resolution over canopy-snow edges

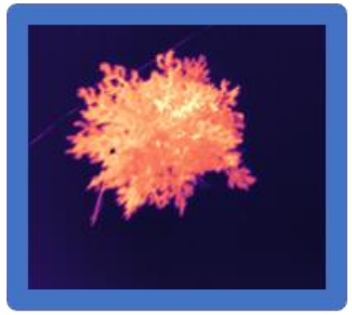


As image resolutions decreased:

Tracked **temperature distributions** and **"mixed pixel fraction"** of canopy

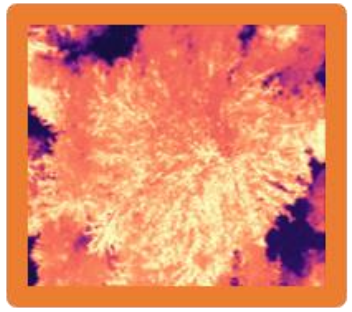
The fraction of forest canopy contained within **mixed pixels increases** as image resolution decreases, more significantly for “sparse forest”

Sagehen



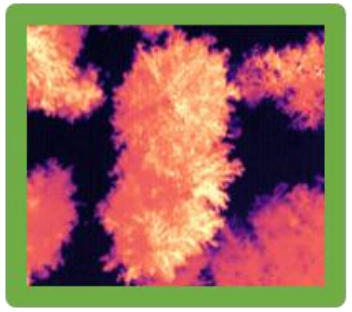
single tree

Davos #1



denser forest

Davos #2



tree cluster

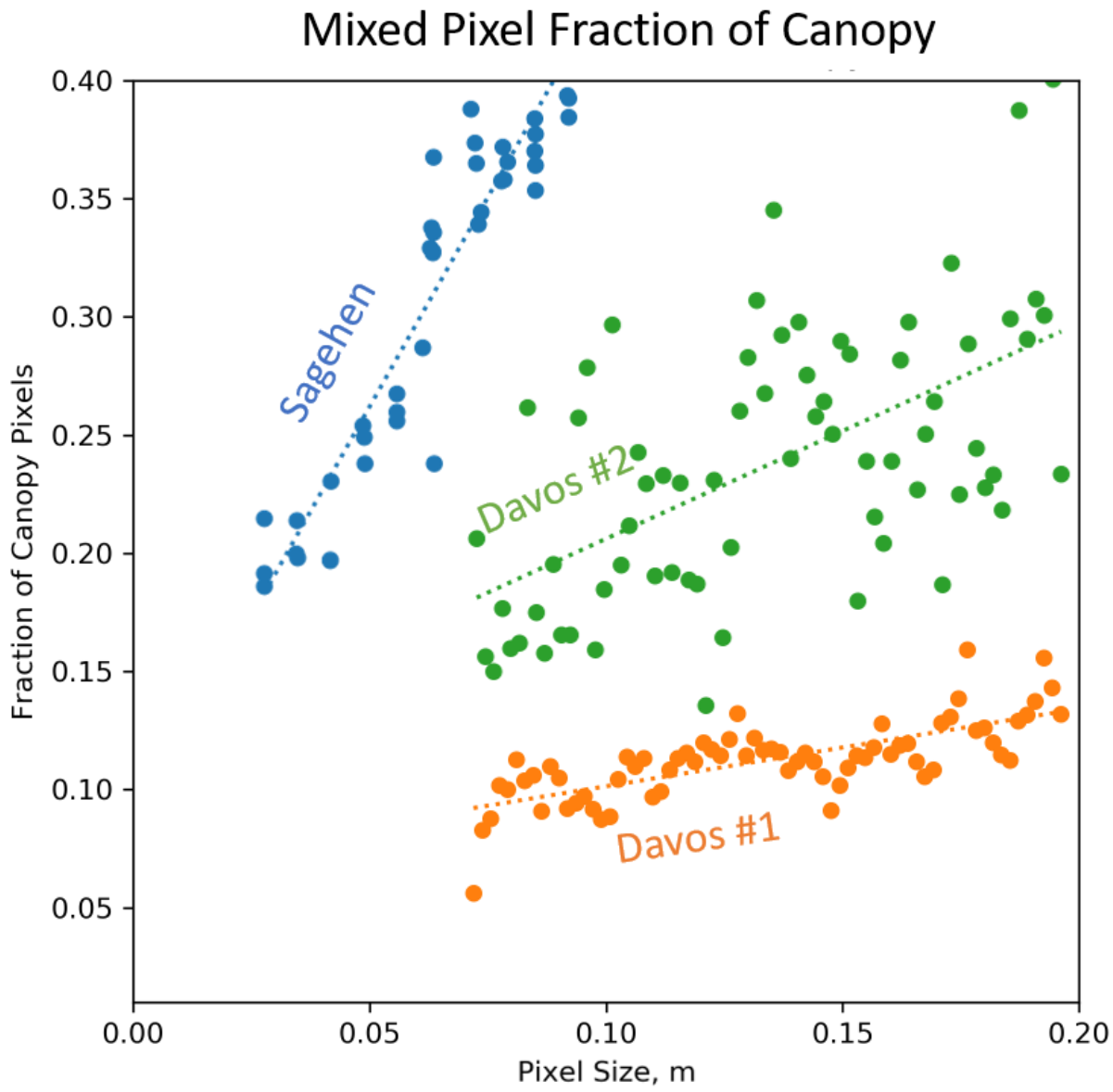
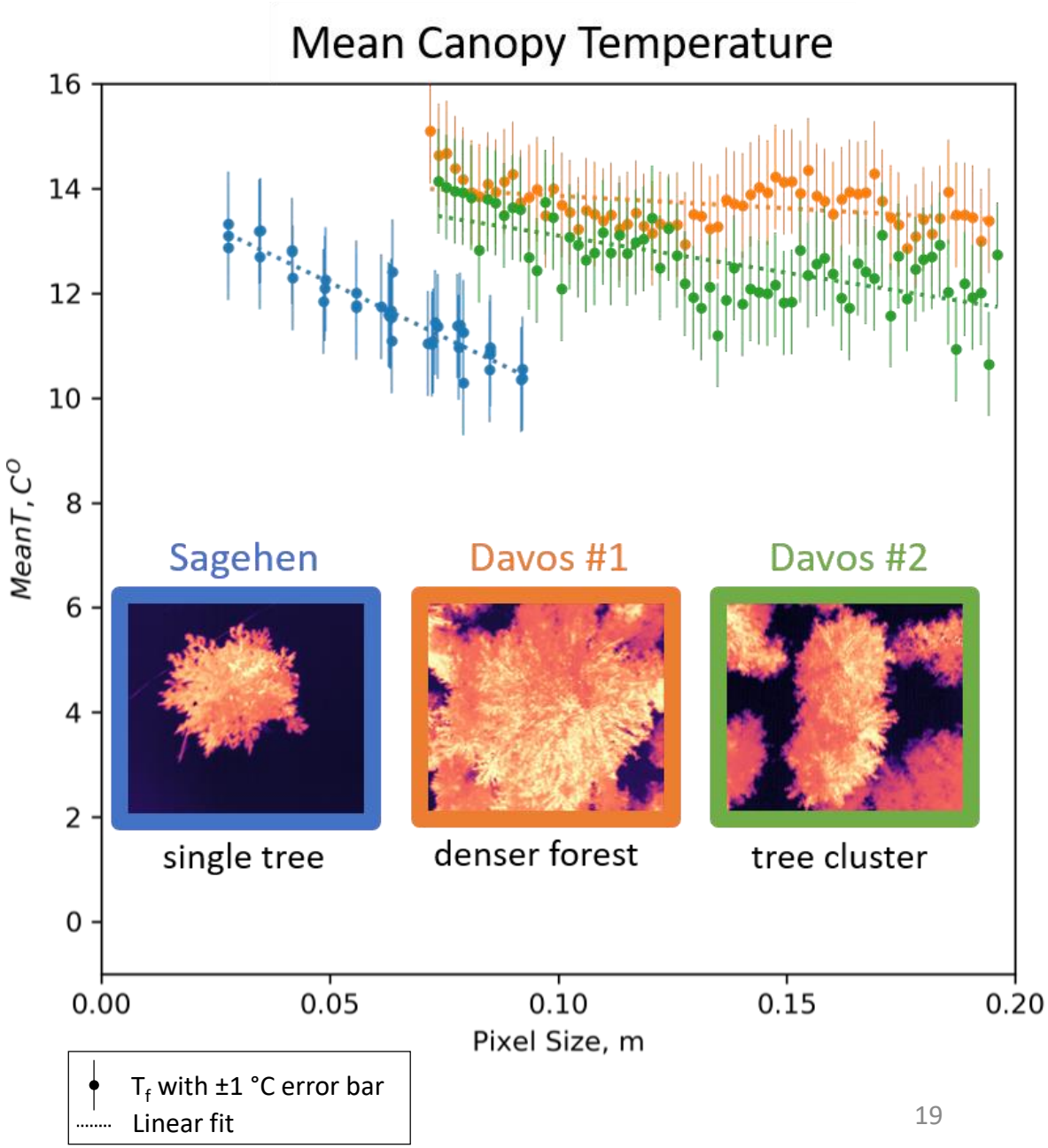


Image-wide mean temperatures are preserved, but the **mean canopy temperature decreases** at forest edges as image resolutions decrease

These effects are more significant for the sparsely forested areas

How does forest configuration impact TIR observations?

