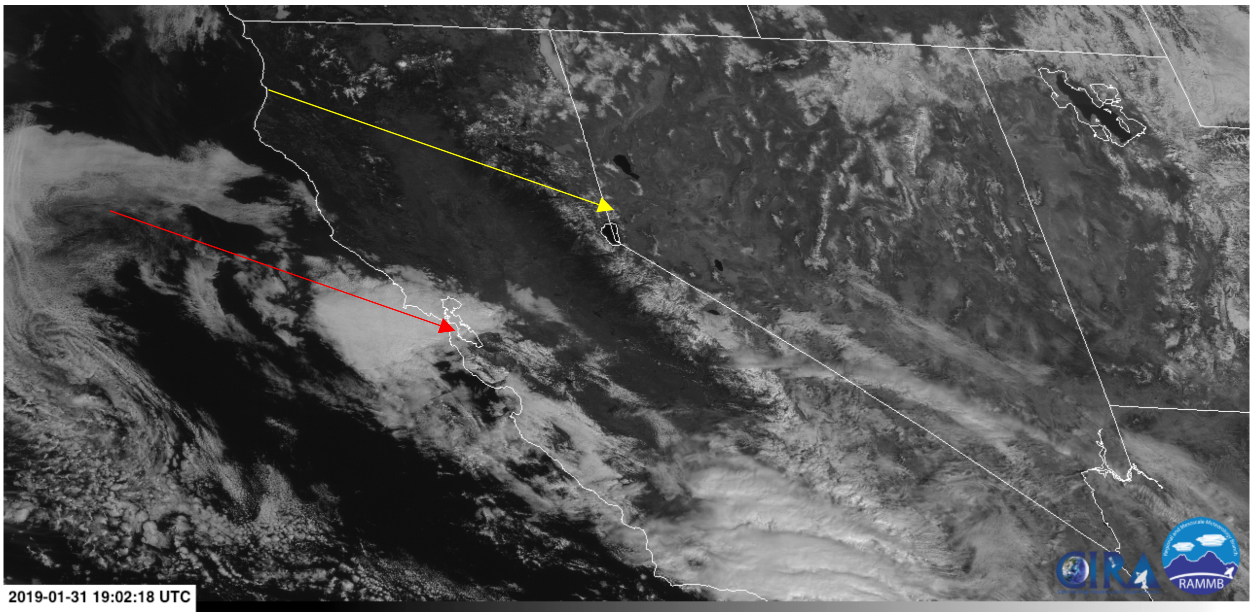
Name:________________________________

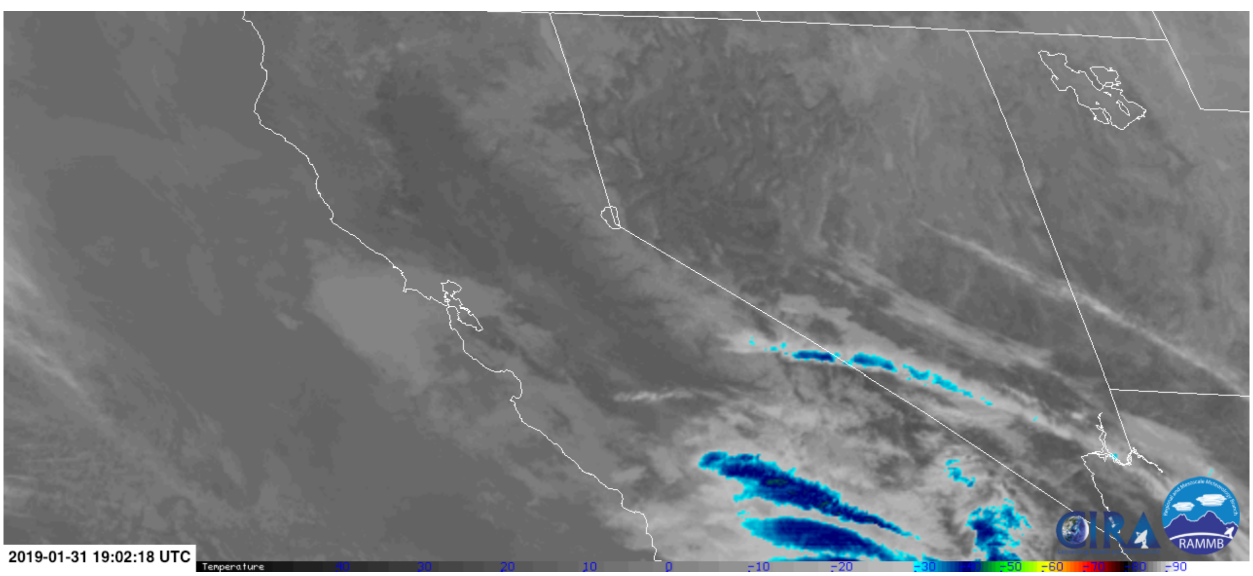
MR3522: Remote Sensing of the Atmosphere and Ocean
Practice Exam

1. For the following questions, consult the below imagery from GOES-17. The yellow arrow points close to Reno, Nevada. The red arrow points at San Francisco.

Channel 2 Brightness Value

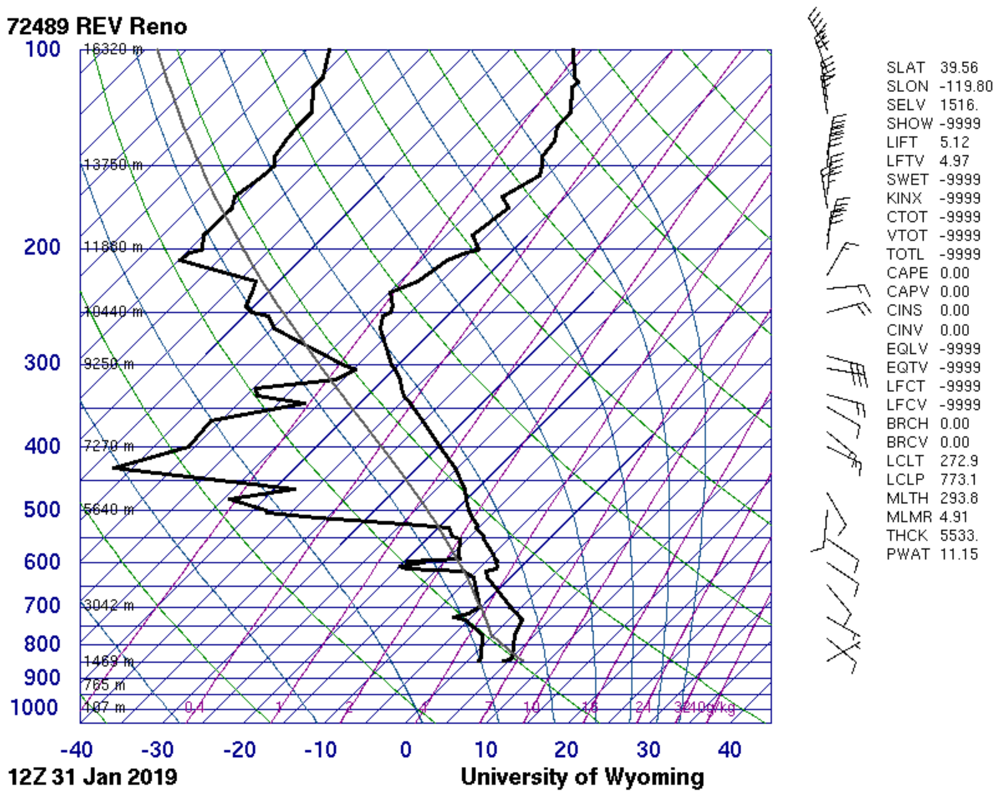


Channel 13 Brightness Temperature



Also consider the below sounding from Reno at 1200 UTC.

Name:________________________________



a. In the space below on the left, sketch approximate weighting functions for the 6.19 micron and 7.34 micron GOES bands at Reno. On the right, in a separate drawing, sketch the same but for an atmospheric profile in which specific humidity at every level is 50% of that indicated in the sounding. At most, only two or three peaks per function are needed; you need not represent every local maximum in the weighting functions. You will be graded primarily on two things: 1) Where the peaks of the weighting functions for the two bands are relative to each other in each plot, and 2) The relative shapes of the two weighting functions for the same band in the different plots. In the first plot, indicate for which of the two bands the atmosphere is most optically thick. Let the ordinate be height/pressure and the abscissa be the value of the weighting function.

