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FURTHER ANALYSIS OF UNIVERSITY OF DAR ES SALAAM TANZANIA BRALUP RESEARCH PAPER NR 33 - THE USE OF WINDMILLS IN TANZANIA - by Martin Parkes, September 1974.

by ALEXANDER WEIR, BULAWAYO, ZIMBABWE - OCTOBER 1995 - reissued December 1999.

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ACKNOWLEDGEMENTS December 1999.

Thanks to University Dar es Salaam Morogoro (now Sokoine University) , to Uni Dsm Bralup, to Martin Parkes, to Judy Parkes, to Roland Reichel from UniDsm Mechanical Engineering Department, and to everyone who worked with me on the windmill projects. When Martin was doing this work I thought maybe he was wasting his time, but when a little bit later we got into making prototype wind machines we quickly realised that good matching or gearing was extremely important and that of course the economics of WECs was the determinant factor in deciding their feasibility. I revamped this report 1995 but the internet was still only really starting at that point in time - it is now mature enough to be a suitable medium for this kind of study. Although this report is on Tanzania wind data, its findings are probably valid worldwide.

Postscript December 1999 - windspeed distributions in principal are meant to be logonormal. And for any given windrun produced by a windspeed cup counter anemometer it is possible in theory to have a wide variation of wind patterns - e.g. a very narrow band of windspeeds or a very wide band. This report in practice found no appreciable variation - i.e. not only a logonormal distribution but the same shape of logonormal for all instumented Tanzanian locations (but if you look at the graphs you can spot some which are a bit different). One would expect that sites which are coastal or lakeside would have some significant differences, but this was not shown in the data. If the algorithms found in this report are useable then they should eliminate a whole lot of experimental windsite evaluation measurement using sophisticated instruments - just use the old fashioned mechanical cup counter anemometer. And if the condition of these CCA's is suspect then just compare the last say 10 years data - despite variations from year to year the trend line for windrun per year should be horizontal - if it has a downward trend over some years then almost certainly the CCA bearings are becoming tighter, and the original value from some years ago should probably be used.

Apologies that some of the graphs are not too well labelled - I included them anyway - but most have a good explanation.

Any questions, especially since a lot of the explanation jumps steps, then just email me -

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EXECUTIVE SUMMARY

By mathematical simulation of windspeed data from Tanzania collected in 1974, some approximation formulae and values have been derived which are of general application WORLDWIDE for the following:

- estimating wind energy yields from cup counter anemometer data, for potential site assessment and as a basis for economic and technical feasibility studies.

- optimising the loading of impulse type wind energy converters (e.g. conventional windpumps) at time of installation or at any time thereafter, so as to maximise technical energy output and of course economic rate of return on annual and seasonal bases.

Additionally, it was determined that 5 top Tanzanian locations may produce economic teturn periods of 3-4 years at competitive international energy costings IF durable low-cost WEC's of unit cost US$ 50-00 per square metre cross sectional area and peak efficiency of 20% can be designed and constructed.

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INTRODUCTION

In 1974 Martin E Parkes published a Research Paper "The Use of Windmills in Tanzania" (through University of Dar es Salaam, Bureau of Research and Land Use Planning - BRALUP - Paper Nr 33). This contained data for 59 cup counter anemometer sites throughout Tanzania, also Beaufort data for 13 sites and Pitot Tube Anemograph data for 4 sites. These sites were to some extent duplicated, enabling some cross-checking of data sources....

In 1976 Alex Weir, who had worked beside Parkes at University of Dar es Salaam Agricultural Engineering Department in Morogoro Tanzania, got involved with Student Projects constructing prototype Wind Energy Converters. This led to him continuing the windspeed data analysis utilising Parkes' figures; this material was published as part of Weir's MPhil thesis in 1978.

In 1995, Weir cast an eye over the original report and over the thesis, and decided that there were potentially still some valuable information and techniques to be extracted from the original data.

Weir's methodology was to use computer simulation and computer graphics to analysis the data; both these techniques were effectively not available when the original work was done by Parkes and by Weir.

The findings affect not only Tanzania and the named locations within Tanzania, but are also applicable to site evaluation, windmill installation and the assessment of existing windpower sites worldwide.

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FINDINGS

The findings are as follows:

1. Parkes' Anemograph data analysis (for 4 sites) was fairly inaccurate and could not really be used directly as an absolute indication on windpower potential.

2. However the Beaufort data correlated well with the Cup counter anemometer (cca) data.

3. Parkes' figure of 5 mph (2.24 metres/second) as the cut-in speed for the Casella Mark II cca was found to be accurate.

4a. The maximum useable energy by an impulse type Wind Energy Converter (WEC) was found to be very closely correlated to the average windspeed as obtained from a Casella Mark II cca, by the following formula -

E = 20.1 * (vcca)^1.50

where E is integral of windspeed cubed with time, measured at 2 metres above ground level over short grass; note that as above this is the maximum useable wind energy by an impulse type WEC; it is obtainable at a certain value of cut in speed (or vci) - see more below.

vcca is indicated average cca wind velocity at 2 metres above ground level over short grass cover.

This formula was found to be valid between vcca values of 0 to 5.00 metre/second at 2 metres height above ground level over short grass, for both monthly and for annual readings, for 13 sites throughout Tanzania (Mwanza, Mtwara, Tanga, Lindi, Kigoma, Mbeya, Songea, Dodoma, Zanzibar, Tabora, Dar es Salaam, Iringa, and Moshi).

4b. Additionally, the total available energy was also found to be very closely correlated to vcca, by the following formula -

E = 30.0 * (vcca)^1.50

This formula was found to be valid between vcca values of 0 to 5.00 metre/second at 2 metres height above ground level over short grass, for both monthly and for annual readings, for 13 sites throughout Tanzania (Mwanza, Mtwara, Tanga, Lindi, Kigoma, Mbeya, Songea, Dodoma, Zanzibar, Tabora, Dar es Salaam, Iringa, and Moshi).

This is of great value for dealing with aerofoil type WEC's such as fast propeller wind electric generators (small and large) and Darrieus Rotor WEC's.

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CUT IN WINDSPEEDS

5. The optimal cut in speed for (4a) above is also well correlated to the average windspeed as obtained by a Casella Mark II cca, by the following formula:

vciopt = 2.2 + (0.78 * vcca)

where vciopt is optimum cut-in windspeed at 2 metres above ground level over short grass.

and vcca is indicated average cca wind velocity at 2 metres etc etc..

6a. For cases where the optimum vci was departed from, then the following relationships were found to apply:

- if the vci were lowered so that the extractable energy fell to 80% of the maximum possible (as per (4) above, then the vci was approx 0.67 times its

optimum value (as per (5) above.

i.e. if vci = 0.67 * vciopt then E = 0.80 * E max.

- similarly if lowered to produce an extractable energy of 90% of maximum, vci was found to be 0.78 times optimum

i.e. if vci = 0.78 * vciopt then E = 0.90 * E max.

- similarly if RAISED to produce 90% energy level, then the vci raised to 1.26 times its optimum value.

i.e. if vci = 1.26 * vciopt then E = 0.90 * E max.

- finally if raised to produce 80% of maximum energy level then vci became 1.38 times vciopt.

i.e. if vci = 1.38 * vciopt then E = 0.80 * E max.

Thus relatively high extraction efficiencies are still obtainable over a wide range of cut-in speeds; this is fortunate, since most sites have significant seasonal variations and also since most WEC's do not have easily variable cut-in speeds - thus it is important to tune the WEC to the load so as to optimise energy yields for the site in question.

6b. The WEC indicated windspeeds were also computed by the same iteration techniques for the 13 Beaufort Data Sites. The findings were well correlated to mean indicated cca windspeed, by the formulae:

vwecind = 0.50 + (0.60 * vcca) for vci = 0.67 * vciopt

vwecind = 0.45 + (0.53 * vcca) for vci = 0.78 * vciopt

vwecind = 0.30 + (0.35 * vcca) for vci = 1.00 * vciopt

vwecind = 0.15 + (0.214 * vcca) for vci = 1.26 * vciopt

vwecind = 0.10 + (0.16 * vcca) for vci = 1.38 * vciopt

Note that the above potentially enables assessment of existing windpower sites if the revolutions or pump strokes are recorded for weekly, monthly and yearly periods, AND if the blade tip speed ratio is known (i.e. revolutions per minute at a high known windspeed, when for example v/vci > 5); for such conditions, and where cca data is available or can be guesstimated, then the existing set cut-in windspeed can be estimated without relatively complicated testing as in (15) below.... Then if it is found to be too high or too low to produce a best energy yield pattern over the year, it can be adjusted. Restating the above in mathematical terms, if vwecind and vcca are both known or can be estimated, then vci/vciopt can be calculated; getting a good ratio of vci/vciopt is important to optimise annual and seasonal energy yields.

6c. The WEC (operational hours/total period hours) were also computed by the same iteration techniques for the 13 Beaufort Data Sites. The findings were very variable and could not be well correlated to mean indicated cca windspeed; BUT in general terms one could say that a WEC which operates 40% of the total time during a period is probably operating at the vciopt (optimum cut-in windspeed for that period); similarly operating 60% of the total time indicates that it is set with a vci such that the lower 80% energy extraction level is attained (i.e. at 0.67 * vciopt); and operating at only 20% of the total time during a period indicates that it is probably operating at the upper 80% energy extraction level (i.e. at 1.38 * vciopt). These measures, although very variable for the 13 locations and 12 months, may be a good rough-and-ready measure to evaluate the cut-in windspeed matching of existing WEC's (but who is going to stay up all night and watch the thing going round or not?; computer monitoring of a WEC can of course easily produce such utilisation factors.....).

7a. The significance of (6a) above is to do with seasonal windspeed and windpower variations - often for practical reasons it is impossible or undesirable to alter the cut-in speed of the WEC-load combination (e.g. by varying the length of the crank or the cylinder diameter on a windpump). Thus with seasonal variations obviously it is not possible to operate at maximum extraction efficiency during every month. Thus it is desirable to choose the vci so as to best meet energy demands throughout the year. Different strategies may be chosen, depending on the application, for example it may be decided to maximise energy output during the low season, even at the expense of total energy yield over the 12 months; or it may be decided to maximise annual energy yield, despite operating less efficiently during the low season....

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TANZANIAN DATA APPLIED

7b. The above formulae were applied to 59 Tanzanian locations for which monthly average indicated cca wind velocity data was available.

These average annual indicated windspeeds were from 0.63 metre/second to 3.28 metre/second, with an average value for the 59 sites of 1.88 m/s.

These gave optimum cut-in windspeeds of from 2.69 to 4.76 m/s, with an average value of 3.67 m/s.

The lowest and highest energy yield months were noted, and the ratios of the values of vciopt for these lowest and highest months were found to lie in the range of 0.47 through 0.94, with an average of 0.78; similarly, the ratios of vciopt for the lowest month to the vciopt for the annual situation were found to lie in the range of 0.55 through 0.97, with an average of 0.87; only 3 locations out of 59 were outside the 90% energy band ratio of 0.78. This indicates that an optimisation strategy to select a single value of vci for year-round operation will result in an annual energy yield of more than 90% of absolute maximum for 56 of the 59 locations - i.e. such a strategy of basing vcibest on the vciopt for the worst month of the year seems good.

Using this strategy of setting the vciopt at that for the worst month (as long as that worst month vciopt was greater than or equal to the 90% energy yield band of 0.78 * vciopt annual), then a value of vcibest was determined for each of the 59 locations. These varied from 2.53 through 4.13 m/s, with an average value of 3.22 m/s.

These vcibest values were graphed against vcca (average indicated annual windspeed), and gave a good correlation with a best-fit formula of :

vcibest = 2.2 + (0.52 * vcca)

Note that this is similar to the vciopt formula as in (5) above.

Note also that if monthly vcca figures are available then really vcibest should be worked out from the vciopt figures for each month, and NOT by using this 0.52 formula....

7c. The seasonal variability of wind energy for the 59 Tanzanian locations was examined graphically - it was found that for most locations there was a clear trend with a peak August-October and a trough December-January; by comparison, to consider rainfall, for Dar es Salaam, rainfall is usually close to zero June-September, with rain starting October and building up steadily to a peak April-May.

8. On a practical note, vci is often not the actual physical cut-in speed (since the pump tends to stop at

the difficult part of the cycle) - more on this later and how to assess the performance of existing windpump installations.

9. Summarising so far, we see that if we have cca data for a site, then we can calculate the energy yields for all types of WEC. We can also calculate the best cut-in speeds for impulse type WEC's so as to maximise energy yields and to minimise seasonal energy yield variations or otherwise to optimise seasonal behaviour.

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ECONOMICS

If we have cost data and efficiency/ performance data on WEC-load systems then we can calculate whether the use of WEC's is economic for the location in question. This obviously depends also greatly on interest rates, current and projected energy costings, and profit and loss and cash flow projections. If we have an existing WEC on the site then we can evaluate whether it is extracting a suitable amount of energy according to the formulae as above. If not, and if the WEC is an impulse type WEC, then we can examine whether the cut-in speed setting is a factor causing the lack of energy yield (or whether it is something else).

10. It should be mentioned also here that the variation of windspeed and wind energy with height is calculable by the formula $v/v2 = \log(h/r)/\log(2/r)$, where r is roughness parameter, typically 0.02 metres for short grass; values for speed and for energy (v^3) variations with height are tabulated below, using a r = 0.02:

Height	Windspeed	Wind Energy
2	1.00	1.00
6	1.23	1.90
10	1.35	2.46
16	1.45	3.06
100	1.85	6.33

11. For converting the energy values to watts, kilowatts etc, then the formula E = 0.5 pAv^3 should be used,

where p is air density - this is 1.23 kg/metre^3 at sea level, and 1.18 kg/m3 at 1000 metres altitude, 1.12 kg/m3 at 2000 metres altitude, and 1.07 kg/m3 at 3000 metres altitude; A is WEC cross sectional or swept area in metres^2; v^3 is the Energy integral in metre^3/second^3, as in items (4a) and (4b) above.

12a. The following approximate peak efficiencies apply to WEC types (exact peak efficiency depends on precise design and on production quality) :

Fast Propeller 42%

Darrieus Rotor 42%

Multiblade impulse 20%

Savonius Rotor 15%

Note that the 20% and 15% values are applicable with the energy yields as in (4b) for impulse type WEC's.

12b. Note that if calculations are to be done with water pumping, then a piston pump can be reckoned on average to be 60% efficient (due to valve losses and piston friction losses, and that power required can be calculated by the formula:

P = d.g.h.(v/t) / e

where d = density of water (1 kg/litre)

g = gravitational constant 9.81 metre/sec^2

h = head in metres

v/t = volume per time - flowrate in litres/second

e = efficiency (take as 0.6 as above)

13a. Note that 1995 energy costs are typically (as per the Economist newspaper, 7-13 October 1995) :

US$ per kiloWatt-Hour of electrical energy

Fossil fuel power stations 0.05 - 0.08

Hydro Electric 0.05 - 0.10

Nuclear Power 0.10 - 0.20

Wind Power 0.10 - 0.20

Biomass/ ethanol 0.20 +

Solar power stations 0.20 +

Solar photovoltaic 0.30 +

Wave Power 0.30

13b. WEC Costings are quite variable, but can be said to be approximately:

Conventional windpump (without pump) US$ 250/m^2

Wind Electric Generator (large) US$ 120/m^2

Low Cost Impulse Type WEC's (e.g. cretan sail) US$ 50/m^2

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WORKED EXAMPLES

14a. Worked example nr 1:

A windsite has an average cca indicated windspeed of 3.0 metres per second. It is proposed to install a 6 metre diameter multiblade windmill at a mean height of 6 metres above ground level, over short grass (2 cm roughness factor). Air density is 1.23 kg/m3 (sea level value); the peak efficiency of the windmill is estimated at 20% (normal). Calculate energy yield per year and also monetary value generated if the resultant mechanical energy is costed at US$ 0.10 per kilowatt hour. Calculate also the optimal cut-in windspeed for the WEC-load to achieve these figures.

Use our formula Emax = 20.1 * (vcca^1.50) to give 104.44 m3/s3 of maximum useable energy by a impulse type WEC at 2 metres above ground level. WEC cross sectional area is (6 * 6 * PI / 4) = 28.27 m2; thus with density of 1.23 then maximum useable power flux is

(104.44 * 28.27 * 1.23 * 0.5) = 1816 watts

With 20% peak efficiency, then average generated power = 1816 * 0.2 = 363 watts mechanical energy.

Converting the above figures for 2 metres above ground level to 6 metres above ground level, we have 363 * 1.90 = 690 watts average mechanical power output. Over 8760 hours per year this gives 690 * 8760 / 1000 = 6044 kiloWatt-Hour of mechanical energy per year.

With a costed value of US$ 0.10 per kWatt-hour we have value added per year = 6044 * 0.10 = US$ 604-40.

Rate of return and interest rate calculations can be taken from there on.... obviously capital cost and durability/longevity are also major considerations here.

Using the formula as in (5) above, vciopt = 2.2 + (0.78 * 3.0) = 4.54 metre/second at 2 metres above ground level; this is equivalent to (4.54 * 1.23)

= 5.58 metre/second at 6 metres above ground level.

4b. Worked example nr 2: with 5 locations of the 59 Tanzanian having greater than 85 m3/s3 wind value average and also 5 having greater than 60 m3/s3 wind value on a worst-month basis, and using low-cost WEC's of US$ 50-00/m2, and using WEC peak efficiencies of 20%, with air density of 1.23 kg/m3 and a WEC mean height of 6 metres, and with energy costing of US$ 0-10/kWh, then calculate value added/year for unit capital investment....

The above produces returns of US$ 17.40 per annum per investment of US$ 50-00 for an average annual basis, and US$ 12.28 p.a. per investment of US$ 50-00 for a worst-month basis.

These correspond to approximately 3 years and 4 years payback periods respectively, which could be classified as moderately yielding investments; note that the investments are expected to last 20 years without major repairs or maintenance.

However, note that these figures are for the best 10% of locations only; also that they depend on having VERY low-cost WEC's - typically one fifth the unit cost of conventional commercial multivane windpump WEC's; it is not sure that durable machines of this type can be produced for that kind of price.

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PRACTICAL ASSESSMENT OF CUT IN WINDSPEED

15. We return to the practical assessment of the cut-in windspeed of a WEC-load combination as mentioned in (8) above. One way of doing this is by sampling data for the WEC at one relatively high windspeed and 2 or more moderate windspeed; while doing this try to exclude inertia effects caused by the WEC speeding up and slowing down - i.e. try to get steady wind and a constant rotor speed - 'steady-state' conditions.

Then with your 3 or more data points, apply the formula:

(v/vci)^2 = a - (b * vblade/v)

where v = windspeed, vci is cut-in windspeed, vblade is speed of blade (tip or mean speed may be used - it is immaterial for this purpose - or you can even use revolutions per minute, revs per second, or radians per second angular velocity), and a and b are constants.

You have 3 unknowns - vci, a and b - of which only vci is of interest; if you have 3 equations you can solve for vci, by algebra or by computer iteration; if you have more that 3 data points use any 3 to establish the values of vci, a and b and then run through the other data points to check accuracy.

To do this type of measurement well, I strongly recommend using a video camera and the following technique:

Paint or otherwise mark one of the WEC sails or blades; use a digital watch or stopwatch watch which counts ideally to 0.01 seconds; use some kind of windspeed measuring device - ideally an expensive hand-held anemometer with low or zero starting torque and analog dial or digital speed readout. Film all three simultaneously with the watch and anemometer in the near foreground and the WEC in the background; probably use manual focus and keep focus on the 2 instruments - the WEC should still be visible. Play back on slow motion and/or freeze frame/still and write down or computer enter the relevant data for analysis. As an alternative to the expensive hand-held anemometer use a home made device such as a standard table tennis ball on a fixed length of thread or standard-size plastic straw - watch out of course for wind direction shifts... Such a device has of course to be calibrated against such an expensive hand- held anemometer, against a cca, or in a windtunnel...

16a. Alternatives.

An anemometer can be fitted with some inexpensive electronics so as to feed signals to the com ports of a standard PC - thus with some fairly basic database software with telecomms built in then a complete log of instantaneous windspeed and direction for 1 or several years can be collected; to do this probably 2 comms ports would be used - one for speed and one for direction, but a more sophisticated box could feed one comms port only - the signal comes once per anemometer revolution, and the direction determines the character (e.g. ascii 40 through 127 or 40 to 240) transmitted; the PC clock is used to determine the exact timing of each revolution (to 0.01 second); additionally, if it is desired to monitor a windpump, then another comms port can receive a signal every time the pump shaft reaches top or bottom of stroke (through another black box and a proximity or electro-mechanical switch). Note that a fast PC could operate this software under Windows and still be used at the same time for accounting, word processing, spreadsheet, other database etc applications without serious performance degradation - i.e. a dedicated PC would NOT be required.... Most PC's can take up to 4 comms port cards without problems.

