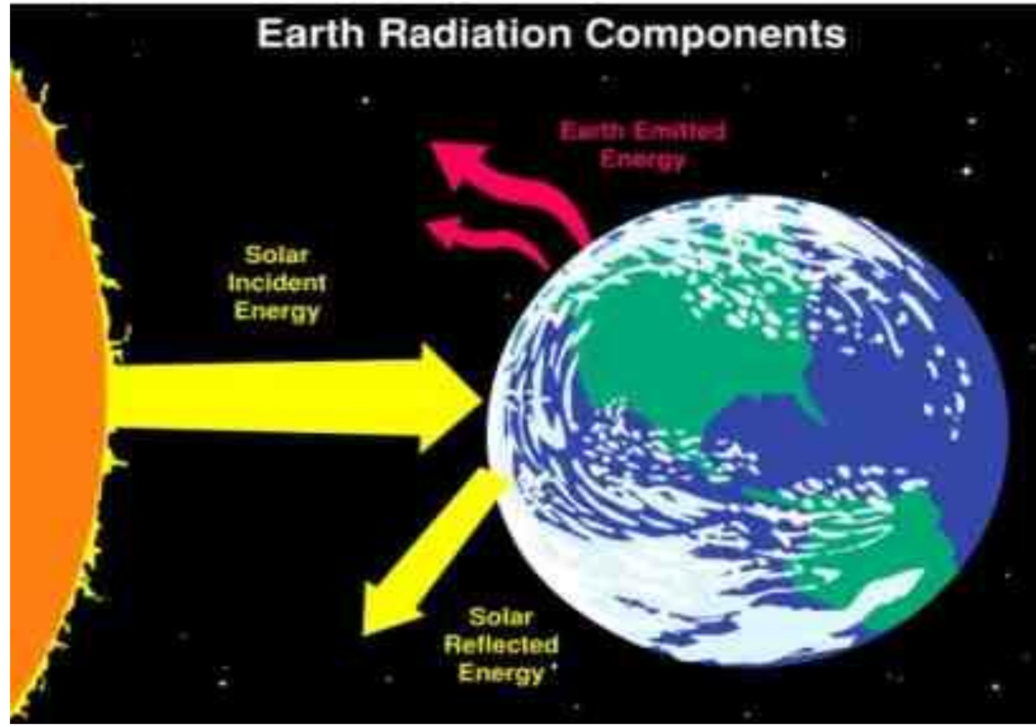
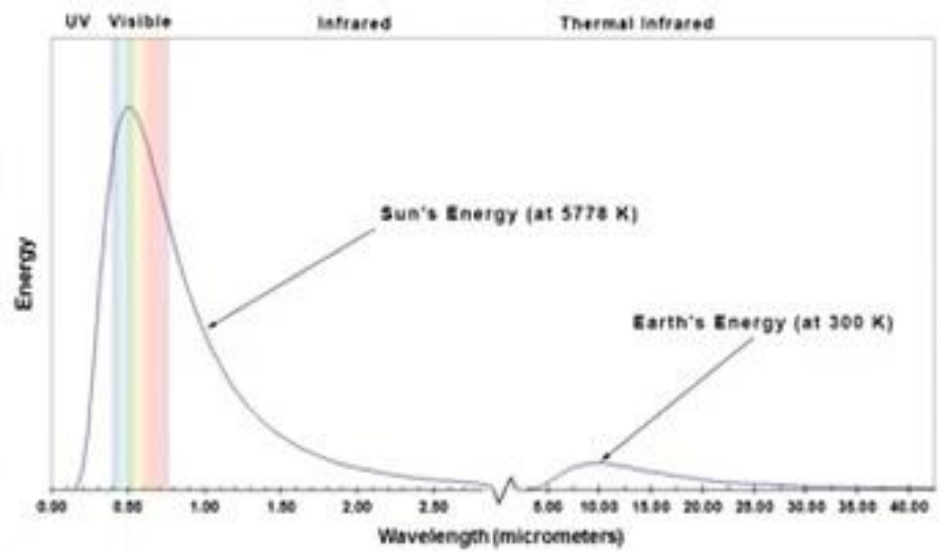
Thermal Infrared Remote sensing (3-14 microns)

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

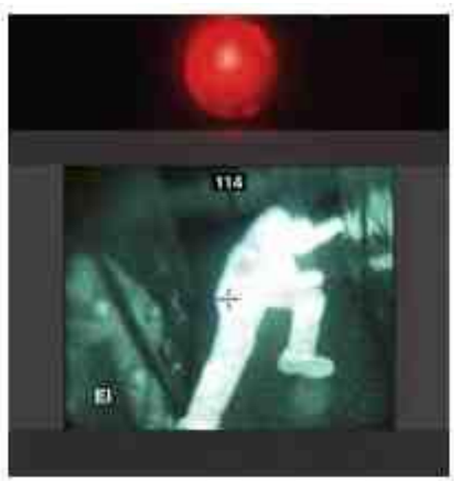
- Works day / night (temperatures above 0 K = -273 Celsius)

- Usually lower pixel resolution as there is less energy to capture





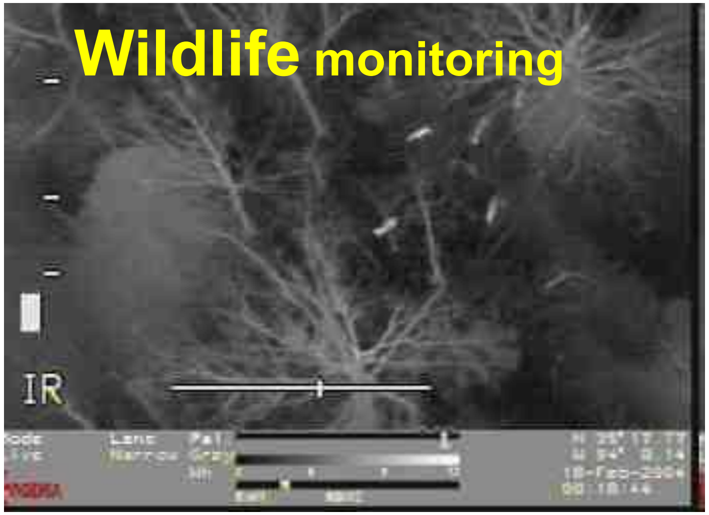
Thermal Infrared (3-14 microns)



Thermal IR can 'see' through

haze and smoke - but not clouds

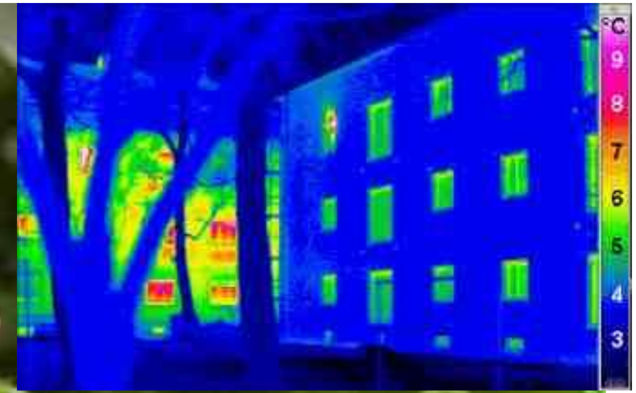
A comparison of a thermal image and an ordinary photograph. The plastic bag is mostly transparent to long-wavelength infrared, but the man's glasses are opaque.


Wildlife monitoring
IR


© DLR


Drones with thermal cameras used to locate Koalas in Australian bush fires

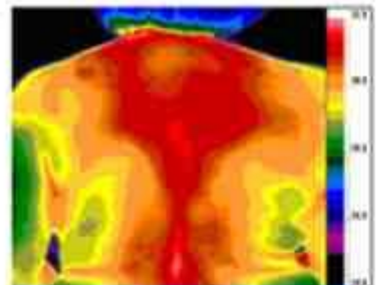
Welcome to Thermography Northern BC



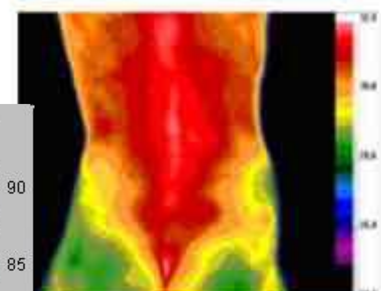
Home | Who is it for? | What is thermography | FAQ | Your appointment | Contact/Fees | Forms

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

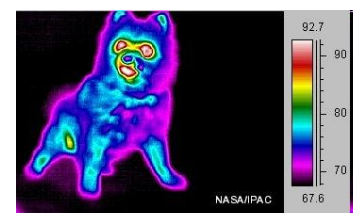
- Arthritis
- Breast Health Evaluation
- Carpel Tunnel Syndrome
- Chronic Low Back Pain
- Chronic Nerve Injury
- Complex Regional Pain Syndrome
- Fibromyalgia
- Headache / Sinus Pain
- Neck and Back Problems
- Pain Evaluation
- Referred pain
- Visualization of Pain
- Repetitive Strain Injuries
- Soft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



Fibromyalgia or Chronic Fatigue



Chronic Back Ache



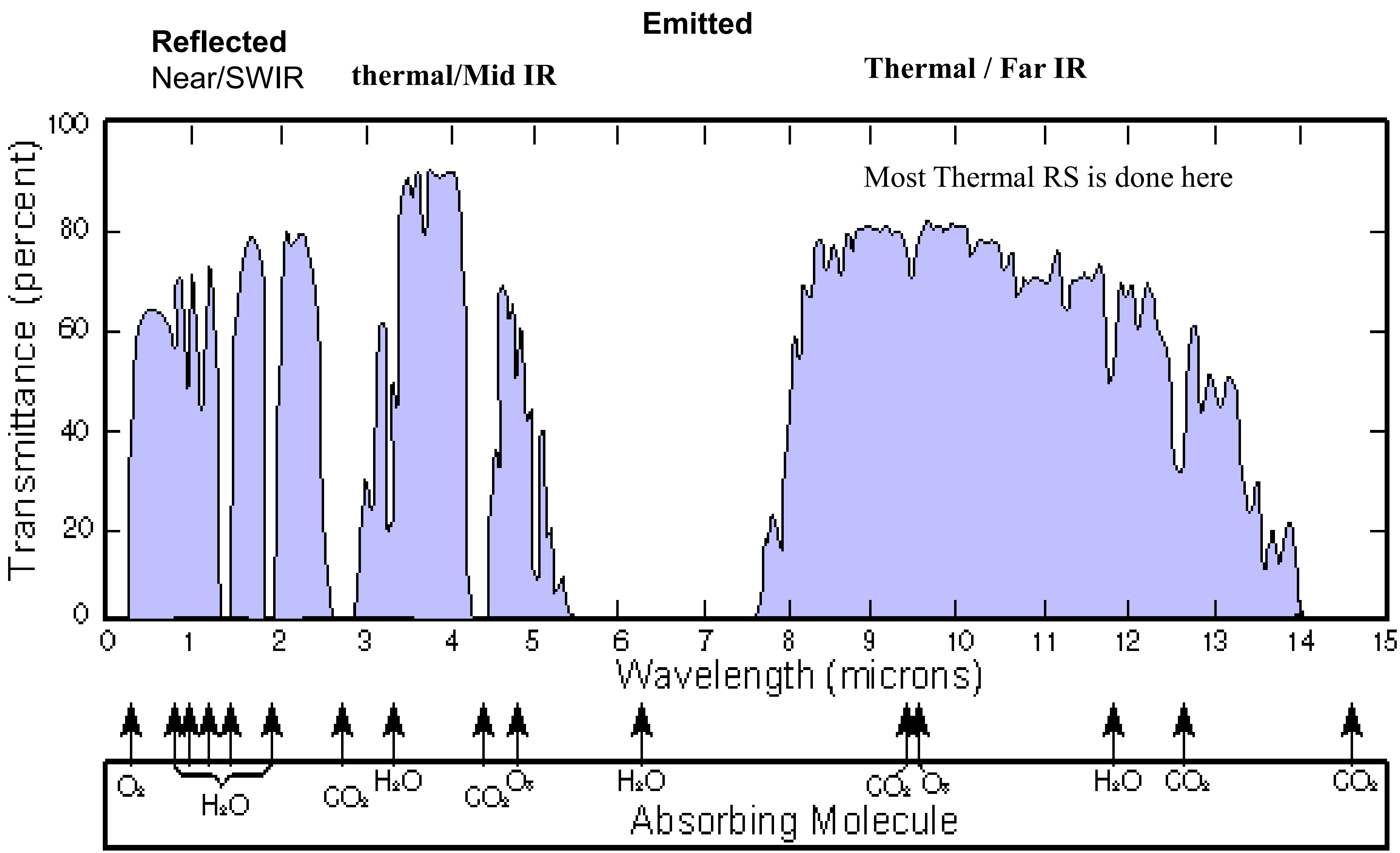
Normal colour and thermal images of Sacramento, CA

