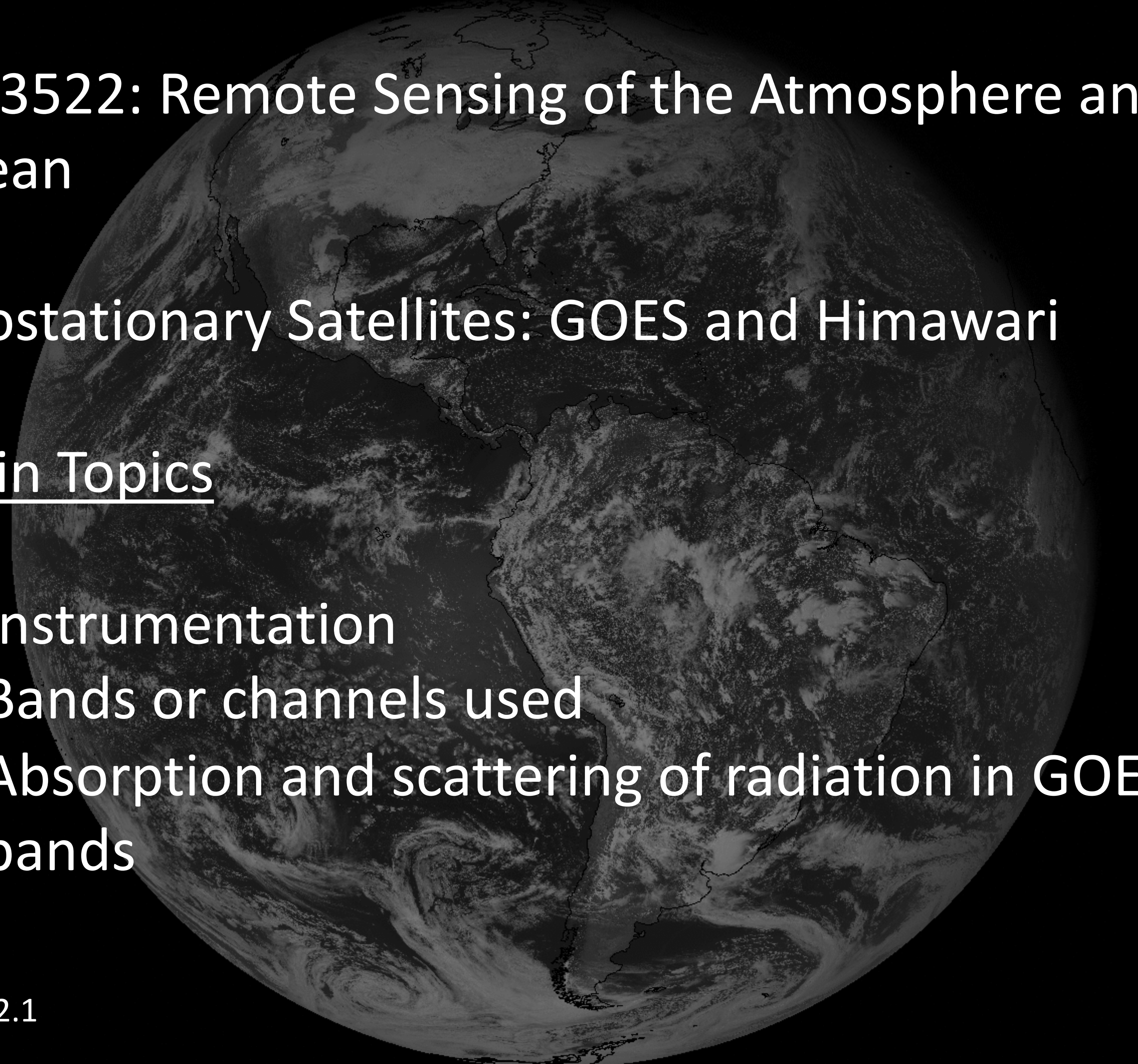


MR3522: Remote Sensing of the Atmosphere and Ocean

Geostationary Satellites: GOES and Himawari

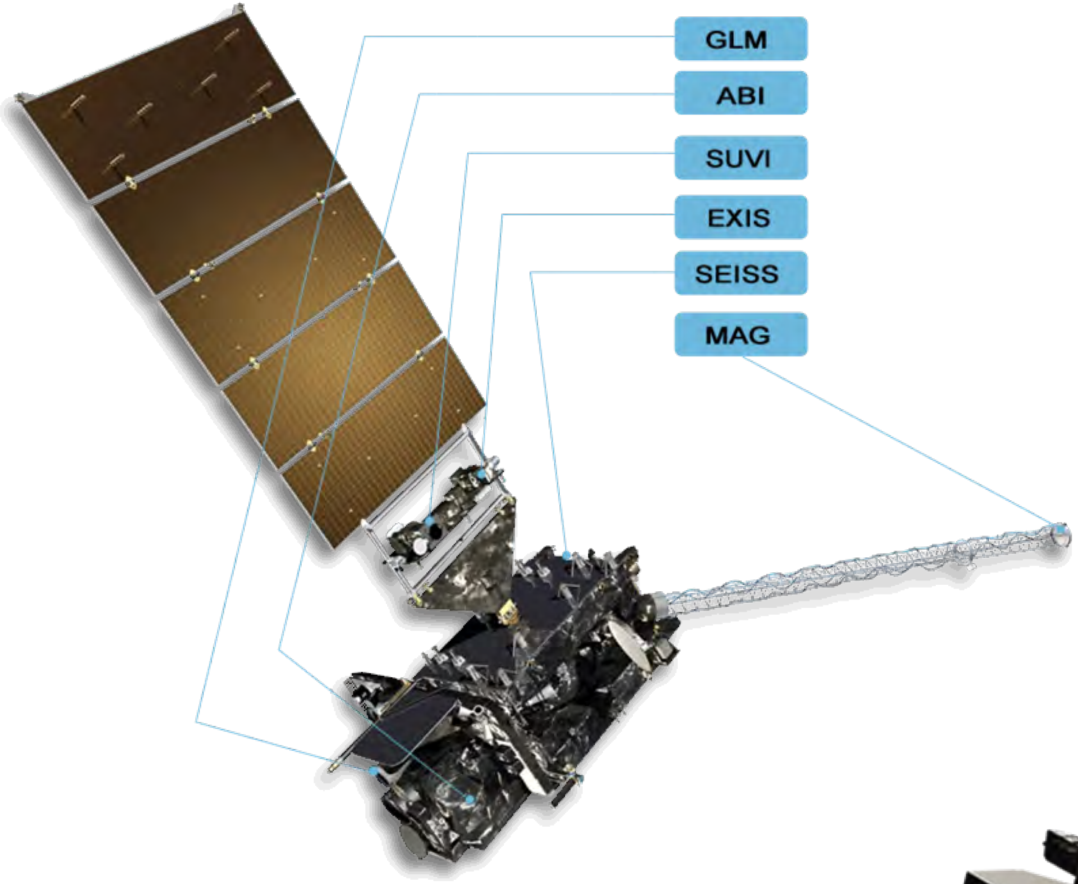
Main Topics

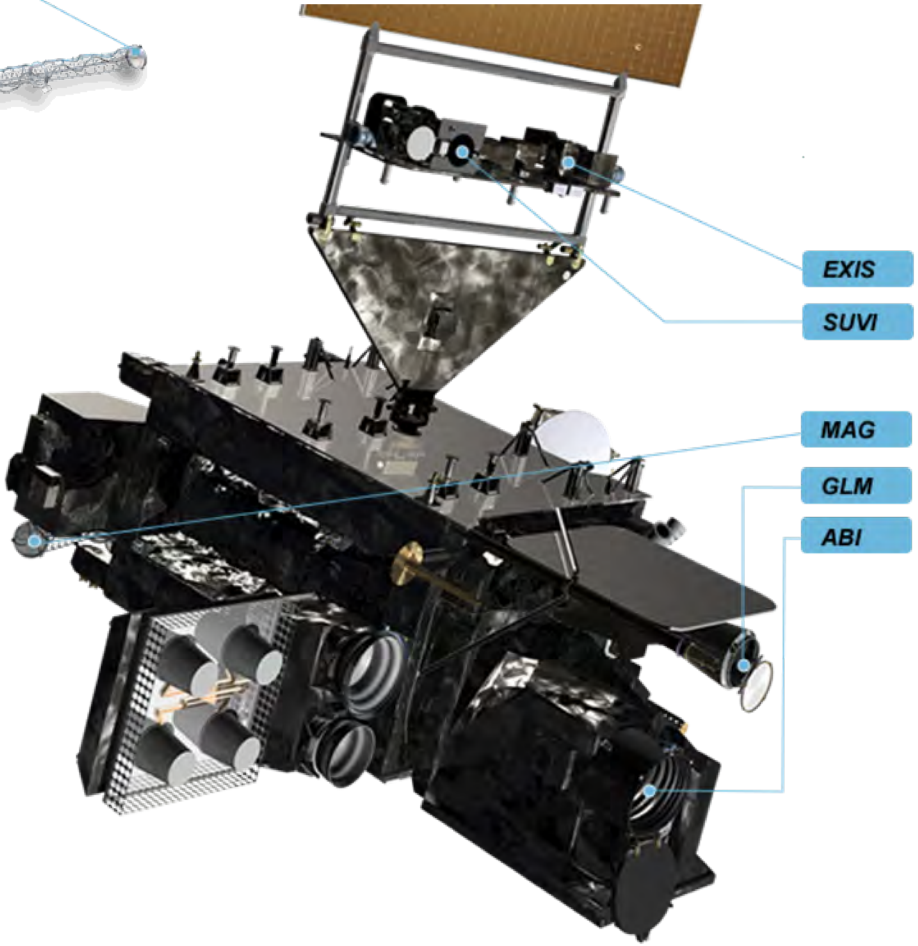
- Instrumentation
- Bands or channels used
- Absorption and scattering of radiation in GOES bands

Module 2.1

GOES Instrumentation

NASA/NOAA






42,164 km

Features of New GOES and Himawari Satellites

- 16 channels or bands; no radiometer or “sounder” needed

- Can take full disk image every 5 minutes, or concurrently, disk images every 15 minutes, U.S. every 5 minutes, and two mesoscale regions every 30–60 seconds.

- Compared to 3rd generation, GOES-16 and GOES-17 have 3x more channels (spectral resolution), 4x the spatial resolution (up to 0.5 km spacing in the red band), and ~5x the temporal resolution.

NOAA/NASA

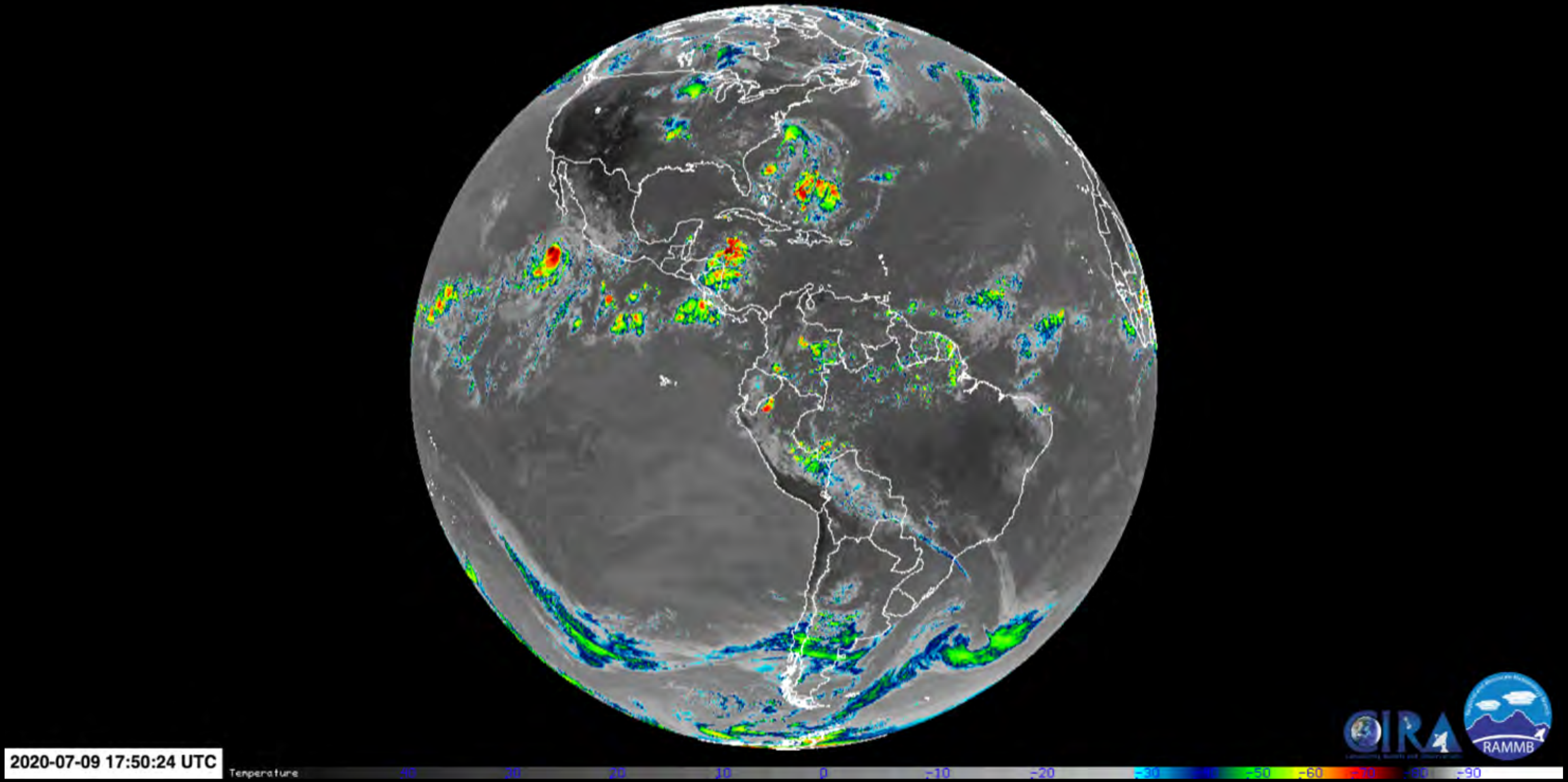
Himawari has no 1.378 µm band, but has a “green” band at 0.51 µm.

Table 1. Summary of the wavelengths, resolution, and sample use and heritage instrument(s) of the ABI bands. The minimum and maximum wavelength range represent the full width at half maximum (FWHM or 50%) points. [The Instantaneous Geometric Field Of View (IGFOV).]

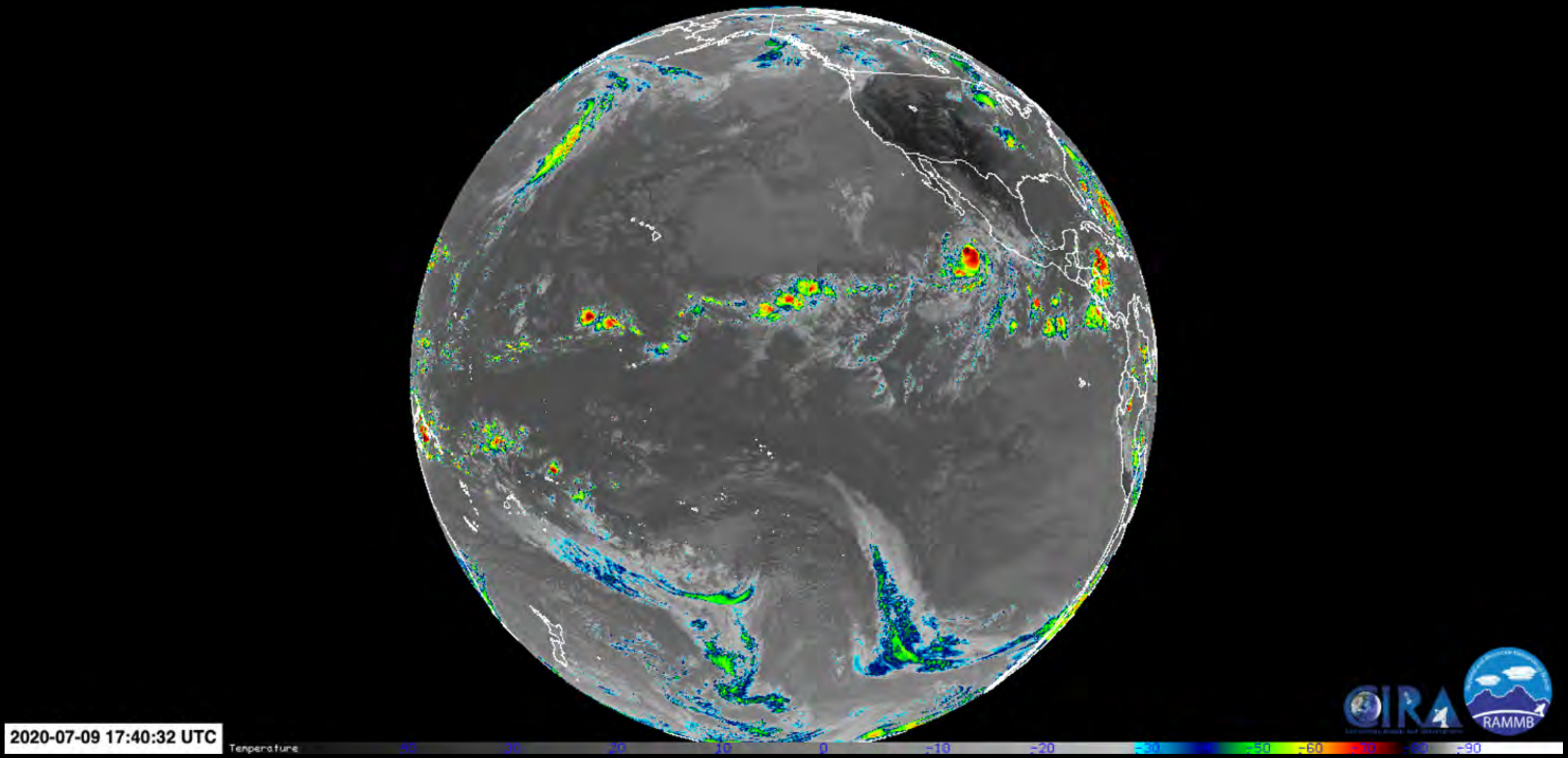
Future GOES imager (ABI) band	Wavelength range (µm)	Central wavelength (µm)	Nominal subsatellite IGFOV (km)	Sample use	Heritage instrument(s)
1	0.45–0.49	0.47	1	Daytime aerosol over land, coastal water mapping	MODIS
2	0.59–0.69	0.64	0.5	Daytime clouds fog, insolation, winds	Current GOES imager/ sounder
3	0.846–0.885	0.865	1	Daytime vegetation/burn scar and aerosol over water, winds	VIIRS, spectrally modified AVHRR
4	1.371–1.386	1.378	2	Daytime cirrus cloud	VIIRS, MODIS
5	1.58–1.64	1.61	1	Daytime cloud-top phase and particle size, snow	VIIRS, spectrally modified AVHRR
6	2.225–2.275	2.25	2	Daytime land/cloud properties, particle size, vegetation, snow	VIIRS, similar to MODIS
7	3.80–4.00	3.90	2	Surface and cloud, fog at night, fire, winds	Current GOES imager
8	5.77–6.6	6.19	2	High-level atmospheric water vapor, winds, rainfall	Current GOES imager
9	6.75–7.15	6.95	2	Midlevel atmospheric water vapor, winds, rainfall	Current GOES sounder
10	7.24–7.44	7.34	2	Lower-level water vapor, winds, and SO_2	Spectrally modified current GOES sounder
11	8.3–8.7	8.5	2	Total water for stability, cloud phase, dust, SO_2 rainfall	MAS
12	9.42–9.8	9.61	2	Total ozone, turbulence, and winds	Spectrally modified current sounder
13	10.1–10.6	10.35	2	Surface and cloud	MAS
14	10.8–11.6	11.2	2	Imagery, SST, clouds, rainfall	Current GOES sounder
15	11.8–12.8	12.3	2	Total water, ash, and SST	Current GOES sounder
16	13.0–13.6	13.3	2	Air temperature, cloud heights and amounts	Current GOES sounder/ *GOES-12+* imager

Source: Schmit, T.J., Gunshor, M.M., Menzel, W.P., Gurka, J.J., Li, J., Bachmeier, A.S., 2005, Introducing the Next-Generation Advanced Baseline Imager on GOES-R, Bulletin of the American Meteorological Society, v. 86, p. 1079-1096.

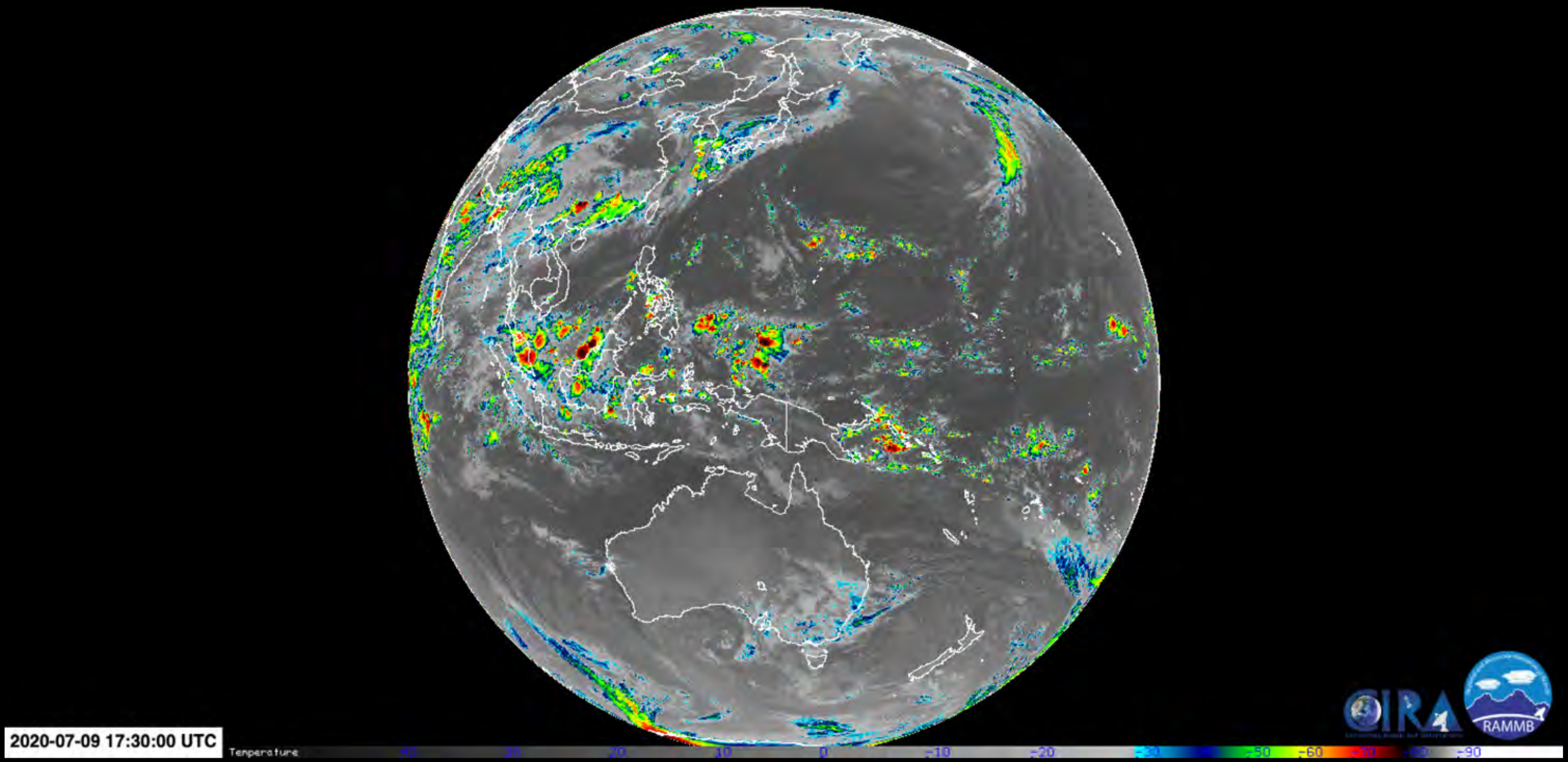
GOES-East (16)


2020-07-09 17:50:24 UTC
Temperature
40
30
20
10
0
-10
-20
-30
-50
-60
-70
-80
-90
CIRA
RAMMB

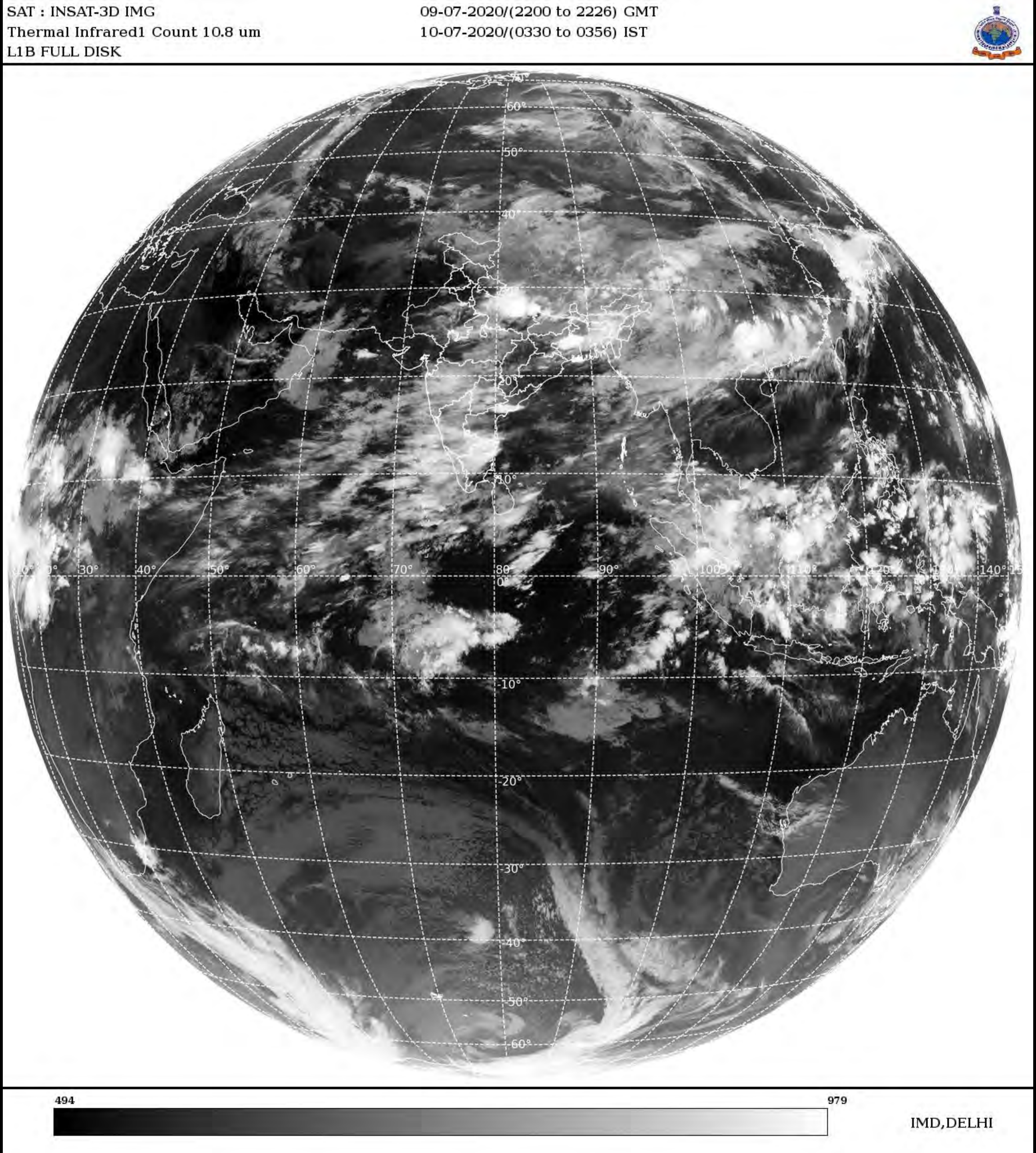
GOES-West (17)


2020-07-09 17:40:32 UTC
Temperature
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
CIRA
RAMMB

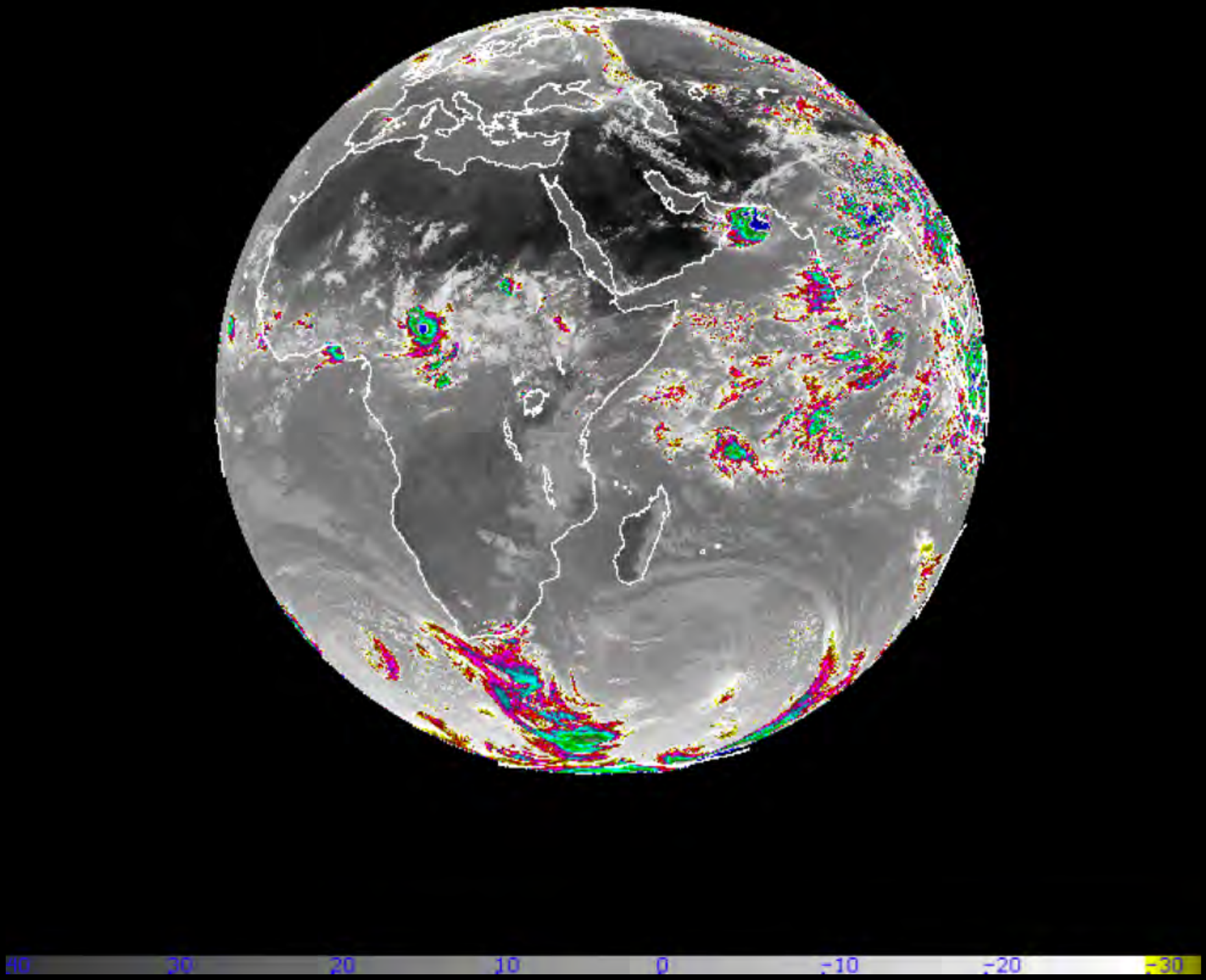
Himawari-8


2020-07-09 17:30:00 UTC
Temperature
40
30
20
10
0
-10
-20
-30
-50
-60
-70
-80
-90
CIRA
RAMMB

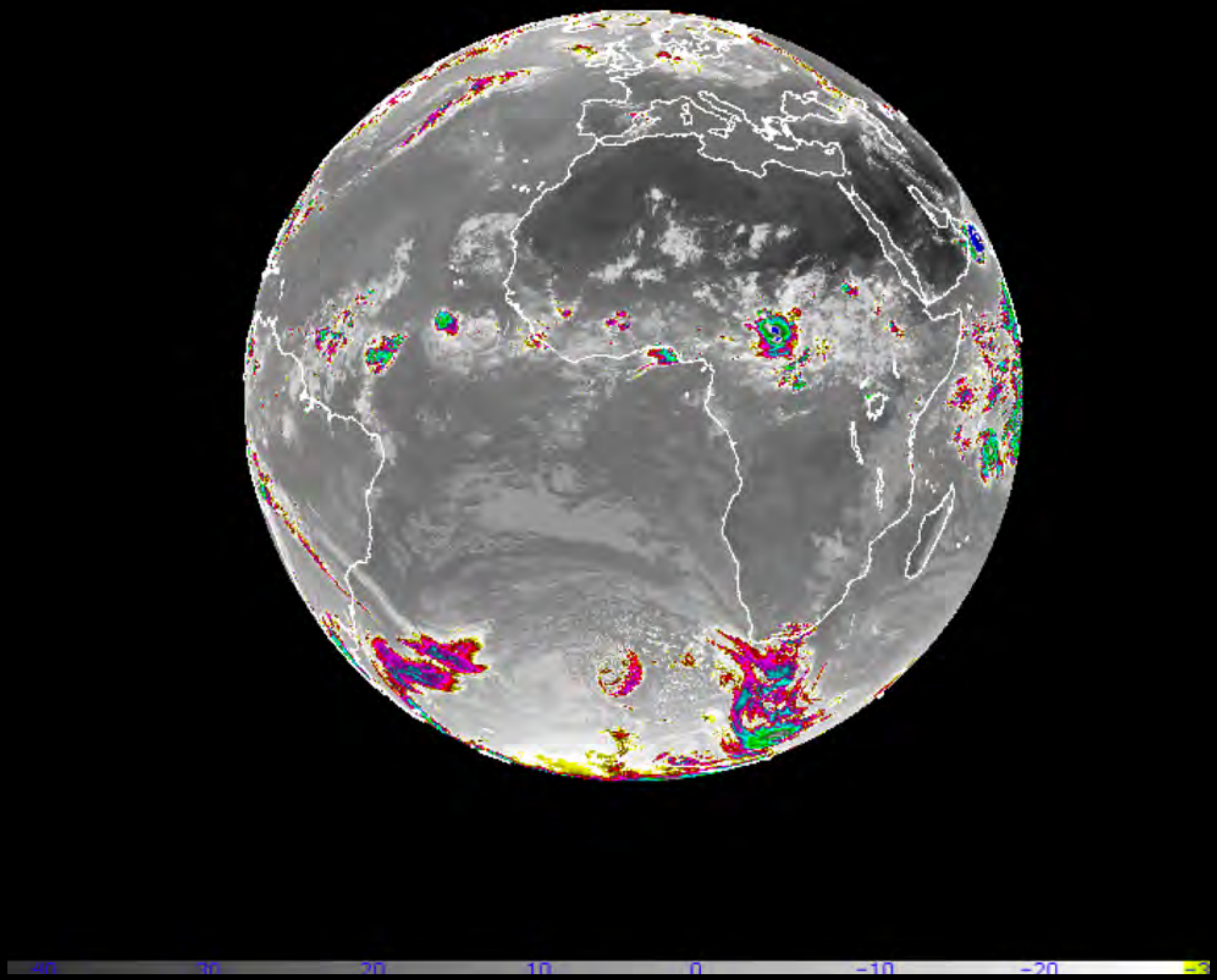
INSAT-3D

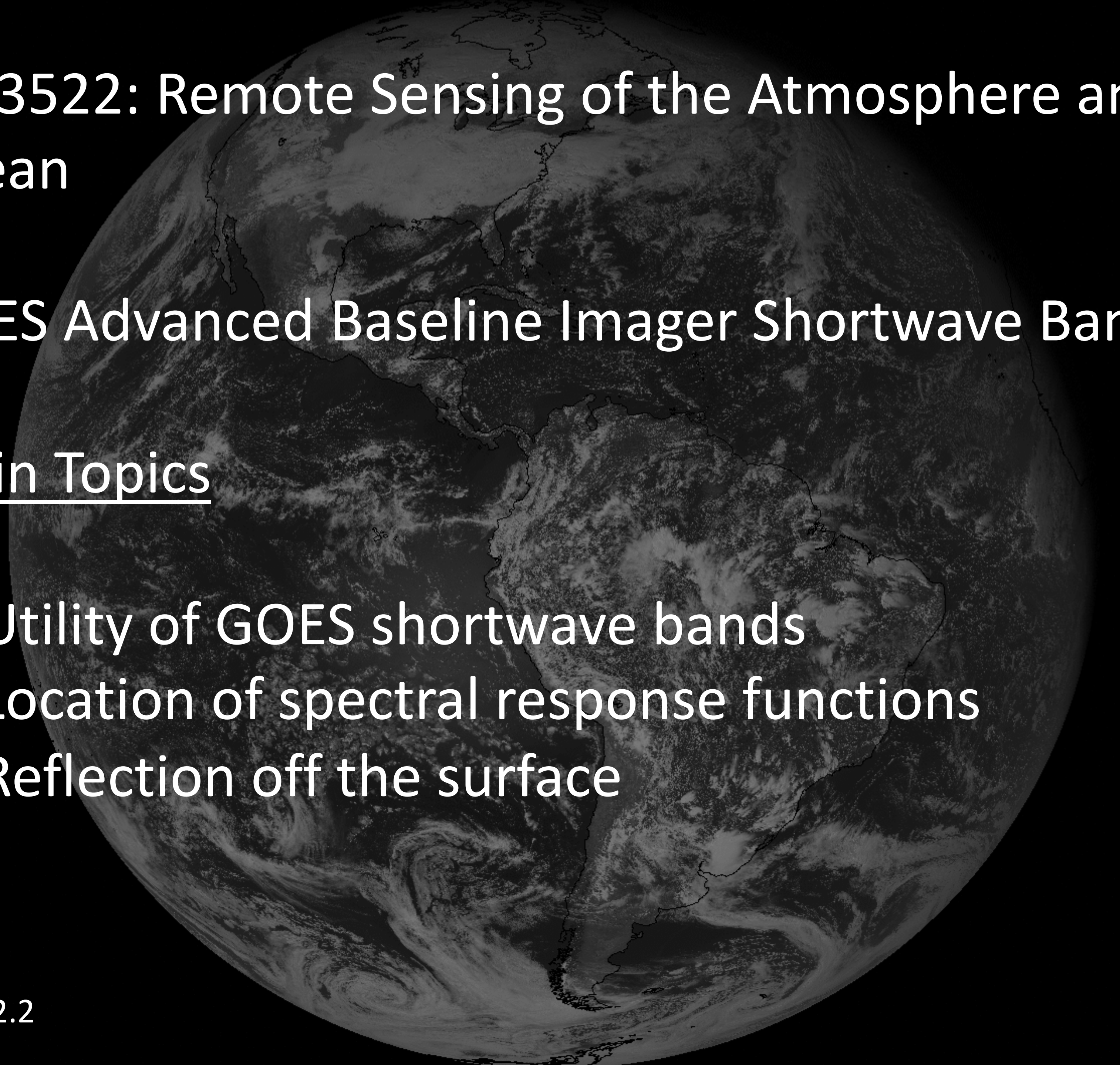

SAT : INSAT-3D IMG
Thermal Infrared1 Count 10.8 um
L1B FULL DISK
09-07-2020/(2200 to 2226) GMT
10-07-2020/(0330 to 0356) IST
494
979
IMD,DELHI

Meteosat-8



Meteosat-11





MR3522: Remote Sensing of the Atmosphere and Ocean

GOES Advanced Baseline Imager Shortwave Bands

Main Topics

- Utility of GOES shortwave bands
- Location of spectral response functions
- Reflection off the surface

Module 2.2

NOAA/NASA

Himawari has no 1.378 µm band, but has a “green” band at 0.51 µm.

Table 1. Summary of the wavelengths, resolution, and sample use and heritage instrument(s) of the ABI bands. The minimum and maximum wavelength range represent the full width at half maximum (FWHM or 50%) points. [The Instantaneous Geometric Field Of View (IGFOV).]

