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# Isosurface Display of 3-D Scalar Fields from a Meteorological Model on Google Earth

## by Giap Huynh, Chatt Williamson, and Yansen Wang

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Computational and Information Sciences Directorate, ARL

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**14. ABSTRACT**
This report documents the implementation of the "marching cubes" algorithm for constructing isosurfaces of a three-dimensional scalar field for display within Google Earth. It also describes a user-friendly Google Earth graphical user interface (GUI) menu designed to accomplish this task with minimal input from the user. The resulting isosurface is then displayed automatically in Google Earth's three-dimensional display and saved in a Keyhole Markup Language (KML) file. This GUI is developed specifically to support the Three-Dimensional Wind Field (3DWF) model in order to showcase its results and capabilities.

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# 1. Introduction

The Three-Dimensional Wind Field (3DWF) model is a microscale mass consistent diagnostic model (Wang et al., 2005, 2010) developed by the U.S. Army Research Laboratory. Its three-dimensional (3-D) geo-referenced (in latitude, longitude, and altitude) wind field output can be displayed in various ways using the free and popular Google Earth™ software. Google Earth offers not only relatively accurate geo-referenced imagery that can directly accommodate the 3DWF model's 3-D gridded wind field output, but also provides high resolution satellite imagery at various levels of detail textured over the application's representation of the underlying terrain. In Huynh et al. (2012), we discussed visualization of 3DWF model output using contours on arbitrary vertical or horizontal cross sections, contours on terrain-following surfaces, wind vector profiles, and wind vector fields on terrain-following surfaces; however, there is a need to expand the visualization capabilities to include isosurfaces of model output, which will enable researchers and model users alike to further investigate the behavior of the wind in complex terrain. Different volume visualization techniques have been applied in many areas of research such as in medical imaging and wind field modeling. However, for the scope of this report, we have adopted the popular "marching cubes" (MC) algorithm (Lorensen and Cline, 1987) to construct the triangulated isosurface facets representing a constant surface of wind speed. An excellent review of the algorithm is presented by Newman and Yi (2006).

This technical report documents the implementation of the MC algorithm to construct 3-D isosurfaces of the magnitude of the three wind components (u, v, w), as well as wind speed. In order to display model results using Google Earth, code must be developed to output the isosurfaces using Google Earth's Keyhole Markup Language (KML). The saved KML file can then be visualized using Google Earth or distributed through the Internet. This report also provides a brief description of the design of a user-friendly graphical user interface (GUI) menu to assist the 3DWF model users in generating isosurfaces for display.

# 2. Isosurface Extraction and Visualization

Volumetric visualization techniques have been applied in various research fields. Medical imaging in particular has historically had a specific need to render volumetric data as surfaces of constant density. Other fields of science and research also have similar needs to render volumetric data either collected through experimentation or produced through modeling. For example, visualizing an isosurface of microscale meteorological model outputs, such as wind speed, temperature, moisture, or concentration fields, provides the model user insight into the behavior of these atmospheric parameters over complex terrain. The MC algorithm, first

described by Lorensen and Cline (1987), is a common technique for extracting isosurfaces from a set of volumetric data. This algorithm is a sequential-traversal method, which, as the name implies, marches through a set of cubes (voxels) of gridded data, as shown in figure 1. Lorensen and Cline's work was done in the medical imaging field, but the algorithm they describe can be broadly applied to other disciplines where isosurface extraction is needed. The algorithm combines speed and simplicity, through lookup tables, to extract one or more triangulated surface facets that intersect the cube (voxel). These facets are then connected together to form the 3-D isosurface. The isosurface can then be displayed using a visualization platform such as the popular and freely available Google Earth.
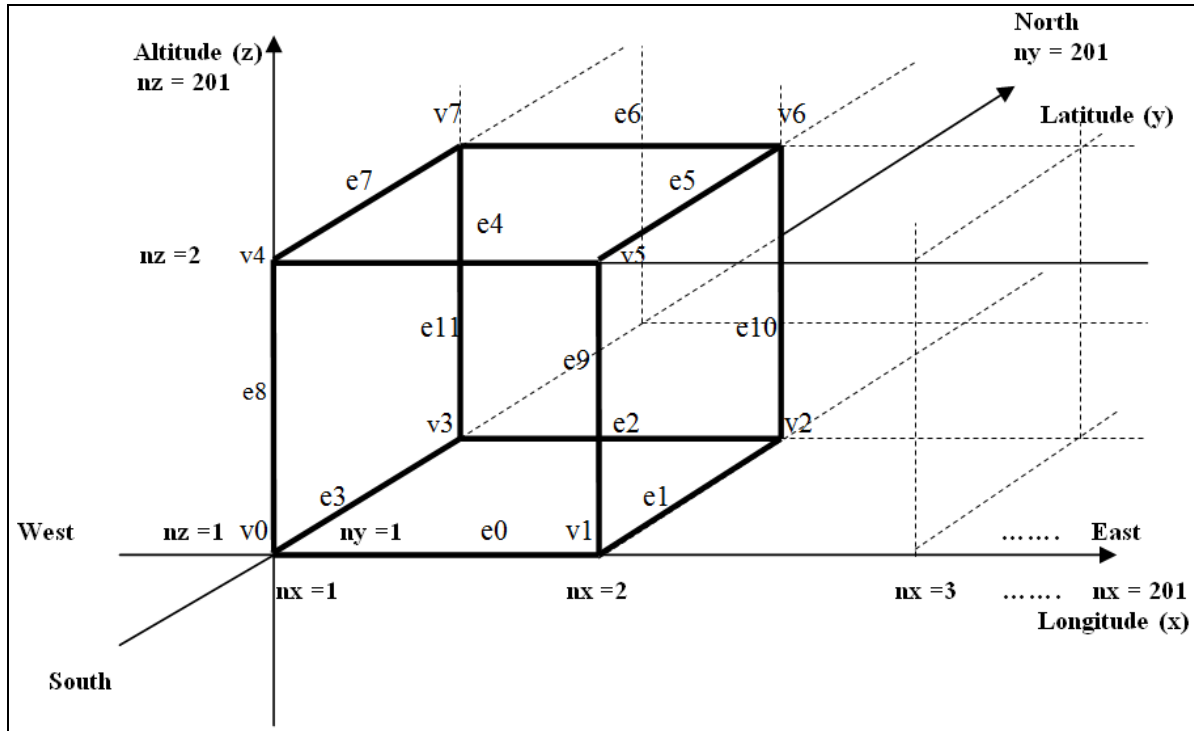


Figure 1. Vertex and edge indexing of a cube.

## 2.1   The Marching Cubes Algorithm

The fundamental idea behind the MC algorithm is to march through each gridded cube (voxel) one at a time extracting facets of the isosurface that intersect that given cube. Summarizing Lorensen and Cline (1987) with a slight modification for our use, the algorithm is as follows:

1.  Read the gridded data to be processed into memory.

2.  Classify or categorize the type of a given cube by comparing the values of the eight vertices to the user-specified surface constant assigning it an index.

3.  Use the index and a precomputed lookup table to determine which edges are intersected by the isosurface.

4. For each intersected edge, compute the location of the intersection using linear interpolation.

5. Output the triangular facets of the isosurface in KML format.

Note that we omit the computation of the vertex normals. Thus, following these steps, for a given set of volumetric data such as gridded micro-scale meteorological model output, a set of facets of constant value can be extracted.

### 2.1.1 Gridded Cube Classification

As illustrated in figure 1, a cube is defined by 8 vertices and the 12 edges that connect the vertices. Following a standard indexing convention, we label the vertices and edges as indicated. During the extraction process in order to classify a cube, each vertex is assigned two values: first a scalar value of the parameter that we are interested in extracting isosurfaces of, and second, a Boolean value indicating the state of the vertex. The state of the vertex is set to 1 if the vertex is on or above the isosurface or is set to 0 otherwise. Since the cube has eight vertices, we can encode the state of the cube's vertices relative to the current isosurface value as an eight bit integer. This indicates that there are $2^8$ or 256 possible configurations; however, as discussed in Lorensen and Cline (1987), this is reduced to 14 patterns of facets using both topological and symmetry arguments. The original algorithm produces no more than four facets of the isosurface in the current cube. Actually, there are 15 patterns if one includes the null set, i.e., there are no facets of the isosurface intersecting the cube (voxel). These patterns, or cases, are illustrated in figure 2, where the "marked" vertices are below the isosurface.
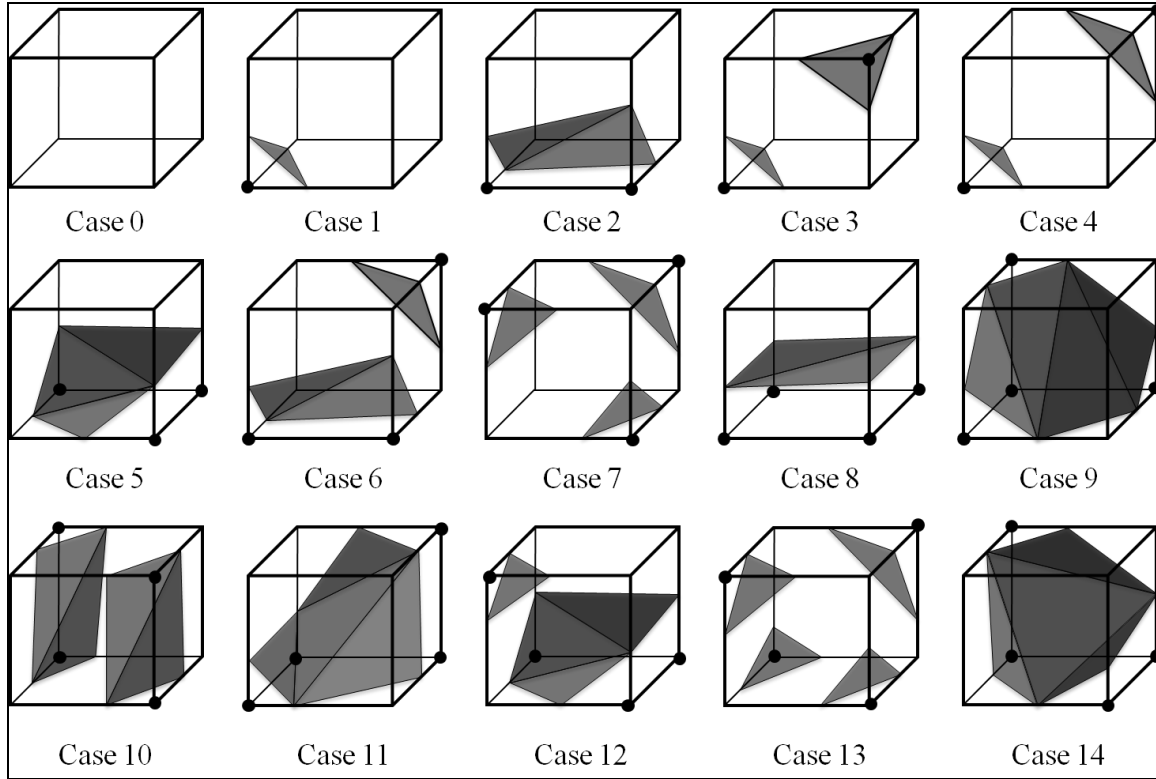
Figure 2. The 15 basic cube facetizations once reduced by topological and symmetry arguments (Lorensen and Cline, 1987).

