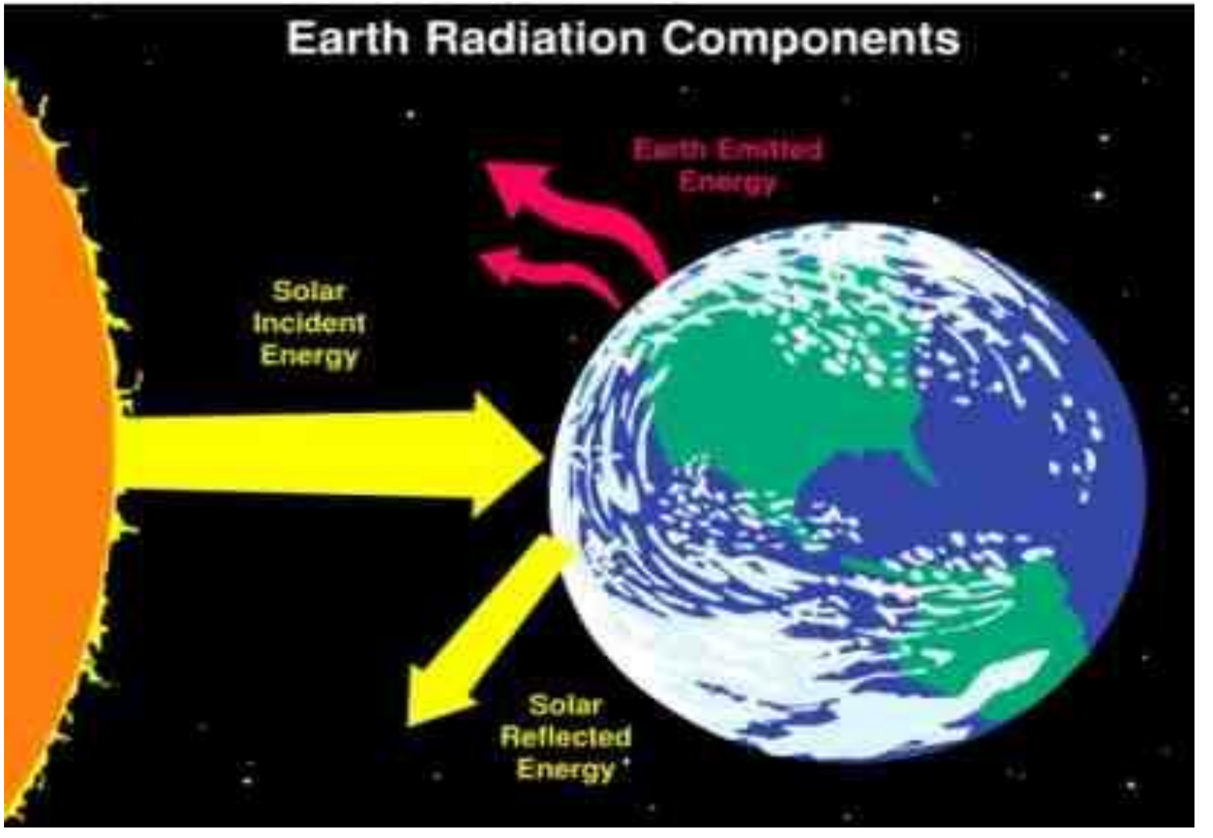
Thermal Infrared Remote sensing (3-14 microns)

Features of thermal RS:



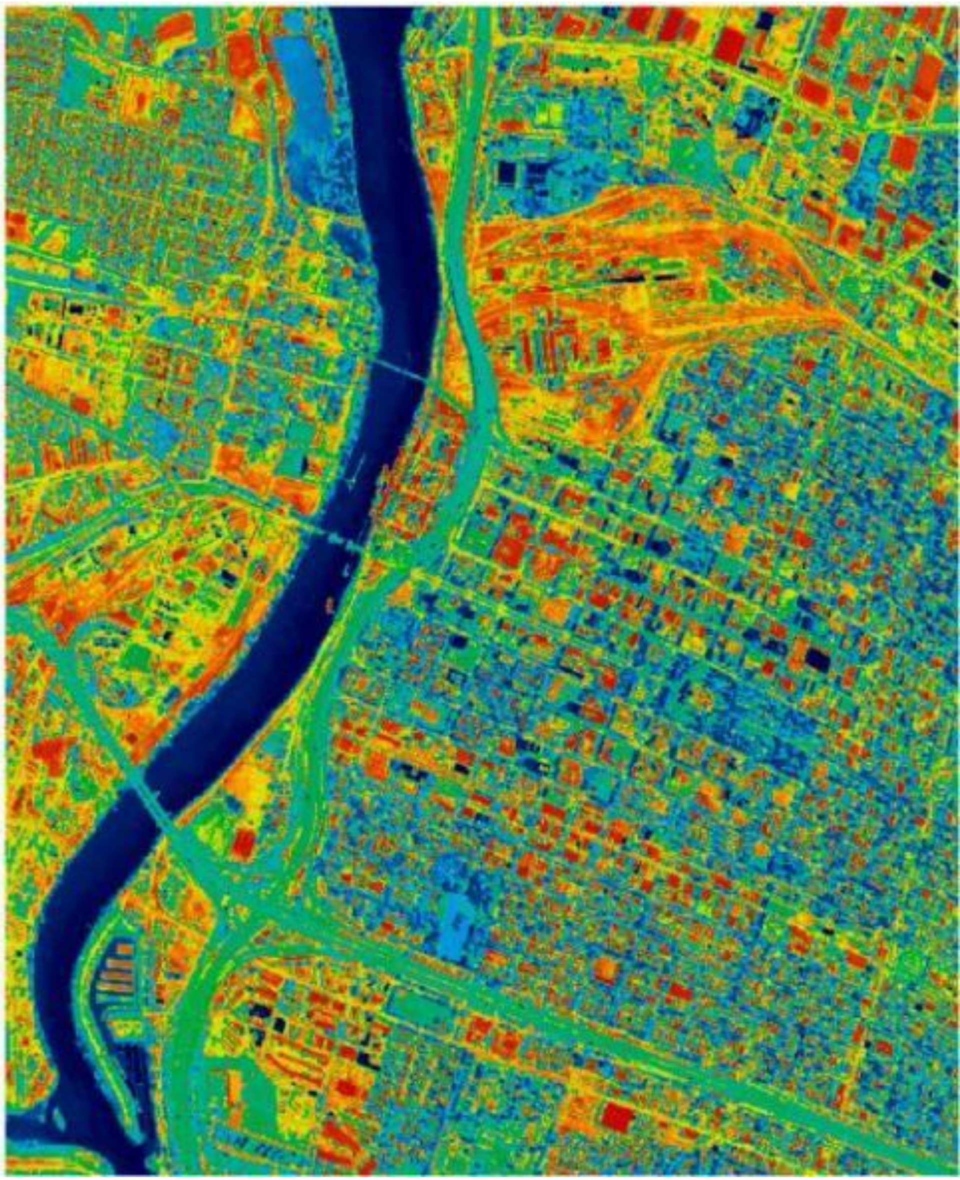
records longer wavelengths and a measure of temperature as it is emitted <u>NOT</u> reflected IR

- Works day / night (temperatures above 0 K = -273 Celsius)

Usually lower pixel resolution as there is less energy to capture

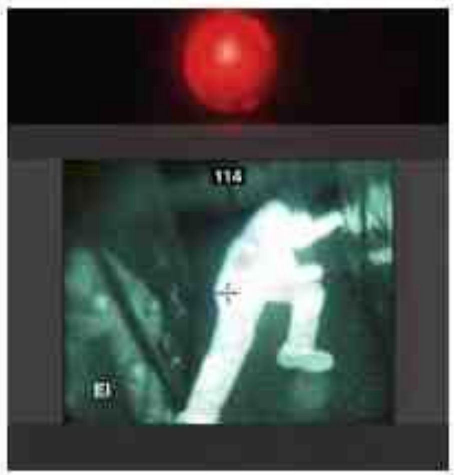
Normal colour and thermal images of Sacramento, CA

Colour composite in RGB



Thermal band in pseudocolour

Thermal Infrared (3-14 microns)



