UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

SEP 17 2009

OFFICE OF
AIR QUALITY PLANNING
AND STANDARDS

MEMORANDUM

SUBJECT: Model Clearinghouse Review of Use of Non-default Radius for Determining Surface Roughness Length for AERMET

FROM: Tyler Fox, Leader
Air Quality Modeling Group, C439-01

TO: Stanley Krivo, Regional Meteorologist
Air Quality Modeling & Transportation Section, EPA Region 4

R. Scott Davis, Chief
Air Quality Modeling & Transportation Section, EPA Region 4

INTRODUCTION

In response to your memorandum of June 25, 2009, the Model Clearinghouse has reviewed Region 4's position on the proposed use of a non-recommended, project-specific radius in the determination of surface roughness parameters by Kentucky NewGas (KYNG), to be used in the processing of meteorological data in AERMET. The applicant asserts that "significant discontinuities in land cover" exist "just beyond the recommended 1 kilometer upwind distance" at the Bowling Green, KY (BWG) airport tower location and at the proposed KYNG project site location, justifying the use of a larger radius of influence (greater than the recommended default radius of 1 kilometer) for estimating surface roughness. This condition is identified in the current *AERMOD Implementation Guide* (EPA, 2009) as one of three situations for which a non-default radius may be considered on a case-by-case basis.

The applicant presented an analysis of the variation of surface roughness as a function of study radius by wind direction sector for each location (BWG and KYNG) based on application of the AERSURFACE tool (EPA, 2008) as evidence that the condition cited in the *AERMOD Implementation Guide* exists, and as evidence to support the proposed use of non-default radii of 2.4 kilometers for BWG and 1.8 kilometers at KYNG. Use of these larger radii would result in larger values of surface roughness length for the BWG site. Region 4 concluded that a site-specific radius of 1.6 kilometers is appropriate for both sites based on the AERSURFACE analysis provided by the applicant.

MODEL CLEARINGHOUSE RESPONSE

While the applicant provided an interesting study of the sensitivity of AERSURFACE roughness estimates to variations in study radius at these two sites, they failed to offer any rationale that would justify their assertion that use of roughness values based on the larger radii in AERMET would provide more accurate estimates of boundary layer scaling parameters for input to AERMOD. Instead, the explanation provided with the analysis states that "the resulting surface roughness data" based on varying the study radius "across the entire parametric range of surface roughness study area radius values cited in the *AERSURFACE User's Guide* . . . demonstrate[s] that significant LULC discontinuities occur beyond the default 1 km study area radius." However, the mere fact that roughness estimates increase with increasing radius is not evidence that the higher roughness values are more representative inputs for AERMET. Since meteorological tower sites are generally characterized by relatively open exposures by design, one might expect a similar pattern of increasing roughness with increasing radius at most airport sites.

The applicant also failed to provide any analysis of the actual land cover characteristics at the sites that would indicate a significant discontinuity just beyond the default radius of 1 kilometer. Instead, the following two criteria are cited by the applicant to justify the selection of a specific radius by wind sector based on the AERSURFACE analysis; 1) "the point at which the influence of the LULC element(s) begins to decrease"; or 2) "the inflection point in the curve occurring after 1 km" based on a mathematical fit to the variations in roughness with radius. No explanation is offered of the physical relevance of these criteria that would justify their use in determining an appropriate radius for surface roughness.

Given the lack of any technical rationale based on the physics of boundary layer modeling to justify use of a non-default radius for determining surface roughness, the Model Clearinghouse cannot support Region 4's position on this application. While this response applies to the analysis for both the BWG and KYNG sites, the intended use of the surface roughness values at the proposed KYNG project site and their relevance to this analysis are not explained in the Region 4 request. Since the guidance clearly states that the surface roughness input to AERMET should reflect characteristics at the meteorological monitoring location, the Clearinghouse has no comment on the appropriate determination of surface roughness at the KYNG site.

As part of our review of this request, we have identified a potential issue regarding the temporal representativeness of 1992 NLCD for the BWG site for recent data periods, later than about 2000. Based on significant land cover changes that have occurred within close proximity of the meteorological tower at BWG that are not reflected in the 1992 NLCD, we recommend adjusting the roughness estimates based on AERSURFACE for the WNW through N sectors. Note that this recommendation does not imply any assessment or endorsement of the representativeness of the BWG airport data for this application. Region 4 has not requested, and we have not conducted any review of the issue of meteorological data representativeness.

A more detailed discussion of the technical issues related to this Model Clearinghouse request is provided below, including a discussion of the potential issue of temporal representativeness of land cover data for the BWG site.

DISCUSSION OF TECHNICAL ISSUES

The determination of appropriate surface characteristics for input to AERMET, including albedo, Bowen ratio, and surface roughness length, has been identified as an important issue with the implementation of the AERMOD model. The AERSURFACE tool was developed to assist with this determination by providing an objective methodology that can be applied with available digitized land cover data. As part of the development of AERSURFACE, the recommended methodology for determining surface characteristics documented in the AERMET user's guide (EPA, 2004) was reassessed. This reassessment resulted in revisions to the recommended methodology that were documented in the January 2008 update to the *AERMOD Implementation Guide* and implemented within AERSURFACE. These revisions affected all three surface characteristics, but the revisions for surface roughness are likely to have the most significant impact on modeling analyses.

The specification of a radius of influence for estimating the effective surface roughness length for purposes of determining boundary layer scaling parameters for the AERMOD model is a complex technical challenge, as discussed in the *AERMOD Implementation Guide*. The goal is to determine an effective roughness length that will accurately estimate the turbulent energy in the boundary layer when processed in AERMET with the observed wind speed. Using a roughness value that is too large will result in an overestimation of the turbulent energy in the atmosphere and a mischaracterization of plume dispersion. A number of research papers, including those referenced in the *AERMOD Implementation Guide* and the AERMET user's guide, suggest that the height of the internal boundary layer (IBL) generated in response to a change in surface roughness will reach a depth of at least 10m, the nominal measurement height for most airport observation towers, within a distance of 1 kilometer or less across a full range of atmospheric stabilities and roughness values. These studies suggest that the necessary fetch distance for the IBL to reach the standard airport measurement height could be 500 meters or less in many cases. While there is a recognized dependence of the appropriate fetch distance on atmospheric stability and surface roughness, accounting for such dependence within the AERSURFACE tool entails significant technical and practical challenges. As noted in the *AERMOD Implementation Guide*, we feel that it is appropriate to take into account the fact that surface roughness effects in AERMOD are generally more important for stable atmospheric conditions than for neutral/unstable conditions, and that meteorological monitoring sites are typically characterized by relatively open (low roughness) exposures when establishing a recommended radius to use for determining the effective surface roughness. Both of these factors would tend to increase the necessary fetch distance, and the current recommended radius of 1 kilometer takes these factors into account.

It is also important to recognize that studies of IBL growth are typically based on relatively idealized settings with a single transition from one surface characteristic to another in order to simplify the analysis of these boundary layer processes. In practical applications of AERSURFACE (or equivalent tools) to support AERMOD modeling, the surface characteristics surrounding the meteorological tower location will usually reflect a higher degree of variability then is represented by these field studies. This patchy heterogeneity characteristic of most sites imposes limits on the degree of sophistication in the analysis methods that can be justified based on scientific principles. In addition to these technical/scientific challenges, several aspects of the available land cover data present practical challenges, including the accuracy and temporal representativeness of the land cover classifications for a specific site, and the uncertainties associated with assigning representative roughness values for some land cover categories that span a wide range of surface roughness characteristics, such as the "Commercial/Industrial/ Transportation" category in 1992 NLCD that usually accounts for a significant fraction of the land cover at airport sites.

Given the challenges and potential uncertainties associated with determining appropriate surface roughness values for input to AERMET, we are inclined to assign considerable weight to consistency in the application of the AERSURFACE tool (or equivalent tools) at this stage in the implementation of the AERMOD modeling system. Therefore, we would require a compelling justification to support the use of a non-default radius for determining the effective surface roughness for input to AERMET, a requirement that has not been met in this case. These challenges also contribute to the position clearly stated in the *AERMOD Implementation Guide* that AERSURFACE is not currently considered to be part of the AERMOD regulatory modeling system, although the recommended methodology should still be followed unless an adequate justification can be provided to support an alternative method.

Recognizing the importance of this issue to the implementation of AERMOD, we are continuing to assess the recommended methodology to ensure that it represents the best possible approach given the tools and data currently available. A recent aspect of this ongoing assessment has involved comparisons of AERSURFACE roughness estimates to values derived independently from observed wind data using a "gust factor method" (GFM) (Wieringa, 1980; Wieringa, 1993; Verkaik and Holtslag, 2007) with 1-minute ASOS wind data. The GFM is based on the concept that the gustiness of the horizontal wind is a measure of the level of turbulence within the boundary layer flow and can be correlated with the effective surface roughness length. The GFM is comparable to the recommended methodology for estimating the surface roughness length described in Section 6.6.3 of the EPA's *Meteorological Monitoring Guidance for Regulatory Modeling Applications* (EPA, 2000) based on the turbulence intensity, i.e., the ratio of σ_u, the standard deviation of the horizontal wind speed fluctuations, and $\overline{u}$, the mean wind speed. Wieringa (1993) refers to the GFM as "a poor-man's version" of the turbulence intensity method.

Preliminary results from comparisons of AERSURFACE roughness estimates with the GFM provide some objective support for the appropriateness of the current recommended default radius of 1 kilometer for determining surface roughness. Results from applying the GFM to winds measured at RDU airport in Raleigh-Durham, NC, were presented at the 2009 EPA Regional, State, Local Modelers Workshop[1]. The AERSURFACE and GFM results for RDU both show a significant increase in roughness for the NW sectors compared to other sectors, associated with a forest canopy within about 200-300 meters of the meteorological tower (shown in slide 9). In contrast, as shown on slide 10, "a significant discontinuity in land cover just

[1] http://www.cleanairinfo.com/regionalstatelocalmodelingworkshop/archive/2009/presentations/01%20Monday%20PM/Brode_RSL2009_AERSURFACE_Update.pdf

beyond 1 kilometer" from the meteorological tower exists for the SE sectors, with a tree canopy just beyond 1 kilometer and mostly open grasses and runways within 1 kilometer. However, neither AERSURFACE nor the GFM roughness estimates show any evidence of a significant influence from the trees for the SE sectors. For comparison, slide 11 shows AERSURFACE roughness estimates based on a radius of 3 kilometers that was recommended prior to the release of AERSUFACE and based on the original recommendation of using a simple area-weighted arithmetic average rather than the inverse-distance weighted geometric mean of surface characteristics. Results based on the original recommended methodology drastically overestimate the surface roughness in comparison to the GFM and the current methodology. These and other comparisons based on the GFM appear to lend support for the current recommendations implemented in AERSURFACE. We intend to update the *AERMOD Implementation Guide* as appropriate based on knowledge gained from these assessments, and are inclined to deemphasize or remove the reference to situations where a non-default radius may be considered on a case-by-case basis.

As part of our review of the Region 4 request, we have also applied the GFM to estimate surface roughness for the BWG site, using available 1-minute ASOS wind data for 2006 through 2008. The results of this test, presented in Figure 1, show generally good agreement between AERSURFACE estimates using the default 1 kilometer radius and GFM estimates across most sectors. The AERSURFACE roughness estimates are slightly higher than the GFM estimates for the 240°-270° sector highlighted in the Region 4 memorandum as showing a significant increase in roughness with increasing radius. However, significant differences between the AERSURFACE and GFM estimates are found for the WNW through N sectors, with higher roughness estimates based on the GFM than AERSURFACE. These differences appear to be attributable to a significant change in land cover for those sectors for the 2006-2008 period used in the GFM compared to the 1992 NLCD used in AERSURFACE. A review of the aerial photo provided with the Region 4 request taken in March 1993 shows indications of a golf course under construction in very close proximity to the meteorological tower (within about 50 meters). More recent aerial photos show the completed golf course surrounding a residential community and other commercial buildings. Figure 2 provides an aerial photo of the site from 2008. The proximity of this change in land cover to the meteorological tower contributes to the significantly higher roughness values for those sectors based on the GFM than estimated by AERSURFACE based on 1992 NLCD, which depicts the area as "Urban/Recreational Grasses".

These comparisons of roughness estimates for BWG based on AERSURFACE and the GFM provide some objective support for the Model Clearinghouse response to the Region 4 request regarding use of a non-default radius for estimating surface roughness values for use in processing the BWG meteorological data. They also illustrate the importance of assessing the temporal representativeness of the land cover data for the meteorological data period being processed. In this case, use of AERSURFACE roughness estimates with recent meteorological data for BWG (later than about 2000) could significantly underestimate the surface roughness for the WNW through N sectors. We would recommend adjusting the surface roughness values estimated by AERSURFACE based on these GFM results for upwind sectors between about 270° and 30° when processing BWG data for recent years, while using AERSURFACE estimates based on the default 1 kilometer radius for other sectors.

REFERENCES

EPA, 2000. Meteorological Monitoring Guidance for Regulatory Modeling Applications. EPA-454/R-99-005. U.S. Environmental Protection Agency, Research Triangle Park, NC (Available @ www.epa.gov/scram001/).

EPA, 2004. User's Guide for the AERMOD Meteorological Preprocessor (AERMET). EPA-454/B-03-002. U.S. Environmental Protection Agency, Research Triangle Park, NC (Available @ www.epa.gov/scram001/).

EPA, 2008. AERSURFACE User's Guide. EPA-454/B-08-001. U.S. Environmental Protection Agency, Research Triangle Park, NC (Available @ www.epa.gov/scram001/).

EPA, 2009. AERMOD Implementation Guide. U.S. Environmental Protection Agency, Research Triangle Park, NC (Available @ www.epa.gov/scram001/)

Verkaik, J.W. and A.A.M. Holtslag, 2007. Wind profiles, momentum fluxes and roughness lengths at Cabauw revisited. *Boundary-Layer Meteor.*, **122**, 701-719.

Wieringa, J., 1980. Representativeness of wind observations at airports. *Bull. Amer. Meteor. Soc.*, **61**, 962-971.

Wieringa, J., 1993. Representative roughness parameters for homogeneous terrain. *Boundary-Layer Meteor.*, **63**, 323-363.

cc: Richard Wayland, C304-02
Bill Harnett, C504-01
Raj Rao, C504-01
Roger Brode, C439-01
EPA Regional Modeling Contacts

Figure 1. Surface Roughness Estimates by Sector for BWG Airport - AERSURFACE vs. GFM

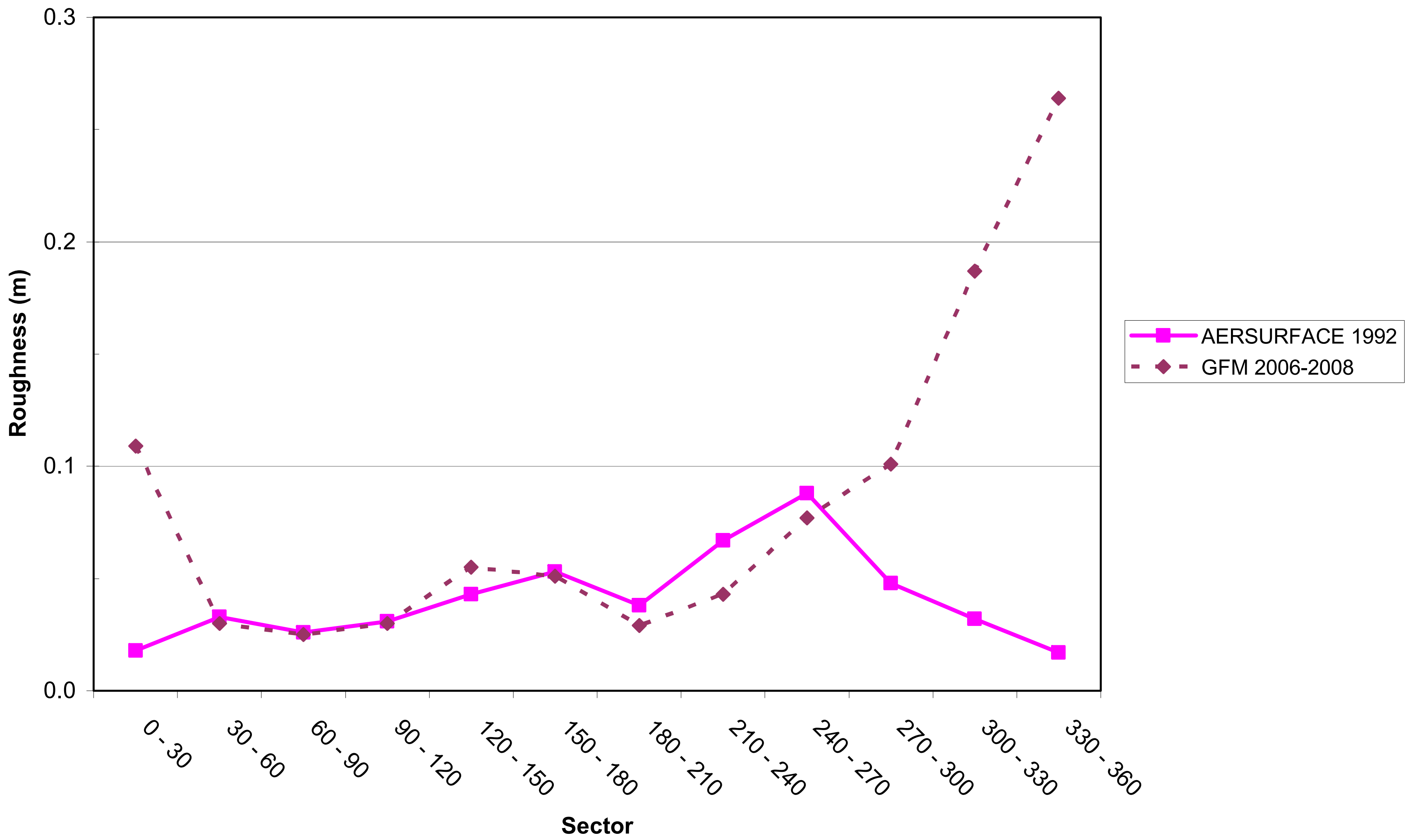


Figure 2. Aerial Photo of BWG Site from 2008 Showing Tower Location and 1 Kilometer Radius

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 4
ATLANTA FEDERAL CENTER
61 FORSYTH STREET
ATLANTA, GEORGIA 30303-8960

June 25, 2009

MEMORANDUM

SUBJECT: Kentucky NewGas Project – Site-Specific, Non-Default Radius for Roughness Determination

FROM: Stanley Krivo, Regional Meteorologist
Air Quality Modeling & Transportation Section

THRU: R. Scott Davis, Chief
Air Quality Modeling & Transportation Section

TO: Tyler Fox, Model Clearinghouse Coordinator
OAQPS, Air Quality Modeling Group

This memorandum requests Model Clearinghouse opinion on the use of non-recommended, project-specific radius in the determination of surface roughness parameters to be used in the processing of meteorological data in AERMET.