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6	2.225–2.275	2.25	2	Daytime land/cloud properties, particle size, vegetation, snow	VIIRS, similar to MODIS
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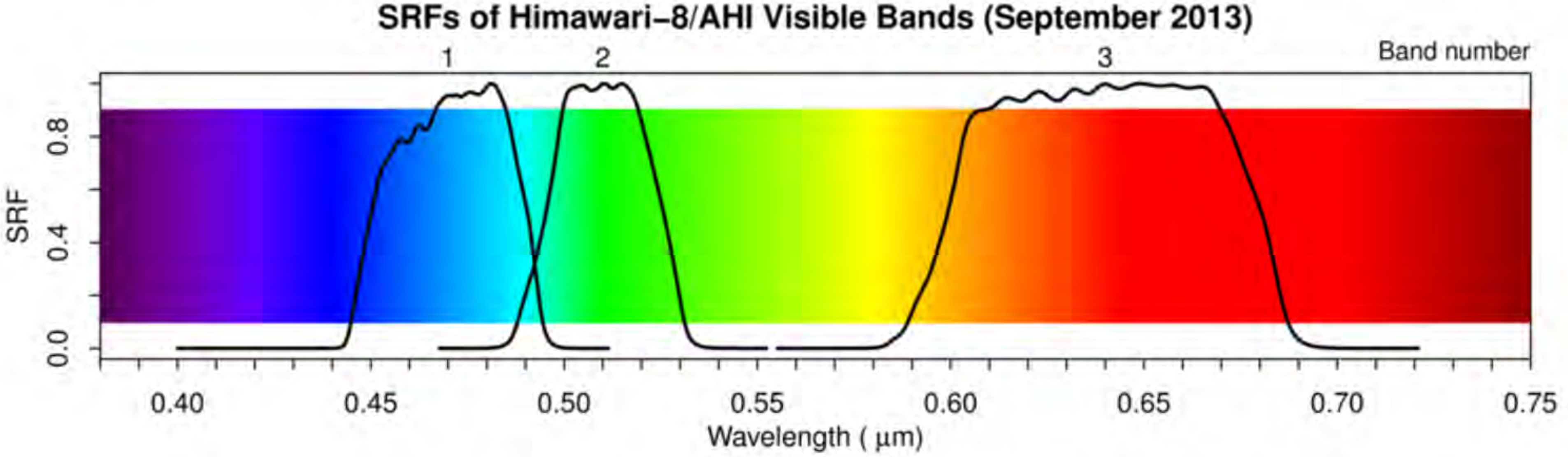
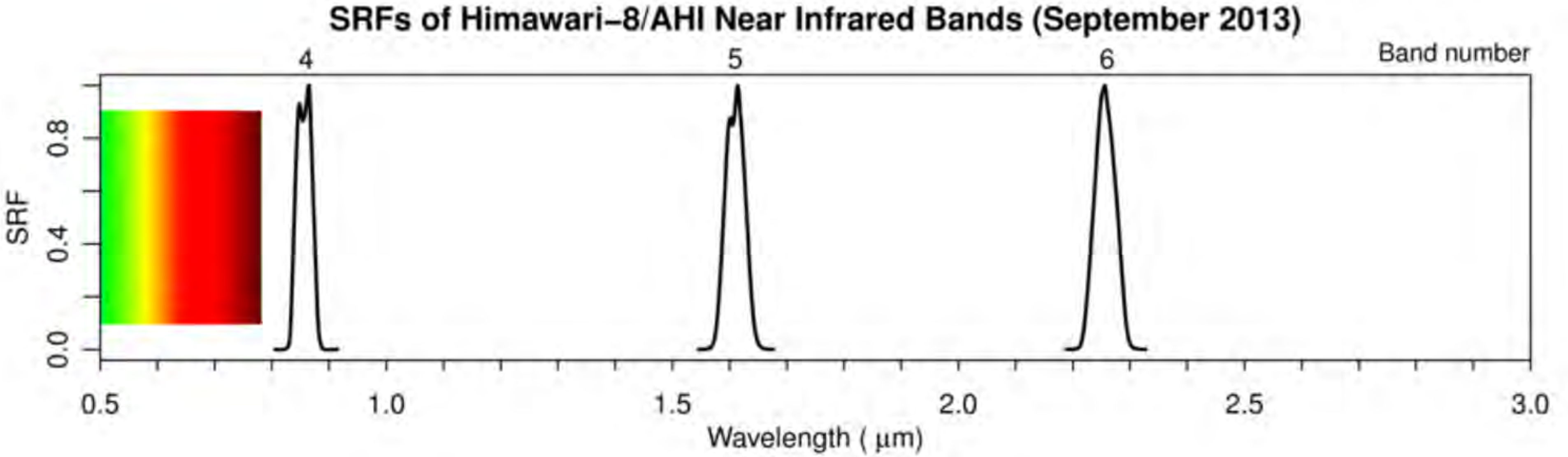
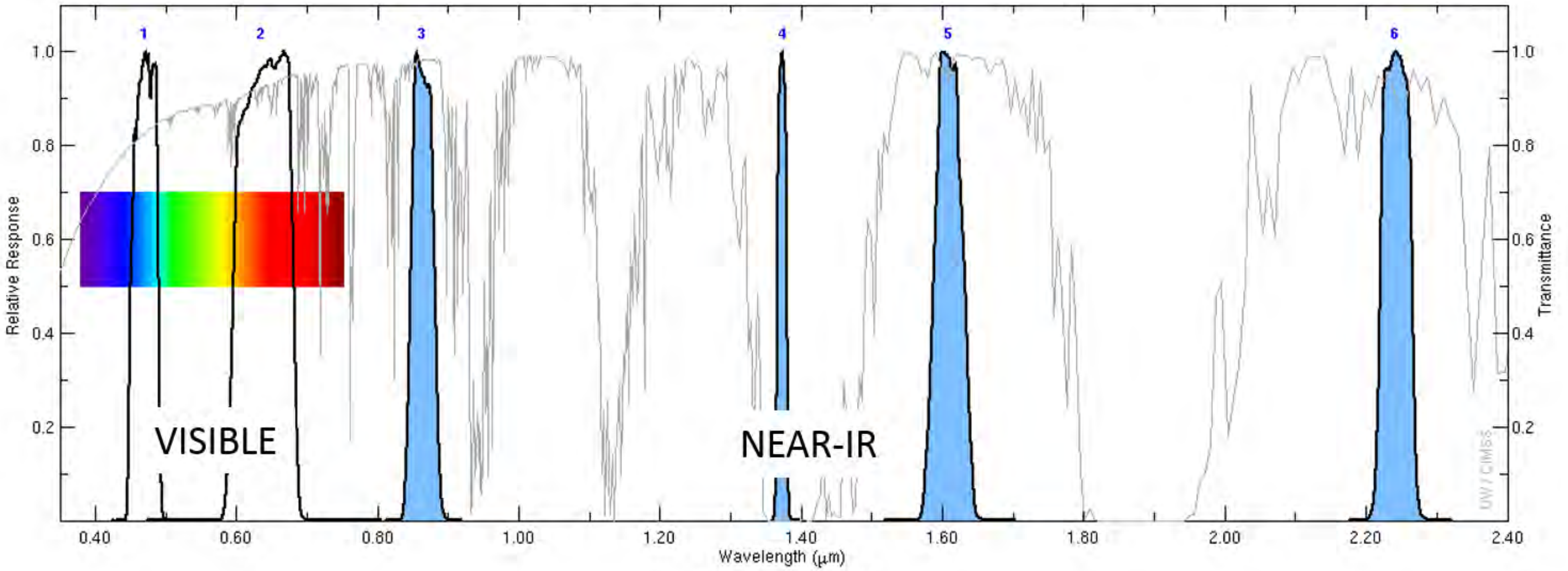
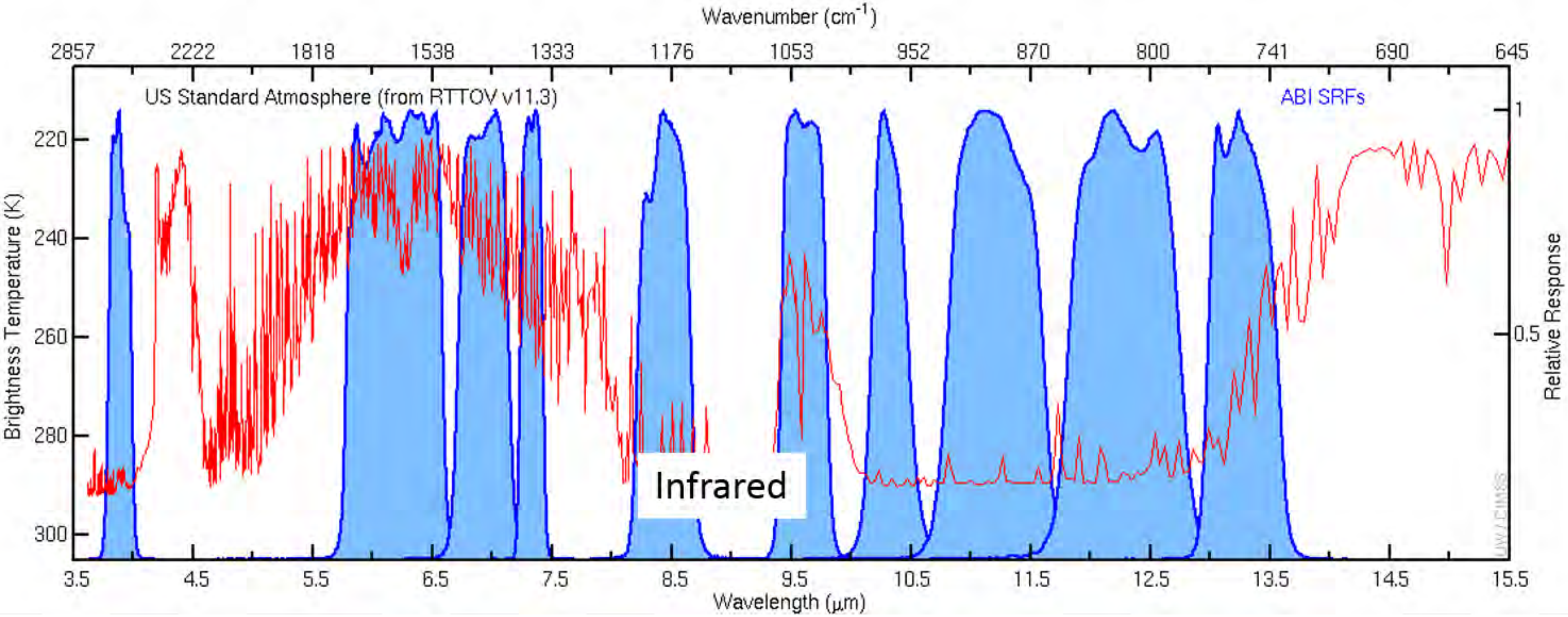


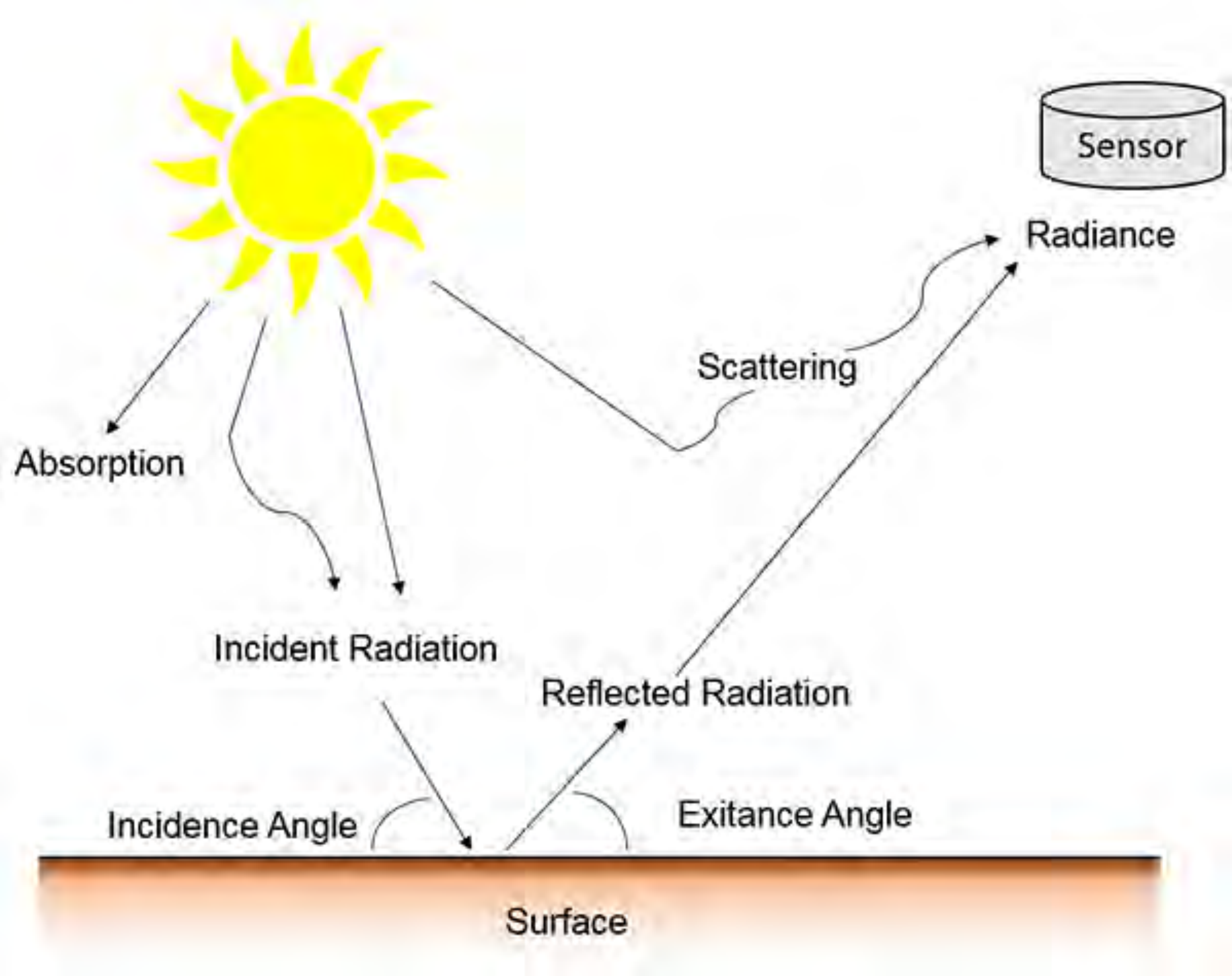
RGB VALUES FOR VISIBLE WAVELENGTHS by Dan Bruton (http://www.physics.sfasu.edu/astro/color/spectra.html)

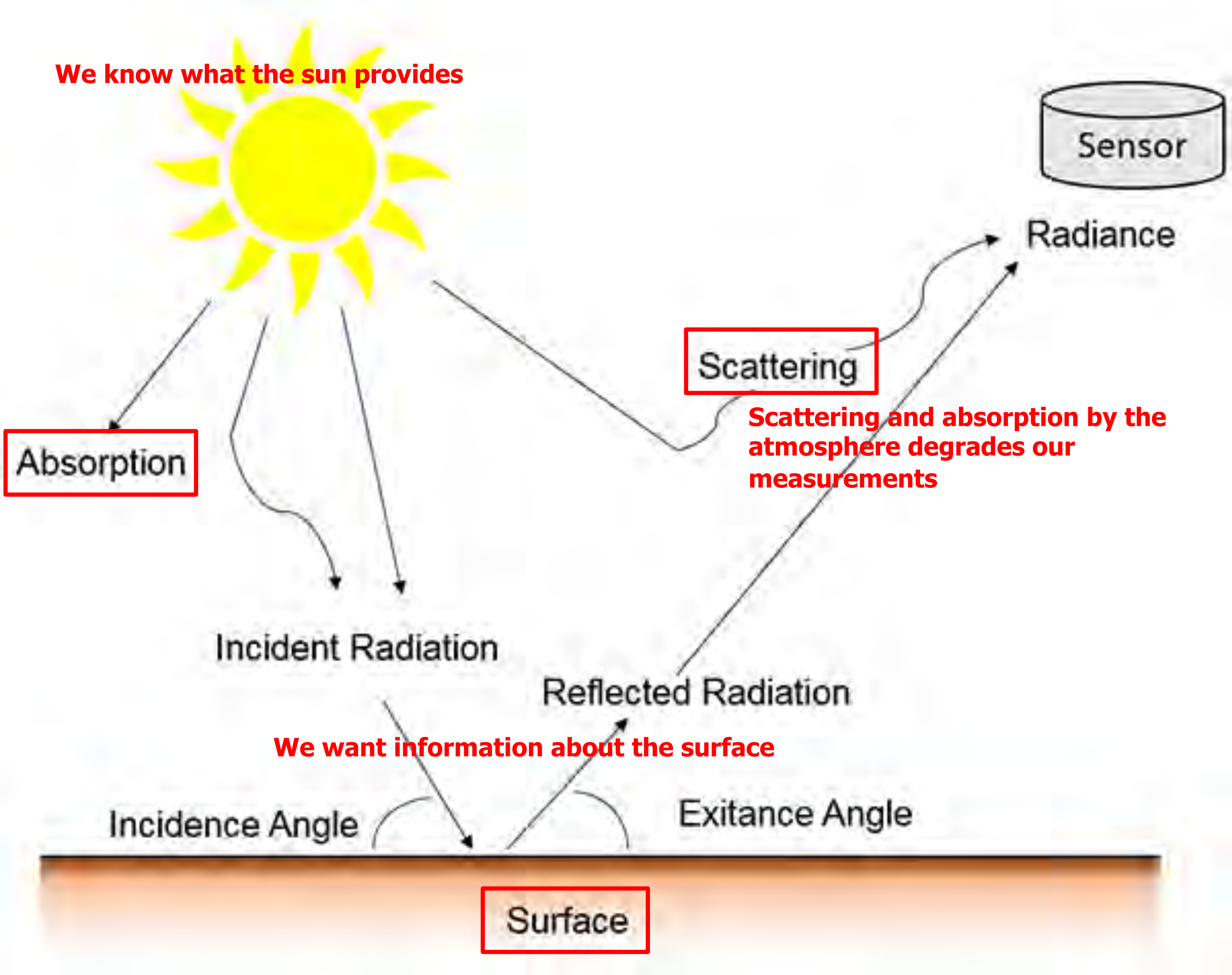


Spectral response functions (SRFs) describe the sensitivity of each spectral band to radiation as a function of wavelength.


1
2
3
4
5
6
VISIBLE
NEAR-IR
Relative Response
Transmittance
1.0
0.8
0.6
0.4
0.2
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
2.20
2.40
Wavelength (μm)
UW / CIMSS


Wavenumber (cm-1)
2857
2222
1818
1538
1333
1176
1053
952
870
800
741
690
645
US Standard Atmosphere (from RTTOV v11.3)
ABI SRFs
Brightness Temperature (K)
220
240
260
280
300
Relative Response
1
0.5
Infrared
3.5
4.5
5.5
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5
14.5
15.5
Wavelength (μm)
UW / CIMSS

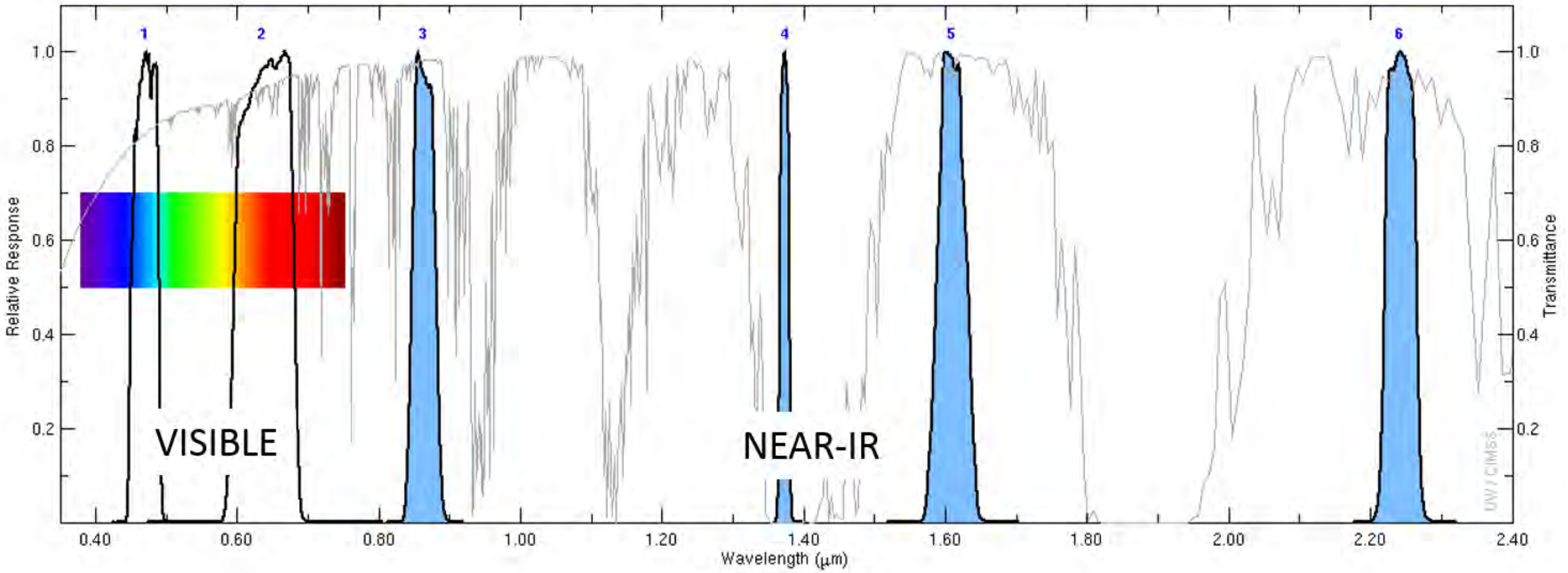

Sensor
Radiance
Scattering
Absorption
Incident Radiation
Reflected Radiation
Incidence Angle
Exitance Angle
Surface

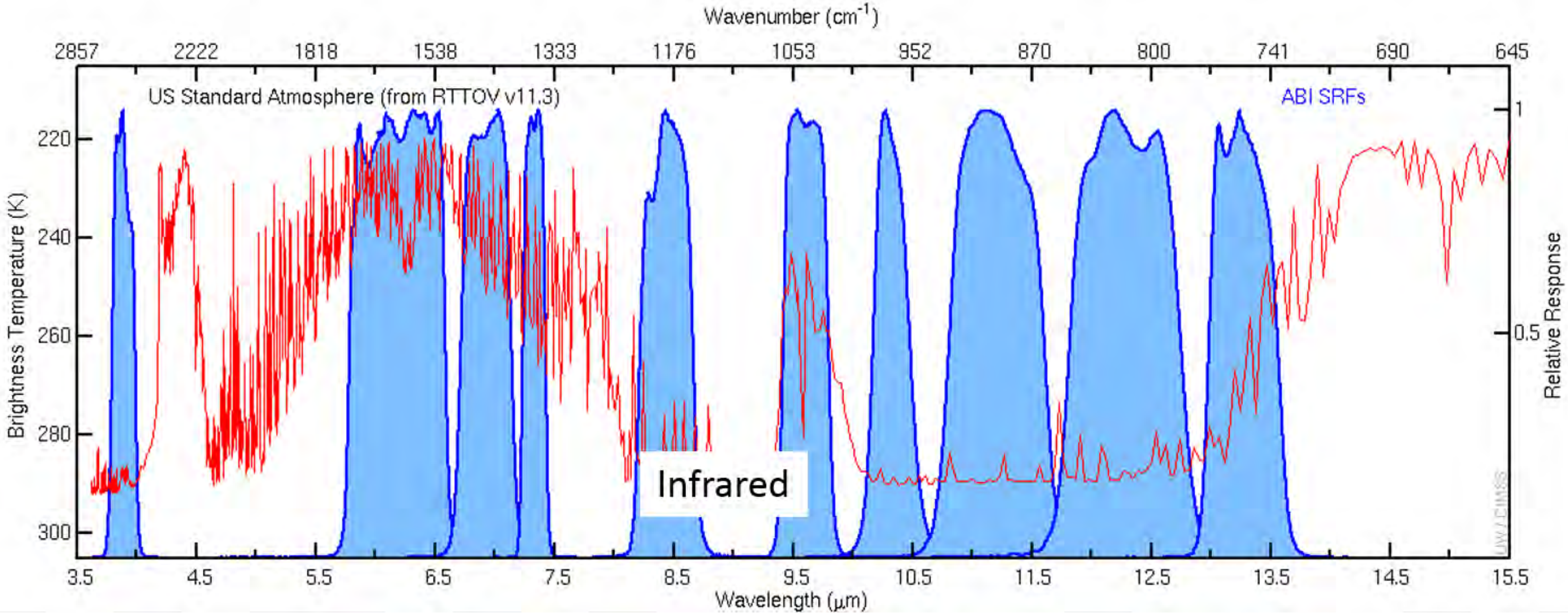


We know what the sun provides

Scattering and absorption by the atmosphere degrades our measurements

We want information about the surface

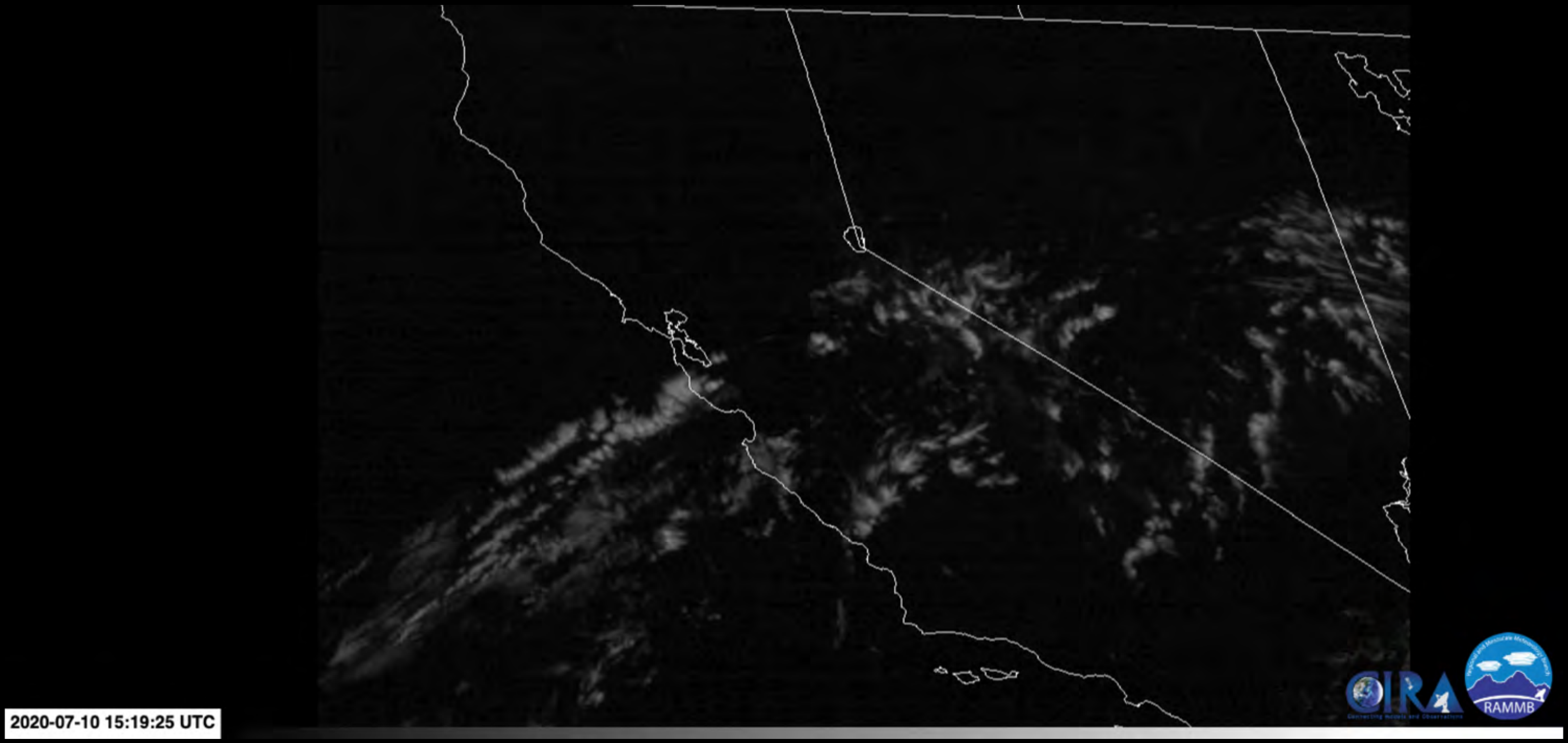

1
2
3
4
5
6
VISIBLE
NEAR-IR
Relative Response
Transmittance
Wavelength (μm)
0.2
0.4
0.6
0.8
1.0
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
2.20
2.40
UW / CIMSS


Wavenumber (cm^{-1})
2857
2222
1818
1538
1333
1176
1053
952
870
800
741
690
645
US Standard Atmosphere (from RTTOV v11.3)
ABI SRFs
Infrared
Brightness Temperature (K)
Relative Response
220
240
260
280
300
1
0.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5
14.5
15.5
Wavelength (μm)
UW / CIMSS

Band 2 (640 nm)

2020-07-10 15:22:25 UTC

Band 4 (1380 nm)



2020-07-10 15:19:25 UTC

The general radiative transfer solution for a scattering atmosphere is:

$$L_t(\lambda,\theta,\varphi) = L_0(\lambda,\theta,\varphi)e^{-\delta(\lambda)/\mu} + \int_0^{\delta(\lambda)} \frac{\int_{4\pi}\gamma_s(\mathbf{r},\mathbf{r}',\lambda,\mathbf{X})L(\mathbf{r}',\lambda,\mathbf{X})d\Omega'}{\sigma_e(\lambda,z)} e^{-\delta(\lambda,z)/\mu}\frac{d\delta}{\mu}$$

Where the surface radiance (L_0) is due to reflection
of the downward radiative flux at the surface
(read section 3.6 - Kidder & Vonder Haar)

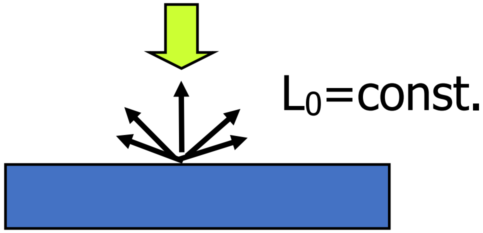
This is for reflected solar radiation only!

The reflection properties of various surfaces
can be a complex function of incoming and outgoing directions

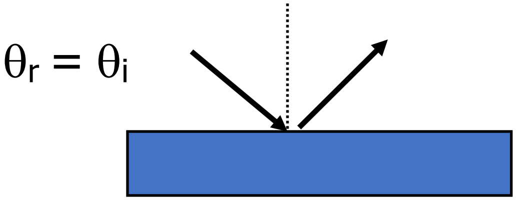
… commonly called the bidirectional reflectance, $\gamma_r(\theta_r,\phi_r;\theta_i,\phi_i)$

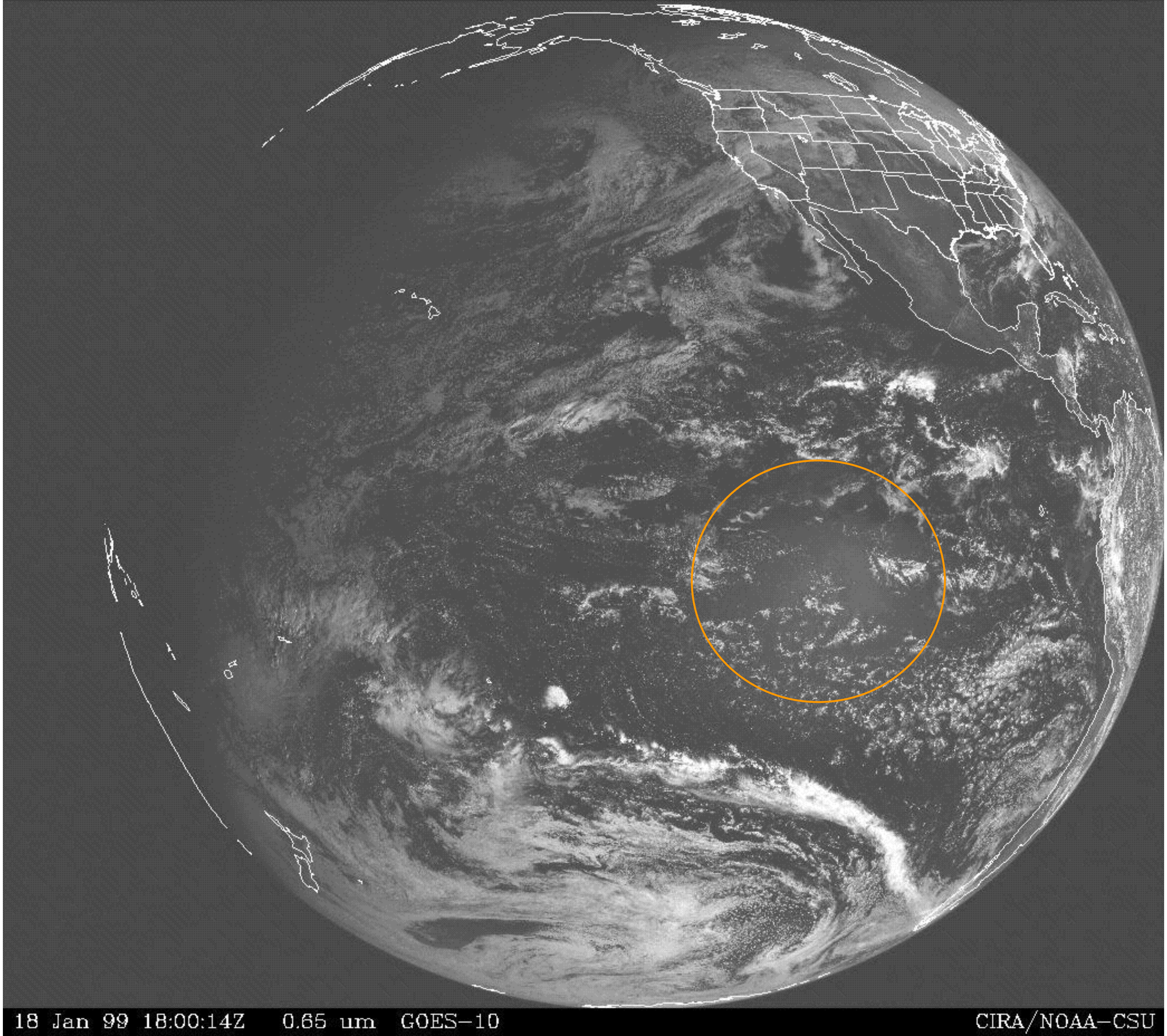
Common approximations to surface reflectance include:

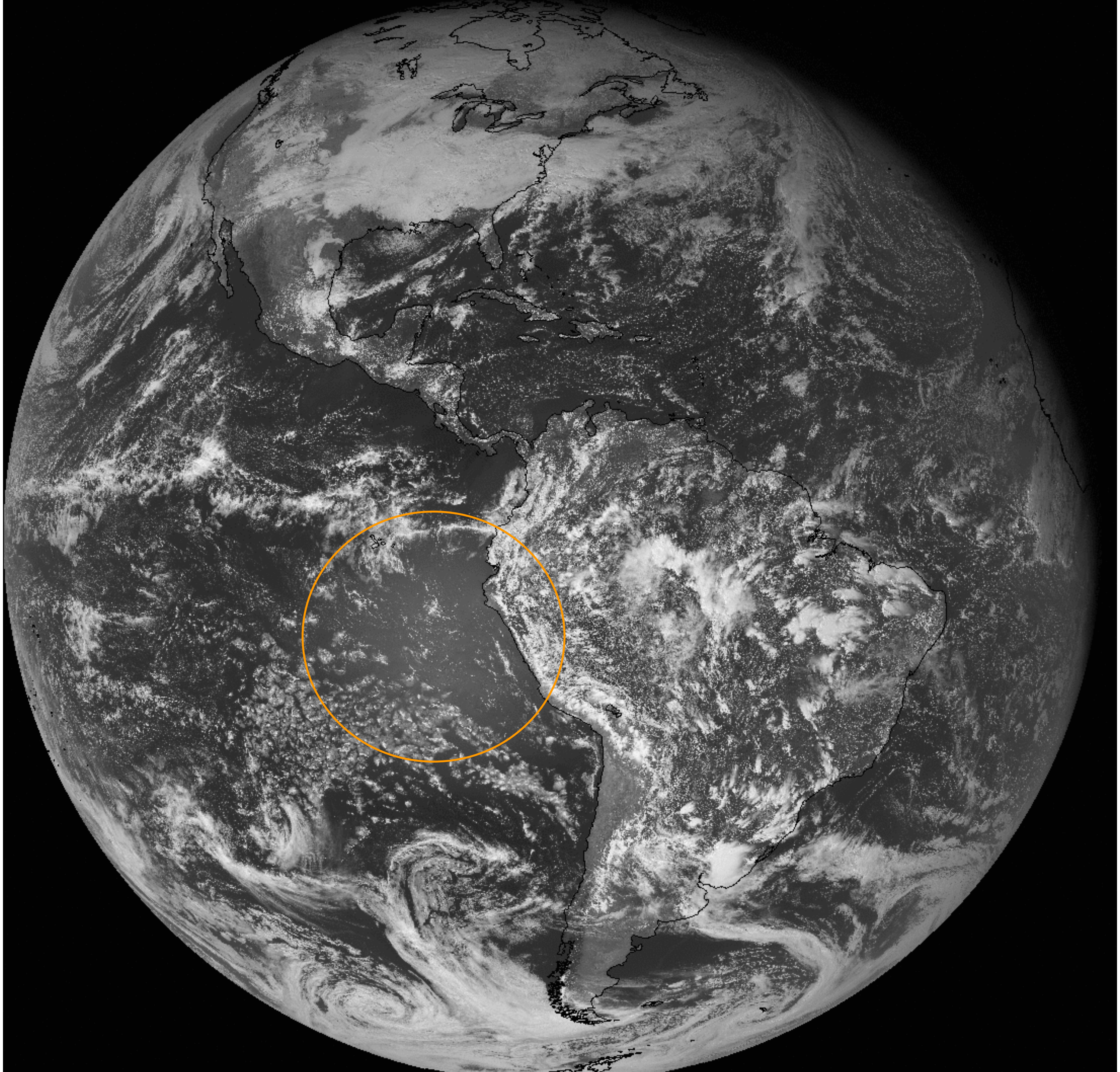
Lambertian or isotropic reflectance

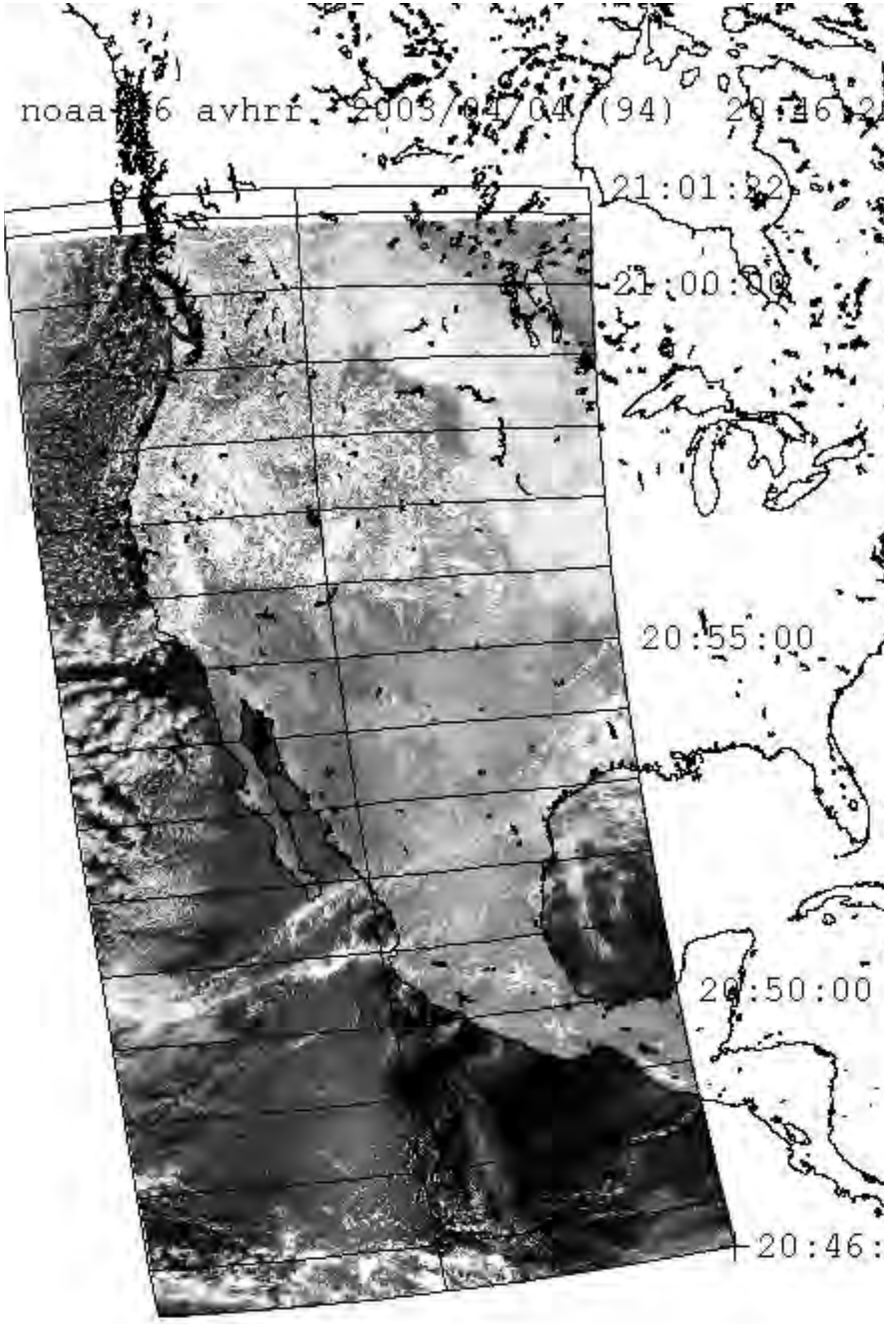


Specular or “mirror-like”

