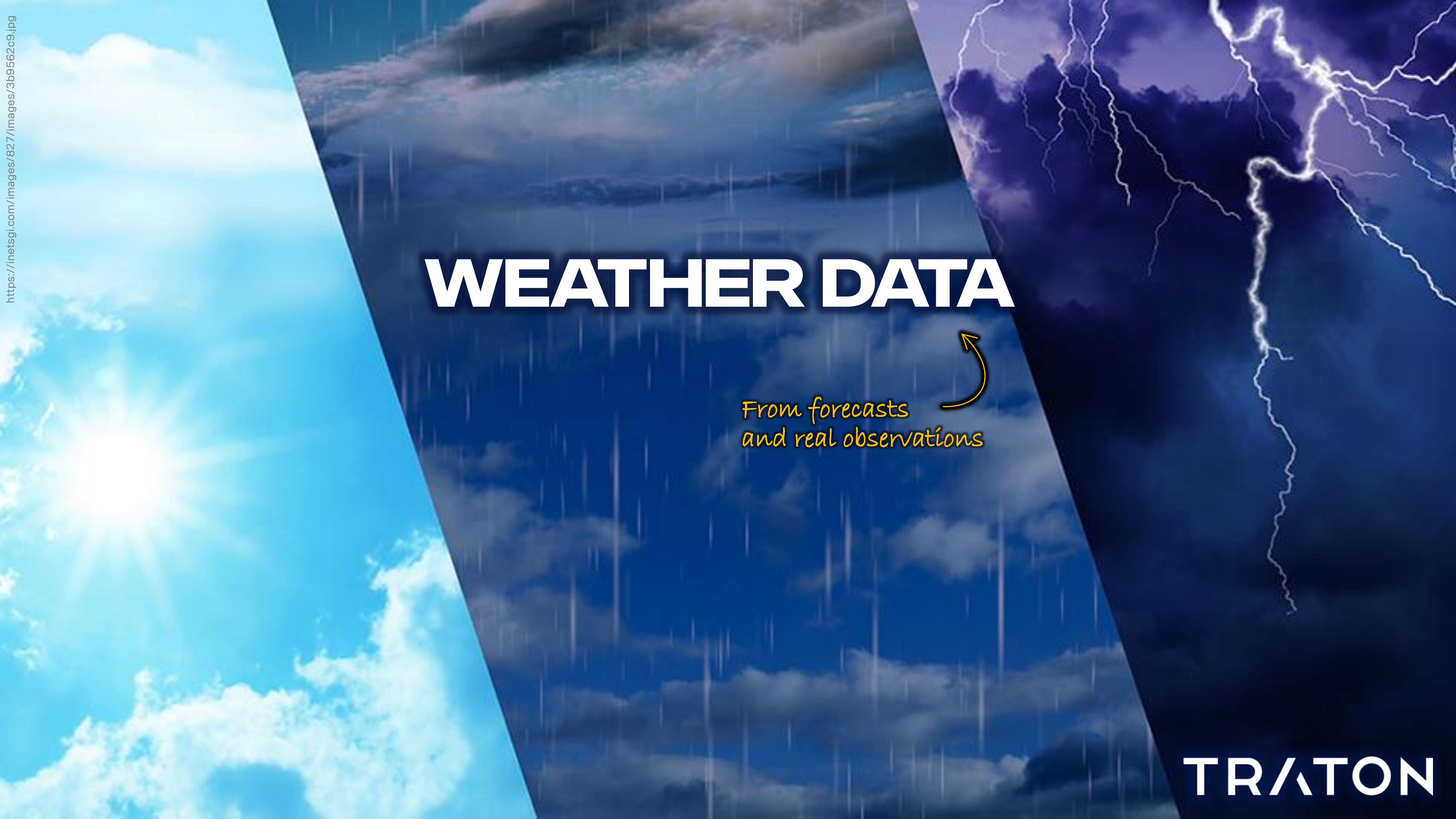
ADDING WEATHER DATA TO ANALYSES OF VEHICLE SYSTEMS

Performance and robustness thereof!

RENO FILLA
TRATON GROUP R&D

2026-02-04

TRATON


https://inetsgi.com/images/827/images/3b9562c9.jpg
WEATHER DATA
From forecasts
and real observations

RENO FILLA

PhD from LiU (IEI, 2011)
Fluid Power and Mechatronics

Energy Efficiency
Electromobility and Energy Systems
Automation and Human Factors

20 years at Volvo CE, R&D
Senior Technology Specialist

7+ years at Scania/Traton, R&D
Expert Engineer

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WE'VE GOT A PROBLEM

(Industry and Academia)

Performance of <u>any</u> vehicle is affected by weather

- Directly
  - Air temperature
  - Air pressure
  - Air humidity
  - Wind speed + direction
  - Precipitation (rain, snow, hail …)
  - Cloudiness and solar radiation (effectiveness of solar panels)
- Indirectly: road (friction + rolling resistance)
  - Ice, snow, water on road
  - Surface temperature
  - Ground temperature

Major energy sinks:

- Powertrain losses
- Elevation change
- Air resistance
- Rolling resistance

WE'VE GOT A PROBLEM (Industry and Academia)

Weather changes all the time

We usually ignore this (or only roughly approximate it)

- in analysis of recorded operation
- in simulation
- in component/system dimensioning

We risk that…

- we write off poor performance as due to bad weather and thus miss real deviations
- we design products with poor performance robustness due to insufficient testing in bad conditions

By picking safe, nominal environmental conditions we ignore the variability that exists in the real world.

We do this at our own peril.

WE'VE GOT A SOLUTION

(Industry and Academia)

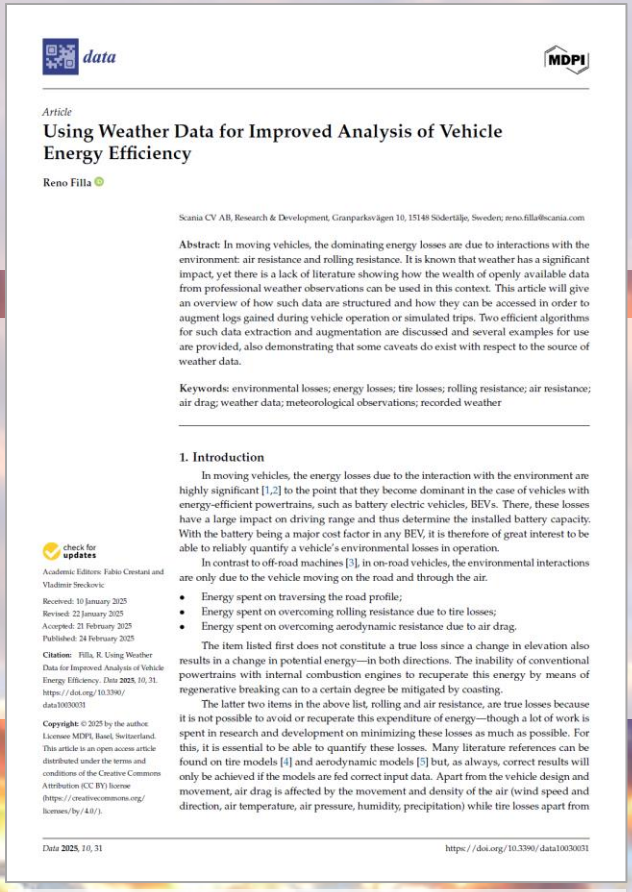
We now have

- data
- tools
- methods

Main idea: Make it easy to combine observed or forecasted weather with vehicle logs

- recorded operation
- simulated missions

(more to come)



data MDPI

Article

Using Weather Data for Improved Analysis of Vehicle Energy Efficiency

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Abstract: In moving vehicles, the dominating energy losses are due to interactions with the environment: air resistance and rolling resistance. It is known that weather has a significant impact, yet there is a lack of literature showing how the wealth of openly available data from professional weather observations can be used in this context. This article will give an overview of how such data are structured and how they can be accessed in order to augment logs gained during vehicle operation or simulated trips. Two efficient algorithms for such data extraction and augmentation are discussed and several examples for use are provided, also demonstrating that some caveats do exist with respect to the source of weather data.

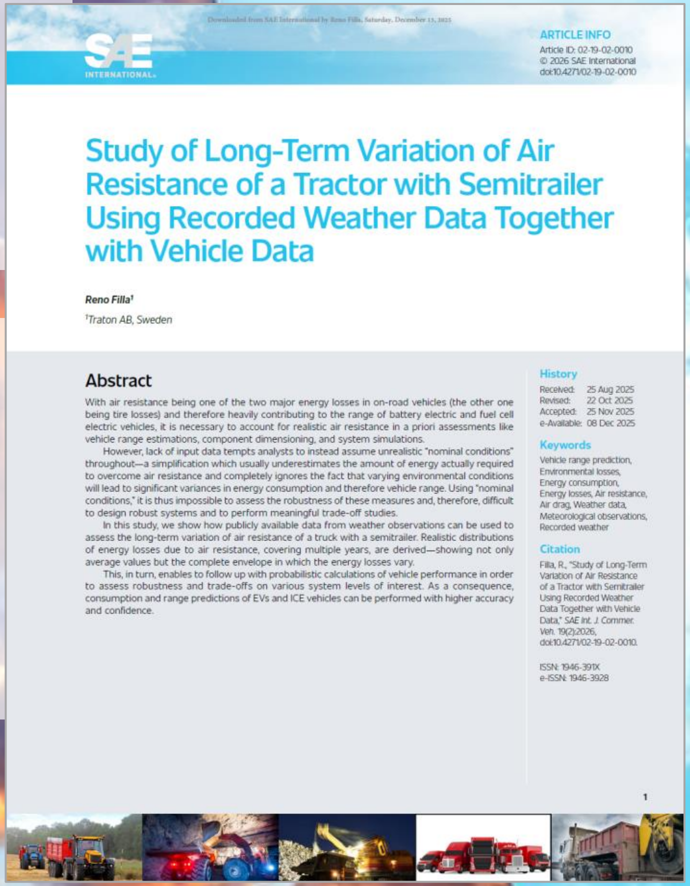
Keywords: environmental losses; energy losses; tire losses; rolling resistance; air resistance; air drag; weather data; meteorological observations; recorded weather

1. Introduction

In moving vehicles, the energy losses due to the interaction with the environment are highly significant [1,2] to the point that they become dominant in the case of vehicles with energy-efficient powertrains, such as battery electric vehicles, BEVs. ...

Data 2025, 10, 31 https://doi.org/10.3390/data10030031

https://doi.org/10.3390/data10030031



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Study of Long-Term Variation of Air Resistance of a Tractor with Semitrailer Using Recorded Weather Data Together with Vehicle Data

Reno Filla[1]

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Abstract

With air resistance being one of the two major energy losses in on-road vehicles (the other one being tire losses) and therefore heavily contributing to the range of battery electric and fuel cell electric vehicles, it is necessary to account for realistic air resistance in a priori assessments like vehicle range estimations, component dimensioning, and system simulations.

However, lack of input data tempts analysts to instead assume unrealistic "nominal conditions" throughout—a simplification which usually underestimates the amount of energy actually required to overcome air resistance and completely ignores the fact that varying environmental conditions will lead to significant variances in energy consumption and therefore vehicle range. Using "nominal conditions," it is thus impossible to assess the robustness of these measures and, therefore, difficult to design robust systems and to perform meaningful trade-off studies.

In this study, we show how publicly available data from weather observations can be used to assess the long-term variation of air resistance of a truck with a semitrailer. Realistic distributions of energy losses due to air resistance, covering multiple years, are derived—showing not only average values but the complete envelope in which the energy losses vary.

This, in turn, enables to follow up with probabilistic calculations of vehicle performance in order to assess robustness and trade-offs on various system levels of interest. As a consequence, consumption and range predictions of EVs and ICE vehicles can be performed with higher accuracy and confidence.

History
Received: 25 Aug 2025
Revised: 22 Oct 2025
Accepted: 25 Nov 2025
e-Available: 08 Dec 2025

Keywords
Vehicle range prediction, Environmental losses, Energy consumption, Energy losses, Air resistance, Air drag, Weather data, Meteorological observations, Recorded weather

Citation
Filla, R., "Study of Long-Term Variation of Air Resistance of a Tractor with Semitrailer Using Recorded Weather Data Together with Vehicle Data," SAE Int. J. Commer. Veh. 19(2):2026, doi:10.4271/02-19-02-0010.

