An Analysis of Solar Opportunity Recharging for Electrified Tactical Vehicles

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Agenda

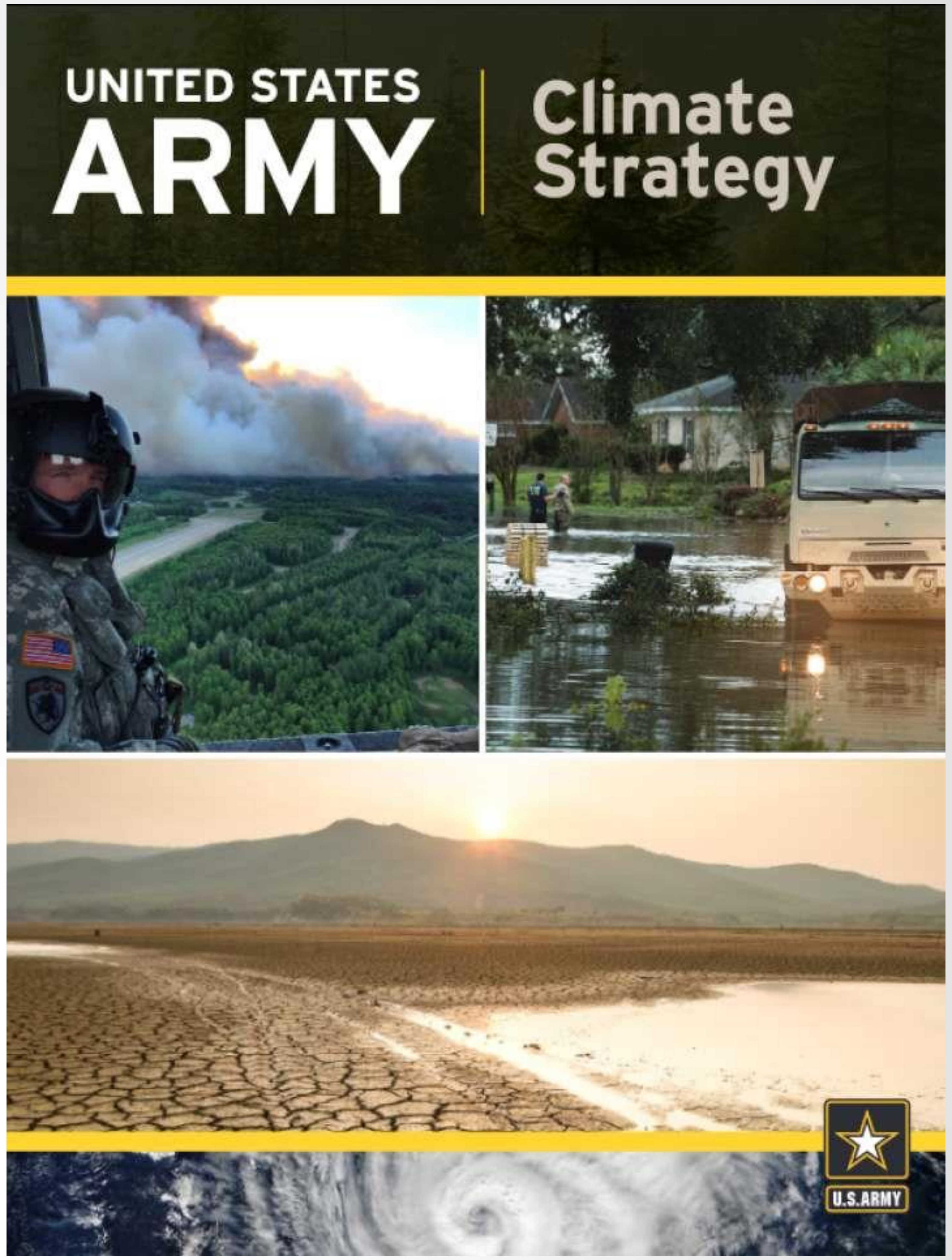
- Tactical Vehicles and Move to Electrification
- Solar Recharging Options
- Data Extraction from NTC Dataset
- Drive-cycle development
- Vehicle behaviors and energy consumption
- Solar production
- Implications
- Questions

Tactical Vehicle and the Army's Move to Electrification

- Tactical vehicles in the U.S. Army fleet are wheeled, versatile, and often lightly armored, providing mobility and protection for occupants.

- Secretary of the Army Christine E. Wormuth issued the Army Climate Strategy, which aims to field hybrid-drive tactical vehicles by 2035 and fully electric ones by 2050.

- Electrified tactical vehicles offer advantages such as increased torque, lower noise, and decreased thermal signatures, despite challenges like battery weight and logistical issues in recharging in austere environments.



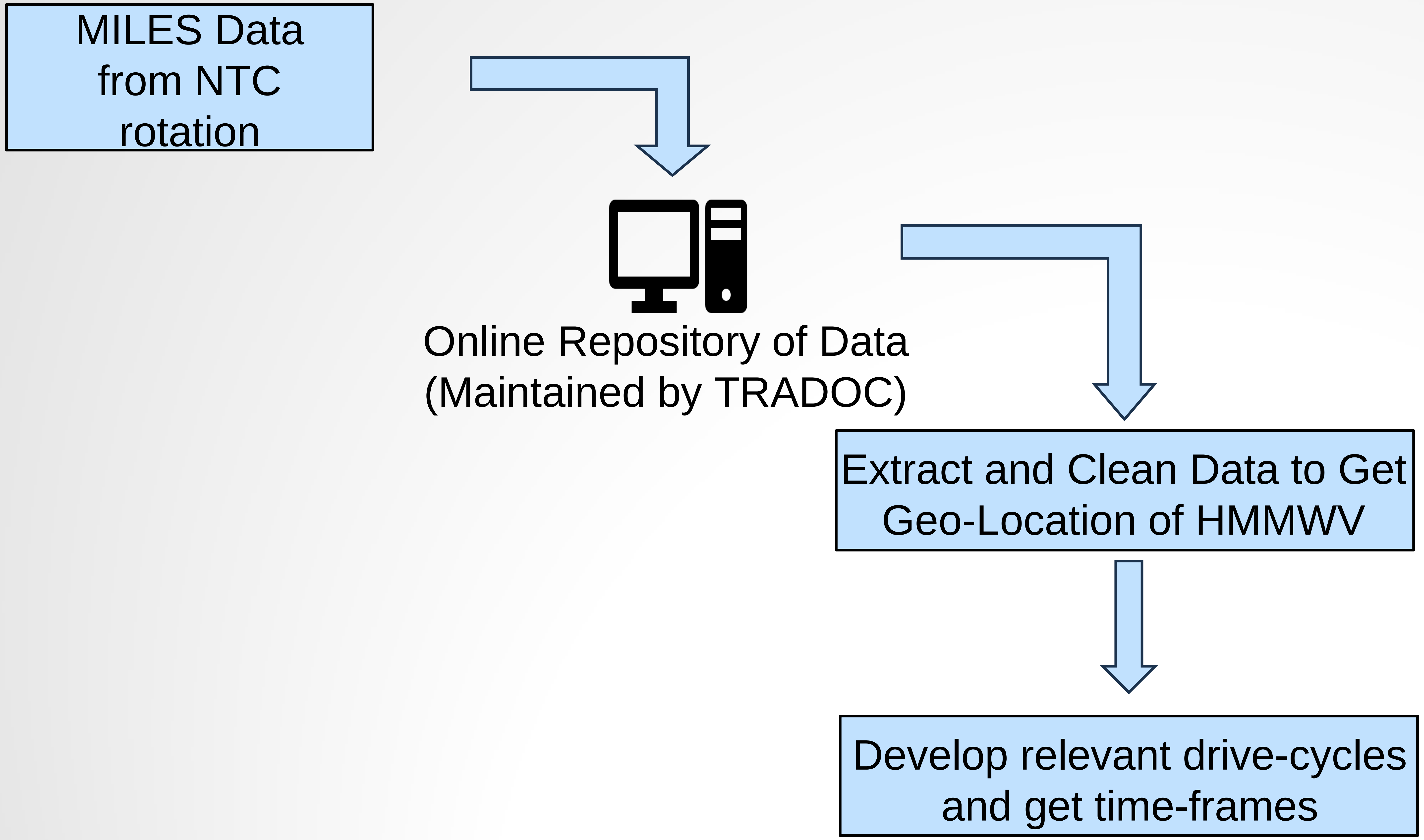
Solar Recharging

- Electric vehicles offer soldiers the advantage of reducing reliance on fuel resupply, as they can be recharged from various sources, including generators and local grids.

