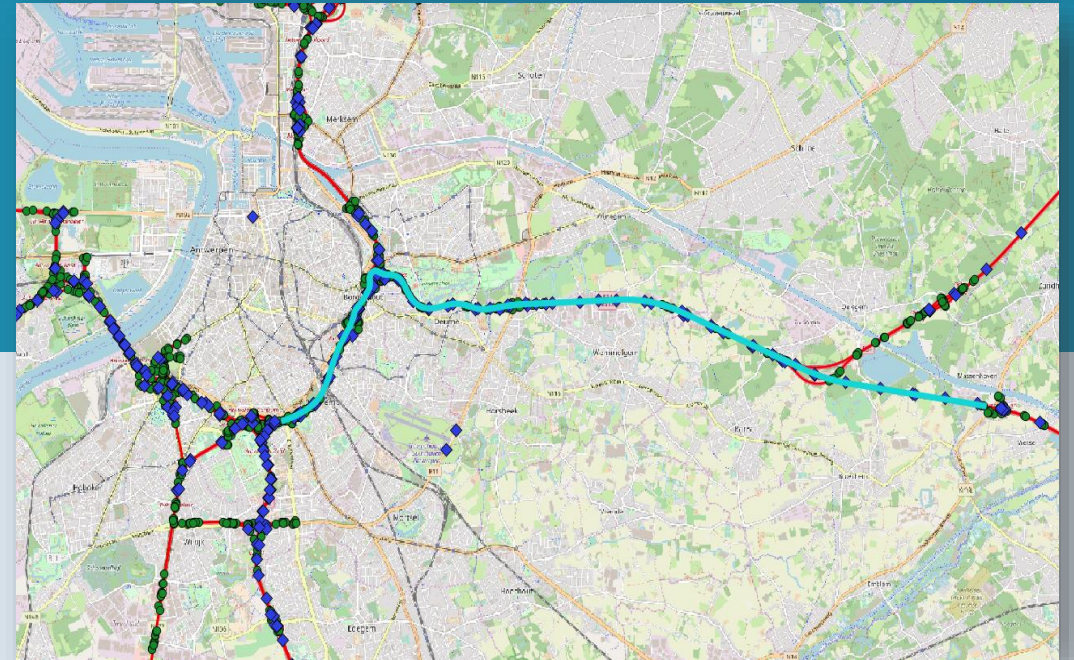
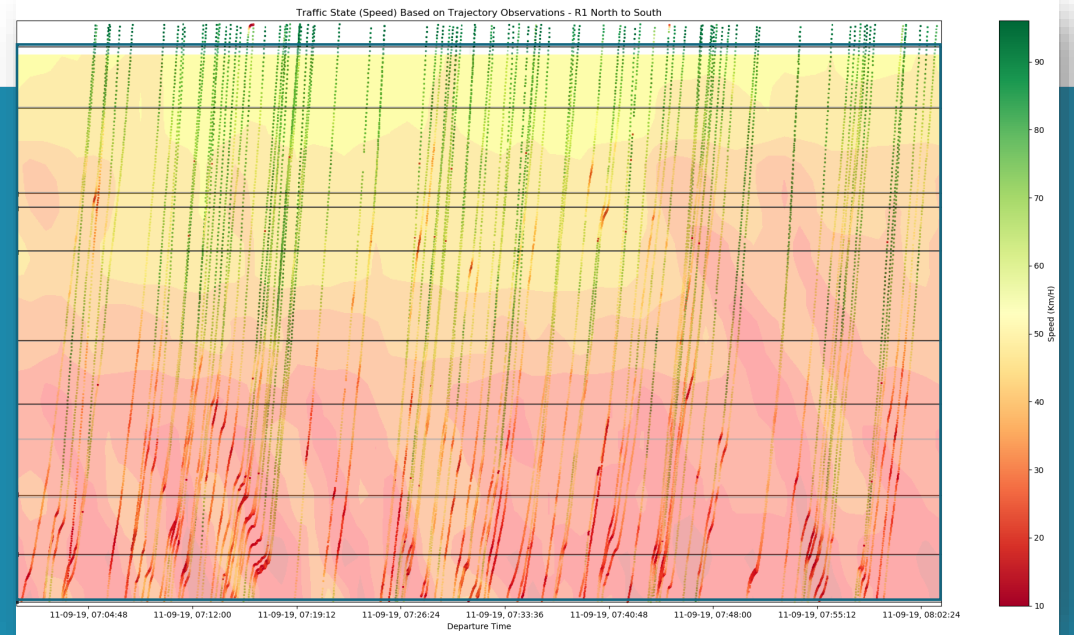


Traffic impact monitoring at the future Flemish AV test site

data fusion for detailed traffic state
reconstruction

Prof. Chris Tampère – KU Leuven CIB (B)
Willem Himpe, Sajid Raza, Ismail Abuamer, Ali Arman



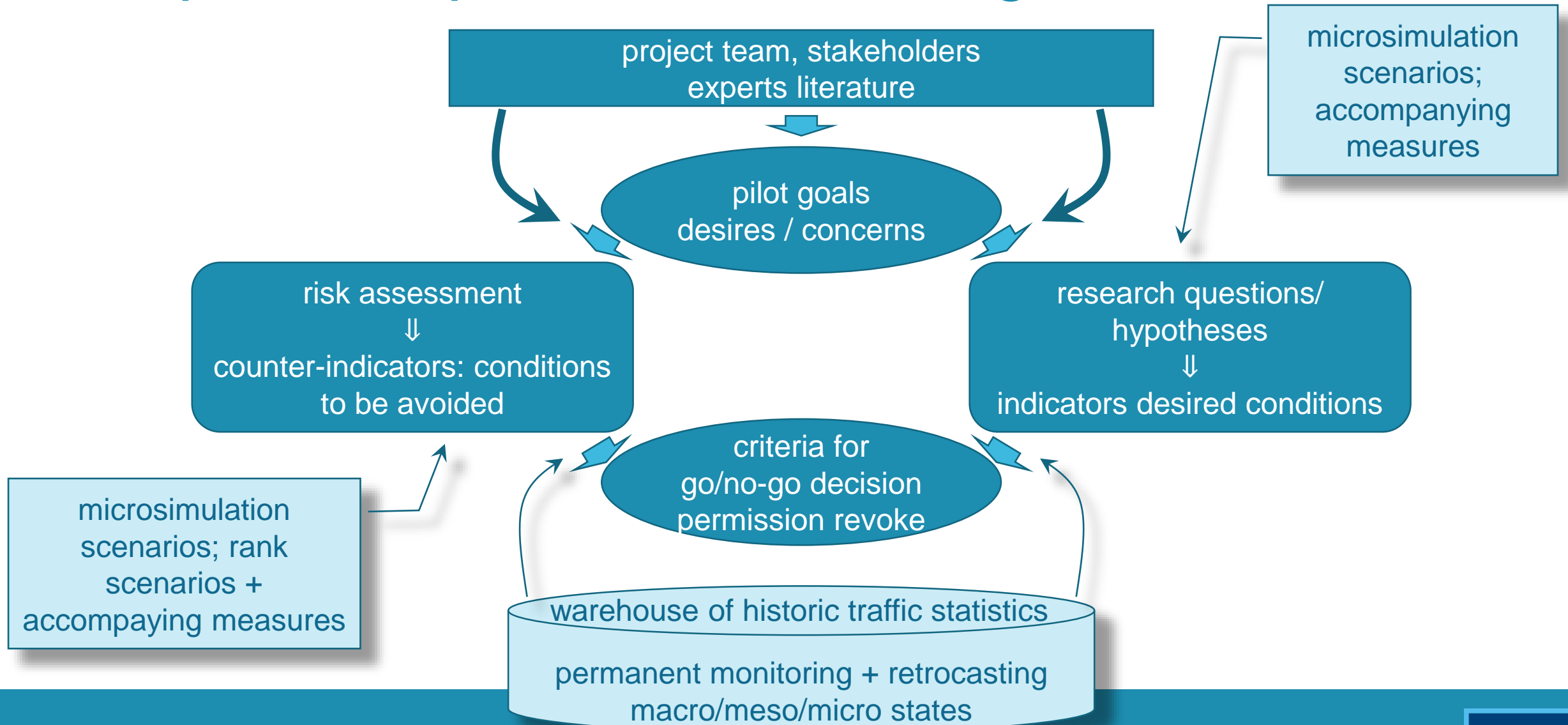
Positioning/motivation

- BE testsite is new + intended to be permanent for future trials
 - no trials (with traffic impact) foreseen during current project CONCORDA (EU-CEF)
 - objective = build technical + assessment support enabling such trials
- KUL's work focus:
 - data collection
 - capacity, data warehouse, software tools building
 - data analysis for decision support before/during/after trials

Example use case: workflow hypothetical trial (e.g. truck platooning – focus on traffic analysis needs)

- NB: technical needs and tests = other partners (IMEC, Flem.Gov.)
- Stages
 - A – pre-trial: pilot scenario design
 - B – during trial: pilot monitoring and scenario refinement
 - C – post-trial: trial assessment and extrapolation
- Main developments
 - data warehouse + historical traffic operations stats of testsite
 - detailed traffic operations monitoring
 - workflow data → microsimulation
 - microsimulation of scenarios + accompanying measures

