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EUROCONTROL Guidance Material for Minimum Safe Altitude Warning
Appendix D-1: Enhancement of MSAW for Skyguide

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Appendix D-1: Enhancement of MSAW for Skyguide

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Abstract

Skyguide's current MSAW system is fairly basic, and is applied around the GVA and ZRH final approach areas. Skyguide's Safety Nets Task Force (SNTF) is conscious of the functional shortcomings in the current MSAW system, and furthermore is aware of a possible future requirement for Skyguide to implement MSAW Swiss-wide.

This study investigates the feasibility of extending the implementation of MSAW beyond its current boundaries (to cover areas including Mont Blanc) and the effectiveness of using of digital terrain data.

Keywords

Safety Nets	Polygon	Nuisance Alert
MSAW	Inhibition	Prediction
DTED	Warning Time	
AMP	Alert	

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CONTENTS

FOREWORD

Skyguide's MSAW system was installed in 1999. It is currently applied in the vicinity of Geneva and Zurich airports. Despite having some technical limitations, the system is in daily operational use and it is known that controllers trust it.

In the first half of 2008, Skyguide and EUROCONTROL, supported by QinetiQ and Deep Blue, collaborated to study possible enhancements of the MSAW function.

This document is one of a set of two documents that describe the actions undertaken and the results achieved. The document set includes:

- Appendix D-1: Enhancement of MSAW for Skyguide [This Document]
- Appendix D-2: Functional Hazard Assessment of MSAW for Skyguide

The document set forms a Case Study in applying the optimisation and safety assurance guidance material that supports the EUROCONTROL Specification for MSAW, and as such is guidance material in its own right.

Note however that specific solutions identified in the document should not be adopted without performing similar analysis to determine their applicability in the target environment.

1. INTRODUCTION

1.1 Overview of the Study

Skyguide's MSAW system was installed in 1999. It is currently applied in the vicinity of Geneva and Zurich airports. Despite having some technical limitations, the system is in daily operational use and it is known that controllers trust it.

Dating back to 2004, Skyguide's Safety Nets Task Force (SNTF) has been conscious of difficulties in trying to overcome functional shortcomings of the MSAW system, which have existed due to a lack of international regulatory guidance and available Best Practices. This was one of the drivers to get Skyguide deeply involved in the Eurocontrol SPIN Task Force. Awareness of possible obligations under ECIP to implement MSAW throughout Skyguide's Area of Responsibility was another reason to welcome this MSAW Case Study which has been undertaken under the SPIN framework.

This study considered MSAW for Geneva and focussed mainly on the performance aspects of MSAW. However, it also addressed other practical issues related to set up and maintenance of the system.

1.2 Study Objectives

The objectives of the study were to find answers to the following key questions:

- Scalability: what needs to change in the existing MSAW implementation to make it usable for the entire Skyguide area of interest?
- Volumes (hand designed polygons) versus DTED: what is the best option for Skyguide?
- Detection versus prediction: what is the best option for Skyguide?
- Operational Philosophy: are the current key choices with respect to track eligibility sustainable?

In particular, the study examined the combination of DTED with prediction, compared to polygons both with and without prediction.

On the issue of eligibility, in Geneva, tracks are only subject to MSAW if they are correlated with a flight plan and squawking an IFR code. This report examines whether this choice is suitable for an extended MSAW system.

1.3 Report Structure

The key elements of the current MSAW system are described in chapter 2 of this study. The analysis method and tools are described in chapter 3. A detailed description of the steps taken in the study and the results are presented in chapter 4. Conclusions are drawn in chapter 5, and recommendations are made in chapter 6. A list of abbreviations is included in chapter 7.

Most of the pictures and diagrams in this report are contained in chapter 8. These pictures show, amongst other things, the MSAW polygons that were used, pertinent MSAW situations and the geographical distribution of MSAW alerts.

Many of these pictures were produced using Google Earth™. The KML files used to draw the polygons, funnels and tracks can be found on www.eurocontrol.int/safety-nets if the reader wishes to examine the pictures using Google Earth™ (a free version is available at earth.google.com). The use of Google Earth™ (see section 3.5) greatly facilitated the discussions in the study team and with operational staff.

2. MSAW AT GENEVA

2.1 MSAW Polygons

Skyguide's current MSAW system works on the basis of detecting aircraft tracks that penetrate predefined volumes of airspace. These MSAW volumes have been carefully defined off-line by Skyguide engineers with the assistance of experienced controllers.

The MSAW volumes for Geneva are shown in Figure 8-1. They extend to a maximum of 30 NM from the airport. Each MSAW volume is defined as a polygon with a fixed ceiling height. The majority of the coverage is based on pre-defined Minimum Vectoring Altitudes (MVAs) with each MSAW polygon ceiling set 350ft below the respective MVA.

In addition, Skyguide employ the MSAW function for Approach Path Monitoring (APM). This has been achieved by defining numerous small MSAW polygons along the line of the runway final approach paths (GVA RWY 23 and 05). When viewed in 3D, these small polygons resemble a staircase. See Figure 8-2 and Figure 8-3.

A hole in the MSAW polygon coverage can be seen close to Geneva. This gap in the polygons is designed to prevent nuisance alerts for aircraft on arrival to or departure from Annemasse airport (joining and leaving flights).

No prediction is applied in the MSAW system. If an eligible aircraft penetrates one of the defined MSAW volumes then an alert is immediately generated which may then be displayed to the controller, depending on whether the controller has already manually inhibited the track from MSAW alerting.

2.2 Track Eligibility and Inhibition

An aircraft is eligible for MSAW processing if it is correlated with a flight plan, and its SSR code is not on a pre-defined VFR or Military (MIL) code list. On the face of it, this scheme should work well. However, there is sometimes a mismatch between the flight rules for an aircraft and the allocated SSR code. For example, a flight may be allocated an SSR code which indicates IFR, yet the flight takes off VFR joining IFR later (This includes not only the Annemasse situation described above, but also includes all airports/airfields close to Geneva). In other cases a flight may be squawking an SSR code indicating IFR but may then "leave" making a VFR approach, and as a consequence proceed intentionally below the MVA into an MSAW polygon.

The controller has the facility to inhibit MSAW for selected tracks. This is usually done for visual approaches or departures, and VFR traffic squawking an IFR SSR code (joining flights). The controller knows these flights will remain close to the terrain to have visual references, and therefore an MSAW alert would just be a distraction.

2.3 MSAW Performance

The current MSAW system generates around 15 alerts per day on average. Normally, however, not all of these would result in an alert (visual or audible) at the CWP, since the controller has the facility to disable MSAW for specific tracks, and also to acknowledge an alert that is in progress. (In the case of MSAW being disabled, the track label indicates this so the controller remains aware that MSAW is disabled for this particular track).

Whether these alerts could be defined as a nuisance or not is debatable, since the controllers appear to have learnt to expect a small number of unnecessary alerts which they can easily suppress.

Most essentially, verbal comments from controllers indicate that they trust the current MSAW system.

Since this study examines the effect of increasing the coverage of MSAW over a wider geographical area, it is almost inevitable that the alert rate will increase. It is a widely held view that a large number of nuisance alerts can lead to controllers becoming desensitized to alerts, and hence not paying due attention to alerts when they occur. In the Skyguide case, the controller may disable tracks from MSAW processing, too many alerts could still be an issue, even if it just one of workload. Therefore, in this study the number and nature of alerts will be measured.

3. METHODOLOGY AND TOOLS

3.1 Overview of Analysis Methodology

The central theme in this study was the use of a fast time MSAW model to measure the performance of MSAW in a variety of configurations. These configurations included:

- Extension of MSAW polygons to cover parts of the Alps and the Jura mountains
- The use of Digital Terrain Elevation Data (DTED) for conflict detection
- The use of inhibition volumes to minimise alerts for aircraft on final approach
- MSAW using various types of prediction and parameter settings

The work was carried out in a series of steps. The precise steps and the results of each stage of the analysis are explained in detail in chapter 4.

3.2 MSAW Optimisation Objectives

Essentially, the object of MSAW design and optimisation is to maximise the number of conflicts which are alerted with adequate warning time and minimise the number of nuisance alerts.

These objectives are, to some extent, incompatible with each other and therefore need to be prioritised. The question of which of these priorities is the most important will arise later in this report, and may be a factor in Skyguide's ultimate decision of whether to use DTED, polygons or a combination of both.

The need to balance the warning time and the nuisance alert rate will also influence the parameters, particularly the prediction time, which may be used for conflict detection in MSAW.

3.3 Data Samples

The data used for this study comprised radar track recordings made at Skyguide premises in Geneva. The sample period covered 25 days in September and October 2006. Not all the recorded days were complete, so the total recording duration was in fact around 23 days, 5½ hours; large enough for statistical significance in the results.

Later in the study, this data was complemented by artificial scenarios. These data comprised 12 track situations in the vicinity of Geneva. These scenarios are described in more detail later in chapter 4.

3.4 MSAW Model and STRACK

During the course of this study, both the track recordings and the artificial scenarios were input into the fast-time MSAW model in order to measure the performance of MSAW. The performance results of each run were recorded in the MSAW alert results files.

The STRACK display tool was essential for the analysis, being used to visualise the recorded system tracks and the modelled MSAW alerts together on the same display. [STRACK is a contracted form of Surveillance TRACK display].

All the tools were written in the C programming language, running on a PC under the Fedora operating system. STRACK uses standard Motif/X-Windows libraries.

The inputs to and outputs from the MSAW model and STRACK are shown diagrammatically in Figure 3-1 below:

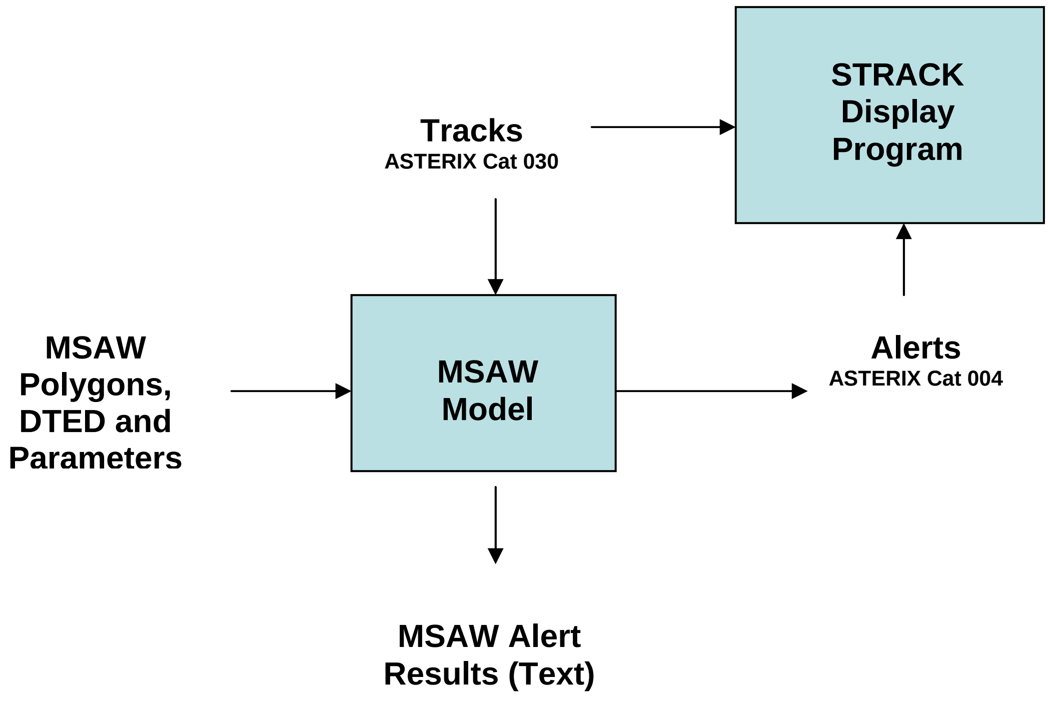


Figure 3-1 Analysis Process using the MSAW Model and STRACK

3.4.1 MSAW Model

The MSAW model is a simulation tool capable of modelling not only the current Skyguide MSAW system, but it is also flexible enough to allow the testing of a number of additional features. The model runs in fast time, generating a weeks worth of results typically in less than thirty minutes.

The Skyguide MSAW model was taken, and was further enhanced to meet the requirements of this study. In particular, the following features were introduced:

- The import of Digital Terrain Elevation Data (DTED) for conflict detection
- Prediction algorithms for conflict detection
- Use of MSAW inhibition volumes

The processing stages in the MSAW model are shown in

Figure 3-2 below:

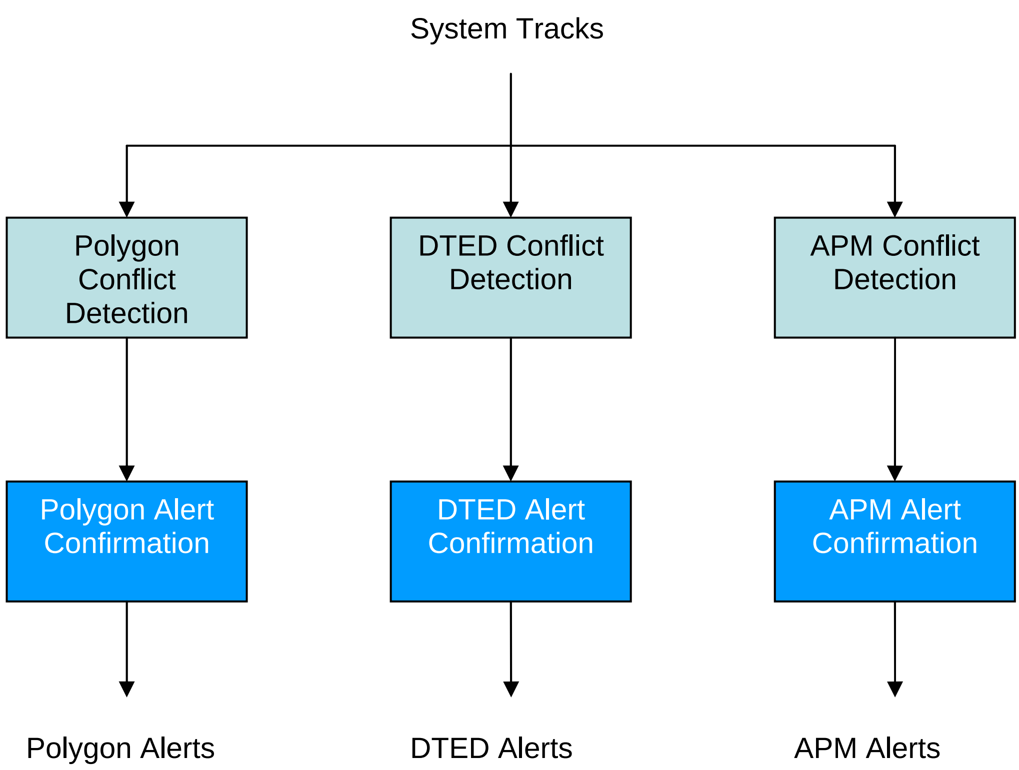


Figure 3-2 Processing Stages in the MSAW model

Note that although the MSAW model is capable of modelling APM, this feature was not used for this study.

Various files, defining essential parameters, the terrain, the MSAW polygons, and a list of SSR codes were input into the MSAW model each time it was run.

An extract from the MSAW polygon definition file is shown in Figure 8-4. The polygon definition file contains the polygons used for MSAW conflict detection. Each polygon definition includes the name of the polygon, a ceiling altitude in feet, and a list of points defined in latitude and longitude.

The parameters to be applied were specified in a simple text file, an example of which is shown in Figure 8-5. The parameters include activation flags for various parts of the MSAW model, as well as the critical conflict detection thresholds.

The full VFR/MIL code list is shown in Figure 8-6. This comprises a number of SSR code blocks that are automatically suppressed from MSAW alerting.

The model generated two types of output; the alert results as a text file (described in section 3.4.2) and a binary file of ASTERIX Category 4 (Safety Nets) records, for input into STRACK.

3.4.2 MSAW Conflict Detection using Polygons

MSAW conflict detection against polygons as implemented in the current Skyguide MSAW system is illustrated in Figure 3-3 below:

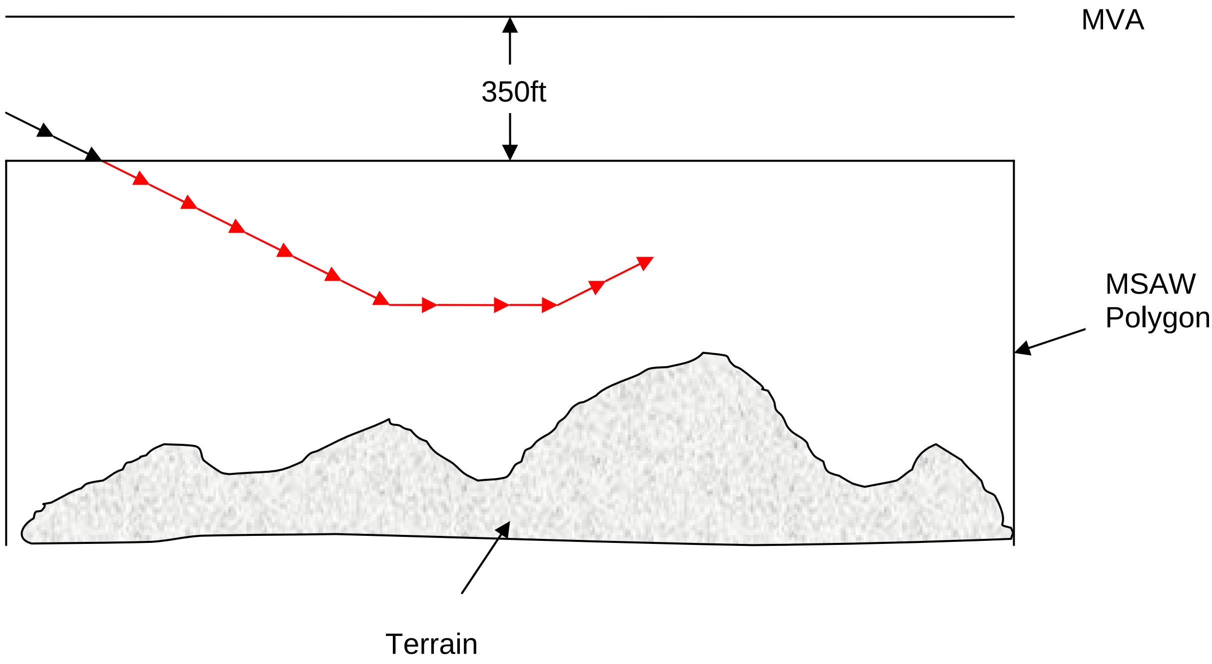


Figure 3-3 Illustration of MSAW conflict detection using polygons

The MSAW surface is typically (though not always) defined 350ft below the MVA. The MVA has to assure 1000ft clearance above the highest obstacle with a 5NM lateral buffer in non-mountainous terrain, and 2000ft clearance above the highest obstacle with a 5NM lateral buffer in mountainous terrain. (Note that in some circumstances the lateral buffer may be 3NM). Since the MVA varies through the airspace, the MSAW surface consists of numerous polygons. An MSAW alert is triggered whenever an MSAW eligible aircraft enters one of the pre-defined polygons, irrespective of whether the aircraft entered through the wall or ceiling.

3.4.3 MSAW Conflict Detection using DTED

MSAW conflict detection using DTED is normally based on linear prediction, which projects forwards from the current track position for a certain look-ahead time. The key parameters are the DTEDWarningTime and DTEDVerticalMargin, which are illustrated in Figure 3-4 below:

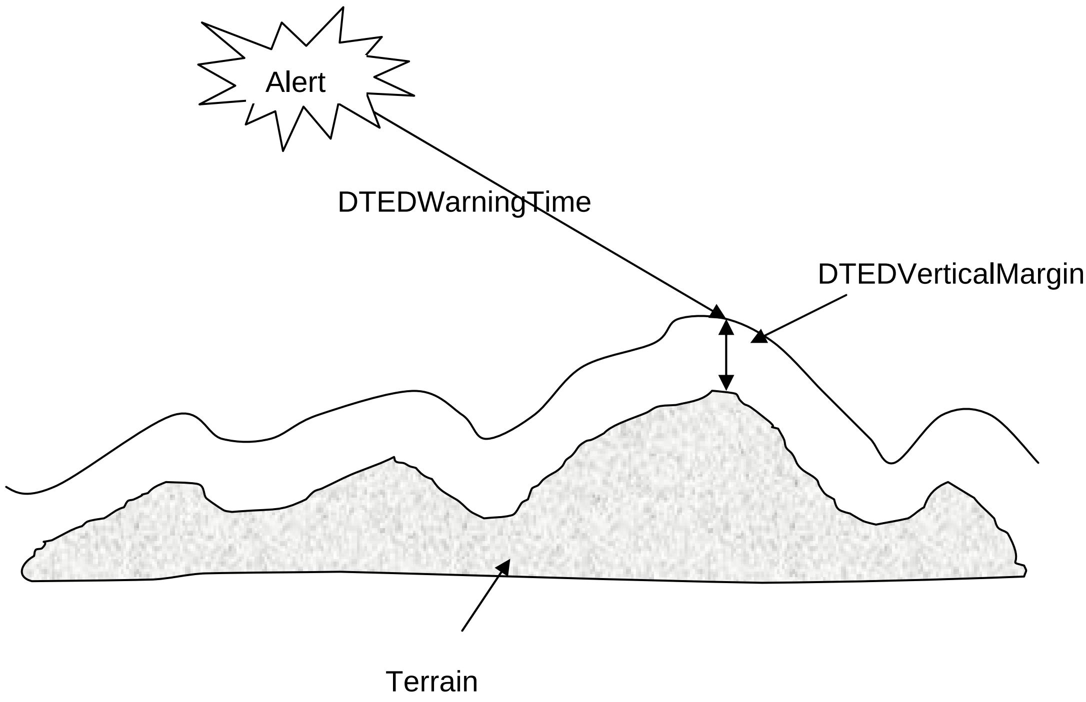


Figure 3-4 Illustration of the MSAW conflict detection using DTED

DTEDVerticalMargin is the safety margin above the terrain which is used as the point of conflict in the DTED part of the MSAW model. Note that this margin is usually set taking into account the characteristics of the DTED data, and the safety margin judged to be sufficient. For much of a geographical area this terrain plus the vertical margin is likely to be substantially below the MVA

The DTEDWarningTime parameter is used in the alert confirmation stage to determine whether an alert should be issued at the current time.

Setting the DTEDWarningTime to zero would effectively mean that no prediction is applied. In this study, prediction was always used in relation to DTED data, starting from a DTEDWarningTime of 35 seconds.

3.4.4 Digital Terrain Elevation Data (DTED)

DTED was sourced for this study on DVD.

For convenient input in the MSAW model, the source data was converted first to a fine grid with a cell size of 1/8 x 1/8 nautical miles. Each cell contained the highest elevation which fell within the lateral bounds of the cell. Hence, the grid represented a worst case elevation, based upon the source data.

Three important questions arise when considering DTED data, including:

- Where can the ANSP source appropriate data from?
- What is the accuracy and integrity of a particular data source?
- What liability issues arise from using a particular source of data?

There are various sources of digital height data available, some of it freely downloadable from the internet and some only available by purchasing from the appropriate national body, or other organisations. Generally speaking the better data is not freely available. The data that is available differs from one country to another, so it is difficult to give general guidance here.

It is recommended that, whenever possible, the integrity of any DTED data source is checked, by comparing one source against another. A very effective method is to subtract the height values of one source from the height values of another, and then to display the height differences on a colour-coded map. Good sources of data will normally show close agreement. Note that some allowance must be made for the different method used for data acquisition. For example, Shuttle Radar Topography Mission (SRTM) is a surface model and not a terrain model – the height measurements include tree tops and not the ground. Comparison of SRTM data against some other data sources will exhibit naturally occurring differences.

The MSAW system parameters should be set taking into account the characteristics of the data source, such as the horizontal and vertical accuracy and whether the data represents terrain or the Earth’s surface. For example, under ICAO Pan Ops, a margin of 45 metres (148ft) is required to be added to terrain to take account of vegetation.

3.4.5 MSAW Alert Results Files

An example MSAW results file is shown in Figure 8-7. As can be seen, the file provides the number of MSAW alerts of each type (DTED and polygon alerts), as well as pertinent information relating to each alert including the identity and location of the flight, and the time and duration of the alert.

The alert statistics are also recorded for each type of flight; correlated IFR, correlated VFR, correlated military, uncorrelated IFR, uncorrelated VFR, uncorrelated military.

Additional information for MSAW polygon alerts, indicated in the file as GTM (General Terrain Monitoring), includes the polygon that has been infringed at the start of the alert.

The information for DTED alerts includes the *time to conflict* at the start of the alert. The metric is easy to derive when prediction is applied for MSAW, since it is simply part of the prediction algorithm. If no prediction was applied then the time to conflict would be zero. The *time to conflict* gives an indication of the warning time that has been achieved, but since it is derived from a uniform motion assumption (linear prediction), the measure will inevitably have some error.

3.4.6 STRACK Display Program

The STRACK program is a dynamic display tool for visualising system tracks, radar plots and safety nets alerts on a number of display windows including plan view and vertical view. In the plan view window, useful map features, such as MSAW volumes can be shown.

In this study, the STRACK display program was used to visualise the MSAW volumes, the geographic distribution of alerts (see Figure 8-8 for an example, which is described fully later in the report) and specific situations. One weakness of STRACK for this study was that it did not represent the terrain or MSAW polygons very well which is innately three dimensional.

3.5 Google Earth™

Google Earth™ was used for the visualisation of the MSAW volumes as well as specific situations in relation to the volumes and terrain.

Google Earth™ is a virtual globe visualisation program which overlays data obtained from satellite imagery and aerial photographs. It can show terrain and map features. Usefully for this study, Google Earth™ can also read and display KML files.

KML is a file format used to display geographic information. In this study it was used to display the MSAW polygons and specific situations.

The MSAW polygons can be seen in Figure 8-1, Figure 8-2 and Figure 8-3.

Virtual globe programs provide powerful visualisations. Nevertheless, it should be remembered that the terrain data used in an operational MSAW system is likely to be slightly different to that used by virtual globe software, and furthermore the 3D terrain visualisation is only a representation of the actual situation.

Under no circumstances should virtual globe software be used in an operational ATM environment or as part of a safety critical system without the express permission of the software producer, since the integrity of the data may not be assured.

4. ANALYSIS AND RESULTS

4.1 Initial Examination of the Geographical Distribution of MSAW Alerts

The aim, at this stage, was to obtain a picture of the geographical distribution of MSAW alerts, in order to know where to focus attention in subsequent steps in the study.

The performance of the current MSAW system, using polygons, was already reasonably well known by Skyguide. To gain an immediate insight into the alert hotspots, the MSAW model was run on one day of traffic, using the current polygons (i.e. detection of polygon infringement) as well as the DTED data unrestricted in geographical area. The only geographical restriction on the DTED alerts was imposed by the coverage of the system track recording.

The DTED parameters used at this stage of the study were:

DTEDWarningTime 35s   DTEDVerticalMargin 150ft

The positions of the aircraft at the start of each MSAW alert were extracted and plotted in STRACK to show where the alert hotspots were located, and are shown in Figure 8-8. Note that the DTED alerts were not restricted in geographical area, so show a much wider spread than the polygon alerts.

