"KNEADING": THE ADJUSTMENT OF INSTRUMENTAL PHASE AND GAIN PARAMETERS TO SUPPRESS ERROR PATTERNS IN A SYNTHESIS MAP.

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SUMMARY

Often, particular unnatural-looking patterns appear in a synthesis map. An experienced observer can recognize the type of error that produced them and may even be able to apply the corrections necessary to get a better-looking map. A systematic approach is described in this paper: A model of the errors most likely to occur is fitted to the patterns in the map, and the fitted parameters are used to apply corrections. The presence of a point source that can serve as a reference is required. This requirement limits the applicability of the method, but is met by quite a few objects of interest. Where interference from other sources would be too strong, their influence may be reduced by CLEANing the map prior to model fitting. One example of the results for atmospheric position scintillation and one for baseline calibration errors will be shown.

1. INTRODUCTION

In this short contribution I shall report some work on adaptive error removal which I have been doing over the past few years. In doing so, I cannot avoid returning to some of the discussion we had on the application of closure phase techniques in connected-interferometer systems. I hope to do so in a way that may clarify the situation, although I have not been able in this short time to put every detail in its correct place.

Adaptive correction of observational data is a procedure familiar to most experimentalists. One usually has some a priori notions about the possible outcomes of an experiment, as well as some knowledge about the nature of artefacts that can be introduced through the measuring procedure. This information may be used to isolate the hard facts from the artefacts as well as possible. In this paper, I shall present examples of a systematic application of this concept to sky maps obtained with the Synthesis Radio Telescope at Westerbork.

C. van Schooneveld (ed.), Image Formation from Coherence Functions in Astronomy, 47-53.

The nature of some of the simple and most common error patterns to be found in these maps has been described in my previous contribution (Hamaker, this volume). Such errors as 12-hour grating rings and AB-rings are easily identified, and instrumentel parameters specified in the data reduction process may be adjusted so as to make them disappear. This is what one might call the manual version of the procedure which has come to be known in our Institute as "kneading". Some observers have developed considerable skill at it, even for less easily identifiable errors such as deviations in a single antenna (R.G.Strom, private communication).

Computerised kneading is a logical next step. It allows much more complex situations to be handled at the expense of much less labour. On the other hand there is the obvious danger that the computer will carry the process too far; it may mistake parts of the true source for errors and, in "correcting" for them, mutilate the source and introduce new spurious structures. Close guidance by a human operator must be considered an indispensible ingredient to a successful kneading programme. Furthermore, the error model to be used should be designed with the smallest number of degrees of freedom that is adequate to describe the important errors.

2. FIRST EXAMPLE: LARGE-SCALE ATMOSPHERIC ERRORS

My first example concerns large-scale atmospheric errors. The uncorrected map, fig. 1a, clearly shows the characteristic streaks discussed earlier (Hamaker, this volume). As I described, these result from an apparent random wandering of the source field during the observation. To get rid of them one must somehow align the individual corrugations (Hamaker, loc. cit.) to their correct positions.

It should be noted at this point that the map (including the strong point source) is directly derived from the measured data. It satisfies whatever closure phase conditions one might derive from the same data and, since these closure phases contain no position information, will continue to do so regardless of any shifting around of the contributing corrugations. Other information is needed for making the alignments.

In the present case we may use the strong unresolved source as a reference, aligning its responses in all corrugations to coincide in a single point. This procedure is highly successful, as demonstrated by the result in fig. 1b. It should be emphasized however, that reference

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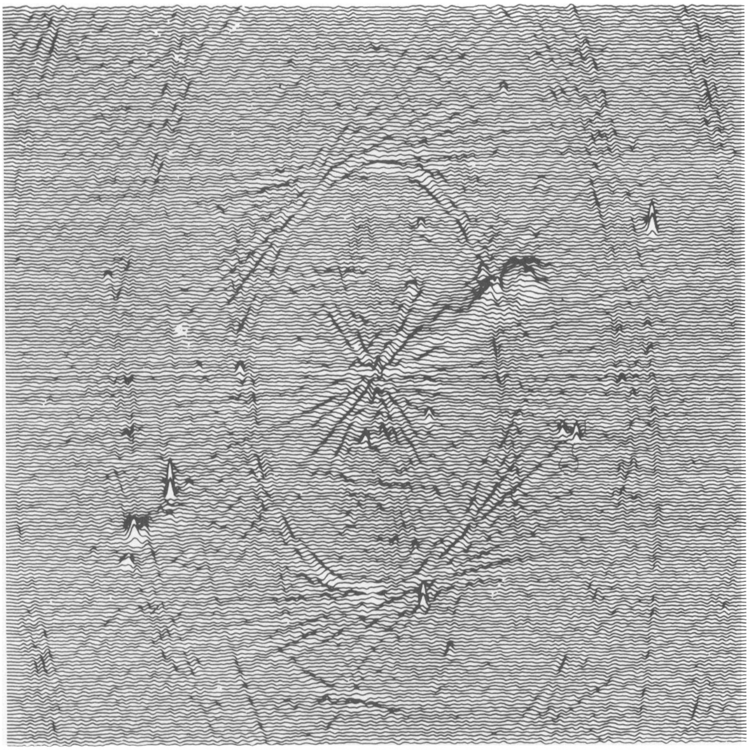
Fig. 1. (opposite page). a (top): Map of 3C236 made from four 12-hour observations. To better display the weak features, a point source has been subtracted at the centre, whose strength would correspond to about twice the height of the picture. The residual map clearly shows the atmospheric streaks associated with this source superimposed on the extended source structure. b (bottom): The same map after application of the "kneading" procedure described in Chapter 2.



