19th International Road Weather Conference 2018, SK, Smolenice

Route based road condition forecast using mobile sensors

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KS-Consulting

Trial Routes

No	Area	Maintenance Group	Forecast Provider	Route Length
1	BAB A9 Bayern	AM Greding	DWD, GWC, FORECA, DTN, meteoblue,	ca. 50 km
2	Viechtach St2139 Bayern	SM Viechtach	DWD, GWC, FORECA, DTN, meteoblue	ca. 14 km
3	BAB A4 Bergisch Gladbach	BASt	DWD, GWC, FORECA, DTN, meteoblue	ca. 55 km

Project duration: October 2018 until October 2017

Aquisition of mobile data: Oct. 2015 … April 2016
and Oct. 2016 ... April 2017

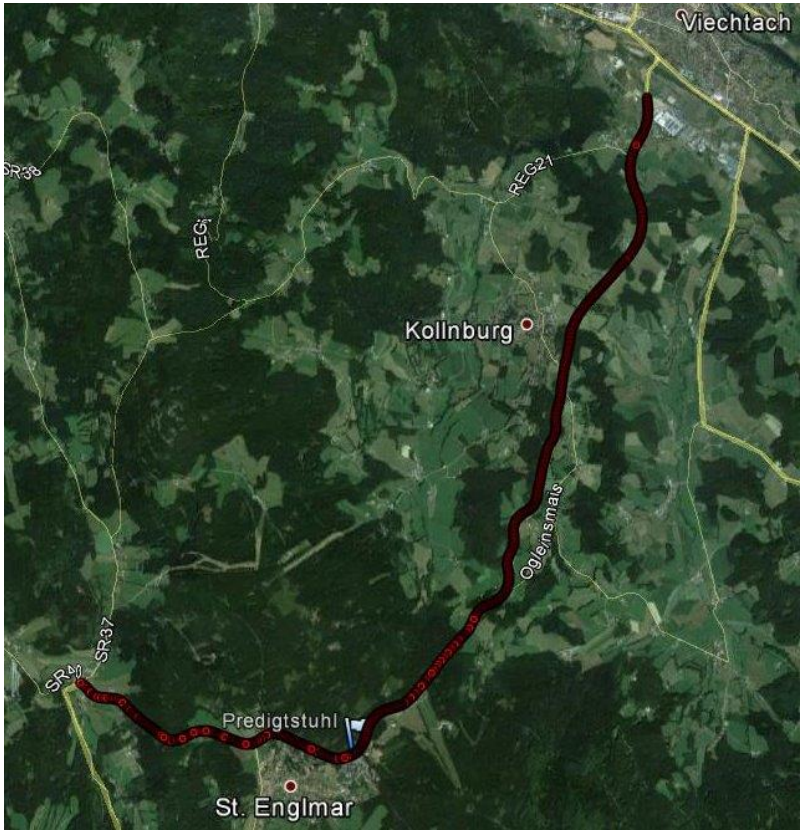
Positions of the trial routes

BAB A9 Greding

ca. 50 km

SWS Offenbau
SWS Gelbelsee

AM Greding



St2139 Viechtach

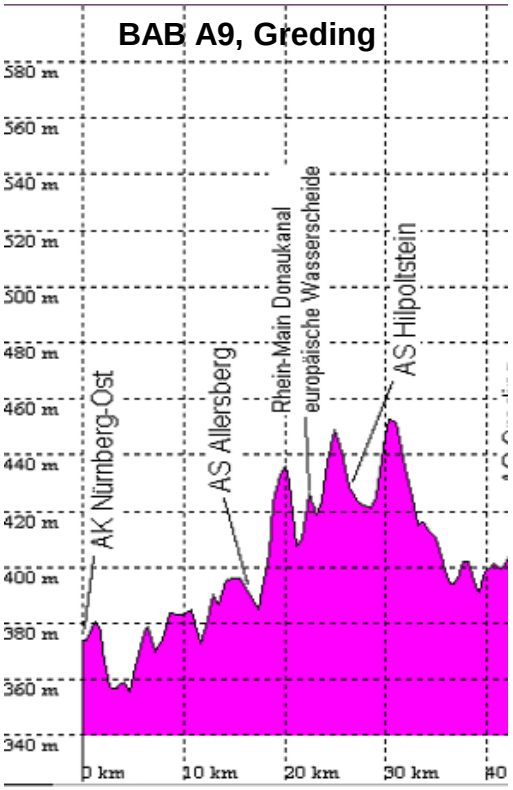
ca. 14,4 km

SWS Predigtstuhl

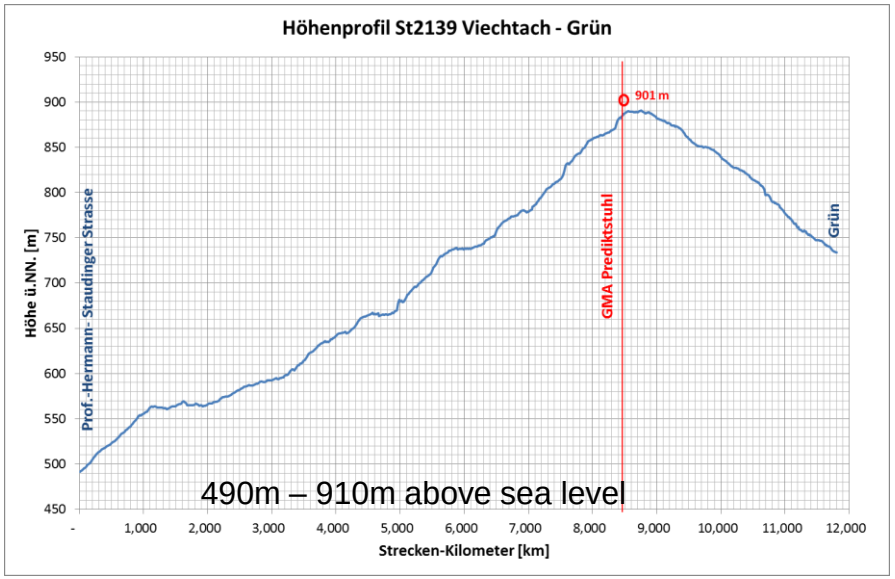
SM Viechtach

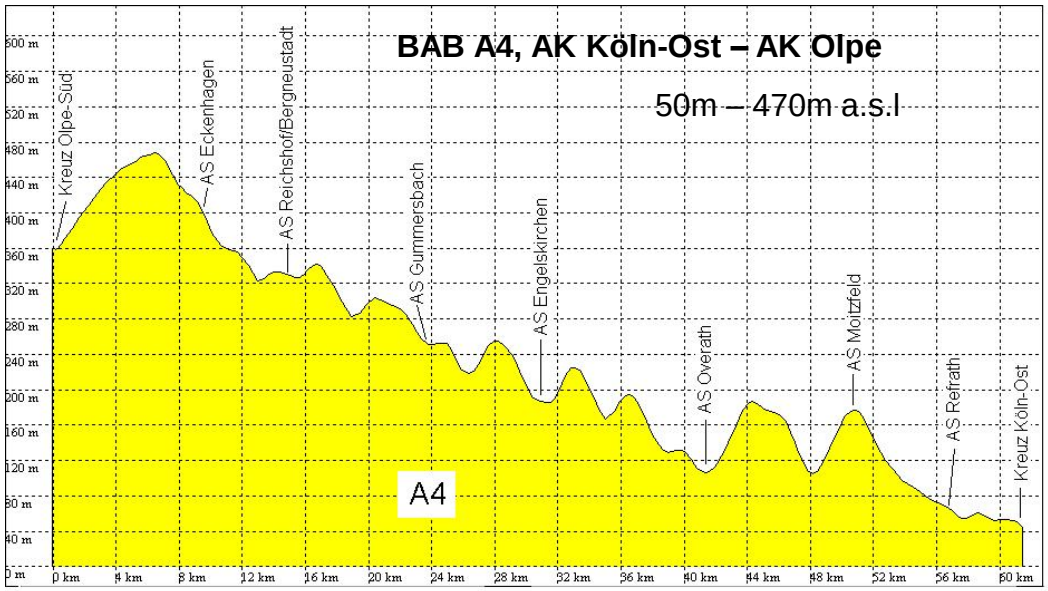
BAB A4 AK Köln – AK Olpe, ca. 55 km, SWS Testfeld BASt, BASt

Altitude profiles of the trial routes



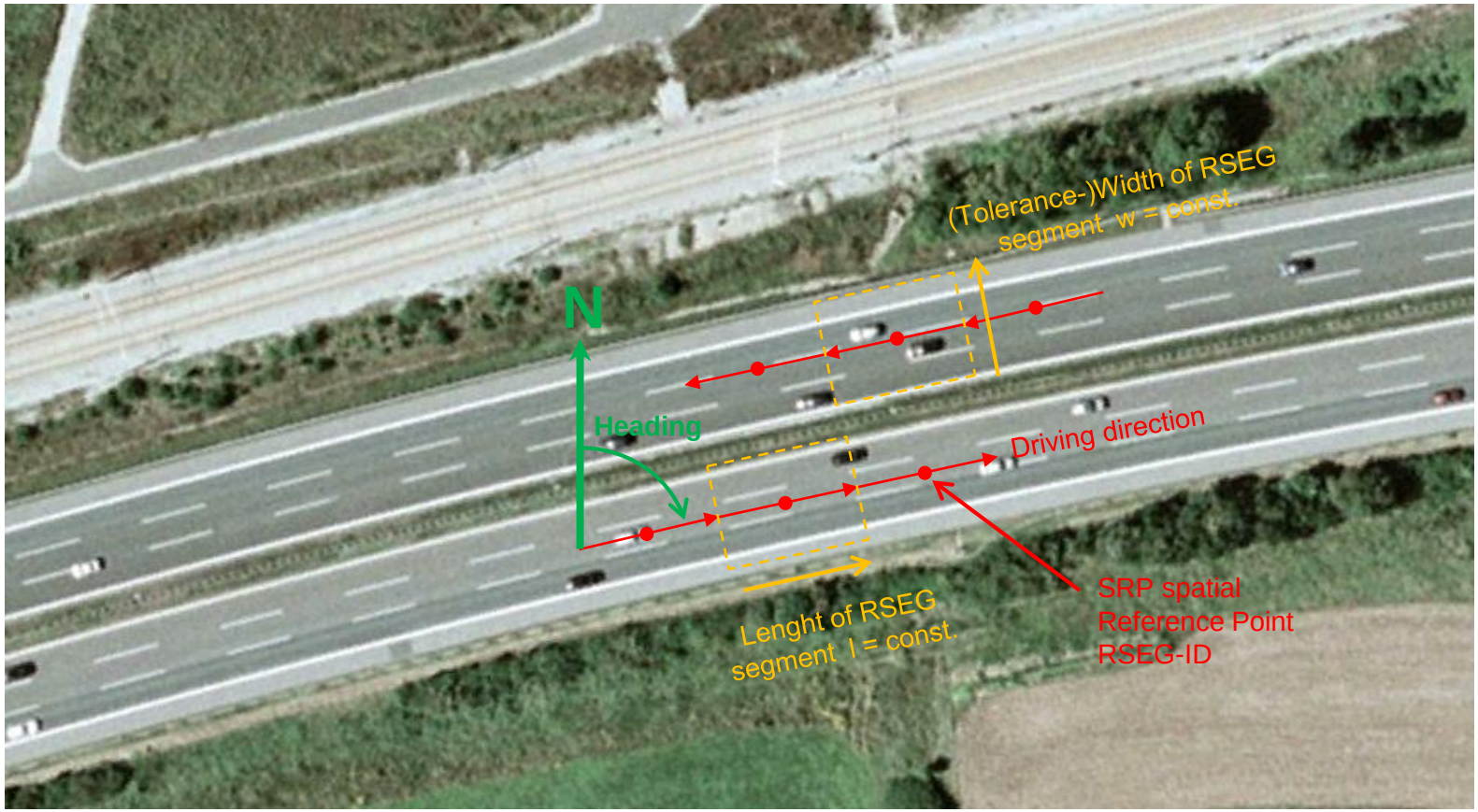
370m – 520m above sea level





Digital route map model

- Every route will be defined by a sequence (polygon) of equidistant (on planar projection) spatial reference points.
- The reference points are defined by their WGS84 coordinates (latitude and longitude) represented by decimal degrees. The altitude (in [m] above sea level) of the reference point is the surface of the road pavement. A spatial reference point is approximately (within the spatial tolerance borders) located in the middle of the normal driving lane.
- Every data will be allocated to road segments (RSEG). A road segment is defined by a spatial reference point and has assigned a RSEG identifier. The reference point is in the center of the road segment. See principle drawing below:

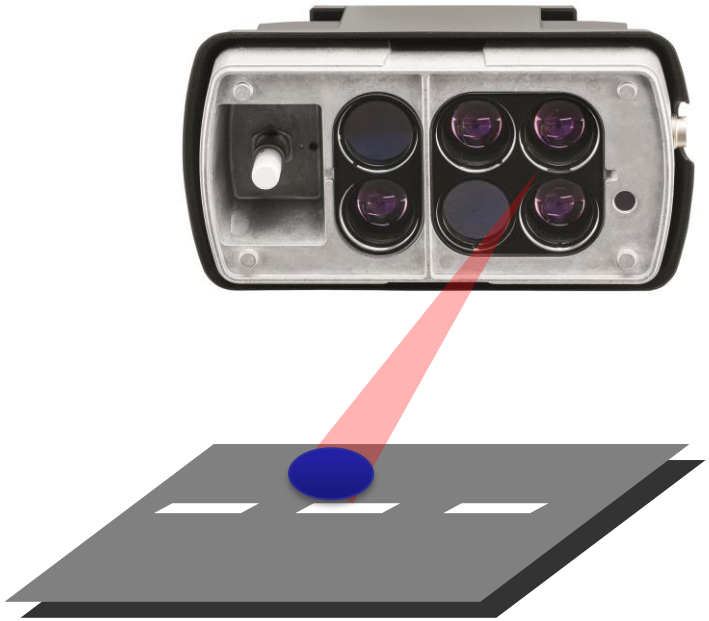


Mobile measurement on maintenance vehicles

Acquired road condition data

Sensor-Type: MARWIS Lufft

- Road surface temperature [°C]
- Dew point temperature [°C] (ambient)
- Water film thickness [µm] (water equivalent)
- Ice percentage [%]
- Friction [..] (estimated weather related tire friction)
- Road surface condition [enum]

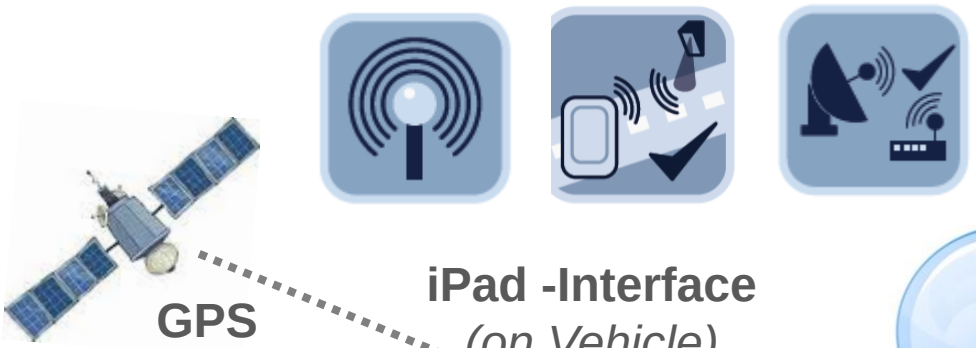


Acquired spatial data:

- Latitude [WGS83, Dezimal-Grade, 7 stellig]
- Longitude [WGS83, Dezimal-Grade, 7 stellig]
- Altitude above see level [m]
- Course [°]
- Speed [m/s]

Mobile measurement on maintenance vehicles

Prinzipial data flow



GPS
Localisation

iPad -Interface
(on Vehicle)

Data Cloud

MARWIS-App

Server
micKS/Lufft

Export Data for assessments

SmartView Collector

Mobile Measurement on maintenance vehicles
Setup AM Greding

Spreader truck at
AM Greding

Mobile Measurement on maintenance vehicles
Setup SM Viechtach

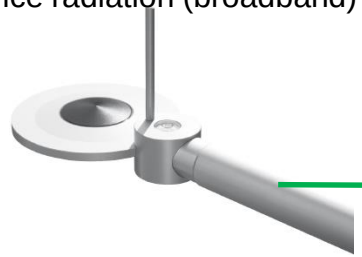
Spreader truck of
SM Viechtach

Measurement distance to
surface ca. 2m!