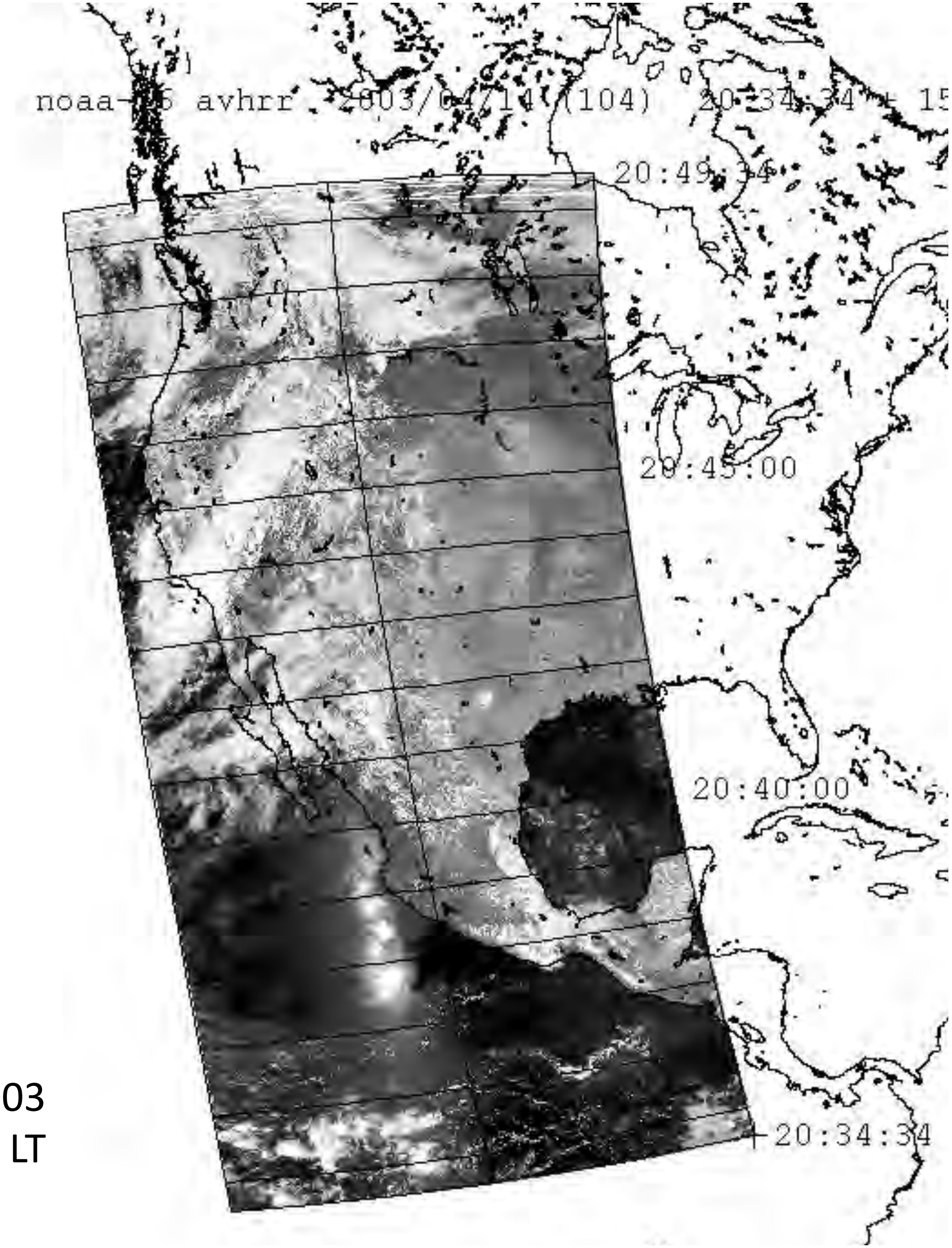



18 Jan 99 18:00:14Z
0.65 um
GOES-10
CIRA/NOAA-CSU

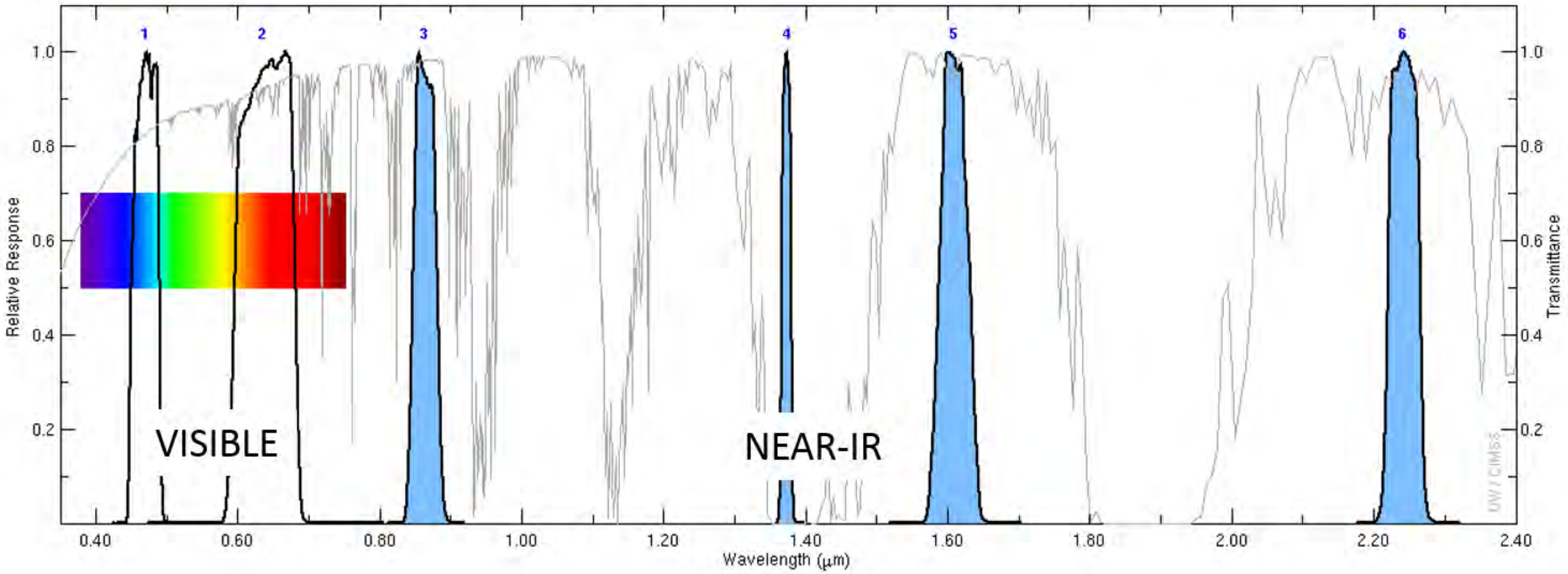


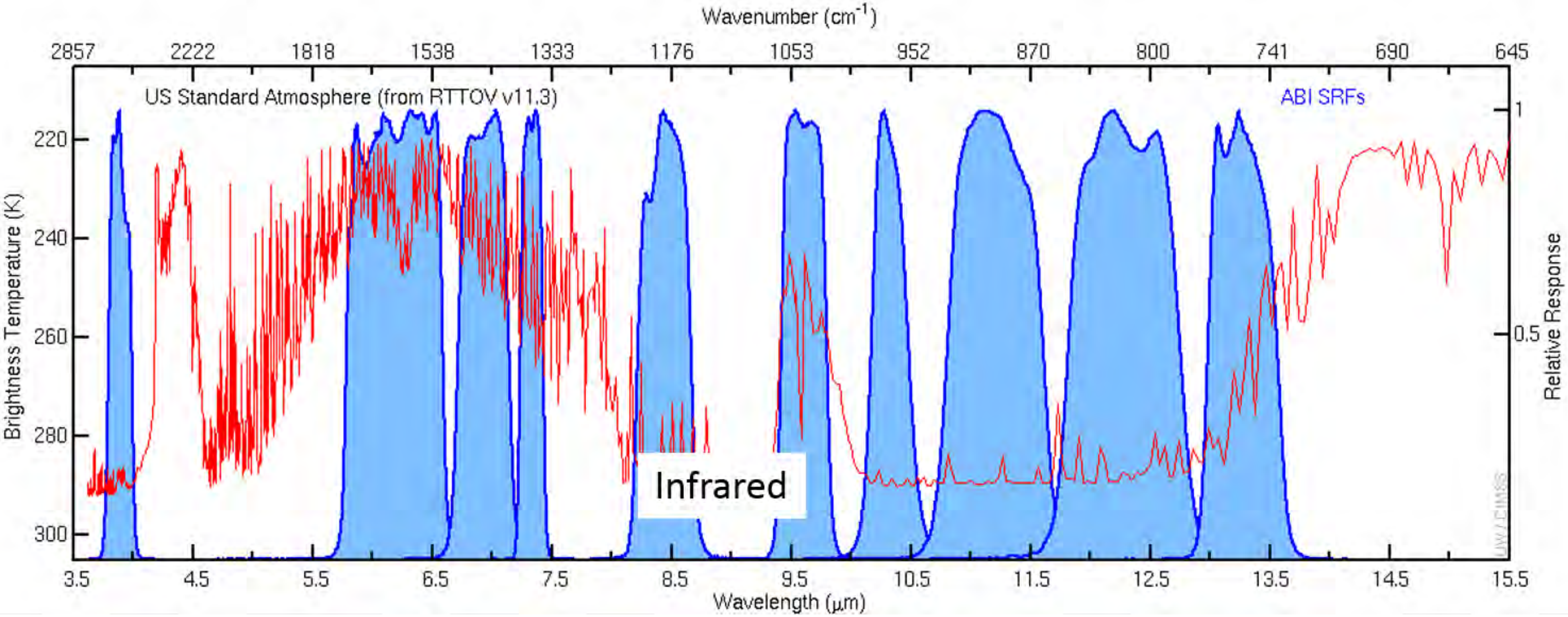


Apr 4, 2003
13:50 LT



Apr 14, 2003
13:40 LT


1
2
3
4
5
6
VISIBLE
NEAR-IR
Relative Response
Transmittance
1.0
0.8
0.6
0.4
0.2
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
2.20
2.40
Wavelength (μm)
UW / CIMSS


Wavenumber (cm^{-1})
2857
2222
1818
1538
1333
1176
1053
952
870
800
741
690
645
US Standard Atmosphere (from RTTOV v11.3)
ABI SRFs
Infrared
Brightness Temperature (K)
220
240
260
280
300
Relative Response
1
0.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5
14.5
15.5
Wavelength (μm)
UW / CIMSS

Band 2 (640 nm)

2020-07-10 15:22:25 UTC

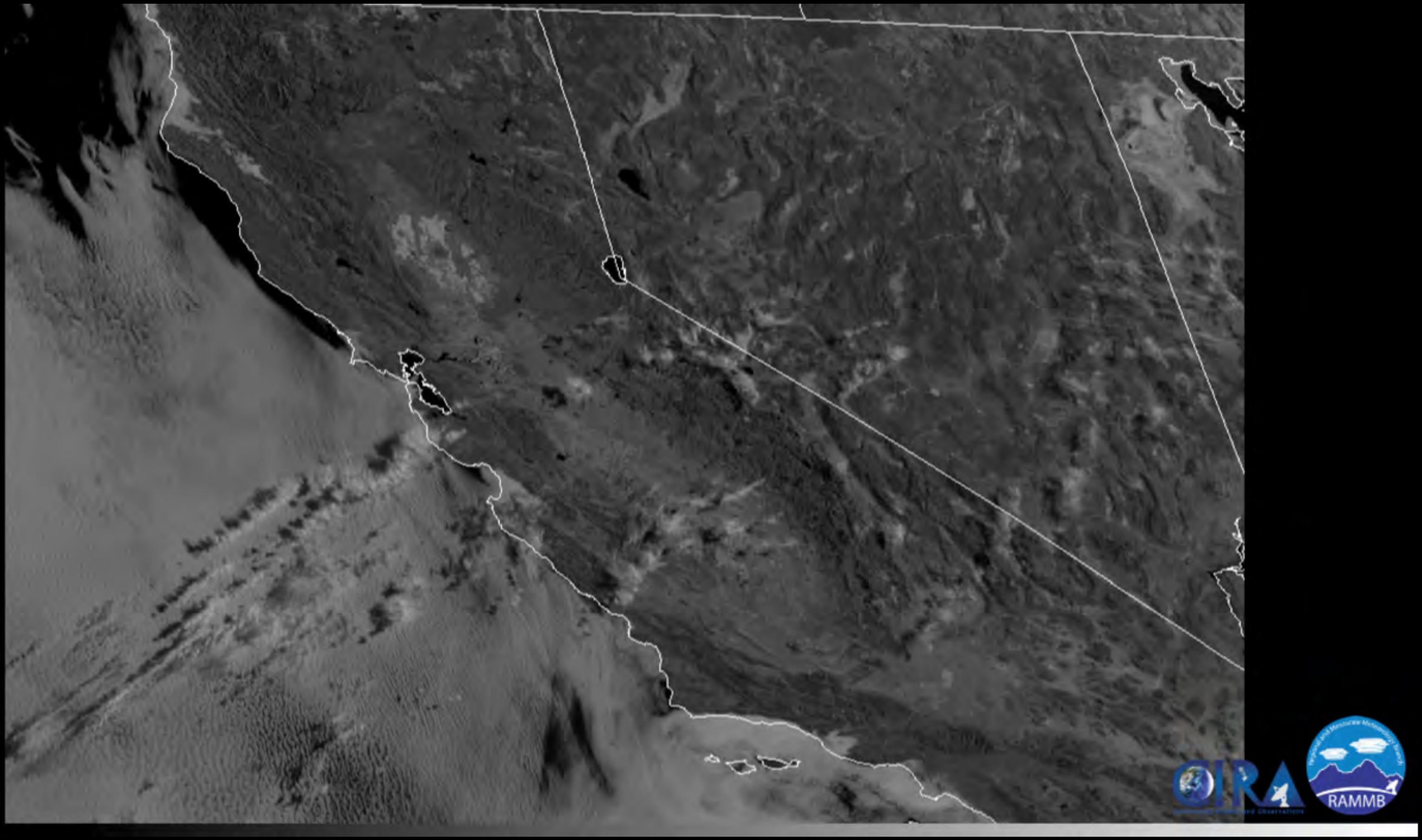
http://cimss.ssec.wisc.edu/goes/OCLOFactSheetPDFs/ABIQuickGuide_Band02.pdf

Band 1 (470 nm)

2020-07-10 15:25:25 UTC

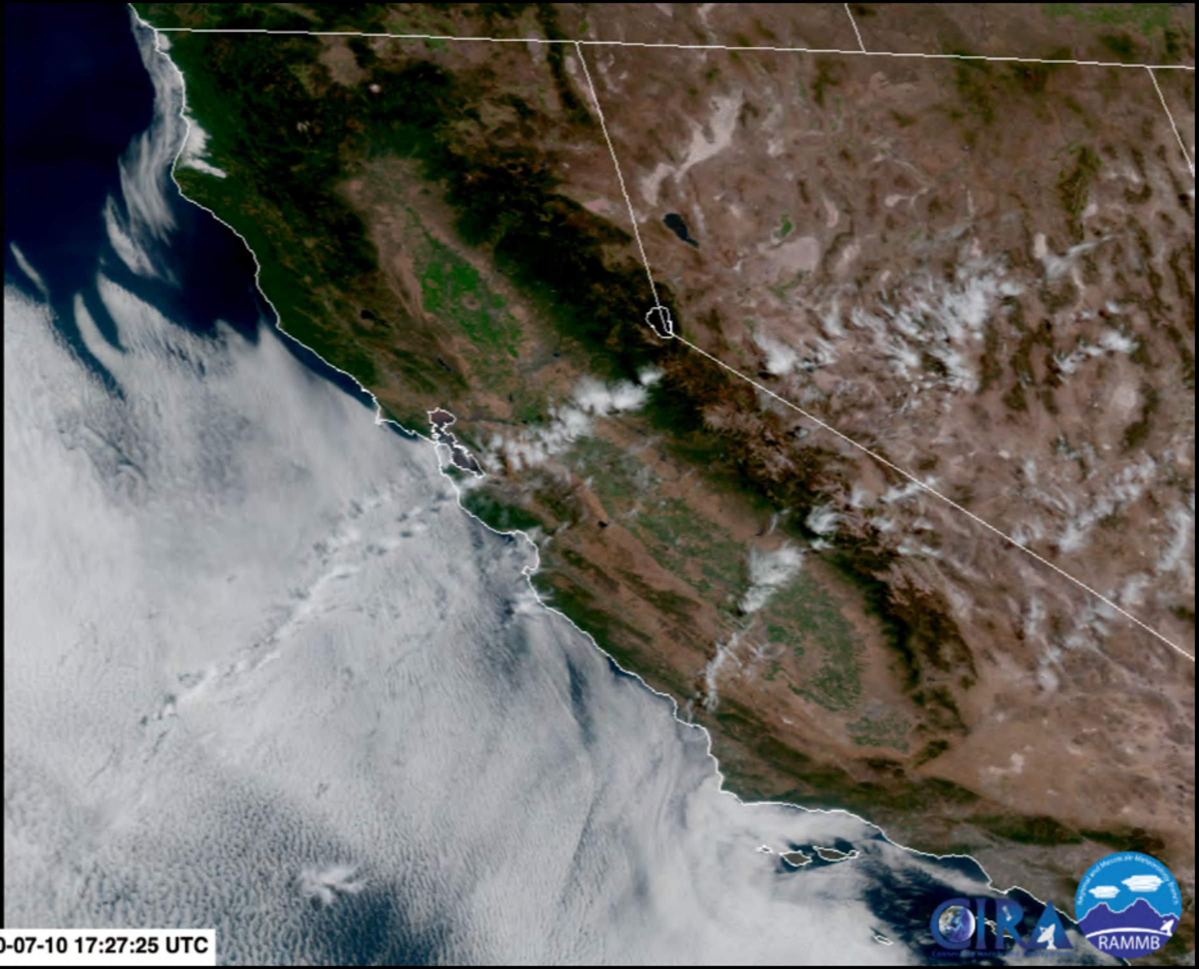
http://cimss.ssec.wisc.edu/goes/OCLOFactSheetPDFs/ABIQuickGuide_Band01.pdf

Band 3 (860 nm)



2020-07-10 15:20:25 UTC

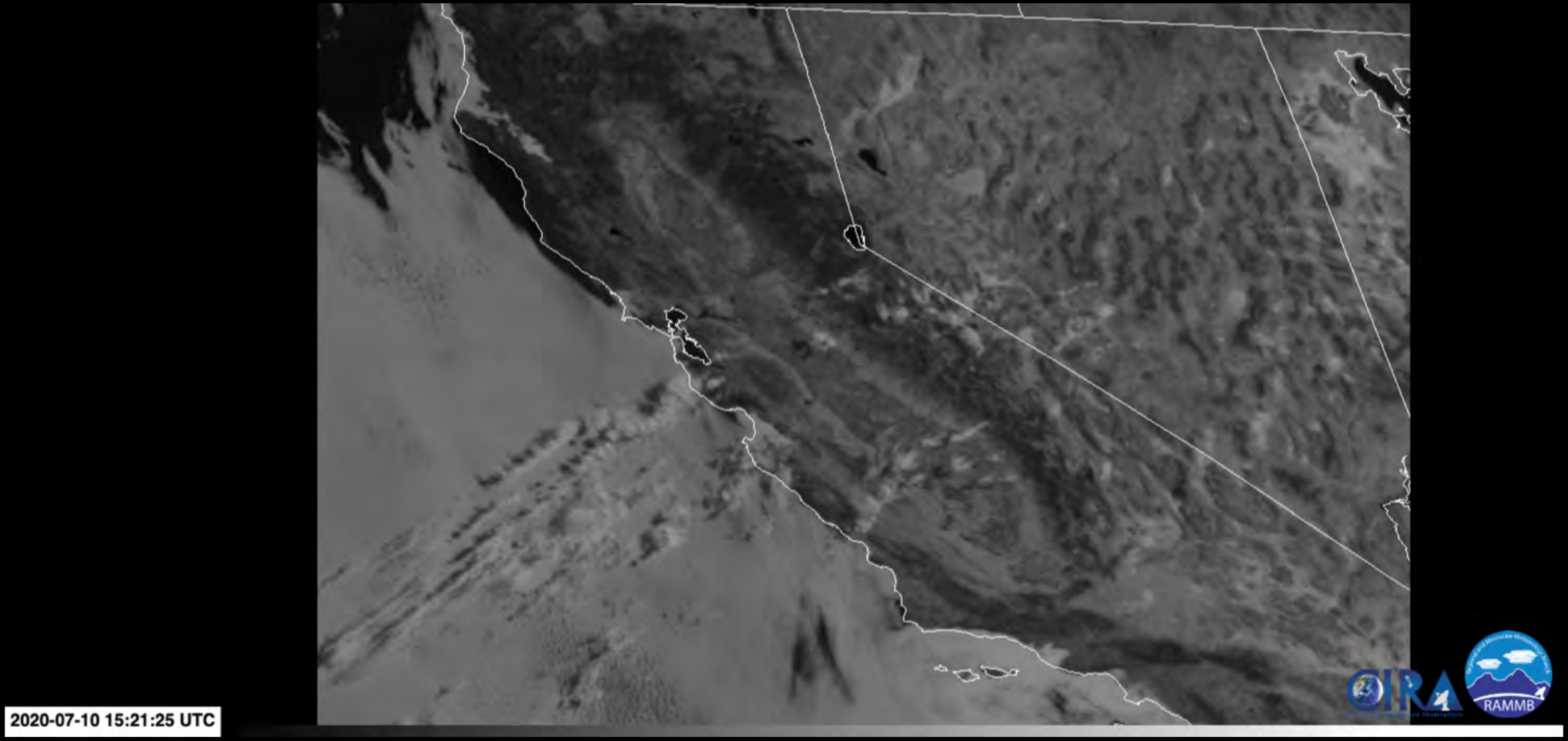
http://cimss.ssec.wisc.edu/goes/OCLOFactSheetPDFs/ABIQuickGuide_Band03.pdf



2020-07-10 17:27:25 UTC

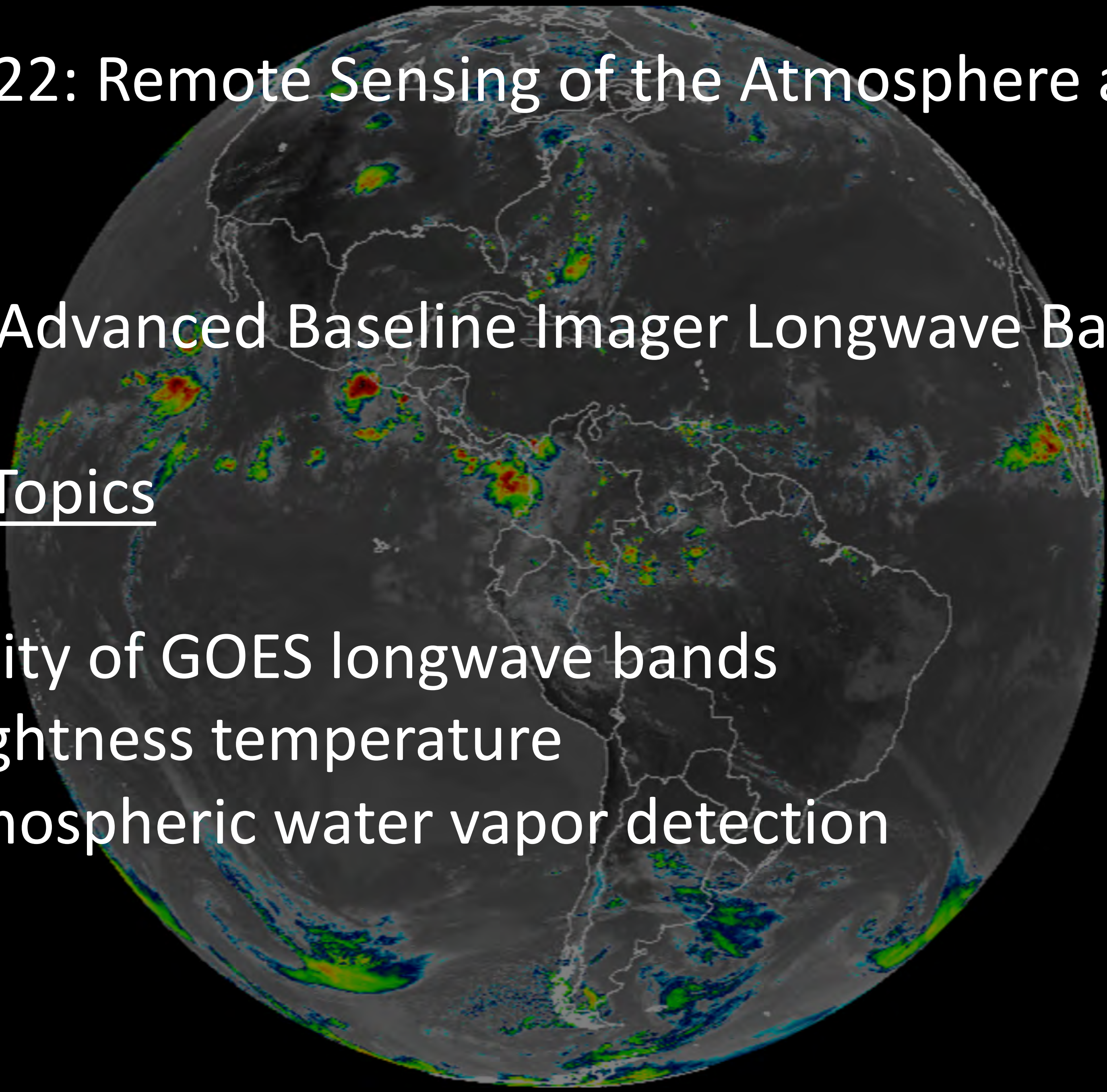
Band 5 (1.61 µm)

Band 6 (2.24 µm)



MR3522: Remote Sensing of the Atmosphere and Ocean

GOES Advanced Baseline Imager Longwave Bands



Main Topics

- Utility of GOES longwave bands
- Brightness temperature
- Atmospheric water vapor detection

Module 2.3

Idealized Case #2

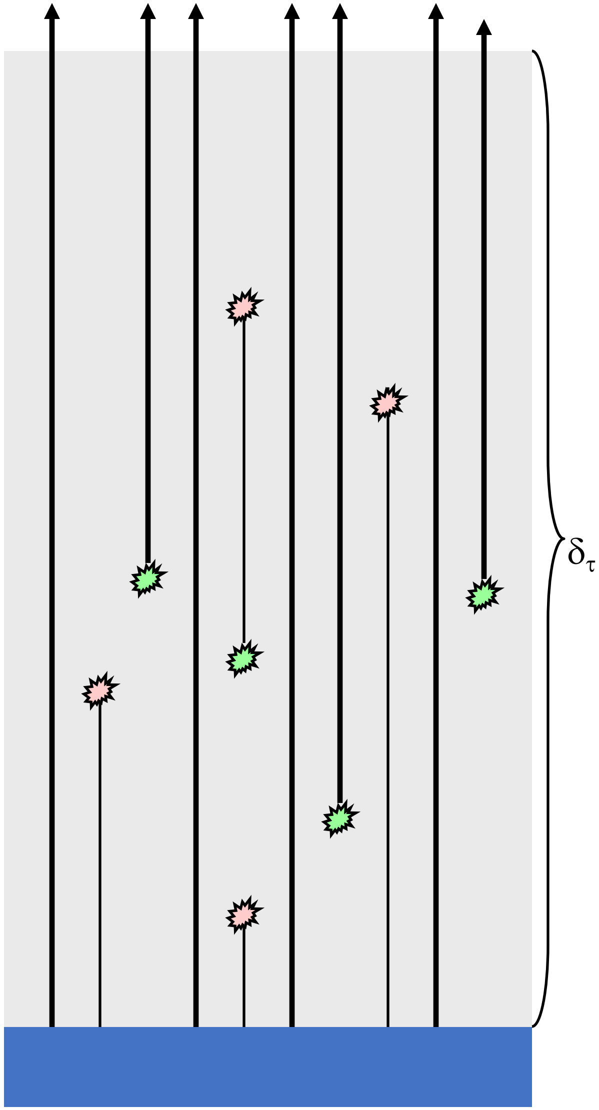
Emitted Path Radiance Only

Here emission is the only source of photons and there is **no scattering**, so $\sigma_e = \sigma_a$.

$$J_\lambda(z) = \sigma_{a,\lambda}(z)\, B_\lambda(T(z))$$

$$\varepsilon_{s,\lambda} = \sigma_{a,\lambda} \longrightarrow L(\delta_t;\mu,\phi) = \varepsilon_{s,\lambda} B_\lambda(T_s)$$

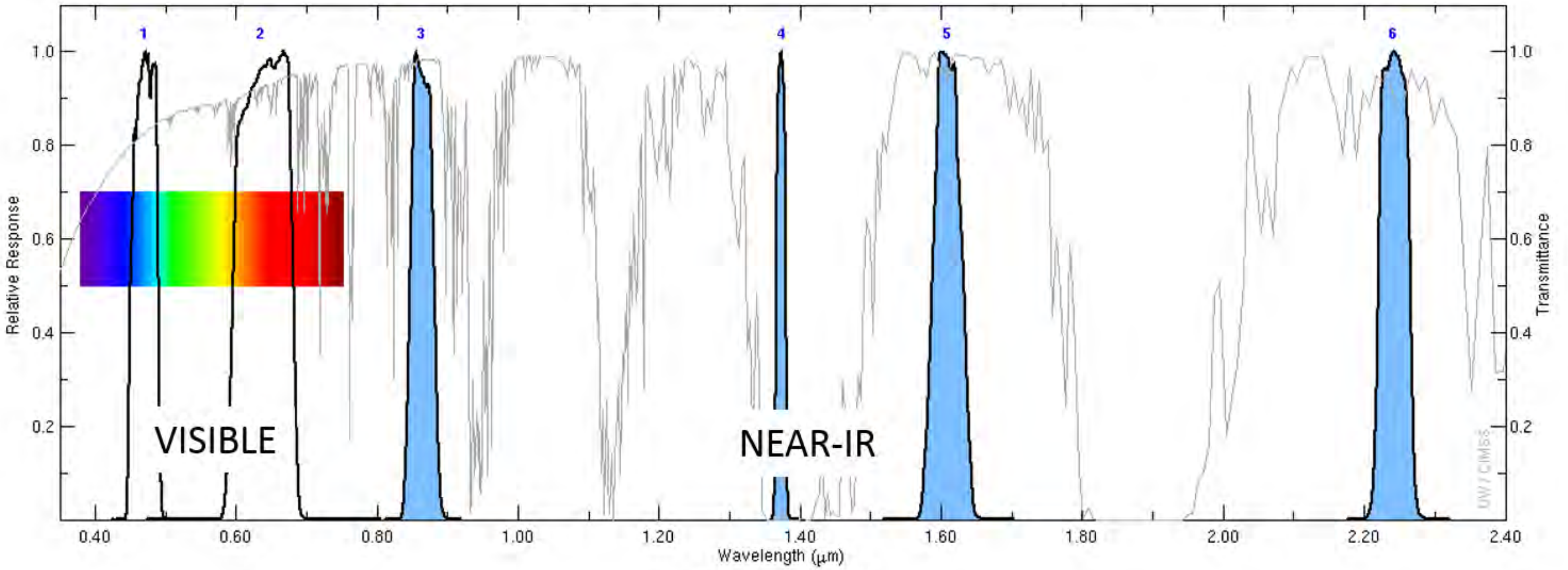
Kirchhoff's Law

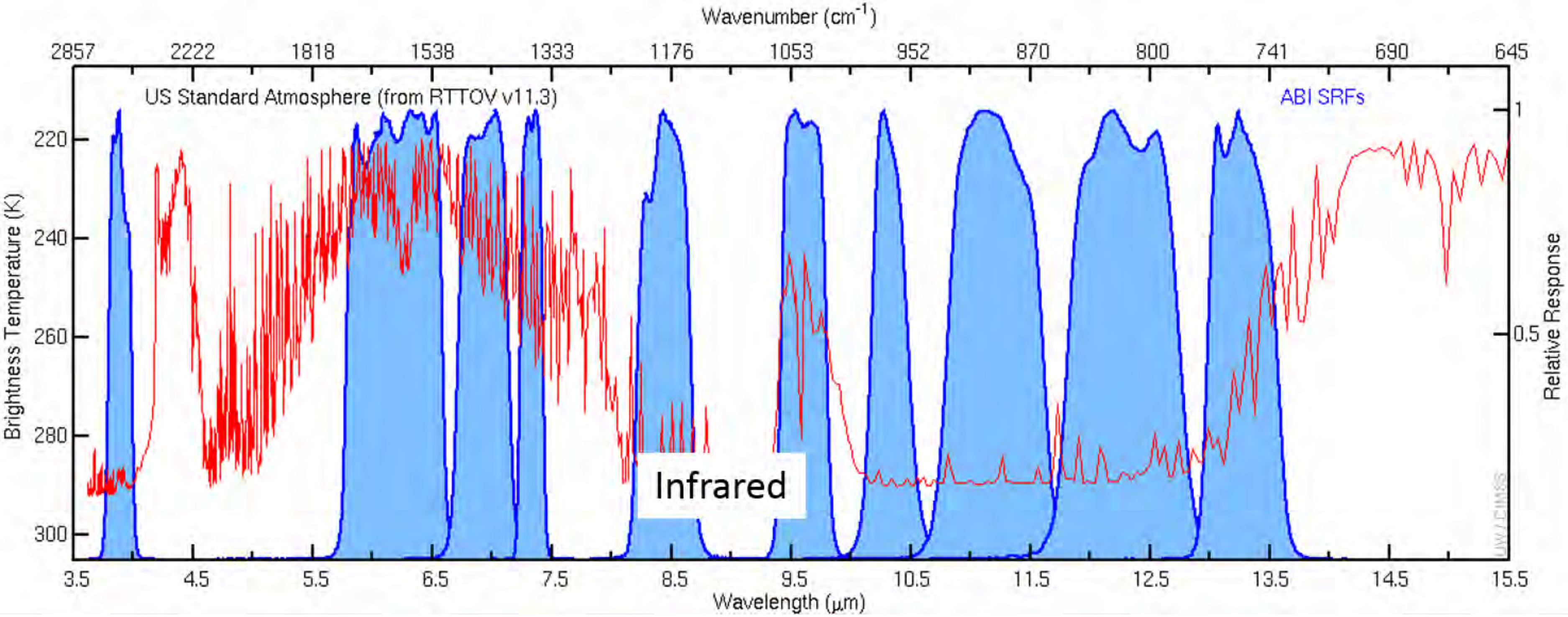


Solution:

$$L(0;\mu,\phi) = L(\delta_t;\mu,\phi)e^{-\delta_t/\mu} + \int_0^{\delta_t} \frac{J(\delta';\mu,\phi)}{\sigma_e(\delta')} e^{-\delta'/\mu} \frac{d\delta'}{\mu}$$

$$L(0;\mu,\phi) = \varepsilon_{s,\lambda} B_\lambda(T_s) e^{-\delta_t/\mu} + \int_0^{\delta_t} B_\lambda(T(z)) e^{-\delta'/\mu} \frac{d\delta'}{\mu}$$


1
2
3
4
5
6
VISIBLE
NEAR-IR
Relative Response
Transmittance
0.2
0.4
0.6
0.8
1.0
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
2.20
2.40
Wavelength (μm)
UW / CIMSS

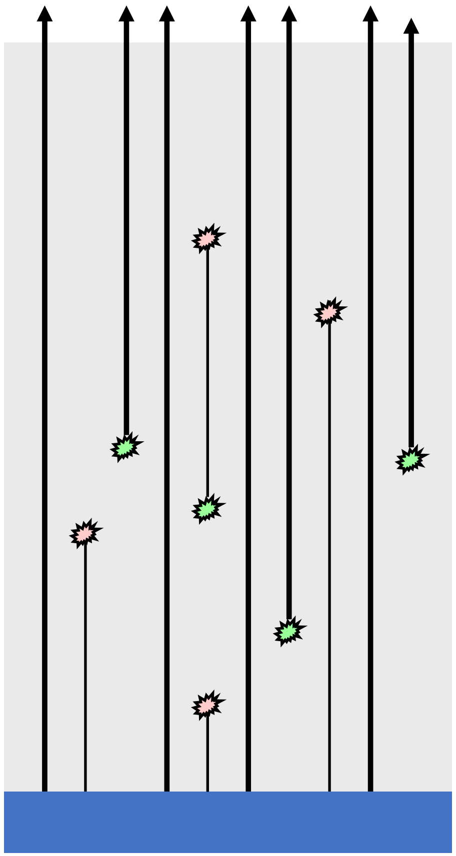

Wavenumber (cm^{-1})
2857
2222
1818
1538
1333
1176
1053
952
870
800
741
690
645
US Standard Atmosphere (from RTTOV v11.3)
ABI SRFs
Brightness Temperature (K)
220
240
260
280
300
Relative Response
1
0.5
Infrared
3.5
4.5
5.5
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5
14.5
15.5
Wavelength (μm)
UW / CIMSS

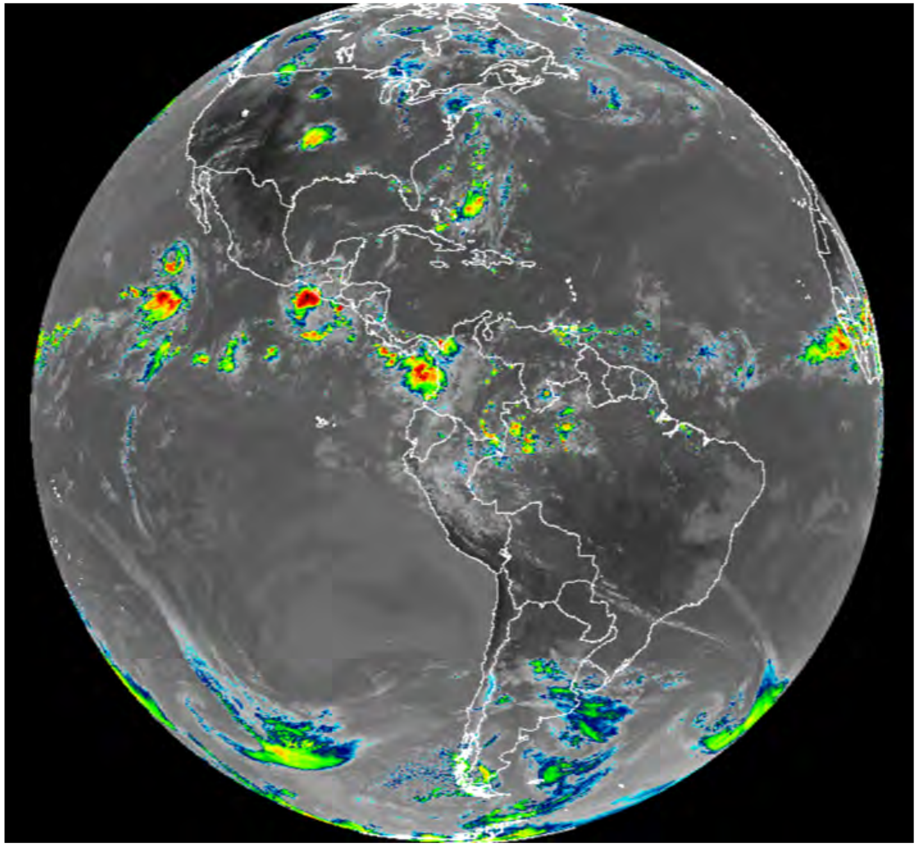
Brightness temperature is defined as

the temperature a blackbody would need
to emit the radiance measured by a satellite (L_t)

That is, if L_t was emitted by a blackbody, what would its temperature be?

$$L_t \Rightarrow B(\lambda, T_B) = \frac{2\hbar c^2}{\lambda^5\left(e^{\hbar c/\lambda k T_B} - 1\right)} \quad \text{and} \quad T_B = \frac{\hbar c}{\lambda k \ln \frac{2\hbar c^2}{\lambda^5 L_t}}$$





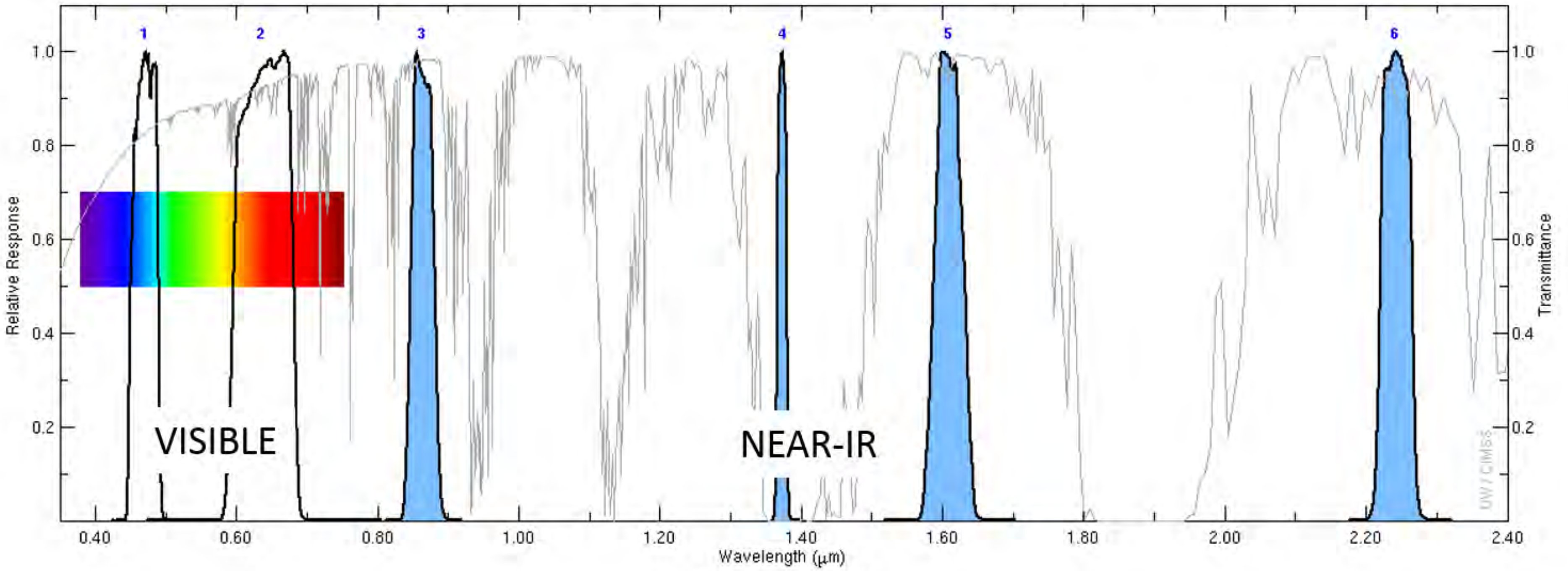
T_B
(from GOES Ch 13)

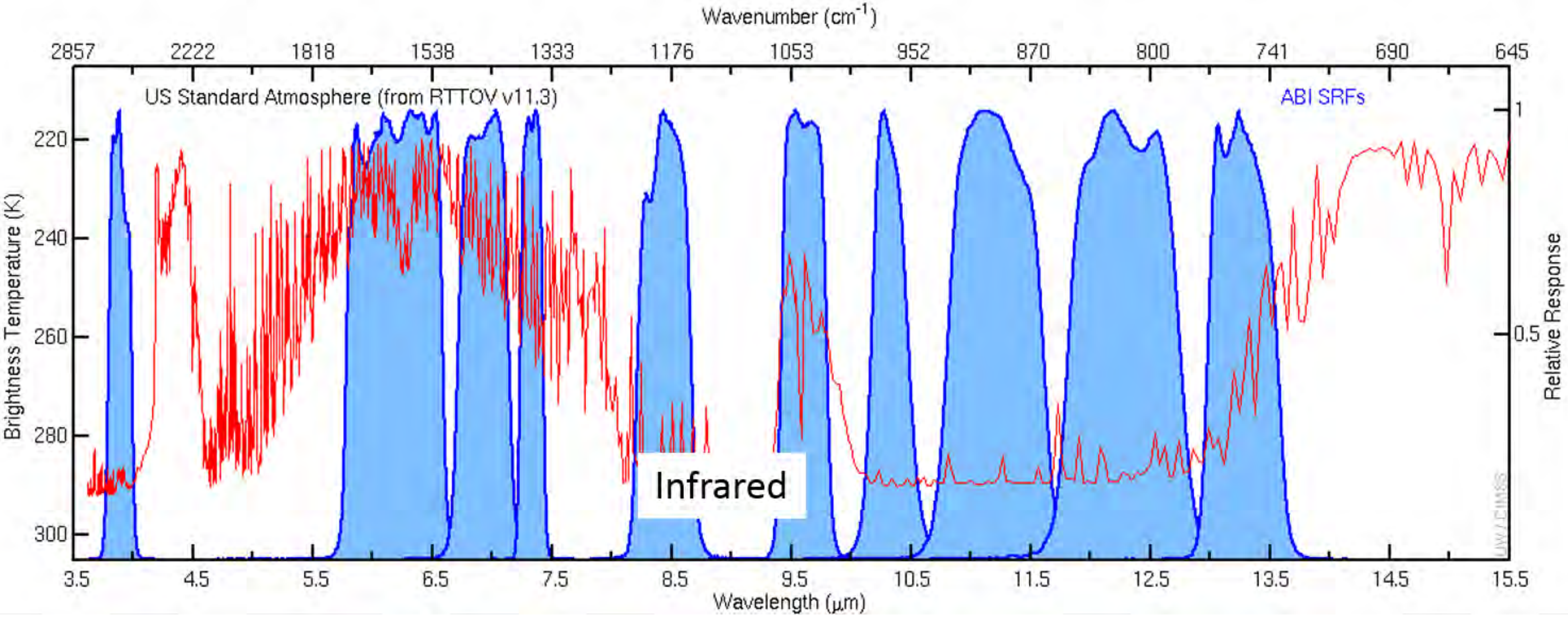
Brightness temperature is not necessarily actual temperature!