Issue Explanation

The AERMOD Implementation Guide (Dated March 19, 2009) recommends the use of a 1 kilometer (km) radius about the location of interest to process the land cover data to determine the effective surface roughness for input to AERMET. This guide provides for exceptions to the recommended 1 km default distance that may be considered on a case-by-case basis for applications involving:

1) Site-specific wind speed measurements taken at heights well above 10 meters;
2) Situations with significant discontinuities in land cover just beyond the recommended 1 km upwind distance, or;
3) Sites with significant terrain discontinuities (e.g. the top of a mesa or narrow, steep valley).

Kentucky NewGas (KYNG) believes that both the meteorological observation site and the project application site meet the second exception – significant discontinuities just beyond 1 km. Their analyses resulted in radii of 2.4 km for the Bowling Green National Weather Service (NWS) site and 1.8 km for the KYNG application site. Our assessment of the provided analyses and the exception terms resulted in a site-specific radius of 1.6 km for both of these sites. We request Model Clearinghouse review of the analyses and the recommended radii for the roughness determination. We also request the Model Clearinghouse provide any recommended additional analyses and/or information that should be considered in this assessment.

KY NewGas Analyses and Position

In a Prevention of Significant Deterioration (PSD) application for the proposed KYNG facility, they state that the land cover figures (Attachment 1 - Figure D-5, and Attachment 2 – Figure D-6) show significant discontinuities in the land use surrounding the Bowling Green NWS (BWG) site, the source of the meteorological measurements used in the air quality impact modeling, and the project location just beyond the 1 km recommended radius justifying the use of larger site-specific radii for these locations.

The applicant also performed iterative AERSURFACE runs for the BWG and KYNG locations for a range of radius values. The raw AERSURFACE surface outputs and plots of the resultant surface roughness values for the various radii are provided in the attached spreadsheets. The applicant believes these plots demonstrate significant land cover discontinuities beyond the default 1 km radius for both the BWG and KYNG sites. The applicant used the sectors clearly showing discontinuities to establish site-specific radius for each site. They determined that a radius of 2.4 km is required at the BWG site to include the sharp land use discontinuity occurring just beyond 1 km to the west and northwest. They determined that a radius of 1.8 km is required to include the influence of the sharp land cover discontinuity occurring just beyond 1 km to the southwest, west, and northwest from the KYNG site.

The following AERSURFACE analyses and land use/land cover (LULC) plots have been provided, in electronic format, to support their radius selections.

Attachment 1 - KY NewGas Modeling Report Figure D-5
Figures of land use and land cover about the proposed project location.
Attachment 2 - KY NewGas Modeling Report Figure D-6
Figures of land use and land cover about the Bowling Green Airport
Attachment 3 - BWG LULC Discontinuity Test v1.5
EXCEL spreadsheet with the Bowling Green sector by sector raw measurements and analyses
Attachment 4 - KYNG LULC Discontinuity Test v1.1
EXCEL spreadsheet with the KY NewGas sector by sector raw measurements and analyses
Attachment 5 - TrinityAnalysesExpln051309
Trinity Consultant's explanation of the analyses performed and resultant selected radius for BWG and KYNG

Region 4 Analyses and Recommendation

Review of the land cover for KYNG site in Figure D-5 reveals land cover changes just beyond 1 km (i.e., between 1.0 and 1.5 km). The changes occur in the northeast, southeast, southwest, and northwest directions from the proposed project location. The BWG site in Figure D-6 also reveals land cover changes just beyond the 1 km radius (i.e., between 1.0 and 1.5 km) to the west, northwest, and north of the tower. The expected magnitude of the roughness changes associated with these land cover changes cannot easily be determined from these figures. The magnitudes of the change in roughness are implicitly included in the results of the iterative radius AERSURFACE runs.

The changes in surface roughness with increased radius are provided in the EXCEL spreadsheet analyses. The sector dependent plots of the AERSURFACE developed roughness values for the various radii show, for most sectors, small non-significant changes as the radius is increased beyond the 1 km recommended values. The plots for a few sectors show steep slopes or large changes in roughness between 1.0 km to about 1.6 km (e.g., Sector 9 for BWG and Sectors 1, 7, 8, and 9 for KYNG). Based on the provided analyses it is Region 4's recommendation that a site specific BWG radius of 1.6 km and a site-specific KYNG radius of 1.6 km be used in the AERSURFACE roughness determination.

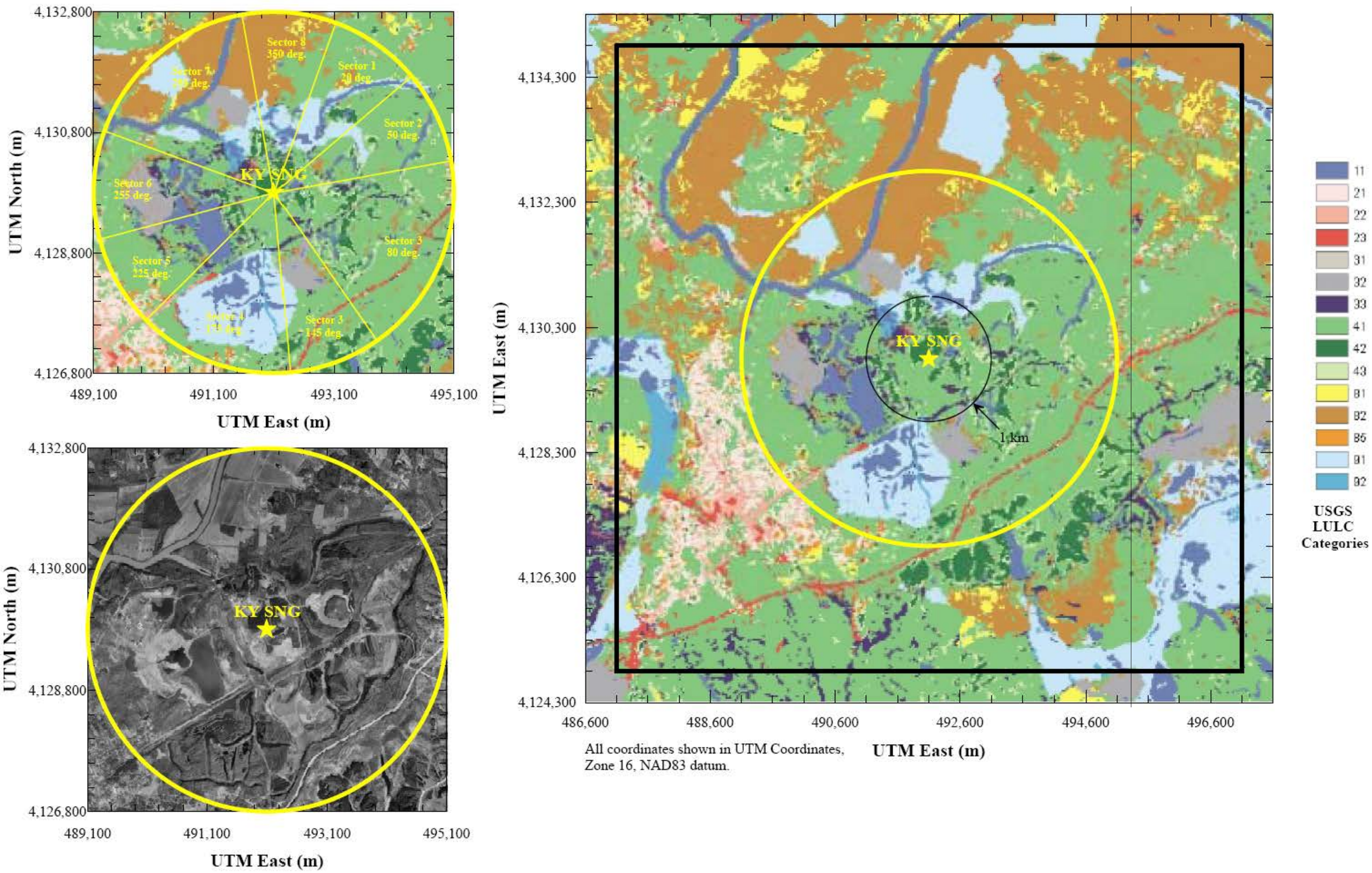
We believe these distances are within the range that would be considered "just beyond the recommended 1 km" and have changes in roughness that are large enough to be considered significant.

Please contact Stanley Krivo of the EPA Region 4 staff at (404) 562-9123 if you have any questions or need further information.

Attachment

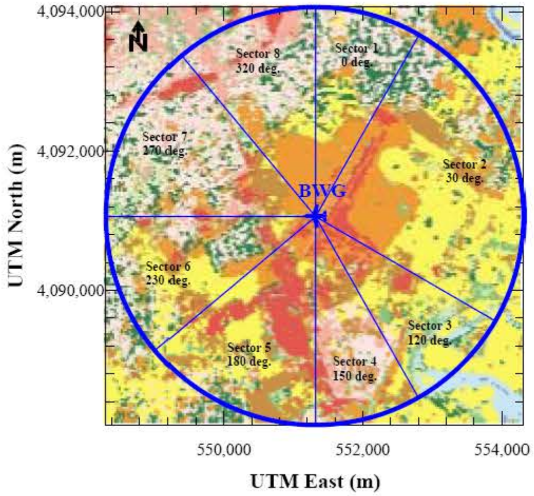
1. CD containing electronic copies of Attachments 1-5

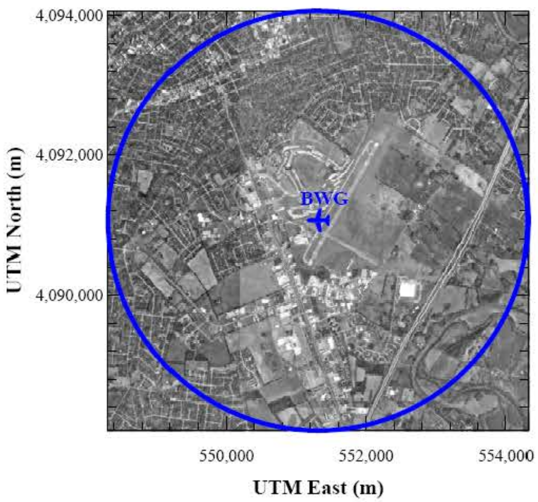
FIGURE D-5. LANDUSE AND LAND COVER SURROUNDING THE PROPOSED KENTUCKY NEWGAS FACILITY



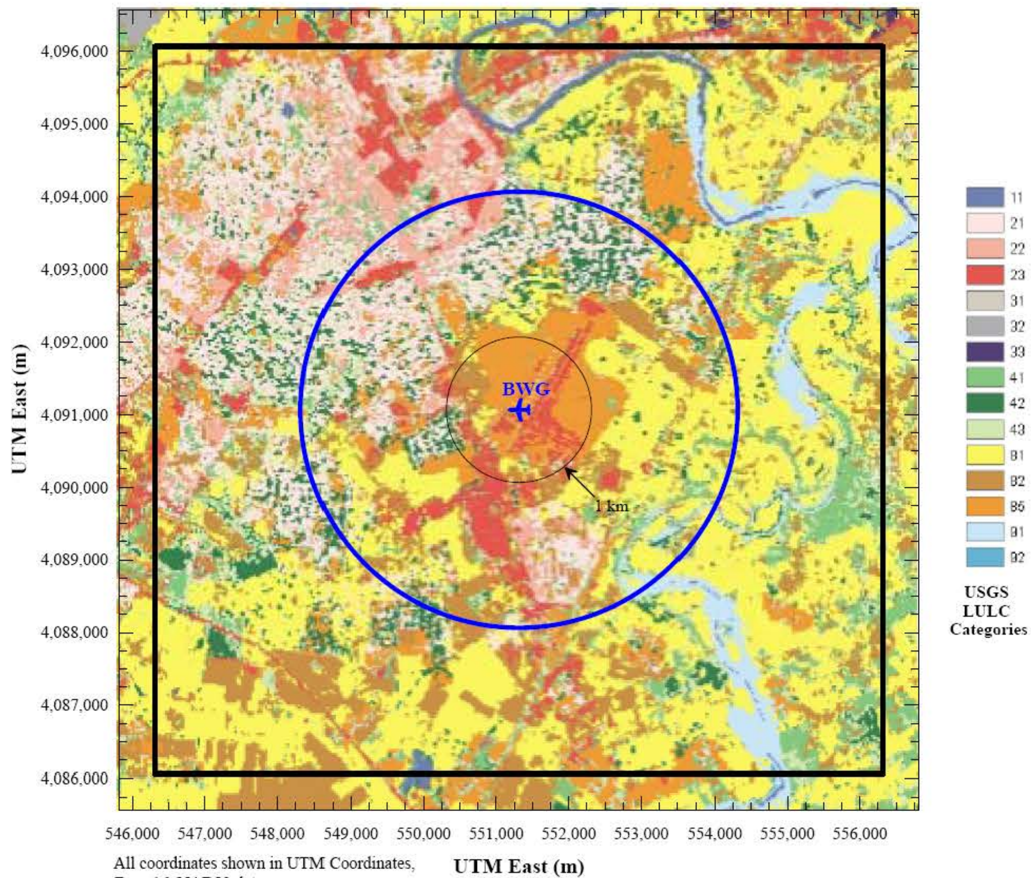
Note: Aerial image downloaded from Microsoft Terraserver and is dated 2/28/97. Visual inspection of the site currently

FIGURE D-6. LANDUSE AND LAND COVER SURROUNDING THE BWG AIRPORT

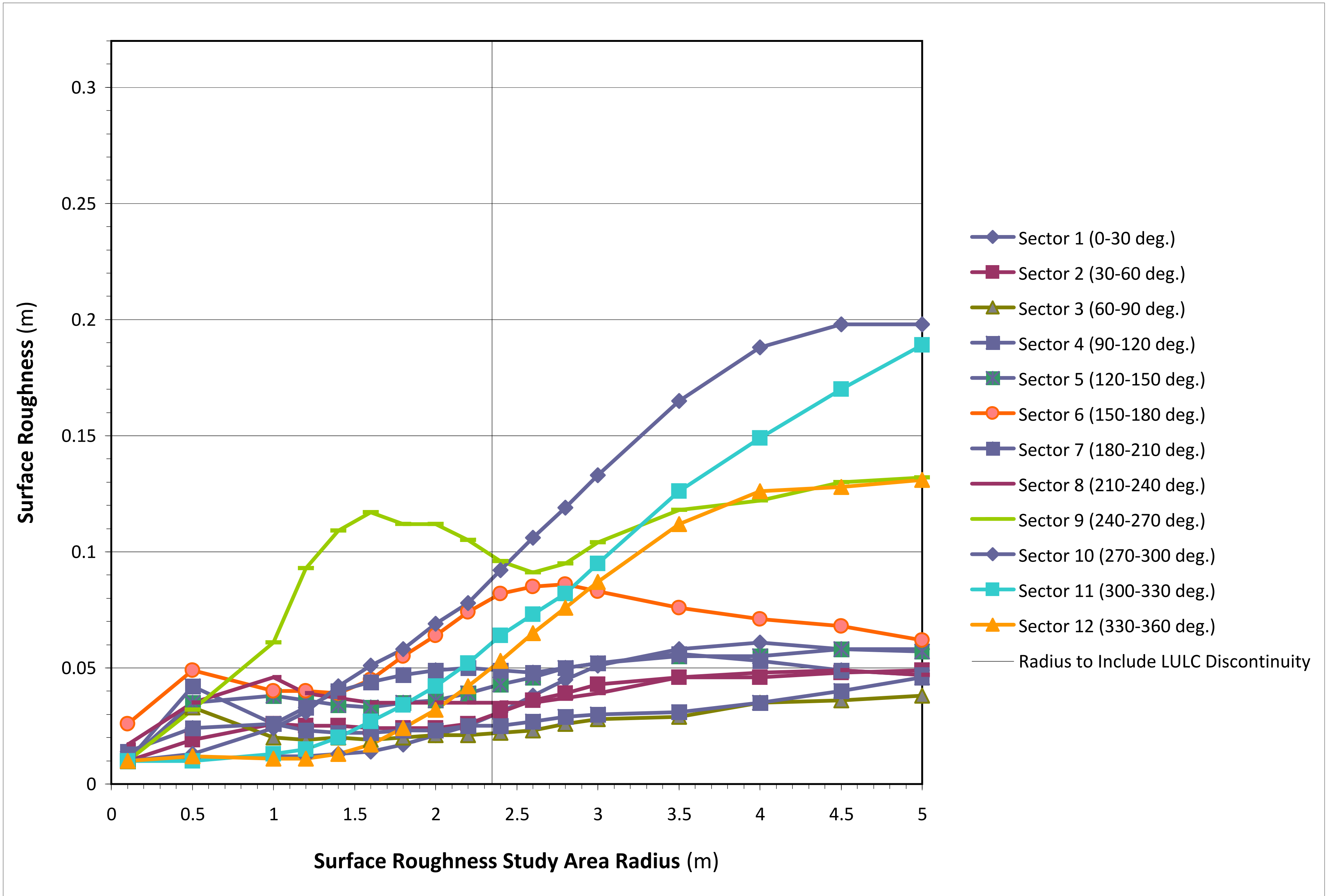




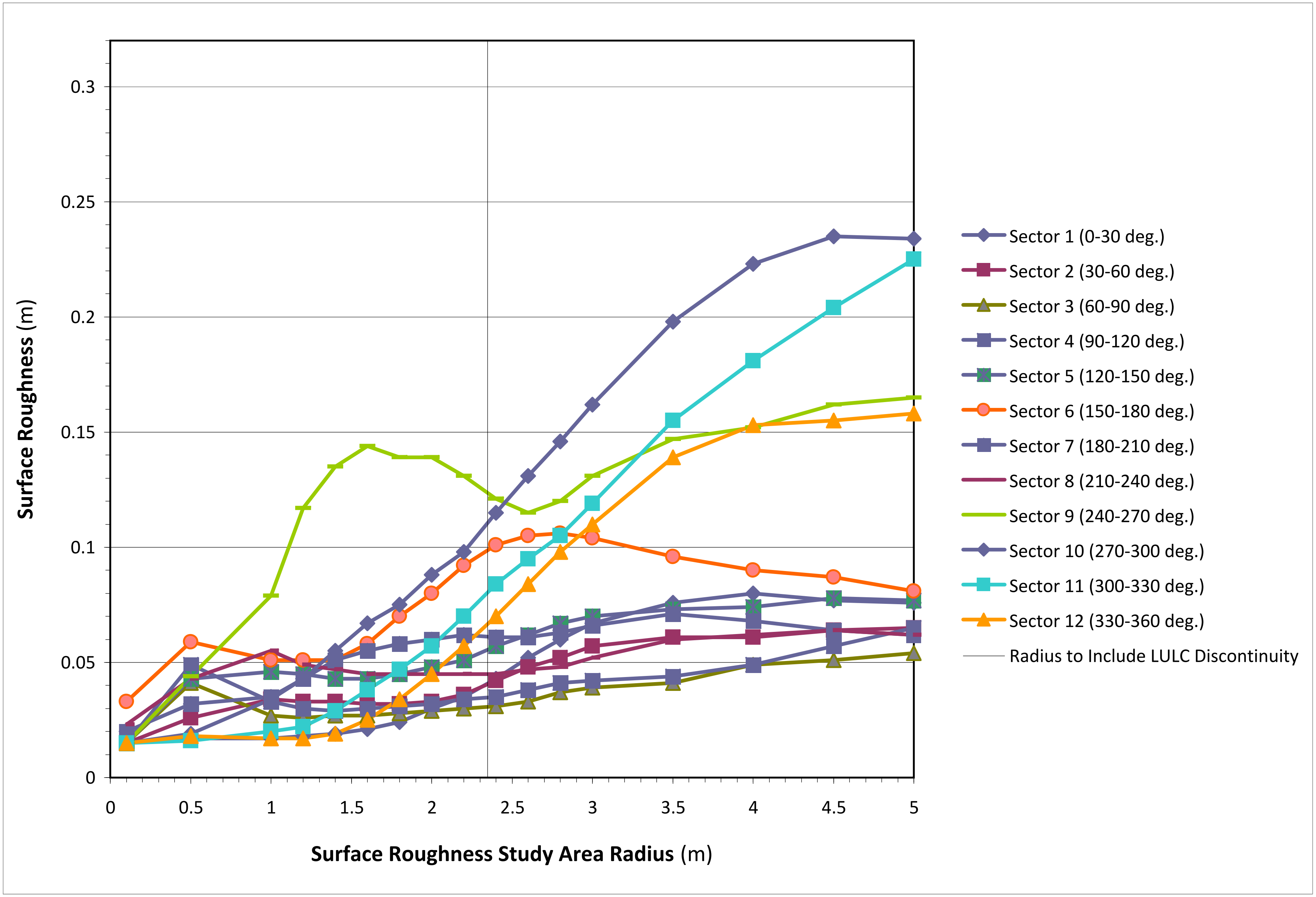
Note: Aerial image downloaded from Microsoft Terraserver and is dated 3/29/93. Visual inspection of the NLCD 2001 data for BWG shows the image is representative.



