EOFDM 3rd conference

Géraud de RIVALS
Flight Operations Analysis

Landing Trajectory Computation

Introduction

- Flight Data Monitoring programs use trajectories for
  - Touch-down location
  - Approach monitoring
  - Runway overrun risk monitoring
    - Comparisons with remaining runway lengths
    - Detection of poor landing performances

- Common assumption of these programs: good accuracy of the trajectory
  - Is it true?
  - How to assess the accuracy?
  - How to improve the accuracy?

Introduction

Flight Operations Analysis @ Airbus

≈ 1.000.000 flights

> 20 operators

Flight Tests Department @ Airbus

Trajectory Computation
+
Trajectory accuracy assessment

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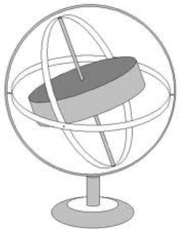
Trajectories available on board



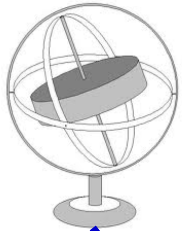
IRS

- Needs initialization (at the gate)
- Short term good accuracy
- Long term poor accuracy (2Nm/h)

GPS

- Good accuracy (GPS Primary 0.056Nm)
- Depends on Satellite configuration

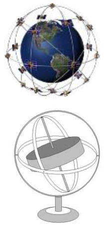
Trajectories available on board



FMS

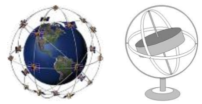
Computes trajectory from:

- GPS, IRS, ILS, VOR, DME
- EPE: Estimated Position Error

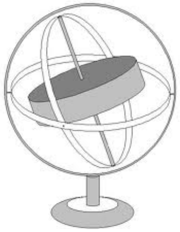


GPIRS / HYBRID

Trajectories available on board



GPIRS



IRS

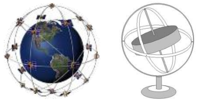
GPS

FMS

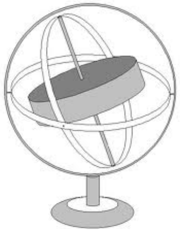
DMC/EFIS

Displays the FMS trajectory

Trajectories available on board



GPIRS



IRS

GPS

FMS

DMC/EFIS

AIRBUS

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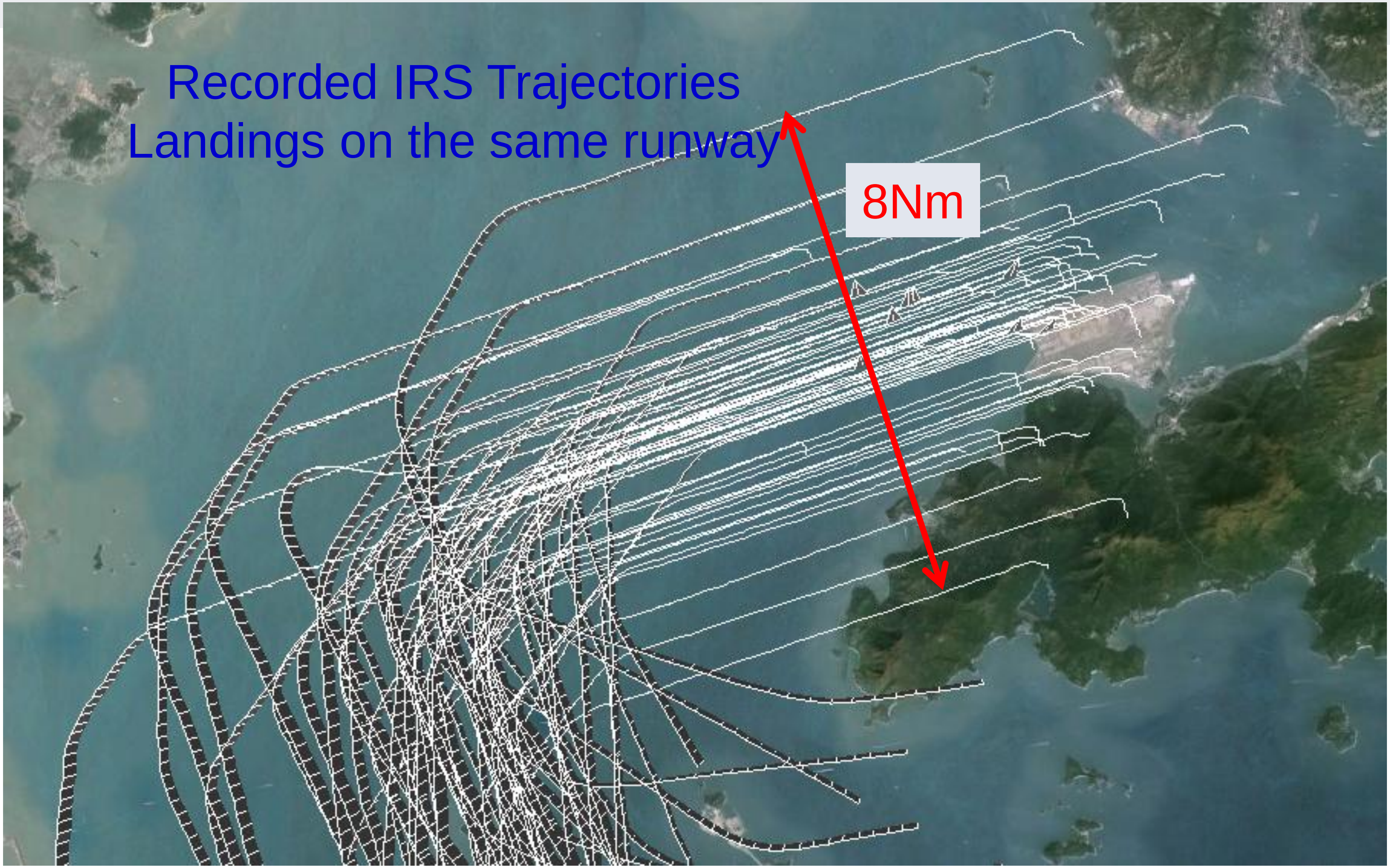
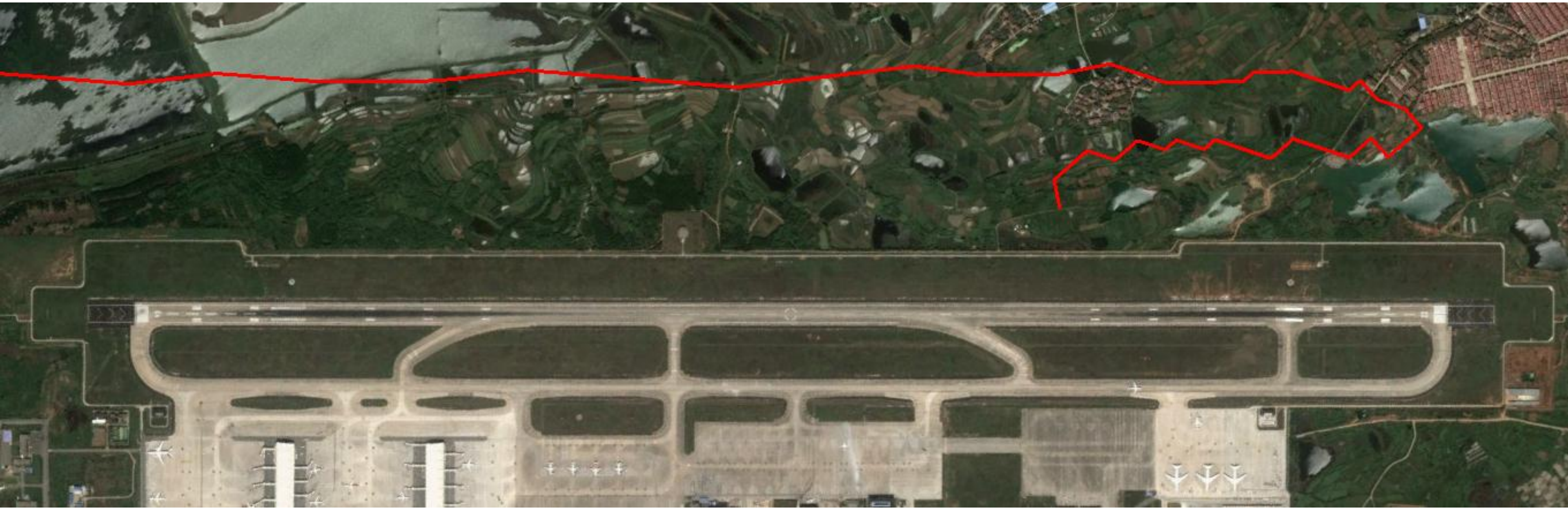

