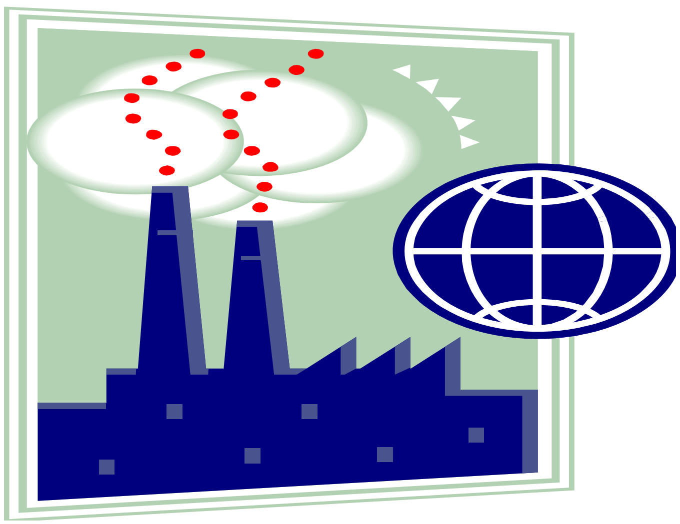
AERSURFACE Update



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Outline

- Review of current AERSURFACE Tool
- Implementation issues with AERSURFACE
- Efforts to validate AERSURFACE
- Plans for enhancing AERSURFACE

AERMOD Met Data Needs

- AERMOD designed to accept same meteorological data as ISCST3: NWS surface and upper air data
- AERMOD also designed to accept more robust on-site meteorological data, including multi-level profiles of wind, temperature and turbulence
- However, more advanced boundary layer algorithms in AERMOD require user-specified surface characteristics:
  - Albedo
  - Bowen ratio
  - Surface roughness
- Sensitivity to surface characteristics has been one of the main implementation issues with AERMOD

What is AERSURFACE?

- *AERSURFACE* is a tool designed to assist with determining surface characteristics data (albedo, Bowen ratio & surface roughness) for use in AERMET and/or AERSCREEN
- Initial version of *AERSURFACE* was released on SCRAM on January 11, 2008
- *AERSURFACE* is <u>not</u> currently considered part of the AERMOD regulatory modeling system
  - This is due to issues and limitations of available land cover data and other complexities (e.g., dependence of effective roughness on stability, potential influence of terrain-induced turbulence, etc.)

AERSURFACE Design

- AERSURFACE incorporates recommended method for estimating surface characteristics from land cover data in Section 3.1 of *AERMOD Implementation Guide*
- Surface roughness calculation method:
  - Inverse-distance weighted geometric mean of gridded roughness values within default 1km radius of wind measurement site, based on user-defined wind sectors
- Bowen ratio calculation method:
  - Geometric mean of gridded Bowen ratio values within 10x10km domain, with no sector or distance dependence
  - Typically centered on wind measurement site but may be centered on application site per Section 3.1.2 of *AERMOD Implementation Guide* if majority of sources are elevated releases
- Albedo calculation method:
  - Same as for Bowen ratio, except based on arithmetic mean

AERSURFACE Design

- Current version of AERSURFACE supports 1992 National Land Cover Data (NLCD) files, with 21 categories at 30 meter horizontal resolution
- Several options with default values and user choices:
  - Number and width of sectors (up to 12 sectors ≥ 30°)
  - Output monthly, seasonal, or annual data
  - Wet/dry/normal conditions for Bowen ratio
  - Snow vs. no snow cover
  - Arid vs. Non-arid
  - Airport vs. Non-airport location

1992 NLCD Land Cover Categories

Table 1: USGS NLCD 92 Land Use Categories

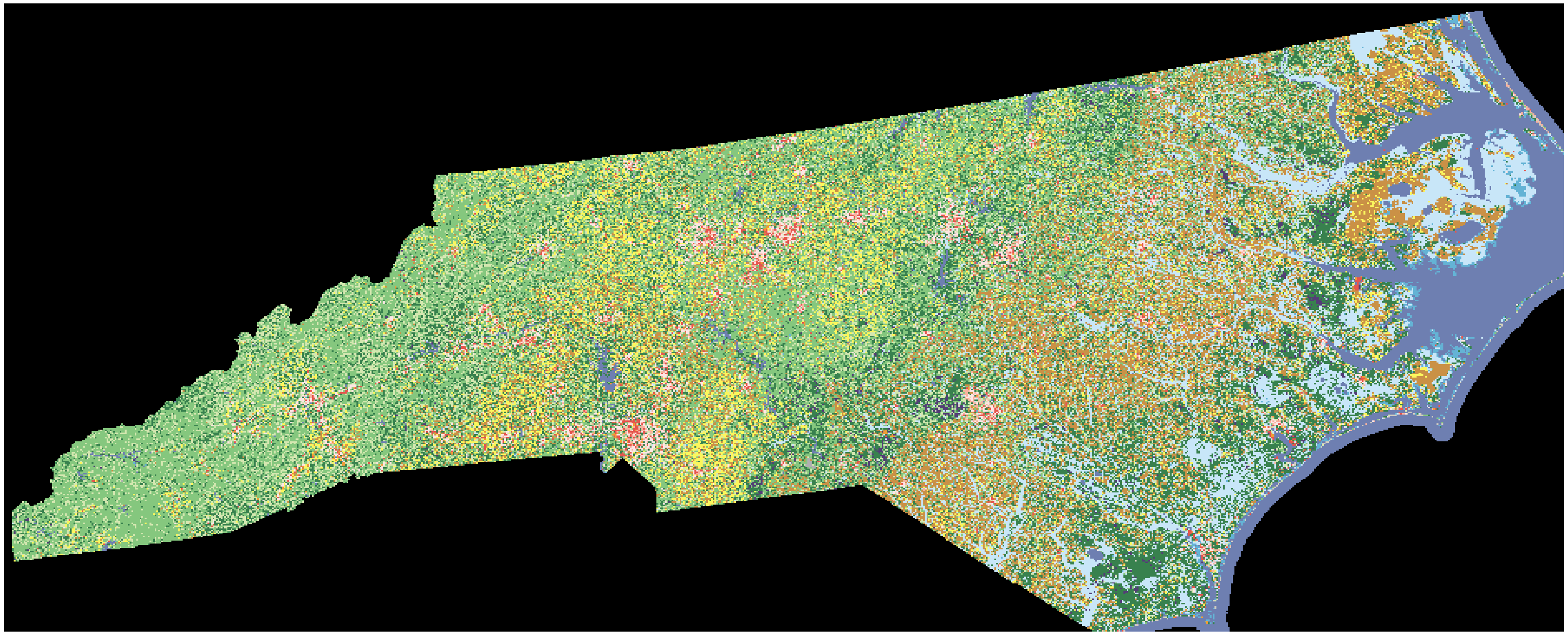
Classification Class	Land Use Category
Water	Open Water
	Perennial Ice/Snow
Developed	Low Intensity Residential
	High Intensity Residential
	Commercial/Industrial/Transportation
Barren	Bare Rock/Sand/Clay
	Quarries/Strip Mines/Gravel Pits
	Transitional
Forested Upland	Deciduous Forest
	Evergreen Forest
	Mixed Forest
Shrubland	Shrubland
Non-natural Woody	Orchards/Vineyards/Other
Herbaceous Upland	Grasslands/Herbaceous
Herbaceous Planted/Cultivated	Pasture/Hay
	Row Crops
	Small Grains
	Fallow
	Urban/Recreational Grasses
Wetlands	Woody Wetlands
	Emergent Herbaceous Wetlands

AERSURFACE Surface Characteristics

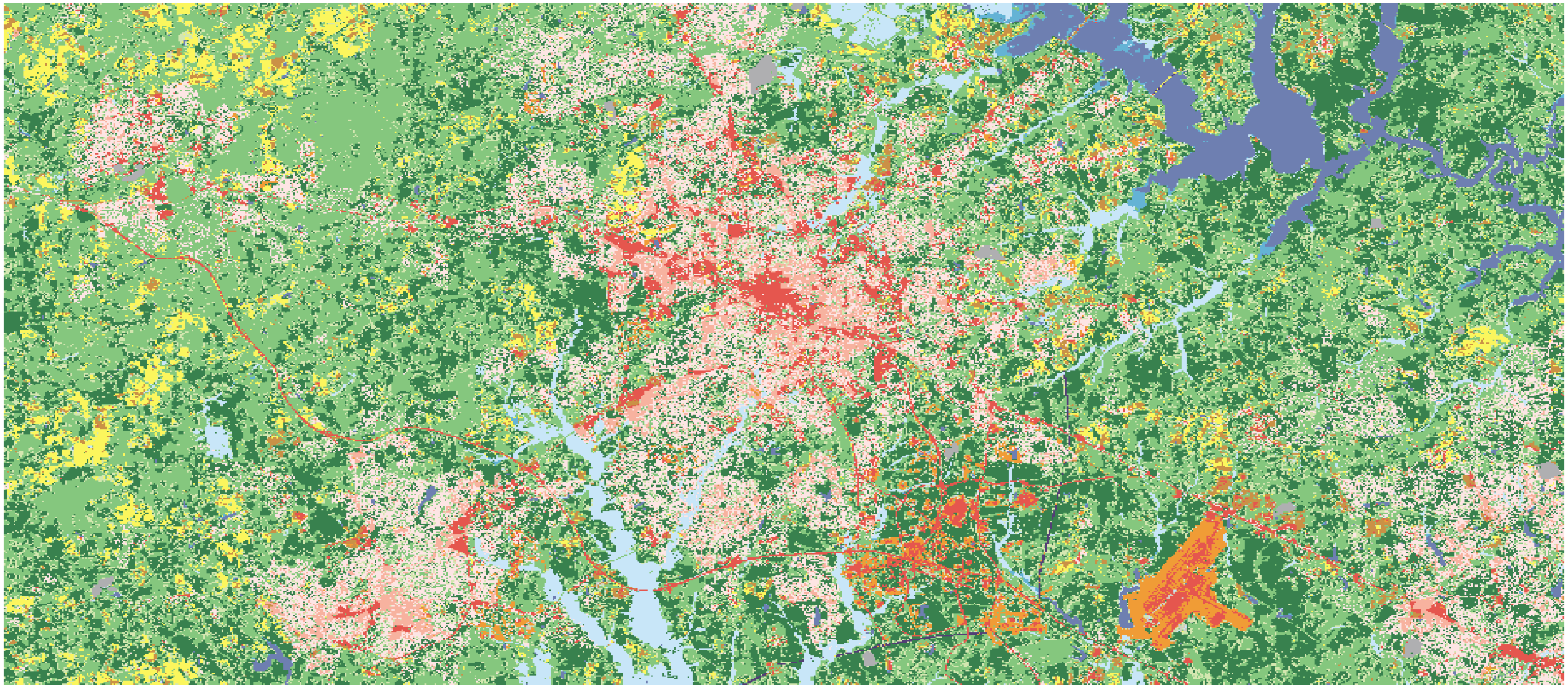
Class Number	Class Name	Seasonal Surface Roughness[1] (m)					Reference(s)
		1	*2*	*3*	*4*	*5*	
11	Open Water	0.001	0.001	0.001	0.001	0.001	Stull[2]
12	Perennial Ice/Snow	0.002	0.002	0.002	0.002	0.002	Stull[2]
21	Low Intensity Residential	0.54	0.54	0.50	0.50	0.52	40% 22 + 50% 43+ 10% 85[3]
22	High Intensity Residential	1	1	1	1	1	AERMET[4]
23	Commercial/Industrial/Transport (Site at Airport)	0.1	0.1	0.1	0.1	0.1	5%: 22 & 95%: 31[5]
	Commercial/Industrial/Transport (Not at Airport)	0.8	0.8	0.8	0.8	0.8	80%: 22 & 20%: 31[5]
31	Bare Rock/Sand/Clay (Arid Region)	0.05	0.05	0.05	NA	0.05	Slade[6]
	Bare Rock/Sand/Clay (Non-arid Region)	0.05	0.05	0.05	0.05	0.05	Slade[6]
32	Quarries/Strip Mines/Gravel	0.3	0.3	0.3	0.3	0.3	Estimate[7]
33	Transitional	0.2	0.2	0.2	0.2	0.2	Estimate[8]
41	Deciduous Forest	1.3	1.3	0.6	0.5	1	AERMET[4]
42	Evergreen Forest	1.3	1.3	1.3	1.3	1.3	AERMET[4]
43	Mixed Forest	1.3	1.3	0.95	0.9	1.15	(41+42)/2[9]
51	Shrubland (Arid Region)	0.15	0.15	0.15	NA	0.15	50% 51 (Non-Arid)[10]
	Shrubland (Non-arid Region)	0.3	0.3	0.3	0.15	0.3	AERMET[4]
61	Orchards/Vineyards/Other	0.3	0.3	0.1	0.05	0.2	Garratt[11]
71	Grasslands/Herbaceous	0.1	0.1	0.01	0.005	0.05	AERMET[4]
81	Pasture/Hay	0.15	0.15	0.02	0.01	0.03	Garratt[11] & Slade[12]
82	Row Crops	0.2	0.2	0.02	0.01	0.03	Garratt[11] & Slade[12]
83	Small Grains	0.15	0.15	0.02	0.01	0.03	Garratt[11] & Slade[12]
84	Fallow	0.05	0.05	0.02	0.01	0.02	31 & 81,82,83[13]
85	Urban/Recreational Grasses	0.02	0.015	0.01	0.005	0.015	Randerson[14]
91	Woody Wetlands	0.7	0.7	0.6	0.5	0.7	(43+92)/2[15]
92	Emergent Herbaceous Wetlands	0.2	0.2	0.2	0.1	0.2	AERMET[4]

[1] Values are listed for the following seasonal categories: *1 - Midsummer with lush vegetation; 2 - Autumn with unharvested cropland; 3 - Late autumn after frost and harvest; or winter with no snow; 4 - Winter with continuous snow on ground; 5 - Transitional spring with partial green coverage or short annuals*

USGS NLCD 1992 Example Data



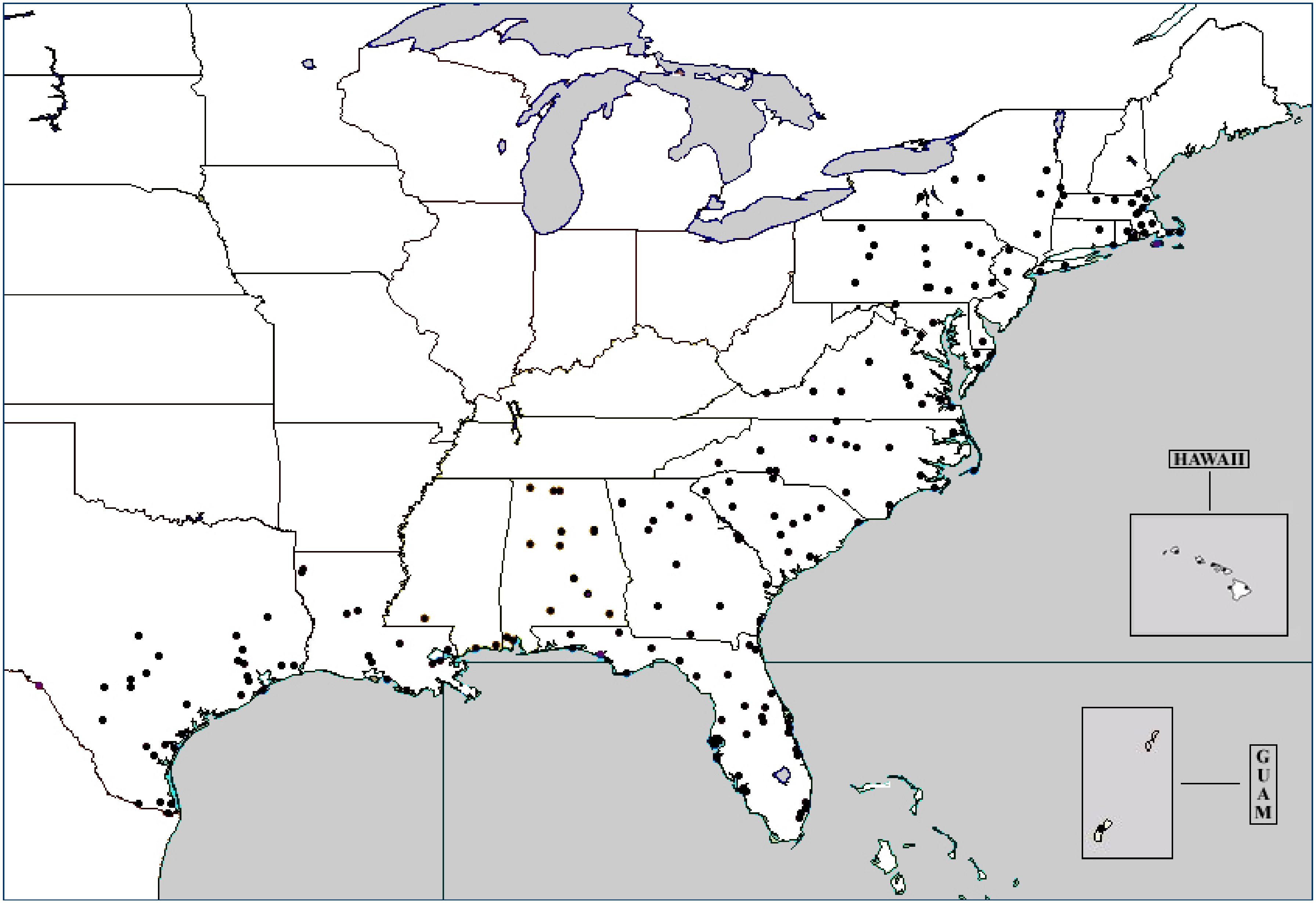
USGS NLCD 1992 Example Data



AERSURFACE Implementation Issues

- Uncertainties regarding ASOS met station locations – a key AERSURFACE input
  - Excel file with ASOS station locations available on NCDC website is unreliable for location information
  - Additional location data available for about 200 ASOS stations as part of tropical cyclone wind study appears to be generally reliable, with some exceptions
  - Many locations differ between NCDC and cyclone wind study by several hundred meters (median value of about 500m)
  - For example, RDU tower location is off by over 2km!
  - Use of erroneous station locations in AERSURFACE could invalidate results

ASOS Met Station Locations – Cyclone Wind Study



ASOS Met Station Locations

Comparison of ASOS Station Locations from Two References

		NCDC ASOS List		ASOS Cyclone Wind Study						
Call	WBAN	Lat-ASOS	Lon-ASOS	Lat-PHOTO	Lon-PHOTO	Delta-Lat	Delta-Lon	Dist (km)	ST	Station Name
KIJD	54767	41.7419	72.1836	41.7420	72.1830	0.000	0.001	0.061	CT	Willimantic Windham Airport
KAQW	54768	42.6958	73.1708	42.6970	73.1700	-0.001	0.001	0.143	MA	North Adams Harriman
KBED	14702	42.4700	71.2894	42.4680	71.2940	0.002	-0.005	0.498	MA	Bedford Hanscom Field
KBOS	14739	42.3606	71.0106	42.3590	71.0200	0.002	-0.009	0.956	MA	Boston Logan Intl Airport
KBVY	54733	42.5842	70.9175	42.5840	70.9160	0.000	0.002	0.151	MA	Beverly Municipal Airport
KCQX	94624	41.6875	69.9933	41.6880	69.9930	-0.001	0.000	0.060	MA	Chatham Municipal Airport
KEWB	94726	41.6764	70.9583	41.6750	70.9570	0.001	0.001	0.193	MA	New Bedford Municipal Airport
KFIT	4780	42.5519	71.7558	42.5520	71.7560	0.000	0.000	0.017	MA	Fitchburg Municipal Airport
KHYA	94720	41.6686	70.2800	41.6690	70.2710	0.000	0.009	0.900	MA	Hyannis Barnstable Municipal Airp
KMVY	94724	41.3931	70.6150	41.3920	70.6170	0.001	-0.002	0.226	MA	Martha's Vineyard Airport
KORE	54756	42.5700	72.2911	42.5720	72.2780	-0.002	0.013	1.327	MA	Orange Municipal Airport
KOWD	54704	42.1908	71.1736	42.1910	71.1740	0.000	0.000	0.042	MA	Norwood Memorial Airport
KPYM	54769	41.9097	70.7294	41.9070	70.7280	0.003	0.001	0.308	MA	Plymouth Municipal Airport
KTAN	54777	41.8756	71.0211	41.8760	71.0210	0.000	0.000	0.046	MA	Taunton Municipal Airport
KFWN	54793	41.2003	74.6231	41.2000	74.6170	0.000	0.006	0.606	NJ	Sussex Airport
KSMQ	54785	40.6239	74.6694	40.6170	74.6670	0.007	0.002	0.731	NJ	Somerville Somerset Airport
KVAY	93780	39.9406	74.8411	39.9500	74.8500	-0.009	-0.009	1.297	NJ	Mount Holly South Jersey Regiona
KALB	14735	42.7481	73.8033	42.7470	73.7990	0.001	0.004	0.446	NY	Albany County Airport
KBGM	4725	42.2078	75.9814	42.2070	75.9800	0.001	0.001	0.159	NY	Binghamton Regional Airport
KELM	14748	42.1594	76.8919	42.1570	76.9030	0.002	-0.011	1.132	NY	Elmira Corning Regional Airport
KGFL	14750	43.3411	73.6103	43.3380	73.6100	0.003	0.000	0.312	NY	Glens Falls Airport
KISP	4781	40.7939	73.1017	40.8000	73.1000	-0.006	0.002	0.634	NY	Islip Long Island Macarthur Airport
KJFK	94789	40.6553	73.7956	40.6330	73.7670	0.022	0.029	3.622	NY	New York J F Kennedy Intl Airport
KPEO	54778	42.6425	77.0564	42.6440	77.0530	-0.002	0.003	0.370	NY	Penn Yan Airport
KPOU	14757	41.6267	73.8842	41.6260	73.8820	0.001	0.002	0.226	NY	Poughkeepsie Dutchess Co Airpo
KPSF	14763	42.4272	73.2892	42.4170	73.2890	0.010	0.000	1.022	NY	Pittsfield Municipal Airport
KSYR	14771	43.1092	76.1033	43.1110	76.1040	-0.002	-0.001	0.195	NY	Syracuse Hancock Intl Airport
KUCA	94794	43.1450	72.3839	43.1440	75.3840	0.001	-3.000	300.011	NY	Utica Oneida County Airport
KPVD	14765	41.7219	71.4325	41.7230	71.4330	-0.001	-0.001	0.117	RI	Providence Green State Airport
KUUU	14787	41.5300	71.2836	41.5300	71.2840	0.000	0.000	0.039	RI	Newport State Airport
KWST	14794	41.3497	71.7989	41.3500	71.7990	0.000	0.000	0.030	RI	Westerly State Airport
KDDH	54781	42.8914	73.2469	42.8940	73.2490	-0.003	-0.002	0.332	VT	Bennington Morse State Airport

AERSURFACE Implementation Issues

- Resources available to verify or determine ASOS tower locations:
  - National Climatic Data Center (NCDC) website includes station history information including aerial photos through the Multi-Network Metadata System (MMS), but is not always reliable;
  - Tower location may show up on Google Earth aerial photos, but may be difficult to distinguish between ASOS site and other airport installations;
  - Photos of tower site from 8 directions are available through NCDC site for about 200 stations included in the cyclone wind study;
  - Some state agencies may have compiled reliable information for airports in their states;
  - ISHD (TD-3505) surface data includes coordinates, but may not be reliable, and may vary depending on type of observation

AERSURFACE Implementation Issues

- NLCD land cover categories are not ideal for estimating surface roughness:
  - For example, 1992 NLCD "Commercial/Industrial/Transportation" category includes airport runways, roadways, parking lots, parking decks, industrial complexes, and commercial buildings, including the Sears Tower, which spans the complete range of surface roughness characteristics;
  - Given the importance of this category to roughness estimates, AERSURFACE includes an option to specify whether the location is an airport or non-airport site;
    - Airport option assigns more weight to runways and roads than buildings for the Commercial/Industrial/Transportation category;
    - Non-airport option assigns more weight to buildings for this category.
  - 2001 NLCD data is not any better than 1992 NLCD, and in some ways worse (as shown later)

NLCD 2001 Land Cover Class Definitions

11. Open Water

12. Perennial Ice/Snow

21. Developed, Open Space - Areas with some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover.

22. Developed, Low Intensity - Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover.

23. Developed, Medium Intensity - Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover.

24. Developed, High Intensity - Highly developed areas, includes apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80-100 percent of the total cover.

