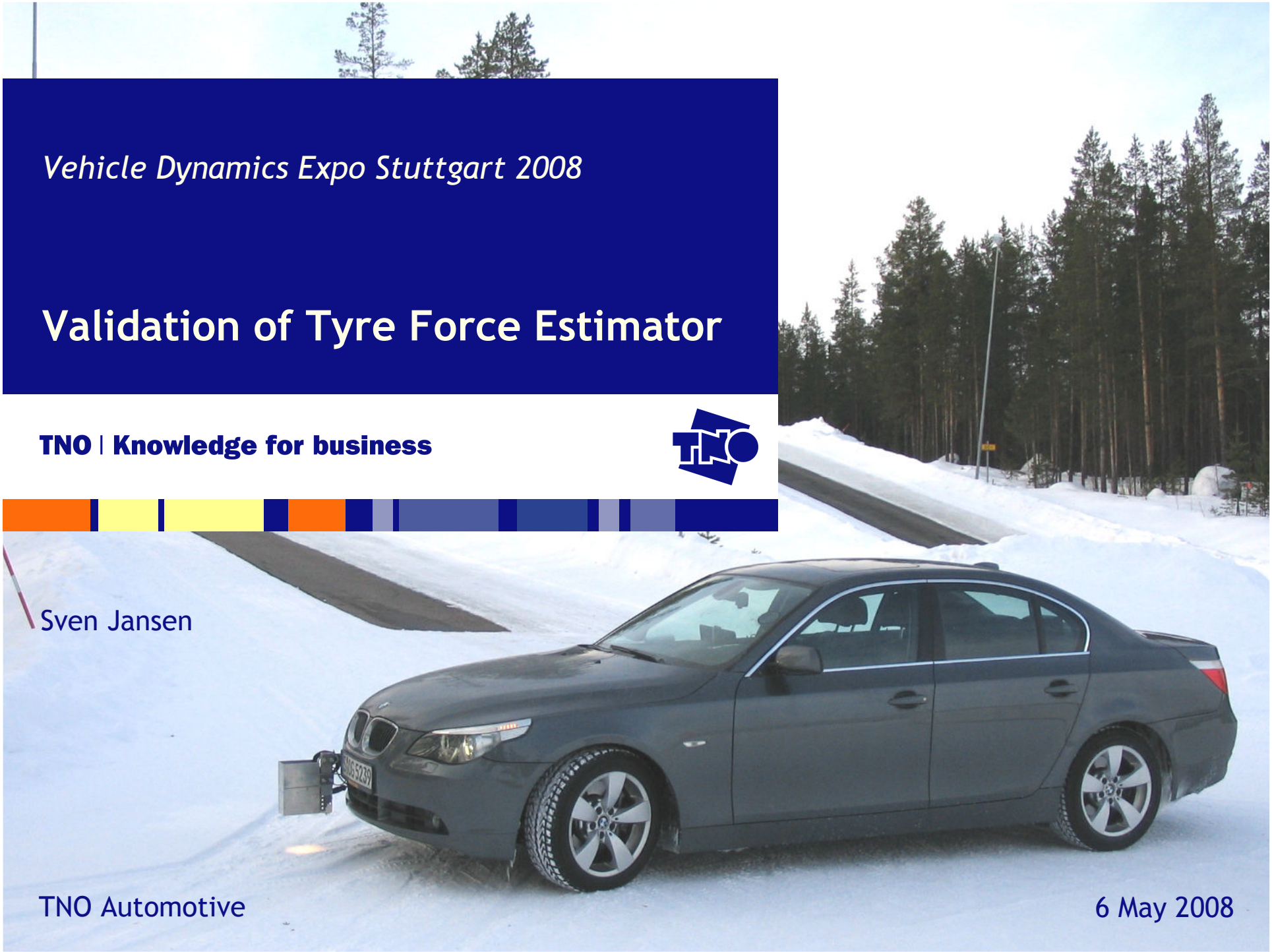
Vehicle Dynamics Expo Stuttgart 2008

Validation of Tyre Force Estimator

TNO | Knowledge for business



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TNO in a Nutshell

- TNO is the Netherlands' Organization for Applied Research
- ~~75~~ 76 years of experience
- Independent R&D organization
- 5,000 employees world-wide
- HQ in Delft, the Netherlands
- Annual turnover approx. 550 M€

Contents

- **Background**
  - Why use vehicle motions for tyre assessment
- **Tyre Force Estimator method and tool**
- **Validation results**
- **Summary**

Challenges for assessment of tyre slip characteristics

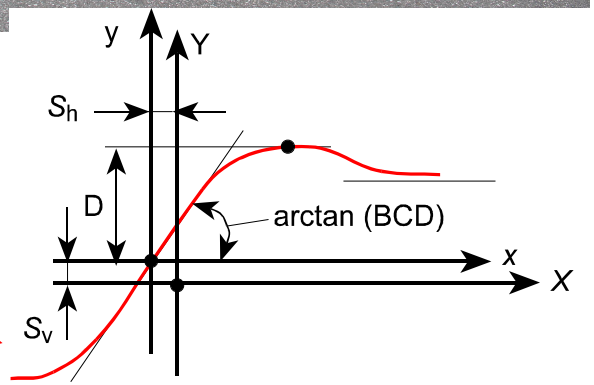
- **Tyre characteristics depend on operating conditions**
  - Road texture, Road curvature, Tyre temperature, Speed, etc...
- **Benchmarking/Ranking of tyres important for design choices in tyre development and in vehicle setup but ranking on tyre test equipment not always consistent!**
- **Relation between subjective vehicle assessment and tyre characteristics more important then tyre performance assessment**
- **Existing tyre testing methods laborious, costly, inflexible, etc...**

Advantages of using vehicle motions

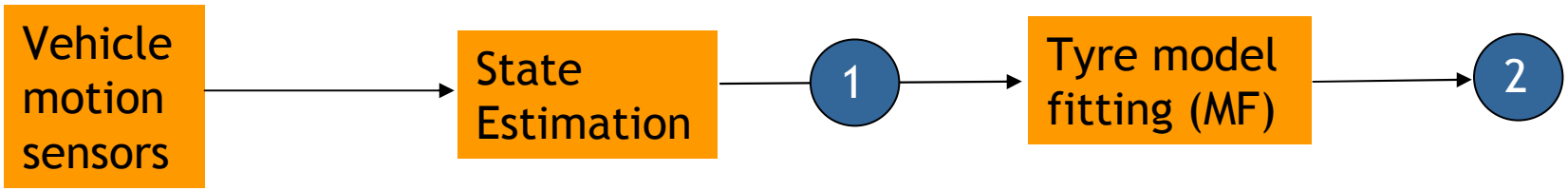
- Limited vehicle instrumentation
- Assessment for actual vehicle operating conditions (surface, speed, thermal load, ...)
- Easy change of tyres, can be combined with subjective evaluation
- Fast and cost effective!

