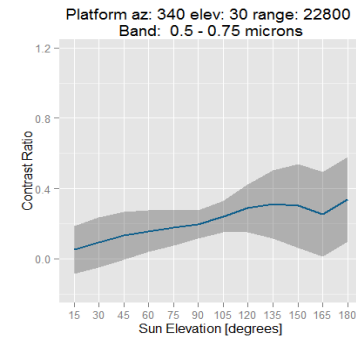
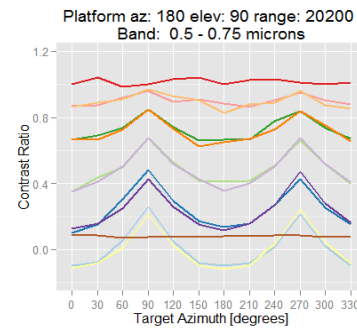
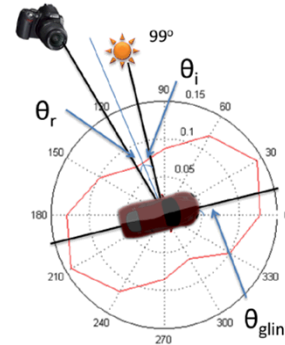
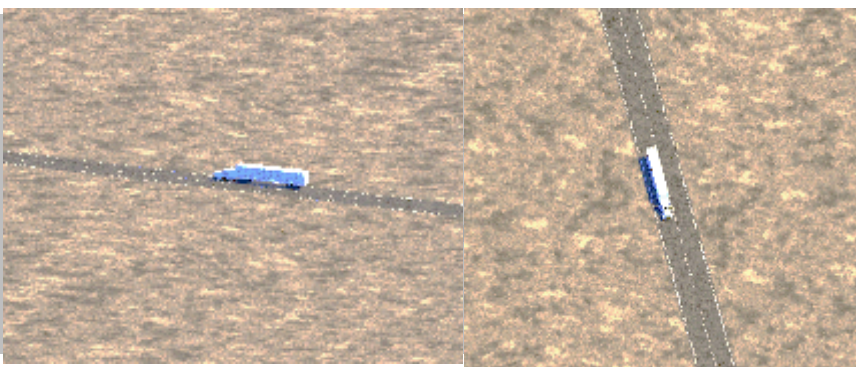


Exceptional service in the national interest



Modeling Tri-Directional Reflectance Distribution Functions with Application to Sub-Pixel Target Detection

Joshua D. Zollweg, Prabal Nandy
Swiss Tech Convention Center
IEEE WHISPERS 2014

Outline

- Introduction to Tri-Directional Reflectance Distribution Function (TRDF)
- Methodology
- Results and Analysis
- Conclusions
- Future Work
- References
- Acknowledgements

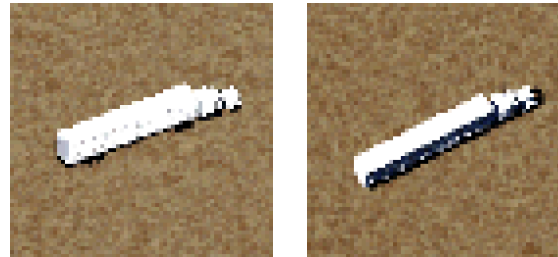
Introduction

- Bi-Directional Reflectance Distribution Function (BRDF)
 - Varying illumination geometry
 - Varying viewer geometry
 - Used for *surfaces* which are flat or representable with microfacets

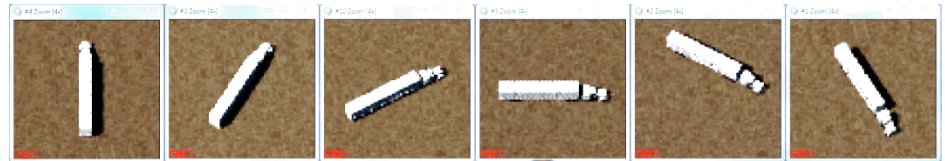
- Tri-Directional Reflectance Distribution Function (TRDF)
 - Varying illumination geometry
 - Varying viewer geometry
 - Varying target geometry
 - Used for complex *scenes* with three-dimensional relief

Introduction

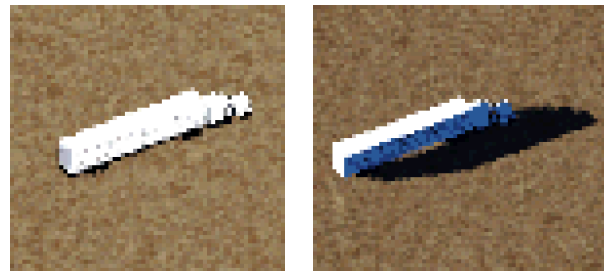
- Changing viewer position



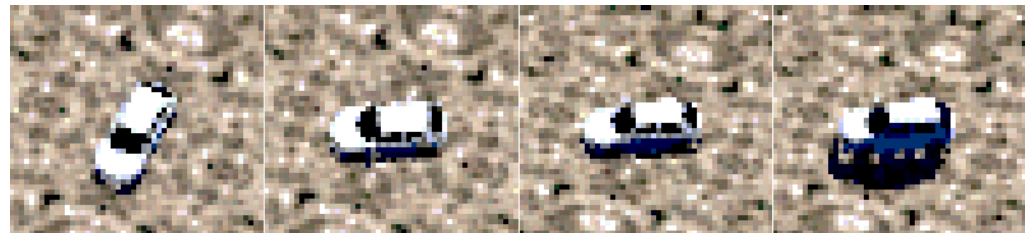
- Changing truck orientation



- Changing illumination location

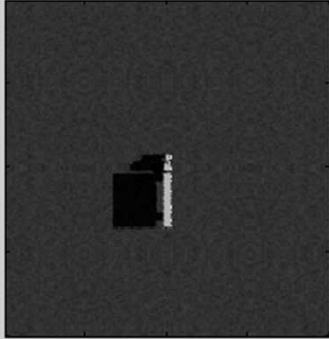


- Changing vehicle/
background

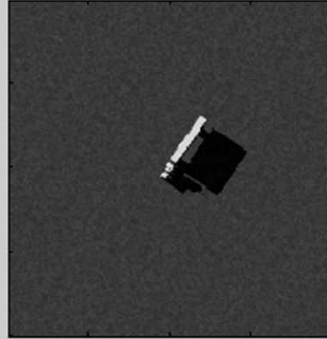


Introduction

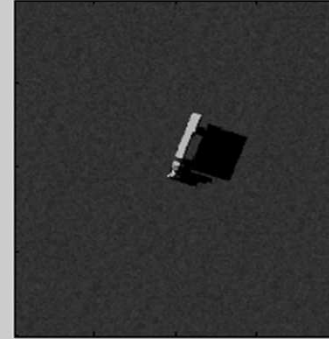
Platform az = 180 elev = 90 range = 20200
Target az = 0 Sun elev = 15



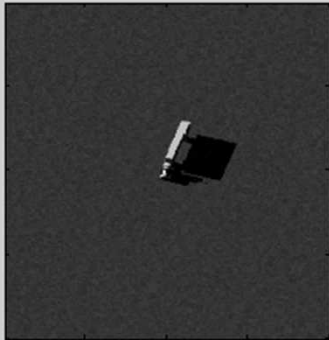
Platform az = 325 elev = 75 range = 20400
Target az = 0 Sun elev = 15



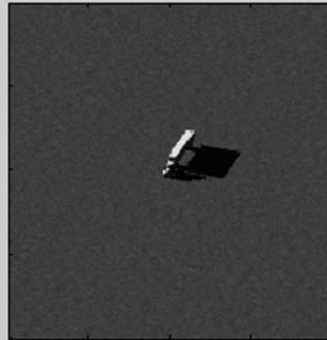
Platform az = 339 elev = 60 range = 20900
Target az = 0 Sun elev = 15



