USWB Evaporation

April 17, 2018

1 United States Weather Bureau Method for Evaporation

This method is based on the Penman equation for evaporation, and is dependant on the daily average air temperature, relative humidity, daily solar radiation, and the average daily wind speed

In [1]:
```
import numpy as np
import pandas as pd
import math
import matplotlib.pyplot as plt
import seaborn as sns
%matplotlib inline
```

In [2]:
```
hollis = pd.read_csv("data/Hollis.csv")
hollis.head()
```

Out[2]:

	Date / Time	AirTC (Avg)	RH	SlrkW (Avg)	SlrjJ (Tot)	WS ms (Avg)	\
0	7/17/2014 15:30	26.94	67.85	0.412	609.3776	1.667	
1	7/17/2014 16:00	26.89	69.88	0.387	696.9075	1.618	
2	7/17/2014 16:30	26.45	73.05	0.154	277.9549	1.753	
3	7/17/2014 17:00	26.27	73.78	0.183	328.9092	1.879	
4	7/17/2014 17:30	25.95	75.34	0.060	107.9211	1.944	

	Wind Dir	T108 C (Avg)	HBr3W	Rain mm (Tot)
0	335.900	31.21	221.5	0.0
1	59.220	31.45	221.4	0.0
2	52.930	31.25	221.3	0.0
3	2.172	30.91	220.9	0.0
4	33.750	30.47	220.8	0.0

In [3]:
```
df = hollis[["Date / Time", "RH", "SlrkW (Avg)", "WS ms (Avg)", "T108 C (Avg)"]]    #U
df.columns = ['date', 'humidity', "energy", "wind", 'temp']
df.dropna(inplace=True)
df["date"] = pd.to_datetime(df.date).dt.normalize()
df.describe()
```

```
/usr/local/lib/python3.5/dist-packages/ipykernel_launcher.py:3: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame
```

```
See the caveats in the documentation: http://pandas.pydata.org/pandas-docs/stable/indexing.html
  This is separate from the ipykernel package so we can avoid doing imports until
/usr/local/lib/python3.5/dist-packages/ipykernel_launcher.py:4: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame.
Try using .loc[row_indexer,col_indexer] = value instead

See the caveats in the documentation: http://pandas.pydata.org/pandas-docs/stable/indexing.html
  after removing the cwd from sys.path.
```

Out[3]:

	humidity	energy	wind	temp
count	20054.000000	20054.000000	20054.000000	20054.000000
mean	80.269694	0.174742	1.167754	27.002141
std	54.656236	0.262976	0.797486	2.911931
min	0.612000	0.000000	0.000000	20.460000
25%	7.816250	0.000000	0.429000	24.770000
50%	91.100000	0.003000	1.087000	26.440000
75%	119.000000	0.294000	1.739000	28.960000
max	217.200000	1.150000	4.445000	37.270000

Notice the quite high and low humidity values? Wind and temp make sense and I don't know what energy is supposed to look like. Humidity will be fixed later on

In [4]:
```
df = df.groupby('date', as_index=False, sort=False).mean()
df.head()
```

Out[4]:

	date	humidity	energy	wind	temp
0	2014-07-17	81.728235	0.072294	1.359412	28.745294
1	2014-07-18	89.427083	0.058667	1.032292	24.944583
2	2014-07-19	86.988125	0.126229	1.284333	25.877708
3	2014-07-20	88.730833	0.096042	1.010750	25.772083
4	2014-07-21	82.476458	0.204146	1.176583	27.385000

In [5]:
```
df.loc[df.humidity < 70, 'humidity'] = 80
df.loc[df.humidity > 100, 'humidity'] = 80
df.describe()
```

Out[5]:

	humidity	energy	wind	temp
count	420.000000	420.000000	420.000000	420.000000
mean	82.476255	0.174555	1.166152	27.004829
std	4.369920	0.049676	0.395389	1.336323
min	76.369583	0.016667	0.383313	23.325000
25%	80.000000	0.140318	0.864198	25.968125
50%	80.000000	0.179625	1.134688	26.921667
75%	83.773906	0.210214	1.442302	28.067812
max	99.952083	0.277042	2.390104	30.116458

