12.1 Radar visualization and occultation in 4-dimensions using Google Earth

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1. INTRODUCTION

Weather radar information is mapped and animated in 3-dimensions using COLLADA models on Google Earth. Radar beam occultation is theoretically calculated for the entire NEXRAD system using Digital Terrain Models (DTM), and is combined with NEXRAD reflectivity to verify signal blockage patterns. Occultation patterns for the entire NEXRAD system have been released for public use and inspection at http://wxazygy.com/. Recent enhancements to occultation techniques include beam blockage at higher spatial resolution using Synthetic Aperture Radar (SAR), blockage or extraneous signals due to manmade objects such as buildings and towers, and seasonal impacts related to attenuation by vegetation canopies.

2. Radar Beam Propagation Geometry

The National Weather Service currently serves near real-time radar information in GIS-Ready formats through its RIDGE service at http://radar.weather.gov. The current RIDGE service provides 2-dimensional products as each radar scans through 360 degrees azimuth at its lowest beam elevation angle, which is nominally about one-half degree above the horizon. We are accustomed to seeing these products draped on the surface as ground overlays, mapping radar reflectivity or radial velocity as a function of position {lon, lat} and animated in time. This is a useful service, and we are now taking it with us on portable handheld devices. The message is clear to the casual user: any radar "echo" over your location means there should be precipitation on or above you. But sometimes there are no radar "echoes" over my location and I'm getting soaked!

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So what's going on? The answer can be found in the third dimension. Radar beams propagate horizontally through the atmosphere along Great Circles, but do not usually follow a straight path or "ray" in the vertical dimension. As shown in Figure 1 for "standard" atmospheric conditions, radio beams are normally refracted downward towards the Earth. Any departure from this "standard" path is known as Anomalous Propagation (AP). If the radar beam encounters an obstacle such as terrain or buildings, power is removed from the radio beam and a radio "shadow" appears behind the obstacle. This effect is known as "occultation".

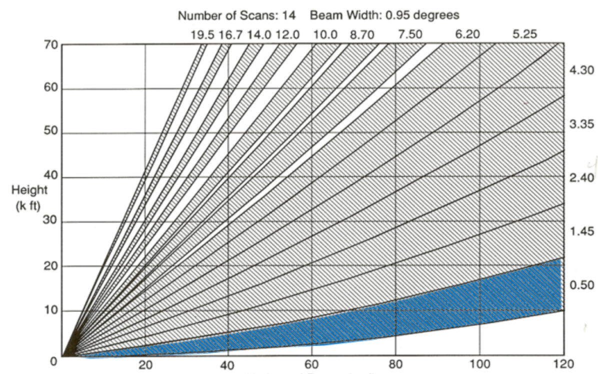

Figure 1 – Flat Earth geometry, from FMH-11 (2005). Although radar beams are normally refracted downward "towards" the Earth surface, flat Earth plots add Earth curvature, so they appear to go "up". Compare with Figure 2.

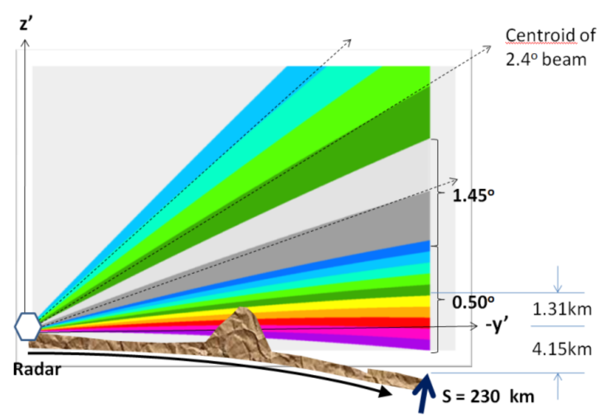

Figure 2 – Adapted from FMH-11 (2005) for Virtual Globe geometry with WGS-84 horizontal datum. When Earth curvature is included, radar beam propagation paths can be seen to refract downwards "towards" the Earth surface.