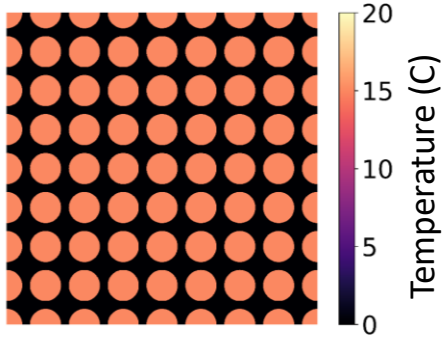


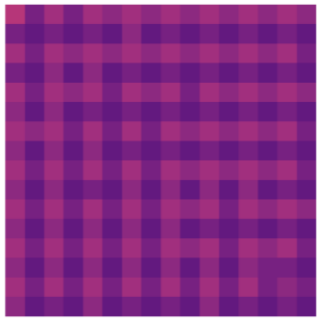
Synthetic Forest Surface Temperature Maps

Ground Truth

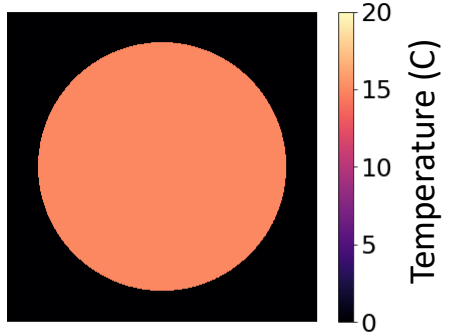
Simulated Observation

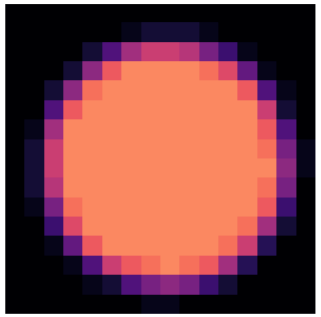
Sparse Forest Stand f_{veg}= 0.5





Dense Forest Stand f_{veg}= 0.5

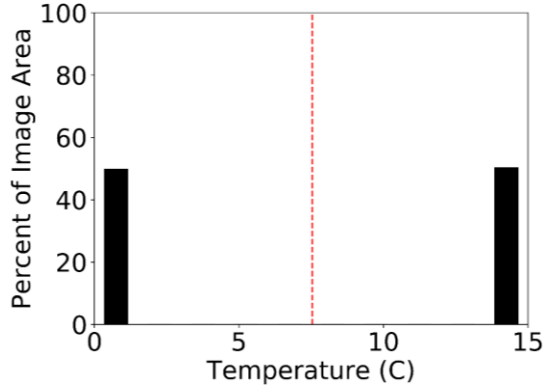


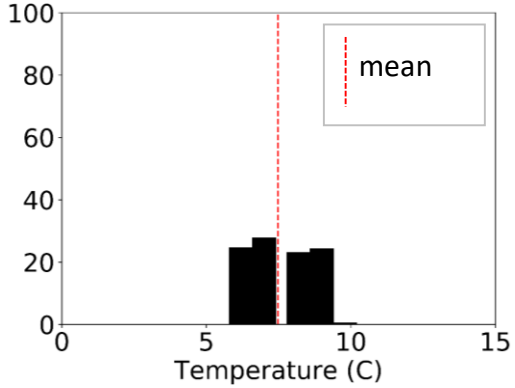


Surface Temperature Distributions

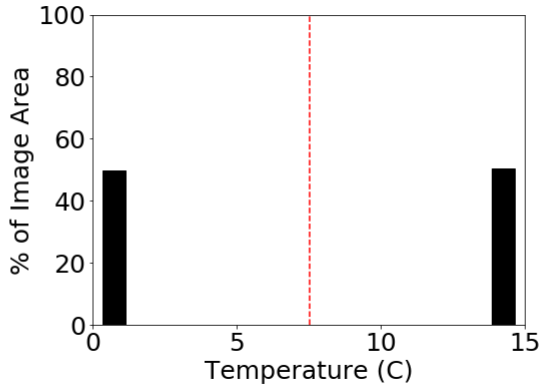
Ground Truth

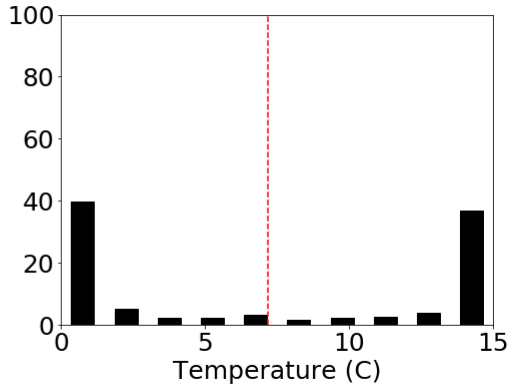
Simulated Observation





Distribution **is NOT preserved**





Distribution **is preserved** when > 3 pixels

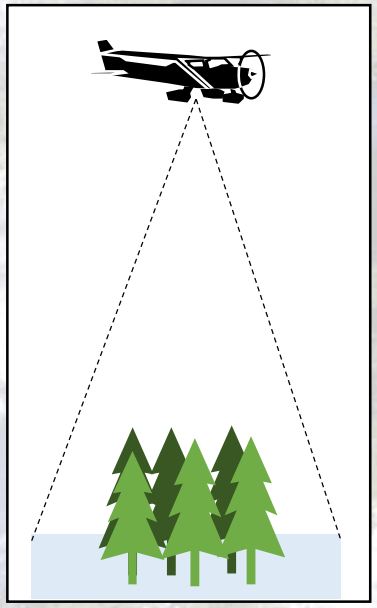
In lower resolution TIR imagery:

- Forest configuration controls the observed temperature distribution
- F_{veg} only controls the observed mean temperature

Image Resolution Summary

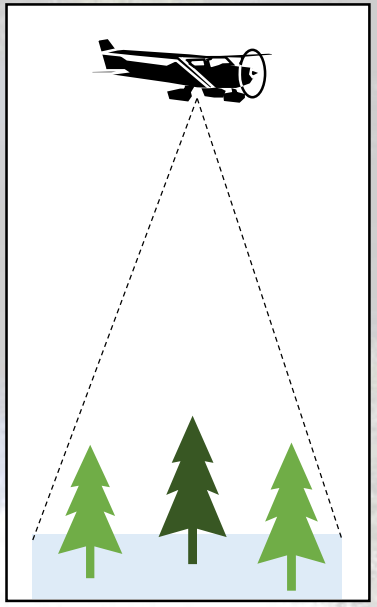
- While means are preserved at lower resolutions, **forest edge temperatures are biased low due to mixed pixels**

- **Forest configuration** (amount of edges) will determine how well the true temperature distribution is represented in TIR observations



Large stands and gaps:

Tf and Tss represented by temperature end-members



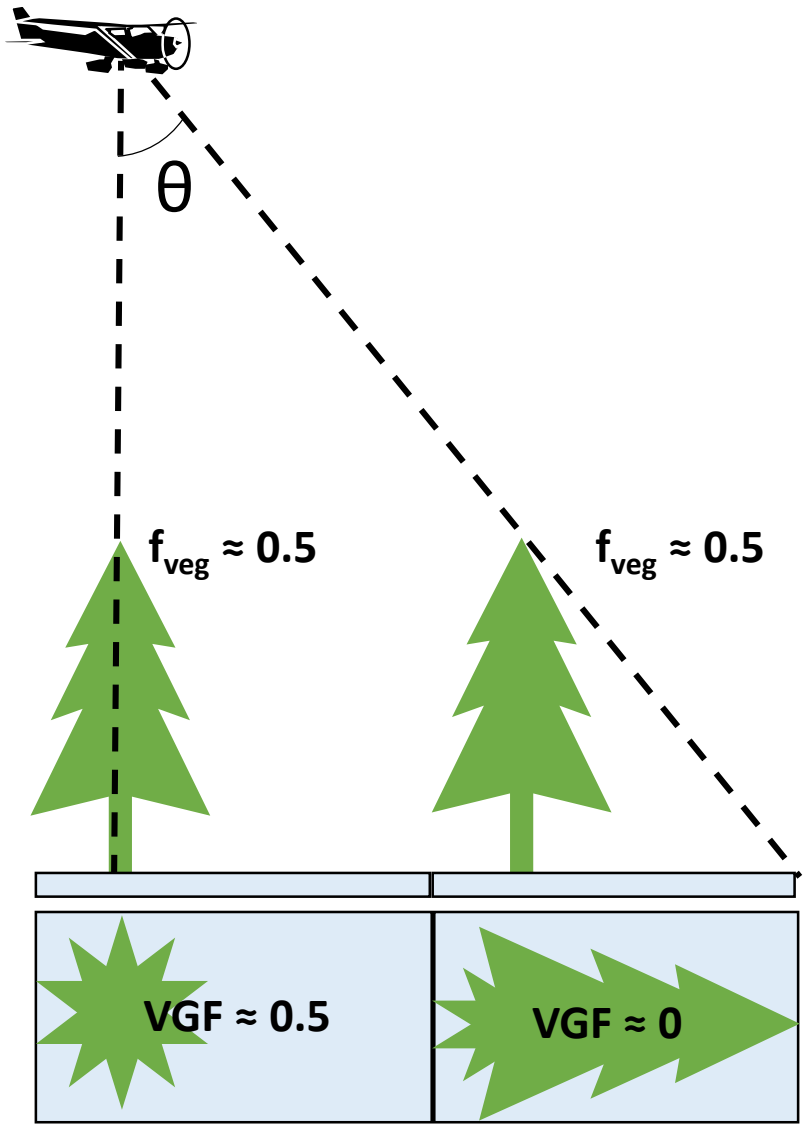
Small stands and gaps:

Tf and Tss mixed

How representative of true surface temperatures are our airborne TIR observations over forests and snow?

