Cartographic Perspectives
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From the Editor

Greetings NACIS Members:

This issue marks my entry into the cartographic foray as *CP* Editor. The opportunity to serve as Editor came as a surprise to me when a phone call suggested that I consider running for the position. After additional conversations and much deliberation, I agreed to place my name in the candidate pool. Now, I am now writing to you as *CP* Editor. I want to thank the NACIS Board of Directors for their vote of confidence in me as *CP* Editor. Many of you know very little about me and my background. However, I hope that over the next three years that I will be able to become more familiar to all of you through the upcoming issues of *CP*, through the NACIS community, through the annual conferences and good conversation. The transition period with the interim Editor Scott Freundschuh has gone very smoothly, been extremely valuable in learning the ropes of editorship, and pointed me in the correct azimuth. Appreciation is also directed toward Jim Anderson, the Assistant Editor, who helped me with timelines and the details of the publication process.

I would like to take this opportunity to introduce the members of *CP*'s Editorial Board.

In the proverbial 'changing of the guard' that took place when I stepped into this position, I have selected a very talented and diverse membership for *CP*'s Edito-

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In this Issue

Cartographic Perspectives

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(*letter from the editor continued*)

rial Board. New members of the board include: *Sarah Battersby* from the University of South Carolina; *Hugh Howard* from Los Rios: American River College; *Patrick Kennelly* from Long Island University CW Post Campus; *Amy Lobben* from the University of Oregon; *Keith Rice* from the University of Wisconsin at Stevens Point; and *Julia Seimer* from the University of Regina. *CP* welcomes a few returning board members. These include: *Matthew Edney* University of Southern Maine and University of Wisconsin-Madison, *Amy Griffin* from the University of New South Wales-ADFA; *Mark Harrower* from the University of Wisconsin, *Mike Leitner* from the Louisiana State University, *Margaret Pearce* from Ohio University. I am grateful to these talented individuals for agreeing to help maintain *CP*'s outstanding content that its readers expect. I look forward to working with them over the next few years.

There have also been a few changes to the various section editor positions. The Cartographic Collections section is headed by

(*continued on page 3*)

(*letter from the editor continued*)

Robert Kibbee and *Angie Cope*, both are retuning editors of this section. Robert comes from Cornell University and Angie is from the AGS Library. Look for their continuing contributions to the discussion of interesting map collections. The Mapping: Methods & Tips' introduces *Bill Buckingham* from the University of Wisconsin as new section editor. This section will continue to provide interesting information on the technical side of map making. Visual Fields will be overseen by *Michael Hermann*. While not new to *CP* or the NACIS community, Michael serves in a dual role as NACIS President and will provide *CP* readership with notable examples of cartographic excellence. The Book Review section will continue to be handled by *Mark Denil* from Conservation International. Mark will bring us timely reviews on books having a cartographic theme. Look for each section's content as the issues unfold. I know you won't be disappointed.

One of the biggest changes that will impact the journal's readability and style is the use of a professional copyeditor. Mary Spalding was brought on to serve as copyeditor beginning with this issue. Mary graduated from Frostburg State University with a BA in English. She earned an MA in English from West Virginia University and a Masters in Library Information Science from the University of South Carolina. Mary writes that one of her favorite classes of her entire formal education was a course in Physical Geography. Too bad she didn't have a course in cartography?... Mary is currently Assistant Professor of English, Potomac State College of West Virginia University. We welcome Mary on board *CP* and look forward to her attention to detail.

This issue happens to be a special issue on map projections. The peer-reviewed articles cross a number of different map projection topics. First up is a paper written by Bernhard Jenny, Tom Patterson, and Lorenz Hurni entitled *Flex Projector-Interactive Software for Designing World Map Projections*. Many of you recall seeing the Flex Projector presented at last year's NACIS conference in St. Louis. If you missed the presentation on this software, you owe it to yourself to read this article, download the software, and give it a try. The next paper is by Waldo Tobler entitled *Unusual Map Projections*. Tobler presents his usual imaginative look into the variety of map projections, several of which are uncommon but certainly intriguing. After reading Tobler's paper, you will never look at map projections in the same way.

As with previous issues *CP* presents interesting material to the NACIS community. *CP*'s content is the most important element to the survivability of the journal. Without it, the journal will falter. I want all NACISites to consider *CP* to be their publication outlet for research, novel mapping techniques, views and opinions, new and unusual maps, and all map collections. I know there is much that is happening in the mapping world out there. *CP* and its readership would like to hear about it.

In closing, I have been associated with NACIS for ten years. My fondness for the NACIS community centers on the many fine individuals that constitute this society. I offer this issue to you for your contemplation and reading pleasure. I welcome your questions, comments, and discrepancies.

Fritz Kessler

The Cover

Title: Pretty Lies, 1995
24" x 30.5", oil and acrylic on wood panel

Susanne Slavick
Andrew W. Mellon Professor of Art
Carnegie Mellon University

Pretty Lies is from a series of paintings inspired by antiquated cartography, especially those maps using projections that inevitably distort the world. The information offered by such maps (in this case, one by Bernard Sylvanus from 1511) is erased and replaced by amorphous atmospheres and sinuous elements that alternate between forked tongues and less vitriolic ribbons. They poke and probe at cartography's presumed objectivity.

Maps and the Internet: What a Mess It Is and How To Fix It

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The promise of the Internet for cartography has faded into stark realities of commercialism, connectivity problems and confusion about what represents quality in Internet mapping. Accessing the Internet is still problematic and a great digital divide separates the developed from the developing world. Interaction with the online map, the single greatest advantage of maps and the new medium, has been either poorly implemented or not incorporated at all. The commercial aspect of the Internet has been turned upside down. We pay to access the Internet, not for its content. As a result, there is little competition to improve the quality of online maps, other than for bragging rights, and little incentive to create quality content. On top of this, in many parts of the world, access to the Internet by computer is expensive or inconvenient and people prefer to use the Internet through their mobile phone. Almost all new users to the Internet are connecting through mobile devices and a small screen that is hardly suitable for the display of maps. While a de-centralized system like the Internet is impossible to fix in traditional ways, solutions must be found for making the medium more accessible and useful for maps. National and international organizations can play a key role in providing examples of what is possible with maps and the Internet. Low-cost, easy-to-use tools also need to be made available so that online cartographers can create quality content.

INTRODUCTION

Begun in the late 1960s as an experiment in failsafe file exchange between computers, the Internet has evolved into a fascinating, if problematic, worldwide communications medium. The incorporation of the World Wide Web protocol in the early 1990s dramatically expanded its use. According to the Internet WorldStats web site, it is now estimated that one sixth of the human population uses the Internet on a regular basis (2007). Some estimates put the daily page count at over 47 trillion (Rangarajan 2007).

The expansion of the mobile Internet through cell phones has been particularly astounding since 2000, but delivering content is still in the early stages of development. Cell phone companies have entered into agreements with search providers like Google and Yahoo, thus acknowledging the need to make the use of the Internet similar between desktop computers and cell phones (Rangarajan 2007). Analysis of consumer usage for one mobile Internet service in other countries shows that user habits are similar to desktop users'. The data also shows that, even though consumers face an initial orientation hurdle using the Internet on a small screen without a keyboard and mouse, once they adapt, their usage grows steadily month after month (Rangarajan 2007). The level of Internet use through cell phones in the United States is much lower than in many other countries.

Maps represent a major component of Internet traffic. Common web mapping sites, including MapQuest, Yahoo, and Google Maps, each report making millions of maps per day. According to ComScore Media Matrix, AOL's Mapquest had 45.1 million US visitors during February 2007, Yahoo had 29.1 million users, and Google maps had 22.2 million U.S. visitors (Liedtke 2007). People now look to the Internet to find all manner of maps, and it has clearly become the new medium for cartography.

But, this new medium is not without its problems. The security and reliability of the Internet is increasingly under attack. Some warn of a digital Armageddon brought on by spammers, hackers, phishers and cyberterrorists. They argue that the Internet is "at the tipping point of overwhelming abuse and complexity" (Anthes 2007). In addition, the neutrality of the Internet is being challenged by Internet Service Providers (ISPs) that want to restrict access to competing sites. Many countries place restrictions on Internet access for political purposes. In less-developed and moderately developed parts of the world, the use of the Internet is beyond the financial means of most people, contributing to a great "digital divide." Most new users of the Internet are accessing its resources with the tiny screen of mobile phones, much different from desktop computer systems that, in contrast, are using increasingly larger screens.

While map use has expanded rapidly with the new medium, the quality of Internet maps has not evolved appreciably over the last decade. Attempts to introduce higher quality, vector-based maps have not progressed beyond experimentation. The high cost of developing and maintaining map servers has become a stark reality for many map providers, and the lack of a revenue stream for content providers makes it increasingly difficult to both provide content and maintain servers.

Clearly, all is not well in the world of maps and the Internet. This paper examines the major problems associated with the Internet and Internet maps.

Problems with Internet Access

In contrast to what we might like to believe, the Internet is not a free and open system of data communications. The constraints that limit people's access to the Internet include governmental restrictions, business decisions, and the costs of hardware, software, and connectivity. In addition, the mobility requirements of the user make it difficult to maintain a connection. Other access problems include language barriers, users' varied educational levels, and the general complexity of the system.

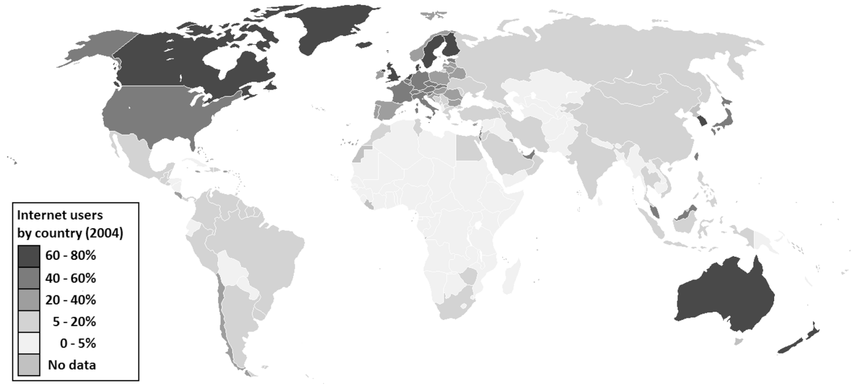
Sometime during 2006, the Internet added its 1 billionth user. As Rezwan (2007) points out, adding the next billion will be a major challenge. The Internet is becoming more fragmented, and international borders are increasingly visible. The large gap between rich and poor is apparent by the level of Internet access. The notion of a free, common, global Internet that can unite the world is merely an illusion.

One of the most vexing problems with the Internet is the cost of access. In addition to hardware requirements, monthly fees for Internet access can strain most budgets. In developed countries, people forfeit their traditional telephone and television cable connections to pay for Internet access. In the developing parts of the world, telephone and television cable connections have yet to be installed, so there is no money to save by switching services.

Global Digital Divide

The developed nations are benefiting enormously from the information age while developing nations are struggling to keep pace. This difference in technological progress is widening the economic disparity between the most developed nations of the world (primarily Canada, the United States, Japan, South Korea, Western Europe and Australasia) and developing ones (primarily Latin America, Africa, and Southeast Asia), thus creating a digitally fostered divide (Lu 2001). Unlike the traditional notion of the "digital divide" between social classes, the "global digital divide" is essentially a geographical division. Figure 1 shows the percentage of Internet users by country.

Many see mobile devices as the great equalizer of the digital divide. The PC, for most of the world's poor, is too expensive, too complicated and needs more power. The mobile phone is far more ubiquitous, and stories are emerging from developing countries of how the new communication devices are helping farmers find better prices for their agricultural products.



http://upload.wikimedia.org/wikipedia/commons/5/5b/Internet_users_en.png

Figure 1. The percentage of Internet users by country. (see page 67 for color version)

Governmental Restrictions on Internet Access

Many governments are becoming increasingly concerned about the potentially de-stabilizing role of the Internet. In particular, the new social networking aspect of the Internet can unite groups of people in dissent or protest. Governmental efforts are increasing in some countries to limit access to the Internet or specific Internet sites. Two examples are noted here.

The relationship between the largest Internet company, Google, and the largest country in the world, China, is noted for its pragmatism. Google recognizes the size of China's Internet market and China recognizes the power of Google's online enterprise. Google has so far escaped from being banned in China by agreeing to limit what is displayed as a result of certain Internet searches through Google's search engine. The results of a Google.cn search are filtered by people working for Google in California so as not to bring up any results concerning the Tiananmen Square protests of 1989, sites supporting the independence movements of Tibet and Taiwan or the Falun Gong, and other information perceived to be harmful to the People's Republic of China (Wikipedia 2007).

The second example comes from Belarus. In February 2007, Belarusian authorities expanded restrictions on Internet usage, requiring owners of Internet cafes and computer clubs to keep logs of Web sites accessed by users and report them to security services. Internet usage is already subject to restrictions in Belarus (Associated Press 2007). Citizens must present identification documents to use Internet cafes, and Internet access for offices and private users is controlled by a state monopoly. Criticizing President Alexander Lukashenko and other senior government officials remains a criminal offense in Belarus.

Net Neutrality

Net neutrality is the principle that Internet users can go to any website, run any web application, and attach any device to the network without restriction by the Internet service provider. Two companies in the United States, AT&T and BellSouth, have proposed a high-speed broadband network that would be separate from the public Internet, providing its own video service at a guaranteed level of quality. The concern is that these broadband providers will create a fast Internet for their own services – at a premium price – and a slow lane for everyone else. A premium Internet service might also effectively impose a class structure for the control of spam or online security (Bicknell 2006a).