Platform az = 341 elev = 45 range = 21700
Target az = 0 Sun elev = 15



Platform az = 340 elev = 30 range = 22800
Target az = 0 Sun elev = 15

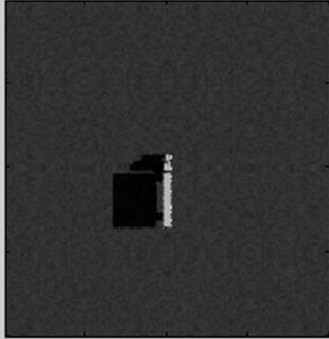


Platform az = 335 elev = 15 range = 24100
Target az = 0 Sun elev = 15

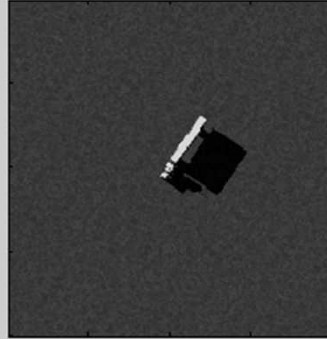


Introduction

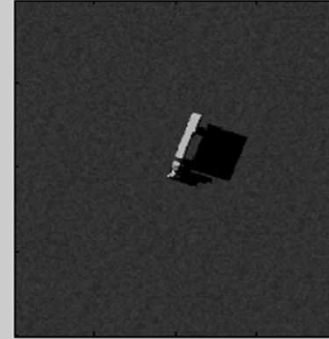
Platform az = 180 elev = 90 range = 20200
Target az = 0 Sun elev = 15



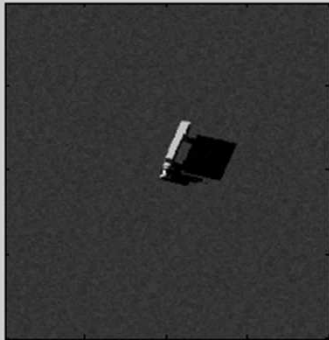
Platform az = 325 elev = 75 range = 20400
Target az = 0 Sun elev = 15



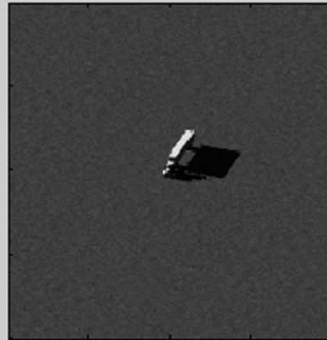
Platform az = 339 elev = 60 range = 20900
Target az = 0 Sun elev = 15



Platform az = 341 elev = 45 range = 21700
Target az = 0 Sun elev = 15



Platform az = 340 elev = 30 range = 22800
Target az = 0 Sun elev = 15



Platform az = 335 elev = 15 range = 24100
Target az = 0 Sun elev = 15



Methodology

- Select target and backgrounds
 - Semi truck and passenger car targets – Painted white
 - Desert sand background
- Select illumination, viewer, and target geometries to consider
 - Viewer geometry
 - [(Zenith,Azimuth)]: [(0, 0) (30,120) (50,180) (44,150) (45,145) (45,220) (50,185)]
 - Illumination geometry
 - [(Zenith,Azimuth)]: [(0, 0) (92,88) (78,99) (64,111) (51,126) (40,147) (35,175) (38,205) (47,229) (59,245) (73,258) (87,269)]
 - Vehicle orientation
 - Pointing azimuth: [0, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330]
- Use DIRSIG and MODTRAN to simulate at-aperture radiance imagery

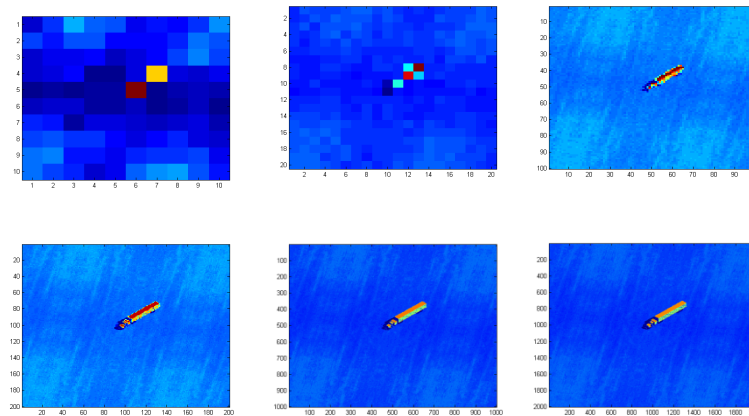
Methodology

■ Resolution Study

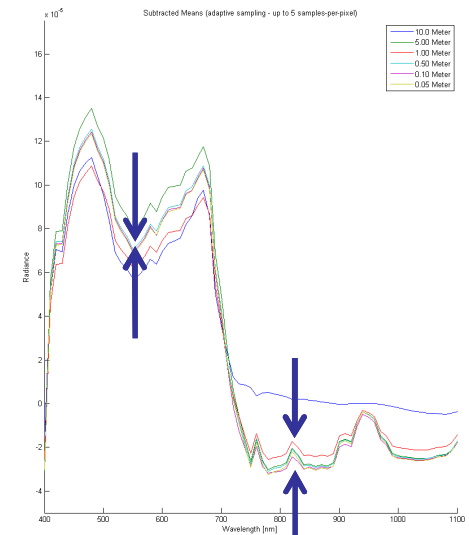
- DIRSIG is a ray tracing code used here in a reverse ray tracing mode
- Spatial resolution of simulation must adequately sample target geometry
- Coarsest sufficient resolution of simulation determined with a resolution study



Pixel subsampling



Varied GSD simulations



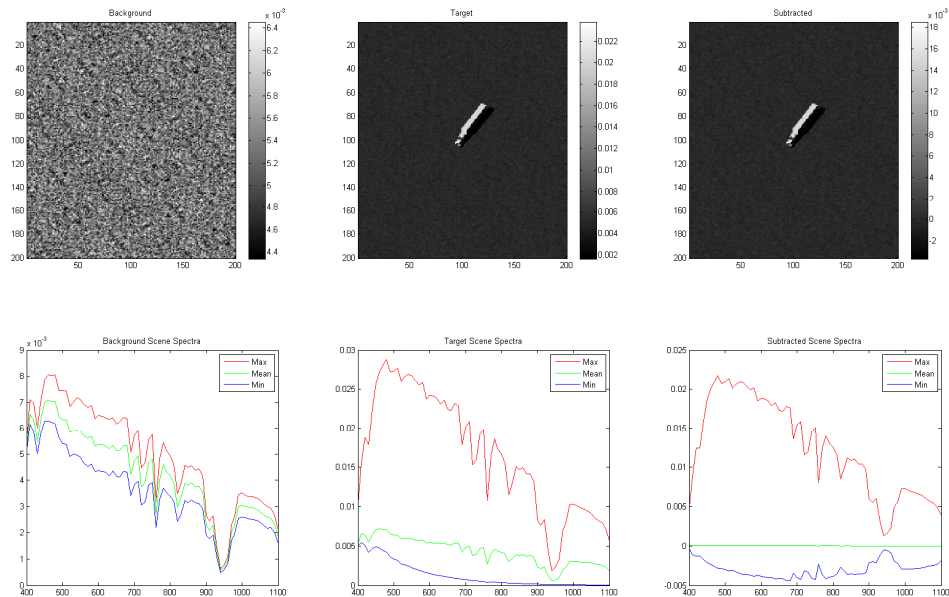
Spectra agree closely at finer GSDs

Methodology

$$CT_{x,y,z} = \frac{\sum_{GSD} (T_{x,y,z} - B_{x,y,z})}{\sum_{GSD} (T_{nadir,nadir,n/a} - B_{nadir,nadir,n/a})}$$