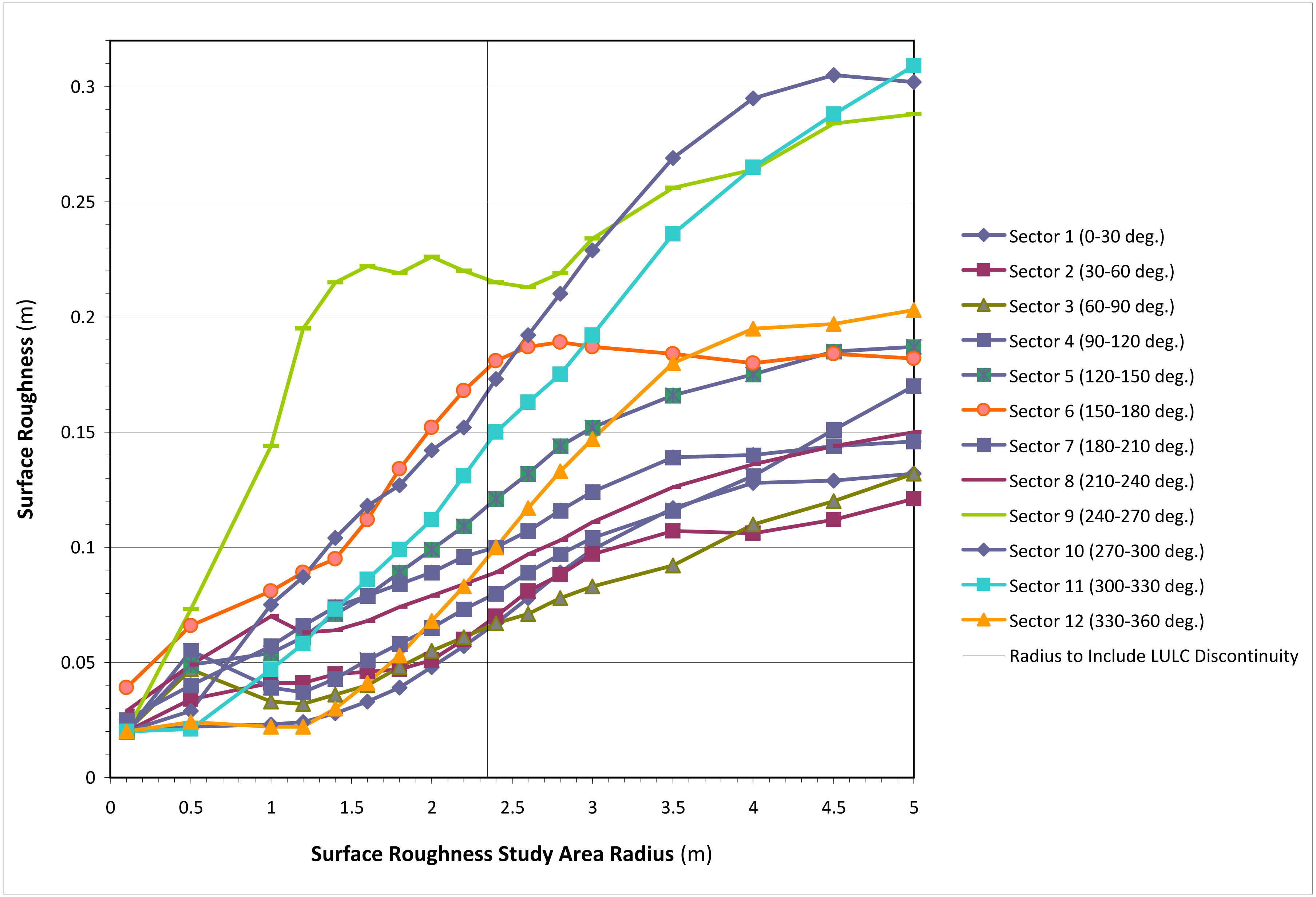
All coordinates shown in UTM Coordinates, Zone 16, NAD83 datum.



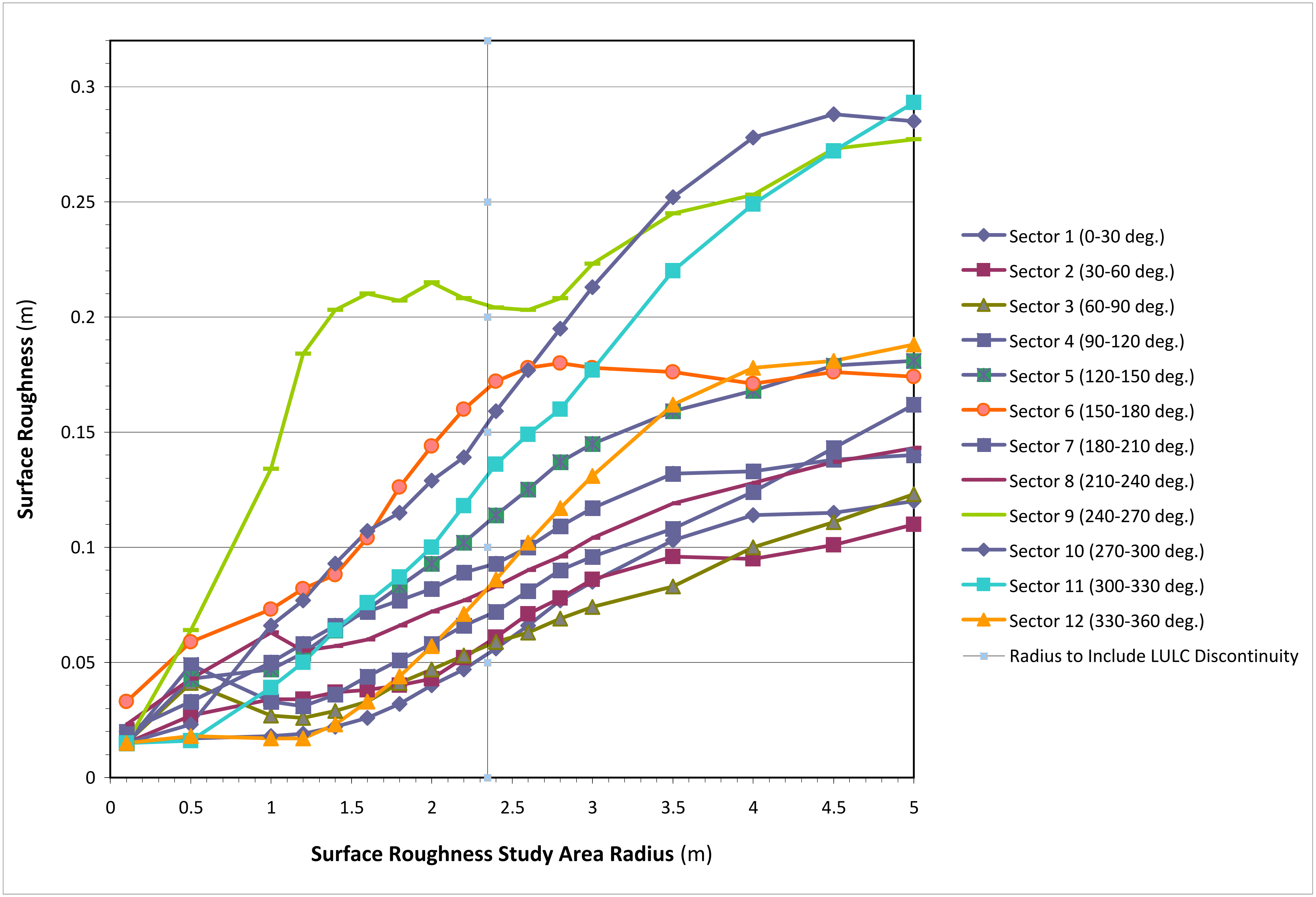
Season 1-Winter

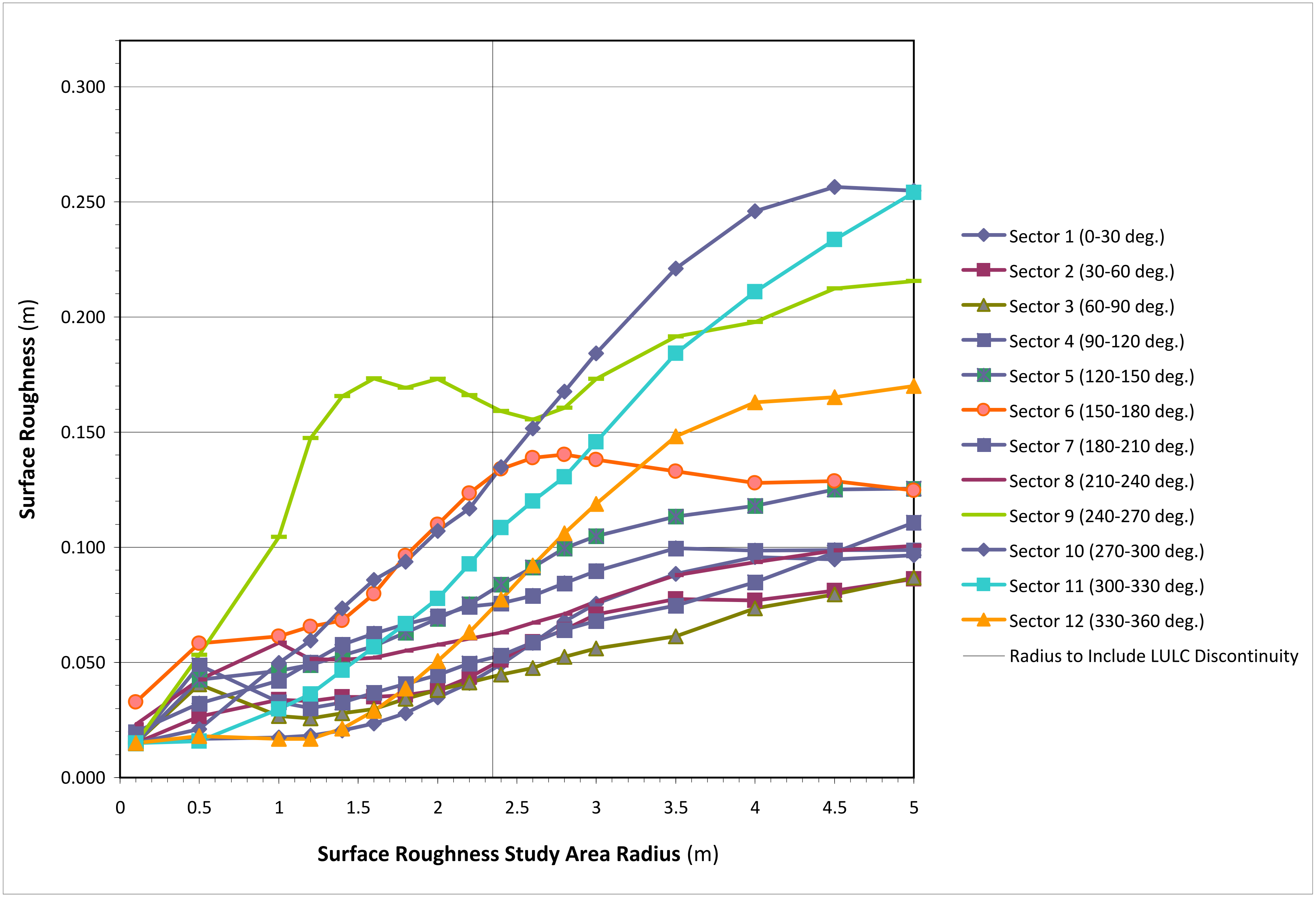


Surface Roughness (m)
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Surface Roughness Study Area Radius (m)
Sector 1 (0-30 deg.)
Sector 2 (30-60 deg.)
Sector 3 (60-90 deg.)
Sector 4 (90-120 deg.)
Sector 5 (120-150 deg.)
Sector 6 (150-180 deg.)
Sector 7 (180-210 deg.)
Sector 8 (210-240 deg.)
Sector 9 (240-270 deg.)
Sector 10 (270-300 deg.)
Sector 11 (300-330 deg.)
Sector 12 (330-360 deg.)
Radius to Include LULC Discontinuity

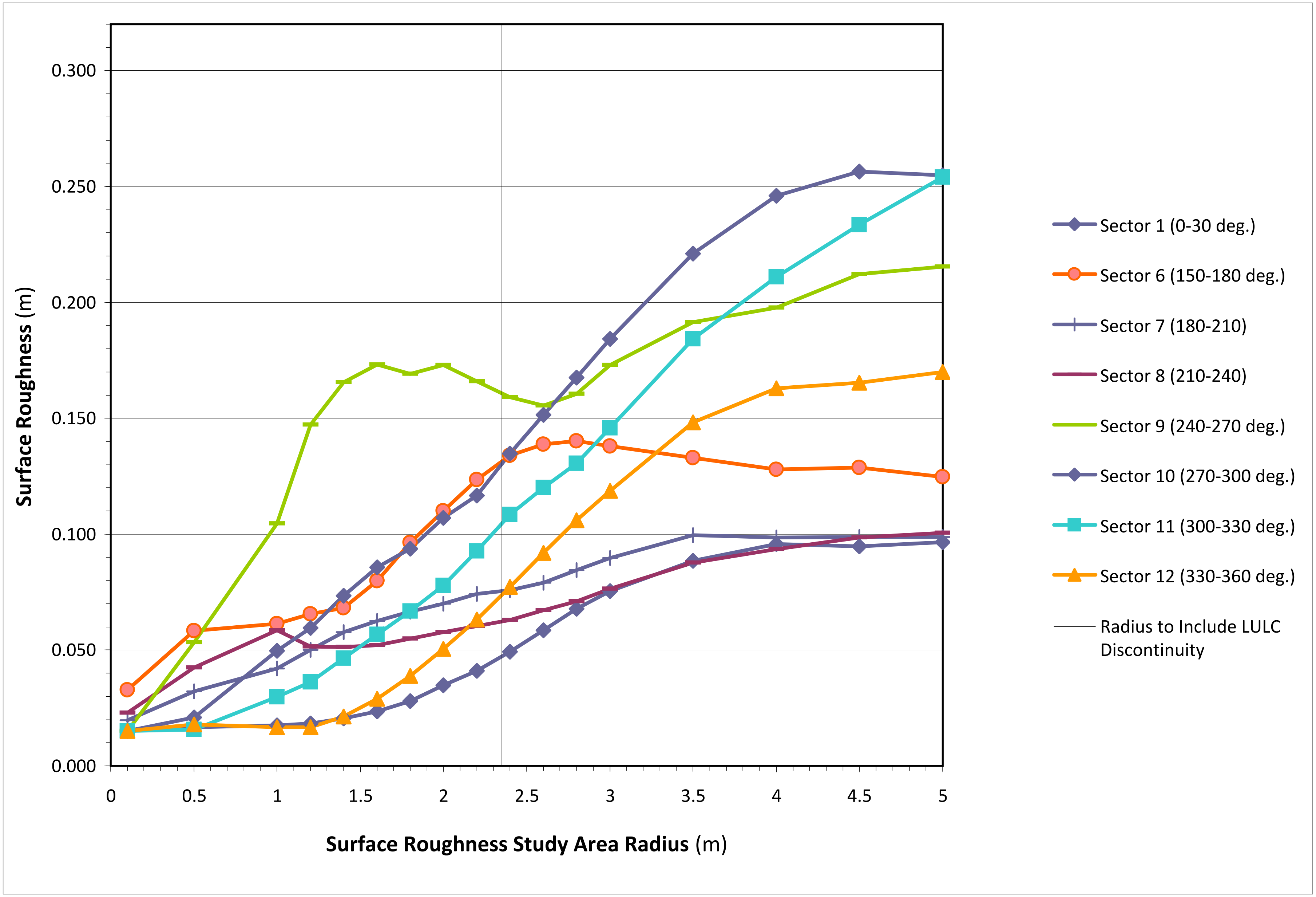


Season 3-Summer

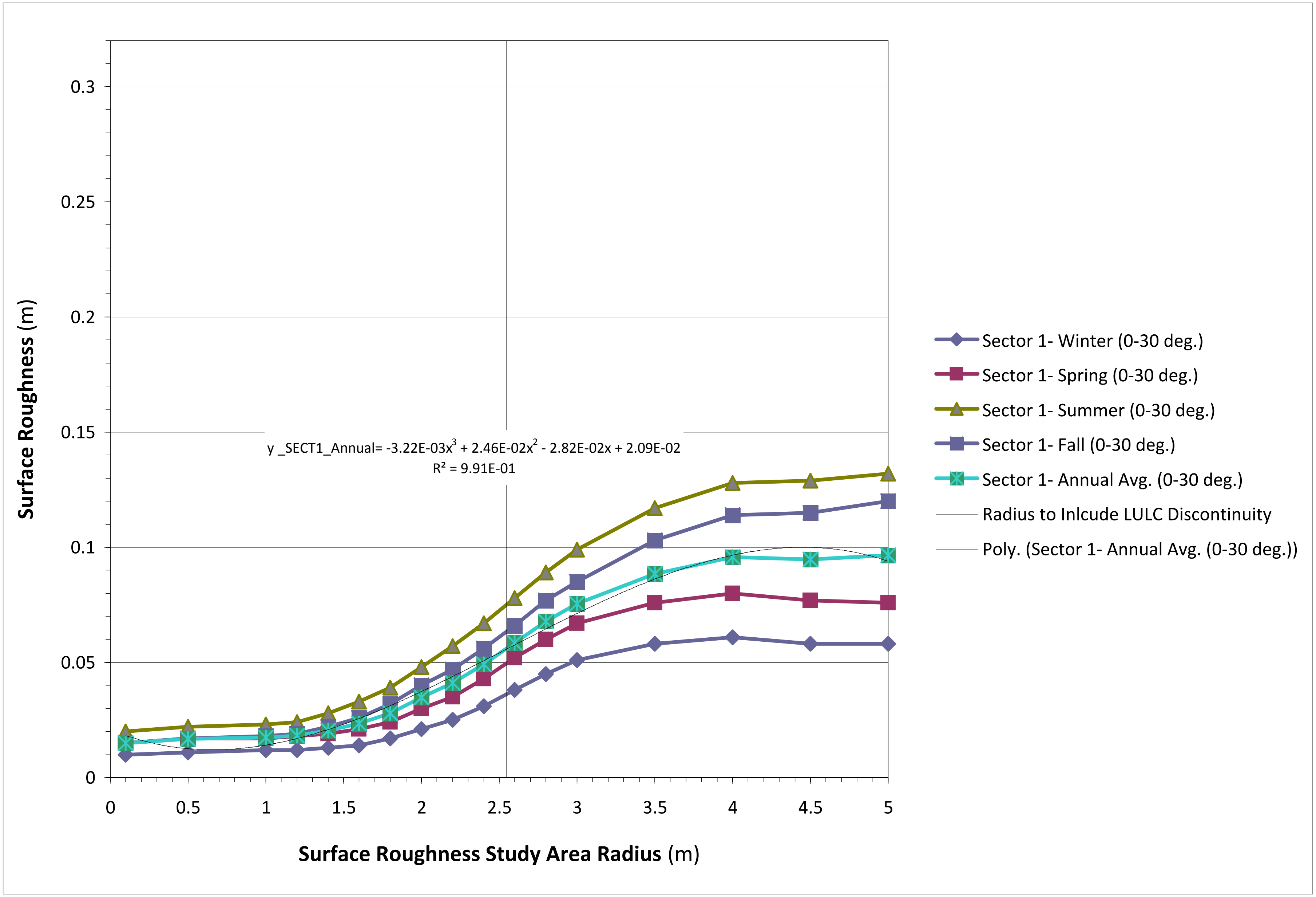

Surface Roughness (m)
0
0.05
0.1
0.15
0.2
0.25
0.3
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Surface Roughness Study Area Radius (m)
Sector 1 (0-30 deg.)
Sector 2 (30-60 deg.)
Sector 3 (60-90 deg.)
Sector 4 (90-120 deg.)
Sector 5 (120-150 deg.)
Sector 6 (150-180 deg.)
Sector 7 (180-210 deg.)
Sector 8 (210-240 deg.)
Sector 9 (240-270 deg.)
Sector 10 (270-300 deg.)
Sector 11 (300-330 deg.)
Sector 12 (330-360 deg.)
Radius to Include LULC Discontinuity