A – pre-trial: pilot scenario design



B – during trial: pilot monitoring & scenario refinement

- pilot in different runs
 - during run
 - monitor realtime conditions for (counter-)indicators
 - data collection for ex-post analysis
 - between runs
 - data processing for feedback next run
 - scenario refinement
 - (counter-)indicator refinement

realtime monitoring and
prediction of traffic operations
phenomena

```
graph LR; A[realtime monitoring and prediction of traffic operations phenomena] --> B[monitor realtime conditions for (counter-)indicators]; C[detailed traffic operations reconstruction] --> D[data processing for feedback next run]
```

detailed traffic operations
reconstruction

C – post trial: assessment and extrapolation

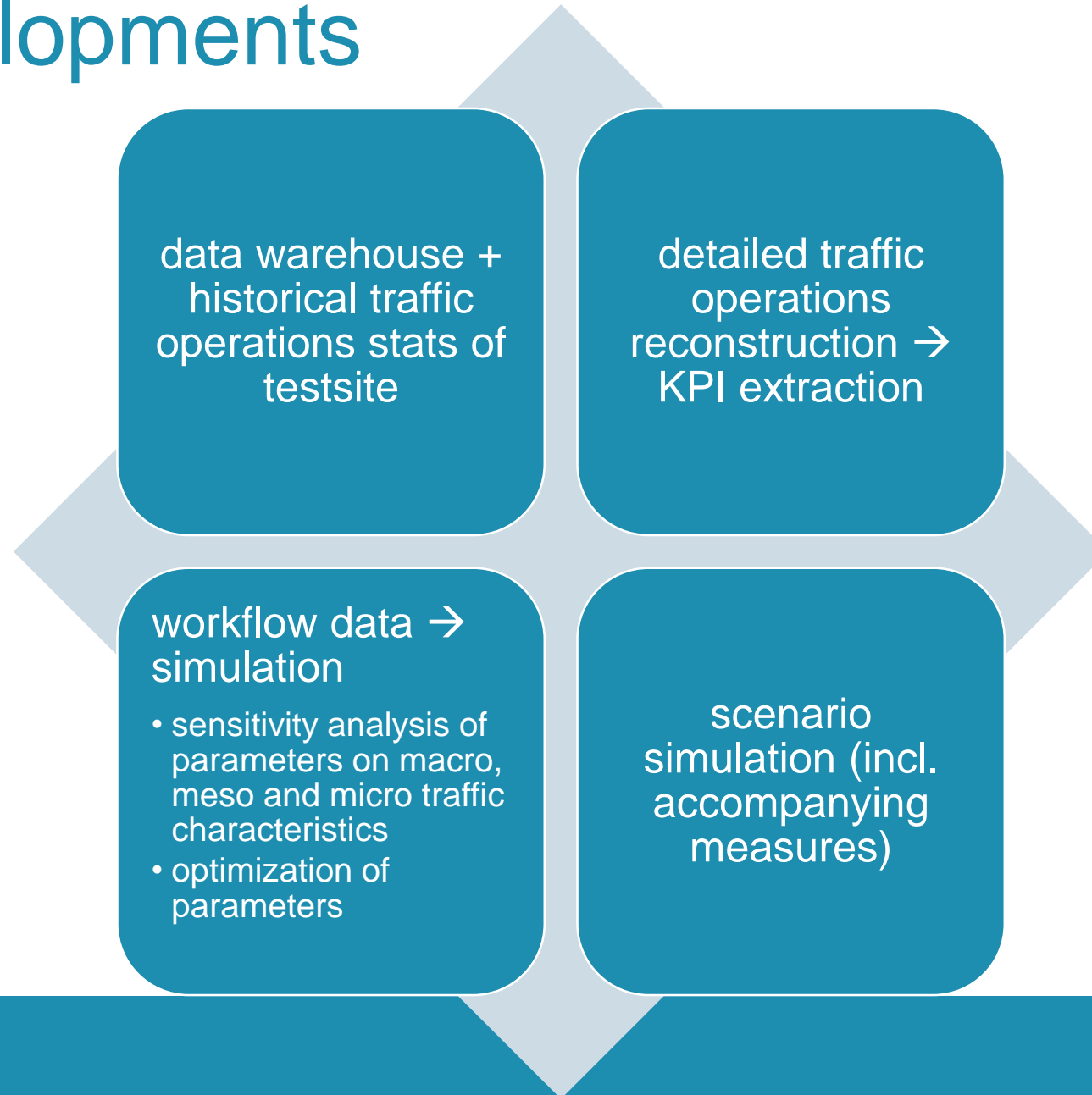
- pilot goals assessment
 - KPI extraction
- traffic simulation
 - update behavioural specs and calibration
 - Δ -analysis reference vs. observed behavior
 - re-calibrate parameters
 - update microsim specs
 - extrapolate scenario in microsim
 - pilot scenario design refinement → A

detailed traffic operations
reconstruction

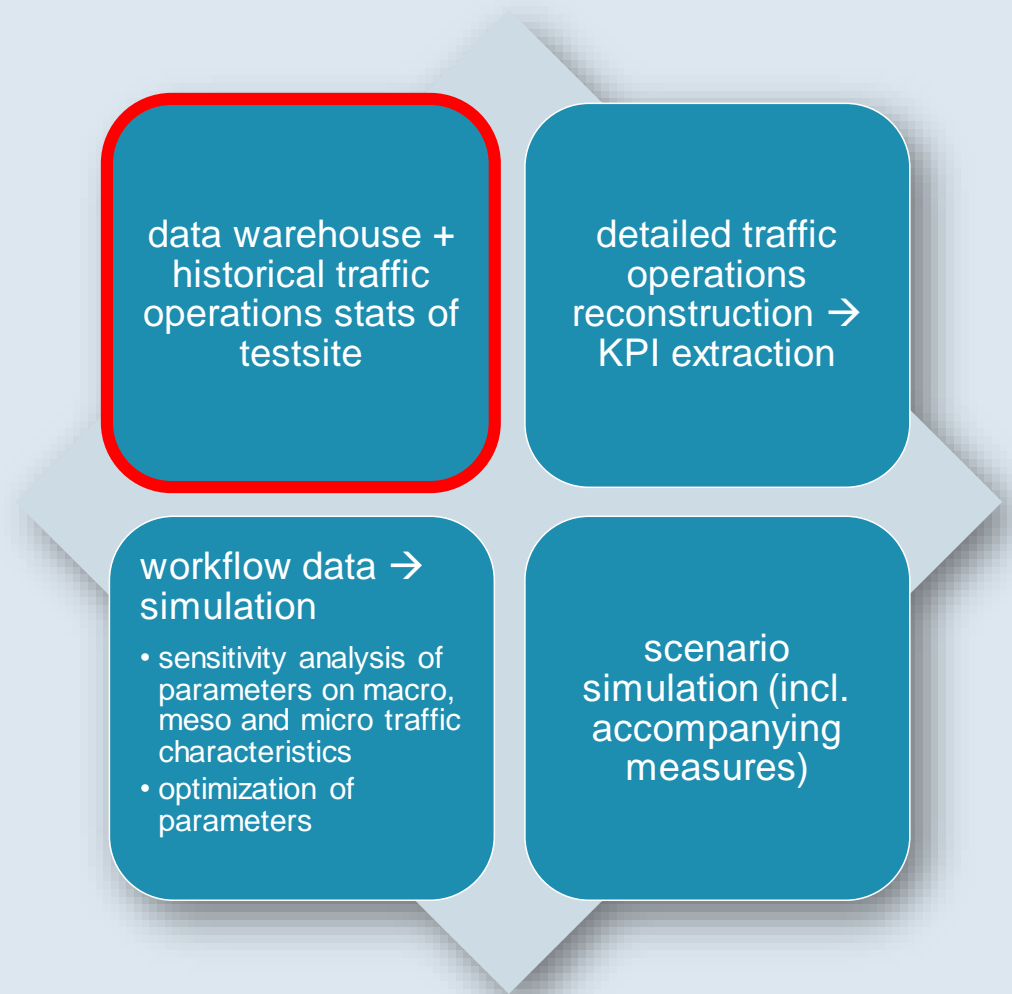
microsimulator parameter
sensitivity analysis

microsimulation scenarios;
evaluate accompanying
measures

Main developments



data warehouse + historical traffic operations stats of testsite

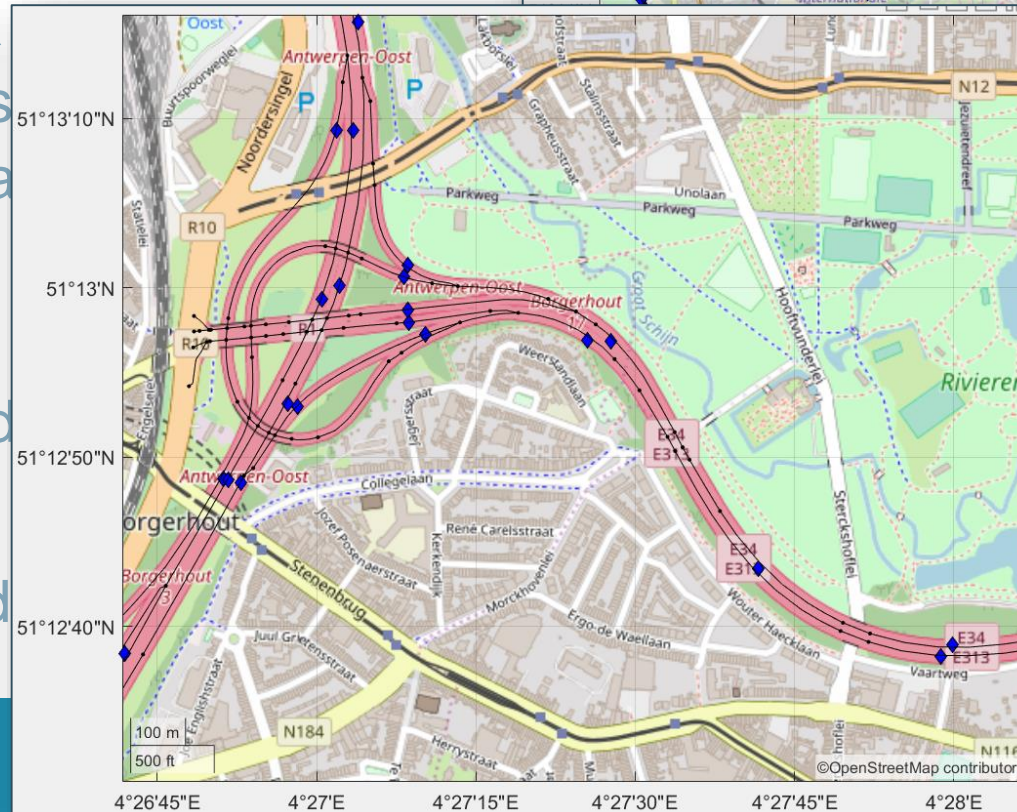
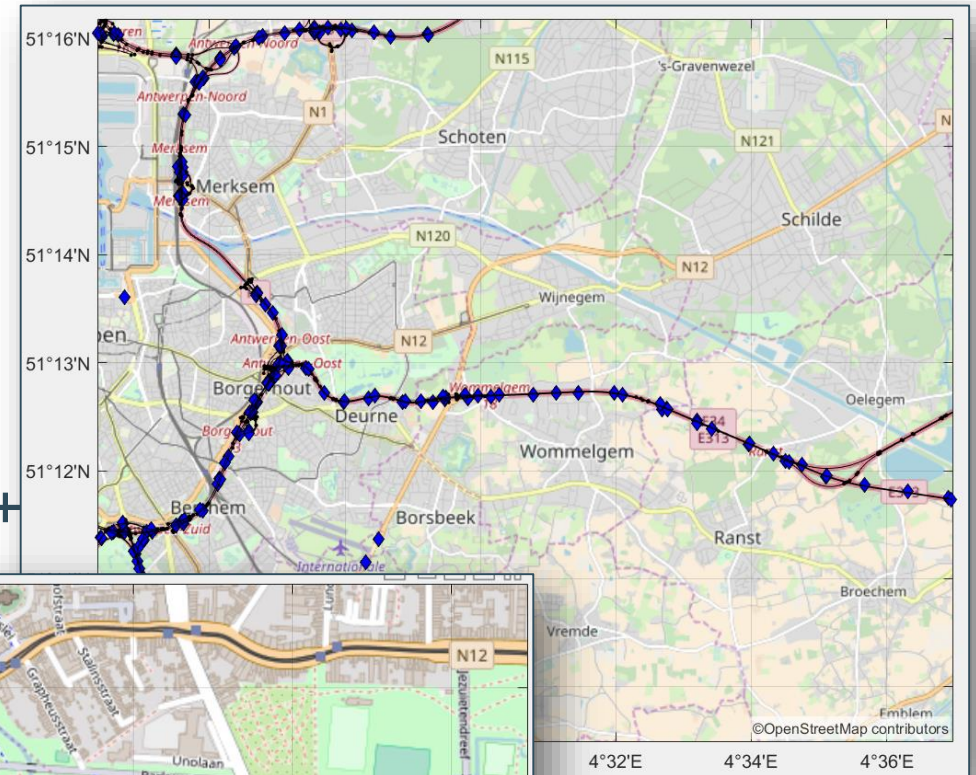


