Determination and Visualization of Uncertainties in 4D-Trajectory Prediction

Paul Weitz, German Aerospace Center (DLR)

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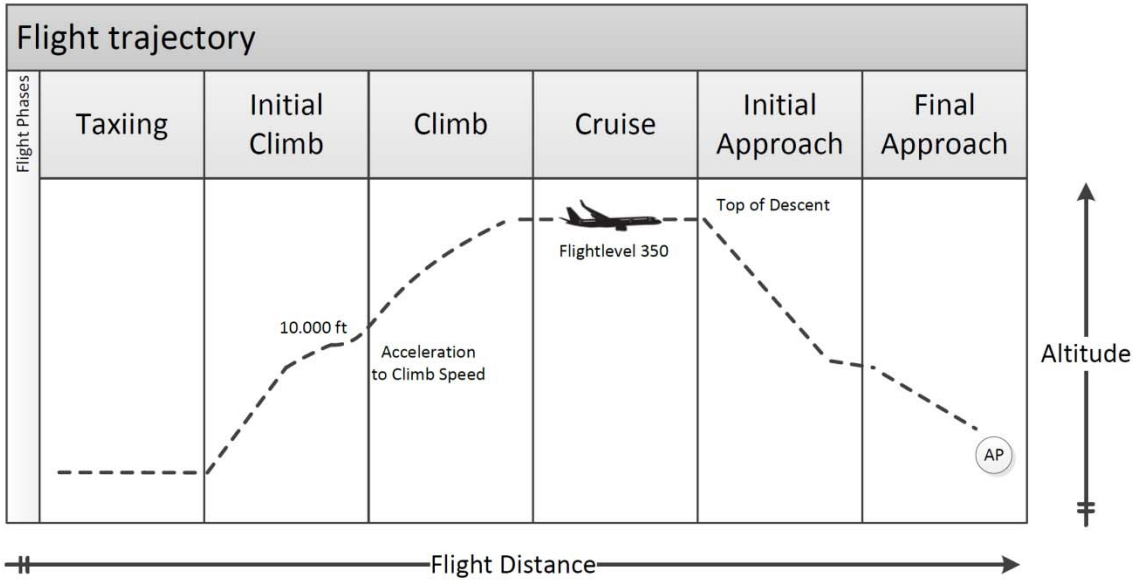
Agenda

- Motivation and Problem
- Fundamentals
- Concept
  Simulation, Metrics, Data Model
- Results
- Conclusion and Future Research

Motivation I

- Increasing utilization of airspace capacity
- Predominantly at the TCA
- High separation standards in tactical ATM
- High controller workload in sectors • congestion
  - 5 % of European Flights are delayed at take off
- Approach to solution: 4D-Trajectories



[based on Craig Wanke et. al: Modeling Traffic Prediction Uncertainty for Traffic Management Decision Support]

Motivation II

- 4D-Trajectories have great potential to increase:
  - Efficiency
  - Environmental friendliness
  - Punctuality
- Optimize Route for:
  - Avoiding conflicts
  - Reduction of noise and pollutant
  - Implementation of innovative flight operations

- Supporting tools for ATM actors
- Visual analyze of airspace
- Early conflict detection and resolution

Statement of the problem

- Calculation of trajectory is based on various parameters
  - Meteorological conditions
  - Aircraft performance
- The actual value of a parameter can deviate from the forecast

- Deviation of actual from predicted trajectory
  - uncertain prediction

- Aim: Determine uncertainty before take off

  - Which accuracy of the prediction can be maintained?
  - Which area around the aircraft is influenced?

Approach: Development of a tool
to determine, analyze and visualize the uncertainty

Objectives

- Analysis of the contributing parameters
- Development of a metric for evaluation of trajectory uncertainties

- Preparation of fast-time simulation scenario
- Simulation of parameter variation

- Measurement of the impact on trajectory

- Implement the concept as a tool in our common reporting suite EWMS “Extensible Workflow Management for Simulations”

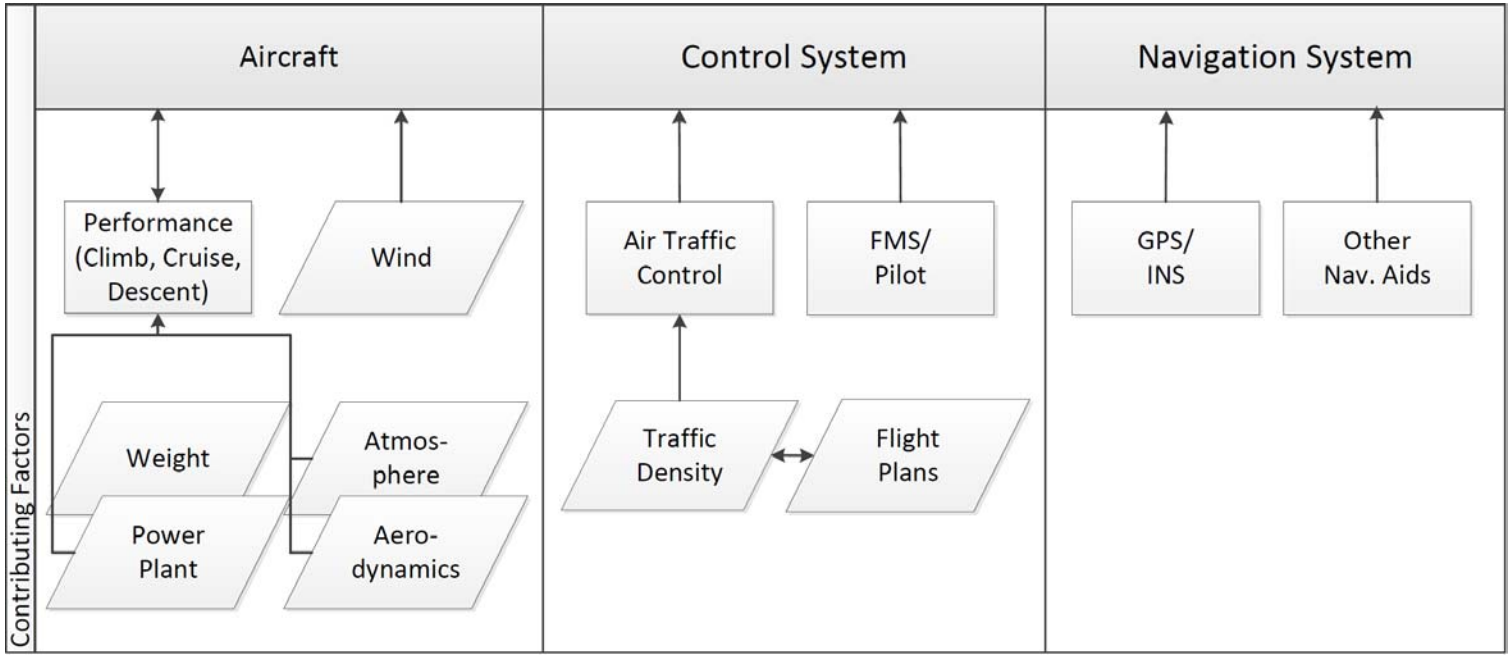
- Development of a display to visualize the uncertainties in a quantitative and qualitative way

