137 MHz Weather Satellite Imagery

Why, how and what is it?

Basic Questions of Remote Sensing

The Geographer asks

"What can I learn from this image?"

The Physicist asks

“Why is there an image?”

What features of the earth's surface can we see from space, and why can we see them?

This is principally a problem of the generation, transmission and absorption of electromagnetic energy

Elements of a Remote Sensing System

- A source of EM energy
  - Natural: thermal radiation
    - Broad spectrum
  - Artificial: radio transmitters, lasers, etc
    - Narrow spectrum
- A transmission path
  - We need to be able to “see” the earth from space
- A surface whose response to the radiation is not uniform

The First Point

What is the source of the E-M radiation?

Planck's Law
Black Body Radiation

$$s(\lambda) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}$$

s = Radiant Energy

Decreasing wavelength increases energy

Decreasing wavelength decreases energy

Increasing temperature increases energy

...eng...

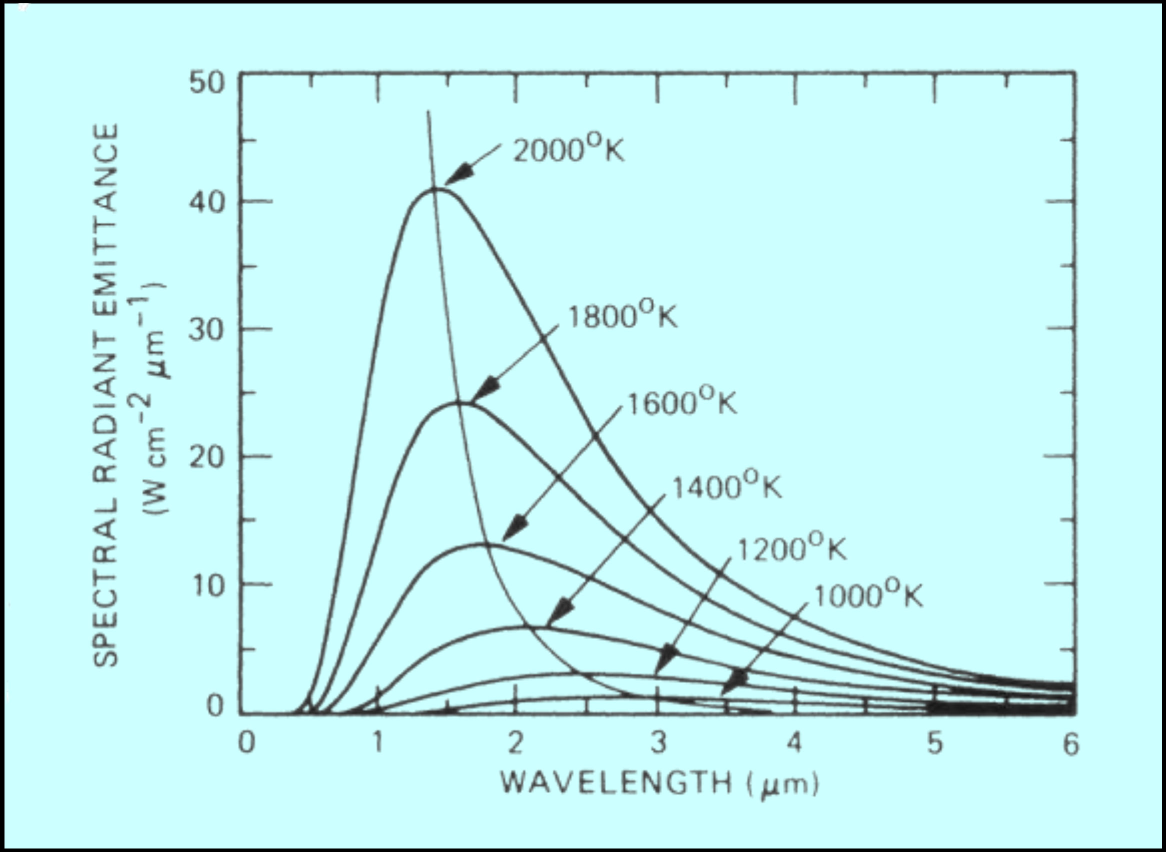
...erat...

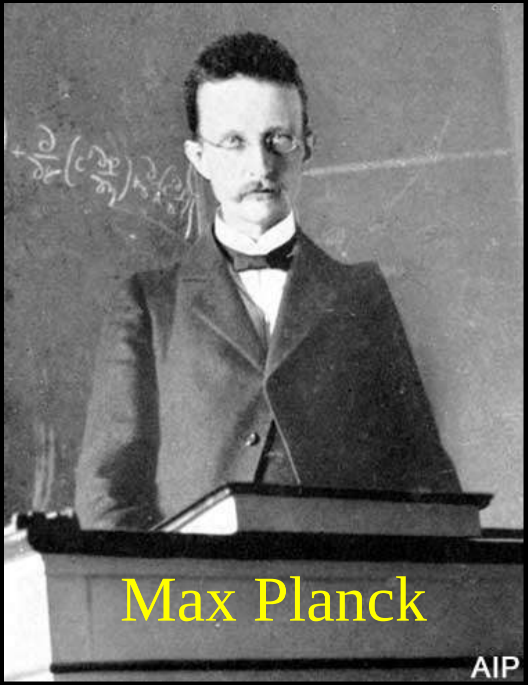
...of...

k = Boltzmann's Constant

h = Planck's Constant

And here's what it looks like





Max Planck

Properties of a Black Body

A Black Body is a perfect emitter and absorber of energy

No object at the same temperature as a Black Body can emit more energy than the Black Body

Nothing is a perfect Black Body but some are very close

EVERYTHING warmer than 0K emits Black Body radiation!

- Integrate over all λ to give total energy (Stefan-Boltzmann Law)

$$S = \sigma T^4, \ \sigma = 5.669 \times 10^{-8} \mathrm{Wm}^{-2}\mathrm{K}^{-4}$$

- Differentiate wrt λ, set to 0, gives S_{max} as a function of T (Wien's Displacement Law)

$$\lambda_m = \frac{a}{T}, \quad a = 2898 \mu\mathrm{mK}$$

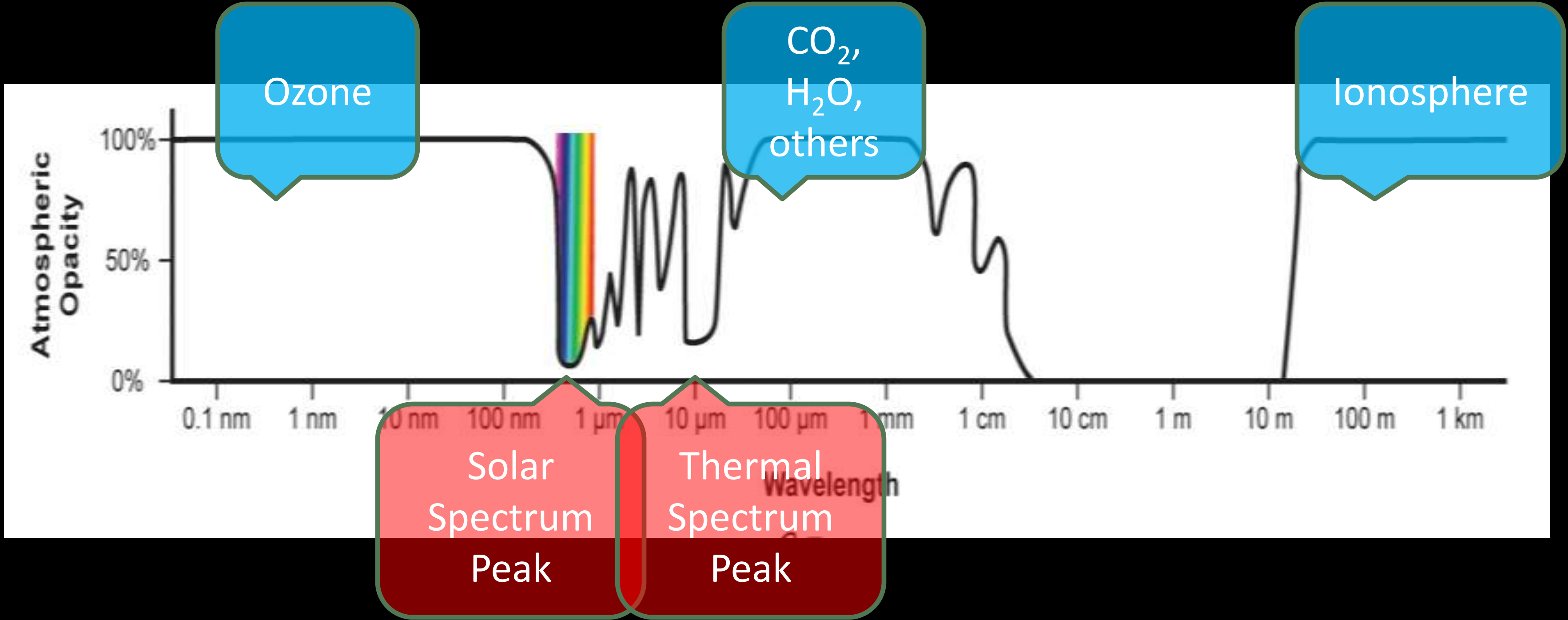
Sun T=6000K, λ_{peak}=500nm

Earth T=300K, λ_{peak}=10μm

The Second Point

Why can we see the earth's surface from space?