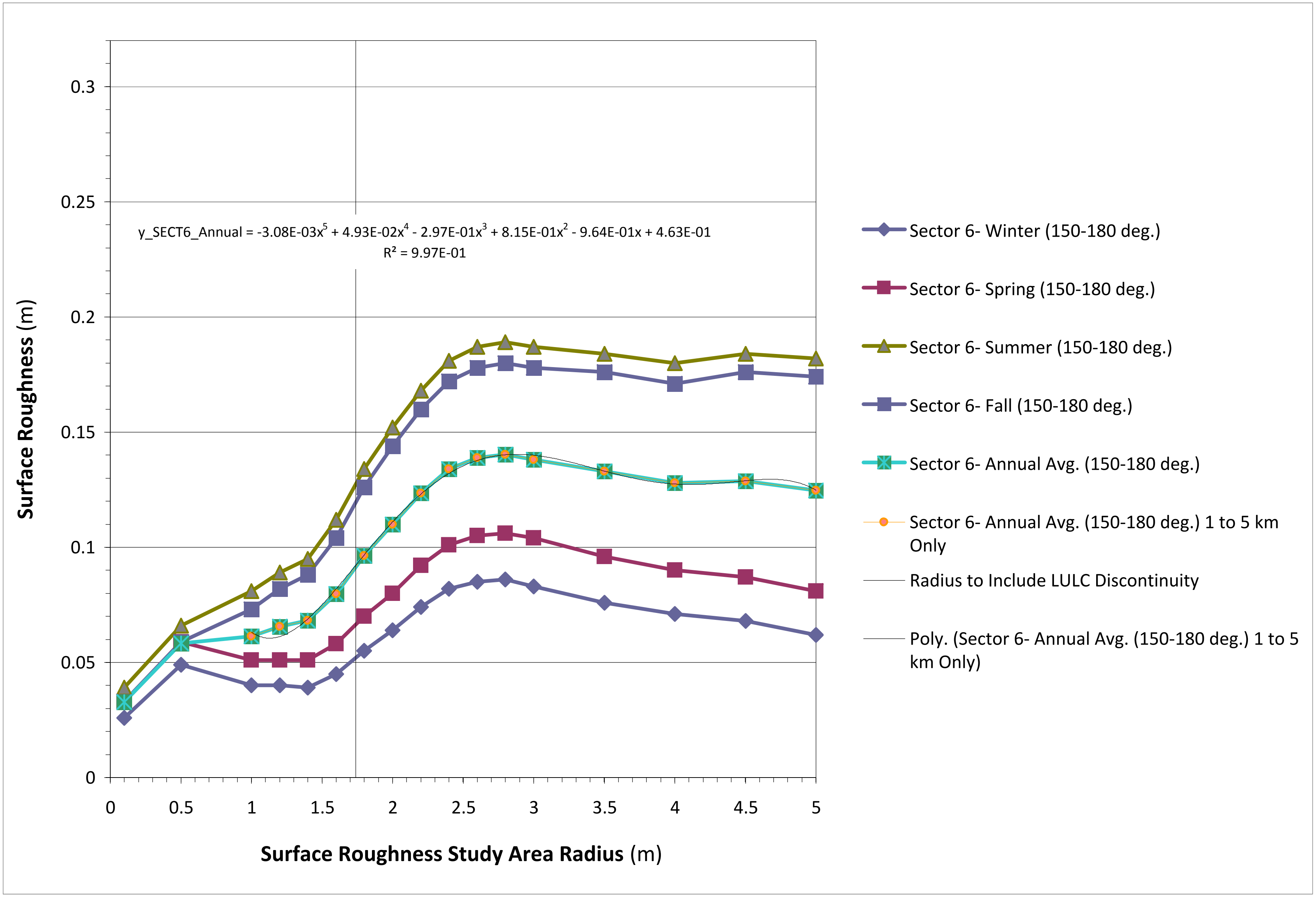

Surface Roughness (m)
0.300
0.250
0.200
0.150
0.100
0.050
0.000
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Surface Roughness Study Area Radius (m)
Sector 1 (0-30 deg.)
Sector 2 (30-60 deg.)
Sector 3 (60-90 deg.)
Sector 4 (90-120 deg.)
Sector 5 (120-150 deg.)
Sector 6 (150-180 deg.)
Sector 7 (180-210 deg.)
Sector 8 (210-240 deg.)
Sector 9 (240-270 deg.)
Sector 10 (270-300 deg.)
Sector 11 (300-330 deg.)
Sector 12 (330-360 deg.)
Radius to Include LULC Discontinuity

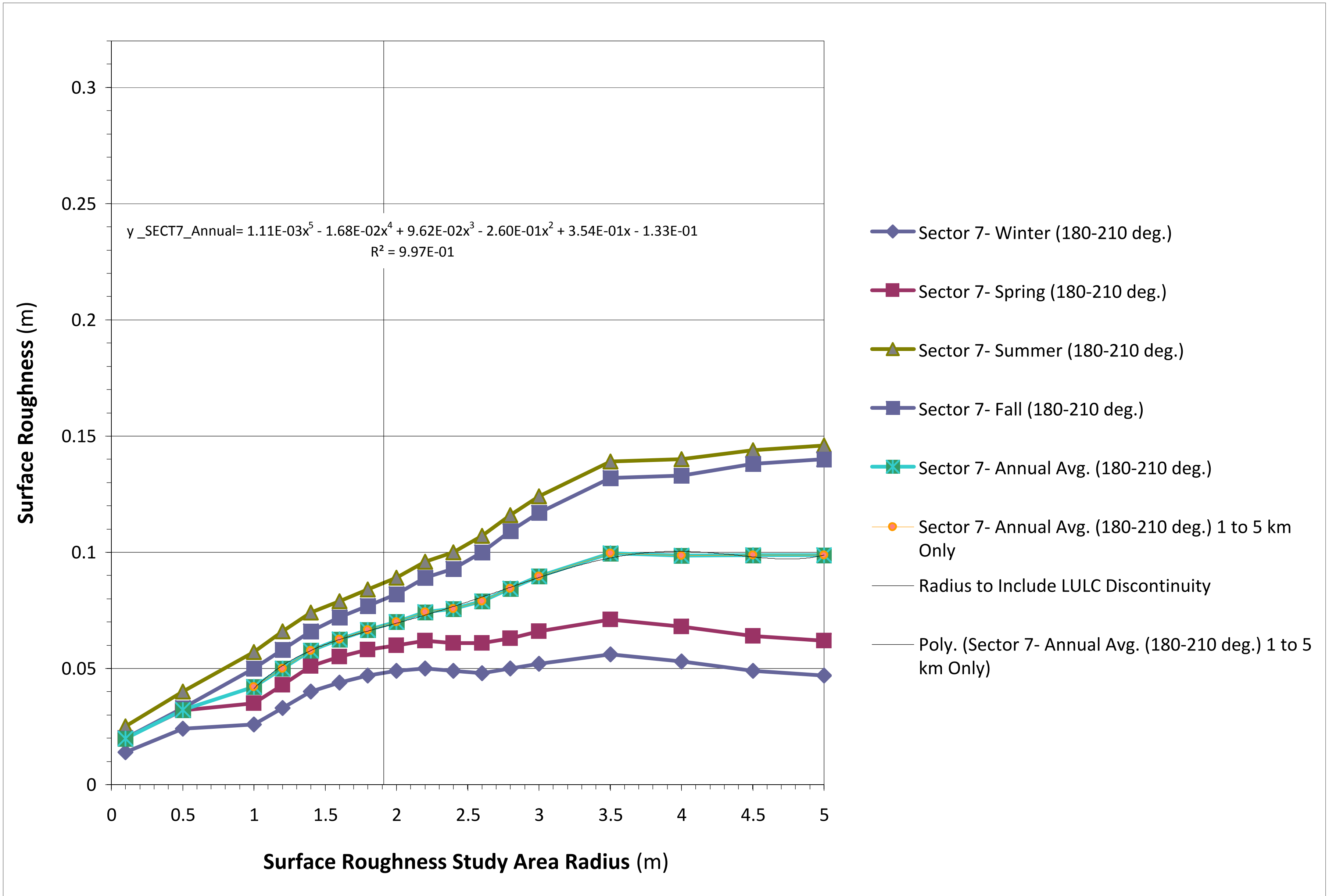
Annual



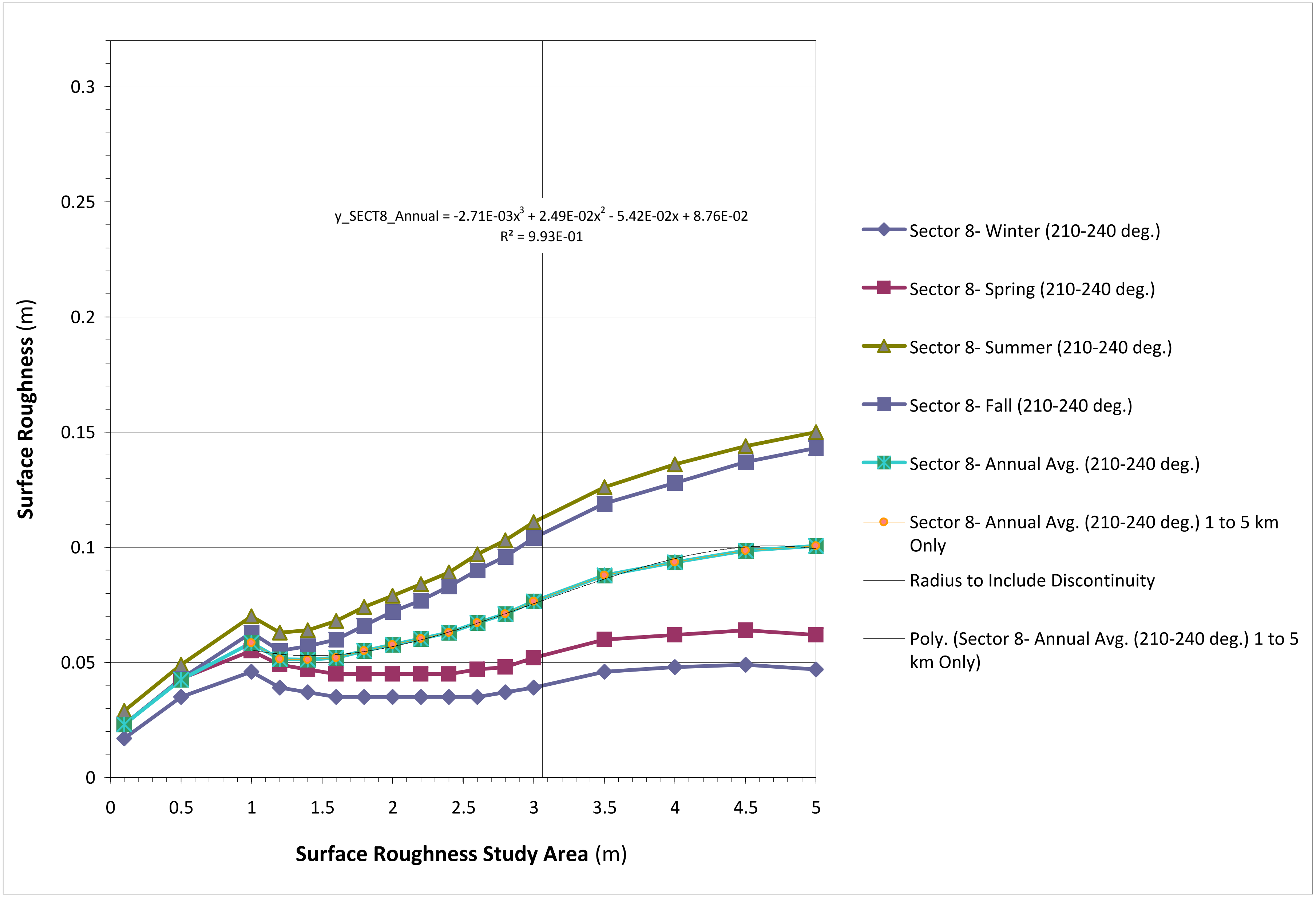
0.300
0.250
0.200
0.150
0.100
0.050
0.000
Surface Roughness (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Surface Roughness Study Area Radius (m)
Sector 1 (0-30 deg.)
Sector 6 (150-180 deg.)
Sector 7 (180-210)
Sector 8 (210-240)
Sector 9 (240-270 deg.)
Sector 10 (270-300 deg.)
Sector 11 (300-330 deg.)
Sector 12 (330-360 deg.)
Radius to Include LULC Discontinuity

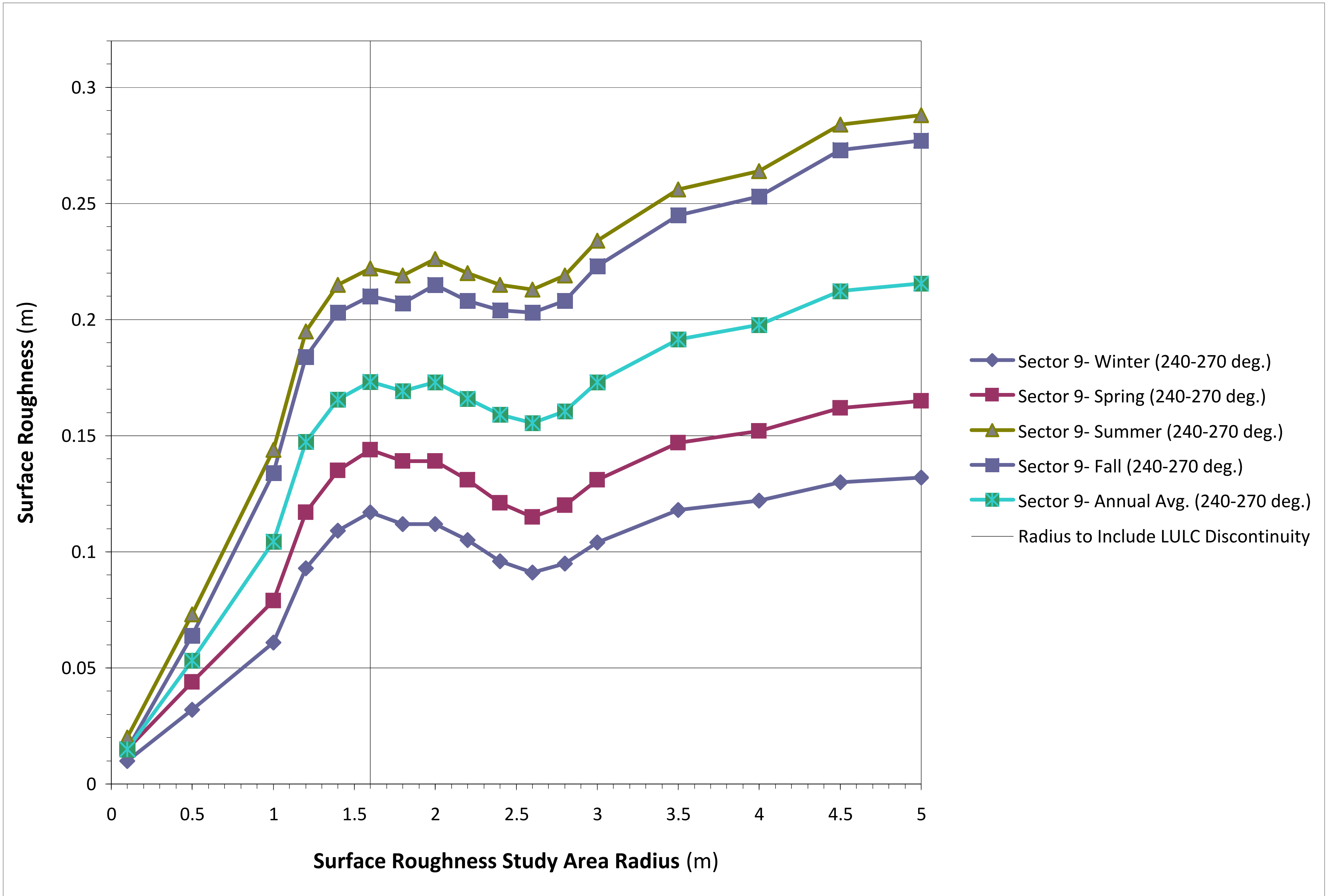

Surface Roughness (m)
0.3
0.25
0.2
0.15
0.1
0.05
0
y _SECT1_Annual= -3.22E-03x^3 + 2.46E-02x^2 - 2.82E-02x + 2.09E-02
R² = 9.91E-01
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Surface Roughness Study Area Radius (m)
Sector 1- Winter (0-30 deg.)
Sector 1- Spring (0-30 deg.)
Sector 1- Summer (0-30 deg.)
Sector 1- Fall (0-30 deg.)
Sector 1- Annual Avg. (0-30 deg.)
Radius to Inlcude LULC Discontinuity
Poly. (Sector 1- Annual Avg. (0-30 deg.))

