

Supplementary Materials for “What are different measures of mobility changes telling us about emissions during the COVID-19 pandemic?”

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Introduction

This supporting information contains eight additional sections with two tables and nine figures. Table S1 provides the locations of the study regions and the date of the first governmental restrictions. Table S2 provides the total number of governmental traffic detectors for all study regions. Figure S1 shows the TomTom congestion index and Apple mobility data for four cities in Asia. Figure S2 shows the annual traffic cycle of the local governmental data and the monthly mean temperature of the urban study regions. Figure S3 shows the weekly traffic cycle before and since the first local governmental restrictions in response to the COVID-19 pandemic. Figure S4 shows the scatter comparison of the TomTom congestion data and Apple mobility data to the local governmental data with weekly mean data. Figure S5 shows the time series of vehicle miles travelled (VMT), Average Miles per Hour (AvMph) and TomTom data related to 2019. Figure S6 shows the correlation of VMT to Apple and TomTom and the correlation of AvMph to Apple and TomTom. Figure S8 and Figure S9 show the analysis plots for Los Angeles, California.

Text S1. Selection of regions for case studies

Table S1: Study regions used in this work.^a

Area	Latitude, Longitude	First COVID-19 restrictions
Oslo, Norway	59.912, 10.758	03/13/20
Norway	(57.961, 80.828), (4.525, 20.349)	03/13/20
Munich, Germany	48.137, 11.576	03/21/20
San Francisco Bay Area, USA	37.774, -122.431	03/19/20
Los Angeles, USA	34.052, -118.244	03/19/20
California, USA	(32.5, 42.0), (-124.4, -114.13)	03/19/20
Cape Town, South Africa	-33.919, 18.423	03/26/20

^aLocation and date of first COVID-19 governmental restriction of study sites [7, 6, 2, 5, 12]

Table S2: Number of detector stations in study regions

Area	Number of Detectors
Oslo, Norway	50 ^a
Norway	1811 ^b
Munich, Germany	8920
San Francisco Bay Area, USA	11263 ^c
Los Angeles, USA	11188 ^d
California, USA	44987 ^e
Cape Town, South Africa	44

^aIn 2019 and 2020 only 20 stations were continuously available for Oslo. ^bIn 2019 and 2020 only 1172 stations were continuously available for Norway. ^cAt 3910 highway stations. ^dAt 4878 highway stations. ^eAt 18360 highway stations. [8, 3, 4, 11]

Text S2. TomTom congestion index and Apple mobility data for Asian cities

Apple and TomTom data for cities on the Asian continent are shown in Figure S1. The solid lines are referenced to the request volume (for Apple) and congestion index (for TomTom) on January 13, 2020. The dashed line visualizes TomTom data that where each day is referenced to the same weekday of the same calendar week in 2019.

Interestingly, for TomTom the solid lines show a bigger deviation from their base value compared to the dashed lines indicating a large dependency on the baseline value.

