Programming Task 3
Photo-ionization

Trym Varland
Git: tva050
UiT - Norges Arktiske Universitet

May 15, 2023

Theory

Photo-Ionization

Photo-ionization is a process, where we have atom, molecules or ions is ionized by absorbing photon of sufficient energy. When a photon is absorbed, it can transfer enough energy to a electron such that it is removed from the bound state, hence creates a free electron and positive ion. The energy required to ionize a atom or molecule is typically in the ultraviolet or higher energy range. In our case, the energy will be by the solar radiation.

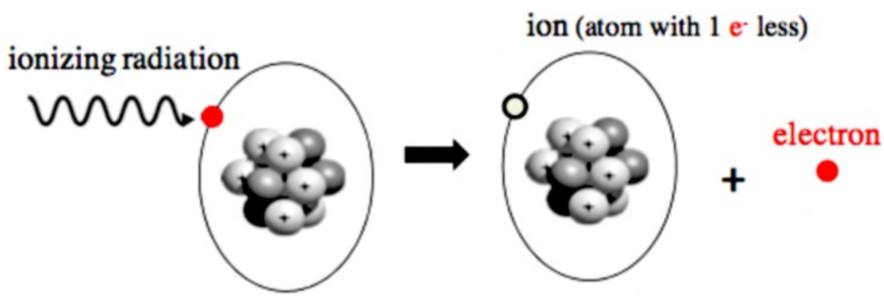


Figure 1: Illustration of the photo-ionization process. Fig from [1]

Photo-Electrons

Photo-electrons are the electrons that are emitted, from the photo-ionization process. These photo-electrons that are emitted, can take part of different important processes in the upper atmosphere. One of these process is for example the formation of the ionosphere, where the density of photo-ionized particles is high enough to inflict with radio waves. The photo-electrons created in the photo-ionization process can collide with natural particles transferring the energy and ionize them. This can lead to a cascade of ionization, which creates a layer of ionized gas. Photo-electron can also effect the chemistry and dynamics in the upper atmosphere.

Task 1: Make functions that calculate the production rate of photo-electrons as a function of altitude and energy.

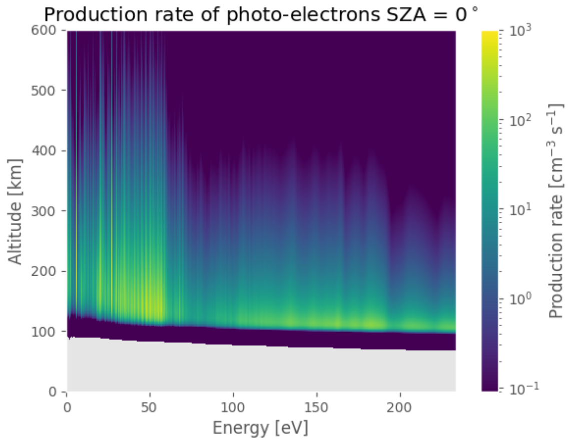
To be able to calculate the production rate of photo-electrons, we first gone need to calculate the electron energy.

$$E = hc(\frac{1}{\lambda_{th}} - \frac{1}{\lambda_{th}(j,l)})(eV) \tag{1}$$

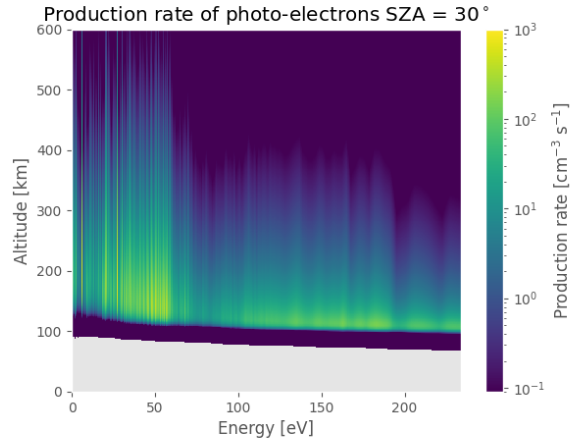
Where h is Planck's constant and c is the speed of light. $\lambda_t h(j,l)$ is the threshold wavelength, which is defined by the electronic state l of species j. Than we can calculate the production rate of photo-electrons with energy E at altitude z, which is given by.