Recorded IRS Trajectories
Landings on the same runway
8Nm

Recorded trajectory per airline

Airline 1

Source	IRS 
Nb bits	20
Latitude Resolution	38m
Sampling rate	¼ Hz



Recorded trajectory per airline

Airline 2

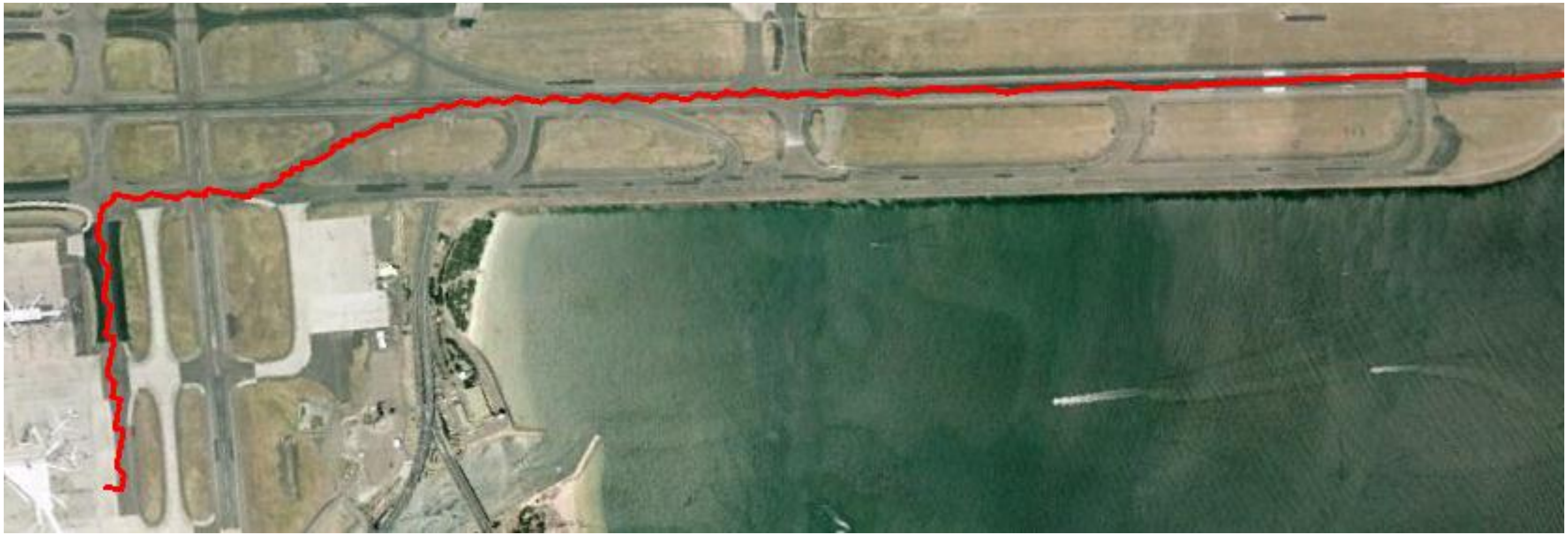
Source	IRS	GPS
Nb bits	20	21
Latitude Resolution	38m	19m
Sampling rate	¼ Hz	1Hz

AIRBUS

Recorded trajectory per airline

Airline 3

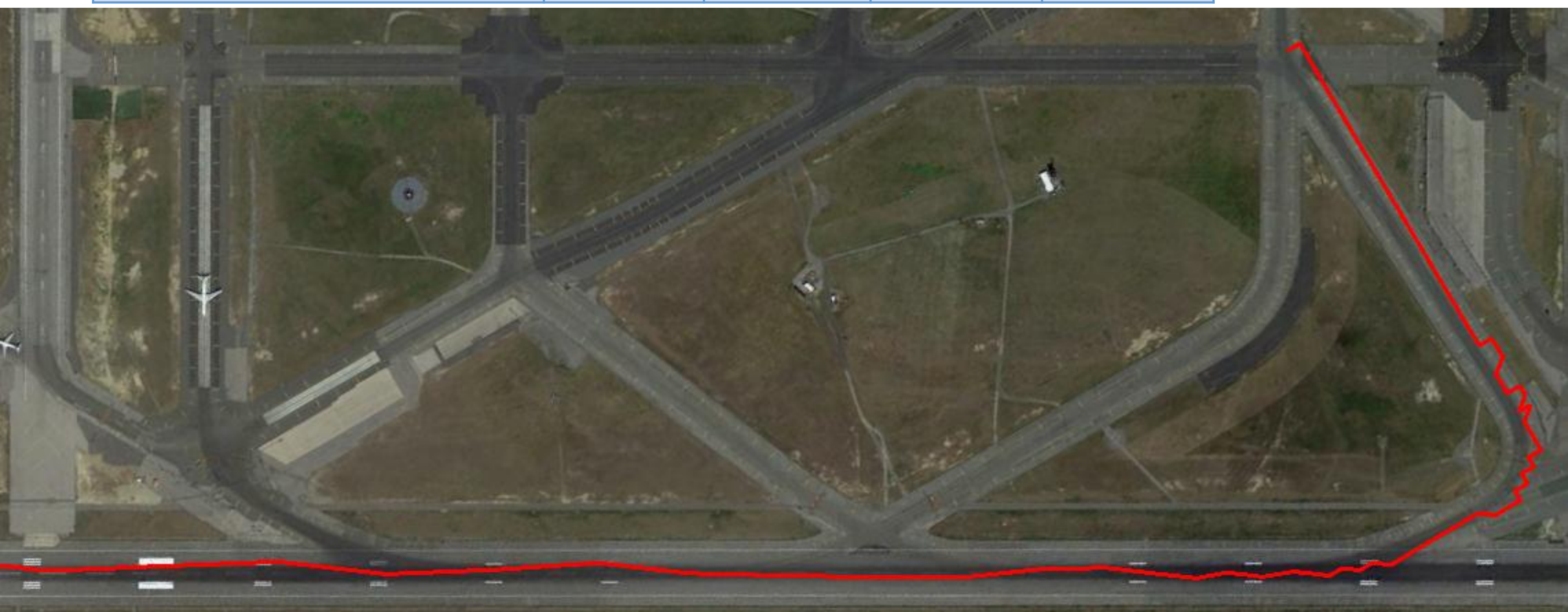
Source	IRS	GPS	FMS
Nb bits	20	21	21
Latitude Resolution	38m	19m	19m
Sampling rate	¼ Hz	1Hz	1Hz



Recorded trajectory per airline

Airline 4

Source	IRS	GPS	FMS	DMC
Nb bits	20	21	21	21
Latitude Resolution	38m	19m	19m	19m
Sampling rate	¼ Hz	1Hz	1Hz	½ Hz

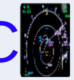


Recorded trajectory per airline

Airline 5

Source	IRS	GPS	FMS	DMC	GPS
Nb bits	20	21	21	21	32
Latitude Resolution	38m	19m	19m	19m	1cm
Sampling rate	¼ Hz	1Hz	1Hz	½ Hz	4 Hz

Recorded trajectory per airline: comparison of the selections

Source	IRS 	GPS 	FMS 	DMC 	GPS 
Nb bits	20	21	21	21	32
Latitude Resolution	38m	19m	19m	19m	1cm
Sampling rate	¼ Hz	1Hz	1Hz	½ Hz	4 Hz

Recommendation for the selection of the recorded trajectory:

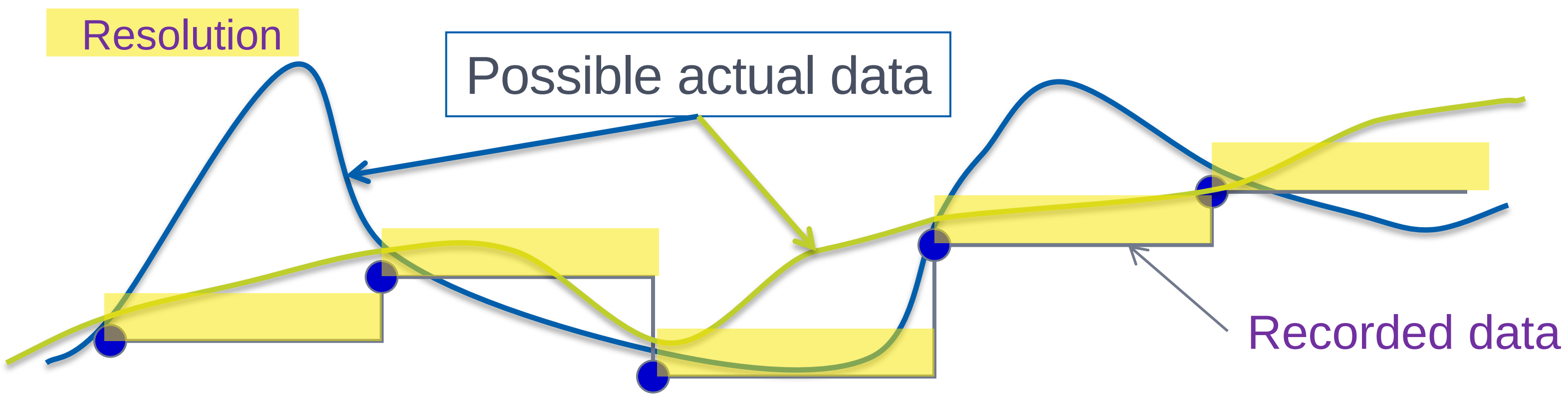
Source: FMS or DMC

Nb bits: 21

Sampling rate: 4Hz

GS = 140kts ≈ 70m/s

Resolution & Sampling Rate: impact on the trajectory accuracy



Impact of Sampling Rate:

- Recorded Point = True Point
- Between True Points: unknown values

Impact of Resolution (most of the cases):