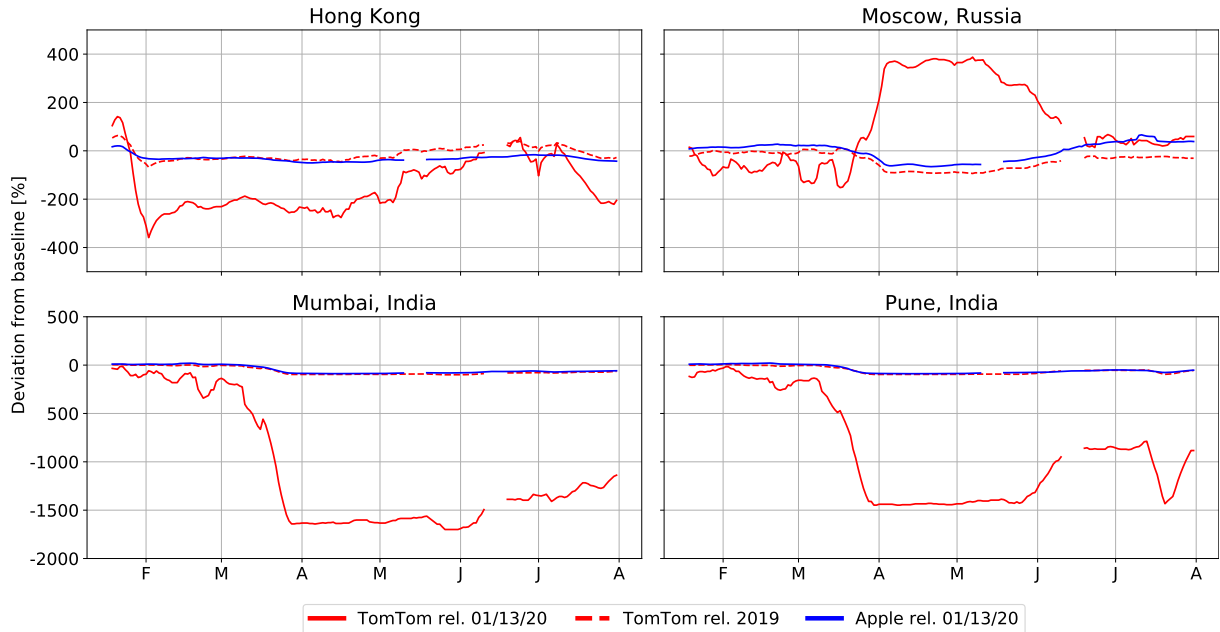


Figure S1: **Time series comparison of Apple and TomTom.** Rel.2019: relative to corresponding day in 2019, meaning the same weekday of the same calendar week. A 7 days rolling mean is applied to the data. [1, 9]

Text S3. Seasonality and temperature in urban study regions

Figure S2 includes the monthly average temperature at the study regions for the year 2019 on the right y-axis. The temperature is, as the traffic count, given in its monthly deviation from the yearly mean related to the yearly mean.

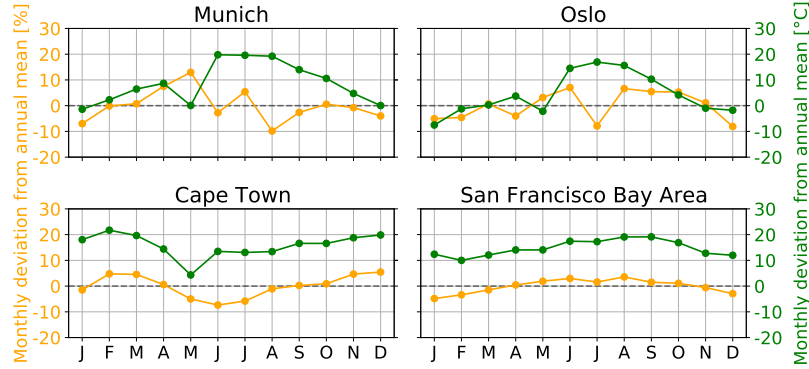


Figure S2: **Annual traffic and temperature cycle.** Deviation of the mean monthly data value of the corresponding month in 2019 to the mean of the year 2019. [8, 3, 4, 11, 10]

Text S4. Weekly cycle splitted in before and since governmental restrictions

Figure S3 shows the weekly traffic cycle splitted in the period before the first governmental COVID-19 restrictions and since. We observe noticeably differences for Apple in Munich, and Oslo, for TomTom in Munich, Oslo, San Francisco, and Los Angeles, and for governmental data especially in California and Cape Town. These differences might be due to the COVID-19 pandemic as well as to usual seasonal changes.