Extended thermal mapping with radition for sky aperture ice car equipment

BASt equipment

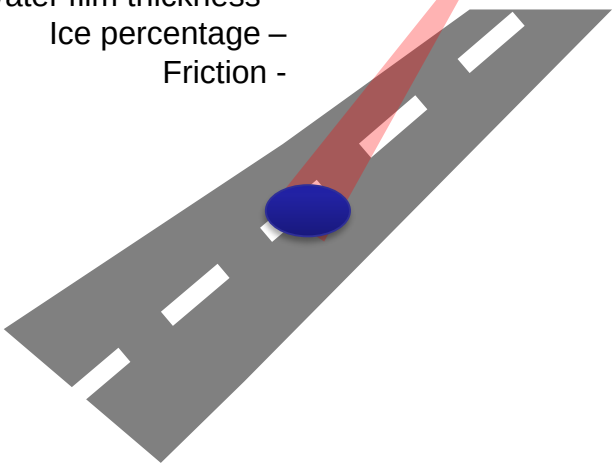
NR Lite2
Balance radiation (broadband)



CNR 4
Net Radiometer

WS301-UMB
Wetter Sensor
Air temperature -
Dew point temperature -
Global radiation -
Air pressure -

MARWIS-UMB
Road sensor
Surface temperature -
Road condition -
Water film thickness –
Ice percentage –
Friction -



UMB serial and Power Supply

Apple iPAD Tablet
Mobile network
&MARWIS-App

UMB FieldBus

24Vdc

1x ANACON
UMB Modul

DC/DC 12/24 Vdc

12 Vdc, On Board Power Supply,

Mobile Network

Internet access

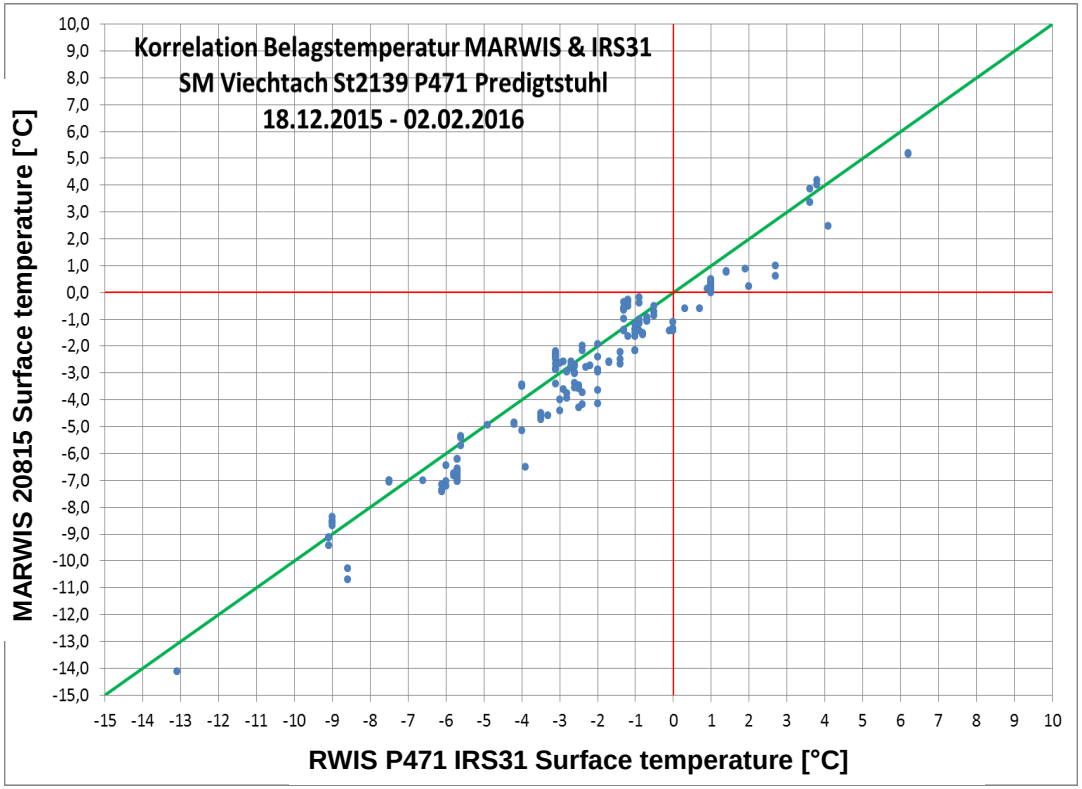
Extended thermal mapping with radition for sky aperture ice car setup

Plausibility check of surface temperature MARWIS LKW
Comparison at RWIS P471 Predigtstuhl St2139

Correlation of the surface temperature reported by the MARWIS on the maintenance vehicle when driving past the location of the RWIS to the surface temperature reported by the embedded sensor (IRS31) over the same period.

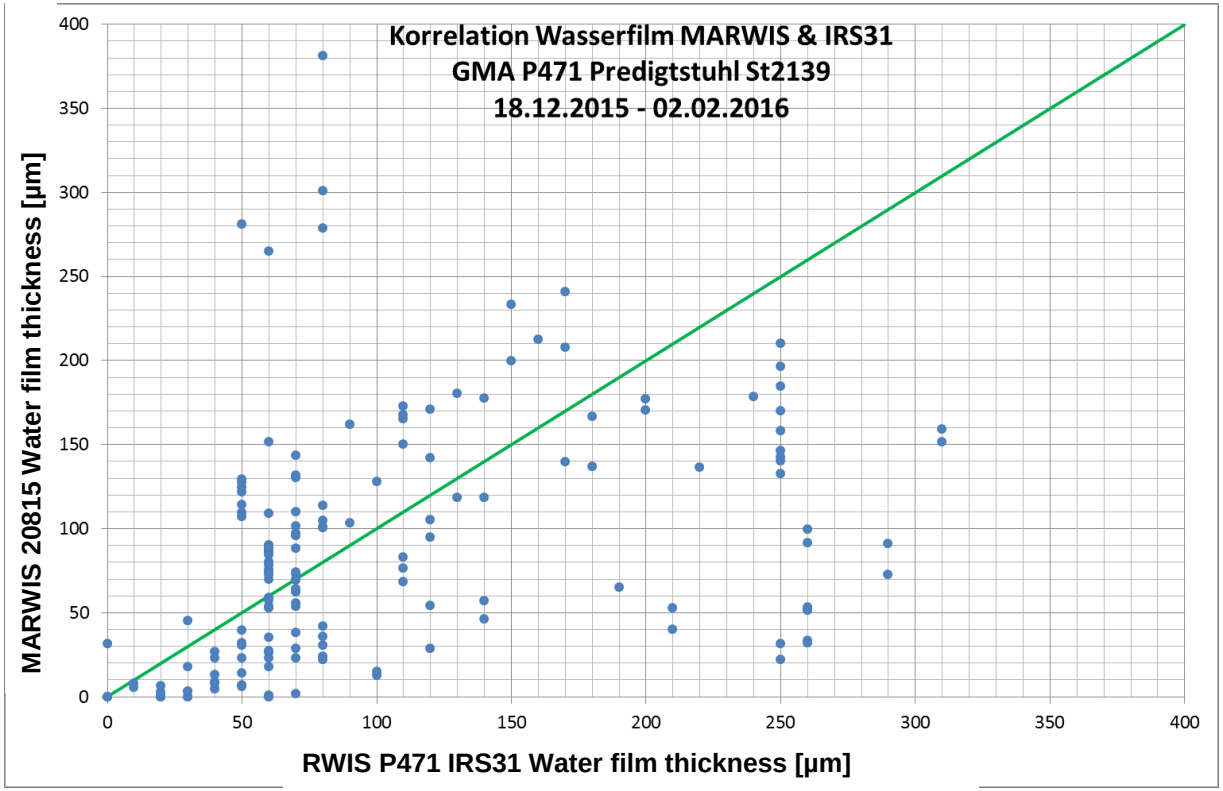
Taking into account the different weather and road conditions and despite the additional local and temporal inaccuracies of the measurements, the values are even within the theoretically tolerance for the sensors!

The simple mean deviation (bias) over all data is + 0.5 ° C and the value for the mean absolute deviation is ± 0.8 ° C. The table shows the differences separately according to the road conditions reported by MARWIS and IRS31.



Differentiation acc. to road conditions			
		BIAS RST	AbsDiff RST
0	Dry	- 1,0	± 1,0
1	Damp	- 0,5	± 0,7
2	Wet	+ 0,3	± 0,3
3	Ice	- 0,3	± 0,7
4	Snow/Ice	- 0,7	± 0,9
	all	+ 0,5	± 0,8

Plausibility check of waterfilm thickness MARWIS LKW Comparison at RWIS P471 Predigtstuhl St2139



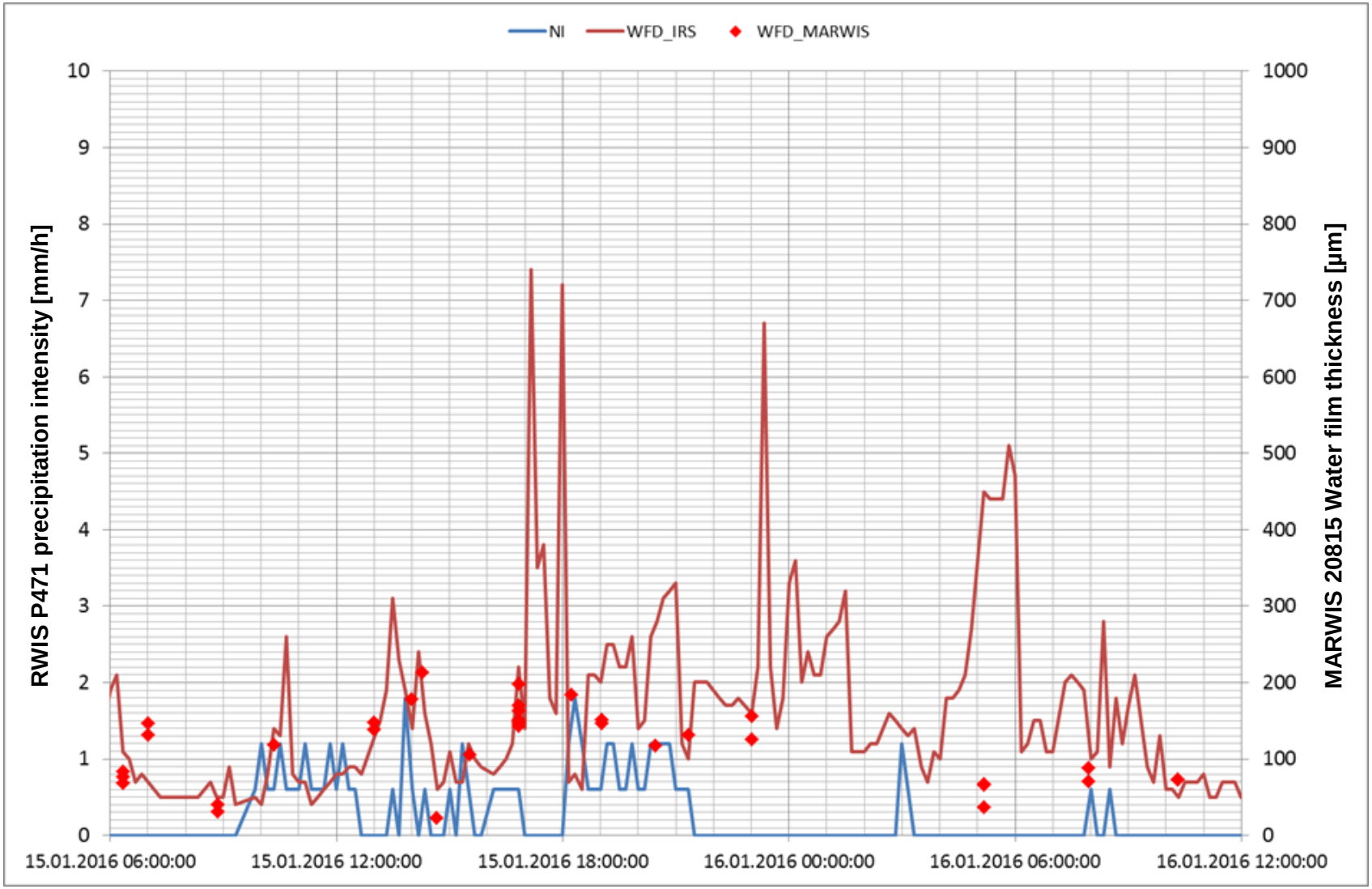
Basically, it is to be expected that a direct comparability of the water film heights, as the adjacent plot shows, is not given. For several different reasons:

- Distribution of water film heights over the surface naturally extremely variable
- Local and temporal uncertainty of the mobile measurement in direct comparison with the stationary measurement
- Different measuring methods with different cross sensitivities and accuracies,

It is not to be expected under real operating conditions, as above, that the direct comparison with stationary, embedded sensors will give better results, because the natural fluctuations over the surface and uncertainties are dominant.