31. Barren Land (Rock/Sand/Clay)

32. Unconsolidated Shore

41. Deciduous Forest

42. Evergreen Forest

43. Mixed Forest

51. Dwarf Scrub

52. Shrub/Scrub

71. Grassland/Herbaceous

72. Sedge/Herbaceous

73. Lichens

74. Moss

81. Pasture/Hay

82. Cultivated Crops

90. Woody Wetlands (with additional breakdown for coastal areas)

95. Emergent Herbaceous Wetlands (with additional breakdown for coastal areas)

No Urban/Recreational Grasses category in 2001 NLCD; grassy areas around runway classified as Developed, Open Space (Cat 21).

AERSURFACE Implementation Issues

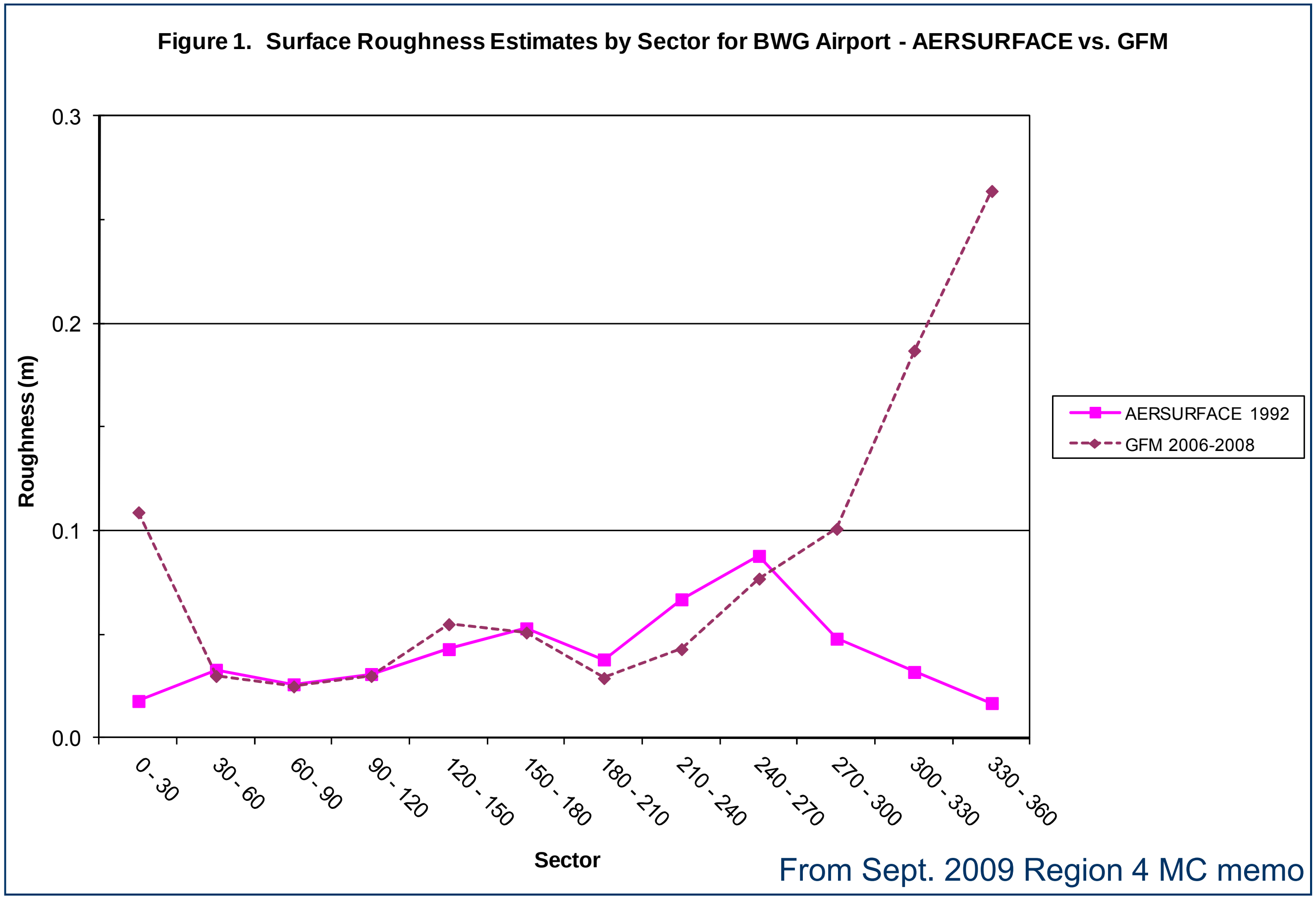
- Temporal representativeness of 1992 land cover data relative to the meteorological data period may be an issue in some cases:
  - Sept. 2009 EPA Region 4 Model Clearinghouse memo regarding use of non-default radius in AERSURFACE highlighted this issue, with residential community and golf course being built within about 50 meters of the ASOS site beginning around 1993:

BWG March 1993

BWG June 2004

AERSURFACE Implementation Issues

- Higher roughness values at BWG for NW to NE sectors based on Gust Factor Method[1] for 2006-08 reflect influence from land cover changes:



From Sept. 2009 Region 4 MC memo

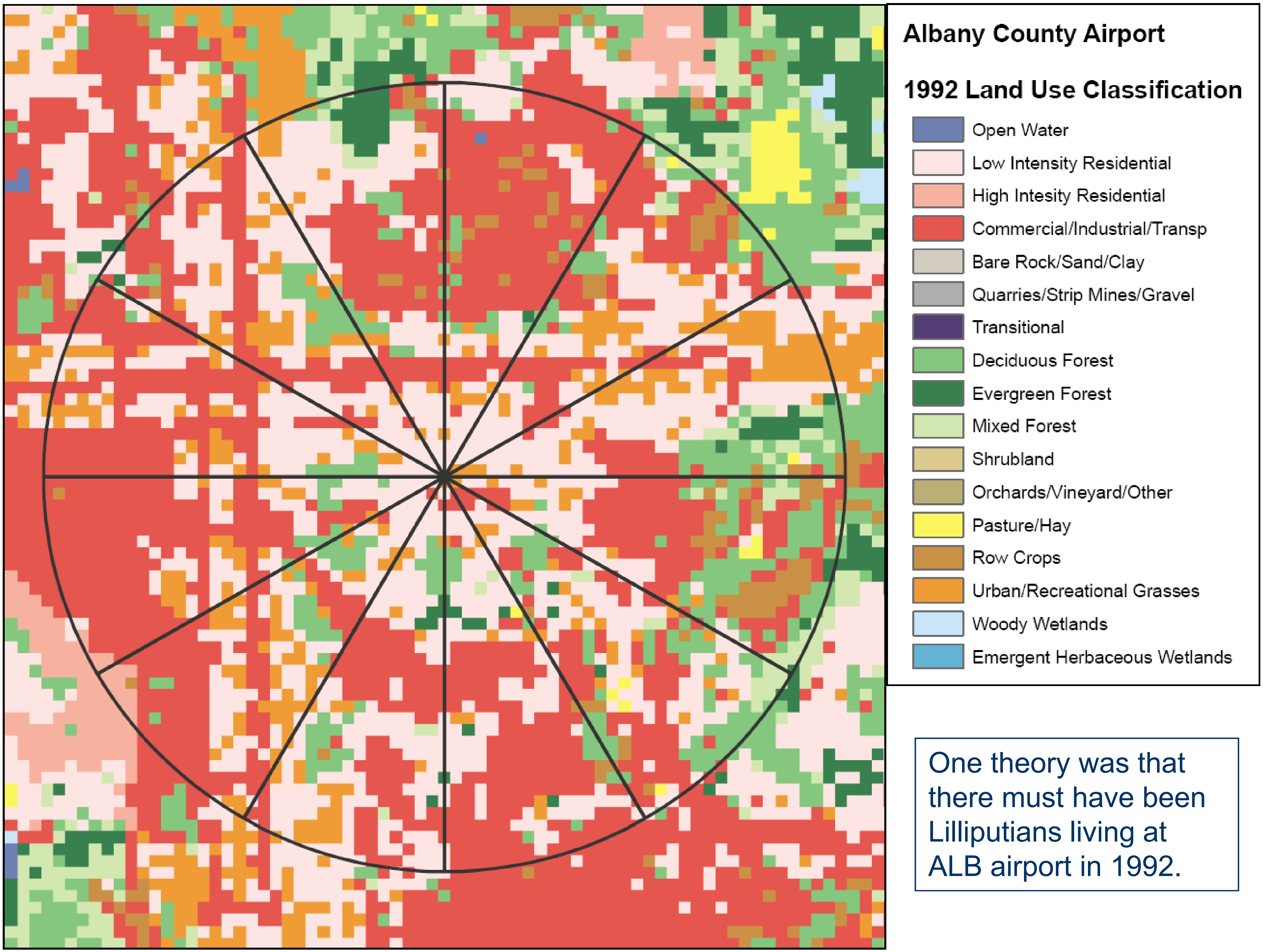
[1] The Gust Factor Method (GFM) is discussed in more detail below.

AERSURFACE Implementation Issues

- Misclassification of land cover categories may compromise the representativeness of land cover data for some sites:
  - Users should compare land cover data to other information, such as aerial photos, to assess representativeness – Google Earth includes option to view aerial photos from different times, depending on what's available for a given site;
  - Next two slides show example of 1992 NLCD land cover misclassification for the Albany, NY (ALB) site, where much of the airport is classified as Low Intensity Residential (cat 21), rather than the more appropriate category of Urban/Recreational Grasses (cat 85)

Albany County Airport

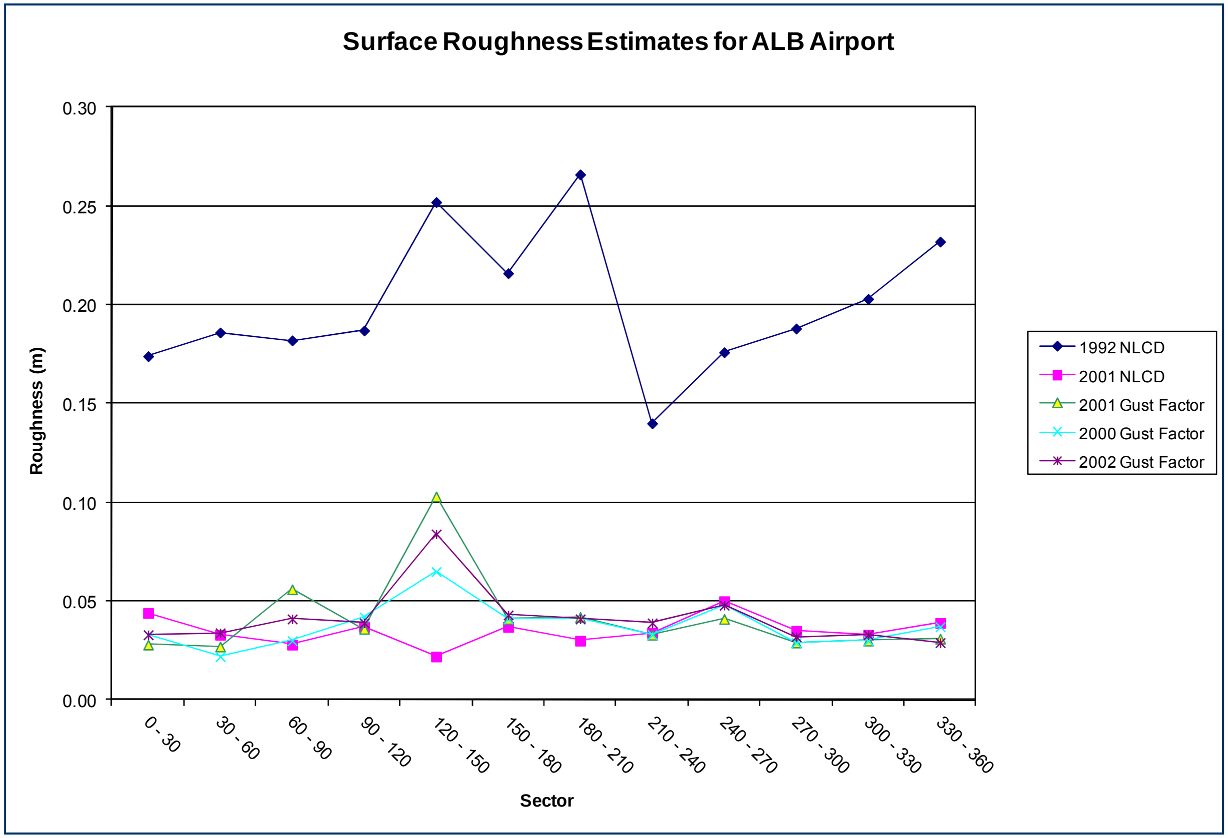
Eastern NYS 2004 1-foot Natural Color Orthophoto



One theory was that there must have been Lilliputians living at ALB airport in 1992.

AERSURFACE Implementation Issues

- Comparison with GFM results for ALB shows significant overestimates for 1992 NLCD, but much better agreement with 2001 NLCD (from internal Beta version):



Implementation Issue - z_0 Tables

- User commented that use of weighted arithmetic-mean average for some categories in surface roughness tables based on mixture of other land cover categories is not consistent with use of weighted geometric-mean (GM) averages in AERSURFACE
- In response to this comment roughness estimates for a few 1992 NLCD categories have been revised to reflect a weighted GM of mixed land cover characteristics; the weights were also adjusted based on a review of the category definitions:
  - Category 21 – Low Intensity Residential
  - Category 23 – Commercial/Industrial/Transportation
  - Category 43 – Mixed Forest
  - Category 91 – Woody Wetlands
- New z_0 values tend to be slightly lower than original values (next slide shows old vs. new values)
- The impact of these revisions was tested for four ASOS sites indicating generally better agreement with Gust Factor Method with new z_0 values:
  - ATL, BHM, and CHA show influences from Cat 21 & Cat 23;
  - CHS shows influence from Cat 23

Pending Roughness Value Changes

Revised Values of Surface Roughness (m) for the NLCD92 based on Geometric Means

Class Number	Class Name	Seasonal Surface Roughness[1] (m)					Reference
		1	*2*	*3*	*4*	*5*	
21	Low Intensity Residential – Current	0.54	0.54	0.50	0.50	0.52	40% 22 + 10% 43+ 50% 85 – Arithmetic
	Low Intensity Residential – Proposed	0.40	0.40	0.30	0.30	0.40	50% 22 + 25% 43+ 25% 85 – Geometric
23	Commercial/Industrial/Transp (Site at Airport) – Current	0.1	0.1	0.1	0.1	0.1	5%: 22 & 95%: 31 – Arithmetic
	Commercial/Industrial/Transp (Site at Airport) – Proposed	0.07	0.07	0.07	0.07	0.07	10%: 22 & 90%: 31 – Geometric
	Commercial/Industrial/Transp (Not at Airport) – Current	0.8	0.8	0.8	0.8	0.8	80%: 22 & 20%: 31 – Arithmetic
	Commercial/Industrial/Transp (Not at Airport) – Proposed	0.7	0.7	0.7	0.7	0.7	90%: 22 & 10%: 31 – Geometric
43	Mixed Forest – Current	1.3	1.3	0.95	0.9	1.15	50% 41+ 50% 42 – Arithmetic
	Mixed Forest – Proposed	1.3	1.3	0.9	0.8	1.1	50% 41+ 50% 42 – Geometric
91	Woody Wetlands – Current	0.7	0.7	0.6	0.5	0.7	50% 43+ 50% 92 – Arithmetic
	Woody Wetlands – Proposed	0.5	0.5	0.4	0.3	0.5	50% 43+ 50% 92 – Geometric

[1] Values are listed for the following seasonal categories: *1 - Midsummer with lush vegetation; 2 - Autumn with unharvested cropland; 3 - Late autumn after frost and harvest; or winter with no snow; 4 - Winter with continuous snow on ground; 5 - Transitional spring with partial green coverage or short annuals*

Implementation Issues

- Revisions to calculation methods and default domain/distances incorporated in AERSURFACE, compared to original method in AERMET User's Guide (3km area-weighted), has resulted in significant differences in modeled concentrations in some cases
- Some concerns expressed regarding revised recommendations, and basis for default 1km roughness radius has been questioned
- Use of non-default roughness radius submitted to Model Clearinghouse by Region 4
  - MC response cites determination of appropriate surface characteristics as an important issue with the implementation of the AERMOD model, and the importance of consistency in the application of the AERSURFACE tool (or equivalent tools) at this stage in the implementation of the AERMOD modeling system
- Implementation issues highlight need to validate AERSURFACE methodology and/or develop more robust method to estimate effective surface roughness based on site characteristics

“Validating” AERSURFACE Roughness Estimates

- Comparison of AERSURFACE roughness values with Gust Factor Method (GFM) based on Wieringa (BAMS, 1980) using 1-minute ASOS wind data, may provide method to “validate” AERSURFACE
- Preliminary findings from GFM:
  - GFM roughness estimates appear to be reasonable based on actual site characteristics
  - results generally compare well with AERSURFACE estimates when land cover is “well-defined” by the NLCD data
  - results show significant impact of temporal variation for some sites
  - results highlight problems with land cover definitions for some sites; also may flag potential errors in tower location

Description of Gust Factor Method

- Gust Factor Method (GFM) for estimating surface roughness presented by Wieringa in BAMS (1980) and QJROC (1976):

$$G = 1 + (1.42 + 0.3 \ln [(10^3/Ut) - 4])/\ln (z/z_0)$$

where G = gust factor

U_t = gust wavelength (m); function of anemometer specs and sampling time

z = anemometer height (m)

z_0 = effective surface roughness (m)

Wieringa recommends using peak and mean wind speeds over 10-minute period for cases where average WS > 10 kt

- Verkaik and Holtslag (BLM, 2007) revisited Cabauw data and found good results from GFM

Description of Gust Factor Method

- Section 6.6.3 of EPA's *Meteorological Monitoring Guidance for Regulatory Modeling Applications* (EPA-454/R-99-005, Feb. 2000) indicates that "the recommended method for estimating the effective roughness length is based on single level gustiness measurements σ_u:"

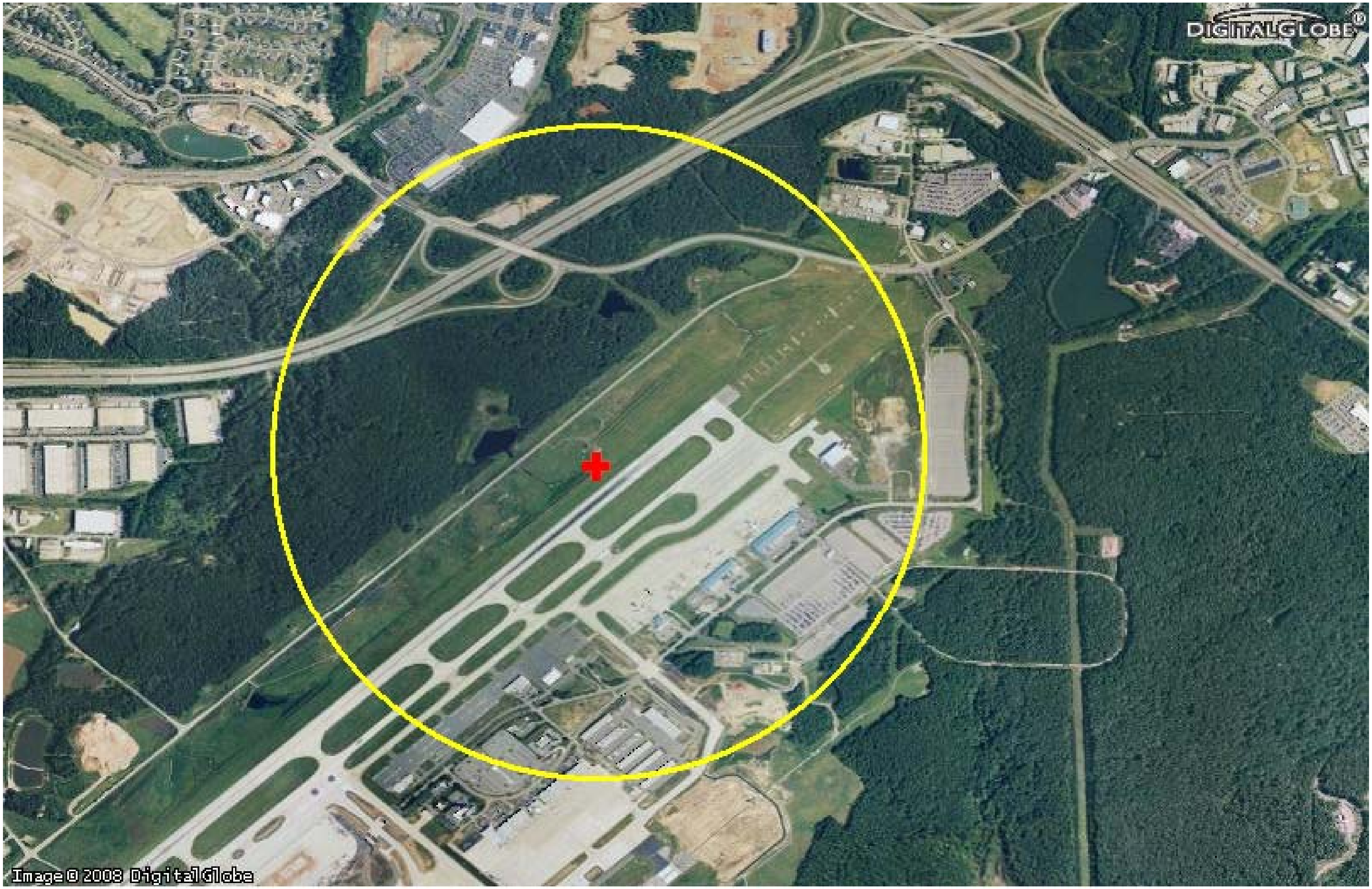
$$\frac{\sigma_u}{\overline{u}} = \frac{1}{\ln(z/z_0)} \qquad (6.6.11)$$

