Knowing your slope on the track: Getting the most out of GPS and power data

Stefan Wolf and Dietmar Saupe

Multimedia Signalprocessing
Department of Computer and Information Science
University of Konstanz, Germany

Science & Cycling

Düsseldorf, Germany
29.06.2017

DFG

Science & Cycling
28–29 June 2017, Düsseldorf, Germany

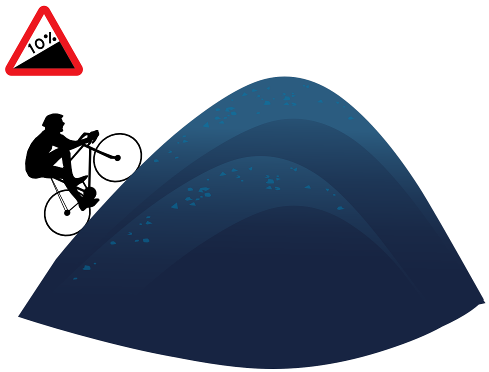
Universität Konstanz

Distribution of work

gain in kinetic energy
0.0%

rolling resistance
4.4%

bearing resistance
0.1%



air resistance
3.6%

grade resistance
91.8%

Available data

GPS (Leica GPS900 Differential GPS)

Pro:
- High accuracy

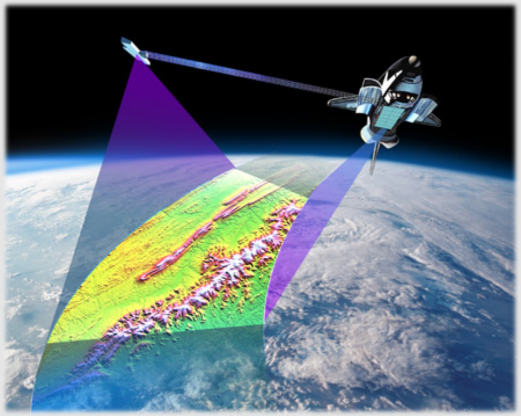
Con:
- Obstacles near road
- Heavy and bulky equipment

Barometric (Garmin Edge 1000)

Pro:
- Easy to use

Con:
- Drift

Elevation map (SRTM1, www.gpsies.com)



Pro:
- Consistent values

Con:
- Coarse mesh of 30x30m

Available data

GPS (Leica GPS900 Differential GPS)

Pro:
- High accuracy

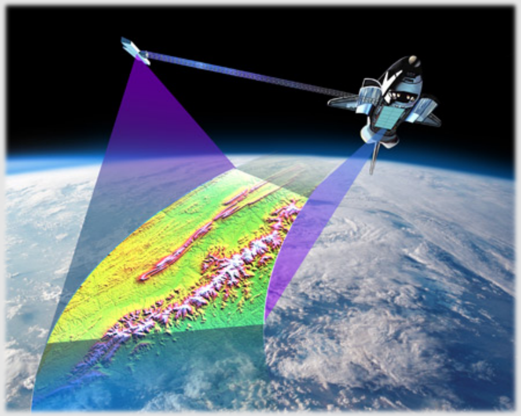
Con:
- Obstacles near road
- Heavy and bulky equipment

Barometric (Garmin Edge 1000)

Pro:
- Easy to use

Con:
- Drift

Elevation map (SRTM1, www.gpsies.com)



Pro:
- Consistent values

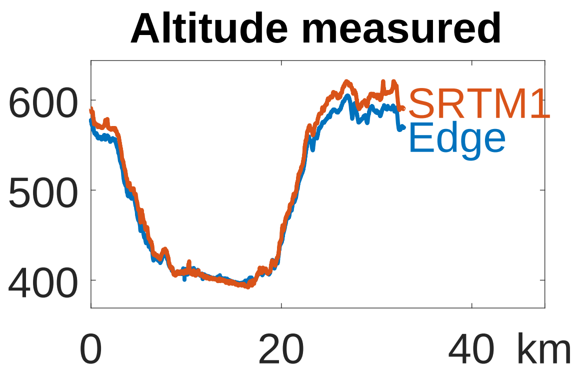
Con:
- Coarse mesh of 30x30m

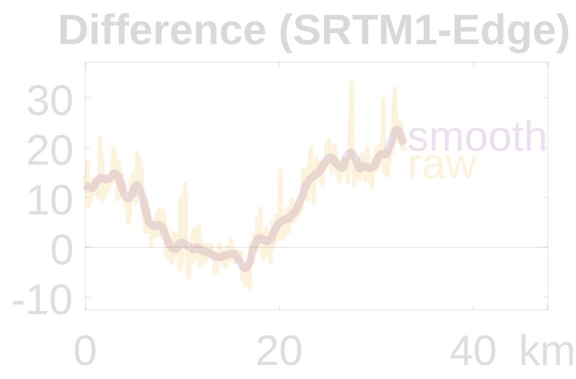
Power (SRM) and Speed (Garmin)