Colour composite in RGB

Thermal band in pseudocolour

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

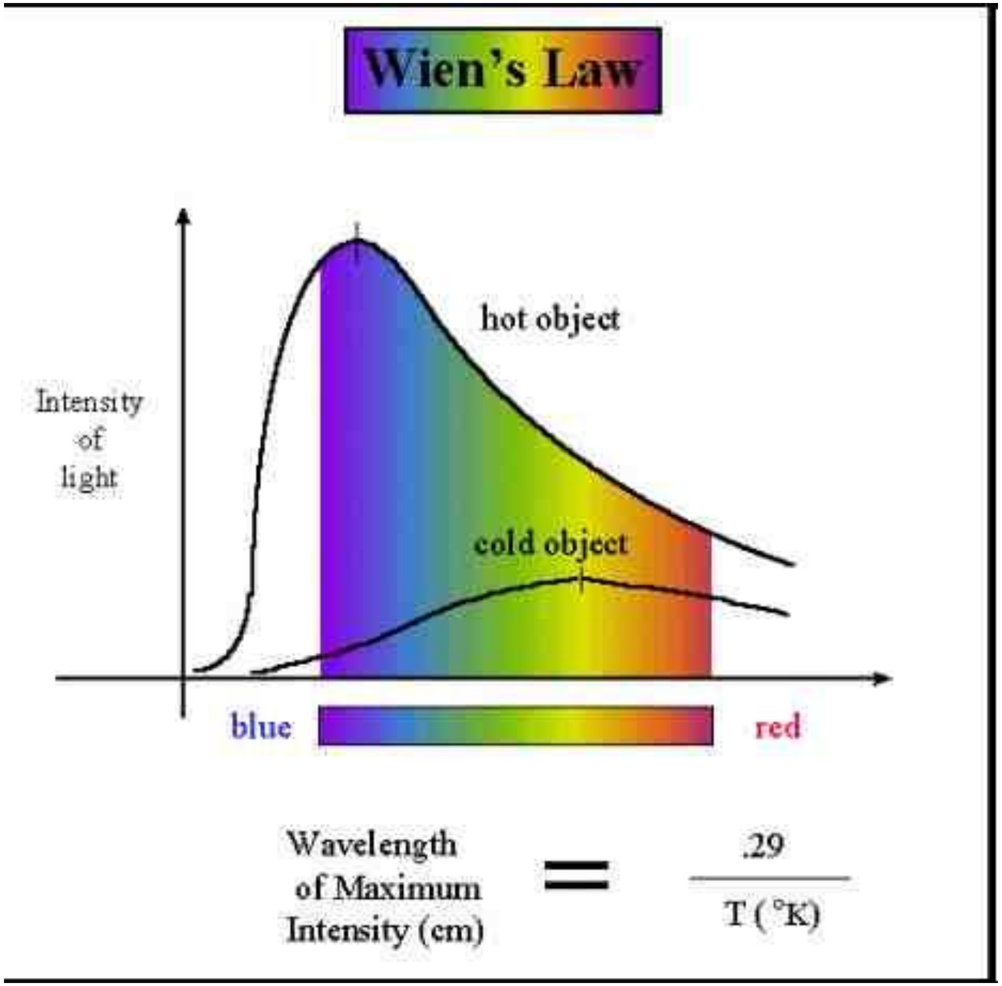
In 5 - 8 micrometres, energy is **absorbed by water vapour** in the atmosphere.

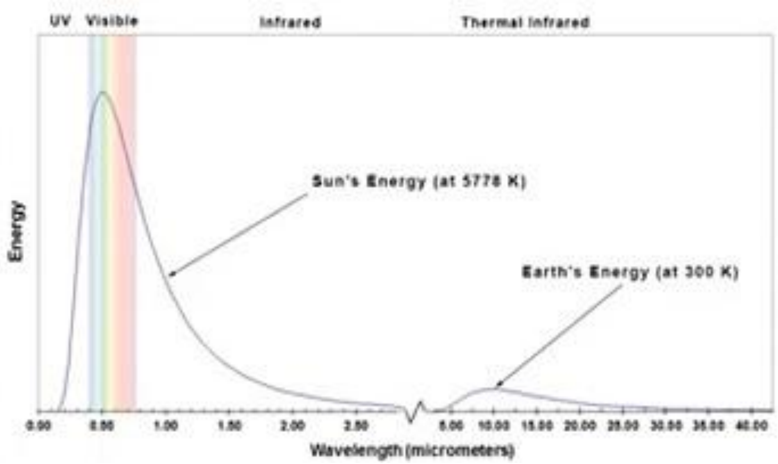


2. Wavelength & Temperature

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 Kelvin (microns)

-> so the (cooler) 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 <u>reflected</u> solar energy
Energy in Mid/Far IR is <u>emitted</u> 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 (perfect) 'black body' at the same temperature.

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

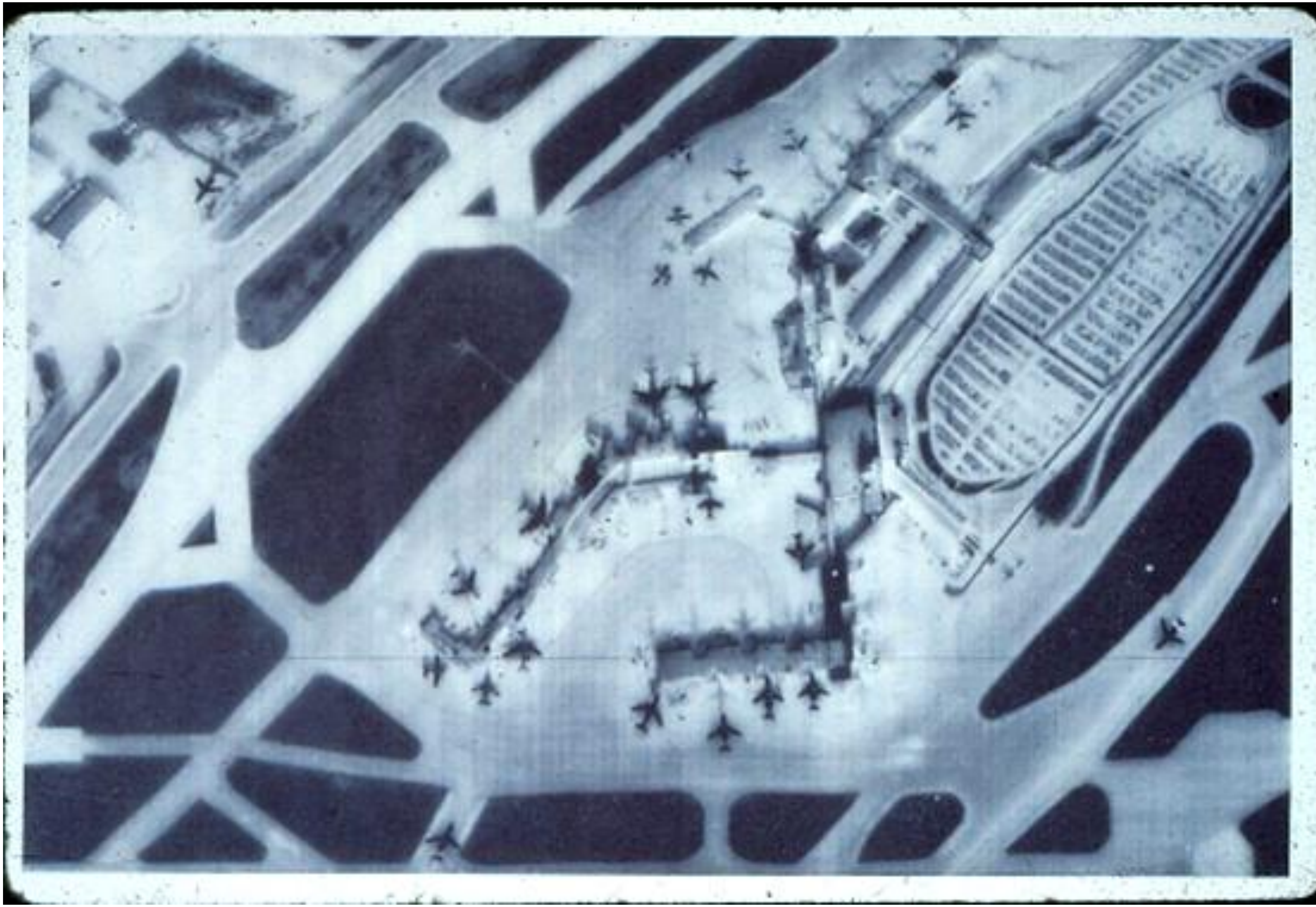
i.e. Actual temperature = $\sqrt[4]{DN / \text{emissivity}}$

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
we use an infrared thermal radiometer to 'ground truth' e.g. sea buoys

Dusseldorf airport thermal image – relative temperatures



Daytime image - – note the 'ghost' plane shadows

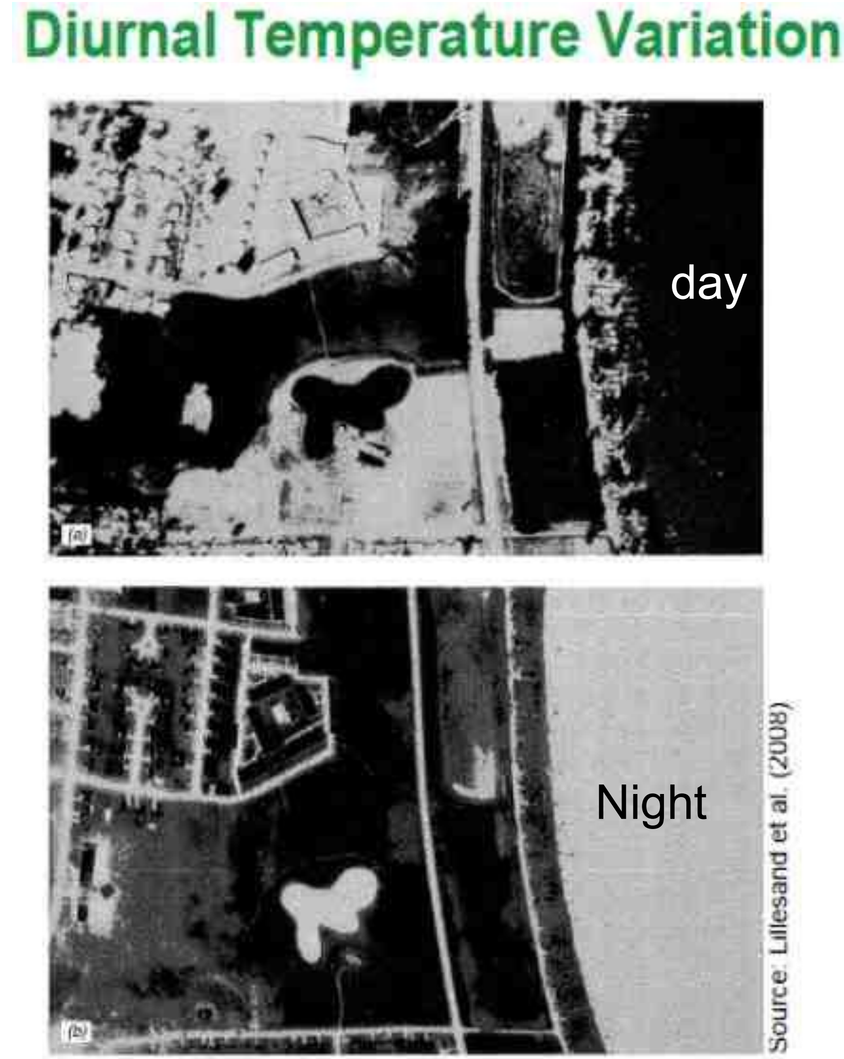
4. Thermal Capacity of Surfaces:
the role of water in moderating temperature

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.