1. The emitting body might not be a blackbody.
2. Radiation could be depleted along the path to the sensor.

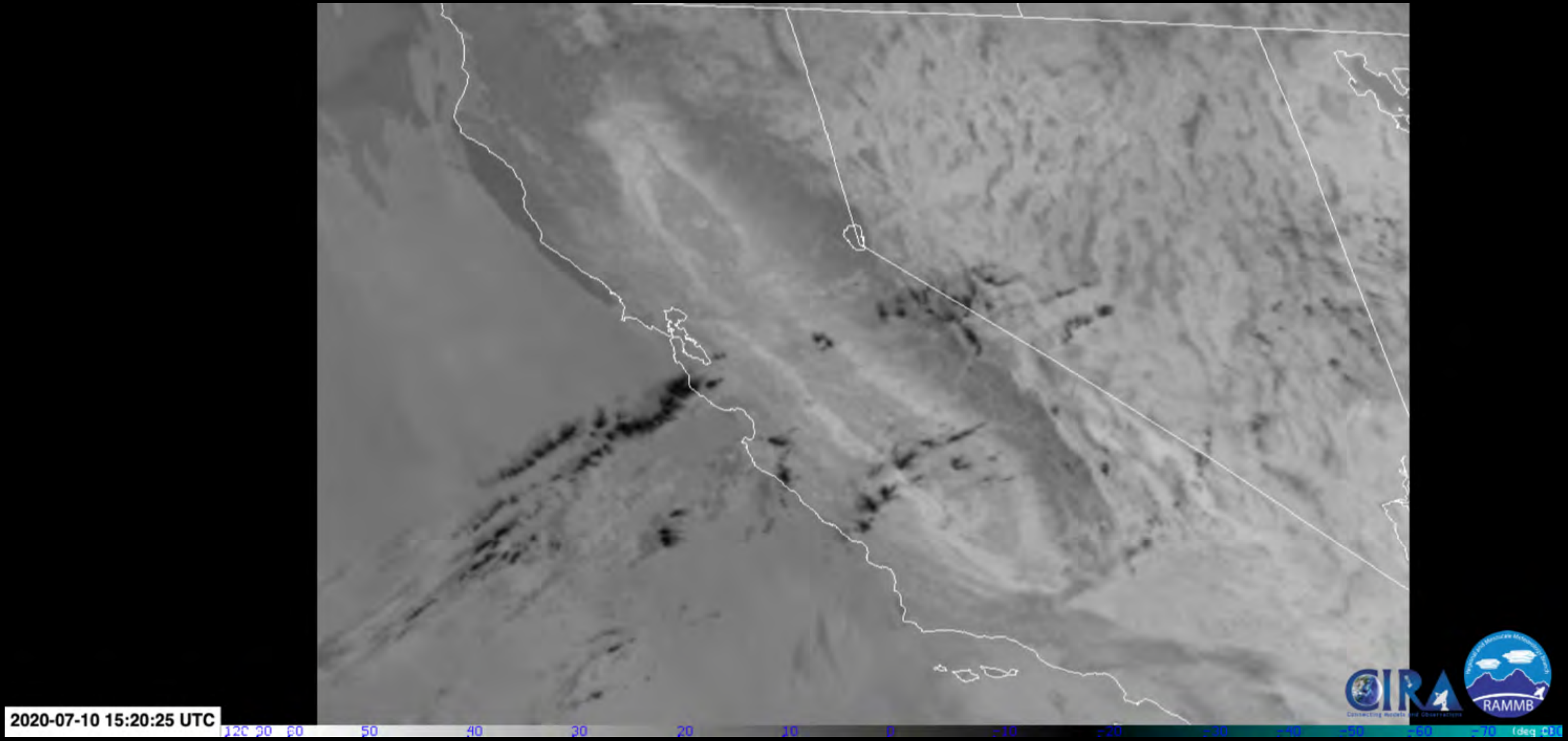
$$L_t(\lambda,\theta,\varphi) = \varepsilon_s(\lambda,\theta) B(\lambda,T_s)\tau_d(\lambda) + \int_p^0 B(\lambda,T(p)) \frac{d\tau_d(\lambda,p)}{dp} dp$$

For a cloud (an efficient absorber and emitter if ~100 meters or more thick) with an optically thin atmosphere (to the wavelength of interest) above it, the brightness temperature is approximately the cloud top temperature. Knowledge of the atmospheric sounding could help determine cloud top height.

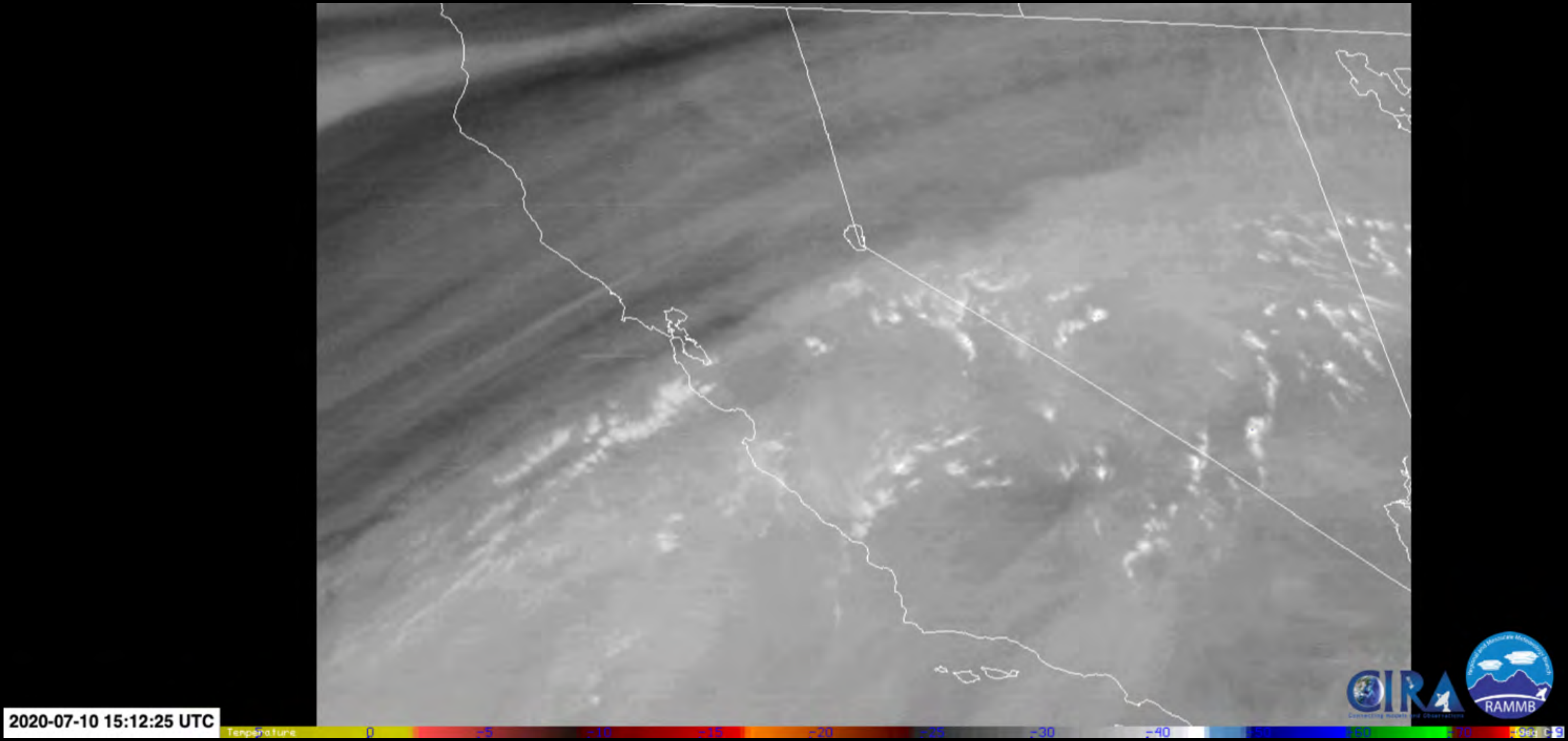

1
2
3
4
5
6
1.0
0.8
0.6
0.4
0.2
Relative Response
Transmittance
VISIBLE
NEAR-IR
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
2.20
2.40
Wavelength (µm)
UW / CIMSS


Wavenumber (cm-1)
2857
2222
1818
1538
1333
1176
1053
952
870
800
741
690
645
US Standard Atmosphere (from RTTOV v11.3)
ABI SRFs
Brightness Temperature (K)
220
240
260
280
300
Relative Response
1
0.5
Infrared
3.5
4.5
5.5
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5
14.5
15.5
Wavelength (µm)
UW / CIMSS

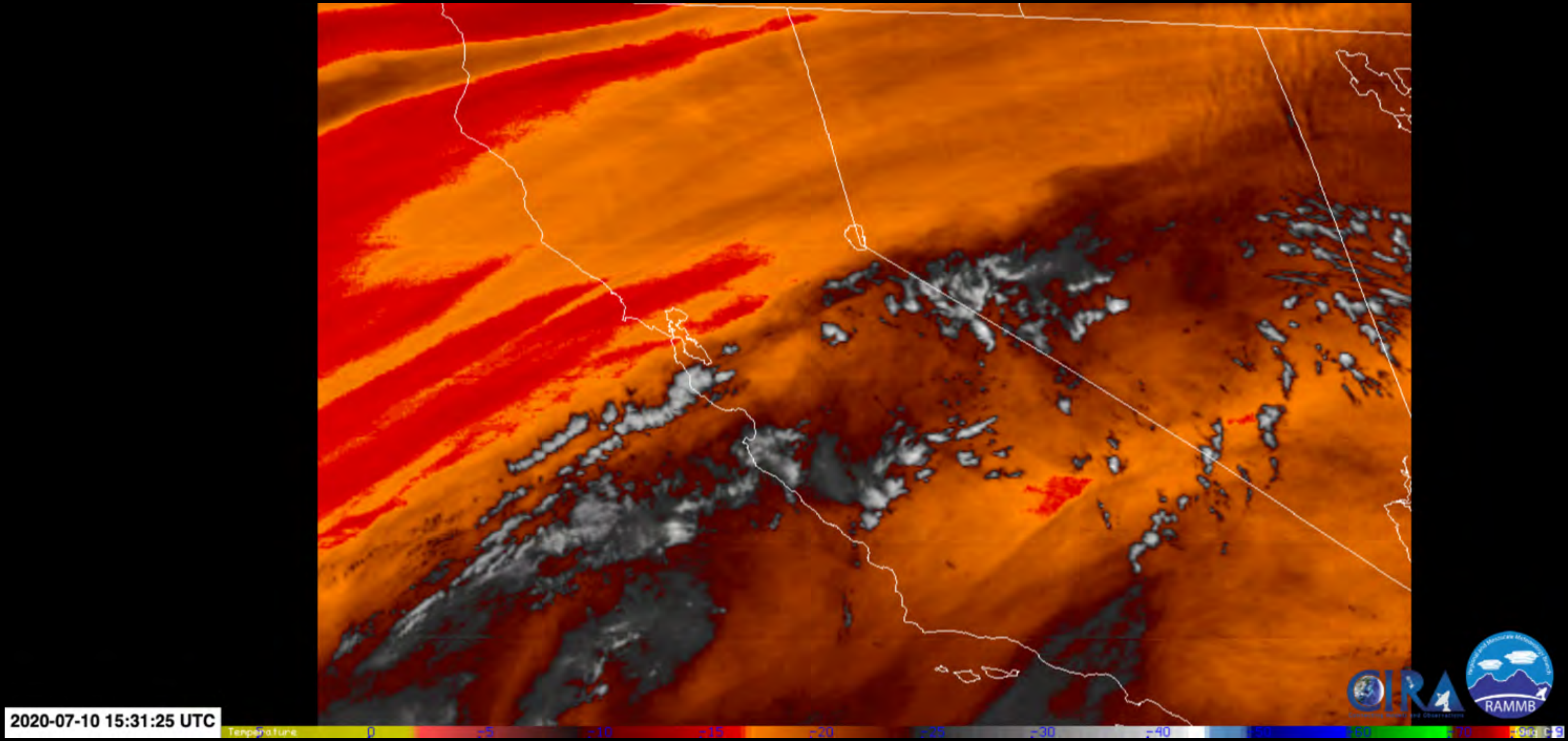
Band 7 (3.90 µm)


2020-07-10 15:20:25 UTC
120
90
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
(deg C)
CIRA
RAMMB

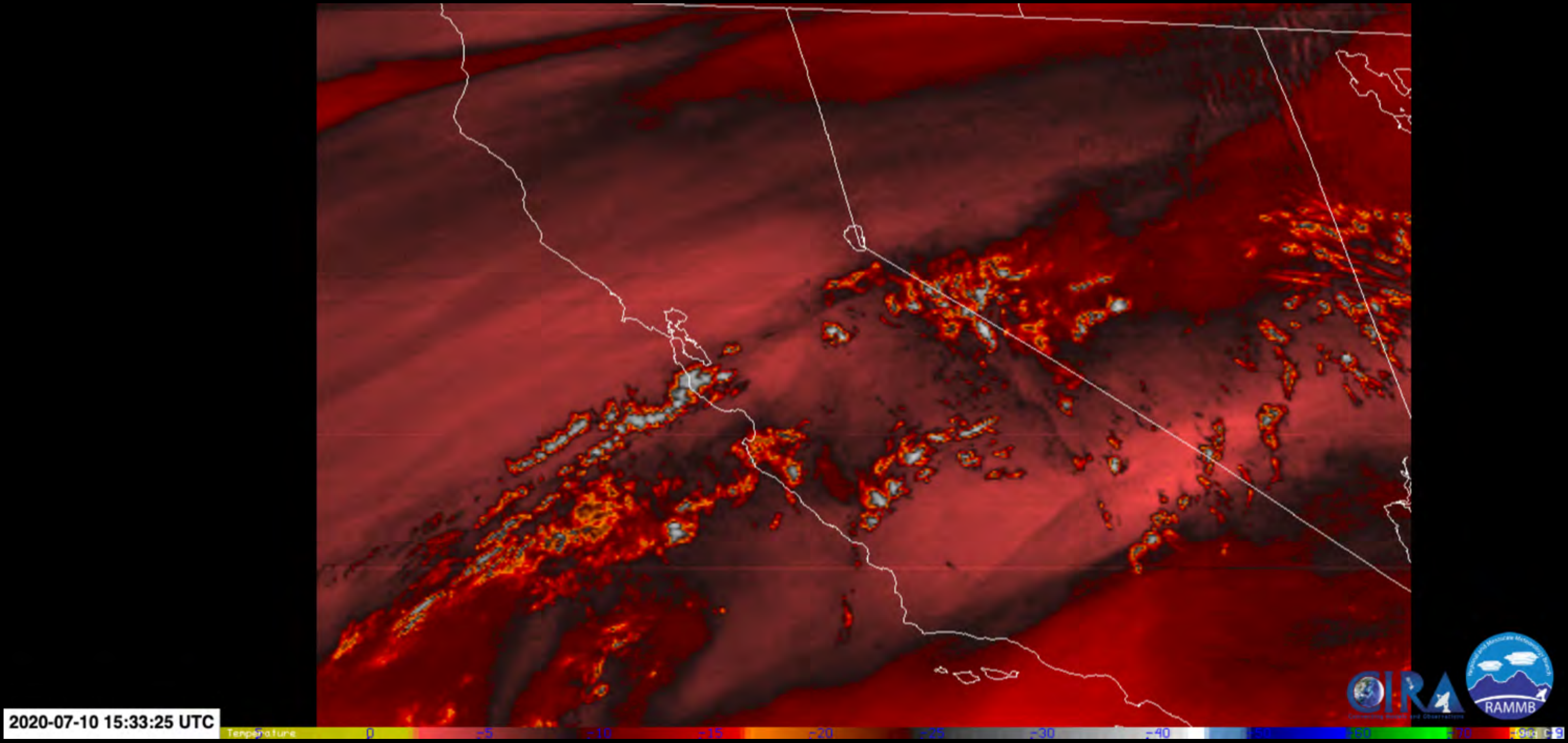
Band 8 (6.19 µm)

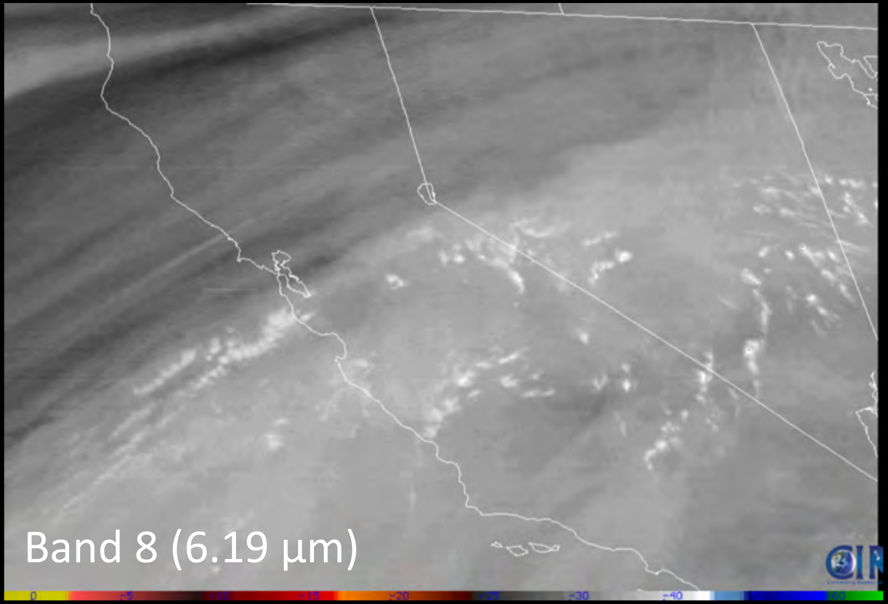

2020-07-10 15:12:25 UTC
Temperature
0
-5
-10
-15
-20
-25
-30
-40
-60
CIRA
RAMMB

Band 9 (6.95 µm)

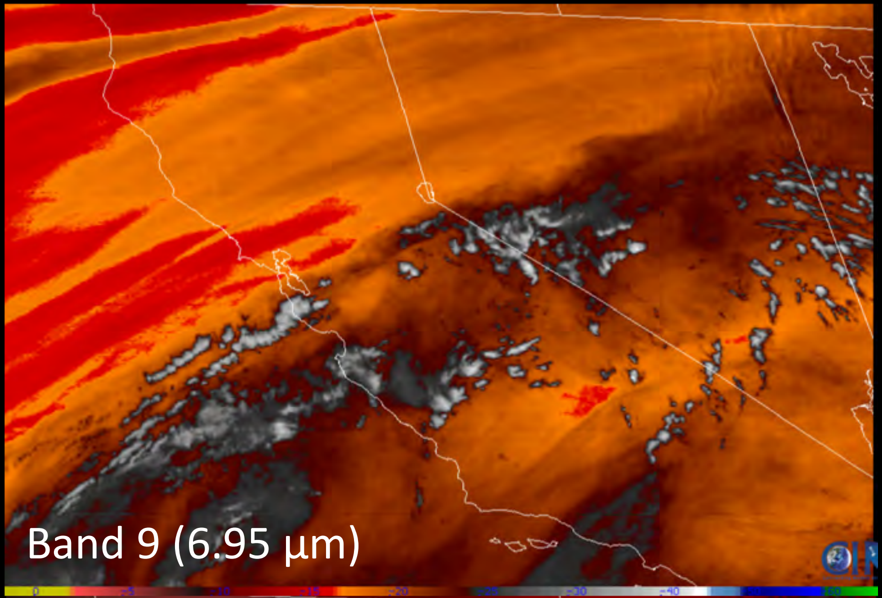

2020-07-10 15:31:25 UTC
Temperature
0
-5
-10
-15
-20
-25
-30
-40
-50
-60
-70
RAMMB
CIRA

Band 10 (7.34 µm)

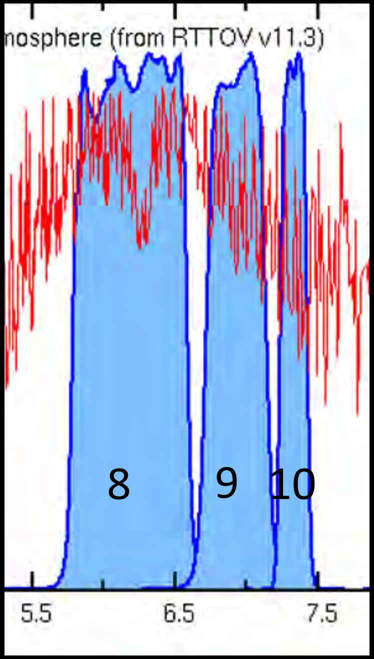


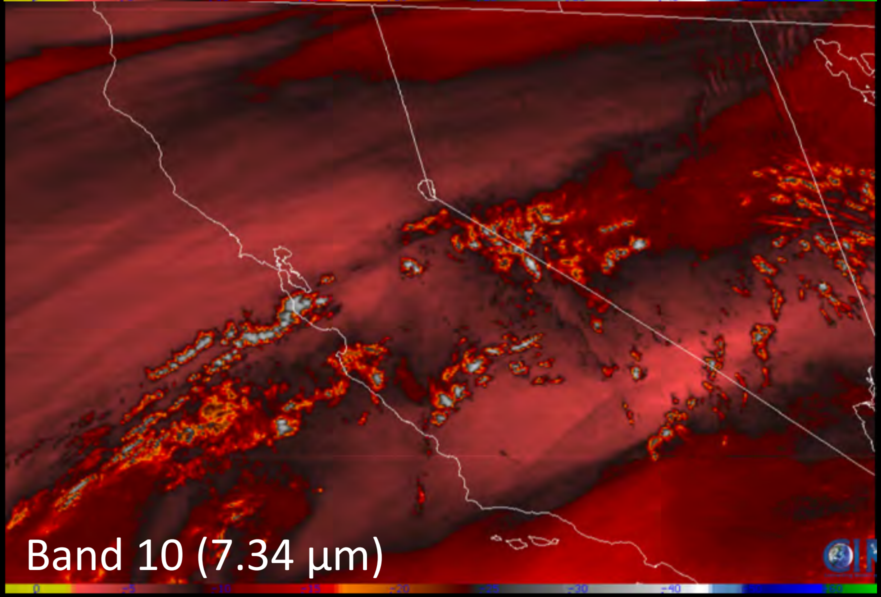


Band 8 (6.19 µm)



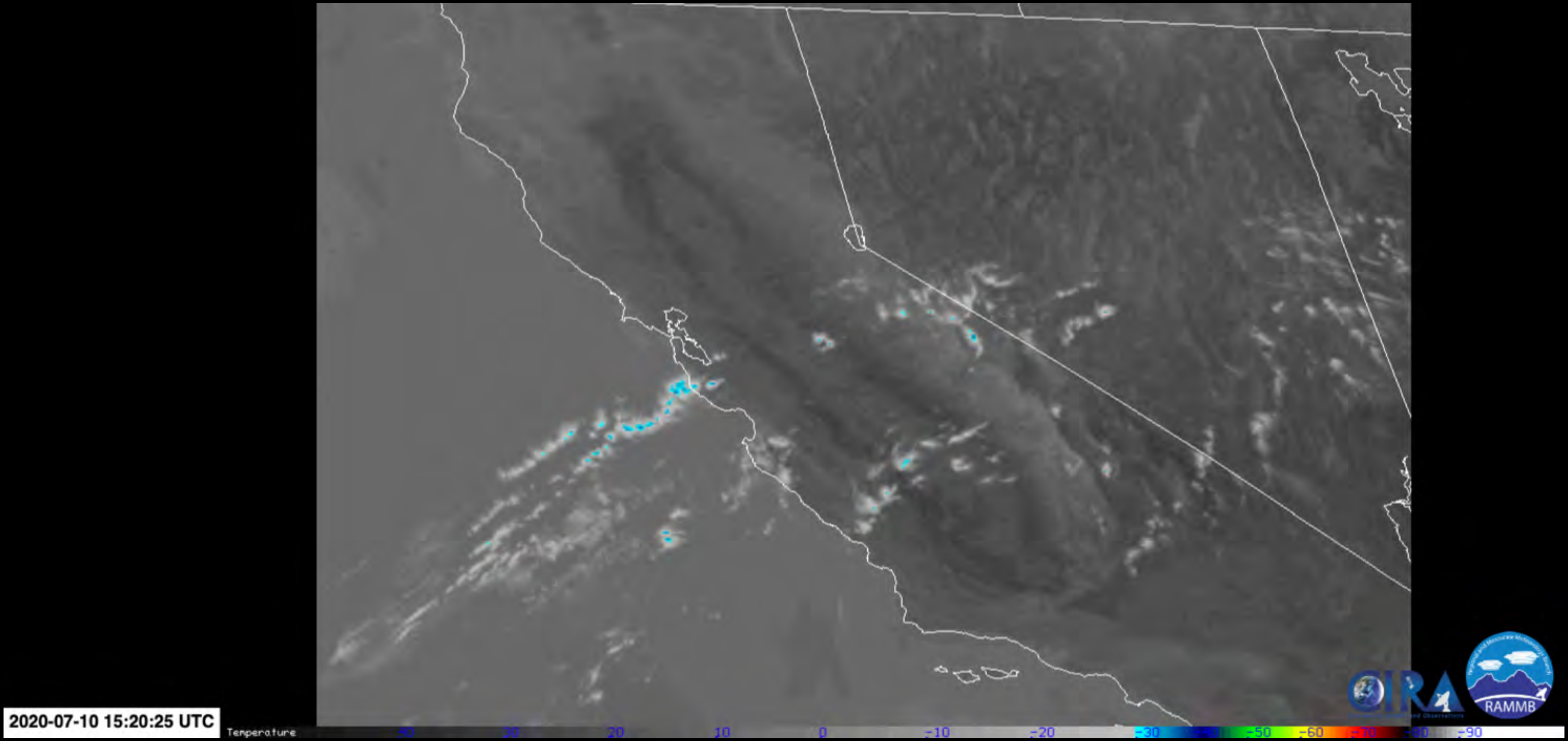
Band 9 (6.95 µm)



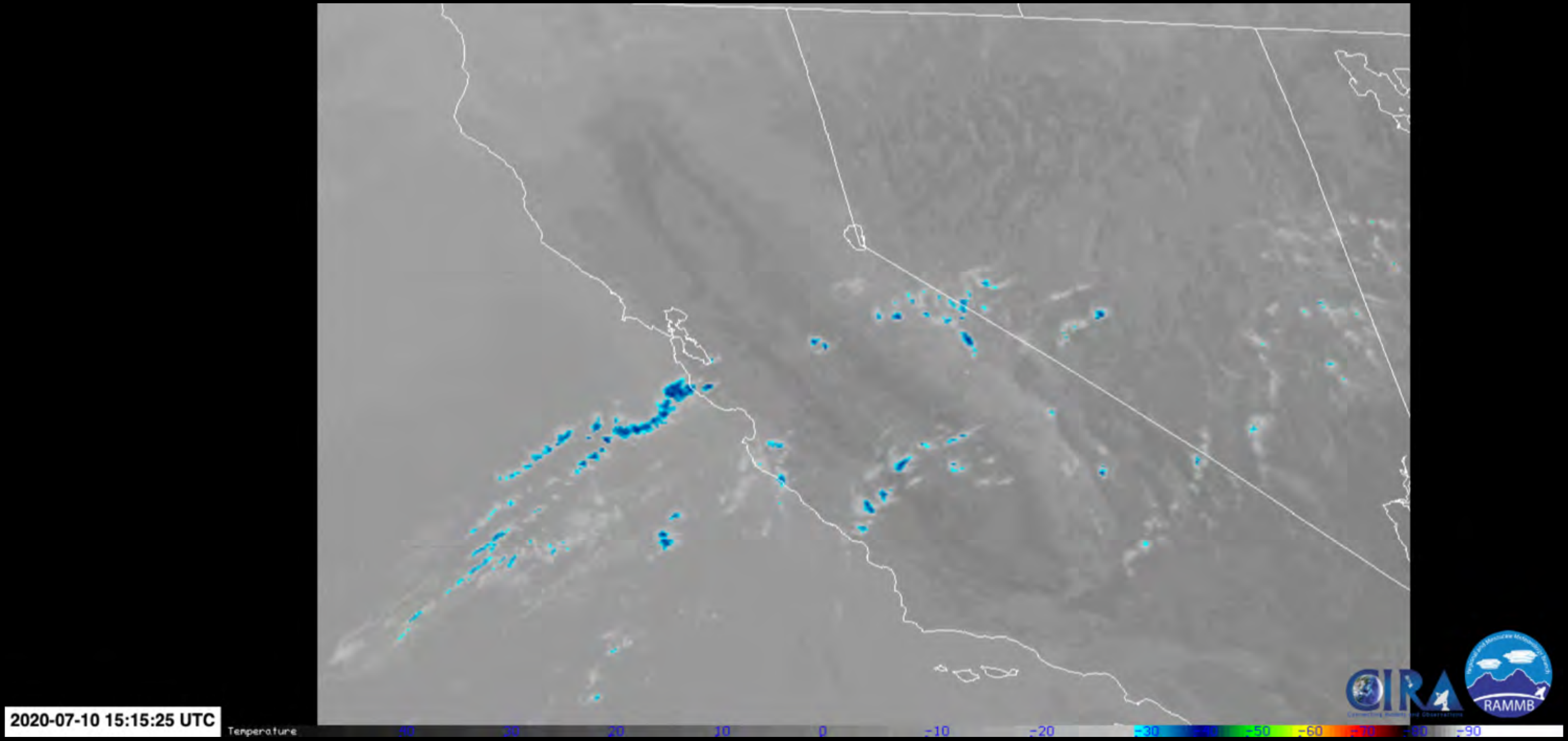


Band 10 (7.34 µm)

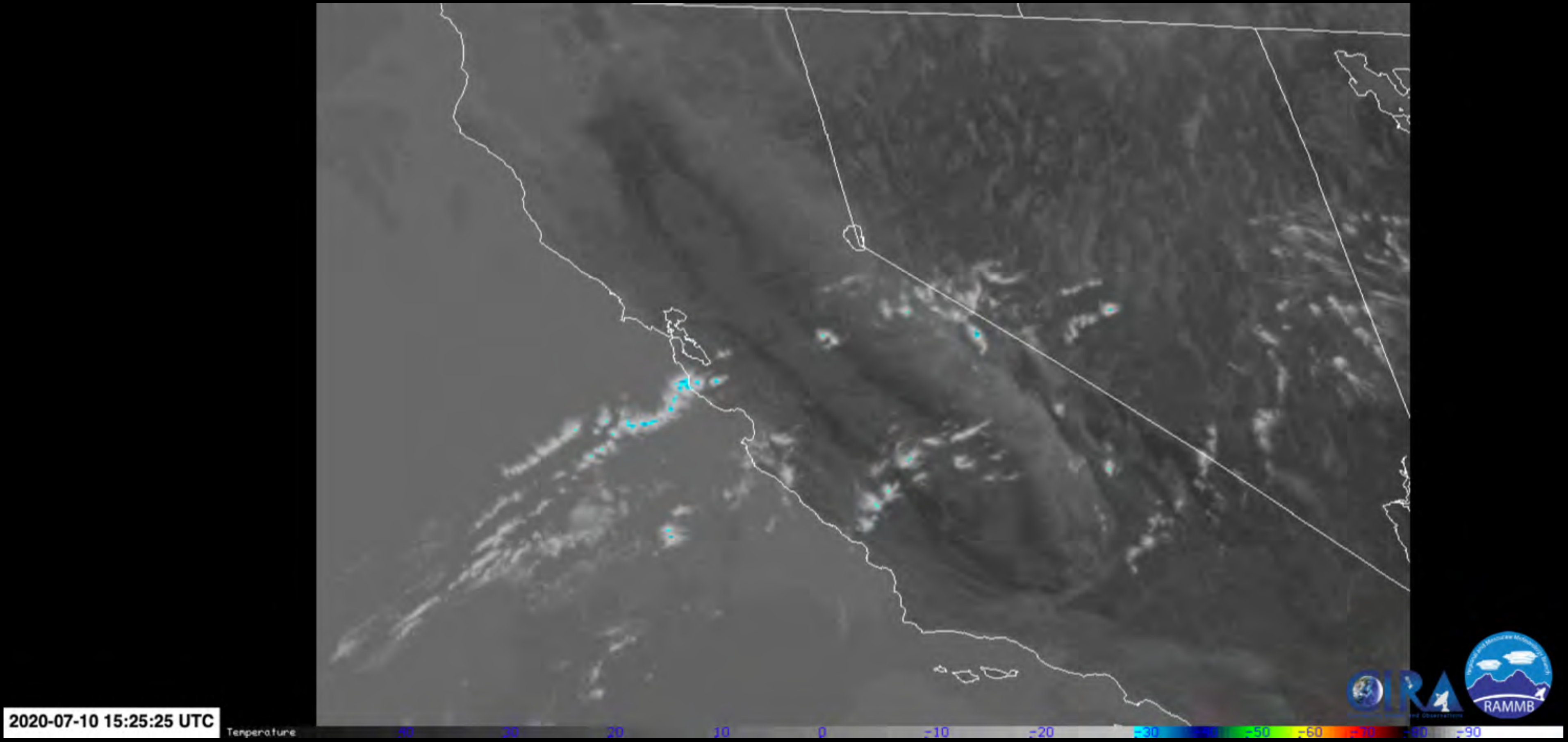
Band 11 (8.5 μm)


2020-07-10 15:20:25 UTC
Temperature
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
CIRA
RAMMB

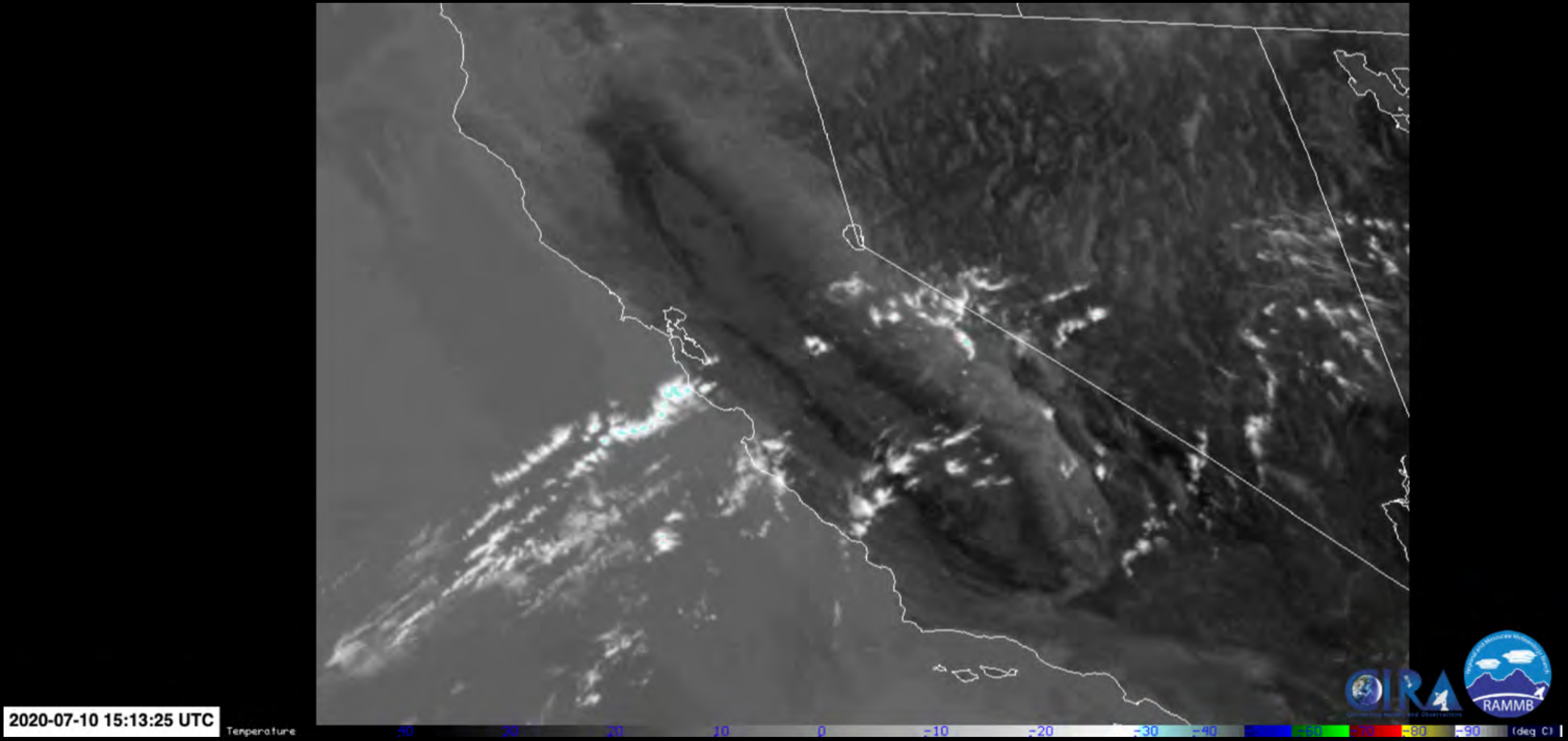
Band 12 (9.61 µm): Ozone band



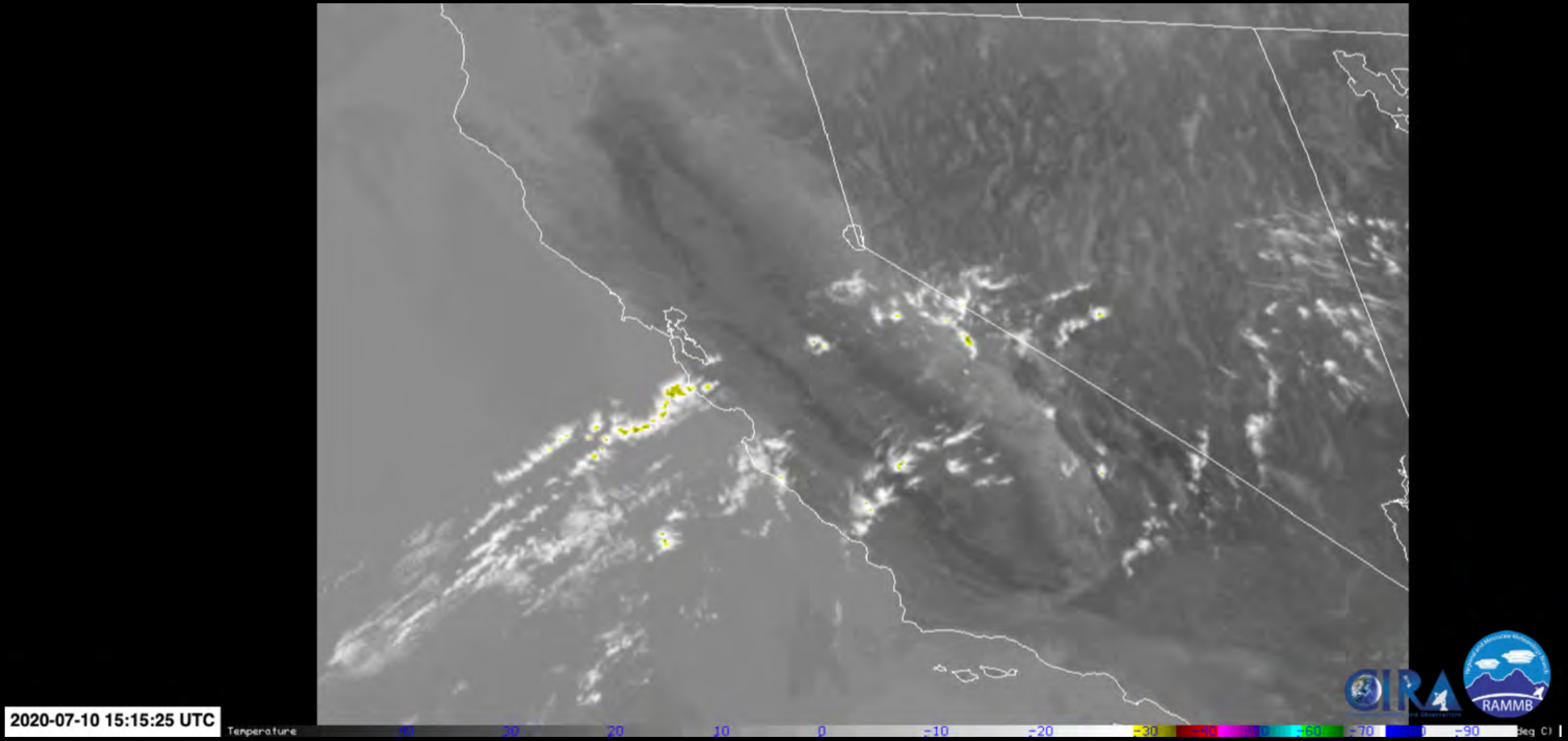
Band 13 (10.35 µm)



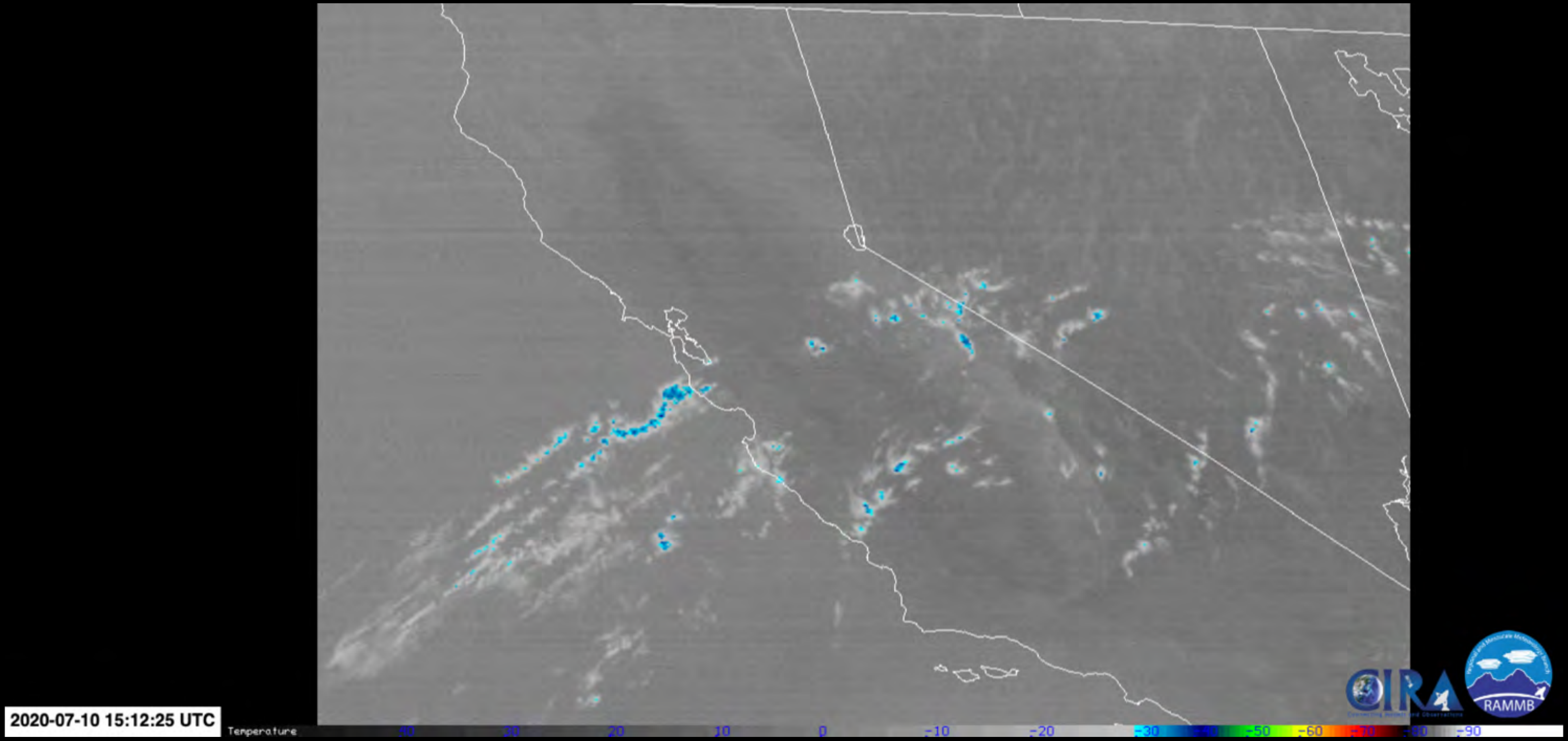
Band 14 (11.2 µm)



Band 15 (12.3 µm)



Band 16 (13.3 µm)



MR3522: Remote Sensing of the Atmosphere and Ocean

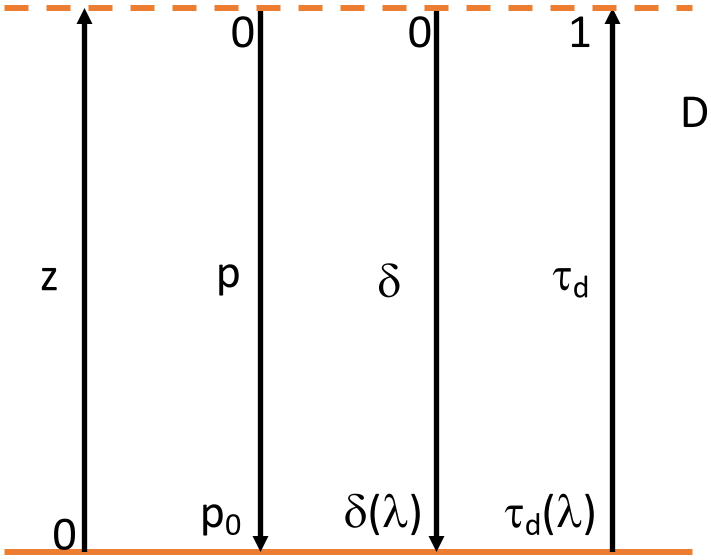
Weighting Functions

Main Topics

- Interpreting weighting functions
- Relationship between optical depth and weighting functions

Module 2.4

We can express variance in direct transmittance with height in terms of the weighting function.