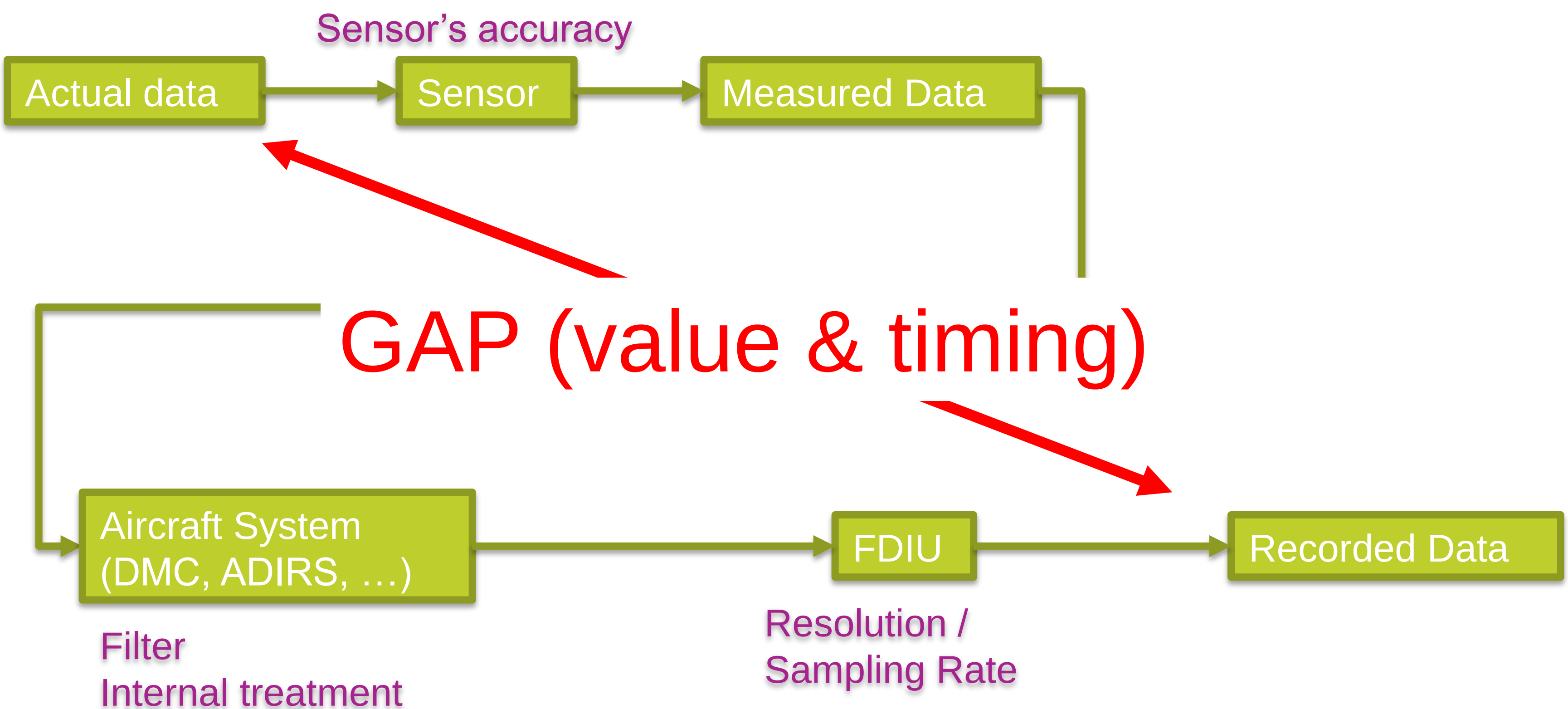
e.g. Actual Ground Speed = 138.8kts, resolution 1kt => recorded GS = 138kts

→ Our recommendation to reduce the impact of the resolution:

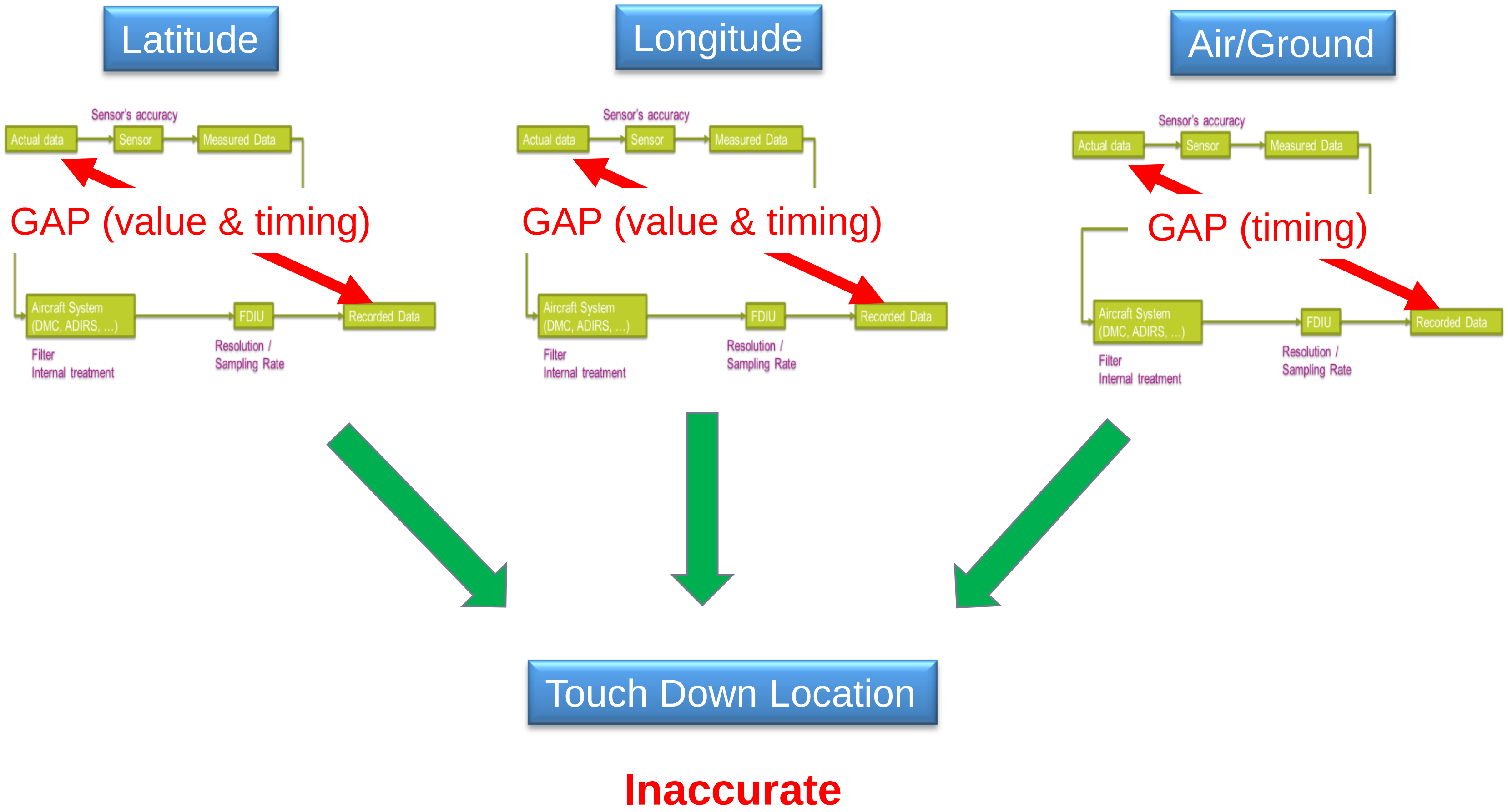
Add half of a Resolution

Accumulation of errors in the signal chain

- **Recorded** Data gives an **approximation** of the **measured** Data on board (which is an approximation of the actual data)



Example: Touch down location from recorded data



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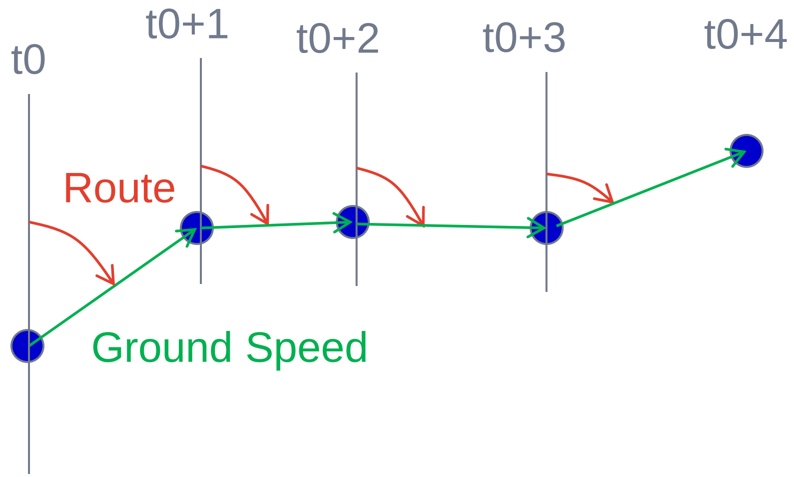
Post treatment trajectory computation

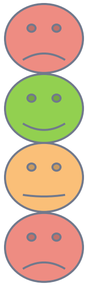
- Available trajectories on board may have poor accuracy
- Post treatment computation thanks to the available parameters?
  - Lateral
  - Longitudinal
  - And time: link with events (e.g. touch down)
- A 3-step method is presented here

Post treatment: trajectory computation step 1

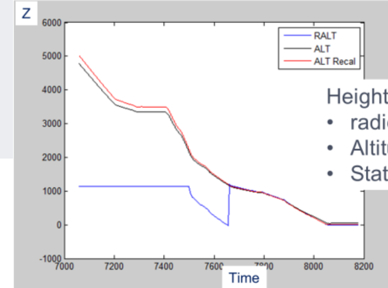
Step 1 - f(Ground speed, route)



- Needs good initialization at t0 (position)
- Easy to compute
- Needs route (or heading & drift angle)
- Adds up the errors along the integration