16b. One suggestion - since cca's appear to give a good indication of windpower availability, why not remount them at 6 or 10 metres above ground level to give readings less prone to interference by long grass or buildings - they can be read using binoculars, and readings can be corrected for the height difference; the catch of course to this is that remounting at 6 or 10 metres modifies the cut-in speed - a large reason why there are good correlations between cca data and real or simulated impulse type WEC's is that a cca is itself an impulse type WEC with a cut-in windspeed not much below the band in which we are interested; mounting cca's at a higher height would take their operating conditions further from this practical band range......

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RESERVATIONS

16c. RESERVATIONS - this study, although practically oriented, is largely theoretical, especially since there was not even one practical case of data from a windpower site which detailed energy yield over an annual or even monthly period. Despite this, the Author is reasonably convinced that the data is quite accurate and very useable. The 2 major ways in which reality departs from the simulation is to do with WEC inertia and with wind gusting - sometimes the good windspeeds are unusable by a WEC since it takes too long to respond to brief bursts of wind; also the fact is that for a windpump the applied torque is NOT truly constant over one revolution of the WEC - there is a peak torque, which is the point where the WEC tends to stop when the wind falls. In practice this can be minimised or eliminated by counterbalancing the shaft or the rotor, but putting counterbalancing weights on the rotor can give bad out-of-balance effects if and when the rotor gets to high speed. Of course if computer-logged data as in (16a) above can be matched to known inertias and known torque cycle variation, then true simulations over (8760 * 3600) seconds per year can be done for each location and then more accurate data can be obtained.

One other reservation is of course that for a pump, the water table can vary with the seasons, thus increasing the applied torque and cut-in windspeed as the water table drops.....

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SUMMARY

17. Final Summary - the above techniques can enable an individual, farmer, extension worker, windmill manufacturing company, NGO, organisation or

Government to assess potential and existing windpower sites and WE installations based on cheap and already-available cca data, without recourse to expensive and time consuming speciality instrument studies. They also enable the optimisation of impulse type WEC's at time of installation and at any time thereafter. The data analysis is therefore applicable not only to Tanzania but to all countries worldwide, developing and developed.

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APPENDIX A - Technical data and Methodology:

The beaufort data was for 13 locations, for 12 months plus year total, giving hours for 7 speed bands 0 through 11 metre/second at 2 metres above ground level - 91 data pairs per location, 1183 data pairs total. Data was input manually using dbase3+, and data entry checking (using checksums) was performed within the program as detailed below.

The anemograph data was similar, for 4 locations, approx 364 data pairs total; heights were all 10 metres - these were corrected; some windspeeds were in mph not knots - all were converted to metre/second.

The cca data was 13 data points (monthly plus annual) for 59 locations - 767 data points total.

All beaufort and anemograph data was converted to cumulative hours and to metre/second at 2 metres height.

Total energy for the 221 location-periods (17 locations * 12 months + 1 annual) was calculated as a straight integral of v^3.dt, using velocity steps of 0.1 metre/second (100 steps on average per location-period).

Windrun was also calculated as integral of cca speed wrt time, using 3 different possible cut-in speeds for the Casella Mark II cca's - 1.2 m/s, 1.7 m/s and 2.24 m/s.

The maximum impulse WEC extractable energy for each location-period was calculated by stepping through a range of cut-in windspeeds using iterative techniques; this was stored, as was the optimum cut-in windspeed vciopt corresponding to this Emax. The formula used was similar to that described in (15) above - the characteristic of an impulse type WEC; the integral was taken as vci^2 * vblade, where vblade/v tends to 1.00 as v/vci tends to infinity.

Then for each location period the vci values corresponding to 80% and 90% of Emax, both above and below vciopt were calculated using iterative techniques.

The program was written in Clipper 87 and took approximately 7 hours to run through on a 386DX with 12 msec hard drive. Graphs as below were done in Harvard Graphics, using ascii data import from data exported by the program to text files. These graphs for space and cost reasons are not included with this report as standard, BUT CAN BE SUPPLIED on floppy disc and/or hard copy if requested; they are of course central to much of the value of this report, and certainly central to proving that the report's findings are valid.

For the 13 beaufort sites and separately for the 4 anemograph sites the vcca simulated were compared with the vcca actuals. For the beaufort data it was found that the cca simulated and actual were a very good correlation using a cca cut-in windspeed of 2.24 m/s (as stated by Parkes); for the anemograph data there was no fit whatsoever using any of the 3 possible cut-in windspeeds - thus it was decided to discard the anemograph data as inaccurate for all purposes and applications.

The total energy, maximum impulse energy and vciopt were now graphed against the vcca simulated (all these 4 values were simulated), from the beaufort data only, i.e. discarding the anemograph data. This gave very good fits on the 2 energies, and less good but very useable on vciopt. The formulae as per (4a), (4b) and (5) above were obtained from these graphs.

The 80% and 90% vci's were now compared with the vciopt's - the 0.67, 0.78, 1.26 and 1.38 ratios were established as good fits as per (6) above.

The cca data for the 59 sites were processed to give Emax and vciopt for the 12 months plus annual average; also a recommended vcibest, which depended on seasonal variability, and the resultant values of Ebest extractable from that year-round cut-in speed. The data was presented in sequence of descending annual wind energy and in sequence of worst month wind energy (see appendix 2 below).

The seasonal energy yield data was also presented in context of normal rainfall occurrence, so as to give some indication as to complementary or otherwise energy requirement for water pumping.

home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind201.htm

APPENDIX B - PROCESSED DATA FOR 59 TANZANIAN LOCATIONS

59 TANZANIAN LOCATIONS IN DESCENDING SEQUENCE OF AVERAGE ANNUAL IMPULSE WEC ENERGY YIELD (M3/S3):

MBULU 111, OLDUVAI CAMP 102, LOLIONDO 98, TANGA 88, MTWARA 87, MWANZA 86, ABERCORN 85, MBEYA 84, SAO HILL 82, IGERI 78, AMANI 78, FORT HILL 77, MBARALI 77, TABORA OBSERVATORY 70, MWAMALA 65, CHUKWANI ZANZIBAR 64, DAR AIRPORT 63, SUMBAWANBGA 60, KIGOMA 56, KONGWA 55, KISAUNI 54, LINDI 52, MUSOMA 51, MWANHALA 50, KILOMBERO 50, IRUNDI WEST FOREST 48, SONGEA AIRPORT 48, IRINGA NDULI 46, TABORA AIRPORT 46, UKIRIGURU 46, MOMBO 46, KONDOA 45, KUBAGA 45, SAME 44, CHUNYA 42, BUKOBA 42, MARIKTANDA RI 39,

SONGEA TOWN 39, KILINDONI MAFIA 38, DAR ES SALAAM 38, NGORONGORO 37, BIHARAMULO 37, KILWA KIVINJE 36, NGAWAZI, MUFINDI 35, ILONGA 35, ARUSHA CHINI 35, TENGERU 30, ARUSHA TPRI 30, WATI PEMBA 30, KARANGA 30, NJOMBE 28, BWANGA SUB ST 28, MOSHI 23, NKHATA BAY 22, NGOMENI 20, LYAMUNGU 18, IRINGA 17, NACHINGWEA 15, CHIVANJEE ESTATE 10,

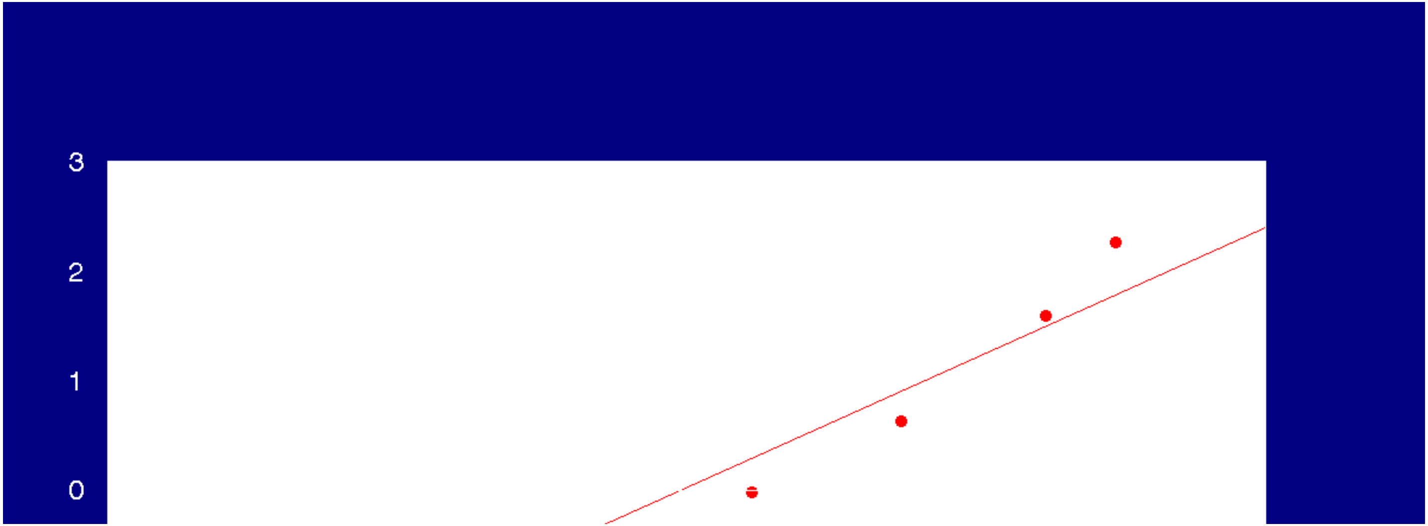
59 TANZANIAN LOCATIONS IN DESCENDING SEQUENCE OF WORST MONTH IMPULSE WEC ENERGY YIELD (M3/S3):

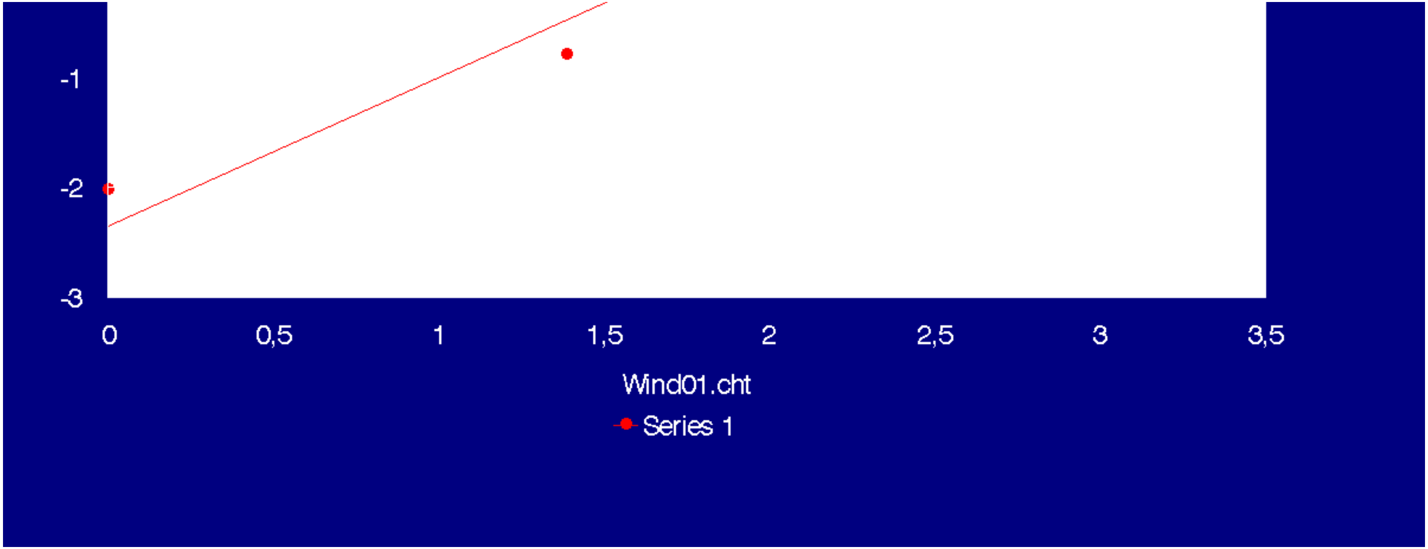
LOLIONDO 78, MBULU 70, AMANI 65, MWANZA 63, MTWARA 60, TANGA 60, IGERI 57, MBEYA 51, OLDUVAI CAMP 51, KILOMBERO 46, KIGOMA 43, SAO HILL 43, DAR AIRPORT 43, MUSOMA 43, ABECORN

42, KISAUNI 37, LINDI 37, UKIRIGURU 33, BUKOBA 33, TABORA OBSERVATORY 33, CHUKWANI ZANZIBAR 33, MWAMALA 31, MWANHALA 31, SUMBAWANBGA 30, MARIKTANDA RI 29, KONDOA 29, FORT HILL 28,

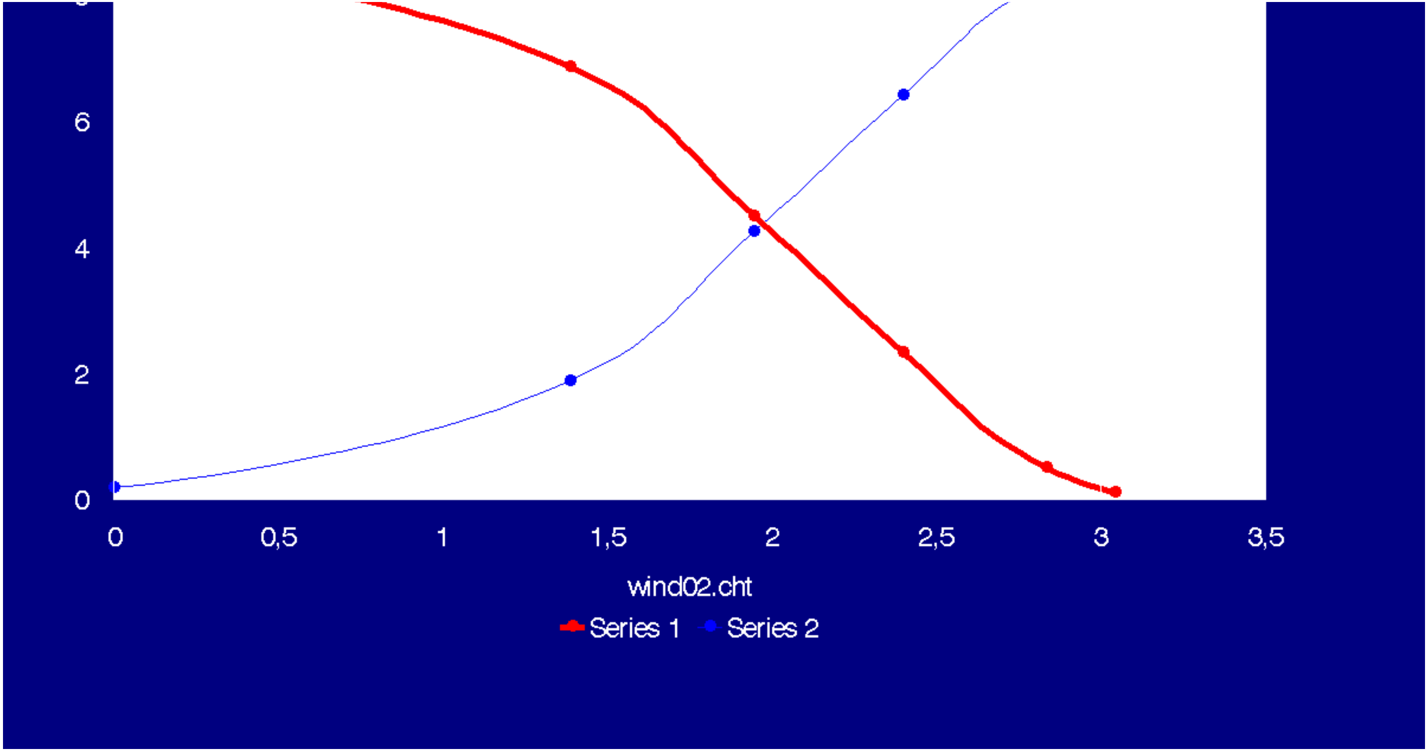
SONGEA AIRPORT 28, IRINGA NDULI 28, MOMBO 28, SAME 28, NGORONGORO 28, KONHWA 26, TENGERU 26, MBARALI 25, ARUSHA CHINI 24, TABORA AIRPORT 23, SONGEA TOWN 23, KILINDONI, MAFIA 23, ILONGA 22, WATI, PEMBA 22, KUBAGA 21, BWANGA SUB ST 20, KILWA KIVINJE 20, ARUSHA TPRI 20, DAR ES SALAAM 19, NJOMBE 19, BIHARAMULO 18, KARANGA 16, CHUNYA 16, NGAWAZI, MUFINDI 15, LYAMUNGU 13, NKHATA BAY 12, NGOMENI 12, MOSHI 12, IRINGA 8, NACHINGWEA 7, CHIVANJEE ESTATE 6. vciopt were calculated using iterative techniques.

