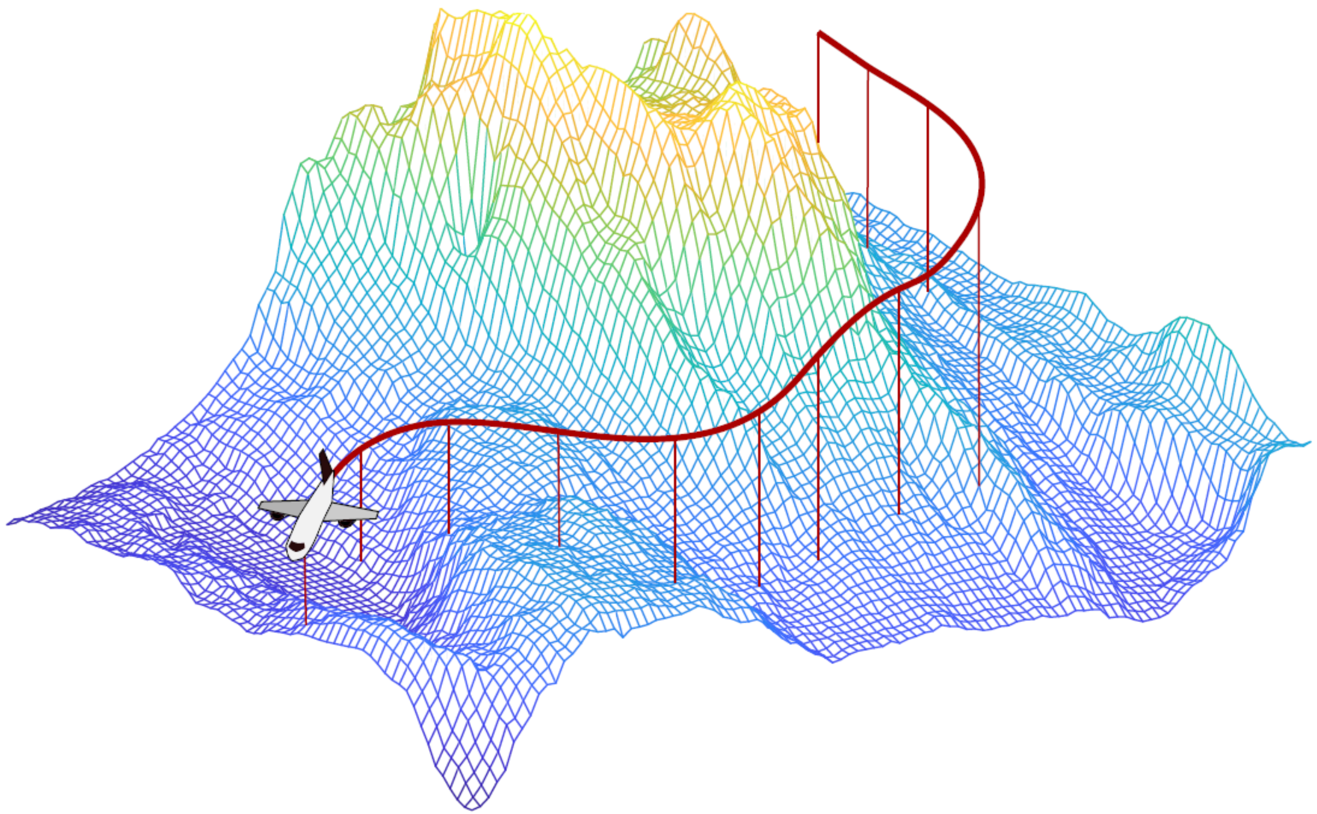
Controlled Flight Into Terrain Analyses in Flight Data Monitoring

Using Terrain Data



This presentation is based on the thesis of Niclas Bähr, supervised at the Flight Safety Group of TUM FSD

Classical FDM Data

Index	time_s	lat_rad	lon_rad	gs_mDs	gamma_rad	psi_rad	gpws_terrain_pullup_on	gpws_terrain_alert_on	gpws_too_low_terrain_m4_on
80032	48909	0,696047	-0,540716	239,21646	-0,008437	1,362942	0	0	0
80048	48911	0,696032	-0,540812	239,21646	-0,010738	1,363709	0	0	0
80064	48913	0,696017	-0,540911	238,702016	-0,006903	1,363709	0	0	0
80080	48915	0,695999	-0,541004	238,702016	-0,006903	1,362942	0	0	0
80096	48917	0,695984	-0,541097	238,702016	-0,005369	1,361408	0	0	0
80112	48919	0,695969	-0,541199	238,702016	-0,004602	1,359874	0	0	0
80128	48921	0,695954	-0,541291	238,702016	0	1,361408	0	0	0
80144	48923	0,695939	-0,541384	238,702016	-0,003835	1,363709	0	0	0
80160	48925	0,695924	-0,541486	238,702016	-0,006903	1,363709	0	0	0
80176	48927	0,695906	-0,541579	238,187572	-0,008437	1,361408	0	0	0
80192	48929	0,695891	-0,541672	238,187572	-0,009204	1,359874	0	0	0
80208	48931	0,695876	-0,541771	238,187572	-0,009204	1,360641	0	0	0
80224	48933	0,695861	-0,541864	238,187572	-0,009204	1,362175	0	0	0
80240	48935	0,695846	-0,541957	238,187572	-0,008437	1,362175	0	0	0
80256	48937	0,695831	-0,542055	238,187572	-0,003835	1,362175	0	0	0
80272	48939	0,695813	-0,542148	238,187572	0	1,362175	0	0	0