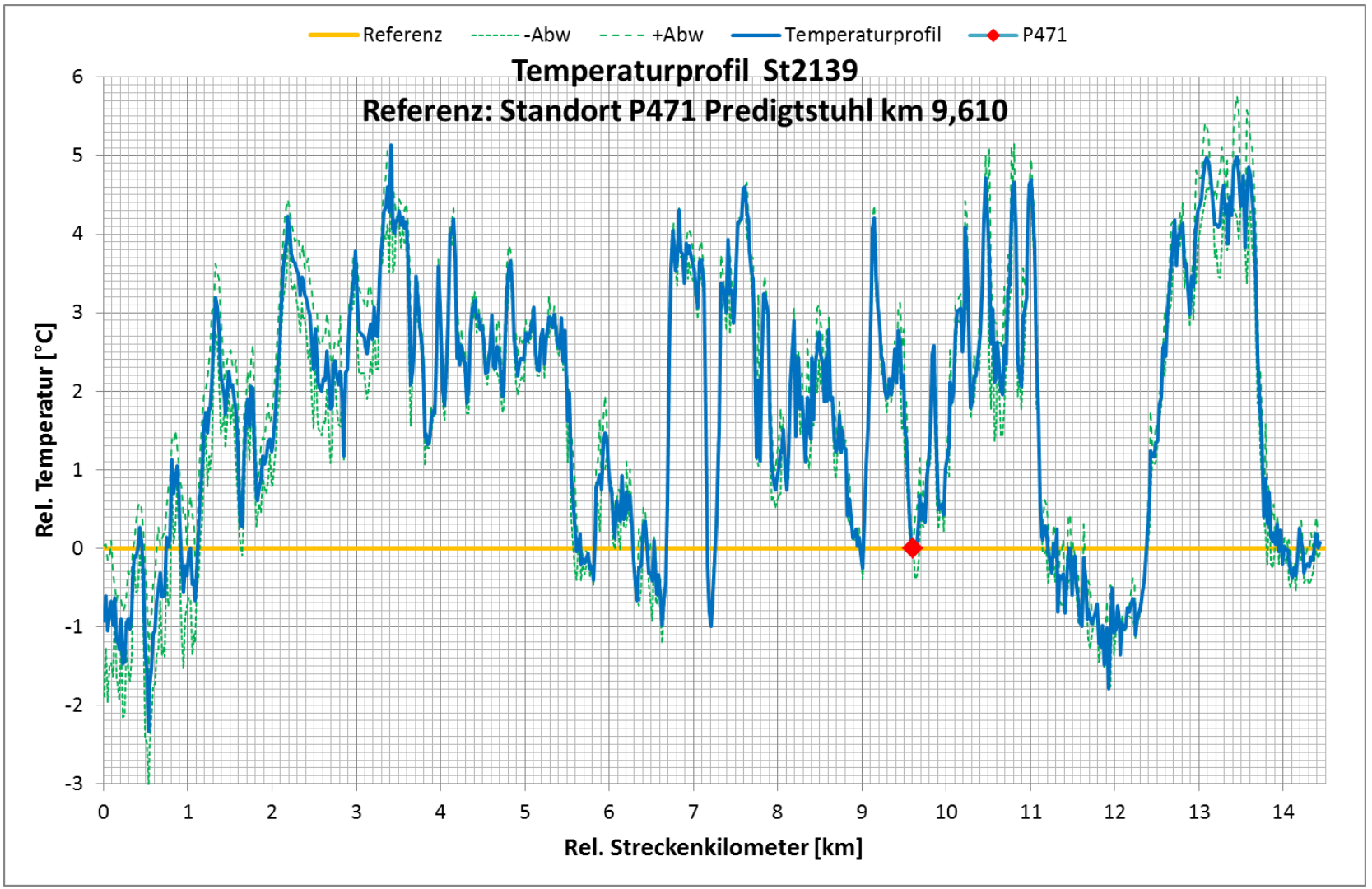
Condition	BIAS	MAE
Dry	28,8	± 16,1
Damp	19,0	± 5,3
Wet	30,7	± 65,5
Ice	26,3	± 96,0
Snwo/Ice	33,3	± 69,4
all	**28,9**	**± 68,6**

Plausibility check of waterfilm thickness MARWIS LKW
Comparison at RWIS P471 Predigtstuhl St2139



Thermal Mapping assessments with „IceCar“
Thermal profile of the trial route (St2139)

Summarized relative temperature profile on the segment covered by all 4 TM test drives with marking of the standard deviation. Reference point is the GMA Predigtstuhl on RSEG_ID: 20000481



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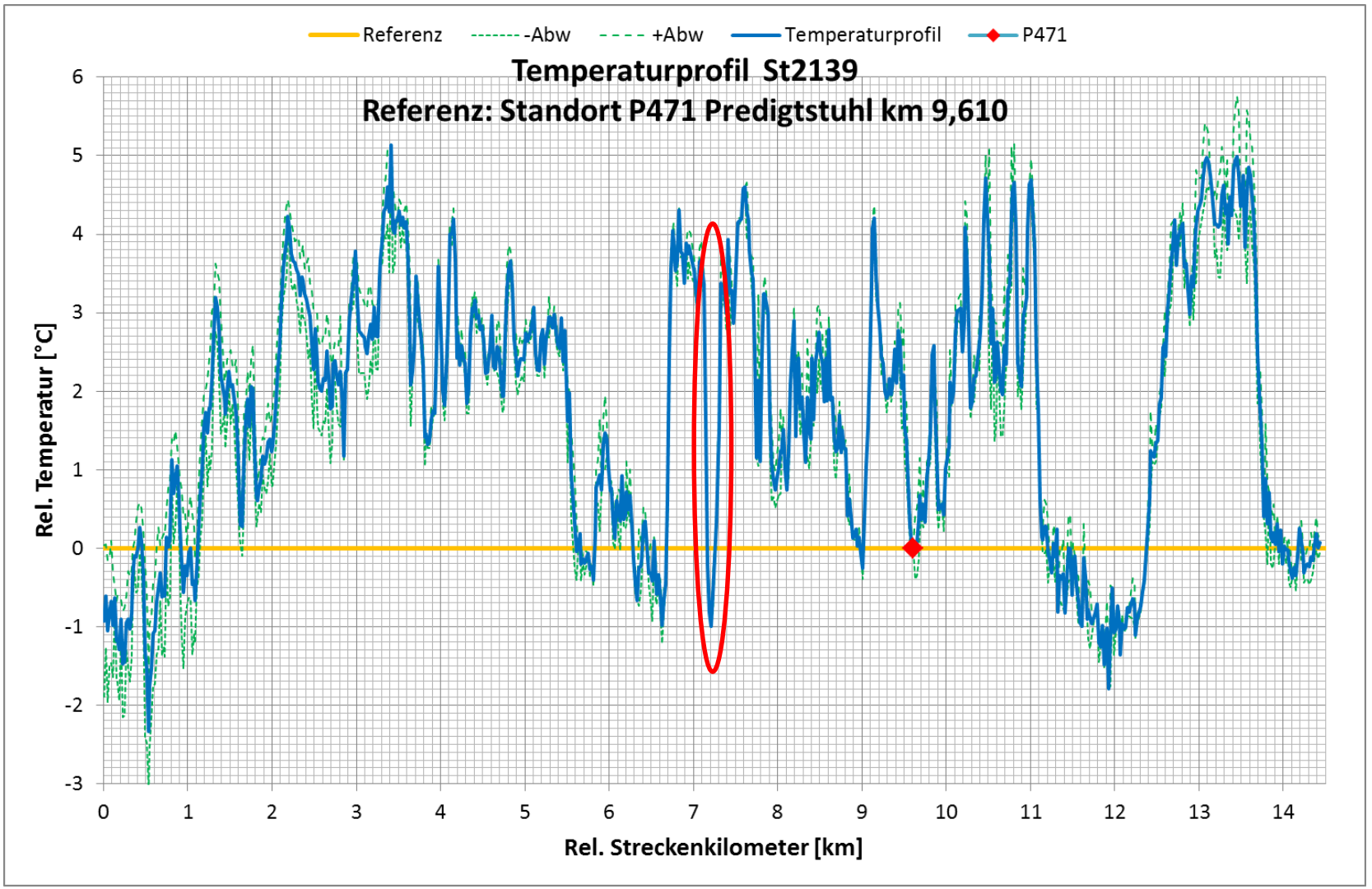

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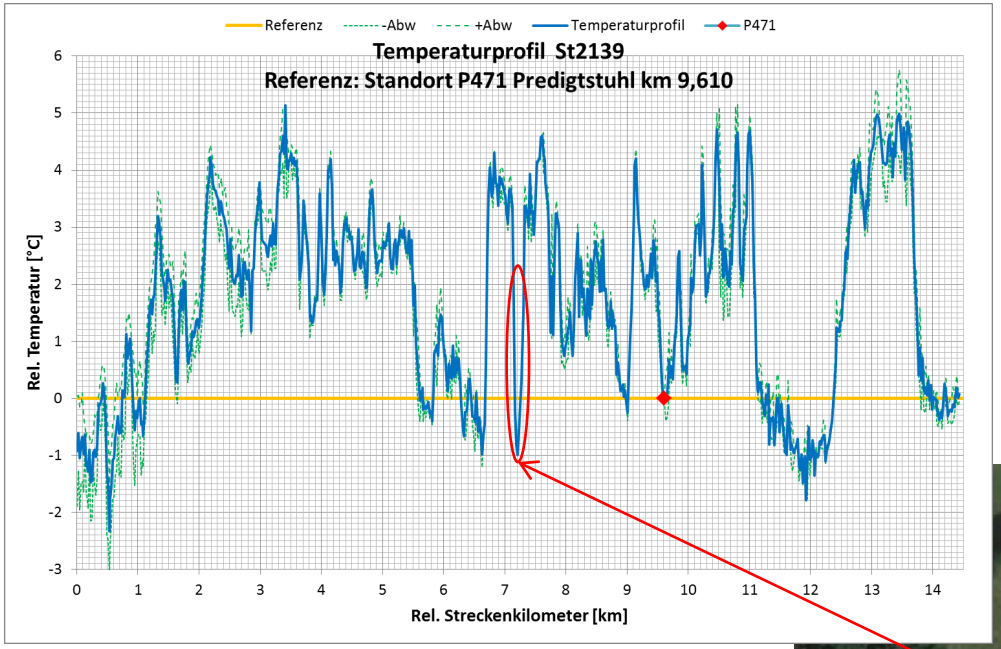
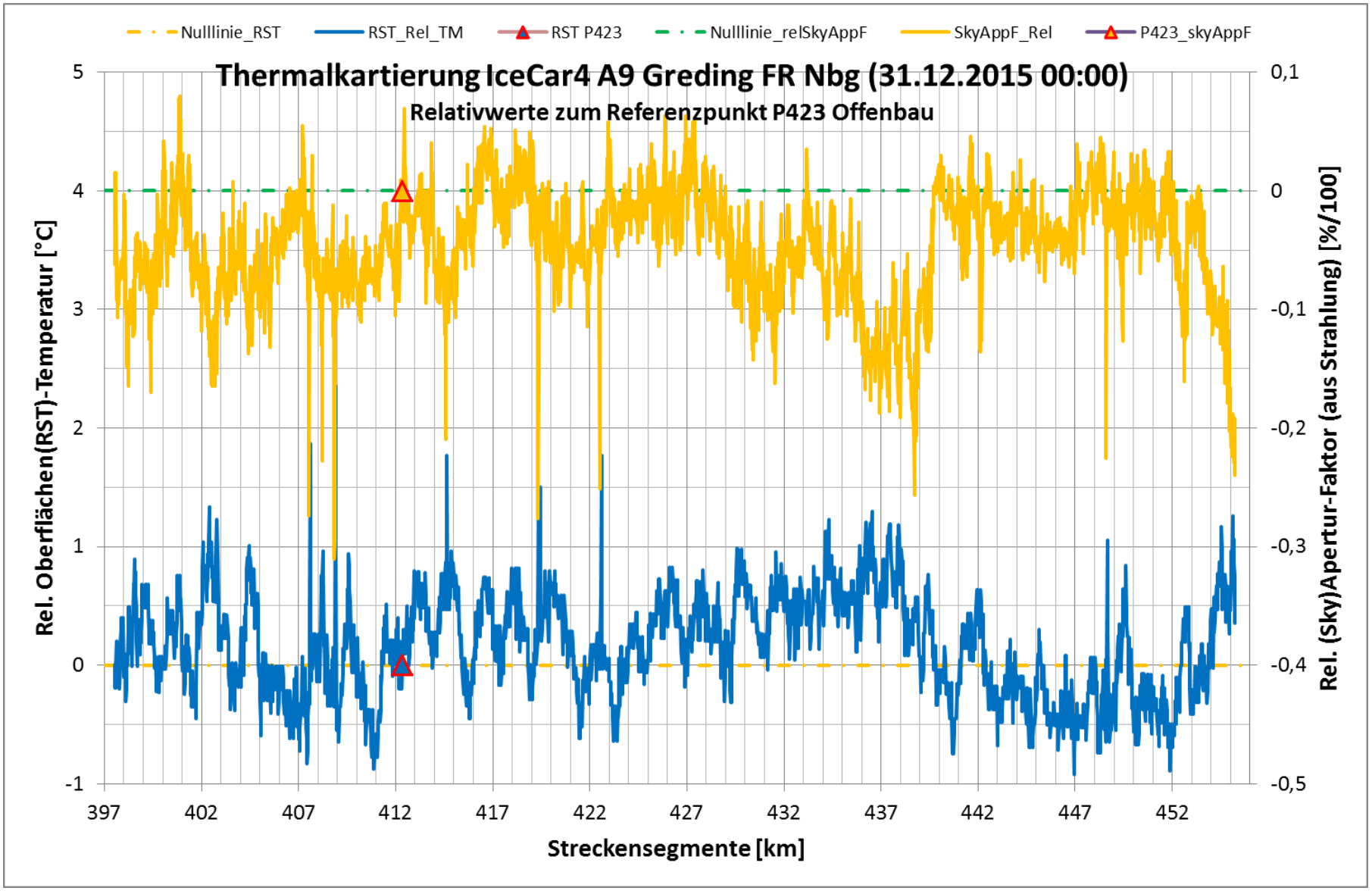
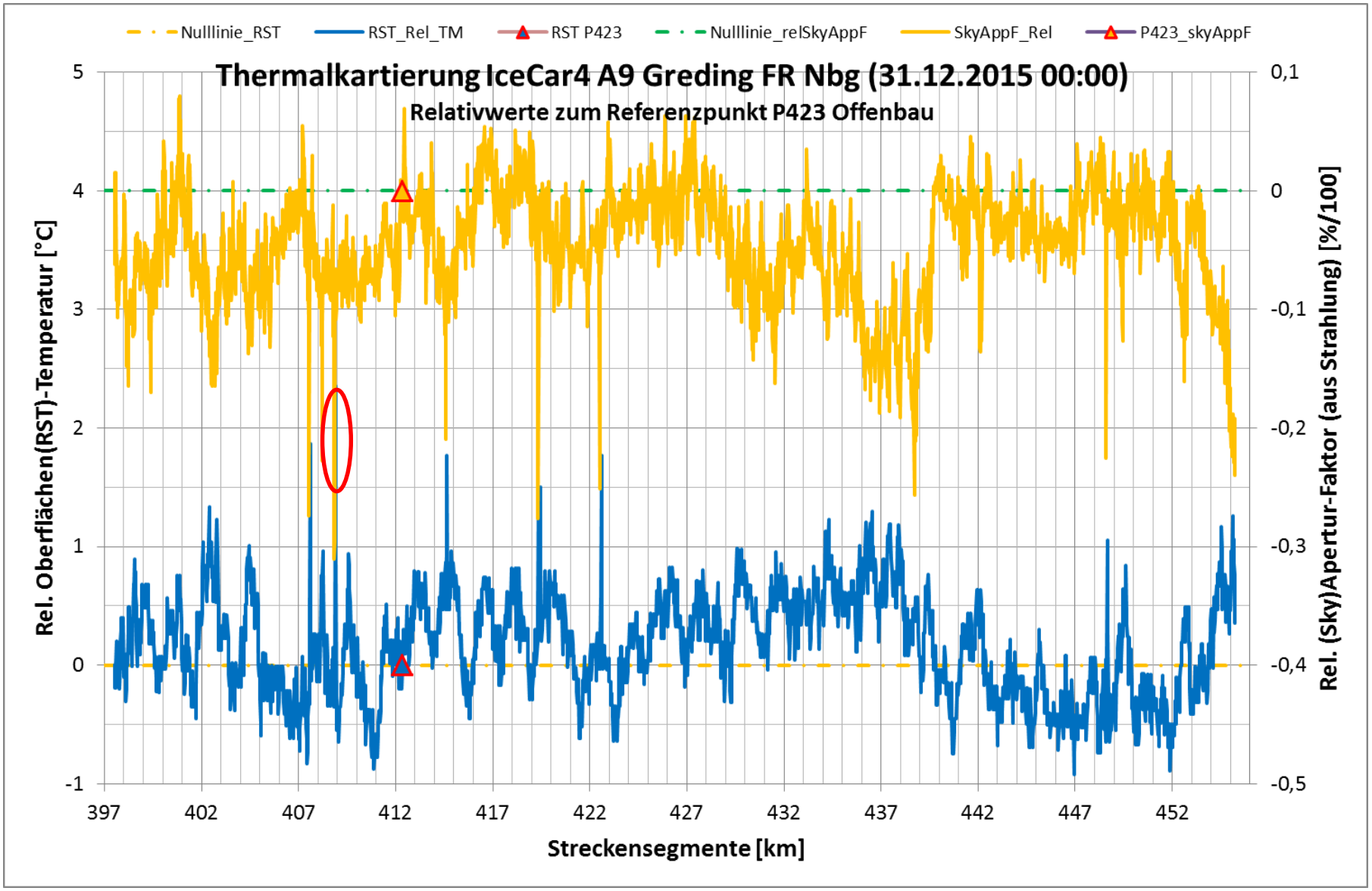