■ Contrast Ratio

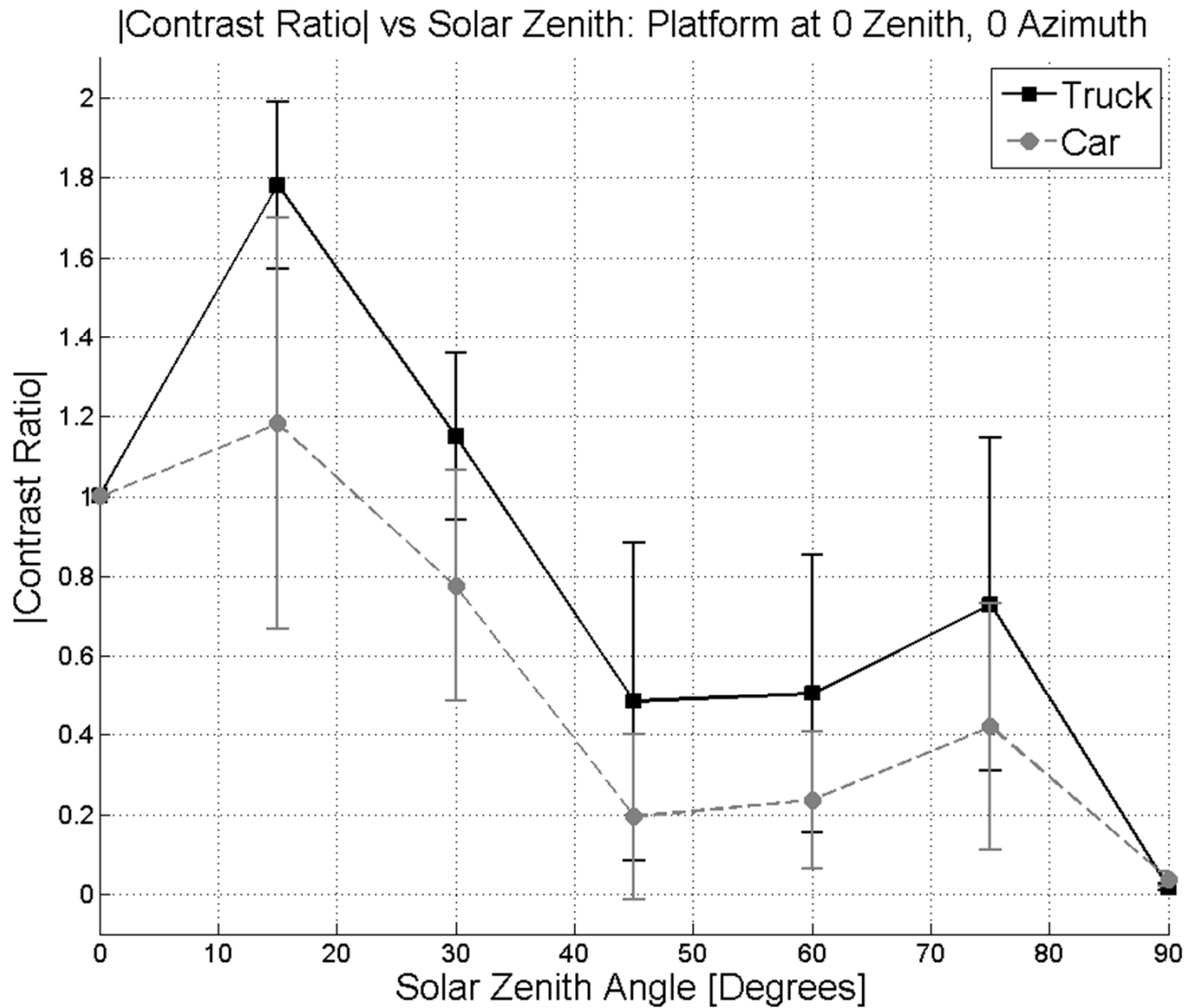
- An intuitive way to analyze the relative detectability of various TRDF scenarios
- Ratio of arbitrary background-subtracted TRDF case to background-subtracted nadir/nadir reference case



Results and Analysis

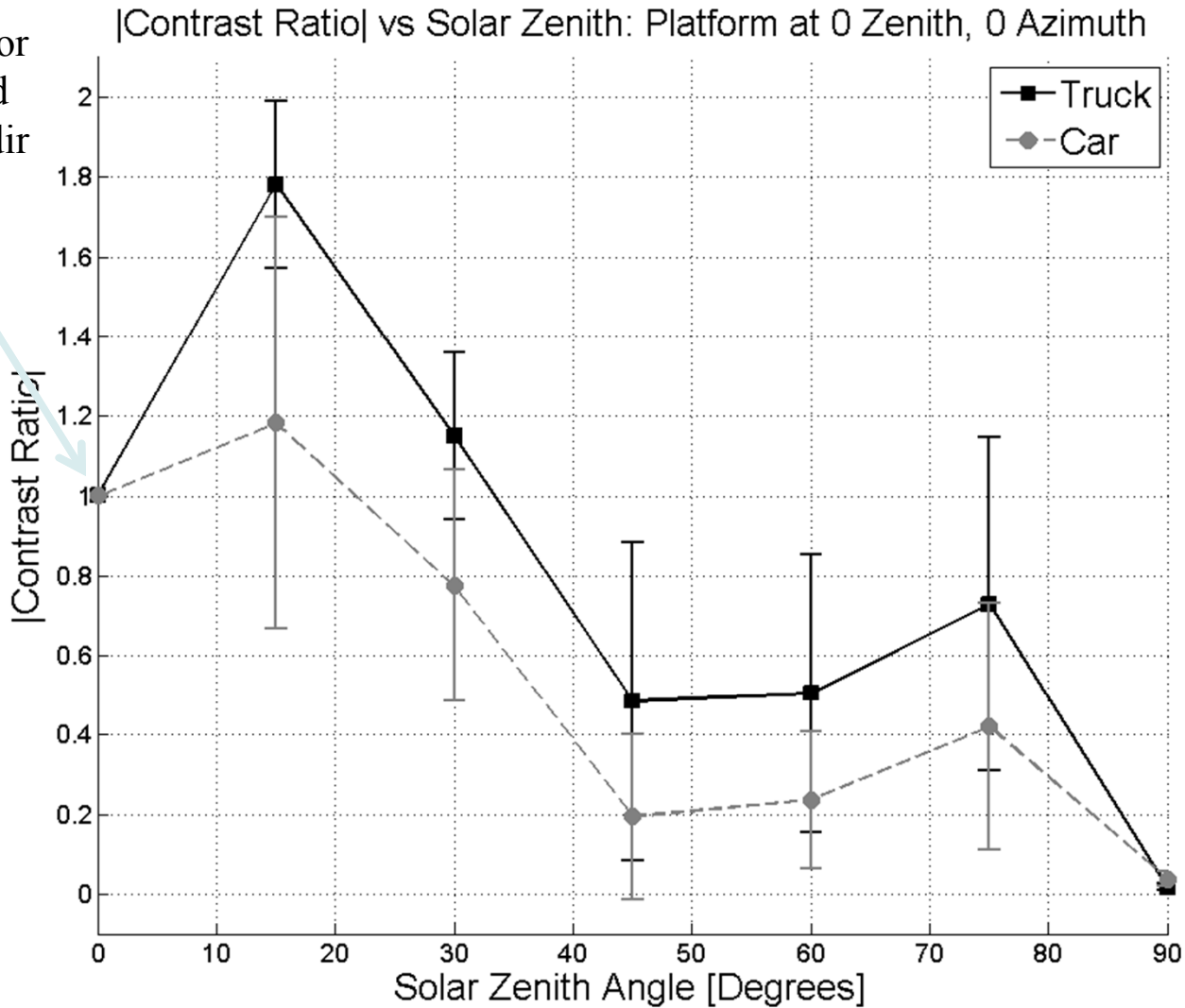
- Many ways to “slice” TRDF databases
 - Observer
 - Zenith
 - Azimuth
 - Illumination
 - Zenith
 - Azimuth
 - Target orientation
 - Materials
 - Target
 - Background
 - Spectral bands
- High dimensional data!