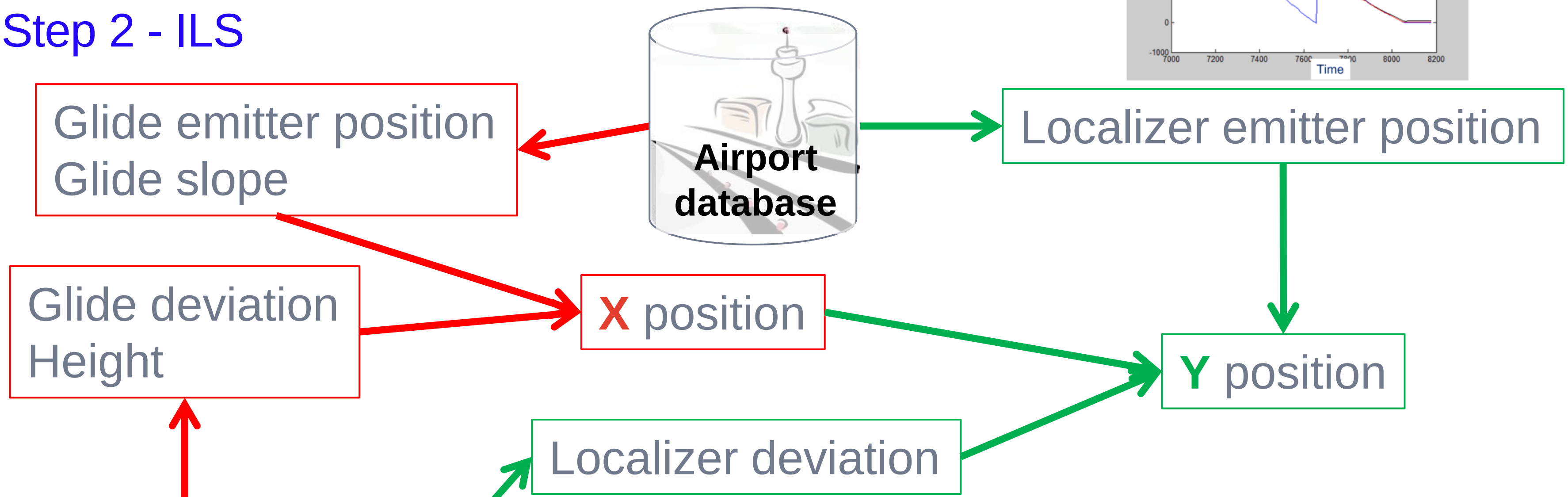


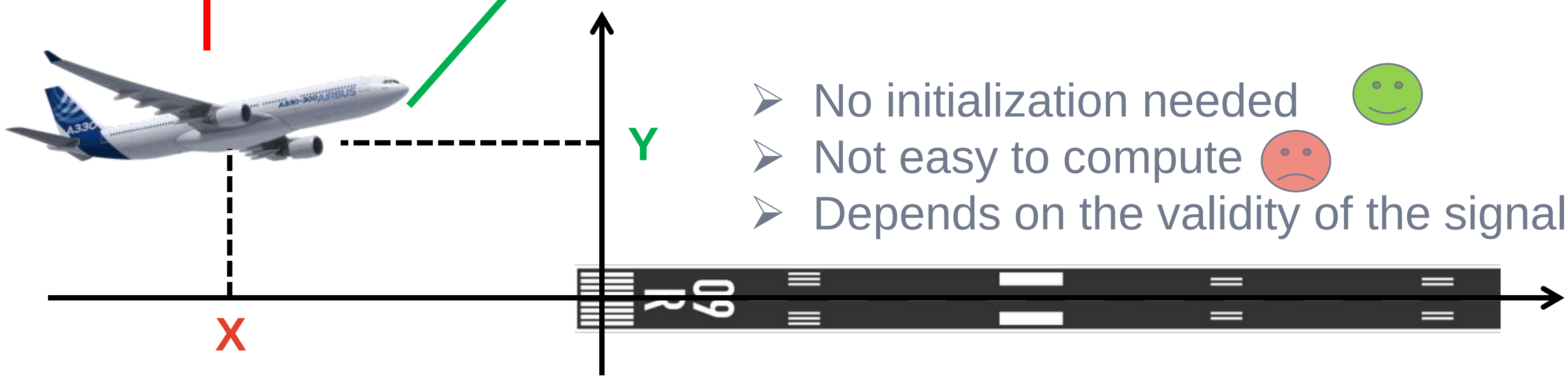
Post treatment: trajectory computation step 2



Height computed out of:
- radio-height
- Altitude
- Static air temperature

Step 2 - ILS

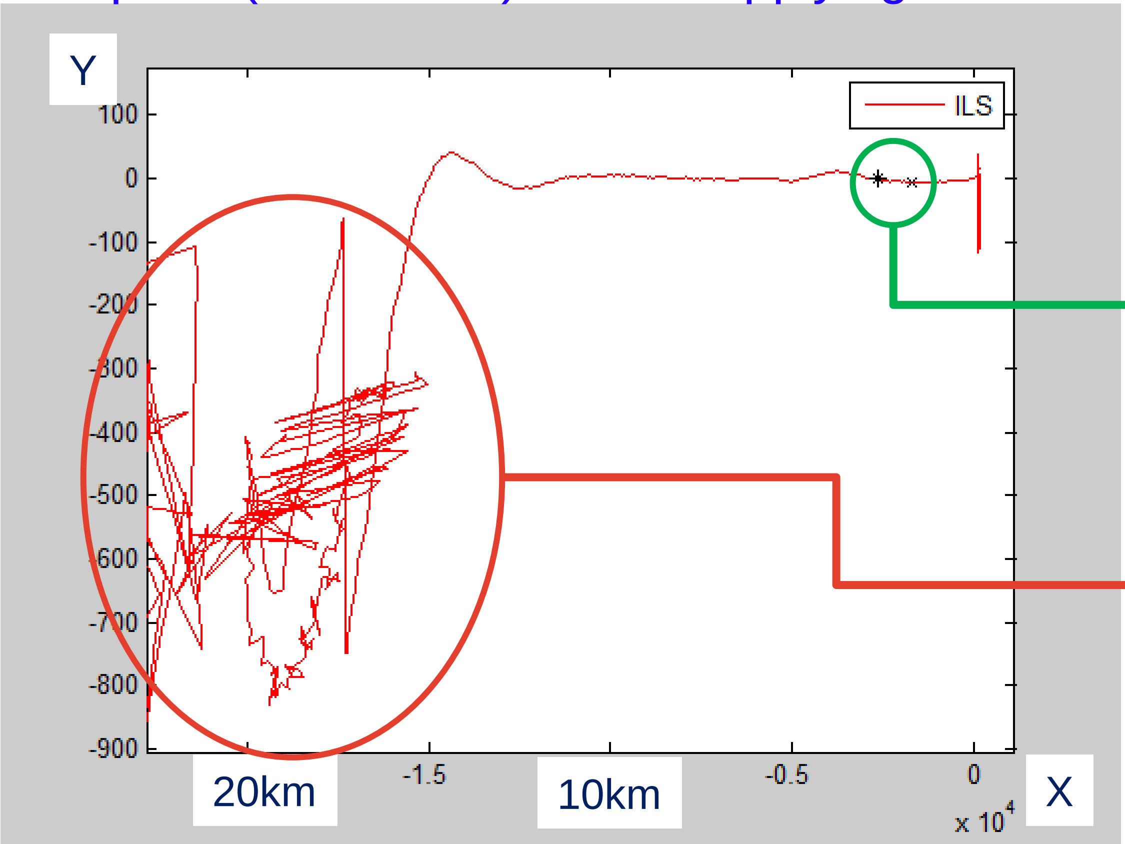




- No initialization needed
- Not easy to compute
- Depends on the validity of the signals