home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind202.htm UNKNOWN

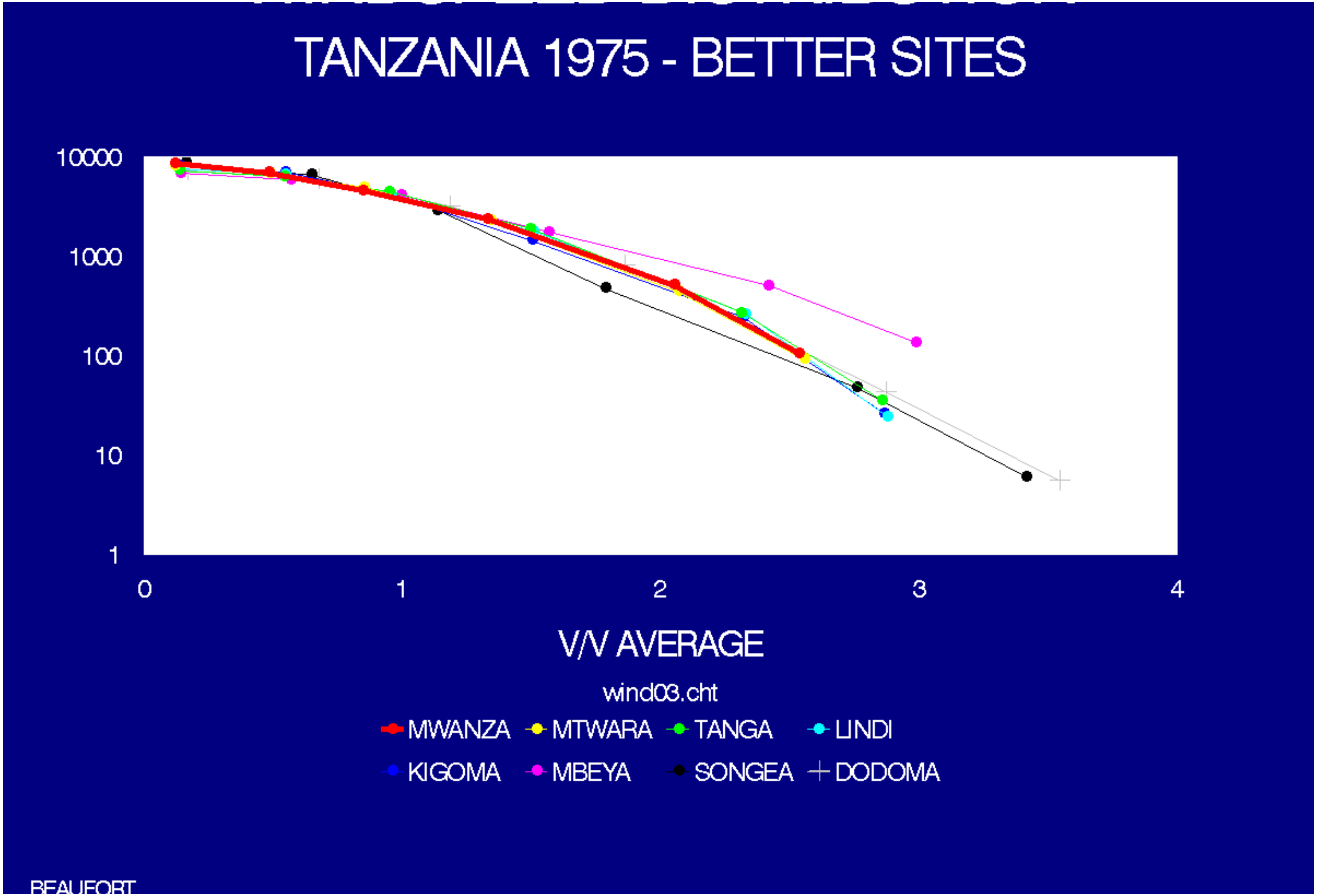




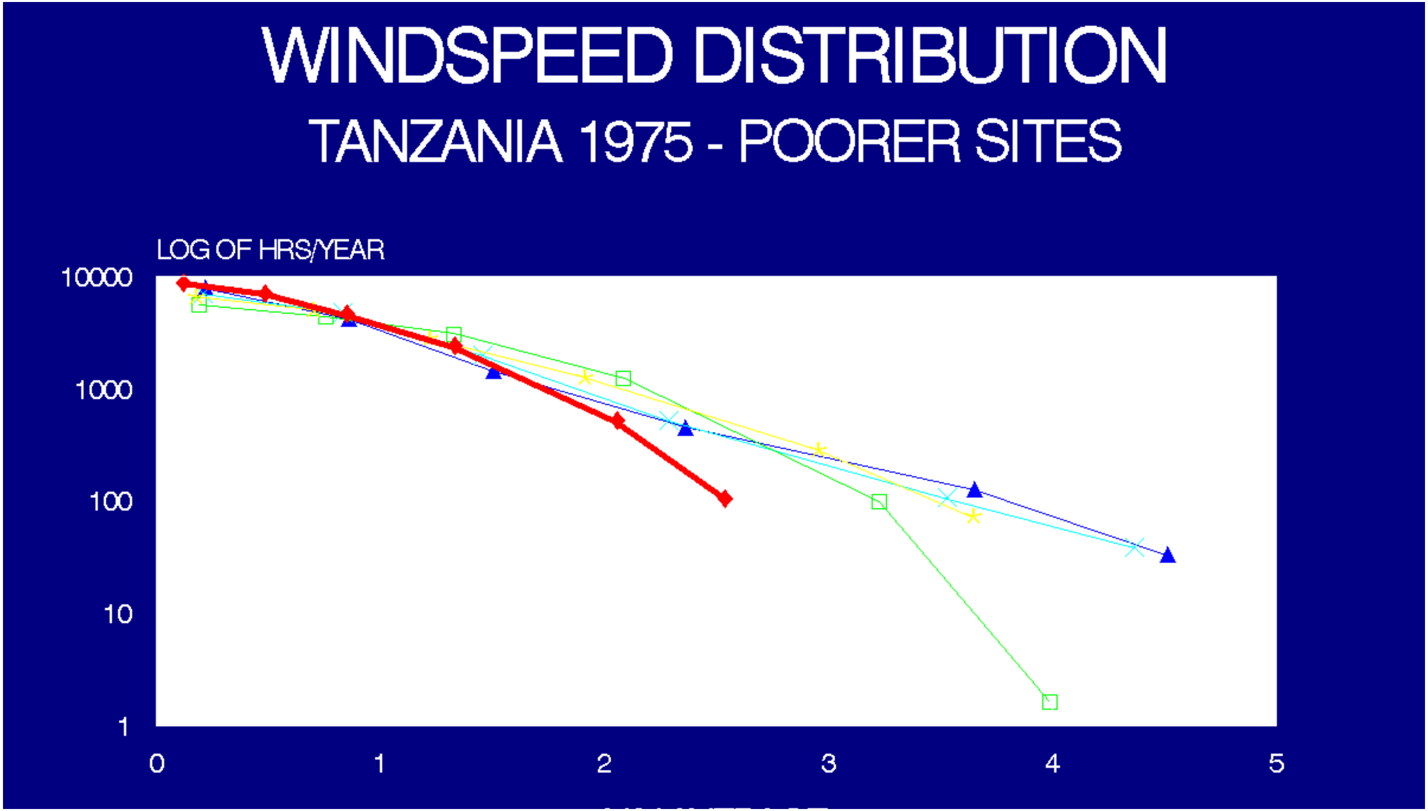
home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind203.htm UNKNOWN

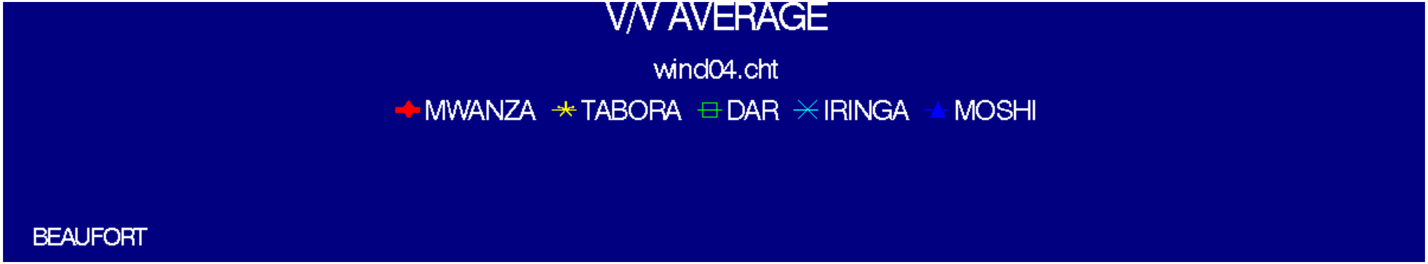


[home](#).[cd3wd](#).[ar](#).[cn](#).[de](#).[en](#).[es](#).[fr](#).[id](#).[it](#).[ph](#).[po](#).[ru](#).[sw](#) [wind204.htm](#) WINDSPEED DISTRIBUTION - TANZANIA 1975 - BETTER SITES - BEAUFORT DATA

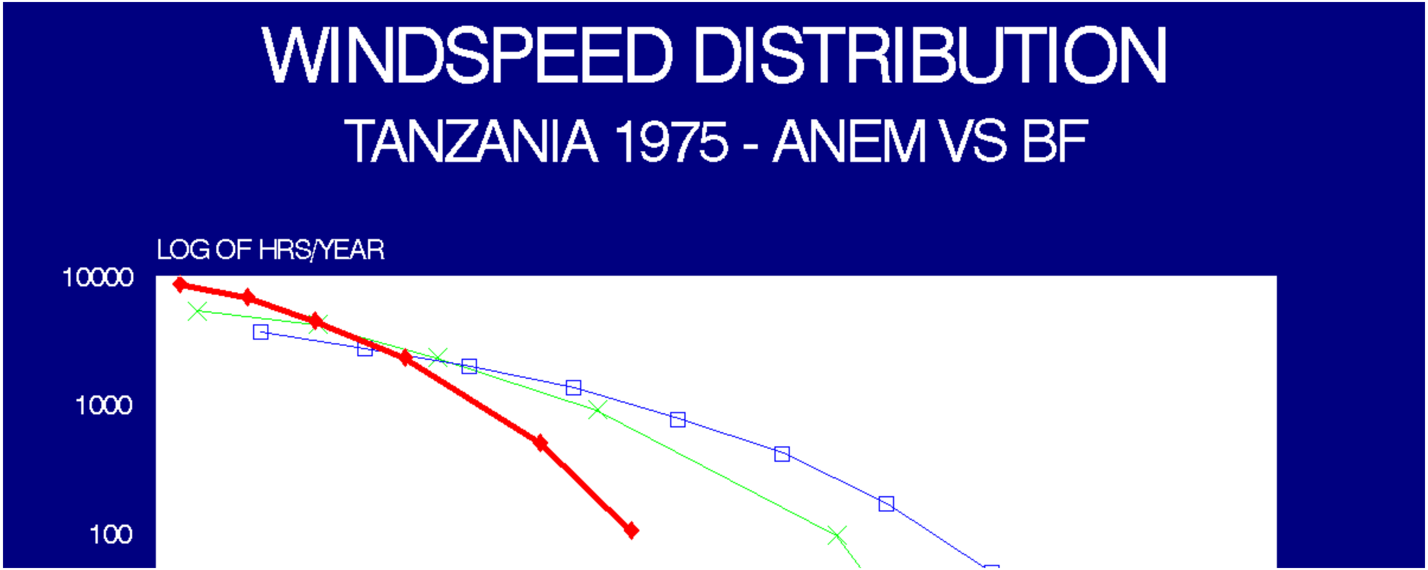

TANZANIA 1975 - BETTER SITES
10000
1000
100
10
1
0
1
2
3
4
V/V AVERAGE
wind03.cht
MWANZA
MTWARA
TANGA
LINDI
KIGOMA
MBEYA
SONGEA
DODOMA
BEAUFORT

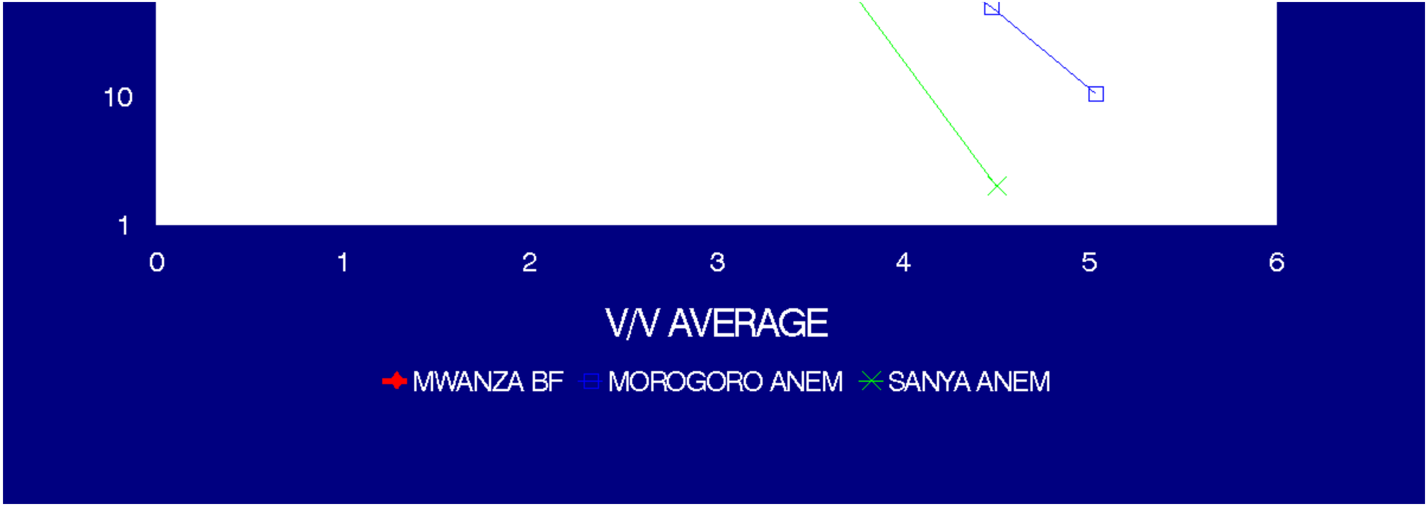
[home](#).[cd3wd](#).[ar](#).[cn](#).[de](#).[en](#).[es](#).[fr](#).[id](#).[it](#).[ph](#).[po](#).[ru](#).[sw](#) [wind205.htm](#) WINDSPEED DISTRIBUTION - TANZANIA 1975 - POORER SITES - BEAUFORT DATA



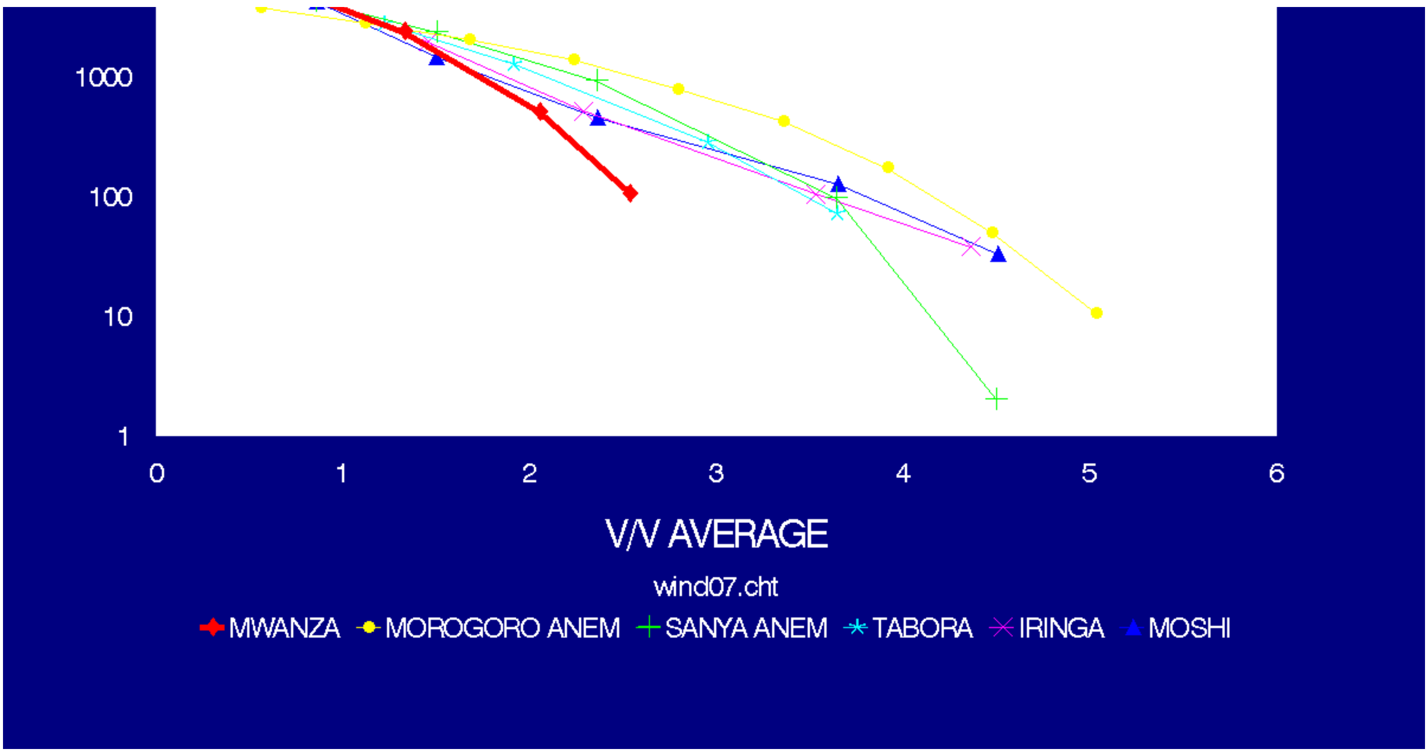


home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind207.htm WINDSPEED DISTRIBUTION - TANZANIA 1975 - ANEMOMETER DATA VS. BEAUFORT DATA

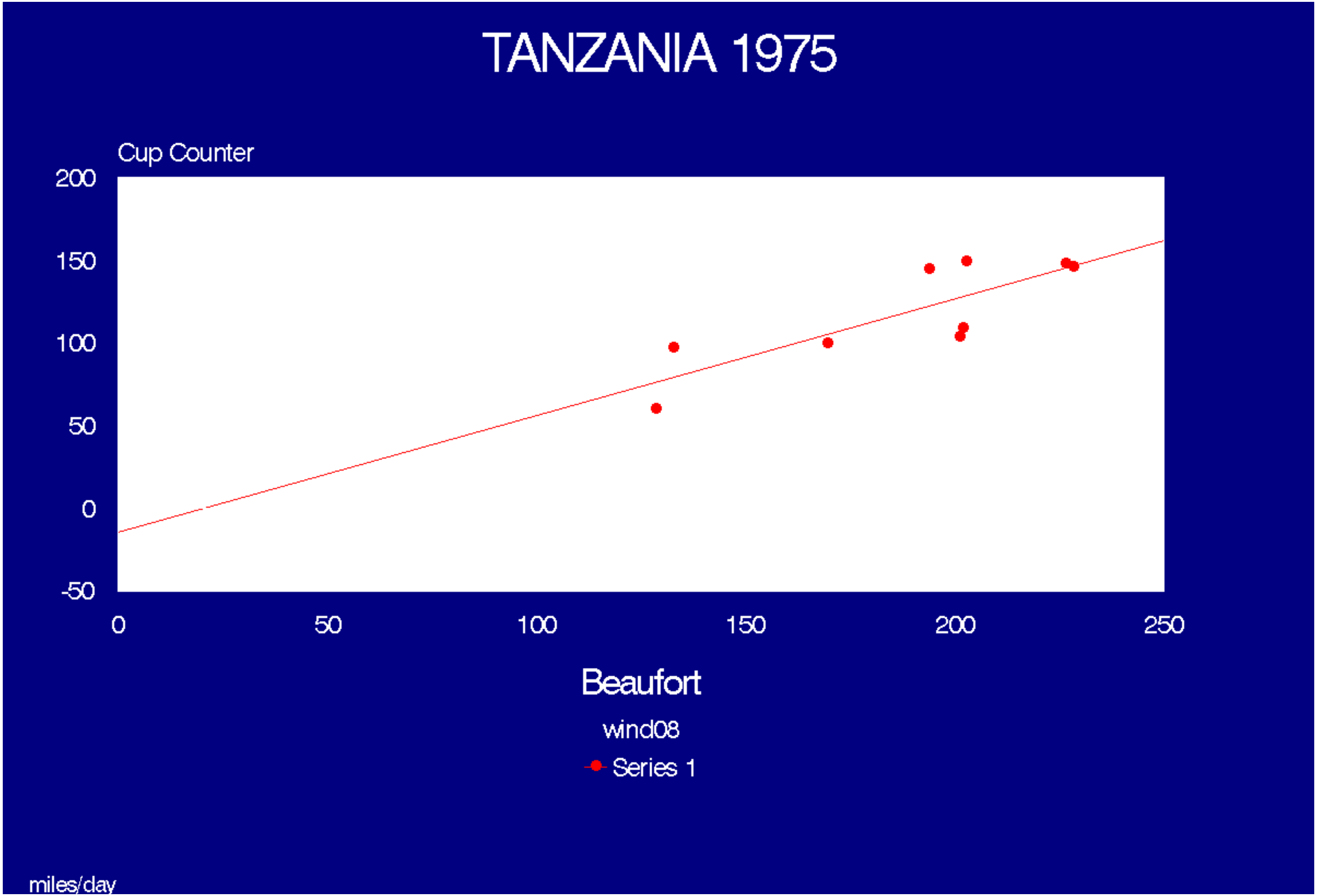




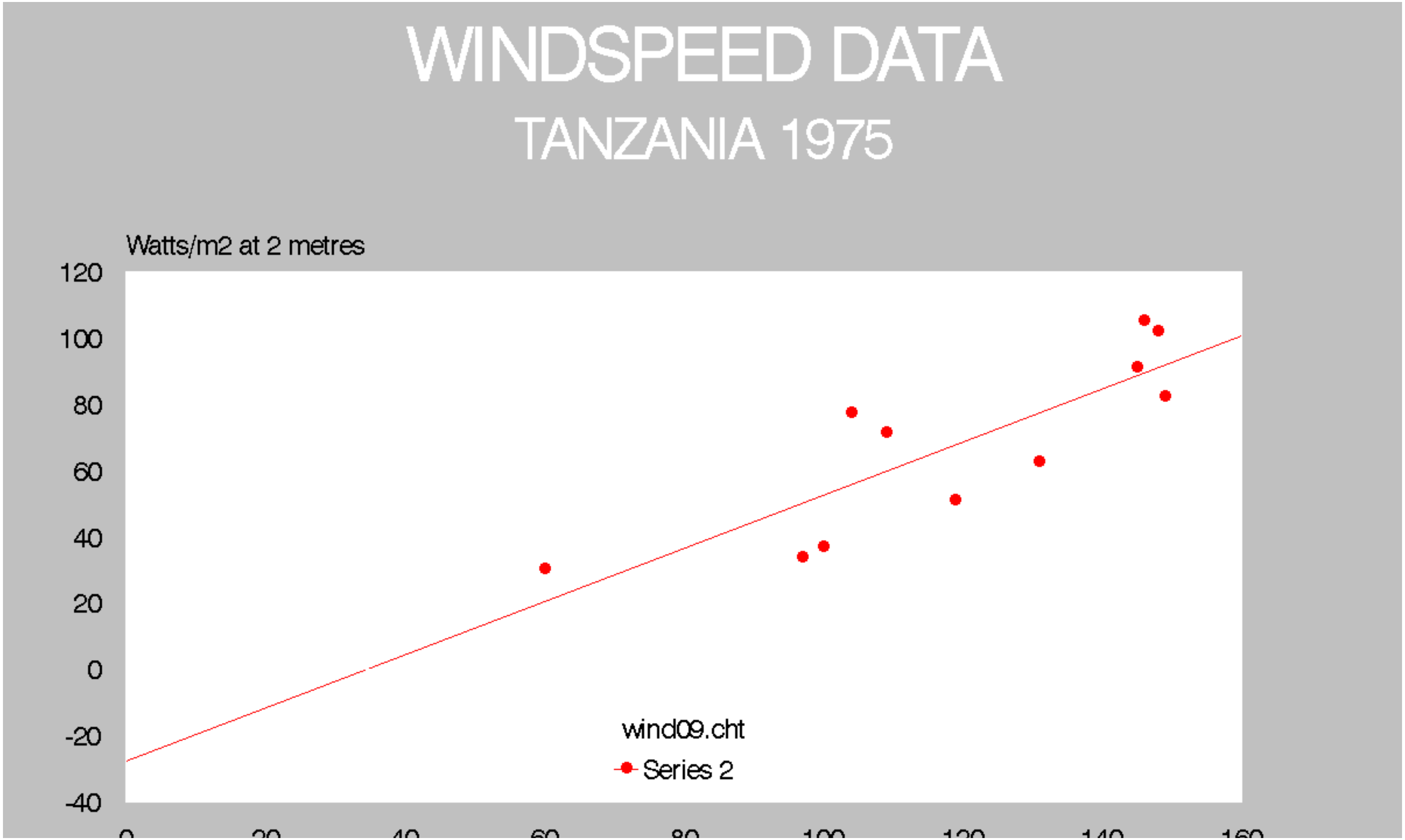
home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind208.htm WINDSPEED DISTRIBUTION - TANZANIA 1975 - POORER SITES

