EGM703 – Advanced Active and Passive Remote Sensing

Week 1, Part 4: Converting Radiance to Temperature

What is Temperature, anyway?

- Recall:
  - All substances made of atoms/molecules
  - Above absolute zero (0 K): atoms/molecules have vibrational motion
  - They also emit (radiate) energy
- Temperature: a measure of the average energy of atoms/molecules
  - High temperature: more energy (heat)
- *Kinetic* temperature: what you measure in contact with object/substance
- *Radiant* temperature: what you measure with remote sensing

Radiance values

- Recall: raw images must be converted to radiance
- Images must be calibrated:
  - Internal to the sensor
  - External
- For Landsat images:

$$L_{\lambda} = a * DN + b$$

  - i.e., a linear rescaling based on minimum/maximum radiance

Planck's Law of blackbody radiation

- Assuming a perfect blackbody:

$$L_\lambda = L(\lambda, T) = \frac{2hc^2}{\lambda^5}\left(\frac{1}{e^{hc/\lambda kT} - 1}\right)$$

- In other words:
  - L_λ depends on λ and T
  - If we can measure L_λ, we can calculate (radiant) T
- Note: most objects are not perfect blackbodies ($\varepsilon_\lambda < 1$)

Units	
L_λ	W sr^{-1} m^{-3}
λ	m
h	J s
k	J K^{-1}
c	m s^{-1}
T	K

Brightness temperature

- We can invert Planck's law to calculate brightness temperature:

$$T_b = \frac{hc}{k\lambda \ln\left(2hc^2 / L_\lambda \lambda^5 + 1\right)}$$

- *h*, *c*, and *k* are constants
  - For a given sensor, so is λ
- Can simplify:

$$T_b = \frac{K_2}{\ln\left(K_1 / L_\lambda + 1\right)}$$

$$K_2 = \frac{hc}{k\lambda}$$

$$K_1 = \frac{2hc^2}{\lambda^5}$$

Emissivity correction

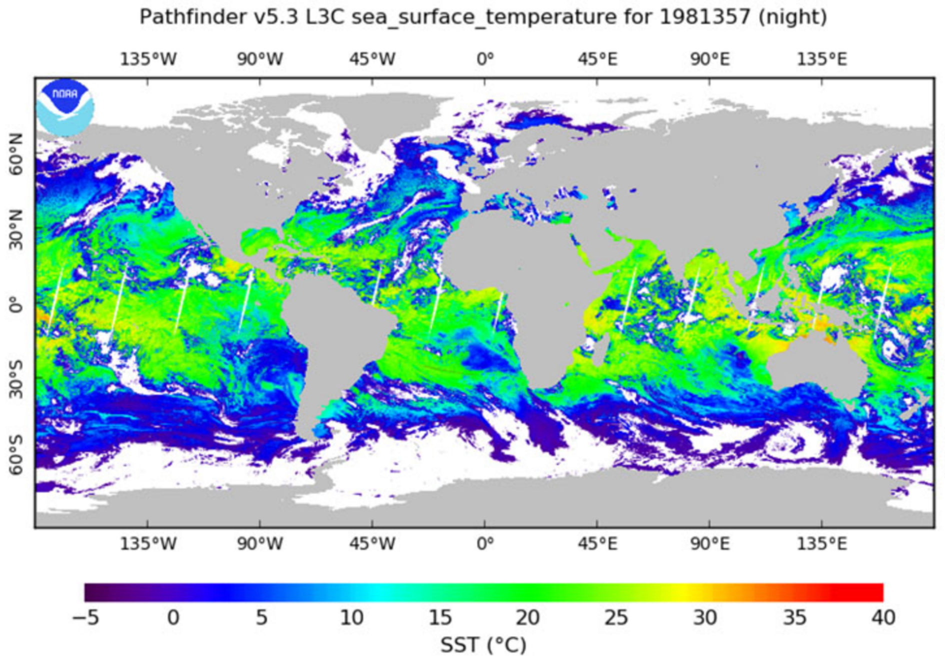
- This is assuming a blackbody with $\varepsilon_\lambda = 1$
  - As we have seen, this usually isn't true
- Need to correct for $\varepsilon_\lambda < 1$ (Artis and Carnahan, 1982):

$$T_s = \frac{T_B}{1 + \left(k \lambda T_B / hc\right) \ln\left(\varepsilon_\lambda\right)}$$

