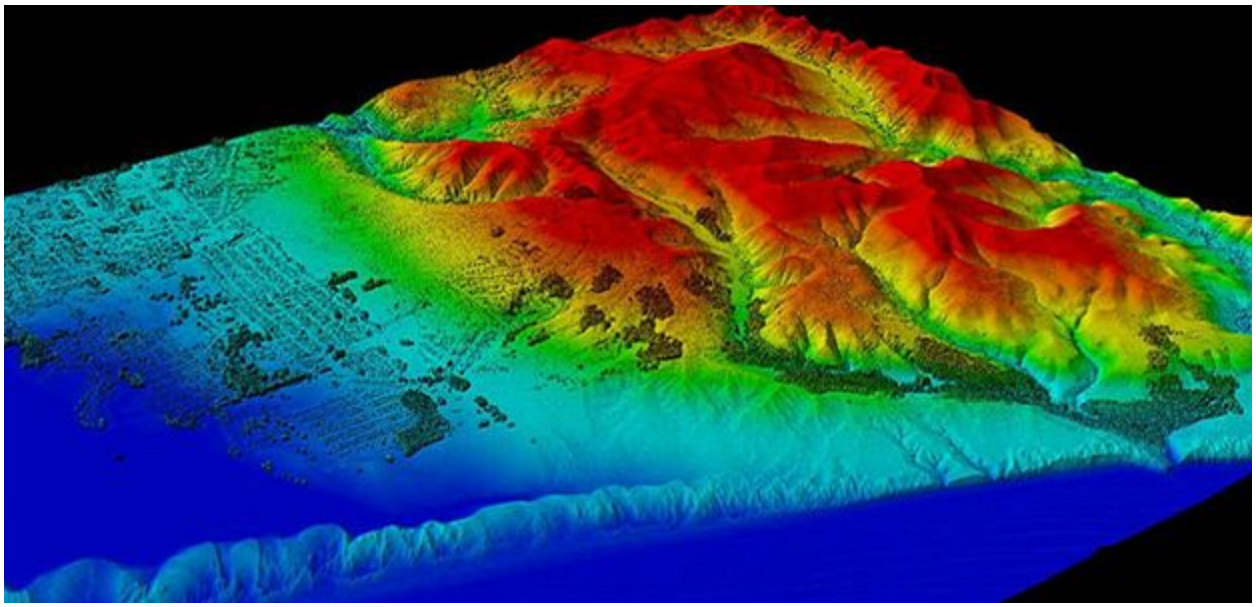
Science Olympiad at Princeton University

Princeton Science Olympiad Invitational
Remote Sensing Exam



Team Name:_____

Team Number:_____ **Raw Score:**_____

Tiebreaker: 1 / 2 / 3 **Place:**_____

Directions: You have 50 minutes to complete this exam. You may have with you a scientific calculator, a single notesheet, and pencils. Point values for each question will be indicated. You may split the test but be sure to turn in all portions to the test proctor after the exam is finished.

Part 1: Multiple Choice (One Point Each)

1. Rank these materials from smallest to highest albedo.

   I. Snow
   II. Asphalt
   III. Bare Soil
   IV. Green Grass

   a. I. II. III. IV.
   b. I. III. IV. II.
   c. I. IV. III. II.
   d. II. III. IV. I.
   e. II. IV. III. I.

2. Letôs say youôre taking an image of an area to gather data on the temperature of a forest fire in that area. What resolution do you **necessarily** need in your scanner?

   a. Spectral
   b. Spatial
   c. Radiometric
   d. Temporal
   e. Two of the Above

3. What is Spectral Radiant Emittance?

   a. Amount of incident energy on a surface per unit area and per unit time
   b. Power emitted per area per wavelength
   c. Amount of energy being emitted or reflected on a particular area per unit solid angle per unit time
   d. Power emitted per area
   e. None of the Above

4. What is the relationship between along track and across track scanners?

   a. Along track has more moving parts and is more expensive than across track
   b. Along track has less moving parts and is more expensive than across track
   c. Along track has less moving parts and is less expensive than across track
   d. Along track has more moving parts and is less expensive than across track
   e. None of the Above

5. What is the LandSat 7 band combination (3, 2, 1) typically used for?

   a. Traditional false color images
   b. Discerning between snow and ice coverage
   c. Detecting healthy vegetation
   d. Remote sensing urban settings
   e. None of the above

