TQ5: Earth Surface Composition and Change

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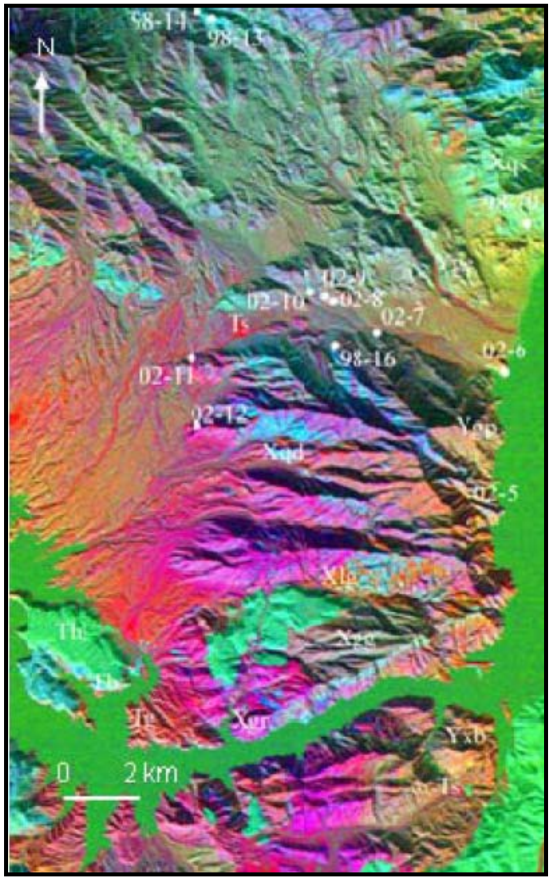
TQ5: Overarching Question

- What is the composition and thermal property of the exposed surface of the Earth? How do these factors change over time and affect land use and habitability?

TQ5a: What is the spectrally observable mineralogy of the Earth's surface and how does this relate to geochemical and surficial processes? (DS 114)



Simulated HyspIRI image for the area around Lake Mead, Nevada. Three TIR bands are processed with a decorrelation stretch algorithm and displayed in red, green and blue respectively, demonstrating the potential of TIR bands to uniquely map surficial geology. Image Credits: Simon Hook, JPL

Science Issue:

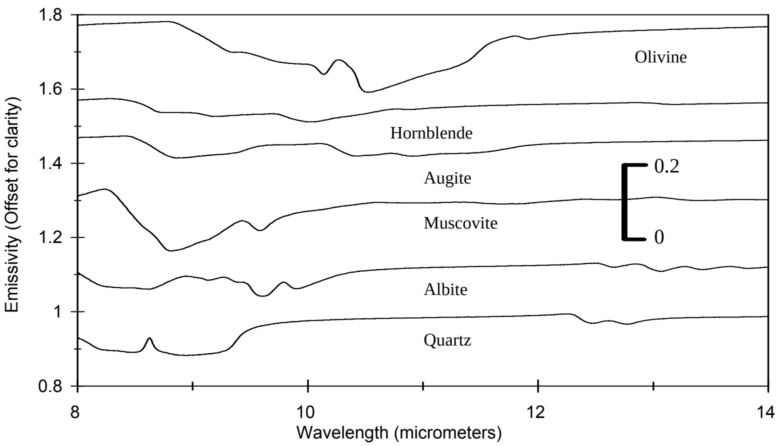
- Composition of the exposed surface and of the Earth holds clues to the origin of the surface material.
- Geochemical and surficial process constantly alter the composition of the material.
- Between day and night Earth surface composition remains the same but temperature changes, due to thermal inertia.
- Emissivity variations are useful to discriminate the felsic and mafic rock composition, and for mapping structures.
- Can mapping the spectrally observable mineralogy help to identify areas of mineralization? Can we improve our understanding of the geology and evolution of areas that are currently not well mapped?

Tools:

- HyspIRI day and night TIR images over selected sites.
- Field observations and published geological maps.
- Temperature emissivity separation (TES) algorithms.

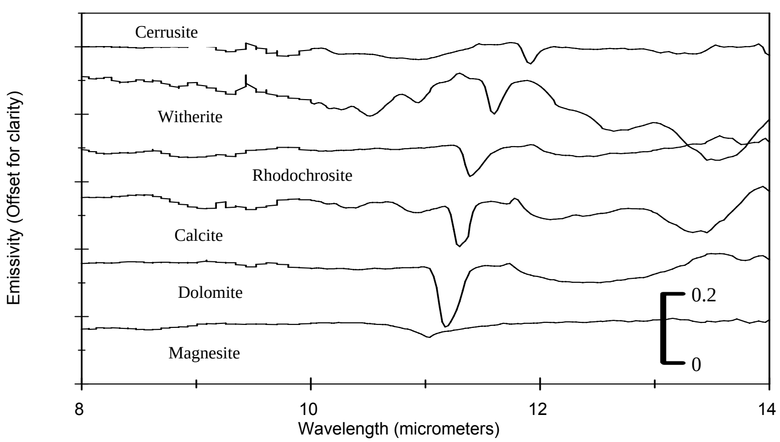
Approach:

- Develop and apply TES algorithm.
- Correlate emissivity in processed images to lithology based on the knowledge that framework silicates, such as quartz and feldspar, show min. emissivity at shorter wavelengths (8.5 μm). Silicates with sheet, chain, and isolated tetrahedral structure show minimum emissivity at progressively longer wavelengths (Hunt, 1980).
- Map temperatures during day and night to extract further information about properties of surface (thermal inertia).



