Single channel and split-window SSTs from Landsat in Antarctica

Tasha Snow[1] (tsnow@mines.edu); Michael Field[1], Ellianna Abrahams[2], Facu Sapienza[2]; Whyjay Zheng[2], Elena Savidge[1], Fernando Perez[2], Jonathan Taylor[3], Waleed Abdalati[4,5], Ted Scambos[4], Matthew Siegfried[1],

[1] Colorado School of Mines, Department of Geophysics, [2] University of California Berkeley, [3] Stanford University, [4] Cooperative Institute for Research in Environmental Sciences, [5] University of Colorado Boulder

1. Introduction

Landsat recently released its Collection 2 Level 2 Surface Temperature (ST) product, marking the first comprehensive calculations of surface temperatures from the four-decade-long Landsat mission sequence.

Producing surface temperatures requires complex integration of Landsat imagery with external atmospheric datasets and model outputs, to compensate for the lack of dual thermal bands (Landsat 4/5/7) and other bands required for atmospheric correction (Landsat 4/5/7/8/9).

Although Landsat provides a reliable surface temperature product, gaps still exist for sea surface temperature (SST) retrievals:

1) ST algorithm not optimised for acquiring sea surface temperatures
For example, the Landsat 8-9 ST algorithm:

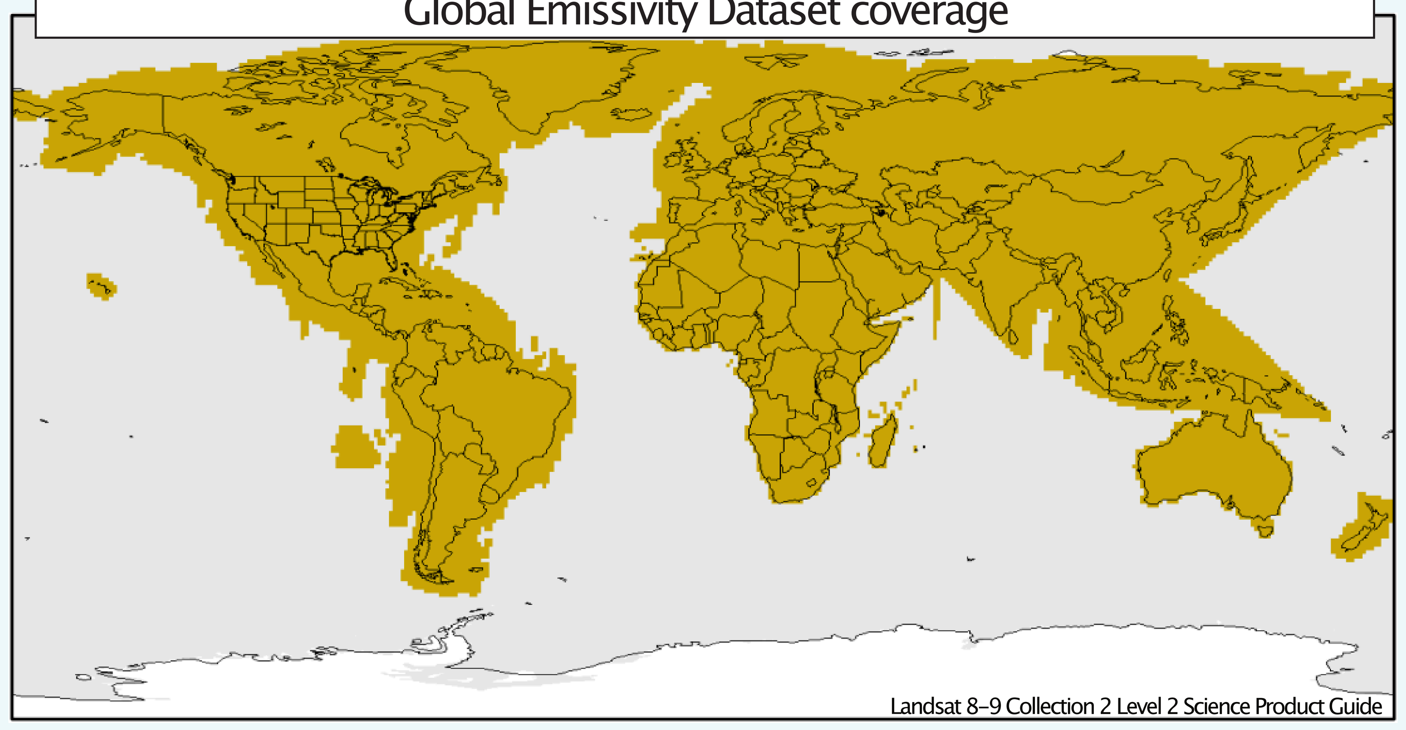
$$ST = b_0 + \left(b_1 + b_2\frac{1-\epsilon}{\epsilon} + b_3\frac{\Delta\epsilon}{\epsilon^2}\right)\frac{T_i+T_j}{2} + \left(b_4 + b_5\frac{1-\epsilon}{\epsilon} + b_6\frac{\Delta\epsilon}{\epsilon^2}\right)\frac{T_i-T_j}{2} + b_7(T_i-T_j)^2$$