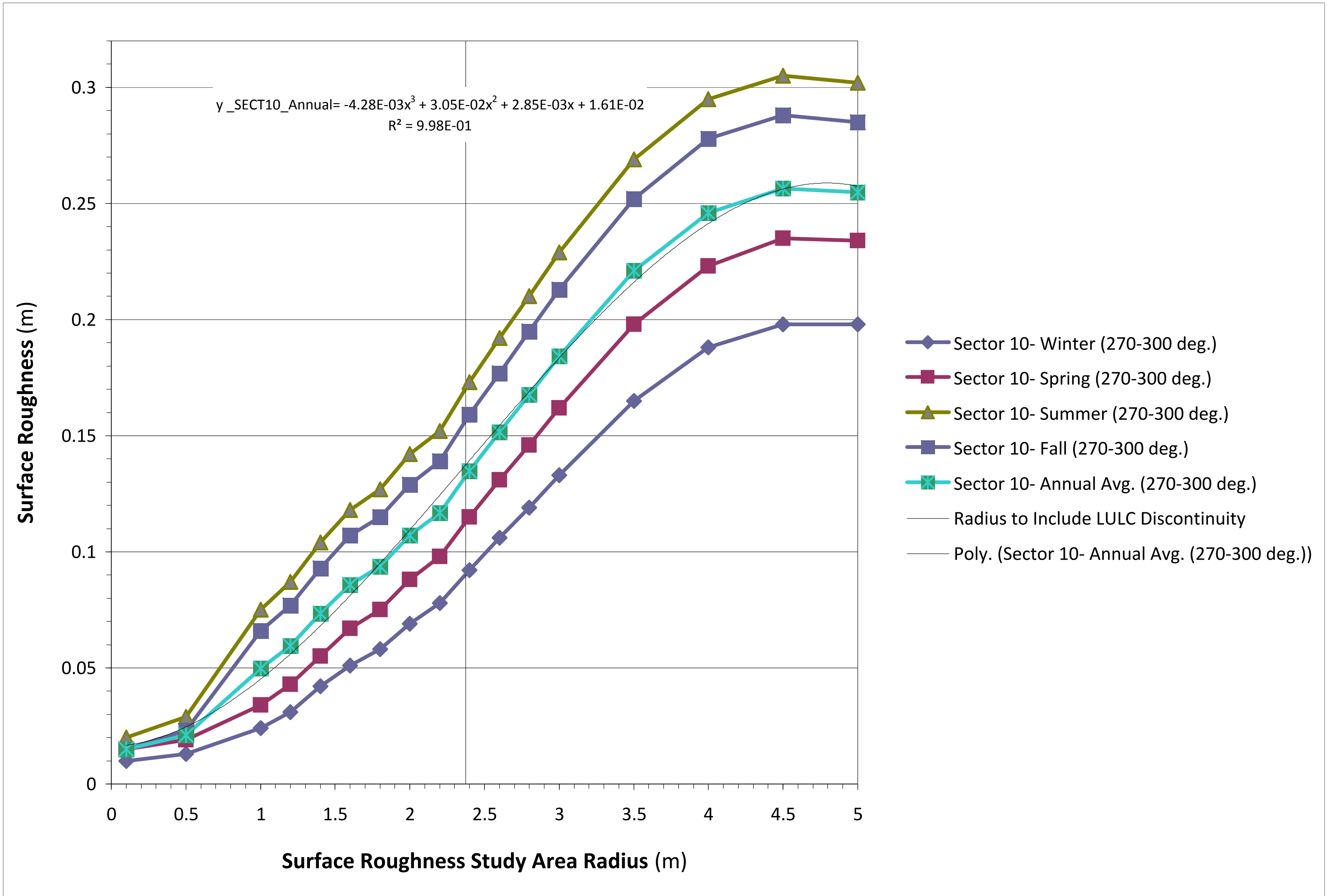

y_SECT6_Annual = -3.08E-03x^5 + 4.93E-02x^4 - 2.97E-01x^3 + 8.15E-01x^2 - 9.64E-01x + 4.63E-01
R² = 9.97E-01
Surface Roughness (m)
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Surface Roughness Study Area Radius (m)
Sector 6- Winter (150-180 deg.)
Sector 6- Spring (150-180 deg.)
Sector 6- Summer (150-180 deg.)
Sector 6- Fall (150-180 deg.)
Sector 6- Annual Avg. (150-180 deg.)
Sector 6- Annual Avg. (150-180 deg.) 1 to 5 km Only
Radius to Include LULC Discontinuity
Poly. (Sector 6- Annual Avg. (150-180 deg.) 1 to 5 km Only)



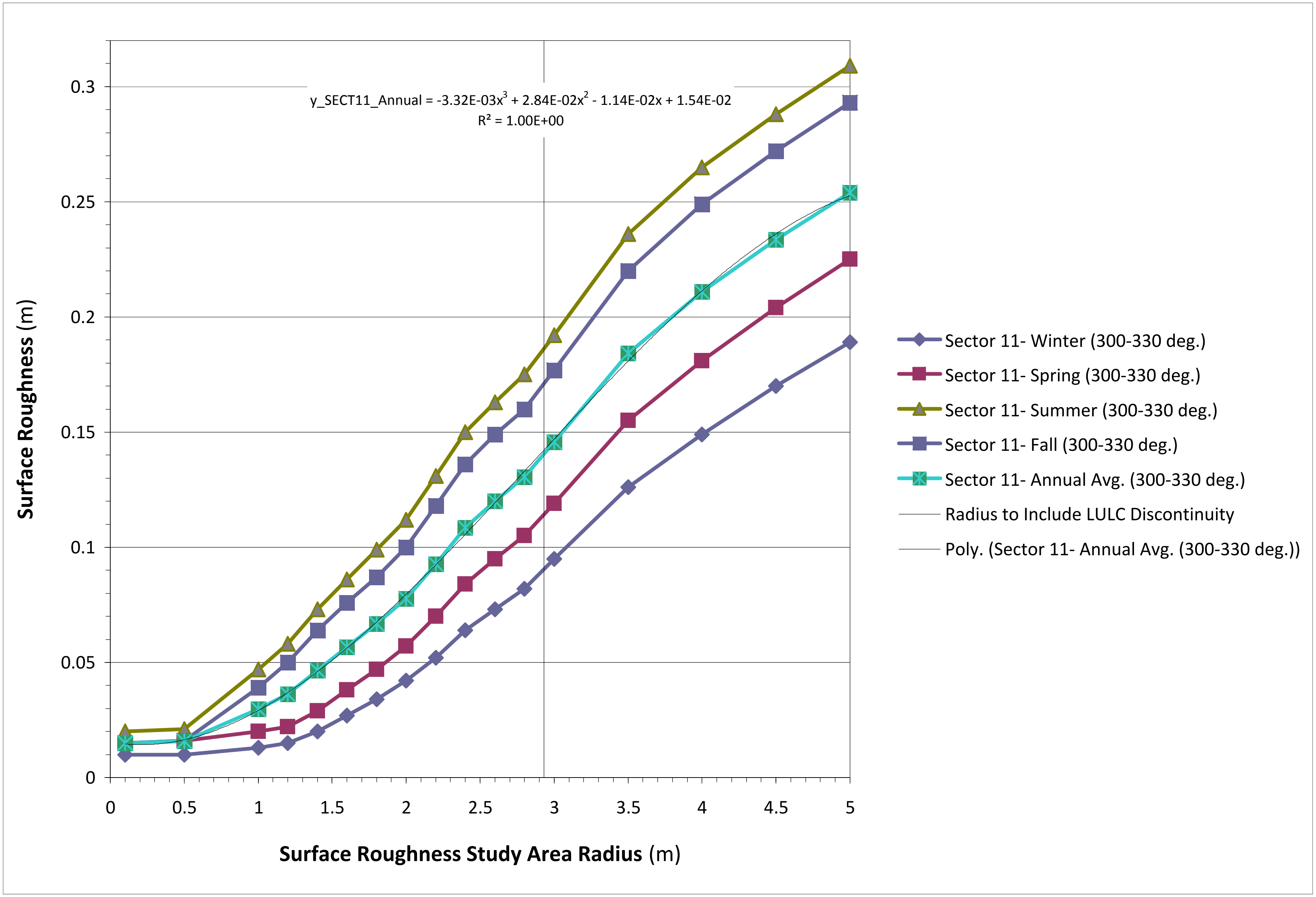
y _SECT7_Annual= 1.11E-03x5 - 1.68E-02x4 + 9.62E-02x3 - 2.60E-01x2 + 3.54E-01x - 1.33E-01
R² = 9.97E-01
Surface Roughness (m)
Surface Roughness Study Area Radius (m)
0
0.05
0.1
0.15
0.2
0.25
0.3
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Sector 7- Winter (180-210 deg.)
Sector 7- Spring (180-210 deg.)
Sector 7- Summer (180-210 deg.)
Sector 7- Fall (180-210 deg.)
Sector 7- Annual Avg. (180-210 deg.)
Sector 7- Annual Avg. (180-210 deg.) 1 to 5 km Only
Radius to Include LULC Discontinuity
Poly. (Sector 7- Annual Avg. (180-210 deg.) 1 to 5 km Only)

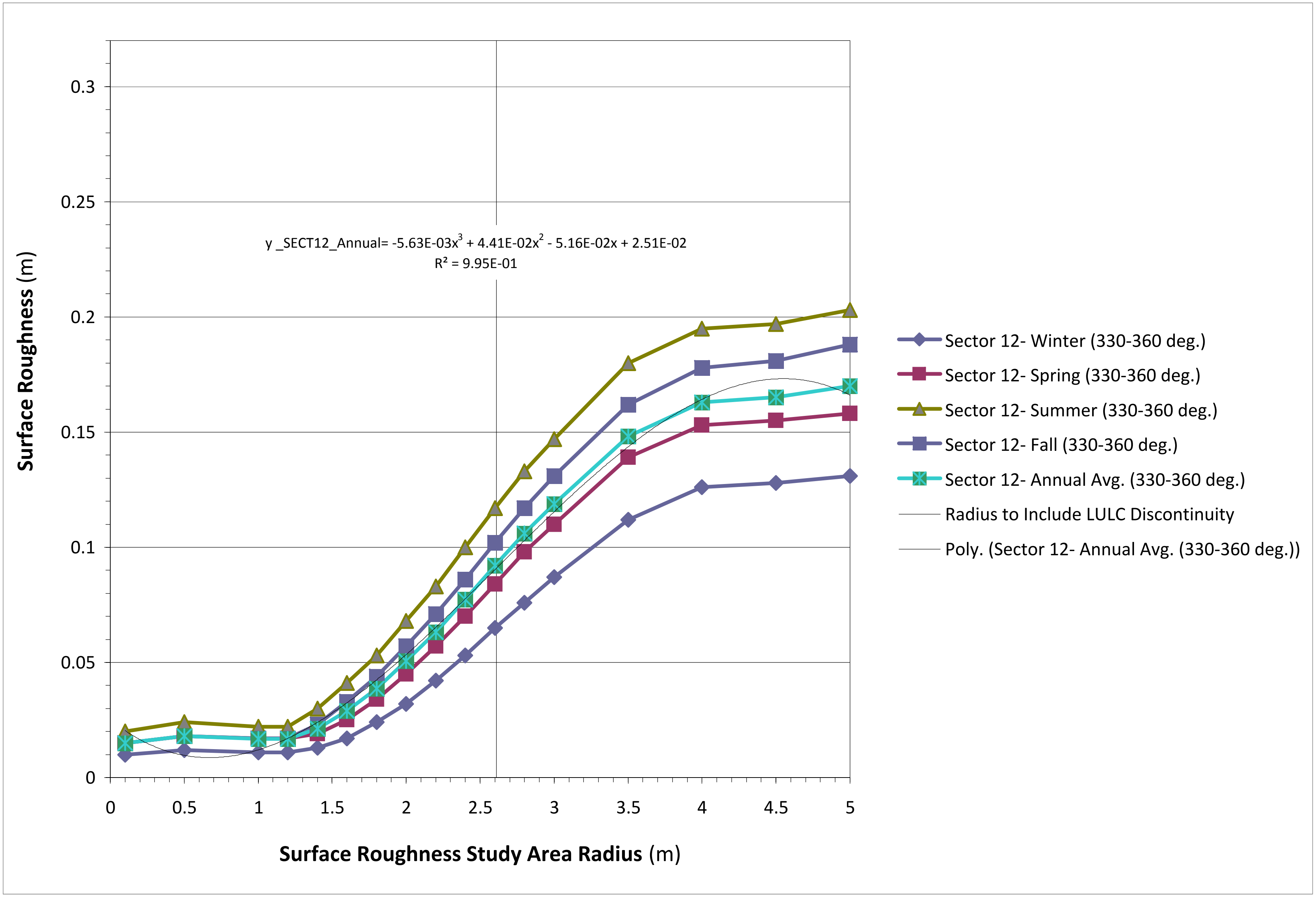

y_SECT8_Annual = -2.71E-03x3 + 2.49E-02x2 - 5.42E-02x + 8.76E-02
R² = 9.93E-01
Surface Roughness (m)
0
0.05
0.1
0.15
0.2
0.25
0.3
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Surface Roughness Study Area (m)
Sector 8- Winter (210-240 deg.)
Sector 8- Spring (210-240 deg.)
Sector 8- Summer (210-240 deg.)
Sector 8- Fall (210-240 deg.)
Sector 8- Annual Avg. (210-240 deg.)
Sector 8- Annual Avg. (210-240 deg.) 1 to 5 km Only
Radius to Include Discontinuity
Poly. (Sector 8- Annual Avg. (210-240 deg.) 1 to 5 km Only)

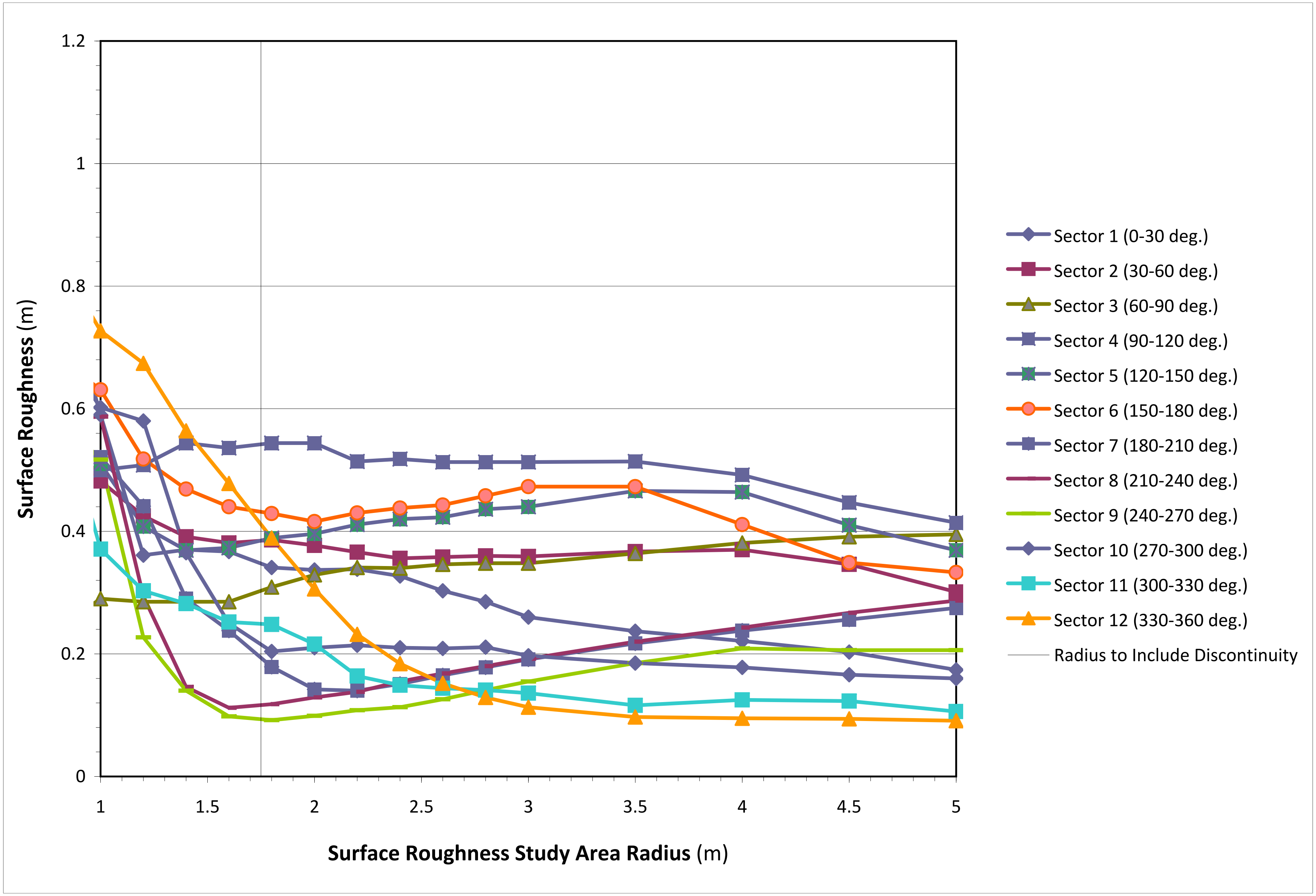

0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Surface Roughness (m)
Surface Roughness Study Area Radius (m)
Sector 9- Winter (240-270 deg.)
Sector 9- Spring (240-270 deg.)
Sector 9- Summer (240-270 deg.)
Sector 9- Fall (240-270 deg.)
Sector 9- Annual Avg. (240-270 deg.)
Radius to Include LULC Discontinuity