Vint Cerf, chairman of Icann and co-creator of the TCP/IP standard, warns against creating a two-tier web system. He believes that "the remarkable social impact and economic success of the Internet is directly attributable to the architectural characteristics that were part of its design" (Bicknell 2006b). The Internet was designed with no gatekeepers over new content or services, an end-to-end model that allows people at each point on the network to innovate free of any central control (Bicknell 2006b).

A New Internet

All of the technical problems inherent in the Internet have prompted some to propose an entirely new Internet that specifically addresses the security and privacy issues. A group of computer scientists at Stanford University argue that complexity is crushing the Internet. They point out that the original Internet design was based on the idea that users were immobile and connected by wires. This is no longer the case (Casado et al. 2007).

The group proposes a prototype network that centralizes security rather than placing it around the network in firewalls or in client-based virus detection programs. In his prototype, all communications are turned off by default. A host joining the network must get explicit permission from a centralized server before it can connect to anything except that server. In addition, the server won't grant permission unless it is able to determine the location and identity of the requestor (Casado et al. 2007). The proposed centralized server acts as an administrator and essentially monitors all computers connected to the Internet. Such a system would be in sharp contrast to the existing Internet that was specifically designed to not be dependent upon a centralized server. Destroying the server could easily stop an Internet based on a centralized server.

Internet Addiction

Finally, the Internet is leading to social problems. Specifically, there is concern about excessive Internet use by some people–variously termed Internet addiction, problematic Internet use, pathological Internet use, and compulsive Internet use. There is no consensus on how to diagnose the problem in individuals, but there is agreement that some people are overdoing the amount of time they spend on the Internet (Payne 2006). The problem is getting more serious attention as the use of the Web grows. According to a 2005 survey, Internet users average about 3.5 hours online each day (Payne 2006). Rather than using the term "addiction," Yellowlees and Marks (2007) simply define a class of individuals as having problematic Internet use (2007). These include people who have a history of impulse control and addictive disorders. The American Psychiatric Association is considering listing Internet addiction in the next edition of its diagnostic manual (Payne 2006).

Problems with Internet Maps

The problems addressed to this point deal with the Internet in general. A whole series of other additional problems can be identified with Internet maps.

Accuracy

An incident in California during December 2006 has brought the accuracy of online maps under public scrutiny. While traveling in northern California, the Kim family from San Francisco turned onto a small logging road. After becoming stranded on the road during a snowstorm, the husband walked for help and died shortly before his family was found by a search party. The road is normally impassable in winter–a fact well known to locals—but Google Maps, Live Local, and Ask.com recommends the route (Fulbright 2006). The incident brought public warnings about Internet maps. A number of problematic routing examples were subsequently cited with routes that appear to be a shortcut but are seasonal or dangerous–or routes that contain outright errors. The problem is made worse through the use of turn-by-turn directions that are offered by the Internet mapping sites. Many users prefer these directions to the associated maps, effectively leaving them lost when they deviate from the written directions.

Maintaining Servers

In contrast to the finality of printing a map, the work of maintaining an Internet map server is never complete. New data or new Internet protocols make it necessary to make continual updates to a server. A case in point is the difficulty of maintaining the US Census Bureau Tiger Map Server ("TMS") (US Census 2007).

The TMS system came online in 1995 "to demonstrate cost efficient delivery of public data and research and development of the Census Bureau applications on the Internet" (US Census 2007). It has been operating since on two Silicon Graphics servers, each with 200MB of RAM and 9GB SCSI-2 disk drives – miniscule numbers by today's standards. The server is still in operation thirteen years later, but no contingency has been made to transfer the server software or the data to another computer. When these computers fail, the system will cease. There are many map servers in different parts of the world that cannot be upgraded or migrated to another computer and will soon fade away.

The Google Maps Effect

Google Maps was introduced in 2005 and has revolutionized online mapping. Implementing a new server/client system called AJAX, Google Maps increases the level of interaction between the user's computer and the map server. Panning is accomplished effortlessly by moving the mouse from side-to-side, and the scroll button can be used to zoom in and out. Map updates are almost instantaneous. Combining maps and satellite imagery, the stand-alone Google Earth application also has a devoted user-base.

The Google interface has transformed online mapping and left other sites seeming instantly inferior. Once a map user has used the Google Map interface, they don't want to use any other type of interactive map. Essentially, Google Map has eclipsed ten years of work in server/client interactive mapping that was based mostly on the server constructing a map in raster format and embedding this into a web page that was returned to the user. A typical reaction by many to this older form of interactive online mapping is, "Why can't this site be like Google Maps?" Google Maps also allows users to enter their own information onto the map that can be shared with other users (Liedtke 2007), and its Application Programming Interface (API) allows programmers to construct their own maps. Of course, the hidden secret of Google Maps is that it uses the Mercator projection. The scale varies constantly as the map is moved to the north or south.

Any new technology will naturally involve a considerable amount of experimentation. But, in the case of online mapping and web-based GIS, a great deal of money and effort has been expended on creating interactive mapping sites. Converting these to the new Google Map standard will require a great deal of effort because of the new way that the map is transferred to the user's computer. Switching to the new AJAX method for online map presentation will be time-consuming and expensive.

Mobile Mapping

The main application of mapping for mobile devices is navigation assistance or wayfinding. While the primary purpose of wayfinding with maps is to get to the destination with as little effort as possible, the secondary purpose is the creation of a mental map of the route that will aid in finding the location again without the use of a map. In other words, the purpose of the map in wayfinding is to create a mental construct such the map will be rendered meaningless when the same task is performed again. The map succeeds by becoming irrelevant.

In contrast, when using a mobile device for wayfinding, the user is directed to a location with minimal mental effort by the user. In addition, the schematic depictions presented on the mobile device are often too simplistic to create a functional mental map of the environment. Because there is little overlap between the map and the environment, the quality of the resultant mental map is compromised. It is very likely that the user will need to get instructions from the device again for not only the return trip but for any future trip to the same location. The mobile device has succeeded by creating a permanent dependence on the device.

Being *told where you are* bypasses the process of *finding out where you are,* thus hindering the formation of mental maps. *Finding out where you are* helps to form a mental map, a mental conception of where you have been and where you need to go. Mobile mapping devices, like navigation systems in general, do not seem to contribute to the formation of long-term mental maps.

The Open Source Dilemma

A variety of open source software projects have had a major impact on all forms of computing, especially server-based applications. A prime example is Apache, the main application in use for web servers. Open source online mapping applications are also in widespread use—the main example being MapServer.

While open source software is "free," installing and using the software is complicated and time-consuming. Creating a simple-to-use installation procedure and application user interface is not a primary focus for open source developers. The user interface is often left to the person who is installing the software. Updating open source software is also complicated. So, while the software is free, one must deal with cumbersome interfaces and less than appealing online mapping sites. MapServer sites, and there are hundreds of these around the world, mostly implement a non-Google map interface that many users now find frustrating.

Open source developers have also given little attention to improving the graphic quality of the maps themselves. While the software provides a more feasible and cost-effective approach to implement online mapping, the movement is designed primarily for programmers and suffers from not easily allowing input from a broad range of individuals who could make non-programming type of improvements. In short, open source is only open to programmers. A broader developer- and user-community could have a major influence in creating high-quality online mapping sites.

Solutions and Summary

With all of its problems, the Internet remains an amazing communications system. New applications are continually introduced and new users are joining the system every day. Because the Internet is an unmanaged, non-centralized system, a central authority cannot fix it. Internet users and organizations of users will define the future Internet.

While the development of Internet cartography has been at least as significant as that of the printed map, a considerable amount of effort is still required to make the new medium a truly effective and useful means of conveying and analyzing spatial information in the form of maps. Hundreds of millions of map users have been introduced to interactive maps through the Internet. Online interactive mapping sites represent how most younger people have learned to use maps. New mapping sites, such as Google Maps, are quickly embraced by Internet users looking for new ways to map the world. The mass appeal of the Google Earth product is another indication of the public's desire to interact with maps and satellite images in new and exciting ways.

National and international organizations like NACIS and the International Cartographic Association (ICA) have a major role to play in defining the function and form of Internet maps. Online map galleries sponsored by the organizations could be used to highlight innovative map displays. Cooperation and active participation with open source efforts can lead to meaningful improvements in this type of software. Hands-on workshops and seminars, such as those conducted by the Maps and the Internet Commission of the ICA, are a valuable way of conveying advances in technology to a broad and diverse audience. Although we might lament the passing of the paper era in cartography, it is necessary to embrace the changes that the Internet brings to the discipline and seek improvements in the science and technology of a new Internet cartography.

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Flex Projector–Interactive Software for Designing World Map Projections

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Flex Projector is a free, open-source, and cross-platform software application that allows cartographers to interactively design custom projections for small-scale world maps. It specializes in cylindrical, and pseudocylindrical projections, as well as polyconical projections with curved parallels. Giving meridians non-uniform spacing is an option for all classes of projections. The interface of Flex Projector enables cartographers to shape the projection graticule, and provides visual and numerical feedback to judge its distortion properties. The intended users of Flex Projector are those without specialized mathematical expertise, including practicing mapmakers and cartography students. The pages that follow discuss why the authors developed Flex Projector, give an overview of its features, and introduce two new map projections created by the authors with this new software: the A4 and the Natural Earth projection.

Flex Projector is available at www.flexprojector.com.

INTRODUCTION

Despite the central importance of projections to mapmaking, prior to the release of Flex Projector few cartographers have ever created a map projection. Explanations for this lack of involvement include the ready availability of existing map projections; the time and tedium associated with designing projections, with no guarantee of success; and, the general lack of mathematical expertise needed to devise projections. It is an opaque undertaking to all but a few. Not that these barriers have prevented cartographers from informally experimenting with new projection designs. In the pre-digital era, pencils, graph paper, French curves, and optical devices were the tools of choice for such tinkering. Today, programs such as Adobe Photoshop and Illustrator offer innumerable graphical tools for changing the appearance of a projection with just the click of a mouse. What cartographer in an uninhibited moment has not thought about adjusting the width-to-height proportions of a map so that it would fit better in a graphical layout, or perhaps applying a transformation filter to portray the world with a unique new shape? It is completely natural that mapmakers should want control over the look of world map projections beyond what is possible by adjusting the parameters of existing map projections. In an era when nearly all aspects of mapmaking are customizable by the user, map projection design has been a bastion of specialization.

> *"In an era when nearly all aspects of mapmaking are customizable by the user, map projection design has been a bastion of specialization."*

Taking a cue from the way cartographers work, Flex Projector offers a suite of graphical tools and interactive feedback for the design of custom world map projections. Guiding the software design was the idea that shape and form are the primary determinants for selecting a projection—

Initial submission, December 4, 2007; revised submission, February 29, 2008; final acceptance, March 4, 2008

an acknowledgement that maps are inherently graphical. Flex Projector, however, is more than just a glorified graphical application for reshaping how the world looks. It alters the internal geometry of existing projections to create new projections, provides the user with detailed information about the angular, areal, and scale distortion properties, imports and exports data in a variety of graphics and GIS formats, and saves new projections as text files that others can reproduce. It is a mapping application.

Lessons from the Robinson Projection

Flex Projector uses a graphical approach to map projection design similar to that used by Arthur H. Robinson for devising the famous projection that shares his name. In 1961, Robinson was commissioned by Rand McNally to design a world map projection that, among other criteria, was uninterrupted, had limited distortion, and was pleasing to the eye of general viewers (Robinson, 1974). He came up with a very simple idea: instead of devising a mathematical formula that relates longitude and latitude intersections on the sphere to X/Y coordinates on the map, he developed two sets of tabular parameters by trial and error. The first table described the length of parallels for every five degrees of increasing latitude (the horizontal arrows in Figure 1). The second table of parameters defined the distance of each parallel from the equator, also in steps of five degrees of increasing latitude (the vertical arrows in Figure 1). Interpolation determined the coordinates of points for intervals finer than five degrees.

". . . instead of devising a mathematical formula that relates longitude and latitude intersections on the sphere to X/Y coordinates on the map, Robinson developed two sets of tabular parameters by trial and error."

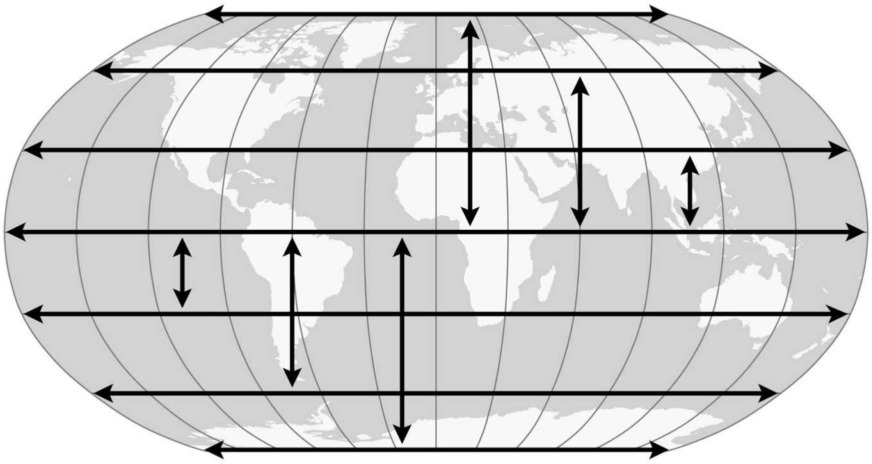


Figure 1. Two sets of tabular parameters define the Robinson projection shown here with horizontal arrows (length of parallels) and vertical arrows (distance of parallels from equator). Note: not all parameters appear in the illustration.

