Simulating North American Impact Craters with ArcView & Excel

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Abstract

Impact craters in North America from the ArcAtlas: Our Earth CD were statistically analyzed in order to build a model to randomly generate impact events and analyze their geographic distribution and environmental impact. Using the simulation modeling, random impact craters are generated in Excel® and then displayed in ArcView®. Statistical measures were then used to predict the incidence and severity of impacts in North America from comets and asteroids.

A Pattern Analysis of North American Impact Craters

Introduction and Background

Each day the earth's atmosphere is subjected to thousands of micrometeors colliding and burning up due to the friction generated at entry or landing undetected in the earth's lithosphere or oceans. But the earth's solid surface has been rippled by larger stones hurled from space in the past, and is most likely a target for future assaults. In the inner section of the solar system there is visual evidence of impacting events on Mars, Mercury, and our Moon. Until just recently, scientists believed that the earth was immune from such cratering events due to the nature and thickness of our atmosphere (Hamilton). Bolides, or simply comet and asteroid fragments, burn up in Earth's atmosphere from the heat generated by the frictional interaction with atmospheric gases. Or, if the entry angle is oblique, bolides just carom off the Earth's outer layer, hurtling in a new direction in space. Any existing surficial evidence of cratering was attributed to explosive volcanic events, such as, 1980's Mt. St. Helens eruption (Shoemaker).

Pioneering work by Walter Alvarez and Gene Shoemaker changed the scientific community's focus to investigating extraterrestrial origins of impact structures. Shoemaker focused on the relatively young Barringer Crater in Arizona, where no volcanic material was evident, to support his impact theory of crater origin. Walter Alvarez's study and location of the Chicxulub impact crater, correlating with the time of dinosaur extinction, provided supporting evidence to the impact-dinosaur extinction theory. (Alvarez) When the comet Shoemaker-Levy9, crashed into Jupiter in 1994, the world suddenly realized that impact events are still on-going, and a present day danger on earth.

In the last decade over 150 impact crater sites have been identified world-wide (Komedchikov). More than forty have been found in North America alone (see table 1), and recently an approximately 30 million year old impact crater buried under the Chesapeake Bay in Virginia has been reported and studied (Poag). A recent report in the Washington Post details a near miss of an asteroid impact predicted to strike earth in 2029 (Gugliotta). Earth impact events are still on-going; while the timing of large impact events is measured on a scale of millennia, the devastating effects from such impacts have scaled from regional destruction in the Barringer event (Kring) to monumental devastation in the Chicxulub event (Alvarez).

Problem Description

"Is the geographic dispersal of the 40-plus suspected impact sites in North American distributed in a random pattern, or a non-random pattern?" was the initial question addressed. Initially a shotgun modeling approach was used to create a random geographic distribution of impact craters. Using Excel®, 20,000 crater events were randomly generated between latitudes 15° N and 85° N, and longitudes 50° W and 170° W. Those parameters were selected as they contained with in their bounds, the North American continent (Canada, United States, and Mexico). The flaw in generating random latitude and longitude coordinates in such a manner, is that it produces far too many crater events in the northern latitudes. Because the Earth is a spheroid, there is far less area per degree of latitude and degree of longitude the closer one gets to the poles (Campbell). The error in random distribution is a result of the earth's spherical projection

Table 1: Combined Data for All North American Impact Events from PASSC, LAPL, and ArcAtlas

PASSC_ ID	Crater_ Name	Location	lat_dd	lon_dd	POINT_X	POINT_Y	diameter_ km	age_mya	exposed	drilled	Area_km_ est	Perim_km_ est	Souce
1	Ames	Oklahoma, U.S.A.	36.25000000	-98.20000000	-98.0020000000	36.0025000000	16.0000	470.0000	N	Y	201.06	50.27	L,P
3	Barringer	Arizona, U.S.A.	35.03333333	-111.01666667	-111.0167007540	35.0333290078	1.1800	0.0490	Y	Y	1.09	3.71	L,N,P
4	Beaverhead	Montana, U.S.A.	44.60000000	-113.00000000	-113.0000000000	44.0060000000	60.0000	600.0000	Y	N	2827.43	188.50	L,P
6	Brent	Ontario, Canada	46.08333333	-78.48333333	-78.4833297615	46.0833282440	3.8000	396.0000	N	Y	11.34	11.94	L,N,P
7	Calvin	Michigan, USA	41.83333333	-85.95000000	-85.0095000000	41.0083333333	8.5000	450.0000	N	Y	56.75	26.70	L,P
8	Carswell	Saskatchewan, Canada	58.45000000	-109.50000000	-109.4999999940	58.4500007673	39.0000	115.0000	Y	Y	1194.59	122.52	L,N,P
9	Charlevoix	Quebec, Canada	47.53333333	-70.30000000	-70.3000030650	47.5333290224	54.0000	342.0000	Y	Y	2290.22	169.65	P
10	Chesapeake Bay	Virginia, U.S.A.	37.28333333	-76.01666667	-76.0001666667	37.0028333333	90.0000	35.5000	N	Y	6361.73	282.74	L,P
59	Chicxulub	Yucatan, Mexico	21.33333333	-89.50000000	-89.0050000000	21.0033333333	170.0000	64.9800	N	Y	22698.01	534.07	L,P
11	Clearwater East	Quebec, Canada	56.08333333	-74.11666667	-74.1166687092	56.0833282504	26.0000	290.0000	Y	Y	530.93	81.68	L,N,P
12	Clearwater West	Quebec, Canada	56.21666667	-74.50000000	-74.5000000110	56.2166709907	36.0000	290.0000	Y	Y	1017.88	113.10	L,N,P
58	Cloud Creek	Wyoming, USA	43.11666667	-106.75000000	-106.0075000000	43.0011666667	7.0000	190.0000	N	Y	38.48	21.99	P
14	Couture	Quebec, Canada	60.13333333	-75.33333333	-75.0033333333	60.0013333333	8.0000	430.0000	Y	N	50.27	25.13	L,P
15	Crooked Creek	Missouri, U.S.A.	37.83333333	-91.38333333	-91.3833312981	37.8333282381	7.0000	320.0000	Y	N	38.48	21.99	L,N,P
16	Decaturville	Missouri, U.S.A.	37.90000000	-92.71666667	-92.7166671808	37.9000015210	6.0000	300.0000	Y	Y	28.27	18.85	L,N,P
17	Deep Bay	Saskatchewan, Canada	56.40000000	-102.98333333	-102.9832992440	56.4000015182	13.0000	99.0000	N	Y	132.73	40.84	L,N,P
18	Des Plaines	Illinois, U.S.A.	42.05000000	-87.86666667	-87.0086666667	42.0005000000	8.0000	280.0000	N	Y	50.27	25.13	L,P
19	Eagle Butte	Alberta, Canada	49.70000000	-110.50000000	-110.5000000130	49.7000007650	10.0000	65.0000	N	Y	78.54	31.42	L,N,P
20	Elbow	Saskatchewan, Canada	50.98333333	-105.9928333333	-105.9928333333	50.0098333333	8.0000	395.0000	N	Y	50.27	25.13	L,P
21	Flynn Creek	Tennessee, U.S.A.	36.28333333	-85.66666667	-85.6666564919	36.2833290119	3.8000	360.0000	Y		11.34	11.94	L,N,P
22	Glasford	Illinois, U.S.A.	40.60000000	-89.78333333	-89.0078333333	40.0060000000	4.0000	430.0000	N	Y	12.57	12.57	L,P
23	Glover Bluff	Wisconsin, U.S.A.	43.96666667	-89.53333333	-89.5333328233	43.9666709875	8.0000	500.0000	Y	Y	50.27	25.13	L,N,P
24	Gow	Saskatchewan, Canada	56.45000000	-104.48333333	-104.4832992590	56.4500007554	5.0000	250.0000	Y	N	19.63	15.71	L,N,P
25	Haughton	Nunavut, Canada	75.36666667	-89.68333333	-89.6666564891	75.3666686958	24.0000	23.0000	Y	N	452.39	75.40	L,N,P
26	Haviland	Kansas, U.S.A.	37.58333333	-99.16666667	-99.1666564992	37.5833282532	0.0100	0.0010	Y	N	0.00	0.03	L,N,P
27	Holleford	Ontario, Canada	44.46666667	-76.63333333	-76.6333312867	44.4666709838	2.3500	550.0000	N	Y	4.34	7.38	L,N,P
28	Ile Rouleau	Quebec, Canada	50.68333333	-73.88333333	-73.8833312935	50.6833305375	4.0000	300.0000	Y	N	12.57	12.57	L,N,P
29	Kentland	Indiana, U.S.A.	40.75000000	-87.40000000	-87.4000015210	40.7499999885	13.0000	97.0000	Y	Y	132.73	40.84	L,N,P
30	La Moinerie	Quebec, Canada	57.43333333	-66.61666667	-66.5999984643	57.4333305279	8.0000	400.0000	Y	N	50.27	25.13	L,N,P
31	Manicouagan	Quebec, Canada	51.38333333	-68.70000000	-68.6999969506	51.3833313081	100.0000	214.0000	Y	Y	7853.98	314.16	L,N,P
32	Manson	Iowa, U.S.A.	42.58333333	-94.55000000	-94.5166702174	42.5833282431	35.0000	73.8000	N	Y	962.11	109.96	L,N,P
33	Maple Creek	Saskatchewan, Canada	49.80000000	-109.10000000	-109.0010000000	49.0080000000	6.0000	75.0000	N	Y	28.27	18.85	L,P
34	Marquez	Texas, U.S.A.	31.28333333	-96.30000000	-96.0030000000	31.0028333333	12.7000	± 2	N	Y	126.68	39.90	L,P
35	Middlesboro	Kentucky, U.S.A.	36.61666667	-83.73333333	-83.7333297629	36.6166687009	6.0000	300.0000	Y	Y	28.27	18.85	L,N,P
36	Mistastin	Newfoundland/Labrador, Canada	55.88333333	-63.30000000	-63.2999992377	55.8833313017	28.0000	36.4000	Y	N	615.75	87.96	L,N,P
37	Montagnais	Nova Scotia, Canada	42.88333333	-64.21666667	-64.0021666667	42.0088333333	45.0000	50.5000	N	Y	1590.43	141.37	L,N,P
38	New Quebec	Quebec, Canada	61.28333333	-73.66666667	-73.6666565002	61.2833290146	3.4400	1.4000	Y	N	9.29	10.81	L,N,P
39	Newporte	North Dakota, U.S.A.	48.96666667	-101.96666667	-101.0096666667	48.0096666667	3.2000	500.0000	N	Y	8.04	10.05	L,P
40	Nicholson	Northwest Territories, Canada	62.66666667	-102.68333333	-102.6832961960	62.6666717590	12.5000	400.0000	N	N	122.72	39.27	L,N,P
41	Odessa	Texas, U.S.A.	31.75000000	-102.48333333	-102.4832992470	31.7500000013	0.1600	0.0500	Y	Y	0.02	0.50	L,N,P
42	Pilot	Northwest Territories, Canada	60.28333333	-111.01666667	-111.0167007540	60.2833290219	6.0000	445.0000	Y	N	28.27	18.85	L,N,P
43	Presqu'ile	Quebec, Canada	49.71666667	-74.80000000	-74.0080000000	49.0071666667	24.0000	500.0000	Y	N	452.39	75.40	L,P
44	Red Wing	North Dakota, U.S.A.	47.60000000	-103.55000000	-103.5500030470	47.5999984798	9.0000	200.0000	N	Y	63.62	28.27	L,N,P
45	Rock Elm	Wisconsin, U.S.A.	44.71666667	-92.23333333	-92.0023333333	44.0071666667	6.0000	505.0000			28.27	18.85	P
46	Saint Martin	Manitoba, Canada	51.78333333	-98.53333333	-98.5333328370	51.7833290046	40.0000	220.0000	N	Y	1256.64	125.66	L,N,P
47	Serpent Mound	Ohio, U.S.A.	39.03333333	-83.40000000	-83.4000015238	39.0333290050	8.0000	320.0000	Y	Y	50.27	25.13	L,N,P
48	Sierra Madera	Texas, U.S.A.	30.60000000	-102.91666667	-102.9167022580	30.6000003843	13.0000	100.0000	Y	Y	132.73	40.84	L,N,P
49	Slate Islands	Ontario, Canada	48.66666667	-87.00000000	-87.0000000000	48.0066666667	30.0000	450.0000	Y	N	706.86	94.25	L,P
50	Steen River	Alberta, Canada	59.50000000	-117.63333333	-117.6333007810	59.5166702173	25.0000	91.0000	N	Y	490.87	78.54	L,N,P
51	Sudbury	Ontario, Canada	46.60000000	-81.18333333	-81.1833267185	46.5999984871	250.0000	1850.0000	Y	Y	49087.39	785.40	L,N,P
52	Upheaval Dome	Utah, U.S.A.	38.43333333	-109.90000000	-109.9000015150	38.4333305343	10.0000	170.0000	Y	Y	78.54	31.42	L,N,P
53	Viewfield	Saskatchewan, Canada	49.58333333	-103.06666667	-103.0006666667	49.0058333333	2.5000	190.0000	N	Y	4.91	7.85	L,P
54	Wanapitei	Ontario, Canada	46.75000000	-80.75000000	-80.7333297849	46.7333297775	7.5000	37.2000	N	N	44.18	23.56	L,N,P
55	Wells Creek	Tennessee, U.S.A.	36.3833333300	-87.66666667	-87.6666565038	36.3833313118	12.0000	200.0000	Y	Y	113.10	37.70	L,N,P
56	West Hawk	Manitoba, Canada	49.76666667	-95.18333333	-95.1833267221	49.7666702224	2.4400	351.0000	N	Y	4.68	7.67	L,N,P
57	Wetumpka	Alabama, U.S.A.	32.51666667	-86.16666667	-86.0016666667	32.0051666667	6.5000	81.0000	Y	Y	33.18	20.42	P
2	Avak	Alaska, U.S.A.	71..250000	-156.63333330	-156.0063333330	71..00250000	12.0000	95.0000	N	Y	113.10	37.70	L,P
0	Bee Bluff	U.S.A.	29.0333309114	-99.8499984730	-99.8499984730	29.0333309114	2.4000	40.0000			4.52	7.54	N
0	Lac Couture	Canada	60.1333313104	-75.3333434953	-75.3333434953	60.1333313104	8.0000	425.0000			50.27	25.13	N