Direct Transmittance, $\tau_d = e^{-\delta(\lambda,p)/\mu}$

The probability that a photon of wavelength λ will directly (without interaction) propagate to the top of the atmosphere from vertical position p.

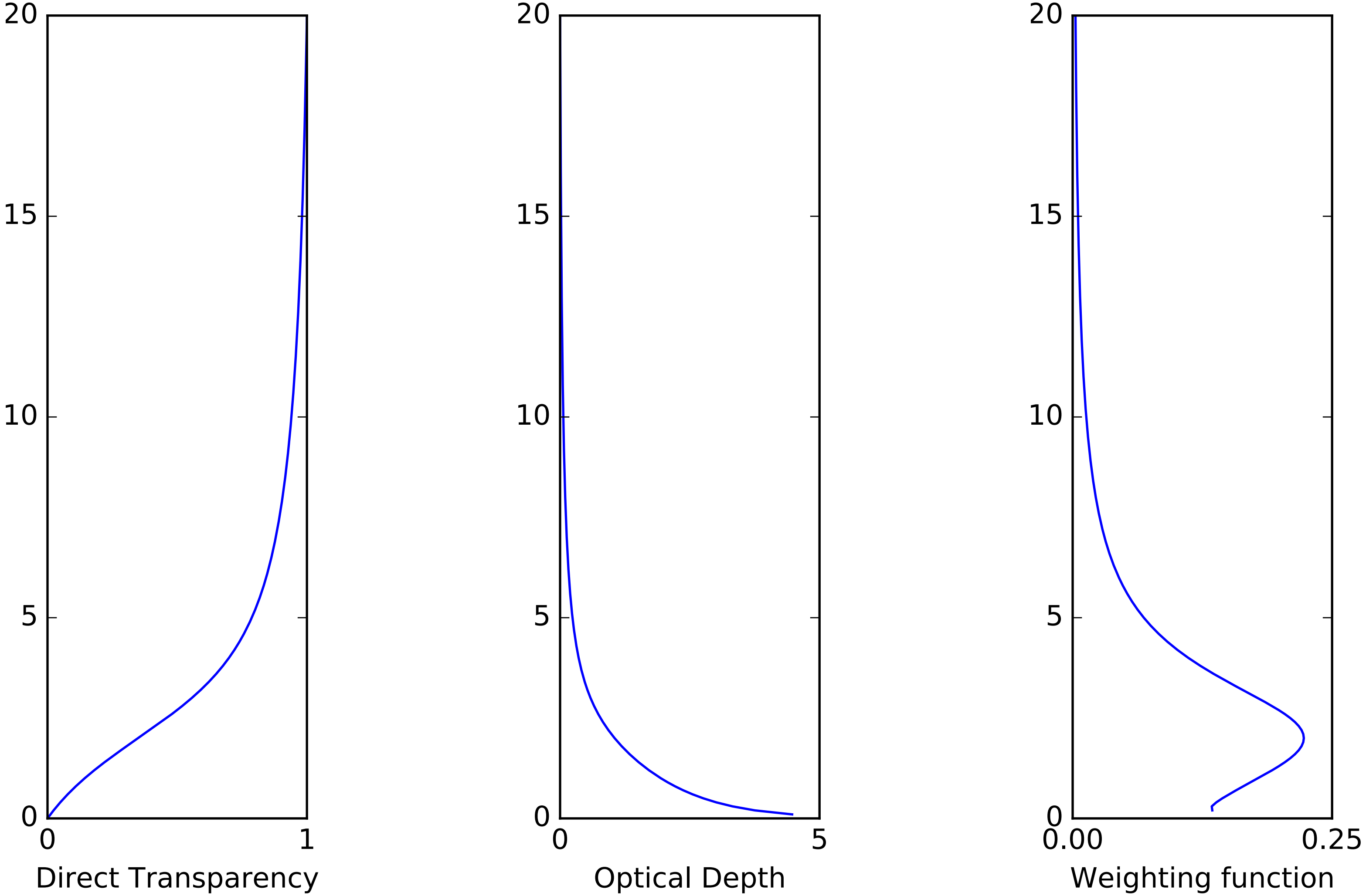
$$W = \frac{d\tau_d(\lambda,p)}{dp} = e^{-\delta(\lambda,p)/\mu}\left(-\frac{d\delta}{\mu dp}\right)$$

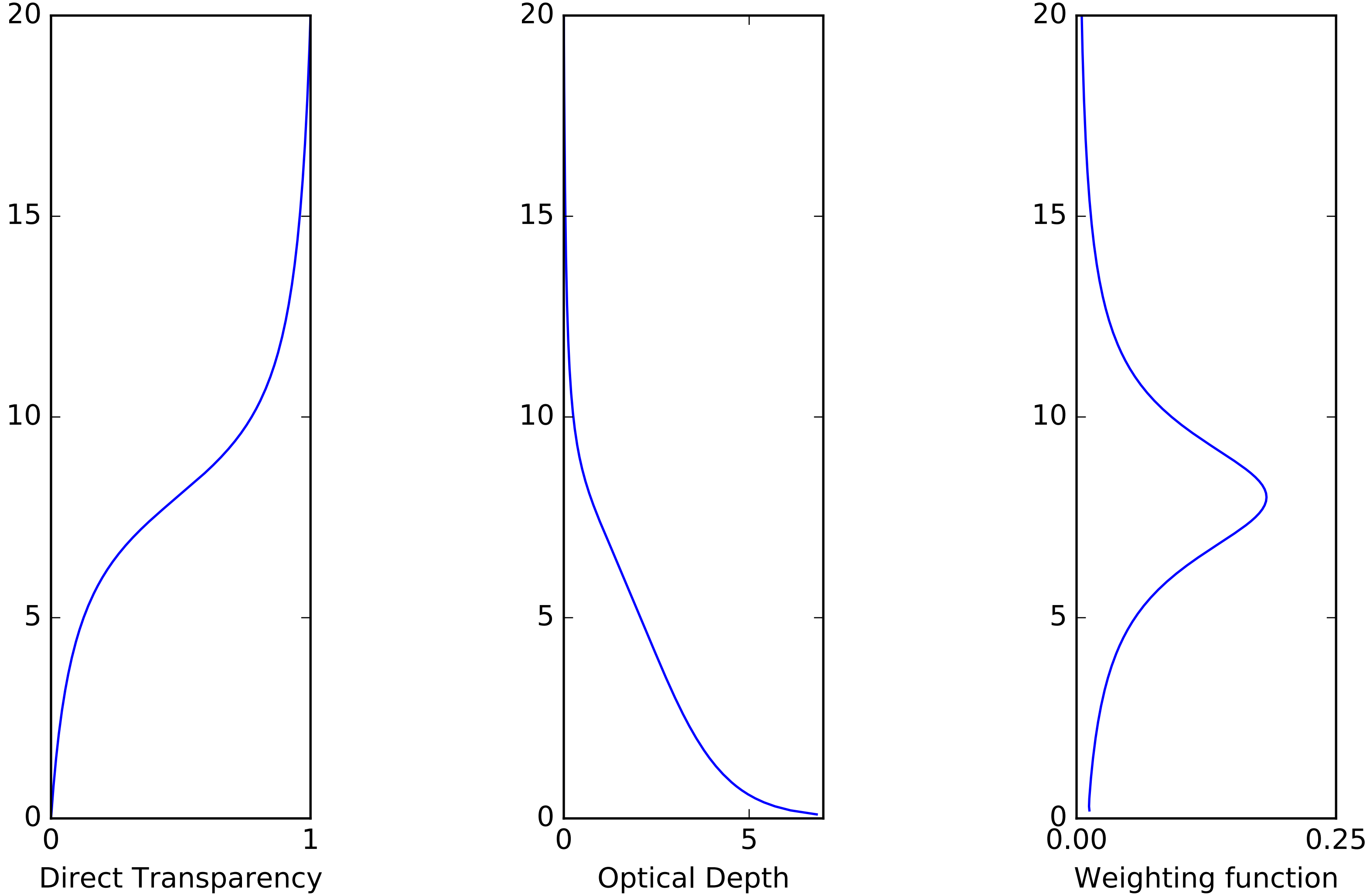
$$L_t(\lambda,\theta,\varphi) = \varepsilon_s B(\lambda,T_s)\overset{\tau_d(\lambda)}{e^{-\delta(\lambda)/\mu}} + \int_0^{\delta(\lambda)} B(\lambda,T(z))\,\overbrace{e^{-\delta(\lambda,z)/\mu}\frac{d\delta}{\mu}}^{\div\,-dp}$$

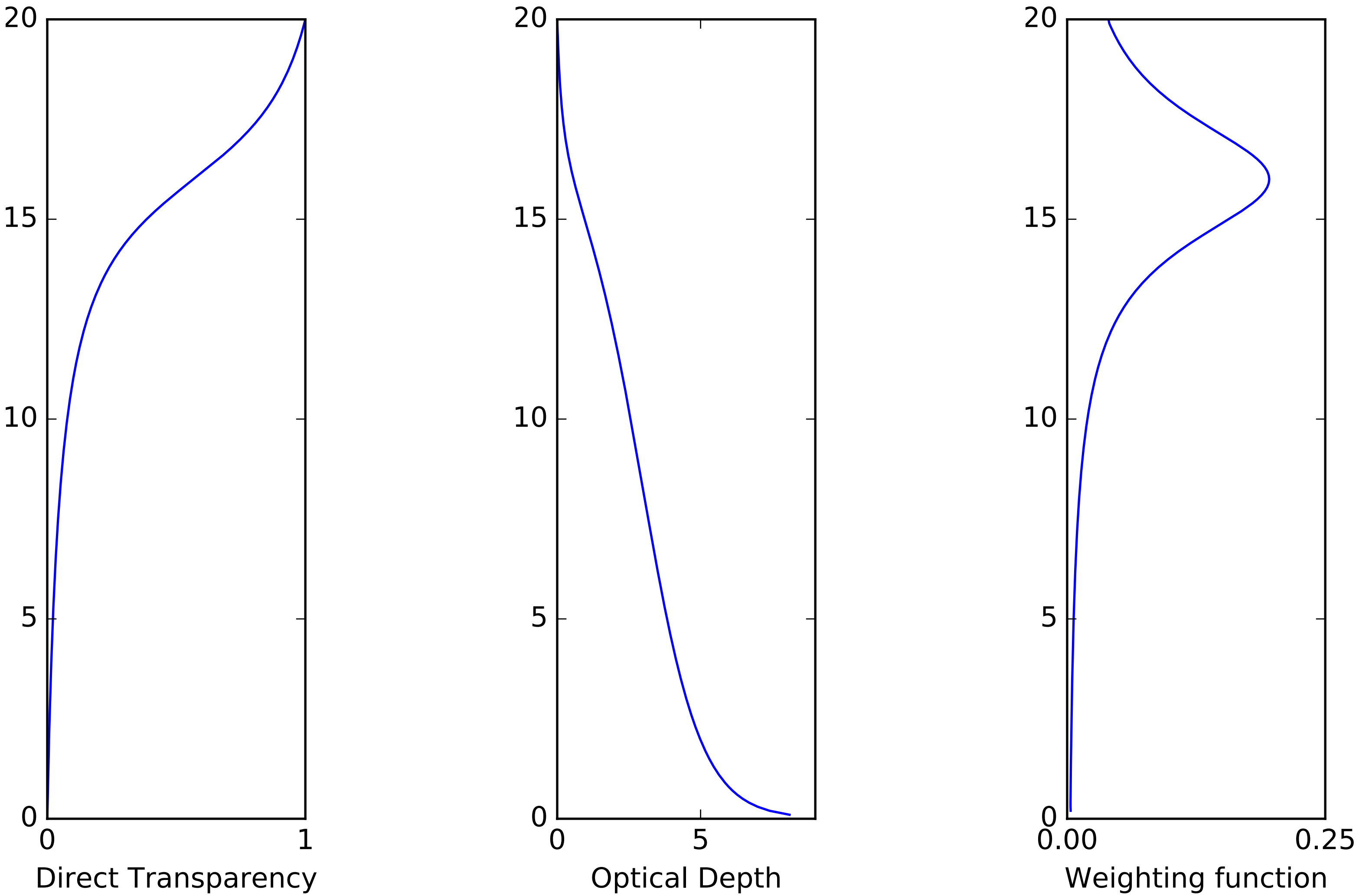
So,

$$L_t(\lambda,\theta,\varphi) = \varepsilon_s(\lambda,\theta)B(\lambda,T_s)\tau_d(\lambda) + \int_p^0 B(\lambda,T(p))\frac{d\tau_d(\lambda,p)}{dp}dp$$

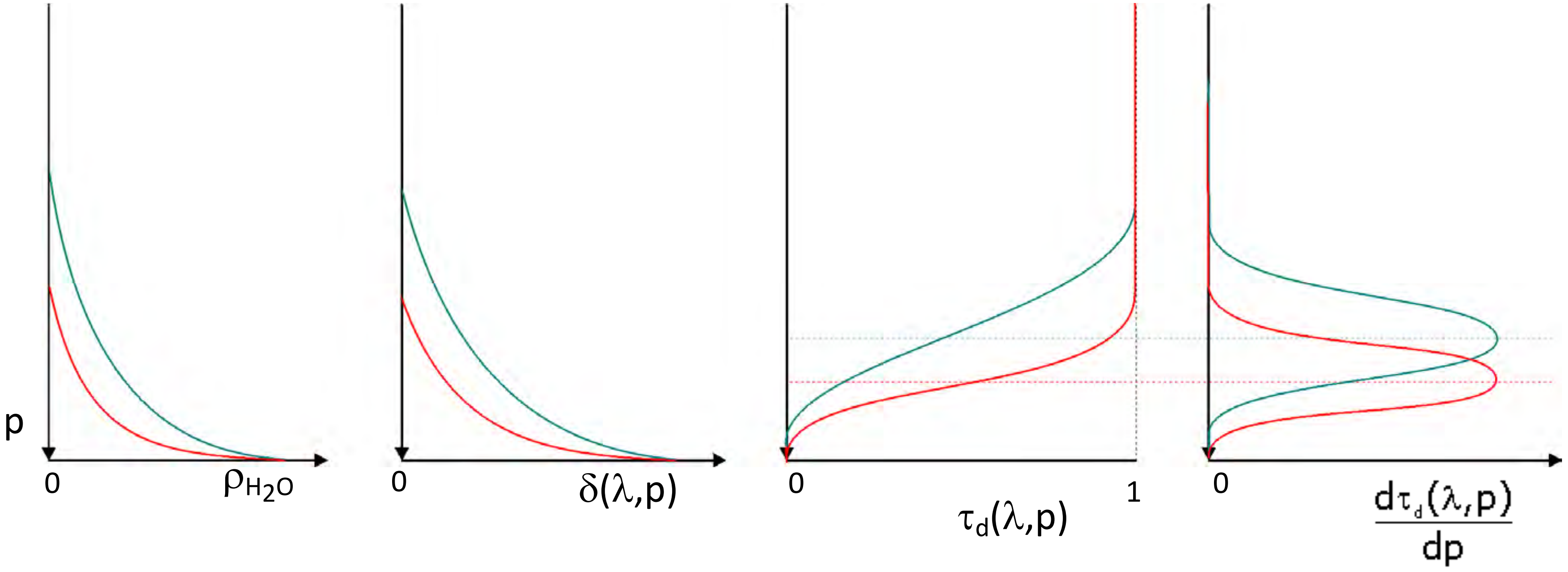
$\frac{d\tau_d(\lambda,p)}{dp} =$ Weighting Function $\Rightarrow$ Peak of W is at p where the path radiance contributes most to L_t

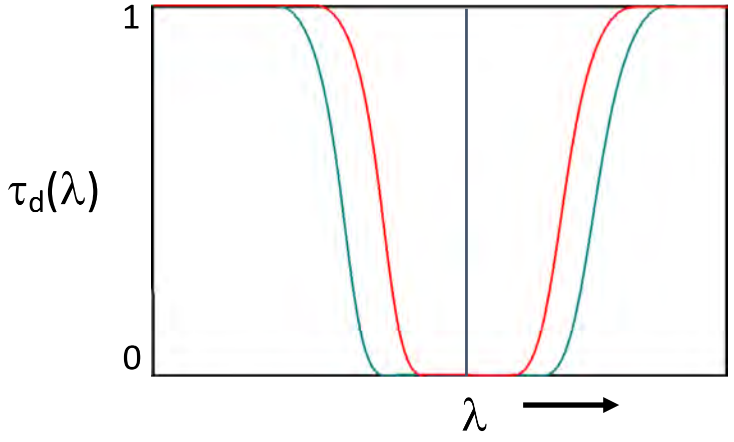

20
15
10
5
0
0
1
Direct Transparency
20
15
10
5
0
0
5
Optical Depth
20
15
10
5
0
0.00
0.25
Weighting function


20
15
10
5
0
0
1
Direct Transparency
20
15
10
5
0
0
5
Optical Depth
20
15
10
5
0
0.00
0.25
Weighting function


20
15
10
5
0
0
1
Direct Transparency
20
15
10
5
0
0
5
Optical Depth
20
15
10
5
0
0.00
0.25
Weighting function

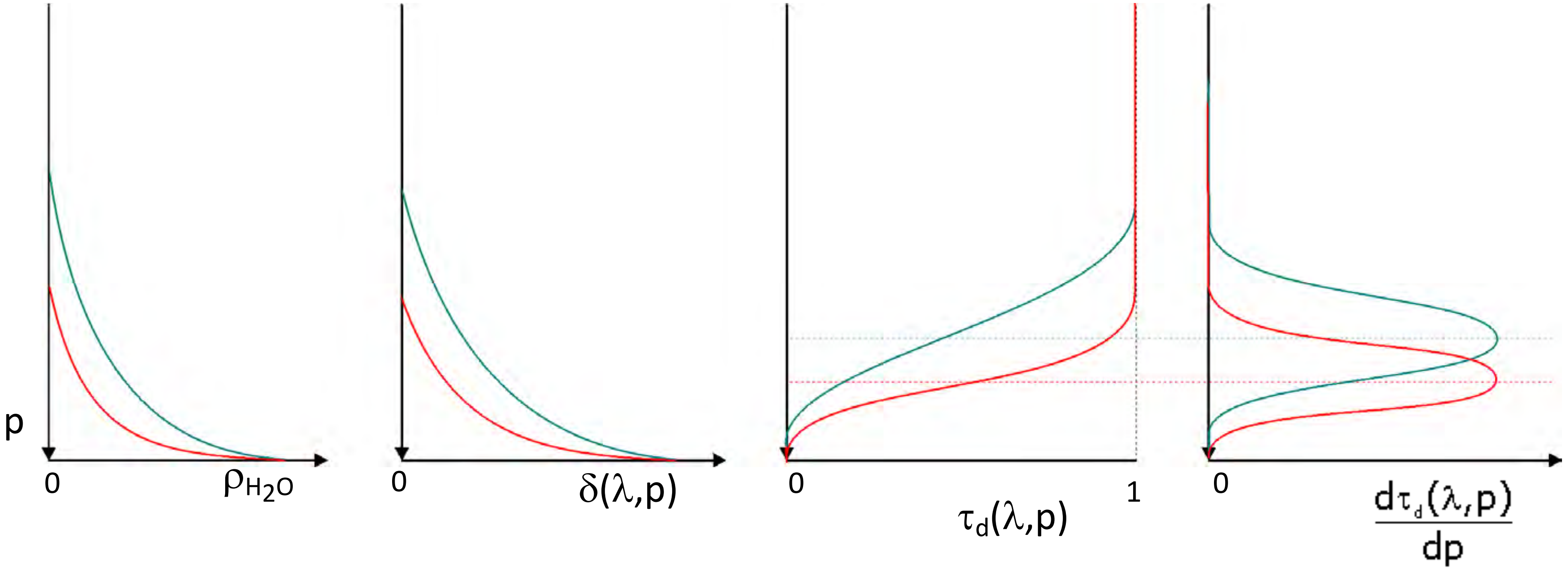
One wavelength, two concentration profiles, two different weighting functions

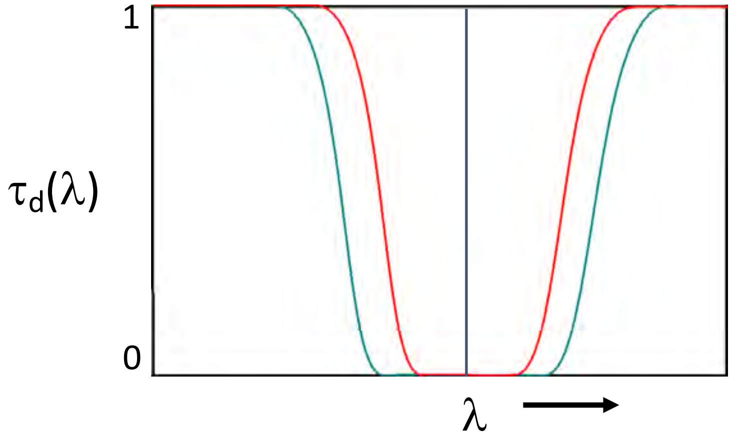


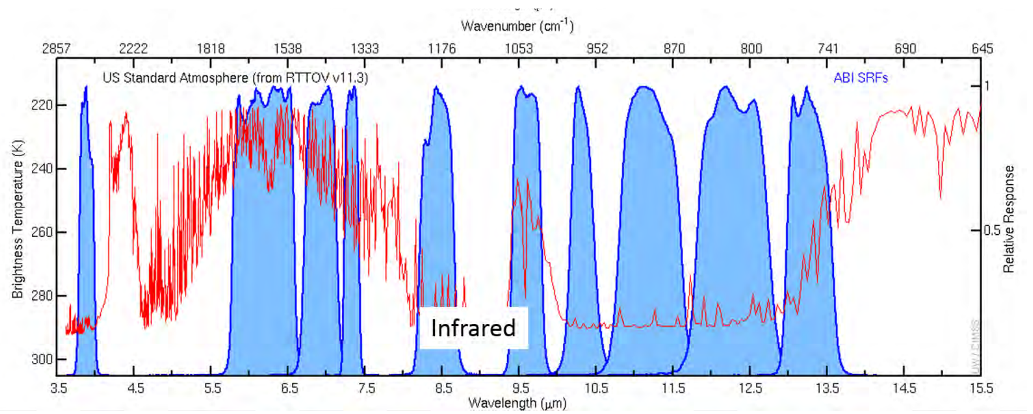


$$L_t(\lambda,\theta,\varphi) = \varepsilon_s(\lambda,\theta)B(\lambda,T_s)\tau_d(\lambda) + \int_p^0 B(\lambda,T(p))\frac{d\tau_d(\lambda,p)}{dp}dp$$

One wavelength, two concentration profiles, two different weighting functions

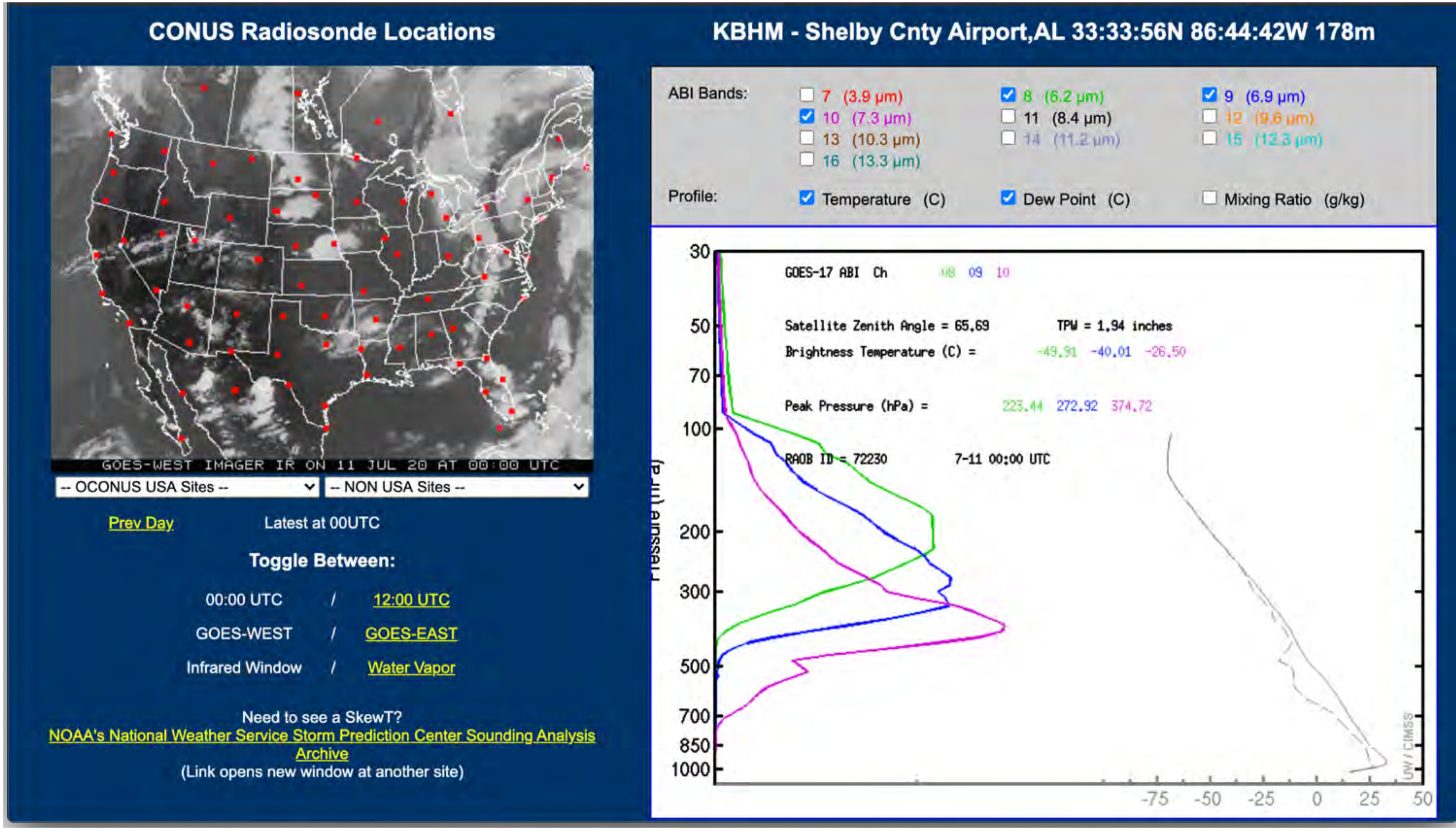






$$L_t(\lambda,\theta,\varphi) = \varepsilon_s(\lambda,\theta)B(\lambda,T_s)\tau_d(\lambda) + \int_p^0 B(\lambda,T(p))\frac{d\tau_d(\lambda,p)}{dp}dp$$

Moist Environment



CONUS Radiosonde Locations

-- OCONUS USA Sites --

-- NON USA Sites --

Prev Day

Latest at 00UTC

Toggle Between:

00:00 UTC / 12:00 UTC

GOES-WEST / GOES-EAST

Infrared Window / Water Vapor

Need to see a SkewT?

NOAA's National Weather Service Storm Prediction Center Sounding Analysis Archive

(Link opens new window at another site)

KBHM - Shelby Cnty Airport,AL 33:33:56N 86:44:42W 178m

ABI Bands:

☐ 7 (3.9 µm)
☑ 8 (6.2 µm)
☑ 9 (6.9 µm)
☑ 10 (7.3 µm)
☐ 11 (8.4 µm)
☐ 12 (9.6 µm)
☐ 13 (10.3 µm)
☐ 14 (11.2 µm)
☐ 15 (12.3 µm)
☐ 16 (13.3 µm)

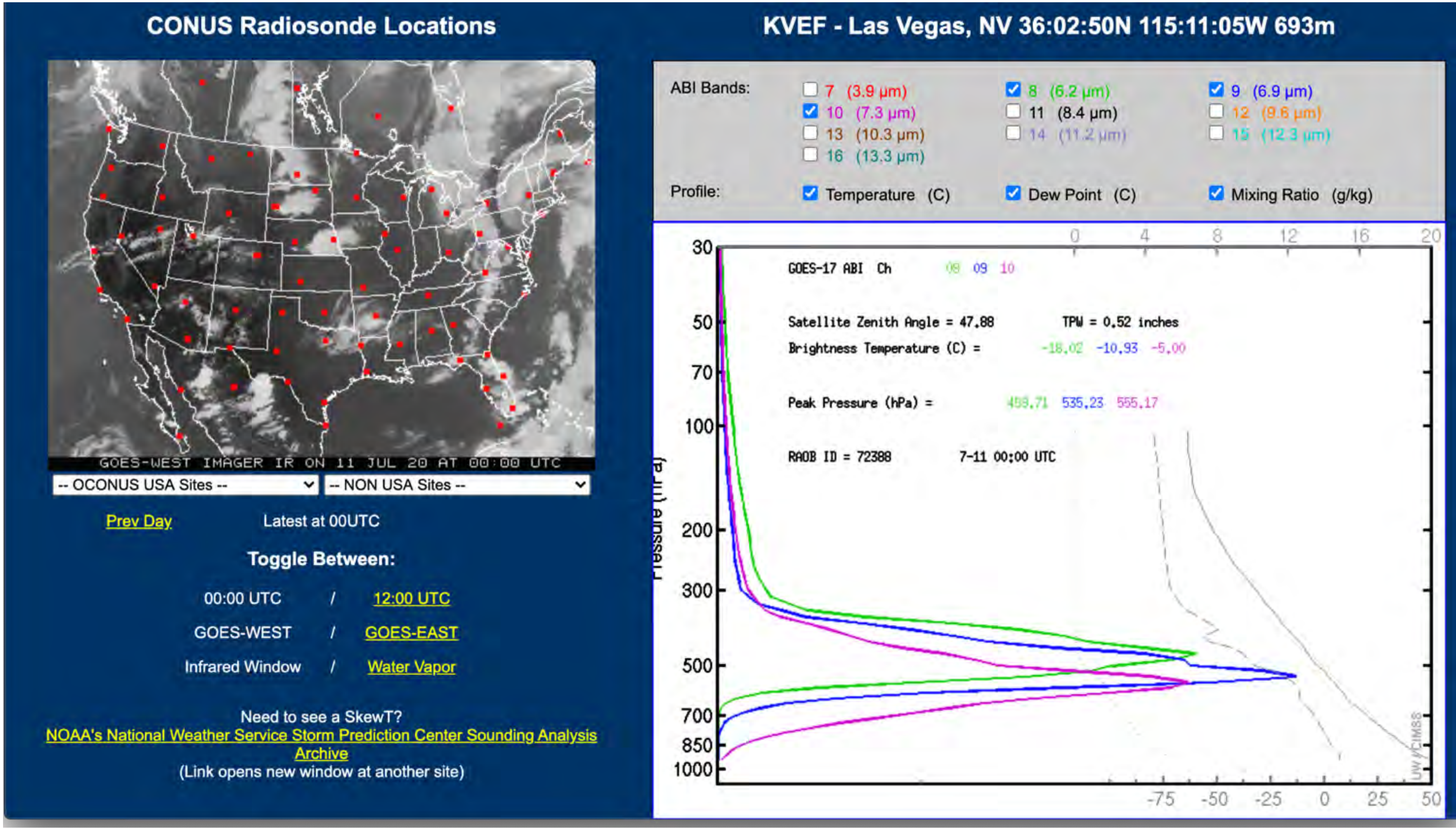
Profile:

☑ Temperature (C)
☑ Dew Point (C)
☐ Mixing Ratio (g/kg)

```
GOES-17 ABI  Ch        08  09  10

Satellite Zenith Angle = 65.69        TPW = 1.94 inches
Brightness Temperature (C) =       -49.91  -40.01  -26.50

Peak Pressure (hPa) =           223.44  272.92  374.72

RAOB ID = 72230        7-11 00:00 UTC
```

https://cimss.ssec.wisc.edu/goes/wf/

Dry Environment



CONUS Radiosonde Locations

GOES-WEST IMAGER IR ON 11 JUL 20 AT 00:00 UTC

-- OCONUS USA Sites --

-- NON USA Sites --

Prev Day

Latest at 00UTC

Toggle Between:

00:00 UTC / 12:00 UTC

GOES-WEST / GOES-EAST

Infrared Window / Water Vapor

Need to see a SkewT?

NOAA's National Weather Service Storm Prediction Center Sounding Analysis Archive

(Link opens new window at another site)

KVEF - Las Vegas, NV 36:02:50N 115:11:05W 693m

ABI Bands:

☐ 7 (3.9 µm) ☑ 8 (6.2 µm) ☑ 9 (6.9 µm)

☑ 10 (7.3 µm) ☐ 11 (8.4 µm) ☐ 12 (9.6 µm)

☐ 13 (10.3 µm) ☐ 14 (11.2 µm) ☐ 15 (12.3 µm)

☐ 16 (13.3 µm)

Profile: ☑ Temperature (C) ☑ Dew Point (C) ☑ Mixing Ratio (g/kg)

GOES-17 ABI Ch 08 09 10

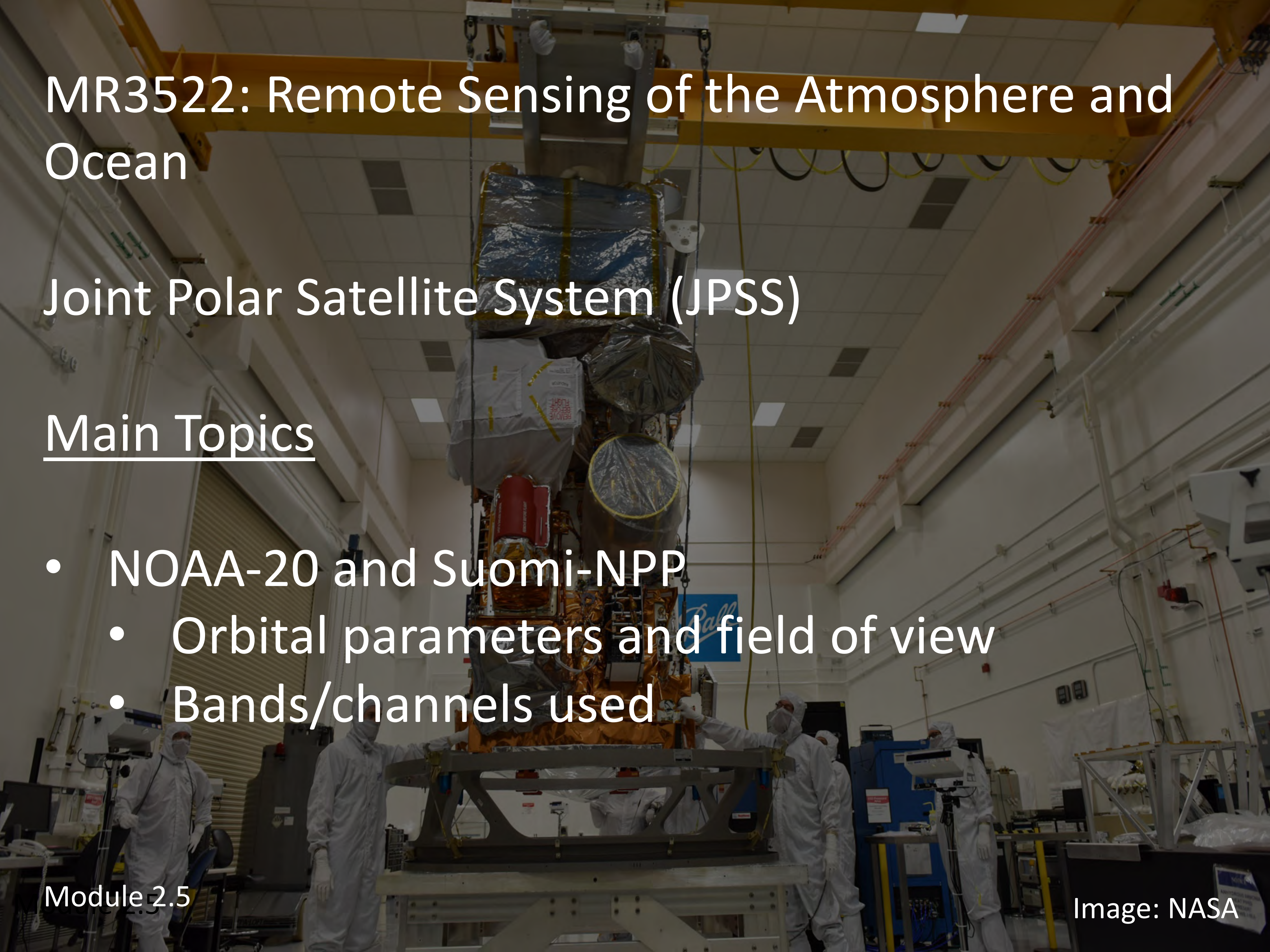
Satellite Zenith Angle = 47.88 TPW = 0.52 inches

Brightness Temperature (C) = -18.02 -10.93 -5.00

Peak Pressure (hPa) = 459.71 535.23 555.17

RAOB ID = 72388 7-11 00:00 UTC

https://cimss.ssec.wisc.edu/goes/wf/



MR3522: Remote Sensing of the Atmosphere and Ocean

Joint Polar Satellite System (JPSS)

<u>Main Topics</u>

- NOAA-20 and Suomi-NPP
  - Orbital parameters and field of view
  - Bands/channels used

Module 2.5

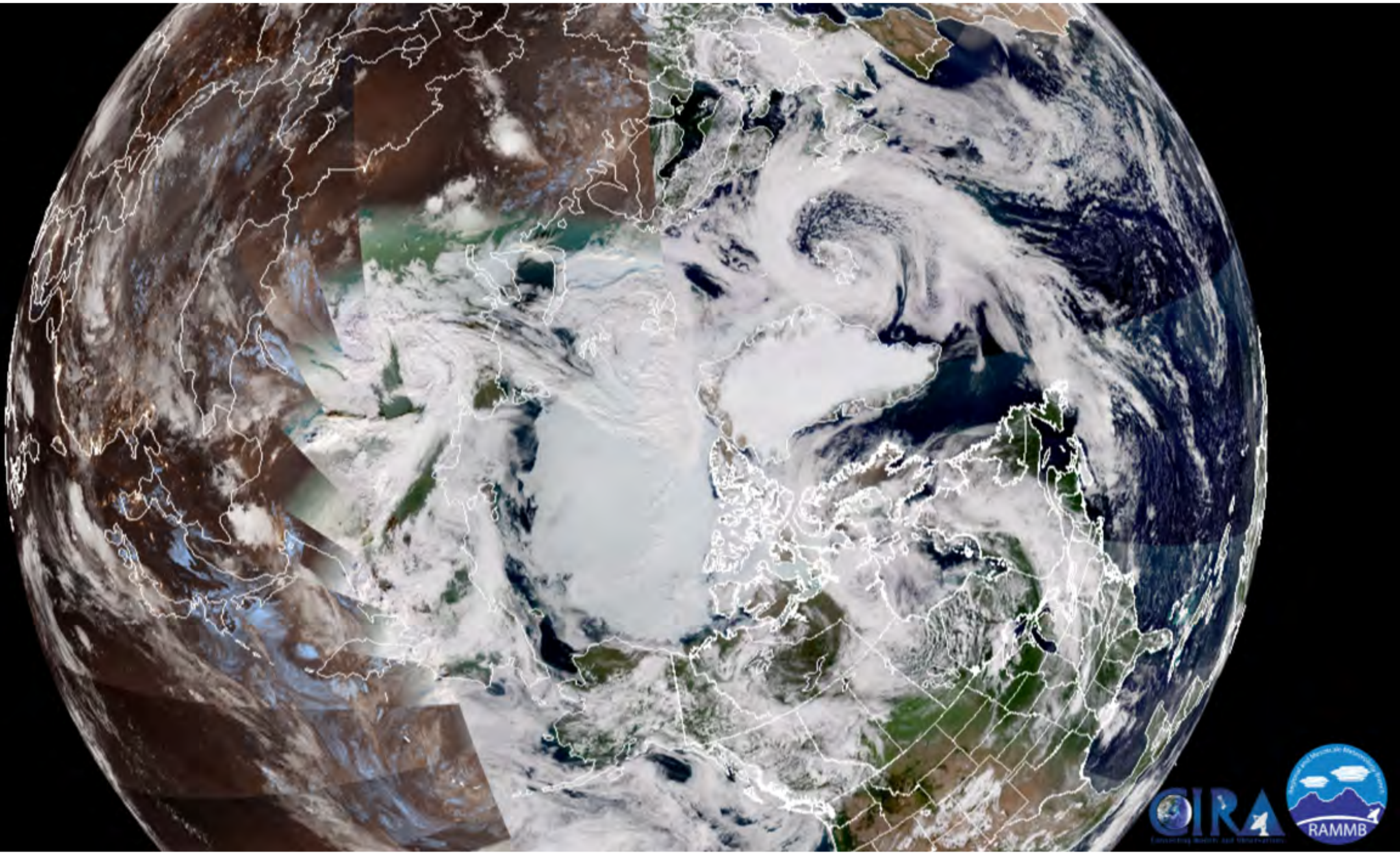
Image: NASA

Satellites in JPSS

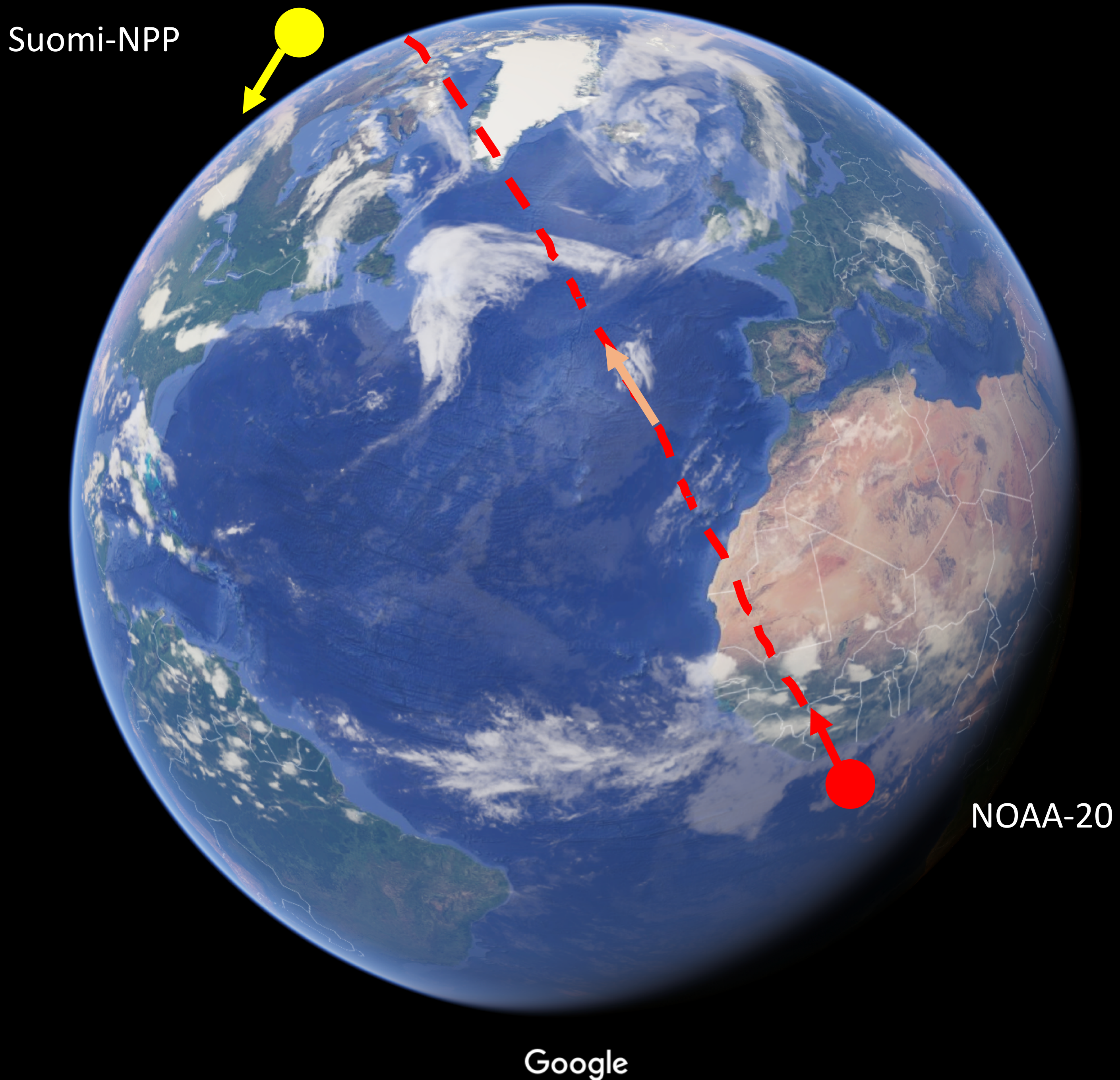
- Suomi National Polar-orbiting Partnership (NPP)
- NOAA-20
- Three other satellites with future planned launch dates

Orbit: Sun-synchronous, daytime ascending, equator crossing time of 1:30PM

- NOAA-20 is about 50 minutes behind of Suomi-NPP so crosses a little to the west.