Robinson used an iterative process to create his pseudocylindrical projection, evaluating the appearance and relative relationships of landmasses in a succession of drafts. He started by estimating values for the length and spacing of parallels and then plotted the positions of continents on the resulting graticule. When the look of the projection was less than satisfactory, as was typically the case early on, Robinson made compensating adjustments and drafted a new projection. He repeated this process, a sort of graphic successive approximation, until it became obvious that further adjustments would produce no improvement, at least to the eyes of the author (Robinson, 1974, p. 151–152). The Robinson projection was well received by cartographers and widely used, including by the National Geographic Society (Garver, 1988).

Arthur Robinson's task would have been greatly simplified had he employed Flex Projector. The graphical user interface of Flex Projector allows the user to alter the length of parallels and their distance from the equator, just as Robinson did. The results immediately appear on screen with a graticule and sample coastline dataset. Flex Projector extends Robinson's methodology in two major ways. (1) Robinson's projection uses straight parallels. With Flex Projector, bending parallels to concave or convex curves is possible, in a manner similar to the arced parallels seen on the popular Winkel Tripel projection. (2) Robinson's projection distributed meridians with even spacing along the equator. This resulted in a *true* pseudocylindrical projection, where meridians are equidistant on all parallels (Snyder, 1993, p. 189). Flex Projector provides the option to distribute meridians with uneven spacing.

NEW PROJECTIONS NEEDED

Popular map projections, which give shape to our mental image of the world, fall in and out of vogue over time. Take for example National Geographic Society (NGS), which used the Van der Grinten I as its world map projection from 1922 to 1988, a notably long run. In 1988, the NGS switched to the Robinson projection, originally called the orthophanic projection, meaning "pleasing to the eye". The Robinson projection is still popular today mostly because of the balanced appearance of major landmasses. It has a classic shape that looks the way a world map should look to the eyes of many readers. The Robinson era at National Geographic, however, came to an end in 1998 when the staff chose the Winkel Tripel projection as its replacement, primarily because its compact form fit better on a two-page atlas spread. Other map publishers have followed suit and the Winkel Tripel has risen from relative obscurity to become common today. Readers of *National Geographic* will no doubt see a switch to another world map projection in the future.

"The principal goal of Flex Projector is to give cartographers and the mathematical layperson a means to design new map projections that are pleasing to look at, functional, and minimize shape and area distortion."

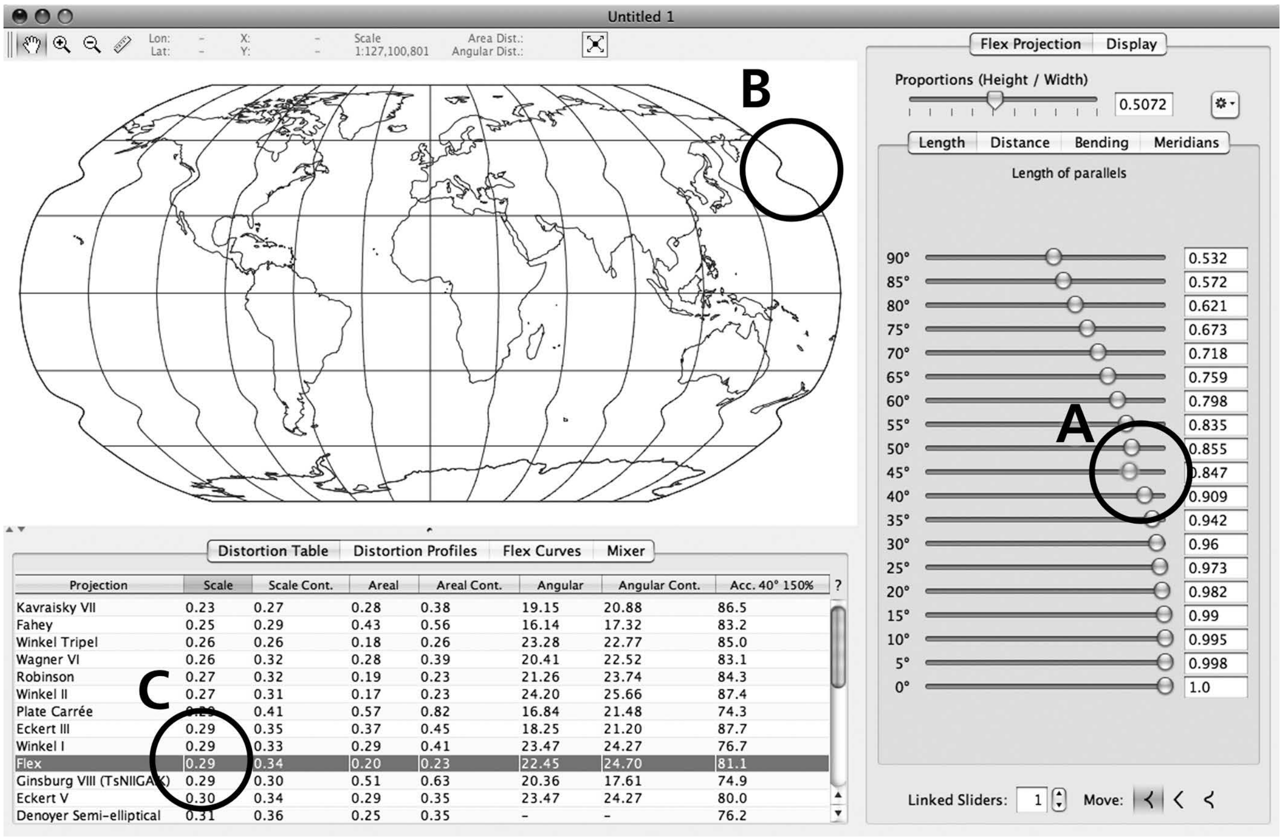
Considering that hundreds of map projections already exist, is there really a need for an application like Flex Projector? To answer this question one only has to peruse the world maps in popular atlases. Chances are good that you will find only a half-dozen or so map projections in common use, including the Eckert IV, Goode Homolosine, Miller Cylindrical, Mercator, Mollweide, Robinson, and Winkel Tripel projection. This scarcity-amidst-plenty paradox is in part due to the staid preferences of map publishers who are unwilling to risk sales by exposing readers to unfamiliar world map projections. Educational publishers in the US prefer to use only one world map projection in a text for consistency and to avoid confusing students (Bosacki, 2007). Other factors in the lack of diversity are the many published projections designed exclusively for large and medium-scale maps, not small-scale world maps; projections created for purely mathematical reasons and never intended for everyday mapmaking; and projections that are whimsical. For example, the Apple projection, which depicts the world in the shape of an apple with a bite taken out of it (Strebe, 1999), will probably never appear in the *National Geographic Atlas of the World*. Personal taste is also a major selection criterion; any given cartographer may or may not like an otherwise appropriate projection favored by others. For all of the reasons above, the number of acceptable projections for making world maps for general audiences is small.

The principal goal of Flex Projector is to give cartographers and the mathematical layperson a means to design new map projections that are pleasing to look at, functional, and minimize shape and area distortion. By expanding the pool of people who can design projections, our hope is for a proliferation of new projections tailored to meet the specific needs of cartographers. And from this might emerge the next blockbuster world map projection.

FLEX PROJECTOR 1.0–OVERVIEW

A freeware application based on Java 1.5, Flex Projector is cross-platform compatible on Linux, Mac OS X, and Windows. The authors of this article developed the core of the application, including the graphical interface, the algorithms for adjusting the projection, and the code for loading, visualizing and exporting geographical data. The source of projections (other than the Flex Projection created by the user) is Jerry Huxtable's Java port of the widely used PROJ.4 library (Huxtable 2007, Evenden 2005). The user licence allows others to inspect the code, and add their own extensions. Cubic spline interpolation algorithms govern the shape of projections created in Flex Projector; however, the graphic interface shields the average user from this underlying technology.

When designing the interface of Flex Projector, it was the authors' hope that users would have little need for the manual. Upon opening Flex Projector for the first time, the user sees a graphic user interface comprised of three components (Figure 2). The panel in the upper left is a world map in the familiar Robinson projection. To the right of the map is the Flex Projector panel with sliders that control the shape of the projection, and which beckon the user to experiment. Moving any of the sliders results in an immediate change to the Robinson projection, which then ceases to be a Robinson projection and starts on its way to becoming an entirely new projection. Below the map is the Distortion table, which reports in real-time the amount of distortion contained in the modified "Flex" projection, including comparisons to common world map projections.



Scale 1:127,100,801

Proportions (Height / Width) 0.5072

Length of parallels

90°	0.532
85°	0.572
80°	0.621
75°	0.673
70°	0.718
65°	0.759
60°	0.798
55°	0.835
50°	0.855
45°	.847
40°	0.909
35°	0.942
30°	0.96
25°	0.973
20°	0.982
15°	0.99
10°	0.995
5°	0.998
0°	1.0

Linked Sliders: 1 Move:

Projection	Scale	Scale Cont.	Areal	Areal Cont.	Angular	Angular Cont.	Acc. 40° 150%
Kavraisky VII	0.23	0.27	0.28	0.38	19.15	20.88	86.5
Fahey	0.25	0.29	0.43	0.56	16.14	17.32	83.2
Winkel Tripel	0.26	0.26	0.18	0.26	23.28	22.77	85.0
Wagner VI	0.26	0.32	0.28	0.39	20.41	22.52	83.1
Robinson	0.27	0.32	0.19	0.23	21.26	23.74	84.3
Winkel II	0.27	0.31	0.17	0.23	24.20	25.66	87.4
Plate Carrée	[illegible]	0.41	0.57	0.82	16.84	21.48	74.3
Eckert III	0.29	0.35	0.37	0.45	18.25	21.20	87.7
Winkel I	0.29	0.33	0.29	0.41	23.47	24.27	76.7
Flex	0.29	0.34	0.20	0.23	22.45	24.70	81.1
Ginsburg VIII (TsNIIGA K)	0.29	0.30	0.51	0.63	20.36	17.61	74.9
Eckert V	0.30	0.34	0.29	0.35	23.47	24.27	80.0
Denoyer Semi-elliptical	0.31	0.36	0.25	0.35	–	–	76.2

Figure 2. Action–Reaction: Moving a slider (A) in Flex Projector, in this case to the left, results in commensurate changes to the map (B) and in the distortion table (C).

Flex Projector Panel

The heart of Flex Projector, the sliders in this panel relate to the upper right (northeast) quadrant of the displayed map projection. Because projections created in Flex Projector have bi-lateral symmetry, the software automatically mirrors the information in the upper right quadrant to calculate the shape of the rest of the world. The four tabs at the top of the panel access sliders for adjusting:

- Length of parallels (see Figure 2 above)
- Distance of parallels from the equator
- Convex or concave bending of parallels
- Distribution of meridians

The *Linked Sliders* option at the bottom of the panel allows the movement of multiple sliders simultaneously. Increasing the number of linked sliders generally produces projections with smoother, more uniform shapes. The *Move Sliders* option works in conjunction with *Linked Sliders* to constrain the movement of sliders to peaked, linear, or bell-curve shapes. An additional slider on the top of the panel, the *Proportions* slider, offers a quick method to alter the height-to-width ratio of a projection.

With the basic controls described above a user can adjust a projection to an almost infinite variety of shapes, including adjusting the position of the central meridian to any longitude. However, it is not possible to design every type of projection. The current version of Flex Projector is limited to map projections that show the entire world, have an equatorial aspect (the latitude of origin is always the equator), that are symmetrical relative to the central meridian and the equator, and uninterrupted. (A later version of the application may address some of these limitations). All projections designed in Flex Projector use a spherical earth model. A more complicated ellipsoidal model would not significantly enhance the geometry of small-scale world maps of the type that Flex Projector was conceived to create.

". . . a user can adjust a projection to an almost infinite variety of shapes . . ."

Because mistakes are invariably made while working on a new projection, Flex Projector gives the user unlimited undos to go back to a previous state. If a projection is completely beyond hope, the *Options/Reset to Projection* button at the top right allows the user to reload a fresh Robinson projection, or one of dozens of other projections.

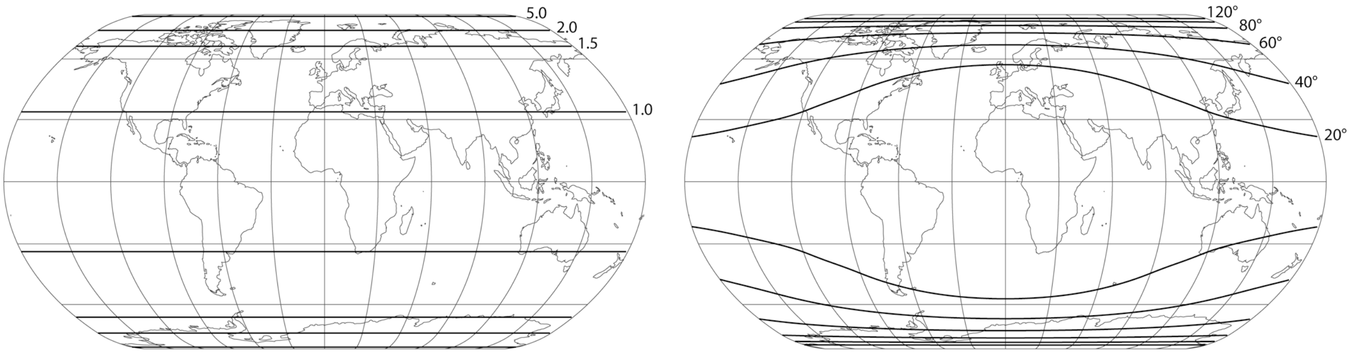
Display Panel

The *Display* panel contains displayable options that aid in the construction of a projection. By clicking the *Show Second Projection* button, the user can choose a second map projection that appears as a ghosted template behind the current Flex projection. The second projection serves as a visual reference for gauging the design of the Flex projection. The user can change the color of both the Flex and Second projection in the *Preferences* drop menu.