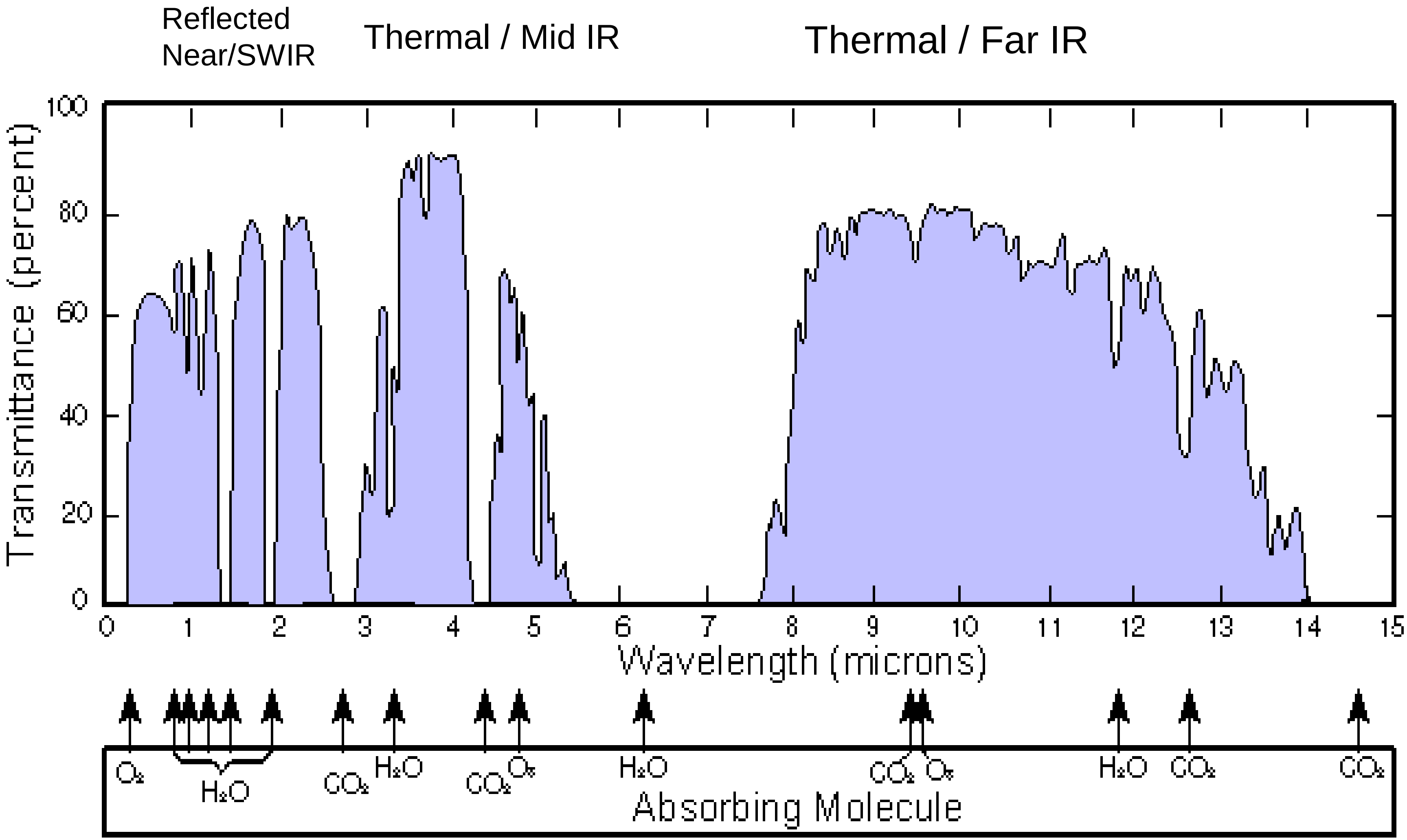
Thermal IR can 'see' through

haze and smoke - but not clouds

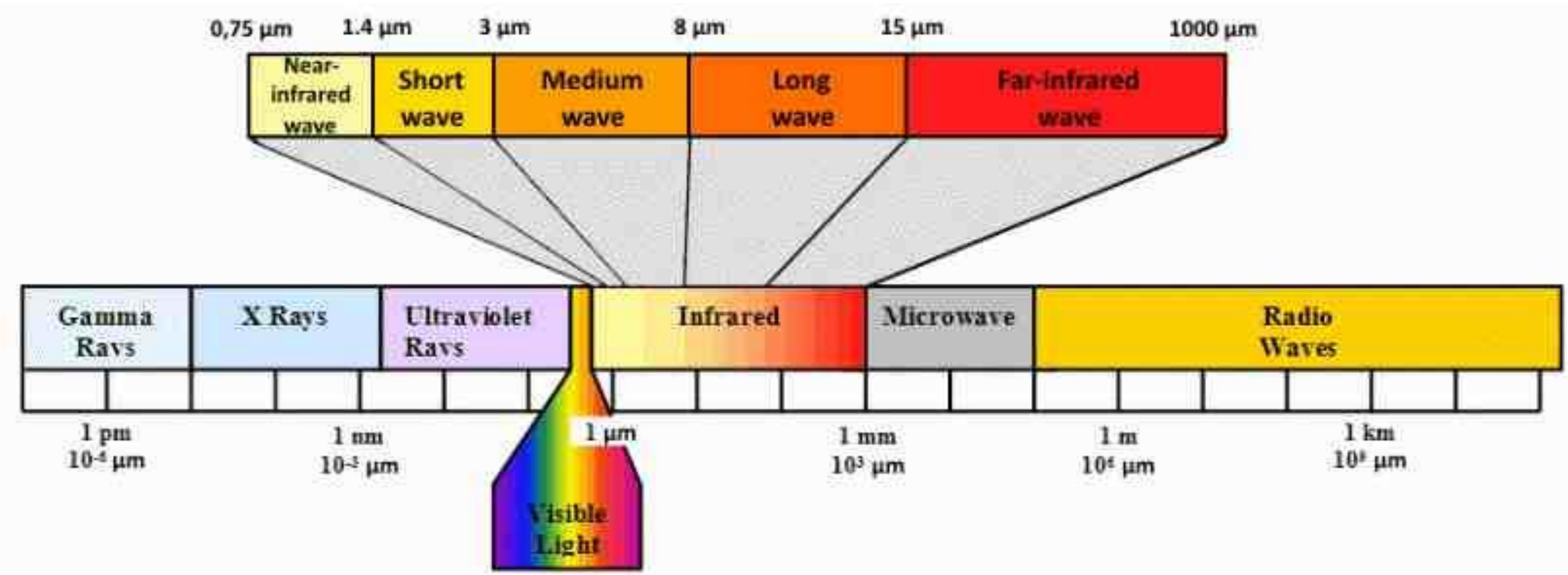
A comparison of a thermal image and an ordinary photograph. The plastic bag is mostly transparent to long-wavelength infrared, but the man's glasses are opaque.

1. Thermal Wavelengths (3-14 μm) windows:3-5,8-14

In 5 - 8 micrometres, energy is **absorbed by water vapour** in the atmosphere.



Bands NIR SWIR MIR TIR



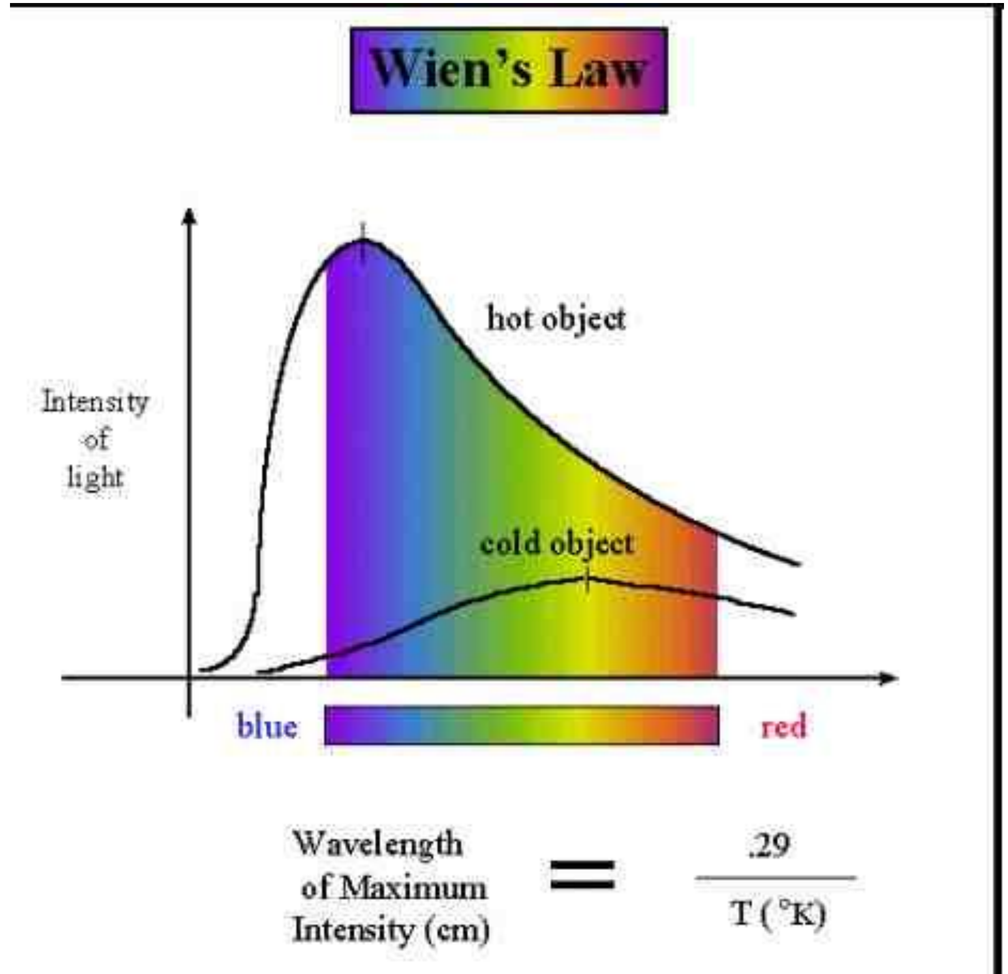
Visible, Near-IR/SWIR wavelengths are reflected and also absorbed by the earth's surface. Thermal IR is emitted terrestrial energy, absorbed from the sun and then emitted.

2. Wavelength & Temperature

.... All objects emit energy if their temperature is above 0 Kelvin (= -273C)

Wien's Law: the maximum emission of energy from a body occurs at a wavelength **inversely** proportional to its temperature

Named for Wilhelm Wien



Wavelength = 2898 /temp K (microns)

-> so earth radiates energy at longer wavelengths than the sun

Wien's Equation: max energy wavelength (micrometres)

= **2898 / Temperature (K)**

Earth (temp = 27°C = 300K) = 2898 / 300 = 9.5

(thermal IR/long)

Forest fire (temp = 600K) = 2898 / 600 = 4.8

(thermal IR / mid)

SUN (temp= 6000K) = 2898 / 6000 = 0.5

(green)

Energy in VNIR/SWIR is reflected solar energy
Energy in Mid/Far IR is emitted terrestrial energy
There is no solar energy beyond ~ 4.5 microns

3. Brightness Temperature (DN) & Emissivity

Emissivity = the relative power of a surface to emit heat by radiation.

It is the ratio of energy radiated by a particular material to the energy radiated by a 'black body' at the same temperature.

Brightness Temperature (DN) = emissivity x temperature ^{4}

i.e. Actual temperature = $\sqrt[4]{DN\ /\text{emissivity}}$

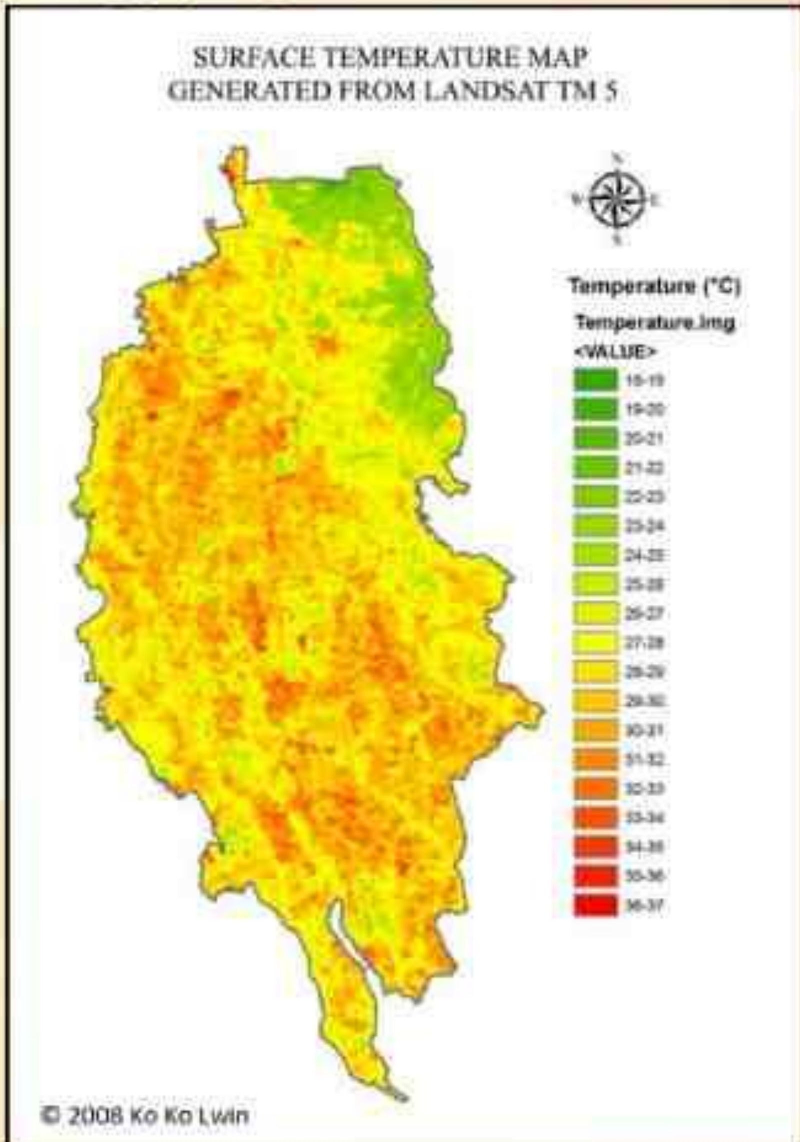
Sample emissivity values:

Water	0.99
Wet soil	0.95
Dry soil	0.92
Snow	0.85
Sand	0.76

Result: features with similar DNs may have different temperatures and vice versa ; we use an infrared thermal radiometer to 'ground truth' e.g. sea buoys

Converting thermal DN values to radiance → temperatures This could be a topic for advanced RS

3.3 Apply Algorithms *(continued)*



Step1. Conversion of the Digital Number (DN) to Spectral Radiance (L)

L = LMIN + (LMAX - LMIN) * DN / 255
Where
L = Spectral radiance
LMIN = 1.238 (Spectral radiance of DN value 1)
LMAX = 15.600 (Spectral radiance of DN value 255)
DN = Digital Number

Step2. Conversion of Spectral Radiance to Temperature in Kelvin

$$T_B = \frac{K_2}{\ln\left(\frac{K_1}{L} + 1\right)}$$

Where
K_1 = Calibration Constant 1 (607.76)
K_2 = Calibration Constant 2 (1260.56)
T_B = Surface Temperature

Step3. Conversion of Kelvin to Celsius

$T_B = T_B - 273$

Tsukuba City surface temperature map generated from Landsat TM5 satellite acquired by 1987-05-21, 11:00AM Local Time (JST)

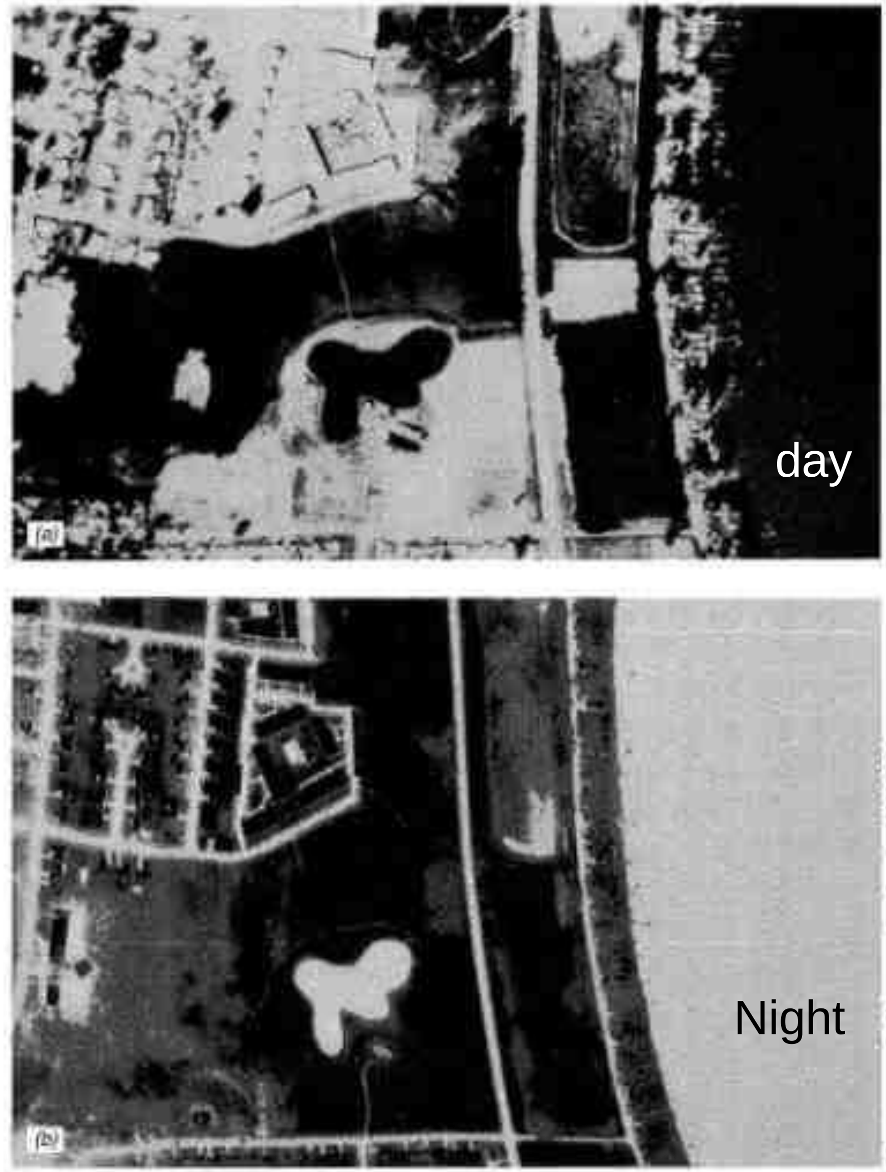
4. Thermal Capacity of Surfaces: the role of water

Thermal capacity determines how well a material stores heat. Water has a very high capacity

water heats up and cools down slowly, as it absorbs Visible / IR during the day and releases energy at night as thermal IR

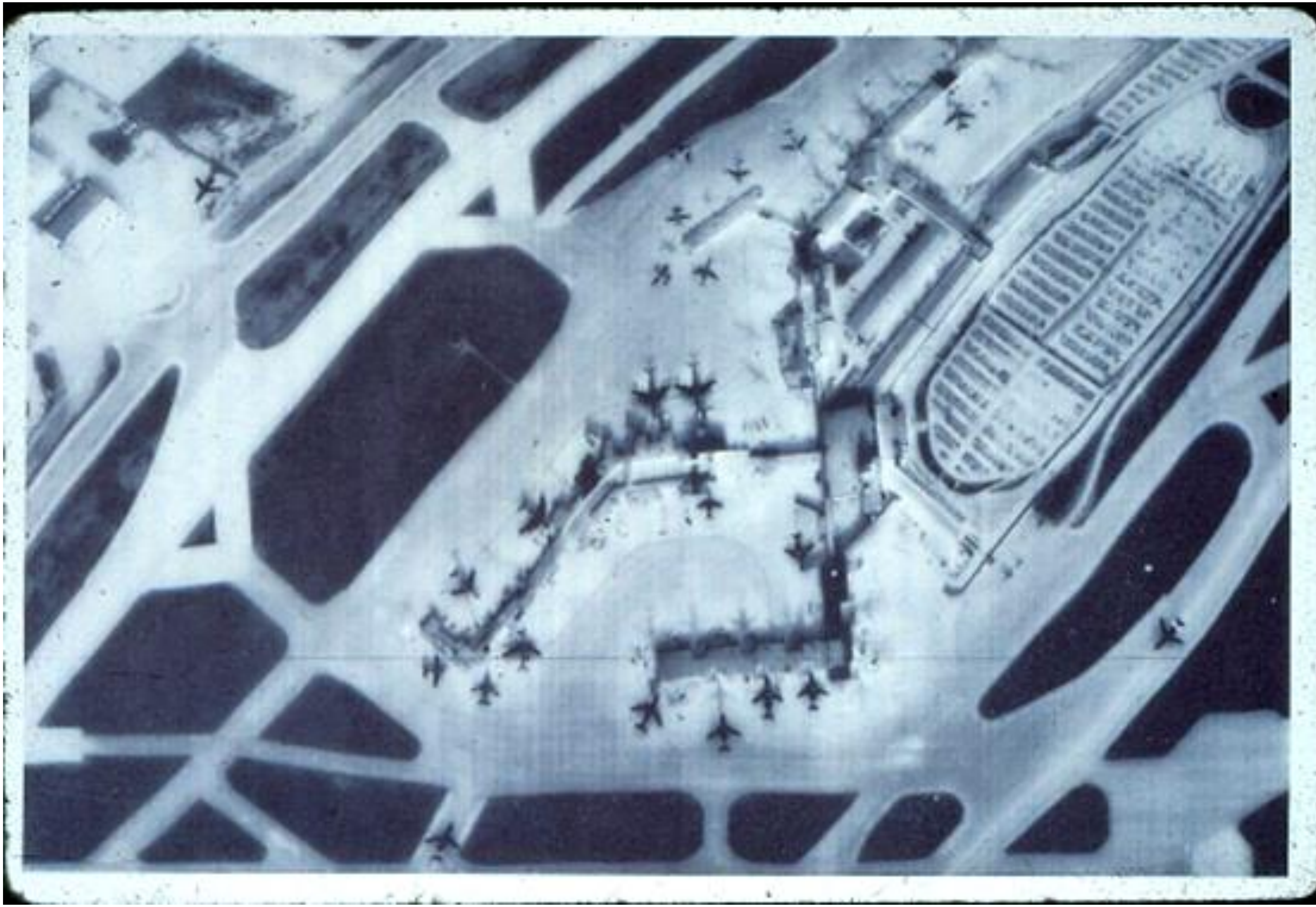
In temperate climates, water is warmer in winter than land surfaces and cooler in summer; and may be warmer at night than land and cooler during the day.