- In austere areas where fuel resupply is unreliable, solar recharging presents a viable option. Dismounted soldiers currently use solar blankets for battery recharging.

- A common solar blanket size is 300 W, utilizing monocrystalline silicon cells with 12 percent efficiency, weighing approximately 10 kg and covering around 24 square feet.

National Training Center Dataset



- Army brigade combat teams go to the National Training Center (NTC) for realistic training exercises.
- All vehicles and personnel are outfitted with MILES gear, which includes a GPS tracker which is logged.
- Data from the MILES gear are available through an online data repository.

Data Extraction and Drive Cycle Development

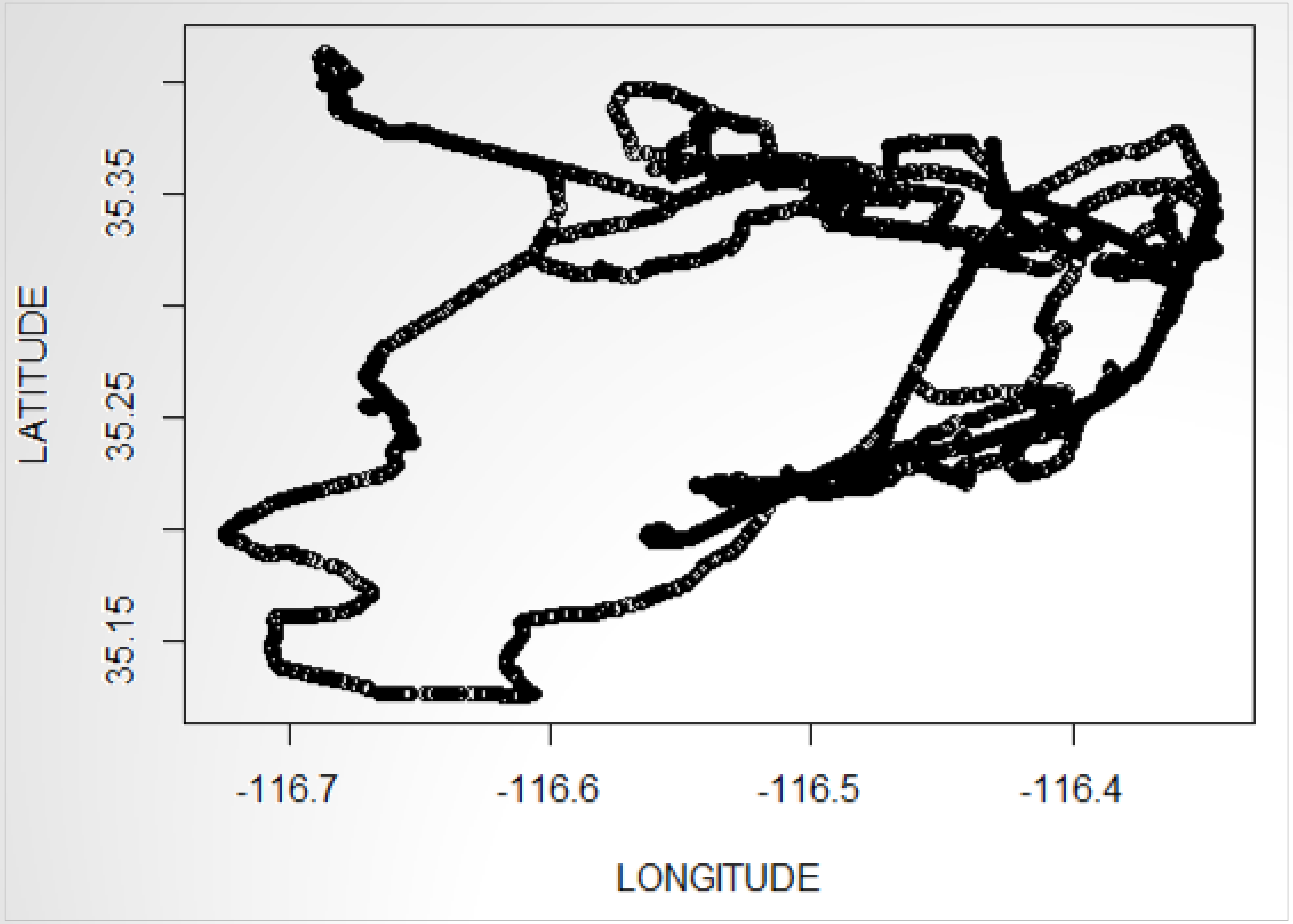
Process:

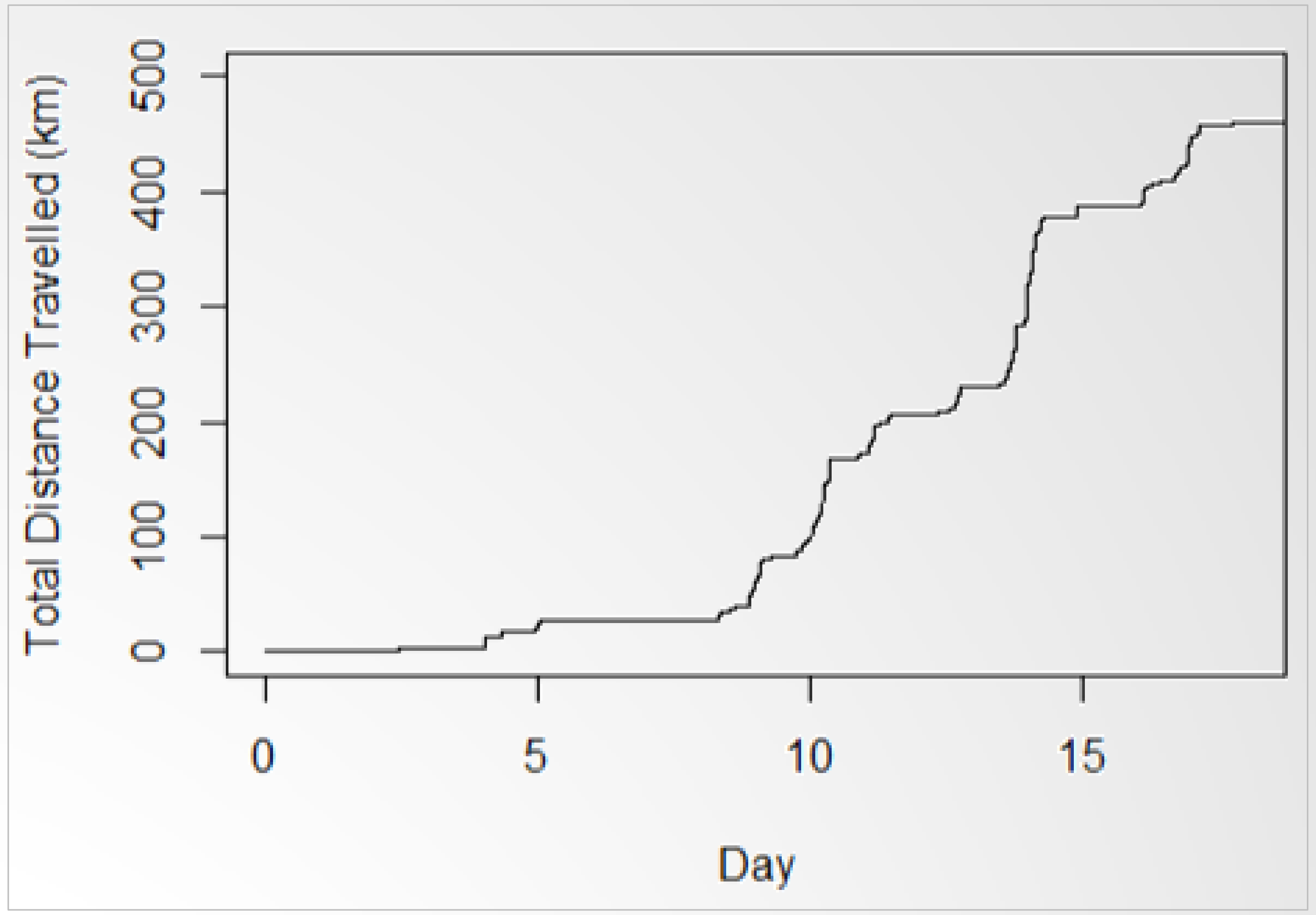
1. Import Dataset
2. Filter Dataset for one specific vehicle type
3. Identify all unique vehicle ID for that vehicle type
4. For a given vehicle ID, sort the data by time
5. Remove corrupted data
6. Using longitude and latitude, determine the distance travelled between consecutive data points
7. Using longitude and latitude, determine the change in elevation between consecutive data points based off terrain map
8. Aggregate distances and elevations across multiple-day rotations
9. Interpolate distances for fixed time steps
10. Calculate the velocity and change in elevation at each time step

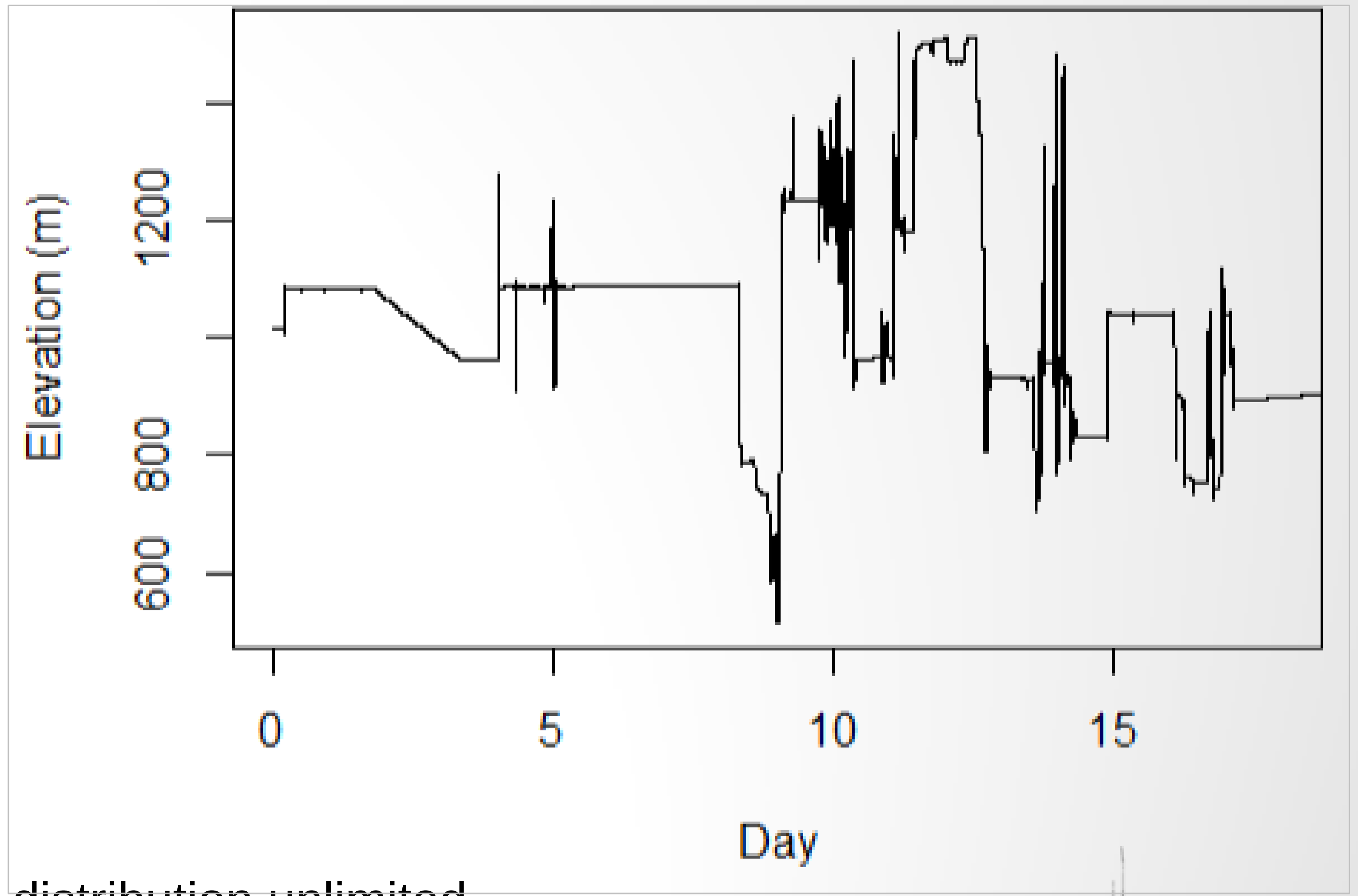
Data analysis was performed in RStudio

```r
library(dplyr)



#M1078 = FMTV, M109A = Paladin, M1A = ABrams, M2A = Bradley

vix_type <- NTC_Data %>% filter(grepl('HMMWV',CONCRETE_CLASS_TYPE))

sensitivity_constant_array = c(0.25, 0.5, 0.75, 1, 1.5, 2)
sens_av_idle = c(0,0,0,0,0,0)

for (sens in 1:6) {

vix_idle_time = 0
vix_move_time = 0
vix_off_time = 0
vix_distance = 0
all_stop_times = 0

sensitivity_constant = sensitivity_constant_array[sens]
idle_standard = 1*sensitivity_constant
idle_max = 4*sensitivity_constant

for (vix_name in 1:length(unique(vix_type$ENTITY_STATE_VALUE))) {
   print(vix_name)

   j <- unique(vix_type$ENTITY_STATE_VALUE)[vix_name]
#   j <- unique(vix_type$ENTITY_STATE_VALUE)[1]

   vix <- NTC_Data %>% filter(grepl(j,ENTITY_STATE_VALUE))
   #   plot(vix$LONGITUDE, vix$LATITUDE)

   vix <- vix %>% filter(LONGITUDE < -116)
   vix <- vix %>% filter(LONGITUDE > -117)
   vix <- vix %>% filter(LATITUDE > 35)
   vix <- vix %>% filter(LATITUDE < 36)

   vix <- vix[order(vix$WHEN_UTC),]
#   par(mfrow = c(1,1))
#   plot(vix$LONGITUDE, vix$LATITUDE)

   if (length(vix$LATITUDE) > 100) {

      DDistance = 0
      UTC = 0
      for (val in 1:length(vix$LONGITUDE)) {
         #  print(val)
         if (val > 1) {
            DDistance = c(DDistance, DDistance[val-1] + sqrt((90.725*vix$LONGITUDE[val]
            UTC = c(UTC, 1e-7*(vix$WHEN_UTC[val] - vix$WHEN_UTC[1])/60)
         }
      }

      time_vector = 1:trunc(max(UTC))
      distance2 = approx(UTC, DDistance, time_vector)
```