6. How do smooth surfaces appear in a remote sensing image compared to rough surfaces?
    a. Smooth surfaces have better spatial resolution
    b. Smooth surfaces are darker in color due to diffuse reflection
    c. Smooth surfaces are darker in color due to specular reflection
    d. Smooth surfaces have less noise
    e. Two of the Above
7. An instrument on AURA is the Microwave Limb Sounder. What and how does it function?
    a. It is a passive sensor and takes ozone, water vapor, and greenhouse gas readings at the upper troposphere
    b. It is an active sensor and takes carbon dioxide, and aerosol readings at the upper troposphere
    c. It is a passive sensor and takes ozone, water vapor, and greenhouse gas readings at the top of the atmosphere
    d. It is an passive sensor and takes carbon dioxide, and aerosol readings at the upper troposphere
    e. Two of the Above
8. What accounts for fluctuation(s) is Keeling Curve?
    a. Uptake of CO_2 by autotroph photosynthesis
    b. Escape of CO_2 from carbonate sediments
    c. Release of CO_2 from the decomposition of leaves
    d. Two of the Above
    e. All of the Above
9. Which statement is inconsistent with passive sensing scanning systems?
    a. Passive sensing systems require an external radiation source
    b. Passive sensing involves pushbroom scanning
    c. SAR is not a type of passive sensing
    d. All of the Above
    e. None of the Above
10. What are the advantages of lidar over radar?
    a. Lidar provide images with less noise
    b. Lidar are passively sensed
    c. Lidar are less expensive instruments
    d. All of the Above
    e. None of the Above
11. Which of these statements about ozone is false?
    a. Stratospheric ozone is a greenhouse gas
    b. The ozone layer is necessary for shielding the Earth from harmful UV rays
    c. CFCs are found to react with ozone and are attributed to the hole in the ozone layer
    d. Ozone has a relatively long lifetime in the troposphere
    e. All of the Above are True

12. What orbital path do satellites on the A Train follow?
    a. It is geosynchronous and crosses the equator at 11:30 pm solar time
    b. It is sun synchronous and crosses the equator at 1:30 pm solar time
    c. It is geosynchronous and crosses the equator at 1:30 solar time
    d. It is sun synchronous and crosses the equator at 11:30 pm solar time
    e. None of the Above
13. What is the purpose of a low earth orbit?
    a. GPS satellites
    b. Communication satellites
    c. Human Spaceflight
    d. Two of the Above
    e. All of the Above
14. Which of these is a disadvantage of remote sensing as a tool?
    a. Difficulties with image interpretation
    b. Coarse Resolution
    c. Uncertainty and distortion with measurements
    d. Two of the Above
    e. All of the Above
15. Which of these satellites would most likely be in a geostationary orbit?
    a. Hubble Space Telescope
    b. GOES
    c. OCO-2
    d. LandSat
    e. None of the Above
16. What do instruments do Terra and Aqua have in common?
    a. AMSR-E
    b. CERES
    c. MODIS
    d. MISR
    e. ETM+
    f. Two of the Above
17. Why is OCO not a part of A-Train?
    a. The project was scrapped due to lack of funding
    b. The satellite was disabled in orbit due to equipment malfunction
    c. The satellite was destroyed due to launch vehicle failure
    d. The project was renamed OCO-2, hence they are the same
    e. None of the above
18. What phenomenon can be attributed to Rayleigh scattering?
    a. The oceans are blue
    b. The sky is blue
    c. Plants are green
    d. Two of the above
    e. All of the above

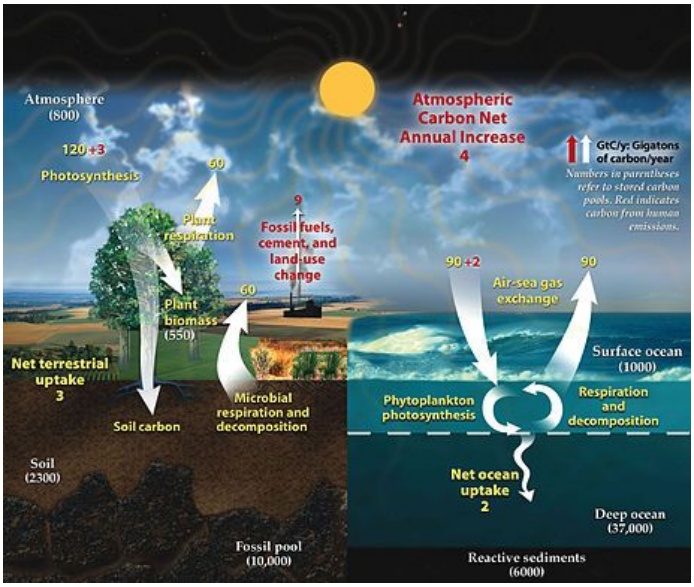
19. Which of the following would most likely cause nonselective scattering with visible light?
    a. Cloud cover
    b. VOCs
    c. Carbon dioxide
    d. CFCs
    e. None of the Above
20. Which of the following is not a greenhouse gas?
    a. Water Vapor
    b. Tropospheric Ozone
    c. Carbon Dioxide
    d. Two of the Above
    e. None of the Above
21. What are the differences between a spectrometer and a radiometer?
    a. A spectrometer are standalone systems that are highly accurate in analyzing multiple spectral ranges
    b. A radiometer are much more simple and only measures a specific wavelength range
    c. A spectrometer are not standalone and require a set of optics to correctly work
    d. Two of the Above
    e. None of the Above
22. Which of the following is a short lived greenhouse gas (< 5 years) relative to the other three?
    a. CO
    b. SF_6
    c. N_2O
    d. CH_4
    e. None of the Above