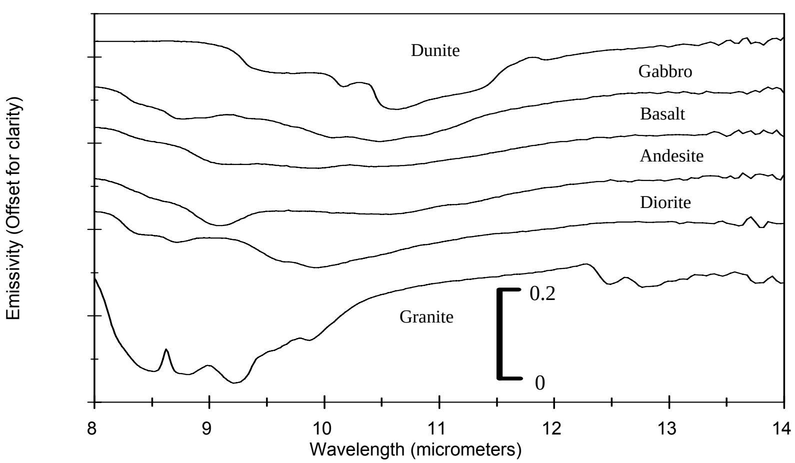
Silicate Minerals

- Silicate absorption peak: near 10 μm
- Cause is Si-O stretching or reststrahlen band.
- Framework silicates, such as quartz and feldspar, show min. emissivity at shorter wavelengths (8.5 μm).
- Silicates with sheet, chain, and isolated tetrahedral structure show minimum emissivity at progressively longer wavelengths (Hunt, 1980).



Carbonate Minerals

- Carbonate minerals have a diagnostic sharp feature around 11.2 μm which moves to slightly longer wavelengths as the atomic weight of the cation increases.

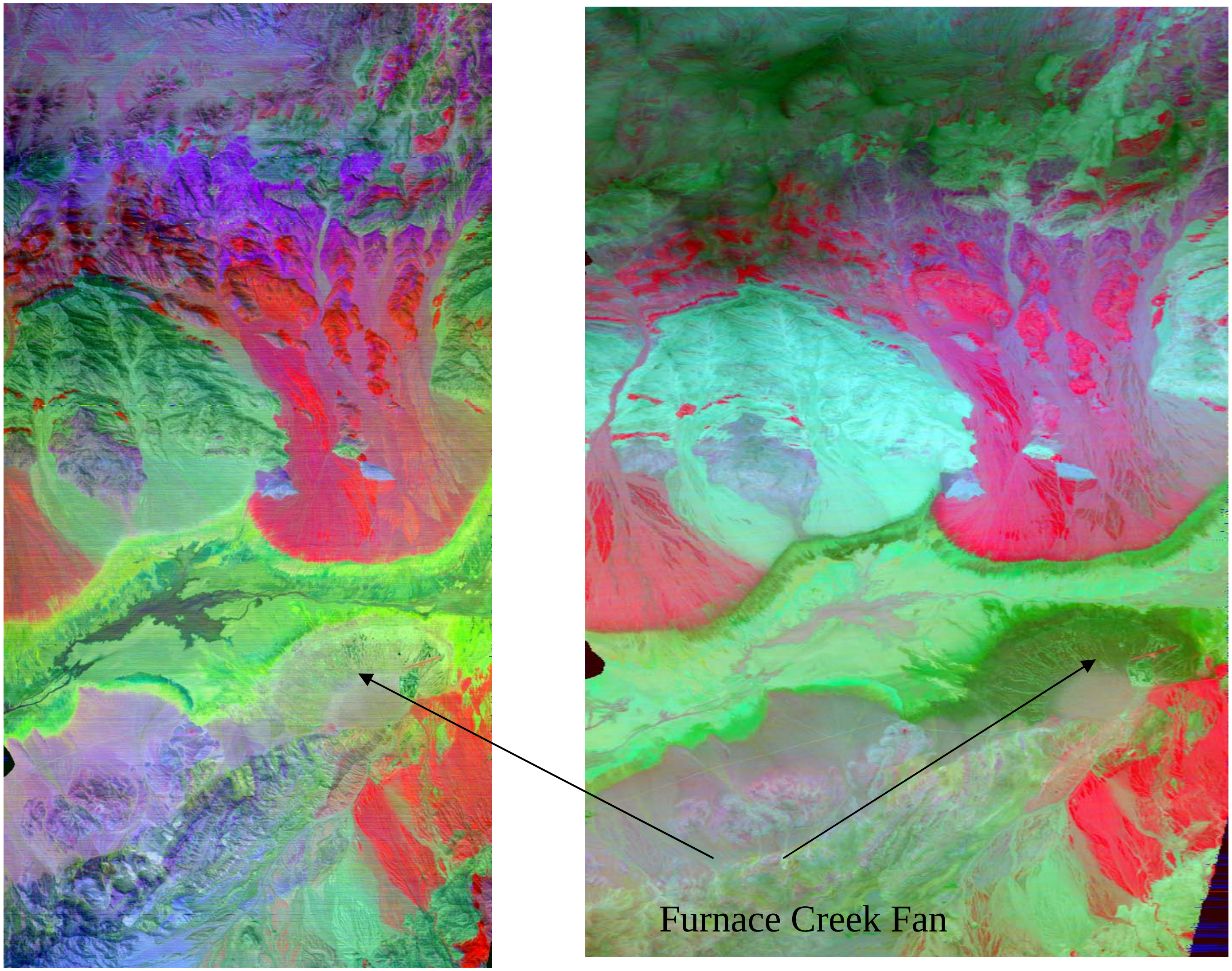


Igneous Rocks

- A similar trend is observable in igneous rocks

Note: These spectral emissivity variations are useful to discriminate the felsic and mafic rock composition, and for mapping structures.

Geological Mapping



TIMS 5,3,1 RGB; 7-22-1983; 28 m

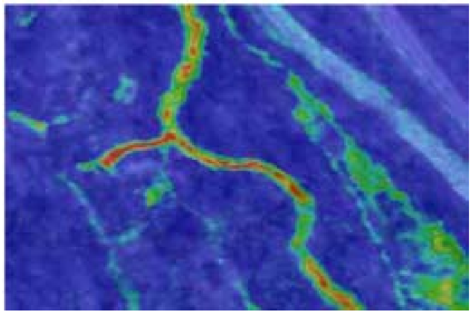
TIMS 5,3,1 RGB; 7-21-1983; 28 m

Day

Night

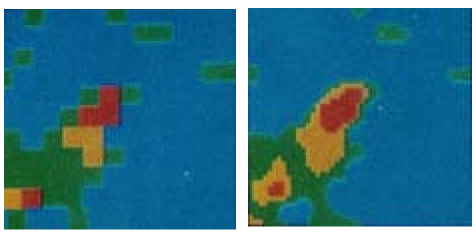
Image Credits: Simon Hook, JPL

TQ5b: What is the nature and extent of man-made disturbance of the Earth's surface associated with exploitation of renewable and non-renewable resources? How do these vary over time? (DS 227)



Airborne TIR image (top) showing elevated temperatures in shades of red, orange and green.