Turning on *Tissot's Indicatrices*, *Isolines of Areal Distortion*, and *Isolines of Maximum Angular Distortion* shows where distortion occurs in a projection (Figure 3). Also available are controls for setting the graticule density and choosing a central meridian other than the Greenwich Meridian, which is the default.

Distortion Table

Flex Projector offers various numerical indices for assessing projection distortion (see the bottom-left table in Figure 2): (1) the weighted mean error



Areal Distortion

Angular Distortion

Figure 3: Isolines of areal (left) and angular (right) distortion for the Natural Earth projection.

for overall scale distortion, (2) the weighted mean error for areal distortion, and, (3) the mean angular deformation index. These indices compute distortion for the entire globe and for terrestrial areas only (Canters, 2002). The Acceptance index is an additional numerical measure that summarizes overall projection distortion (Čapek, 2001). As the user modifies a Flex projection, the *Distortion Table* automatically updates every change and ranks the projection compared to other well-known world projections from best (top) to worst (bottom).

Associated with the *Distortion table* are tabs that display *Distortion Profiles* and *Flex Curves*. The information in these graphs alerts the user about otherwise unseen distortion irregularities in a projection.

Data

Flex Projector reads and projects vector, raster, and elevation data from common GIS and raster formats. The Flex Projector website provides public domain vector, shaded relief, and Natural Earth II data to begin making publication-quality maps. Detailed vector data layers import directly into Flex Projector via the *File* drop menu. The following data formats can be imported: ESRI Shape for vector data, ESRI ASCII GRID for gridded raster elevation and thematic data, and a variety of image formats, such as JPEG, TIFF, PNG, and BMP. Flex Projector can export to these formats: DXF, ESRI Shape, Adobe Illustrator, JPEG, PDF, PNG, SVG, TIFF, and Ungenerate.

"The software assumes that any raster images with a 2:1 aspect ratio are in the Plate Carrée projection and automatically georeferences them."

When reprojecting raster data, users have the choice of using nearest neighbor or bi-cubic interpolation. The software assumes that any raster images with a 2:1 aspect ratio are in the Plate Carrée projection and automatically georeferences them. Flex Projector can work with images large enough for wall maps. For example, making the Natural Earth projection (described in a later section) involved reprojecting an image measuring 16,200 x 8,100 pixels in size. Reprojected vector data saved in Adobe Illustrator (AI) format, include a bounding box indicating the maximum area extent. These boxes allow the user to register raster art visually to vector maps in graphical applications.

Map designers can share projections created in Flex Projector by saving the projection parameters as text files that others using Flex Projector can read and use. Projections created in Flex Projector are currently not transferable to other map projection applications.

HOW TO DESIGN A NEW MAP PROJECTION

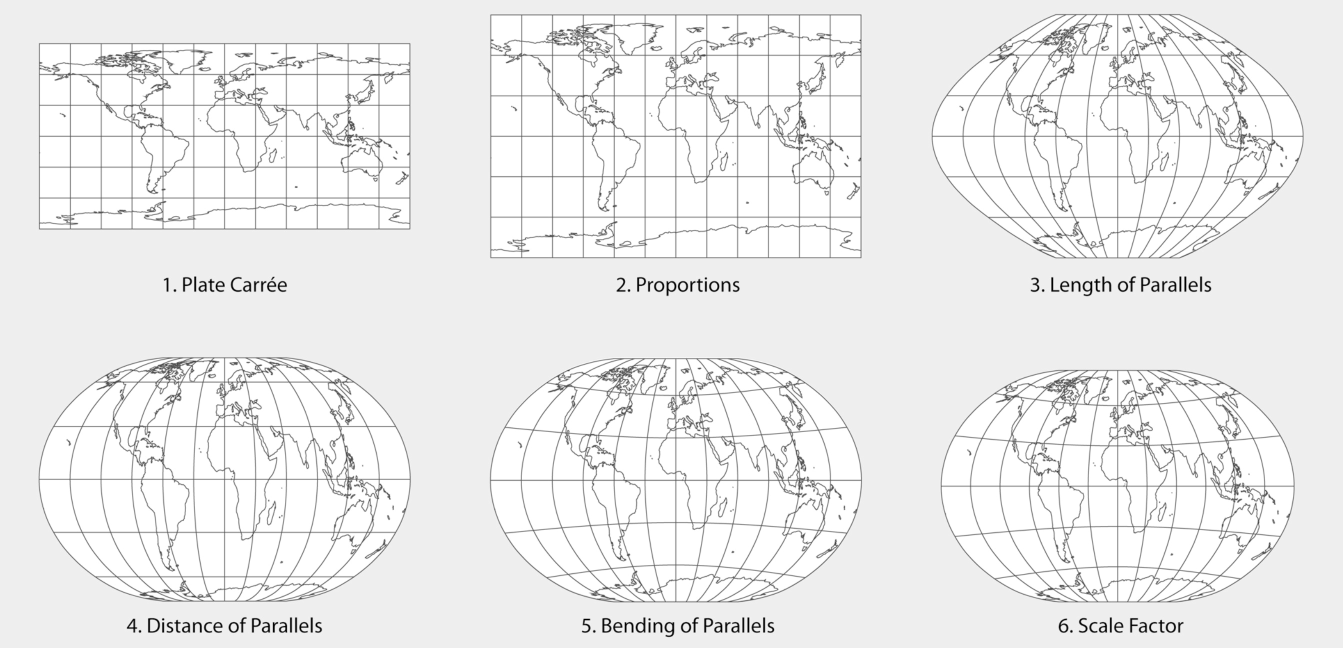
The steps below outline a sample workflow in Flex Projector that leads to a customized projection we call the "A4" projection (Figure 4), which has similarities to the Winkel Tripel projection. Characteristics of the A4 projection include a compact form factor, arcing parallels, a straight pole line, and meridians that are regularly spaced along the equator. Designing the A4 projection involved six steps:

1. The procedure started with the Plate Carrée projection opened via the *Reset* dialog.
2. Increasing the height-to-width proportion from 0.50 to 0.655 made the map fit better on an A4 sheet in landscape format with extra space in the margins.
3. Adjusting the length of parallels (with the *Linked Sliders* option selected) curved the meridians and the overall shape of the map. Using a repetitive trial-and-error method assured that arcs were smooth and had the desired curvature.
4. Decreasing the distance of parallels from the equator selectively at high latitudes compressed the polar areas, moderating the areal distortion found there.
5. Bending of the parallels reduced the north-south elongation of Africa and South America. The pole lines received no bending.
6. Applying a scale factor of 0.7785 minimized the total areal distortion of the graticule, reducing the apparent scale of the map.

> *"Employing an iterative process, the user would assess the shape of the graticule and appearance of major landmasses after each adjustment."*

Creating a new projection like the A4 projection described by the simple steps above would, in reality, require frequent use of the undo-redo functionality of Flex Projector to evaluate variations. Employing an iterative process, the user would assess the shape of the graticule and appearance of major landmasses after each adjustment. Distortion information obtained from isolines, indices of distortion, and Tissot's indicatrices would also guide the design decisions.

In a real-world workflow, the recommended way to design a new projection is usually not to start with the Plate Carrée projection, but with a predefined projection closer to that of the desired final. For example, when making the A4 projection, starting with the Winkel Tripel projection would simplify steps 1–4 as described above, avoiding unnecessary major adjustments to the shape of the graticule.



1. Plate Carrée
2. Proportions
3. Length of Parallels
4. Distance of Parallels
5. Bending of Parallels
6. Scale Factor

Figure 4. Designing the A4 projection.

An illustration of the A4 projection and its parameters can be found in Appendix A.

EDUCATIONAL USERS

Students and teachers are among the intended users of Flex Projector. With its hands-on interface and interactive feedback, Flex Projector is fun to use and entices students to explore how to make map projections. A mathematical background is not required. For teachers, the software provides a unique environment for devising creative assignments. For example: ask students to design a world map projection for a hypothetical publishing company, similar to what Arthur Robinson did for Rand McNally. When designing a new projection, students would have no choice but to think critically about projection characteristics as part of the creative process. And requiring students to name their creation after themselves, as is the convention with naming projections, would motivate them to do a better job.

"When designing a new projection, students would have no choice but to think critically about projection characteristics as part of the creative process."

Other advantages for education include:

- Learning the importance of defining design objectives before beginning work on a new projection.
- By giving students real-time feedback about angular, areal, and scale distortion, Flex Projector reinforces the idea that every projection design involves making significant compromises.
- Students can compare the projections they make against published projections. Besting the distortion rating of a famous map projection is a worthwhile and achievable objective.
- Universal access: Flex Projector is free, will run on most computers, and uses common data formats.
- Advanced students with computer programming experience can modify the source code to extend the capability of Flex Projector.

NATURAL EARTH PROJECTION

That Flex Projector is useful for production cartography should be abundantly clear to those who have read this far. In this section, we discuss the making of a new projection customized to portray the Natural Earth II dataset, from which the projection takes its name (Figure 5). Natural Earth II is a raster map dataset of the planet in the Plate Carrée projection that features natural environment colors, terrestrial shaded relief, and sea floor shaded relief with depth tints (Patterson, 2007).

The impetus for creating the Natural Earth projection was dissatisfaction with existing world map projections for displaying physical data. World physical maps typically employ two classes of projections: cylindrical and pseudocylindrical. Cylindrical projections are widely used for maps with sea floor relief, a preference that is perhaps a throwback to the traditional use of the Mercator projection for ocean navigation. Using the Mercator projection for a reference map, however, is less than ideal because of the extreme areal exaggeration in high latitudes. For example, the World Ocean Floor map published by National Geographic in 1975 uses the Mercator projection and omits areas beyond 75 degrees of latitude, to keep the map to a reasonable size. When making a map with raster digital data the polar problem is even worse because of poor data quality found in these areas, which degrades even further with enlargement. Even the more moderate Miller Cylindrical projection with less polar distortion than the Mercator suffers from this problem. For example, reprojecting raster data from the Plate Carée to the Miller Cylindrical projection stretches the north-south axis of Greenland by nearly 200 percent, damaging image quality in the process. For this reason, and because the world is not rectangular in shape, we removed cylindrical map projections from consideration.

"Using the Mercator projection for a reference map, however, is less than ideal because of the extreme areal exaggeration in high latitudes."

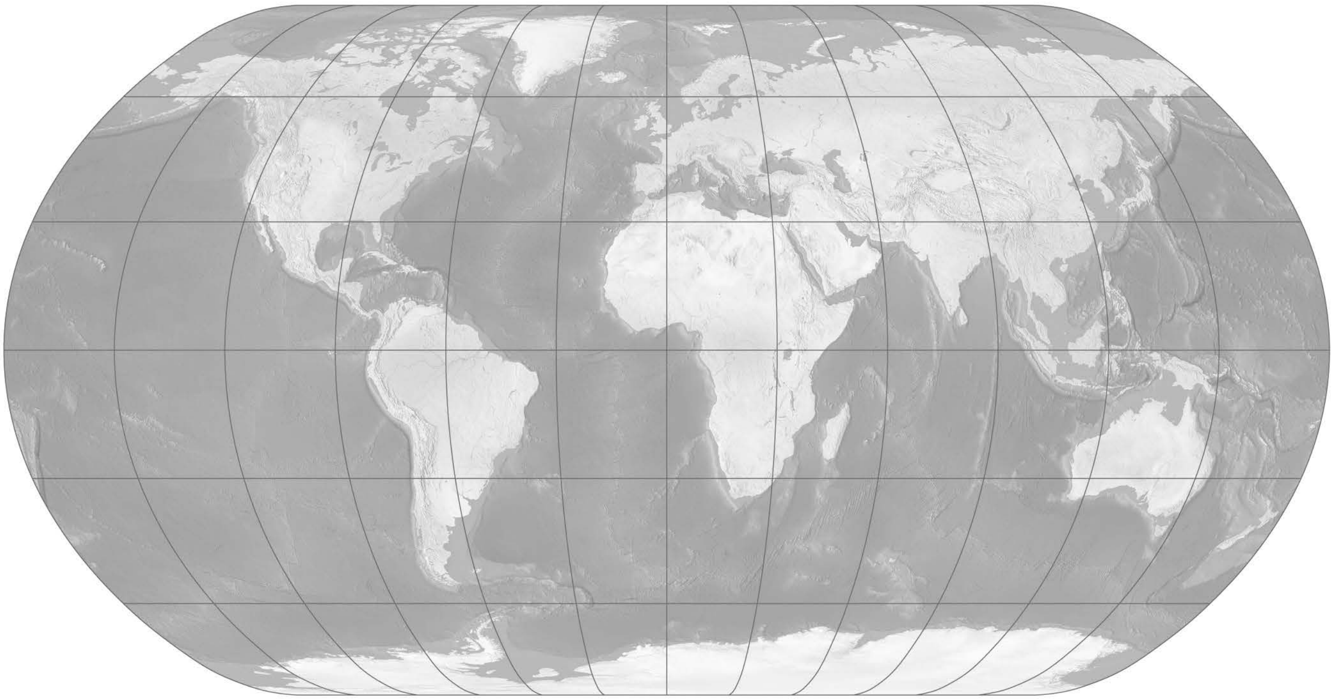


Figure 5. The Natural Earth projection applied to the Natural Earth II dataset. (see page 68 for color version)

Pseudocylindrical projections are better suited for presenting raster data because their arcing meridians converge toward the poles, compressing the size of these areas and tightening image quality. By selectively diminishing the distance of parallels from the equator in high latitudes even more polar compression is possible. An added benefit to curved meridians is a more rounded shape that hints that the projection is a 2D representation of a 3D sphere. In selecting a pseudocylindrical projection to display the Natural Earth II dataset the following requirements were sought:

- No graticule: creating a projection that could "stand alone" without the supporting framework of a graticule was important. Because pseudocylindrical projections have straight parallels, readers can judge the relative latitude of areas without the presence of a graticule. However, some popular pseudocylindrical projections, for example, the Eckert IV and Mollweide, have ovoid shapes that look too soft and capsule-like without a graticule. The projection needed to have a strong shape.
- Wall map: the Winkel Tripel (not a pseudocylindrical projection because of its curved parallels) and other projections with compact forms apply to situations where space is limited, such as the printed page. By contrast, wall maps are largely free of horizontal space constraints and can afford to portray the world with greater breadth and detail.
- Conventional appearance: a projection with pleasing lines and minimal distortion that would not detract from the Natural Earth II data presented on it was a high priority. As an example of what was not desired, the Sinusoidal projection with its sharply pointed poles and top-like shape would attract unwanted attention to itself. The ideal projection needed to be both functional and rather familiar in appearance.