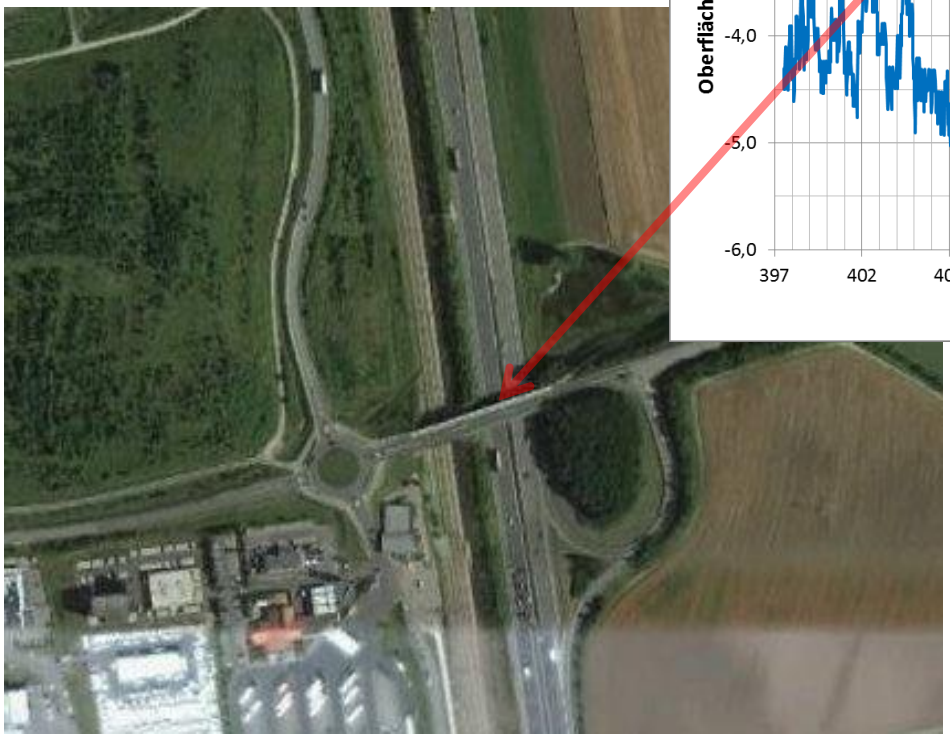
Thermal Mapping assessments with „IceCar“
Thermal profile of the trial route A9

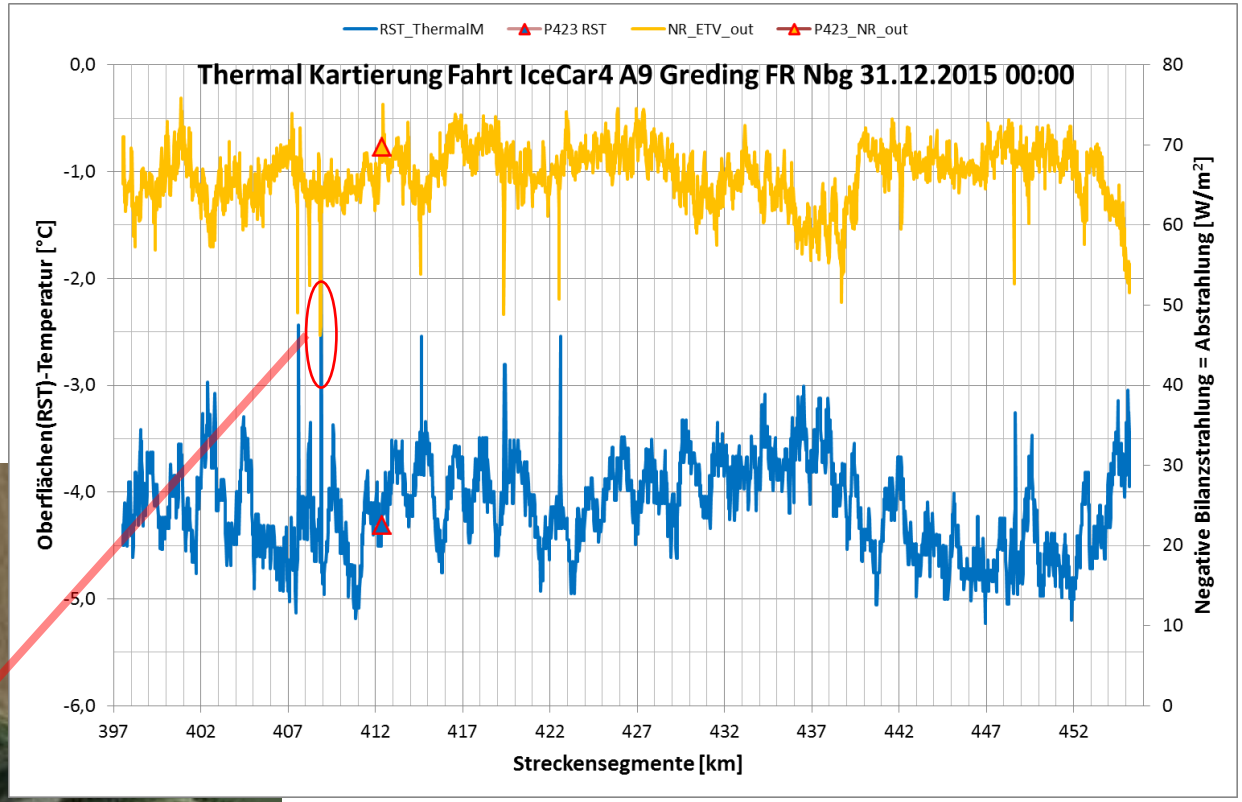


Thermal Mapping assessments with „IceCar“
Thermal profile of the trial route A9



Thermal Mapping assessments with „IceCar“
Thermal profile of the trial route A9



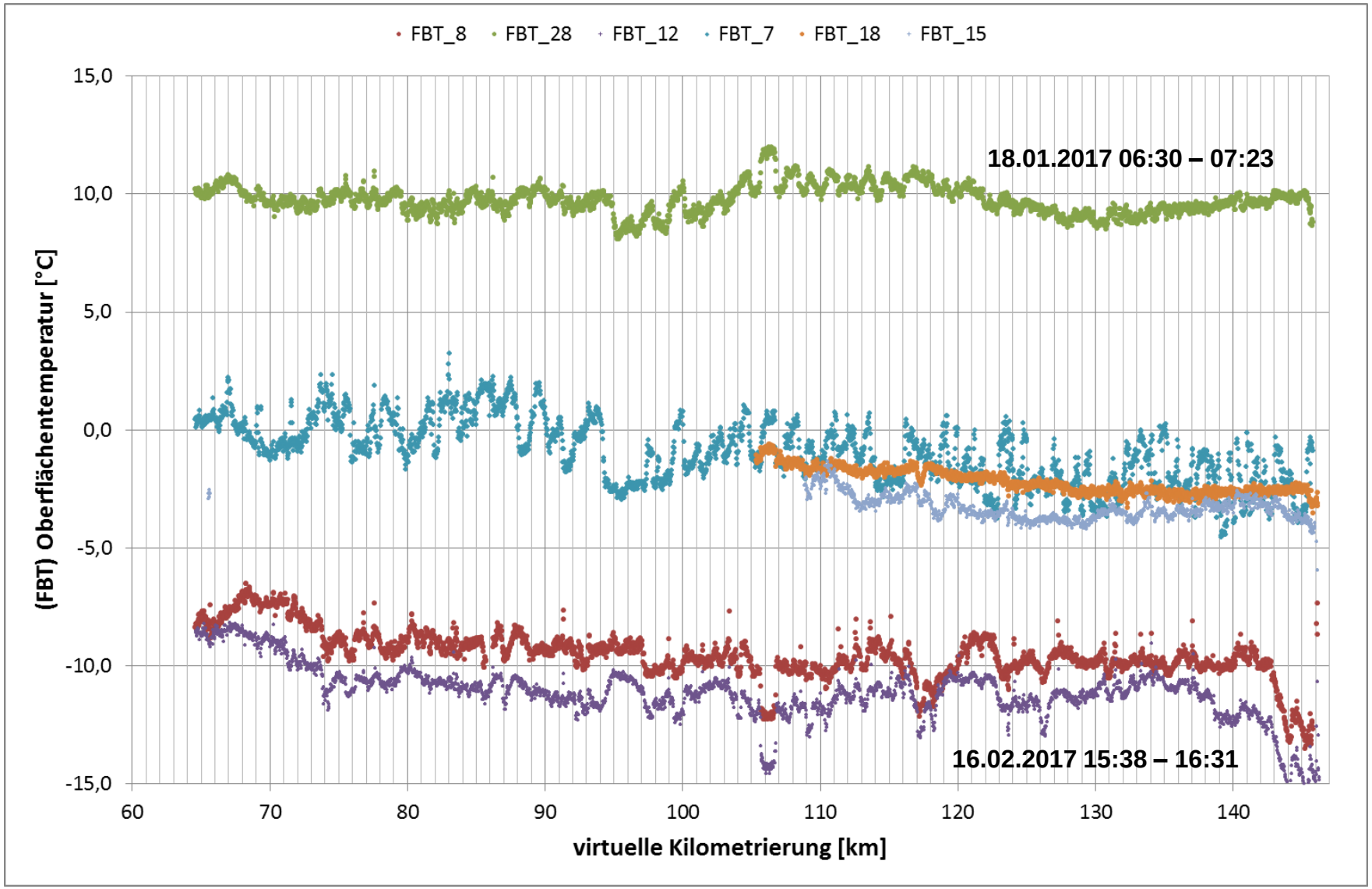


All increases in pavement temperature are identified as bridges over the highway. At the same time the radiation power decreases.

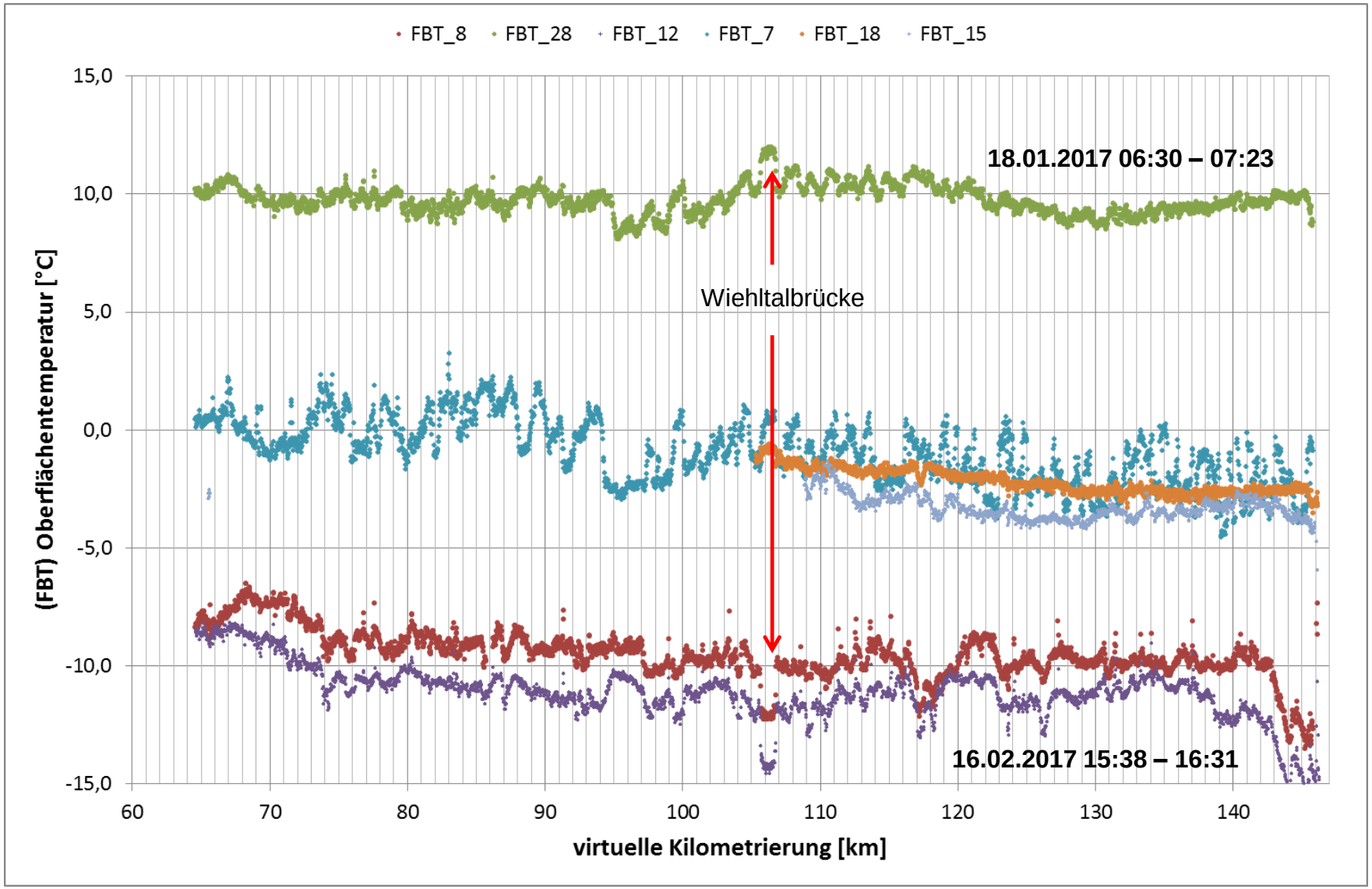
Example: AS Hiltpoldstein / Sindersdorf A9 / St2238?
Increase pavement temperature from -4.5 ° C to -1.8 ° C
Outgoing radiation power from 64 W/m² to 46 W/m²
Stretch of bridge approx. 25 m!