Part 2: Short Answer and Calculations (Point values will be specified) <u>Please show all work to earn full credit!</u>

1. The carbon cycle is key to climate change processes. **(Tiebreaker 1)**

   a. Sketch the carbon cycle. The following are key words you must include: Photosynthesis, Decay, Respiration, Sedimentation, Fossilization, Combustion, Weathering. Note not all of the processes in the carbon cycle are covered by the keywords above, make sure you include all relevant parts of the cycle! (6 Points)

   A diagram that encompasses the seven keywords above (0.5 points each) with arrows in the correct direction. Also includes ocean and bicarbonate/carbonate cycling (2.5 points)



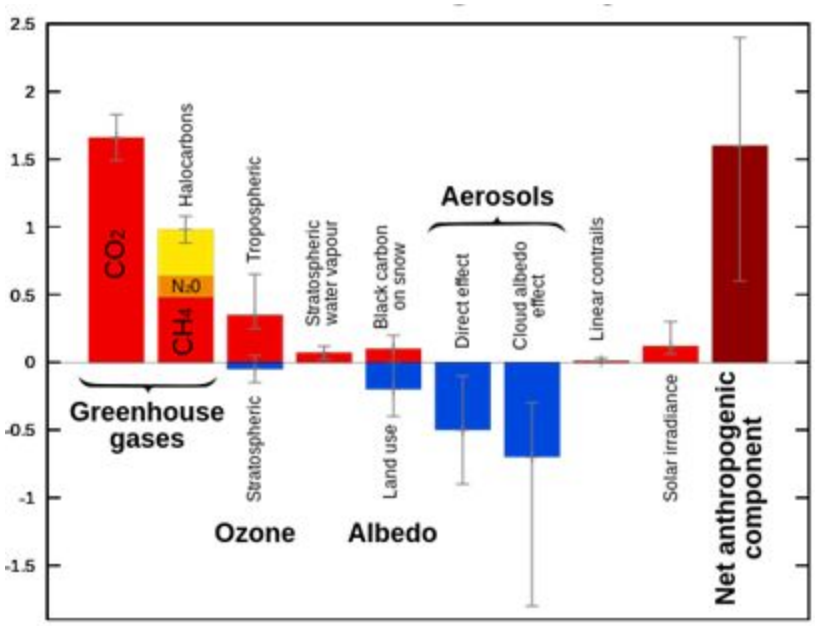
   b. Explain how rise in atmospheric carbon dioxide gases influences the balance of bicarbonate and carbon dioxide in the ocean. Explain what this means for the pH of the ocean. What would theoretically to the pH and balance of bicarbonate and carbon dioxide due to rising temperatures? (3 Points)

   Rise in atmospheric carbon dioxide gases increases the amount of dissolved carbon dioxide in the ocean (1 Point). This decreases the pH/makes the ocean more acidic (1 Point). Theoretically, less carbon dioxide would be soluble due to rising temperatures. This would result in a higher pH/more basic ocean (1 Point)

   c. Write out the chemical equations for the reactions for photosynthesis and the dissolving of carbonate rock. (2 Points)

   $CaCO_3 + CO_2 + H_2O \rightarrow Ca(HCO_3)_2$
   $6CO_2 + 6H_2O$ ------> $C_6H_{12}O_6 + 6O_2$
   (0.5 Points for correct chemicals in each equation, 0.5 Points for correct balancing)

2. Analyze the following diagram



a. The following measures a value called óRFô. What does RF stand for? (1 point)
Radiative Forcing
b. Given the name of óRFô, what are some plausible units for this value? (1 point)
W/(m^2) - if it's power over an area in any units (1 Point)