Uncertainties in Trajectory Prediction

Definition:

- Uncertainty describes the possible deviation of the actual from the predicted flight path

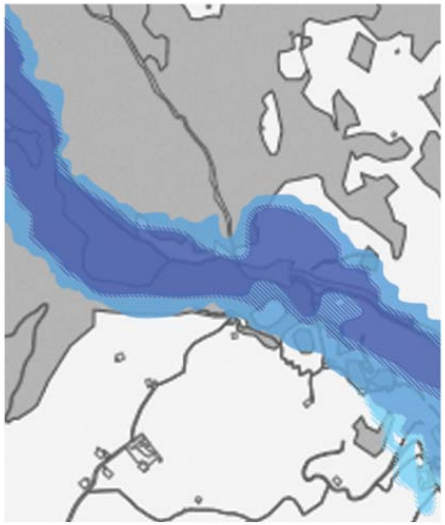
Factors contributing to trajectory uncertainties:

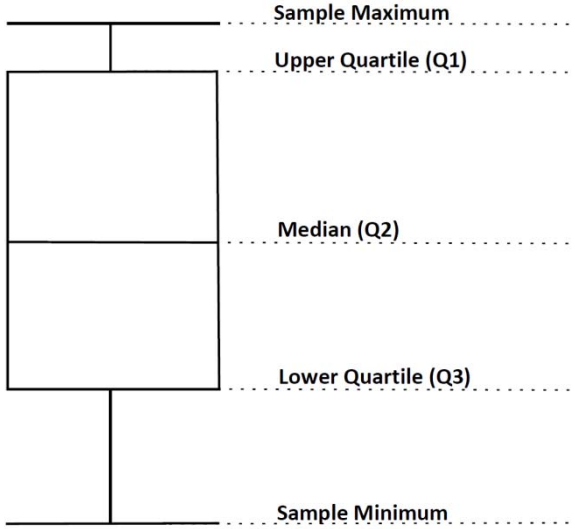


[based on Jinwhan Kim et. Al: Trajectory Uncertainty Modeling for Queueing Analysis of the National Airspace System. NASA]

Visualization of Uncertainties

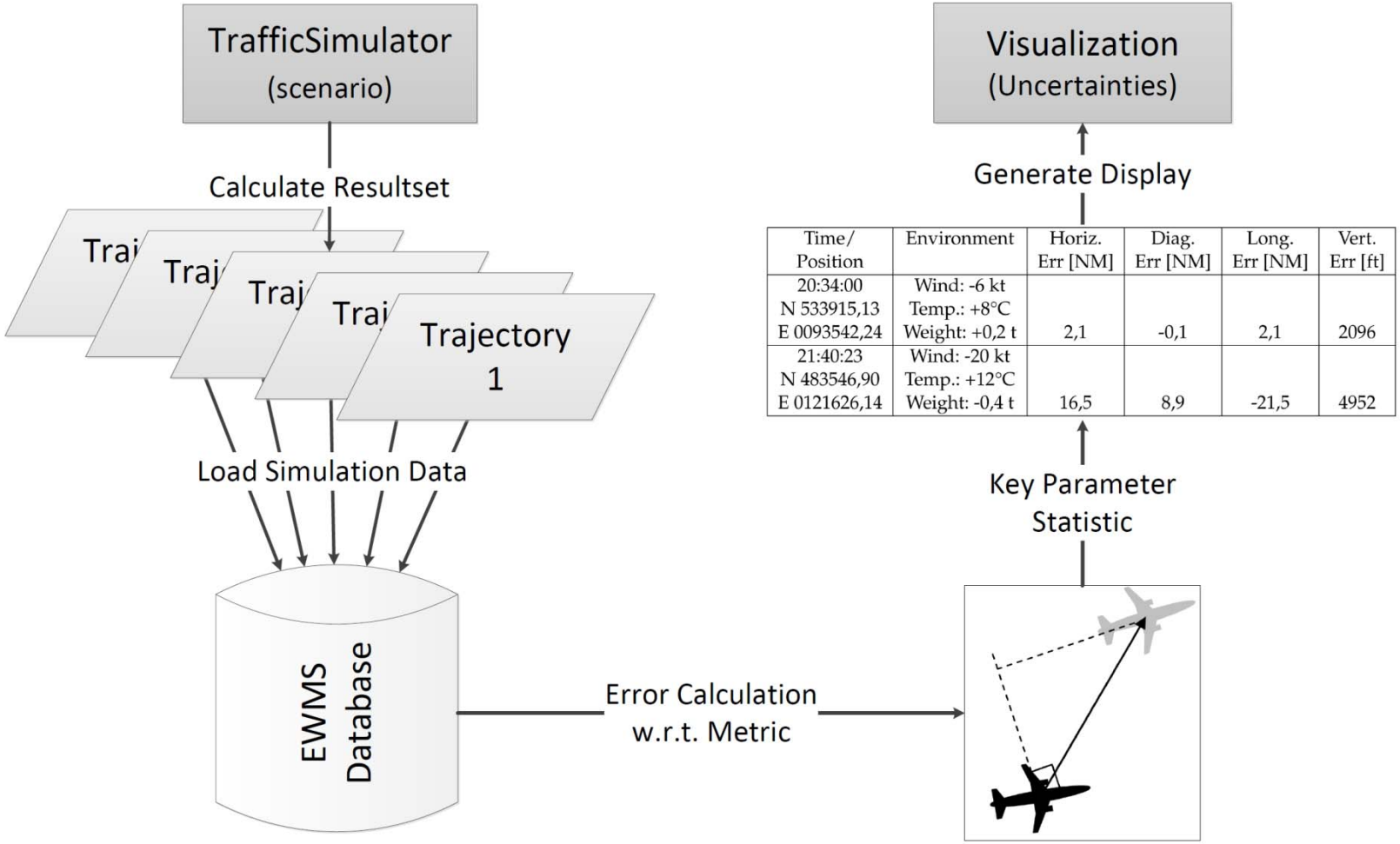
- Issue:
  - Combination of certain and uncertain data
  - Complexity of data structure
- Classification of data and separate evaluation
- Different surface structure, color and shade
- Types of visualization