Name:________________________________

b. What would the weighting function look like for an atmosphere completely absent of water vapor and N_2O?

c. Will the cloud near and offshore San Francisco Bay appear as reflective in GOES Channel 4 imagery? Explain your reasoning.

d. Near Reno, would the 640 nm band or the 10.35 micron band have a larger single-scattering albedo? Again, explain your reasoning.

e. Sketch a Planck function describing emittance for the cloud offshore San Francisco Bay, assuming it emits as a blackbody. On the same plot, and using the same assumption, sketch a Planck function for the clouds denoted by the blue area (lower brightness temperature) in southern California. **Label each function and your axes. Make especially sure that the peaks of the two functions are correctly represented relative to one another.**

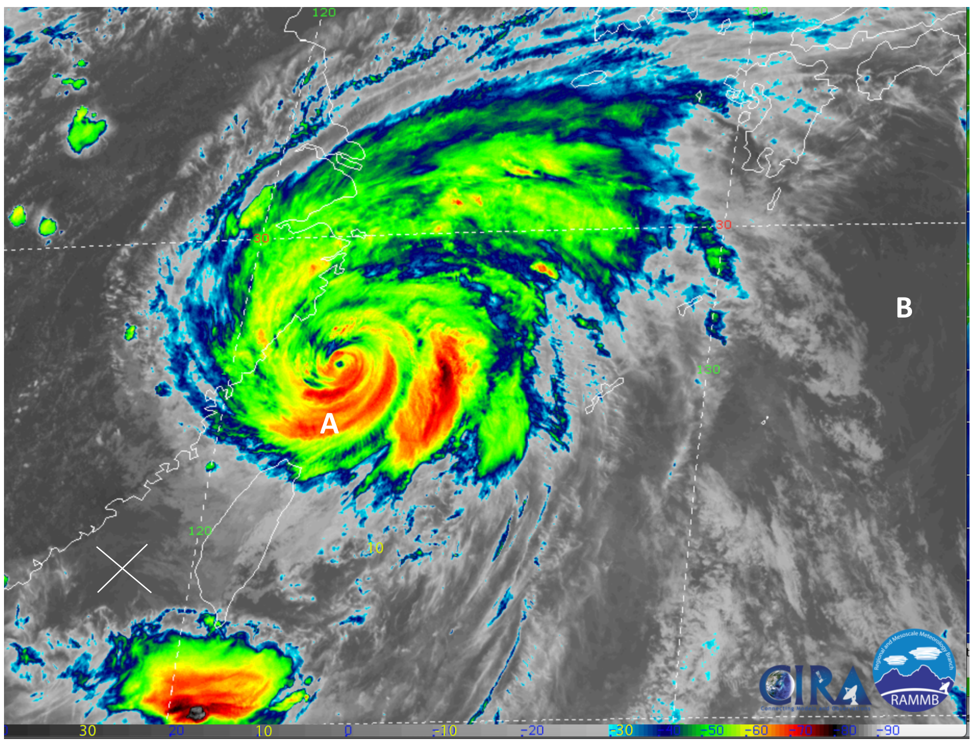
Name:________________________________

2. Suppose that a passive remote sensing detector is located at 20 km above the ground. The volume absorption coefficient of the atmosphere beneath the sensor is described as

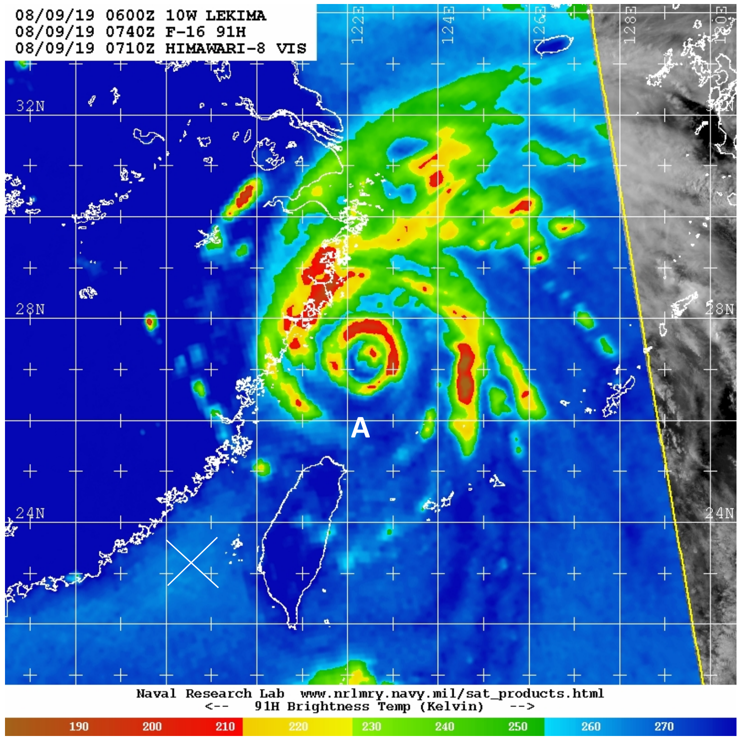
$$\sigma_a(z) = 0.1e^{-\frac{z}{H}}$$

where H is the scale height of the atmosphere, or 8.0 km. No scattering occurs at the wavelength detected by the sensor. Compute the direct transmissivity of the 0–20 km layer for along a vertical path.

3. Below are 11 μm and 91 GHz brightness temperatures of Typhoon Lekima at 0740 UTC 9 August 2019, respectively from Himawari-8 and SSMI. On the following page, answer the questions about the scene:



Name:________________________________



a. Why is the brightness temperature of the cloud-free area to the west of Taiwan (white X) so different between the two bands?

b. Which sensor observed the greater scene-averaged radiance? Why?

c. The brightness temperature at Point A at 11 µm is about -70°C, and the brightness temperature at 91 GHz is about -10°C. Why is the IR brightness temperature colder at Point "A"? What kind of cloud is being sensed by IR at Point "A"?

Name:______________________________

d. Would the difference in brightness temperature between GOES-17 6.2 μm and 7.3 μm bands be larger at letter "A" or letter "B"? Explain your answer.

e. Sketch Planck functions for emitters at responsible for the radiation received at the Himawari-8 sensor at Point "A" and "B". Make both the abscissa and ordinate linear axes (i.e. no log-log scale). Label the two functions and your axes. You need not include specific numbers on your plots. **Mostly importantly, ensure that the two functions are correctly represented relative to each other.**

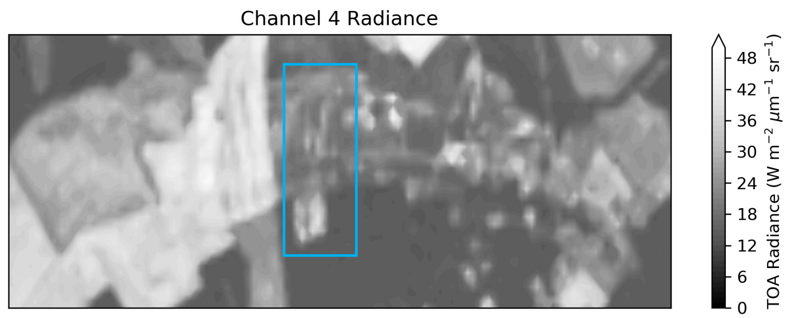
f. On the graph to the right, sketch weighting functions for the 11 μm IR and 91 GHz microwave bands at Point "A", again making sure that, most importantly, they are drawn correctly relative to each other. You need not label your axes. Assume the ordinate is height increasing upward and the abscissa is W increasing to the right.

4. Which MODIS band would be most effective for detecting tropopause folds (where stratospheric air is transported downward to altitudes well below the mean tropopause level)? Explain the rationale for your answer.

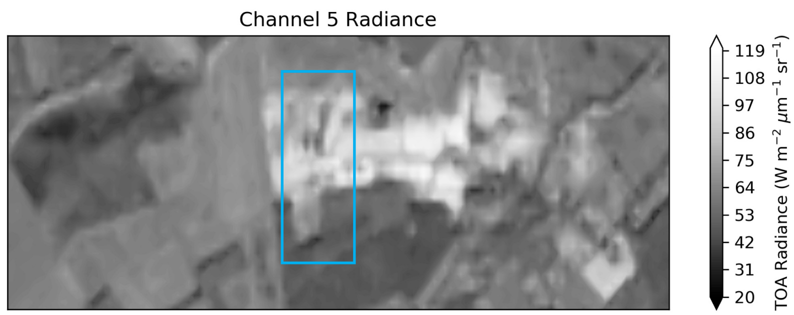
Name:_______________________________

5. The following Landsat 8 scene is from a farm in northeastern North Carolina, about an hour away from Norfolk, VA. The date was 5 October 2018, and soybeans were growing in the field. Plotted are radiance and reflectance from Channels 4 and 5 recorded during a daytime descending node of the satellite's orbit. The red contour in the third panel outlines 0.04 reflectance, and the red contour in the fourth panel outlines 0.20 reflectance.

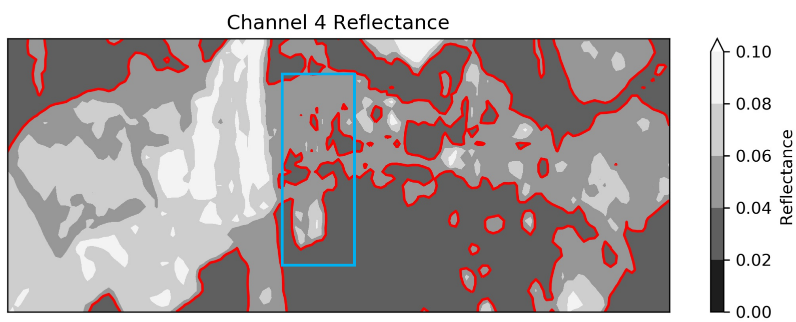
Panel 1



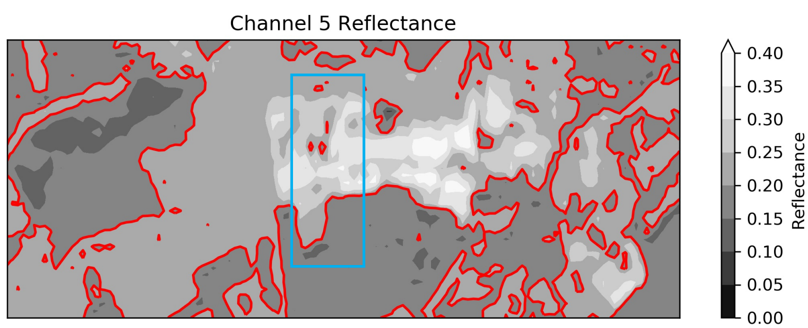
Panel 2



Panel 3



Panel 4



Name:_______________________________

a. Order the following four from highest to lowest. Explain your answer. You will receive no credit if your explanation is not provided or is incorrect (i.e. no credit for guessing).
    i. Average radiance in this scene from Landsat 8 Channel 8
    ii. Average radiance in this scene from GOES-16 Channel 2
    iii. Average radiance in this scene from Landsat 8 Channel 4
    iv. Average radiance in this scene from MODIS Channel 13

b. By drawing on **the third panel** above (but incorporating information from all four panels), circle the largest contiguous area in the outlined blue box shown on the first panel where the soybean crop was least productive.

