American Journal of Energy Engineering
2016; 4(4): 40-44
http://www.sciencepublishinggroup.com/j/ajee
doi: 10.11648/j.ajee.20160404.12
ISSN: 2329-1648 (Print); ISSN: 2329-163X (Online)

Communication

Heinrich Hertz, M King Hubbert, Craig Bohren and Wind Power

Dulli Chandra Agrawal

Department of Farm Engineering, Banaras Hindu University, Varanasi, India

Email address:
Dca_bhu@yahoo.com

To cite this article:
Dulli Chandra Agrawal. Heinrich Hertz, M King Hubbert, Craig Bohren and Wind Power. *American Journal of Energy Engineering.* Vol. 4, No. 4, 2016, pp. 40-44. doi: 10.11648/j.ajee.20160404.12

Received: November 25, 2016; **Accepted**: December 19, 2016; **Published**: January 18, 2017

Abstract: The free convections of the fluids water and air over the globe lead to evaporation of water and generation of winds, respectively. Heinrich Hertz and M King Hubbert both assign $40000 \cdot 10^{12}$W solar power for evaporation of water and subsequent annual rainfall of around one meter over the globe. However, Hertz has mentioned two estimates $400 \cdot 10^{12}$W and $4000 \cdot 10^{12}$W in his handwritten lecture notes of 1885 for the wind power. This ambiguity is resolved in present paper showing wind power is of the order $400 \cdot 10^{12}$W on the basis of his statement that winds should be of the same order of magnitude as that involved in rainfall. This estimate for wind power also matches with the value $370 \cdot 10^{12}$W assigned by M King Hubbert. Craig F Bohren's observation that heat transfer coefficient for water is 120 times larger than air is shown to be equal to the ratio of solar power going into evaporation and wind channels. Both Hertz's and Hubbert's estimates for evaporation and wind channels further show that solar power for evaporation is two order magnitudes more than solar power generating the winds.

Keywords: Solar Power, Earth, Evaporation, Wind Power, Heinrich Hertz, M King Hubbert, Craig Bohren

1. Introduction

Water and air are two important members of the Earth's family. The former occupies not only two-third part of its surface but its presence can be seen in the remaining portion also such as in lakes, rivers, trees, plants, lands, human beings, animals, and so on. Air, another member, surrounds this water body called atmosphere exerting an average pressure of 101325 Pa per unit area. The solar radiation intercepted by the Earth-atmosphere system causes natural convections in both water and air preventing the Earth from overheating. The former leads to evaporation of water and subsequent rainfall while the latter generates the wind. Heinrich Rudolf Hertz [1] and M King Hubbert [2] both have assigned the same value $Q_{EV\&PP}^{Hertz} = Q_{EV\&PP}^{Hubbert} = 40000 \cdot 10^{12} W$ for the solar power going in the evaporation of water over the globe; this value is very much consistent with the average annual rainfall of around one meter [1,3,4] on the Earth− a well known fact in meteorology. However, the fraction of solar energy participating in wind generation over the globe is rather ambiguous. Heinrich Rudolf Hertz [1] in his handwritten lecture notes in German delivered on 20 April 1885 at Karlsruhe and later on after a gap of 110 years translated by Mulligan and Hertz [1] had mentioned two estimates $400 \cdot 10^{12} W$ and $4000 \cdot 10^{12} W$ for wind power differing by a factor of 10, whereas M King Hubbert [2] has assigned a value $370 \cdot 10^{12} W$ for it. The aim of the present paper is to resolve this ambiguity as well as also examine the possibility of any relationship between these two channels.

This paper will discuss the role played by water over the globe vis-a-vis the case if there would have been no water on the Earth; it not only prevents the overheating of the Earth the potential energy gained by hot moist air once it is lifted by buoyancy force a circulation pattern is formed due to the cold fluid from the sides coming to occupy the place generated by the vertical movement of hot fluid "*to the height at which it becomes a liquid i.e., at which the vapour condenses.*"According to Hertz *"if we were able to collect all the rain from all sides at the height above the Earth at which it is formed, and direct it through turbines as it returns to the sea, then we could obtain from such turbines an amount of work that would exceed that of our steam engines by a factor of*