Example: A9 FR Nuremberg clear night 31.12.2015 00:00

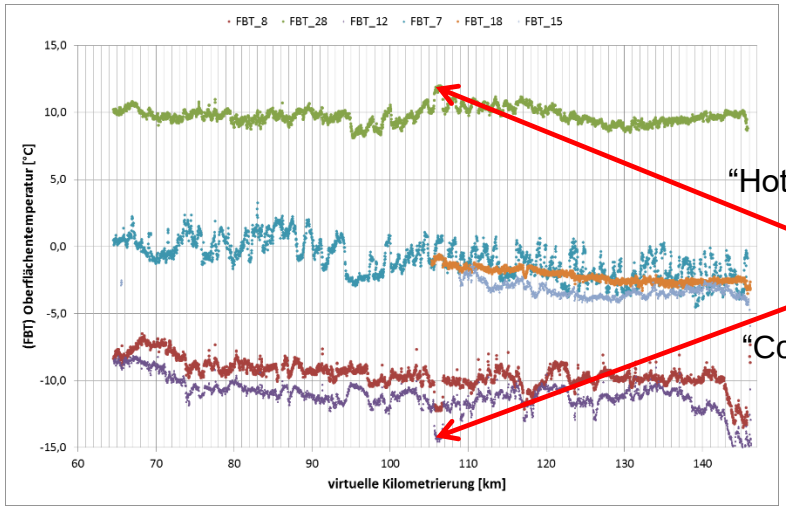
Mobile measurement drives with „IceCar5“ from BASt
Thermal profile of the route A4 direction Cologne



Mobile measurement drives with „IceCar5“ from BASt
Thermal profile of the route A4 direction Cologne



Mobile measurement drives with „IceCar5“ from BASt
Thermal profile of the route A4 direction Cologne



“Hotspot”

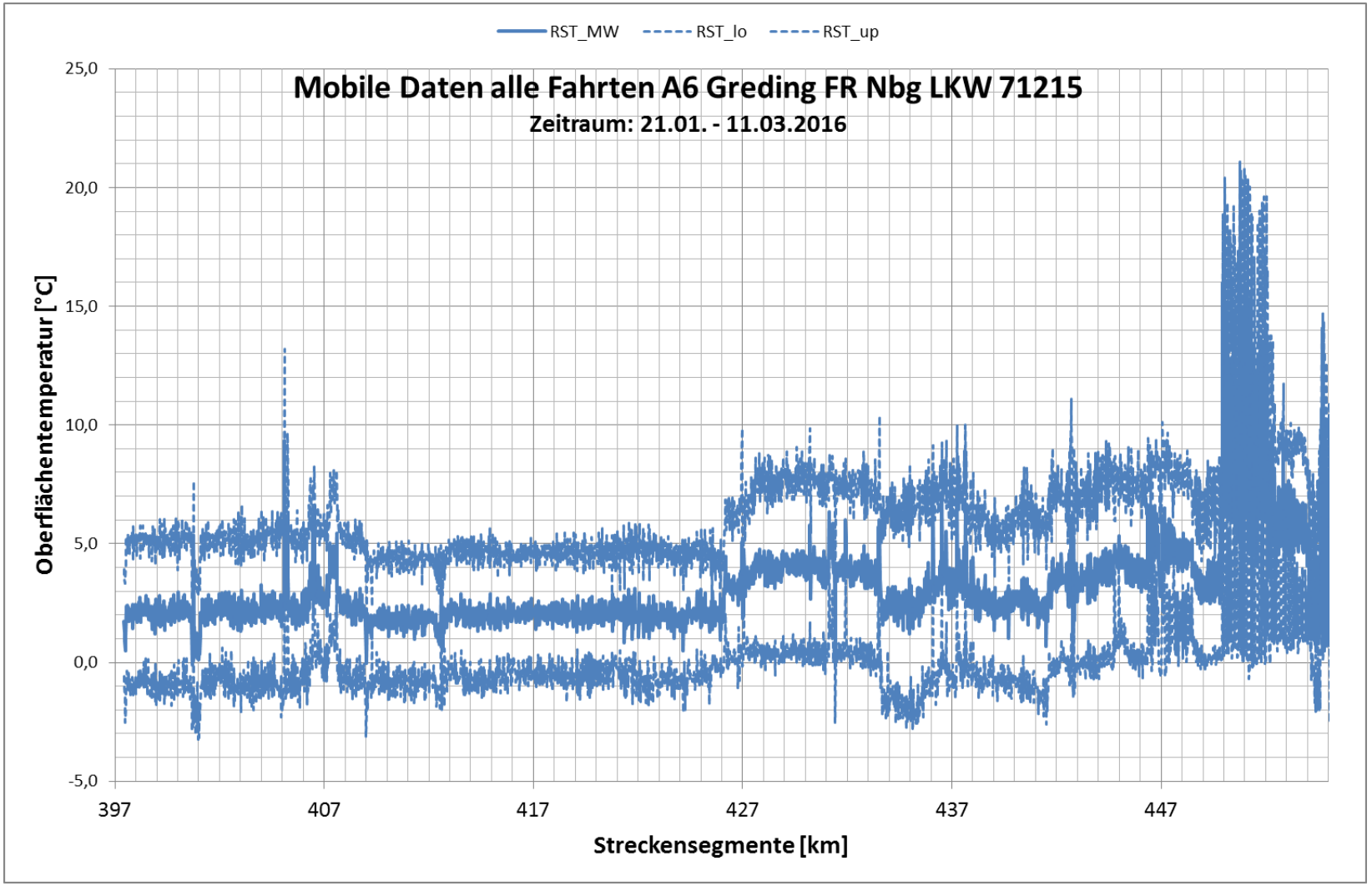
Wiehltalbrücke

“Coldspot”

Same segment shows different behavior in different weather situations!

Thermal profile of the trial route A9 direction Nürnberg

Relative temperature profile from all drive of the maintenance truck (71215) on the A9 in all different weather conditions.
As expected, shows less variation compared to TM on a clear night.
Nevertheless, there are some features to identify that often appear in the same place.



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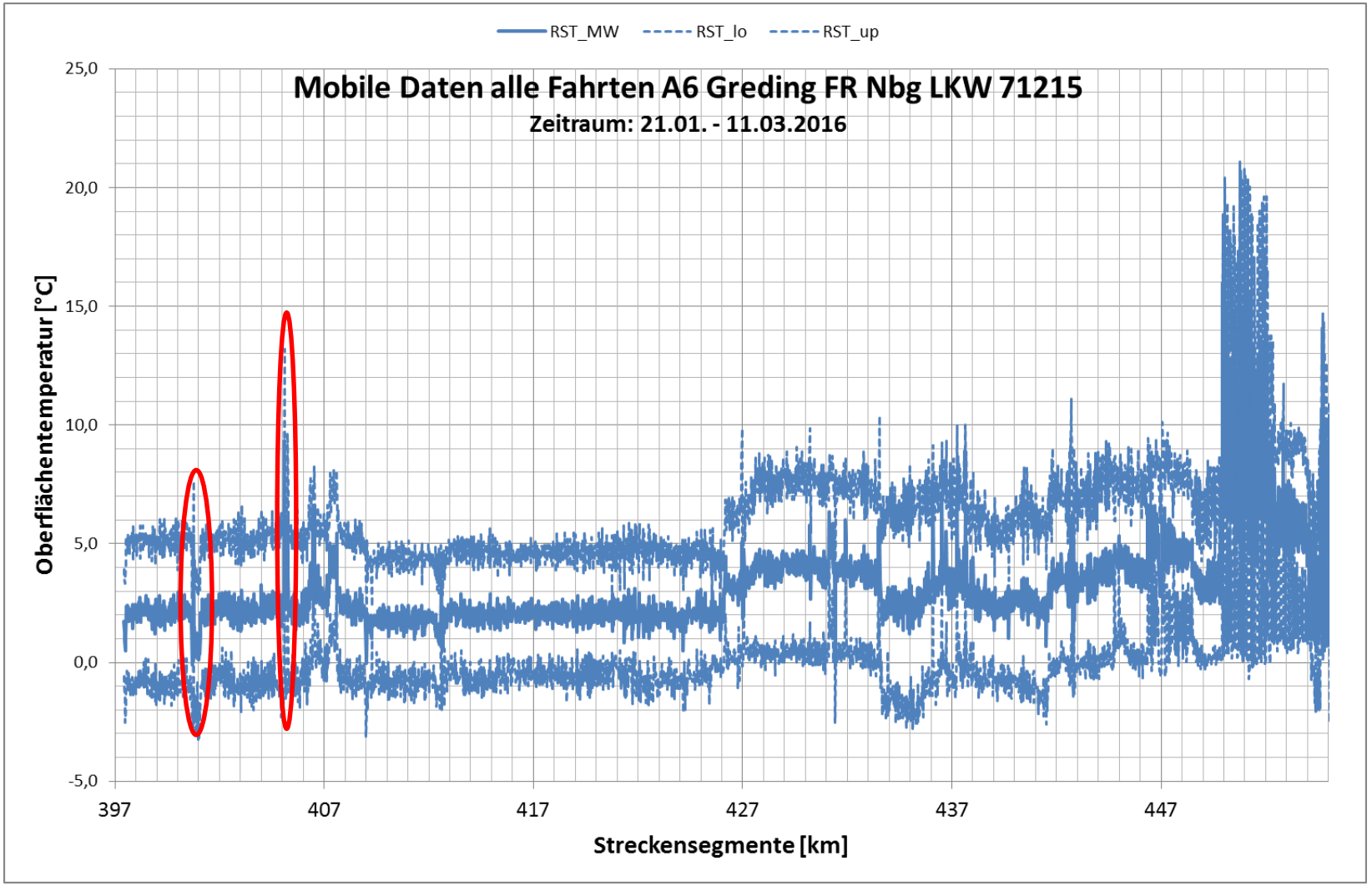


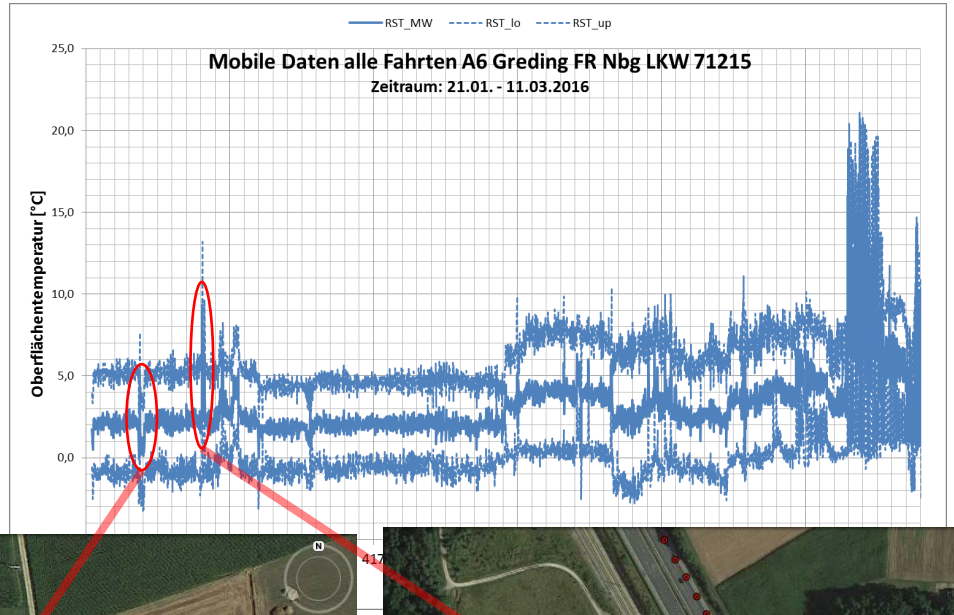
Thermal profile of the trial route A9 direction Nürnberg

Statistical curve thermal profile from all drives of the truck 71215
AM Greding in all occurring weather situations during a winter period.

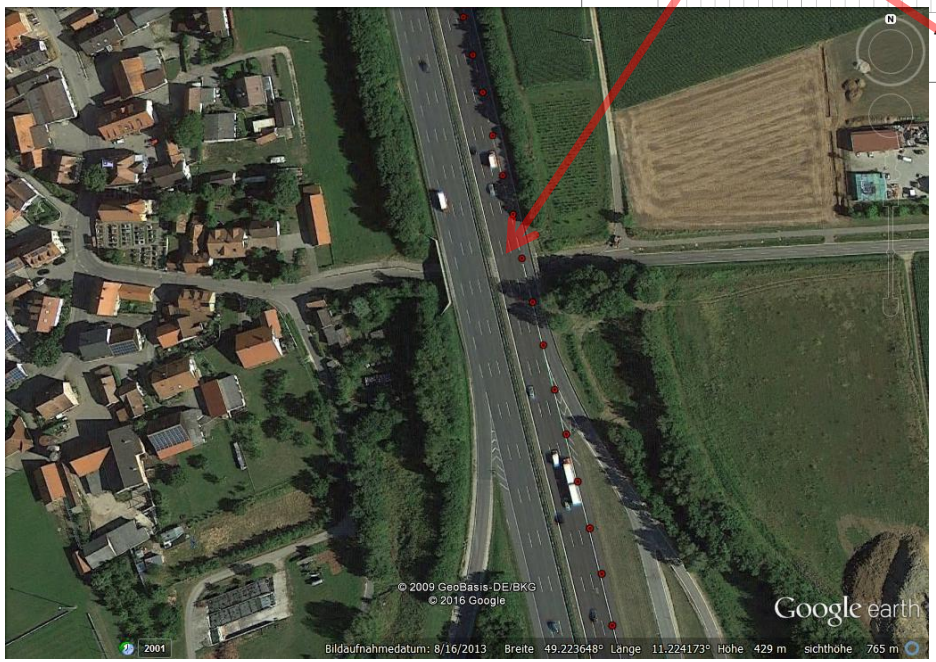
2 Examples for route based features:

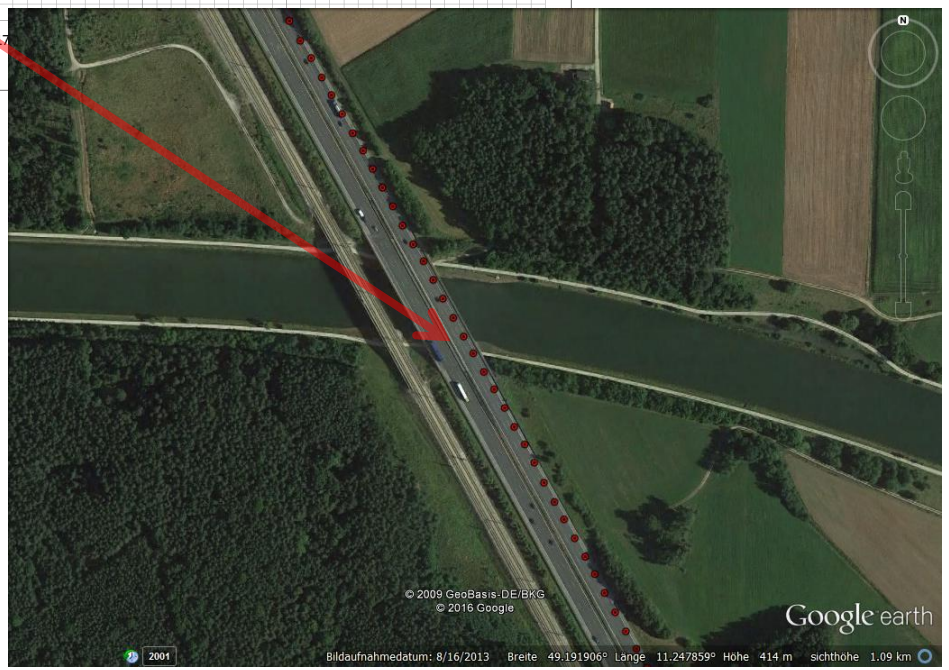
"Cold-Spot"

Undercrossing at Göggelsbuch
Dimension ca. 30m
RSEG_ID 11002738 km 400,460



"Hot-Spot"
Main-Donau-chanel-Bridge
RSEG_ID: 11002499
km 405,260
Length ca. 125m





Profile of the waterfilm thickness route A9 dir. Nnbg.

