Target detectability in regional-scale AEM surveys

David Annetts
CSIRO
26 Dick Perry Av
KENSINGTON 6151
david.annetts@csiro.au

Juerg Hauser
CSIRO
26 Dick Perry Av.
KENSINGTON 6151
juerg.hauser@csiro.au

SUMMARY

Direct detection of drillable targets is among the primary goals of airborne electromagnetic surveys. As larger government funded regional surveys move towards large (> 5 km) line spacings, it is natural to question the likelihood of such surveys of directly detecting orebodies. A natural subsequent question relates to the degree to which data from such surveys can characterise orebodies. Here we model a Tempest prospecting system and address the first question though a numerical modelling study of 1024 targets with all model parameters randomised. We show that the likelihood of target detection decreases with increasing line spacing. A generally-conductive regolith as it is common in Australia means that target detectability increases with increasing time. We show that while over 80% targets are detectable at 16.2 ms using a line spacing of 1 km, at most 24% of targets are detectable with a 10 km line spacing. We address target characterisation by inverting numerical modelling data. We show that is possible to recover correct parameters within a few percentage points for targets with strike lengths less than 6.5 km provided such targets are bisected by a flight line. Our results suggest that Tempest-based surveys with line spacing less than 2.5 km are required to detect discrete targets in a tenement and that surveys with a line spacing of 1 km are optimal when direct target detection is a survey goal.

Key words: Airborne electromagnetic, forward modelling, inverse modelling detectability, line spacing

INTRODUCTION

Airborne electromagnetic surveys are commonly used to map variations in electrical conductivity over large areas. Results have been successfully interpreted with particular application to mapping large-scale structures in mineral exploration (Costelloe, 2014) and groundwater (Annetts et al, 2017) applications. Recent trends (Poudjom Djomani, 2018) have been towards larger surveys with large (at least 5 km) line spacing. Hauser et al. (2015) note that the lateral resolution of maps is directly related to survey line spacing.

Surveys may be funded by Governments in order to provide evidence of an area's prospectivity or to map physical property variation or structure, amongst many other reasons. Rarely is direct target detection a goal. Green et al (1998) suggest that "… generally, the mapping goal is not sustainable in an economic sense" and that "We must find orebodies."

Larger mining and exploration companies may find regional-scale datasets useful as a base for an exploration program that will require infill surveying. However, smaller companies may not have such options. For such companies, direct detection of targets in regional surveys is more important.

We address the utility of target detection in regional AEM surveys in this paper two parts. Firstly, we investigate the likelihood of target detection as survey line spacing is varied. Then, we investigate the degree to which it is possible to characterise a simple target on the basis of a single overflying flight line.

TARGET DETECTION

We consider a 20 km x 20 km area in which 1024 targets are randomly-located within the central 10 km x 10 km. Target and regolith parameter variation is presented in Table 1. All parameters were drawn from a normal distribution. All modelling used the CSIRO code LeroiAir (Raiche et al, 2007) and assumes a nominal Tempest AEM prospecting system with all flight lines running from west to east. Models were run using stations spaced 25 m apart over 20 km lines to assure spatial anomaly closure, with a 50 m line spacing to allow for various degrees of decimation.

Table 1: Range of variation of model parameters. Target width was derived from the target's aspect ratio. The target's reference point falls within ±10 m of the origin.

Parameter	Minimum	Maximum	σ^2
Regolith thickness (m)	.002	100	28.93
Regolith resistivity (Ωm)	1	200	57.41
Basement resistivity (Ωm)	250	1000	215.13
Target conductance (S)	1	1000	288.95
Target dip angle (°)	10	170	46.21
Target strike angle (°)	60	120	12.25
Target strike length (m)	250	2500	651.30
Target aspect ratio	0.95	2	0.30

Three-component responses from models employing parameters described in Table 1 run the gamut from barely detectable, through detectable only in the latest few gates to easily visible from early times.

In order to assess a target's detectability in a particular model, we employ a simple metric for the anomaly A *viz.* $A = t/b - 1$ where t is the response at any station and b is the background (layered-earth) response. When considering transverse components, we define $A = t$ since b is identically 0 for this component.