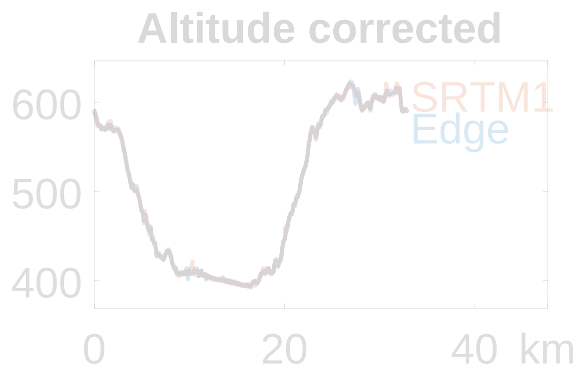
What are suitable methods to determine the slope?

What error can be expected?

Altitude correction



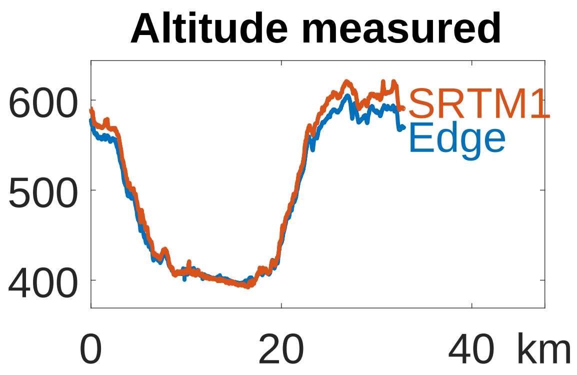


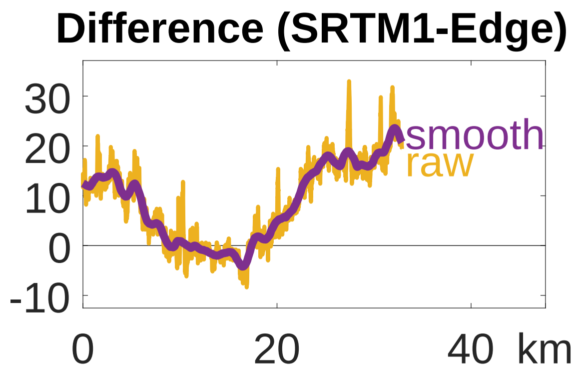


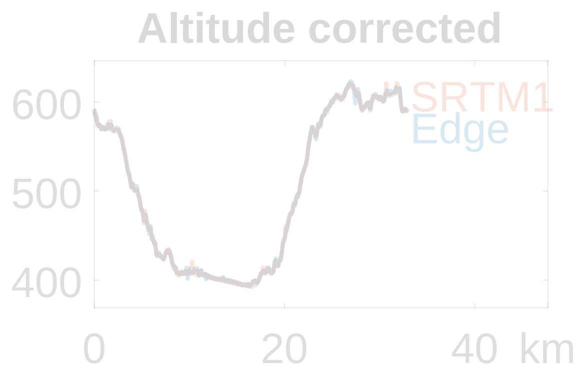
Goal:

- Global adaptation to SRTM1
- Local accuracy of Edge 1000

Altitude correction







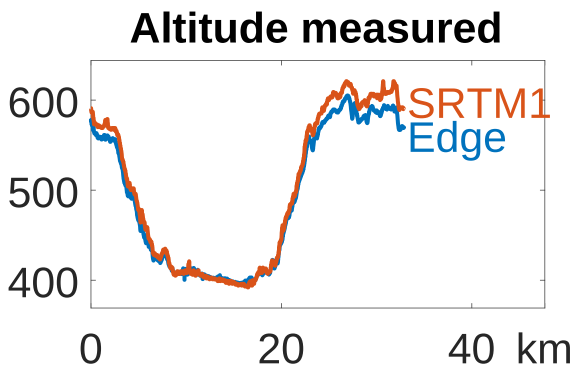
Calculate difference:

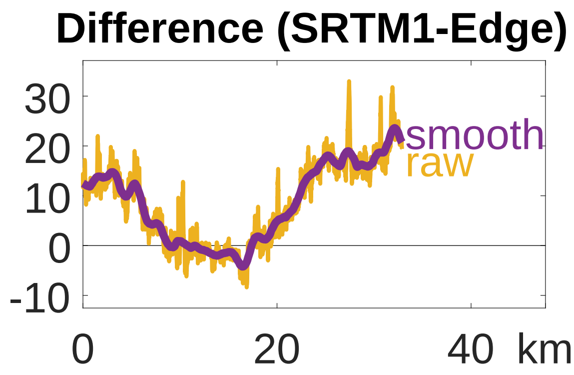
- Difference between SRTM1 and Edge 1000 data