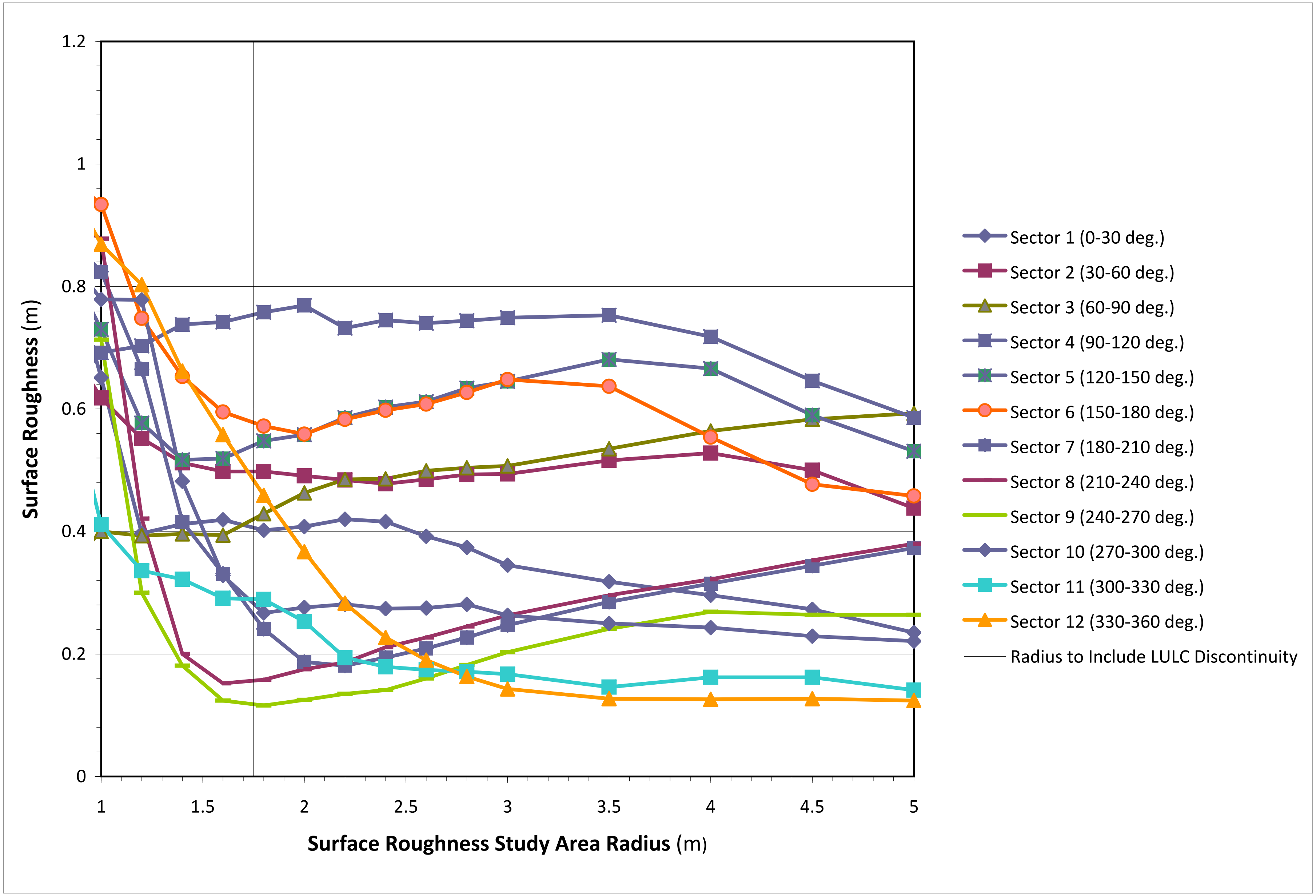
y _SECT10_Annual= -4.28E-03x^3 + 3.05E-02x^2 + 2.85E-03x + 1.61E-02
R² = 9.98E-01
Surface Roughness (m)
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Surface Roughness Study Area Radius (m)
Sector 10- Winter (270-300 deg.)
Sector 10- Spring (270-300 deg.)
Sector 10- Summer (270-300 deg.)
Sector 10- Fall (270-300 deg.)
Sector 10- Annual Avg. (270-300 deg.)
Radius to Include LULC Discontinuity
Poly. (Sector 10- Annual Avg. (270-300 deg.))


y_SECT11_Annual = -3.32E-03x3 + 2.84E-02x2 - 1.14E-02x + 1.54E-02
R² = 1.00E+00
Surface Roughness (m)
0
0.05
0.1
0.15
0.2
0.25
0.3
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Surface Roughness Study Area Radius (m)
Sector 11- Winter (300-330 deg.)
Sector 11- Spring (300-330 deg.)
Sector 11- Summer (300-330 deg.)
Sector 11- Fall (300-330 deg.)
Sector 11- Annual Avg. (300-330 deg.)
Radius to Include LULC Discontinuity
Poly. (Sector 11- Annual Avg. (300-330 deg.))

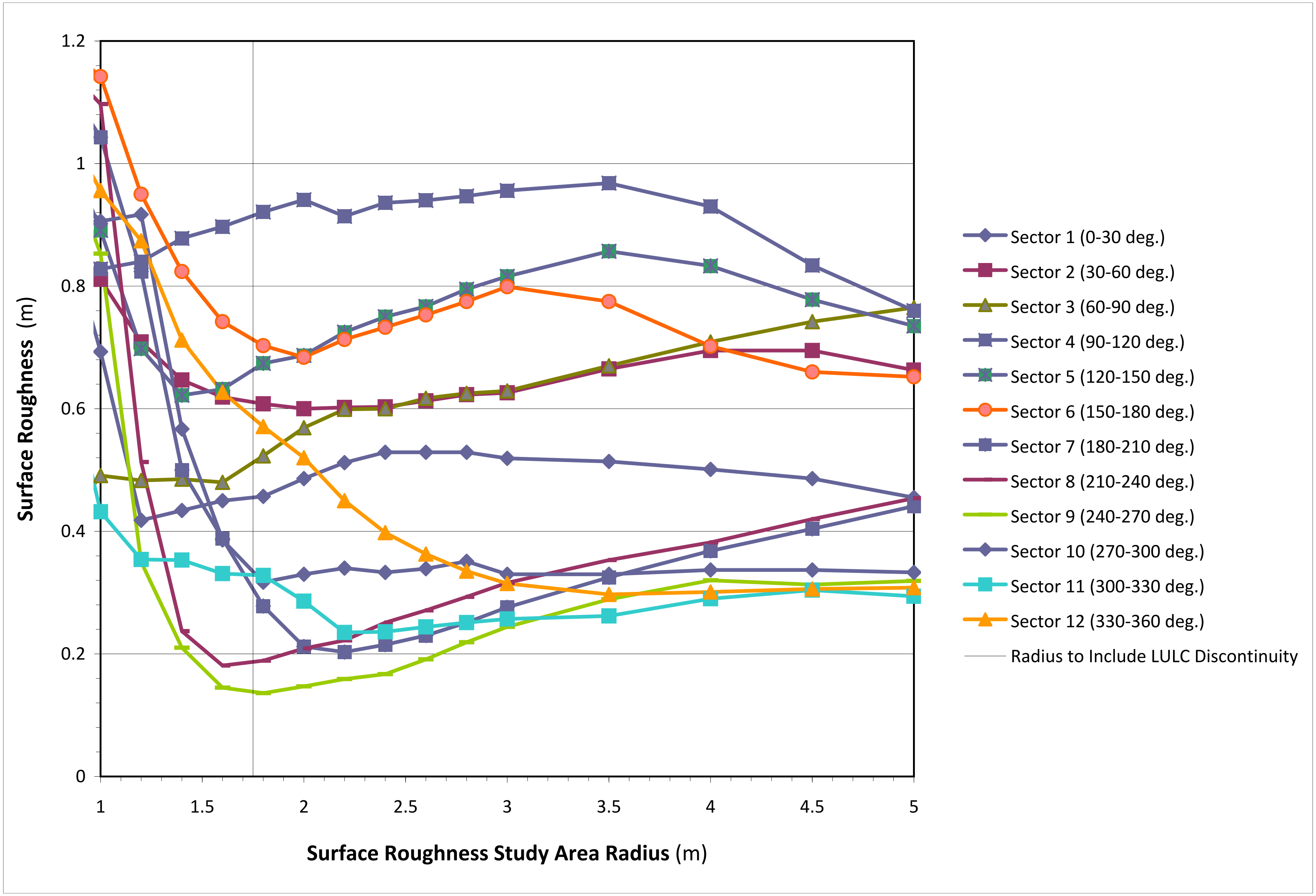

y _SECT12_Annual= -5.63E-03x³ + 4.41E-02x² - 5.16E-02x + 2.51E-02
R² = 9.95E-01
Surface Roughness (m)
Surface Roughness Study Area Radius (m)
0
0.05
0.1
0.15
0.2
0.25
0.3
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Sector 12- Winter (330-360 deg.)
Sector 12- Spring (330-360 deg.)
Sector 12- Summer (330-360 deg.)
Sector 12- Fall (330-360 deg.)
Sector 12- Annual Avg. (330-360 deg.)
Radius to Include LULC Discontinuity
Poly. (Sector 12- Annual Avg. (330-360 deg.))



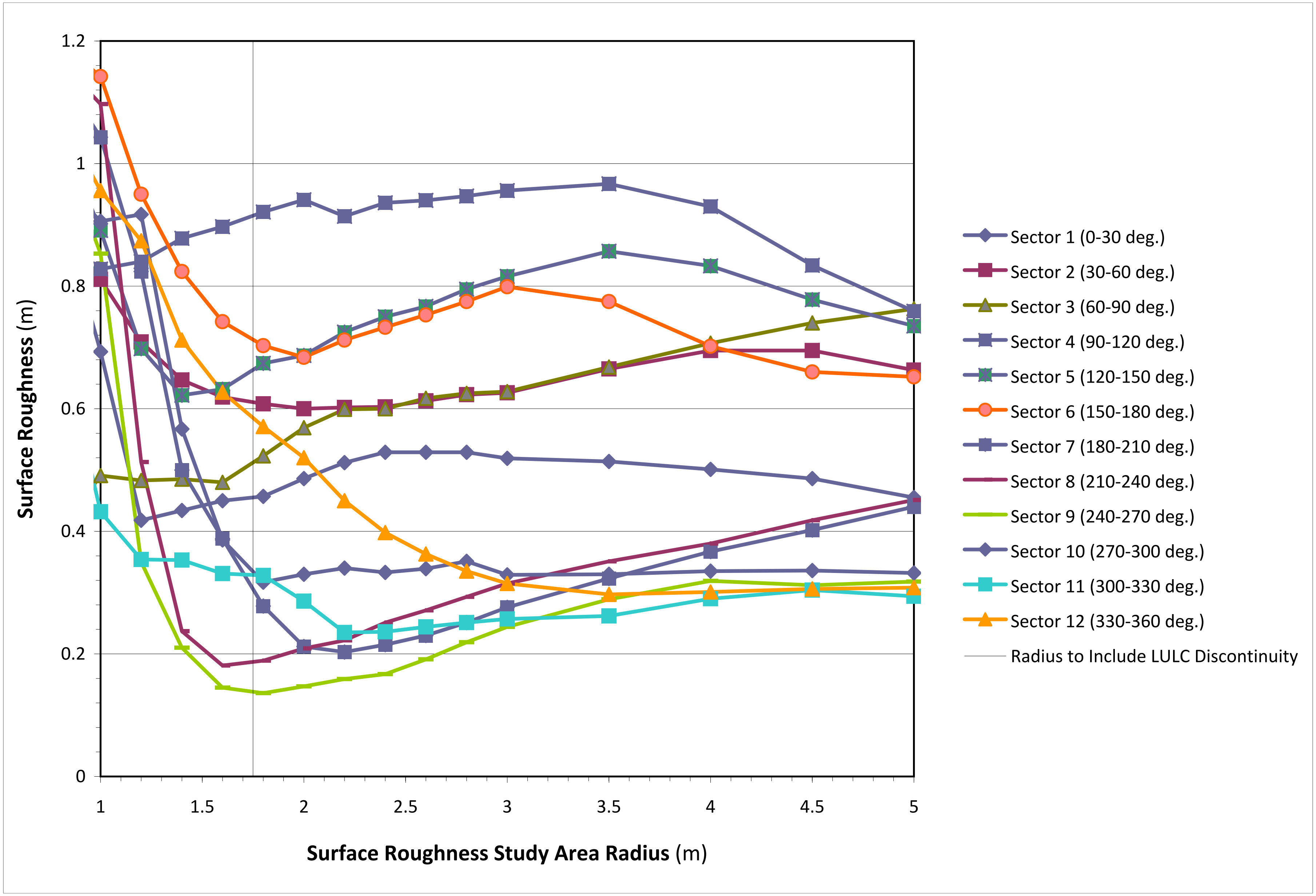
Surface Roughness (m)
1.2
1
0.8
0.6
0.4
0.2
0
1
1.5
2
2.5
3
3.5
4
4.5
5
Surface Roughness Study Area Radius (m)
Sector 1 (0-30 deg.)
Sector 2 (30-60 deg.)
Sector 3 (60-90 deg.)
Sector 4 (90-120 deg.)
Sector 5 (120-150 deg.)
Sector 6 (150-180 deg.)
Sector 7 (180-210 deg.)
Sector 8 (210-240 deg.)
Sector 9 (240-270 deg.)
Sector 10 (270-300 deg.)
Sector 11 (300-330 deg.)
Sector 12 (330-360 deg.)
Radius to Include Discontinuity

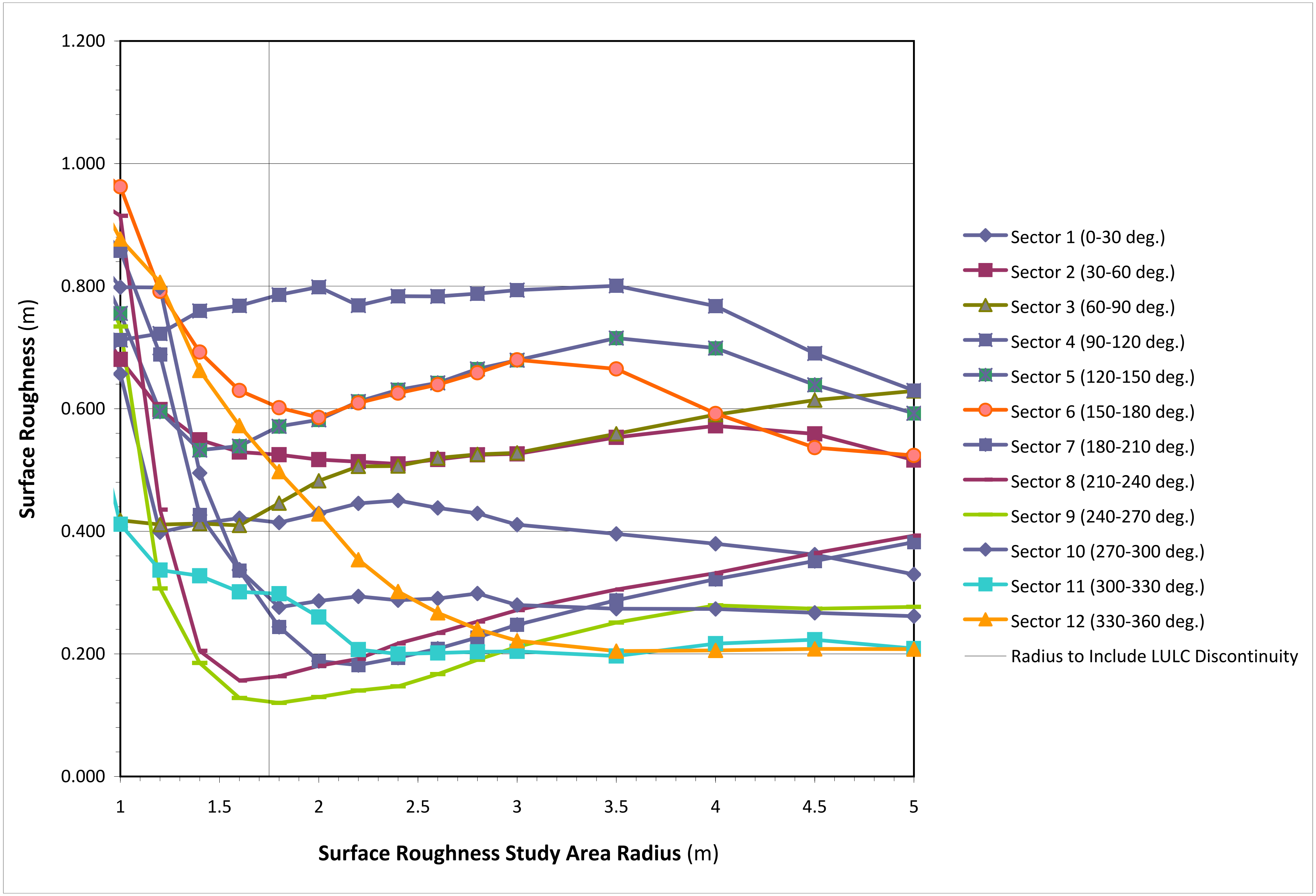

1.2
1
0.8
0.6
0.4
0.2
0
Surface Roughness (m)
1
1.5
2
2.5
3
3.5
4
4.5
5
Surface Roughness Study Area Radius (m)
Sector 1 (0-30 deg.)
Sector 2 (30-60 deg.)
Sector 3 (60-90 deg.)
Sector 4 (90-120 deg.)
Sector 5 (120-150 deg.)
Sector 6 (150-180 deg.)
Sector 7 (180-210 deg.)
Sector 8 (210-240 deg.)
Sector 9 (240-270 deg.)
Sector 10 (270-300 deg.)
Sector 11 (300-330 deg.)
Sector 12 (330-360 deg.)
Radius to Include LULC Discontinuity

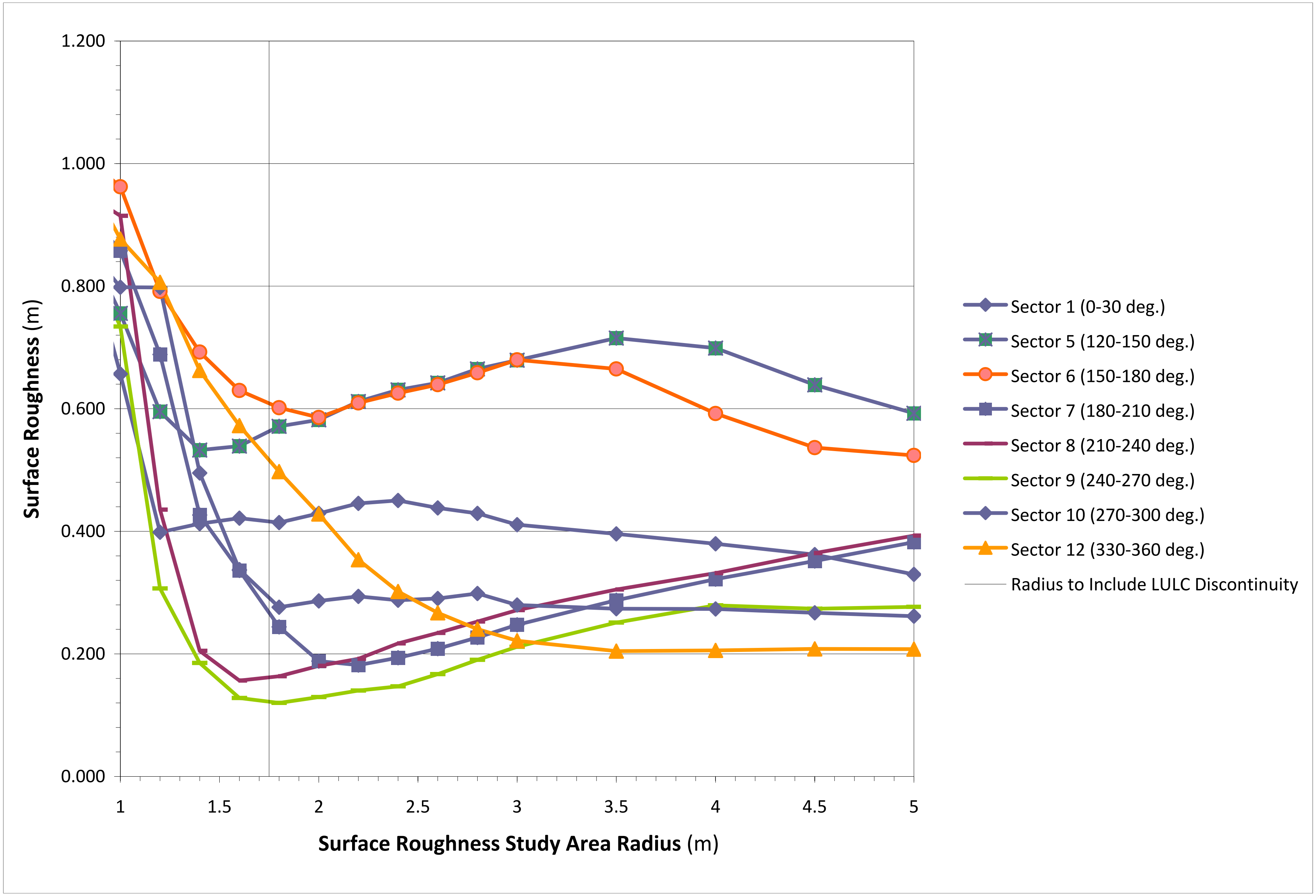
Attachment 4 -KYNG LULC Discontinuity Test v1.1.xls

