Correlation of Ontario Wind Farm Power Output with Wind Farm Separation

A major problem with wind power is that wind is unreliable. The wind speed can vary quickly, up and down, causing grid instability and the need for always-on energy generation back-up. An argument used by the wind industry is that if the wind is low or changing somewhere, then elsewhere it will be high or changing to compensate.

A way to test this is to measure the correlation between the power outputs of different wind farms. This has been done and the results presented below through the pair correlation function C where,

$$C = \frac{\frac{1}{N}\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sigma_x \sigma_y}$$

x_i is the i^{th} power output from the first wind farm of the pair and y_i is the i^{th} power output from the second wind farm. For the present analysis *i* represents the hourly power output measurements published by the Ontario Electricity System Operator (IESO) for the year August 2007 to July 2008 (December 2007 to July 2008 for Ripley).This represents 24 x 366 or 8784 pairs of measurements for each correlation function (5856 for the Ripley pairings). In the above formula, $\bar{x}$ and $\bar{y}$ are the average power outputs of the first and second wind farms and σ_x and σ_y are their standard deviations.

The pair correlations were calculated for all pairs of the 5 operating wind farms: Amaranth (Melancthon) near Shelbourne, Kingsbridge near Goderich, Prince I and II near Sault St. Marie, Port Burwell on the shore of Lake Erie and Ripley, off Lake Huron, north of Goderich; 10 pairs in all. For each wind farm the nameplate power output, the average power output and the standard deviation of the power output are shown in Table 1 in absolute and ratio form.

Table 1: Parameters for the Ontario Wind Farms

Wind Farm	Name-Plate Power (MW)	Average Power Output (MW)	Standard Deviation (MW)
Amaranth	67.5	19.4 or 29%	19
Kingsbridge	39.6	13.7 or 35%	13
Port Burwell	99	27.3 or 28%	29
Prince I and II	189	55.3 or 29%	54
Ripley (8 months)	76	24.1 or 32%	21
All Combined	471	30%	

For the combined wind farm system, the annual average power output was a respectable 30% of the name-plate power. Assuming that the low-hanging fruit have been picked first, this fraction (the capacity factor) will perhaps go down as more wind farms come on line. However, it compares well with Germany with its well developed system of wind farms where the fraction was below 20% in 2005 and 2006.

The standard deviations are high, about 100% of the average power outputs. This reflects the strong variability of the wind speed.

Table 2 shows the 10 pair correlations for the 5 wind farms. Read the table as you would a mileage chart. For instance, the pair correlation between the power outputs of Port Burwell and Ripley is 0.56. A correlation of 1 corresponds to perfect correlation. A correlation of 0 corresponds to no correlation or complete independence.

Table 2: Hourly Pair Correlation Between Wind Farms.

	Amaranth	Kingsbridge	Port Burwell	Prince I & II	Ripley
Amaranth					
Kingsbridge	0.73				
Port Burwell	0.62	0.65			
Prince I & II	0.36	0.49	0.28		
Ripley	0.85	0.91	0.56	0.43	

It is most instructive to graph the pair correlation as a function of the separation of the wind farms. One might expect that the correlation would be close to 1 for nearby wind farms and close to 0 for distant wind farms. Table 3 shows the estimated separations of the 5 wind farms from each other.