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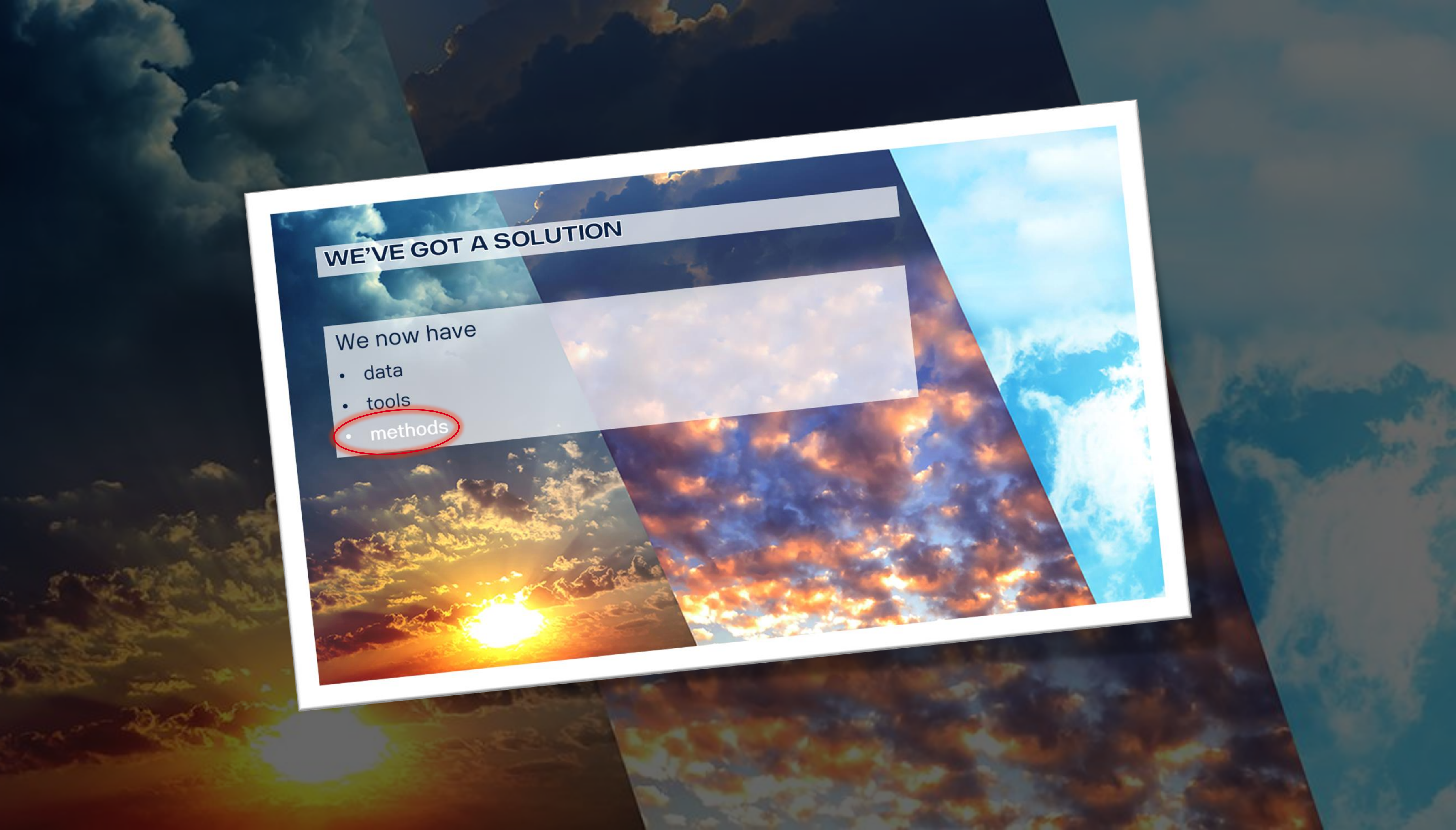
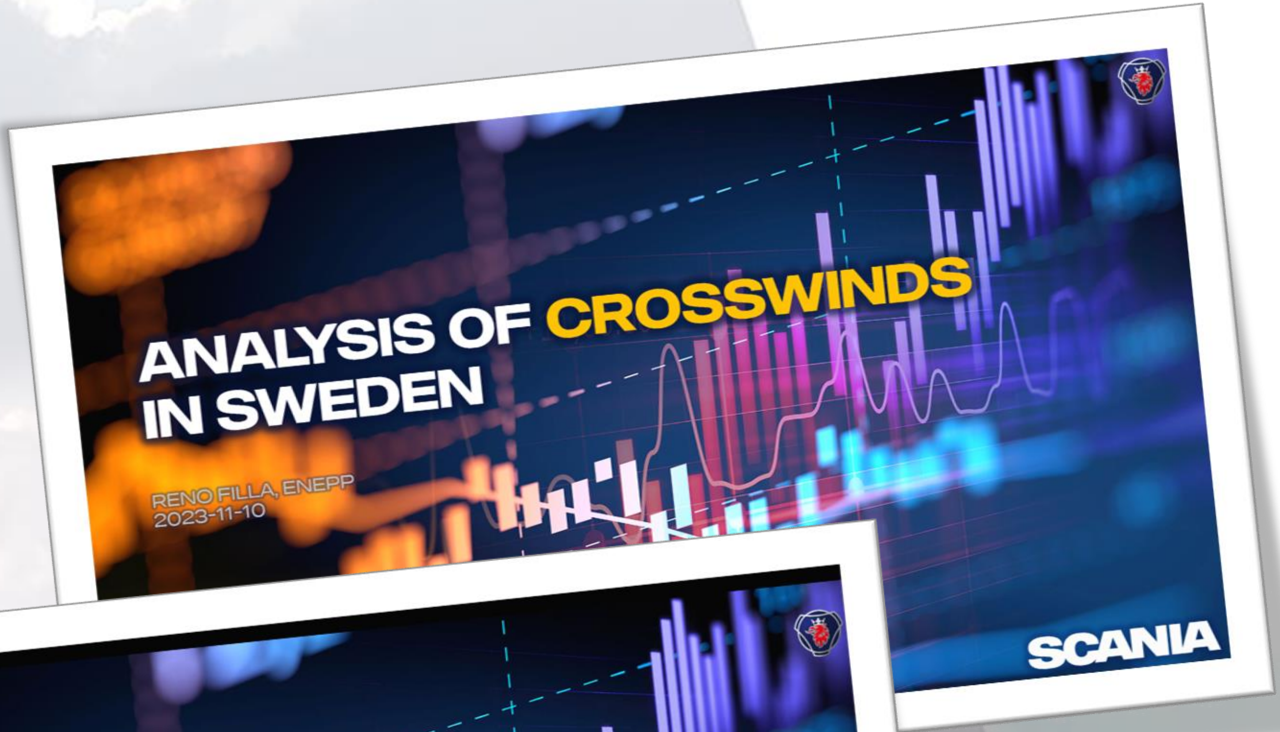
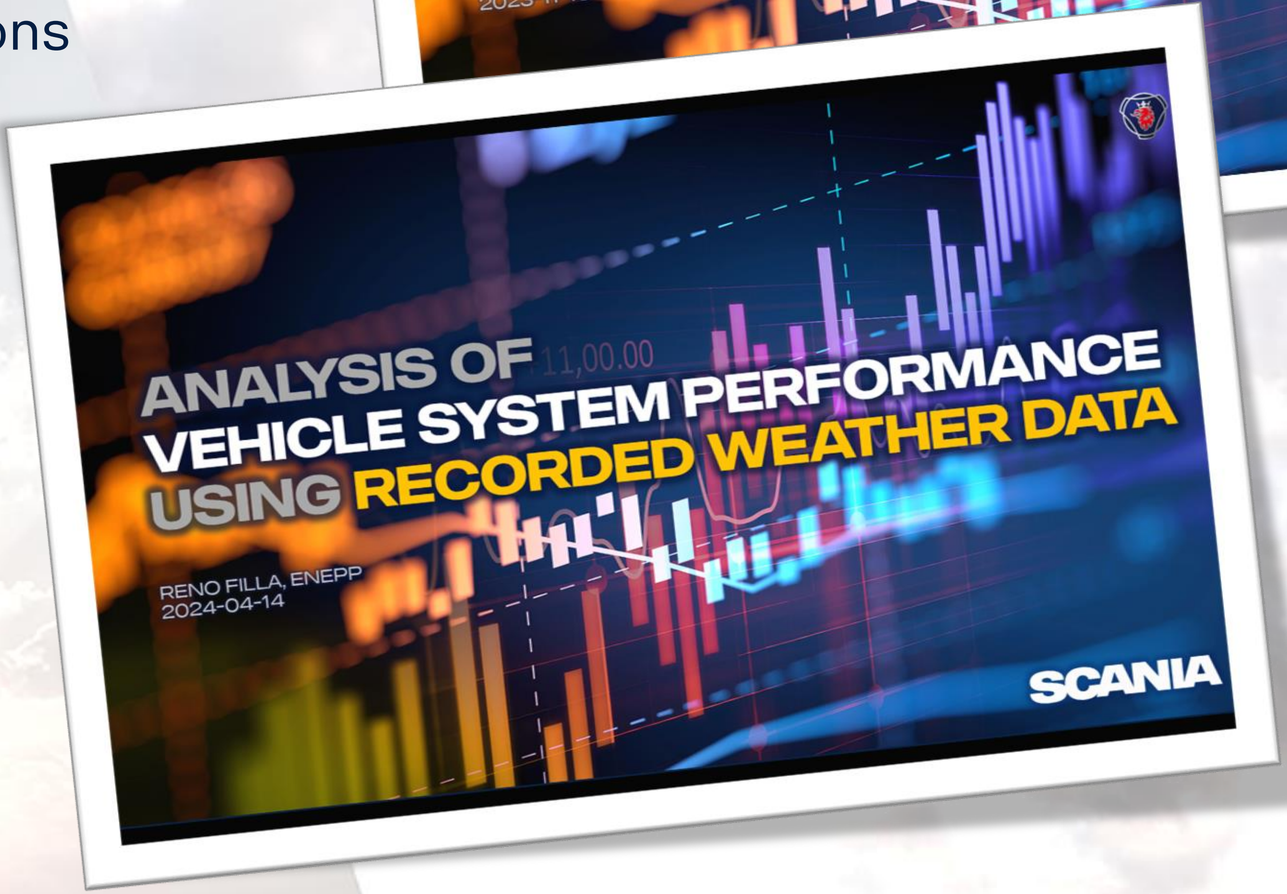

