**MR3522 Lab 2: Computing Sea Surface Temperature (SST) Using IR Radiance**

Purpose: Compute SST near the Continental U.S. using infrared brightness temperature data from geostationary satellite.

**For your lab assignment, answer any questions that are bolded and in red below. Please provide your answers in a different color.**

*Starting up*

1. Log in to your JupyterLab. In the file viewer, go to “MR3522/Lab2” and double click SST.ipynb to open the Jupyter notebook.
2. Show line numbers in each cell by clicking “View” -> “Show Line Numbers” in the menu bar.

*Creating plots of SST*

*Background information. Please read!*

The python code has the capability to read in data from Channels 2, 14, and 15 from GOES-16 at 1400, 1600, and 1800 UTC on 10–23 July 2017. We will compute SST for the “CONUS” GOES-16 domain, which is centered over the U.S. East Coast but also includes the West Coast. I have built a very simple cloud mask into the code. If the Channel 2 reflectance exceeds the value of “thres” (second cell), then the code assumes that a cloud is present at that grid point. This is not how a real cloud mask works, but it will serve as a decent first guess for our purposes in this lab.

The ”Functions for plotting” cells contain the code that controls the plot making. You may need to change variables like vmin and vmax, which control the range of values represented by the colors. Whenever you make a change to either cell, re-run the cell. To run just once cell, click on it and press the “Run” button at the top of the notebook interface. If any of the figures show up with just a drop-down menu but no figure, try selecting a different field then switching to any field as needed. Two figures will show up if you run all the code. The top figure plots several variables for only one time, with a slider available to adjust the time and a drop-down menu to control the variable. The second figure shows 1) a composite SST for all the days at 1600 UTC only, or 2) a composite SST for all the days between 1400 and 1800 UTC depending on the quantity selected from the drop-down menu.

In the first figure panel, the title of each figured is labeled by the variable plotted and the time. The format of the time is *yyyy-doy-hour*, such that 201719114 means year = 2017, day of year = 191, and hour = 1400 UTC.

We will use the multi-channel SST algorithm for AVHRR to estimate SST using GOES-16 data. This won’t be perfect, but the answers should look physically reasonable. The regression algorithm looks like the below equation for daytime SST retrievals using AVHRR data from NOAA-19:

SST = -278.74596 + 1.01922 T11 + 1.72270(T11-T12) + 0.80263 (T11-T12)(sec φ-1)

in which T11 is the brightness temperature for the 11-micron band (Channel 4 for AVHRR), and T12 is the brightness temperature for the 12-micron band (Channel 5 for AVHRR). The two channels are similar to channels 14 and 15 on GOES-16 (see class notes), in that respectively, they represent the 11- and 12-micron bands. Φ is the zenith/elevation angle of the satellite at each data point. The coefficients above are hard-coded into the python code.

**For the first few questions, use the top plot in the notebook. Five different variables can be plotted. You can choose to plot those variables at 39 different times.**

1. Change thres to 1 (2nd cell) if it isn’t already set to 1. **Think about the implications of this as you proceed through the lab. You don’t need to include the answer in the lab, but it will help you with later questions**.
2. In the first cell beneath “Functions for Plotting”, make vmin in Line 38 to something between -50 and 0. You will change this to about 15 later. This controls the lowest SST that will be explicitly represented by a color on the plot of SST you make. Run the code. You can use the square icon in the figure panel and drag a rectangle on a figure to zoom in.
   1. **According to the plot you made, what is the surface temperature over the southern part of Lake Michigan near Chicago (about 42.2°N, 87.15°W; you can see coordinates if you scroll over map and read the coordinates that appear immediately below the figure)? Does this make sense?**

**About -50°C, so obviously this is too cold.**

* 1. **What is the reported surface temperature near the Golden Gate strait?**

**About 9°C.**

* 1. **About what is the reported surface temperature in the Yucatán Channel (between the Yucatán Peninsula of México and Cuba)? Keep track of the approximate latitude/longitude coordinates of the point you used to estimate SST here.**

**About 28–29°C**

1. In Line 16 of the first cell under “Functions for plotting”, make sure vmin is 0 and vmax is 1. Then plot solar reflectance (the reflectance of the 640 nm band “interpolated” to the same 2 km grid as the IR data).
   1. **Why was the SST what you saw in Question 2?**

**Clouds emitted IR radiation from higher in the atmosphere than the ground. The clouds emitted at a cooler temperature. The temperature seen in Question 3a, b represented something closer to that of cloud-top than the ground. However, because the Yucatán Channel was free of cloud, the temperature seen there is probably close to the actual SST.**

* 1. **Include the plot of reflectance in the lab write-up, and circle at least two other areas where reported SST is very low.** (You can save a figure by hitting the save button at the bottom of the panel immediately to the left of the figure. The filename of the saved figure will show up in the file viewer, from which you can right-click and download.)