Classical FDM Data

Problems:
- low sampling rates
- single bit source

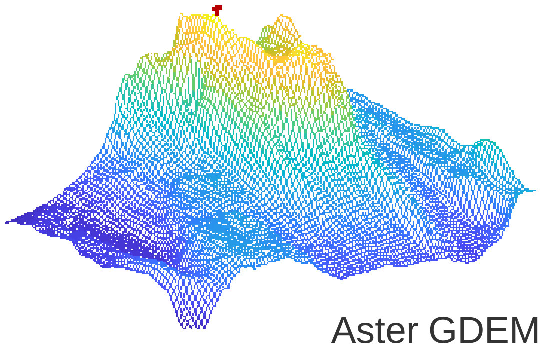
⇒ CFIT data in FDM is unreliable

Solution:
Use terrain database, position and velocity data, instead of recorded CFIT alerts

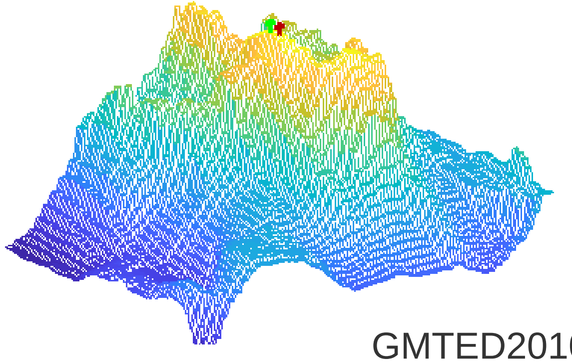
Databases and Properties

Properties \ Databases	**ASTER GDEM**	**GTOPO30**	**GMTED2010**	**SRTM**
Coverage	83°N to 83°S	90°N to 90°S	84°N to 56°S	60°N to 57°S
Mesh resolution	1 arc second	30 arc seconds	30/15/7.5 arc seconds	1 arc second
Tile size	1° by 1°	50° by 40°	40° by 30°	1° by 1°