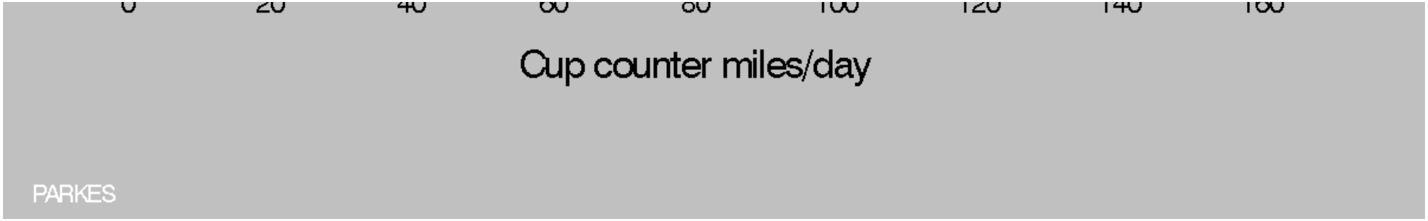


home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind209.htm COMPARISON - CUP COUNTER VS. BEAUFORT

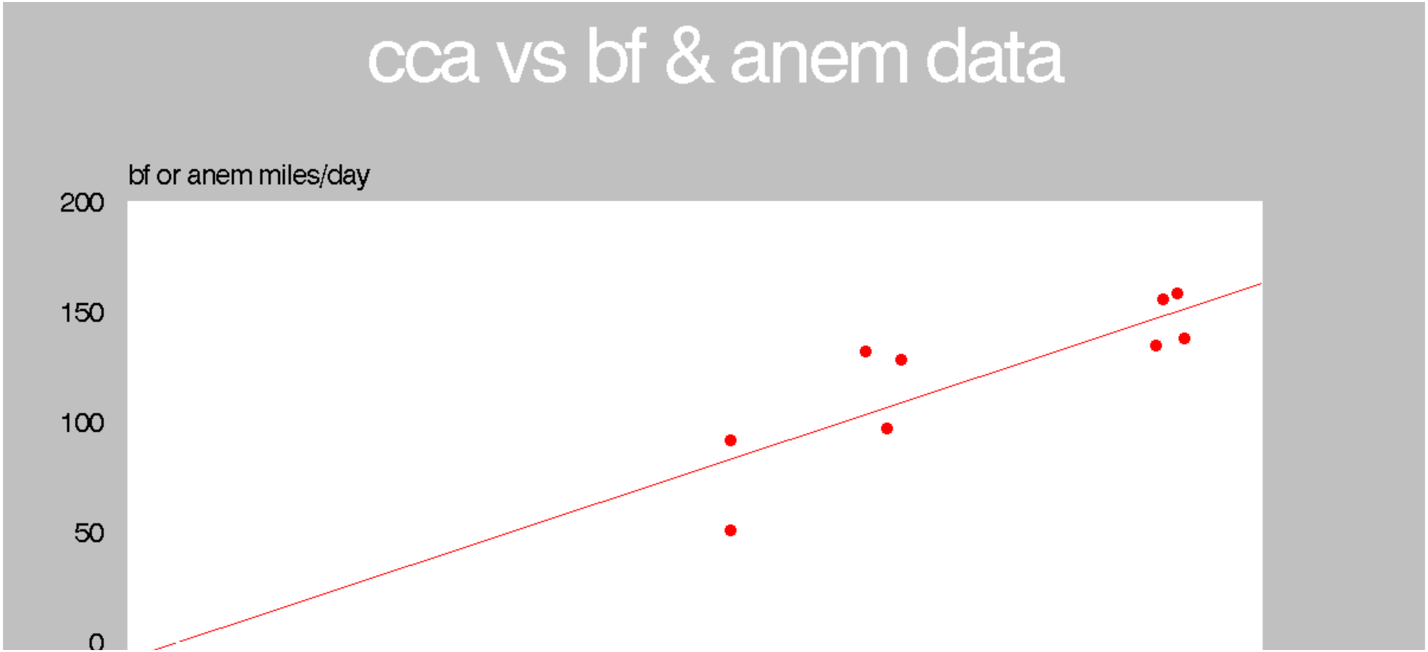

TANZANIA 1975
Cup Counter
200
150
100
50
0
-50
0
50
100
150
200
250
Beaufort
wind08
Series 1
miles/day

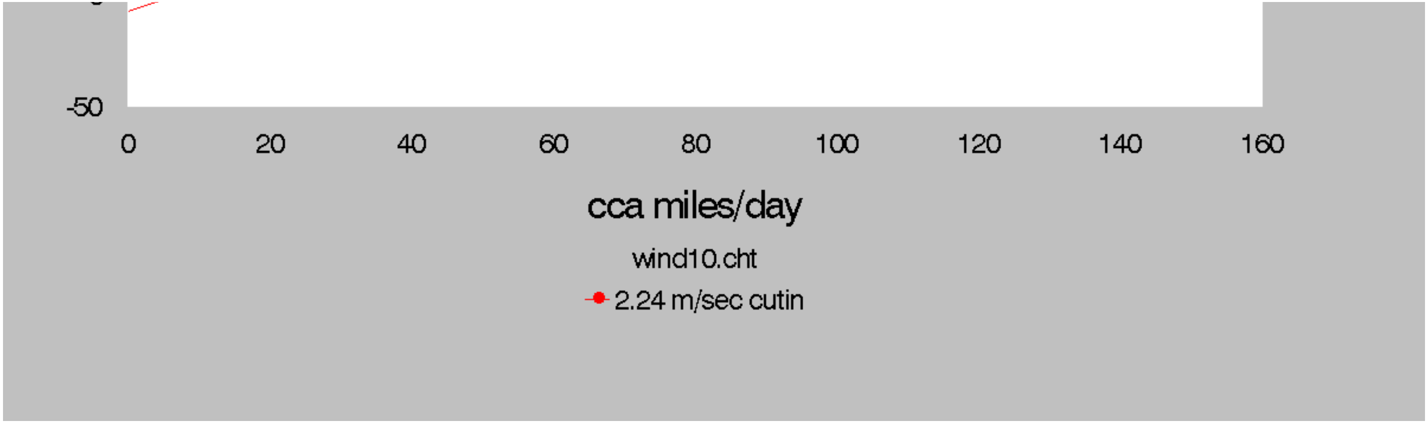
home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind210.htm ENERGY YIELD VS. CUP COUNTER WINDRUN



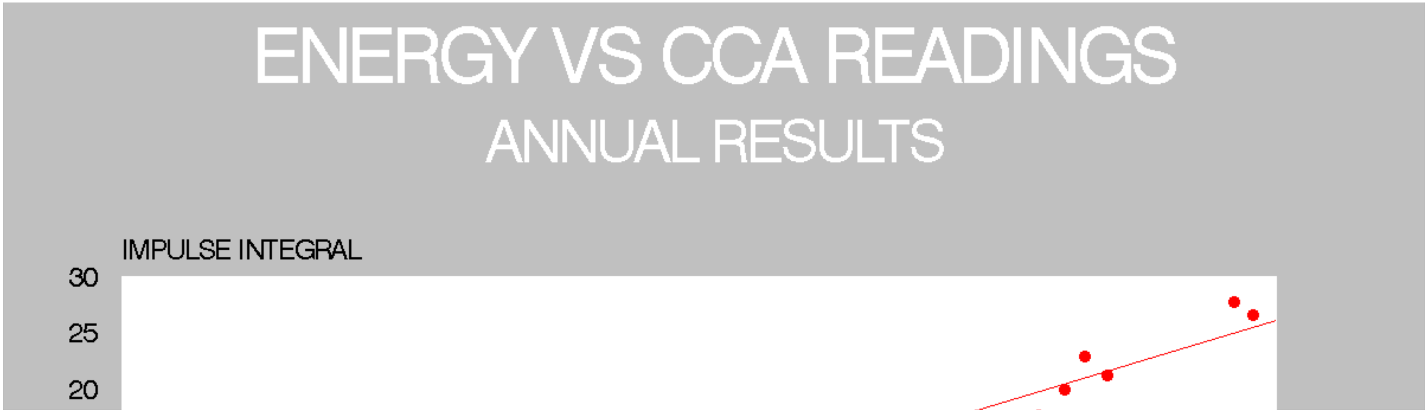


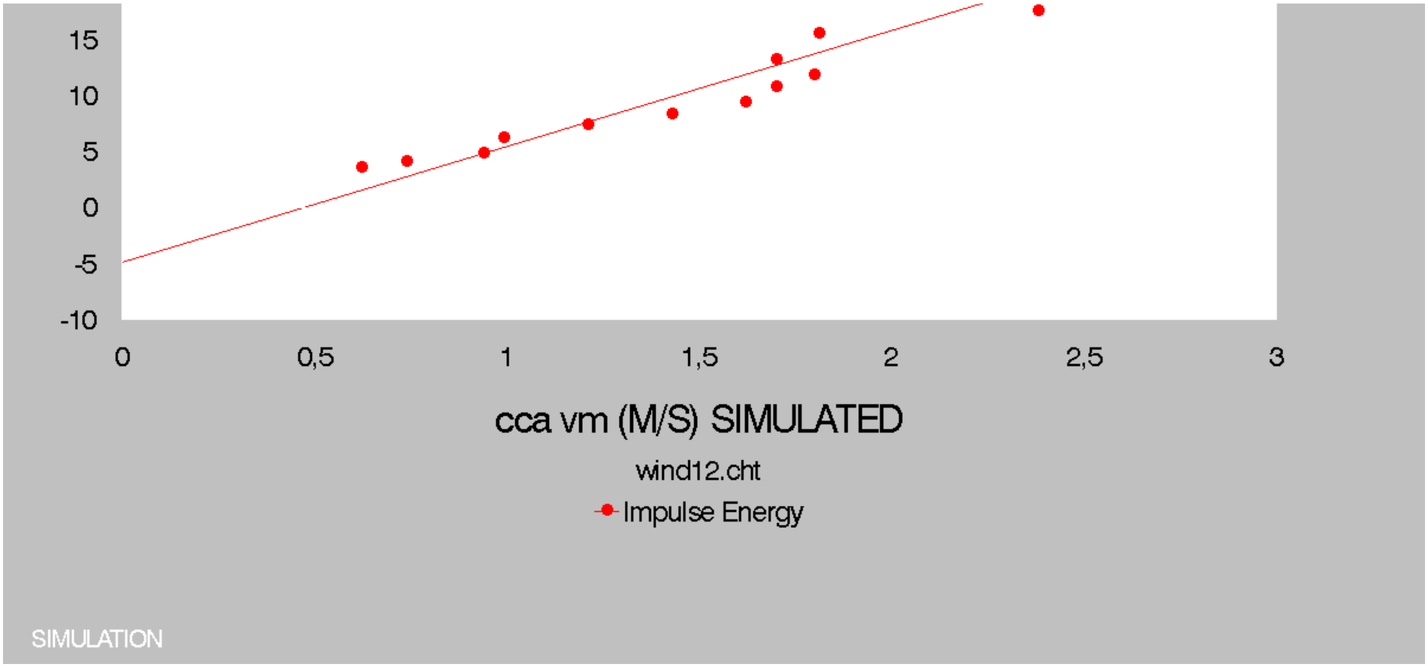
home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind212.htm CCA VS BEAUFORT OR ANEMOMETER DATA



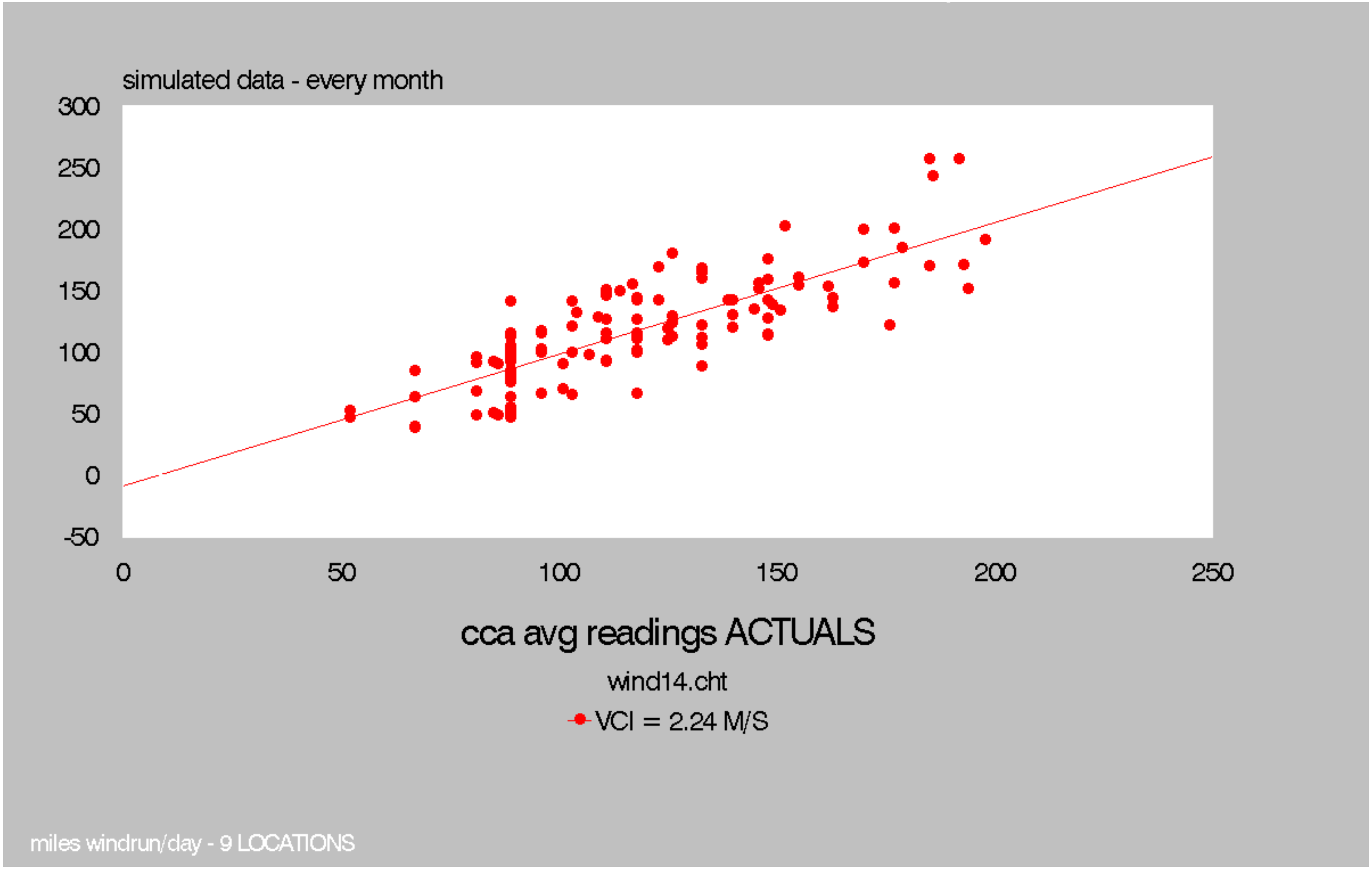


home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind214.htm IMPULSE ENERGY VS. SIMULATED CCA AVG. WINDSPEED

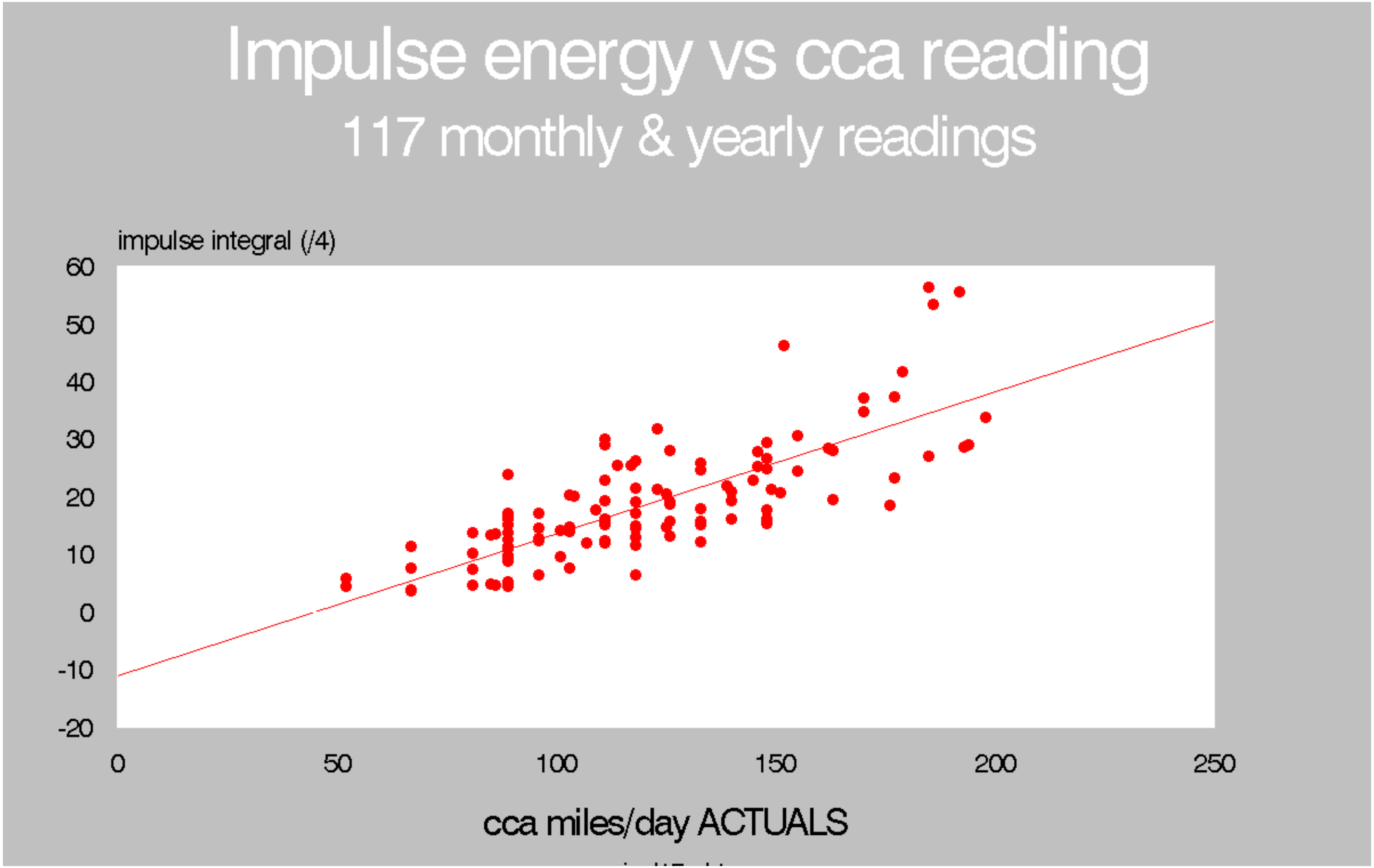


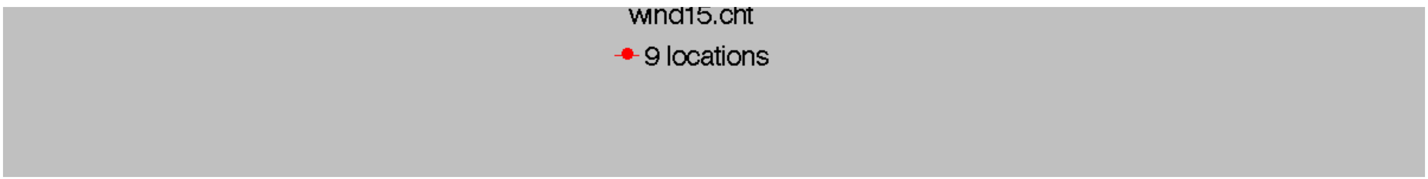


home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind215.htm CCA VS. ANEM AND BEAUFORT DATA - FOR CUT-IN WINDSPEED 2.24 METRE/SEC

