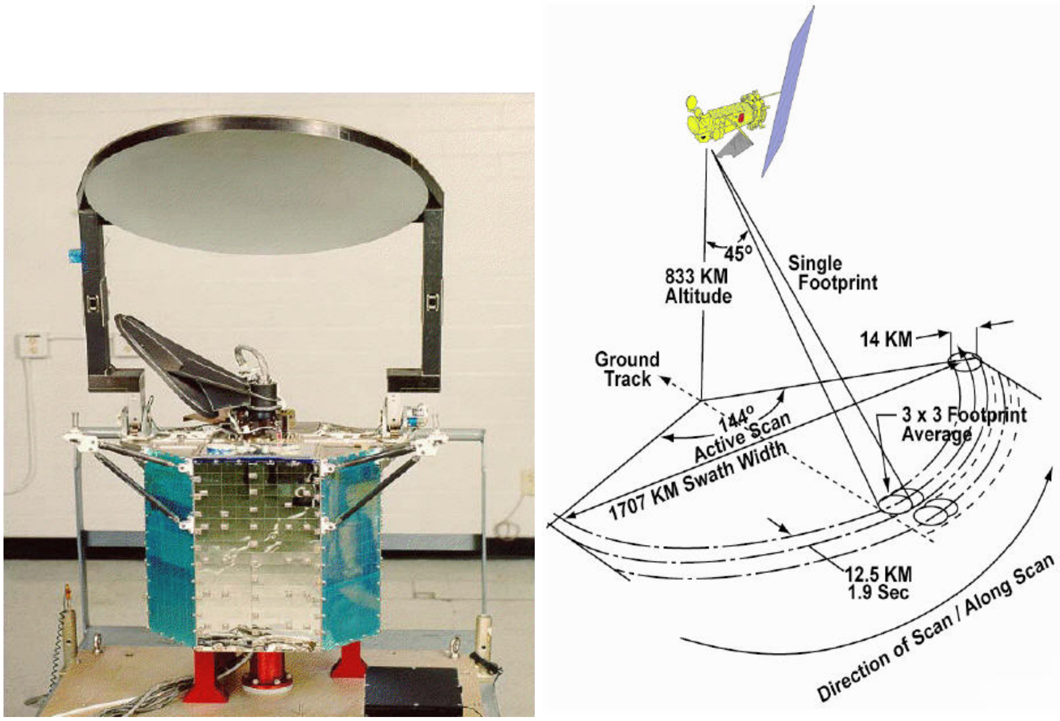

Figure 1: The SSMIS instrument and scan geometry.

Remote sensing of sea ice

Summary

The amount of sea ice in the arctic has been declining for decades, and the goal is project is to gain some insight in how microwave remote sensing can monitor sea ice. We do this by createing a simplified model for the detection of sea ice by microwave radiometry. The model is to be created in a step–by–step manner. We will start by looking at the instrument we will use, then move on to make a forward model of the instrument. Finally we will implement an inverse model to extract sea ice consentrations from the measured data.

The satellite

The satellite we are modelling is the Special Sensor Microwave Imager/Sounder (SSMIS). SSMIS is a 24-channel, passive microwave radiometer designed to obtain a variety of polarized atmospheric temperature, moisture, and land variables under most weather conditions. Channel frequencies range from 19 GHz to 183 GHz, measures different polarizations and are obtained over a swath width of approximately 1707 km. The spacecraft orbits the earth at an orbit of 833 km and the SSMIS has an antenna diameter of 60 cm.