3. The speed of light in an unknown medium is measured to be 2.76 x 10^8 m/s.

a. What is the index of refraction of the medium? (2 Points)
Statement of formula n = c/v (0.5 Points)
Correct values placed into the equation n = (3.00 x 10^8 m/s)/(2.76 x 10^8 m/s)
Correct answer n = 1.087
b. A beam of light traveling through the medium makes contact with the air. What is the angle it needs to hit the air for there to be total internal refraction? (2 Points)
Statement of Snell's Law $n_1\sin\theta_1 = n_2\sin\theta_2$ (0.5 Points)
Rearrangement and substitution of $n_1 = 1$ for air and $\theta_1 = 90$ (0.5 Points)
Substitution of $n_2 = 1.087$ (0.5 Points) (If this is incorrect from the previous question, do not give them the points)
Solving for $\theta_2 = 66.92$ degrees (0.5 Points)

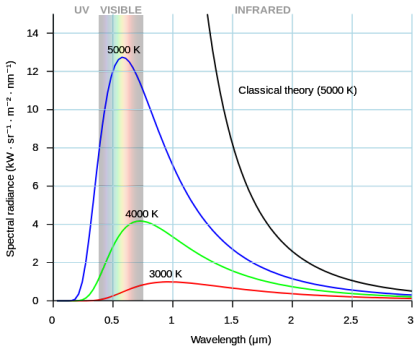
4. Using classical mechanics, scientists in the late 19th and early 20th century were unable to explain the blackbody phenomenon.

a. What quantum mechanics principle did Max Planck employ to finally solve the Blackbody Phenomenon with Planckôs Law? (1 Point)

The quantization of light waves into discrete ‘quanta’ (photons).

b. What happens to the wavelength of maximum intensity of the blackbody as temperature increases. What happens to the maximum intensity itself? Draw a graph to show your answer (4 Points)

As the temperature increases, the wavelength of maximum intensity of the blackbody decreases. Show this with the fact that Wein’s Displacement Law has maximum wavelength inversely proportional to temperature (1 Point) Maximum intensity itself increases, as shown by Stefan-Boltzmann’s Law (1 Point)



The test taker needs to show the progression from a lower temperature (ex. 3000 K) to a higher temperature (4000 K), shifts the curve to the left and increases the maximum of the curve (1 Point) The graph needs to have wavelength on the x axis, and intensity on the y axis while disregarding units (1 Point)

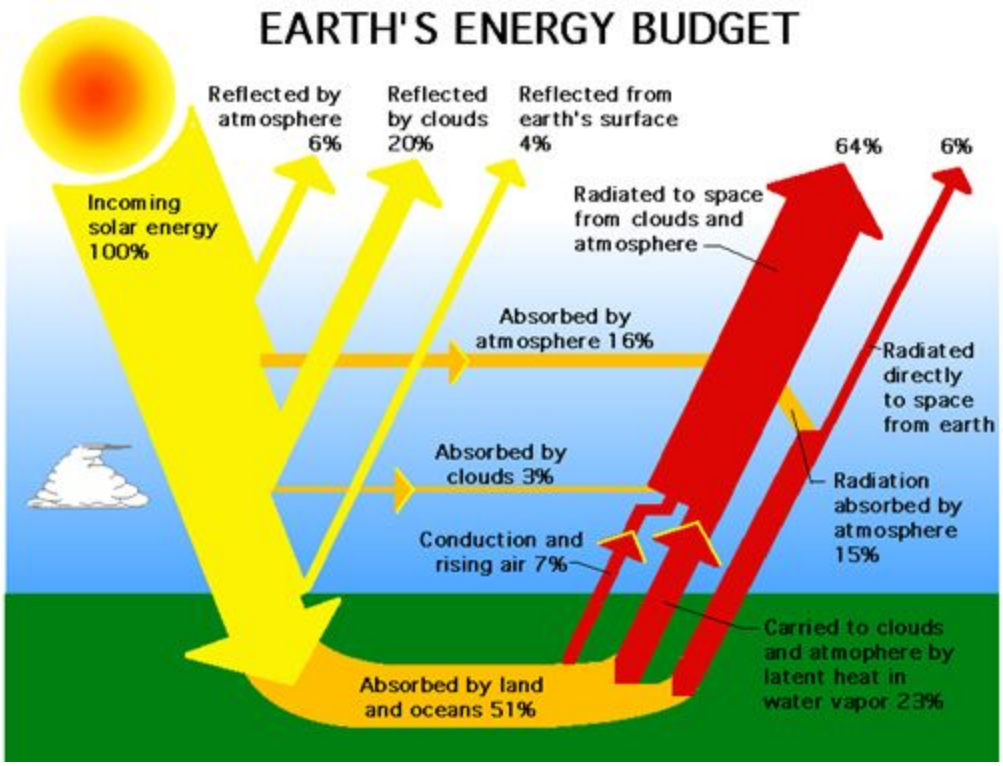
c. A particular blackbody has a temperature of 5760 K. What is the wavelength at which the blackbody emits at maximum intensity? (2 Points)