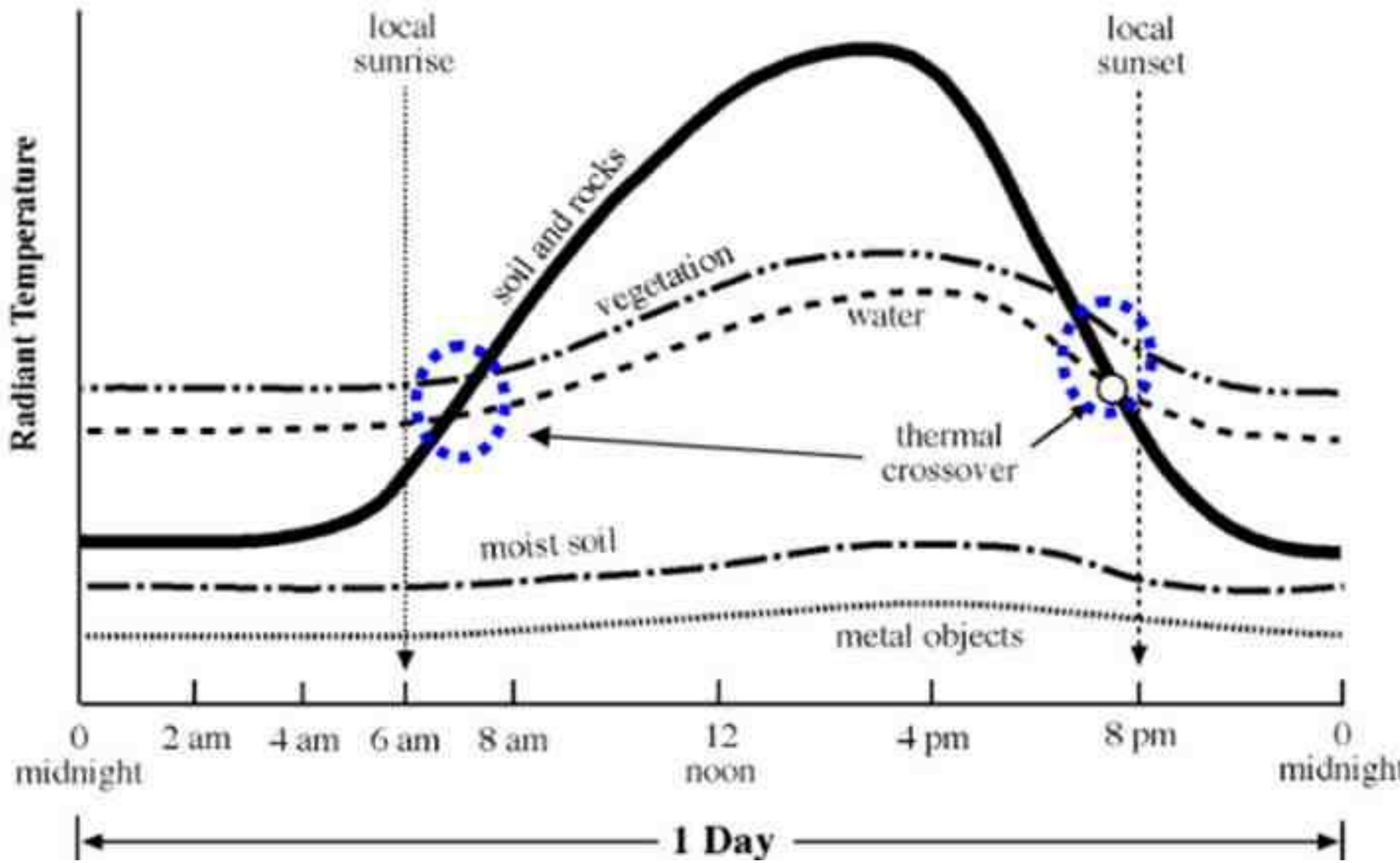
Overall **night-time** is better to avoid shadows; Time of day is critical in understanding thermal



Land / water

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.



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 - not the most ideal time for thermal remote sensing

– except for ‘ascending orbits’ on the 'dark side of the earth'

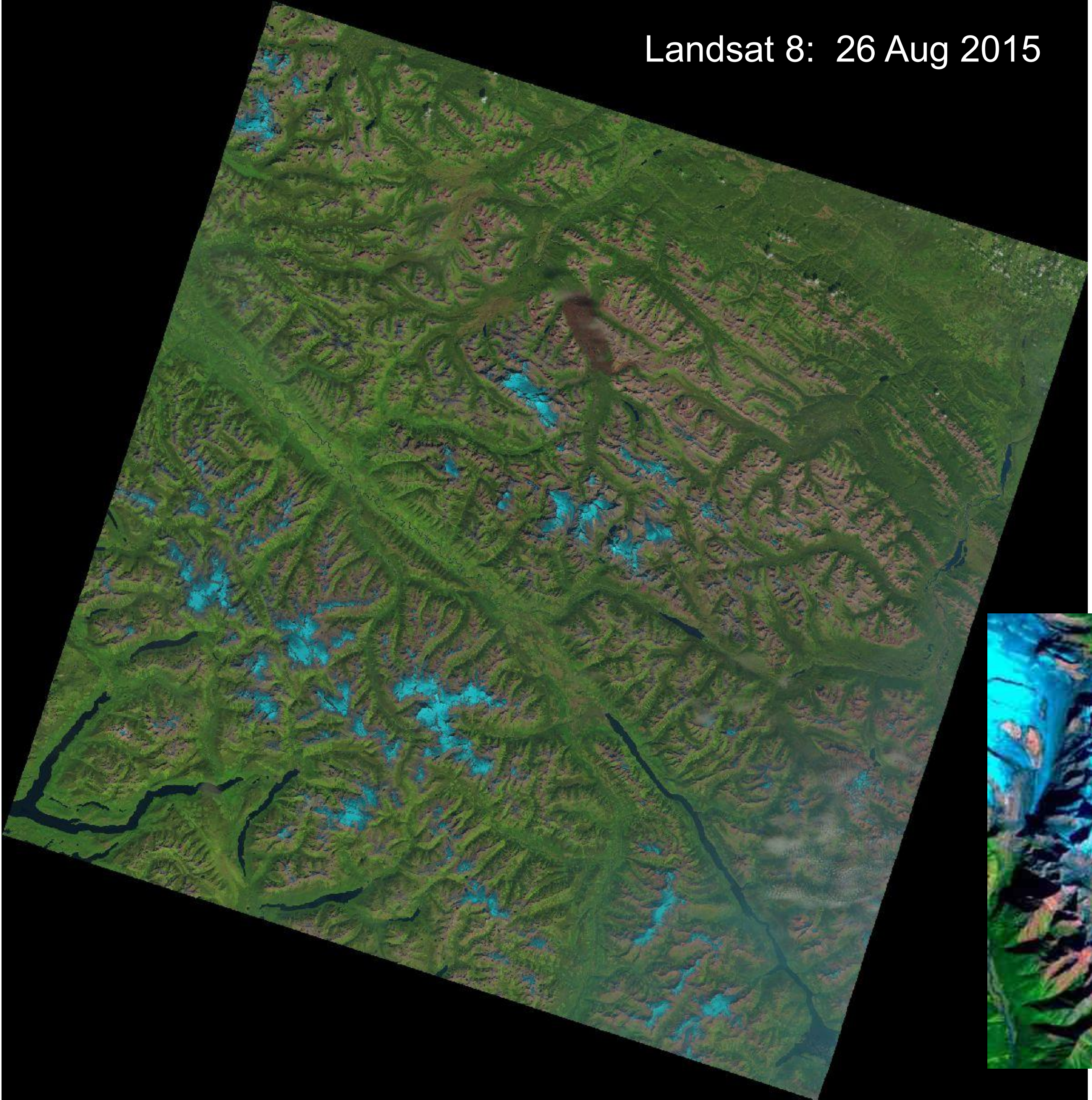
Sensors, wavelength, resolution:

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	TIRS
Landsat 9 (2021):	10.6-11.2; 11.5-12.5	100m	TIRS

Prince George Landsat 5   September 2011: Band 6 - thermal-IR

'Brightness temperature' – related to surface thermal qualities; warmer bowl, cool NW corner ?

Landsat 8: 26 Aug 2015

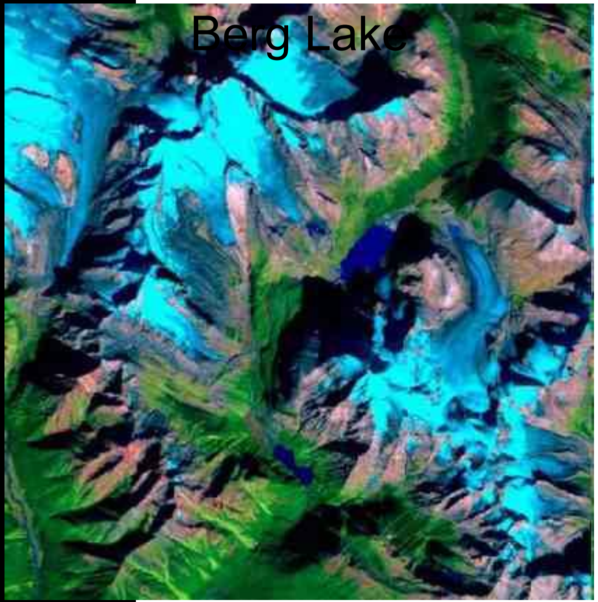


The Trench / Mt. Robson

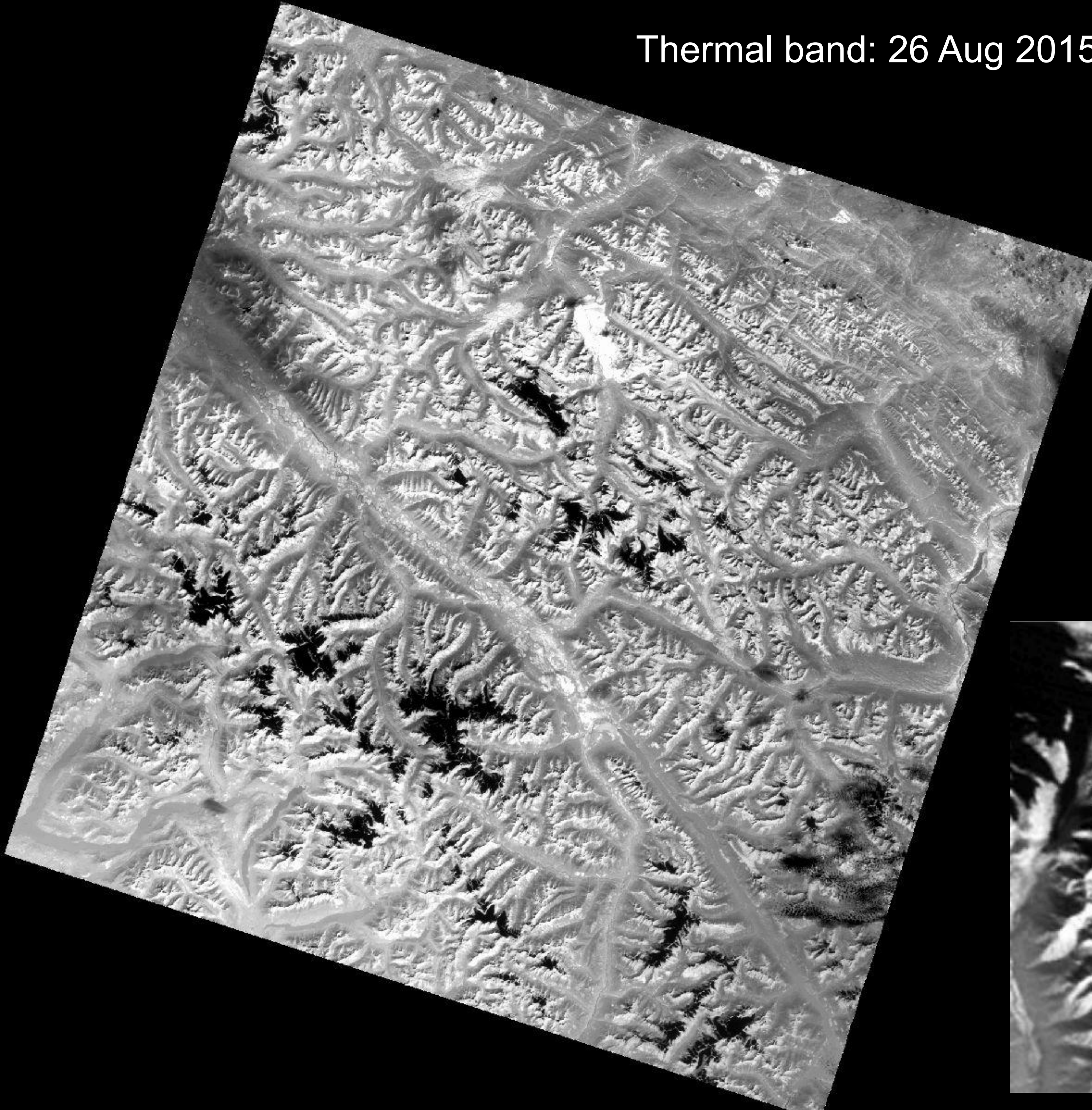
Glaciers (blue)
Red fire in upper centre

Light clouds in SE

Inset: Robson / Berg Lake



Thermal band: 26 Aug 2015



Note fire in white – hotter but due to absence of trees, not any current burning

Glaciers are dark, due to lower temperatures
Lower temps in NW corner of trench, maybe due to recent moisture from rain
Cooler clouds in SE

Thermal applications: Landsat and other sensors (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 ????

