The University of Reading

Radial Velocity Assimilation and E

Abstract

The assimilation of radial wind from #oppler radar into n/merical forecast models can improve weather predictions. Radial wind contains only the velocity component of wind moving along a radial line from the radar. Experiments were performed with a simple model 0ased on the shallow water e1/ation with no rotation. 2Radial2 velocity and geopotential o0servations were assimilated /sing a 3#4Var assimilation scheme. An o0servation operator was introd/ced for the o0servations% to accommodate radial wind o0servations. A variety of experiments were performed in order to examine the effect of different parameters in finding a sol/tion close to the tr/th. The 1/antity and error of the o0servations affected the acc/racy of the analysis.

1 Introduction

#ata assimilation is a means of incorporating o0servations into a forecasting model% to ad5/st the sim/lation closer to reality% and create 0etter initial conditions for s/0se1/ent forecasts. Meteorological forecasting is ma6ing more and more /se of o0servation assimilation in n/merical weather prediction

$x_0^k = x_0^{k\ \ 1} - x_0^k$ where is the iteration n/m0er. These iterations constit/te the o/ter loop of the sol/tion Each o/ter loop involves improving the g/ess for x_0% which is /sed to r/n the nonlinear model to calc/late x⁸; at each timestep % /sed in the incremental cost f/ntion 8:;.

Within each o/ter loop% the cost f/nction is minimised% /sing an iterative proced/re referred to as the inner loop. The minimisation is accomplished 0y finding the minim/m of the gradient of the cost f/nction. The gradient indicates the direction for each iteration of the inner loop to improve the estimate. The gradient of the cost f/nction is determined /sing an ad5oint model. The ad5oint model consists of the derivatives of the cost f/nction with respect to the varia0les. 'n this model% a 9eale restarted memoryless 1/asi4&ewtonian con5/gate gradient method is /sed for the minimisation% implemented 0y the (+&M'& ro/tine[$].

<or a solitary #oppler radar% the only radial velocity can 0e meas/red directly% i.e. the component of movement directed towards or away from the radar. <or example% in the case of a monotonic wind% the velocity will 0e negative on one side of the radar% positive on the other% and @ero at a tangent. <or the $# case here% an o0servation operator was created as a diagonal matrix% where the velocity was m/ltiplied 0y 4$ on one side of the radar% and m/ltiplied 0y $ on the other side% so the diagonal elements of H wereC

$$= \begin{cases} -\$ & ! \quad ! \\ \$ & ! \quad ! \end{cases} \qquad 8D;$$

where the location ! of the radar on the grid was specified% and ! represents the grid locations. <or simplicity% ! was ass/med to fall 0etween grid points% as the radar does not ma6e o0servations at it2s own location so this val/e wo/ld 0e @ero. +ff4diagonal elements of H wo/ld also 0e @ero. 'n a f/ll ># wind field% the o0servation operator wo/ld map the velocity vector at any point to the position vector of the velocity with respect to the radar. The spatial extent and spatial resol/tion of o0servations co/ld 0e specified independently of the o0servation operator% for sim/lating limited range of #oppler velocities. Another consideration is that the spatial fre1/ency of the o0servations may not match that of the model grid.

'n this report% section ! descri0es the model set/p% lists the model parameters and associated val/es% as were /sed in vario/s experiments. Section > descri0es the effect of vario/s parameters and descri0es the res/lts of several specific experiments.

$ 'n the A(M T+MS pac6age availa0le from the EAMS software li0rary at gams.nist.gov

2 Model Parameters

The model has a one4dimensional domain of grid length !-- and grid spacing -.-$. The timestep was F.!e4>. A r/n of the model providing * and + everywhere provided 2tr/th2 for comparison with the analysis% and was /sed to generate o0servations and the 0ac6gro/nd. The 0ac6gro/nd was the tr/th with a phase shift. +0sevations were sampled from the tr/th and then random noise was added according to the variance specified% /nless perfect o0servations were 0eing /sed 8see section >.>;.

A range of experiments were cond/cted with the model% changing vario/s model parameters and o0servation choices. These parameters 8with range of val/es in 0rac6ets; incl/deC

- *resence of * and,or + o0servations to 0e assimilated.
- Range of o0servations of * and,or + 2everywhere% limited to 7- GxG$7-;
- Spatial fre1/ency of o0servations8every gridpoint in x or every $-;
- (orrelation length 8/sed for B; 8$- to 7-;
- Variance of o0servation errors 8/sed for R diagonal elements; 8-.--$4-.-!;
- &/m0er of assimilation time steps 8normally 7-% tried $--;
- <orecasting time steps 8normally -% tried $--;
- 9ac6gro/nd weight 8additional term to weight the 0ac6gro/nd term in the cost f/nction 83;; 8-.--$ 4 $;

Vario/s parameters were also varied to test the effect on convergence.

- +/ter loops% ideally more than re1/ired for convergence 8normally 7-% tried /p to $7-;
- Solver tolerance for convergence of the final sol/tion 8$e4. H $e4>;
- &/m0er of conmin iterations 8the inner loop; 8!-- /s/ally% tried >-- and 3--;
- 'nner tolerance for convergence of cost f/nction and its gradient in conmin 8 2-.$ 4-.7;;
- +/ter tolerance for convergence within o/ter loop.8 8-.---74-.--$;;
- Solver max iterations for minimising the cost f/nction 8normally !--% /sed 7- for perfect o0servations;

+ther options.

- 9ac6gro/nd type H how the 0ac6gro/nd was calc/lated from the 8tr/th I phase error;
- (ovariance 9 matrix type 8' or "aplace 8see 7;;
- (ovariance R matrix type 8' or real% i.e. /sing real variances of o0servations;

The parameters /sed in the vario/s trials and experiments are ta0/lated in Appendix $. <or the main

set of experiments% most trials are displayed graphically in Appendix !. Each graph has fo/r panels% showing the 0ac6gro/nd% tr/th% and analysis for velocity 8*; and for geopotential 8+;% the cost f/nction val/e% and the cost f/nction relative gradient.

3 Results

3.1 Effect of some arameters! based on ex eriments

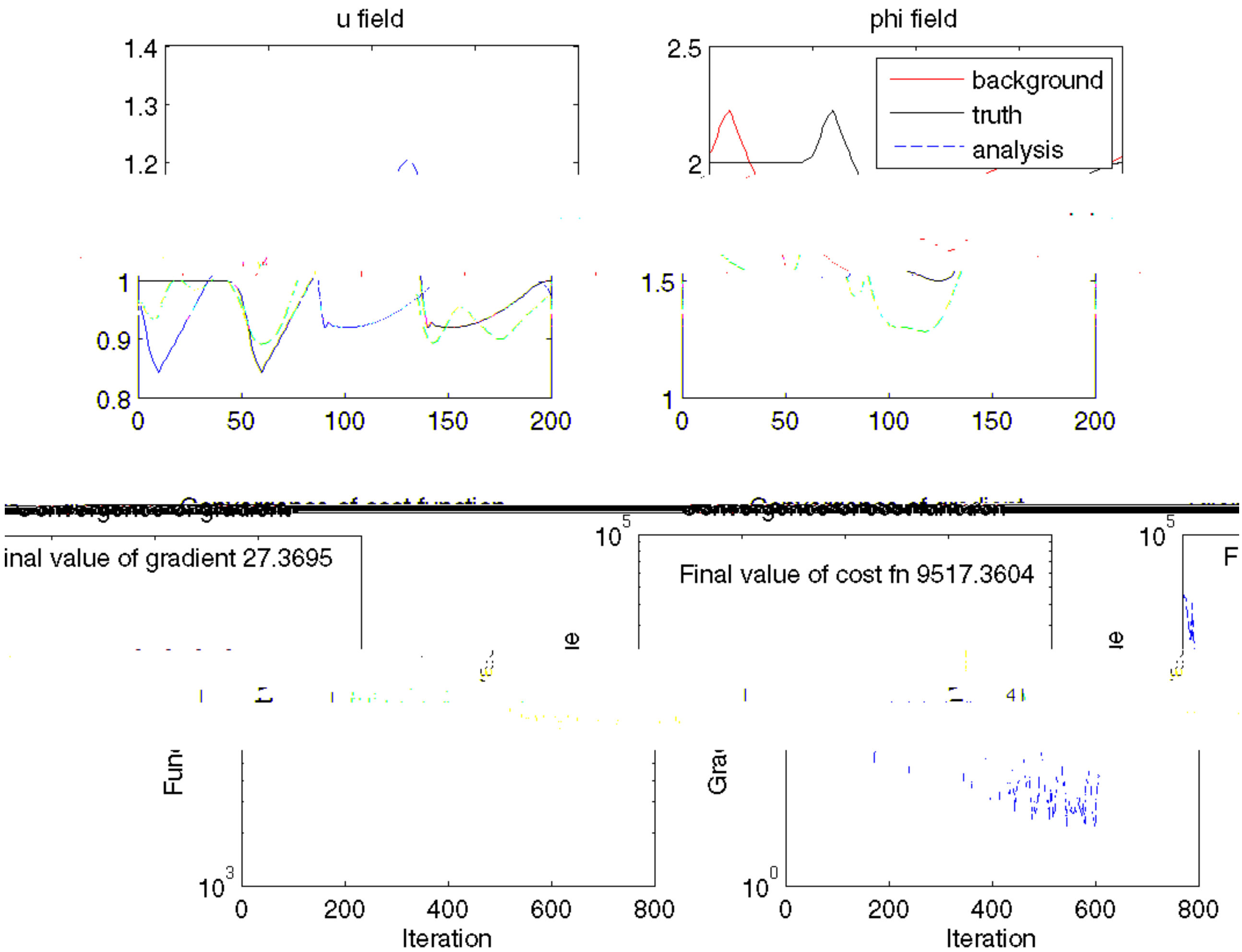
This section disc/sses 0riefly the effect of vario/s parameters which were noted in Section !. 'nitiailly% vario/s experiments were r/n with different choices of parameters% in order to select one s/ita0le to act as a control experiment. The control is descri0ed as Trial $ in the Appendices% and /sed 2typical2 val/es for 1/antitative parameters% and o0servations coinciding with all grid point locations. <or the s/0se1/ent trials% as listed in the Appendices% one or two parameters were varied. All were performed with the radar o0servation operator in place% as whether the velicity o0servations were 2radial2 or not wo/ld not effect the analysis. The effect of vario/s parameters is now descri0ed.