The Kavraiskiy VII and Robinson projections—both of which are compromise projections that are neither conformal nor equal area but are rated well for overall distortion—came closest to fulfilling the above requirements. However, each projection had at least one undesirable characteristic. The Kavraiskiy VII, with its 0.5774 height-to-width proportions, depicts tropical and mid latitude areas with minimal distortion, but exaggerates the size of high latitude areas—Antarctica is enormous. The Robinson projection, with its 0.5072 height-to-width proportions, suffers from the opposite problem: it is slightly too wide and its sides bulge outwards. When centered on the Greenwich Meridian, this results in too much angular distortion in Alaska, Kamchatka, and New Zealand (and the adjacent ocean floor) near the map edges.

Seeking the best characteristics of each, the Natural Earth projection is an amalgam of the Kavraiskiy VII and Robinson projections, plus additional enhancements (Figure 6). Making the Natural Earth projection in Flex Projector started with the Robinson projection. In the first step, the height-to-width proportion was increased from 0.5072 to 0.52, to give it slightly more height. The Kavraiskiy VII was then loaded as a second projection in the background and given the same width as the Robinson projection. Using the Kavraiskiy VII as a template, the parallels on the Robinson projection were each increased in length to four decimal points of precision, to match the bounding meridians of the Kavraiskiy VII. The projection then took on a completely new form, similar to that of a truncated Kavraiskiy VII projection. The final procedure for creating the Natural Earth projection was decreasing the length of the pole lines by a small amount and giving the corners (where the pole lines and bounding meridians meet) a rounded appearance. This involved trial and error experimentation and hours of contemplative staring at draft projections before deciding on the final (See Appendix B for Natural Earth projection parameters).

"Seeking the best characteristics of each, the Natural Earth projection is an amalgam of the Kavraiskiy VII and Robinson projections . . ."

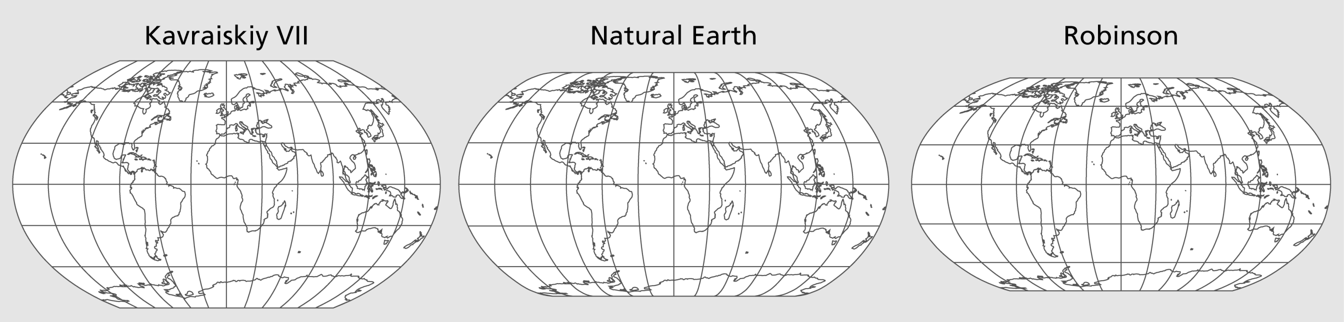


Figure 6. The Natural Earth projection combines characteristics of the Kavraiskiy VII and Robinson projections.

Designing the Natural Earth projection with rounded corners served five purposes:

1) They suggest that the projection represents a spherical Earth.
2) Rounding corners and the related action of lessening the length of pole lines reduced the size of polar areas, thereby making Antarctica appear smaller.
3) At the top and bottom of the projection, meridians converge inward toward implied poles, suggesting that the poles are in fact points instead of straight lines.
4) Aesthetics: from iPod music players, to Jaguar automobiles to the Mona Lisa, curves convey classic elegance.

5) The tightly rounded corners of the Natural Earth projection are unique among commonly used pseudocylindrical projections, helping to differentiate it.

Because the Natural Earth projection derives from two projections with low overall distortion, its distortion values fall somewhere between those of the Kavraiskiy VII and Robinson. Distortion values for the Natural Earth projection could be slightly better. Graphical considerations, rather than slavish attention to improving distortion, drove the design decisions. The final result was a projection with cleaner lines and whose distortion was still well within acceptable limits (See Appendix C for distortion tables of the Natural Earth projection).

As a compromise projection, the Natural Earth projection is not equal area and in fact exaggerates the size of high latitude areas. Despite our egalitarian desire to show all areas on a map at their true relative sizes, on physical maps exaggerating the size of high latitudes serves a useful purpose. Most land on Earth lies at high latitudes in the northern hemisphere and these areas also have highly complex coasts. Greenland and India, for example, are landmasses of roughly comparable shape and area, one at high latitudes and the other low. The fjorded Greenland coast is 44,000 kilometers in length, while the smooth coast of India measures only 7,000 kilometers. (Taking into account that the northern boundary of India does not include coast, unlike Greenland, the difference is still considerable). Showing Greenland at a slightly greater scale improves the legibility of its coast. Not that tropical areas lack for attention on the Natural Earth projection: with its equatorial aspect and when centered on the Greenwich Meridian, the projection yields Africa-centric maps. The central location and regular outline of that continent invariably attract the reader's eyes.

"It is the authors' hope that Flex Projector will democratize the creation of world map projections . . ."

The Natural Earth projection was designed specifically for making maps centered on the Equator and Greenwich Meridian, 0 latitude, 0 longitude. The distribution of the continents when centered there has a pleasing balance and symmetry—especially Antarctica. (That the Greenwich Meridian is an ideal place to graphically divide the world is entirely good luck). The 180-degree meridians bisect the Ross Sea, indenting the coast on the left and right map margins to make the Antarctic continent appear less large. The coast also trends in the same direction as the meridians converging toward the South Pole, emphasizing the projection shape. Symbolism is also evident in the shape of Antarctica, which appears as a pair of white-gloved hands holding a precious object—Earth—and directs the reader's eyes north across the Southern Ocean toward warmer regions. The effect is not unlike the skies on Heinrich Berann's alpine panoramas with carefully positioned clouds that draw the reader's eyes toward landscape features of interest (Patterson, 2000). Moving the Natural Earth projection center point only 20 degrees to the east or west ruins this effect.

CONCLUSION

It is the authors' hope that Flex Projector will democratize the creation of world map projections and encourage users to develop innovative and useful new map projections, as Arthur Robinson did nearly 50 years ago. For the first time ever, a user-friendly tool is available to do this.

While designing the A4 and the Natural Earth projection with Flex Projector, we identified possible interface enhancements that could further ease the making of new projections. Placing the sliders directly on the graticule would eliminate the need for a separate panel alongside the map. Or the graticule could itself be adjustable—the user could design a projection by manipulating the graticule by dragging its nodes with the mouse. Also, enhanced interpolation methods could support irregularly spaced control points. The user could then freely add points to the bounding meridian where needed, similar to how Bézier curves behave in vector drawing programs.

Exchanging projection files created in Flex Projector with other mapping applications would be useful. Since the software is open-source, developers can extract portions of the code and extend their applications to read and interpret descriptions of projections designed with Flex Projector. By doing this, other mapping applications need not provide tools for the design of new projections.

Having an application like Flex Projector freely available to everyone is bound to create some problems. For instance, with the proliferation of new projections it is a certainty that a few will have shoddy designs, including peculiar shapes and large amounts of distortion that the reader is not aware of. The need to document new map projections is another concern. Without the text file that describes a projection created in Flex Projector, the projection is not reproducible nor will it register with other projections. Then there is the challenge of what to call a new projection. Instead of the convention of naming a projection after oneself, some users will opt for more descriptive and eclectic names. The authors of this paper broke with convention when naming the A4 and Natural Earth projections.

The problems mentioned above, however, are minor when weighed against the benefit that Flex Projector brings to cartography: a simple means to create new map projections. Over the last two decades sophisticated technology has made other subfields of cartography accessible to non-specialists, and the profession has adapted as a result. Flex Projector continues this trend.

ACKNOWLEDGMENTS

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See **Appendix A for the Parameters of the A4 Projection**

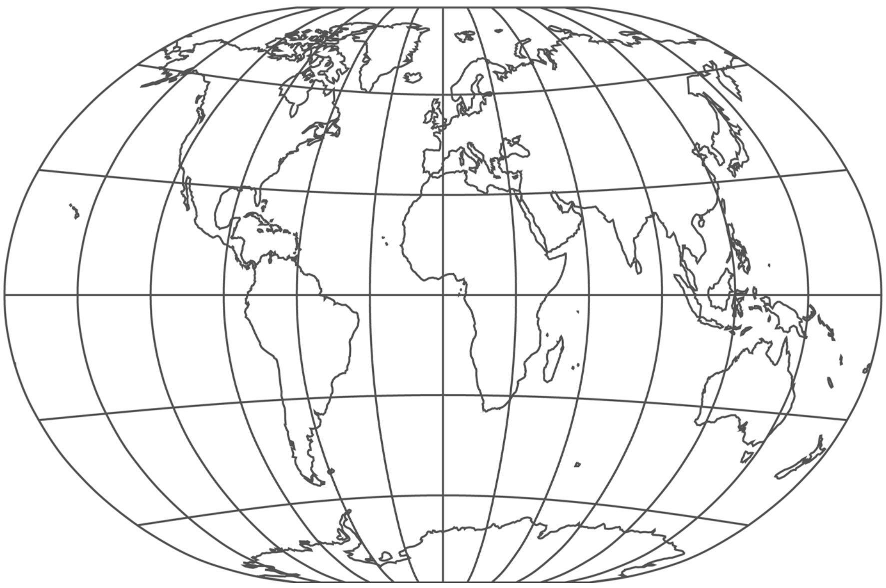

Figure 7. The A4 projection.

APPENDIX A: PARAMETERS OF THE A4 PROJECTION

The following table lists the parameters for the A4 projection for Flex Projector 1.0. Note: the A4 projection uses a linear distribution of meridians. These values equal 0 and are not listed here.

Latitude	Length of Parallels	Distance of Parallels from Equator	Bending of Parallels (Cosine)
0	1	0	-0.2218
5	0.998	0.075	-0.2214
10	0.991	0.1496	-0.2198
15	0.98	0.2235	-0.2166
20	0.965	0.2955	-0.2123
25	0.946	0.366	-0.2068
30	0.922	0.435	-0.2
35	0.895	0.502	-0.1919
40	0.864	0.567	-0.1824
45	0.828	0.629	-0.1716
50	0.789	0.6885	-0.1593
55	0.745	0.746	-0.1455
60	0.697	0.801	-0.1301
65	0.647	0.85	-0.113
70	0.596	0.893	-0.0943
75	0.54	0.93	-0.0737
80	0.479	0.959	-0.0512
85	0.415	0.982	-0.0267
90	0.333	1	0
Height / width			0.655
Scale			0.7785
Direction of meridians at poles			62°

APPENDIX B: PARAMETERS OF THE NATURAL EARTH PROJECTION

The following table lists the parameters for the Natural Earth projection for Flex Projector 1.0. Note: the Natural Earth projection does not bend parallels and uses a linear distribution of meridians. These values equal 0 and are not listed here.

Latitude	Length of Parallels	Distance of Parallels from Equator
0	1	0
5	0.9988	0.062
10	0.9953	0.124
15	0.9894	0.186
20	0.9811	0.248
25	0.9703	0.31
30	0.957	0.372
35	0.9409	0.434
40	0.9222	0.4958
45	0.9006	0.5571
50	0.8763	0.6176
55	0.8492	0.6769
60	0.8196	0.7346
65	0.7874	0.7903
70	0.7525	0.8435
75	0.716	0.8936
80	0.6754	0.9394
85	0.627	0.9761
90	0.563	1
Height / width		0.52
Scale		0.8707
Direction of meridians at poles		60°

APPENDIX C: DISTORTION TABLES FOR THE A4 AND THE NATURAL EARTH PROJECTIONS

Below are three tables comparing the A4 and the Natural Earth projections to other widely used projections. Note: lower distortion values are better. For details on the computation of these distortion values, see Canters and Decleir (1989).

Weighted mean error for overall scale distortion

Kavraiskiy VII	0.23
Natural Earth	*0.25*
Winkel Tripel	0.26
Robinson	0.27
Plate Carrée	0.29
A4	*0.30*
Eckert IV	0.36
Miller Cylindrical	0.39
Mollweide	0.39

Weighted mean error for areal distortion

Eckert IV	0
Mollweide	0
A4	*0.15*
Winkel Tripel	0.18
Robinson	0.19
Natural Earth	*0.19*
Kavraiskiy VII	0.28
Plate Carrée	0.57
Miller Cylindrical	1.30

Mean angular deformation index

Miller Cylindrical	7.63
Plate Carrée	16.84
Kavraiskiy VII	19.15
Natural Earth	*20.56*
Robinson	21.26
Winkel Tripel	23.28
A4	*27.38*
Eckert IV	28.73
Mollweide	32.28

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Unusual Map Projections[1]

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In this paper I look at azimuthal projections, equal area projections, and spherical and map distances, with emphasis on less known variants.