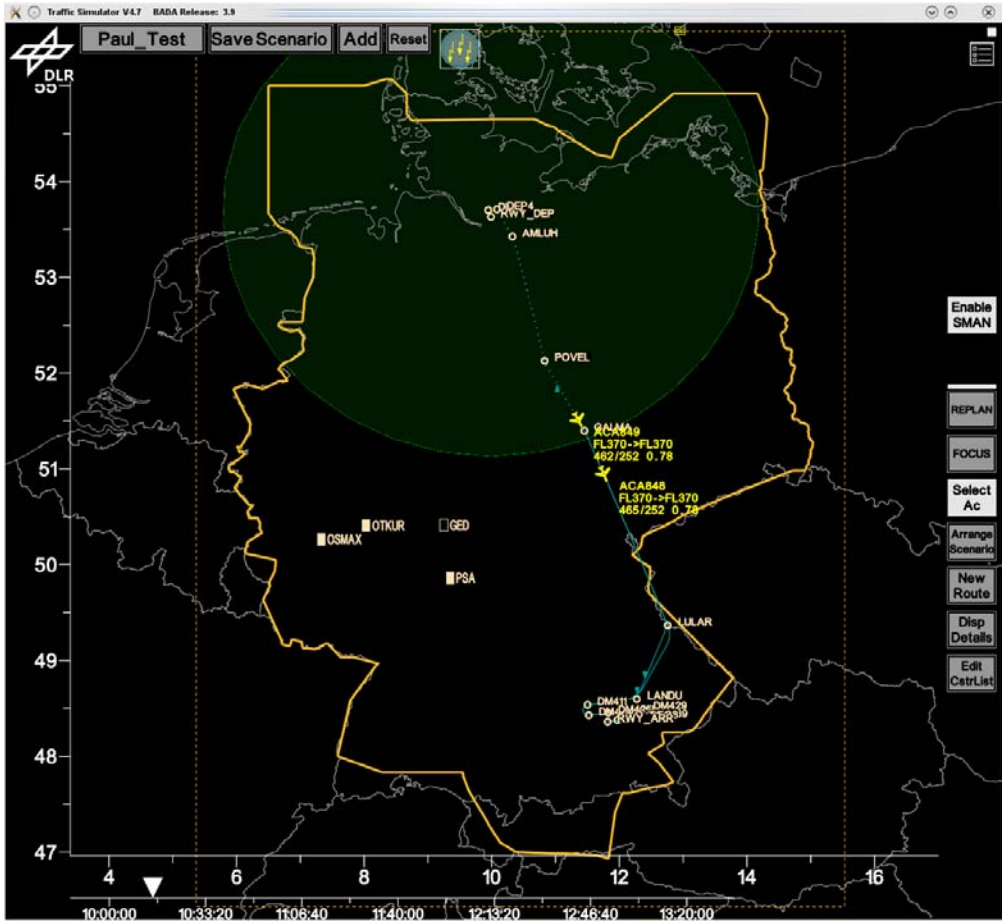
[according to Melanie Kunz et. al: Uncertainty Visualization in Hazard Maps for Consistent Decision Making]

Concept - Workflow



Time/ Position	Environment	Horiz. Err [NM]	Diag. Err [NM]	Long. Err [NM]	Vert. Err [ft]
20:34:00 N 533915,13 E 0093542,24	Wind: -6 kt Temp.: +8°C Weight: +0,2 t	2,1	-0,1	2,1	2096
21:40:23 N 483546,90 E 0121626,14	Wind: -20 kt Temp.: +12°C Weight: -0,4 t	16,5	8,9	-21,5	4952

Concept: Simulation [*TrafficSim*]



Required Information:

- Flight Plan
- Way Points
  - *Constraints*
- Aircraft Performance Data
  - *BADA, Perf_Parms*
- Meteorological Conditions

Simulation:

- Variation of parameter makes in sum 2,028 different trajectories for the same route
- Distance: ~ 450 NM
- Fuel Flow: ~ 3,200 kg

Simulation II

Wind Direction in Degree [°]							
0	+ 45	+ 90	+ 135	+ 180	+ 225	+ 270	+ 315

Wind Speed at Ground [*kn*]				
0	+ 10	+ 20	+ 30	+ 50

Temperature at Ground				
- 5°C (23°F)	+ 5°C (41°F)	+ 15°C (59°F)	+ 25°C (77°F)	+ 35°C (95°F)

Cruise Speed [*Ma*]		
0.72	0.78	0.82

Weight of Aircraft [*kg*]					
97% 65 857	90% 61 312	80% 54 500	70% 47 687	60% 40 875	50% 34 062

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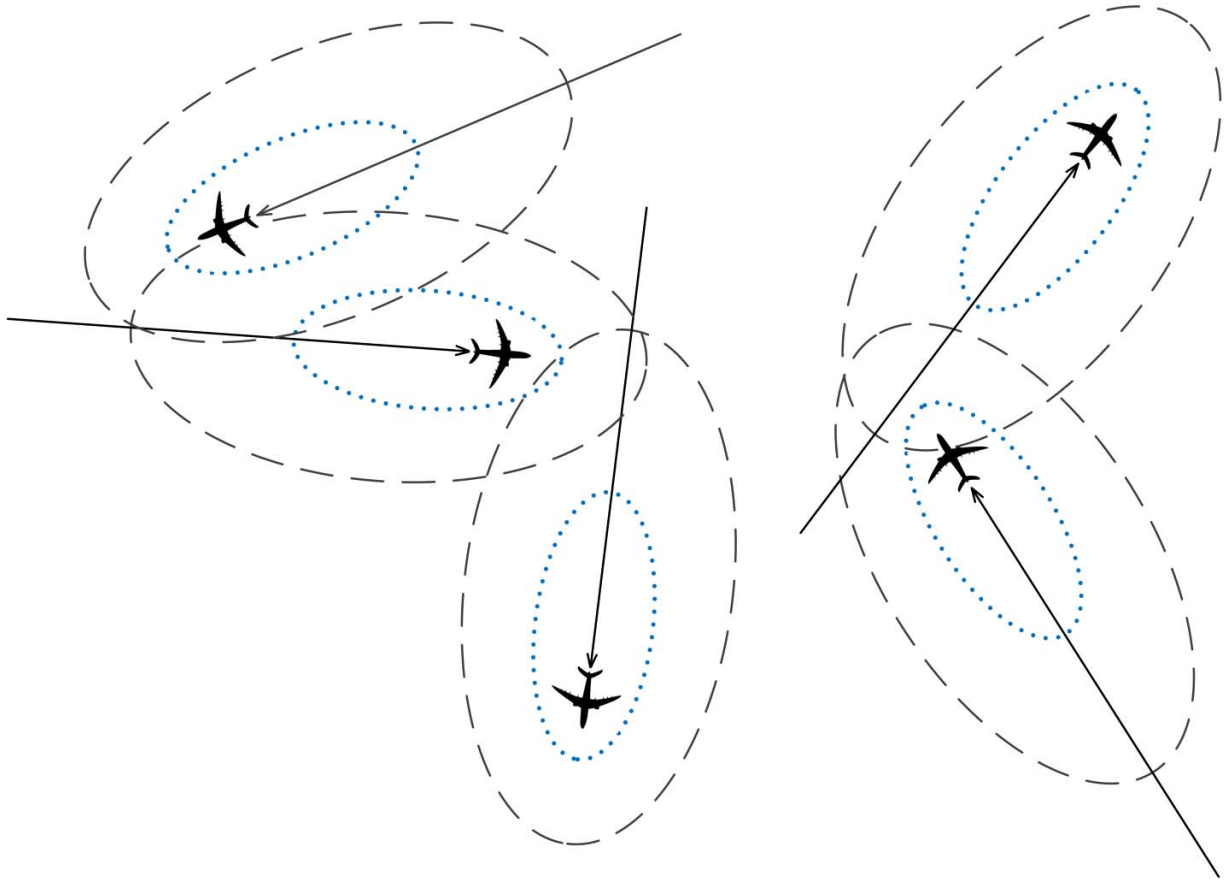
Metrics