1.1 Relative Humidity

First, a component of relative humidity is calculated based on the the average daily relative humidity f, in percent.

$$X = 1 - \frac{f}{100}$$

```
In [6]: df['CRH'] = 1 - (df['humidity'])/100
        df.head()
```

Out[6]:

	date	humidity	energy	wind	temp	CRH
0	2014-07-17	81.728235	0.072294	1.359412	28.745294	0.182718
1	2014-07-18	89.427083	0.058667	1.032292	24.944583	0.105729
2	2014-07-19	86.988125	0.126229	1.284333	25.877708	0.130119
3	2014-07-20	88.730833	0.096042	1.010750	25.772083	0.112692
4	2014-07-21	82.476458	0.204146	1.176583	27.385000	0.175235

1.2 Dewpoint Temperature

$$T_d = T_a - \left[(14.55 + 0.114T_a)X + [(2.5 + 0.007T_a)X]^3 + (15.9 + 0.117T_a)X^{14}\right]$$

where Ta is the average daily temperature in degrees Celsius. Yes, that's quite an equation

```
In [7]: df['DT'] = df['temp']-(14.55+0.114*df['temp'])*df['CRH']+((2.5+0.007*df['temp'])*df['CI
        df.head()
```

Out[7]:

	date	humidity	energy	wind	temp	CRH	DT
0	2014-07-17	81.728235	0.072294	1.359412	28.745294	0.182718	25.608225
1	2014-07-18	89.427083	0.058667	1.032292	24.944583	0.105729	23.128177
2	2014-07-19	86.988125	0.126229	1.284333	25.877708	0.130119	23.643083
3	2014-07-20	88.730833	0.096042	1.010750	25.772083	0.112692	23.828889
4	2014-07-21	82.476458	0.204146	1.176583	27.385000	0.175235	24.393200

1.3 Dimensionless Ratios

$$\frac{\Delta}{\Delta + \gamma} = \left[1 + \frac{0.66}{(0.00815T_a + 0.8912)^7}\right]^{-1}$$

Just do it. Delta is the gradient of saturated vapour pressure and Gamma is something called the psychromatic constant

```
In [8]: df['ratiodelta'] = (1+(0.66/(0.00815*df['temp']+0.8912)**7))**-1
        df.head()
```

Out[8]:

	date	humidity	energy	wind	temp	CRH	DT	\
0	2014-07-17	81.728235	0.072294	1.359412	28.745294	0.182718	25.608225	
1	2014-07-18	89.427083	0.058667	1.032292	24.944583	0.105729	23.128177	
2	2014-07-19	86.988125	0.126229	1.284333	25.877708	0.130119	23.643083	
3	2014-07-20	88.730833	0.096042	1.010750	25.772083	0.112692	23.828889	
4	2014-07-21	82.476458	0.204146	1.176583	27.385000	0.175235	24.393200	

```
   ratiodelta
0    0.776076
1    0.740312
2    0.749521
3    0.748493
4    0.763804
```

$$\frac{\gamma}{\Delta+\gamma} = 1 - \frac{\Delta}{\Delta+\gamma}$$

```
In [9]: df['ratiogamma'] = 1 - df['ratiodelta']
        df.head()
```

Out[9]:

	date	humidity	energy	wind	temp	CRH	DT	ratiodelta	ratiogamma
0	2014-07-17	81.728235	0.072294	1.359412	28.745294	0.182718	25.608225	0.776076	0.223924
1	2014-07-18	89.427083	0.058667	1.032292	24.944583	0.105729	23.128177	0.740312	0.259688
2	2014-07-19	86.988125	0.126229	1.284333	25.877708	0.130119	23.643083	0.749521	0.250479
3	2014-07-20	88.730833	0.096042	1.010750	25.772083	0.112692	23.828889	0.748493	0.251507
4	2014-07-21	82.476458	0.204146	1.176583	27.385000	0.175235	24.393200	0.763804	0.236196