It is instructive to examine the response of a model. Figure A1 shows highlights of Model 701 with regolith thickness (R_k) and resistivity (R_ρ) 2.5 m and 164 Ωm respectively and basement resistivity (B_ρ) of 906 Ωm. The 947 S (T_S) target had a strike length (T_L) of 2411 m, a width (T_W) of 1666 m, a strike angle ($T_{Str.}$) of 66.2° and a dip angle (T_{Dip}) of 93°.

Panels C and D present inline and vertical component profiles (respectively) for the closest flight line to the model's reference point. Model plan, north-vertical and east-vertical sections are presented in Panels E, F and G. Panels A and B present the maximum anomaly amplitude for a number of flight line separations. Despite the clear anomaly in Panels C and D, using the criterion that a target can be detected with an amplitude five times that of the background, it can be seen from Panels A and B, that flight lines spaced greater than 2 km apart do not detect the target. Therefore, unless the target in Model 701 is directly overflown, it is unlikely to be detected. Indeed, even if it were overflown by widely-separated flight lines, small anomalies suggest that determination of the target's strike angle (amongst other parameters of interest) would be difficult.

Maximum anomaly amplitudes in each gate for all models, can be plotted as a function of target strike length for 1 km flight lines. Figure A2 compares maximum anomaly amplitude as a function of target strike length for 0.01 ms (Panel A), 0.17 (Panel B), 1.73 (Panel C) and 16.4 ms (Panel D). As expected, given the moderately thick and conductive nature of the regolith, target detectability using 1 km flight lines increases with later measurement time. Short targets, targets with strike lengths less than (e.g.) 500 m, are less detectable at a given time than longer ones, although this only becomes apparent at later times (Panels C and D). Figure 5 also suggests that for the nominal Tempest AEM system studied here, the inline component is a better indicator of anomaly amplitude than the vertical component.

It is useful to compare target detectability as a function of strike length for different flight line separations. Figure A3 plots inline and vertical target detectability as a function of strike length at 16.2 ms for flight lines with separations of 1 km (Panel A), 5 km (Panel B), 10 km (Panel C) and 20 km (Panel D). The reduction in the percentage of detectable targets with increasing flight line spacing is evident.

Figure 1 plots target detectability as a function of line separation and time as a summary over the 1024 models. Panel A shows detectability for inline component while Panel B shows detectability employing vertical component. Figures 5 and 6 show that a combination of late measurement times and flight lines spaced no further than 2.5 km are required to detect at least 50% of targets in the survey area under ideal conditions, and that a survey line spacing of 1 km is optimal for surveys designed to directly-detect targets.

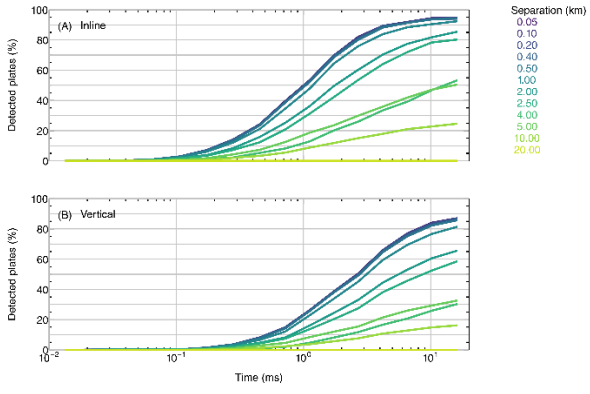

Figure 1: Target detectability as a function of measurement time and survey line spacing. Generally, closely-spaced survey lines and late measurement times are required to maximise detection likelihood.

TARGET CHARACTERISATION

Ideally, AEM responses could be analysed in the presence of a horizontally-layered regolith, employing data collected from a number of flight lines to ensure accurate estimation of both strike length and strike angle. For example, Hauser et al, (2016) show that a total of four lines (two overflying, and two over background) were sufficient to resolve thin plate parameters. However, when employing data from regional surveys with large line spacing, such ideal conditions may not be achieved. Therefore, we attempt to invert, using LeroiAir (Raiche et al, 2008), for target parameters on the basis of a single flight line as might be the case in a regional survey. We compute the response of finite-length targets using LeroiAir (Raiche et al, 2007) and the response of the 2.5D model using ArjunAir (Raiche et al, 2007). The 2.5D model used a 10 m wide target to achieve the same conductance as the LeroiAir targets.

