

Integration of a Terrain Database for TAWS Event Monitoring

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TAP From Lisbon to the World

2018



92 332 Total Flights

Narrow Body – 79780 flights

Wide Body – 12552 flights

Leading airline to Brazil – Daily connections to São Paulo and Rio

Expanding destinations in USA – JFK, MIA, BOS, ORD, SFO, IAD

Connections to all major European capitals

Regular flights to North Africa, Angola and Mozambique

TAP Safety Figures Overview

2018



Flight Data

97.36% Monitored Flights
129171 Registered Events



Reporting

1901 Forms – Pilots
1810 Forms – Cabin Crew
816 Forms – Ground Ops
49 Forms – Corporate
281 Forms – Fatigue
141 Forms – Human Factors



Monitoring

Monthly Managed Reports
Operational Risk Assessments
Hazard Log



Survey

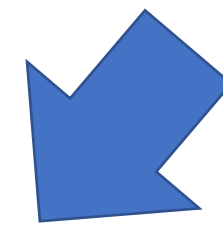
Cabin Safety Concerns

Objectives

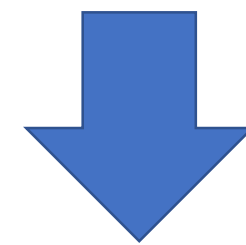
- Development of a tool that reproduces the behavior of a Terrain Awareness Warning System (TAWS);
- Creating a method to validate TAWS events;
- Integrate terrain databases to monitor hazardous situations;
- Using Google Earth as a visual analysis tool.

Terrain Awareness Warning System (TAWS)

TAWS comprises all systems used to prevent Controlled Flight Into Terrain (CFIT)

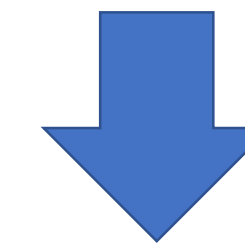


Ground Proximity Warning System (GPWS)



Uses aircraft parameters (radio altitude, indicated airspeed, vertical speed, glideslope beam deviation) and flight envelopes to warn pilots of dangerous situations

Enhanced Ground Proximity Warning System (EGPWS)



Additionally, uses terrain, obstacle, and airport runway databases to provide enhanced protection

EGPWS – Basic Modes

- Divided in 5 basic modes (original GPWS) and a few additional enhanced functions;
- Aural and visual warnings are generated when flight envelope is broken.

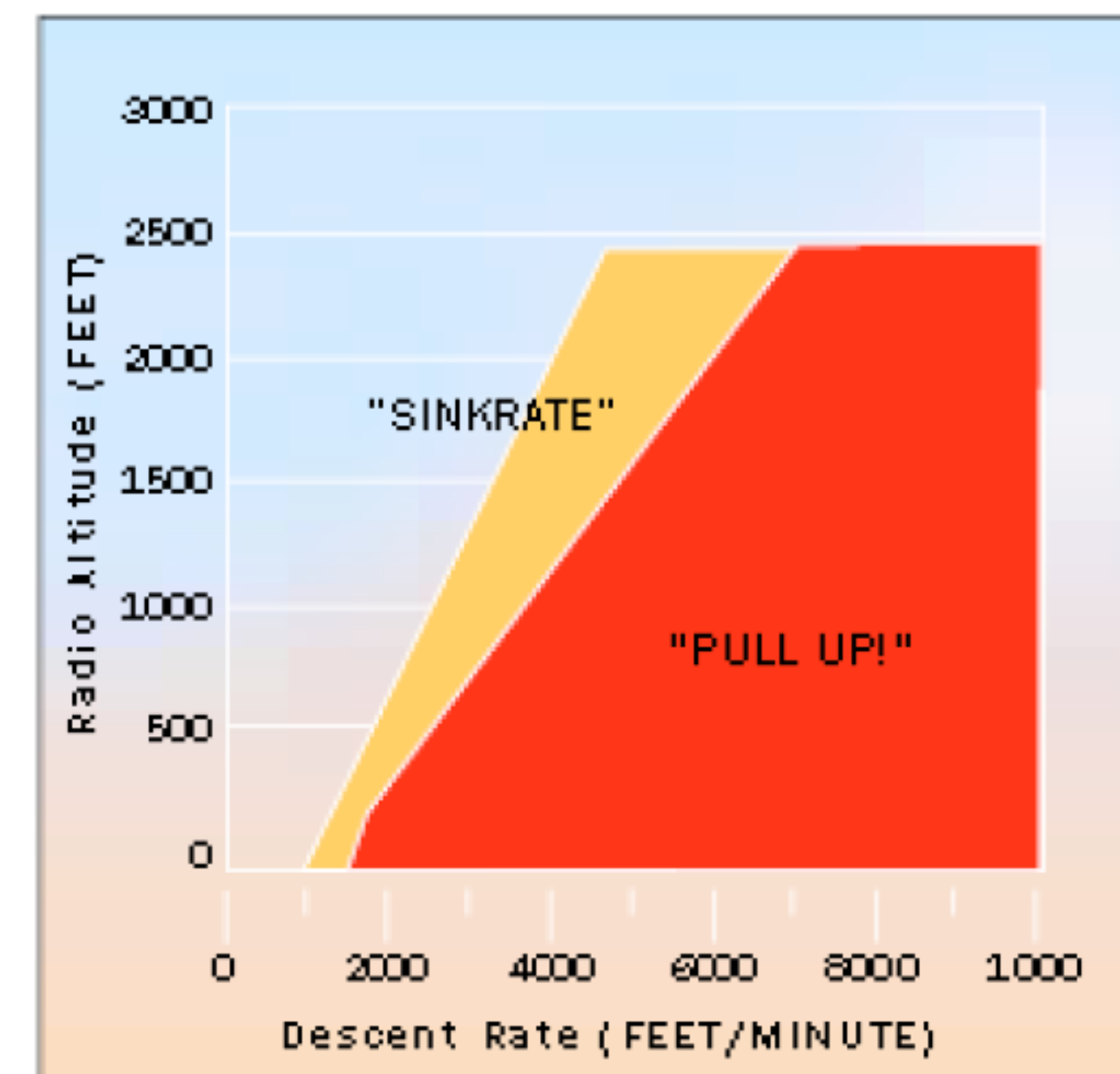
Mode 1 – Excessive Descent Rate

Mode 2 – Excessive Terrain Closure Rate

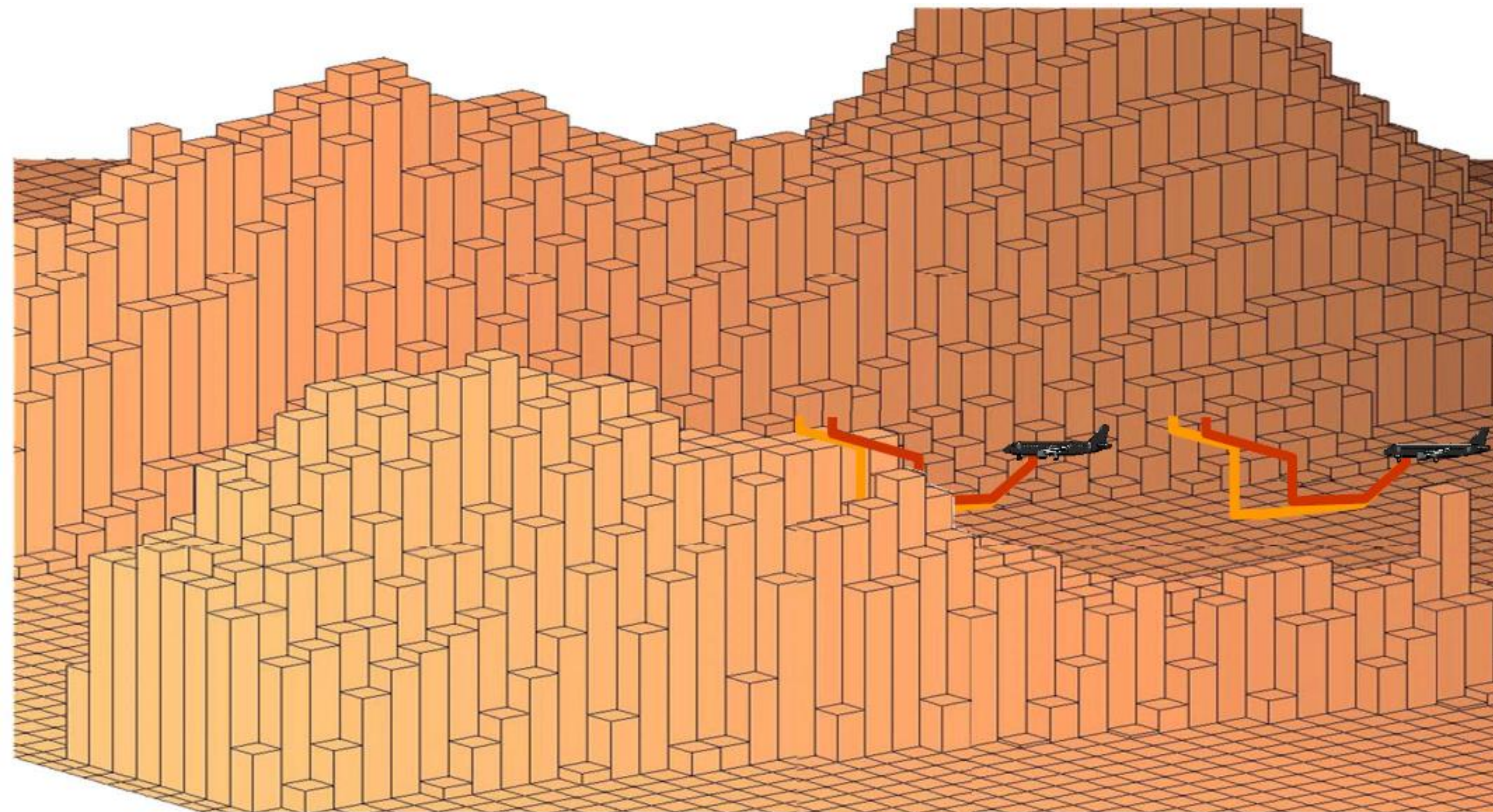
Mode 3 – Altitude Loss After Takeoff or Go Around