where

- ST is the desired surface temperature $[K]$;
- b_k (for $k = 0, 1, \ldots, 7$) are sensor-dependent (and potentially water-vapor-dependent) coefficients that are derived through a training process;
- i and j correspond to the two thermal bands (Bands 10 and 11 for TIRS);
- $\Delta\epsilon = \epsilon_i - \epsilon_j$ or the difference in band-effective emissivities;
- $\epsilon = (\epsilon_i + \epsilon_j)/2$ or the average of the band-effective emissivities;
- T_i, T_j are the apparent temperatures in the two thermal bands.

2) Algorithm requires optical, thermal, and ASTER emissivity inputs; therefore, ST not produced at night or around Antarctica

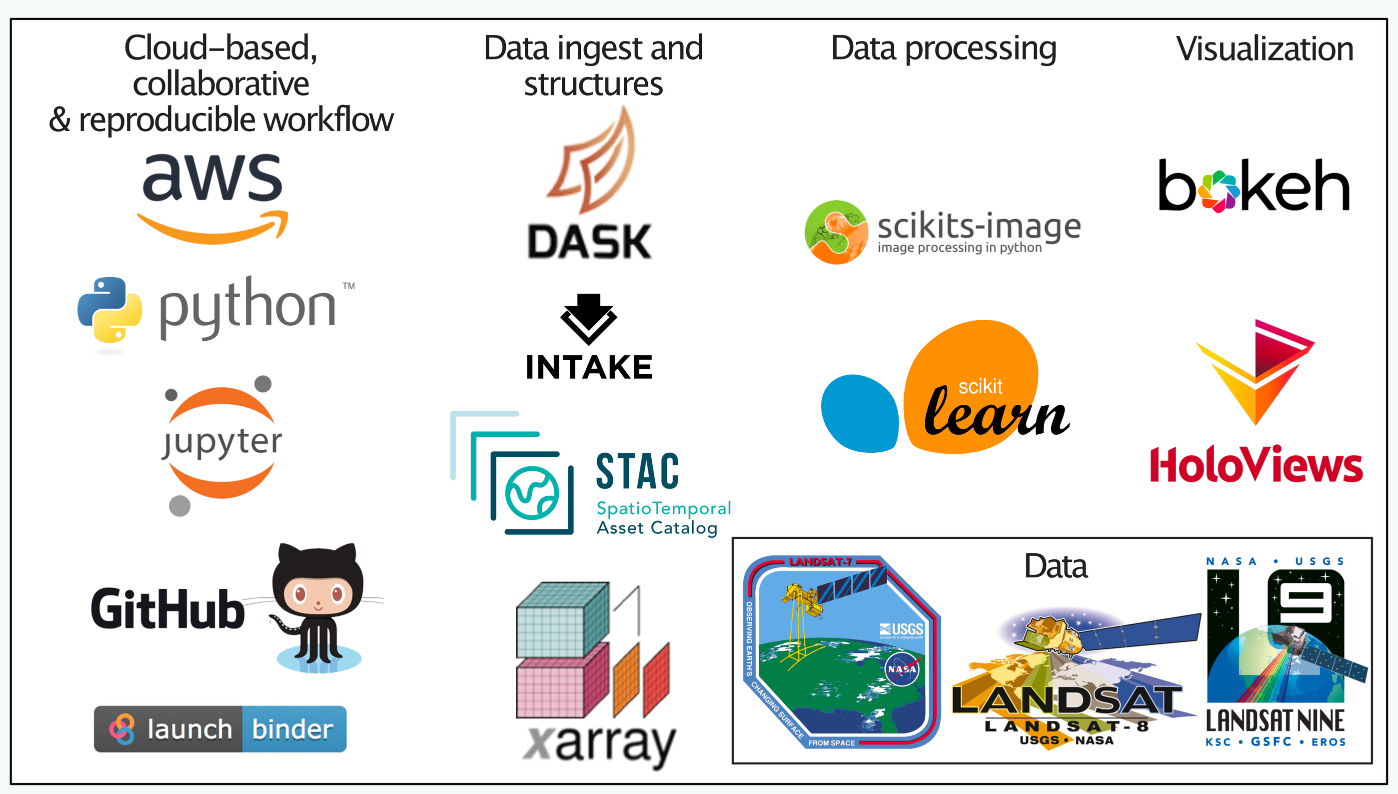
Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Emissivity Dataset coverage