- Section 6.6.3 also recommends using the median z_0 value (by sector if appropriate) based on cases with WS > 5 m/s
- Wieringa (1993) refers to the GFM as "a poor-man's version" of the turbulence intensity method described above

Application of Gust Factor Method

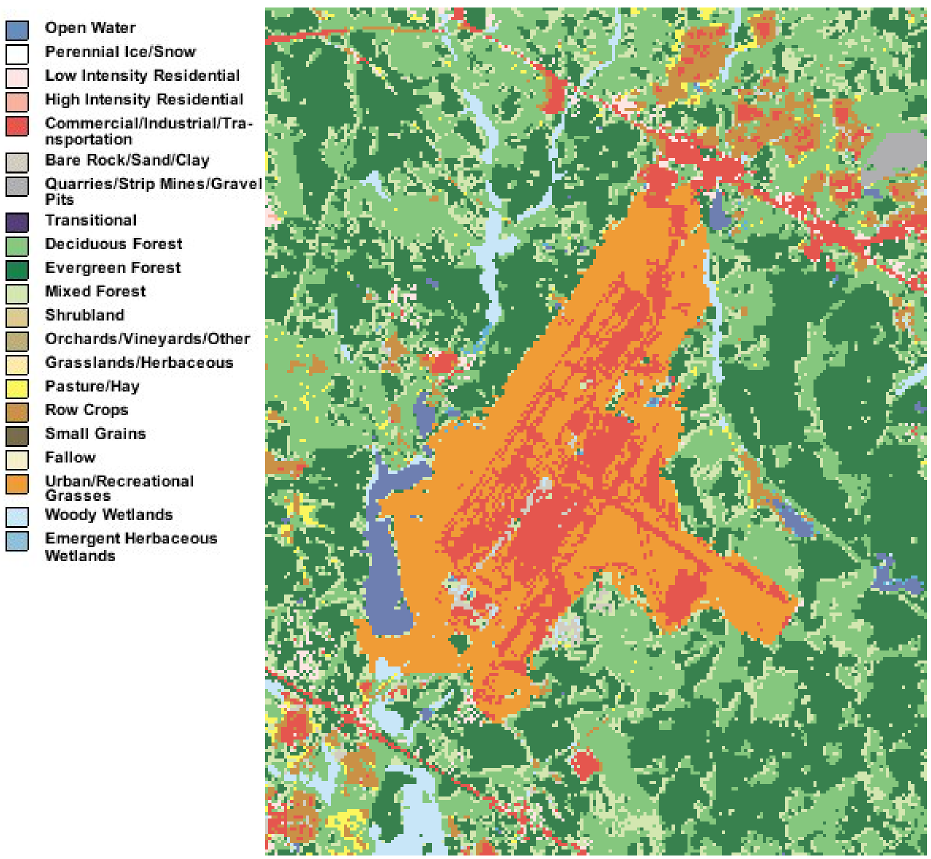
- 1-minute ASOS wind data (TD-6405) includes the 2-minute average WS and peak WS reported every minute
- Peak and mean wind speeds reported in whole knots; recently confirmed that all ASOS wind speeds are truncated, rather than rounded, to whole knots
- Peak winds are based on block 5-second averages for pre-sonic sites and rolling 3-second averages for sites with sonic anemometers; these differences affect specification of U_t
- Roughness estimates are based on median value for cases with mean WS > 10 knots consistent with Wieringa
- Inconsistent format and quality of 1-minute ASOS data files also presents a practical challenge to application of GFM

RDU Airport ASOS Site – 1 km Radius

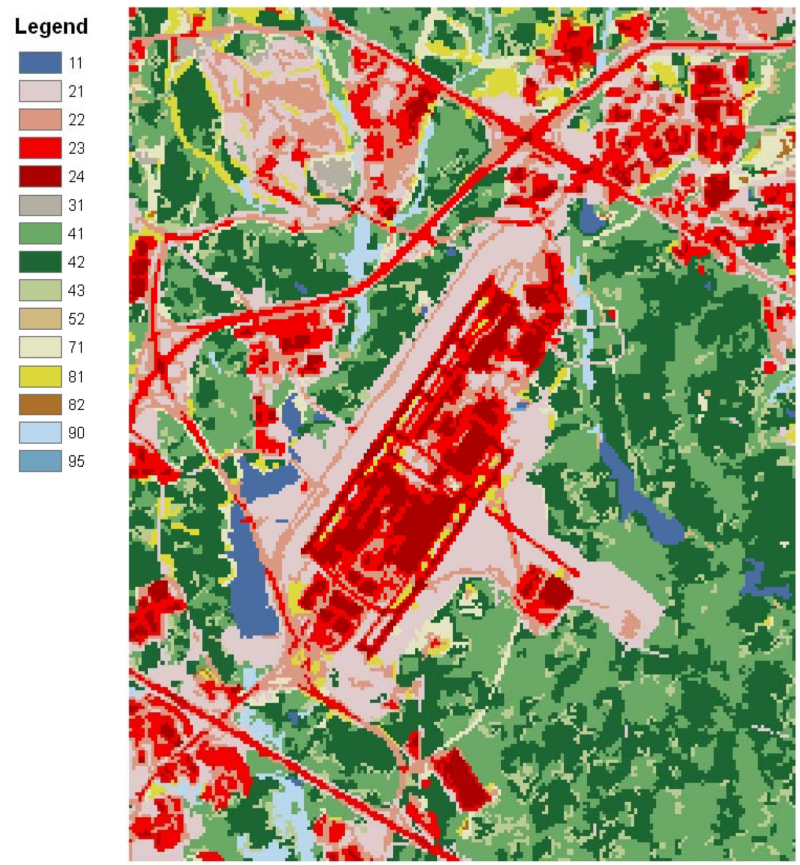


NLCD 1992 vs. NLCD 2001 for RDU

1992 Data

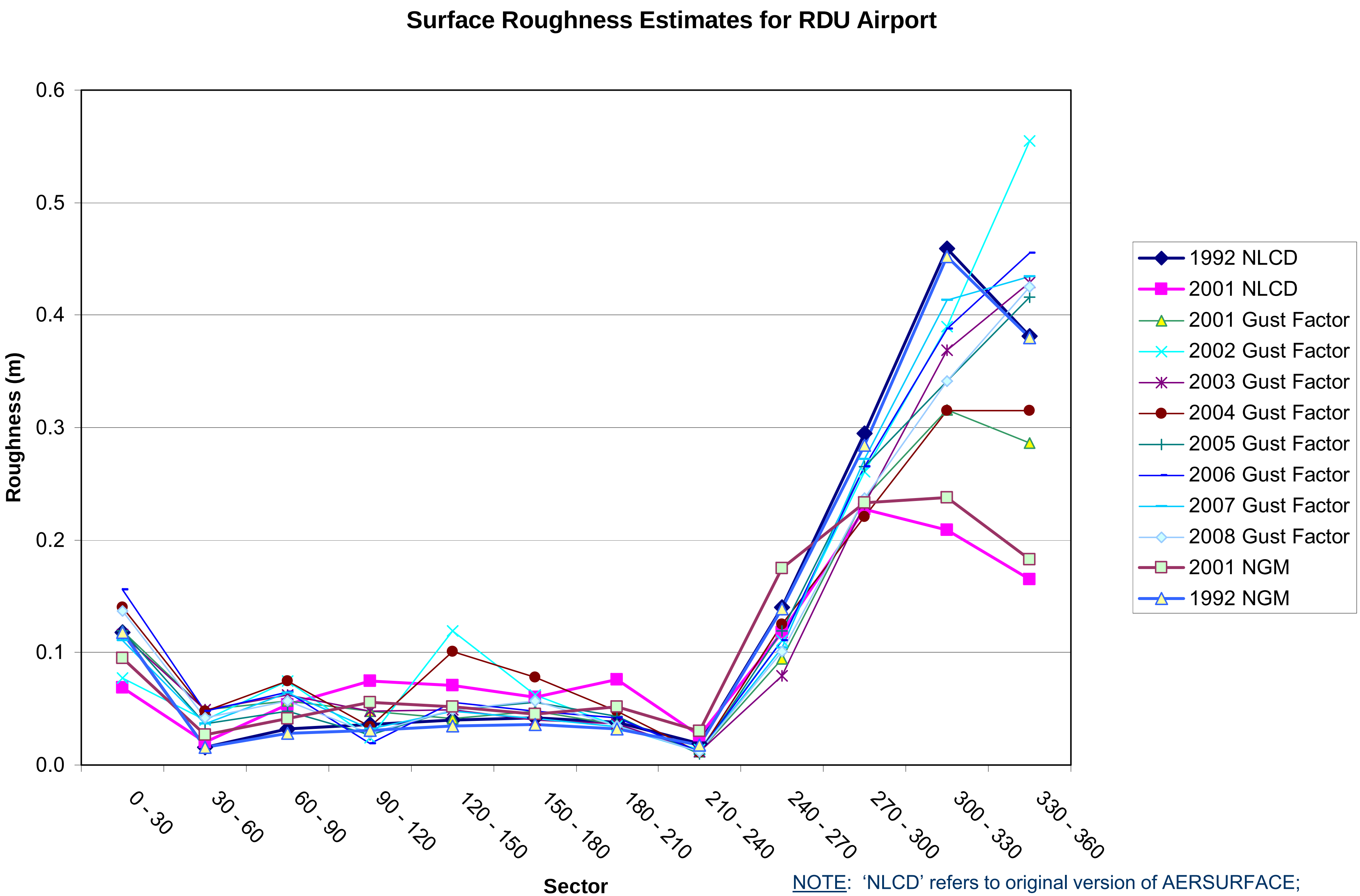


2001 Data



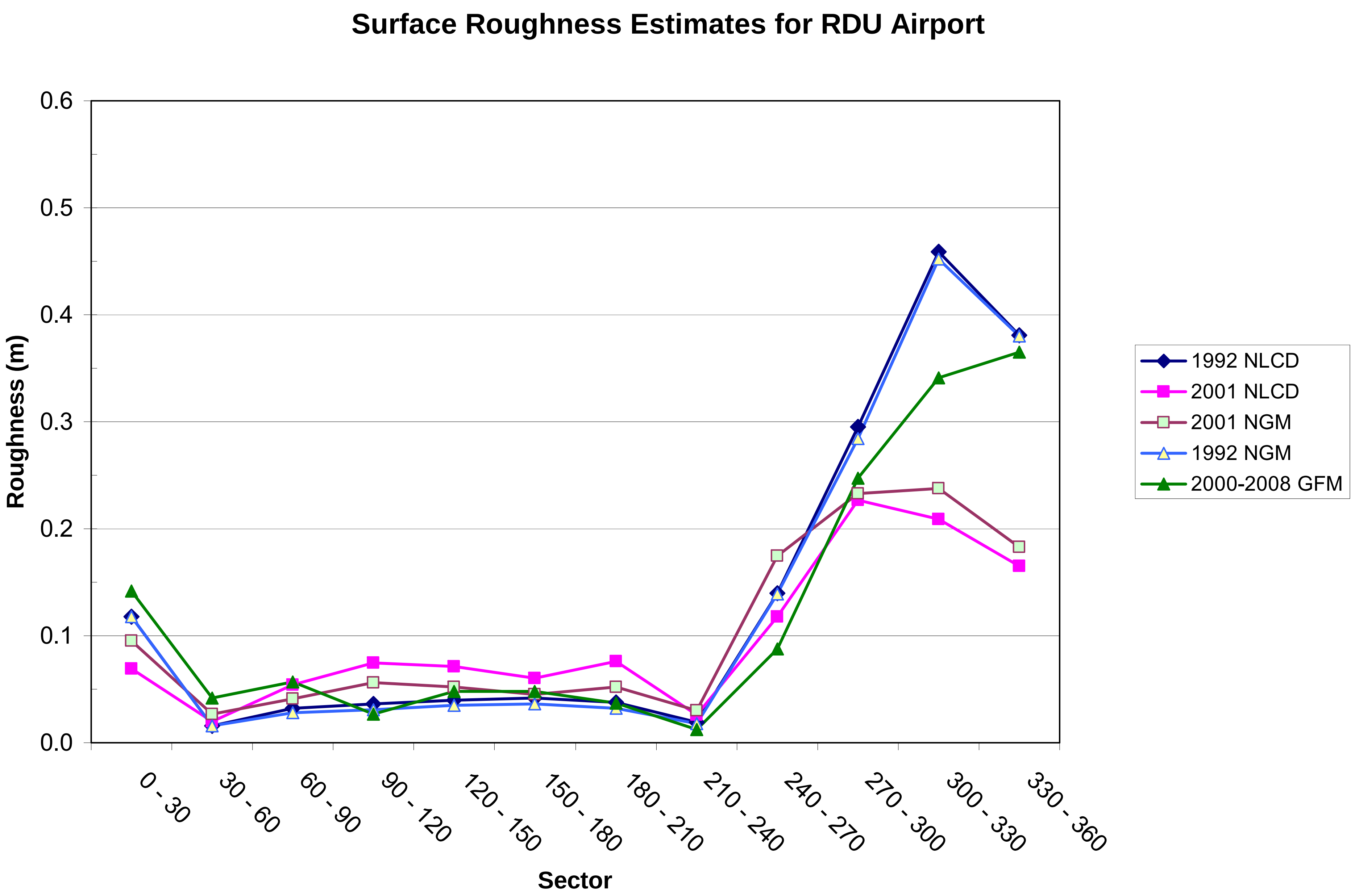
Airport ASOS Photos for RDU (2000)

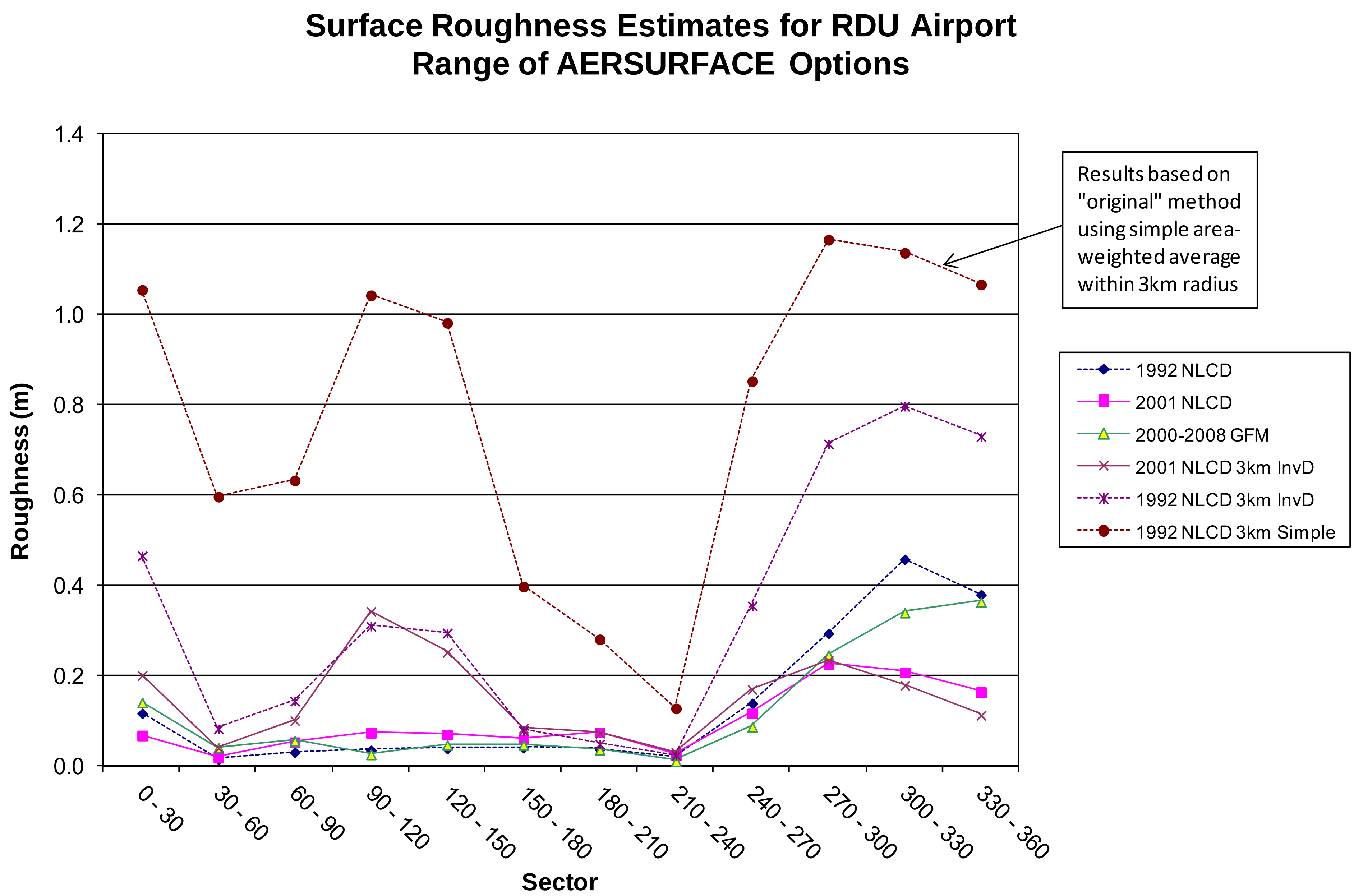
Roughness Estimates based on Gust Factor Method – RDU



NOTE: 'NLCD' refers to original version of AERSURFACE;
'NGM' refers to New Geometric Mean weighted values in revised Beta version of AERSURFACE.

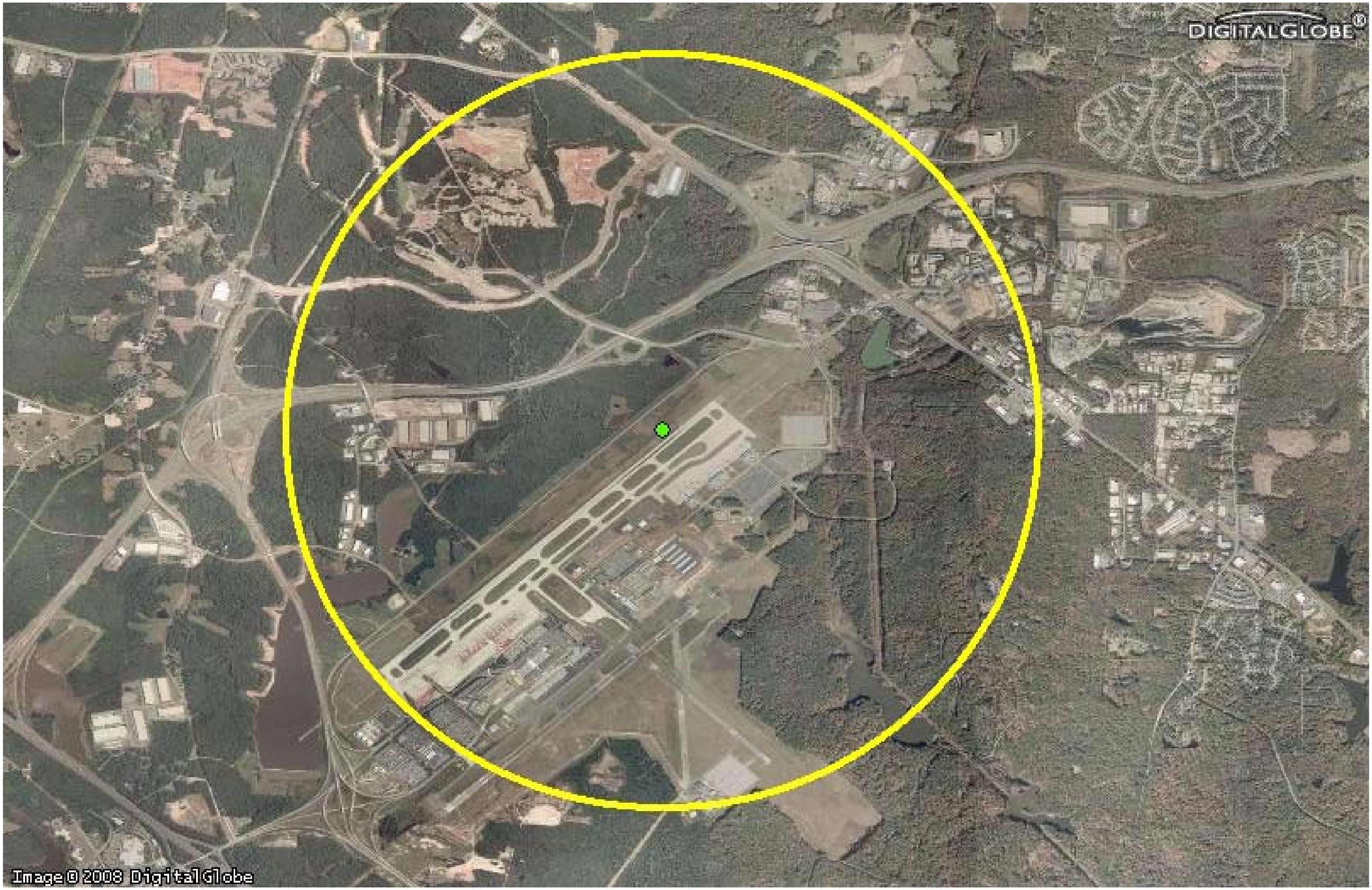
Roughness Estimates based on Gust Factor Method – RDU





Surface Roughness Estimates for RDU Airport
Range of AERSURFACE Options
Roughness (m)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0 - 30
30 - 60
60 - 90
90 - 120
120 - 150
150 - 180
180 - 210
210 - 240
240 - 270
270 - 300
300 - 330
330 - 360
Sector
Results based on "original" method using simple area-weighted average within 3km radius
1992 NLCD
2001 NLCD
2000-2008 GFM
2001 NLCD 3km InvD
1992 NLCD 3km InvD
1992 NLCD 3km Simple