Analysis: Illumination Angle



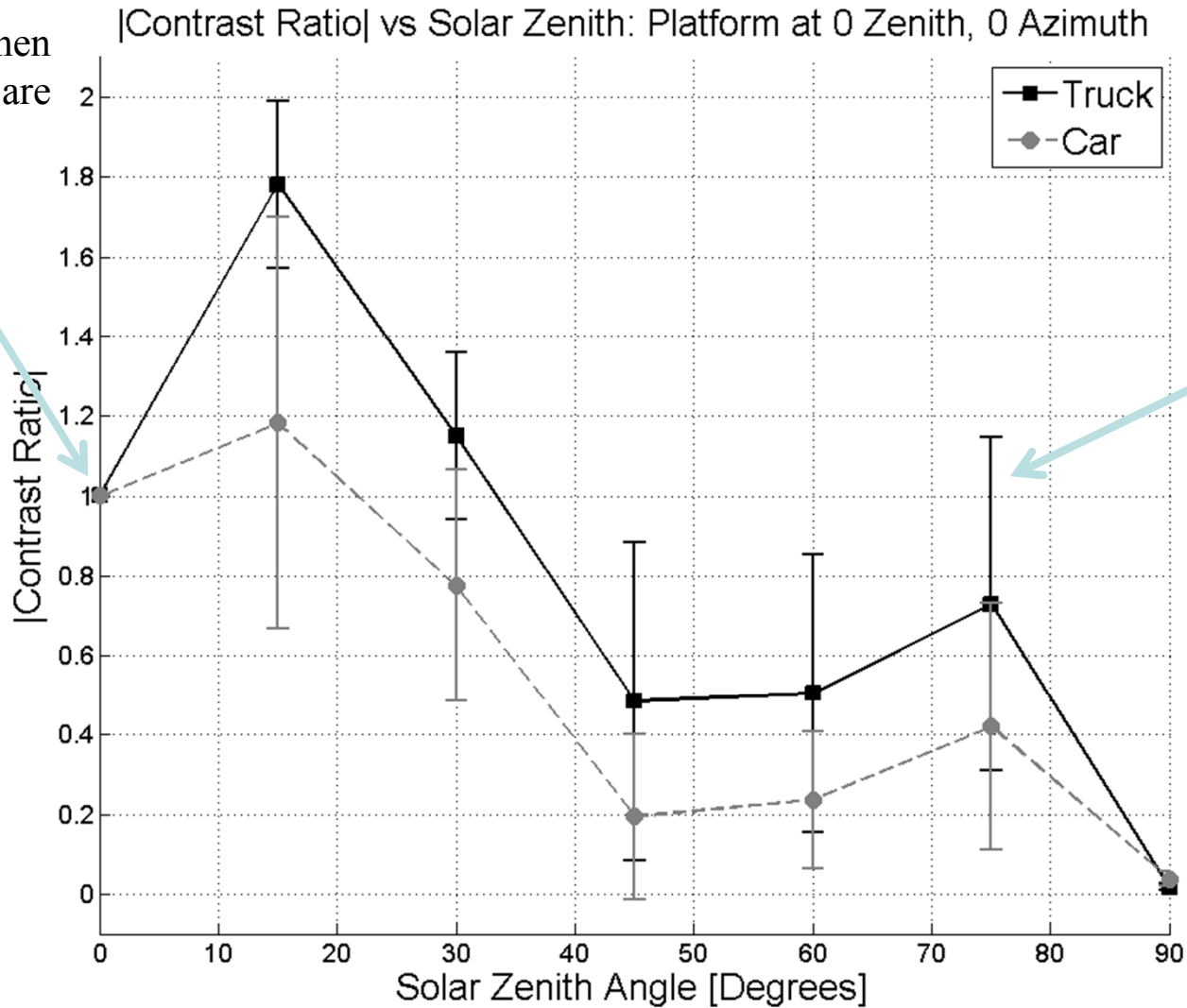
Analysis: Illumination Angle

CR always 1 for when sun and viewer are nadir



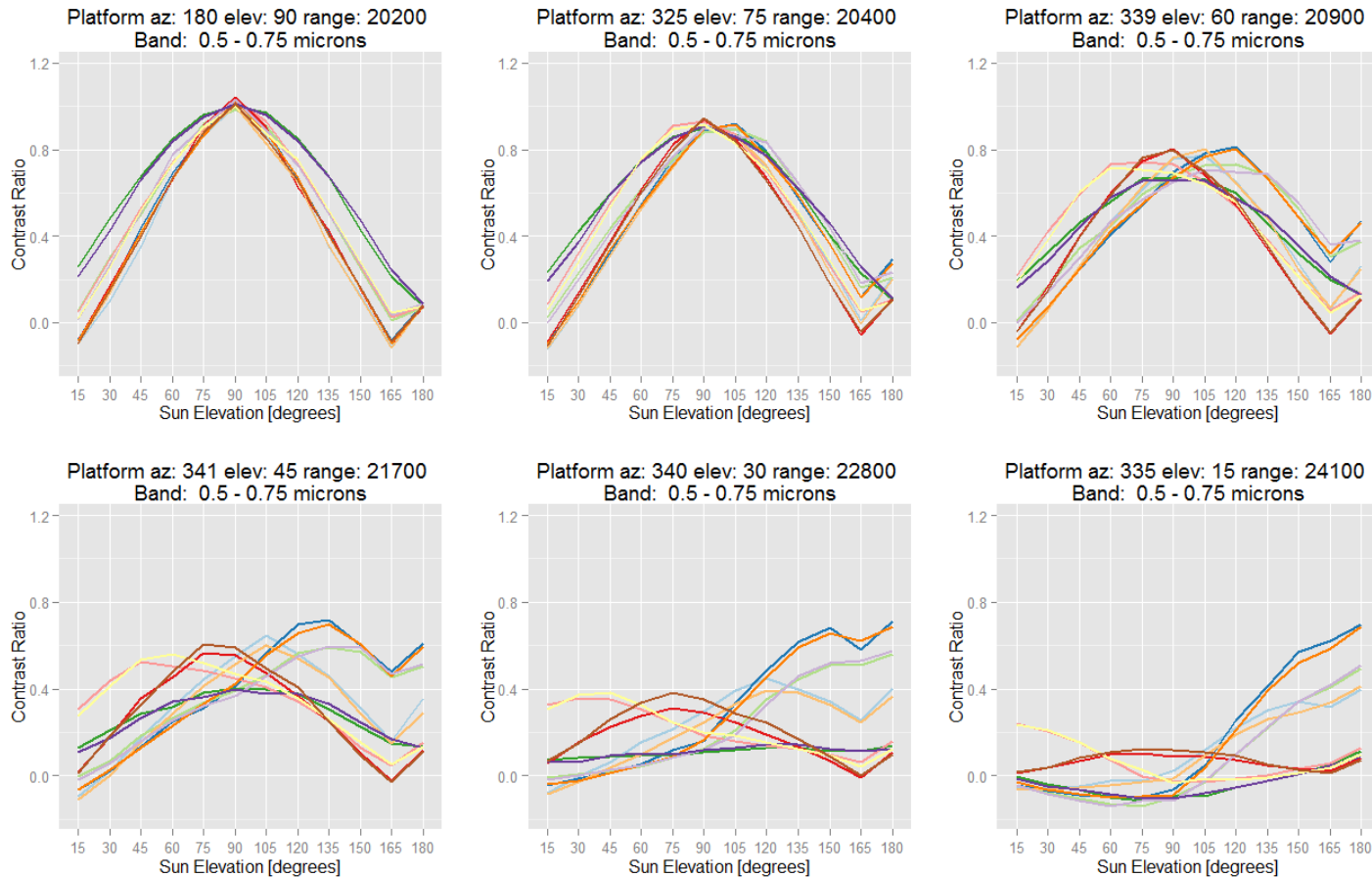
Analysis: Illumination Angle

CR always 1 when sun and viewer are nadir



Variation due to target rotation

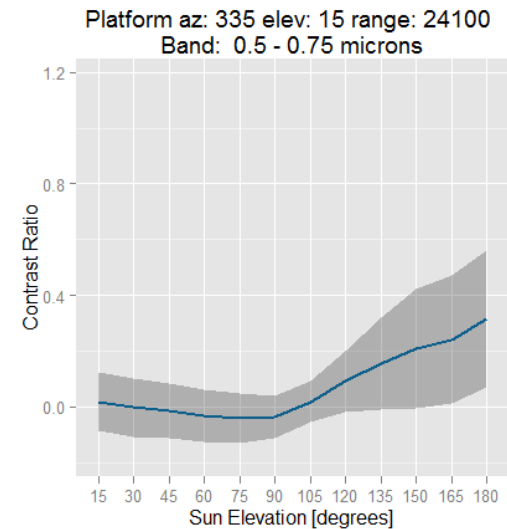
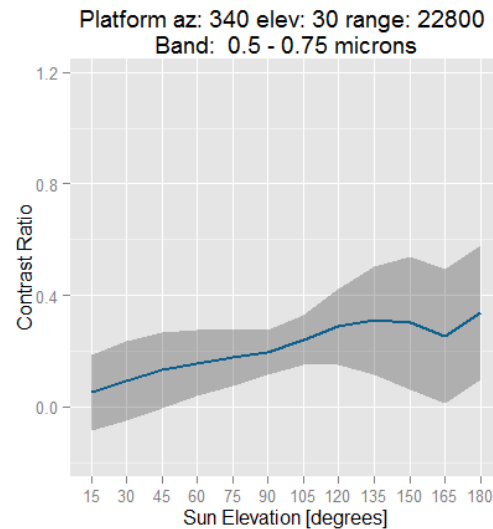