Diurnal Temperature Variation



Source: Lillesand et al. (2008)

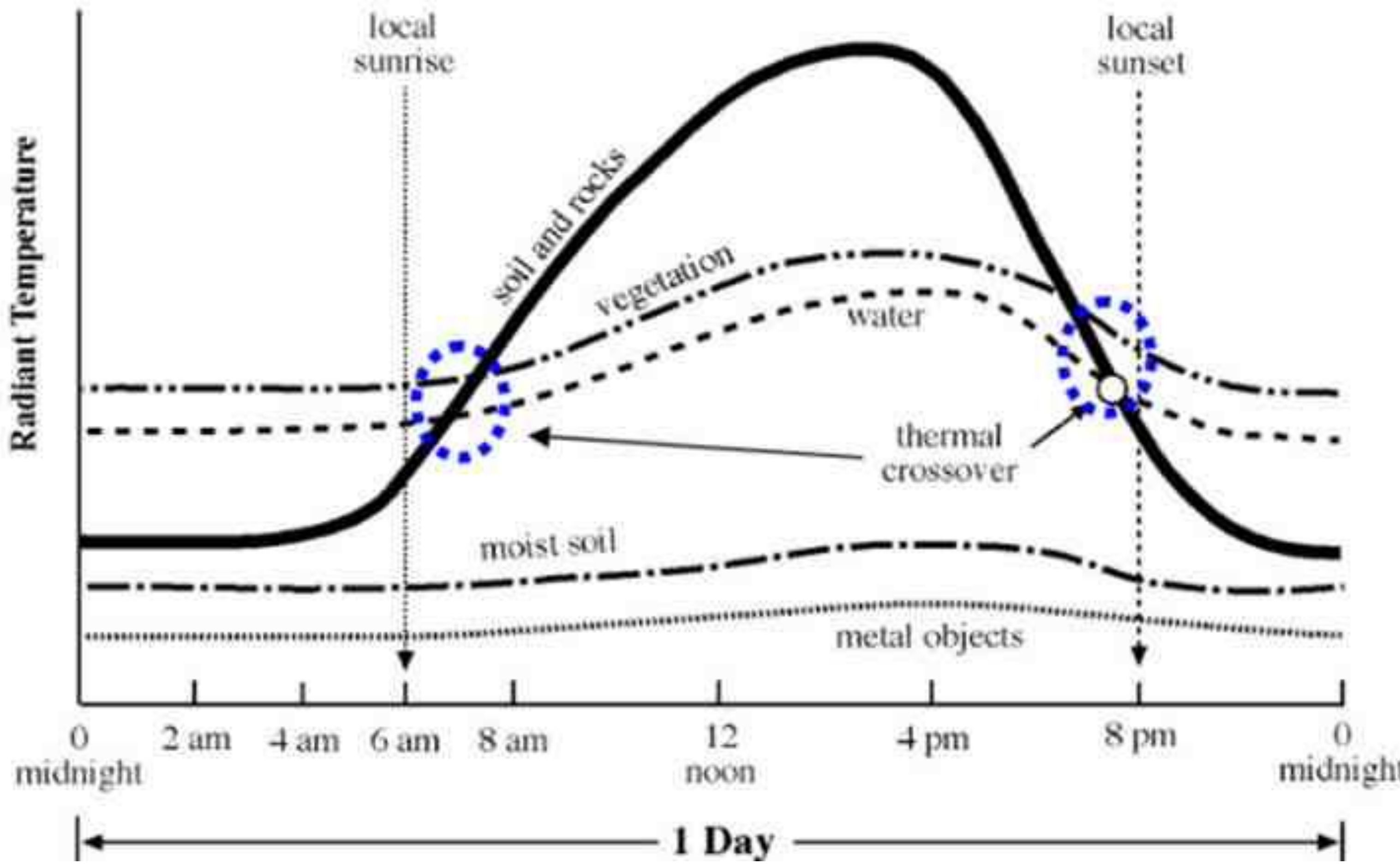
Dusseldorf airport thermal image



Daytime image - – note the ‘ghost’ plane shadows

Diurnal variation – and thermal crossovers

The diurnal or seasonal times when land and water are equal in temperature and scanned images show least contrast. Such '**crossover** periods ' should be avoided in thermal sensing.



Practical considerations in thermal remote sensing

- Lower thermal wavelengths can get mixed with the small amount of reflected solar energy (3-5 microns).

- Night-time is preferred to avoid shadowing (topographic / clouds) and solar heating.

- The larger the pixel area, the finer temperature differences can be detected. .... Temperature resolution can be as fine as 0.1° C.

- pixel size is larger (courser resolution), than for reflected bands .... as there is less energy to capture (only outgoing radiation)

Landsat thermal bands

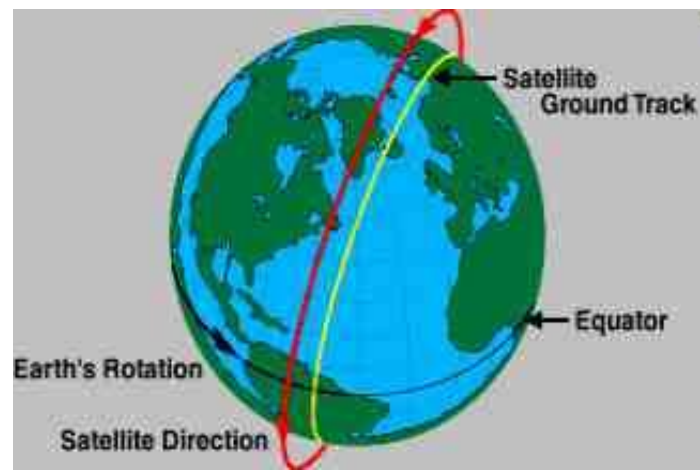
Landsat thermal bands are affected by:

- low radiance = reduced DN range (60-120m pixels)
- shadows (10.30am)
- recent moisture
- it is mostly daytime so not ideal for thermal remote sensing

– except for 'ascending orbit' on the 'dark side of the earth'

Sensors, wavelength, resolution:

Landsat 4/5 TM:	10.45-12.4	120m
Landsat 7 ETM+:	10.31-12.46	60m
Landsat 8 (2013):	10.3-11.3; 11.5-12.5	100m
Landsat 9 (2021):	10.6-11.2; 11.5-12.5	100m



Sun-synchronous orbit

Prince George Landsat 5 TM Band 6 - thermal-IR

‘Brightness temperature’ – related to surface thermal qualities

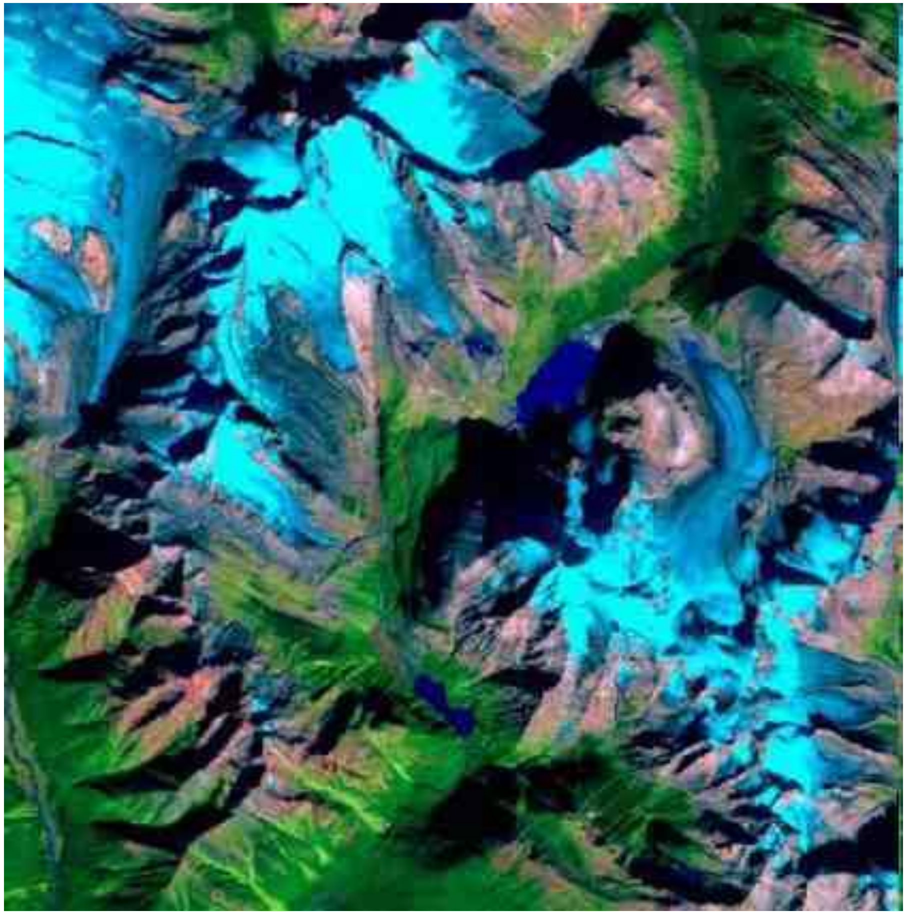
Thermal characteristics Mt. Robson, TM 543 composite/ thermal band 6

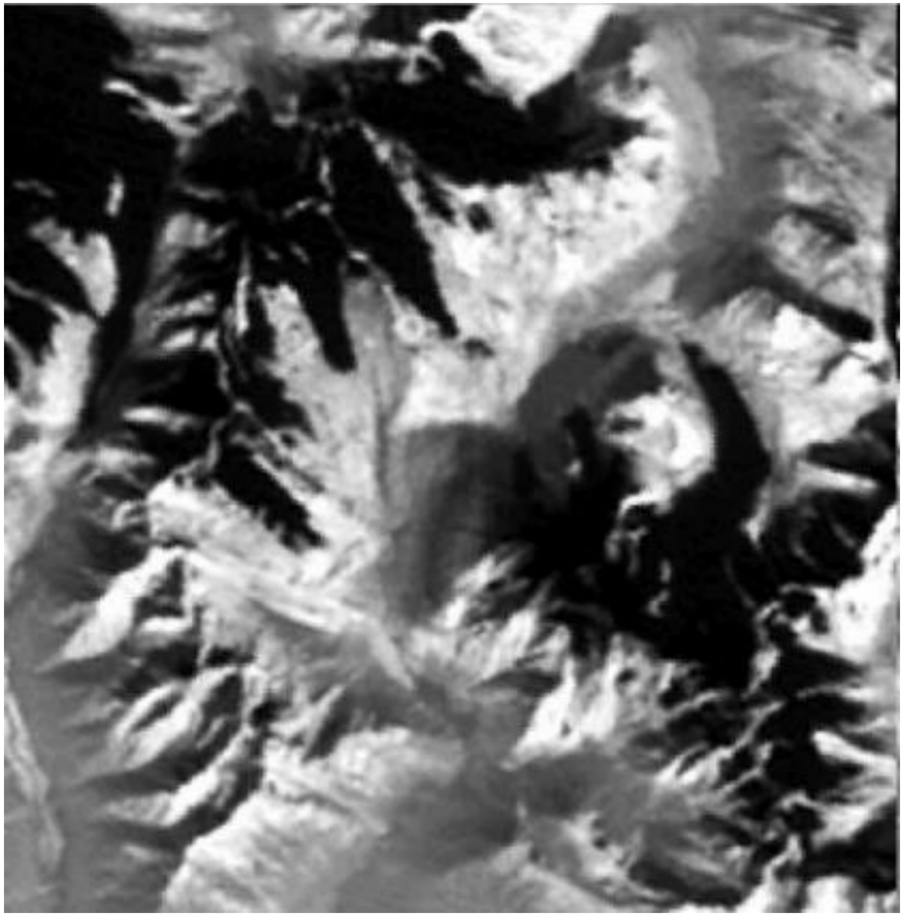
Water cooler (darker) during day, but reversed at night .. due to heat transfer