Mode 4 – Unsafe Terrain Clearance

Mode 5 – Excessive Deviation Below ILS Glideslope



EGPWS – Terrain Ahead Warning



Uses a worldwide internal terrain database and a function's envelope to predict hazardous situations



Implementation Methods

R Programming Language and Flight Data Files (.csv for example)



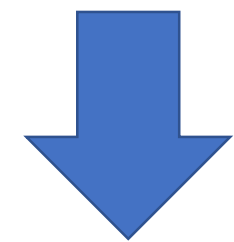
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1	CUT	T	TIME_R	ORIGIN	DESTINAT	FLIGHT	PH	RUNWAY	FM_FWC	ALT	STDC	HEIGHT	RA	LD1	RA	LD2	VRTG	FPAC	LATG	LONG	TOUCH	D	AP	EGD1	AP	EGD2	ATS	EGD	ATS	ACT	AP	INST	I	ATHR	OFF	I	ASC	GSC	TAS	IVVR
511	0	4073	10:56:02	ORY	LIS		6	21	6	3608		3176	142.0	115.5	0.87	0.016	-0.03	0.18		0	0	1	1	1	1	1	1	0	168.75	134.00	175	1728								
512	0	4081	10:56:02	ORY	LIS		6	21	6	3636		3204	192.5	141.0	0.84	0.031	-0.04	0.18		0	0	1	1	1	1	1	1	0	170.50	135.00	176	1488								
513	0	4089	10:56:06	ORY	LIS		6	21	6	3660		3228	215.5	160.0	0.90	0.047	0.00	0.18		0	0	1	1	1	1	1	1	0	175.13	136.00	178	1312								
514	0	4097	10:56:06	ORY	LIS		6	21	6	3676		3244	239.0	168.5	0.96	0.041	0.02	0.19		0	0	1	1	1	1	1	1	0	175.88	137.00	183	1248								
515	0	4105	10:56:06	ORY	LIS		6	21	6	3696		3264	272.5	189.5	1.07	0.053	-0.01	0.20		0	0	1	1	1	1	1	1	0	176.50	137.00	183	1392								
516	0	4113	10:56:06	ORY	LIS		6	21	6	3720		3288	268.5	206.5	1.00	0.043	-0.04	0.19		0	0	1	1	1	1	1	1	0	177.50	138.00	184	1504								
517	0	4121	10:56:10	ORY	LIS		6	21	6	3748		3316	306.0	237.0	0.96	0.027	-0.03	0.18		0	0	1	1	1	1	1	1	0	177.50	139.00	185	1504								
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519	0	4137	10:56:10	ORY	LIS		6	21	6	3796		3364	324.5	266.5	0.94	0.043	0.01	0.18		0	0	1	1	1	1	1	1	0	176.75	140.00	183	1376								
520	0	4145	10:56:10	ORY	LIS		6	21	6	3820		3388	345.5	279.5	0.93	0.041	-0.01	0.17		0	0	1	1	1	1	1	1	0	177.75	141.00	185	1264								
521	0	4153	10:56:14	ORY	LIS		6	21	6	3836		3404	370.0	305.5	0.93	0.045	-0.01	0.17		0	0	1	1	1	1	1	1	0	177.38	142.00	186	1120								
522	0	4161	10:56:14	ORY	LIS		6	21	6	3856		3424	370.5	304.5	0.94	0.061	-0.00	0.17		0	0	1	1	1	1	1	1	0	180.88	143.00	185	1040								
523	0	4169	10:56:14	ORY	LIS		6	21	6	3868		3436	371.5	305.0	1.02	0.055	0.00	0.18		0	0	1	1	1	1	1	1	0	180.75	144.00	189	976								
524	0	4177	10:56:14	ORY	LIS		6	21	6	3892		3460	381.0	315.5	0.96	0.045	0.06	0.18		0	0	1	1	1	1	1	1	0	183.13	145.00	189	992								
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526	0	4193	10:56:18	ORY	LIS		6	21	6	3924		3492	399.5	322.0	1.07	0.066	0.01	0.18		0	0	1	1	1	1	1	1	0	187.25	147.00	192	1088								
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528	0	4209	10:56:18	ORY	LIS		6	21	6	3956		3524	426.5	359.0	0.95	0.061	-0.02	0.16		0	0	1	1	1	1	1	1	0	186.25	150.00	196	1248								
529	0	4217	10:56:22	ORY	LIS		6	21	6	3976		3544	456.5	377.0	0.98	0.059	0.01	0.16		0	0	1	1	1	1	1	1	0	188.50	151.00	195	1184								
530	0	4225	10:56:22	ORY	LIS		6	21	6	3996		3564	490.0	425.5	0.96	0.057	0.00	0.16		0	0	1	1	1	1	1	1	0	190.00	152.00	197	1152								
531	0	4233	10:56:22	ORY	LIS		6	21	6	4012		3580	496.5	428.5	0.98	0.051	-0.00	0.15		0	0	1	1	1	1	1	1	0	191.25	153.00	199	1072								
532	0	4241	10:56:22	ORY	LIS		6	21	6	4032		3600	516.5	447.0	1.00	0.051	0.01	0.16		0	0	1	1	1	1	1	1	0	191.63	154.00	200	1072								
533	0	4249	10:56:26	ORY	LIS		6	21	6	4048		3616	529.0	462.0	0.92	0.051	0.02	0.16		0	0	1	1	1	1	1	1	0	190.25	155.00	201	1024								
534	0	4257	10:56:26	ORY	LIS		6	21	6	4064		3632	532.0	472.0	0.95	0.051	-0.02	0.15		0	0	1	1	1	1	1	1	0	191.63	156.00	199	928								
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536	0	4273	10:56:26	ORY	LIS		6	21	6	4092		3660	561.5	481.5	0.98	0.072	-0.02	0.15		0	0	1	1	1	1	1	1	0	197.13	159.00	203	848								
537	0	4281	10:56:30	ORY	LIS		6	21	6	4108		3676	568.0	495.0	1.05	0.076	-0.00	0.16		0	0	1	1	1	1	1	1	0	197.25	160.00	207	880								
538	0	4289	10:56:30	ORY	LIS		6	21	6	4120		3688	596.5	518.0	1.00	0.061	0.02	0.16		0	0	1	1	1	1	1	1	0	198.38	161.00	207	960								
539	0	4297	10:56:30	ORY	LIS		6	21	6	4136		3704	610.5	539.5	1.02	0.055	-0.01	0.15		0	0	1	1	1	1	1	1	0	200.00	162.00	208	1008								
540	0	4305	10:56:30	ORY	LIS		6	21	6	4152		3720	608.5	545.0	1.00	0.063	-0.02	0.15		0	0	1	1	1	1	1	1	0	200.13	164.00	210	1008								
541	0	4313	10:56:34	ORY	LIS		6	21	6	4168		3736	603.5	541.0	1.00	0.061	-0.00	0.14		0	0	1	1	1	1	1	1	0	203.75	165.00	210	1008								
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544	0	4337	10:56:34	ORY	LIS		6	21	6	4220		3788	623.0	562.0	0.98	0.064	-0.01	0.14		0	0	1	1	1	1	1	1	0	205.25	168.00	215	1056								
545	0	4345	10:56:38	ORY	LIS		6	21	6	4236		3804	632.5	567.0	0.96	0.063	-0.04	0.14		0	0	1	1	1	1	1	1	0	206.25	169.00	215	1008								
546	0	4353	10:56:38	ORY	LIS		6	21	6	4256		3824	642.0	566.0	1.00	0.068	0.02	0.14		0	0	1	1	1	1	1	1	0	207.75	171.00	217	992								
547	0	4361	10:56:38	ORY	LIS		6	21	6	4268		3836	640.5	567.0	0.96	0.064	0.00	0.14		0	0	1	1	1	1	1	1	0	209.88	172.00	218	960								
548	0	4369	10:56:38	ORY	LIS		6	21	6	4288		3856	647.5	578.0	0.96	0.072	0.00	0.14		0	0	1	1	1	1	1	1	0	210.75	173.00	220	960								