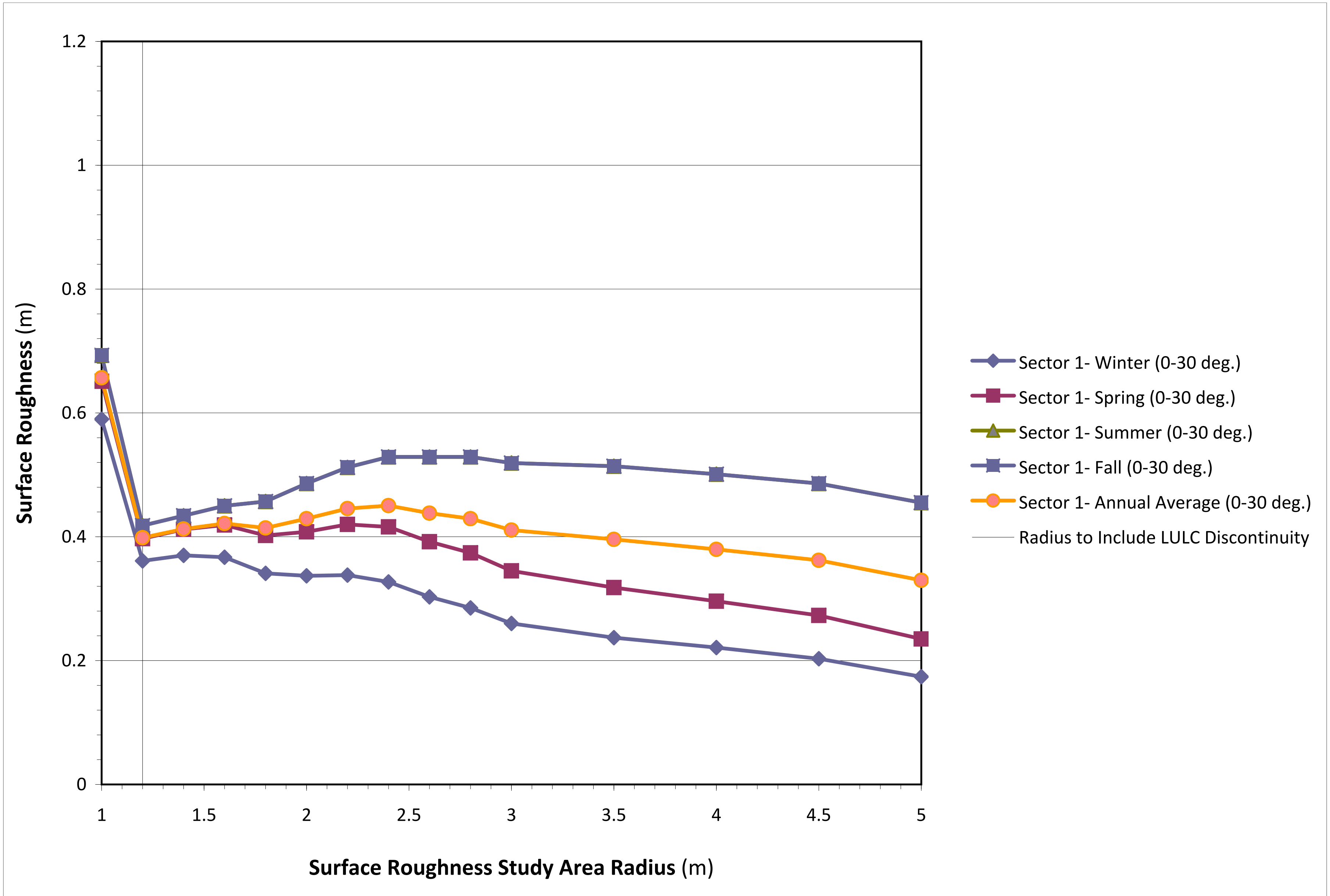


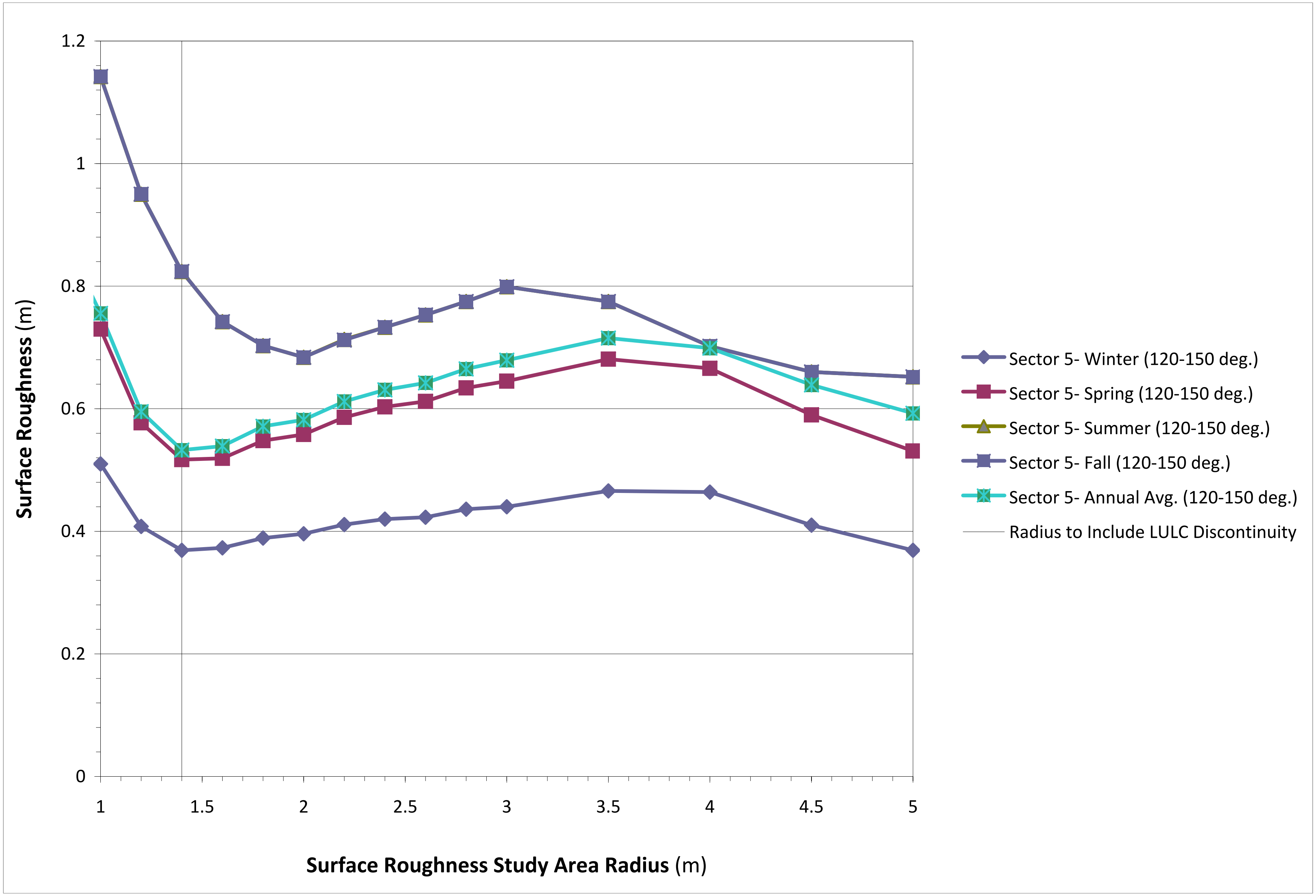
Season 3-Summer


1.2
1
0.8
0.6
0.4
0.2
0
1
1.5
2
2.5
3
3.5
4
4.5
5
Surface Roughness (m)
Surface Roughness Study Area Radius (m)
Sector 1 (0-30 deg.)
Sector 2 (30-60 deg.)
Sector 3 (60-90 deg.)
Sector 4 (90-120 deg.)
Sector 5 (120-150 deg.)
Sector 6 (150-180 deg.)
Sector 7 (180-210 deg.)
Sector 8 (210-240 deg.)
Sector 9 (240-270 deg.)
Sector 10 (270-300 deg.)
Sector 11 (300-330 deg.)
Sector 12 (330-360 deg.)
Radius to Include LULC Discontinuity

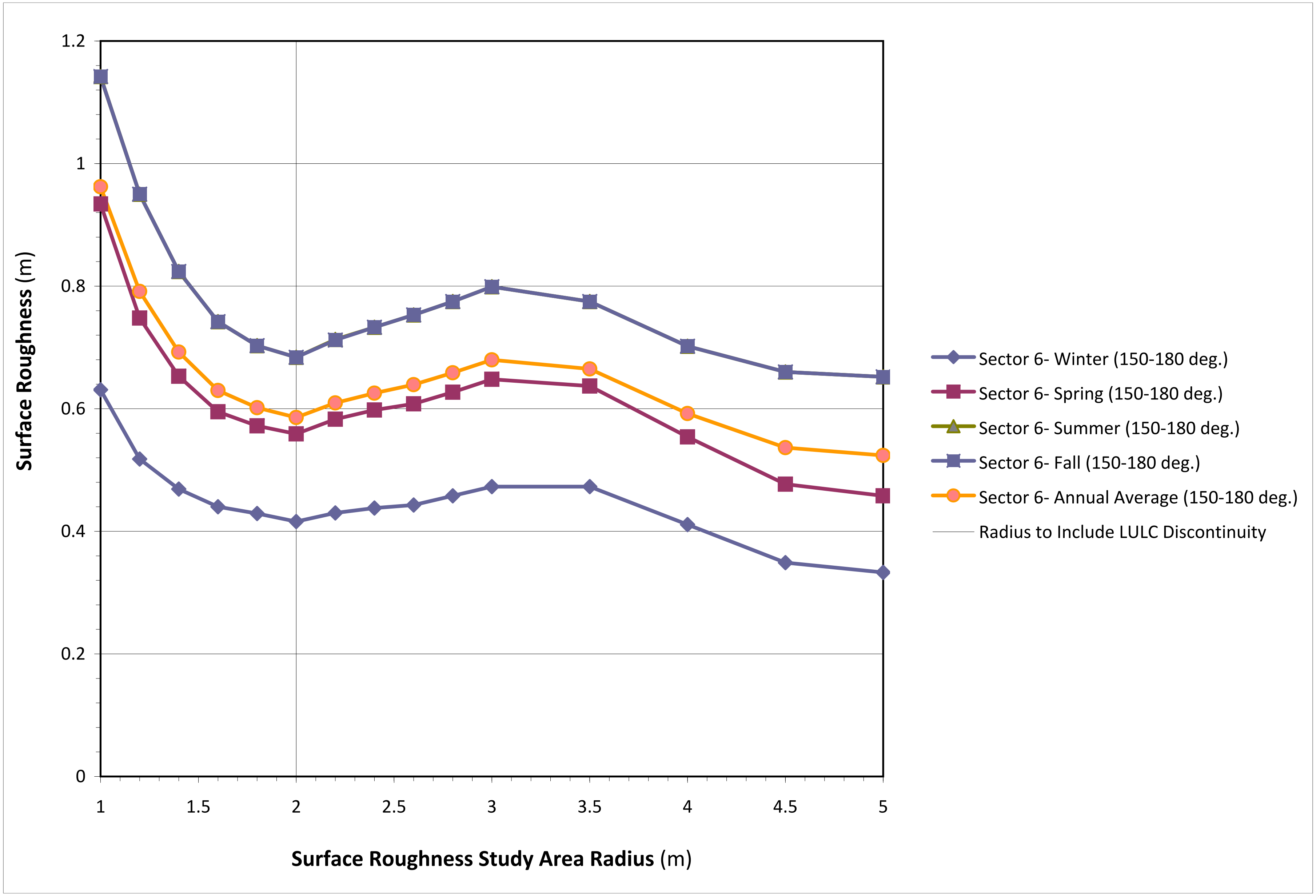

Surface Roughness (m)
1.200
1.000
0.800
0.600
0.400
0.200
0.000
1
1.5
2
2.5
3
3.5
4
4.5
5
Surface Roughness Study Area Radius (m)
Sector 1 (0-30 deg.)
Sector 2 (30-60 deg.)
Sector 3 (60-90 deg.)
Sector 4 (90-120 deg.)
Sector 5 (120-150 deg.)
Sector 6 (150-180 deg.)
Sector 7 (180-210 deg.)
Sector 8 (210-240 deg.)
Sector 9 (240-270 deg.)
Sector 10 (270-300 deg.)
Sector 11 (300-330 deg.)
Sector 12 (330-360 deg.)
Radius to Include LULC Discontinuity

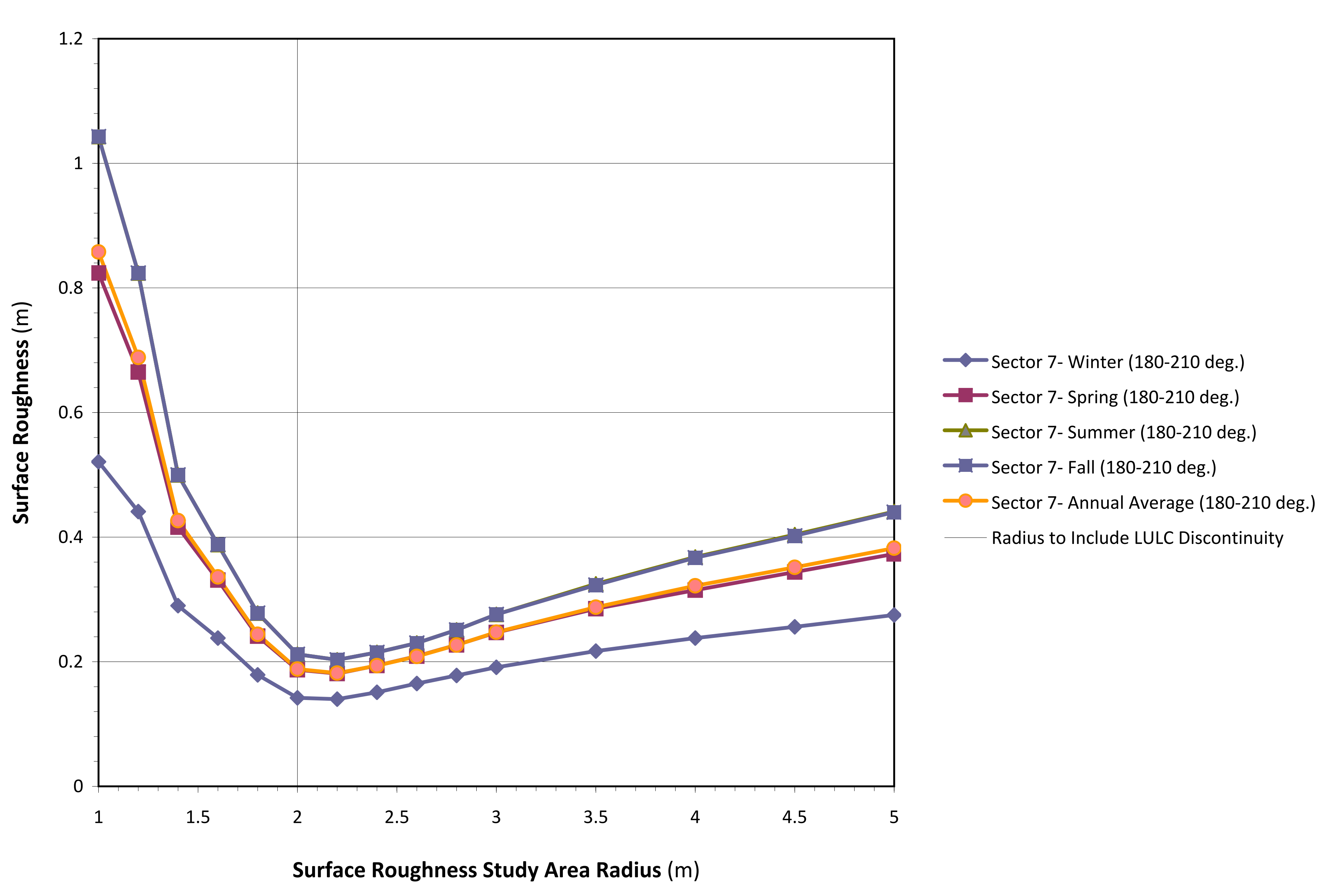

1.200
1.000
0.800
0.600
0.400
0.200
0.000
Surface Roughness (m)
1
1.5
2
2.5
3
3.5
4
4.5
5
Surface Roughness Study Area Radius (m)
Sector 1 (0-30 deg.)
Sector 5 (120-150 deg.)
Sector 6 (150-180 deg.)
Sector 7 (180-210 deg.)
Sector 8 (210-240 deg.)
Sector 9 (240-270 deg.)
Sector 10 (270-300 deg.)
Sector 12 (330-360 deg.)
Radius to Include LULC Discontinuity