Keywords: Azimuthal projections, equal area maps, distance, simplifying coordinates.

Introduction

To begin it is useful to remark on some basic facts. The surface of the earth is two dimensional, which is why only (but also both) latitude and longitude are needed to pin down a location. Many authors, and textbooks mistakenly refer to it as three-dimensional. Yes, it is embedded in three dimensions, but the surface is a curved, closed, and bumpy two-dimensional surface. The graticule on the earth rides up and down over hill and dale. Map projections convert this surface to a flat two-dimensional surface. All map projections preserve the two dimensionally of the surface.

All map projections also result in distorted maps. Since the time of Ptolemy the objective has been to obtain maps with as little distortion as possible. But Mercator changed this by introducing the idea of a systematic distortion to assist in the solution of a problem. Mercator's famous anamorphose is a nomogram that helps solve a navigation problem. His idea caught on. Thus it is useful to think of a map projection as you are used to thinking of graph paper: logarithmic and semi-logarithmic scales and probability plots and so on, are employed to bring out different aspects of data being analyzed. Map projections can be used in a similar manner to solve problems and are not only for geographic display. This, however, is not a common use in Geographic Information Systems.

"But Mercator changed this by introducing the idea of a systematic distortion to assist in the solution of a problem."

Unusual Projections

Azimuthal map projections always show correct directions from their center. What varies is the map distance, relative to the spherical distance. The most common form represents the map within a circle. Thus the cylindrical-like azimuthal projection developed by J. Craig (1910) in Cairo, shown here with the center at the intersection of the Greenwich meridian and the Equator is unusual (Figure 1). A different center using Craig's projection will yield a different shape but will remain an azimuthal projection.

"Azimuthal map projections always show correct directions from their center. What varies is the map distance, relative to the spherical distance."

The radial distance on the different 'circular' azimuthal projections is extremely variable. Over two dozen have been named. In textbooks the conventional representation is to show the gnomonic, stereographic, equi-

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[1] Based on an invited presentation at the 1999 meeting of the Association of American Geographers in Hawaii. The full presentation can be seen at http://www.geog.ucsb.edu/~tobler/presentations/ and titled Unusual Map Projections, Honolulu, 1999.

Initial submission, January 28, 2008; final acceptance, March 11, 2008

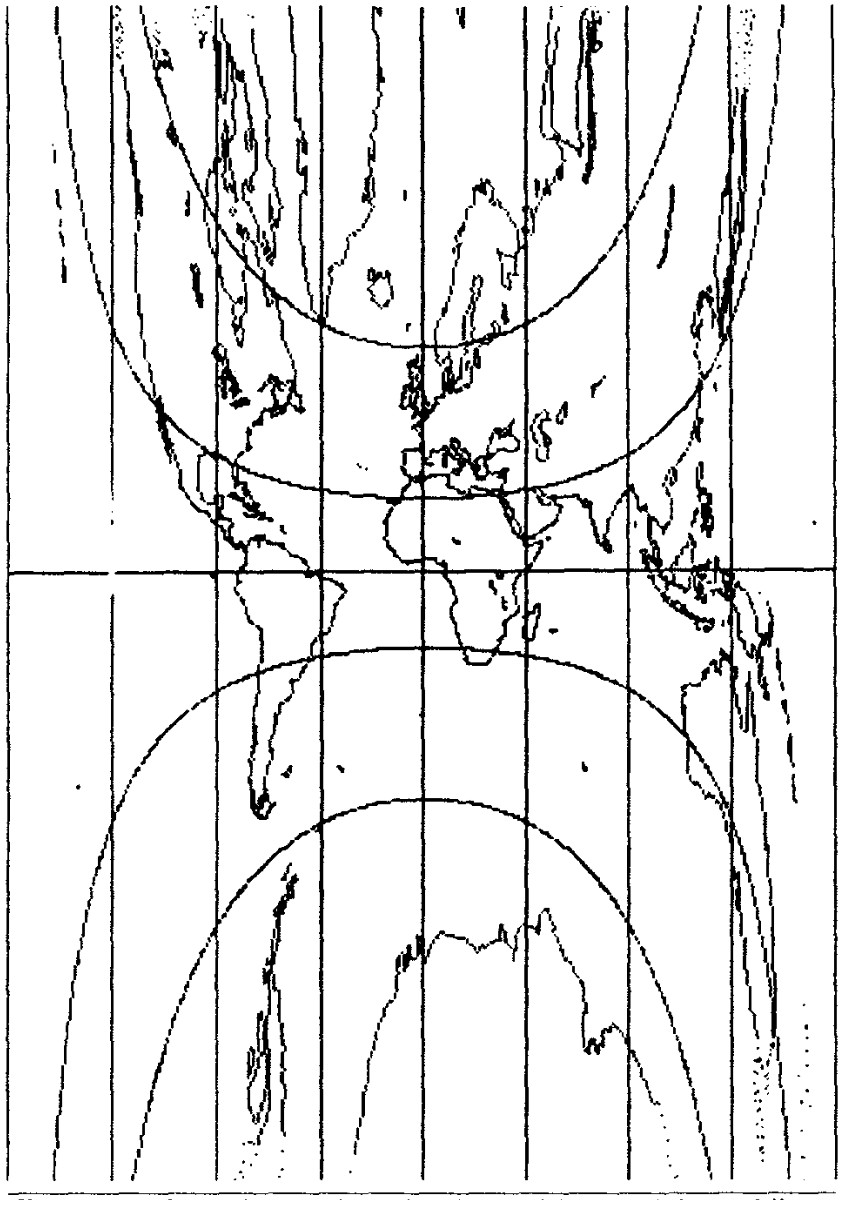

Figure 1. An unusual azimuthal projection invented by J. Craig (1910). Azimuths from the center are correctly depicted.

distant, orthographic and Lambert equal area projections by a polar view of latitudinal circles. On this type of diagram the variation in the distances from the center of the map is shown by variation in the spacing of the parallels. An alternate view is showing the curves in a graph of map distances versus spherical distances (Figure 2).

The X-axis represents the distance on the sphere, and the Y-axis represents the same distance (to scale) on the map. Take an increment (one centimeter, say) on the X-axis, and then move up to the curve. Then move across to the Y-axis to find the amount by which the spherical distance has changed. The advantage of this representation is that the slope of the curve quickly reveals the distance change. It is also an approximation to the areal enlargement. For example, if the slope is greater than one, the map area is enlarged. If the slope is less than one the map distances shrink. If the slope is equal to one we have the azimuthal equidistant pro-

"The advantage of this representation is that the slope of the curve quickly reveals the distance change. It is also an approximation to the areal enlargement."

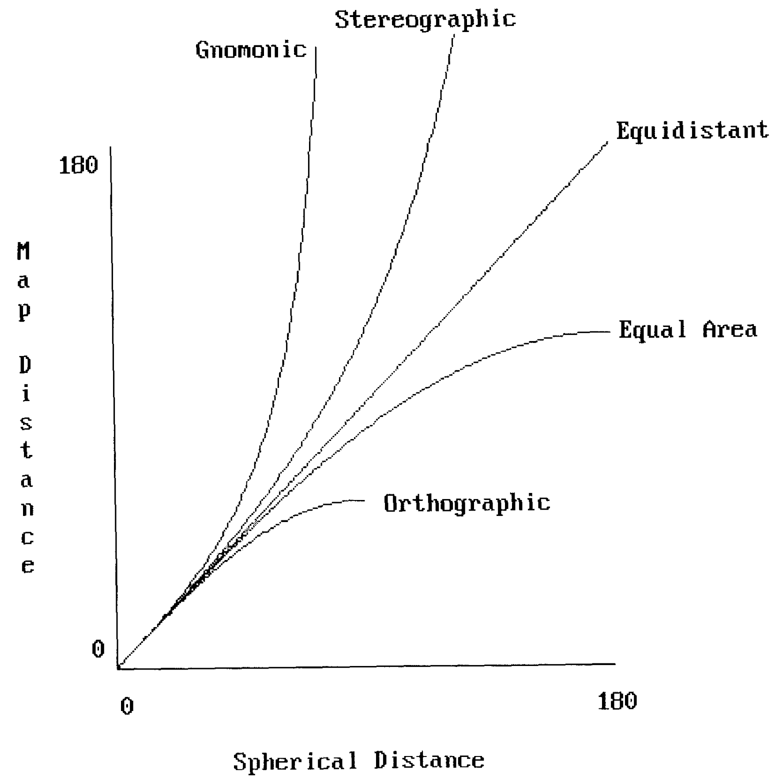

Figure 2. Radial distance display of azimuthal projections. Spherical distances along the X axis, map distances along the Y axis.

jection. In this view, Snyder's (1987) 'Magnifying Glass' projection appears as a kinked line (Figure 3).

In studying migration about the Swedish city of Asby, Hägerstrand (1957) used the logarithm of the actual distance as the radial scale. This enlarges the scale in the center of Asby, near which most of the migration takes place. Actually, but not generally shown, there is a small hole in the middle of the map since the logarithm of zero is minus infinity. This logarithmic azimuthal projection can easily be represented in the same graphic form as Snyder's 'Magnifying Glass' projection.

"Retro-azimuthal projections show the direction to, not from, a center."

Figure 4 shows two new map versions in the same form as quarter circles, one giving an azimuthal myopic view $\{r=(2\pi-\rho^2)^{\frac{1}{2}}\}$ and the other an anti-myopic view $\{r=\pi -(\pi^2-\rho^2)^{\frac{1}{2}}\}$. Popular today are also azimuthal maps on which the distance from the center is represented as fractional powers such the square or cube root of the spherical distance (Figure 5). It is also possible to scale azimuthal maps in terms of cost distances.

Retro-azimuthal projections show the direction to, not from, a center. For these maps it is also possible to choose different the distances to the center. One use was to let British colonials know in which direction to point their radio antennas to receive a signal sent from Rugby in the U.K (Hinks, 1929; Reeves, 1929). These unusual projections generally contain a hole inside of the map and a portion of the area overlaps itself (Tobler, 2002). The size of the overlap, and the void, depends on the latitude of the map center. Several retro-azimuthal projections are demonstrated in a computer program from Axion Spatial Imaging.

"Equal area projections are such that map areas are proportional to spherical areas."

Equal area projections are such that map areas are proportional to spherical areas. They are obtained by setting the differential of surface area on a sphere equal to that of a flat map. The consequent differential equa-

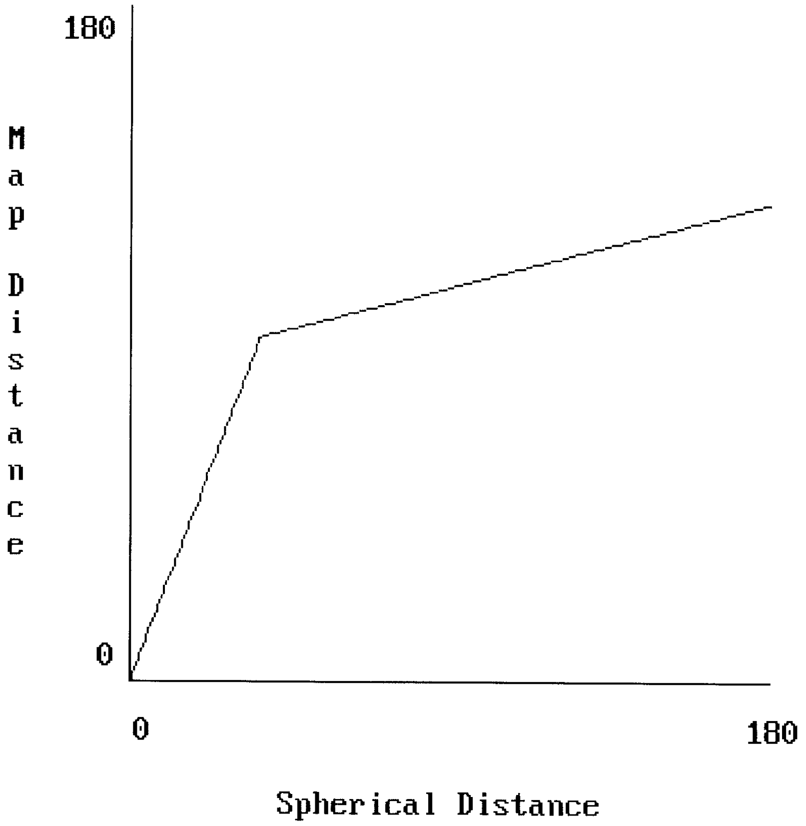

Figure 3. Snyder's magnifying glass azimuthal projection in the radial distance form, with two scales and a discontinuity.

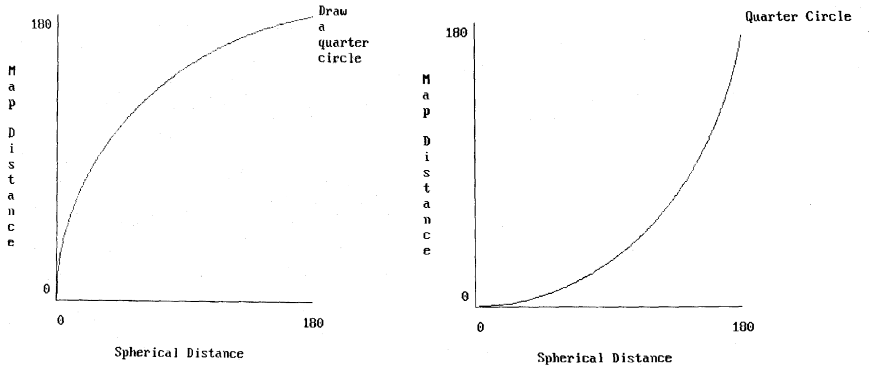

Figure 4. Two new azimuthal projections: myopia version (left) and anti-myopia version (right).

tion has many solutions and thus depends on additional conditions. One such condition is to fit the maps into a particular shape. Quite a number of such shapes have been obtained. Here are a few new ones. It is relatively easy to fit equal area maps into regular N sided polygons. One computer program can do them all, starting with a triangle, for which N = 3. The case of a pentagon (N = 5) is shown here (Figure 6). Beyond about twenty it is not very interesting because the maps all converge to Lambert's (1772) azimuthal equal area projection with a circular boundary.