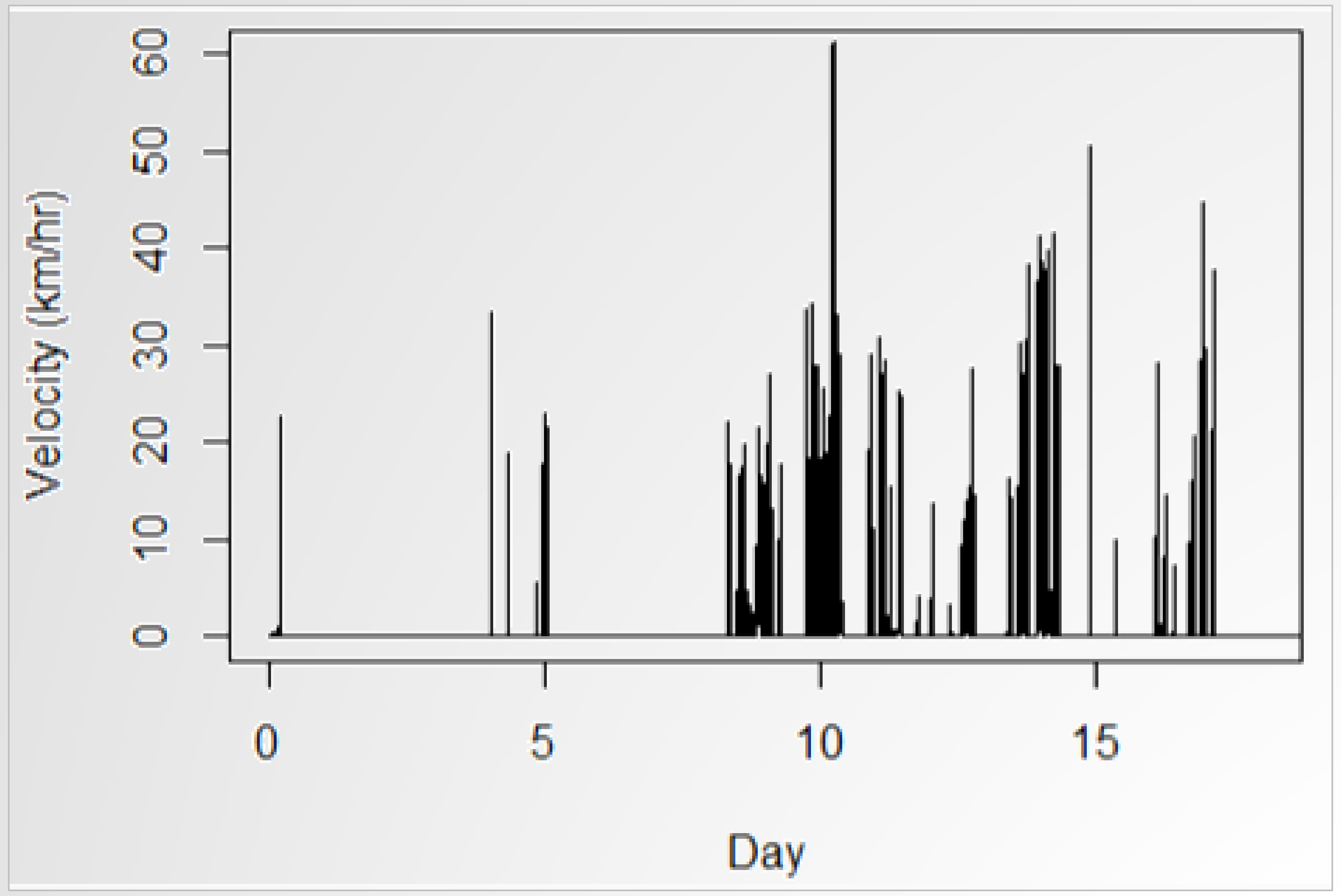
Data Outputs

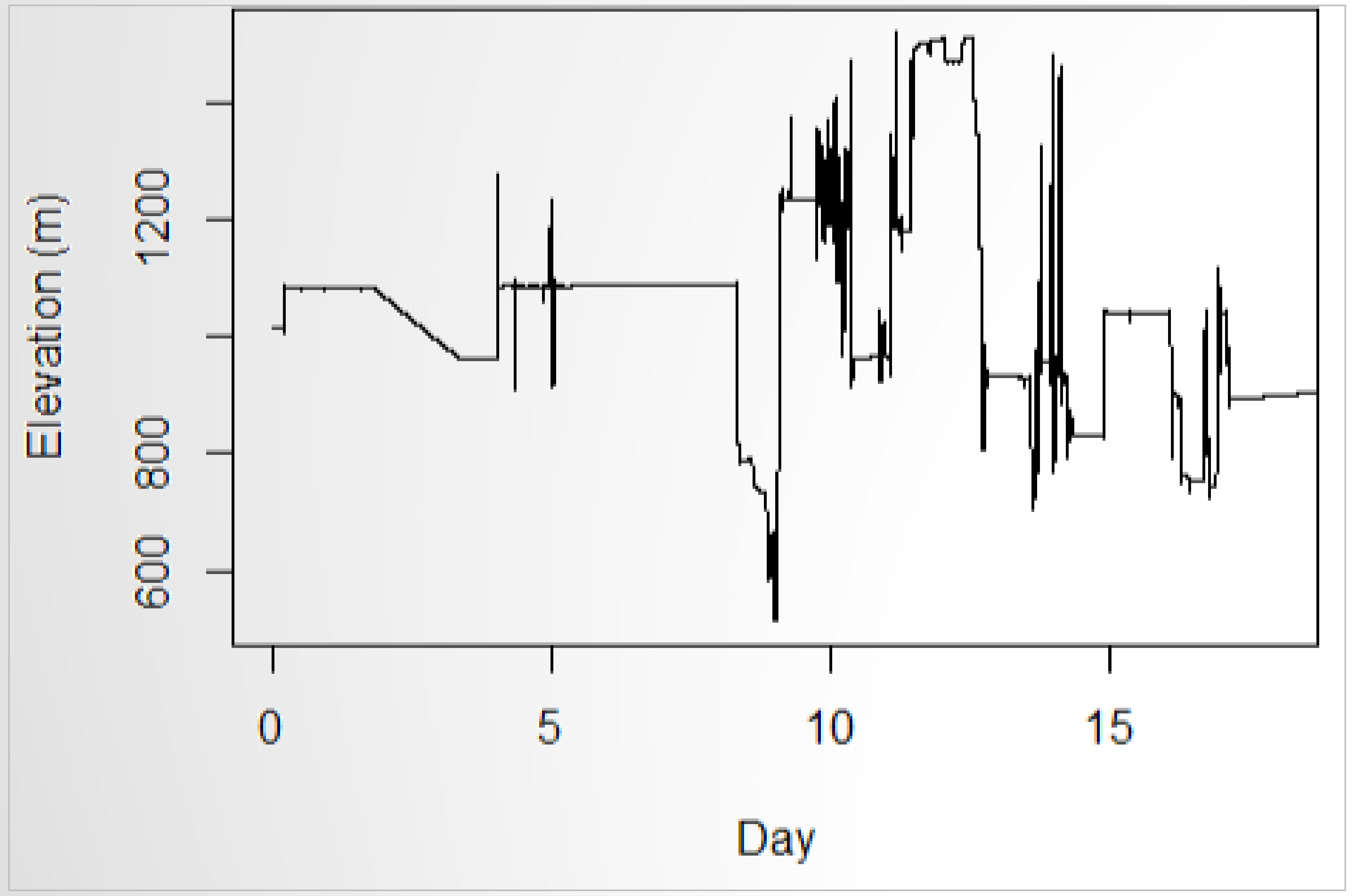






Energy Consumption





Velocity and incline of travel are known. Can calculate power required for acceleration, overcoming incline, drag, rolling resistance, and accessories:

$$P_{accel} = m\frac{\Delta v}{\Delta t}v$$

$$P_{incline} = mg\sin\theta \ v$$

$$P_{drag} = 0.5\, C_d A\rho\, v^3$$

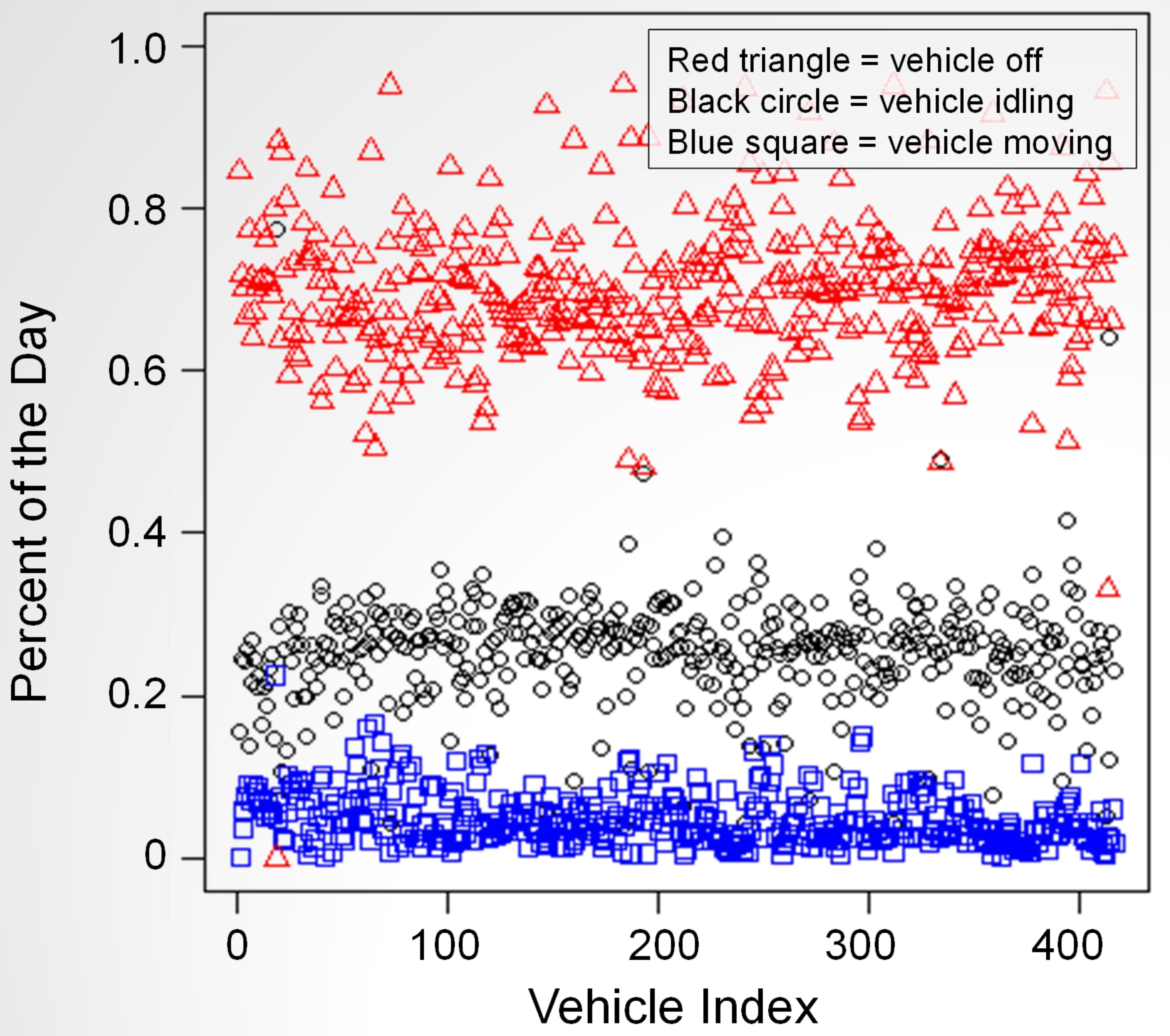
$$P_{rolling} = C_r mgv$$

If the vehicle is stationary during daylight hours, the amount of energy from solar energy (300 W solar blanket) can be calculated:

$$P_{solar} = (300W)\sin(TOD \times 7.33 - 2.1)$$

TOD = Time of Day → 0 at midnight, 1 at 11:59PM

Vehicle Stationary Times

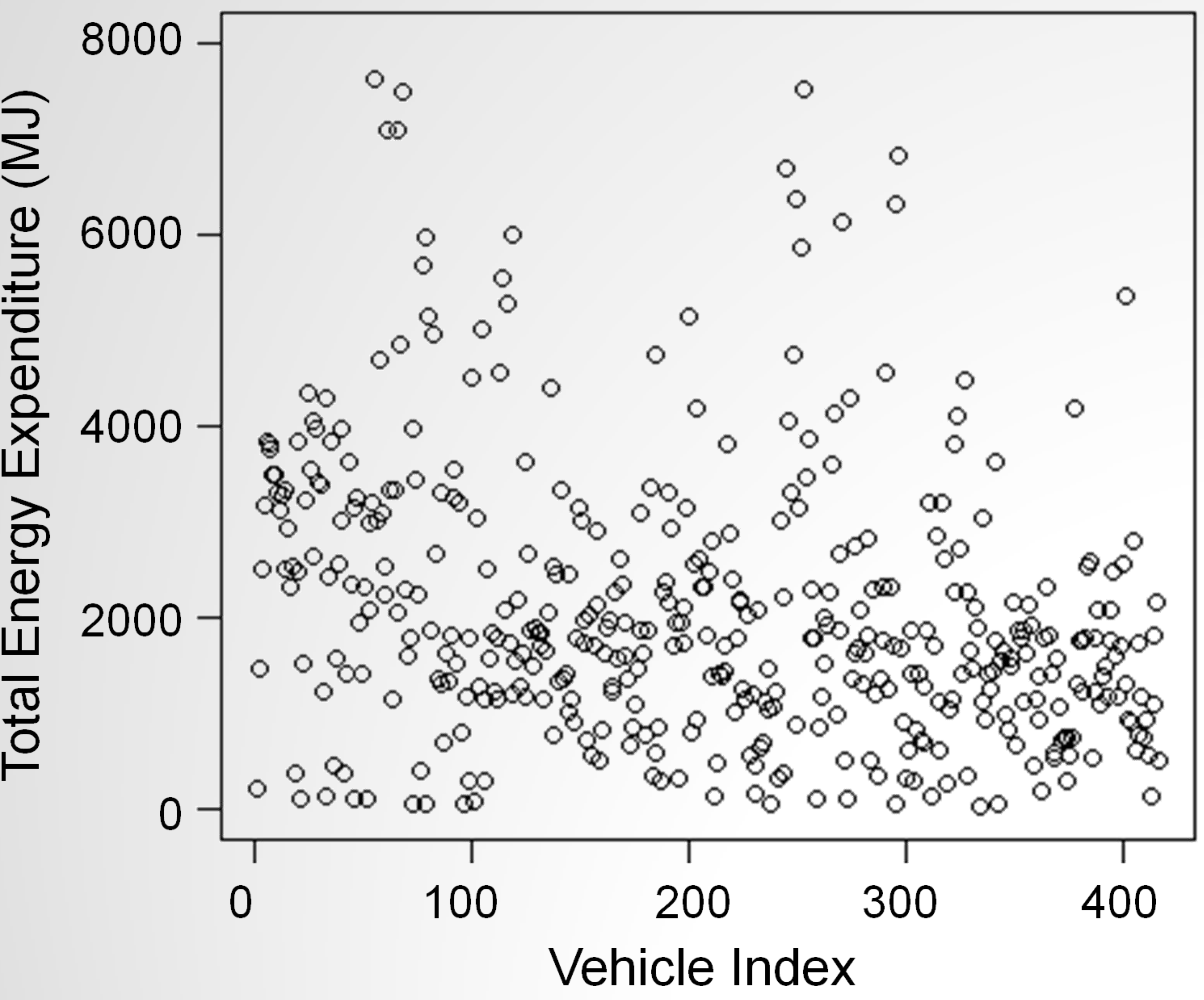


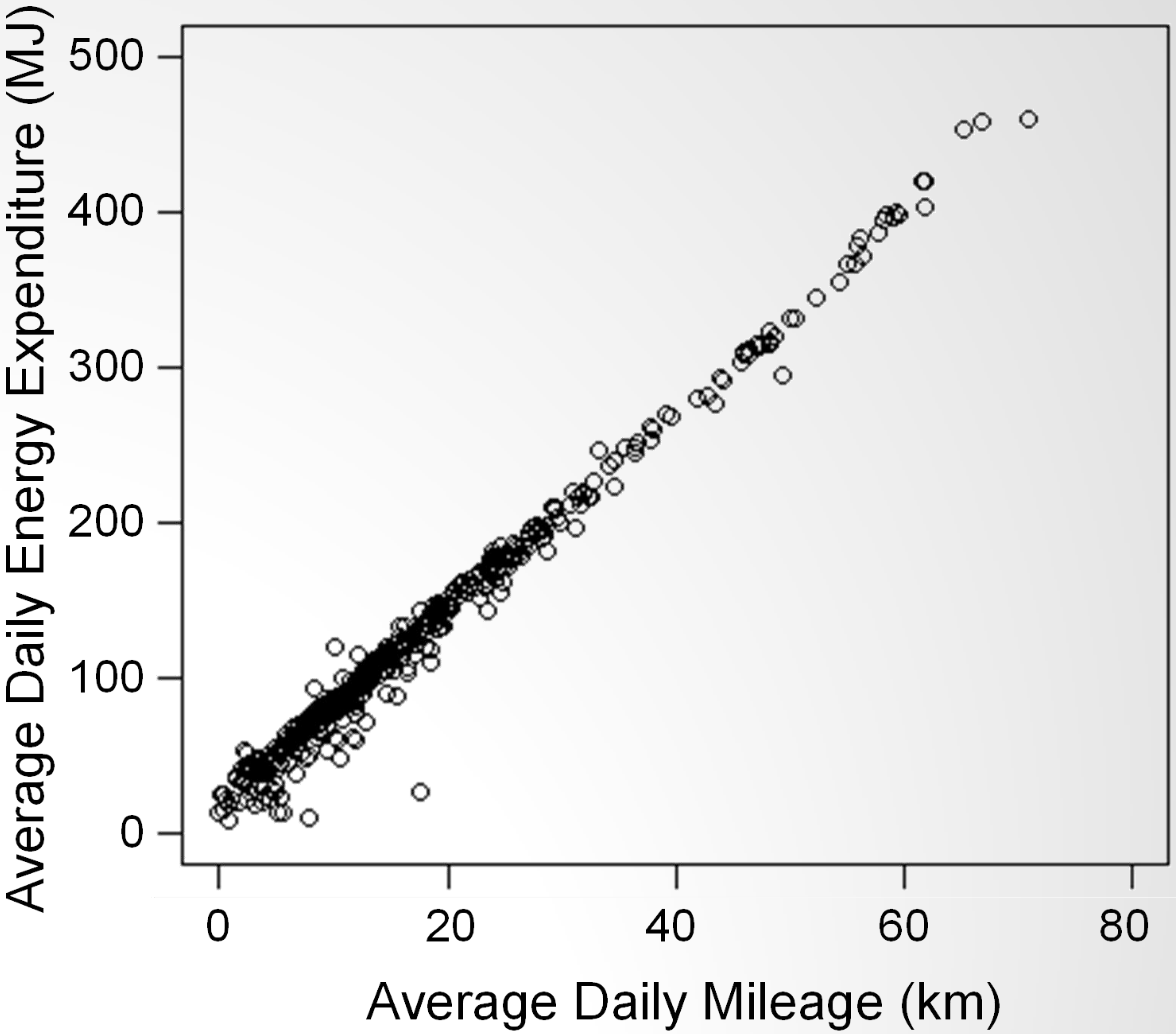
Vehicles are stationary or idling for the bulk of the day (opportunity for solar recharging)

