Brightness temperature of the ocean surface

Exercise 1: measurement of sea surface salinity

Discuss the requirements for the measurement of sea surface salinity S_{ss} from $f = 1.4$ GHz brightness temperature T_B. Assume we want to know S_{ss} with an accuracy of 0.2 g/kg. Determine the required measurement accuracy for S_{ss} at about 15-25 g/kg. Assume that we perfectly know a given sea surface temperature $T_{ss} = 20°$C.

Where can we expect problems for other salinties and temperatures? Have a look at climatologies of temperature and salinity http://icdc.zmaw.de/ocean.html

Exercise 2: sea surface temperature

You want to measure the ocean surace temperature (at about T_{ss}=20°C). The radiometer system is operating at 10 GHz with a sensitivity of 0.6 K for a single measurement. Calculate the uncertainty for the temperature retrieval. Assume a calm ocean surface and a salinity S_{ss}=30 g/kg.

Exercise 3: Incidence angle and polarization

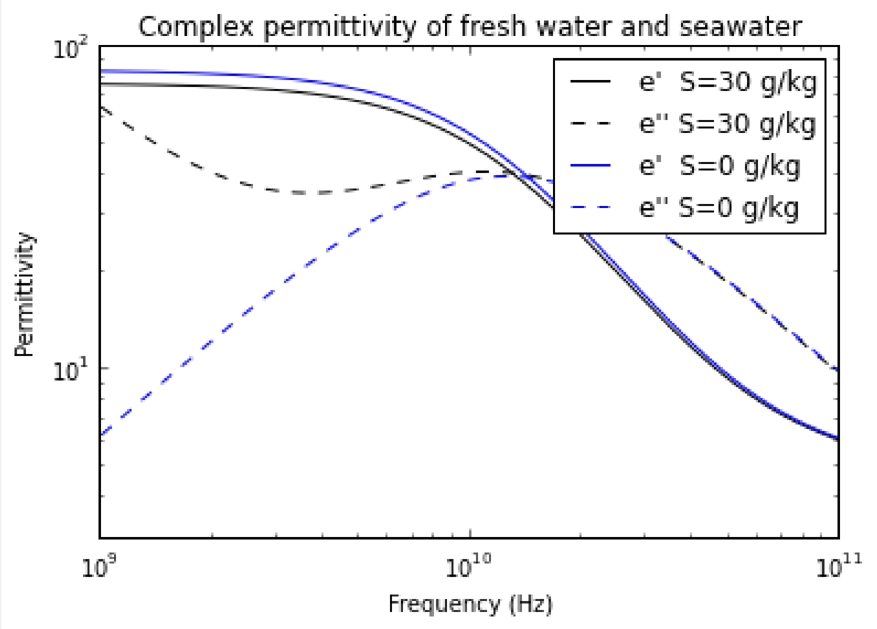
Calculate the emissivity for horizontal and vertical polarization at the SSM/I-frequencies as a function of the incidence angle for two different dielectric surfaces, e.g. ice ($\epsilon \approx 3.17$) and water. Estimate the Brewster angles.

The complex dielectric constant of seawater

Klein and Swift (1977), An Improved Model for- the Dielectric Constant of Sea Water at Microwave. Frequencies, lEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. AP–25, NO. 1, JANUARY 1977.

```
def eps_water_func(T,S,f):
    """Complex dielectric constant of seawater by Klein and Swift (1977)"""
    T=T-273.15
    omega=2*pi*f
    eps_0=8.854*10**(-12)
    eps_inf=4.9

    eps_s_T=87.134-1.949*10**(-1)*T-1.276*10**(-2)*T**2+2.491*10**(-4)*T**3
    a_ST=1.+1.613*10**(-5)*S*T-3.656*10**(-3)*S+3.210*10**(-5)*S**2-4.232*10**(-7)*S**3
    eps_s=eps_s_T*a_ST

    tau_T0=1.768*10**(-11)-6.086*10**(-13)*T+1.104*10**(-14)*T**2-8.111*10**(-17)*T**3
    b_ST=1.+2.282*10**(-5)*S*T-7.638*10**(-4)*S-7.760*10**(-6)*S**2+1.105*10**(-8)*S**3
    tau=tau_T0*b_ST

    delta=25-T
    beta=2.0333*10**(-2)+1.266*10**(-4)*delta+2.464*10**(-6)*delta**2-S*(1.849*10**(-5)
        -2.551*10**(-7)*delta+2.551*10**(-8)*delta**2)
    sigma_25S=S*(0.182521-1.46192*10**(-3)*S+2.09324*10**(-5)*S**2-1.28205*10**(-7)*S**3)
    sigma=sigma_25S*exp(-delta*beta)
    eps_water=eps_inf+(eps_s-eps_inf)/(1+1j*omega*tau)-1j*sigma/(omega*eps_0)
    return eps_water
```

```
f=linspace(1e9,1e11,1000)# Frequency
T=273.0+10 # Temperature
S=30.0 # Sea water salinity S=30
eps_sw=eps_water_func(T,S,f)
S=0.0 # Fresh water
eps=eps_water_func(T,S,f)

loglog(f,real(eps_sw),'k-',label=r"e' S=30 g/kg")
loglog(f,-imag(eps_sw),'k--',label=r"e'' S=30 g/kg")
loglog(f,real(eps),'b-',label=r"e' S=0 g/kg")
loglog(f,-imag(eps),'b--',label=r"e'' S=0 g/kg")
legend()
xlabel('Frequency (Hz)')
ylabel(r'Permittivity')
title('Complex permittivity of fresh water and seawater')
axis([1e9,1e11,3,100])
show()
savefig('permittivity_seawater.png',dpi=150)
```



