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THESIS

THE IMPACT OF BACKGROUND RESOLUTION ON TARGET AQUISITIONS WEAPONS SOFTWARE (TAWS) SENSOR PERFORMANCE

by

Charles M. Pearcy II

March 2005

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13. ABSTRACT (maximum 200 words)

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THE IMPACT OF BACKGROUND RESOLUTION ON TARGET AQUISITIONS WEAPONS SOFTWARE (TAWS) SENSOR PERFORMANCE

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Submitted in partial fulfillment of the
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ABSTRACT

This study evaluated the sensitivity of TAWS detection range calculations to the spatial resolution of scenario backgrounds. Sixteen independent sites were analyzed to determine TAWS background. Multispectral satellite data were processed to different spatial resolutions from 1m to 8km. The resultant imagery was further processed to determine TAWS background type. The TAWS background type was refined to include soil moisture characteristics. Soil moisture analyses were obtained using in situ measurements, the Air Force's Agricultural-Meteorological (AGRMET) model and the Army's Fast All-seasons Soil Strength (FASST) model. The analyzed imagery was compared to the current default 1° latitude by 1° of longitude database in TAWS. The use of the current default TAWS background database was shown to result in TAWS ranges differing from the 1m standard range by 18-23%. The uncertainty was reduced to 5% when background resolution was improved to 8km in rural areas. By contrast, in urban areas the uncertainty was reduced to 14% when spatial resolution was reduced to 30m. These results suggest that the rural and urban designations are important to the definition of a background database.

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First, I would like to thank the Lord, without His blessing none of this would be possible. Next, I would like to thank my family who thought they were going to an easy assignment where they would see me more often. I certainly could not have done all of this without my advisors Ken and Andy whose advice and contacts made a master's thesis in unresearched territory not only doable, but much more bearable. There are numerous individuals in various agencies without whose help only a shadow of this thesis would exist to include Col. Mary Lockhart, Lt Col Marie Walters, Dr. Guy Seeley, Dr. Susan Frankenstein, Dr. Paul Hanson, Dr. Phil Durkee, .John Eylander, Leandro Delgado, Brian Cutler, Bob Creasey, and many more.

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I. INTRODUCTION

A. CONCEPT AND PURPOSE

When we go to war and search for our enemy, we want to see them before they see us. If the enemy sees us first, they will have the opportunity to deploy active camouflage (such as white phosphorous, fog oil and hexachloroethane smokes), to deploy decoys, to perform evasive maneuvers, or to fire first. Knowing when we will see the enemy in relation to when they will see us is critical to our war fighting capability.

Target Acquisitions Weapon Software (TAWS) is the current computer program used by the Department of Defense (DoD) to predict the minimum detection range or when we can see the enemy with our weapon systems. It replaced the Electro Optical Decision Aid (EOTDA) software (Gouveia et al., 1999). Many parameters are considered in the TAWS model. Target, background, sortie characteristics, and weather information are all considered as part of the analysis to determine the sensor performance including detection of targets and lock on range. This thesis explores the sensitivity of TAWS sensor performance to background conditions and delineates the tradeoff between the background resolution versus the increase in accuracy of the resulting TAWS prediction. The question being asked in this study of an operational system is "What level resolution background database is accurate enough to minimize the effects of poor background determination on the minimum detectable range."

B. BACKGROUND

Background effects have been the subject of studies with respect to impact on TAWS performance. O'Brien et al. (2003) considered background effects for snow and sparse and dense vegetation were determined to have significant interactions with clutter levels for night vision goggles (NVGs), and significant interactions with season, precipitation and cloud cover for infrared (IR) sensors. O'Brien et al. (2003) also noted that 500m resolution was insufficient to capture the background/clutter interactions for NVGs, but that 100m resolution showed some of the interactions. Yepez (1993) performed an unsupervised classification, no human intervention only computer algorithms, of Landsat-5 satellite imagery of Hanscom AFB, MA and showed this technique to be capable of providing adequate results for an automatic background determination for EOTDA. TAWS currently uses an optional background database of 1° latitude by 1° longitude based on the Normalized Difference Vegetation Index (NDVI), DeFries and Townshend (1994a), i.e. Defries and Townshend pixels. A 1°x1° background resolution is quite coarse when compared to Yepez' Landsat-5 work for which the resolution was approximately 28m, i.e. Yepez pixels. About 350 Yepez pixels are averaged in one midlatitude Defries and Townshend's pixel. Many background types explicitly available in TAWS cannot be accounted for with a 1°x1° sized background database. Backgrounds involving urban or man-made changes to the environment such as roads and parking lots, and areas of sharp background change such as coastal regions and leeside of mountains are among the examples of regions not readily resolvable by the Defries and Townshend's database. In addition, the background variability within a Defries and Townshend pixel is likely to be significant. A poorly determined background has the potential to have a very different minimum detectable range.

The work of Yepez (1993) and Defries and Townsend (1994a) on database resolution issues guided procedures in this thesis. In this thesis, 1m resolution satellite imagery of 16 different sites will be analyzed and characterized as one of the TAWS background surface types. Then the same imagery will be degraded into coarser and coarser resolutions ending at 8km, the original resolution of Defries and Townshend's developed databases. Comparisons will be made between subsequent TAWS runs, taking the 1m resolution as the standard range, for each resolutions background categorization. This will determine the resolution where the least amount of change, or uncertainty, in the range from the 1m standard TAWS range occurred.

II. METHODOLOGY

A. GENERAL

The evaluation for the optimal background database resolution required analyses of three separate steps. All three are related to remote sensing technology or its limitations.

First, the remote sensing data was taken from the Ikonos and Quickbird satellites, which allowed for a base resolution of 1m and served as the standard for the rest of the resolutions. The satellite imagery was then analyzed using *Erdas Imagine*'s Iterative Self Organizing Data Analysis Technique (ISODATA) algorithm (Tou and Gonzalez, 1974) to determine background types and the subsequent analysis was applied not only to the image but to its coarsened versions as well. The background type of a constant, single point in the image was noted for each resolution for later TAWS runs and comparisons.

Second, soil moisture was determined from in situ measurements, from Agricultural Meteorology Model (AGRMET) archive data from the Air Force Weather Agency (AFWA) or from the experimental Fast All seasons Soil Strength (FASST) model from the Cold Regions Research and Engineering Laboratory (CRREL) at the US Army Corps of Engineers, in that order of preference.

Third, weather data was obtained from in situ measurements and carefully analyzed from archived data at Plymouth State University (Plymouth, 2005) and The University of Wyoming (University, 2005). The TAWS default background data were collected to serve as a basis for comparison. The details of the methodologies used in the data analysis will be covered in this section.

B. REMOTE SENSING DATA

Satellite-based sensor (remote sensing) data allowed questions in this study to be asked with expectations of valuable answers. There are 30 original sites, each chosen in a different $1^{\circ}x1^{\circ}$ square of the current TAWS background database. All sites are within the United States and have both a multispectral and a panchromatic image available. Further, all selected images had to be and are cloud-free. Eight sites were chosen for in situ soil moisture measurements, one site was chosen for prior ground-truthing, a direct validation of the actual ground conditions not relying on remote sensing methods, and the remaining 21 sites are scenes of cloud-free imagery obtained from the Commercial Satellite Imagery Library (CSIL) maintained by the National Geospatial-Intelligence Agency (NGA). A sub image of approximately 1 minute by 1 minute was chosen for analysis. The sub image was chosen on the basis of the most available ground-truthing. Where more than one area of good ground-truthing was available, the area closest to the satellite when it took the picture was chosen. This prevented 16 of the original 30 sites from being airport runways. A 5 by 5, 300m by 350m, dot grid was created with the exception of Eielsen AFB, AK where the dot grid was 200m by 350m due to its higher latitude. This 5 by 5 dot grid was laid across each sub image and the point with the best ground-truthing closest to the center of the sub image was the point monitored for changes in background due to resolution changes. Areas with in situ soil moisture measurements were always considered to be the best ground-truthed point.

An effort was made to spread the sites across the United States to catch a wide array of climates. Figure 1 shows the locations of the sites. Only 16 of the original sites were able to be analyzed, but the location of incomplete sites is shown for reference to future work. There was a seasonal bias with more imagery in summer and fall, and the least amount of imagery in spring. Figure 2 shows the time of year or seasonal distribution of the sites. Section 1 will give a description and the ground-truth used for each site. Section 2 will detail the process for the surface analysis of the imagery. Section 3 will review the uncertainty in the analysis.

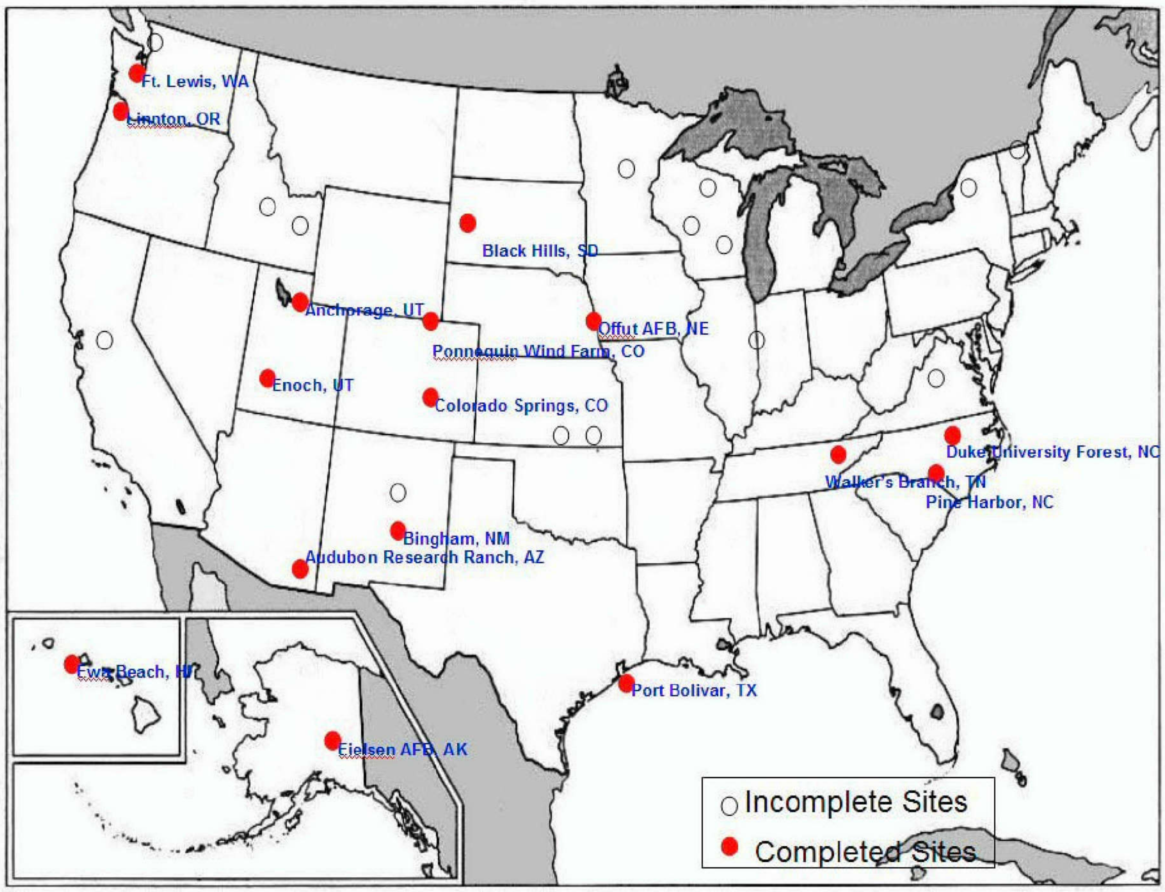

Figure 1. **Spatial distribution of Satellite Imagery.**

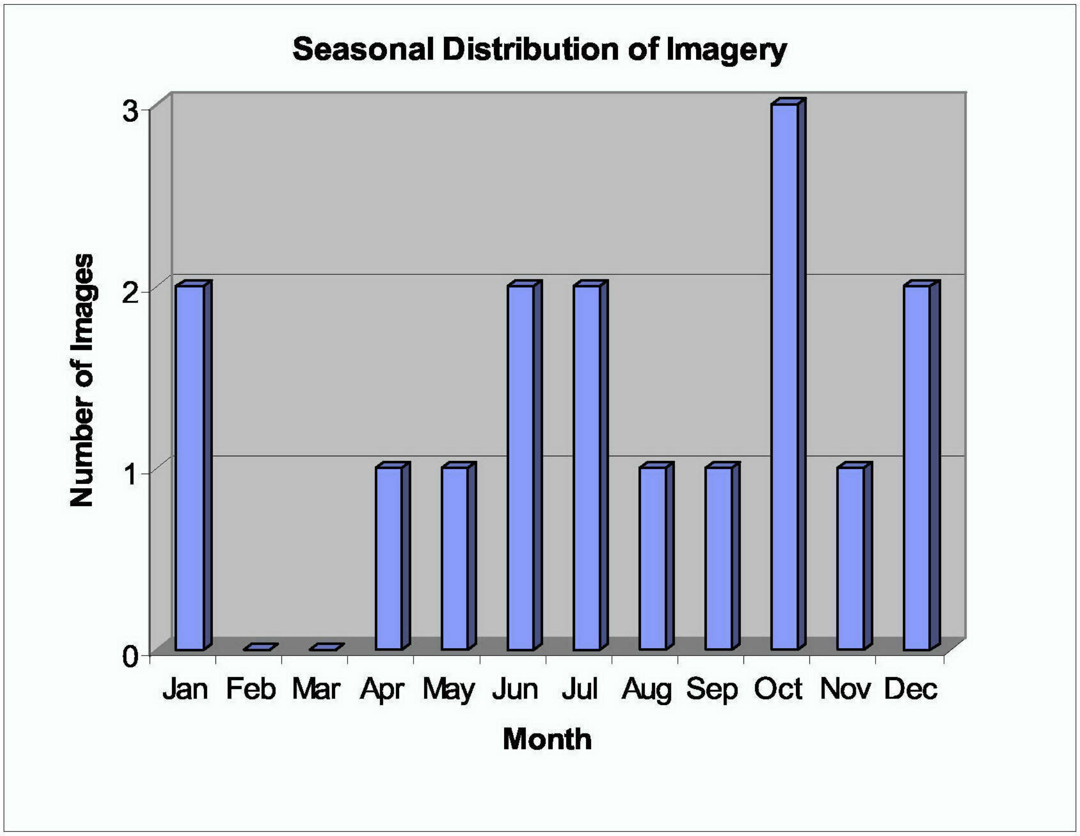

Figure 2. Time of year distribution of Satellite Imagery

1. Sites and Ground-Truthing

Site selection was partially made on the basis of ground-truthing, which relied significantly on persons at or familiar with the site. Hence, availability and cooperation of these persons were important. A printed image of each site was taken and different TAWS background types were marked based on the ground-truth information to be used as a guide in the analysis.