There was clearly a concentration of alerts around Geneva airport. Less concentrated clusters could also be identified around other airports. Many of the airports are not under Skyguide ATC (e.g. Milan, Turin), and therefore were not of concern in this study. However, the aerodromes at Lausanne and Sion were well within the scope of this study and the number of alerts in the vicinity of this airport, as well as other airports, would need to be addressed.

Figure 8-9 shows the same picture zoomed in on Geneva airport to show the distribution of alerts that occur in the immediate vicinity of the airport. The impression is of a very large number of DTED alerts on the final approach path, a few around Annemasse (just South East of Geneva) and a number of MSAW (polygon) alerts close to the Jura mountain range (bottom left in the figure).

The observations were quantified by counting the number of DTED alerts in various parts of the airspace and the result is presented in Figure 8-10.

4.2 Inhibition Area for Geneva

Given the large number of nuisance alerts for aircraft on final approach to Geneva, the obvious next step was to construct an MSAW inhibition area to cover aircraft on a Geneva final approach path. The Geneva inhibition area is shown in Figure 8-11. In this area, inhibition was applied to both polygon and DTED alerts.

In an operational MSAW system, monitoring of the final approach path may be appropriately covered by APM, which would normally override the MSAW function in the final approach segment.

4.3 MSAW (DTED) Parameter Sensitivity Analysis within the Current MSAW Geographical Area

At this point in the study, the aim was to measure how sensitive the DTED alert rate was to the two key parameters, namely DTEDWarningTime and DTEDVerticalMargin.

The meaning of the parameters is illustrated in Figure 4-1 below:

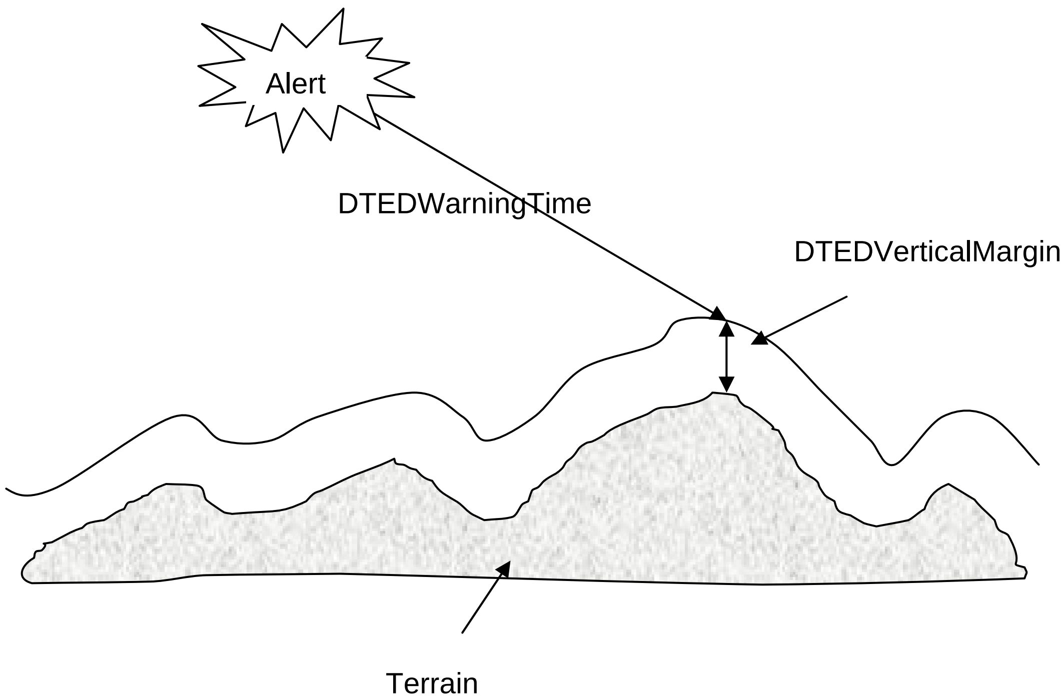


Figure 4-1 Illustration of the DTEDWarningTime and DTEDVerticalMargin parameters

DTEDVerticalMargin is the safety margin above the terrain which is used as the point of conflict in the DTED part of the MSAW model.

The DTEDWarningTime parameter is used in the alert confirmation stage to determine whether an alert should be issued at the current time.

The DTED conflict detection was limited to the geographical area of the current MSAW polygons, and furthermore all alerts were inhibited within the Geneva final approach inhibition area. This would allow the DTED alert rate and the MSAW (polygon) alert rate to be directly compared.

The MSAW model was run several times in order to determine alert rate against the MSAW polygons, moreover to determine how sensitive the DTED alert rate was to the key parameters. Each execution of the model was done over the 25 day data sample. At this stage, the alerts from correlated IFR flights were counted.

The results of the alert rate measurements are shown in Figure 8-12 and Figure 8-13.

Figure 8-12 shows the mean DTED alert rate when DTEDVerticalMargin was set to 150ft and DTEDWarningTime was gradually increased.

Figure 8-13 shows the mean DTED alert rate when DTEDWarningTime was set to 35s and DTEDVerticalMargin was increased to 900ft, in increments of 150ft.

It was anticipated that the DTED alert rate would be more sensitive to the DTEDWarningTime parameter than to the DTEDVerticalMargin parameter, and this was indeed found to be true.

The mean daily alert rate for MSAW (polygon) alerts was 14.76; this is in fact a measure of the current Skyguide MSAW alert rate. In the runs of the model, the DTED alert rate exceeded the MSAW (polygon) alert rate when the DTEDWarningTime parameter was set to 75 seconds. Although 15 alerts per day may currently be tolerable to controllers within the confined area where the current MSAW is functioning, it was not possible to determine at this stage in the study whether the same would apply to an MSAW system expanded over a larger geographical area and whether the resulting number of alerts would be manageable for controllers.

4.4 Extending the MSAW Polygons

The next step was to extend the geographical coverage of the MSAW polygons over a wider area, in particular over the Alps and the Jura mountain ranges, South and North of Geneva respectively.

The extended polygons are shown in Figure 8-14, and are based on the Minimum Vectoring Altitudes (MVAs) around Geneva. Each polygon extending the MSAW coverage had its height set to 350ft below the MVA.

4.5 Geographical Distribution of alerts over the Extended MSAW area

The MSAW model was then set to the following configuration:

- MSAW (polygon) alerts active in the extended MSAW area
- DTED alerts active in the extended MSAW area
- Inhibition area active for Geneva airport approach
- DTEDWarningTime = 35s
- DTEDVerticalMargin = 150ft

The model was then run using the 25 day sample of data. The positions of the aircraft at the start of each MSAW alert were extracted and plotted in STRACK to show where the alert hotspots were located. Only correlated IFR flights were used at this stage of the analysis.

The results are shown in Figure 8-15 and Figure 8-16.

The geographical distribution of MSAW (polygon) alerts (Figure 8-15) showed distinct clusters around Lausanne (LSGL), Chambery (LFLB), Sion (LSGS) and to the South and West of Geneva.

A sample of these alerts was examined in detail. They were found to be mainly due to:

- Aircraft on final approach to Lausanne
- Aircraft on approach to Chambery
- Aircraft climbing out of Sion, coming into radar cover below the MSAW surface (as defined by the polygons).
- Geneva arrivals and departures infringing the MSAW polygons (West-South-West of Geneva) in the vicinity of the Jura.
- A broad spread of alerts to the east of Geneva.

The geographical distribution of DTED alerts (Figure 8-16) indicated concentrations around Lausanne, Annecy and Chambery, and a sparse scattering elsewhere. The alerts around the airports were for aircraft on or close to final approach, each one being a potential nuisance to controllers.

4.6 Inhibition Volumes over the Extended MSAW Area

Following from the geographical distributions, the obvious next step was to carefully construct more inhibition volumes around the identified airports in order to reduce the number of unwanted MSAW alerts for aircraft on final approach or on departure.

However, there were also areas of airspace where alerts would be of no interest to controllers at Geneva ACC. These areas included:

- Chambery TMA
- Lyon TMA
- Sectors to the South East and East of Geneva.

A comprehensive set of inhibition volumes was produced with valuable guidance of Skyguide controllers. In these volumes, all MSAW alerts – polygon and DTED alerts – would be inhibited. Figure 8-17 shows these volumes. They include the airports of Geneva, Lausanne and Sion, Chambery and Lyon TMA, and the Eastern sectors that are outside of Geneva control.

On a practical level, the inhibition volumes around the airports were designed on the basis of keeping them as small as possible, whilst also allowing for the suppression of the vast majority of nuisance alerts which lay in clusters around the airport.

From a Safety Nets perspective, it is desirable to maximise the amount of controlled airspace that has some type of MSAW or APM protection, rather than simply suppressing MSAW alerts with inhibition volumes, as was done here.

4.7 Situations that Clip the MSAW Polygons

As well as the alerts around airports, it was further observed that a number of infringements of the MSAW polygons involved aircraft that were just clipping the polygon for a few seconds. An example of a Geneva departure clipping an MSAW polygon is given in Figure 8-18.

In such cases, the MSAW alert was very short in duration, and the vast majority of these would be an unnecessary distraction for the controller.

To mitigate this, a predictive element was added to the MSAW polygon function.

If the aircraft was predicted to be clear of the MSAW polygons within a parameterised number of seconds, then no alert would be produced. The prediction time parameter was called the Polygon Clipping Time.

To produce an alert, the aircraft had to be within an MSAW polygon, and predicted to still be within an MSAW polygon (not necessarily the same one) within the Polygon Clipping Time. Hence, the situations which just clipped the polygons produced no MSAW (polygon) alert.

Figure 4-2 below illustrates how this prediction was used:

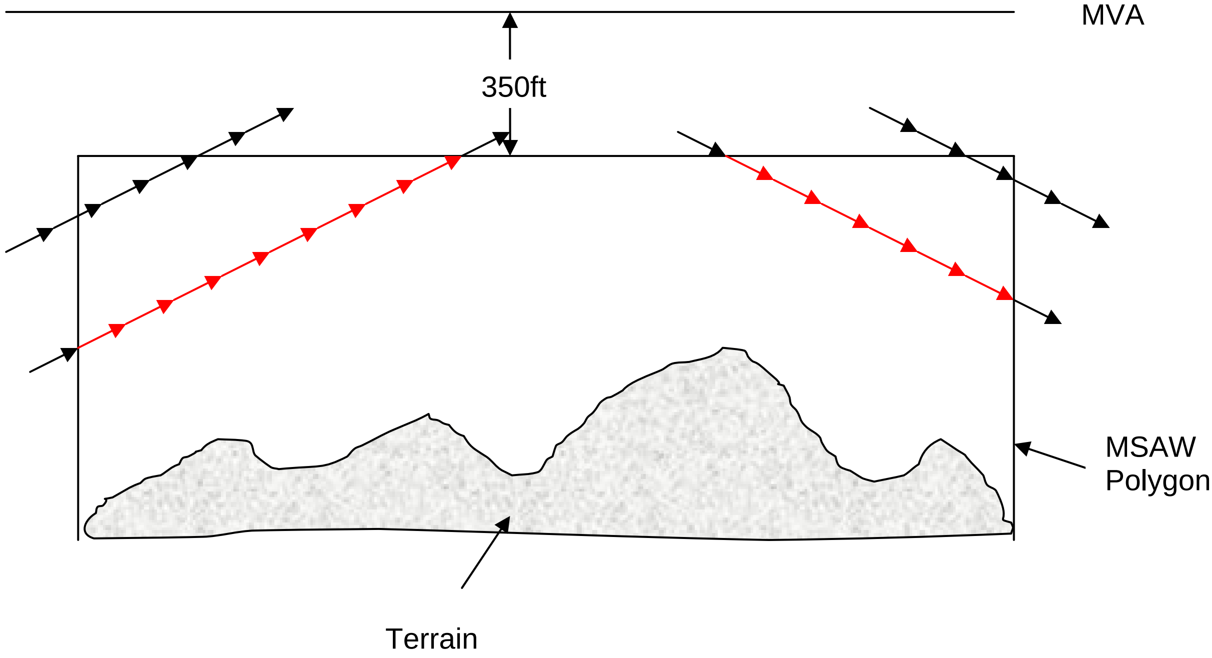


Figure 4-2 Illustration of Clipping the MSAW Polygon

To produce an alert, the aircraft must be predicted to remain in a polygon for at least the Polygon Clipping Time, as indicated by the red portion of the track.

The MSAW model was run several more times (on the 25 day sample) in order to assess the impact of extending the MSAW polygons, of implementing the inhibition volumes, and of including a short prediction.

The runs that were done in respect of MSAW (polygon) alert rate performance are summarised in the table below:

Run	Polygons Extended	Airspace Inhibited	Polygon Clipping Time (seconds)
P1	No	None	0
P2	Yes	None	0
P3	Yes	Geneva, Lausanne, Sion and around, Chambery TMA, Lyon TMA	0
P4	Yes	Geneva, Lausanne, Sion and around, Chambery TMA, Lyon TMA	10
P5	Yes	Geneva, Lausanne, Sion and around, Chambery TMA, Lyon TMA	20
P6	Yes	Geneva, Lausanne, Sion and around, Chambery TMA, Lyon TMA	30
P7	Yes	Geneva, Lausanne, Sion and around, Chambery TMA, Lyon TMA	40

The mean daily alert rates for correlated IFR flights for these runs are shown in Figure 8-19. The table (above) is reproduced next to the figure in section 8 for ease of reference.

Run P1 represents the current Skyguide MSAW system. Run P2 modelled what would happen if the polygons were extended to include the Alps without introducing inhibition volumes, and in Run P3 onwards show the effect of introducing the inhibition volumes, and the additional effect of the clipping algorithm.

The present MSAW alert rate (as measured by the MSAW model) is just under 15 alerts per day.

Extending the MSAW coverage using polygons would more than triple the alert rate to near 49 alerts per day; an increase in alert rate is inevitable when the geographic area is expanded.

Introducing the inhibition volumes reduced the daily alert rate by about 44% to around 27 alerts per day.

Introducing the clipping algorithm (runs P4, P5, P6 and P7) further reduced the alert rate by up to 12.6%. The final alert rate achieved (in run P7) was just over 21 alerts per day.

It may be possible to remove more of the nuisance alerts with careful lowering of selected MSAW polygons and the introduction of APM. However, the sculpting of the MSAW polygons to be closer to the terrain would be a very time consuming task, and might not result in a significant reduction in the nuisance alert rate. Furthermore, by doing so, one would tend towards a hand-made approximation of digital terrain data, which is unlikely to be as accurate as the original DTED source data.

It should be noted that in the current MSAW system, the controller has the facility to inhibit alerts for individual flights, such as those flying visual approaches, departures or VFR on an IFR code. In reality, the number of alerts presented to the controller would be less than the results indicate, since in many cases the controller will have inhibited a flight from MSAW processing before it enters a polygon. In other cases, the controller may inhibit a flight after the alert starts. Nevertheless, each modelled alert represents potential workload for the controller.

Of further note is the fact that in the current system, each flight that is inhibited no longer triggers MSAW alerts until that flight is re-enabled by the controller.

4.8 MSAW (Polygon) Alert Rate Performance using Conflict Prediction

The MSAW model was then configured to add a predictive element to the MSAW polygon alert detection logic.

It was immediately recognised that simply adding prediction to the current MSAW system would be impractical since it would result in an ever escalating nuisance alert rate. It was therefore decided to lower the MSAW polygons before introducing the prediction. Hence, all the runs that used prediction employed MSAW polygons that were 500ft lower than the current MSAW polygons (i.e. nominally 850ft, rather than 350ft below the MVA).

The MSAW model was run using look-ahead times from 0 to 65 seconds. In all these runs the full set of defined inhibition volumes were used. The alert rate results are shown in Figure 8-20. It was seen that the maximum prediction time that could be used before the alert rate really began to take off was around 15 seconds. At the end of the scale, a prediction time of 65 seconds resulted in a very large 227 alerts per day.

4.9 MSAW (DTED) Alert Rate Performance

The MSAW model was run many more times in order to measure the mean daily alert rate for the DTED function in a variety of configurations:

The DTEDWarningTime parameter was varied between 35 and 65 seconds, and the DTEDVerticalMargin was varied between 150 and 750 ft.

In all these runs the full set of defined inhibition volumes were used.

The full results for all these runs are presented in Figure 8-22. The results from the earlier runs (using current MSAW coverage) are shown for comparison in Figure 8-21.

The results show that the DTED alert rate starts from a very low baseline of just over alert per day. Extending the warning time and the vertical margin inevitably increased the number of DTED alerts.

However, the results clearly indicate that the DTED function in the MSAW model (with moderate parameter values) produced significantly fewer alerts than the MSAW polygon function. `

4.10 The Duration of MSAW alerts

It was observed that many of the MSAW (polygon) alerts lasted for some considerable time; much longer than the DTED alerts.

In order to make a comparison, the MSAW (polygon) and DTED alert durations were counted over a 7 day subset of the 25 day sample. The results were taken from MSAW (polygon) run P6 and one of the DTED runs (DTEDWarningTime = 45s, DTEDVerticalMargin = 300ft), which were both considered fairly representative runs.

Over the 7 day period, there were 205 MSAW polygon alerts and 36 DTED alerts. The results are shown in Figure 8-23.

A broad spread of alert durations was observed for the MSAW (polygon) function. The mean duration was 76.9 seconds, but short duration alerts (less than 10 seconds) and long duration alerts (> 300 seconds) were also quite common. The statistics reflect the fact that the short duration alerts are generally just clipping the polygon, and the longer duration alerts are most likely VFR flights squawking IFR, which in the operational system would be inhibited by the controller.

The DTED alerts were generally much shorter in duration than the MSAW (polygon) alerts. The mean DTED alert duration was 15.5 seconds, with a minimum of 4 seconds (just one track update) to a maximum of 84 seconds. Nevertheless, even with quite wide parameters, the DTED alert durations would not be expected to be comparable to the MSAW polygon alert durations.

Figure 4-3 below illustrates why the DTED alert conditions generally exist for a much shorter period than the polygon alert conditions. Put simply, in most cases, the polygon will be infringed before the DTED alert is detected. Further in most circumstances, the DTED alert will terminate as soon the aircraft climbs or levels off.

In the diagram, the MSAW polygon alert is indicated in red, and the DTED alert in blue.

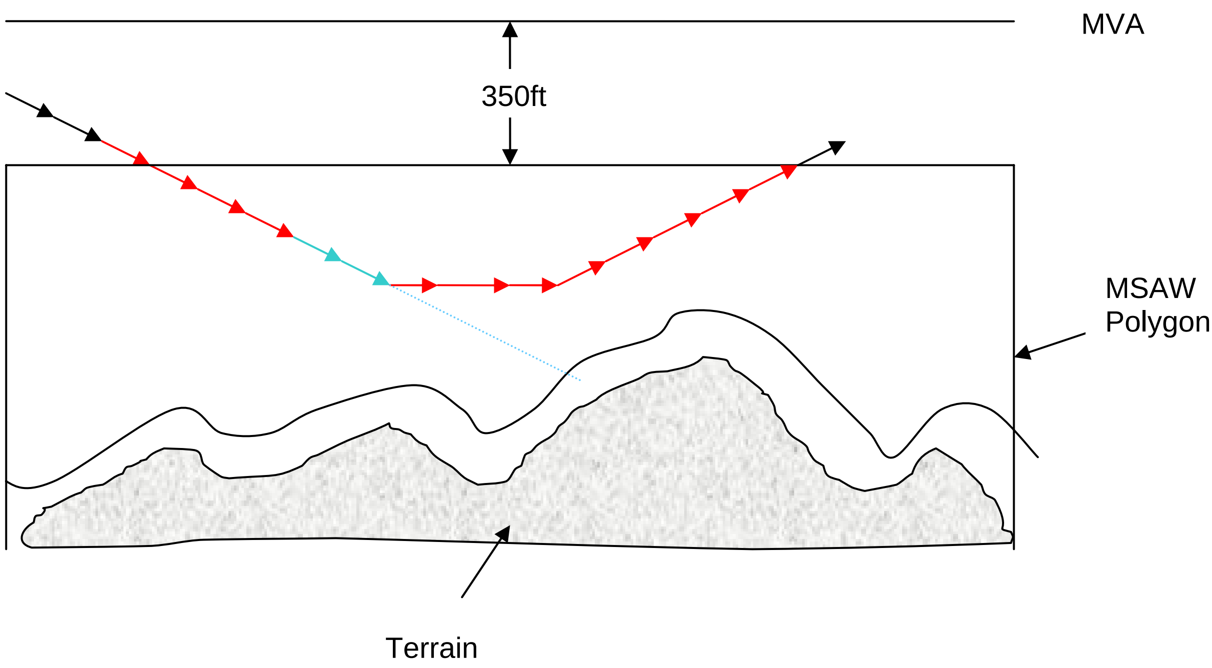


Figure 4-3 Illustration of the duration of DTED and MSAW (polygon) alerts

It is important to note that it is current practice for the Skyguide controllers to acknowledge the MSAW alerts. Hence, in reality, it is unlikely that an alert would be ongoing for a significant period of time.

4.11 MSAW (DTED) Alert Rate for Different Types of Flight

The number of DTED alerts of various types of flight was recorded in the MSAW model results. The types of flight were:

- Correlated IFR
- Correlated VFR
- Correlated Military
- Uncorrelated IFR
- Uncorrelated VFR
- Uncorrelated Military

The alert rates for these types of flight and are presented in Figure 8-24, with the exception of Correlated Military for which there were far too few alerts to provide a statistically significant result.

The results show that correlated IFR traffic generates fewer MSAW alerts than any other. If MSAW were configured to alert on uncorrelated flights, the alert rate would be huge and unmanageable for controllers.

The number of alerts depends not only on the amount of traffic of that type, but also on how the traffic behaves. VFR flights in particular tend to fly close to the ground in order to maintain a visual reference, and would inevitably generate a very significant number of MSAW alerts.

4.12 Review of MSAW Performance So Far

Taking the alert rate results alone, it would appear that the best MSAW configuration would use the DTED function with a short warning time parameter (DTEDWarningTime) and a small vertical margin (DTEDVerticalMargin) above the terrain.

However, as outlined in Section 3.2, MSAW has two competing objectives:

- To alert all conflicts with adequate warning time
- To minimise the nuisance alert rate

In reality, the optimum MSAW configuration will achieve an appropriate balance between alert rate and warning time. At one extreme, there may never be sufficient time to resolve the conflicts. At the other extreme, there may be so many alerts that the controllers no longer respond to them, either because controllers have become desensitized to the alerts, or because of excessive workload.

Therefore, the objective of the next stage of this study was to examine the warning time performance of MSAW, in order to try to achieve the right balance of warning time and alert rate.

4.13 MSAW Warning Time Statistics

A tool was produced which measured the warning times, in terms of the time differences between a MSAW (polygon) alert, a MSAW (DTED) alert and the time to reach the terrain (DTED) itself.

The program worked by taking each system track and extrapolating it until it reached the terrain, or exited the area of interest. Tracks not reaching the terrain did not provide a measure. However, for those tracks that did reach the terrain, whilst on their predicted course, the time of the MSAW (polygon) alert, and time of the MSAW (DTED) alert were noted, as well as the time of reaching the terrain itself.

The pertinent events and times of these events are indicated below:

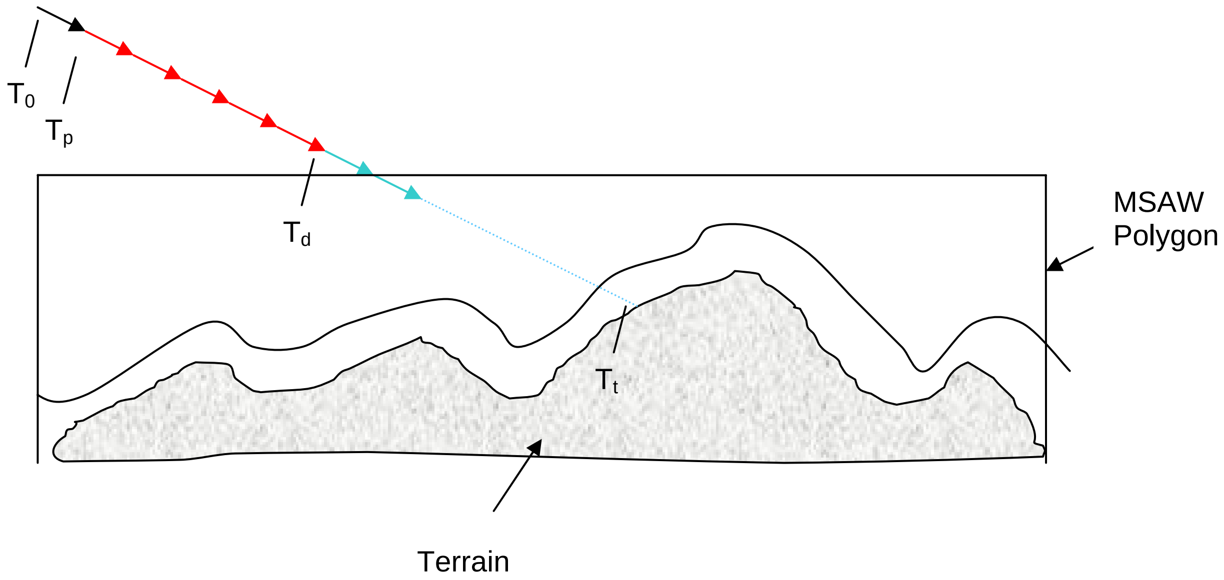


Figure 4-4 Times recorded by the Warning Time Statistics tool

The time of the track is T_0. The track is extrapolated all the way through to $T_{t,}$ the time at which the aircraft would strike the terrain (if it were to maintain its heading and vertical rate). During this extrapolation, the time of the MSAW alerts are noted, T_p being the time of the modelled MSAW (polygon) alert, and T_d being the time of the modelled MSAW (DTED) alert.

Then, the achieved warning time for each MSAW (DTED) alert was computed as:

$$T_t – T_d$$

and the warning time for each MSAW (polygon) alert was computed as:

$$T_t - T_p$$

The measured mean warning times for various MSAW configurations are shown in Figure 8-25. The configurations are summarised below:

WT Run 1	Extended MSAW coverage, polygons, no prediction
WT Run 2	Extended MSAW coverage, polygons lowered by 500ft, 15 second prediction
WT Run 3	Extended MSAW coverage, polygons lowered by 500ft, 35 second prediction
WT Run 4	Extended MSAW coverage, DTED, 35 seconds warning time, 300ft vertical margin
WT Run 5	Extended MSAW coverage, DTED, 65 seconds warning time, 300ft vertical margin

The most pertinent warning time distributions are shown in Figure 8-26, Figure 8-27, Figure 8-28 and Figure 8-29. The graphs show the results for correlated IFR traffic and uncorrelated VFR traffic, for two MSAW configurations (WT Run 1 and WT Run 4):

- MSAW polygon – MSAW extended area with no prediction
- MSAW DTED – Warning Time = 35s, Vertical Margin = 300ft

Many more results (for different types of flight and MSAW configurations were examined). However, the distributions are not sufficiently different to the presented graphs to justify including them in this report.

Nevertheless, these four graphs support some significant observations, as described below:

Warning times for correlated and uncorrelated tracks

The warning times for both types of MSAW (polygons and DTED) never reaches zero for correlated IFR traffic (Figure 8-26 and Figure 8-28). The peak of the warning time distribution is always non-zero. On the other hand, there are always a significant number of uncorrelated flights with zero warning time (Figure 8-27 and Figure 8-29). Investigations of the traffic showed that the reason for this is that the tracks for uncorrelated flights tended to initiate close to the ground (when they came into radar cover). This clearly demonstrates that if uncorrelated tracks were included in MSAW there would be a significant proportion of tracks with zero warning time.

