An overview of thermal infrared and visible-to-shortwave infrared instrument calibration activities for SnowEx Grand Mesa

Christopher J. Crawford
Landsat Science Team Scientist
Science Liaison, EROS Calibration Center of Excellence (ECCOE)
ASRC Federal InuTeq, contractor to the U.S. Geological Survey EROS

Prior Affiliations
Earth System Science Interdisciplinary Center,
University of Maryland-College Park
Cryospheric Sciences Laboratory, NASA Goddard
Space Flight Center

Contributors
C. Chickadel, U of Washington
D. Hall, U of Maryland; NASA/GSFC
M. Holm, NASA/GSFC
P. Houser, George Mason U
D. Jennings, NASA/GSFC
M. Jhabalva, NASA/GSFC
E. Kim, NASA/GSFC
J. Lundquist, U of Washington
A. Lundsford, NASA/GSFC
C. Polashenski, CRREL
E. DeMarco, NASA/GSFC
A. Wu, NASA/GSFC

C.J. Crawford, August 8, 2017, NASA SnowEx Workshop
Presentation Overview

(1) SnowEx ground and airborne thermal infrared (TIR) instrument calibration
(2) Visible-to-shortwave infrared (VSWIR) ground instrument calibration
(3) Why SnowEx calibration/validation (Cal/Val) matters
(4) TIR/VSWIR snow measurement / science requirements

Presentation Objectives

(1) Briefly describe SnowEx TIR instrument calibration techniques and communicate initial results on laboratory, P-3 airborne and ground meteorological station cross-calibration.

(2) Briefly describe VSWIR ground instrument calibration techniques and communicate results on the VSWIR spectrometer cross-calibration efforts.

(3) Offer the SnowEx project some recommendations on calibration & planning for future campaign years.

Hall et al. The Infrared Sensor Suite for SnowEx 2017. IGARS Proceedings, 2017
SnowEx TIR Instruments

(1) Everest Interscience EnviroTherm TIR sensor (transfer standard)
   (1) FOV = 10°
   (2) 8-14 micron temperature response in C
   (3) Temperature range = -30 C to 80 C
   (4) +/- 0.3 C accuracy

(2) Contact TIR Thermometer (cross-calibration verification)
   (1) Contact probe
   (2) +/- 0.2 C accuracy

(3) KT-15 82D Remote Thermometer (airborne P-3)
   (1) FOV = 2 degree (100 m at 10,000 ft AGL)
   (2) 8-14 micron temperature response in C
   (3) Temperature range = -50 C to 50 C

(4) Quantum Well Infrared Photodetector (QWIP) (airborne P-3)
   (1) FOV = 11 x 9 degrees (~1.8 meters at 10,000 AGL)
   (2) 7-10 micron response function in digital counts
   (3) ~0.02 C accuracy

(5) Apogee MI-210 (Grand Mesa meteorological towers)
   (1) FOV = 22° half angle
   (2) 8-14 micron temperature response in C
   (3) +/- 0.2 C accuracy
SnowEx TIR Blackbody Sources

(1) NASA/GSFC Code 618 Laboratory Blackbody (stable source)
   (1) Emissivity > 0.98
   (2) Temperature range -10 °C to 79 °C
   (3) Precision < 0.001 C
   (4) Accuracy +/- 0.2 C

(2) Everest Interscience Portable Blackbody (NIST traceable field source)
   (1) Emissivity > 0.98
   (2) Temperature range 0 °C to 120 °C
   (3) Accuracy +/- 0.1 C

(3) Portable Contact Blackbody (cross-calibration verification)
   (1) Emissivity = > 0.98
   (2) Temperature range: fluctuations with ambient

*SnowEx At-Sensor Target TIR Requirement was within 1°C
**Equation 1** (Fuchs and Tanner 1966)

\[ R = e \sigma T^4 \]

where:
- \( R \) is the energy flux of electromagnetic radiation
- \( e \) is the emissivity of any surface
- \( \sigma \) is Stefan-Boltzmann constant
- \( T \) is temperature in degrees Kelvin

**Equation 2** (Fuchs and Tanner 1966)

\[ W(\lambda)d\lambda = e_\lambda E(\lambda, T)d\lambda + (1-e_\lambda)B(\lambda, T_\delta)d\lambda \]

where:
- \( W(\lambda)d\lambda \) outward flux of thermal energy \( \lambda \)
- \( e_\lambda \) is emissivity of surface at wavelength
- \( E(\lambda, T) \) is value of Planck’s energy distribution law and surface temperature
- \( B(\lambda, T_\delta) \) is the radiant energy flux incident on the surface from the surrounding integrated radiative temperature
TIR Laboratory Calibration

**Verified Instrument Calibration Spec:**
\[ y = 0.9870x + 0.01528 \]

**Unable to Verify Instrument Calibration Spec:**
\[ y = 0.96007x + 2.8812 \]

**Warm Offset:**

**Cold Offset:**
TIR P-3 Airborne Cross-Calibration
TIR Ground Meteorological Tower Cross-Calibration

C.J. Crawford, August 8, 2017, NASA SnowEx Workshop
TIR Meteorological Tower Snow Surface Temperature

C.J. Crawford, August 8, 2017, NASA SnowEx Workshop
Benchmarking Against On-Orbit Landsat-7 ETM+ TIR (Feb. 15, 2017)

*USGS EROS Provisional Landsat 4-8 Surface Temperature (ST) Product

Based on JPL (G. Hulley) and RIT (J. Schott)
ASTER GED and MODTRAN single-band inversion algorithms
Summary of TIR Challenges & The Way Forward