120,000. In nature, of course, the falling rain drives no turbines; nevertheless, the large quantity of energy provided by the free fall of the water is disposed of. What, then, becomes of it? It is directly converted into heat; each individual falling drop heats up a little on contact with the air that rubs against it, and gives out this heat to the air and to the Earth on which it falls." It is further emphasized by Hertz that *"the number of drops hitting the Earth is so great that 600 thousand million horses would have to be harnessed to a machine, which through friction would produce an equal amount of heat. Of course, it is clear that not all the rain falls directly down on the Earth at sea level; about one-quarter of it falls on dry land, and this is (on averaging over all continents) some 440 meters above sea-level.....and it corresponds to a constant power of about 20 thousand million horse-power....; from it clearly results the power of all flowing water"* over the globe. On the other hand "*if the surface of the Earth were free of a cover of water, the heating of atmosphere from the top to down [5] Sun would create a stable arrangement of layers of different temperatures, which does not lead to turbulence. Thus the static and immobile atmosphere would serve for no other purpose than the warming of the Earth. It would by day heat the surface of the Earth more strongly on average than the atmosphere becomes heated, but then this more strongly heated surface would at night again radiate more heat. As long as the sun-light falls on a barren wasteland, these will also in fact be the result occurring. As far as that is concerned, we may perhaps speak of this component of the Sun's energy as that of an especially efficient heating system, but at the same time not attribute to any broader role. In reality, however, the greater portion of the Earth's surface is indeed covered with water, which evaporates.....and indeed not on a very small scale. Every year, we may assume that on the average a water layer a meter high over the entire Earth is converted into the water-vapour"*. These observations justify the statement by Heinrich Hertz [1] that*"if the atmosphere were dry, the temperature differences existing in it would by themselves give rise merely to movements of minor significance.....the principal cause of ocean currents is likewise to be sought not directly in temperature differences in the atmosphere but much more in the winds, which must also be considered as an indirect consequence of the evaporation of the water"*. To sustain the above mentioned sequence of processes the Sun must constantly supply solar energy to evaporate the water and the gravity keeps on lifting the moist air for rainfall. This lead Heinrich Hertz to hypothesise that "*the work which provides the support for the wind is of the same order of magnitude as that involved in rainfall."* In spite of the fact that the physics of the atmosphere is not so simple as presented above, rather it is quite complex, the students will also learn some important findings such as the average annual rainfall over the globe is around one meter, the solar power into evaporation channel is $40000 \cdot 10^{12} W$ and into wind channel it is $400 \cdot 10^{12} W$, and evaporation channel consumes two order magnitudes more power than that responsible for winds on the Earth. This paper will also motivate the experts [6-8] in the field of meteorology to review and re-examine their estimates on wind power over the globe.

2. M King Hubbert

M King Hubbert [2] has given the division of the intercepted solar energy $174000 \cdot 10^{12} W$ over the globe into various channels as follows:

$$\begin{aligned}
&\text{Direct reflection into the space, } Q_{Albedo}^{Hubbert} = 52000 \cdot 10^{12} \text{ W} \\
&\text{Direct conversion into heat, } Q_{Heat}^{Hubbert} = 82000 \cdot 10^{12} \text{ W} \\
&\text{Evaporation and precipitation, } Q_{EV\&PP}^{Hubbert} = 40000 \cdot 10^{12} \text{ W} \qquad (1) \\
&\text{Winds, waves, convection \& } currents, Q_{Wind}^{Hubbert} = 370 \cdot 10^{12} \text{ W} \\
&\text{Photosynthesis, } Q_{Photosynthesis}^{Hubbert} = 40 \cdot 10^{12} \text{ W}
\end{aligned}$$

It may be noted from the estimates presented above that the ratio $Q_{EV\&PP}^{Hubbert} / Q_{Wind}^{Hubbert} \approx 108$ which signifies that solar power going into evaporation channel is two orders of magnitude larger than the corresponding solar power responsible for winds.