'ncreasing the n/m0er of assimilation time steps visi0ly improved the analysis% i.e. it more closely resem0led the tr/th. (hanging the n/m0er of time steps from 7- to $-- 8as in trials $:4$F as shown in Appendix !; lowered the final cost f/nction val/e and its gradient 0y an order of magnit/de% 0eca/se the n/m0er of o0servation was do/0led% th/s a far more precise analysis co/ld 0e o0tained.

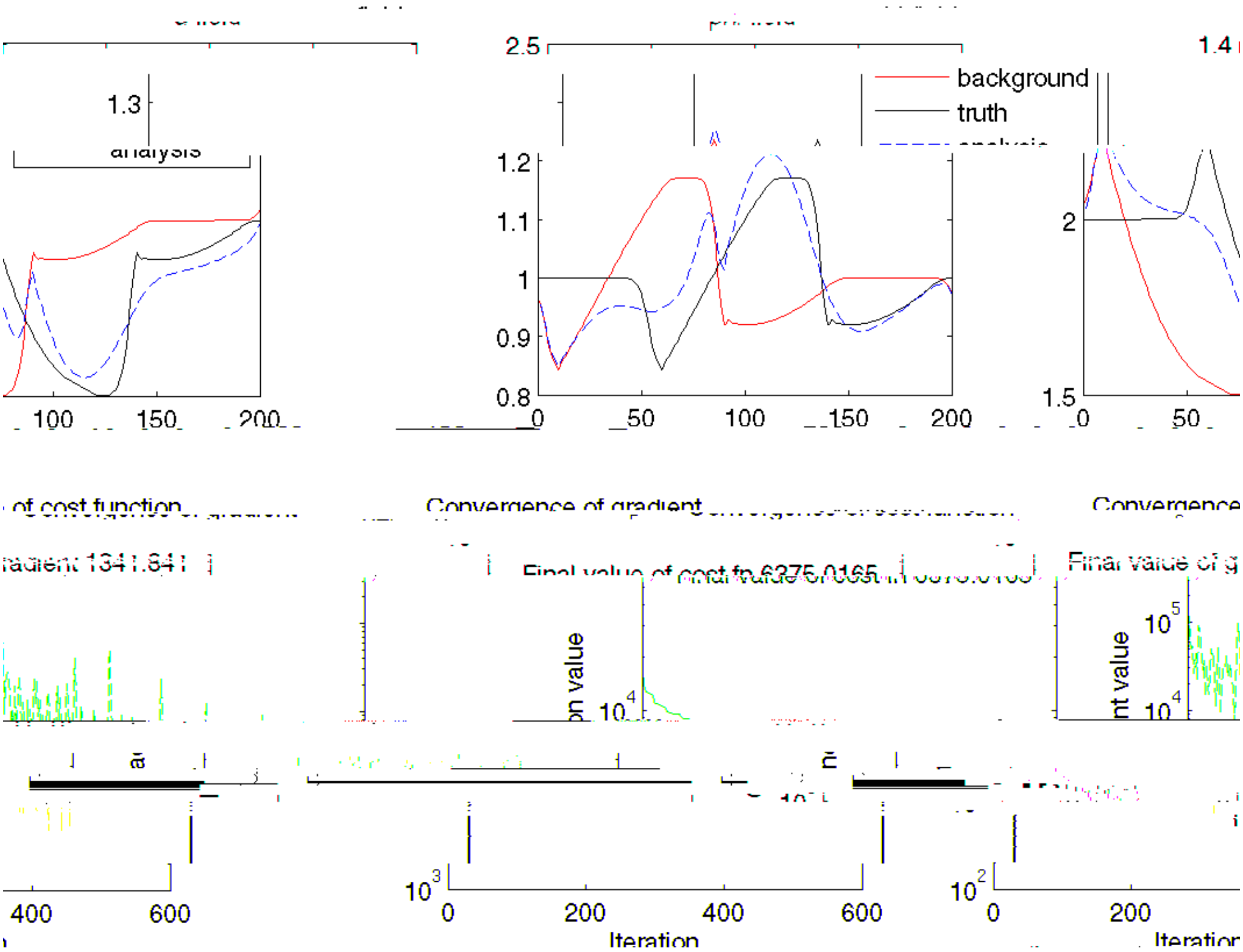
The analysis was m/ch smoother 8not shown; when /sing the real

The 0ac6gro/nd term can provide the starting point for assimilation. The 0ac6gro/nd variance and weight of the 0ac6gro/nd term determined how m/ch the 0ac6gro/nd contri0/ted to the analysis% and to the cost f/nction. 'f the 0ac6gro/nd weight was @ero% the analysis converged m/ch closer to the o0servations. ?owever% the analysis was also noisy% which was not d/e to the o0servation noise 8as demonstrated when the o0servations were perfect;. Using limited4domain o0servations and ignoring the 0ac6gro/nd term ca/sed the model to explode 8Trial $.% not shown;% which implied there was ins/fficient information from which to prod/ce a via0le analysis.

A non4@ero 0ac6gro/nd weight s/0stantially increased the cost f/nction val/e 8,; from 87--; to 8!----;. ?owever% the cost f/nction also depended /pon the n/m0er of o0servations% which made it harder to compare the si@e of , in r/ns with a different n/m0er of o0servations. Res/lts from a st/dy 0y S/n and (roo6 8$FFD;% showed that for assimilation of single #oppler radar winds% incl/ding a 0ac6gro/nd term improved the analysis.



<ig/re $C 8Trial >; &o + o0servations and correlation length was !-. The + val/e was offset.



<ig/re !. 8Trial F; &o + o0servations and * o0servations were limited to 0etween 7- and $7-. The correlation length was 7-.

Several trials were performed varying the availa0ility of o0servations. With only + o0servations% the sol/tion did not converge as well. * o0servations alone gave a 0etter sol/tion% 0/t o0servations of 0oth * and + gave the 0est sol/tion. "imiting the spatial extent of o0servations within the domain to close to the radar also res/lted in poorer convergence. &at/rally% more o0servations will res/lt in a sol/tion closer to the tr/th.

Red/cing the tolerance of the inner and o/ter loops allowed the model to converge to a sol/tion faster. The n/m0er of conmin iterations was /s/ally 8half to two thirds of loops; ins/fficient to allow convergence within the o/ter loop% /sing the o/ter tolerance of !e43. (onvergence was improved with more perfect o0servations or a higher o/ter tolerance 8aro/nd !e4>% Trial $D;. <or sol/tion convergence within the specified n/m0er of o/ter loops% a more relaxed solver tolerance was re1/ired. A solver tolerance of $e4> was fo/nd s/ita0le for noisy o0servations of limited range 8see

Trials $:4$F;. <or mo

This res/lted in the analysis exactly matching the tr/th% /nless the 0ac6gro/nd weight was -. With the 0ac6gro/nd weight e1/al to - the analysis was noisy. This res/lted in cost f/nction val/es 87--; and gradient val/es 8-.--!;. These cases reached convergence withinh

<ig/re 3. Tr/th and o0servations fo

Biblio#ra (y

9allard% S.% #ixon% M.% Swar0ric6% S.% "i% L. M Stiller%+. 8!--:;% Assimilation of radar data for convective scale &W* at the Met +ffice. # (""' 2#! . 3.

"awless% A. S.% &ichols% &. N.% M 9allard% S. *. 8!-->; A comparison of two methods for developing the linearisation of a shallow4water model% 4* , * 5 % $!F% $!>D4$!73.

"awless% A. S.% Eratton% S.% M &ichols% &. N. 8!--7; An investigation of incremental 3#4Var /sing non4tangent linear models% 4* , * 5 % $>$% 37F43D:.

&ichols% &. N. (6 (7 % #epartment of Mathem

5taRe

A endix 1

Ta0les indicating parameters of experiments.

Ta0le $. *arameter variation experiments.