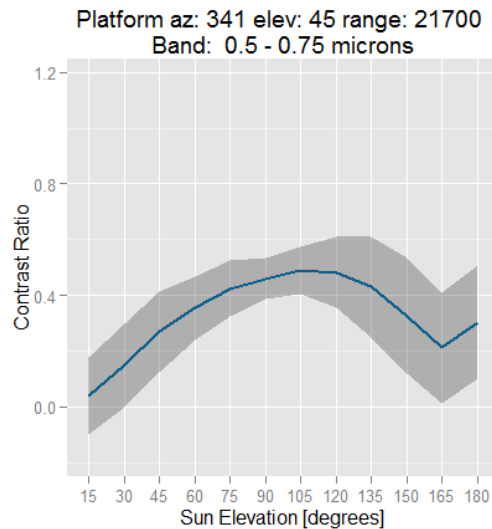
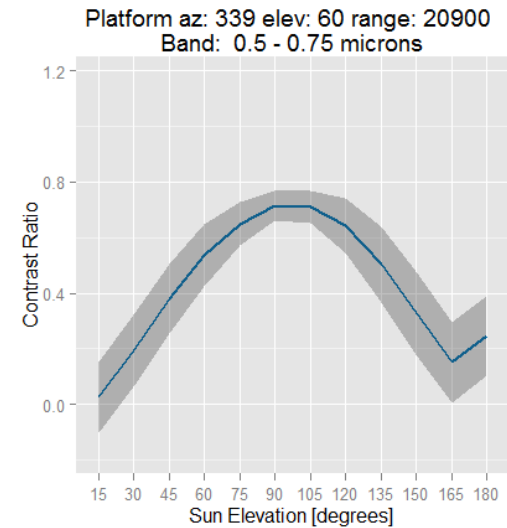
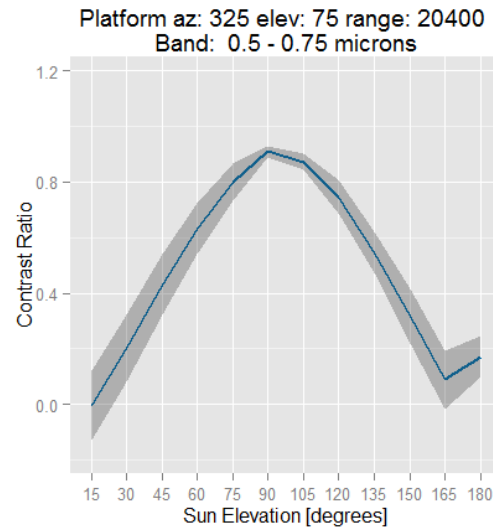
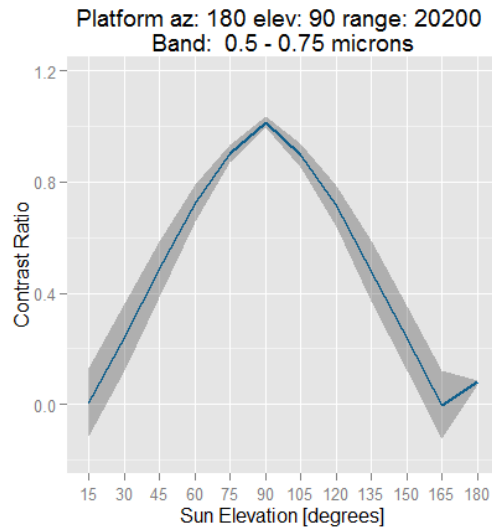
Analysis: Illumination Orientation



Target Azimuth

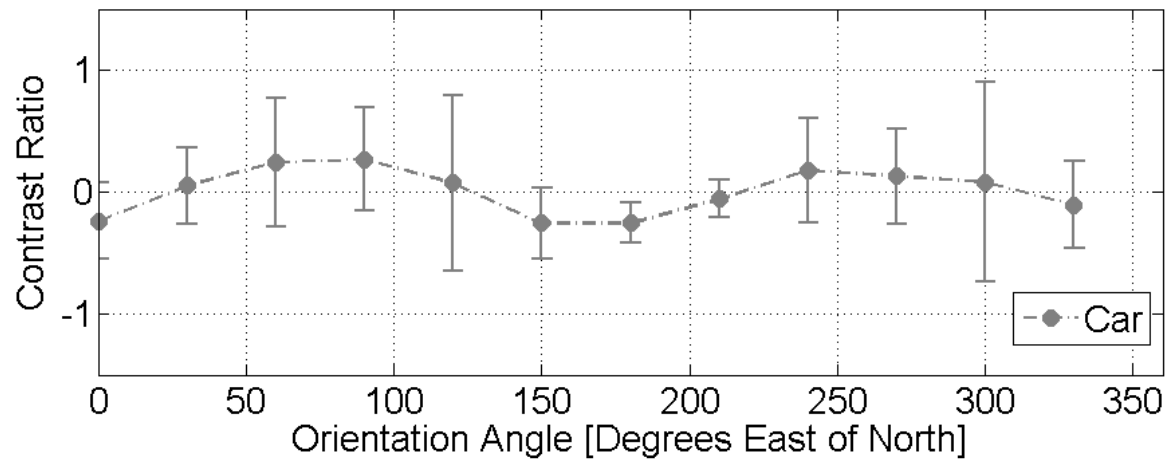
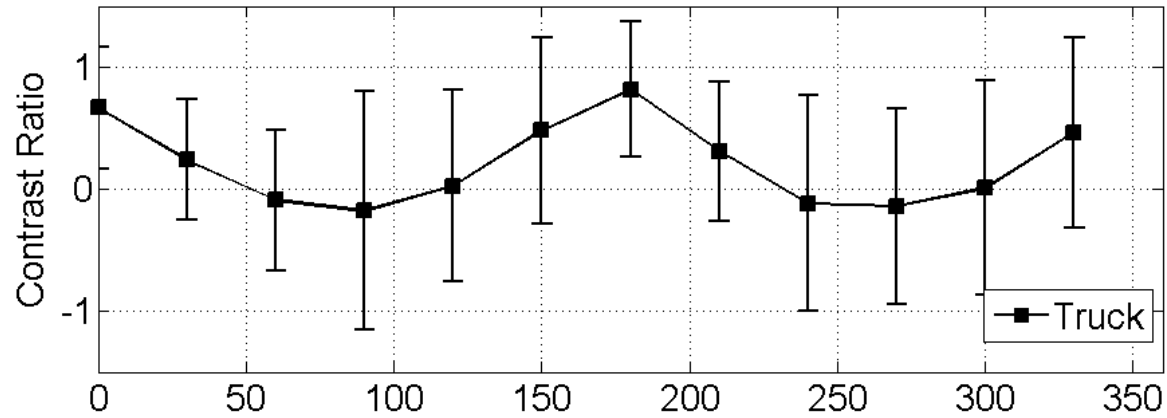
0 30 60 90 120 150 180 210 240 270 300 330