Smooth difference:

- Use Gaussian smoothing with $\sigma = 500\,\mathrm{m}$

Altitude correction



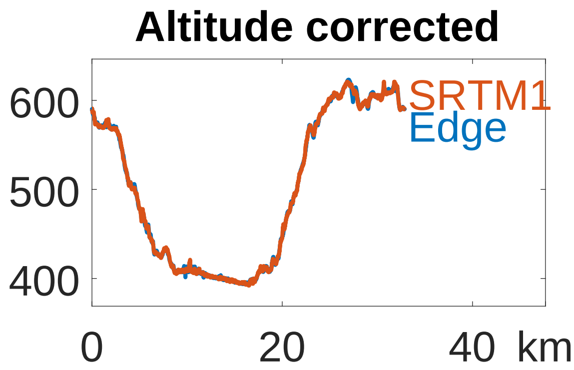


Correct altitude profile:

- Add the smoothed difference to the Edge 1000 data

Result:

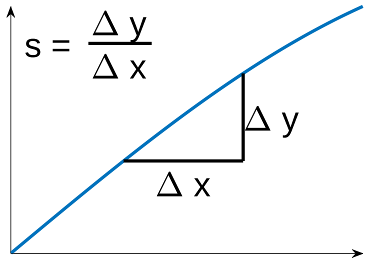
- Global differences removed
- Local differences preserved