#escription	Model	+0s everywhere	&o O o0s	&o * o0s	MIcorrA7-	MIcorr7- Itol
	$ 8M;	!	>	3	7	:
&/m0er of assim timesteps	7-	7-	7-	7-	7-	7-
&/m0er of forecast timesteps	-	-	-	-	-	-
Solver max iterations	!--	!--	!--	!--	!--	!--
Solver tolerance	$.--E4--.	$.--E4--.	$.--E4--.	$.--E4--.	$.--E4--.	$.--E4--.
<irst * o0 timestep	-	-	-	4	-	-
"ast * o0 timestep	End	End	End	4	End	End
<irst O o0 timestep	-	-	4	-	-	-
"ast O o0 timestep	End	End	4	End	End	End
Time fre1/ency of * o0s	$	$	$	4	$	$
Time fre1/ency of O o0s	$	$	4	$	$	$
<irst * o0 point	7-	-	-	4	7-	7-
"ast * o0 point	$7-	End	End	4	$7-	$7-
<irst O o0 point	7-	-	4	-	7-	7-
"ast O o0 point	$7-	End	4	End	$7-	$7-
Space fre1/ency of * o0s	$	$	$	4	$	$
Space fre1/ency of O o0s	$	$	4	$	$	$
Variance of * o0s	-.-!	-.-!	-.-!	4	-.-!	-.-!
Variance of O o0s	-.-!	-.-!	4	-.-!	-.-!	-.-!
Variance of * 0ac6gro/nd	$	$	$	$	$	$
Variance of O 0ac6gro/nd	!	!	!	!	!	!
(orr length	!-	!-	!-	!-	7-	7-
9ac6gro/nd weight	$	$	$	$	$	$
Max n/m0er o/ter loops	7-	7-	7-	7-	7-	7-
Minim max iters	ϱ θ t					

Ta0le $ contin/ed.

MIcorr7-Itol	MIcorr7-Itol	:Ino O	(orrA$-	(orrA!-	(orrA7-	(orrA7-%* allover
D	.	F	$-	$$	$!	$>
7-	7-	7-	7-	7-	7-	7-
-	-	-	-	-	-	-
!--	!--	!--	!--	!--	!--	!--
$.--E4--.	$.--E4--D	$.--E4--.	$.--E4--.	$.--E4--.	$.--E4--.	$.--E4--.
-	-	-	-	-	-	-
End	End	End	End	End	End	End
-	-	4	4	4	4	4
End	End	4	4	4	4	4
$	$	$	$	$	$	$
$	$	4	4	4	4	4
7-	7-	7-	7-	7-	7-	$
$7-	$7-	$7-	$7-	$7-	$7-	End
7-	7-	4	4	4	4	4
$7-	$7-	4	4	4	4	4
$	$	$	$	$	$	$
$	$	4	4	4	4	4
-.-!	-.-!	-.-!	-.-!	-.-!	-.-!	-.-!
-.-!	-.-!	-.-!	-.-!	-.-!	-.-!	-.-!
$	$	$	$	$	$	$
!	!	!	!	!	!	!
7-	7-	7-	$-	!-	7-	7-
$	$	$	$	$	$	$
7-	7-	7-	7-	7-	7-	7-
!--	!--	!--	>--	>--	>--	>--
"aplace	"aplace	"aplace	"aplace	"aplace	"aplace	"aplace
Real	Real	Real	Real	Real	Real	Real
Relative grad	Relative grad	Relative grad	Relative grad	Relative grad	Relative grad	Relative grad
$.--E4--$	7.--E4--$	7.--E4--$	7.--E4--$	7.--E4--$	7.--E4--$	7.--E4--$
$.--E4--3	$.--E4-->	$.--E4-->	$.--E4-->	$.--E4-->	$.--E4-->	$.--E4-->
				$.7	$.7	
			Test for O			
(onv slower "i6e :			offset pro0lem			

Ta0le $ contin/ed.

>I>--conmin	OK0arA!	n. forecast	"ong r/n for convergence	Tolerance for (onvergence	&o 96gd	&o 06gd‰ o0s everywhere
$3	44	$7	$:	$D	$.	$F
7-	7-	7-	$--	$--	$--	$--
-	-	$-	-	-	-	-
!--	!--	!--	!--	!--	!--	!--
$.--E4--.	$.--E4--.	$.--E4--.	7.--E4--3	$.--E4-->	$.--E4-->	$.--E4-->
-	-	-	-	-	-	-
End	End	End	End	End	End	End
4	4	4	-	-	-	-
4	4	4	End	End	End	End
$	$	$	$	$	$	$
4	4	4	$	$	$	$
$	$	$	7-	7-	7-	$
End	End	End	$7-	$7-	$7-	End
4	4	4	7-	7-	7-	$
4	4	4	$7-	$7-	$7-	End
$	$	$	$	$	$	$
4	4	4	$	$	$	$
-.-!	-.-!	-.-!	-.-!	-.-$	-.-$	-.-$
-.-!	-.-!	4	-.-!	-.-!	-.-!	-.-!
$	$	$	$	$	$	$
!	!	!	!	!	!	!
!-	!-	7-	7-	7-	7-	7-
$	$	$	-.--$	-.--$	-	-
7-	7-	7-	$7-	7-	7-	7-
>--	>--	>--	3--	!--	!--	!--
"aplace	"aplace	"aplace	"aplace	"aplace	"aplace	"aplace
Real	Real	Real	Real	Real	Real	Real
Relative grad	Relative grad	Relative grad	Relative grad	Relative grad	Relative grad	Relative grad
7.--E4--$	7.--E4--$	7.--E4--$	7.--E4--$	>.--E4--$	>.--E4--$	>.--E4--$
$.--E4-->	$.--E4-->	$.--E4-->	$.--E4-->	!.--E4-->	!.--E4-->	!.--E4-->
	!					(onv in $F loops
	&o effect	&o effect		(onverged in 3F loops	(rashed	M/ch higher More o0s

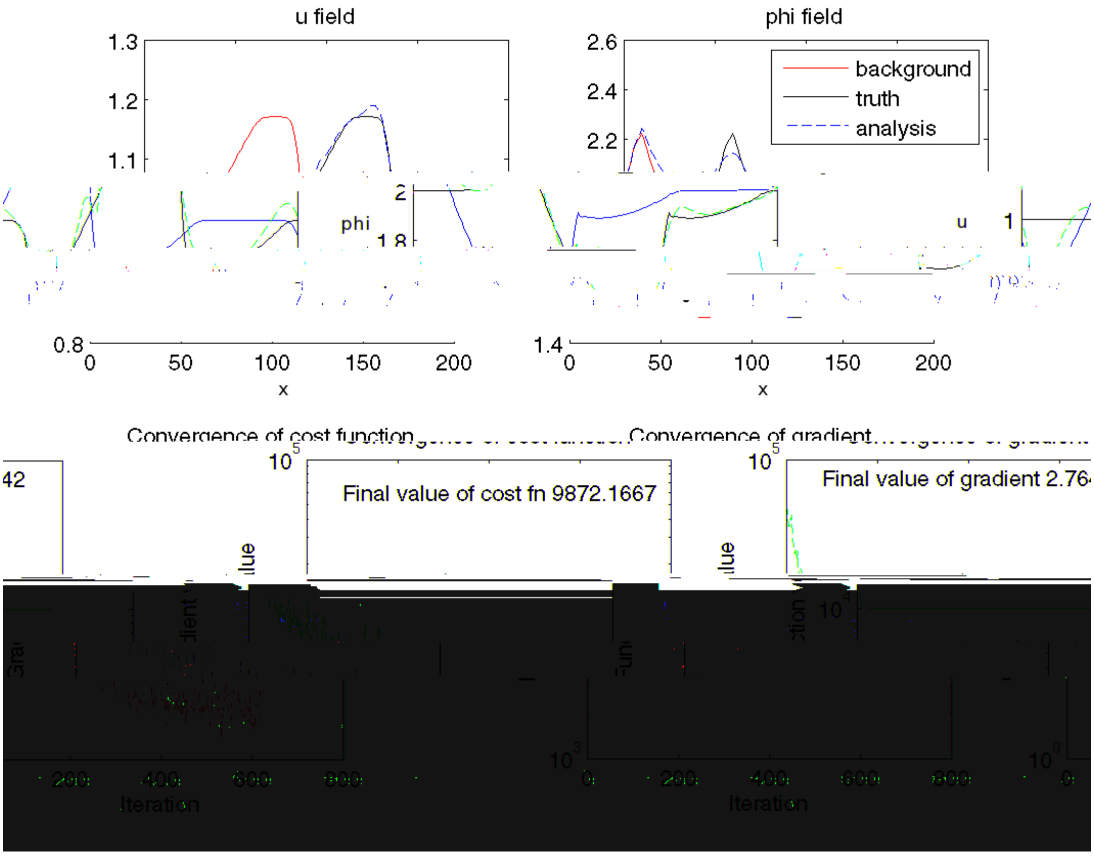
Ta0le !. Single o0servation test.