1. TIR camera bias
2. Image resolution
3. **View angle**

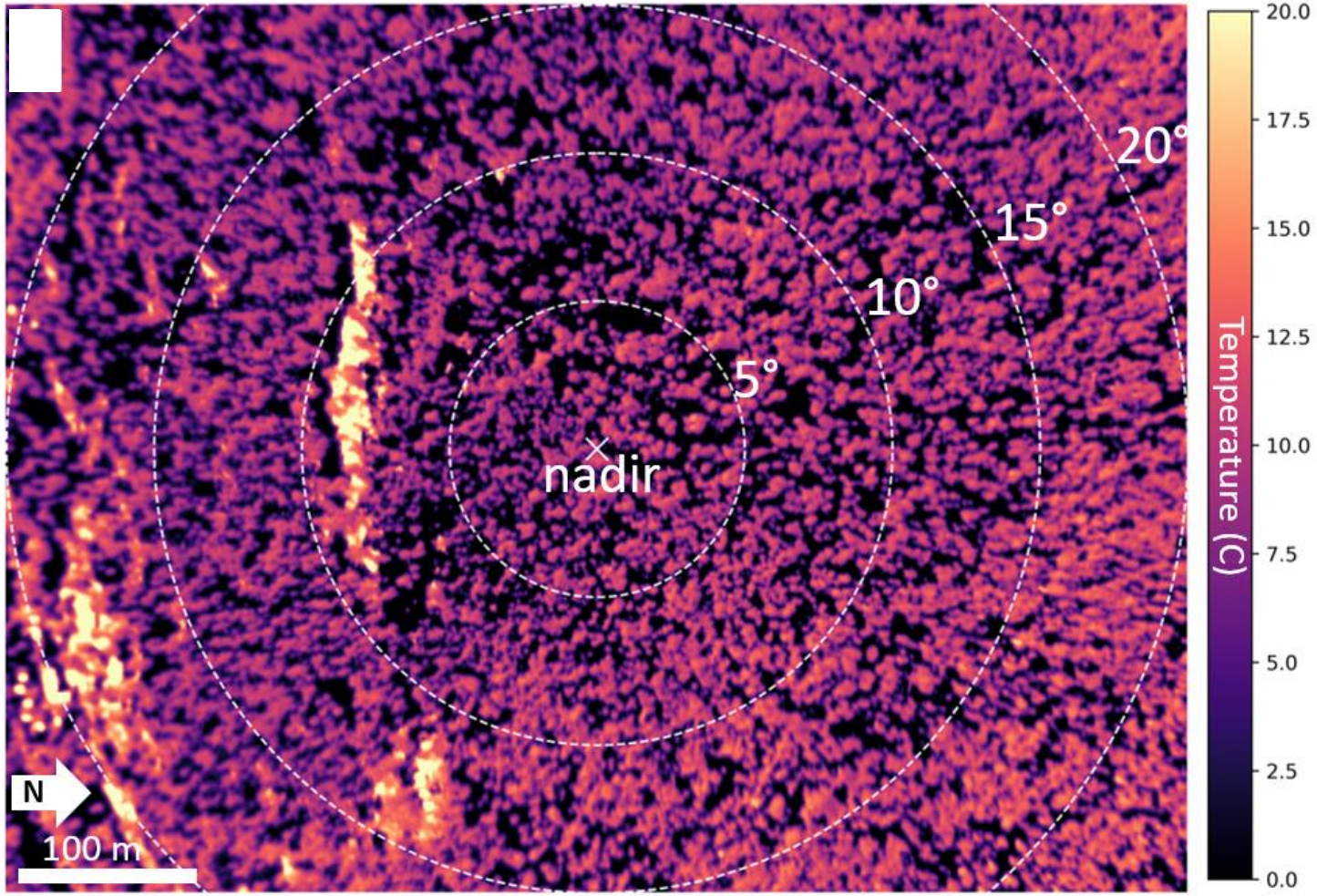
Off-Nadir View Angles

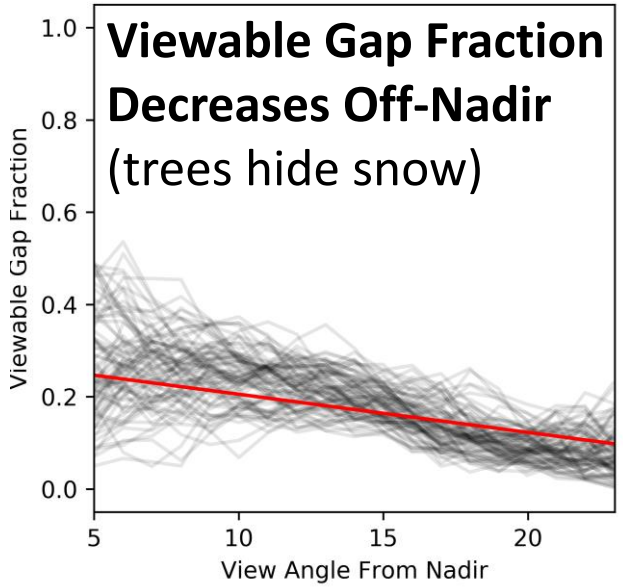


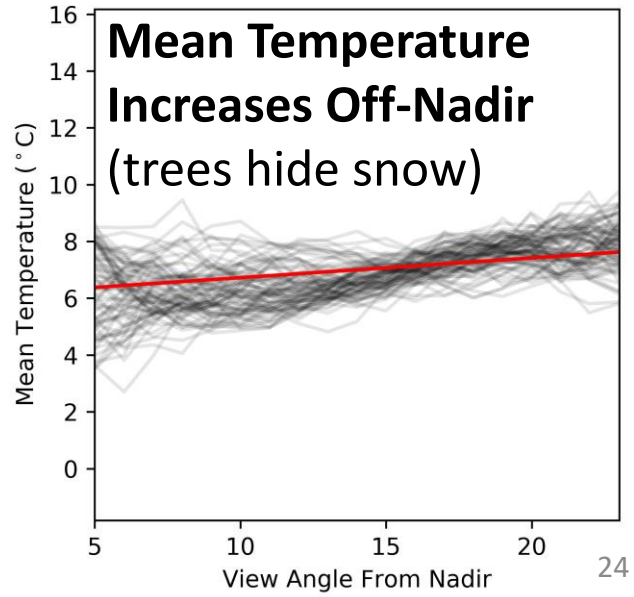
Adapted from Liu et al., 2008

Off-nadir view angles changes the **viewable gap fraction** (VGF), even over areas with constant fractional vegetated area (f_{veg})

Airborne TIR imagery can contain a **wide range of view angles** even with nadir-pointed cameras due to relatively low flight altitude (compared to satellites) and camera field of view



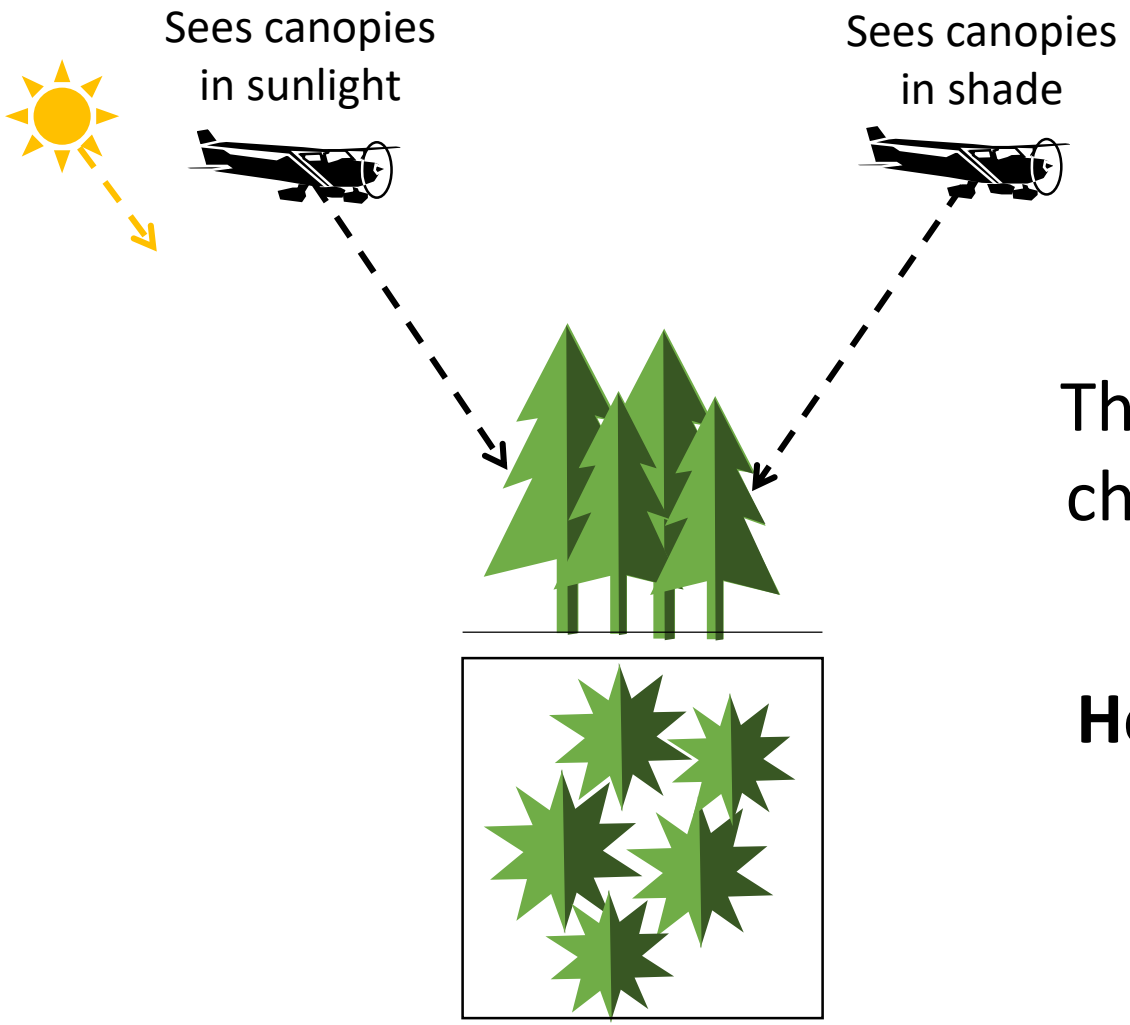




- TIR images contain view angles 0-25°
- VGF, mean T computed for concentric view angle bins