Significant fuel losses associated with extended idling periods

Vehicles are only actually moving for an average of 70 minutes per day

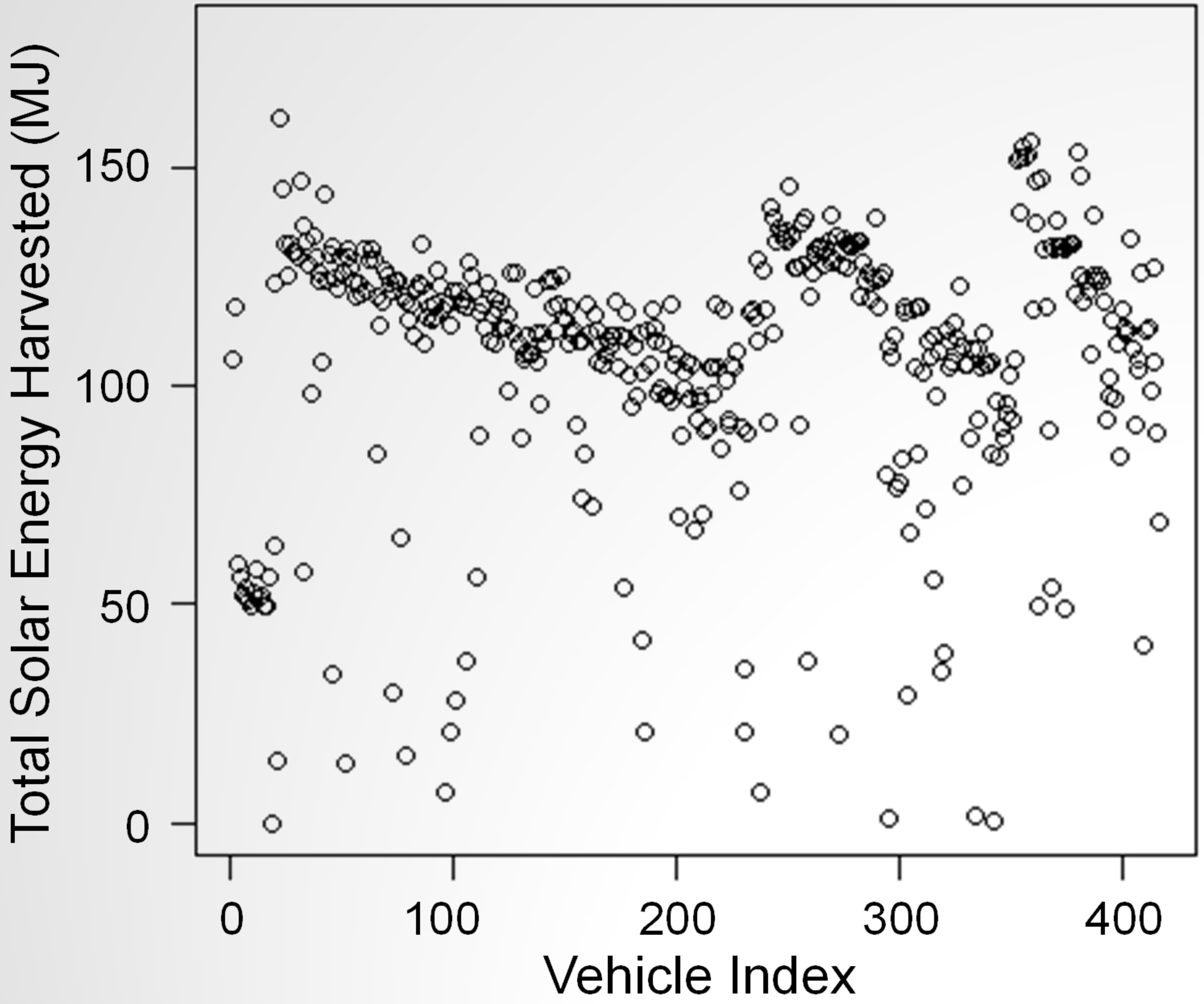
Vehicle Energy Consumption

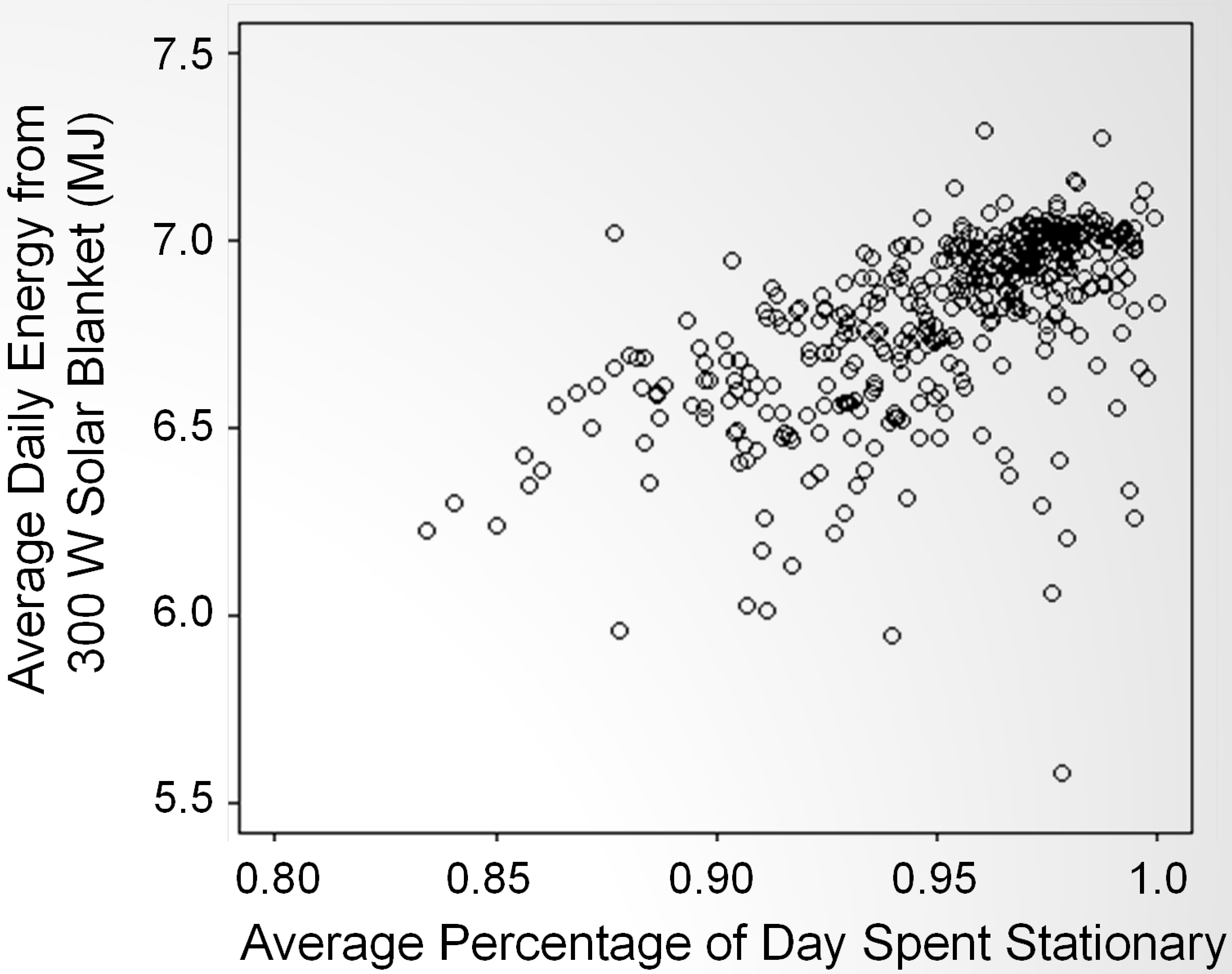




Average tactical vehicle used 2060 MJ over rotation. This equates to 150 MJ per day