$$P_z^e(E) = \sum_j \sum_l \sum_\lambda n_z(j)\sigma_j^i(\lambda)p_j^i(l,\lambda_{th},\lambda)I_z(\lambda) \tag{2}$$

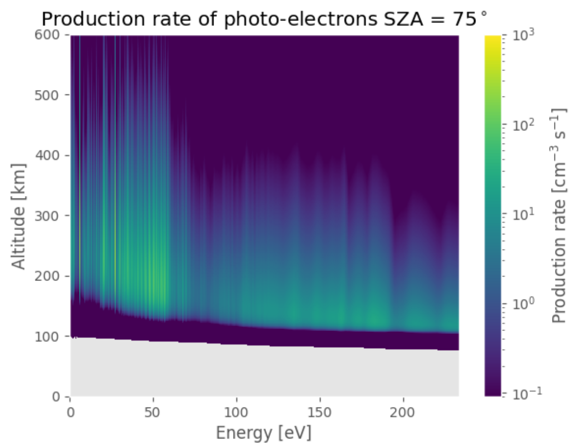
Where $I_z(\lambda)$ is the intensity of the solar irradiance. By computing equation for the production rate of photo-electrons 2, we would predict that will have bigger production-rate of photo-electrons higher up in the atmosphere. This is because most of the short wavelength (high frequency hence high energy) photons, are mostly absorbed in the upper atmosphere. That would say less of these photons, reach the lower atmosphere (under 120km). But we will find that the biggest production rate of photo-electron, is where we start to have a denser atmosphere which would at a round the E-region and the F1-region. This comes clear by looking at figure 2, where we have the plot of the production rate of the photo-electrons as function of altitude and energy. The stronger the color is, the higher the production rate is. In plot 2a, we see clearly that when the solar zenith angle is zero we have the highest production rate of photo-electrons compered with the other plots.



(a) Photo-electron prod rate, SZA= 0°



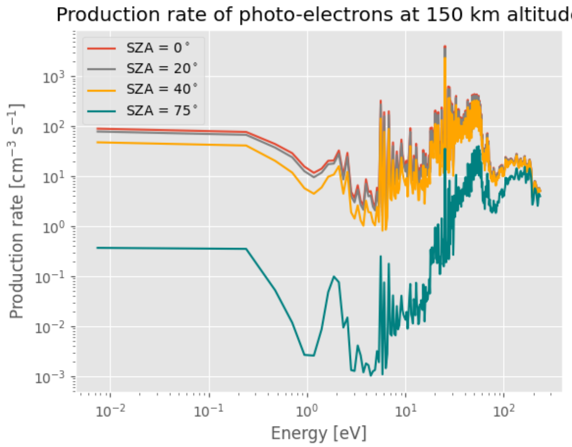
(b) Photo-electron prod rate, SZA= 30°



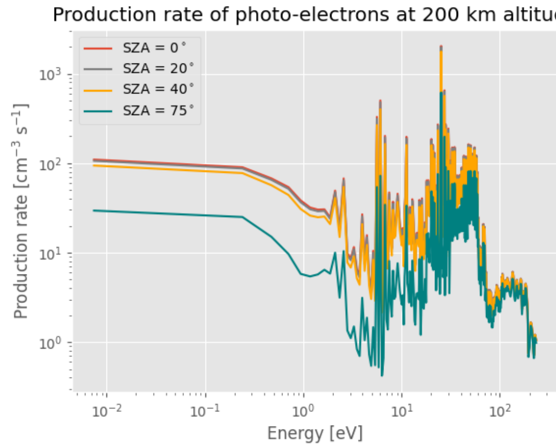
(c) Photo-electron prod rate, SZA= 75°

Figure 2: Plot of the production rate of photo-electrons as function of altitude and energy. Here wee have the altitude on the y-axis and the energy on the x-axis, the stronger the colors is the higher the production rate is.