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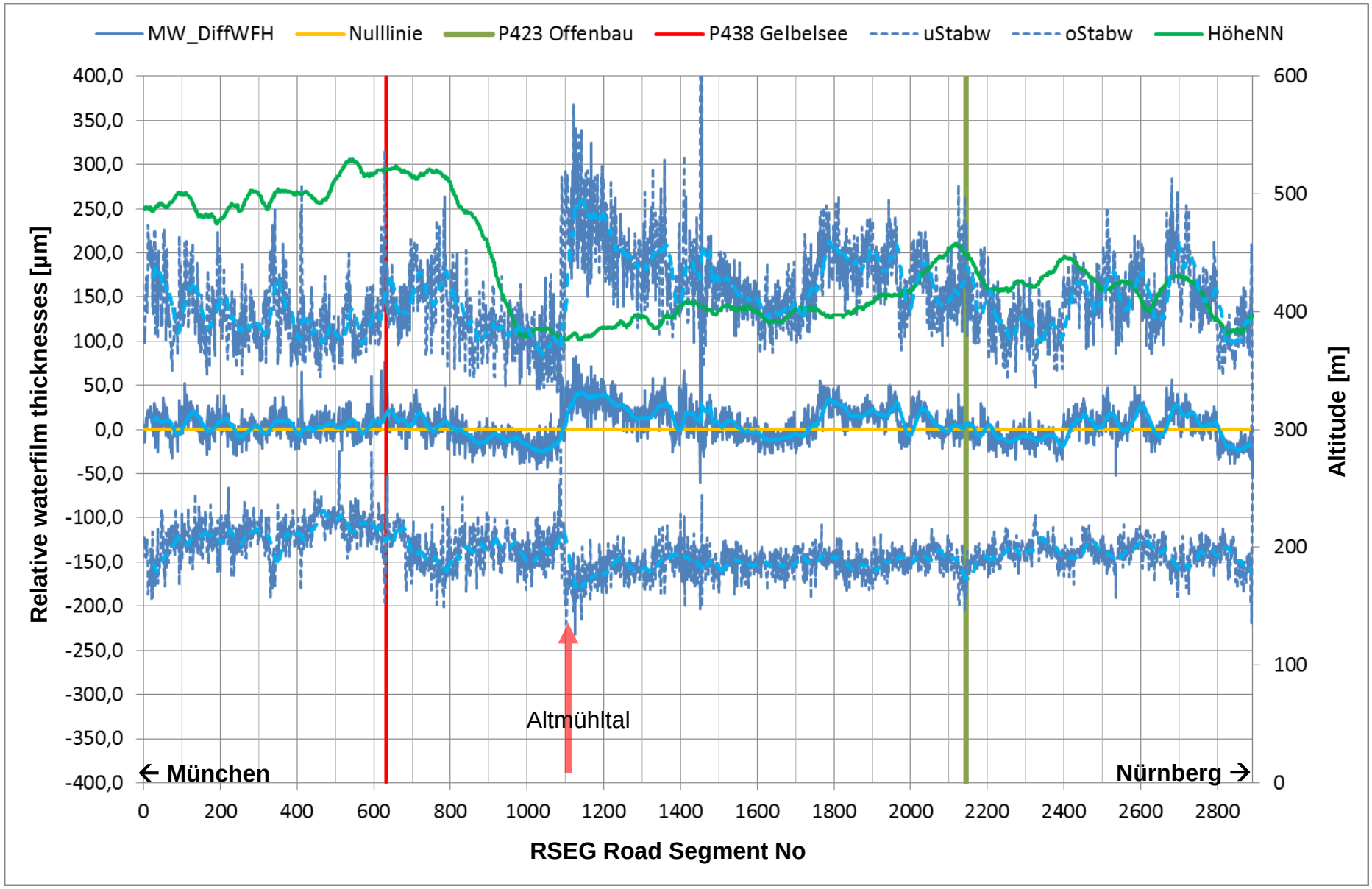
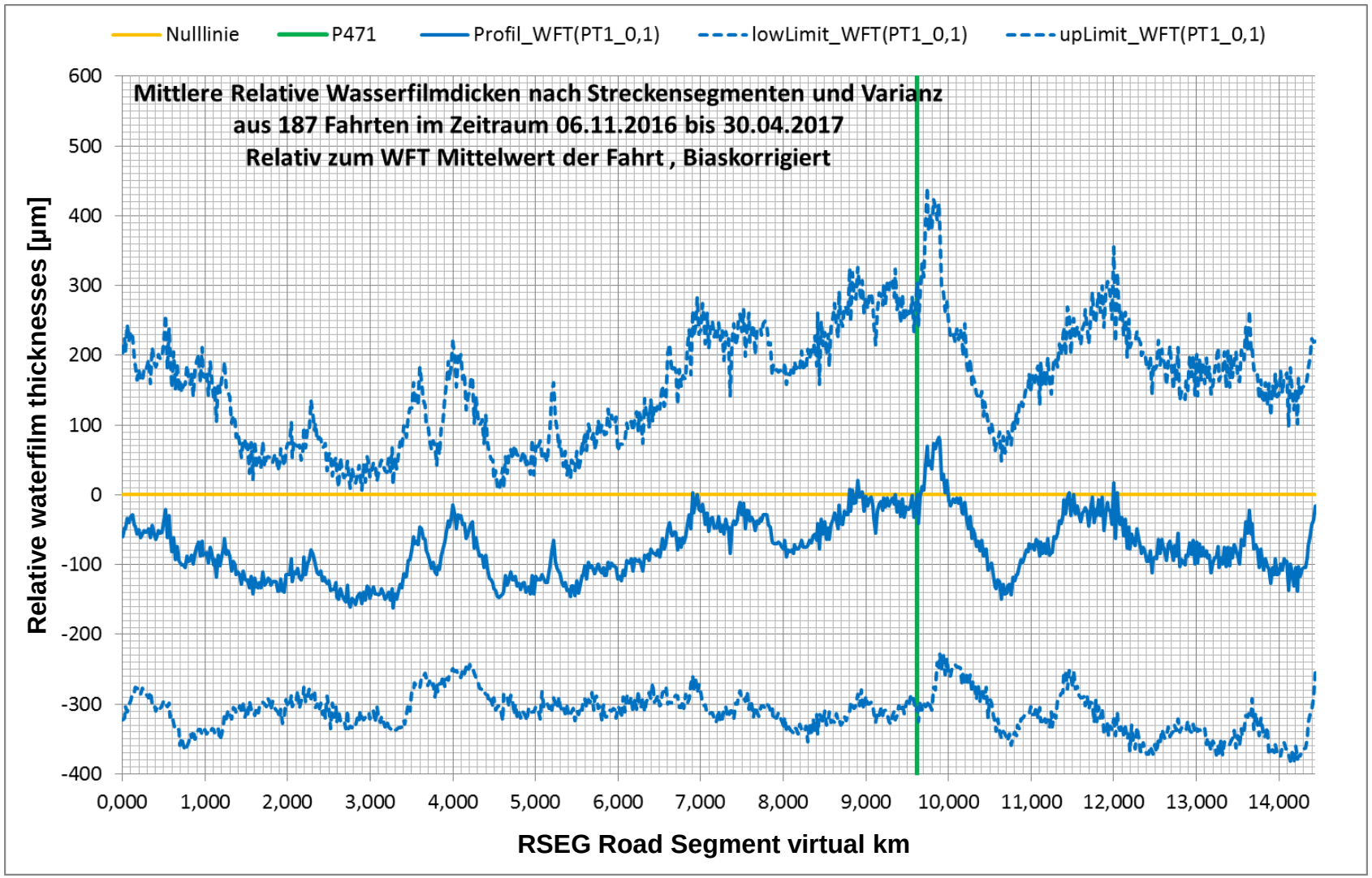


Profile of the waterfilm thickness route A9 dir. Nnbg.

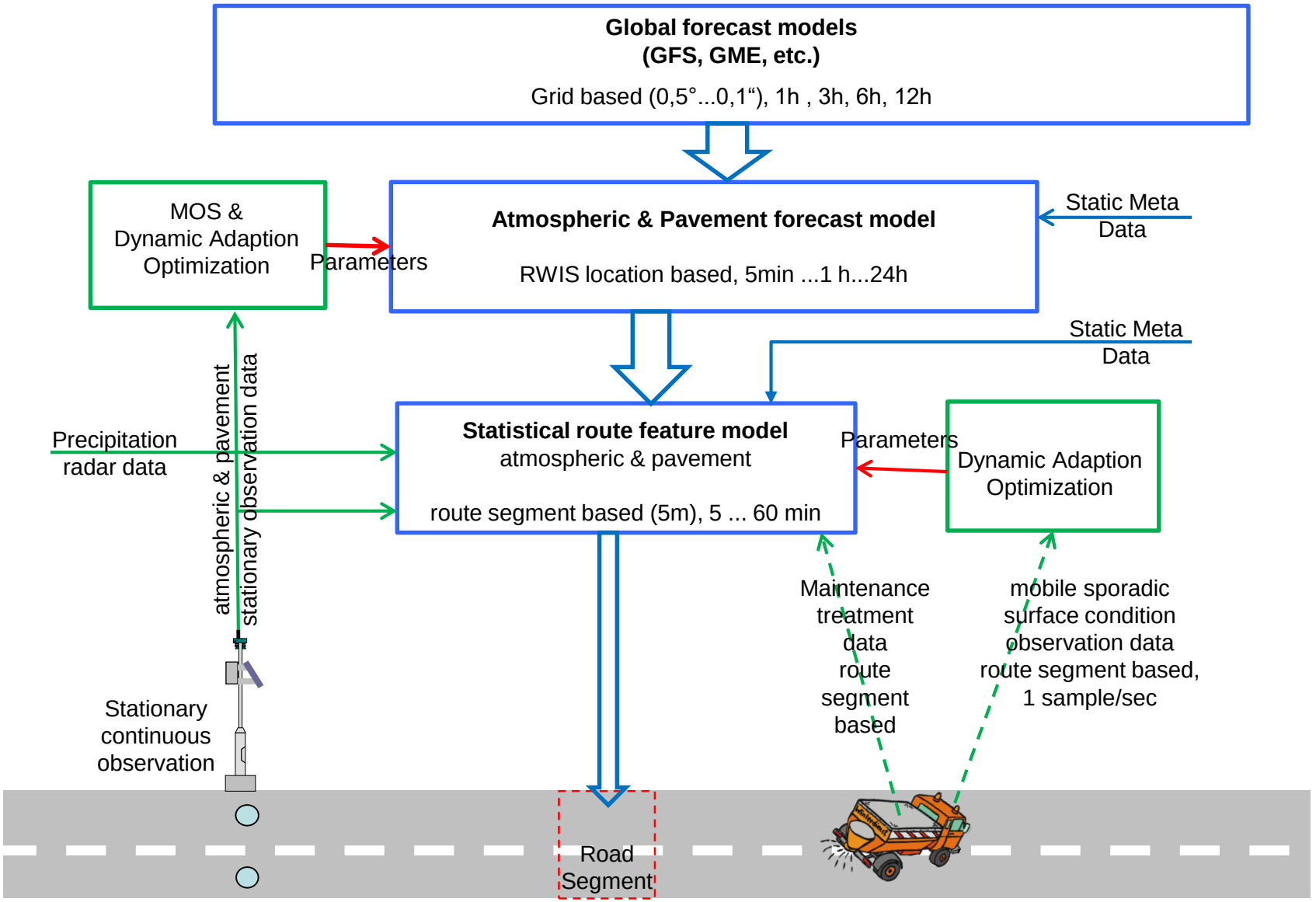
Altmühltal

The statistical distribution of the water film thicknesses over the road segments shows pretty much in the area of the junction Altmühltal (where the terrain is also lowest), at the confluence of Schwarzach and Anlauter, and Altmühl, a striking change in wetness. In the direction of Munich, where the terrain rises relatively steeply, the wet is significantly lower and less Variant than in the direction of Nuremberg where obviously the moisture is clearly more cumulative.