3. Heinrich Hertz

According to Mulligan and Hertz [1], Heinrich Hertz in his lecture notes "*demonstrates his ability to provide meaningful estimates of the known energy resources of the Earth, and to use order-of-magnitude calculations in a manner worthy of an Enrico Fermi*". He enriches our understanding of the wind power over the globe. He teaches us that "the work which provides the support for the wind is of the same order of magnitude as that involved in rainfall." He further writes in his lecture notes– "*Indeed, the exact amount of work, which solar energy must constantly supply to keep the fluids of the Earth in motion – is very hard to determine. Most likely it is quite possible for that part of the work that is used for maintaining the rainfall. We know approximately the mass of the falling water; we know the height at which it becomes liquid [i.e., at which the vapour condenses] and to which it must therefore be lifted, and we find from this that a constant rate of work of about 600 thousand million horsepower is required for this lifting.*" One can convert this estimate in SI units by making use of the relation $1\ hp = 745.7\ W$ and arrive at

$$\begin{aligned}
WindPower &= 600 \cdot 1000 \cdot 10^{6} hp = 6 \cdot 10^{11} \cdot 745.7\ W \\
&= 4 \cdot 10^{14} W \qquad (2)
\end{aligned}$$

However, in the very next paragraph Mulligan and Hertz [1] find in the translated version of the said lecture notes that the above power will also be equivalent to the power generation capacity by all the collected "*rain from all sides at the height [above the Earth] at which it is formed, and direct it through turbines as it returns to the sea, then we could obtain from such turbines an amount of work that could exceed that of our steam engines by a factor of 120,000.*" This point has been further elaborated by Mulligan and Hertz [1] in their footnote-20; if this ratio happens to be "*correct, the value given above for the power required to lift the water required*

for rainfall would be $120\,000\,(50\,million\,hp) = 6 \cdot 10^{12}\,hp = 4 \cdot 10^{15}\,W$. *This is a factor of 10 larger than that given by Hertz at the end of previous paragraph. Since Hertz gives no numerical values for either the mass of water lifted or the height to which it is lifted, it is impossible to track down the source of this discrepancy.*"The 50 million horsepower mentioned above is the presumed unit by Heinrich Hertz to measure the solar power in terms of it; this emerged on the basis of all those 110,000 steam engines existing on the Earth during that period and they were supposed to have worked for one year duration to produce 50 million horsepower.

This discrepancy can be resolved since Heinrich Hertz has indeed given clues for the mass of water-vapour being lifted, has discussed steam engine performing work for it and the height to which it is lifted. First, let us find out the amount of water-vapour being lifted. On page 41, the fourth line of the last paragraph states that "*every year, we may assume that on the average a water layer a meter high over the entire Earth is converted into water-vapour— at the poles indeed far less, but on the other hand in the vast tropical zone substantially more.*" One can use this statement to write the expression for the volume of water evaporating annually as

$$Volumeofwaterevaporatingannually = \frac{4\pi}{3}(a+\delta)^3 - \frac{4\pi}{3}a^3 = 4\pi a^2 \cdot \delta m^3 \quad (3)$$

Here a is the radius of the Earth,$\delta \sim 1\,meter$ is the height of water evaporating from the surface of the Earth annually. Multiplying the above expression with density of water $10^3\,kg/m^3$, putting $a = 6.37 \cdot 10^6 meters$, $\delta = 1\,meter$ gives the amount of water evaporating per year as $5.1 \cdot 10^{17} kg$.This amounts to the rate of evaporation being$\sim 1.6 \cdot 10^{10}\,kg/s$. The steam engine performing the job of lifting and height to which this water is lifted will be calculated on basis of the writings of Heinrich Hertz in the sequel.

According to Hertz the solar energy $Q_{EV\&PP}^{Hertz} = 40000 \cdot 10^{12} W$ going into evaporation channel serves "*as the heat source for a gigantic steam engine, which provides the power for the movement of the clouds, the winds, and the oceans. We can say that it serves to maintain the meteorological working of the Earth. For, as meteorology progresses, it becomes even more clear that the principal driving force for all the more vigorous atmospheric movements is to be sought in the latent heat of the water vapour contained in the atmosphere. If the atmosphere were dry, the temperature differences existing in it would by themselves give rise merely to movements of minor significance,*" It will be worth devoting couple of lines on the phrase- latent heat brings vigorous atmospheric movement. The wet air being lighter moves up, cools down at certain heights (to be estimated later on in this paper) gets converted into fine droplets and float in the air as clouds. The released latent heat heats up the air which rises to higher heights. The bigger drops move downwards and in this process the air in contact gets heated due to friction, it slows down the speeds to its terminal velocity, finally collides with the Earth and gives its total kinetic energy to the Earth; colliding water may once again start evaporating depending upon the temperature, humidity, etc at that moment. Although amount of heat involved for individual drop may be insignificant but the number of hitting drops is so great that 600 thousand million horsepower [1] would be required to achieve it. About one-quarter of the raindrops [1] would fall on the continents which on the average are 440 meters above the sea-level and this provides power for the flow of water towards the sea; this justifies the importance of latent heat which provides motion to the atmosphere. Students are advised to read references [9] and [10] for a detailed description of role of water vapour in the atmosphere.