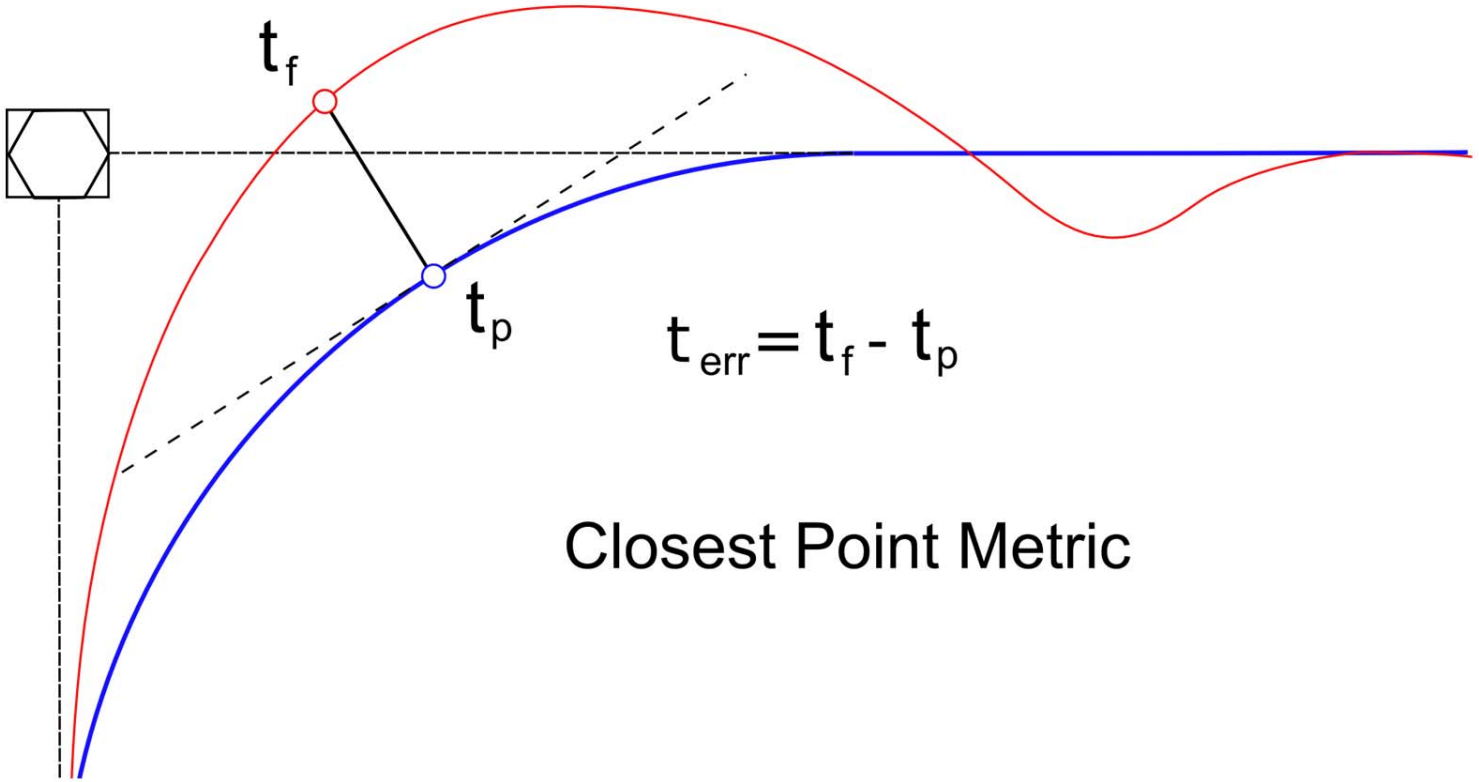
How to describe Uncertainties?

- At any time of flight an ellipsoid defines possible location



Closest Point Metric for Temporal Deviation

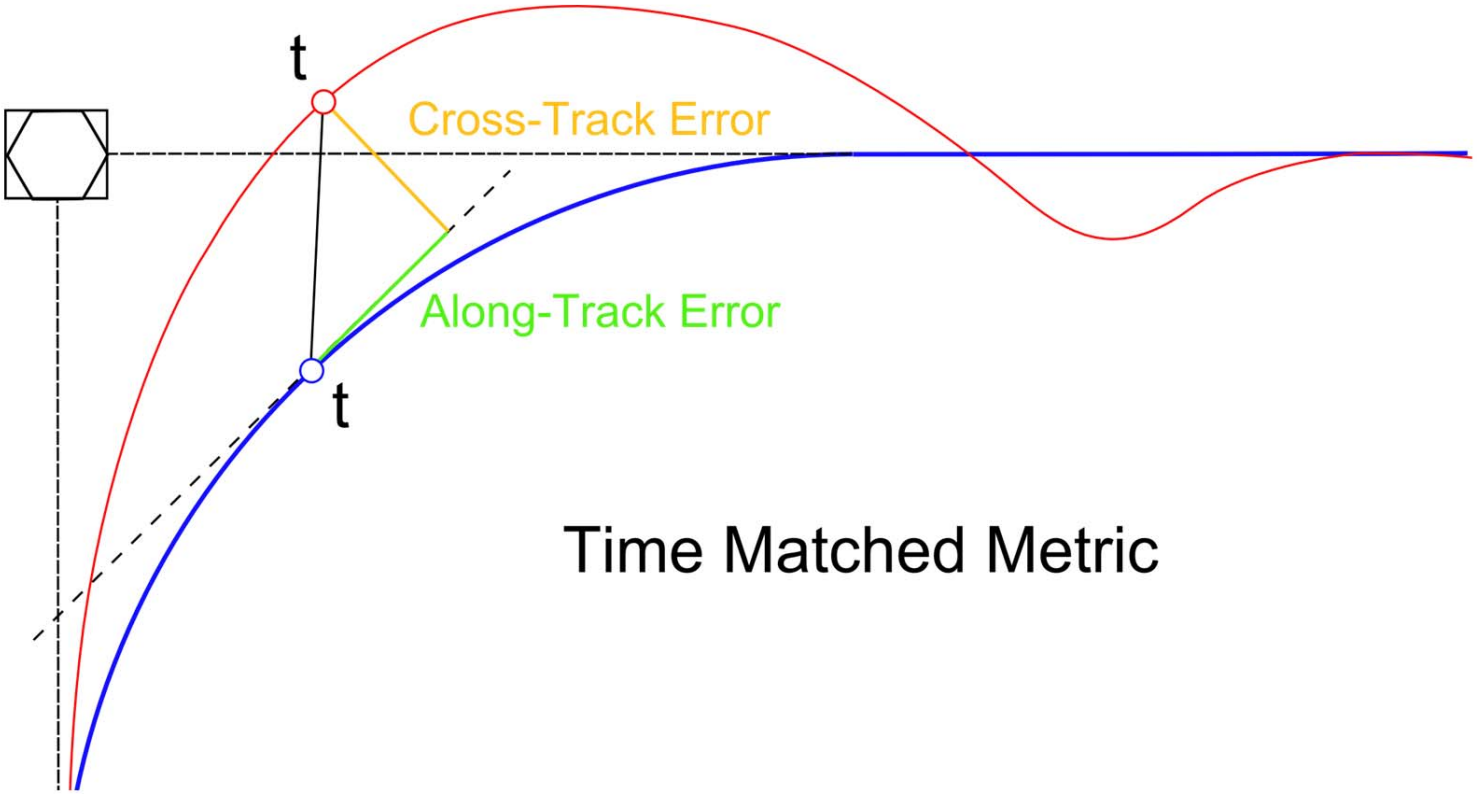
- Determination of the closest positions (predicted and actual trajectory)
- Difference between times $\widehat{=}$ temporal error