- Note: this approach neglects atmospheric component of L_λ (or assumes it's already corrected)

Advanced Very High Resolution Radiometer (AVHRR)

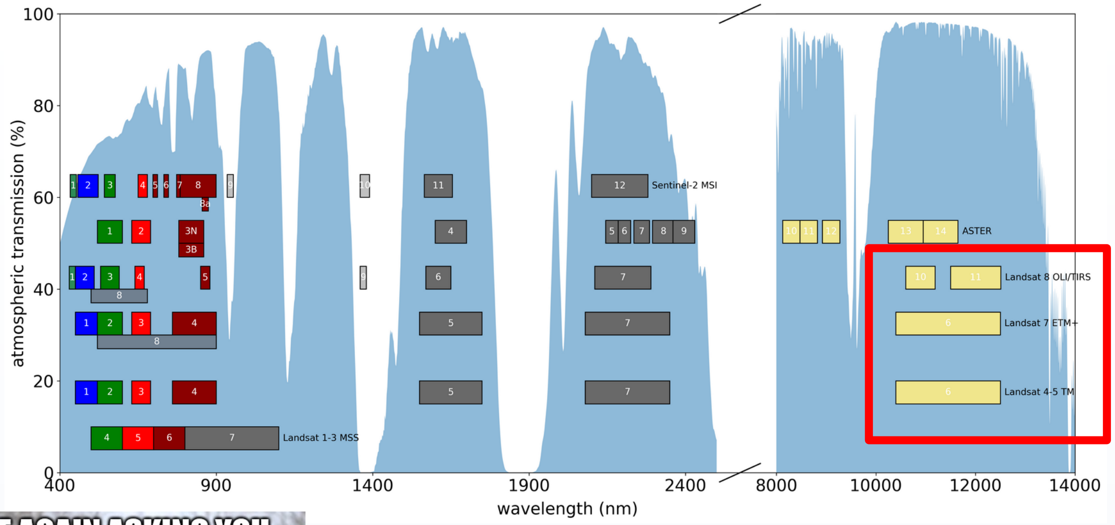
- First launched: 1978
- Modes:
  - Local area coverage (LAC): ~1.1 x 1.1 km resolution
  - Global area coverage (GAC): ~1.1 x 4 km resolution
- Two versions (either 4 or 5 bands)
  - Version 1:
    - Band 4: 10.50 – 11.50 µm
  - Version 2:
    - Band 4: 10.30 – 11.30 µm
    - Band 5: 11.50 – 12.50 µm
- Succeeded by VIIRS
- earthdata.nasa.gov

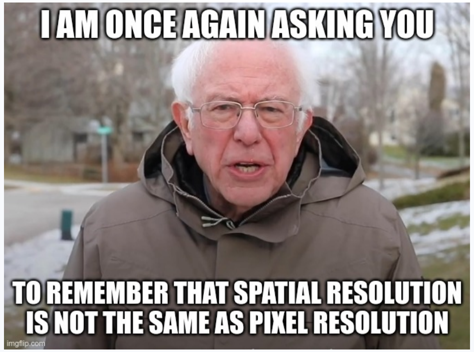


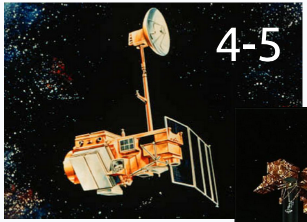
NOAA NCEI

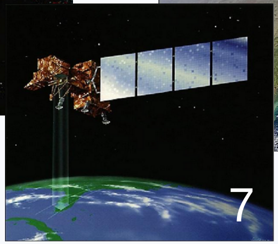
The Landsat program

- Landsat 4/5 TM band 6
  - Coverage: 1982 – 2011
  - 10.4 – 12.5 µm
  - 120 m spatial resolution*
- Landsat 7 ETM+ band 6
  - Coverage: 1999 – (ongoing)
  - 10.4 – 12.5 µm
  - 60 m spatial resolution*
- Landsat 8 TIRS
  - Coverage: 2013 – (ongoing)
  - Band 10: 10.6 – 11.19 µm
  - Band 11: 11.5 – 12.51 µm
  - 100 m spatial resolution*
- Landsat 9 TIRS: coming soon!
- earthexplorer.usgs.gov