State Wien’s Displacement Law $_{max}$ = (constant)/Temperature (0.5 Points)

Substitute Constant and temperature $_{max}$ = $(2.90\times10^{-3}\ m\cdot K)/(5760\ K)$ (0.5 Points)

Correct Answer $_{max}$ = 503.47 nm (1 Point)

5. Analyze the following diagram **(Tiebreaker 3)**



a. Given the following diagram and the temperature and radius of the Sun (5777 K, 695700 km) and the distance from the Earth to the Sun is 149,600,000 km, and the radius of the Earth is 6,371 km, calculate the amount of energy absorbed by the land and oceans in watts. Assume albedo a is zero. (4 Points)
Statement of Stefan-Boltzmann's Law $L = 4\pi R^2\sigma T^4$ (1 Point)
Substitution of $\sigma = 5.67 \times 10^{-8}$ Wm^2/K^4, R = 696700000 m, and T = 5777 K into the above equation and solving to get 3.84×10^{26} W. (1 Point).
Assuming the albedo is a, the incident energy from the Sun to the Earth is $P_{in} = (L_o(1 - A)(\pi R_E^2)/(4\pi d^2)$. Plugging in the values we get $P_{in} = 8.88 \times 10^{22}$ W. (1 Point).
Multiplying by 0.51, we get 4.53×10^{22} W.

b. Name two types of EM radiation that are most likely reflected and not absorbed by the Earth. (2 Points)
Any two of the following - UV, X-ray, Infrared, or Microwave (2 Points for two of the above).
c. Derive a formula for the effective temperature of the Earth. Be sure to list all steps and explain the motivation for each step. Assume the Earth has an albedo a, radius R_E, that the Sun has a luminosity L_o and a distance from the Earth of d.(6 Points)
$P_{out} = 4\pi R_E^2\sigma T^4$ (1 point) (The 'luminosity' of the Earth give by Stefan Boltzmann Law)

$P_{in} = (L_o(1 - A)(\pi R_E^2)/(4\pi d^2)$ (2 Points) (The amount of energy absorbed from the Sun by the Earth) (Note the use of albedo to show the amount of energy absorbed by the the fraction of the Earth facing the Sun with area/volume fraction)

Set $P_{out} = P_{in}$ and solve for the temperature and solve. (1 Point)

$T = ((L_o(1 - A))/(16\sigma\pi d^2))^{1/4}$ (2 Points for correct arithmetic to get into this page.)

d. What is the difference between the effective temperature formula calculated above and the surface temperature? That is, what assumptions did you make for the effective temperature formula and how does this affect the temperature calculated compared to the surface temperature? (3 Points)

With effective temperature, we assume Greenhouse effect is negligible (1 Point). The Earth's net emissivity is the same as that it absorbs from the Sun (1 Point). Not all the incident energy on the Earth is absorbed by surface - some of it is reflected. (1 Point).

e. Using the formula obtained in c. calculate the effective temperature of the Earth. Assume albedo a = 0 (1 Point)

$T = ((L_o(1 - A))/(16\sigma\pi d^2))^{1/4}$ (Statement of the equation (0.5 Points), if the equation is incorrect, not points for the subsequent calculations).

Substitution of values into the equation $T = (L_o/(16\sigma\pi d^2))^{1/4}$ we get T = 255 K (0.5 Point).

6. If the frequency of a light wave is 625 MHz

a. What is the energy of the photon in J? (2 Points)

State equation E = hv (0.5 Points)

Substitute values $E = (6.626 \times 10^{-34}$ Js)$(625 \times 10^6$ Hz) (0.5 Points)

Solve for $E = 4.141 \times 10^{-25}$ J (1 Point)

b. What is the wavelength of the light wave in m? (2 Points)

Dimensional analysis - multiply 625 MHz by 10^6 Hz to get 625×10^6 Hz (1 Point)

$= c/v = (3.00 \times 10^6$ m/s)$/(625 \times 10^6$ Hz) = 0.48 m (1 Point)

c. What color is the light wave? (1 point)

Not visible light, no color

7a. What type of infrared wavelengths do plant leaves reflect diffusely? (1 Point)

Near Infrared and Shortwave Infrared Wavelengths (0.5 Points Each)

b. What is responsible for this reflection? (1 Point)

Mesophyll or Chloroplasts (Cell Structure) (0.5 Points)

Free Water (0.5 Points)