Implementation Methods

Uneventful Flights



Flights with EGPWS Warnings
(basic + enhanced)

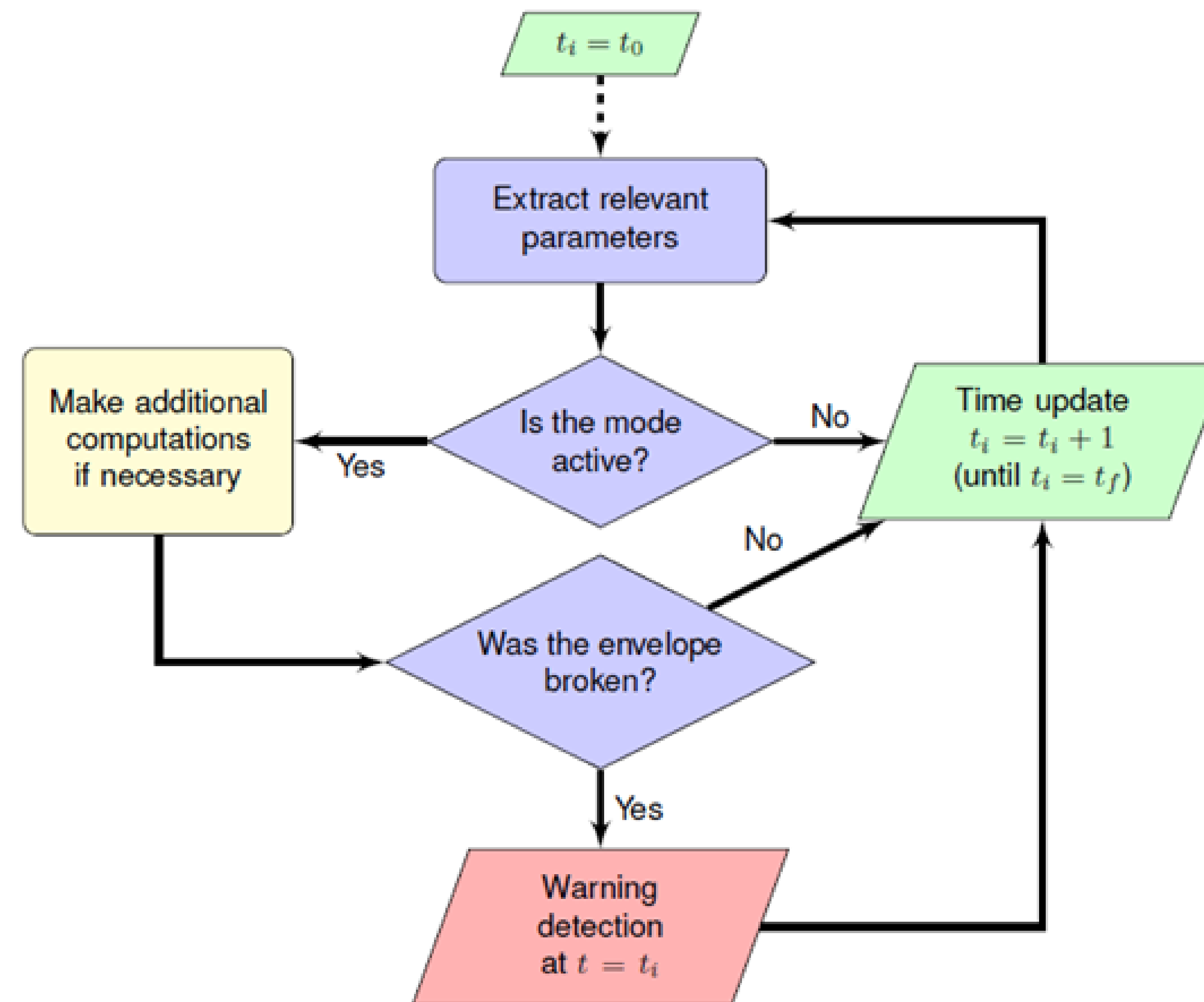


Test and validate the developed algorithms

The developed tool will allow to:

- Monitor EGPWS Events and check where the envelope for each mode was broken;
- Provide a visual analysis tool.

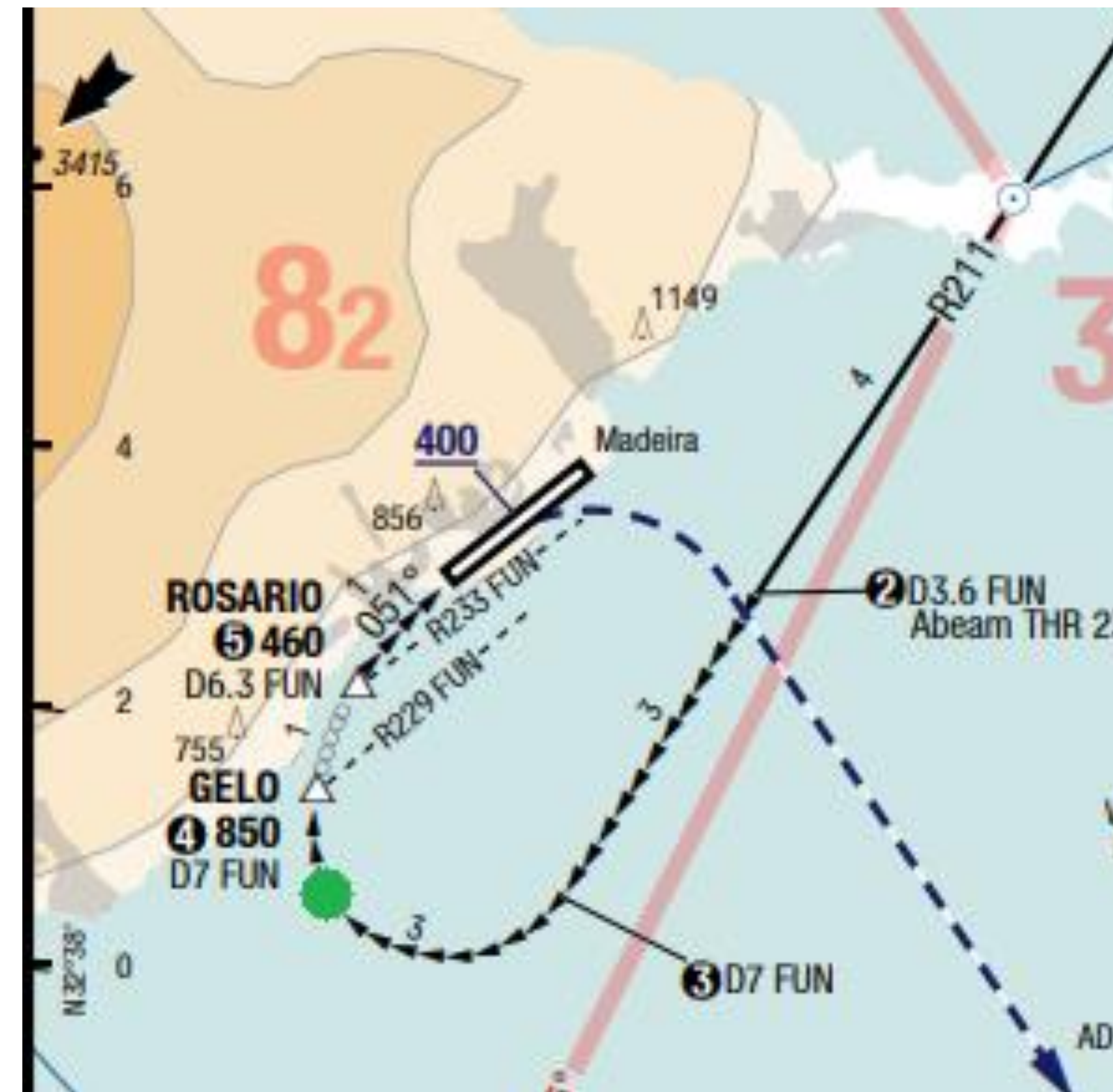
Rationale for EGPWS Modes Warning Detection



Terrain Ahead Warning – Funchal Case Study

Why Funchal?

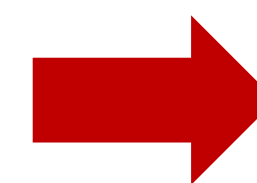
- “Terrain Ahead” Warnings;
- Runway proximity to a hill;
- Frequent crosswinds during final approach;
- Low computational effort required.