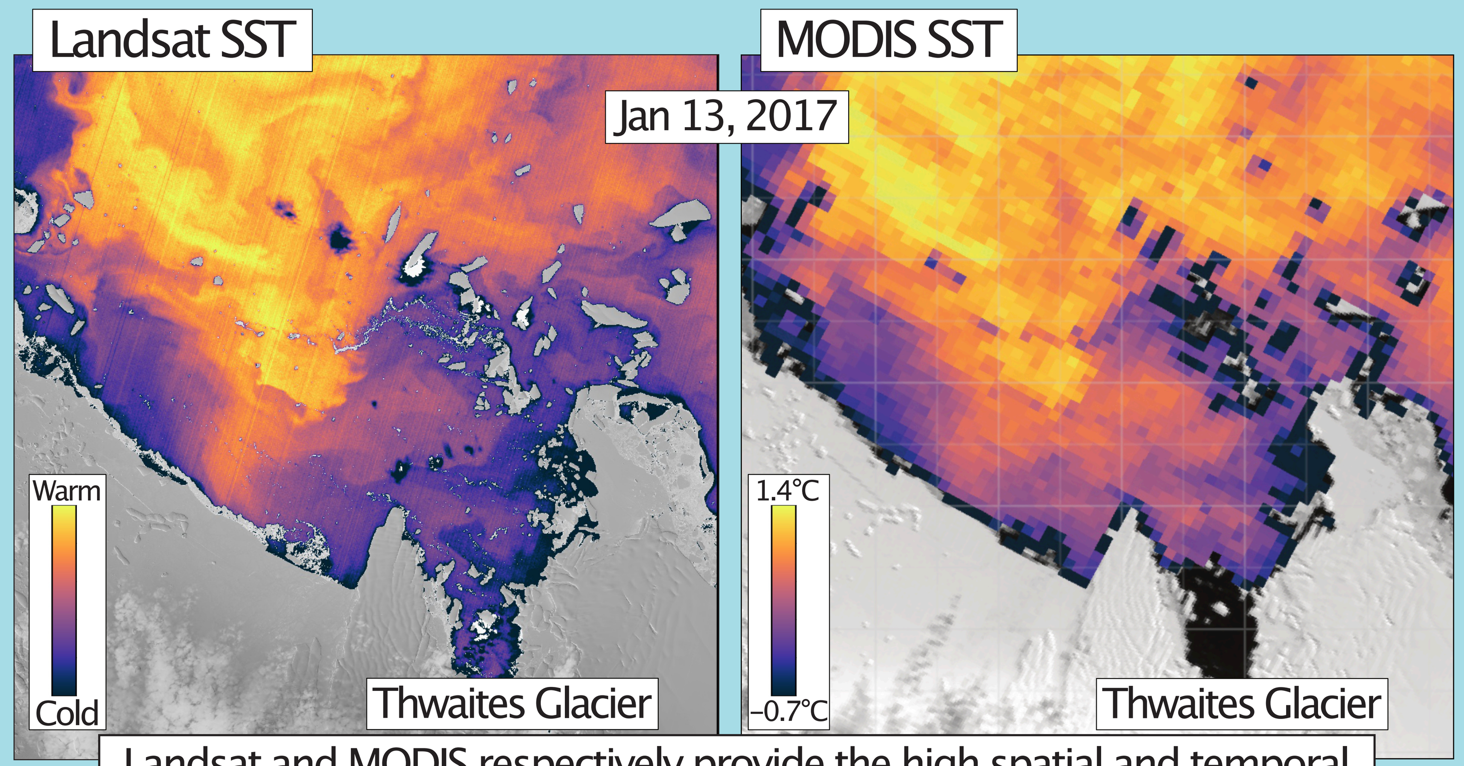
Low sun angles (solar zenith angle >76°) are not processed due to high uncertainties