Comparing distributions for polygons and DTED

Considering correlated IFR traffic only, the warning time distributions show that the expected warning time performance for MSAW (DTED) is well defined (Figure 8-28). That is, with a warning time parameter set to 35s, the minimum warning time is in the 30-40 seconds column, and the spread of the warning times is very narrow.

The warning time distribution for MSAW (polygons) is much broader in comparison, and the minimum warning time is less clear cut (Figure 8-26).

The MSAW polygon warning time distribution for uncorrelated VFR traffic (Figure 8-27) is much broader still. The long tail on the distribution becomes increasingly meaningless as the straight line assumption used to compute the warning time becomes more inaccurate over time.

4.14 MSAW Performance against Artificial Scenarios

Skyguide produced twelve simulated scenarios for the assessment of MSAW performance. These scenarios are summarised in the table below:

Scenario	Description	Polygon Penetration	Risk of CFIT	Figure
1	Departure DIPIR_4A. Normal	No	No	Figure 8-30
2	Departure DIPIR_4A. Turns too early	Yes	No	Figure 8-31
3	KONIL_4A. Normal	No	No	Figure 8-32
4	KONIL_4A. Too low	Yes	No	Figure 8-33
5	Arrival GG502. OK	No	No	Figure 8-34 & Figure 8-36
6	Arrival GG502. Turns too late an penetrates MSAW polygon	Yes	No	Figure 8-35 & Figure 8-36
7	KONIL_4C. Normal	No	No	Figure 8-37 & Figure 8-39
8	KONIL_4C. Turns too wide and penetrates MSAW polygon	Yes	Yes	Figure 8-38 & Figure 8-39
9	LIRKO arrival. OK	No	No	Figure 8-40
10	LIRKO arrival. Too low	Yes	Yes	Figure 8-41
11	PETAL departure. OK	No	No	Figure 8-42
12	PETAL departure too low	Yes	No	Figure 8-43

The twelve scenarios are shown in Figure 8-30 to Figure 8-43 inclusive. The track is shown as a blue circle with an orange velocity vector. Whilst in a polygon the track is shown as white. In scenarios 8 and 10, the timing of a DTED alert is shown in yellow. The settings used to obtain these result are discussed in section 4.16

It can be seen that only scenarios 8 and 10 have any significant risk of CFIT. The other scenarios have no significant risk of CFIT, even though half of them infringe an MSAW polygon.

The MSAW (polygon) function always provided an alert on penetration of the respective polygon. This is shown as white tracks in the figures.

For the DTED function, the MSAW model was run numerous times with various values for DTEDWarningTime and DTEDVerticalMargin, and the alerts compared against the timing of the penetration of the respective polygon.

The DTED part of the MSAW model was only able to alert for scenarios where there was some risk of CFIT (Scenarios 8 and 10). For other scenarios where the MSAW polygon was penetrated, the aircraft was found either to be climbing clear of the terrain, or was level and separated both laterally and vertically by a considerable margin. This support the general observation that in most circumstances even when the MSAW polygon is infringed the risk of CFIT is negligible.

The alert performance of the DTED function is summarised for scenario 8 in the table below:

		DTEDWarningTime / seconds			
		35	**45**	**55**	**65**
Vertical Margin / ft	**150**	-4	+12	+24	+32
	300	-4	+20	+28	+36
	450	+4	+20	+28	+36
	600	+8	+20	+32	+36
	750	+8	+20	+32	+36

The numbers in the table show start time of the DTED alert relative to the MSAW (polygon) alert (polygon penetration) as a number of seconds. Yellow cells represent a DETD alert after the MSAW polygon penetration. Green cells represent a DTED alert before MSAW polygon penetration. For example, with DTEDWarningTime set to 35 seconds and DTEDVerticalMargin set to 450ft, the DTED alert occurred 4 seconds before the MSAW (polygon) alert.

The alert performance of the DTED function is summarised for scenario 10 in the table below:

		DTEDWarningTime / seconds			
		35	**45**	**55**	**65**
Vertical Margin / ft	**150**	-	-	-	-
	300	-	-	-	-
	450	-80	-72	-68	-64
	600	-68	-60	-48	-40
	750	-68	-60	-48	-40

In this scenario, the DTED alert always triggered some time after the penetration of the MSAW polygon. However, it is judged that the risk of CFIT only became significant after the aircraft track had penetrated the polygon, and therefore the relative lateness of the alert was probably not an issue.

4.15 Enhanced Vertical Prediction for MSAW (DTED)

Improvements to the vertical prediction algorithm were driven by a desire to increase the warning time performance of MSAW whilst minimising the impact on the alert rate.

By examining the DTED alerts for both real and the simulated scenarios, it was possible to make a number of observations:

- Nearly all DTED alerts were for aircraft in descent.
- Extending the DTEDWarningTime increased the number of nuisance alerts, due to aircraft in descent being predicted to conflict with terrain.
- Aircraft in level flight or climbing were reasonably immune to the effect of increasing DTEDWarningTime, yet, in principle, climbing or level aircraft could also be at risk of CFIT.

Considering these points, it was clear that in some circumstances (i.e. if an aircraft was level or climbing) the warning time could be extended significantly whilst having negligible impact on the nuisance alert rate. However, it was also desirable to increase the warning time for aircraft on descent.

A new vertical prediction algorithm was designed and implemented in the DTED part of the MSAW model, with the aim of increasing the warning time performance whilst limiting the impact on the alert rate.

With the new algorithm, the prediction that is computed depends on the current vertical attitude of the aircraft. In the simpler case of the aircraft level or climbing, then the prediction continues up to DTEDLookAheadTime2, with a margin applied of DTEDVerticalMargin2.

This prediction is shown in vertical view below:

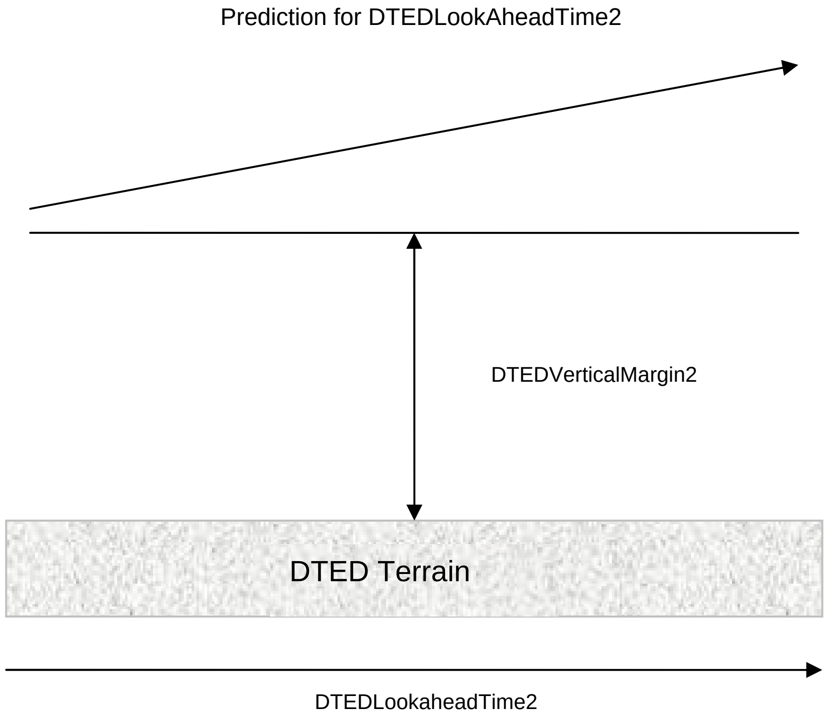


Figure 4-5 Vertical Prediction for Level or Climbing Aircraft

On the other hand, if the aircraft is currently descending, the algorithm breaks the vertical prediction down into two segments, the first one based on a continued descent, and the second one based on an assumed level off.

This prediction is shown in the diagram below:

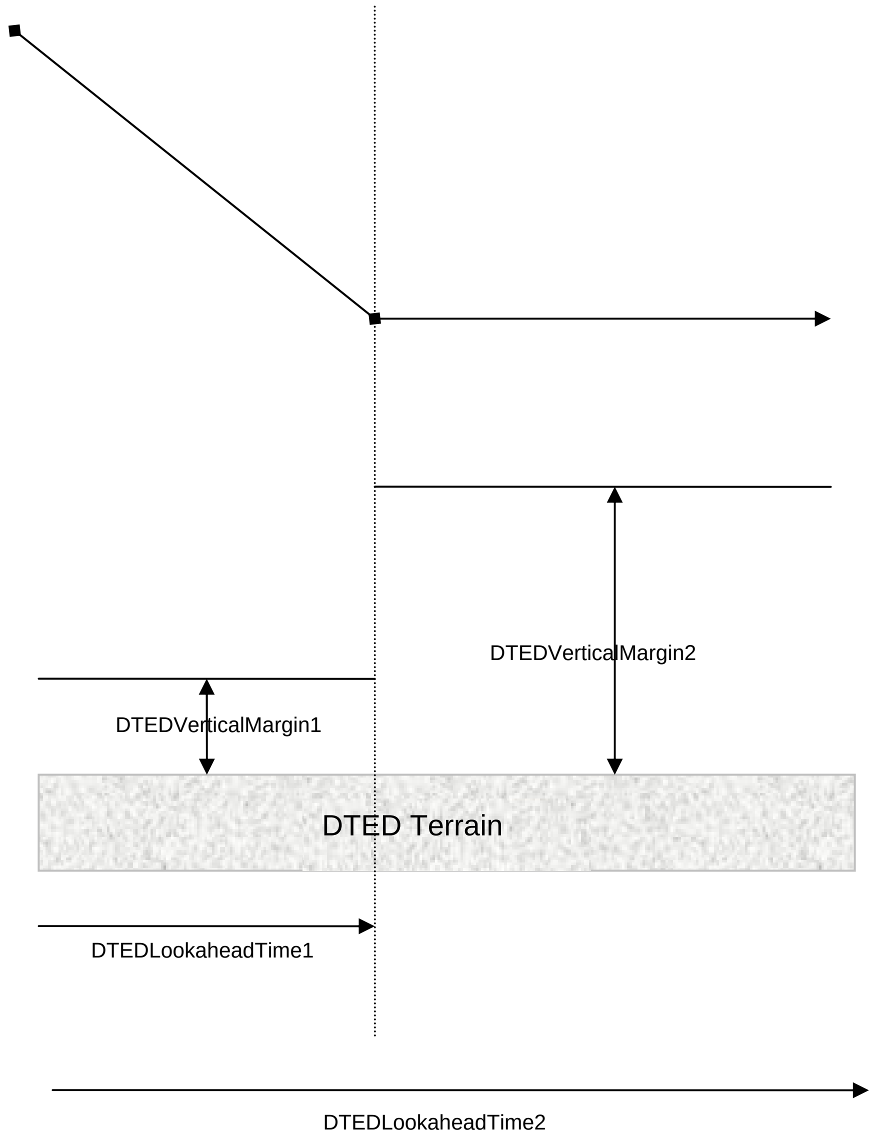


Figure 4-6 Vertical Prediction for Descending Aircraft

Whatever the prediction that is applied, DTEDWarningTime remains independent of the look-ahead time parameters. A conflict detected within the overall prediction time (DTEDLookAheadTime2) can generate an MSAW alert, as long as it was within DTEDWarningTime.

4.16 Performance of the Level Off Prediction Algorithm

This MSAW model was run twice on the 25 day sample and the artificial scenarios, using the extended MSAW polygon coverage and the full range of airport inhibition volumes.

The table below summarises the parameter settings that were used for the two runs, and the results obtained for the 25 day sample and scenarios 8 and 10 from the artificial set.

	Run E1	**Run E2**
DTEDLookAheadTime1	35s	35s
DTEDLookAheadTime2	75s	55s
DTEDWarningTime	65s	55s
DTEDVerticalMargin1	150ft	400ft
DTEDVerticalMargin2	600ft	600ft
Mean Daily Alert Rate	7.45	5.64
Scenario 8 alert time (relative to MSAW polygon)	+36s	+28s
Scenario 10 alert time (relative to MSAW polygon)	-68s	-68s

Figure 8-38 and Figure 8-41 show the alerts raised by run E2 for scenarios 8 and 10. The yellow track positions indicate the timing of the DTED alert. The white track positions indicate that the track is in an MSAW polygon.

For scenario 8, run E1 alerted 36 seconds before infringement of the respective polygon, and run E2 alerted 28 seconds before infringement. However, the daily alert rate for run E2 was significantly less than for E1.

Comparing the result for run E2 with the previous prediction method, it can be seen that to achieve the same warning time performance for scenarios 8 and 10 requires DTEDWarningTime to be 55 seconds and DTEDVerticalMargin to be 450ft. From Figure 8-44, it can be seen that the level off prediction produced only a moderate alert rate (fewer than 4 per day for correlated IFR flights). On the other hand, a straight line prediction with 55s warning time and 450ft vertical margin produced an average daily alert rate of 14.08.

5. CONCLUSIONS

5.1 Overview

There are some general lessons that can be learnt from this study that are useful for all ANSPs. However, it should be noted that the detailed results (warning time and alert rate statistics) apply only to the specific environment – MSAW for Skyguide in the area around Geneva.

If the study were repeated in other environments then the results would be different, and the final conclusions may not be the same as here.

Furthermore, the recommendations are not ossified, but further work is required to address the cost-benefit and also to consider liability issues.

5.2 The Analysis Method

This study clearly demonstrates the power of an MSAW model, which was used here to:

- Measure the effect of extending the MSAW geographical coverage
- Trial new algorithms
- Execute some steps in the optimisation process

To carry out the study, it was absolutely essential that the MSAW model was easily modifiable, and highly parameterised.

The method also involved the use of powerful display tools which allowed each alert to be studied in detail and the location of alert hotspots to be seen.

5.3 MSAW around Airports

Without specific means of mitigation, some major hotspots for MSAW were found to occur around airports, usually for aircraft on final approach, but also sometimes for departures.

Introducing Approach Path Monitor (APM) would be most desirable. Where used, approach APM funnels could supersede the MSAW function for the final approach segment of flight.

However, APM was outside the scope of the study, so the means of mitigation was limited to the use of inhibition volumes around the airports.

5.4 Comparison of MSAW Polygon and DTED performance

In general, the DTED alert rate was significantly lower than the MSAW (polygon) alert rate. The DTED alert rate only exceeded the MSAW (polygon) alert rate when very wide parameters were used.

The table below summarises the key alert rate and warning time results for correlated IFR traffic, for a selection of the assessment runs.

Description of Run	Mean Daily Alert Rate	Mean Warning Time (s)
Extended MSAW polygons no prediction	27.29	67.34
Extended MSAW coverage, polygons lowered by 500ft, 15 second prediction	22.25	80.0
Extended MSAW coverage, polygons lowered by 500ft, 35 second prediction	70.64	93.92
DTED, 35 seconds warning time, 300ft vertical margin	1.42	43.66
DTED, 65 seconds warning time, 300ft vertical margin	21.26	74.41

The bare statistics would suggest that simply extending the polygons (no prediction) is a sub-optimal solution, since the second entry in the table (15 seconds prediction) achieves a greater warning time with a fewer number of alerts. The third entry in the table (polygons, 35 seconds prediction) gains extra warning time, but with a severe increase in the number of alerts.

It is essential to note that the mean warning times given in the table do not reveal anything about the MSAW warning time distributions. Wider operational issues, such as the most appropriate time to issue an alert are also important.

In particular, the DTED warning time distributions were much narrower than those for polygons, indicating that with DTED, the warning time achieved was fairly consistent with a definite minimum warning time regardless of the specific situation.

The DTED warning time distributions were narrow, and the minimum warning time was defined by the DTEDWarningTime parameter. To estimate the mean warning time for other values of DTEDWarningTime one may interpolate between the two DTED results shown in the table. Hence, with

DTEDWarningTime set to 45 and 55 seconds, one would expect a warning time of around 54 and 64 seconds respectively.

The warning time results for MSAW using polygons yielded much broader distributions. These graphs indicated some alerts for correlated IFR flights with warning times in excess of 4 minutes. Whilst this is certainly a long warning time, it is unlikely that a controller would need to respond immediately to such an alert in order to reduce the risk of CFIT. On the other hand, the shortest warning times were down to 10 seconds or less.

There were twelve artificial scenarios, six of which included penetration of an MSAW polygon. When run against the artificial scenarios, the MSAW (polygon) function unsurprisingly produced alerts for all six infringements. On the other hand, the DTED function, alerted for just two scenarios.

These different alerting behaviours are due to the fact that the penetration of a polygon does not necessarily involve a risk of CFIT. Indeed the aircraft could be climbing well clear of the terrain.

There is no doubt that in real traffic there are some IFR flights that fly below the minimum vectoring altitudes (MVAs), which are not at risk of CFIT, and for which no DTED alert would be generated, even though the aircraft infringe the minima.

The best DTED performance was achieved with the enhanced vertical prediction algorithm, which assumed that a descending aircraft would after a time level off. This method provided a better trade off between warning time and nuisance alert rate than a normal linear prediction.

5.5 General Lessons Learnt

This section considers more general conclusions, which are applicable to ANSPs in general.

One clear conclusion is that the MSAW model provided a powerful way of measuring the performance of MSAW, without the need to make any changes to the operational system. The use of an accurate model for this type of study, for setting up MSAW in a particular environment, and for parameter optimisation is highly recommended for all ANSPs.

MSAW is generally not applicable to the final approach segment. APM should be applied here instead, or otherwise MSAW should be inhibited by the use of inhibition areas or volumes. MSAW should also be inhibited in the immediate airport environs.

Skyguide’s nuisance alert rate with polygons stems to some extent from the geography; in particular, the Jura mountain range lies very close to Geneva airport. This leads to MSAW (polygon) alert hot spots generated by aircraft on approach to or departure from Geneva. ANSPs with a similar environment may find it difficult to achieve satisfactory MSAW performance with polygons, and may also find that DTED data gives a better performance overall.

Other countries, with a less mountainous geography may find that MSAW can work adequately well with polygons, although it is still expected that DTED will provide better performance since, even in gentle terrain, the DTED is a much closer model of the terrain than hand-crafted MSAW polygons. Carrying out a similar study in an area of Europe with more benign terrain than Switzerland could provide a worthwhile comparison.

ANSPs are also likely to find that MSAW can only be satisfactorily applied to correlated IFR aircraft tracks. Including VFR aircraft in MSAW is likely to increase the alert rate to an intolerable level.

6. RECOMMENDATIONS

The objectives of this study were to find answers to the following key questions:

- Scalability: what needs to change in the existing MSAW implementation to make it usable for the Skyguide area of interest?
- Volumes (hand designed polygons) versus DTED: what is the best option for Skyguide?
- Detection versus prediction: what is the best option for Skyguide?
- Operational Philosophy: are the current key choices with respect to track eligibility sustainable?

In particular, the study examined the combination of DTED with prediction, compared to polygons both with and without prediction.

This section answers these questions, and also highlights the next steps for Skyguide.

6.1 Scalability: What needs to change?

In principle, the current Skyguide MSAW system could be extended in geographical coverage. Since there is no facility to define inhibition volumes (e.g. around airports such as Lausanne), it would be necessary to construct the polygons so as to leave appropriate gaps in the coverage.

With polygons (and with suitable inhibition volumes), around 27 alerts per day should be expected (roughly a doubling of the current alert rate), and a mean warning time of around 67 seconds. However, the spread of warning times is, and will continue to be very broad, with a few alerts providing insufficient warning to a potential CFIT, and a significant number of other alerts occurring at a time when no real risk of CFIT exists.

The number of alerts could be reduced slightly by introducing clipping algorithms.

6.2 Polygons versus DTED: What is the best option?

In terms of alerting performance, the study indicates that DTED data offers the best solution for extending the geographical coverage of the Skyguide MSAW system.

Some practical difficulties may need to be overcome with respect to obtaining suitable DTED data, checking the integrity of the DTED data and investigating liability issues before it is used in an operational system.

It is recommended that, whenever possible, the integrity of any DTED data source is checked, by comparing one source against another. An effective method is to subtract the height values of one source from the height values of another, and then to display the height differences on a colour-coded map. Good sources of data will normally show close agreement. However, some allowance must be made for the different methods used for data acquisition.

Nevertheless, assuming that the DTED data can be (or has been) verified for accuracy and integrity, then this type of data would be suitable for extending MSAW for Skyguide.

In comparison to DTED data, MSAW polygons produce a much larger number of alerts. The MSAW polygon alerts provide a warning that the user-defined minimum altitude (usually based on the MVA) has been infringed, regardless of whether there is an increased risk of CFIT. On the other hand, the DTED based version of MSAW generally only alerts if there is a real risk of CFIT.

In summary, it is recommended that the primary means for extending the geographical coverage of MSAW is DTED.

Polygons in specific limited areas may still have their use, and it might therefore be prudent for a new MSAW system to support both DTED and polygon processing chains, with separate parameters (as the MSAW model does). Any polygons should to be defined carefully, in order to keep the number of nuisance alerts to a minimum.

6.3 Detection versus Prediction: What is the best option?

The study compared the MSAW performance using polygons with and without prediction. The results showed that, using prediction, MSAW could produce both more warning time and a lower alert rate.

The DTED algorithm always included a predictive element. DTED data could have been used with a vertical margin, but no prediction. However, when it comes to preventing CFIT, it has to be expected that no performance benefit could be gained by essentially ignoring the tracks heading and vertical rate.

The best DTED performance was achieved with a specially formulated “level-off” assumption as part of the prediction.

6.4 Operational Philosophy: Sustainable choices?

The alert rate statistics for the various types of flight (correlated/uncorrelated; IFR/VFR/MIL) show that the Skyguide philosophy of subjecting only correlated IFR flights to MSAW succeeds in maintaining a relatively low alert rate.

If uncorrelated flights and/or VFR flights were included, the number of alerts would be considerably greater, and many of these alerts would occur as soon as the aircraft came into surveillance cover. Because VFR traffic is trying to stay close to the ground (to maintain a visual reference), in almost all cases, the alerts would have to be classed as a nuisance.

In short, Skyguide appear to have made the right choice when it comes to aircraft eligibility, and the selection of only correlated IFR flights for MSAW processing should be maintained for an extended MSAW system.

6.5 Next Steps

This study answers many of the essential questions that Skyguide have about extending the geographical coverage of MSAW. Nevertheless, there are a few remaining issues that need to be addressed.

Firstly, Skyguide need decide whether to enhance the MSAW system before extending its geographical coverage. The cost/benefit aspects of this need to be addressed by Skyguide. In any event, the MSAW system will perform best when using DTED data and including prediction.

Assuming that Skyguide choose to enhance the MSAW system, they should take time to locate the best source(s) of DTED data. Some effort will also need to be spent to investigate the nature of the data and its accuracy, since this will have an influence on the selected MSAW parameters, such as the vertical margin. All issues related to legal liability of using DTED data should also be investigated.

MSAW performance should be optimised further using the MSAW model. This is a very important step, since it will allow the operational impact of the new system to be assessed before putting it into operational service.

Finally, Skyguide should address how they wish to monitor aircraft on final approach. APM normally takes over from the MSAW processing for aircraft on the final approach segment. The appropriate solution for APM needs to be investigated, and the spatial boundary between MSAW and APM also needs to be defined.