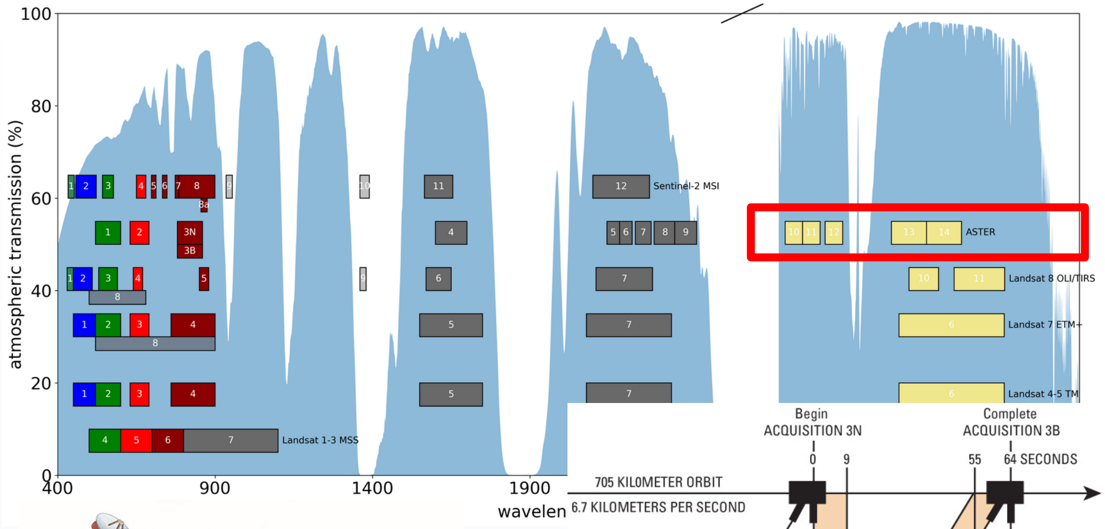


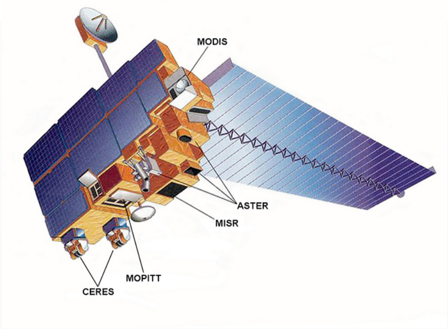


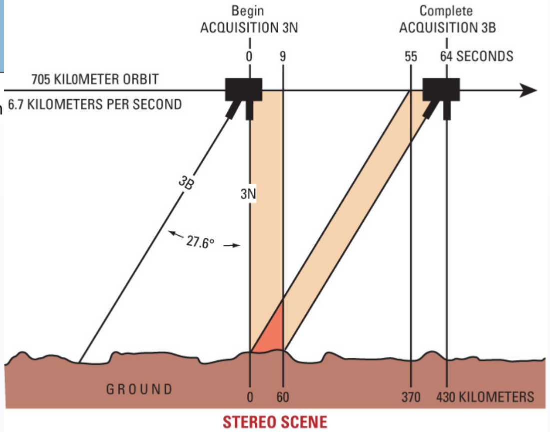


ASTER

- Coverage: 2000 – (ongoing)
- Thermal Infrared:
  - Band 10: 8.125 – 8.475 µm
  - Band 11: 8.475 – 8.825 µm
  - Band 12: 8.925 – 9.275 µm
  - Band 13: 10.25 – 10.95 µm
  - Band 14: 10.95 – 11.65 µm
  - 90 m spatial resolution
- Level-2 products include temperature, emissivity
- search.earthdata.nasa.gov







Summary

- In thermal infrared, satellites measure radiance
- Once calibrated, can calculate brightness temperature from radiance values
- To get land surface temperature, need emissivity
  - Should also correct atmospheric effects
- Lots of satellites have thermal infrared sensors

Additional resources

- Lillesand, Kiefer & Chipman – Chapter 4.11
- AVHRR [USGS EROS Archive]
- Landsat Calibration & Validation [USGS]
- Artis and Carnahan, 1982
  [Remote Sens. of Env.]
- Avdan and Jovanovska, 2016 [Journal of Sensors]
- Jiménez-Muñoz et al., 2014 [IEEE Geosci. Remote Sens. Lett.]