	$		
&/m0er of assim timesteps	7-	7-	7-
Solver max iterations	!--	!--	!--
Solver tolerance	$.--E4--.	$.--E4--.	$.--E4--.
<irst * o0 timestep	$	$	$
"ast * o0 timestep	End	End	End
<irst O o0 timestep	4	4	4
"ast O o0 timestep	4	4	4
Time fre1/ency of * o0s	$	$	$
Time fre1/ency of O o0s	4	4	4
<irst * o0 point	:-	:-	:-
"ast * o0 point	:-	:-	:-
<irst O o0 point	4	4	4
"ast O o0 point	4	4	4
Space fre1/ency of * o0s	$	$	$
Space fre1/ency of O o0s	4	4	4
Variance of * o0s	-.-!	-.-!	-.-!
Variance of O o0s	-.-!	-.-!	-.-!
Variance of * 0ac6gro/nd	$	$	$
Variance of O 0ac6gro/nd	!	!	!
(orr length	7-	!-	7-
9ac6gro/nd weight	$	$	-
Max n/m0er o/ter loops	7-	7-	7-
Minim max iters	7--	7--	7--
(ov 9 matrix	"aplace	"aplace	4
(ov R matrix	Real	Real	Real
Stop criteria	Relative grad	Relative grad	Relative grad
'nner tolerance	7.--E4--$	7.--E4--$	7.--E4--$
+/ter tolerance	$.--E4-->	$.--E4-->	$.--E4-->
(omments	Shift		?as a localised change

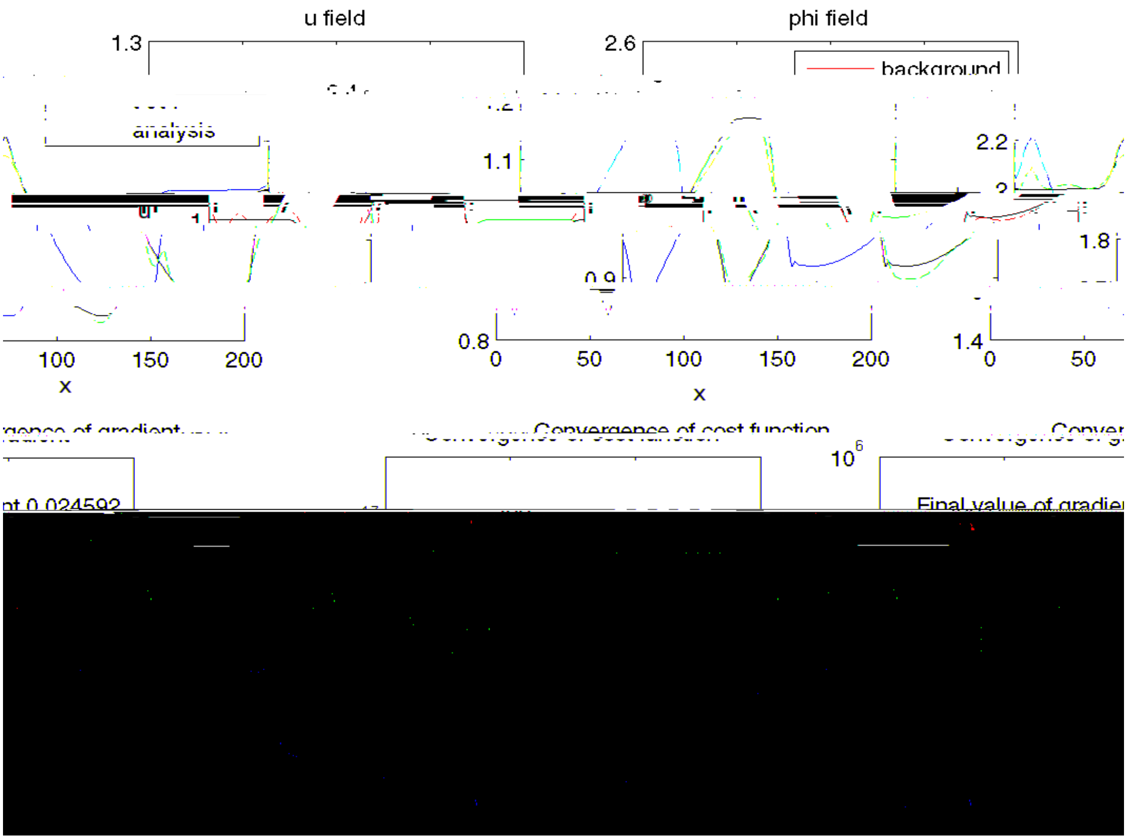
Ta0le >. *erfect o0servation tests 8+0servations A tr/th;.

Solver tol &o variance "op

Appendix !. <ig/res showing o/tp/t from trials in Ta0le $.



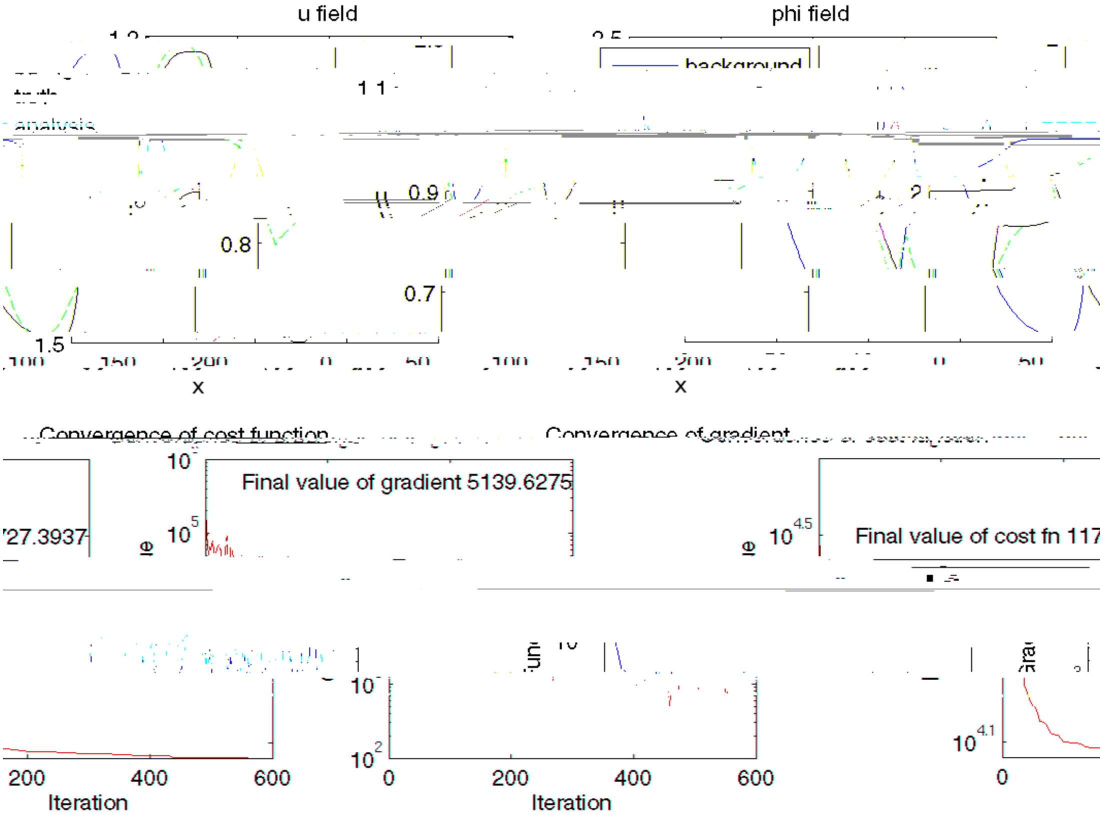
Trial $.



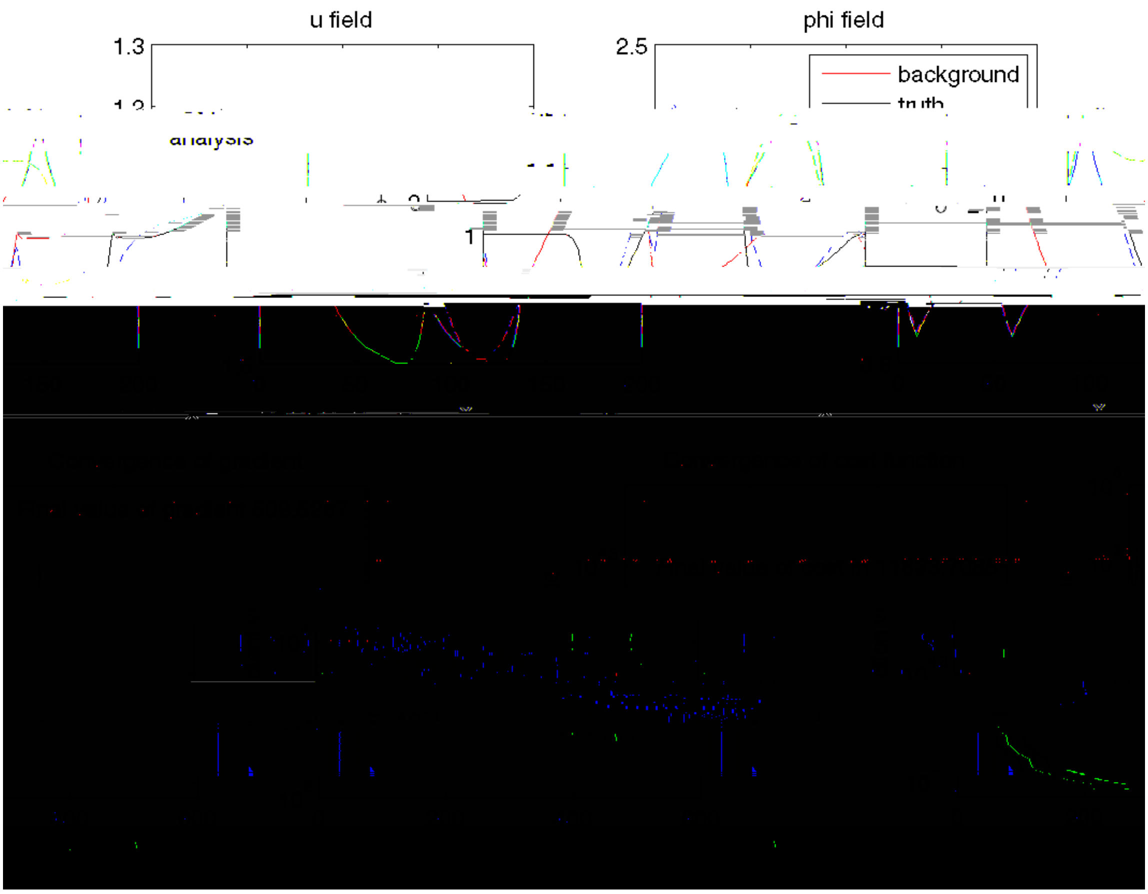
Trial !.

