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Abstract

Open site measurement on the electromagnetic interference is the most direct and universally accepted standard approach for measuring radiated emissions from an equipment or the radiation susceptibility of a component or equipment. A site is qualified for testing EMI or not is decided by the antenna measurements. In this work, we use data from setups with different factors to find relations of measurement and the situation of antenna. A one change point model has been used to fit observed measurements and compare the differences with two kinds of antenna (broadband antenna and dipole antenna). However, with only one change point model it may not give a suitable fit for all data sets in this work. Therefore, we have tried other models and applied them to the data. Furthermore, we try to set up another standard more strict than ±4dB based on statistical inference results in deciding whether a site is a better one with more precision in measuring EMI values. Finally, a program by Matlab with a complete analysis based on the procedure performed here is provided, so that it may be used as a standard tool for evaluating whether a site is with good measurement quality in practice.

Keywords : EMI, Change point model, The Wilcoxon signed ranks test,
The Friedman test, AIC.

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1 Introduction

The electromagnetic environment is an integral part of the world in which we live. Various apparatus such as radio and television broadcast stations, communication transmitters, and other radar and navigational aids radiate electromagnetic energy during their normal operation. These are intentional radiations of electromagnetic energy into the environment. Many appliances such as automobile ignition systems and industrial control equipment used in everyday life also emit electromagnetic energy, although these emissions are not an essential part of normal operation. Many other examples of unintentional radiators are ubiquitous. The electromagnetic environment created by these intentional and unintentional sources, when sufficiently strong, interferes with the operation of many electrical and electronics equipment and systems. Integrated circuits, which are today extensively used in many instruments of apparatus, including information technology products. Suffer the most from EMI. In extreme cases, EMI may cause burnout of such devices. In circuits involving digital signals, the effect of EMI could be one of increasing the bit error rates or malfunctioning of the circuit. In case of analog signals, EMI increases the noise levels and leads to a degraded operation of circuits and systems.

The above examples are not a comprehensive list of experiences in all fields. These are indicative of recent experience and concerns that serve as an illustration of the type of EMI problems that continue to be experienced. The object is not to raise an alarm but to point out that EMI/EMC is today a multidimensional problem, calling for constant attention in the design and practical use of all electrical and electronics apparatus and systems, particularly in communications and control.

Whether a site is qualified for testing EMI or not is decided by the antenna measurements. In this work, we use data from setups with different factors to find relations of measurement and the situation of antenna. In Wang et al. (2004), a one change point model had been used to fit observed measurements and compared the differences with two kinds of antenna (broadband antenna and dipole antenna). Detecting the change point problem have been discussed by many authors, for example, Page (1954,1955,1957) used the nonparametric method (CUSUM) to give a one-sided test for a change in the mean of a distribution, Hudson (1966) and other authors use the maximum likelihood and least square methods etc to estimate the change points. However, with only one change point model it may not give a suitable fit for all data sets in this work. So, we will also try other models in this work and apply them to the data. In Section 2 we give a description of data sets and present a test for repeated measurements. In Section 3, we use three criteria to determine the suitable model for the data. In Section 4, we use the model obtained in Section 3 to find the confidence band of the measurements and compare them with the ideal values which site is good for antenna measurements. Finally, a program by Matlab with a complete analysis based on the procedure performed here is provided. So that, it may be used as a standard tool for evaluating whether a site is with good measurement quality in practice.

2 Data description

Open site measurement is the most direct and universally accepted standard approach for measuring radiated emissions from an equipment or the radiation susceptibility of a component or equipment. The basic principle of measurement (Equipment Under Test) testing radiated emissions is with the EUT switched on, the receiver is scanned over the specified frequency range to measure electromagnetic emissions from the EUT and determine the compliance of these data with the stipulated specifications. With the help of a proper test site and a calibrated receiving antenna, radiated emissions from equipment under test over a specified frequency band can be measured observing various precautions. Similarly, using a calibrated transmitting antenna, susceptibility of equipment under test can be checked under specified field conditions. If these measurements are done in a room, or an enclosed area, it is possible that reflections or scattered signals from walls, floor, and ceiling will be present. The presence of such scattered signals will corrupt the measurements. However, if these measurements are done in a proper open-area test site, the scattered signals and reflections will not be present. In this work, all of our data are from open-area test work, where different test setups in these experiments are listed below.

Table 1-1. The different setups of experiments

factor	level	explanation
site	metal screen	metal screen upon the ground
	metal plane	metal plane upon the ground
antenna	bb	broadband antenna
	dp	dipole antenna
polarization of antenna	hor	horizontal
	ver	vertical
h1	1m,1.5m,2m,2.75m,3m	transmit antenna height
h2	1-4m,2.75-4m	receive antenna height
R	3m,10m	antenna separation relative to ground plane

At every setup, measurements from frequency 30MHz to 1000MHz are recorded, the sample size is denoted by n and experiments at each setup are repeated for d times at different days. The detailed lists about our data is given in Table 1-2.

It should be noted that under setups of broadband antenna in obs2003-2 and obs2004-1, the operator used one broadband antenna to measure at frequency from 30MHz to 200MHz and then changed to another broadband antenna to measure from frequency 250MHz to 1000MHz, two of these broadband antenna have different structure which can be observed easily from the scatter plot.

Table 1-2.

Note that according to Akria (1990,1992) the theoretical formula of NSA's valus and E_D^{MAX} can be expressed as

$NSA_{TH} = -20log(f_M) + 48.9 - E_D^{MAX}$,

where f_M= frequency in MHz, E_D^{MAX}= maximun received field,

and the formula of E_D^{MAX}(vertical and horizontal) is

$$E_{DH}^{MAX} = \frac{\sqrt{49.2}(d_2^2 + d_1^2|\rho_H|^2 + 2d_1d_2|\rho_H|\cos[\Phi_H - \frac{2\pi}{\lambda}(d_2 - d_1)])^{1/2}}{d_1 d_2}$$

$$E_{DV}^{MAX} = \frac{\sqrt{49.2}R^2(d_2^6 + d_1^6|\rho_V|^2 + 2d_1^3d_2^3|\rho_V|\cos[\Phi_V - \frac{2\pi}{\lambda}(d_2 - d_1)])^{1/2}}{d_1^3 d_2^3}$$

$$E_D^{MAX}(ideal) = 48.9 - 20log(f_M) - ideal$$

$$E_D^{MAX}(measurement) = 48.9 - 20log(f_M) - measurement.$$

We first draw scatter plots with measurement versus frequency (Figure A) and measurement versus log(freq) (Figure B) respectively in order to find some information about these four setups of data. While observing the scatter plots, it can be seen that the graph fluctuates more when the frequency is lower than 200MHz. This phenomenon is apparent when the data is from broadband antenna with vertical polarization in obs2003-1 and in obs2003-2 as R=3m. This phenomenon will be discussed further later. From the scatter plot (measurement versus log(freq)), we also see that some of the graphs are very close to straight lines, but sometimes it seems to have slope change after certain point. Another thing attracts our attention is that the repeated measurements sometimes seem to have significant differences. So, tests for comparing whether these repeated measurements are similar without systematic differences will be performed.

These four sets of data each with two or three repeated measurements respectively are as listed in Table 1-2. In this work, we use the Friedman Test and Wilcoxon Signed Ranks Test presented in the Appendix to do the comparisons. The results for testing the differences among the repeated measurements are presented in Table I.

Table 2. The data situation have significant differences among the repeated measurement

	data name	site	antenna	polarization of antenna	h1	h2	R	d
D1	obs2003-1	metal screen	bb	horizontal	1m	1-4m	10m	3
D2	obs2003-2	metal screen	bb	vertical	2.75m	1-4m	10m	2
D3	obs2003-2	metal screen	dp	horizontal	2.75m	1-4m	10m	2
D4	obs2003-2	metal screen	dp	horizontal	3m	1-4m	10m	2
D5	obs2003-2	metal screen	dp	vertical	2.75m	2.75-4m	10m	2
D6	obs2003-2	metal screen	dp	vertical	3m	2.75-4m	10m	2
D7	obs2003-2	metal screen	dp	vertical	3m	2.75-4m	3m	2
D8	obs2004-1	metal plane	bb	horizontal	2m	1-4m	10m	3
D9	obs2004-2	metal plane	bb	vertical	1.5m	1-4m	10m	3

Table 2 shows the cases which have significant differences in the repeated measurements. We will make some modification to these data in the model fitting later.

3 Model Fitting and Prediction

Following that of Wang et al. (2004), we use a one change point model to fit data which is expressed as follows:

$$y_t = \beta_0 + \beta_1 t + \beta_2 (t - t_1) I_{[t>t_1]} + \varepsilon_t$$

$$where y_t = \text{measurement}, \quad t = \log_{10}(\text{freq}), \quad t_1 = \log_{10}(\text{change point})$$

$$I_{[t>t_1]} = \begin{cases} 0 & \text{if} \quad t \leq t_1 \\ 1 & \text{if} \quad t > t_1 \end{cases} .$$

We choose the point which makes the SSE of the fitted models the smallest as the change point estimator. The estimation method in this work is different from that in Wang et al. (2004). First, we do not have ideal value for all setups, so we could not use E_D^{MAX} to conjecture the location of change point at the beginning. Secondly, the minimum SSE we find here is the global minimum for all frequencies that were measured. The results show that one change point model is suitable for some setups such as broadband antenna, horizontal in obs2003-1, obs2004-2 and dipole antenna with horizontal, R=10m in these four sets of data (See Table II, III, IV, V). But, it does not suitable to setups with broadband antenna, horizontal in obs2003-2 and obs2004-1. This result is somewhat confusing, because obs2004-1 and obs2004-2 comes from the same site. So, a two change point model has been fitted. There are two reasons for us to use this model. First, we observe from the scatter plot (measurement versus log(freq)) that it seems the regression line has changed the slop twice and later we learned that there had been a change of antenna with the same type at some frequencies during the experiments. The two change model is as follows:

$$y_t = \beta_0 + \beta_1 t + \beta_2 (t - t_1) I_{[t>t_1]} + \beta_3 (t - t_2) I[t > t_2] + \varepsilon_t \ ,$$

$$y_t = \text{measurement}, \quad t = \log_{10}(\text{freq}),$$

$$t_1 = \log_{10}(\text{the first change point}),$$

$$t_2 = \log_{10}(\text{the second change point}),$$

$$I_{[t>t_1]} = \begin{cases} 0 & \text{if} \quad t \le t_1 \\ 1 & \text{if} \quad t > t_1 \end{cases}, \qquad I_{[t>t_2]} = \begin{cases} 0 & \text{if} \quad t \le t_2 \\ 1 & \text{if} \quad t > t_2 \end{cases}.$$

We also estimate these two change points which make the SSE of the fitting model to be the smallest. To compare the performances of the two change point model with the fitted one change point model, AIC criterion is used instead of the SSE, as the number of the parameter should be considered also. Akaike's Information Criterion (AIC) was proposed by Akaike (1974) to determine the number of change points that fits the data best, while attempting to avoid overfitting. Hurvich and Tsai (1989) modified AIC to AICc in order to decide the number of change points for small samples. In this work, we use both AIC and AICc as the criteria in choosing models. The formula of AIC and AICc are

$$AIC = N \ln(\frac{SSE}{N}) + 2 \cdot 2(k+1) \ ,$$
$$AICc = N \ln(\frac{SSE}{N}) + \frac{n(n+2(k+1))}{n-2(k+1)-2} \ .$$

where N is the number of observations, k is the number of change points. We can see that the AIC and AICc of two change point model is less then one change point model especially in the setups in broadband antenna, horizontal in obs2003-2 and obs2004-1. But, when we use two change point model to fit data in obs2003-1 and obs2004-2, we do not have a better result. As we know, if the change-point's location is at the end of its data, this does not make sense. Furthermore, if the values of AIC and AICc between two models are close, we will consider the one change point model.

Besides the change point model, we consider the jump point model at the same time. As the setup is dipole antenna, vertical, h1=2.75m, h2=2.75-4m, R=10m, the scatter plot appears to have a jump point in certain frequency. So, we try to use this model and expect to have better result. The one jump model is as follows:

$$y_t = \beta_0 + \beta_1 t + \beta_2 I_{[t>t_m]} + \varepsilon_t \ ,$$

$$y_t = \text{measurement}, \quad t = \log_{10}(\text{freq}), \quad t_m = \log_{10}(\text{jump point}),$$

$$I_{[t>t_m]} = \begin{cases} 0 & \text{if} \quad t \le t_m \\ 1 & \text{if} \quad t > t_m \ . \end{cases}$$

We select the experiment point which makes the SSE of models be the smallest. As the result, the MSE, AIC, AICc of one jump model is smaller then one change point model for the setups is dipole antenna, vertical, h1=2.75m, h2=2.75-4m, R=10m.

Since in the above section, we have that there are differences between different days in some setups (See Table 2). In those cases, we will first fit model individually in order to check whether they have the same change point or jump point. For example, in obs2003-1, D1 has difference between day1 and the other days, but we have observed they that have the same change point at 160MHz .

So we use model :

$$\begin{aligned} y_t &= \beta_0 + \beta_1 t + \beta_2 (t - t_1) I_{[t>t_1]} + \beta_3 I_{[day2,day3]} \\ &\quad + \beta_4 t I_{[day2,day3]} + \beta_4 (t - t_1) I_{[t>t_1]} I_{[day2,day3]} + \varepsilon_t \ , \\ y_t &= \text{measurement}, \quad t = \log_{10}(\text{freq}), \quad t_1 = \log_{10}(\text{change point}), \\ I_{[t>t_1]} &= \begin{cases} 0 & \text{if} \quad t \le t_1 \\ 1 & \text{if} \quad t > t_1 \ , \end{cases} \quad I_{[day2,day3]} = \begin{cases} 0 & \text{if} \quad day1 \\ 1 & \text{if} \quad day2 \quad or \quad day3 \ . \end{cases} \end{aligned}$$

to fit them, and then we have that they are different in constant term. As last, we try to minus the measurement in the first day in D1 0.8 and then use one change point model to analyse it. In D9, we use the same model (change point: 250MHz) to check the differences from different days, and find there is no significant difference. In D5, we use a one jump point model (jump point:140MHz) and the terms of different days in addition to check the significant of repeated measurement,and the result is not significant. In D2, D3, D4, D6, D7, D8, we use the similar method to check the significant of repeated measurement. After examining the significant differences in repeated measurements, the repeated measurement in D7, D8 is significant. Because we will focus on the relation of measurements and ideal values in the next section, the setups which has been changing antenna during experiment (broadband antenna in obs2003-2 and obs2004-1) and the setups without corresponding ideal values will not been discussed in the Section 4.

In general, if a qualified antenna measurement recorded at different frequencies do not exceed the ideal value ±4dB, we would regard this site as a suitable site for measuring EMI. After using a regression model to fit data, the 95% confidence band is obtained for the observations at each setup. When a change point model is used to fit broadband antenna with horizontal, h1=2m in obs2003-1 and obs2004-2, the confidence band with the change point models are within the range of ideal values ±4dB at all frequencies tested. But in other setups, the confidence bands are not always within the range of ideal values ±4dB. According to this, the percentage of the 95% confidence band at each point lie within the ideal values ±4dB is computed in other setups. In Table VI in the appendix , we provide the length of 95% confidence band, UCL (upper confidence limit) minuses ideal value, LCL (lower confidence limit) minuses ideal value and the percentage of the 95% confidence band at each point lie within the ideal values ±4dB in obs2003-1 and obs2004-2. In Section 4, these percentages and MSE are used as a reference to all which site is better in measuring the EMI values.

4 Results and Discussions

Under the theoretical formula of E_D^{MAX}, there is an indeterminate value, that is h_2 selected from 1-4m or 2.75-4m. So, the ideal values are explicit but values with error. The data sets we have in this work only that of obs2003-1 and obs2004-2 have ideal values. Actually, we can compute each ideal value under different conditions once we have h_2. But, in our data, we do not get the information about h_2. So, we only focus on obs2003-1, obs2004-2 and do some analyses in this section. Because of the results for the change point model fitted to the measurements in obs2003-1 and obs2004-2 quite well, the change point model is whether suitable for describing ideal values or not is of interest. In this section, we first use change point model to approximate the ideal values and the results are listed in Table 3-1.

Table 3-1. Results of using one change point model to fit the ideal values

	cp	regression line	MSE	R^2
bb,hor,h1=1m	150MHz	$y = 84.712 + (-37.3901)t + 16.266(t - t_1)I_{[t>t_1]}$	0.0605	0.999
bb,hor,h1=2m	80MHz	$y = 77.164 + (-36.001)t + 15.469(t - t_1)I_{[t>t_1]}$	0.0308	0.999
bb,ver,h1=1m	400MHz	$y = 43.754 + (-18.555)t + (-4.463)(t - t_1)I_{[t>t_1]}$	0.0669	0.999
bb,ver,h1=1.5m	250MHz	$y = 43.093 + (-18.014)t + (-4.728)(t - t_1)I_{[t>t_1]}$	0.0638	0.999
dp,ver,h1=2m	80MHz	$y = 77.164 + (-36.010)t + 15.469(t - t_1)I_{[t>t_1]}$	0.0308	0.999
dp,ver,h1=2.75m	120MHz	$y = 47.714 + (-19.679)t + (-2.084)(t - t_1)I_{[t>t_1]}$	0.1056	0.999

By Table 3-1, we can see that the R^2 is close to 1 for every ideal value data set. After drawing the 95% confidence bands, it can be seen that the confidence bands are within the interval with limits at ideal ±4dB. The change point model is quite suitable for approximating the ideal value data. From results of the approximate ideal value model, it seems the confidence band of the ideal value may be used to set up another standard more strict than the ±4dB for deciding whether a site is a better one with more precision in measuring EMI values.

In Table VI in the appendix, we can see that the 95% confidence band do not always fall within the ideal values ±4dB. We list the minimum percentage of each setups in obs2003-1 and obs2004-2 in Table 3-2. Table 3-3 shows the minimum percentage by fitting jump point model in setup with dipole antenna, vertical, h1=2.75m. The minimum percentage in obs2004-2 is clearly higher than those in obs2003-1 when the antenna situation is broadband antenna, vertical. But the setup with dipole antenna, vertical shows the opposite result.

