**Name:\_\_\_\_\_\_\_\_\_Key\_\_\_\_\_\_\_\_\_\_**

**MR3522 Lab 6: Multi-Instrument Analysis of Tropical Convection**

Purpose: Use infrared brightness temperatures from a geostationary satellite, microwave brightness temperatures from an SSMI/S satellite, and radar data to investigate a precipitating cloud population in the central equatorial Indian Ocean.

*Starting up*

1. In the file viewer of your JupyterLab, go to “MR3522/Lab6” and double click tropicalconvection.ipynb.
2. Show line numbers in each cell by clicking “View” -> “Show Line Numbers” in the menu bar.

*About the code* ***(Please read before running code)***

*readradar.py:* Reads radar data.

*readsat.py*: Reads geostationary and SSMI/S data.

*tropicalconvection.ipynb*: This is the driver code. It feeds variables to the other codes to aid in plotting. This is the one you will run.

The last three cells in the Jupyter notebook plot, respectively, METEOSAT data, SSMI data, and radar data. For the SSMI and radar data, you may scroll over with a mouse and get latitude, longitude, and the data value. For METEOSAT data, only the latitude and longitude are shown when scrolling over. The thick red line on the METEOSAT plots represents the 240 K contour. You can count the different shades of gray from that red line in increments of 5 K to determine the temperature at any location, and the color bar will help you determine which direction to count.

In the last cell, multiple options for plotting are available. In addition to the different variables, you may plot different sweeps based on the elevation angle of the antenna. Anything above sweep = 7 will throw an error. You may also turn on or off a filter to remove ground clutter. Whenever you change anything in this cell, please be patient as a few seconds may be required to load from the large dataset. Since we are using an external resource to run the lab, we have a limited amount of memory we can use to store data.

Finally, the code sometimes misbehaves for reasons I have not yet determined, so you may have to change the plotted variable in the drop-down menu for each cell when you first run the code in order to make the plots display correctly.

*About the data:*

The data captures a rain event in the vicinity of the S-PolKa (dual-frequency dual-polarization S- and Ka-band radar system) radar when it was situated in the central equatorial Indian Ocean in late 2011. The particular event for focus in this lab occurred around 1250 UTC 15 October 2011. Some showers occurred near the radar site, and a line of convection was present to the southeast of the radar. The data includes 1) dual-polarimetric radar variables from S-band, radar reflectivity factor (dB*Z*) from Ka-band, 7.3- and 11-micron brightness temperatures from Meteosat, and 19, 22, 37, and 92 GHz brightness temperatures from SSMI/S.

*Plotting:*

This is the approximate equation to convert range and elevation angle to height:

, *r’* = 4/3\*radius of Earth.

You can select the height as a variable from the drop-down menu of radar data.

The color bar attached to the plot will tell you the height, and the numbers beneath the plot will also provide you latitude/longitude coordinates. Note for reference the following conversion between sweep number and elevation angle.

|  |  |
| --- | --- |
| Sweep Number | Elevation angle (degrees) |
| 0 | 0.5 |
| 1 | 1.5 |
| 2 | 2.5 |
| 3 | 3.5 |
| 4 | 5 |
| 5 | 7 |
| 6 | 9 |
| 7 | 11 |

1. Run the entire code. Three plots should appear. (If any data do not appear, just toggle the drop-down menu back and forth once and it should work.)
   1. **What are the approximate coordinates (within 1/10 degree in latitude and longitude) of the most intense (highest reflectivity) convection within the radar domain (150 km range)?**

**Around 1.3°S, 73.4–73.5°E**

* 1. **Record the S-band reflectivity (a range 5–10 dB wide is OK) at that location for the lowest elevation angle in this echo. Also record the 92H brightness temperature, and 7.3- and 11-micron brightness temperatures at the same location.**

**Radar reflectivity factor is about 53 dBZ. 92H brightness temperature is about 192K. 11-micron and 7.3-micron brightness temperatures are around 205K.**

1. By default, you are looking at data from the 0.5° elevation angle. Changing sweep to 1 will cause the 1.5° elevation angle to plot. The key for which values of sweep correspond to which elevation angles is found in the table above.
   1. **What is the maximum height of 30 dBZ echo?**

**The dataset has a 12 km high 30 dB*Z* echo; however, the 30 dBZ echoes to the southeast of the radar are generally about 8 km above the surface, and the top of the cloud is higher. You would first need to find a couple of points at which the reflectivity drops from above 30 dBZ to below 30 dBZ as a function of altitude. Then you need to find the range (not the lat/lon distance) along the ray path, and plug it, and the elevation angle at which the 30 dBZ echo top was observed, into the equation above.**