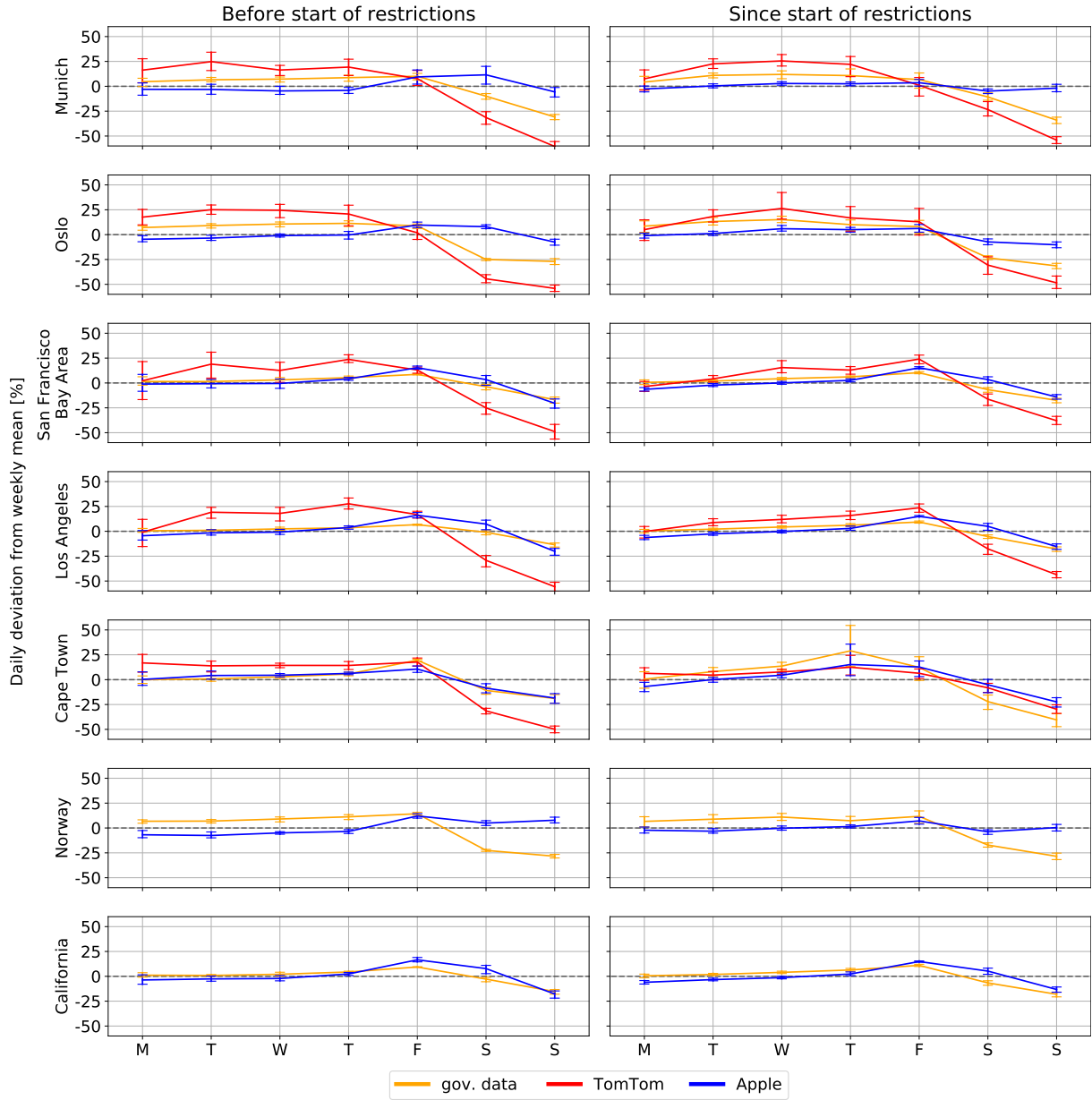


Figure S3: **Comparison of weekly cycle** of governmental data, Apple, and TomTom for all study sites before and since the individual lockdown period with 2σ error bars.

Text S5. Comparison of TomTom congestion index and Apple mobility data with governmental data in weekly resolution

Figure S4 shows the scatter comparison of TomTom's congestion index and Apple's mobility data to the governmental data. All data is referenced to January 13, 2020 and then the mean of one calendar week is calculated. The overall trend of the daily scatter comparison is also given in this figure.