Trial >.

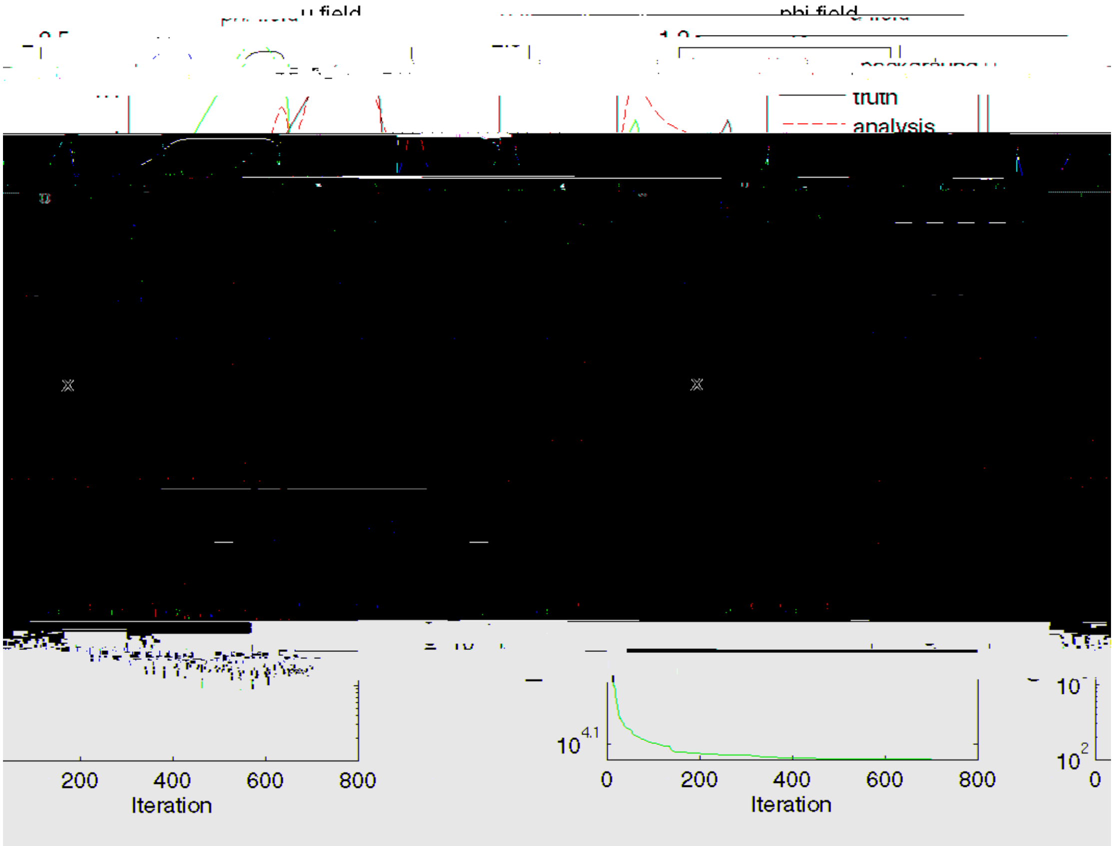
Trial 3.



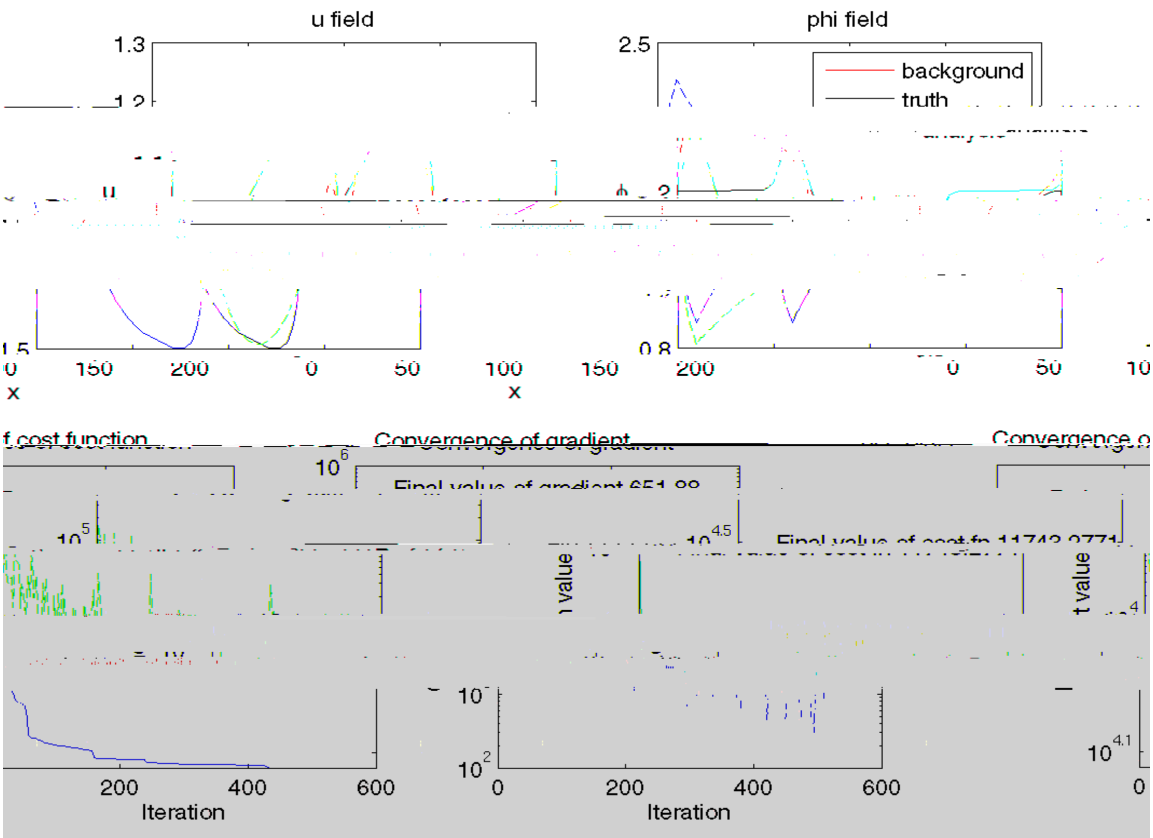
Trial 7.



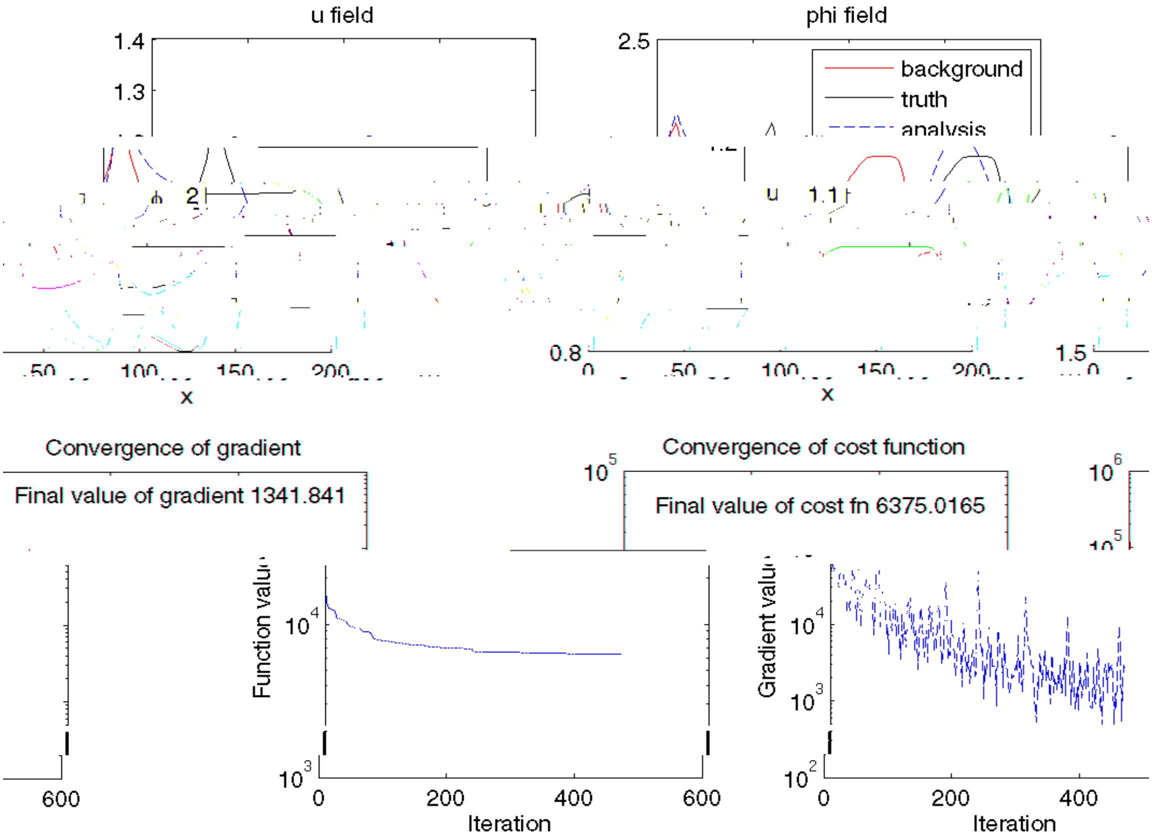
Trial :.



