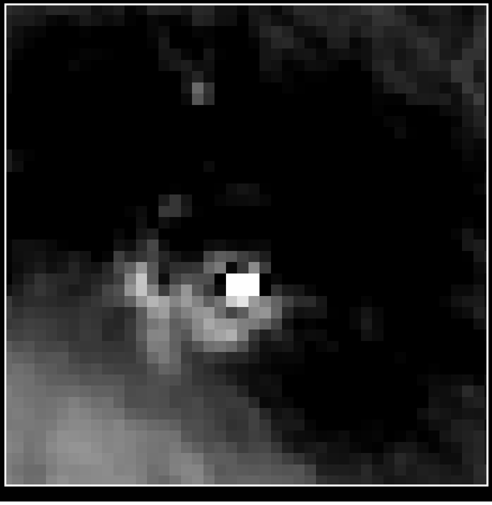
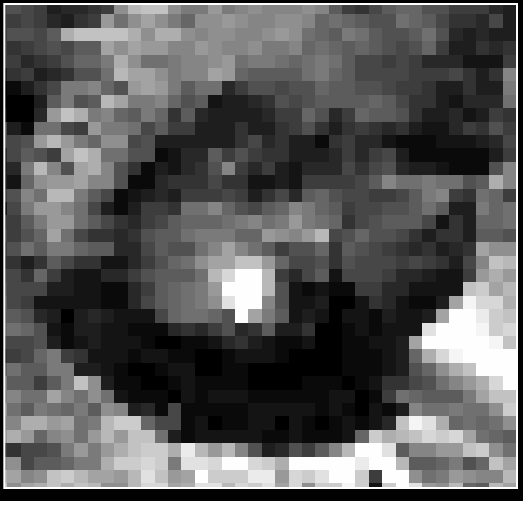
Remote Sensing of Volcanic Thermal Features with HyspIRI

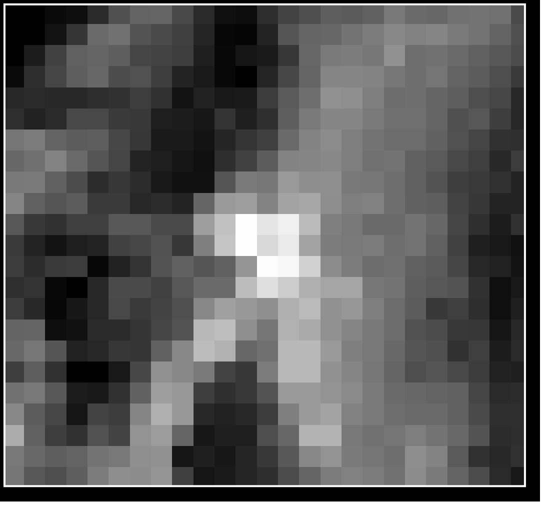
R. Greg Vaughan

USGS, Astrogeology Science Center, Flagstaff, AZ

August 12, 2009, 2nd HyspIRI NASA Decadal Survey Mission Science Workshop , Pasadena, CA







HyspIRI Science Questions

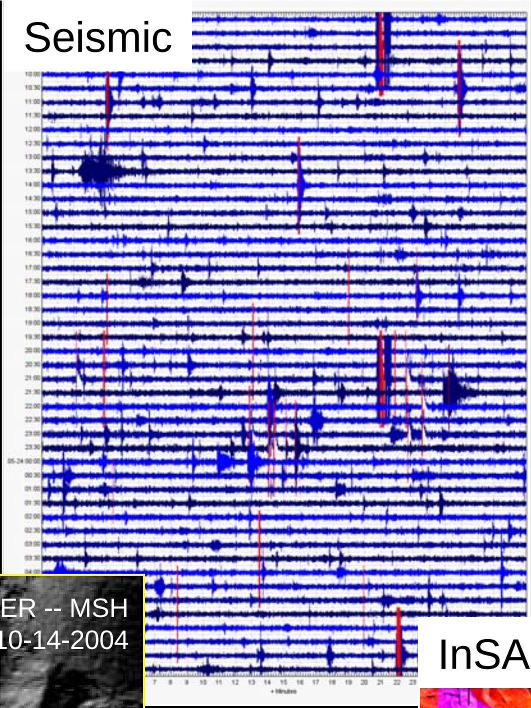
1) How can we help predict and mitigate volcanic hazards through detection of transient thermal phenomena? (TQ1)

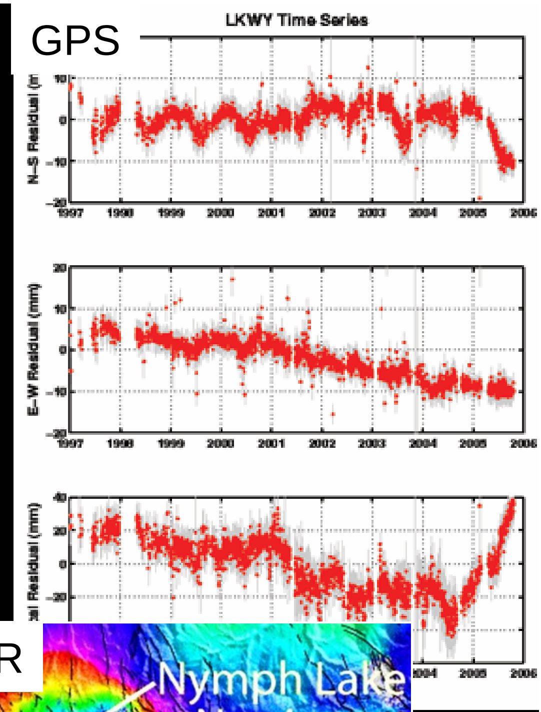
2) How do volcanoes signal impending eruptions through changes in surface temperature and thermal flux? (CQ3)

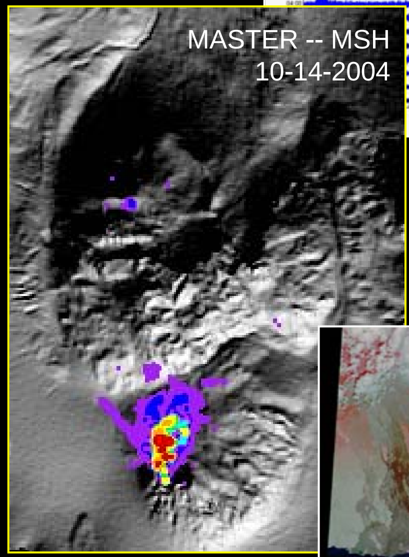
3) How do variations in volcanic thermal features, such as crater lakes, relate to volcanic processes? (CQ3)

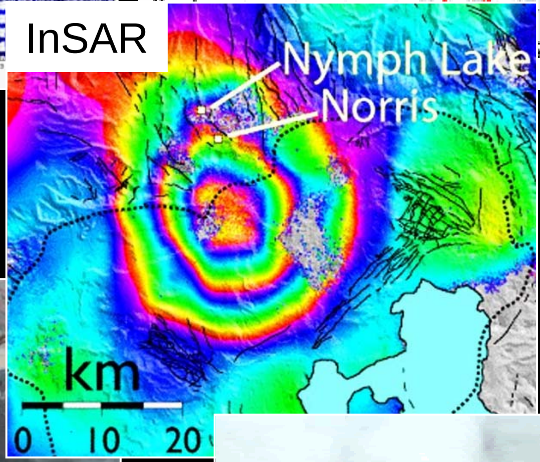
Volcano Monitoring

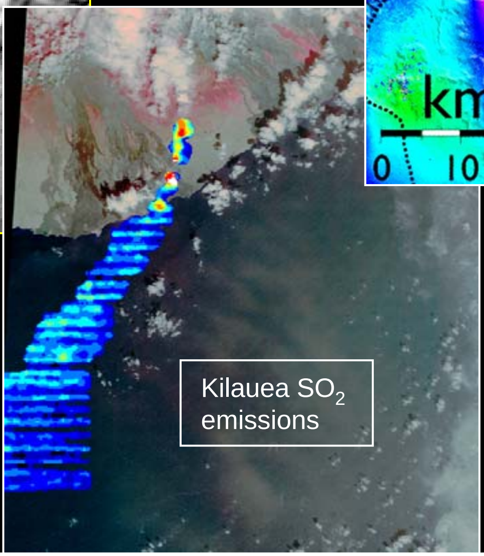
1) Seismic Activity
2) Ground Deformation
3) Gas/Ash Emissions
4) Thermal Emissions