Profile of the waterfilm thickness route St2139 Viechtach



Principle approach for route based forecast and modeling of route features



Method approaches for modeling of route properties

1. **Statistical Transfer Function:**
   → Derivation of the target quantities for a segment from the same quantity at a reference station
   → simplest approach: linear transfer function of the form:

$$RST_{RSEG} = RST_{REF} \bullet c_{FBT,WC,RSEG} + b_{FBT,WC,RSEG}$$

$$DPT_{RSEG} = DPT_{REF} \bullet c_{TPT,WC,RSEG} + b_{TPT,WC,RSEG}$$

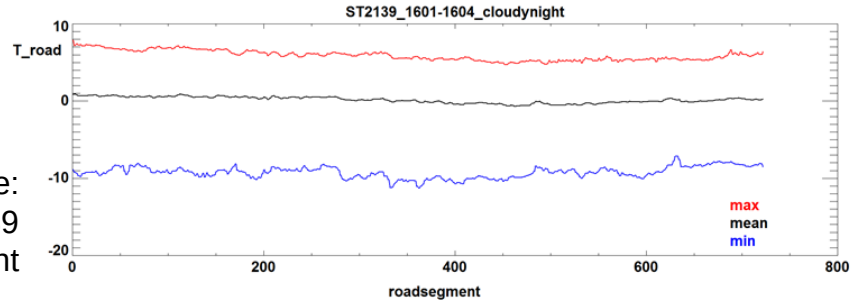
$$WFT_{RSEG} = WFT_{REF} \bullet c_{WFD,WC,RSEG}$$

For each size and each road segment (RSEG) and weather class (WC) there is a linear coefficient c and an offset b (except for WFT)

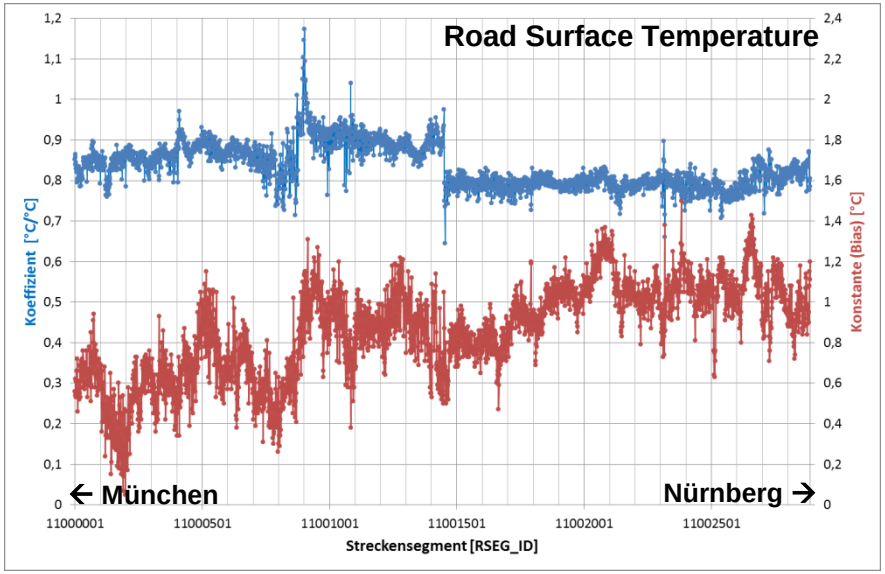
→ Determination of parameters c and b via linear regression from mobile data from the segment of many measurement drives and the stationary data measured at the same time at the reference station.
→ **Minimization of deviations due to the definition of weather classes!**

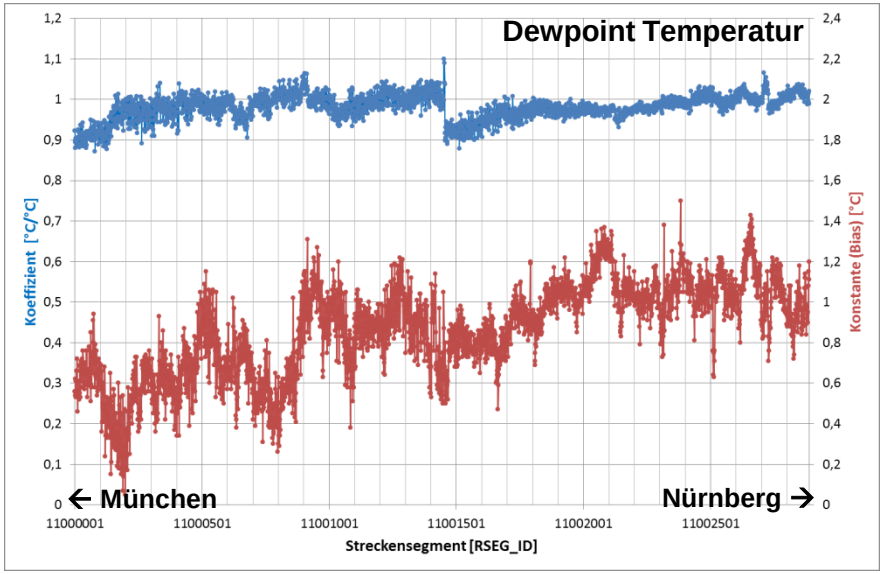
2. **Weather Classified Standard Profiles:**
   → Derivation of the target quantity of a route segment from the standard profile of the currently prevailing weather class and determination of the starting value from RWIS reference station or nearby weather station or area forecast.
   → Determination of the standard profiles:
   Related data of numerous measurement trips each within a short period and with the same weather class.

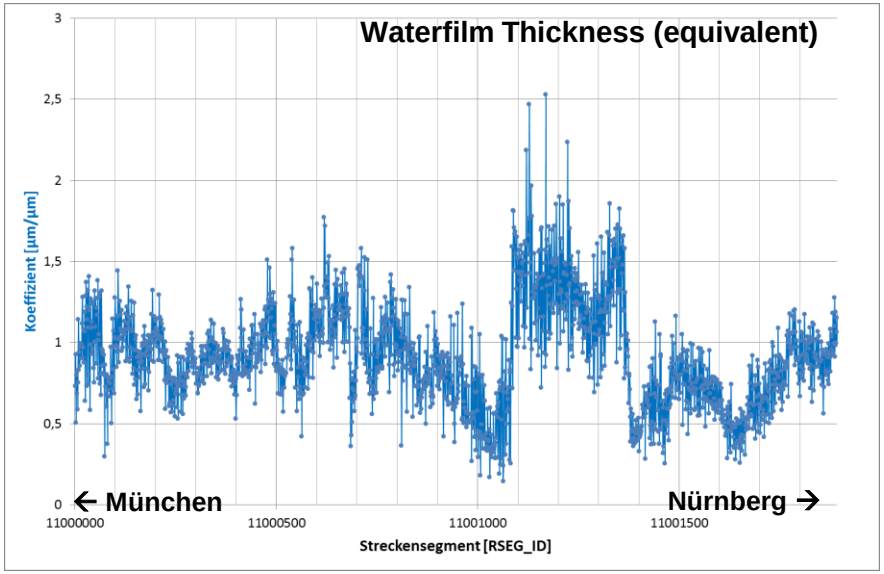
example:
Standard Profil St2139
cloudynight



Parameters of transfer function for A9 Greding / Reference: RWIS Offenbau II





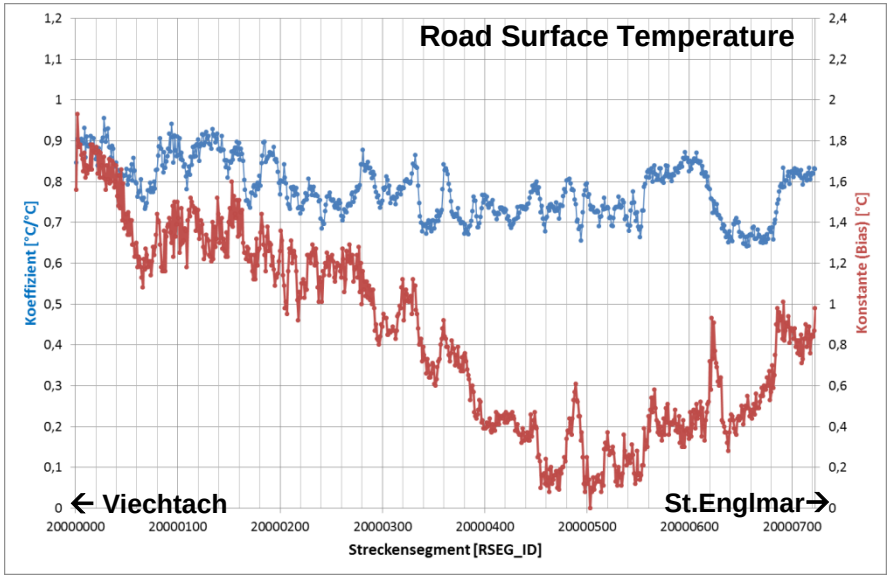


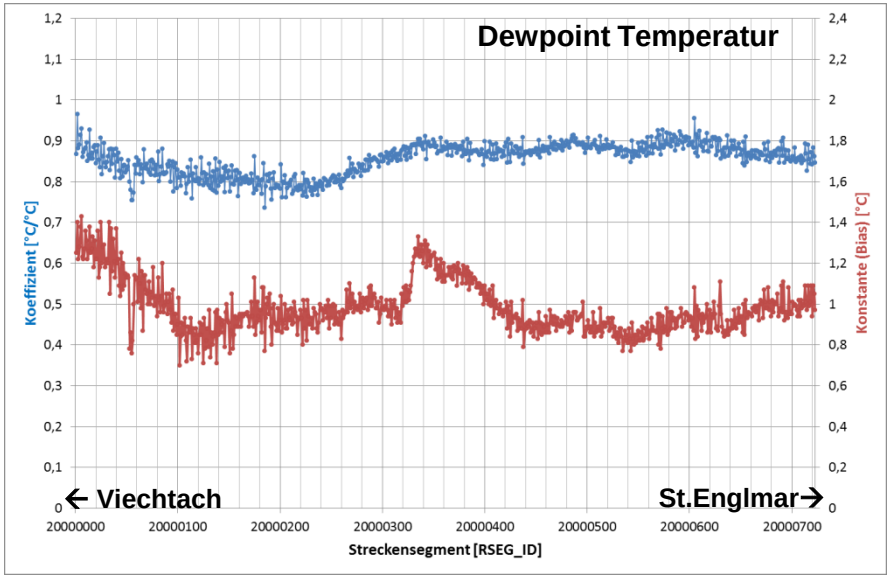
Regression parameters calculated from all collected mobile sample data in relation to the reference station data

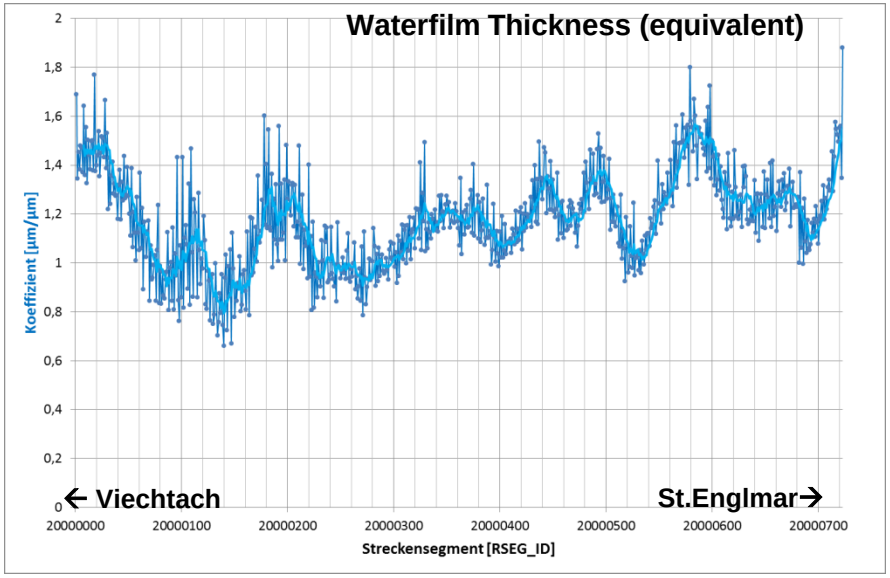
Throughout winter 2016/17

Without weather classes!

Parameters of transfer function for St2139 Viechtach / Reference: RWIS Predigtstuhl







Regression parameters calculated from all collected mobile sample data in relation to the reference station data

Throughout winter 2016/17

Without weather classes!

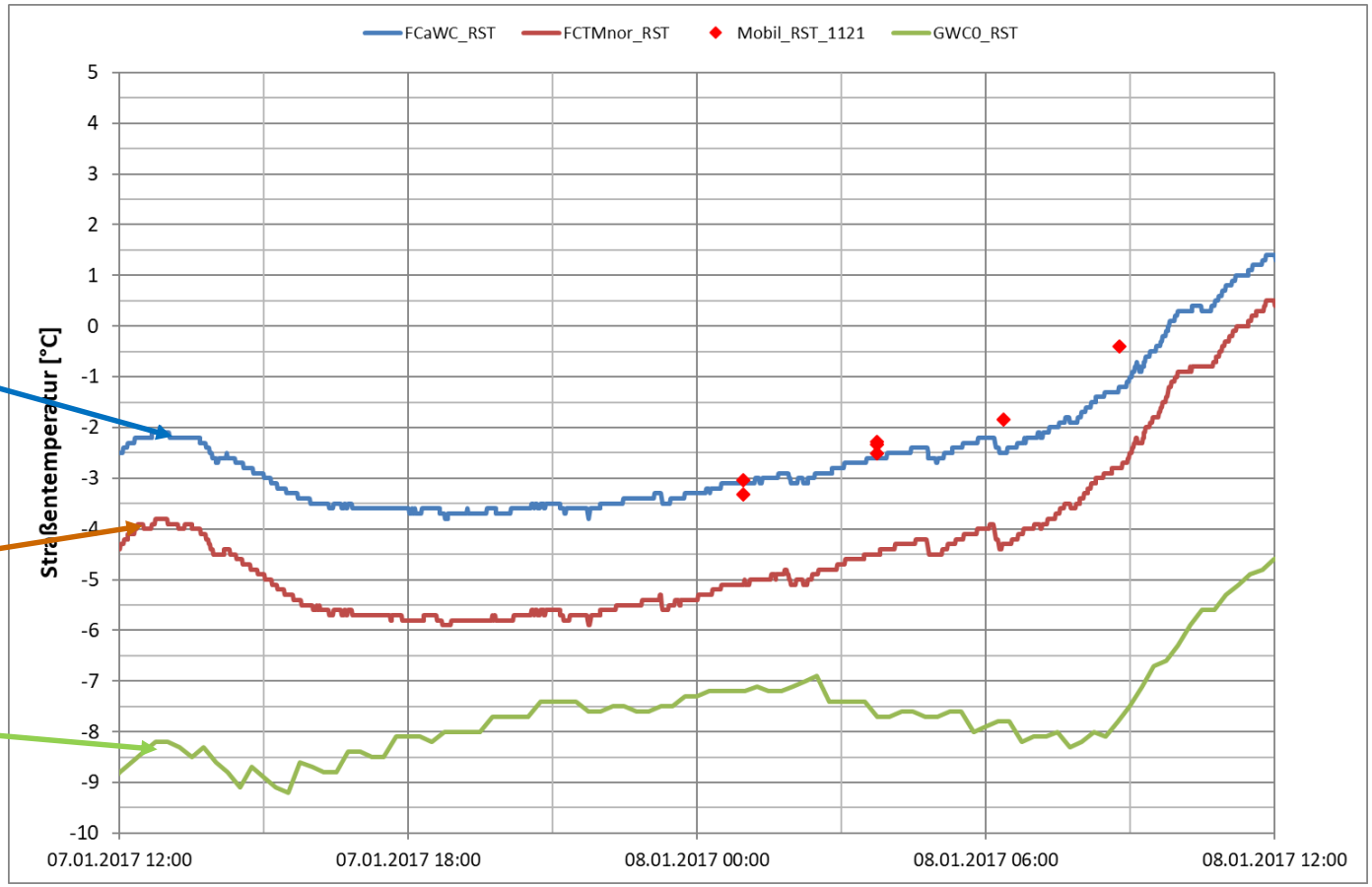
Modeling of route properties using transfer funktion and reference RWIS
Proof of the concept: Road Segment: AS Altmühltal, A9