Table 3-2. The minimum percentage of the 95% confidence band at each point lie within the ideal values ±4dB (one change point model)

	obs2003-1	obs2004-2
broabband hor h1=1m	1	0.9991
broabband hor h1=2m	1	1
broabband ver h1=1m	0.9258	0.9581
broabband ver h1=1.5m	0.8926	0.9922
dipole hor h1=2m	1	0.9955
dipole ver h1=2.75m	0.9555	0.8799

Table 3-3. The minimum percentage of the 95% confidence band at each point lie within the ideal values ±4dB (one jump point model)

	obs2003-1	obs2004-2
dipole ver h1=2.75m h2=2.75-4m	0.9580	0.8979

Actually, we know that the percentage is controlled by MSE and the distance between the ideal values and the predicated values. So, we should consider more about the effect from the differences between measurements and the ideal values. Table VII in the appendix shows the difference between ideal values and observations. We decompose them into four terms as

$$\sum(obs - ideal)^2 = \sum(obs - \overline{Y})^2 + \sum(\overline{Y} - \widehat{Y}_{obs})^2 + \sum(\widehat{Y}_{obs} - ideal)^2 + \text{others}$$

By Table VII, we can see that the pure error sum of squares of all setups in obs2004-2 are smaller than those in obs2003-1. Also, the differences between prediction and ideal values in setups with broadband antenna, vertical in obs2003-2 are smaller than those in obs2003-1, but the others are not. The site with metal plane upon the ground may not always improve the bias of observations from the ideal values of measuring from sites with metal screen upon the ground. But, it can reduce the pure error sum of squares. Because of the computation of the data costs time, we write a program using Matlab to do the job. With the help of the GUI (Graphic User Interface) in Matlab we can design a user interface for the operators to use while measuring EMI values. We have illustrated this interface step by step in the Appendix.

5 Conclusion

The objective of the work is to develop a quantitative method of evaluating the quality of radiated emissions test sites including both open area test sites (OATS) and electromagnetic anechoic chambers. At present quality of OATS is determined by a comparison of measured normalized site attenuation (NSA) with the theoretical values at predetermined test frequencies within the range from 30 MHz to 1000 MHz. If the deviations do not exceed ±4dB for all the frequencies, the OATS or alternative site is considered to be acceptable.

Measured NSA data are being collected on a yearly basis in the test sites. However, such data are not analyzed to obtain maximum information. From technical point of view measured NSA data contain much useful knowledge about the electromagnetic characteristics of the test site. To extract such useful information a change point linear regression model has been developed to fit the measured data in Wang et al. (2004). In this work, we use a different criterion and searching method to improve the model fitted. By the powerful computing ability of modern computers, an interface has been developed so the data can be analyzed on line and the results can be used to inspect and make adjustment immediately. Some more works need to be done in the future. Firstly, the residual analysis should be enforced to check the validity of the assumptions. From the graphs of ACF, PACF, the residual still seems to have some periodic pattern. How to resolve this problem will be discussed in the future. Secondly, the two change point model seems having good fit for obs2003-2 and obs2004-1 but with small difference. We discover that the location of the two change points for broadband antenna in obs2003-2 and obs2004-1 are the same although under different transmit antenna heights ($h1$) therefore this phenomenon is still consistent with the theoretical results. Although we should collect more data to understand whether the antenna changing during experiments would change the pattern of the measurements so that two change point model seems to more suitable. Thirdly, the minimum percentage of setup in obs2003-1 as dipole antenna, vertical in obs2003-1 is higher than those in obs2004-2. This is because the differences between measurements and the ideal values in obs2003-1 are smaller than obs2004-1. That is, the place with metal plane which we choose to do the experiments may improve only the errors from measuring, but it does not seem to reduce the differences between measurements and ideal values for every setups. This result interests us to query the effect of metal plane in theory for all setups. Finally, there are still a lot of phenomenon and problems to be investigated in the future, and more well designed experiments would be very much needed.

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Appendix

1. The theoretical formula of E_D^{MAX}

$$E_{DH}^{MAX} = \frac{\sqrt{49.2}(d_2^2 + d_1^2|\rho_H|^2 + 2d_1 d_2|\rho_H|\cos[\Phi_H - \frac{2\pi}{\lambda}(d_2 - d_1)])^{1/2}}{d_1 d_2}$$

$$E_{DV}^{MAX} = \frac{\sqrt{49.2}R^2(d_2^6 + d_1^6|\rho_V|^2 + 2d_1^3 d_2^3|\rho_V|\cos[\Phi_V - \frac{2\pi}{\lambda}(d_2 - d_1)])^{1/2}}{d_1^3 d_2^3}$$

where

$$\rho_H = \frac{\sin\gamma - (K - j60\lambda\sigma - \cos^2\gamma)^{1/2}}{\sin\gamma + (K - j60\lambda\sigma - \cos^2\gamma)^{1/2}}$$

$$\rho_V = \frac{(K - j60\lambda\sigma)\sin\gamma - (K - j60\lambda\sigma - \cos^2\gamma)^{1/2}}{(K - j60\lambda\sigma)\sin\gamma - (K - j60\lambda\sigma - \cos^2\gamma)^{1/2}}$$

$$d_1 = [R^2 + (h_2 - h_1)^2]^{1/2} \qquad d_2 = [R^2 + (h_2 + h_1)^2]^{1/2}$$

Legend :

h_1 = fixed transmit antenna height

h_2 = variable height receive antenna height

R = antenna separation relative to ground plane

K = relative dielectric constant

σ = conductivity of plane ground

ρ = reflection coefficient

φ = phase angle of reflection coefficient

λ = wavelength or frequency of interest

$\gamma = arctan(\frac{h_1+h_2}{R})$

2. The Wilcoxon Signed Ranks Test :

data form : the data consist of n observations $(x_1, y_1), (x_2, y_2), ..., (x'_n, y'_n)$ on the respective bivariate random variables $(X_1, Y_1), (X_2, Y_2), ..., (X'_n, Y'_n)$.

Find the n differences $D_i = Y_i - X_i$.

The absolute difference

$$|D_i| = |Y_i - X_i| \qquad i = 1, 2, ..., n'$$

are then computed for each of the n' pairs $(X_i - Y_i)$. The Rank 1 is given to the pair (X_i, Y_i) with the smallest absolute difference $|D_i|$; the Rank 2 is given to the pair with the second smallest absolute difference; and so on,with the rank n (n$\leq n'$) being assigned to the pair with the largest absolute difference. If several pairs the average of the ranks that would have otherwise been assigned.

Test Statistic : Let R_i,called the signed rank,be defined for each pair(X_i, Y_i) as fallows.

$$R_i = \begin{cases} \textit{the rank assigned to } (X_i, Y_i) & \text{if} \quad Y_i > X_i \\ \textit{the negative of the rank assigned to } (X_i, Y_i) & \text{if} \quad Y_i < X_i \end{cases}$$

The test statistic is the sum of the positive signed ranks

$$T = \Sigma(R_i \textit{ where } D_i \textit{ is positive})$$

3. The Friedman Test

data form : the data consist of b mutually independent k-variate random variables $(X_{i1}, X_{i2}, ..., X_{ik})$, called b blocks, i=1,2,...,b. The random variable X_{ij} is in block i and is associated with treatment j. Let $R(X_{ij})$ be the rank, from 1 to k, assigned to X_{ij} within block i. That is, for block i the random variables $X_{i1}, X_{i2}, ..., X_{ik}$ are compared with each other and the rank 1 is assigned to the smallest observed value, the rank 2 to the second smallest, and so on to the rank k, which is assigned to the largest observation in the block i. Ranks are assigned in all of the b blocks. Use average ranks in case of ties. Then sum the ranks for each treatment to obtain R_j where :

$$R_j = \sum_{i=1}^{b} R(X_{ij}) \qquad j = 1, 2, ...k$$

Test Statistic :

$$T = \frac{12}{bk(k+1)} \sum_{j=1}^{k} (R_j - \frac{b(b+k)}{2})^2$$

4. Software

We use Matlab to develop a program with user interface to analyze our data. Here is the beginning graph.

Figure 1-1. The beginning of user interface

Steps in using software:

step 1: Typing data name into the "DataName" edit.

step 2: Select the model we want to fit.

step 3: If the ideal value exists, marking the term "ideal exise??" and typing the ideal value name into the "idealName" edit.

step 4: Typing how much percent confidence band we want.

step 5: Push the "Run" button.

step 6: Select different setup to read.

step 7: Push the "Graph" button to draw graphs. After using this program, we have the result as follows :

Figure 1-2. The display of user interface

After running this program with a real data set, we will obtain the values of change point location, coefficients of regression line, MSE, R-square, F statistics, p-value, AIC and AICc. According to Figure 1-2, we have graphs under the outputs for more analysis.

Table I The results of comparisons for observations in different days

I -1 obs2003-1 (Friedman test) (d = 3)

antenna	polarization	h1	h2	rank		test statistics	asymp. sign
broadband	horizontal	1m	1-4m	day1	2.78	26.419	≈ 0
				day2	1.46		
				day3	1.76		
broadband	horizontal	2m	1-4m	day1	2.22	5.143	0.076
				day2	1.67		
				day3	2.11		
broadband	vertical	1m	1-4m	day1	2.22	2.583	0.275
				day2	1.80		
				day3	1.98		
broadband	vertical	1.5m	1-4m	day1	2.22	4.667	0.097
				day2	1.67		
				day3	2.11		
dipole	horizontal	2m	1-4m	day1	2.07	0.906	0.636
				day2	1.85		
				day3	2.07		
dipole	vertical	2.75m	2.75-4m	day1	2.19	3.089	0.213
				day2	1.74		
				day3	2.07		

I -2 obs2003-2 (Wilcoxon test) (d = 2)

antenna	polarization	h1	h2	R	test statistics	asymp. sign
broadband	horizontal	2.75m	1-4m	10m	-1.902	0.057
broadband	horizontal	3m	1-4m	10m	-0.043	0.966
broadband	vertical	2.75m	1-4m	10m	-2.727	0.006
broadband	vertical	3m	1-4m	10m	-0.973	0.331
dipole	horizontal	2.75m	1-4m	10m	-3.044	0.002
dipole	horizontal	3m	1-4m	10m	-2.993	0.003
dipole	vertical	2.75m	2.75-4m	10m	-3.720	≈ 0
dipole	vertical	3m	2.75-4m	10m	-3.719	≈ 0
broadband	horizontal	2.75m	1-4m	3m	-0.314	0.753
broadband	horizontal	3m	1-4m	3m	-1.686	0.092
broadband	vertical	2.75m	1-4m	3m	-1.532	0.125
broadband	vertical	3m	1-4m	3m	-1.836	0.066
dipole	horizontal	2.75m	1-4m	3m	-0.107	0.915
dipole	horizontal	3m	1-4m	3m	-1.629	0.103
dipole	vertical	2.75m	2.74-4m	3m	-2.270	0.023
dipole	vertical	3m	2.75-4m	3m	-3.378	0.001

I -3 obs2004-1 (Friedman test) (d = 3)

antenna	polarization	h1	h2	rank		test statistics	asymp. sign
broadband	horizontal	1m	1-4m	day1	2.00	1.895	0.388
				day2	1.88		
				day3	2.13		
broadband	horizontal	2m	1-4m	day1	1.56	11.049	0.004
				day2	2.27		
				day3	2.17		
broadband	vertical	1m	1-4m	day1	1.88	1.117	0.572
				day2	1.98		
				day3	2.15		
broadband	vertical	1.5m	1-4m	day1	1.96	1.814	0.404
				day2	2.15		
				day3	1.90		
dipole	horizontal	2m	1-4m	day1	1.88	0.789	0.674
				day2	2.04		
				day3	2.08		
dipole	vertical	2.75m	2.75-4m	day1	2.10	0.816	0.665
				day2	1.88		
				day3	2.02		
dipole	horizontal	3m	1-4m	day1	1.94	0.745	0.689
				day2	1.96		
				day3	2.10		
dipole	vertical	3m	2.75-4m	day1	2.08	0.426	0.808
				day2	1.94		
				day3	1.98		

I -4 obs2004-2 (Friedman test) (d = 3)

antenna	polarization	h1	h2	rank		test statistics	asymp. sign
broadband	horizontal	1m	1-4m	day1	2.06	4.200	0.122
				day2	2.11		
				day3	1.83		
broadband	horizontal	2m	1-4m	day1	2.13	5.450	0.066
				day2	2.09		
				day3	1.78		
broadband	vertical	1m	1-4m	day1	1.81	3.659	0.161
				day2	2.09		
				day3	2.09		
broadband	vertical	1.5m	1-4m	day1	2.39	11.143	0.004
				day2	1.89		
				day3	1.72		
dipole	horizontal	2m	1-4m	day1	1.89	0.727	0.695
				day2	2.04		
				day3	2.07		
dipole	vertical	2.75m	2.75-4m	day1	2.04	0.165	0.921
				day2	1.94		
				day3	2.02		

Table II The fitted models and results for obs2003-1 in different setups.

II-1 broadband hor h1=1m h2=1-4m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 69.365 + (-28.648)t		2	3.9333	0.9770	3364.75	<0.01	196.215	112.903
1CP	y = 83.922 + (-36.44) t + 14.27 $(t-t_m)I$		4	0.6779	0.9961	6635.13	<0.01	-27.596	56.204
160	-22.169								
1JP	y = 77.789 + (-33.112) t + 5.55 I		4	1.9908	0.9887	2242.31	<0.01	59.6697	143.47
300									
2CP	y = 96.263 + (-44.196) t + 8.878 $(t-t_m)I$ + 12.92 $(t-t_n)I$		6	0.6281	0.9965	4298.32	<0.01	-31.9073	52.627
45-160	-35.291	-22.3991							

II-2 broadband hor h1=2m h2=1-4m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 56.654+ (-23.848)t		2	2.4757	0.9791	3704.55	<0.01	75.403	158.715
1CP	y = 79.128 + (-36.692) t + 15.595 $(t-t_m)I$		4	0.4634	0.9961	6710.88	<0.01	-58.389	25.411
80	-20.733								
1JP	y = 54.873 + (-21.562) t + (-4.011) I		4	1.0814	0.9911	2861.66	<0.01	10.2352	94.0352
50									
2CP	y = 112.467 + (-58.673) t + 25.203 $(t-t_m)I$ + 12.874 $(t-t_n)I$		6	0.4154	0.9967	4494.29	<0.01	-65.384	19.1504
35-90	-33.47	-20.5961							

II-3　broadband ver h1=1m h2=1-4m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 42.8961 + (-18.142)t		2	3.144	0.9553	1687.88	<0.01	94.771	178.083
1CP	y = 37.27 + (-15.214) t + (-14.436) $(t-t_m)I$		4	1.924	0.9733	937.043	<0.01	56.891	140.691
400	-29.649								
1JP	y = 37.6414 + (-15.403) t + (-4.2783) I		4	1.8915	0.9738	953.423	<0.01	55.5247	139.325
500									
2CP	y = (-27.235) + 26.878 t + (-42.809) $(t-t_m)I$ + (-12.825) $(t-t_n)I$		6	1.708	0.9769	635.602	<0.01	49.123	133.657
35-400	-15.931	-28.755							

II-4　broadband ver h1=1.5m h2=1-4m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 43.42 + (-18.259)t		2	3.144	0.9509	1530.79	<0.01	103.726	187.038
1CP	y = 34.928 + (-13.792) t + (-12.039) $(t-t_m)I$		4	1.797	0.9755	1023.02	<0.01	51.376	135.176
250	-25.831								
1JP	y = 35.985 + (-14.316) t + (-4.899) I		4	2.0103	0.9726	911.742	<0.01	60.4614	144.261
300									
2CP	y = 34.266 + (-13.423) t + (-15.78) $(t-t_m)I$ + 12.549 $(t-t_n)I$		6	1.697	0.977	651.386	<0.01	48.5941	133.128
250-600	-29.203	-16.6544							

II-5 dipole hor h1=2m h2=1-4m

Model		m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 58.77 + (-25.146)t	2	3.033	0.977	3361.68	<0.01	91.854	175.166
1CP	y = 83.469 + (-39.261) t + 17.538 $(t-t_m)$I	4	0.604	0.9955	5731.94	<0.01	-36.9138	46.886
80	-21.723							
1JP	y = 56.737 + (-22.534) t + (-4.5827) I	4	1.2079	0.9911	2854.46	<0.01	19.194	102.994
50								
2CP	y = 85.309 + (-40.411) t + 20.396 $(t-t_m)$I + (-3.097) $(t-t_n)$I	6	0.566	0.996	3672.96	<0.01	-40.341	44.1932
80-250	-20.015 -23.112							

II-6 dipole ver h1=2.75m h2=2.75-4m

Model		m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 51.023 + (-21.426)t	2	2.531	0.974	2925.09	<0.01	77.189	160.501
1CP	y = 37.273 + (-13.44) t + (-9.436) $(t-t_m)$I	4	2.053	0.979	1208.78	<0.01	62.192	145.962
70	-22.876							
1JP	y = 52.3704 + (-23.157) t + 3.0354 I	4	1.7612	0.98216	1413.29	<0.01	49.7447	133.545
50								
2CP	y = 56.272 + (-25.603) t + 43.811 $(t-t_m)$I + (-41.341) $(t-t_n)$I	6	1.801	0.982	829.417	<0.01	53.411	137.946
50-60	18.208 -22.801							

Table III The fitted models and results for obs2003-2 in different setups.