7. LIST OF ABBREVIATIONS

APM	Approach Path Monitor
ASTERIX	All purpose Structured Eurocontrol surveillance Information eXchange
ATC	Air Traffic Control
ACC	Area Control Centre
CFIT	Controlled Flight Into Terrain
DPM	Departure Path Monitor
DTED	Digital Terrain Elevation Data
ECIP	European Convergence and Implementation Plan
IFR	Instrument Flight Rules
KML	Keyhole Markup Language
MVA	Minimum Vectoring Altitude
MSAW	Minimum Safe Altitude Warning
SNTF	(Skyguide) Safety Nets Task Force
SSR	Secondary Surveillance Radar
VFR	Visual Flight Rules

8. FIGURES

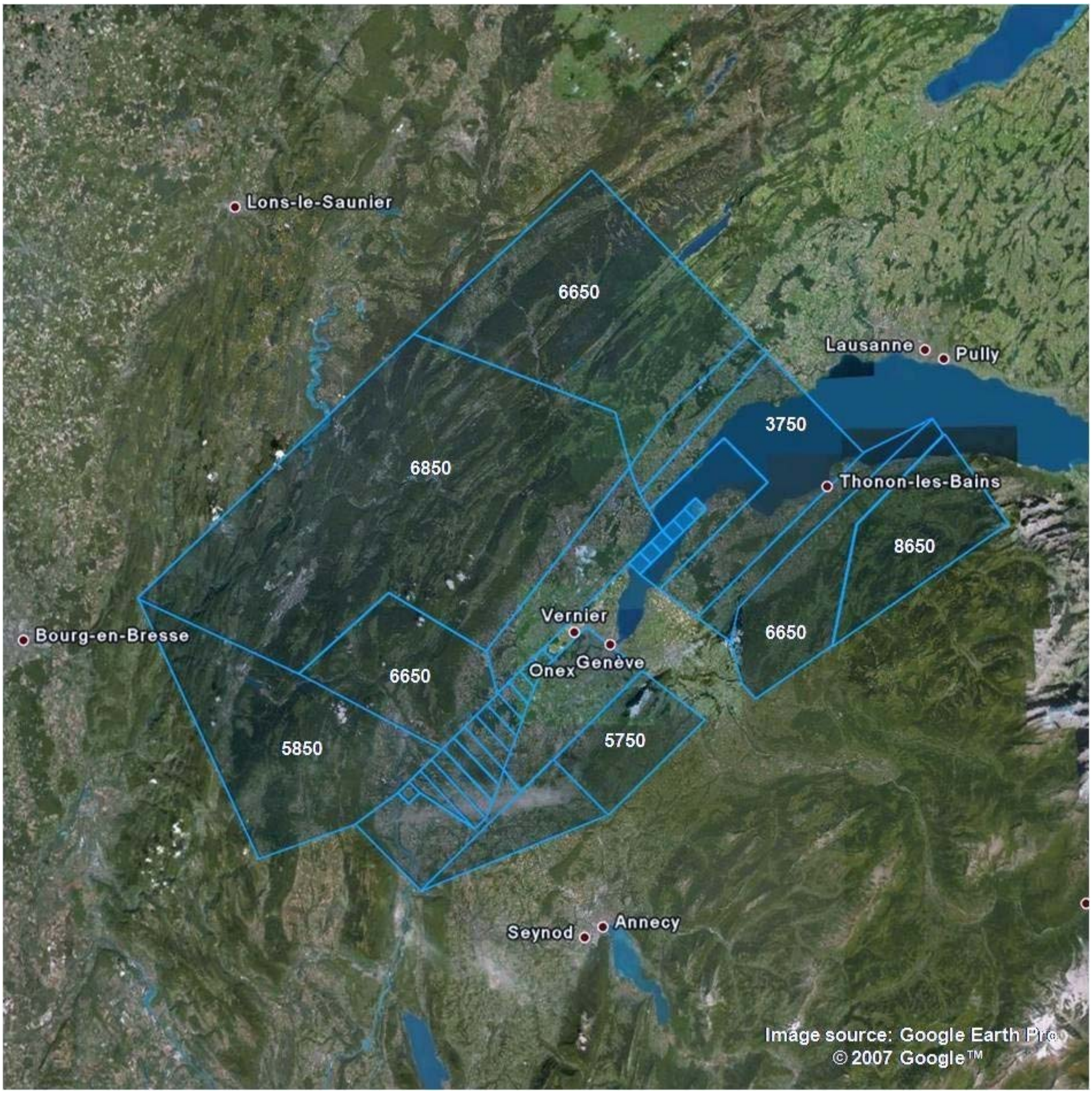


Figure 8-1 Birds Eye view of the current MSAW polygons in use at Geneva ACC (height in feet)

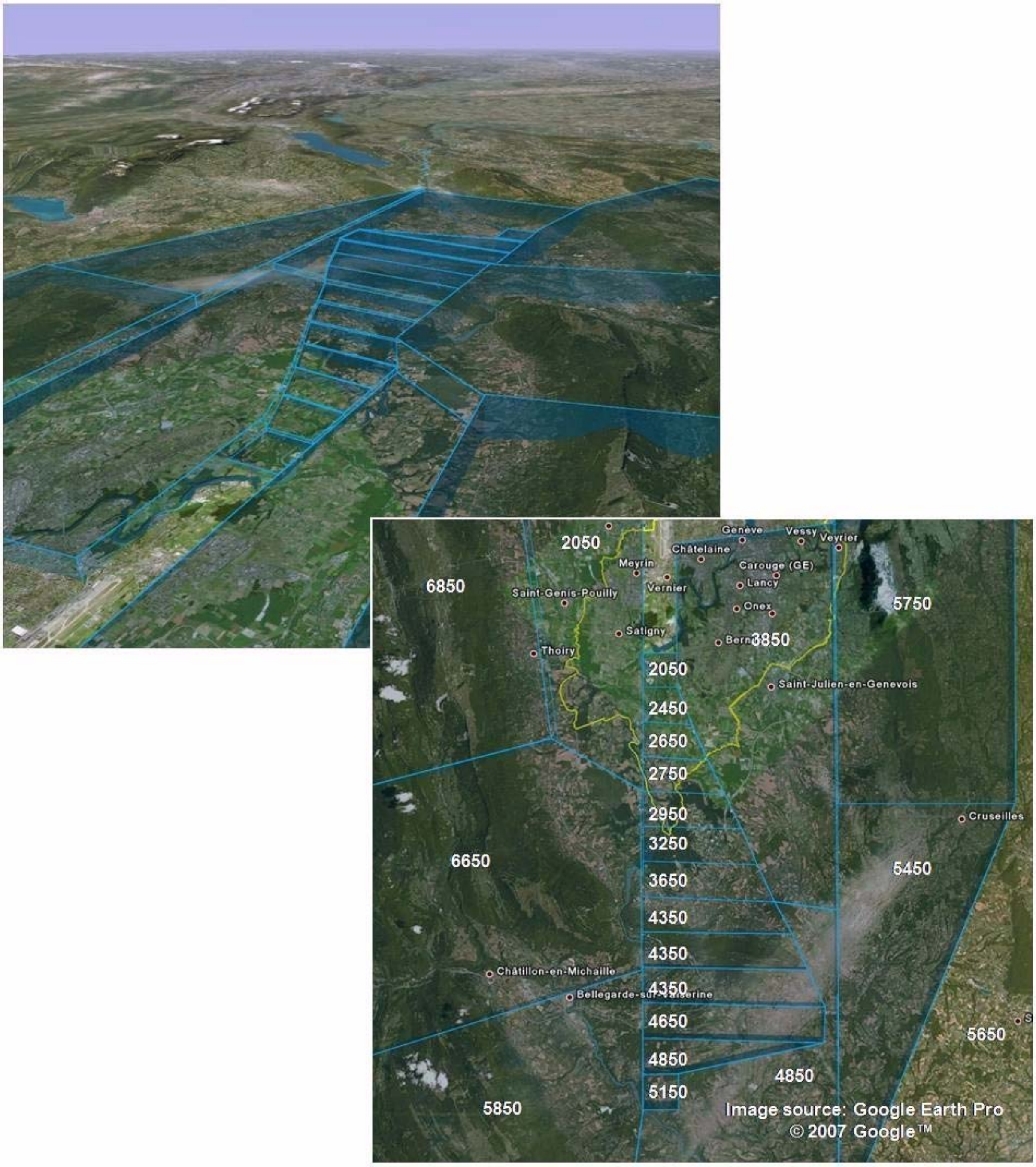


Figure 8-2 MSAW Polygons for Geneva final approach – Runway 05 (height shown in feet)

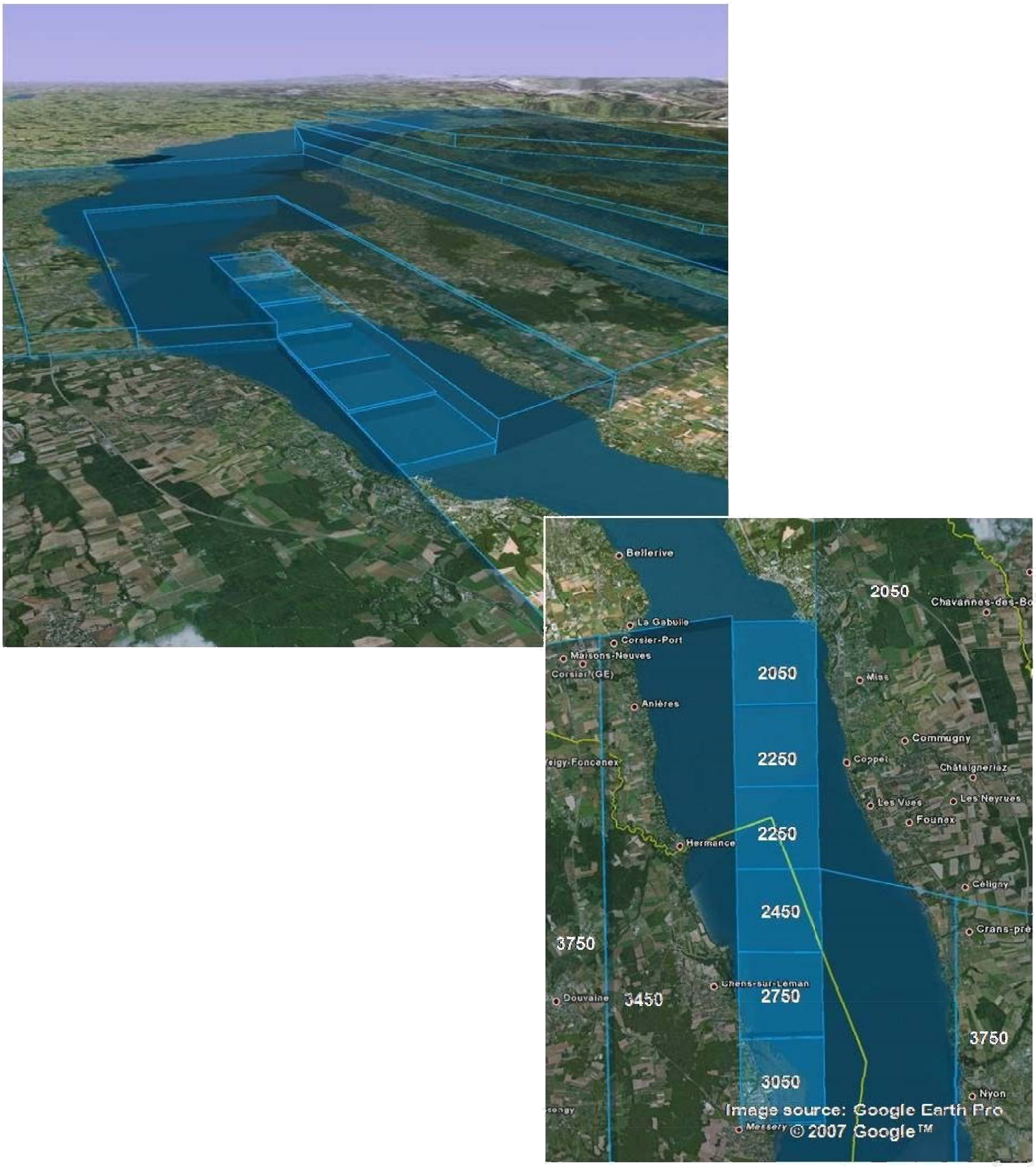


Figure 8-3 MSAW polygons for Geneva final approach – Runway 23 (height shown in feet)

```
CENTER 46°14'20"N 06°06'06"E

#MSAWG30 5150
MSAW73 46°02'47"N 05°48'47"E
MSAW78 46°03'29"N 05°49'48"E
MSAW80 46°02'47"N 05°50'49"E
MSAW74 46°02'05"N 05°49'48"E

#MSAWGBE 4250
CRANS 46°21'58"N 06°11'09"E
MSAW87 46°23'39"N 06°10'12"E
MUIDS 46°26'54"N 06°13'27"E
MSAW06 46°32'03"N 06°21'18"E
MSAW89 46°30'58"N 06°22'59"E

#MSAWGBO 3750
CRANS 46°21'58"N 06°11'09"E
MSAW89 46°30'58"N 06°22'59"E
MSAW08 46°24'33"N 06°31'56"E
MSAW94 46°14'01"N 06°16'26"E
MSAW95 46°15'49"N 06°12'58"E
MSAW04 46°22'40"N 06°23'03"E
MSAW03 46°25'31"N 06°19'00"E
MSAW88 46°20'57"N 06°12'02"E
```

Figure 8-4 Extract from MSAW Polygon Definition File

```
GTMActive 1
GTMProcessNonCorrel 0
GTMProcessCorrelVFR 0
GTMProcessCorrelMIL 0
GTMLookAheadTime 10
DTEDActive 1
DTEDProcessNonCorrel 0
DTEDProcessCorrelVFR 0
DTEDProcessCorrelMIL 0
DTEDLookAheadTime 55
DTEDWarningTime 45
DTEDVerticalMargin 450
APMAboveActive 0
APMBelowActive 0
```

Figure 8-5 Example Parameter for the MSAW model

```
VFR
- 4201 - 4277
- 4501 - 4557
- 5101 - 5127
- 7000 - 7077
- 7740 - 7747
- 7760 - 7765

MIL
- 1500 - 1577
- 1600 - 1677
- 5400 - 5477
- 6100 - 6130
```

Figure 8-6 VFR/MIL code list used by the MSAW model

Number Of Conflicts: APM 0: GTM 43: DTED 10

GTM Alerts: 43

Track Num	ModeA (oct)	VFR MIL	Time HH:MM:SS	X NM	Y NM	Z ft	GTM Imm	TimeTo Cnflct	Duration seconds	Volume Name
110	5734	IFR	06:49:36	41.67	13.25	6370.0	Imm	0	387	MSAWEXT10
862	3222	IFR	06:58:07	-2.58	-14.89	5570.0	Imm	0	104	MSAWEXT2
691	7555	IFR	07:11:44	18.02	-3.03	9100.0	Imm	0	4	MSAWEXT10
2342	3214	IFR	07:12:08	-7.62	-3.42	6570.0	Imm	0	4	MSAWGCR
462	4766	IFR	07:13:51	-2.80	-22.31	4570.0	Imm	0	52	MSAWEXT5
1368	5756	IFR	07:31:00	39.97	5.42	6870.0	Imm	0	208	MSAWEXT11
1748	5737	IFR	07:58:32	20.80	22.06	4170.0	Imm	0	140	MSAWEXT4
4034	6751	IFR	08:34:36	22.45	10.91	8200.0	Imm	0	191	MSAWGHE
1999	5764	IFR	09:03:32	33.75	-12.45	15600.0	Imm	0	8	MSAWEXT12
612	5756	IFR	09:20:47	46.41	-28.02	17600.0	Imm	0	99	MSAWEXT12
205	6710	IFR	09:22:08	14.39	18.58	5570.0	Imm	0	316	MSAWEXT1
612	5756	IFR	09:25:07	51.75	-12.81	11200.0	Imm	0	8	MSAWEXT12
612	5756	IFR	09:25:19	51.41	-11.78	10300.0	Imm	0	20	MSAWEXT12
3789	5756	IFR	09:26:48	47.69	-6.75	8600.0	Imm	0	36	MSAWEXT12
1597	4030	IFR	10:07:16	39.66	-22.27	17600.0	Imm	0	168	MSAWEXT12
2062	5775	IFR	10:09:04	-5.86	-4.62	6270.0	Imm	0	4	MSAWGCR
401	7116	IFR	10:26:20	-21.06	1.34	4870.0	Imm	0	4	MSAWGNG
2112	5762	IFR	10:27:04	-5.95	-5.28	5870.0	Imm	0	8	MSAWGCR
684	4303	IFR	10:43:00	33.91	-12.22	16300.0	Imm	0	36	MSAWEXT12
3167	7516	IFR	11:09:12	47.20	21.03	9500.0	Imm	0	132	MSAWEXT10
462	4766	IFR	11:37:27	-5.08	-41.41	10500.0	Imm	0	255	MSAWEXT10
109	5744	IFR	12:14:24	18.95	16.77	5170.0	Imm	0	48	MSAWEXT1
109	5744	IFR	12:15:28	16.08	19.42	5170.0	Imm	0	16	MSAWEXT1
109	5744	IFR	12:16:08	15.50	21.86	6070.0	Imm	0	12	MSAWEXT4
1888	4725	IFR	12:34:11	-2.92	-22.05	4170.0	Imm	0	64	MSAWEXT5
2822	4476	IFR	12:50:24	44.75	-7.45	9200.0	Imm	0	67	MSAWEXT12
415	4476	IFR	12:51:59	45.94	-12.12	11500.0	Imm	0	239	MSAWEXT12
2374	2327	IFR	13:29:07	2.78	-11.61	6470.0	Imm	0	124	MSAWEXT8
2767	5743	IFR	13:55:48	20.44	16.25	3370.0	Imm	0	164	MSAWEXT4
1757	3270	IFR	14:42:51	-4.56	-18.88	5616.0	Imm	0	108	MSAWEXT2
2536	5721	IFR	14:46:24	20.42	17.12	3416.0	Imm	0	100	MSAWEXT4
2797	5730	IFR	14:57:27	33.84	-12.33	16775.0	Imm	0	8	MSAWEXT12
1888	4725	IFR	15:16:19	21.47	-29.47	17500.0	Imm	0	8	MSAWEXT12
1888	4725	IFR	15:18:27	16.75	-21.84	13500.0	Imm	0	248	MSAWEXT11
2933	5741	IFR	15:20:00	18.58	27.44	3889.0	Imm	0	256	MSAWEXT4
1888	4725	IFR	15:22:43	7.00	-9.12	5962.0	Imm	0	156	MSAWEXT8
642	4725	IFR	15:28:43	3.73	-16.48	4062.0	Imm	0	12	MSAWEXT8
2143	5727	IFR	16:47:36	33.92	-12.61	17000.0	Imm	0	8	MSAWEXT12
3886	1140	IFR	17:53:16	14.14	25.00	6635.0	Imm	0	148	MSAWEXT4
689	3324	IFR	18:36:48	-1.83	-11.69	5435.0	Imm	0	211	MSAWGFI
2617	5703	IFR	19:12:12	-6.61	-5.88	6135.0	Imm	0	20	MSAWGCR
2180	5564	IFR	20:21:48	17.38	-10.69	13100.0	Imm	0	23	MSAWEXT11
2180	5564	IFR	20:22:32	16.17	-7.12	10600.0	Imm	0	32	MSAWEXT10

GTM Alerts for each MSAW Volume

Initial MSAW Volume = MSAWGCR, GTM Alerts = 4
Initial MSAW Volume = MSAWGFI, GTM Alerts = 1
Initial MSAW Volume = MSAWGHE, GTM Alerts = 1
Initial MSAW Volume = MSAWGNG, GTM Alerts = 1
Initial MSAW Volume = MSAWEXT1, GTM Alerts = 3
Initial MSAW Volume = MSAWEXT2, GTM Alerts = 2
Initial MSAW Volume = MSAWEXT4, GTM Alerts = 6
Initial MSAW Volume = MSAWEXT5, GTM Alerts = 2
Initial MSAW Volume = MSAWEXT8, GTM Alerts = 3
Initial MSAW Volume = MSAWEXT10, GTM Alerts = 5
Initial MSAW Volume = MSAWEXT11, GTM Alerts = 3
Initial MSAW Volume = MSAWEXT12, GTM Alerts = 12

```
DTED Alerts: 10

Track ModeA  VFR    Time       X       Y       Z      DTED  TimeTo   Duration
 Num  (oct)  MIL  HH:MM:SS     NM      NM      ft     Imm   Cnflct    seconds

3355  7147  IFR   06:15:40   5.58    5.19   3870.0  Nrm      51.4          8
 862  3222  IFR   06:59:15  -3.62 -18.94   3770.0  Nrm      51.2         36
1368  5756  IFR   07:31:00  39.97    5.42   6870.0  Imm       0.0          4
 548  5747  IFR   07:59:52   5.36    4.97   3570.0  Nrm      52.1          4
 612  5756  IFR   09:25:23  51.19 -11.52  10200.0  Imm      20.8         16
3789  5756  IFR   09:27:00  48.27   -5.81   8100.0  Imm      21.1         28
3167  7516  IFR   11:10:20  47.44   16.53   7570.0  Nrm      52.3          8
3886  1140  IFR   17:53:56  17.09   24.81   4735.0  Nrm      50.8         36
 689  3324  IFR   18:40:08  -3.36 -20.06   2835.0  Nrm      48.2         12
1467  4003  IFR   21:15:08   7.81    7.34   4635.0  Nrm      54.8          4
```

Figure 8-7 Example MSAW alert results file

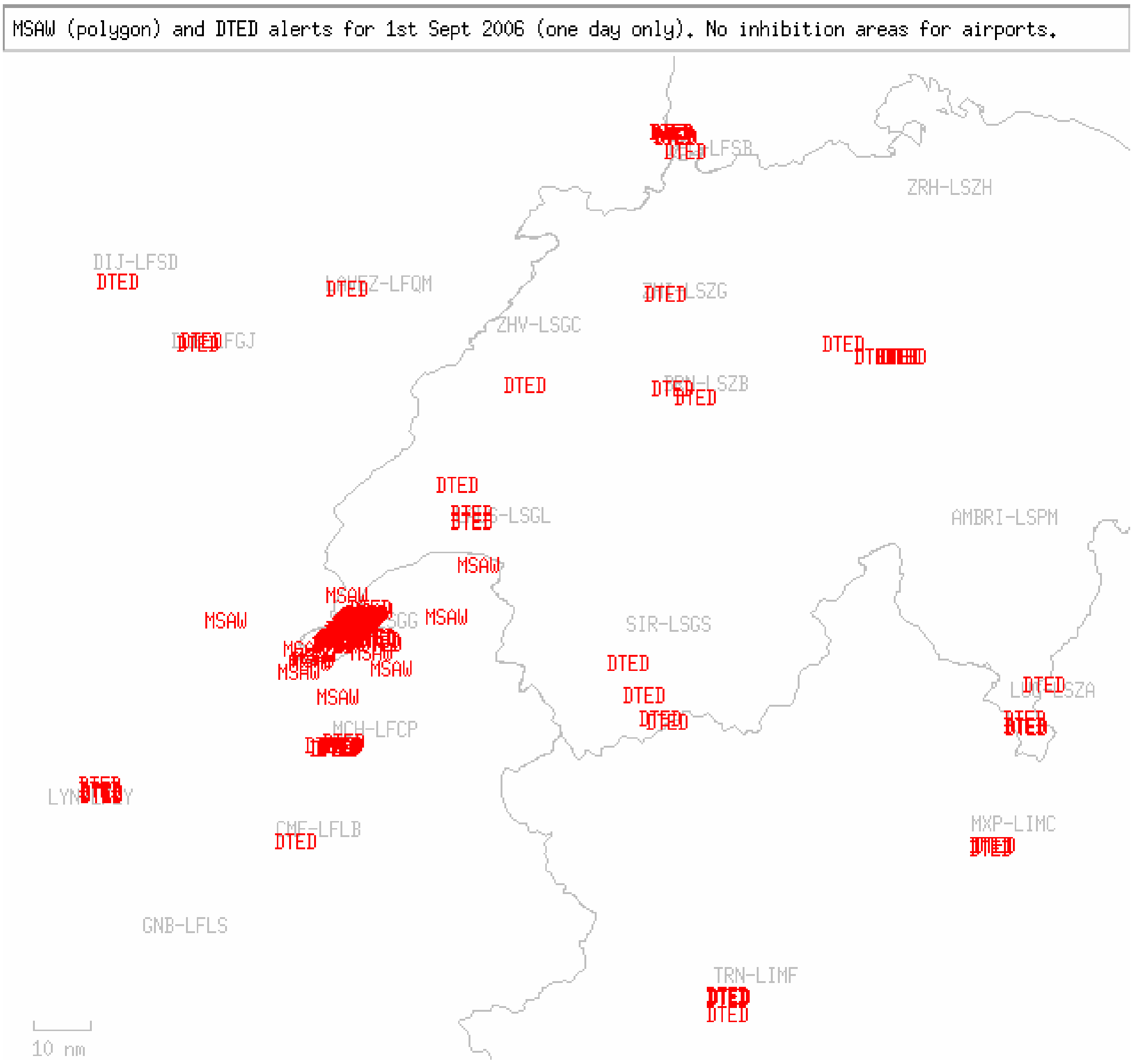


Figure 8-8 Distribution of MSAW (polygon) and DTED alert alerts for 1st September 2006 – Correlated IFR flights only

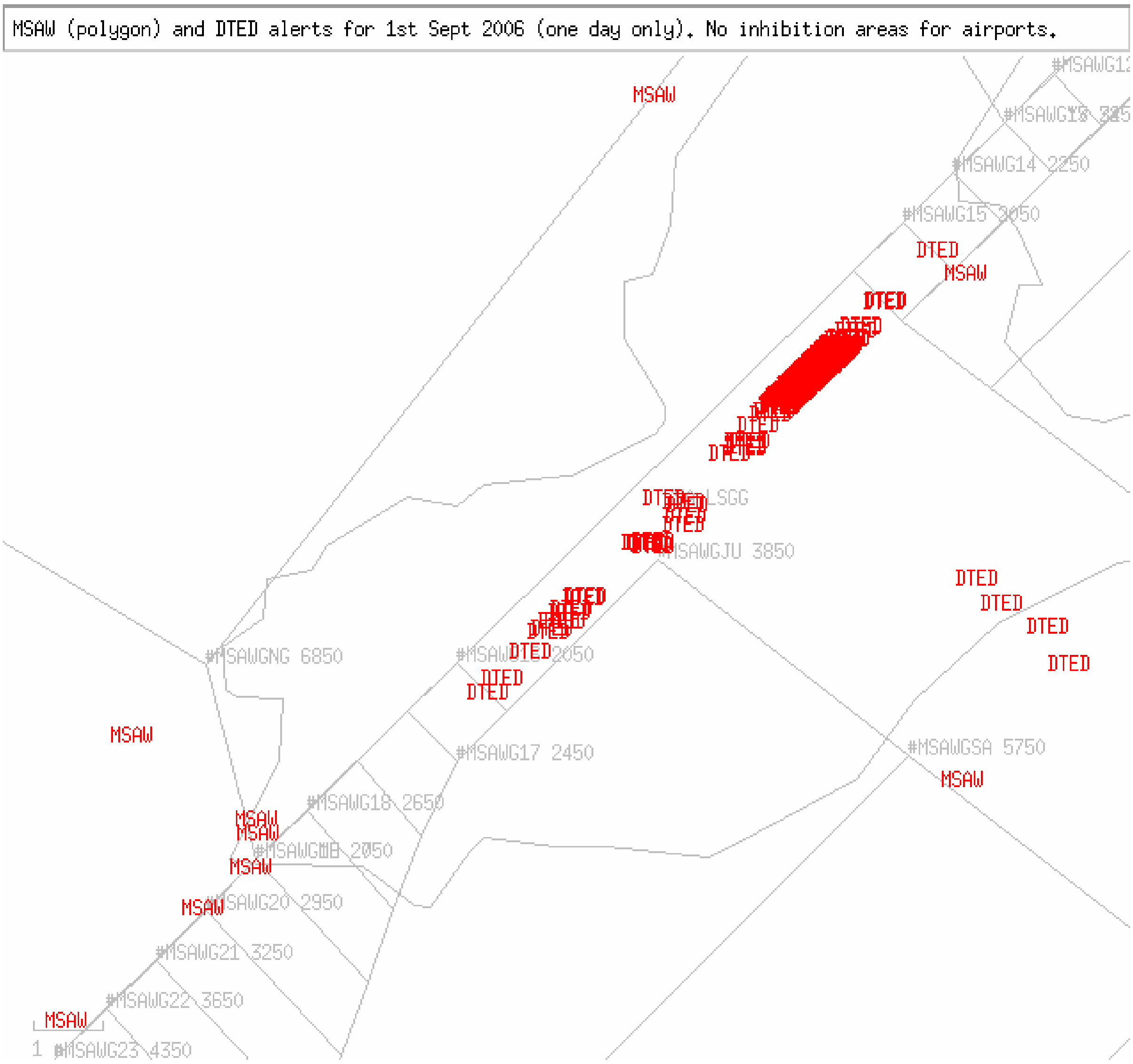
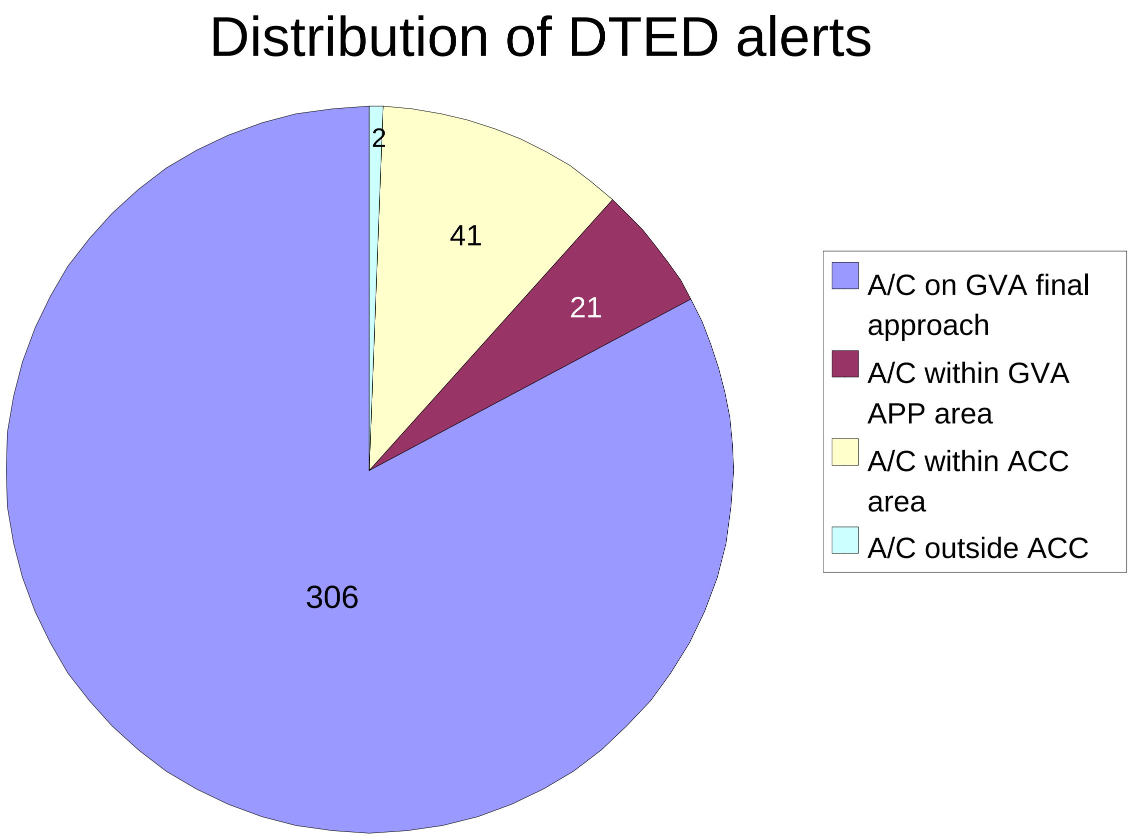