Hertz talks about a steam engine which will provide useful work for atmospheric movement. On page 42, left column, second new paragraph, one can read the description of the steam engine having "*surface of the sea as the boiler, then we must take as the condenser the layer of air in which the clouds are formed. This latter layer is cooler than the boiler, and it must be so, for otherwise absolutely no conversion of heat into any kind of work would be possible. The difference [in temperature] is, however, not great; we can hardly assume that the difference between the temperature of the Earth and that of the cloud-covering layer amounts to more than* 15℃ *on the average. But a steam engine, whose condenser is only* 15℃ *colder than its boiler can, even with the most perfect design, convert at most about* $1/20$ *of the heat provided into useful work. The large sun-machine of which we are speaking, however, is far from actually reaching this theoretically possible maximum; probably it achieves scarcely one-third of it.....*" This engine provides an estimate for the useful work the sun-engine must constantly supply to keep the fluids of the Earth in motion. This statement also fixes the height at which raindrops are formed and subsequently fall to be discussed below.

4. Useful Work Done by the Sun-Machine

The estimate of useful work done by the sun-engine may be obtained following the facts mentioned above. The maximum efficiency of heat engine can be written as

$$\eta_{Sun-engine} = 1 - \frac{Temperatureofcondenser}{Temperatureofboiler} \quad (4)$$

For the Earth at 300 K, and its cloud-cover at 285 K we have efficiency

$$\eta_{Sun-engine} = 1 - \frac{285}{300} = 0.05 = 5\% \quad (5)$$

This value corresponds to $1/20$ of the energy available into useful work as mentioned by Hertz

$$usefulwork = \eta_{Sun-engine} \cdot Q_{EV\&PP}^{Hertz} \quad (6)$$

Putting the value of solar energy going into evaporation we get

$$usefulwork = 0.05 \cdot 40000 \cdot 10^{12} = 2000 \cdot 10^{12} W \quad (7)$$

Following the statement of Hertz that sun-machine achieves scarcely one-third of it; this amounts to actual work being done in lifting water

$$Actualusefulbeingdone \sim 600 \cdot 10^{12} W \quad (8)$$

so that the fluids of Earth are constantly in motion. The value of wind power (2) is comparable with the work being done (8) for maintaining the rainfall as was stipulated by Heinrich Hertz. Once the useful work has been done, that is the water has been lifted, the atmosphere comes into motion as per steps described earlier. Hertz elaborates that, of course, in actual practice "*the falling rain drives no turbines; nevertheless, the large quantity of energy provided by the free fall [of the water] is disposed off. What, then, becomes of it? It is directly converted into heat; each individual falling drop heats up a little on contact with the air and to the Earth on which it falls. Although this amounts to very little heat from each individual drop, the number of all the drops hitting the Earth is so great 600 thousand million horses would have to be harnessed to a machine, which through friction would produce an equal amount of heat. Of course, it is clear that not all the rain falls directly down on the Earth at sea-level; about one-quarter of it falls on dry land, and this (on averaging over all continents) some 440 meters above sea level.....from it clearly results the power of all flowing waters.*"

5. Height of the Formation of Rain Drops

Temperature drop of15℃ will occur at what height can be evaluated on the basis of well known lapse rate [11].The dry adiabatic lapse rate depends only on the ratio of g to the specific heat capacity per unit mass of air. Its value is about $10\ ℃/km$. This is higher than observed on average primarily because condensation of water vapour acts to lower the lapse rate. The average is closer to half the dry adiabatic lapse rate, that is about $5\ ℃/km$; this amounts to height via the ratio $15\ ℃/5\ ℃ perkilometer = 3\ km$ at which vapour condenses into droplets which can be passed collectively through hypothetical turbines for generation of power as discussed by Heinrich Hertz [1]. Now it is known to us that the rate of water-vapour evaporation is $1.6 \cdot 10^{10}\ kg/s$ and it is lifted to altitude $3\ km$ where it condenses; the power involved in its lifting against the gravity comes out to be using $(mass \cdot accelerationduetogravity \cdot height)$

$$1.6 \cdot 10^{10} \frac{kg}{second} \cdot 9.8 \frac{meter}{second^2} \cdot 3000\ meter = 470 \cdot 10^{12} W \quad (9)$$