WE'VE GOT A SOLUTION
We now have
• data
• tools
• methods

METHODS

Use cases for

- Statistical distributions
- Time series data

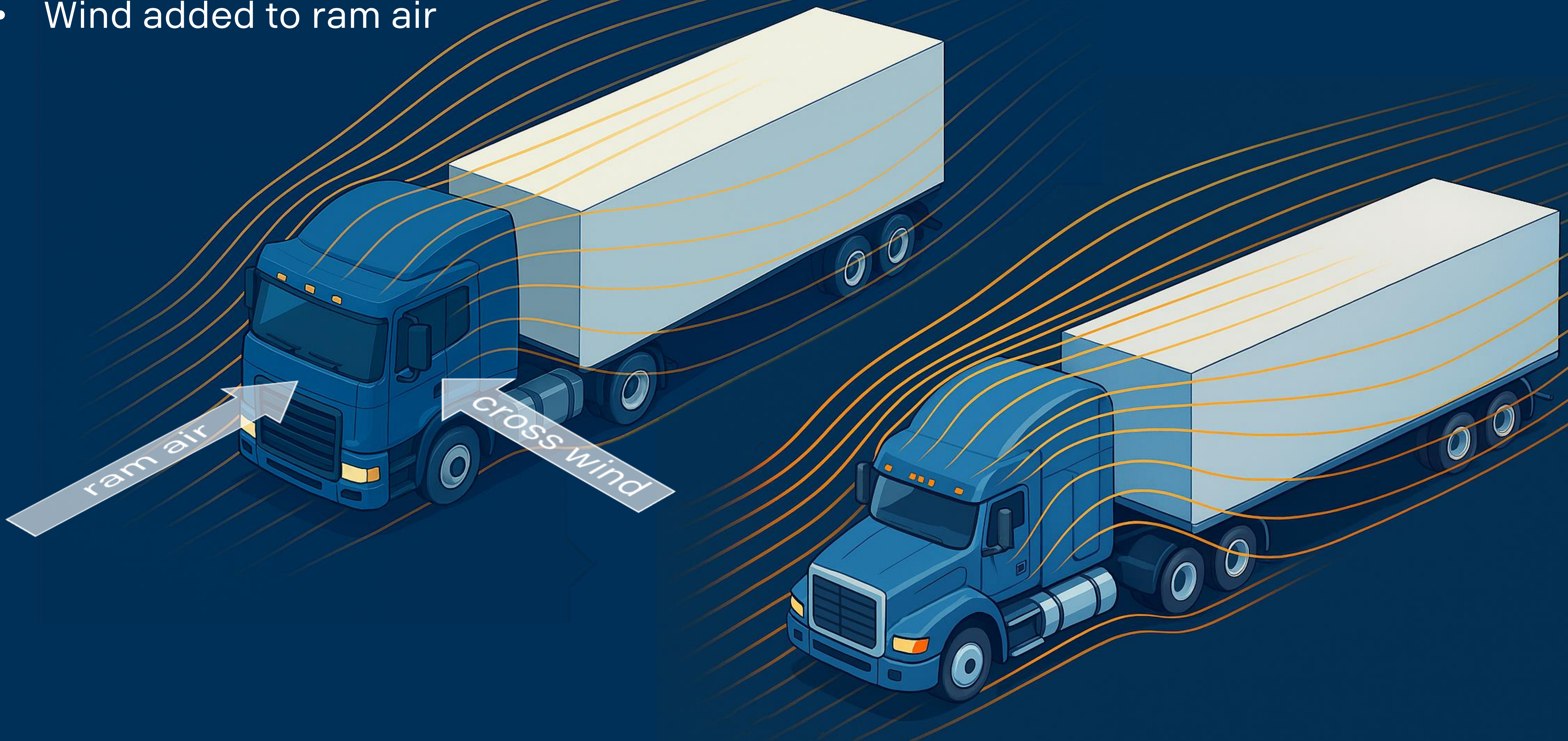




AERODYNAMICS

Air resistance in realistic conditions

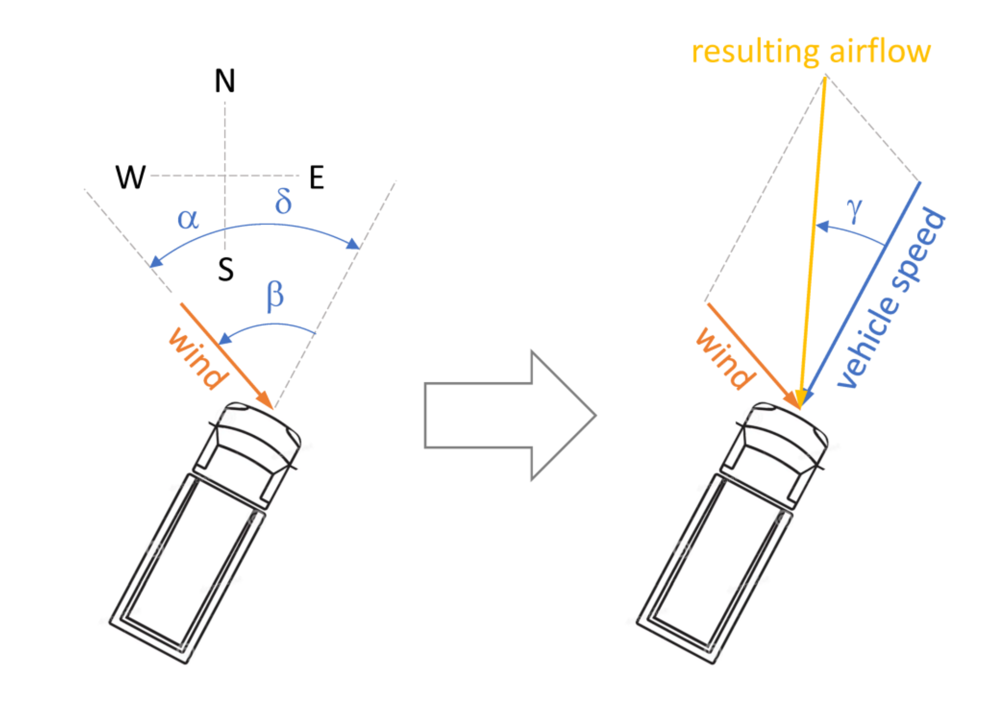
- Wind added to ram air

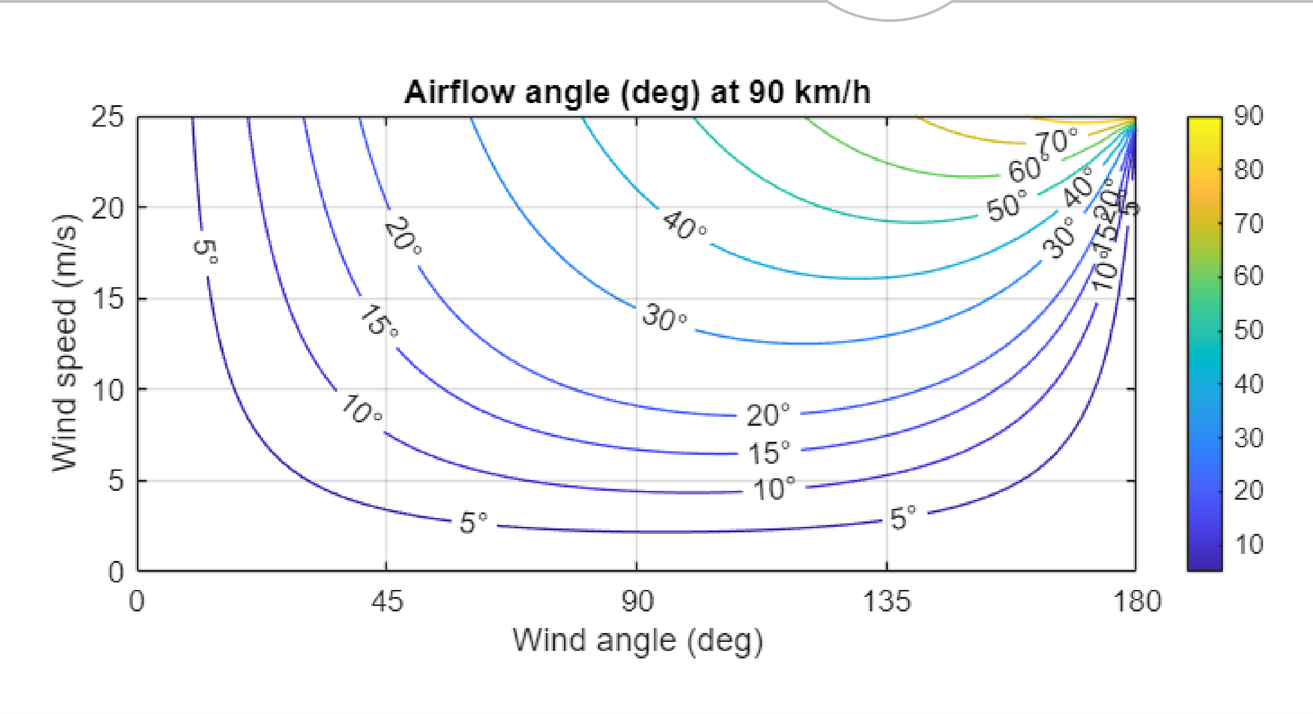


Air resistance in realistic conditions

- Wind added to ram air

How much do energy losses due to air resistance vary due to weather?

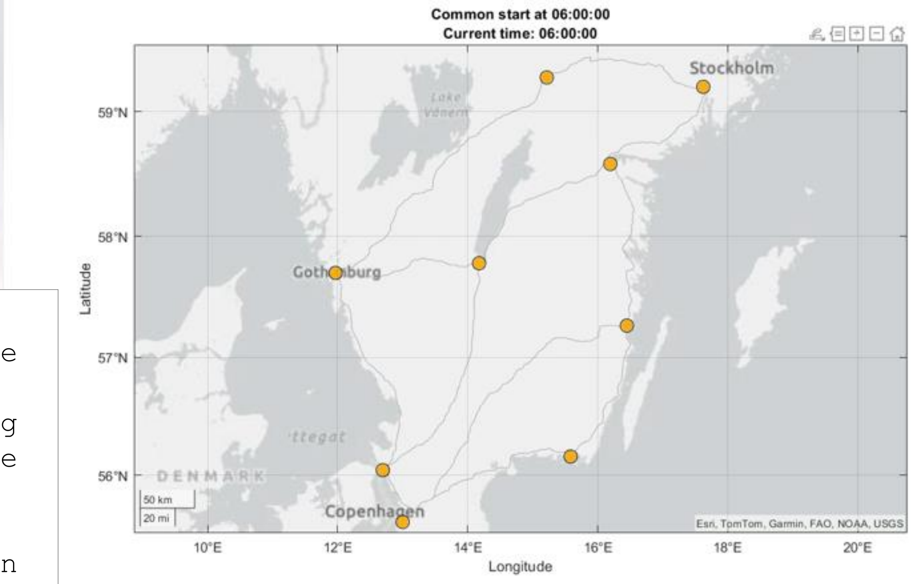


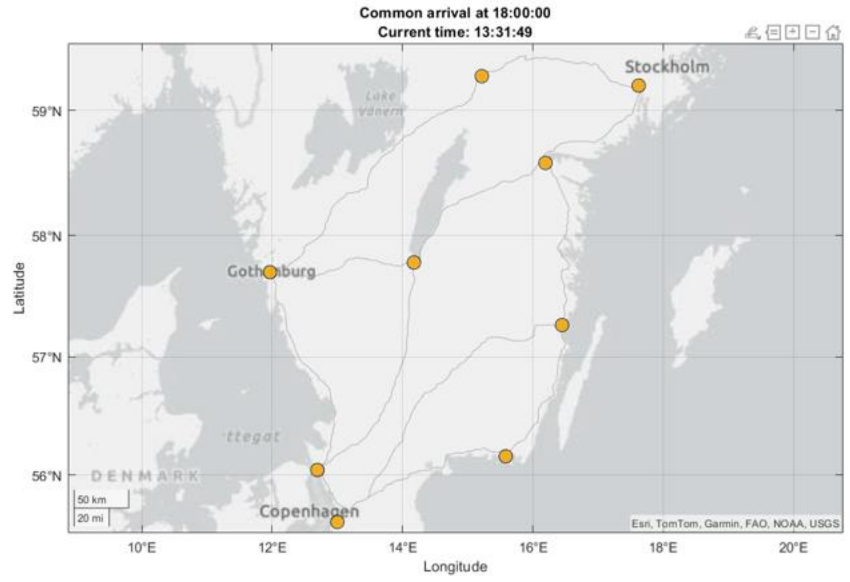


Create + analyse <u>synthetic</u> time-series data

- 11 routes over major roads in Mid/South Sweden
  - Realistic vehicle speed (typical traffic)
  - Speed limits obeyed, max 90 km/h
- Driven 2× a day in both directions
  1. Common start at 06:00 LT
  2. Common arrival at 18:00 LT
- Combine with recorded weather
  - For each day over up to 5 years
- Analyse energy losses
  - Air resistance
  - Rolling resistance

Göteborg	↔	Örebro
Örebro	↔	Södertälje
Göteborg	↔	Jönköping
Jönköping	↔	Norrköping
Norrköping	↔	Södertälje
Malmö	↔	Göteborg
Helsingborg	↔	Jönköping
Malmö	↔	Oskarshamn
Malmö	↔	Karlskrona
Karlskrona	↔	Oskarshamn
Oskarshamn	↔	Norrköping





Advantage of analyzing these two major losses isolated: independent of type of powertrain

Create + analyse synthetic time-series data

Time	Timestamp_UTC	Latitude	Longitude	Distance_incr	Distance_cum	Elevation	Heading	Speed	Speed_limit
0	2024-03-04 11:52:29	57.712	11.968	0	0	1.6533	70.658	5	13.889
2.0211	2024-03-04 11:52:31	57.712	11.968	10.105	10.105	1.6965	70.658	5	13.889
4.0422	2024-03-04 11:52:33	57.712	11.968	10.105	20.211	1.7251	76.829	5	13.889
6.0009	2024-03-04 11:52:35	57.712	11.968	9.7938	30.005	1.8006	70.658	5	13.889
8.022	2024-03-04 11:52:37	57.712	11.969	10.105	40.11	1.8833	77.579	5	13.889
10.097	2024-03-04 11:52:39	57.712	11.969	10.375	50.485	1.9658	76.829	5	13.889
12.056	2024-03-04 11:52:41	57.712	11.969	9.7937	60.279	2.0419	70.658	5	13.889
14.077	2024-03-04 11:52:43	57.712	11.969	10.105	70.384	2.072	113.36	5	13.889

Matlab/Python toolbox

Scania-internal development by Reno Filla, started in 2019

- HERE: routing + typical traffic + speed limits
- Google: resample to high resolution + elevation
  25m intervals = 1Hz sampling at 90 km/h
- HERE: match back to road
- Trafikverket: recorded weather (REST API + VViS)
- SMHI: recorded weather

$$E_{air\_drag} = \int F_{air\_drag} v_{veh}\, dt$$

$$F_{air\_drag} = \frac{\rho_{air}}{2} v_{air}^2 c_D(\gamma) A$$

Create + analyse <u>synthetic</u> time-series data

Time	Timestamp_UTC	Latitude	Longitude	Distance_incr	Distance_cum	Elevation	Heading	Speed	Speed_limit
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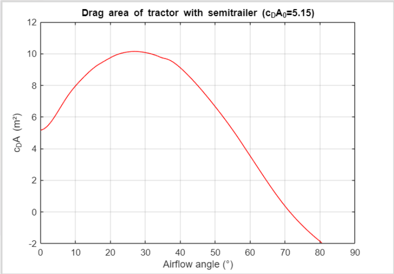