Figure 8-9 Distribution of MSAW (polygon) and DTED alerts in Geneva final approach segment (1st Sept 2006) – Correlated IFR flights only



Area of Airspace	**DTED alerts**
GVA Final Approach	306
In MSAW Coverage but not on Final Approach	0
In GVA APP area	21
In GVA ACC area	41
Outside GVA ACC	2
Total	370

Figure 8-10 Distribution of DTED alerts for 1st September 2006 – correlated IFR flights only

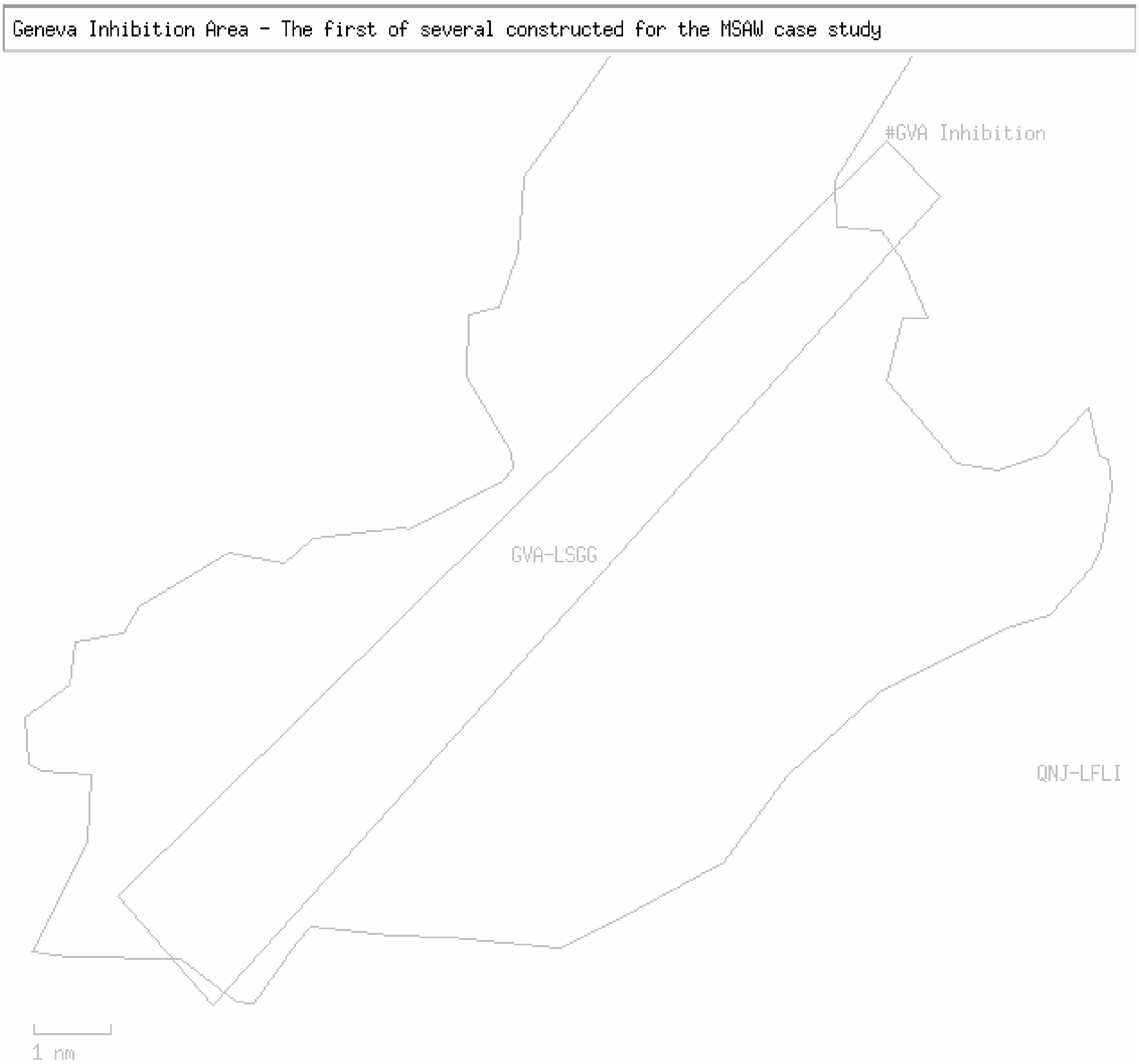


Figure 8-11 MSAW Inhibition Area constructed for Geneva final approach

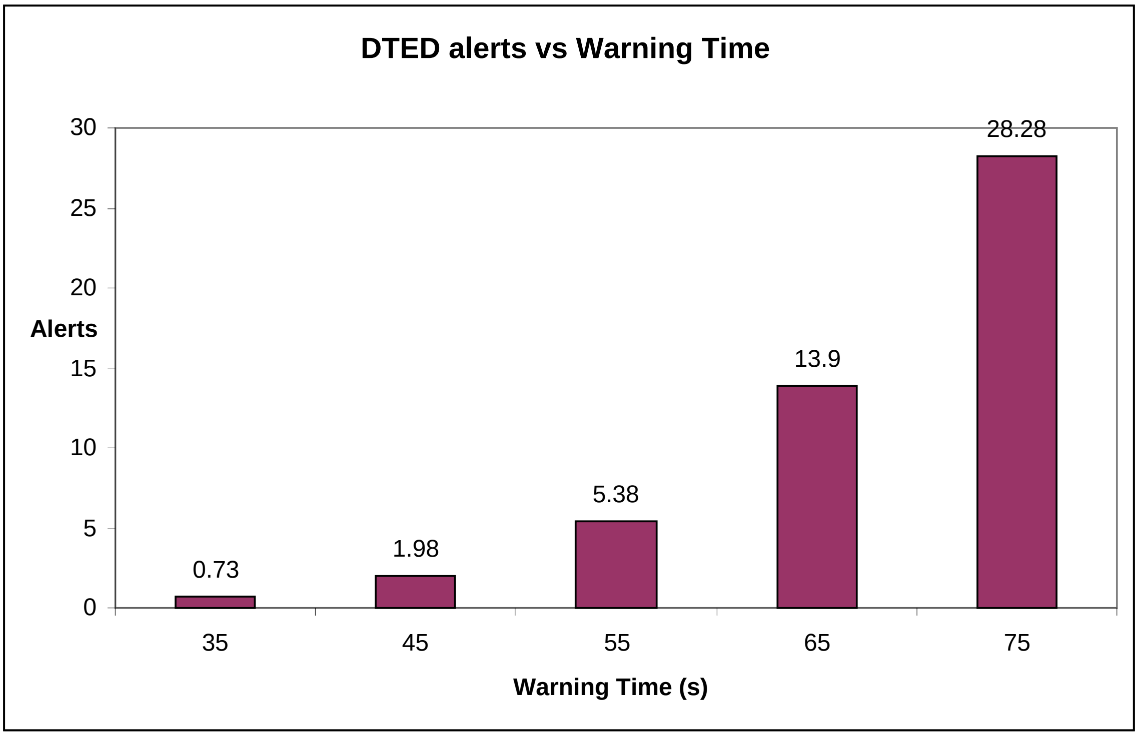


Figure 8-12 Mean DTED daily alert rate verses Warning Time parameter (Vertical Margin = 150ft) – Correlated IFR flights only

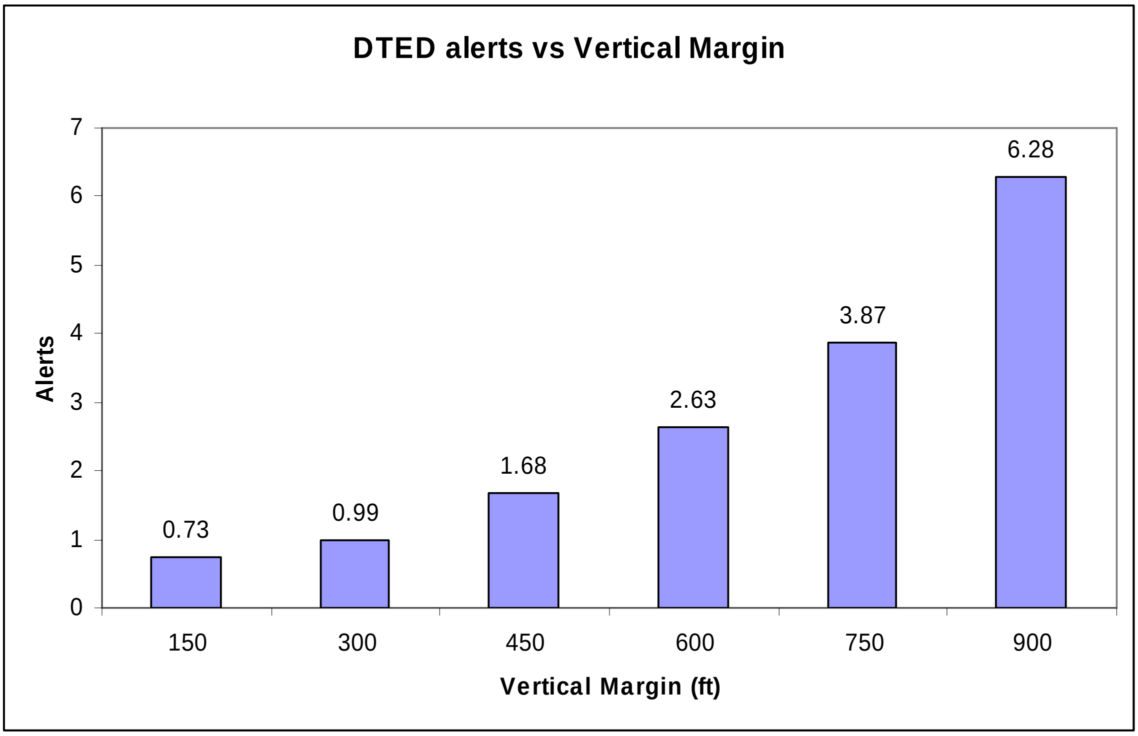


Figure 8-13 Mean DTED daily alert rate verses Vertical Margin parameter (Warning Time = 35s) – Correlated IFR flights only

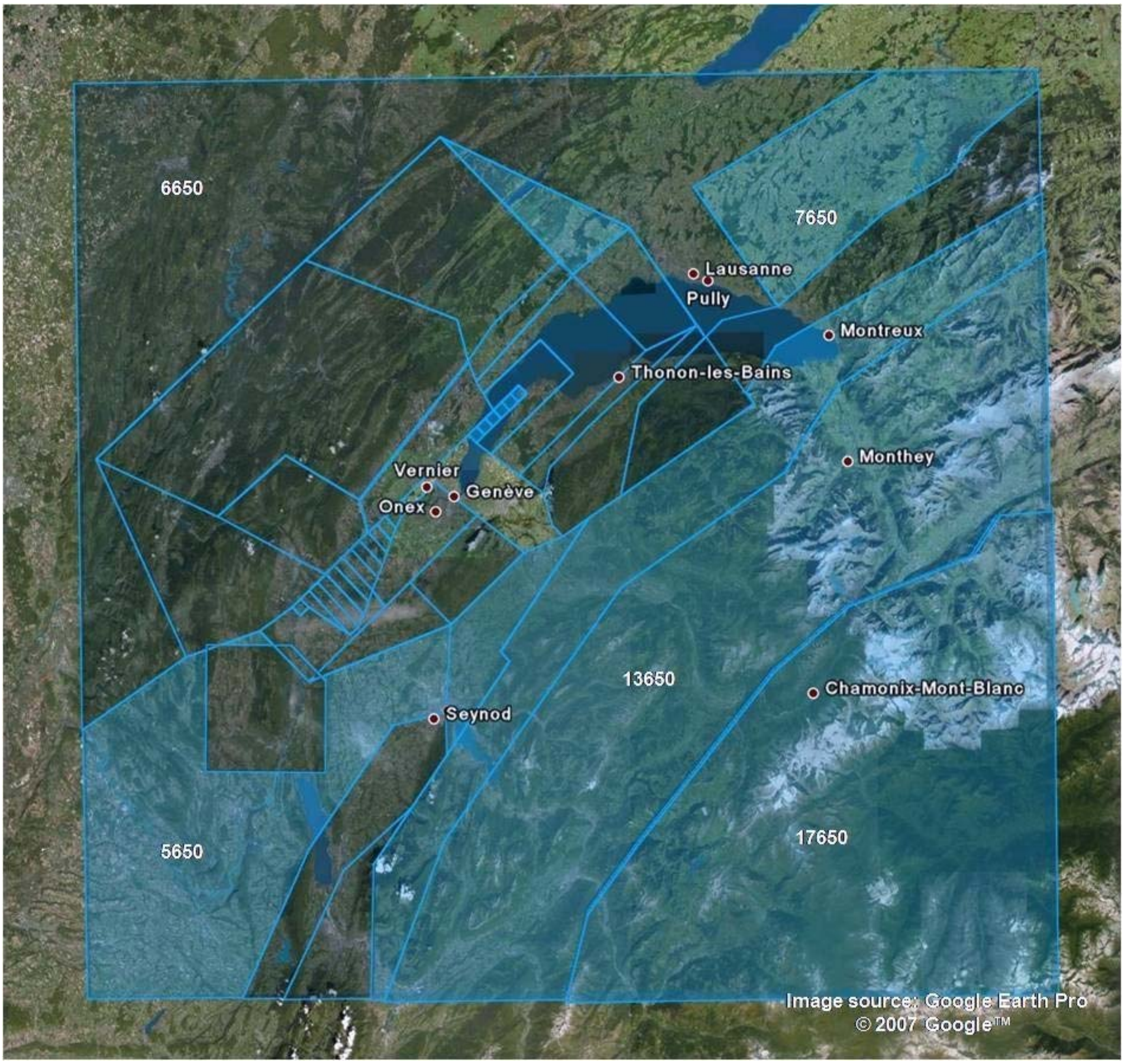


Figure 8-14 Bird's eye view of the MSAW polygons after having been extended (height in feet)

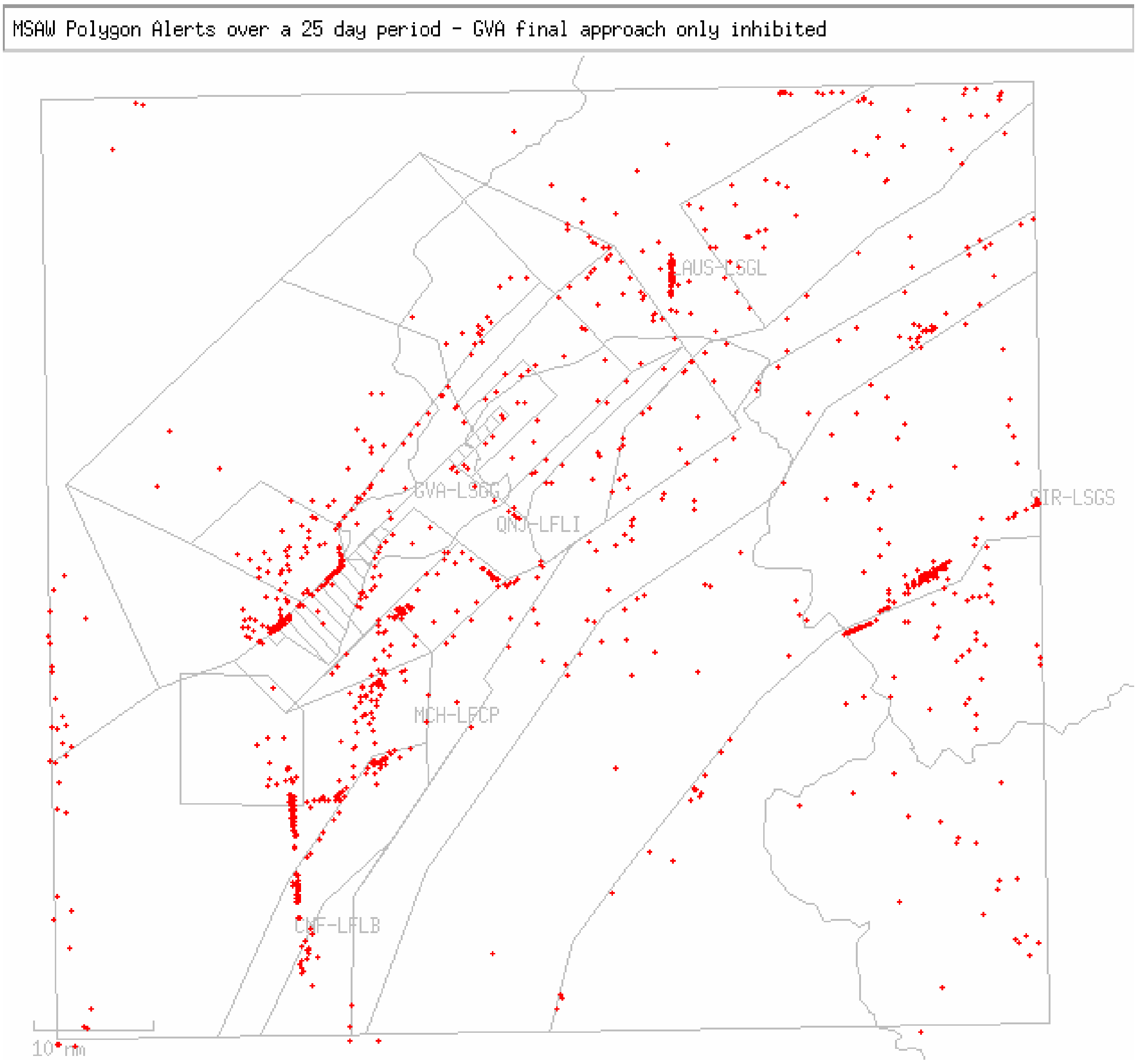


Figure 8-15 Geographical distribution of MSAW (polygon) alerts over the 25 day data sample

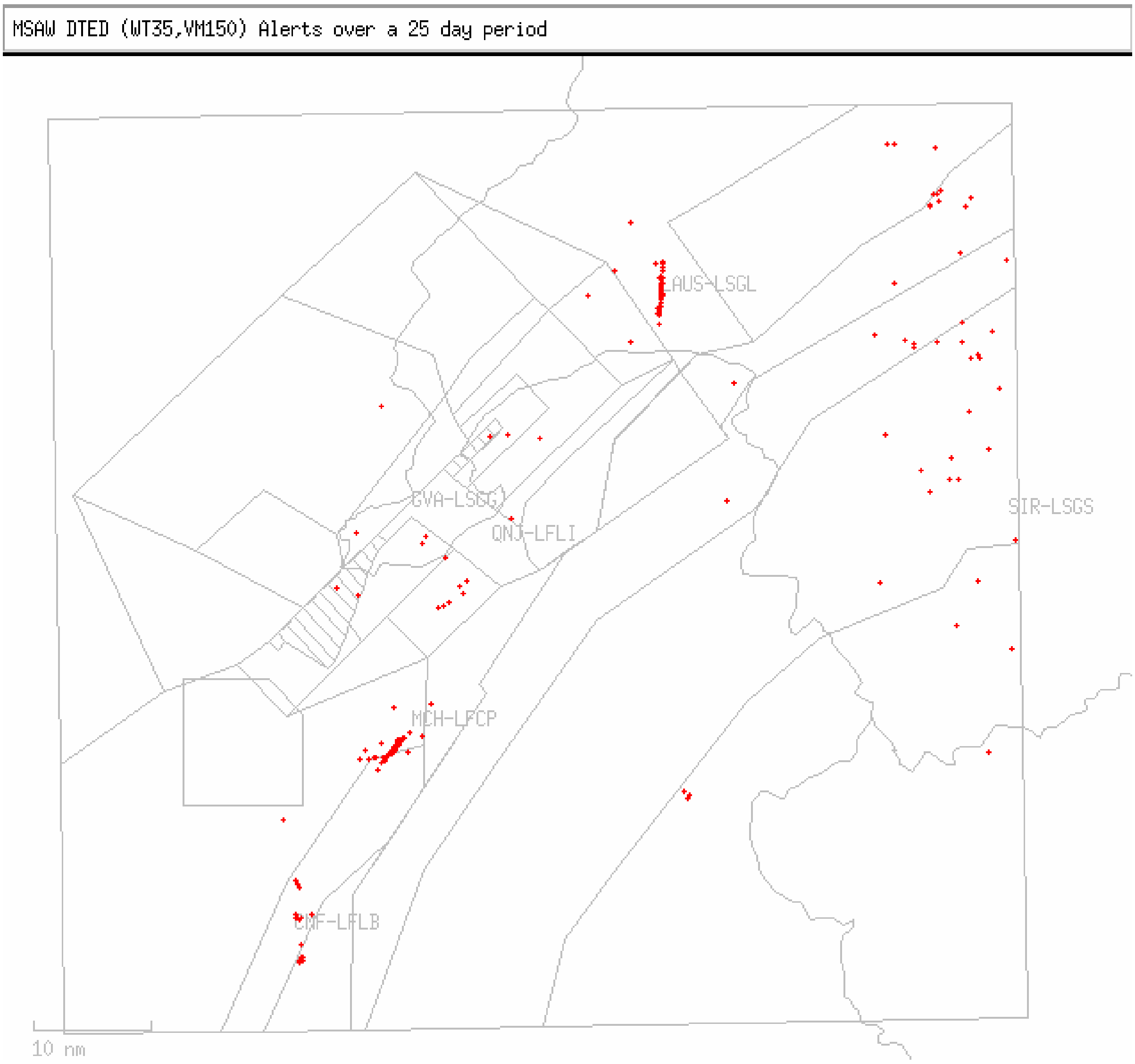


Figure 8-16 Geographical distribution of DTED alerts over the 25 day data sample

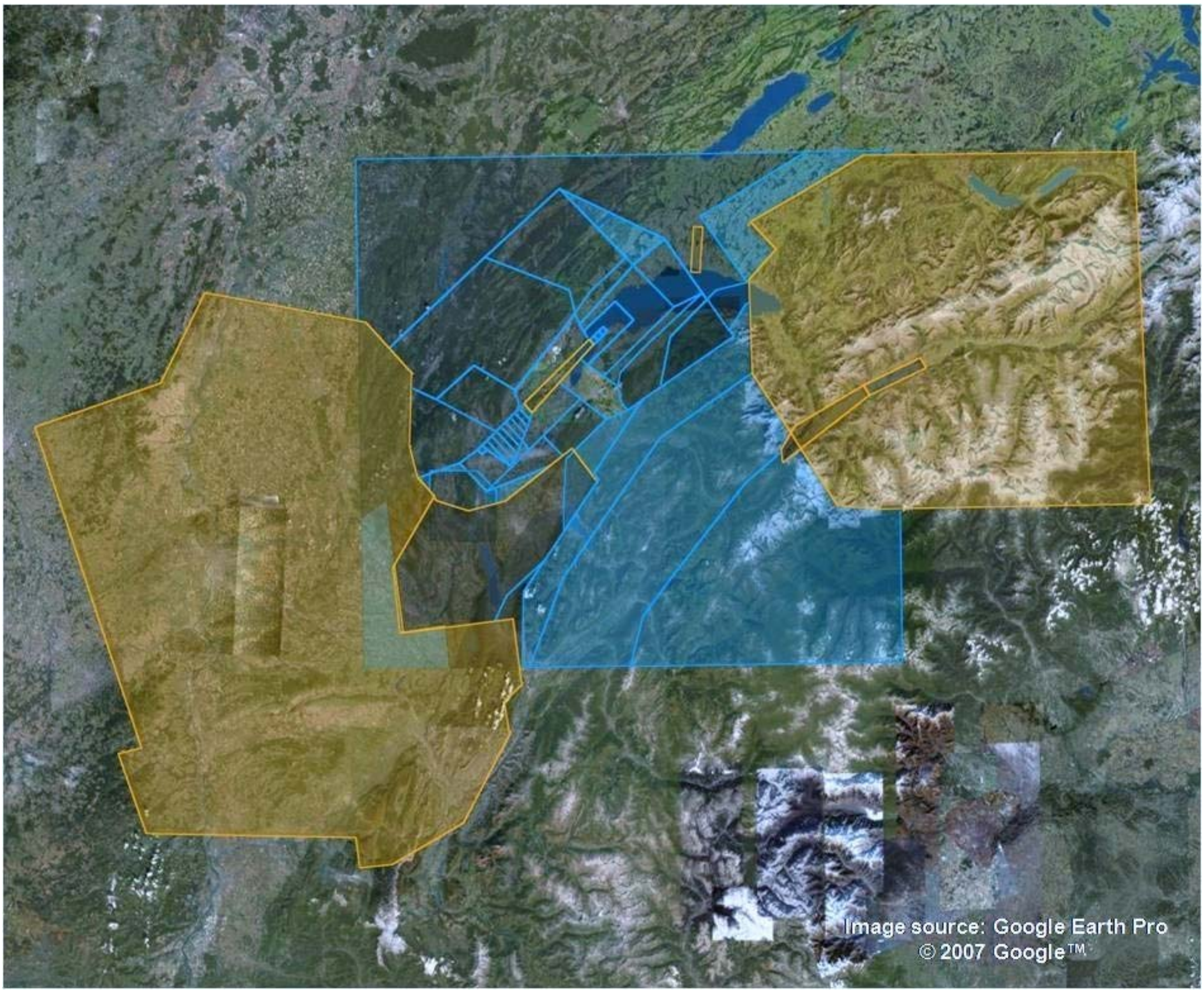
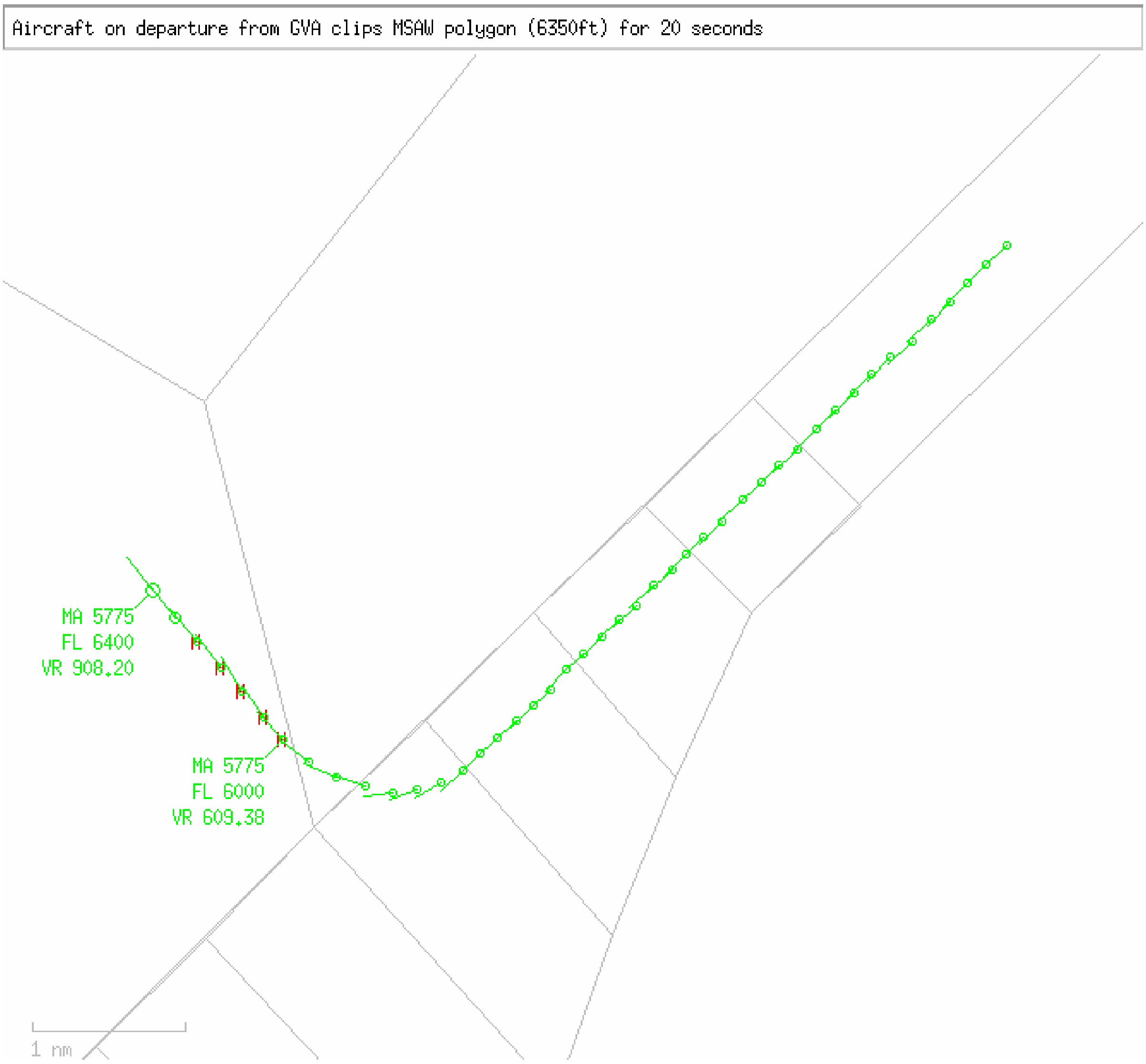


Figure 8-17 MSAW Inhibition Volumes – covering Geneva, Lausanne, Chambery TMA, LYON TMA (to the west), Sion departures and a broad area around Sion to the East.