Analysis: Illumination Orientation



Analysis: Target Orientation

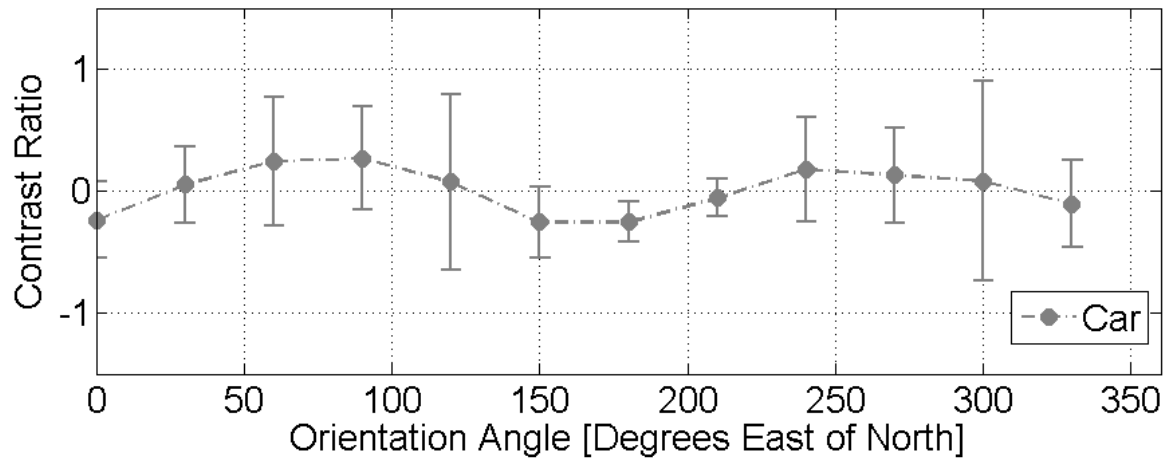
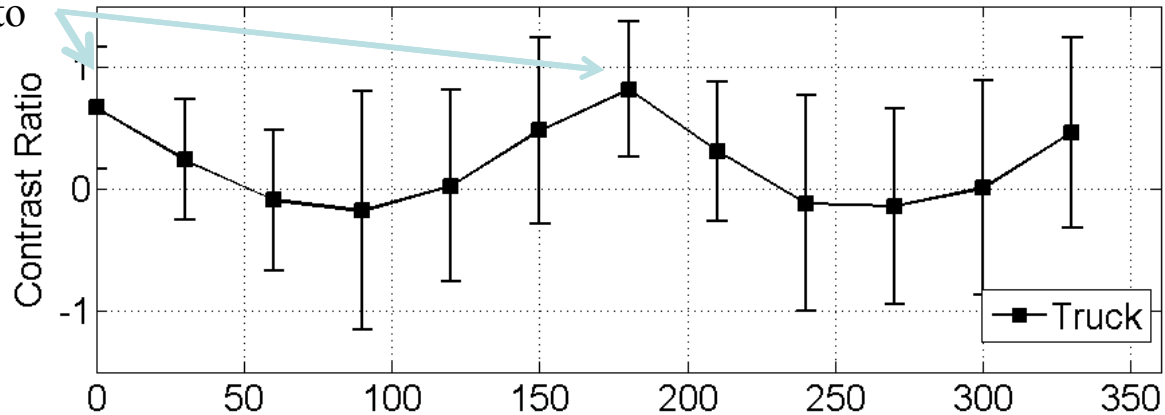
Contrast Ratio vs Target Orientation: Plat at 30 Zenith, 339 Azimuth



Analysis: Target Orientation

CR greatest when truck is broadside to sensor

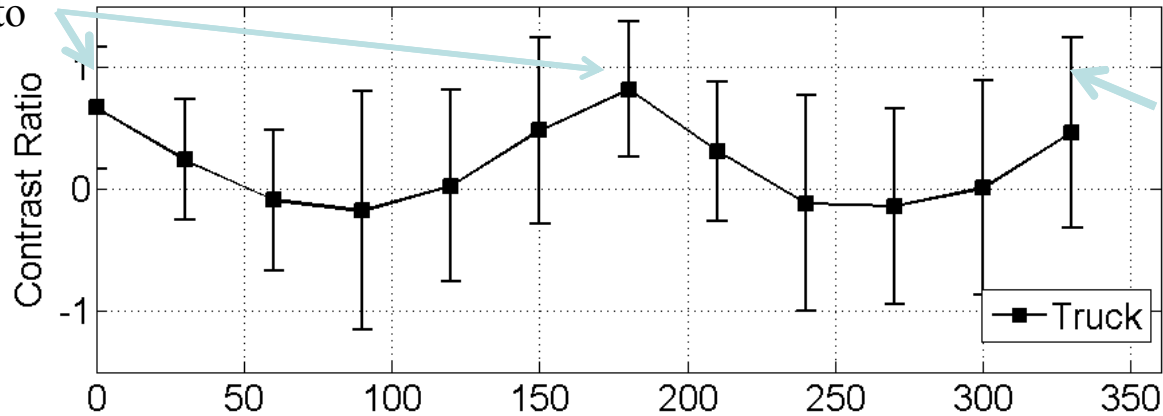
Contrast Ratio vs Target Orientation: Plat at 30 Zenith, 339 Azimuth



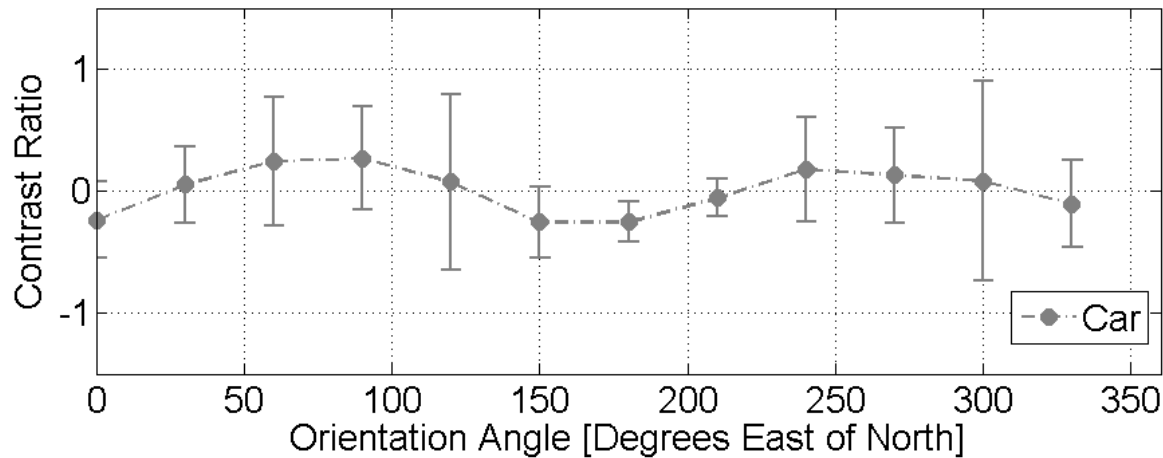
Analysis: Target Orientation

CR greatest when truck is broadside to sensor

Contrast Ratio vs Target Orientation: Plat at 30 Zenith, 339 Azimuth



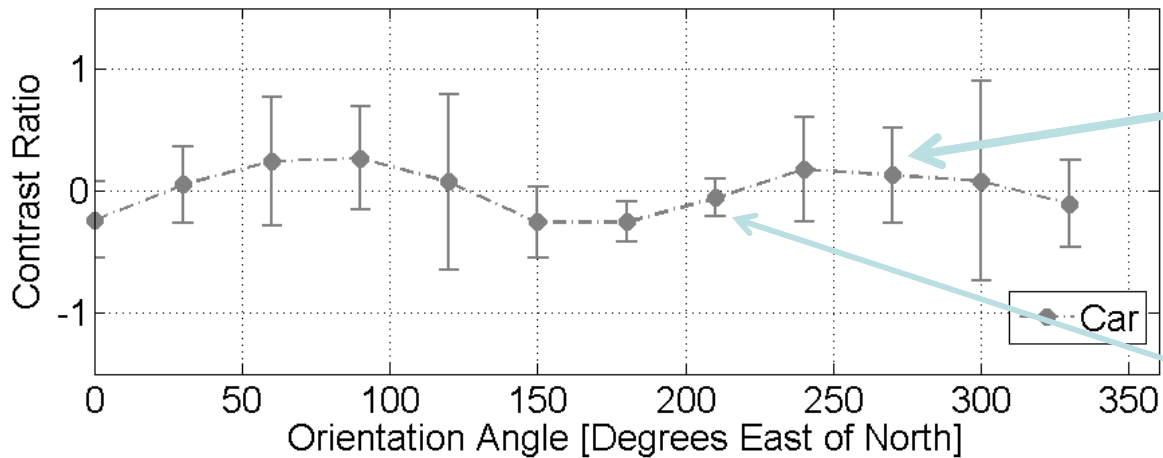
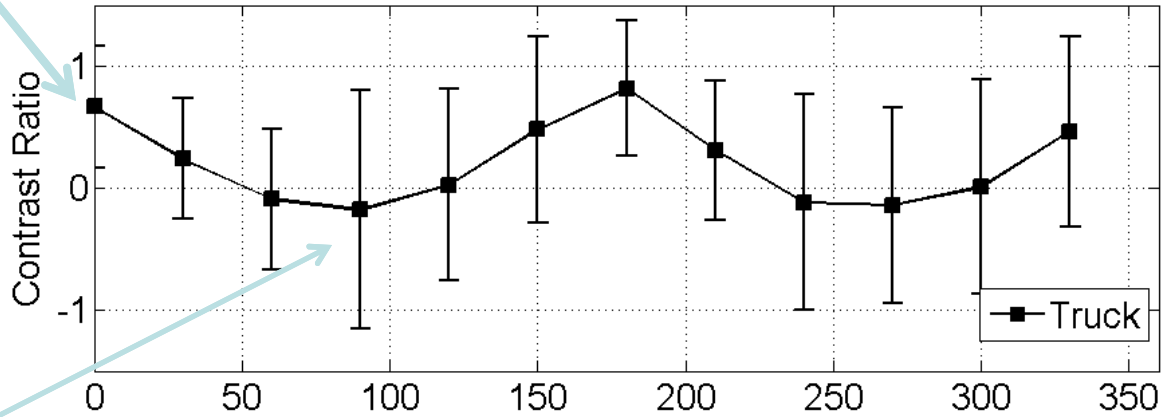
Variation due to changing sun angle



