Exercise Three: Modeling Solar Radiation

In this exercise you will calculate the annual instantaneous solar radiation at two locations and hourly insolation for the summer solstice and autumnal equinox for one location.

$$Q = S_0 \left(\frac{\bar{d}}{d}\right)^2 \cos\theta_s$$

Part One: Calculate the annual instantaneous solar radiation for Newark, Delaware (latitude (ϕ) = 39.4°) and Manaus, Brazil (latitude (ϕ) = -3.0°).

Calculating Instantaneous Insolation:
Q = Insolation [Wm^{-2}] at TOA
S_0 = Solar constant
q_s = solar zenith angle
d_{bar} = mean earth/sun distance
d = actual earth/sun distance

1.) Find the eccentricity correction $\left(\frac{\bar{d}}{d}\right)^2$ using Spencer's fourier series.

NOTE: the eccentricity correction ranges between 0.9666 – 1.0351

$$\left(\frac{\bar{d}}{d}\right)^2 = 1.000110 + 0.034221\cos(\theta_d) + 0.001280\sin(\theta_d) + 0.000719\cos(2\theta_d) + 0.000077\sin(2\theta_d)$$

$$\theta_d = \frac{2\pi d_n}{365}$$

θ_d = time of year (radians), d_n = day number (Jan 1 = 0, Dec 31 = 364)
radians/degree conversion = π/180

2.) Find the declination (δ) as a function of Julian day.

$$\delta = 0.006918 - 0.399912\cos(\theta_d) + 0.070257\sin(\theta_d) - 0.006758\cos(2\theta_d) + 0.000907\sin(2\theta_d)$$
$$-0.002697\cos(3\theta_d) + 0.001480\sin(3\theta_d)$$

3.) Find the solar zenith angle (θ_s) as a function of the declination.

$$\cos\theta_s = \sin\phi\sin\delta + \cos\phi\cos\delta\cos h$$

NOTE: h is the hour angle and is equal to zero at local noon and increases in magnitude by pi/12 or 15° for every hour before and after noon.

Program Setup:
Declarations - declare all integers, constants, and arrays

```
Integers:             do loop indices (i,j)
Constants (real):     solar constant (So=1367.0)
                      hour angle at solar noon (h0=0.0)
Arrays (real):        latitude(1:2)
                      days(1:365)
                      insolation - Qd(1:365,1:2)
Other #'s:            julian days (dn)
                      time of year (thetad)
                      eccentricity
                      declination
                      zenith angle (cosz)
                      pi & radians-to-degree conversion
```

Calculations and do loops – calculate the instantaneous insolation at solar noon for both locations (1:365,1:2)

Calculate pi and conversion factor: `pi = acos(-1.0)`
`dr = pi/180.0`
Set latitudes: `lat(1) = 39.4`
`lat(2) = -3.0`

Note: Fortran calculate angles in radians not degrees. Therefore you must convert the latitudes, which are in degrees, to radians. You can do this when you define them or in the calculation itself.

Set up do loops:

```
do i=1,2         !one for each location
     do j=1,365 !calculate value for each day
          day(j) = real(j)
          julian_day = day(j) - 1.0
          thetad = …
          ec = …
          d = …
          cosz = …
          Qd (j,i) = …
     end do
end do
```

Graphs - raph Q for Newark and Manaus on the same graph.
Remember to open gpl before calling gpl then close it after the gpl call and use GPLR

Set up your graph using:
x=day(1:365) NOTE: this refers to day values 1 to 365
y=Qd(1:365,1:2)
xlabel='Days'
ylabel='Insolation (Wm-2)'

Part Two: Calculate and graph the hourly insolation at Newark, DE on June 21st (day 172) and August 22 (day 265).

1.) Find the eccentricity correction for July 21 and August 22.
2.) Find the declination (δ) for July 21 and August 22.
3.) Find the hour angle for every hour for the day. → h = pi/12*(12-hr)
4.) Find the solar zenith angle (θ_s) for every hour of the day.
5.) Calculate hourly values for Q.
6.) Graph Q for Newark on the same graph.

Programming notes:
- Declare new values for hourly calculations.
- You'll need to calculate values for thetad, eccentricity, and declination for Julian day 171 and 264 (because dn = 172, 265). Do this in a do loop i=1,2
- Create a loop j=1,24 to calculate hourly values of hour angle, cosz, and Qh.
- Calculate cosz using the Newark latitude only (lat(1))

```
Dn(1) = 171           !julian day number for June 21st
Dn(2) = 264           !julian day number for August 22
Do i=1,2
     Thetad = (2.0*pi*dn(i))/365.0
     Ec = …
     D = …
     Do j=1,24
          hr(j) = real(j)
          h = pi/12.0 * (12.0-hr(j)) !hour angle
          cosz = …              !use only Newark lat
          Qh(j,i) = …
```

- Add an if statement specifying that if Qh(h,i) < 0 make Qh(h,i) = 0.0

```
     if (Qh(h,i) < 0.0) then
          Qh(h,i) = 0.0
     else
           Qh(h,i) = Qh(h,i)
     end if
      end do
  end do
```

- Graph the two curves using GPLR and x = hr(1:24) and y=Qh(1:24,1:2)