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sources as outstanding as this one within an observed field are rare. Where they are either weaker or partly resolved it remains to be seen how much one can achieve.

Particularly in these more complicated situations, methods of the type described by Wilkinson (this volume) to handle closure phase data could be valuable. One might, for instance, from the "dirty" map derive a window defining the extent of the source and then use a Wilkinson-type iterative procedure to eliminate all structures outside and ensure positivity inside. Such possibilities are certainly worth further investigation.

3. SECOND EXAMPLE: INSTRUMENTAL DRIFTS

Fig. 2a shows a map in which the effects of the known deficiencies of the synthesized beam have been removed by CLEANing and restoring with a beam having no sidelobes (Schwarz, this volume). The presence of residual circular structures reveals the occurrence of instrumental drifts. The patterns around the central source stand out quite clearly: one should be able to analyse them in terms of contributions from individual interferometers and apply appropriate corrections.

To do this, an error model containing the major effects of simple offsets and drifts (Hamaker, this volume) is constructed and its parameter values determined by a least-squares fit. With these values, the model is then added as a correction to the theoretical synthesized beam. The corrected beam, representing a better approximation to the true instrumental profile, should give better results when used instead of the theoretical beam in CLEANing.

Contrary to the previous example, the error pattern is weak compared to the brightness of the extended source component. Precautions must therefore be taken to prevent contamination of the fitted error parameters by this component. This can be attempted in either of two ways. One may remove most of the effect of the source by CLEANing with the theoretical beam before proceeding with the model fit; or the region of the contaminating source may be excluded from the data base for the fit. The best results are to be expected when the two methods are applied together.

Fig. 2. (opposite page). a (top): The central part of a map of 3C66 made from two 12-hour observations. The largest ring is a residual 12-hour grating response. Halfway out an AB-ring can be recognized. The remaining quasi-circular structures are not readily identified. b (bottom): The same map after application of the "kneading" procedure described in Chapter 3. Three features formerly masked by the instrumenten errors now stand out clearly: There is no bridge between the two source components; the extended source can be traced to its very ends; and the point source is recognized to be extended.

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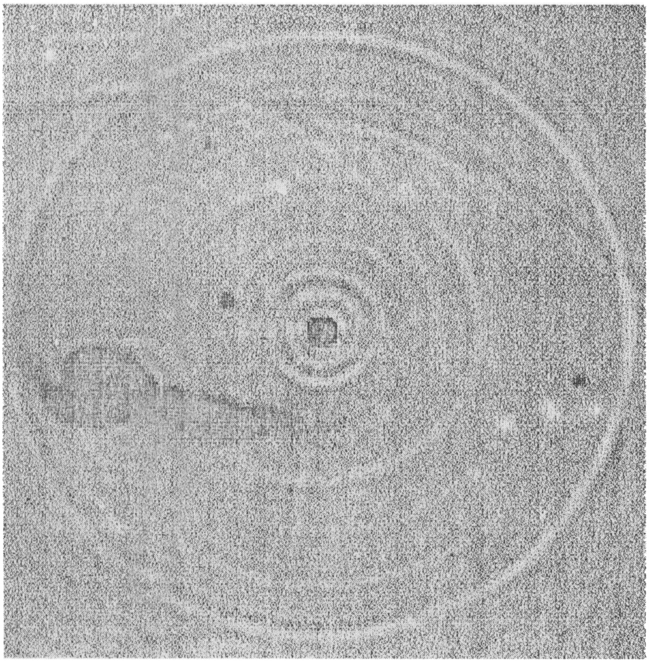