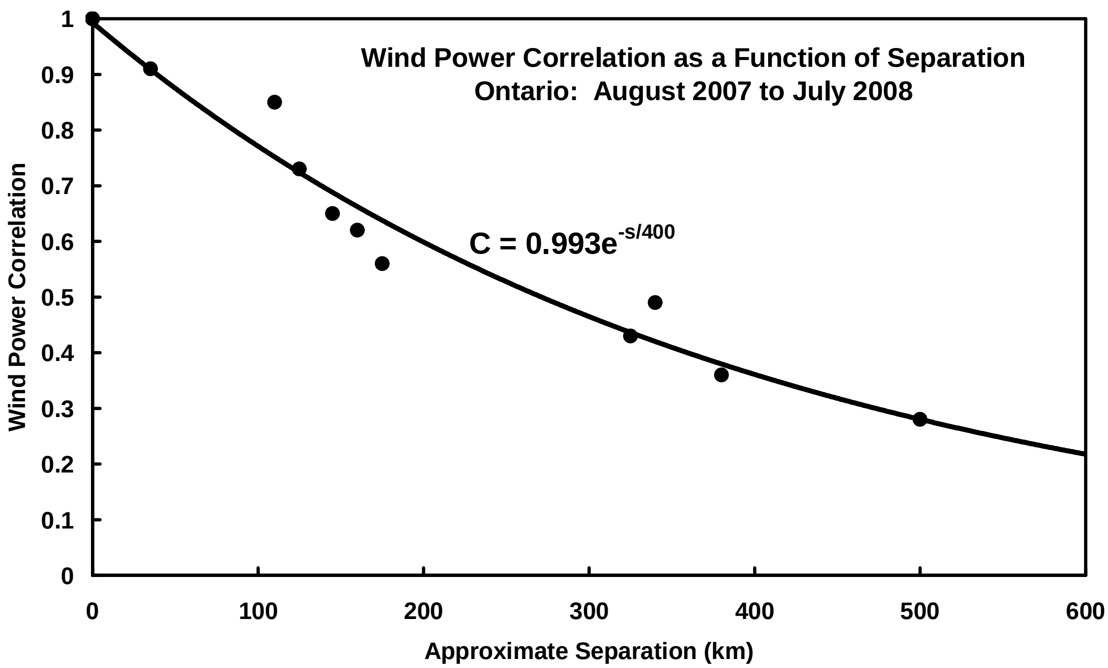
Table 3: Approximate Separation (km) Between Wind Farms.

	Amaranth	Kingsbridge	Port Burwell	Prince I & II	Ripley
Amaranth					
Kingsbridge	125				
Port Burwell	160	145			
Prince I & II	380	340	500		
Ripley	110	35	175	325	

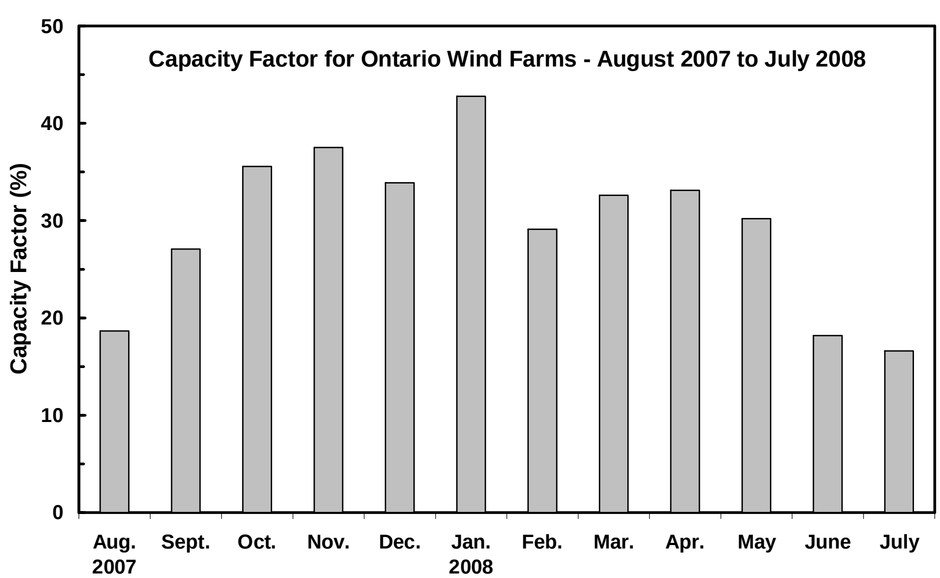
Such a graph is shown below. Quite remarkably, we see that the correlation is a very well behaved function of the separation. The solid line is a trial function:

$$C = Ae^{-s/s_0}$$

where A and s_0 are constants and s is the separation between wind farms. The constants are A = 0.993, very close to the expected value of 1, and s_0 = 400 km. That is the correlation decays exponentially with a decay length of 400 km.



To put this result in perspective, we learn that, in Ontario, for wind farms much closer that 400 km apart, the power outputs will rise and fall together. For wind farms much further than 400 km apart, the power outputs will be uncorrelated and may compensate for each others variability. This is of course a generalization of the striking behaviour shown by the agreement with the exponential decay.



These pair correlations address only the question of the variability of the power output on the short time scale. Another issue is the variability on the longer time scale and in particular the dip in the capacity factor, the ratio of actual power output to the name-plate power, in the summer months and the need for peak power in these summer months. For the same interval, August 2007 to July 2008, the capacity factor for the Ontario wind farms is shown in the second figure above.

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