# Chapter 4

# Rescuing the Separation approach: Oettinger's extension

In this chapter a processing method is described and evaluated, which is based on Larsen's program and which is supposed to solve the problems of that approach mentioned in section 3.2.2. It has been published in Oettinger et al. [2001]. Again, I have reprogrammed this method in a non-robust way. It has been tested and it could be stated that it with synthetic data satisfies the expectation that it removes the biasing influence of noisy remote data on the SNS results without leaving a trace. However, these experiments are not documented here, I'm going to measured data immediately. My demonstrative station is DAM at the SW end of the profile with Belsk and WIA as references (see fig. 1). In the following sections, this special method is motivated once more, its single steps are introduced, and its results evaluated.

## 4.1 A remote reference approach stabilizes the Separation tensor

As described in section 3.2.2, uncorrelated noise in the remote records leads to a typical bias in the Separation tensor (fig. 3.7), which causes incomplete Separation (equation 3.3) and results, in general, in bad MT impedances (fig. 3.8) and biased CN transfer functions (3.9). The quoted examples were synthetic data, but the situation is analog with measured ones:

Fig. 4.1 shows the Separation tensor of station DAM with Belsk as reference. The

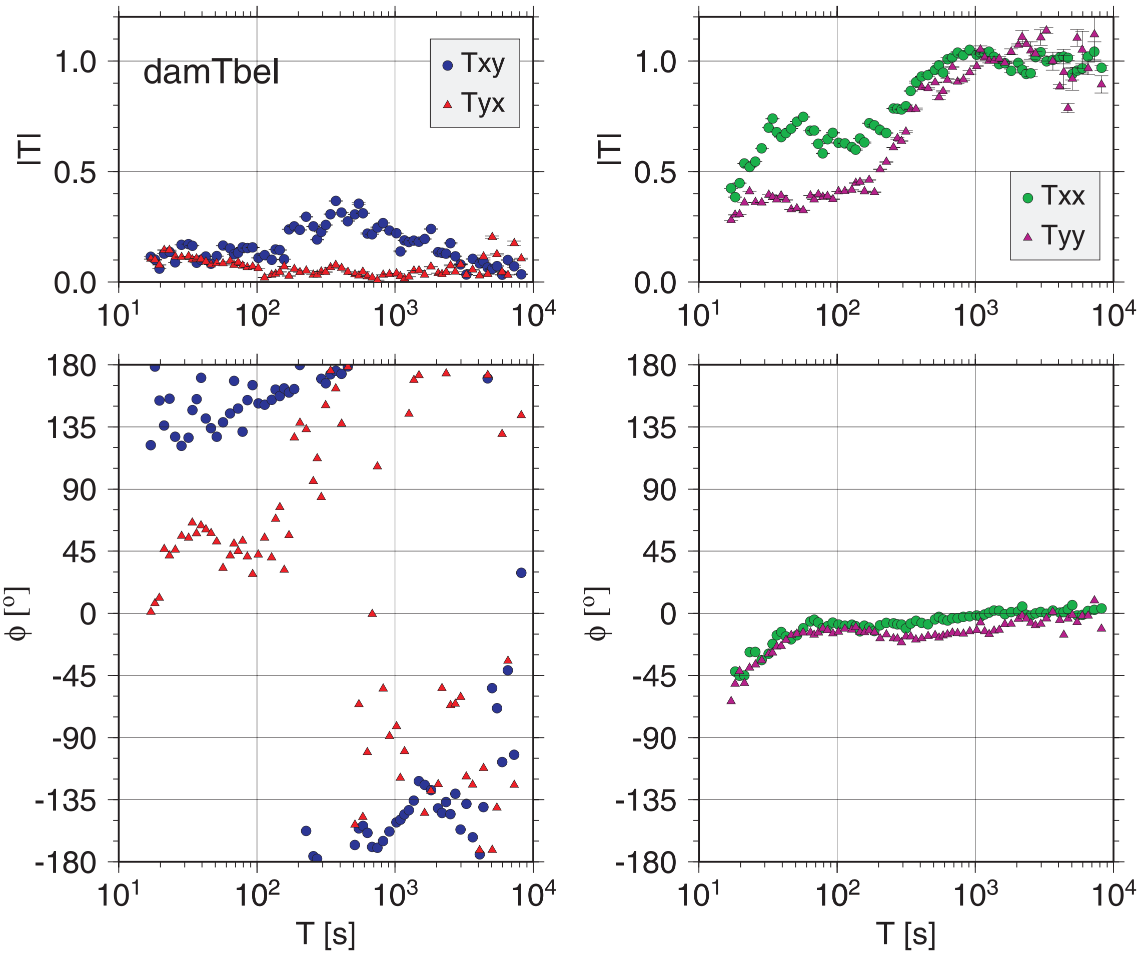


**Figure 4.1:** The tensor separating DAM by means of Belsk (fig. 1) has a huge downwards bias in $T_{xx}$ and $T_{yy}$ due to uncorrelated noise in Belsk.

dropping bias is strong. Unfortunately, even observatories are not free from noise, in this case the nearest DC railway is suited in a distance of only 15 km. Especially when magnetic activity is low, the consequences are as unpleasant as shown. Fortunately, the distance to DAM is 450 km, so a correlation of noise is highly improbable. The MT impedances are unbiased (fig. 4.2) and for most periods equal to the RR result (fig. 4.3) with some evident outliers. The latter appear at periods where the matrix inversion within the least-square solution was numerically relatively inaccurate. It is not astonishing that this happens if we take into account that the $4 \times 4$ matrix can be rather ill-conditioned, e.g. if $\mathbf{B^{CU}}$ is much smaller than $\mathbf{B^{MT}}$ (cf. equ. 3.19). Accordingly, the corresponding CN curves (fig. 4.4) indicate by their untypical phases at short periods, that the Separation is at least incomplete, if not failed, although $\rho_a$ possesses partly the expected CN features. Yet more explicitely than in the example of fig. 3.9, a part of the MT signal remained in the $\mathbf{B^{CU}}$ channels due to a too small Separation tensor (see equation 3.3).

So, if the bias in the Separation tensor leads to such problems in $\mathbf{Z^{MT}}$ and $\mathbf{Z^{CN}}$, something has to be done against that bias. Under such assumptions, the following steps have been proposed (Oettinger et al. [2001]):
There is required a second remote site with all properties described in section 2.3. It provides us with horizontal magnetic data of the shape

$$\mathbf{B^{R2}} = \begin{pmatrix} B^{R2}_{x1} & B^{R2}_{y1} \\ B^{R2}_{x2} & B^{R2}_{y2} \\ \vdots & \vdots \\ B^{R2}_{xN} & B^{R2}_{yN} \end{pmatrix}. \tag{4.1}$$

Then the Remote Reference approach for impedances (equation 2.9) is adapted very simply. This leads in the given case to the RR solution of the Separation tensor

$$\left(\mathbf{T^{RR}}\right)^T = \left(\mathbf{B^{R2}}^\dagger \mathbf{B^{R}}\right)^{-1} \mathbf{B^{R2}}^\dagger \mathbf{B}. \tag{4.2}$$

In contrast to the usual solution for $\mathbf{T}$ (eq. 2.5), this one avoids auto spectra and thereby a bias due to uncorrelated noise in $\mathbf{B^R}$. However, like there it holds that the variances of both transfer functions ($\mathbf{B^{R2}} \leftrightarrow \mathbf{B^R}$ and $\mathbf{B^{R2}} \leftrightarrow \mathbf{B}$) add and the result will be less smooth than $\mathbf{T}$ with one reference. That price has to be paid for the unbiased result. Obviously one needs even more data in order to correlate three

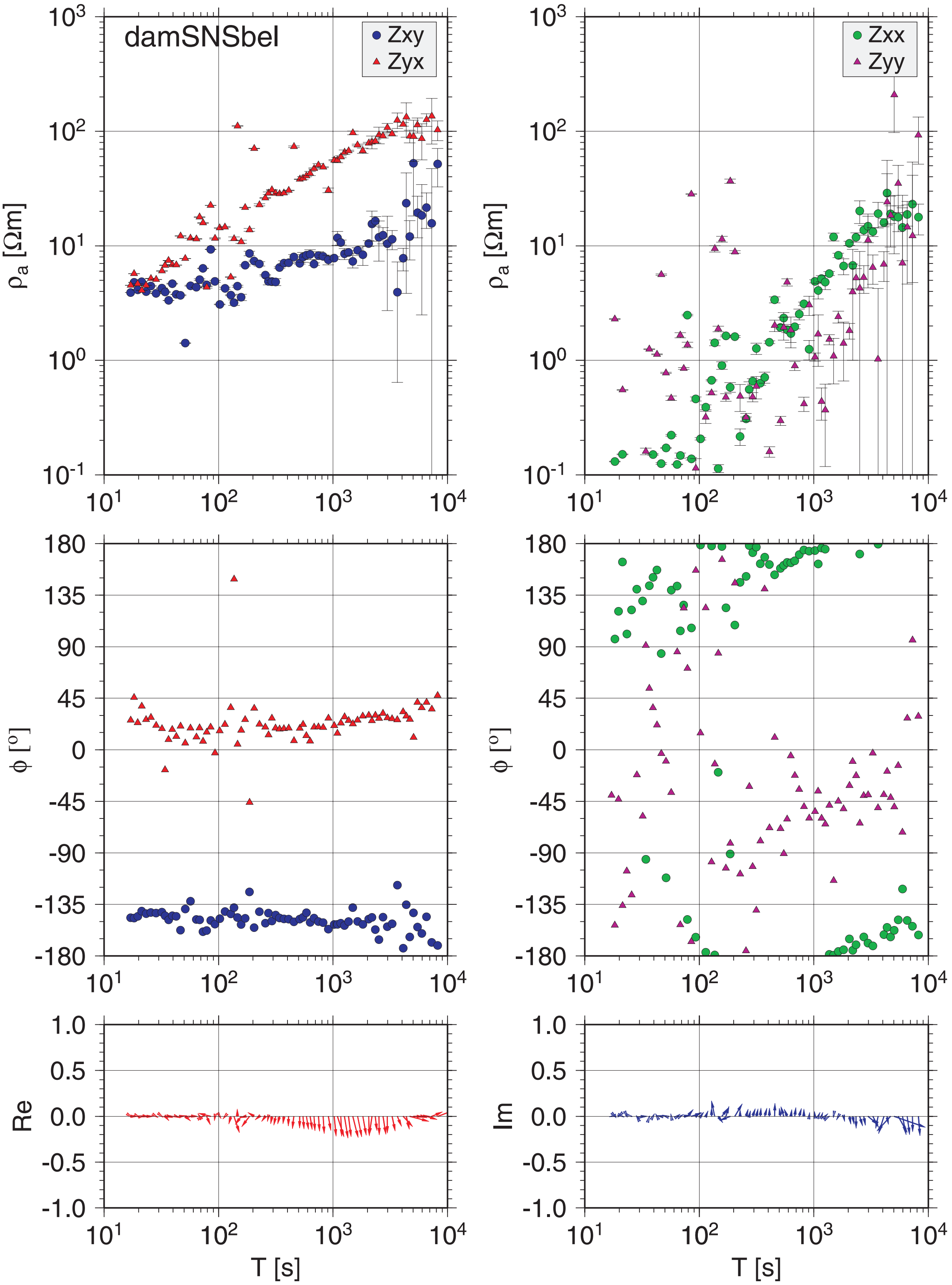


**Figure 4.2:** Magnetotelluric transfer functions for station DAM with Belsk as reference obtained with the SNS method. The formal equality with the RR result (fig. **??**) postulated by Egbert (s. section 3.2.2) is broken by a number of outliers which can be explained by numerical problems during the inversion of an ill-conditioned $4 \times 4$ matrix.