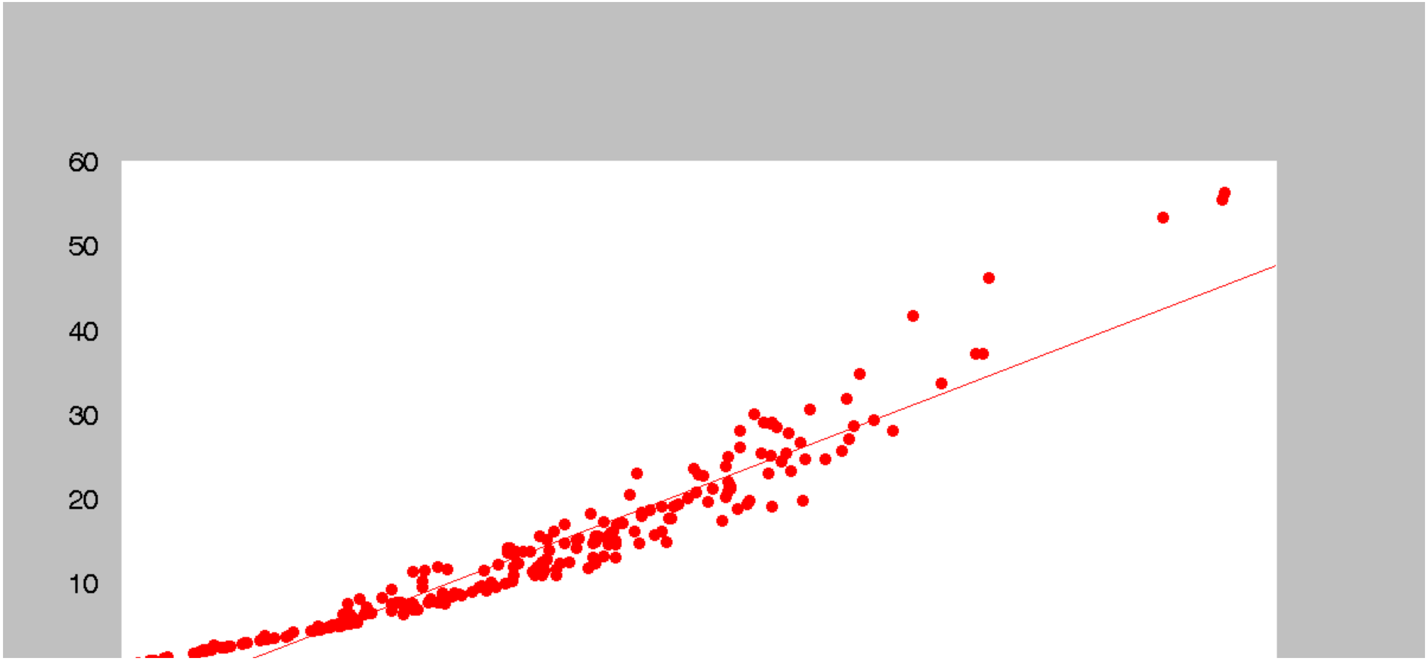

simulated data - every month
300
250
200
150
100
50
0
-50
0
50
100
150
200
250
cca avg readings ACTUALS
wind14.cht
VCI = 2.24 M/S
miles windrun/day - 9 LOCATIONS

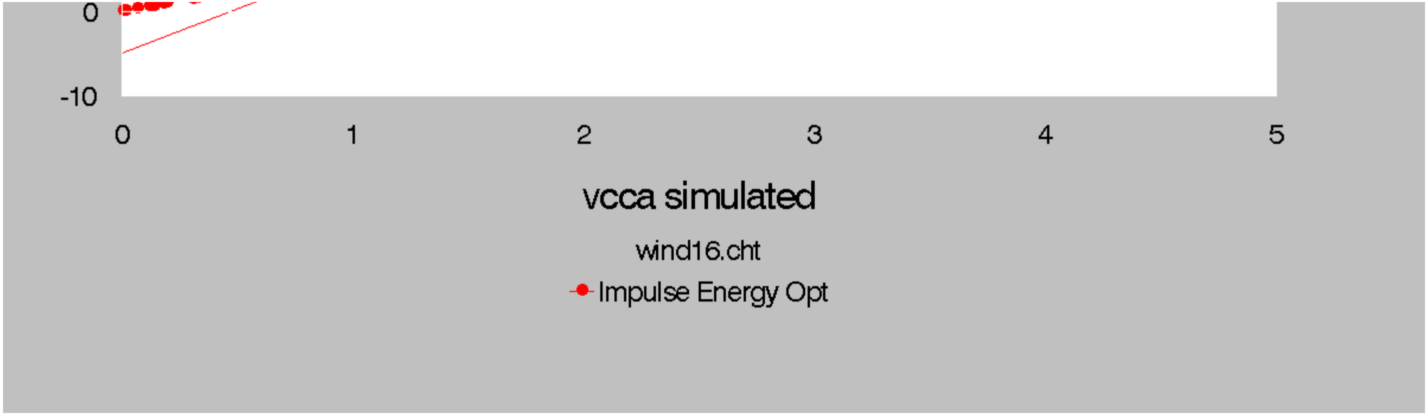
home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind216.htm IMPULSE ENERGY VS. CCA READINGS



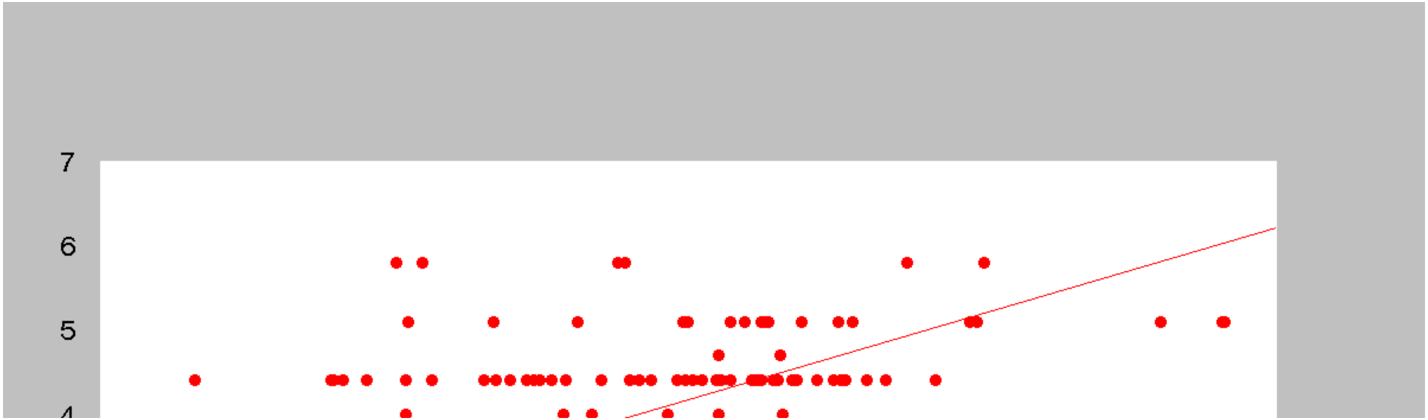


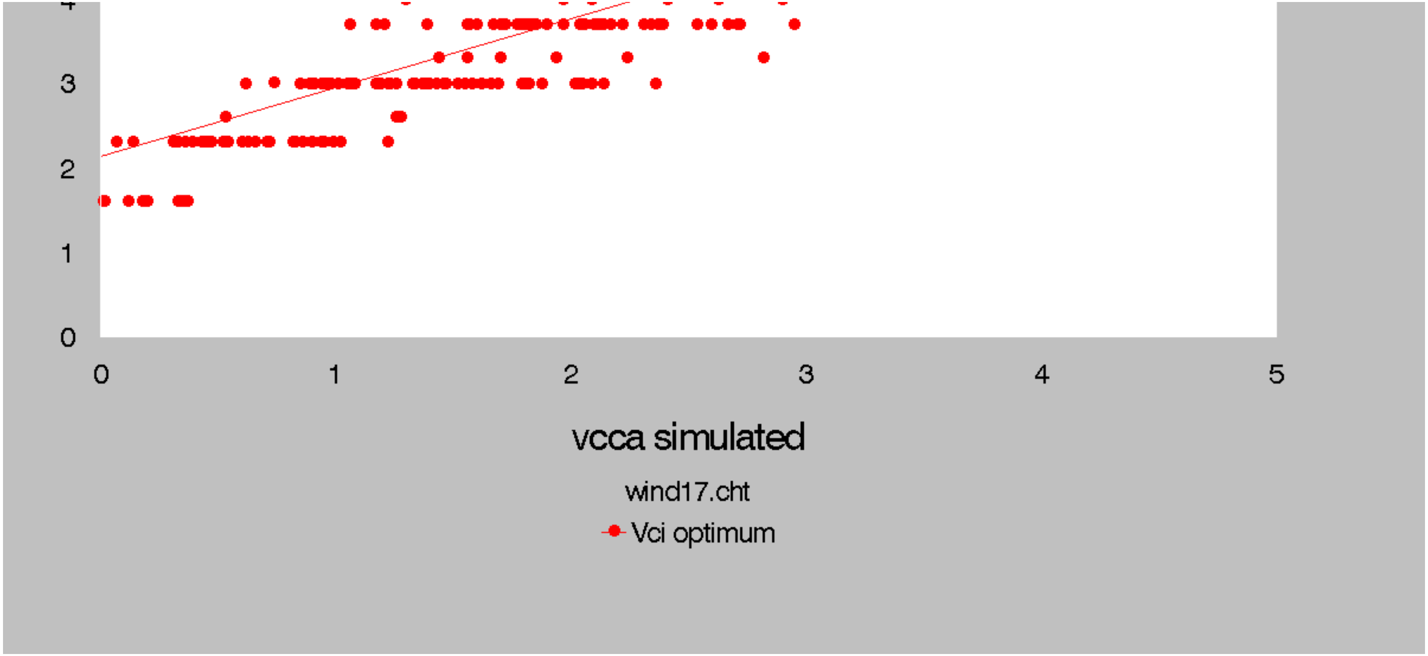
home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind217.htm OPTIMAL IMPULSE ENERGY VS. SIMULATED AVG. CCA WINDSPEED



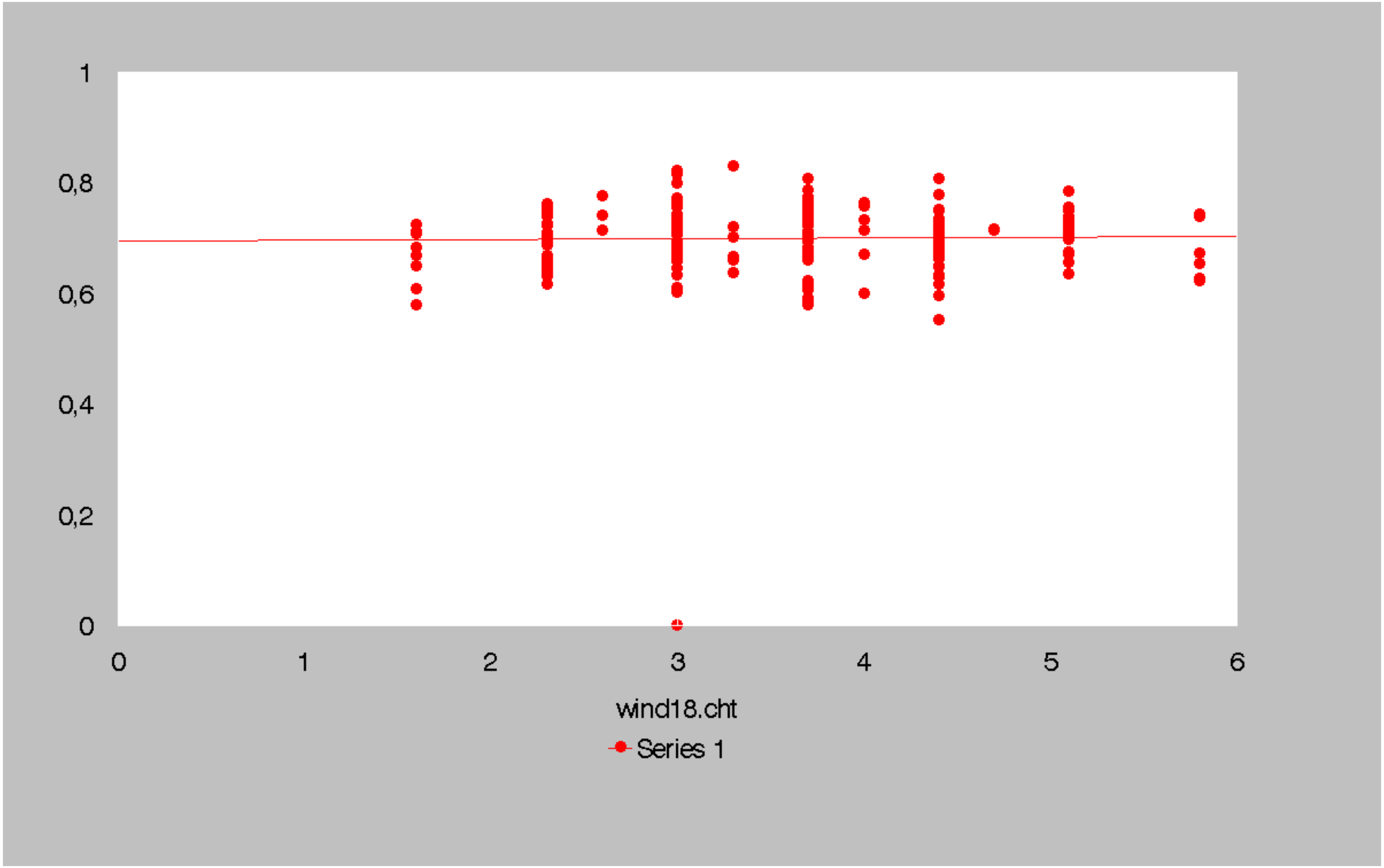


home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind218.htm OPTIMUM CUT-IN WINDSPEED VS. AVG. CCA WINDSPEED

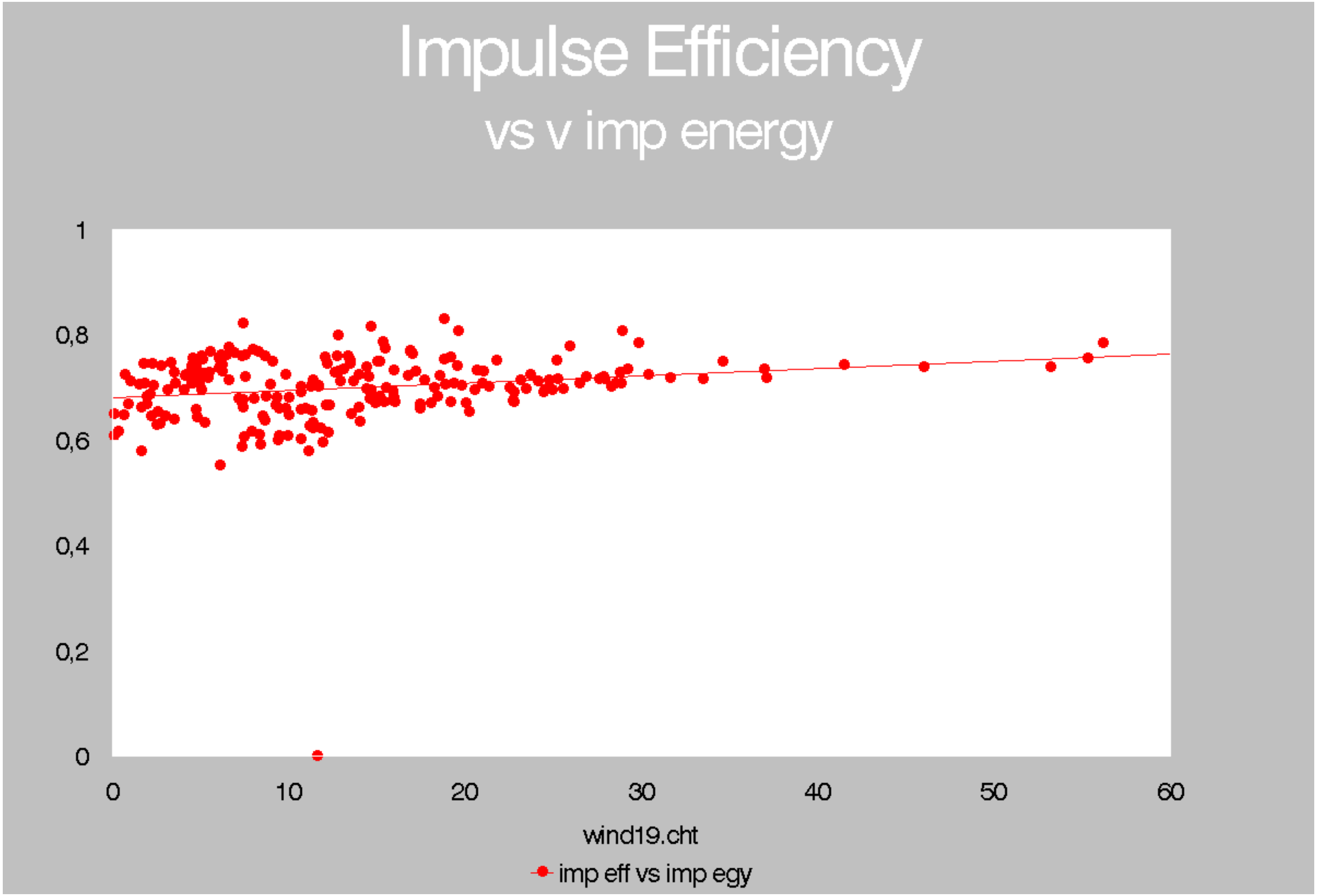




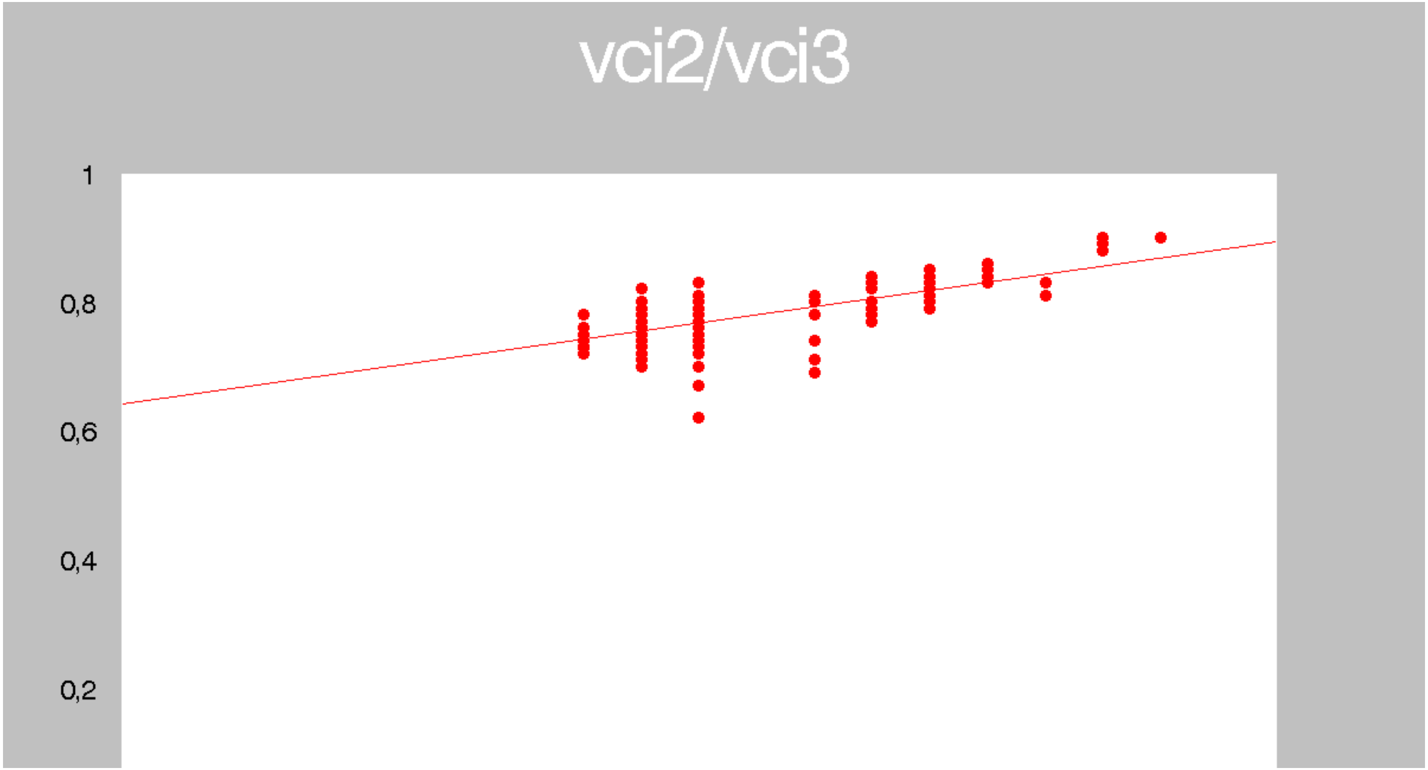
home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind219.htm IMPULSE EFFICIENCY VS. CUT-IN WINDSPEED