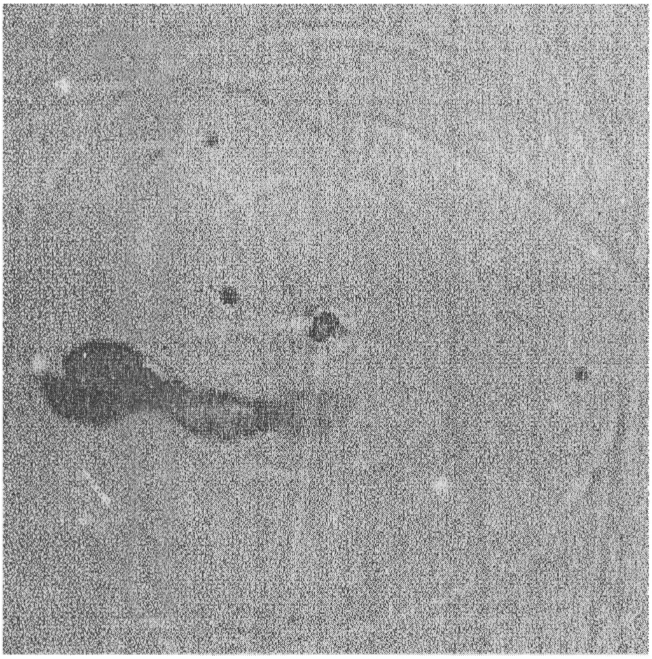

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For the present example the end result is shown in fig. 2b. Indeed the rings are all gone except for some weak "high-order" parts, which were deliberately not included in the model in order to minimize the risk of spurious source pickup. For the peak in the extended source, the residue of the 12-hour ring has changed in appearance but has not completely vanished. I suspect that some weakly shift-variant error must be responsible (e.g. antenna pointing).

The figure shows the central source to be slightly extended in position angle 45°. If the program had been left unguided, it would have proceeded on the assumption of a point source and produced an incorrect estimate of the error beam. The occurrence of this sort of situation not expected by the computer must continually be anticipated.

In cases where the source and error distribution are difficult to disentangle, iterating the process is conceivable. One then arrives at a procedure again closely resembling Wilkinson's (this volume) although differing in detail due to the different nature of the missing information.

4. CONCLUDING REMARKS

The examples shown are the only two in which the kneading technique has been applied so far. They demonstrate the potential of the method but give no clue as to the range of situations in which it may be successfully applied. The impact of various sources of trouble will have to be assessed in further practical tests and simulations. Owing to the large programming efforts involved, progress is expected to be slow.

Due to time and space limitations, this presentation has by necessity been brief and sketchy. More elaborate accounts will be submitted elsewhere (Astronomy and Astrophysics, 1979?).

ACKNOWLEDGEMENTS

I am indebted to R.G. Strom for prompting the study of 3C236 and sorting out the problems of producing a fine map from my somewhat messy computer output. The study of 3C66 could not have been done without the hard work of A.M.J. Vossen, who has spent a year translating theoretical concepts into a program package that worked in spite of frightening hardware limitations. The Westerbork Synthesis Radio Telescope is operated by the Netherlands Foundation for Radio Astronomy with the financial support of the Netherlands Organization for the Advancement of Pure Research (Z.W.O.).

DISCUSSION

Comment E.B. FOMALONT
After removing the extended structure we are left with a dirty beam associated with the point-source which applies to the observation coverage and imperfections. Instead of analyzing the error beam for the phase imperfections, why not use this dirty beam directly to clean the source?
Reply J.P. HAMAKER
One problem is that you need an antenna pattern of linear size twice that of the map, so you must somehow entrapolate. I could not think of a better way to do this than by model fitting.
Reply R.J. ALLEN
In relation to this question I wish to make the following comment. The procedure of using the actual response of a point source on the map as the "dirty beam" in a clean operation has indeed been tried in a number of cases. It is unsatisfactory in that the noise inevitably present on the map seriously limits the level to which the clean operation can be carried. Since astronomers are almost always interested in looking at the faintest extended features which may be present on the map, the procedure outlined above is not useful. The method used by Hamaker employs as much of the physics as is known about the actual instrumental instabilities in order to construct a model of them, thereby rejecting the effects of noise to a high degree.

Comment D. SRAMEK
It was shown earlier by Dr. Baldwin that self calibrating on a point source in the field can lead to a false symmetric image on the map. How is this avoided with your technique?
Reply J.P. HAMAKER
I do use part of the phase information rather than completely disposing with it as Baldwin does. What I do is to fit a linear slope to the array of observed phases for each hour angle and retain the residual phases. The underlying assumption (which I did not have time to discuss) is that the slope represents the large-scale atmosphere, whereas the residuals carry information related to the source structure.

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