Here we develop Landsat single-channel and split-window SST algorithms that will allow for integration with GHRSST products and will also be developed as an on-demand, cloud-based, user-customizable data product.

2. Landsat SSTs processed in a cloud workflow



Objective: Create a GHRSST-suitable Landsat SST product that includes Antarctica and design a cloud-based workflow that will provide the framework for on-demand data processing and serving, allowing users to specify algorithms and atmospheric data inputs and models to retrieve Landsat SSTs optimized for their scientific needs



Landsat and MODIS respectively provide the high spatial and temporal resolution imagery required to study ice-plagued Antarctic coastlines

3. Landsat SST processing pipelines

Cloud detection with XGBoost (distributed, gradient-boosted decision tree library [1]) to supplement the provided Landsat CFMask cloud identification [2]

Single channel algorithm

Calibrate thermal band to radiance

Apply a pixel-by-pixel atmospheric correction:

- Retrieve coincident NASA MERRA-2 reanalysis temperature, relative humidity, and ozone for each geopotential height (42), as well as total precipitable water [3]
- Estimate atmospheric propagation of thermal infrared using MODTRAN (MODerate resolution atmospheric TRANsmission model) with inputs from MERRA-2
- Apply correction using: [4]

$$(L_\lambda - L_{(\lambda\uparrow)})/\tau_\lambda - (1-\epsilon_\lambda) * L_{(\lambda\downarrow)} = \epsilon_\lambda B_\lambda(T_S)$$

L_λ is the at-sensor thermal radiance
ϵ_λ is surface emissivity
$B_\lambda(T_S)$ is blackbody radiance B_λ at surface temperature T_S as given by Planck's Law
$L_{(\lambda\uparrow)}$ and $L_{(\lambda\downarrow)}$ are atmospheric upwelling and downwelling longwave radiance
τ_λ is the transmittance from ground to satellite

Split-window algorithm

Derive brightness temperatures from thermal bands

Apply a Non-Linear SST (NLSST) algorithm: [5,6]

$$SST = a_1T_{11} + a_2T_{sfc}(T_{11} - T_{12}) + a_3(T_{11} - T_{12})(\sec\theta - 1) + a_4$$

T_{11} and T_{12} are brightness temperatures in the 11 μm and 12 μm channel
T_{sfc} is the reference SST
θ is the solar zenith angle
a_k $(k = 1{-}4)$ are algorithm coefficients derived from validation match-ups