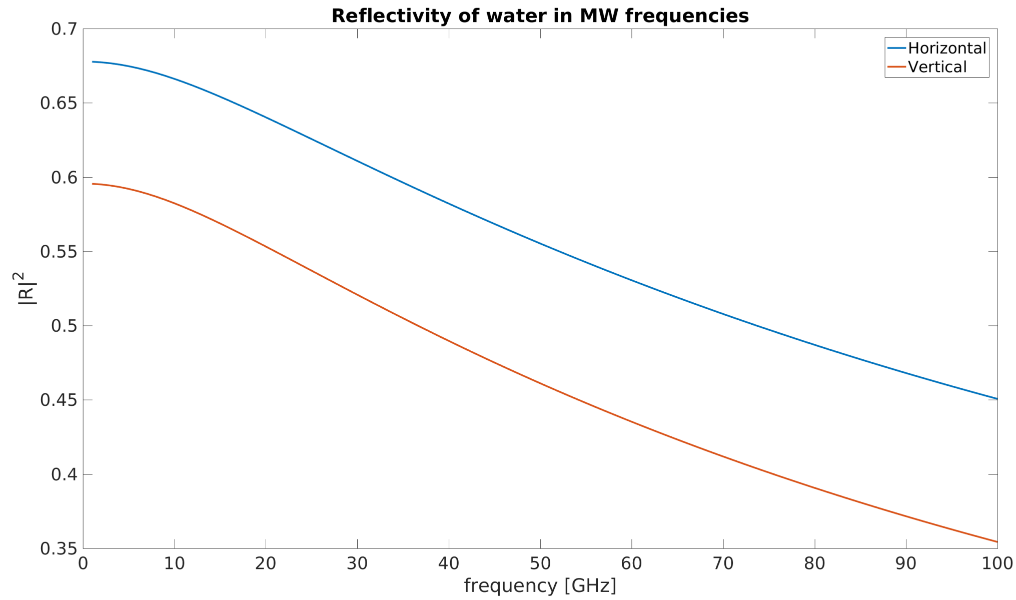

Figure 2: The figures shows the reflectivity of water at 45 degree incidence angle for vertical and horizontal polarisations

> **Task 1**
>
> What is the footprint/resolution of the lowest and highest frequency channel of the instrument?

The project

Step 1: Emissivity from Sea and ice

The first task in any remote sensing application is to create a *forward model*, which models the measurement setup we have. In this case you need to make a forward model which calculates the radiance emitted from sea and ice for two different polarizations at frequencies covering 10-90 GHz. For this we need to first calculate the emissivity of the surface. Figure 2 shows the reflectivity of water at different frequencies and polarizations. The curves can be approximated with the following polynomials

- $R_{horizontal,water} = 0.7363 - 0.001967f - 1.4 \cdot 10^{-5} \cdot f^2 + 1.205 \cdot 10^{-7} \cdot f^3$
- $R_{vertical,water} = 0.5419 - 0.002863f - 8.664 \cdot 10^{-6} \cdot f^2 + 1.199 \cdot 10^{-7} \cdot f^3$

where f is the frequency in GHz. For ice the reflectivity is constant with frequency and given as

- $R_{horizontal,ice} = 0.1555$
- $R_{vertical,ice} = 0.0242$

Task 2

Make a function/script that plots the reflectivity and emissivity of water as a function of frequency given using the polinomial formulas above.

Step 2: Thermal emission from Sea and ice

Now that you have calculated the emissivity of the two surfaces we can move on and calculate the radiance emitted from the the two surfaces.

Task 3

Make a function/script that plots the brightness temperature of water and sea ice for different temperatures, frequencies and polarizations. A test value is that the brightness temperature for water measured at horizontal polarisation at 50 GHz for a temperature of 273 K should be 104.3 K.

Step 3: The forward model

We can now create the complete forward model. The model shall include effects of the surface, where the functions developed above are used. The output of the function is a vector holding the brightness temperature for each input frequency. The input is (1) A vector of frequencies. (2) If vertical or horizontal polarisation is measured (for each frequency). (3) Ice temperature. (4) Ice fraction, the fraction of the pixel covered with ice.

That is, the task is to make a function calculating the measured brightness temperature for a down-looking radiometer. If the forward model function is denoted as `seaice_fm`, a possible solution could look like:

```
v       = [19.7 19.7 37 37 85.5 85.5]*1e9;
pol     = 'vhvhvh';
temp_ice = 270;
icefrac = 0.5;
Tb      = seaice_fm(v,pol,temp_ice,icefrac)
```

The output vector `Tb` has (of course) the same length as the frequency vector. The example above models the three double polarisation frequency channels of SSM/I (a meteorlogical satellite used by the United States Air Force).

Task 4

Make a forward model of the instrument.
A test case is that the brightness temperature for a case with a sea ice concentration of 0.7 and an ice temperature of 270 K measured at 50 GHz with horizontal polarization should be around 190.9 K.

Task 5

Add random noise to your forward model.

Step 4: Retrieval

Simulated measurements will here be inverted by making least squares fits. The instructions are here detailed, to help out those with no experience of least squares fits. So do not be frightened by the length of the text, it does not mean that the problem necessarily takes a very long time to solve.

When you have implemented the solution, start by testing that it works by making simple tests, by inverting simulated values. Use the frequencies and polarisation of SSM/I as starting point (see above).