Post treatment: trajectory computation step 3

Step 3 – (GS, Route) + ILS + applying corrections



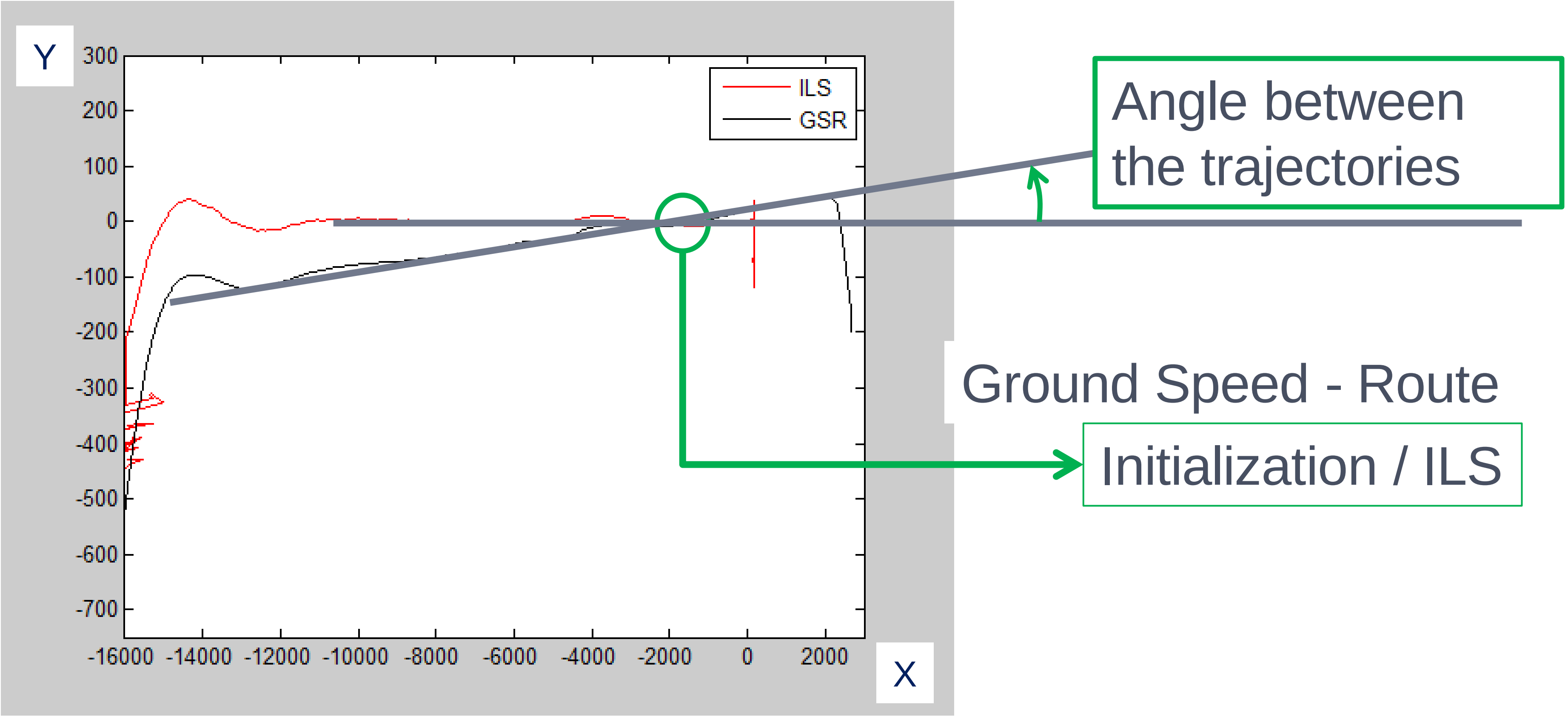
ILS trajectory

Used for the initialization of the trajectory

Too far from the runway: ILS perturbed

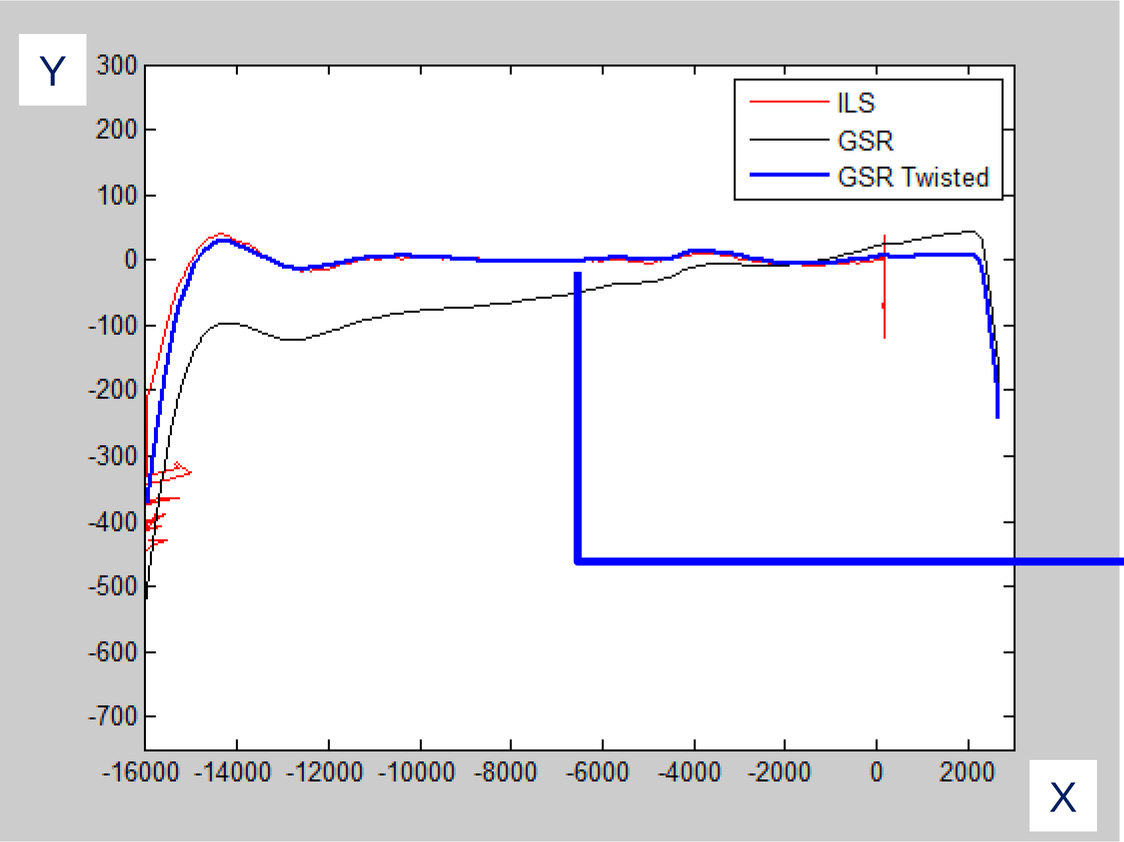
Post treatment: trajectory computation step 3

Step 3 – (GS, Route) + ILS + applying corrections



Post treatment: trajectory computation step 3

Step 3 – (GS, Route) + ILS + applying corrections



Twisted trajectory: final result

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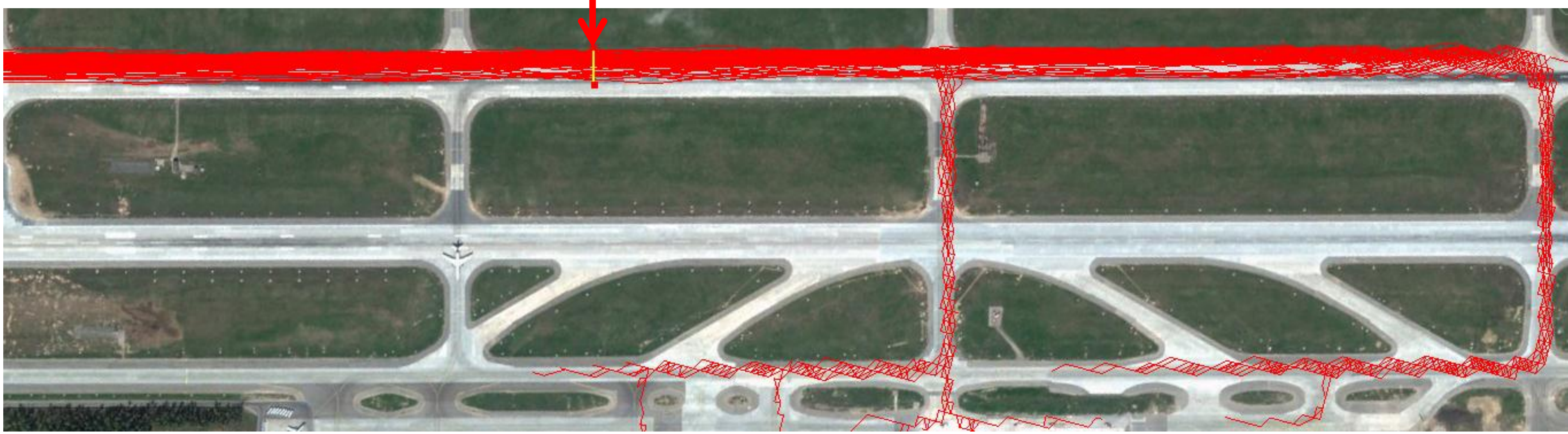
Accuracy assessment using visual technique