a. Eielson AFB, AK

Located at 64° 39' 24.2"N 146° 59' 54.4"W, this is the area near the base ski slope. This site is largely dense forest cut by the occasional asphalt road and the base ski resort. Imagery was taken on 21 May 2002. Ground-truth for this location was based on the personal memory of Capt Darren Sokol, USAF, who had been stationed there. [1]

b. Audubon Research Ranch, AZ

Located at 31° 35' 27.3"N 110° 30' 31.5"W, is the Appleton-Whittell Reaserch Ranch of the National Audubon Society near the city of Elgin. This site is largely grassland with a few dirt roads, a streambed and a couple of buildings. Imagery was taken on 1 June 2001. Ground-truth was acquired via personnel correspondence with Linda Kennedy, assistant director of the ranch, and imagery from the ranch's website (Audubon, 2005).

c. Ponnequin Wind Farm, CO

Located at 40° 59' 28.2"N 104° 49' 48.2"W, is a facility for generating electricity on the Wyoming-Colorado border. This site was largely rocky grasslands with significant amounts of quartz, interspersed by a few roads and metal wind turbines. Imagery was taken on 5 Oct 2003. Ground-truthing was done by Maj Andy Riter, USA, in an experiment by the NPS Physics Department and included vegetation and soil samples in addition to a narrative description. Images from the Ponnequin Wind Farm's website (Fort, 2005) supplemented Maj Riter's ground-truth.

d. Colorado Springs, CO

Located at 38° 47' 1.6"N 104° 44' 56.0"W, is the section of Colorado Springs surrounding Deerfield Park. This site is half residential area and half grassy field. Imagery was taken on 10 October 2002. Ground-truth was based on the personal memory of Capt Brandon Alexander, USAF who had attended the Air Force Academy, supplemented by images and maps from the Colorado Springs city parks website (Colorado, 2005) and various real estate properties for sale on the internet. This later source is no longer available due to the sale of the properties. [2]

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1 Capt Sokol is an AFIT officer who attended NPS with the author.

2 Capt Alexander is an AFIT officer who attended NPS with the author.

e. Ewa Beach, HI

Located at 21° 19 24.6"N 158° 00' 47.3"W, is the section of Ewa Beach that is just south of the Hawaii Prince Golf Club. This site is a conglomerate of widely differing urban subjects to include residential areas, commercial shopping centers, public schools, recreational parks, construction sites and undeveloped fields. Imagery was taken on 15 December 2002. Ground-truth was via a personal visit on 24 December 2004 accompanied by Cara Tatafu, a local resident.

f. Walnut River Water Shed, KS

Located at 37° 31' 15.0"N 59° 51' 18.0"W, this is the now defunct Walnut River Water Shed Ameriflux site. The imagery was taken on 31 December 2002. This site was not used in the 16 ground-truthed sites due to time constraints. However, it was one of the sites used in the soil moisture comparison in Section C. Permission to use the data from this site was generously given by the primary investigator Dr. David R. Cook of the Argonne National Laboratory.

g. Offut AFB, NE

Located at 41° 7' 49.7"N 95° 55' 24.1"W this is the section of Offut AFB that includes the Air Force Weather Agency building. This site is essentially a runway, associated buildings, and a neighboring agricultural field. The imagery was taken on 8 April 2004. Ground-truth was based on the personal memory of Capt Jason Blackerby, USAF who had been stationed there. [3]

h. Duke University Forest, NC

Located at 35° 58' 41.4"N 79° 05' 39.1"W, is the AmeriFlux Duke Forest – loblolly pine site. This site is largely dense forest with an occasional house or gravel road. Imagery was taken on 3 June 2002. Ground-truth was done by a personal visit on 23 September 2004 to the site, accompanied by a

3 Capt Blackerby is an AFWA officer who attended NPS with the author

tour of the facilities with the primary investigator, Dr. Ram Oren. Detailed data were kindly provided by Dr. Oren.[4][5]

i. Pine Harbor, NC

Located at 35° 7' 22.1"N 81° 1 20.6"W, is a community on the North Carolina side of Lake Wylie. This site is a heavily wooded residential area on the edge of a lake. Imagery was taken on 21 December 2002. Ground-truth was acquired via a personal visit on 21 September 2004.

j. Bingham, NM

Located at 33° 50 27.7N 106° 17 12.6W, this site is between the town of Bingham and the northern boundary of White Sands Missile Range. This site is desert brush with a few buildings and dirt roads connected to a single asphalt highway. Imagery was taken on 18 November 2003. Ground-truth was acquired via a personal visit on 4 February 2005, and an interview with a local rancher, Dewey Brown.

k. Linnton, OR

Located at 45° 36' 3.6"N 122° 49' 26.7"W, this site is a small residential area hugging Forest Park. This site is almost entirely dense forest except for the small residential area. Imagery was taken on 17 August 2002. Ground-truth was acquired via a personal visit on 28 August 2004.

l. Black Hills National Forest, SD

Located at 44° 9' 29"N 103° 39' 00"W, this site is the Black Hills Ameriflux site. This site is dense forest with gravel fire roads running through it. Imagery was taken 2 September 2002. Ground-truth was done through correspondence with Mr. Eric Rowell, a remote sensing analyst with The National Center for Landscape Fire Analysis at the University of Montana who had been to the site, and supplemented by photographs on Mr. Rowells website (Rowell, 2005). Permission to use the data from this site was generously given by the

4 This research was supported by the Office of Science (BER), U.S. Department of Energy, Grant No. DE-FG02-95ER62083, and through its Southeast Regional Center (SERC) of the National Institute for Global Environmental Change (NIGEC) under Cooperative Agreement No. DE-FC02-03ER63613.

5 Soil moisture data was supported by The Department of Energy, Office of Biological Research.

primary investigator Dr. Tilden Meyers of the National Oceanographic Atmospheric Agency - Atmospheric Turbulence and Diffusion Division.

m. Walkers Branch, TN

Located at 35° 57' 47.0"N 84° 17' 3.7"W this site is the Walkers Branch Ameriflux Site. This site is predominantly forest with some roads and thinning areas. Imagery was taken on 22 October 2001. Imagery was used with kind permission from Dr. Dennis Baldocchi of University of California, Berkeley. Ground-truth was acquired via a personal visit on 22 September 2004 accompanied by the principal investigator of the Walkers Branch Throughfall Site, Dr. Paul Hanson. Due to a data loss, weather and soil moisture were determined from the neighboring Walkers Branch Throughfall Site. Permission to use the data from this site was generously given by the primary investigator Dr. Paul Hanson of the Oak Ridge National Laboratory.[6]

n. Port Bolivar, TX

Located at 29° 22' 0.4"N 94° 45' 43.4"W this site is located on the isthmus across the entrance to Galveston Bay from the city of Galveston. This site is a swampy isthmus with human development to include commercial, residential and recreational areas. Imagery was taken on 4 January 2003. Ground-truth was done entirely via photographs on the internet from the sites of Fort Travis (Crystal, 2005), Point Bolivar Lighthouse (Coast, 2005) and Fisherman's Cove Motel (Fisherman's, 2005).

o. Anchorage, UT

Located at 41° 6' 0.1"N 112° 1' 11.6"W this site is an industrial park in the unincorporated town of Anchorage near Hill AFB. This site is predominantly the industrial park with a few shops and houses around the edges Imagery was taken on 29 July 2003. Ground-truth was done via a personal visit on 4 September 2004 accompanied by Holly Pearcy, a local resident.

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6 "Data (specify type) were obtained from the Walker Branch Throughfall Displacement Experiment (TDE) Data Archive (web address) funded by the Program for Ecosystem Research, Environmental Sciences Division, Office of Biological and Environmental Research, U.S. Department of Energy."

p. Enoch, UT

Located at 37° 45' 11.1"N 113° 5' 2.1"W this site is a farm in a small town to the north of Cedar City. This site is predominantly fallow fields with a little scrubland and a few buildings. Imagery was taken on 21 January 2003. Ground-truth was acquired via a personal visit on 3 September 2004 accompanied by Holly Pearcy a local resident, supplemented by interviews with Mr. Hunter and Becky Stahling, two of the property owners.

q. Fort Lewis, WA

Located at 47° 2' 54" 122° 30' 2"W this site is in the section of the fort known as Johnson's Marsh. This site is a small marsh, about ¼ of the 1' x 1' image is surrounded by forest with the occasional road. Imagery was taken on 28 June 2003. Ground-truth was acquired via a personal visit on 27 August 2004.

r. Incomplete Sites

Fourteen (14) sites, including the Walnut River site mentioned above, were not completed. However for the reference of future work TAWS weather files and ground-truth exists for nearly every site. The only work required is the analysis of the imagery.

2. Image Processing

Processing was necessary to convert the spectral signatures of the satellite imagery into TAWS background categories. Each site came with a 1m resolution panchromatic image and a 4m resolution multi spectral image taken at the same time. These were the first two resolutions in the series of comparisons. The subsequent imagery resolutions are 15m, 30m, 100m, 250m, 500m, 1km, 4km, and 8km. The 1°x1° resolution was from the already existing database within TAWS. All analysis was conducted using *Erdas Imagine*.

The panchromatic image required that a resolution merge with the multispectral imagery be performed in order to have a spectral signature for analysis. A principal component method (Welch and Ehler, 1987) with a cubic convolution re-sampling technique (Atkinson, 1985) was used. In the principal component method the panchromatic image is assumed to contain only overall scene luminance; all interband variations are contained in the multi spectral imagery. The panchromatic image is remapped, to allow the retention of spectral signatures from the multispectral image, so that the histogram shape is kept constant, but the numerical range of the values is shifted (Welch and Ehler, 1987). Cubic convolution re-sampling uses an average of 16 pixels in a 4x4 pixel window to determine the output datafile value through an approximated cubic function (Atkinson, 1985).

All resolutions coarser than 4m were degraded directly from the 4m multispectral data through the *Erdas Imagine* degrade function. The degrade function allowed the pixels to be averaged together to form the larger pixel (Leica, 2003). An integer scaling factor is used to determine the new pixel size. The original pixels were assumed to be exactly 4m - a passable approximation. The actual pixel size varies according to orbit viewing angle and terrain slope. All imagery of viewing angles 60 degrees or greater had been removed from further consideration to help keep pixel size close to 4m. However, approximately 1/3 of the imagery came with no viewing angle information. The integral scaling factor also limited the actual size of the degraded pixel. A 4m pixel could be scaled to 196m (factor of 7) or 256m (factor of 8). The scaling factor that brought the image closest to the desired resolution was used. A sample of the degraded resolutions of the urban Offut AFB, NE site and the rural Bingham, NM site are in Figures 3 and 4. A site was designated as urban if 50% or more of its land surface was covered by buildings, roads, or paved surfaces. All other sites were designated as rural sites.