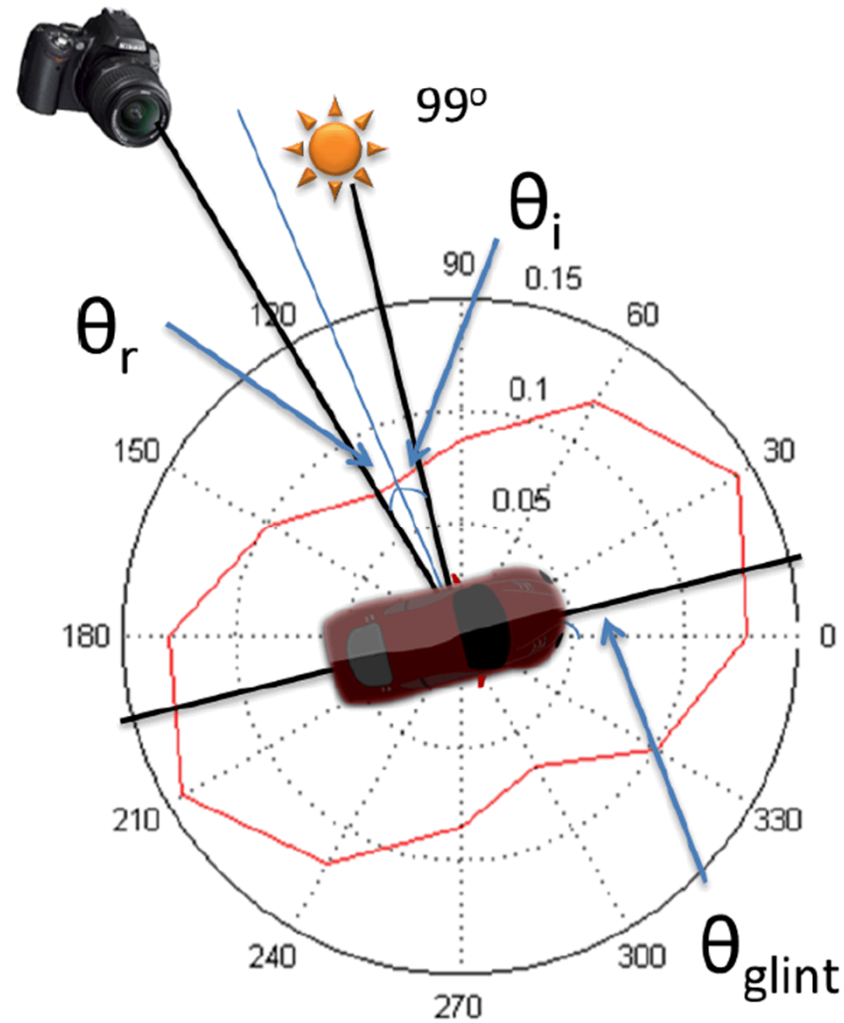
Analysis: Target Orientation



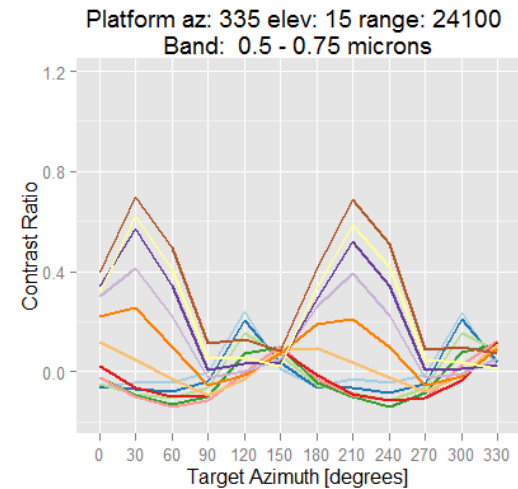
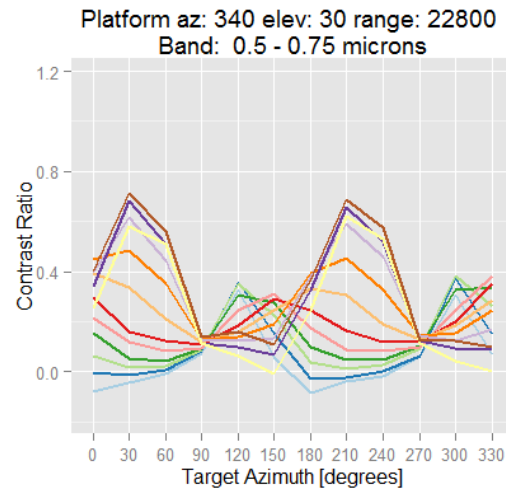
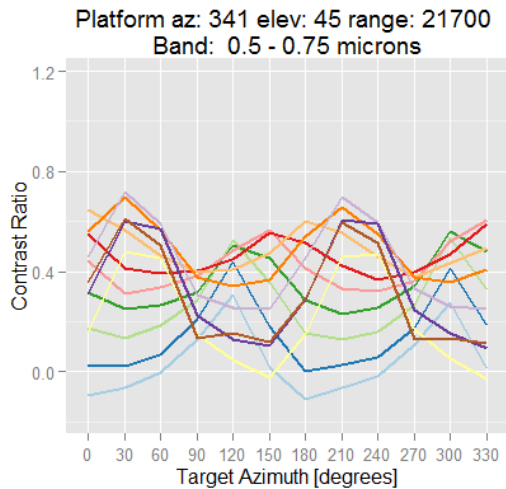
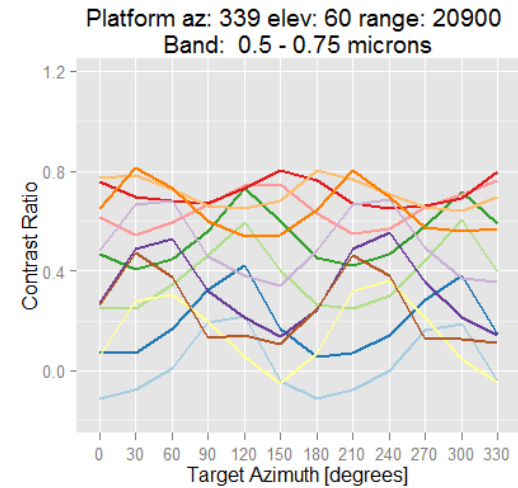
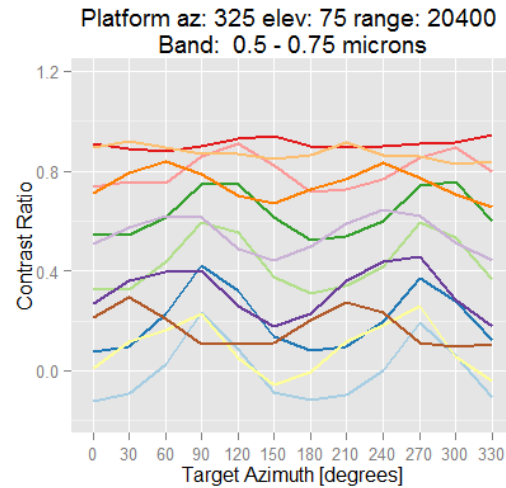
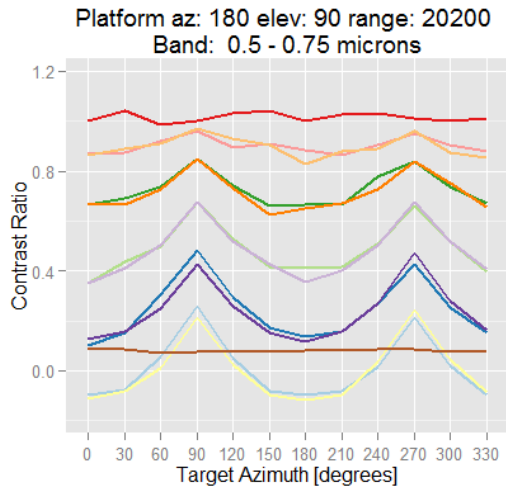
Contrast Ratio vs Target Orientation: Plat at 30 Zenith, 339 Azimuth