One must be careful when implementing and using the MC algorithm. Dürst pointed out that some of the cases can be faceted in multiple ways. Since the facetizations for certain classes are not unique, this can lead to ambiguities and extracted surfaces that are not topologically consistent. There are seven classes, or cases, that have been demonstrated to be ambiguous (see e.g., van Gelder, et al. [1994], Natarajan [1994], and Chernyaev [1995]). The ambiguous cases are Cases 3, 4, 6, 7, 10, 12, and 13. A common example of a topologically inconsistent isosurface due to these ambiguities is illustrated in figure 3.
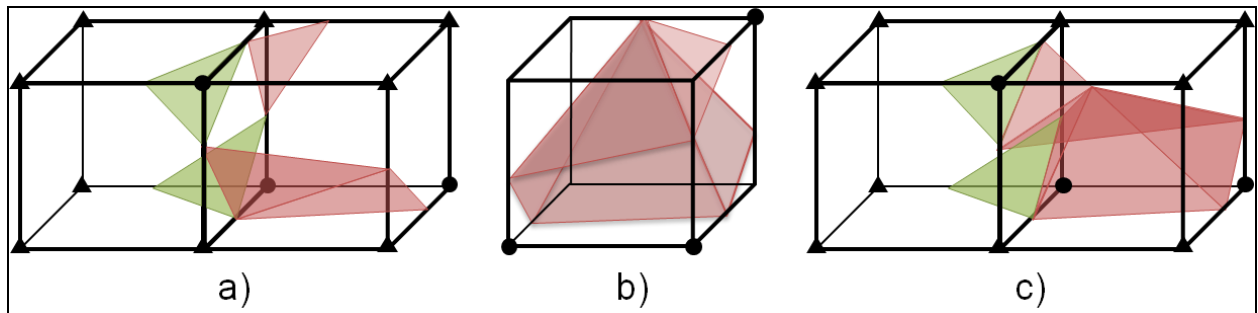


Figure 3. An example of an ambiguity arising from topologically incompatible facetizations in neighboring grid cells. Panel (a) illustrates the topologically inconsistent surface when a member of Case 3 is adjacent to a member of Case 6, panel (b) is an alternate facetization of Class 6, and panel (c) is a topologically consistent surface created by using the alternate facetization.

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As illustrated in figure 3a, when a member of Case 3 (left cube) is adjacent to a member of Case 6 (right cube), the default facetizations result in a topologically inconsistent surface. This combination results in a "hole" in the surface. This topological inconsistency can be mended by using the alternate facetization for Case 6, often labeled Case 6c, shown in figure 3b and illustrated in figure 3c. It is important to point out that the topological inconsistency illustrated in figure 3a does not occur for all Case 3 cubes with an adjacent Case 6 cube. Recall that each of the cases has at least two vertex configurations that result in the same facetization due to topological reduction arguments. Here we have used the term "member" of a case to indicate that this is one of the possible configurations that results in topologically inconsistent surface. Though not illustrated, it can be shown that if the lower right corner on the back face of the Case 6 cube is above the surface and the upper right corner on the front face of the same cube is below the surface, then the default facetization will result in a topologically consistent surface.

## 2.1.2 Encoding of Cube Vertices and Edges

As discussed previously, the state of the vertices of a given cube can be encoded using an 8-bit integer. We can also encode the state of the edges of the cube in a similar manner. Since there are 12 edges, we can encode each edge state as intersected or not. This will yield a set of 12 bits, which when ordered can be encoded as a set of three hexadecimal values. Figure 4 is an example of an encoded cube of type Case 1. The vertex marked v0 is below the isosurface. From inspection, one can see that edges labeled e0, e3, and e8 are intersected by the isosurface. Tables 1 and 2 are the vertex and edge states, respectively, for the cube represented in figure 4. Following the encoding scheme, a lookup table can be created where the index into the lookup table is given by the vertex state and the value is the edge state. The lookup table, also referred to as the edgeTable is provided in the appendix.
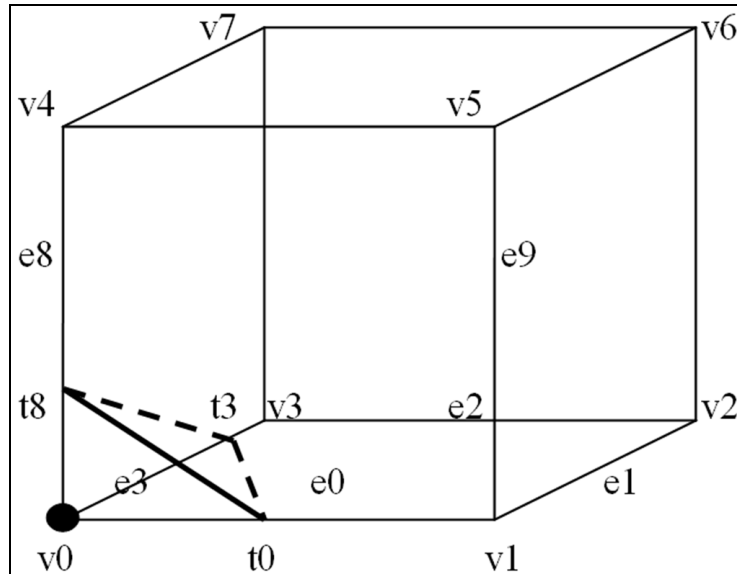


Figure 4. Isosurface facet for type Case 1, where the marked vertex v0 is below the isosurface.

Table 1. Example of a cube vertex encoding for Case 1 type cube represented in figure 4.

| Vertex Index | v7 | v6 | v5 | v4 | v3 | v2 | v1 | v0 | Index Value |
|---|---|---|---|---|---|---|---|---|---|
| Bit (above/below) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |

Table 2. Example of a cube edge encoding for Case 1 type cube represented in figure 4.

| Edge Index | e11 | e10 | e9 | e8 | e7 | e6 | e5 | e4 | e3 | e2 | e1 | e0 | Encoded Hex Value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bit (intersected/not) | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | |
| Hex Value | 0x100 | | | | 0x000 | | | | 0x009 | | | | 0x109 |

## 2.1.3 Locating Isosurface Intersection on Marked Edges and Facet Orientation

Referring to figure 4 in the previous example, we note that the three vertices of the facet are the intersection points marked t0, t3, and t8, which are on edges e0, e3, and e8, respectively. There are two things that must be done before the facet is fully defined: (1) locate the intersection point of the isosurface on the edge and (2) determine the ordering of the vertices of the triangle. The first can be accomplished using a simple linear interpolation to be described below and the second depends on whether the marked vertex is above or below the surface.

For the microscale meteorological model referred to previously, the grid is a standard Cartesian grid. We can locate any point in the domain by the tuple (x,y,z). Thus, for figure 4, we can represent vertex v0 by its tuple $(x_{v0}, y_{v0}, z_{v0})$. The adjacent vertices can be represented in a similar fashion. Furthermore, for scalar values on the model grid we define the value anywhere along the connecting edge of two vertices as

$$s(x, y, z) = \frac{s_{v1} - s_{v0}}{x_{v1} - x_{v0}}(x - x_{v0}) + s_{v0}. \tag{1}$$

Since $s$ is known, solving for $x$ yields

$$x = \frac{(x_{v1} - x_{v0})(s - s_{v0})}{s_{v1} - s_{v0}} + x_{v0}. \tag{2}$$

This same derivation holds true for both $y$ and $z$ as well. Therefore, we represent the intersection point along any edge as follows:

$$x_{t0} = \frac{(x_{v1} - x_{v0})(s - s_{v0})}{s_{v1} - s_{v0}} + x_{v0},$$

$$y_{t0} = \frac{(y_{v1} - y_{v0})(s - s_{v0})}{s_{v1} - s_{v0}} + y_{v0}, \tag{3}$$

$$z_{t0} = \frac{(z_{v1} - z_{v0})(s - s_{v0})}{s_{v1} - s_{v0}} + z_{v0}.$$

In practice we also consider how close the isosurface is to a given vertex in value, as well as how near in value two adjacent vertices are. So if $|s - s_{v0}| < 1e^{-5}$ or $|s_{v1} - s_{v0}| < 1e^{-5}$, then we assign the point of intersection as $(x_{v0}, y_{v0}, z_{v0})$.

## 2.2 Programming

In order to expand the capabilities of our current modeling and visualization framework (Huynh et al., 2012) we implemented the MC algorithm and extended capabilities of the GUI as described in this section.