III-1 broadband hor h1=2.75m h2=1-4m R=10m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 52.335 + (-22.296)t		2	2.474	0.9791	2153.79	<0.01	45.445	95.99
1CP	y = 95.506 + (-49.059) t + 27.983 $(t-t_m)I$		4	1.496	0.9879	1197.81	<0.01	23.171	74.599
45	-21.0765								
1JP	y = 53.699 + (-21.279) t + (-3.8824) I		4	1.5826	0.9872	1131.78	<0.01	25.859	77.2876
35									
2CP	y = 80.845 + (-39.531) t + 21.759 $(t-t_m)I$ + (-16.013) $(t-t_n)I$		6	0.748	0.994	1446.01	<0.01	-8.315	44.485
60-500	-17.773	-33.785							

III-2 broadband hor h1=3m h2=1-4m R=10m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 50.769+ (-21.629)t		2	2.328	0.9791	2154.53	<0.01	42.5097	93.055
1CP	y = 89.681 + (-45.752) t + 25.222 $(t-t_m)I$		4	1.547	0.9867	1088.62	<0.01	24.782	76.21
45	-20.53								
1JP	y = 51.967 + (-20.698) t + (-3.5524) I		4	1.5962	0.9863	1057.34	<0.01	26.1624	77.591
35									
2CP	y = 87.643 + (-44.89) t + 26.665 $(t-t_m)I$ + (-15.95) $(t-t_n)I$		6	0.735	0.994	1384.43	<0.01	-9.157	43.643
50-500	-17.7838	-33.733							

III-3　broadband ver h1=2.75m h2=1-4m 10m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 50.069 + (-20.928)t		2	2.382	0.9772	1971.31	<0.01	43.616	94.161
1CP	y = 46.109 + (-18.832) t + (-10.374) $(t-t_m)I$		4	1.75	0.984	900.538	<0.01	30.687	82.115
400	-29.206								
1JP	y = 53.802 + (-23.484) t + 3.0742 I		4	1.66503	0.9847	947.281	<0.01	28.2959	79.7244
90									
2CP	y = 67.527 + (-31.845) t + 17.720 $(t-t_m)I$ + (-13.081) $(t-t_n)I$		6	1.111	0.9903	856.668	<0.01	10.639	63.439
60-250	-14.125	-27.206							

III-4　broadband ver h1=3m h2=1-4m R=10m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 50.234 + (-20.982)t		2	2.881	0.9727	1638.15	<0.01	52.748	103.293
1CP	y = 46.545 + (-19.03) t + (-9.662) $(t-t_m)I$		4	2.37	0.9785	667.761	<0.01	45.242	96.671
400	-28.692								
1JP	y = 46.951 + (-19.254) t + (-3.2475) I		4	2.1418	0.9805	740.464	<0.01	40.3828	91.8114
600									
2CP	y = 64.707 + (-29.97) t + 13.543 $(t-t_m)I$ + (-15.089) $(t-t_n)I$		6	1.846	0.984	517.158	<0.01	35.027	87.827
60-400	-16.428	-31.517							

III-5 dipole hor h1=2.75m h2=1-4m R=10m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 53.4 + (-22.935)t		2	1.160	0.9906	4859.2	<0.01	9.094	59.64
1CP	y = 73.192 + (-34.709) t + 13.247$(t-t_m)$I		4	0.438	0.9966	4317.12	<0.01	-35.8	15.628
60	-21.462								
1JP	y = 52.8055 + (-21.688) t + (-2.59749) I		4	0.5696	0.9956	3316.14	<0.01	-23.187	28.2409
45									
2CP	y = 70.957 + (-33.278)t + 10.714 $(t-t_m)$I + 4.06 $(t-t_n)$I		6	0.37	0.9972	3070.06	<0.01	-42.159	10.641
60-400	-22.5642	-18.504							

III-6 dipole hor h1=3m h2=1-4m R=10m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 52.557 + (-22.582)t		2	1.796	0.9851	3043.74	<0.01	30.066	80.611
1CP	y = 88.998 + (-44.805) t + 23.782 $(t-t_m)$I		4	0.582	0.9954	3166.34	<0.01	-22.199	29.23
50	-21.023								
1JP	y = 53.917 + (-21.526) t + (-4.032) I		4	0.7944	0.9937	2313.86	<0.01	-7.2243	44.2042
35									
2CP	y = 85.395 + (-42.459) t + 20.303 $(t-t_m)$I + 11.184 $(t-t_n)$I		6	0.336	0.9975	3290.83	<0.01	-46.703	6.097
50-600	-22.157	-10.973							

III-7 dipole ver h1=2.75m h2=2.75-4m R=10m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 51.892 + (-21.94)t		2	1	0.9911	5156.56	<0.01	1.9938	52.539
1CP	y = 53.49 + (-22.781) t + 6.397 $(t-t_m)I$		4	0.875	0.9926	1968.3	<0.01	-2.575	48.854
500	-16.384								
1JP	y = 49.028 + (-20.217) t + (-1.89763) I		4	0.7878	0.9933	2188.38	<0.01	-7.6263	43.8023
140									
2CP	y = 48.715 + (-20.03)t + (-7.879) $(t-t_m)I$ + 10.778 $(t-t_n)I$		6	0.666	0.9946	1555.8	<0.01	-13.941	38.859
120-300	-27.91	-17.132							

III-8 dipole ver h1=3m h2=2.75-4m R=10m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 51.709 + (-21.813)t		2	1.36	0.9879	3750.21	<0.01	16.719	67.265
1CP	y = 53.416 + (-22.703) t + 19.642 $(t-t_m)I$		4	1.002	0.9915	1702.58	<0.01	3.93	55.358
700	-3.061								
1JP	y = 48.107 + (-19.645) t + (-2.3864) I		4	1.0131	0.9913	1684.12	<0.01	4.44825	55.8768
140									
2CP	y = 47.698 + (-19.405)t + (-6.129) $(t-t_m)I$ + 15.47 $(t-t_n)I$		6	0.786	0.9936	1305.6	<0.01	-5.956	46.844
100-500	-25.534	-10.064							

III-9 broadband hor h1=2.75m h2=1-4m R=3m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 28.698 + (-15.62)t		2	2.849	0.9523	918.133	<0.01	52.207	102.753
1CP	y = 25.626 + (-14.003) t + (-12.297) $(t-t_m)I$		4	2.346	0.9624	375.548	<0.01	44.758	96.187
500	-26.301								
1JP	y = 25.774 + (-14.081) t + (-2.8921) I		4	2.2881	0.9833	385.451	<0.01	43.5549	94.983
600									
2CP	y = 29.129 + (-15.935) t + 18.733 $(t-t_m)I$ + (-32.7) $(t-t_n)I$		6	1.8295	0.972	291.863	<0.01	34.583	87.383
250-400	2.798	-29.901							

III-10 broadband hor h1=3m h2=1-4m R=3m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 29.109 + (-15.813)t		2	2.748	0.955	975.396	<0.01	50.485	101.03
1CP	y = 26.509 + (-14.445) t + (-10.407) $(t-t_m)I$		4	2.421	0.9621	371.898	<0.01	46.256	97.684
500	-24.8524								
1JP	y = 26.418 + (-14.397) t + (-2.6616) I		4	2.2887	0.9641	394.16	<0.01	43.568	94.9966
600									
2CP	y = 30.097 + (-16.422) t + 18.587 $(t-t_m)I$ + (-30.979) $(t-t_n)I$		6	1.913	0.9714	285.117	<0.01	36.721	89.521
250-400	2.1652	-28.8135							

III-11 broadband ver h1=2.75m h2=1-4m R=3m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 33.879 + (-16.957)t		2	2.0997	0.9696	1468.05	<0.01	37.563	88.108
1CP	y = 29.718 + (-14.767) t + (-16.658) $(t-t_m)I$		4	1.0354	0.9857	1008.82	<0.01	5.4915	56.92
500	-31.425								
1JP	y = 30.2158 + (-15.028) t + (-2.3864) I		4	1.1118	0.9846	938.441	<0.01	8.9111	60.3397
600									
2CP	y = 31.569 + (-15.794) t + 12.752 $(t-t_m)I$ + (-29.078) $(t-t_n)I$		6	0.764	0.9899	823.342	<0.01	-7.304	45.496
250-400	-3.0411	-32.1189							

III-12 broadband ver h1=3m h2=1-4m R=3m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 33.815 + (-16.932)t		2	1.9584	0.9715	1569.32	<0.01	34.2198	84.765
1CP	y = 28.972 + (-14.369) t + (-12.686) $(t-t_m)I$		4	0.941	0.987	1106.15	<0.01	0.8957	52.324
400	-27.0543								
1JP	y = 30.382 + (-15.124) t + (-3.3965) I		4	1.0956	0.9848	947.752	<0.01	8.209	59.6375
600									
2CP	y = 31.354 + (-15.683) t + 11.532 $(t-t_m)I$ + (-27.271) $(t-t_n)I$		6	0.718	0.9904	872.795	<0.01	-10.311	42.489
250-400	-4.151	-31.4217							

III-13 dipole hor h1=2.75m h2=1-4m R=3m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 40.631 + (-20.435)t		2	1.145	0.9884	3911.18	<0.01	8.441	58.986
1CP	y = 36.368 + (-18.01) t + (-3.18) $(t-t_m)I$		4	1.091	0.9894	1369.35	<0.01	7.9996	59.428
90	-21.190								
1JP	y = 37.1892 + (-18.469) t + (-2.1804) I		4	0.8779	0.9914	1705.11	<0.01	-2.4265	49.0021
180									
2CP	y = 80.778 + (-46.639) t + 34.793 $(t-t_m)I$ + (-9.643) $(t-t_n)I$		6	0.697	0.9935	1291.04	<0.01	-11.723	41.073
40-80	-11.846	-21.48912							

III-14 dipole hor h1=3m h2=1-4m R=3m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 39.493 + (-19.959)t		2	1.9574	0.9794	2181.69	<0.01	34.1952	84.741
1CP	y = 40.604 + (-20.552) t + 27.8297 $(t-t_m)I$		4	1.742	0.9824	819.929	<0.01	30.4532	81.882
800	7.2775								
1JP	y = 41.238 + (-21.5848) t + (-2.4751) I		4	1.4374	0.9855	996.554	<0.01	21.2388	72.667
60									
2CP	y = 55.419 + (-30.308) t + 63.883 $(t-t_m)I$ + (-54.959) $(t-t_n)I$		6	1.288	0.988	668.522	<0.01	10.7514	70.551
60-70	33.5751	-21.384							

III-15 dipole ver h1=2.75m h2=1-4m R=3m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 41.919 + (-19.918)t		2	0.768	0.9918	5538.49	<0.01	-10.72	39.526
1CP	y = 39.738 + (-18.688) t + 1.698 $(t-t_m)I$		4	0.769	0.9921	1844.55	<0.01	-8.795	42.634
100	-16.9902								
1JP	y = 43.2248 + (-20.974) t + 1.4561 I		4	0.5968	0.9938	2380.55	<0.01	-20.9541	30.4744
70									
2CP	y = 55.467 + (-28.517) t + 27.671 $(t-t_m)I$ + (-19.926) $(t-t_n)I$		6	0.468	0.9954	1824.64	<0.01	-30.867	21.933
60-80	-0.8457	-20.7715							

III-16 dipole ver h1=3m h2=1-4m R=3m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 40.373 + (-19.221)t		2	1.385	0.9842	2859.83	<0.01	17.587	68.132
1CP	y = 41.1414 + (-19.621) t + 18.742 $(t-t_m)I$		4	1.3096	0.9857	1009.63	<0.01	16.7698	68.1984
800	-0.879								
1JP	y = 42.492 + (-20.778) t + 1.9879 I		4	1.0803	0.9882	1227.03	<0.01	7.5313	58.9599
80									
2CP	y = 56.664 + (-29.375) t + 41.118 $(t-t_m)I$ + (-32.232) $(t-t_n)I$		6	0.708	0.993	1129.12	<0.01	-11.015	41.785
70-90	11.743	-20.489							

Table IV The fitted models and results for obs2004-1 in different setups.

IV-1 broadband hor h1=1m h2=1-4m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 74.26 + (-30.616)t		2	5.708	0.9742	2640.36	<0.01	127.387	201.74
1CP	y = 124.224 + (-60.34) t + 33.442 $(t-t_m)I$		4	1.082	0.9952	4744.11	<0.01	9.557	84.466
60	-26.899								
1JP	y = 72.764 + (-27.479) t + (-6.5339) I		4	1.9245	0.9915	2657.22	<0.01	51.0212	125.93
45									
2CP	y = 123.527 + (-59.88) t + 51.435 $(t-t_m)I$ + (-19.58) $(t-t_n)I$		6	0.697	0.9971	4428.82	<0.01	-20.292	55.458
70-100	-8.447	-28.027							

IV-2 broadband hor h1=2m h2=1-4m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 62.479+ (-26.242)t		2	7.096	0.9571	1560.55	<0.01	143.056	217.409
1CP	y = 112.49 + (-55.996) t + 33.475 $(t-t_m)I$		4	2.501	0.9985	1519.42	<0.01	69.885	144.794
60	-22.521								
1JP	y = 60.998 + (-23.135) t + (-6.471) I		4	3.4289	0.9798	1102.09	<0.01	92.606	167.515
45									
2CP	y = 109.925 + (-54.37) t + 57.693 $(t-t_m)I$ + (-30.528) $(t-t_n)I$		6	0.247	0.9986	9344.71	<0.01	-94.866	-19.116
80-140	3.32	-17.2051							

IV-3 broadband ver h1=1m h2=1-4m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 49.298 + (-20.861)t		2	4.392	0.9579	1593.26	<0.01	108.515	182.868
1CP	y = 41.021 + (-16.424) t + (-12.006) $(t-t_m)I$		4	2.714	0.9747	874.69	<0.01	75.758	150.667
250	-28.43								
1JP	y = 58.607 + (-26.65) t + 6.4632 I		4	1.4673	0.9863	1636.87	<0.01	31.4895	106.399
120									
2CP	y = 64.605 + (-30.508) t + 29.289 $(t-t_m)I$ + (-27.923) $(t-t_n)I$		6	0.5404	0.9951	2690.46	<0.01	-38.58	37.17
80-180	-1.219	-29.142							

IV-4 broadband ver h1=1.5m h2=1-4m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 51.378 + (-21.604)t		2	7.6998	0.933	974.743	<0.01	148.937	223.29
1CP	y = 42.806 + (-17.01) t + (-12.433) $(t-t_m)I$		4	5.988	0.9493	425.157	<0.01	132.743	207.652
250	-29.4429								
1JP	y = 63.020 + (-28.846) t + 8.084 I		4	3.1486	0.9734	828.939	<0.01	86.4672	161.39
120									
2CP	y = 77.572 + (-37.752) t + 42.225 $(t-t_m)I$ + (-35.745) $(t-t_n)I$		6	1.3362	0.989	1190.9	<0.01	26.6	102.35
80-180	4.4727	-31.2727							

IV-5 dipole hor h1=2m h2=1-4m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 55.346 + (-23.904)t		2	1.7467	0.9869	5260.49	<0.01	42.1262	116.479
1CP	y = 79.456 + (-38.247) t + 16.137($t-t_m$)I		4	0.6818	0.995	4529.5	<0.01	-23.697	51.213
60	-22.1101								
1JP	y = 53.948 + (-22.236) t + (-2.8963) I		4	0.9909	0.9928	3109.2	<0.01	3.2296	78.1388
50									
2CP	y = 80.4597 + (-38.905)t + 45.183 ($t-t_m$)I + (-28.864) ($t-t_n$)I		6	0.6258	0.9955	2962.25	<0.01	-28.011	47.7395
70-80	6.2774	-22.5866							

IV-6 dipole ver h1=2.75m h2=2.75-4m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 52.356 + (-22.392)t		2	1.9571	0.9833	4119.72	<0.01	50.317	124.67
1CP	y = 47.008 + (-19.417) t + (-4.538) ($t-t_m$)I		4	1.7404	0.9856	1547.76	<0.01	43.783	118.692
120	-23.9542								
1JP	y = 55.3099 + (-24.782) t + 3.2942 I		4	0.9912	0.9918	2734.74	<0.01	3.2507	76.1598
70									
2CP	y = 77.273 + (-38.364) t + 56.243 ($t-t_m$)I + (-42.376) ($t-t_n$)I		6	0.4898	0.9961	3334.95	<0.01	-45.655	30.095
60-80	17.8791	-24.4969							

IV-7 dipole hor h1=3m h2=1-4m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 53.873 + (-23.199)t		2	2.5486	0.9798	3395.84	<0.01	69.3309	143.684
1CP	y = 105.538 + (-55.92) t + 33.537($t-t_m$)I		4	1.9092	0.9853	1519.46	<0.01	50.4486	125.358
40	-22.3821								
1JP	y = 55.011 + (-22.316) t + (-3.37288) I		4	1.8879	0.9854	1536.92	<0.01	49.6383	124.547
35									
2CP	y = 100.392 + (-52.493)t + 53.588 ($t-t_m$)I + (-24.598) ($t-t_n$)I		6	1.3901	0.9896	1257.65	<0.01	29.4501	105.2
50-70	1.096	-23.502							

IV-8 dipole ver h1=3m h2=1-4m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 55.092 + (-23.725)t		2	1.1824	0.9909	7655.02	<0.01	14.0363	88.3892
1CP	y = 74.1501 + (-35.348) t + 12.4375 ($t-t_m$)I		4	0.8731	0.9935	3464.58	<0.01	-5.8851	69.024
50	-22.91								
1JP	y = 54.647 + (-22.7927) t + (-1.942) I		4	0.8678	0.9935	3485.67	<0.01	-6.3191	68.59
45									
2CP	y = 76.2839 + (-36.694)t + 26.6404 ($t-t_m$)I + (-13.3415) ($t-t_n$)I		6	0.7498	0.9945	2423.23	<0.01	-14.9962	60.754
60-80	-10.0536	-23.3951							

Table V The fitted models and results for obs2004-2 in different setups.