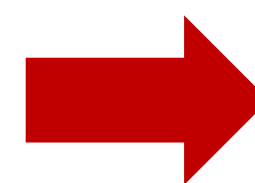
Digital Elevation Model Creation (SRTM Database)



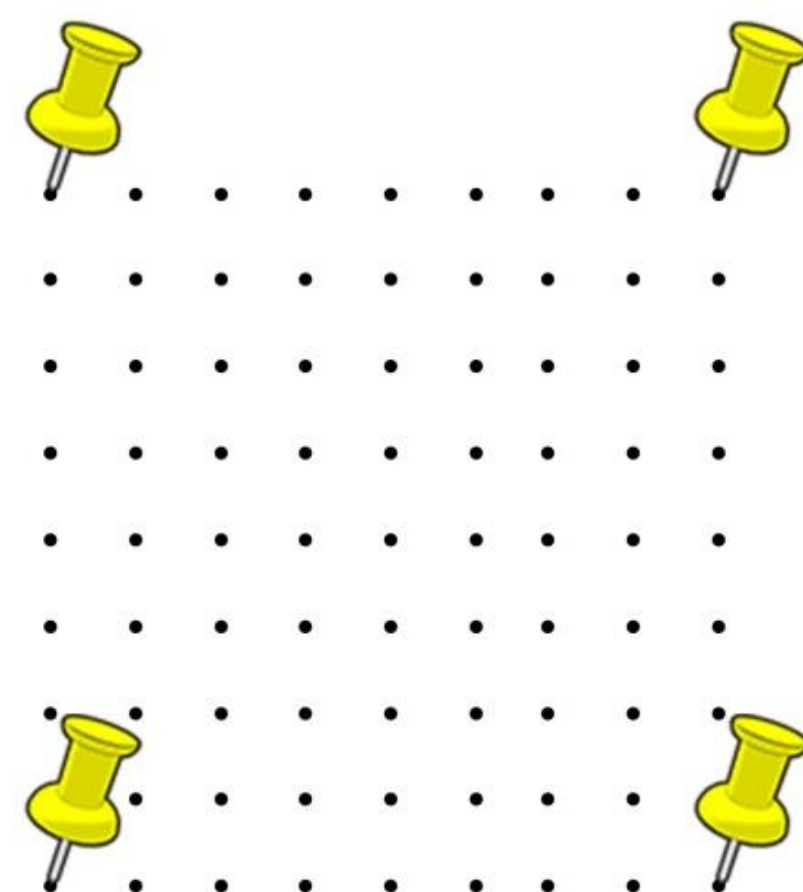
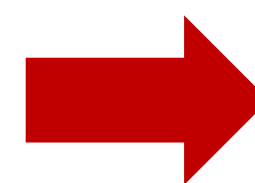
Digital Elevation Model Creation (SRTM Database)



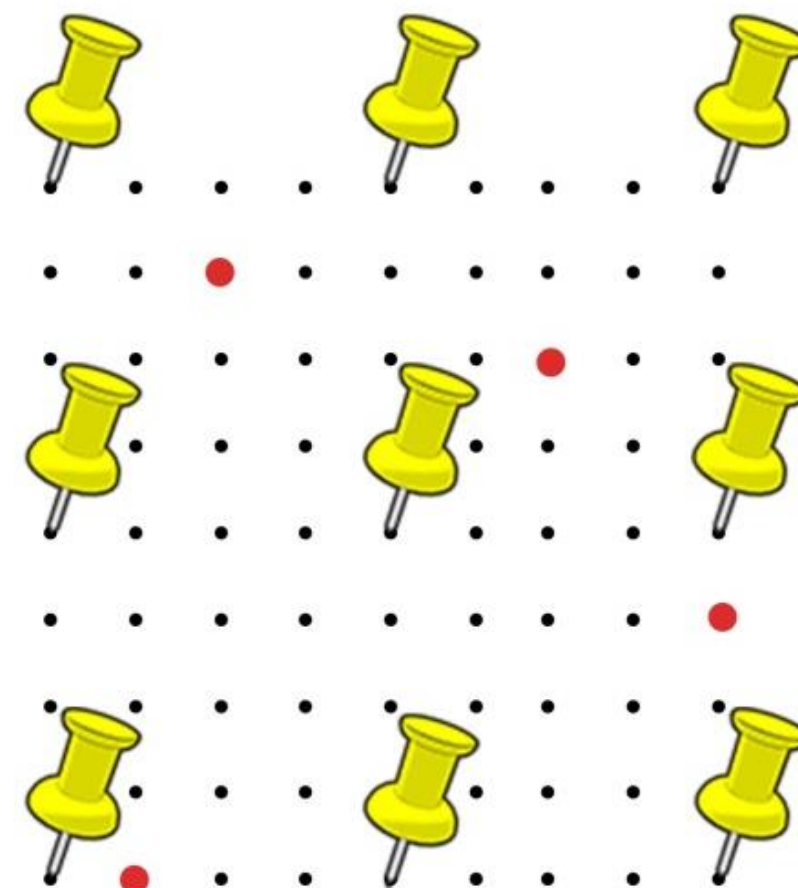
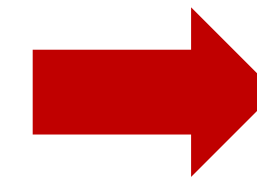
Digital Elevation Model Creation (SRTM Database)



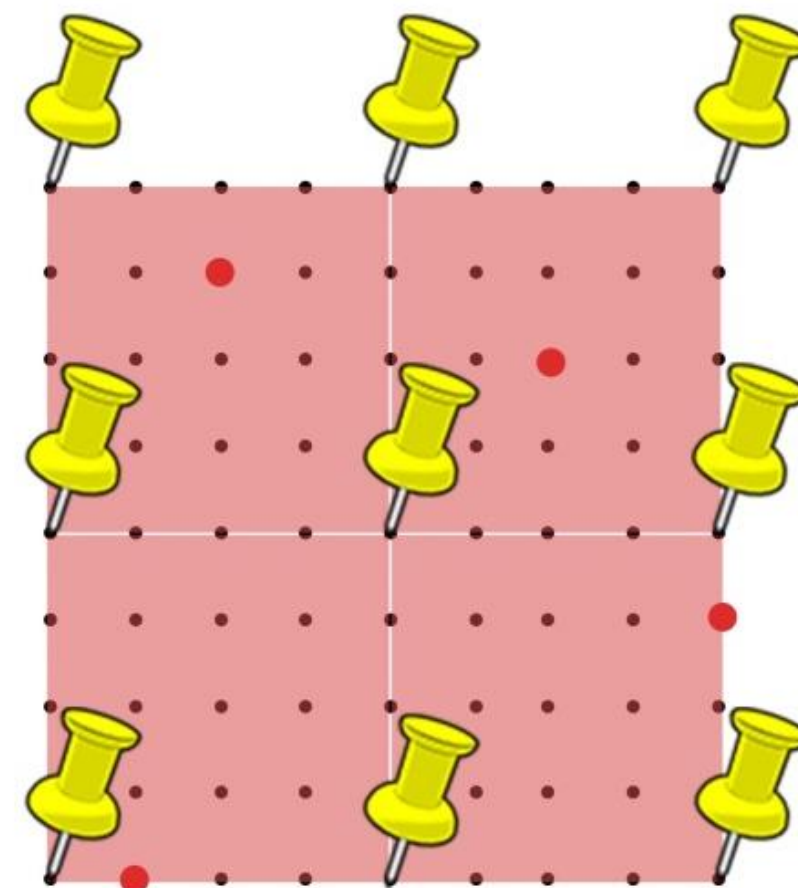
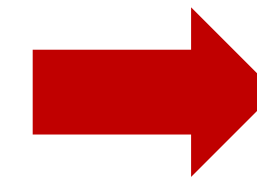
Digital Elevation Model Creation (SRTM Database)



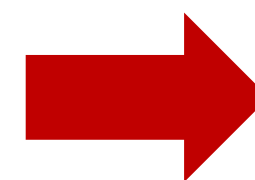
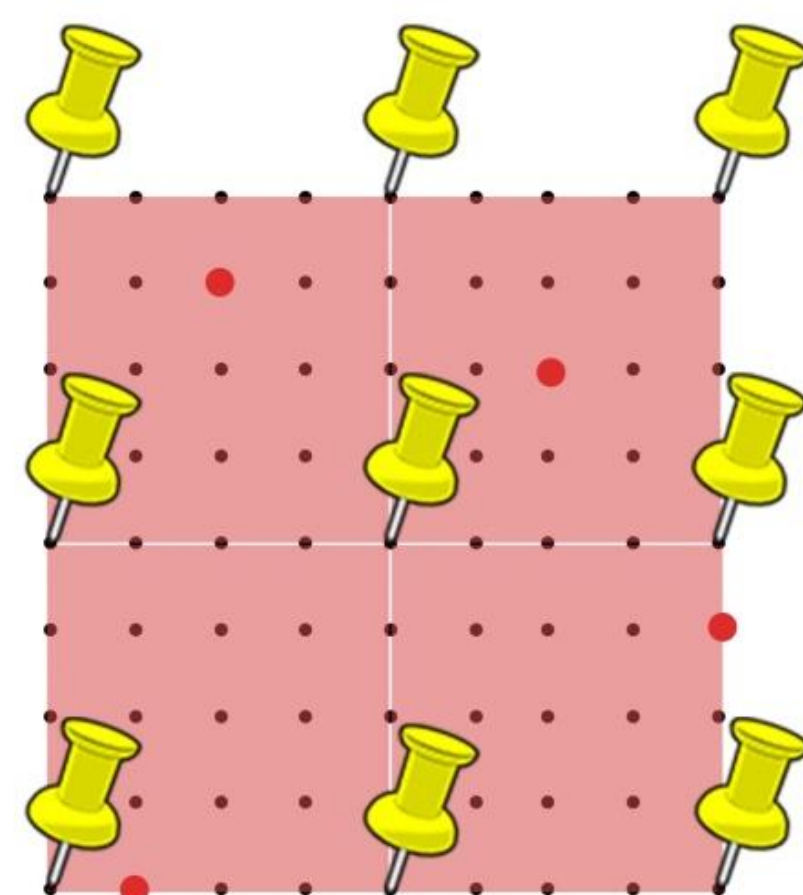
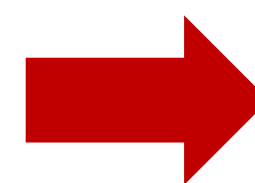
Digital Elevation Model Creation (SRTM Database)