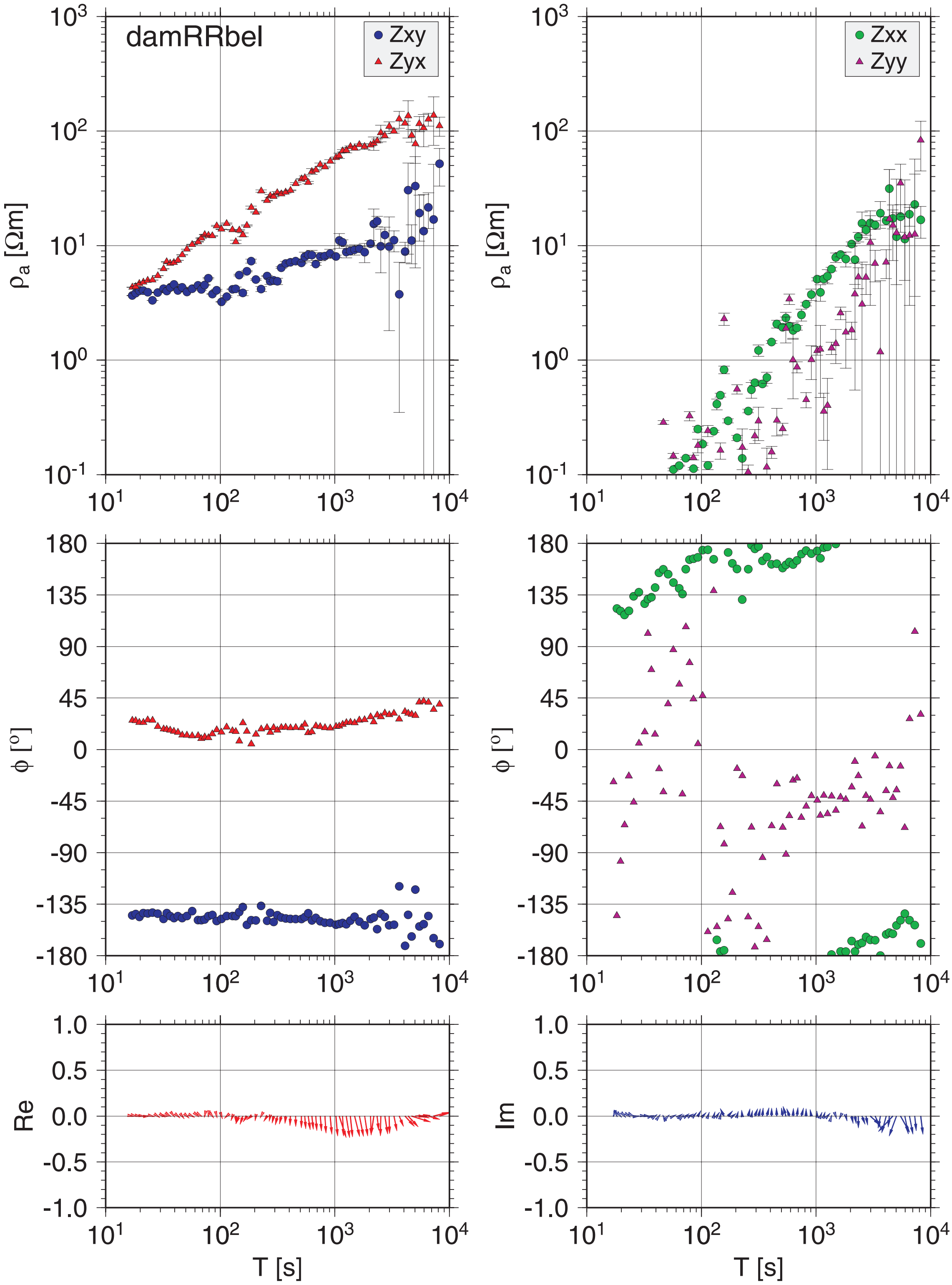


**Figure 4.3:** The RR results for station DAM with Belsk as reference. With the RR method only a $2 \times 2$ matrix, which is by its nature rather well-conditioned, is inverted. Therefore the curves behave much smoother than those obtained by the SNS method in fig. 4.2.

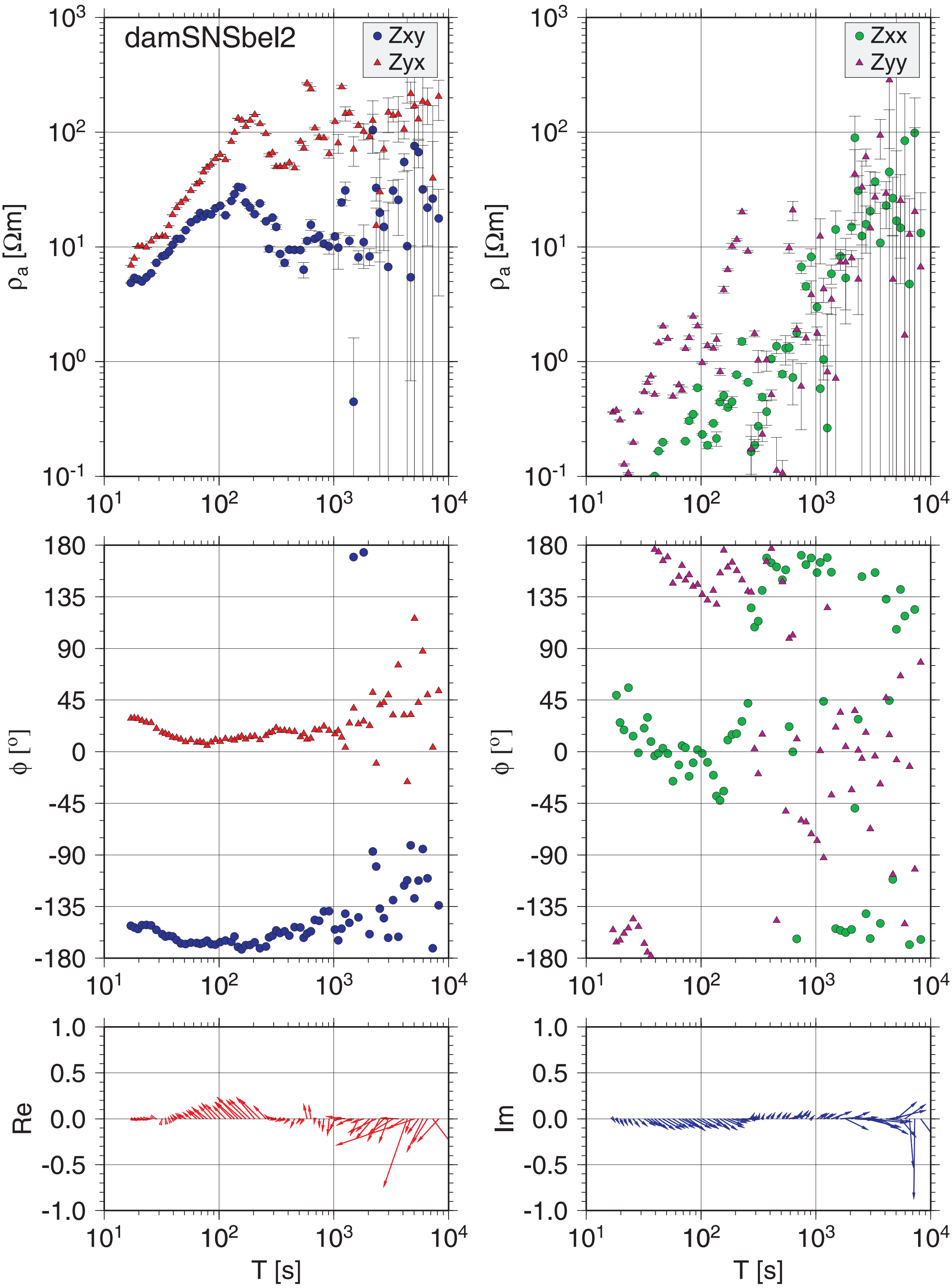


**Figure 4.4:** CN transfer functions by the SNS method. A glance at short period phases of $Z_{xy}$ and $Z_{yx}$ shows that the Separation is incomplete since they are far from zero degree.