not containing equal areas between lines of longitude and latitude, although they appear that way on some 2-dimensional projections. (See figure 1 and figure 2 to compare the apparent random distribution on a "flat map" to the concentration of events in northern latitudes when viewed from a spherical view.) Therefore, a comparison between randomly generated events and the known events could not accurately be made, even when using the Chi square statistic.

Figure 1: 20,000 randomly generated impact craters in North America (using Projections of the World, Geographic)

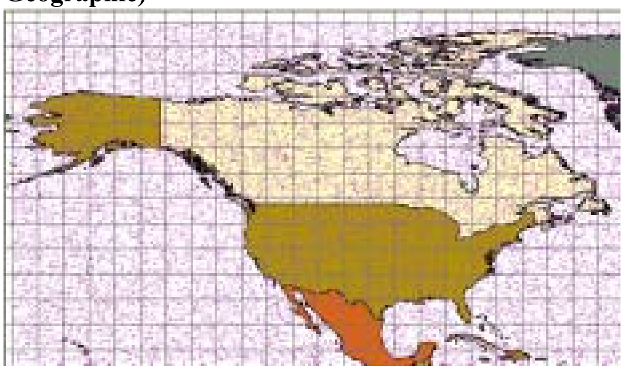
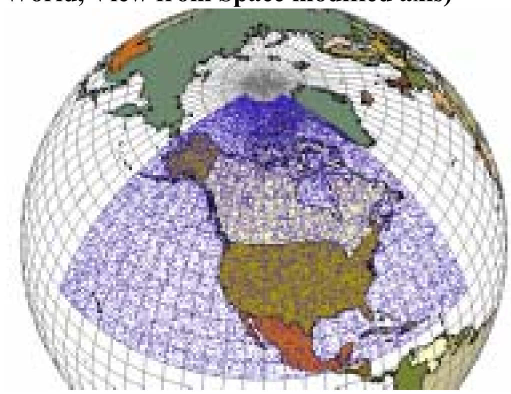


Figure 2: 20,000 randomly generated impact craters in North America (using map Projections of the World, View from Space modified axis)



System

For Geo450/ISAT580, Environmental GIS the model comparison is improved upon by randomly generating points of latitude and longitude using a spherical modeling approach. A comparison was made of the actual crater distribution to the modeled distribution using measures of central tendency and the nearest neighbor spatial statistical analysis technique. Initial data from the chi square statistic, suggest that the crater distribution is not a random pattern. (See table 2 and table 4 for a comparison of statistics regarding non-randomness of the impact events.)

The environmental effect of an impact event is modeled on Kring's data regarding the Barringer Crater in Arizona. A comparison of the ratio between the Barringer Crater diameter and Barringer impact zones was extrapolated to other crater diameters and their impact zones. These zones of effect will be created around the modeled impact site using the buffer function in ArcGIS9®. The Chesapeake Bay impact event was chosen to extrapolate and model environmental effect. While crater impact events are rare from the perspective of a human time scale, they have occurred in the past, and recent near-misses of asteroids with the earth, all but assure they will be of importance in the future. Guy Gugliotta reports "…calculations as the probability of the 1,000 foot-wide stone missile hitting Earth rose from one chance in 170 to one in 38. They had never measured anything as potentially dangerous to the Earth. Impact would come on Friday the 13th in April 2029." Of course, newer calculations show this predicted impact as a near miss.

Stakeholders & Obstacles

Stakeholders are all inhabitants of the planet, governments, citizens, and emergency and medical personnel. Of course the topic is of interest to astronomers, professional and amateur, as well as those involved in the Space Watch Project at University of Arizona and avid fans of near earth objects. A major obstacle is the infrequency of significant impactor events and the time scale involved. Only the recent, 1994, impact event on Jupiter and the 1905 Tunguska event contribute any urgency to the study of the issues involved as an Earth hazard or as an environmental destructor.

Questions Addressed

How does the spatial distribution of North American impact events compare to randomly distributed modeled impact events?

What are the environmental effects of such impacts at Barringer Crater, Arizona?