MODIS: thermal bands 20-36

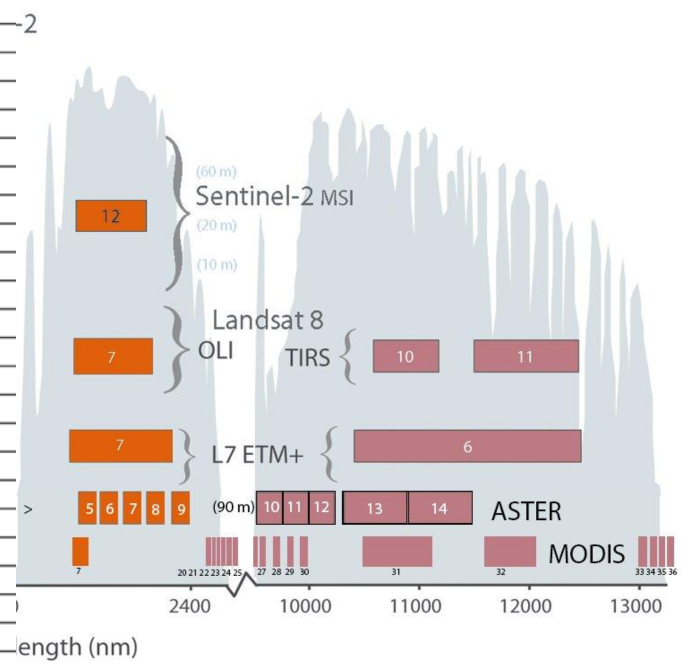
Primary Use	Band	Band Range[1]	Bandwidth[2]	Spectral Radiance[3]	Central Wavelength[4]
Land/Cloud/Aerosols Boundaries	1	0.620 – 0.670	41.8	21.8	0.659
	2	0.841 -0. 876	39.4	24.7	0.865
Land/Cloud/Aerosols Properties	3	0.459 – 0.479	17.6	35.3	0.470
	4	0.545 – 0.565	19.7	29.0	0.555
	5	1.230 – 1.250	24.5	5.4	1.240
	6	1.628 – 1.652	29.7	7.3	1.640
	7	2.105 – 2.155	52.9	1.0	2.130
Ocean Colour/ Phytoplankton/ Biogeochemistry	8	0.405 – 0.420	11.8	44.9	0.415
	9	0.438 – 0.448	9.7	41.9	0.443
	10	0.483 – 0.493	10.6	32.1	0.490
	11	0.526 – 0.536	11.8	27.9	0.531
	12	0.546 – 0.556	10.4	21.0	0.565
	13	0.662 – 0.672	10.1	9.5	0.653
	14	0.673 – 0.683	11.4	8.7	0.681
	15	0.743 – 0.753	10.0	10.2	0.750
	16	0.862 – 0.877	15.5	6.2	0.865
Atmospheric Water Vapour	17	0.890 – 0.920	35.7	10.0	0.905
	18	0.931 – 0.941	13.7	3.6	0.936
	19	0.915 – 0.965	46.3	15.0	0.940
Surface/Cloud Temperature	20	3.660 - 3.840	36.4	0.45(300K)	3.750
	21	3.929 - 3.989	182.6	2.38(335K)	3.959
	22	3.929 - 3.989	85.7	0.67(300K)	3.959
	23	4.020 - 4.080	88.2	0.79(300K)	4.050
Atmospheric Temperature	24	4.433 - 4.498	87.8	0.17(250K)	4.465
	25	4.482 - 4.549	93.7	0.59(275K)	4.515
Cirrus Clouds Water Vapour	26	1.360 - 1.390	94.3	6.00	1.375
	27	6.535 - 6.895	254.6	1.16(240K)	6.715
	28	7.175 - 7.475	325.3	2.18(250K)	7.325
Cloud Properties	29	8.400 - 8.700	369.2	9.58(300K)	8.550
Ozone	30	9.580 - 9.880	300.6	3.69(250K)	9.730
Surface/Cloud Temperature	31	10.780 - 11.280	510.3	9.55(300K)	11.030
	32	11.770 - 12.270	493.5	8.94(300K)	12.020
Cloud Top Altitude	33	13.185 - 13.485	13.335	4.52(260K)	13.335
	34	13.485 - 13.785	13.635	3.76(250K)	13.635
	35	13.785 - 14.085	13.935	3.11(240K)	13.935
	36	14.085 - 14.385	14.235	2.08(220K)	14.235

[1] Bands 1 to 36 are in μm
[2] Bandwidth values are in nm
[3] Spectral radiance values are in $Wm^{-2}\ \mu m^{-1}\ sr^{-1}$
[4] Central wavelength values are in μm

Sentinel 3A/B 2016/2018

3 thermal bands 1km pixels
= 'MODIS like'

Mid-IR 3.78 microns
Far IR 10.80 / 12.0



MODIS has highest spectral res.
ASTER is on the same platform

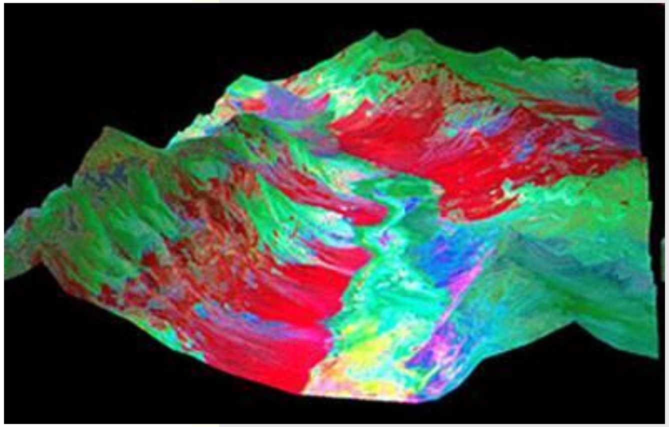
ASTER Instrument Characteristics

Launched onboard Terra satellite 1999

Thermal bands

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

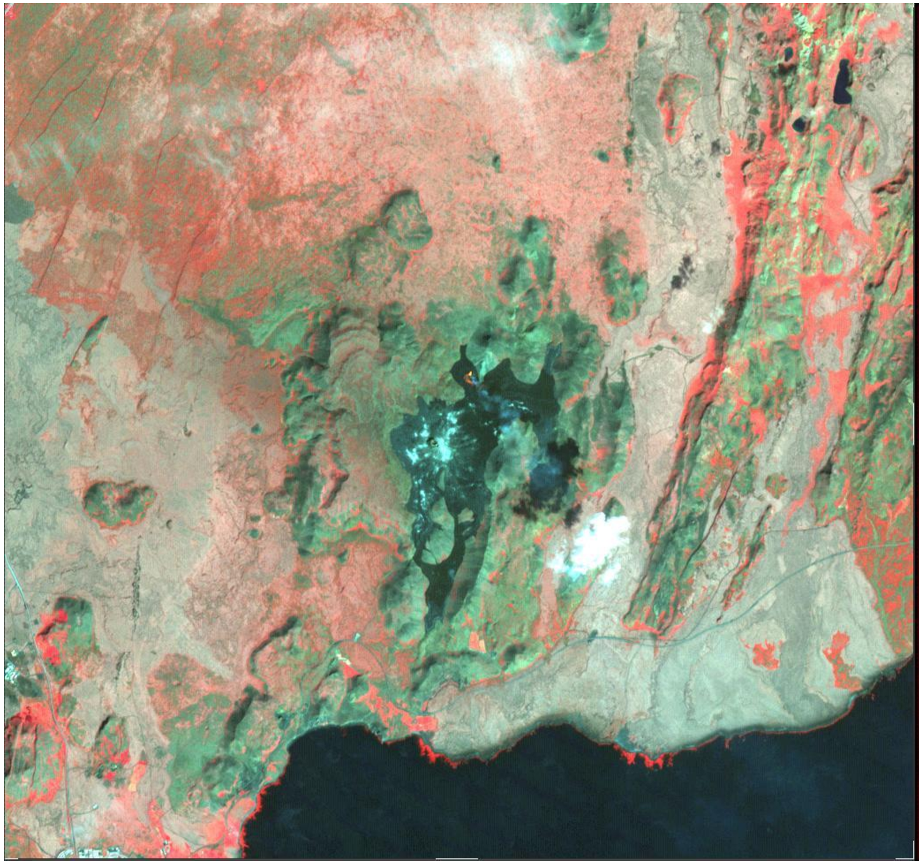
Thermal colour composite



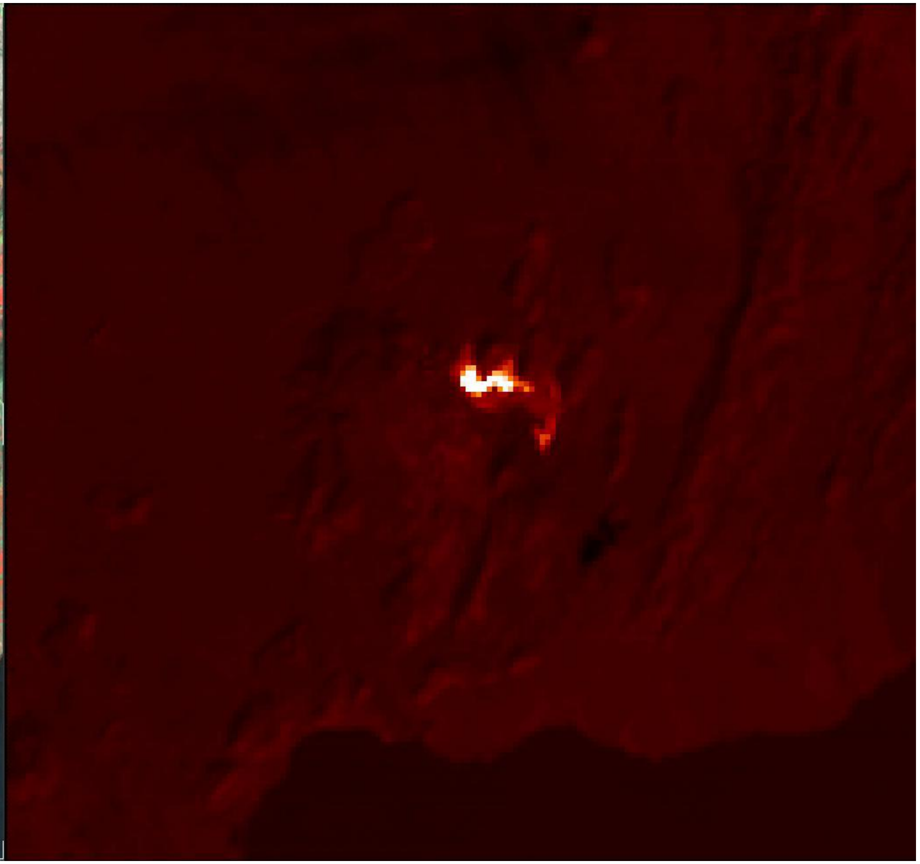
ASTER thermal bands: Death Valley
Blue = Band 10
Green = Band 12
Red = Band 13