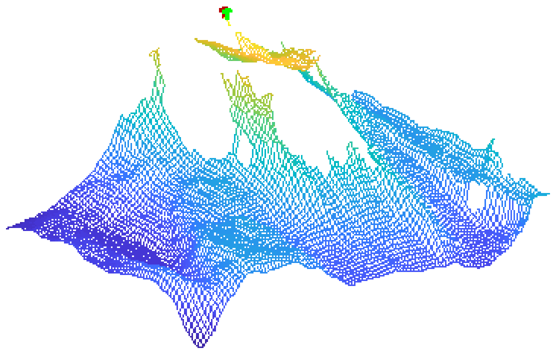
Visualization



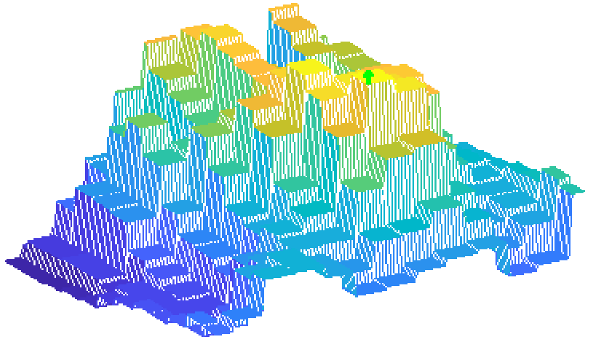
Aster GDEM



GMTED2010



SRTM

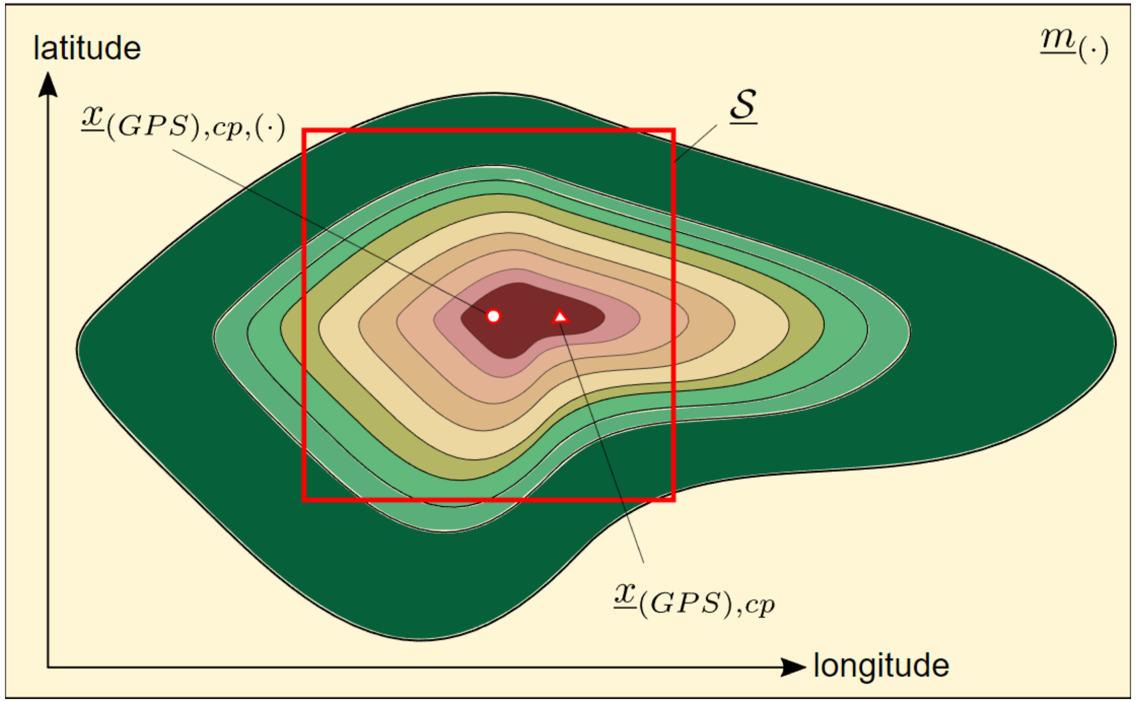


GTOPO30

Databases Evaluation using Mountain Summits

Why mountain summits:
- Height of summits is easily accessible
- Accuracy of summit data higher than of terrain data

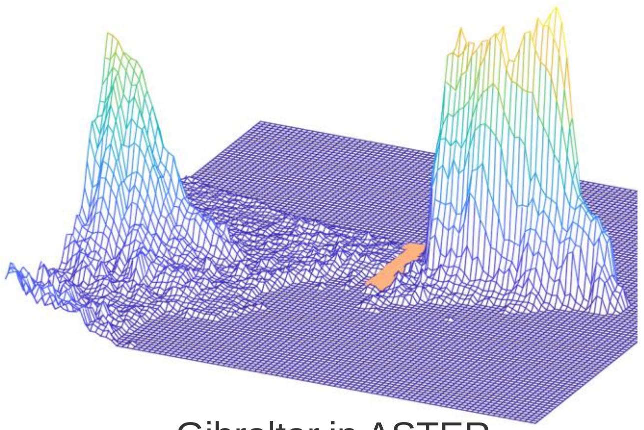
Evaluation:
- Define an area $\underline{S}$ around a summit
- Search maximum height in terrain data within $\underline{S}$
- Compute difference between summit height and maximum found in terrain data
- Compute an average of results from many summits



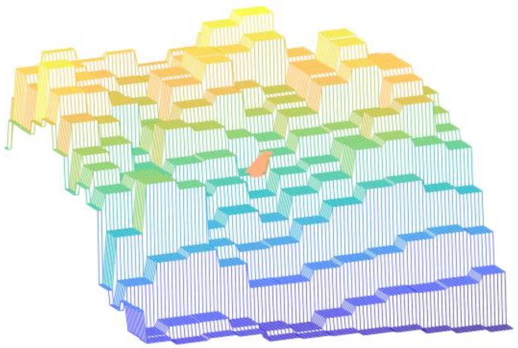
Databases Evaluation using Airport Runways

Evaluation:

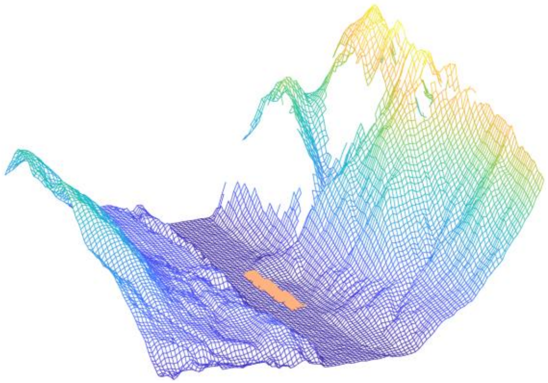
- Use airport elevation from aerodrome reference point (ARP)
- Compute difference of height in terrain data and ARP
- Compute an average of results from different runways



Gibraltar in ASTER



Courchevel in GTOPO30



Innsbruck in SRTM

Terrain Database Selection

Mountains:

$\Delta\overline{h}_{cp,(ASTER)}$	$\Delta\overline{h}_{cp,(SRTM)}$	$\Delta\overline{h}_{cp,(GTOPO)}$	$\Delta\overline{h}_{cp,(GMTED)}$
37m	48m	191m	73m

Acherkogel
Ararat
Ben Nevis
Carrantuohill Corno Grande
Dachstein
Demirkazik
Dagi
Elbrus
Etna
Galdhøpiggen
Janga
Kaskasapakte
Mont Blanc
Monte Cinto
Mytikas
P. d. Midi d'Ossau
Pico del Teide
Psiloritis
Punta La Marmora
Seebergspitze
Slieve Donard
Snowdon
Uschba Vesuv
Zugspitze

Airports:

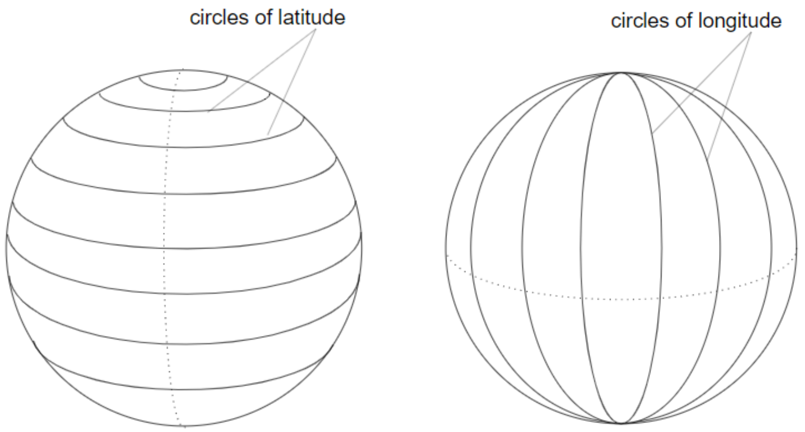
$\Delta\overline{h}_{cp,(ASTER)}$	$\Delta\overline{h}_{cp,(SRTM)}$	$\Delta\overline{h}_{cp,(GTOPO)}$	$\Delta\overline{h}_{cp,(GMTED)}$
8m	13m	111m	9m

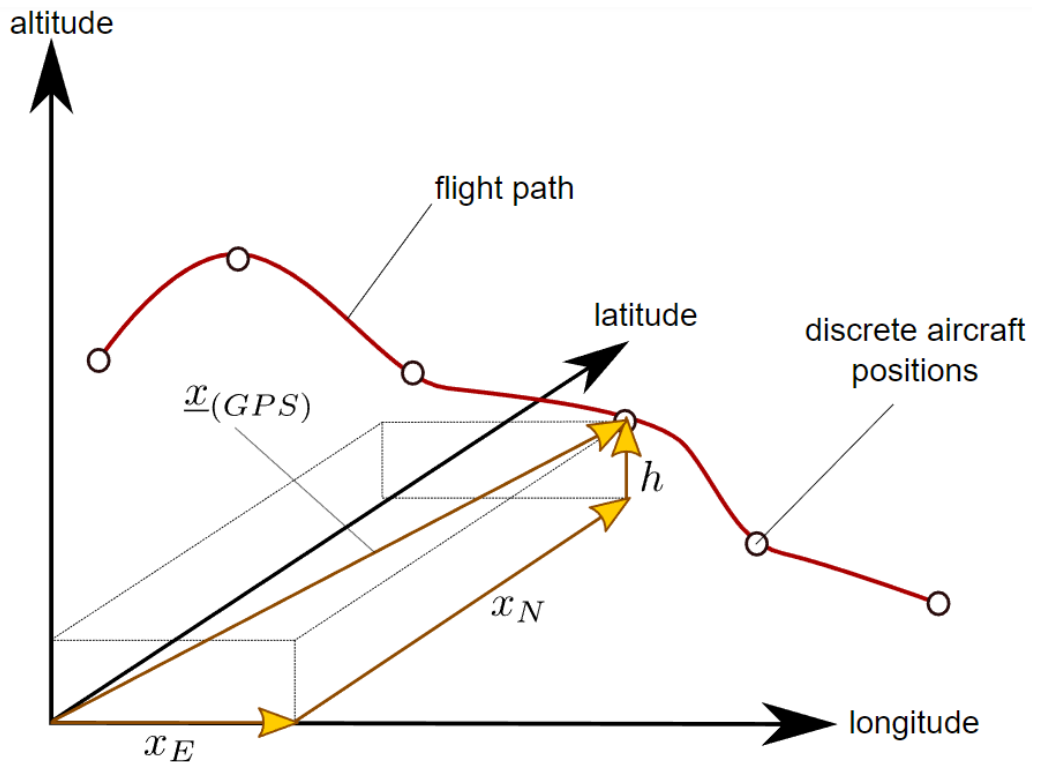
Courchevel
Honduras
Innsbruck
Lukla
Madeira
Tegucigalpa

Position Vector from FDM Data

Position vector:

- $\underline{x}_{(GPS)} := \begin{bmatrix} x_N \\ x_E \\ h \end{bmatrix}$
- Flight path is a collection of position vectors