Analysis: Target Orientation



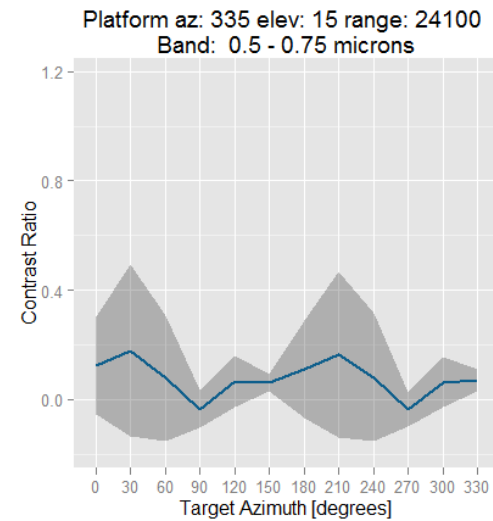
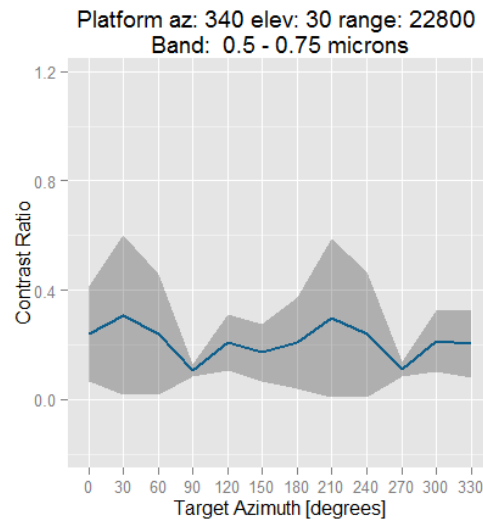
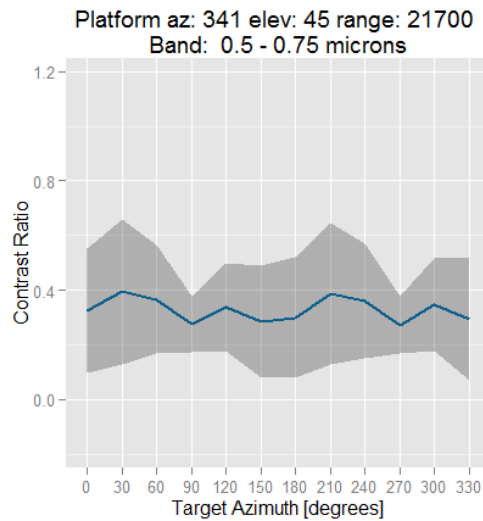
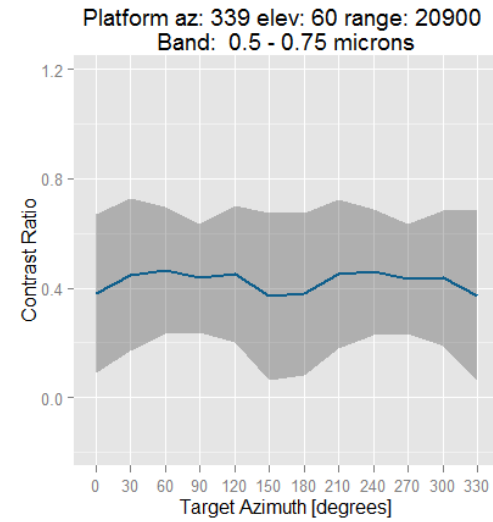
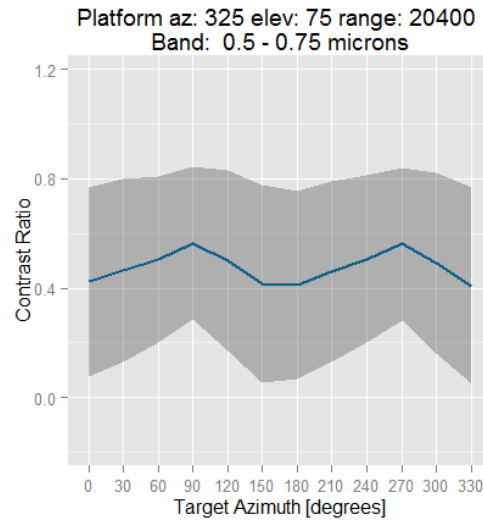
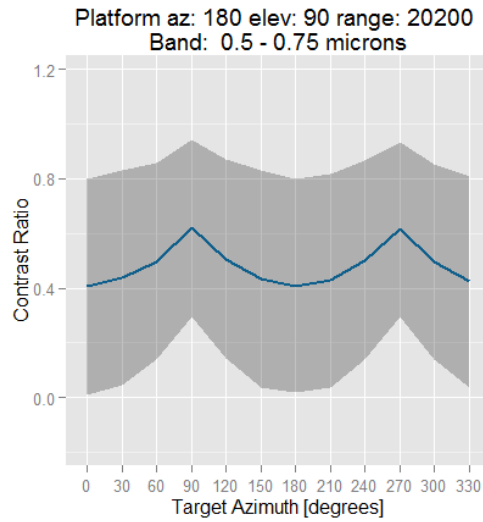
Analysis: Target Orientation



Sun Elevation



Analysis: Target Orientation



Conclusions

- Three dimensional scenes result in complex TRDF scenarios
- Gross-scale glint and shadow effects are not easily modeled with traditional BRDF parameterizations
- Component of nonlinear mixing in unresolved target detection applications
- TRDF is difficult to predictively conceptualize
- TRDF data can be large
- TRDF data can be of significant value to target detection applications

Future Work

- Simulate
 - Additional vehicle/paint combinations
 - Additional background materials
 - Finer rotational resolution
 - Fully sampled illumination and viewer geometries

- Develop
 - Parameterized TRDF model
 - Scenario definition tool for rapid detectability analysis
 - Target and target pose recovery algorithms

References

- [1] David Gillis, Jeffrey Bowles, Emmett J Ientilucci, and David W Messinger, “A generalized linear mixing model for hyperspectral imagery,” in *SPIE Defense and Security Symposium*. International Society for Optics and Photonics, 2008, pp. 69661B–69661B.
- [2] John R. Schott, Scott D. Brown, Rolando V. Raqueno, Harry N. Gross, and Gary Robinson, “Advanced synthetic image generation models and their application to multi/hyperspectral algorithm development,” 1999.
- [3] Alexander Berk, Lawrence S Bernstein, and David C Robertson, “Modtran: A moderate resolution model for lowtran,” Tech. Rep., DTIC Document, 1987.
- [4] California Institute of Technology, “ASTER spectral library,” California Institute of Technology, California, USA, 2000.
- [5] Emmett J. Ientilucci and Scott D. Brown, “Advances in wide-area hyperspectral image simulation,” 2003.
- [6] Kenneth E Torrance and Ephraim M Sparrow, “Theory for off-specular reflection from roughened surfaces,” *JOSA*, vol. 57, no. 9, pp. 1105–1112, 1967.
- [7] Lihong Su, Yuxia Huang, MJ Chopping, A Rango, and JV Martonchik, “An empirical study on the utility of brdf model parameters and topographic parameters for mapping vegetation in a semi-arid region with misr imagery,” *International Journal of Remote Sensing*, vol. 30, no. 13, pp. 3463–3483, 2009.

Acknowledgements

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- Dylan Anderson
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