### 2.2.1 Implementation of Marching Cubes Algorithm in Fortran90

While the original exposition by Lorensen and Cline (1987) regarding MC limited the number of facets to four, we have chosen to adopt and implement a revised method discussed and made available by Bourke (1994), which can accommodate up to five facets for a given grid cube. While the published code from Bourke (1994) is in the public domain, it was originally implemented in the $C^{++}$ programming language as part of a facet extraction and display program using the OpenGL application programming interface. For our purposes, it was advantageous to port the algorithmic portion of this code using Fortran90. Porting the algorithmic portion of the $C^{++}$ code to Fortran90 was relatively straightforward. Figure 5 is an example of a test case that was used to confirm that the porting and implementation of the algorithm to Fortran90 was consistent and correct. Figure 5 is the rendering of a sphere extracted from a simple data set displayed within the Google Earth framework.
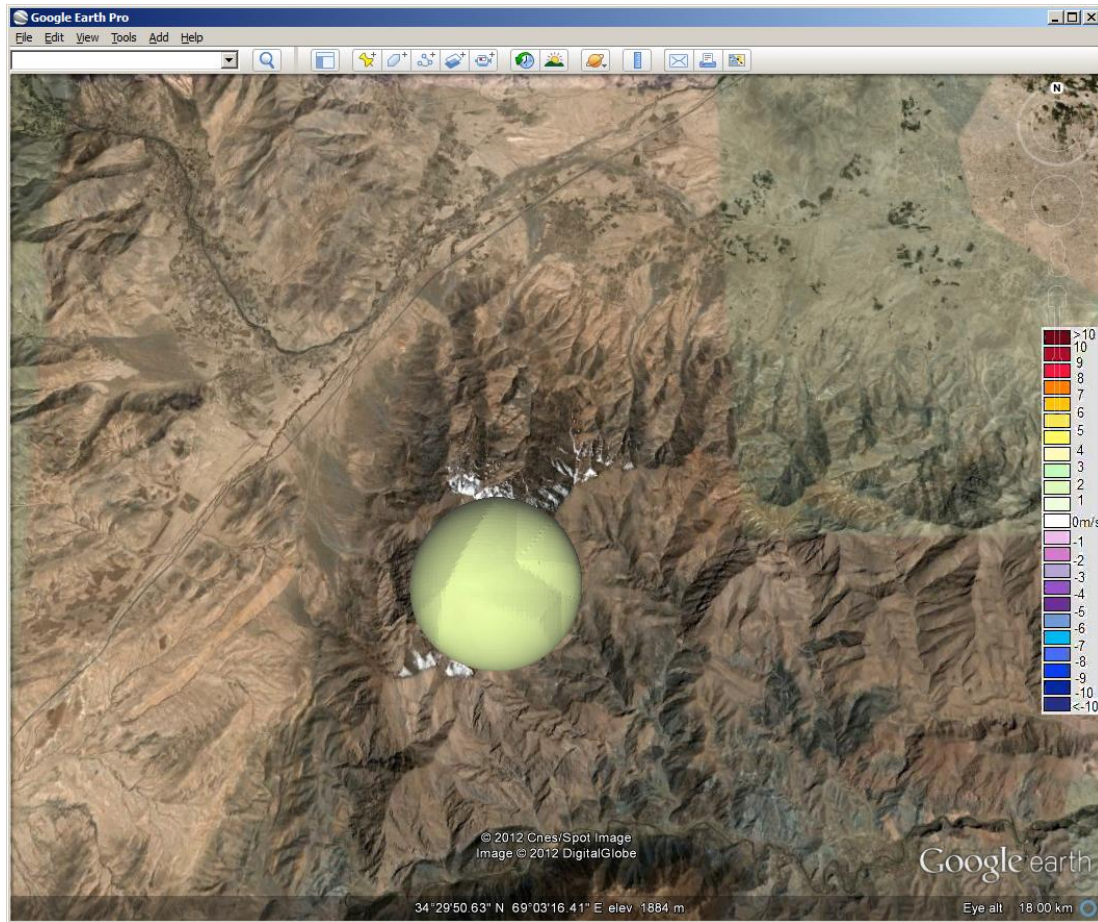
Figure 5. Isosurface of a simple sphere displayed within Google Earth.

The implementation of MC presented here takes as input the "isovalue" to be faceted and the model grid variable to be processed. Once the model output has been processed an output file is produced, which contains the isosurface(s) encoded in KML. This file can then be read into Google Earth and visualized. Listing 1 is an excerpt of a typical output for the isosurface extraction. The excerpt contains a single facet represented as a single <Polygon> element in KML, an <ScreenOverlay> element to indicate the scale or magnitude of the isosurface, and a <Camera> element to facilitate an initial viewing angle. We also implemented the capability to observe the time evolution of the isosurface.

Listing 1. Excerpt from KML file produced using the implementation of MC algorithm.

| KML Preamble | <?xml version="1.0" encoding="UTF-8"?><br><kml xmlns="http://earth.google.com/kml/2.2"><br><Folder><br><name>Frame with TimeSpans</name> |
|---|---|
| Facet using KML <Polygon> | <Placemark><br><Style><br><PolyStyle><color>DD0080FF</color><outline>0</outline><fill>1</fill><br></PolyStyle><br></Style><br><visibility>1</visibility><br><Polygon><br><extrude>0</extrude><altitudeMode>relativeToGround</altitudeMode><br><outerBoundaryIs><LinearRing><coordinates><br>68.9885101318359,34.4565925598145,618.657104492188<br>68.9885101318359,34.4565620422363,620<br>68.9884872436523,34.4565925598145,620<br>68.9885101318359,34.4565925598145,618.657104492188<br></coordinates></LinearRing></outerBoundaryIs><br></Polygon><br></Placemark> |
| Excerpted | ………<br>………<br>……… |
| Scale using KML <ScreenOverlay> | <ScreenOverlay><br><Icon><href>file:///C:/3DWF/wspdspec.jpg</href></Icon><br><overlayXY x="1" y="0.45" xunits="fraction" yunits="fraction"/><br><screenXY x="1" y="0.45" xunits="fraction" yunits="fraction"/><br><rotationXY x="0" y="0" xunits="fraction" yunits="fraction"/><br><size x="0" y="0" xunits="fraction" yunits="fraction"/><br></ScreenOverlay> |
| Initial Viewpoint using KML <Camera> | <Camera><br><longitude>68.97          </longitude><latitude>34.43<br></latitude><altitude>15000</altitude><br><range>30000</range><tilt>5</tilt><heading>0</heading><br></Camera> |
| KML Termination | </Folder><br></kml> |

## 2.2.2 GUI and Google Earth Display

As in Huynh et al. (2012), we have implemented this extension to the modeling system capabilities using a combination of Fortran90 modules and a GUI using HyperText Markup Language version 4 (HTML v4) and JavaScript (JS). Figure 6 is a screen capture of the GUI used to extract an isosurface from a 3DWF model grid.

Figure 6. GUI for isosurface extraction.

The GUI takes input from the user requesting information such as the model output file to be processed, which scalar field to extract an isosurface of, and what the desired isosurface value is. The initial viewpoint is taken as the center of the 3DWF model domain with the domain coverage indicated by a yellow bounding square. The user can also process a number of model output files to produce an isosurface that evolves with time. The resultant animation from this feature, however, is quite resource intensive when visualized within Google Earth application and its use is not recommended at this time.

Once the processing of the model data is completed and a KML file has been generated the output the file containing the isosurface(s) can be visualized within Google Earth. Two examples of extracted isosurfaces are given in figures 7 and 8.
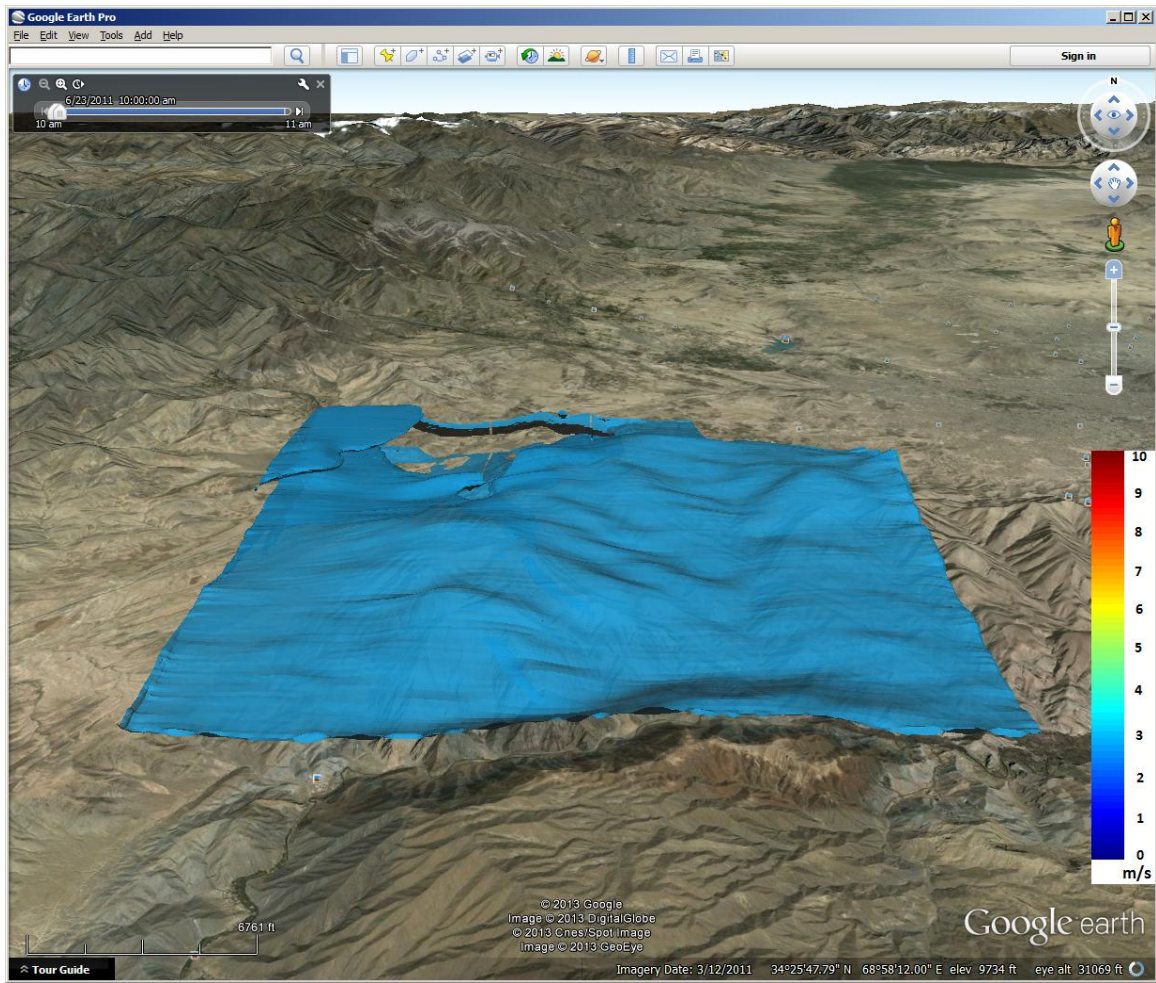
Figure 7. Isosurface display of 3 m/s wind speed for a model domain volume of 10x10x4 km.