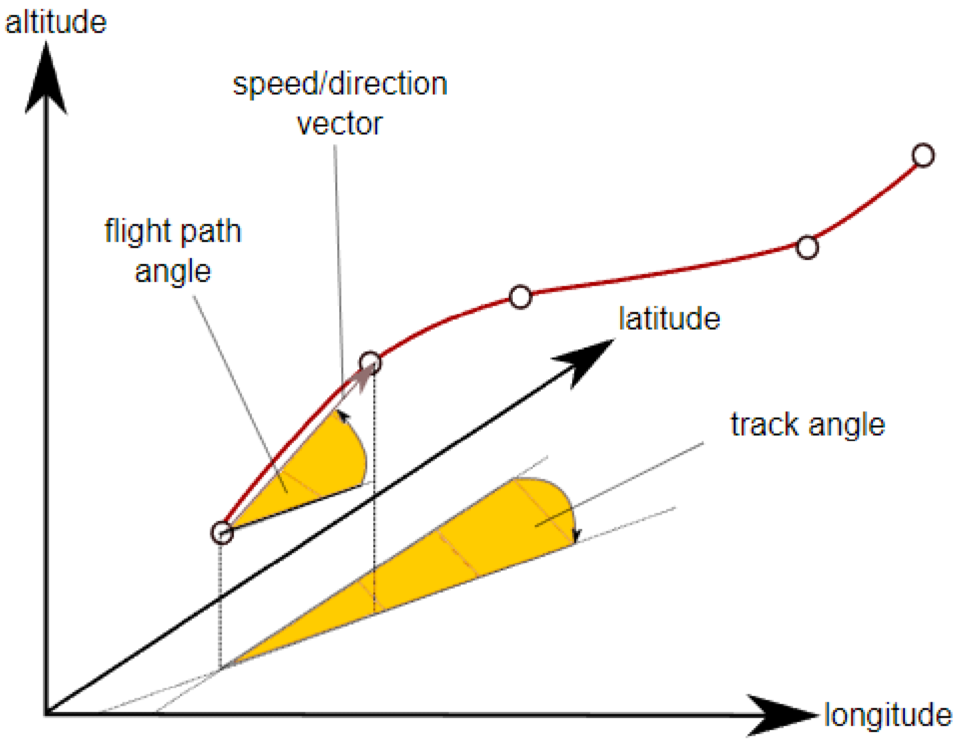
Velocity Vector from FDM Data

Velocity vector:

$$\underline{\dot{x}} = V \begin{bmatrix} \cos(\gamma)\cos(\psi) \\ \cos(\gamma)\sin(\psi) \\ \sin(\gamma) \end{bmatrix}, \quad \begin{matrix} \gamma\ flight\ path\ angle \\ \psi\ track\ angle \\ V = |\underline{\dot{x}}| \end{matrix}$$

Velocity vector in terms of ground speed:

$$\underline{\dot{x}} = V_H \begin{bmatrix} \cos(\psi) \\ \sin(\psi) \\ \tan(\gamma) \end{bmatrix}, V_H = V cos(\gamma)$$

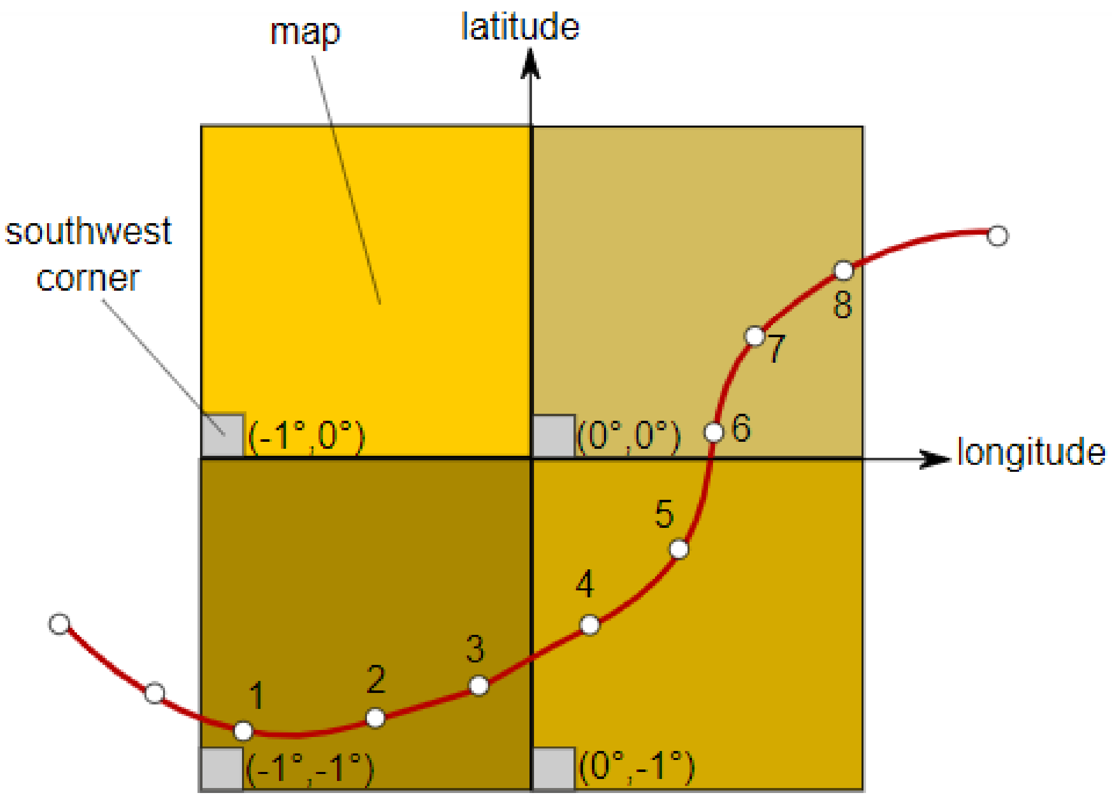


Selecting the fitting ASTER Tiles

Flight path:
- Collection of positions with latitude and longitude

Floor operation:
- Top off latitude and longitude
- Get list of associated terrain data tiles