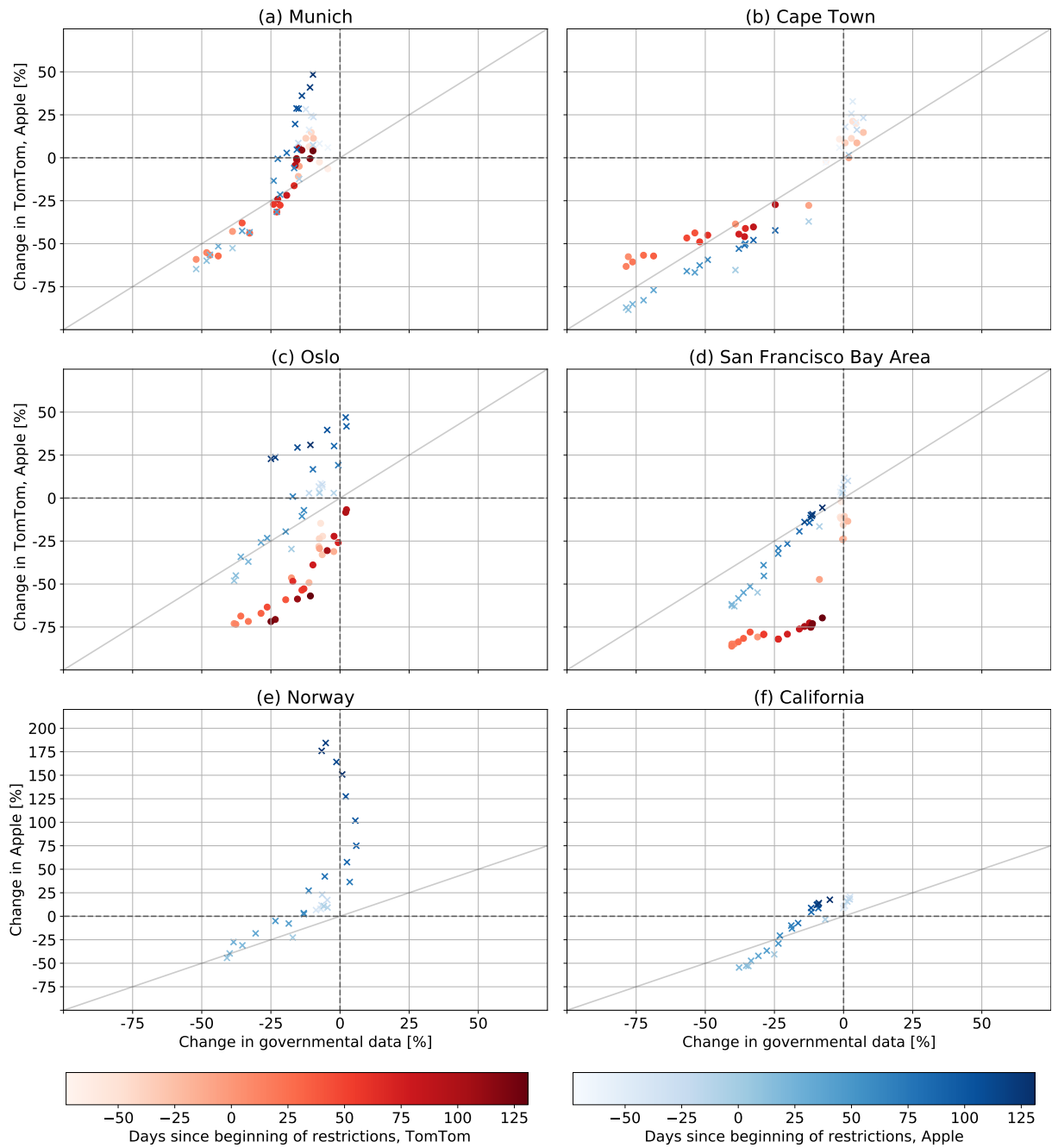


Figure S4: **Comparison of different measures of traffic flow.** Weekly mean deviation from 01/13/20 for the study sites Oslo, Munich, San Francisco Bay Area, Cape Town, Norway, and California.