1.4 Effective Net Radiation

$$Q_n = 0.00714Q_s + 0.00000526Q_s(T_a+17.8)^{1.87} + 0.00000394Q_s^2 - 0.00000000239Q_s^2(T_a-7.2)^2 - 1.02$$

where Qs is the daily solar radiation in calories per square centimeter. We need to do a conversion since the data we have is in kilowatt-hours

```
In [10]: df['energy'] = df['energy']*86.011
```

```
In [11]: df['rad'] = 0.00714*df['energy']+0.00000526*df['energy']*(df['temp']+17.8)**1.87+0.000
         df.head()
```

Out[11]:

	date	humidity	energy	wind	temp	CRH	DT	ratiodelta	ratiogamma	rad
0	2014-07-17	81.728235	6.218089	1.359412	28.745294	0.182718	25.608225	0.776076	0.223924	-0.932620
1	2014-07-18	89.427083	5.045979	1.032292	24.944583	0.105729	23.128177			
2	2014-07-19	86.988125	10.857097	1.284333	25.877708	0.130119	23.643083			
3	2014-07-20	88.730833	8.260640	1.010750	25.772083	0.112692	23.828889			
4	2014-07-21	82.476458	17.558787	1.176583	27.385000	0.175235	24.393200			

```
1    0.740312    0.259688 -0.954218
2    0.749521    0.250479 -0.875854
3    0.748493    0.251507 -0.910545
4    0.763804    0.236196 -0.779909
```

1.5 Vapour Pressure Difference

$$e_s - e_a = 33.86\left[(0.00738T_a + 0.8072)^8 - (0.00738T_d + 0.8072)^8\right]$$

where es is the saturation vapour pressure in millibars nd ea is the vapour pressure at the temperature of the air

```
In [12]: df['vapour'] = 33.86*(((0.00738*df['temp']+0.8072)**8)-((0.00738*df['DT']+0.8072)**8))
         df.head()
```

Out[12]:

	date	humidity	energy	wind	temp	CRH	DT	ratiodelta	ratiogamma	rad	vapour
0	2014-07-17	81.728235	6.218089	1.359412	28.745294	0.182718	25.608225	0.776076	0.223924	-0.932620	6.626309
1	2014-07-18	89.427083	5.045979	1.032292	24.944583	0.105729	23.128177	0.740312	0.259688	-0.954218	3.258145
2	2014-07-19	86.988125	10.857097	1.284333	25.877708	0.130119	23.643083	0.749521	0.250479	-0.875854	4.163760
3	2014-07-20	88.730833	8.260640	1.010750	25.772083	0.112692	23.828889	0.748493	0.251507	-0.910545	3.627889
4	2014-07-21	82.476458	17.558787	1.176583	27.385000	0.175235	24.393200	0.763804	0.236196	-0.779909	5.913547

1.6 Evaporation

$$E_a = (e_s - e_a)^{0.88}(0.42 + 0.0029v_p)$$

where vp is average wind speed in kilometers per day. Therefore we need to do another conversion since the wind speed we have is in meters per second apparently

```
In [13]: df['wind'] = df['wind']/100*86400
```

```
In [14]: df['evapA'] = df['vapour']**0.88*(0.42+0.0029*df['wind'])
         df.head()
```

Out[14]:

	date	humidity	energy	wind	temp	CRH	DT	ratiodelta	ratiogamma	rad	vapour	evapA
0	2014-07-17	81.728235	6.218089	1174.531765	28.745294	0.182718	25.608225	0.776076	0.223924	-0.932620	6.626309	20.205992
1	2014-07-18	89.427083	5.045979	891.900000	24.944583	0.105729						
2	2014-07-19	86.988125	10.857097	1109.664000	25.877708	0.130119						
3	2014-07-20	88.730833	8.260640	873.288000	25.772083	0.112692						
4	2014-07-21	82.476458	17.558787	1016.568000	27.385000	0.175235						

```
1  23.128177    0.740312    0.259688 -0.954218  3.258145   8.501129
2  23.643083    0.749521    0.250479 -0.875854  4.163760  12.764774
3  23.828889    0.748493    0.251507 -0.910545  3.627889   9.176786
4  24.393200    0.763804    0.236196 -0.779909  5.913547  16.091793
```