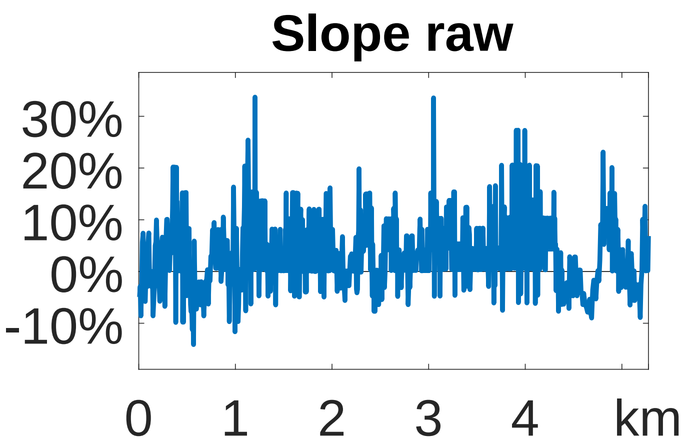


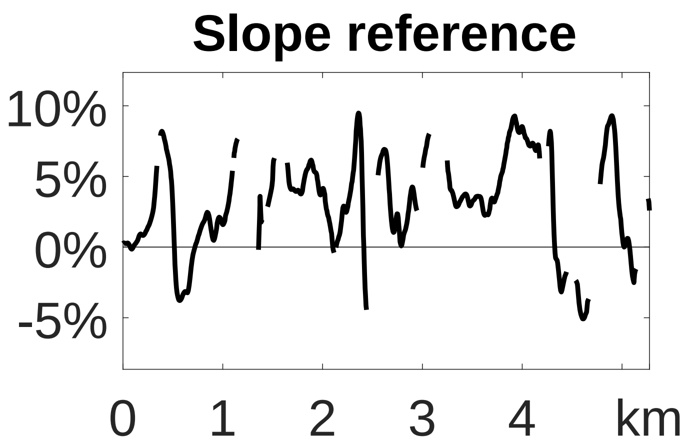
Slope

Simple method:
- Difference quotient

Problem:
- Amplifies noise

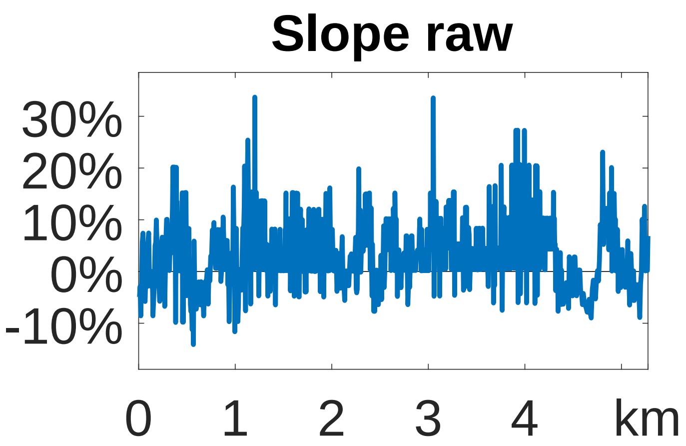


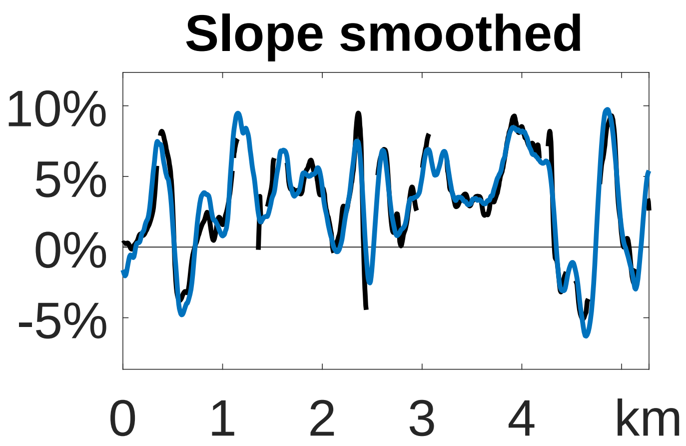




Slope by 'Gaussian'-Method (GAU)

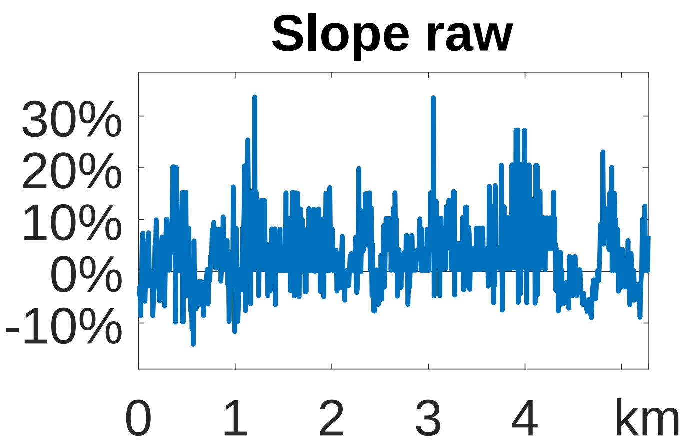
1. Smooth altitude profile with Gaussian filter
2. Calculate slope by difference quotient

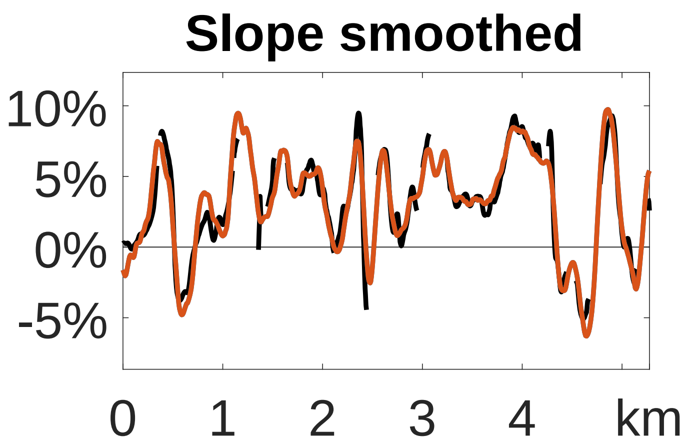




Slope by Savitzky–Golay filter (SGO)

Savitzky-Golay filter provides smoothed slope and altitude directly by polynomial approximation