Fagradalsfjall Volcano, Iceland. August 15, 2022

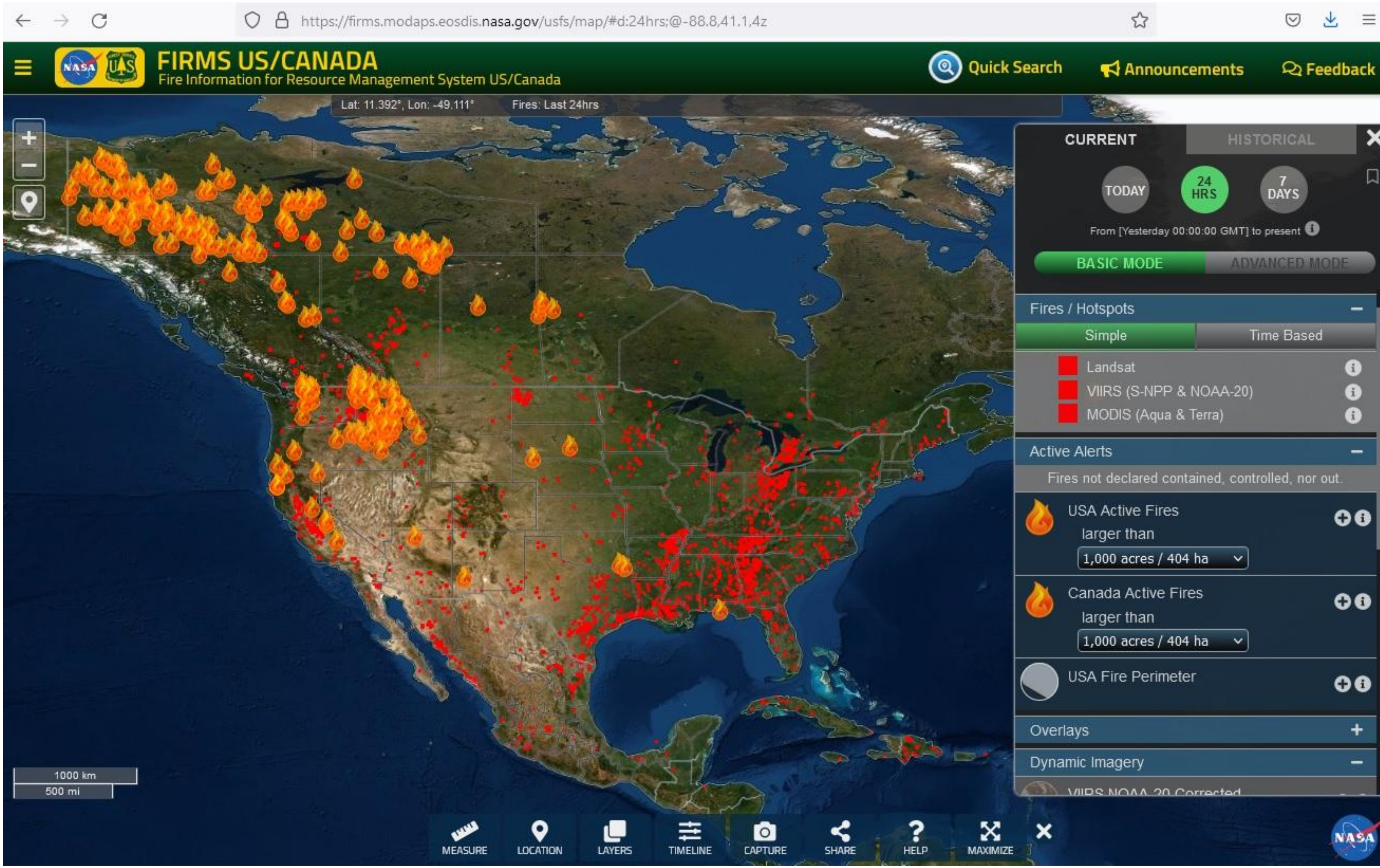
ASTER NIR-Red-Green



Thermal

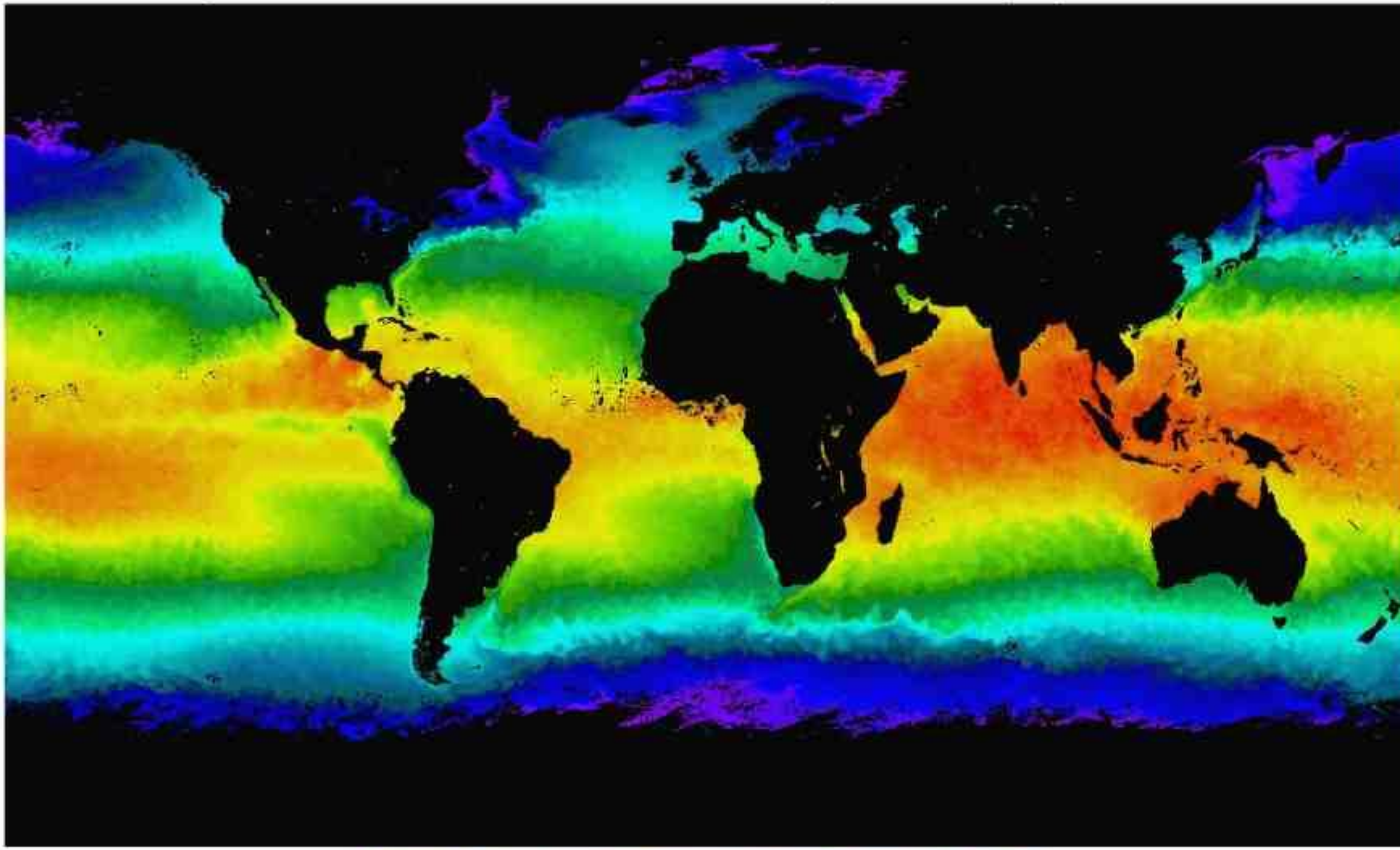


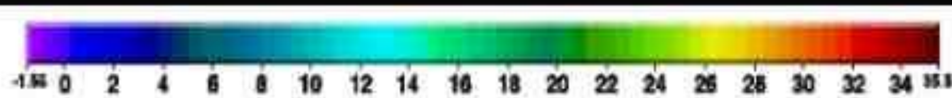
Fires – MODIS



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

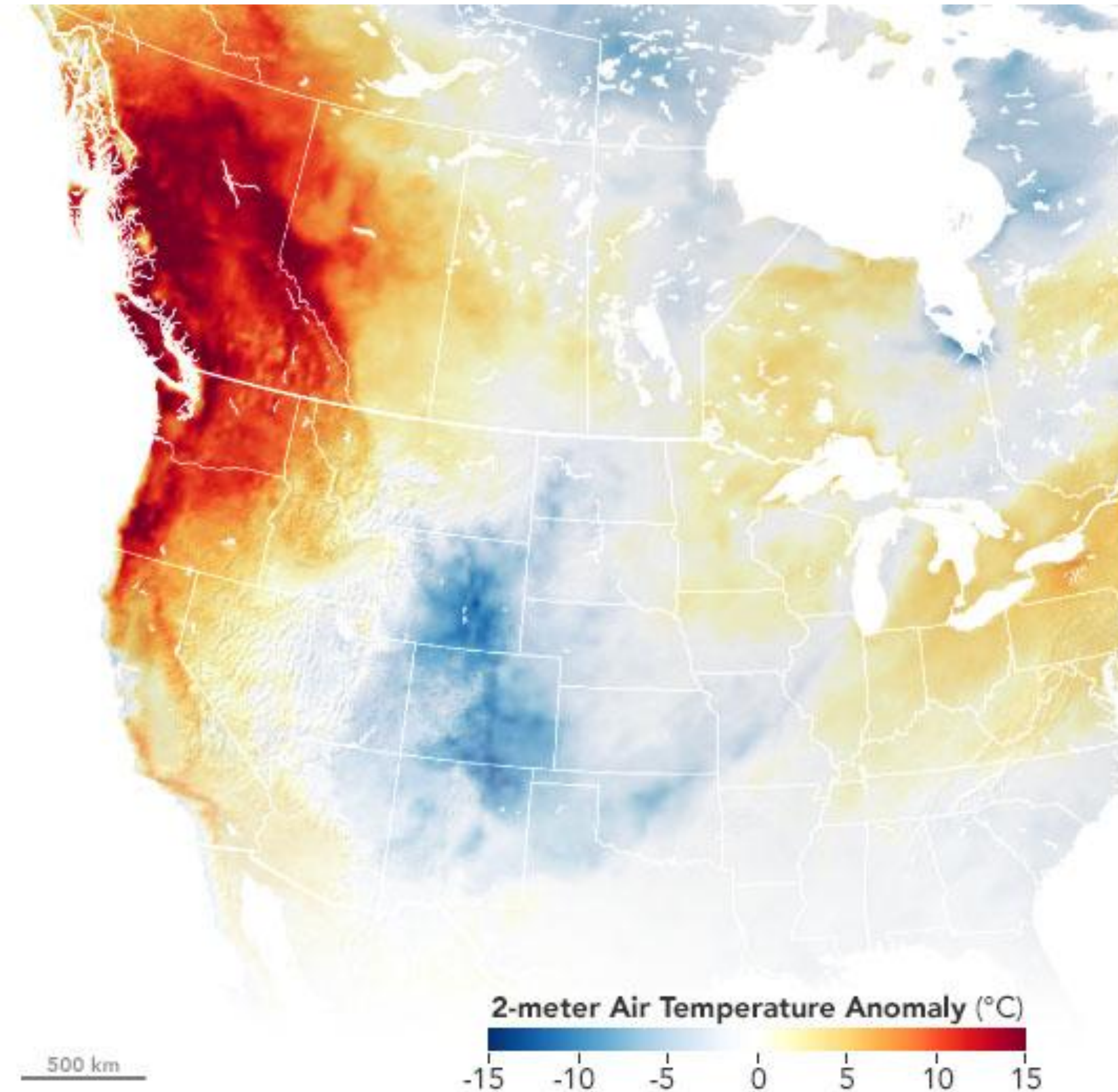
Aqua MODIS Sea Surface Temperature, April 2004