Value per 1° bin in each image

Linear trend for all images



Azimuth View Angle

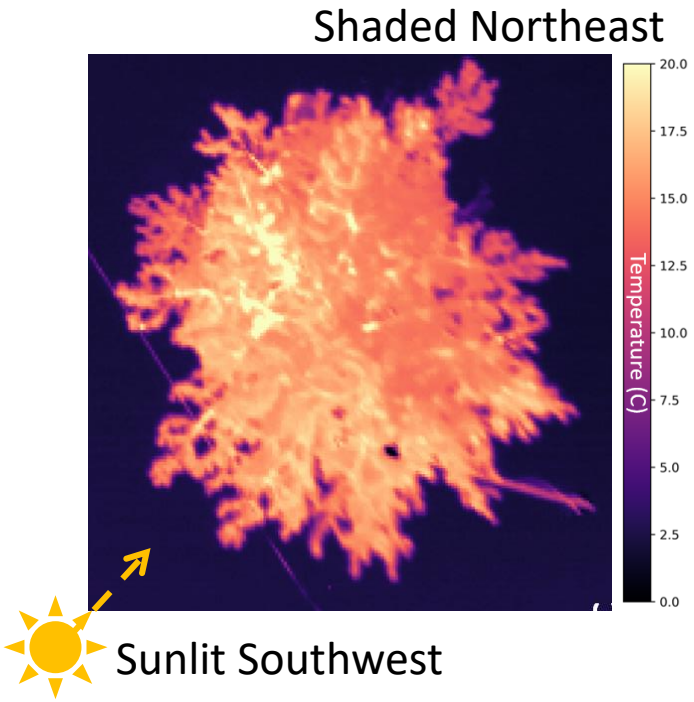
(Which side of the tree hides snow?)

The **azimuthal** direction of off-nadir views will change which side of tree canopies are visible

Heating from incident sunlight could then impact the retrieved canopy surface temperatures

Azimuth View Angle

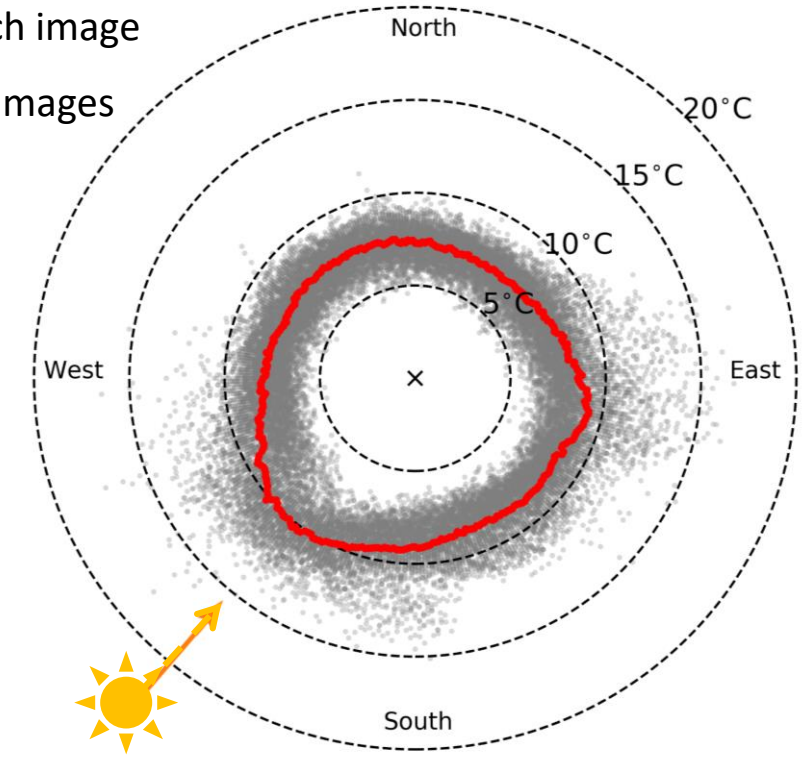
≈2.5 °C warmer when viewed from the southwest



- Snow pixels masked out
- Mean T computed for radial 1° azimuth bins

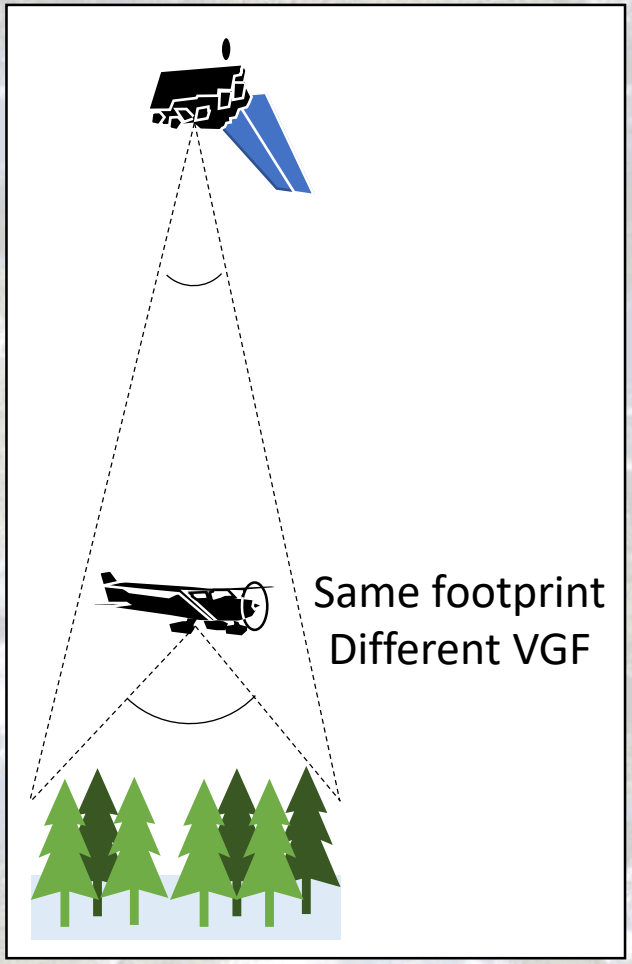
Mean canopy temperature per 1° azimuth bin:

- within each image
- across all images

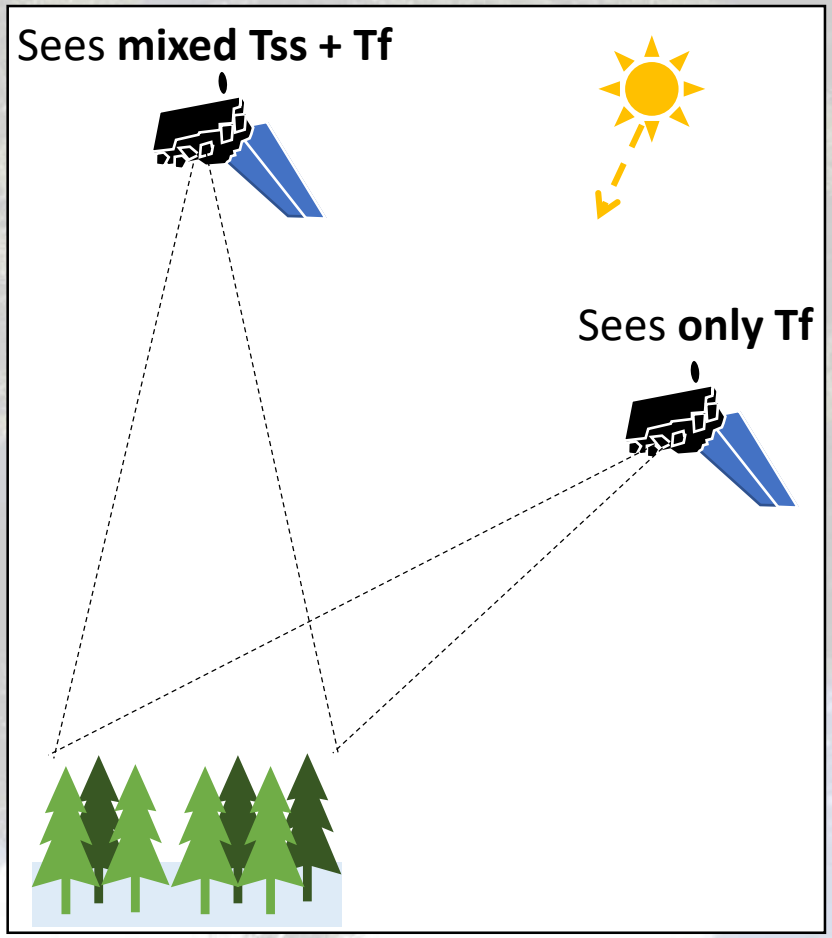


View Angle Summary

Airborne & satellite TIR comparisons need to **consider difference of view angles**



Off-nadir viewing could provide **"unmixed" upper canopy temperatures**



Conclusions:

1. Demonstrated a TIR camera bias correction method using the constant surface temperature of **melting snow as a reference**

2. Retrieval of the surface temperature distribution of forests and snow depends on **image resolution** and **forest configuration**

3. Off-nadir observations over forests
   - **Hinder snow surface temperature observations**
   - **Allow unmixed canopy temperature observations**

Thank you!