When you are sure that it works, you can test to add noise to the simulated measurements. How much noise can be added before the results are affected too much?

Repeat this when using less observation channels. For example, remove 85.5 GHz, or use just horizontal polarisation. How many channels are needed to maintain stable results? And which channels do you select to obtain stable results with few channels?

Solution: The brightness temperature, T_b, of channel j can here be written as

$$T_b^j = c(1-r_i^j)T_i + (1-c)(1-r_w^j)T_w,$$

where c is the sea ice concentration, r_i^j is the reflectivity of sea ice (for frequency and polarisation of concern), T_i is the (physical) temperature of ice, r_w^j is the reflectivity of open water and T_w is the temperature of water.

The least squares fit can be made in several ways. The variables we want to determine are c and T_i (T_w can be assumed to be known within a few kelvin. Why?). The first step towards a first solution is to rearrange the expression to

$$T_b^j - (1-r_w^j)T_w = -c(1-r_w^j)T_w + cT_i(1-r_i^j).$$

We get then a matrix equation of the form $\mathbf{Kx} = \mathbf{y}$:

$$\begin{bmatrix} -(1-r_w^1)T_w & (1-r_i^1) \\ -(1-r_w^2)T_w & (1-r_i^2) \\ \vdots & \vdots \\ -(1-r_w^n)T_w & (1-r_i^n) \end{bmatrix} \begin{bmatrix} c \\ cT_i \end{bmatrix} = \begin{bmatrix} T_b^1 - (1-r_w^1)T_w \\ T_b^2 - (1-r_w^2)T_w \\ \vdots \\ T_b^n - (1-r_w^n)T_w \end{bmatrix},$$

where n is the number of measured brightness temperatures. The unknowns in $\mathbf{x}$ can now be obtained by a least squares procedure. How to do this in the program language can usually be found in the online documentation of this language.

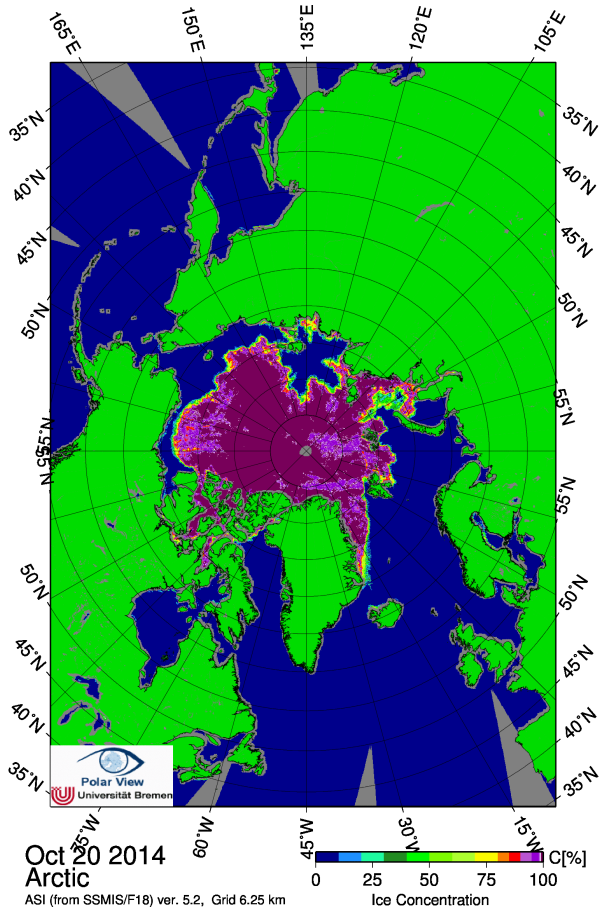

Figure 3: Sea ice map from SSMIS

Task 6

Implement the least squares retrieval as described above. Find out the maximum amount of noise you can allow in your instrument (using all 6 channels).

Challenge: Realistic case

Try to formulate the foward model for a case where a cloud layer is present between the satellite and the surface. The transmissivity of a liquid water cloud, t, in the microwave region (absorption only) is given by the following formula:

$$t = 10^{\frac{-lwp\cdot 0.6\cdot f^{1.9}}{10\cdot\cos(\phi)}}, \tag{1}$$

where lwp is the liquid water path of the cloud in m (typically in the order of 1 mm), f the frequency in GHz and ϕ the incidence angle of the instrument. Play around with the model and see how much water can be added before the instrument is no longer able to accurately retrieve the seaice temperature and concentration.