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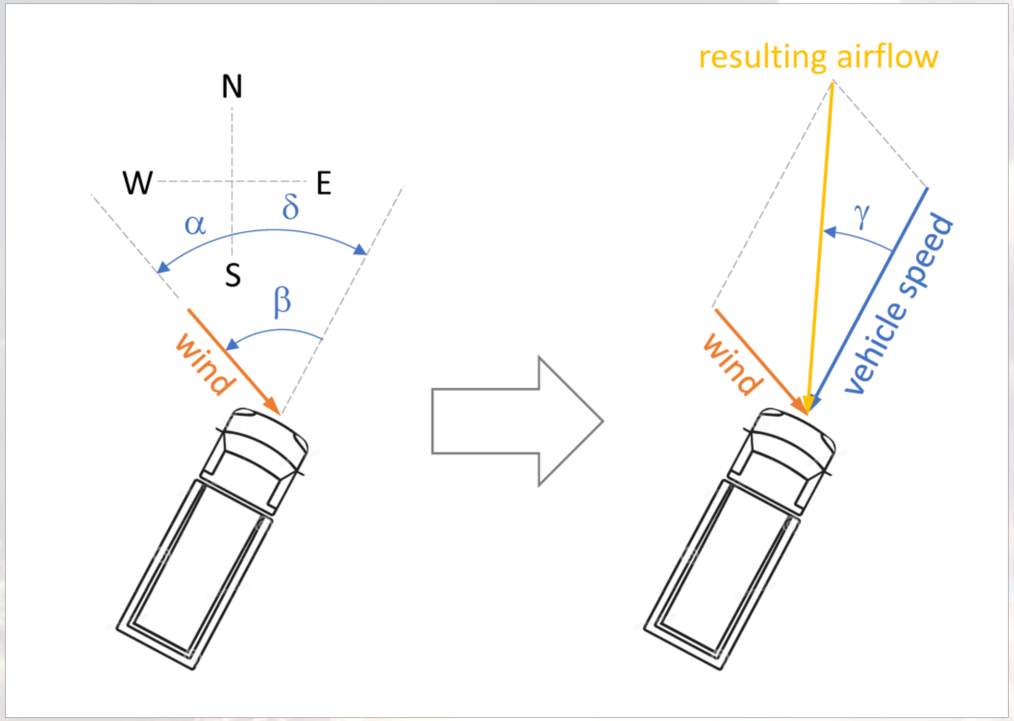
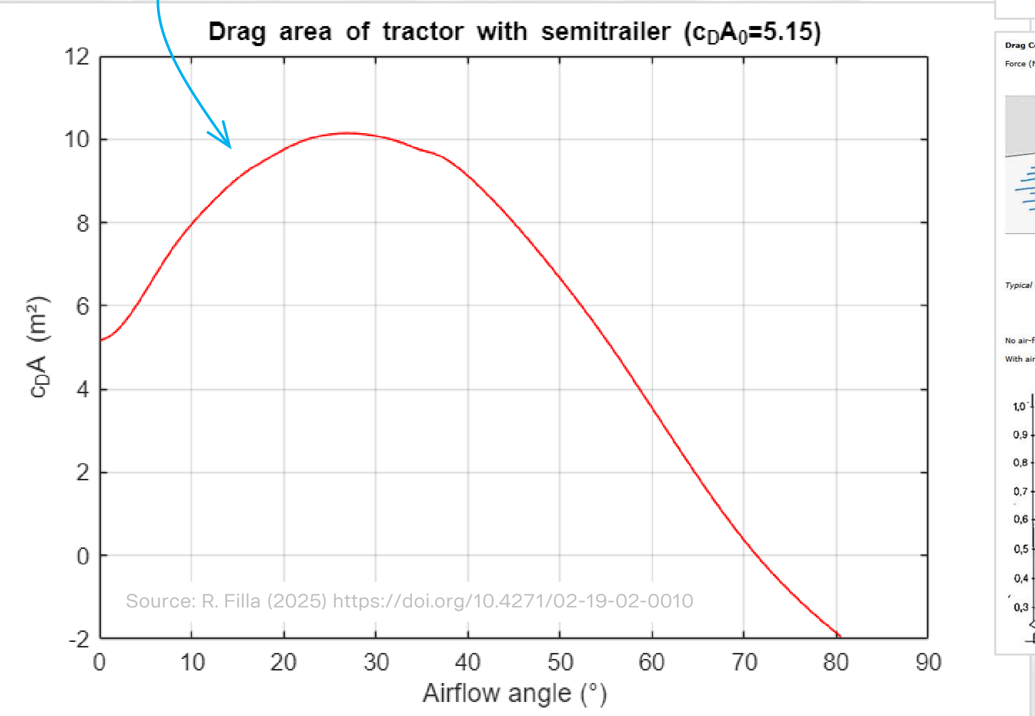
Air resistance in realistic conditions

- Wind added to ram air



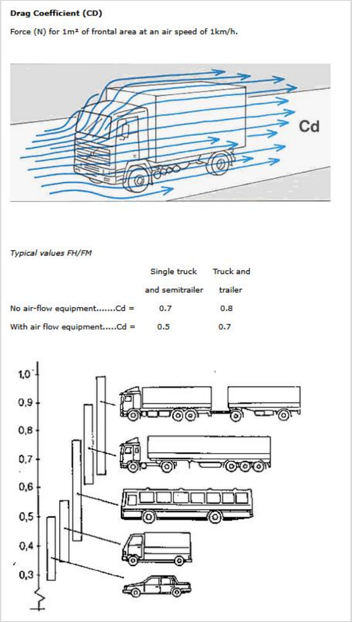
back-calculated
combining data from
- M. Askerdal et al. (2024)
- Volvo Trucks PERF



Askerdal, M., Fredriksson, J., and Laine, L., "Development of Simplified Air Drag Models Including Crosswinds for Commercial Heavy Vehicle Combinations," Vehicle System Dynamics 62, no. 5 (2024): 1085-1102, doi:https://doi.org/10.1080/00423114.2023.2213786.


Development of simplified air drag models including crosswinds for commercial heavy vehicle combinations

https://doi.org/10.1080/00423114.2023.2213786


Drag Coefficient (CD)

Force (N) for 1m² of frontal area at an air speed of 1km/h.

Typical values FH/FM

	Single truck and semitrailer	Truck and trailer
No air-flow equipment.......Cd =	0.7	0.8
With air flow equipment.....Cd =	0.5	0.7

https://vbi.truck.volvo.com/portal/perfman/020_terminology/drag_coefficient_%28cd%29.htm

Create + analyse synthetic time-series data

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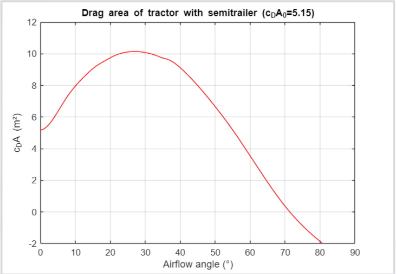


$$F_{air\_drag} = \frac{\rho_{air}}{2} v_{air}^2 c_D(\gamma) A$$

TrV

air temperature

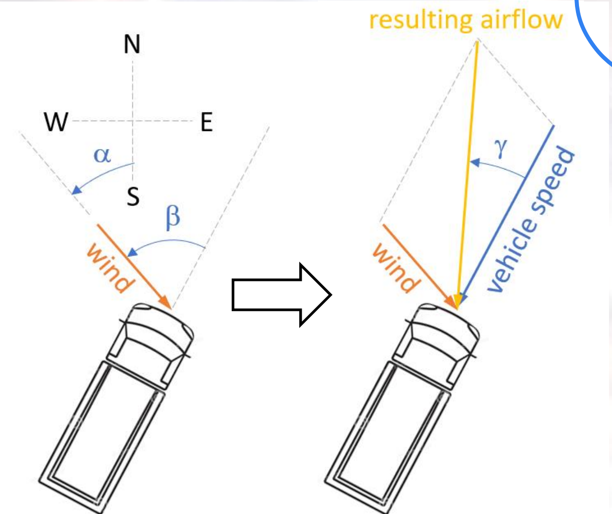
SMHI

air pressure

air humidity

elevation (altitude)