Data collection

- detector loop data
 - macro: minute aggregated traffic variables
 - micro: individual vehicle passage registrations + speeds
- high-resolution floating car data
 - bulk: individual trajectories sampled 1s
 - specific: d-GPS test drive campaigns
- vehicle-mounted sensors
 - test vehicle status variables
 - video observations surrounding traffic
- historical accident database
- drone images → full trajectory dataset

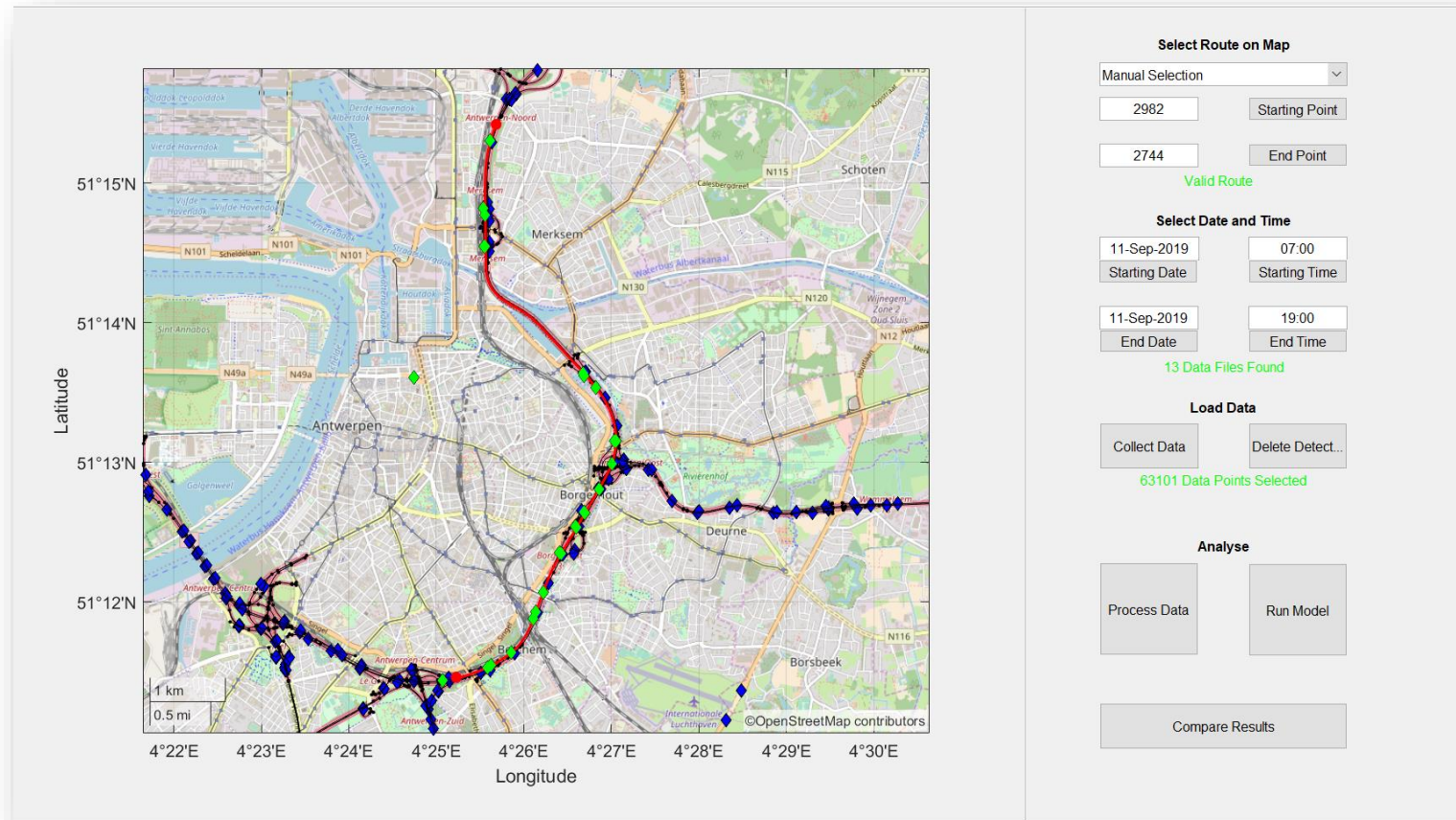
Data collection

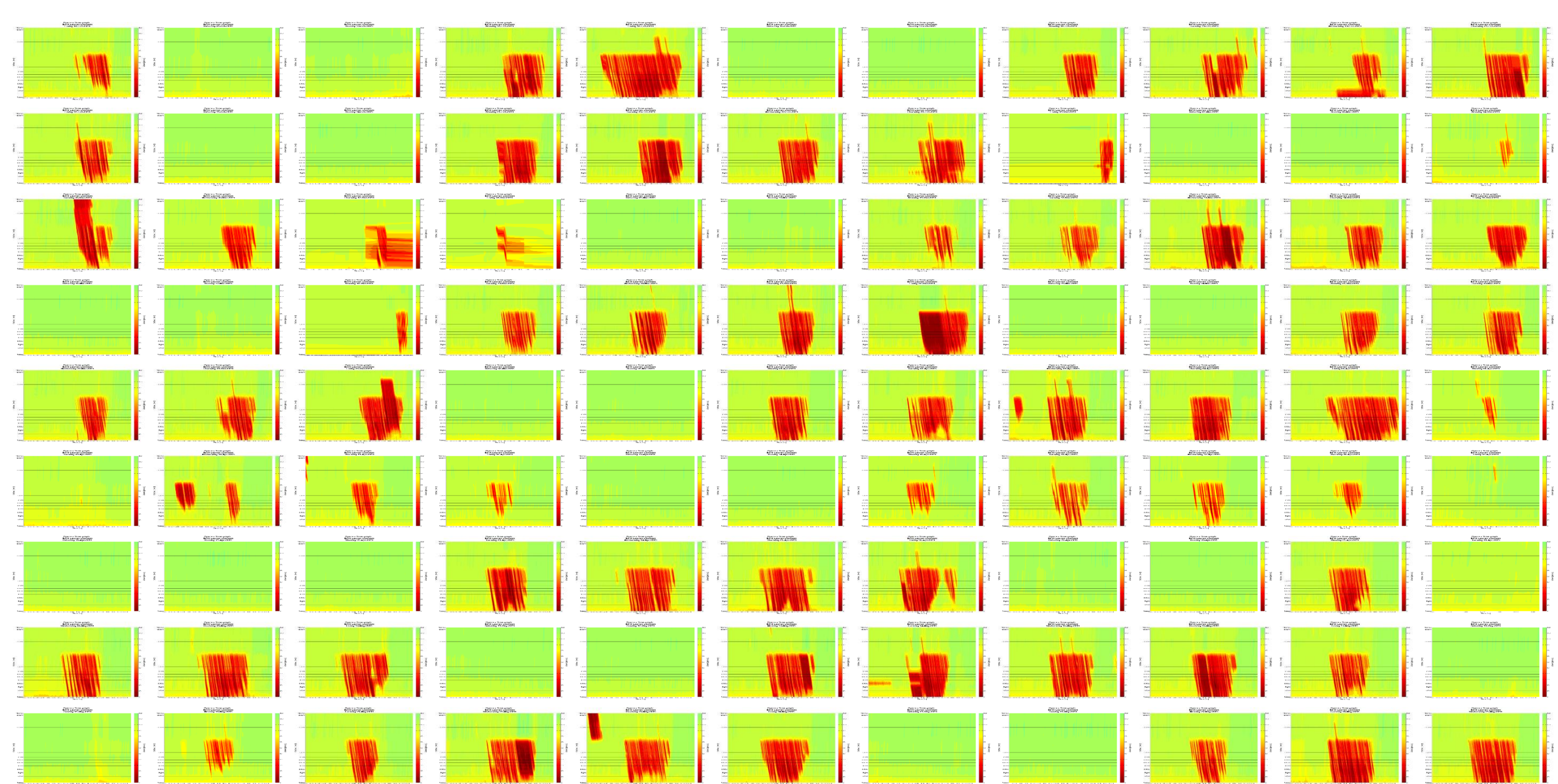
- detector loop data
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- high-resolution floating car data
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- vehicle-mounted sensors
 - test vehicle status variables
 - video observations surround
- historical accident database
- drone images → full trajectory d