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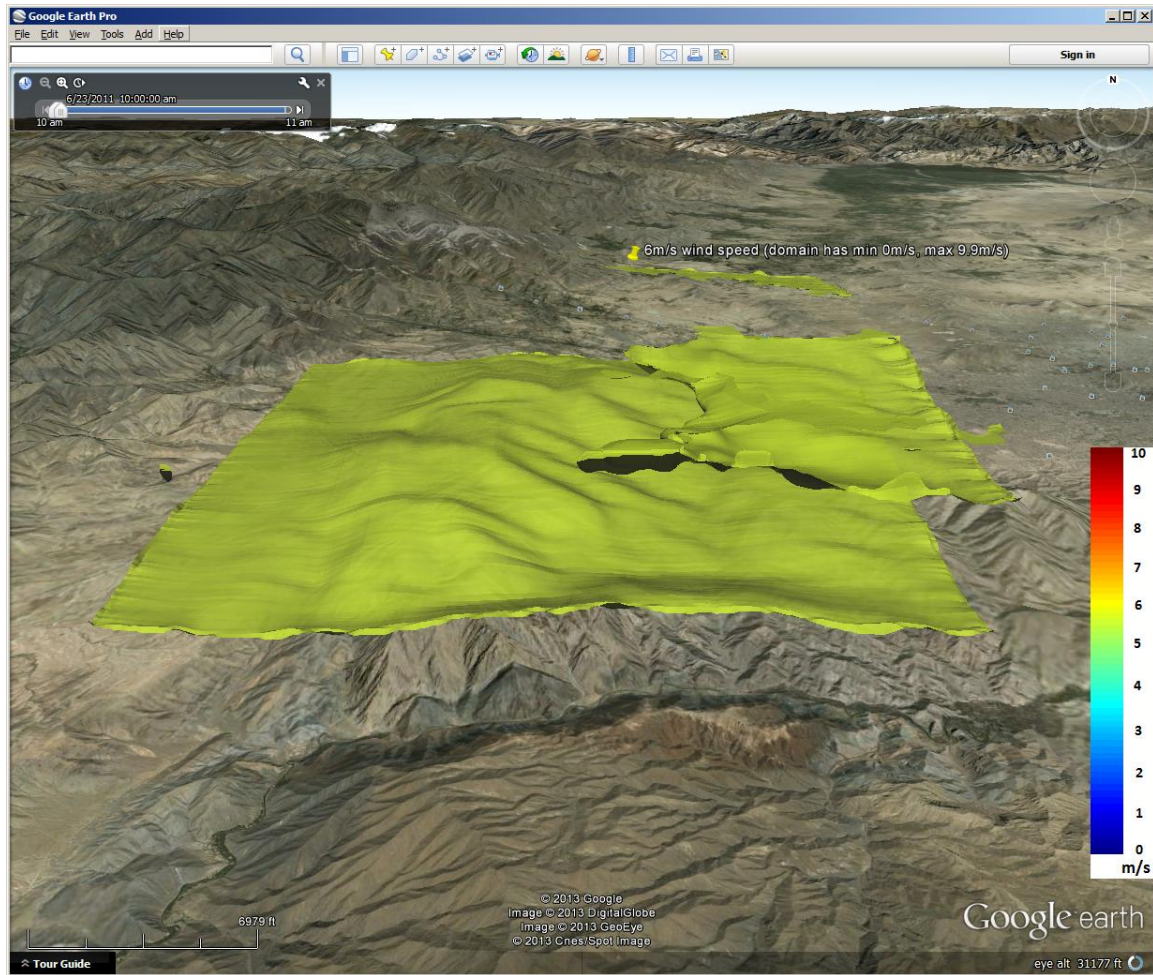
Figure 8. Isosurface display of 6 m/s wind speed for the same domain in figure 7.

Figure 7 displays the isosurface of 3 m/s wind speed over a model domain near Kabul, Afghanistan, diagnosed by the 3DWF model. Figure 8 is identical in space and time to figure 7 except an isosurface with a value of 6 m/s is displayed. The 3DWF model grid used in figures 7 and 8 covered 10x10x4 km (with dx=dy=50 m and dz=20 m). As expected, with higher wind speeds aloft, the vertical extent of the 3 m/s isosurface extends from 258 to 1560 m above the lowest terrain elevation in the model domain (1891 m above sea level [ASL]), while the 6 m/s isosurface had a greater extent starting at 600 m above the lowest model terrain elevation extending to 3980 m over the same elevation.

The color scale to the right is produced using the <ScreenOverlay> KML element. It has 64 levels of resolution with the maximum and minimum values mapped to the maximum and minimum values of the scalar that is being visualized. The place marker also gives the value of the extracted isosurface that corresponds to the color scale to the right. The Google Earth Timescale element is also used to indicate the model valid time for the displayed data. This can also be used to animate the isosurface in time if the user has enabled that feature of the extraction

tool. The Timescale tool can be operated manually by the user to advance the evolution of the isosurface in time or set it to automatically advance. Using the Google Earth navigation tools, the user can observe the extracted isosurface from many different views to analyze the underlying data. The Google Earth platform provides visual context to the 3DWF model user. This context is especially useful in areas with complex terrain or significantly built up urban and suburban area. The visual context also provides users with indications as to why the model output is behaving as it is, for example, is there an object that may be damming or retarding the flow field?

### 2.2.3 Visualizing Scalar Data in General

The development of this isosurface extraction module is not limited to model grid output from the 3DWF or Atmospheric Boundary Layer Experiment (ABLE) model output. This extraction utility can be extended to process concentration fields provided by a dispersion model. Figures 9 and 10 are examples of this extension.
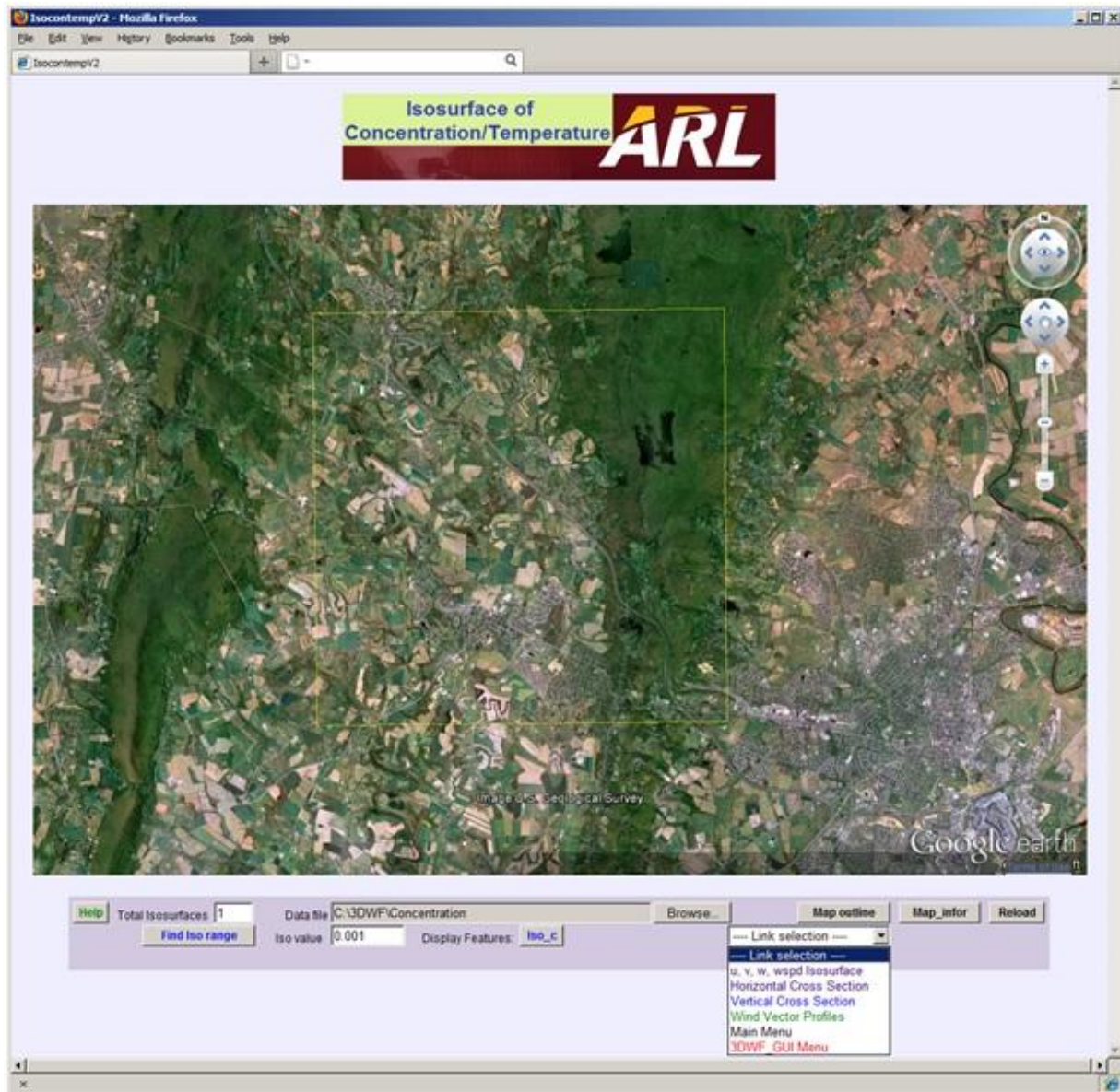
Figure 9. Extended GUI for Isosurface extraction of concentration or temperature.
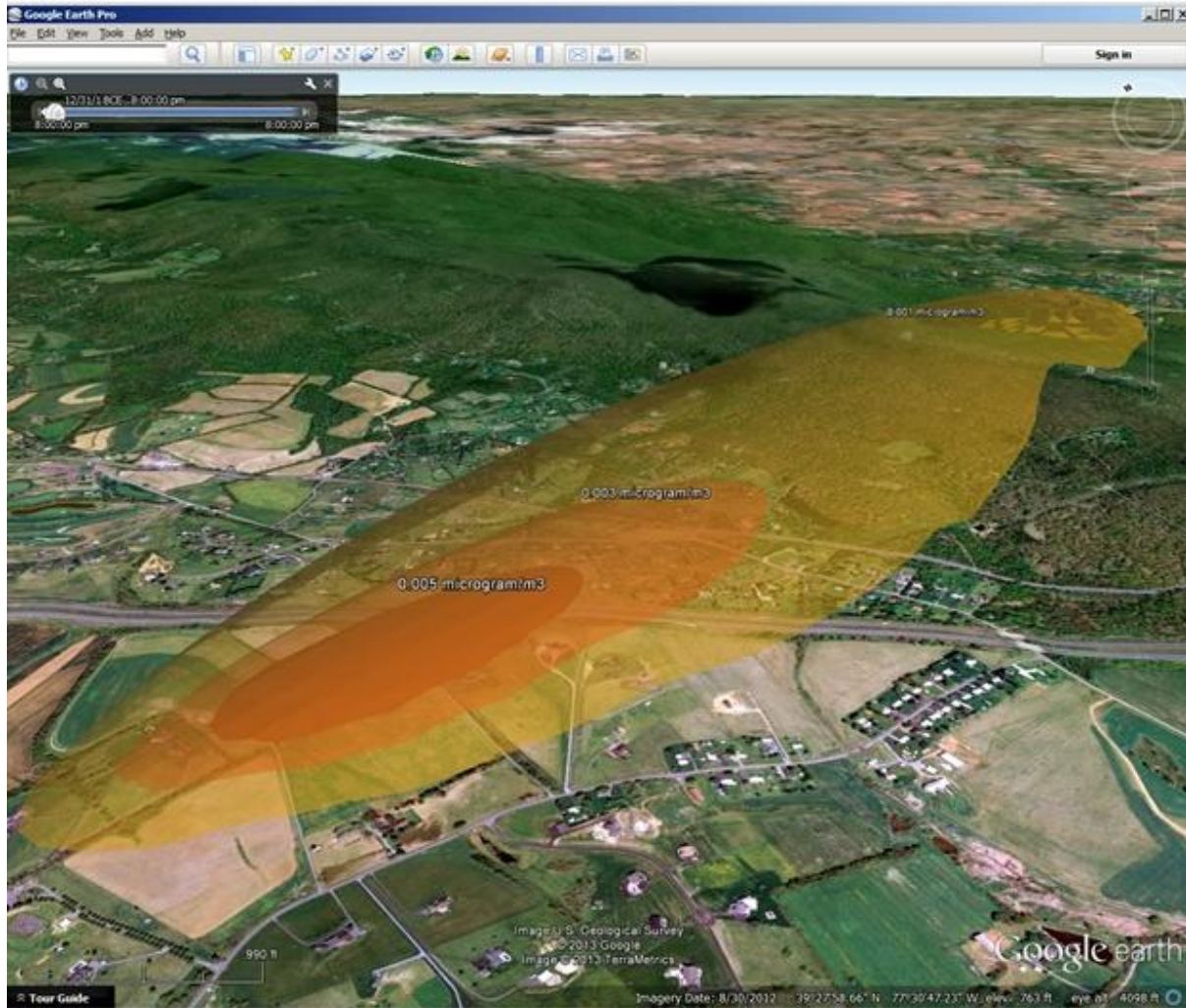
Figure 10. Isosurfaces of a contaminate plume with surface generated for 0.001, 0.003, and 0.005 μg/m$^3$.