Digital Elevation Model Creation (SRTM Database)

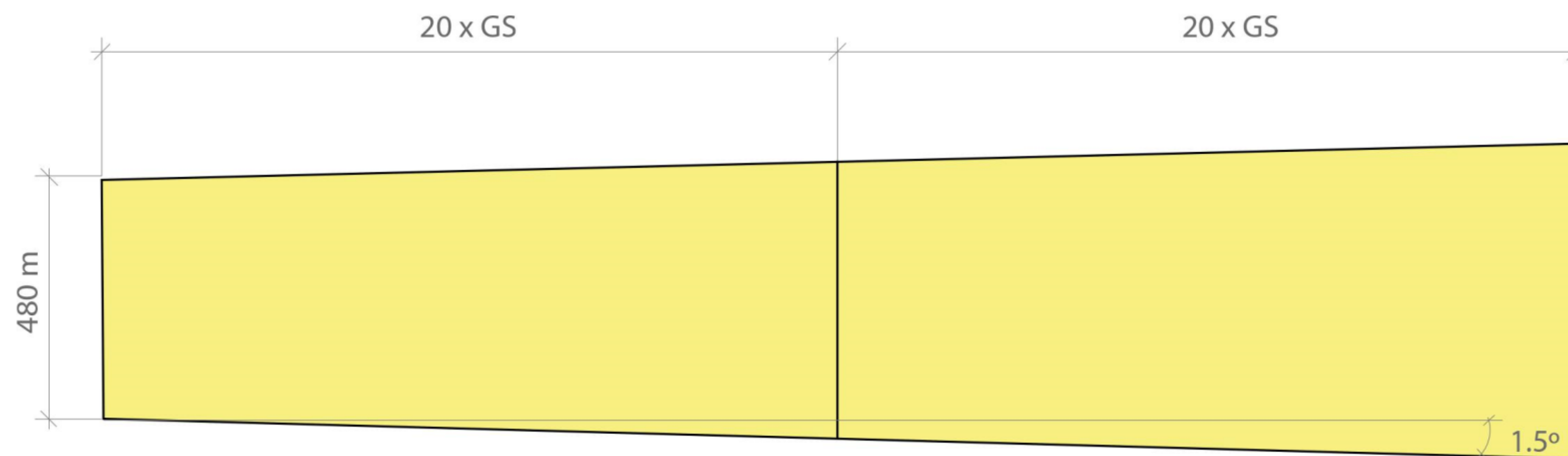


Digital Elevation Model Creation (SRTM Database)