Simulation of the forcast for one road segment (20m) of
Road surface temperature

Transfer function without weather classification

Comparison with simulation using Thermal mapping method

Comparison with numerical NowCasting from GWC



Reference station: Offenbau II, P423

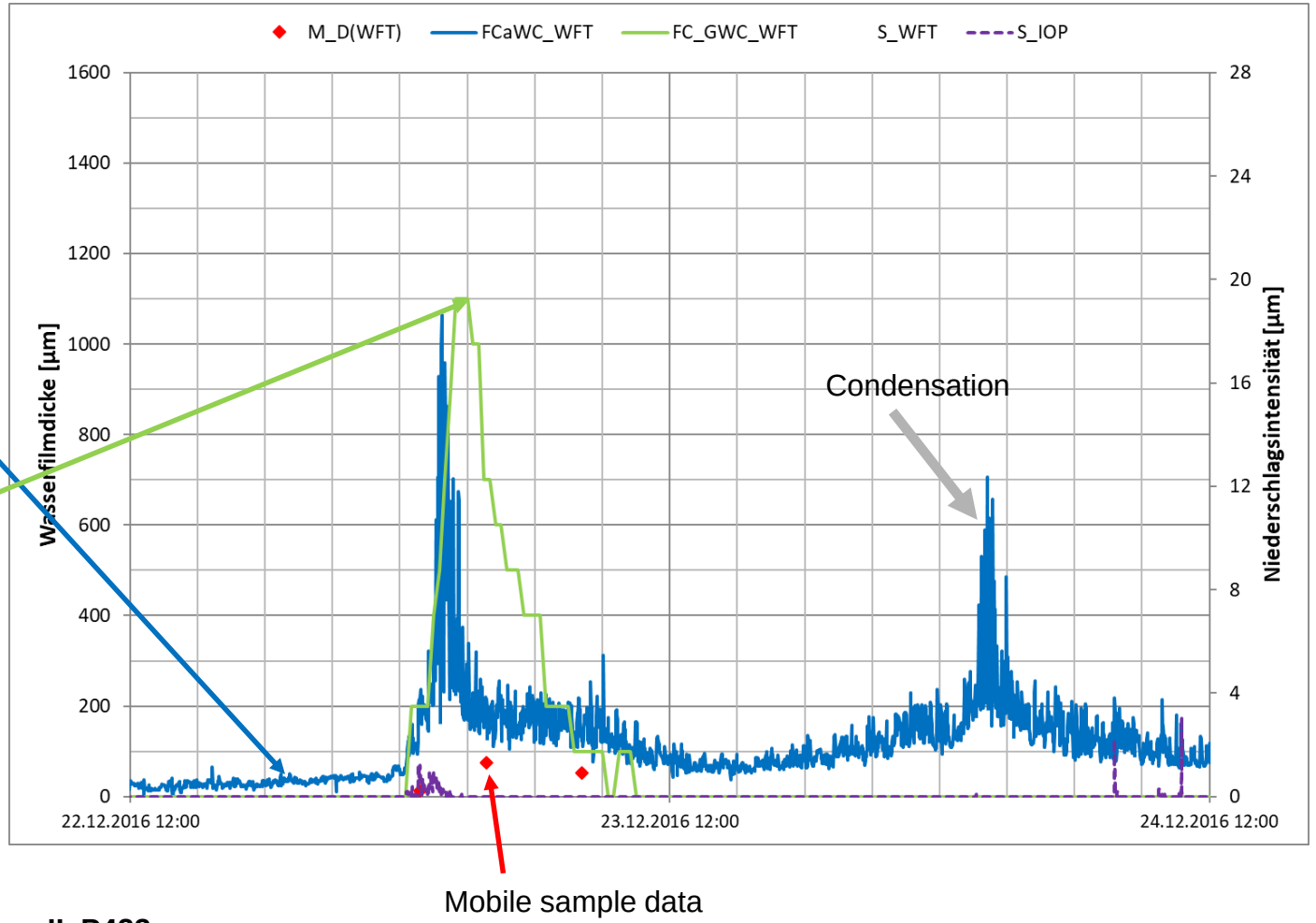
Road segment: No 1121, A9, AS Altmühltal, dir. Nbg.

Modeling of route properties using transfer funktion and reference RWIS
Proof of the concept: Road Segment: AS Altmühltal, A9

Simulation of the forcast for one road segment (20m) of
Waterfilm Thickness

Transfer function without weather classification

Comparison with numerical NowCasting from GWC



Reference station: Offenbau II, P423

Road segment: No 1121, A9, AS Altmühltal, dir. Nbg.

Modeling of route properties using transfer funktion and reference RWIS
Proof of the concept: Segment: 622, St2139, km 12.420

Simulation of the forcast
for one road segment (20m)
of
Waterfilm Thickness

Transfer function without
weather classification

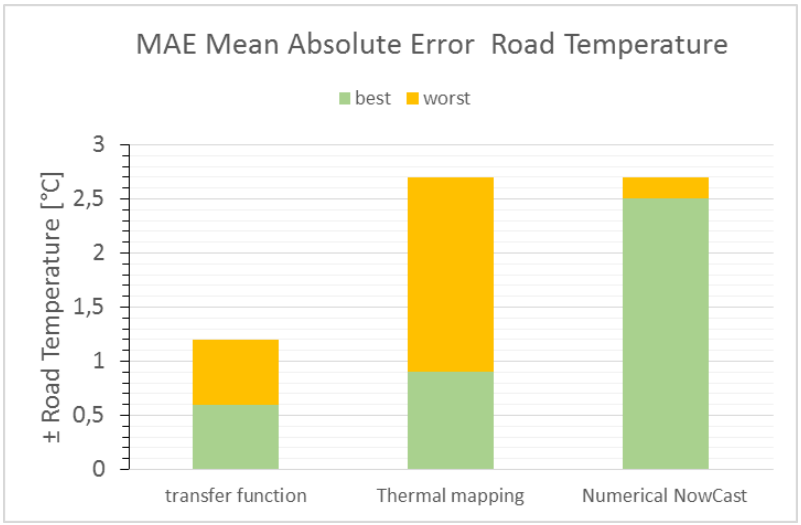
Comparison with numerical
NowCasting from GWC

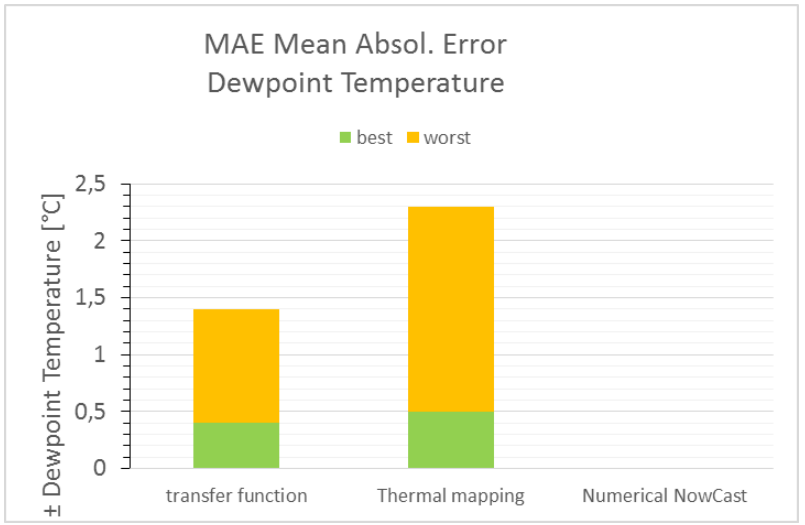
Mobile sample data

Reference station: Predigtstuhl, P471

Road segment: 622, St2139, km 12.420

Modeling of route properties using transfer funktion and reference RWIS
Proof of the concept: results over all segments and routes





Comparison of methods for modeling of route properties in connection with reference station (RWIS)
MAE = Mean Absolute Error

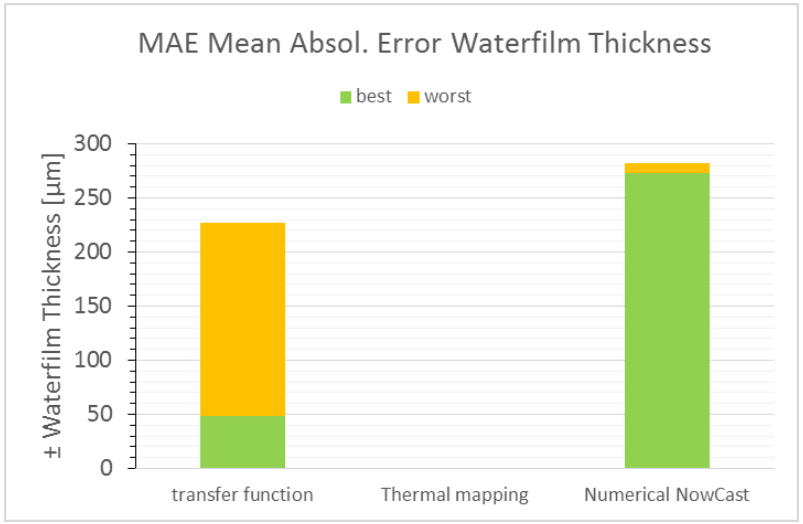
Linear transfer function:

Linear statistical transfer function of mobile data in relation to the data of a stationary reference station.

Here: without weather classification!

Thermal mapping:

Deriving the rout segment properties from data of the reference station using a unique measured thermal profile of the route Thermal mapping method



For comparison:

GWC:

Nowcasting the route properties from a numerical model (without using measurement data)

From Global Weather Corp. (GWC)

Method approaches for modeling of route properties some suitable weather classes

For transfer function:

RST

	Net radiation or RST-AT		Surface condition	
Weather Class RST	NetRad<0 or ≤ 1,5°C	NetRad. >0 or > 1,5°C	dry	Not dry
1	X		X	
2		X	X	
3	X			X
4		X		X

DPT & WFT

	Wetbulb difference RST-WBT		Type of Precip		
Weather Class WFT	< 2,5°C	≥ 2,5°C	No	Rain	Snow
1	X		X		
2		X	X		
3	X			X	
4		X		X	
5	X				X
6		X			X

Suitable criterias for Weather classes:

For road surface temperature:

1. Radiation situation
2. contamination condition on surface

For waterfilm and dew point:

1. Evaporation and condensation conditions
   → Wetbulb temperature difference to surface temperature
2. Contamination condition on surface

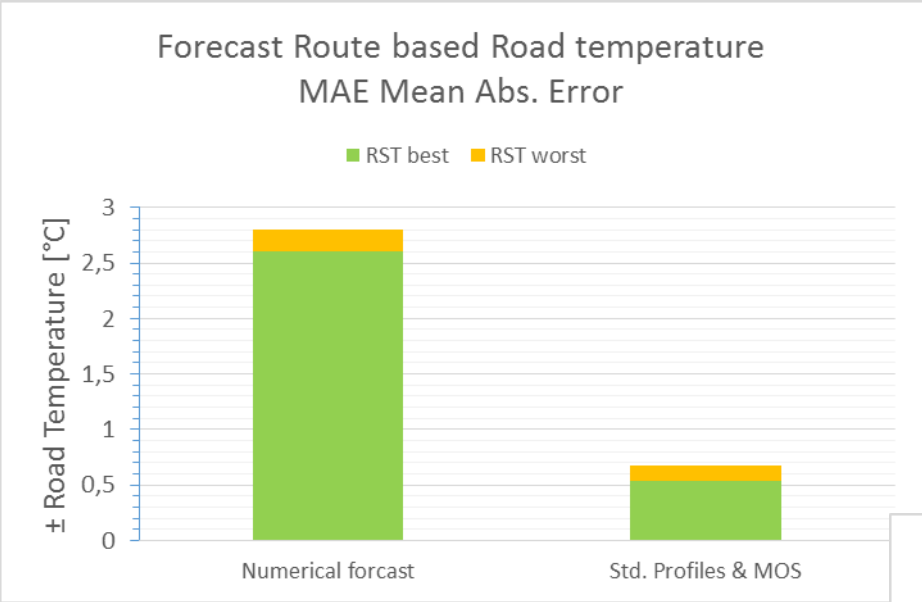
For standard route profiles:

Klassen	Kriterium	Kürzel	Messfahrten 2015/2016	Messfahrten 2016/2017
Tagsüber bewölkt	(Bewölkung >65%)	cloudyday	27	24
Nachts bewölkt	(Bewölkung >65%)	cloudynight	36	41
Tagsüber heiter-wolkig	(Bewölkung 20%-65%)	halfcloudyday	8	4
Nachts heiter-wolkig	(Bewölkung 20%-65%)	halfcloudynight	13	9
Tagsüber wolkenlos	(Bewölkung <20%)	nocloudsday	6	7
Nachts wolkenlos	(Bewölkung <20%)	nocloudsnight	10	40

Validation of road weather forecast providers who have participated

Abbr.	Provider	Dissemination, products, explanations
DWD	Deutscher Wetterdienst SWIS Offenbach, Deutschland	SWIS forecasts based on RWIS locations for all highway RWIS Resolution 1h to 24h Horizon data is available via GDS FTP.
GWC	Global Weather Corp. Boulder, Colorado, USA	Planning to offer road weather information on small-scale sections of the route via traffic information provider INRIX throughout Germany and Europe. Pushed the forecast data on the project FTP server!
MBA	meteoblue AG Basel, Schweiz	Route based athmospheric weather forecast in spatial resolution of 3 to 0.1 km, datasets via API. Cover of the test routes in steps. Are picked up regularly by Task Scheduler and archived on the project FTP server
FOR	FORECA LTD Espoo, Finnland	Provide road weather forecasts also in Germany, small-scale surface forecasts on runways for airports. Provides segment forecasts with a resolution of 20m to the project starting winter 2016
DTN	DTN (ehem. Telvent DTN, Schneider Electric), Burnsville, MN 55337, USA	Supplies pavement forecasts for the position of the smoothing detection systems in Switzerland and offers for all of Europe.

Validation of route based forecast
Example: results of method validation against mobile ground truth

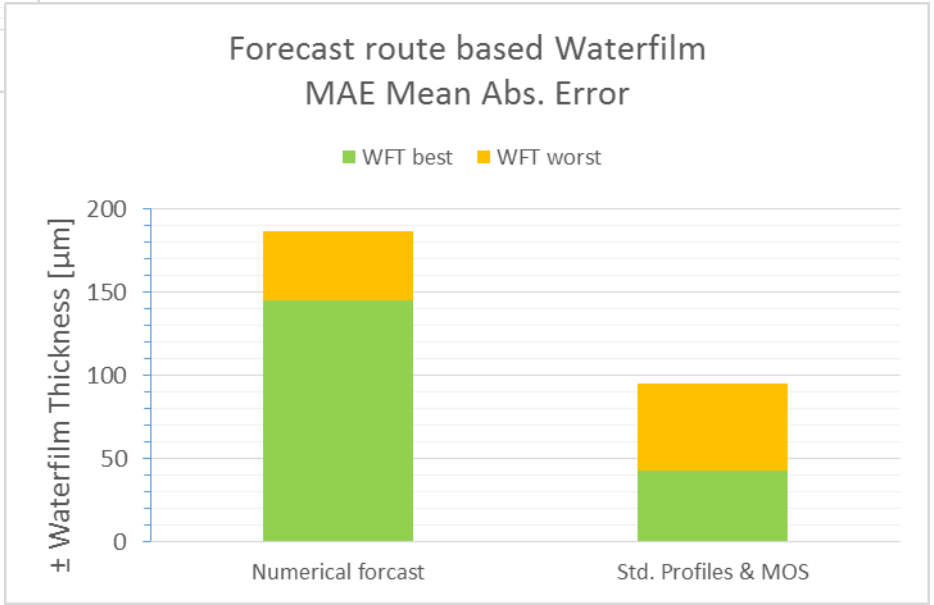


Numerical Forecast (state of the art):

2 provider which supply route based forecasts (GWC, FORECA)

Std. Profiles & MOS:

Proof of the concept using standard profiles method and forecast methods with downscaling and MOS (model output statistics) on RWIS reference



Thank you for attention!

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