List of Tiles:
- Sort out duplicates



CFIT Trajectory, as Linear Extrapolation with Velocity

CFIT Trajectory:

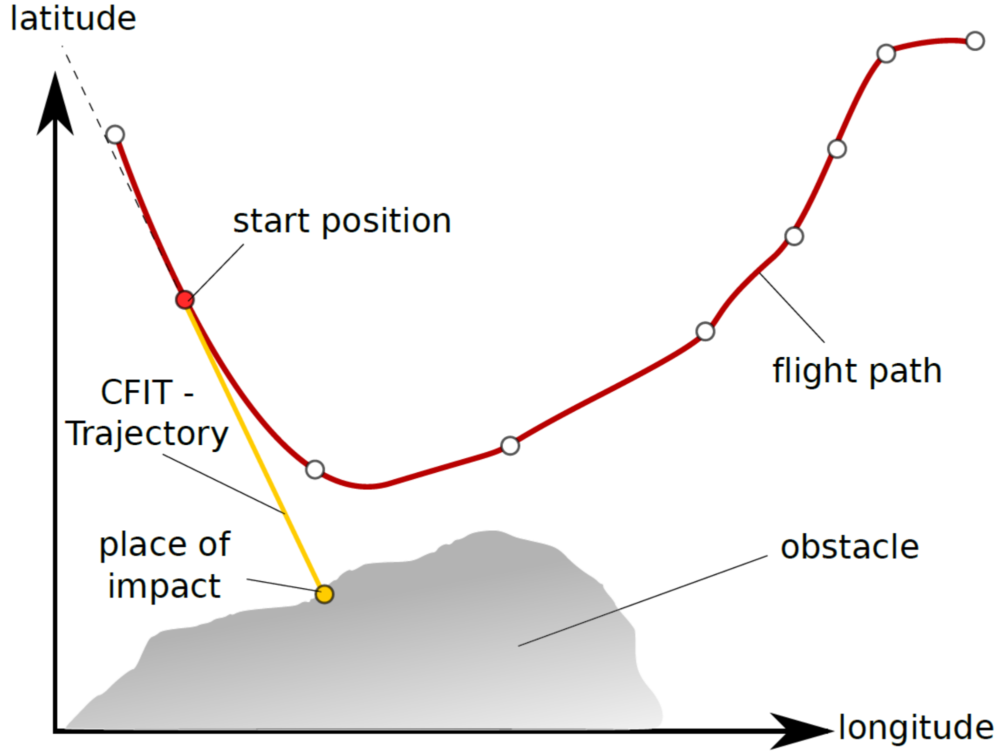
- Linear extrapolation of flight path
- $\underline{\tau}_{(GPS)}(t) \coloneqq \underline{x}_{(GPS)} + t \cdot \underline{\dot{x}}$

Virtual place of impact:

- First point where elevation in extrapolated flight path is larger than in the terrain data

Virtual time to impact:

- Time from start position to virtual impact point, given the speed at the start position



CFIT Incident Definition

CFIT incident conditions:

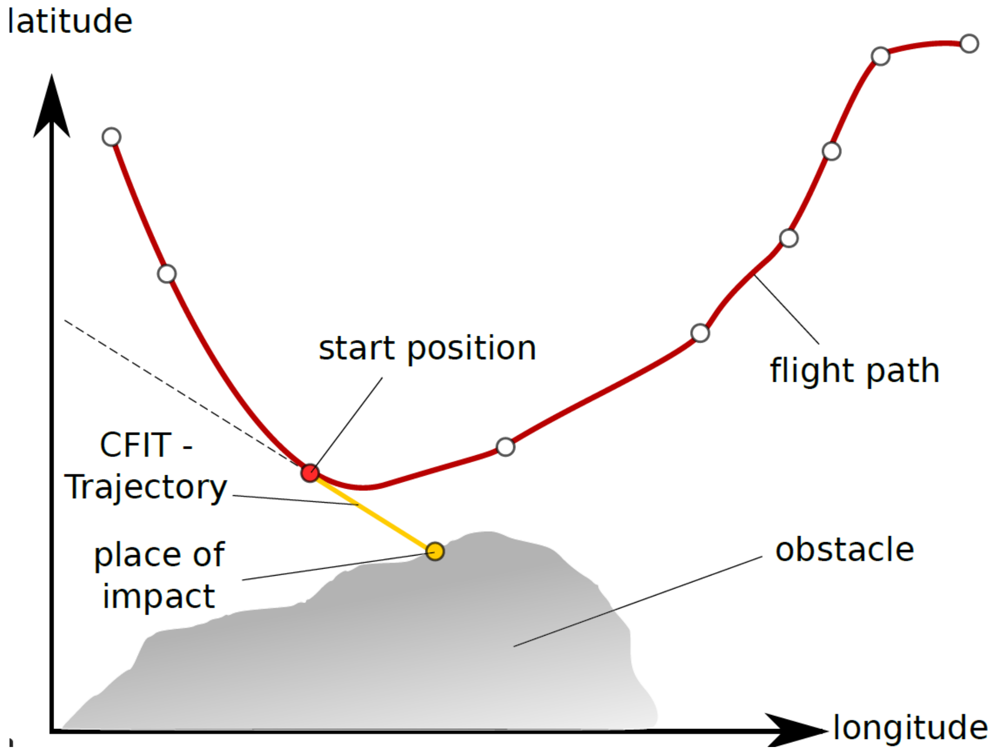
- Virtual impact point is not in runway area
- Virtual time to impact less than 60 seconds