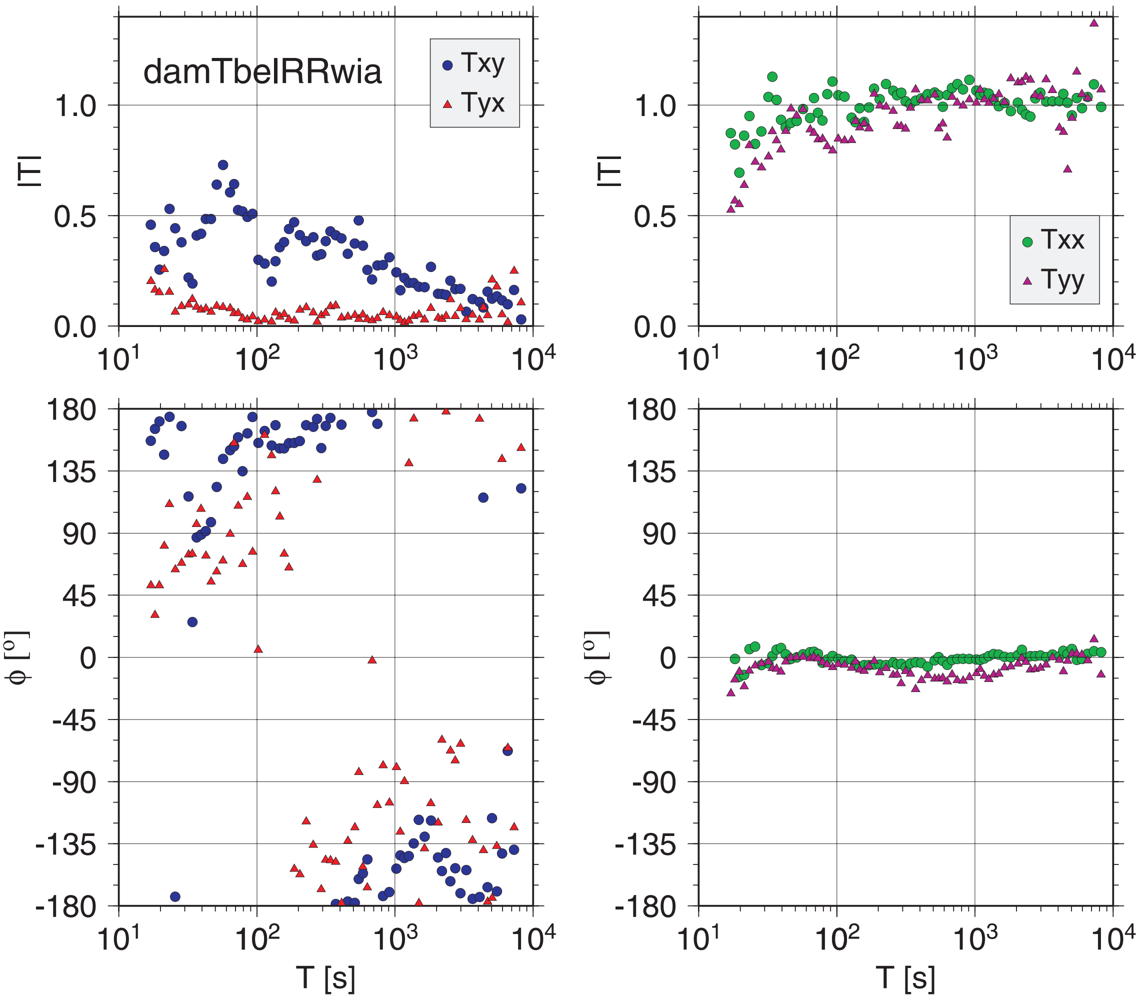


**Figure 4.5:** The Separation tensor as in fig. 4.1, but with WIA as second reference. The down-bias in $T_{xx}$ and $T_{yy}$ has vanished, but the general quality suffers from a significant scattering.

stations than to correlate two if stable transfer functions between them are required. Fig. 4.5 demonstrates the result of that calculation for our example with WIA as second reference. The bias is corrected, but unfortunately, the curves scatter significantly.

The idea to repair the Separation tensor with a second remote site is an important progress, even independently of whether it guarantees the Signal-Noise Separation better results or not. Here **T** is just an auxiliary means, but it can be regarded as stand-alone result, too. There can be derived from it Perturbation vectors (Schmucker [1970]) which do a good job visualizing anomalous current systems in the subsurface, and they can even be used as input for the inversion of a conductivity model, as already mentioned in section 3.1.1. Hence it is necessary to be able to

calculate it in a bias-free way.
Equation 4.2 has yet another interesting consequence: Since it, in principle, consists of the transfer functions $\mathbf{B^{R2}} \leftrightarrow \mathbf{B^{R}}$ and $\mathbf{B^{R2}} \leftrightarrow \mathbf{B}$, it is insensitive to noise that is correlated between $\mathbf{B}$ and $\mathbf{B^{R}}$. So it becomes possible to chose also stations as first references which would be absolutely inadequate for the original method. This can get some importance if one has to refer a whole network of stations to one particular site[1] although it contains noise correlated to that of other stations of this network. That's why this approach enabled an improvement of the results in fig. 2.11 with Belsk as second remote site (fig. 4.6). From this latter example it can nicely be seen that the stability of $\mathbf{T^{RR}}$ depends more on the data quality of local and first reference site than on that of the second one.

## 4.2 Supporting independency of input variables

Returning to the corrected Separation tensor of site DAM, the results of the Signal-Noise Separation carried out with it are shown in figs. 4.7 (MT) and 4.9 (CN). They are rather disappointing. The MT curves are hardly different from the single-site results in fig. 4.8, and the CN ones are not improved either when compared with fig. 4.4. Again, the Separation has failed, obviously in an even higher degree than with the biased $\mathbf{T}$.

The reason for it can be found quickly: The disturbances in the remote channels go into the resulting transfer functions not only via the biased Separation tensor, but also via the reconstruction of $\mathbf{B^{MT}}$ (equ. 3.2) and via the subtraction of the latter constituting $\mathbf{B^{CU}}$ (equ. 3.3). This means, if $\mathbf{B^{R}}$ contains significant disturbances $\delta\mathbf{B^{R}}$ and $\mathbf{T}$ is corrected for them, they go positively into $\mathbf{B^{MT}}$ and negatively into $\mathbf{B^{CU}}$ like

$$\mathbf{B^{MT}} = \mathbf{B^{MT}_{true}} + \delta\mathbf{B^{R}} \tag{4.3}$$

and

$$\mathbf{B^{CU}} = \mathbf{B^{CU}_{true}} - \delta\mathbf{B^{R}}. \tag{4.4}$$

It means also, that the bigger $\delta\mathbf{B^{R}}$ is (in terms of modulus), the more correlated will be $B^{MT}_{x,y}$ and $B^{CU}_{x,y}$, and the less unique becomes the solution for $\mathbb{Z}$. Insofar it must be stated, that the correction of $\mathbf{T}$ for bias via $\mathbf{B^{R2}}$ and the subsequent neglect of $\mathbf{B^{R2}}$ in the reconstruction of $\mathbf{B^{MT}}$ has a rather counterproductive effect on the processing

[1] If $\mathbf{T}$ is regarded as stand-alone transfer function, the reference has to be chosen according to its subsurface that must be horizontally layered, preferably. For background information, see the literature given above.

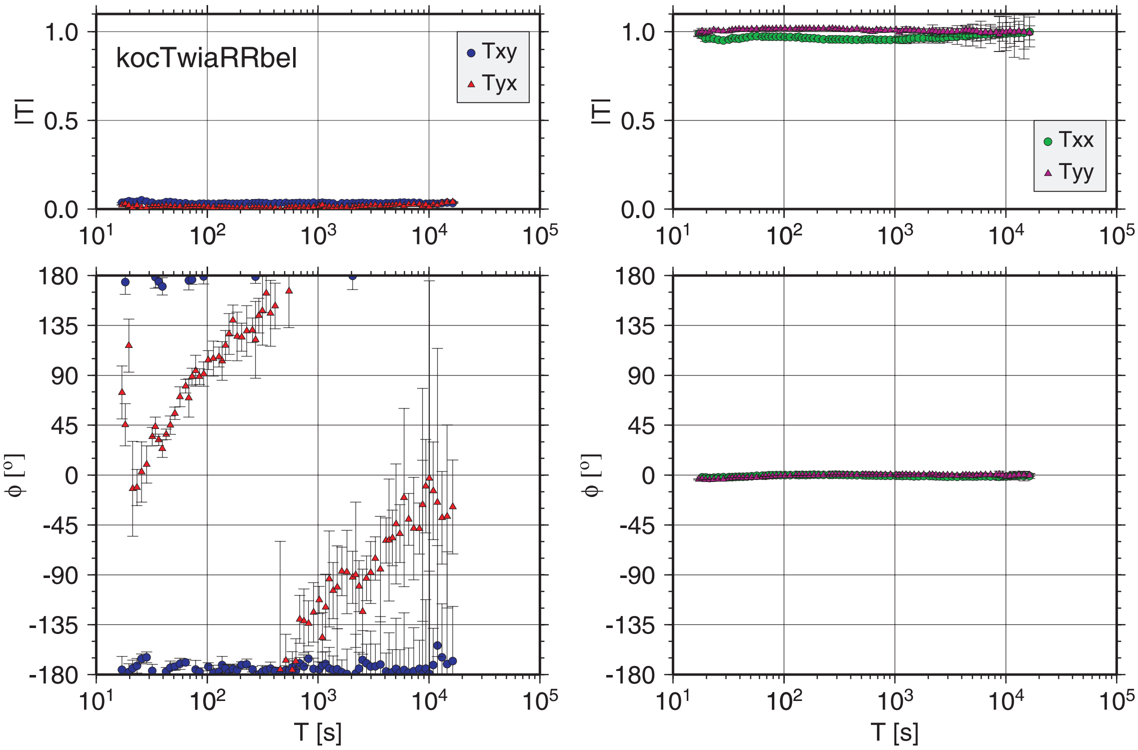


**Figure 4.6:** The horizontal magnetic tensor between sites KOC and WIA as it should be. In contrast to fig. 2.11, where it was affected by a dropping bias due to statistic noise in WIA and by a phase shift due to correlated noise between both locations, the tensor is undistorted and close to unity as it is supposed to be between near-by sites. This has been achieved by means of Belsk as a second remote site beyond the reach of the correlated noise emitted by the northernmost railway line in fig. 1.