V-1 broadband hor h1=1m h2=1-4m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 70.279 + (-29.04)t		2	4.081	0.9768	3332.12	<0.01	115.891	199.202
1CP	y = 83.569 + (-36.078) t + 15.39 $(t-t_m)I$		4	0.593	0.9967	7796.03	<0.01	-38.393	45.407
200	-20.6879								
1JP	y = 76.102 + (-32.056) t + 5.647 I		4	1.8579	0.9897	2471.99	<0.01	54.0728	137.873
600									
2CP	y = 84.213 + (-36.447) t + 11.139 $(t-t_m)I$ + 16.325 $(t-t_n)I$		6	0.319	0.9982	8713.9	<0.01	-86.79	-2.256
160-600	-25.308	-8.9839							

V-2 broadband hor h1=2m h2=1-4m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 58.551+ (-24.715)t		2	1.8525	0.9854	5316.79	<0.01	51.916	135.228
1CP	y = 78.994 + (-36.397) t + 14.517 $(t-t_m)I$		4	0.1825	0.9985	18228.3	<0.01	-133.868	-50.068
80	-21.8807								
1JP	y = 57.7895 + (-22.886) t + (-3.847) I		4	0.6364	0.9951	5209.97	<0.01	-32.7081	51.0919
45									
2CP	y = 78.328 + (-35.981) t + 13.612 $(t-t_m)I$ + 14.583 $(t-t_n)I$		6	0.12	0.9991	16655.1	<0.01	-166.025	-81.491
80-800	-22.369	-7.7866							

V-3 broadband ver h1=1m h2=1-4m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 45.094 + (-19.118)t		2	2.105	0.9726	2800.34	<0.01	62.253	145.565
1CP	y = 33.154 + (-12.183) t + (-8.194) $(t-t_m)I$		4	1.749	0.9778	1128.99	<0.01	49.203	133.003
70	-20.377								
1JP	y = 46.3419 + (-20.721) t + 2.81187 I		4	1.4425	0.9817	1374.74	<0.01	33.5734	117.373
50									
2CP	y = 96.9979 + (-53.462) t + (52.311) $(t-t_m)I$ + (-19.735) $(t-t_n)I$		6	1.0331	0.9872	1158.25	<0.01	8.400	92.934
40-70	-1.151	-20.886							

V-4 broadband ver h1=1.5m h2=1-4m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 46.784 + (-19.693)t		2	2.1907	0.9731	2854.47	<0.01	65.498	148.809
1CP	y = 41.571 + (-16.95) t + (-7.3912) $(t-t_m)I$		4	1.5668	0.9812	1341.55	<0.01	40.2694	124.069
250	-24.3412								
1JP	y = 41.9076 + (-17.107) t + 5.647 I		4	1.5624	0.9813	1345.39	<0.01	40.0422	123.842
300									
2CP	y = 113.682 + (-64.122) t + 48.618 $(t-t_m)I$ + (-8.192) $(t-t_n)I$		6	1.2974	0.9849	975.674	<0.01	26.855	111.389
35-200	-15.504	-23.6952							

V-5 dipole hor h1=2m h2=1-4m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 55.102 + (-23.847)t		2	1.7914	0.9848	5119.33	<0.01	49.1957	132.507
1CP	y = 80.239 + (-38.749) t + 16.745 $(t-t_m)I$		4	0.7221	0.994	4272.67	<0.01	-22.4701	61.33
60	-22.0041								
1JP	y = 53.751 + (-22.011) t + (-3.305) I		4	0.9977	0.9917	3085.43	<0.01	3.71339	87.5134
50									
2CP	y = 85.508 + (-40.843) t + 20.476 $(t-t_m)I$ + (-3.305) $(t-t_n)I$		6	0.659	0.995	2813.18	<0.01	-28.0725	56.4617
60-250	-20.367	-23.672							

V-6 dipole ver h1=2.75m h2=2.75-4m

Model			m	MSE	R^2	F	p-value	AIC	AICc
SL	y = 52.516 + (-22.421)t		2	1.821	0.983	4452.01	<0.01	50.514	133.826
1CP	y = 46.981 + (-19.4) t + (-4.692) $(t-t_m)I$		4	1.543	0.986	1756.36	<0.01	39.039	122.839
125	-24.0916								
1JP	y = 55.247 + (-24.744) t + 3.23768 I		4	0.8806	0.99178	3096.99	<0.01	-6.3971	77.4029
70									
2CP	y = 77.251 + (-38.35) t + 56.008 $(t-t_m)I$ + (-42.14) $(t-t_n)I$		6	0.4351	0.996	3777.48	<0.01	-61.647	22.8872
50-60	17.658	-22.801							

Table VI　The percentage of the 95% confidence band at each point line within the ideal values ±4db

VI-1　broadband horizontal h1=1m h2=1-4m R=10m

obs2003-1					obs2004-2				
freq	length	LCL-ideal	UCL-ideal		freq	length	LCL-ideal	UCL-ideal	
30	5.4046	-2.4065	2.9981	1	30	5.0428	-2.0437	2.9991	1
35	5.3619	-2.1246	3.2373	1	35	5.0079	-1.7416	3.2664	1
40	5.33	-2.0219	3.3081	1	40	4.9816	-1.6207	3.361	1
45	5.306	-1.8738	3.4321	1	45	4.9615	-1.4561	3.5054	1
50	5.2877	-1.7321	3.5556	1	50	4.946	-1.2992	3.6469	1
60	5.2636	-1.5054	3.7582	1	60	4.9248	-1.0453	3.8795	1
70	5.2506	-1.4383	3.8122	1	70	4.9125	-0.9544	3.9581	1
80	5.2448	-1.3487	3.8961	1	80	4.906	-0.8434	4.0626	0.9997
90	5.244	-1.3122	3.9317	1	90	4.9035	-0.7877	4.1159	0.9995
100	5.2466	-1.2809	3.9657	1	100	4.9039	-0.7387	4.1652	0.9991
120	5.2587	-1.4723	3.7864	1	120	4.9102	-0.8986	4.0117	1
125	5.2627	-1.5204	3.7424	1	125	4.9127	-0.9394	3.9732	1
140	5.2764	-1.7207	3.5557	1	140	4.9213	-1.1194	3.8019	1
150	5.2865	-1.9175	3.3689	1	150	4.9279	-1.3037	3.6242	1
160	5.2971	-2.1442	3.1529	1	160	4.935	-1.5185	3.4165	1
175	5.2849	-1.9009	3.384	1	175	4.9464	-1.8283	3.1181	1
180	5.2814	-1.8704	3.411	1	180	4.9503	-1.9716	2.9786	1
200	5.2699	-1.7791	3.4909	1	200	4.9665	-2.5306	2.4359	1
250	5.2534	-1.7193	3.5342	1	250	4.9356	-2.32	2.6156	1
300	5.2479	-1.7719	3.476	1	300	4.9208	-2.2507	2.6701	1
400	5.254	-1.9448	3.3092	1	400	4.9166	-2.2333	2.6833	1
500	5.2711	-2.1018	3.1693	1	500	4.9295	-2.2447	2.6849	1
600	5.293	-2.2681	3.0249	1	600	4.9506	-2.2933	2.6573	1
700	5.3171	-2.4643	2.8527	1	700	4.9756	-2.3908	2.5848	1
800	5.3419	-2.5624	2.7795	1	800	5.0025	-2.404	2.5986	1
900	5.3669	-2.9089	2.4579	1	900	5.0303	-2.6761	2.3542	1
1000	5.3916	-2.9357	2.4559	1	1000	5.0583	-2.6367	2.4216	1

VI-2 broadband horizontal h1=2m h2=1-4m R=10m

obs2003-1					obs2004-2				
freq	length	LCL-ideal	UCL-ideal		freq	length	LCL-ideal	UCL-ideal	
30	4.5525	-1.4469	3.1056	1	30	2.857	-0.2982	2.5588	1
35	4.4731	-1.3636	3.1095	1	35	2.8071	-0.21	2.5972	1
40	4.4196	-1.2647	3.1549	1	40	2.7736	-0.1039	2.6696	1
45	4.3849	-1.2242	3.1606	1	45	2.7518	-0.0548	2.6969	1
50	4.3638	-1.2926	3.0711	1	50	2.7385	-0.1137	2.6248	1
60	4.3501	-1.3911	2.959	1	60	2.7299	-0.1914	2.5386	1
70	4.3612	-1.6531	2.7081	1	70	2.7369	-0.4316	2.3054	1
80	4.3875	-2.0941	2.2934	1	80	2.7534	-0.8506	1.9029	1
90	4.3759	-1.7488	2.6271	1	90	2.7461	-0.5662	2.18	1
100	4.3666	-1.5928	2.7737	1	100	2.7403	-0.4644	2.2758	1
120	4.353	-1.5277	2.8253	1	120	2.7317	-0.4927	2.239	1
125	4.3504	-1.494	2.8564	1	125	2.7301	-0.4798	2.2503	1
140	4.344	-1.4112	2.9328	1	140	2.7261	-0.4548	2.2714	1
150	4.3407	-1.4308	2.9099	1	150	2.7241	-0.5093	2.2147	1
160	4.3381	-1.4107	2.9275	1	160	2.7224	-0.5218	2.2006	1
175	4.3351	-1.4161	2.9191	1	175	2.7206	-0.5724	2.1481	1
180	4.3344	-1.3693	2.965	1	180	2.7201	-0.5399	2.1802	1
200	4.3322	-1.4169	2.9153	1	200	2.7187	-0.6404	2.0783	1
250	4.3312	-1.4257	2.9055	1	250	2.7181	-0.7606	1.9575	1
300	4.334	-1.4687	2.8652	1	300	2.7198	-0.894	1.8258	1
400	4.3451	-1.5646	2.7804	1	400	2.7268	-1.1312	1.5956	1
500	4.3592	-1.781	2.5783	1	500	2.7357	-1.4561	1.2796	1
600	4.3744	-1.7302	2.6442	1	600	2.7452	-1.4934	1.2518	1
700	4.3897	-1.8259	2.5638	1	700	2.7548	-1.6631	1.0917	1
800	4.4048	-1.8358	2.569	1	800	2.7643	-1.7367	1.0276	1
900	4.4195	-1.8037	2.6158	1	900	2.7735	-1.7606	1.0129	1
1000	4.4337	-1.8595	2.5742	1	1000	2.7824	-1.8662	0.9162	1

VI-3 broadband vertical h1=1m h2=1-4m R=10m

obs2003-1					obs2004-2				
freq	length	LCL-ideal	UCL-ideal		freq	length	LCL-ideal	UCL-ideal	
30	9.024	-6.4156	2.6084	0.9258	30	8.9013	-5.9923	2.9089	0.9581
35	8.9794	-6.1118	2.8675	0.9511	35	8.7079	-5.4112	3.2967	0.9835
40	8.9451	-5.777	3.1681	0.9708	40	8.5836	-4.8556	3.728	0.9948
45	8.9182	-5.5418	3.3764	0.9804	45	8.5088	-4.4414	4.0675	0.9982
50	8.897	-5.3274	3.5696	0.9867	50	8.4704	-4.0796	4.3908	0.9985
60	8.8664	-4.9168	3.9496	0.9944	60	8.4682	-3.4432	5.025	0.992
70	8.8467	-4.6255	4.2212	0.9967	70	8.53	-2.9897	5.5404	0.9778
80	8.8342	-4.4016	4.4327	0.9972	80	8.5047	-3.0587	5.446	0.9812
90	8.8268	-4.1761	4.6507	0.9966	90	8.4848	-3.0911	5.3938	0.9829
100	8.823	-3.9704	4.8526	0.9951	100	8.4691	-3.1156	5.3535	0.9841
120	8.8227	-3.6749	5.1478	0.9906	120	8.4464	-3.2177	5.2287	0.9876
125	8.8238	-3.6452	5.1786	0.9899	125	8.4421	-3.2768	5.1653	0.9891
140	8.8288	-3.4965	5.3323	0.9863	140	8.4316	-3.3745	5.0572	0.9913
150	8.8334	-3.3547	5.4787	0.982	150	8.4264	-3.3824	5.044	0.9916
160	8.8387	-3.2838	5.5549	0.9794	160	8.4222	-3.4514	4.9708	0.9929
175	8.8477	-3.2804	5.5673	0.979	175	8.4177	-3.6422	4.7755	0.9956
180	8.8509	-3.2682	5.5828	0.9784	180	8.4165	-3.6909	4.7256	0.9961
200	8.8647	-3.1712	5.6935	0.9739	200	8.4135	-3.8218	4.5917	0.9973
250	8.9026	-3.1646	5.738	0.9722	250	8.4134	-4.2964	4.117	0.9988
300	8.9423	-3.3891	5.5532	0.9801	300	8.4198	-4.9131	3.5067	0.9938
400	9.0205	-2.7291	6.2914	0.9374	400	8.4418	-4.8699	3.5719	0.9944
500	8.9069	-2.9457	5.9612	0.9601	500	8.4688	-4.2581	4.2107	0.9987
600	8.8964	-3.2881	5.6083	0.9777	600	8.4971	-3.8857	4.6114	0.9972
700	8.9457	-3.7977	5.1479	0.9909	700	8.5255	-3.7641	4.7615	0.9958
800	9.0307	-4.2597	4.771	0.9955	800	8.5534	-3.6597	4.8937	0.9942
900	9.1375	-4.7298	4.4078	0.9953	900	8.5804	-3.6155	4.9649	0.9932
1000	9.2574	-5.1464	4.111	0.9913	1000	8.6065	-3.561	5.0456	0.992

VI-4 broadband vertical h1=1.5m h2=1-4m R=10m

obs2003-1					obs2004-2				
freq	length	LCL-ideal	UCL-ideal		freq	length	LCL-ideal	UCL-ideal	
30	8.7584	-6.6235	2.1349	0.8926	30	8.178	-4.3555	3.8226	0.9988
35	8.7039	-6.2196	2.4843	0.9366	35	8.1271	-4.1648	3.9624	0.9995
40	8.6625	-5.8987	2.7638	0.9607	40	8.0886	-4.0284	4.0601	0.9998
45	8.6307	-5.5883	3.0424	0.9766	45	8.0588	-3.8806	4.1782	0.9995
50	8.6059	-5.307	3.2989	0.9861	50	8.0356	-3.7446	4.291	0.999
60	8.5713	-4.7818	3.7895	0.9956	60	8.0033	-3.4706	4.5328	0.9976
70	8.5503	-4.3947	4.1557	0.9982	70	7.9838	-3.2955	4.6883	0.9961
80	8.5384	-4.0885	4.4499	0.9981	80	7.9726	-3.1729	4.7997	0.9947
90	8.5327	-3.8912	4.6415	0.997	90	7.9673	-3.1373	4.83	0.9943
100	8.5314	-3.7216	4.8097	0.9953	100	7.9661	-3.1123	4.8538	0.9939
120	8.5376	-3.4168	5.1208	0.9903	120	7.9719	-3.0573	4.9146	0.9929
125	8.5405	-3.3628	5.1777	0.9891	125	7.9746	-3.0592	4.9155	0.9929
140	8.5513	-3.247	5.3043	0.986	140	7.9847	-3.0985	4.8863	0.9934
150	8.56	-3.1646	5.3954	0.9833	150	7.9928	-3.1104	4.8824	0.9935
160	8.5694	-3.1559	5.4135	0.9827	160	8.0016	-3.1899	4.8118	0.9946
175	8.5848	-3.4003	5.1845	0.9891	175	8.016	-3.5567	4.4593	0.9981
180	8.5902	-3.1718	5.4184	0.9827	180	8.021	-3.3666	4.6544	0.9965
200	8.6124	-3.214	5.3984	0.9834	200	8.0418	-3.5526	4.4892	0.9979
250	8.6711	-2.7799	5.8912	0.9613	250	8.0966	-3.4226	4.674	0.9964
300	8.6119	-2.5956	6.0163	0.9517	300	8.0413	-3.1223	4.919	0.993
400	8.5683	-2.7011	5.8672	0.9614	400	8.0005	-3.0431	4.9575	0.9922
500	8.5769	-3.0087	5.5683	0.977	500	8.0086	-3.206	4.8026	0.9947
600	8.6115	-3.3713	5.2403	0.9879	600	8.0409	-3.4495	4.5914	0.9971
700	8.6599	-3.7247	4.9352	0.9938	700	8.0861	-3.7017	4.3844	0.9986
800	8.7157	-3.9506	4.7651	0.996	800	8.1382	-3.8393	4.2989	0.999
900	8.7754	-4.3018	4.4736	0.9974	900	8.194	-4.1123	4.0817	0.9995
1000	8.837	-4.5145	4.3225	0.9971	1000	8.2515	-4.2549	3.9966	0.9992

VI-5 dipole horizontal h1=2m h2=1-4m R=10m

obs2003-1					obs2004-2				
freq	length	LCL-ideal	UCL-ideal		freq	length	LCL-ideal	UCL-ideal	
30	5.1979	-1.2227	3.9752	1	30	5.7755	-3.9855	1.79	1
35	5.1071	-1.3057	3.8014	1	35	5.6066	-3.9952	1.6114	1
40	5.0461	-1.352	3.6941	1	40	5.5064	-3.9922	1.5142	1
45	5.0064	-1.4404	3.566	1	45	5.4557	-4.0489	1.4067	0.9998
50	4.9824	-1.6249	3.3575	1	50	5.4409	-4.2146	1.2263	0.9989
60	4.9668	-1.9258	3.041	1	60	5.4845	-4.5046	0.9799	0.9956
70	4.9794	-2.3605	2.6189	1	70	5.466	-3.7684	1.6976	1
80	5.0095	-2.9523	2.0572	1	80	5.452	-3.3375	2.1145	1
90	4.9962	-2.6568	2.3393	1	90	5.441	-3.0575	2.3835	1
100	4.9855	-2.5455	2.44	1	100	5.4324	-2.9601	2.4723	1
120	4.97	-2.5578	2.4123	1	120	5.4201	-2.9963	2.4238	1
125	4.9671	-2.5414	2.4257	1	125	5.4178	-2.9852	2.4326	1
140	4.9598	-2.5069	2.4529	1	140	5.4123	-2.9655	2.4468	1
150	4.9561	-2.5559	2.4002	1	150	5.4096	-3.0234	2.3862	1
160	4.9531	-2.5633	2.3898	1	160	5.4075	-3.0392	2.3684	1
175	4.9497	-2.607	2.3427	1	175	5.4053	-3.0944	2.3109	1
180	4.9488	-2.5723	2.3765	1	180	5.4048	-3.0634	2.3414	1
200	4.9463	-2.665	2.2813	1	200	5.4036	-3.1696	2.234	1
250	4.9451	-2.7696	2.1756	1	250	5.4047	-3.3026	2.1021	1
300	4.9483	-2.8912	2.0571	1	300	5.4094	-3.4473	1.9621	1
400	4.961	-3.1115	1.8495	1	400	5.4237	-3.7036	1.7201	1
500	4.9772	-3.4247	1.5524	1	500	5.4405	-4.0444	1.3961	0.9998
600	4.9945	-3.4534	1.5411	1	600	5.4579	-4.0954	1.3625	0.9996
700	5.012	-3.6164	1.3956	1	700	5.4753	-4.2772	1.1981	0.9984
800	5.0292	-3.6847	1.3444	1	800	5.4921	-4.3617	1.1304	0.9976
900	5.0459	-3.7043	1.3417	1	900	5.5085	-4.3954	1.113	0.9972
1000	5.0622	-3.8064	1.2558	1	1000	5.5242	-4.5102	1.014	0.9955