Prerequisites for success:

- Not dedicated to one specific vehicle
- Sufficient accuracy for ranking and basic tyre model parameter assessment
- Easy data processing



Tyre Force Estimator method



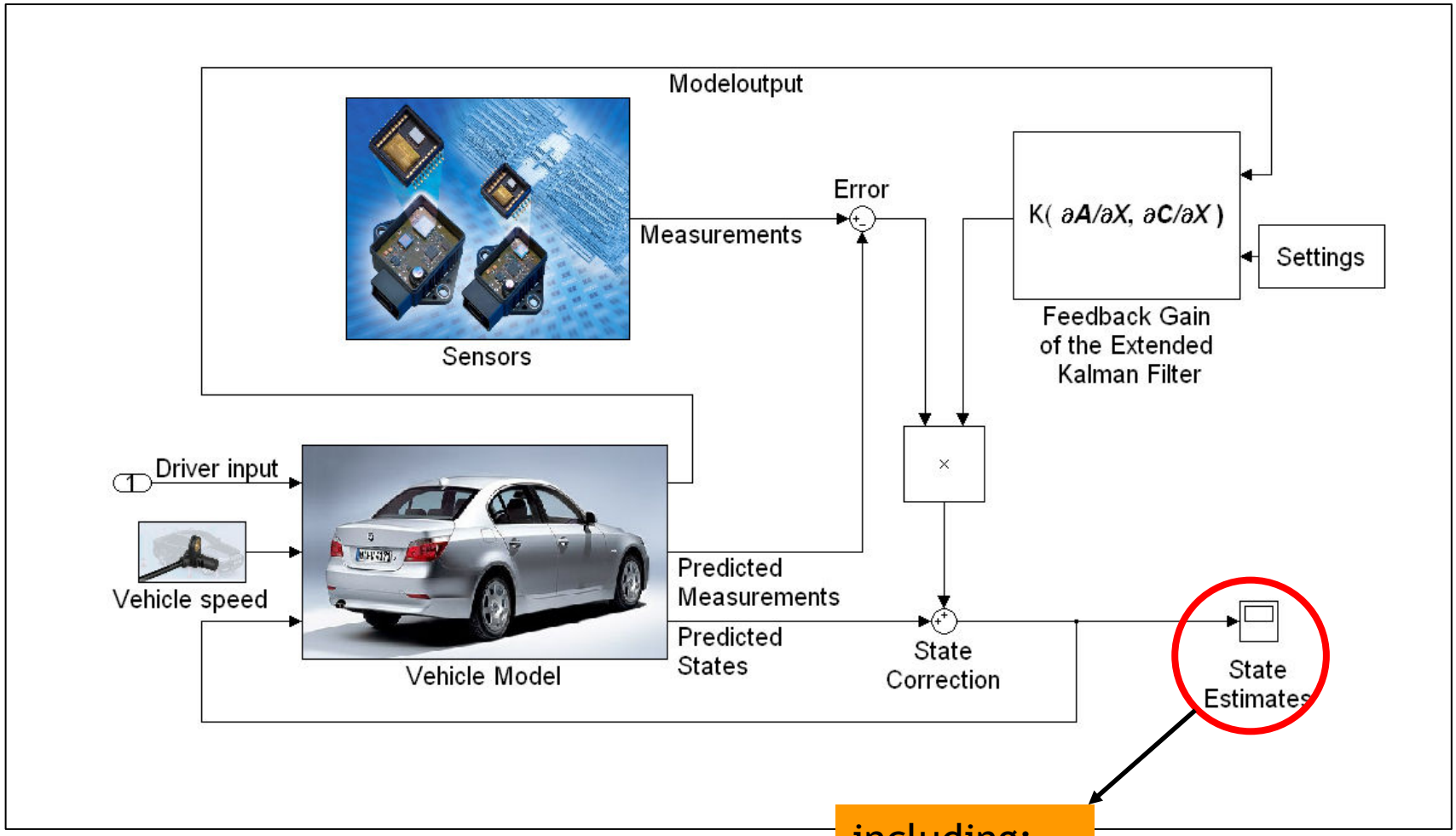
1 Time histories of tyre forces and slip angle

- Evaluation for specific conditions (e.g. exertion of friction potential in curves)
- No specific test protocol required

2 Tyre characteristics

- Tyre comparison in terms of basic characteristics
- Dedicated test protocol

State Estimator concept

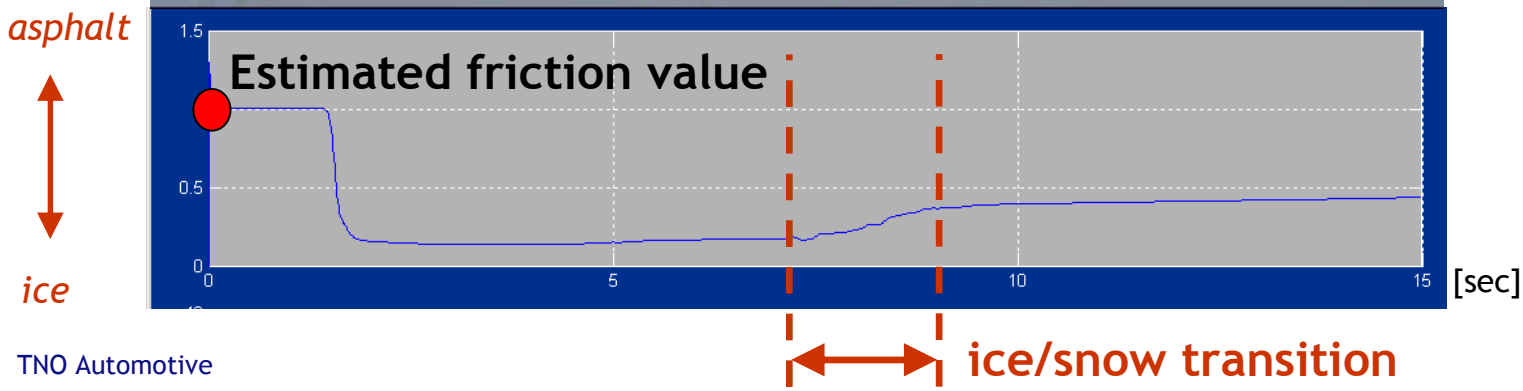


including:

Tyre forces

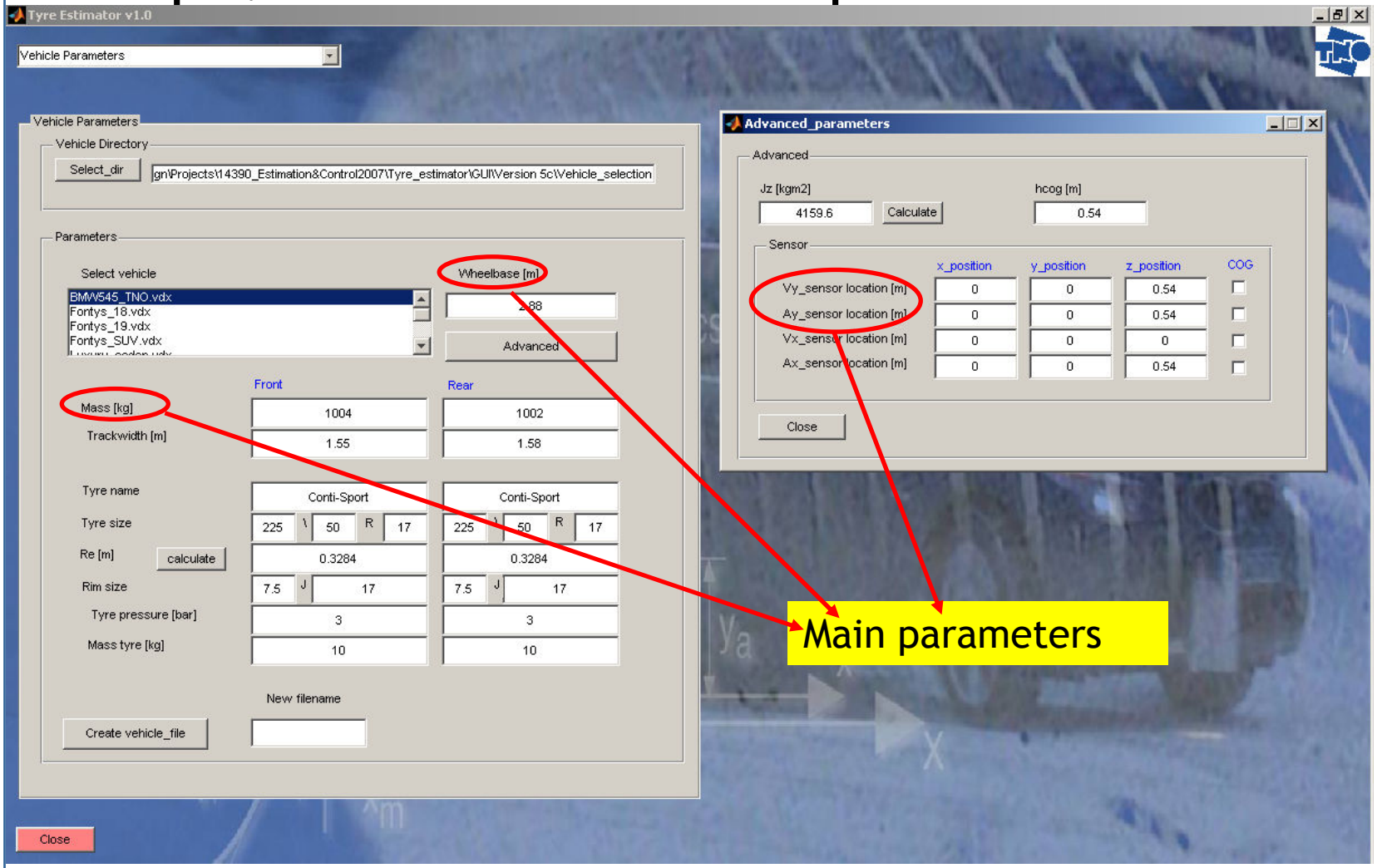
Slip angles

Example: Friction estimation



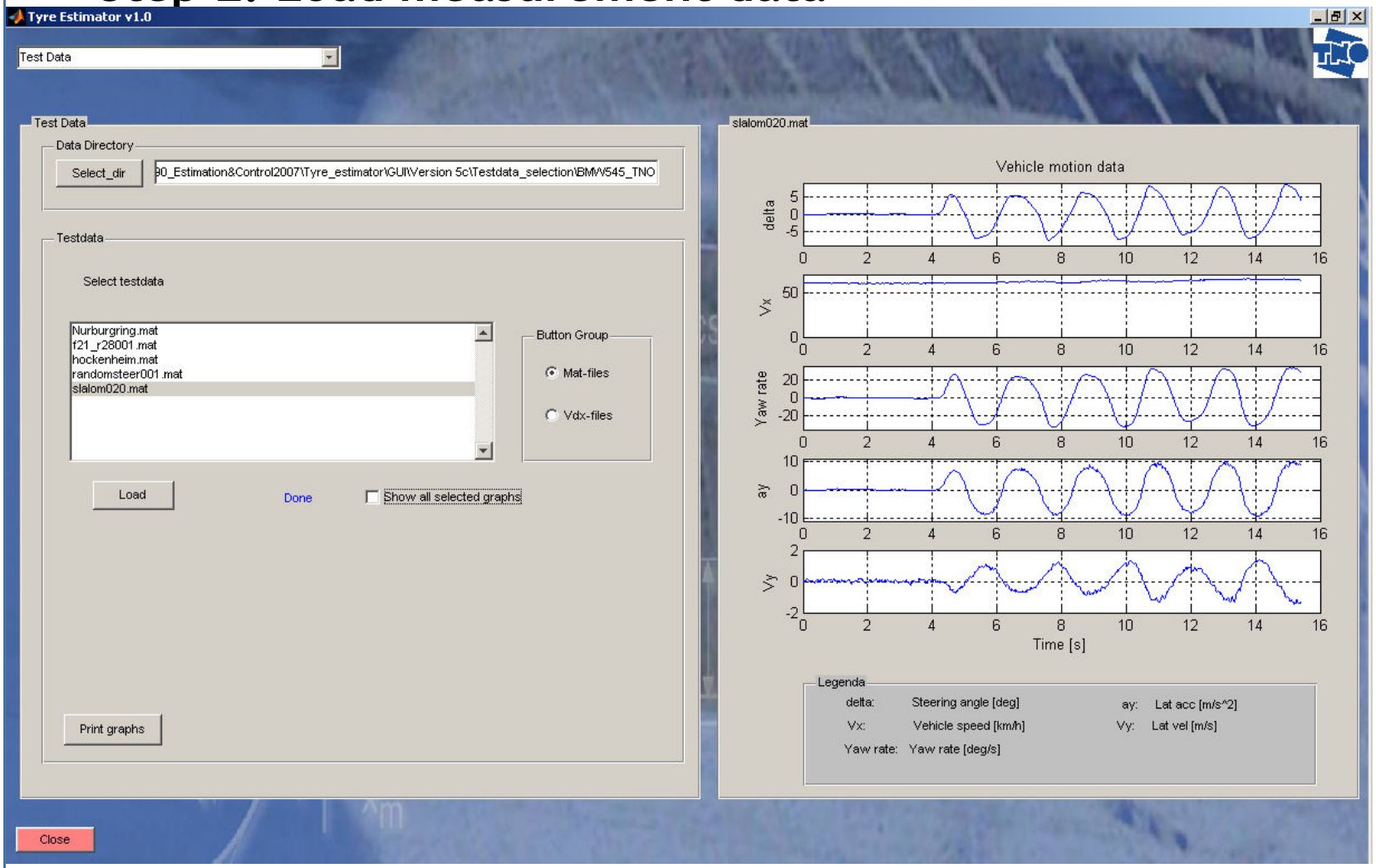
Tyre Force Estimator tool

- **Step 1: Define vehicle & sensor parameters**



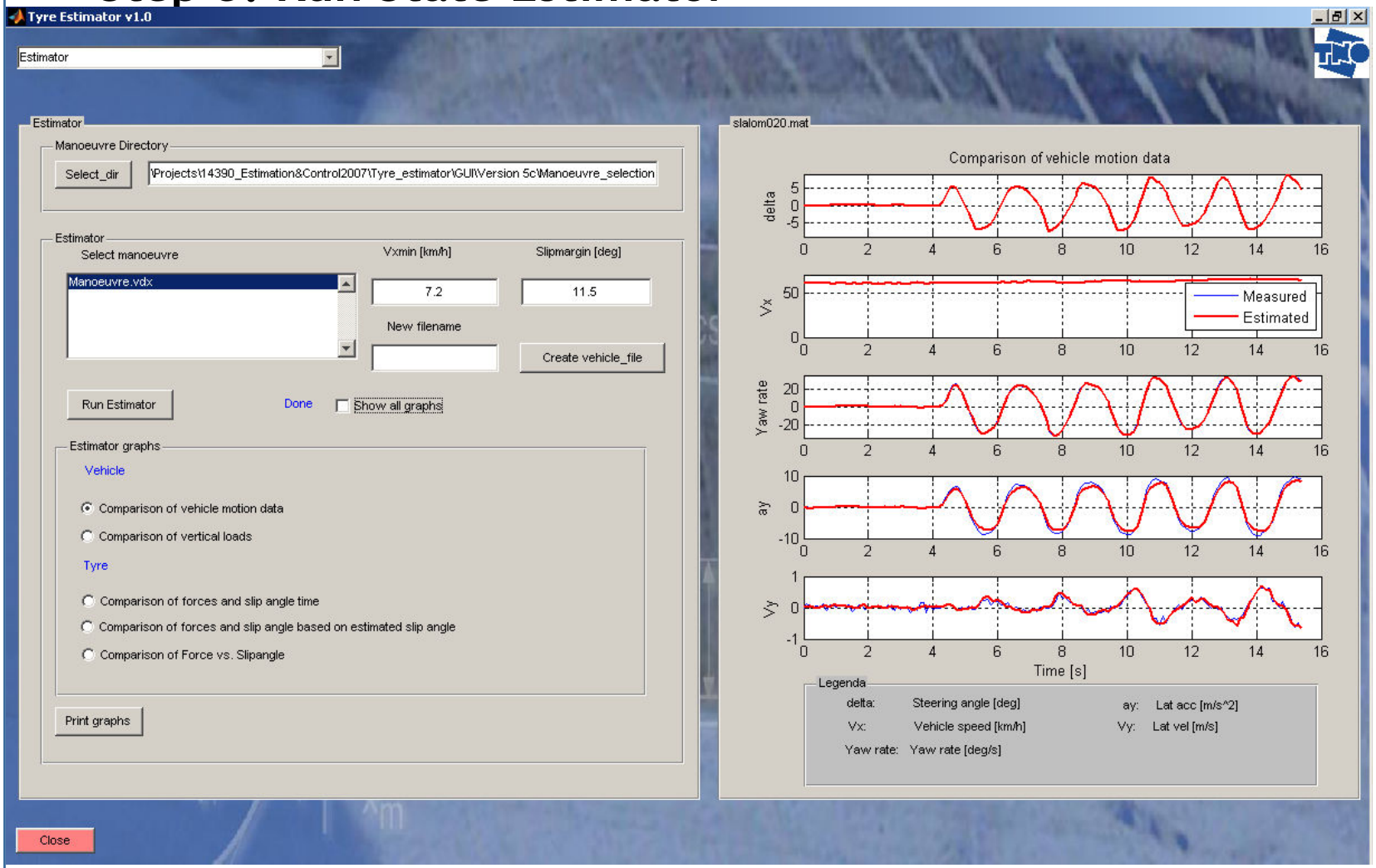