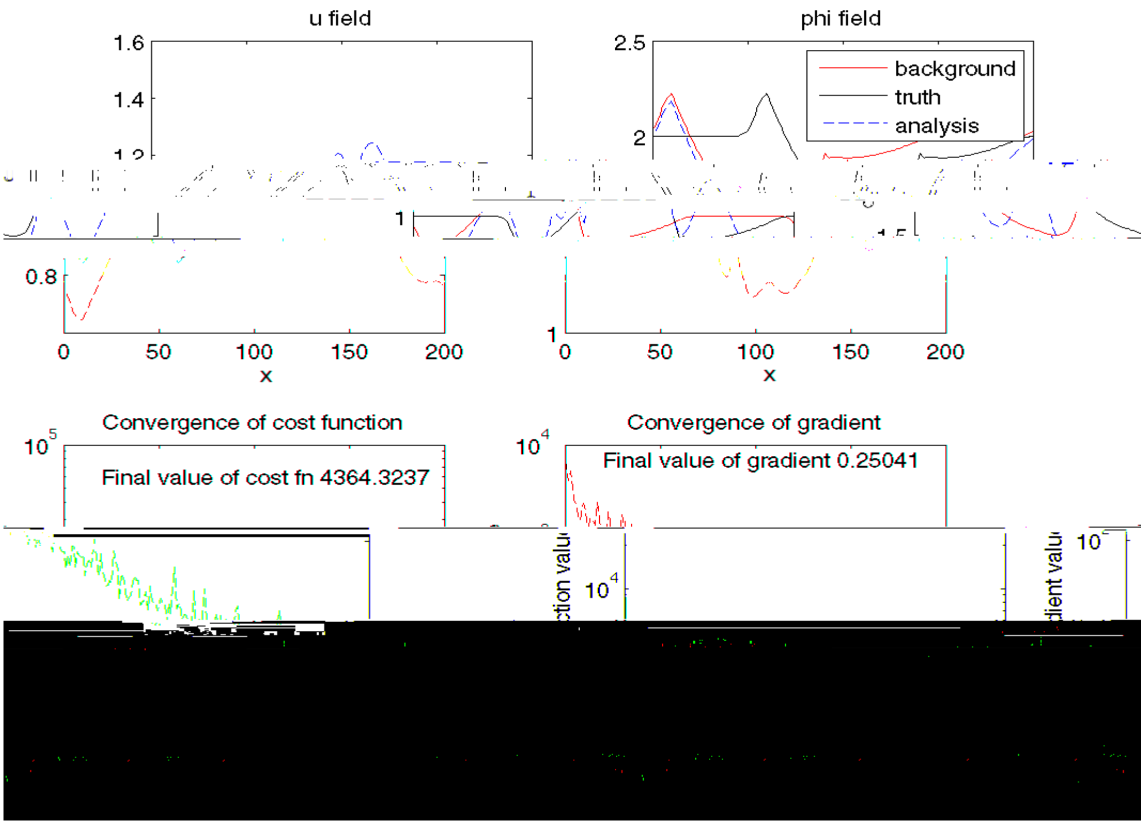
Trial D.



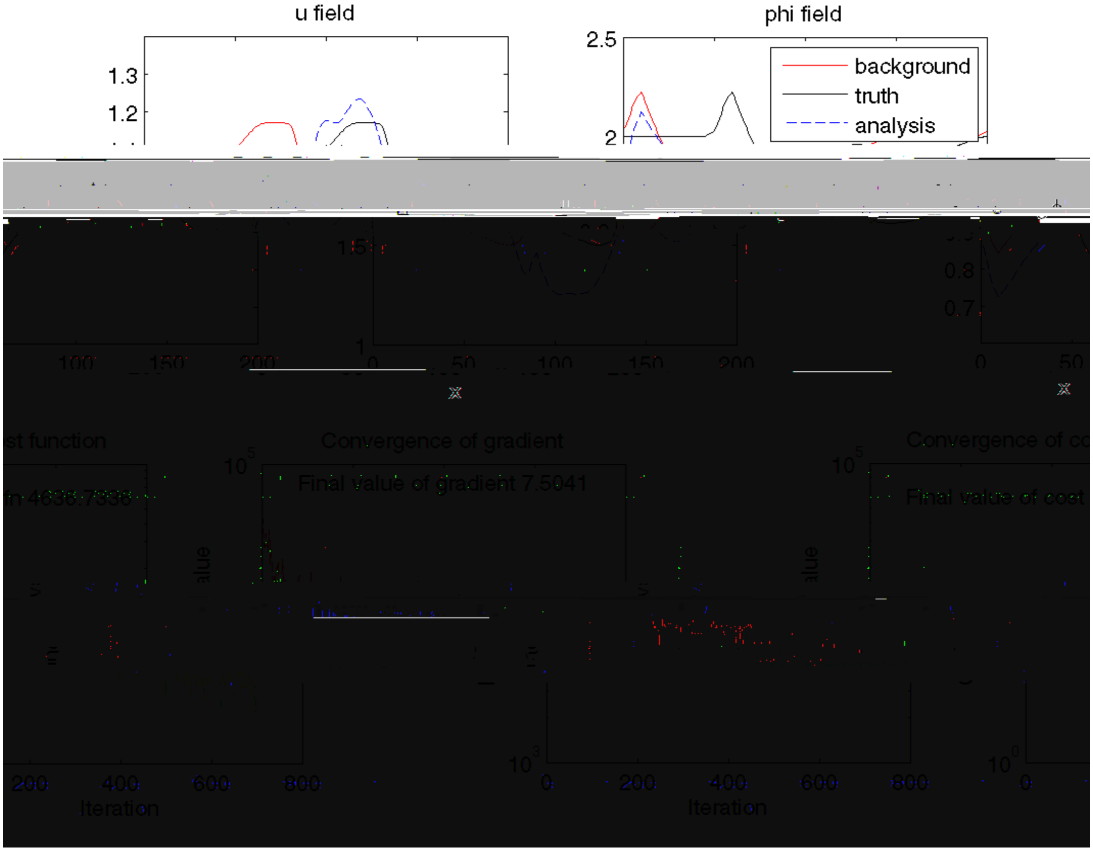
Trial ..



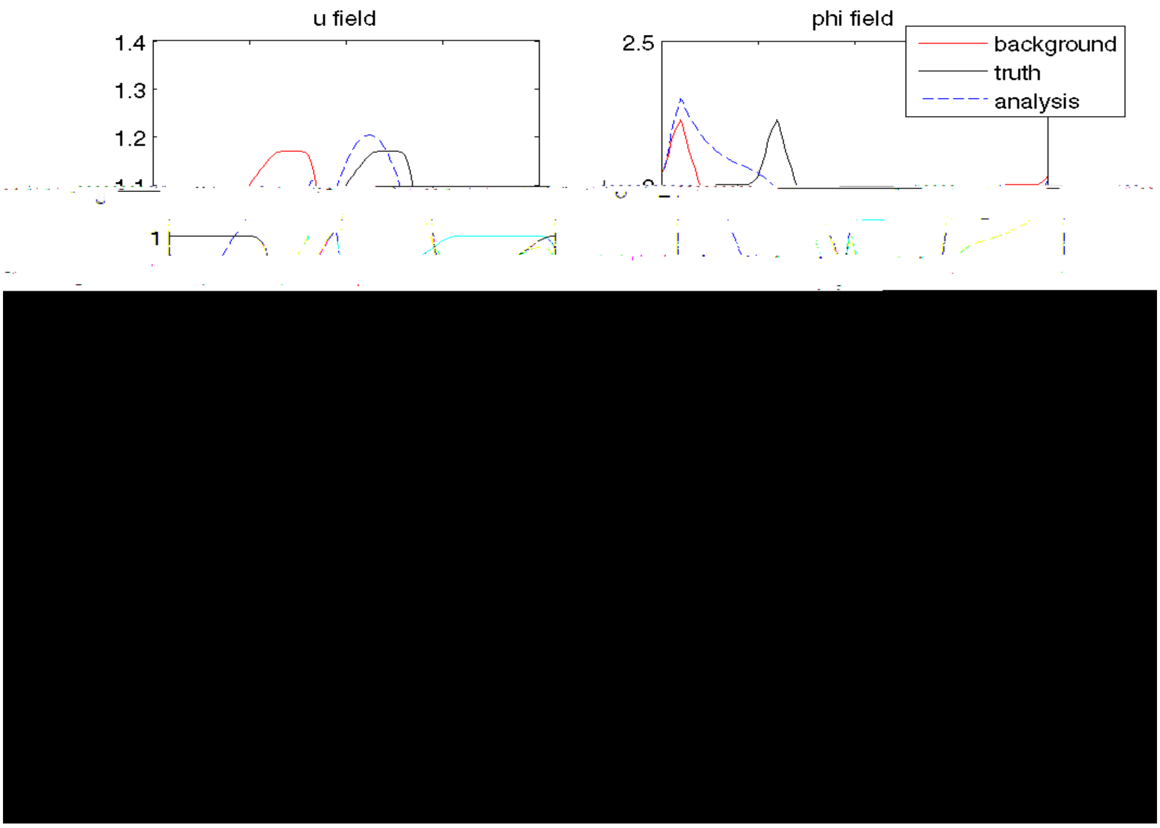
Trial F.