The above estimate of power available in the rain water is comparable to the projected wind power in (2) as was stipulated by Heinrich Hertz [1]. This shows that the discrepancy of the factor 10 faced by Mulligan and Hertz [1] in the translated version might have been due to some overwriting in the hand written lecture notes. These values for the wind power (vide 2 and 9) are very much consistent with magnitude $370 \cdot 10^{12} W$ assigned for the wind power (1) by M King Hubbert [2] in his classic paper where he has discussed the breakup of solar energy intercepted by the Earth.

6. Craig F Bohren

The above magnitude of wind power is further justified by the work of Craig Bohren [12] when coupled with the breakup of solar energy by Heinrich Hertz [1] and M King Hubbert [2] as will be shown in the sequel. Recently Craig Bohren [12] has shown that heat transfer coefficient for the fluid water is 120 times larger than that for air in a study while he compares the cooling of a human being in standing position when he takes a dip in a pond with the case in the presence of still air. This ratio must also be equivalent to the ratio of solar power going into evaporation and wind channels. Indeed, this is true as per projections of solar power going into evaporation and precipitation channel $Q_{EV\&PP}^{Hertz} = Q_{EV\&PP}^{Hubbert} = 40000 \cdot 10^{12} W$ and wind channel $Q_{Wind}^{Hertz} = 400 \cdot 10^{12} W$ by Heinrich Hertz [1] or $Q_{Wind}^{Hubbert} = 370 \cdot 10^{12} W$ by M King Hubbert [2]; the ratio in these cases are $Q_{EV\&PP}^{Hertz}/Q_{Wind}^{Hertz} \sim 100$ and $Q_{EV\&PP}^{Hubbert}/Q_{Wind}^{Hubbert} \sim 108$, respectively. This brings the works of Heinrich Hertz, M King Hubbert and Craig F Bohren consistent with each other. Another important finding of this paper is that solar power responsible for evaporation is two order magnitudes bigger than the power available for winds. Since $40000 \cdot 10^{12} W$ brings an average annual rainfall [1, 3, 4] of around one meter which matches with the recorded data [3] over the years and hence solar power responsible for winds proposed by Hertz and Hubbert must also be true.

7. Discussion and Conclusion

According to Heinrich Hertz "every year, we may assume that on the average a water layer a meter high over the entire Earth is converted into water-vapour– at the poles indeed far less, but on the other hand in the vast tropical zone substantially more." This corresponds to $2.74\ mmd^{-1}$ of evaporation rate on the average over the entire globe. Antonopoulos, Gianniou and Antonopoulos [13] have made use of an artificial neural network (ANN) technique to estimate daily evaporation from Lake Vegoritis located in northern Greece. The surface area and the maximum depth of the lake ranged from $31\ to\ 32.1\ km^2$, and 39 to 40 m, respectively, in 2003–2004; their estimate of evaporation $2.8\ mmd^{-1}$ matches with that of Heinrich Hertz. As far as wind power [14] is concerned according to Betz's law [15] which says the maximal achievable extraction of wind power by a wind turbine is 59.3% of the total kinetic energy of the air flowing through the turbine; this puts an upper limit on the electric power that can be extracted theoretically comes out to be $59.3\% \cdot 400 \cdot 10^{12} W \sim 2.37 \cdot 10^{14} W$. This is almost 40 times more than the total world electric power [16] installed capacity $5.25 \cdot 10^{12} W$.

Lastly it would be worth mentioning the 3-D weather/climate hypothetical model of Jacobson and Archer [17]. In this model the wind turbines were thought to be spaced around the world and extracted kinetic energy from the wind, converting it to electricity, and returning the electricity as heat energy back to the atmosphere after its use. The model accounted for the transfers of kinetic, potential, radiative, and latent heat energies in 3-D, thus accounted for the 3-D structure and dynamics of the atmosphere. They find ~250 TW at 100 m and ~380 TW at 10 km. They didn't calculate the power available in the whole atmosphere; however, as per personal communication with Jacobson [18] the estimate will be less than 1000 TW. As far as Hubbert's calculation is concerned it may be referred to as 0-D estimate that did not

account for all processes in the atmosphere. One simple example is that it did not account for the return of electricity as heat, which gives rise to more potential energy, which converts to more kinetic energy, and so on.