Tyre Force Estimator tool

- **Step 2: Load measurement data**



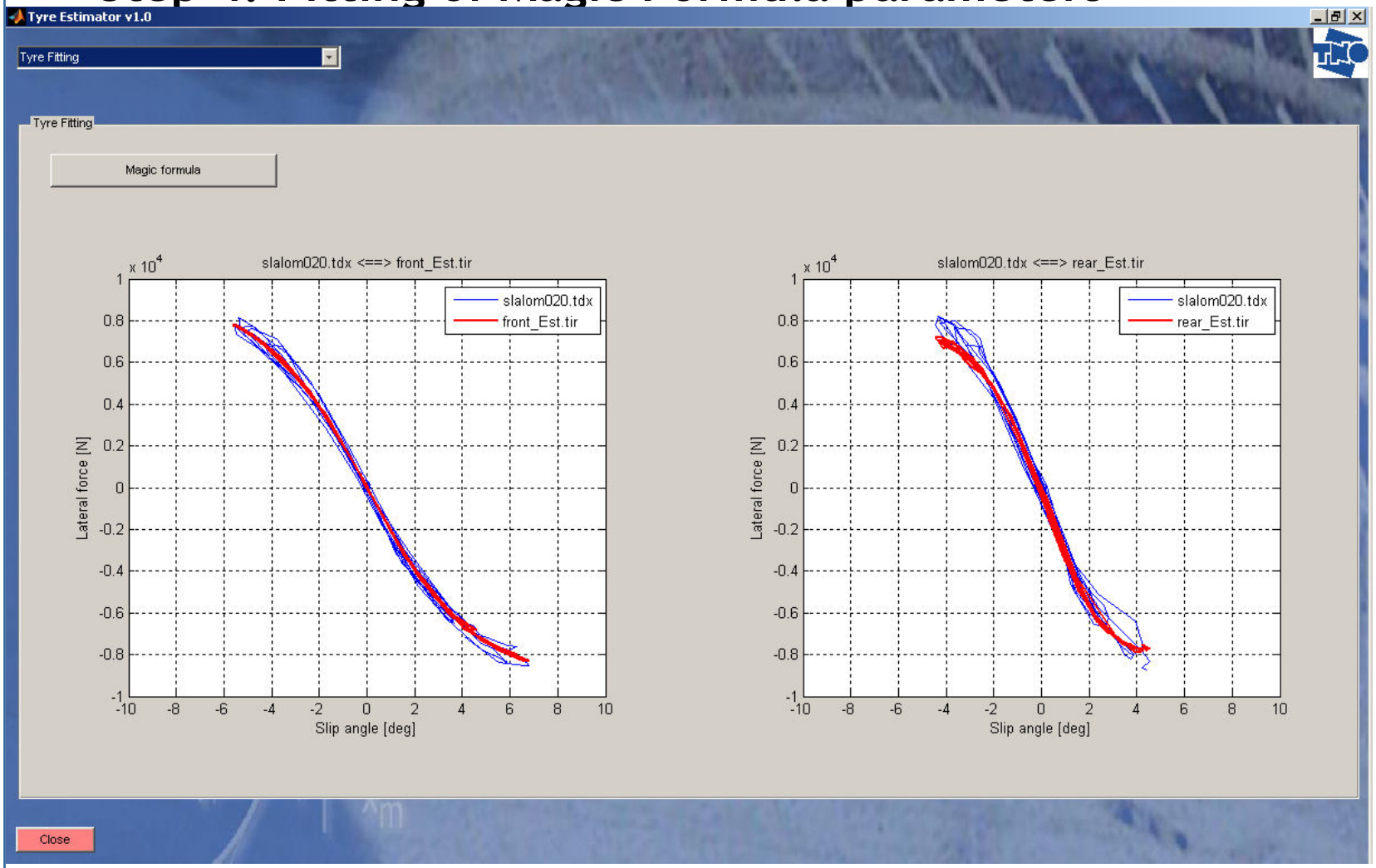
Tyre Force Estimator tool

- **Step 3: Run State Estimator**



Tyre Force Estimator tool

- **Step 4: Fitting of Magic Formula parameters**