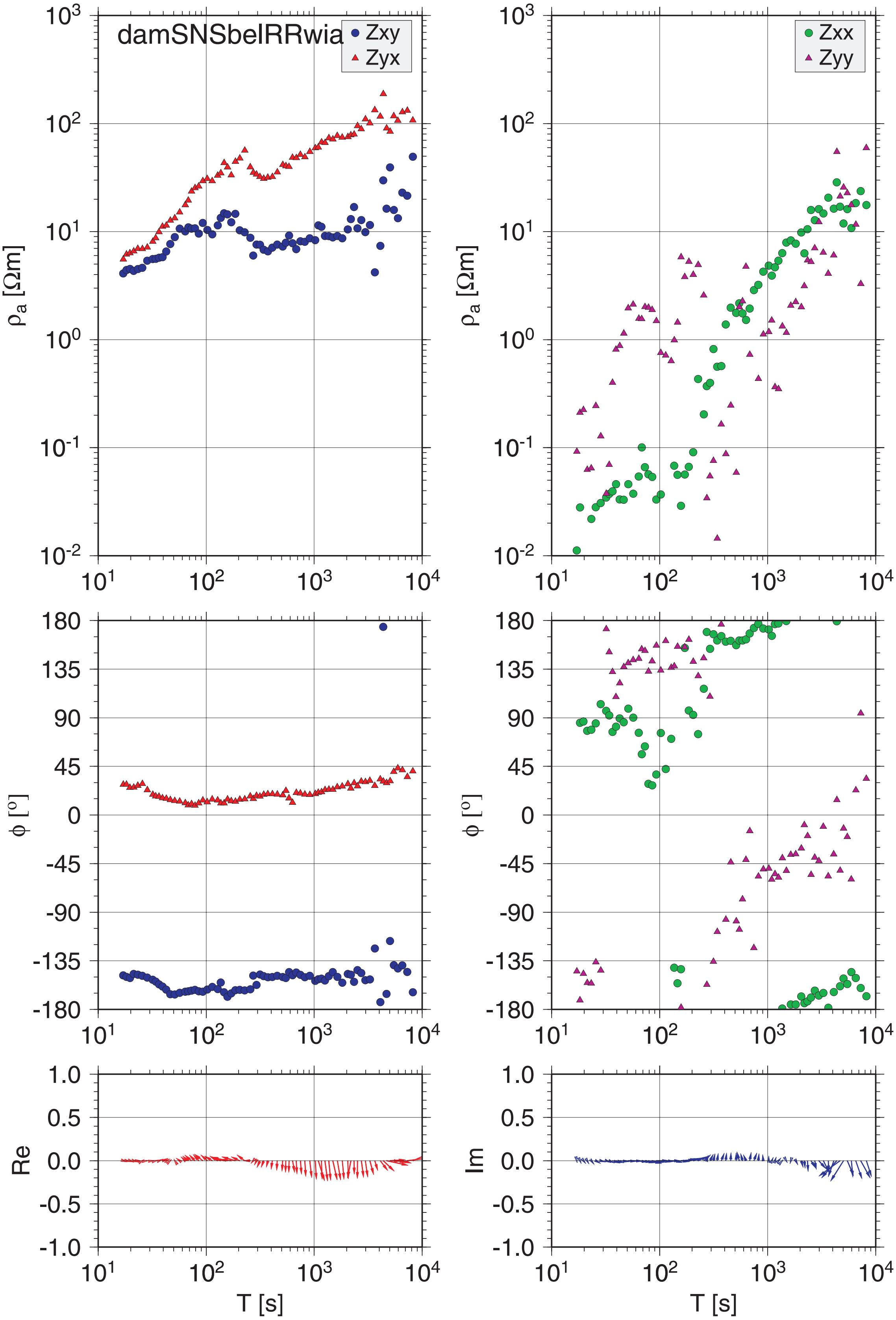


**Figure 4.7:** MT transfer functions obtained with the SNS with the stabilized **T** from fig. 4.7. Comparison with the single site result in fig. 4.8 shows, that there is hardly a difference. The Separation failed.

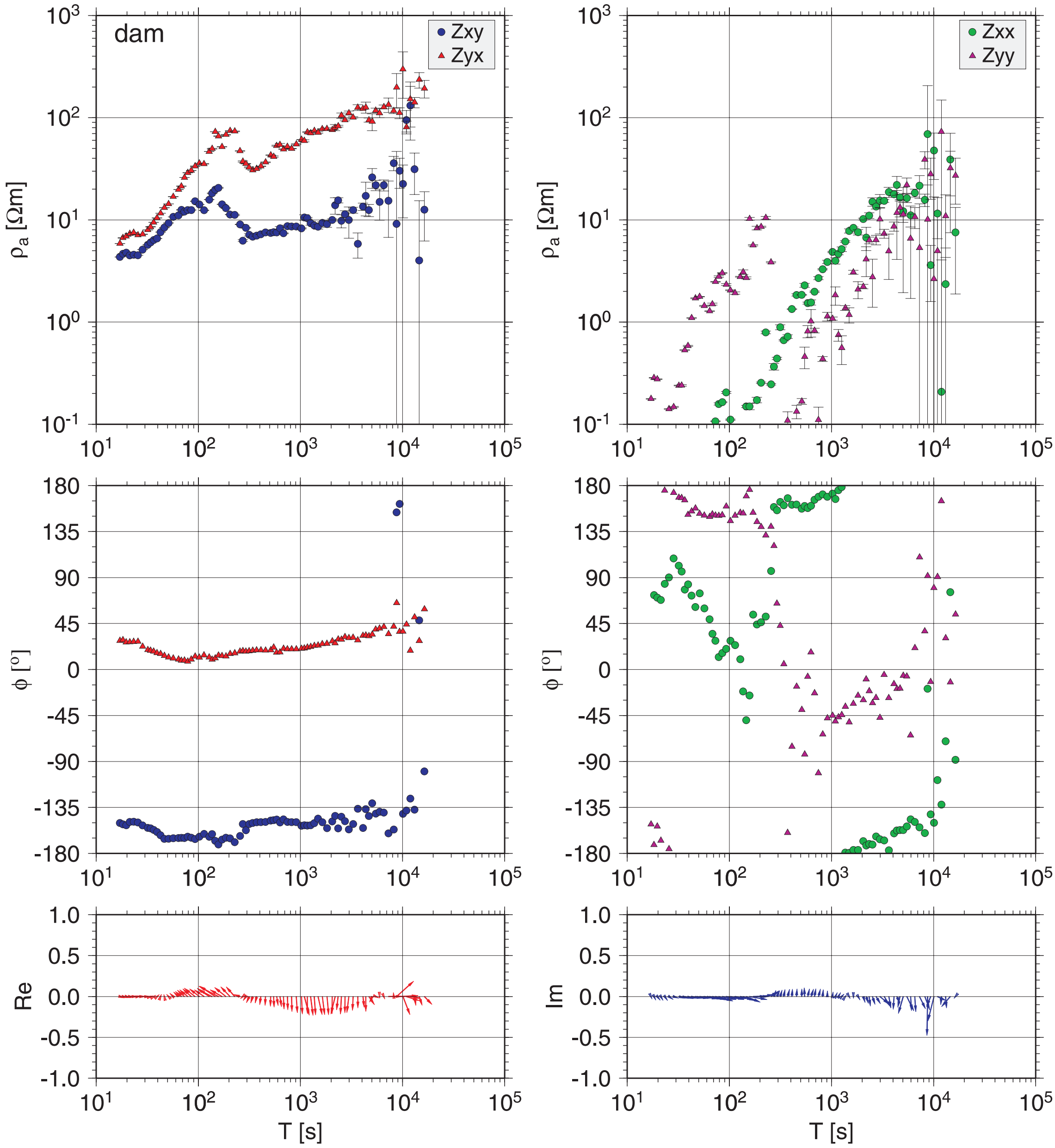


**Figure 4.8:** For comparison, the single site results of station DAM.

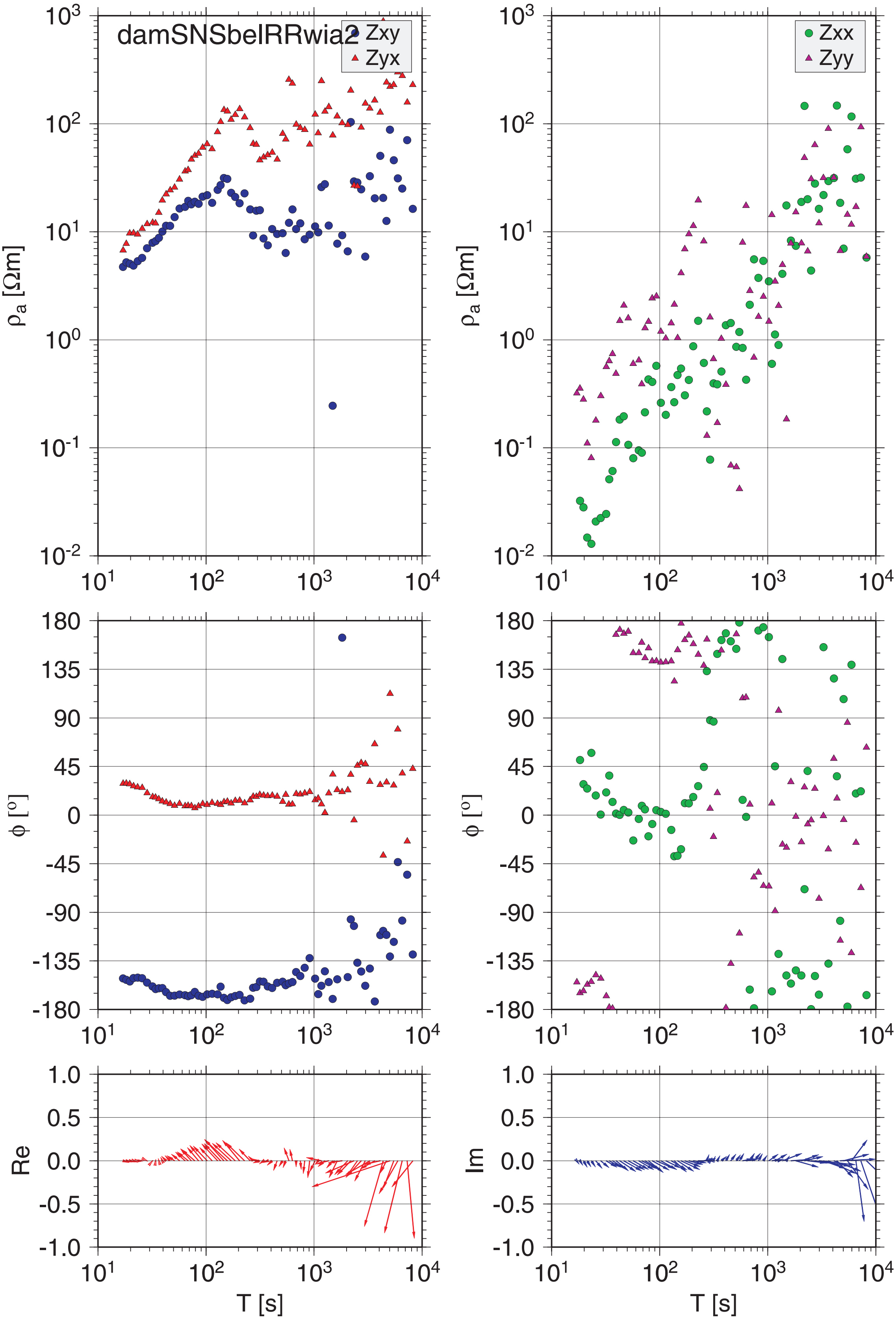


**Figure 4.9:** The CN transfer function obtained with the stabilized Separation tensor (fig. 4.5) don't show any improvement compared to those calculated with the biased **T** (fig. 4.4).

result. This is not unexpected from a mathematical point of view (pers. comm. K. Nowożyński) and must result in the statement, that Oettingers extension on this stage is not usable. Larsen's original method achieves by down-weighting of $\mathbf{T}$, that the remote noise hardly enters $\mathbf{B^{MT}}$, thus the correlation to $\mathbf{B^{CU}}$ is small and the Separation is possible at least so far, that there are reasonable differences to the single-site result. But this is not a tragedy. It seems to be a feature of the SNS method that its problems introduced by each single step can be compensated by a further step. Oettinger's extension has such a second stage. It consists of a twofold execution of the Separation each with a different unbiased Separation tensor. This second stage is labeled SNS(RR-RR), whereas the method described so far is called SNS(RR-LS) in the article (Oettinger et al. [2001]).