Recorded trajectory + ½ resolution

Source = DMC

585 flights

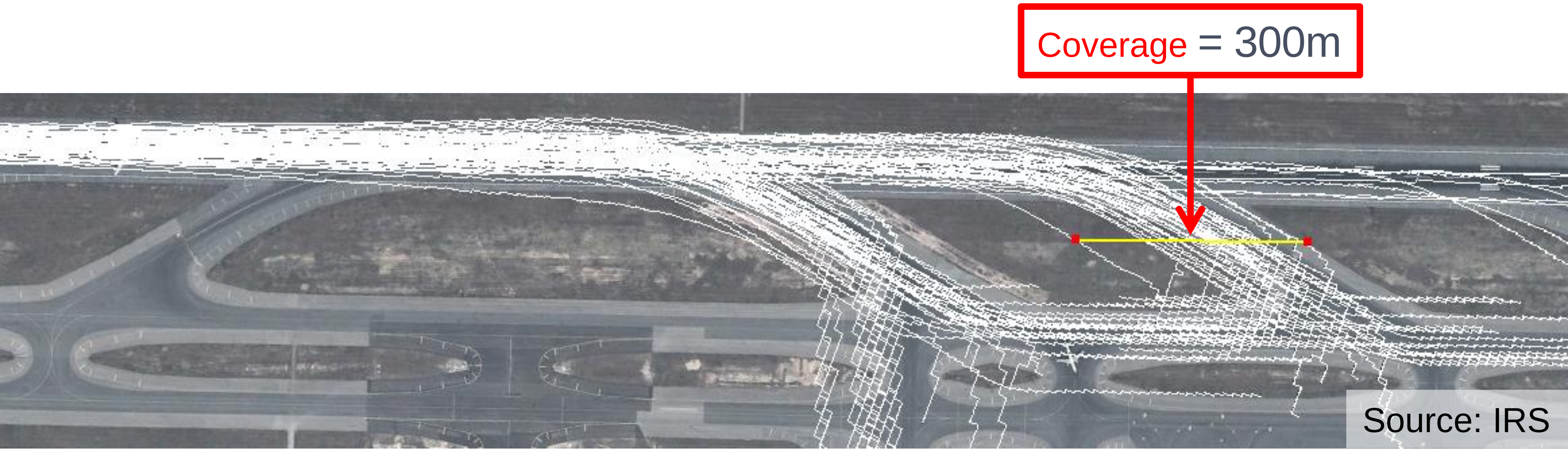
Coverage = 70m



Accuracy assessment using visual technique

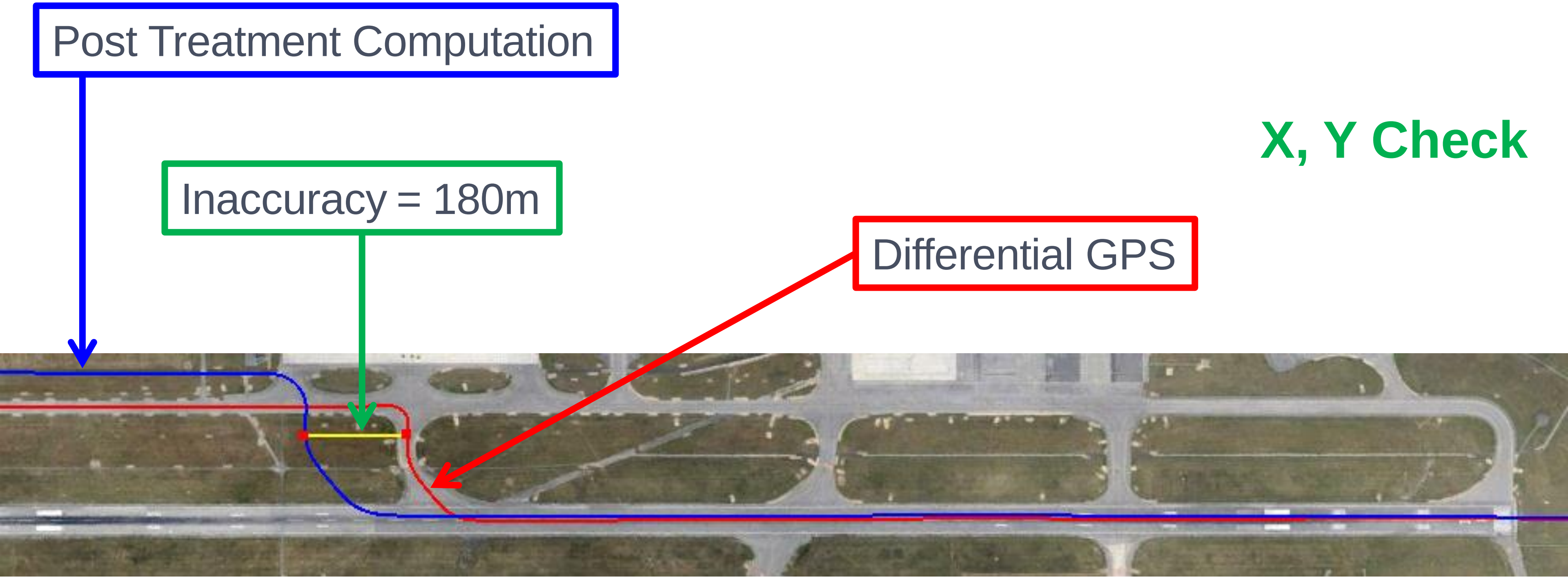
Post Treatment computation

102 flights



Accuracy assessment: cross check using Flight Test data

- Flight Test Data (A380 MSN1):
  - DGPS position (30cm accuracy) => set as the reference
  - Post Treatment computation compared to the reference



Accuracy assessment: cross check using Flight Test data

- Flight Test Data (A380 MSN1):
  - DGPS position (30cm accuracy) => set as the reference
  - Post Treatment computation compared to the reference

Time Check

Post Treatment Computation

Differential GPS

Inaccuracy @ Touch Down
60m

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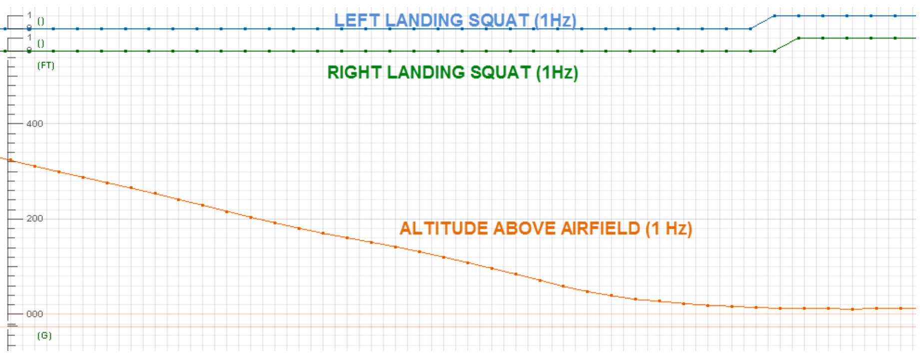
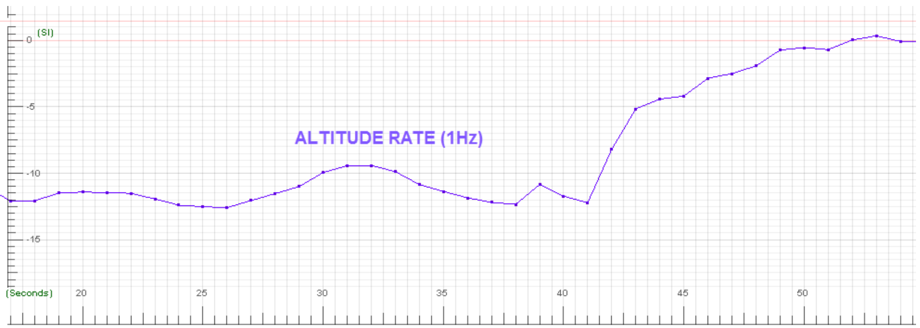
Touchdown detection - VZ post computation





Objective:

Compute an accurate vertical speed with sufficient sampling rate for analyzing aircraft's impact on ground.

Problem:

On most common flight data recorders, simple derivation of altitude (or radio-altitude) is not satisfactory because of its sampling rate (1 Hz).

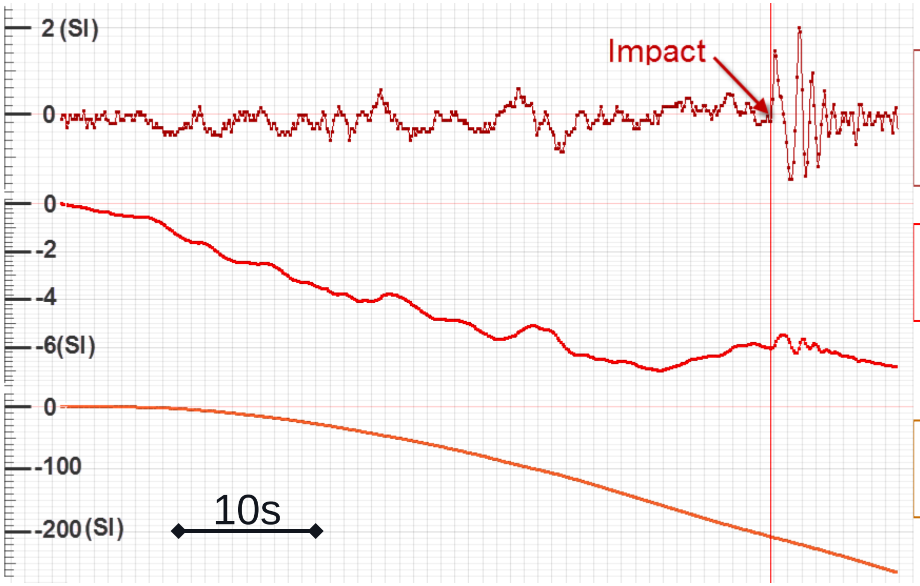
Solution:

Use the accelerometers with a sufficient sampling rate (8 Hz) and combine the results with the recorded altitude above airfield (1Hz) to compute the vertical speed.

Touchdown detection - VZ post computation

1st step:

Computation of elevation above runway = double integration of computed vertical acceleration $ACCZ_C$



$ACCZ_C$= function(aircraft's attitude and accelerometers)
Vertical acceleration calculated in runway coordinates

VZ_C = Integration of $ACCZ_C$
Computed Vertical speed

1st integration

Z_C = integration of VZ_C
Computed elevation above runway

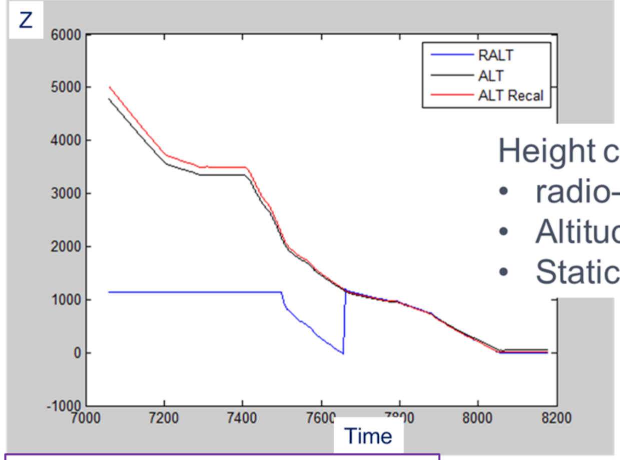
2nd integration

3 unknown constants:

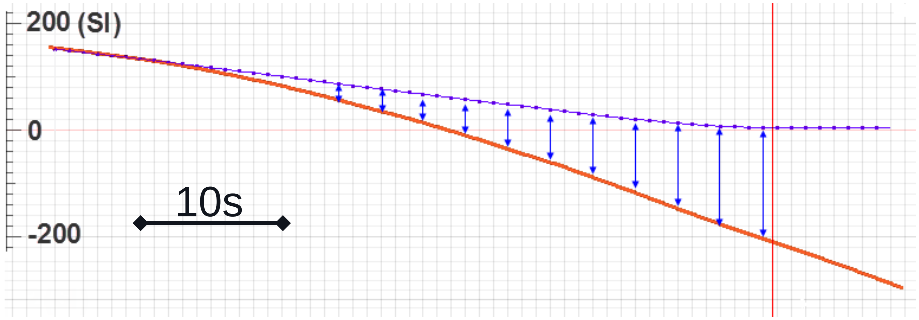
- Accelerometer bias (**C**)
- **VZ_i** = initial vertical speed
- **Z_i** = initial elevation above runway

Touchdown detection - VZ post computation

2nd step:
Get the unknown constants (C, Vz_i, Z_i).