RDU Airport ASOS Site – 3 km Radius



ATL Airport ASOS Site – circa 2000

Legend

GlobeXplorer_44.jpg

RGB

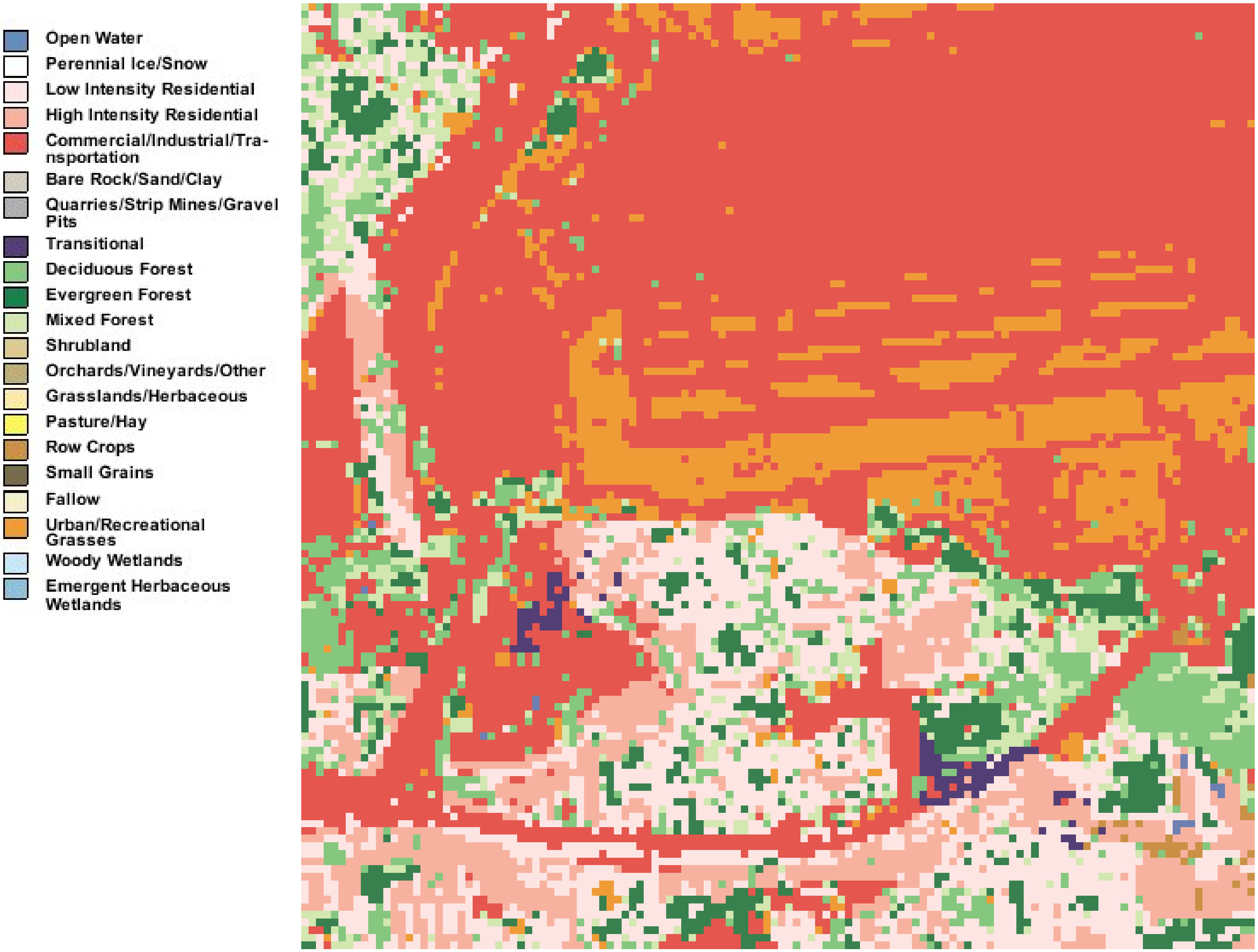
Red: Band_1

Green: Band_2

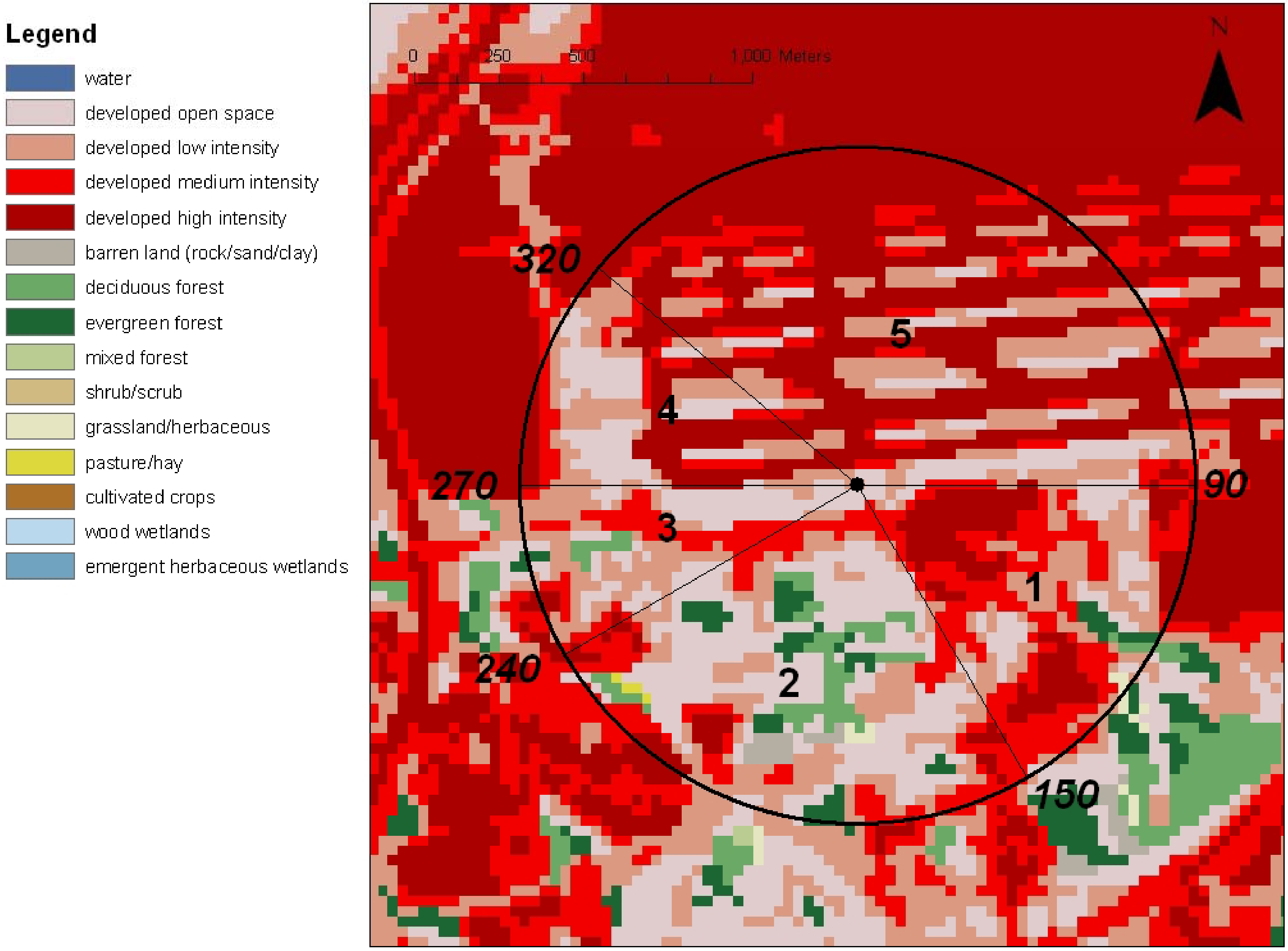
Blue: Band_3

Circle shows 1km radius

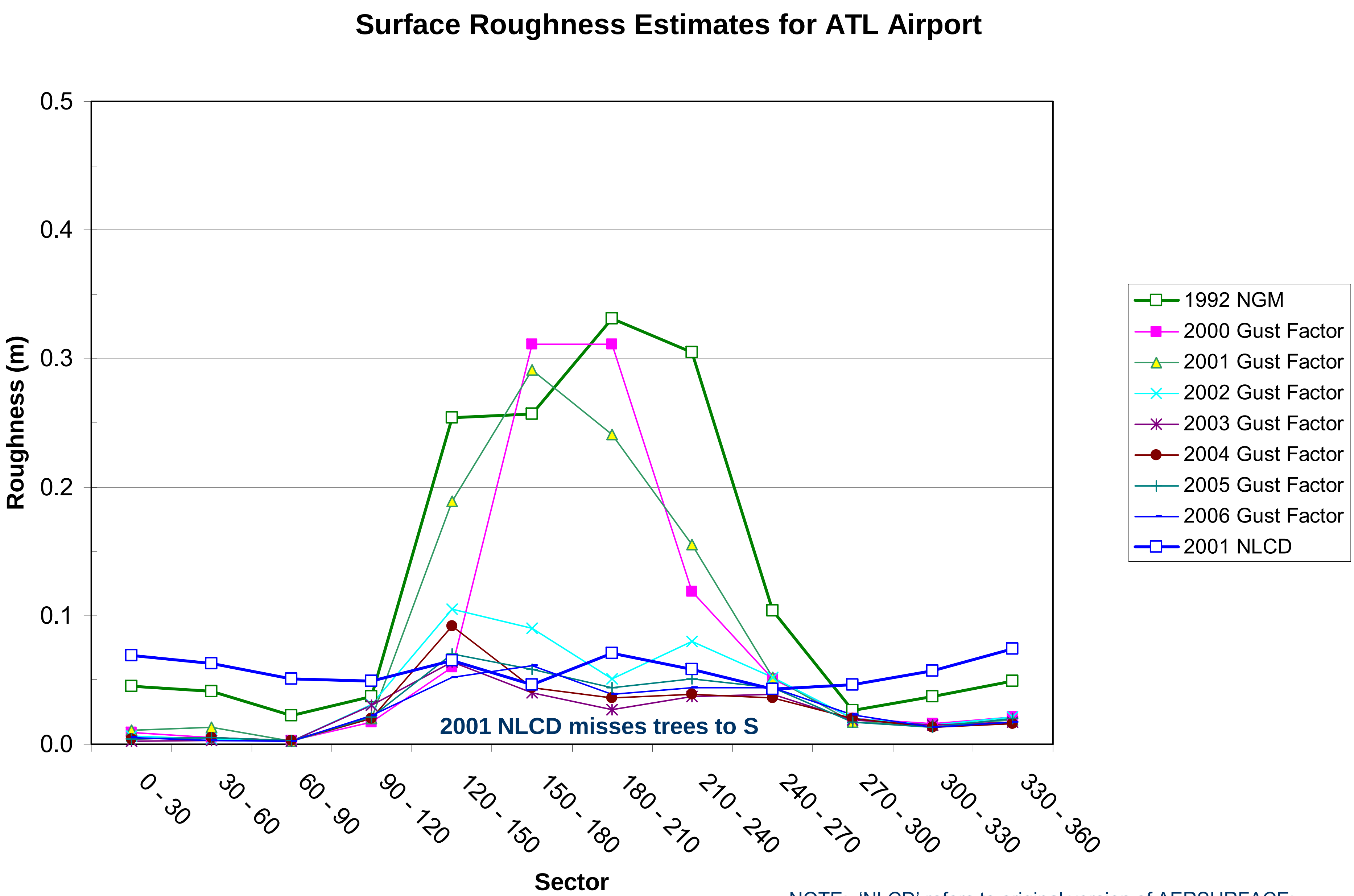
1992 NCLD for ATL Airport



2001 NCLD for ATL Airport

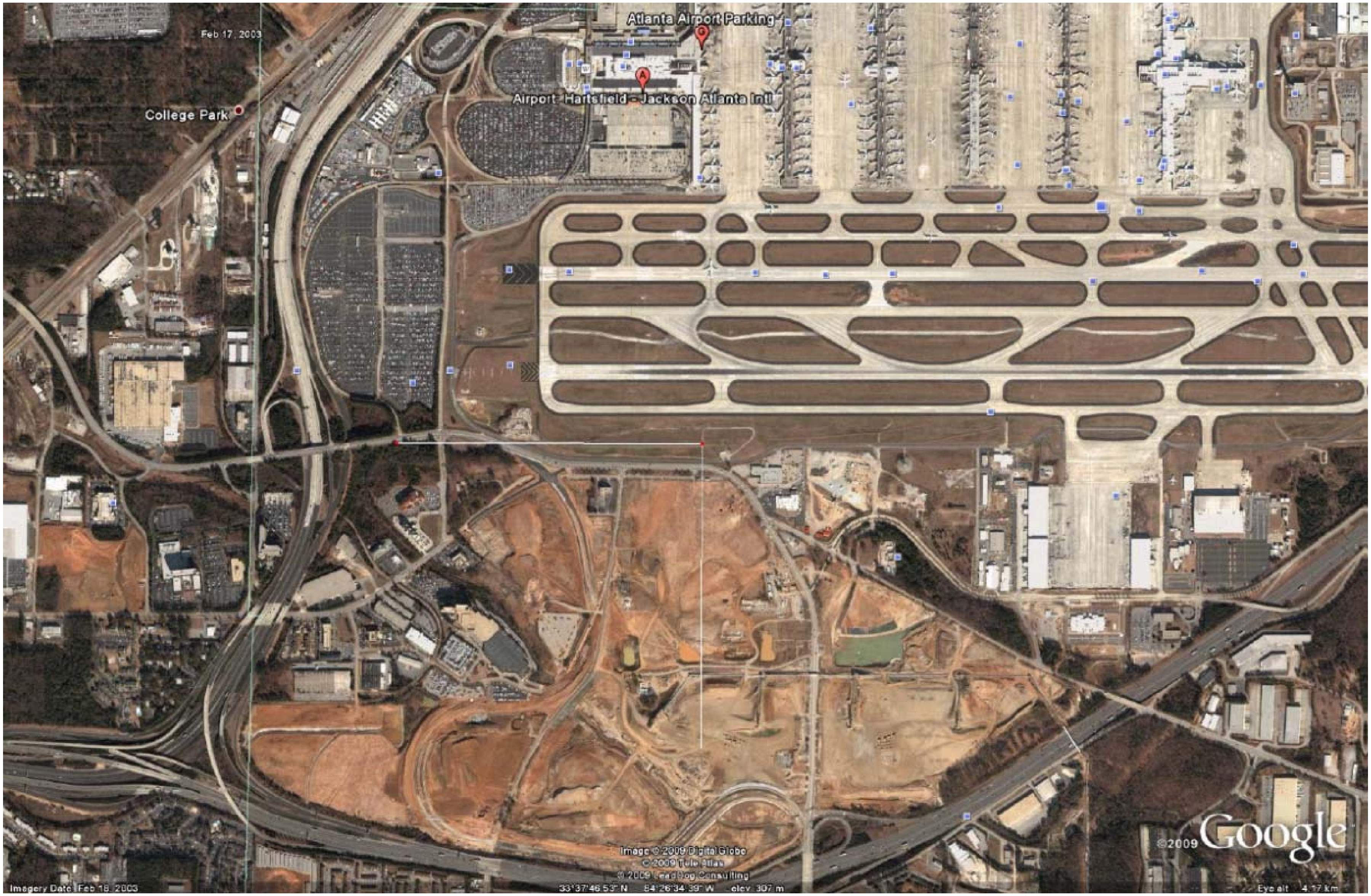


Airport ASOS Photos for ATL (1999)



NOTE: 'NLCD' refers to original version of AERSURFACE; 'NGM' refers to New Geometric Mean weighted values in revised Beta version of AERSURFACE.

ATL Airport ASOS Site – February 2003



Lines show 1km radius

ATL Airport ASOS Site – circa 2000

Legend

GlobeXplorer_44.jpg

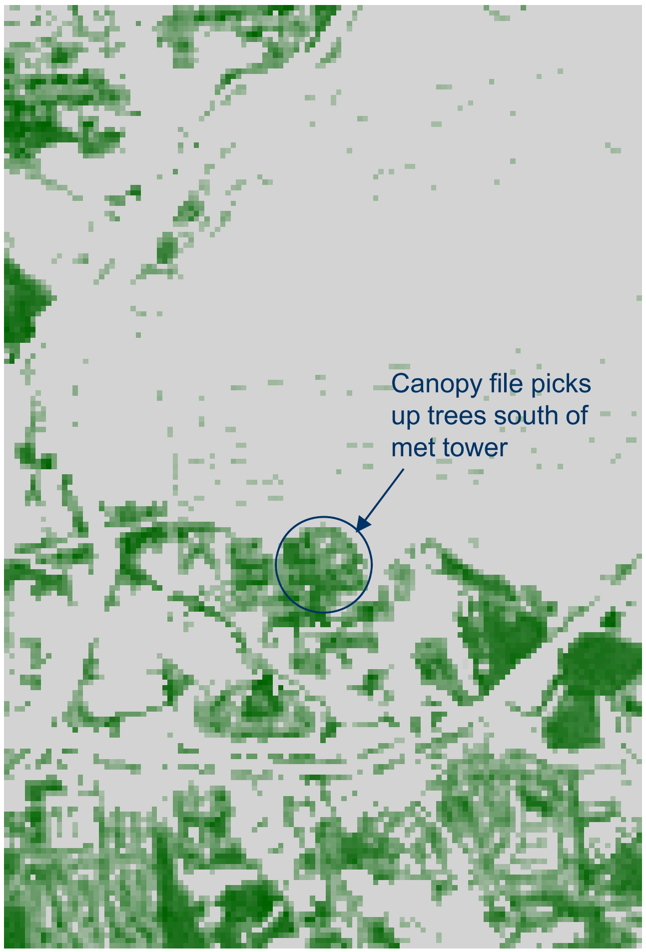
RGB

- Red: Band_1
- Green: Band_2
- Blue: Band_3

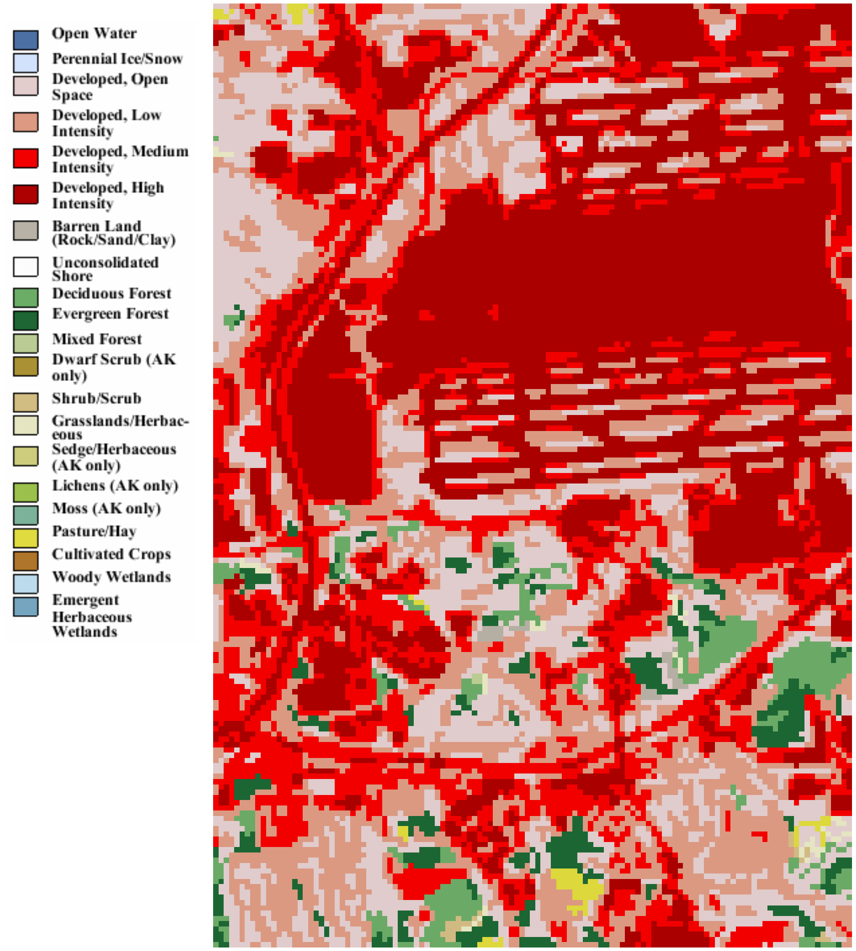
Circle shows 1km radius

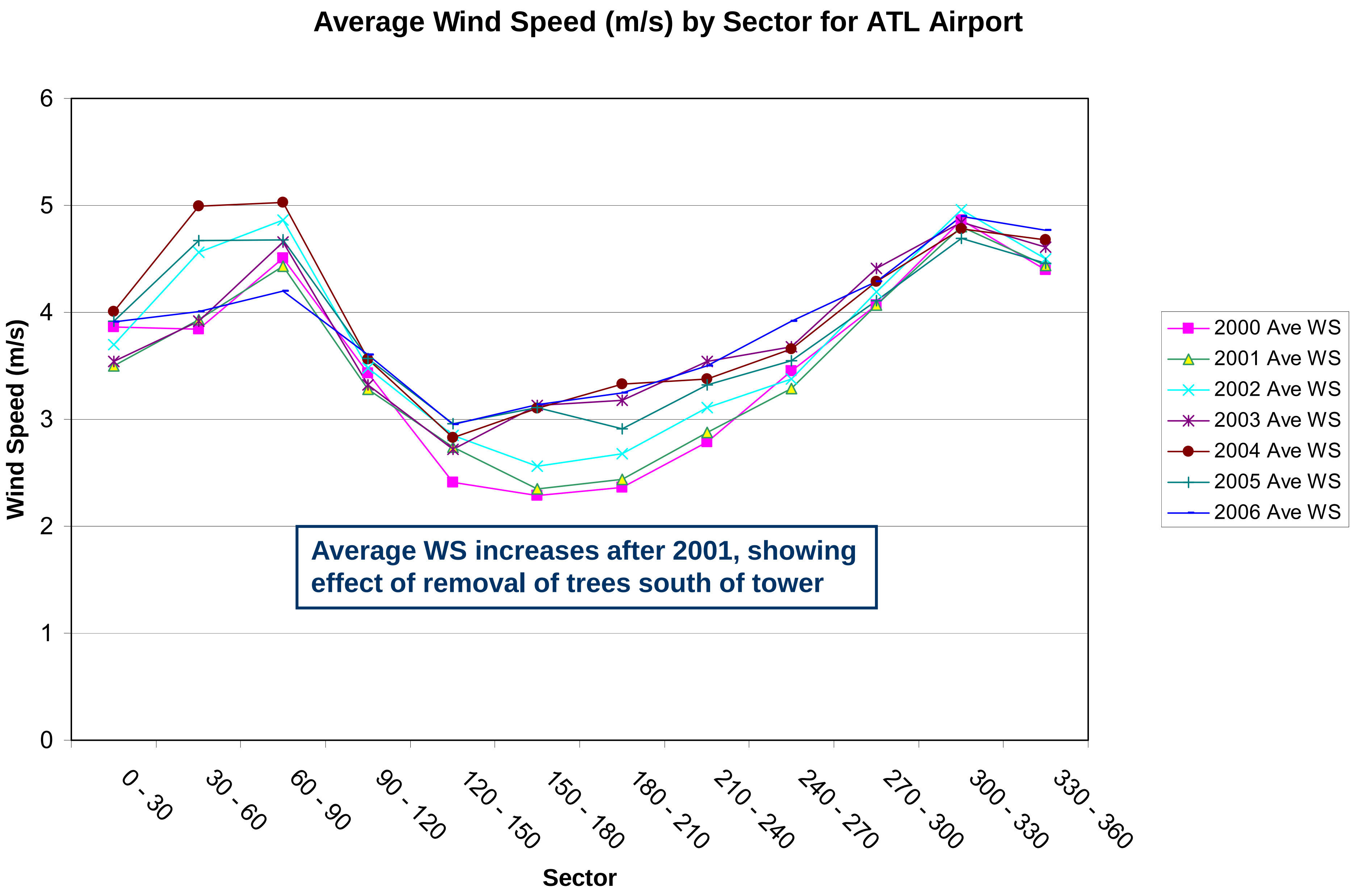
2001 Canopy and NLCD for ATL

2001 Canopy Data



2001 NLCD




Average Wind Speed (m/s) by Sector for ATL Airport
Wind Speed (m/s)
0
1
2
3
4
5
6
0 - 30
30 - 60
60 - 90
90 - 120
120 - 150
150 - 180
180 - 210
210 - 240
240 - 270
270 - 300
300 - 330
330 - 360
Sector
Average WS increases after 2001, showing effect of removal of trees south of tower
2000 Ave WS
2001 Ave WS
2002 Ave WS
2003 Ave WS
2004 Ave WS
2005 Ave WS
2006 Ave WS

Evaluating New Method for Effective Roughness in AERSURFACE

Introduction

- The recommended default radius of 1km for estimating surface roughness in AERSURFACE has been raised as an issue by the modeling community, and was the subject of a 2009 Model Clearinghouse memo.
- The *AERMOD Implementation Guide* identifies three situations where a non-default radius may be considered on a case-by-case basis, but no clear guidance is available on how to determine an appropriate radius.
- AERMIC developed a methodology for determining an appropriate fetch and effective roughness based on the characteristics of the site using an Internal Boundary Layer (IBL) approach, referred to as the Effective Roughness Method (ERM).
- An important parameter in the IBL approach is the height of the boundary layer (H) used to define the fetch, based on a multiple of the anemometer height (z_{anem}).
- Comparisons of roughness estimates using the new IBL approach with estimates based on the current AERSURFACE method and the gust factor method (GFM) for several sites have examined values of H = 5*, 6* and 10^*z_{anem}.
- A value of $H=6^*z_{anem}$ generally provides the best results, and is consistent with Wieringa's (1976) suggestion of 60 meters as a "roughness blending height".