Description of Key Data Layers

Data Identification & Description

The classroom activity "Analyzing North American Meteorite Impact Sites", sponsored the American Geologic Institute (AGI), has students plot the forty suspected impact sites in North America, and graph a comparison of crater age versus crater size. That lesson was the impetus for this analysis and modeling project. Data for the location, crater age, and crater size, was garnered from several sources; <u>ESRI's ArcAtlas: Our Earth CD-ROM</u>, and from both the University of Arizona's Department of Planetary Science, Lunar and Planetary Laboratory (LPAL) data, and the Planetary and Space Science Centre (PASSC) Earth Impact Database from the University of New Brunswick. These last two sources were included to reflect more recent impact discoveries and deletion of sites (Bees Bluff) no longer considered of impact origin. As an example, ESRI's <u>ArcAtlas</u> data set did not include the Chicxulub crater event, nor the Chesapeake crater event. Additionally, the university sources serve as alternate populations to compare to randomly generated events. In last fall's impact model, random impact locations were generated in Excel®, and compared to a data set of 54 known impacts. The known data set was comprised of the 53 events from LAPL and an additional impact event from information contained in King's "The Wetumpka Impact Crater and the Late Cretaceous Impact Record". For the current statistical analysis, comparison is made between the 40 impact events in <u>ArcAtlas</u>, 53 impact events from LAPL, 57 impact events from PASSC, and randomly generated modeled events.

Data Layers

Four data layers are incorporated into the **North American Impact Craters Project** and are named:

Overview_NA_Impact_Craters;
Barrington_Crater_AZ;
Chesapeake_Bay_Crater_VA;

Environmental_Effect_Comparison; and
Other_NA_Impacts.

The first layer is a view of the 40 impact events from the ArcAtlas, portraying the point pattern formed by the craters across North America in Projects of the World, Geographic. In this layer an exploration of the spatial statistical analysis is conducted. The **Overview_NA_Impact_ Craters** layer displays the mean center of both the known impact events and the modeled random impact events. The central tendency of the point data is also graphically represented by the central mean distance, a circle shape and calculation of one standard deviation's distance from the mean center of the point data. Additionally, an ellipse shape is shown in the ellipse directional distance statistic. The **Overview_NA_Impact_Craters** layer contains the following themes:

xyimpact_AZU_wgs84_2mn_cntr – mean center of LAPL events.
central_mean_random2 – mean center of spherically randomly generated events.
standard_distance_naterdd – standard distance circle measure of 40 impact craters from ArcAtlas.
ellipse_dir_dist_naterdd – ellipse directional distance measure of 40 impact craters from ArcAtlas.
naterdd_point - is the point data set of 40 impact events on the North American continent in the Lithosphere folder of ESRI's ArcAtlas CD-rom.
random_craters_NA - points were generated randomly using formula for a sphere (cmu) by creating formula in Excel® spreadsheet. (See discussion under data changes for formula). For the Northern Hemisphere 20,000 points were randomly generated. Those points that intersected the shape files of the United States, Canada, or Mexico, were selected out and saved.
craters_random_spherical – spherically randomly generated points for the Northern Hemisphere.
latlong – reference grid from ESRI data.
MEX_States – state shapes for Mexico from ESRI data.
US_States – state shapes for the United States from ESRI data.
CNTRY92 – worldwide country shapes from ESRI data.
WORLD30 – ocean background and grid from ESRI data.
central_mean – calculated from naterdd using ArcToolbox, Geospatial Statistics, represents the central tendency, or average location for 40 impact sites from naterdd shape file.
central_mean_random - calculated from naterdd using ArcToolbox, Geospatial Statistics, and represents the central tendency for 1300 impact sites from random.

The second layer, **Barrington_Crater_AZ**, is a view displaying the various environmental impact buffers based on the research conducted by the LAPL at the University of Arizona. It contains the **naterdd_point** file displaying the 40 impact sites from the ArcAtlas, as well as, the **latlong** and **STATE**S (US) files from the ESRI data folders. The impact site buffers show the relative size of objects and zones of environmental consequence. For a comparison of size, two buffers were created, one for the iron meteor (**iron_meteor**), and a second to represent the Barringer Crater, (**az_crater_diam**). Buffers were also drawn to show the lethal area, where all biota was destroyed on impact, (**death_zone**), and the extent of the fireball blast at impact (**fireball)**. Areas of less serious consequence were buffered, showing the extent of flying debris, areas of maiming, and the extent of hurricane force winds. These areas have files named **shrapnel**, **maim_zone2**, **maim_zone1**, and **windzone**, respectively.

The third layer, **Chesapeake_Bay_Crater_VA**, shows the impact site on the tip of Virginia's eastern shore near Nansemond. Its discovery and verification is too recent to have been included in the ESRI ArcAtlas data set on craters. The location of the Cheasapeake impact crater has been extracted from the literature and the databases maintained by PASSC and LAPI. Buffer zones were constructed for the same parameters discussed in the Barringer impact event, meteor, crater diameter, death zone, fireball, maiming zones 1 and 2, and hurricane force wind zones. The files have the same nomenclature as the Arizona event with the appellation of "VA" added for Virginia. The same legend format was used for both Virginia and Arizona buffers. The buffer zones for the Chesapeake Bay crater event were extrapolated from the Arizona data using a simple ratio and calculating in Excel®. The ratio used:

(Barrringer crater buffer zone) / (Barringer crater diameter km) =
(unknown Chesapeake crater buffer zone) / (Chesapeake crater diameter km)

The rationale follows a straight line extrapolation from the Barringer events to the Chesapeake Bay event.

The **Environmental_Effect_Comparison** layer is simply a compilation of the themes from the Barringer Crater impact event and the themes from the extrapolated event that occurred in the Chesapeake Bay 30 million years ago. The comparison is made between the regional Arizona event and the larger Chesapeake Bay event. This layer combines the buffers from the Arizona and Virginia impact events and the standard ESRI **STATE**S (US) and **latlong** shapefiles.

The final layer, **Other_NA_Impacts**, compares the central tendencies and other spatial statistic of the point data pattern of impact crater sites using the three different data sets of the recognized events and those hypothesized by randomly generating points on sphere. The **Other_NA_ Impacts** contains the following themes:

- **random_sphere_na2** -144 random event locations intersecting the North America shape.
- **central_mean_random2** - the mean center of the 2000 random events generated.
- **random_craters_na** -1600 random event locations intersecting North America shape.
- **central_mean_naterdd** – mean center point of all 40 naterdd craters.
- **XYImpact_AZU_wgs84_2_mn_cntr** – mean center point of 53 LAPL craters in geographic wgs84 sphereoid.
- **ellipse_dir_dist_naterdd** – directional distance ellipse for the 40 naterdd craters.
- **XYImpact_AZU_wgs84_2ddellipse** – directional distance ellipse for 53 LAPL craters.
- **XYImpact_AZU_clark1866_2** – 53 crater events from LAPL in geographic Clark 1866 spheroid.
- **naterdd_point** – 40 crater events from ArcAtlas.
- **CNTRY92** - worldwide country shapes from ESRI data.

Data Changes

The original data on impact craters for North America was in ArcInfo coverage and was imported from ArcAtlas into ArcGIS9 using a Personal Geodatabase. It was imported using the Import/Feature Class (Multiple) function. On the "rev_impact.mxd", the .dbf file that was created as an import, was added as data to a blank map. "Add Data to ArcMap/Display XYdata was used to obtain latitude and longitude values for the points of impact from ArcAtlas.

For the impact features found at LAPL and PASSC sites, the location was listed in degree° minute' format. The data was pasted into an Excel® spreadsheet, and new columns for decimal degree position were created. The minute values were divided by 60 and added as decimal equivalents to the degree values for each latitude and longitude. All the references to N for north were removed, and the references to W, for west were converted to negative (-) symbols. Additionally, estimated calculations for area and circumference of the craters were made by simplifying the model and assuming the craters were circular. Using the diameter column and the formula for circumference, =PI()*diameter , and the formula for area, =PI()*((diameter/2)^2), these were added. References to age were changed by deleting references to plus and minus values, and the greater than or less than symbols. The final Excel® product was then saved as a .dbf4 file and added to ArcGIS9. Then the .dbf4 file was exported as data and saved as a shape file.

In order to randomly generate points on a sphere the following methodology was used:

> Set up a coordinate system (z,phi) where z is an axis that runs from south pole to north pole (z = -R to +R, where R is the sphere's radius), and where phi is the longitude, which runs (say) between 0 and 2 pi (radians). The area of a surface patch between z and z+dz, phi and phi+dphi then depends only on dz and dphi, not at all on z or phi.
> To generate a random point on the sphere, it is necessary only to generate two random numbers, z between -R and R, phi between 0 and 2 pi, each with a uniform distribution
> To find the latitude (theta) of this point, note that z=Rsin(theta), so theta=sin-1(z/R); its longitude is (surprise!) phi. (http://www-2.cs.cmu.edu/~mws/rpos.html)

Where in Excel® the equations used are:

z =RAND()*radius of the earth
phi =RAND()*PI()*2
latitude (theta) =DEGREES(ASIN(z/earth radius))
longitude (phi)=IF(phi<=PI(),phi*180/PI(),(phi-(2*PI()))*180/PI())

The spreadsheet was then saved as .dbf4 and added to ArcGIS9, and then exported as data and saved as a shape file.