Verified by sea buoys

All water = same surface emissivity

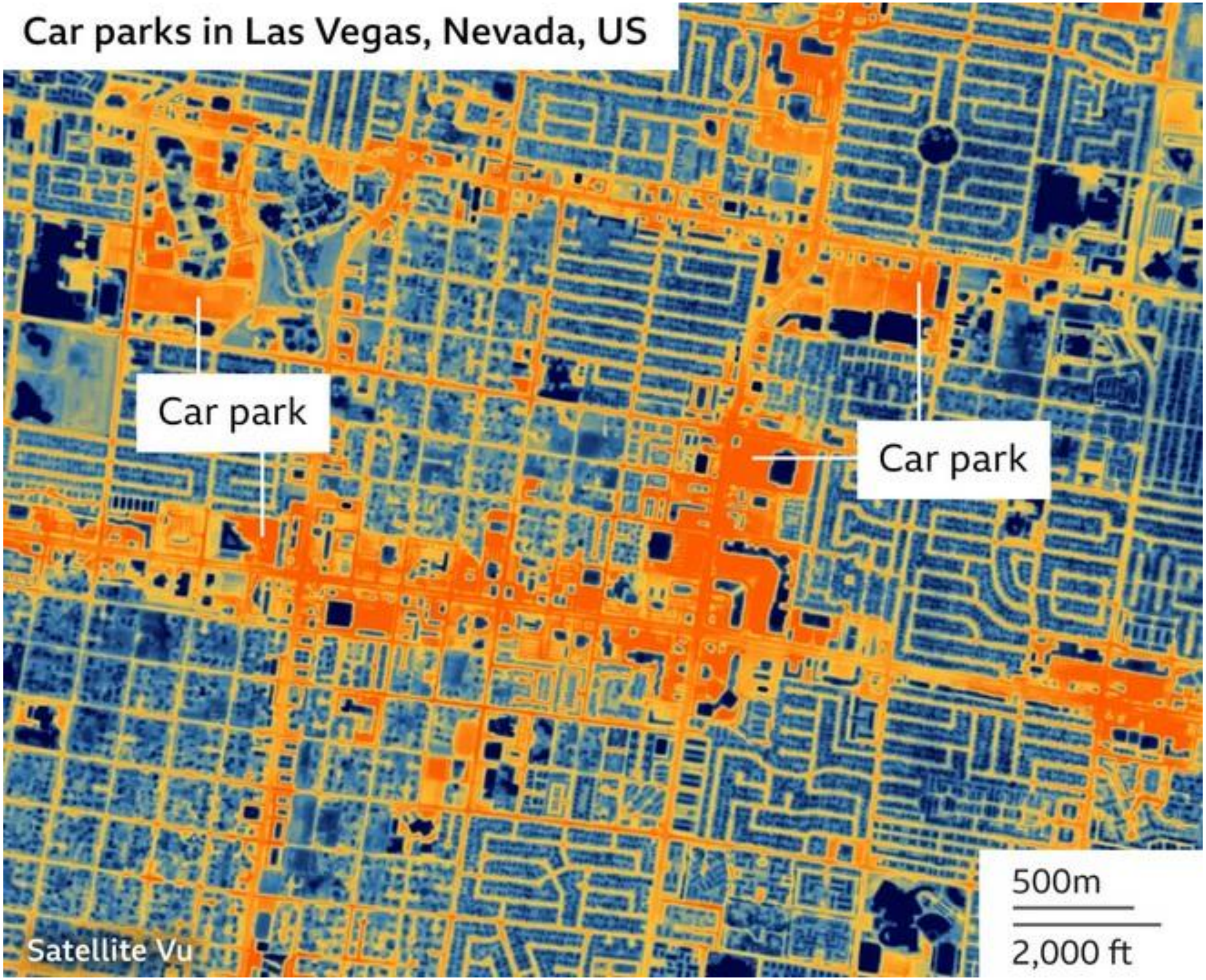


BC Heat dome

June 27, 2021
GOES imagery

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

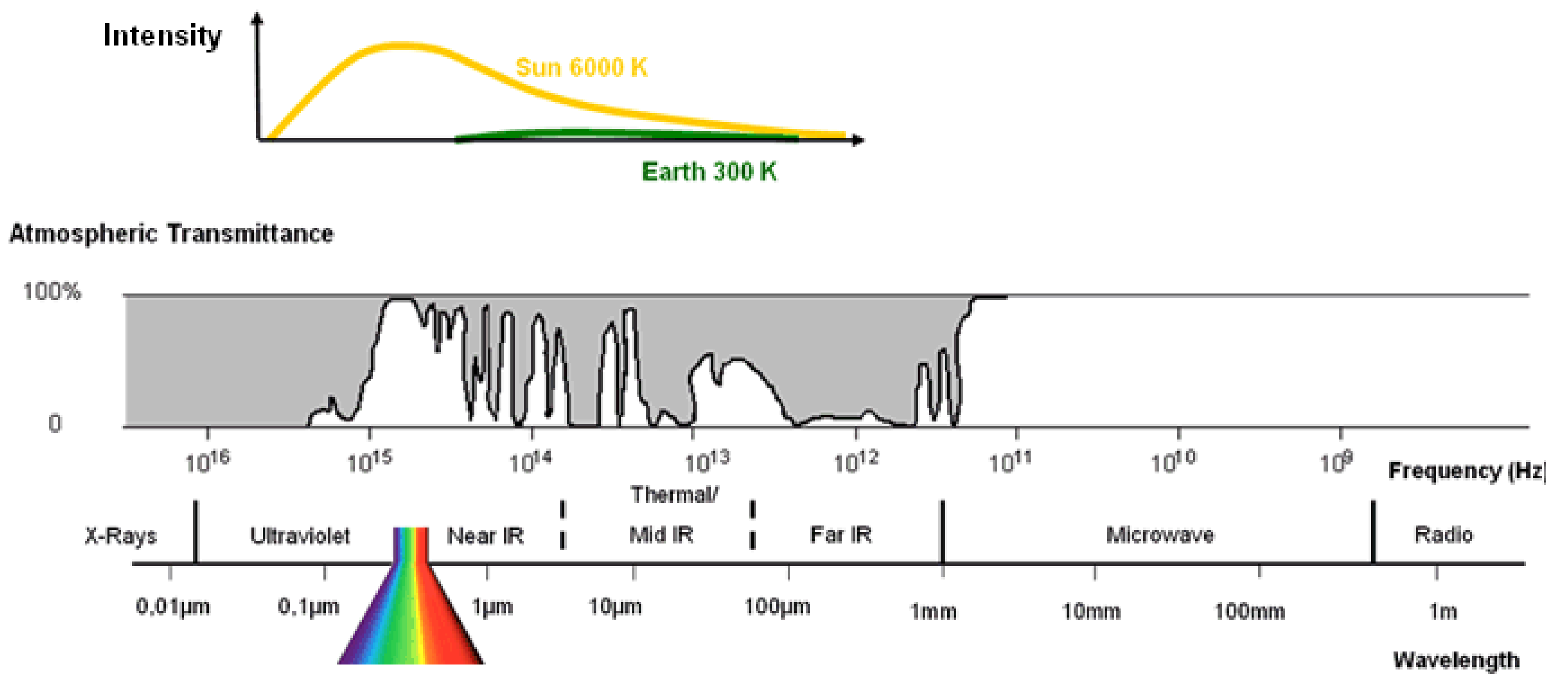
https://www.satellitevu.com



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

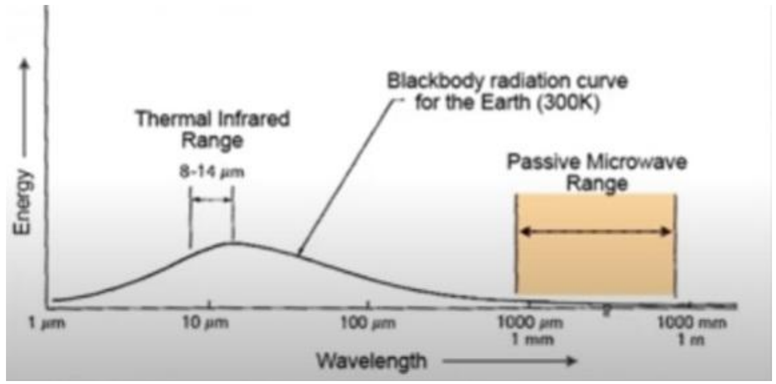
Microwave Sensing: 1mm to 1 metre (mostly 1cm-30cm)

These wavelengths beyond the infra-red can **'see through' clouds and light rain**, but there is a low amount … why we use these wavelengths for communication, and pixels need to be large e.g. 10-25 km



Thermal wavelengths see through smoke; microwave through clouds
Both can be used day / night assuming temperature is > 0 Kelvin (-273°C)

Passive microwave sensing is a continuation of recording thermal energy.
The signal is a **brightness temperature** but there is less terrestrial energy to sense, so a large pixel, ~ 10-25km is needed for radiometric resolution.



Digital Numbers give a measure of temperature which needs some conversion

Radiance (DN) = temperature x emissivity

Remote sensing at microwave wavelengths is effective because they are …

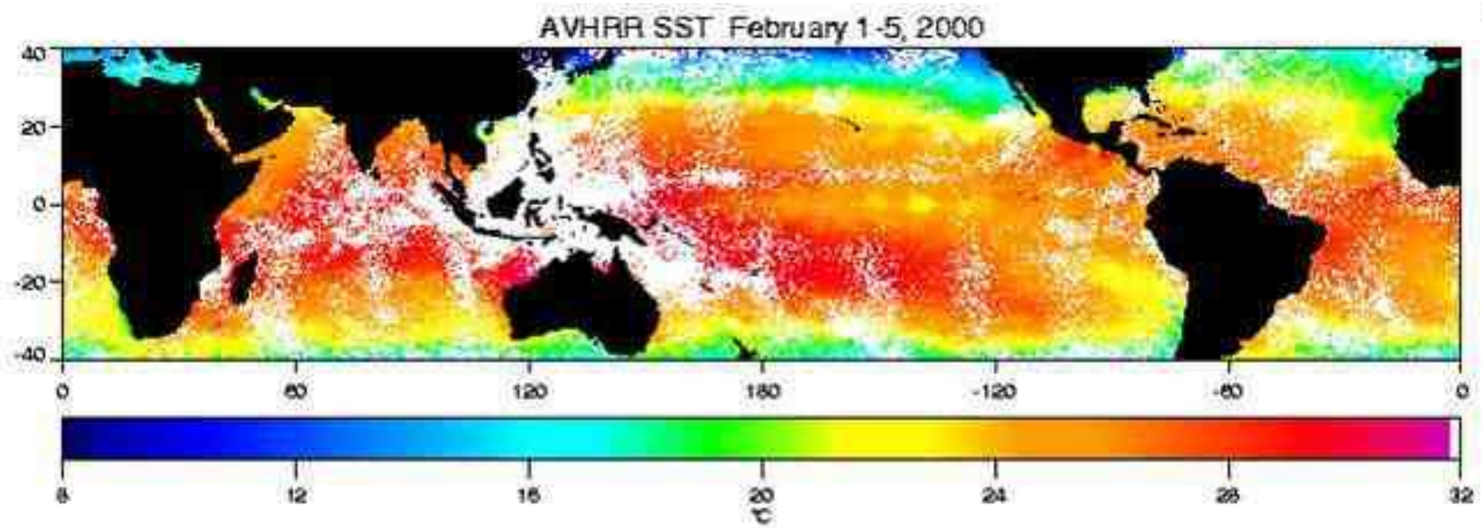
unaffected by clouds

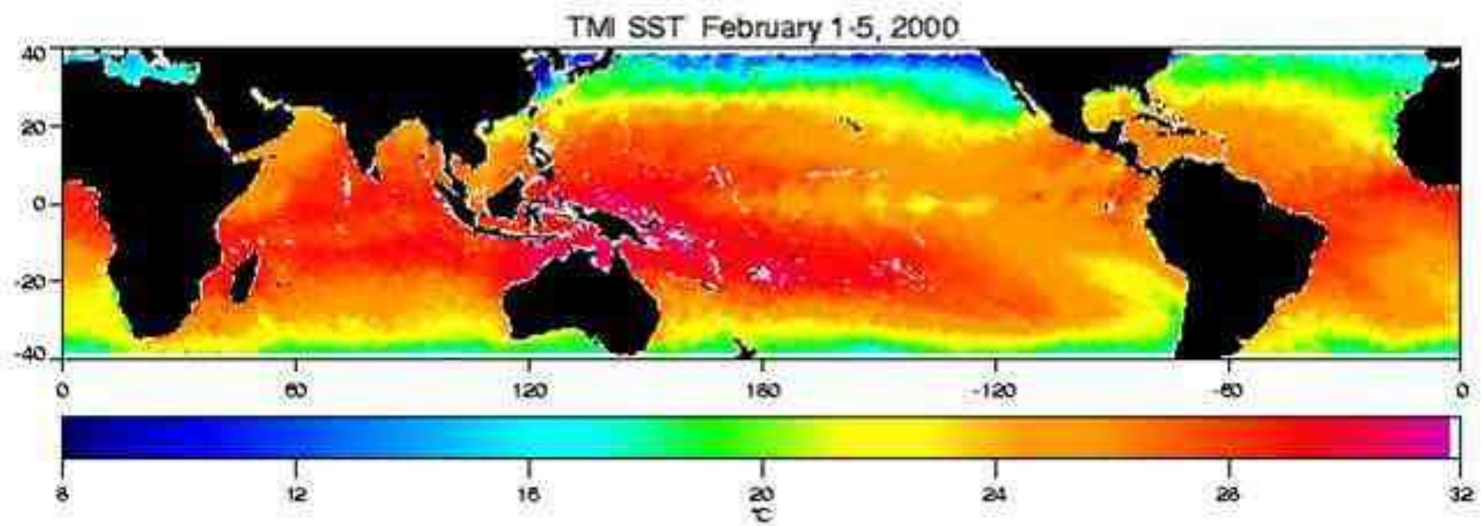
- **Microwave sensors: SMMR TMI-TRMM AMSR SSM/I ESMR**

It is used to monitor oceans, soil moisture, snow, sea ice cover and sea temperature.