The atmosphere is opaque at most wavelengths



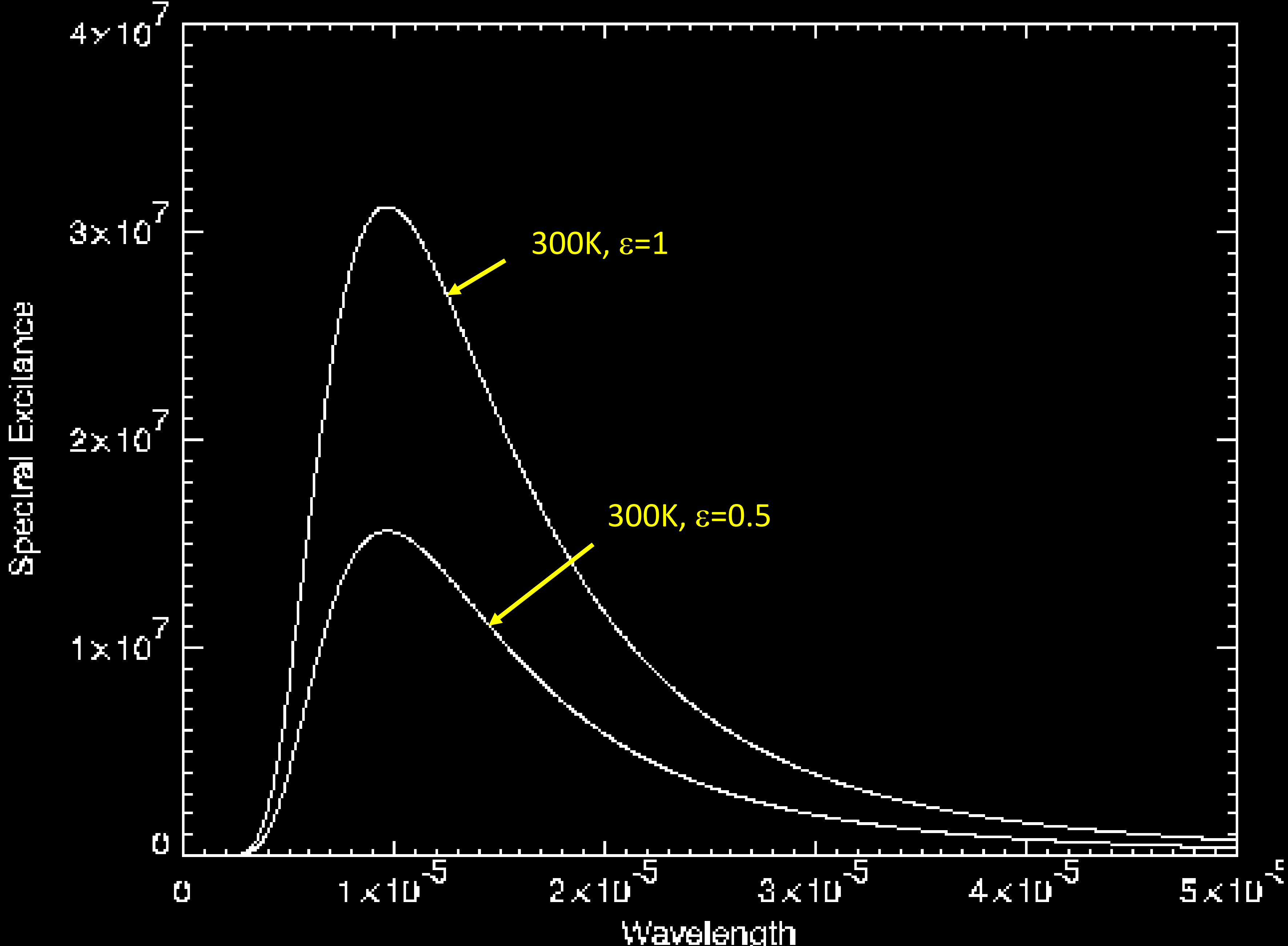
Only in the visible, infrared and microwave regions are there 'atmospheric windows'

- Most objects are not as efficient at radiating as a black body, so emit

$$S'(\lambda) = \epsilon(\lambda)S(\lambda)$$

$$\epsilon(\lambda) = \frac{S'(\lambda)}{S(\lambda)}$$

- ε is the emissivity, the ratio of the actual emittance of an object to that of a black body at the same temperature.

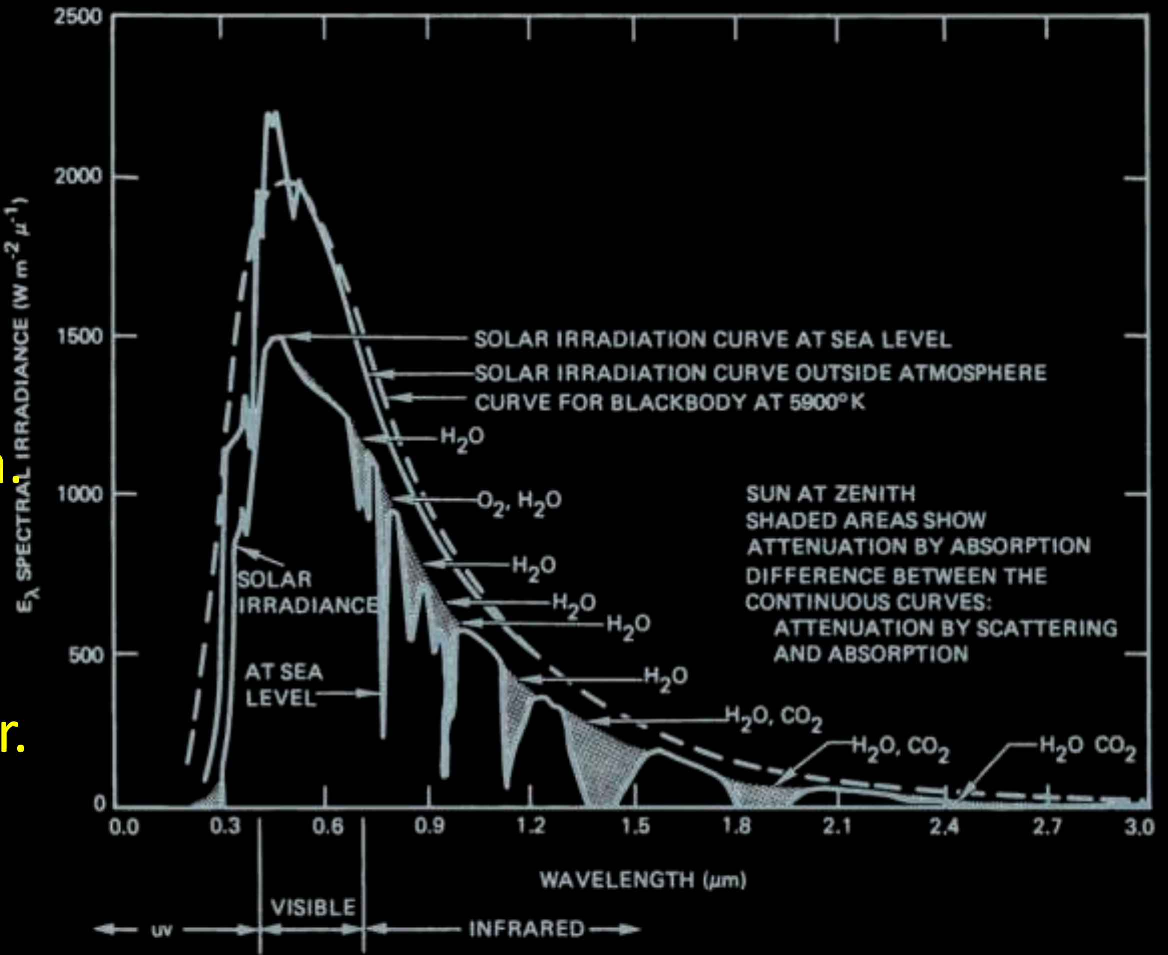


4×10^7
3×10^7
2×10^7
1×10^7
0
Spectral Excitance
0
1×10^-5
2×10^-5
3×10^-5
4×10^-5
5×10^-5
Wavelength
300K, ε=1
300K, ε=0.5

Not all the radiation that hits the top of the atmosphere reaches the ground.

There are losses to scattering and absorption.

These same processes affect upgoing radiation, and must be corrected for.



Sun illumination spectral irradiance at the Earth's surface. (From Chahine, et al. 1983.)

Top of the atmosphere: S=1471 W/m^2 (the Solar Constant)
Ground level: about half, ~700 W/ m^2

From: *The Physics and Techniques of Remote Sensing*, 2nd Ed. Charles Elachi, 2007

Temperature Estimation

Satellite measures: $L(\lambda)$ Spectral Radiance (radiant flux /unit bandwidth/unit angle)

If the source is Lambertian (radiates equally in all directions):

$$L(\lambda) = S(\lambda)/\pi$$

We measure L(λ), estimate S (λ), and then invert Planck's Law to get temperature.

Brightness Temperature

The temperature of a perfect radiator (black body) that has a certain emittance S

i.e. A black body at 300K emits $S = 9.9 \times 10^{7}$ W m^{-2} m^{-1} sr^{-1} at $\lambda = 10^{-5}$m.

So, if this value is emitted by any object, its brightness temperature is 300K, no matter what its true thermodynamic, or physical temperature is.