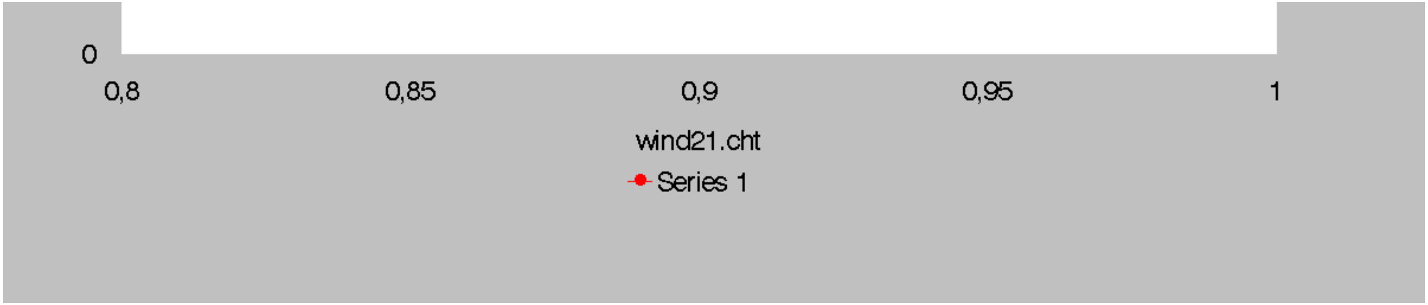


home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind221.htm IMPULSE EFFICIENCY VS. IMPULSE ENERGY

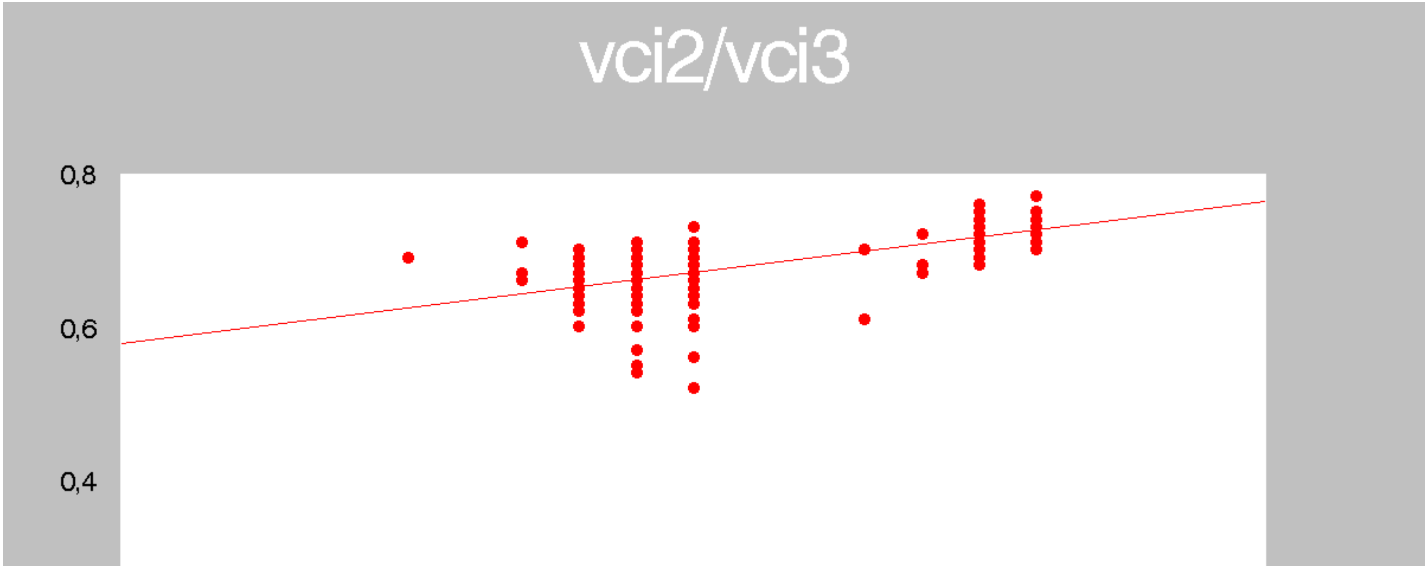

Impulse Efficiency
vs v imp energy
1
0,8
0,6
0,4
0,2
0
0
10
20
30
40
50
60
wind19.cht
imp eff vs imp egy

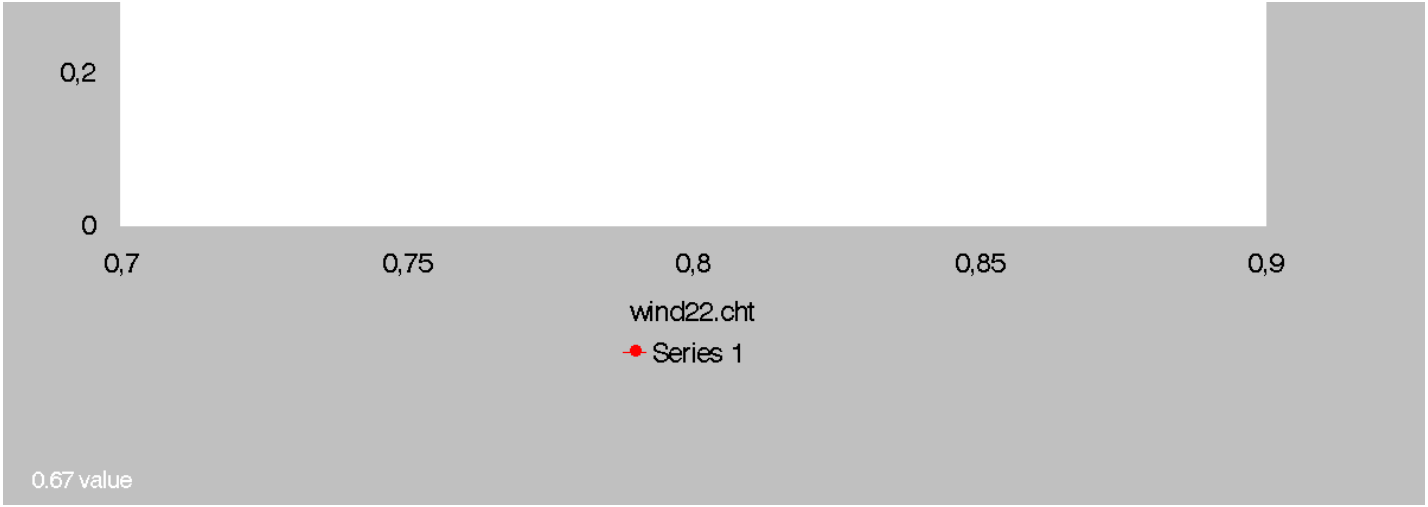
home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind222.htm VCI2 / VCI3



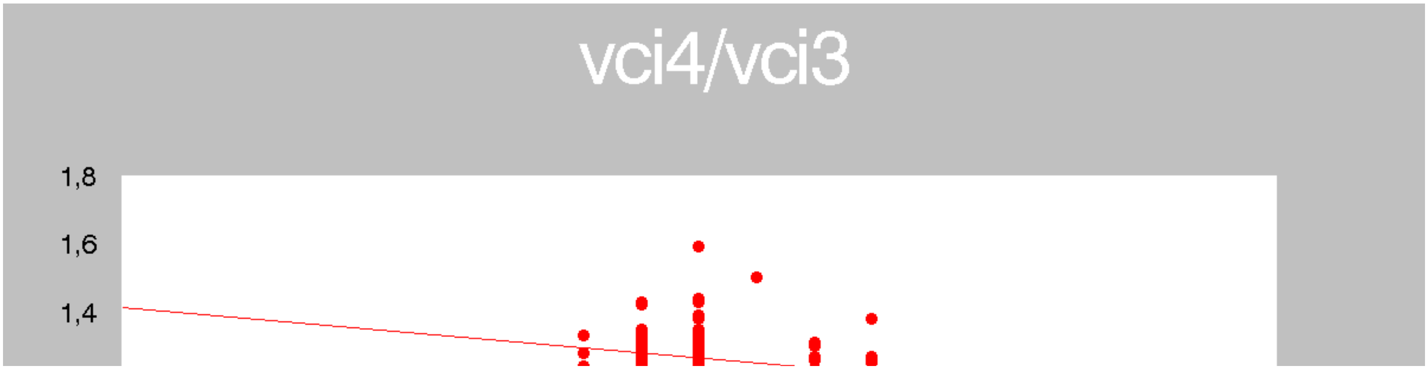


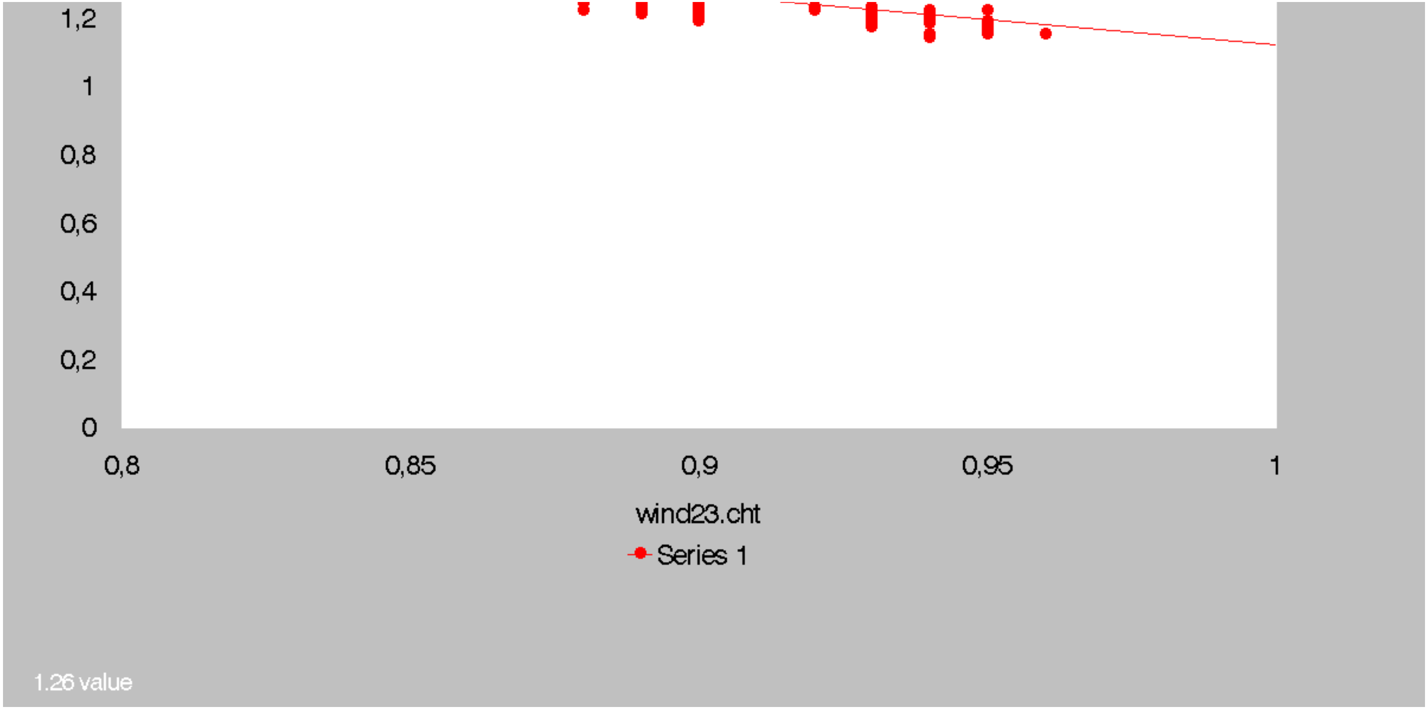
home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind223.htm VCI2 / VCI3 (0.67 VALUES)



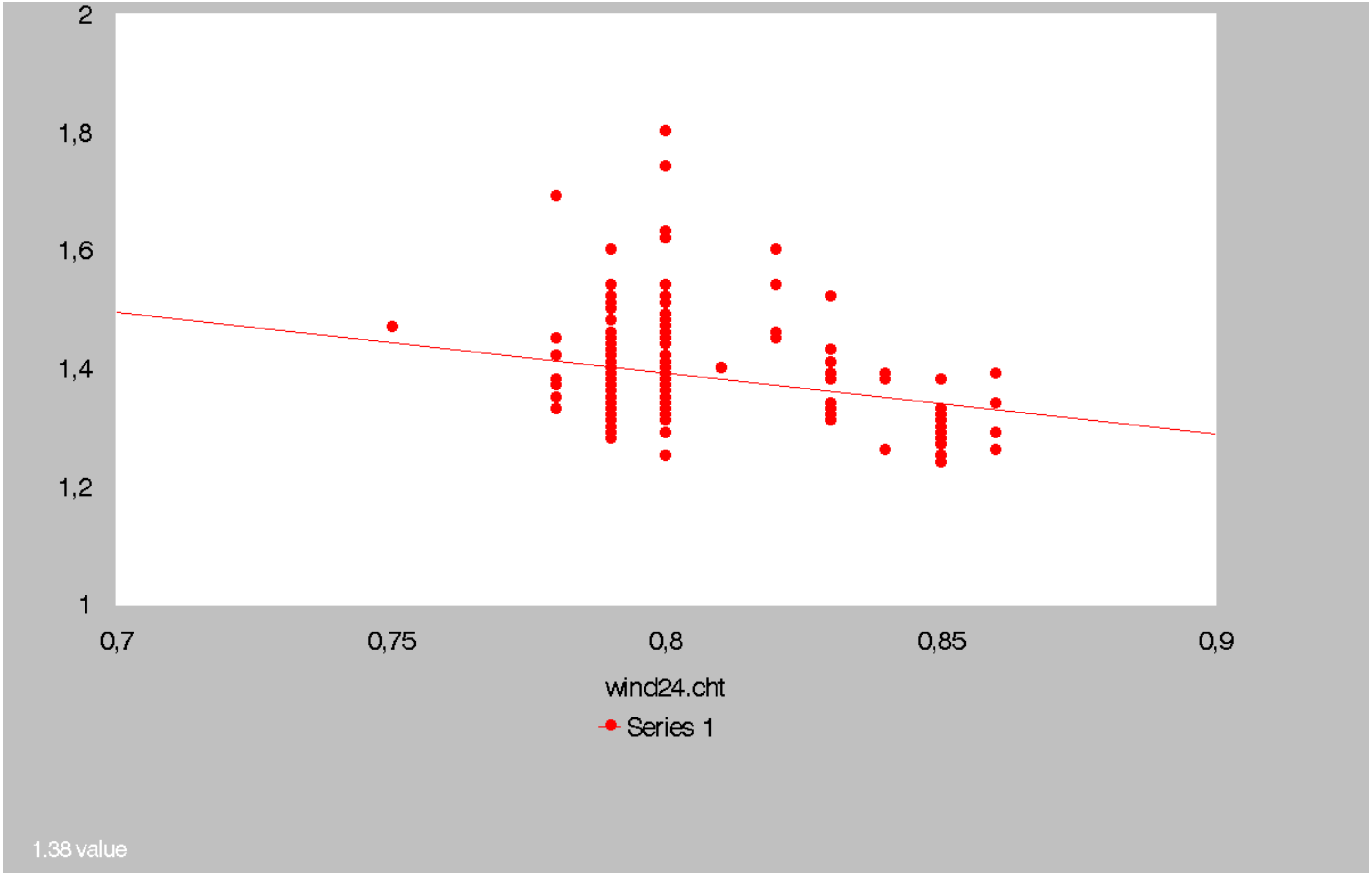


home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind224.htm VCI4 / VCI3 VS. EFFICIENCY

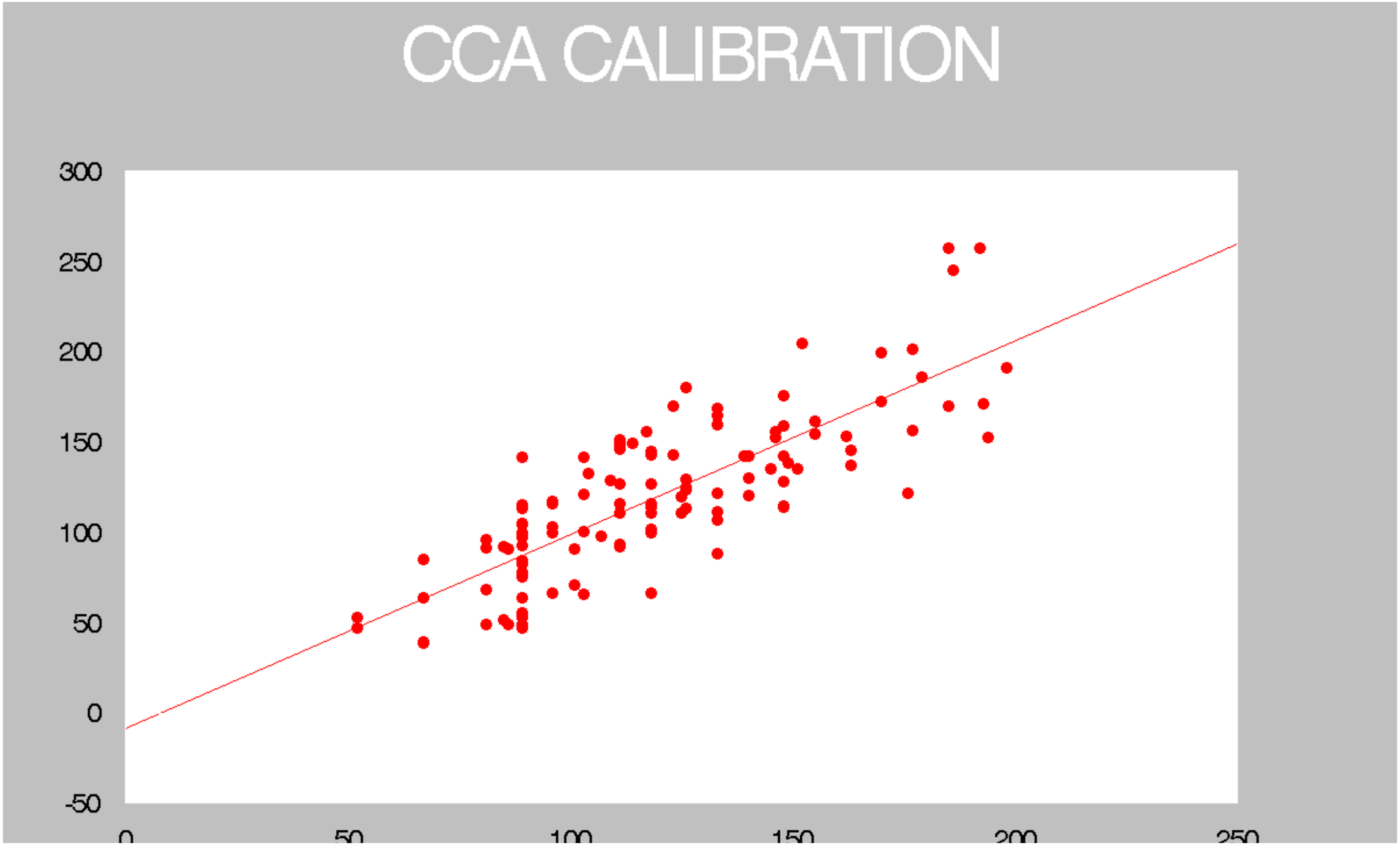


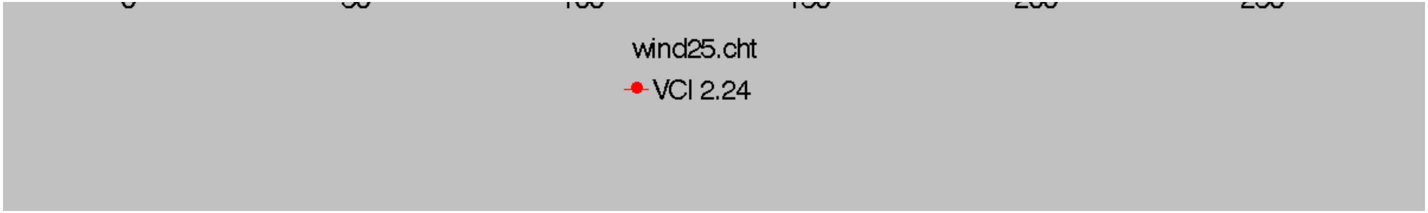


home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind225.htm VCI5 / VCI3 VS. EFFICIENCY