Figure 9 is an extended GUI to accommodate the extraction of scalars in general. In particular the GUI has been extended to extract isosurfaces of scalars such as plume concentration and temperature. Figure 10 is the display of three isosurfaces of a modeled contaminate plume. There are three isosurfaces that are displayed with the isovalue set to 0.001, 0.003, and 0.005 μg/m$^3$. The facets include an alpha channel for translucent rendering.

## 3.  Conclusion

In support of performance and capability improvement of the 3DWF model, we previously developed a 3-D visualization system using Google Earth as our scientific visualization platform. This system was capable of displaying horizontal and vertical cross sections of model wind field output, vector wind profiles, and a vector wind field on a terrain-following surface. Through the adoption of Google Earth as a visualization platform, we provided the user with visual context of the 3DWF model output. In this report, we have documented the extension of visualization capabilities by implementing the MC algorithm for isosurface extraction and visualization. The isosurface extraction capability was not limited to the output from the 3DWF model, but was extended to include other scalar output such as contaminate concentration plumes and atmospheric temperatures.

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# Appendix. edgeTable and triTable Lookup Tables

Tables A-1 and A-2 provide the lookup tables used.

Table A-1. edgeTable listing the 256 possible edge intersections.

|     | 0        | 1        | 2        | 3        | 4        | 5        | 6        | 7        |
|----:|----------|----------|----------|----------|----------|----------|----------|----------|
| 0   | x'000'   | x'109'   | x'203'   | x'30a'   | x'406'   | x'50f'   | x'605'   | x'70c'   |
| 1   | x'80c'   | x'905'   | x'a0f'   | x'b06'   | x'c0a'   | x'd03'   | x'e09'   | x'f00'   |
| 2   | x'190'   | x'099'   | x'393'   | x'29a'   | x'596'   | x'49f'   | x'795'   | x'69c'   |
| 3   | x'99c'   | x'895'   | x'b9f'   | x'a96'   | x'd9a'   | x'c93'   | x'f99'   | x'e90'   |
| 4   | x'230'   | x'339'   | x'033'   | x'13a'   | x'636'   | x'73f'   | x'435'   | x'53c'   |
| 5   | x'a3c'   | x'b35'   | x'83f'   | x'936'   | x'e3a'   | x'f33'   | x'c39'   | x'd30'   |
| 6   | x'3a0'   | x'2a9'   | x'1a3'   | x'0aa'   | x'7a6'   | x'6af'   | x'5a5'   | x'4ac'   |
| 7   | x'bac'   | x'aa5'   | x'9af'   | x'8a6'   | x'faa'   | x'ea3'   | x'da9'   | x'ca0'   |
| 8   | x'460'   | x'569'   | x'663'   | x'76a'   | x'66'    | x'16f'   | x'265'   | x'36c'   |
| 9   | x'c6c'   | x'd65'   | x'e6f'   | x'f66'   | x'86a'   | x'963'   | x'a69'   | x'b60'   |
| 10  | x'5f0'   | x'4f9'   | x'7f3'   | x'6fa'   | x'1f6'   | x'0ff'   | x'3f5'   | x'2fc'   |
| 11  | x'dfc'   | x'cf5'   | x'fff'   | x'ef6'   | x'9fa'   | x'8f3'   | x'bf9'   | x'af0'   |
| 12  | x'650'   | x'759'   | x'453'   | x'55a'   | x'256'   | x'35f'   | x'055'   | x'15c'   |
| 13  | x'e5c'   | x'f55'   | x'c5f'   | x'd56'   | x'a5a'   | x'b53'   | x'859'   | x'950'   |
| 14  | x'7c0'   | x'6c9'   | x'5c3'   | x'4ca'   | x'3c6'   | x'2cf'   | x'1c5'   | x'0cc'   |
| 15  | x'fcc'   | x'ec5'   | x'dcf'   | x'cc6'   | x'bca'   | x'ac3'   | x'9c9'   | x'8c0'   |
| 16  | x'8c0'   | x'9c9'   | x'ac3'   | x'bca'   | x'cc6'   | x'dcf'   | x'ec5'   | x'fcc'   |
| 17  | x'0cc'   | x'1c5'   | x'2cf'   | x'3c6'   | x'4ca'   | x'5c3'   | x'6c9'   | x'7c0'   |
| 18  | x'950'   | x'859'   | x'b53'   | x'a5a'   | x'd56'   | x'c5f'   | x'f55'   | x'e5c'   |
| 19  | x'15c'   | x'055'   | x'35f'   | x'256'   | x'55a'   | x'453'   | x'759'   | x'650'   |
| 20  | x'af0'   | x'bf9'   | x'8f3'   | x'9fa'   | x'ef6'   | x'fff'   | x'cf5'   | x'dfc'   |
| 21  | x'2fc'   | x'3f5'   | x'0ff'   | x'1f6'   | x'6fa'   | x'7f3'   | x'4f9'   | x'5f0'   |
| 22  | x'b60'   | x'a69'   | x'963'   | x'86a'   | x'f66'   | x'e6f'   | x'd65'   | x'c6c'   |
| 23  | x'36c'   | x'265'   | x'16f'   | x'066'   | x'76a'   | x'663'   | x'569'   | x'460'   |
| 24  | x'ca0'   | x'da9'   | x'ea3'   | x'faa'   | x'8a6'   | x'9af'   | x'aa5'   | x'bac'   |
| 25  | x'4ac'   | x'5a5'   | x'6af'   | x'7a6'   | x'0aa'   | x'1a3'   | x'2a9'   | x'3a0'   |
| 26  | x'd30'   | x'c39'   | x'f33'   | x'e3a'   | x'936'   | x'83f'   | x'b35'   | x'a3c'   |
| 27  | x'53c'   | x'435'   | x'73f'   | x'636'   | x'13a'   | x'033'   | x'339'   | x'230'   |
| 28  | x'e90'   | x'f99'   | x'c93'   | x'd9a'   | x'a96'   | x'b9f'   | x'895'   | x'99c'   |
| 29  | x'69c'   | x'795'   | x'49f'   | x'596'   | x'29a'   | x'393'   | x'099'   | x'190'   |
| 30  | x'f00'   | x'e09'   | x'd03'   | x'c0a'   | x'b06'   | x'a0f'   | x'905'   | x'80c'   |
| 31  | x'70c'   | x'605'   | x'50f'   | x'406'   | x'30a'   | x'203'   | x'109'   | x'000'   |

Table A-2. triTable listing the ordered edge connection graph for each facetization.