8. List the four satellites that are part of the Earth Observing System but not a part of A-Train that are still active (4 Points). Afterwards, explain the purpose of each of the satellites you listed and name one instrument onboard (4 Points). **(Tiebreaker 2)**

Any four of the following (SMAP, LandSat 8, SORCE, Terra, GRACE, LandSat 7, NMP/EO-1) (1 Point Each)

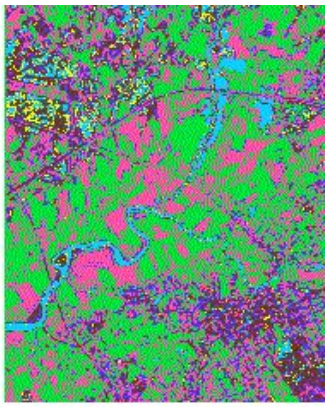
(2 Points Each)
SMAP - Measure surface soil moisture and freeze-thaw state
LandSat 8 - Supply the world with global land surface images
SORCE - Improve our understanding of the Sun
Terra - Provide global data on the state of the atmosphere, land, and oceans
GRACE - Measure Earth's mean and time-variable gravity field
LandSat7 - Supply the world with global land surface images
NMP/EO-1 - Demonstrate new technologies and strategies for improved Earth observations

9. The images below show image enhancements done to an original image (1). Describe what has been done with each modification and what the proper name of each modification are. (6 Points)

1

2

3



4

5

Image 2 is a contrast stretch enhancement (0.5 points). It involves expanding the range of brightness values so that dark areas are darker and bright areas are brighter (1 point).

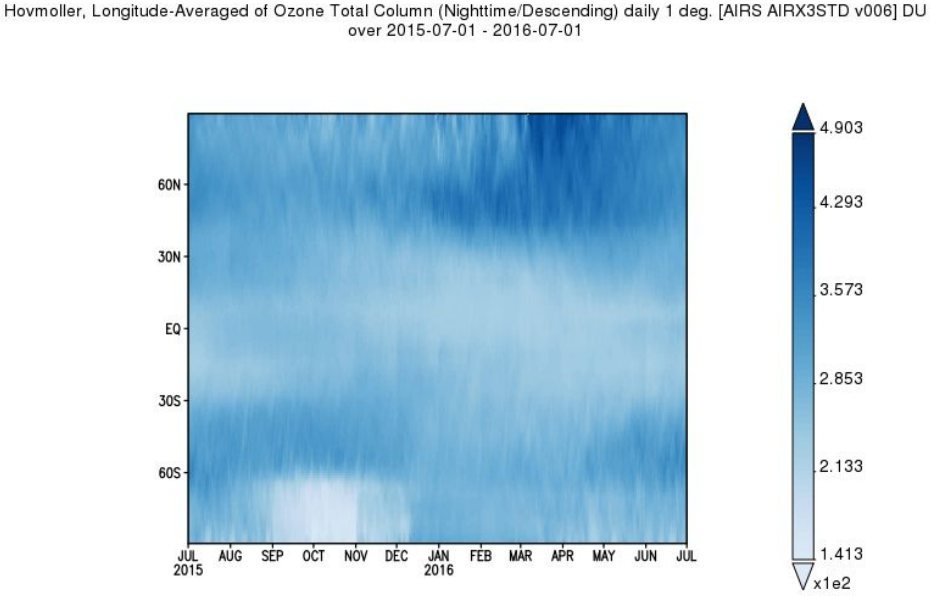
Image 3 is an intensity slicing enhancement (0.5 points). This reduces the number of discrete levels of grey (brightness so to say). The resulting levels are then displayed as discrete colors (1 point).

Image 4 is a high pass filter enhancement (0.5 points). This filter produces an image that emphasizes areas of spatial detail. The enhanced image would look sharper and crisper (1 point).

Image 5 is merely an inverted color scheme (0.5 points). This displays the grey areas as lighter shades and light areas as darker, greyer shades (1 point).