**b. Can you see the top of all convection with this radar volume? How do you know?**

**No. The highest elevation angle shows echoes as strong as 20–25 dB*Z*.**

1. Click the button to turn on the clutter filter, which will replot the reflectivity. **What did the clutter filter remove?**

**Echoes near the radar. These were non-meteorological targets on the islands.**

1. Next, plot the variable “vel”, which is the Doppler velocity.
2. Suppose ASCAT made a pass over the exact area at the exact same time. **What wind direction would it indicate within the radar domain?** There are not multiple answers to this question, but an approximate azimuthal direction is OK. 0, 90, 180, and 270 degrees are due north, east, south, and west, respectively. **Note**: A *northerly* wind, for example, is one that is *out of the north*, and has a compass direction of 0°.

**Since the question asks about ASCAT winds, we want to find the near-surface wind direction. To do this, plot the velocity at a low elevation angle (1.5° is often better than 0.5° so that you can see above the ground/sea clutter). In this case, the wind is about 260°, or out of the west-southwest. We can tell this because to the WSW of the radar, inbound velocities are detected close to the radar. To the ENE of the radar, outbound velocities are detected. The echoes yielding these velocities re not meteorological, but they may represent bugs or sea spray.**

1. **Above the freezing level located at 5 km, which direction were the winds?**

**Probably around 60°. Pick a high sweep, and if possible look at the inbound and outbound velocities on opposite sides of the radar. Compare velocities at a long range to ensure that the velocities are representative of the atmosphere well above the ground (in this case above 4.5–5 km, or the approximate freezing level in the Tropics). The key is to look at velocities at the 5-degree elevation angles (3.5 deg is OK too). At around 0.9°S, 74.0°E, strong inbound velocities were observed. But further WSW down the line of convection, radial velocities were outbound. If we can find a few radials along which the radial velocity is close to zero in the convective line, then we can deduce that the wind direction is perpendicular to that radial. Such a radial is seen at around 150°. Since we know the wind is east-northeasterly, that means the direction is around 60°.**

1. Next, we will look at the dual-polarimetric variables.
   1. **Are there any indications (large *Z*, *KDP*, *ZDR*, and low *ρHV*) of hail?**

**Highest *KDP* is around 1, which is co-located with reflectivity around 50 dBZ. ZDR in this area is scarcely greater than 1. In this case, we probably assume that hail is not present since the echo is only 50–55 dB*Z*, and also importantly, the correlation coefficient is near 1 everywhere. However, in colder environments, small hail can be observed at lower reflectivity.**

* 1. **Given the environmental regime (tropical ocean), why does this make sense?**

**Vertical motions over tropical oceans are generally quite weak because updrafts are not typically strongly buoyant. Also, the mean temperature profile is too warm. Ice that falls below the 0°C level will melt substantially before reaching the ground.**

1. Plot the Ka-band reflectivity (varname = “dbzk”) at any elevation angle.
   1. **Is more or less convection seen? Why?**

**Less. The beam is attenuated by water vapor and liquid water.**

* 1. **Is there any convection seen by Ka-band (particularly at low elevation angles) that is not seen by S-band? If so, why?**

**Yes, particularly to the east of the radar. This occurs for echoes containing droplets that are too small for an S-band radar to see. In other words, the Ka-band radar is more *sensitive* than the S-band radar.**

1. Plot the lowest sweep of S-band reflectivity (varname = “refl”) data again. Pick a point where reflectivity exceeds 40 dBZ. **Record in your lab write-up the latitude and longitude coordinates of that point, and record the reflectivity and differential reflectivity also. Don’t forget to convert from logarithmic to linear units for *Z* and *ZDR*.** Assume a Z-R relationship of Z = 127.5R1.47 and a Z-ZDR-R relationship of R = 0.0085\**Z*0.92\**DR*-5.24.
   1. **Calculate the estimated rain rate at this point using both relationships.**

**Your answer will depend on the values selected for Z and ZDR. Linearize Z and ZDR before plugging into equation.**

* 1. **Which is bigger and why might it be?**

**Again, your answer depends on the values selected. Very large values of ZDR will tend to yield smaller rain rate estimates than Z alone. This is because at high ZDR (e.g. > 2 dB), the Z-R relationship alone overestimates the liquid water content contained within the population’s oblate drops. Not considering KDP, if ZDR is lower than 0.25 dB, the Z-R relationship should be used.**

1. **Based on infrared and microwave brightness temperatures, argue for or against the following statement: “The tropospheric moisture content where rain was not occurring was substantially (10mm or more) less than within 10 km of a raining area.”** You may want to adjust the contour interval when plotting microwave data, depending on the channel you plot. Note that the red contour in the plots of METEOSAT data represents the 240K contour.