Strictly speaking, there are two possibilities to derive unbiased Separation tensors, if one has reference data of two remote sites $\mathbf{B^R}$ and $\mathbf{B^{R2}}$. Beside of that described by equation 4.2, one can estimate

$$\left(\mathbf{T^{R2}}\right)^T = \left(\mathbf{B^R}^\dagger \mathbf{B^{R2}}\right)^{-1} \mathbf{B^R}^\dagger \mathbf{B} \tag{4.5}$$

too, i.e. the transfer function between reference no. 2 and local site, corrected by reference no. 1. This offers in turn, two ways to separate:

$$\mathbf{B_I^{MT}} = \mathbf{B^R}\left(\mathbf{T^{RR}}\right)^T; \;\; \mathbf{B_I^{CU}} = \mathbf{B} - \mathbf{B_I^{MT}} \tag{4.6}$$

and

$$\mathbf{B_{II}^{MT}} = \mathbf{B^{R2}}\left(\mathbf{T^{R2}}\right)^T; \;\; \mathbf{B_{II}^{CU}} = \mathbf{B} - \mathbf{B_{II}^{MT}}. \tag{4.7}$$

Of course, both $\mathbf{B_I^{MT,CU}}$ and $\mathbf{B_{II}^{MT,CU}}$ are affected by errors as indicated by equations 4.3 and 4.4. But, since these errors have their origin in $\mathbf{B^R}$ on the one hand and in $\mathbf{B^{R2}}$ on the other hand, they are not correlated with each other. In contrast, the "true" values of $\mathbf{B_I^{MT,CU}}$ and $\mathbf{B_{II}^{MT,CU}}$ are equal. Hence, one can count on that the influence of those errors can be suppressed if there are, again, auto spectra substituted by cross spectra as follows:

We define analog to equation 3.11

$$\mathbb{B}_{\mathbb{I}} = \left( \mathbf{B_I^{MT}} \;\; \mathbf{B_I^{CU}} \right) \tag{4.8}$$

and

$$\mathbb{B}_{\mathbb{II}} = \left( \mathbf{B_{II}^{MT}} \;\; \mathbf{B_{II}^{CU}} \right). \tag{4.9}$$

Thereby, we substitute the auto spectra from Larsen's solution (equation 3.15) and obtain as first way to the SNS(RR-RR) solution

$$\mathbb{Z}_{\mathbb{I}}{}^T = \left(\mathbb{B}_{\mathbb{II}}{}^\dagger \mathbb{B}_{\mathbb{I}}\right)^{-1} \mathbb{B}_{\mathbb{II}}{}^\dagger \mathbb{E} \tag{4.10}$$

and

$$\mathbb{Z}_{\mathbb{III}}{}^{T} = \left(\mathbb{B}_{\mathbb{I}}{}^{\dagger}\mathbb{B}_{\mathbb{III}}\right)^{-1}\mathbb{B}_{\mathbb{I}}{}^{\dagger}\mathbb{E} \tag{4.11}$$

as second one.
Both solutions will be unbiased in $\mathbf{Z^{CN}}$, but more scattering in all components than the SNS result as always when the RR technique is applied (Oettinger et al. [2001]). $\mathbb{Z}_{\mathbb{I}}$ will be the preferable solution if already $\mathbf{T^{RR}}$ is determined better than $\mathbf{T^{R2}}$ (or, what is equivalent, if the RR result with the first remote site is better than with the second one), and *vice versa*.
I want to emphasize that the SNS(RR-RR) method does very successfully what it is supposed to do with synthetic data. I. e. it reduces problems arising from correlated input variables. There is an explicit measure for such problems. It can be found in the off-diagonal elements of the covariance matrix. It has already been mentioned in section 1.3.1 that the covariance matrix is the product of that matrix, which is inverted during the solution procedure, and the residual of the corresponding conditional equation, normalized by the number of degrees of freedom of this problem. I also mentioned that essentially, its diagonal elements are the variances of the solution's elements.
E. g., the covariance matrix for the first line of Larsen's $\mathbb{Z}$ (equation 3.12) is constructed like

$$COV = \frac{1}{N-4}\left(\mathbb{B}^{\dagger}\mathbb{B}\right)^{-1}\begin{pmatrix}\delta E_{x1}\\ \vdots \\ \delta E_{xN}\end{pmatrix}^{\dagger}\begin{pmatrix}\delta E_{x1}\\ \vdots \\ \delta E_{xN}\end{pmatrix}. \tag{4.12}$$

| $T = 32\,s$ | $Z_x^{MT}$ | $Z_y^{MT}$ | $Z_x^{CN}$ | $Z_y^{CN}$ |
|---|---|---|---|---|
| $Z_x^{MT}$ | 0.0014487 | 0.0005641 | 0.0003511 | 0.0006530 |
| $Z_y^{MT}$ | 0.0005641 | 0.0053910 | 0.0000318 | 0.0010178 |
| $Z_x^{CN}$ | 0.0003511 | 0.0000318 | 0.0009406 | 0.0003787 |
| $Z_y^{CN}$ | 0.0006530 | 0.0010178 | 0.0003787 | 0.0026531 |

The table above shows it explicitly for the example of DAM with Belsk at a period of $32\,s$. As long as the matrix to be inverted is constructed from auto spectra, the covariance matrix is symmetric. Its element 31 (third row, first column) is interesting for our purposes, since it depends on correlation between $B_x^{MT}$ and $B_x^{CU}$, as well as element 42 that indicates correlation between $B_y^{MT}$ and $B_y^{CU}$. In the ideal case of really independent input variables not only they, but all off-diagonal elements should be zero. Thus a glance at the magnitude of covariances can inform about which data situation and processing scheme is rather beneficial or harmful for the uniqueness of the solution. Displaying element 31 for a synthetic case study, fig. 4.11 shows that there are two conditions under which the covariance is significantly increased: The first-stage extension of the SNS after Oettinger SNS(RR-LS) and his full extension if there is no correlated noise present in the data. The first case is what I aimed at: The SNS(RR-LS) method increases the problems with correlated input channels, the SNS(RR-RR) technique decreases them back to the normal level of the original SNS, at least if the data contain CN. If they do not, it is easy to imagine that covariance is increased, since then $B_x^{CU}$ consists to 100 percent of $-\delta\mathbf{B}^{\mathbf{R(2)}}$ which is, of course, correlated to $\mathbf{B}^{\mathbf{MT}}$ according to the argument around equations 4.3 and 4.4. So it could be stated that the SNS(RR-RR) technique satisfies the necessity to compensate for the Tartar caught in the SNS(RR-LS) method.

The result of this method applied to our real data example (fig. 4.10) shows, that this has been a Pyrrhic victory, since the scattering of MT curves is even higher than in the original SNS method(cf. fig. 4.2). Regarding the curves' quality of $\mathbf{T}^{\mathbf{RR}}$ in fig. 4.5 ($\mathbf{T}^{\mathbf{R2}}$ is not shown, it scatters even worse), this is, maybe, not astonishing. Therefore I conclude that a multiple of the available data amount is required to obtain reasonable MT transfer functions. The CN result (fig. 4.12) is, however, improved with regard to the original SNS (fig. 4.4): The curves are stable in a limited period range and behave there as expected. For the other periods, either the Separation tensors have been too inaccurate or there was no correlated noise at all. Both guesses are plausible for the shortest periods. A glance at the covariances (fig. 4.13, this time element 42) informs that the SNS(RR-RR) approach has a beneficial effect here too.

For the rest of the profile in fig. 1, the results are generally similar. The simple Separation tensor after Larsen is biased, no matter to which remote site it is referred. Its wrong features make the Separation incorrect and reasonable CN transfer functions impossible, whereas MT results are unbiased, but less smooth than corresponding RR ones. $\mathbf{T}$ can be reconstructed without bias by means of a second remote site, but a heavy price is paid for it in form of strong scattering. The application of SNS(RR-LS) often leads to a failure of the Separation visible in MT and CN results which are hardly different from single-site ones. The SNS(RR-RR) delivers rather scattered MT results, whereas the CN curves are generally better than those by SNS or SNS(RR-LS).
Oettinger, who worked with a modified version of Larsen's robust code, observes occasionally serious stability problems of the SNS(RR-RR) results, too (Oettinger et al. [2001]). So the huge data demand of this method overstrains not only my non-robust program. He recommends to remain with the SNS(RR-LS) method in such cases. Having described here why I found this step unusable, I cannot agree with this. Generally,