c. Estimate the NDVI at the location from the above question. Write down and label the values of the variables you used to make these estimates. Next, estimate NDVI in a nearby area of conifers (loblolly pine). *To identify conifers, remember, surface reflectance is not the same as top of atmosphere reflectance, but it may be proportional to it!* For the conifers, indicate the point you used on the figure in a way that differentiates it from the point you drew for part B (like drawing an X or an arrow pointing to the location).

d. Landsat 8 recorded the exact same scene on 3 September 2018, or 32 days prior, at 1540 UTC.
    i. Not including 3 September or 5 October, how many times did Landsat 8 record this scene between those two dates?
    ii. What time did Landsat 8 pass over the scene on 5 October?
    iii. If the inclination of Landsat 8 is 98°, what is the northernmost latitude at which a sub-satellite point of Landsat 8 can be located?
    iv. Is the satellite moving toward the northeast or toward the southwest relative to the ground during this scene?

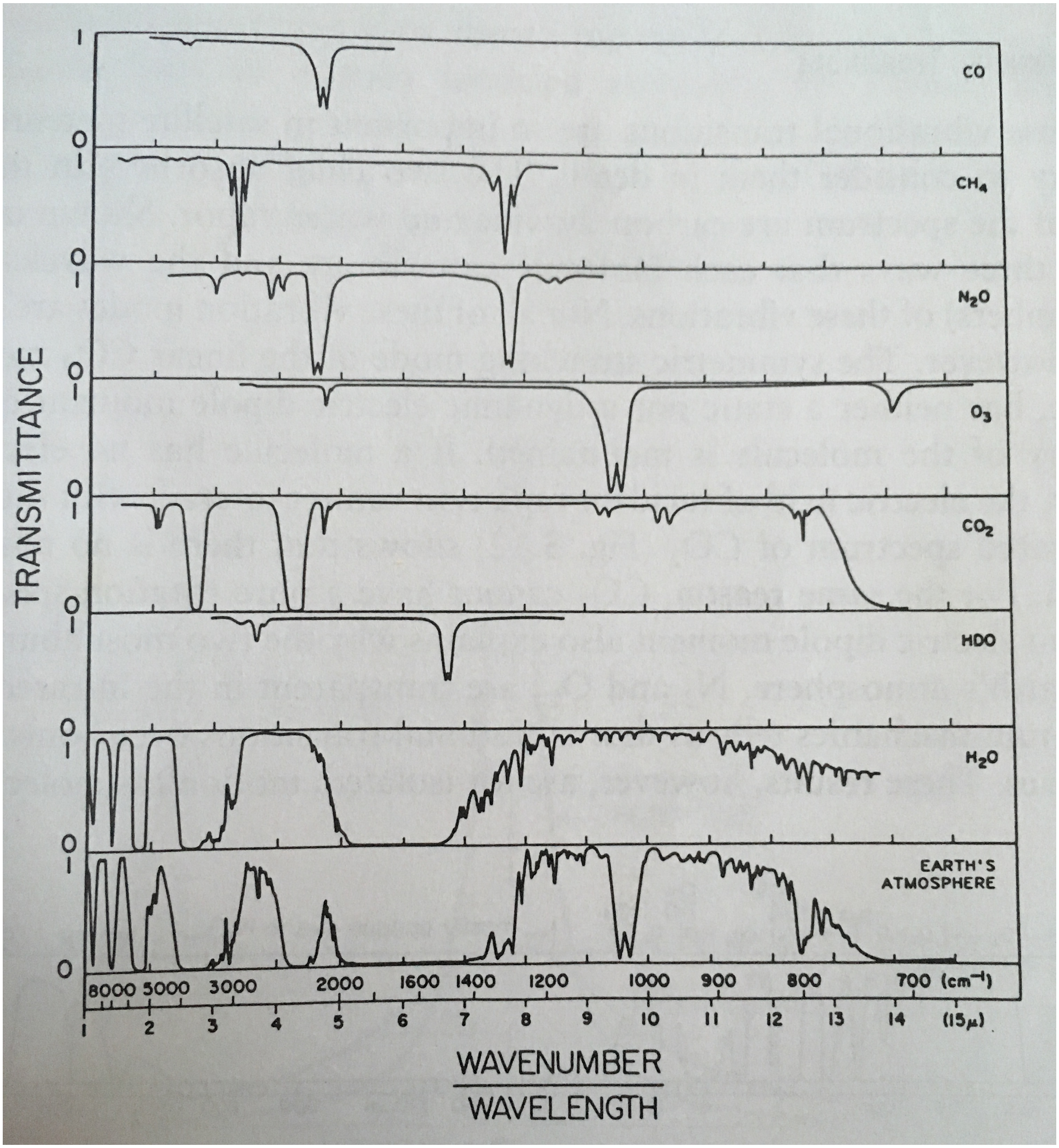
Name:______________________________

6. Suppose you were tasked with creating a new channel for GOES between 1 and 15 um that would detect changes in top-of-atmosphere radiance associated with nitrous oxide (N_2O). Assume that you know exactly what the column-integrated value of water vapor and CO is in the atmosphere everywhere. What wavelength would you choose as the center for the new band, and why would you choose it?

7. Estimate the altitude (above ground level) of geostationary orbit. Newton's gravitational constant, G, is 6.67×10^{-11} N m^2 kg^{-2}, the mass of Earth is about 5.97×10^{24} kg, and the radius of Earth is about 6370 km. State any assumptions in your calculation. Just writing down the altitude of geostationary orbit is not sufficient; you need to show how that number is obtained.

Transmittance of various atmospheric constituents with average total Earth atmospheric transmittance in last row

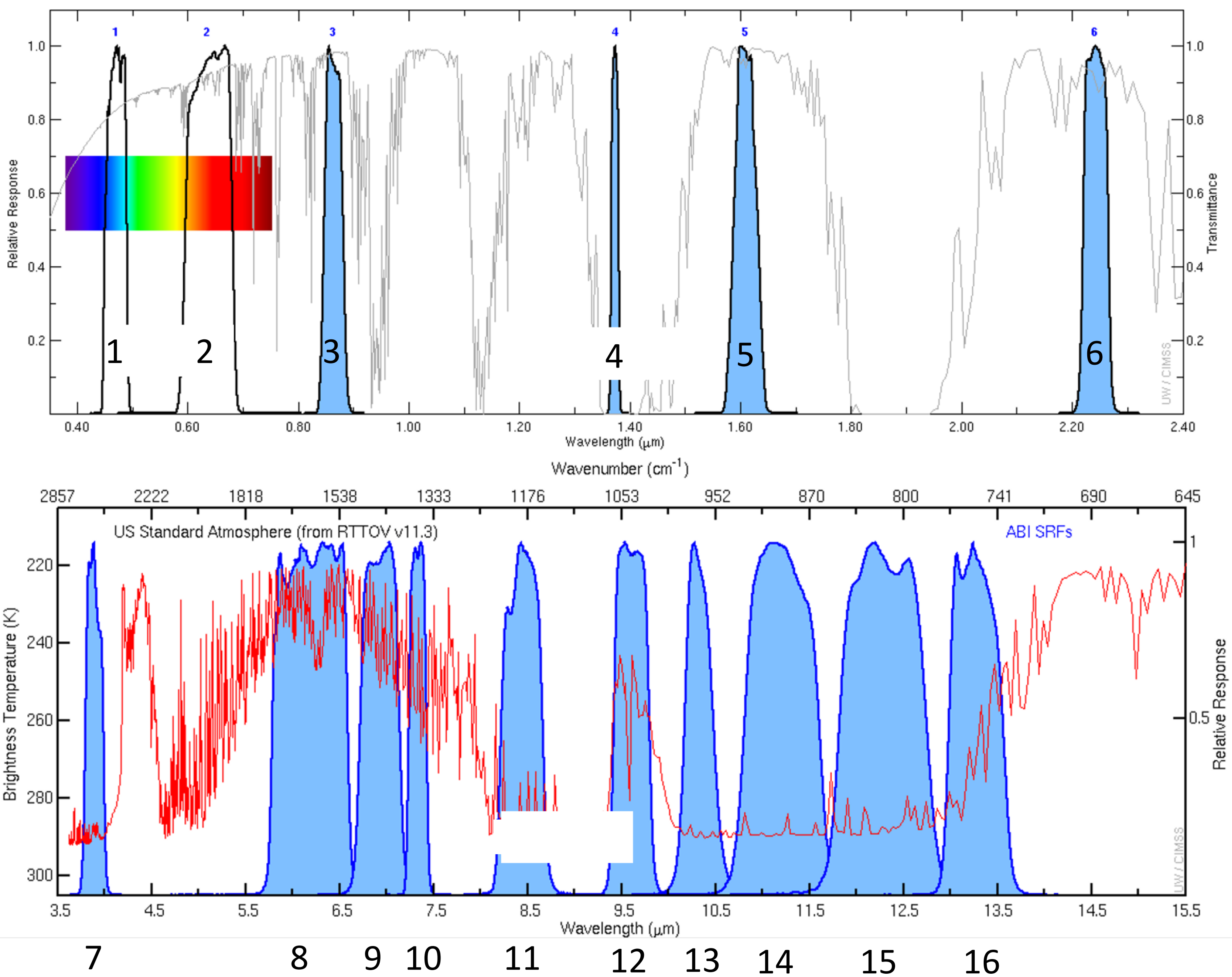
See the next page for more details about the total transmittance from 400 nm to 15 microns.