| # | code | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | x'000' | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 1 | x'109' | 0 | 8 | 3 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 2 | x'203' | 0 | 1 | 9 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 3 | x'30a' | 1 | 8 | 3 | 9 | 8 | 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 4 | x'406' | 1 | 2 | 10 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 5 | x'50f' | 0 | 8 | 3 | 1 | 2 | 10 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 6 | x'605' | 9 | 2 | 10 | 0 | 2 | 9 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 7 | x'70c' | 2 | 8 | 3 | 2 | 10 | 8 | 10 | 9 | 8 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 8 | x'80c' | 3 | 11 | 2 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 9 | x'905' | 0 | 11 | 2 | 8 | 11 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 10 | x'a0f' | 1 | 9 | 0 | 2 | 3 | 11 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 11 | x'b06' | 1 | 11 | 2 | 1 | 9 | 11 | 9 | 8 | 11 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 12 | x'c0a' | 3 | 10 | 1 | 11 | 10 | 3 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 13 | x'd03' | 0 | 10 | 1 | 0 | 8 | 10 | 8 | 11 | 10 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 14 | x'e09' | 3 | 9 | 0 | 3 | 11 | 9 | 11 | 10 | 9 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 15 | x'f00' | 9 | 8 | 10 | 10 | 8 | 11 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 16 | x'190' | 4 | 7 | 8 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 17 | x'099' | 4 | 3 | 0 | 7 | 3 | 4 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 18 | x'393' | 0 | 1 | 9 | 8 | 4 | 7 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 19 | x'29a' | 4 | 1 | 9 | 4 | 7 | 1 | 7 | 3 | 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 20 | x'596' | 1 | 2 | 10 | 8 | 4 | 7 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 21 | x'49f' | 3 | 4 | 7 | 3 | 0 | 4 | 1 | 2 | 10 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 22 | x'795' | 9 | 2 | 10 | 9 | 0 | 2 | 8 | 4 | 7 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 23 | x'69c' | 2 | 10 | 9 | 2 | 9 | 7 | 2 | 7 | 3 | 7 | 9 | 4 | -1 | -1 | -1 | -1 |
| 24 | x'99c' | 8 | 4 | 7 | 3 | 11 | 2 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 25 | x'895' | 11 | 4 | 7 | 11 | 2 | 4 | 2 | 0 | 4 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 26 | x'b9f' | 9 | 0 | 1 | 8 | 4 | 7 | 2 | 3 | 11 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 27 | x'a96' | 4 | 7 | 11 | 9 | 4 | 11 | 9 | 11 | 2 | 9 | 2 | 1 | -1 | -1 | -1 | -1 |
| 28 | x'd9a' | 3 | 10 | 1 | 3 | 11 | 10 | 7 | 8 | 4 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 29 | x'c93' | 1 | 11 | 10 | 1 | 4 | 11 | 1 | 0 | 4 | 7 | 11 | 4 | -1 | -1 | -1 | -1 |
| 30 | x'f99' | 4 | 7 | 8 | 9 | 0 | 11 | 9 | 11 | 10 | 11 | 0 | 3 | -1 | -1 | -1 | -1 |
| 31 | x'e90' | 4 | 7 | 11 | 4 | 11 | 9 | 9 | 11 | 10 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 32 | x'230' | 9 | 5 | 4 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 33 | x'339' | 9 | 5 | 4 | 0 | 8 | 3 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 34 | x'033' | 0 | 5 | 4 | 1 | 5 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 35 | x'13a' | 8 | 5 | 4 | 8 | 3 | 5 | 3 | 1 | 5 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 36 | x'636' | 1 | 2 | 10 | 9 | 5 | 4 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 37 | x'73f' | 3 | 0 | 8 | 1 | 2 | 10 | 4 | 9 | 5 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 38 | x'435' | 5 | 2 | 10 | 5 | 4 | 2 | 4 | 0 | 2 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 39 | x'53c' | 2 | 10 | 5 | 3 | 2 | 5 | 3 | 5 | 4 | 3 | 4 | 8 | -1 | -1 | -1 | -1 |
| 40 | x'a3c' | 9 | 5 | 4 | 2 | 3 | 11 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 41 | x'b35' | 0 | 11 | 2 | 0 | 8 | 11 | 4 | 9 | 5 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 42 | x'83f' | 0 | 5 | 4 | 0 | 1 | 5 | 2 | 3 | 11 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 43 | x'936' | 2 | 1 | 5 | 2 | 5 | 8 | 2 | 8 | 11 | 4 | 8 | 5 | -1 | -1 | -1 | -1 |
| 44 | x'e3a' | 10 | 3 | 11 | 10 | 1 | 3 | 9 | 5 | 4 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 45 | x'f33' | 4 | 9 | 5 | 0 | 8 | 1 | 8 | 10 | 1 | 8 | 11 | 10 | -1 | -1 | -1 | -1 |
| 46 | x'c39' | 5 | 4 | 0 | 5 | 0 | 11 | 5 | 11 | 10 | 11 | 0 | 3 | -1 | -1 | -1 | -1 |
| 47 | x'd30' | 5 | 4 | 8 | 5 | 8 | 10 | 10 | 8 | 11 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 48 | x'3a0' | 9 | 7 | 8 | 5 | 7 | 9 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 49 | x'2a9' | 9 | 3 | 0 | 9 | 5 | 3 | 5 | 7 | 3 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 50 | x'1a3' | 0 | 7 | 8 | 0 | 1 | 7 | 1 | 5 | 7 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 51 | x'0aa' | 1 | 5 | 3 | 3 | 5 | 7 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 52 | x'7a6' | 9 | 7 | 8 | 9 | 5 | 7 | 10 | 1 | 2 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 53 | x'6af' | 10 | 1 | 2 | 9 | 5 | 0 | 5 | 3 | 0 | 5 | 7 | 3 | -1 | -1 | -1 | -1 |
| 54 | x'5a5' | 8 | 0 | 2 | 8 | 2 | 5 | 8 | 5 | 7 | 10 | 5 | 2 | -1 | -1 | -1 | -1 |
| 55 | x'4ac' | 2 | 10 | 5 | 2 | 5 | 3 | 3 | 5 | 7 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 56 | x'bac' | 7 | 9 | 5 | 7 | 8 | 9 | 3 | 11 | 2 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 57 | x'aa5' | 9 | 5 | 7 | 9 | 7 | 2 | 9 | 2 | 0 | 2 | 7 | 11 | -1 | -1 | -1 | -1 |
| 58 | x'9af' | 2 | 3 | 11 | 0 | 1 | 8 | 1 | 7 | 8 | 1 | 5 | 7 | -1 | -1 | -1 | -1 |
| 59 | x'8a6' | 11 | 2 | 1 | 11 | 1 | 7 | 7 | 1 | 5 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 60 | x'faa' | 9 | 5 | 8 | 8 | 5 | 7 | 10 | 1 | 3 | 10 | 3 | 11 | -1 | -1 | -1 | -1 |
| 61 | x'ea3' | 5 | 7 | 0 | 5 | 0 | 9 | 7 | 11 | 0 | 1 | 0 | 10 | 11 | 10 | 0 | -1 |
| 62 | x'da9' | 11 | 10 | 0 | 11 | 0 | 3 | 10 | 5 | 0 | 8 | 0 | 7 | 5 | 7 | 0 | -1 |
| 63 | x'ca0' | 11 | 10 | 5 | 7 | 11 | 5 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |

| # | Hex | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 64 | x'460' | 10 | 6 | 5 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 65 | x'569' | 0 | 8 | 3 | 5 | 10 | 6 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 66 | x'663' | 9 | 0 | 1 | 5 | 10 | 6 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 67 | x'76a' | 1 | 8 | 3 | 1 | 9 | 8 | 5 | 10 | 6 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 68 | x'66' | 1 | 6 | 5 | 2 | 6 | 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 69 | x'16f' | 1 | 6 | 5 | 1 | 2 | 6 | 3 | 0 | 8 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 70 | x'265' | 9 | 6 | 5 | 9 | 0 | 6 | 0 | 2 | 6 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 71 | x'36c' | 5 | 9 | 8 | 5 | 8 | 2 | 5 | 2 | 6 | 3 | 2 | 8 | -1 | -1 | -1 | -1 |
| 72 | x'c6c' | 2 | 3 | 11 | 10 | 6 | 5 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 73 | x'd65' | 11 | 0 | 8 | 11 | 2 | 0 | 10 | 6 | 5 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 74 | x'e6f' | 0 | 1 | 9 | 2 | 3 | 11 | 5 | 10 | 6 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 75 | x'f66' | 5 | 10 | 6 | 1 | 9 | 2 | 9 | 11 | 2 | 9 | 8 | 11 | -1 | -1 | -1 | -1 |
| 76 | x'86a' | 6 | 3 | 11 | 6 | 5 | 3 | 5 | 1 | 3 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 77 | x'963' | 0 | 8 | 11 | 0 | 11 | 5 | 0 | 5 | 1 | 5 | 11 | 6 | -1 | -1 | -1 | -1 |
| 78 | x'a69' | 3 | 11 | 6 | 0 | 3 | 6 | 0 | 6 | 5 | 0 | 5 | 9 | -1 | -1 | -1 | -1 |
| 79 | x'b60' | 6 | 5 | 9 | 6 | 9 | 11 | 11 | 9 | 8 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 80 | x'5f0' | 5 | 10 | 6 | 4 | 7 | 8 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 81 | x'4f9' | 4 | 3 | 0 | 4 | 7 | 3 | 6 | 5 | 10 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 82 | x'7f3' | 1 | 9 | 0 | 5 | 10 | 6 | 8 | 4 | 7 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 83 | x'6fa' | 10 | 6 | 5 | 1 | 9 | 7 | 1 | 7 | 3 | 7 | 9 | 4 | -1 | -1 | -1 | -1 |
| 84 | x'1f6' | 6 | 1 | 2 | 6 | 5 | 1 | 4 | 7 | 8 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 85 | x'0ff' | 1 | 2 | 5 | 5 | 2 | 6 | 3 | 0 | 4 | 3 | 4 | 7 | -1 | -1 | -1 | -1 |
| 86 | x'3f5' | 8 | 4 | 7 | 9 | 0 | 5 | 0 | 6 | 5 | 0 | 2 | 6 | -1 | -1 | -1 | -1 |
| 87 | x'2fc' | 7 | 3 | 9 | 7 | 9 | 4 | 3 | 2 | 9 | 5 | 9 | 6 | 2 | 6 | 9 | -1 |
| 88 | x'dfc' | 3 | 11 | 2 | 7 | 8 | 4 | 10 | 6 | 5 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 89 | x'cf5' | 5 | 10 | 6 | 4 | 7 | 2 | 4 | 2 | 0 | 2 | 7 | 11 | -1 | -1 | -1 | -1 |
| 90 | x'fff' | 0 | 1 | 9 | 4 | 7 | 8 | 2 | 3 | 11 | 5 | 10 | 6 | -1 | -1 | -1 | -1 |
| 91 | x'ef6' | 9 | 2 | 1 | 9 | 11 | 2 | 9 | 4 | 11 | 7 | 11 | 4 | 5 | 10 | 6 | -1 |
| 92 | x'9fa' | 8 | 4 | 7 | 3 | 11 | 5 | 3 | 5 | 1 | 5 | 11 | 6 | -1 | -1 | -1 | -1 |
| 93 | x'8f3' | 5 | 1 | 11 | 5 | 11 | 6 | 1 | 0 | 11 | 7 | 11 | 4 | 0 | 4 | 11 | -1 |
| 94 | x'bf9' | 0 | 5 | 9 | 0 | 6 | 5 | 0 | 3 | 6 | 11 | 6 | 3 | 8 | 4 | 7 | -1 |
| 95 | x'af0' | 6 | 5 | 9 | 6 | 9 | 11 | 4 | 7 | 9 | 7 | 11 | 9 | -1 | -1 | -1 | -1 |