CFIT number:

- Sum of start positions, a CFIT incident is detected

Criticality ζ of an incident:

- Criticality is rated inverse propotional to virtual time to impact



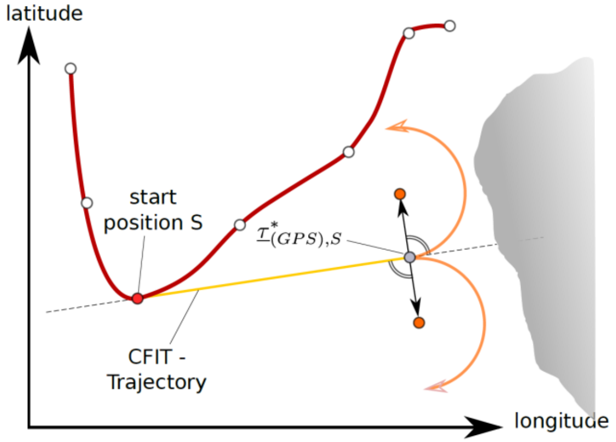
Risk Quantification

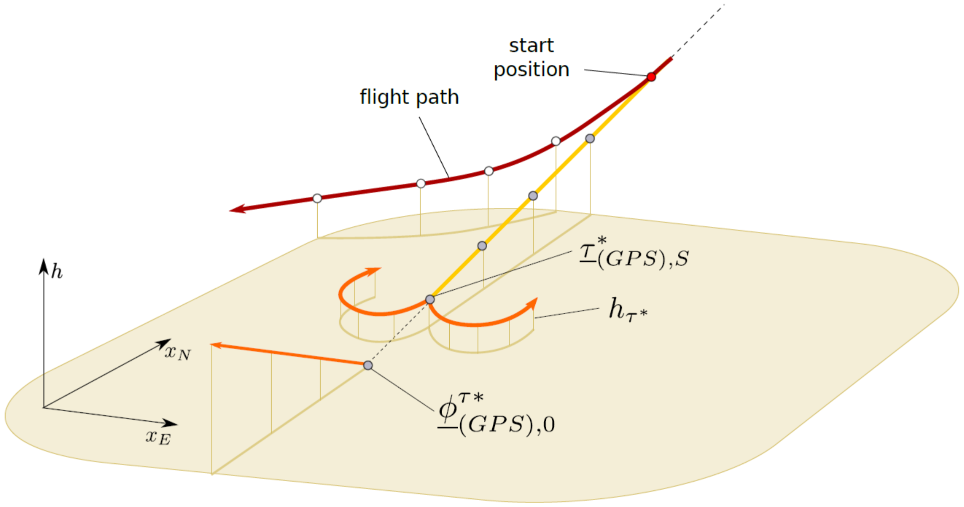
Idea:

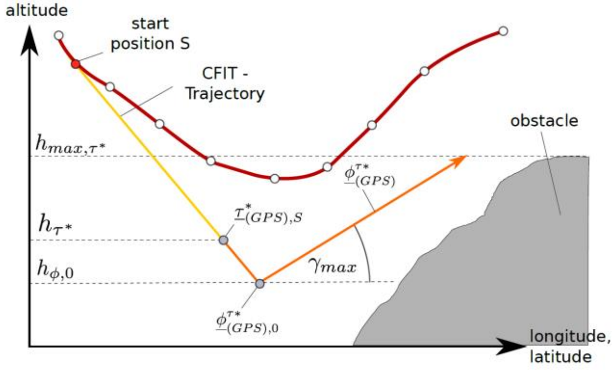
- Risk 100% is defined with the point of no return (PONR)

PONR:

- Point of the CFIT trajectory, where an accident is unavoidable

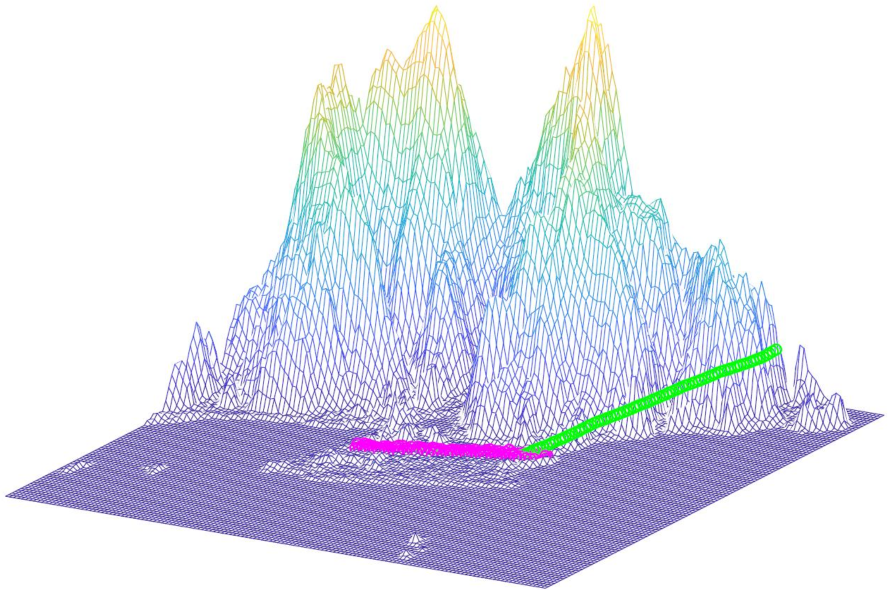


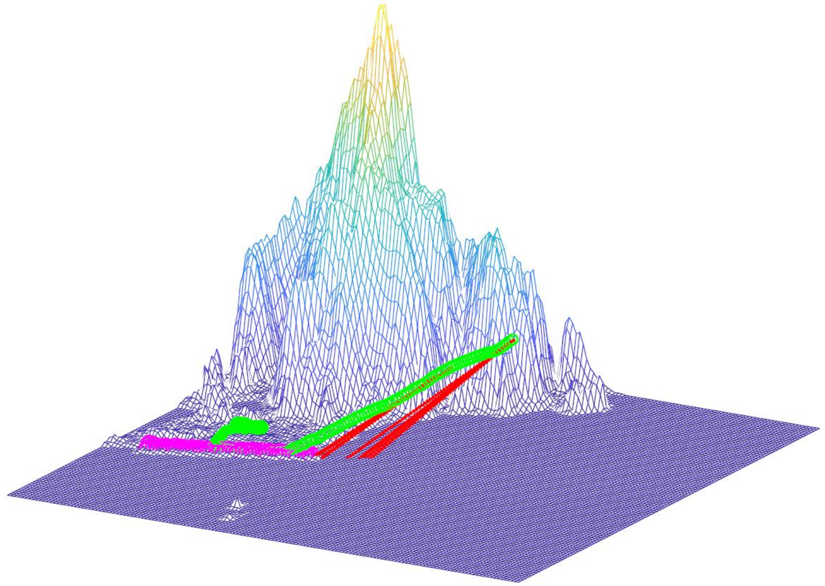




Results for Final Approach

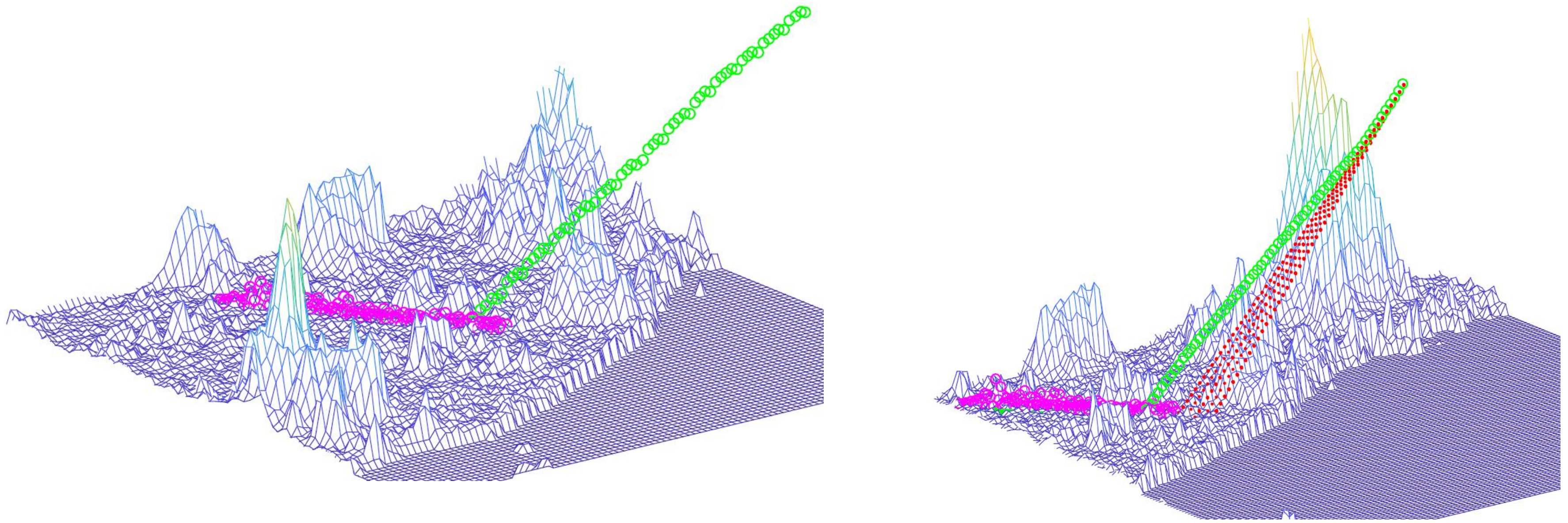
VHHH final approach	Left	Right	∅ of 23 flights
N_{CFIT}	0	10	2.18
ζ	0	0.0121	0.0016





Results for Final Approach

RKSI final approach	Left	Right	∅ of 6 flights
N_{CFIT}	0	13	3.83
ζ	0	0.0139	0.0072



Questions

Further reading:
https://mediatum.ub.tum.de/doc/1403391/1403391.pdf