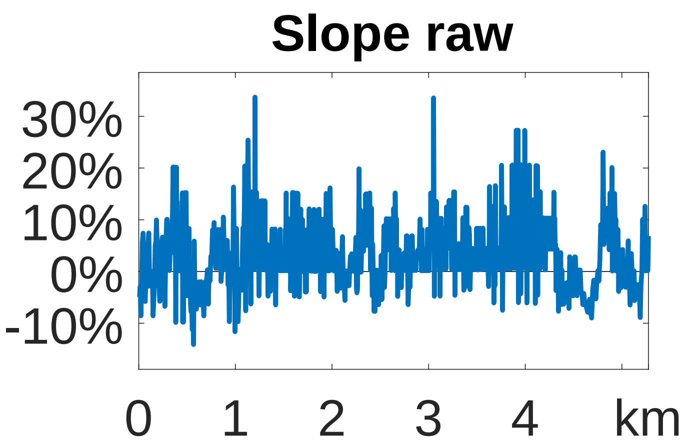


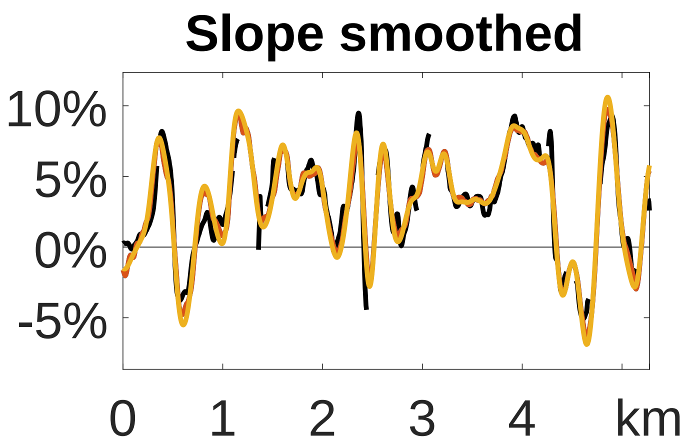
Slope by Tikhonov regularization (TIK)

Calculate slope directly by Tikhonov regularization:

$$\min_{s} \|As - \hat{y}\|^2 + \alpha \|Ds\|^2$$

A: integrator
$\hat{y}$: measurements
D: differential operator
α: smoothing factor





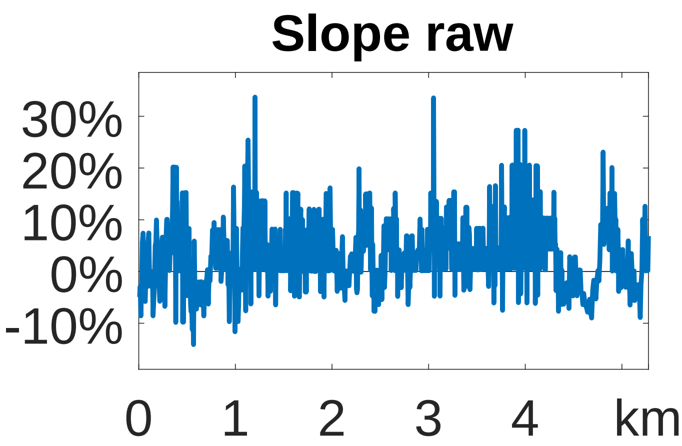
Slope by Model (MOD)

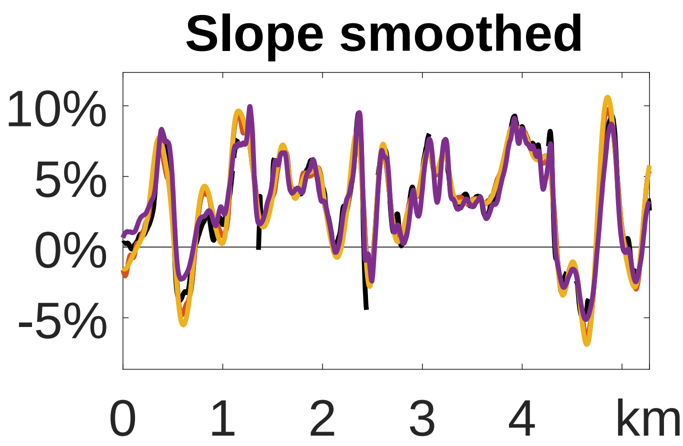
Mechanical model of cycling dynamics:

$$\underbrace{mgvs}_{B} + \underbrace{\mu mgv + (\beta_0 v + \beta_1 v^2) + \left(m + \frac{I_w}{r_w^2}\right) av + \frac{1}{2} c_d \rho A v^3 - \eta P}_{c} = 0$$

Solve linear equation system:

$$s = -B^{-1} c$$

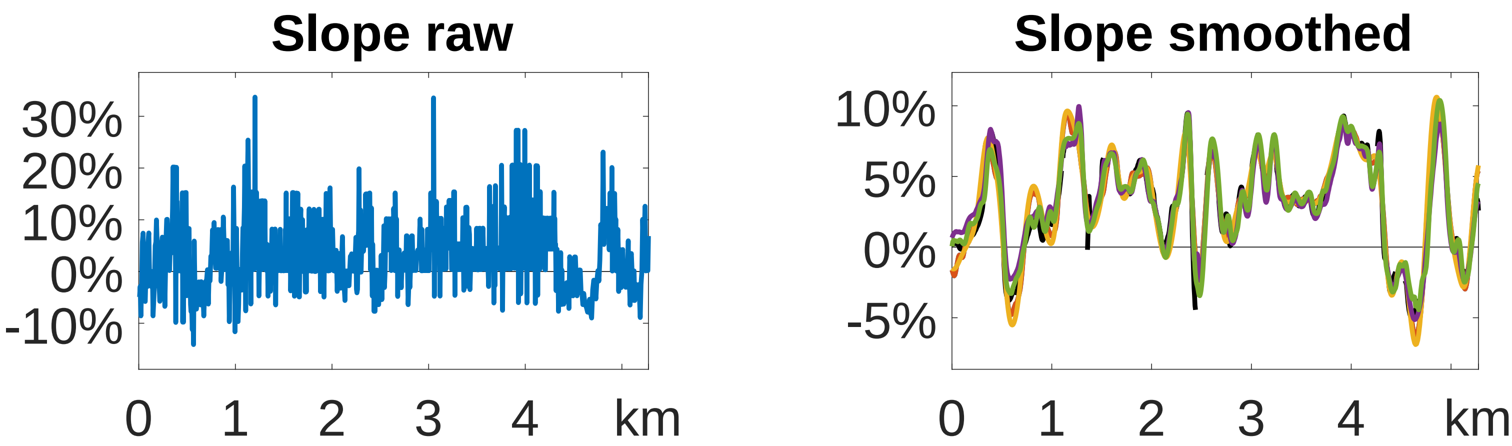




Slope by Tikhonov regularization with model extension (TIM)

Extend Tikhonov regularization functional:

$$\min_s \|As - \hat{y}\|^2 + \alpha \|Ds\|^2 + \beta \|Bs + c\|^2$$



Experiment and data analysis

Course

- Length: 5.3 km
- Mainly uphill with short downhill sections

Measurements

- Three rides
- Different days
- Good weather conditions

Experiment and data analysis

Course

- Length: 5.3 km
- Mainly uphill with short downhill sections

Measurements

- Three rides
- Different days
- Good weather conditions

DGPS ground truth

- Use only very good quality datapoints (accuracy better than 5 cm)
- Smooth altitude with Gaussian filter ($\sigma = 15\,\mathrm{m} \approx 4$ datapoints)
- Slope by difference quotient

Experiment and data analysis

Course

- Length: 5.3 km
- Mainly uphill with short downhill sections

Measurements

- Three rides
- Different days
- Good weather conditions

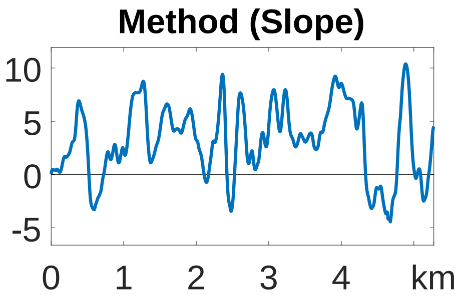
DGPS ground truth

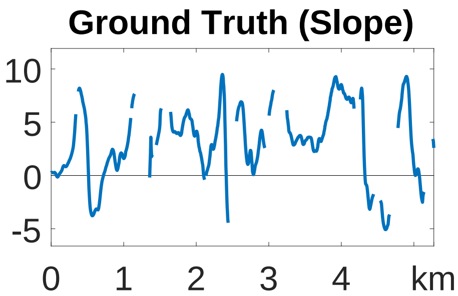
- Use only very good quality datapoints (accuracy better than 5 cm)
- Smooth altitude with Gaussian filter ($\sigma = 15\,\mathrm{m} \approx 4$ datapoints)
- Slope by difference quotient

Method parameters

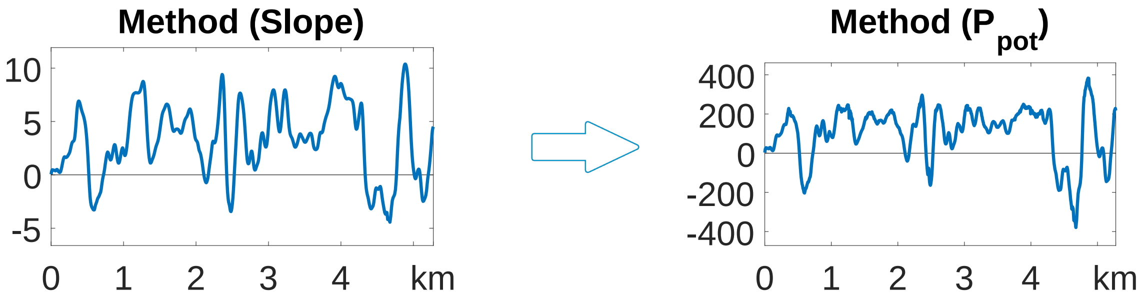
- Parameters (filters and regularization) are determined for each method and each ride for best fit with ground truth