"It is relatively easy to fit equal area maps into regular N sided polygons."

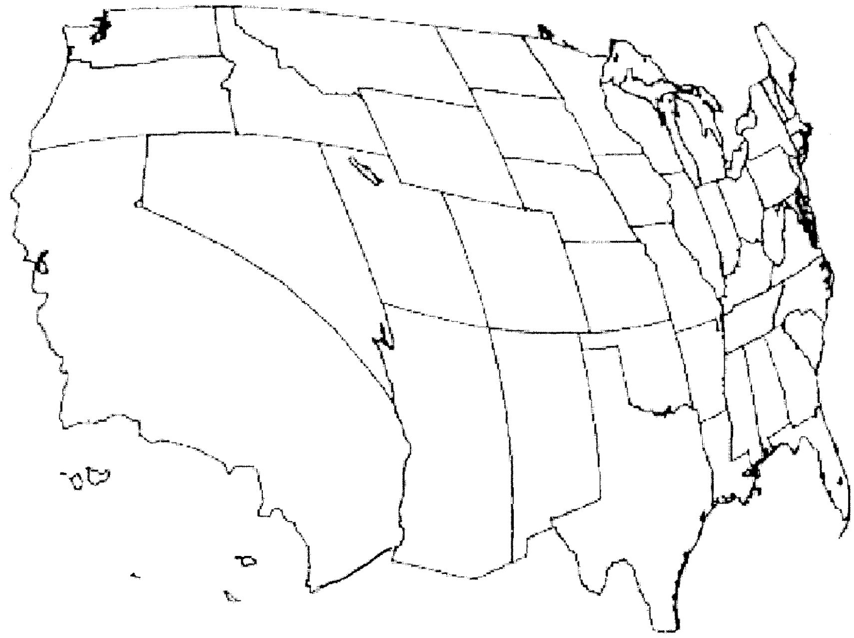

Figure 5. The Santa Barbaran View. Cube root distance azimuthal projection centered on Santa Barbara.

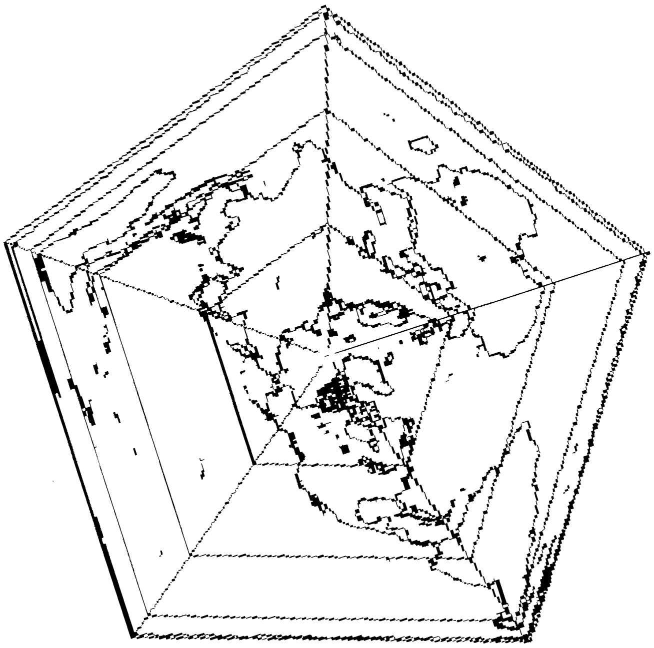

Figure 6. A new equal area map in a polygon. This is the polar case in a pentagon.

Maps on the five platonic solids have also been known for a long time (Fisher and Miller, 1944). They can be equal area or conformal. The gnomonic projection is particularly easy to do on the surface of these solids. Apparently they have never been done on the surface of a pyramid. The next illustration is a special case of an equal area projection having N pointed triangular protrusions on an N-sided base. For three lobes, the base is a triangle (this folds into a tetrahedron) with four lobes we get the pyramid (Figure 7). For six lobes the base is a hexagon. Again, all can be drawn using just one computer program with N as parameter. Conformal versions are also possible.

Composite equal area projections are perhaps of little value, but are fun. The combining technique works with most polycylindric and pseudocylindric projections including the Lambert cylindrical, Mollweide's (1805) projection and the sinusoidal, and those of Craster, Eckert, Boggs, etc., and with Tobler's (1974) hyperelliptical system of projections. All are equal area projections, all maintain the length of the equator, and all meridians meet the equator at a right angle. Therefore these projections can be joined at the equator to have one projection for the Northern hemisphere, and another for the Southern hemisphere. Figure 8 shows an example, with

"Composite equal area projections are perhaps of little value, but are fun."

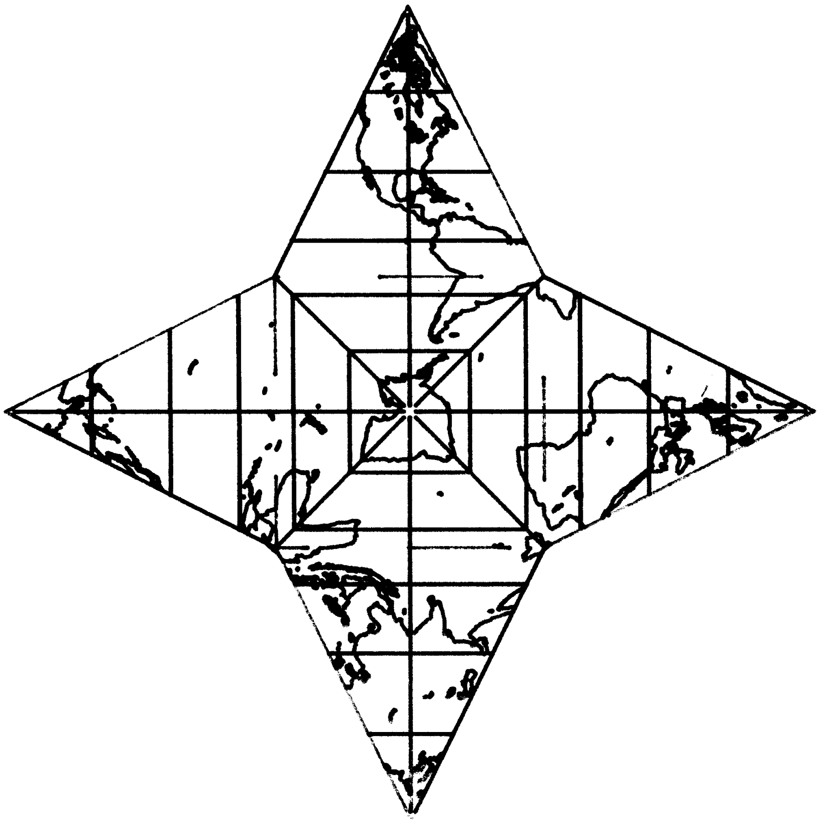

Figure 7. An equal area projection on a pyramid (North polar case). (Cut out and glue together).

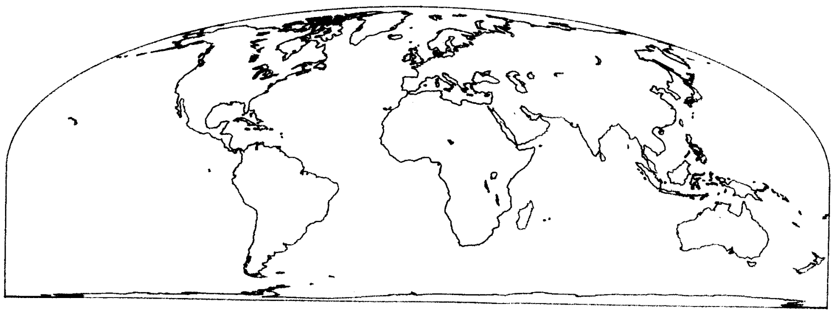

Figure 8. An equal area projection combining two projections. Mollweide's projection above Lambert's cylindrical equal area projection.

Mollweide's projection on top and Lambert's equal area cylindrical projection as the Southern base.

Affine transformations of equal area maps can yield more variants. An example is Mollweide's projection converted into an equal area circle (Figure 9). The equations are X′ = 2X, Y′ = Y/2, where X and Y are the original Mollweide coordinates and the primes denote the new coordinates. Another gives an equal area square obtained from Lambert's equal area cylindrical projection (Figure 10).

"In addition to directions and areas, geographers who use maps are also concerned with distances."

"Computing coordinates from distances is known as trilateration, it is also known as multi-dimensional scaling."

In addition to directions and areas, geographers who use maps are also concerned with distances. In general, all spherical distances cannot be correctly preserved on maps. But from one location, we have the equidistant azimuthal projection; the two-point equidistant projection is not often used but is occasionally appropriate. Chamberlin (1947) has given an approximate solution using three spherical distances. In order to best preserve all distances from more than three points one can used advanced techniques. Computing coordinates from distances is known as trilateration, it is also known as multi-dimensional scaling (Tobler, 1996). If one takes road distances from a Rand McNally (or other) road atlas and uses these distances to compute the location of the places, one can then interpolate the latitude-longitude graticule, and from this draw a map with state boundaries and coastlines. The resulting map projection (Figure 11) illustrates the distortion introduced by the road system.

Furthermore, Tissot's (1881) indicatrix can be used to calculate the angular and areal distortion, as well as the distance distortion, in every direction, at each map location. These measures provide indications of the

Figure 9. Mollweide's equal area projection affinely modified to fit in a circle. The equal area property is retained.

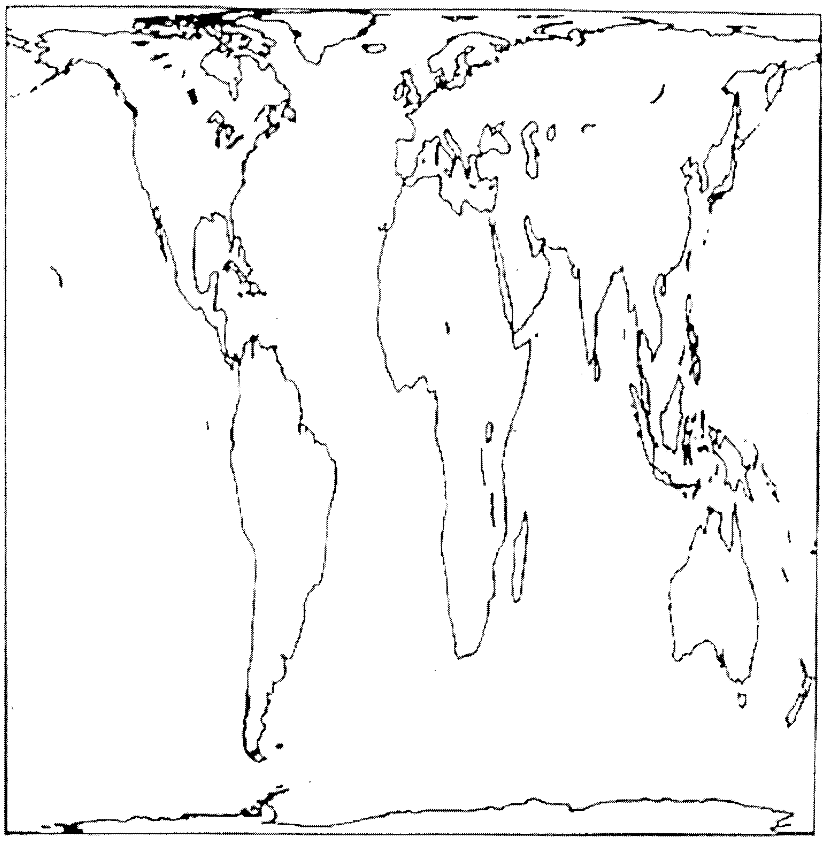

Figure 10. Lambert's cylindrical equal area projection affinely modified to fit in a square. The equal area property is retained. The equations are $X' = X / \pi^{1/2}$, $Y' = \pi^{1/2} Y$, *where X and Y are the original Lambert coordinates.*

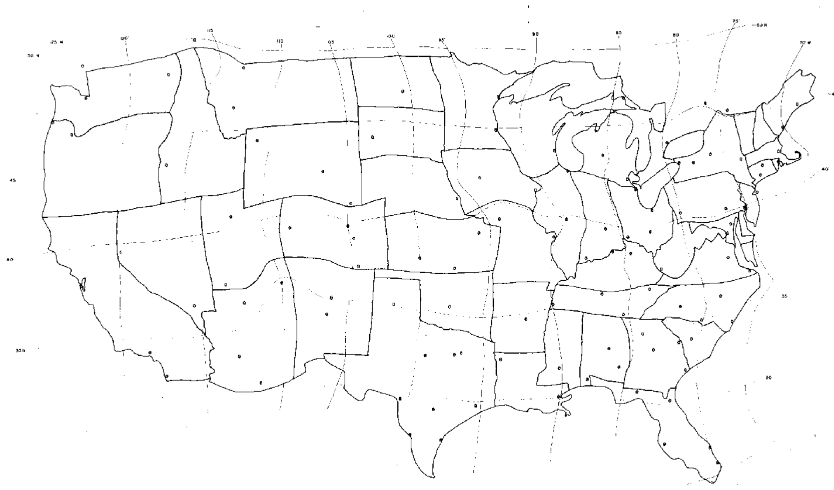

Figure 11. Student rendition of a road distance map of the United States, fitting distances from an atlas table. Graticule and state boundaries interpolated.

impacts of a road system, suggesting the use of map projections in transportation studies. Instead of using road distances, travel times or costs, or great circle distances, one can also construct a map to preserve, in the least squares sense, loxodromic (rhumb line) distances, a hypothesis being that Portolan Charts made prior to 1500 AD might have used such distances in their construction (Figure 12).