[based on ERASMUS – Air Trajectory Prediction]

Time Matched Metric for Spatial Deviation

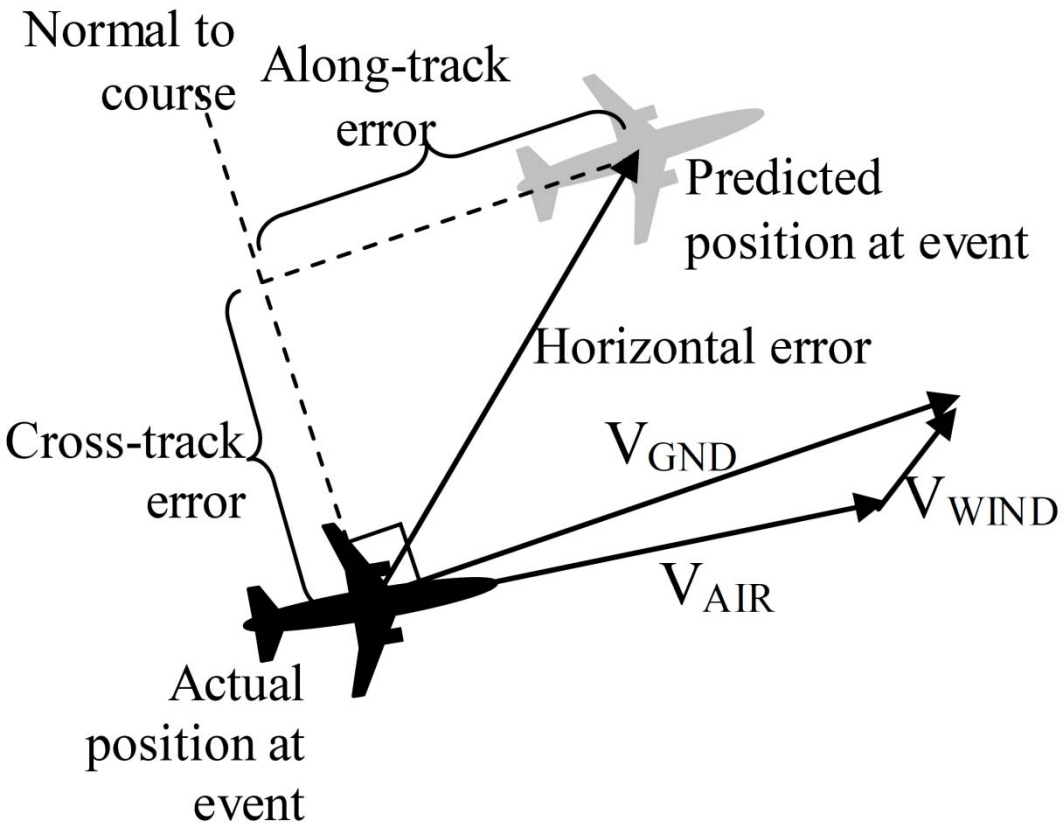
- Determination of the positions at the same point in time
- Distinguish different dimensions and bearing



[based on ERASMUS – Air Trajectory Prediction]

Spatial Deviation

Horizontal Error

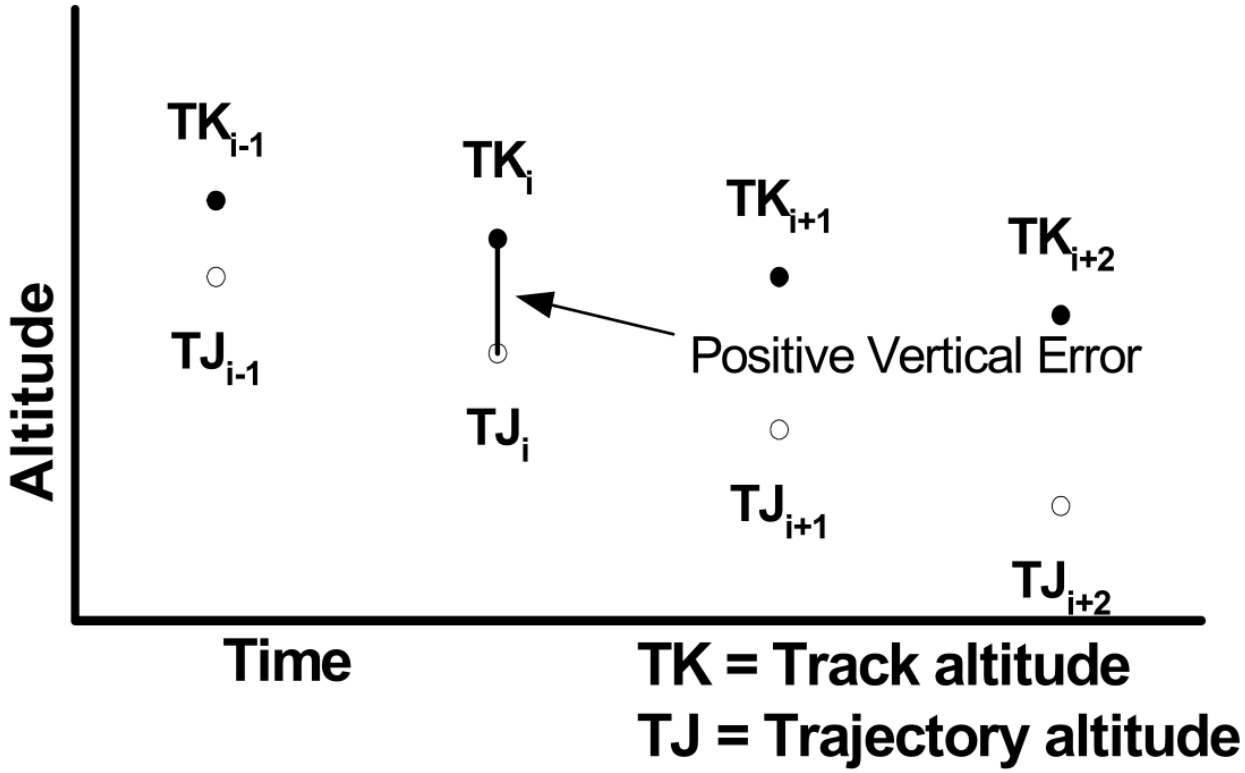


[nach Stephane Mondoloni et.al: Assessing trajectory prediction performance - metrics definition]