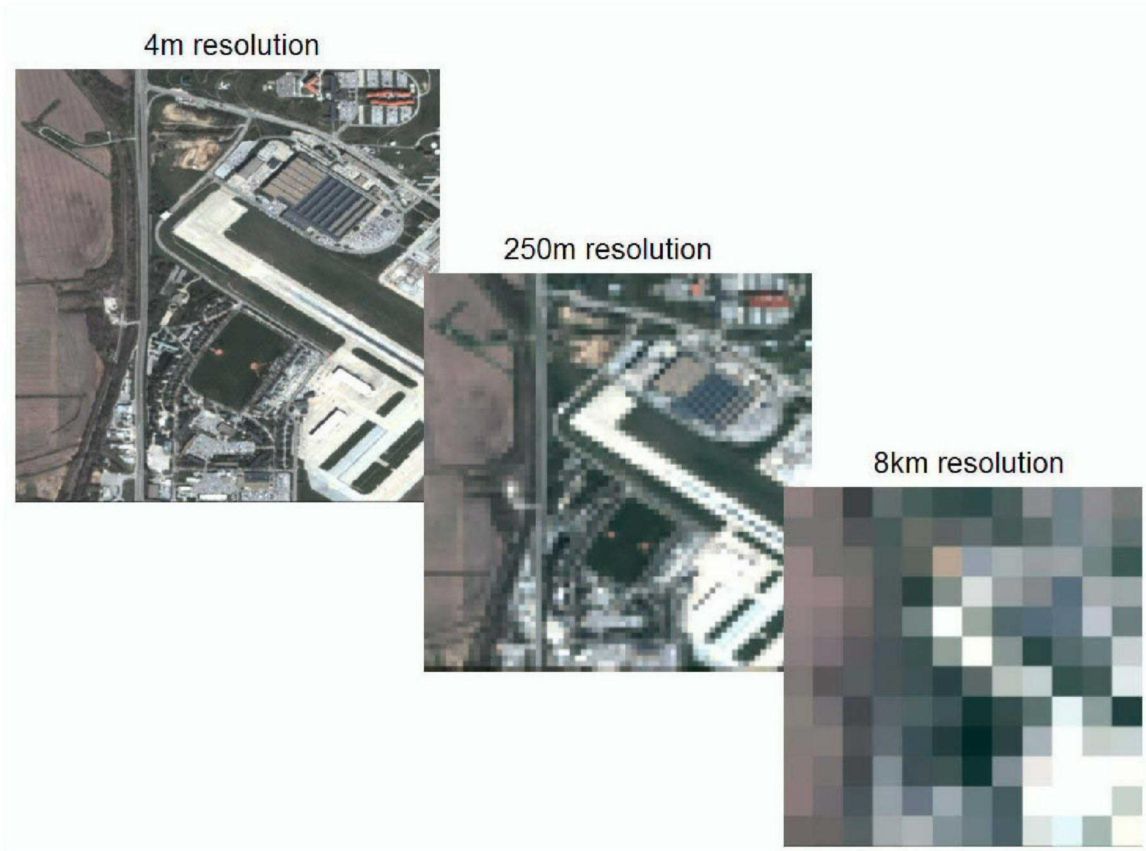

Figure 3. **Offut AFB, NE, an urban site, sample image degradation.**

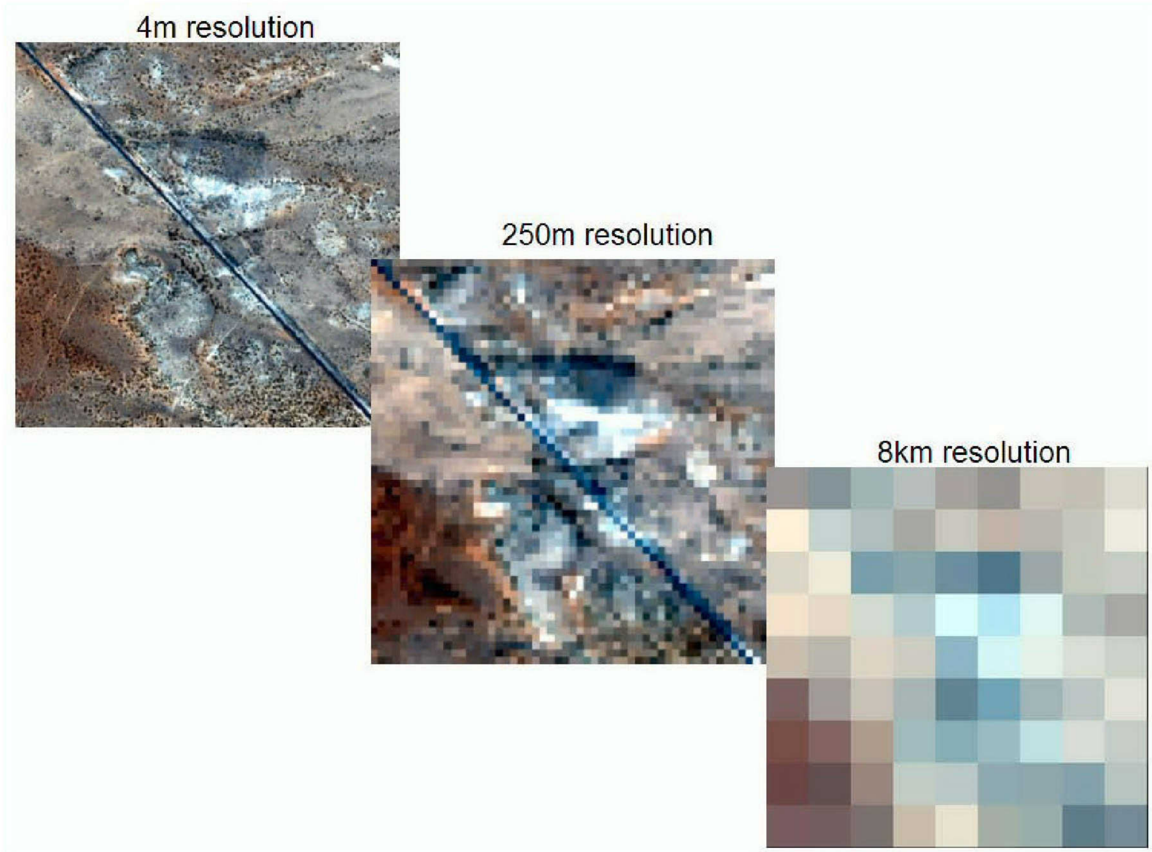

Figure 4. Bingham, NM, rural site, sample image degradation.

The original 4m multispectral imagery was analyzed and the resulting spectral signature set was applied to each resolution degradation. However, the shifted histogram from the principal component method in the panchromatic resolution merge, 1m image, necessitated a separate analysis from the 4m analysis. For this separate analysis, the process described in the following paragraph was applied to each site twice once for the 1m image, and once for the 4m image. The 4m analysis was applied to the remaining degraded resolutions.

For image analysis, the image was first ground-truthed. Second a determination was made as to whether the site was primarily urban or rural. Third, an unsupervised classification by the computer was performed. Fourth, ground-truth was used to refine the unsupervised classification into TAWS background classifications. Ground-truth and urban/rural designation for each site was conducted as described in the preceding sections. The sub image is then run through the ISODATA unsupervised classification breaking the image into 40 classes. A 99% convergence threshold was used and max iterations were set high enough to ensure convergence. A diagonal axis with one standard deviation, the default *Erdas Imagine* setting, was used (Leica, 2003). Once the 40 classes were determined each one was highlighted on the original sub image and, using ground-truth information, was labeled as to its surface characteristics. The classes were then merged to create TAWS background categories. An example of what the classes looked like at each stage is in Figures 5 and 6 for the Offut AFB and Bingham sites.

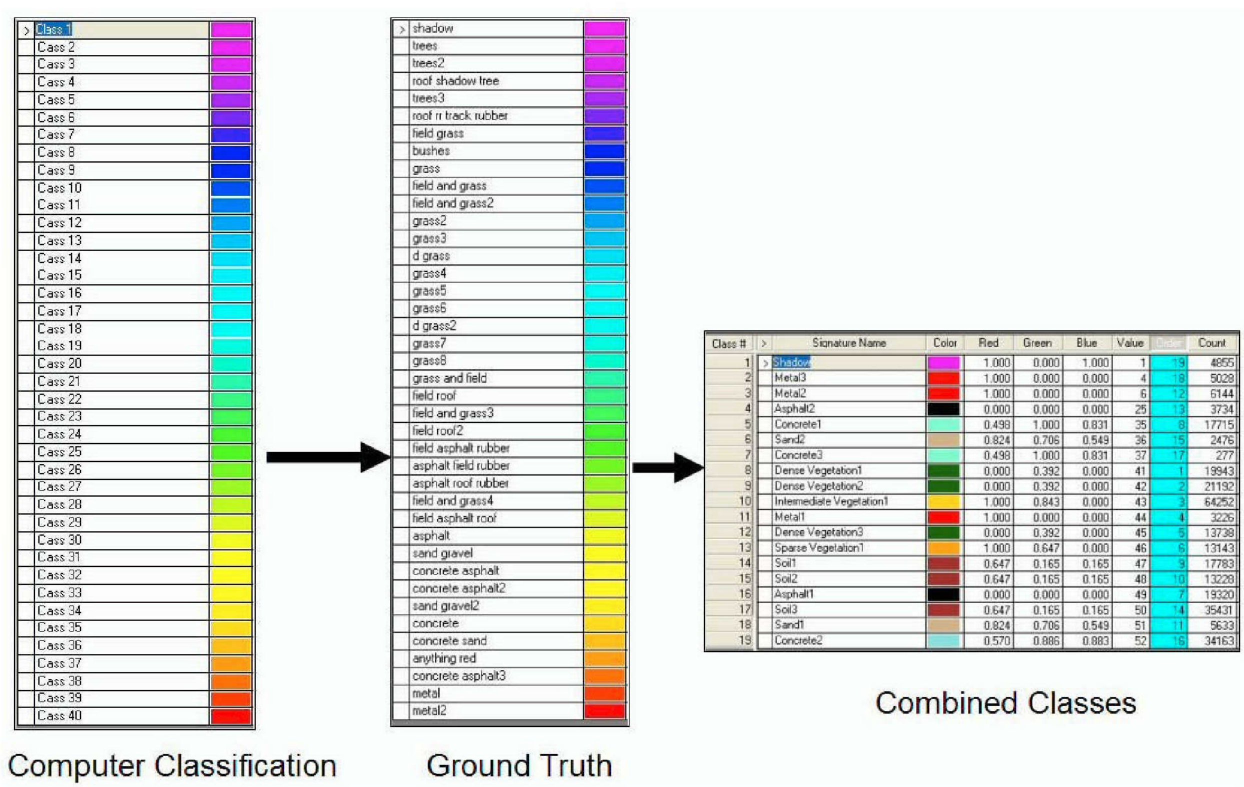

Figure 5. Classes as determined by the 3 step process for the Offut AFB site.

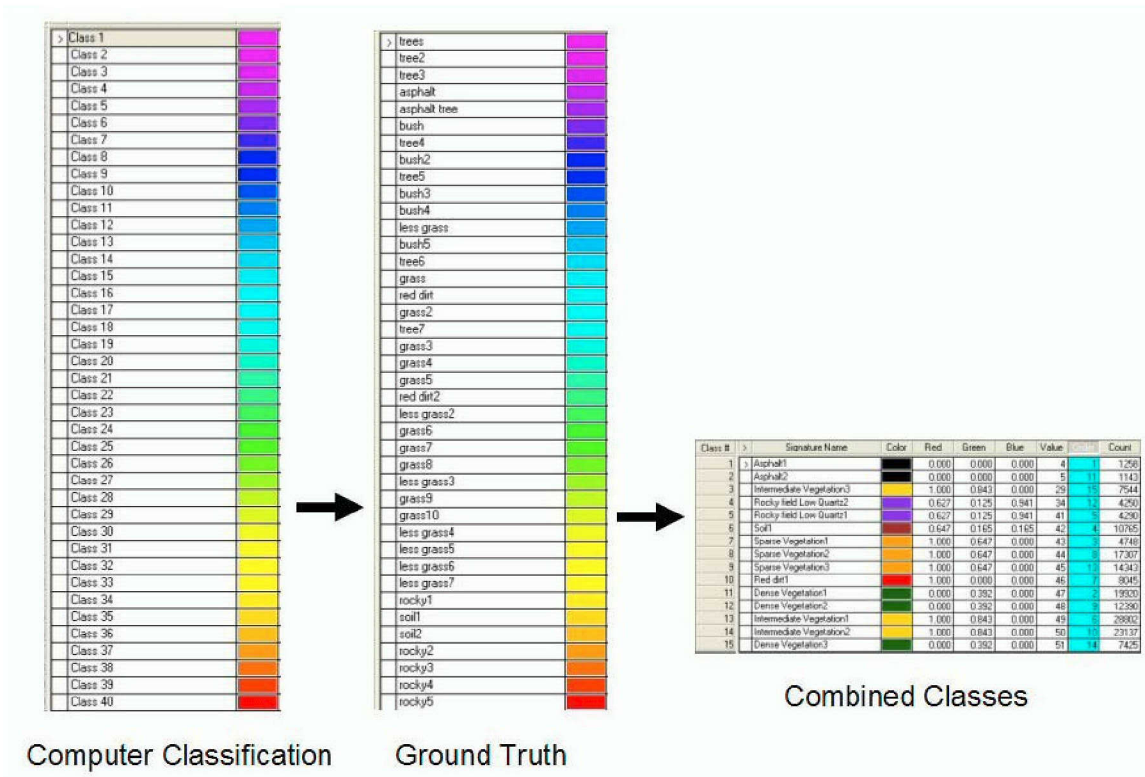

Figure 6. Classes as determined by the 3 step process for the Bingham site

After the final set of classes was determined they were overlaid to produce an image most consistent with ground truth information. The highlighted column in the final classification set in Figures 5 and 6 show the overlay order for the Offut AFB site. A flaw of this analysis method is that it tends to over analyze and allows a pixel to have more than one value. Therefore a single pixel may be analyzed as water, asphalt, and dense vegetation all at once. Ground-truth minimizes the misanalysis caused by multi-classed pixels, by allowing a human-being to selectively merge and delete computer generated classes and then carefully overlay them to hide the majority of the remaining misanalyzed pixels. No other form of sub-pixel classification was used. Significant misanalysis was not accepted close to target areas where the changing background resolution was monitored. Some misanalyses far from target areas were allowed to persist if correcting them meant misanalyzing the target area. For example, a grass field could have false asphalt pixels in it, but if correcting that meant turning the asphalt road near the target into a grass field, it was left alone. The final analysis appears as in Figures 7 and 8, for the Offut AFB and Bingham sites.

The 1m resolution proved difficult to remove stray, misanalyzed pixels without forcing the analysis. Because the 1m analysis was not applied to other resolutions, so long as a small area around the target point was clear of misanalyzed pixels, the analysis was accepted. The dramatic increase in misanalyzed pixels could be contributed to the finer resolution allowing for higher clutter levels, as well as the panchromatic resolution merge causing the histogram to shift.