Validation

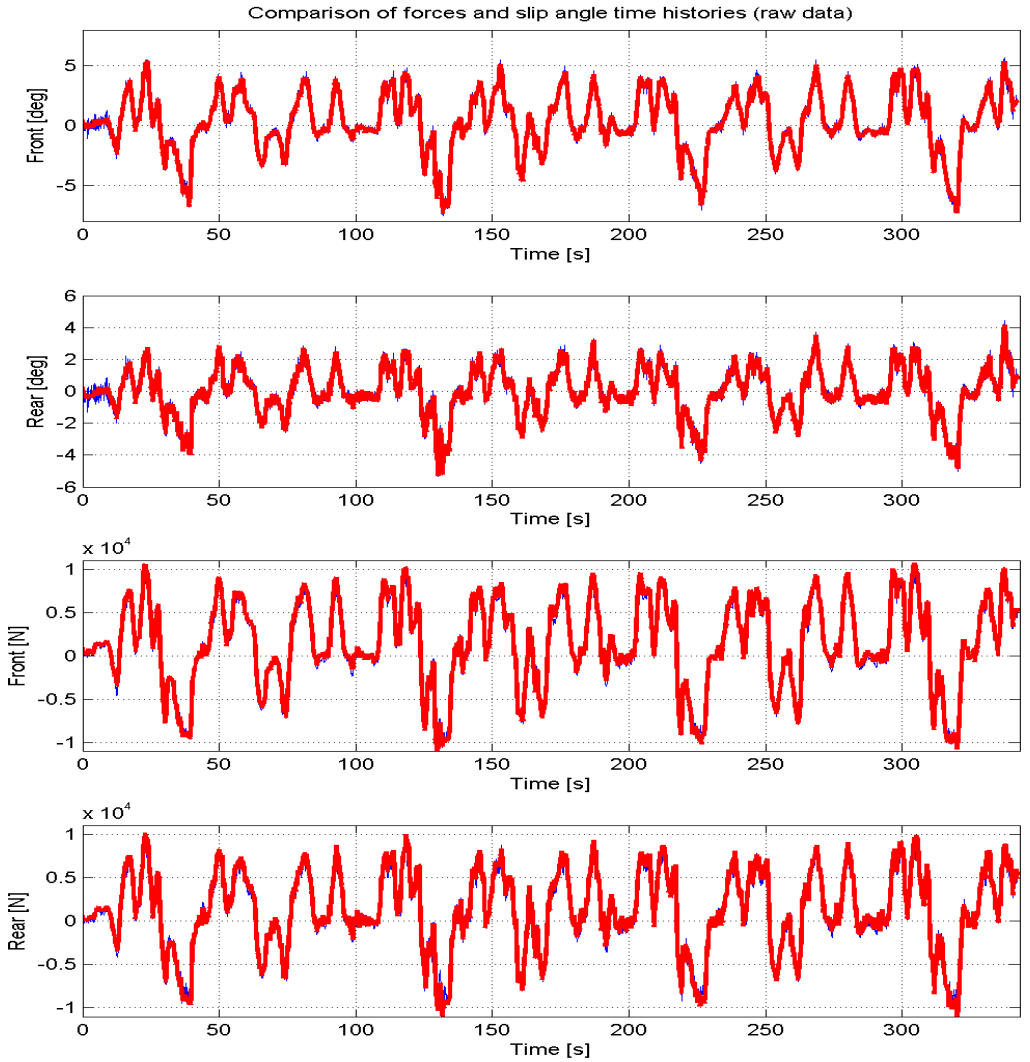
1. Dedicated measurement with vehicle equipped with wheel force transducers
2. Comparison of time histories of measured forces and estimated forces
3. MF-Fit of measured forces