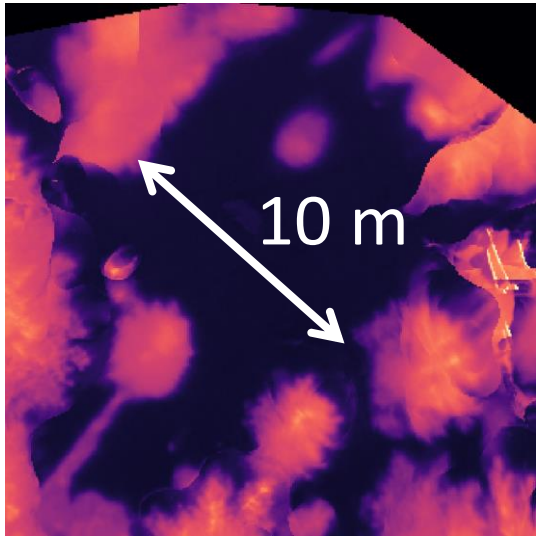
Dan Clark
Clemens Hiller
Tobias Jonas
Greg Maust
Ron Morcom
Sarah Petersen
Bill Retzlaff
Nick Rutter
David Shean
Jenna Weiner

Contact:
spestana@uw.edu
@stevenpest

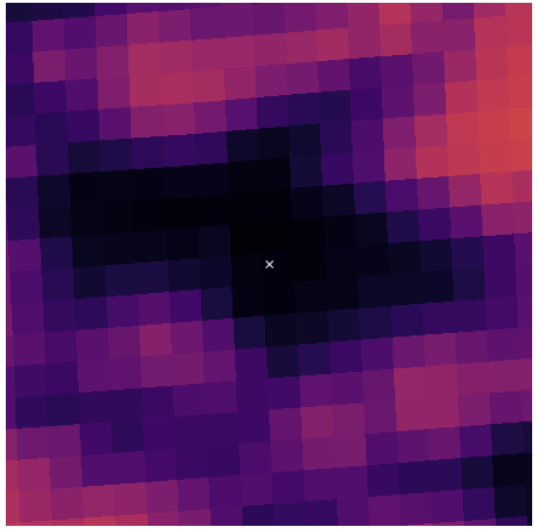
Supplemental Slides

Attempting to resolve snow surface temperature within small forest gaps is limited by the combined effects of **image resolution** (mixed pixels) and **view angles**

UAS Visible

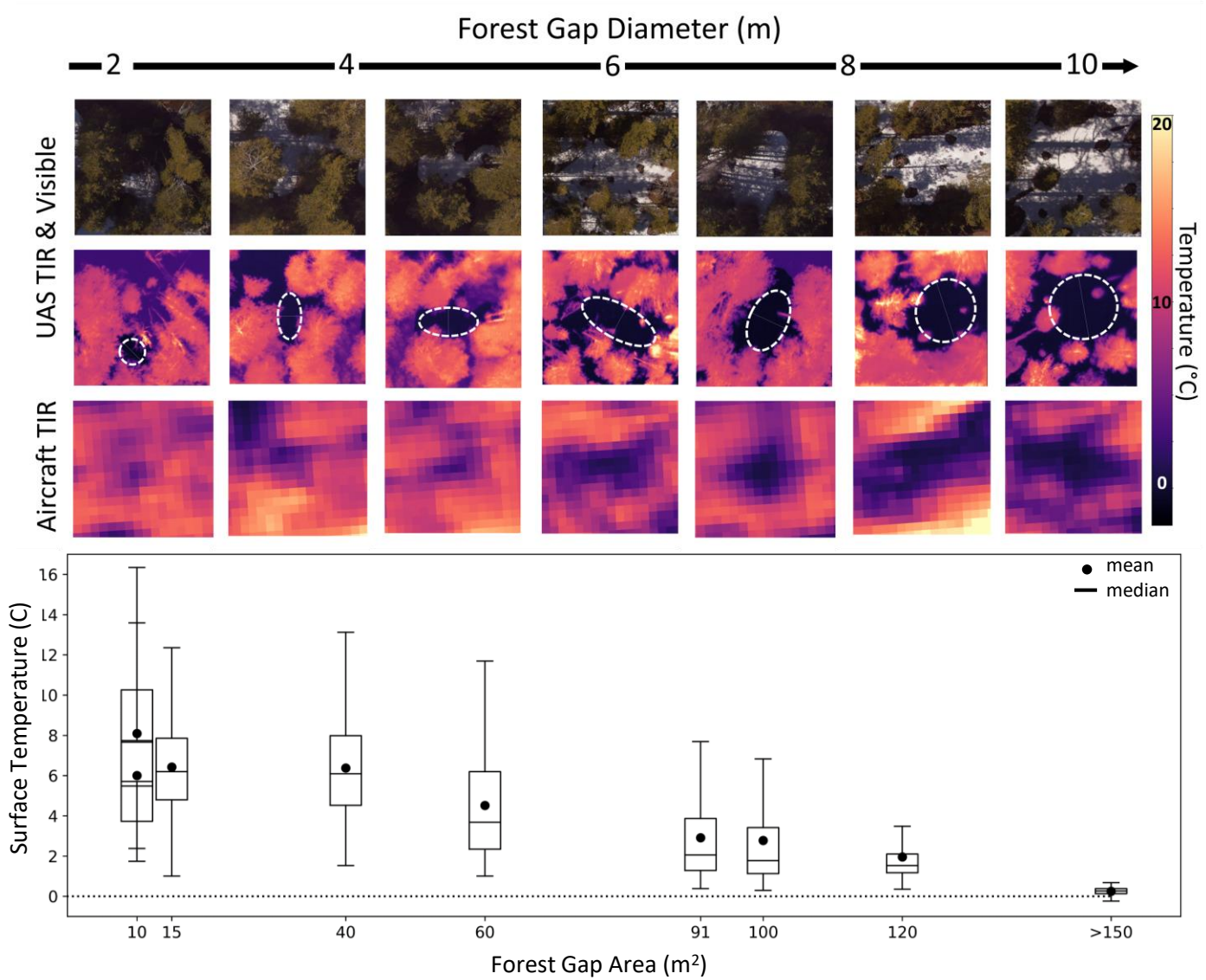


UAS TIR



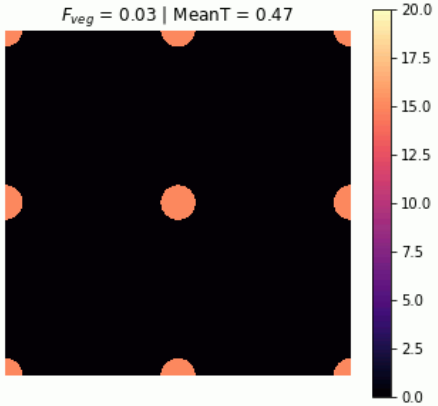
Aircraft TIR

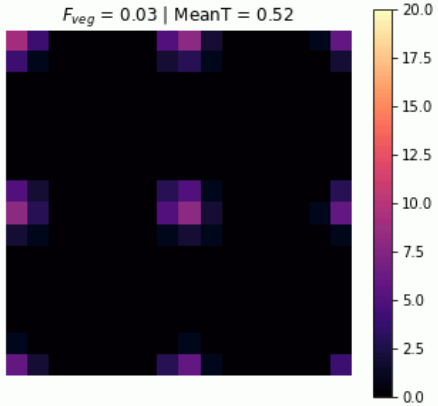
Snow in gaps < 10 m in diameter were obscured by the surrounding trees due to effects of mixed pixels (~1.5 m/px) and view angles (0-25°)

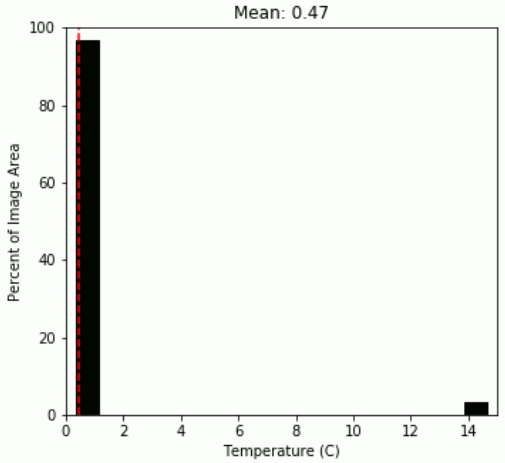


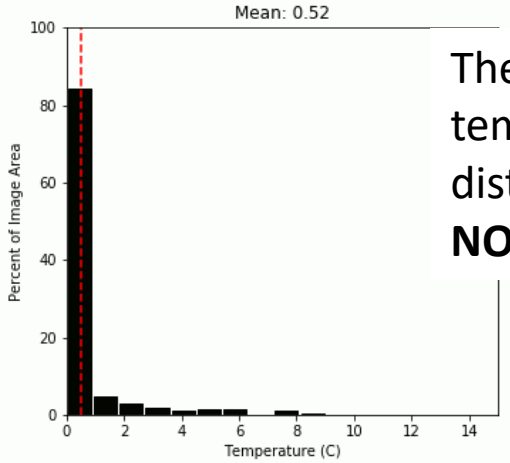
Mean temperature is a function of f_{veg}
Temperature distribution is affected by forest configuration

Sparse Forest









The underlying temperature distribution **is NOT preserved**

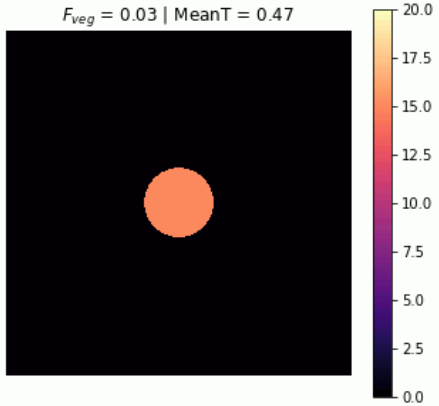
True Surface Temperatures (1 cm)