| # | Hex | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 96 | x'650' | 10 | 4 | 9 | 6 | 4 | 10 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 97 | x'759' | 4 | 10 | 6 | 4 | 9 | 10 | 0 | 8 | 3 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 98 | x'453' | 10 | 0 | 1 | 10 | 6 | 0 | 6 | 4 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 99 | x'55a' | 8 | 3 | 1 | 8 | 1 | 6 | 8 | 6 | 4 | 6 | 1 | 10 | -1 | -1 | -1 | -1 |
| 100 | x'256' | 1 | 4 | 9 | 1 | 2 | 4 | 2 | 6 | 4 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 101 | x'35f' | 3 | 0 | 8 | 1 | 2 | 9 | 2 | 4 | 9 | 2 | 6 | 4 | -1 | -1 | -1 | -1 |
| 102 | x'055' | 0 | 2 | 4 | 4 | 2 | 6 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 103 | x'15c' | 8 | 3 | 2 | 8 | 2 | 4 | 4 | 2 | 6 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 104 | x'e5c' | 10 | 4 | 9 | 10 | 6 | 4 | 11 | 2 | 3 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 105 | x'f55' | 0 | 8 | 2 | 2 | 8 | 11 | 4 | 9 | 10 | 4 | 10 | 6 | -1 | -1 | -1 | -1 |
| 106 | x'c5f' | 3 | 11 | 2 | 0 | 1 | 6 | 0 | 6 | 4 | 6 | 1 | 10 | -1 | -1 | -1 | -1 |
| 107 | x'd56' | 6 | 4 | 1 | 6 | 1 | 10 | 4 | 8 | 1 | 2 | 1 | 11 | 8 | 11 | 1 | -1 |
| 108 | x'a5a' | 9 | 6 | 4 | 9 | 3 | 6 | 9 | 1 | 3 | 11 | 6 | 3 | -1 | -1 | -1 | -1 |
| 109 | x'b53' | 8 | 11 | 1 | 8 | 1 | 0 | 11 | 6 | 1 | 9 | 1 | 4 | 6 | 4 | 1 | -1 |
| 110 | x'859' | 3 | 11 | 6 | 3 | 6 | 0 | 0 | 6 | 4 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 111 | x'950' | 6 | 4 | 8 | 11 | 6 | 8 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 112 | x'7c0' | 7 | 10 | 6 | 7 | 8 | 10 | 8 | 9 | 10 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 113 | x'6c9' | 0 | 7 | 3 | 0 | 10 | 7 | 0 | 9 | 10 | 6 | 7 | 10 | -1 | -1 | -1 | -1 |
| 114 | x'5c3' | 10 | 6 | 7 | 1 | 10 | 7 | 1 | 7 | 8 | 1 | 8 | 0 | -1 | -1 | -1 | -1 |
| 115 | x'4ca' | 10 | 6 | 7 | 10 | 7 | 1 | 1 | 7 | 3 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 116 | x'3c6' | 1 | 2 | 6 | 1 | 6 | 8 | 1 | 8 | 9 | 8 | 6 | 7 | -1 | -1 | -1 | -1 |
| 117 | x'2cf' | 2 | 6 | 9 | 2 | 9 | 1 | 6 | 7 | 9 | 0 | 9 | 3 | 7 | 3 | 9 | -1 |
| 118 | x'1c5' | 7 | 8 | 0 | 7 | 0 | 6 | 6 | 0 | 2 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 119 | x'0cc' | 7 | 3 | 2 | 6 | 7 | 2 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 120 | x'fcc' | 2 | 3 | 11 | 10 | 6 | 8 | 10 | 8 | 9 | 8 | 6 | 7 | -1 | -1 | -1 | -1 |
| 121 | x'ec5' | 2 | 0 | 7 | 2 | 7 | 11 | 0 | 9 | 7 | 6 | 7 | 10 | 9 | 10 | 7 | -1 |
| 122 | x'dcf' | 1 | 8 | 0 | 1 | 7 | 8 | 1 | 10 | 7 | 6 | 7 | 10 | 2 | 3 | 11 | -1 |
| 123 | x'cc6' | 11 | 2 | 1 | 11 | 1 | 7 | 10 | 6 | 1 | 6 | 7 | 1 | -1 | -1 | -1 | -1 |
| 124 | x'bca' | 8 | 9 | 6 | 8 | 6 | 7 | 9 | 1 | 6 | 11 | 6 | 3 | 1 | 3 | 6 | -1 |
| 125 | x'ac3' | 0 | 9 | 1 | 11 | 6 | 7 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 126 | x'9c9' | 7 | 8 | 0 | 7 | 0 | 6 | 3 | 11 | 0 | 11 | 6 | 0 | -1 | -1 | -1 | -1 |
| 127 | x'8c0' | 7 | 11 | 6 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 128 | x'8c0' | 7 | 6 | 11 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 129 | x'9c9' | 3 | 0 | 8 | 11 | 7 | 6 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 130 | x'ac3' | 0 | 1 | 9 | 11 | 7 | 6 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 131 | x'bca' | 8 | 1 | 9 | 8 | 3 | 1 | 11 | 7 | 6 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 132 | x'cc6' | 10 | 1 | 2 | 6 | 11 | 7 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 133 | x'dcf' | 1 | 2 | 10 | 3 | 0 | 8 | 6 | 11 | 7 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 134 | x'ec5' | 2 | 9 | 0 | 2 | 10 | 9 | 6 | 11 | 7 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 135 | x'fcc' | 6 | 11 | 7 | 2 | 10 | 3 | 10 | 8 | 3 | 10 | 9 | 8 | -1 | -1 | -1 | -1 |
| 136 | x'0cc' | 7 | 2 | 3 | 6 | 2 | 7 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 137 | x'1c5' | 7 | 0 | 8 | 7 | 6 | 0 | 6 | 2 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 138 | x'2cf' | 2 | 7 | 6 | 2 | 3 | 7 | 0 | 1 | 9 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 139 | x'3c6' | 1 | 6 | 2 | 1 | 8 | 6 | 1 | 9 | 8 | 8 | 7 | 6 | -1 | -1 | -1 | -1 |
| 140 | x'4ca' | 10 | 7 | 6 | 10 | 1 | 7 | 1 | 3 | 7 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 141 | x'5c3' | 10 | 7 | 6 | 1 | 7 | 10 | 1 | 8 | 7 | 1 | 0 | 8 | -1 | -1 | -1 | -1 |
| 142 | x'6c9' | 0 | 3 | 7 | 0 | 7 | 10 | 0 | 10 | 9 | 6 | 10 | 7 | -1 | -1 | -1 | -1 |
| 143 | x'7c0' | 7 | 6 | 10 | 7 | 10 | 8 | 8 | 10 | 9 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 144 | x'950' | 6 | 8 | 4 | 11 | 8 | 6 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 145 | x'859' | 3 | 6 | 11 | 3 | 0 | 6 | 0 | 4 | 6 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 146 | x'b53' | 8 | 6 | 11 | 8 | 4 | 6 | 9 | 0 | 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 147 | x'a5a' | 9 | 4 | 6 | 9 | 6 | 3 | 9 | 3 | 1 | 11 | 3 | 6 | -1 | -1 | -1 | -1 |
| 148 | x'd56' | 6 | 8 | 4 | 6 | 11 | 8 | 2 | 10 | 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 149 | x'c5f' | 1 | 2 | 10 | 3 | 0 | 11 | 0 | 6 | 11 | 0 | 4 | 6 | -1 | -1 | -1 | -1 |
| 150 | x'f55' | 4 | 11 | 8 | 4 | 6 | 11 | 0 | 2 | 9 | 2 | 10 | 9 | -1 | -1 | -1 | -1 |
| 151 | x'e5c' | 10 | 9 | 3 | 10 | 3 | 2 | 9 | 4 | 3 | 11 | 3 | 6 | 4 | 6 | 3 | -1 |
| 152 | x'15c' | 8 | 2 | 3 | 8 | 4 | 2 | 4 | 6 | 2 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 153 | x'055' | 0 | 4 | 2 | 4 | 6 | 2 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 154 | x'35f' | 1 | 9 | 0 | 2 | 3 | 4 | 2 | 4 | 6 | 4 | 3 | 8 | -1 | -1 | -1 | -1 |
| 155 | x'256' | 1 | 9 | 4 | 1 | 4 | 2 | 2 | 4 | 6 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 156 | x'55a' | 8 | 1 | 3 | 8 | 6 | 1 | 8 | 4 | 6 | 6 | 10 | 1 | -1 | -1 | -1 | -1 |
| 157 | x'453' | 10 | 1 | 0 | 10 | 0 | 6 | 6 | 0 | 4 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 158 | x'759' | 4 | 6 | 3 | 4 | 3 | 8 | 6 | 10 | 3 | 0 | 3 | 9 | 10 | 9 | 3 | -1 |
| 159 | x'650' | 10 | 9 | 4 | 6 | 10 | 4 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 160 | x'af0' | 4 | 9 | 5 | 7 | 6 | 11 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 161 | x'bf9' | 0 | 8 | 3 | 4 | 9 | 5 | 11 | 7 | 6 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 162 | x'8f3' | 5 | 0 | 1 | 5 | 4 | 0 | 7 | 6 | 11 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 163 | x'9fa' | 11 | 7 | 6 | 8 | 3 | 4 | 3 | 5 | 4 | 3 | 1 | 5 | -1 | -1 | -1 | -1 |
| 164 | x'ef6' | 9 | 5 | 4 | 10 | 1 | 2 | 7 | 6 | 11 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 165 | x'fff' | 6 | 11 | 7 | 1 | 2 | 10 | 0 | 8 | 3 | 4 | 9 | 5 | -1 | -1 | -1 | -1 |
| 166 | x'cf5' | 7 | 6 | 11 | 5 | 4 | 10 | 4 | 2 | 10 | 4 | 0 | 2 | -1 | -1 | -1 | -1 |
| 167 | x'dfc' | 3 | 4 | 8 | 3 | 5 | 4 | 3 | 2 | 5 | 10 | 5 | 2 | 11 | 7 | 6 | -1 |
| 168 | x'2fc' | 7 | 2 | 3 | 7 | 6 | 2 | 5 | 4 | 9 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 169 | x'3f5' | 9 | 5 | 4 | 0 | 8 | 6 | 0 | 6 | 2 | 6 | 8 | 7 | -1 | -1 | -1 | -1 |
| 170 | x'0ff' | 3 | 6 | 2 | 3 | 7 | 6 | 1 | 5 | 0 | 5 | 4 | 0 | -1 | -1 | -1 | -1 |
| 171 | x'1f6' | 6 | 2 | 8 | 6 | 8 | 7 | 2 | 1 | 8 | 4 | 8 | 5 | 1 | 5 | 8 | -1 |
| 172 | x'6fa' | 9 | 5 | 4 | 10 | 1 | 6 | 1 | 7 | 6 | 1 | 3 | 7 | -1 | -1 | -1 | -1 |
| 173 | x'7f3' | 1 | 6 | 10 | 1 | 7 | 6 | 1 | 0 | 7 | 8 | 7 | 0 | 9 | 5 | 4 | -1 |
| 174 | x'4f9' | 4 | 0 | 10 | 4 | 10 | 5 | 0 | 3 | 10 | 6 | 10 | 7 | 3 | 7 | 10 | -1 |
| 175 | x'5f0' | 7 | 6 | 10 | 7 | 10 | 8 | 5 | 4 | 10 | 4 | 8 | 10 | -1 | -1 | -1 | -1 |