from synthetic vehicle log



wind direction

wind speed

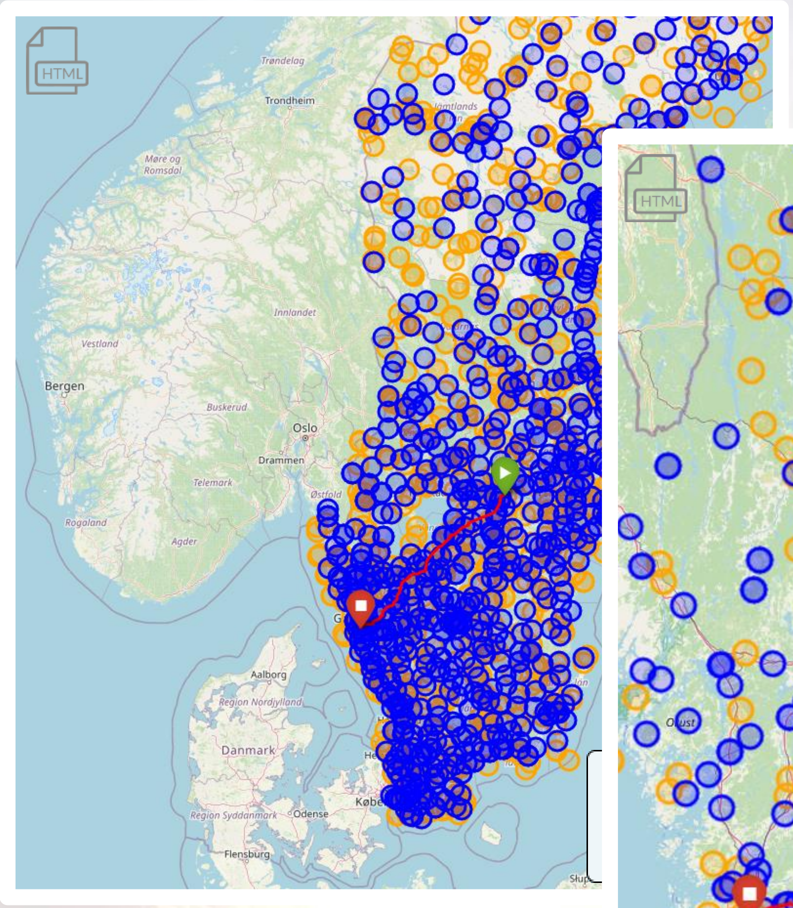
TrV

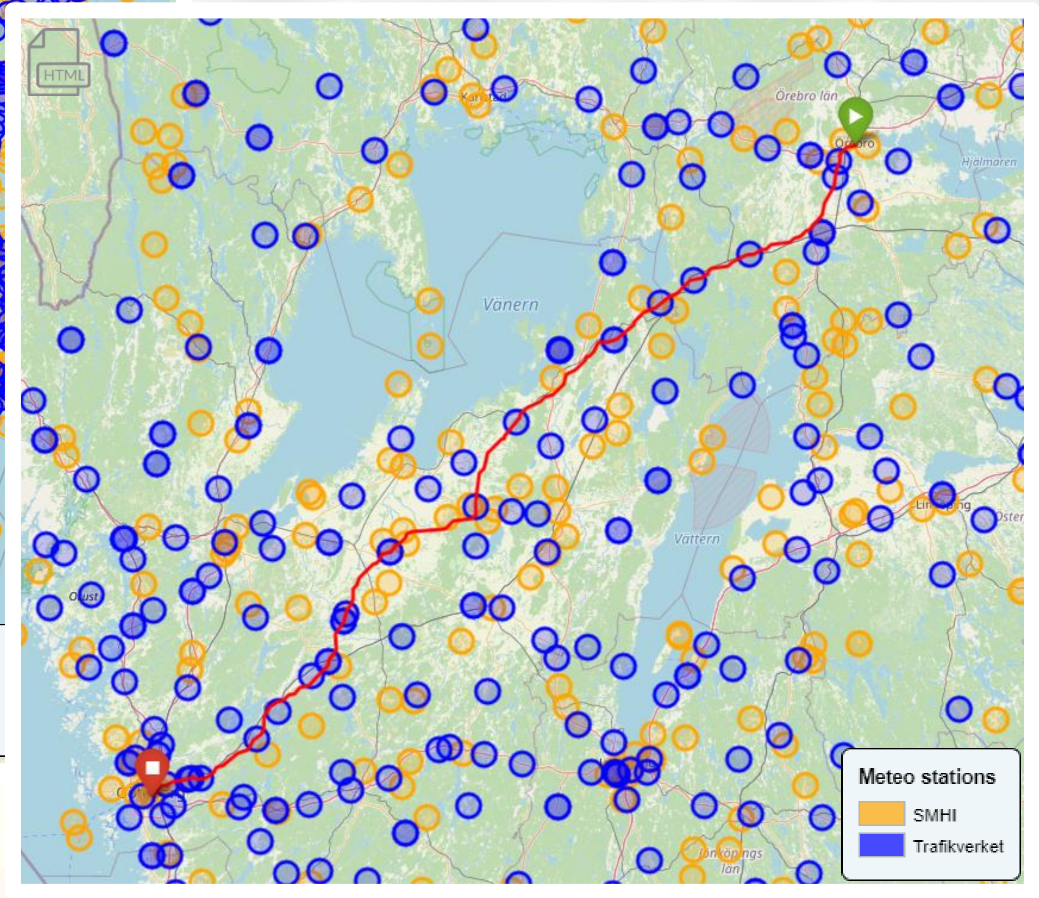
vehicle heading

vehicle speed

log

Create + analyse <u>synthetic</u> time-series data





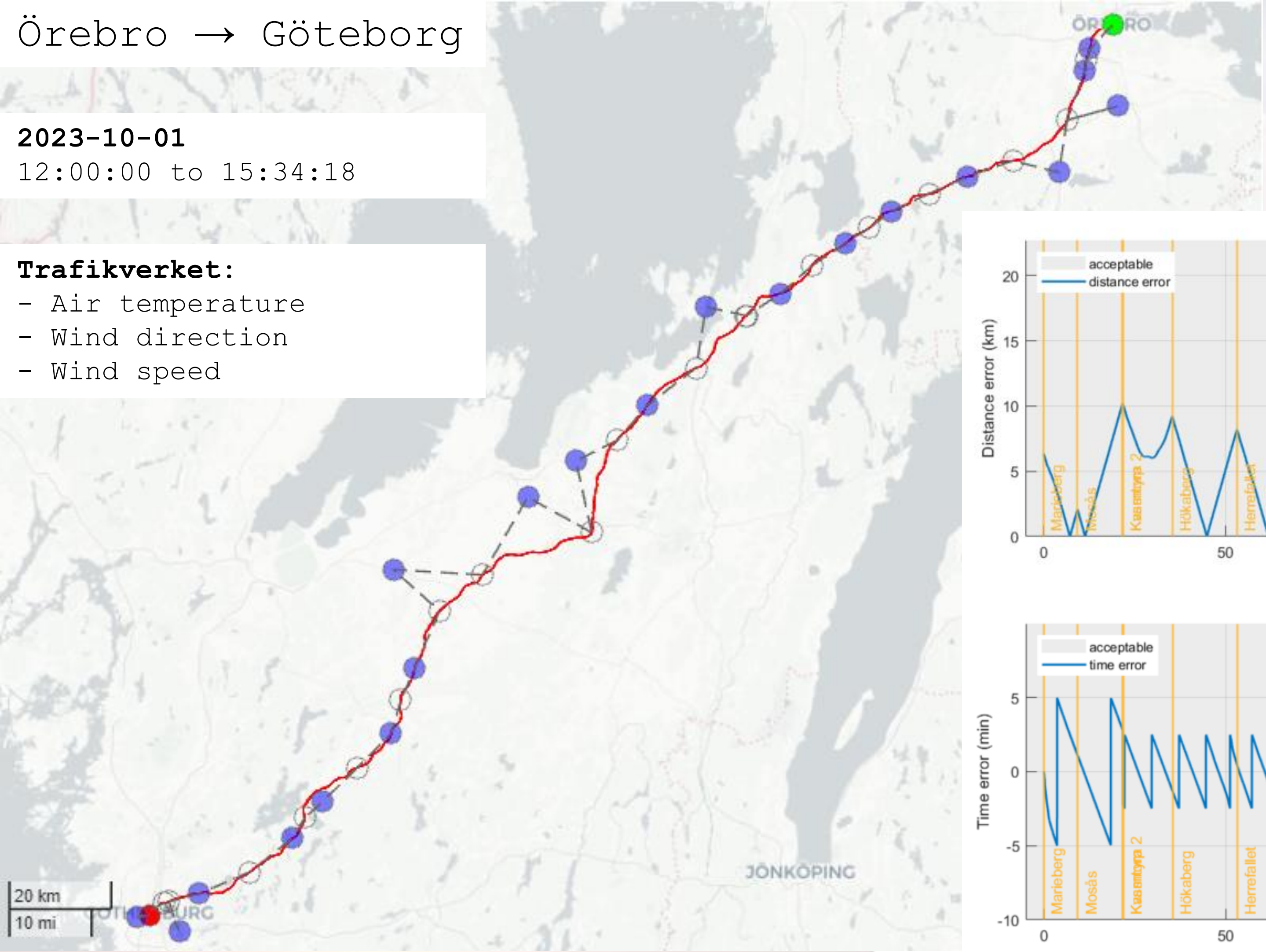
Örebro → Göteborg

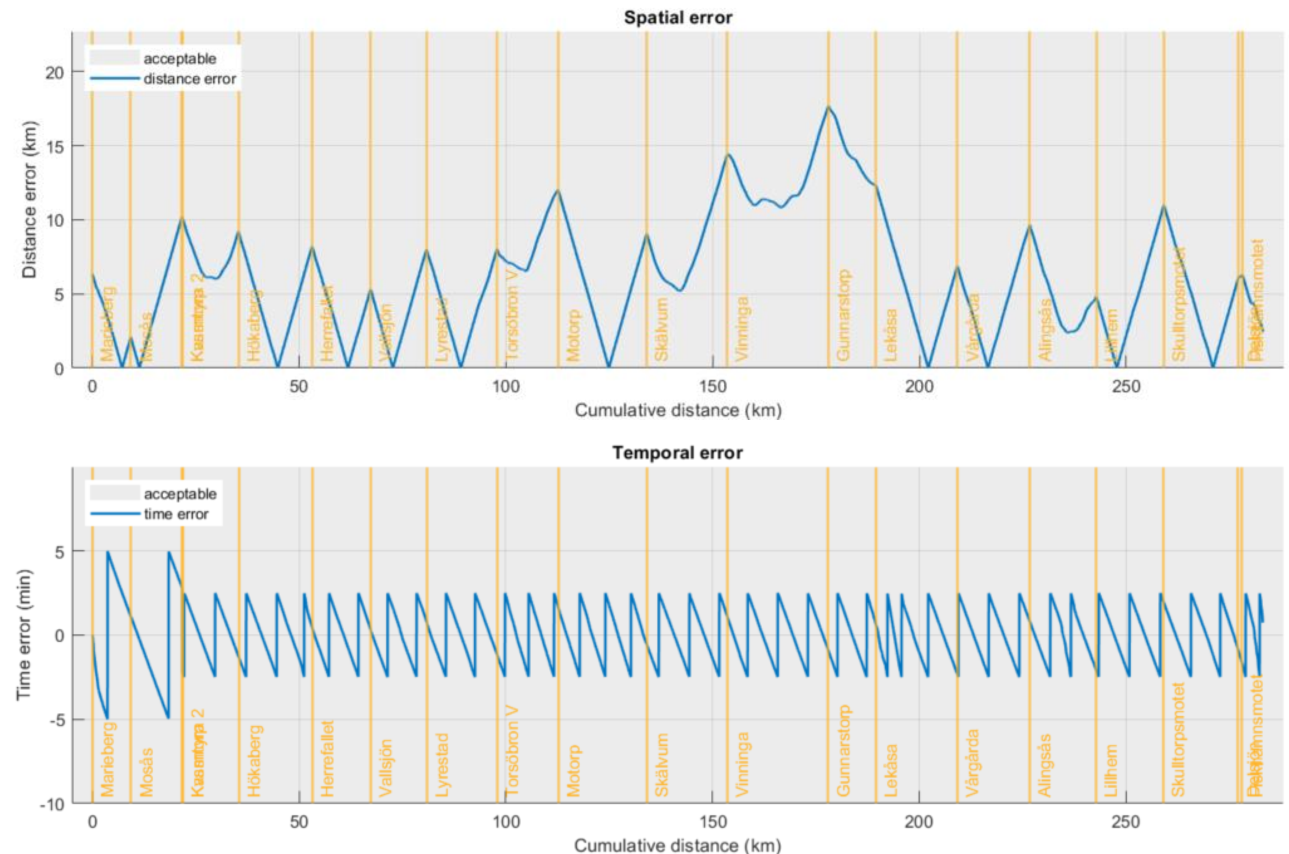
Create + analyse synthetic time-series data

Örebro → Göteborg

2023-10-01
12:00:00 to 15:34:18

Trafikverket:
- Air temperature
- Wind direction
- Wind speed



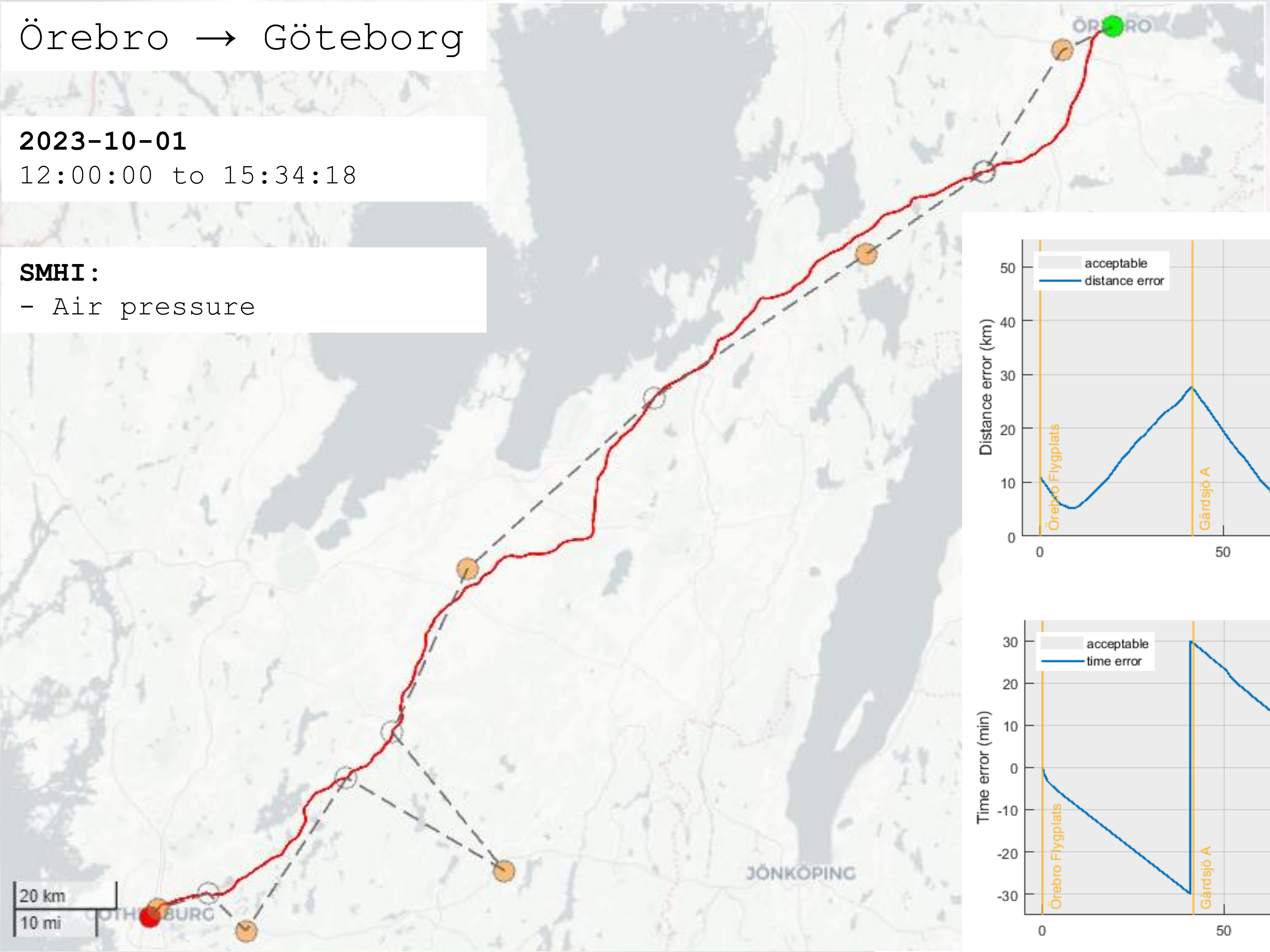


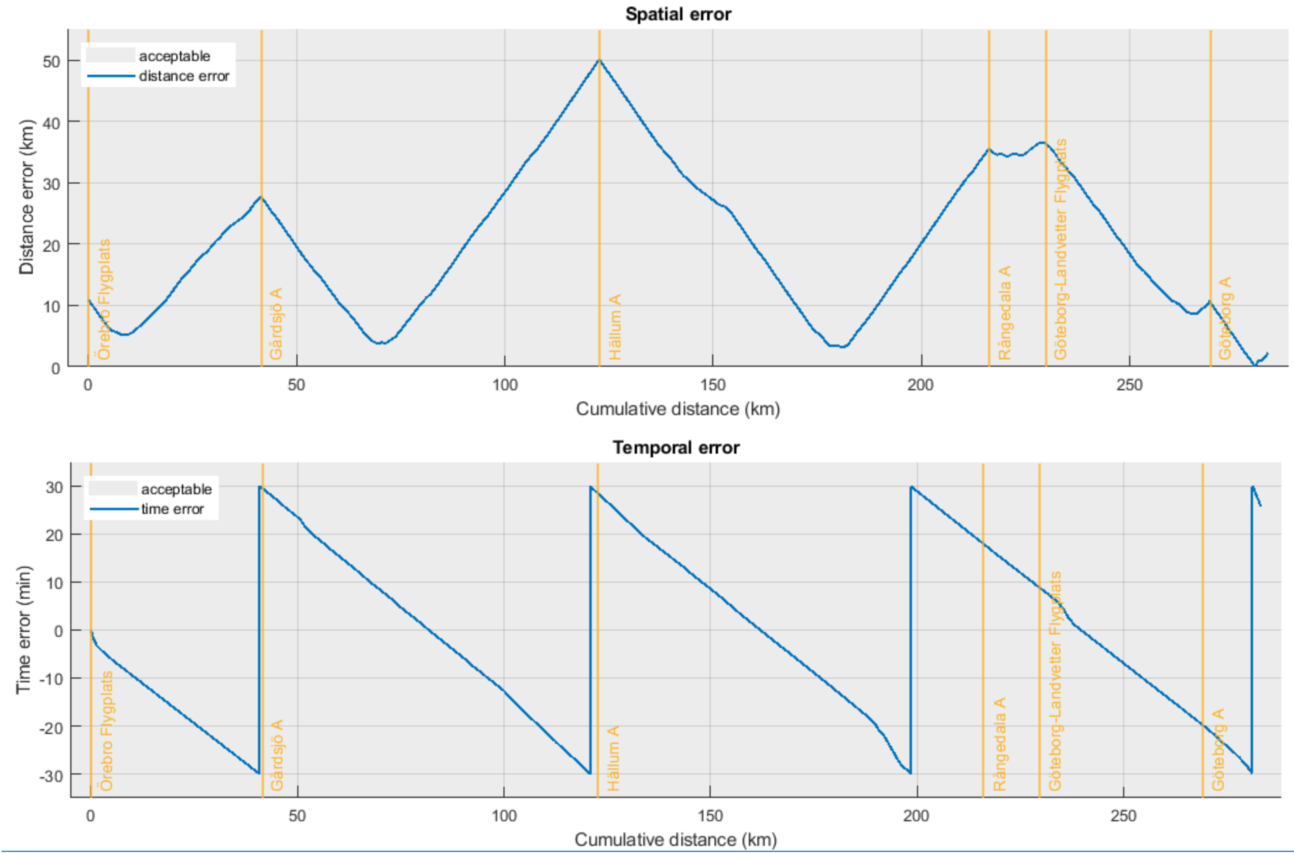
Create + analyse synthetic time-series data