4. MF-Fit of estimated forces

5. Comparison of force versus slip characteristics

Comparison of time histories
Mini-Hockenheim @ Papenburg

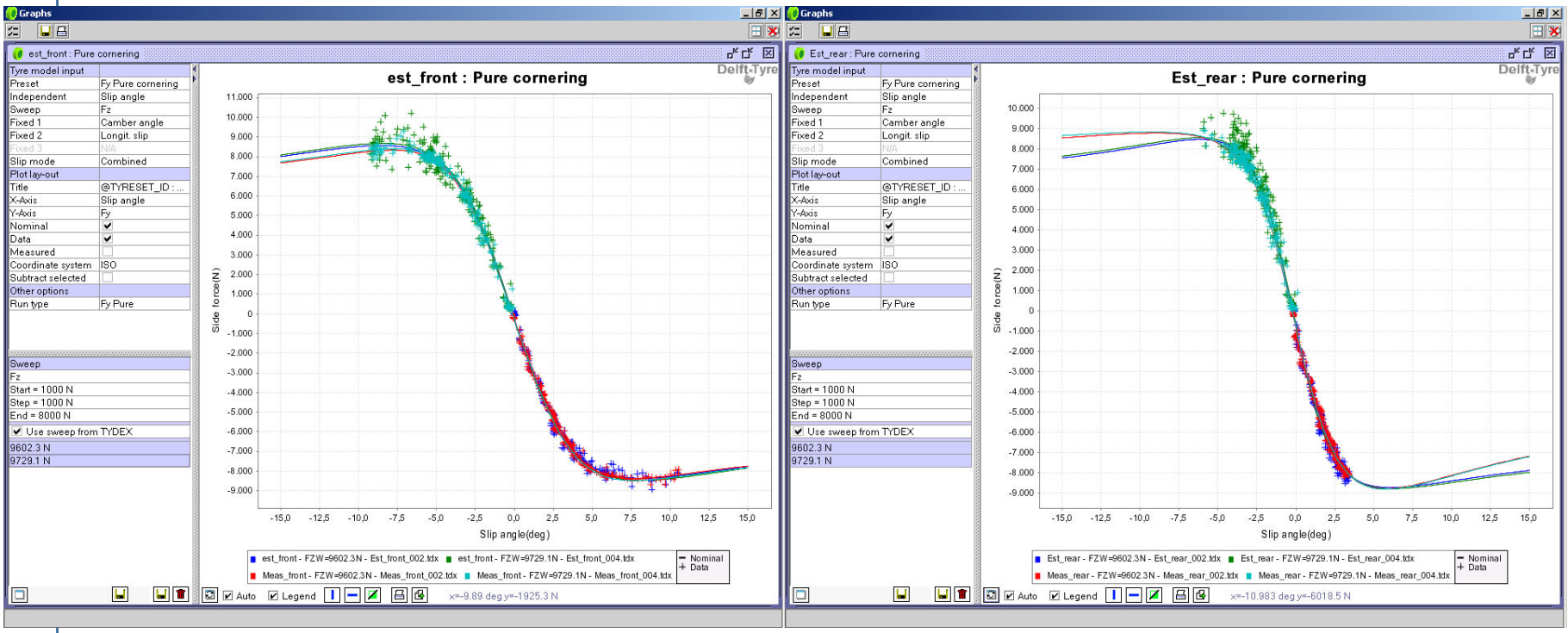
- Front slip angle
- Rear slip angle
- Front lateral force
- Rear lateral force