Text S6. Correlation of TomTom, Apple, VMT, and average speed in San Francisco Bay Area

Figure S5 shows the time series of vehicle miles travelled (VMT), Average Miles per Hour (AvMph) and TomTom data related to 2019. While VMT and congestion decreases, the average speed increases.

Figure S6 shows the correlation of of Apple and TomTom data to VMT and average speed. Average speed shows a higher but inverse correlation to congestion than to Apple's mobility data. VMT shows a higher correlation with Apple's mobility data than with TomTom's congestion index.

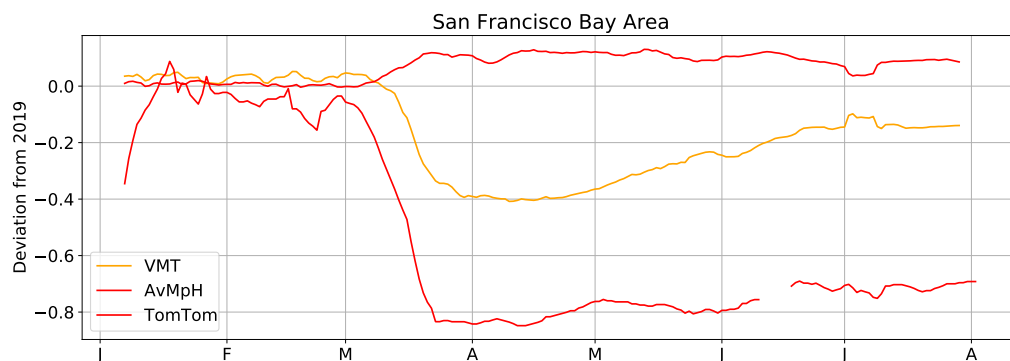


Figure S5: **Timeseries comparison in San Francisco Bay Area.** San Francisco Bay Area, comparison of deviation from 2019 of Vehicles Miles Travelled (VMT), Average speed (Mph) calculated from VMT/VHT (VHT: Vehicle Hours Travelled), and TomTom. 4 days rolling mean applied.

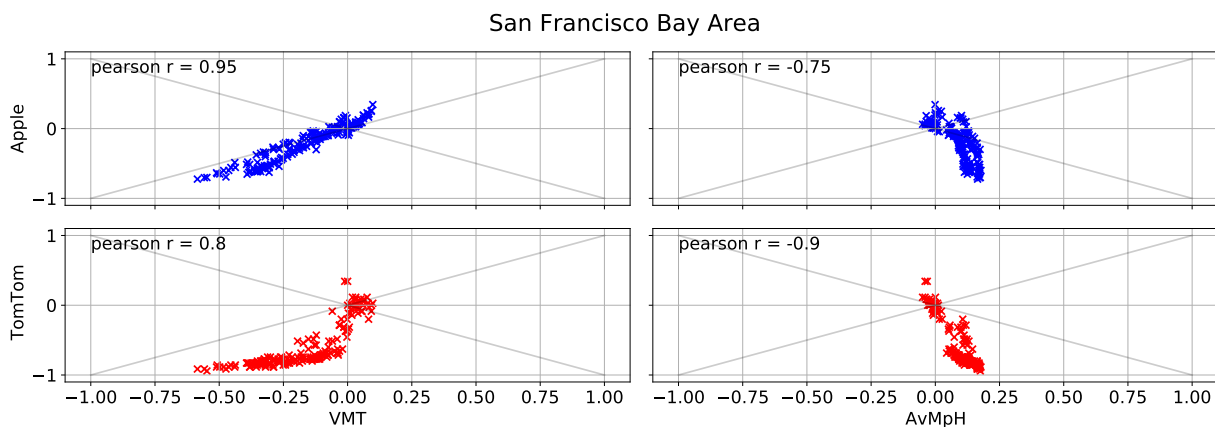


Figure S6: **Correlation of TomTom to average speed and Apple to vehicle miles travelled in San Francisco - Bay Area.**

Text S7. Emission time series for San Francisco Bay Area

Figure S7 shows the summed up monthly emissions for San Francisco Bay Area. January is not taken into account, as the time series starts on January 13, 2020.