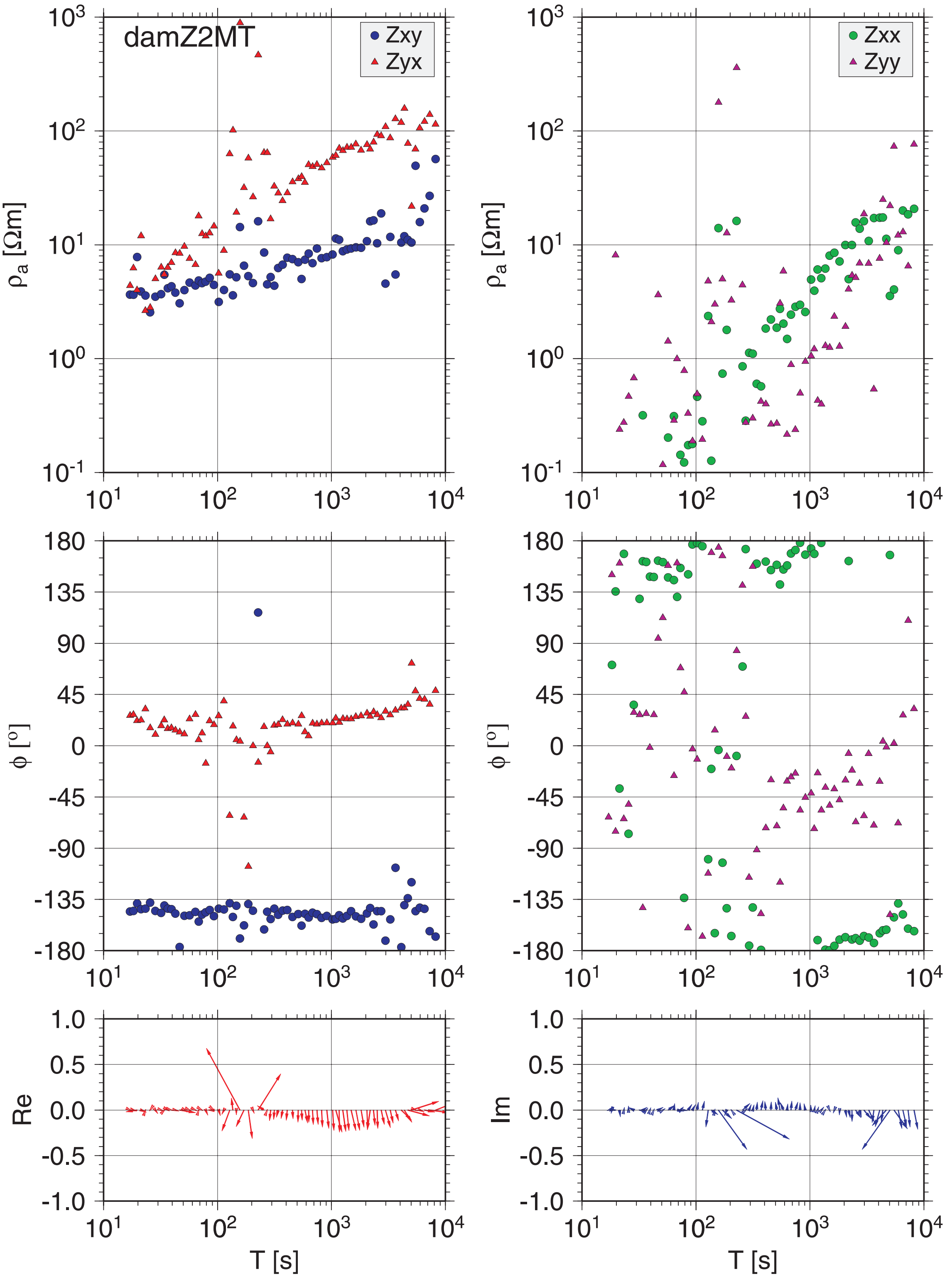


**Figure 4.10:** The MT results obtained after the SNS(RR-RR) method for site DAM with Belsk as first and WIA as second reference are even more scattering than the original SNS result in fig. 4.2.

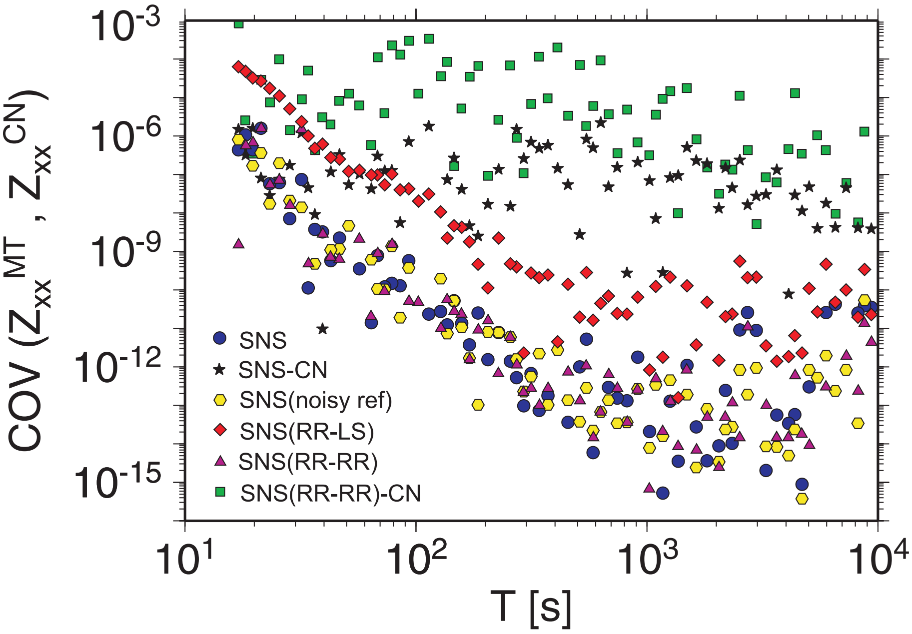


**Figure 4.11:** Covariances between $Z_{xx}^{MT}$ and $Z_{xx}^{CN}$ for synthetic data and several processing techniques over the period. A lack of correlated noise in the SNS technique (green squares and black stars) as well as the SNS(RR-LS) method *per se* (red diamonds) enhance the covariance indicating that the uniqueness of the solution is endangered or lost. Noise in the reference has no significant influence on the covariance.

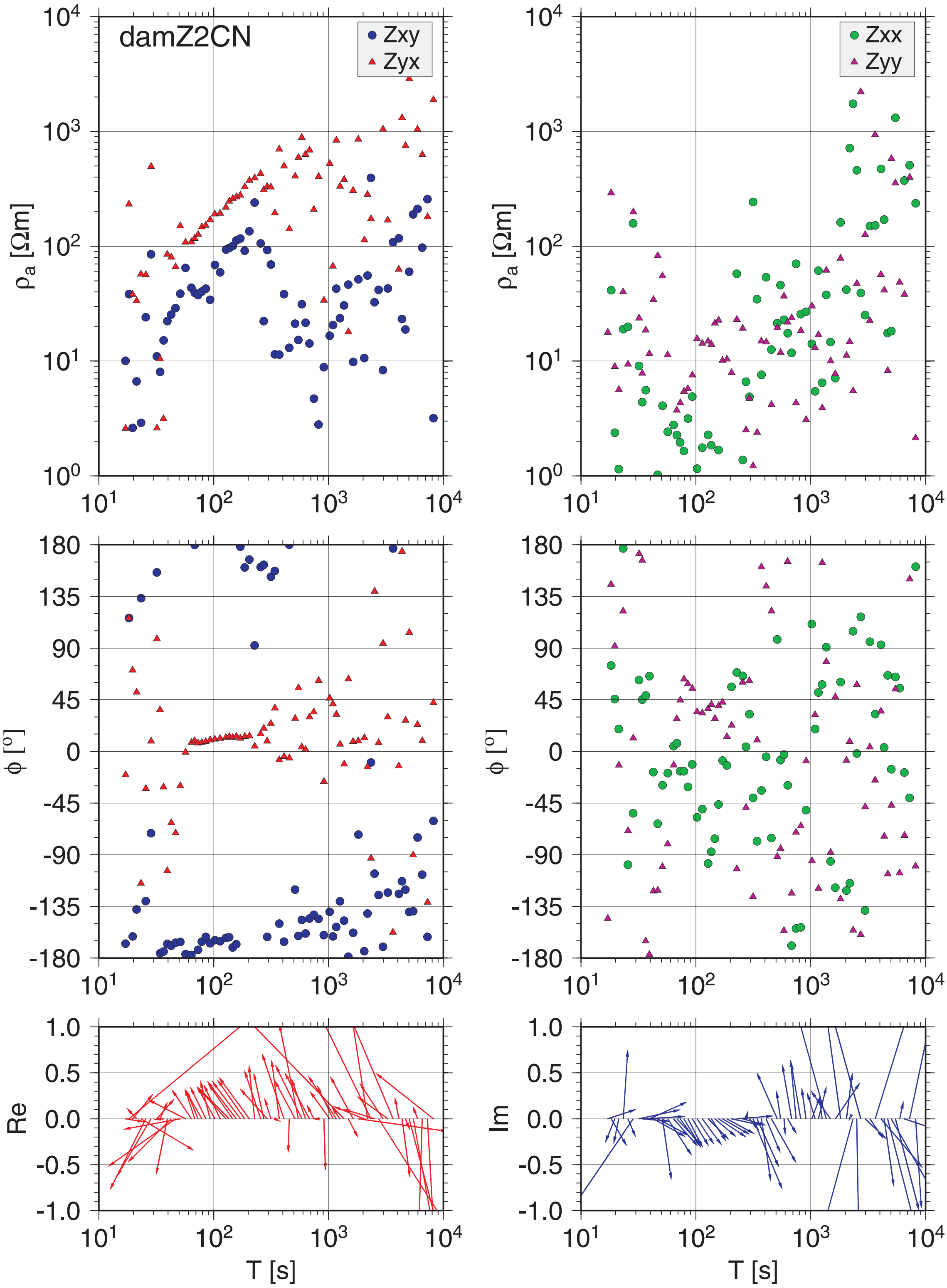


**Figure 4.12:** The CN results obtained after the SNS(RR-RR) method for site DAM with WIA as first and Belsk as second reference show reasonable results for the off-diagonal elements in a limited period range around 100 *s*.

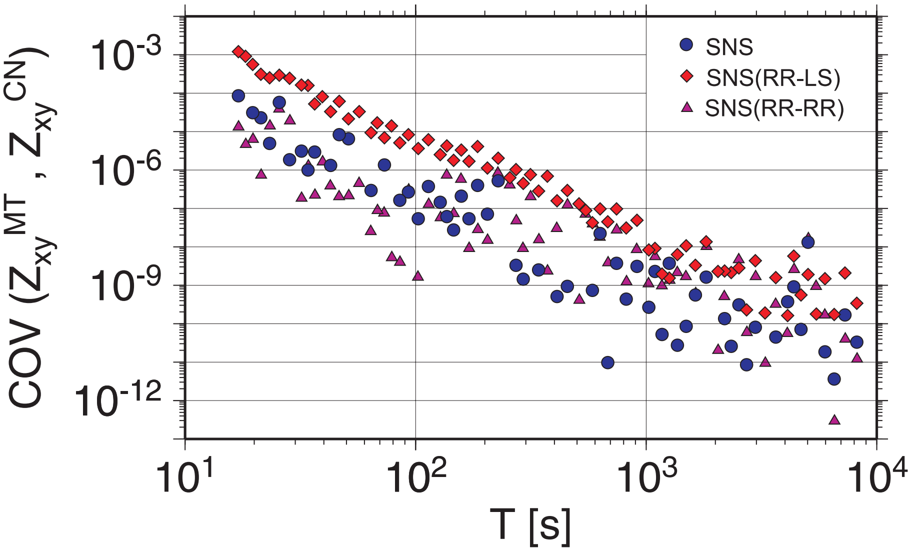


**Figure 4.13:** Covariances between $Z_{xy}^{MT}$ and $Z_{xy}^{CN}$ over the period for results by several processing techniques for station DAM. The SNS(RR-LS) method has covariances enlarged partly by factor 100 with respect to the classical SNS. The SNS(RR-RR) method is a remedy for that.

from my least-square point of view, I cannot recommend the way to separate magnetic variation data into "two sources"[2], into independent input variables for signal and noise, at all. The advantages of the SNS method, i. e. decreased error bars in Larsen's original technique and clean CN transfer functions in Oettinger's extension, do not outweight the evident risks of that processing algebra: In practise, the inflation of the model parameter space by $\mathbf{Z^{CN}}$ can lead to numerical problems, since a $4 \times 4$ matrix has to be inverted, which is in absence of correlated noise close to singularity. In contrast, with the RR method we have to invert a $2 \times 2$ matrix only, which is by its nature well-behaved[3]. Furthermore, the algebraic structure of Larsen's SNS method is not able to yield smoother or "less biased" MT transfer functions than the RR technique, as Egbert had already stated. So if Larsen's original code with or without Oettinger's modifications has produced better processing results than other established algorithms, it must be due to its special "procedures independent of conditional equations"or at least due to the combination of them with the introduced scheme (e. g. strong smoothing over the Separation tensor only).