MA = Mode A code, FL = Tracked Height, VR = Vertical Rate

Figure 8-18 Example situation showing an aircraft on departure from Geneva clipping an MSAW polygon (6350ft ceiling)

Run	Polygons extended	Airspace Inhibited	Polygon Clipping Time (seconds)
P1	No	None	0
P2	Yes	None	0
P3	Yes	Geneva, Lausanne, Sion and around, Chambery, Lyon.	0
P4	Yes	Geneva, Lausanne, Sion and around, Chambery, Lyon.	10
P5	Yes	Geneva, Lausanne, Sion and around, Chambery, Lyon.	20
P6	Yes	Geneva, Lausanne, Sion and around, Chambery, Lyon.	30
P7	Yes	Geneva, Lausanne, Sion and around, Chambery, Lyon.	40

Cell colour	Mean Daily Alert Rate
	0 – 2
	2 – 4
	4 – 8
	8 – 16
	16 – 32
	32 – 64
	64 – 128
	More than 128

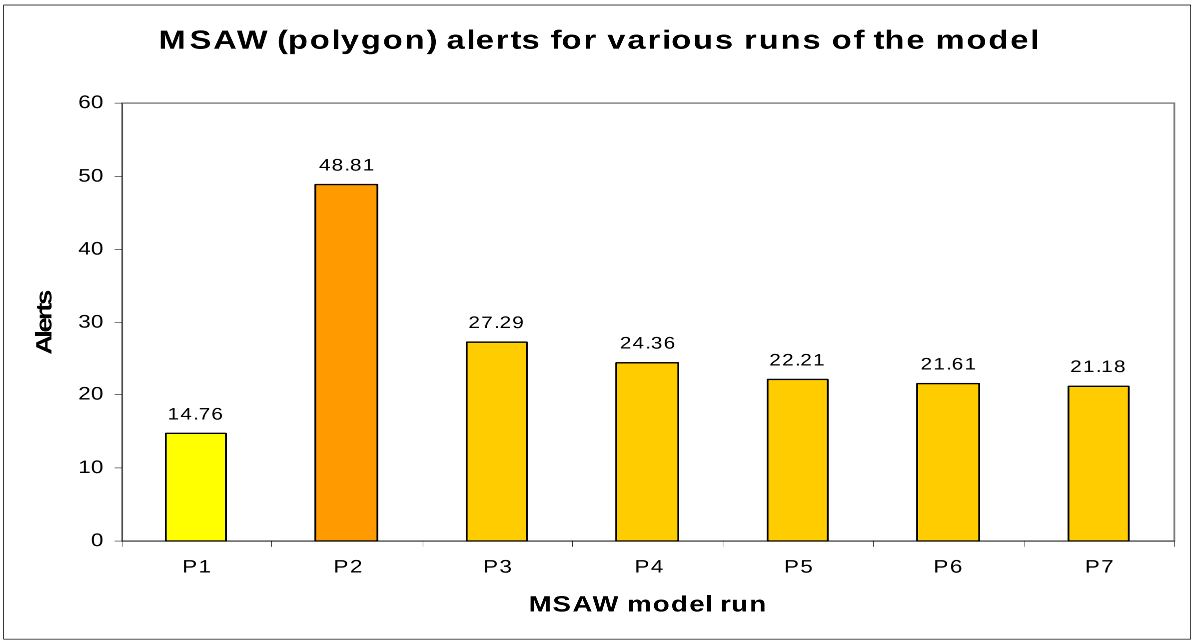


Figure 8-19 Mean MSAW (polygon) daily alert rate for various runs of the MSAW model – Correlated IFR flights only

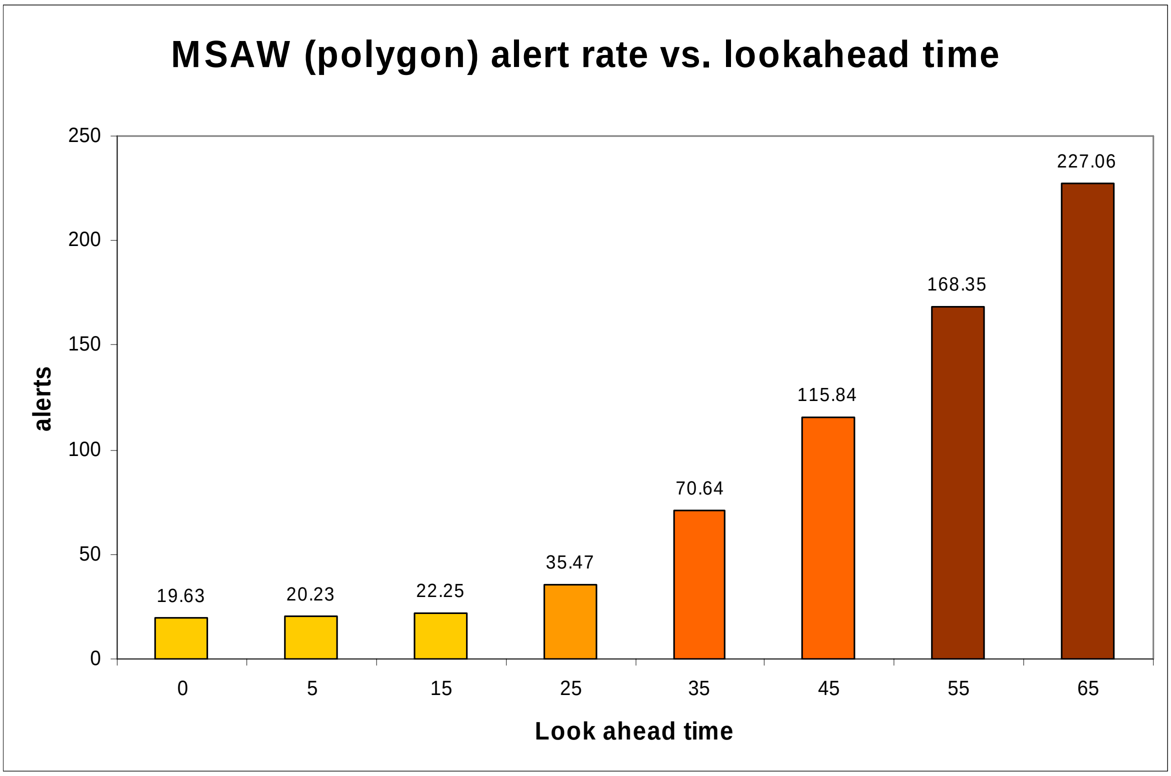


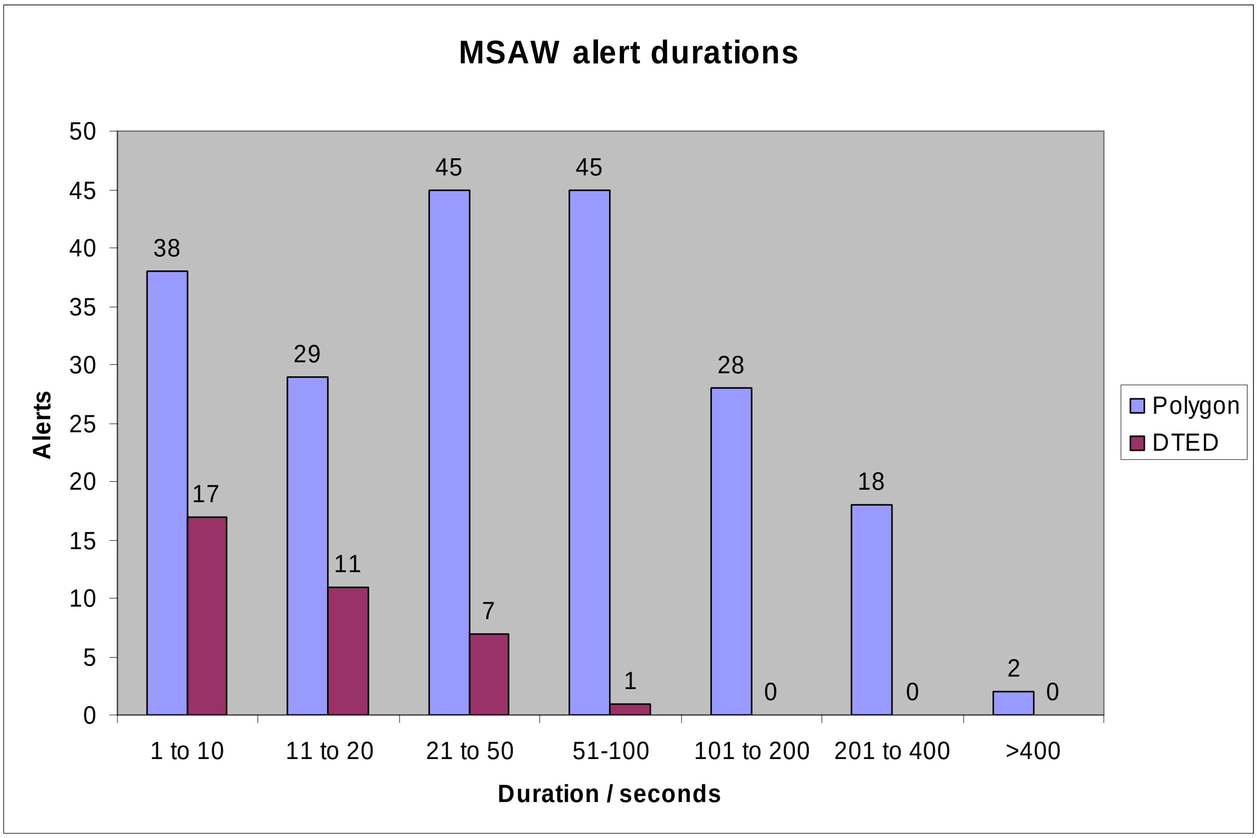
Figure 8-20 Mean MSAW (polygon) daily alert rate vs. look ahead time – MSAW polygons lowered by 500ft – Correlated IFR flights only

		DTEDWarningTime / seconds			
		35	45	55	65
Vertical Margin / ft	150	0.73	1.98	5.38	13.9
	300	0.99			
	450	1.68			
	600	2.63			
	750	3.87			

Figure 8-21 Mean DTED daily alert rate for various runs of the MSAW model. Current geographical coverage – Correlated IFR flights only

		DTEDWarningTime / seconds			
		35	45	55	65
Vertical Margin / ft	150	1.12	2.71	4.52	16.14
	300	1.42	3.53	9.64	21.26
	450	2.32	5.94	14.08	29.06
	600	3.74	8.74	19.20	41.07
	750	5.04	12.53	27.33	64.70

Figure 8-22 Mean DTED daily alert rate for various runs of the MSAW model Extended geographical coverage, Inhibition Volumes – Correlated IFR flights only



Mean Durations : MSAW (Polygon) = 76.9 seconds; DTED = 15.5 seconds.

Figure 8-23 Distribution of MSAW (polygon) and DTED alert duration.

Correlated IFR Flights

Vertical Margin / ft		DTEDWarningTime / seconds 35	45
	150	1.12	2.71
	300	1.42	3.53
	450	2.32	5.94
	600	3.74	8.74

Uncorrelated IFR Flights

Vertical Margin / ft		DTEDWarningTime / seconds 35	45
	150	49.76	52.34
	300	59.36	60.35
	450	61.12	63.41
	600	60.26	61.34

Correlated VFR Flights

Vertical Margin / ft		DTEDWarningTime / seconds 35	45
	150	9.30	10.12
	300	8.52	8.78
	450	8.70	9.13
	600	8.91	10.33

Uncorrelated VFR Flights

Vertical Margin / ft		DTEDWarningTime / seconds 35	45
	150	143.64	158.15
	300	175.28	187.85
	450	204.42	220.22
	600	240.84	255.39

Uncorrelated MIL Flights

Vertical Margin / ft		DTEDWarningTime / seconds 35	45
	150	11.67	13.26
	300	15.71	17.13
	450	17.26	18.12
	600	16.19	16.44

Figure 8-24 Mean DTED daily alert rate for various types of flight

WT Run 1	Extended MSAW coverage, polygons, no prediction
WT Run 2	Extended MSAW coverage, polygons lowered by 500ft, 15 second prediction
WT Run 3	Extended MSAW coverage, polygons lowered by 500ft, 35 second prediction
WT Run 4	Extended MSAW coverage, DTED, 35 seconds warning time, 300ft vertical margin
WT Run 5	Extended MSAW coverage, DTED, 65 seconds warning time, 300ft vertical margin

	Mean Warning Time / seconds				
	WT Run 1	**WT Run 2**	**WT Run 3**	**WT Run 4**	**WT Run 5**
Correlated IFR	67.34	80.0	93.92	43.66	74.41
Correlated VFR	99.3	101.53	109.13	59.15	73.35
Uncorrelated IFR	83.89	83.76	84.13	35.22	47.3
Uncorrelated VFR	137.35	137.57	138.09	49.36	67.74
Uncorrelated MIL	96.5	96.5	96.5	46.05	55.37

Figure 8-25 Mean Warning Times for MSAW in various configurations

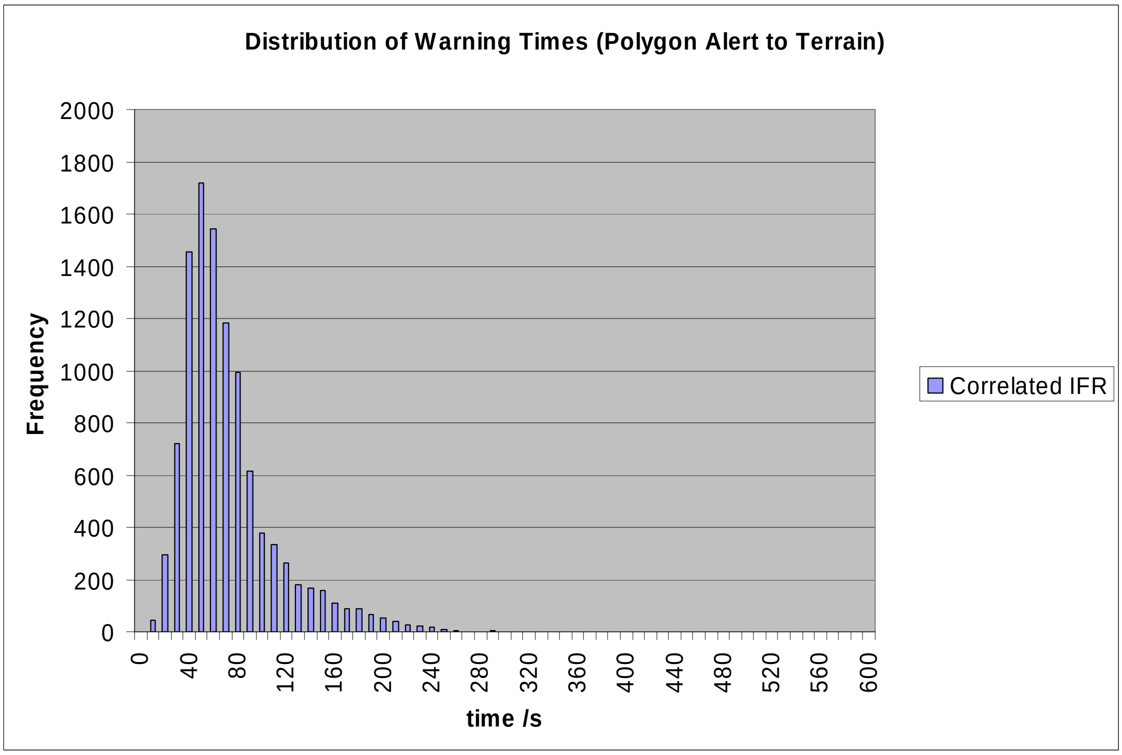


Figure 8-26 MSAW (polygon) warning time distribution for correlated IFR flights

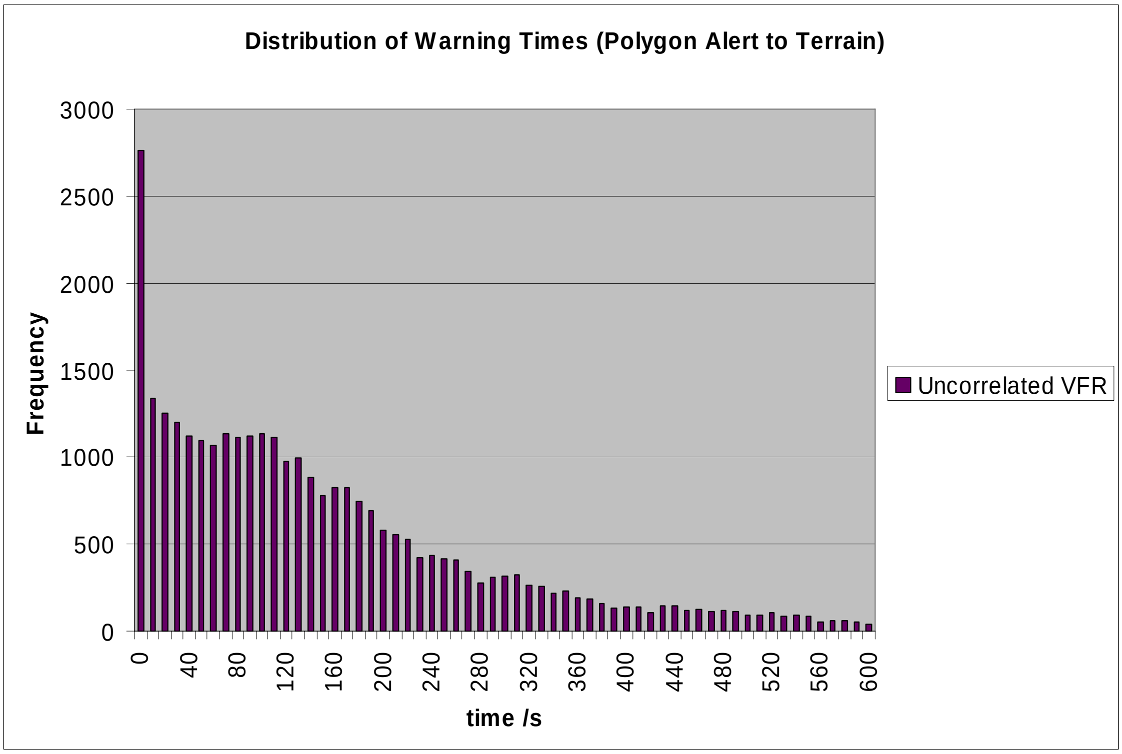


Figure 8-27 MSAW (polygon) warning time distribution for uncorrelated VFR flights

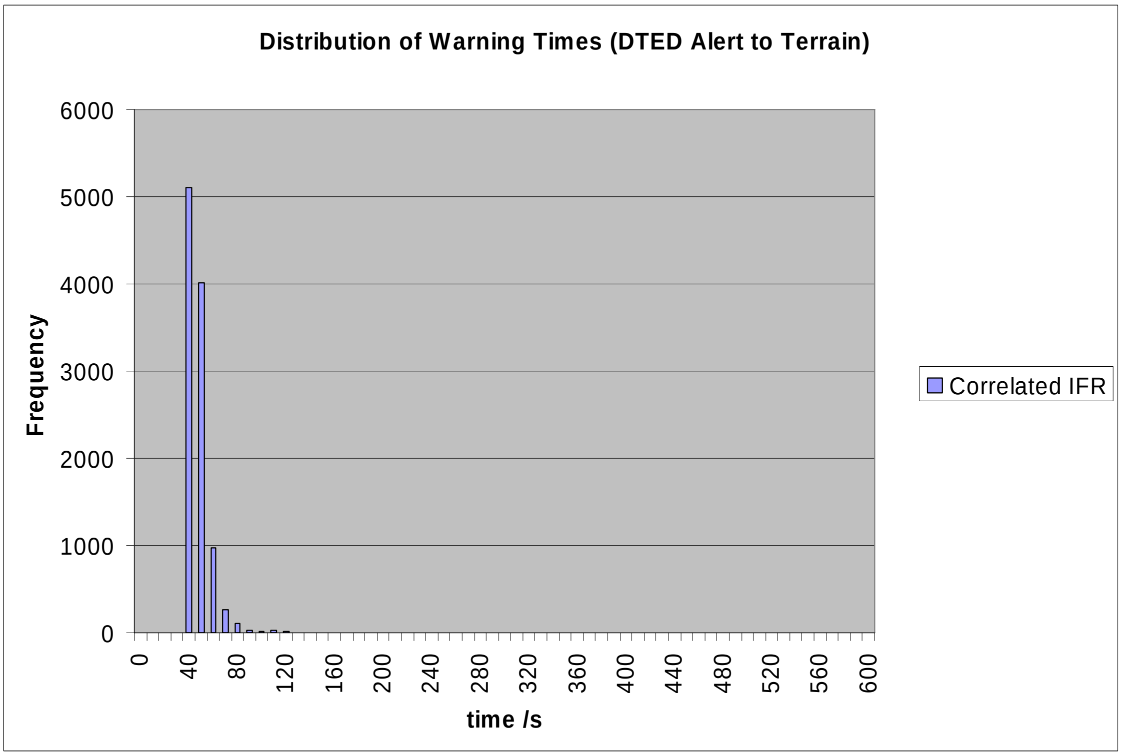


Figure 8-28 MSAW (DTED) warning time distribution for correlated IFR flights

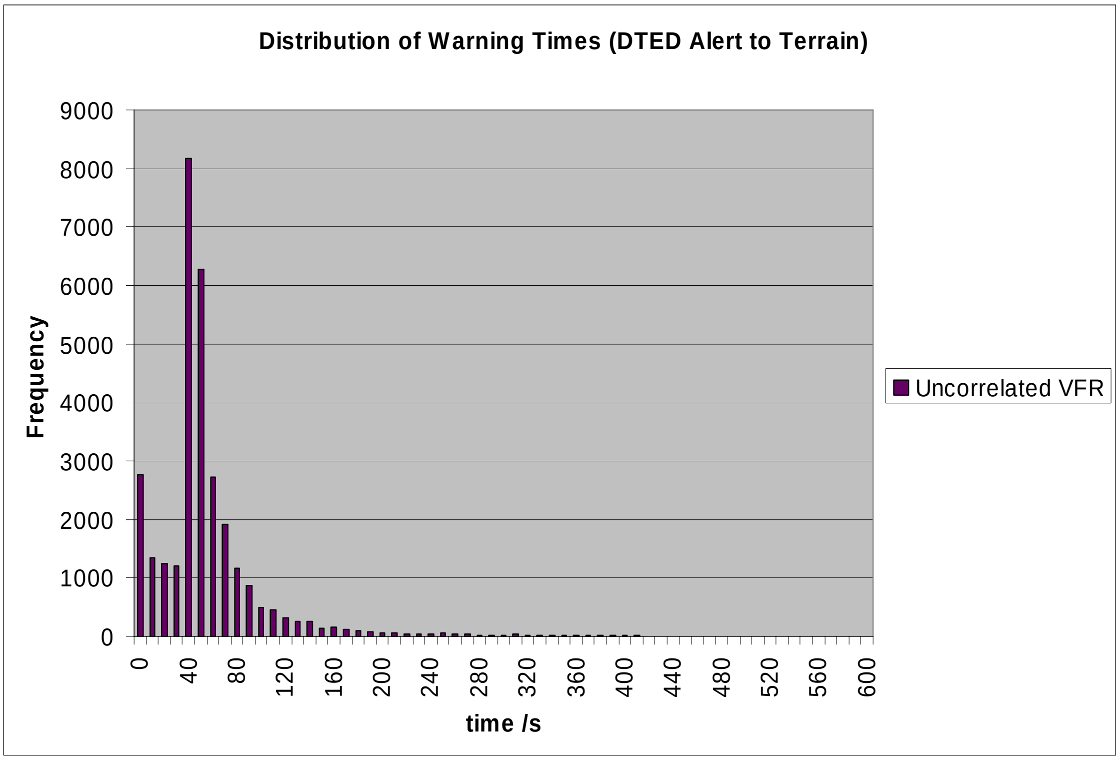


Figure 8-29 MSAW (DTED) warning time distribution for uncorrelated VFR flights

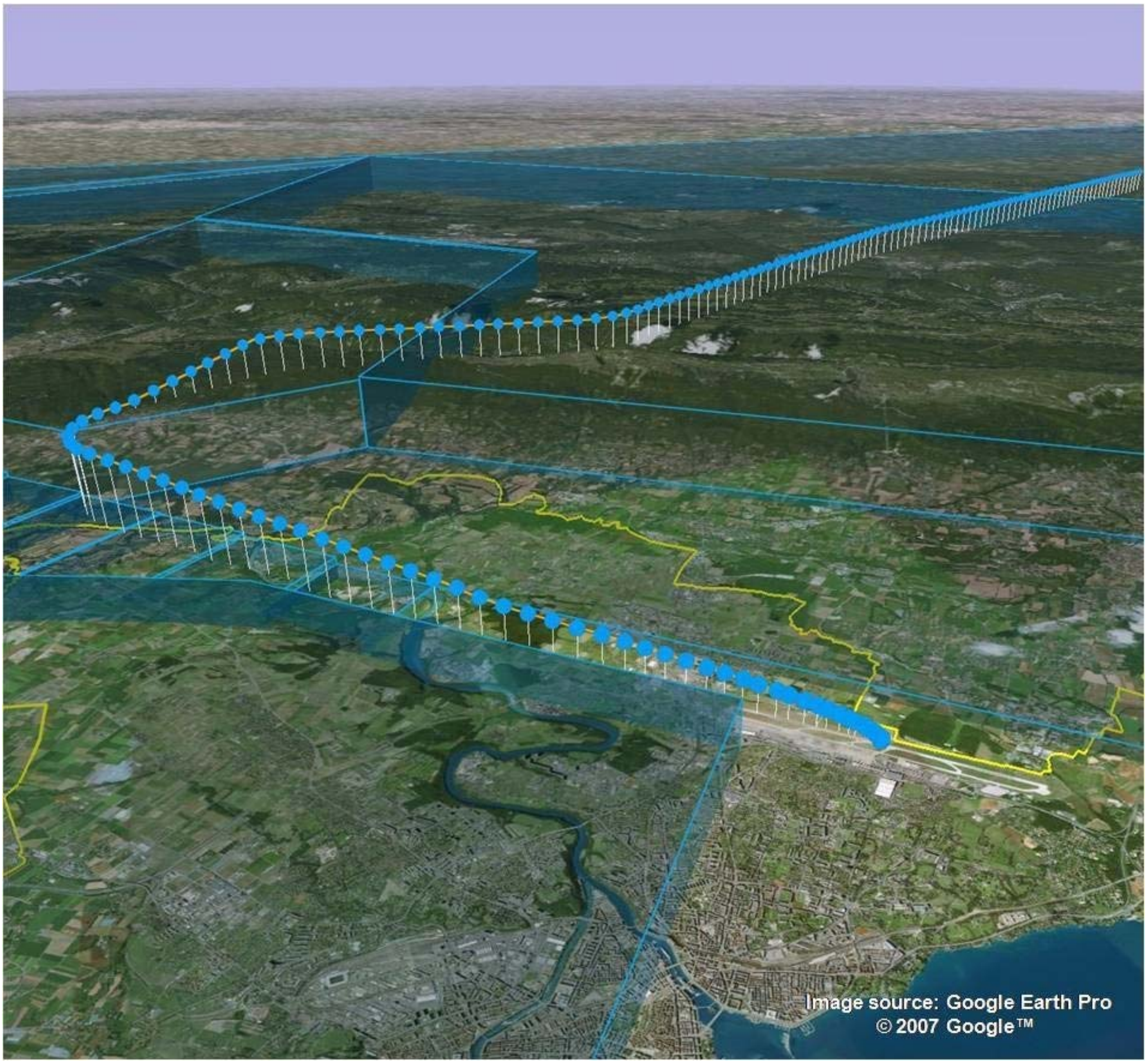


Figure 8-30 MSAW Scenario 1: Departure DIPIR 4A. Normal.