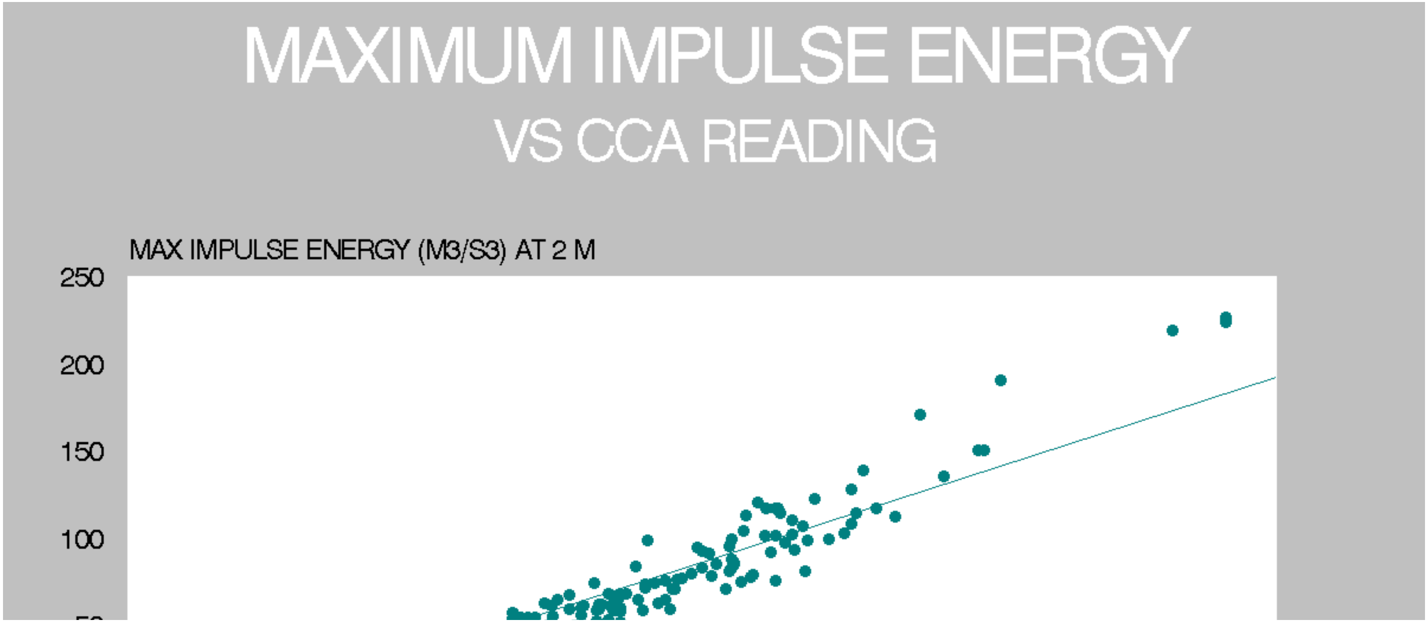

2
1,8
1,6
1,4
1,2
1
0,7
0,75
0,8
0,85
0,9
wind24.cht
Series 1
1.38 value

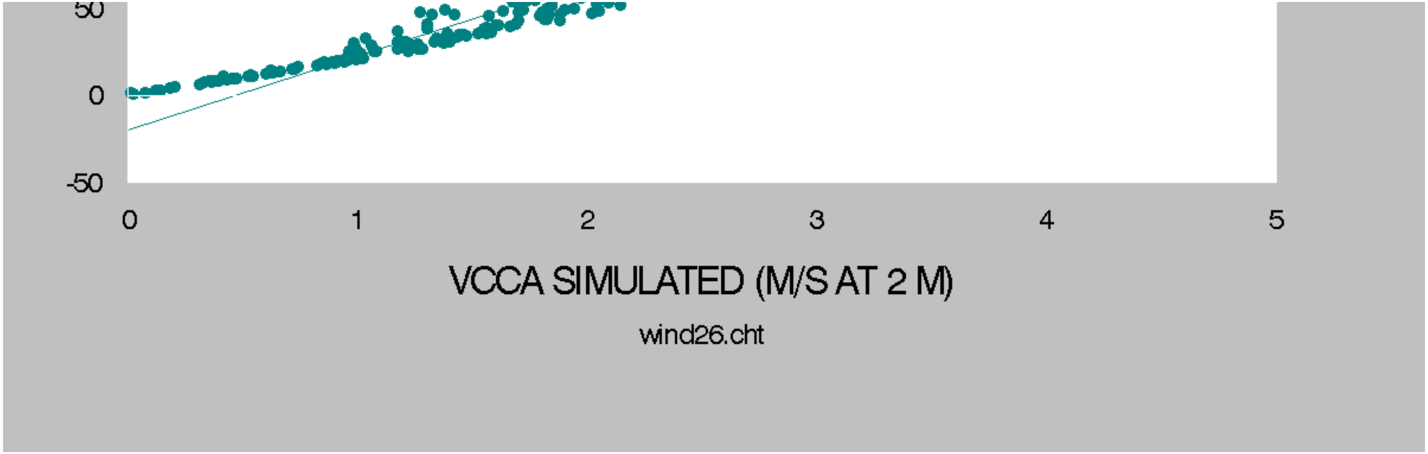
home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind226.htm CCA CALIBRATION FOR CUT-IN WINDSPEED = 2.24 METRE/SEC



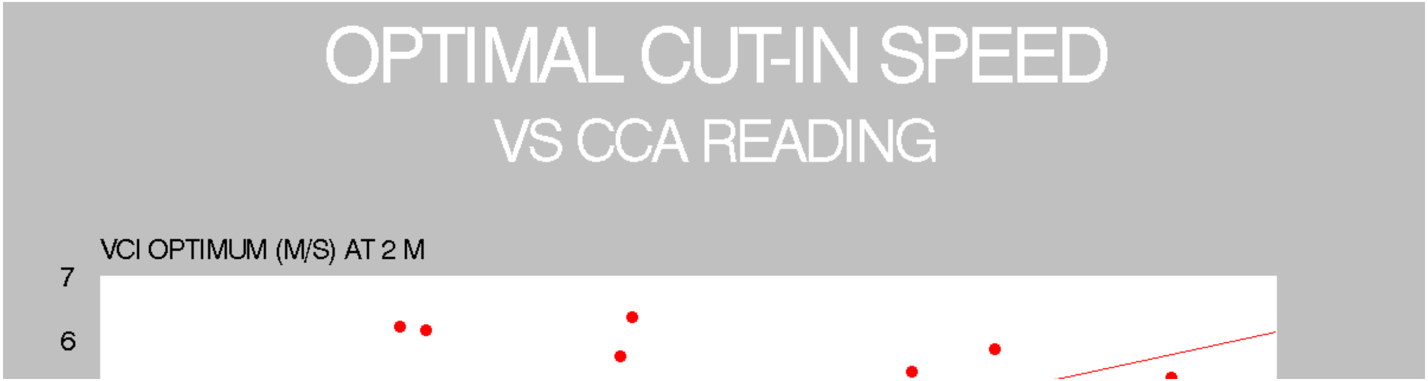


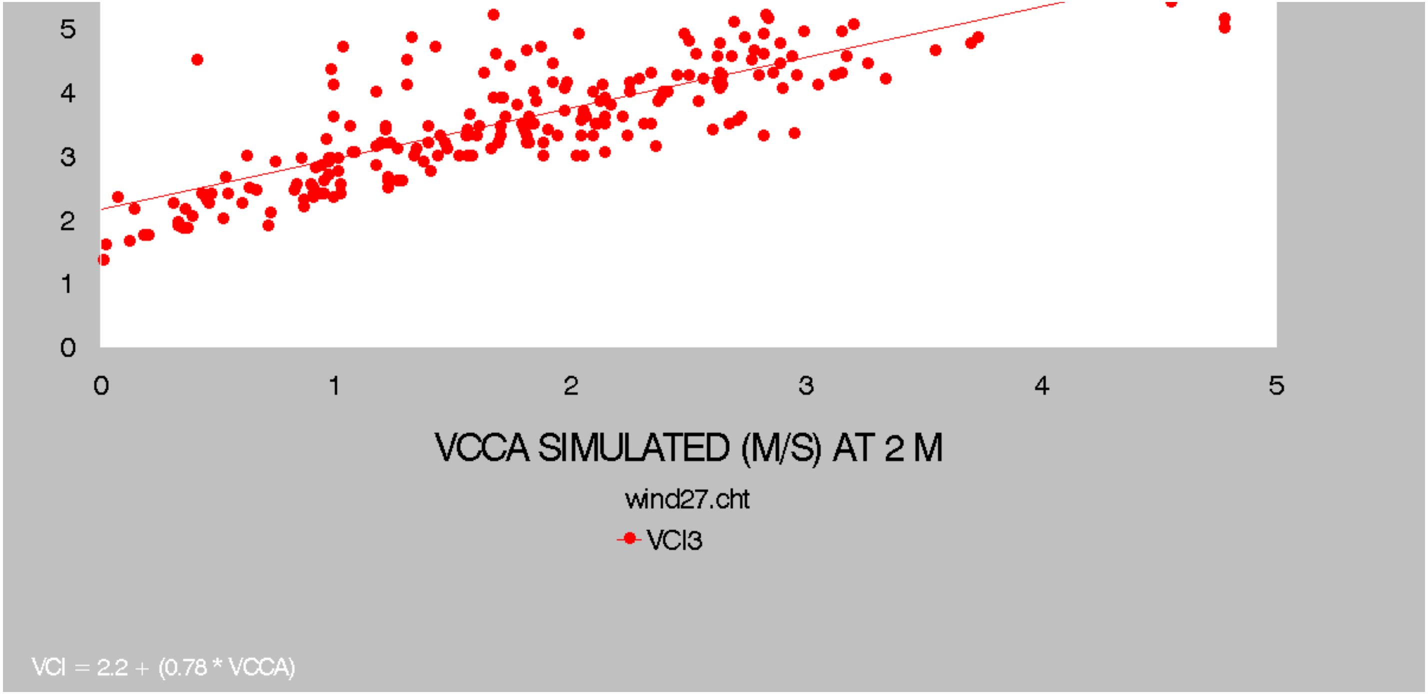
home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind227.htm MAXIMUM IMPULSE ENERGY VS CCA AVG. WINDSPEED



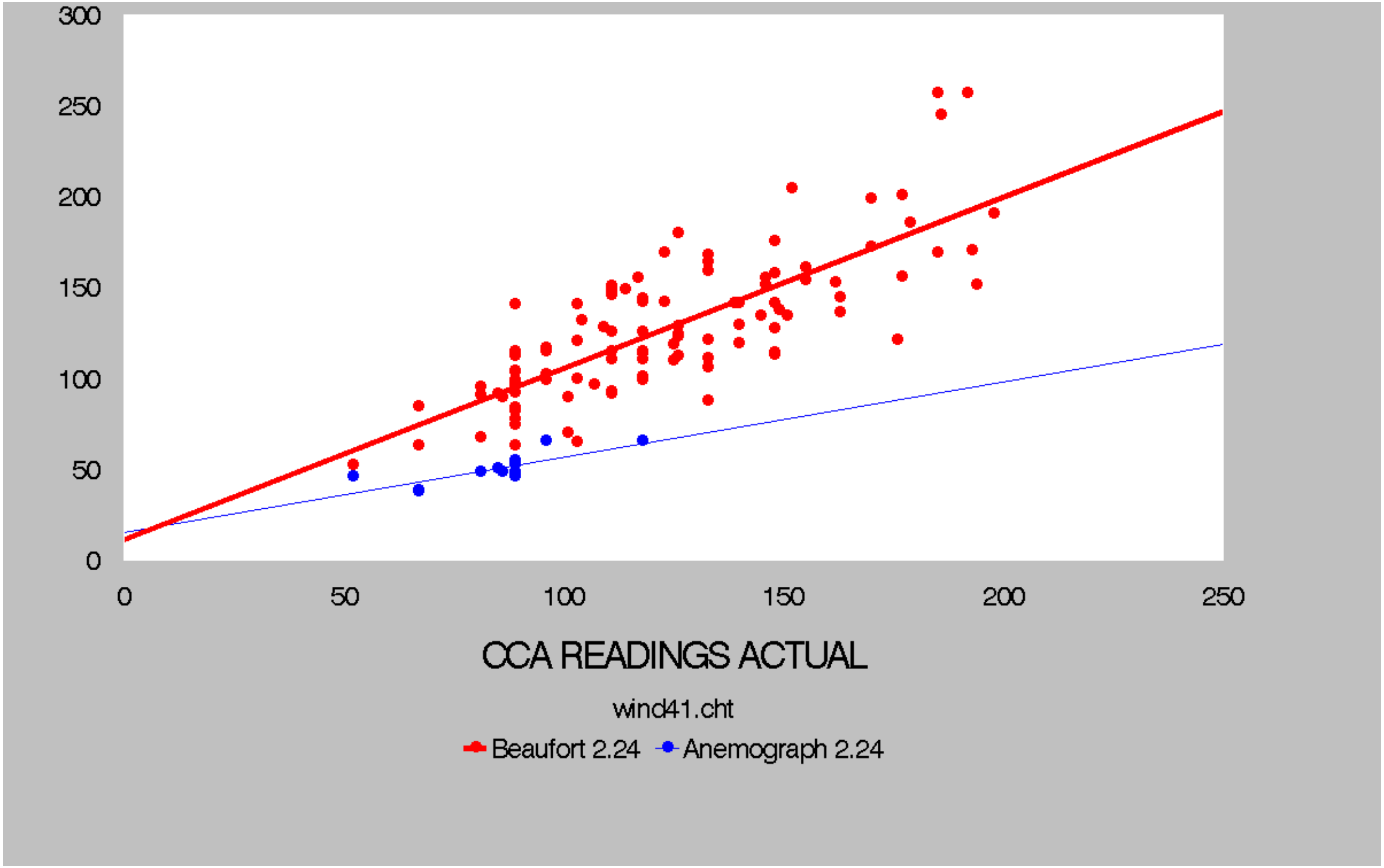


home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind241.htm OPTIMAL CUT-IN WINDSPEED VS. CCA AVG. WINDSPEED



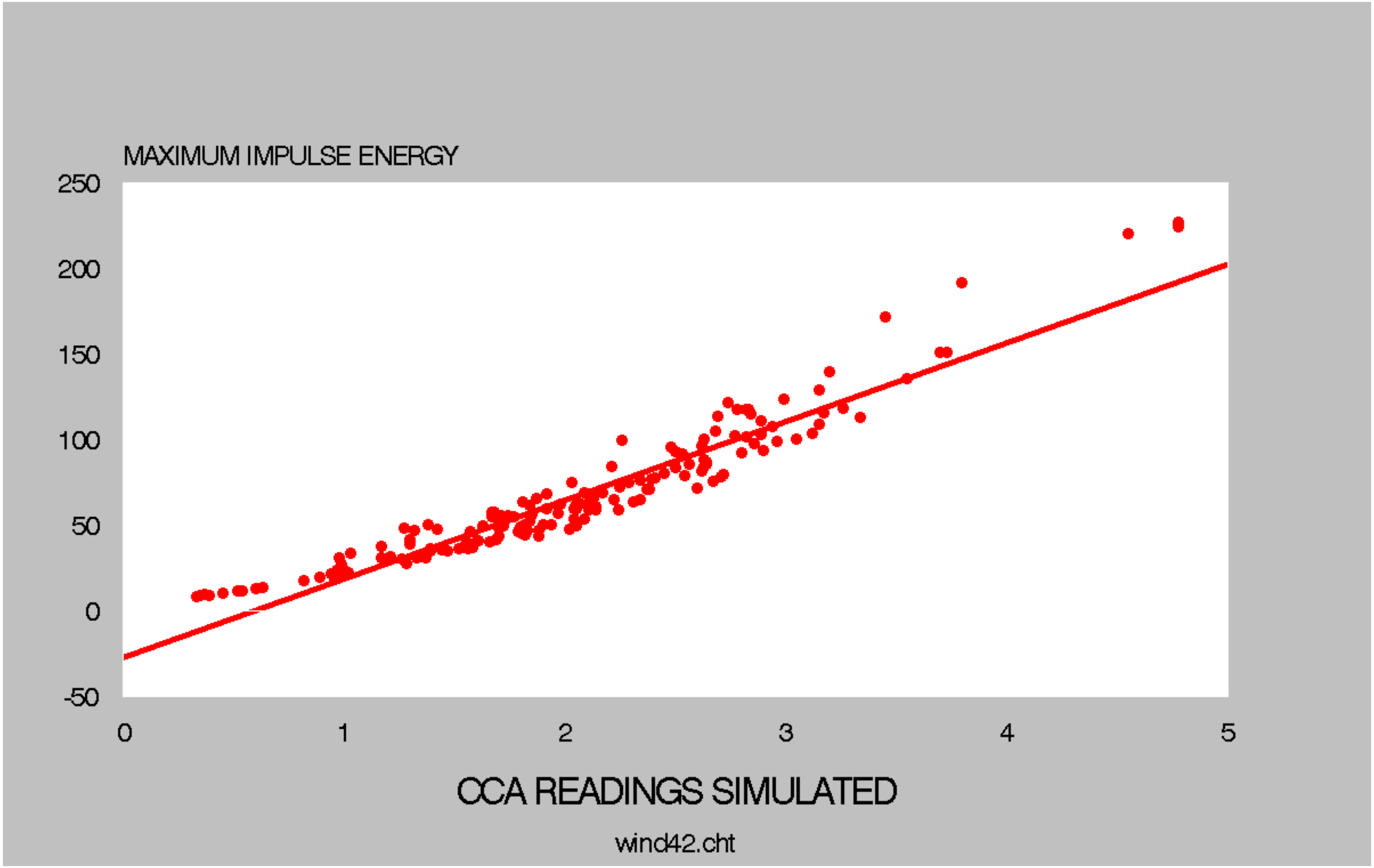


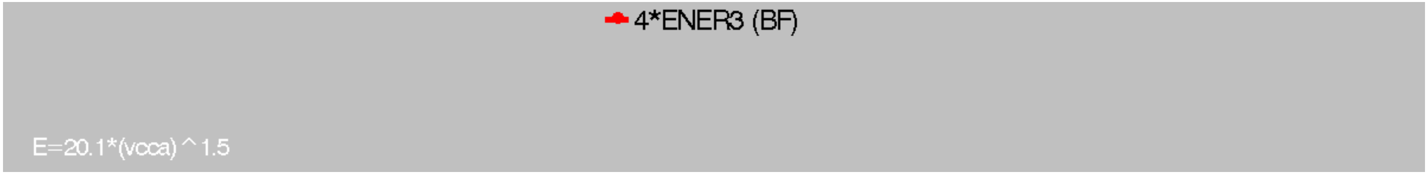
home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind242.htm SIMULATED VS. ACTUAL CCA READINGS



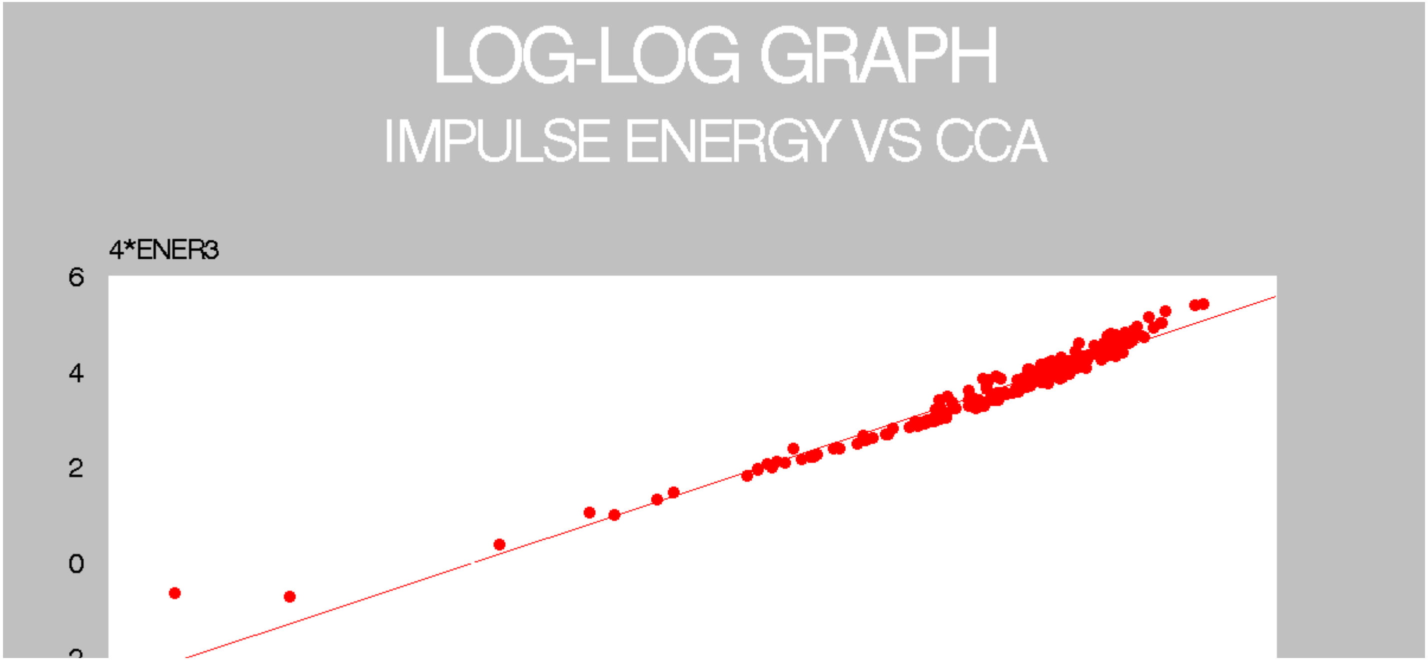
home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind243.htm MAXIMUM IMPULSE ENERGY VS.