Envelope Features

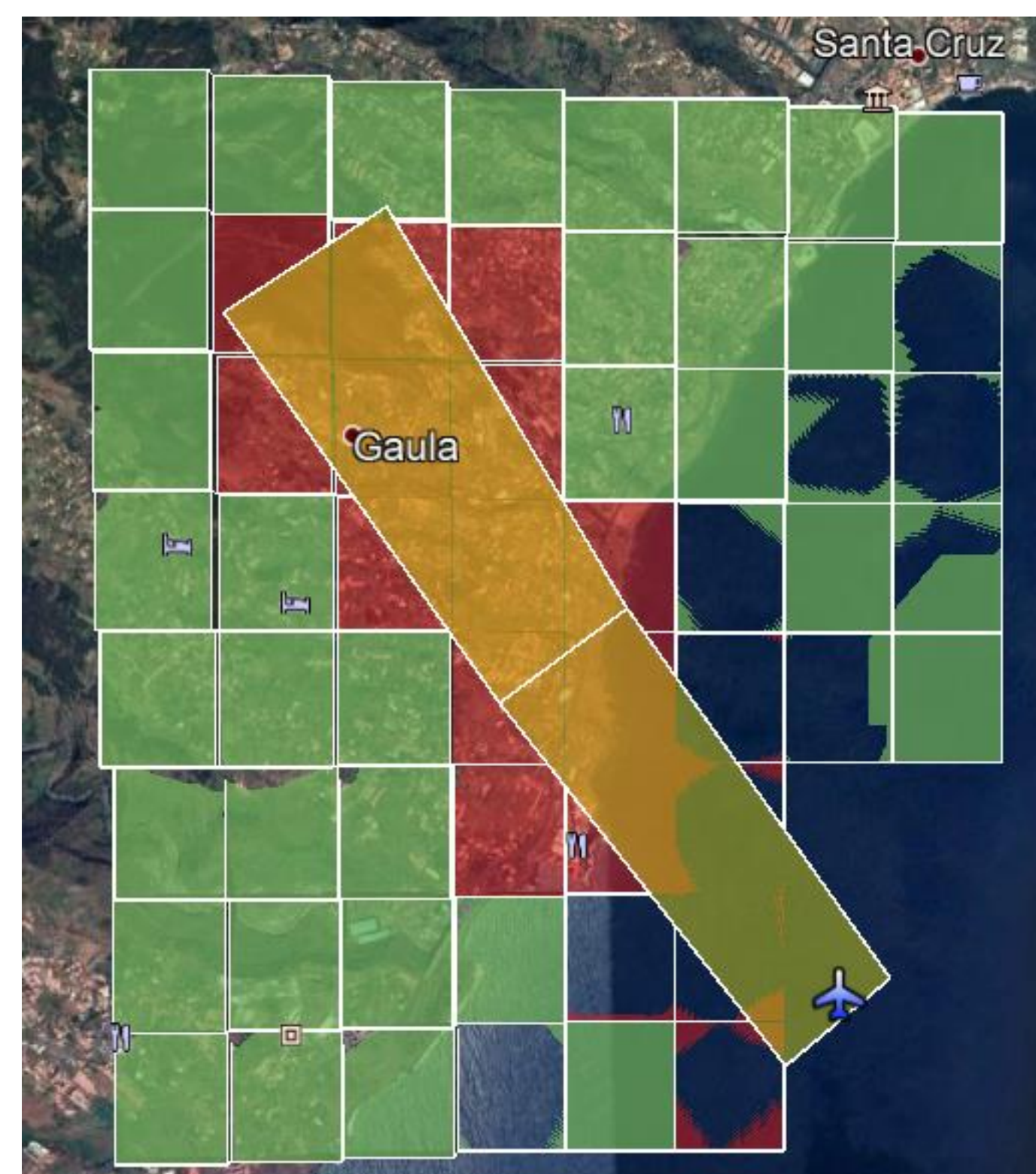
Top View



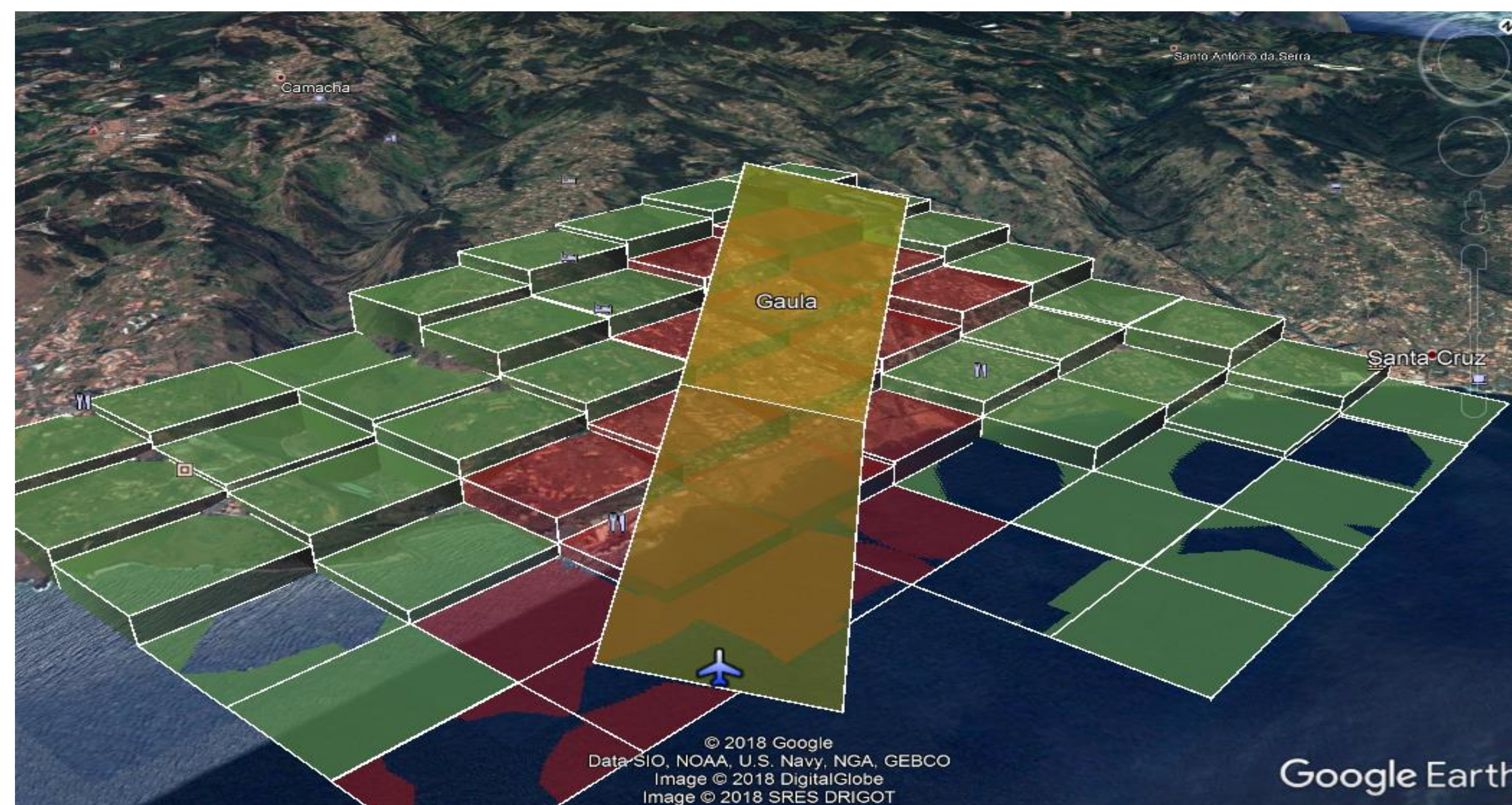
Side View



Conflict Detection

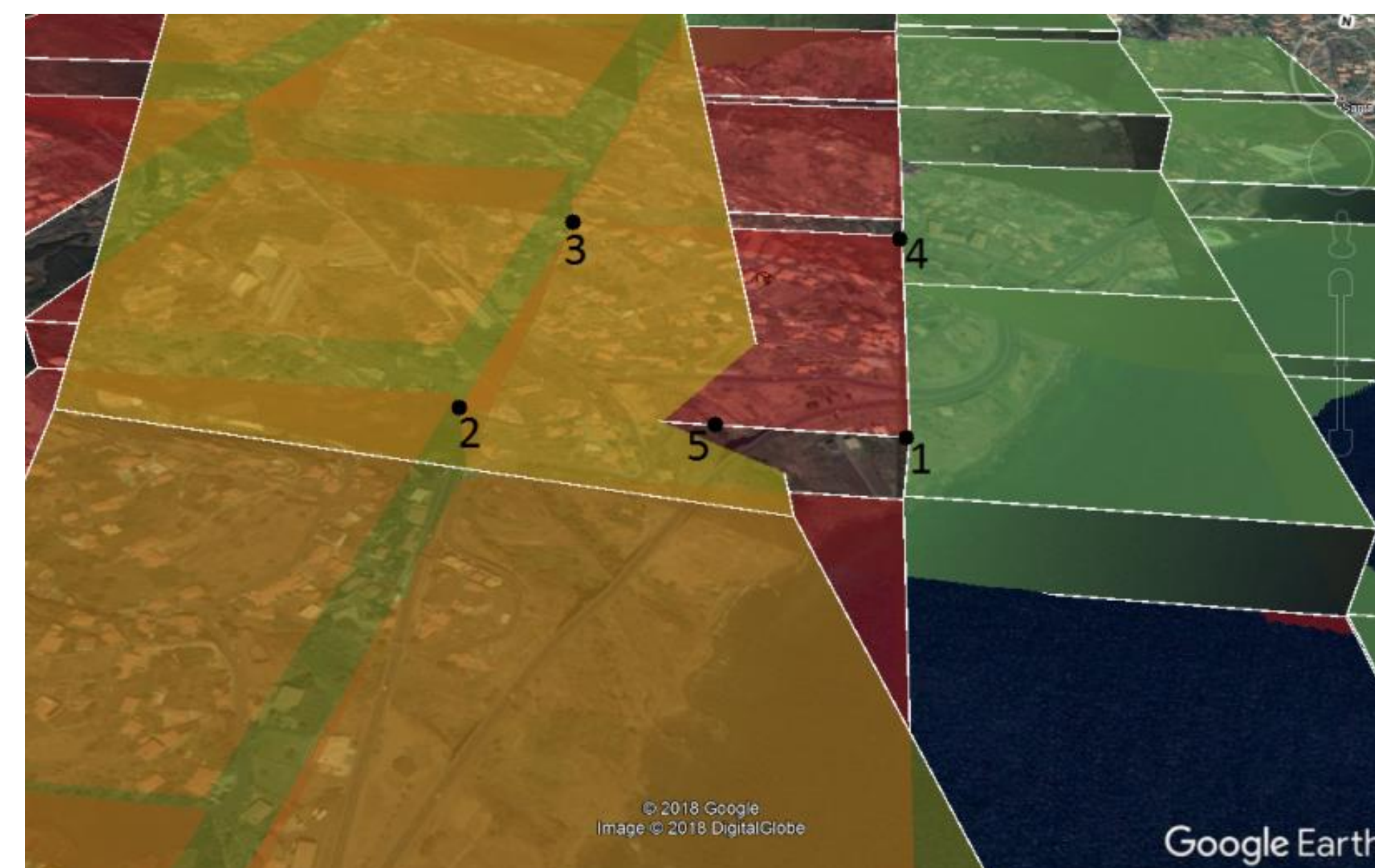


Top View



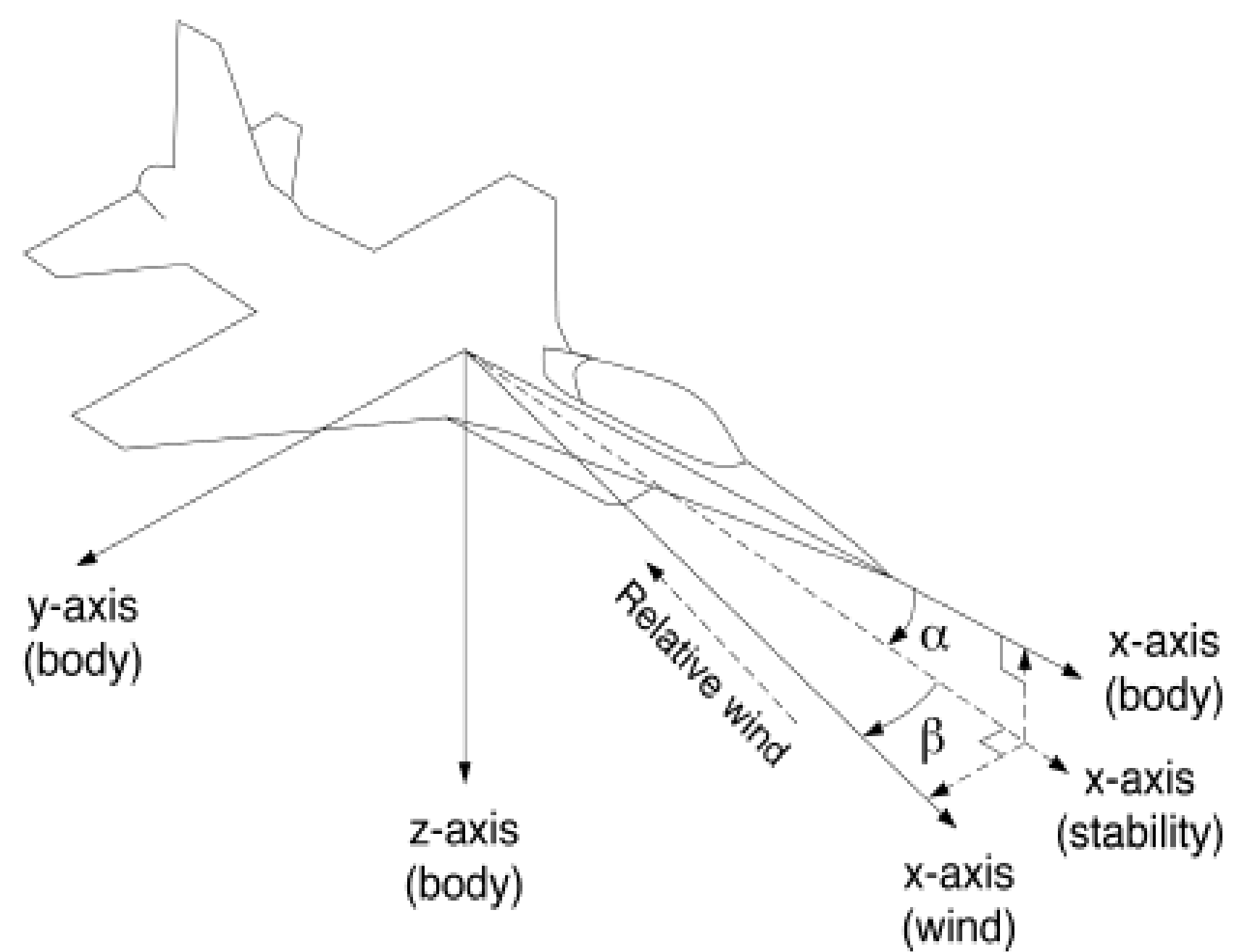
Aircraft View

Conflict Detection

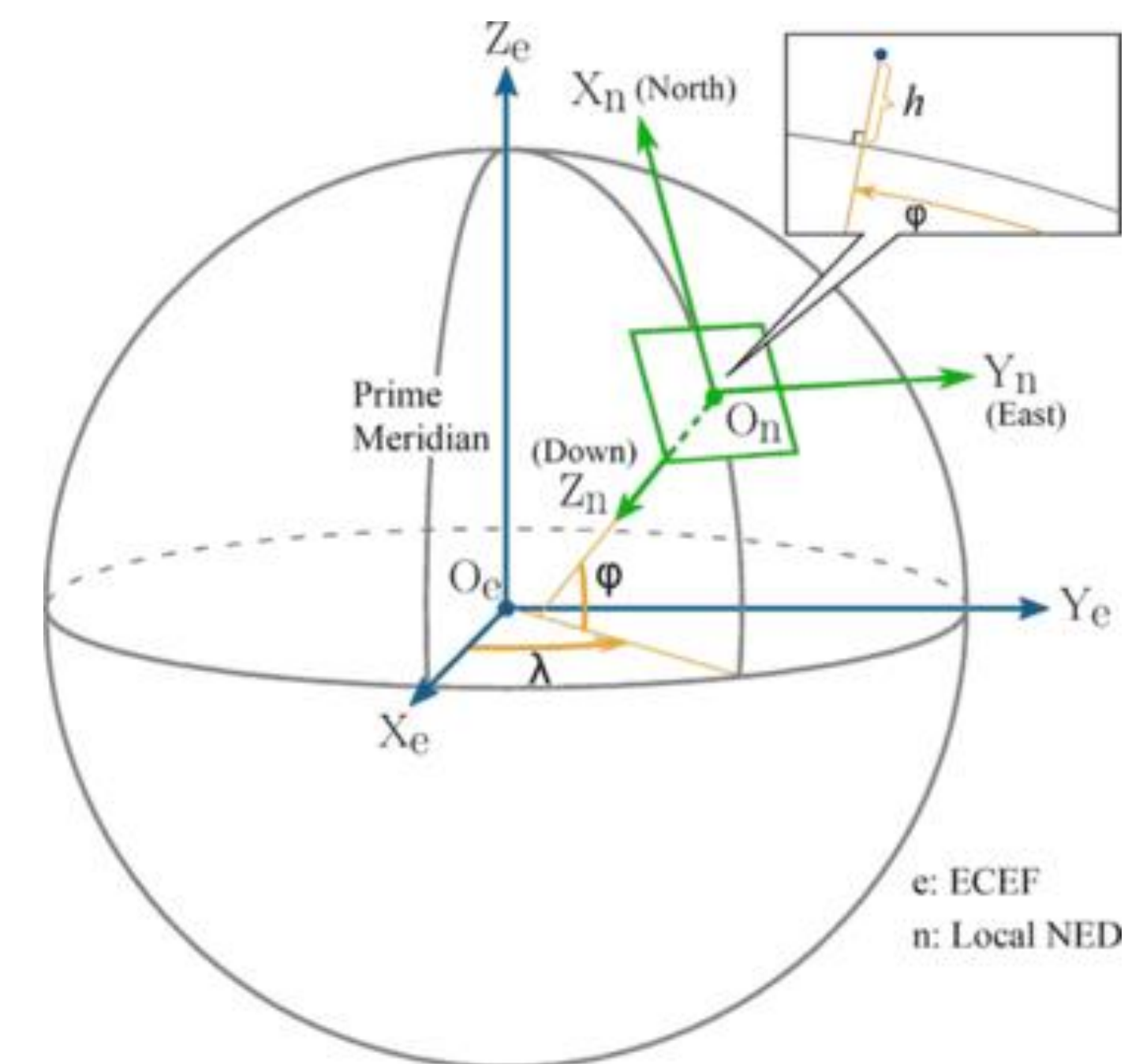


Conflict Detection

Envelope



Terrain Cells