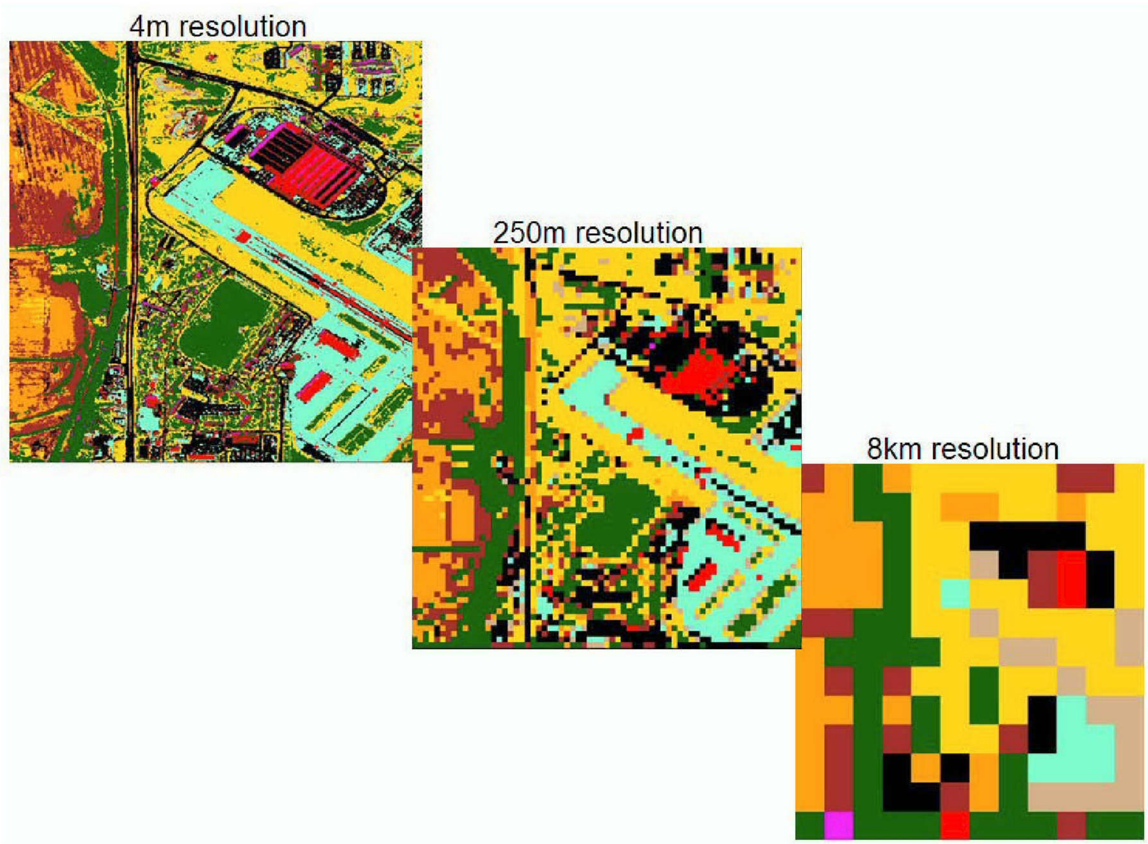

Figure 7. Final analysis of Offut AFB satellite imagery.

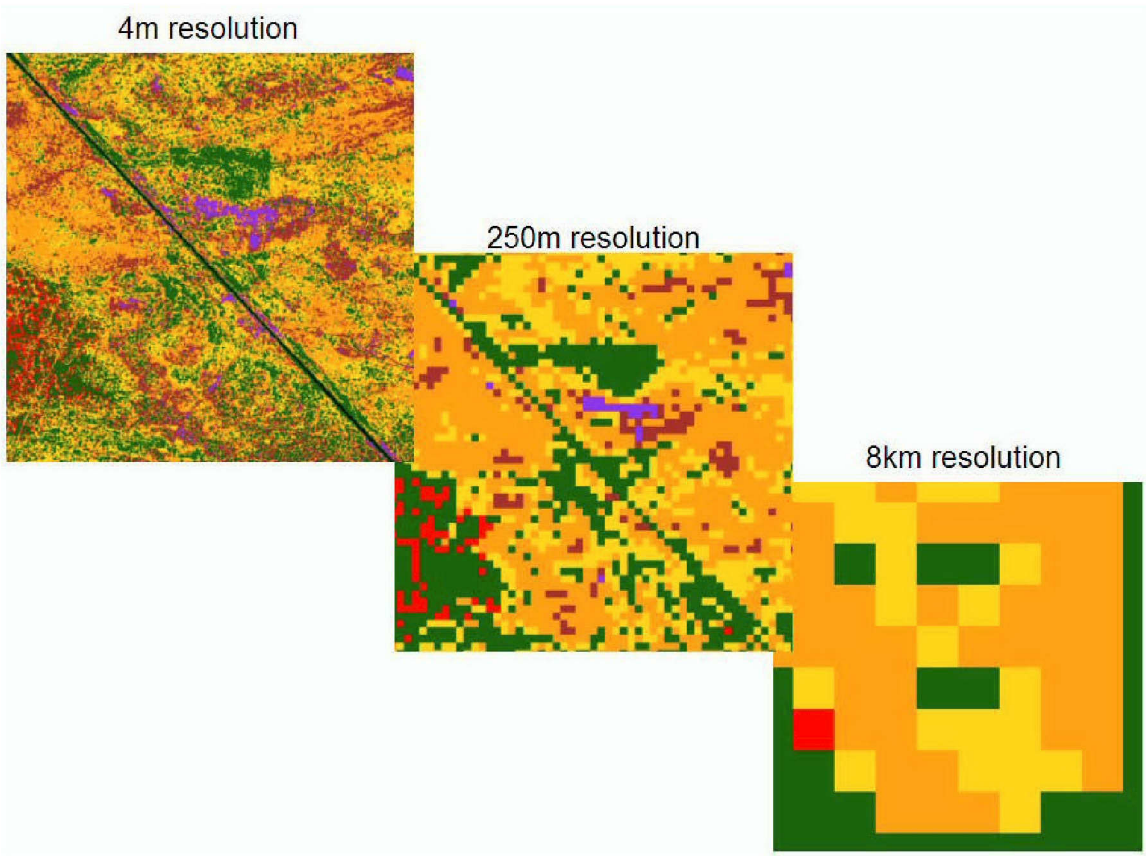

Figure 8. Final analysis of Bingham satellite imagery.

3. Analysis of Uncertainty of Terrain Classification

The uncertainty of the terrain classification analysis involved the overlap of each class with the other background classes. The mean intensity and standard deviation of each band in each class was taken and placed in an Excel worksheet. Then each class range of intensity was checked for cross over into another class. A nominal TAWS run was performed for each different background class. Where crossovers existed, the absolute difference of the 2 different ranges for the respective TAWS backgrounds was taken. Then the difference was averaged with other crossovers with respect to the total possible amount of crossovers to produce a site specific average absolute range difference due to the uncertainty of the site's classes. For urban, rural and total sites as seen in Section III, these differences were averaged, for the respective sites in question and applied to the following formulae for a lower and upper bound on the uncertainty:

$$\left(\left| \frac{R - D/2}{R} - 1 \right|, \left| \frac{R + D/2}{R} - 1 \right| \right)$$

where R is the average range for that resolution of the group of sites in question and D is the average range difference for the respective group computed as listed above.

Backgrounds that are not within TAWS set of backgrounds, namely metal and shadowed regions, were ignored in the uncertainty calculations as there is no valid TAWS background to generate a range. In addition, where there was more than one class of the same background type only the primary class was used in the uncertainty calculations. This was because secondary classes were often used to fill in stray pixels and larger amounts of misanalyzed pixels were accepted because secondary classes were layered behind the primary classes, visually hiding the majority of their misanalysis. An example of color overlap is shown in Figure 9. Similar results are found in others bands and other sites. The metal and shadow groups were thrown out of the calculation. Dense and intermediate vegetation classes clearly overlap, but dense vegetation and concrete obviously do not.

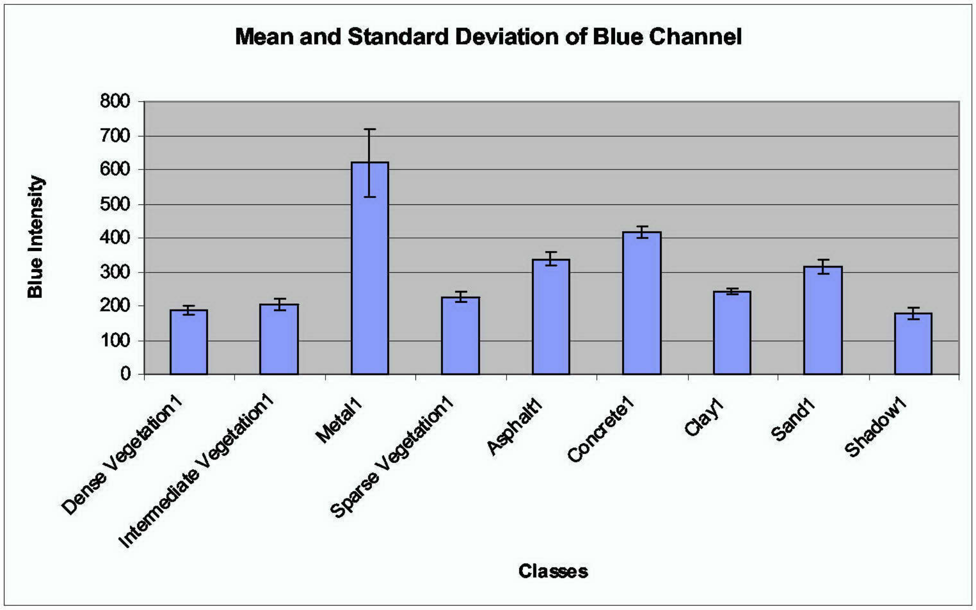

Figure 9. Sample of uncertainty from the Offut AFB site.

C. SOIL MOISTURE DATA

In analyzing satellite imagery for TAWS background categories, it is impossible to determine soil moisture quantitatively from optical satellite imagery. The TAWS sensitivity guide cites soil moisture both surface and depth as having a moderate impact on the TAWS run outcome. The impact of soil moisture will receive extra treatment in this thesis to expand the background characterizations of satellite analysis. Following is a review of how TAWS uses soil moisture and a review of the two models used to approximate soil moisture.

1. TAWS Applications

TAWS 3.2 has three background characterizations that use soil moisture, vegetation, soil and rocky field. Their use of soil moisture has been expanded below through a study of the TAWS 3.2 source code. Two of the categories soil and rocky field are treated by the same algorithms and so will be combined below as soil.

a. Soil Backgrounds

Soil moisture categories are necessary for soil background specification. For example, soil categories require user input for "surface moisture" and "depth moisture" in three levels, dry, intermediate and wet. The values are respectively, 0, 0.5, 1, in a non-dimensional volumetric ratio of moisture to soil. The TAWS subroutine then does five iterations through 13 levels of soil from 0.25 to 250cm to determine the background soil temperature. The surface moisture parameter is used more frequently than the depth moisture. Surface moisture is used as a switch for changing soil heat content algorithms and turning evaporation on and off. Soil moisture is used in conjunction with soil type to determine the different soil layers conduction rates and max heat capacity. The surface moisture value is used for layers 1-8, 0.25-62.5cm, and depth moisture is used for layers 9-13 (62.5-250cm). Layers 8 and 9 where surface and depth moisture interface are at the same depth and layers 10-12 are also all at the same depth of 125cm.

The gravel soil type does not use any soil moisture to calculate its conduction rate and max heat capacity. There are some variables that are calculated using depth moisture. However, these are not used in the soil subroutine but are saved to a global variable set. From this review, it appears that the gravel soil type is completely independent of depth moisture.

b. Vegetation Background

The vegetation category requires user input for "soil moisture" in 3 levels - dry, intermediate and wet. The "soil moisture" input is actually depth moisture and has the respective values of 0, 0.25, and 1 in a non-dimensional volumetric ratio of moisture to soil. It is important to note that the intermediate value is different than in the soil backgrounds. Surface moisture is internally fixed at a value of 0.2. The difference in surface and depth moisture values from the soil categories may be due to parameterizing the effects of vegetative root structure. In the vegetation subroutines a total soil moisture parameter is most often used, but with a 90% weight on the user determined depth moisture, making vegetation more dependant on depth moisture than the soil categories. From an operational point of view this is transparent because the user determines only the depth moisture.

The vegetation category has switches that change heat content algorithms and turn evapotranspiration on and off like the soil categories, but unlike the soil categories, soil moisture is only one factor involved in the switches making it more complicated to make these internal changes. The TAWS vegetation subroutine does five iterations through 14 layers - one layer for vegetation and 13 layers for soil from .25cm to 250cm. Soil moisture is used to determine soil layer conductance but not max heat capacity. The internal surface moisture is used for layers 2-9 (0.25cm-62.5cm) and the user determined depth moisture for layers 10-14 (62.5cm-250cm). The interface layers 9 and 10 are both at the same depth of 62.5cm and layers 10-13 are all at 125cm.

2. Approximation Methods

Due to the difficulty of determining soil moisture through Ikonos/Quickbird imagery, two models for approximating soil moisture were tested against in situ measurements at three Ameriflux sites, the Duke University –loblolly pine site, NC, the Black Hills National Forest site, SD, and the now defunct Walnut River Watershed site, KS (Oak, 2005). The models were run and in situ measurements were collected for the day corresponding to the Ikonos images used in the background analysis.

a. AGRMET

AGRMET is the Air Forces near real time, agricultural meteorological analysis model. One of the calculated parameters of AGRMET is soil moisture, at four levels sfc-10cm, 10-40cm, 40-100cm, and 100-200cm. AGRMET has no actual soil moisture inputs, but initializes itself with precipitation, making its output highly sensitive to a proper precipitation analysis. Currently in situ measurements and satellite estimated precipitation are used with the in situ measurements having precedence. (Air, 2005) AGRMET is currently on the JAAWIN website for the sfc-10cm and 10-40cm levels. The 10-40cm level is ideal for TAWS surface moisture, but the ideal level for TAWS depth moisture, 100-200cm, is not on the JAAWIN website. AGRMET archived products were used as the satellite imagery was generally a year or more old.

b. FASST

FASST is a soil strength model run as part of the Army's Battlespace Terrain reasoning and Awareness research program, by the Engineer Research and Development Center – Cold Regions Research and Engineering Laboratory. One of the key elements in soil strength is soil moisture and as such, this 1-D model calculates an energy and water budget that quantifies the flow of heat and water within the soil and at its interfaces. Soil moisture inputs are possible (Frankenstein, 2004). Individual 14 day runs for each case were compiled from raw meteorological data.

c. Measurements

The Duke Forest and Black Hills sites both used an average of four equidistant probes which integrated moisture from the surface to 30cm. The Walnut River site used a single probe to measure soil moisture from surface to 5cm.