Height computed out of:
- radio-height
- Altitude
- Static air temperature



Z_R = Height above runway

Z_C = integration of VZ_C
Computed elevation above runway

$Z_R - Z_C$

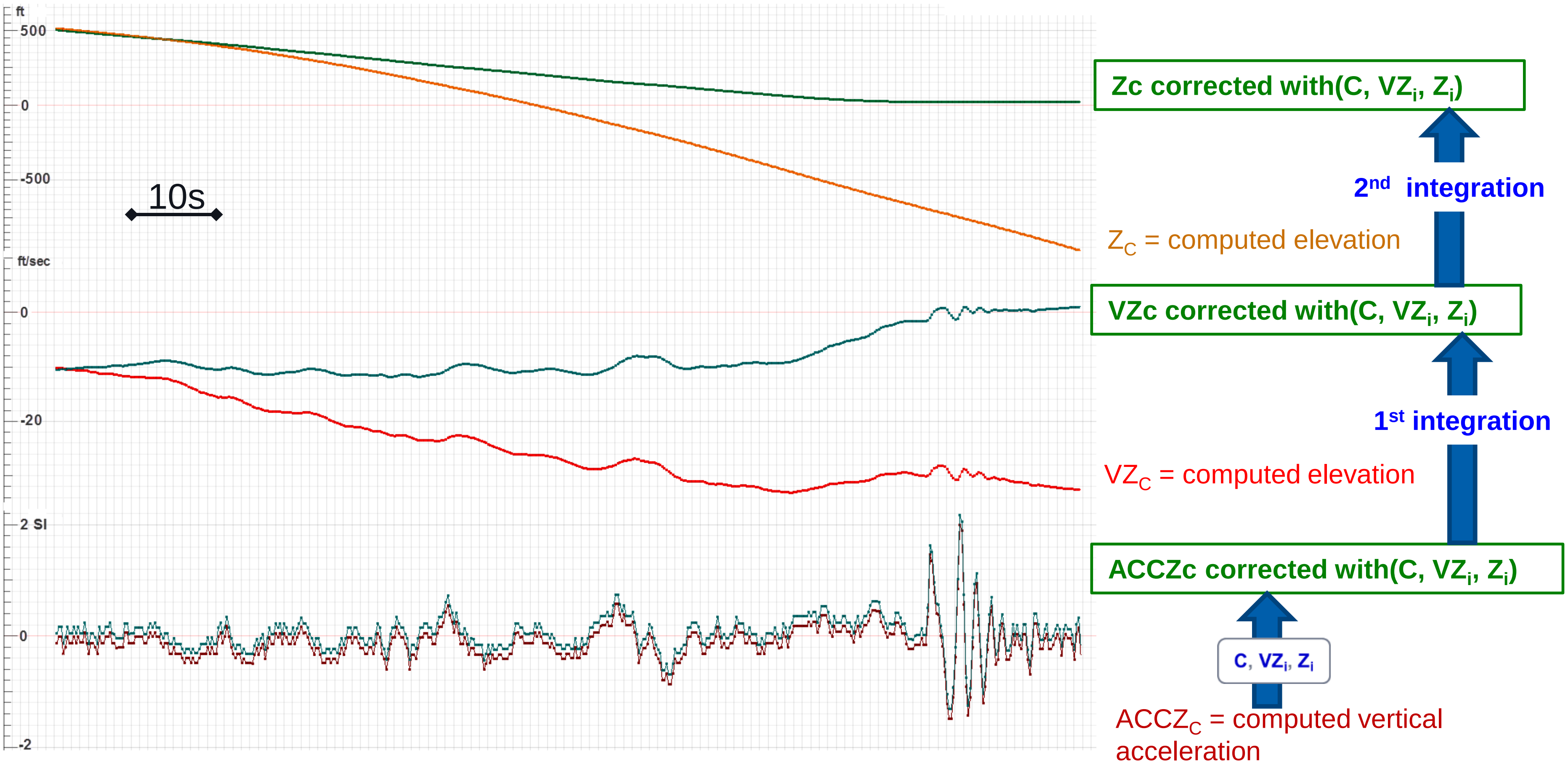
Least Square Method

C, VZ_i, Z_i

Touchdown detection - VZ post computation

3rd step:

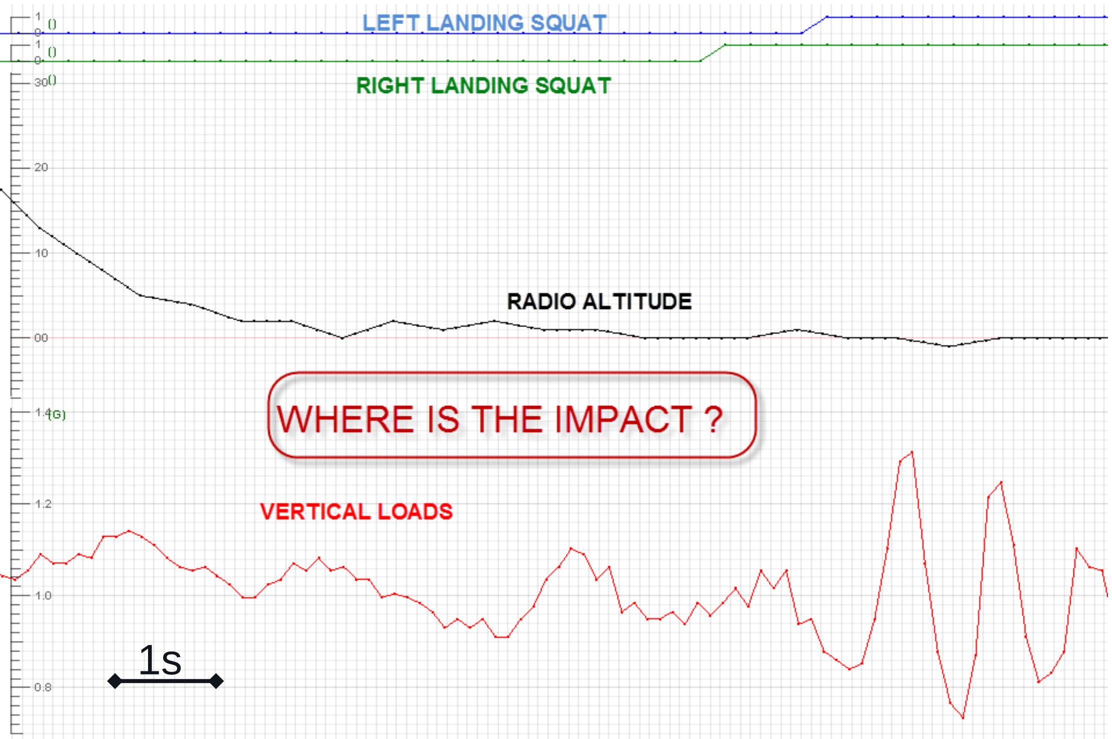
Re-compute Vz thanks to the constants



Touchdown detection

How to define the impact?

- **Wheel spin up**
- **Gears compressed**
- **Increase of vertical load factor**



Objective:

Compute an accurate time of touchdown for characterization of impact on ground.

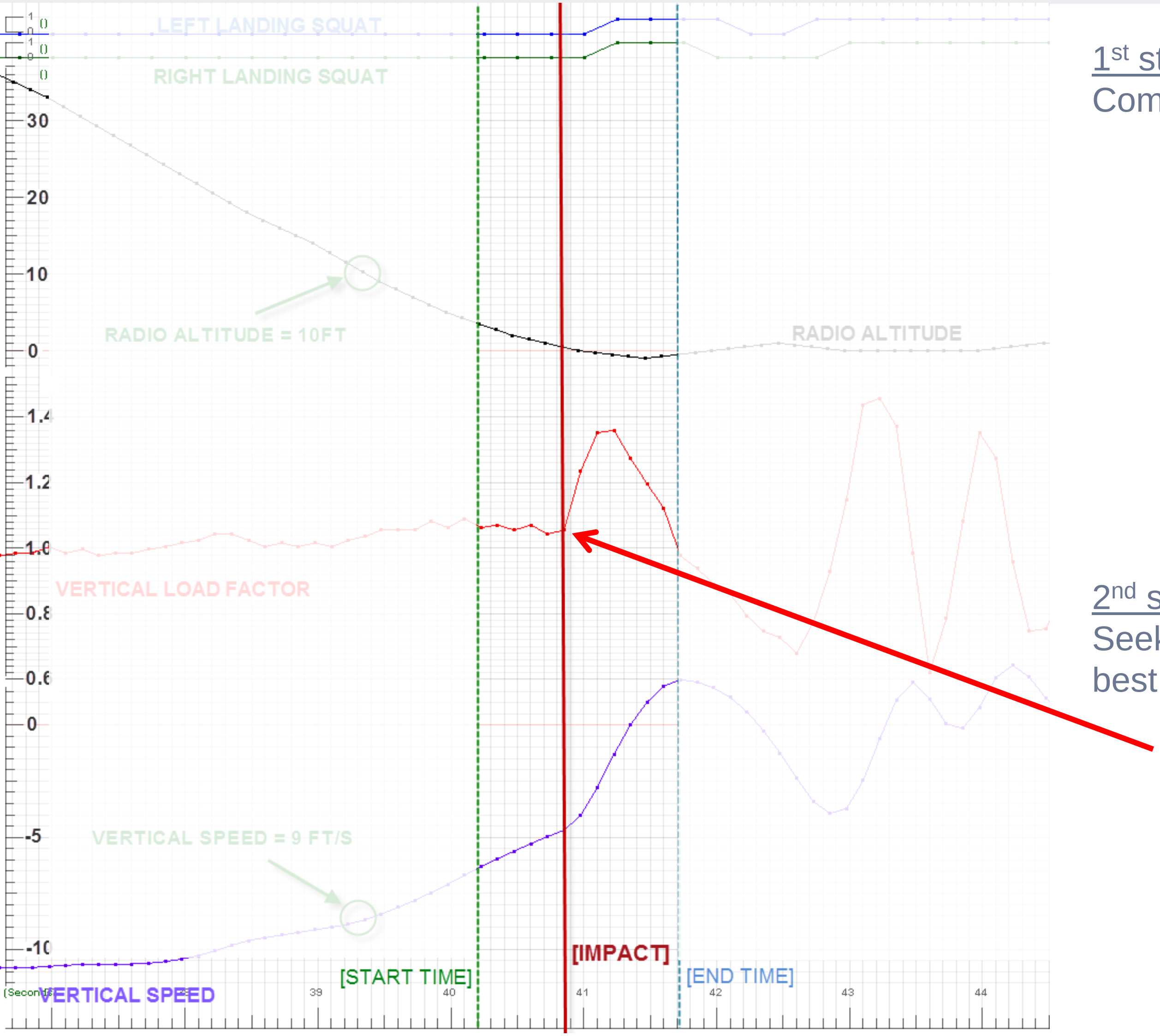
Problem:

On most common flight data recorders, landing squats are recorded at 1 Hz, which is not satisfactory .