**The statement is false. The air was drier where rain was not occurring, but not much—and certainly not by 10 mm. The key is looking at the 22 GHz microwave brightness temperature in a non-raining part of the radar domain was about 257K. The brightness temperature near the raining area was about 260K. In other words, nowhere in the radar domain did the 22 GHz channel see much emission from the ocean surface because so much water vapor was present.**

1. **If a space-borne cloud radar flew from north to south (or south to north) along the 72°E longitude, what might it see that the ground-based S-band radar cannot?**

**Upper-tropospheric clouds containing small frozen targets.**

1. **For the same space-borne cloud radar, suppose it were viewing downward at 1.25°S, 73.6°E. Would the observed reflectivity be largest at the top or the bottom of the cloud. What about for a ground-based radar of the same wavelength/frequency?**

**It would be largest at the top of the cloud. A ground-based radar of the same frequency would observe highest reflectivity close to the ground. In either case, the cloud radar (Ka- or W-band) will be attenuated by liquid water and water vapor, and the power returned to the receiver decreases rapidly as a function of range through either.**

1. **Is the peak of the 6-micron weighting function higher in the atmosphere at 0.5°N, 73°E or 1.5°S 73°E?**

**It’s higher where more water vapor is present, therefore, near 1.5°S 73°E.**

1. **Is the sea surface temperature in this location greater than or less than 290K? How do you know?**

**It’s greater than 290K. The 11-micron IR brightness temperature is observed in an atmospheric window, in which we can observe radiance from the surface presuming clouds are not in the way. Within the clear-air part of the domain, the 11-micron brightness temperature was 290–300K. The ocean is not a perfect blackbody, so the actual ocean temperature is something more than 290–300K.**

1. **Why does no microwave channel detect the isolated convective elements in the northwestern portion of the ground-based radar domain?**

**The horizontal resolution of space-based passive microwave data is too low to capture isolated, shallow convection.**

1. In the “Plotting function for METEOSAT data”, comment out lines 15, 16, 28, and 29 (i.e. put a # at the front of those lines). In the “Plotting function for SSMI data”, comment out Lines 21 and 22. Re-run these cells, then replot the IR, WV, and whatever microwave data at which you want to look. Note the new ranges of latitudes and longitudes plotted for the METEOSAT and SSMI data. You’ll see that the radar can’t see far enough to capture other interesting features. The radar was located to the northwest of a large mesoscale convective system.
2. Look at some cloud near 2°N, 74.6°E. Or some cloud near 5.6°S, 80.4°E. The 11-micron brightness temperatures are between 250 and 260K depending on exactly where you look. At 0.69°S, 73.15°E, KAZR observed similar cloud with tops near 12 km high. But the temperature at 12 km is much colder than 250–260K.However, the sounding from the same location indicated a temperature at 12 km of about 220K. **Explain why such a large (30–40K) difference exists between actual cloud top temperature and the brightness temperature observed at 11 microns.**

**The clouds in this location are high, thin cirrus clouds. Their temperature is about 220K; however, they are optically thin; therefore, unlike deep cumulonimbus clouds full of liquid water, they do not absorb all of the emission from the surface or farther down in the atmosphere. The reported brightness temperature represents a blend of emissions from the cirrus cloud and from warmer objects below the cloud.**

1. **At 70°E, approximate the northernmost and southernmost latitudes of the Intertropical Convergence Zone based on the total precipitable water apparent from the observations you have available.** (Tip: Use microwave data and/or change the -10 and 10 in Lines 2 and 5 of the “Read in METEOSAT data” cell to -20 and 20.)

**Identify the ITCZ based on the region of high water vapor concentrations. About 7°S to 3.5°N. This is the region of higher microwave brightness temperatures at 22 GHz, for example. To the north of 3.5°N and south of 7°S, 22 GHz brightness temperature is generally less than 245K, meaning that more emissions came from the ocean surface. This indicates that only the air between 3.5°N and 7°S is very moist along 70°E. At other longitudes, the meridional extent of the ITCZ differs. The answer can be deduced from 19 GHz and 37 GHz channels as well, but the 22 GHz and is more sensitive to water vapor absorption. The 7.3-micron brightness temperature can also be used, but the ITCZ Is not as obviously well defined.**