The lowest elevation beam in Figure 2 (0.5 degrees) is further subdivided into ten equal angular intervals and color-coded to assist visual interpretation of the degree of occultation. This color scheme is provided in Figure 3. It is our intent to convey degree of occultation, where reds/yellows indicate occultation greater than 50% (generally considered "bad") and greens/blues indicate occultation less than 50% (generally considered "good"). This symbolization is consistent with National Weather Service (NWS) operational usage, where beams that are occulted more than 50% are considered blocked.

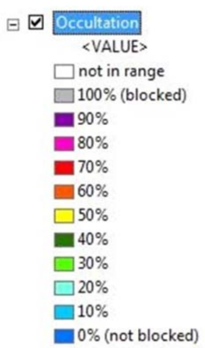

Figure 3 – Occultation color scale for all figures in this paper.

Mt. Ranier provides an excellent example of the situation depicted in Figure 2. A Range Height Indicator (RHI) depiction of the Seattle, WA NEXRAD (KATX) is shown in Figure 4 for the 160 degree azimuth beam (True North bearing). At this azimuth angle, Mt. Ranier can be seen occulting about 90% of the beam volume. Since beam energy is roughly Gaussian in vertical distribution, we would expect the 160 degree azimuth beam to be free of echoes at greater range.

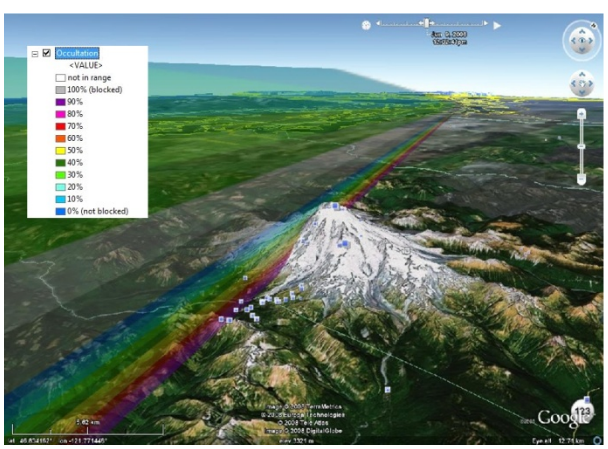

Figure 4 – RHI cross section for Seattle, WA NEXRAD (KATX) at 160 degree beam azimuth.

3. Modeling the Radar Beam Surface

COLLADA models are used with the Keyhole Markup Language (KML) to generate compressed KML/COLLADA packages (*.KMZ) for Virtual Globes such as Google Earth and ArcGlobe. It is important to note that Google Earth draws COLLADA models with respect to a tangent plane defined within the corresponding KML <Placemark>. Other Virtual Globes such as ESRI's ArcGlobe may draw COLLADA models w.r.t the Earth surface OR a tangent plane, so we need to be careful and pay close attention. As shown in Figure 5, KML will define a tangent plane using the coordinates of point P {x,y,z}, defined with respect to the WGS-84 spheroid. ESRI's ArcGlobe supports additional spheroids beyond the WGS-84 datum. Once the tangent plane is defined, a gridded surface can be used to approximate the curvature for radar beam propagation as shown in Figure 6.

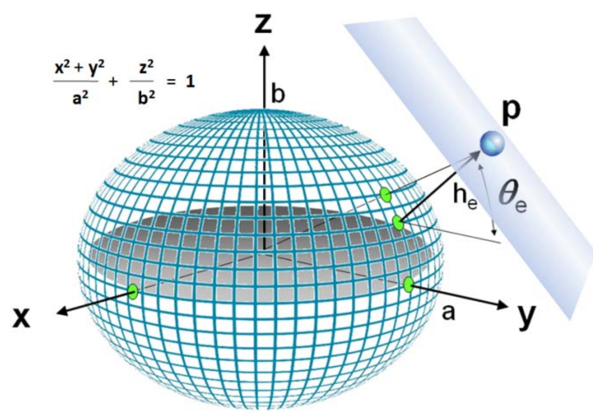

Figure 5 – Google Earth COLLADA models are drawn on the tangent plane. GE claims to adopt the WGS-84 spheroid.