Corresponding field photo showing Acid Mine Drainage. The impact occurs at different spatial scales. Source: Ackman T.E., 2003.



Barren, locally warmer patches in a coal mining area (left). Landsat TM TIR band picks up the temperature anomalies associated with such patches (top). Source: Gupta & Prakash, IJRS, 1998.

Science Issue:

- Mining of non-renewable resources such as oil and gas, coal, other minerals are almost always associated with adverse environmental impacts such as acid mine drainage, locally exposed dry patches, thermal plumes, etc. Impacted regions often show difference in surface composition and temperature from the background that can be detected and monitored using time sequential TIR images.

Tools:

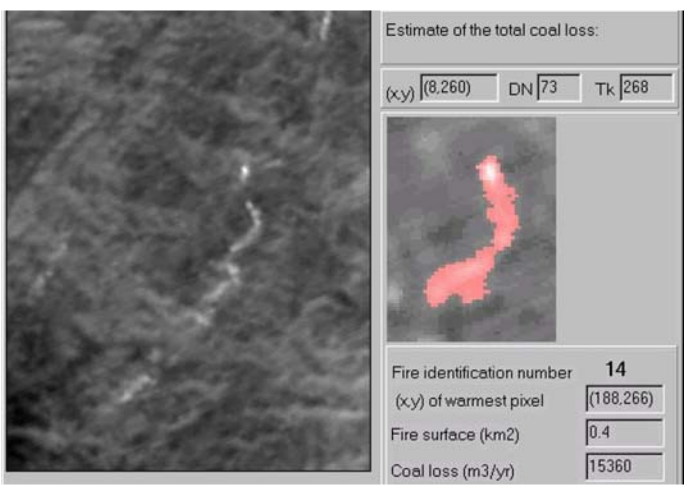
- HyspIRI TIR data, preferably day and night images, at spatial resolution ≤ 60 m and NEΔT < 0.2 K and monthly temporal repeat.
- Mining area maps, information on associated structures eg. power plants, mineral processing facilities.
- Field based temperature measurements. Modeled or real data on rate of change of anomaly area, if possible.

Approach:

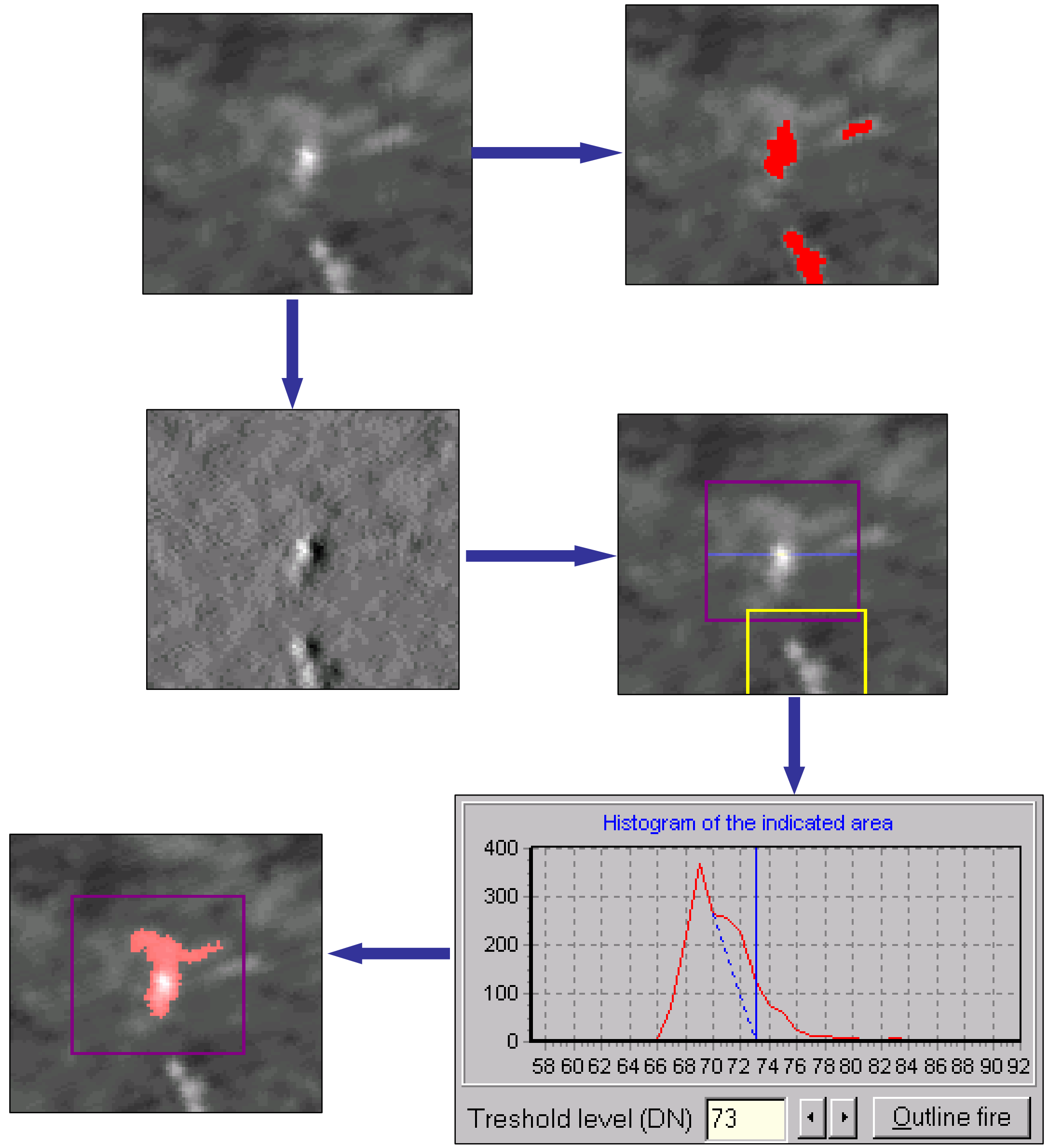
- Calculate temperature image after accounting for target emissivity. Ascertain a threshold to delineate the anomalous areas from background based on a image statistics, slope change in histogram, or guided by field knowledge.
- Monitor changes in temperature anomaly with time using multi-temporal data. Correlate mapped changes with known increase/decrease in resource exploitation activities.