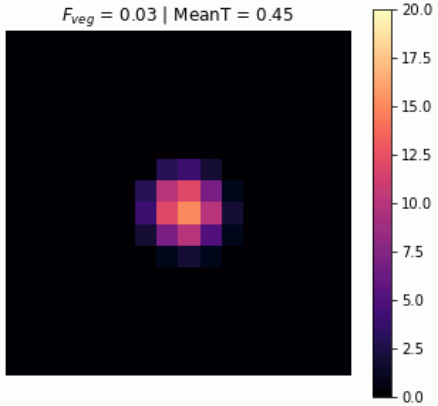
Upscaled to ~ 1.3 m

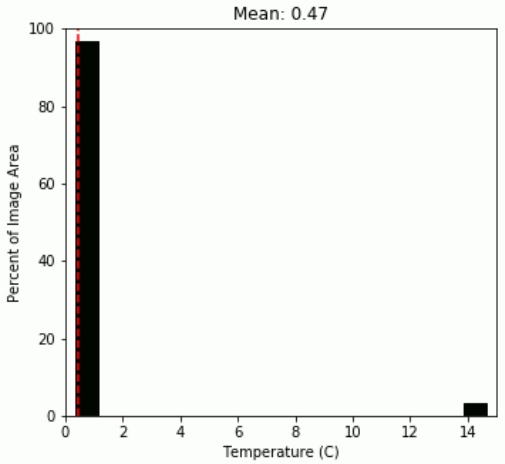
True Temperature Distributions

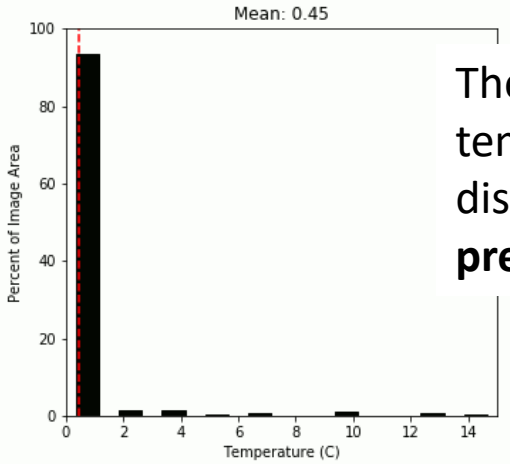
Upscaled Temperature Distributions

Dense Forest





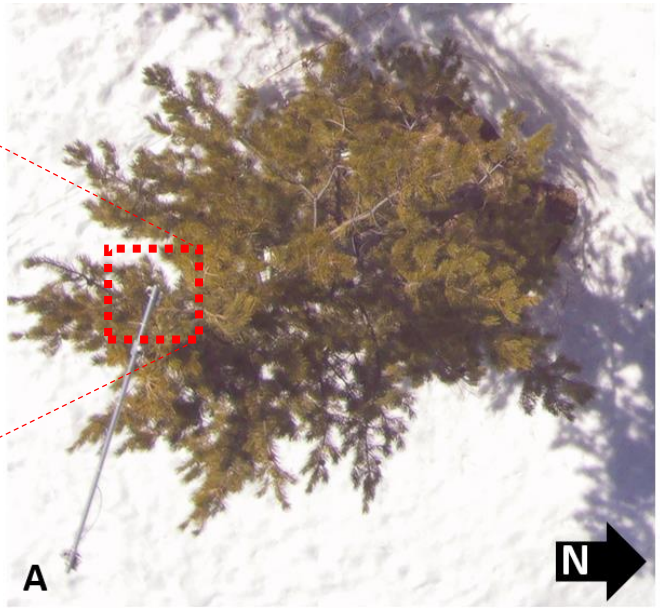


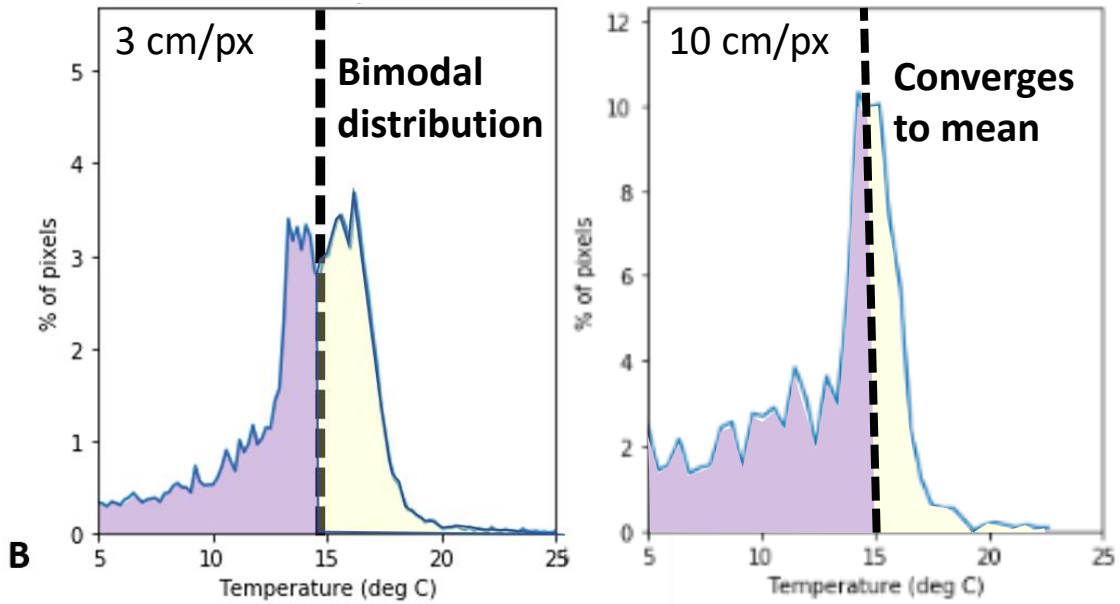


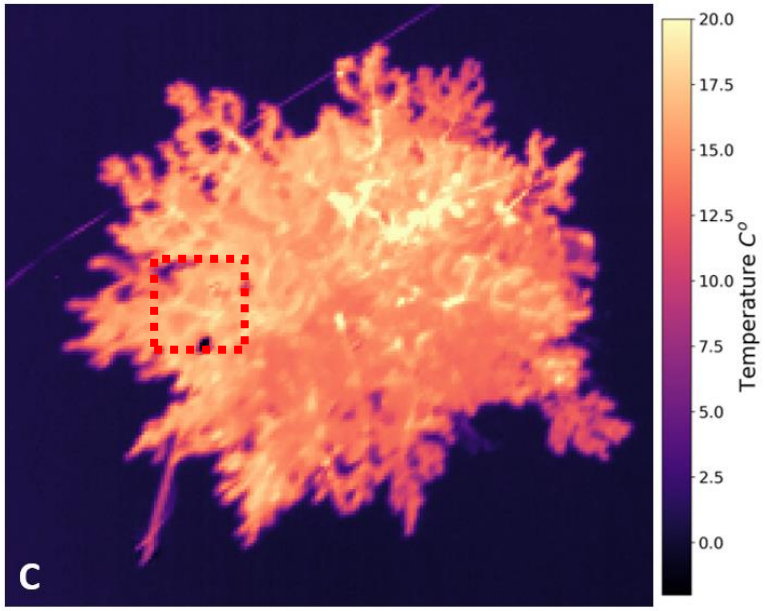
The underlying temperature distribution **is preserved**

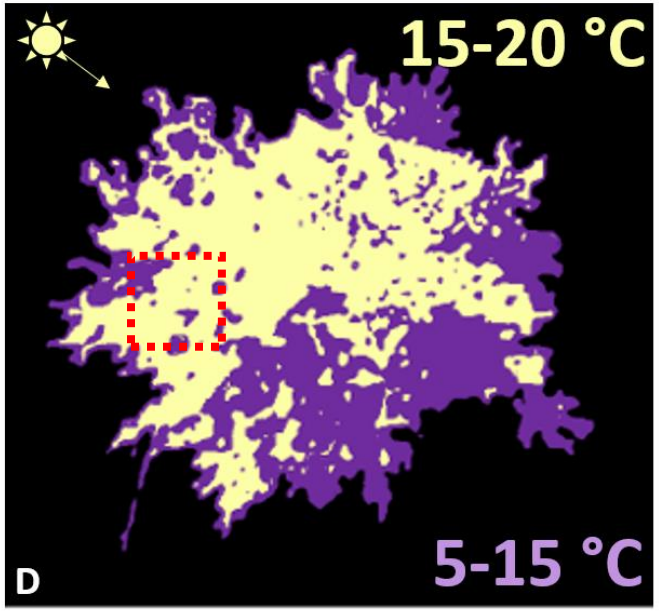
Sunlit and shaded canopy portions blur together at lower resolutions