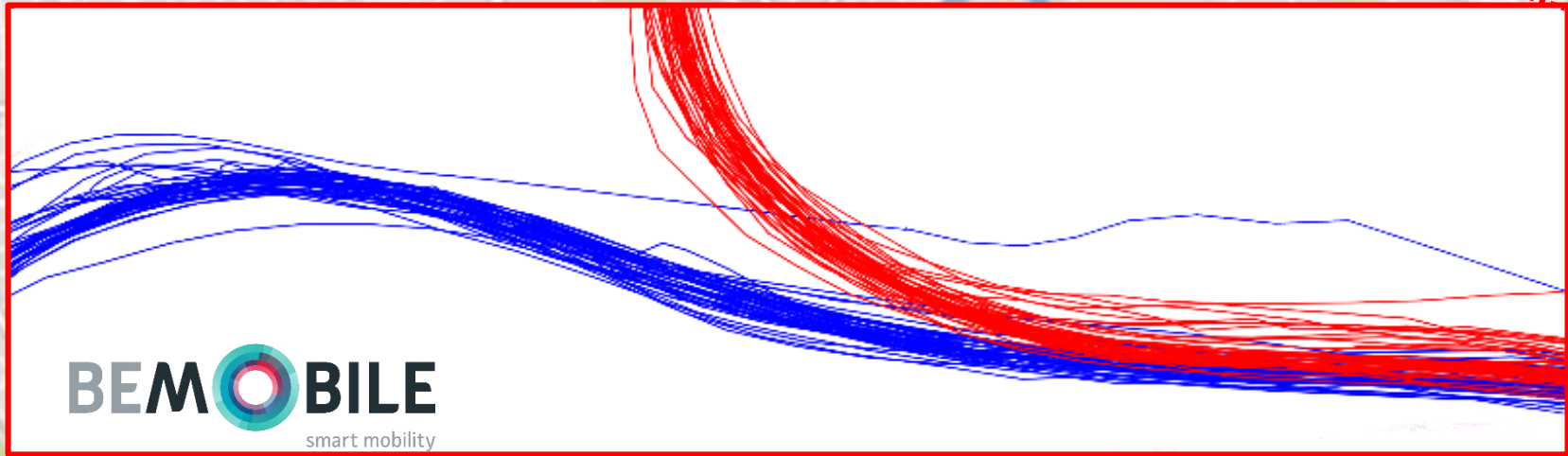
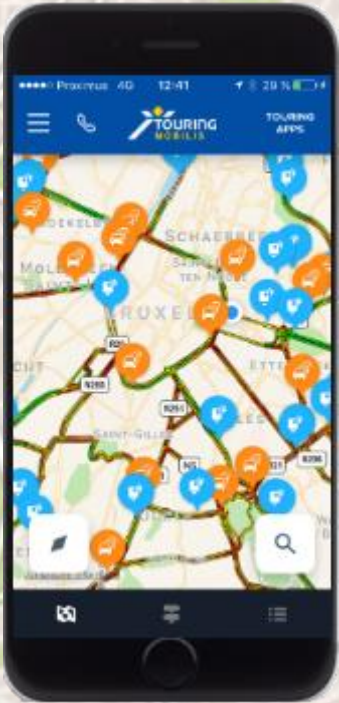


Open Traffic Center

- historic database macro data
- querying
 - interactive GUI
 - bulk scripts in matlab or python
- automatic macro model generation
- automatic corridor OD estimation
- simple what-if scenarios

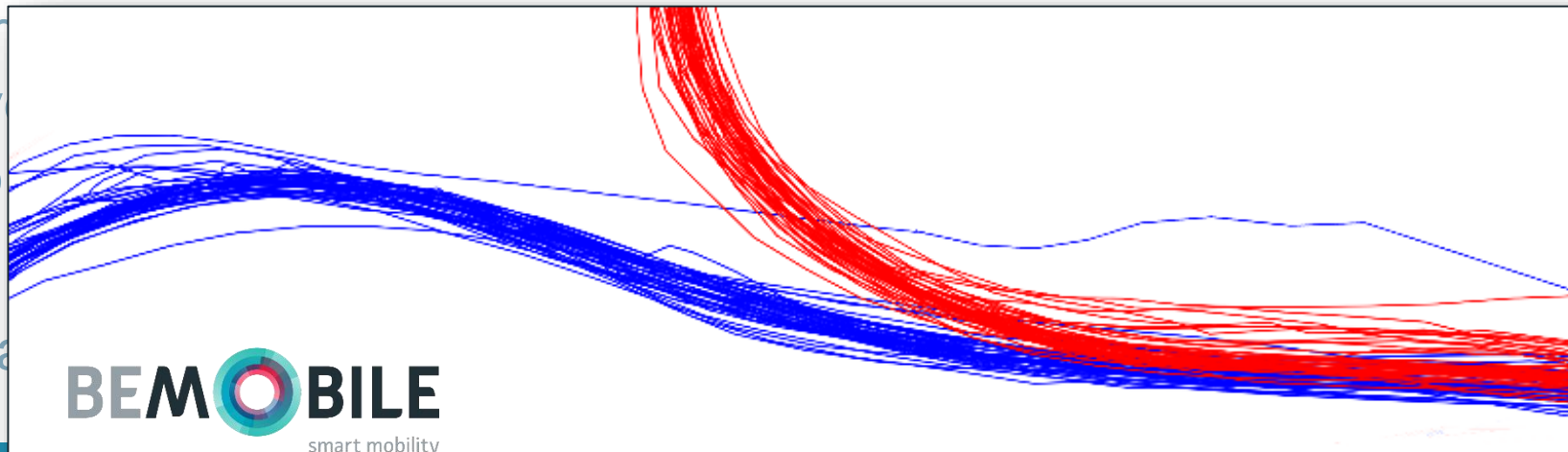






Data collection

- detector loop data
 - macro: minute aggregated traffic variables
 - micro: individual vehicle passage registrations + speeds
- high-resolution floating car data
 - bulk: individual trajectories sampled 1s; (1 year and counting)
 - specific: d-GPS test drive campaigns (2 so far; 1 scheduled)
- vehicle-mounted sensors
 - test vehicles
 - video cameras
- historical data
- drone imagery





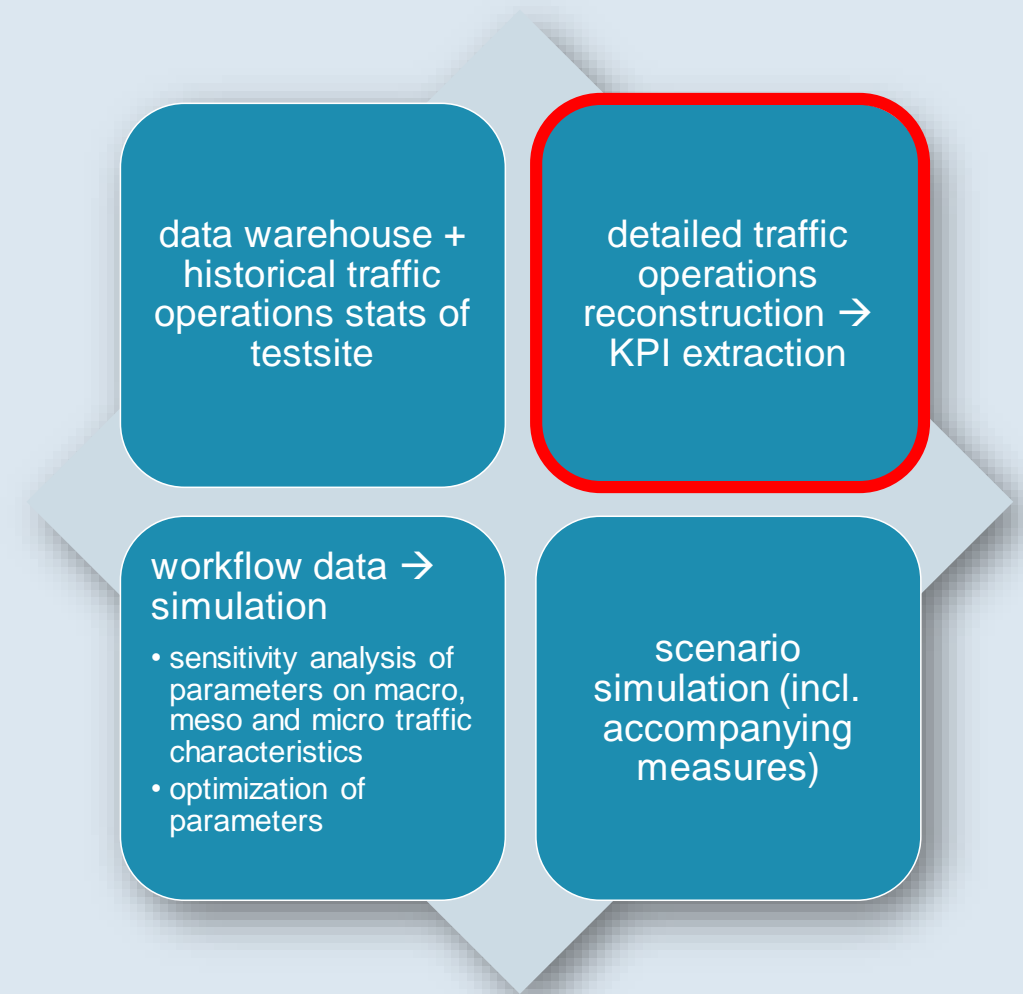
Vlaanderen
is mobiliteit &
openbare werken

Data collection



- drone images → full trajectory dataset

Detailed traffic state reconstruction

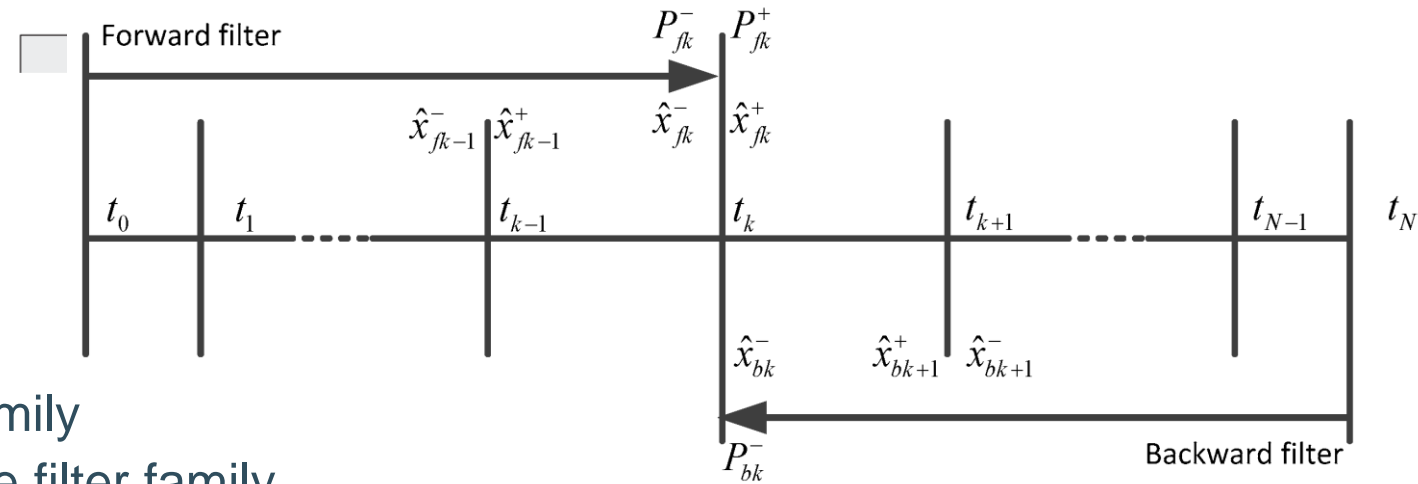


Towards a systematic fusion and filtering of all data sources

- What we want?
 - most likely trajectory, given all direct and indirect observation data
 - GPS positions (prior filtered with unknown filter and parameters)
 - macro reconstruction of speed field per lane
 - e.g. ASM (adaptive smoothing method) or Van Erp's method
 - individual vehicle passages at loops
 - trajectory
 - position over time relative to axis of road
 - reconstructed from data
 - can we identify lane and lane changes?
 - mesocopic traffic state estimation: given observed trajectories, reconstruction of all other trajectories