Photo credit: Denis Pone


Photo credit: A. Prakash

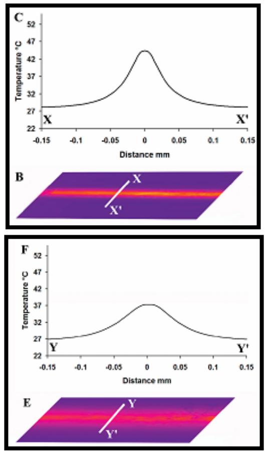


Example of quantitative estimation of impact using TIR data



Source: Rosema et al., 1999

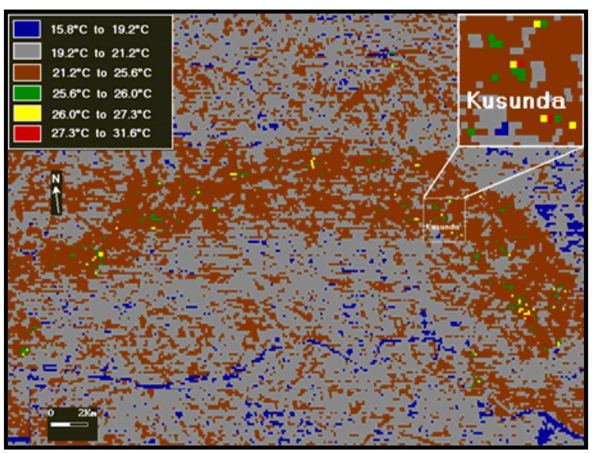
TQ5c: How do surface temperature anomalies relate to deeper thermal sources, such as hydrothermal systems, buried lava tubes, underground coal fires and engineering structures? How do changes in the surface temperatures relate to changing nature of the deep seated hot source? (DS 243)



Temperature profile over buried hot source: Top: shallow source -narrow peaky anomaly. Bottom: deeper source - broad subtle anomaly. Berthelote et al., Bull Volc., 2007

Active lava tube, Kilauea Volcano, Hawaii. Photo Credit: Heliker C.

Underground coal fires in Jharia coalfield, India. Photo credit: Prakash A.



Processed Landsat TM Band 6 image showing locations of underground coal fires, Jharia Coalfield, India. Prakash et al., IJRS, 1997.

Science Issue:

- Locating underground sources of heat, estimating their depth, characterizing their nature (size, intensity), monitoring changes if any, is important for understanding processes operating in the Earth's interior (lava tubes), surface impacts of these sources (underground coal fires), and for maintaining critical infrastructure (thermosyphons installed to prevent permafrost from thawing).
- Can the surface temperature anomaly caused by these sources provide insight to the above issues?

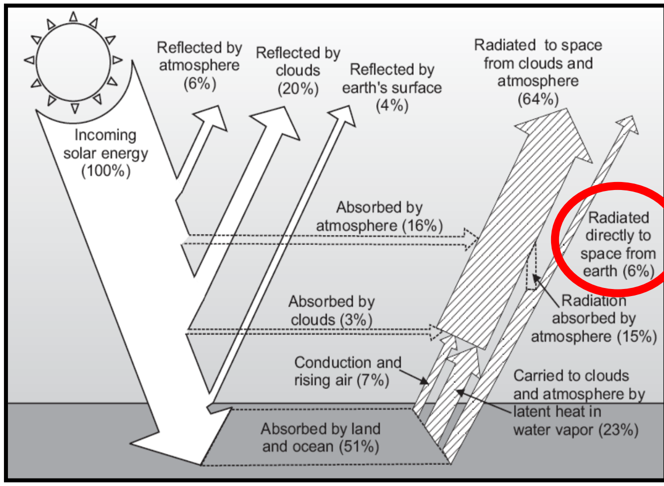
Tools:

- HyspIRI day and night TIR images taken in 3+ bands in 8-12 um range with NEΔT < 0.2 K; Spatial resolution ≤ 60 m; temporal repeat weekly.
- Numerical models for depth estimation based on linear heat flow in a semi-infinite medium. Field information for validation, if available.

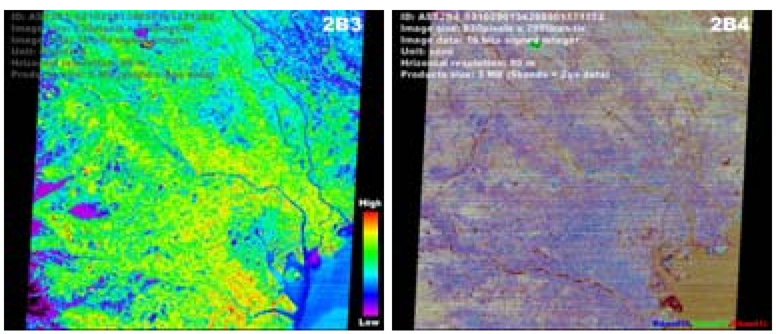
Approach:

- Generate temperature image account for target emissivity.
- Extract several temperature profiles across the identified hot spots, extending profile to the background temp areas.
- Fit extracted temperature profile to empirically derived or physical depth models. Monitor temperature profile to estimate change in nature or depth of source.

TQ5d: What is the spatial distribution pattern of Earth surface temperatures and emissivities and how do these influence the Earth's heat budget?



Earth's Heat Energy Budget. Source: Manual of Remote Sensing, 2008. After NASA's Earth Radiation Budget Experiment.



Earth surface temperature (left) and emissivity derived from ASTER's five TIR channels using the established temperature emissivity separation (TES) algorithm. Source: Aster data products.

Science Issue:

- Land surface has diverse composition with variable emissivity.
- Amount of energy emitted by the land surface is not well understood.