GOES ABI Spectral Response Functions

Gray line on top panel is atmospheric transmittance.
Red line on bottom panel is brightness temperature as a function of wavelength for a standard atmosphere.

Channel numbers are labeled on or under panels.



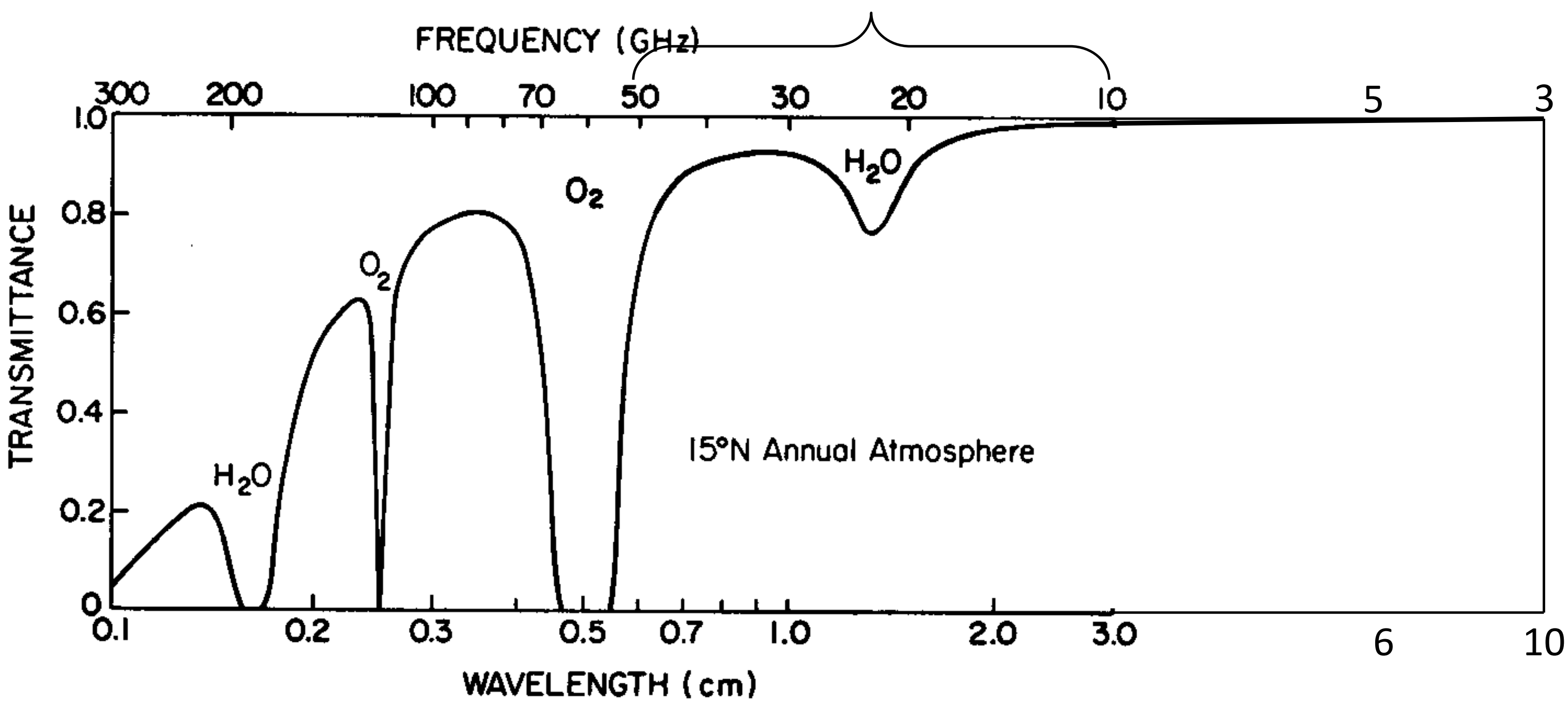

FREQUENCY (GHz)
300
200
100
70
50
30
20
10
5
3
TRANSMITTANCE
1.0
0.8
0.6
0.4
0.2
0
H2O
O2
O2
H2O
15°N Annual Atmosphere
0.1
0.2
0.3
0.5
0.7
1.0
2.0
3.0
6
10
WAVELENGTH (cm)

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)
1	0.45–0.49	0.47	1
2	0.59–0.69	0.64	0.5
3	0.846–0.885	0.865	1
4	1.371–1.386	1.378	2
5	1.58–1.64	1.61	1
6	2.225–2.275	2.25	2
7	3.80–4.00	3.90	2
8	5.77–6.6	6.19	2
9	6.75–7.15	6.95	2
10	7.24–7.44	7.34	2
11	8.3–8.7	8.5	2
12	9.42–9.8	9.61	2
13	10.1–10.6	10.35	2
14	10.8–11.6	11.2	2
15	11.8–12.8	12.3	2
16	13.0–13.6	13.3	2

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.

Bands for Moderate Resolution Imaging Spectroradiometer (MODIS) aboard Terra and Aqua satellites

Bands 8–16 are narrow bands designed for ocean color/chlorophyll detection.

Band	Bandwidth (nm)
1	620 - 670
2	841 - 876
3	459 - 479
4	545 - 565
5	1230 - 1250
6	1628 - 1652
7	2105 - 2155
8	405 - 420
9	438 - 448
10	438 - 493
11	526 - 536
12	546 - 556
13	662 - 672
14	673 - 683
15	743 - 753
16	862 - 877
17	890 - 920
18	931 - 941
19	915 - 965
Band	Bandwidth (microns)
20	3.660 - 3.840
21	3.929 - 3.989
22	3.929 - 3.989
23	4.020 - 4.080
24	4.433 - 4.498
25	4.482 - 4.549
26	1.360 - 1.390
27	6.535 - 6.895
28	7.175 - 7.475
29	8.400 - 8.700
30	9.580 - 9.880
31	10.780 - 11.280
32	11.770 - 12.270
33	13.185 - 13.485
34	13.485 - 13.785
35	13.785 - 14.085
36	14.085 - 14.385

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

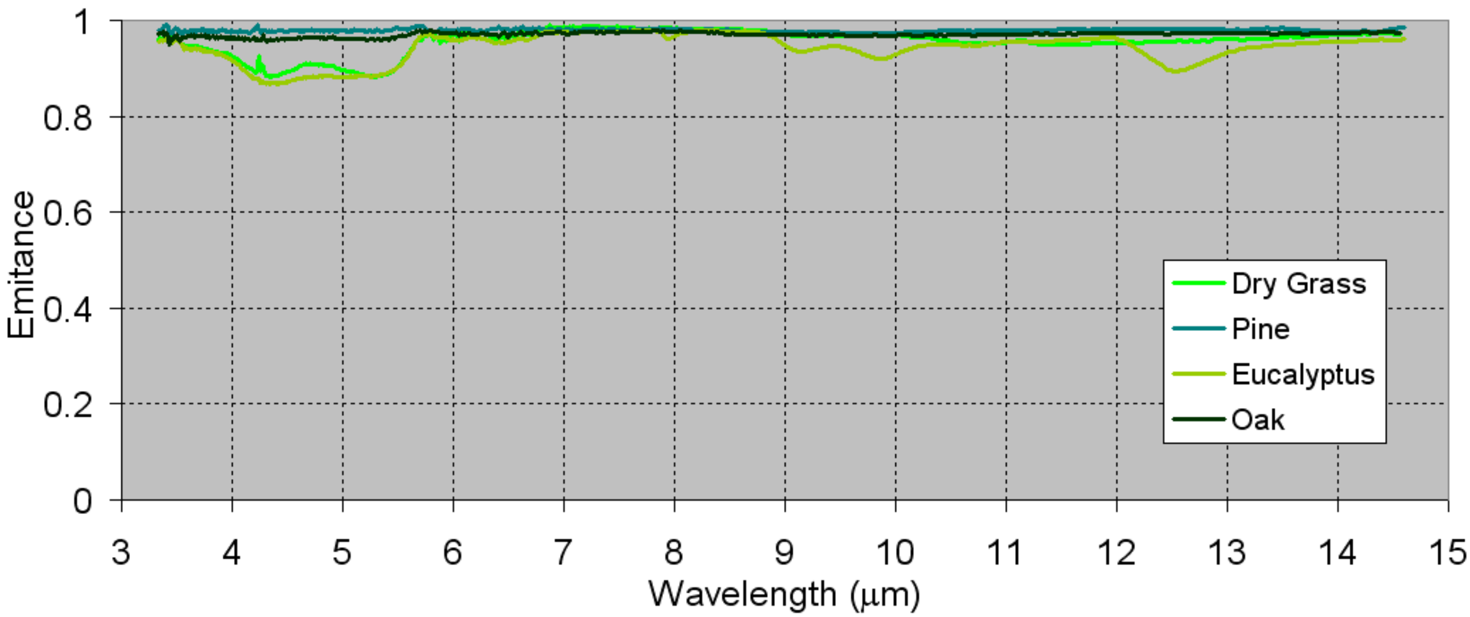
Landsat 4 and 5 bands

Landsat 4-5 Thematic Mapper (TM)