**This may vary for each person. Circling any location where clouds are obviously present is OK.**

1. Plot brightness temperature for the 11- and 12-micron bands. Change the variable name in the drop-down menu to Channel 14 or Channel 15 Brightness Temperature as appropriate and make sure vmin is 290 and vmax is 300 in Lines 22 and 27 of the first cell beneath “Function for plotting”. You can view the brightness temperature map on different days by using the Image Number scroller above the plots. After done with this question, change vmin back to 200, and re-run the cell containing it.
   1. **Select a dark spot over the Gulf of México or the Atlantic Ocean east of Florida. What is the 11-micron band brightness temperature? Is the 12-micron band brightness temperature higher or lower? Why is it higher or lower?**

**The 11-micron brightness temperature is around 294K, and the 12-micron brightness temperature is around 291–292K. The 12-micron brightness temperature is lower because water vapor absorbs more radiation at 12 microns than at 11 microns.**

* 1. **If you were comparing the same two bands in a clear-sky Arctic environment over open ocean with no sea ice, would you expect that the two brightness temperatures would be closer or farther apart?**

**The temperatures would be closer together because the water vapor concentration in an Arctic environment would likely be very small, meaning the atmosphere would be more highly transparent to both 11 and 12 micron radiation.**

* 1. **What is the 11-micron band brightness temperature for the location over the Yucatán Channel you examined? You will use this again in Question 7.**

**Something between or close to 294 and 296K depending on the exact point selected.**

1. In Line 38 in the first cell beneath “Functions for plotting”, change vmin for SST to something close to 15. Change thres in the 2nd cell of the entire notebook to 0.04 and rerun that cell plus all the subsequent cells. A hint at what changing thres does can be found at Lines 11 or 17 of the second cell beneath “Functions for plotting”.
   1. **Why did so much of the analysis disappear? (There may be multiple answers, but I’m mainly looking for the reason SST analyses disappeared over the ocean.)**

**When thres is decreased to 0.04, any data where reflectance exceeds 4% is not considered. In other words, wherever a cloud is or might be present based on this crude cloud mask, SST cannot be calculated because we might compute the cloud-top brightness temperature and not surface brightness temperature.**

**For the following question, consult the bottommost figure produced when running the code. Specifically, examine the SST for 1600 UTC only.**

1. Look at the 1600 only plot in the second figure panel. Some anomalous looking horizontal bars will appear, like the one over Nevada or the one over the western Caribbean at the bottom right of the figure. Ignore those; they occur where some missing Channel 2 data was located in one of the solar radiance files. The plot you get represents the average surface temperature at 1600 UTC over a 14-day period in July 2017.
   1. **Why is there a large open spot with no SST plotted over the Caribbean Sea?** (Plot the reflectance or brightness value for one of the files at 1600 UTC for a hint. If you plot reflectance, consider changing vmax to something like 0.1 in Line 16 of the first cell under “Functions for plotting”.)

**Sun glint**

1. **Now look at the 1400–1800 plot in the second figure panel.** You may still see some anomalous looking horizontal bars. Just ignore them.
   1. **Why do you now see SST reported for the Caribbean Sea southeast of Jamaica? (Think about what the variable “thres” does again.)**

**We are now averaging over three different times of day. Between 14 UTC and 18 UTC, the location of sun glint moves westward. Therefore, all of the Caribbean Sea sometimes experiences a period where reflectance is low and SST can be computed. At 16 UTC, sun glint always prevented SST estimation in the same location if clouds did not.**

* 1. **What is the updated SST in the southern part of Lake Michigan that you looked at in Question 2?**

**Around 21–22°C**

* 1. **About what was the SST in Monterey Bay?**

**Around 13–14°C**

* 1. **Why is no data shown along the southeast coast of Florida over land?**

**The highly urbanized area (building tops, roads, etc.) are highly reflective of visible light. If you look elsewhere, you can trace out urbanization along some major Interstate highways.**

* 1. **Why do you see a land surface temperature approximation over the Colorado Rockies but not over the Plains in eastern Colorado?**

**Reflectance is low over the relatively dark barren rocks of the high Rockies. The grassy plains of eastern Colorado are more reflective.**

* 1. **What is the SST in the Yucatán Channel? Is it similar to what you answered in Question 4c when you previously estimated temperature in this location? (At least is it more similar than the temperatures reported for Lake Michigan in Questions 2a and 7b?) Why or why not?**

**27–29°C. It is similar to the previous answer in Question 5c because clouds were not present in that single image. SST is slow to change with time in this tropical location.**

1. **Use the SST for Question 7f and the brightness temperature from Question 4c for the following question. Suppose there is no water vapor, ozone, or carbon dioxide in the atmosphere. However, you observed the same brightness temperature in the 11-micron band as you did in Question 4c.** 
   1. **In this hypothetical situation, what would the brightness temperature be for the 12-micron band?**

**The same as the 11-micron brightness temperature.**

* 1. **What would the multi-channel SST be using the equation above for AVHRR? How much do we underestimate SST if we ignore water vapor absorption along the path?**

**The second two terms of the MCSST equation go to zero, so the approximate temperature would be the same as the brightness temperature. It would be about 6 degrees cooler than the derived SST in Question 8g. Six degrees represents the underestimate of surface temperature caused by ignoring water vapor.**

* 1. **Does the zenith/elevation angle of the satellite at any point on the Earth’s surface impact the SST in this hypothetical situation? Why or why not?**

**It would not, mathematically because the last term goes to zero in this hypothetical situation. Physically, the angle does not matter because if no water vapor is present in the atmosphere, then increased path length of radiation through the atmosphere does not cause increased absorption of that radiation.**