With initial models employing correct parameters, and allowing allow parameters to vary, we are able to recover most model parameters within a few percentage points when targets have strike lengths less than 6.5 km. This is illustrated in Figure 2. When targets are longer than 6.5 km, recovery of strike length is not possible although remaining parameters are reasonably accurate. Knowledge of any or all of regolith and basement parameters generally improves recover of remaining parameters.

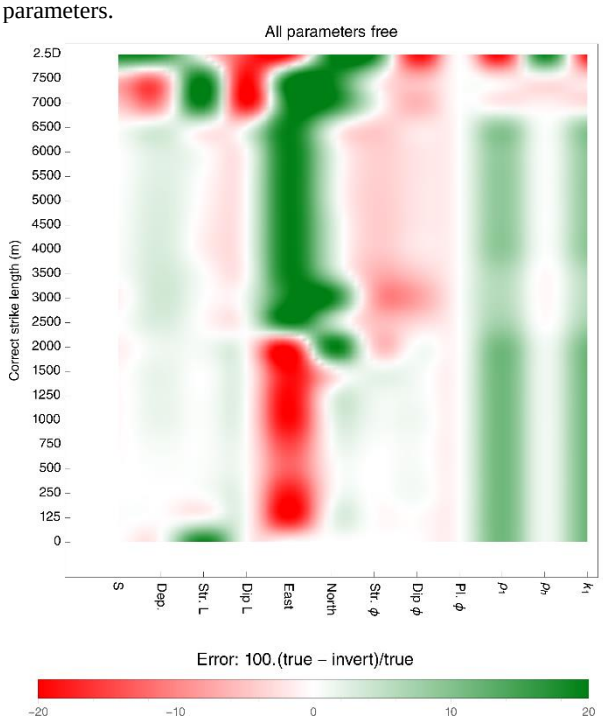

Figure 2: Dependence of model recovery error on strike length. Large errors in the eastern reference point result from this value's proximity to 0. Generally, parameter recovery is good when strike lengths are less than 6.5 km.

Figure 2 suggests that the response of a 2.5D target cannot be recovered by an inversion scheme based on a thin target. This is because the late-time response of 2.5D and finite-length inductively-thin targets are significantly different. Because these differences extend to earlier times, recovery of all model parameters is affected and guiding the solution using a correct initial model (with very long target), is no help. A corollary to

this is that inverting for a 2.5D model cannot be recommended, since any conductive geological feature will be assumed to be infinitely long.

As might be expected, accurate recovery of target parameters is diminished when targets are offset from flight lines. For short targets, parameter recovery is good when targets are offset from the flight line by 25% of their strike length. However, as shown in Figure 3, recovery of strike length is not possible for targets longer than 2.5 km, and becomes worse with increasing target offset.

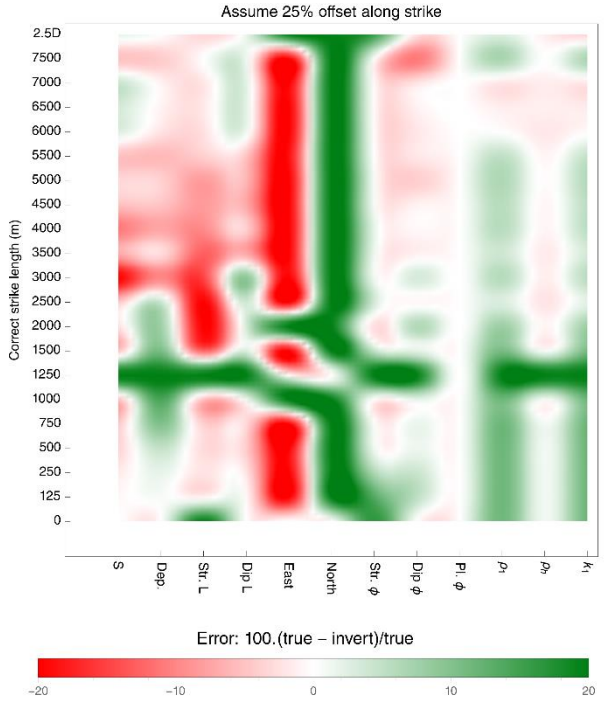

Figure 3: Dependence of model recovery error on target strike length when target in not bisected. Initial models here were offset 25% of the correct strike length towards north.