VI-6 dipole vertical h1=2.75m h2=2.75-4m R=10m

obs2003-1					obs2004-2				
freq	length	LCL-ideal	UCL-ideal		freq	length	LCL-ideal	UCL-ideal	
30	9.6426	-6.2004	3.4422	0.9555	30	8.1925	-4.5714	3.6211	0.9974
35	9.4331	-5.5954	3.8377	0.9815	35	8.1114	-4.4296	3.6817	0.9983
40	9.2985	-5.1075	4.191	0.9919	40	8.0523	-4.3251	3.7271	0.9989
45	9.2174	-4.6544	4.563	0.9952	45	8.0089	-4.1958	3.8131	0.9994
50	9.1758	-4.3485	4.8272	0.9947	50	7.9773	-4.1677	3.8096	0.9995
60	9.1735	-3.8115	5.3619	0.9869	60	7.9385	-4.0845	3.8541	0.9998
70	9.2404	-3.4448	5.7957	0.9726	70	7.9218	-4.0749	3.8469	0.9998
80	9.213	-3.6576	5.5553	0.9816	80	7.9194	-4.0987	3.8207	0.9997
90	9.1915	-3.817	5.3744	0.9867	90	7.9264	-4.0946	3.8318	0.9998
100	9.1744	-4.0553	5.1192	0.9918	100	7.9401	-4.1891	3.7509	0.9994
120	9.1498	-4.9543	4.1955	0.9938	120	7.9799	-4.8452	3.1347	0.9941
125	9.1451	-5.1575	3.9876	0.9912	125	7.9916	-4.995	2.9967	0.9915
140	9.1338	-4.4778	4.6561	0.9956	140	7.9704	-4.3701	3.6003	0.9986
150	9.1281	-4.3603	4.7678	0.9952	150	7.959	-4.2863	3.6727	0.9991
160	9.1236	-4.1993	4.9244	0.9941	160	7.9495	-4.1568	3.7927	0.9996
175	9.1187	-4.1871	4.9316	0.9941	175	7.938	-4.1886	3.7493	0.9994
180	9.1174	-4.1663	4.9511	0.9939	180	7.9348	-4.1818	3.753	0.9995
200	9.1141	-4.1114	5.0027	0.9933	200	7.9245	-4.179	3.7455	0.9995
250	9.1141	-4.1283	4.9858	0.9935	250	7.9122	-4.3076	3.6046	0.9989
300	9.1211	-4.2431	4.878	0.9945	300	7.9115	-4.5149	3.3967	0.9977
400	9.1449	-4.5131	4.6318	0.9956	400	7.9276	-4.9329	2.9947	0.9925
500	9.1741	-4.7446	4.4295	0.9951	500	7.9545	-5.2811	2.6735	0.9838
600	9.2048	-5.0713	4.1335	0.9924	600	7.9858	-5.7043	2.2815	0.9638
700	9.2356	-5.3181	3.9175	0.9881	700	8.0186	-6.0336	1.985	0.9378
800	9.2657	-5.4598	3.8059	0.9847	800	8.0518	-6.2473	1.8045	0.9149
900	9.295	-5.5446	3.7504	0.9824	900	8.0846	-6.396	1.6885	0.8963
1000	9.3233	-5.6055	3.7178	0.9806	1000	8.1167	-6.5145	1.6022	0.8799

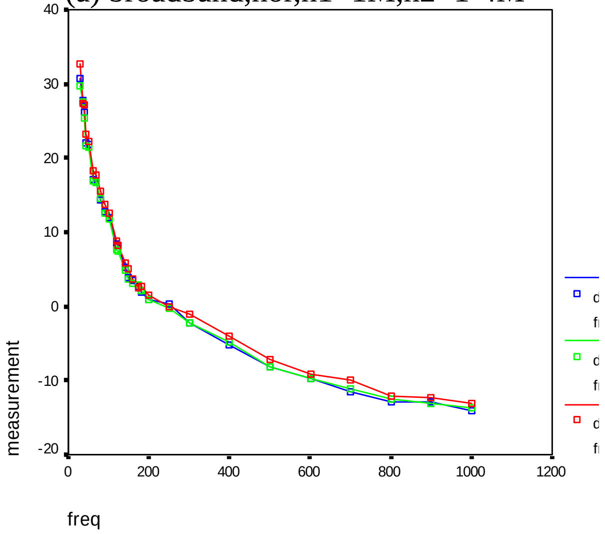
VI-8 dipole vertical h1=2.75m h2=2.75-4m R=10m (jump point model)

obs2003-1					obs2004-2				
freq	length	LCL-ideal	UCL-ideal		freq	length	LCL-ideal	UCL-ideal	
30	8.6582	-4.9641	3.6941	0.9934	30	6.0756	-3.1404	2.9352	1
35	8.6532	-5.1119	3.5414	0.9908	35	6.0681	-3.3932	2.6749	1
40	8.6521	-5.2542	3.3979	0.9877	40	6.0644	-3.6263	2.4381	1
45	8.6536	-5.3395	3.3141	0.9854	45	6.0632	-3.7914	2.2718	1
50	8.6568	-5.5007	3.1561	0.9802	50	6.0639	-4.0239	2.0399	0.9999
60	8.5855	-2.6632	5.9223	0.958	60	6.0688	-4.3857	1.6832	0.9978
70	8.5536	-2.8976	5.6561	0.9729	70	6.0768	-4.7462	1.3306	0.9918
80	8.5291	-3.1282	5.4009	0.9829	80	6.069	-1.8395	4.2294	0.999
90	8.51	-3.3032	5.2068	0.9883	90	6.0504	-2.0959	3.9544	1
100	8.4948	-3.5552	4.9396	0.9935	100	6.0354	-2.4206	3.6147	1
120	8.4729	-4.4778	3.9951	0.9982	120	6.0132	-3.4688	2.5444	1
125	8.4688	-4.6863	3.7825	0.9965	125	6.0089	-3.7053	2.3036	1
140	8.4588	-4.021	4.4378	0.9983	140	5.9982	-3.1178	2.8804	1
150	8.4538	-3.9124	4.5414	0.9977	150	5.9926	-3.0564	2.9362	1
160	8.4498	-3.7595	4.6904	0.9965	160	5.988	-2.9477	3.0404	1
175	8.4455	-3.7585	4.687	0.9965	175	5.9827	-3.008	2.9747	1
180	8.4444	-3.7413	4.7031	0.9964	180	5.9812	-3.01	2.9712	1
200	8.4415	-3.6994	4.7421	0.996	200	5.9768	-3.04	2.9368	1
250	8.4417	-3.7437	4.6981	0.9964	250	5.973	-3.236	2.737	1
300	8.4482	-3.8805	4.5677	0.9975	300	5.9752	-3.4964	2.4789	1
400	8.4698	-4.1845	4.2853	0.9986	400	5.9888	-3.9946	1.9942	1
500	8.4962	-4.4418	4.0544	0.9983	500	6.0076	-4.4019	1.6057	0.9975
600	8.524	-4.7893	3.7347	0.9955	600	6.0283	-4.8715	1.1568	0.9878
700	8.5517	-5.0534	3.4983	0.9917	700	6.0496	-5.2387	0.8109	0.968
800	8.5789	-5.2099	3.369	0.9885	800	6.0707	-5.4842	0.5865	0.9447
900	8.6053	-5.3076	3.2976	0.9861	900	6.0914	-5.6603	0.4312	0.9213
1000	8.6307	-5.38	3.2508	0.9841	1000	6.1116	-5.8026	0.309	0.8979

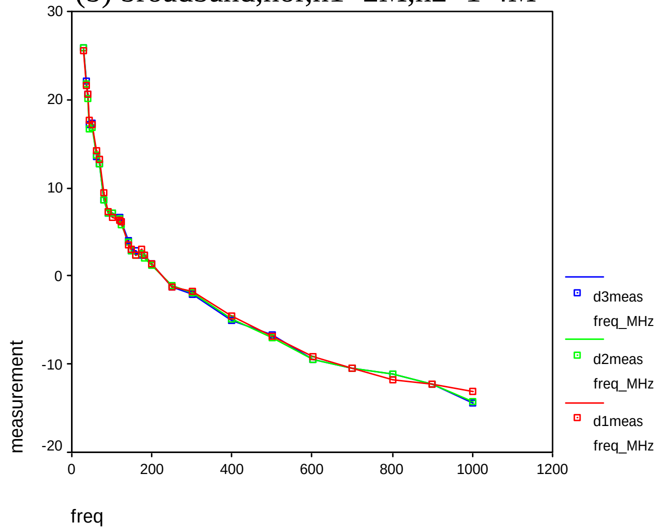
Figure A . The scatter plots of measurements versus frequency