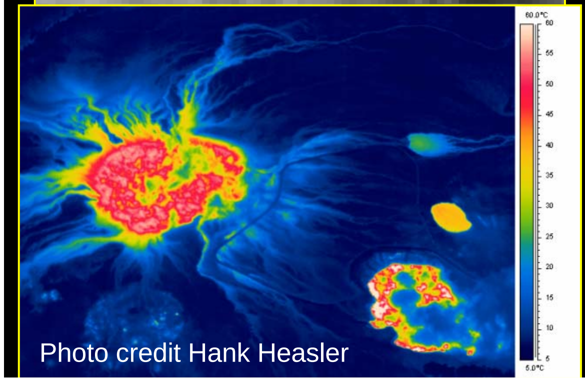










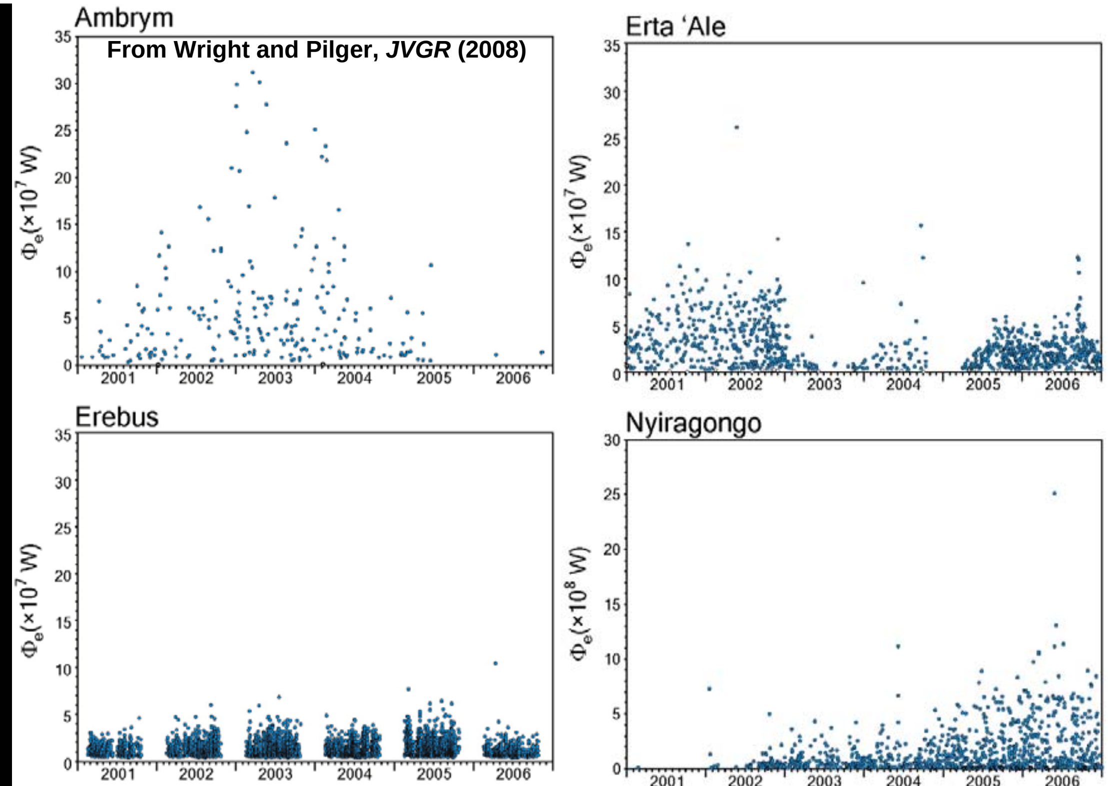


Monitoring Volcanic Thermal Emissions

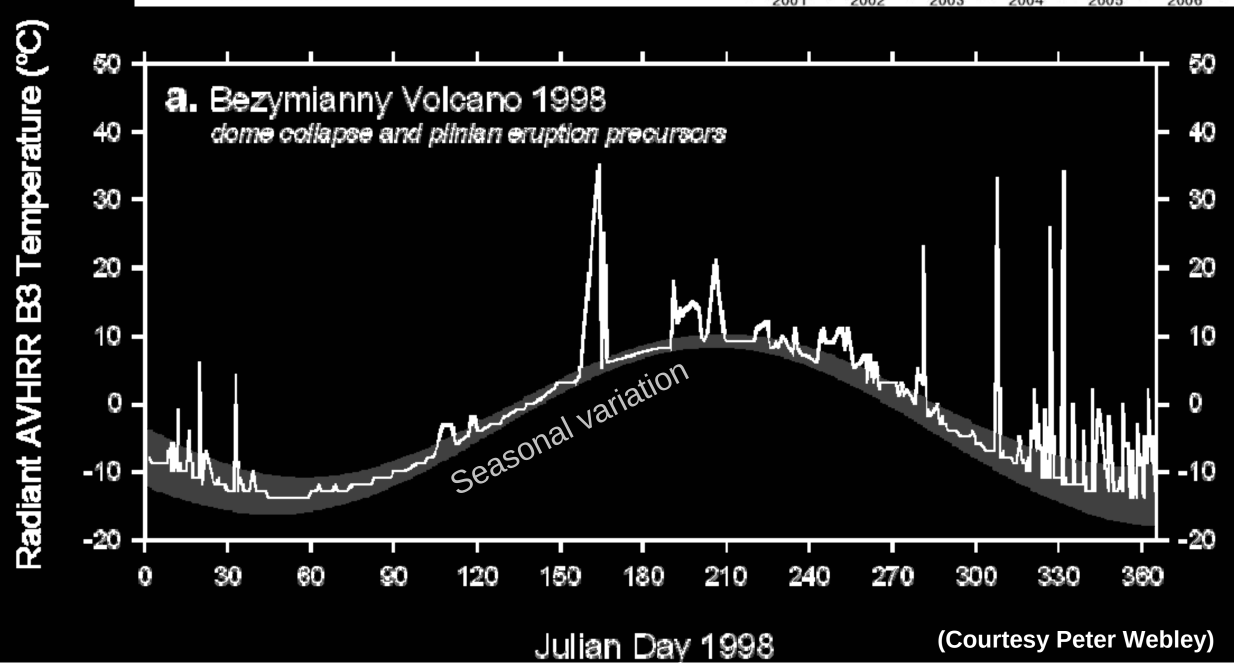
1) **Background studies**

2) Monitoring on-going activity in near real-time / thermal anomaly alarms

3) Sub-pixel thermal mixing



From Wright and Pilger, *JVGR* (2008)



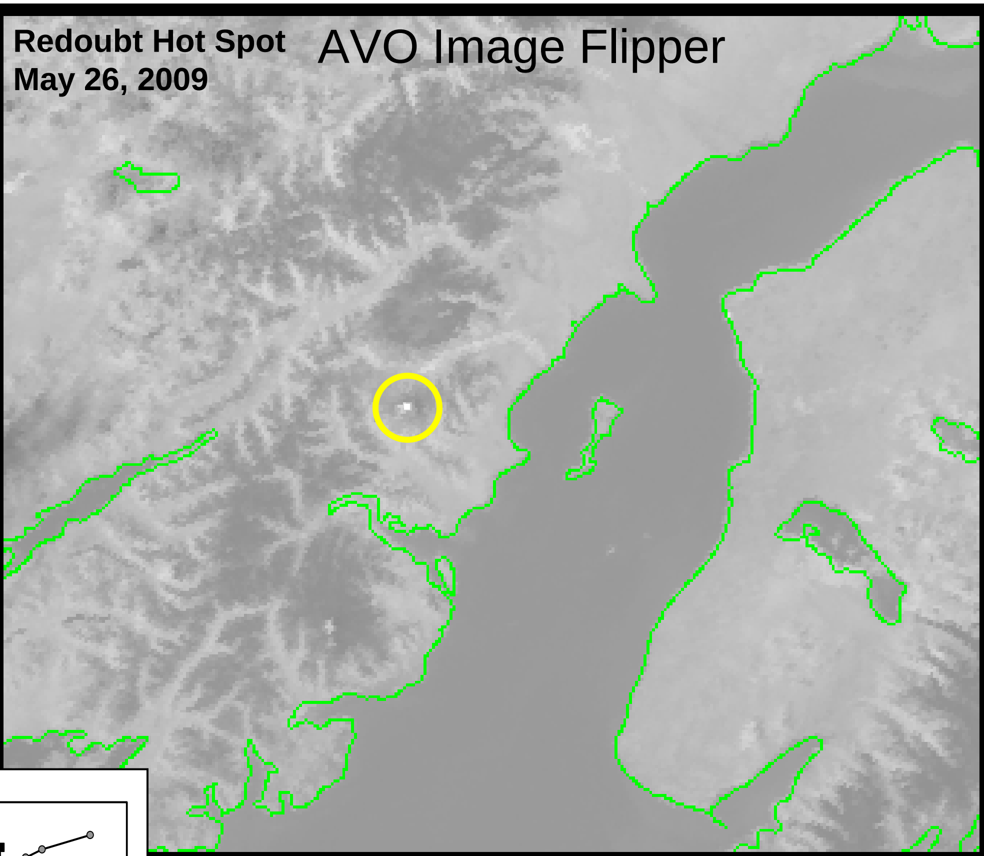
(Courtesy Peter Webley)

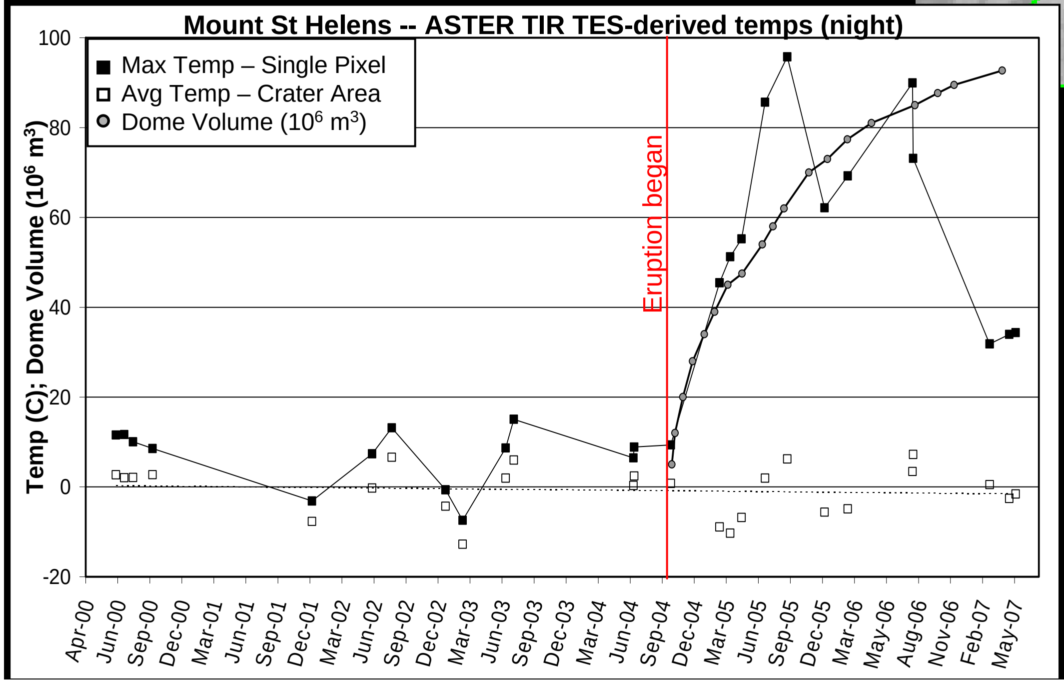
Monitoring Volcanic Thermal Emissions

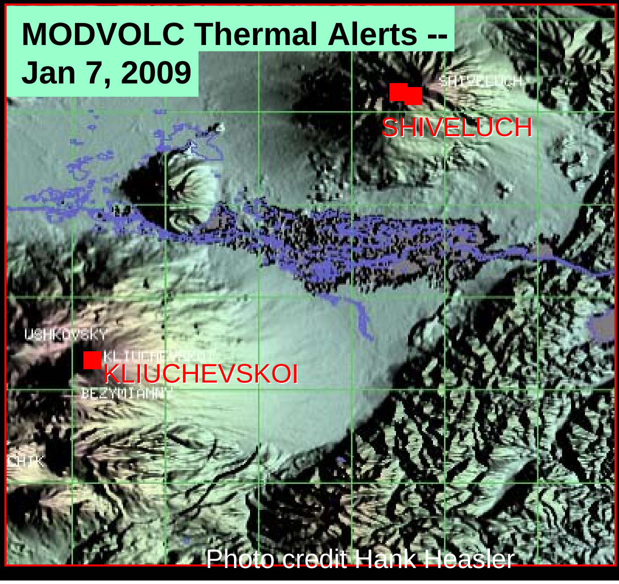
1) Background studies

2) <u>Monitoring on-going activity in near real-time / thermal anomaly alarms</u>