Relationship between Brightness Temperature and Thermodynamic Temperature

$S' = \varepsilon S$

so

$$T_B = \frac{hc}{\lambda k} \frac{1}{\ln\left[\frac{2hc^2}{S'\lambda^5} + 1\right]}$$

and

$$T_T = \frac{hc}{\lambda k} \frac{1}{\ln\left[\frac{2h\varepsilon c^2}{S'\lambda^5} + 1\right]}$$

$$T_T \geq T_B$$

$\varepsilon < 1$ so the argument of the ln decreases, decreasing the value of the ln, increasing the value of its inverse, and consequently of T

Example:

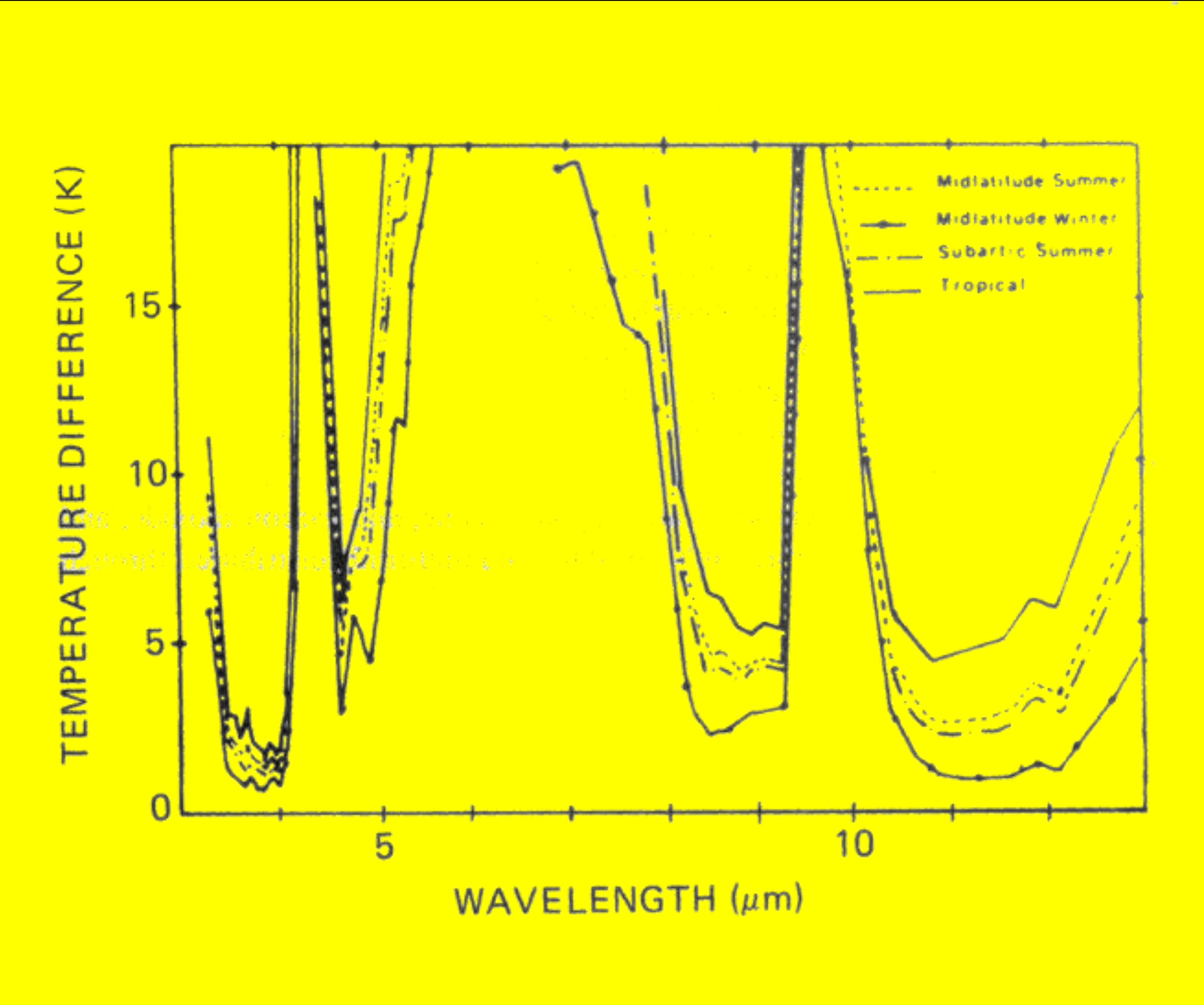
At 10μm, a 300K black body emits $S=9.9\times10^{7}$ W m^{-2} m^{-1} sr^{-1}

A grey body, with $\varepsilon=0.5$, at the same temperature and wavelength emits half as much radiation: $S'=4.9\times10^{7}$ W m^{-2} m^{-1} sr^{-1}

Using this value in the inversion of Planck's Law gives $T_B=262$K.

We can ALWAYS compute a brightness temperature of an object, but to estimate the true temperature of it, we must know its emissivity. (and atmospheric effects)