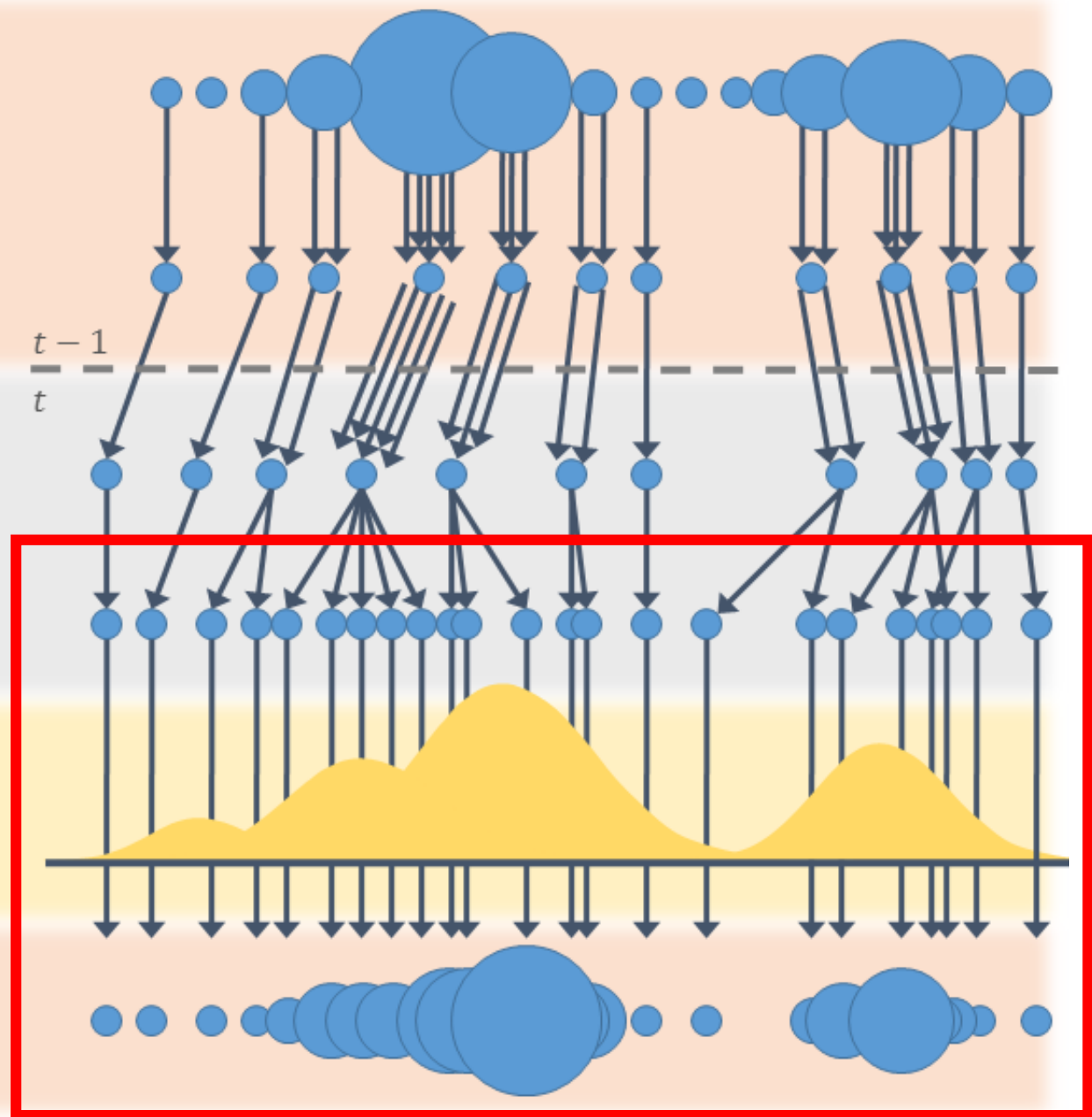
Candidate Bayesian methods

- recursive formulations
 - modeling assumptions
 - linear, Gaussian: Kalman filter family
 - non-linear, non-Gaussian: particle filter family
 - measurement bias/colored noise: state augmentation
 - implementations
 - forward-filtering backward-smoothing (e.g. RTS smoothing)
 - two-filter smoothing
- non-recursive formulations
 - offline estimation allows for less computationally demanding approaches following same concept
 - batch least squares estimation



(source: Jiang et al 2017)

- **Begin** with weighted samples from $t-1$
- **Resample:** draw samples according to $\{w_{t-1}\}_{n=1:N}$
- **Drift:** apply motion model (no noise)
- **Diffuse:** apply noise to spread particles
- **Measure:** weights are assigned by likelihood response
- **Finish:** density estimate



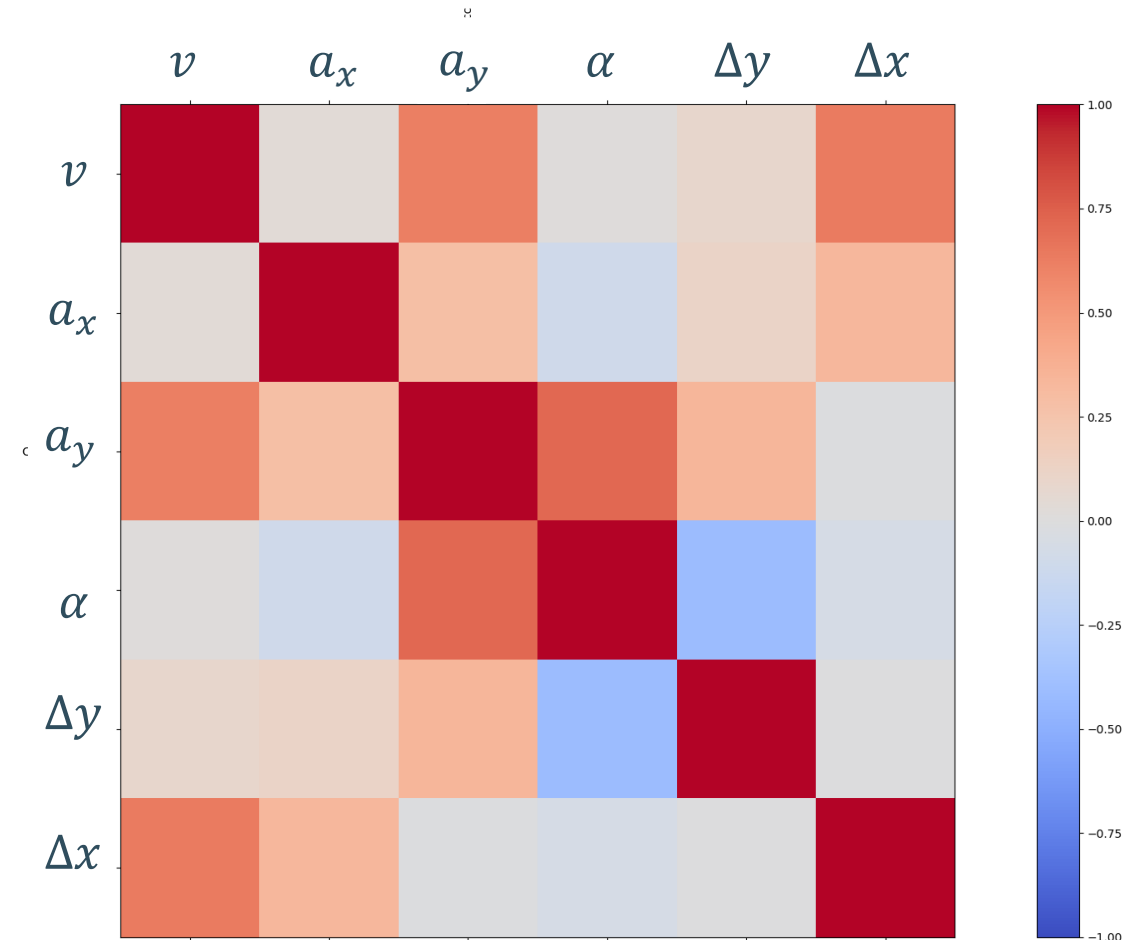
Essential empirical input

- Bayes:

“likelihood of particle x_i^- conditioned on measurement y is proportional to $p(y|x_i^-)$ ”

→ we need error statistics of data sources!