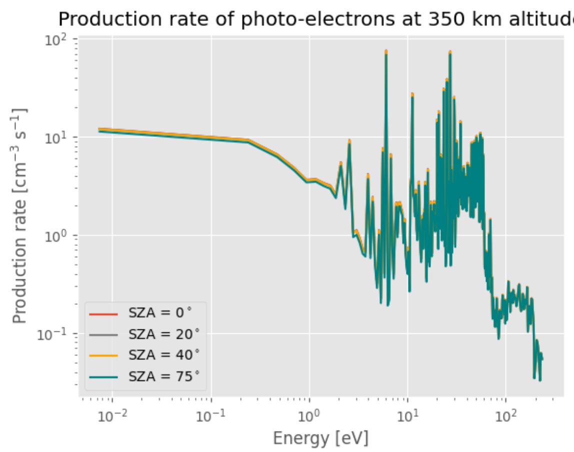
In figure 3, we have plots of the production rate of photo-electrons as function of energy. Where each individual plot, have a specific altitude. From the plot we can see that, when we approach a higher altitude, the photo-electron production rate becomes more and more the same beside having different solar-zenith angles(SZA). This makes sense, since the photons will effect the same value of particles in the upper part of the atmosphere when we have different SZA. But when the altitude is smaller, more of photons with large SZA will be absorbed of particles on the way down.



(a) Photo-electron prod rate, altitude 150km



(b) Photo-electron prod rate, altitude 200km



(c) Photo-electron prod rate, altitude 350km

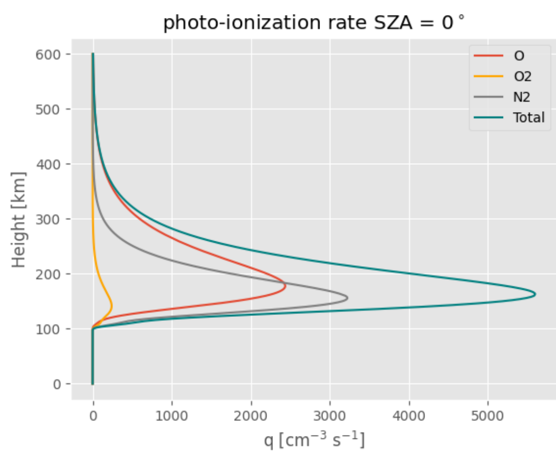
Figure 3: These plots shows the production rate at the y-axis and the energy on the x-axis, each plot represent a specific altitude.

Task 2: Make functions that calculate the photo-ionization profiles as a function of altitude.

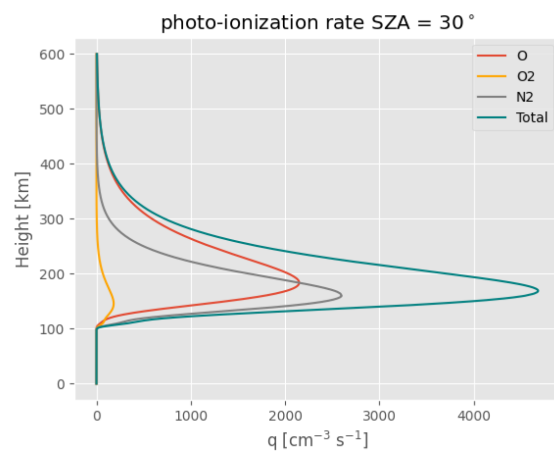
Now we gone make a function that calculate the photo-ionization as a function of altitude. To do this we need to calculate the photo-ionization rate, which we do by adding up all the photo-ionization events, given by.

$$q_j^i(z,l) = n_j(z)\int_0^{\lambda_{th}} I(z,\lambda)\sigma_j^i(\lambda)p_j(\lambda,l)d\lambda \tag{3}$$

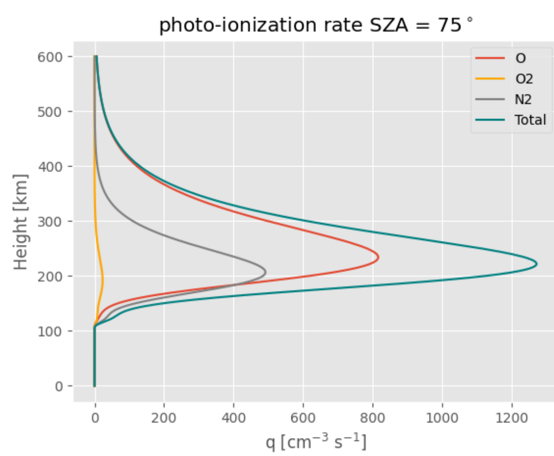
This the photo-ionization rate of species j at altitude z. When computing/plotting the photo-ionization rate, we get the photo-ionization profile. We would expect to see, that we have the biggest photo-ionization rate at the F1- and the F2-region (upper atmosphere) but this will vary with the solar-zenith angle (I). Which possible to see out the equation for the photo-ionization 3, this comes clear by looking at the plot in figure 4. In the plots in figure 4, we have the photo-ionization production rate at the x-axis and on the y-axis we have the height (km). In plot 4a where the solar-zenith angle is zero degrees, we have the biggest photo-ionization production rate. Compered with the plots 4b and 4c, where the solar-zenith angle is 30- and 75-degrees. Which makes sense, since when the solar-zenith angle is at zero degrees the probability for ionization is bigger. We can also see that when the solar-zenith angle is increasing the peaks for the ionization rate, goes towards a higher altitude. This is predicted since, when the solar-zenith angle is zero degrees the photons will propagate further down in the atmosphere. That would say, when **n** increases and **I** will decrease as we go down in the atmosphere.