A-1 The scatter plots of measurements versus frequency for obs2003-1

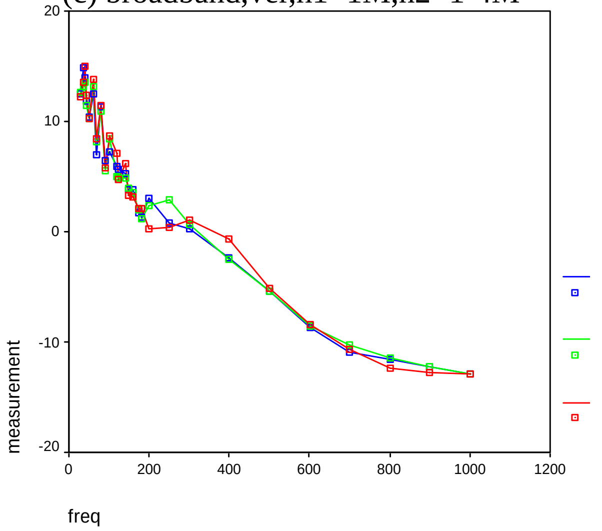
(a) broadband,hor,h1=1M,h2=1-4M



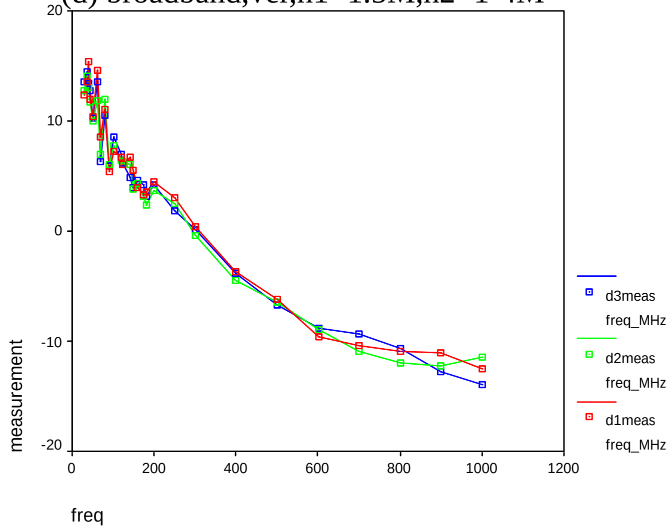
(b) broadband,hor,h1=2M,h2=1-4M



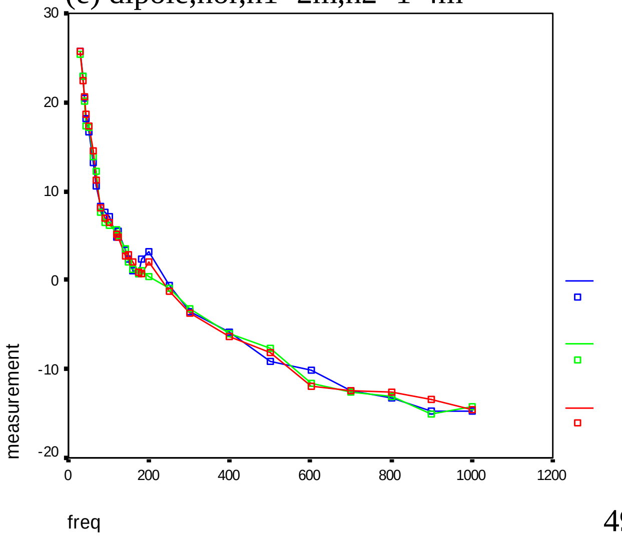
(c) broadband,ver,h1=1M,h2=1-4M



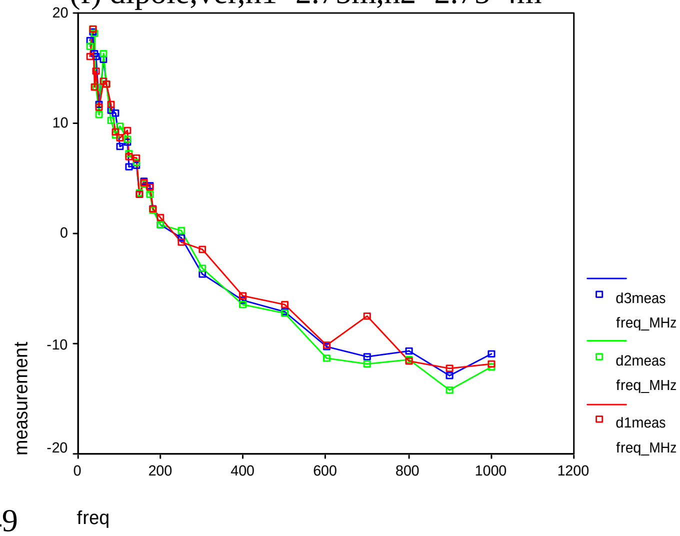
(d) broadband,ver,h1=1.5M,h2=1-4M



(e) dipole,hor,h1=2m,h2=1-4m

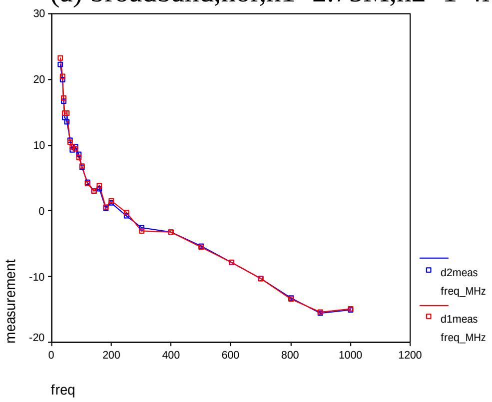


(f) dipole,ver,h1=2.75m,h2=2.75-4m

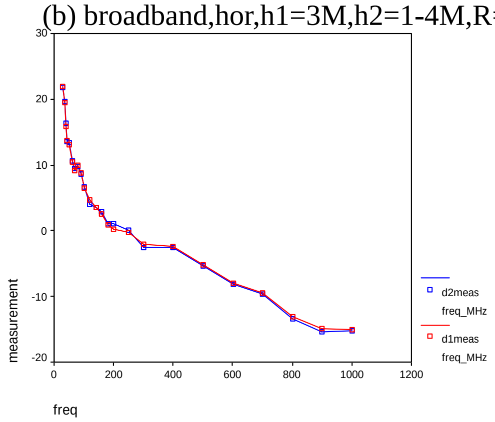


A-2 The scatter plots of measurements versus frequency for obs2003-2

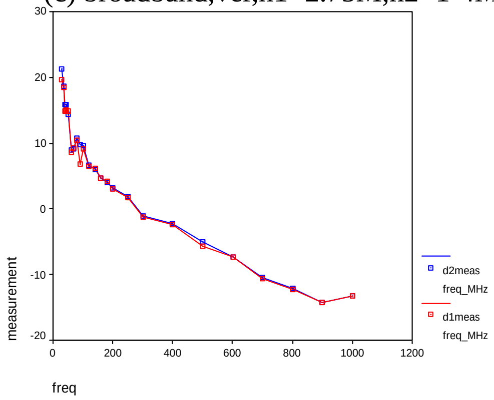
(a) broadband,hor,h1=2.75M,h2=1-4M,R=10



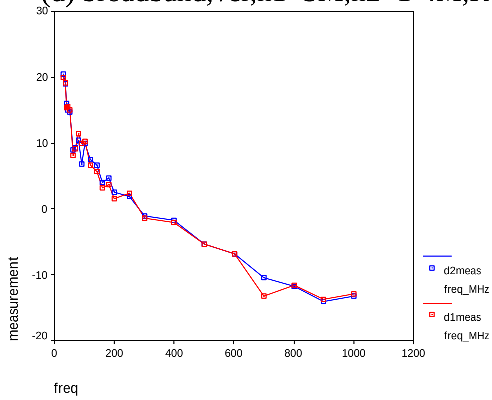
(b) broadband,hor,h1=3M,h2=1-4M,R=10



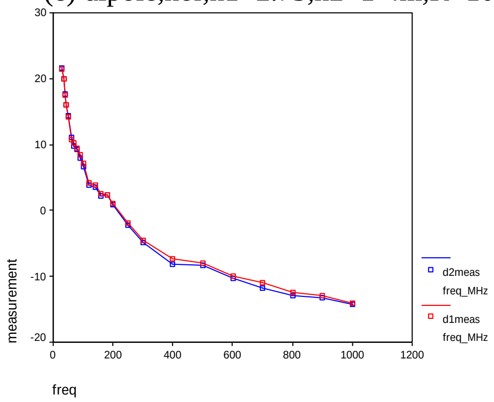
(c) broadband,ver,h1=2.75M,h2=1-4M,R=10



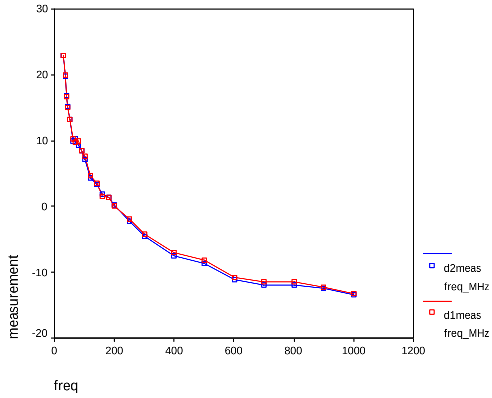
(d) broadband,ver,h1=3M,h2=1-4M,R=10



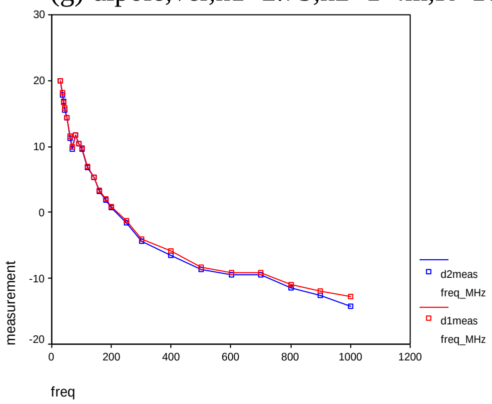
(e) dipole,hor,h1=2.75,h2=1-4m,R=10



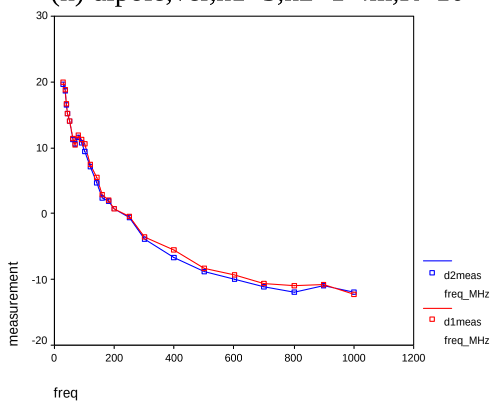
(f) dipole,hor,h1=3,h2=1-4m,R=10



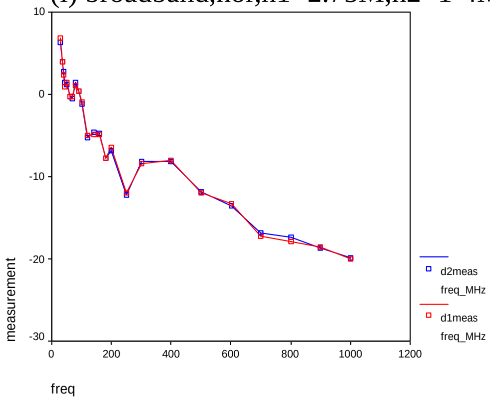
(g) dipole,ver,h1=2.75,h2=1-4m,R=10



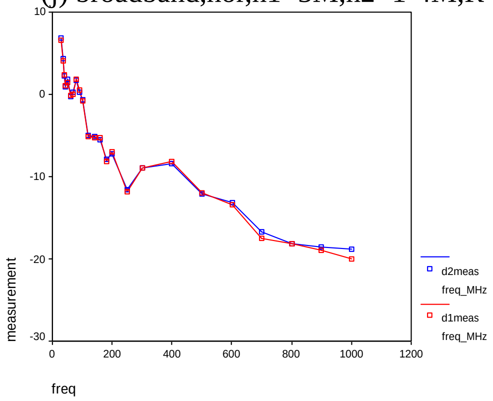
(h) dipole,ver,h1=3,h2=1-4m,R=10



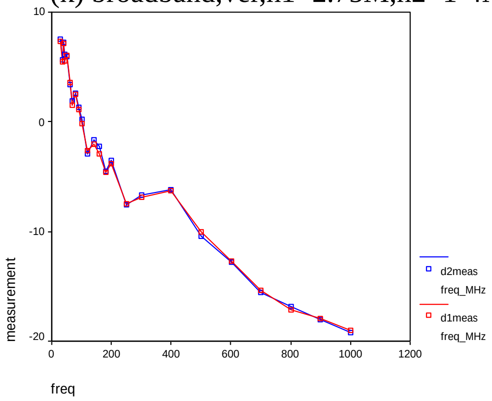
(i) broadband,hor,h1=2.75M,h2=1-4M,R=3



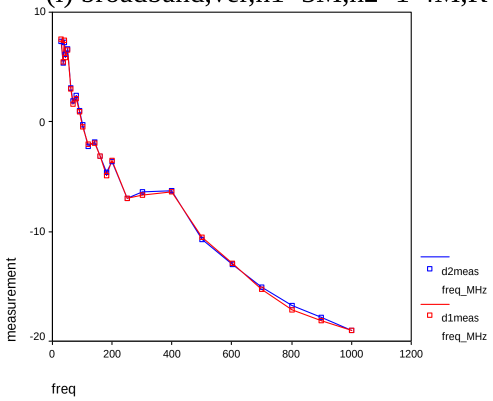
(j) broadband,hor,h1=3M,h2=1-4M,R=3



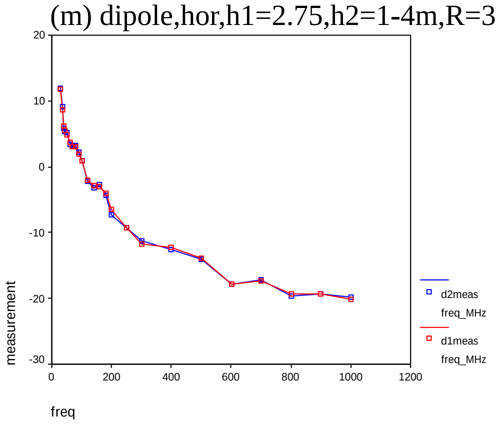
(k) broadband,ver,h1=2.75M,h2=1-4M,R=3



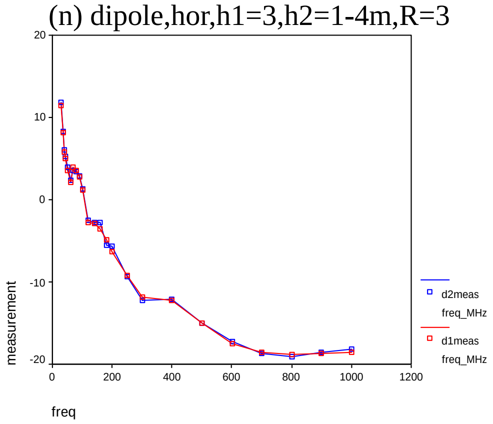
(l) broadband,ver,h1=3M,h2=1-4M,R=3