3. Comparison of Methods

Soil moisture values from the archived AGRMET, initialized FASST (with an accurate soil moisture value at the start of a 14 day spin up) and uninitialized FASST (with the default soil moisture based on soil type at the start of a 14 day spin up) were compared to in situ observations. An average of the difference of the methods from the observations is in Figure 10 below.

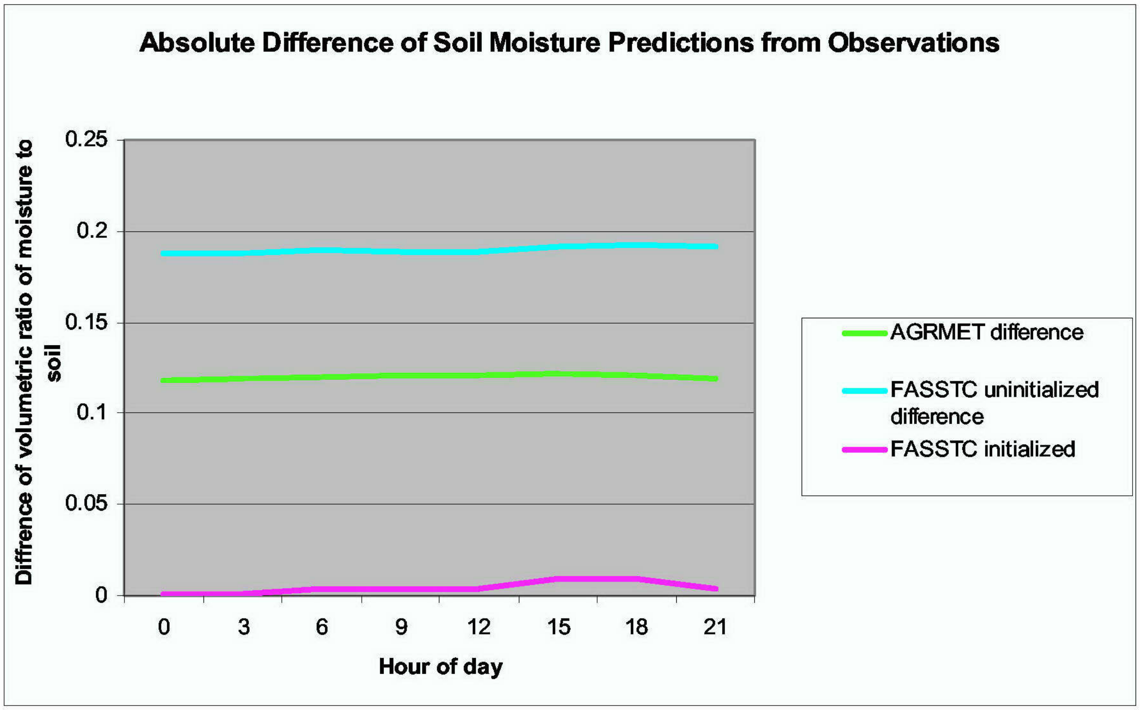

Figure 10. Absolute Difference of Soil Moisture Predictions from Observations

The initialized version of FASST performed nearly perfectly, but there is the stipulation of having an accurate soil moisture value to initialize it. AGRMET performed the next best, and unitialized FASST, run on default values, pulled in third. Due to the difficulty of obtaining archived soil moisture values, the initialized FASST method was not used. Archived AGRMET products were the first choice in determining the soil moisture of sites without measurements and so long as an archived product was available within 6 days of the satellite image it was used. The assumption being that soil moisture changes slowly. The uninitialized FASST was used in cases with no AGRMET archive available.

The comparison above should not be construed as a verification of the models involved. This analysis was intended for a quick way to prioritize estimation methods for this thesis only. First, there are only three samples. The models are very different from each other. AGRMET was made to run without soil moisture inputs and FASST was made to run without soil moisture if need be; it was intended to be initialized and is successful with only one accurate initial value.

D. WEATHER DATA

The weather data was taken first from in situ measurements, then from subjective analysis of archived observations and surface charts from Plymouth State University (Plymouth, 2005) and from archived upper air soundings from the University of Wyoming (University, 2005). Surface data interpolations took into account distance from reporting stations and changes in elevation. Boundary layer height and upper air averages were assumed to be the same as the closest upper air station taking into consideration elevation changes as TAWS weather parameters are entirely in relation to ground level or AGL. For boundary layer and upper air information data between 12z and 00z, conceptual Figures 11 and 12 were used to interpolate boundary layer behavior (Stull, 2001). The figures assume high pressure with no frontal passage,.a relatively good assumption as only cloud free imagery was used.

The following interpolation method was used. The noon, midnight, sunset, sunrise points on Figure 6 were converted to zulu time. The sunset and sunrise times were determined by TAWS 3.2s luminance model and rounded to the nearest hour, then all times were placed on a copy of Figure 6 at the indicated location. The S1-S6 points were given a time, rounded to a whole hour, based on linear interpolation between the noon, midnight, sunrise and sunset. S1 is .67 of the time from noon to sunset. S2 is .28 of the time from sunset to midnight. S3 is 0.78 of the time from midnight to sunrise. S4 - S6 are respectively 0.40, 0.55, and 0.8 of the time from sunrise to noon. On occasion S4 and S5 would be the same hour; in that case the times were adjusted so that each one had a different hour.

Figure 12 is an estimate of the daily variance of the boundary layer height at S1-S6 on Figure 11. The 12z and 00z boundary layer heights were determined by first looking for a temperature inversion in the soundings raw data, second looking for a wind shift, third a surface inversion, if present, would be considered, and fourth the tropopause was used. Dew point was not used to determine a boundary layer height. The 12z and 00z boundary layer heights were then placed in Figure 12 at the appropriate place taking the times on Figure 11 into account. The TAWS 3 hourly boundary layer values were interpolated between the measurements and Figure 12s relative boundary layer soundings.

The upper air temperature/dew point averages were the average of all measured values from the top of the boundary layer to 15km AGL. The sounding data was in mean sea level (MSL) so a conversion based on the station elevation was done. Values between 12z and 00z were interpolated based on the fact that lower boundary layer heights bring in warmer and moister air into the average and meteorological reasoning.

Using Offut AFB as an example, the soundings were taken from Omaha, NE and the Figure 11 zulu times for noon, midnight, sunrise, and sunset were 1800, 0600, 1200, and 0100, respectively. The times of S1-S6 are 23z, 02z, 11z, 14z, 15z, and 17z, respectively. The 08 April 2004 12z (08/12z) and 09 April 2004 00z (09/00z) soundings show a boundary layer height at 1759m and 2185m MSL, respectively. With MSL converted to AGL, considering an Omaha station elevation of 350m, the boundary layer heights become 1409m and 1835m. With meters converted to hundreds of feet, the boundary layer heights become 46 and 60 for 08/12z and 09/00z, respectively. Looking at the times for Figure 11 12z is at sunrise or between S3 and S4, and 00z is between S1 and sunset. The 12z and 00z boundary heights are taken directly from the soundings, but 15z, 18z, and 21z must be interpolated. The 15z corresponds to S5 which has a lower boundary layer height in Figure 12 than at 12z so the value of 40 is given. 18z and 21z are between S6 and S1 where the boundary layer height only slightly increases with time so the heights of 56 and 58 are given. For the upper air temperature/dew point averages, the 15km AGL top was converted to AGL by adding the station elevation, so that all measured values between the boundary layer height and 15350m were averaged. Because there was no 15350m measurement the closest one was used and the averages for 08/12z and 09/00z were from 1759m-15240m, and 2185m-15240m, respectively. The actual values were -29°/-52°, and -26°/-41° Celsius. 09/00z has a higher boundary layer height so we correctly expect the temperature average to decrease, but there must be moisture advection in the upper levels for the dew point to increase in spite of an increasing boundary layer height. So the dew point averages will all increase with time, 15z will have a warmer temperature average than 12z due to a lower boundary layer height and 18z and 21z will have temperature averages cooler than 12z but a little warmer than 00z. So the interpolated values are -30° /-50°, -27°/-47°, and -27°/-43° Celsius, respectively. The same process was done in between skewts for other Offut AFB times and other sites.

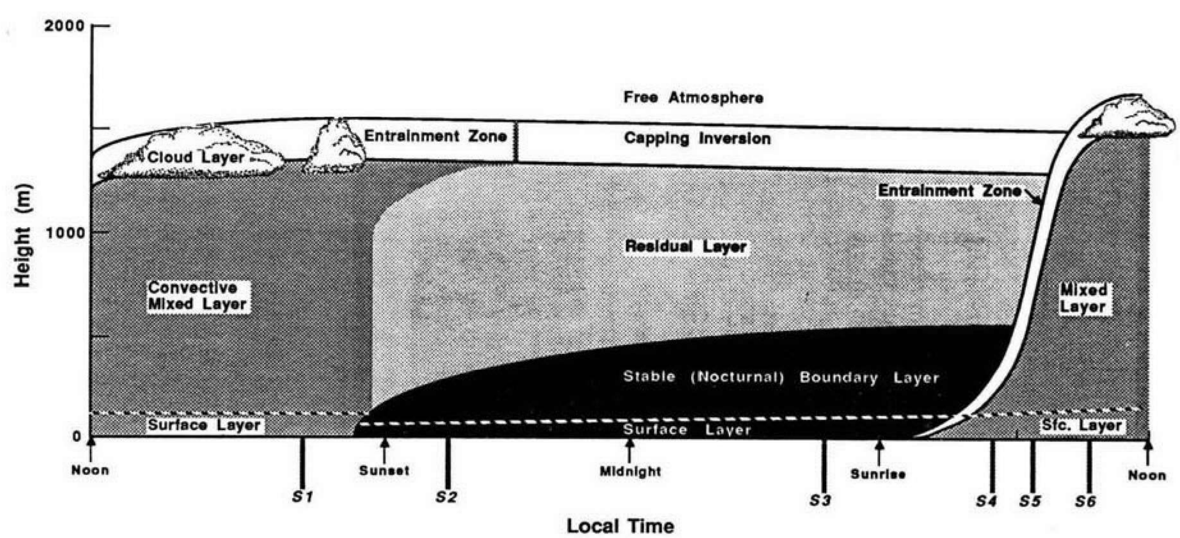

Figure 11. Diurnal variation of the boundary layer over land (Stull, 2001)

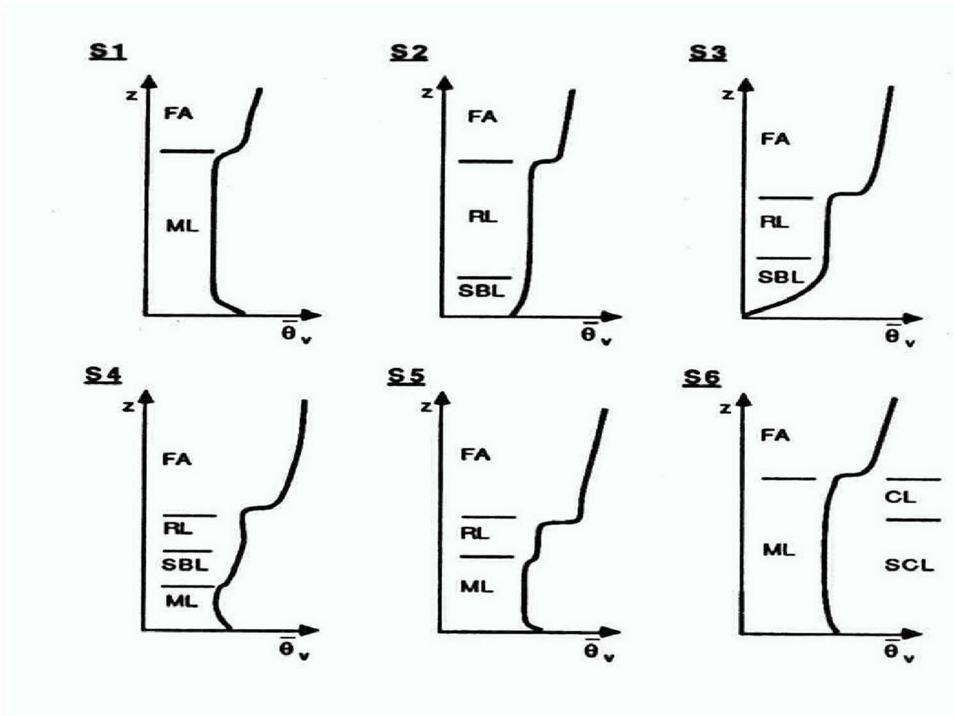

Figure 12. Change of boundary layer height corresponding to points in Figure 11 (Stull, 2001)

III. RESULTS

Once the various background types for TAWS were determined, each was run through the TAWS 3.2 model to obtain a range. All TAWS runs had nominal settings of the T-62 Tank version C, medium clutter, sensor 1004 and a flight level of 10000 feet. The range values came from a table with 50% probability of detection. For the purposes of this comparison the TAWS standard range is the range for the 1m resolution background. The site designation urban/rural, the soil moisture method used and the background type for each resolution can be found in Appendix A.

Figure 13. The mean range for urban and rural sites for wide field of view (WFOV) and narrow field of view (NFOV).