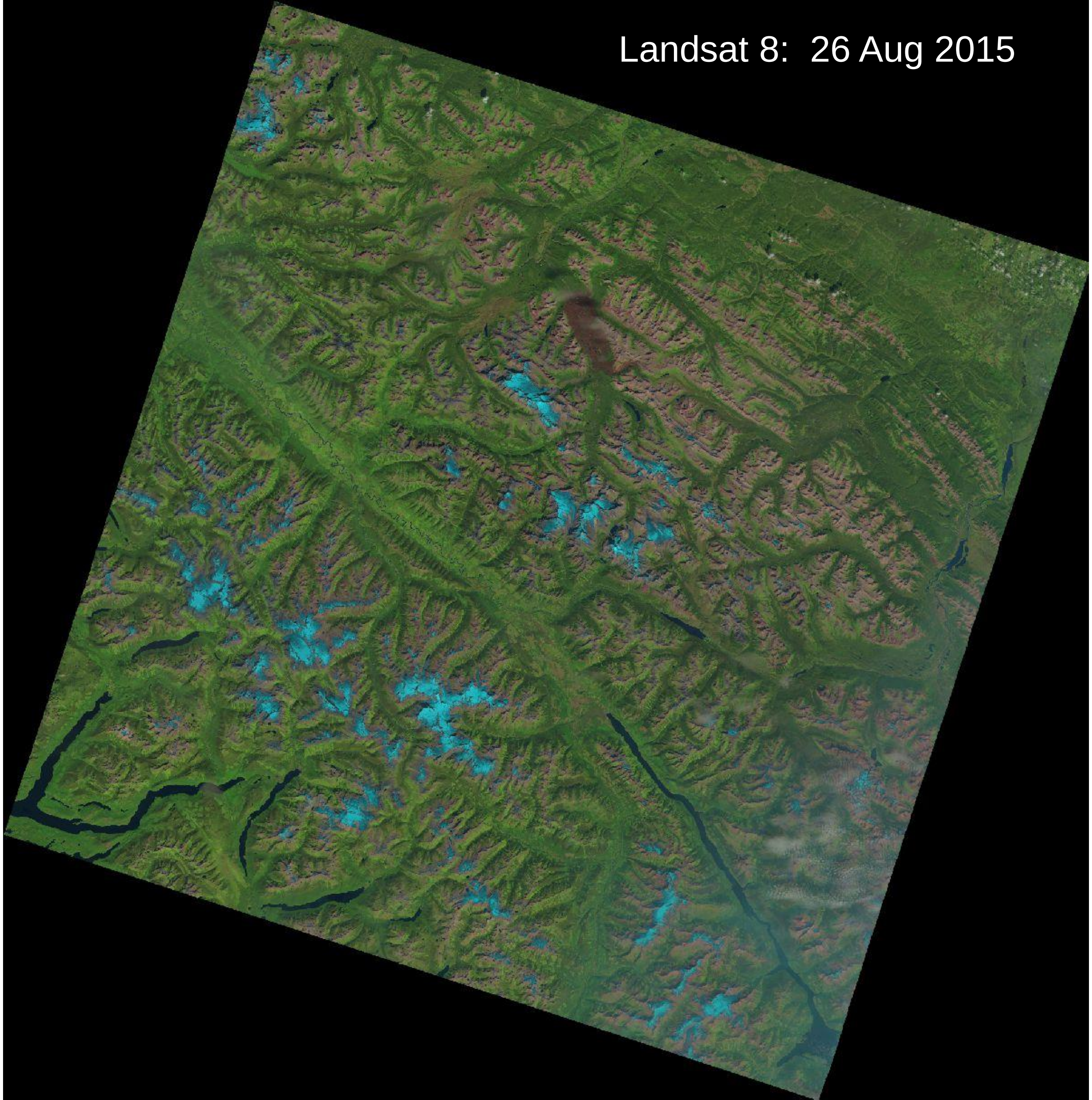
Vegetation cooler than surroundings in day, warmer at night (leaves have moisture)

Grass warmer during day than forest, cooler-darker at night through heat loss

Damp ground: the effect of absorbed water: cooler in day, warmer at night

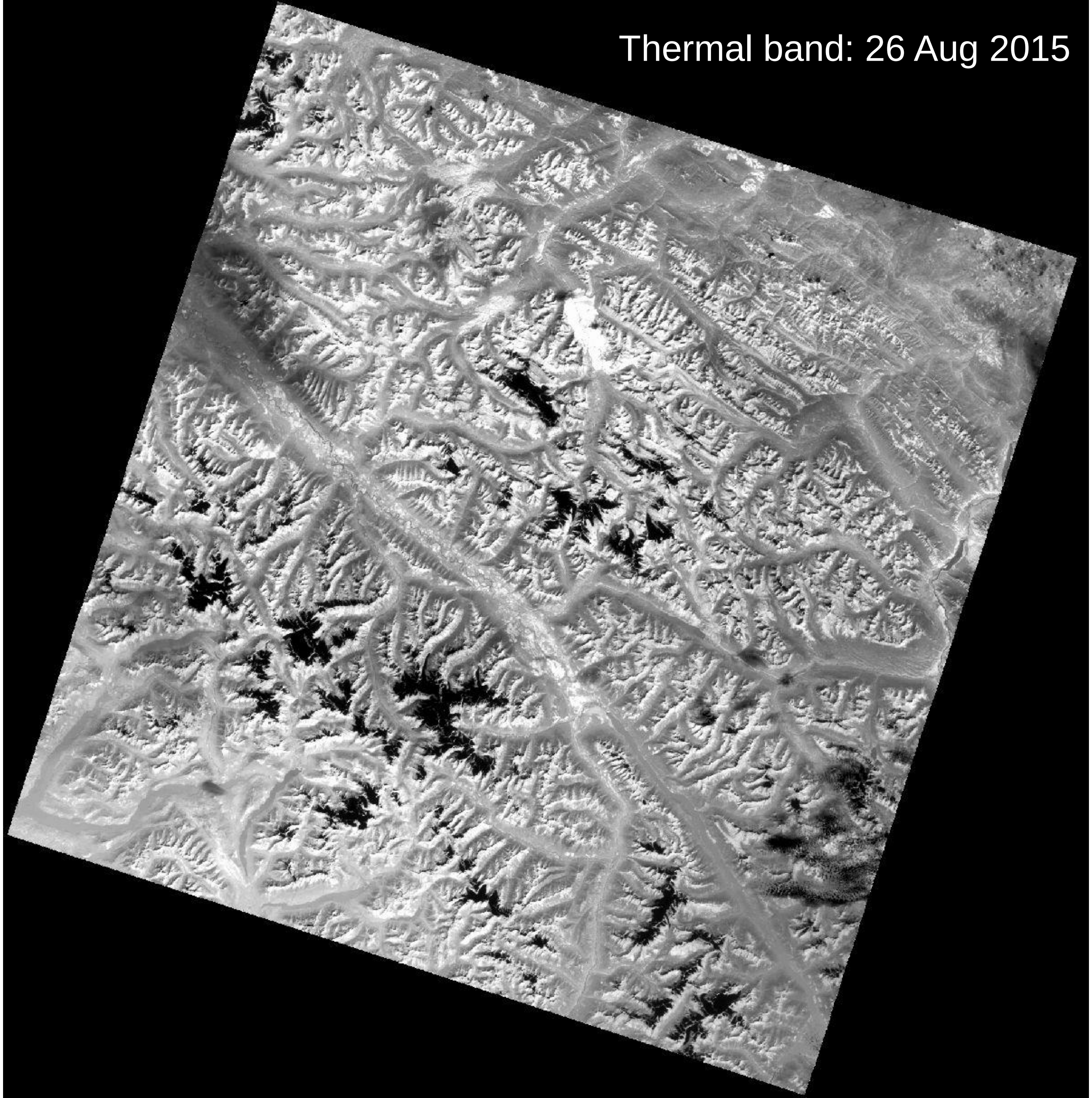






Landsat 8: 26 Aug 2015

Thermal band: 26 Aug 2015



TM band 6

operators activate Thematic Mapper Band 6 on Landsat occasionally at night to obtain thermal images: S.Ontario 9:32 pm, August 22,1982

The land appears moderately cool (darker tones), the cities are brighter; a mottled pattern of warmer waves in Lake Ontario.

These waves relate to thermoclines -overturning effects- in this deeper (237 m) lake.

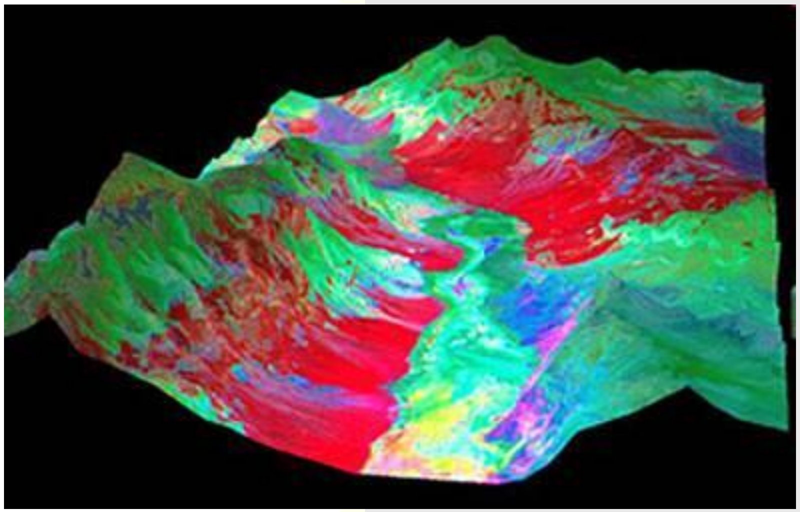
Lake Erie is uniformly "hot" because its shallowness (less than 67 m) inhibits this type of circulation.