3) Sub-pixel thermal mixing





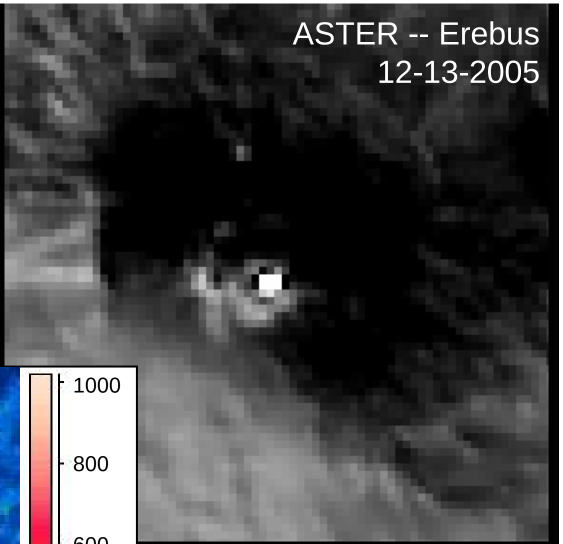


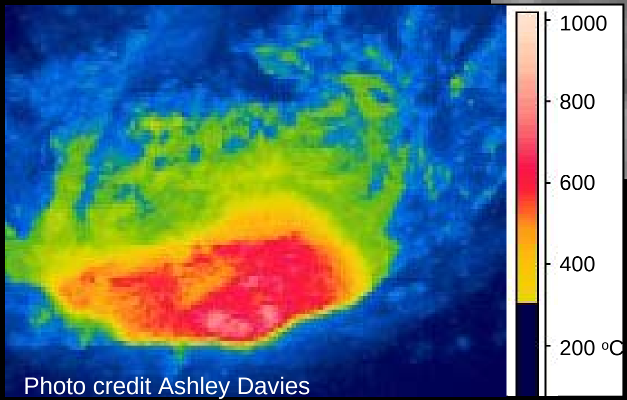
Monitoring Volcanic Thermal Emissions

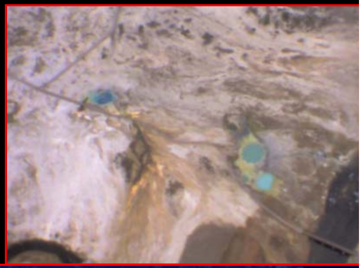
1) Background studies

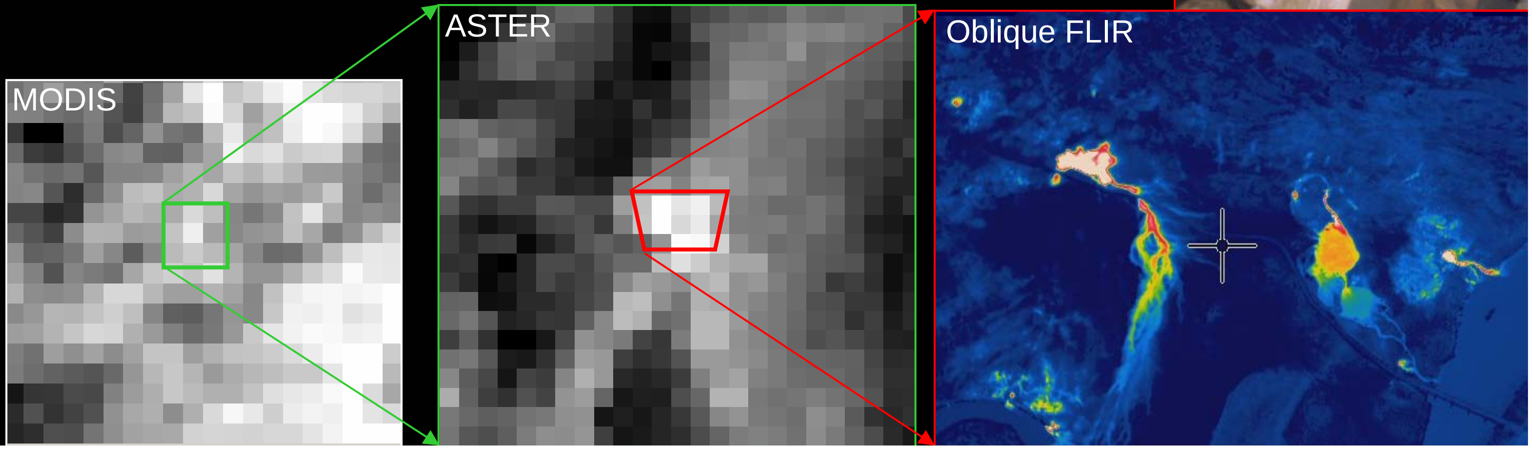
2) Monitoring on-going activity in near real-time / thermal anomaly alarms

3) **Sub-pixel thermal mixing**









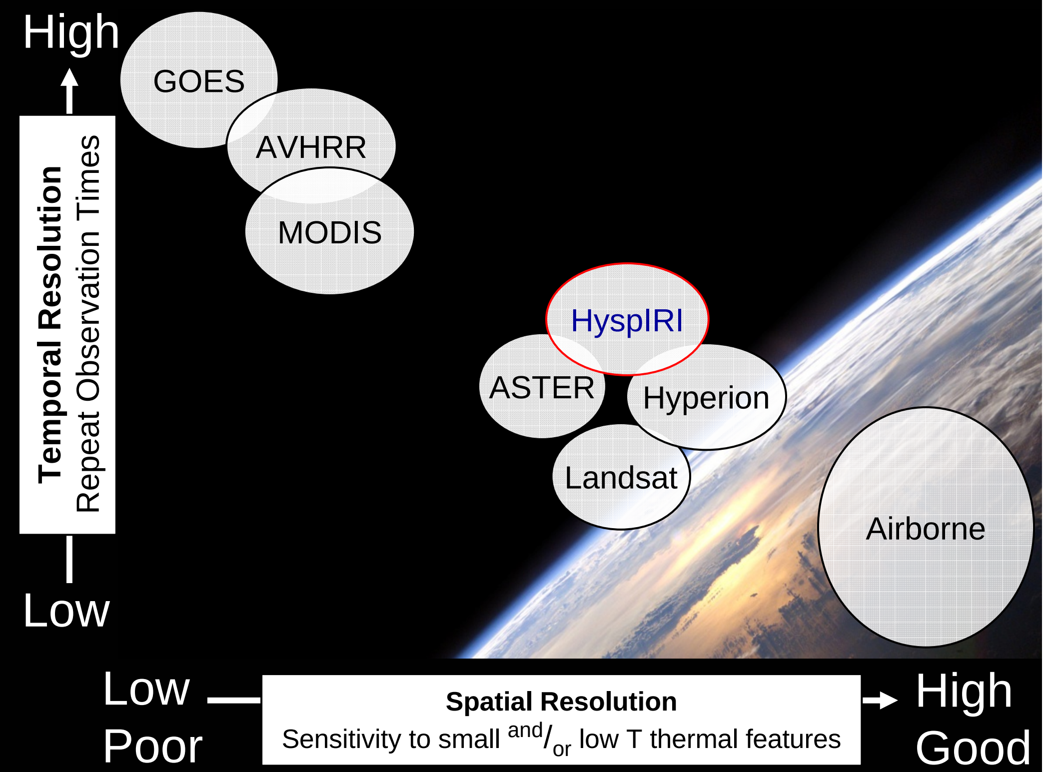
Measuring Volcanic Thermal Emissions

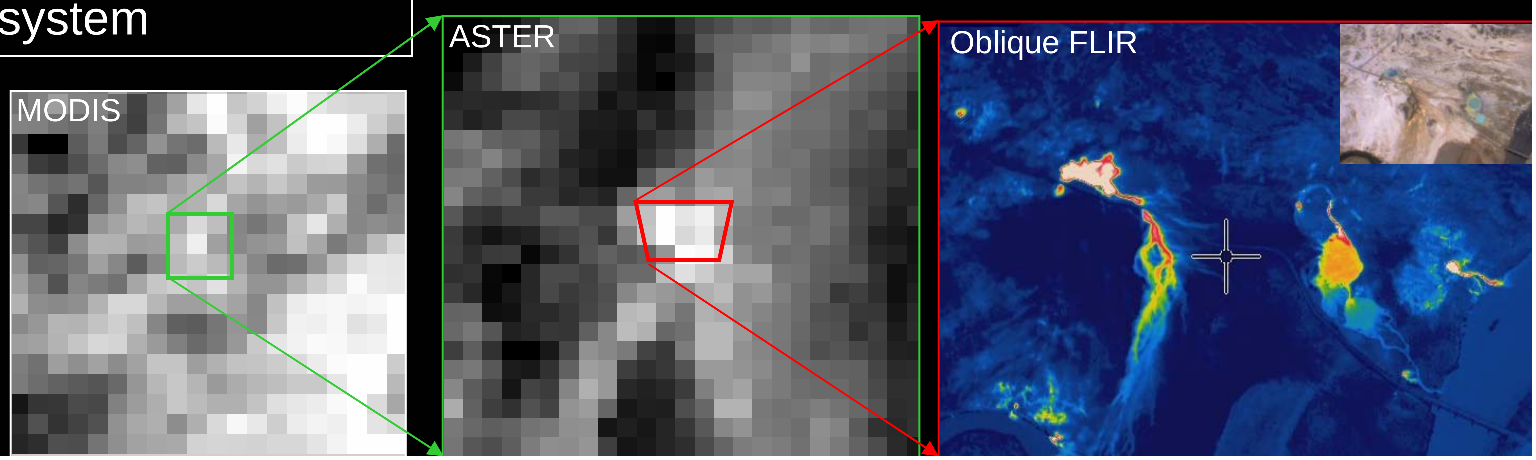
1) Trade-off between temporal and spatial resolution

2) Many thermal features are smaller than the pixels

3) Coarse resolution data necessarily miss some thermal features (that are too small or too cool)

4) Subtle thermal features are important in interpreting the activity of a volcanic / hydrothermal system



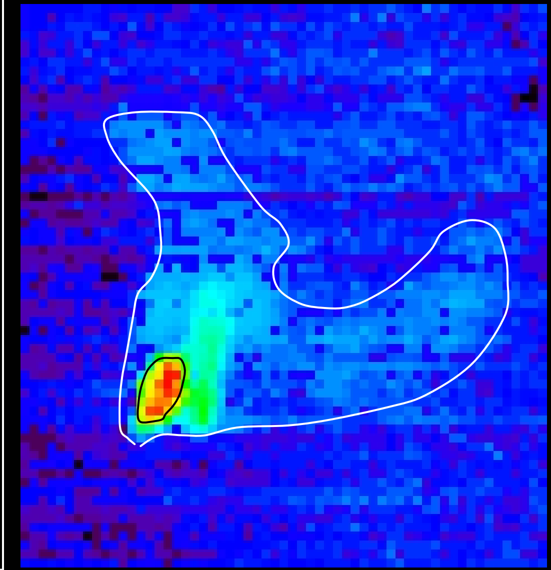


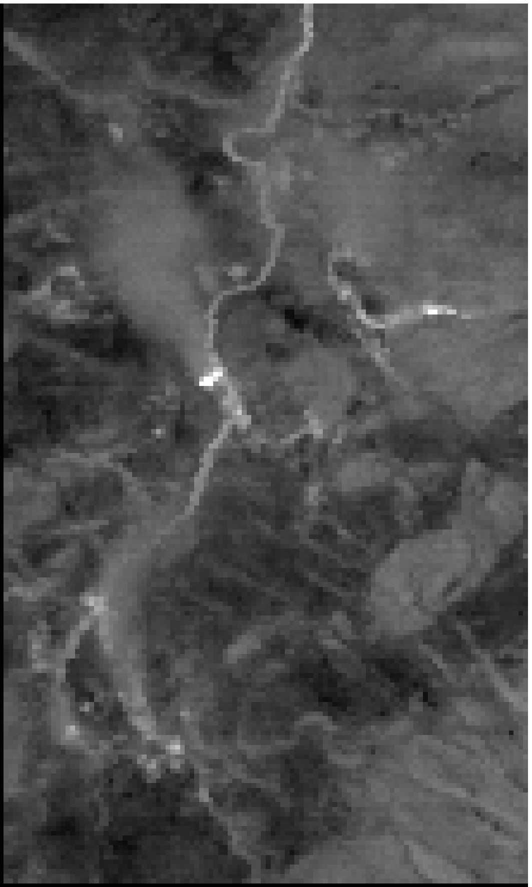
Volcanic Thermal Features

1) Vapor Features
   Vents/Fumaroles; Mud pots
   H_2O, CO_2, SO_2, H_2S

2) Water Features
   Geysers; Hot Springs/Pools; Crater Lakes; Thermal Sea Water; Melting Ice

3) Lava Features
   Lava Lakes; Lava Flows; Lava Domes; Lava Fountains; Pyroclastic Flows