Örebro → Göteborg

2023-10-01
12:00:00 to 15:34:18

SMHI:
- Air pressure



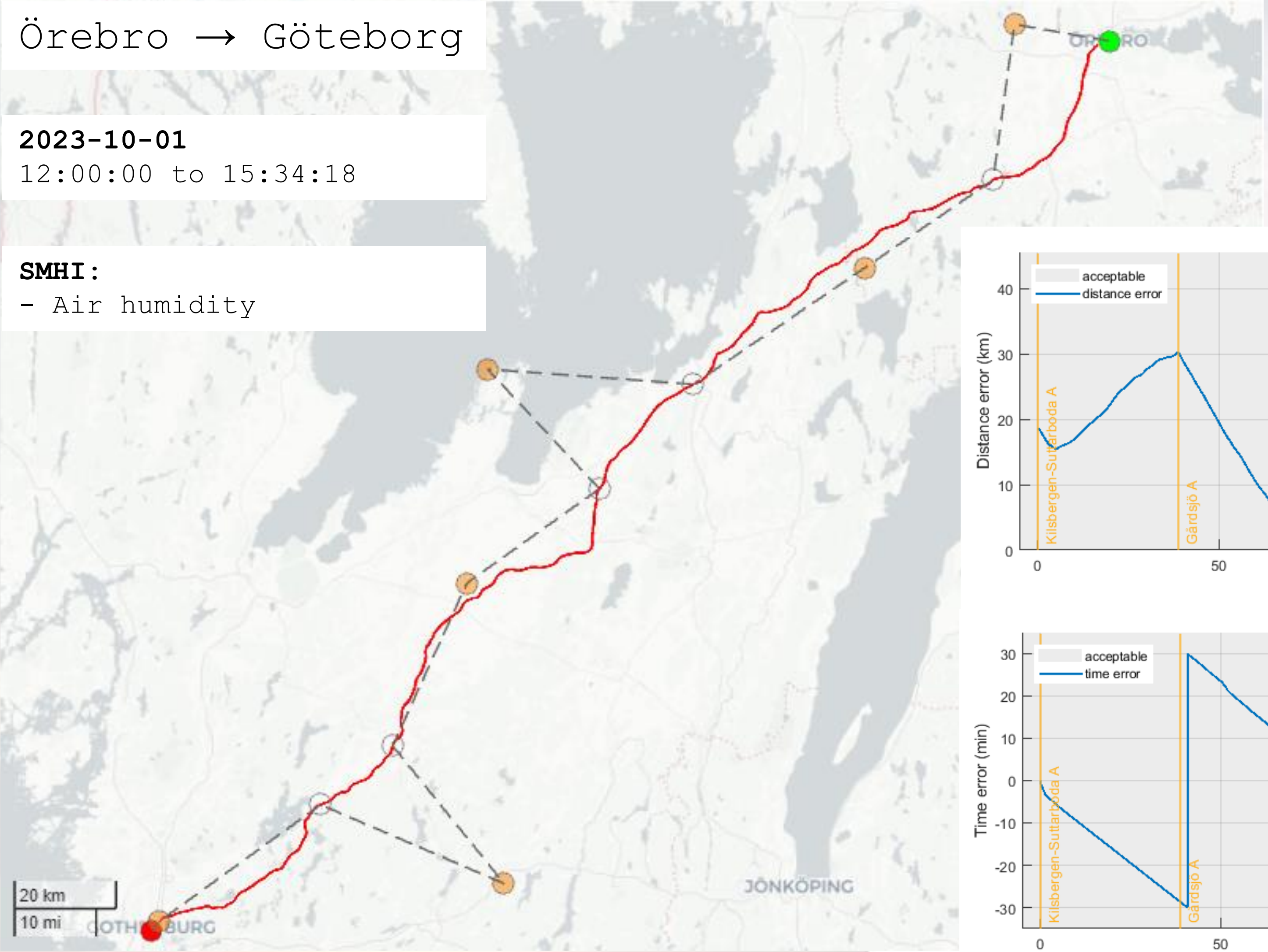


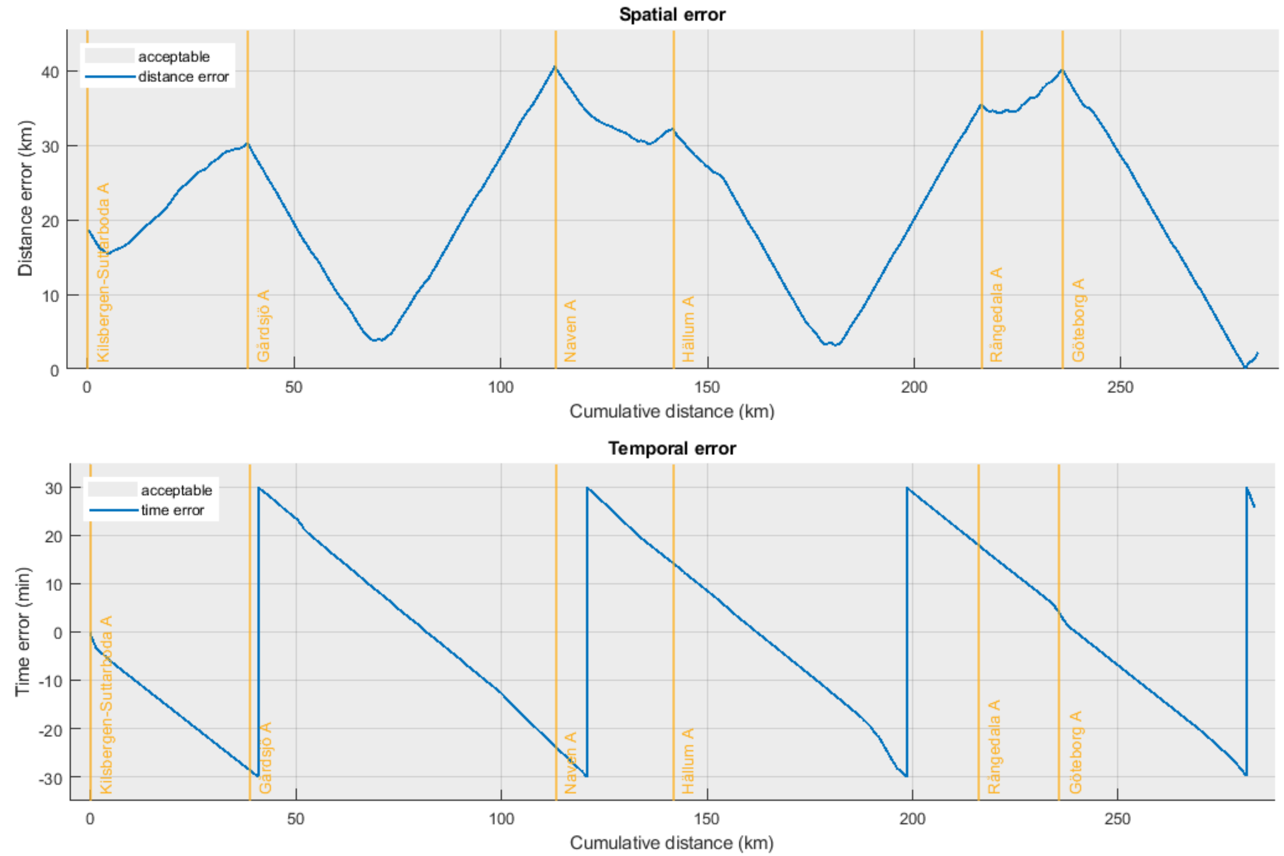
Create + analyse synthetic time-series data

Örebro → Göteborg

2023-10-01
12:00:00 to 15:34:18

SMHI:
- Air humidity





Create + analyse synthetic time-series data

from synthetic vehicle log

Computed and aggregated for
- 11 routes
- 2 directions
- 2 times a day
- each day for 5 years

= 190 h of processing
(one-time effort)

from CFD simulations

TrV

air t

SMHI

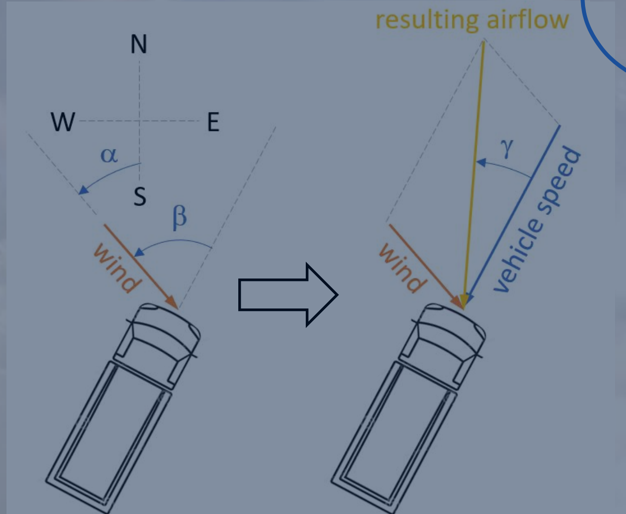
air p

air hu

elevation (altitude)

from synthetic vehicle log

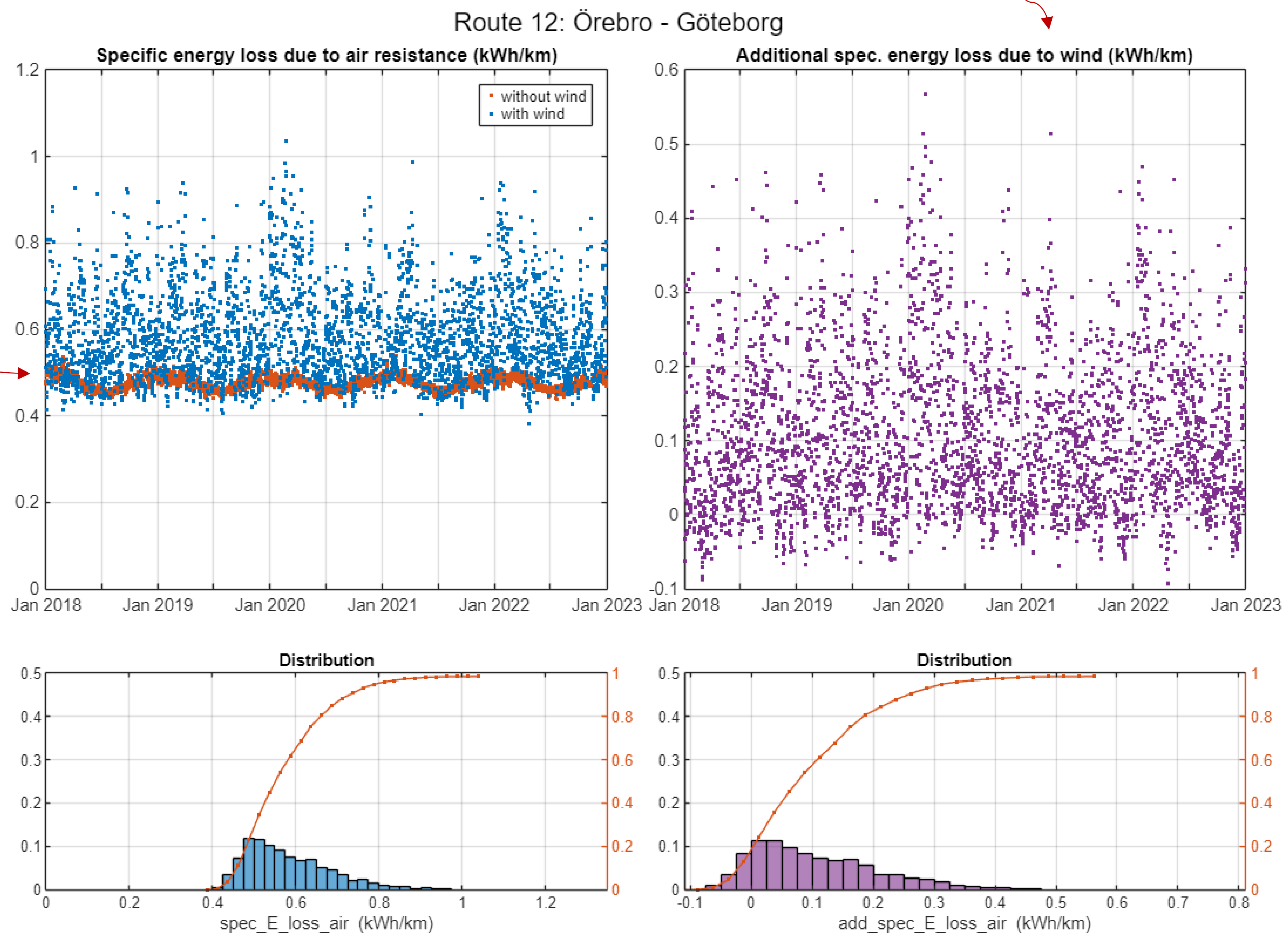
$$\frac{}{2} v_{air}^2 c_D(\gamma) A$$



wind direction
wind speed
TrV

vehicle heading
vehicle speed
log

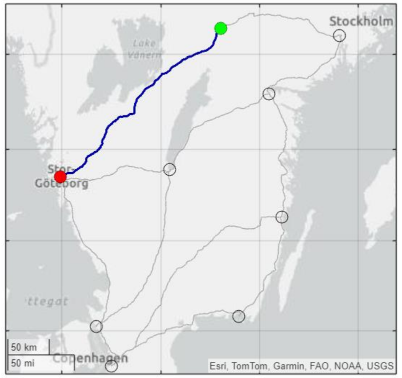
diff with wind to without wind
= robustness