By the way, the idea that numerical instabilities due to the additional model parameters become more probable than before (in SNS and SNS(RR-RR)) or that "new"and

[2]another name of the SNS method

[3]It consists mainly of the natural magnetic variations which are generally equally distributed, but not correlated in x and y direction.

“old”model parameters can be correlated (in SNS(RR-LS)) and thereby endanger the solution for the applied regression scheme, is not quoted by the authors, neither by Oettinger et al. [2001] nor by Larsen et al. [1996]. The latter mention a “collinearity problem”, but only in connection with the time series rotation in order to give reasons for it.

Anyway, there is an improvement with the non-robust SNS(RR-RR) method compared to SNS and SNS(RR-LS) if it is about CN transfer functions. Their meaning will be treated of in the next section.

## 4.3 Information about correlated-noise sources

The CN transfer functions have a serious advantage compared to MT ones: The decision whether a result is reasonable or not is doubtless, since it is known how that curves must look like if correlated noise is present. If one obtains very scattering curves instead of continuous ones, it means that there is no correlated noise verifiable. If a resulting curve is continuous, but does not fit into the expected CN pattern, one has to suspect that the Separation has failed, especially if the curve traces the corresponding single-site result. We have seen there in the last section, that certain branches of the SNS method have such a tendency. However, proper CN transfer functions look as follows:

The $\rho_a$-curves are straight lines rising in an angle of $45^o$ if plotted in a log-log coordinate system with equidistant subdivision of both axes. Phases are constant over period at either $0^o$ or $180^o$. Induction arrows have a constant direction over period and a not very varying length, which can easily exceed the order of magnitude of all known induction-caused tippers if the station is located close to a CN emitter. Real arrows point thereby towards the source of the correlated noise, imaginary ones in the opposite direction. Furthermore, imaginary arrows are shorter than their real counterparts. All these features are shown by the example of station BLE in fig. 4.14. Note that the arrows are rotated by $90^o$. Originally, real ones point east towards the railway (cf. fig. 1).

These shapes are caused in the following way: We have already mentioned that the emissions of artificial sources of correlated noise can approximately be described by a horizontal electromagnetic dipole. Within its near-field, no induction process takes place, but its electromagnetic field propagates as in the static case. Due to this, there are missing features typical for induction processes like the phase shift between electric

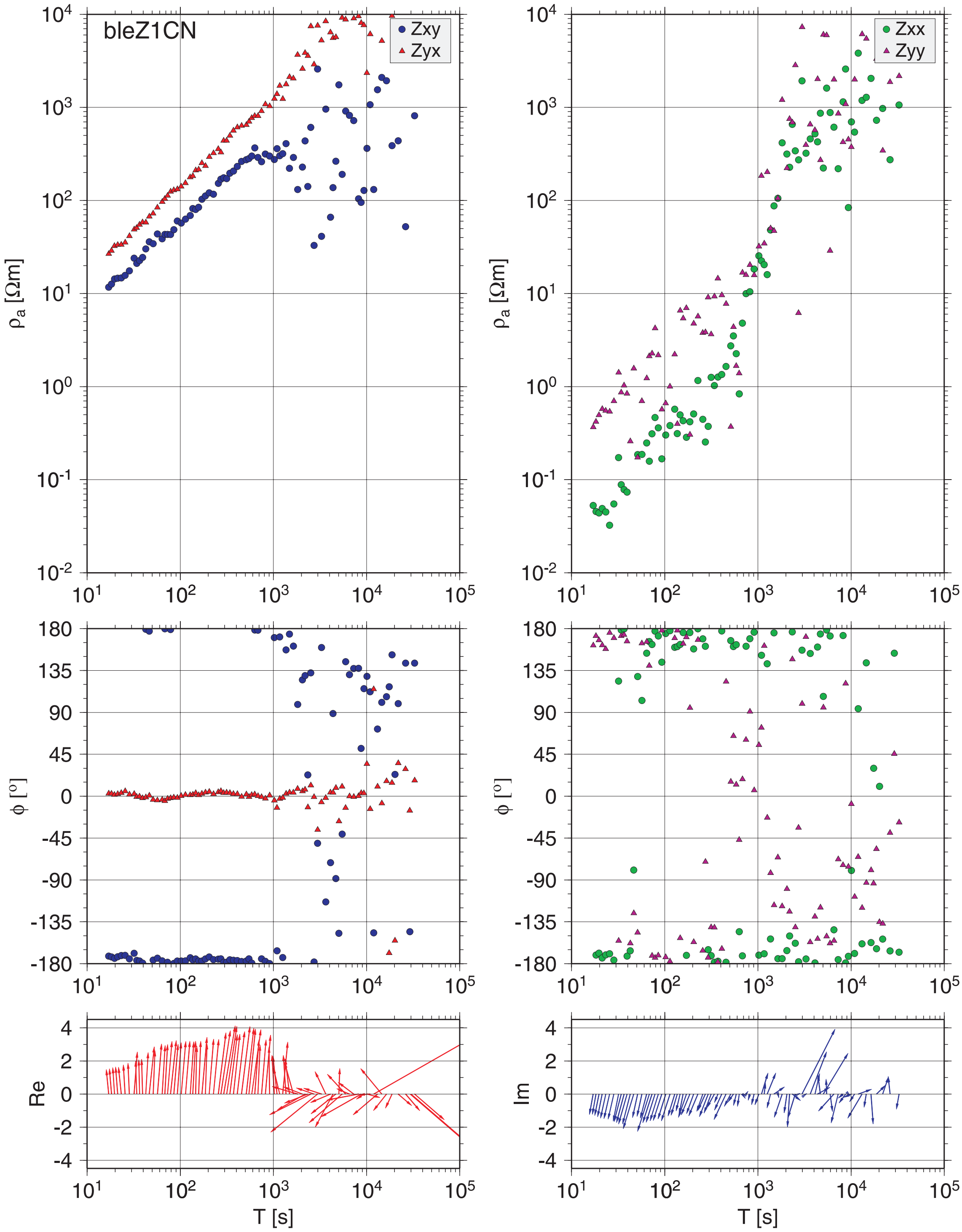


**Figure 4.14:** CN transfer functions of station BLE (see fig. 1) obtained after Oettinger, second stage. First remote site is Belsk, second WIA. For better visibility, the arrows have been rotated by $90^o$ ccw.

and magnetic field and a possible dependency of ratio of those fields on frequency. The $45^o$ rise comes from the multiplication of the impedance's square modulus with the period (cf. equation 1.5), the impedance itself is simply constant. The direction of real CN arrows is reverse to those induced by conductivity contrasts. This can be explained by the different location of their sources. Induction anomalies are more ore less deeply embedded in the subsurface, CN sources, in contrast, lie slightly above the Earth's surface. It is a simple geometric consideration by means of Biot-Savart's law to derive the arrows' direction from it.
So it is possible to conclude from correlated-noise transfer functions to some properties of their source: If they are clear, explicit, and stable over period in the terms above, they testify the presence of strong, even dominant correlated noise at the given site. Beside of this, the real induction arrows make the most important statement indicating the direction in which the source is situated. Fig. 4.16 demonstrates how consequently this is done. All arrows of stations close to DC railways point towards these lines. For comparison, the corresponding induction arrows ridded of CN influence by means of the RR technique are not attracted by railways (fig. 4.17).

There is a further, at least qualitative information that can be derived about the source of disturbances, i.e. about its distance to the station. If the CN transfer functions are not stable at shortest periods, but only at somewhat longer ones, this indicates that the source is not situated in the nearest proximity, since short period CN signals have already been attenuated due to a certain distance. This can be nicely observed in the lower panel of fig. 4.15. It shows pseudo sections of correlated-noise transfer functions of the LT-7 profile, but only for sites and periods where they are stable. Black triangles above the upper panel mark locations where the profile crosses DC railways (cf. fig. 1). It is evident that directly beneath those signs correlated noise is traceable up to the shortest periods, whereas at more distant sites it can be detected only at longer ones. The upper and middle panel of that figure show pseudo sections after the Remote Reference and the single-site method, respectively. They underline the well-known fact that the latter cannot be applied to data containing correlated noise, because this would lower the validity of the transfer functions dramatically.
Concluding for this section, it can be stated that the evidence about the CN sources obtained from the corresponding transfer functions coincides fully with the location of the DC railways. This is not an information that really has an impact on the MT results, e.g. it will never be part of some modeling work. However, this peculiar ability of Signal-Noise Separation methods can possibly help to chose places for further