1. Ground and airborne TIR instrument calibration is challenging due to changing physical (i.e., local winds, radiative heating) and logistical factors

2. Involvement of multiple TIR instruments with different spectral response functions, manufacturer calibration procedures, & variation in blackbody sources introduces additional complexity

3. Limited access to stable and traceable cold blackbody sources to support low temperature studies

4. Local radiative environment, sky radiation and temperature effects, & variations in the emissivity coefficient cannot be overlooked

5. If SnowEx wants to pursue a TIR measurement design, then calibration must be central to this effort to clearly define snow measurement and science needs & requirements
Grand Mesa VSWIR Instrument Calibration / Ground Measurements

GSFC NIST Traceable Source

Snow Transect Measurements (L)

Feb. 13\textsuperscript{th}: SnowEx training
Feb. 14\textsuperscript{th}: VSWIR logistics & protocols
Feb. 15\textsuperscript{th}: TIR ground met tower cross-cal
Feb. 16\textsuperscript{th}: VSWIR science data / ASO flight
Feb. 17\textsuperscript{th}: VSWIR science data
Feb. 18\textsuperscript{th}: VSWIR spectrometer cross-cal

Spectrometer Cross-Calibration

Snow Pit Upwelling (E)

Snow Pit Downwelling (E)
GSFC NIST Traceable Source Characterization

Panel 1. Pre-SnowEx Integrating Sphere Characterization
- GSFC ASD4024 Spectrometer

Panel 2. Field-SnowEx Integrating Sphere Characterization
- GSFC ASD4024 Spectrometer

Panel 3. Post-SnowEx Integrating Sphere Characterization
- GSFC ASD4024 Spectrometer

Panel 4. GSFC Code 513 NIST Source / Bright Level (4 Lamp) Integrating Sphere Stability

C.J. Crawford, August 8, 2017, NASA SnowEx Workshop
CRREL VSWIR Spectrometer Short-term Characterization

Panel 1. NASA/GSFC Code 818 NIST Source / Bright Level (H Lamp) Sphere Output

Panel 2. CRREL ASD16340 Spectrometer Short-term Characterization

Panel 3. CRREL ASD16340 Spectrometer Short-term Characterization
GSFC & CRREL VSWIR Spectrometer Cross-Cal for Grand Mesa

Panel 1: GSFC ASD6034 & CRREL ASD16343 / Bright Level (H Lamp) Sphere Output

Panel 2: GSFC ASD6034 & CRREL ASD16343 / NIST Transable Cross-Calibration

Targeted 2% VSWIR Cross-Calibration Requirement
Achieved 5% VNIR Cross-Calibration
Achieved 20% SWIR1 Cross-Calibration
GSFC VSWIR Snow Pit Measurements (Grand Mesa Week 2)

\[ BHR_{\lambda} = \frac{E_{\text{up,}\lambda}(\theta_v, \theta_o, \Phi)}{E_{\text{down,}\lambda}(\theta_v, \theta_o, \Phi)} \]

where:
- \( \lambda \) is wavelength
- \( E_{\text{up}} \) is upwelling spectral irradiance
- \( E_{\text{down}} \) is downwelling spectral irradiance
- \( \theta_v \) is viewing angle
- \( \theta_o \) is solar zenith angle
- \( \Phi \) is solar azimuth

Why Cal/Val Matters for SnowEx and its Satellite Mission Design

Generic ECCOE Structure

International Cal/Val organization that interacts synergistically with ECCOE.

U.S. Government calibration groups that work closely with the ECCOE.

Organizations that are funded by ECCOE to conduct Cal/Val research.

Organizations and Govt. entities that interact with ECCOE to conduct Cal/Val activities.

External panel of experts that meets at least annually to review ECCOE activities and recommend future directions for Cal/Val work.

USGS EROS Cal/Val Center of Excellence

Peer Review Panel

Collab. Groups

Other Govt. Cal Groups

Affiliates

CEOS WGCV IVOS

CEOS WGCV IVOS
NASA currently has solicitations out on technology innovations under the SLI program [https://sustainablelandimaging.gsfc.nasa.gov](https://sustainablelandimaging.gsfc.nasa.gov)

USGS released RFIs on Landsat 10 and SLI user requirements in 2016 & 2017 [https://remotesensing.usgs.gov/rca-eo/](https://remotesensing.usgs.gov/rca-eo/)

The 2012-2017 USGS Landsat Science Team (LST) has made significant contributions to the requirements process via individual members and within LST working groups [https://landsat.usgs.gov/landsat-science-team-meeting-jul-2017](https://landsat.usgs.gov/landsat-science-team-meeting-jul-2017)

USGS Reston and 2012-2017 USGS LST jointly held a ‘Landsat Spectral Band Workshop’ in May 2017

The outgoing 2012-2017 USGS LST is drafting a recommendation on Science, Measurements, and Data Product Requirements for Landsat 10 and beyond
Calibration Recommendations for Future SnowEx Campaigns

(1) Instrument calibration and cross-calibration between investigators/institutions reduces measurement uncertainty and enables radiometric continuity

(2) Traceability is foundational for evaluating an instrument’s radiometric performance

(4) Adhering to national and international standards fosters a Cal/Val best practices mentality

(5) Cal/Val is often a meticulous and time consuming process that does not always lead to cutting edge science results, but is essential for benchmarking progress

(6) Development of a coordinated SnowEx Cal/Val plan with broad cross-calibration participation is recommended for future campaigns