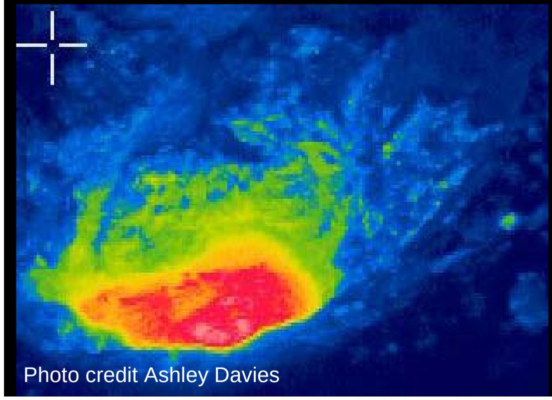
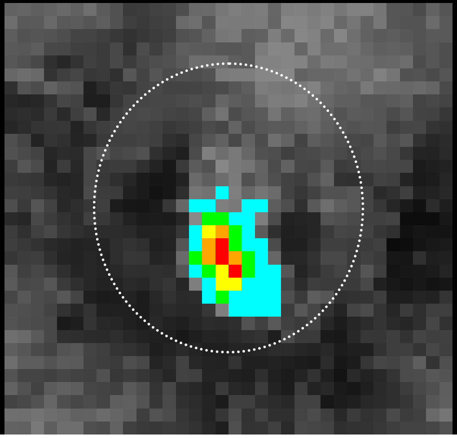
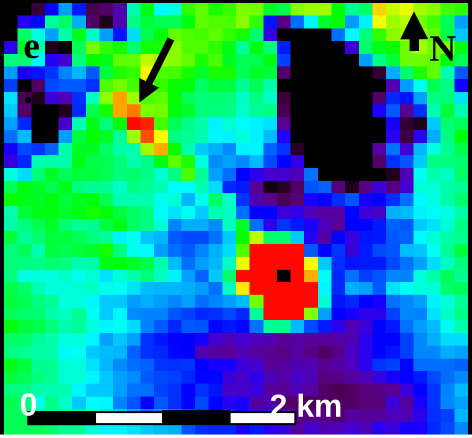


Photo credit Ashley Davies





Mount Erebus Volcano, Antarctica

Active lava lake

32 m across

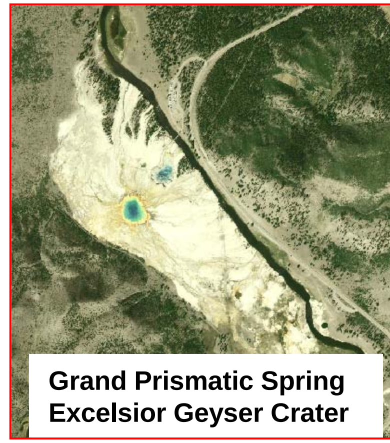
Max Temp = 783 ºC -- Avg Temp = 534 ºC

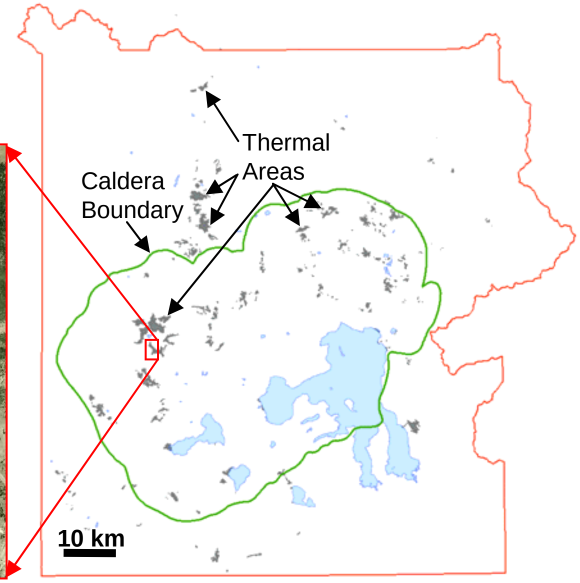
Yellowstone Geothermal Area, USA

Hot Spring Pools

10 – 90 m across

40 – 93 ºC



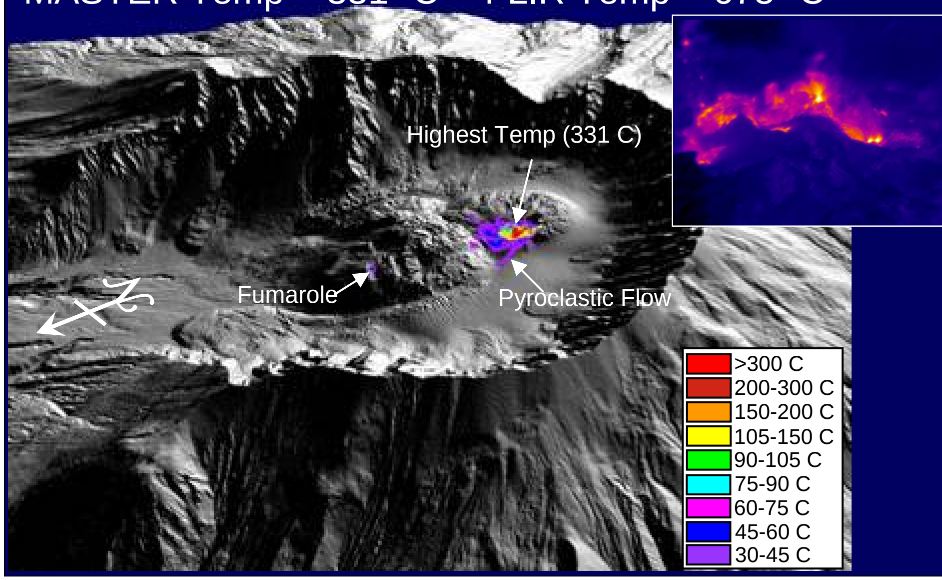


Mount St. Helens, USA

Lava Dome

600 m across

MASTER Temp = 331 ºC -- FLIR Temp = 675 ºC

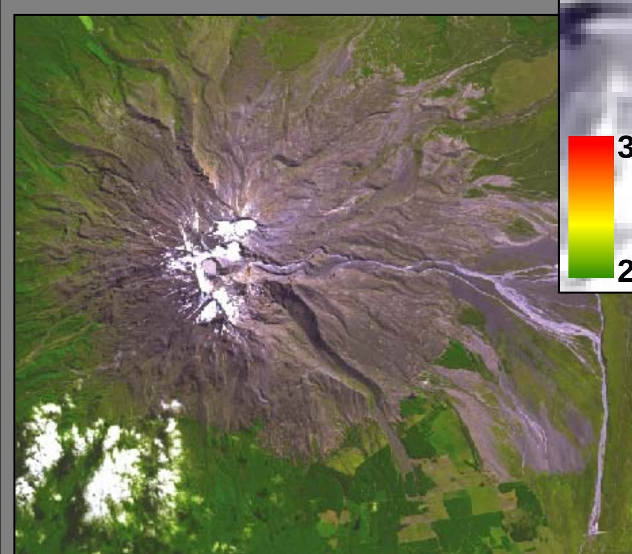


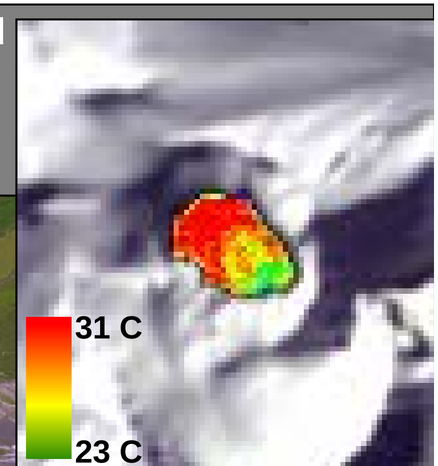
Mount Ruapehu, New Zealand

Crater Lake

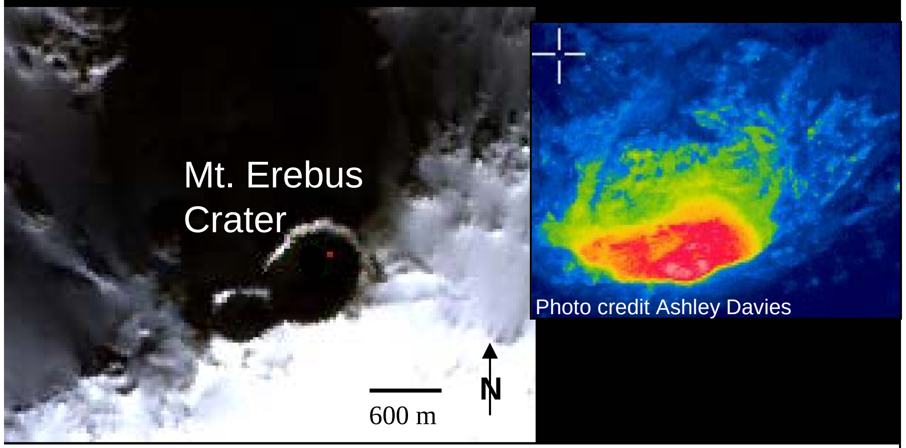
400 – 500 m across

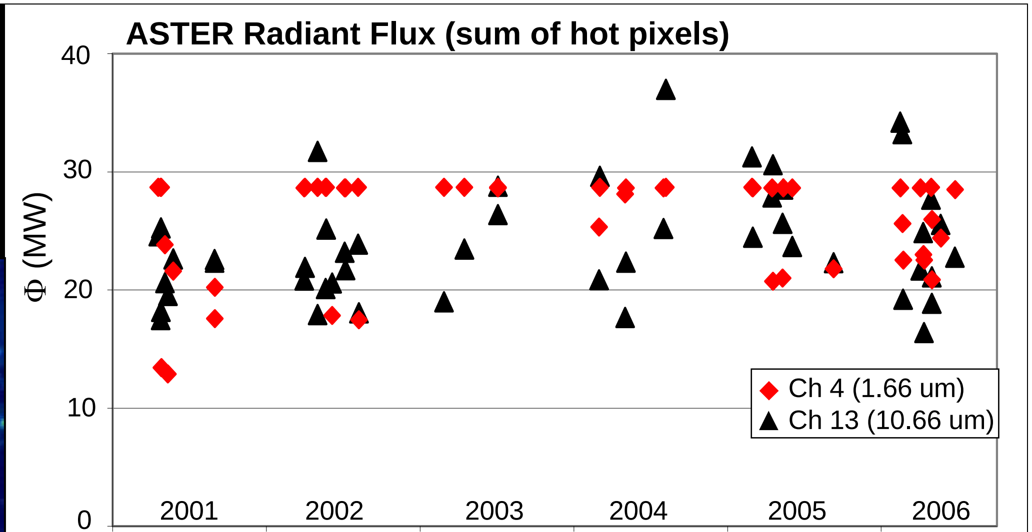
15 – 40 ºC

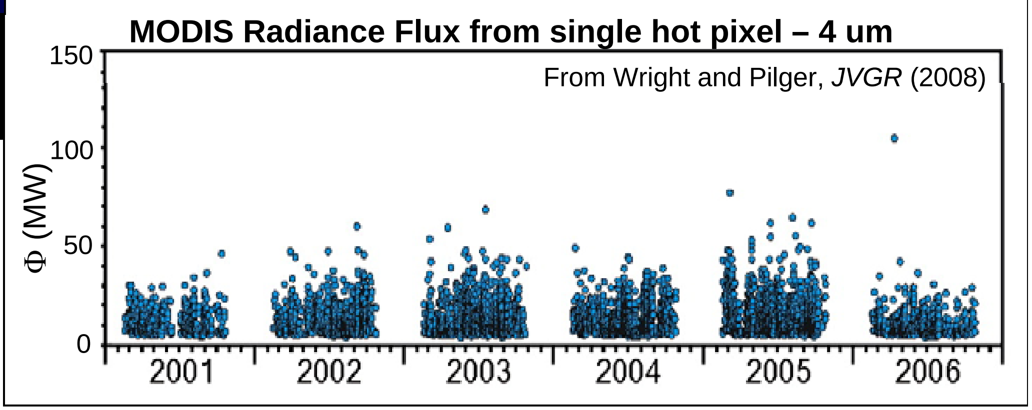




Mount Erebus Volcano, Antarctica
Active lava lake
32 m across
Max Temp = 783 °C -- Avg Temp = 534 °C