In the "rev_impact.mxd" all data was projected into the North America Equidistant Conic projection. Shape files for the U.S., Canada, and Mexico were cut from the projected CNTRY94 file. This re-projection was done in order to control for any problems with distances and recalculating values for nearest neighbor statistic.

Data Limitations

All of the layers created based on the ArcAtlas naterdd impacts, contained no latitude or longitude values, so these values were extracted using the wizards in ArcToolbox. The XY coordinates for the impacts noted at PASSC and LAPL were converted into a decimal degree format from a degree-minute format. A major limitation is that these location XY coordinates do not match up. A comparison of the lat_dd and lon_dd (created by conversion) to POINT_X and POINT_Y (created by ArcToolbox) in table 1 shows this conflict. Where circumference and area for craters are given, this has been calculated or estimated based on the properties of a circular crater. Certainly, existing craters are not perfectly circular, and may in fact be oblong or irregularly shaped.

The impact craters is not a very large data set. Small changes, either additions or deletions, may affect statistical results. Not all suspected impacts are included in all data sets. ArcAtlas ignores major sites in soft sedimentary and near shoreline environments, and many buried sites may, as yet, be undiscovered. The Bee Bluff site from the ArcAtlas has been removed from the recent literature as a crater impact site, while Chicxulub, Chesapeake Bay, and others have been added (Whitehead).

The environmental impact was simply extrapolated from one event, the Barringer Crater, AZ. This represents a small impact, less than 3 km diameter in harder rock. A simple ratio, or linear extrapolation, was constructed for zones of impact and applied to other sites. The Chesapeake Bay crater site is in unconsolidated sedimentary rock and represents a complex crater with a diameter between 85-90 km. Therefore, buffer zones constructed for this site are greatly simplified and may not compare accurately to the simple crater formed from the Barringer impact event.

Spatial Analysis of the System

Analysis Model

The forty known impact craters covering the North American in the ArcAtlas database (naterdd.xxx) were used as the primary source of impact craters. A set of hypothetical impact events was randomly generated in Excel®, first using only random latitude and longitude, and later using a formula for randomly generating points on a sphere (**craters_random_spherical**), to serve as a basis for comparison. Using the data base from the Lunar and Planetary Laboratory at the University of Arizona (LAPL), a third set of North American impact craters (**XYImpact_AZU_clark1866_2**), comprising 53 events, was compiled by converting latitude and longitude in degrees and minutes into decimal degrees, and then importing the spreadsheet into ArcGIS9 and creating a shape file. A fourth set of North American impact craters was imported following the same process, but using the 57 reported impact events in the Earth Impact Database of the Planetary and Space Science Center, University of New Brunswick (PASSC). (See table 1 for all the crater impact events and their sources.)

Spatial statistical analysis tools were applied to each of the data sets. Chi square and average nearest neighbor techniques were applied to describe the point patterns. The geographic distributions were described using mean center, directional distance ellipses, and standard distance circles.

Chi Square – Chi square is a statistical method used to compare observed results to expected results. In this case a comparison was made between different data sets of observed craters and the modeled craters from randomly generated events. The North American continent was divided into regional areas, and using ArcGIS9 the area of each region was found in km^2. A proportion was then set up displaying each region as a fraction of the total. If crater events are entirely random, their proportion in each region should be similar to the proportion of land area contained in each region. Next, a count was made of how many craters are in each region, by using ArcGIS9 and querying for the intersection of the selected region and the data points from a particular crater data base. For each region the number of expected craters was next calculated by multiplying the total number of craters in a data set by the fraction of the land area each region contains. In the ensuing step, the number of expected craters are subtracted from the number of observed craters. A chi square contribution for each area was then calculated by squaring the difference of $observed_{craters}$ minus $expected_{craters}$. Finally the chi square statistic is found by summing the all the regional chi square contributions. Table 3a and Table 3b show the chi square calculations for the three known crater data sets and for the three model generated events. A summary of the chi square statistic is displayed in table 2 below for easier comparison of the data. "If chi-square is 'a lot' bigger than expected something is wrong. Thus one purpose of chi-square is to compare observed results with expected results and see if the result is likely." (physics) The initial findings show that the impact craters are not likely to be random.

These databases were then compared using the ArcToolbox, Spatial Statistics toolbox. The Statistical package the ArcGIS9 was used to statistically describe the impact craters. Tools used were:

Spatial Statistics toolbox (toolsets):

- **Analyzing Patterns** – "impact point data clustered, uniform, or random across the region"
  - **Average Nearest Neighbor Distance**
    - **Euclidea**n Distance Method Nearest Neighbor
    - **Manhattan** Distance Method Nearest Neighbor

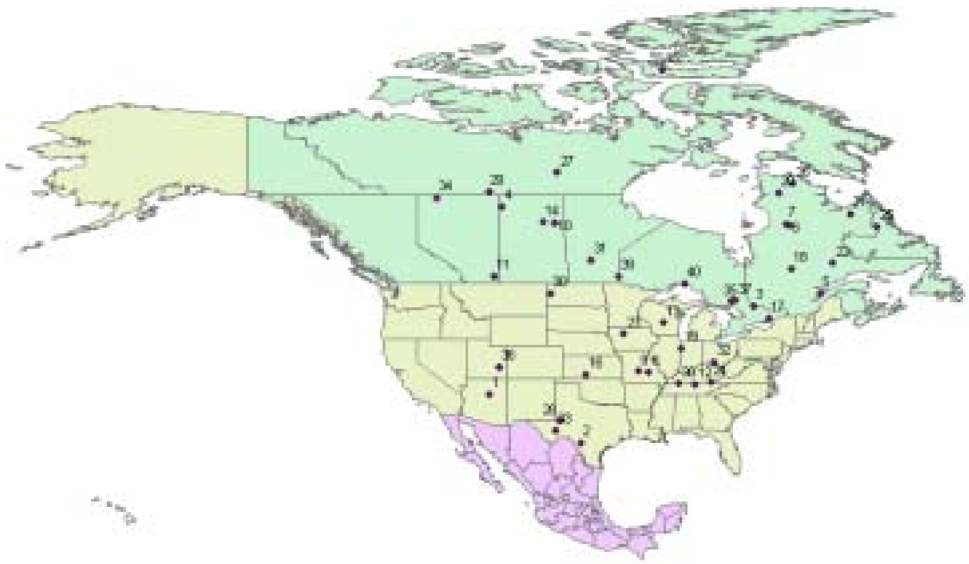
- **Measuring Geographic Distributions** – "identify the center, shape and orientation of the point data, and describe how dispersed are the point features."
  - **Directional Distribution** – "measures directional trend of data (farther from a specified point in one direction than in another direction)"
  - **Mean Center** – "identifies the average geographic center by finding the mean of all latitudes, and all longitudes"
  - **Standard Distance** – "measures the degree to which features are concentrated or dispersed around the points"

The environmental effect of an impact event was assessed by using the data from the Barringer crater in Arizona, and extrapolating with a linear ratio correlation to determine possible effects of a larger event at Chesapeake Bay, Virginia.

Model Results & Analysis

A cursory examination of the spatial distribution of craters plotted on the North American continent shows a concentration of craters located in the interior of the continent in Canada and the United States. No impact events are shown in the southern portion in Mexico or the coastal areas of the United States using the ArcAtlas dataset (Komedchikov). (See Figure 3.)

Figure 3: 40 known impact craters in North America from ArcAtlas Data Base (displayed using Projections of the World, Geographic)



Komedchikov further states that, "More than one-third of the impact craters that are found in North America are located on the continent, mainly in the central and northeastern parts. In Canada they are at the edge of the …crystalline shield…" This observation implies that the crater distribution is not a random occurrence. In table 2, the chi square statistic supports the idea of non-randomness, as values from the three crater data bases are very high. For the known crater data sets, the chi square statistic yields a result of 29.9 for ArcAtlas craters, for the LAPL craters a 32.388, and for the PASSC craters a 31.8. Since the chi square results are far from the expected value of 0 if events were evenly distributed across the regions of North America, a pattern may exist. When data is generated randomly in Excel® to cover the spherical North America, the chi square statistic is reduced to 6.9 for 1600 events, and 3.7 when only 144 events are generated. Both of these chi square statistics are far removed from the chi square statistic of 664 that was initially calculated without controlling for the change of area and distance for locations approaching the polar region. The random model comparison to observed craters, results in a five-fold to ten-fold lower chi square statistic. This strongly suggests that some pattern in crater events exists.