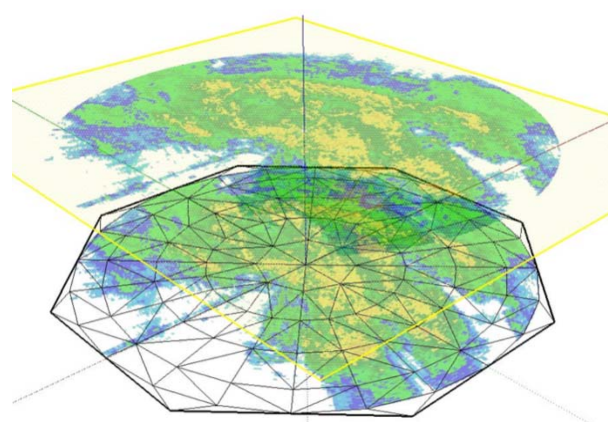

Figure 6 – Google Sketchup drawing of the radar beam propagation surface for 0.5 degree elevation, defined w.r.t. the tangent plane. Radar polar plot images are draped onto this surface.

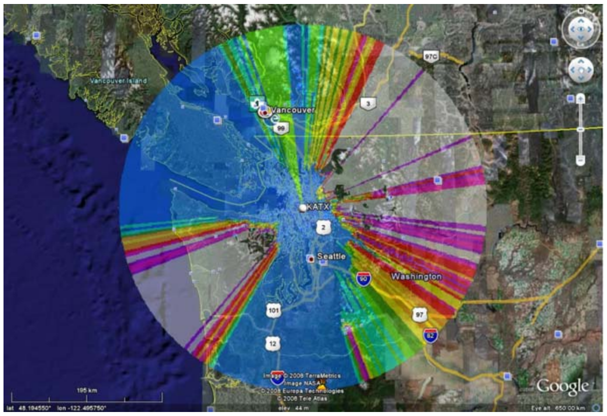

Figure 7 – Occultation pattern for the lowest elevation scan of Seattle, WA NEXRAD (station KATX) in Google Earth. Note total blockage of this elevation scan by terrain to the East and West, and by Mt. Ranier to the SSE. Areas where the terrain layer is higher than the beam centroid can be seen penetrating the coverage.

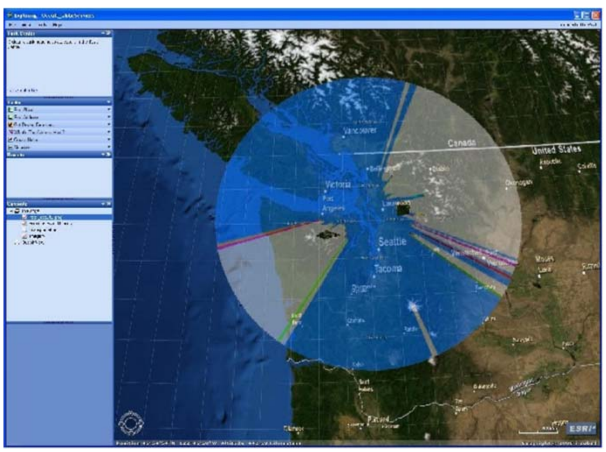

Figure 8 – Occultation pattern for the lowest elevation scan of Seattle, WA NEXRAD (station KATX) in ArcGIS Explorer. The occultation pattern is a 3D service draped upon beam centroid elevation. Virtual Globe features are similar to Google Earth as shown in Figure 7.