Rotation between wind axes and NED axes using Euler angles

Conflict Detection

From geodetic coordinates (Terrain Cells)
to meters (Envelope)

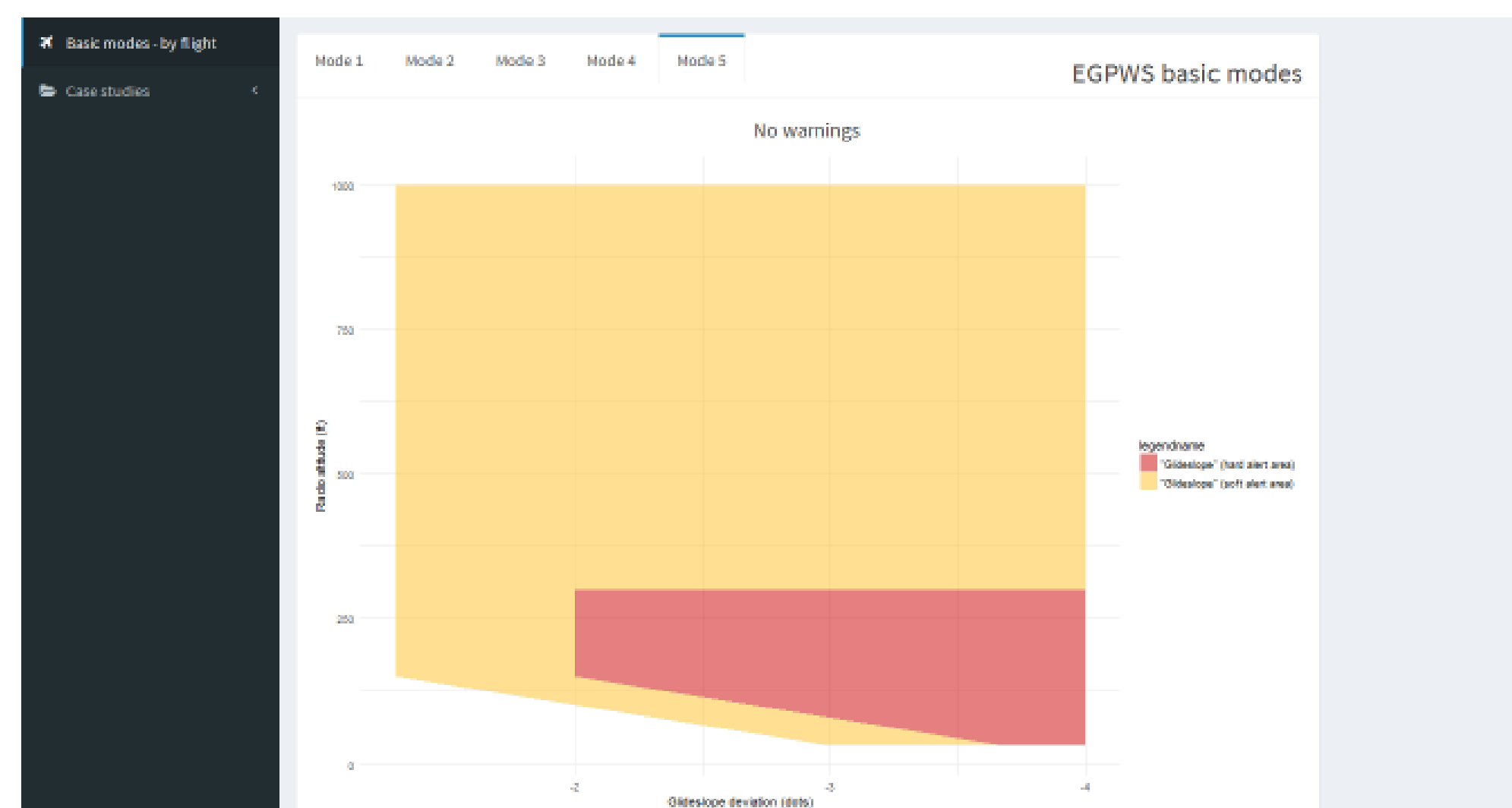
$$1^\circ \text{ latitude} = \frac{a(1-e^2)}{(1-e^2 \sin^2 \phi)^{\frac{3}{2}}} \times \frac{\pi}{180}$$

$$1^\circ \text{ longitude} = \frac{a \cdot \cos \phi}{(1-e^2 \sin^2 \phi)^{\frac{1}{2}}} \times \frac{\pi}{180}$$