(a) Photo-ionization rate, SZA= 0°



(b) Photo-ionization rate, SZA= 30°



(c) Photo-ionization rate, SZA= 75°

Figure 4: Plot for the photo-ionization profiles, where the x-axis is the photo-ionization production rate q and the y-axis shows the height/altitude.

To be able to plot the comparison of the total ionization-profiles, with simplified relations for the solar-zenith angle variation of the peak photo-ionization rate and its altitude. Or better know as the Chapman production profile. We can provide the following equation

$$q = q_{m,0} exp\big[1 - \frac{z - z_{m,0}}{H} - \frac{1}{cos(\chi)} exp\big(-\frac{z - z_{m,0}}{H}\big)\big] \tag{4}$$

Where $q_{m,0}$ is the maximum photo-ionization rate, $z_{m,0}$ is the the highest altitude where we have the most photo-ionization rate and H is the scale height. By using equation 4, we obtain the plot shown in figure 5. As we can see from the plot, it corresponds pretty well with the plots in figure 4. Which we can see because of the magnitude of the peaks and there location in height, it looks like that in plot 5 is somewhat bigger than in 4. Which is expected, since this plot shows a the theoretical photo-ionization production rate.

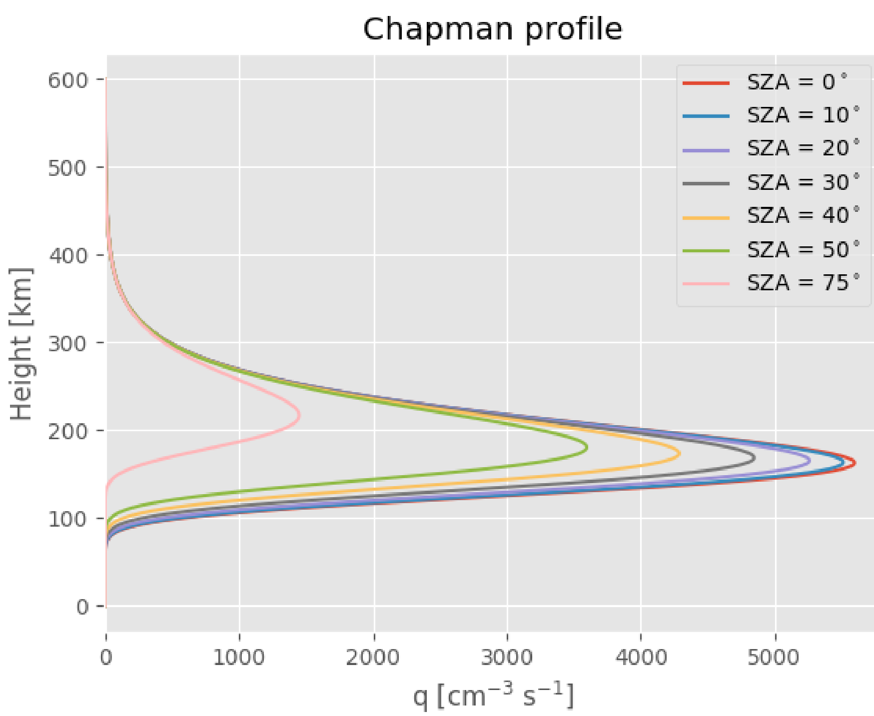


Figure 5: Chapman production profile

Appendix

References

[1] Marcia Silva. Livro: Evolution of ionizing radiation research/ cap. 8 ionizing radiation detectors, 09 2015.