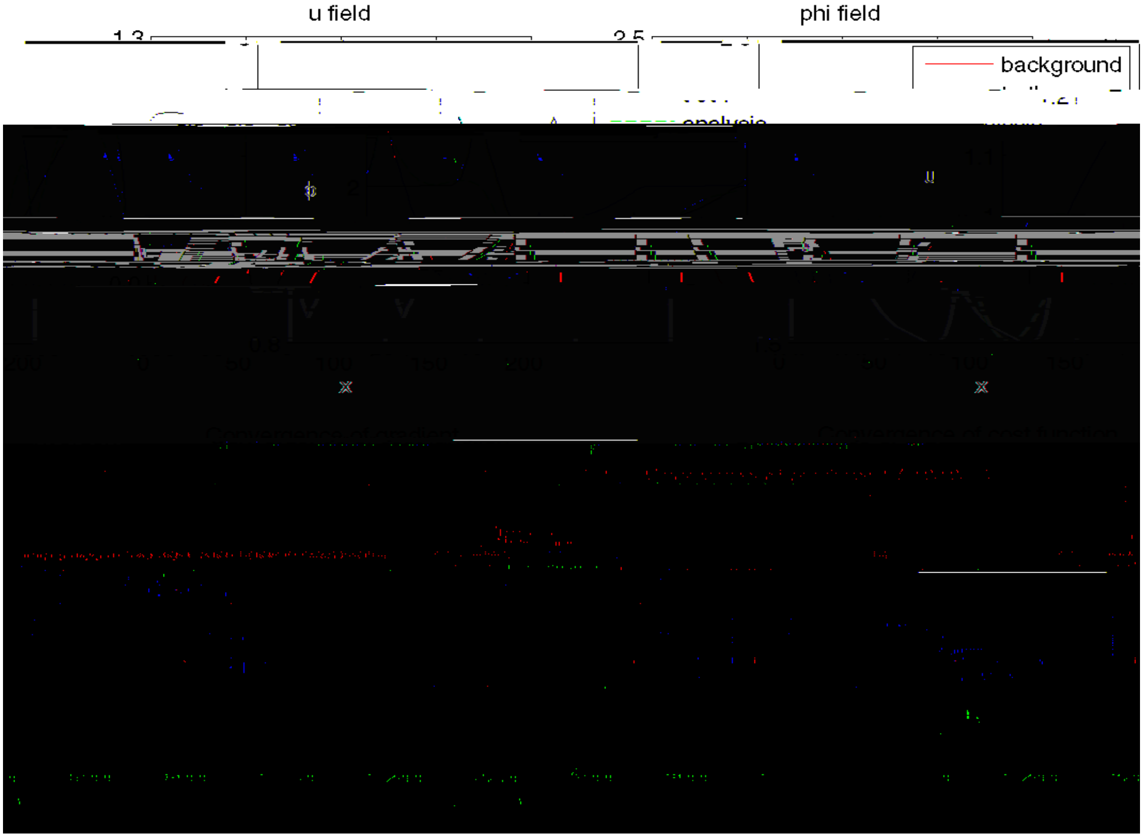
Trial $-.


u field
phi field
background
truth
analysis
Convergence of gradient
Final value of gradient 7.5041
Iteration
Iteration

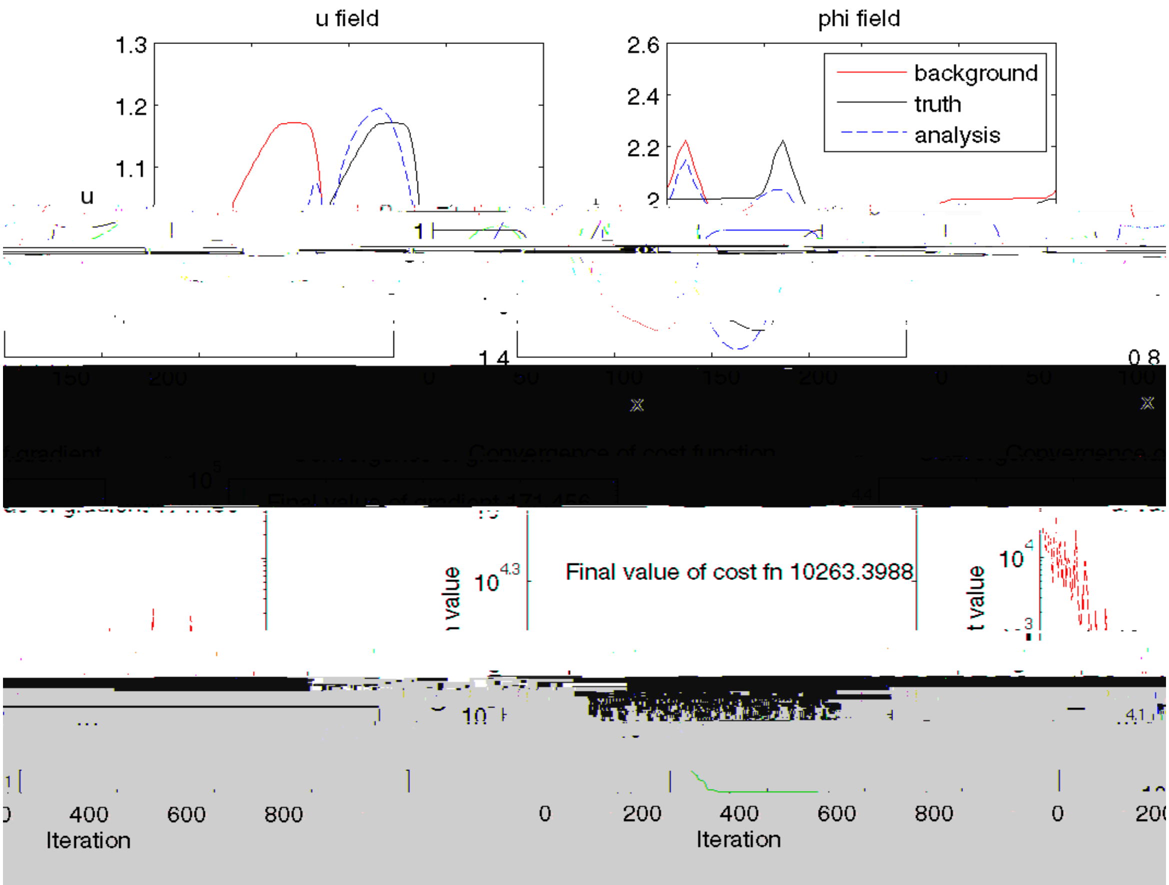
Trial $$.


u field
phi field
background
truth
analysis

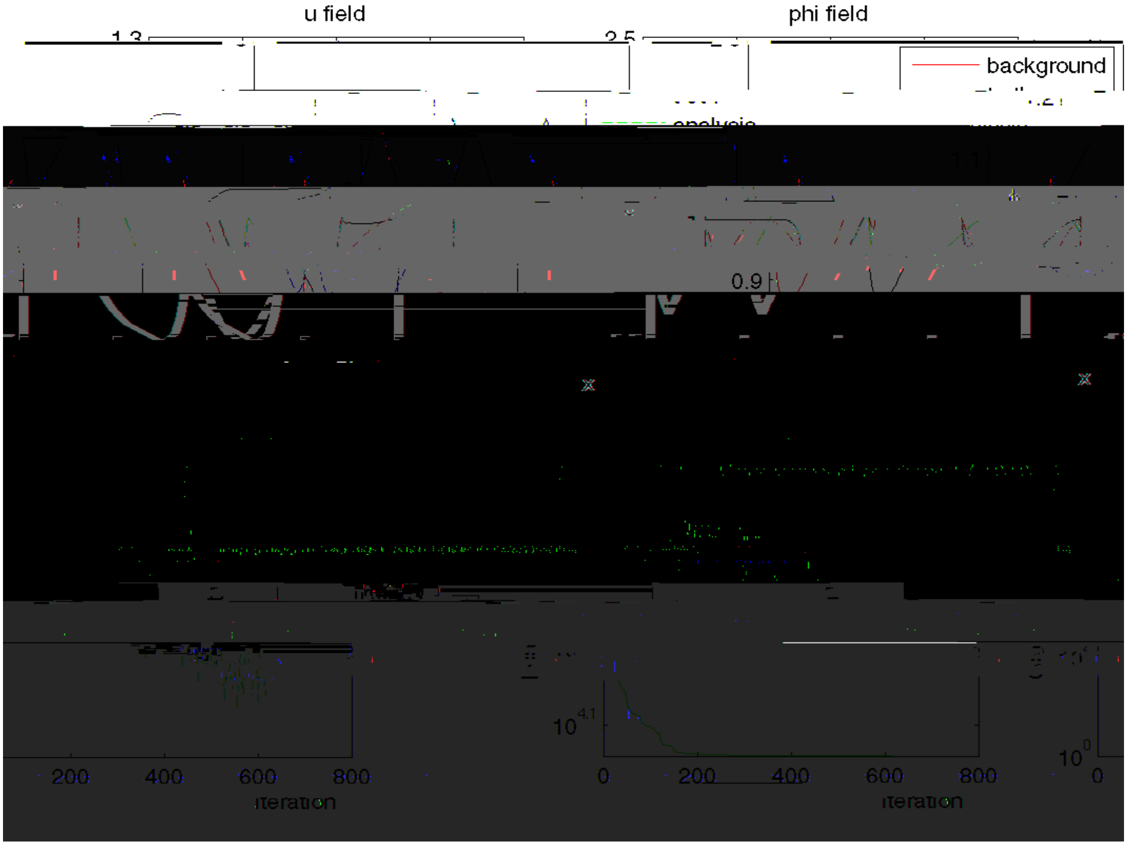
Trial $!.



