MAE 119: Problem session 1

Wednesday, Jan 15, 2020

Problem 1: Theory

Find the following when it is 2:00 PM PST on Feb. 14 in San Diego, CA (32°,-117°):

1. **Solar time**

   For Feb. 14, the day of the year is $n = 45$. With that, we use Eq. 1.4.2, and obtain $B = (n-1) \times 360/365 = 43.39°$. Then we obtain the equation of time E (Eq. 1.5.3)

   $$E = 229.2(0.000075 + 0.001868 \cos B - 0.032077 \sin B - 0.014615 \cos 2B - 0.04089 \sin 2B)$$

   $$E = -14.26 \text{ min} = -14 \text{ min } 16 \text{ s}$$

   which is in agreement with Fig. 1.5.1 (always good to double check). Using (Eq. 1.5.2), we can compute the solar time

   $$\text{Solar time} = \text{Standard time} + 4(\mathrm{L_{st}} - \mathrm{L_{loc}}) + \mathrm{E}$$

   where $L_{st} = 8 \times 15° = 120°$ is the standard meridian for the local time zone PST (GMT-8), and the actual location longitude $L_{loc} = 117$ was given.

   $$\text{Solar time} = 4:00 \text{ PM} + 4 \text{ min}/°(120° - 117°) - 14 \text{ min } 16 \text{ s} = 2:00 \text{ PM} - 2 \text{ min } 16 \text{ s} = 1:57:44 \text{ PM}.$$

2. **Declination δ**

   The declination angle is the angular position of the sun at solar noon with respect to the plane of the equator, it can be estimated using any of the Eqs. 1.6.1.

   $$\delta = 23.45 \sin\left(360 \frac{284 + n}{365}\right) = -13.61°$$

   which is in agreement with values in Table 1.6.1.

3. **Hour angle ω**

   The hour angle ω is the angular displacement of the sun relative to the local meridian at 15° per hour, afternoon is positive. Since our solar time is 1:57:44 PM= 1.96 h after solar noon,

   $$\omega = 1.96 \text{ h} \times 15°/\text{h} = 29.43°.$$

4. **Sun angles: θ_z, α_s, γ_s**

   The solar zenith angle is computed using Eq. 1.6.5., with the latitude $\phi = 32°$

   $$\cos\theta_z = \cos\phi \cos\delta \cos\omega + \sin\phi \sin\delta$$

   $$\theta_z = 53.62°$$

   and the solar altitude angle is its complement

   $$\alpha_s = 90° - \theta_z = 36.37°$$

   Meanwhile, the solar azimuth angle is computed using Eq. 1.6.6.

   $$\gamma_s = sign(\omega) \left| \cos^{-1}\left(\frac{\cos\theta_z \sin\phi - \sin\delta}{\sin\theta_z \cos\phi}\right) \right| = 36.38°$$

   Important: Isn't this a weird value? It depends. The convention for azimuth angles **in the book** is $-90°$ facing south, $-90°$ east, $-180°$ or 180° north and 90° west. **For class and pvlib**, the convention is 180° facing south, 90° east, 0° north and 270° west. Be careful and consistent with the conventions.

5. **Angle of incidence θ for horizontal surface?**

   In this case, the tilt is $\beta = 0$ and $\theta = \theta_z = 53.62°$.

6. **Angle of incidence θ for surface tilted $30°$, facing south**

   In this case, the tilt is $\beta = 30°$ and $\gamma = 0°$ (using the book convention, or 180 for pvlib). Using Eq. 1.6.2.,

$$cos\theta = \sin\delta\sin\phi\cos\beta - \sin\delta\cos\phi\sin\beta\cos\gamma + \cos\delta\cos\phi\cos\beta\cos\omega + \\ \cos\delta\sin\phi\sin\beta\cos\gamma\cos\omega + \cos\delta\sin\beta\sin\gamma\sin\omega$$

$$\theta = 33.1°$$

Problem 2: pvlib

Pvlib is a software tool for solar energy applications, available for Matlab and Python (`https://pvpmc.sandia.gov/applications/pv_lib-toolbox/`). In the context of this class, we recommend using the Matlab package. This first exercise will focus on its installation and basic use.

1. Prepare your folders
   Download pbliv, and extract it in the folder where you will leave your code. For example, in a 'MAE119/code' folder, let's extract the pvlib package in 'MAE119/code/pvlib'

2. Getting started
   In our code folder, let's create a script called 'ProblemSession01.m'. To use pvlib, the first thing we need is to add its folder to the "PATH", a magical place where matlab can use all known functions. We do so with this command 'addpath(genpath('pvlib'))' which will add all scripts in the pvlib folder and subsequent subfolders. Now we are ready to use pvlib! (Note: There are other ways of doing this too.)

3. For December 25 in San Diego (32° N,117° W), obtain and plot the position of the sun during the day, including zenith, azimuth and altitude angles. Obtain and plot the air mass during the day. Obtain and plot the angle of incidence for a panel tilted 30° facing south during the day.

```
%% Add pvlib to path
addpath(genpath('pvlib'));

%% Setup location and time to analyze
today_time=datetime(2019,12,25,0:23,0,0);
% Feed in time and time zone
Time = pvl_maketimestruct(datenum(today_time),-8);


Location = pvl_makelocationstruct(32,-117); %San Diego lat and lon

%% Obtain sun position angles
[SunAz, SunEl, AppSunEl, SolarTime] = pvl_ephemeris(Time,Location);
SunZen=90-SunEl;

%% Plot Solar angles
plot(today_time,SunAz,today_time,SunEl,today_time,SunZen); grid on
legend('Azimuth angle','Elevation angle','Zenith angle')
xlabel('Hour of day'); ylabel('Angle (deg)')
% Why is elevation negative?

%% Another way of plotting (as we've seen in class)
plot(SunAz,SunEl); grid on
xlabel('Azimuth angle (deg)'); ylabel('Elevation angle(deg)')

%% Obtain air mass
AMa = pvl_relativeairmass(SunZen);
%there is also an absolute air mass function, requires pressure
```

```
%% Plot air mass
plot(today_time,AMa); xlabel('Time'); ylabel('Air␣mass');
% there are nan values... why?

%% Setup solar panel orientation and get angle of incidence
SurfTilt = 30; % Array tilt angle (deg)
SurfAz = 180; %Array azimuth (180 deg indicates array faces South)
AOI=pvl_getaoi(SurfTilt,SurfAz,SunZen,SunAz);

%% Plot AOI
plot(today_time,AOI); xlabel('Time'); ylabel('Angle␣of␣incidence␣(deg)')
```