CONCLUSIONS

We have examined two critical aspects of geophysical prospecting viz. the likelihood of detecting a target from Tempest survey data in a tenement-sized area (10 km x 10 km) based on survey line spacing and choice of gate. We showed that the likelihood of a target's detection decreases with increasing survey line spacing and for a given line spacing, with measurement time.

ACKNOWLEDGMENTS

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APPENDIX

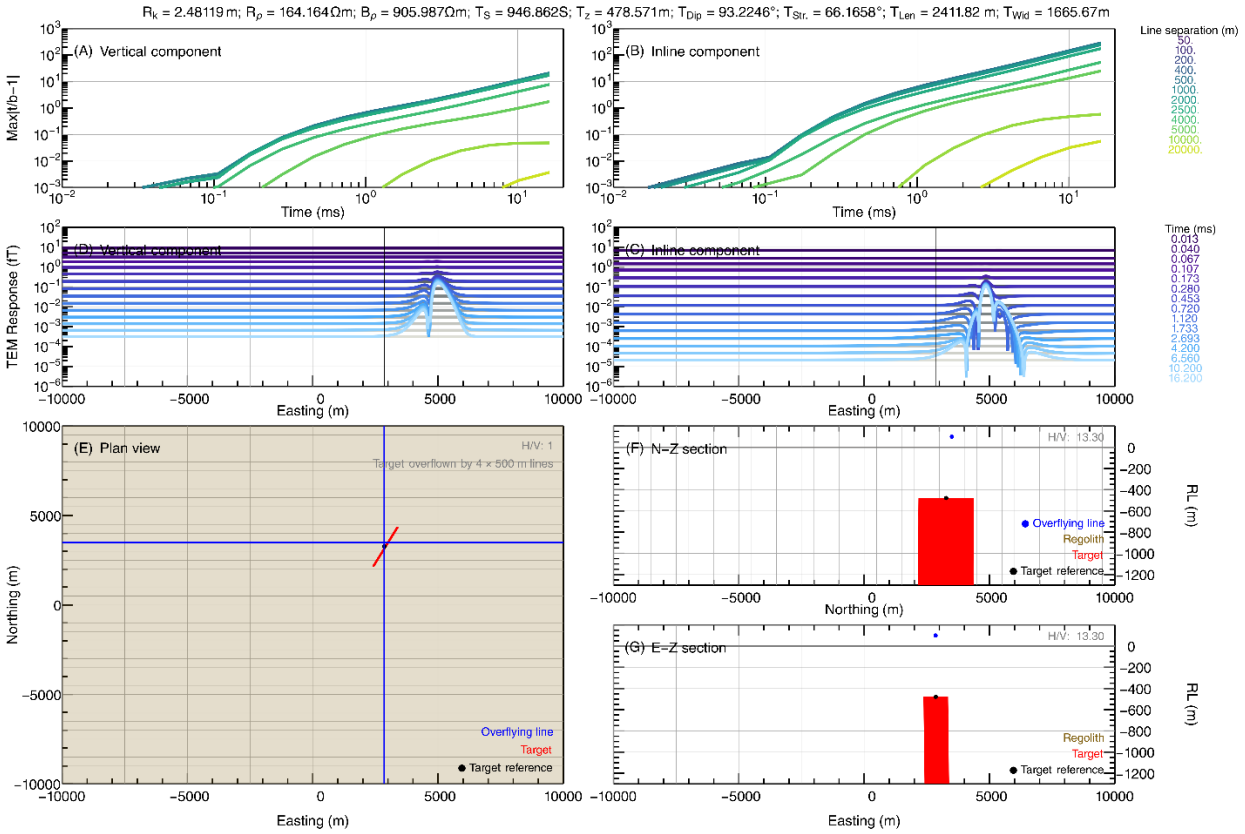

Figure A1: Anomaly amplitude for Model 701 as a function of survey line separation. Panels A and B plot anomaly amplitude. Panels C and D plot inline and vertical model response for the nearest overflight to the target's reference point. Panels E, F and G plot model plan, N-Z and E-Z sections respectively. For model 701, larger anomaly amplitudes are seen in inline-component data, and a line spacing of at most 5 km is required for an anomaly greater than five times background at 1 ms. For vertical component data, this changes to 2 km lines but at a later time.