The spread of the ranges for all resolutions in Figure 13, except the $1^\circ \times 1^\circ$ resolution, shows that for both WFOV and NFOV, rural and urban sites differ significantly in ranges. In the $1^\circ \times 1^\circ$ resolution rural and urban ranges converge because the resolution has become so coarse that 14 of the 16 sites had vegetation dense coverage intermediate growing season dry soil moisture. For resolutions below the $1^{\circ} \times 1^{\circ}$ distinguishing between rural and urban sites is significant on the order of 5km or 16% for WFOV and 3km or 20% for NFOV.

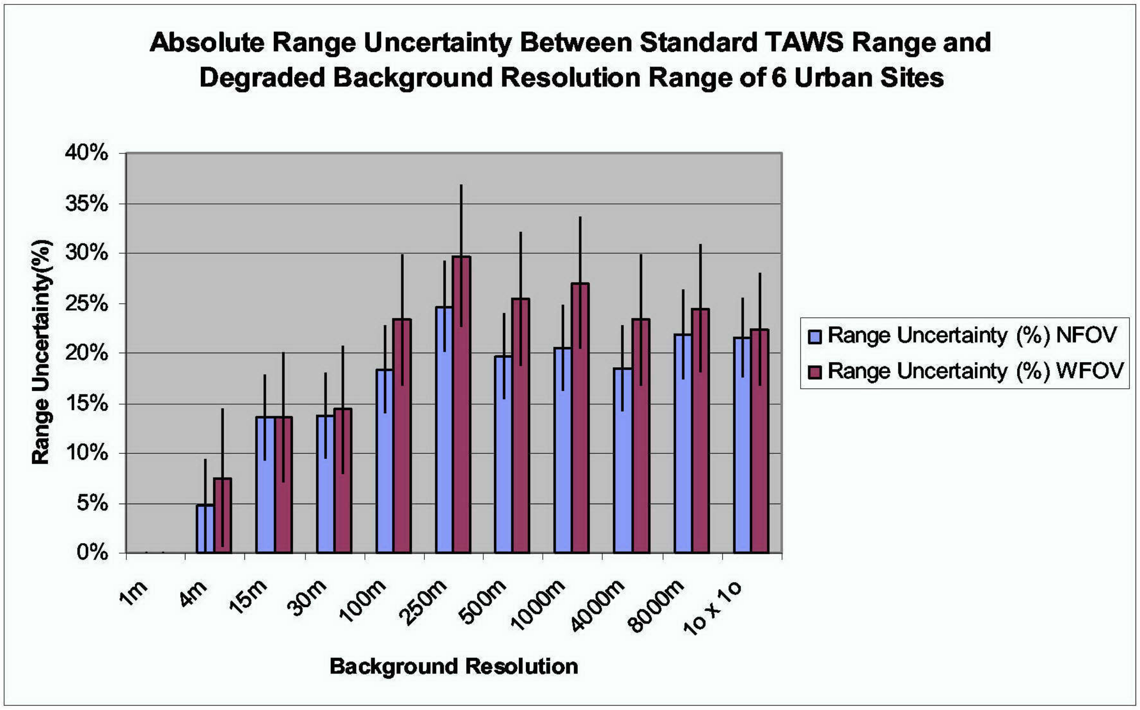

Figure 14. Absolute range uncertainty in percentage between standard TAWS range and degraded background resolution range for urban sites.

In Figure 14, the resolution with the largest range uncertainty for urban sites was at 250m, larger than the $1^{\circ} \times 1^{\circ}$ resolution. In fact for urban sites no significant improvement in range uncertainty is seen until the resolution drops to 30m. The maxima at 250m could possibly be due to a contiguous pixel issue. That is at the 250m resolution many urban features are only one or two pixels of a single class before switching to a different adjacent class, causing greater misanalysis. For resolutions greater than 250m those features are averaged into much larger pixels providing less misanalysis due to bordering classes, and for resolutions smaller than 250m there are many more pixels in the same area allowing for less chance of misanalysis.

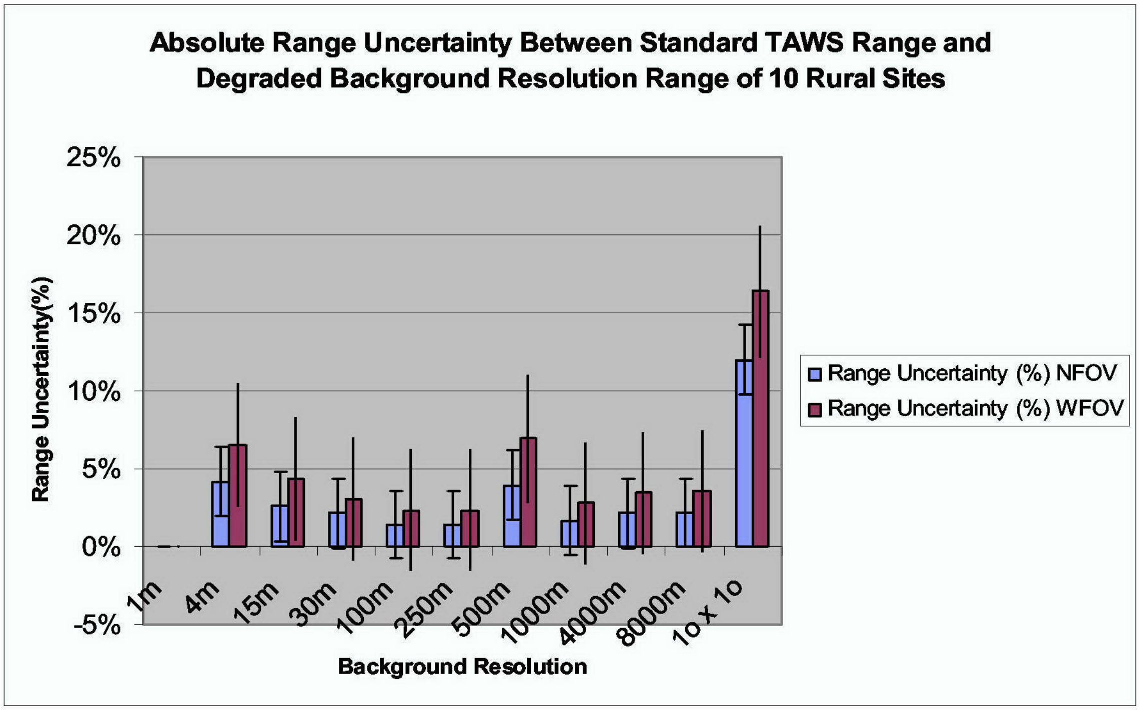

Figure 15. Absolute range uncertainty in percentage between standard TAWS range and degraded background resolution for rural sites.

Rural site uncertainty results, Figure 15, are quite different than those from urban sites in that the uncertainty in range was so small that, for the majority of the resolutions, the uncertainty in terrain analysis was greater than the uncertainty of the TAWS range. The two notable exceptions are the 1^{o}x1^{o} which has range uncertainty comparable to the urban sites, and the very small secondary max at 500m. The secondary max may be due again to the contiguous pixel issue only this time in a rural setting there are larger areas of similar spectral signatures allowing the peak to shift to 500m instead of 250m. In other words, rural sites are more uniform in surface type. To improve the range uncertainty in background for rural areas, any resolution below the 1^{o}x1^{o} would provide significant advantage over the current 1^{o}x1^{o} database. This reinforces the significance of treating rural and urban sites differently as their range uncertainties behave differently.

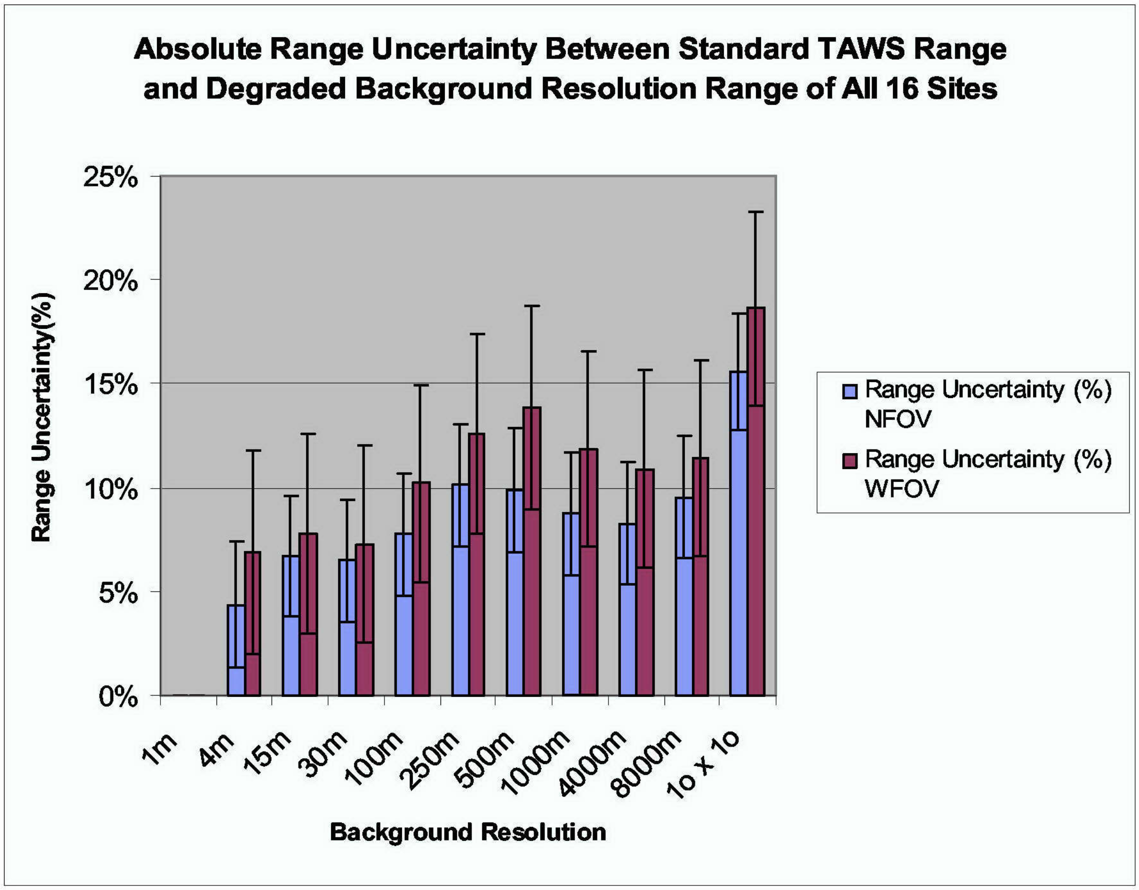

Figure 16. Absolute range uncertainty in percentage between standard TAWS range and degraded background resolution range of all sites

When the urban and rural groups are combined in Figure 16, a minimum is found at 1000m and the best resolution stands at 30m. This is due mainly to the tempering of urban range uncertainty in Figure 14 by the minimal rural uncertainty in Figure 15. This combination of rural and urban groups changes the range uncertainty pattern losing much of the definition found in the separate groups. Rural and urban sites need to stay separate for meaningful results.

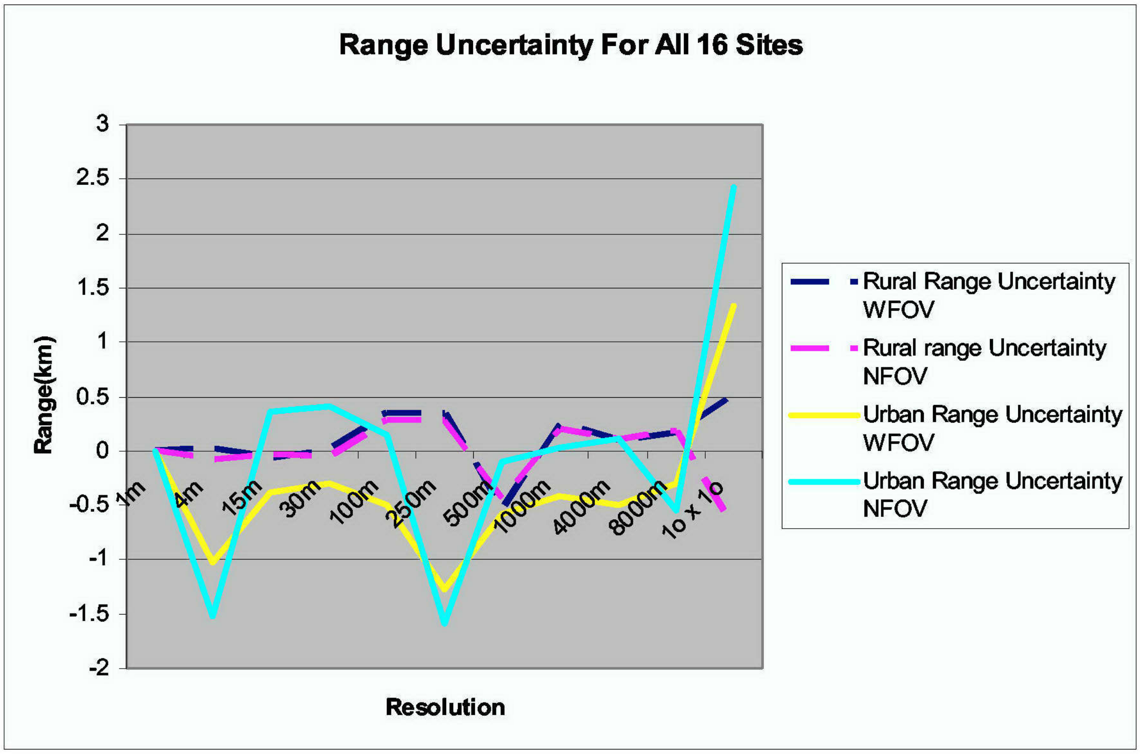

Figure 17. Averaged range uncertainty for all sites

Considering averaged range uncertainty instead of the absolute percentages in Figure 17, we see that for the most part the urban range uncertainty tends to underestimate range. The one significant exception is that the $1^{o}x1^{o}$ greatly overestimates the range. The rural sites range uncertainty stays small and oscillates close to zero until the $1^{o}x1^{o}$ where the oscillation becomes larger. The discontinuity between the $1^{o}x1^{o}$ resolution and the rest of the resolutions is clearly shown here, as is the significant difference in behavior of the urban sites and the rural sites.