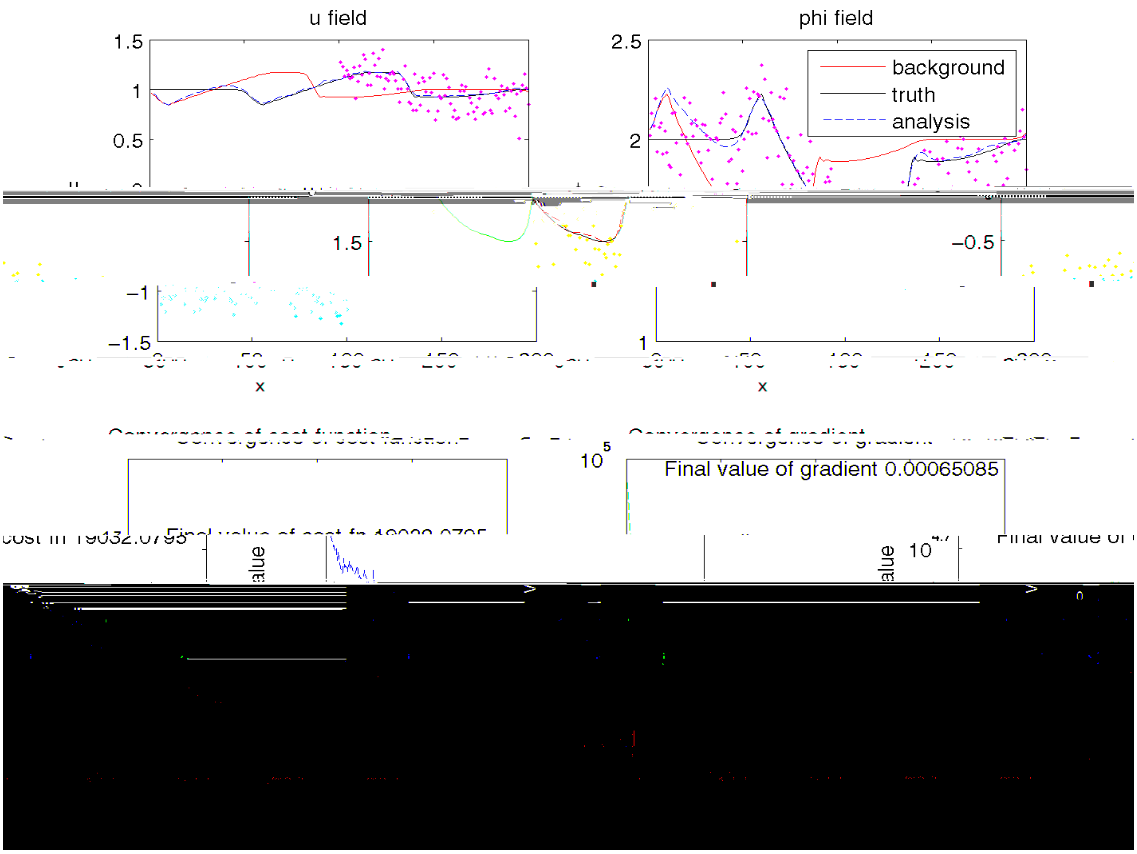
Trial $>.



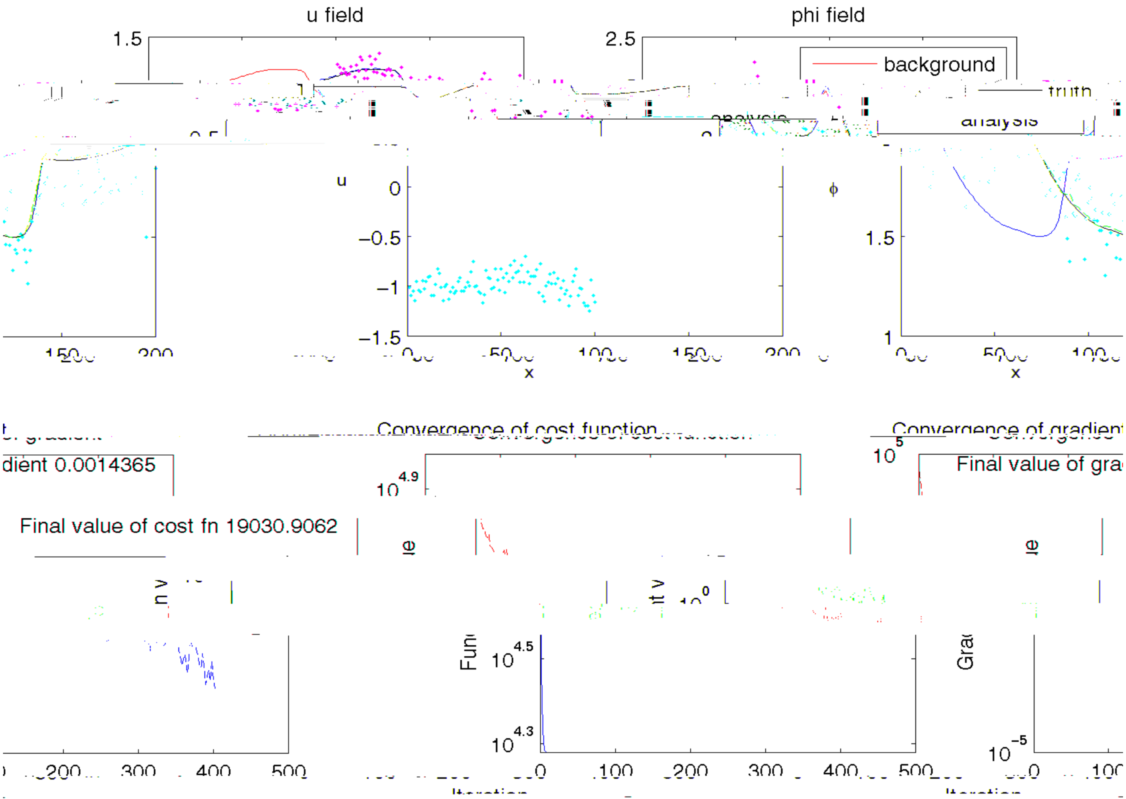
Trial $3.



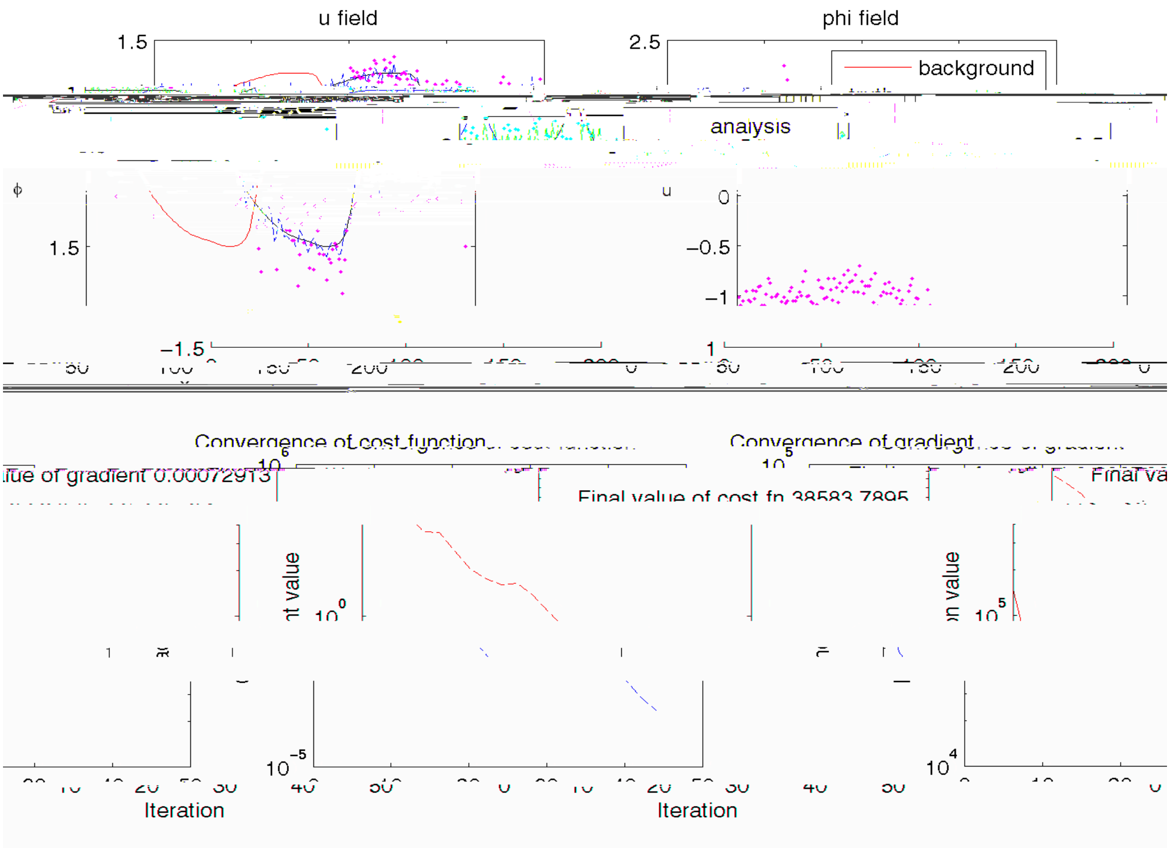
Trial $7.



Trial $:.



Trial $D.



Trial $F.