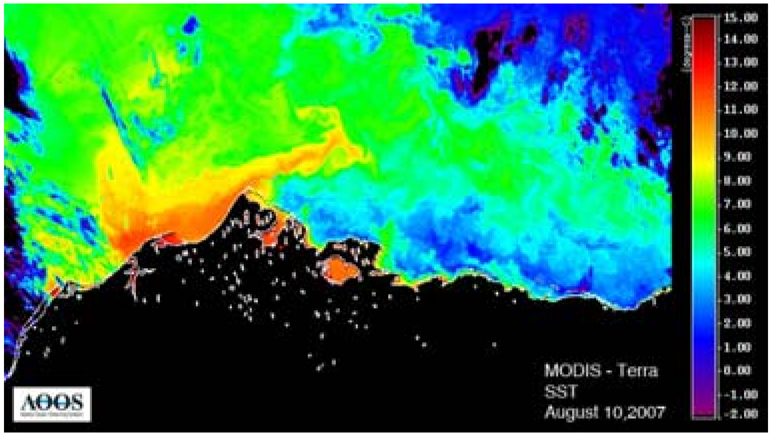
Tools:

- HyspIRI TIR data, 7 bands in 8-12 um range with NEΔT < 0.2 K; spatial resolution ≤ 60 m.
- Atmospherically corrected ground emissivity data.
- Accurate methods of temperature emissivity separation applicable to wide range of materials is needed.
- Current models and estimates of Earth's heat budget.

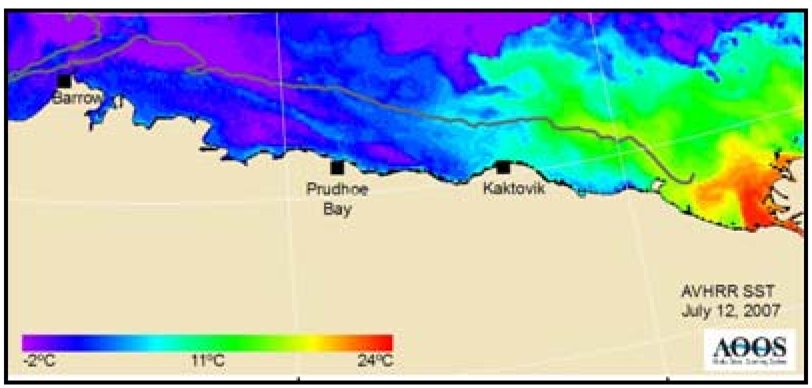
Approach:

- Develop and apply accurate TES algorithm.
- Generate temperature and emissivity products for a variety of Earth surface cover types.
- Estimate global scale temperature emissivity distribution pattern to serve as input to refine current assumptions in Earth heat budget calculation.

TQ5e: What are the water surface temperature distributions in coastal, ocean, and inland water bodies, how do they change, and how do they influence aquatic ecosystems? (DS 378)



SST derived from processes MODIS TIR image of the Arctic Alaska coast. Influence of wind in causing intrusion of warm waters onto the shelf in the western Beaufort Sea is seen. Okkonen et al, 2009



Processed AVHRR TIR image of the coast of the Arctic Alaska coast. Outflow from the Mackenzie River influences temperatures in coastal waters, breakup of sea ice, and thermal habitats of a variety of flora and fauna. Okkonen et al, 2009

Science Issue:

- Aquatic habitats are subject of dynamic temperature regimes, eg. coastal water temperatures vary due to temperatures of the neighboring land surface, outflow from rivers, general ocean circulation patterns, and local wind conditions.
- Flora and fauna in aquatic environments are sensitive to the water temperatures.
- They dynamics of the water temperatures and the controlling processes are not well understood.

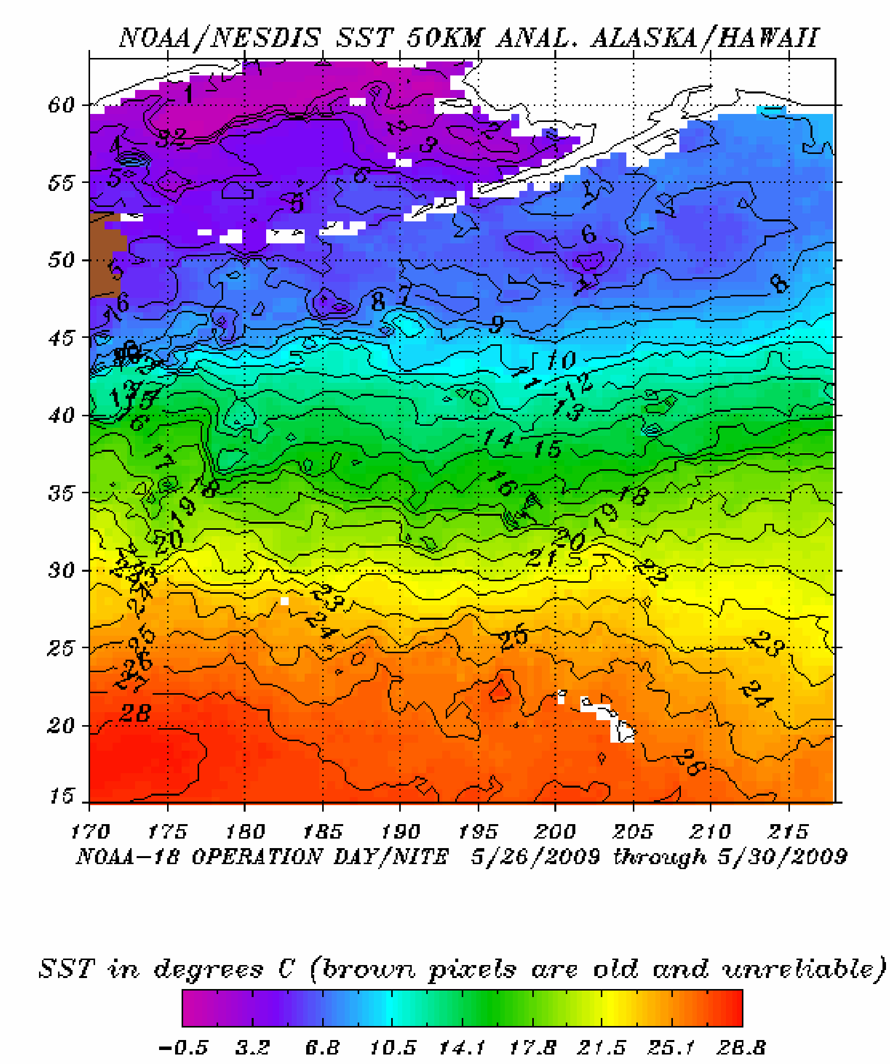
Tools:

- HyspIRI TIR data with NEΔT < 0.2 K and weekly temporal repeat.
- Ancillary data such as high-resolution hydrography and acoustic Doppler current profiler measured currents, bathymetric information, when possible.