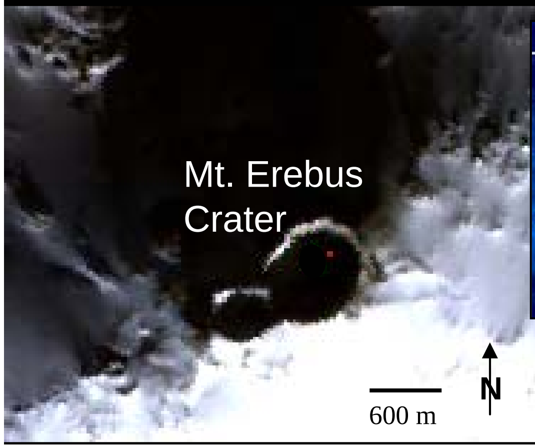


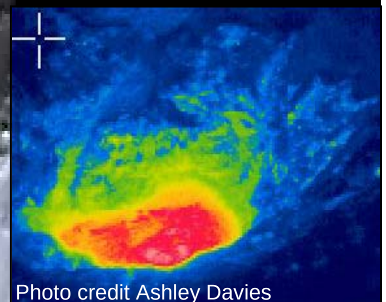


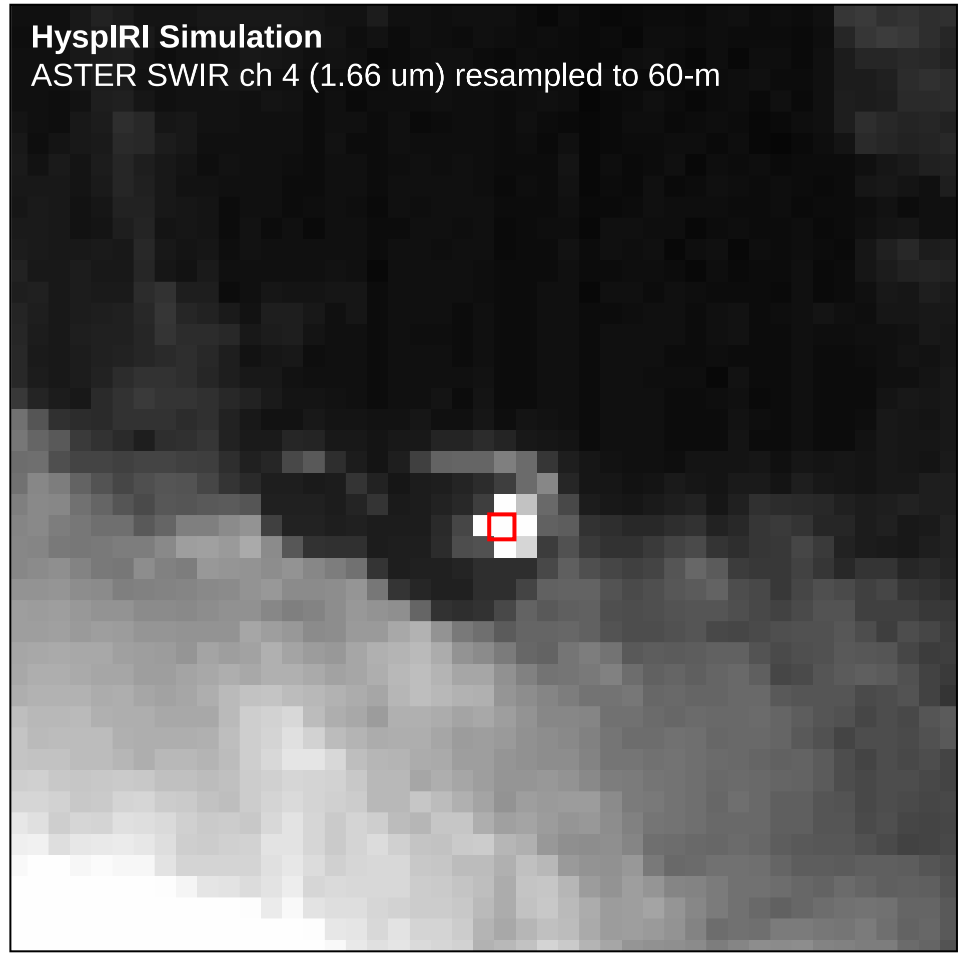
<u>HyspIRI Background Thermal Flux</u>

- Frequency of measurements will likely be better than this example of ASTER from Erebus (low latitude)
- Spatial resolution similar to ASTER class instruments = similar thermal flux measurements (need to sum multiple pixels)
- Sub-pixel issues / Saturation issues

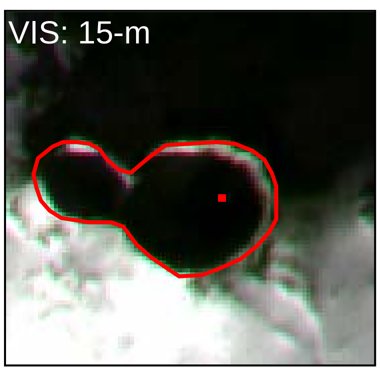
Mount Erebus Volcano, Antarctica
Active lava lake
32 m across
Max Temp = 783 °C -- Avg Temp = 534 °C

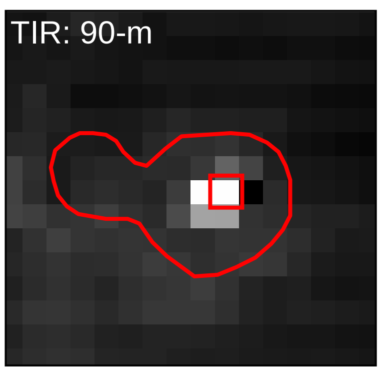


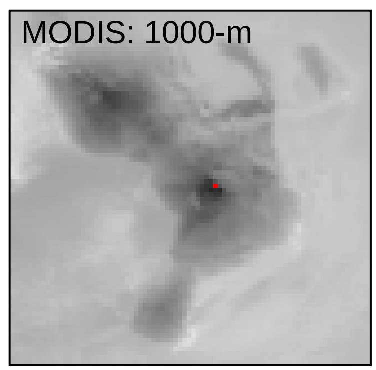




<u>ASTER TIR Dual-Band Sub-pixel Model (Dec 13, 2005)</u>
Single Hottest TIR Pixel = 93 °C
Avg Target Area = **5.2 % (421 m^2)**
Avg Target Temp = **512 ($^+$/- 75) °C**
Radiant Flux from Lake = **8.32 MW**
BG Temp = -15.8 °C

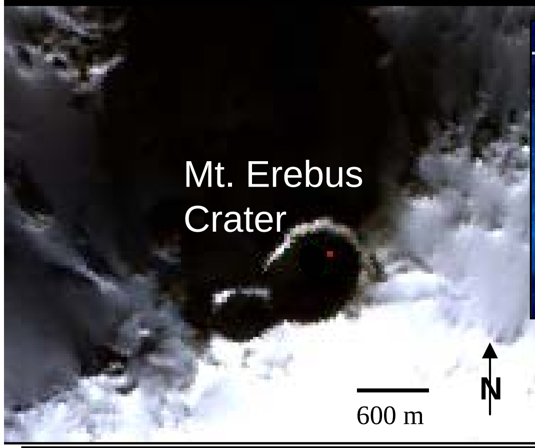






<u>MODIS MIR-TIR Dual-Band Sub-pixel Model (Dec 13, 2005)</u>
Hottest Pixel MIR (4 um) Temp = 55 °C
Hottest Pixel TIR (11 um) Temp = -16 °C
Avg Target Area = **0.15 % (1500 m^2)**
Avg Target Temp = **512 °C**
Radiant Flux from Lake = **30 MW**
BG Temp = -15.8 °C

Mount Erebus Volcano, Antarctica
Active lava lake
32 m across
Max Temp = 783 °C -- Avg Temp = 534 °C



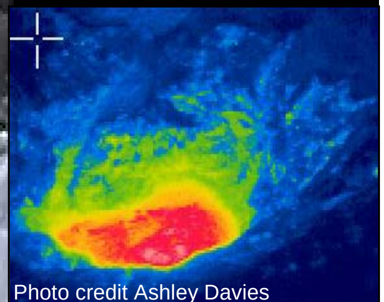
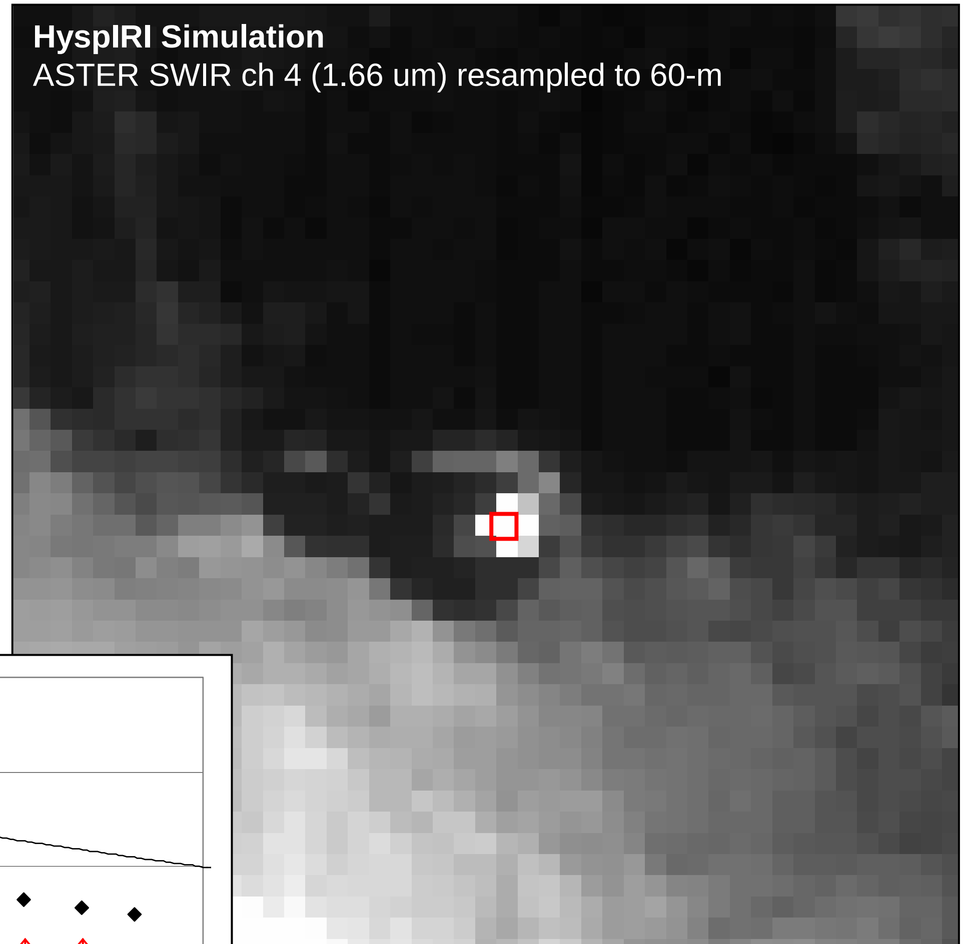
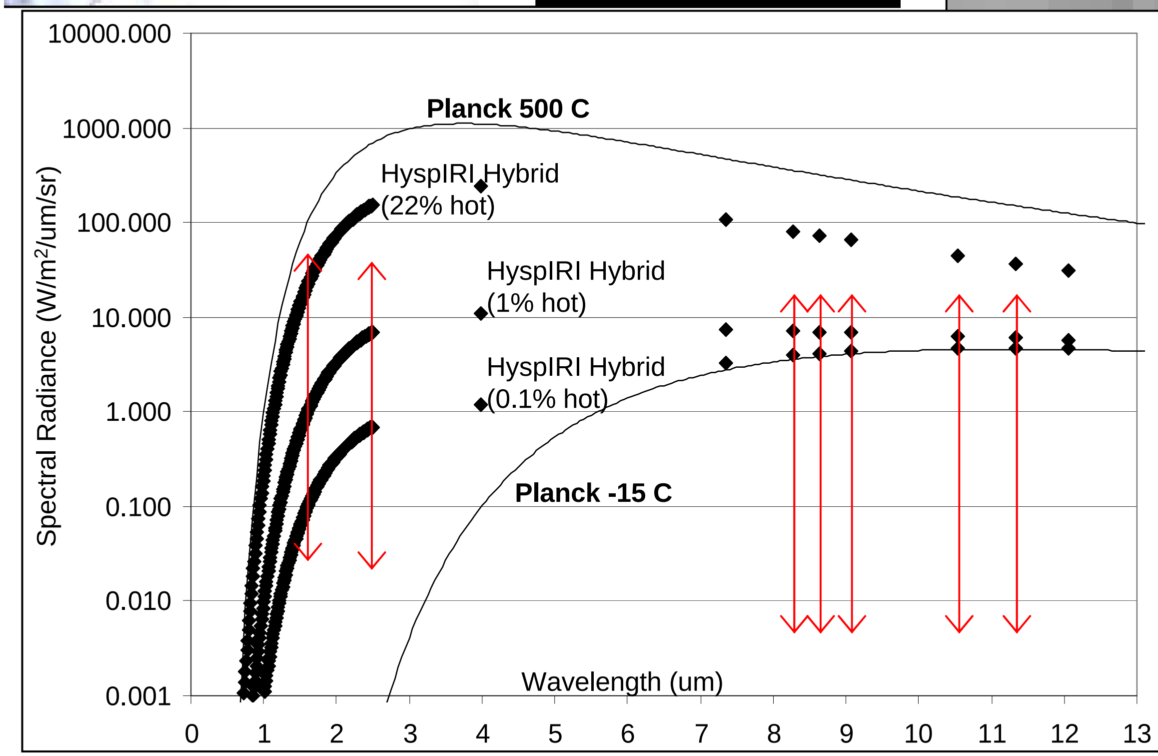