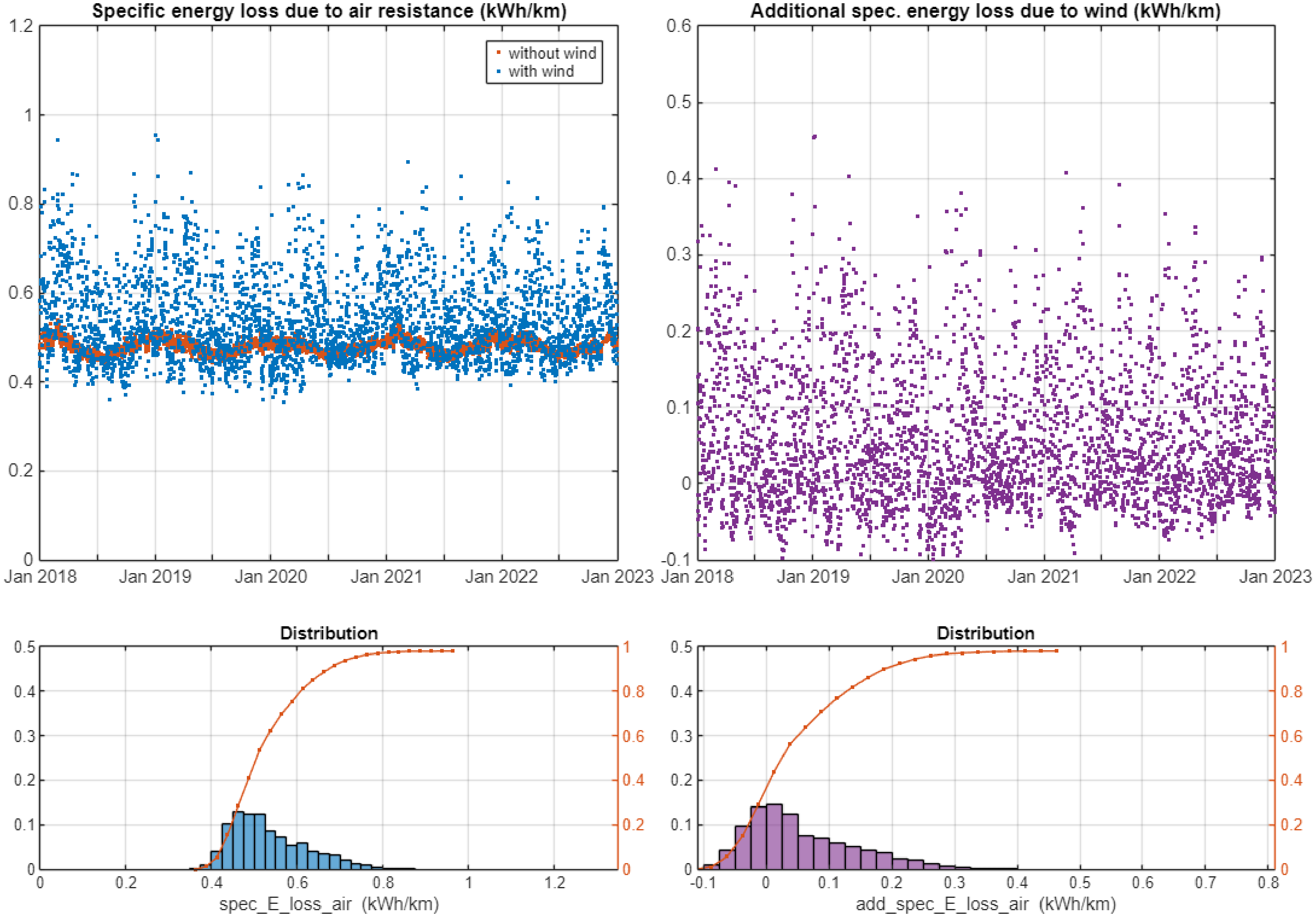
plot without wind
is not a horizontal line
due to air density changing
with air temperature, pressure,
and humidity

sinusoidal variation
due to the seasons
(winter vs summer)

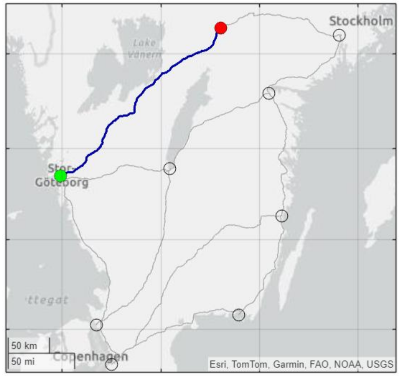
Örebro → Göteborg



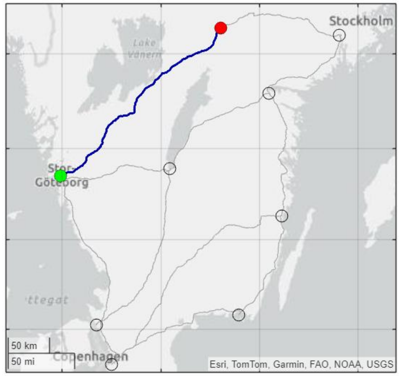
Route 1: Göteborg - Örebro



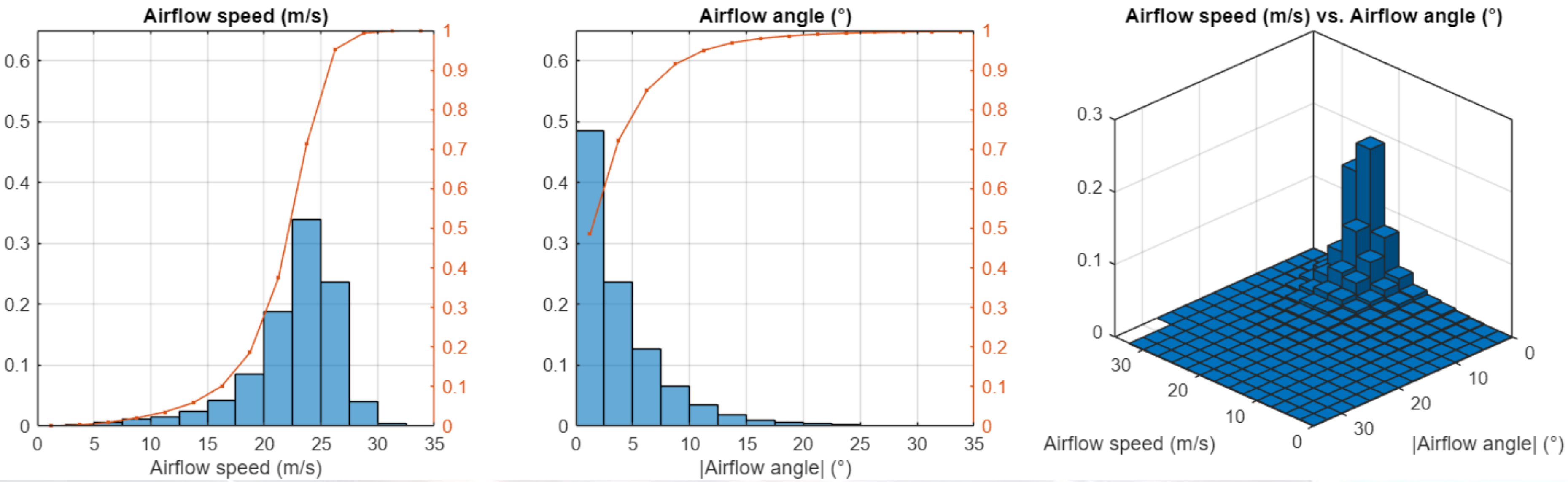
Göteborg → Örebro



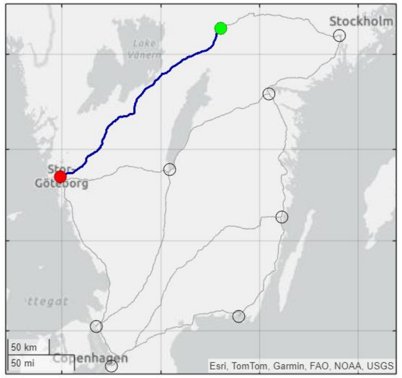
Göteborg → Örebro



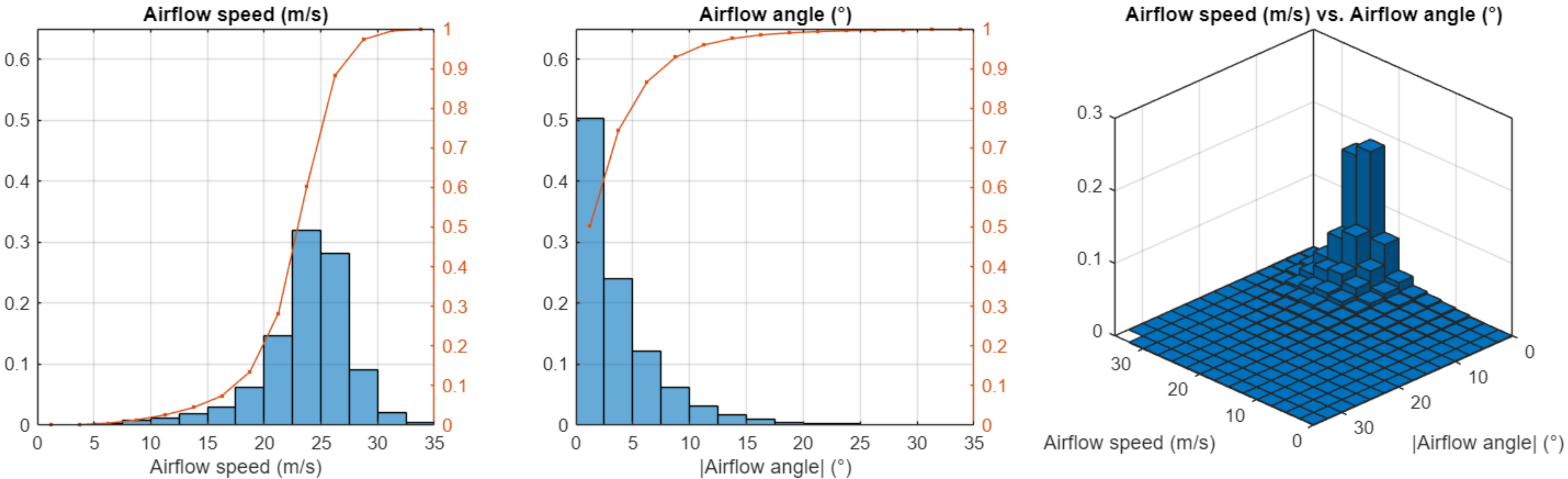
Route 1: Göteborg - Örebro



Örebro → Göteborg

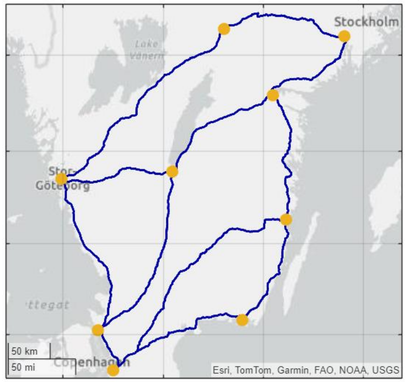


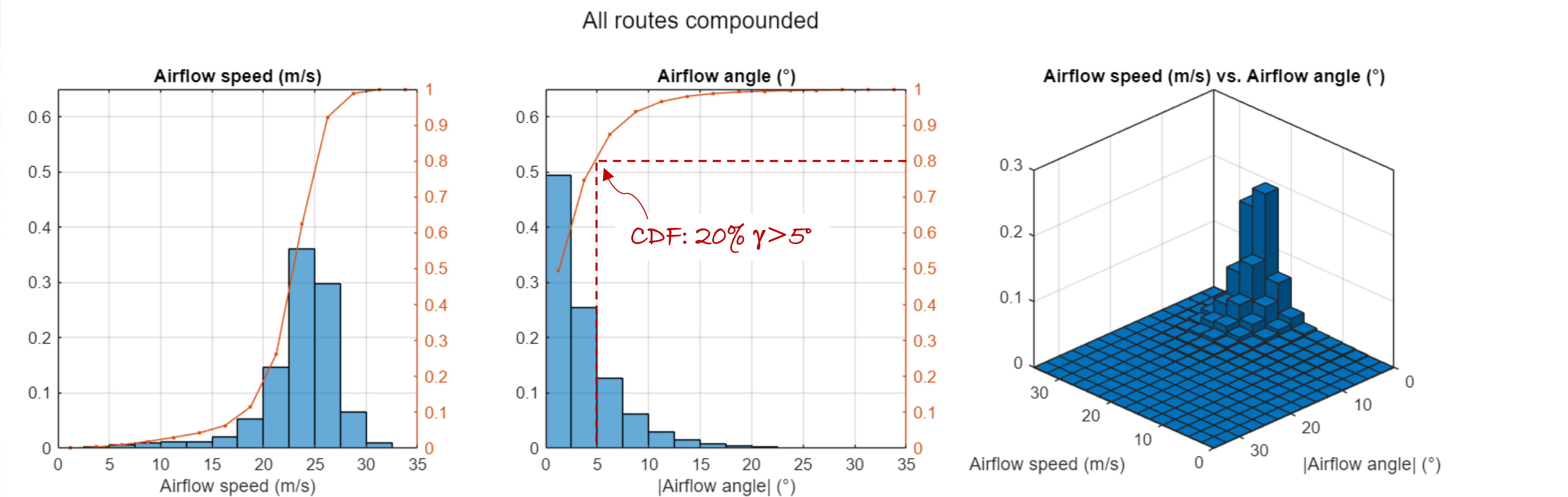
Route 12: Örebro - Göteborg



How useful are historic weather patterns in the times of **Climate Change** ?