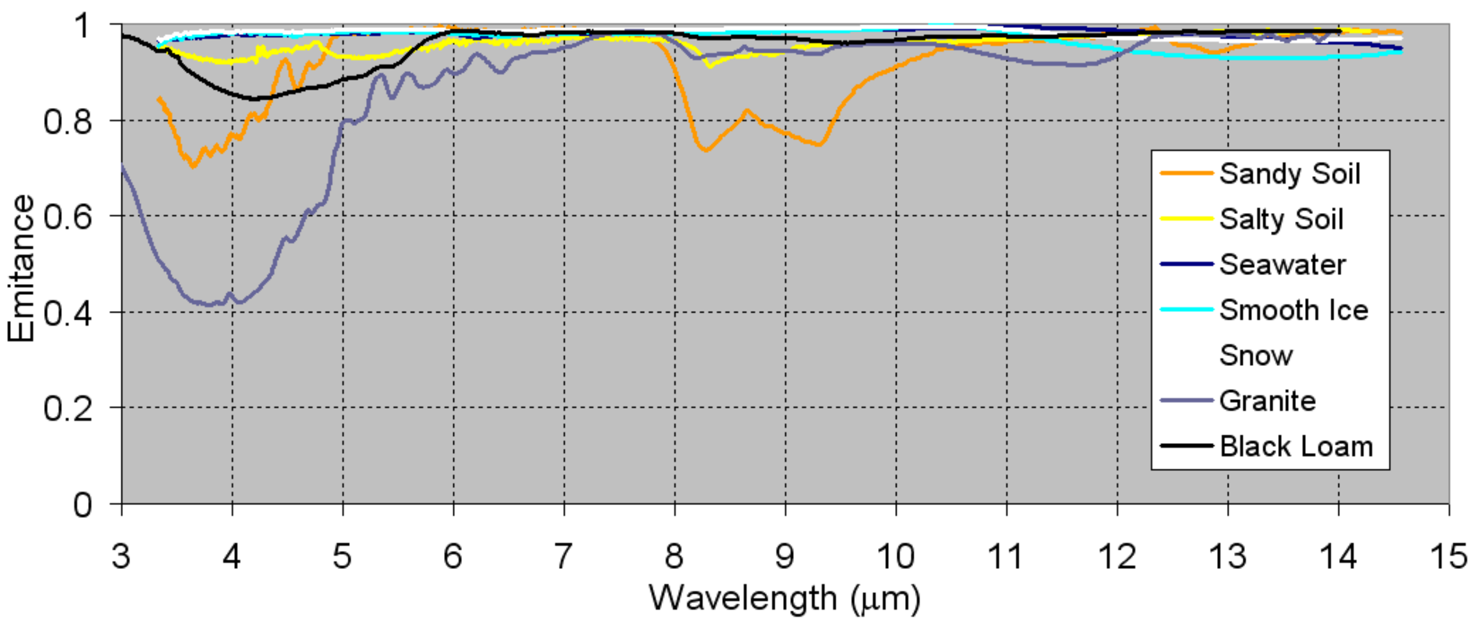
Band	Wavelength
Band 1 - blue	0.45-0.52
Band 2 - green	0.52-0.60
Band 3 - red	0.63-0.69
Band 4 - Near Infrared	0.77-0.90
Band 5 - Short-wave Infrared	1.55-1.75
Band 6 - Thermal Infrared	10.40-12.50
Band 7 - Short-wave Infrared	2.09-2.35
Band 8 - Panchormatic (Landsat 7 only)	0.52-0.90

Band	Wavelength
Band 1	0.435 - 0.451
Band 2	0.452 - 0.512
Band 3	0.533 - 0.590
Band 4	0.636 - 0.673
Band 5	0.851 - 0.879
Band 6	1.566 - 1.651
Band 7	2.107 - 2.294
Band 8	0.503 - 0.676
Band 9	1.363 - 1.384
Band 10	10.60 – 11.19
Band 11	11.50 - 12.51

Daytime descending orbit



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



1
0.8
0.6
0.4
0.2
0
Emitance
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

Equations (You should recognize what each represents)

$$B_\lambda(T) = \frac{2\hbar c^2 \lambda^{-5}}{e^{\frac{\hbar c}{\lambda k T}} - 1}$$

$$\lambda_m T = 2897.9\ \mu m\ K$$

$k = 1.38 \times 10^{-23}$ m^2 kg s^{-2} K^{-1}
$\hbar = 6.62607004 \times 10^{-34}$ m^2 kg s^{-1}
c = 2.99×10^8 m s^{-1}

$$\omega_0 \equiv \frac{\sigma_{s,\lambda}(\boldsymbol{X})}{\sigma_{e,\lambda}(\boldsymbol{X})}$$

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

Below are 3 special cases of the above generalized version of the equation

$$L_t(\lambda,\theta,\varphi) = L_0(\lambda,\theta,\varphi)e^{-\delta(\lambda)/\mu}$$

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

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

$$\begin{aligned} T_B(\nu,\theta,\varphi) = {} & \varepsilon_s(\nu,\theta,T_s,S)T_s\tau_d(\nu) + \\ & [1-\varepsilon_s(\nu,\theta,T_s,S)]T_a[1-\tau_d(\nu)]\tau_d(\nu) + \\ & T_a[1-\tau_d(\nu)] \end{aligned}$$

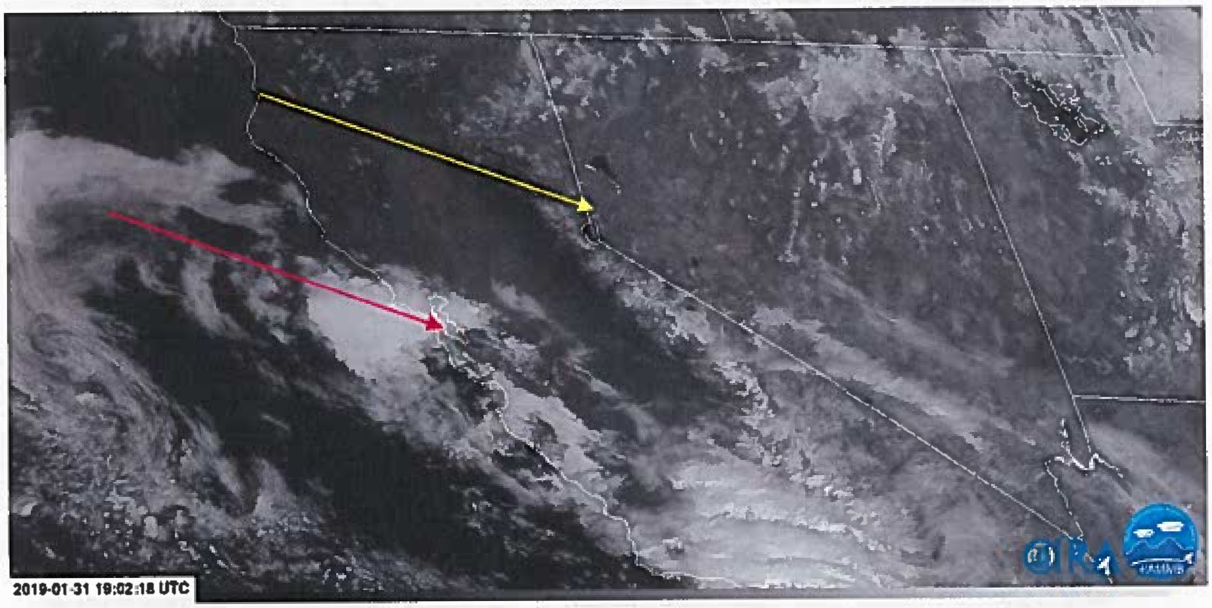
$$F_{gravity} = \frac{GM_{earth}m_{satellite}}{r^2} \qquad a_{centrifugal} = \frac{v^2}{r}$$

Name: Key

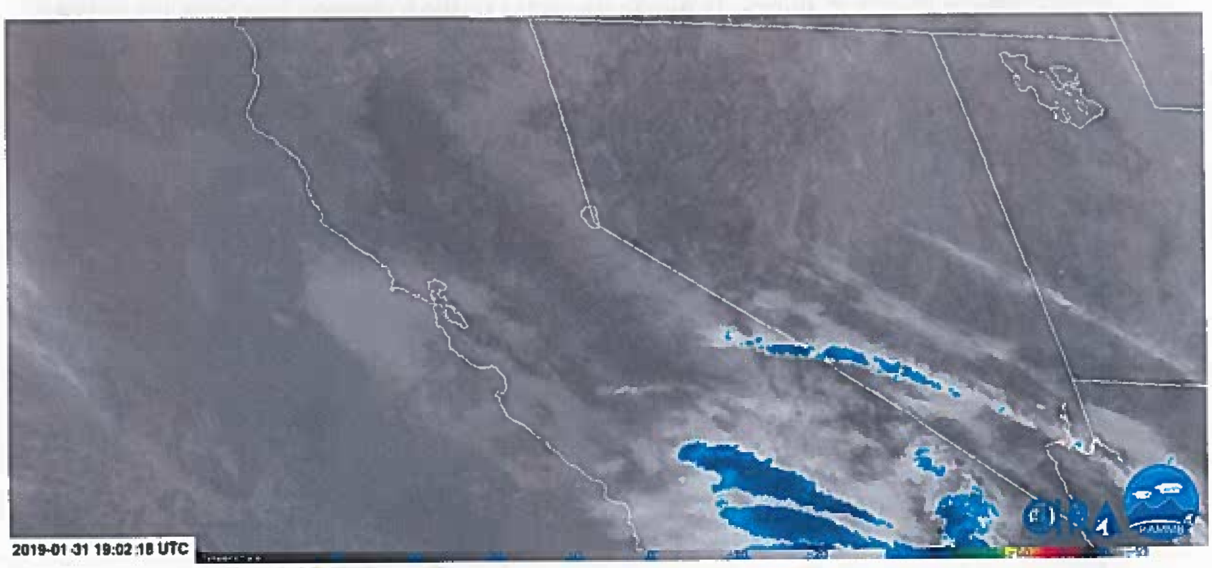
MR3522: Remote Sensing of the Atmosphere and Ocean
Midterm Exam
8 February 2019

1. For the following questions, consult the below imagery from GOES-17. The yellow arrow points close to Reno, Nevada. The red arrow points at San Francisco.