Photo: Adrian Harpold

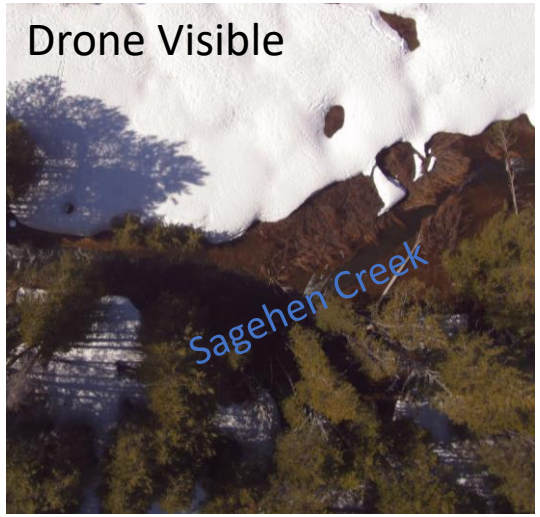


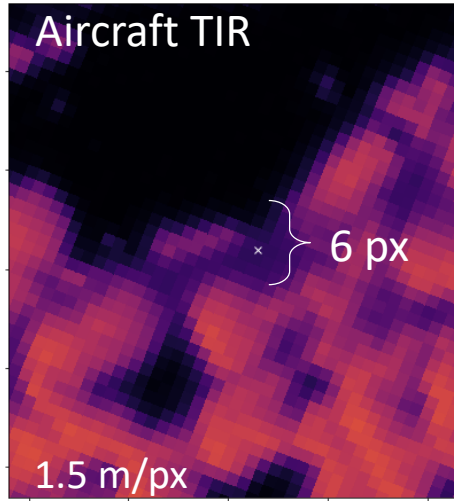


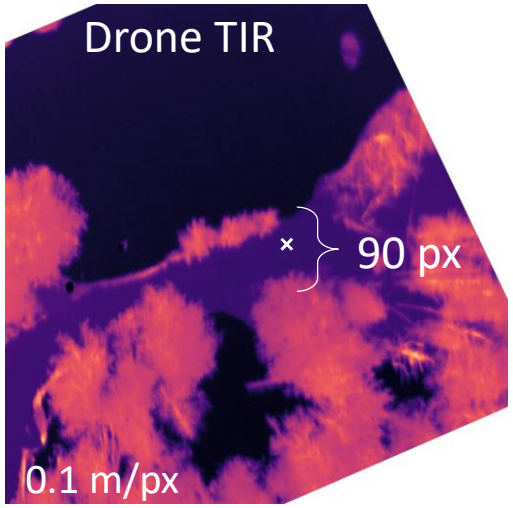


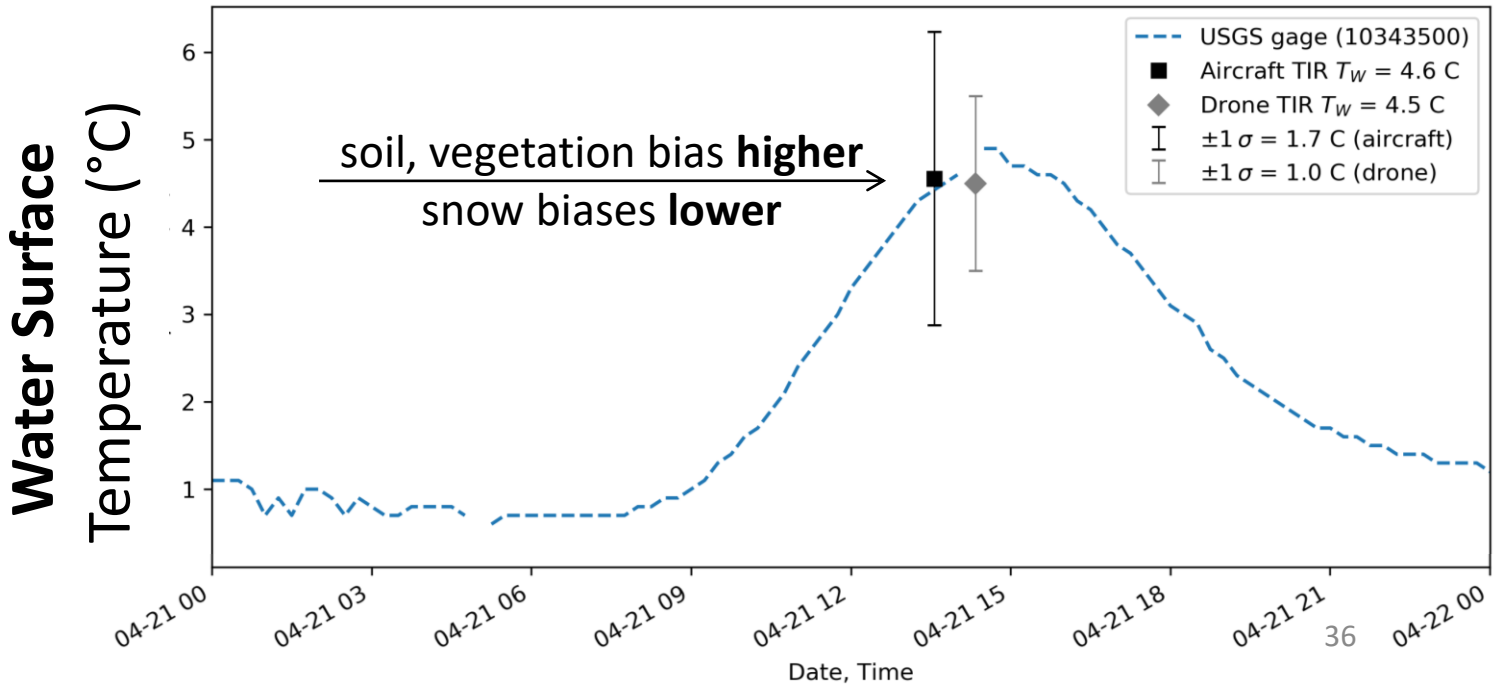


Stream Temperature Retrieval Errors From Adjacent Bank Surfaces



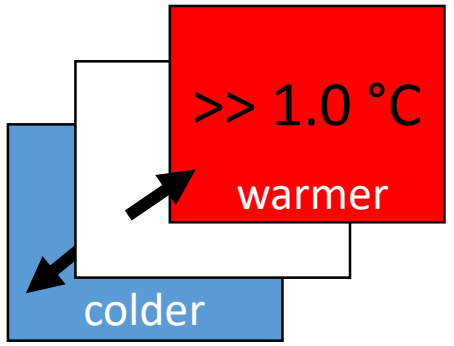






TIR Camera Error Sources and Magnitudes

Bias (camera body temperature changes)
[Budzier & Gerlach, 2015]



Non-Uniformity (vignetting, lens, dead pixels)
[Garnier et al., 1999]

< 1.0 °C

Emissivity (view angle, SSA dependent)
[Dozier and Warren, 1982; Salisbury & D'Aria, 1994]

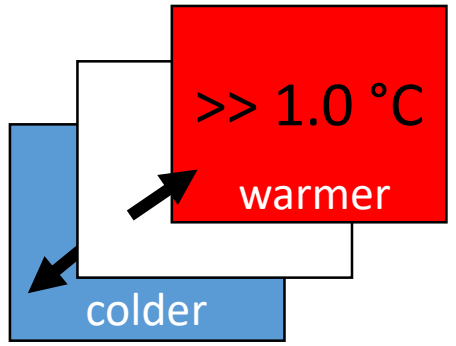
< 0.5 °C

Atmospheric absorption (< 1 km AGL)
[MODTRAN: Berk et al., 1987]

< 0.02 °C

TIR camera bias is the largest source of measurement error here

Bias (camera body temperature changes)
[Budzier & Gerlach, 2015]



Non-Uniformity (dead pixels, vignetting)
[Garnier et al., 1999]

< 1.0 °C

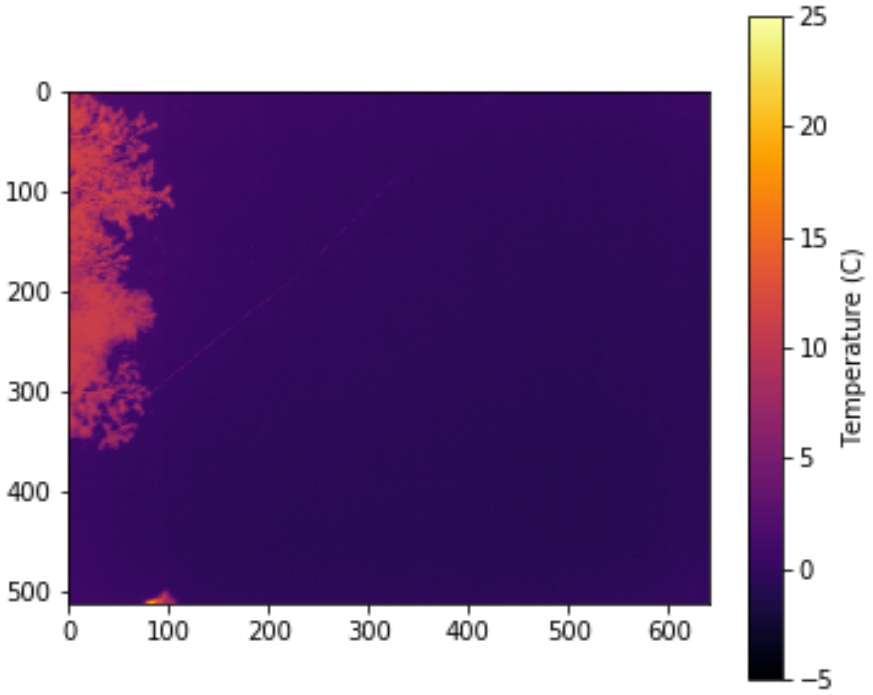
Emissivity (view angle, SSA dependent)
[Dozier and Warren, 1982; Salisbury & D'Aria, 1994]

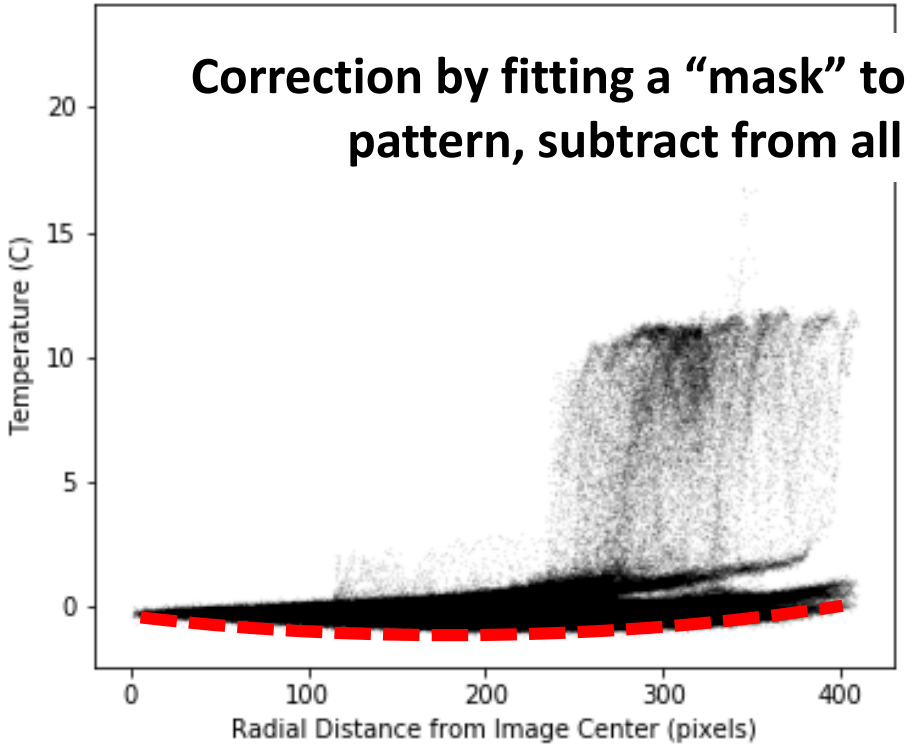
< 0.5 °C

Atmospheric absorption (< 1 km AGL)
[MODTRAN: Berk et al., 1987]