Error estimation

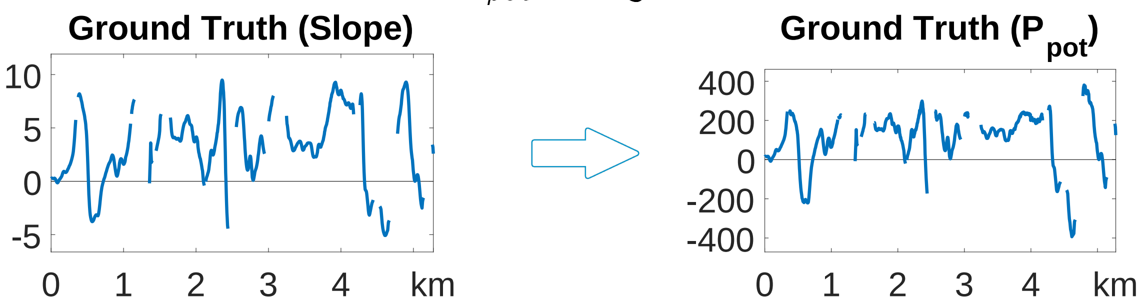




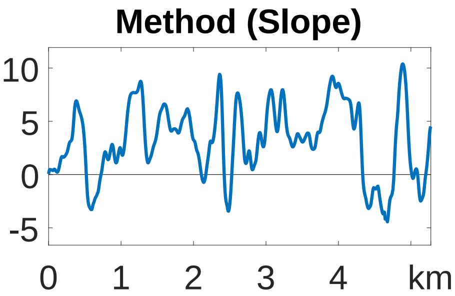
Error estimation

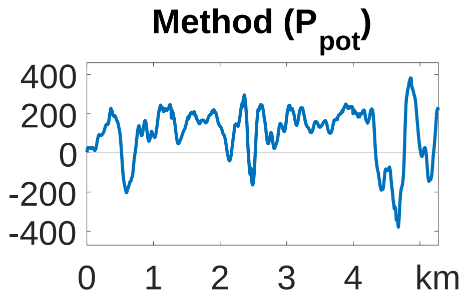


$$P_{pot} = mgsv$$

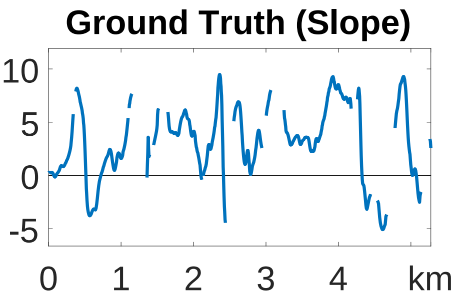


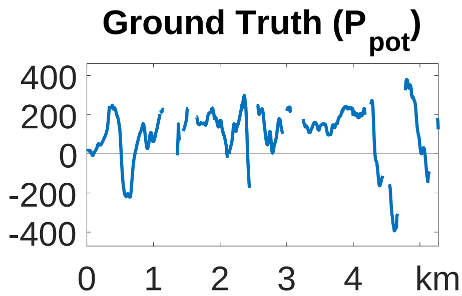
Error estimation





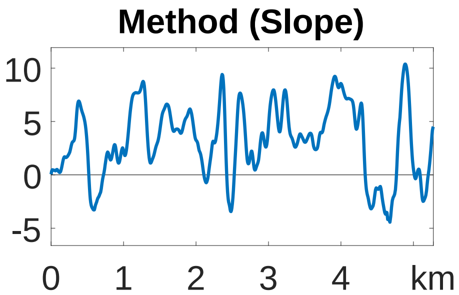
$$P_{pot} = mgsv$$

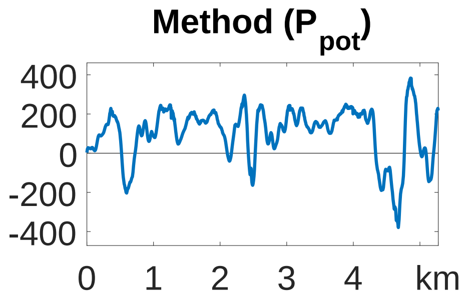




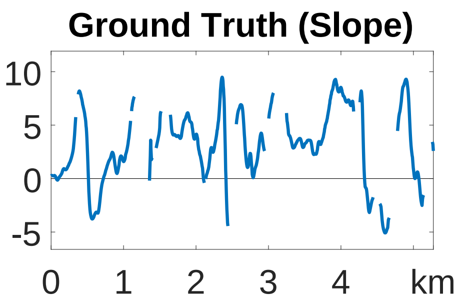
RMSE
ME

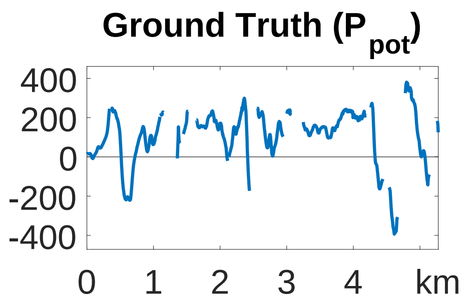
Error estimation





$P_{pot} = mgsv$