The findings of the present paper may be listed as

- The evaporation channel consumes solar power $40000 \cdot 10^{12} W$ which evaporates on theaverage a water layer a meter high over the entire Earth; this value is very much consistent with the average annual rainfall of around one meter on the Earth.
- The ambiguity faced by Mulligan and Hertz in the lecture notes of Heinrich Hertz has been resolved; the solar power into the winds is $400 \cdot 10^{12} W$ rather than $4000.10^{12} W$.
- The above estimate for wind power matches with the proposed value $370 \cdot 10^{12}\, W$ by M King Hubbert.
- Craig Bohren's observation that heat transfer coefficient for the fluid water is 120 times larger than that for air matches with the ratios $Q_{EV\&PP}^{Hertz}/Q_{Wind}^{Hertz} \sim 100$ and $Q_{EV\&PP}^{Hubbert}/Q_{Wind}^{Hubbert} \sim 108$ showing that solar power for evaporation is two order magnitudes more than that generating the winds.

The author is thankful to M Z Jacobson for the correspondence on his publications.

References

[1] Joseph L Mulligan and H. Gerhard Hertz,' An unpublished lecture by Heinrich Hertz: "On the energy balance of the Earth", Am J Phys 65, 36-45 (1997).

[2] Daniel N Lapedes (Editor), Encyclopedia of Energy "Outlook for fuel reserves" contributed by M King Hubbert (McGraw Hill, New York, 1976) 11-23.

[3] Ven Te Chow, David R Maidment and Larry W Mays, Applied Hydrology (McGraw-Hill, New York, 1988) p. 5.

[4] D C Agrawal, "Average annual rainfall over the globe" Phys Teach 51, 540-541 (December 2013).

[5] Hertz apparently means by "from the top to down" (von oben her) that the Sun creates a stable arrangement of layers of different temperatures, which does not lead to turbulence.

[6] Jeff M Gordon and Y Zarmi,"Wind energy as a solar driven heat engine: A thermodynamic approach", Am. J. Phys. 57, 995-998 (November 1989).

[7] M A Barranco-Jimenez and F Angulo-Brown, "A nonendoreversible model for wind energy as a solar driven heat engine", J. Appl. Phys. 80 (9), 4872-4876 (1996).

[8] Alexis De Vos, "Endoreversible Thermodynamics of Solar Energy Conversion", (Oxford University Press, Oxford 1992) p. 21.

[9] D Jacob, "The role of water vapour in the atmosphere. A short overview from a climatic modeller's point of view", Phys. Chem. Earth (A) 26, 523-527 (2001).

[10] J Patterson, "The importance of water vapour in the atmosphere", Journal of the Royal Astronomical Society of Canada, Vol. 20, 201-208 (1926).

[11] Craig F Bohren and Bruce A. Albrecht, Atmospheric Thermodynamics (Oxford University Press, New York 1998) p. 292.

[12] Craig F Bohren, "Why do objects cool more rapidly in water than in still air?" Phys Teach 49, 550-553 (2011).

[13] V Z Antonopoulos, S K Gianniou and A V Antonopoulos (2016): Artificial neural networks and empirical equations to estimate daily evaporation: application to Lake Vegoritis, Greece, Hydrological Sciences Journal, DOI: 10.1080/02626667.2016.1142667.

[14] Brian Hurley, "How Much Wind Energy is there?".

[15] http://www.wse.ie/how-much-wind-energy-is-there/.

[16] Kira Grogg, "Harvesting the Wind: The physics of wind turbines".

[17] http://apps.carleton.edu/campus/library/digitalcommons/assets/pacp_7.pdf.

[18] http://mecometer.com/topic/electricity-installed-generating-capacity/.

[19] M Z Jacobson and C L Archer, "Saturation wind power potential and its implications for wind energy", Proc. Nat. Acad. Sci., 109, 15679-15684 (2012).

[20] M Z Jacobson, personal communication.