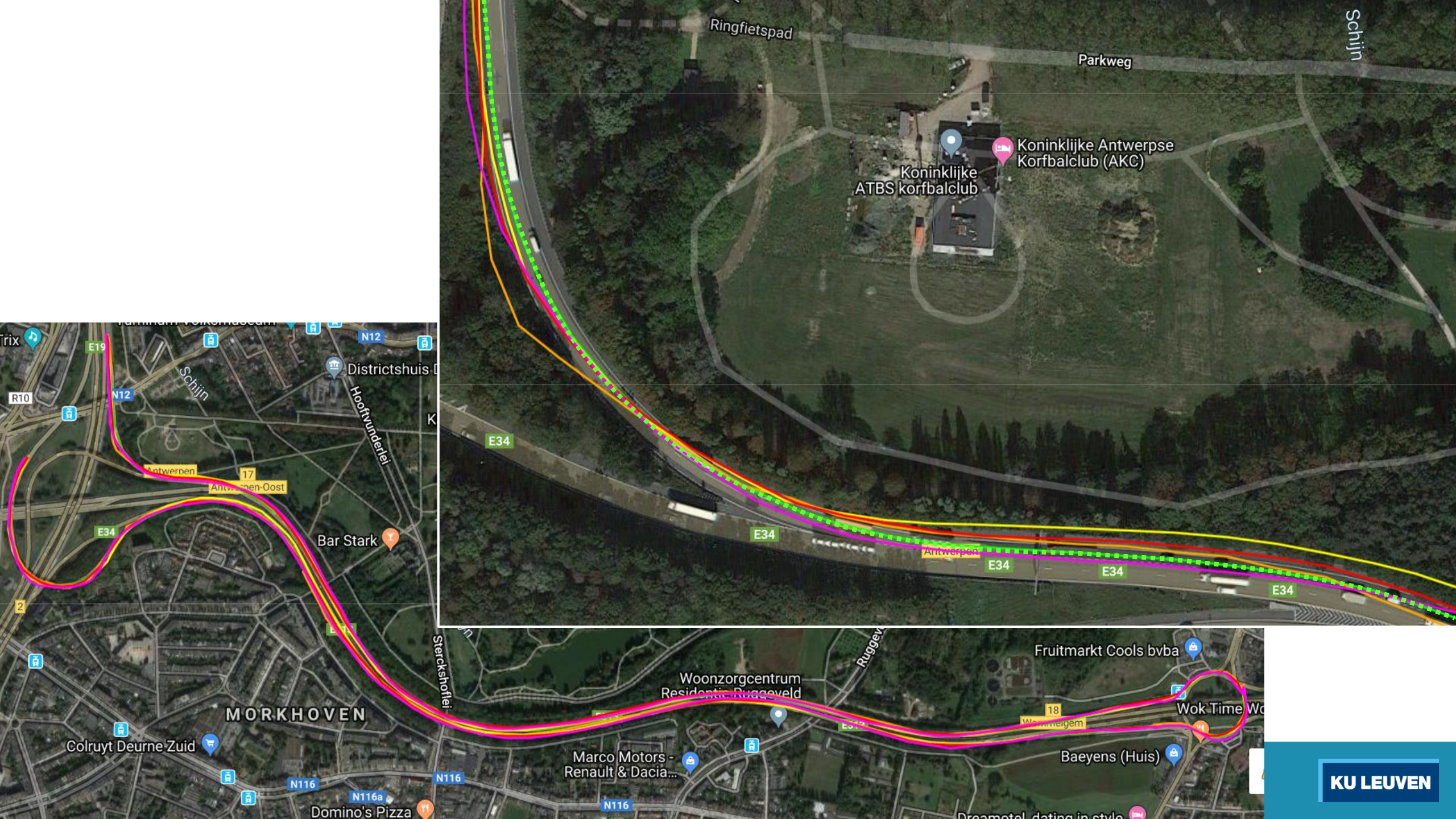
distribution of noise +
model of measurement bias



Trajectory reconstruction: GPS accuracy?!

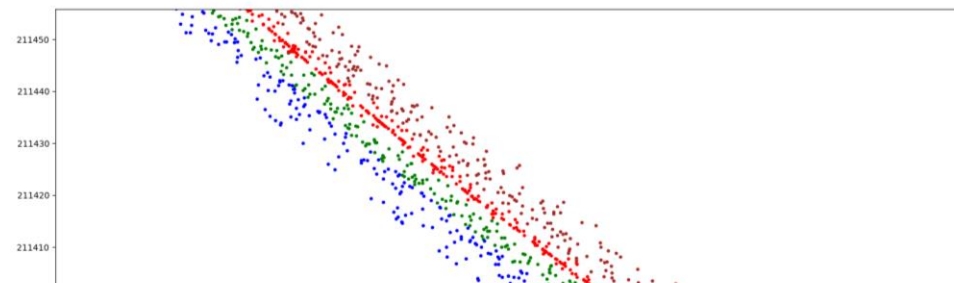
- GPS tracking of commercial smartphones = negatively affected by internal filter smartphone
 - deceptively smooth
 - large (lateral) offsets
- offset correction by regression of d-GPS vs GPS errors
- offset correction by fusion with individual loop data
 - road axis + lane recognition
 - probabilistic mapping onto lane at detector → lat pos correction



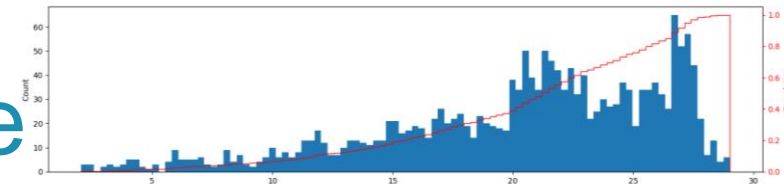
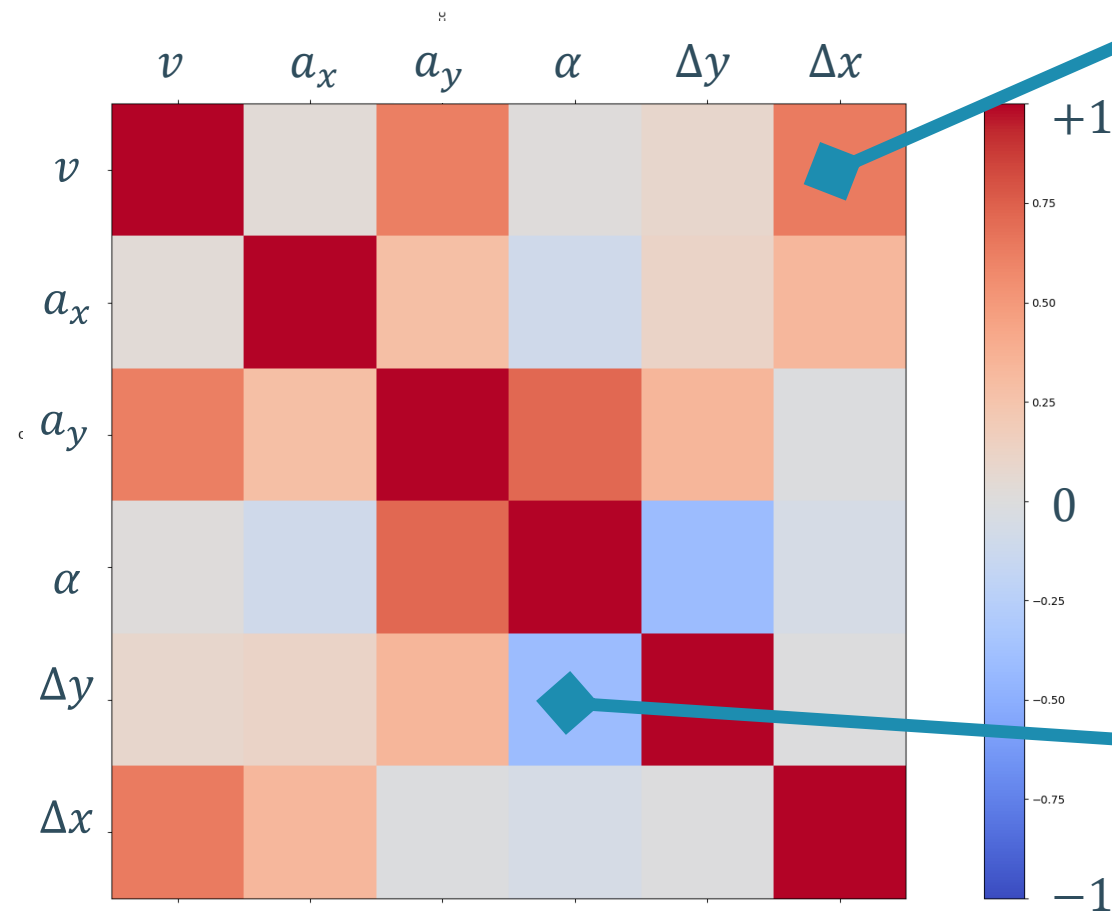


Offset correction by fusion with individual loop data

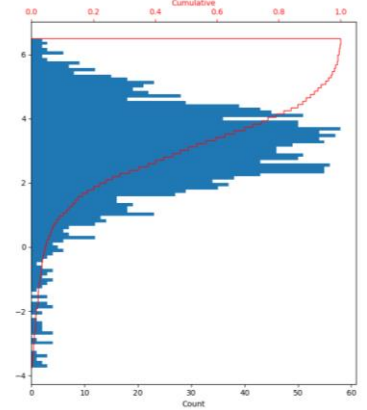
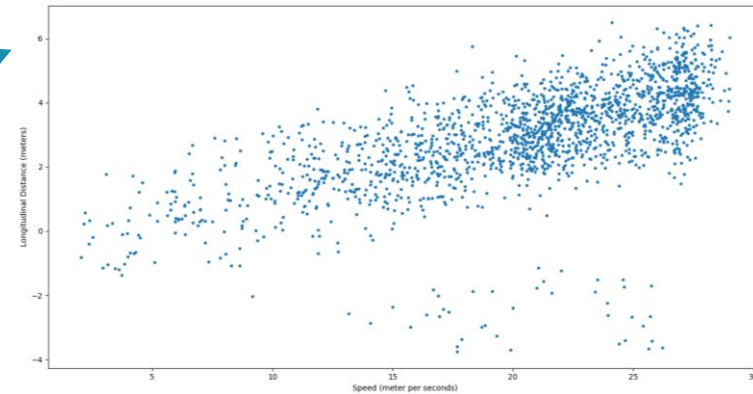
- before correcting lateral position errors:
where is the road??
- road axis + lane recognition



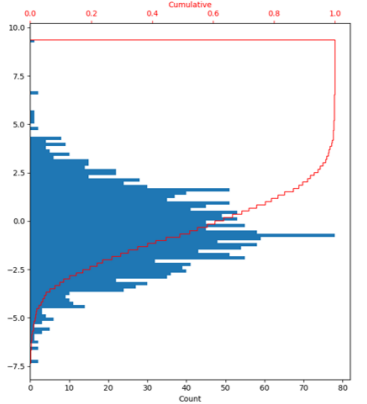
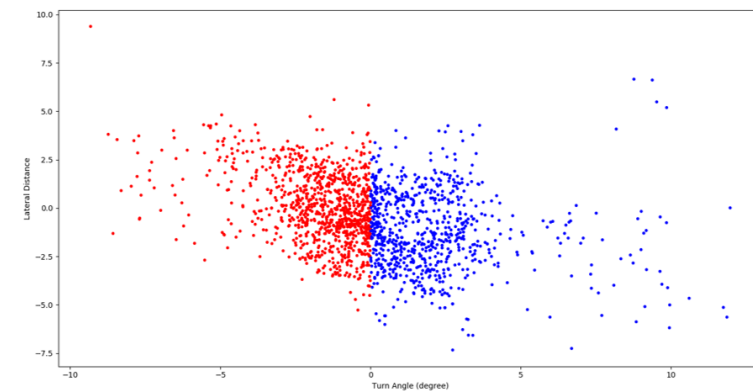
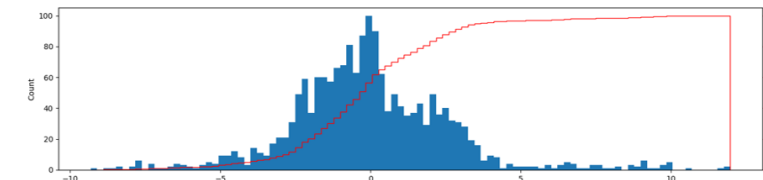
Characterizing d-GPS \leftrightarrow GPS bias+noise