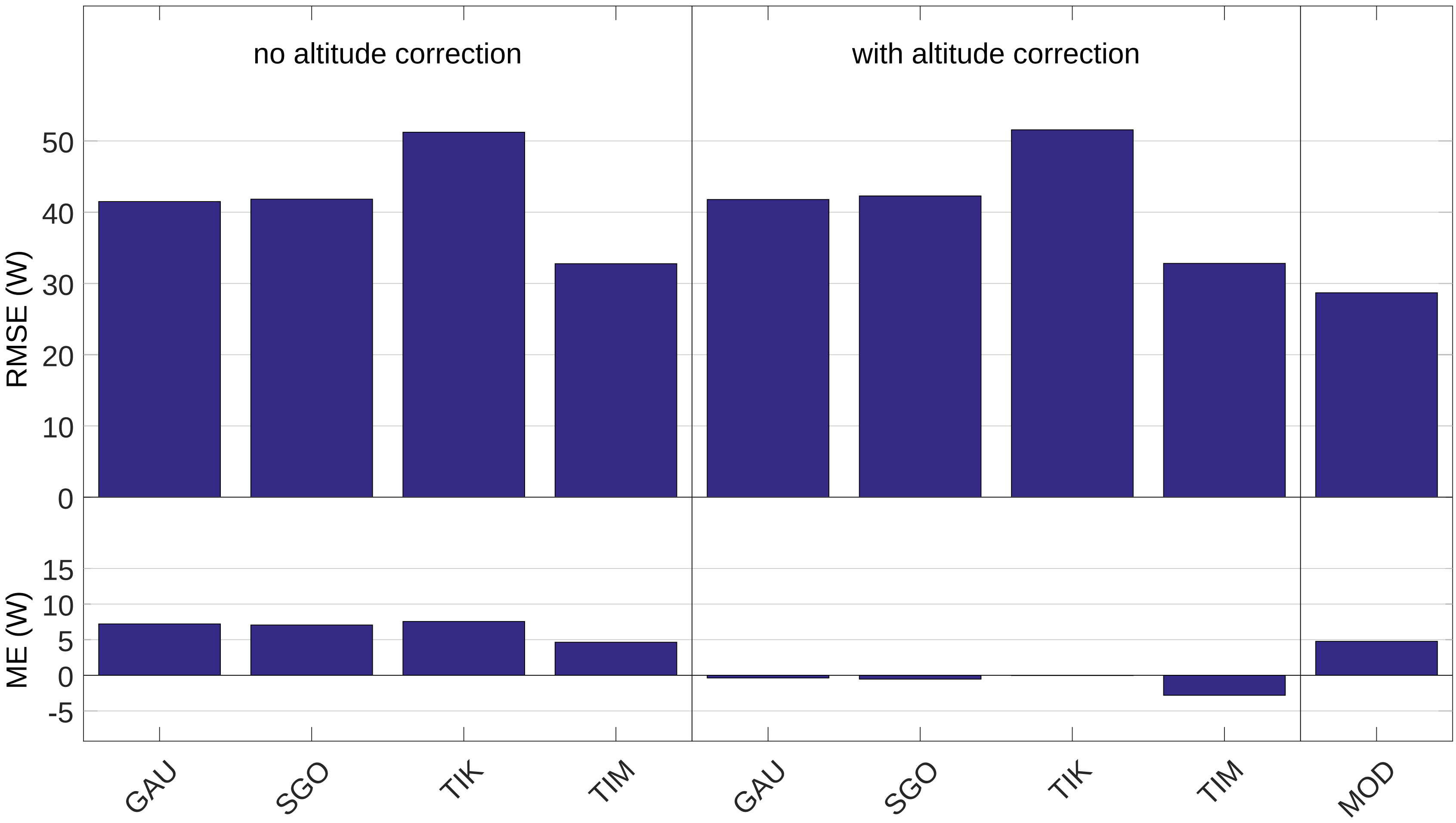
RMSE
ME

Local error (RMSE) vs. global error (ME):

$$v \xrightarrow{model} P \xrightarrow{integral} W'$$

	small local error	small global error

Results


no altitude correction
with altitude correction
RMSE (W)
50
40
30
20
10
0
ME (W)
15
10
5
0
-5
GAU
SGO
TIK
TIM
GAU
SGO
TIK
TIM
MOD

Summary

- Small global error (ME) with altitude correction
- Significant local error (RMSE) for all methods
- Local error is reduced by including speed and power data

Thank you!

https://www.mmsp.uni-konstanz.de/research/powerbike/