Effective Roughness Method

- If we assume that the roughness is constant between two points, the change in the internal boundary layer height, $\boldsymbol{h}$, between these two points is given by:

$$\frac{dh}{dx} = \frac{k}{\ln\left(\frac{h}{z_0}\right)} \qquad (1)$$

- Integrating this equation between points, $\boldsymbol{x_i}$ and $\boldsymbol{x_{i+1}}$, gives:

$$h_{i+1}\left(\ln\left(\frac{h_{i+1}}{z_{0avg}}\right)-1\right) = h_i\left(\ln\left(\frac{h_i}{z_{0avg}}\right)-1\right)+k\left(x_{i+1}-x_i\right) \qquad (2)$$

- Then, the effective roughness is the solution of the integral of Equation (1), assuming that a constant effective roughness, $\boldsymbol{z_{0eff}}$, applies to the region $\boldsymbol{0}$ to $\boldsymbol{x_{rad}}$:

$$h_{ref}\left(\ln\left(\frac{h_{ref}}{z_{0eff}}\right)-1\right)+z_{0eff} = kx_{rad} \qquad (3)$$

Internal Boundary Layers

Internal boundary layers are significantly developed disturbance layers in the near-surface layer, which are generated by horizontal advection over discontinuities of the surface properties (roughness, thermal properties, *etc*.).

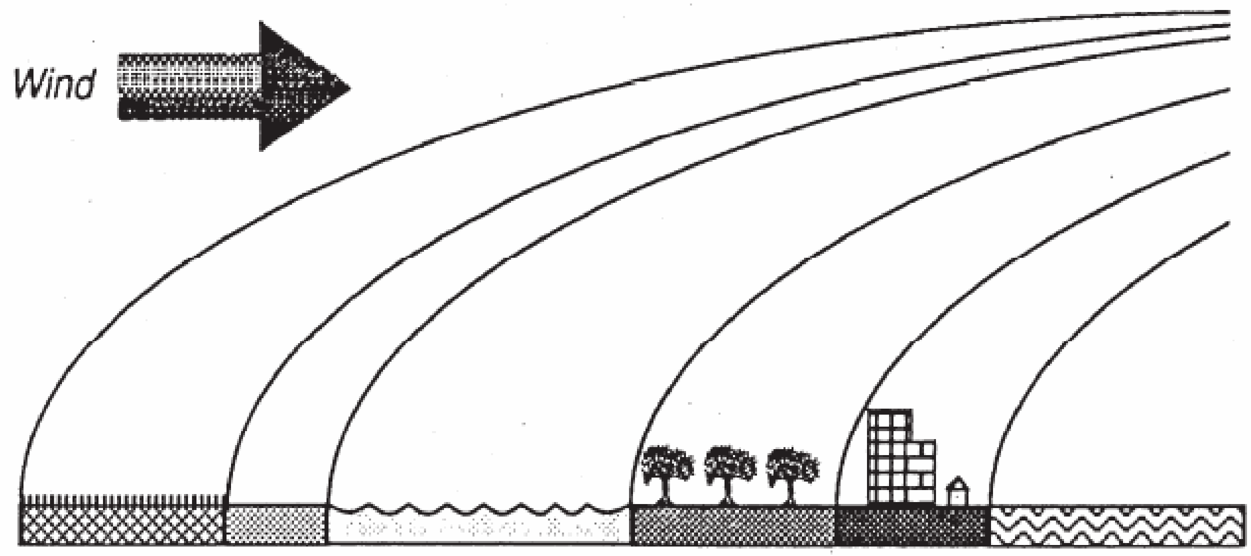


Fig. 3.7. Generation of internal boundary layers above an inhomogeneous surface (Stull 1988)

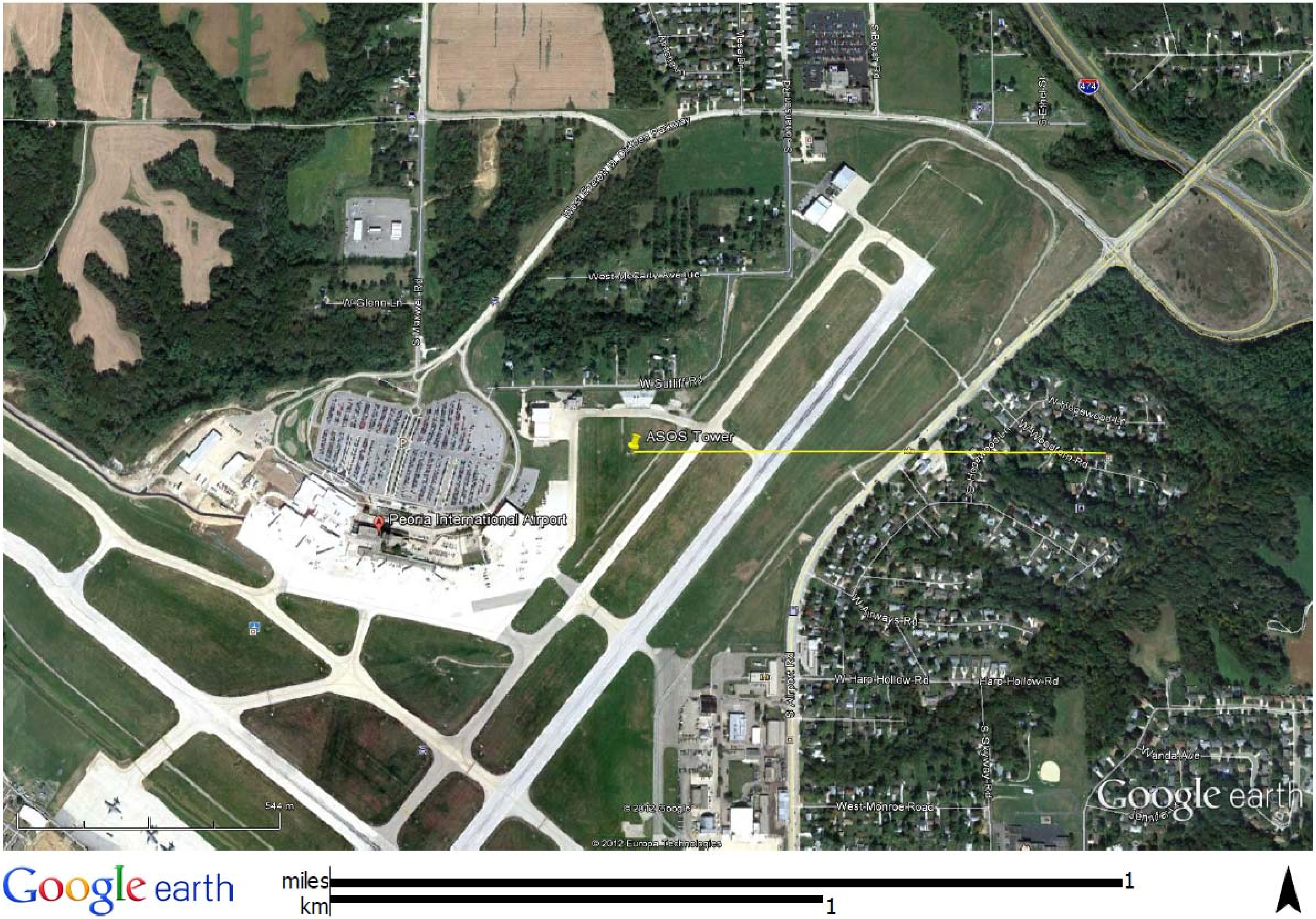
Effective Roughness Method (cont.)

- The approach currently being used for the Effective Roughness Method in a Beta version of AERSURFACE is as follows:
  - Starting at the reference (tower) location, the IBL method is used to estimate the radius needed to reach a height of 6*z moving away from the tower;
  - Since the initial effective radius will tend to weight land cover closest to the tower more, the process is reversed by estimating the radius needed to reach the reference height moving back toward the tower, which would tend to land cover further from the tower higher;
  - This process is iterated until the “outward” and “inward” radii match;
  - Although the “inward” effective radius may be more appropriate since the boundary layer increases with the direction of flow, neither approach is ideal from a physical sense;
  - The final “effective roughness” estimate is based on the geometric mean of the effective roughness values derived from the final “inward” and “outward” approaches

Evaluation of Effective Roughness Method

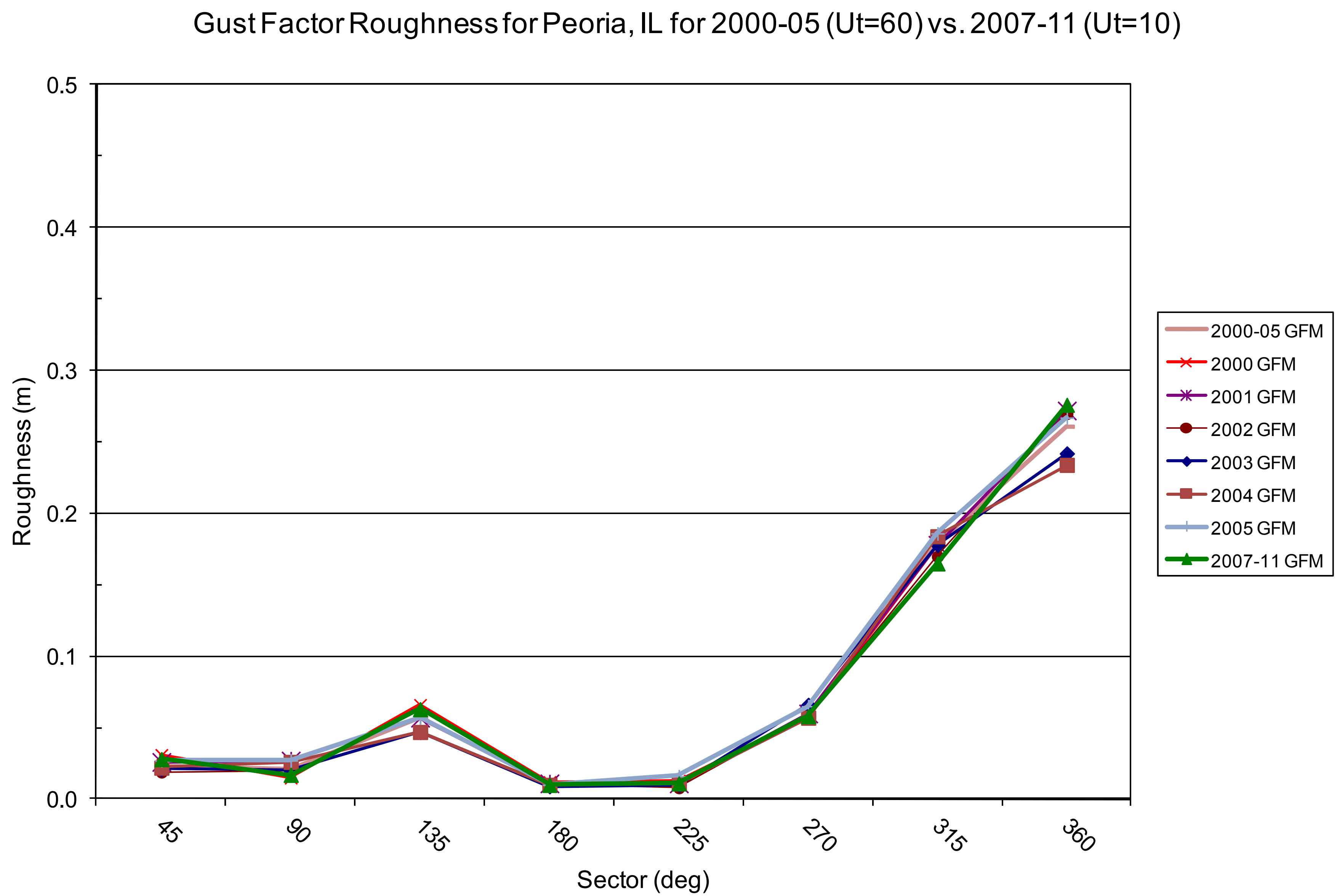
- An important factor that needs to be considered in using the GFM to evaluate methods for estimating effective roughness is the appropriate value of U_t, the gust wavelength, which depends on the response time of the anemometer and the sampling period for the gusts;
- The response time and sampling period for 1-minute ASOS data differ depending on whether the site has been commissioned with a sonic anemometer through the Ice Free Wind (IFW) program;
- Peak gusts for pre-sonic ASOS data are based on block 5-second averages, whereas gusts for IFW-sonic ASOS data are based on rolling 3-second averages; however, the mean wind speeds for both pre- and post-sonic data are based on block 2-minute averages;
- Use of rolling 3-second averages for sonic gust data may introduce a slight bias to overestimate the gust factors since the peak gust associated with a specific 2-minute mean wind could reflect higher 1-second samples outside the period of the 2-minute mean wind;
- Based on available information, values of 60 for U_t for pre-sonic and 10 for post-sonic appear reasonable, as shown below for PIA and RDU

Peoria, IL (PIA) Airport ASOS Site – 1 km Radius

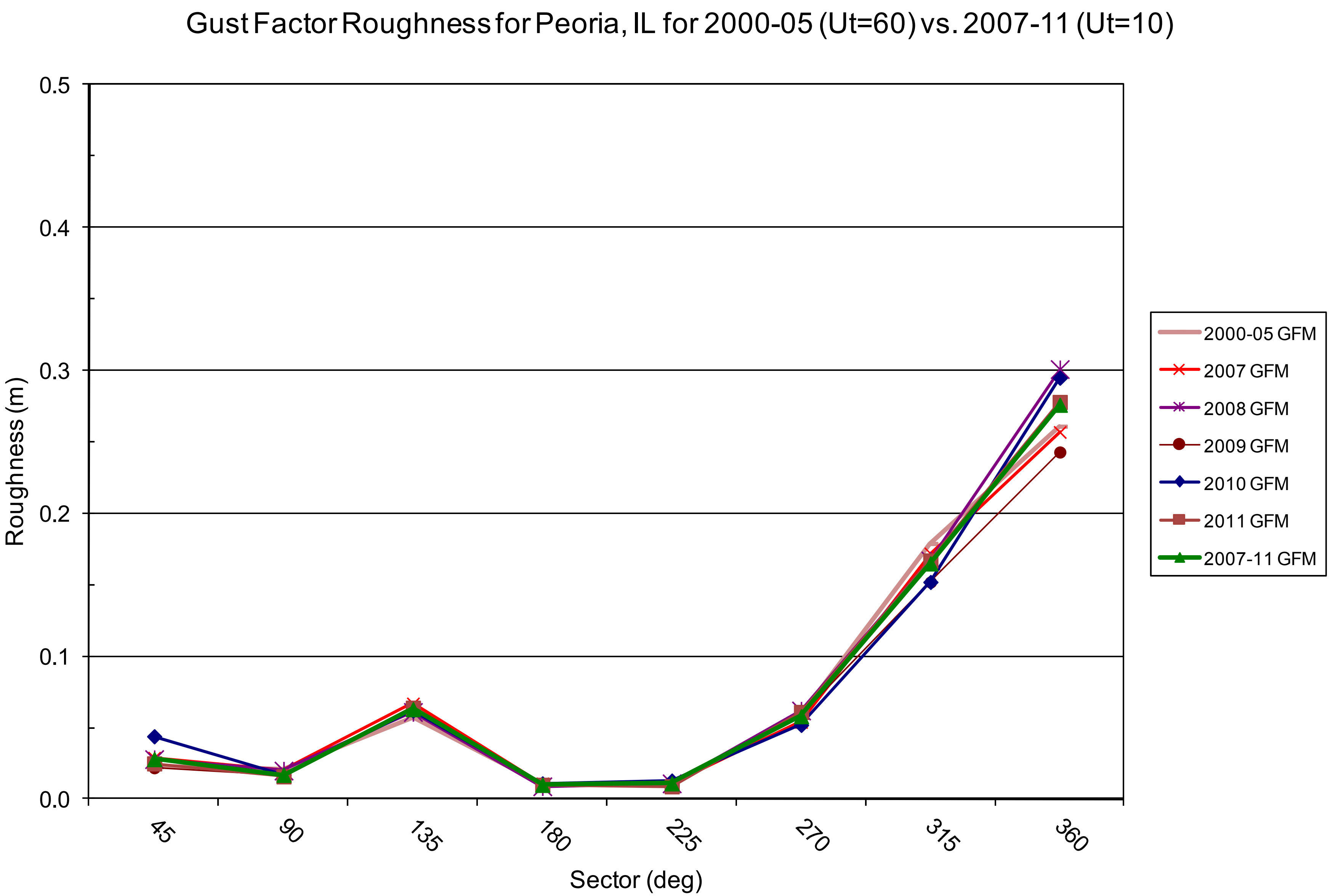


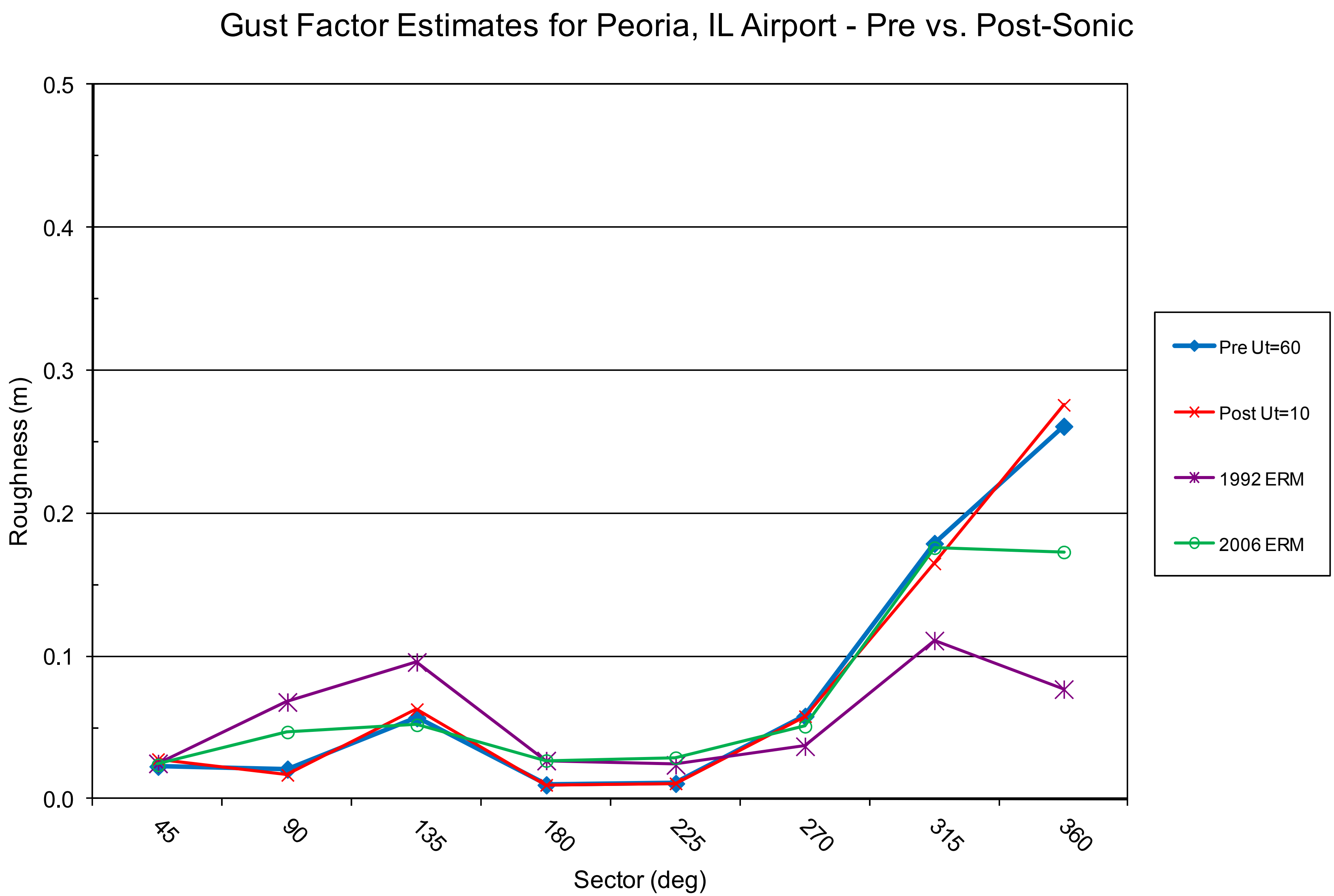
Assessment for PIA

- The Peoria, IL (PIA) ASOS site includes some clear sector-dependent roughness patterns, with trees and residential areas within about 200 meters north of the tower and 400 meters southeast of the tower;
- The PIA ASOS also has shown relatively little change over time, as reflected in limited year-to-year variations in GFM results;
- The PIA site was commissioned with a sonic anemometer in Sept. 2006; with at least five years of pre-sonic and five years of post-sonic 1-min ASOS data available;
- The following slides shown very consistent GFM results based on U_t = 60 for pre-sonic and U_t = 10 for post-sonic data