Landsat and other sensors :thermal applications (short list)

- Geological features (desert areas)
- Volcanic hazard assessment
- Mapping lakes, thermal plumes from power plants
- Surface sea temperatures
- Burnt area mapping and active fires
- Urban heat island effects
- Wildlife monitoring
- Thermography
- Glaciers ????

ASTER Instrument Characteristics

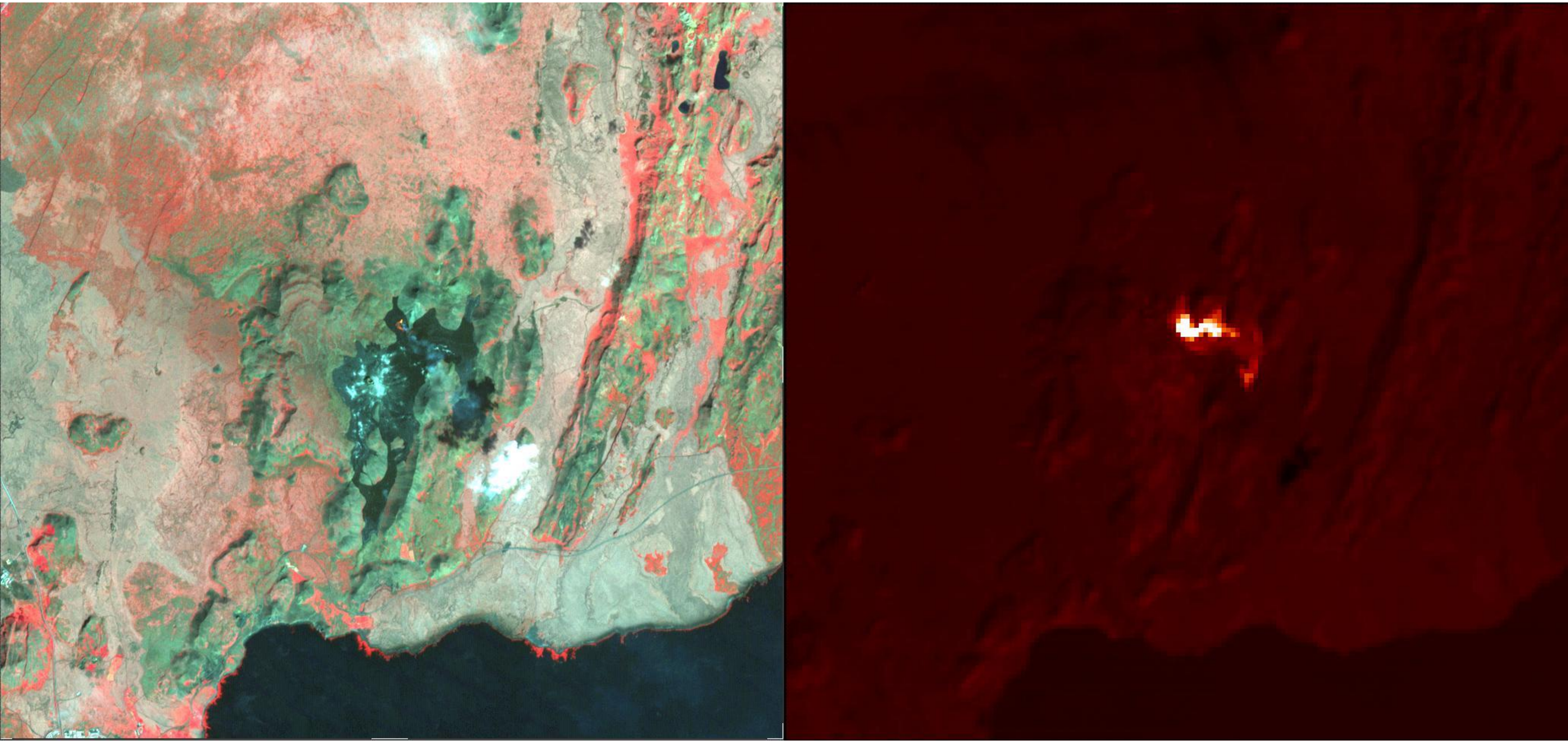
Characteristic	VNIR	SWIR	TIR
Spectral Range	Band 1: 0.52 - 0.60 µm Nadir looking	Band 4: 1.600 - 1.700 µm	Band 10: 8.125 - 8.475 µm
	Band 2: 0.63 - 0.69 µm Nadir looking	Band 5: 2.145 - 2.185 µm	Band 11: 8.475 - 8.825 µm
	Band 3: 0.76 - 0.86 µm Nadir looking	Band 6: 2.185 - 2.225 µm	Band 12: 8.925 - 9.275 µm
	Band 3: 0.76 - 0.86 µm Backward looking	Band 7: 2.235 - 2.285 µm	Band 13: 10.25 - 10.95 µm
		Band 8: 2.295 - 2.365 µm	Band 14: 10.95 - 11.65 µm
		Band 9: 2.360 - 2.430 µm	
Ground Resolution	15 m	30m	90m



ASTER thermal bands: Death Valley
Blue = Band 10
Green = Band 12
Red = Band 13

Fagradalsfjall Volcano, Iceland. August 15, 2022

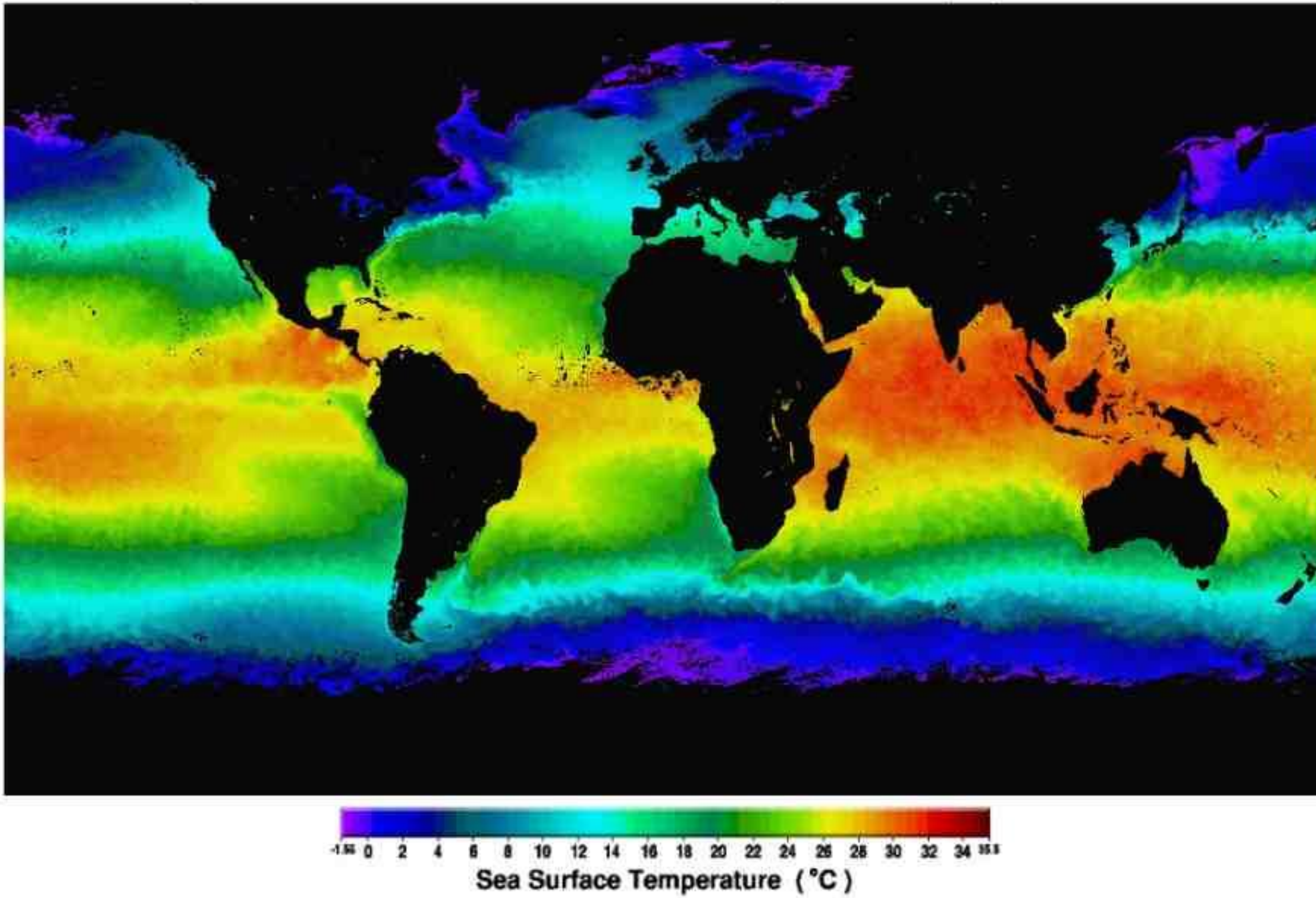
ASTER NIR-Red-Green Thermal



MODIS: Thermal IR bands 20-36, 1km resolution

Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required NE[delta]T(K)[4]
Surface/Cloud Temperature	20	3.660 - 3.840	0.45(300K)	0.05
	21	3.929 - 3.989	2.38(335K)	2.00
	22	3.929 - 3.989	0.67(300K)	0.07
	23	4.020 - 4.080	0.79(300K)	0.07
Atmospheric Temperature	24	4.433 - 4.498	0.17(250K)	0.25
	25	4.482 - 4.549	0.59(275K)	0.25
Cirrus Clouds Water Vapor	26	1.360 - 1.390	6.00	150(SNR)
	27	6.535 - 6.895	1.16(240K)	0.25
	28	7.175 - 7.475	2.18(250K)	0.25
Cloud Properties	29	8.400 - 8.700	9.58(300K)	0.05
Ozone	30	9.580 - 9.880	3.69(250K)	0.25
Surface/Cloud Temperature	31	10.780 - 11.280	9.55(300K)	0.05
	32	11.770 - 12.270	8.94(300K)	0.05
Cloud Top Altitude	33	13.185 - 13.485	4.52(260K)	0.25
	34	13.485 - 13.785	3.76(250K)	0.25
	35	13.785 - 14.085	3.11(240K)	0.25
	36	14.085 - 14.385	2.08(220K)	0.35