Reservoir evaporation is then given by:

$$E = 0.7\left[\frac{\Delta}{\Delta+\gamma}Q_n + \frac{\gamma}{\Delta+\gamma}E_a\right]$$

where E somehow turns out to be in mm

```
In [15]: df['E'] = 0.7*(df['ratiodelta']*df['rad']+df['ratiogamma']*df['evapA'])
         df.head()
```

```
Out[15]:         date   humidity     energy         wind       temp       CRH  \
         0 2014-07-17  81.728235   6.218089  1174.531765  28.745294  0.182718
         1 2014-07-18  89.427083   5.045979   891.900000  24.944583  0.105729
         2 2014-07-19  86.988125  10.857097  1109.664000  25.877708  0.130119
         3 2014-07-20  88.730833   8.260640   873.288000  25.772083  0.112692
         4 2014-07-21  82.476458  17.558787  1016.568000  27.385000  0.175235

                   DT  ratiodelta  ratiogamma       rad    vapour      evapA         E
         0  25.608225    0.776076    0.223924 -0.932620  6.626309  20.205992  2.660569
         1  23.128177    0.740312    0.259688 -0.954218  3.258145   8.501129  1.050859
         2  23.643083    0.749521    0.250479 -0.875854  4.163760  12.764774  1.778587
         3  23.828889    0.748493    0.251507 -0.910545  3.627889   9.176786  1.138545
         4  24.393200    0.763804    0.236196 -0.779909  5.913547  16.091793  2.243579
```

1.7 Monthly Evaporation

```
In [16]: month_df = df[['date', 'E']]
         month_df.set_index('date', inplace=True)
         month_df.head()
```

```
Out[16]:                    E
         date
         2014-07-17  2.660569
         2014-07-18  1.050859
         2014-07-19  1.778587
         2014-07-20  1.138545
         2014-07-21  2.243579
```

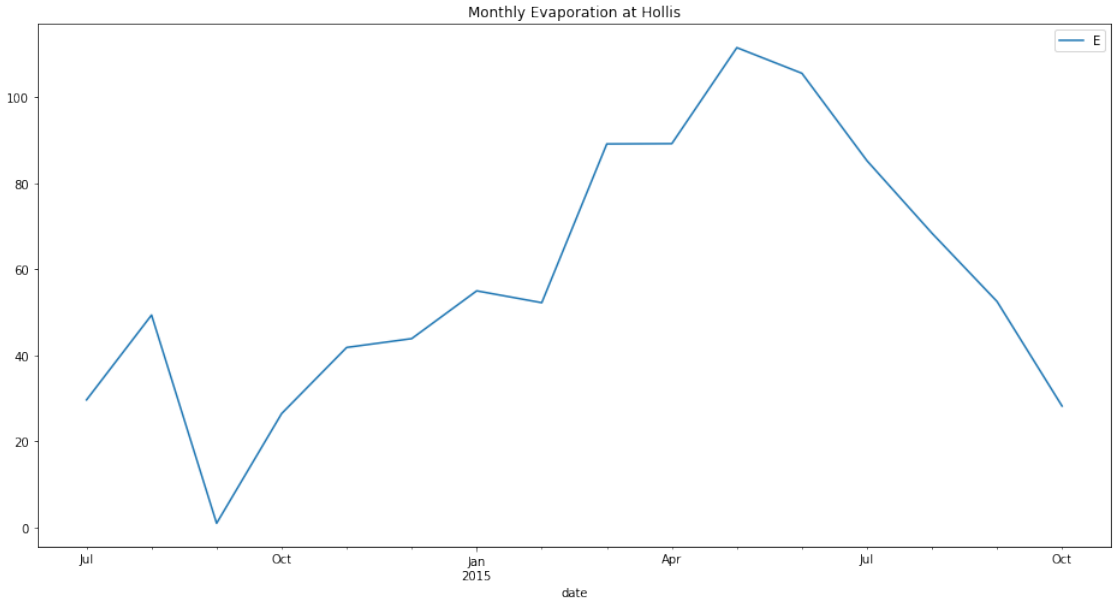
```
In [17]: month_df_sum = month_df.groupby(pd.Grouper(freq="M")).sum()
         month_df_sum.head()
```

```
Out[17]:                     E
         date
         2014-07-31  29.651483
         2014-08-31  49.364594
```

```
2014-09-30   0.981232
2014-10-31  26.470428
2014-11-30  41.832963
```

```
In [18]: month_df_sum.plot(figsize=(16,8), title='Monthly Evaporation at Hollis')
```

```
Out[18]: <matplotlib.axes._subplots.AxesSubplot at 0x7fd19cb10240>
```