Microwave RS is mostly about recording presence of <u>moisture</u>

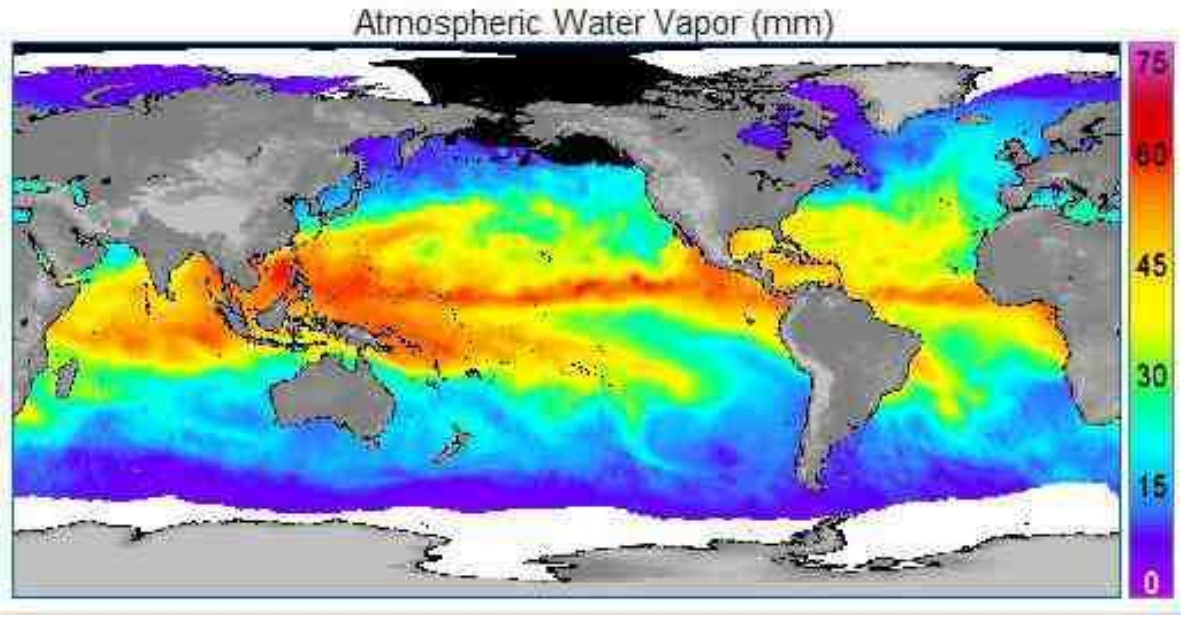
Sea Surface Temperature a. Thermal IR, b. Microwave passive

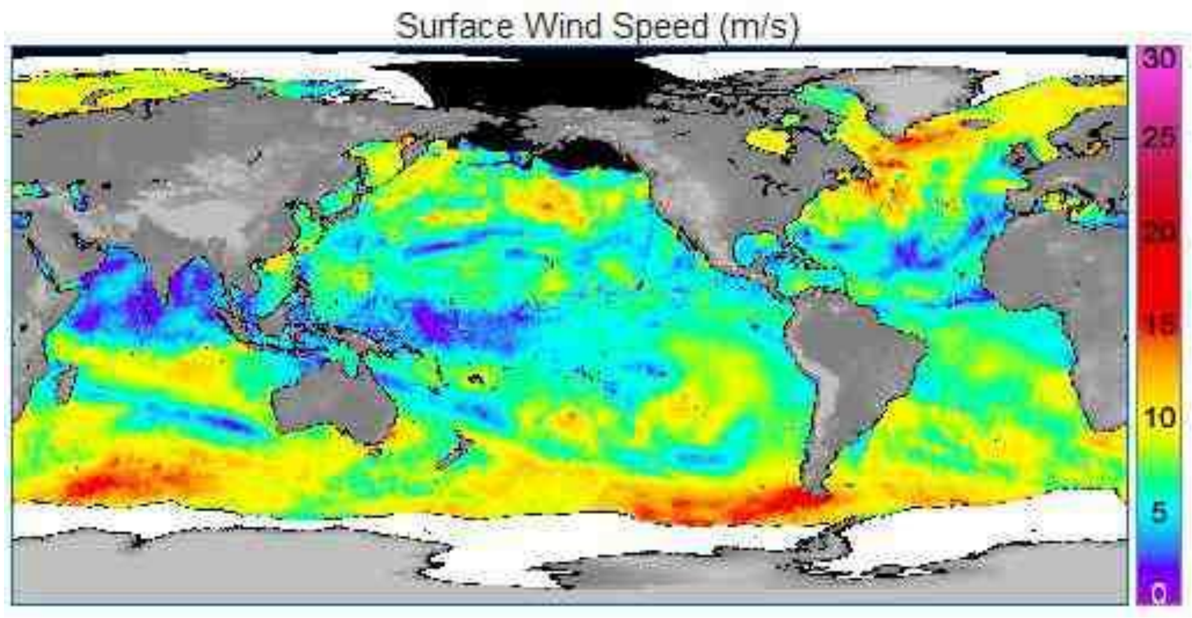


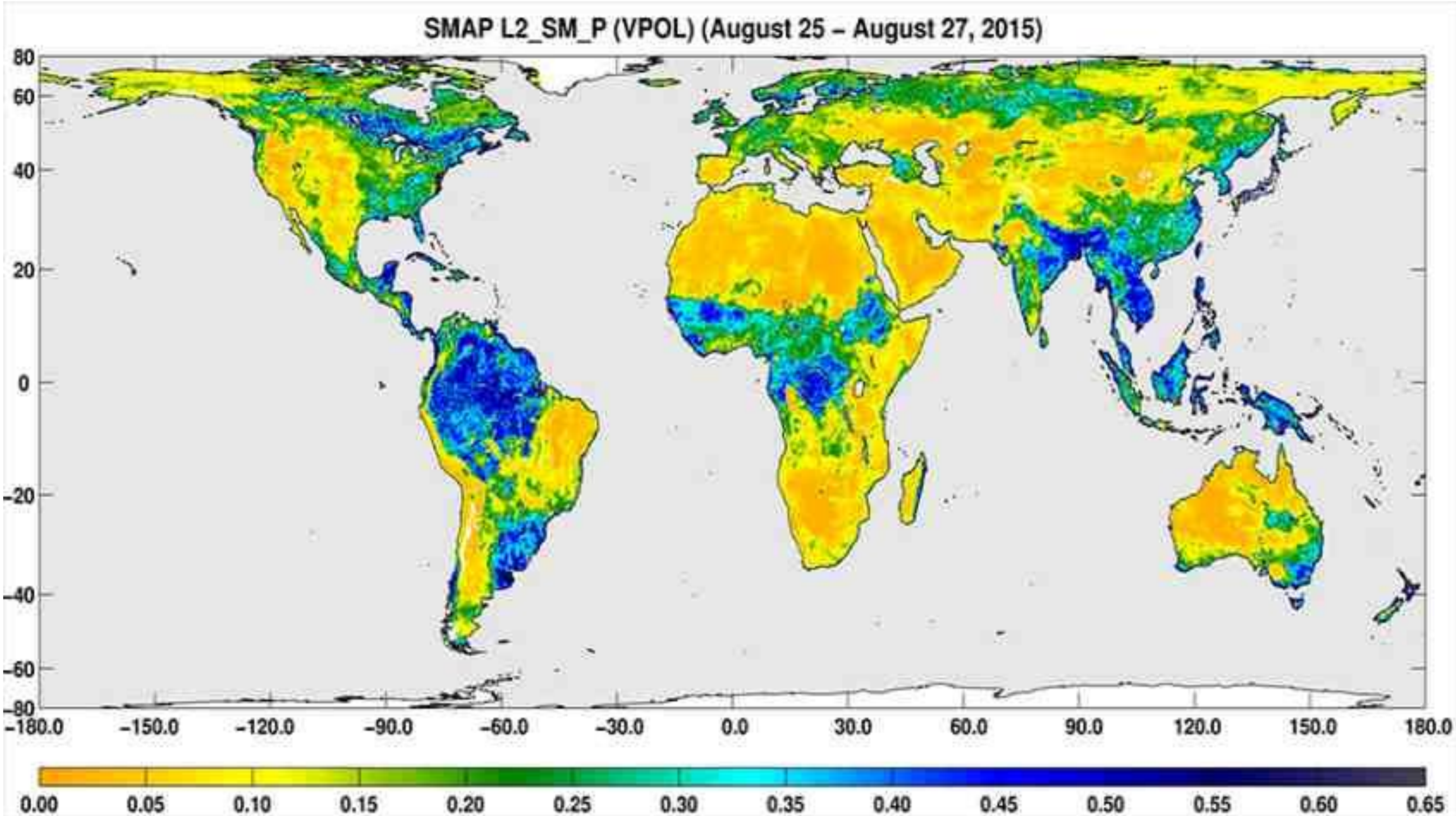


Thermal IR: higher resolution and accuracy; affected by clouds

Microwave: unaffected by clouds, sensitive to precipitation and surface roughness http://www.ssmi.com/ssmi/ssmi_data_weekly.html