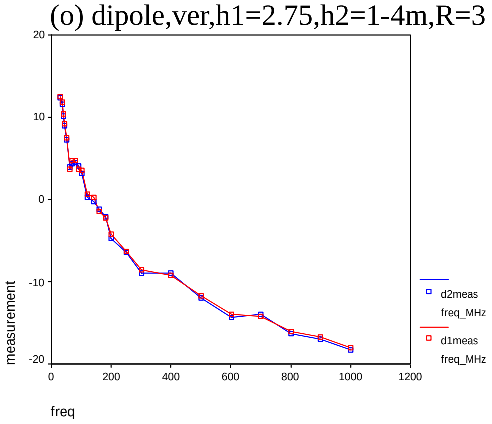
(m) dipole,hor,h1=2.75,h2=1-4m,R=3



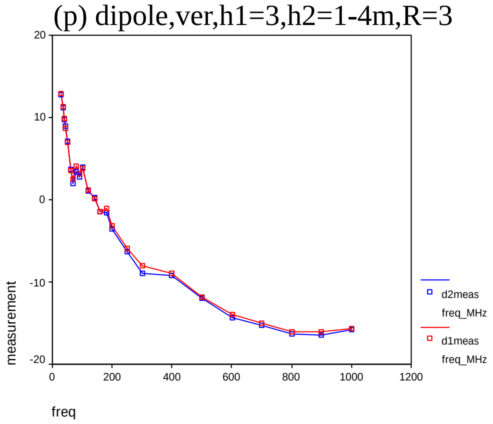
(n) dipole,hor,h1=3,h2=1-4m,R=3



(o) dipole,ver,h1=2.75,h2=1-4m,R=3

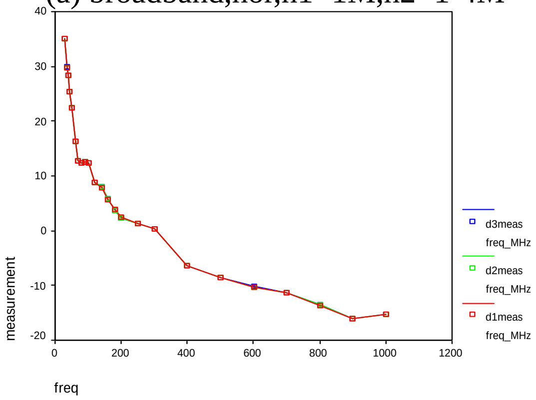


(p) dipole,ver,h1=3,h2=1-4m,R=3

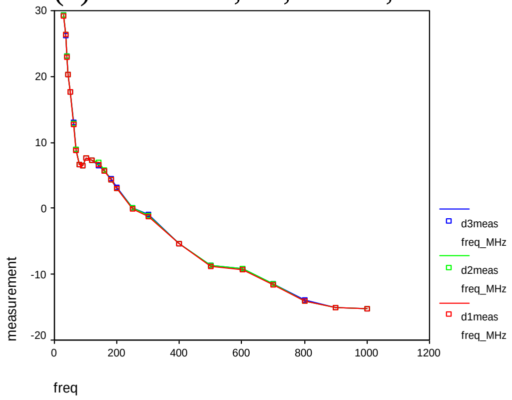


A-3 The scatter plots of measurements versus frequency for obs2004-1

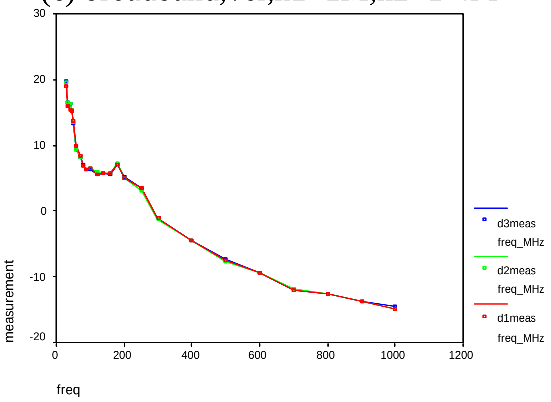
(a) broadband,hor,h1=1M,h2=1-4M



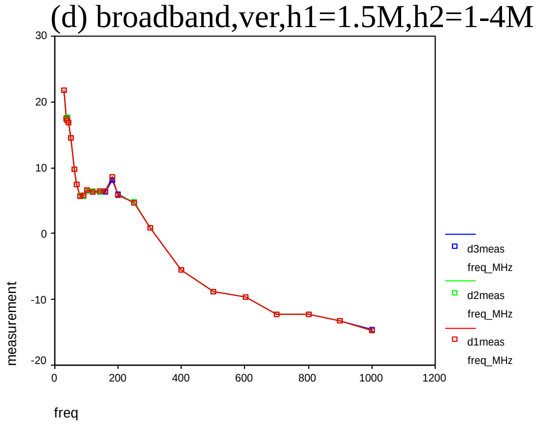
(b) broadband,hor,h1=2M,h2=1-4M



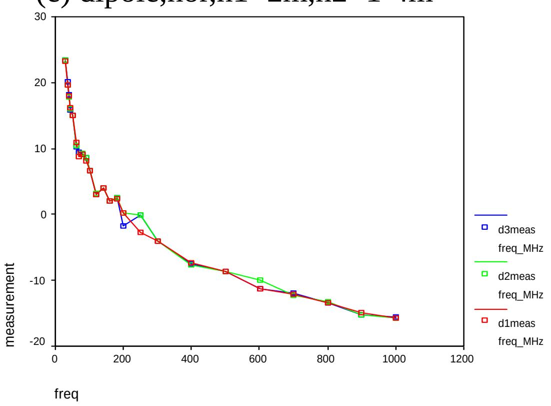
(c) broadband,ver,h1=1M,h2=1-4M



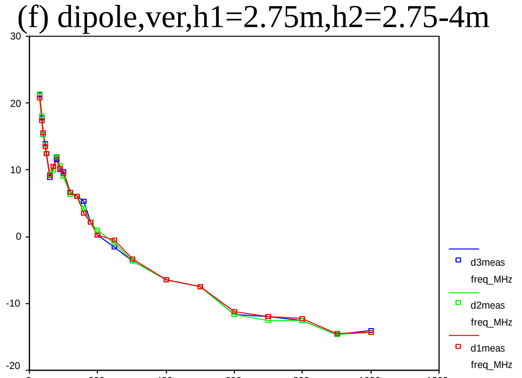
(d) broadband,ver,h1=1.5M,h2=1-4M



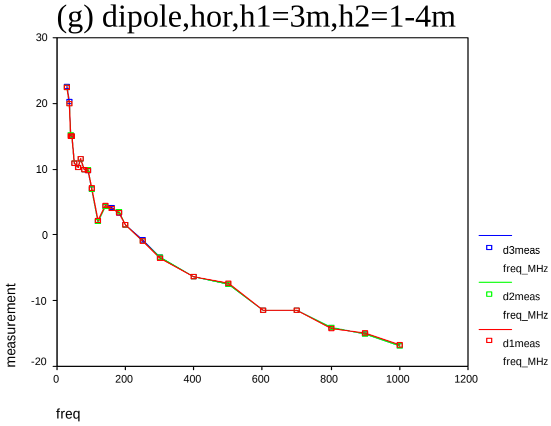
(e) dipole,hor,h1=2m,h2=1-4m



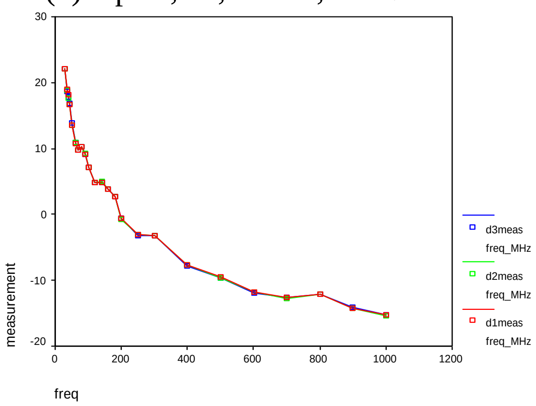
(f) dipole,ver,h1=2.75m,h2=2.75-4m



(g) dipole,hor,h1=3m,h2=1-4m

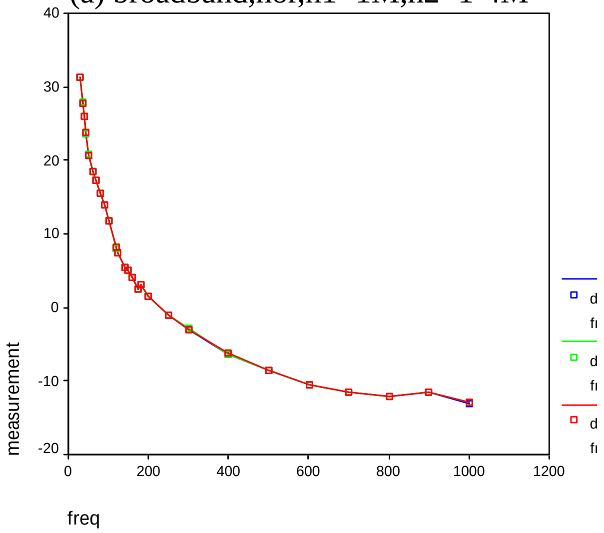


(h) dipole,ver,h1=3m,h2=2.75-4m

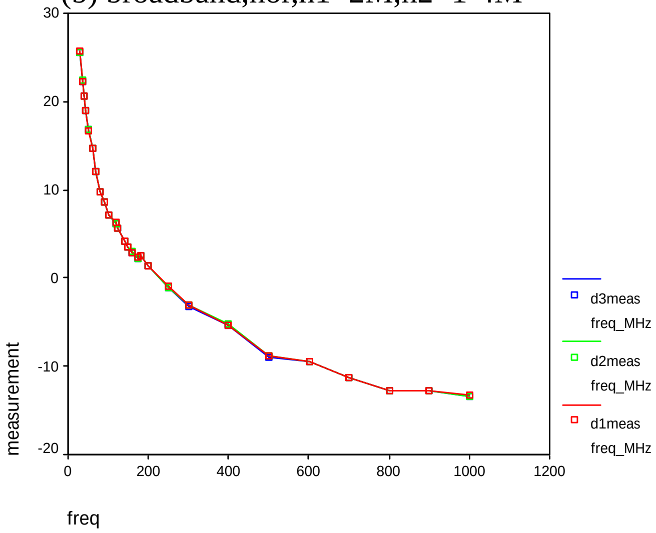


A-4 The scatter plots of measurements versus frequency for obs2004-2

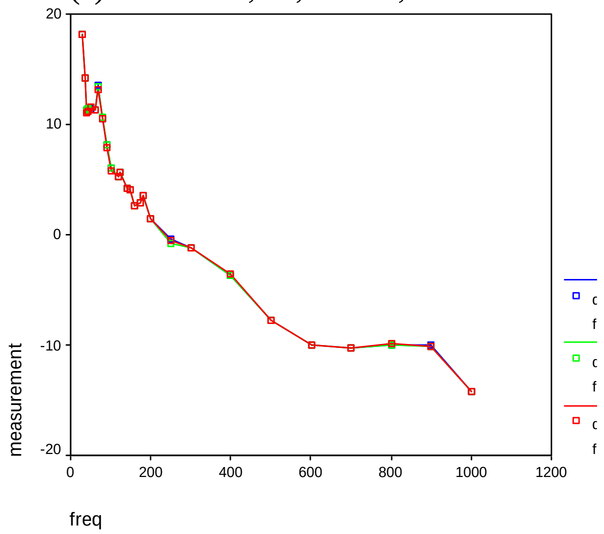
(a) broadband,hor,h1=1M,h2=1-4M



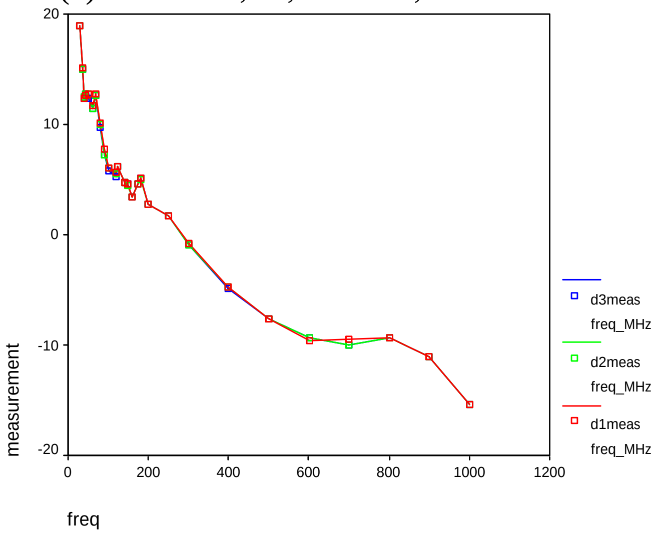
(b) broadband,hor,h1=2M,h2=1-4M



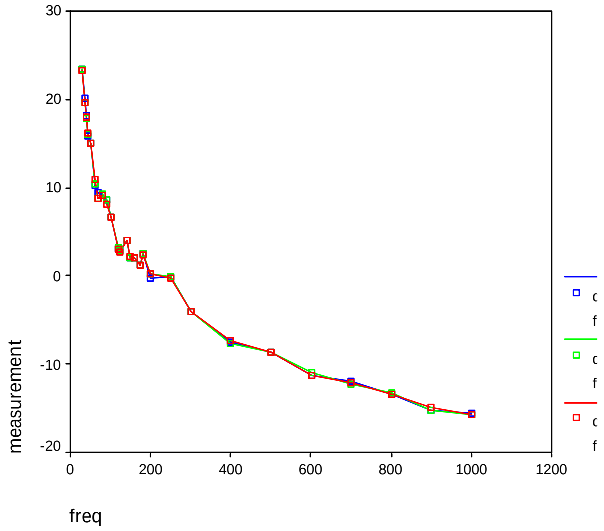
(c) broadband,ver,h1=1M,h2=1-4M



(d) broadband,ver,h1=1.5M,h2=1-4M



(e) dipole,hor,h1=2m,h2=1-4m



(f) dipole,ver,h1=2.75m,h2=2.75-4m

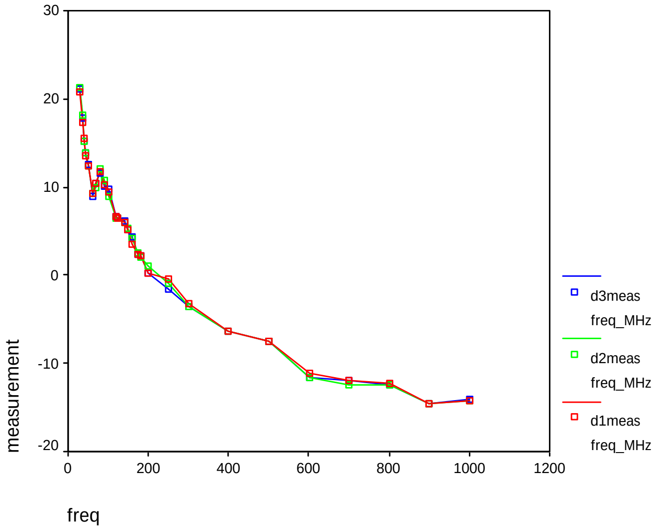
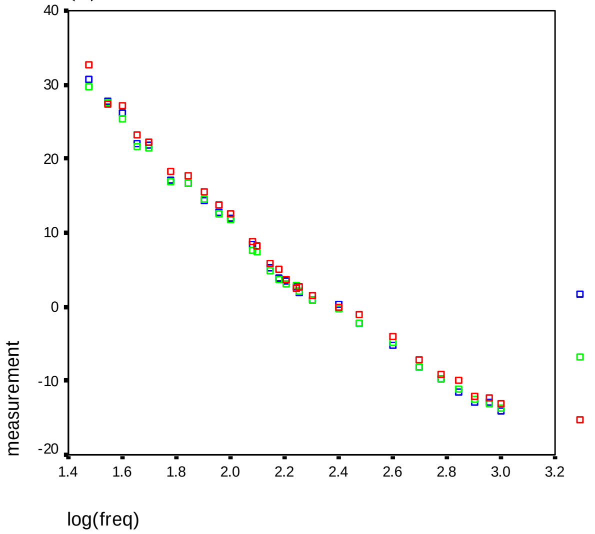


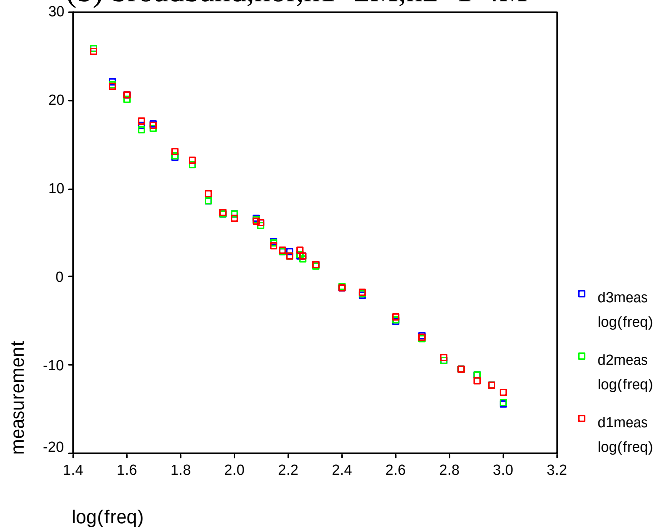
Figure B. The scatter plots of measurements versus log(frequency)