Table 2: Summary Chi Square Statistic for Observed Impact Craters & Crater Models

Observed Crater or Model Crater	Chi Square Statistic
Initial Crater Data Set (ISAT-630) (54 Impacts)	31.853
naterdd Data Set (40 impacts)	29.976
L&Plab Data Set (52 Impacts)	32.388
Passc Data Set (58 Impacts)	31.837
Trial 1: Excel Randomly Generated XY (7162 points intersecting NA shape)	664.273
Trial 2: Excel Randomly Generated XY using formula for points on a sphere (1600 points intersecting NA shape)	6.948
Trial 3: Excel Randomly Generated XY using formula for points on a sphere (144 points)	3.670

Table 3a: Chi Square Statistic for Observed Impact Craters from naterdd, Passc, & L&PLab Data Sets								
Region	Area (sq mi)	Area (Region:Total)	naterdd Data Set		Passc Data Set		L&PLab Data Set	
			$Craters_{Expected}$	$Craters_{obsereved}$	$Craters_{Expected}$	$Craters_{obsereved}$	$Craters_{Expected}$	$Craters_{obsereved}$
SW – U.S.	674010.5	0.081726694	3.3	4	4.7	5	4.2	4
SE – U.S.	538903.2	0.065344358	2.6	3	3.8	5	3.4	4
W – U.S.	1533149.9	0.185901083	7.4	1	10.8	5	9.7	4
MidW – U.S	766026.7	0.092884070	3.7	8	5.4	13	4.8	12
NE –U.S.	178508.6	0.021644946	0.9	0	1.3	0	1.1	0
N- Can.	1506390.9	0.182656434	7.3	3	10.6	3	9.5	3
W – Can.	873062.0	0.105862561	4.2	5	6.1	8	5.5	8
Central-Can.	631536.8	0.076576575	3.1	7	4.4	7	4.0	7
E – Can.	789786.7	0.095765066	3.8	9	5.6	10	5.0	10
Mexico	755752.0	0.091638214	3.7	0	5.3	1	4.8	1
Total	***8247127.3***	***1***	***40***	***40***	***57***	***57***	***53***	***53***
Chi Square			***29.976***		***31.837***		***32.3888***	

Table 3b: Chi Square Statistic for Modeled Impact Craters from Random Excel, Random Spherical XY, & Random Spherical XY_2 Data Sets								
Region	Area (sq mi)	Area (Region:Total)	Random XY Excel		Random Spherical XY		Random Spherical XY_2	
			$Craters_{Expected}$	$Craters_{obsereved}$	$Craters_{Expected}$	$Craters_{obsereved}$	$Craters_{Expected}$	$Craters_{obsereved}$
SW – U.S.	674010.5	0.081726694	585.3	405	130.8	137	11.8	12
SE – U.S.	538903.2	0.065344358	468.0	296	104.6	111	9.4	7
W – U.S.	1533149.9	0.185901083	1331.4	1371	297.4	310	26.8	23
MidW – U.S	766026.7	0.092884070	665.2	553	148.6	143	13.4	17
NE –U.S.	178508.6	0.021644946	155.0	114	34.6	28	3.1	3
N- Can.	1506390.9	0.182656434	1308.2	2065	292.3	284	26.3	27
W – Can.	873062.0	0.105862561	758.2	756	169.4	172	15.2	19
CentralCan	631536.8	0.076576575	548.4	522	122.5	137	11.0	9
E – Can.	789786.7	0.095765066	685.9	642	153.2	135	13.8	15
Mexico	755752.0	0.091638214	656.3	438	146.6	143	13.2	12
Total	***8247127.3***	***1***	***7162.0***	***7162***	***1600.0***	***1600***	***144.0***	***144***
Chi Square			**664.273**		**6.9487**		**3.67**	

Examining table 3b by region, the observed craters from both the 1600 event and 144 random models are very close to the expected number of craters for each region. In the 144 event model all regions are within + or – 4 craters of the expected result. When the number of random events is increased to 1600, the model is within + or – 18 craters of the expected result, while most regions are within + or – 6 or less. The regional results of the model strongly support the success of producing a random distribution of events across North America.

When examining table 3a by region, the skewed distribution of craters by regional differences becomes evident. In all three known crater data sets, the observed minus expected craters are nearly + or –1 for the southeastern and southwestern U.S. While in the northeast, nearly 1 crater is expected and none are observed. In central, eastern, and western Canada and the mid-west U. S., almost double the number of craters are observed than should be expected from a random distribution. This statistical analysis is supported by Komedchikov's observations in ArcAtlas. Mexico, western U.S., and northern Canada have fewer impact craters than would be expected by random events. Mexico should have between 4 and 5 events, but only Chicxulub has been found. Northern Canada should have between 7 and 11 impact events, while only 3 have been listed. And the western U.S., based on its proportional area alone, should have between 7 and 11 events. Only 5 have been reported in that region. The chi square test applied to the unequal regional areas supports the notion that there is some pattern to the distribution of known crater events. The impact events are concentrated in the central region of the U.S. and the more southern sections of Canada. This pattern may be the result of the lithology of the preservation material, rather than the result of the impact events themselves. An overlay of crater events with rock type may provide insight into this aspect.

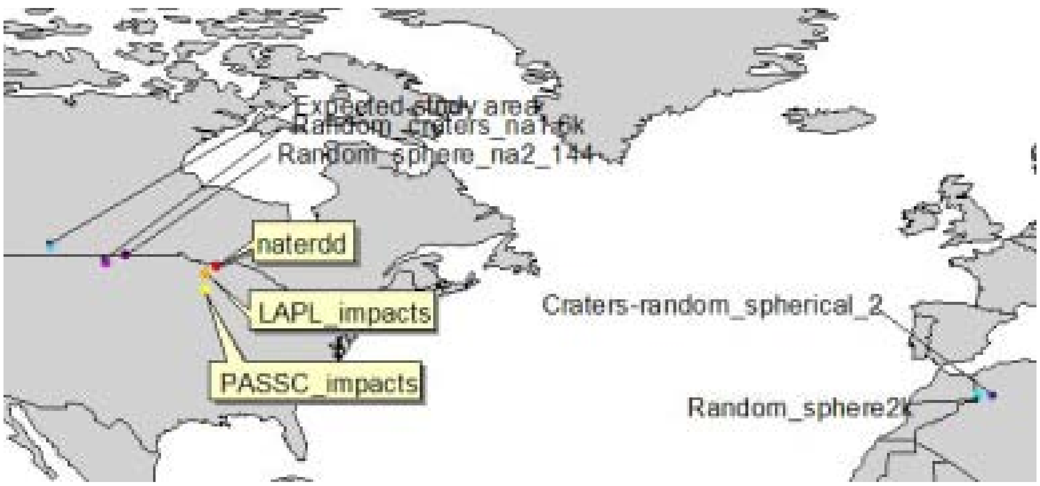
Measures of central tendency used to describe the geographical distribution of point data include mean center, standard distance circle, and standard deviational ellipse. The mean center is the average of all latitude values and the average of all longitude values. The mean center is displayed as a point shape on the map. The mean center results may differ based on how the spatial data is organized, the extent of the defined study area, distortions due to different map projections, and different map scales (Wong). Table 4 shows the mean center latitude and longitude calculated in ArcGIS9 using the Spatial Statistics Tools.

Table 4: Mean Center XY Coordinates

Data Set	Latitude^{o}	Longitude^{o}
naterdd	47.7773	-90.2873
LAPL: XYImpact_AZU_wgs84	46.813	-91.7743
PASSC_impacts	44.924102	-91.68699
Random_craters_na (1600)	48.21821	-103.355474
Random_sphere_na2 (144)	49.090278	-101.125000
Craters-random_spherical (20,000)	32.574483	0.554664
Random_sphere2 (2000)	32.576000	-1.145500
Expected from entire study area (area bounded by 15^{o} N to 85^{o} N, and 50^{o} W to 170^{o} W)	50	-110

Figure 4 displays the mean centers on a world map for visual comparison. The mean centers for the know crater events are located near the U.S.-Canadian border in the central section and are skewed toward the eastern coast. As the population of known craters data sets increases, the mean center moves southward (as impact events are found buried in soft sedimentary deposits in the southeast and Mexico) and adjusts only slightly westward. For reference, the mean center was calculated for the random events generated for the Northern Hemisphere. Their location on either side of the prime meridian and in the mid-latitudes at 32.5^{o}, supports the randomness of the model points. When the mean center for the known craters is compared to the mean center for the model events on the North American continent, the mean center shifts over 10^{o} westward, and only slightly northward. This would be the expected shift, as the random North American points are dispersed more widely east-west, and north-south. The large east-west difference in the mean center between model and known events tends to support the existence of a pattern in the North American craters. Again this may be the result of the younger western lithologies, rather than of the impacting events themselves.

Figure 4: Mean Center display for various data sets



As expected the standard distance measurement displays the same trend. As the population of the model increases the standard mean distance is drawn as a circle radiating from the mean center. The standard mean distance skews eastward, reinforcing the lack of known crater events in the western U.S. The modeled data, with a greater number of points, covers a larger distance and is more centered when compared to both coasts. This represents "how the points in a distribution deviate from the mean center" (Wong). Figure 5 shows the comparison of modeled data to that of the ArcAtlas crater data set. If no pattern were evident, the known craters should more closely match the distance shown in the random model. Even when increasing random events from 144 to 1600 in the model, the standard distance increases only slightly. For the 40 known craters, the standard distance circle is much smaller and skewed eastward. This is indicative of the absence of many known craters in the west.