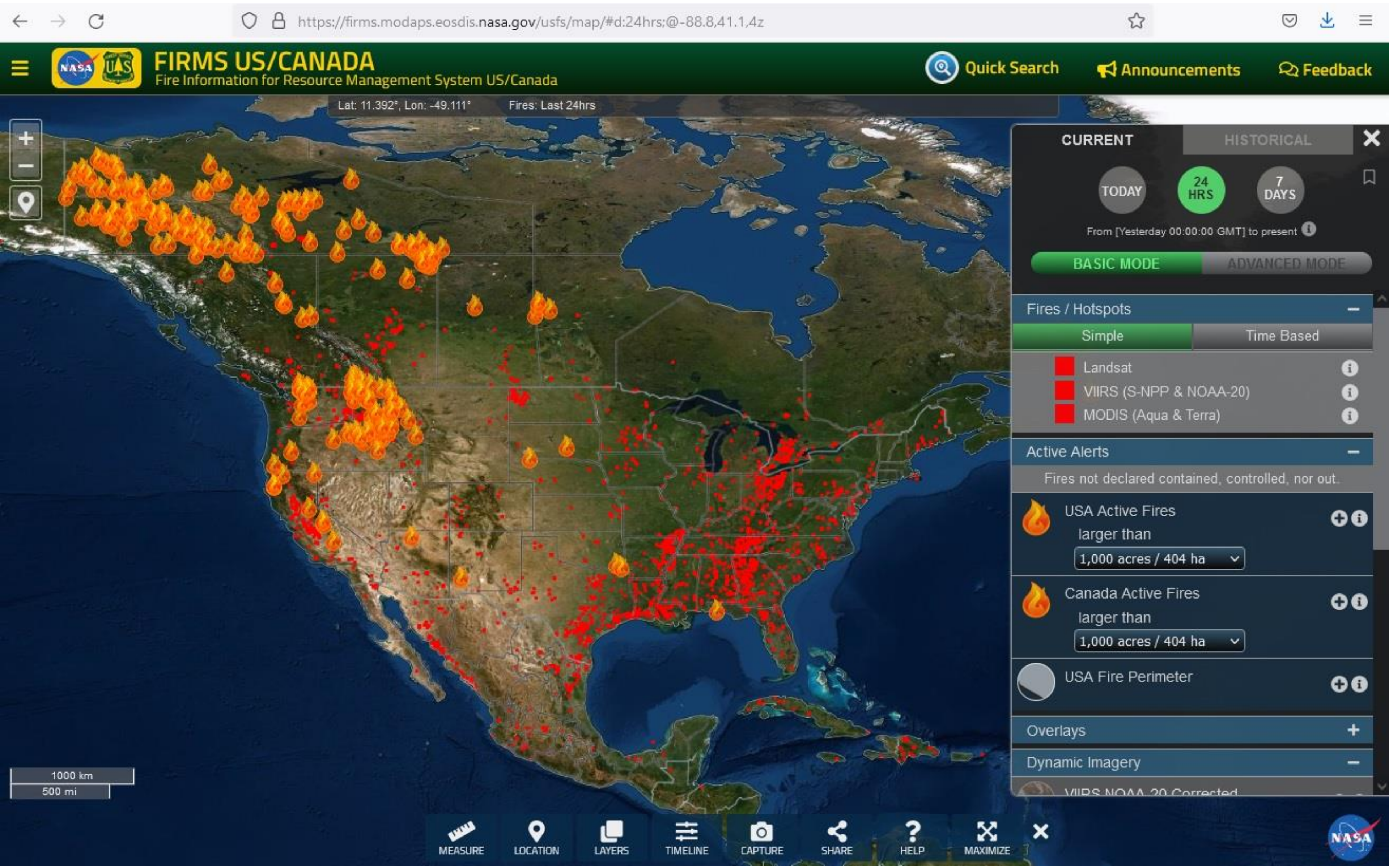
Aqua MODIS Sea Surface Temperature, April 2004



Fires – MODIS

Fires in the Bahamas, Florida and Cuba (03 April 2004, 18:30 UTC) identified using MODIS Aqua and outlined in red on the MODIS 1km active fire map (MODIS)

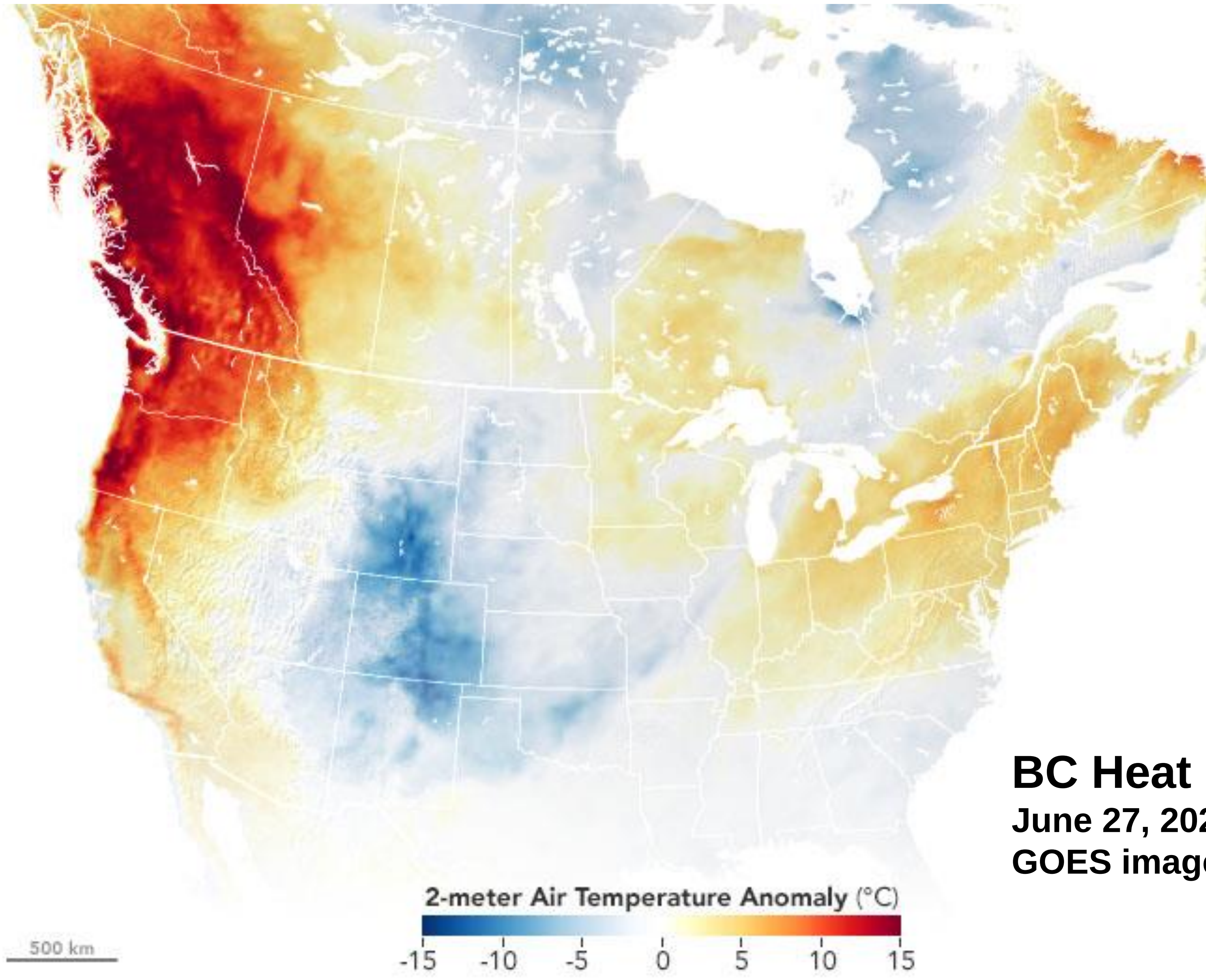
http://activefiremaps.fs.fed.us/



https://firms.modaps.eosdis.nasa.gov/usfs/map

Thermal bands on NOAA (since 1979)

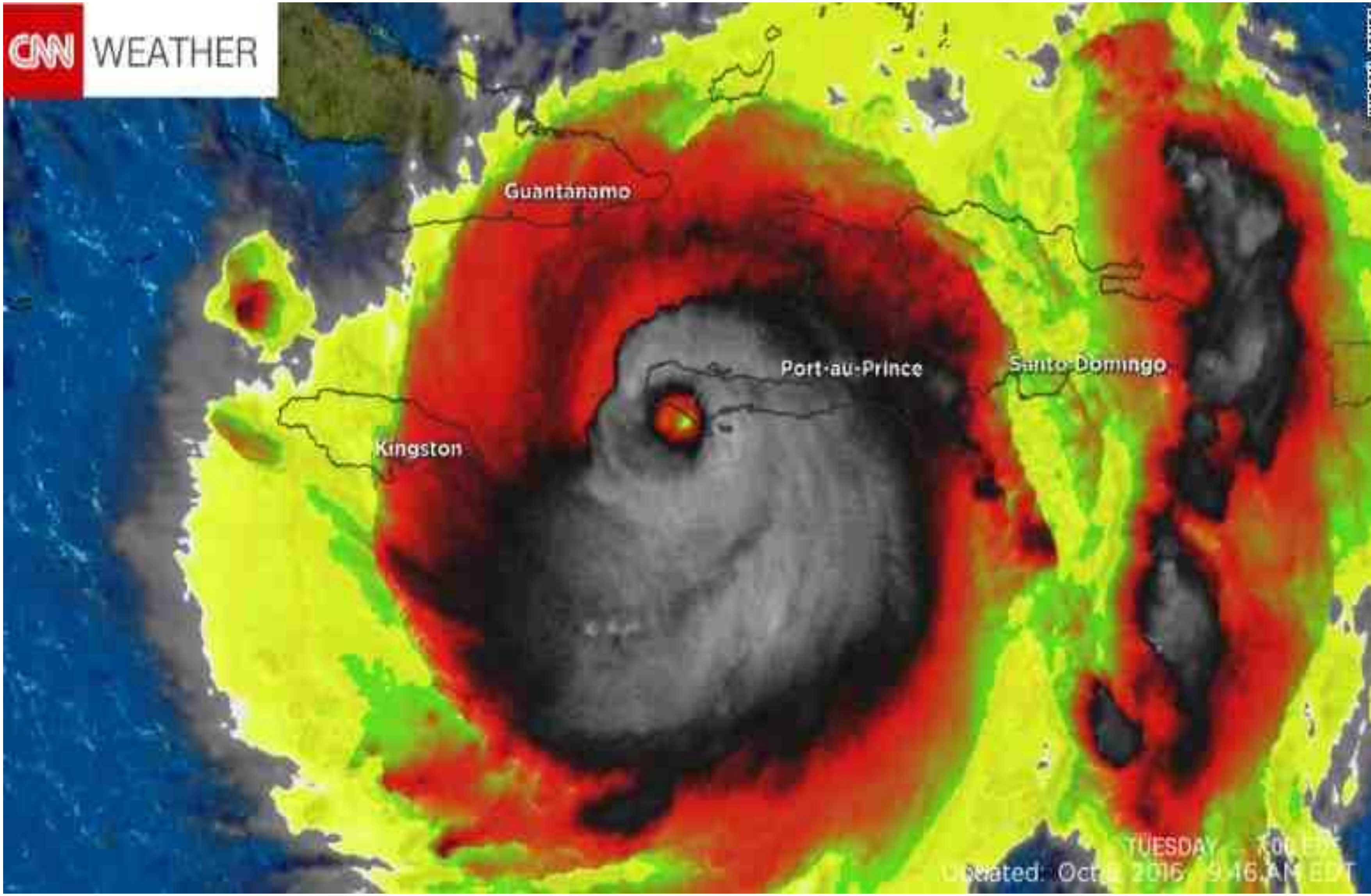
AVHRR/3 Channel Characteristics			
Channel Number	Resolution at Nadir	Wavelength (um)	Typical Use
1	1.09 km	0.58 - 0.68	Daytime cloud and surface mapping
2	1.09 km	0.725 - 1.00	Land-water boundaries
3A	1.09 km	1.58 - 1.64	Snow and ice detection
3B	1.09 km	3.55 - 3.93	Night cloud mapping, sea surface temperature
4	1.09 km	10.30 - 11.30	Night cloud mapping, sea surface temperature
5	1.09 km	11.50 - 12.50	Sea surface temperature