Spatial Deviation

Vertical Error

- $Vertical\ Error = actual\ altitude\ - predicted\ altitude$



[based on Mike Paglione et. al: Implementation and Metrics for a Trajectory Prediction Validation Methodology]

Implementation

Integration of the Concept in *EWMS*

Concept of “Extensible Workflow Management for Simulations” (*EWMS*):

- Common software suite for reporting
- Data processing is independent from the simulator type
- Streamline and simplify simulation data management

- Reporting-Tool to evaluate air traffic simulations extensively, fast and standardized

Implementation - JFreeChart

- Java library to generate diagrams
- Supports functions for export image files, tool tips, zooming
- Cluster results in dependent and independent variables

Independent Variables		**Dependent Variables**		
Callsign	Time	Position [lat,lon,alt]	Minimal Error [NM]	Maximal Error [NM]
LH1423	11:08:59	48.3668269 N 11.8954822 E 1190.34 ft	- 1.5 NM	0.3 NM
LH1423	11:09:18	48.3652935 N 11.8779739 E 961.85 ft	- 1.2 NM	0.2 NM

Implementation – NASA World Wind

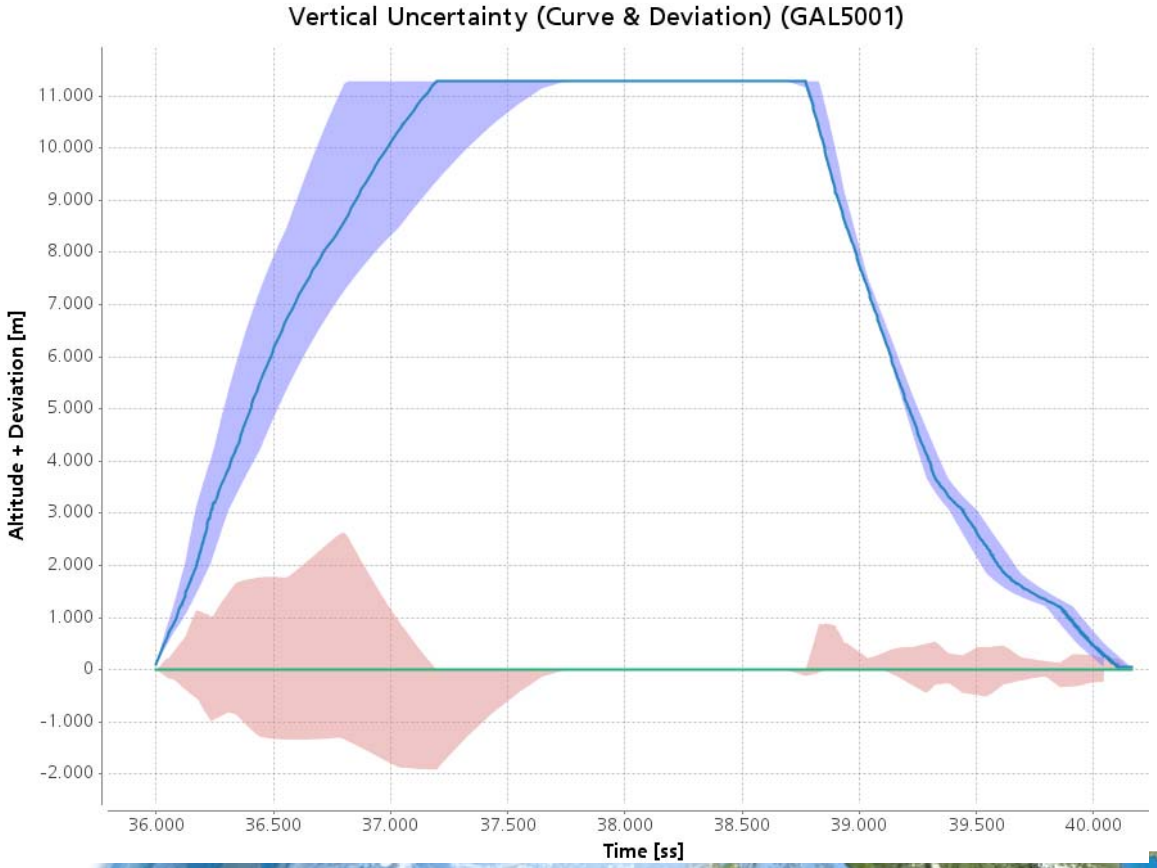
- Three dimensional images in a geo spatial reference system
- Competitive product to Google Earth with focus on scientific investigations
- Maximal resolution is 15 m
- Plot 3D-shapes
  - Cylinders
  - Paths
  - Ellipsoids
- Functions for coordinate transformation
- Add shapes to an layer-model

[http://www.worldwind.arc.nasa.gov]

Results

Uncertainty caused by deviation of weight

- Reference Flight with 75% of MTOW
- Deviation of 20% in weight
- Other parameters remaining constant and no regulation



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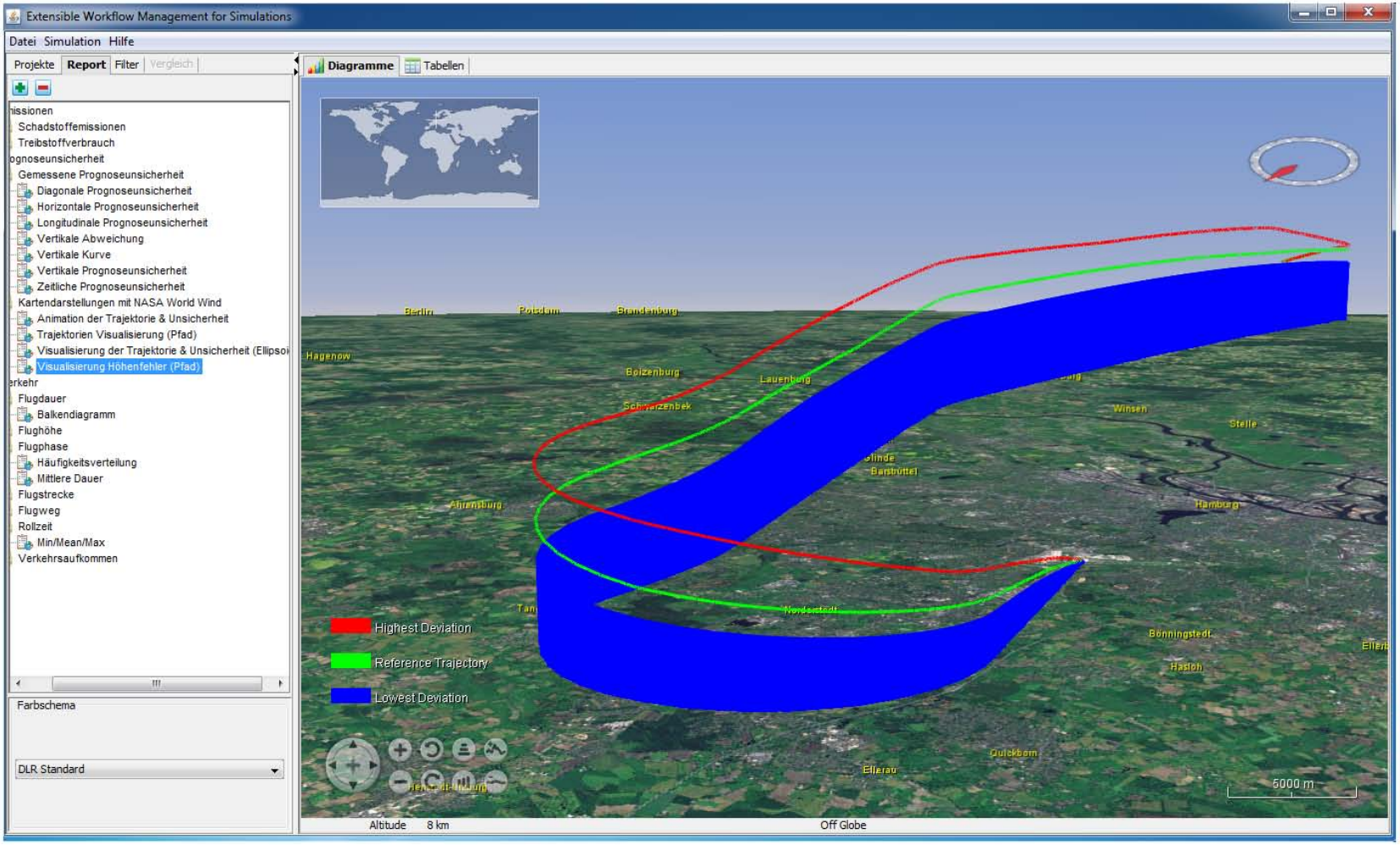
Results

