Home assignment Spring 2025

FYS-3001 Physics of remote sensing

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Fundamentals and Thermal sensing [4 points /20]

Short answers are encouraged, and 400 words/answer is a maximum.

1. What is spectral and spatial resolution? How are these two resolutions connected? [1 point]
2. What is a BRDF? Why are they important for Earth observation from satellites? [1 point]
3. What is the difference between a scanning system and a pushbroom system? And why would one be preferable over the other? [1 point]
4. Not all energy is reflected directly from the Earth. Why is that? And what are the two most important material properties that regulate this? And how do they vary? [1 point]

Practical Surface Sensing – optical remote sensing [8 points / 20]

This problem deals with designing a system for interpretation of a remotely sensed mixed signal.

A modern precision farmer wants to identify where he most needs to apply fertilizer to his grassy fields after ploughing and seeding. The Farmer's Union advised him that he can use the free Sentinel-2 data from the European Copernicus program. There are two nearly identical satellites, S-2A and S-2B, that provide 13 optical and infrared data channels with pixel resolutions of either 10, 20 or 60 m on the ground.

The farmer owns several moderately sized rectangular fields, whose sides are only 50 to 200 m in length, that are spread out on the flat ground in the local mountains (quite typical for northern Norwegian farmers). He wants to know which whole fields need fertilizer the most urgently. The fields will start at 100% bare soil, and he will test each week as the grass starts growing, to identify how well each field is growing (i.e. the amount of grass present), and direct his fertilizer to the worst case each week. Let's just assume that all other effects, like rain and sunshine, are the same for all fields.

You have been hired to design and explain how this can be done and demonstrate the principle to the farmer. You are provided with a zip-file containing:

• Spectral profile of bare soil
• Spectral profile of green grass
• Spectral atmospheric transmission profile
• Sub-band spectra for a set of test fields

and the spectral bands of the satellite system for Sentinel-2.

Spectral bands for the Sentinel-2 sensors[15]

Sentinel-2 bands	Sentinel-2A		Sentinel-2B		
	Central wavelength (nm)	Bandwidth (nm)	Central wavelength (nm)	Bandwidth (nm)	Spatial resolution (m)
Band 1 – Coastal aerosol	442.7	21	442.2	21	60
Band 2 – Blue	492.4	66	492.1	66	10
Band 3 – Green	559.8	36	559.0	36	10
Band 4 – Red	664.6	31	664.9	31	10
Band 5 – Vegetation red edge	704.1	15	703.8	16	20
Band 6 – Vegetation red edge	740.5	15	739.1	15	20
Band 7 – Vegetation red edge	782.8	20	779.7	20	20
Band 8 – NIR	832.8	106	832.9	106	10
Band 8A – Narrow NIR	864.7	21	864.0	22	20
Band 9 – Water vapour	945.1	20	943.2	21	60
Band 10 – SWIR – Cirrus	1373.5	31	1376.9	30	60
Band 11 – SWIR	1613.7	91	1610.4	94	20
Band 12 – SWIR	2202.4	175	2185.7	185	20

a) Read and plot (separately) the three spectral profiles (atmosphere, soil & grass) from the text files. Read the header lines to understand what the numbers (columns of data) are and their units to correctly label the axes. [1 point]

b) Use numerical averaging or integration to convert and plot the spectral profiles as they would appear in the 13 bands of Sentinel-2A (ignore that S-2B is very slightly different). Perhaps plot with both line and markers to indicate the discrete center points of each band. [2 points]

c) Two channels in the middle of the atmospheric transmission profile appear to be very low, one virtually zero. Try to briefly explain why this is by using what you have learned in the course, comparing to the full spectrum, and from the names of the Sentinel-2 bands. Would these channels cause complications for your grass field measurements, explain? [1 point]

Let's assume that a colleague, a GIS expert, has already given you code that will extract the pixels for each field from their geographic locations provided by the farmer. They will take the Sentinel-2A level 2A data and check the cloud mask to avoid pixels under clouds. They also removed the outer boundary pixels because the fields and pixels may be mis-aligned and the edges will be contaminated with roads and trees besides the fields. Since some of your fields are quite small, they can only find consistent useful data from the 10 m. resolution bands. Thus, the inner field pixels (which are considered "clean") are averaged into a single, four-channel spectral profile which you now need to interpret.