Approach:

- Derive water surface temperature images from HyspIRI TIR bands using established temperature estimation algorithm.
- Relate spatial temperature distribution pattern to local conditions (wind, riverine outflow, etc.)
- Relate surface temperature to bulk water temperature where ancillary data is available.

Science Objectives	Measurement Objectives	Measurement Requirements	Instrument Requirements	Other Mission and Measurement Requirements
Earth Surface Composition and Change: What is the composition and thermal properties of the exposed surface of the Earth? How do these factors change over time and affect land use and habitability?				
What is the spectrally observable mineralogy of the Earth's surface and how does this relate to geochemical and surficial processes? [DS 114]	*Mapping spectral* emissivity variations associated with mineralogy and rock type in exposed terranes	Variation in silica content and non-silicate *minerals* based on 8-12 um band shape. (Spectral emissivities towithin 0.5%)	7 bands in 8-12 um range with NEΔT < 0.2 K; spatial resolution < 60 m; temporal repeat quarterly	*Geolocation to subpixel accuracy* Band to band calibration must be validated, in-flight *and radiometric calibration*
What is the nature and extent of man-made disturbance of the Earth's surface associated with exploitation *of renewable* and non-renewable resources? How do these vary over time? [DS 227]	Surface *temperature and* emissivity variations associated *with hydrocarbon and mineral extraction (dumps and pits)*	Variation in mineral content based on 8-12 um band shape including detection of sulfate spectral features. *At scale of mining activities*	*At least 5* bands in 8-12 um range with NEΔT < 0.2 K; spatial resolution < 60 m; temporal repeat monthly	*Geolocation to subpixel accuracy Band to band calibration must be validated, preferably in-flight and radiometric calibration*
How do surface temperature anomalies relate to deeper thermal sources, such as *hydrothermal systems,* buried lava tubes, underground coal fires and engineering structures? How do changes in the surface temperatures relate to changing nature of the deep seated hot source? [DS 243]	Surface temperatures corrected for emissivity variations *for temperature anomalies*	*Measure* variations in temperature with high *accuracy and* precision and spatial resolution	3+ bands in 8-12 um range with NEΔT < 0.2 K; Spatial resolution < 60 m; temporal repeat weekly	Nightime data necessary to minimize radiant interference due to solar heating
What is the spatial distribution pattern of surface temperatures and emissivities and how do these influence the Earth's heat budget?	Surface emissivity variations and temperatures of all surficial cover materials	Complex surface emissivity properties based on 8-12 um band shape	*1 band at 3.98 um and* 7 bands in 8-12 um range with NEΔT < 0.2 K; spatial resolution 60-*500 m*; temporal repeat weekly	Accurate methods of temperature emissivity separation applicable to wide range of materials needed.
What are the water surface temperature *distributions* in-coastal, ocean, and *inland water bodies, how do they change, and how do they influence aquatic ecosystems*? [DS 378]	Spatial and temporal variation in *surface* temperatures	*Measure* variations in temperature with high *accuracy (<0.5 K) and* precision and good to moderate spatial resolution	*1 band at 3.98 um and* 3+ bands in 8-12 um range with NEΔT < 0.2 K; Spatial resolution 50 to 100m; temporal repeat *weekly*	Day and night measurements preferable



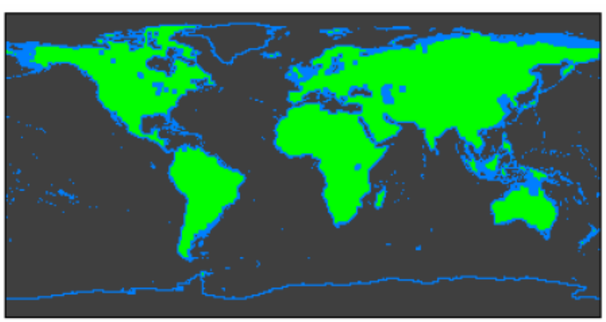
Higher Order Products

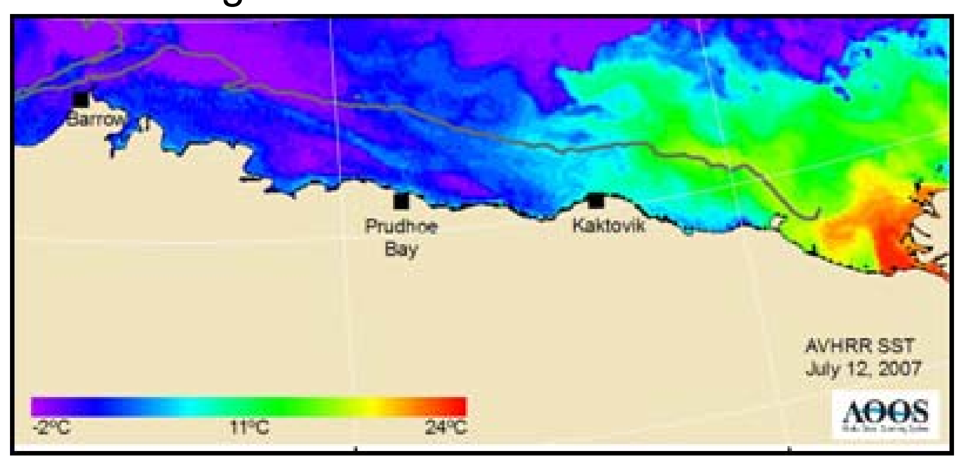
Sea Surface Temperature:

- Surface temperature, particularly in the coastal regions.
- Off shore (<-50m) at full/coarser (?) spatial resolution; Coastal regions at spatial resolution ≤ 60 m and NEΔT < 0.2 K and 5 day to weekly temporal repeat.