BC Heat dome

June 27, 2021

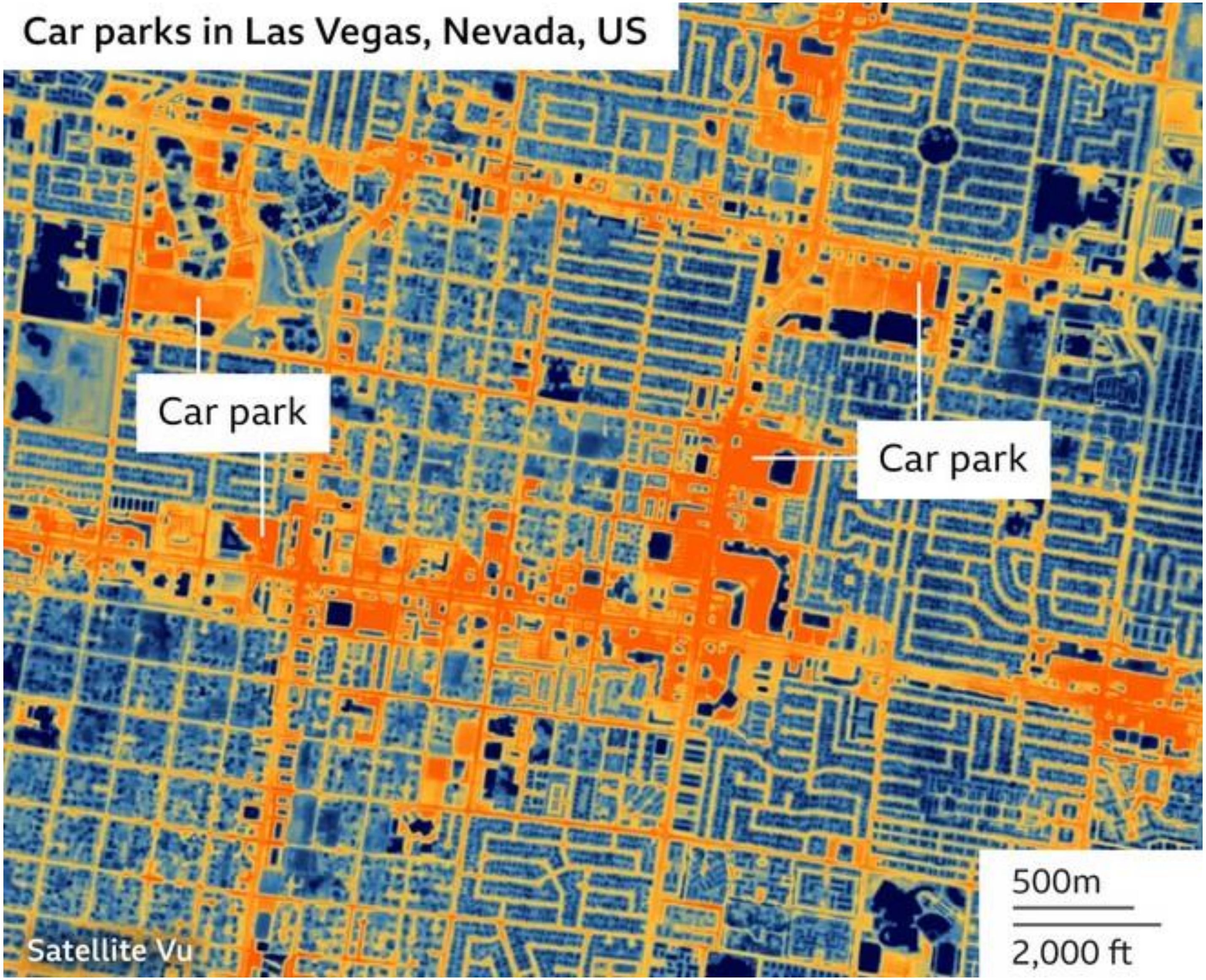
GOES imagery



Hurricane Matthew, October 2016 (GOES) – high clouds = cooler

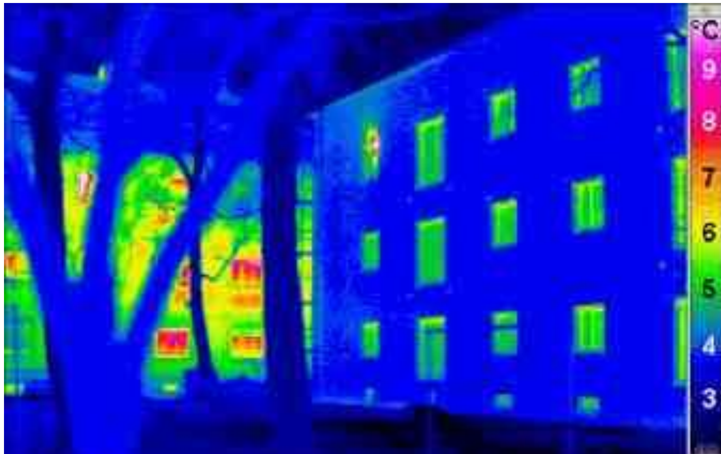
Hotsat-1 resolution - 3.5m   Mid-infrared - 3.4-5.0 μm, launched June 2023

https://www.satellitevu.com



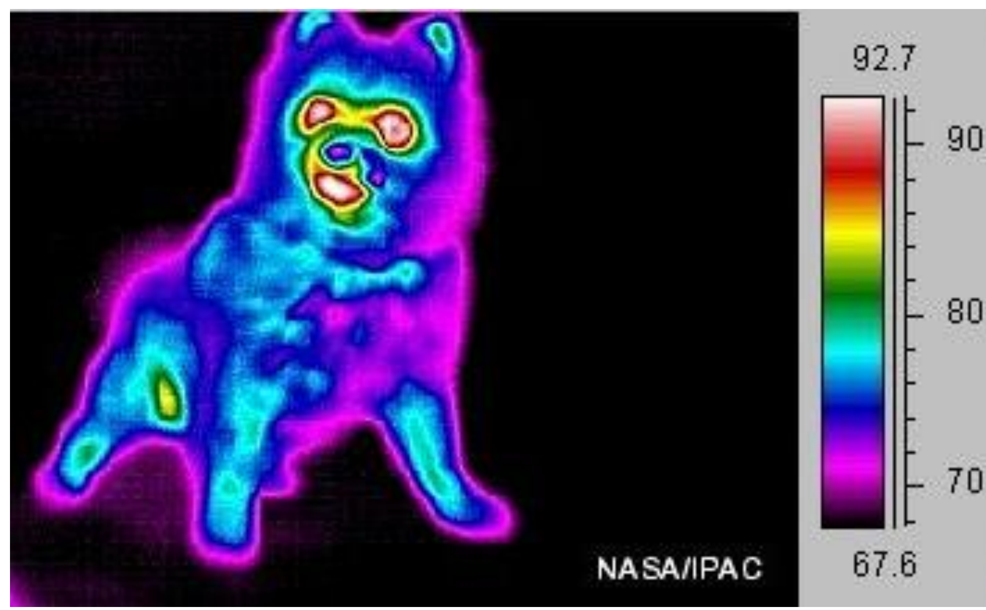
https://www.bbc.com/news/science-environment-67010377

Thermography- Building heat loss



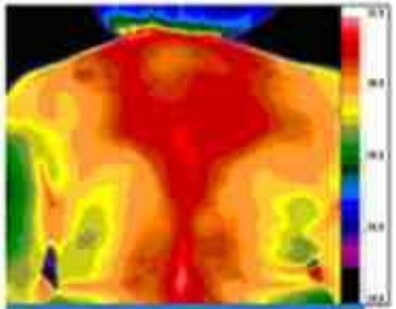
Wildlife monitoring

Drones with thermal cameras used to locate Koalas in Australian bush fires http://coolcosmos.ipac.caltech.edu/image_galleries/ir_zoo/index.html

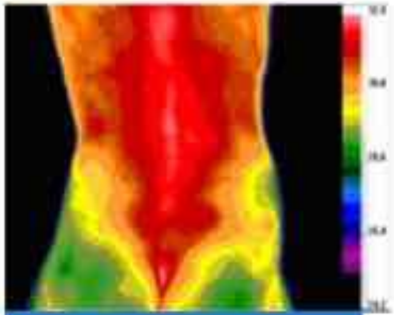


Thermography is a safe, non-invasive screening tool helpful in the diagnosis of the following:

- Arthritis
- Breast Health Evaluation
- Carpel Tunnel Syndrome
- Chronic Low Back Pain
- Chronic Nerve Injury
- Complex Regional Pain Syndrome
- Fibromyalgia
- Headache / Sinus Pain
- Neck and Back Problems
- Pain Evaluation
- Referred pain
- Visualization of Pain
- Repetitive Strain Injuries
- Soft Tissue Injuries/ Sports Injuries
- Stroke Risk Assessment
- Musculo-Skeletal Syndromes
- Whiplash



Fibromyalgia or Chronic Fatigue



Chronic Back Ache