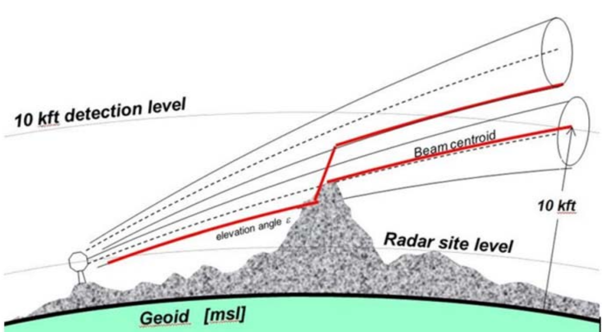

Figure 9 – Radar propagation paths, showing occultation of the lowest elevation beam by terrain. If more than 50% of a beam is removed by occultation, then that beam is considered blocked and radar signals are obtained from the next higher elevation scan.

Radar beam occultation patterns are not new (Maddox et al, 2002), Shipley et al., 2005,2006, 2007, 2008). The results reported here enable public use and understanding of occultation in general, using freely available tools such as Virtual Globes. The challenge is to show where terrain is blocking the NWS weather radar network, and to what degree. GIS provides a straightforward solution by comparing the vertical beam centroid (midpoint of the beam) as a floating surface to a digital terrain model at an appropriate spatial resolution. The resulting pattern for the Seattle, WA NEXRAD (KATX) is shown as a floating surface with Google Earth in Figure 7, and similarly with ArcGIS Explorer in Figure 8. The occultation patterns for all 155 NEXRAD systems are being published as a globeservice in ArcServer 9.3, and are available courtesy of WxAnalyst, LTD at http://wxazygy.com/

A theoretical WSR-88D beam propagation path for initial beam elevation angle ε is shown in Figure 9. The radar beam power distribution is assumed to be symmetric about the beam centroid. The lowest detectable height is defined by the bottom of the beam, which in this paper is called the "Floor". When the occultation criterion is set to Power < 50%, then the Floor is defined by the beam centroid after that centroid grazes an obstacle. The SRI method (Leone et al., 1989) defines the maximum detectable range when the lowest possible beam centroid reaches 10 kft ARL (Above Radar Level), and radar beam elevation angles are presumed to vary continuously.

4. Techniques for Animation

An application using multiple beam elevation angles is shown in Figure 10. When weather radars are located close to terrain obstacles of significant height, then several elevation layers are required to determine the complete sample volume. KML <TimeStamp> can be used to animate such displays, and provide a useful way to animate the beam scanning process. This example required beam elevation up to 4.5 degrees before a completely clear propagation path (assuming no AP) could be obtained.

The NWS RIDGE system now provides us with an opportunity to acquire and animate NEXRAD data in 3D. RIDGE 1 and RIDGE 2 provide level r0 (0.5 degree elevation) radar images in a geographic coordinate system {lon, lat} for use with common map utilities. This approach has a feature of "distorting" the radar scan at higher latitudes, where users are accustomed to local map projections which do not suffer significant spatial