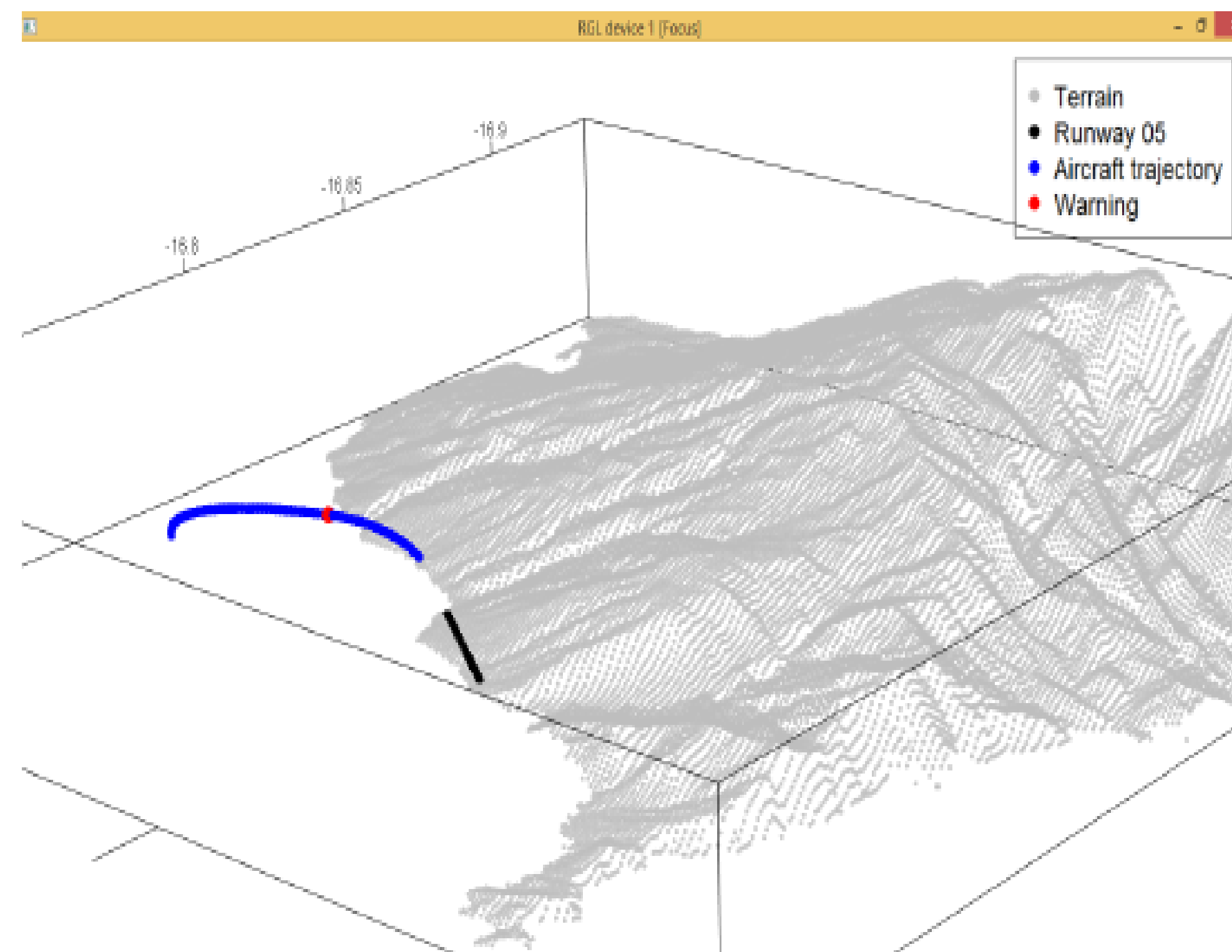
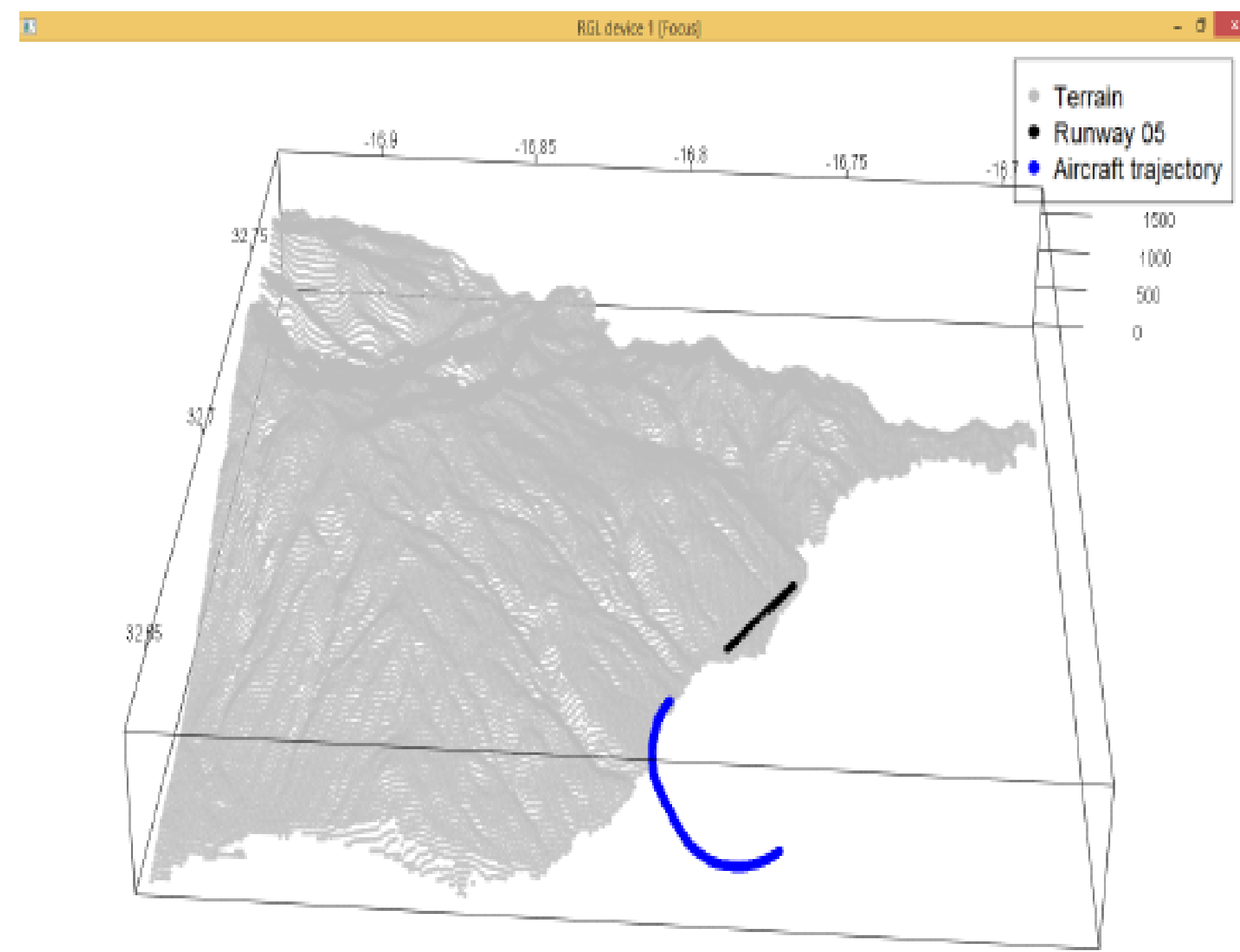
ϕ - Aircraft's latitude
a - Ellipse's semi-major axis
e - Ellipse's eccentricity



Achievements - R_TAWS Tool



Achievements - R_TAWS Tool



Achievements - R_TAWS Tool



Conclusions

- The R_TAWS tool was the first approach in TAP FDM department in trying to replicate these sort of EGPWS events;
- This tool was proven very useful in analysing both EGPWS basic modes and the Terrain Ahead predictive warning, specially because of the visual perspective it provides.
- Although it is a useful tool, it's far from being flawless. Some possible sources of error include:
 - SRTM database being different from the EGPWS unit internal database;
 - Incorrect envelope features for the Terrain Ahead Warning;
 - Lack of obstacle information for specific approaches, this might trigger spurious events for basic modes (however this is a possible future development);
 - Others...

Questions?

Thank you!