< 0.02 °C

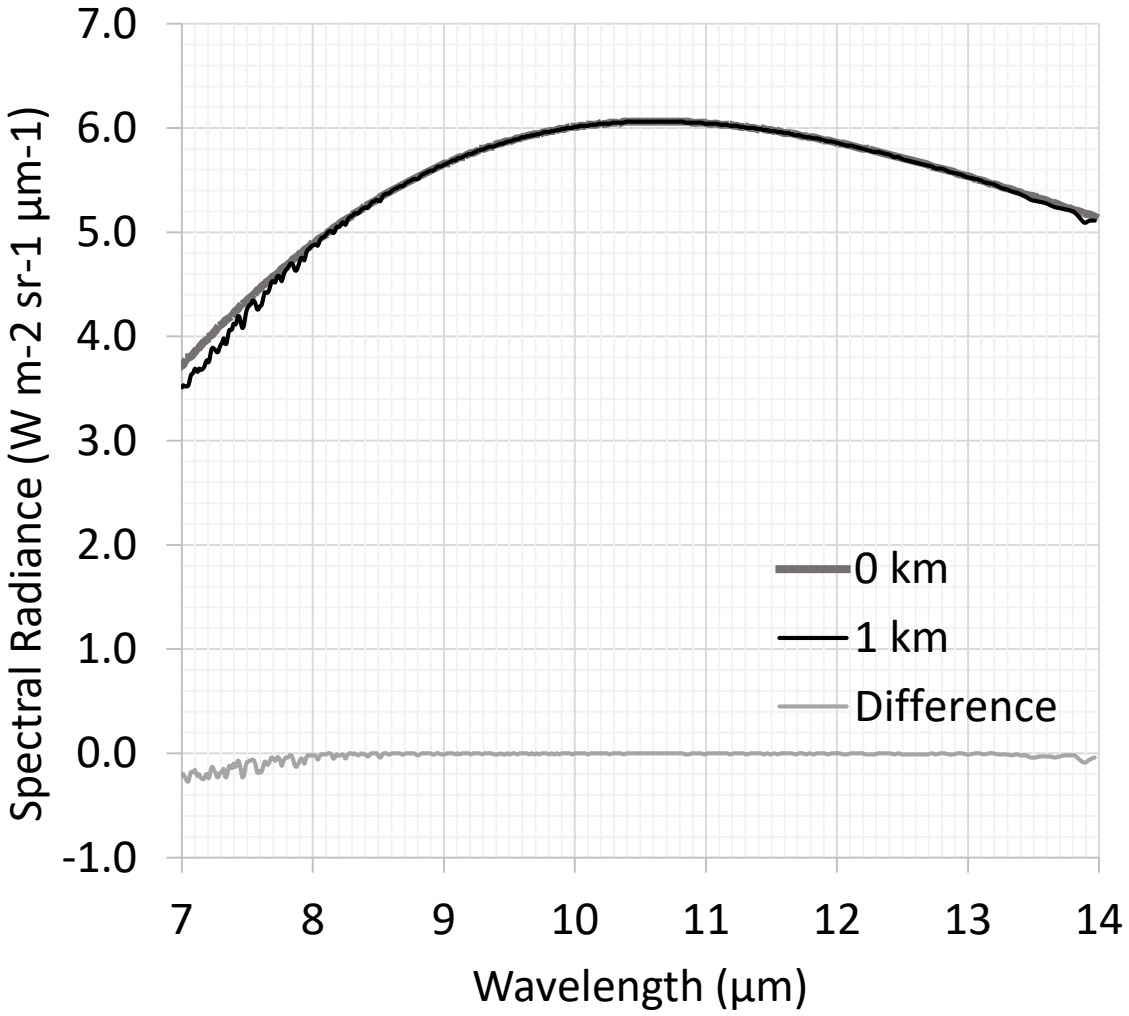
TIR Imager Errors: Vignetting < +1 °C towards image edges





Correction by fitting a “mask” to the vignetting pattern, subtract from all images

Atmospheric Absorption



MODTRAN (Berk et al., 1987)

- Midlatitude winter, clear skies
- 0 - 1 km altitude
- 7-14 µm

< 1% emitted radiance lost, or < 0.02 C

A MODTRAN simulation (Berk et al., 1987) of conditions at the Sagehen site was used to quantify how errors stemming from atmospheric absorption of TIR radiation compare to those from calibration uncertainties. Atmospheric absorption within the TIR wavelengths from 1000 m AGL would account for an underestimation of surface temperature by < 0.02 °C, orders of magnitude smaller than errors stemming the shifting calibration experienced by the aircraft or UAS TIR systems.

Emissivity

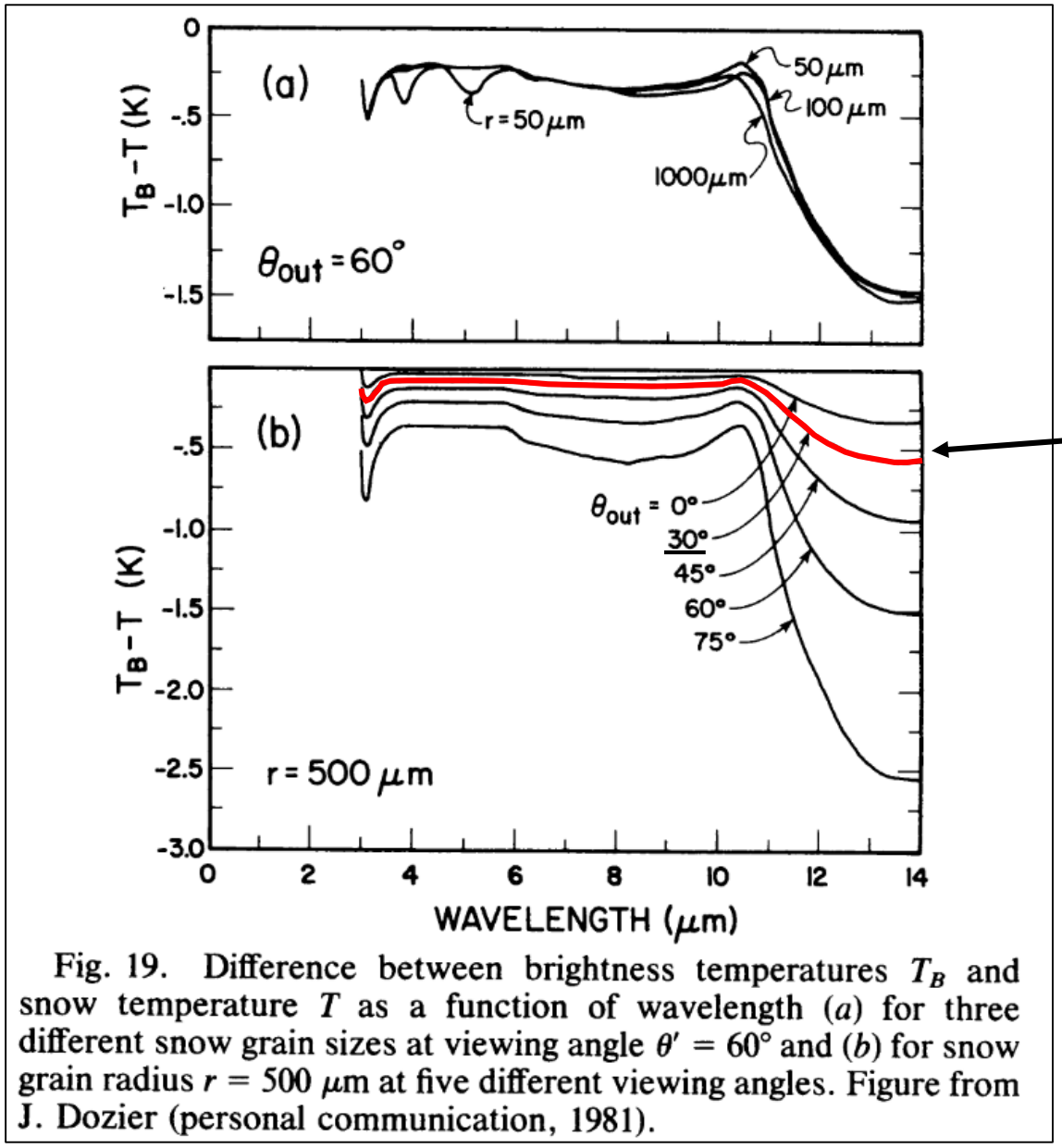


Fig. 19. Difference between brightness temperatures T_B and snow temperature T as a function of wavelength (a) for three different snow grain sizes at viewing angle $\theta' = 60°$ and (b) for snow grain radius $r = 500$ μm at five different viewing angles. Figure from J. Dozier (personal communication, 1981).

Warren, 1982

Snow Emissivity (Dozier and Warren, 1982; Shea & Jamieson, 2010):

- Not grain size dependent (**a**)
- Dependent on view angle ε ≈ 0.94 - 0.99 (**b**)
- Near blackbody ε ≈ 0.99 (10 μm)

< -0.5 C at 20° from nadir

Snow Longwave Reflectance (Hori et al., 2006) :

- < 3%, negligible under low RH, clear-sky, conditions

Vegetation Emissivity (8-14 μm) (Salisbury & D'Aria, 1994):

- Conifer needles ε ≈ 0.99
- Tree bark ε ≈ 0.94