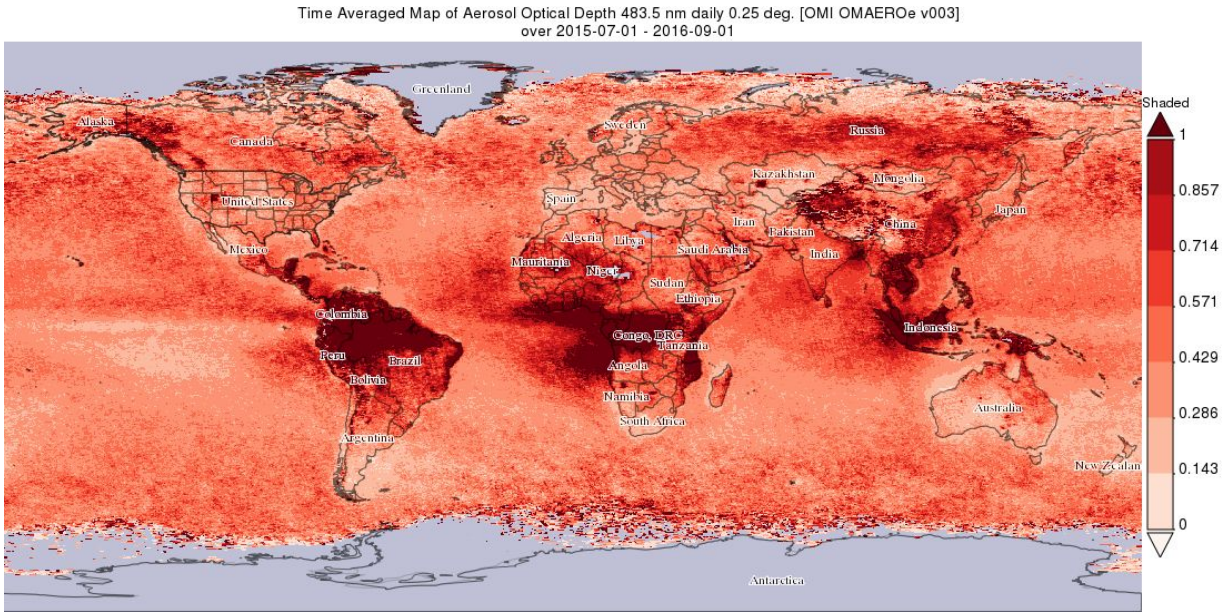
Part 3: Giovanni Data (Point values will be specified) <u>Please show all work to earn full credit!</u>

10. The following Hovmoller diagram measures column ozone levels over one year.



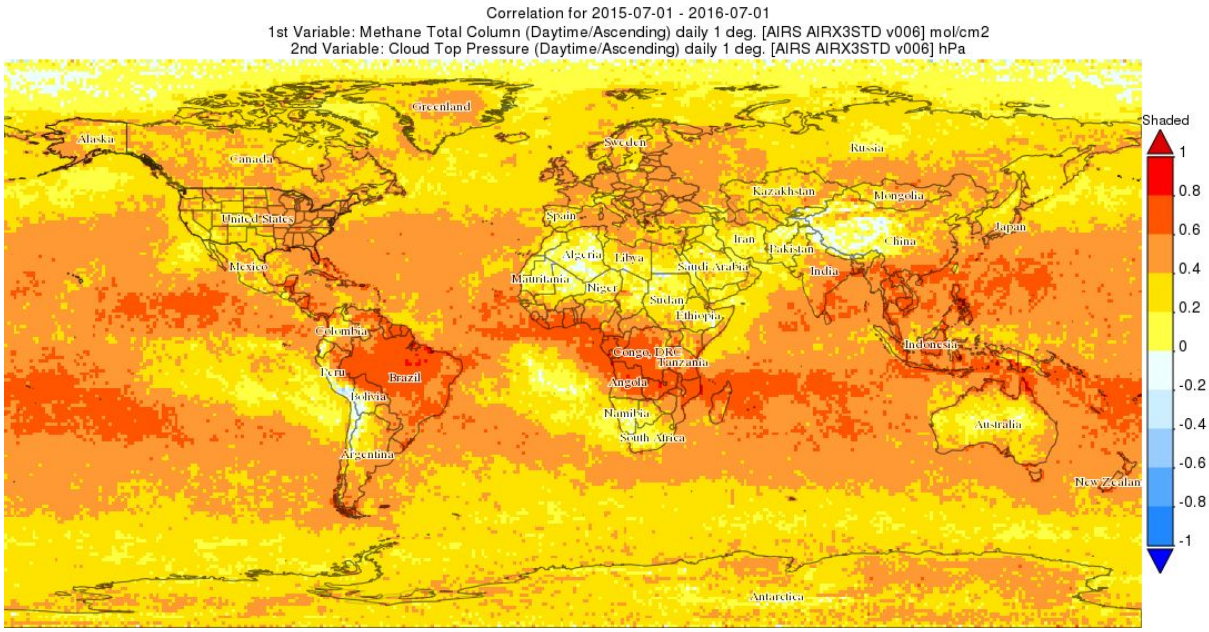
a. What does AIRS stand for? (1)
   Atmospheric Infrared Sounder
b. What satellite is this instrument found on? (1)
   Aqua
c. What phenomenon is indicated by the white area in the bottom left of the diagram? (1)
   Ozone hole
d. Compared to previous years, how does this yearôs instance of this phenomenon compare, in terms of time and location? (2)
   It occurred later and is larger
e. What three conditions are needed for this phenomenon to occur? Be sure to tie these conditions to the time and location of the phenomenon. (6)
   Low temperatures (July/August in the Antarctic) needed to form polar stratospheric clouds (which increase relative abundances of reactive chlorine gases).
   Isolation from air in other stratospheric regions (strong winds over the Southern ocean encircle Antarctica).
   Sunlight (until ~November in the Antarctic) opens up ClO and BrO reactions with ozone.