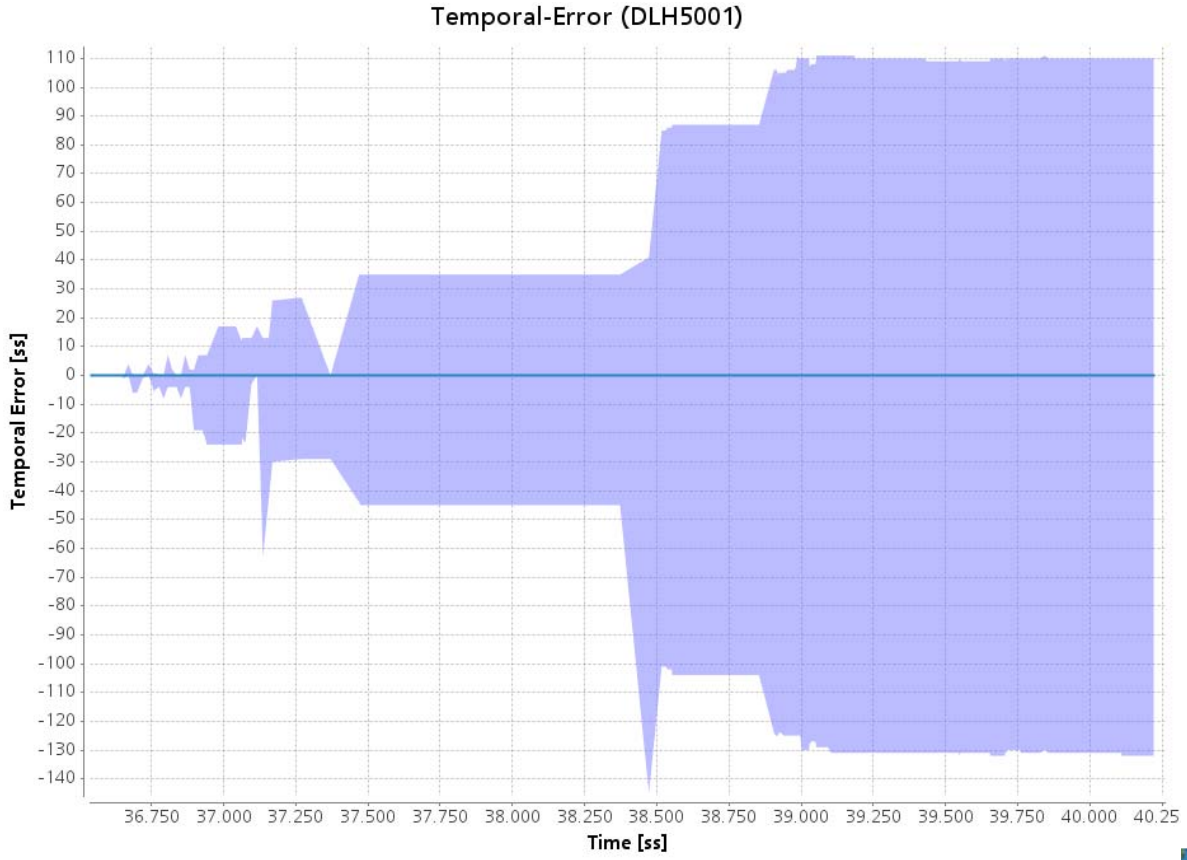
Uncertainty caused by deviation of weight



Results

Uncertainty caused by deviation of speed

- Reference Flight with Ma_{ref} = 0.78 in cruise
- Deviation of $Ma_{dev} = Ma_{ref}$ 0.02
- Other parameters remaining constant and no regulation