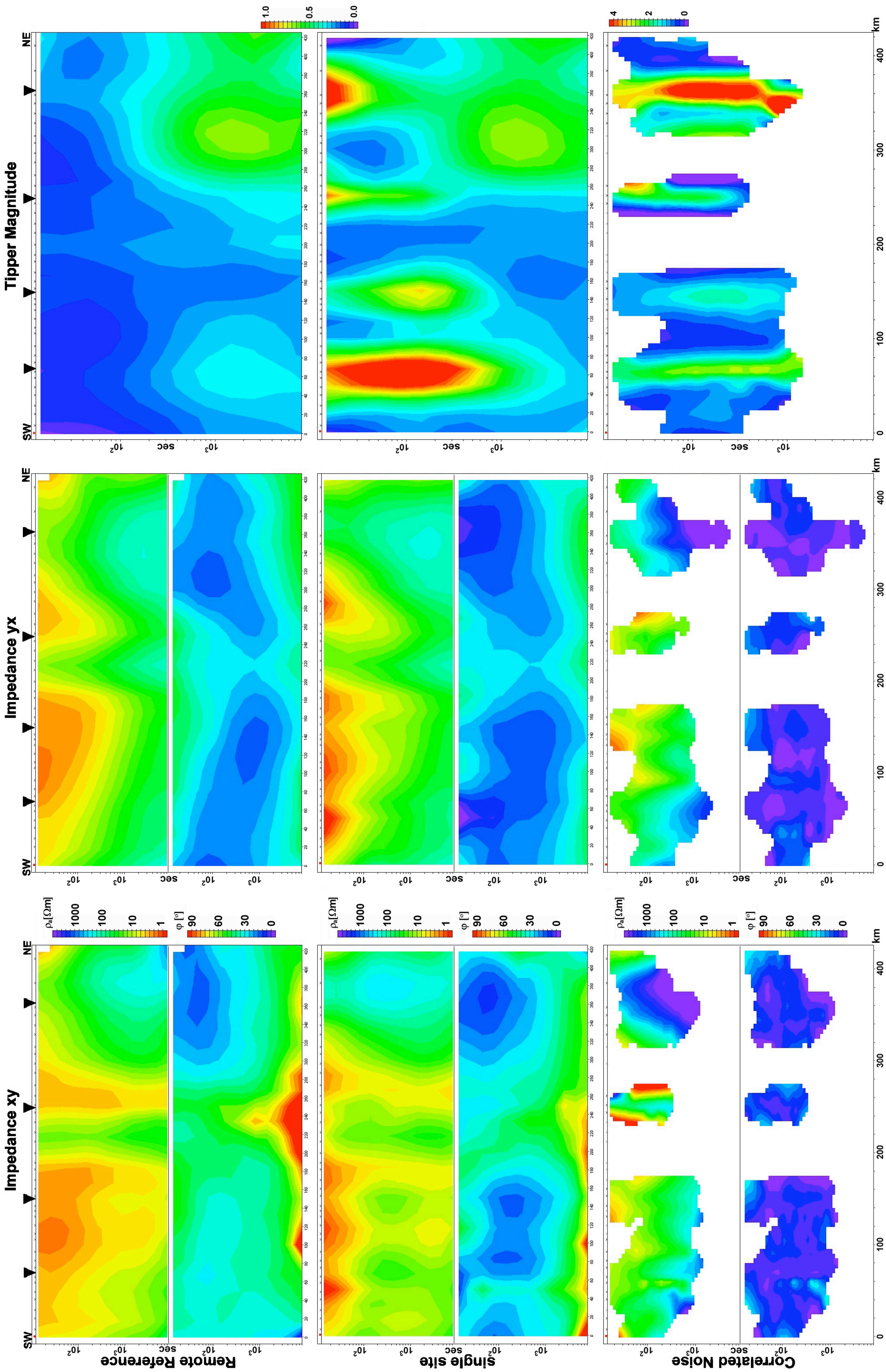


**Figure 4.15:** Processing results obtained with several methods for data of profile LT-7 (fig. 1) as pseudo sections. The CN results stem from Larsen's and Oettinger's method (the latter preponderates) and are plotted only for stable periods and stations.

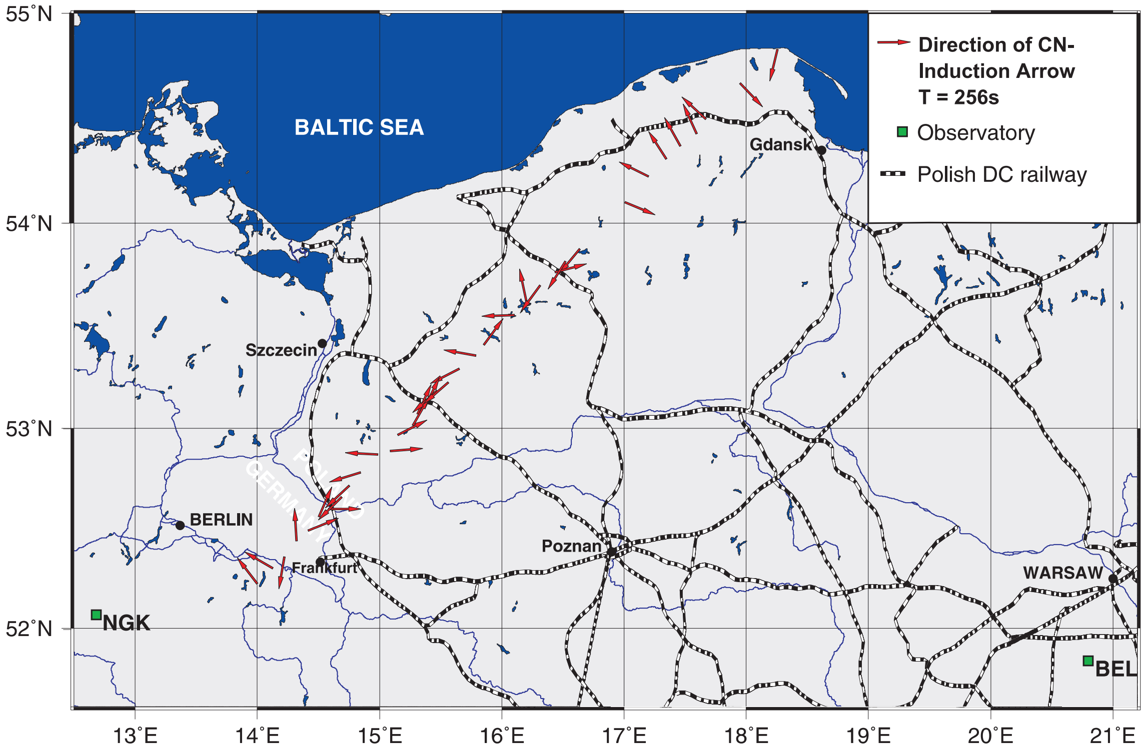


**Figure 4.16:** Real "induction" arrows for the CN part point towards close-by railways. Only their direction matters on this map, length is uniform and without meaning.

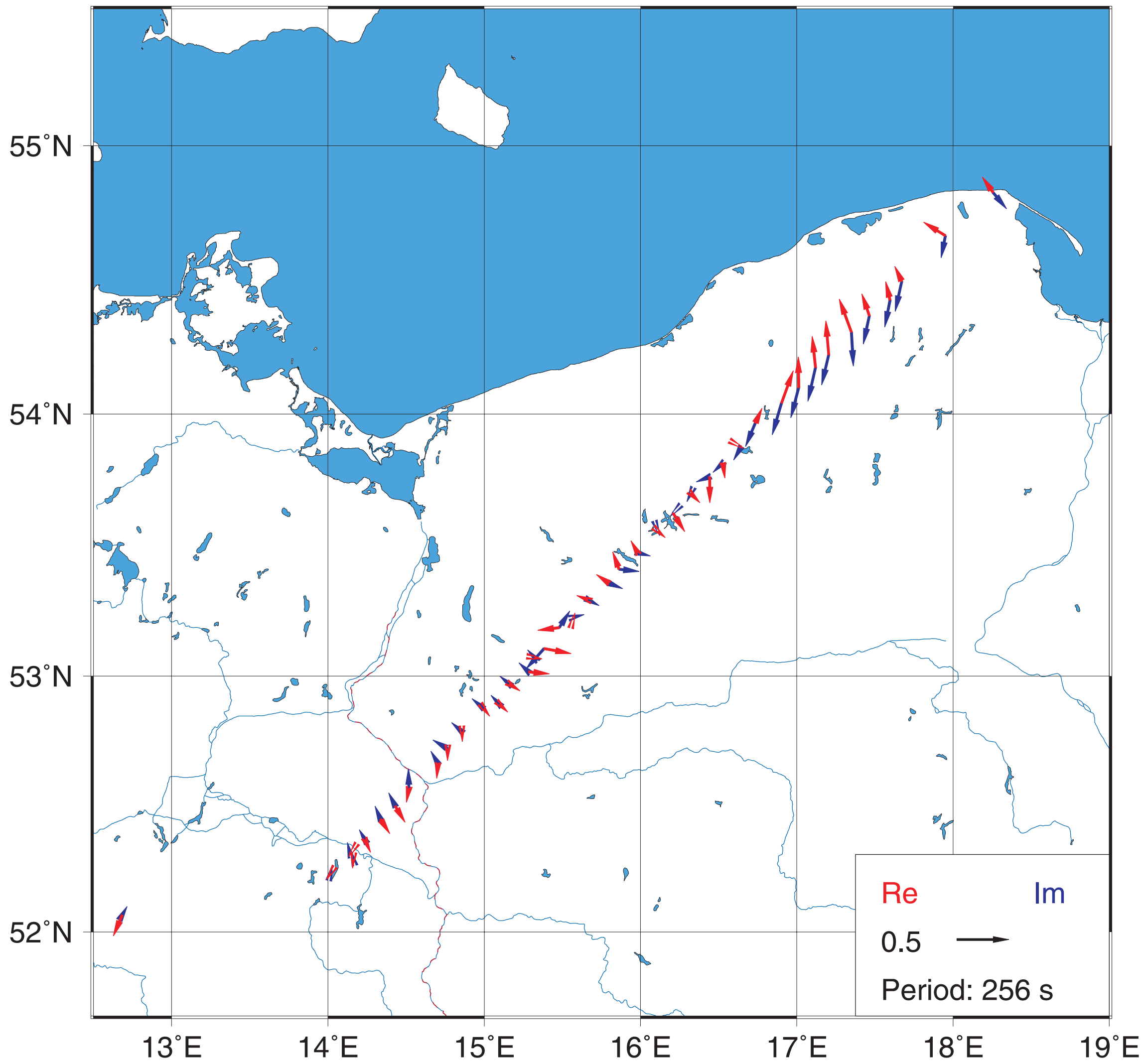


**Figure 4.17:** Induction arrows obtained with the RR method don't show any tendency to the railways (cf. fig. 4.16).

MT sites and for an appropriate reference to ensure a better chance of good transfer function quality. And if it is not as obvious as with Polish railways where CN sources are, this methods can give surprises: E. g. the two southwesternmost arrows in fig. 4.16 indicate a source to the SE of Berlin. Fig. 4.12 that refers to the last site at the SW end of the profile, suggests a certain distance between station and that source. As a matter of fact, there is suited in 30 km distance and arrow direction, the small town Erkner at the East edge of the tiny lake ESE of Berlin (Müggelsee). At this locality there is a terminal of the S-Bahn, a Berlin local traffic railway that is, in contrast to usual German railways, driven by DC current.