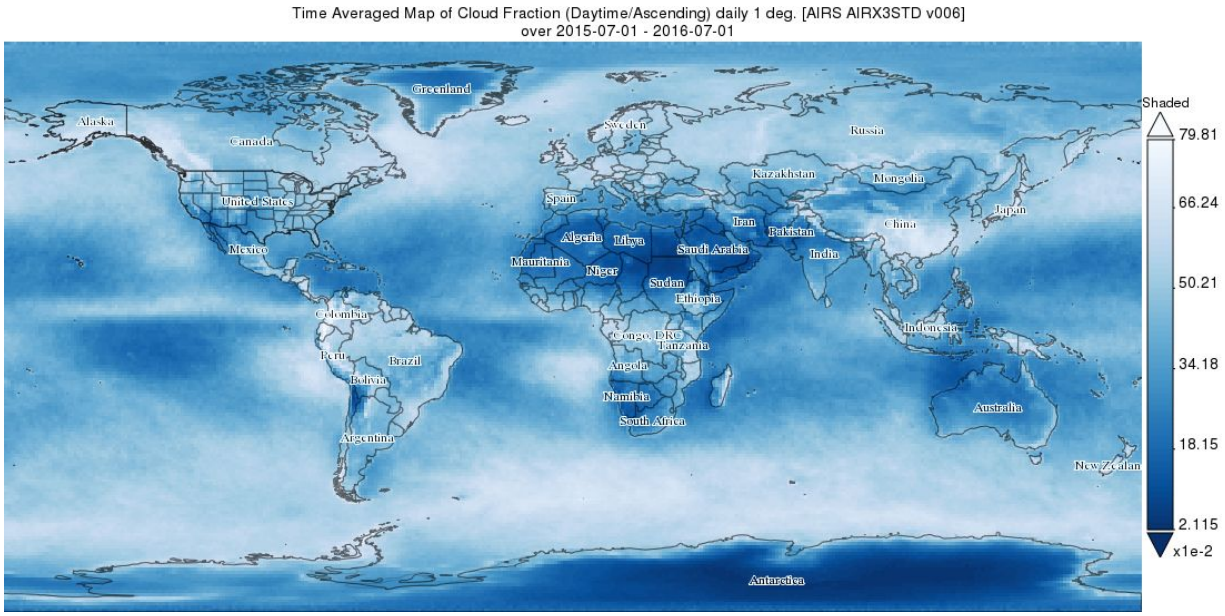
11. The following is a map of aerosol levels in the late summer.



a. What does OMI stand for? (1)
   Ozone Monitoring Instrument
b. What satellite is this instrument found on? (1)
   Aura
c. Does dark red indicate a low or high level of aerosols? (1)
   High
d. What causes the dark red area over the Amazon? (1)
   Land clearing/agricultural fires
e. What causes the red in the Arabian Peninsula? (1)
   Dust storms
f. What causes the red in eastern China? (1)
   Pollution
g. What is the direct aerosol effect? (1)
   It can reflect or absorb sunlight
h. What is the indirect aerosol effect? (1)
   It stimulates the formation of clouds by acting as cloud nuclei
i. In what two ways is stratospheric aerosol formed? (2)
   Oxidation of carbonyl sulfide (OCS) or oxidation of ejected sulfur dioxide (SO2)

12. The following are two maps: the first measures the correlation between column methane and cloud top pressure, and the second cloud cover fraction.





a. What is cloud top pressure used to measure? (1)
   Cloud top height
b. Approximately what percentage of radiative forcing is due to methane? (1)
   20%
c. What biome is the largest methane emitter? (1)
   Wetlands
d. What is the largest methane sink? (1)
   Tropospheric OH

e. The first map ranges from white [r=0] to red [r=1]; there is no blue [r<0]. What explains the positive correlation between the two variables? (2)
Clouds reduce the concentration of tropospheric OH, so with a lack of sink methane concentrations increase.

f. How do these two maps correlate over land? Why might this be? (3)
The correlation between column methane and cloud height is highest when cloud cover is high, and lowest when cloud cover is low. [accept reasonable hypotheses for 'why might this be?']