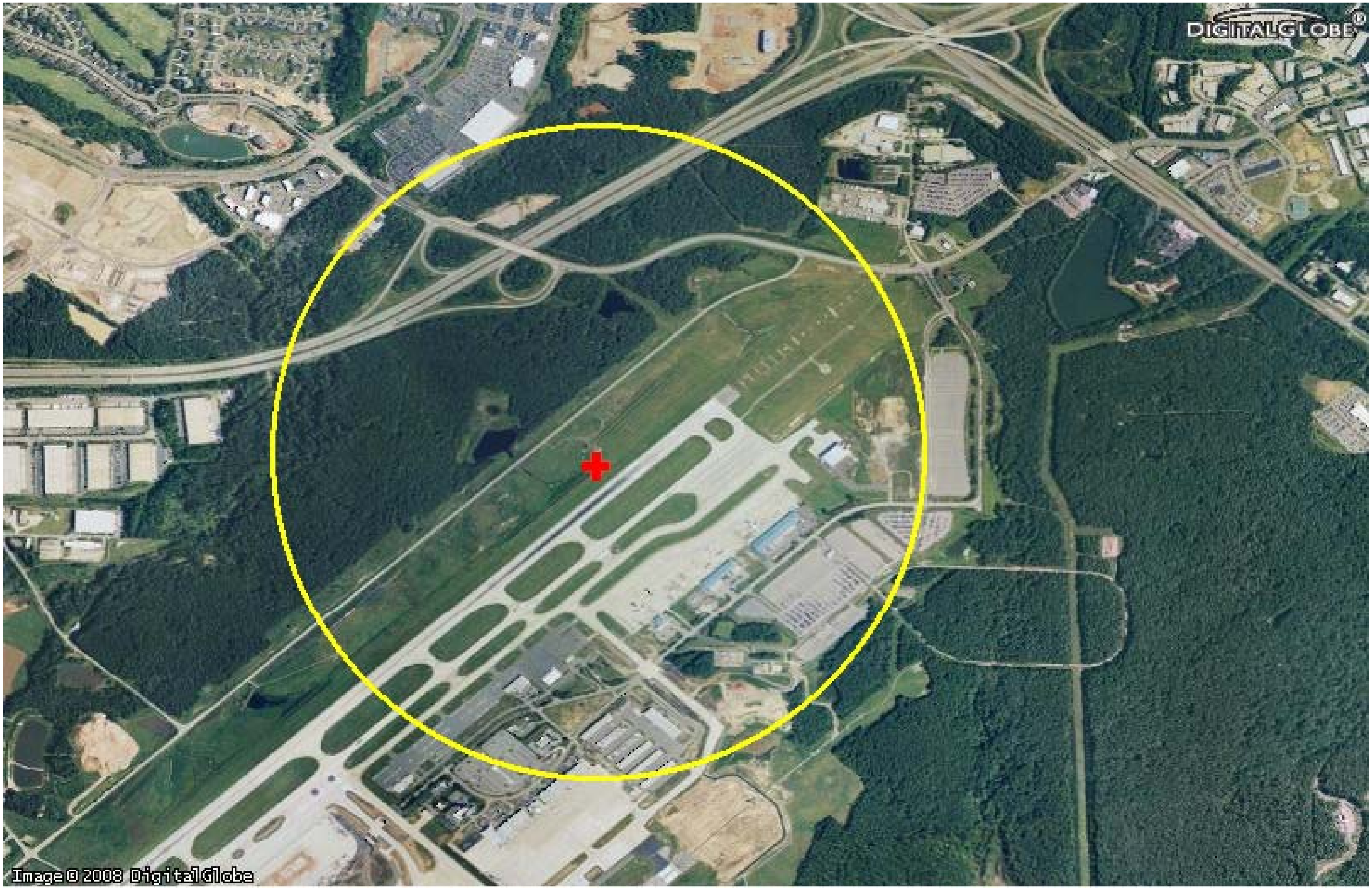


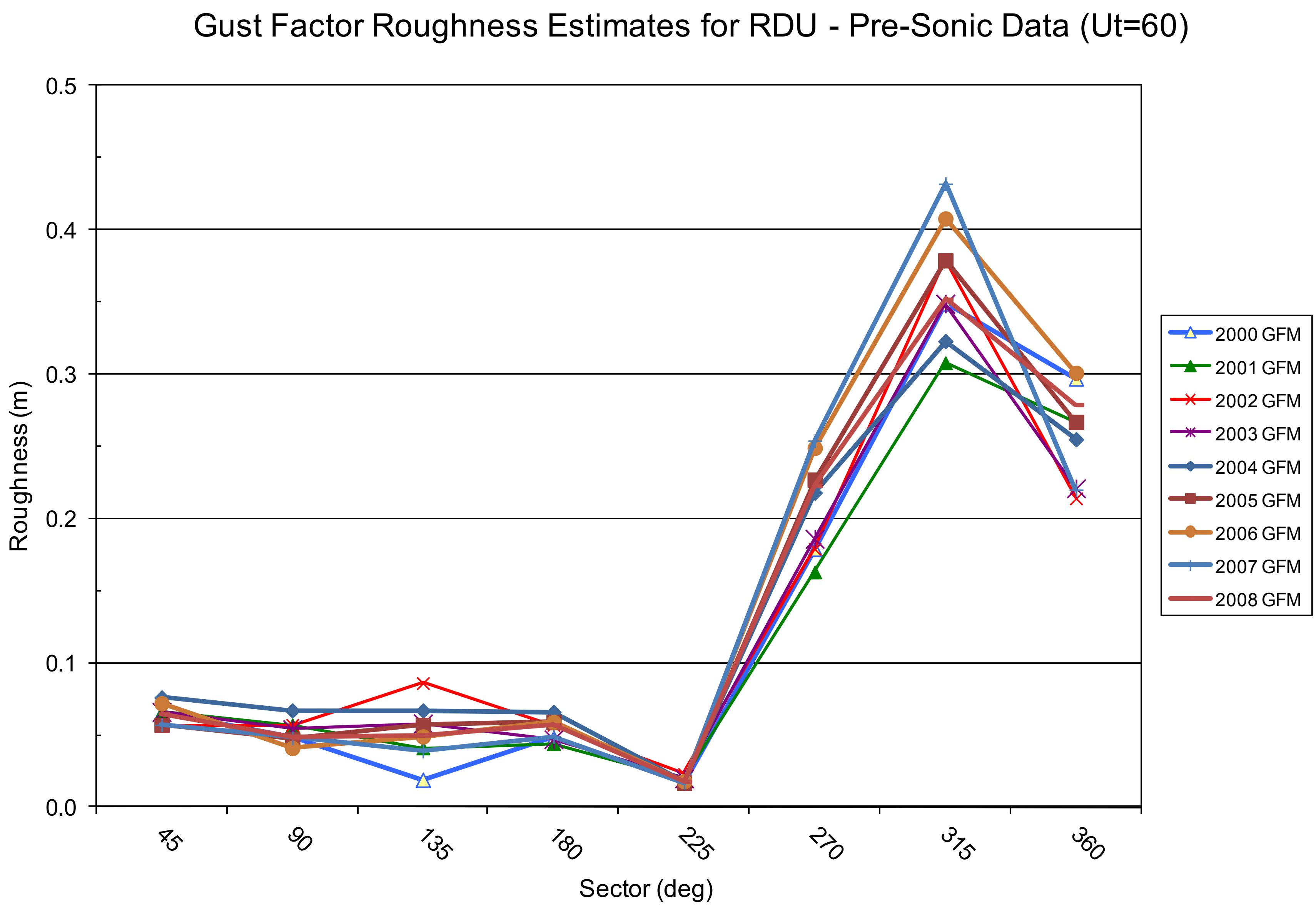
Gust Factor Roughness for Peoria, IL for 2000-05 (Ut=60) vs. 2007-11 (Ut=10)
Roughness (m)
0.5
0.4
0.3
0.2
0.1
0.0
45
90
135
180
225
270
315
360
Sector (deg)
2000-05 GFM
2000 GFM
2001 GFM
2002 GFM
2003 GFM
2004 GFM
2005 GFM
2007-11 GFM


Gust Factor Roughness for Peoria, IL for 2000-05 (Ut=60) vs. 2007-11 (Ut=10)
Roughness (m)
0.5
0.4
0.3
0.2
0.1
0.0
45
90
135
180
225
270
315
360
Sector (deg)
2000-05 GFM
2007 GFM
2008 GFM
2009 GFM
2010 GFM
2011 GFM
2007-11 GFM

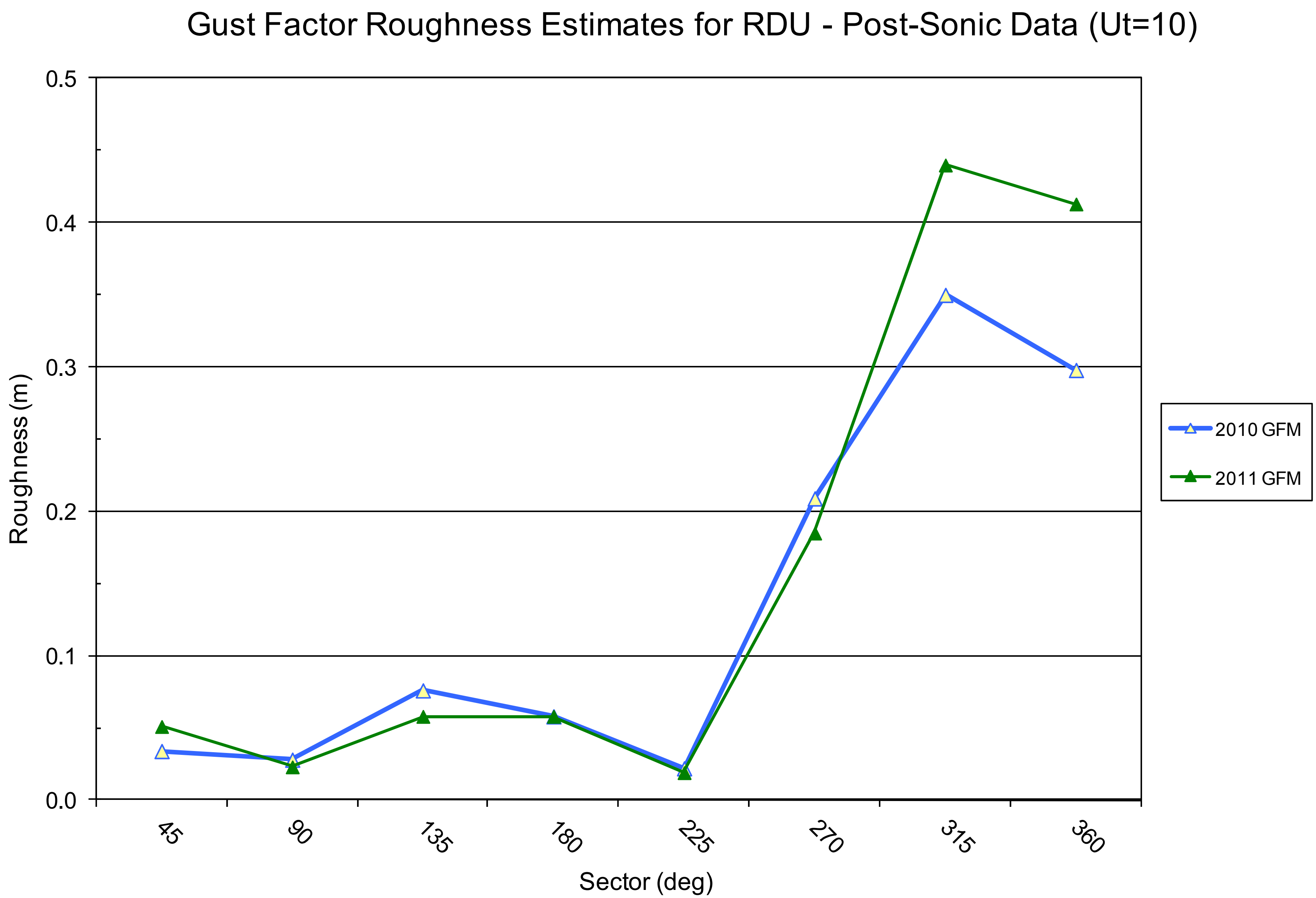

Gust Factor Estimates for Peoria, IL Airport - Pre vs. Post-Sonic
Roughness (m)
0.5
0.4
0.3
0.2
0.1
0.0
45
90
135
180
225
270
315
360
Sector (deg)
Pre Ut=60
Post Ut=10
1992 ERM
2006 ERM

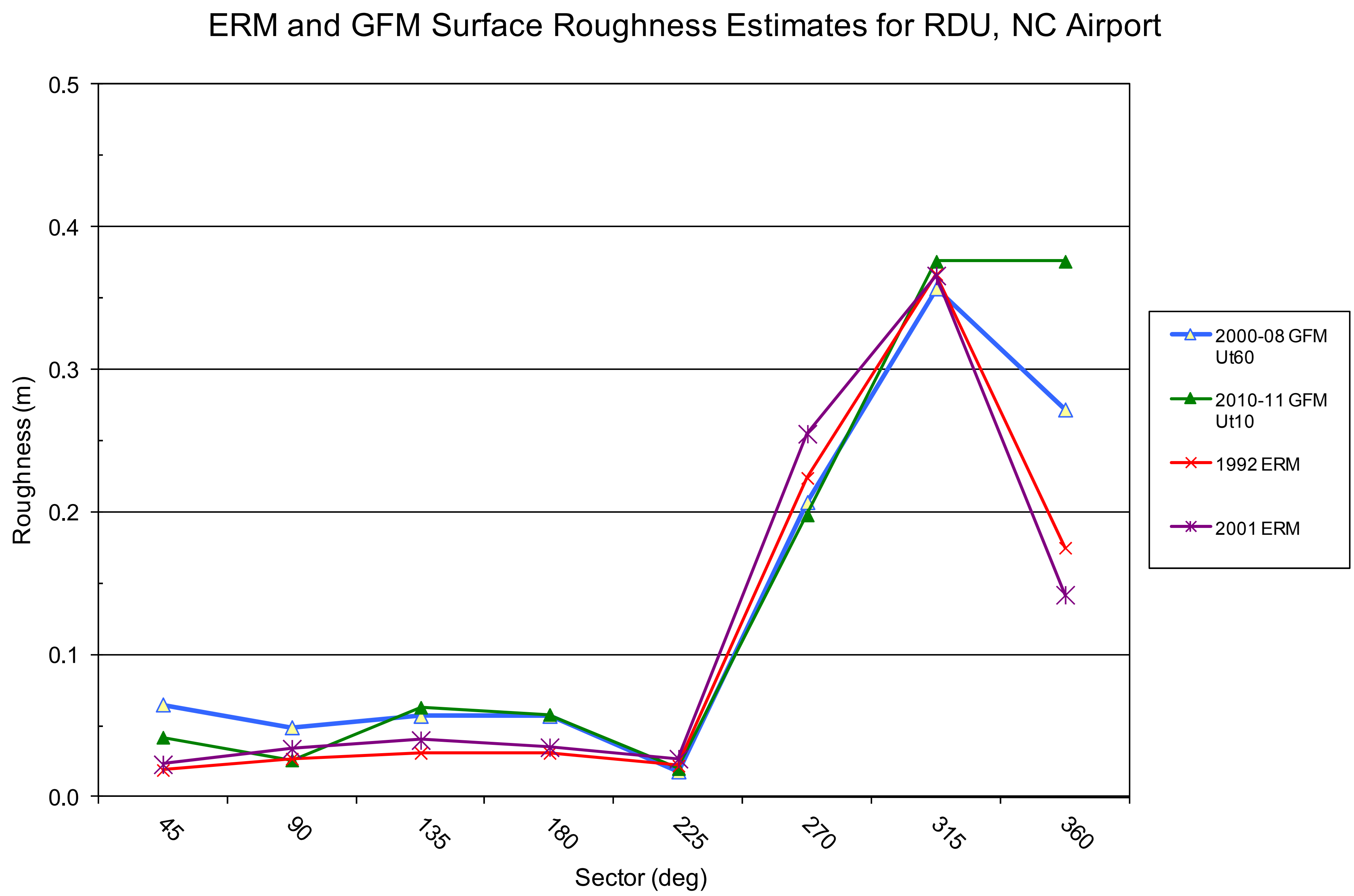
RDU Airport ASOS Site – 1 km Radius



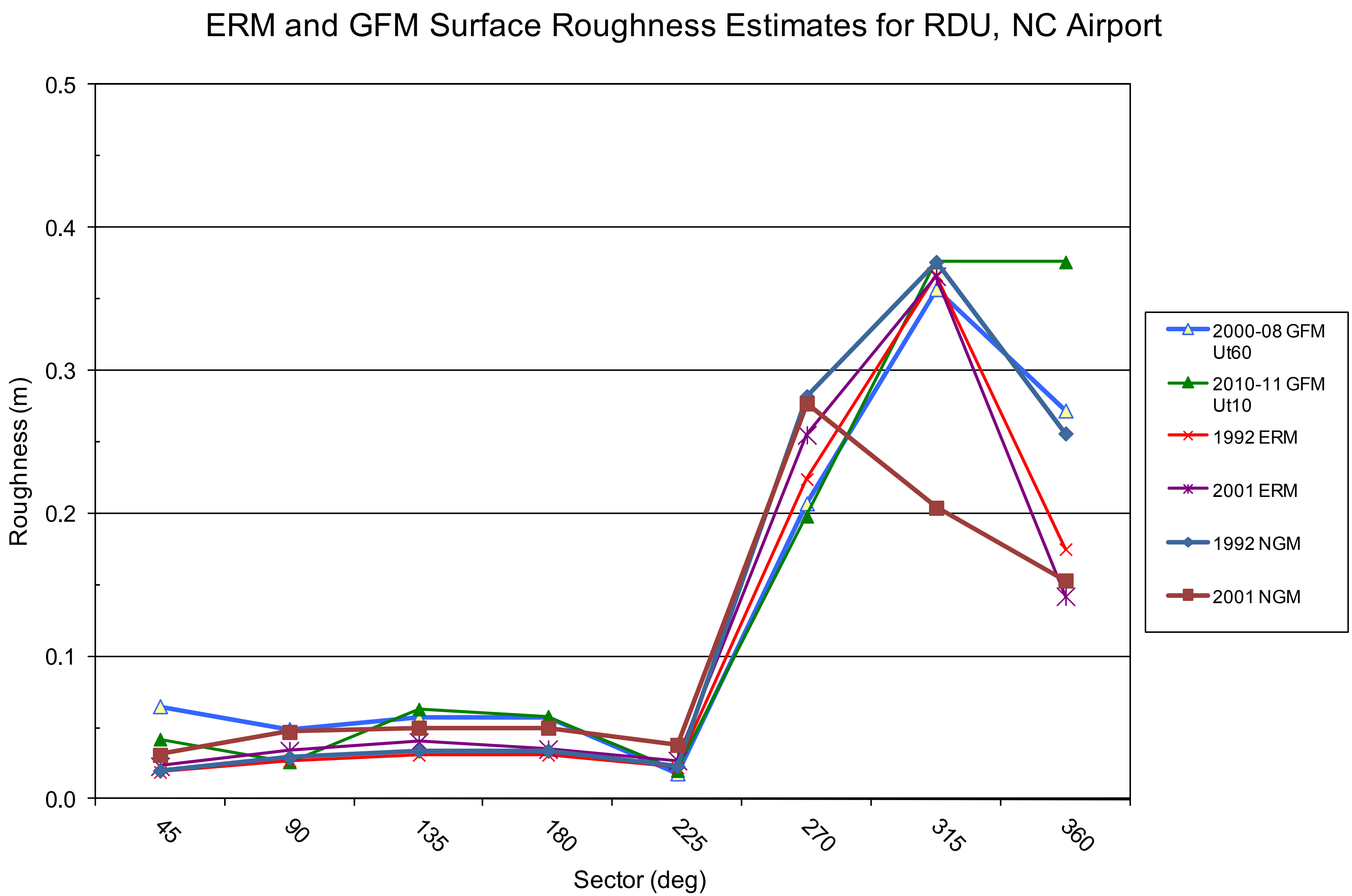


Gust Factor Roughness Estimates for RDU - Pre-Sonic Data (Ut=60)
Roughness (m)
0.5
0.4
0.3
0.2
0.1
0.0
45
90
135
180
225
270
315
360
Sector (deg)
2000 GFM
2001 GFM
2002 GFM
2003 GFM
2004 GFM
2005 GFM
2006 GFM
2007 GFM
2008 GFM


Gust Factor Roughness Estimates for RDU - Post-Sonic Data (Ut=10)
0.5
0.4
0.3
0.2
0.1
0.0
Roughness (m)
45
90
135
180
225
270
315
360
Sector (deg)
2010 GFM
2011 GFM



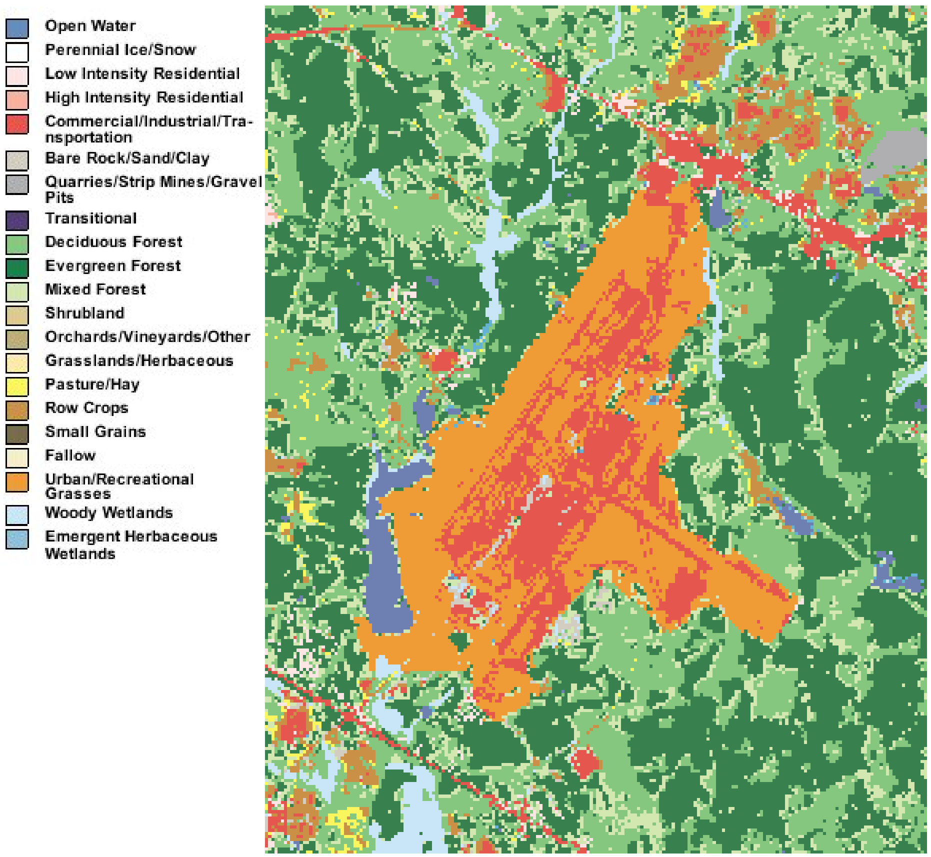
ERM and GFM Surface Roughness Estimates for RDU, NC Airport
0.5
0.4
0.3
0.2
0.1
0.0
Roughness (m)
45
90
135
180
225
270
315
360
Sector (deg)
2000-08 GFM Ut60
2010-11 GFM Ut10
1992 ERM
2001 ERM