Channel 2 Brightness Value

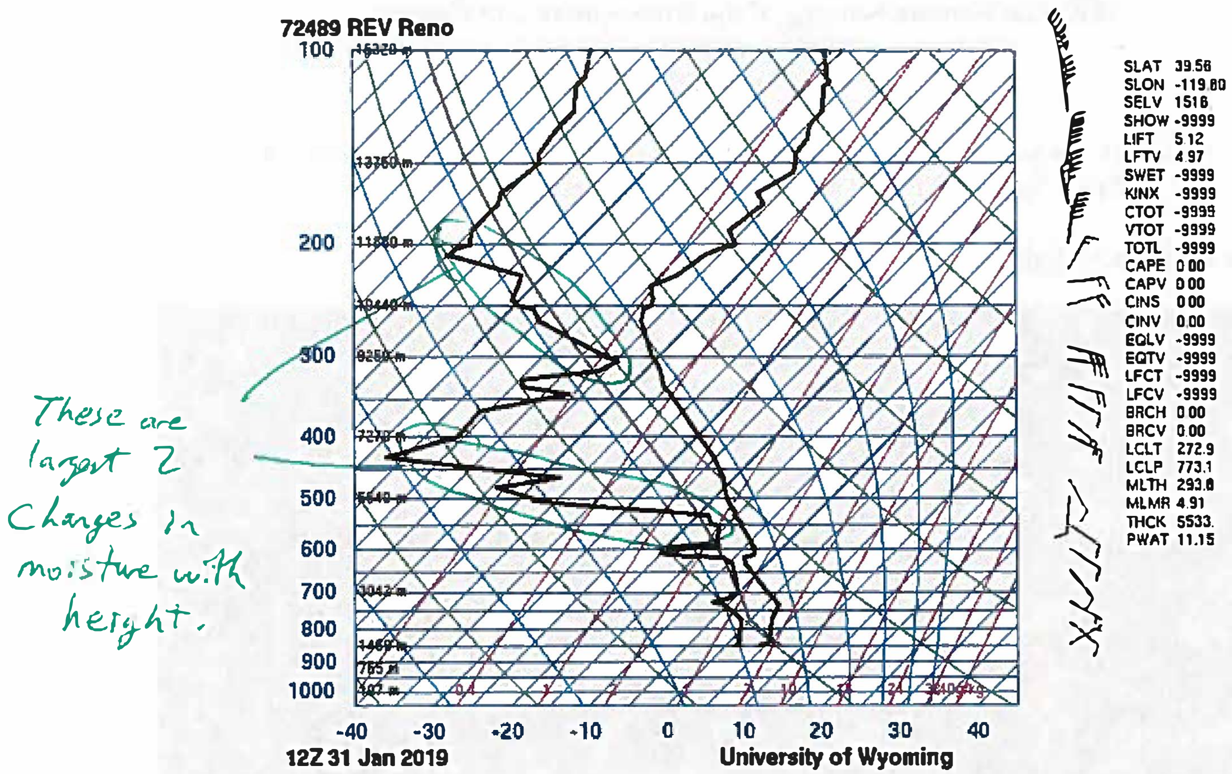


Channel 13 Brightness Temperature

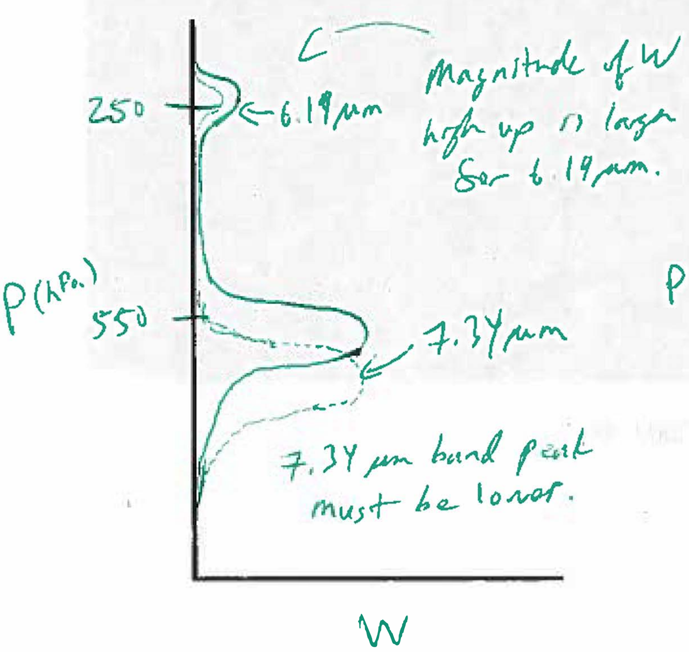


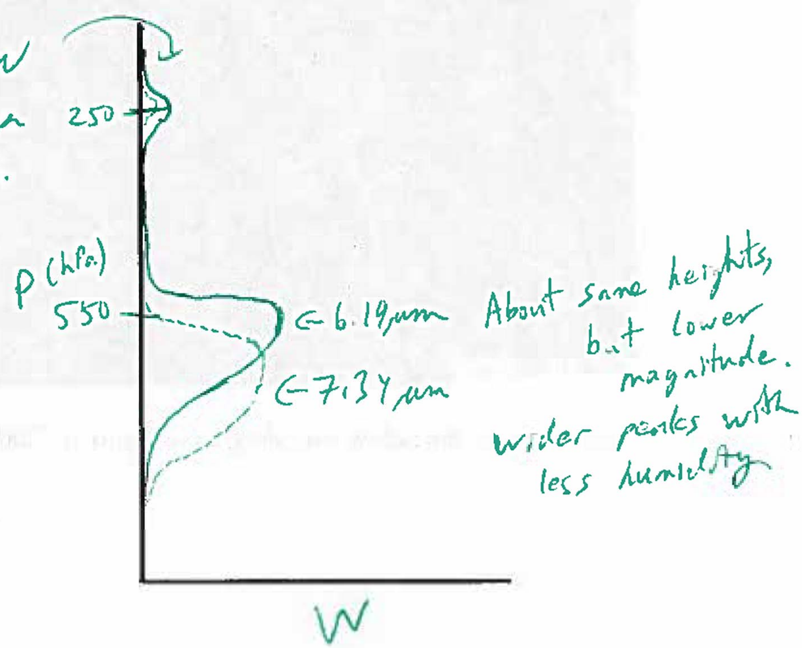
Also consider the below sounding from Reno at 1200 UTC.

Name: Key



a. *(10 points)* In the space below on the left, sketch approximate weighting functions for the 6.19 micron and 7.34 micron GOES bands at Reno. On the right, in a separate drawing, sketch the same but for an atmospheric profile in which specific humidity at every level is 50% of that indicated in the sounding. At most, only two or three peaks per function are needed; you need not represent every local maximum in the weighting functions. You will be graded primarily on two things: 1) Where the peaks of the weighting functions for the two bands are relative to each other in each plot, and 2) The relative shapes of the two weighting functions for the same band in the different plots. In the first plot, indicate for which of the two bands the atmosphere is most optically thick. Let the ordinate be height/pressure and the abscissa be the value of the weighting function.





Name: Key

b. *(5 points)* What would the weighting function look like for an atmosphere completely absent of water vapor and N_2O?

Delta function at ground because atmosphere is perfectly transparent. All emissions from ground reach satellite.