Nadir reflectivity

```
def nadir_reflectivity(T,S,f):
    """Calculate nadir power reflectivity
    for given T [K], S [g/kg] and f[Hz]"""
    eps_sw=eps_water_func(T,S,f)
    n=sqrt(eps_sw)
    R=abs(((n-1)/(n+1)))**2
    return R
```

Fresnel coefficients

The power reflection coefficients for a plane interface between the air and the surface can be expressed as a function of the incidence angle θ

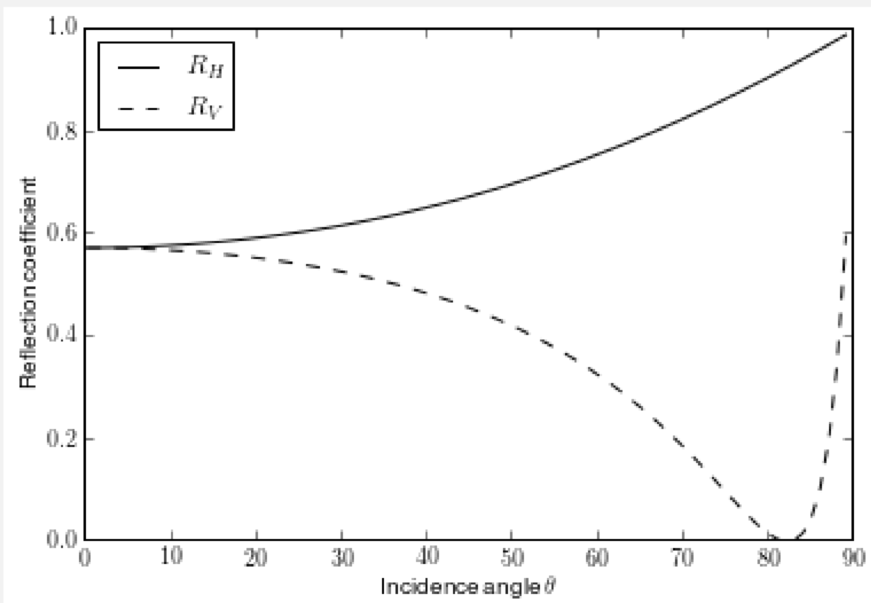
$$\Gamma_{\parallel}(f,\theta) = \left|\frac{\cos\theta - \sqrt{\varepsilon - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon - \sin^2\theta}}\right|^2 \tag{1}$$

$$\Gamma_{\perp} = (f,\theta) = \left|\frac{\varepsilon\cos\theta - \sqrt{\varepsilon - \sin^2\theta}}{\varepsilon\cos\theta + \sqrt{\varepsilon - \sin^2\theta}}\right|^2 \tag{2}$$

Snell's law and $\sin^2 + \cos^2 = 1$ was used in order to express the angle of transmission θ_2 in terms of the incidence angle $\theta_1 = \theta$. These equations are known as Fresnel equations. The parallel and perpendicular field directions are also know as horizontal (H) and vertical (V) polarisations.

```
def fresnel(theta,e):
    rh=((cos(theta)-sqrt(e-sin(theta)**2))/(cos(theta)+sqrt(e-sin(theta)**2)))**2
    rv=((e*cos(theta)-sqrt(e-sin(theta)**2))/(e*cos(theta)+sqrt(e-sin(theta)**2)))**2
    return rh,rv

theta=arange(90)/360.0*2*pi
T=273.15+20.0
S=30.0
f=19.0e9
eps_sw=abs(eps_water_func(T,S,f))
rh,rv=fresnel(theta,eps_sw)
plot(theta*180/pi,rh,'k-',label='$R_H$')
plot(theta*180/pi,rv,'k--',label='$R_V$')
xlabel(r"Incidence angle $\theta$ ")
ylabel(r"Reflection coefficient")
legend(loc=2)
```

```
<matplotlib.legend.Legend at 0xb7d734c>
```



Brightness temperature versus molecular temperature

```
figure(1)
f=1.4e9 # [GHz]
T0=273.13 #[K]
T=T0+linspace(0,42) # Temperature range

Tdown=0 # Downwelling atmospheric radiation [K]
Sa=array([0.,10,14,18,22,26,30,34,38])# Sea water salinities

for S in Sa:
```

```
    R=nadir_reflectivity(T,S,f)
    TB=(1-R)*T+R*Tdown # Brightness temperature
    plot(T-T0,TB,label=str(S)+' g/kg')

legend(loc=2,prop = matplotlib.font_manager.FontProperties(size=10))
axis([0,42,85,110])
xlabel('Sea surface temperature $T_{SST}$ [$^\circ$C]')
ylabel('Brightness temperature $T_B$ [K]')
savefig('Swift_1980_Fig4.png',dpi=75) # Compare to Fig. 6 in Klein and Swift (1977)
show()
```