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IV. CONCLUSION AND RECOMMENDATIONS

Conclusions and recommendations encompass two parts: user background determination, and default background.

A. USER BACKGROUND DETERMINATION

Background determination contributes to about 20% uncertainty in range. With the nominal TAWS settings used in this thesis, the uncertainty tends to underestimate ranges in urban areas possibly causing pilots to not look for the target as soon as they could in an already complex environment, placing them in harms way for a longer period of time. Also for mission planning purposes, borderline conditions for mission completion could be underestimated causing a target to be changed needlessly. Soil moisture is an important part of several background types, but it is difficult for the operational user to estimate accurately. I recommend allowing the TAWS user to directly ingest it from the AGRMET model. Optimal AGRMET levels for TAWS are 10-40cm for surface moisture and 100-200cm for depth moisture.

B. DEFAULT BACKGROUND

The current TAWS default background needs to change, a range uncertainty of up to 22% is not acceptable. Because of the difference in rural and urban sites, I recommend a nested grid approach. First, take an 8km resolution instead of the averaged $1^{\circ}x1^{\circ}$ resolution for the entire globe to improve rural areas. Second, use Landsat imagery, about 30m resolution, to create nested grids for urban areas. The recommended database should also include a seasonal factor for vegetative growing season, such a factor could be automated based on date and latitude as a first approximation. Additionally, a further study could be done of snow sites as none of my sites had snow in them.

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APPENDIX A

The background type by site and resolution can be found by referencing Table 2 in Appendix B. The source of soil moisture estimation is listed under soil as M = measurements, A = AGRMET, and F= FASST. The site type is listed as U = urban and R = rural.

Site	1	4	15	30	100	250	500	1000	4000	8000	1x1	Soil	SType
Eielsen AFB, AK	20	20	20	20	20	20	20	20	20	20	1	F	R
Audobon Research Ranch, AZ	20	20	20	20	20	20	20	20	20	20	1	F	R
Ponnequin Wind Farm, CO	14	14	14	14	14	14	14	14	14	17	1	A	R
Colorado Springs, CO	11	11	11	11	14	14	14	14	14	14	1	A	U
Ewa Beach, HI	173	173	59	59	143	143	143	143	143	143	111	F	U
Offut AFB, NE	155	125	125	125	125	125	125	125	125	59	14	A	U
Duke Forest, NC	11	11	11	11	11	11	11	11	11	11	1	M	R
Pine Harbor, NC	8	4	4	4	8	4	4	4	8	4	1	A	U
Bingham, NM	8	28	28	8	8	8	2	5	5	5	1	A	R
Linnton, OR	20	20	20	20	20	20	20	20	20	20	1	F	R
Black Hills, SD	11	17	11	17	11	11	11	11	11	11	1	M	R
Walker's Branch, TN	11	14	14	11	14	14	14	14	14	14	1	M	R
Port Bolivar, TX	149	149	149	149	149	23	149	161	161	23	1	A	U
Anchorage, UT	26	26	73	46	73	73	46	161	73	46	1	A	U
Enoch, UT	8	5	41	5	41	41	41	41	41	41	1	A	R
Ft. Lewis, WA	186	23	23	23	23	186	186	186	20	23	1	A	R

Table 1. Background type by site and resolution, plus soil moisture source.

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APPENDIX B

Table 2 shows all the possible TAWS backgrounds, to be used with Appendix A.

1	*Vegetation*	Growing State:	*dormant*	Coverage:	*dense*	Soil Moisture:	*dry*
2	*Vegetation*	Growing State:	*dormant*	Coverage:	*dense*	Soil Moisture:	*intermediate*
3	*Vegetation*	Growing State:	*dormant*	Coverage:	*dense*	Soil Moisture:	*wet*
4	*Vegetation*	Growing State:	*dormant*	Coverage:	*intermediate*	Soil Moisture:	*dry*
5	*Vegetation*	Growing State:	*dormant*	Coverage:	*intermediate*	Soil Moisture:	*intermediate*
6	*Vegetation*	Growing State:	*dormant*	Coverage:	*intermediate*	Soil Moisture:	*wet*
7	*Vegetation*	Growing State:	*dormant*	Coverage:	*sparse*	Soil Moisture:	*dry*
8	*Vegetation*	Growing State:	*dormant*	Coverage:	*sparse*	Soil Moisture:	*intermediate*
9	*Vegetation*	Growing State:	*dormant*	Coverage:	*sparse*	Soil Moisture:	*wet*
10	*Vegetation*	Growing State:	*intermediate*	Coverage:	*dense*	Soil Moisture:	*dry*
11	*Vegetation*	Growing State:	*intermediate*	Coverage:	*dense*	Soil Moisture:	*intermediate*
12	*Vegetation*	Growing State:	*intermediate*	Coverage:	*dense*	Soil Moisture:	*wet*
13	*Vegetation*	Growing State:	*intermediate*	Coverage:	*intermediate*	Soil Moisture:	*dry*
14	*Vegetation*	Growing State:	*intermediate*	Coverage:	*intermediate*	Soil Moisture:	*intermediate*
15	*Vegetation*	Growing State:	*intermediate*	Coverage:	*intermediate*	Soil Moisture:	*wet*
16	*Vegetation*	Growing State:	*intermediate*	Coverage:	*sparse*	Soil Moisture:	*dry*
17	*Vegetation*	Growing State:	*intermediate*	Coverage:	*sparse*	Soil Moisture:	*intermediate*
18	*Vegetation*	Growing State:	*intermediate*	Coverage:	*sparse*	Soil Moisture:	*wet*
19	*Vegetation*	Growing State:	*growing*	Coverage:	*dense*	Soil Moisture:	*dry*
20	*Vegetation*	Growing State:	*growing*	Coverage:	*dense*	Soil Moisture:	*intermediate*
21	*Vegetation*	Growing State:	*growing*	Coverage:	*dense*	Soil Moisture:	*wet*
22	*Vegetation*	Growing State:	*growing*	Coverage:	*intermediate*	Soil Moisture:	*dry*
23	*Vegetation*	Growing State:	*growing*	Coverage:	*intermediate*	Soil Moisture:	*intermediate*

24	*Vegetation*	Growing State:	*growing*	Coverage:	*intermediate*	Soil Moisture:	*wet*
25	*Vegetation*	Growing State:	*growing*	Coverage:	*sparse*	Soil Moisture:	*dry*
26	*Vegetation*	Growing State:	*growing*	Coverage:	*sparse*	Soil Moisture:	*intermediate*
27	*Vegetation*	Growing State:	*growing*	Coverage:	*sparse*	Soil Moisture:	*wet*
28	*Soil*	Type:	*average*	Surface Moisture:	*dry*	Depth Moisture:	*dry*
29	*Soil*	Type:	*average*	Surface Moisture:	*dry*	Depth Moisture:	*intermediate*
30	*Soil*	Type:	*average*	Surface Moisture:	*dry*	Depth Moisture:	*wet*
31	*Soil*	Type:	*average*	Surface Moisture:	*intermediate*	Depth Moisture:	*dry*
32	*Soil*	Type:	*average*	Surface Moisture:	*intermediate*	Depth Moisture:	*intermediate*
33	*Soil*	Type:	*average*	Surface Moisture:	*intermediate*	Depth Moisture:	*wet*
34	*Soil*	Type:	*average*	Surface Moisture:	*wet*	Depth Moisture:	*dry*
35	*Soil*	Type:	*average*	Surface Moisture:	*wet*	Depth Moisture:	*intermediate*
36	*Soil*	Type:	*average*	Surface Moisture:	*wet*	Depth Moisture:	*wet*
37	*Soil*	Type:	*loam*	Surface Moisture:	*dry*	Depth Moisture:	*dry*
38	*Soil*	Type:	*loam*	Surface Moisture:	*dry*	Depth Moisture:	*intermediate*
39	*Soil*	Type:	*loam*	Surface Moisture:	*dry*	Depth Moisture:	*wet*
40	*Soil*	Type:	*loam*	Surface Moisture:	*intermediate*	Depth Moisture:	*dry*
41	*Soil*	Type:	*loam*	Surface Moisture:	*intermediate*	Depth Moisture:	*intermediate*
42	*Soil*	Type:	*loam*	Surface Moisture:	*intermediate*	Depth Moisture:	*wet*
43	*Soil*	Type:	*loam*	Surface Moisture:	*wet*	Depth Moisture:	*dry*
44	*Soil*	Type:	*loam*	Surface Moisture:	*wet*	Depth Moisture:	*intermediate*
45	*Soil*	Type:	*loam*	Surface Moisture:	*wet*	Depth Moisture:	*wet*
46	*Soil*	Type:	*sand*	Surface Moisture:	*dry*	Depth Moisture:	*dry*
47	*Soil*	Type:	*sand*	Surface Moisture:	*dry*	Depth Moisture:	*intermediate*
48	*Soil*	Type:	*sand*	Surface Moisture:	*dry*	Depth Moisture:	*wet*
49	*Soil*	Type:	*sand*	Surface Moisture:	*intermediate*	Depth Moisture:	*dry*
50	*Soil*	Type:	*sand*	Surface	*intermediate*	Depth	*intermediate*

				Moisture:		Moisture:	
51	*Soil*	Type:	*sand*	Surface Moisture:	*intermediate*	Depth Moisture:	*wet*
52	*Soil*	Type:	*sand*	Surface Moisture:	*wet*	Depth Moisture:	*dry*
53	*Soil*	Type:	*sand*	Surface Moisture:	*wet*	Depth Moisture:	*intermediate*
54	*Soil*	Type:	*sand*	Surface Moisture:	*wet*	Depth Moisture:	*wet*
55	*Soil*	Type:	*clay*	Surface Moisture:	*dry*	Depth Moisture:	*dry*
56	*Soil*	Type:	*clay*	Surface Moisture:	*dry*	Depth Moisture:	*intermediate*
57	*Soil*	Type:	*clay*	Surface Moisture:	*dry*	Depth Moisture:	*wet*
58	*Soil*	Type:	*clay*	Surface Moisture:	*intermediate*	Depth Moisture:	*dry*
59	*Soil*	Type:	*clay*	Surface Moisture:	*intermediate*	Depth Moisture:	*intermediate*
60	*Soil*	Type:	*clay*	Surface Moisture:	*intermediate*	Depth Moisture:	*wet*
61	*Soil*	Type:	*clay*	Surface Moisture:	*wet*	Depth Moisture:	*dry*
62	*Soil*	Type:	*clay*	Surface Moisture:	*wet*	Depth Moisture:	*intermediate*
63	*Soil*	Type:	*clay*	Surface Moisture:	*wet*	Depth Moisture:	*wet*
64	*Soil*	Type:	*peat*	Surface Moisture:	*dry*	Depth Moisture:	*dry*
65	*Soil*	Type:	*peat*	Surface Moisture:	*dry*	Depth Moisture:	*intermediate*
66	*Soil*	Type:	*peat*	Surface Moisture:	*dry*	Depth Moisture:	*wet*
67	*Soil*	Type:	*peat*	Surface Moisture:	*intermediate*	Depth Moisture:	*dry*
68	*Soil*	Type:	*peat*	Surface Moisture:	*intermediate*	Depth Moisture:	*intermediate*
69	*Soil*	Type:	*peat*	Surface Moisture:	*intermediate*	Depth Moisture:	*wet*
70	*Soil*	Type:	*peat*	Surface Moisture:	*wet*	Depth Moisture:	*dry*
71	*Soil*	Type:	*peat*	Surface Moisture:	*wet*	Depth Moisture:	*intermediate*
72	*Soil*	Type:	*peat*	Surface Moisture:	*wet*	Depth Moisture:	*wet*
73	*Soil*	Type:	*gravel*	Surface Moisture:	*dry*	Depth Moisture:	*dry*
74	*Soil*	Type:	*gravel*	Surface Moisture:	*dry*	Depth Moisture:	*intermediate*
75	*Soil*	Type:	*gravel*	Surface Moisture:	*dry*	Depth Moisture:	*wet*
76	*Soil*	Type:	*gravel*	Surface Moisture:	*intermediate*	Depth Moisture:	*dry*