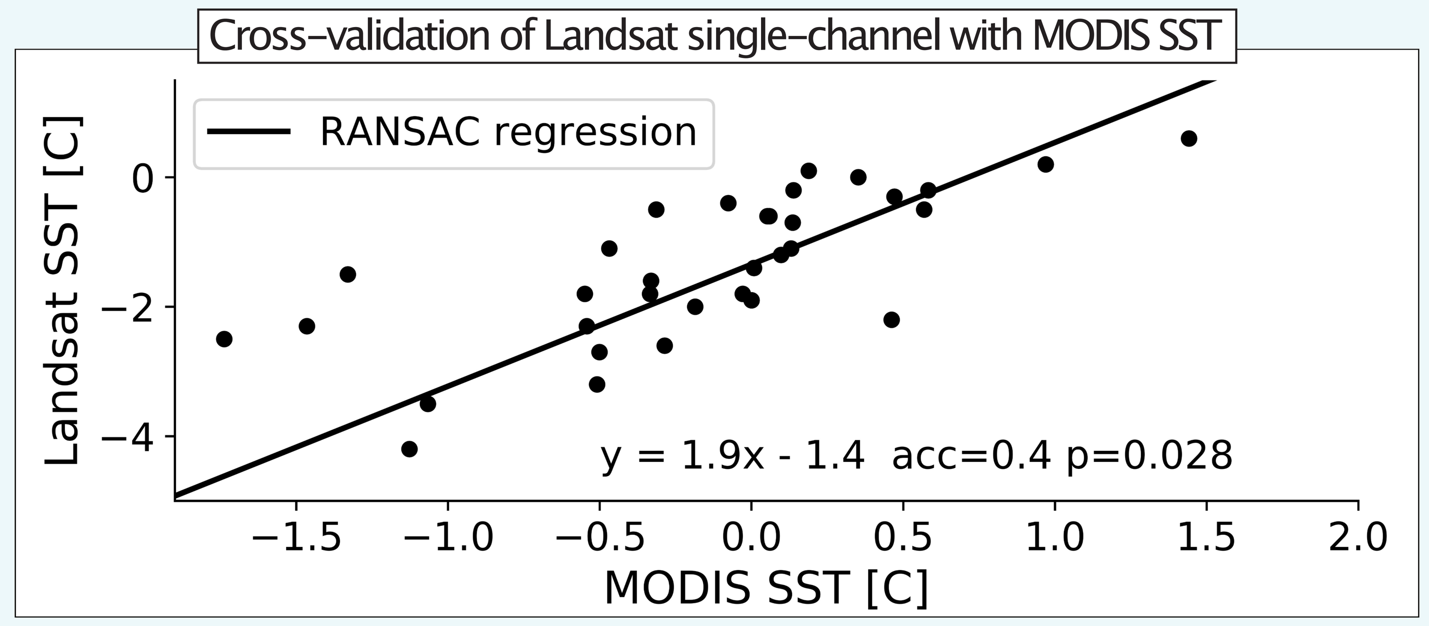
- Reference temperatures derived from the Canadian Meteorological center Global Foundation SST product [7]
- MODTRAN-based simulations train on polar atmospheric profile from the Thermodynamic Initial Guess Retrieval (TIGR) database to generate at-sensor brightness temperatures [8]