Validation:

- Thermal sensors at selected field test sites.
- Comparison with available SST products from AVHRR and MODIS
- Comparison with downscaled AO coupled atmospheric models
- Validation for tropical, temperate, and high latitude regions





Higher Order Products

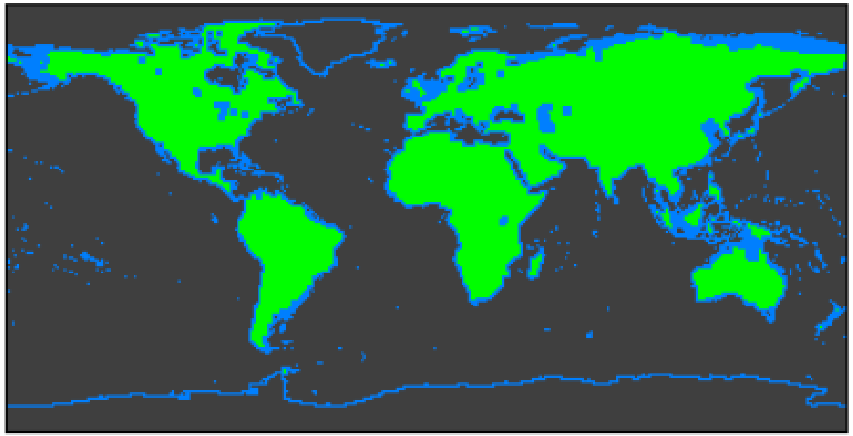


Image Credits: NASA HyspIRI Team

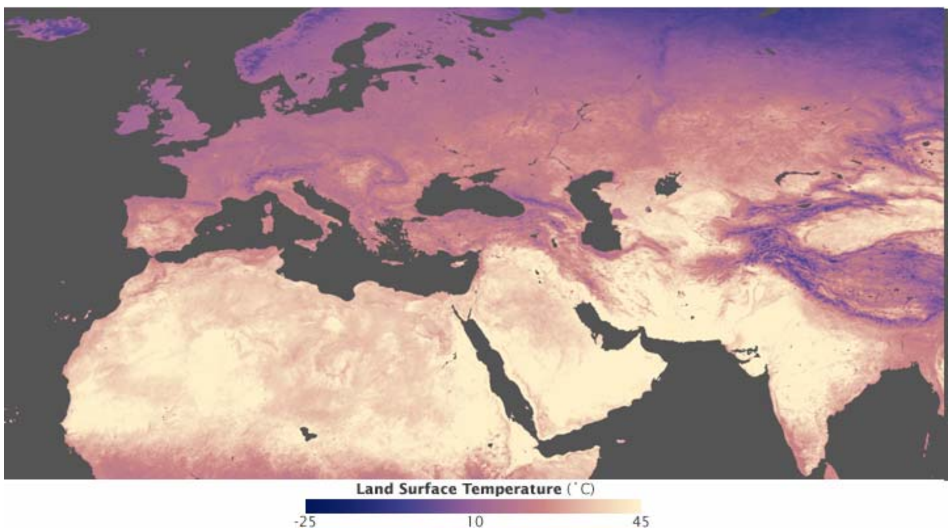


Image Credits: NASA Earth Observatory

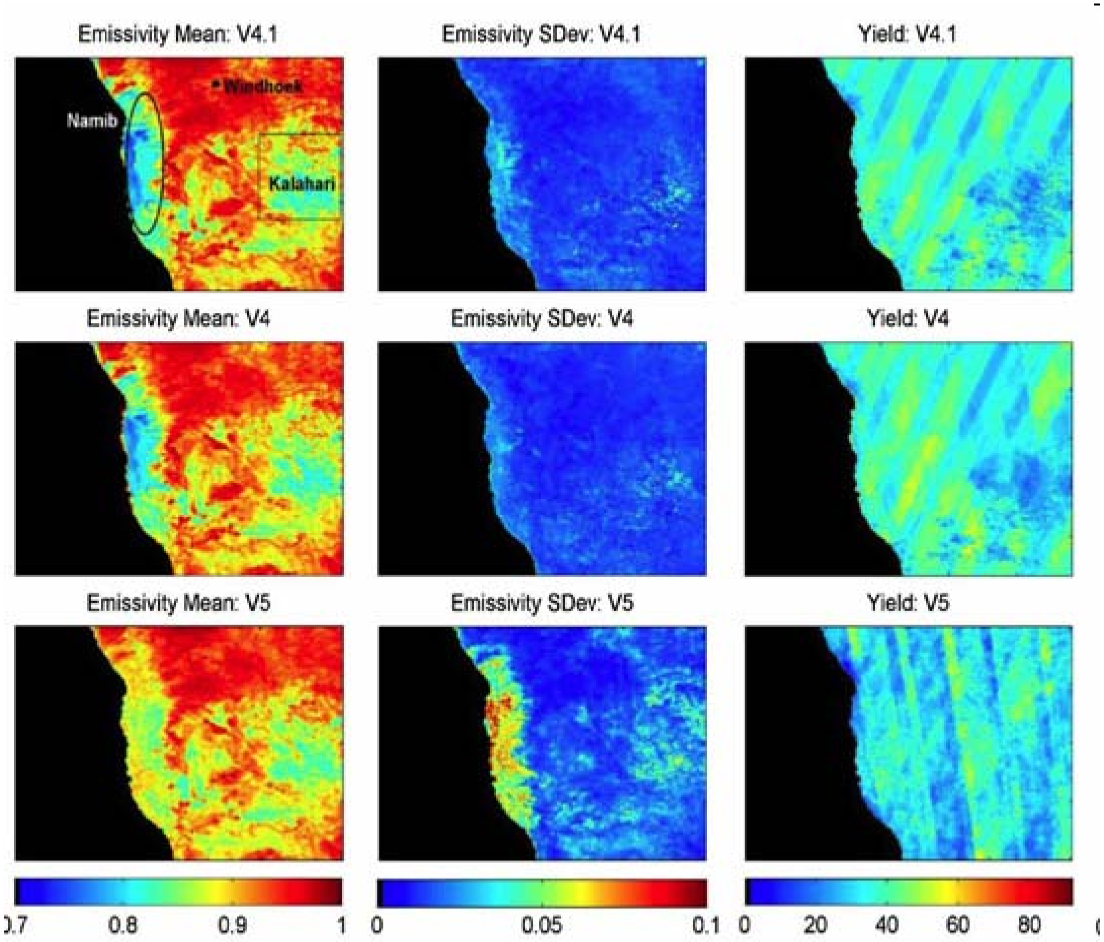
Land Surface Temperature:

- Global land surface temperature (also kinetic temperature)
- Derived using accurate methods of temperature emissivity separation applicable to wide range of materials is needed.
- HyspIRI TIR data, 7 bands in 8-12 um range with NEΔT < 0.2 K; spatial resolution ≤ 60 m.
- Temporal resolution monthly (?)