Comparison of Magic Formula fit of measurement and estimation: Circular test

Front axle

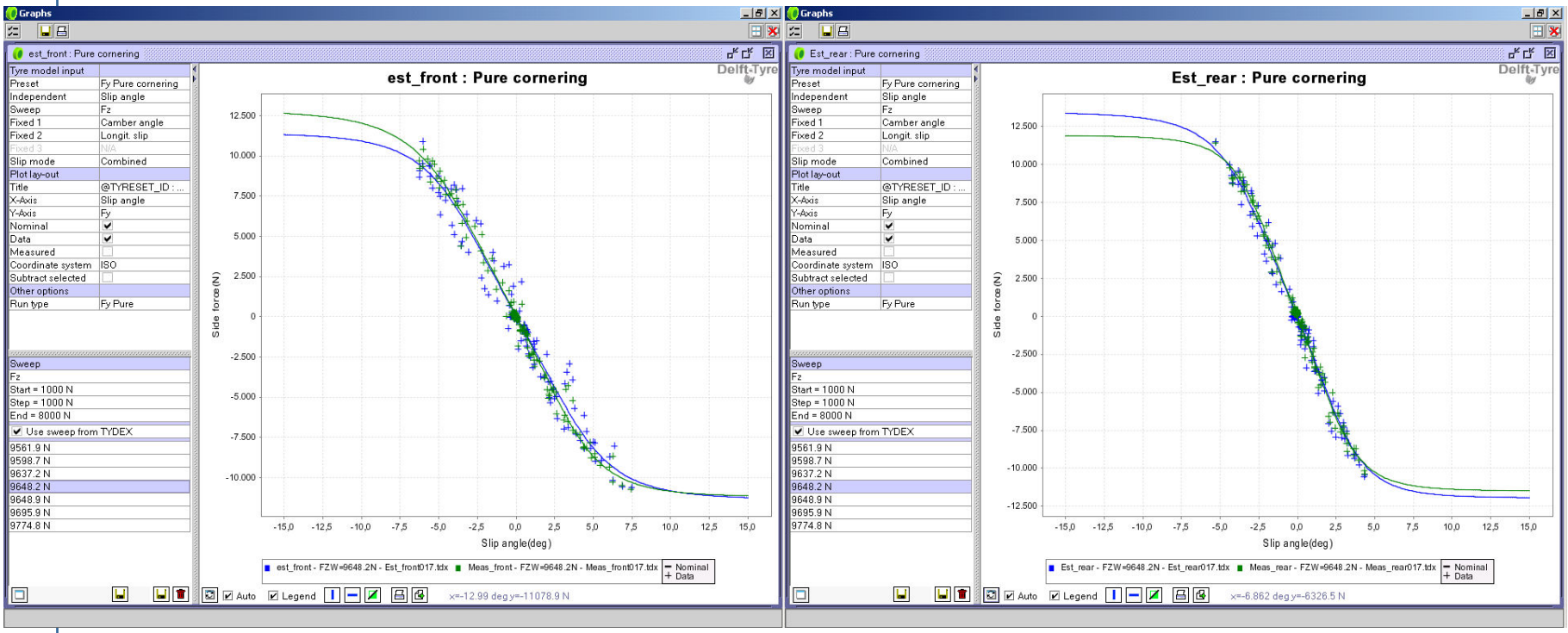
Rear axle



Comparison of Magic Formula fit
Slalom test

Front axle

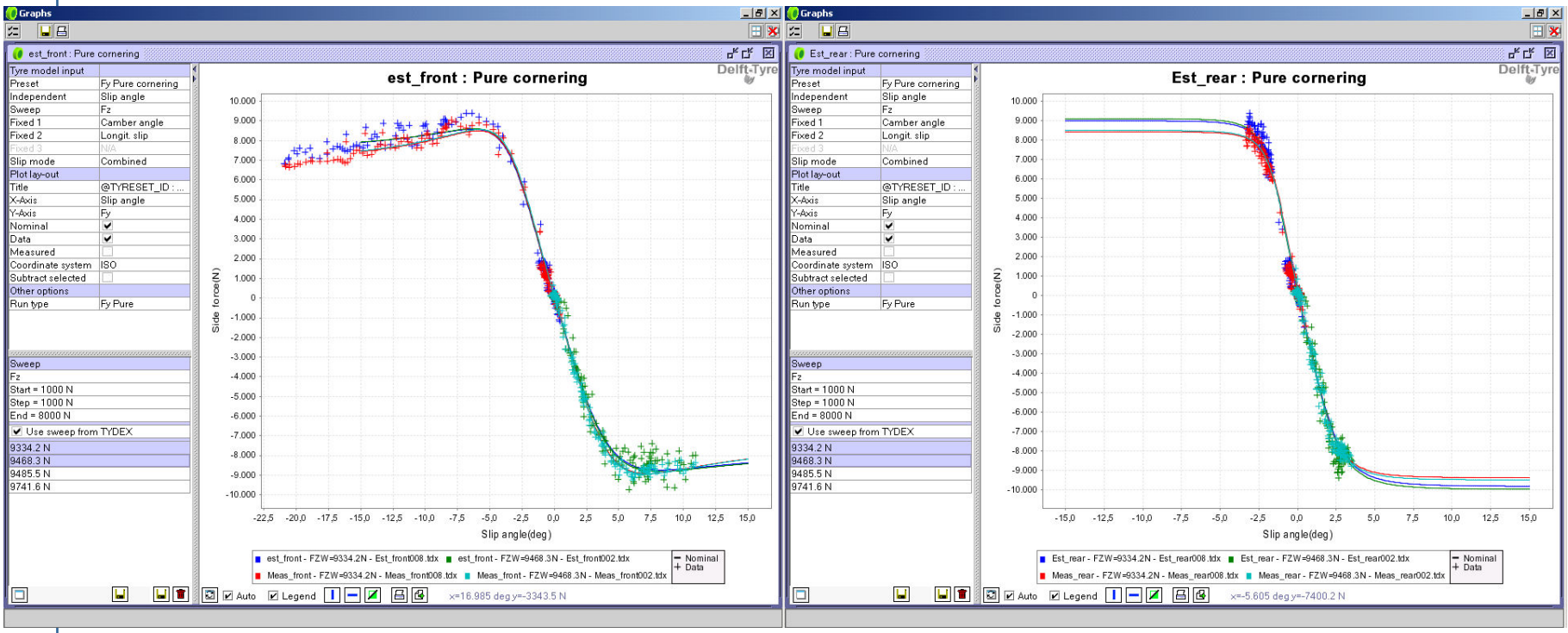
Rear axle



Comparison of Magic Formula fit
Spiral test (severe under steer)