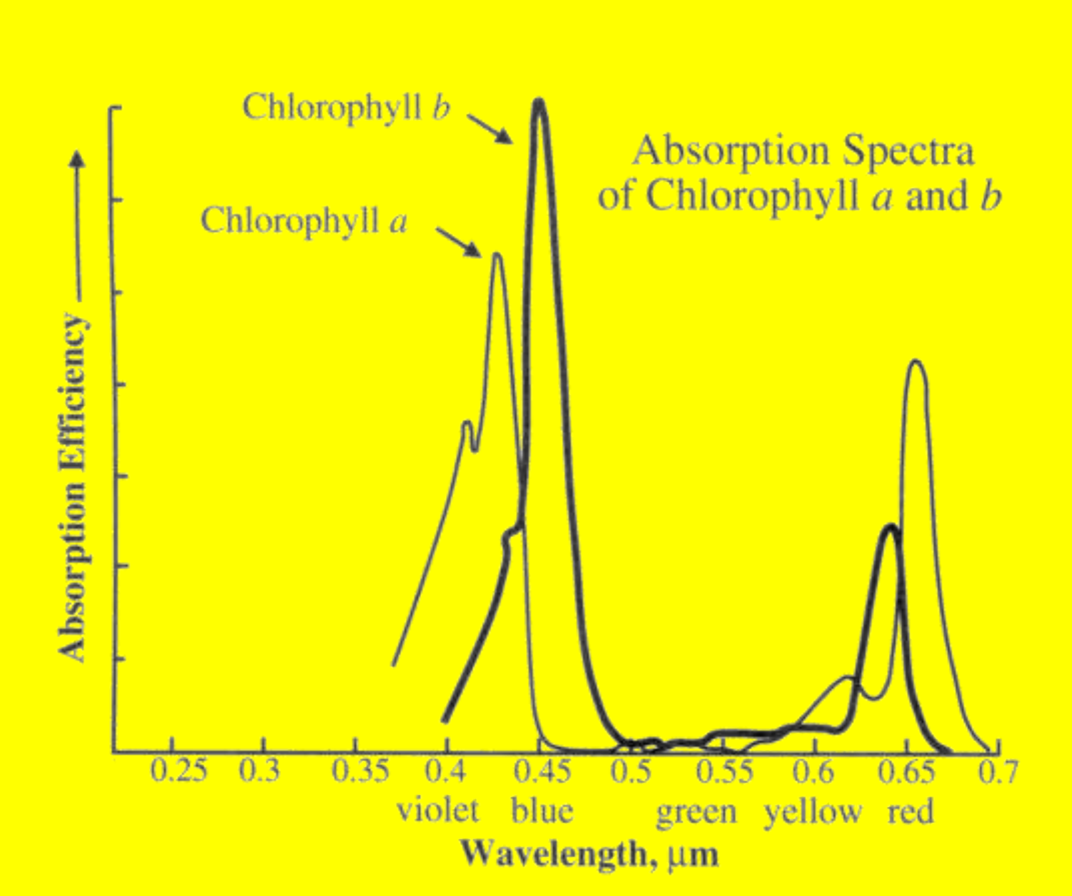
Sea Surface Temperature Estimation



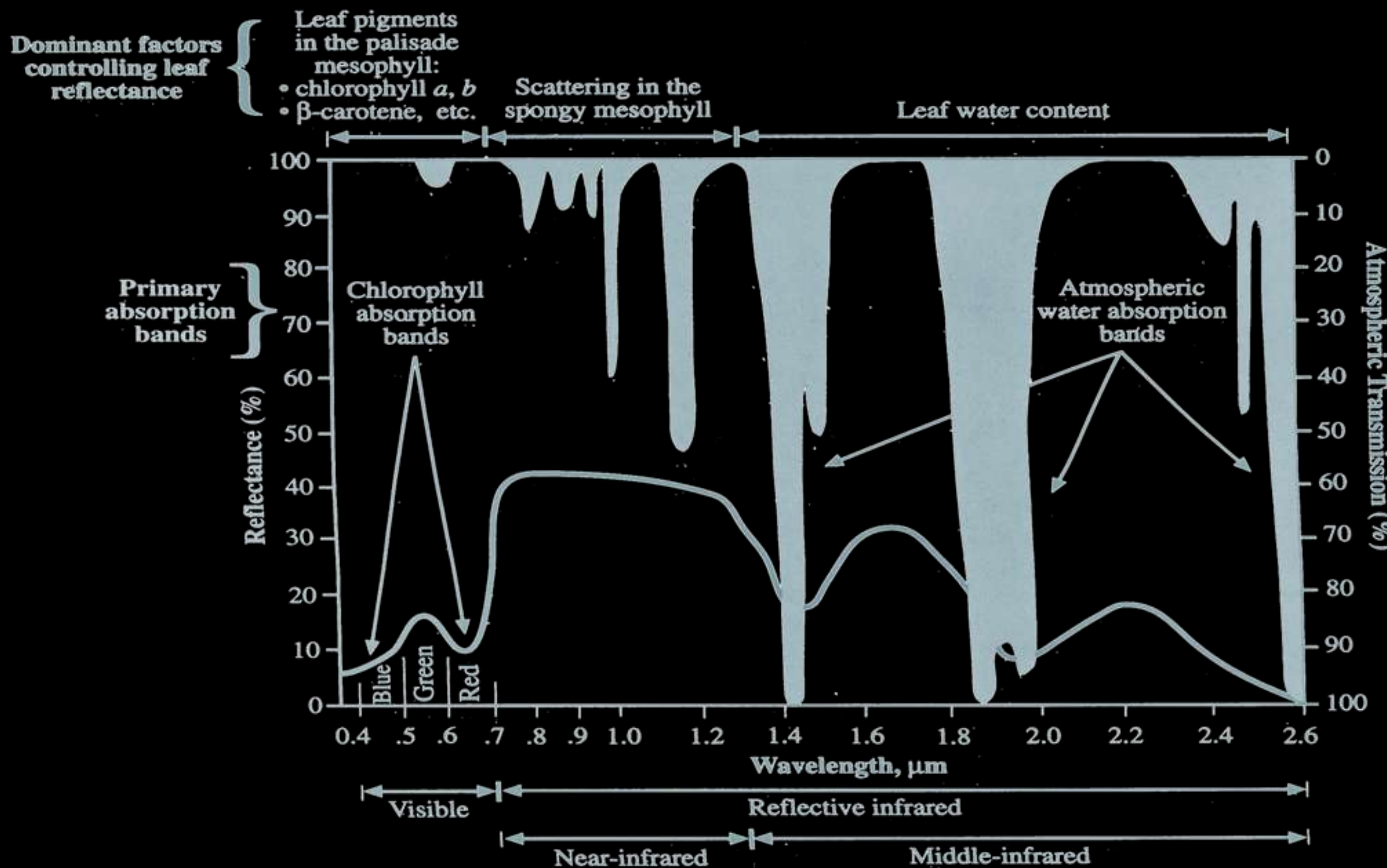
We know the emissivity of sea water (~1) so need only correct for the atmosphere

Imaging Vegetation

All green plants contain chlorophyll which absorbs light in both red and blue regions of the visible spectrum.

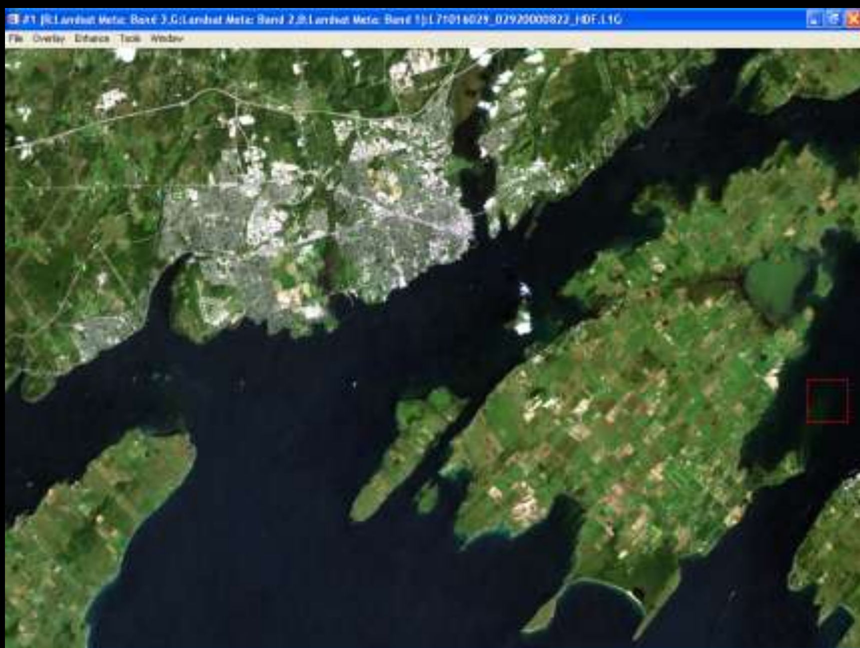


Spectral Response of Healthy Vegetation



From: *The Physics and Techniques of Remote Sensing*, 2nd Ed. Charles Elachi, 2007

Healthy Vegetation:
Low Red values, High Near Infrared Values



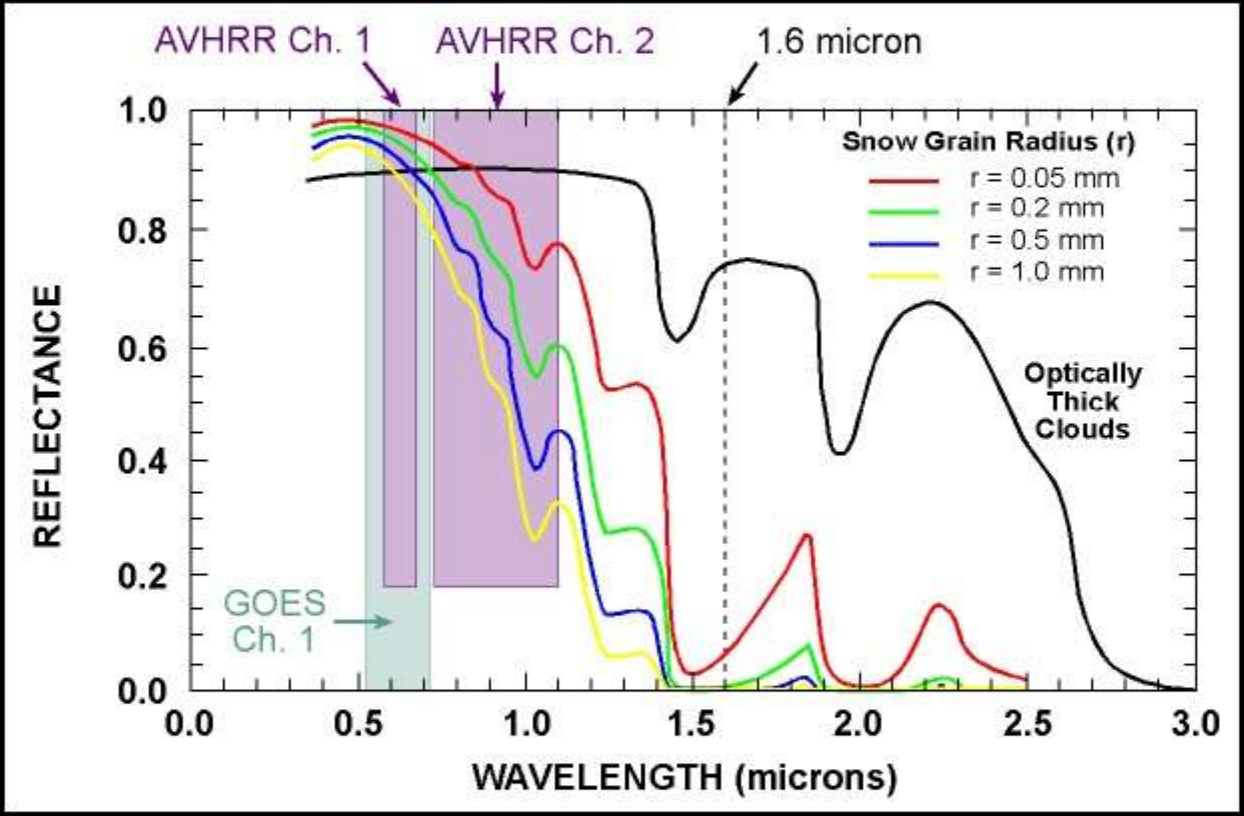
True Colour

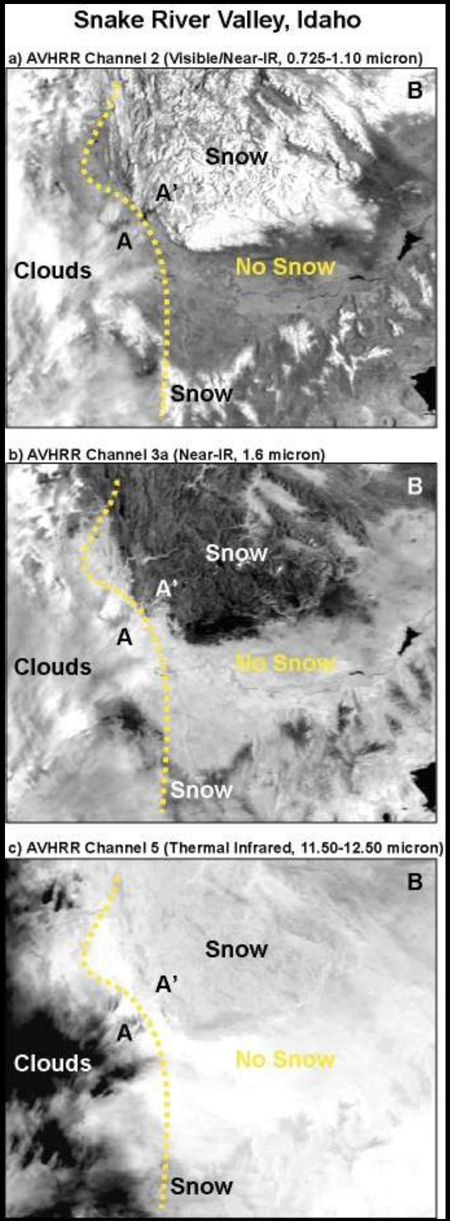
R → R
G → G
B → B
Measured → Displayed

False Colour

NIR → R
R → G
G → B
Measured → Displayed

Ice, Snow and Cloud





Instrument Design Criteria

- For vegetation, estimate reflectivity in red, red shoulder
- For ocean temperature, estimate radiance around 10μm
- For ice and snow, estimate reflectivity at 1.6μm