| 176 | x'b60' | 6 | 9 | 5 | 6 | 11 | 9 | 11 | 8 | 9 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 177 | x'a69' | 3 | 6 | 11 | 0 | 6 | 3 | 0 | 5 | 6 | 0 | 9 | 5 | -1 | -1 | -1 | -1 |
| 178 | x'963' | 0 | 11 | 8 | 0 | 5 | 11 | 0 | 1 | 5 | 5 | 6 | 11 | -1 | -1 | -1 | -1 |
| 179 | x'86a' | 6 | 11 | 3 | 6 | 3 | 5 | 5 | 3 | 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 180 | x'f66' | 1 | 2 | 10 | 9 | 5 | 11 | 9 | 11 | 8 | 11 | 5 | 6 | -1 | -1 | -1 | -1 |
| 181 | x'e6f' | 0 | 11 | 3 | 0 | 6 | 11 | 0 | 9 | 6 | 5 | 6 | 9 | 1 | 2 | 10 | -1 |
| 182 | x'd65' | 11 | 8 | 5 | 11 | 5 | 6 | 8 | 0 | 5 | 10 | 5 | 2 | 0 | 2 | 5 | -1 |
| 183 | x'c6c' | 6 | 11 | 3 | 6 | 3 | 5 | 2 | 10 | 3 | 10 | 5 | 3 | -1 | -1 | -1 | -1 |
| 184 | x'36c' | 5 | 8 | 9 | 5 | 2 | 8 | 5 | 6 | 2 | 3 | 8 | 2 | -1 | -1 | -1 | -1 |
| 185 | x'265' | 9 | 5 | 6 | 9 | 6 | 0 | 0 | 6 | 2 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 186 | x'16f' | 1 | 5 | 8 | 1 | 8 | 0 | 5 | 6 | 8 | 3 | 8 | 2 | 6 | 2 | 8 | -1 |
| 187 | x'066' | 1 | 5 | 6 | 2 | 1 | 6 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 188 | x'76a' | 1 | 3 | 6 | 1 | 6 | 10 | 3 | 8 | 6 | 5 | 6 | 9 | 8 | 9 | 6 | -1 |
| 189 | x'663' | 10 | 1 | 0 | 10 | 0 | 6 | 9 | 5 | 0 | 5 | 6 | 0 | -1 | -1 | -1 | -1 |
| 190 | x'569' | 0 | 3 | 8 | 5 | 6 | 10 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 191 | x'460' | 10 | 5 | 6 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 192 | x'ca0' | 11 | 5 | 10 | 7 | 5 | 11 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 193 | x'da9' | 11 | 5 | 10 | 11 | 7 | 5 | 8 | 3 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 194 | x'ea3' | 5 | 11 | 7 | 5 | 10 | 11 | 1 | 9 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 195 | x'faa' | 10 | 7 | 5 | 10 | 11 | 7 | 9 | 8 | 1 | 8 | 3 | 1 | -1 | -1 | -1 | -1 |
| 196 | x'8a6' | 11 | 1 | 2 | 11 | 7 | 1 | 7 | 5 | 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 197 | x'9af' | 0 | 8 | 3 | 1 | 2 | 7 | 1 | 7 | 5 | 7 | 2 | 11 | -1 | -1 | -1 | -1 |
| 198 | x'aa5' | 9 | 7 | 5 | 9 | 2 | 7 | 9 | 0 | 2 | 2 | 11 | 7 | -1 | -1 | -1 | -1 |
| 199 | x'bac' | 7 | 5 | 2 | 7 | 2 | 11 | 5 | 9 | 2 | 3 | 2 | 8 | 9 | 8 | 2 | -1 |
| 200 | x'4ac' | 2 | 5 | 10 | 2 | 3 | 5 | 3 | 7 | 5 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 201 | x'5a5' | 8 | 2 | 0 | 8 | 5 | 2 | 8 | 7 | 5 | 10 | 2 | 5 | -1 | -1 | -1 | -1 |
| 202 | x'6af' | 9 | 0 | 1 | 5 | 10 | 3 | 5 | 3 | 7 | 3 | 10 | 2 | -1 | -1 | -1 | -1 |
| 203 | x'7a6' | 9 | 8 | 2 | 9 | 2 | 1 | 8 | 7 | 2 | 10 | 2 | 5 | 7 | 5 | 2 | -1 |
| 204 | x'0aa' | 1 | 3 | 5 | 3 | 7 | 5 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 205 | x'1a3' | 0 | 8 | 7 | 0 | 7 | 1 | 1 | 7 | 5 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 206 | x'2a9' | 9 | 0 | 3 | 9 | 3 | 5 | 5 | 3 | 7 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 207 | x'3a0' | 9 | 8 | 7 | 5 | 9 | 7 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 208 | x'd30' | 5 | 8 | 4 | 5 | 10 | 8 | 10 | 11 | 8 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 209 | x'c39' | 5 | 0 | 4 | 5 | 11 | 0 | 5 | 10 | 11 | 11 | 3 | 0 | -1 | -1 | -1 | -1 |
| 210 | x'f33' | 0 | 1 | 9 | 8 | 4 | 10 | 8 | 10 | 11 | 10 | 4 | 5 | -1 | -1 | -1 | -1 |
| 211 | x'e3a' | 10 | 11 | 4 | 10 | 4 | 5 | 11 | 3 | 4 | 9 | 4 | 1 | 3 | 1 | 4 | -1 |
| 212 | x'936' | 2 | 5 | 1 | 2 | 8 | 5 | 2 | 11 | 8 | 4 | 5 | 8 | -1 | -1 | -1 | -1 |
| 213 | x'83f' | 0 | 4 | 11 | 0 | 11 | 3 | 4 | 5 | 11 | 2 | 11 | 1 | 5 | 1 | 11 | -1 |
| 214 | x'b35' | 0 | 2 | 5 | 0 | 5 | 9 | 2 | 11 | 5 | 4 | 5 | 8 | 11 | 8 | 5 | -1 |
| 215 | x'a3c' | 9 | 4 | 5 | 2 | 11 | 3 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 216 | x'53c' | 2 | 5 | 10 | 3 | 5 | 2 | 3 | 4 | 5 | 3 | 8 | 4 | -1 | -1 | -1 | -1 |
| 217 | x'435' | 5 | 10 | 2 | 5 | 2 | 4 | 4 | 2 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 218 | x'73f' | 3 | 10 | 2 | 3 | 5 | 10 | 3 | 8 | 5 | 4 | 5 | 8 | 0 | 1 | 9 | -1 |
| 219 | x'636' | 5 | 10 | 2 | 5 | 2 | 4 | 1 | 9 | 2 | 9 | 4 | 2 | -1 | -1 | -1 | -1 |
| 220 | x'13a' | 8 | 4 | 5 | 8 | 5 | 3 | 3 | 5 | 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 221 | x'033' | 0 | 4 | 5 | 1 | 0 | 5 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 222 | x'339' | 8 | 4 | 5 | 8 | 5 | 3 | 9 | 0 | 5 | 0 | 3 | 5 | -1 | -1 | -1 | -1 |
| 223 | x'230' | 9 | 4 | 5 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 224 | x'e90' | 4 | 11 | 7 | 4 | 9 | 11 | 9 | 10 | 11 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 225 | x'f99' | 0 | 8 | 3 | 4 | 9 | 7 | 9 | 11 | 7 | 9 | 10 | 11 | -1 | -1 | -1 | -1 |
| 226 | x'c93' | 1 | 10 | 11 | 1 | 11 | 4 | 1 | 4 | 0 | 7 | 4 | 11 | -1 | -1 | -1 | -1 |
| 227 | x'd9a' | 3 | 1 | 4 | 3 | 4 | 8 | 1 | 10 | 4 | 7 | 4 | 11 | 10 | 11 | 4 | -1 |
| 228 | x'a96' | 4 | 11 | 7 | 9 | 11 | 4 | 9 | 2 | 11 | 9 | 1 | 2 | -1 | -1 | -1 | -1 |
| 229 | x'b9f' | 9 | 7 | 4 | 9 | 11 | 7 | 9 | 1 | 11 | 2 | 11 | 1 | 0 | 8 | 3 | -1 |
| 230 | x'895' | 11 | 7 | 4 | 11 | 4 | 2 | 2 | 4 | 0 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 231 | x'99c' | 11 | 7 | 4 | 11 | 4 | 2 | 8 | 3 | 4 | 3 | 2 | 4 | -1 | -1 | -1 | -1 |
| 232 | x'69c' | 2 | 9 | 10 | 2 | 7 | 9 | 2 | 3 | 7 | 7 | 4 | 9 | -1 | -1 | -1 | -1 |
| 233 | x'795' | 9 | 10 | 7 | 9 | 7 | 4 | 10 | 2 | 7 | 8 | 7 | 0 | 2 | 0 | 7 | -1 |
| 234 | x'49f' | 3 | 7 | 10 | 3 | 10 | 2 | 7 | 4 | 10 | 1 | 10 | 0 | 4 | 0 | 10 | -1 |
| 235 | x'596' | 1 | 10 | 2 | 8 | 7 | 4 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 236 | x'29a' | 4 | 9 | 1 | 4 | 1 | 7 | 7 | 1 | 3 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 237 | x'393' | 4 | 9 | 1 | 4 | 1 | 7 | 0 | 8 | 1 | 8 | 7 | 1 | -1 | -1 | -1 | -1 |
| 238 | x'099' | 4 | 0 | 3 | 7 | 4 | 3 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 239 | x'190' | 4 | 8 | 7 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 240 | x'f00' | 9 | 10 | 8 | 10 | 11 | 8 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 241 | x'e09' | 3 | 0 | 9 | 3 | 9 | 11 | 11 | 9 | 10 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 242 | x'd03' | 0 | 1 | 10 | 0 | 10 | 8 | 8 | 10 | 11 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 243 | x'c0a' | 3 | 1 | 10 | 11 | 3 | 10 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 244 | x'b06' | 1 | 2 | 11 | 1 | 11 | 9 | 9 | 11 | 8 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 245 | x'a0f' | 3 | 0 | 9 | 3 | 9 | 11 | 1 | 2 | 9 | 2 | 11 | 9 | -1 | -1 | -1 | -1 |
| 246 | x'905' | 0 | 2 | 11 | 8 | 0 | 11 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 247 | x'80c' | 3 | 2 | 11 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 248 | x'70c' | 2 | 3 | 8 | 2 | 8 | 10 | 10 | 8 | 9 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 249 | x'605' | 9 | 10 | 2 | 0 | 9 | 2 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 250 | x'50f' | 2 | 3 | 8 | 2 | 8 | 10 | 0 | 1 | 8 | 1 | 10 | 8 | -1 | -1 | -1 | -1 |
| 251 | x'406' | 1 | 10 | 2 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 252 | x'30a' | 1 | 3 | 8 | 9 | 1 | 8 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 253 | x'203' | 0 | 9 | 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 254 | x'109' | 0 | 3 | 8 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| 255 | x'000' | 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |

# List of Symbols, Abbreviations, and Acronyms

3-D      three-dimensional

3DWF     three-dimensional Wind Field

ABLE     Atmospheric Boundary Layer Experiment

ASL      above sea level

GUI      graphical user interface

HTML    HyperText Markup Language

JS       JavaScript

KML      Keyhole Markup Language

MC      marching cubes

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