B-1 The scatter plots of measurements versus log(frequency) for obs2003-1

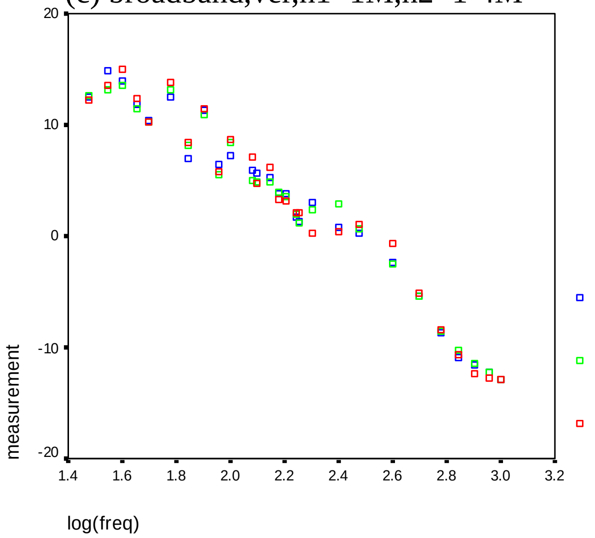
(a) broadband,hor,h1=1M,h2=1-4M



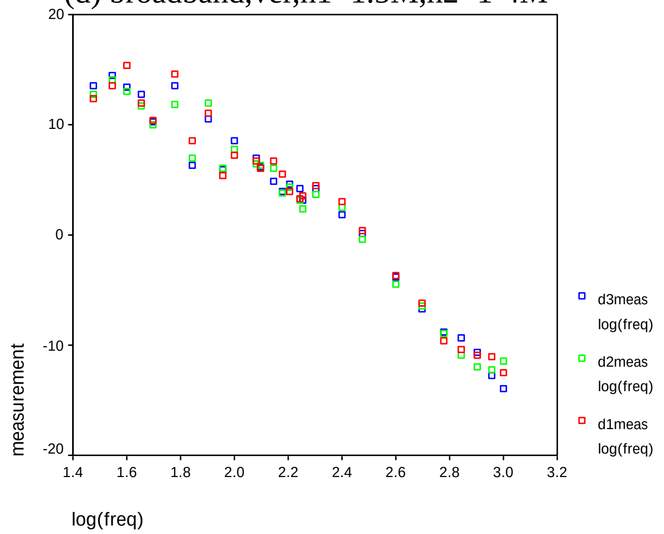
(b) broadband,hor,h1=2M,h2=1-4M



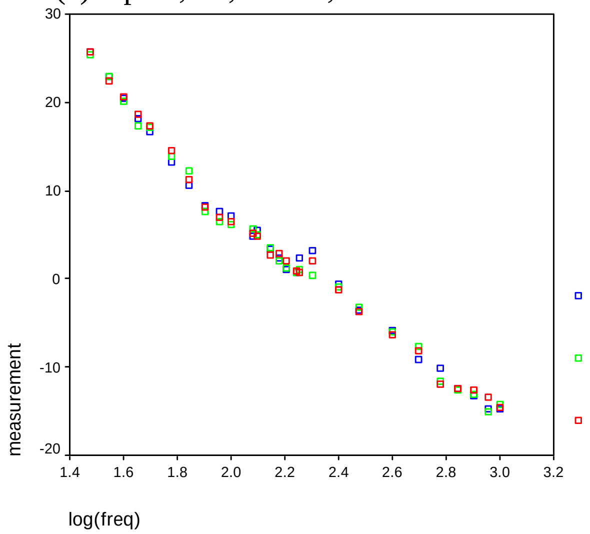
(c) broadband,ver,h1=1M,h2=1-4M



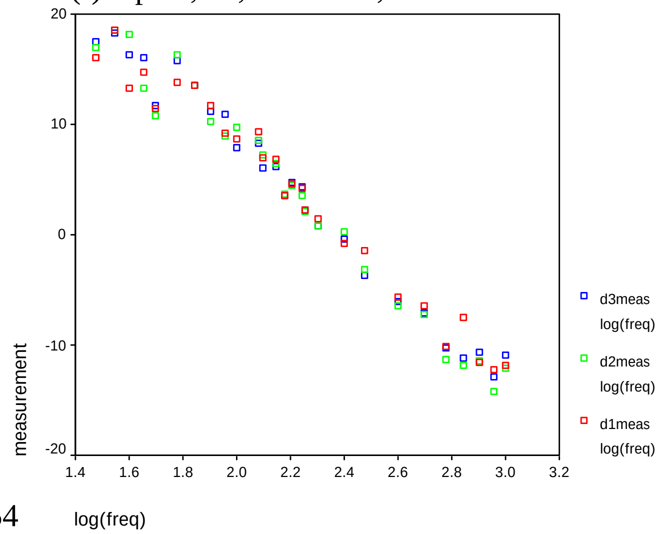
(d) broadband,ver,h1=1.5M,h2=1-4M



(e) dipole,hor,h1=2m,h2=1-4m

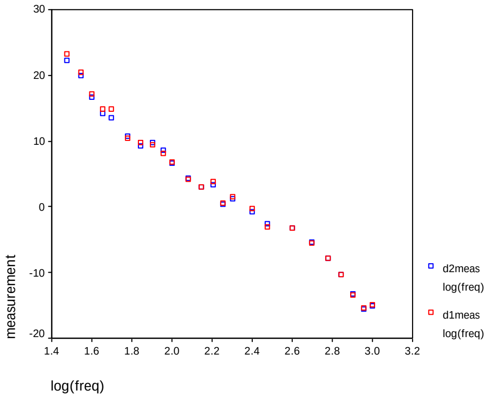


(f) dipole,ver,h1=2.75m,h2=2.75-4m

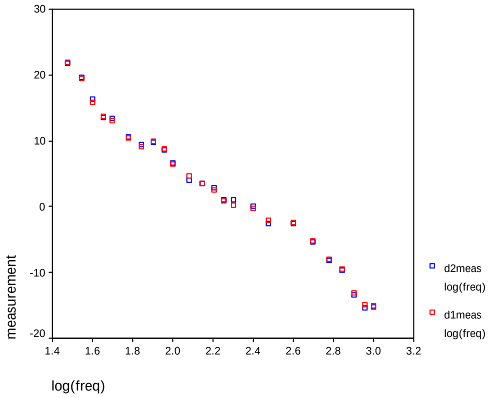


FigureB-2 The scatter plots of measurements versus log(frequency) for obs2003-2

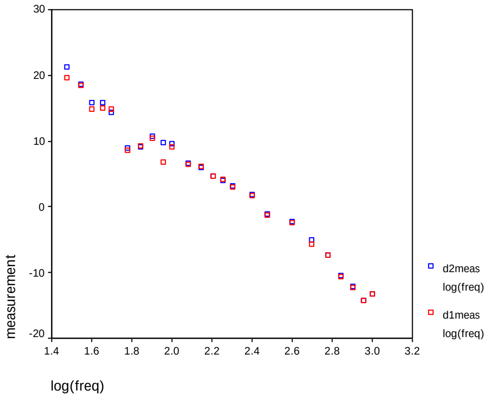
(a) broadband,hor,h1=2.75M,h2=1-4M,R=10



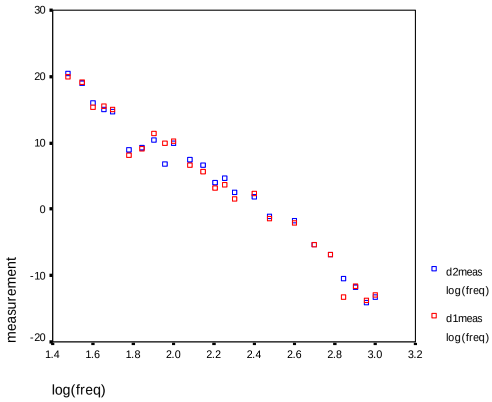
(b) broadband,hor,h1=3M,h2=1-4M,R=10



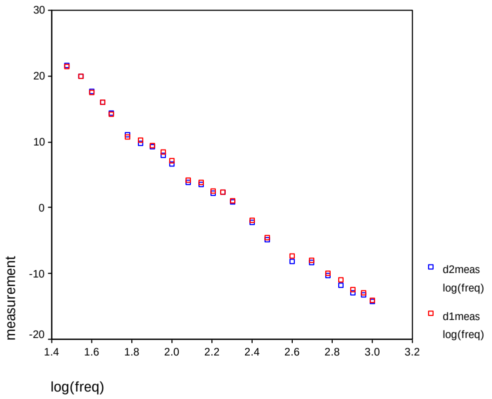
(c) broadband,ver,h1=2.75M,h2=1-4M,R=10



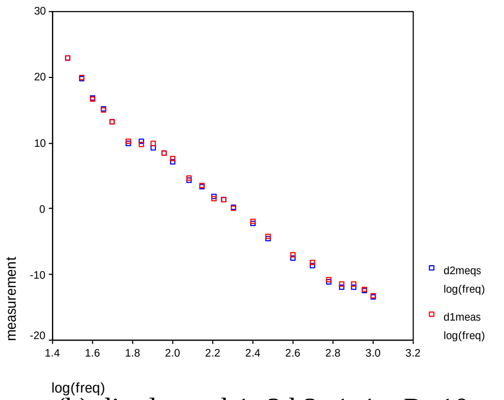
(d) broadband,ver,h1=3M,h2=1-4M,R=10



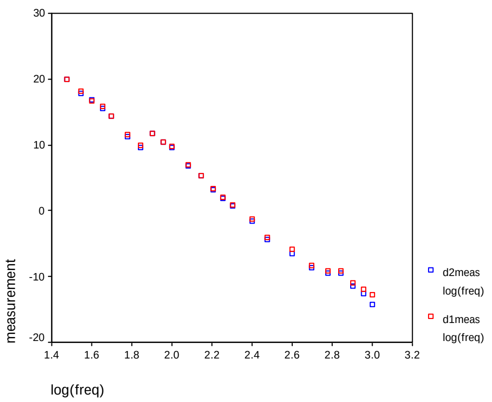
(e) dipole,hor,h1=2.75,h2=1-4m,R=10



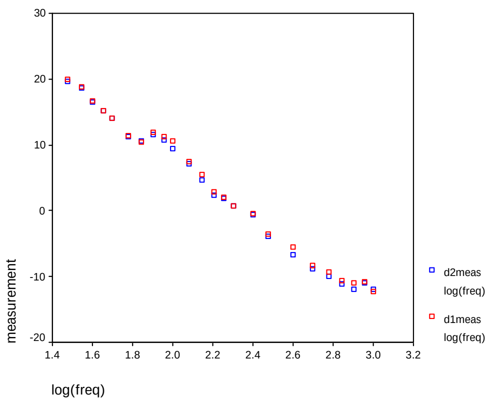
(f) dipole,hor,h1=3,h2=1-4m,R=10



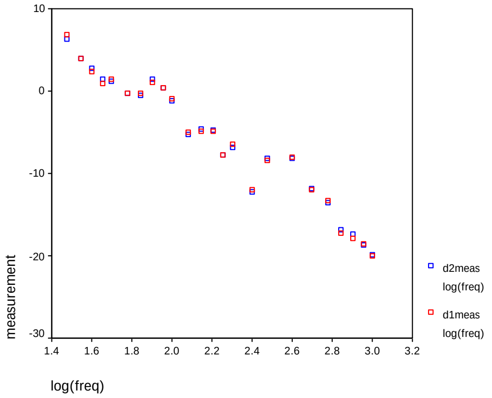
(g) dipole,ver,h1=2.75,h2=1-4m,R=10



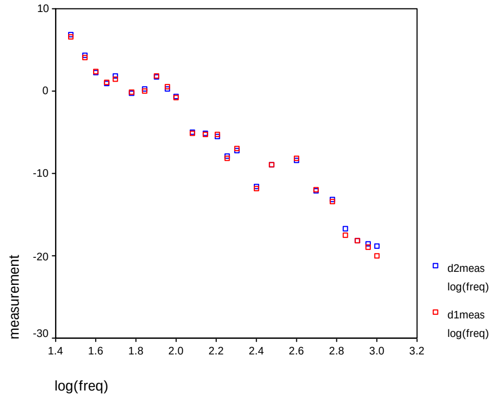
(h) dipole,ver,h1=3,h2=1-4m,R=10



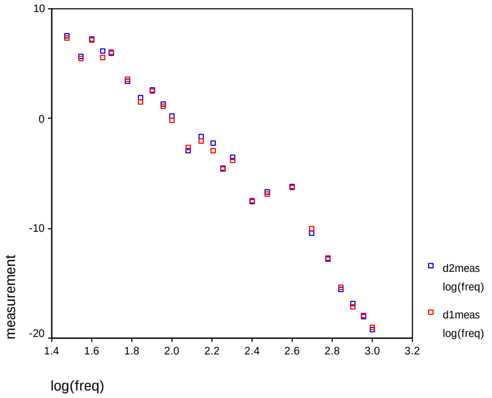
(i) broadband,hor,h1=2.75M,h2=1-4M,R=3



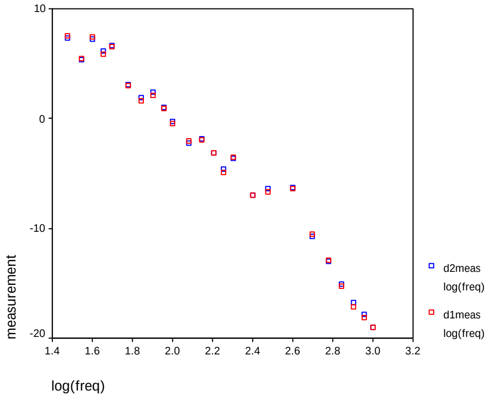
(j) broadband,hor,h1=3M,h2=1-4M,R=3



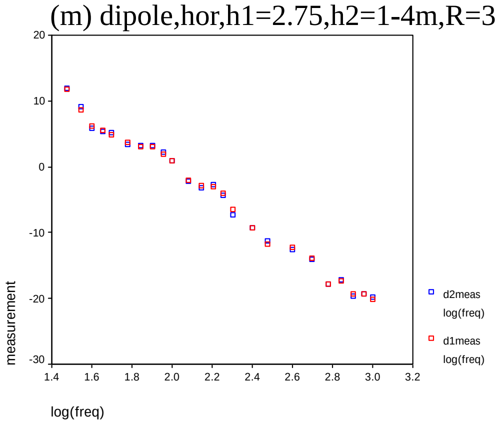
(k) broadband,ver,h1=2.75M,h2=1-4M,R=3



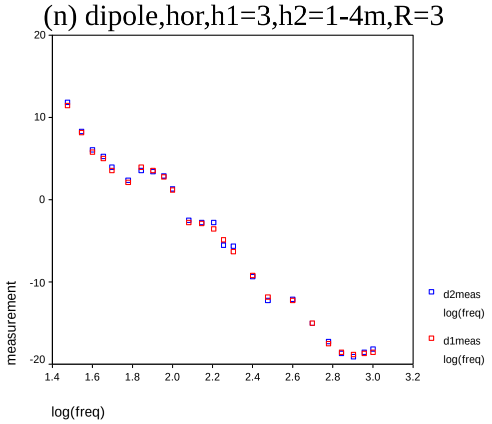
(l) broadband,ver,h1=3M,h2=1-4M,R=3



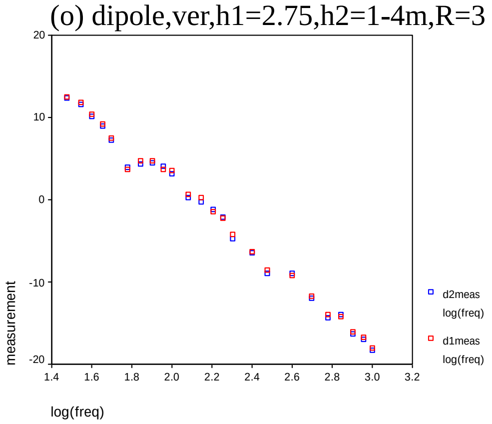
(m) dipole,hor,h1=2.75,h2=1-4m,R=3



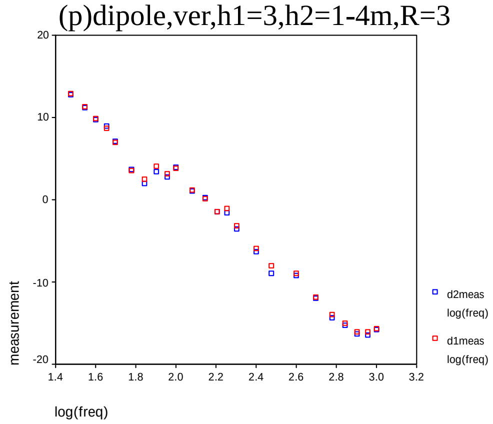
(n) dipole,hor,h1=3,h2=1-4m,R=3



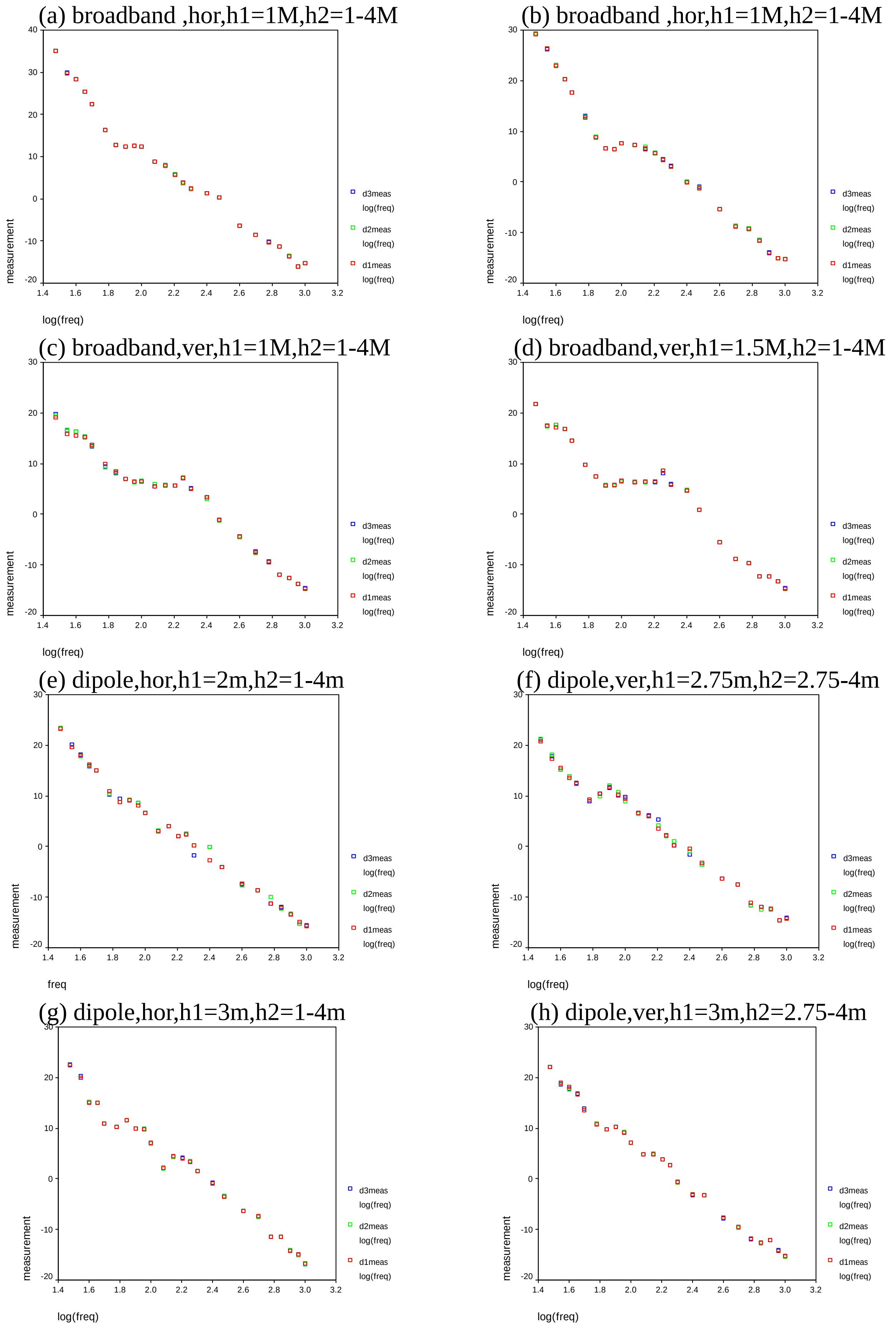
(o) dipole,ver,h1=2.75,h2=1-4m,R=3



(p)dipole,ver,h1=3,h2=1-4m,R=3

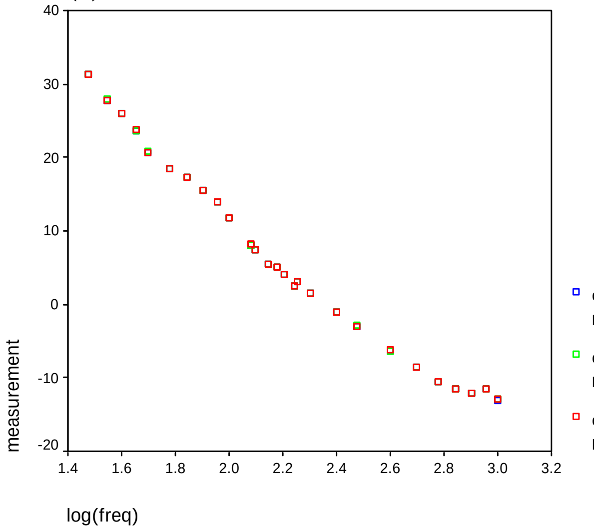


FigureB-3 The scatter plots of measurements versus log(frequency) for obs2004-1

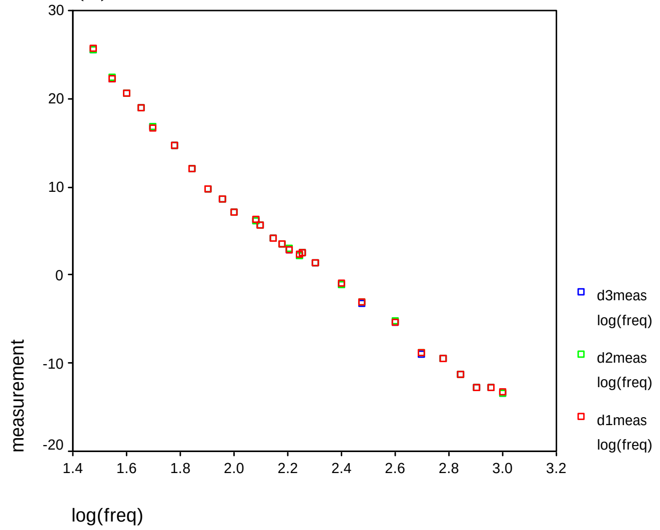


FigureB-4 The scatter plots of measurements versus frequency for obs2004-2

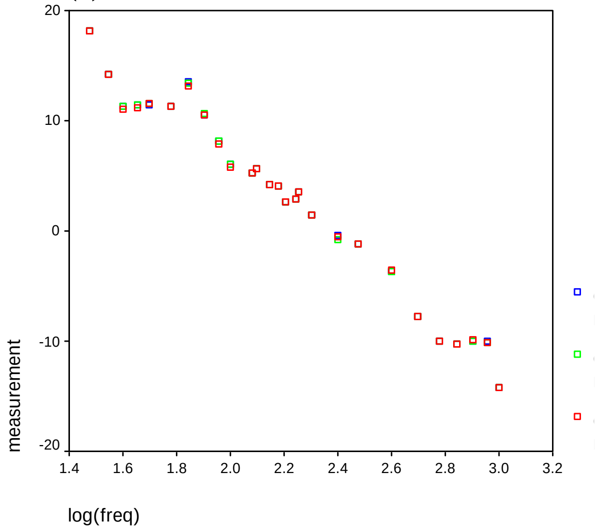
(a)broadband,hor,h1=1M,h2=1-4M



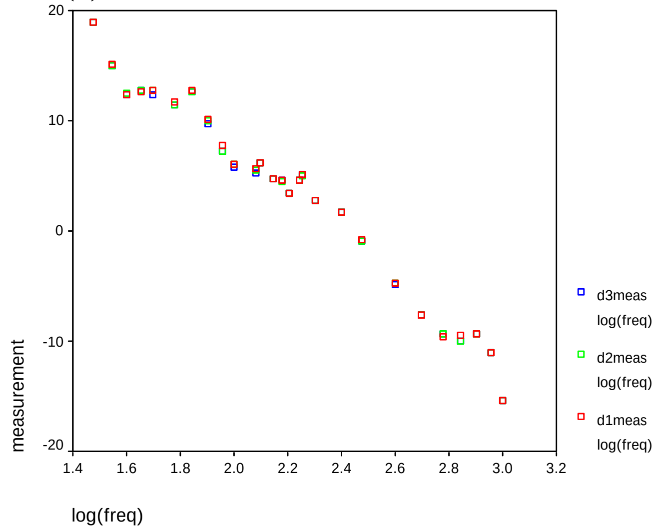
(b) broadband,hor,h1=2M,h2=1-4M



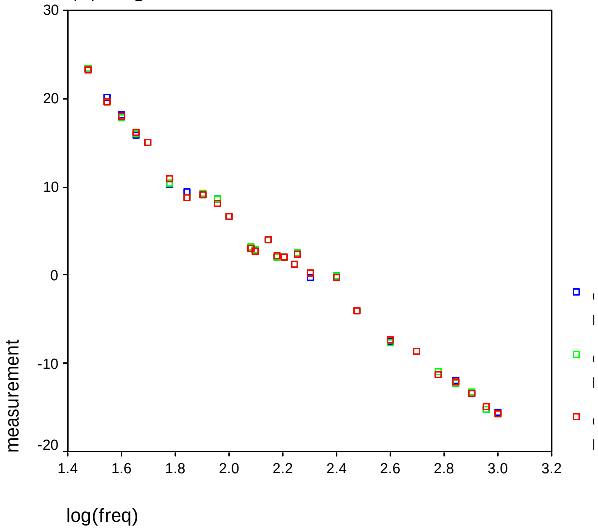
(c) broadband,ver,h1=1M,h2=1-4M



(d) broadband,ver,h1=1.5M,h2=1-4M



(e) dipole,hor,h1=2m,h2=1-4m



(f) dipole,ver,h1=2.75m,h2=2.75-4m

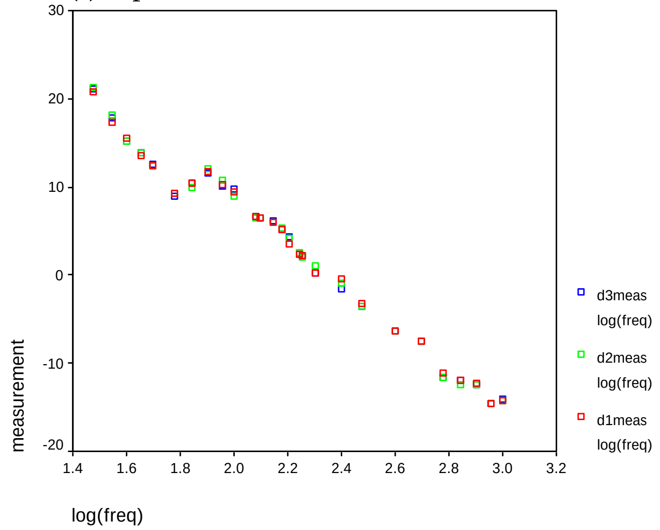


Table VII The decomposition of the difference between ideal values and observations

	setup	$\sum(obs-ideal)^2$	$\sum(obs-\overline{Y})^2$	$\sum(\overline{Y}-\hat{Y}_{obs})^2$	$\sum(\hat{Y}_{obs}-ideal)^2$	*others*
bb, hor h1=1 h2=1-4	obs2003-1	**109.82**	**20.353**	**31.842**	**56.217**	**1.407**
	obs2004-2	**111.77**	**0.0667**	**45.615**	**78.746**	**-12.656**
bb, hor h1=2 h2=1-4	obs2003-1	**72.95**	**4.067**	**31.622**	**36.597**	**0.664**
	obs2004-2	**70.412**	**0.12**	**13.935**	**55.530**	**0.827**
bb, ver h1=1 h2=1-4	obs2003-1	**233.08**	**22.607**	**125.517**	**88.464**	**-3.507**
	obs2004-2	**172.593**	**0.3067**	**134.403**	**52.298**	**-14.416**
bb, ver h1=1.5 h2=1-4	obs2003-1	**236.58**	**27.68**	**110.693**	**100.884**	**-2.677**
	obs2004-2	**140.483**	**0.74**	**119.903**	**33.447**	**-13.607**
dp, hor h1=2 h2=1-4	obs2003-1	**97.67**	**17.687**	**28.837**	**46.261**	**4.885**
	obs2004-2	**157.96**	**1.3267**	**54.278**	**90.153**	**12.202**
dp, ver h1=2.75 h2=2.75 -4	obs2003-1	**175.48**	**47.173**	**110.909**	**33.830**	**-16.432**
	obs2004-2	**192.73**	**3.2933**	**115.53**	**88.141**	**-14.264**