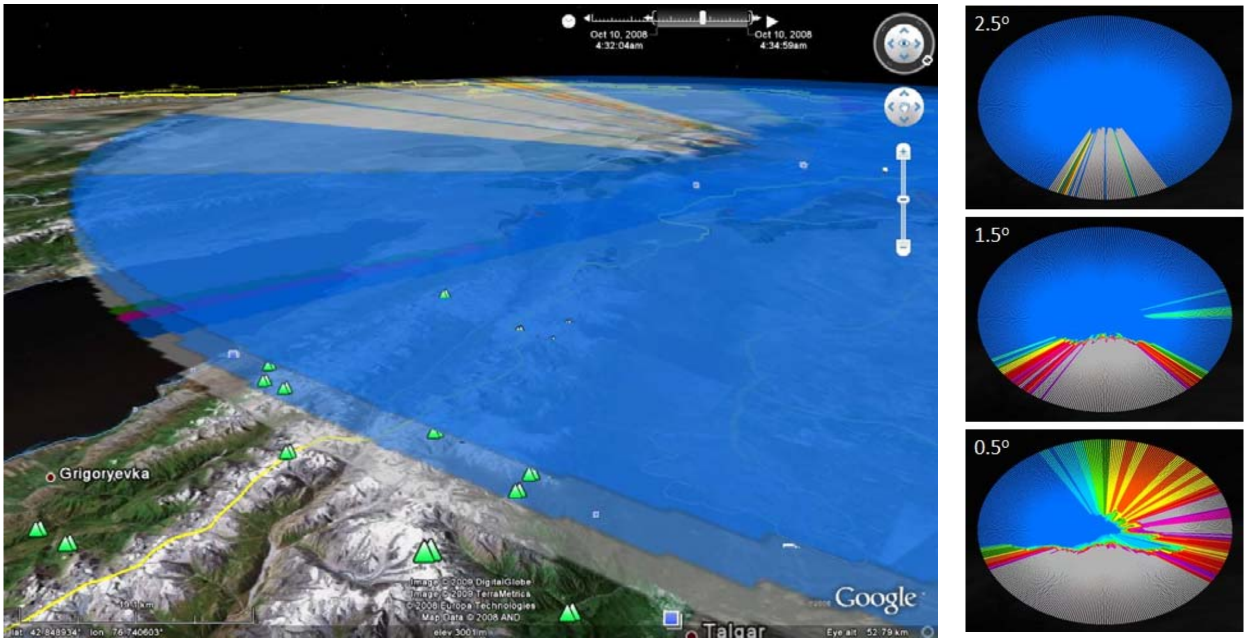

Figure 10 – Occultation for a hypothetical weather radar system at Manas International Airport, Bishkek, Kyrgyzstan. PPI occultation patterns for three primary elevations [0.5, 1.5 and 2.5 degrees] are inset to the right.

distortion. Virtual Globes do not suffer this type of distortion, since they require radar data in the polar plot format. Sample RIDGE data was acquired in the polar coordinate system (courtesy of the Ridge Team, and special thanks to Jason Burks) and is shown coupled with the r0, r1, r2, and r3 COLLADA surfaces in Figure 11 for Hurricane Dolly (data from June 2008). A second view of these four COLLADA surfaces is shown in Figure 12, looking at the inside edge of Hurricane Dolly's eyewall from the NE. The kmz used to generate Figures 11 and 12 is available online at http://wxanalyst.com/radar/ as "Hurricane Dolly 4D KMZ" (navigate to the Texas page and then the KBRO page under the NWS' Southern Region section).

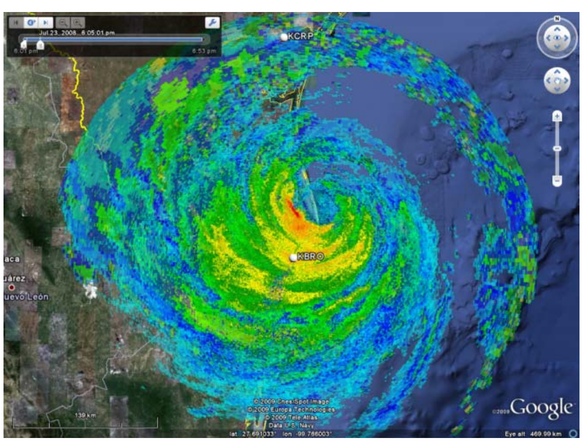

Figure 11 – Hurricane Dolly as seen by NEXRAD for Brownsville, TX (KBRO) at 1800 UTC on 23 June 2008. Elevation scans are shown superimposed for r0, r1, r2, and r3. A sample kmz is available online for demonstration of 4D animation over the hour.