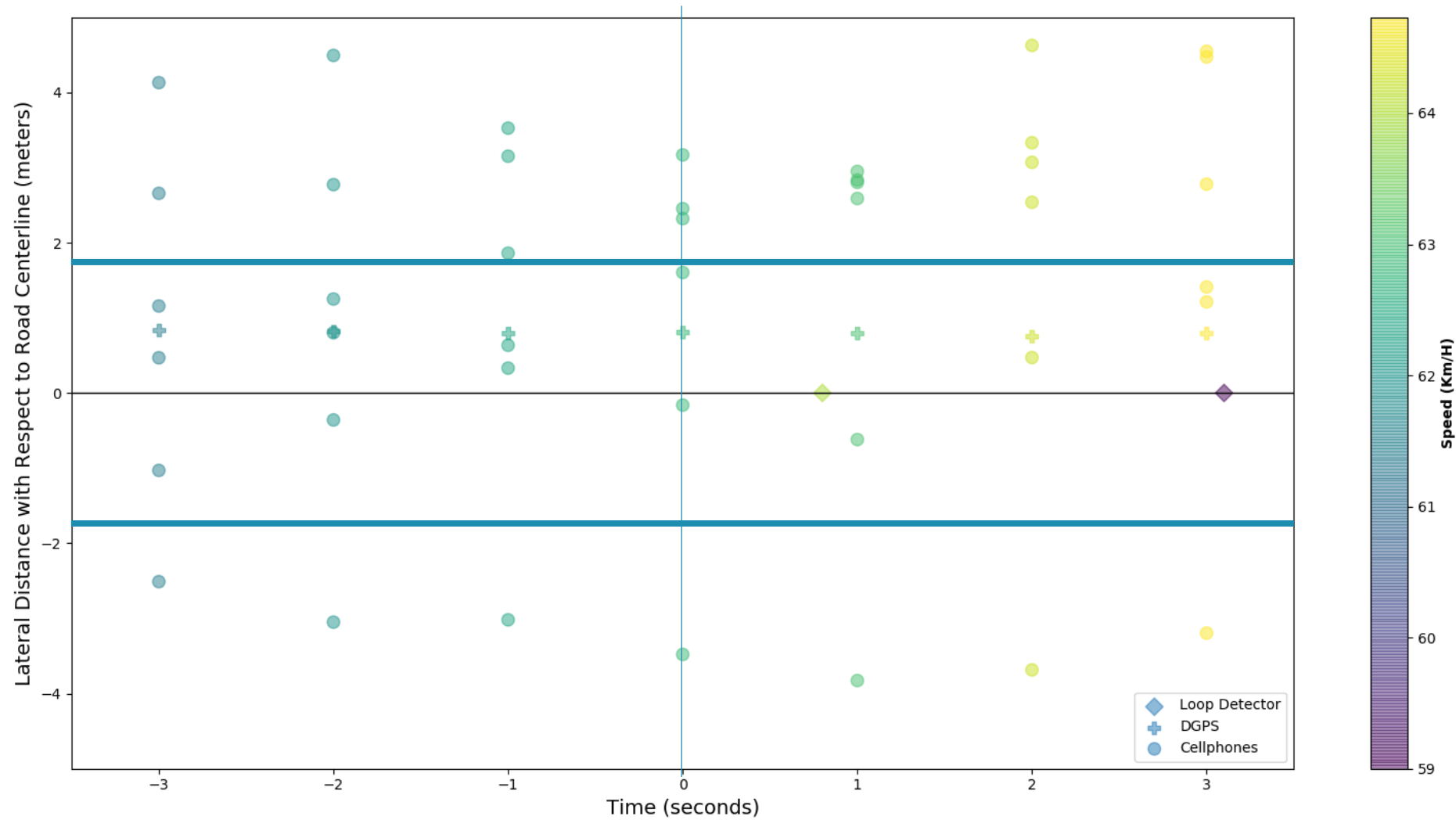
$$\Delta x - v$$



$$\Delta y - \alpha$$

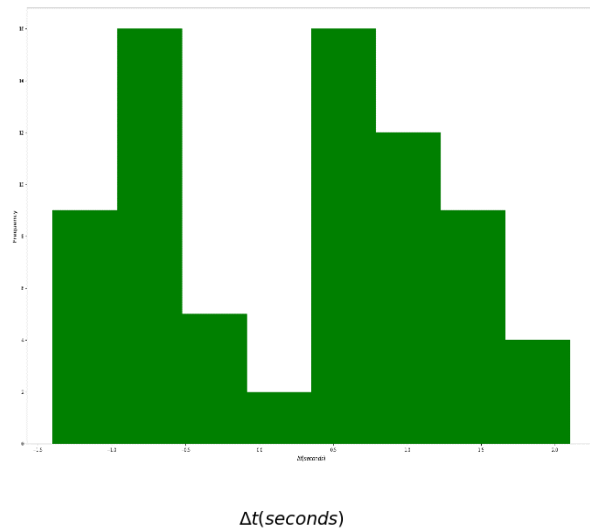


d-GPS vs individual loop data

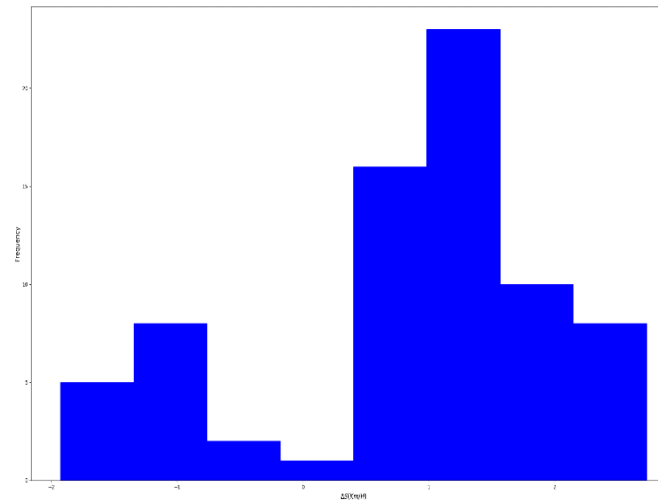


d-GPS vs individual loop data ((very) preliminary results)