- Global sea surface temperature is a critical component in weather forecasting
- Ocean phenomena are large, but vary quickly
- A sensor therefore should give global coverage daily

The Advanced Very High Resolution Radiometer (AVHRR)

AVHRR

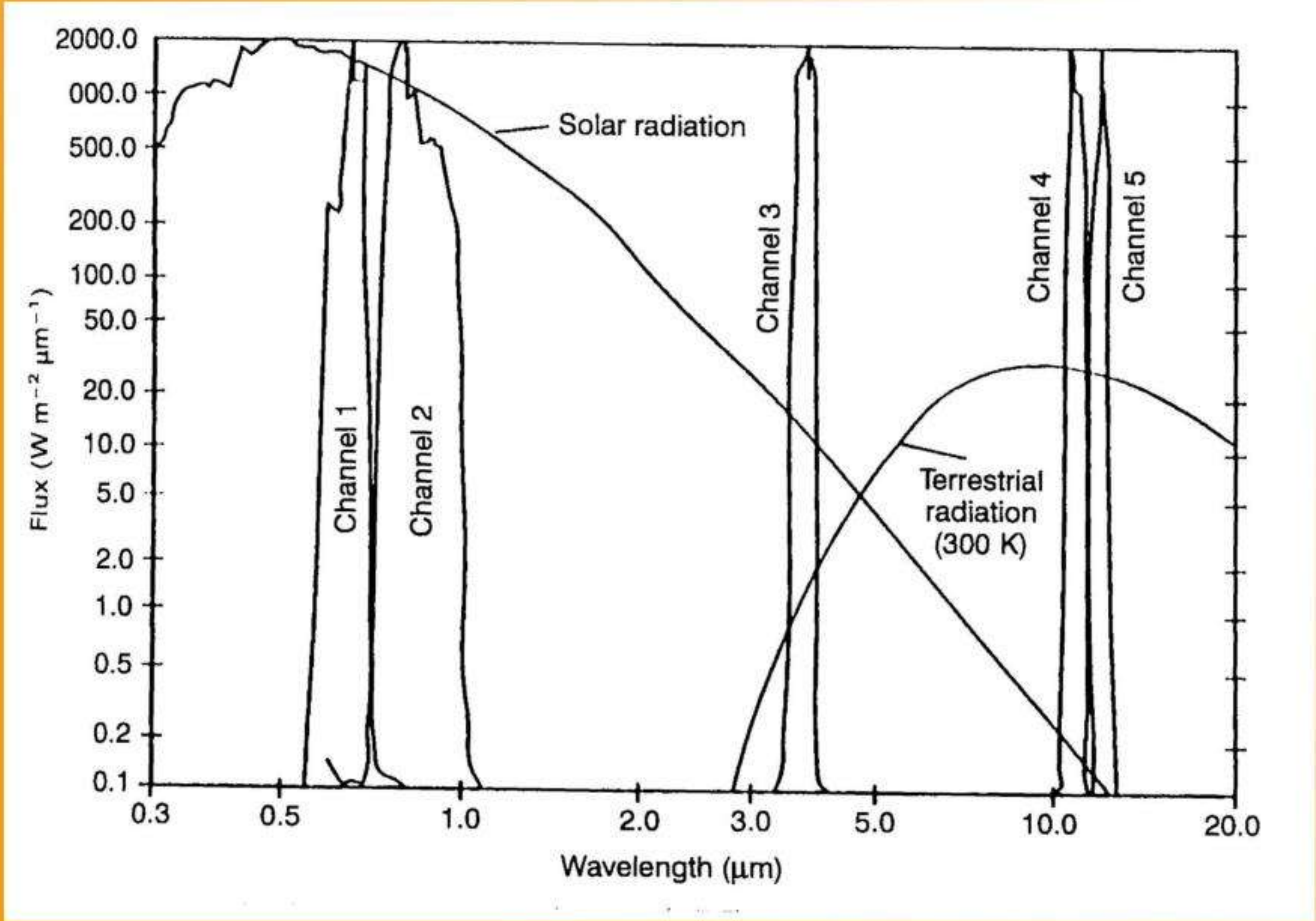
- A five (four, six) channel instrument to map ocean temperature, vegetation, cloud cover.
- Daily coverage
  - 2800km swath width
  - 14.1 orbits/day
- First flown in 1978, at least one in orbit ever since
- On NOAA and Metop satellites
- The basis for the MSU-MR on Meteor M2

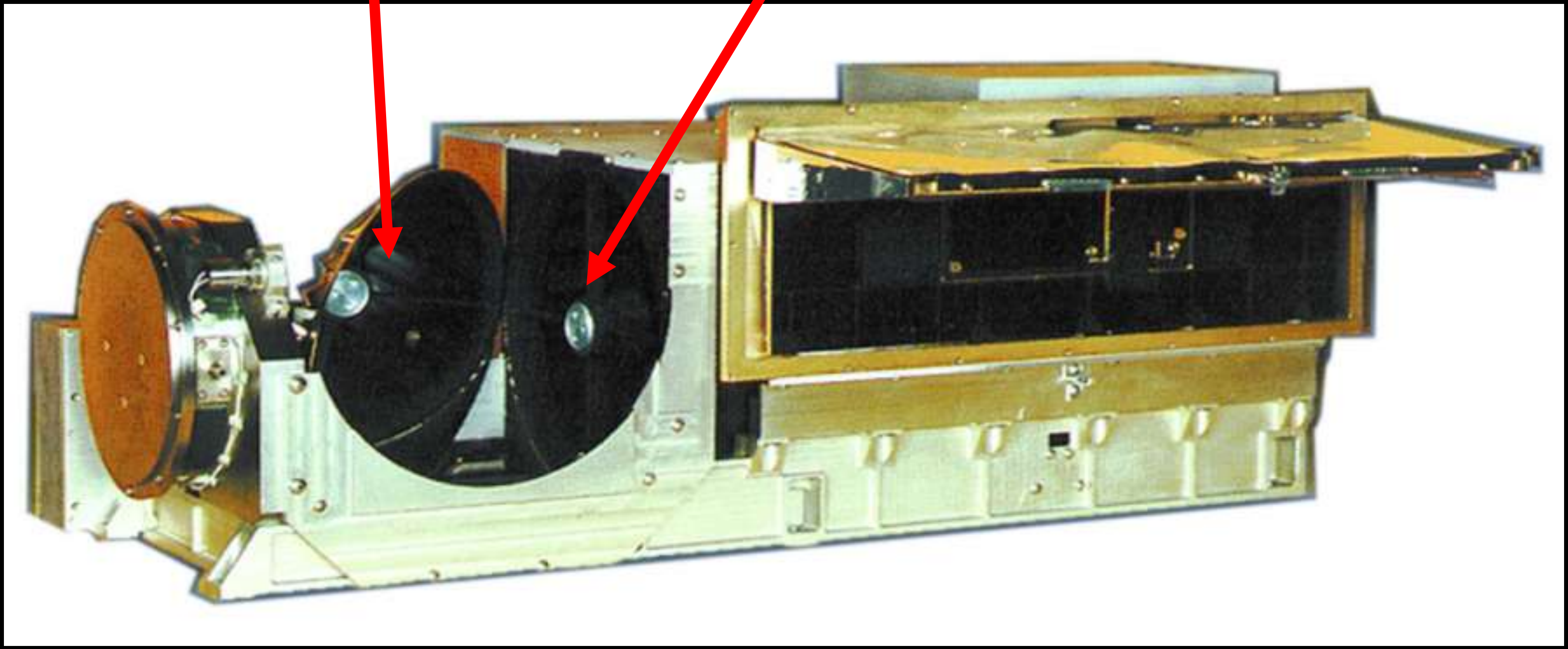
Channels

MSU-MR	AVHRR	Wavelength	Quantity	Content	Usage
1	1	0.58-0.68µm	Reflectance	Visible	Chlorophyll absorption
2	2	0.725-1.0µm	Reflectance	Visible Near IR	Leaf Reflection
3	3a (day)	1.58-1.64µm	Reflectance	Short Wave IR	Snow detection
4	3b (night)	3.55-3.93µm	Emittance	Mid Wave IR	Atmospheric correction
5	4	10.3-11.3µm	Emittance	Thermal IR	Main temperature channel
6	5	11.5-12.5µm	Emittance	Thermal IR	Atmospheric correction

Note: AVHRR(1,2,3b,4,4), AVHRR/2 (1,2,3b,4,5), AVHRR/3 (1,2,3a,3b,4,5)