Track Colour	Meaning
Blue	No MSAW Alert
White	MSAW Polygon Alert
Yellow	DTED Alert (run E1)
Orange	DTED Alert Start (earliest/latest)

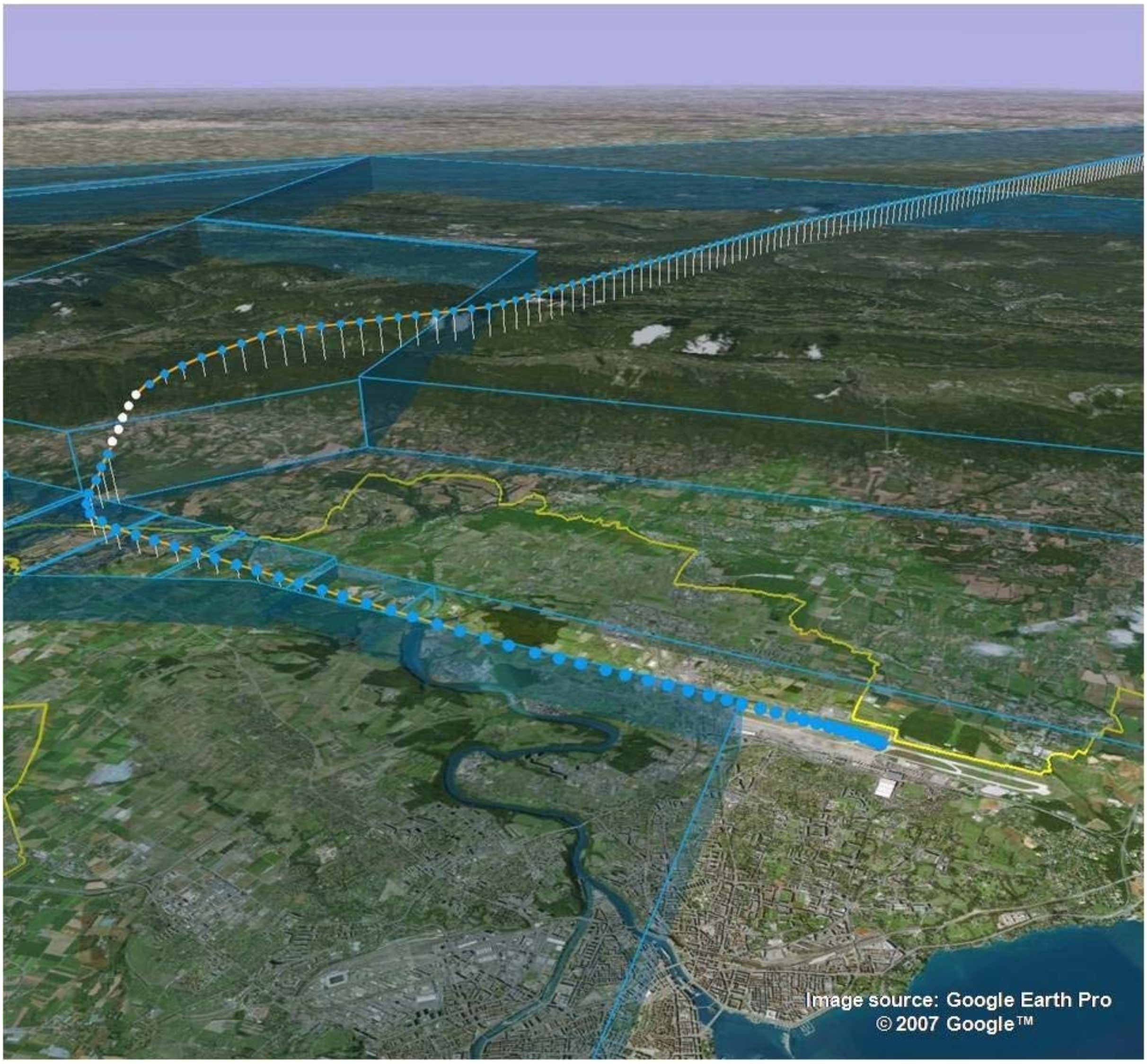


Figure 8-31 MSAW Scenario 2: Departure DIPIR 4A. Turns too early.

Track Colour	Meaning
Blue	No MSAW Alert
White	MSAW Polygon Alert
Yellow	DTED Alert (run E1)
Orange	DTED Alert Start (earliest/latest)

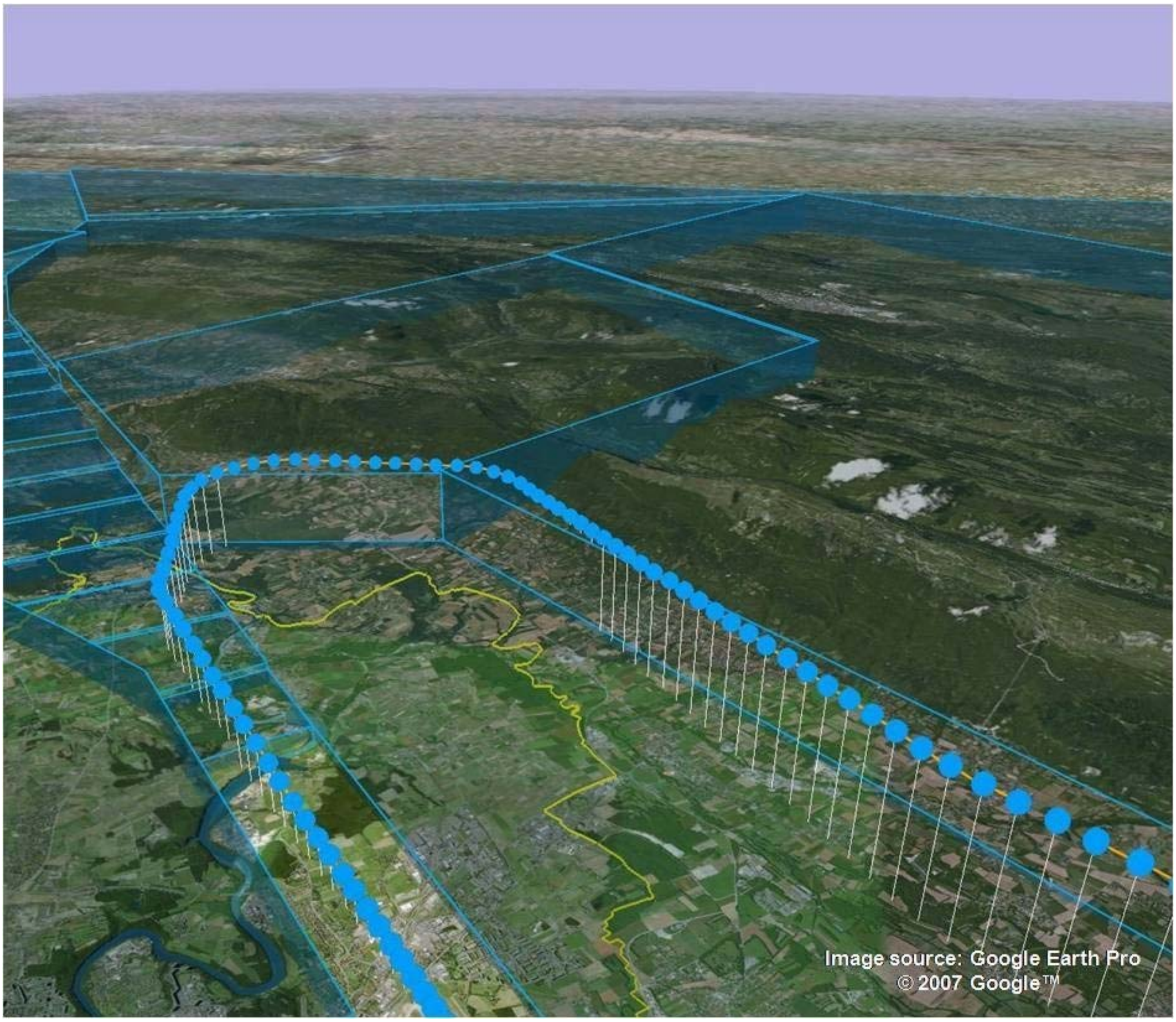


Figure 8-32 MSAW Scenario 3: Departure KONIL 4A. Normal.

Track Colour	Meaning
Blue	No MSAW Alert
White	MSAW Polygon Alert
Yellow	DTED Alert (run E1)
Orange	DTED Alert Start (earliest/latest)

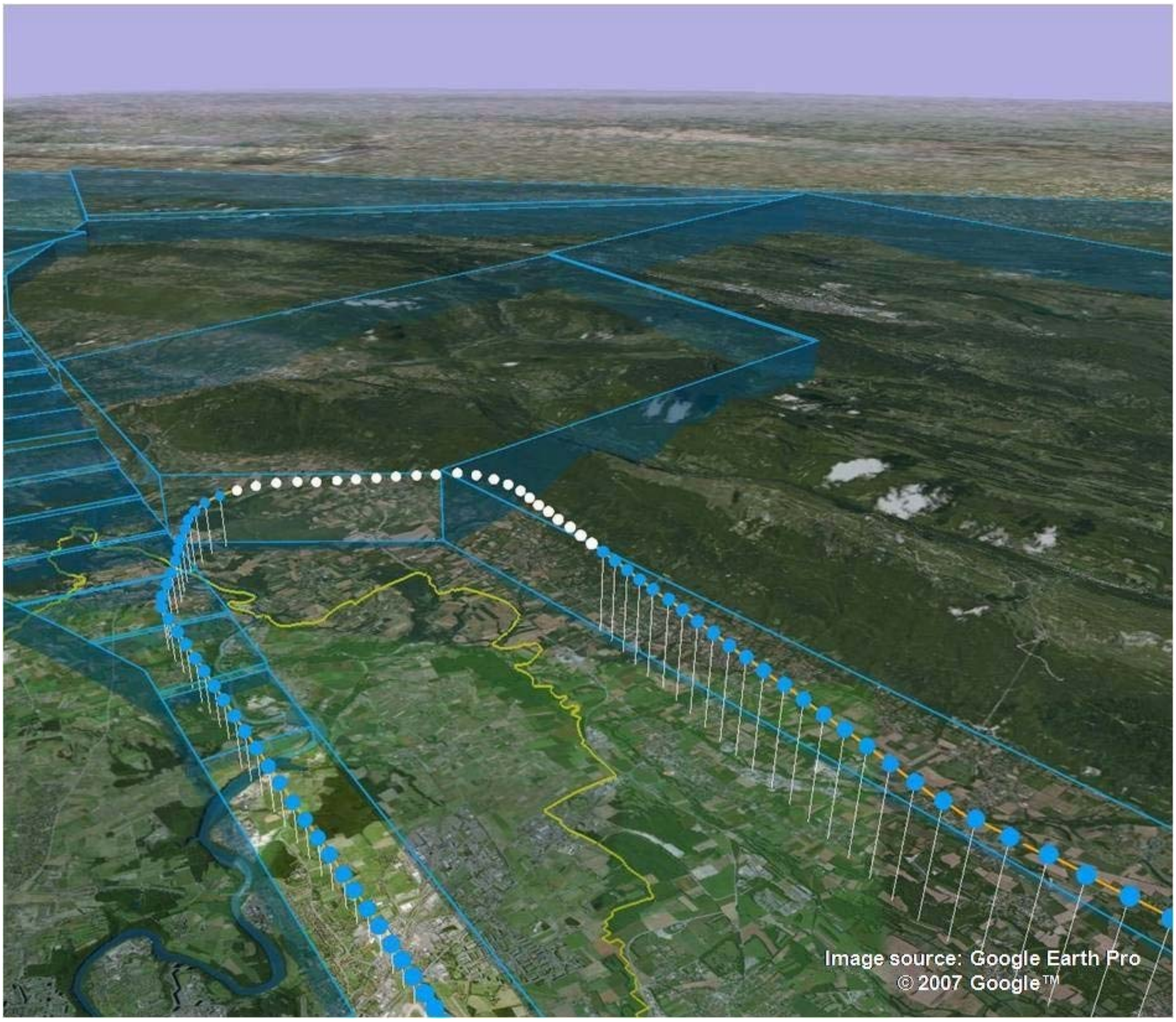


Figure 8-33 MSAW Scenario 4: Departure KONIL 4A.Too Low.

Track Colour	Meaning
Blue	No MSAW Alert
White	MSAW Polygon Alert
Yellow	DTED Alert (run E1)
Orange	DTED Alert Start (earliest/latest)

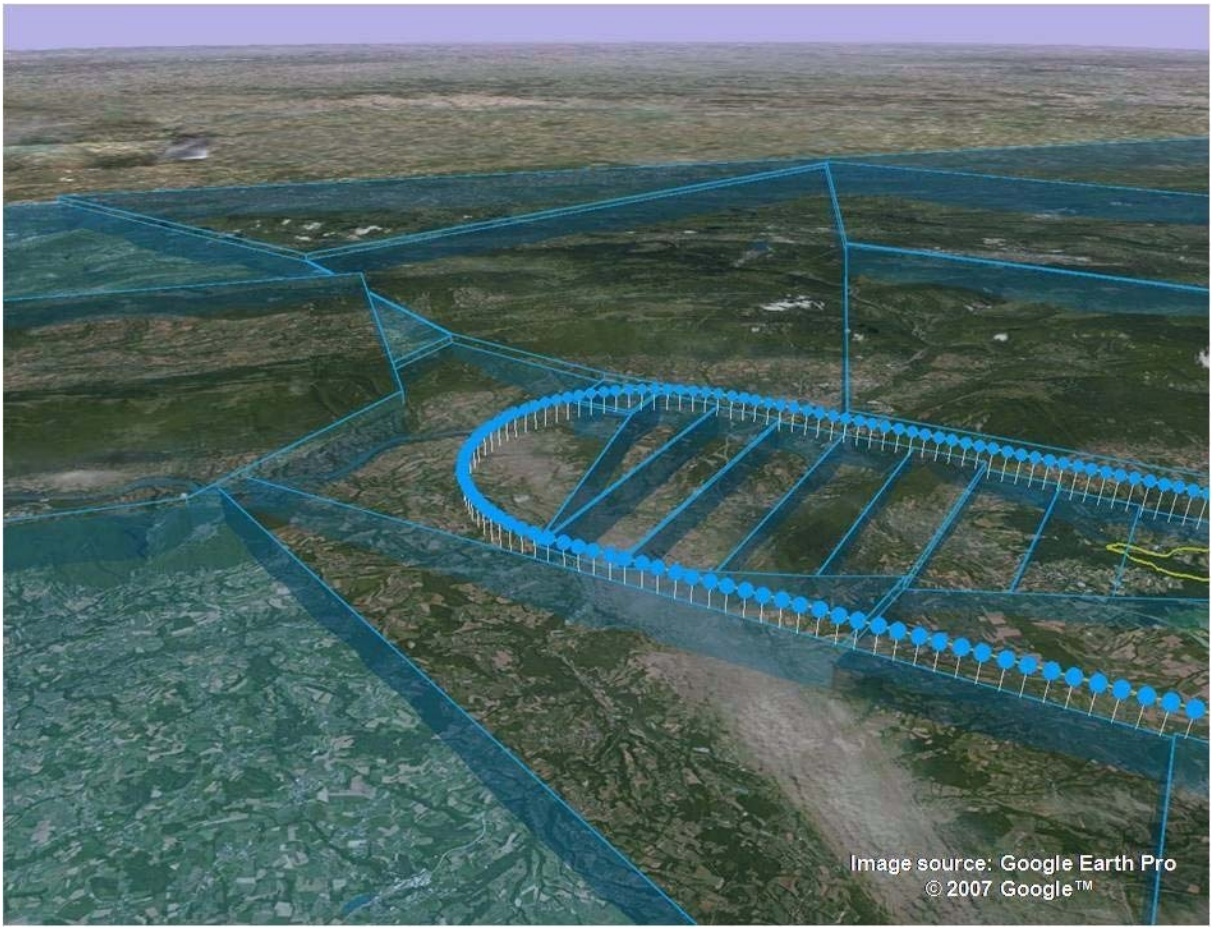


Figure 8-34 MSAW Scenario 5: Arrival GG502. OK.

Track Colour	Meaning
Blue	No MSAW Alert
White	MSAW Polygon Alert
Yellow	DTED Alert (run E1)
Orange	DTED Alert Start (earliest/latest)

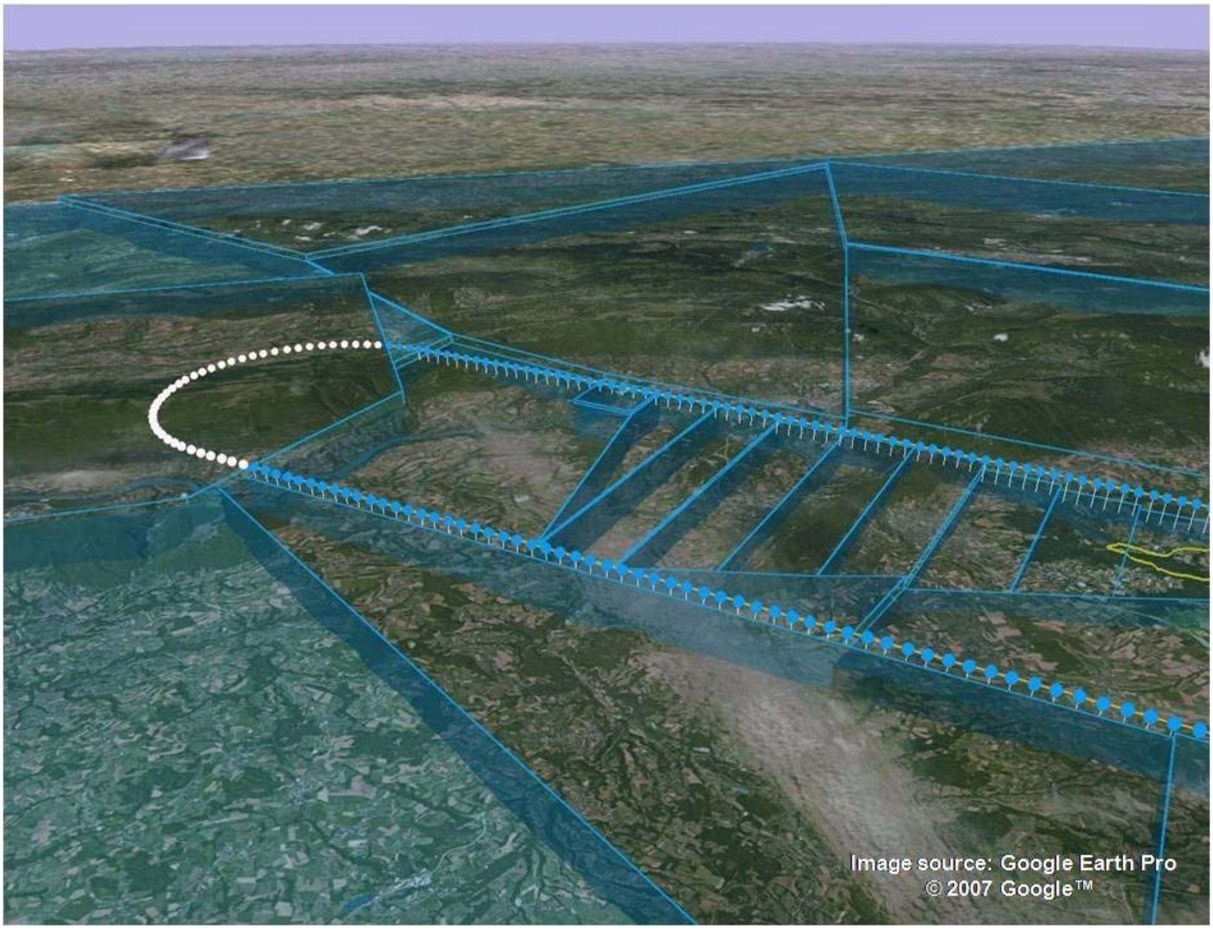


Figure 8-35 MSAW Scenario 6: Arrival GG502. Turns too late and penetrates MSAW polygon

Track Colour	Meaning
Blue	No MSAW Alert
White	MSAW Polygon Alert
Yellow	DTED Alert (run E1)
Orange	DTED Alert Start (earliest/latest)

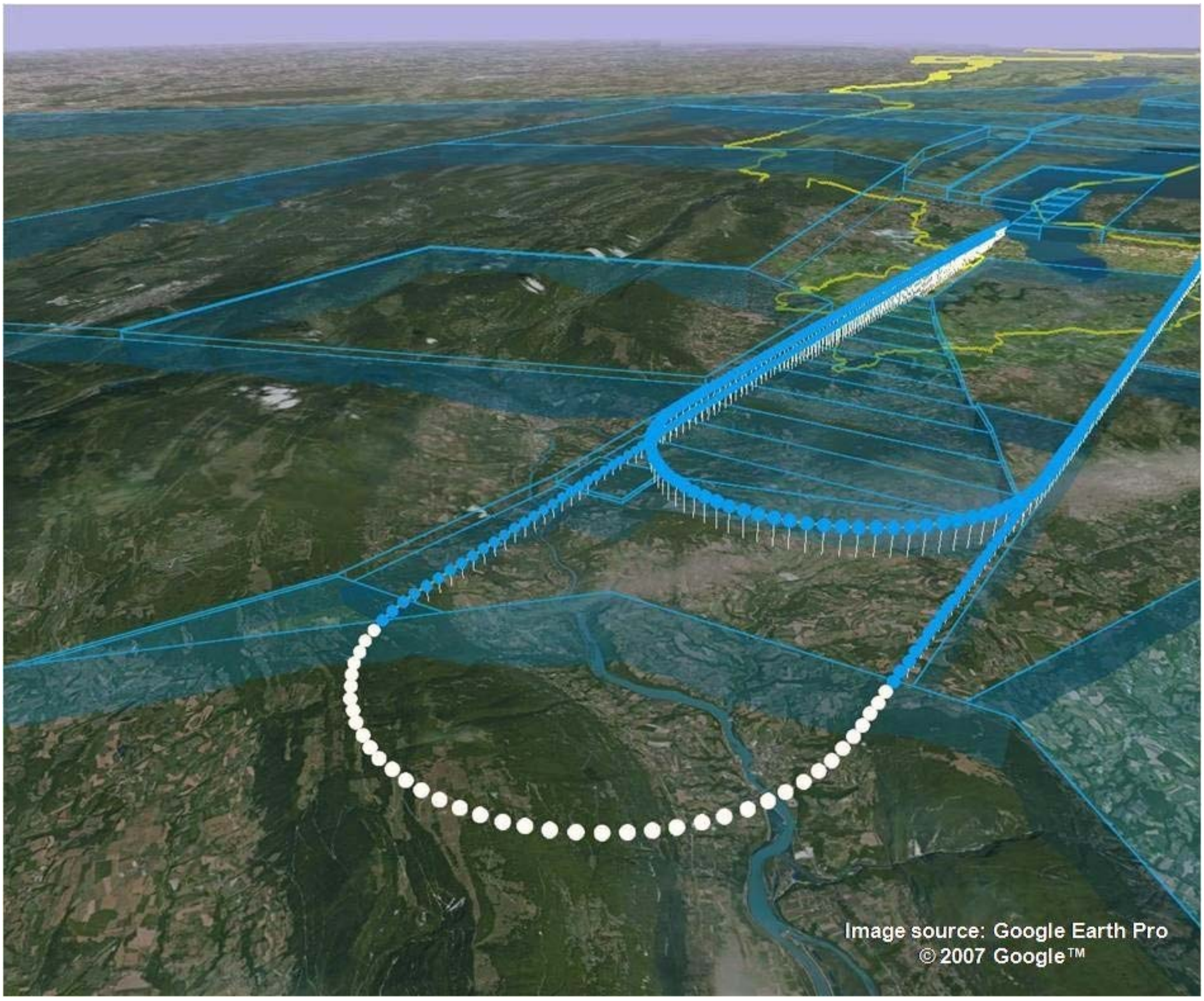


Figure 8-36 MSAW Scenarios 5 and 6 together

Track Colour	Meaning
Blue	No MSAW Alert
White	MSAW Polygon Alert
Yellow	DTED Alert (run E1)
Orange	DTED Alert Start (earliest/latest)

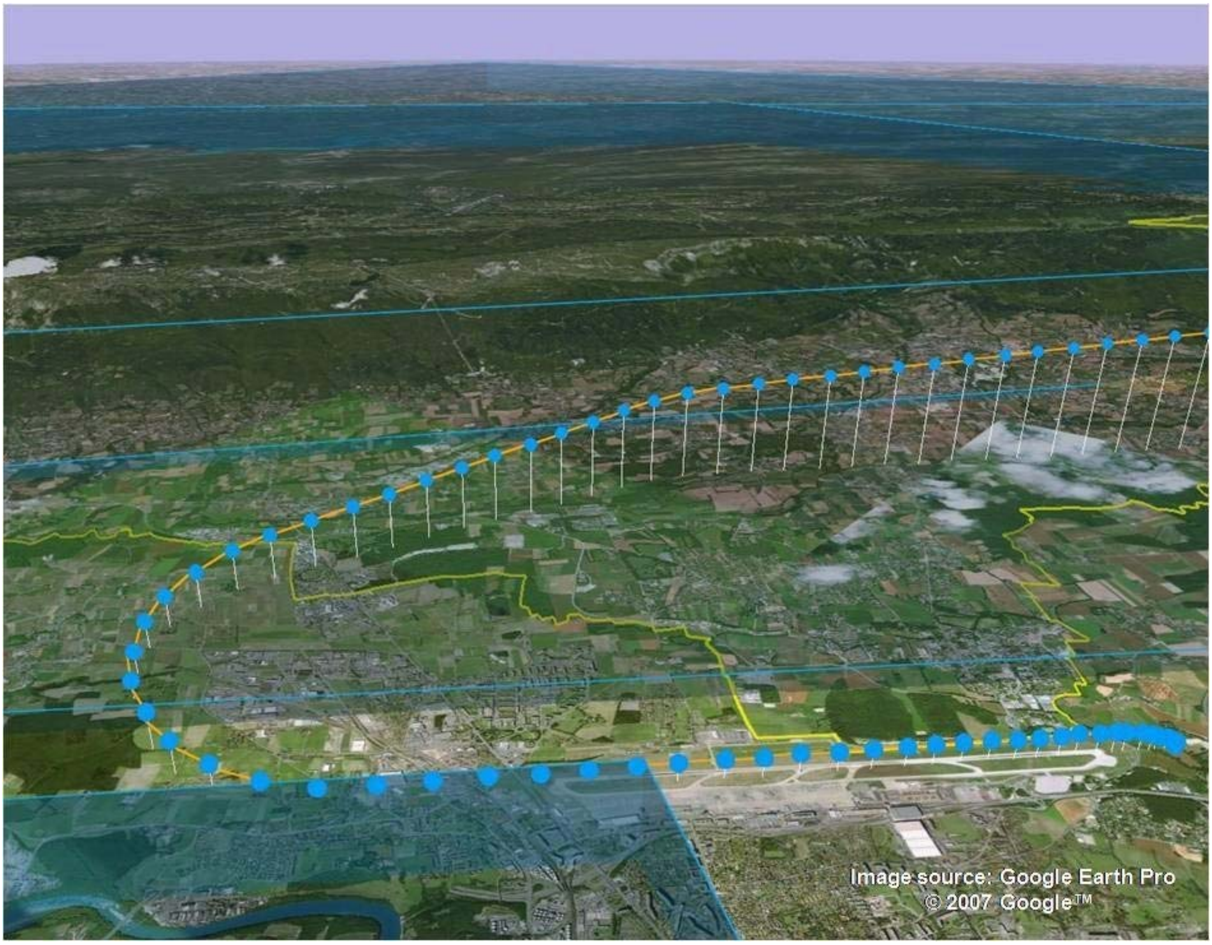


Figure 8-37 MSAW Scenario 7: KONIL 4C. Normal.