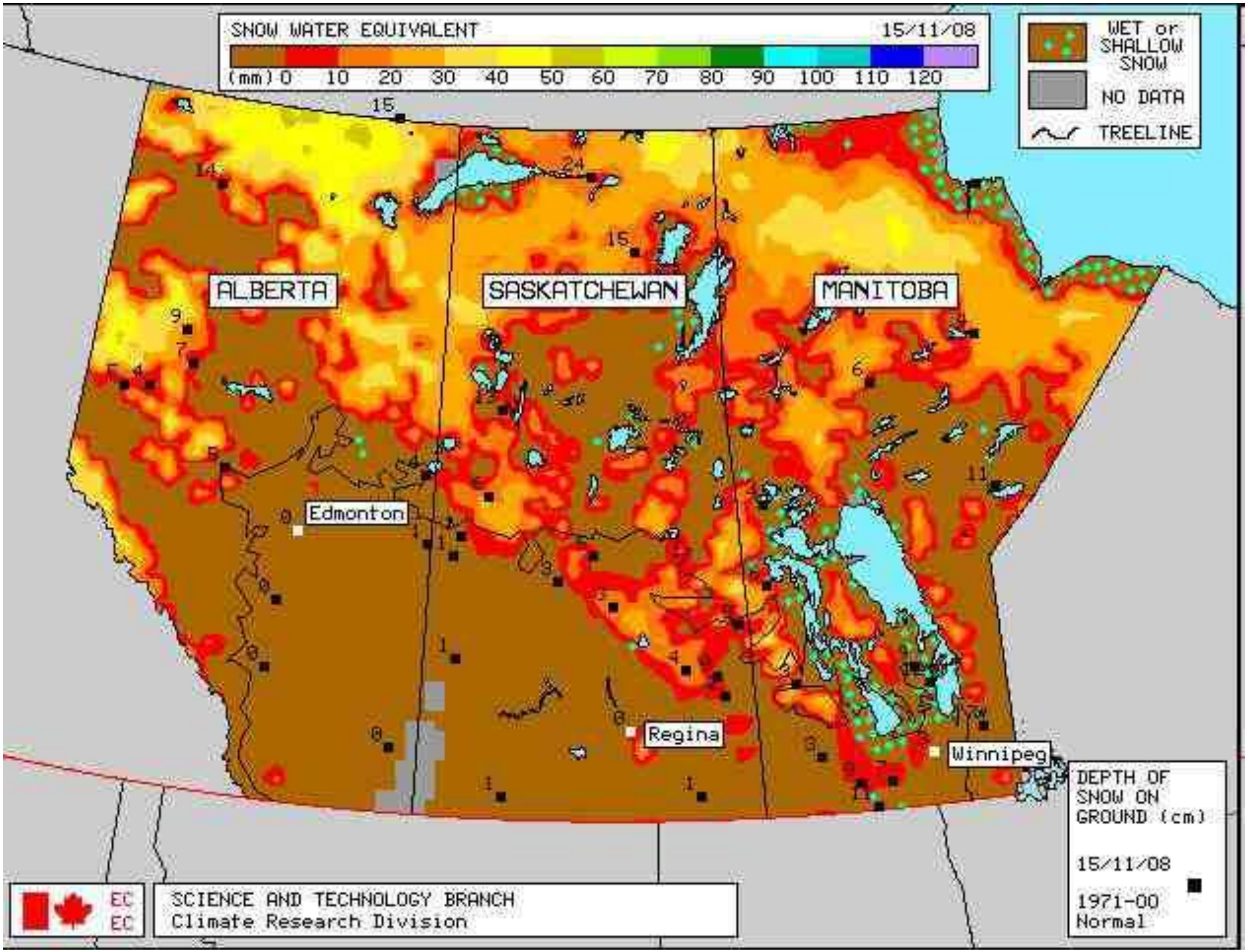






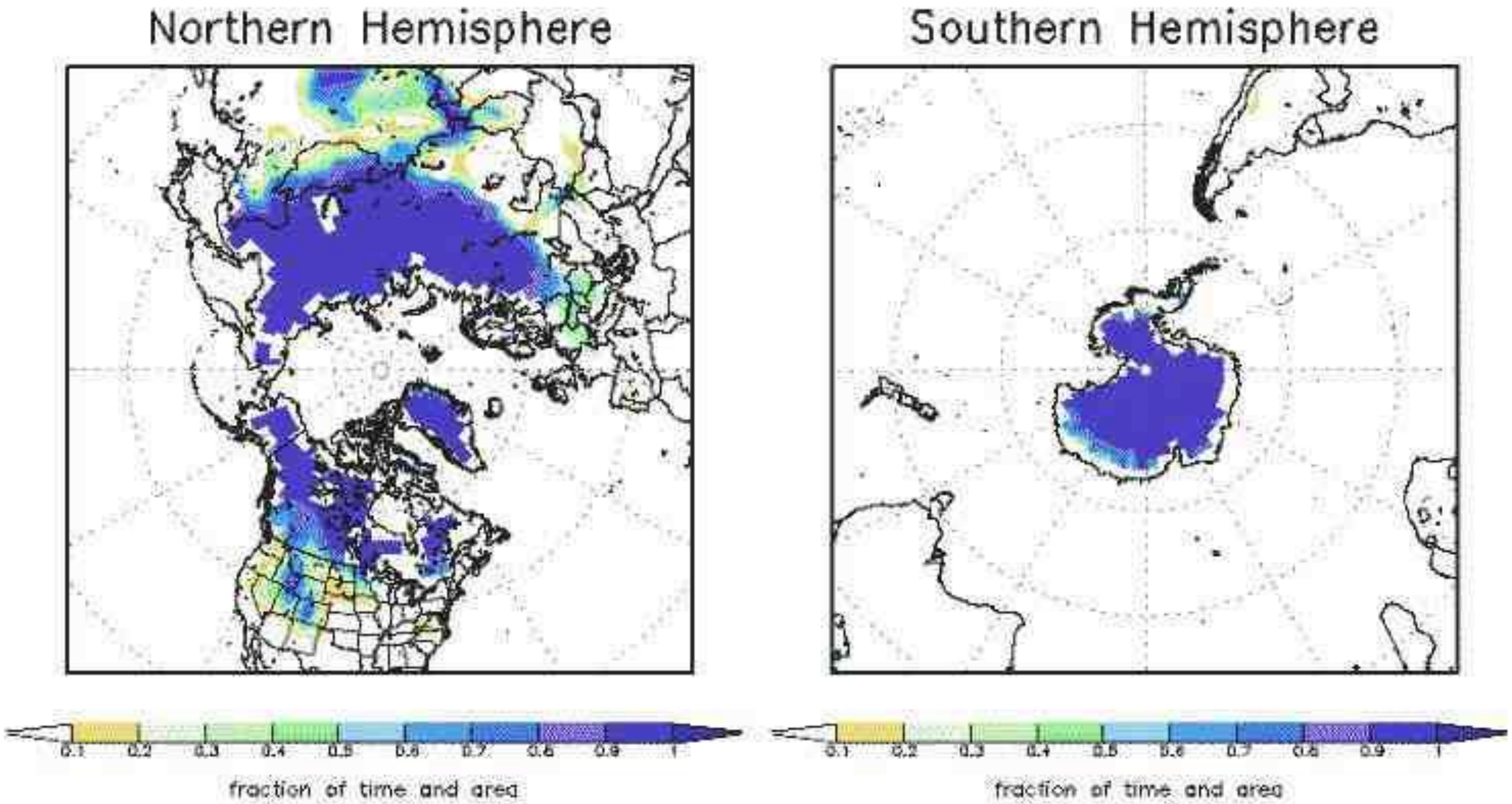
A three-day composite global map of surface soil moisture as retrieved from SMAP's radiometer instrument between Aug. 25-27, 2015. Wetter areas are blue and drier areas are yellow.
Image Credit: NASA: Soil Moisture Active Passive (*SMAP*)

Snow Water Equivalent Map for Canadian Prairies: AMSR-E



SSM/I Snow Cover for Mar 2005

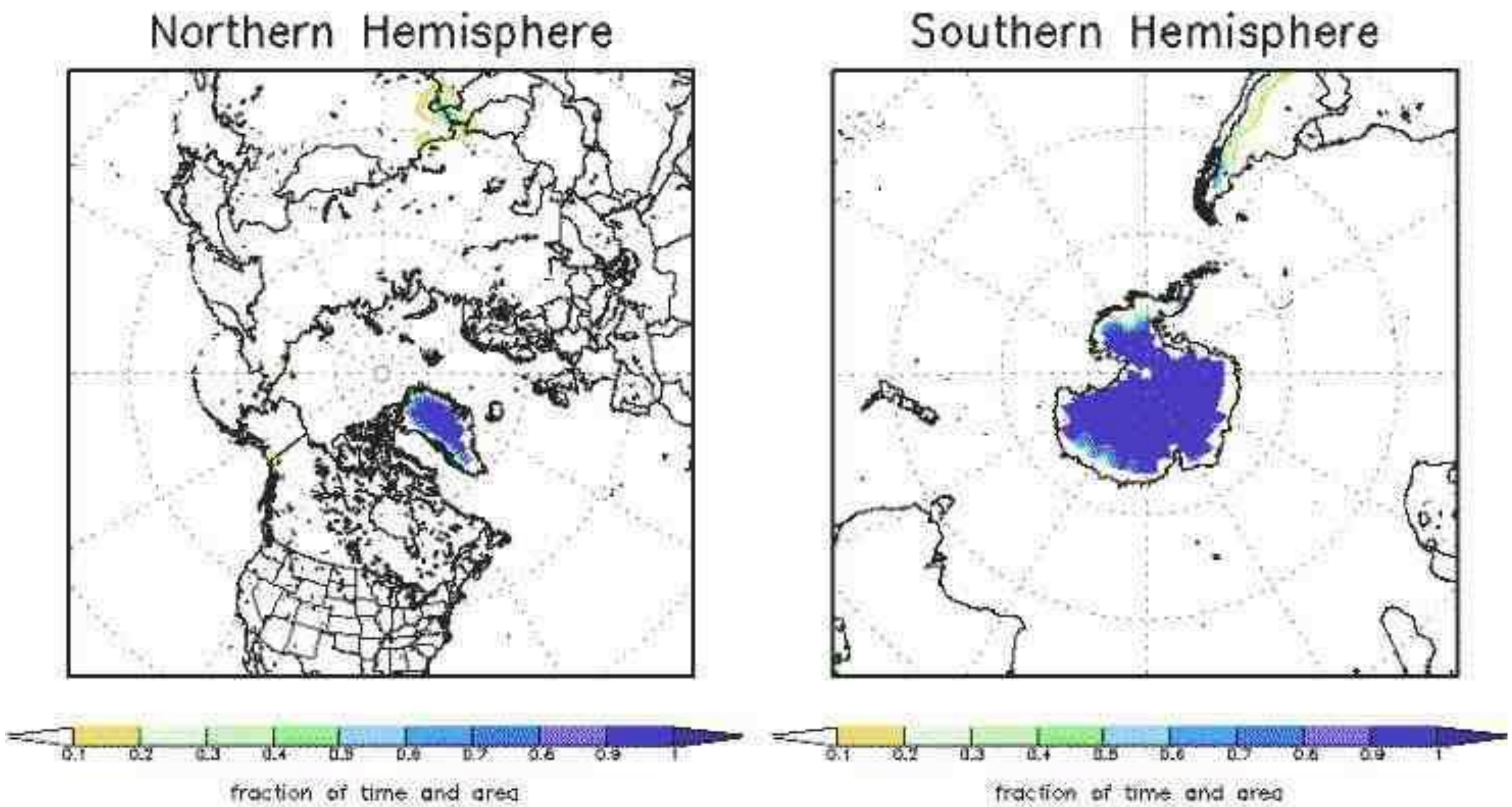
frequency of occurence



4 Apr 2005 NOAA/NESDIS/ORA/SCSB-CICS

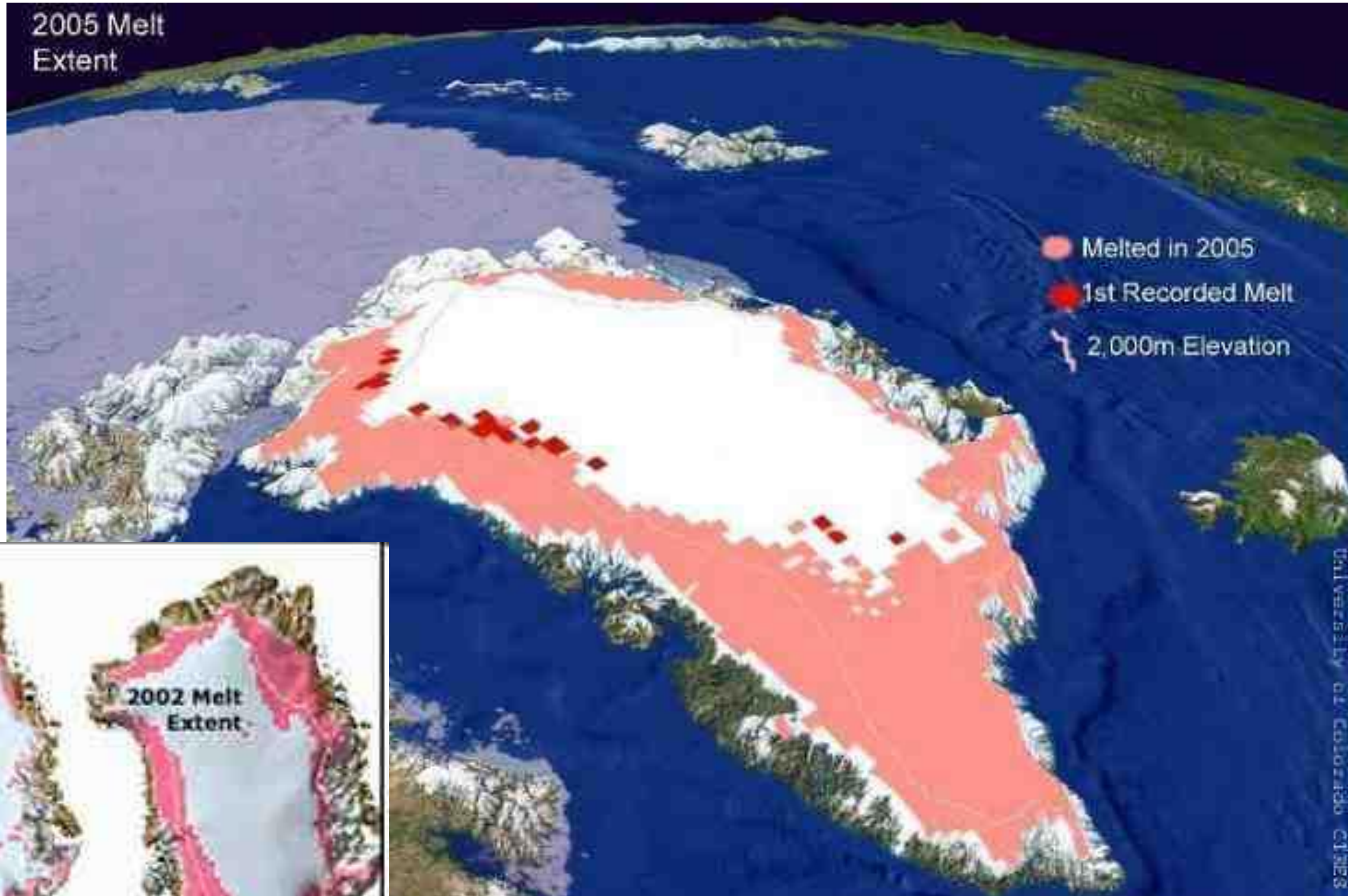
SSM/I Snow Cover for Jul 2005

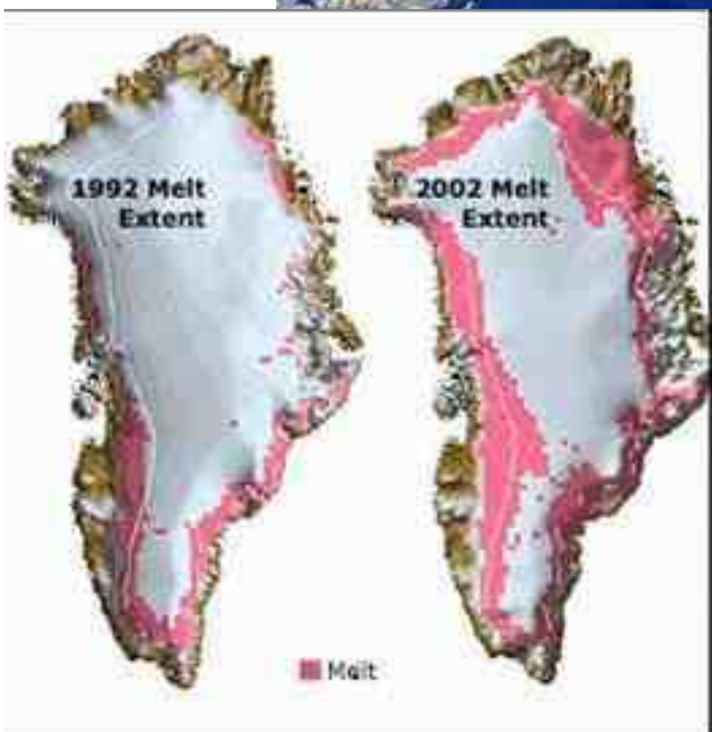
frequency of occurence



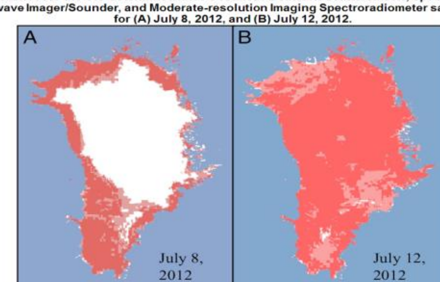
3 Aug 2005 NOAA/NESDIS/ORA/SCSB–CICS

Changes in snowmelt, Greenland





Melt extent over the GIS determined from Oceansat-2 satellite scatterometer, Special Sensor Microwave Imager/Sounder, and Moderate-resolution Imaging Spectroradiometer satellite data for (A) July 8, 2012, and (B) July 12, 2012.



Keegan K M et al. PNAS 2014;111:7964-7967

2012