AVHRR – spectral bands





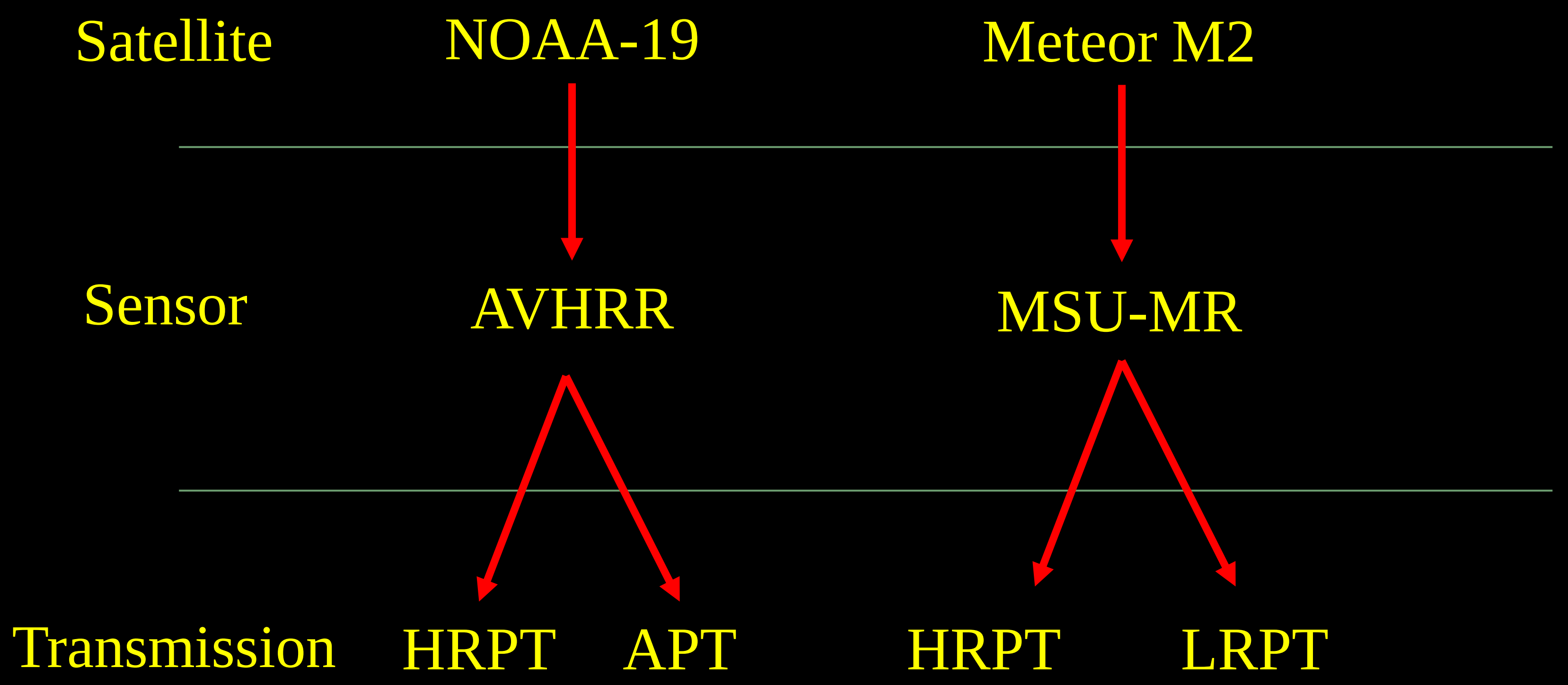
The Instrument

Meteor M2 MSU-MR

Parameter	Value
Band No 1 (VIS= Visible)	0.50 ± 0.2 - 0.70 ± 0.2 µm
Band No 2 (VNIR=Visible Near Infrared)	0.70 ± 0.2 - 1.10 ± 0.2 µm
Band No 3 (SWIR= Short Wave Infrared)	1.60 ±0.50 - 1.80 ± 0.50 µm
Band No 4 (MWIR= Mid Wave Infrared)	3.50 ± 0.50 - 4.10 ± 0.50 µm
Band No 5 (TIR = Thermal Infrared)	10.5 ± 0.50 - 11.5 ± 0.50 µm
Band No 6 (TIR = Thermal Infrared)	11.5 ± 0.50 - 12.5 ± 0.50 µm
Scanning geometry-plane, scanning angle	108º, 54º
Swath width	2800 km
Angular resolution in all spectral channels	1.2 +0.2 mrad
Spatial resolution at nadir	1 km
SNR in bands 1 and 2, in band 3	≥ 200, ≥ 100
Overall relative measurement error of radiance in bands 1-3	10%
Range of radiation temperature measured in bands 4-6	213-313 K
NEDT (Noise Equivalent Differential	
Temperature) at 300 K	≤ 1 K
- Band 4	≤ 0.2 K
- Band 5	≤ 0.2 K
- Band 6	
Overall absolute measurement error at 333 K in bands 4-6	0.5 K
Data quantization	10 bit
Calibration	Use of onboard calibration sources
Data rate	660 kbit/s
Operational mode	Continuous
Instrument mass	≤ 70 kg

tl;dr Different package, same sensor

Terminology



- AVHRR
  - HRPT
    - 5 channels, full resolution, L band – 1.7GHz
  - APT
    - 2 of 5 channels, reduced resolution, 137MHz
- MSU-MR
  - HRPT
    - 6 channels, full resolution, L band – 1.7GHz
  - LRPT
    - 3 of 6 channels, full resolution, 137MHz

The difference between an image and a picture

Image ≠ Picture

They look the same, but…

Image pixel values are mathematically related to the original data	Picture pixel values are only visually related to the original data

Do we have Images or Pictures?

- AVHRR and MSU-MR record 10 bit data
  - HRPT data are all 10 bit
  - BMP files are 8 bit
  - APT sends 10 bit data
  - LRPT sends unknown
- Image or picture? It depends..
  - Is there a defined relationship between the 10 bit and 8 bit data?

I don't know. So far, I have found no information on what Meteor LRPT actually produces.

What to expect from NOAA APT and Meteor M2 LRPT

- Channels 1, 2 usually identical (picture sense) except for vegetation
  - Vegetation shows 2 > 1
- Channel 4 (M2 5) best temperature estimate
- Channel 3a (M2 3) cloud/snow differentiation

Thermal Channel Expectations

- High clouds are always coldest
- In winter
  - Unfrozen water is warmest, warmer than land, snow covered or not.
- In summer
  - Water is usually cooler than land
- Cold → dark, warm → light

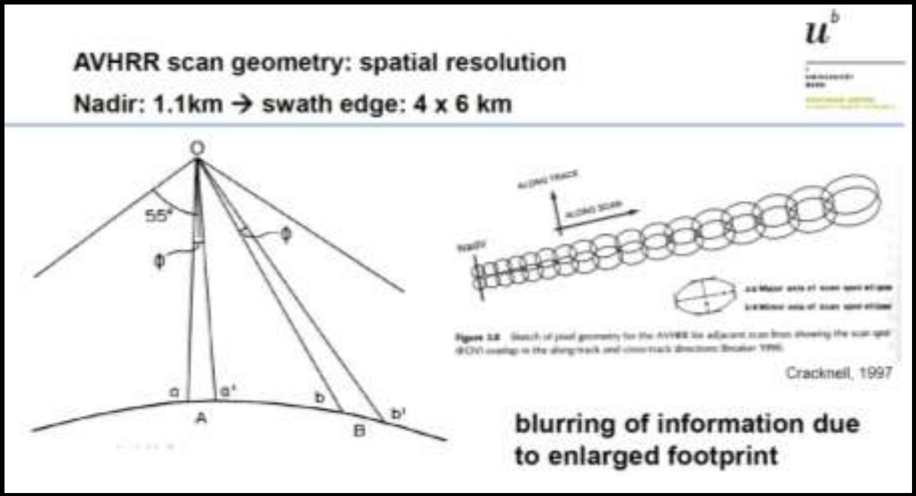
- M2 LRPT imagery
  - Radiometrically calibrated? Unknown.
  - Geometrically corrected? NO

WARNING!
It seems that the software is not assigning colours correctly, using (B,G,R) instead of (R,G,B), no matter what it says

- AVHRR APT Imagery
  - Radiometrically calibrated? NO
  - Geometrically corrected? YES