The standard deviational ellipse shown in figure 6 for the ArcAtlas 40-crater data set indicates that there is a greater distance distribution of craters along the north-south axis than along the east-west axis. The spatial spread and directional trend mirrors the longer north-south axial shape of the North American continent and portrays a greater distribution of craters north to south. The minor east-west axis is narrower and skewed to the east, also supporting the lack of impact events along the western coast of the continent. However, the directional bias may also indicate a pattern of impactor orientation on entry into the Earth's atmosphere. This rotational measure shows a slight northeast to southwest orientation of the known craters. The standard deviational ellipse from the modeled events has a stronger rotational orientation in the opposite direction, trending northwest to southeast (see figure 7). The difference between the model and observed may be indicative of a pattern distribution in the actual events. As of this writing, the calculations for the standard deviational ellipse using the LAPL and PSSC data would not execute in the ArcGIS9 program, and no results were returned. Therefore, no additional validation of the directional trend in observed crater data could be determined.

Figure 5: Standard distance of known craters and 2 modeled crater events.

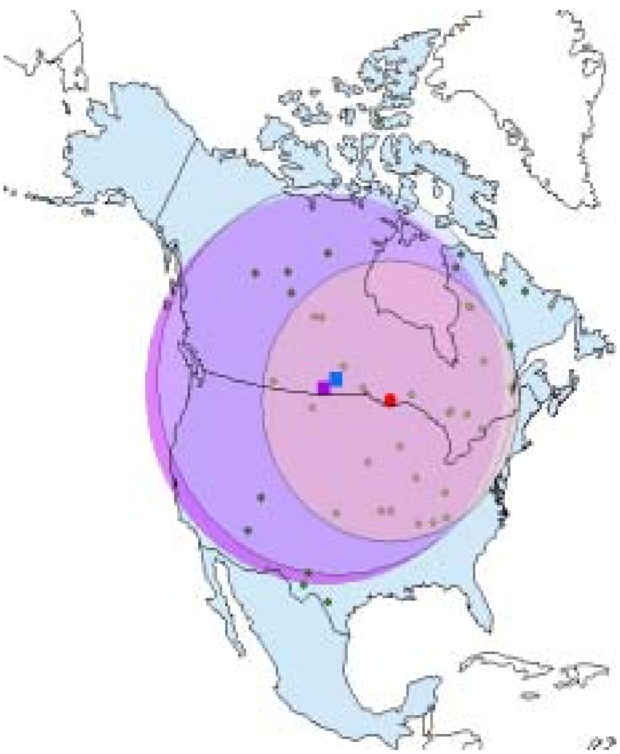


Figure 6: Standard distance, deviational ellipse and mean center for 40 naterdd (<u>ArcAtlas</u>) crater events in NA equidistant conic projection.

The final spatial statistic explored with observed and modeled crater events is the nearest neighbor analysis. This is the opposite of the chi square statistic, where the density was examined as the number of points per square area. The nearest neighbor analysis looks at the spacing by calculating area per point (Wong). In this analysis, the distance from each impact to the next closest impact is measured. There are two methods of measuring distance, Euclidean and Manhattan. The Euclidean distance is measured as a straight line between two points. The calculation employs the formula for finding the hypotenuse of a right triangle using the latitude and longitude coordinates. The Manhattan distance measurement assumes that distances can only be measured in a north-south, or an east-west direction. Imaginary north-south and east-

Figure 7: Standard deviational ellipses for naterdd and model data.

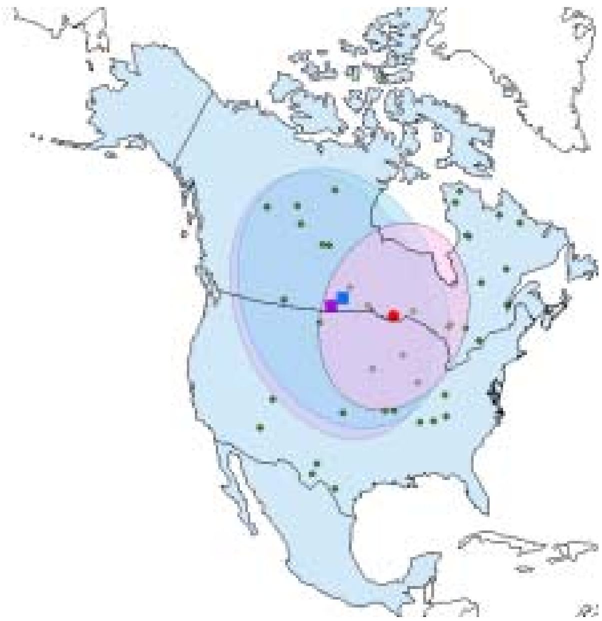
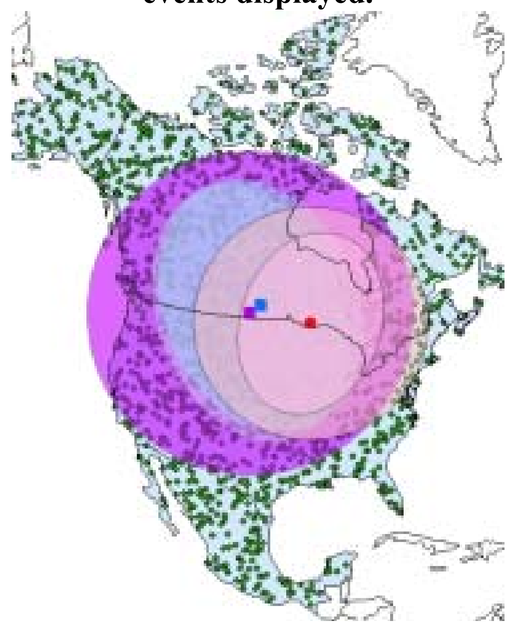


Figure 8: Composite Standard distance, deviational ellipse and mean center for naterdd and model data. With 1600 model events displayed.



west lines are constructed from a point to its nearest neighbor. The distances from the two points to the intersection of the north-south and east-west lines are measured and summed, resulting in the distance measurement with the Manhattan method (Campbell). The nearest neighbor analysis provides an indication of whether the points are arranged in one of five patterns. Point patterns range from **Regular** (an equal interval pattern) to **Dispersed** (widely spread), to **Random**, to **Clustered**, to **Perfectly Concentrated** (Barber). Both Euclidean and Manhattan distance measurements were used in the nearest neighbor analysis, but resulted in conflicting results when applied to the observed craters. (see table 5)

In executing the nearest neighbor statistic on the naterdd shape file using the Euclidean Distance Method the point pattern was described as **Random** "while somewhat dispersed, pattern may be due to random chance"(see figure 9). When the same 40 crater data set was analyzed using the Manhattan Method Distance Nearest Neighbor method results reported the pattern as **Random** "while somewhat clustered, pattern may be due to random chance" (see figure 10). When executing the analysis using the 53 crater data set from LAPL with the Euclidean Distance Method Nearest Neighbor the pattern of points was described as **Dispersed,** "there is less than 1% likelihood that the dispersed pattern could be the result of random chance." (see figure 11) However, when running the analysis on the same 43 craters with the Manhattan Method Distance Nearest Neighbor program the pattern was reported as **Random**, "this pattern is neither clustered or dispersed". (see figure 12)

In order to account for these differences, all data was reprojected into the NAequidistant conic projection and a new analysis conducted. (See ArcGIS9 project rev_impact.mxd.) Additionally, in the reprojected view the nearest neighbor analysis was executed for the random events created for the model. Again results were mixed. The results are summarized in Table 5 and displayed in Figure 9 through Figure 22. In general, when using the Euclidean distance measurement the point pattern crated by known North American craters is described as dispersed. There is conflict as to whether that is due to random chance or not. However, the set of randomly generated events are all described as dispersed, but less than a 1% likelihood that it was due to chance. Since, the events were generated randomly, there is most likely a flaw in using the Euclidean method. This could also be due to the inability to define the geographic extent of the study area. By default the study area is limited to the maximum extent of the point data, and did not include all of the North American Continent.

The nearest neighbor analysis using the Manhattan method also gives mixed results. But when analyzing the randomly generated events for North America, the point pattern is described as neither clustered or dispersed. Since this is in agreement with the method used for producing the random events, this may be the preferred method of measuring the known crater events. In unprojected analysis the 40 craters from ArcAtlas show clustering that may be due to random chance. The 53 craters from LAPL data are described as neither clustered or dispersed. However, when the points are projected into the NA equidistant conic map projection, the cratering events are no longer described as random. However, the 40 point data set is described as clustered, and the 53 point data set is described as dispersed. This apparent conflict may be accounted for when the considering the smaller standard distance of the ArcAtlas data set, and the wider distribution of crater events in the LAPL data set. The LAPL data set includes the east coast crater found in the Chesapeake Bay and extends south to include the Chicxulub crater in Mexico.

Limitations

According to G. M. Barber, boundary, scale, modifiable units, and pattern are four major areas creating difficulty for any statistical analysis of spatial data. Caution is advised for any interpretations. The conflicting results in examining impact data using the nearest neighbor analysis seem to verify or amplify these cautions.

The Boundary Problem according to Barber, explains that in determining the outside bound of a study area shape and orientation of the analysis are effected. “The same point pattern in a tight area would be dispersed, but in a wide area would be clustered, even though the central tendency would be the same, and the pattern is the same. The standard distance or any other measure of dispersion cannot be interpreted independent of the study area.” (Barber, p115) This has presented a particular problem in the crater analysis, since a regular shape could not be defined and the chi square calculations try to correct for the irregular and unequal areas of the regions and the continent. Using the ArcTools, a boundary area was not able to be set and this had particular impact on nearest neighbor analysis. The limiting boundary is the extent of the point data itself. At this juncture, the analysis was not able to be masked by the entire continent shape, and may have resulted in some of the clustering of data.

