CEE6400 Physical Hydrology

Homework 8. Solar Radiation and Evapotranspiration

Date: 11/18/13
Due: 12/4/13

Reading: (for this and future homeworks)
Dingman, S. L., (2002)

- **Appendix E. Radiation on sloping surfaces**

Solar Radiation direct approach handout solarrad.pdf

Dingman, S. L., (2002), Chapter 7

Shuttleworth, W. J., (1993), "Evaporation," in Handbook of Hydrology, Chapter 4, Edited by D. R. Maidment, McGraw-Hill, New York.

Learning Objectives
Be able to calculate incoming solar radiation as a driver of evaporation and snowmelt based on of geographic location (latitude and longitude), date, time of day and atmospheric conditions.

Be able to calculate evaporation from open water surfaces and transpiration from vegetation, using a method appropriate for the information available.

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1. Make sure you understand the workings of the spreadsheet SolarRad.xls from the CD in Dingman. Verify that it treats sunrise and sunset correctly in the integration of daily clear sky radiation (equations E-7 and E-25). Sunrise should be the later of the local slope and horizon sunrise. Sunset should be the earlier of the local slope and horizon sunset. Consider a location with latitude 41^{o}N on November 20. Assume the following weather parameters. Air temperature 10^{o}C, relative humidity 50%, surface albedo 0.3, dust attenuation parameter 0.05.
   a) Report the declination, day angle and eccentricity for this date.
   b) Look up the optical air mass on figure E-4 and enter this in cell D-14. Report the day length, extra terrestrial and clear sky radiation for a horizontal surface.
   c) Explore the sensitivity of radiation to slope. Consider an east-west slope and plot day length, extra terrestrial and clear sky radiation for slope varying from 30^o west facing to 30^o east facing (in 5^o increments). Then consider a north-south slope and plot day length, extra terrestrial and clear sky radiation for slope varying from 30^o south facing to 30^o north facing (in 5^o increments).
   d) Explore the sensitivity of radiation to relative humidity. For a horizontal location with other parameters the same as above plot extra terrestrial and clear sky radiation for relative humidity varying from 0 to 1 (in 0.1 increments).

2. In problem 1 you should have used the equivalent slope concept of appendix E. An alternative direct approach was described in the handout solarrad.pdf.

a) Verify the equivalence of the two approaches by calculating the instantaneous extra terrestrial radiation flux at 11 am on November 20 for the following location:

   Latitude: 41^oN, Slope: 10^o, Azimuth: 70^o

   (i) In the equivalent plane approach report the equivalent latitude (Equation E-23, cell D39) and longitude difference (Equation E-22, cell D38). Adjust the time based on the longitude difference ($t_{adj}=t+\Delta\Omega/15^o$) and use equation E-6 with equivalent latitude and adjusted time to calculate the instantaneous extraterrestrial radiation flux.
   (ii) In the direct approach use equation E-4 to evaluate zenith angle. Then use the handout solarrad.pdf equation (2) to evaluate solar azimuth A, and equation (1) to evaluate solar illumination angle z. Report these angles. Evaluate the instantaneous extraterrestrial radiation flux as $I_{sc}E_o\cos z$ (equation 3 with eccentricity correction included for completeness).

   You should get the same answer for (i) and (ii).

   (iii) Determine the time of local sunset by the equivalent plane approach (T_{ss} from equation E-24b, cell F40). Evaluate cos z from solarrad.pdf equation (1). What answer should you get?
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b) The location used in (a) is in the center of a valley 15 km wide, oriented north - south bounded by mountains on the east and west that rise 1200 m above the valley floor (eg. Cache Valley). This geometry defines the angle of the horizon and direct sunlight only illuminates the location under consideration when the sun is above the horizon, otherwise the valley is in shadow.

   (i) For a range of times (from solar noon - 7 hours to solar noon + 7 hours in hourly increments on November 20) calculate the solar azimuth and solar zenith angle. Display these graphically.
   (ii) Considering the valley geometry calculate the angle to the horizon in the direction of the sun (solar azimuth) for each of the times in (i) and solve for the time when the sun first impacts and last disappears from the location at the center of the valley (remembering that it is sloping).
   (iii) Calculate the daily extra terrestrial solar radiation accounting for shadowing for this location by numerically integrating $I_{sc}E_o\cos z$ between the times evaluated in (ii).
   (iv) Use the spreadsheet solarrad.xls to evaluate the extra terrestrial solar radiation by the equivalent plane approach for this location neglecting the shadowing effects of the horizons.
   (v) Modify the spreadsheet solarrad.xls to evaluate the extra terrestrial solar radiation by the equivalent plane approach between the times computed in (ii) (by evaluating equation E-25 (cell C42) between these times.
   (vi) Explain the reasons for differences between your answers in (iii), (iv) and (v). Which is most accurate?

3. At a weather station near a lake the following measurements are made.

- Air pressure 85 kPa
- Air Temperature 22 ^oC
- Relative humidity 46%
- Net radiation 90 W/m^2
- Wind speed 2.5 m/s at a height of 2.0 m
- Water temperature 19 ^oC
- Surface roughness length $z_o = 4 \times 10^{-4}$ m.

a) Calculate the vapor pressure, dew point, specific humidity and air density.

b) Assume that there is negligible heat flux into the lake and the heat capacity of air at constant pressure $Cp = 1005\ J\ kg^{-1}\ K^{-1}$. Estimate the rate of evaporation from the lake using the following methods.
   i) Priestley Taylor (assume a humid environment)
   ii) Mass Transfer/Aerodynamic
   iii) Combination/Penman
   iv) Energy balance/Bowen Ratio

c) You may have learned that evaporation increases with wind speed. Suppose the wind speed were to double (to 5 m/s at a 2.0 m height). Estimate the increase in evaporation by each method. Explain your results.

4. Dingman Problem 7.1.

5. Dingman Problem 7.2.

6. Dingman Problem 7.6.

7. Complete the Final Exam for the Rainfall Runoff Processes module. Access to the final exam is enabled in the module once you have completed all the end of chapter quizzes. You should have done these in previous homework's.