Track Colour	Meaning
Blue	No MSAW Alert
White	MSAW Polygon Alert
Yellow	DTED Alert (run E1)
Orange	DTED Alert Start (earliest/latest)

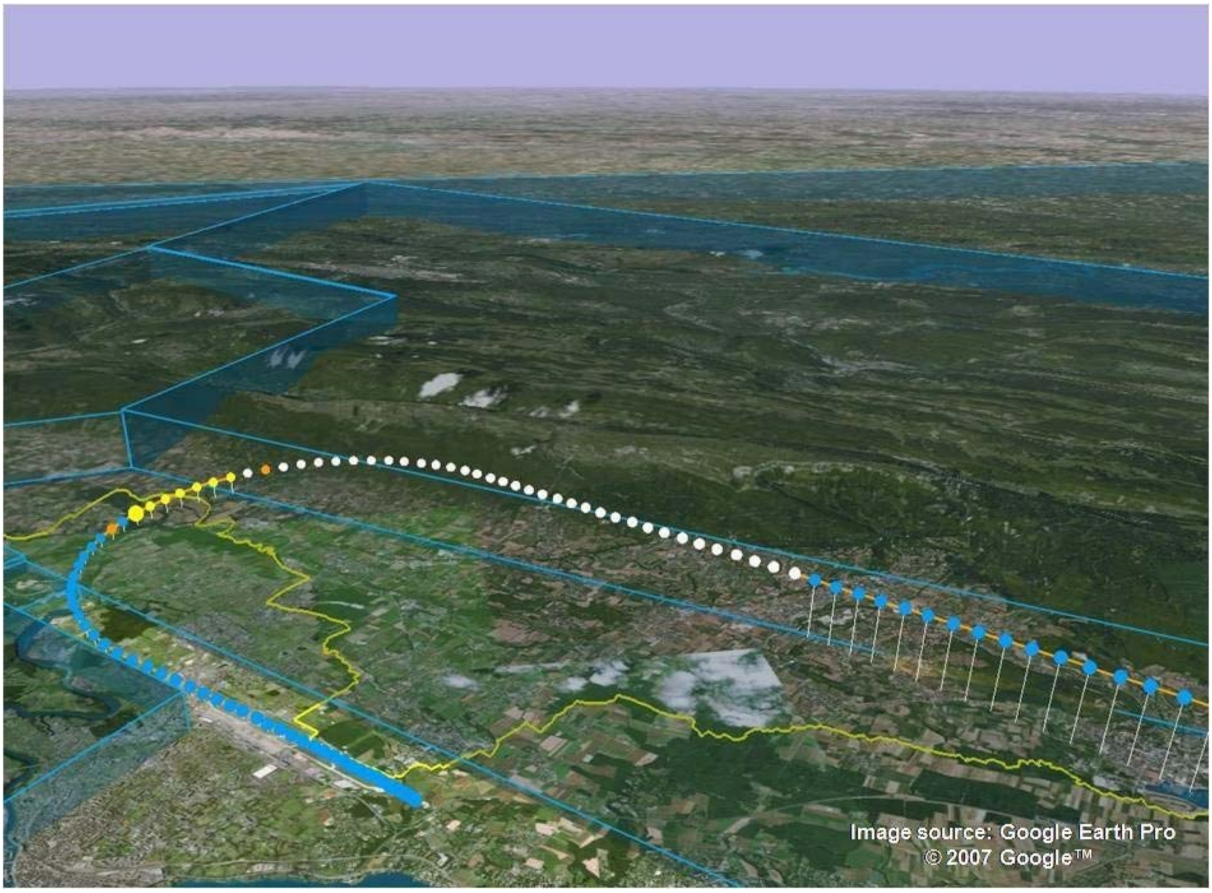


Figure 8-38 MSAW Scenario 8: KONIL 4C. Turns too wide and penetrates polygon

Track Colour	Meaning
Blue	No MSAW Alert
White	MSAW Polygon Alert
Yellow	DTED Alert (run E1)
Orange	DTED Alert Start (earliest/latest)

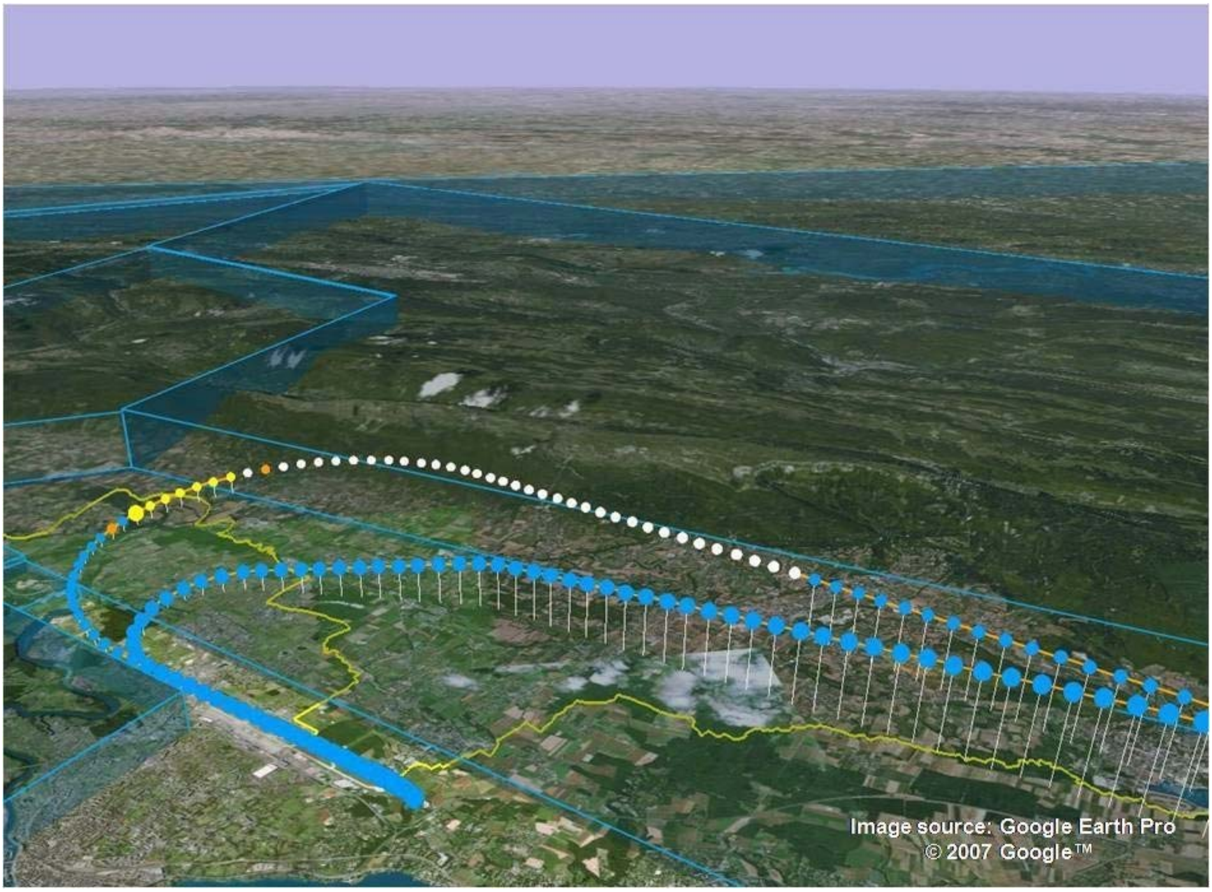


Figure 8-39 MSAW Scenarios 7 and 8 together

Track Colour	Meaning
Blue	No MSAW Alert
White	MSAW Polygon Alert
Yellow	DTED Alert (run E1)
Orange	DTED Alert Start (earliest/latest)

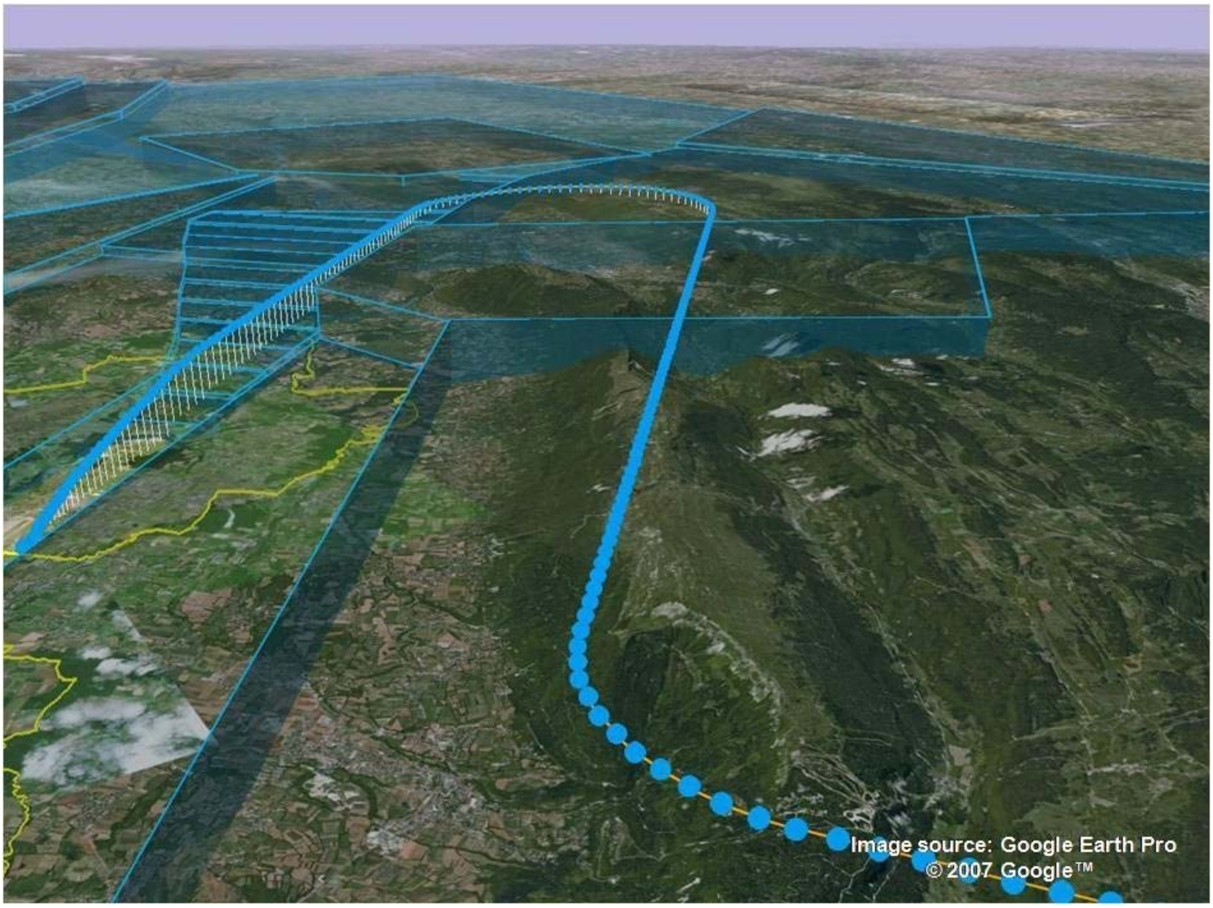


Figure 8-40 MSAW Scenario 9: LIRKO arrival. OK.

Track Colour	Meaning
Blue	No MSAW Alert
White	MSAW Polygon Alert
Yellow	DTED Alert (run E1)
Orange	DTED Alert Start (earliest/latest)

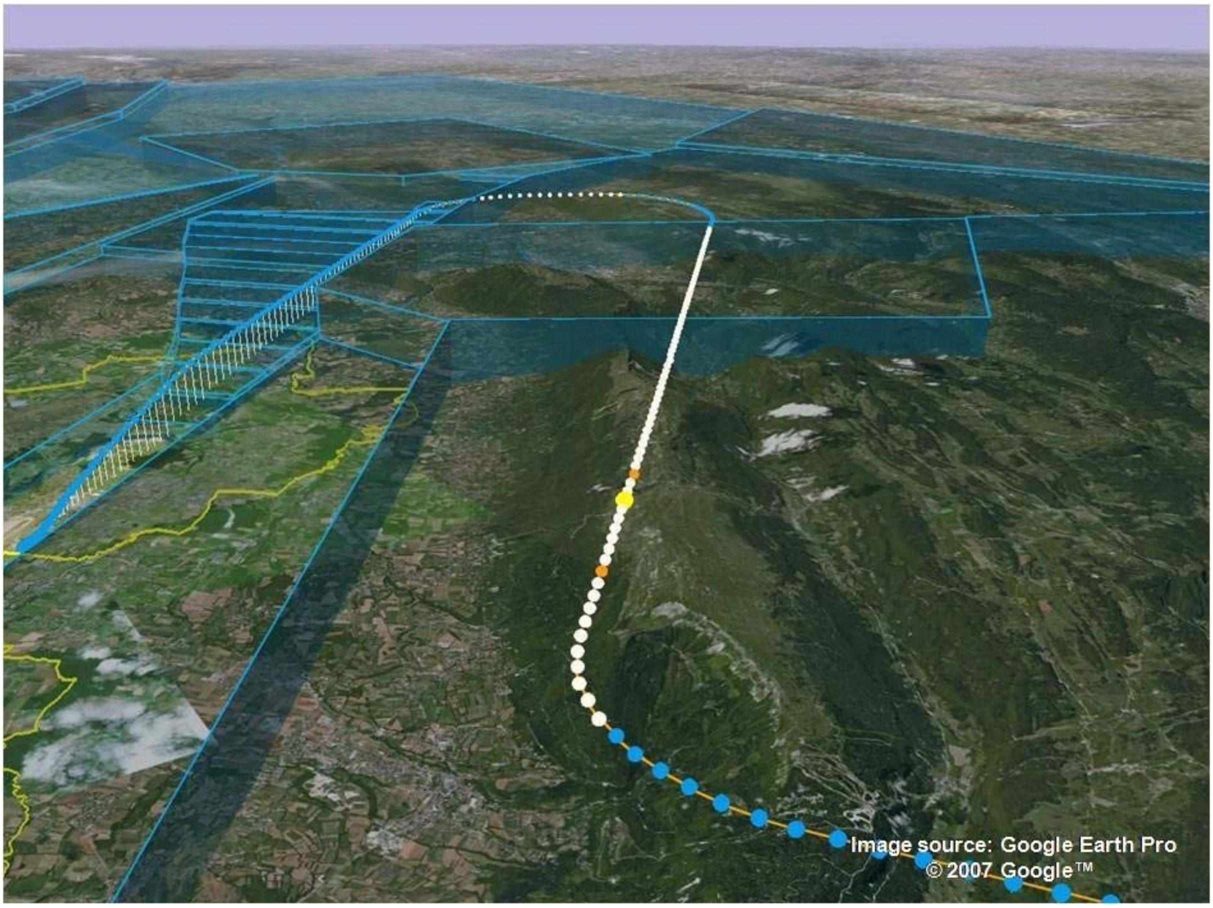


Figure 8-41 MSAW Scenario 10: LIRKO arrival. Too Low.

Track Colour	Meaning
Blue	No MSAW Alert
White	MSAW Polygon Alert
Yellow	DTED Alert (run E1)
Orange	DTED Alert Start (earliest/latest)

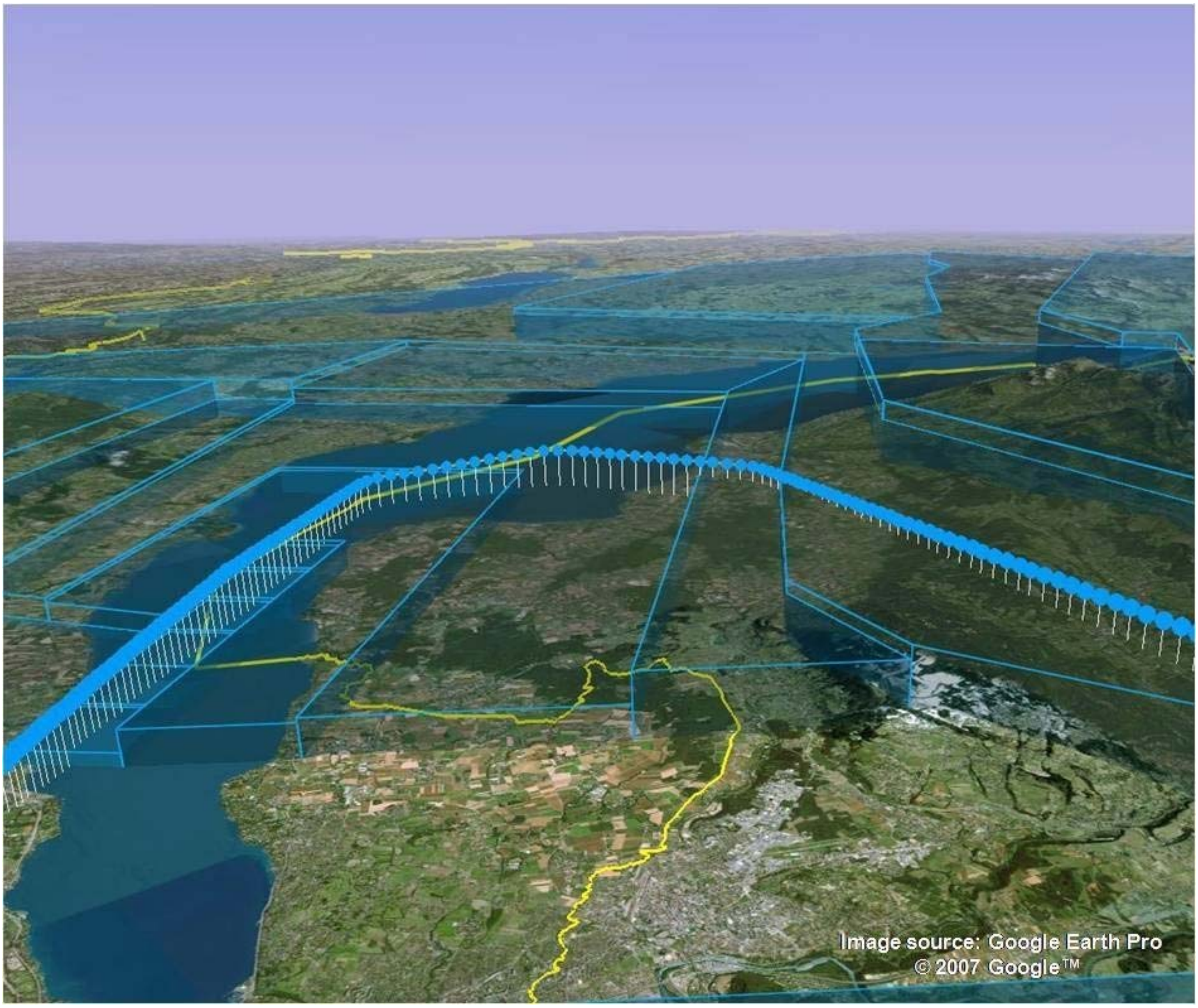


Figure 8-42 MSAW Scenario 11: PETAL departure. OK.

Track Colour	Meaning
Blue	No MSAW Alert
White	MSAW Polygon Alert
Yellow	DTED Alert (run E1)
Orange	DTED Alert Start (earliest/latest)

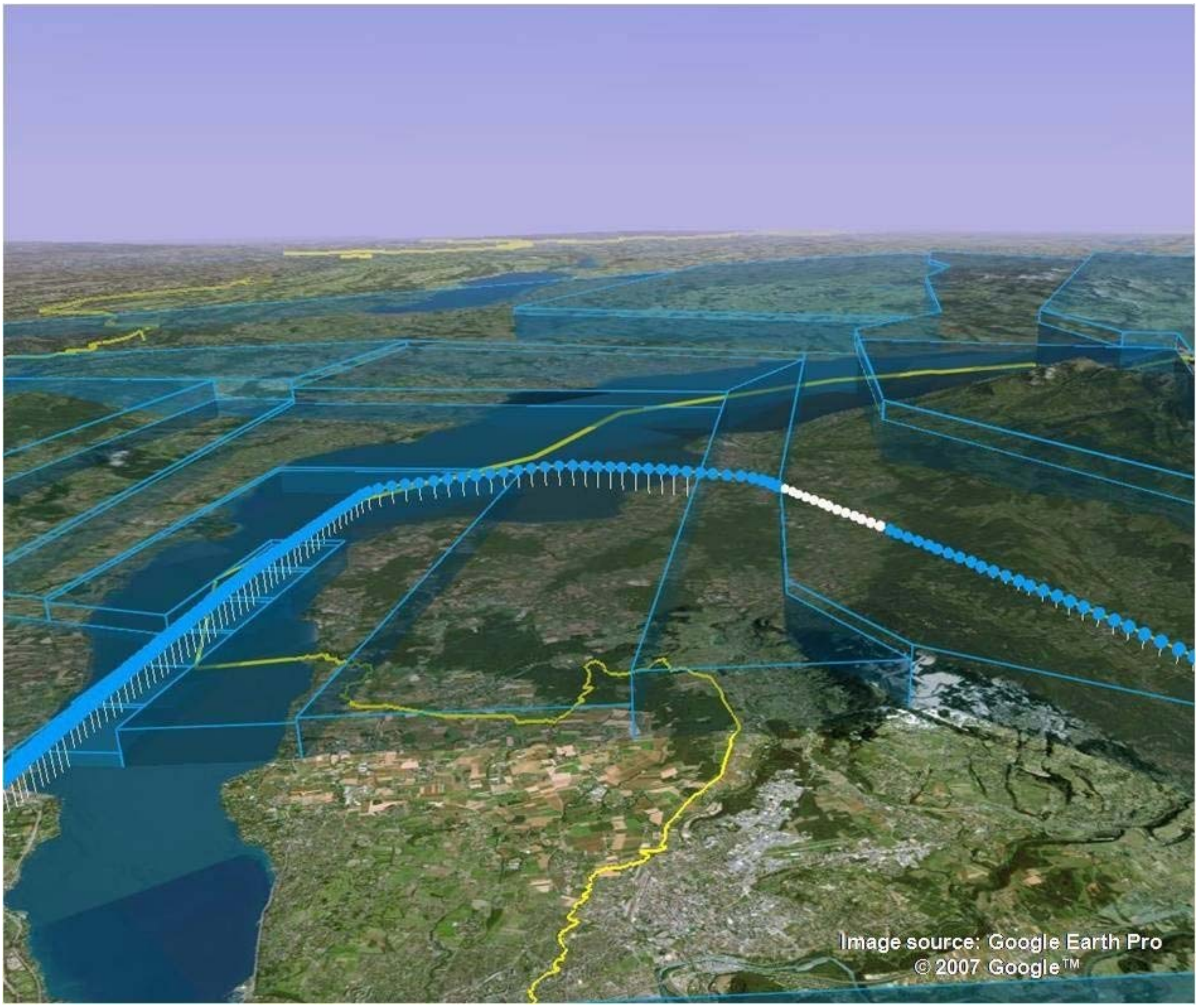


Figure 8-43 MSAW Scenario 12: PETAL departure. Too low.

Track Colour	Meaning
Blue	No MSAW Alert
White	MSAW Polygon Alert
Yellow	DTED Alert (run E1)
Orange	DTED Alert Start (earliest/latest)

	Run E1	**Run E2**
DTEDLookAheadTime1	35s	35s
DTEDLookAheadTime2	75s	55s
DTEDWarningTime	65s	55s
DTEDVerticalMargin1	150ft	400ft
DTEDVerticalMargin2	600ft	600ft
Mean Daily Alert Rate	3.44	2.50

Figure 8-44 Mean DTED daily alert rate using the level-off prediction, Correlated IFR Flights

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