Photo credit Ashley Davies

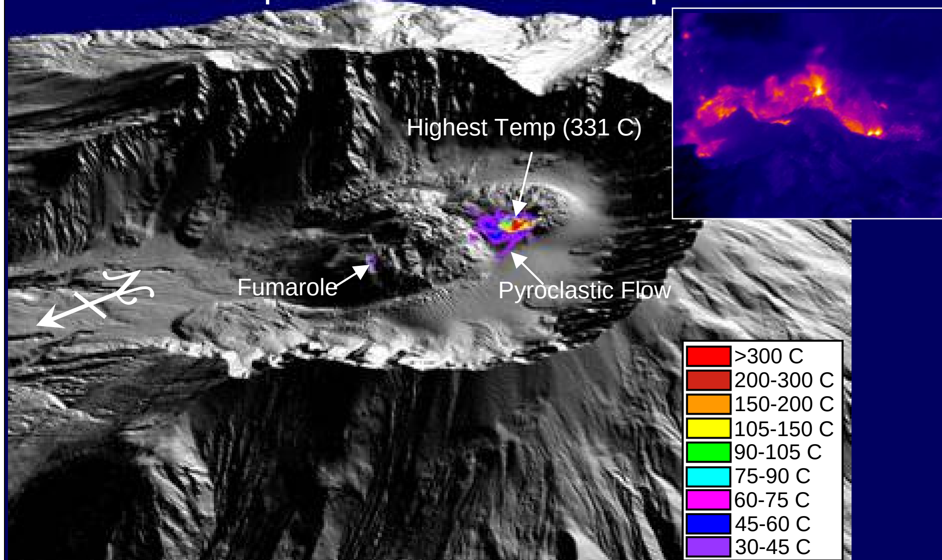




If the lava lake were contained in a single HyspIRI pixel (22% of pixel) it would be saturated at most wavelengths.

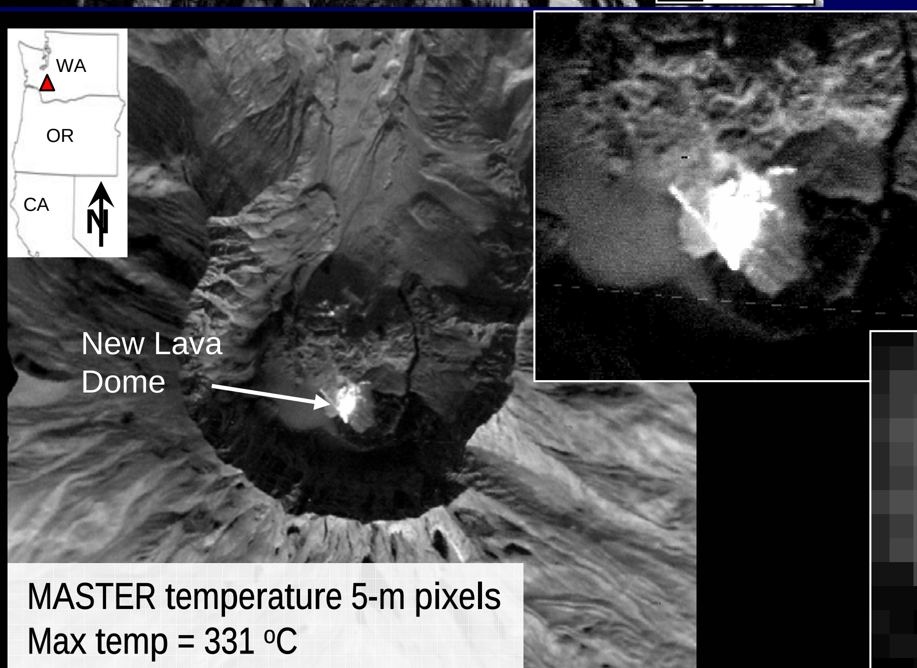
Measureable
Radiance
Range
(ASTER)

Mount St. Helens, USA
Lava Dome
600 m across
MASTER Temp = 331 °C -- FLIR Temp = 675 °C

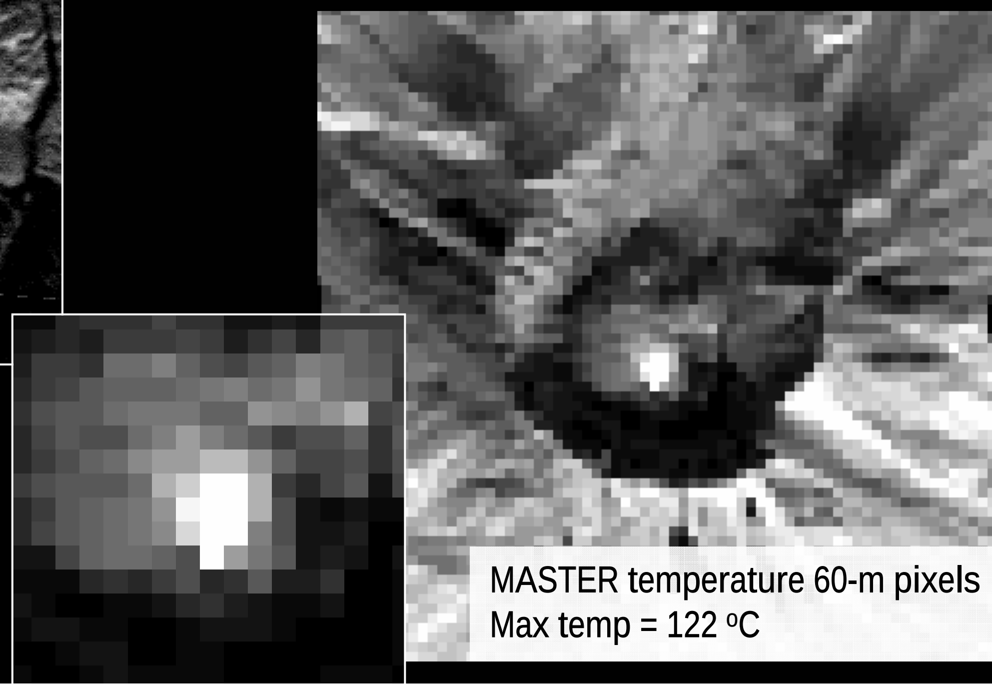


HyspIRI at Mount St. Helens

- Unable to resolve small, narrow spatial features like the 15-m wide pyroclastic flow
- Lower maximum temperature measured due to larger pixels, but thermal flux integrated over whole dome should be similar and should be able to resolve sub-pixel temperatures



MASTER temperature 5-m pixels
Max temp = 331 °C



MASTER temperature 60-m pixels
Max temp = 122 °C

Mount Ruapehu, New Zealand

Crater Lake

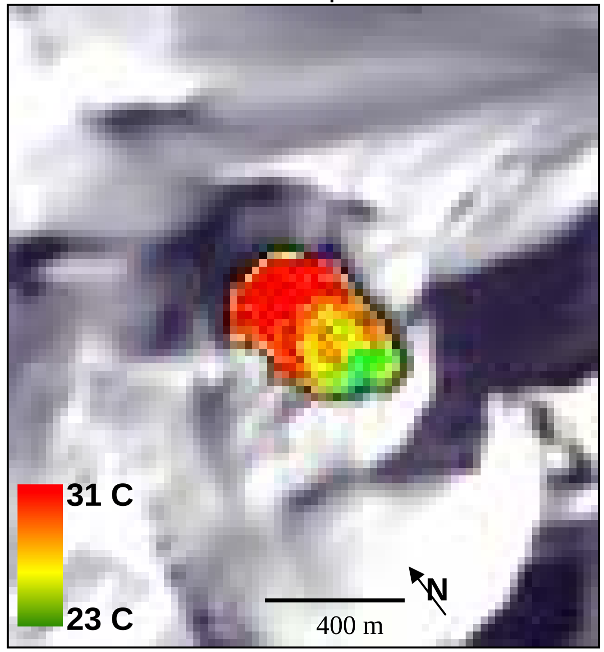
400 – 500 m across

15 – 40 ºC

MASTER Apr 14, 2003 (15-m pixels)