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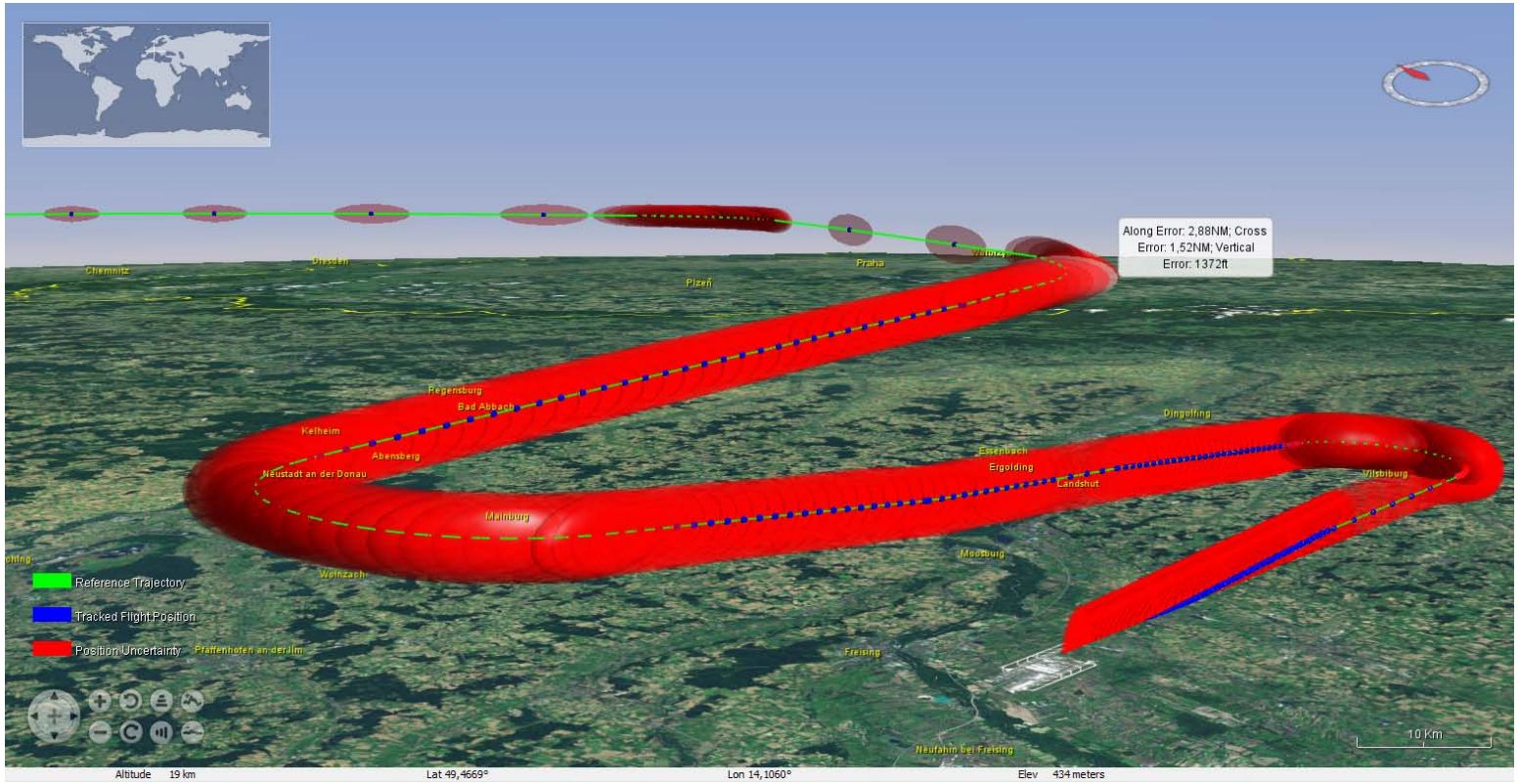
Results

Uncertainty caused by deviation of wind

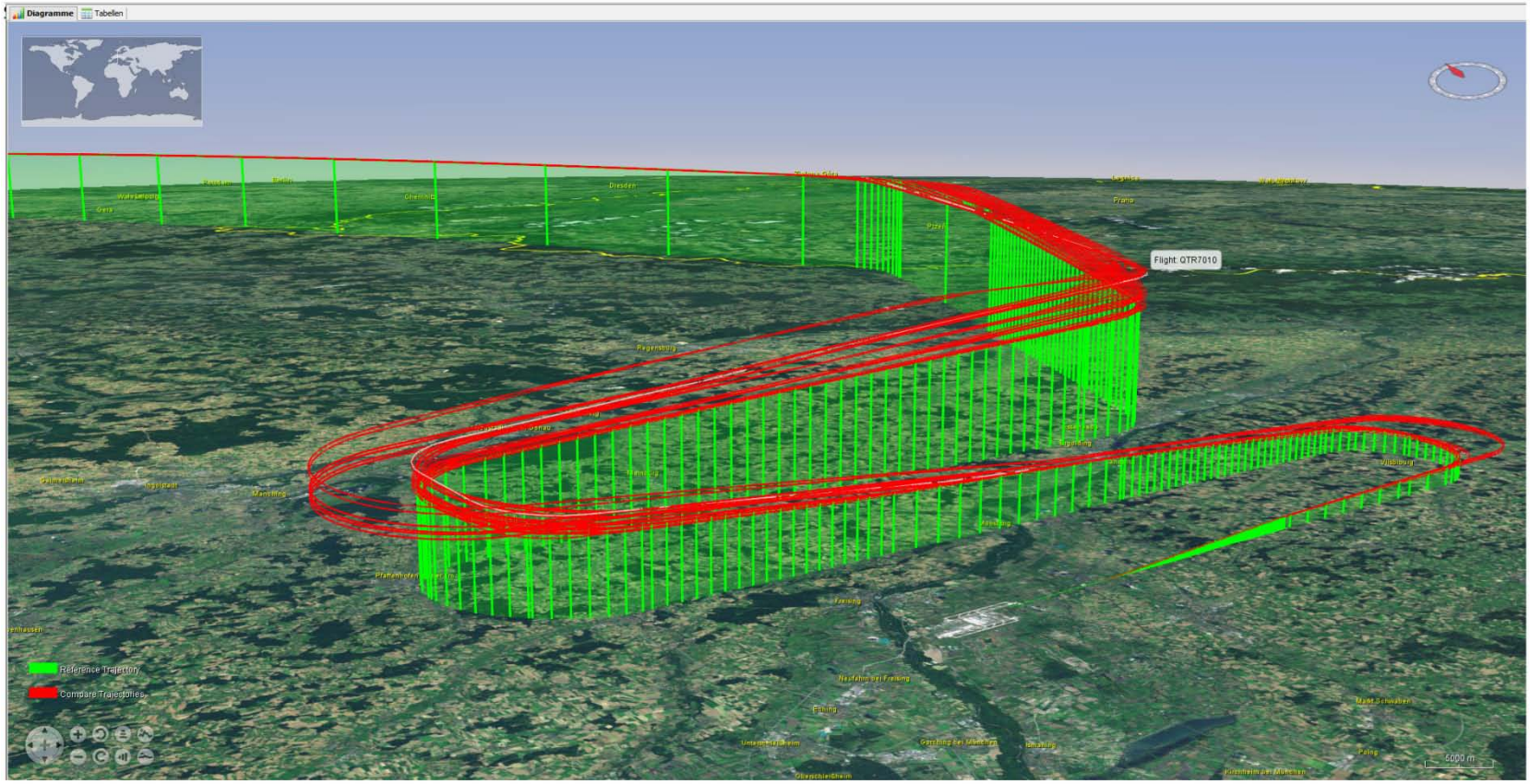
- Reference Flight with wind direction 90
- Deviation of wind speed by 10 kt
- Other parameters remaining constant and no regulation



Results

Simulated Navigation Error

- Different turn radius through RNP deviation



Summary

- Load *TrafficSim*-Data to Database
- Calculating Uncertainties based on a set of trajectories

- *JFreeChart*-Diagrams:
  - horizontal, along-track and cross-track error
  - vertical error
  - temporal error

- 3D-NASA World Wind Visualization:
  - Path of trajectories
  - Vertical uncertainty
  - Uncertainty described by ellipsoids
  - animation

Conclusion

- System to determine and analyze uncertainties in 4D-Trajectory prediction
- Predicted trajectory is visualized with expected deviations

- Report works with *TrafficSim* and further simulation systems

Future Research

- More tests by implementing simulation scenarios with higher traffic density
- Calculate conflict probability by using volume of intersecting ellipsoids

- The better the parameter forecast, the smaller the uncertainties

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Paul Weitz, German Aerospace Center (DLR)

Institute of Flight Guidance

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Internet www.DLR.de

E-mail paul.weitz@dlr.de

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