d) Re-plot the bare soil and grass profiles on a single plot for only the four 10 m resolution channels. Comment on whether you think the profiles, or only some channels, can be used to determine the amount of grass in a field? [1 point]

e) A spectral linear mixing model and how it may be used to work out the amount of grass versus soil in our fields? Linear means that the spectrums mix linearly with the proportion, hence 50% would be halfway between the two profiles. For a two-class mixing problem we then have:

$$\mathrm{R}_{\mathrm{Observed}}(\lambda) = f_{\mathrm{grass}} \times \mathrm{R}_{\mathrm{grass}}(\lambda) + (1 - f_{\mathrm{grass}}) \times \mathrm{R}_{\mathrm{soil}}(\lambda)$$

$$f_{\mathrm{grass}} = \frac{(\mathrm{R}_{\mathrm{Observed}}(\lambda) - \mathrm{R}_{\mathrm{soil}}(\lambda))}{(\mathrm{R}_{\mathrm{grass}}(\lambda) - \mathrm{R}_{\mathrm{soil}}(\lambda))}$$

We have up to four useful channels available, are there any particular channel that you'd recommend being used in this case and why? [1 point]

h) You are provided a set of field sub-profiles from your colleague, in the TestFields.txt file. Use your method to determine the grass fraction for each field and tell the farmer which field needs fertilizer the most. [2 point]

Practical Surface Sensing – passive microwave [8 points / 20]

Passive microwave sensors are an important tool and data source when we establish daily sea ice maps for the Arctic and Antarctic. The long history also means that we can use the data for climatological modeling and assessment. Passive microwaves are often the source behind ice edge imagery, though difference in emissivity between different sea ice types mean that we can also use them for sea ice type classification. One sensor frequently used is the Advanced Microwave Sounding Radiometer 2 (AMSR-2), which is a Japanese satellite. The satellite was launched in 2012 and is still providing data. Some sensor specifics can be found here: https://space.oscar.wmo.int/instruments/view/amsr2 and here: https://www.ospo.noaa.gov/Products/atmosphere/gpds/about_amsr2.html

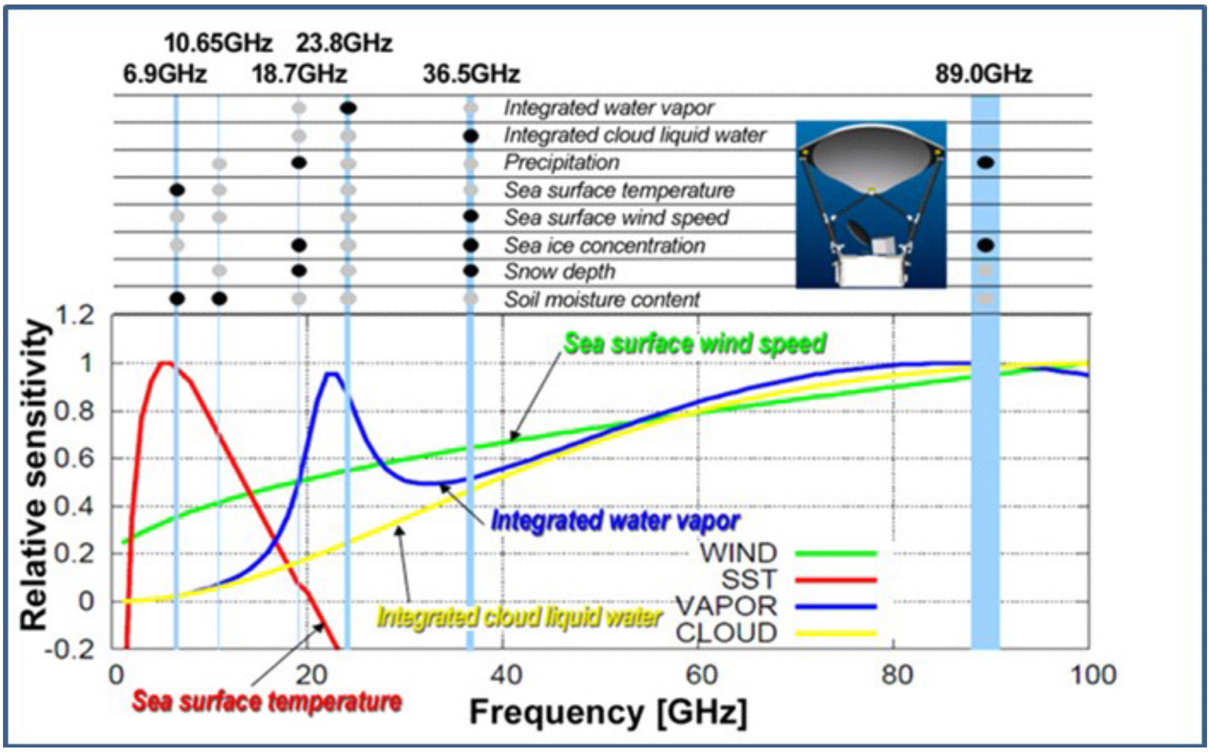


Figure taken from https://www.ospo.noaa.gov/Products/atmosphere/gpds/about_amsr2.html