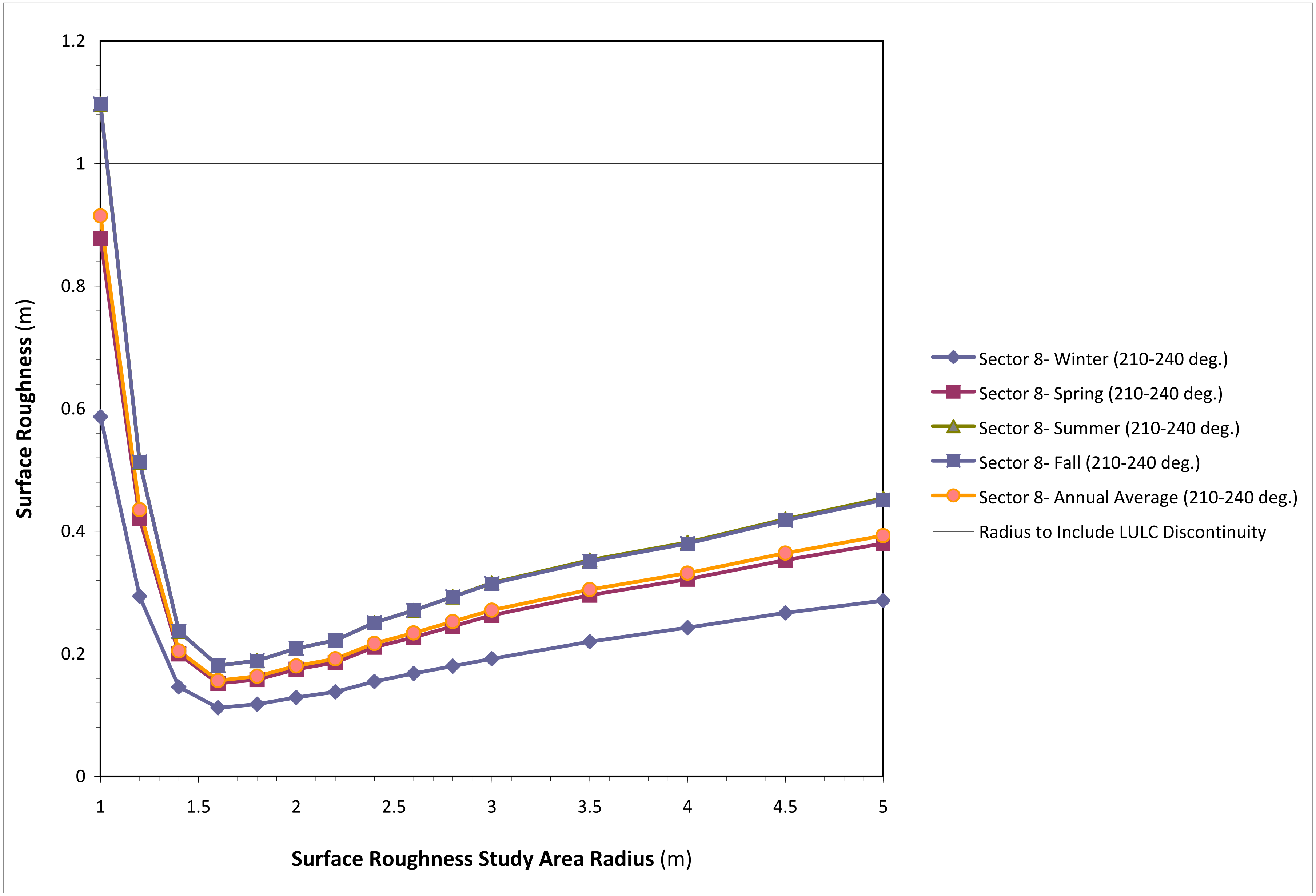

1.2
1
0.8
0.6
0.4
0.2
0
Surface Roughness (m)
1
1.5
2
2.5
3
3.5
4
4.5
5
Surface Roughness Study Area Radius (m)
Sector 1- Winter (0-30 deg.)
Sector 1- Spring (0-30 deg.)
Sector 1- Summer (0-30 deg.)
Sector 1- Fall (0-30 deg.)
Sector 1- Annual Average (0-30 deg.)
Radius to Include LULC Discontinuity

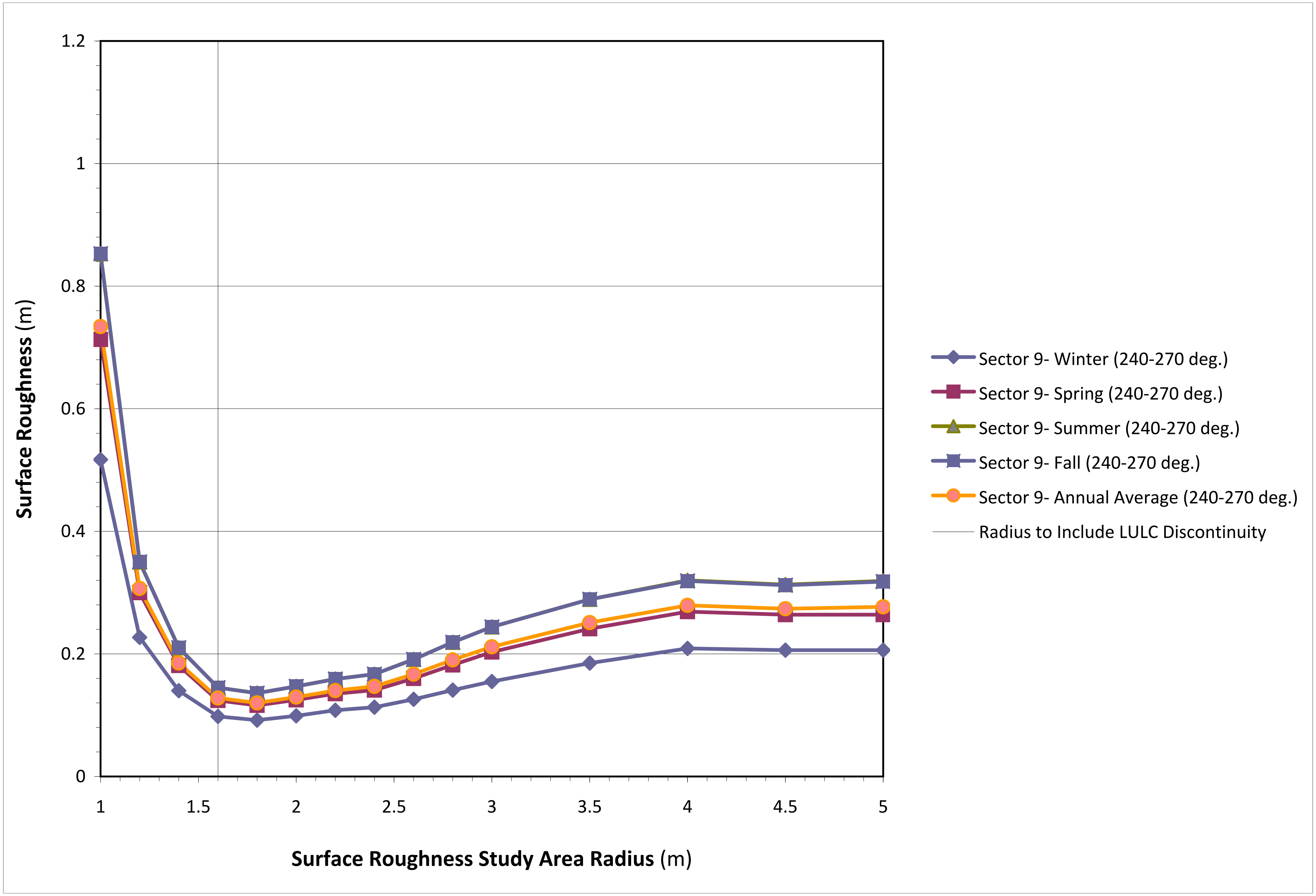


Surface Roughness (m)
1.2
1
0.8
0.6
0.4
0.2
0
1
1.5
2
2.5
3
3.5
4
4.5
5
Surface Roughness Study Area Radius (m)
Sector 5- Winter (120-150 deg.)
Sector 5- Spring (120-150 deg.)
Sector 5- Summer (120-150 deg.)
Sector 5- Fall (120-150 deg.)
Sector 5- Annual Avg. (120-150 deg.)
Radius to Include LULC Discontinuity

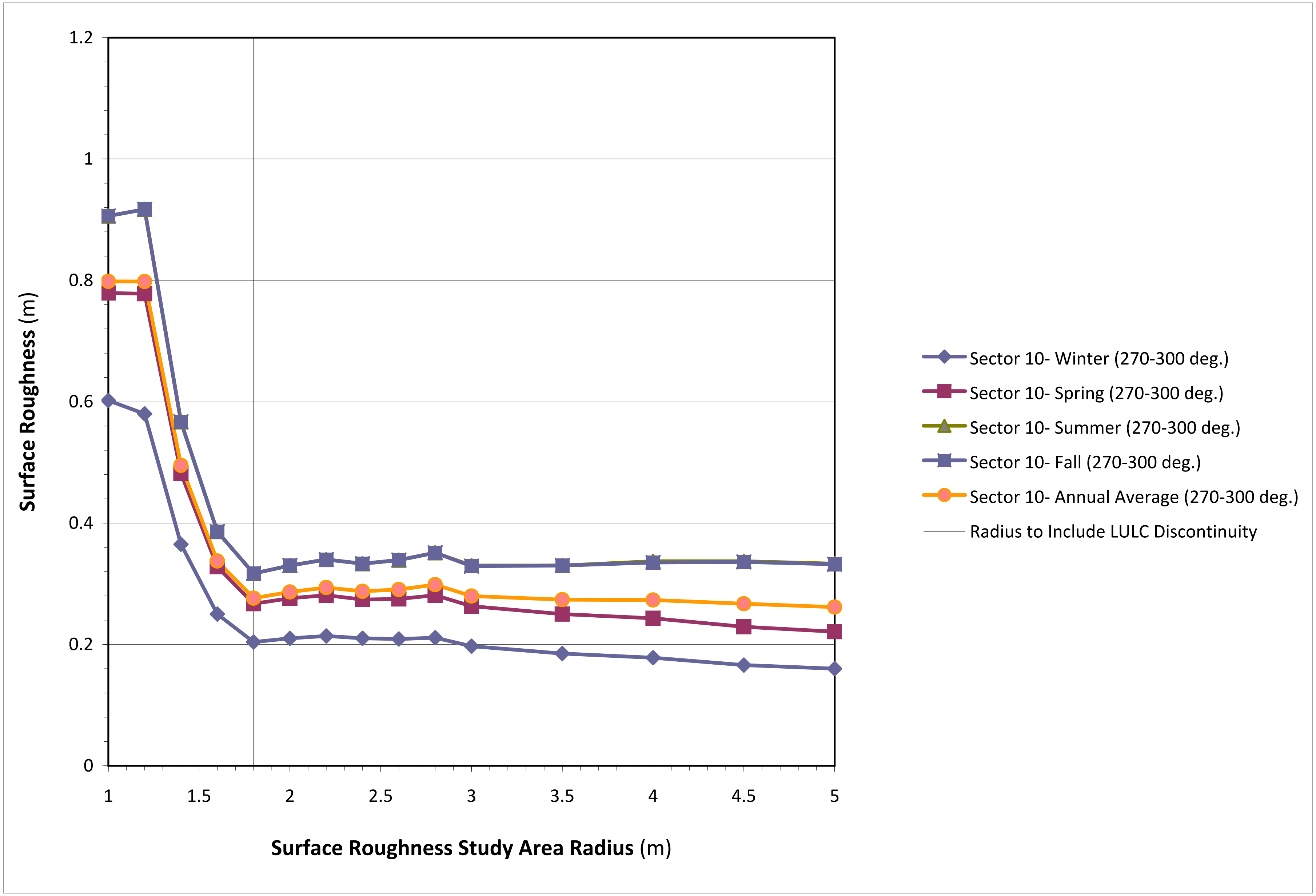

1.2
1
0.8
0.6
0.4
0.2
0
Surface Roughness (m)
1
1.5
2
2.5
3
3.5
4
4.5
5
Surface Roughness Study Area Radius (m)
Sector 6- Winter (150-180 deg.)
Sector 6- Spring (150-180 deg.)
Sector 6- Summer (150-180 deg.)
Sector 6- Fall (150-180 deg.)
Sector 6- Annual Average (150-180 deg.)
Radius to Include LULC Discontinuity

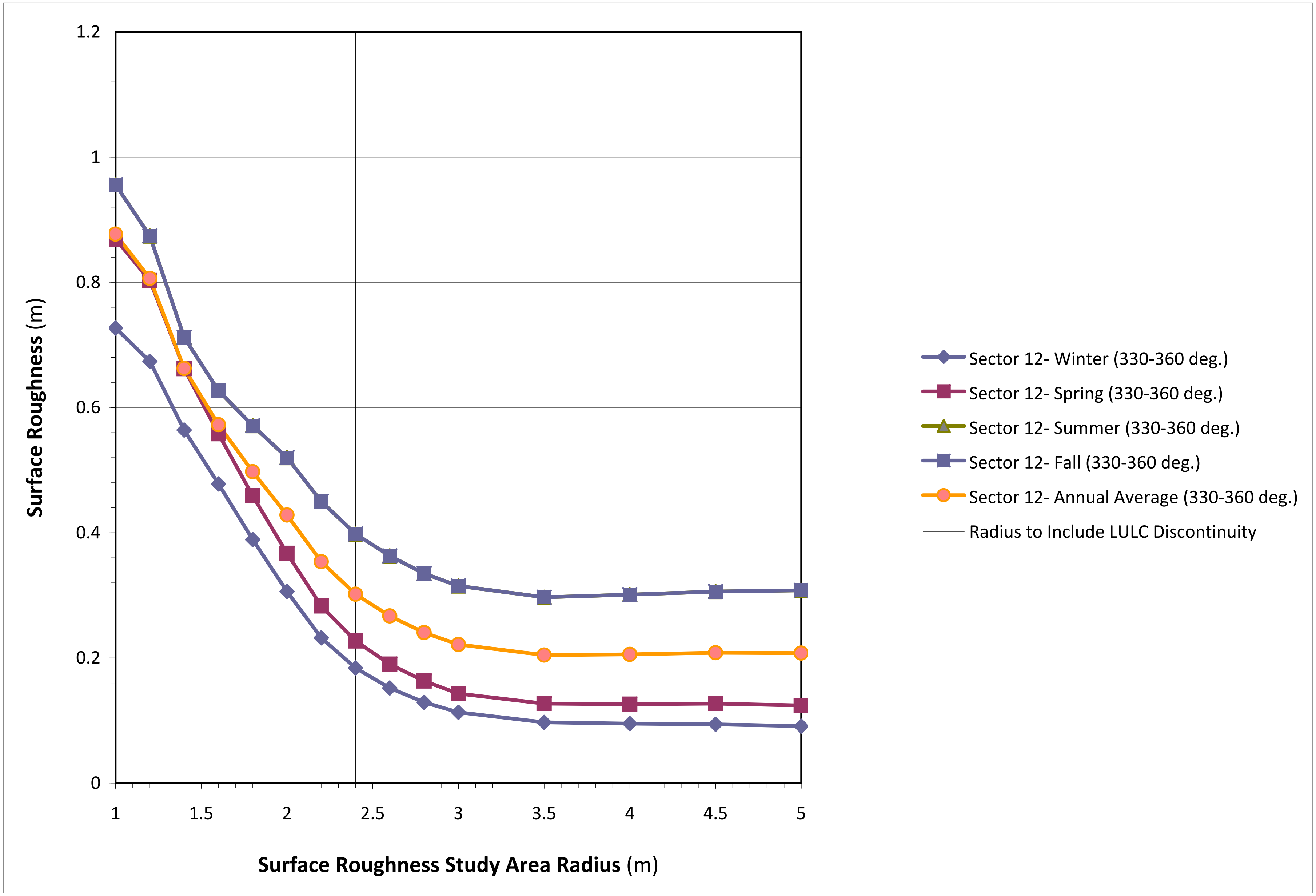

1.2
1
0.8
0.6
0.4
0.2
0
Surface Roughness (m)
1
1.5
2
2.5
3
3.5
4
4.5
5
Surface Roughness Study Area Radius (m)
Sector 7- Winter (180-210 deg.)
Sector 7- Spring (180-210 deg.)
Sector 7- Summer (180-210 deg.)
Sector 7- Fall (180-210 deg.)
Sector 7- Annual Average (180-210 deg.)
Radius to Include LULC Discontinuity


1.2
1
0.8
0.6
0.4
0.2
0
1
1.5
2
2.5
3
3.5
4
4.5
5
Surface Roughness (m)
Surface Roughness Study Area Radius (m)
Sector 8- Winter (210-240 deg.)
Sector 8- Spring (210-240 deg.)
Sector 8- Summer (210-240 deg.)
Sector 8- Fall (210-240 deg.)
Sector 8- Annual Average (210-240 deg.)
Radius to Include LULC Discontinuity



Surface Roughness (m)
1.2
1
0.8
0.6
0.4
0.2
0
1
1.5
2
2.5
3
3.5
4
4.5
5
Surface Roughness Study Area Radius (m)
Sector 9- Winter (240-270 deg.)
Sector 9- Spring (240-270 deg.)
Sector 9- Summer (240-270 deg.)
Sector 9- Fall (240-270 deg.)
Sector 9- Annual Average (240-270 deg.)
Radius to Include LULC Discontinuity


1.2
1
0.8
0.6
0.4
0.2
0
Surface Roughness (m)
1
1.5
2
2.5
3
3.5
4
4.5
5
Surface Roughness Study Area Radius (m)
Sector 10- Winter (270-300 deg.)
Sector 10- Spring (270-300 deg.)
Sector 10- Summer (270-300 deg.)
Sector 10- Fall (270-300 deg.)
Sector 10- Annual Average (270-300 deg.)
Radius to Include LULC Discontinuity


1.2
1
0.8
0.6
0.4
0.2
0
Surface Roughness (m)
1
1.5
2
2.5
3
3.5
4
4.5
5
Surface Roughness Study Area Radius (m)
Sector 12- Winter (330-360 deg.)
Sector 12- Spring (330-360 deg.)
Sector 12- Summer (330-360 deg.)
Sector 12- Fall (330-360 deg.)
Sector 12- Annual Average (330-360 deg.)
Radius to Include LULC Discontinuity

05/29/09

Trinity Consultants Analyses Explanation [Email dated 5/13/09]
Study Area Radius vs. Surface Roughness Plots for Kentucky NewGas

Trinity has conducted iterative AERSURFACE runs for the Bowling Green Warren County Airport (BWG) and the Kentucky NewGas (KYNG) site across the entire parametric range of surface roughness study area radius values cited in the *AERSURFACE User's Guide* and has plotted the resulting surface roughness data to demonstrate that significant LULC discontinuities occur beyond the default 1 km study area radius at both the NWS station and the plant site. The attached spreadsheets provide the raw AERSURFACE surface roughness output (refer to 'Raw AERSURFACE Data' tab in the attached spreadsheets) and the study area radius vs. surface roughness plots (for each individual sector on a season-by-season and annual average basis, refer to 'Seasons 1 to 4' and 'Annual' tabs in the attached spreadsheets). For sectors that clearly showed LULC discontinuities (refer to 'Annual_Sectors with Discont.'), Trinity has either fit a curve to the data to determine mathematically the radius necessary to include the LULC element(s) causing the discontinuity (i.e. the inflection point in the curve occurring after 1 km) or manually set the radius based on the point at which the influence of the LULC element(s) begins to decrease. Based on this thorough site-specific land use analysis, it appears that a study area radius of 2.4 km is required for BWG to include the influence of the sharp LULC discontinuity occurring just beyond 1 km to the west and northwest of the anemometer (refer to Figure D-6 in the modeling report) and a study area radius of 1.8 km is required for the Kentucky NewGas site to include the influence of the sharp LULC discontinuity occurring just beyond 1 km to the southwest, west, and northwest of the site (refer to Figure D-5 in the modeling report).