APT Geometrical Correction

- Simple averaging, performed onboard
- Reduces resolution to 4km



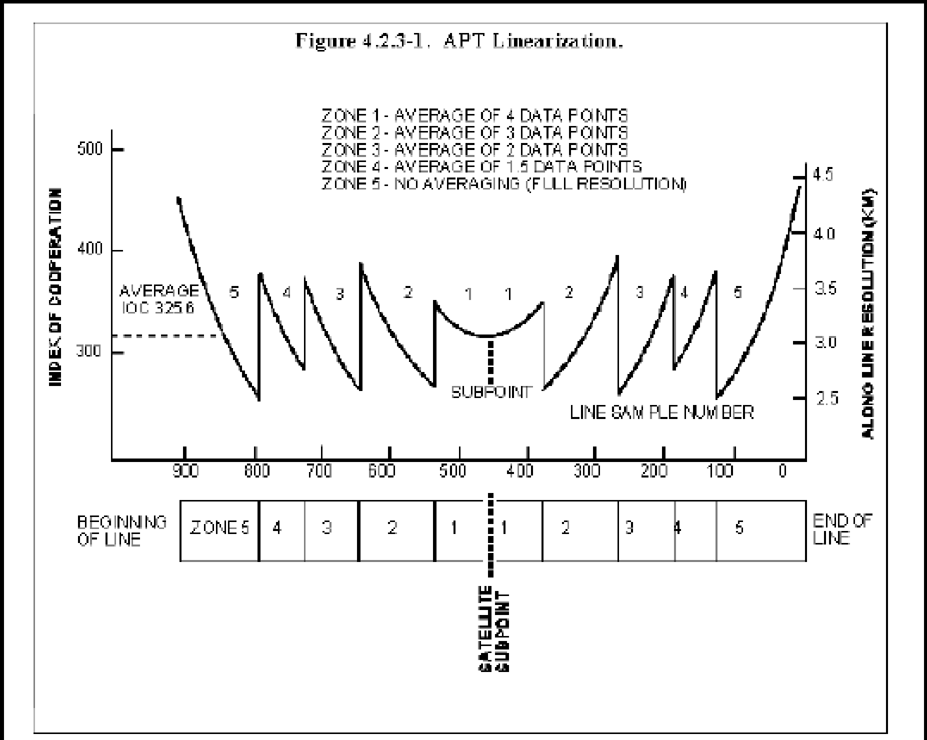
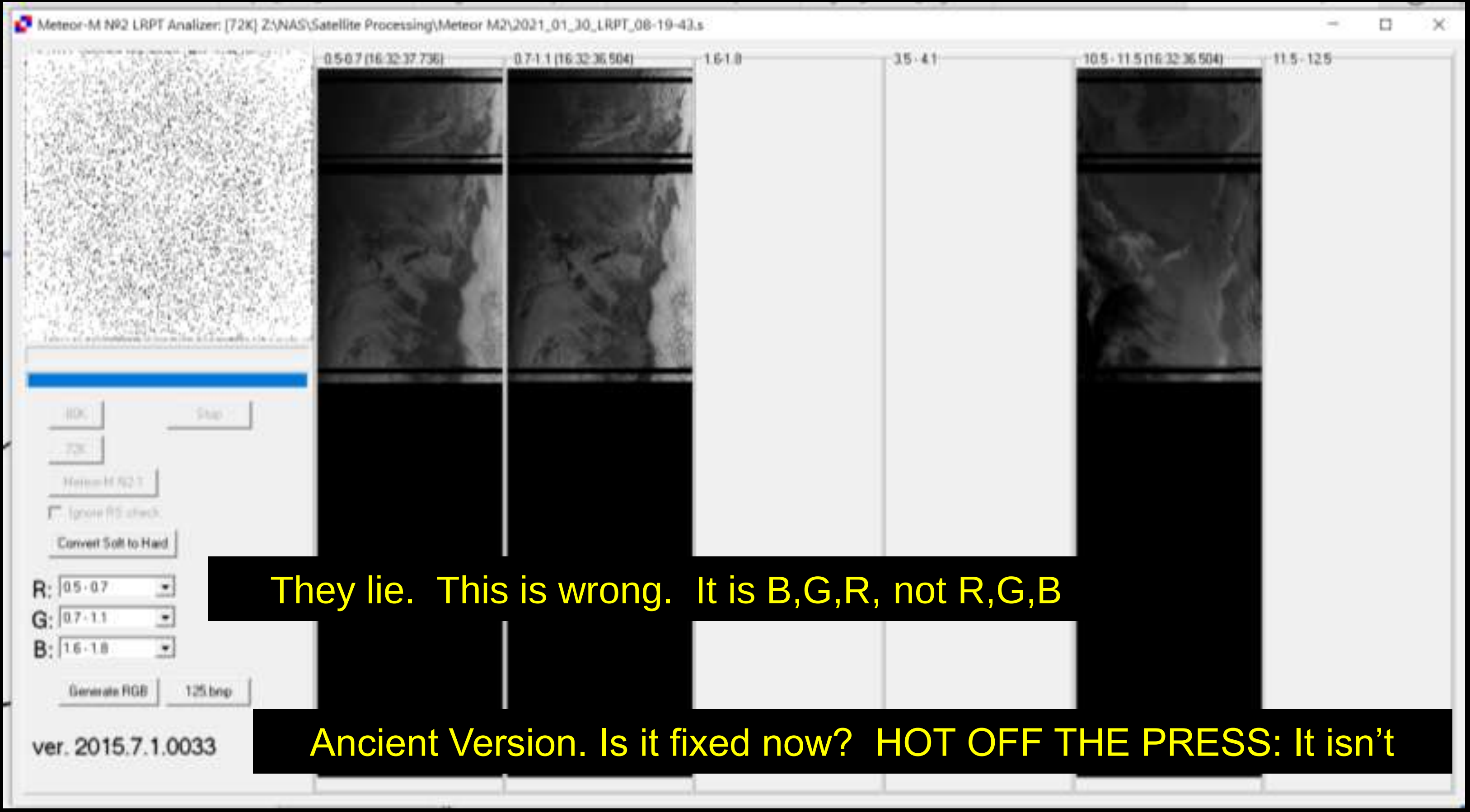


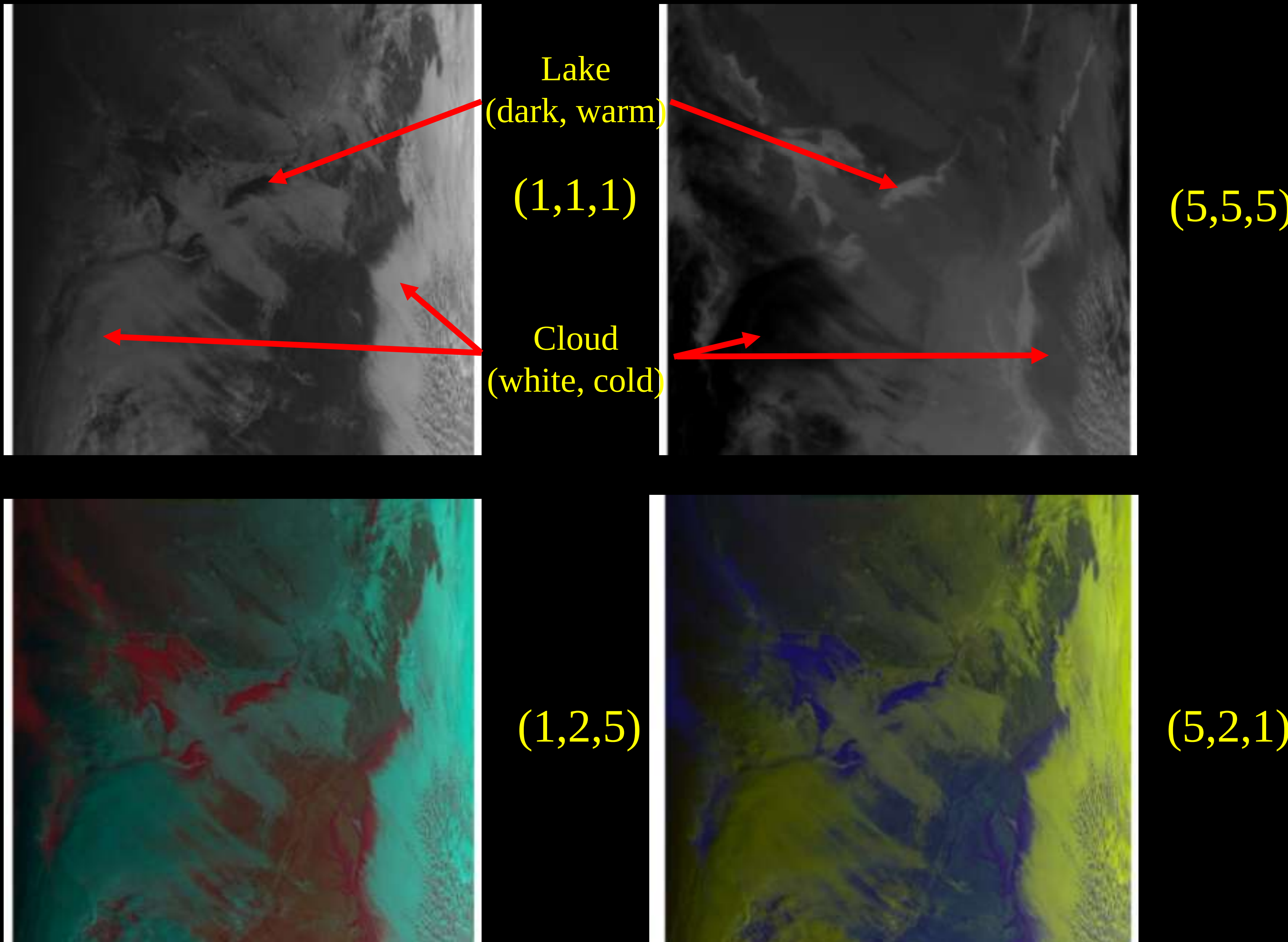
Figure 4.2.3-1. APT Linearization

LRPT Processing

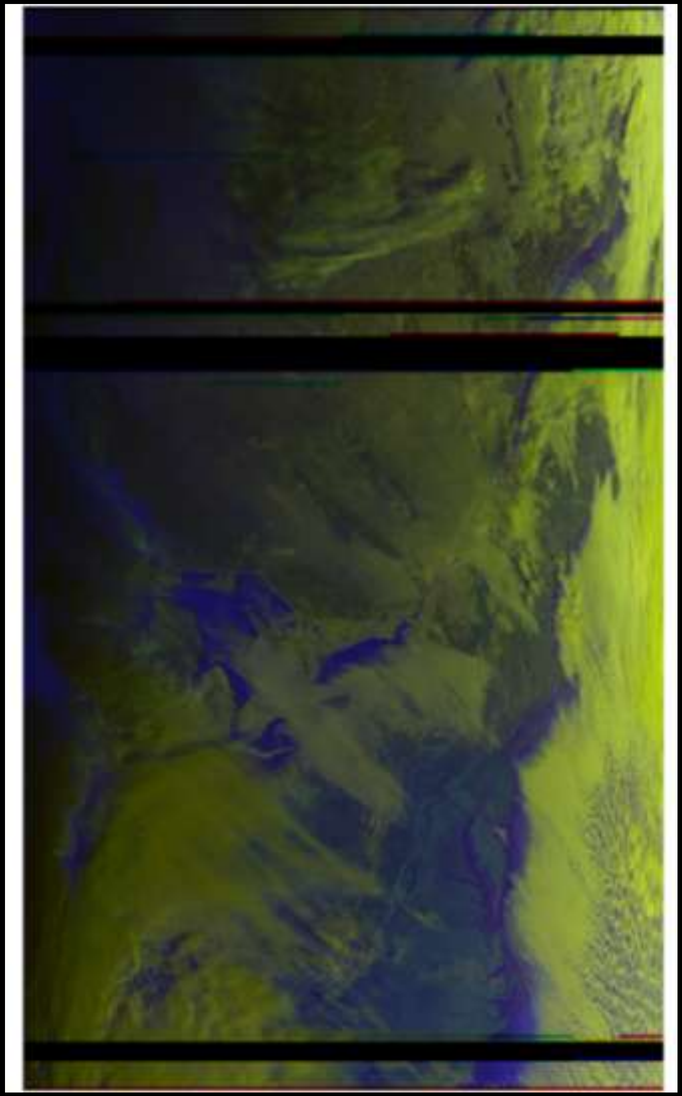


They lie. This is wrong. It is B,G,R, not R,G,B

Ancient Version. Is it fixed now? HOT OFF THE PRESS: It isn't


Lake
(dark, warm)
(1,1,1)
Cloud
(white, cold)
(5,5,5)
(1,2,5)
(5,2,1)