77	*Soil*	Type:	*gravel*	Surface Moisture:	*intermediate*	Depth Moisture:	*intermediate*
78	*Soil*	Type:	*gravel*	Surface Moisture:	*intermediate*	Depth Moisture:	*wet*
79	*Soil*	Type:	*gravel*	Surface Moisture:	*wet*	Depth Moisture:	*dry*
80	*Soil*	Type:	*gravel*	Surface Moisture:	*wet*	Depth Moisture:	*intermediate*
81	*Soil*	Type:	*gravel*	Surface Moisture:	*wet*	Depth Moisture:	*wet*
82	*Soil*	Type:	*desert sand*	Surface Moisture:	*dry*	Depth Moisture:	*dry*
83	*Soil*	Type:	*desert sand*	Surface Moisture:	*dry*	Depth Moisture:	*intermediate*
84	*Soil*	Type:	*desert sand*	Surface Moisture:	*dry*	Depth Moisture:	*wet*
85	*Soil*	Type:	*desert sand*	Surface Moisture:	*intermediate*	Depth Moisture:	*dry*
86	*Soil*	Type:	*desert sand*	Surface Moisture:	*intermediate*	Depth Moisture:	*intermediate*
87	*Soil*	Type:	*desert sand*	Surface Moisture:	*intermediate*	Depth Moisture:	*wet*
88	*Soil*	Type:	*desert sand*	Surface Moisture:	*wet*	Depth Moisture:	*dry*
89	*Soil*	Type:	*desert sand*	Surface Moisture:	*wet*	Depth Moisture:	*intermediate*
90	*Soil*	Type:	*desert sand*	Surface Moisture:	*wet*	Depth Moisture:	*wet*
91	*Snow*	Type:	*fresh*	Depth:	*1-99in*	Condition:	*compact*
92	*Snow*	Type:	*fresh*	Depth:	*1-99in*	Condition:	*windy region*
93	*Snow*	Type:	*fresh*	Depth:	*1-99in*	Condition:	*late in season*
94	*Snow*	Type:	*fresh*	Depth:	*1-99in*	Condition:	*tundra*
95	*Snow*	Type:	*fresh*	Depth:	*1-99in*	Condition:	*undisturbed*
96	*Snow*	Type:	*old*	Depth:	*1-99in*	Condition:	*compact*
97	*Snow*	Type:	*old*	Depth:	*1-99in*	Condition:	*windy region*
98	*Snow*	Type:	*old*	Depth:	*1-99in*	Condition:	*late in season*
99	*Snow*	Type:	*old*	Depth:	*1-99in*	Condition:	*tundra*
100	*Snow*	Type:	*old*	Depth:	*1-99in*	Condition:	*undisturbed*
101	*Snow*	Type:	*rained upon*	Depth:	*1-99in*	Condition:	*compact*
102	*Snow*	Type:	*rained upon*	Depth:	*1-99in*	Condition:	*windy region*
103	*Snow*	Type:	*rained upon*	Depth:	*1-99in*	Condition:	*late in season*
104	*Snow*	Type:	*rained upon*	Depth:	*1-99in*	Condition:	*tundra*
105	*Snow*	Type:	*rained upon*	Depth:	*1-99in*	Condition:	*undisturbed*
106	*Snow*	Type:	*surface melted*	Depth:	*1-99in*	Condition:	*compact*

107	*Snow*	Type:	*surface melted*	Depth:	*1-99in*	Condition:	*windy region*
108	*Snow*	Type:	*surface melted*	Depth:	*1-99in*	Condition:	*late in season*
109	*Snow*	Type:	*surface melted*	Depth:	*1-99in*	Condition:	*tundra*
110	*Snow*	Type:	*surface melted*	Depth:	*1-99in*	Condition:	*undisturbed*
111	*Water*	Clarity:	*clear*				
112	*Water*	Clarity:	*turbid*				
113	*Concrete*	Type:	*interstate highway*	Surface:	*uncolored*	Wetness:	*dry*
114	*Concrete*	Type:	*interstate highway*	Surface:	*uncolored*	Wetness:	*intermediate*
115	*Concrete*	Type:	*interstate highway*	Surface:	*uncolored*	Wetness:	*wet*
116	*Concrete*	Type:	*interstate highway*	Surface:	*black*	Wetness:	*dry*
117	*Concrete*	Type:	*interstate highway*	Surface:	*black*	Wetness:	*intermediate*
118	*Concrete*	Type:	*interstate highway*	Surface:	*black*	Wetness:	*wet*
119	*Concrete*	Type:	*sidewalk*	Surface:	*uncolored*	Wetness:	*dry*
120	*Concrete*	Type:	*sidewalk*	Surface:	*uncolored*	Wetness:	*intermediate*
121	*Concrete*	Type:	*sidewalk*	Surface:	*uncolored*	Wetness:	*wet*
122	*Concrete*	Type:	*sidewalk*	Surface:	*black*	Wetness:	*dry*
123	*Concrete*	Type:	*sidewalk*	Surface:	*black*	Wetness:	*intermediate*
124	*Concrete*	Type:	*sidewalk*	Surface:	*black*	Wetness:	*wet*
125	*Concrete*	Type:	*runway*	Surface:	*uncolored*	Wetness:	*dry*
126	*Concrete*	Type:	*runway*	Surface:	*uncolored*	Wetness:	*intermediate*
127	*Concrete*	Type:	*runway*	Surface:	*uncolored*	Wetness:	*wet*
128	*Concrete*	Type:	*runway*	Surface:	*black*	Wetness:	*dry*
129	*Concrete*	Type:	*runway*	Surface:	*black*	Wetness:	*intermediate*
130	*Concrete*	Type:	*runway*	Surface:	*black*	Wetness:	*wet*
131	*Concrete*	Type:	*parking lot*	Surface:	*uncolored*	Wetness:	*dry*
132	*Concrete*	Type:	*parking lot*	Surface:	*uncolored*	Wetness:	*intermediate*
133	*Concrete*	Type:	*parking lot*	Surface:	*uncolored*	Wetness:	*wet*
134	*Concrete*	Type:	*parking lot*	Surface:	*black*	Wetness:	*dry*
135	*Concrete*	Type:	*parking lot*	Surface:	*black*	Wetness:	*intermediate*
136	*Concrete*	Type:	*parking lot*	Surface:	*black*	Wetness:	*wet*
137	*Concrete*	Type:	*bridge*	Surface:	*uncolored*	Wetness:	*dry*
138	*Concrete*	Type:	*bridge*	Surface:	*uncolored*	Wetness:	*intermediate*
139	*Concrete*	Type:	*bridge*	Surface:	*uncolored*	Wetness:	*wet*
140	*Concrete*	Type:	*bridge*	Surface:	*black*	Wetness:	*dry*
141	*Concrete*	Type:	*bridge*	Surface:	*black*	Wetness:	*intermediate*

142	*Concrete*	Type:	*bridge*	Surface:	*black*	Wetness:	*wet*
143	*Concrete*	Type:	*heavy pad*	Surface:	*uncolored*	Wetness:	*dry*
144	*Concrete*	Type:	*heavy pad*	Surface:	*uncolored*	Wetness:	*intermediate*
145	*Concrete*	Type:	*heavy pad*	Surface:	*uncolored*	Wetness:	*wet*
146	*Concrete*	Type:	*heavy pad*	Surface:	*black*	Wetness:	*dry*
147	*Concrete*	Type:	*heavy pad*	Surface:	*black*	Wetness:	*intermediate*
148	*Concrete*	Type:	*heavy pad*	Surface:	*black*	Wetness:	*wet*
149	*Asphalt*	Type:	*interstate highway*	Surface:	*aged*	Wetness:	*dry*
150	*Asphalt*	Type:	*interstate highway*	Surface:	*aged*	Wetness:	*intermediate*
151	*Asphalt*	Type:	*interstate highway*	Surface:	*aged*	Wetness:	*wet*
152	*Asphalt*	Type:	*interstate highway*	Surface:	*new*	Wetness:	*dry*
153	*Asphalt*	Type:	*interstate highway*	Surface:	*new*	Wetness:	*intermediate*
154	*Asphalt*	Type:	*interstate highway*	Surface:	*new*	Wetness:	*wet*
155	*Asphalt*	Type:	*runway*	Surface:	*aged*	Wetness:	*dry*
156	*Asphalt*	Type:	*runway*	Surface:	*aged*	Wetness:	*intermediate*
157	*Asphalt*	Type:	*runway*	Surface:	*aged*	Wetness:	*wet*
158	*Asphalt*	Type:	*runway*	Surface:	*new*	Wetness:	*dry*
159	*Asphalt*	Type:	*runway*	Surface:	*new*	Wetness:	*intermediate*
160	*Asphalt*	Type:	*runway*	Surface:	*new*	Wetness:	*wet*
161	*Asphalt*	Type:	*parking lot*	Surface:	*aged*	Wetness:	*dry*
162	*Asphalt*	Type:	*parking lot*	Surface:	*aged*	Wetness:	*intermediate*
163	*Asphalt*	Type:	*parking lot*	Surface:	*aged*	Wetness:	*wet*
164	*Asphalt*	Type:	*parking lot*	Surface:	*new*	Wetness:	*dry*
165	*Asphalt*	Type:	*parking lot*	Surface:	*new*	Wetness:	*intermediate*
166	*Asphalt*	Type:	*parking lot*	Surface:	*new*	Wetness:	*wet*
167	*Asphalt*	Type:	*bridge*	Surface:	*aged*	Wetness:	*dry*
168	*Asphalt*	Type:	*bridge*	Surface:	*aged*	Wetness:	*intermediate*
169	*Asphalt*	Type:	*bridge*	Surface:	*aged*	Wetness:	*wet*
170	*Asphalt*	Type:	*bridge*	Surface:	*new*	Wetness:	*dry*
171	*Asphalt*	Type:	*bridge*	Surface:	*new*	Wetness:	*intermediate*
172	*Asphalt*	Type:	*bridge*	Surface:	*new*	Wetness:	*wet*
173	*Asphalt*	Type:	*country road*	Surface:	*aged*	Wetness:	*dry*
174	*Asphalt*	Type:	*country road*	Surface:	*aged*	Wetness:	*intermediate*
175	*Asphalt*	Type:	*country road*	Surface:	*aged*	Wetness:	*wet*
176	*Asphalt*	Type:	*country road*	Surface:	*new*	Wetness:	*dry*
177	*Asphalt*	Type:	*country road*	Surface:	*new*	Wetness:	*intermediate*

178	*Asphalt*	Type:	*country road*	Surface:	*new*	Wetness:	*wet*
179	*Swamp/Marsh*	Growing State:	*dormant*	Coverage:	*dense*	Water Depth:	*1-99ft*
180	*Swamp/Marsh*	Growing State:	*dormant*	Coverage:	*intermediate*	Water Depth:	*1-99ft*
181	*Swamp/Marsh*	Growing State:	*dormant*	Coverage:	*sparse*	Water Depth:	*1-99ft*
182	*Swamp/Marsh*	Growing State:	*intermediate*	Coverage:	*dense*	Water Depth:	*1-99ft*
183	*Swamp/Marsh*	Growing State:	*intermediate*	Coverage:	*intermediate*	Water Depth:	*1-99ft*
184	*Swamp/Marsh*	Growing State:	*intermediate*	Coverage:	*sparse*	Water Depth:	*1-99ft*
185	*Swamp/Marsh*	Growing State:	*growing*	Coverage:	*dense*	Water Depth:	*1-99ft*
186	*Swamp/Marsh*	Growing State:	*growing*	Coverage:	*intermediate*	Water Depth:	*1-99ft*
187	*Swamp/Marsh*	Growing State:	*growing*	Coverage:	*sparse*	Water Depth:	*1-99ft*
188	*Rocky Field*	Quartz Content:	*none*	Surface Moisture:	*dry*	Depth Moisture:	*dry*
189	*Rocky Field*	Quartz Content:	*none*	Surface Moisture:	*dry*	Depth Moisture:	*intermediate*
190	*Rocky Field*	Quartz Content:	*none*	Surface Moisture:	*dry*	Depth Moisture:	*wet*
191	*Rocky Field*	Quartz Content:	*none*	Surface Moisture:	*intermediate*	Depth Moisture:	*dry*
192	*Rocky Field*	Quartz Content:	*none*	Surface Moisture:	*intermediate*	Depth Moisture:	*intermediate*
193	*Rocky Field*	Quartz Content:	*none*	Surface Moisture:	*intermediate*	Depth Moisture:	*wet*
194	*Rocky Field*	Quartz Content:	*none*	Surface Moisture:	*wet*	Depth Moisture:	*dry*
195	*Rocky Field*	Quartz Content:	*none*	Surface Moisture:	*wet*	Depth Moisture:	*intermediate*
196	*Rocky Field*	Quartz Content:	*none*	Surface Moisture:	*wet*	Depth Moisture:	*wet*
197	*Rocky Field*	Quartz Content:	*low*	Surface Moisture:	*dry*	Depth Moisture:	*dry*
198	*Rocky Field*	Quartz Content:	*low*	Surface Moisture:	*dry*	Depth Moisture:	*intermediate*
199	*Rocky Field*	Quartz Content:	*low*	Surface Moisture:	*dry*	Depth Moisture:	*wet*
200	*Rocky Field*	Quartz Content:	*low*	Surface Moisture:	*intermediate*	Depth Moisture:	*dry*
201	*Rocky Field*	Quartz Content:	*low*	Surface Moisture:	*intermediate*	Depth Moisture:	*intermediate*
202	*Rocky Field*	Quartz Content:	*low*	Surface Moisture:	*intermediate*	Depth Moisture:	*wet*
203	*Rocky Field*	Quartz Content:	*low*	Surface Moisture:	*wet*	Depth Moisture:	*dry*
204	*Rocky Field*	Quartz Content:	*low*	Surface Moisture:	*wet*	Depth Moisture:	*intermediate*

205	*Rocky Field*	Quartz Content:	*low*	Surface Moisture:	*wet*	Depth Moisture:	*wet*
206	*Rocky Field*	Quartz Content:	*high*	Surface Moisture:	*dry*	Depth Moisture:	*dry*
207	*Rocky Field*	Quartz Content:	*high*	Surface Moisture:	*dry*	Depth Moisture:	*intermediate*
208	*Rocky Field*	Quartz Content:	*high*	Surface Moisture:	*dry*	Depth Moisture:	*wet*
209	*Rocky Field*	Quartz Content:	*high*	Surface Moisture:	*intermediate*	Depth Moisture:	*dry*
210	*Rocky Field*	Quartz Content:	*high*	Surface Moisture:	*intermediate*	Depth Moisture:	*intermediate*
211	*Rocky Field*	Quartz Content:	*high*	Surface Moisture:	*intermediate*	Depth Moisture:	*wet*
212	*Rocky Field*	Quartz Content:	*high*	Surface Moisture:	*wet*	Depth Moisture:	*dry*
213	*Rocky Field*	Quartz Content:	*high*	Surface Moisture:	*wet*	Depth Moisture:	*intermediate*
214	*Rocky Field*	Quartz Content:	*high*	Surface Moisture:	*wet*	Depth Moisture:	*wet*

Table 2. Possible TAWS Backgrounds.

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