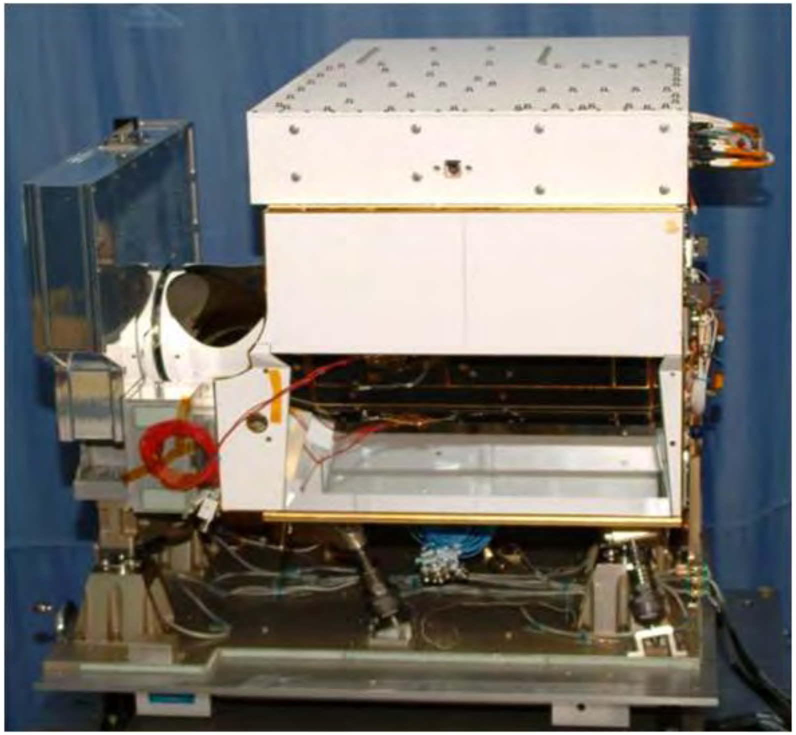


JPSS Composite RGB Image: North Pole View


Suomi-NPP
NOAA-20
Google

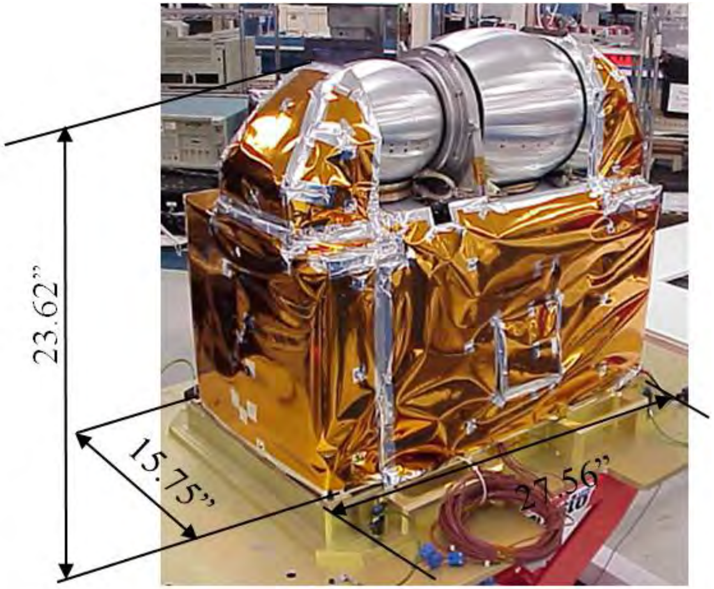
Cross-track Infrared Sounder (CrIS)

- High spectral resolution sounder with over 3,000 spectral channels
- Estimates of atmospheric temperature and humidity profiles
- 14 km nadir data point spacing; 1 km vertical spacing
- Cannot see through clouds



Advanced Technology Microwave Sounder (ATMS)

- 22 channels from 23.8 GHz to 183.3 GHz
- 16–75 km data point spacing
- Can see through clouds because microwave is not scattered as much



https://www.star.nesdis.noaa.gov/jpss

Clouds and the Earth's Radiant Energy System (CERES) FM6 broadband radiometer

- Radiative fluxes, some cloud properties in "high", "middle" and "low" layers
- 20 km spacing of data points at nadir

nasa.gov/image-feature/ceres-fm6/

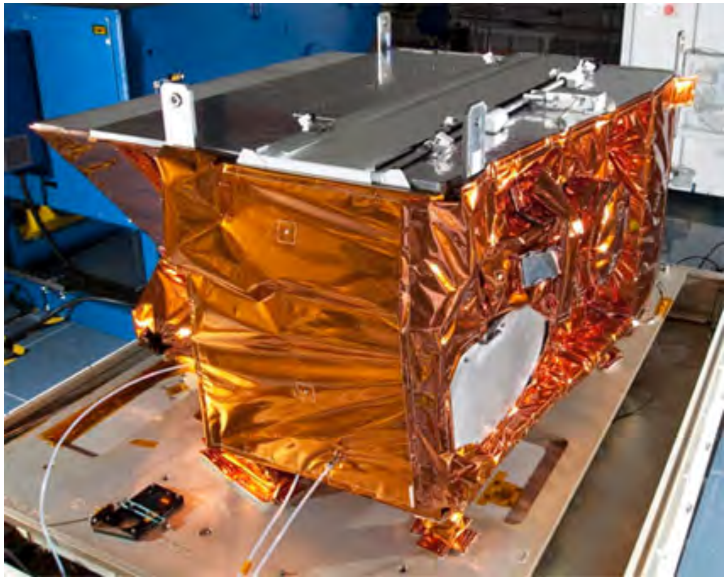
https://ceres.larc.nasa.gov/data/

Ozone Mapping and Profiler Suite (OMPS)

- Three spectrometers for measuring column-integrated ozone and ozone profiles
- 50 km data point spacing for mapper; 250 km for profiler

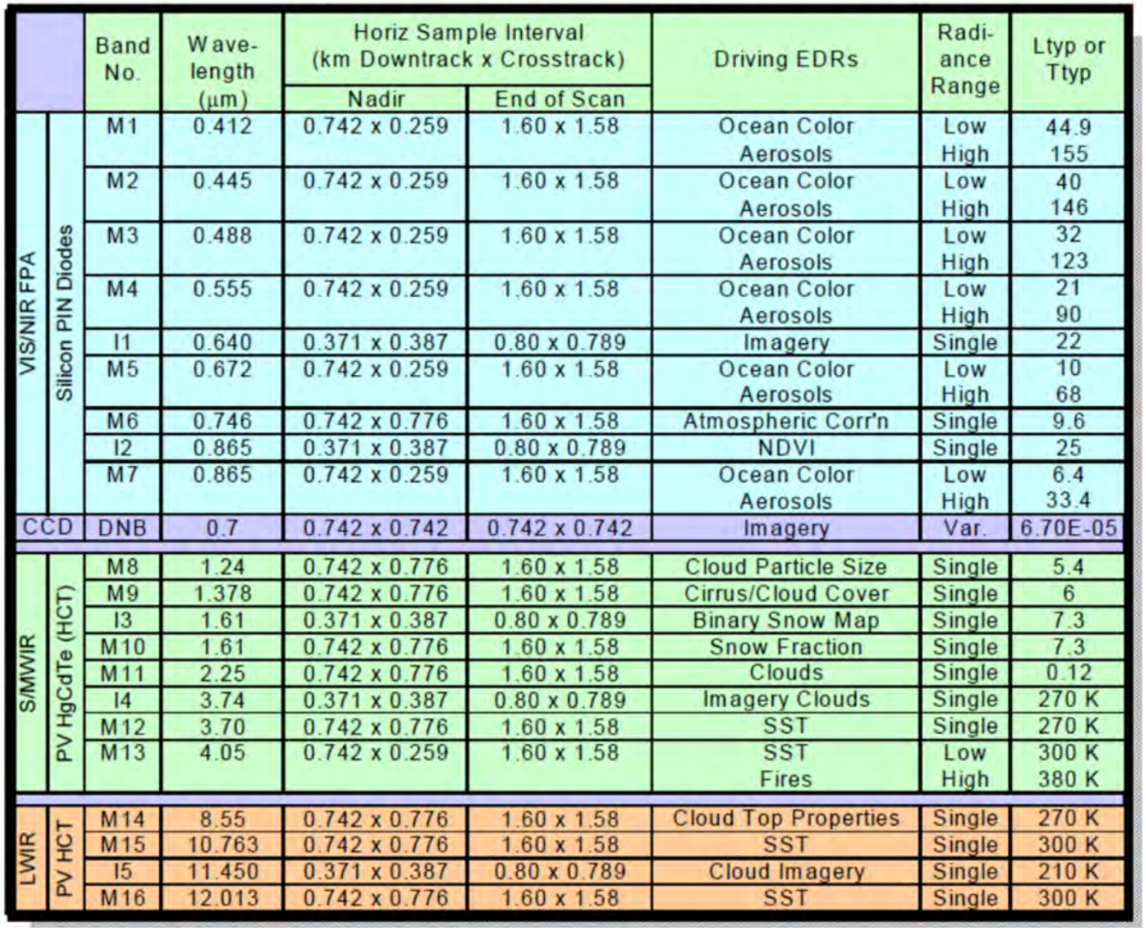
Visible Infrared Imaging Radiometer Suite (VIIRS)

- Most similar to ABI on GOES with multiple sensors in the visible and infrared
- Up to 350 meter data point spacing
- Useful for weather monitoring, ocean color, SST estimates, aerosol detection

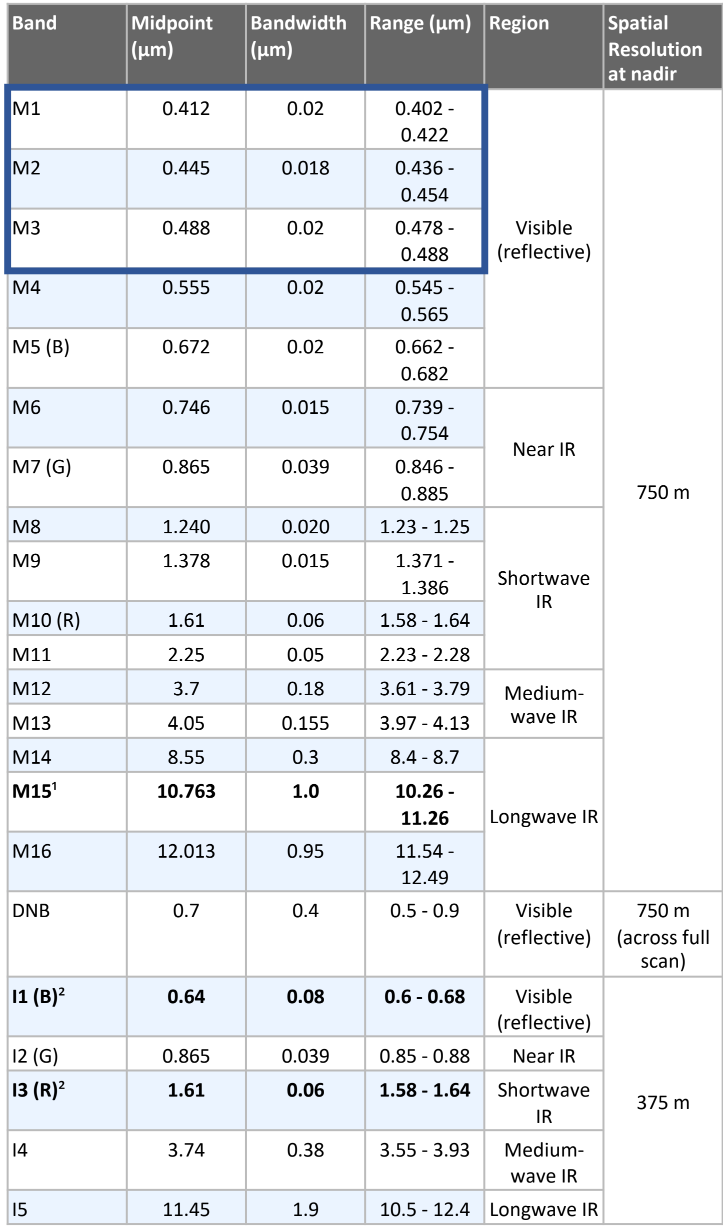


https://www.star.nesdis.noaa.gov/jpss

VIIRS Sensor Bands



		Band No.	Wave-length (µm)	Horiz Sample Interval (km Downtrack x Crosstrack)		Driving EDRs	Radi-ance Range	Ltyp or Ttyp
				Nadir	End of Scan			
VIS/NIR FPA	Silicon PIN Diodes	M1	0.412	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	44.9 155
		M2	0.445	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	40 146
		M3	0.488	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	32 123
		M4	0.555	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	21 90
		I1	0.640	0.371 x 0.387	0.80 x 0.789	Imagery	Single	22
		M5	0.672	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	10 68
		M6	0.746	0.742 x 0.776	1.60 x 1.58	Atmospheric Corr'n	Single	9.6
		I2	0.865	0.371 x 0.387	0.80 x 0.789	NDVI	Single	25
		M7	0.865	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	6.4 33.4
CCD		DNB	0.7	0.742 x 0.742	0.742 x 0.742	Imagery	Var.	6.70E-05
S/MWIR	PV HgCdTe (HCT)	M8	1.24	0.742 x 0.776	1.60 x 1.58	Cloud Particle Size	Single	5.4
		M9	1.378	0.742 x 0.776	1.60 x 1.58	Cirrus/Cloud Cover	Single	6
		I3	1.61	0.371 x 0.387	0.80 x 0.789	Binary Snow Map	Single	7.3
		M10	1.61	0.742 x 0.776	1.60 x 1.58	Snow Fraction	Single	7.3
		M11	2.25	0.742 x 0.776	1.60 x 1.58	Clouds	Single	0.12
		I4	3.74	0.371 x 0.387	0.80 x 0.789	Imagery Clouds	Single	270 K
		M12	3.70	0.742 x 0.776	1.60 x 1.58	SST	Single	270 K
		M13	4.05	0.742 x 0.259	1.60 x 1.58	SST Fires	Low High	300 K 380 K
LWIR	PV HCT	M14	8.55	0.742 x 0.776	1.60 x 1.58	Cloud Top Properties	Single	270 K
		M15	10.763	0.742 x 0.776	1.60 x 1.58	SST	Single	300 K
		I5	11.450	0.371 x 0.387	0.80 x 0.789	Cloud Imagery	Single	210 K
		M16	12.013	0.742 x 0.776	1.60 x 1.58	SST	Single	300 K

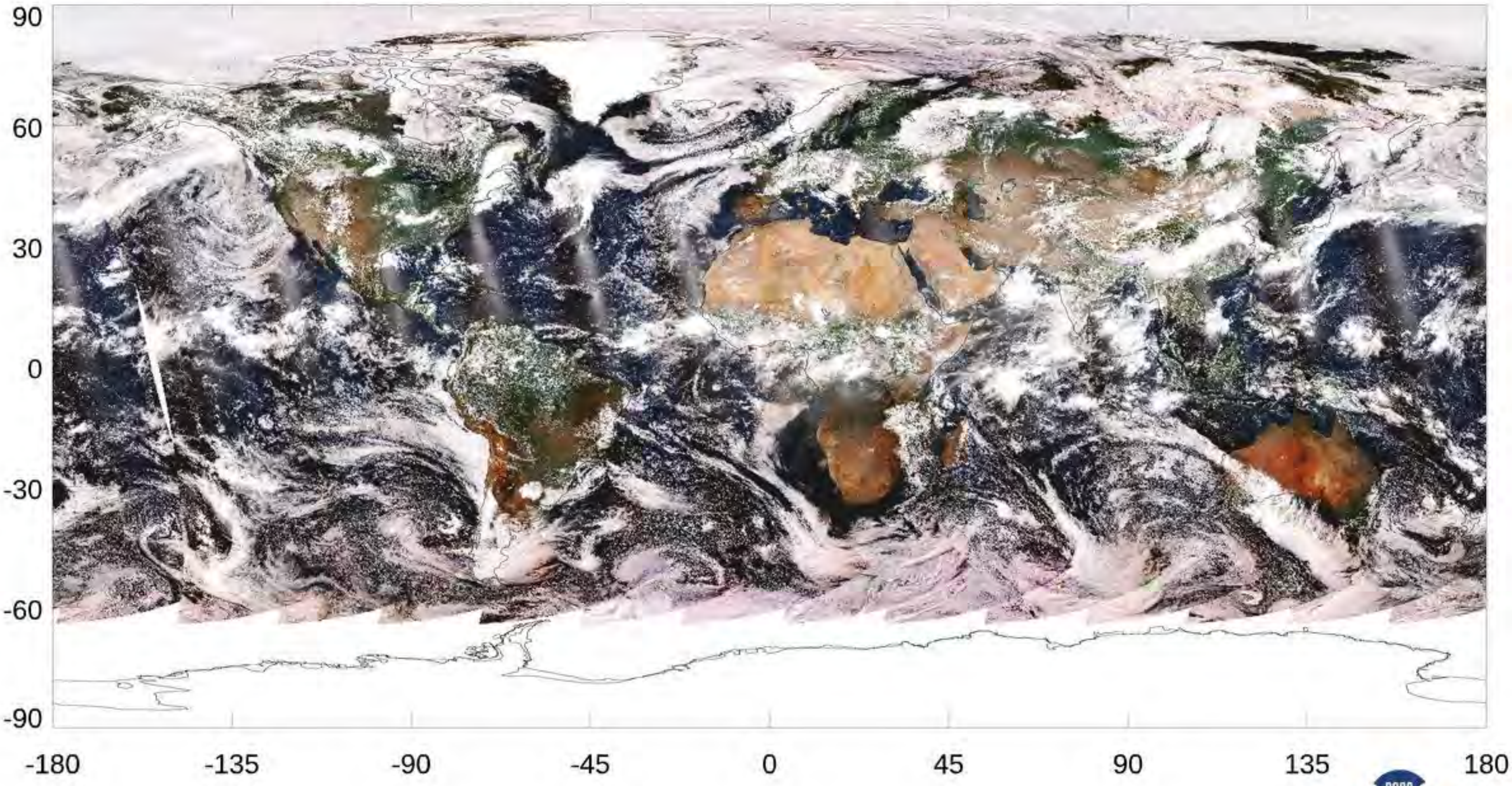


Band	Midpoint (µm)	Bandwidth (µm)	Range (µm)	Region	Spatial Resolution at nadir
M1	0.412	0.02	0.402 - 0.422	Visible (reflective)	750 m
M2	0.445	0.018	0.436 - 0.454		
M3	0.488	0.02	0.478 - 0.488		
M4	0.555	0.02	0.545 - 0.565		
M5 (B)	0.672	0.02	0.662 - 0.682		
M6	0.746	0.015	0.739 - 0.754	Near IR	
M7 (G)	0.865	0.039	0.846 - 0.885		
M8	1.240	0.020	1.23 - 1.25	Shortwave IR	
M9	1.378	0.015	1.371 - 1.386		
M10 (R)	1.61	0.06	1.58 - 1.64		
M11	2.25	0.05	2.23 - 2.28		
M12	3.7	0.18	3.61 - 3.79	Medium-wave IR	
M13	4.05	0.155	3.97 - 4.13		
M14	8.55	0.3	8.4 - 8.7	Longwave IR	
M15[1]	**10.763**	**1.0**	**10.26 - 11.26**		
M16	12.013	0.95	11.54 - 12.49		
DNB	0.7	0.4	0.5 - 0.9	Visible (reflective)	750 m (across full scan)
I1 (B)[2]	**0.64**	**0.08**	**0.6 - 0.68**	Visible (reflective)	375 m
I2 (G)	0.865	0.039	0.85 - 0.88	Near IR	
I3 (R)[2]	**1.61**	**0.06**	**1.58 - 1.64**	Shortwave IR	
I4	3.74	0.38	3.55 - 3.93	Medium-wave IR	
I5	11.45	1.9	10.5 - 12.4	Longwave IR	

High resolution IR imagery; 750 m compared to 2 km with GOES. 11.45 micron imagery has 370 x 387 meter sampling at nadir

Many more band in **blue** light part of visible spectrum; useful for aerosol detection and ocean color

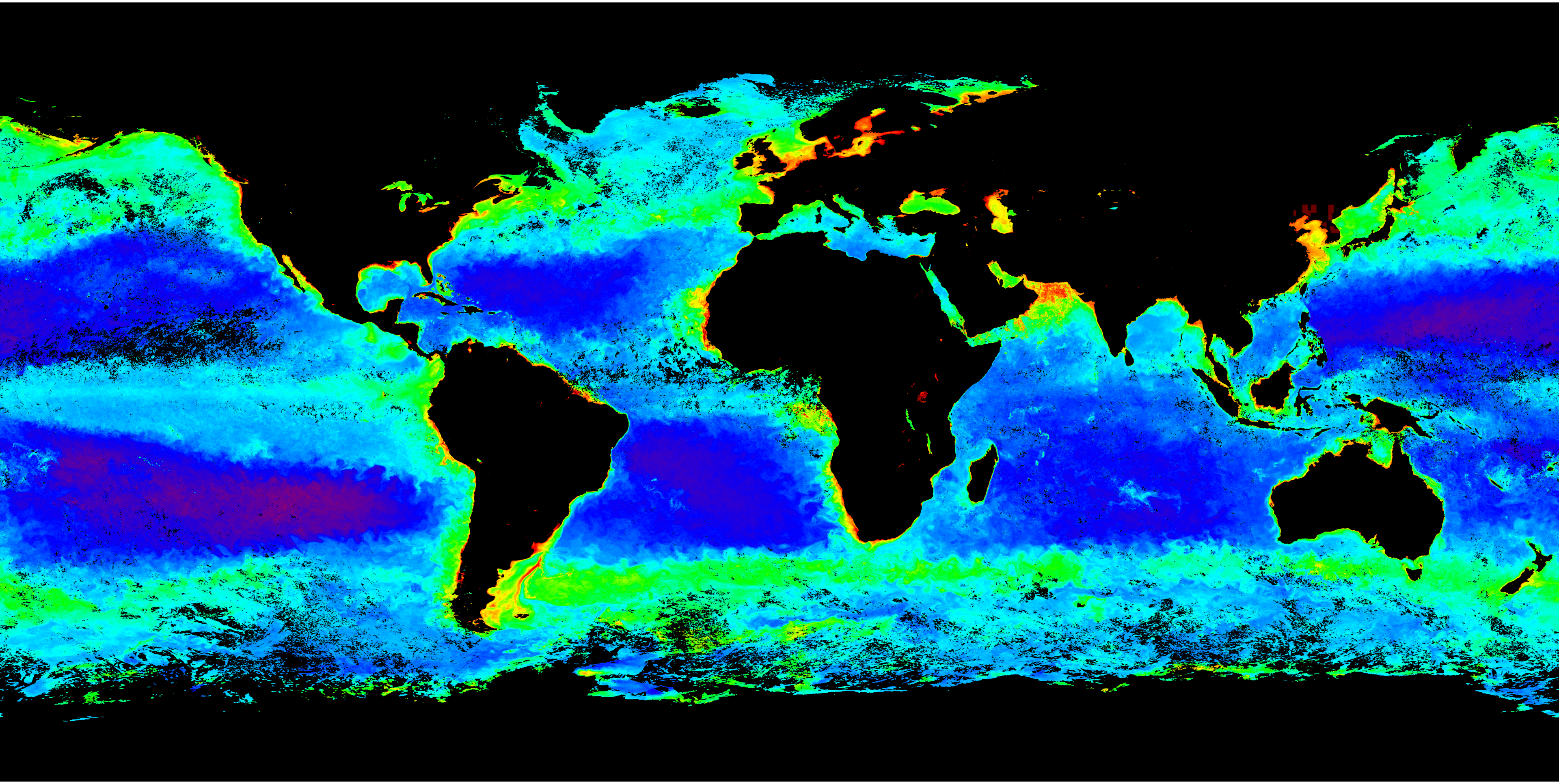
NOAA-20 VIIRS Global True Color Image, 2020-07-17



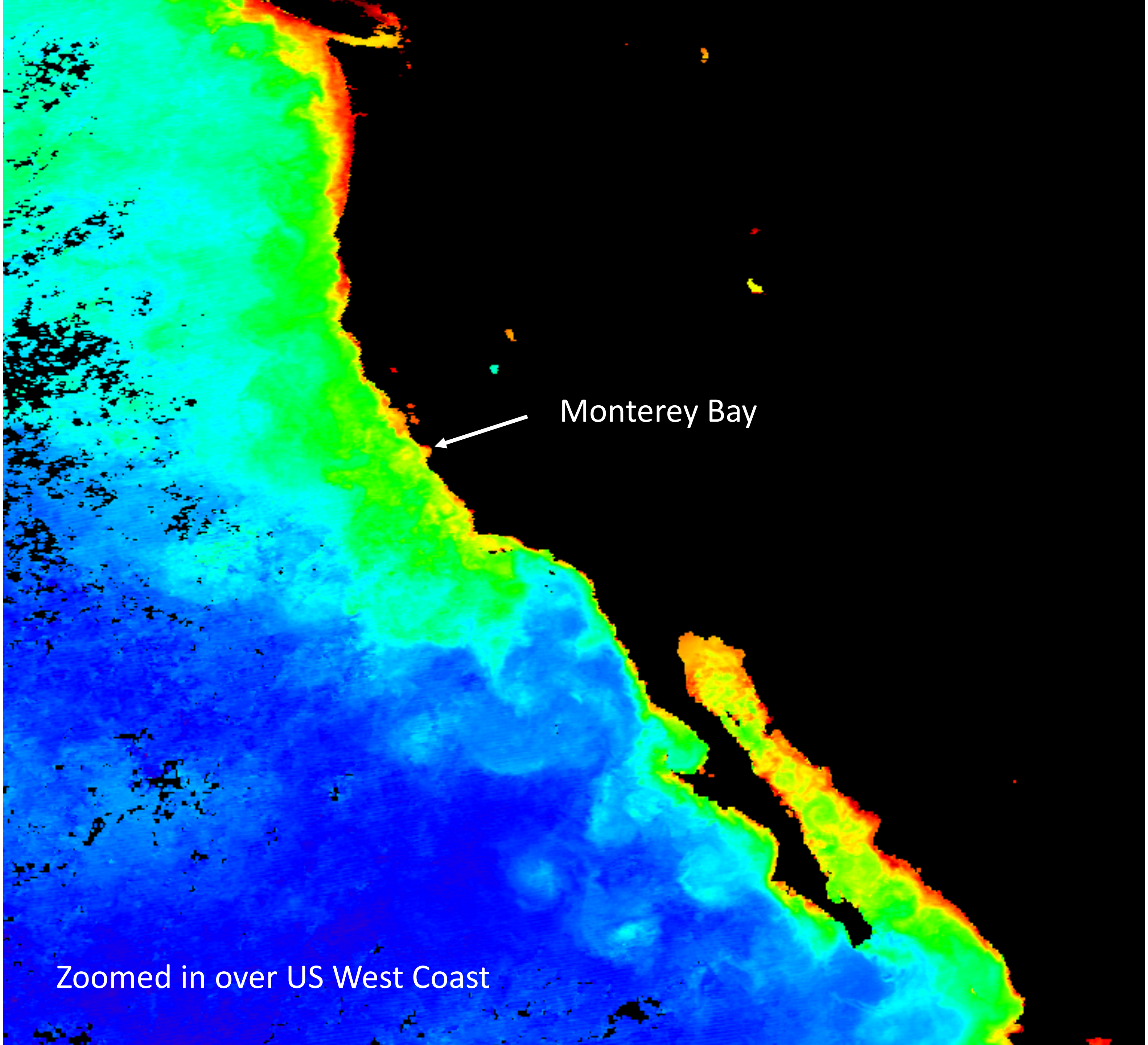
Red:SVM05, Green:SVM04, Blue:SVM03

NOAA / NESDIS / STAR

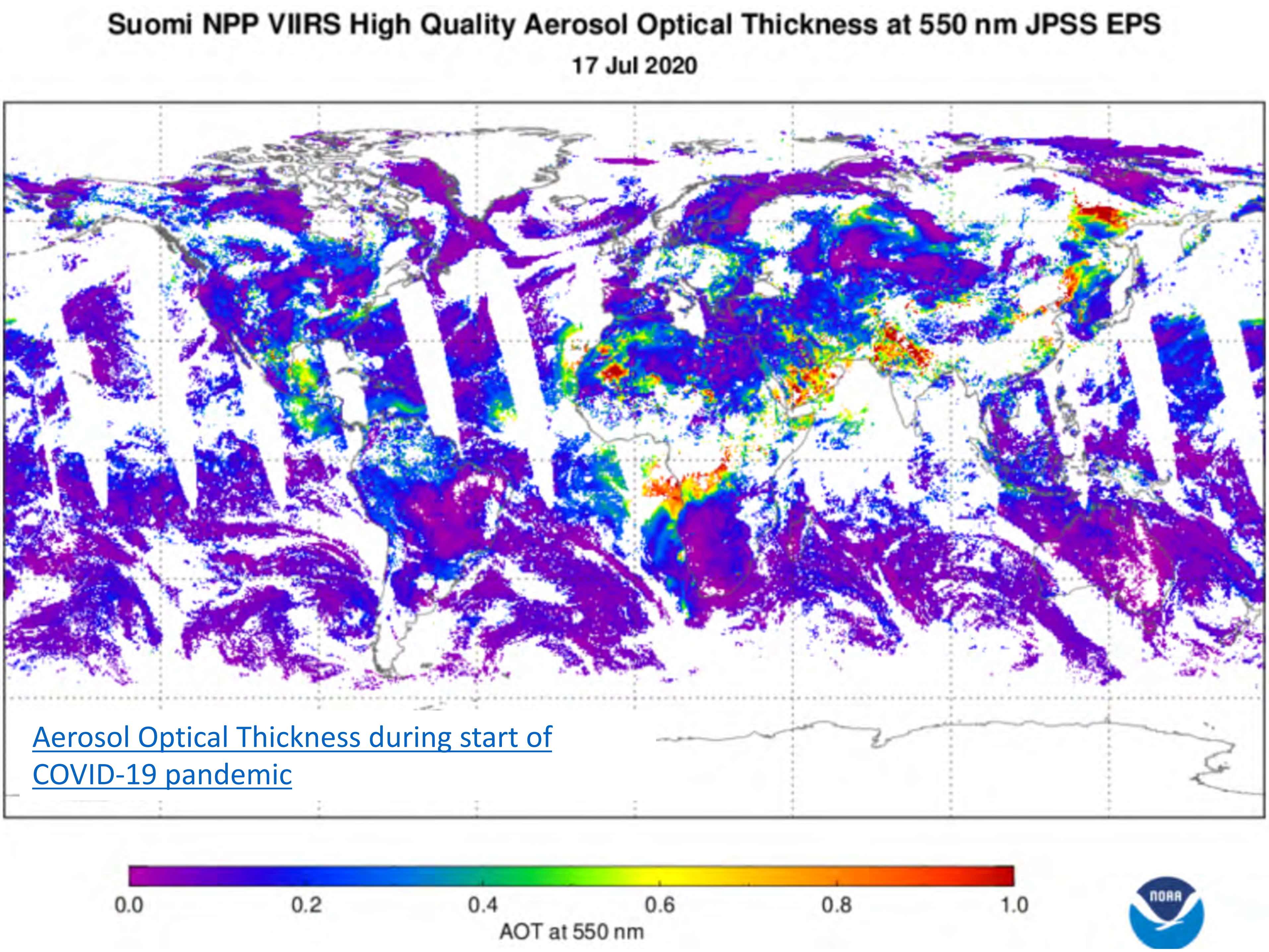
March 2020 average chlorophyll concentration from Suomi-NPP



https://oceancolor.gsfc.nasa.gov/



Zoomed in over US West Coast



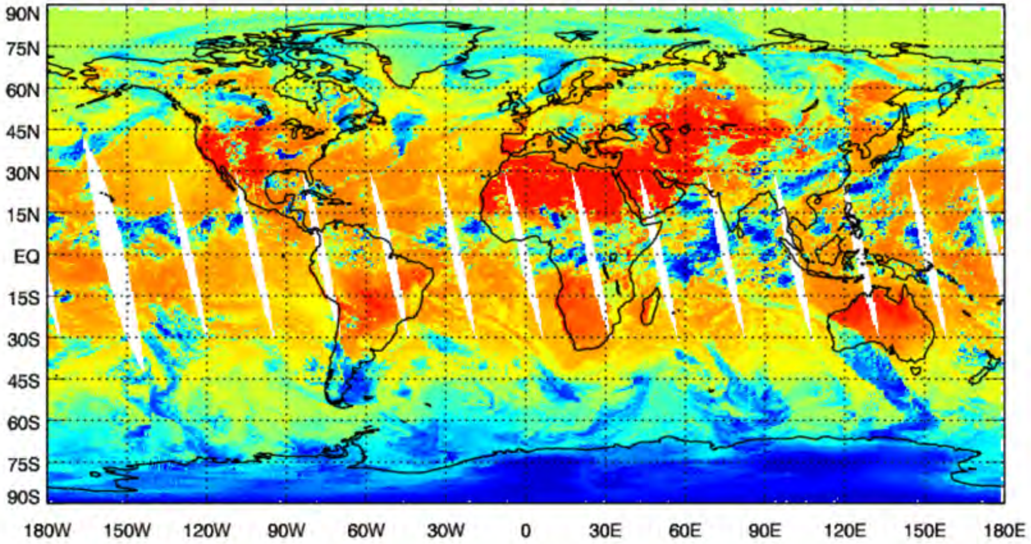
Suomi NPP VIIRS High Quality Aerosol Optical Thickness at 550 nm JPSS EPS

17 Jul 2020

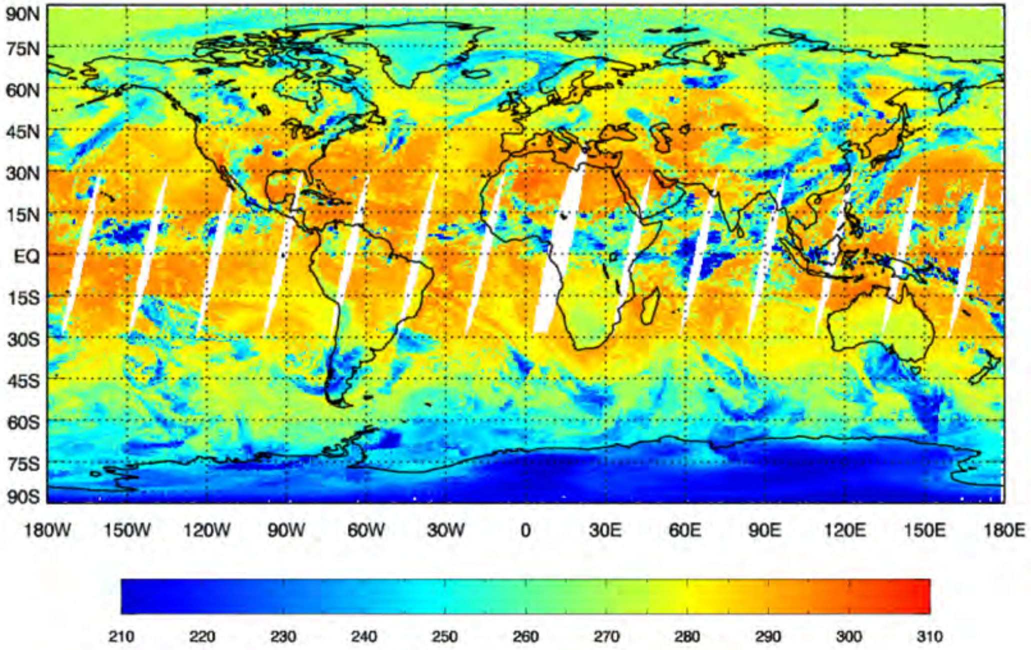
[Aerosol Optical Thickness during start of COVID-19 pandemic]

N20 CrIS FSR BT, 11 μm (900 cm^{-1}), Mapped, Ascending, 07/17/2020

Updated at Jul 18 02:19:38 2020 UTC



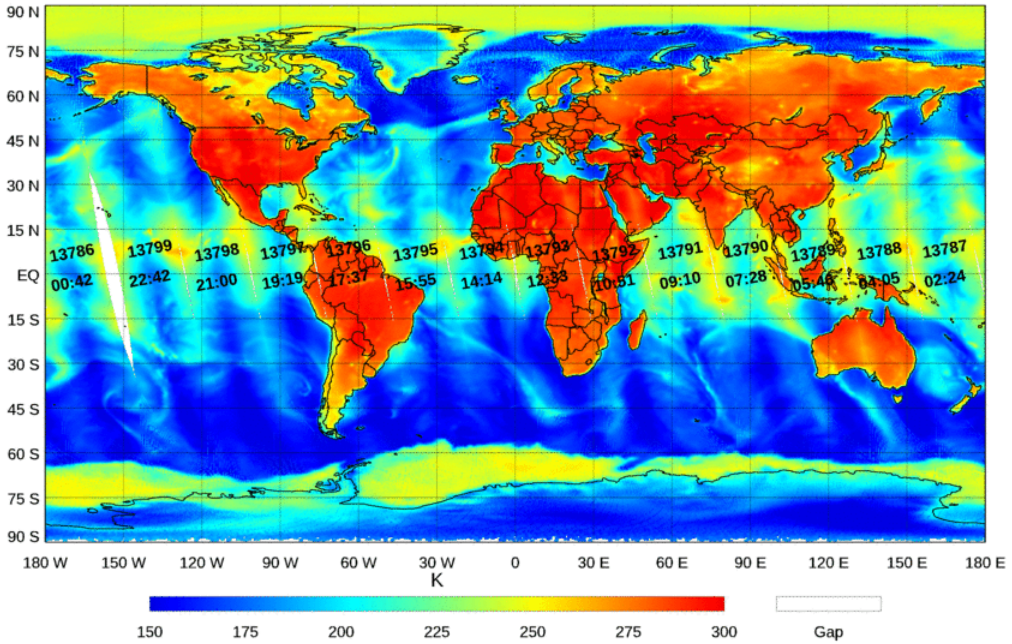
N20 CrIS FSR BT, 11 μm (900 cm^{-1}), Mapped, Descending, 07/17/2020



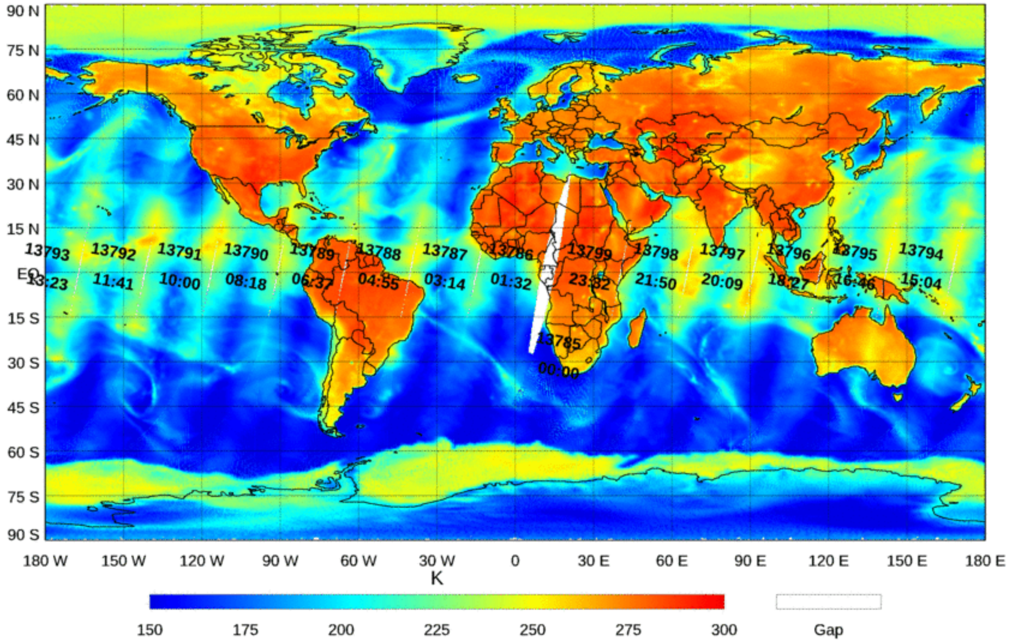
NOAA-20 ATMS SDR Ch.1 23.8 GHz QV-POL
17 Jul 2020