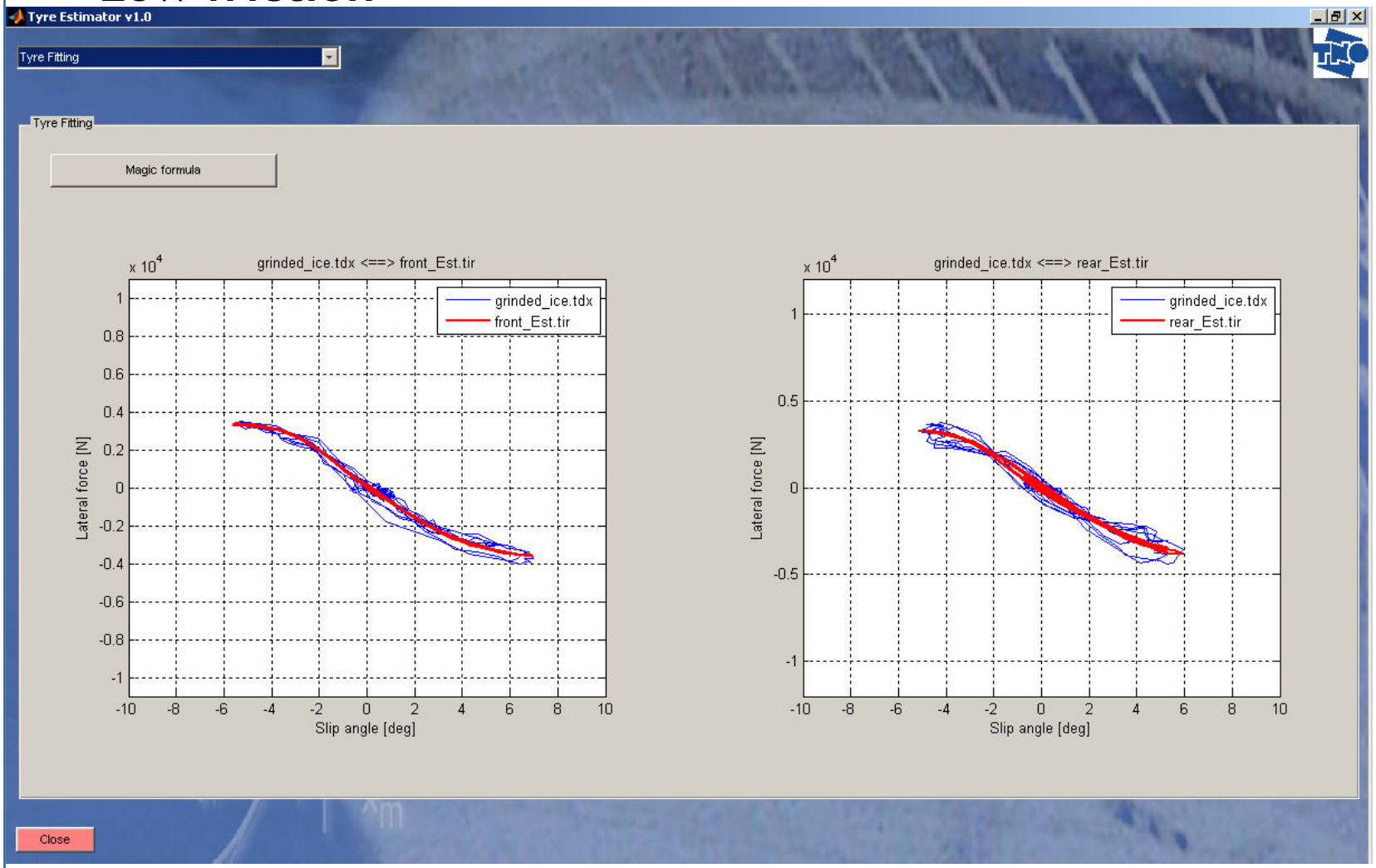
Front axle

Rear axle



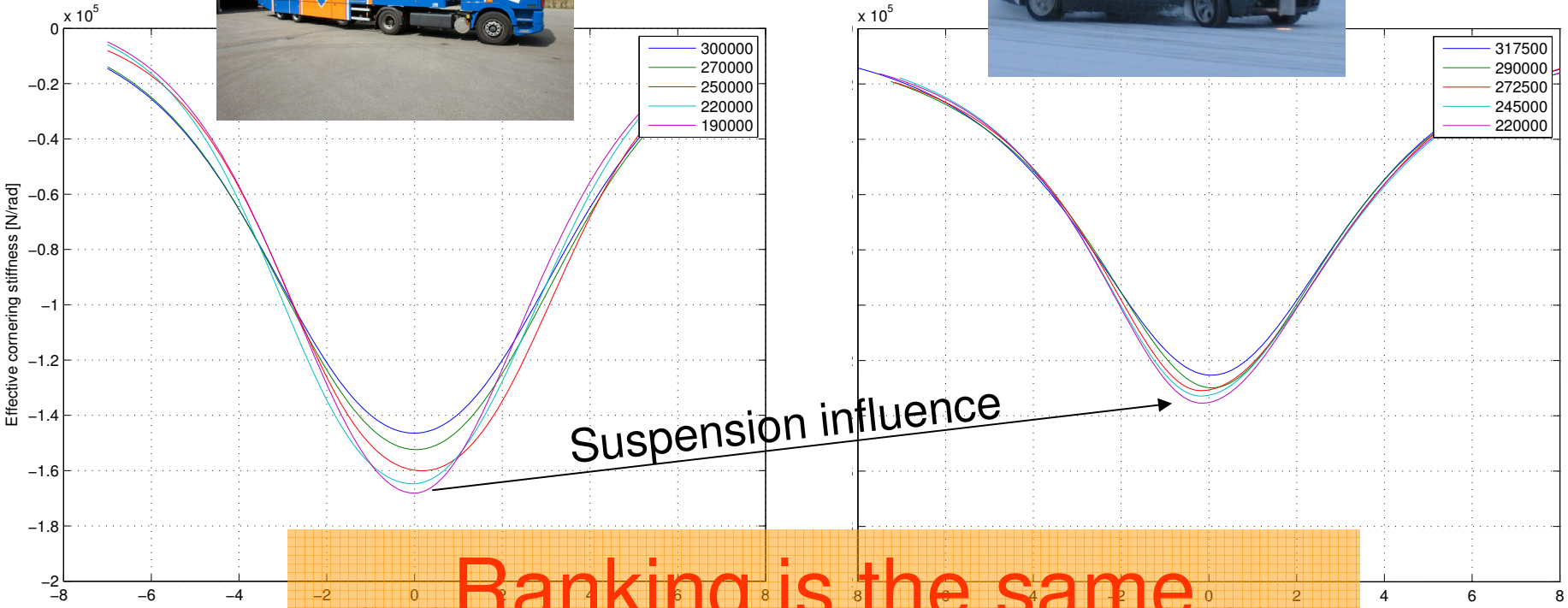
Some additional results...

- Low friction



Some additional results ...

Effective cornering stiffness @ 5 inflation pressures



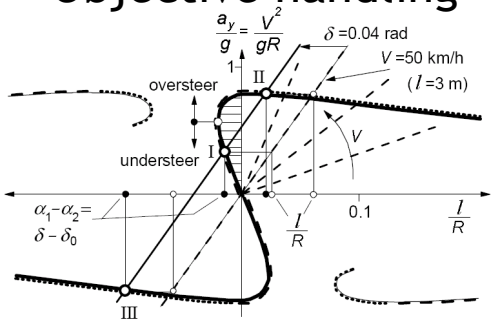
Ranking is the same

Tyre estimator Way of Working

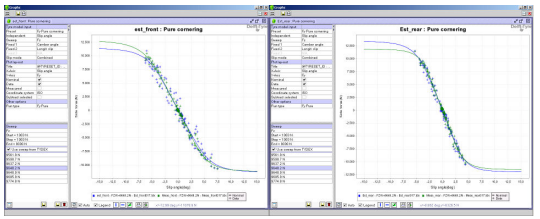
- **Perform set of standard test track tests**
  - Straightforward set of tests is supplied (steady-state circle, etc.)
  - Log ESC sensor data and ground speed
- **Use State Estimation to calculate tyre forces**
- **Use MF-tool to fit tyre characteristics**
  - Result is combination of tyre and suspension characteristics

Subjective handling

Objective handling



Objective tyre characteristics



Tyre estimator applications

- **Tyre estimator identifies combination of tyre and suspension characteristics**
  - Optimisation of tyre and suspension settings
    - tyre type, inflation pressure, tyre wear influences, speed effects, different road surface conditions
    - Suspension adjustment, camber, stabiliser, etc
  - Lap time evaluation
    - Time history of forces
    - Driver feedback
  - Subjective/objective studies
    - Relate driver assessment to estimated characteristics (of combination of suspension and tires!)
  - Input for simple vehicle model (e.g. bicycle model) or control system tuning

Conclusion

- Tyre forces can be estimated from vehicle motions using a State Estimator approach
- The method for tyre force estimation is proven for different vehicles on various road surfaces
- Ranking capability is proven
- The method can be applied using little vehicle instrumentation, simple driving tests and processing is supported with a GUI tool

Current developments

- Truck tyres
- Racing application
- Integration with sensor systems
- Application as a check on tyre condition during vehicle testing
- ....