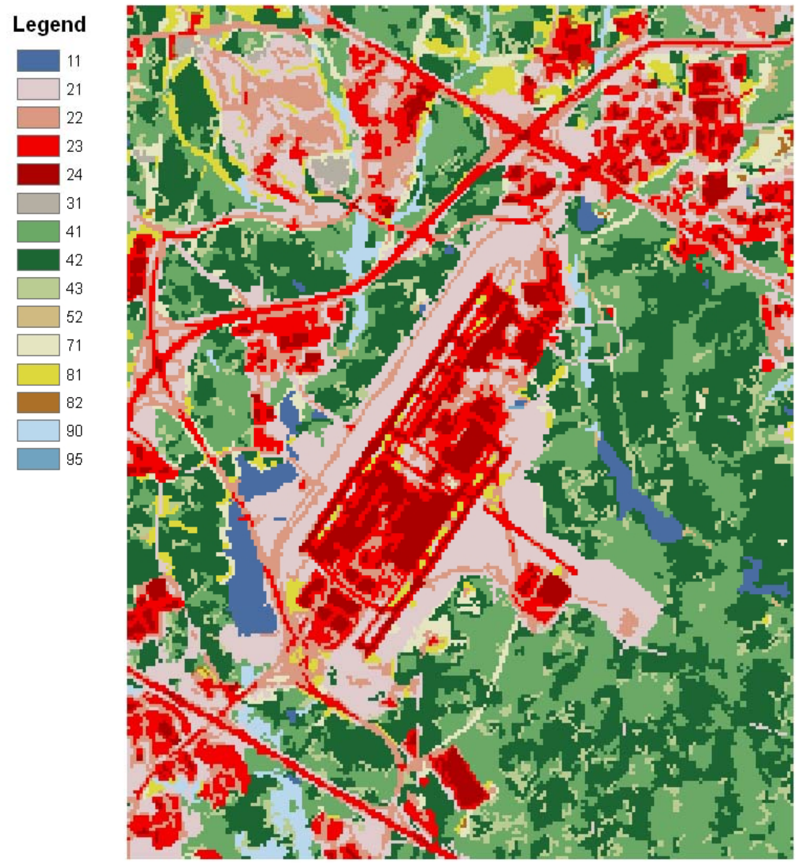
NOTE: 'NGM' refers to New Geometric Mean weighted values
in revised Beta version of AERSURFACE w/ 1km radius

NLCD 1992 vs. NLCD 2001 for RDU

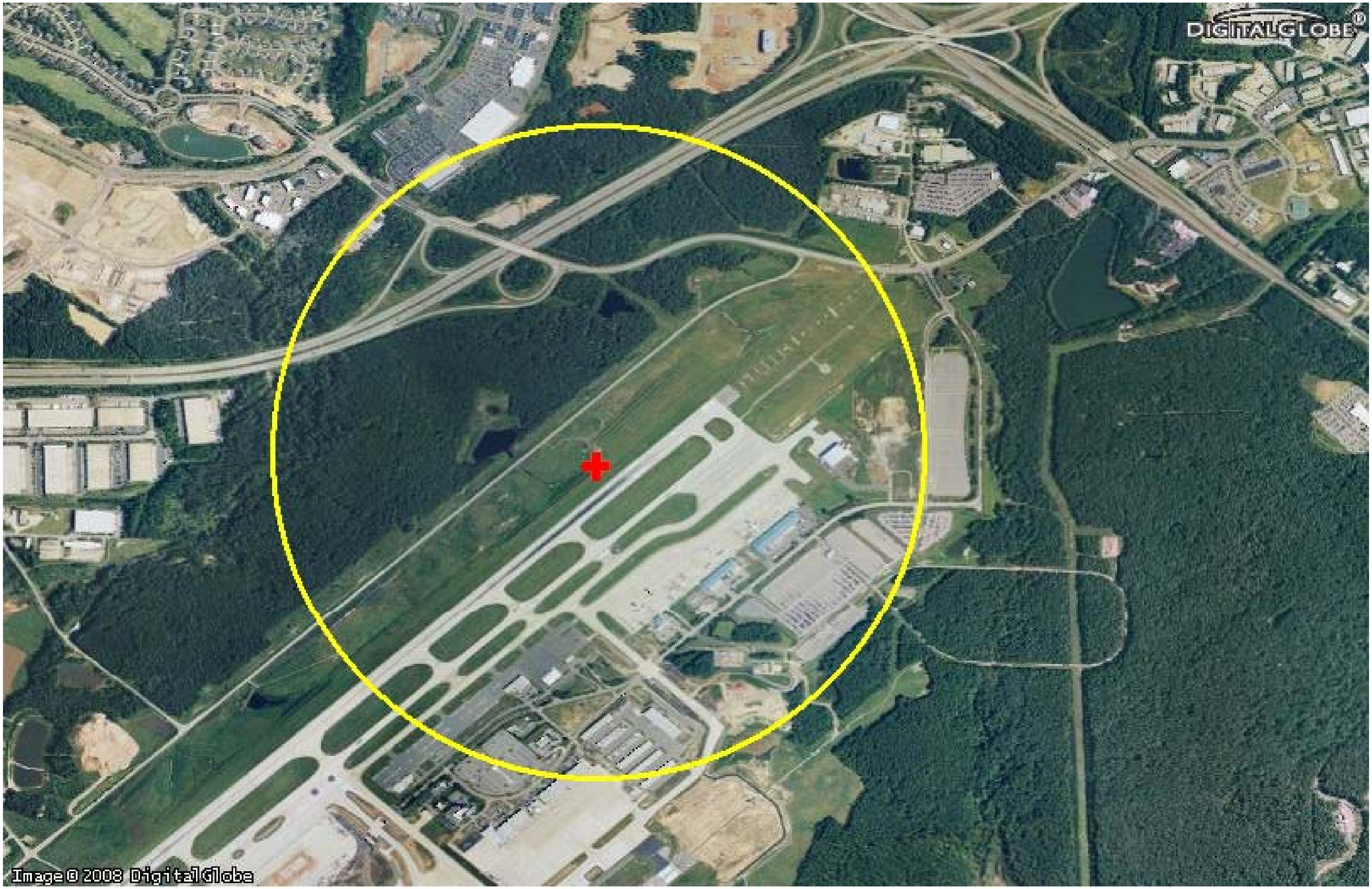
1992 Data



2001 Data



RDU Airport ASOS Site – 1 km Radius



Assessment for RDU

- The 2001 results for RDU with and without Canopy and Impervious data are very similar, as expected since 2001 NLCD data for RDU does not exhibit the issues with 2001 data found elsewhere (e.g. lack of trees in developed areas)
- The ERM effective roughness results based on H_{ref} = 6Z show generally good agreement with GFM estimates for both 1992 and 2001 NLCD data
  - This is consistent with a lack of significant temporal variations in GFM estimates and lack of major land cover changes between 1992 and 2001 for RDU
  - This is also an improvement compared to 1992 vs. 2001 results using original AERSURFACE method, where 2001 underestimated higher roughness sectors due to influence of I-540 within default 1km radius; ERM effective radius for those sectors is about 600-700 meters
  - These results provide good support for incorporating ERM in next AERSURFACE update

ATL Airport ASOS Site – circa 2000

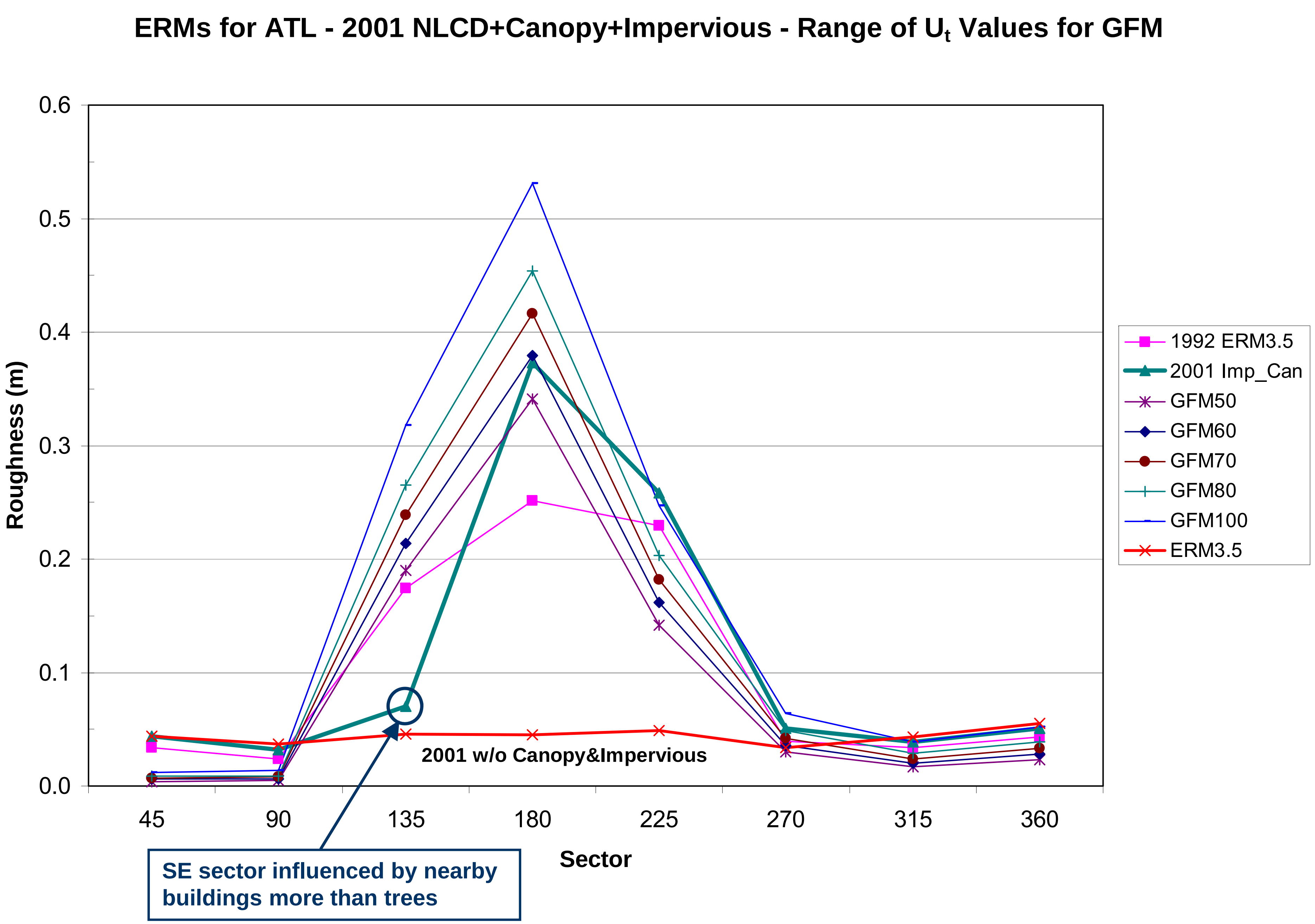
Legend

GlobeXplorer_44.jpg

RGB

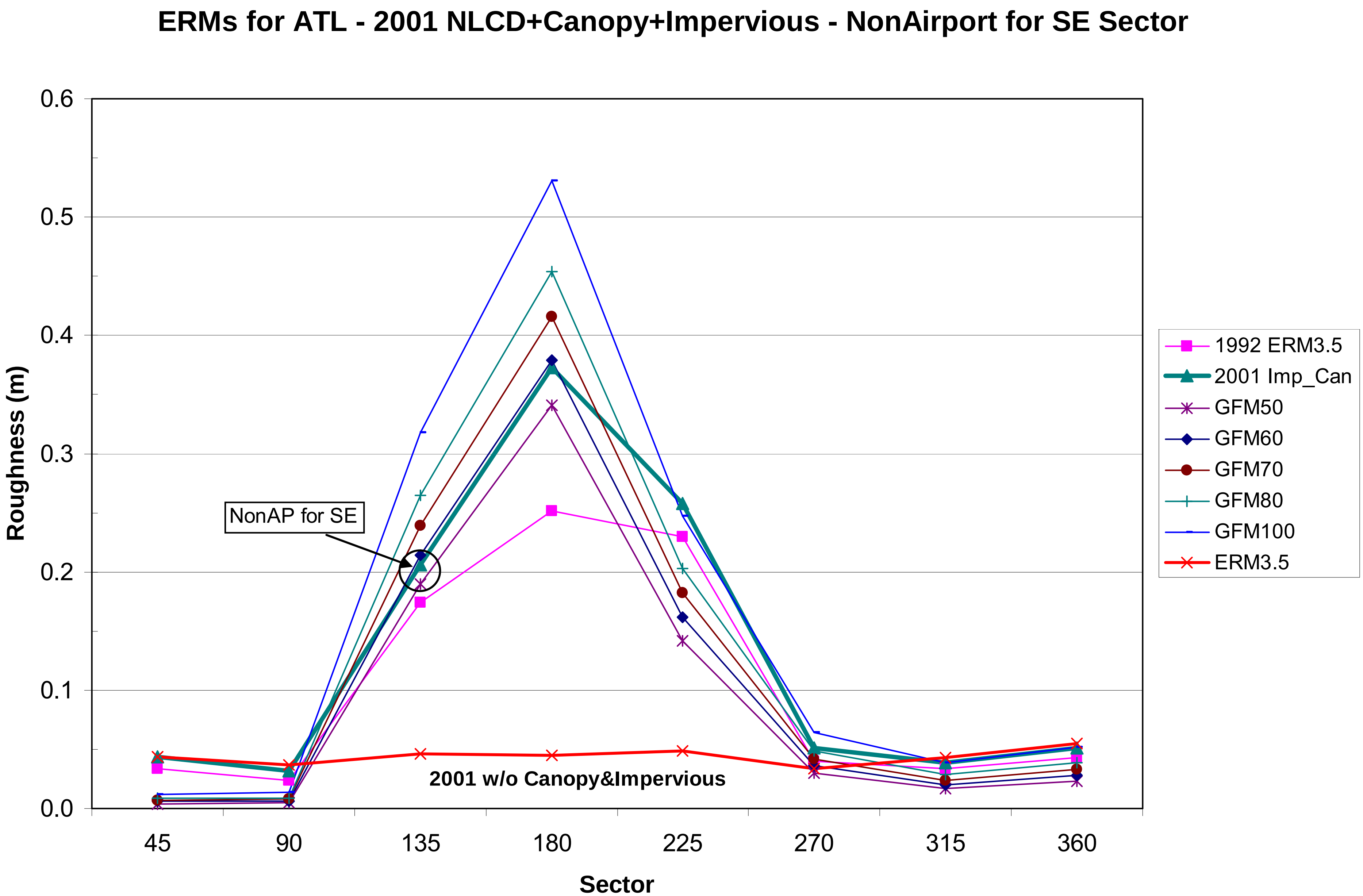
- Red: Band_1
- Green: Band_2
- Blue: Band_3

Circle shows 1km radius



ERMs for ATL - 2001 NLCD+Canopy+Impervious - Range of Ut Values for GFM
Roughness (m)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
45
90
135
180
225
270
315
360
Sector
1992 ERM3.5
2001 Imp_Can
GFM50
GFM60
GFM70
GFM80
GFM100
ERM3.5
2001 w/o Canopy&Impervious
SE sector influenced by nearby buildings more than trees


DIGITALGLOBE®
Buildings close to tower for SE sector
Image © 2008 DigitalGlobe, DigitalGlobe
0
500
1,000
2,000 Meters



ERMs for ATL - 2001 NLCD+Canopy+Impervious - NonAirport for SE Sector
Roughness (m)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
45
90
135
180
225
270
315
360
Sector
NonAP for SE
2001 w/o Canopy&Impervious
1992 ERM3.5
2001 Imp_Can
GFM50
GFM60
GFM70
GFM80
GFM100
ERM3.5

Assessment for ATL

- The 2001 results for ATL with Canopy and Impervious data significantly improve agreement with GFM estimates vs. 2001 NLCD alone, and compare better than 1992 results for the affected sectors
- Results for SE sector highlight the importance of the issue of distinguishing buildings vs. runways for developed areas with 2001 NLCD
  - Use of Non-airport option for SE sector works well in this case, but may not work as well in other cases
  - ATL results also support adoption of ERM in next AERSURFACE update

Future Plans for AERSURFACE

- Update current AERSURFACE to incorporate z_0 adjustments based on weighted GM for a few categories and fix bugs:
  - GeoTIFF file structure; current version assumes “stripped” data and may give incorrect results for “tiled” data
  - Sensitivity of results to distance of tower location from center of pixel
- Release Beta version of AERSURFACE with ERM based on IBL approach
  - Support for 1992, 2001 and 2006 NLCD data, supplemented by 2001/2006 Impervious and 2001 Canopy data:
  - Based on evaluation results to date, ERM approach shows better performance vs. GFM estimates than current approach;
  - Some issues remain, including appropriate IBL height for site-specific data with higher measurement heights
- Release Gust Factor tool for use with 1-min ASOS data

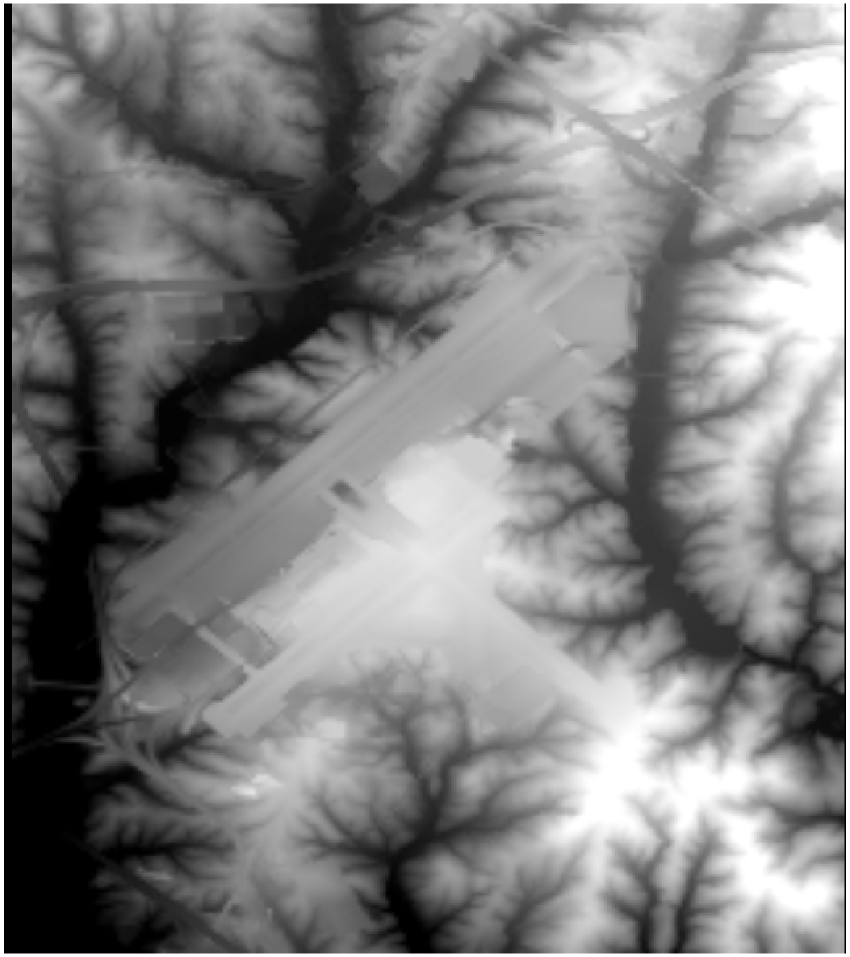
Future[1] Plans for AERSURFACE

- NED and SRTM elevation data are both available at 1-sec (~30m) horizontal resolution for most of U.S. (no SRTM in northern AK)
  - Same resolution as NLCD data (but different projection)
  - NED represents ground elevations
  - SRTM represents elevations of obstacles
  - SRTM-NED elevation provides indication of obstacle heights
- Coupling estimates of average height of obstacles with NLCD data should facilitate better estimates of surface roughness
  - Allows for distinguishing between "highly developed" grid cells (based on impervious land cover fraction) that are runways vs. buildings

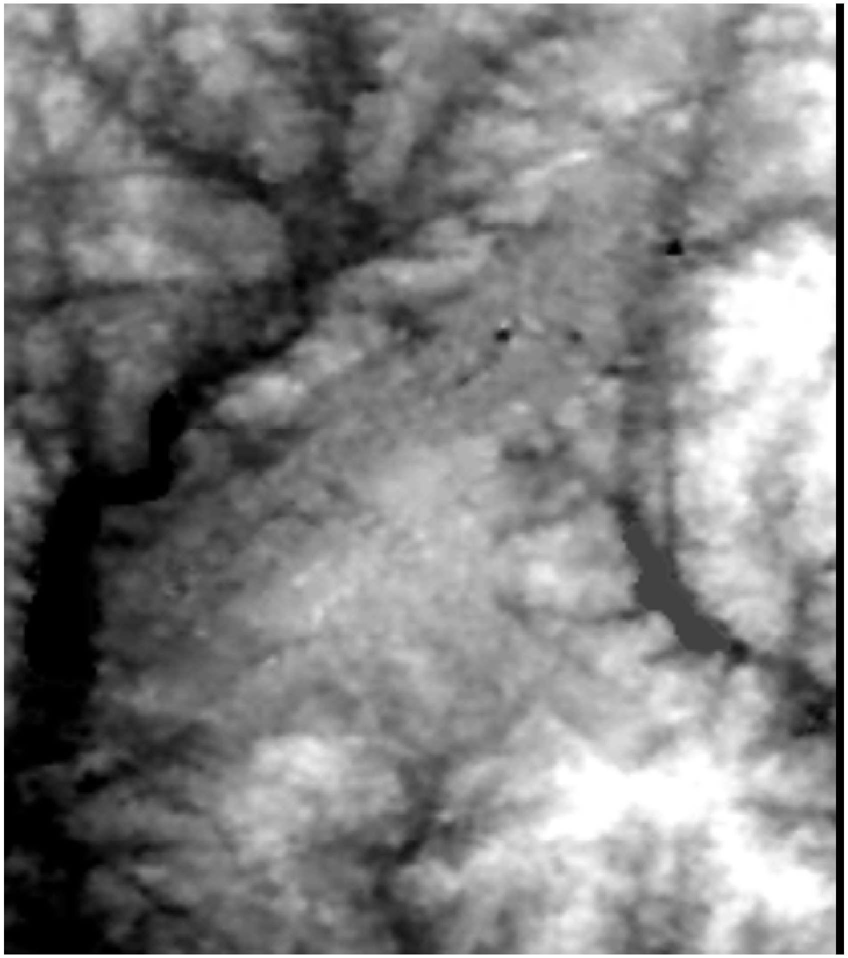
[1] More distant future given other needs and priorities