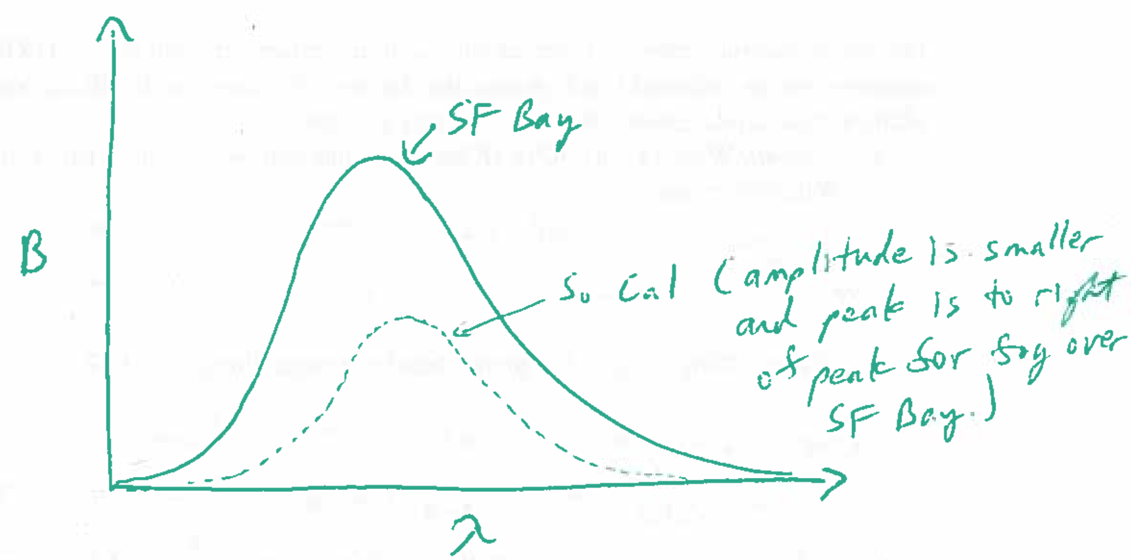
c. *(5 points)* Will the cloud near and offshore San Francisco Bay appear as reflective in GOES Channel 4 imagery? Explain your reasoning.

No. Based on warm 10 μm brightness temperature and high visible reflectance, the cloud is fog. Its emissions will be absorbed by H_2O in the ~1.35 μm band.

d. *(5 points)* Near Reno, would the 640 nm band or the 10.35 micron band have a larger single-scattering albedo? Again, explain your reasoning.

640 nm band. IR radiation is negligibly scattered by air molecules. Absorption coefficient for IR is much larger than scattering coefficient ($\sigma_a >> \sigma_s$).

e. *(5 points)* Sketch a Planck function describing emittance for the cloud offshore San Francisco Bay, assuming it emits as a blackbody. On the same plot, and using the same assumption, sketch a Planck function for the clouds denoted by the blue area (lower brightness temperature) in southern California. **Label each function and your axes. Make especially sure that the peaks of the two functions are correctly represented relative to one another.**



2. (*10 points*) Suppose that a passive remote sensing detector is located at 20 km above the ground. The volume absorption coefficient of the atmosphere beneath the sensor is described as

$$\sigma_a(z) = 0.1e^{-\frac{z}{H}}$$

where H is the scale height of the atmosphere, or 8.0 km. No scattering occurs at the wavelength detected by the sensor. Compute the direct transmissivity of the 0–20 km layer for along a vertical path.

$\tau_d = e^{-\delta/\mu}$, $\mu = \cos\theta$. In this case, $\theta = 0$ for vertical path, so $\tau_d = e^{-\delta}$.

$\delta = \int_z \sigma_e(z)dz$ and $\sigma_e = \sigma_a + \sigma_s$ (σ_s = 0 because no scattering)

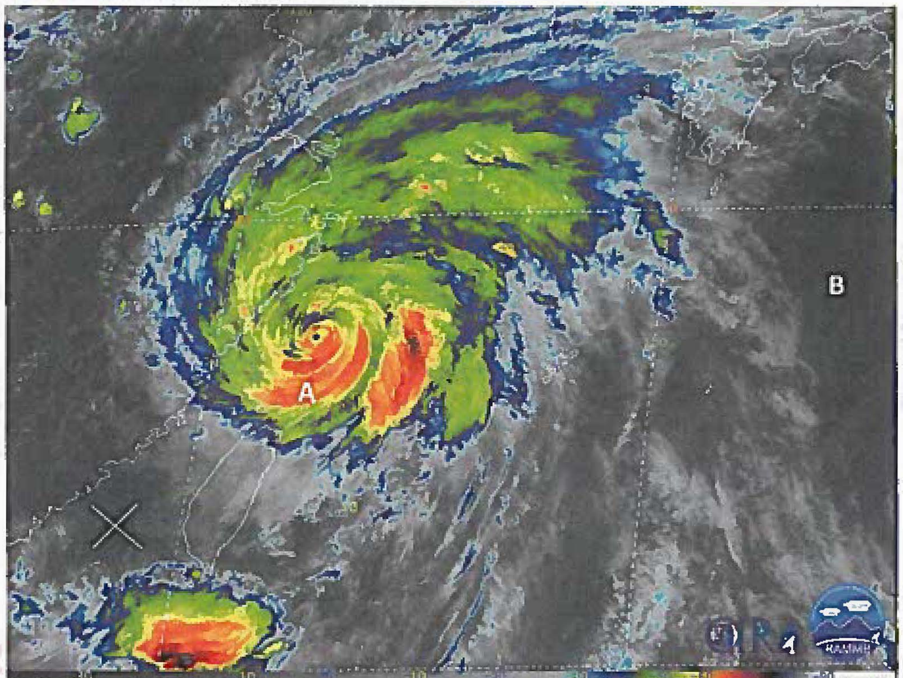
$$\delta = \int_z 0.1e^{-z/H}dz = -0.1He^{-z/H}\Big|_0^{20\,km} = -0.066 + 0.8$$

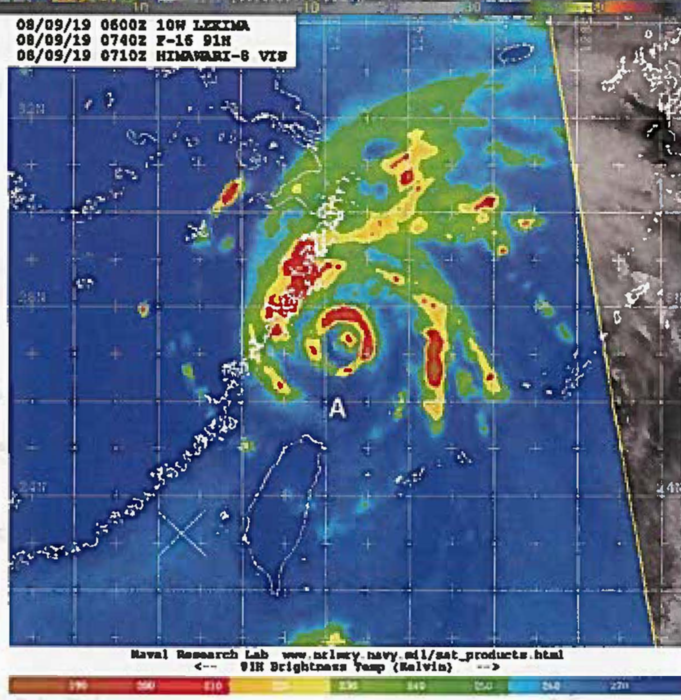
$$= 0.734$$

$$\tau_d = e^{-\delta} = e^{-0.734} = 0.48$$

Name:____________________________

3. Below are 11 μm and 91 GHz brightness temperatures of Typhoon Lekima at 0740 UTC 9 August 2019, respectively from Himawari-8 and SSMI. On the following page, answer the questions about the scene:





Name:______________________________

a. (*5 points*) Why is the brightness temperature of the cloud-free area to the west of Taiwan (white X) so different between the two bands?

11 μm mostly sees emission from the surface. 91 GHz is much for sensitive to water vapor, and sees emission from slightly above surface.

b. (*5 points*) Which sensor observed the greater scene-averaged radiance? Why?

11 μm IR band. It is closer to peak emission on Planck curve for Earth-temperature body (~300 K). Also, most emitters (cloud, ocean, land) are close to blackbodies in IR.

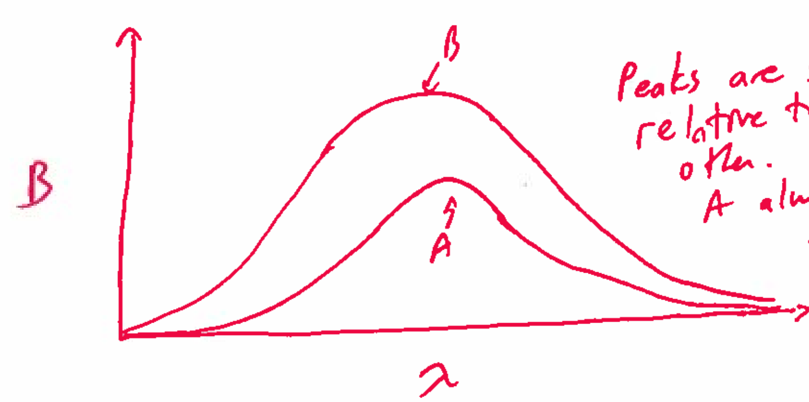
c. (*5 points*) The brightness temperature at Point A at 11 μm is about -70°C, and the brightness temperature at 91 GHz is about -10°C. Why is the IR brightness temperature colder at Point "A"? What kind of cloud is being sensed by IR at Point "A"?

The IR band detected radiation emitted from the top of a high ice cloud because all radiation emitted upward from lower altitudes was absorbed or scattered. However, MW radiation @ 91 GHz passed through the cloud and to space, so the brightness temperature corresponded w/ lower atmospheric temperature. Because 91 GHz is attenuated heavily by liquid water, we know the cloud is made of ice w/ little liquid precip beneath.

d. (*5 points*) Would the difference in brightness temperature between GOES-17 6.2 μm and 7.3 μm bands be larger at letter "A" or letter "B"? Explain your answer.