VIS background

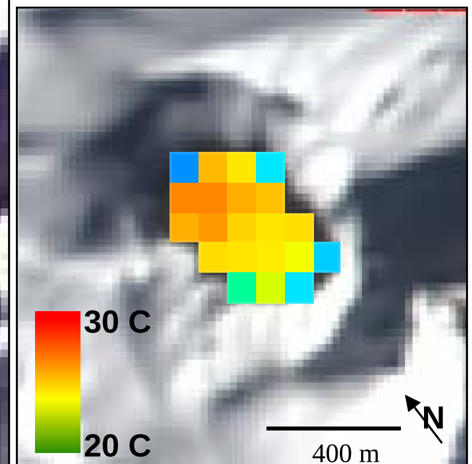
TIR Crater Lake Temps

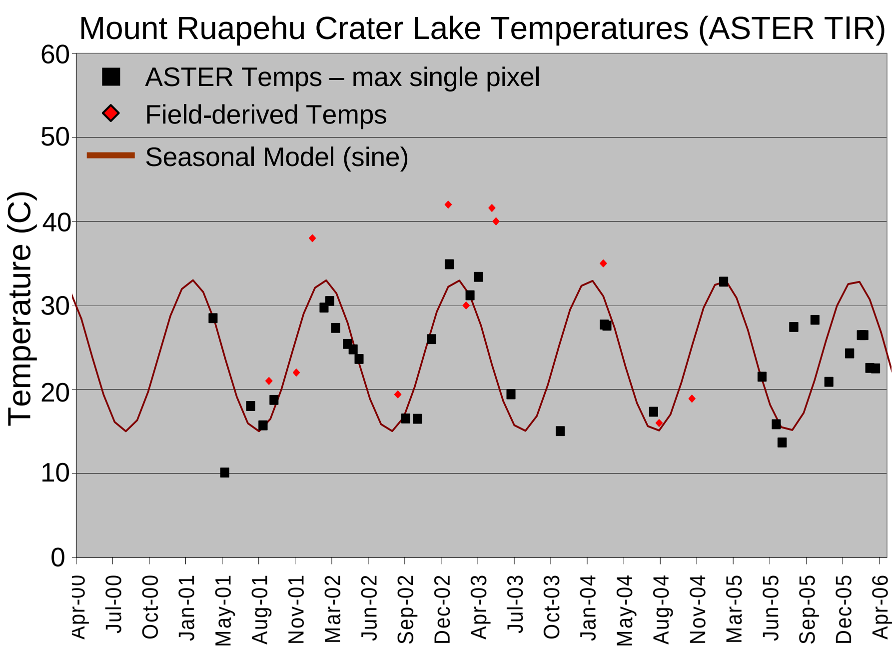


Resampled to 60-m pixels

VIS background

TIR Crater Lake Temps



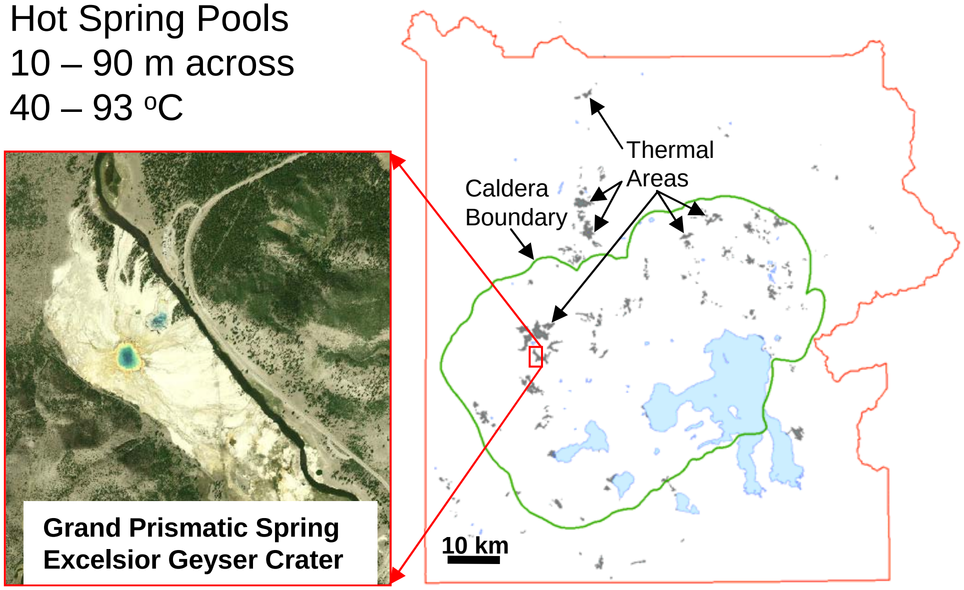


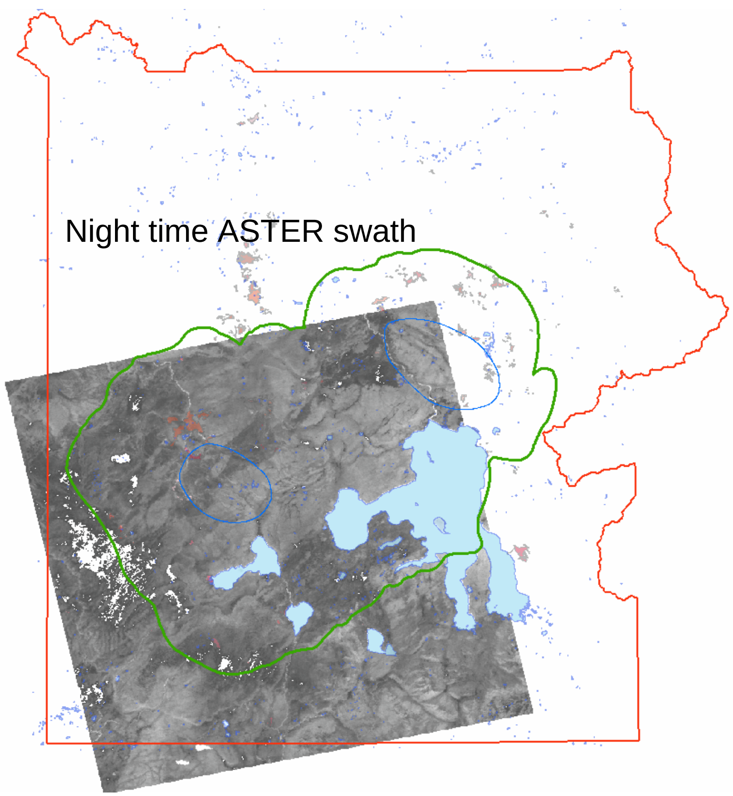
<u>HyspIRI at Mount Ruapehu</u>

- Unable to resolve fine spatial detail of thermal structure of crater lake.
- Max temperature measured over crater lake is comparable to same measurements with smaller pixels; total thermal flux should also be similar.
- More frequent measurements with HyspIRI = more dense time series for determining normal seasonal variations and anomalous thermal variations and less likely to miss thermal events.

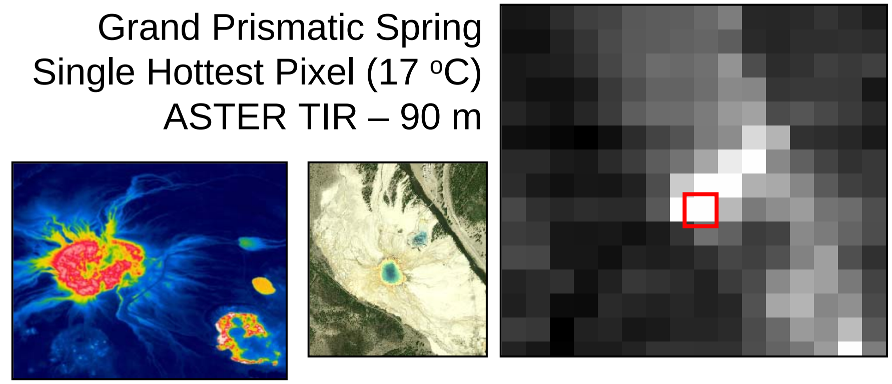
Yellowstone Geothermal Area, USA

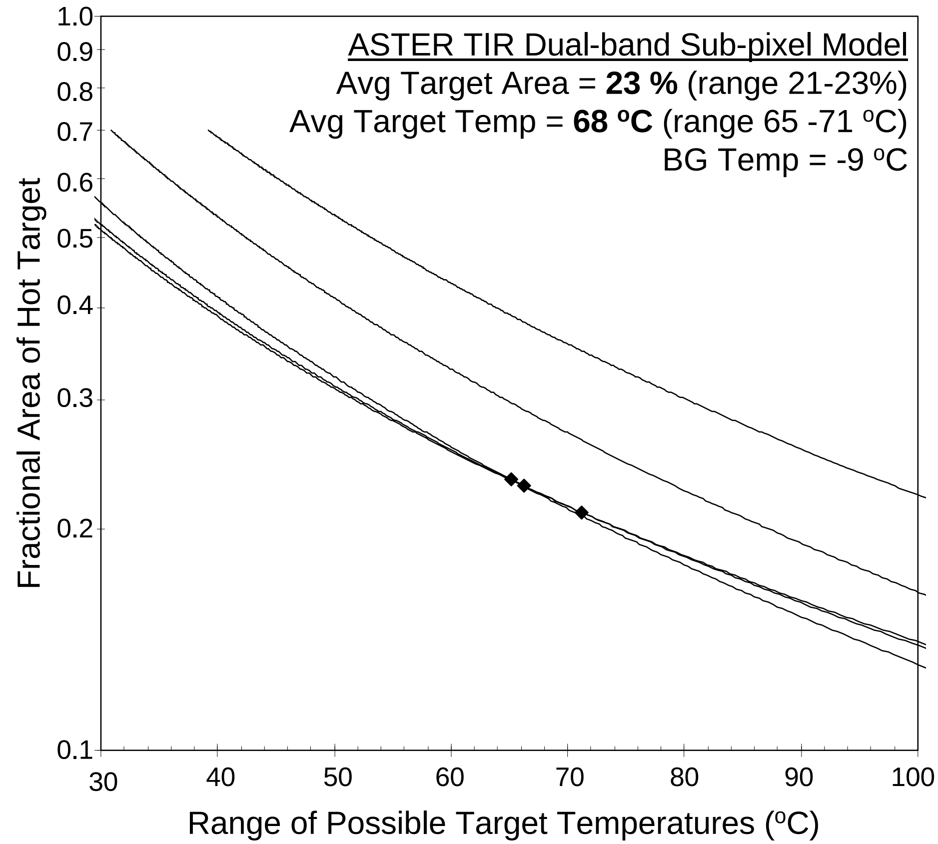
Hot Spring Pools
10 – 90 m across
40 – 93 ºC