SIMULATED CCA READINGS

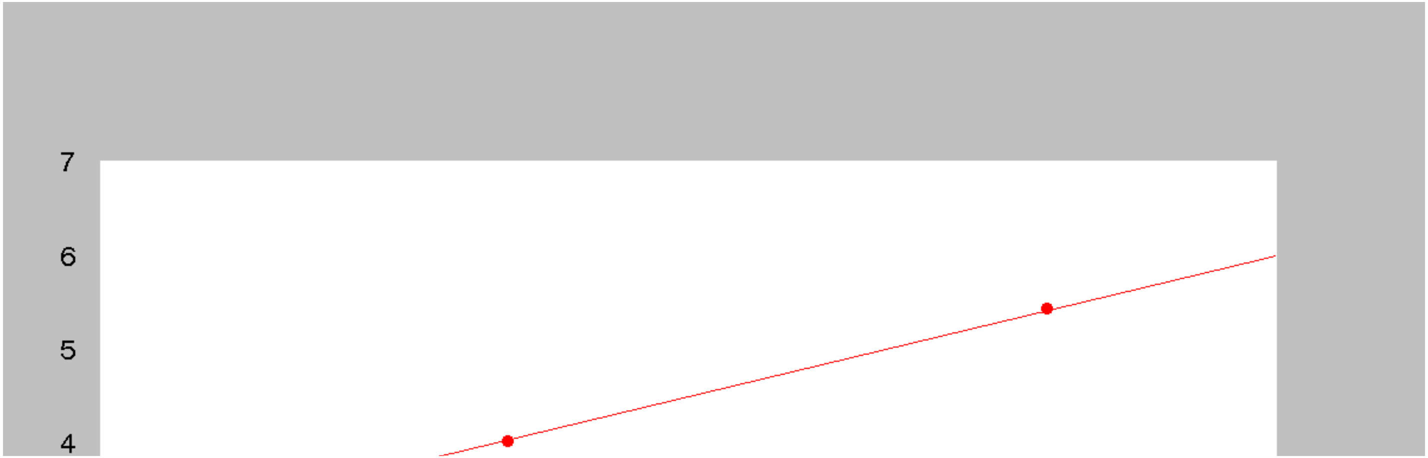


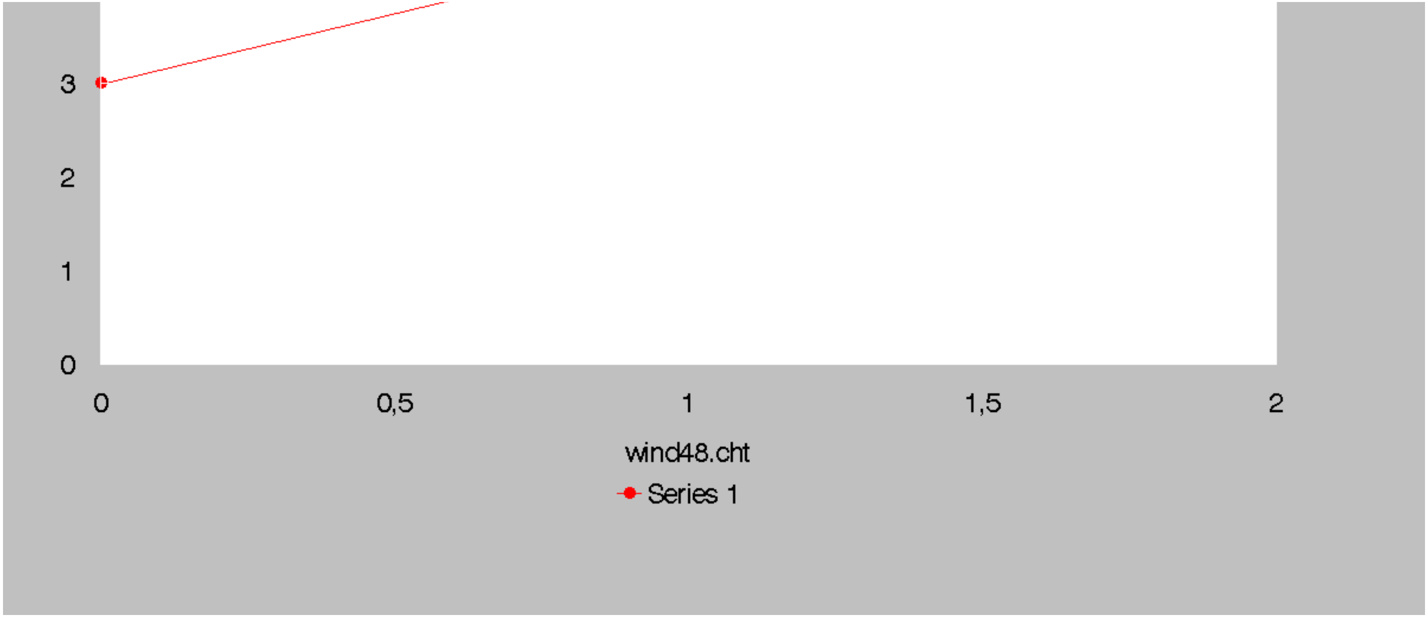


home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind248.htm LOG-LOG GRAPH - IMPULSE ENERGY VS. SIMULATED CCA READINGS

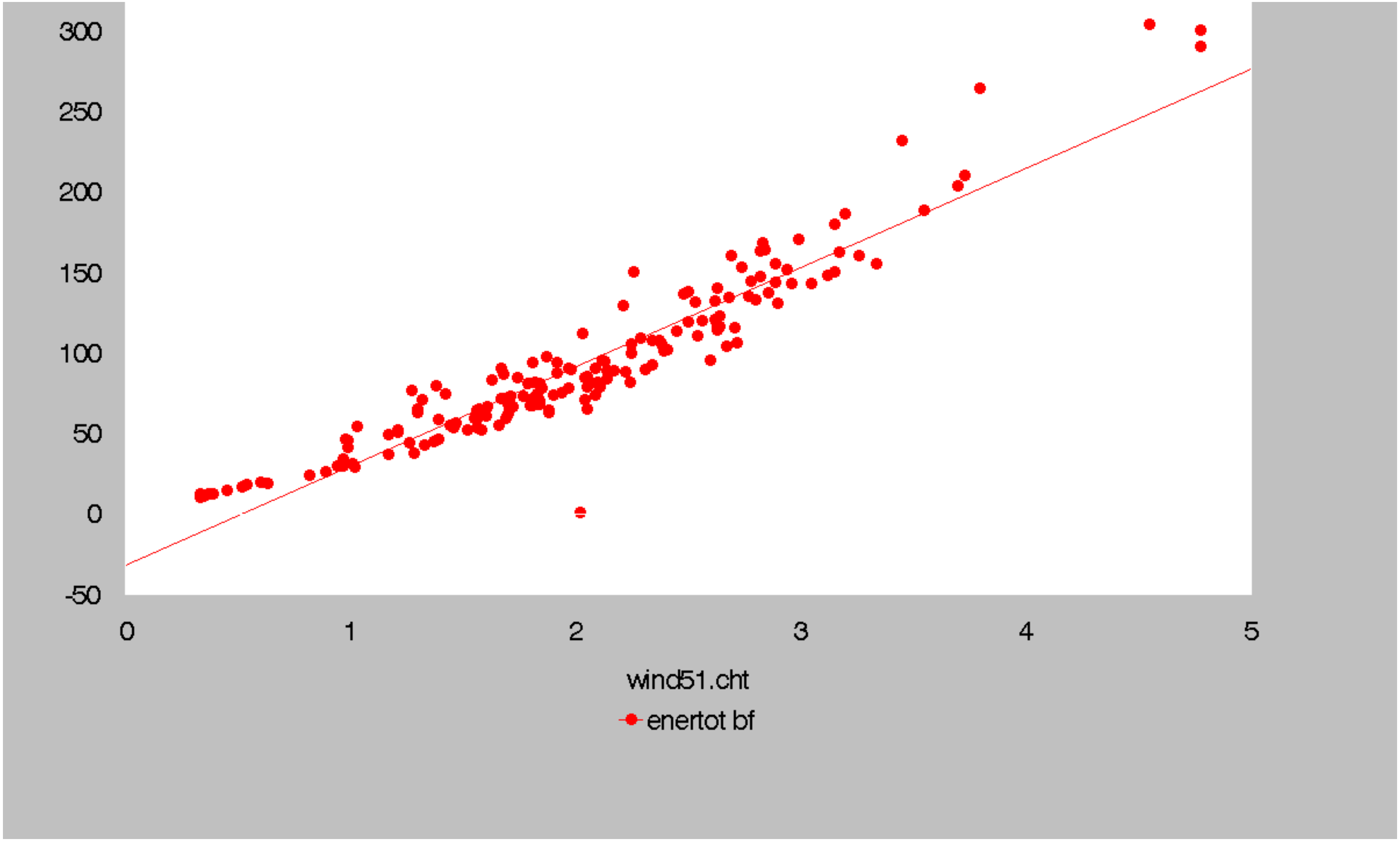


home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind251.htm UNKNOWN

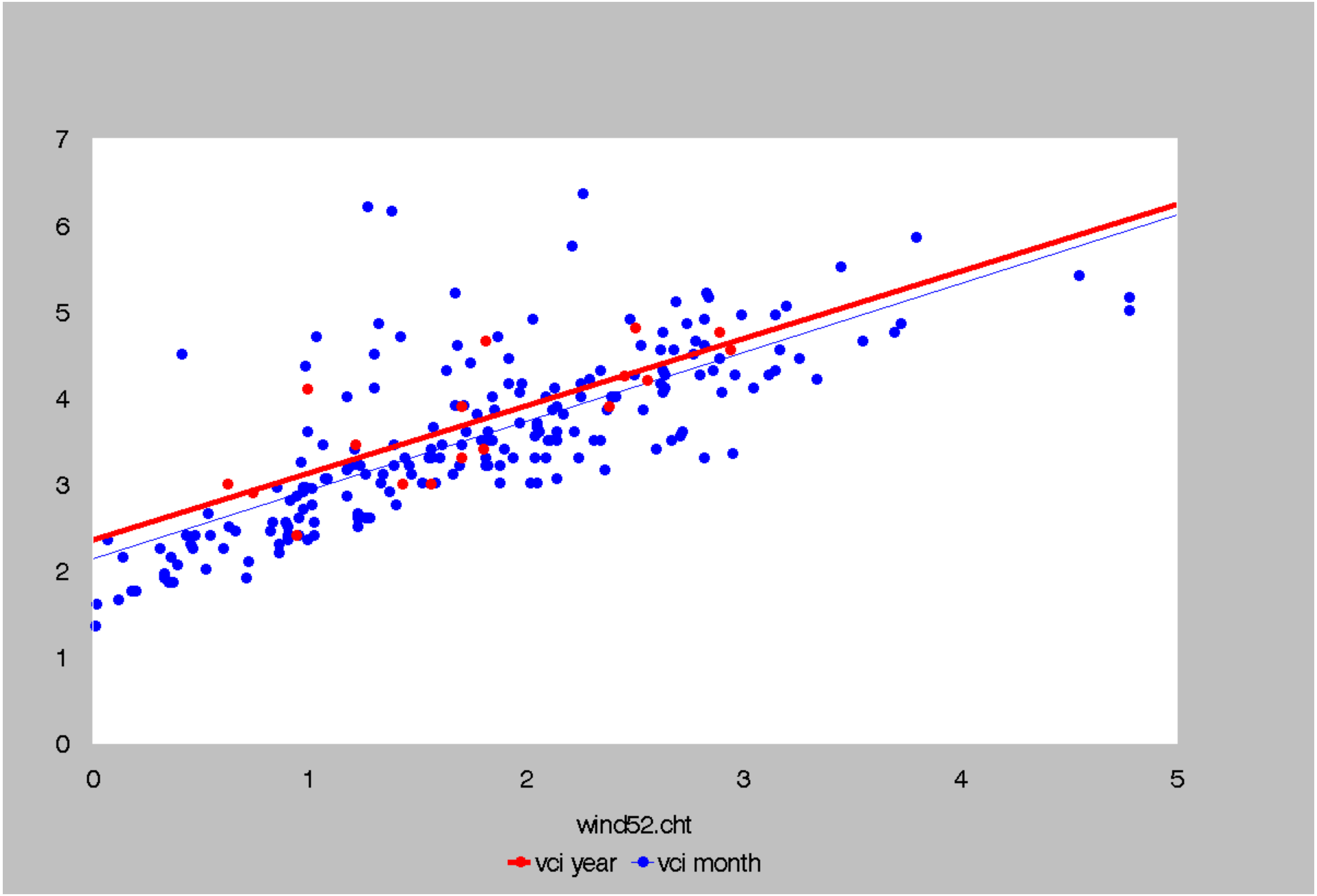




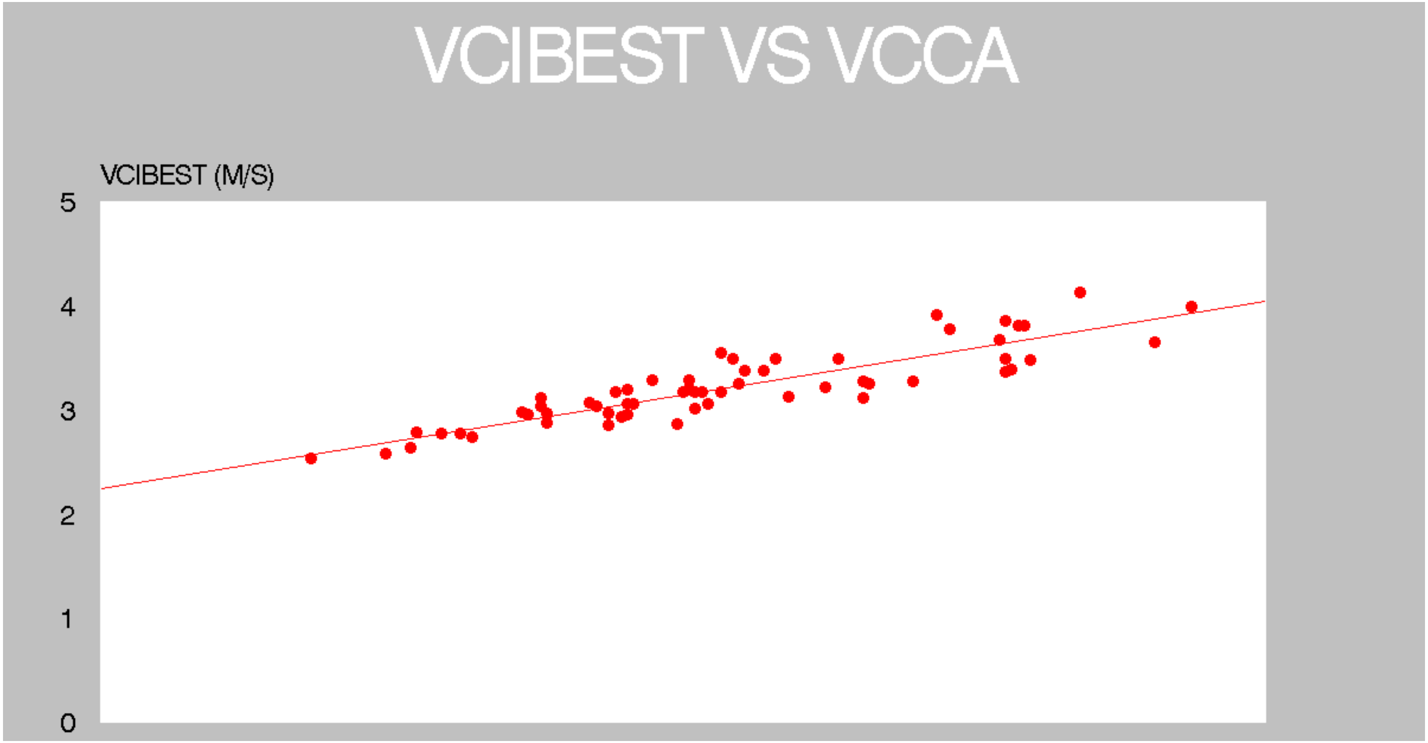
home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind252.htm TOTAL ENERGY VS. AVG WINDSPEED (BEAUFORT DATA)

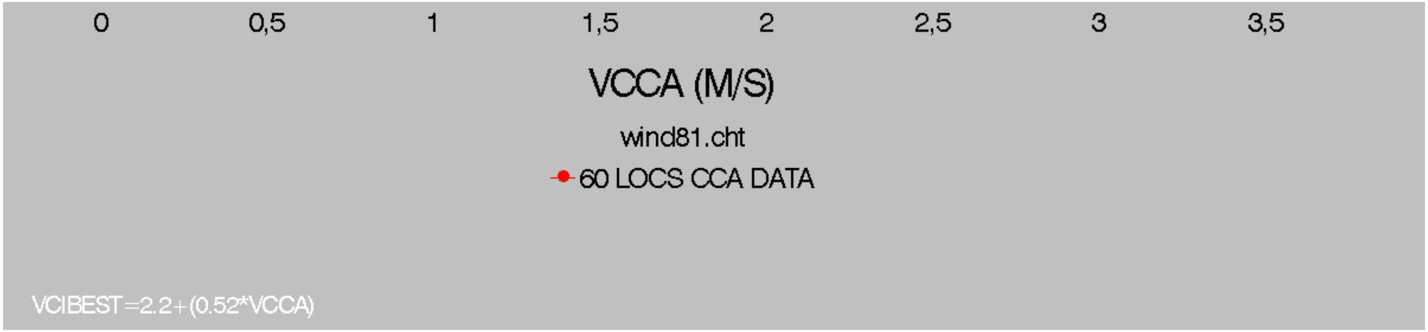


home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw wind281.htm VCI OPTIMUM VS. CCA AVG WINDSPEED


7
6
5
4
3
2
1
0
0
1
2
3
4
5
wind52.cht
vci year
vci month

home.cd3wd.ar.cn.de.en.es.fr.id.it.ph.po.ru.sw OPTIMUM VCI VS. CCA AVG. WINDSPEED (60 LOCATIONS CCA DATA)




0
0,5
1
1,5
2
2,5
3
3,5
VCCA (M/S)
wind81.cht
60 LOCS CCA DATA
VCIBEST=2.2+(0.52*VCCA)