Solution:

Use Vertical Load Factor and previously calculated Vertical speed to compute accurate time of impact.

Touchdown detection



1st step:
Computation Time windows:

- [Start time] = rough calculation of impact based on radio altitude and vertical speed at 10 FT above ground.

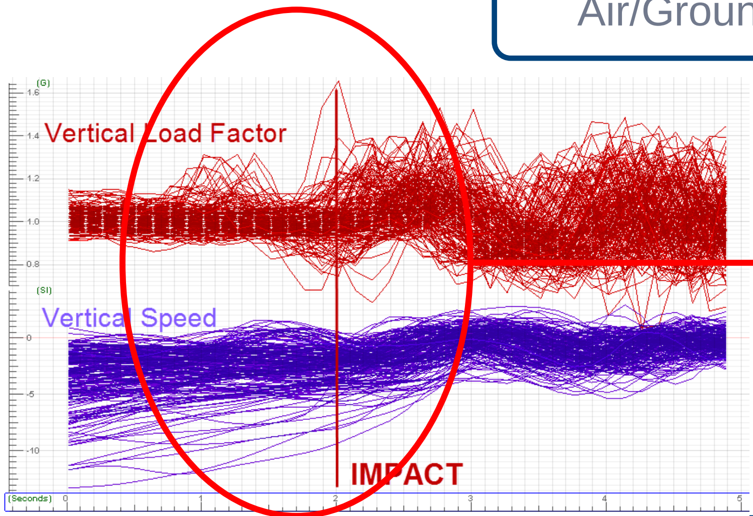
- [End time] = maximum of Vertical speed after [Start time], provided that vertical speed is above a certain threshold.

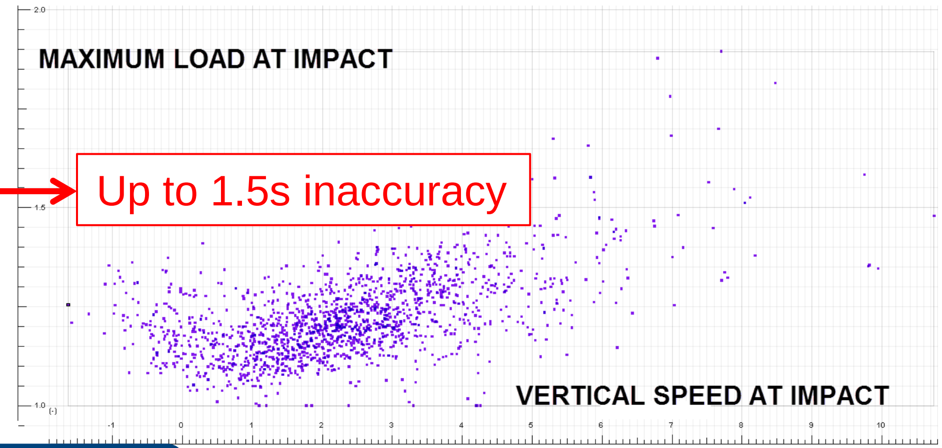
2nd step:
Seek in the time windows the point which best fits to the impact:

- Maximum positive rate of VRTG, provided that radio altitude is below a certain threshold.

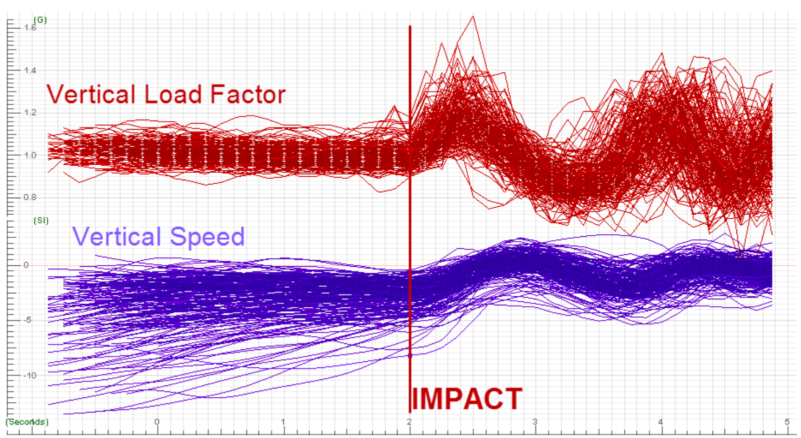
Touchdown detection - Method Comparison

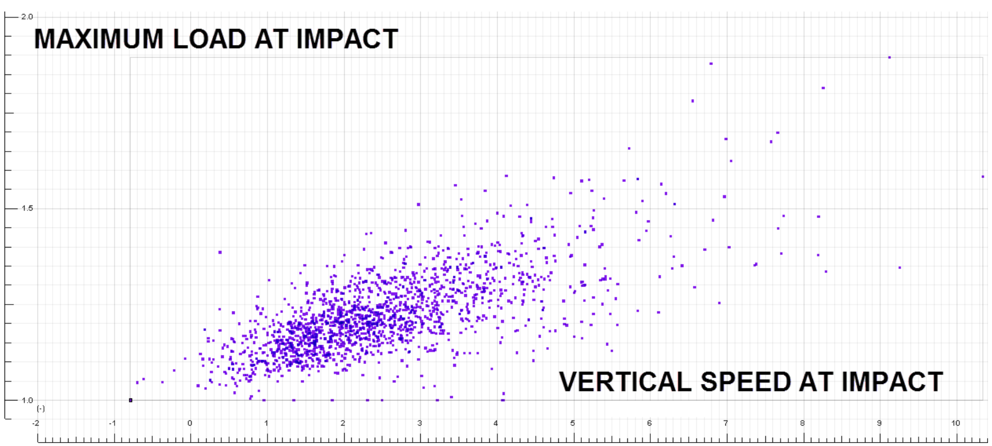
Air/Ground switch method





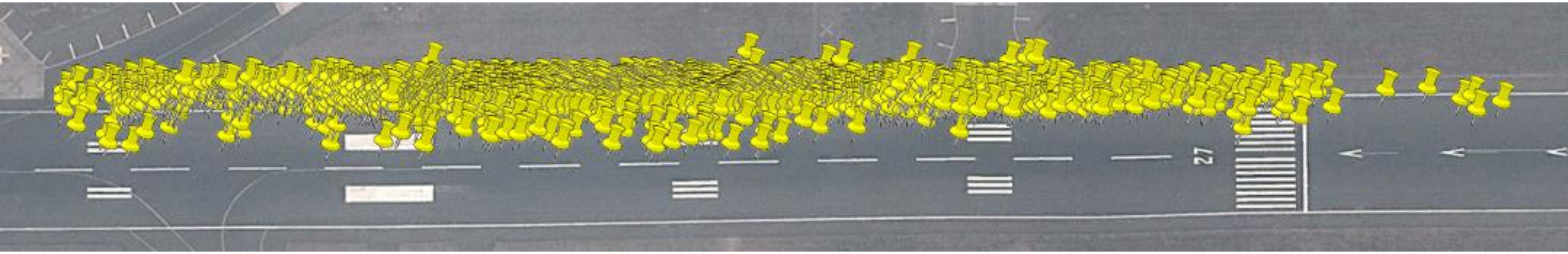
VRTG- VZ method



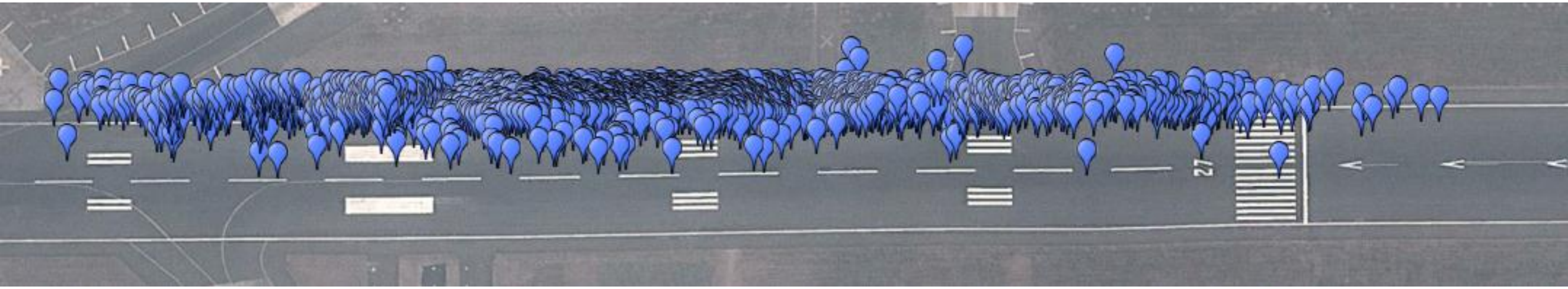


Touchdown detection – Impact position on ground

Touch down location with Air/Ground switch method



Touch down location with Vz method



MINIMUM	MAXIMUM	NB flights
50cm	285m	1662

Contents

Conclusion


Recorded Touch Down locations
Source: DMC


Recorded Touch Down locations
+ 300m inaccuracy
Source: DMC

Conclusion

- Trajectory inaccuracy has to be taken into account to draw any conclusion about:
  - Touch down location, long flare
  - Overrun risk

- Accurate touch-down location requires complex computation

- Trajectory computation afterwards is complex and not as accurate as available trajectory on board
  - Way forward: improve this computation, better assess the accuracy

- Alternatively, whenever possible record FMS trajectory, 21 bits, 4Hz

AIRBUS

Lucky you: record the FMS Trajectory!