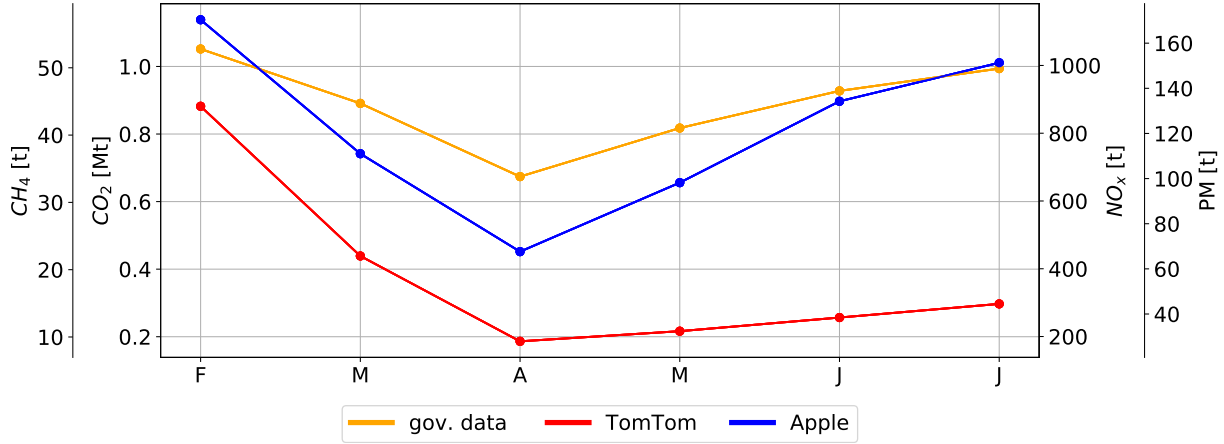


Figure S7: **Monthly emitted trace gas emissions** CH₄, CO₂, NO_x, and PM in San Francisco Bay Area in the time span 02/01/20 - 07/31/20.

Text S8. Investigation of Los Angeles, California

Los Angeles shows similar results for the investigations as San Francisco Bay Area. Following figures show these results.