B. At A, the two brightness temperatures would be about the same — that of cloud top in the TC. At B, differences in water vapor absorption at the two bands would cause the 7.3 μm band to be warmer than 6.2 μm.

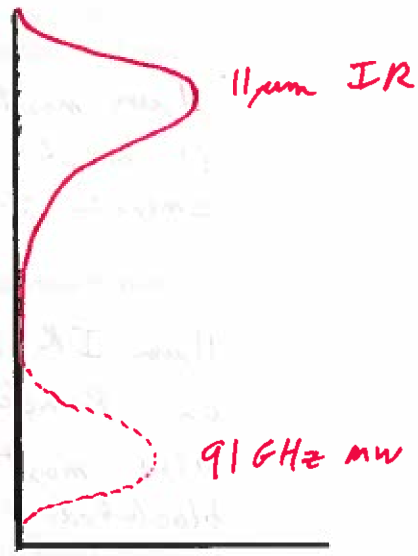
e. (*5 points*) Sketch Planck functions for emitters at responsible for the radiation received at the Himawari-8 sensor at Point "A" and "B". Make both the abscissa and ordinate linear axes (i.e. no log-log scale). Label the two functions and your axes. You need not include specific numbers on your plots. **Mostly importantly, ensure that the two functions are correctly represented relative to each other.**



Peaks are shifted relative to each other. A always lower than B.

Name:______________________________

f. (*5 points*) On the graph to the right, sketch weighting functions for the 11 µm IR and 91 GHz microwave bands at Point "A", again making sure that, most importantly, they are drawn correctly relative to each other. You need not label your axes. Assume the ordinate is height increasing upward and the abscissa is W increasing to the right.



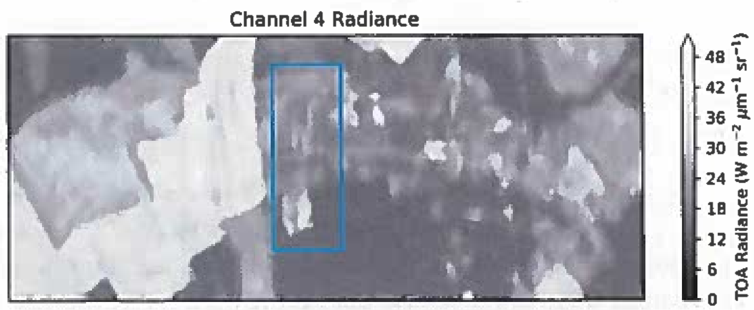
4. (*10 points*) Which MODIS band would be most effective for detecting tropopause folds (where stratospheric air is transported downward to altitudes well below the mean tropopause level)? Explain the rationale for your answer.

Band 30. It sits in an O_3 absorption band, and stratospheric air contains O_3.

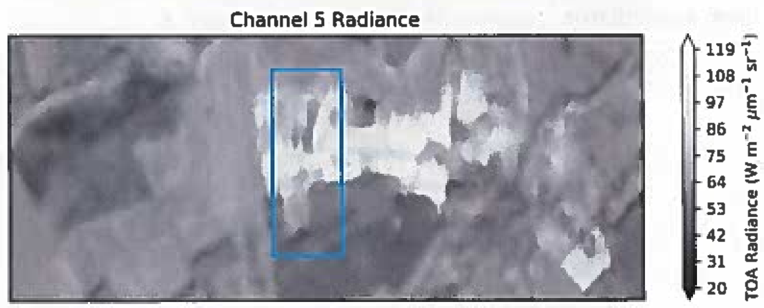
Name: Key

7. The following Landsat 8 scene is from a farm in northeastern North Carolina, about an hour away from Norfolk, VA. The date was 5 October 2018, and soybeans were growing in the field. Plotted are radiance and reflectance from Channels 4 and 5 recorded during a daytime descending node of the satellite's orbit. The red contour in the third panel outlines 0.04 reflectance, and the red contour in the fourth panel outlines 0.20 reflectance.

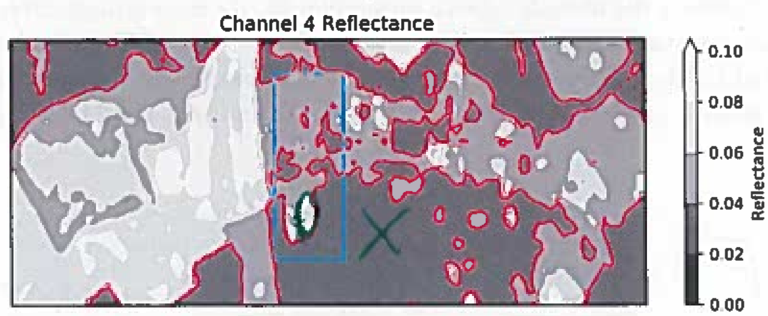
Panel 1



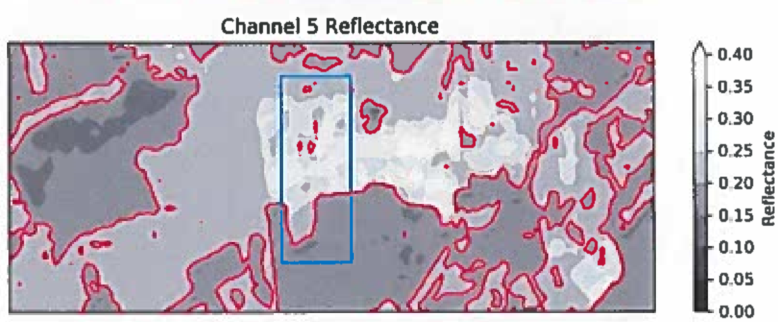
Panel 2



Panel 3



Panel 4



Name: Key

a. *(5 points)* Order the following four from highest to lowest. Explain your answer. You will receive no credit if your explanation is not provided or is incorrect (i.e. no credit for guessing).
   i. Average radiance in this scene from Landsat 8 Channel 8 503 - 676 nm
   ii. Average radiance in this scene from GOES-16 Channel 2 590 - 640 nm
   iii. Average radiance in this scene from Landsat 8 Channel 4 636 - 673 nm
   iv. Average radiance in this scene from MODIS Channel 13 662 - 672 nm

I, II, III, IV ; The bands are all in the visible part of the EM spectrum. II, III, IV are all in red part of visible spectrum. Wider bands will detect more radiation.

b. *(5 points)* By drawing on **the third panel** above (but incorporating information from all four panels), circle the largest contiguous area in the outlined blue box shown on the first panel where the soybean crop was least productive.

c. *(5 points)* Estimate the NDVI at the location from the above question. Write down and label the values of the variables you used to make these estimates. Next, estimate NDVI in a nearby area of conifers (loblolly pine). *To identify conifers, remember, surface reflectance is not the same as top of atmosphere reflectance, but it may be proportional to it!* For the conifers, indicate the point you used on the figure in a way that differentiates it from the point you drew for part B (like drawing an X or an arrow pointing to the location).

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

↑ ↑ reflectances

Unproductive soybeans

$$NDVI = \frac{0.2 - 0.08}{0.2 + 0.08} \approx 0.42$$

Conifers

$$NDVI = \frac{0.15 - 0.02}{0.15 + 0.02} \approx 0.76$$

d. *(10 points)* Landsat 8 recorded the exact same scene on 3 September 2018, or 32 days prior, at 1540 UTC.
   i. Not including 3 September or 5 October, how many times did Landsat 8 record this scene between those two dates? 1
   ii. What time did Landsat 8 pass over the scene on 5 October? 1540 UTC
   iii. If the inclination of Landsat 8 is 98°, what is the northernmost latitude at which a sub-satellite point of Landsat 8 can be located? 82° N
   iv. Is the satellite moving toward the northeast or toward the southwest relative to the ground during this scene? toward southwest

7. (*10 points*) Suppose you were tasked with creating a new channel for GOES between 1 and 15 um that would detect changes in top-of-atmosphere radiance associated with nitrous oxide (N_2O). Assume that you know exactly what the column-integrated value of water vapor and CO is in the atmosphere everywhere. What wavelength would you choose as the center for the new band, and why would you choose it?

Around 4.6μm. There are two potential options: 4.6μm and 7.8μm. However, the 7.8μm band overlaps with an absorption band of CH_4, of which we do not separately know the concentration. The 4.6μm band overlaps with CO and H_2O, and possibly with CO_2, all of which, in this idealized situation, are known. (CO_2 is well-mixed like O_2 and N_2, but this doesn't really matter since ~4.6μm is out of the CO_2 absorption band.)

6. *(10 points)* Estimate the altitude (above ground level) of geostationary orbit. Newton's gravitational constant, G, is 6.67 x 10^{-11} N m^2 kg^{-2}, the mass of Earth is about 5.97 x 10^{24} kg, and the radius of Earth is about 6370 km. State any assumptions in your calculation. Just writing down the altitude of geostationary orbit is not sufficient; you need to show how that number is obtained.

$$F = \frac{GMm}{r^2} = m\frac{\quad}{r}$$

$$v = \frac{2\pi r}{T}$$

Assume $T = 24 hr.$ $= 86400 s$

$$\frac{GM}{r} = v^2$$

$$\frac{GM}{r} = \frac{4\pi^2 r^2}{T^2}$$

And $r = \sqrt[3]{\frac{GMT^2}{4\pi^2}}$ plug in values. $\Rightarrow$ $r \approx 42227 km$

Altitude $= r - 6370 km = \boxed{35857 km}$