- M2 LRPT Imagery
  - We get either 1,2,5 or 1,2,3 (haven't seen this yet)
    - Using the colour coding in the software…
    - (1,2,2) should look like greyscale image, except over vegetation. (G+R= Y , so vegetation is yellow)
    - (1,2,3) is like (1,2,2) except vegetation is green, snow areas not red
    - (1,2,5) should show cold areas cyan, warm areas white (or dark to red).
    - (5,2,1) shows clouds, snow, land yellow, warm water blue



This should be a (1,2,5) image, but is, in fact, a (5,2,1) image.

Image Details:

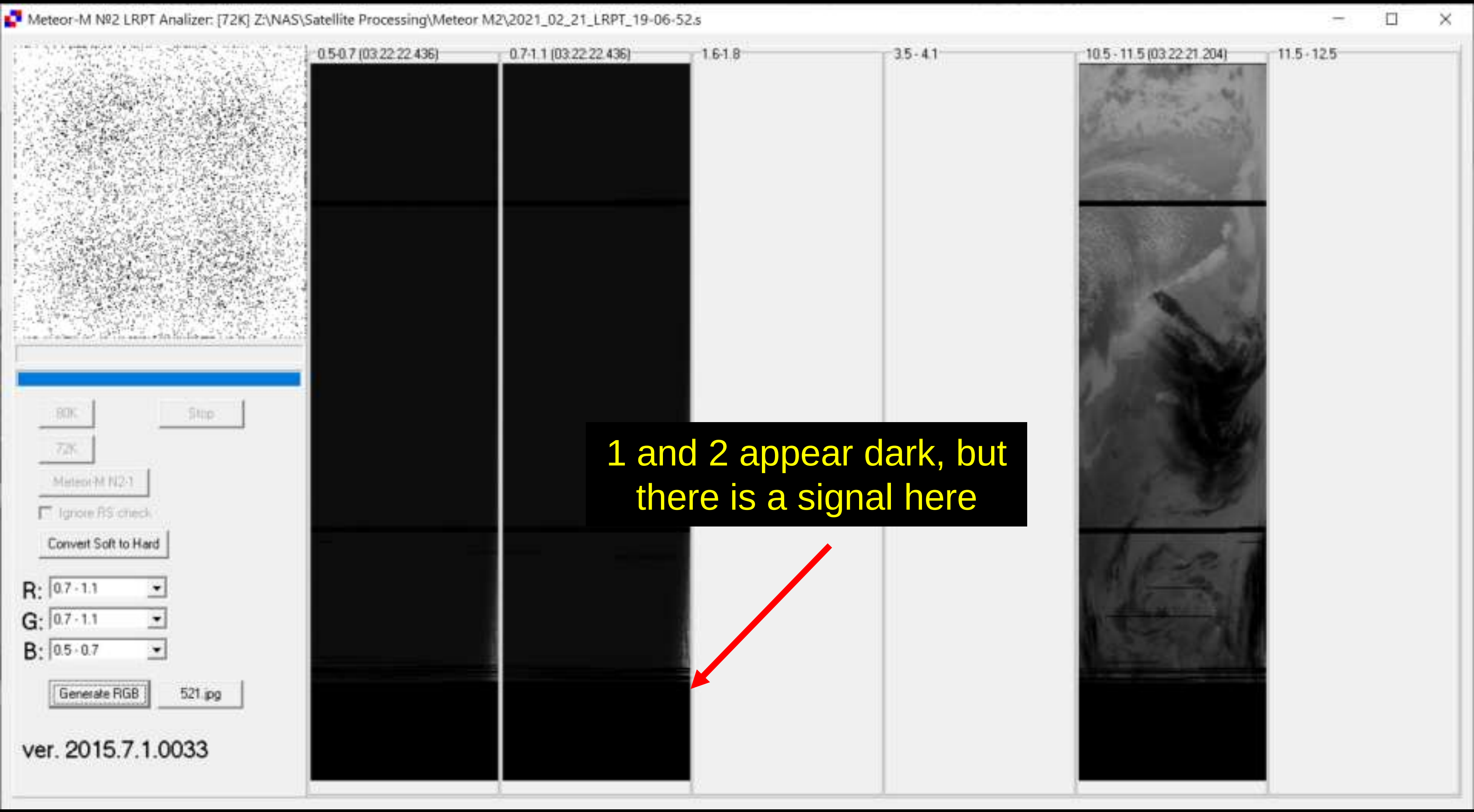
R to L and B to T gradients show early morning sun illumination.

Bright blue shows open water

Bright yellow shows cloud

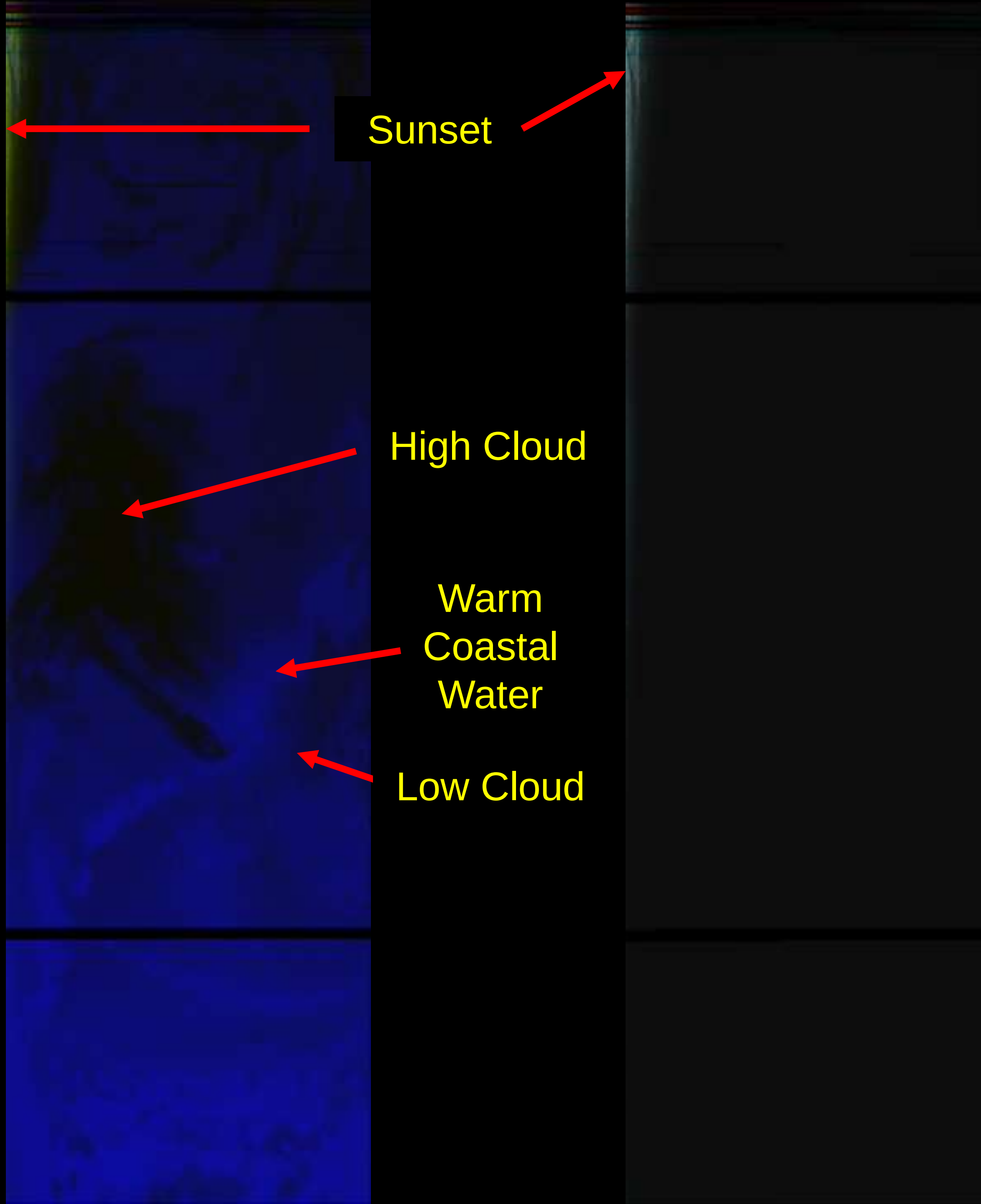
Dimmer yellow is mostly snow covered ground.

Another interesting case



Satellite was ascending (S to N), so image is inverted

(5,2,1)



(2,2,1)


Questions?