4. Linear relationship between MODIS and corrected Landsat SSTs enables cross-calibration

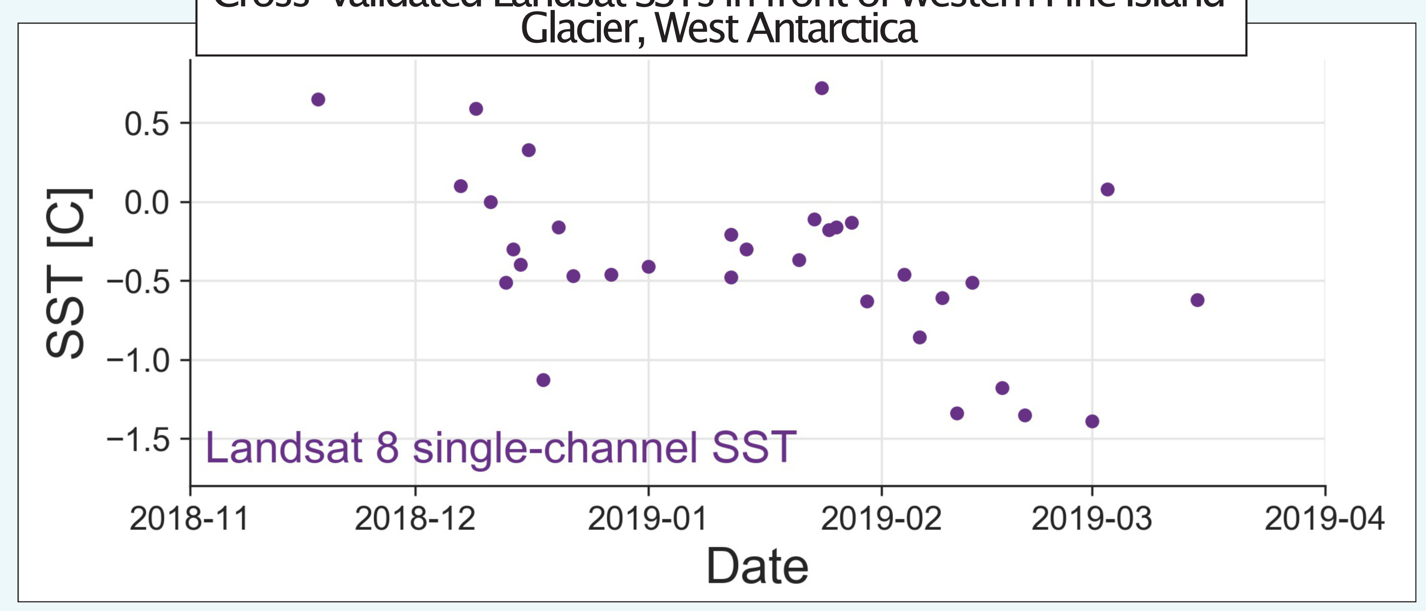
Co-located and contemporaneous in situ buoy measurements not yet available for Landsat in Antarctica

Instead, we implement a cross-calibration study using near-homogenous, sea ice and cloud-free MODIS SSTs

Cross-validation of Landsat single-channel with MODIS SST



Cross-validated Landsat SSTs in front of western Pine Island Glacier, West Antarctica



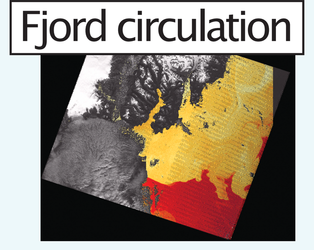
Landsat SSTs have a significant linear relationship with MODIS we use for cross-calibrations

Initial results show promise for producing Landsat SSTs in Antarctica

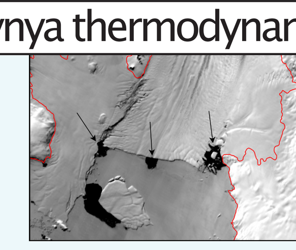
Further work will refine these methods to reduce uncertainty and broaden application to all of Antarctica

5. Intended polar applications

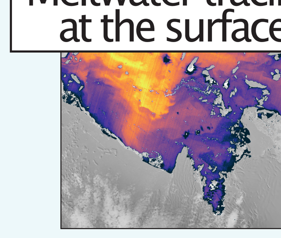
Fjord circulation



Polynya thermodynamics



Meltwater tracing at the surface



6. Future work

Implement the split-window algorithm

Calibration and validation – much is needed in Antarctica and elsewhere

Explore the need for:
- Month-of-year specific coefficients
- Additional water vapor content correction using MODTRAN
- Per-pixel satellite zenith angles

Design the cloud-based, on-demand Landsat SST processing framework based on the ICESat-2 SlideRule project

6. References

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7. Acknowledgements

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Mines Glaciology Laboratory