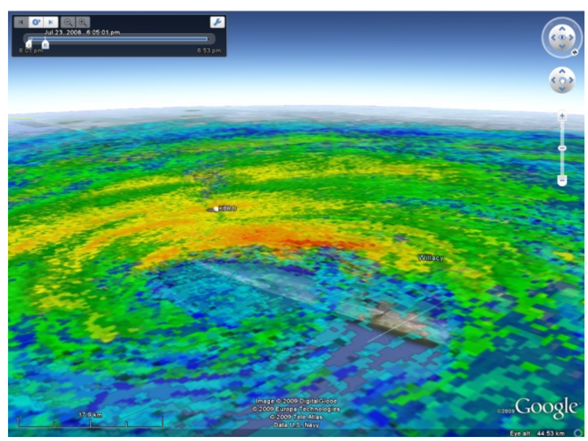

Figure 12 – View of Hurricane Dolly's eyewall from 1800 to 1805 UTC on 23 June 2008, looking from the NE. Four NEXRAD elevations are shown for r0 (0.5^{o}), r1 (1.45^{o}), r2 (2.40^{o}) and r3 (3.35^{o}). A sample kmz is available online for demonstration of 4D animation over the hour using Google Earth.

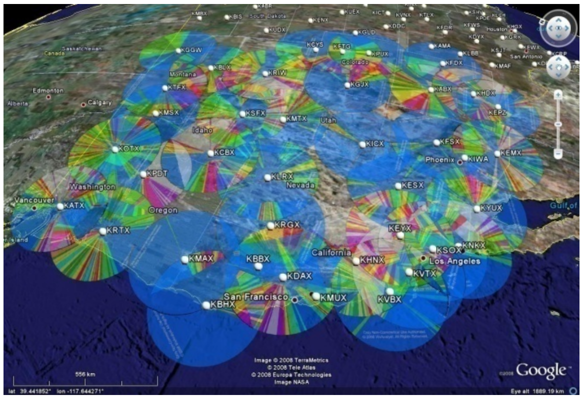

Figure 13 – Western Region

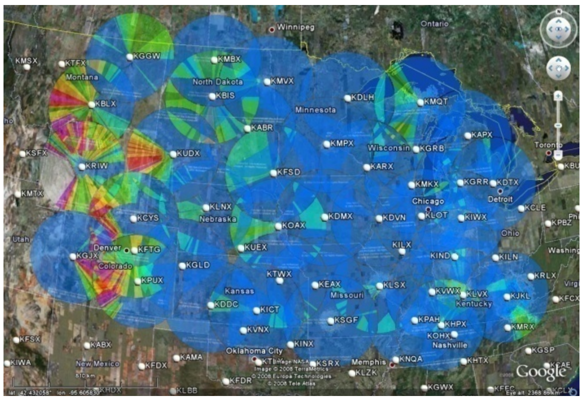

Figure 14 – Central Region

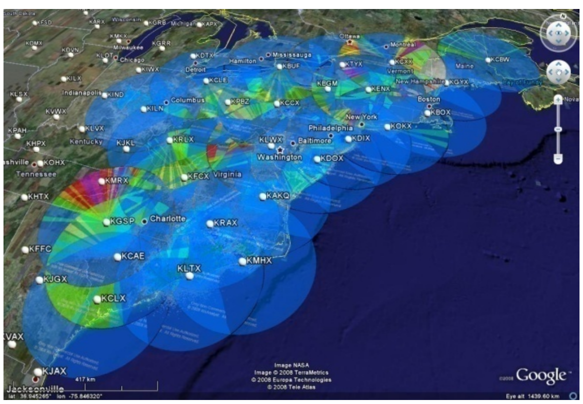

Figure 15 – Eastern Region

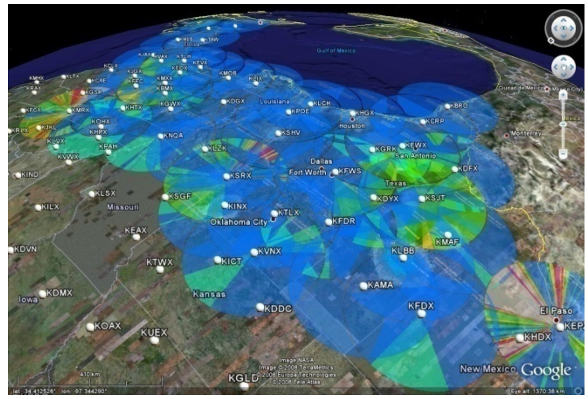

Figure 16 – Southern Region

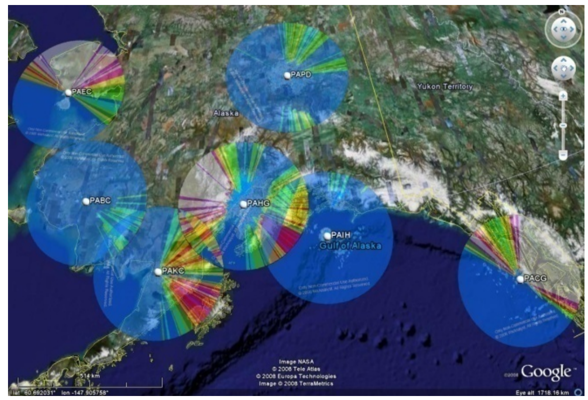

Figure 17 – Alaska Region

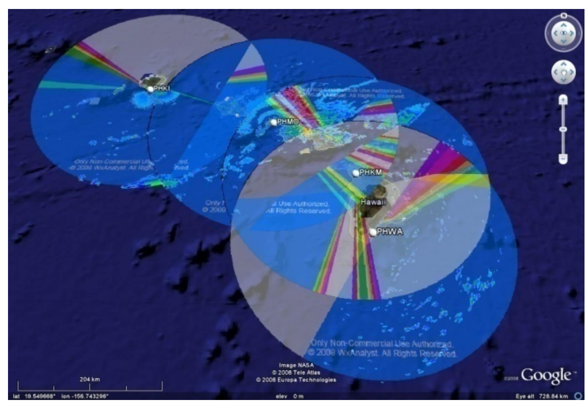

Figure 18 – Hawaiian Islands (Pacific Region)

5. The NEXRAD Occultation Dataset

WxAnalyst LTD is pleased to provide free public access to occultation patterns for the entire NEXRAD network at http://wxazygy.com/. Low resolution 3D radar occultation samples are provided by WxAnalyst for use with Google Earth, and these may be combined with RIDGE radar data to achieve 3-D animations. The data on these pages are freely available for personal use (commercial use subject to licensing and other restrictions). Furthermore, these data should be considered draft, and no warranty or guarantee is provided or implied. WxAnalyst has developed techniques to predict radar occultation on a global basis. Recent advances include efficient GIS calculations at very high spatial resolution, inclusion of manmade structures (buildings and towers), inclusion of vegetation canopies, snow & ice cover, and other obstacles available through high resolution DTM, and propagation effects related to Anomalous Propagation.