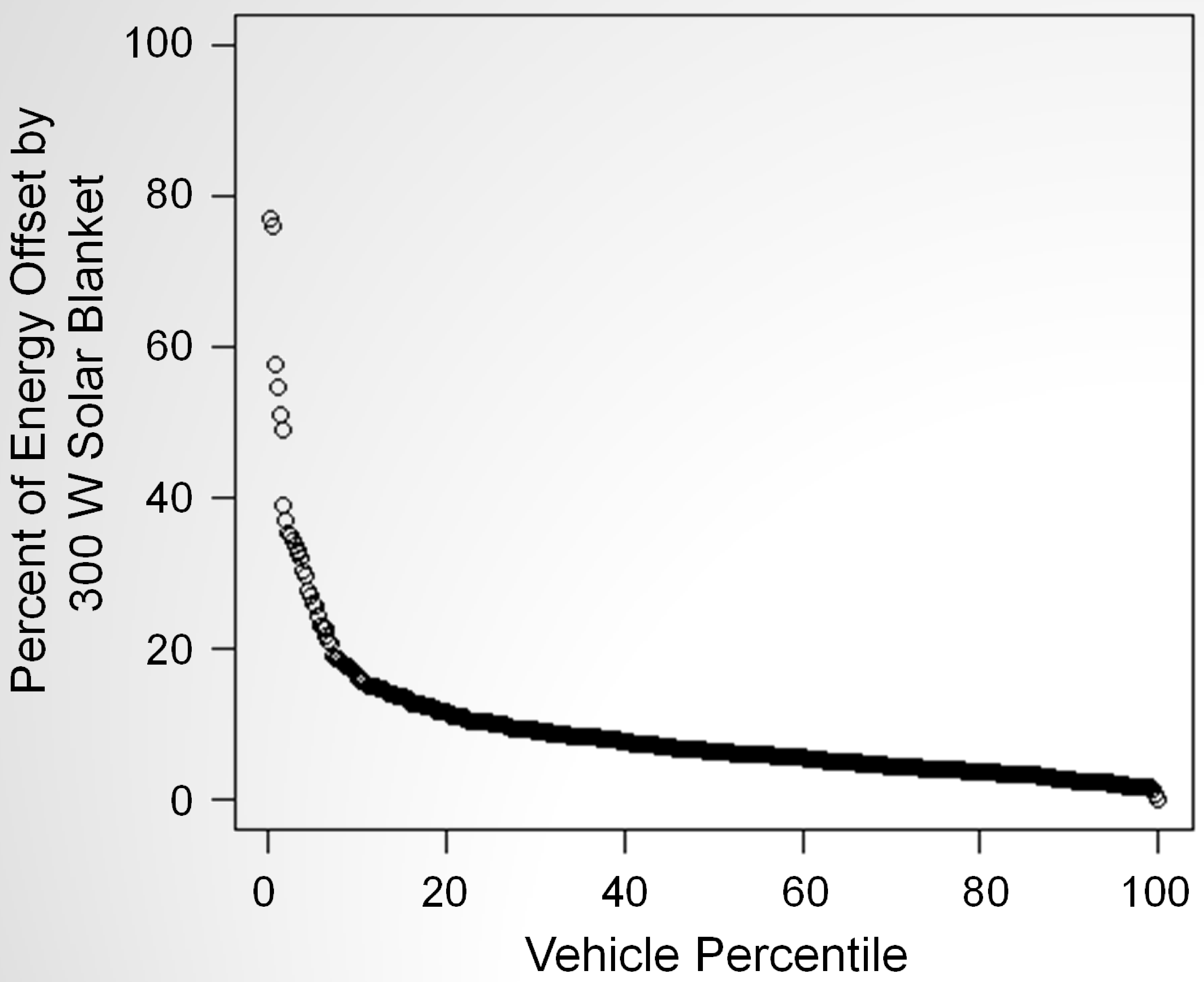
Solar Offset





Average tactical vehicle harvested 106 MJ over rotation. This equates to 7.0 MJ per day

Energy Offset



Approximately 10 percent of energy used by vehicle over NTC rotation could have been offset by solar energy.

Fuel Considerations

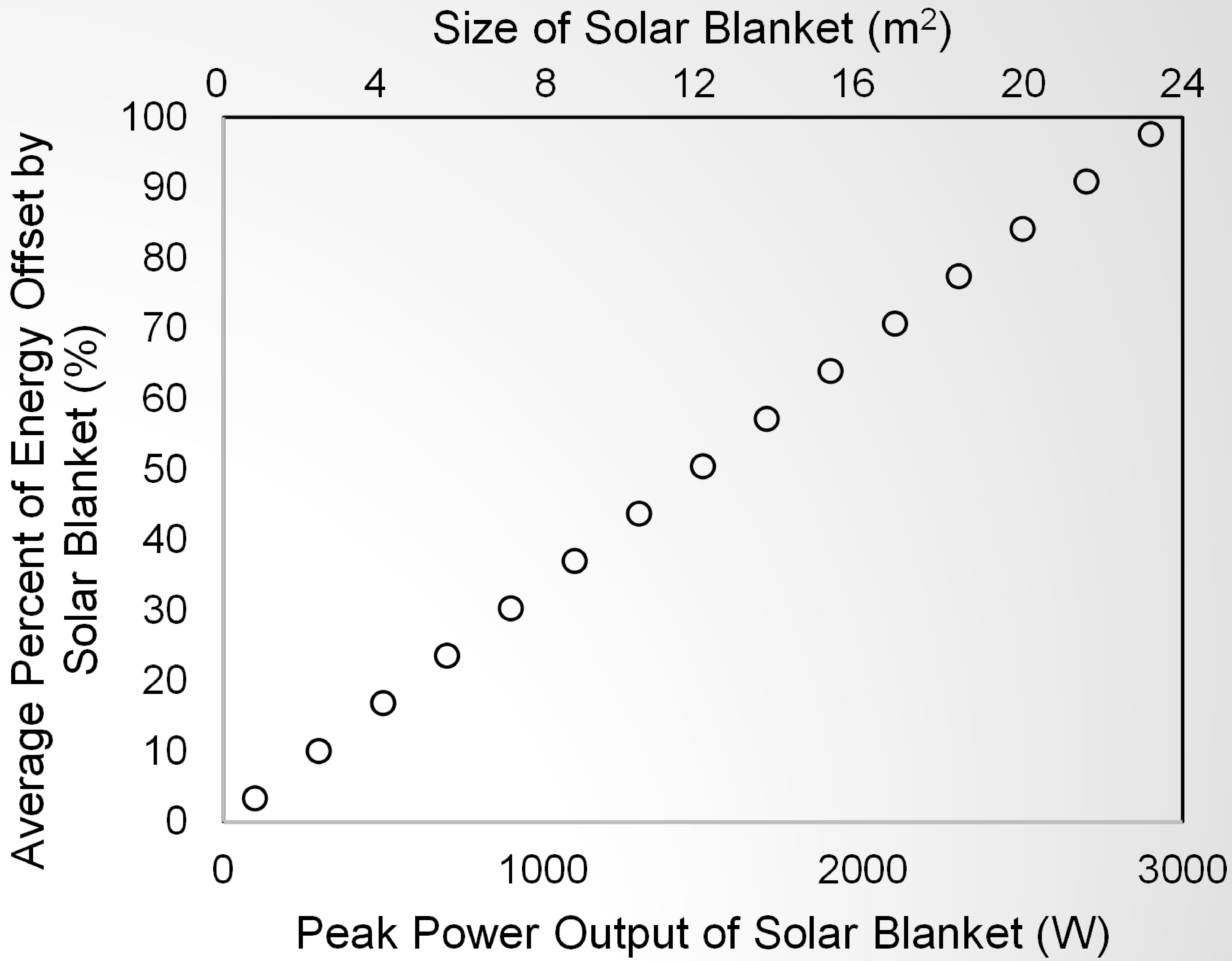
- Assuming a standard diesel engine:
  10.2 kg of JP-8 per day while moving
  24.5 kg per day while idling
  Approximately 34.7 kg (14 gallons) daily

- Electrification (hybridization) → reduces fuel consumption from idling
  34.7 kg of JP-8 reduces to 20.1 kg

- Solar blanket has the potential to reduce it further (approximately another 1.1 kg)

Size and Cost Considerations

- Analysis used a 300 W silicon solar blanket with a footprint of 2.4 square meters.
- Larger blankets are undesirable due to deployment and storage difficulties, though energy production is proportional to blanket size.
- 24 square meter blanket would offset full energy needs for 50% of vehicles.
- Standard silicon cells have 12% efficiency; alternative materials like copper indium gallium diselenide can achieve 24.3% efficiency, reducing the blanket size needed by half, though at a higher cost.



Conclusions

- U.S. Army's effort to electrify tactical vehicles aligns with the Army Climate Strategy and leverage automotive industry advances.
- Electrified vehicles can use solar power for recharging, reducing reliance on fuel resupply and enhancing operational flexibility.
- Analysis of over 400 vehicles during a training exercise at NTC revealed vehicles are stationary most of the time, enabling opportunity charging and showing that 10% of energy needs could be met by 300W solar blanket.
- While solar can provide significant benefits in austere environments, vehicles will still largely depend on fuel for most missions. Solar energy can support limited movements and power electronics when stationary.
- Significant fuel saving possible through electrification due to low engine efficiency at idling. Fuel further reduced by opportunity charging.