NED vs. SRTM Elevations for RDU

NED Data

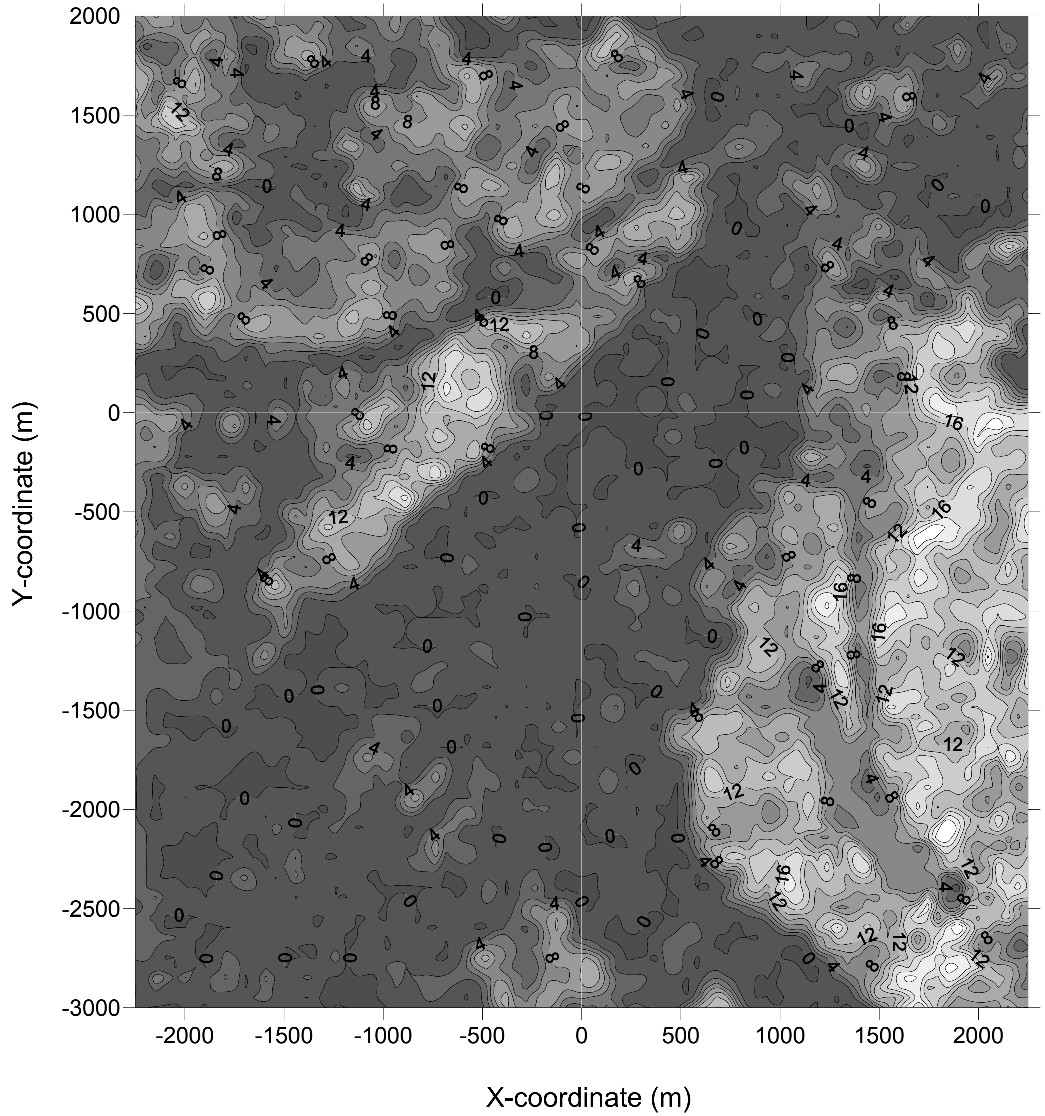


SRTM Data

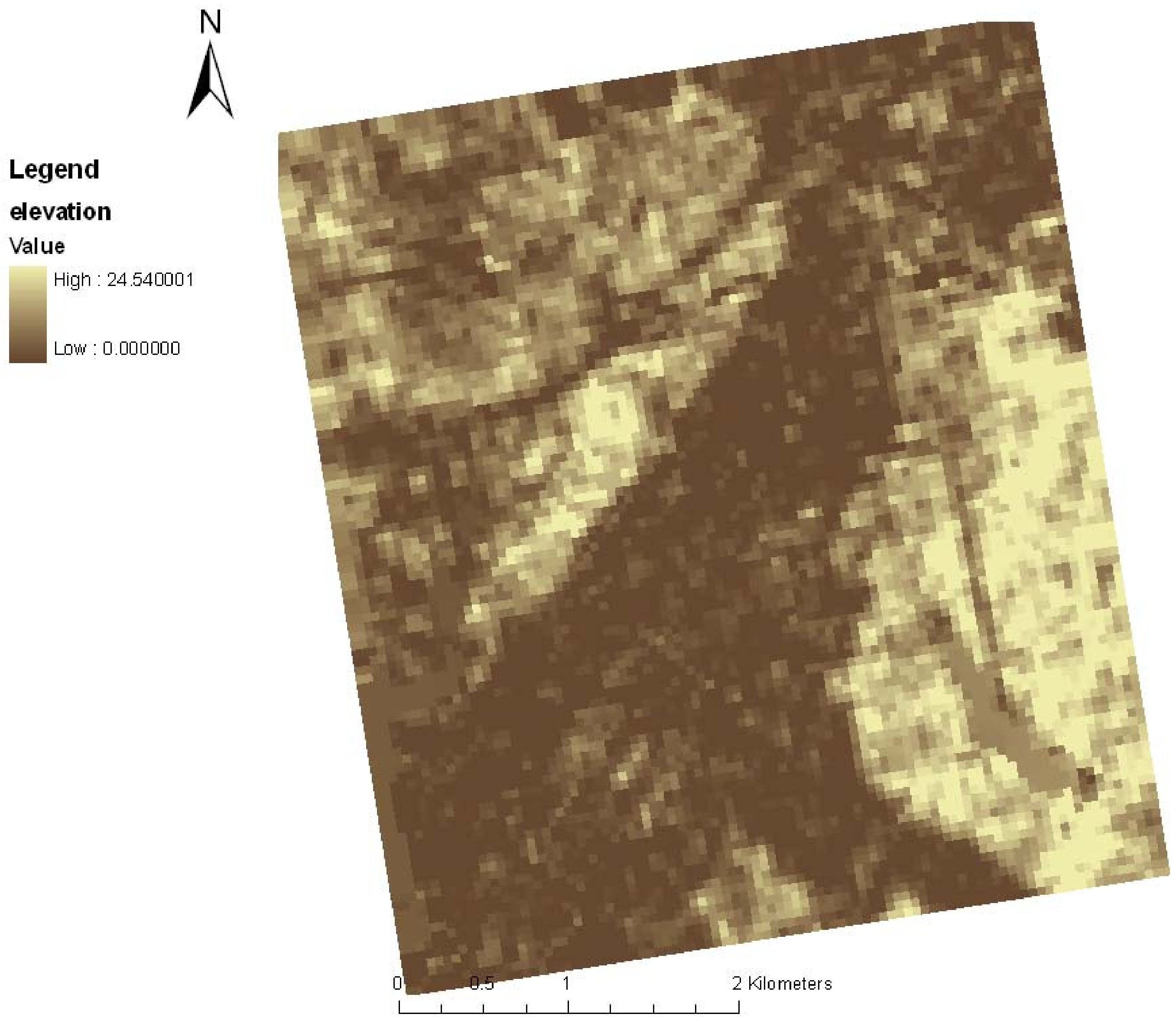


SRTM-NED Elevations for RDU

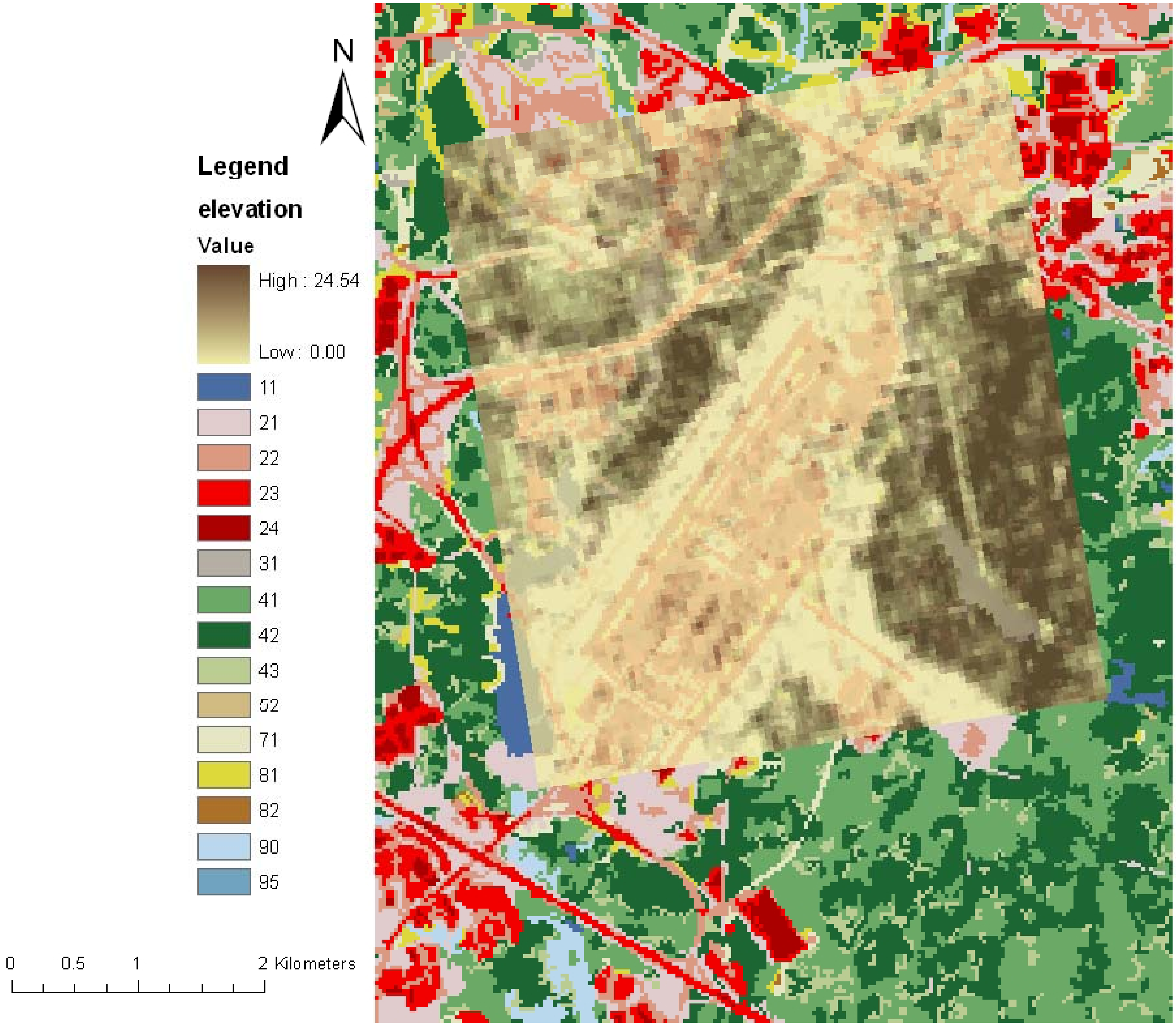
Contour Plot of Elevation Differences (m) from SRTM - NED Data
for Raleigh-Durham International Airport; Met Tower Located at (0,0)



SRTM-NED Elevations for RDU

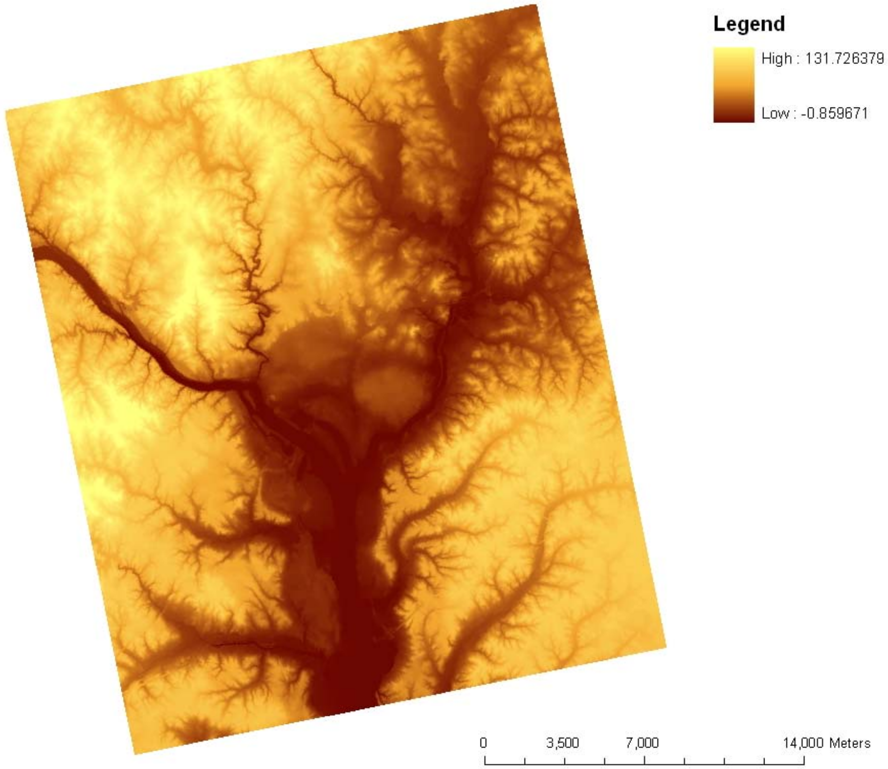


SRTM-NED Elevations for RDU

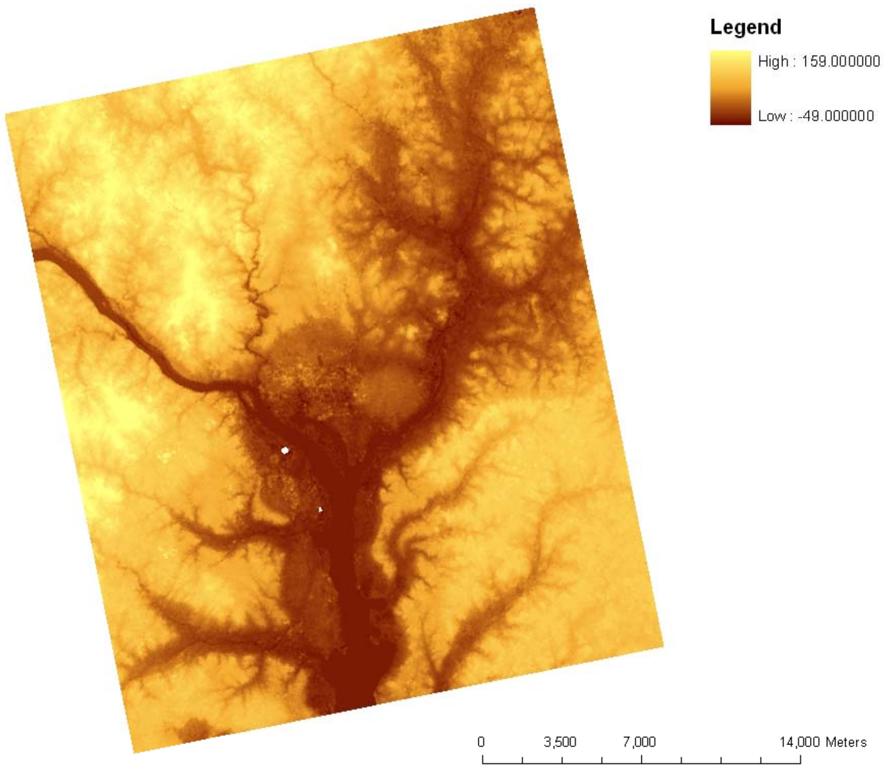


NED vs. SRTM Elevations for DC

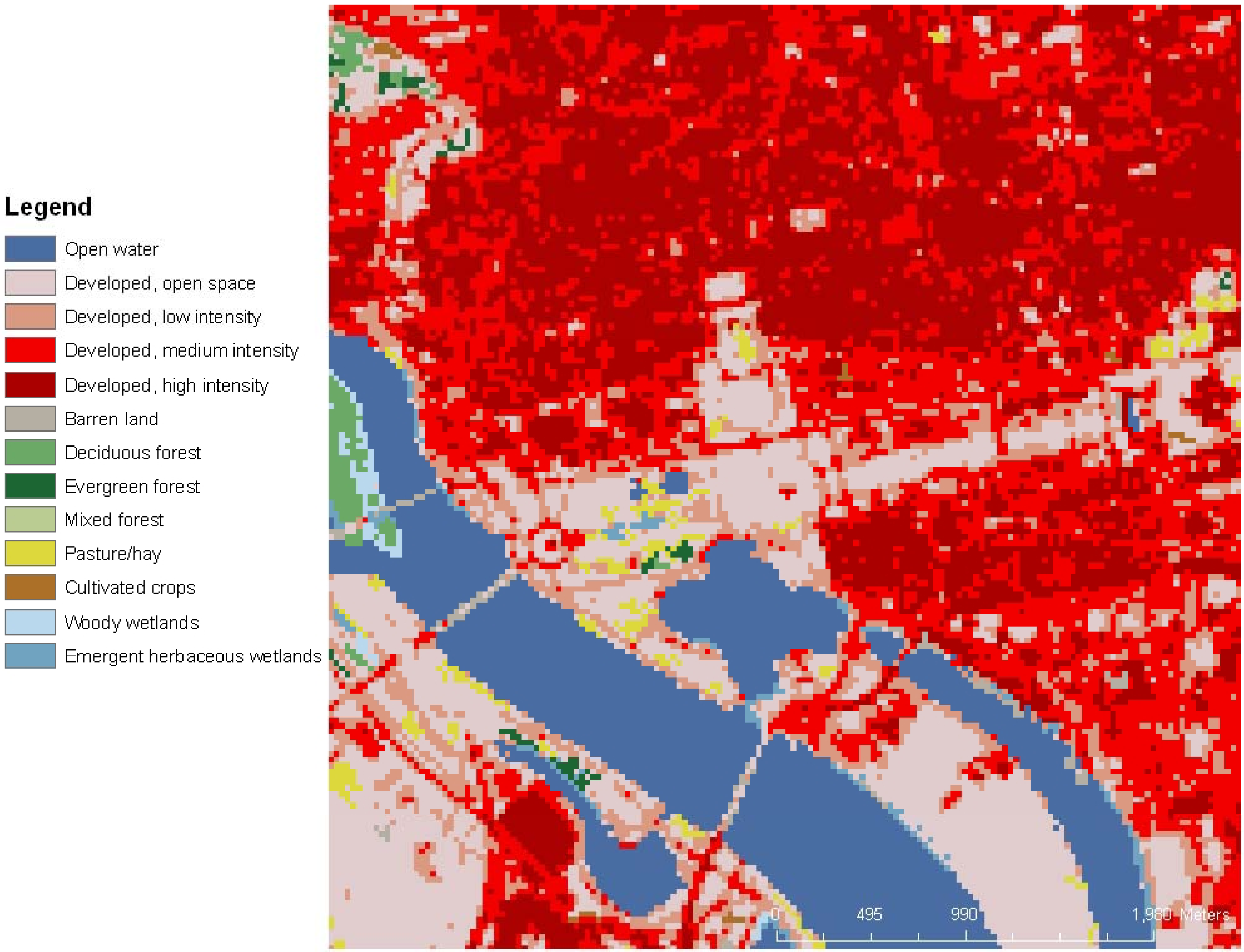
NED Data



SRTM Data



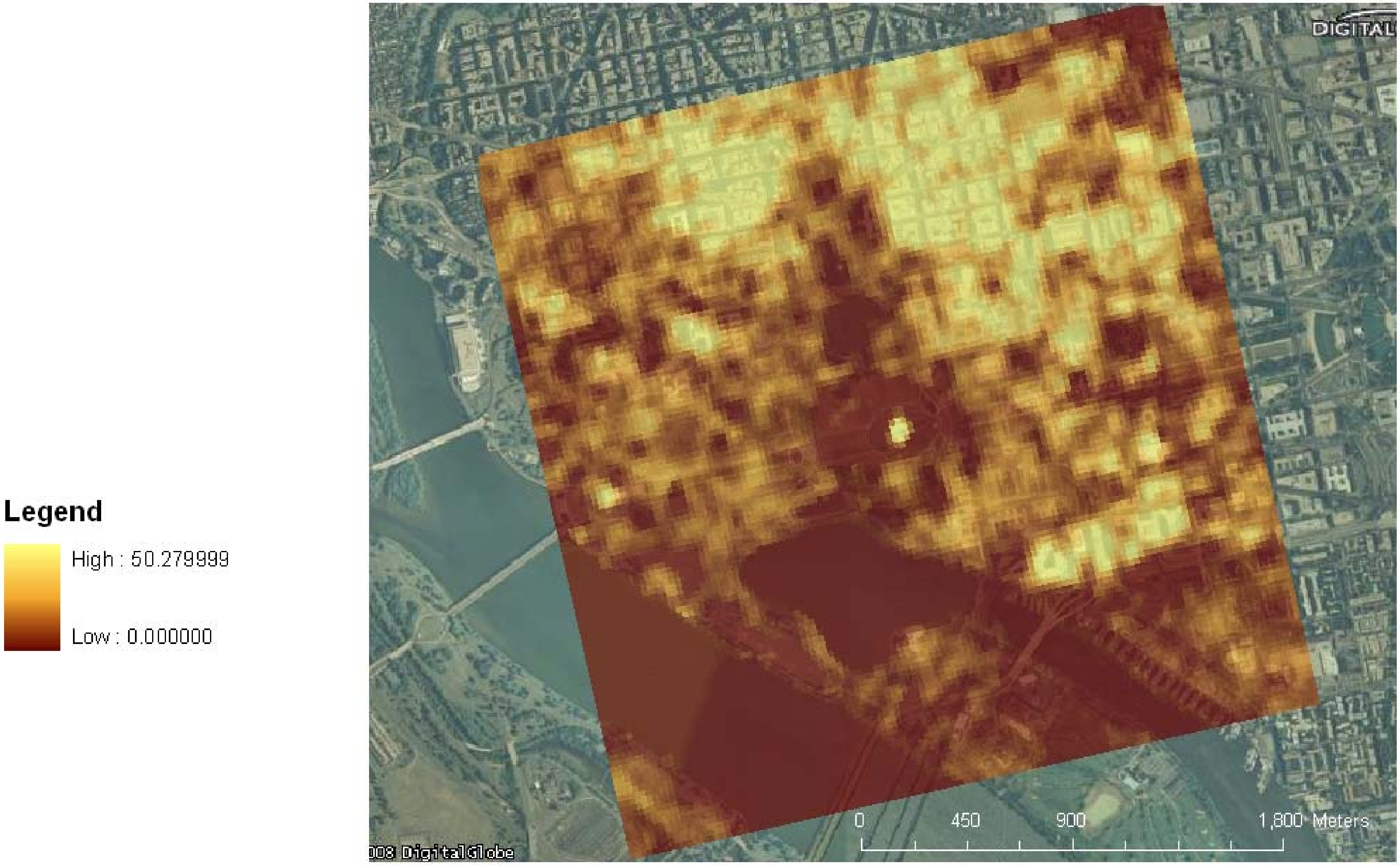
2001 NLCD Data for Downtown DC



Aerial Photo of Downtown DC

Washington Monument

SRTM-NED Elevations for DC



Summary

- One of the main AERMOD implementation issues is sensitivity of the model to surface characteristics
- AERSURFACE tool provides an objective method for determining surface characteristics
- Issues/limitations of NLCD data present many challenges
- Recent "evaluations" of AERSURFACE roughness estimates using the GFM are encouraging, supporting AIG revisions to method (1km, InvDist)
- GFM evaluations also provide support for a new effective roughness method based on an IBL approach
- GFM with 1-minute ASOS data may also provide useful reference for assessing representativeness of NLCD data and accuracy of tower locations for AERSURFACE