Yellowstone
Grand Prismatic Spring
Single Hottest Pixel (17 ºC)
ASTER TIR – 90 m

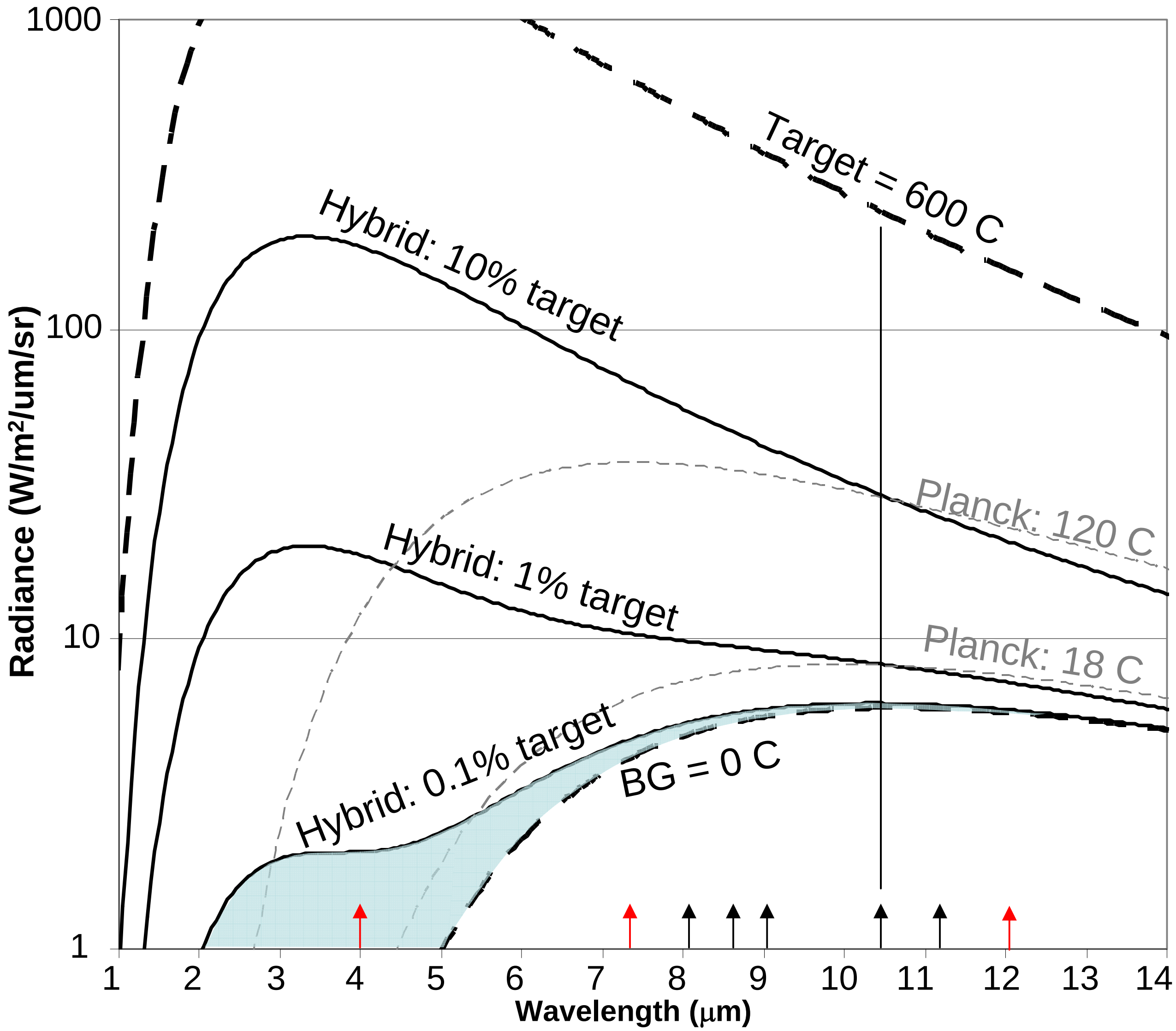


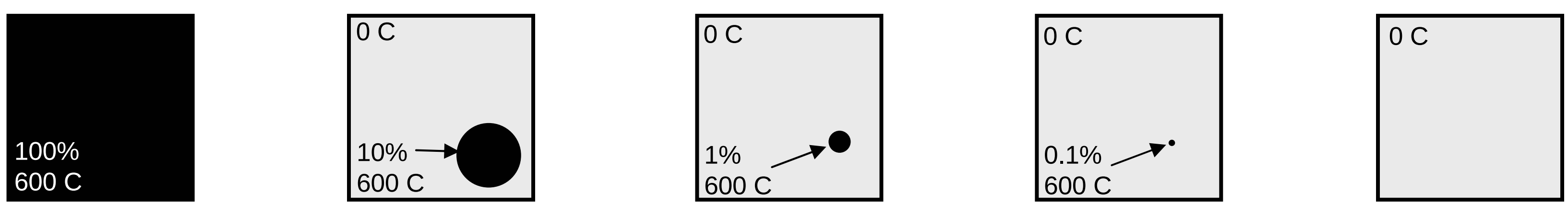


Saturation and Sub-pixel Thermal Mixing

1) How large does a hot sub-pixel feature, of a certain temperature, need to be to saturate a pixel?

2) How large does a hot sub-pixel feature, of a certain temperature, need to be to resolve a thermally mixed pixel?





ch13 Rad = 225 W/m²/um/sr
ch13 PIT = 600 C

ch13 Rad = 28 W/m²/um/sr
ch13 PIT = 120 C

ch13 Rad = 8.2 W/m²/um/sr
ch13 PIT = 18 C

ch13 Rad = 6.2 W/m²/um/sr
ch13 PIT = 2 C

ch13 Rad = 6.0 W/m²/um/sr
ch13 PIT = 0 C

Saturation and Sub-pixel Thermal Mixing

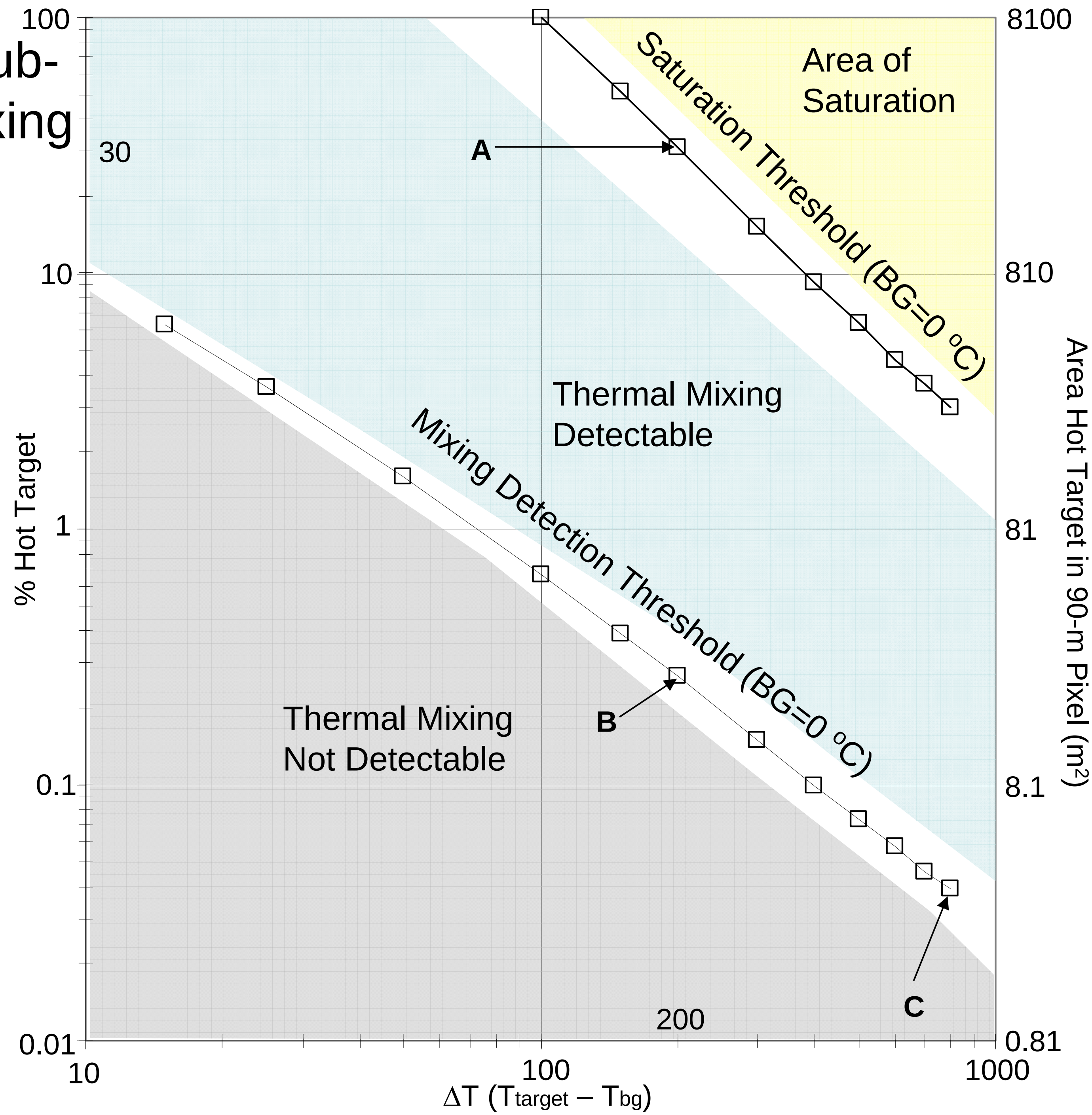
1) How large does a hot sub-pixel feature, of a certain temperature, need to be to saturate a pixel?

2) How large does a hot sub-pixel feature, of a certain temperature, need to be to resolve a thermally mixed pixel?

A – 30%

B – 0.27% (21 m²)

C – 0.04% (3 m²)



TAKE HOME POINTS

1) HyspIRI will be able to pick up where other sensors leave off in building time-series measurements of radiance, temperature, and thermal flux.

2) HyspIRI will fill an important niche in the temporal / spatial resolution trade-off – improving the capabilities of spaceborne thermal monitoring for rapid response to volcanic events, monitoring on-going eruptions, and increasing opportunities to forecast eruptions.

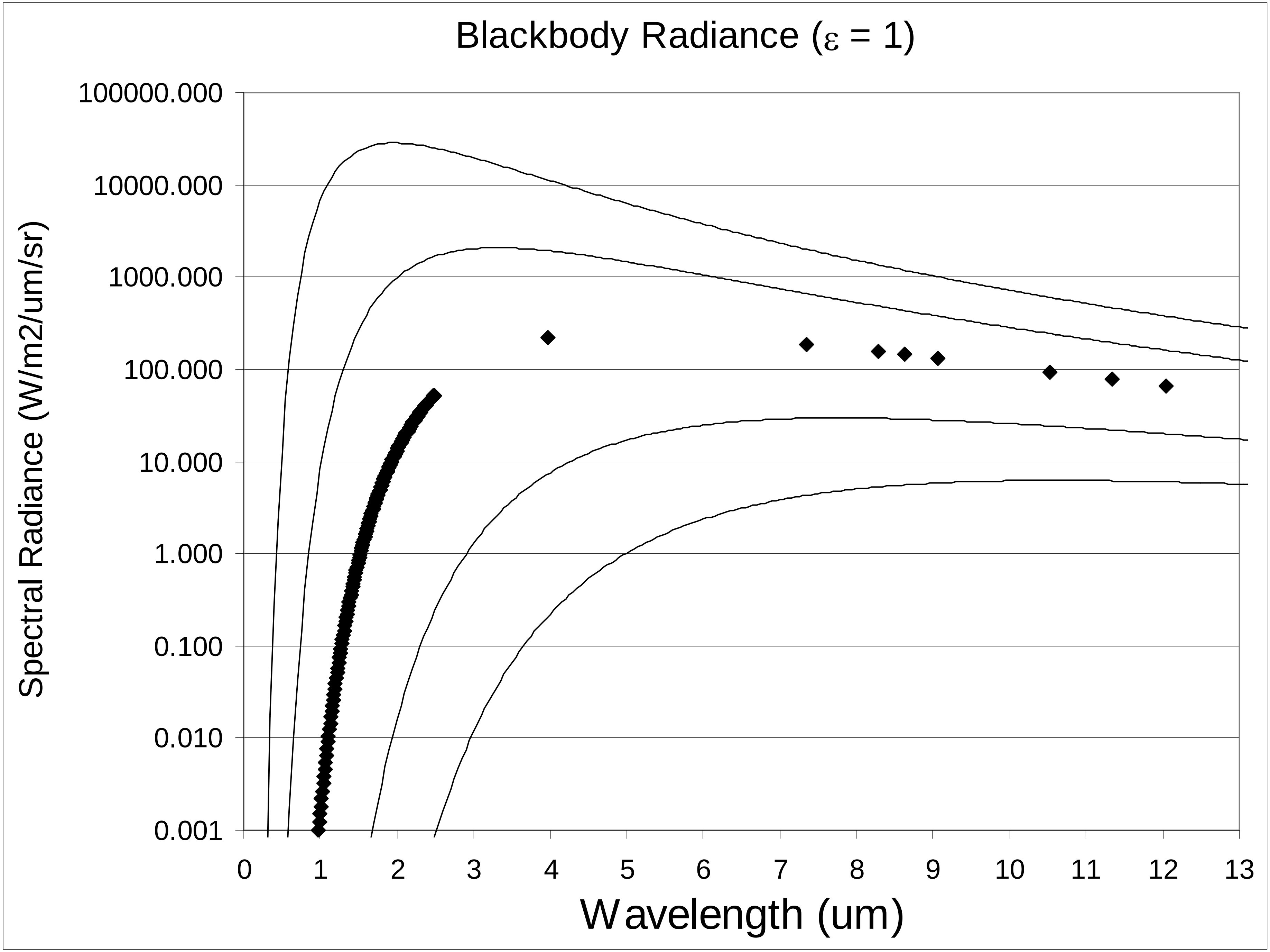
3) The wide spread in wavelength channels will improve sub-pixel thermal modeling as well as increase the sensitivity to a wide range of temperatures, pushing the limits of detection for subtle thermal features.

4) Let's make HyspIRI.

ACKNOWLEDGEMENTS and LOGOS

1) USGS Mendenhall Fellowship Program
2) USGS Volcano Hazards Program, AVO, CVO and YVO
3) National Park Service
4) NASA / Jet Propulsion Laboratory

Extras


Blackbody Radiance (ε = 1)
100000.000
10000.000
1000.000
100.000
10.000
1.000
0.100
0.010
0.001
Spectral Radiance (W/m2/um/sr)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Wavelength (um)