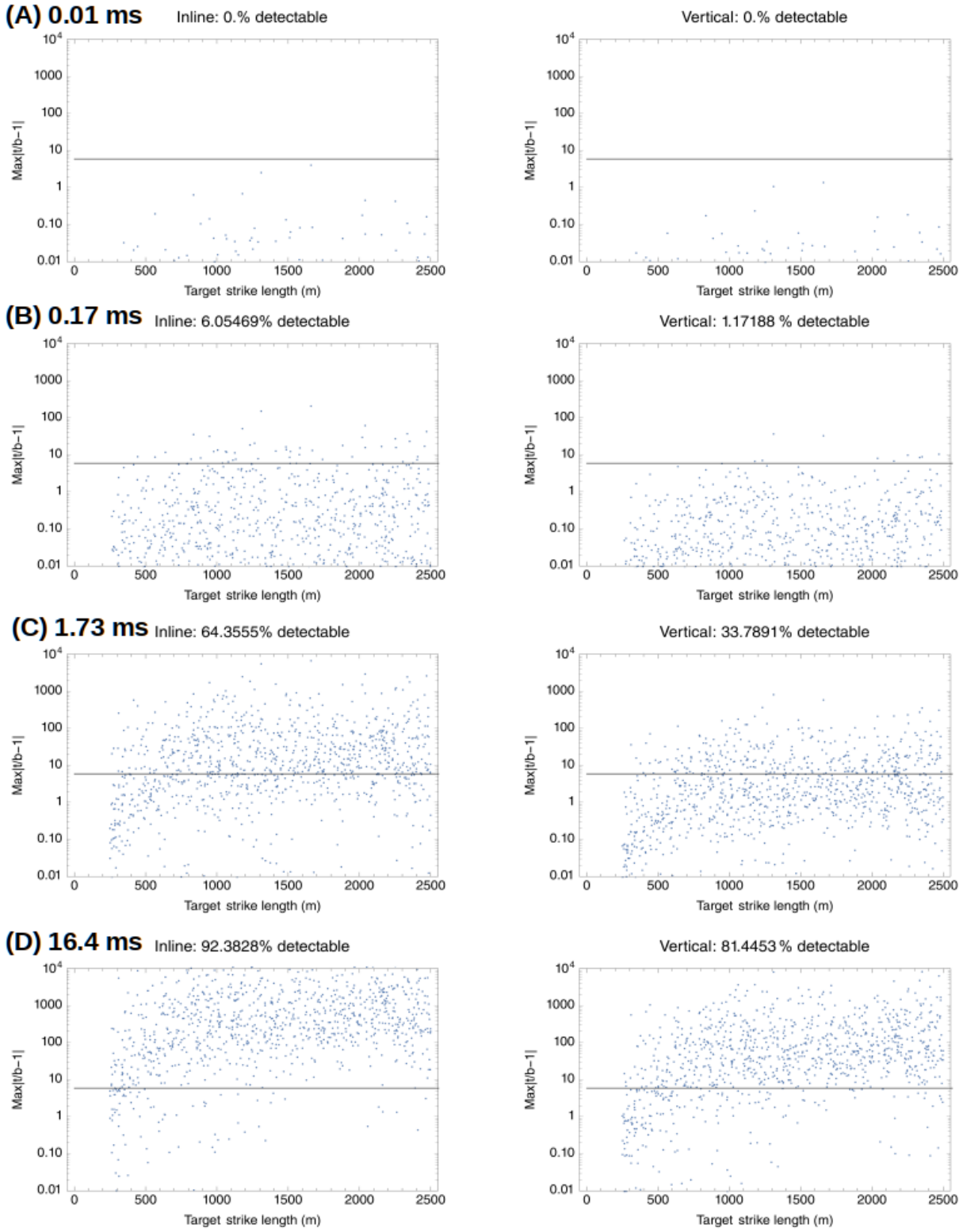

Figure A2: Target detectability for 1 km spaced survey lines as a function of target strike length. Panels A and B compare detectability at 0.01 ms for the inline and vertical component. Similarly Panels C and D compare detectability at 0.17 ms. Panels E and F at 1.73 ms, and Panels G and H at 16.4 ms. At a constant line spacing, the likelihood of targets being detected improves with increasing time.