NOAA / NESDIS / STAR

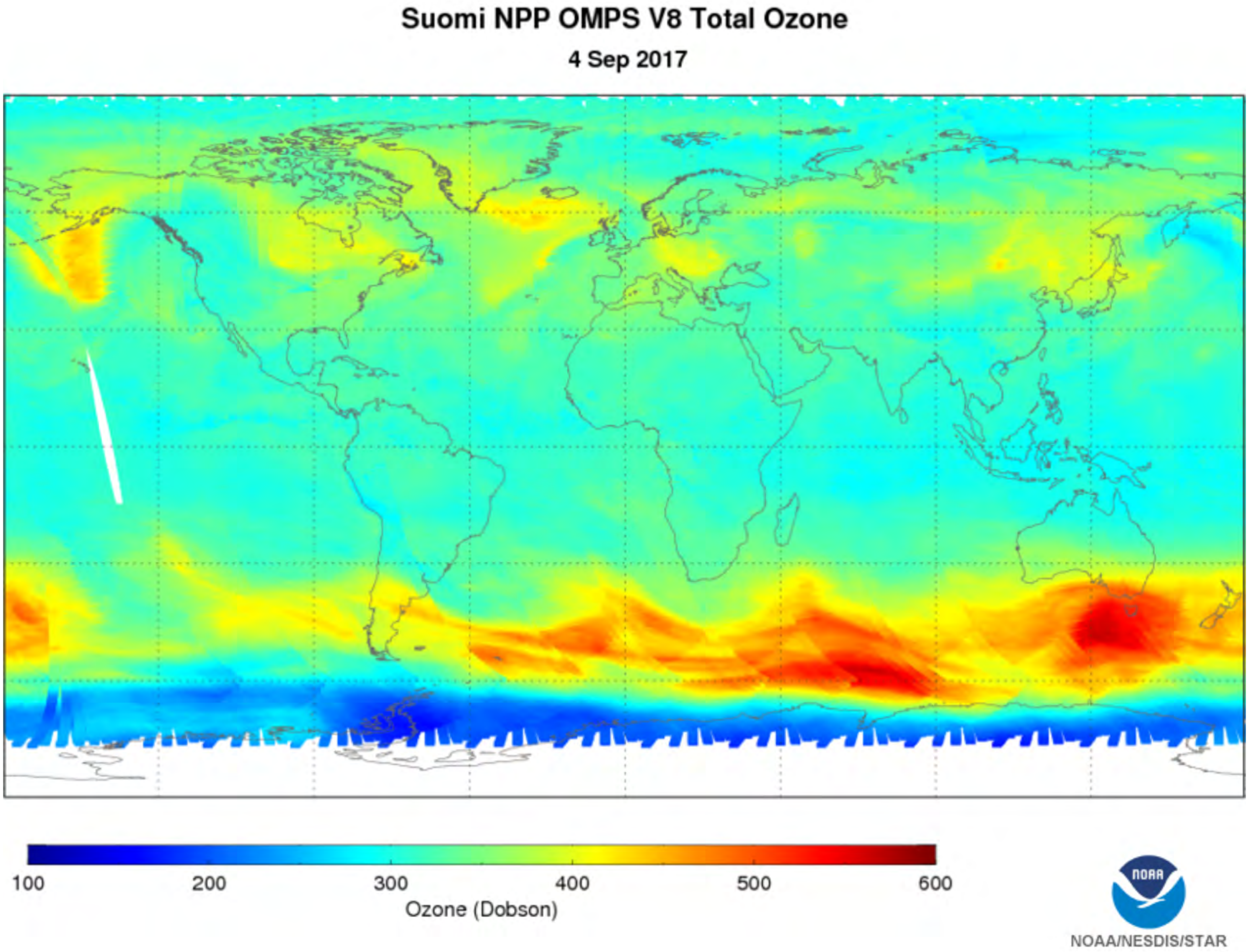
Ascending

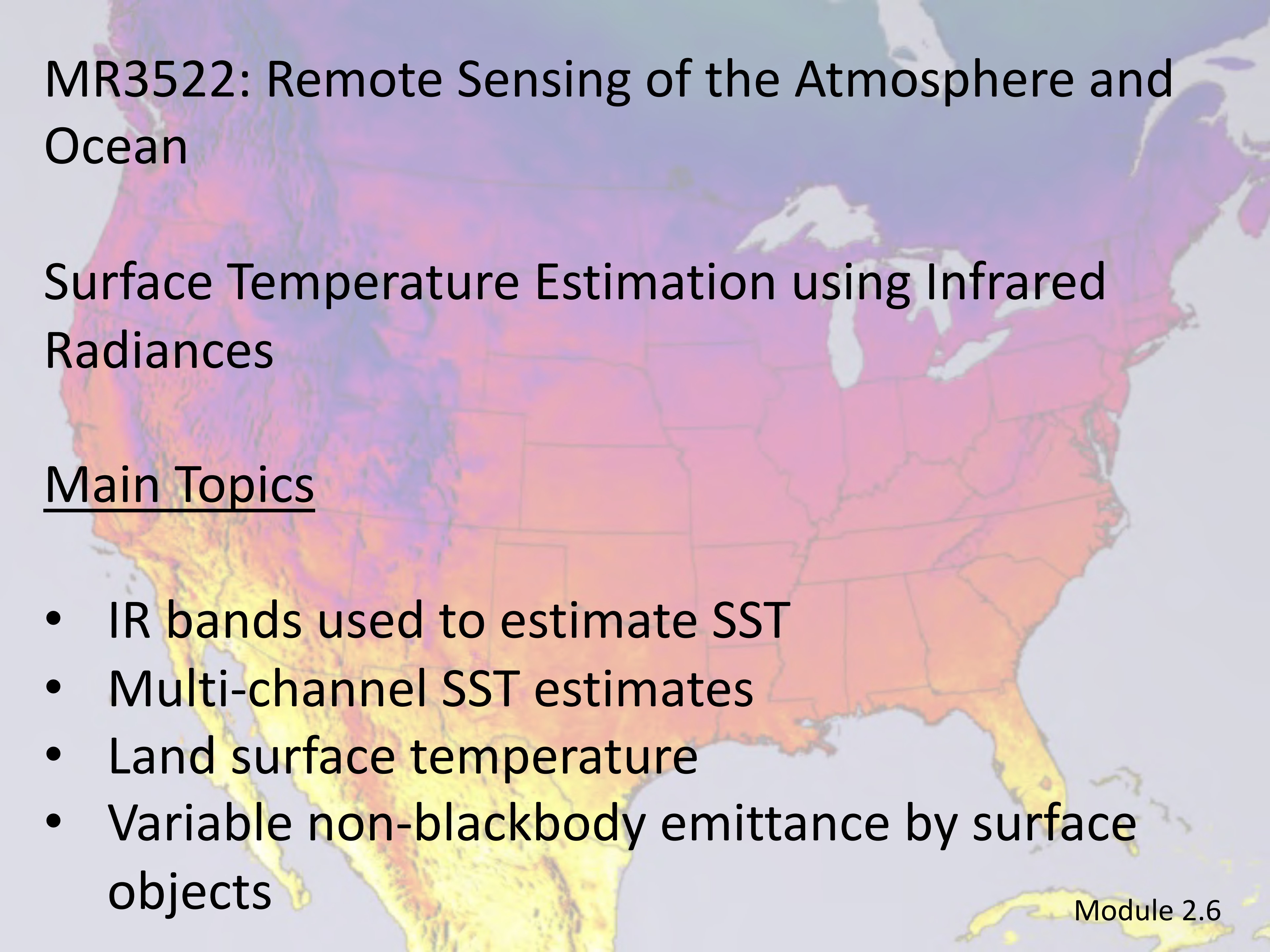


Descending



Created on Jul 18 01:27:17 2020 UTC


Suomi NPP OMPS V8 Total Ozone
4 Sep 2017
100
200
300
400
500
600
Ozone (Dobson)
NOAA
NOAA/NESDIS/STAR



MR3522: Remote Sensing of the Atmosphere and Ocean

Surface Temperature Estimation using Infrared Radiances

Main Topics

- IR bands used to estimate SST
- Multi-channel SST estimates
- Land surface temperature
- Variable non-blackbody emittance by surface objects

Module 2.6

Remember, even in an atmospheric window:

Brightness temperature is not actual temperature!

1) Small amounts of absorption could reduce radiation from surface.
2) Emitting surface may not be a blackbody.

$$T_B = \frac{\hbar c}{\lambda k \; ln \frac{2\hbar c^2}{\lambda^5 L_t}}$$

We can compute brightness temperature from observed radiance.

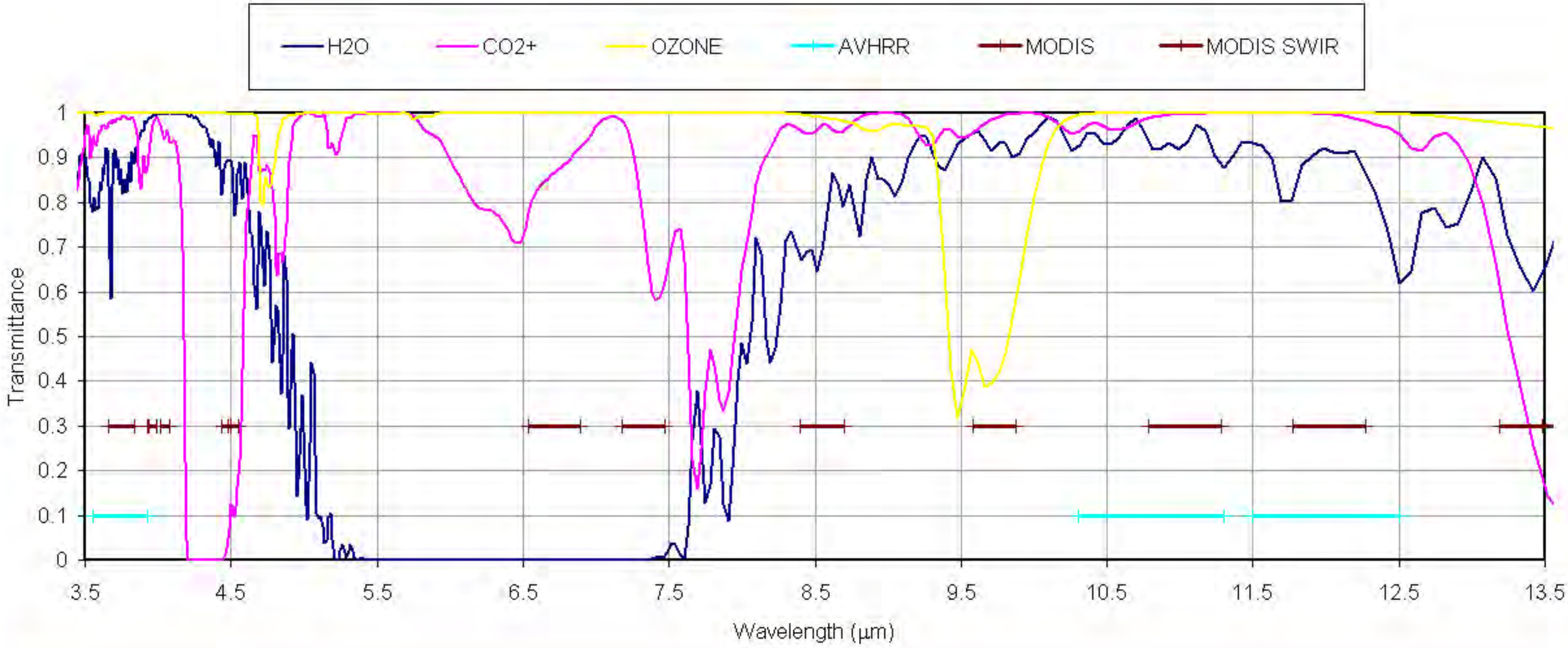
GOAL: Correct brightness temperatures using radiances in multiple bands to actual temperature at surface by accounting for water vapor absorption.

Limitation: This only works in cloud-free areas!

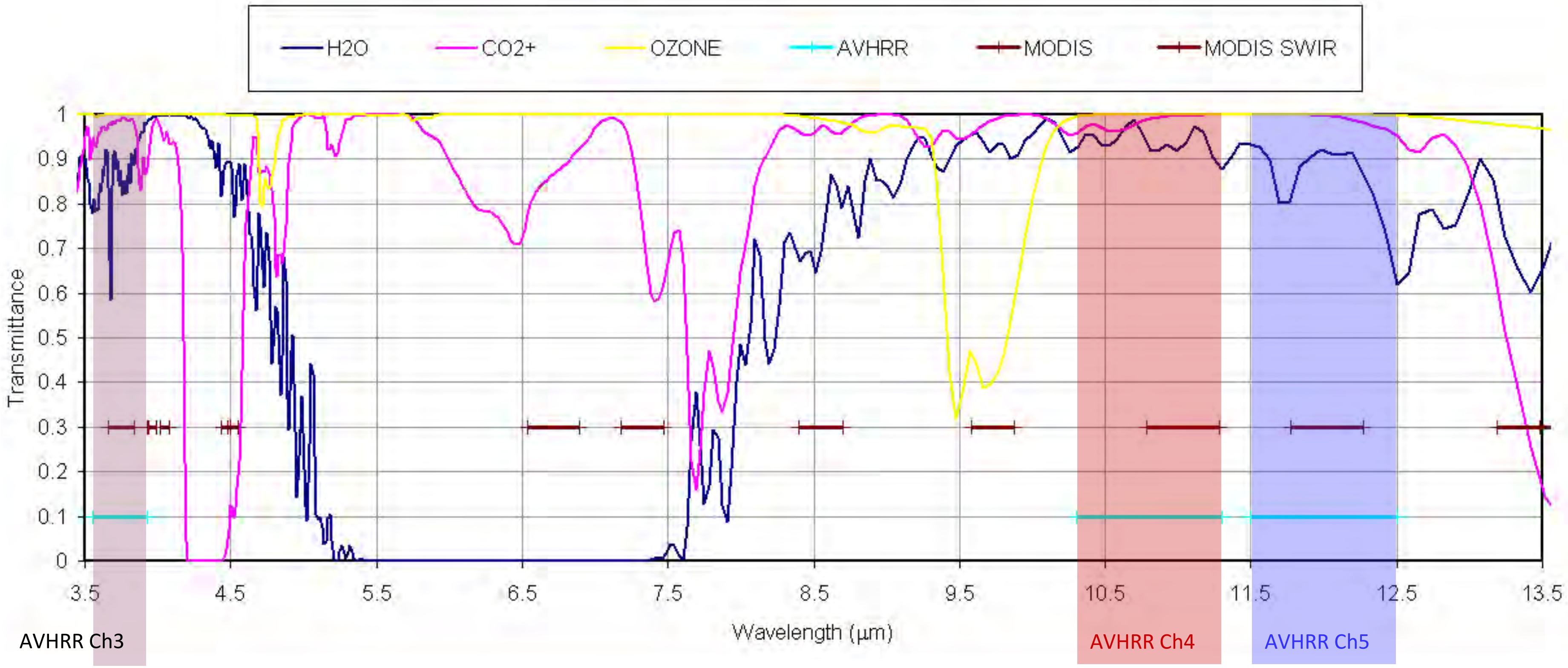
From Schwartzchild's Equation:

$$L_t(\lambda,\theta,\varphi) = \varepsilon_s(\lambda,\theta)B(\lambda,T_s)\tau_d(\lambda) + \int_{p_s}^{0} B(\lambda,T(p))\frac{d\tau_d(\lambda,p)}{dp}dp$$

… and for surface radiance to dominate we need a wavelength in a "window" so $\tau_d(\lambda)$ is large and $d\tau_d(\lambda,p)/dp$ is small above the surface



None of these are in perfect windows so there will always be some contribution from the path term due primarily to absorption/emission by water vapor

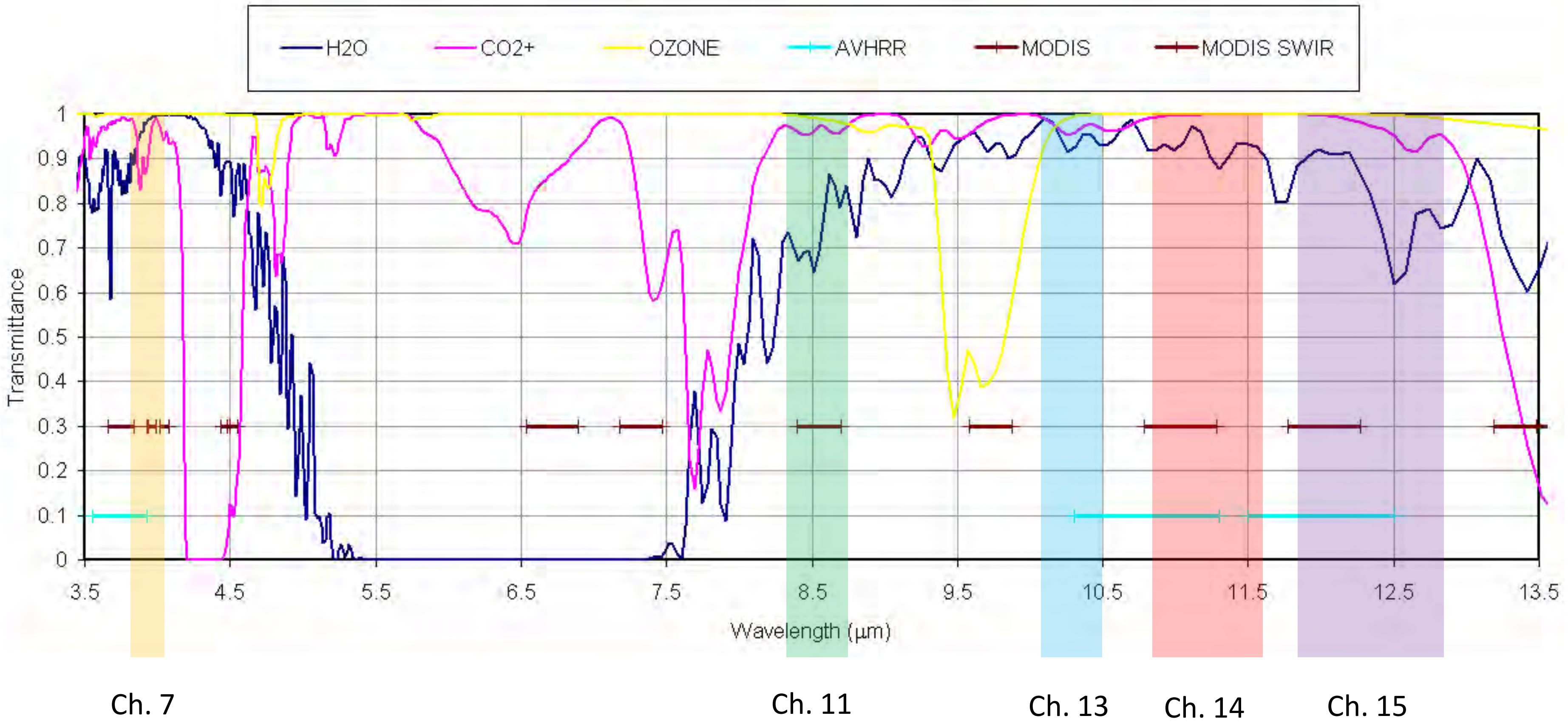


Therefore variations in the AVHRR Ch4 and Ch5 radiance/T_B difference, for example $T_B(11\mu m) - T_B(12\mu m)$ will be due to variations in column water vapor amount

Is this difference > or < 0?

AVHRR (NOAA-19) channels for SST are similar to those used by VIIRS (NOAA-20; M12, M13, M15, M16), except VIIRS has two SWIR channels.

None of these are in perfect windows so there will always be some contribution from the path term due primarily to absorption/emission by water vapor



GOES Channels used for SST algorithm

Does the addition of atmospheric water vapor increase or decrease T_B?

Let's look at a simple case - addition of a homogeneous layer

T_a, $\tau_d=0.9$

T_s, $\varepsilon_s=1$

$$L_t(\lambda,\theta,\varphi) = \varepsilon_s(\lambda,\theta)B(\lambda,T_s)\tau_d(\lambda) + \int_{p_s}^{0} B(\lambda,T(p))\frac{d\tau_d(\lambda,p)}{dp}dp$$

Becomes, $$L_t(\lambda,\theta,\varphi) = B(\lambda,T_s)\tau_d(\lambda) + B(\lambda,T_a)d\tau_d(\lambda)$$

or, $$L_t(\lambda,\theta,\varphi) = B(\lambda,T_s)0.9 + B(\lambda,T_a)0.1$$

10% of the surface-emitted radiance
has been replaced with 10% of the "cooler" path-emitted radiance

T_B decreases (determined by T_s, T_a, and τ_d)

How does the amount of water vapor affect the spectral variation of T_B?

[referring to AVHRR Channel (4) and Channel (5)]

T_a, $\tau_d(4) = 0.95$, $\tau_d(5) = 0.9$

$\delta(4) = -\ln(0.95) = 0.051$, $\delta(5) = 0.105$

(for nadir view)

T_s, $\varepsilon_s = 1$

$$L_t(4,\theta,\varphi) = B(\lambda,T_s)0.95 + B(\lambda,T_a)0.05$$

$$L_t(5,\theta,\varphi) = B(\lambda,T_s)0.9 + B(\lambda,T_a)0.1$$

$$L_t(4,\theta,\varphi) - L_t(5,\theta,\varphi) = [B(\lambda,T_s) - B(\lambda,T_a)]0.05$$

If we double the amount of water vapor, what changes?

δ doubles so… $\delta(4) = 0.102$, $\delta(5) = 0.210$

and, $\tau_d(4) = 0.90$, $\tau_d(5) = 0.81$

vs

Since T_s and T_a don’t change with wavelength, now…

$$L_t(4,\theta,\varphi) = B(\lambda,T_s)0.90 + B(\lambda,T_a)0.10$$

$$L_t(5,\theta,\varphi) = B(\lambda,T_s)0.81 + B(\lambda,T_a)0.19$$

$$L_t(4,\theta,\varphi) - L_t(5,\theta,\varphi) = [B(\lambda,T_s) - B(\lambda,T_a)]0.09$$

MCSST - MultiChannel Sea Surface Temperature

This technique assumes that the true surface temperature
can be derived from a linear composite
of the AVHRR Ch 4 and 5 brightness temperatures
(accounting for water vapor variations)

$$T_s = A + B\,T_4 + C\,T_5$$

A, B, and C can then be determined empirically:

Measure T_S (ship, buoy, etc.) in many places
coincident with measurements of T_4 and T_5 (AVHRR)

Statistically determine A, B, and C that produce a best fit of

$$T_s(x) = A + B\,T_4(x) + C\,T_5(x)$$

Or at night we can also use Ch 3 (3.7μm wavelength) (why?)

$$T_s(x) = D + E\,T_3(x) + F\,T_4(x) + G\,T_5(x)$$

The sea surface temperature lab exercise will give you an opportunity
to examine MCSST calculations first hand

AVHRR Split Window formulation for NOAA-19

Note the night versions that add the 3.7 micron window

Day MCSST Split

$T_s = a_0 + a_1 * band4 + a_2(band4 - band5) + a_3(band4 - band5)(sec(f) - 1)$

Night MCSST Split

$T_s = a_0 + a_1 * band4 + a_2(band4 - band5) + a_3(band4 - band5)(sec(f) - 1)$

Night MCSST Dual

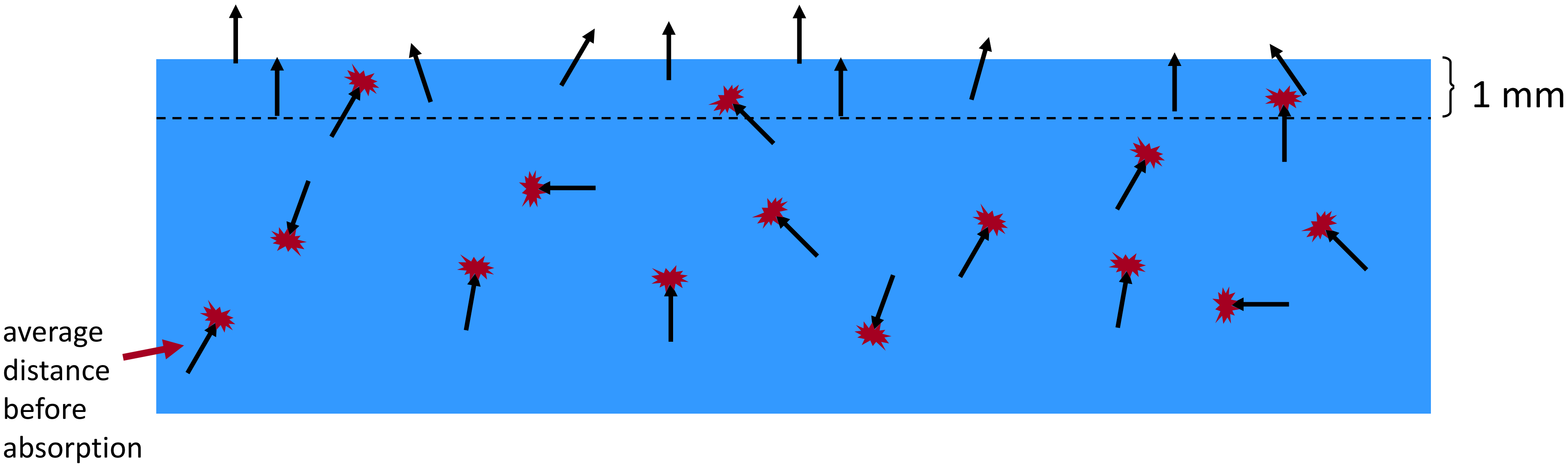
$T_s = a_0 + a_1 * band4 + a_2(band3 - band4) + a_3(sec(f) - 1)$

Night MCSST Triple

$T_s = a_0 + a_1 * band4 + a_2(band3 - band5) + a_3(band3 - band5)(sec(f) - 1)$

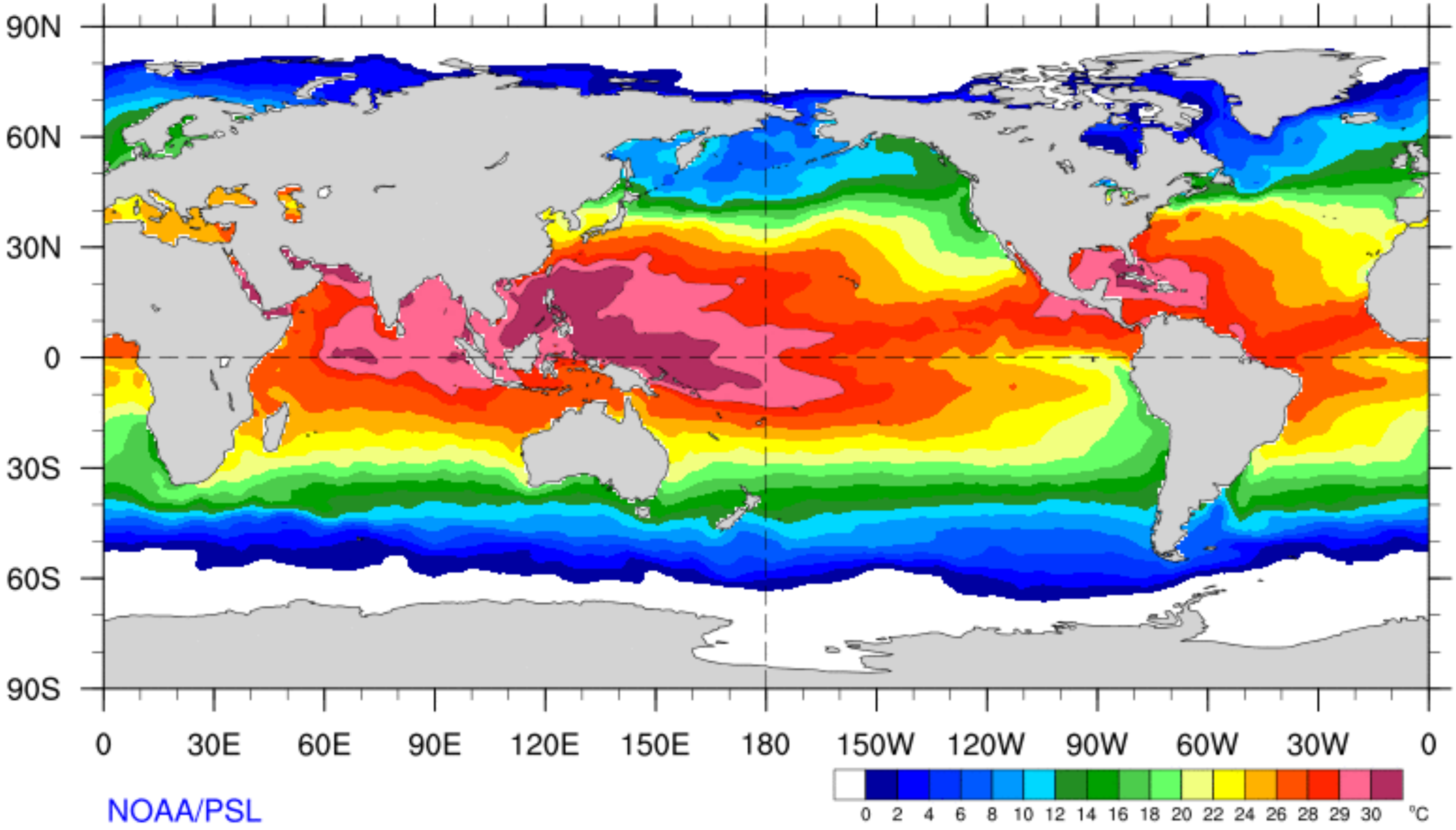
What part of the water column are we “sensing”?

How far can photons travel in water before they are absorbed?



We are sensing just the “skin” temperature of the ocean

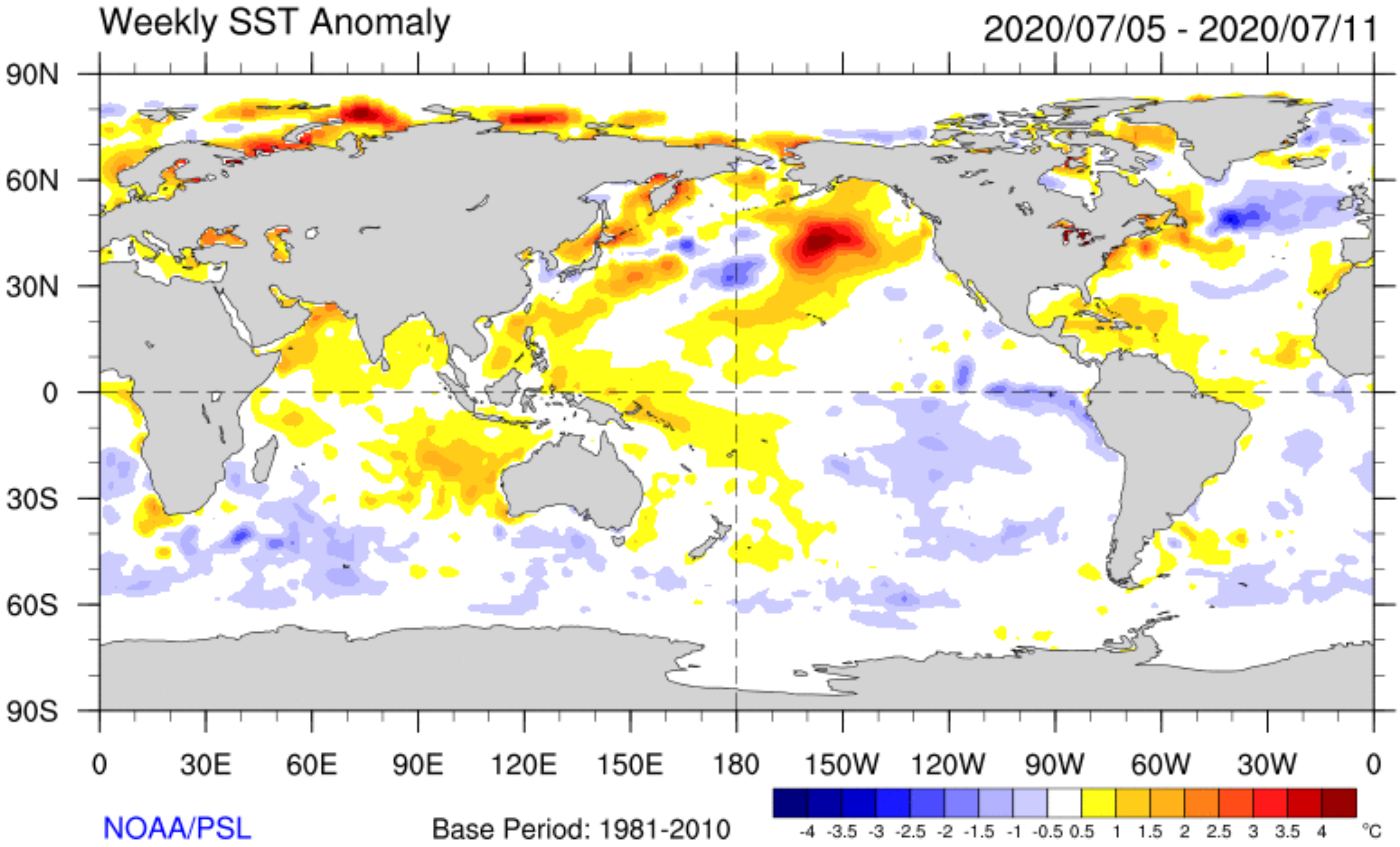
The advantage of the statistical technique is that T_B is correlated to bulk temperature measurements and the coefficients in MCSST correct for the difference between bulk and skin temperature.



Weekly Average SST

2020/07/05 - 2020/07/11

NOAA/PSL



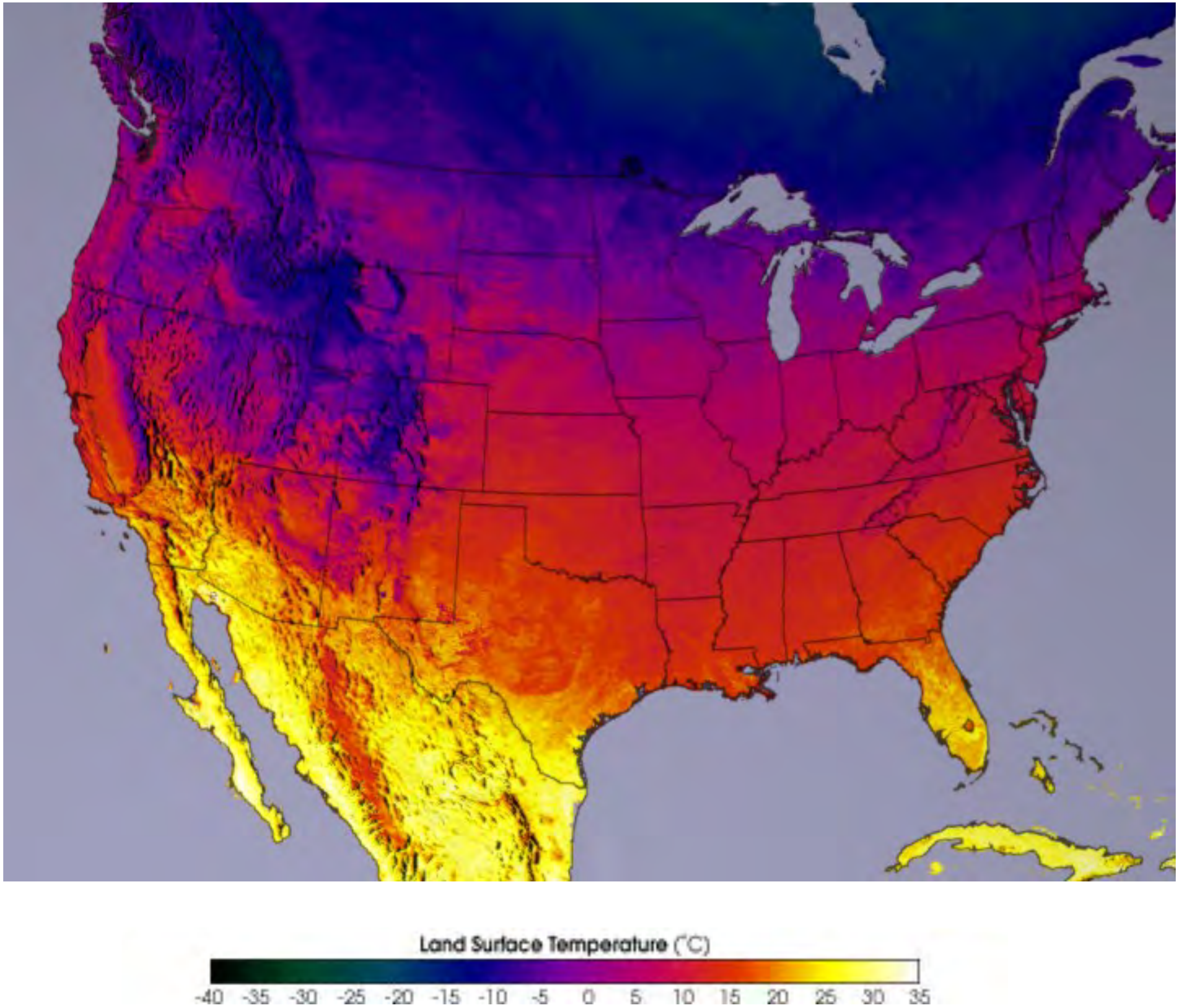
Weekly SST Anomaly

2020/07/05 - 2020/07/11

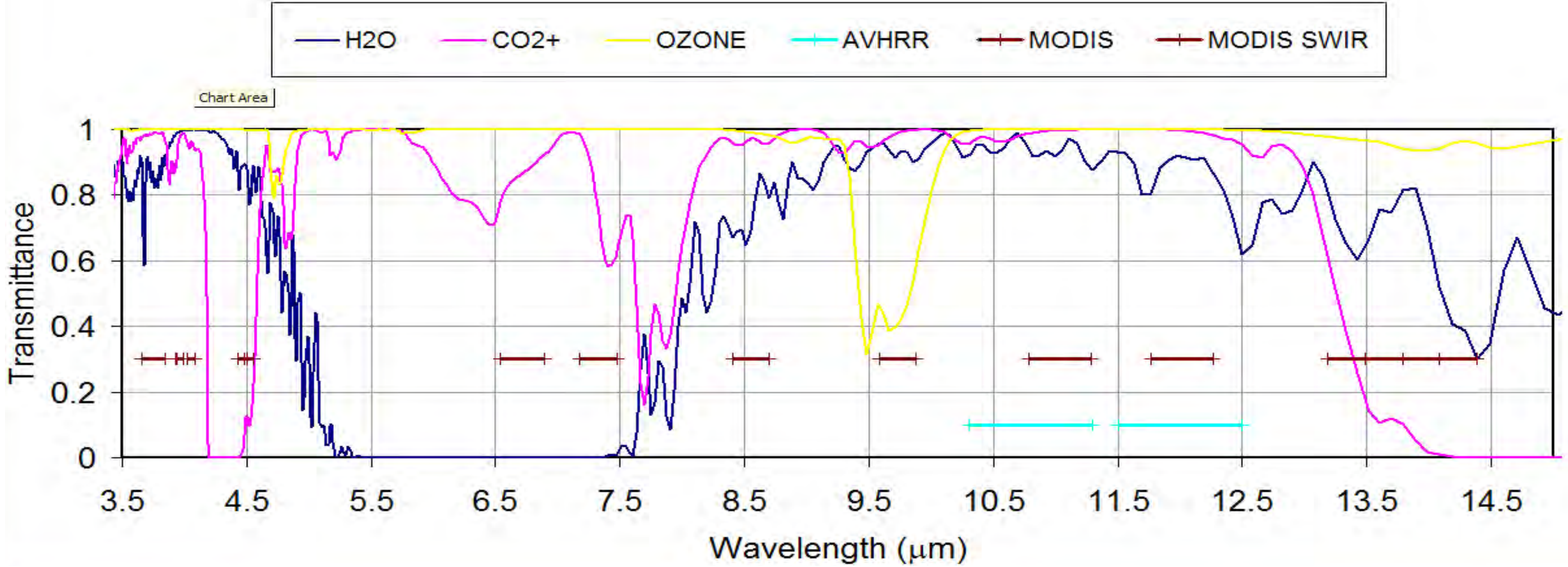
NOAA/PSL

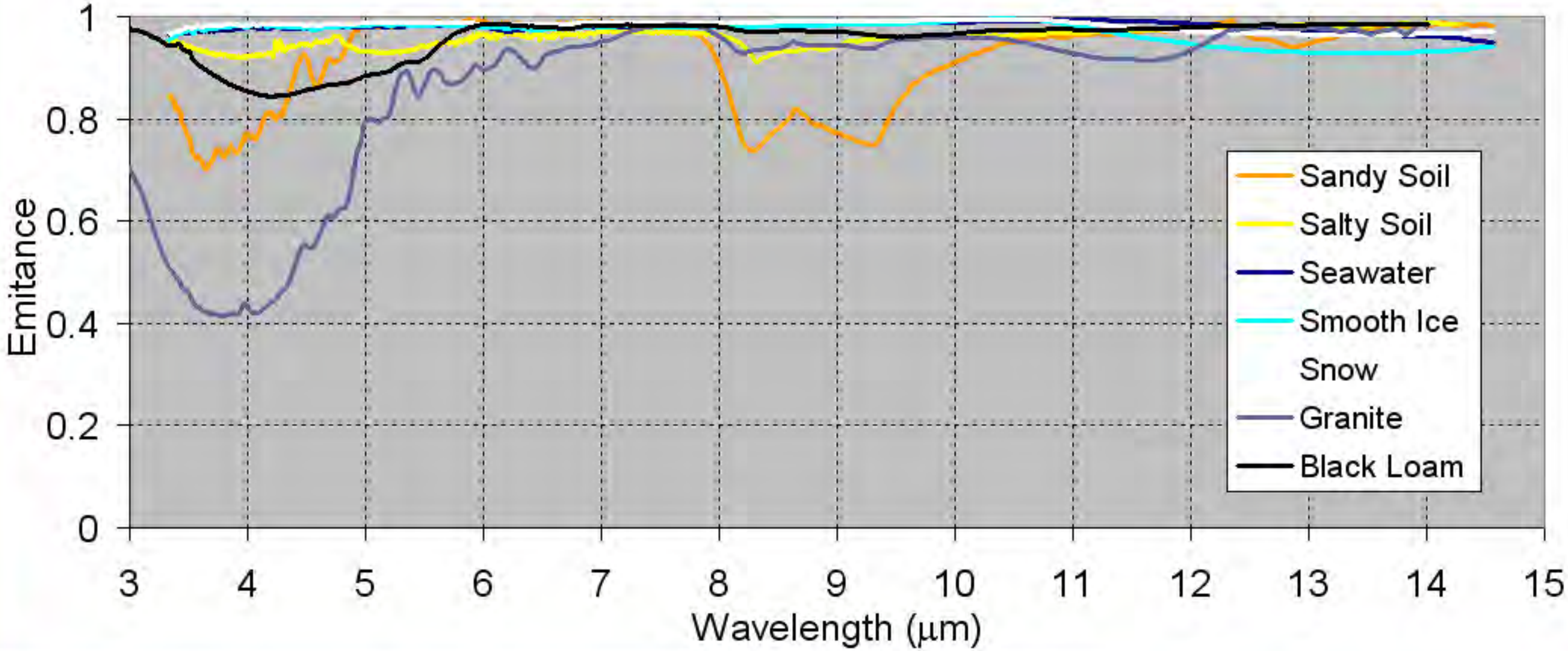
Base Period: 1981-2010

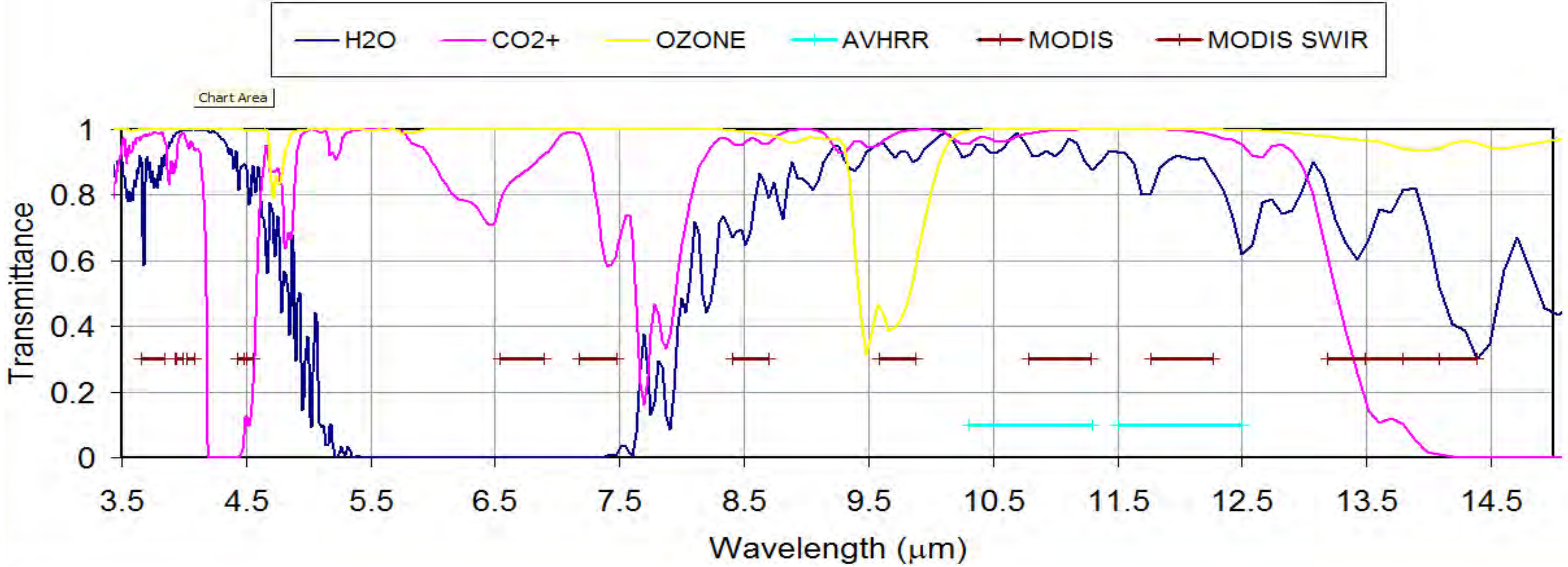
What about **Land** Surface Temperature (LST)?