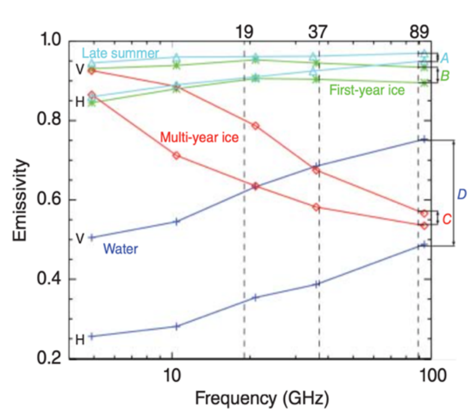
From this figure you can see that the cannels 18.7GHz, 36.5GHz and 89.0GHz is actively used in sea ice concentration mapping.

To answer the questions below there may be several different ways of achieving the desired result and any way is acceptable, because I am more interested in your logic and reasoning. Therefore, it is important to state the thinking behind your decisions.

1. Why can you use the AMSR-2 sensor to say anything about the sea ice? Why are these types of sensors preferable in the polar regions? What parameters are important to consider when using passive microwaves to derive sea ice information? [2 point]
2. Read and plot the different brightness temperatures. The data is given as netcdf, and there are data called Lat and Lon that contain the Latitude and Longitude data. For the respective temperature data use vertical data for 18.7GHz, 36.5GHz and 89.0GHz. We'll focus on an area centered over Svalbard so you should zoom in to include an area approx. 75°N – 85°N and 10°W – 50°E. West is indicated as negative longitude values. What does the difference between the different frequencies tell you? What can the 89GHz channel contribute with? [1 point]
3. Calculate the sea ice concentration (SIC) using the AMSR2 image provided for this exercise. The SIC ranges from 0-100%. To your help you have the figure below, some hints and attached a paper about sea ice where section 9.2.2 and 9.2.4 are particularly useful. For simplicity can the problem be treated as a linear two-type mixture model, open water and sea ice.
   Hints:
   - Assume that the surface temperatures for the different materials (ice and water) are the same.
   - Remember: Tb = εT
   - To derive sea ice maps, using passive microwave data, we rely on some relationships such as the gradient ratio (GR). GR(v1,v2) = [Tb(v1) − Tb(v2)] / [Tb(v1) + TB(v2)]. Where v is frequency. For more information about GR read section 9.2.4 in the attached paper.

   To derive the SIC a few steps are needed:
   1) Identify the open water areas. You need to identify such areas based on your knowledge and with the aid of the figure below and the figures you just made in part 2 of the exercise. Provide a brief explanation on how you did this. What would the gradient values be for the open water areas, an approximate value is sufficient? The GR assumes that a sea ice concentration between 0-15% is open water. Why is a range used and not an exact number? [1 point]

Observations of vertically (V) and horizontally (H) polarized emissivity's ε of sea ice and sea water at an incident angle of 50° from two field campaigns. For frequencies typically used for sea ice concentration retrieval (19, 37, 89 GHz) polarization difference for water, D, is larger than for all sea ice types (A, B, C). You can ignore the late summer ice type.



   2) The next step is to identify sea ice areas. For this exercise you only need to separate sea ice from open water. Again, use your knowledge, with the help of your own figures and the figure provided below to identify a 100% sea ice area.
   3) Set up a two-type mixture model to derive the SIC map. You should provide the map in your answer. [2 point]

4. FYI and MYI has different brightness temperatures, as can be derived using the information in the figure above. What would the GR values in your image within the selected area typically be for the MYI areas? There are some areas within your first figures for this exercise that are FYI areas, indicate these areas in your plot. [1 point]
5. Make a map where we can see the open water, new ice and older ice areas. Hint: New ice can be identified when we have GR (36.5V,18.7V) > -0.02, and an upper range lower than open water areas. Why does this range indicate new ice formation? Apply a landmask to remove Svalbard from the analysis, as Svalbard otherwise have the appearance of sea ice. You can look here for a landmask using Python: https://github.com/CryosphereVirtualLab/public-notebooks/blob/main/S1_ice_water_classification/load_and_calibrate_S1_scene.ipynb
[1 point]

Total out of 20 points, to give 20% of your final grade.