There is also a problem of scale. As the area of study is defined, any smaller or larger units have an impact on the statistical calculations. This may be particularly acute in such a large bounded

Table 5: Comparison of Nearest Neighbor Analysis for Known Craters and Modeled Craters						
Data Set	**Euclidean Method**			**Manhattan Method**		
	Ratio	**Z Score**	**Description**	**Ratio**	**Z Score**	**Description**
Naterdd (ArcAtlas) unprojected	0.88	-1.5 Standard Deviations	While somewhat dispersed the pattern may be due to random chance. Fig. 9	1.12	1.48 Standard Deviations	While somewhat clustered the pattern may be due to random chance. Fig. 10
l&plab (LAPL) unprojected	0.81	-2.6 Standard Deviations	There is less than 1% likelihood that the dispersed pattern could be the result of random chance. Fig. 11	0.99	-0.1 Standard Deviations	The pattern is neither clustered nor dispersed. Fig. 12.
Naterdd (ArcAtlas) NA equidistant conic	0.91	1.1 Standard Deviations	While somewhat dispersed the pattern may be due to random chance. Fig. 13	1.16	2 Standard Deviations	There is less than 5% likelihood that this clustered pattern is the result of random chance. Fig. 14
l&plab (LAPL) NA equidistant conic	0.73	-3.7 Standard Deviations	There is less than 1% likelihood that the dispersed pattern could be the result of random chance. Fig. 21	0.88	-1.7 Standard Deviations	There is less than 5% - 10% likelihood that this dispersed pattern is the result of random chance. Fig. 22
rand_sphere2_projNAEConic (2000 event random model NA equidistant conic)	0.84	-13.6 Standard Deviations	There is less than 1% likelihood that this dispersed pattern could be the result of random chance. Fig. 15			
ran_na2_clip_projNAEC (reprojected 144 event NA random model in NA equidistant conic)	0.78	-5 Standard Deviations	There is less than 1% likelihood that this dispersed pattern could be the result of random chance. Fig. 17	0.97	-0.5 Standard Deviations	The pattern is neither clustered nor dispersed. Fig. 18.
ran_sph_na_clip_projNAEC (reprojected 1600 event NA random model in NA equidistant conic)	0.67	-24.6 Standard Deviations	There is less than 1% likelihood that this dispersed pattern could be the result of random chance. Fig. 19	0.85	-11.2 Standard Deviations	There is less than 1% likelihood that this dispersed pattern could be the result of random chance. Fig. 20

Figure 9: Results of Euclidean Distance Method Nearest Neighbor Analysis for naterdd (ArcAtlas)

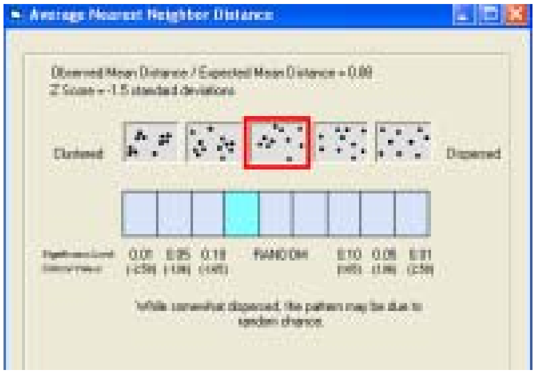


Figure 10: Results of Manhattan Method Distance Nearest Neighbor Analysis for naterdd (ArcAtlas)

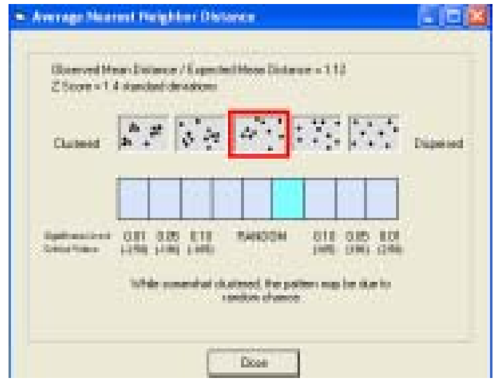


Figure 11: Results of Euclidean Distance Method Nearest Neighbor for l&plab (LAPL)

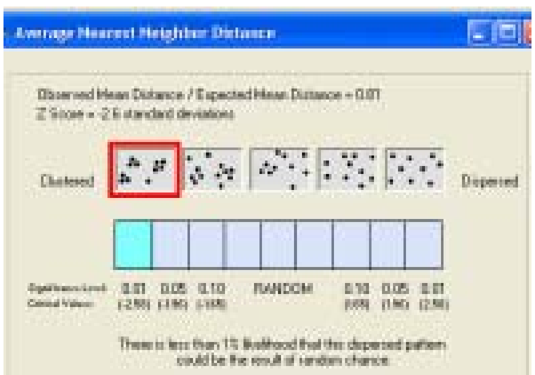


Figure 12: Results of Manhattan Method Distance Nearest Neighbor for l&plab (LAPL)

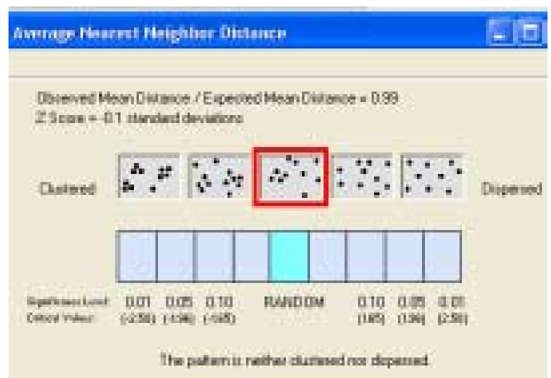


Figure 13: Results of Euclidean Distance Method Nearest Neighbor for projected naterdd (ArcAtlas 40 craters reprojected in NA equidistant conic)

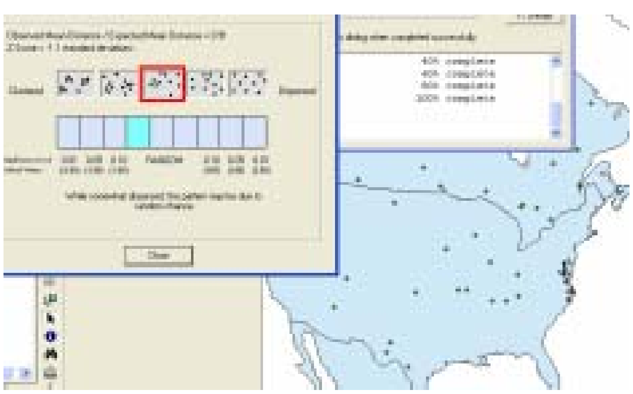


Figure 14: Results of Manhattan Method Distance Nearest Neighbor for projected naterdd (ArcAtlas 40 craters reprojected in NA equidistant conic)

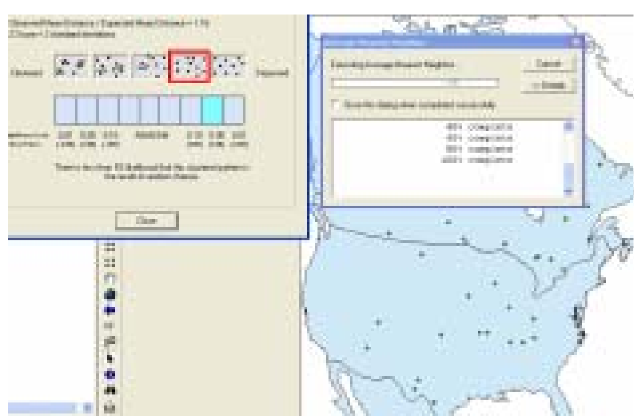


Figure 15: Results of Euclidean Distance Method Nearest Neighbor for rand_sphere2_projNAEConic (reprojected 2000 event random model in NA equidistant conic)

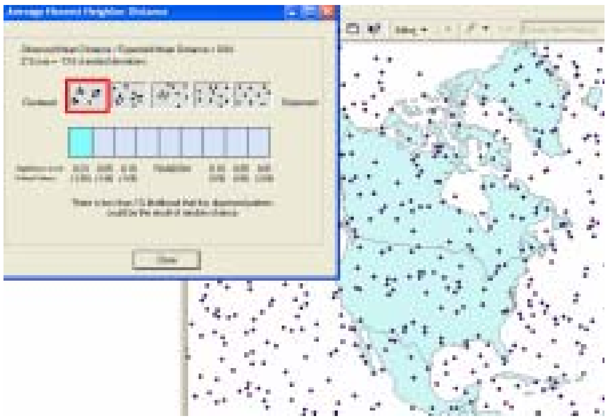


Figure 16: Results of Euclidean Distance Method Nearest Neighbor for ran_na2_clip_projNAEC (reprojected 144 event NA random model in NA equidistant conic)