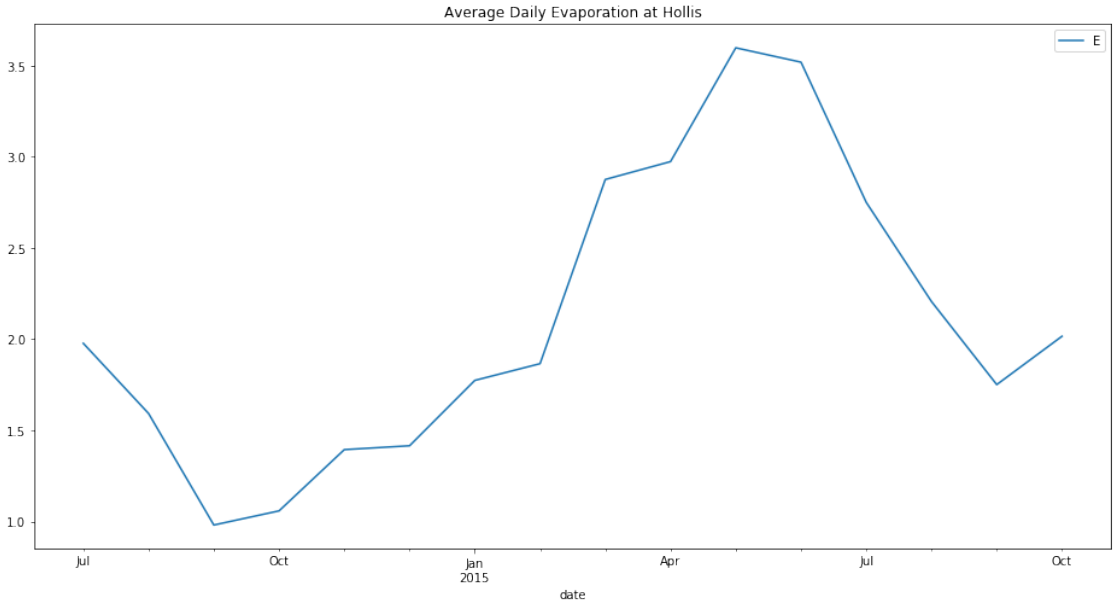



```
In [19]: month_df_avg = month_df.groupby(pd.Grouper(freq="M")).mean()
         month_df_avg.head()
```

```
Out[19]:                   E
         date
         2014-07-31  1.976766
         2014-08-31  1.592406
         2014-09-30  0.981232
         2014-10-31  1.058817
         2014-11-30  1.394432
```

```
In [20]: month_df_avg.plot(figsize=(16,8), title='Average Daily Evaporation at Hollis')
```

```
Out[20]: <matplotlib.axes._subplots.AxesSubplot at 0x7fd19c7b6c88>
```



1.8 Print useable table of values

```
In [21]: month_df_sum.to_csv("results/USWB_total.csv")
         month_df_avg.to_csv("results/USWB_average.csv")
```

1.9 References

https://pubs.usgs.gov/sir/2012/5202/pdf/sir2012-5202.pdf