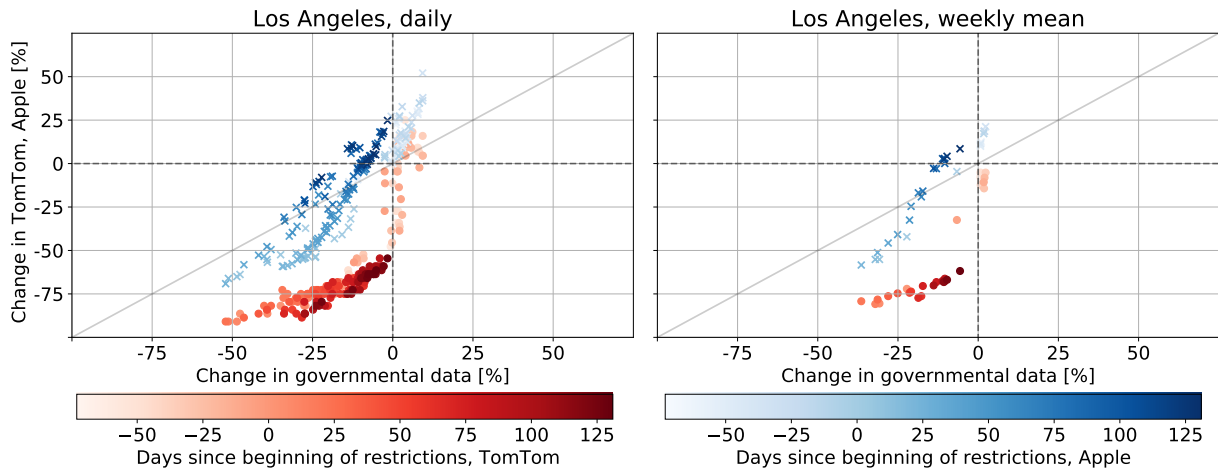
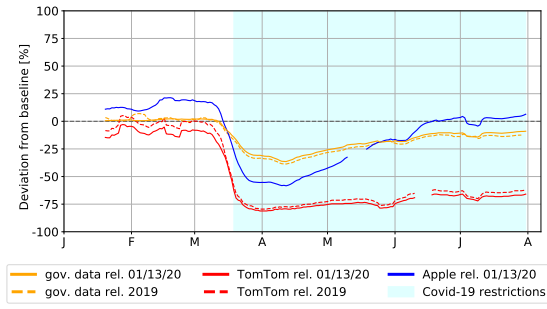
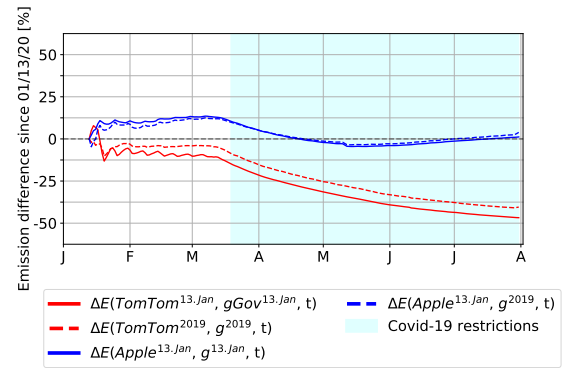


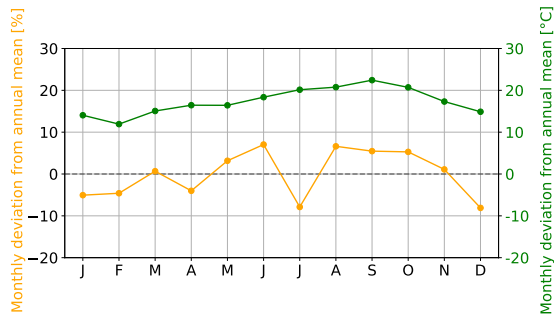
Figure S8: **Comparison of different measures of traffic flow.** The scatter shows the comparison between the governmental data, and Apple and TomTom data. All data is related to the January 13, 2020.



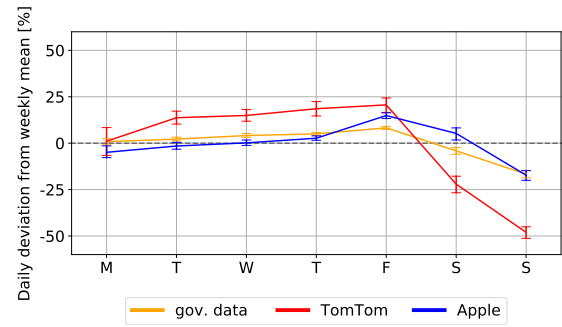
(a) **Timeseries trend comparison.** A 7 days rolling mean is applied.



(b) **Timeseries of the emission difference (ΔE , Equation 1) of TomTom's and Apple's data compared to governmental data.**



(c) **Annual cycle and mean monthly temperature**



(d) **Weekly cycle**

Figure S9: Different supplement plots for Los Angeles, California

References

- [1] Apple Inc. Apple Inc. Mobility Trends Reports, 2020.
- [2] Bavarian State Ministry of the Interior, for Sport and Integration. Corona disaster control, 2020.
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- [9] TomTom International BV. TomTom International BV Traffic Index, 2020.
- [10] University of Dayton. Average Daily Temperature Archive, 2020.
- [11] Western Cape Government, Road Network Information System. Western Cape Government, Road Network Information System, 2020.
- [12] Western Cape Government, South Africa. Coronavirus Response, 2020.