6. CONCLUSIONS

Virtual Globes such as Google Earth and ESRI's ArcGlobe support dramatic user access to weather radar information in four dimensions. Radar occultation maps provide detailed spatial information in three dimensions for regions where signal returns are expected to fade due to radar beam blocking by terrain. Today's virtual Globes will also support animation. Advances in data services by the National Weather Service are providing radar data in formats compatible with Virtual Globes, enabling true 4-dimensional access to radar and correlative information.

Virtual Globe geometry straightens out the radar beam propagation path (Figure 2) as compared to traditional approaches which map radar beam propagation over a "flat Earth" (e.g. Figure 1). In addition, distortions related to 2-dimensional map projections are mostly avoided when radar data are depicted in the spheroidal environment. The Virtual Globe approach utilizes radar data in its natural polar coordinate system without any additional reprocessing. However, the various Virtual Globes may handle COLLADA models differently at this time, so we must proceed cautiously at this time and test extensively.

WxAnalyst has provided free access to NEXRAD occultation patterns as a public service at http://wxazygy.com/.

7. ACKNOWLEDGMENTS

Google Earth and ESRI ArcGIS 9 were used to create the images and datasets of this paper. We wish to thank Ira Graffman, Keith Stellman and Jason Burks (NOAA/NWS), and Steve Ansari (NOAA/NCDC) for their intellectual contributions. The authors also thank WxAnalyst for its generous support.

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