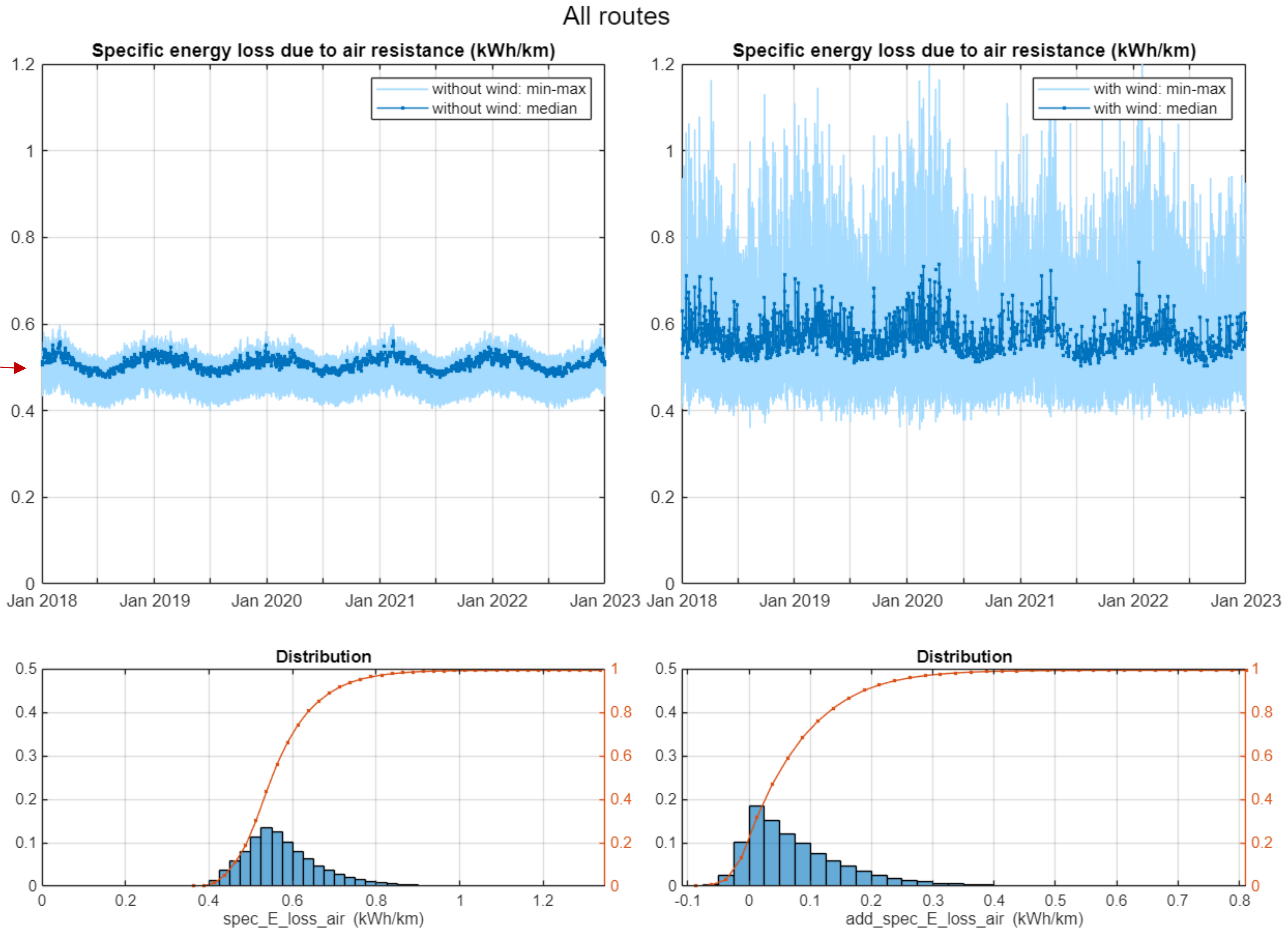
All routes



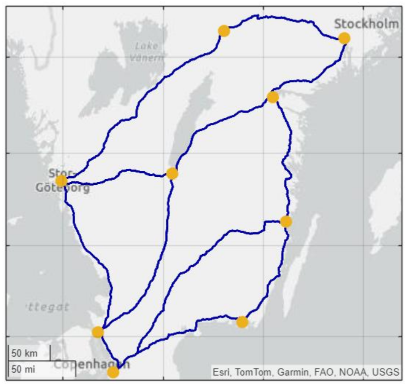


44 data points per day,
all with different air density
due to different air temperature,
pressure, and humidity

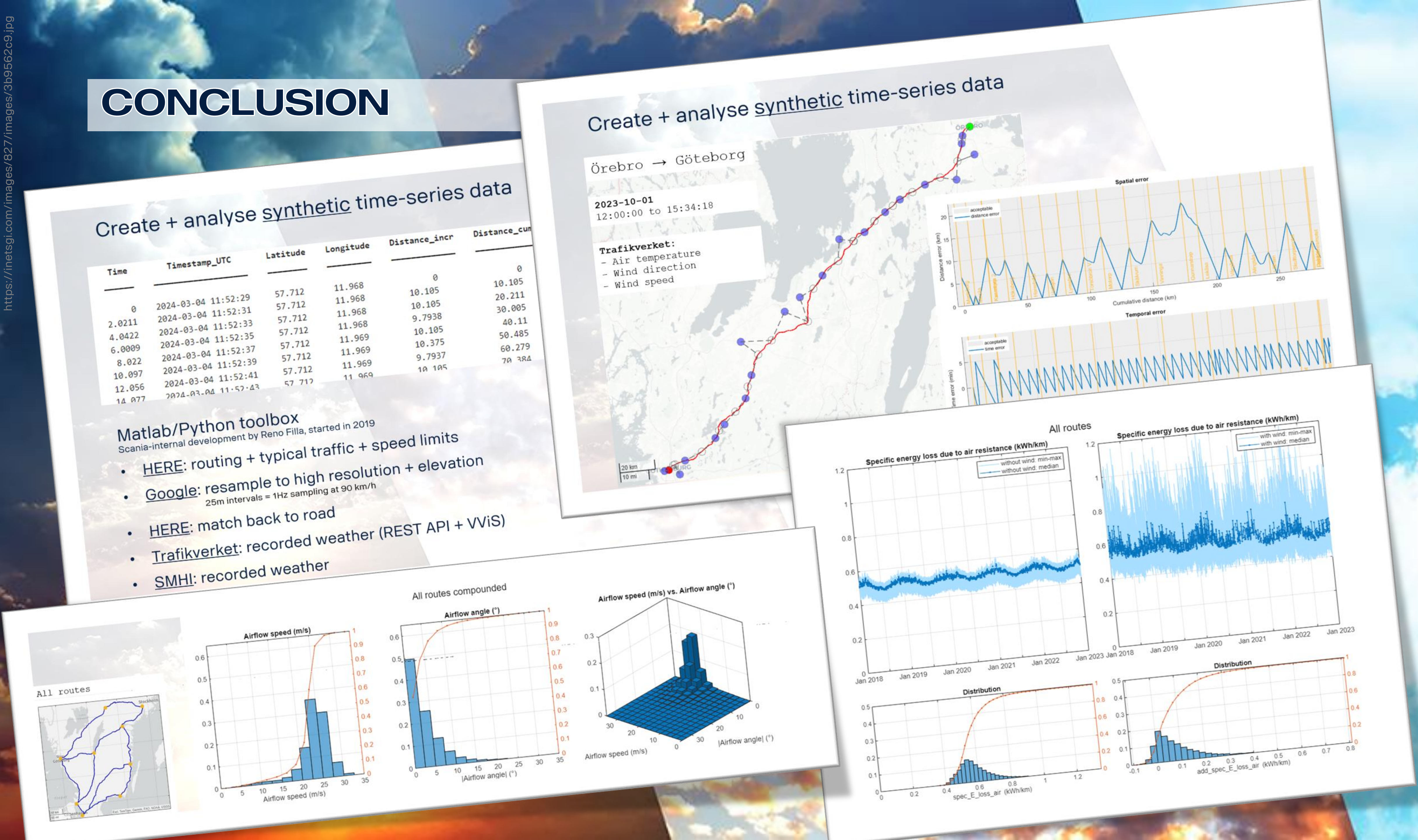
sinusoidal variation
due to the seasons
(winter vs summer)



All routes



CONCLUSION



Create + analyse synthetic time-series data
Time | Timestamp_UTC | Latitude | Longitude | Distance_incr | Distance_cum
0 | 2024-03-04 11:52:29 | 57.712 | 11.968 | 0 | 0
2.0211 | 2024-03-04 11:52:31 | 57.712 | 11.968 | 10.105 | 10.105
4.0422 | 2024-03-04 11:52:33 | 57.712 | 11.968 | 10.105 | 20.211
6.0009 | 2024-03-04 11:52:35 | 57.712 | 11.968 | 9.7938 | 30.005
8.022 | 2024-03-04 11:52:37 | 57.712 | 11.969 | 10.105 | 40.11
10.097 | 2024-03-04 11:52:39 | 57.712 | 11.969 | 10.375 | 50.485
12.056 | 2024-03-04 11:52:41 | 57.712 | 11.969 | 9.7937 | 60.279
Matlab/Python toolbox
Scania-internal development by Reno Filla, started in 2019
• HERE: routing + typical traffic + speed limits
• Google: resample to high resolution + elevation
25m intervals = 1Hz sampling at 90 km/h
• HERE: match back to road
• Trafikverket: recorded weather (REST API + VViS)
• SMHI: recorded weather
Create + analyse synthetic time-series data
Örebro → Göteborg
2023-10-01
12:00:00 to 15:34:18
Trafikverket:
- Air temperature
- Wind direction
- Wind speed
Spatial error
Cumulative distance (km)
Temporal error
All routes compounded
All routes
Airflow speed (m/s)
Airflow angle (°)
|Airflow angle| (°)
Airflow speed (m/s) vs. Airflow angle (°)
All routes
Specific energy loss due to air resistance (kWh/km)
without wind: min-max
without wind: median
with wind: min-max
with wind: median
Distribution
spec_E_loss_air (kWh/km)
add_spec_E_loss_air (kWh/km)

CONCLUSION

(Industry and Academia)

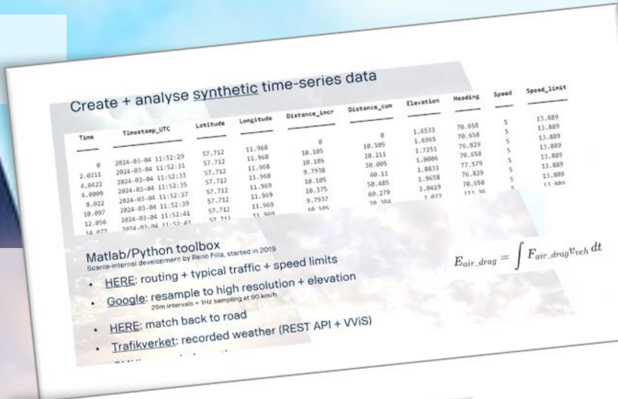
Weather changes all the time

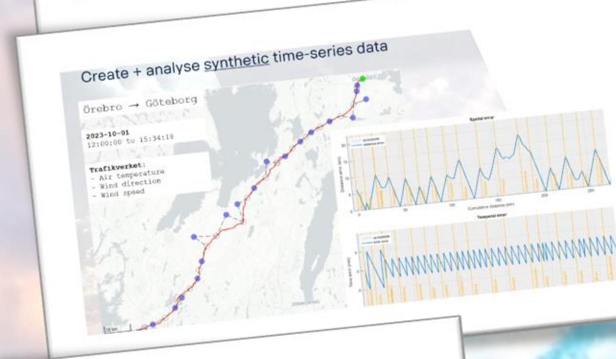
Now we have the data, tools and methods to include this

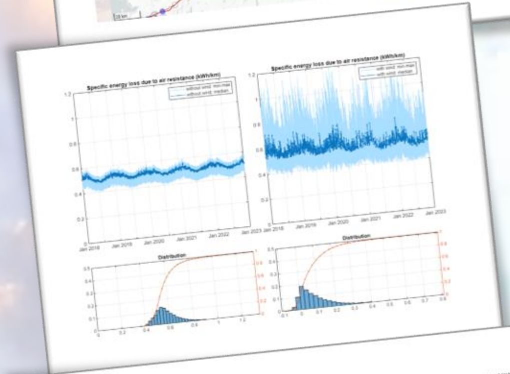
- in analysis of recorded operation
- in simulation
- in component/system dimensioning

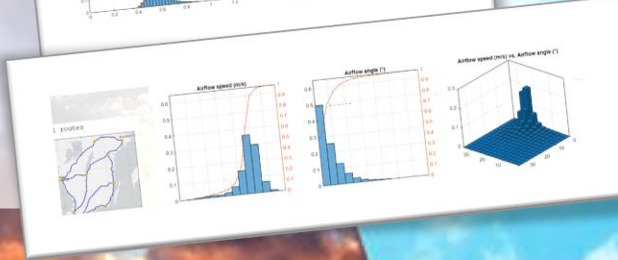
Now we have no more excuses…

- for writing off poor performance as due to bad weather and thus missing real deviations
- for designing products with poor performance robustness due to insufficient testing in bad conditions









THANK YOU!

RENO.FILLA@SE.TRATON.COM

TRATON