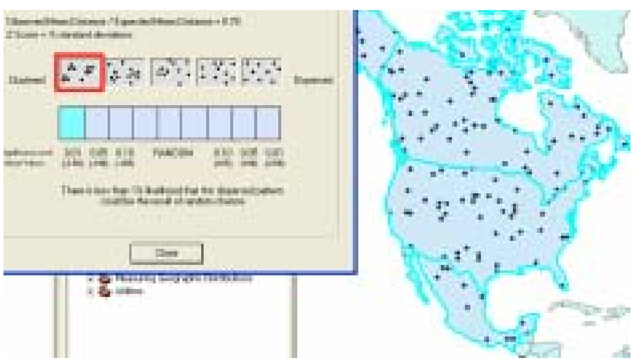


Figure 17: Results of Manhattan Distance Method Nearest Neighbor for ran_na2_clip_projNAEC (reprojected 144 event NA random model in NA equidistant conic)

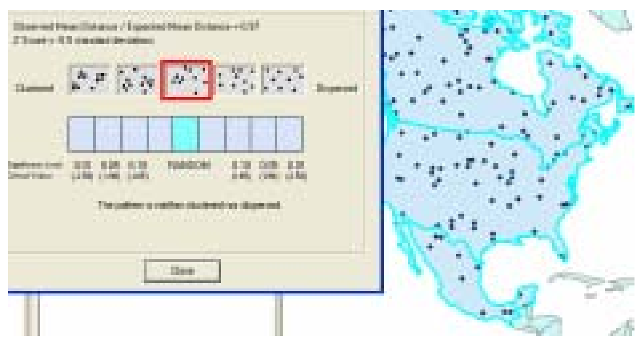


Figure 18: Results of Euclidean Distance Method Nearest Neighbor for ran_sph_na_clip_projNAEC (reprojected 1600 event NA random model in NA equidistant conic)

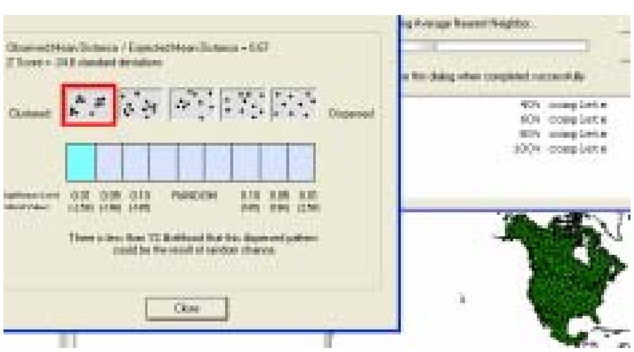


Figure 19: Results of Manhattan Distance Method Nearest Neighbor ran_sph_na_clip_projNAEC (reprojected 1600 event NA random model in NA equidistant conic)

Figure 20: Results of Euclidean Distance Method Nearest Neighbor for reprojected LAPL (NA equidistant conic)

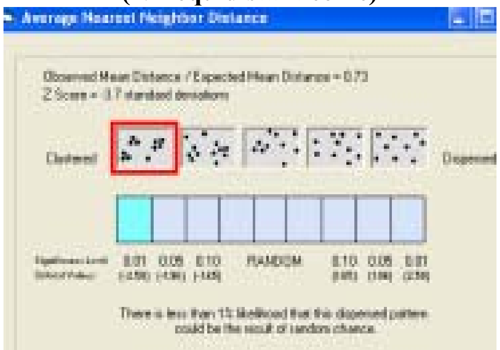
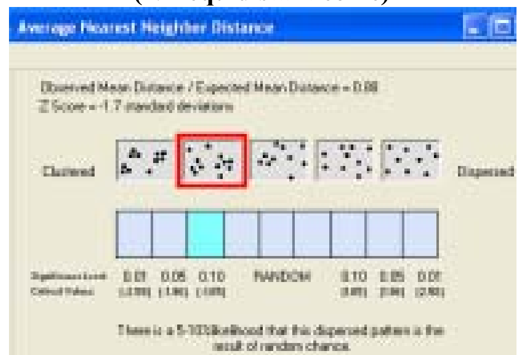


Figure 21: Results of Manhattan Distance Method Nearest Neighbor for reprojected LAPL (NA equidistant conic)



area such as North America. Barber states that, "As the study area is broken down into smaller or larger units for study, the mean, μ, will remain constant, but the variance, σ^2, changes greatly as the unit size changes. This would be particularly true for data sets with a small population." The limitation occurs when interest is in spatial variation, as this spatial variation can be reduced or enlarged with the changing scale. The North American continent shape is certainly a large scale and the population of known impact events is small, therefore the scale problem is a limitation of the crater analysis.

Similar to the scale problem, the Modifiable Units Problem relates to how areal units are modified and may skew results along north-south or east-west axes. The units problem addresses whether the chosen unit reflects the real nature of the impact craters on the globe when not all unit areas are the same (this is the case when looking at the irregular regions in NA). Barber states that it is "Better to join similar zones when data is aggregated, to preserve the variation in the original map as much as possible. The law of geography is that closer places are more alike than distant places, contiguous areal aggregations are likely to be less disruptive than aggregations of areas which are not close together." (Barber, p117) This may have been evident in the selection of regions to conduct the chi square analysis. Alaska, as an example, may have more in common with parts of Canada than with the western U.S.

While statistics for spatial data can be used to summarize the central tendency and dispersion they do not always capture the type of point pattern on the map (Barber). The chi square statistic strongly suggests that the known craters are not random. However, the nearest neighbor analysis used to assess the type of point pattern on the map yields conflicting results. This may be the result of the other limitations placed on statistical spatial analysis and deserves further study.

The study is also limited by the conversion of location from limited latitude and longitude in the degrees minute format, and the conversion to XY coordinates using ArcTools. The exact locations do not match and this may affect any spatial analysis of the system. A final limiting factor is the choice of projection and the conversion of the point data into different projections. The relationships between the points may change depending on the projection chosen for study. Using the bounds of the North American continent may also present limitations of size and affect the study.

Conclusions and Suggested Improvements

Conclusions

A pattern exists for the distribution of impact craters distributed across North America. The pattern is described by statistical methods for central tendency, but the true nature of the dispersion of the pattern may not have been determined. With the smaller ArcAtlas data set, impact events are centered at approximately N 47 ^{o} and W 90^{o}, near the U.S.-Canadian border. When compared to randomly modeled events, the data appear to cluster or group near this mean center point. There is an absence of observed craters in the western U. S., that is supported by statistical analysis using chi square area, indicating that events are not random. As the number of observed craters increases and the geographic area of discovery widens, the point pattern is described as dispersed, but not by random chance.

Proposed Solutions

Different projections need to be explored for use when employing spatial statistical methods. While the NA equidistant conic projection was used to control for distance, other projections to control for equal area and preservation of shape need to be explored. A clearer pattern may emerge if weighted statistical measures are undertaken for the mean center, standard distance, and directional ellipse. Crater age and crater diameter are two possible classes to be used in such weighted measures. The method for defining the study area when employing the nearest neighbor analysis, may also help control the wide variation of results. The nearest neighbor statistic can also be weighted with the same classes for further analysis.

Other spatial statistical methods are available. Quadrat analysis may help define the bounds and dispersion if a system can be defined and overlayed in ArcGIS9. The area of study is divided into evenly sized grids starting at the most southern and western point. Then a count similar to the chi square statistic is conducted. This method would provide and equal area and equal shape basis for comparison and may help explain the variation from the nearest neighbor methods. Another method is the Quartilides. This would require a hand count of all points within certain zones spreading away from the mean center. It may also provide insight into the crater pattern.

Extensions

In addition to other proposed spatial statistical methods, the model can be improved upon by comparing the impact events to a geologic overlay. There a focus on rock type and rock age may help explain the point pattern of the craters. This would help account for the preservation history, where craters have been destroyed by erosion or buried in softer sedimentary structures.

The modeled craters section can be improved upon by using the formulations of Collins and Melosh and Kring and Bailey to describe more than the location of random crater events. Additional parameters of impactor velocity, angle of entry, size of impactor, and density of impactor can be added to truly model the effects of random future event. The simple modeling used to portray the environmental effects can be modified and improved upon (see table 6). Fire models from the impacts and other environmental destructive effects could also be explored.

Table 6: Extrapolated Zones of Environmental Effects			
Impact Zones (km)	**Barringer Crater**	**Chesapeake Bay Crater**	**Chicxulub Crater**
Crater diameter	1.6	90	170
Meteor	0.05	2.8125	5.3125
Death Zone	4	225	425
Fireball	10	662.5	1062.5
Shrapnel	13	731.25	1381.25
Maiming Zone 2	16	900	1700
Maiming Zone 1	24	1350	2550
Hurricane Force Wind Zone	40	2250	4250

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End Notes:

It can not be too strongly stressed that all models are wrong, but that some models are useful. All models are a simplification of the real world, designed to study and gain insight into the complex workings of a natural world. A straight linear modeling of the environmental effects caused by impact events based on the Barringer Crater data is the most simplified of all models. That larger events such as Chesapeake and Chicxulub do not scale linearly, is almost a given. But this over-simplified approach has allowed a visual and comparative display for students in the classroom to see the far ranging effects of impact events in the earth's past, while the subject is still under study by the author. As the time required to learn and grasp the subtleties magnified, it grew beyond the scope and time of this project to refine and correct the initial model. It is the intent of the author to correct this and continue refining the modeling of the impactors for future revisions.

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