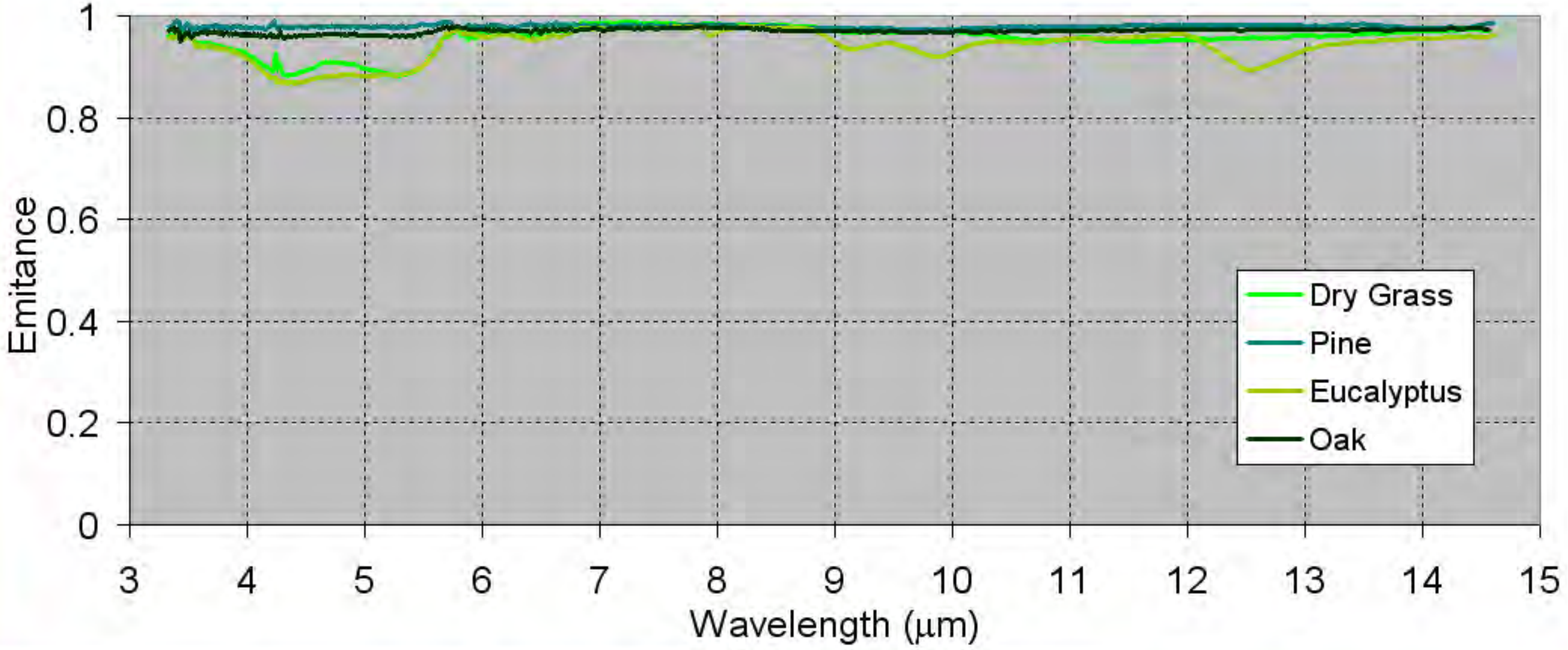


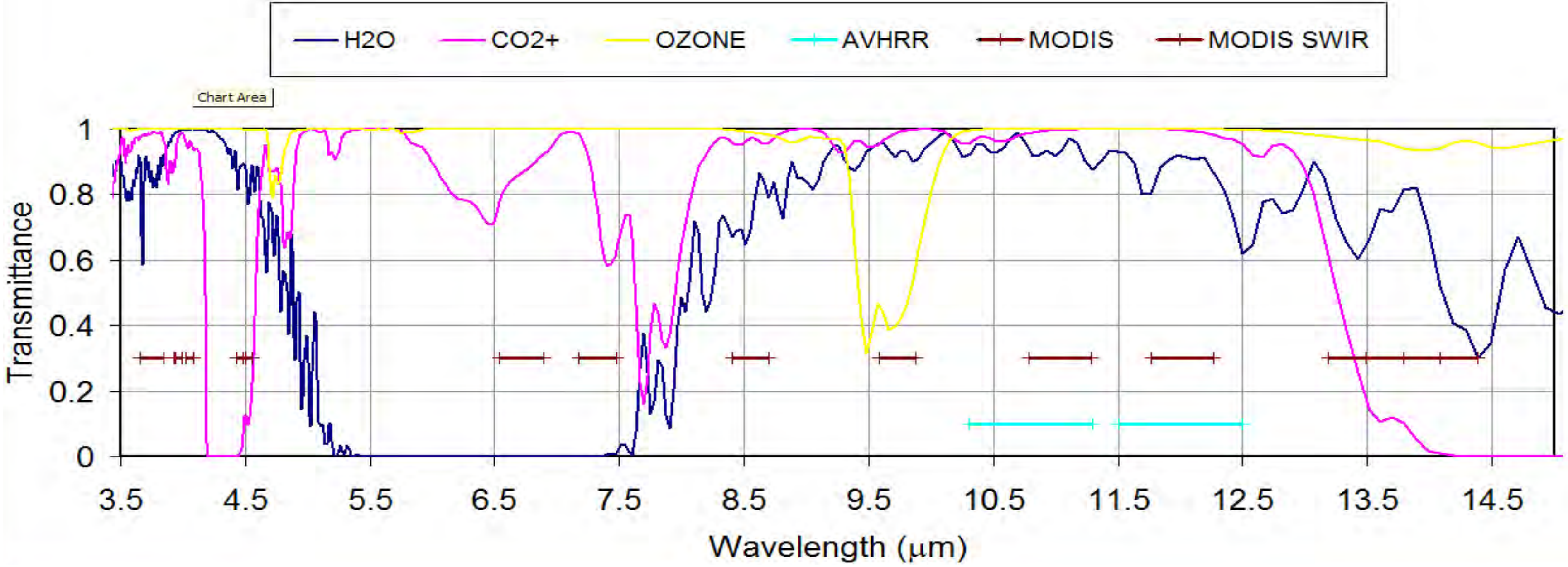
http://earthobservatory.nasa.gov/Newsroom/NasaNews/2002/200204088344.html

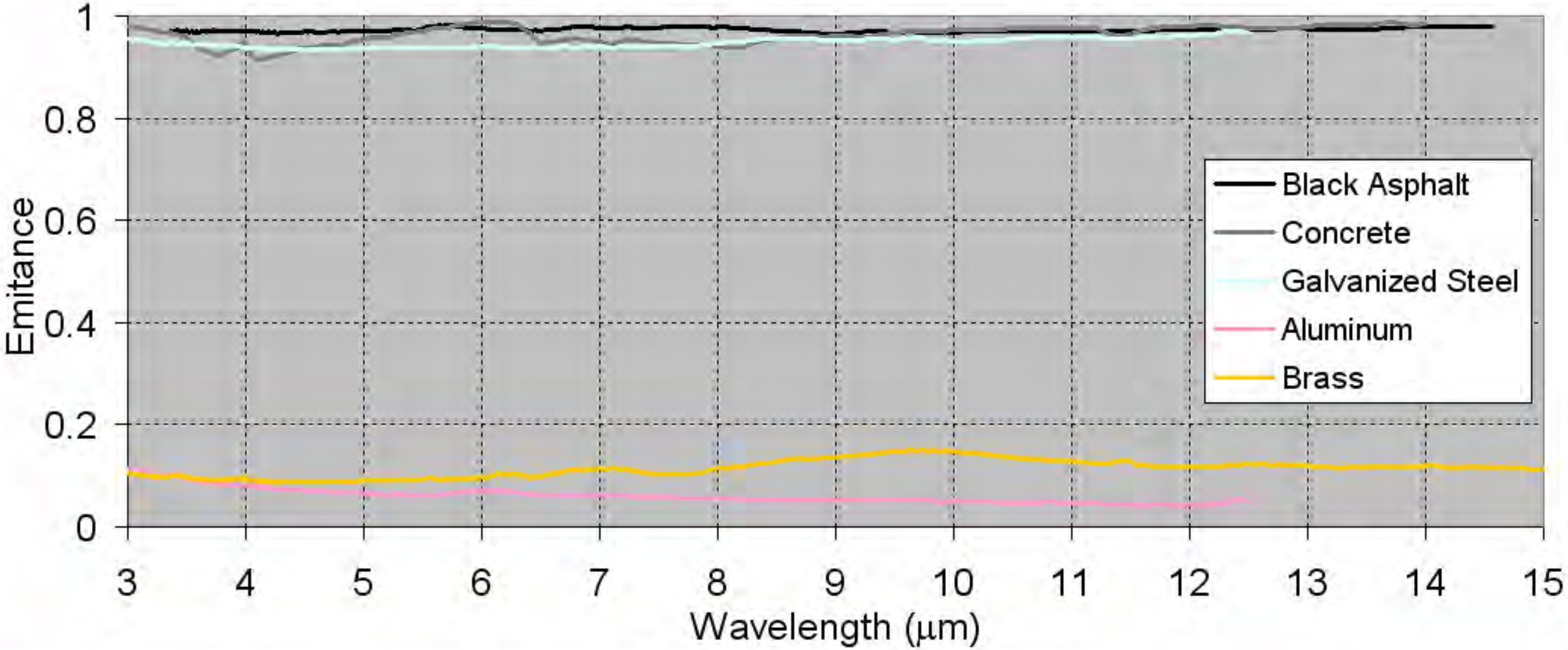

H2O
CO2+
OZONE
AVHRR
MODIS
MODIS SWIR
Chart Area
Transmitance
1
0.8
0.6
0.4
0.2
0
3.5
4.5
5.5
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5
14.5
Wavelength (µm)


Emitance
1
0.8
0.6
0.4
0.2
0
3
4
5
6
7
8
9
10
11
12
13
14
15
Wavelength (µm)
Sandy Soil
Salty Soil
Seawater
Smooth Ice
Snow
Granite
Black Loam


H2O
CO2+
OZONE
AVHRR
MODIS
MODIS SWIR
Chart Area
Transmittance
1
0.8
0.6
0.4
0.2
0
3.5
4.5
5.5
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5
14.5
Wavelength (μm)

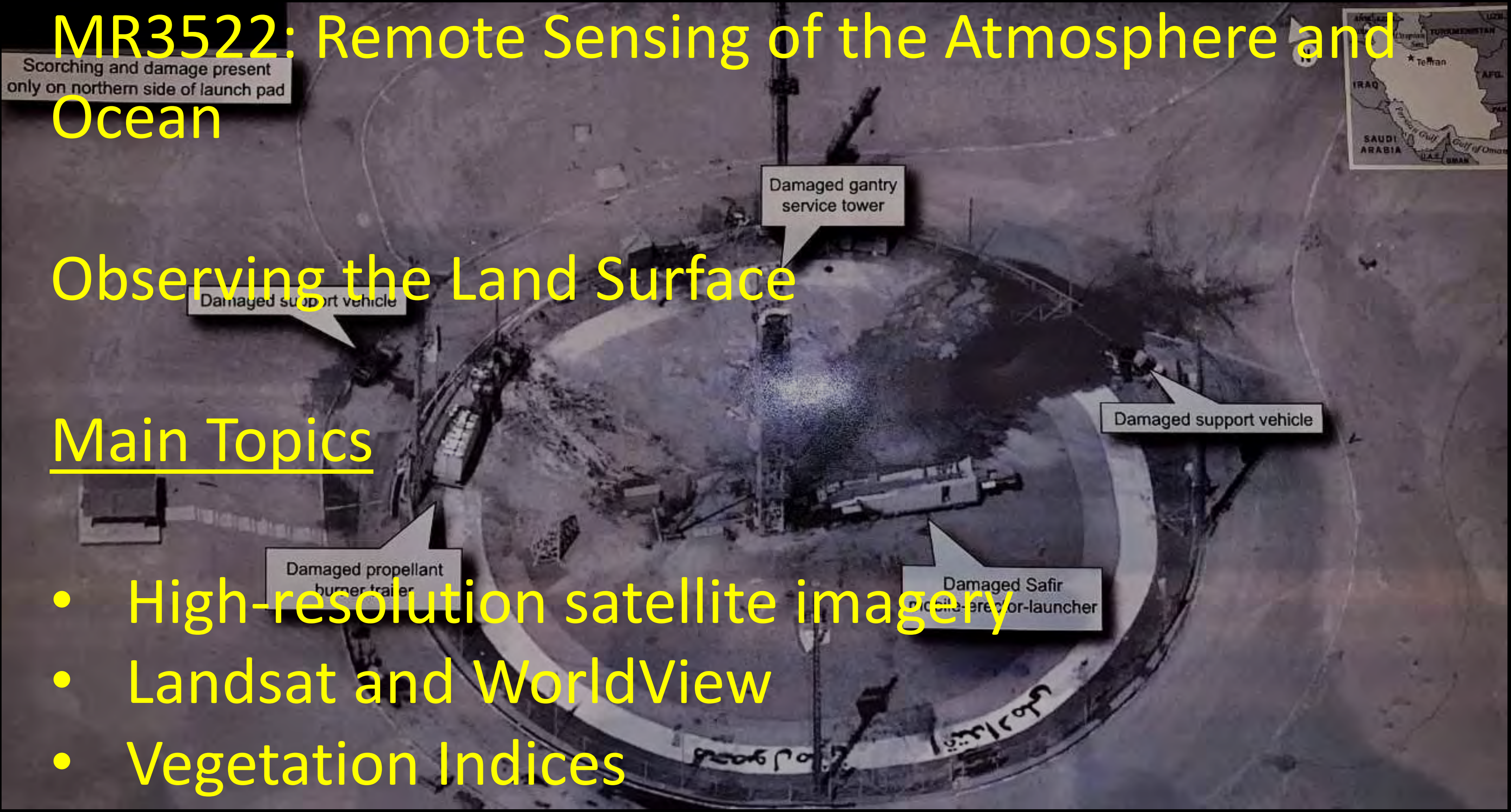

Emitance
1
0.8
0.6
0.4
0.2
0
3
4
5
6
7
8
9
10
11
12
13
14
15
Wavelength (μm)
Dry Grass
Pine
Eucalyptus
Oak


H2O
CO2+
OZONE
AVHRR
MODIS
MODIS SWIR
Chart Area
Transmittance
1
0.8
0.6
0.4
0.2
0
3.5
4.5
5.5
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5
14.5
Wavelength (µm)


Emitance
1
0.8
0.6
0.4
0.2
0
3
4
5
6
7
8
9
10
11
12
13
14
15
Wavelength (µm)
Black Asphalt
Concrete
Galvanized Steel
Aluminum
Brass

MR3522: Remote Sensing of the Atmosphere and Ocean

Observing the Land Surface



Main Topics

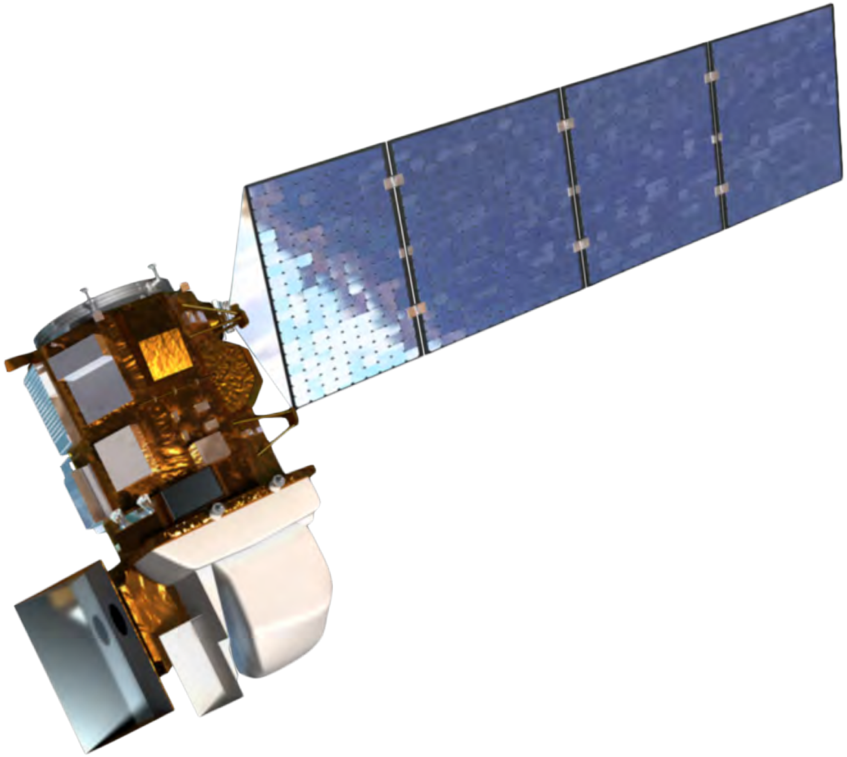
- High-resolution satellite imagery
- Landsat and WorldView
- Vegetation Indices

Credit: Twitter (@realdonaldtrump)
Previously classified imagery

Module 2.7

San Francisco, California, USA
SPOT-5 5m Panchromatic 09-Aug-2002

www.satimagingcorp.com



Landsat 8

- 2 instruments
  - Operational Land Imager (OLI)
    - 9 bands in VIS and near-IR
    - 30x30 meter spatial resolution (15x15 meter panchromatic)
  - Thermal Infrared Sensor (TIRS)
    - 2 bands in Earth IR
    - 100x100 meter spatial resolution

- Altitude: 705 km
- Inclination: 98.2°
- Period: 99 minutes
- Equatorial crossing (descending): 10:11am (Landsat7 at 10:00am)

Landsat 7 Bands (1999–present)

Band	Wavelength	Useful for mapping
Band 1 - Blue	0.45 - 0.52	Bathymetric mapping, distinguishing soil from vegetation, and deciduous from coniferous vegetation
Band 2 - Green	0.52 - 0.60	Emphasizes peak vegetation, which is useful for assessing plant vigor
Band 3 - Red	0.63 - 0.69	Discriminates vegetation slopes
Band 4 - Near Infrared	0.77 - 0.90	Emphasizes biomass content and shorelines
Band 5 - Short-wave Infrared	1.55 - 1.75	Discriminates moisture content of soil and vegetation; penetrates thin clouds
Band 6 - Thermal Infrared	10.40 - 12.50	Thermal mapping and estimated soil moisture
Band 7 - Short-wave Infrared	2.09 - 2.35	Hydrothermally altered rocks associated with mineral deposits
Band 8 - Panchromatic (Landsat 7 only)	0.52 - 0.90	15 meter resolution, sharper image definition

Landsat 8 Bands (2013–present) also planned for Landsat-9 (launch in 2020)

Band	Wavelength	Useful for mapping
Band 1 – Coastal Aerosol	0.435 - 0.451	Coastal and aerosol studies
Band 2 – Blue	0.452 - 0.512	Bathymetric mapping, distinguishing soil from vegetation, and deciduous from coniferous vegetation
Band 3 - Green	0.533 - 0.590	Emphasizes peak vegetation, which is useful for assessing plant vigor
Band 4 - Red	0.636 - 0.673	Discriminates vegetation slopes
Band 5 - Near Infrared (NIR)	0.851 - 0.879	Emphasizes biomass content and shorelines
Band 6 - Short-wave Infrared (SWIR) 1	1.566 - 1.651	Discriminates moisture content of soil and vegetation; penetrates thin clouds
Band 7 - Short-wave Infrared (SWIR) 2	2.107 - 2.294	Improved moisture content of soil and vegetation and thin cloud penetration
Band 8 – Panchromatic (15m)	0.503 - 0.676	15 meter resolution, sharper image definition
Band 9 – Cirrus	1.363 - 1.384	Improved detection of cirrus cloud contamination
Band 10 – TIRS 1	10.60 – 11.19	100 meter resolution, thermal mapping and estimated soil moisture
Band 11 – TIRS 2	11.50 - 12.51	100 meter resolution, Improved thermal mapping and estimated soil moisture

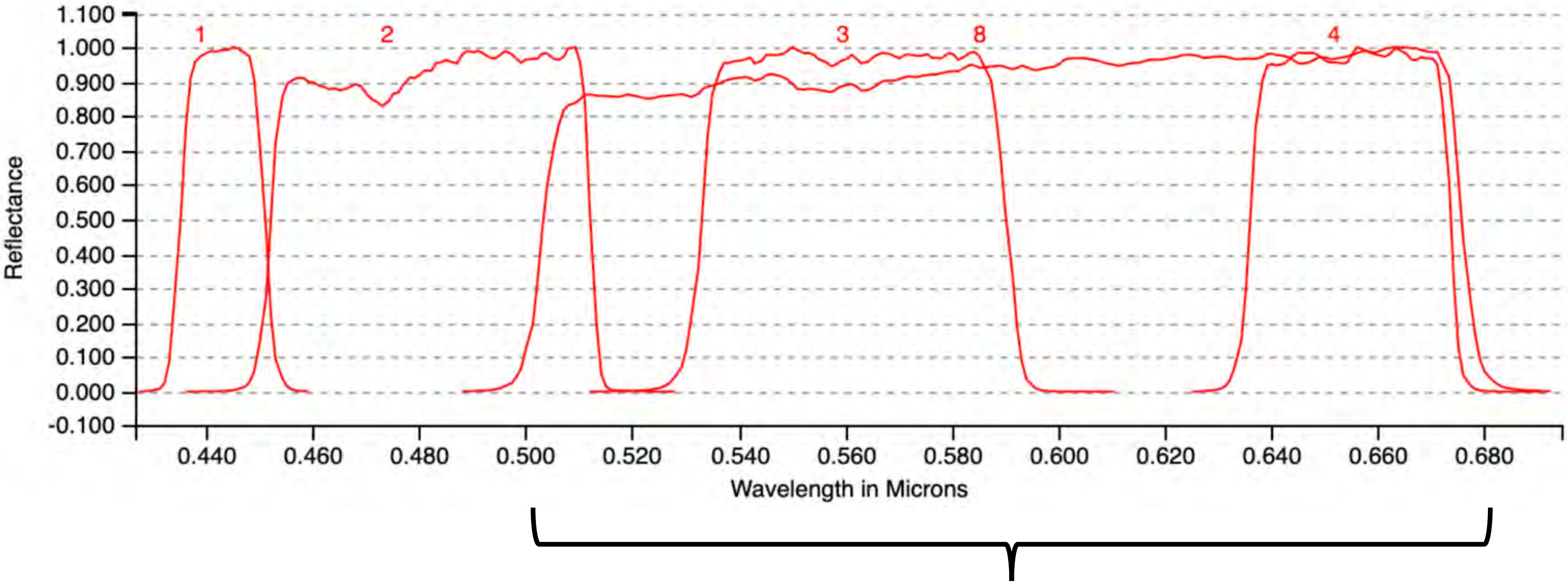
Multispectral vs. Panchromatic Imagery

Multispectral imagery is derived from several discrete bands in the visible part of the EM spectrum. This is the type of true color imagery we have viewed so far.

Panchromatic imagery is derived from a single wide band in the visible part of the spectrum. This imagery usually has higher resolution than multispectral imagery because the large bandwidth (i.e. more total radiance detected by the sensor than in a narrow band) permits the use of smaller detectors.

Pan-sharpening is the process of combining multispectral and panchromatic data from a single instrument to create a single high resolution color image.

Landsat-8 Spectral Response Functions



Panchromatic band

WorldView-3

Design and specifications

Orbit	Altitude: 617 km Type: SunSync, 10:30 am descending Node Period: 97 min.
Life	Spec Mission Life: 7.25 years Estimated Service Life: 10 to 12 years
Spacecraft Size, Mass and Power	Size: 5.7 m (18.7 ft) tall x 2.5 m (8 ft) across 7.1 m (23 ft) across deployed solar arrays Mass: 2800 kg (6200 lbs) Power: 3.1 kW solar array, 100 Ahr battery
Sensor Bands	Panchromatic: 450 - 800 nm 8 Multispectral: Coastal: 400 - 450 nm; Red: 630 - 690 nm Blue: 450 - 510 nm; Red Edge: 705 - 745 nm Green: 510 - 580 nm; Near-IR1: 770 - 895 nm Yellow: 585 - 625 nm; Near-IR2: 860 - 1040 nm 8 SWIR Bands: SWIR-1: 1195 - 1225 nm; SWIR-5: 2145 - 2185 nm SWIR-2: 1550 - 1590 nm; SWIR-6: 2185 - 2225 nm SWIR-3: 1640 - 1680 nm; SWIR-7: 2235 - 2285 nm SWIR-4: 1710 - 1750 nm; SWIR-8: 2295 - 2365 nm 12 CAVIS Bands: Desert Clouds: 405 - 420 nm; Water-3: 930 - 965 nm Aerosol-1: 459 - 509 nm; NDVI-SWIR: 1220 - 1252 nm Green: 525 - 585 nm; Cirrus: 1365 - 1405 nm Aerosol-2: 635 - 685 nm; Snow: 1620 - 1680 nm Water-1: 845 - 885 nm; Aerosol-1: 2105 - 2245 nm Water-2: 897 - 927 nm; Aerosol-2: 2105 - 2245 nm
Sensor Resolution (or GSD, Ground Sample Distance; off-nadir is geometric mean)	Panchromatic Nadir: 0.31 m 20° Off-Nadir: 0.34 m Multispectral Nadir: 1.24 m 20° Off-Nadir: 1.38 m SWIR Nadir: 3.70 m 20° Off-Nadir: 4.10 m CAVIS Nadir: 30.00 m
Dynamic Range	11-bits per pixel Pan and MS; 14-bits per pixel SWIR

Swath Width	At nadir: 13.1 km
Attitude Determination and Control	Type: 3-axis Stabilized Actuators: Control Moment Gyros (CMGs) Sensors: Star trackers, precision IRU, GPS
Pointing Accuracy and Knowledge	Accuracy: <500 m at image start/stop Knowledge: Supports geolocation accuracy below
Retargeting Agility	Time to Slew 200 km: 12 sec
Onboard Storage	2199 Gb solid state with EDAC
Communications	Image ® Ancillary Data: 800 and 1200 Mbps X-band Housekeeping: 4, 16, 32, or 64 kbps real time, 524 kbps stored, X-band Command: 2 or 64 kbps S-band
Max Contiguous Area Collected in a Single Pass (30° off-nadir angle)	Mono: 66.5 km x 112 km (5 strips) Stereo: 26.6 km x 112 km (2 pairs)
Revisit Frequency (at 40°N Latitude)	1 m GSD: <1.0 day 4.5 days at 20° off-nadir or less
Geolocation Accuracy (CE90)	Predicted <3.5 m CE90 without ground control
Capacity	680,000 km^2 per day

Maxar

Scattering (Reflectance of solar radiation)

- Applies to Bands 1 through 9

$$L_t(\lambda,\theta,\varphi) = L_0(\lambda,\theta,\varphi)\,e^{-\delta(\lambda)/\mu} + \int_0^{\delta(\lambda)} \frac{\int_{4\pi} \gamma_s(\mathbf{r},\mathbf{r}',\lambda,\mathbf{X})\,L(\mathbf{r}',\lambda,\mathbf{X})\,d\Omega'}{\sigma_e(\lambda,z)}\, e^{-\delta(\lambda,z)/\mu}\,\frac{d\delta}{\mu}$$

To derive land properties, we want the path radiance to have a small and removable contribution:

Three sources:

scatter by clouds (irremovable)

scatter by molecules (calculable as Rayleigh scatter)

scatter by aerosol particles (implied from some NIR channels)

Not as important because of higher $L_0(\lambda)$ at most λs

Emission (Radiation emitted directly by objects on Earth)

- Applies to Bands 10 and 11

$$L_t(\lambda,\theta,\varphi) = \varepsilon_s B(\lambda, T_s)\,e^{-\delta(\lambda)/\mu} + \int_0^{\delta(\lambda)} B(\lambda, T(z))\; e^{-\delta(\lambda,z)/\mu}\,\frac{d\delta}{\mu}$$

Landsat 8 viewing creation a man-made island out of a reef in the Spratly Islands

2013

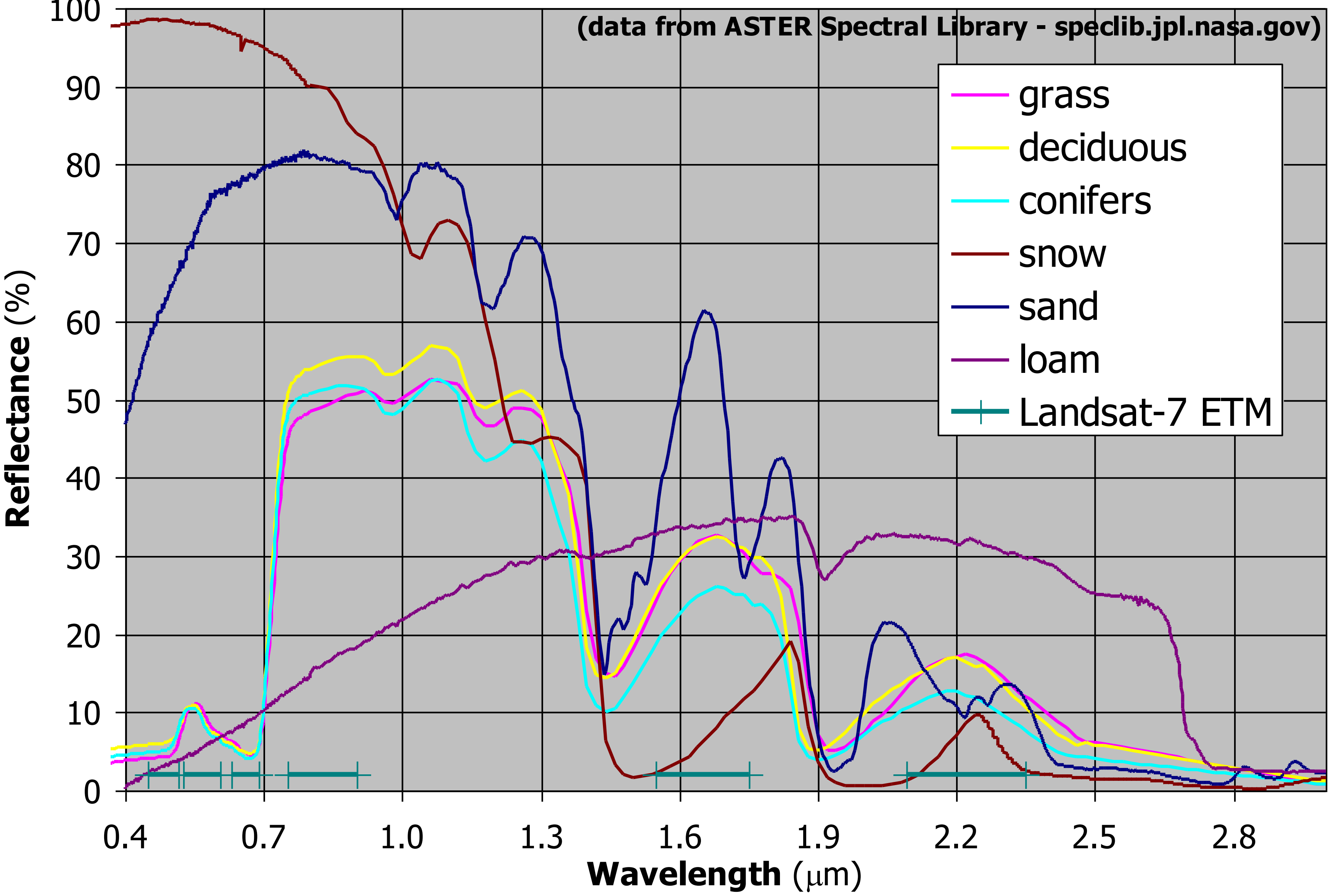
2015

https://landsatlook.usgs.gov/

WorldView-3
March 2020

Santa Lucia
Mountains
(2019)

Surface Reflectance



https://landsat.usgs.gov/spectral-characteristics-viewer

Detecting Vegetation

- One widely used index is the Normalized Difference Vegetation Index (NDVI). The combination of near-IR and red-visible data make this sensitive to chlorophyll.

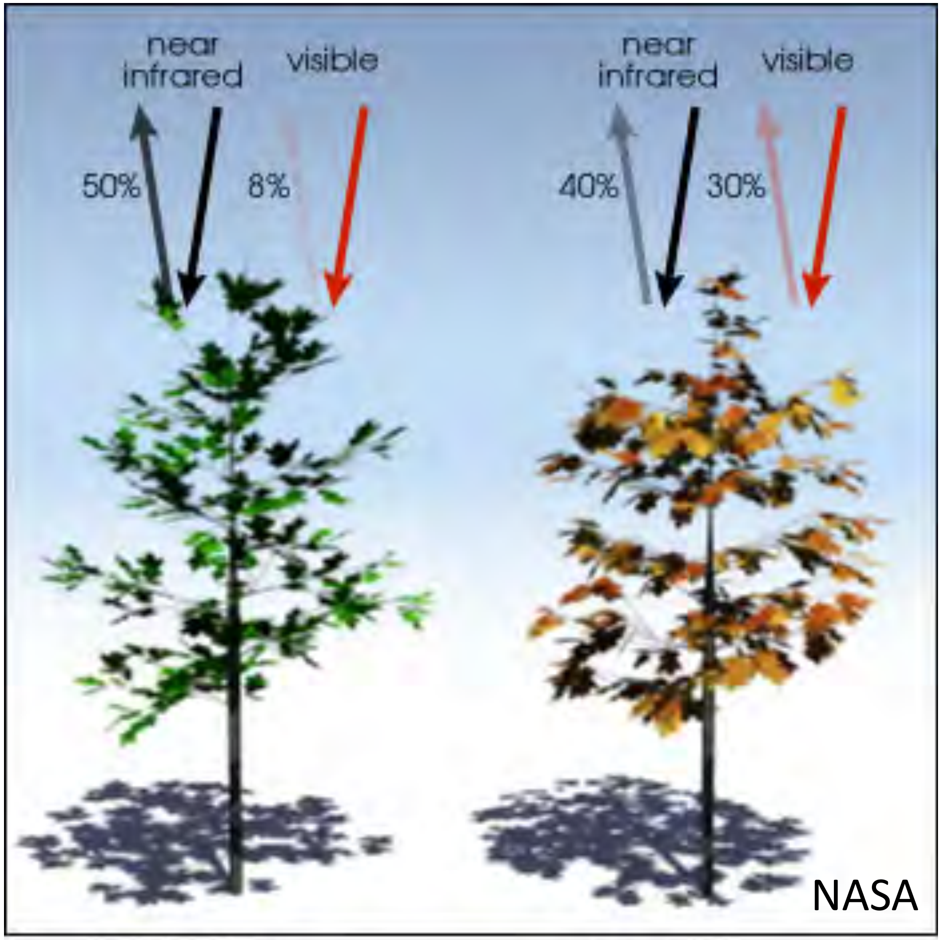
$$NDVI = \frac{NIR - VIS}{NIR + VIS}$$

NIR = Near-IR reflectance

VIS = Visible (Usually red band) reflectance

This can also be computed using GOES data. Which bands would you use?

Some limitations: Often has lots of atmospheric induced or background noise; needs to be smoothed heavily.



NASA

$$\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72 \qquad \frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$$

Detecting Vegetation

- A complimentary alternative to NDVI is the EVI, or Enhanced Vegetation Index. It is more responsive to variations in canopy properties and leaf area index.

$$EVI = \frac{NIR\ - RED}{NIR + a * RED - b * BLUE + c}$$

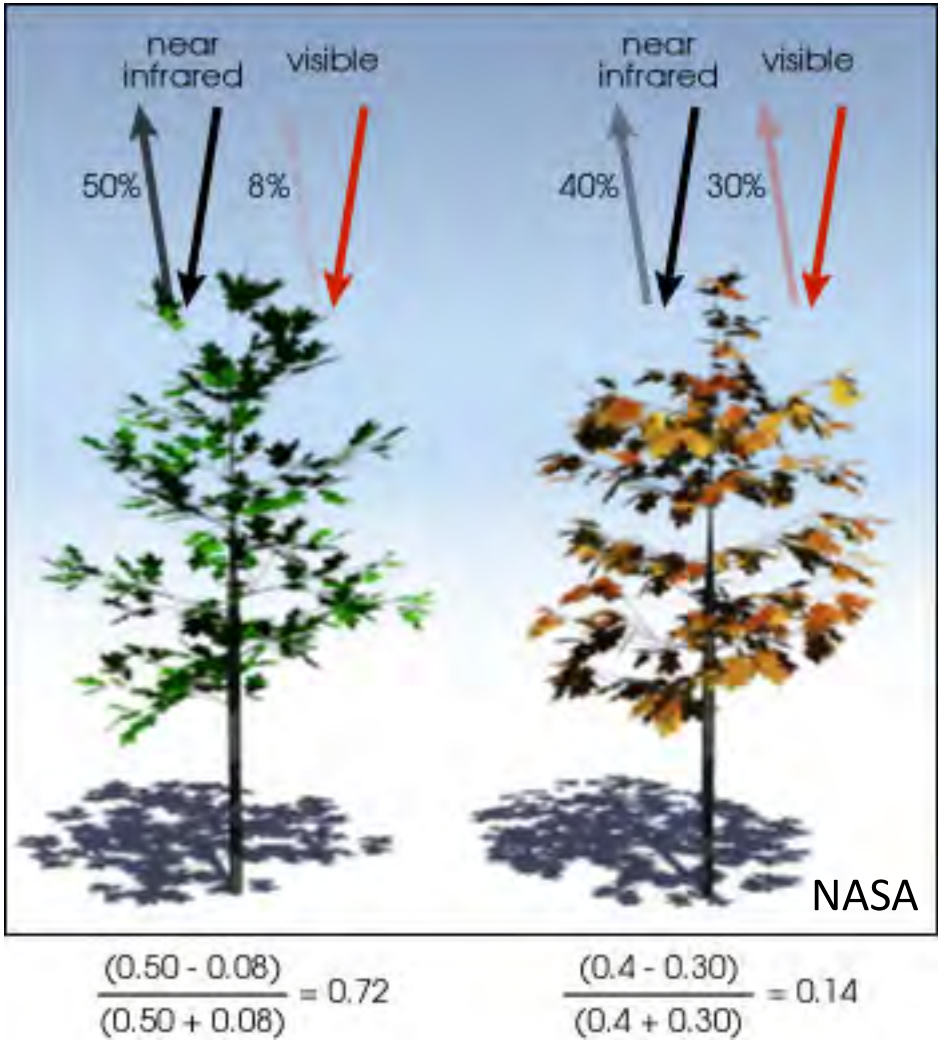
NIR = Near-IR reflectance

RED = red-band reflectance

BLUE = blue-band reflectance

a, b, and c are coefficients that depend on satellite

Some limitations: Signal to noise ratio in blue band is often low; also some old sensors did not have a blue band.



NASA

$$\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72 \qquad \frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$$

NDVI