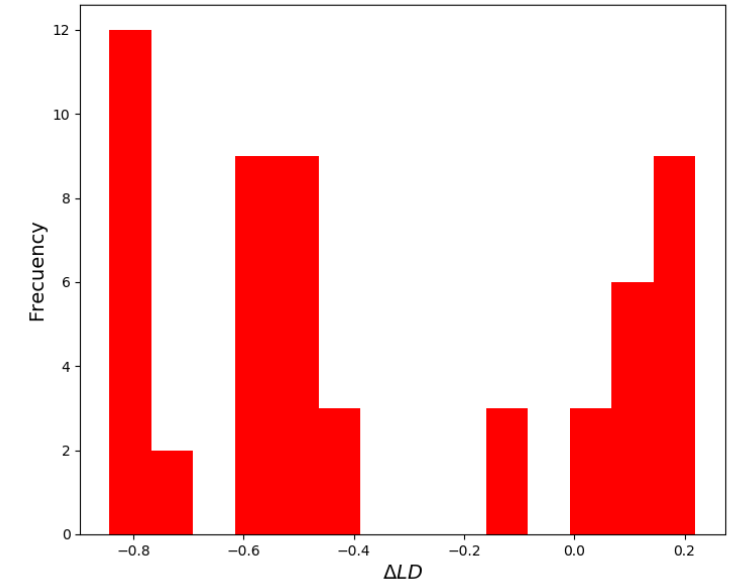
time error



speed error

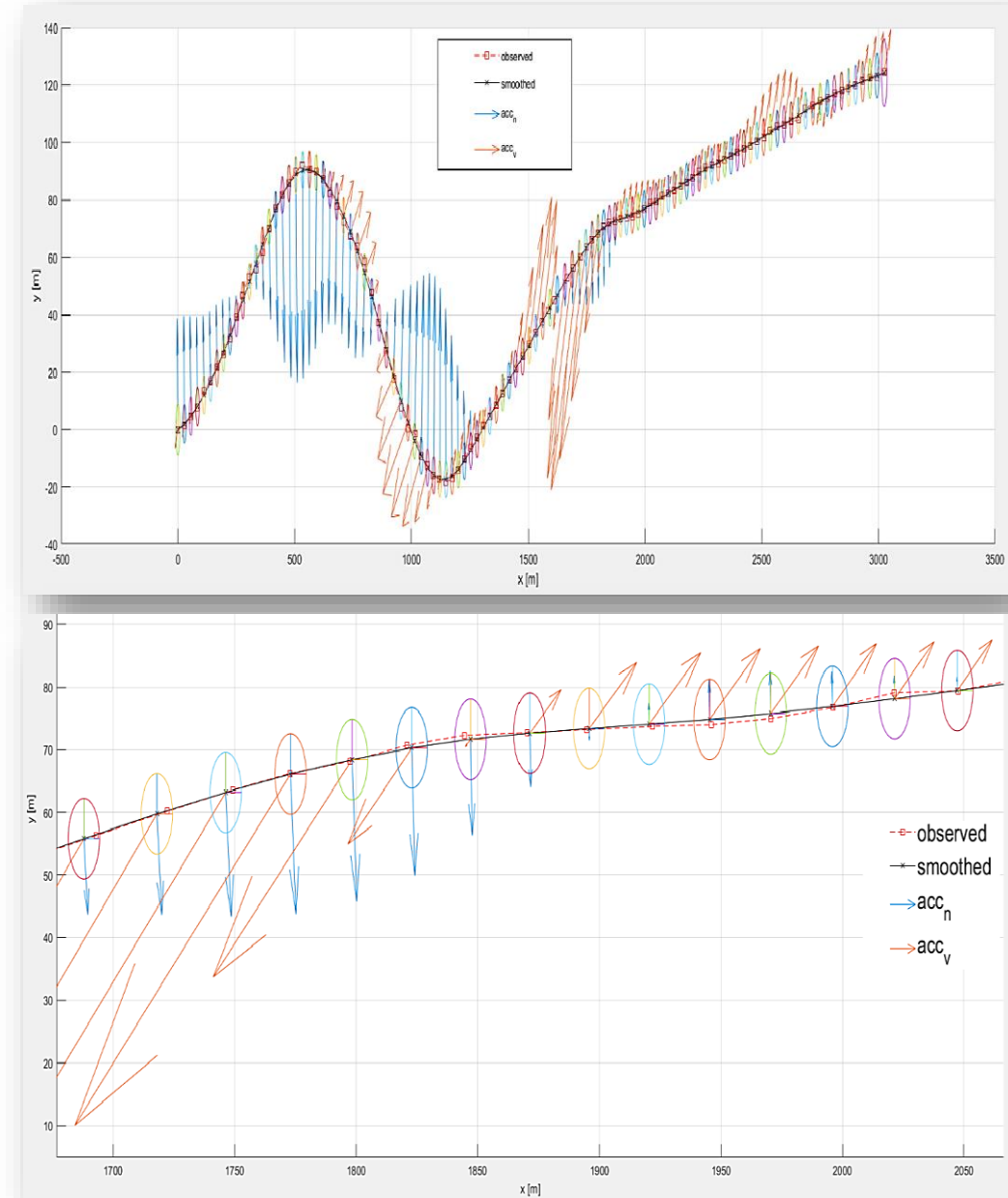


lateral error



Trajectory reconstruction

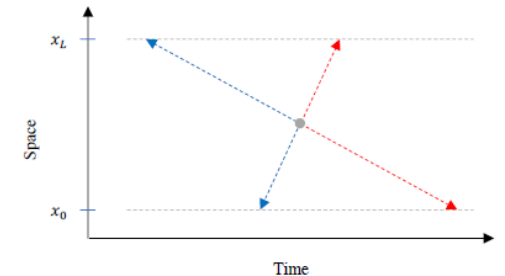
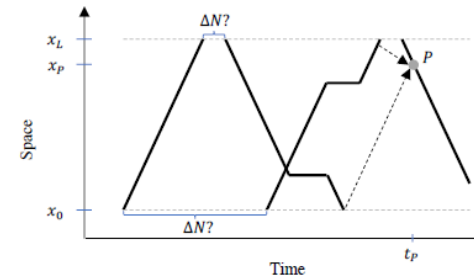
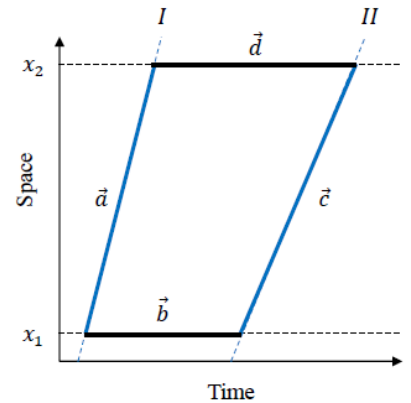
- enhanced RTS smoothing (dynamic-vehicle-model-on-site-based filtering)
 - negatively affected by internal filter smartphone
 - falsely smooth
 - large (lateral) offsets
- offset correction by regression of d-GPS vs GPS errors
- offset correction by fusion with individual loop data
 - road axis + lane recognition
 - probabilistic mapping onto lane at detector → lat pos correction
 - → augmented RTS smoothing
- → corrected trajectories (probabilistically revealing lane changes?)



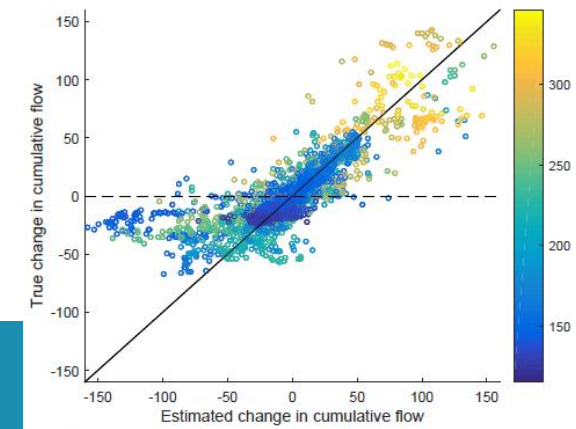
Reconstruction of full trajectory set

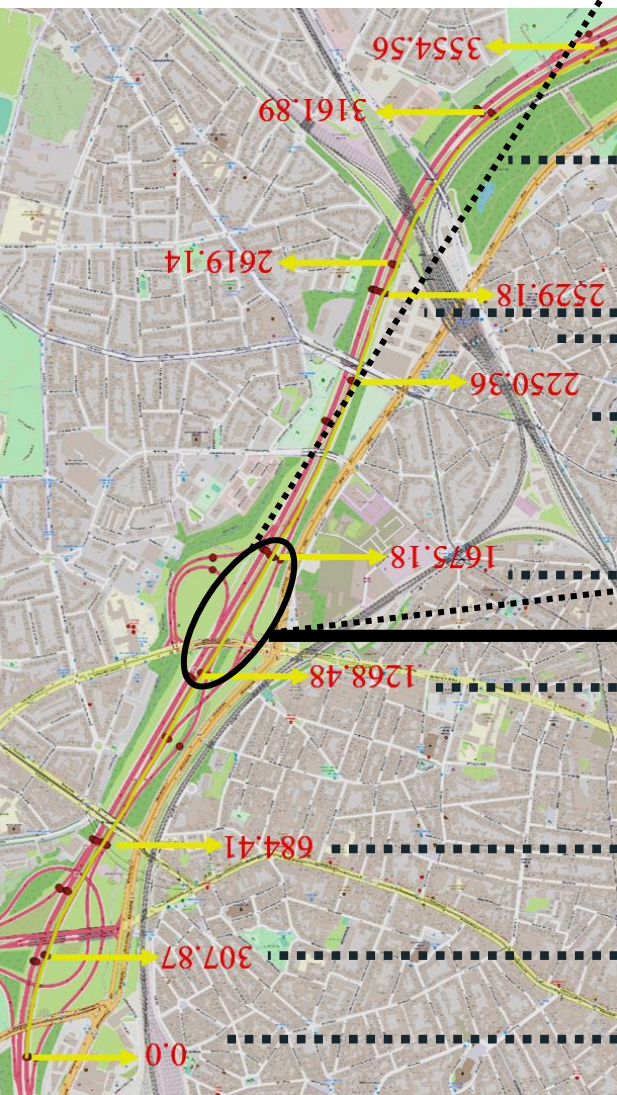
- Principle

- $N(t, x)$ can be reconstructed analytically from traffic flow theory from specific set of known N 's at other (t, x) **IF** no overtaking happens
- detector sites are such known N locations
- vehicle trajectory carries known N -value

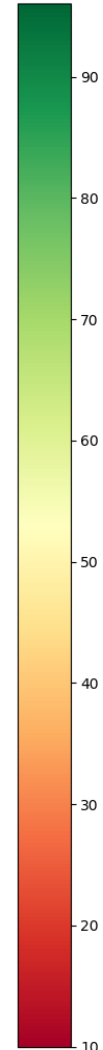
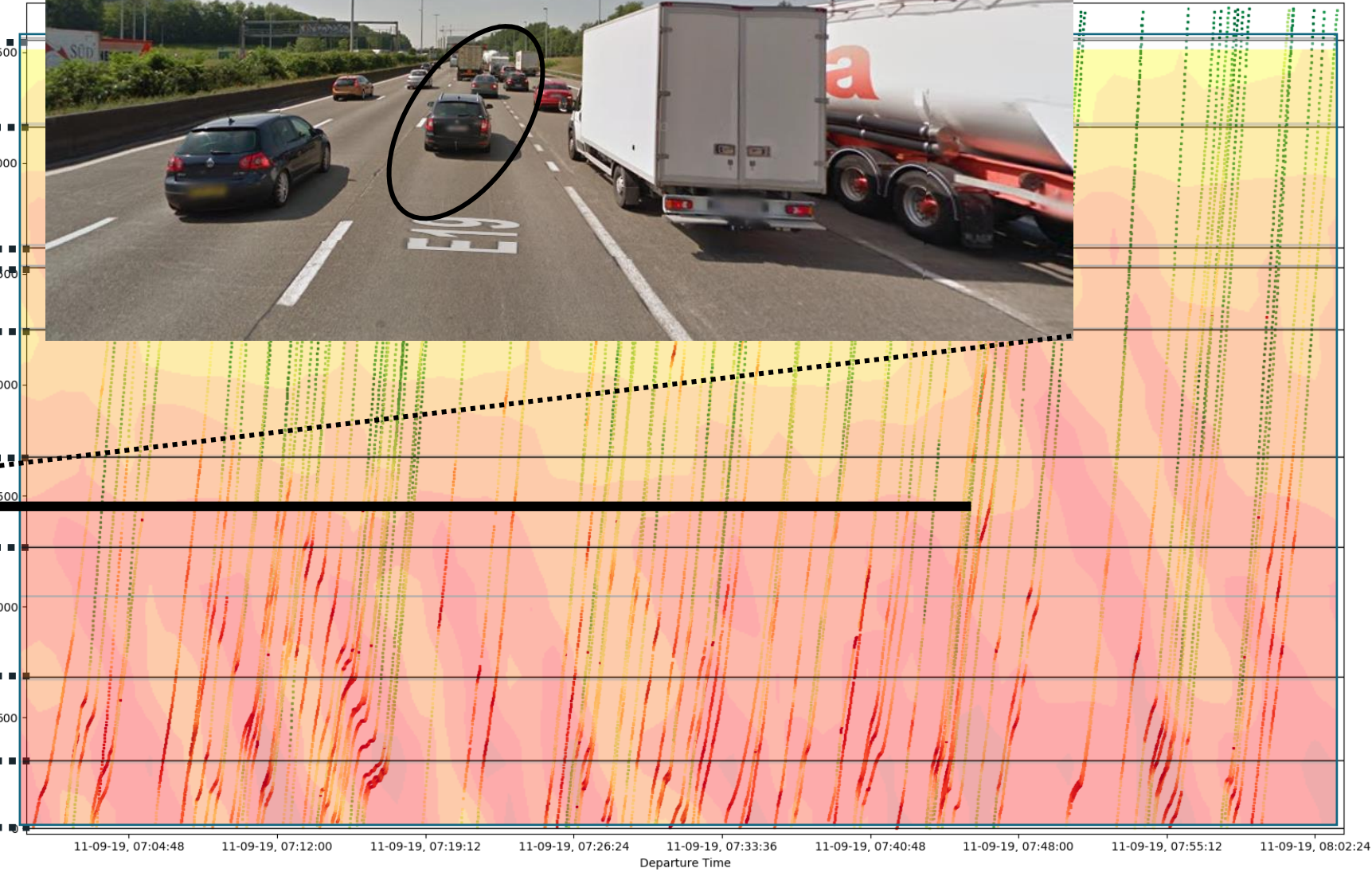


- compensation for overtaking possible when ΔN along trajectory known
- methods (being) developed for ΔN estimation along GPS trajectory using fusion lane macro + lane change stats
 - lane changes, overtakings
- validation data collected using drone





Distance (meters)



Discussion

- any questions?

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