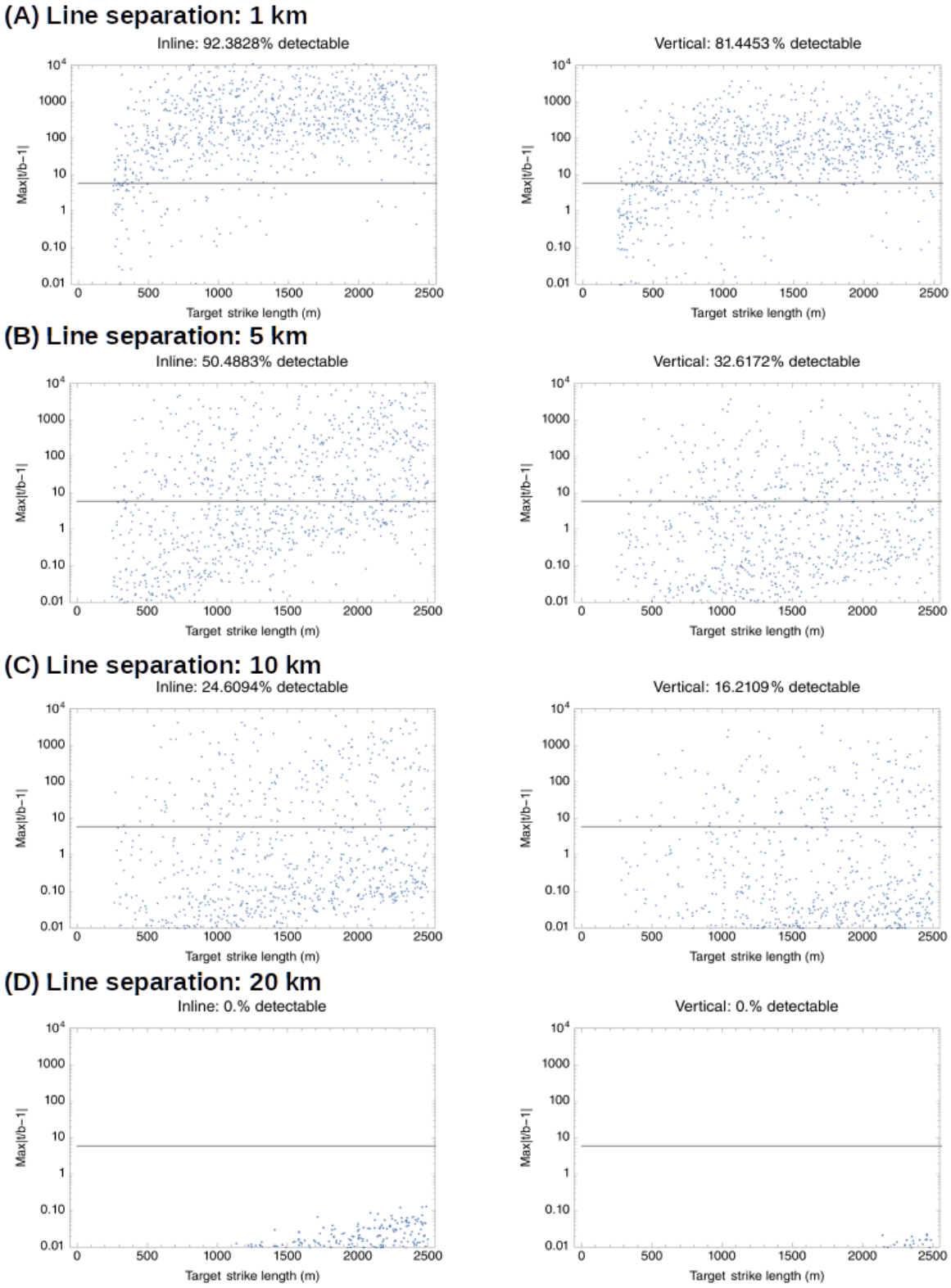

Figure A3: Likelihood of target detectability as a function of line spacing at 16.4 ms. Panels A and B compare detectability for 1 km spaced survey lines for the inline and vertical component. Similarly Panels C and D compare detectability for 5 km spaced survey lines, Panels E and F for 10 km spaced survey lines and Panels G and H for 20 km spaced survey lines. As survey line spacing increases, the likelihood that a target will be detected falls rapidly.