Validation:

- Atmospherically corrected ground emissivity data.
- Comparison with land surface temperatures derived from legacy satellite missions such as MODIS, Landsat and ASTER.
- Comparison with downscaled climate models
- Validation using thermal sensors at selected field sites in tropical, temperate, and high latitude regions.

Higher Order Products



MODIS Land Surface Emissivity Product and Validation using Laboratory Data: Mean emissivity (left panels), standard deviation in emissivity (middle panels), and total yield (right panels) using MOD11B1 tile h19v11 for band 29, and for version 4.1 (top panels), 4 (middle panels), and 5 (bottom panels) from July to Sep, 2004. Source: Hulley and Hook, 2009, RSE vol. 113, pp1313-1318.

Land Surface Emissivity:

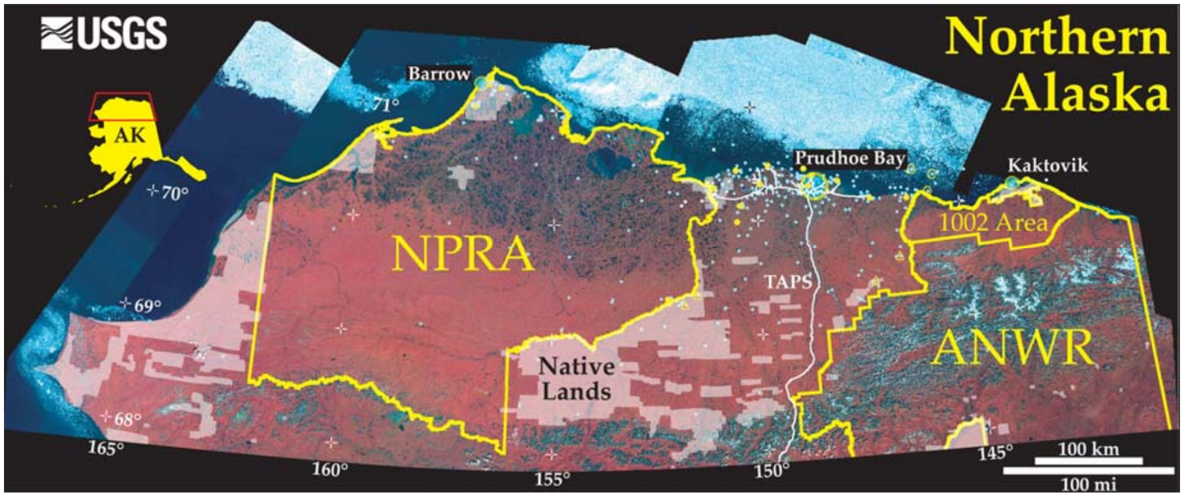
- Global land surface emissivity
- Spatial resolution ≤ 60 m.
- Absolute accuracy 0.05-0.1
- Temporal resolution monthly (?)

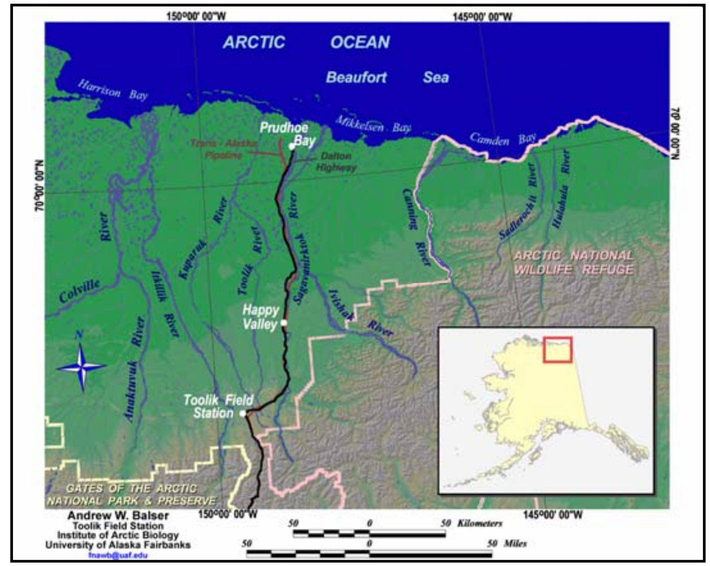
Validation:

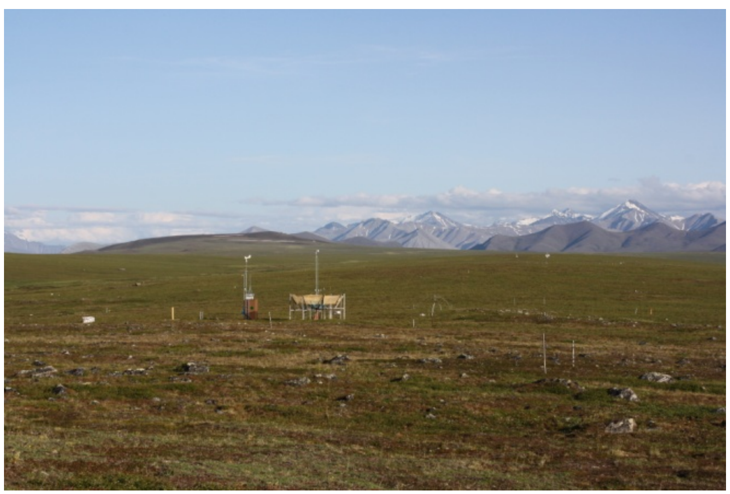
- Comparison with land surface emissivity derived from MODIS and ASTER.
- Using laboratory measurements of samples spanning a variety of landcover types.
- Using atmospherically corrected ground emissivity data.

Preparatory Work

- Acquire Airborne data over selected sites, especially in high latitudes
- Establish validation sites in high latitudes







Instrument set up at Toolik Field Station

Preparatory Work Requires Preparation !!
Watch: http://www.youtube.com/watch?v=K1gnvKZFCq0