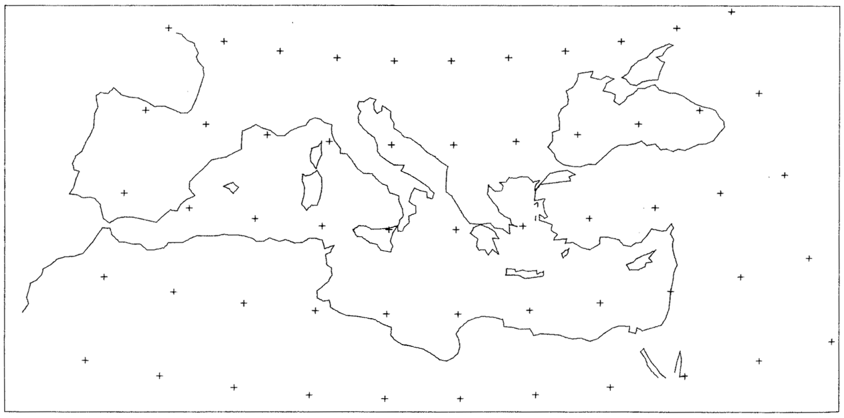

Figure 12. Mediterranean Sea best preserving loxodromic distances.

One additional projection that preserves distances is the Stab-Werner (1514) projection, but it shows distances correctly from only one central location. This is normally one of the poles, most often the North Pole. The projection also happens to be equal area. Oblique versions of Werner's projection are rare, although transverse versions of the closely related Bonne projection have been used. Such an oblique Werner projection is shown here (Figure 13) in the form of a graticule sketched in circa 1960 from line printer output with the center at the latitude and longitude of New York City, and with the central axis directed towards Seattle.

The North Pole can be seen, from the graticule, to north of the center of New York. The map has been rotated so that the New York – Seattle great circle is the horizontal axis. As such this is not a terribly interesting map but it suggests an alternative, as follows. It is often asserted that transportation costs increase at a decreasing rate with geographic distance. In other words, that the cost-distance curve has a concave down shape. On

> *"It is often asserted that transportation costs increase at a decreasing rate with geographic distance. In other words, that the cost-distance curve has a concave down shape."*

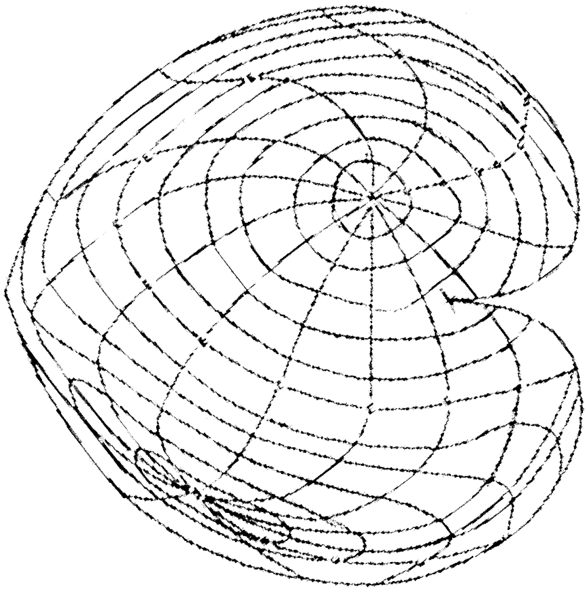

Figure 13. Werner's projection centered at New York, with the central great circle directed towards the left tip. Seattle lies on this great circle at its correct distance from New York. The map is North oriented.

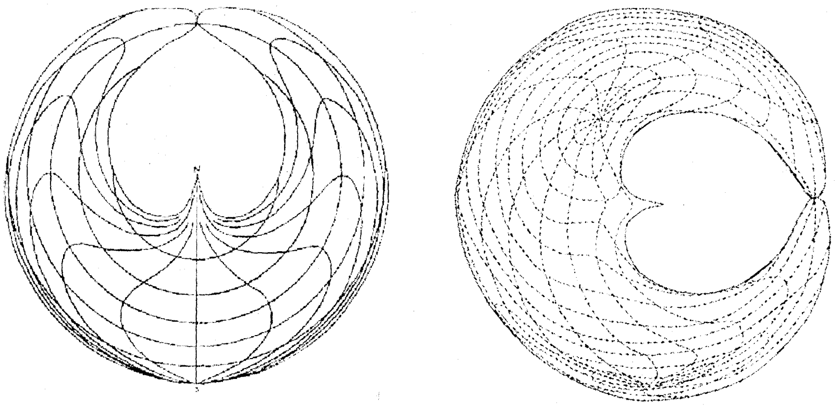

Figure 14. An equal area map using concave down (square root of) spherical distances. Left: polar case graticule to illustrate the properties. Right: centered on New York with the central great circle directed towards Seattle. The map is North oriented.

the map that follows (Figure 14) this cost idea is represented by the square root of the spherical distance from the map center, but the map has also been made to preserve spherical area.

The equations are:

$$X = R\,(2\rho)^{1/2} \sin(\lambda \sin\rho)$$

$$Y = R\,(2\rho)^{1/2} \cos(\lambda \sin\rho)$$

where ρ is the spherical distance from the map center and λ is the longitude. The map has a cordiform hole in the interior. The latitude and longitude of New York has again been chosen as the center and the direction is to Seattle. It has again been rotated so that the New York – Seattle axis is horizontal. The equal area property, along with the concave distance function on this map, allows economic geography to be coupled with cartography. Other concave down distance functions can also be combined with the equal area condition to give difference maps of this type.

"The equal area property, along with the concave distance function on this map, allows economic geography to be coupled with cartography."

A common and useful technique is to use a correctly chosen coordinate system in order to simplify a problem. Instead of using straight meridians and parallels on a cylindrical map projection to show curved global satellite tracks, let us bend the meridians so that the satellite track becomes a straight line. This is more convenient for the automatic tracking of these satellites. What this looks like can be seen in an obscure paper by Breckman (1962) in which a map is designed for a satellite heading southeast from Cape Canaveral. The satellite path has become a straight line, making tracking much easier. Since the satellite does not cross over Antarctica this is therefore not on the map. The track is a 'saw-tooth' line, first South, then North, then South again.

On the next map (Figure 15) the geomagnetic coordinates are straightened in order to simplify the solution of problems involving terrestrial magnetism. This warps the normal geographic coordinates, but so what? It is not difficult to produce such maps graphically; it can also be done analytically. The idea is that we transform the graticule, and map, then study or solve our problem in this new reference frame, and then take the inverse transformation to bring the result back to the more conventional coordinates. This transform-solve-invert paradigm is well known in mathematics (Eves, 1980). This is also an example of how Mercator's idea works, and is one way in which areal cartograms, a generalization of equal area projections, may be used (Tobler, 2004). Kao (1967) provides further examples.

"The idea is that we transform the graticule, and map, then study or solve our problem in this new reference frame, and then take the inverse transformation to bring the result back to the more conventional coordinates."

For quickly displaying geographic data on a computer screen it is not necessary to use a complicated projection such as the transverse Merca-

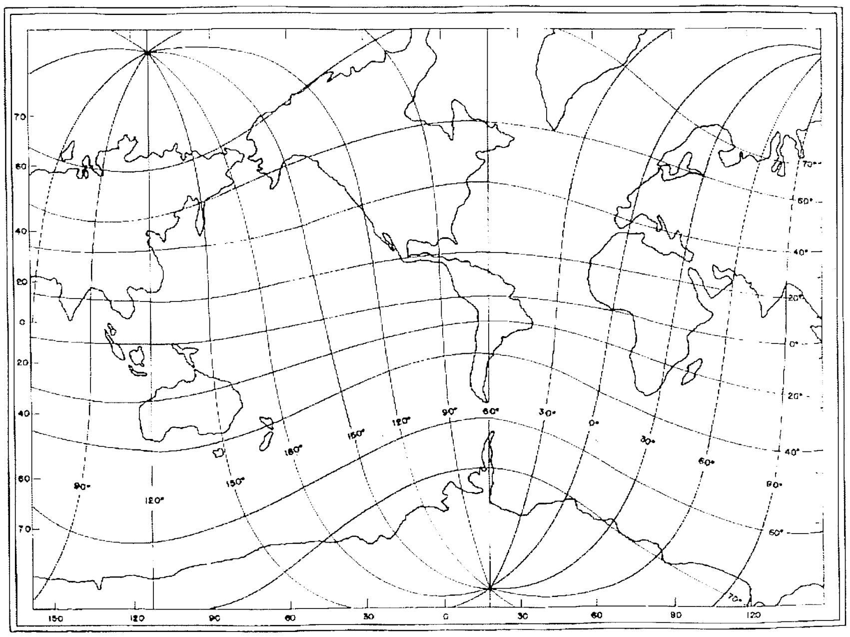

Figure 15. Student rendition straightening magnetic meridians and parallels.

tor. A much simpler set of equations will do, assuming that the data are in latitude and longitude coordinates (Tobler, 1974). Only two parameters are required: the average latitude and the average longitude of the center of the area. The necessary equations are then:

$X = R\{\cos(\varphi_o)\,\Delta\lambda - \sin(\varphi_o)\,\Delta\varphi\,\Delta\lambda\}$

$Y = R\{\Delta\varphi + 0.5\sin(\varphi_o)\cos(\varphi_o)\,\Delta\lambda\,\Delta\lambda\}$,

where R is in kilometers per degree on the mean radius sphere at the center location, $\Delta\varphi$ is the latitude minus the average latitude φ_o, and $\Delta\lambda$ is the longitude minus the average longitude. The X and Y values are then in kilometers. The resulting display is neither equal area nor conformal, but quite accurate and easy to compute for a small area not near either of the poles. The equatorial version for the entire earth – not a small area – will give a bow tie shaped map (Figure 16). Away from the Equator the whole earth can resemble a floppy bow tie. So use this projection only for areas smaller than the whole earth.

> *"The resulting display is neither equal area nor conformal, but quite accurate and easy to compute for a small area not near either of the poles."*

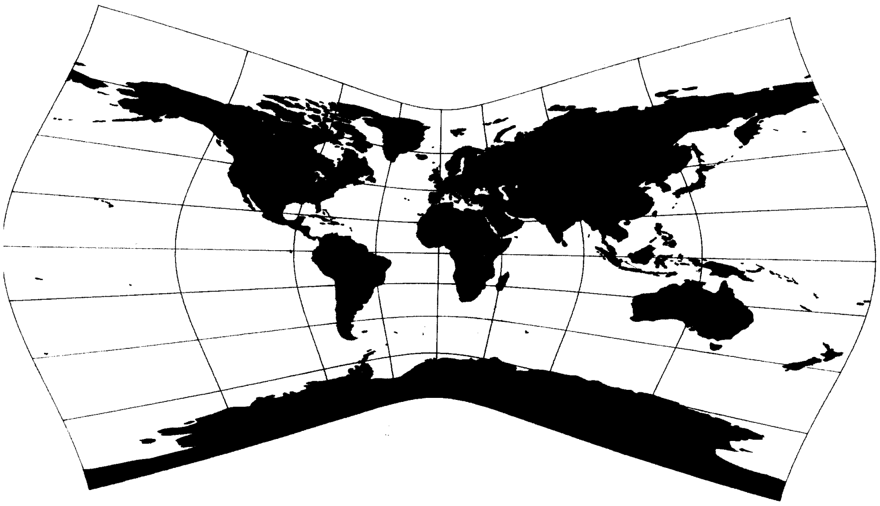

Figure 16. A bow tie projection.

It is sometimes asserted that one disadvantage of a globe is that the entire earth cannot be seen at one time. But, the entire earth can be seen at one time if the transformation $\varphi' = \varphi$ and $\lambda' = \lambda/2$ is used. Here φ is latitude, and λ is longitude. This transformation maps the entire surface of the earth onto one hemisphere. Repeat this for the backside of the globe and hardly anybody will notice that everything appears twice. East-West distances are of course foreshortened. Other versions of this are possible.

Finally

This introduction to a few unusual map projections will, hopefully, convince you that not only can these transformations be useful but also that they can be fun.

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Reviews

The Animated Atlas of Air Traffic over North America
By Michael P. Peterson and Jochen Wendel
Laboratory for Cartography and Geographic Information Systems
University of Nebraska at Omaha, 2006.
Format: Data DVD designed to work on a computer (Mac or PC) and will not work on a DVD player and television. The data DVD is also accompanied by a booklet, ix, pp.44, 27 printed maps, one photograph. Price of DVD unknown to the reviewer. The booklet is spiral bound.
ISBN: 0-9776676-1-8.

Reviewed by Gregory H. Chu
University of Wisconsin-La Crosse

The Animated Atlas of Air Traffic over North America is primarily a collection of animated maps showing what one presumes is a typical day's flight traffic for that continent, compiled from data collected over several months of monitoring. It is supplied on a DVD format disc. The DVD requires a software program called 'Divx' to work. An installation link for this appears for the PC in the autorun screen and Mac software is downloadable from www.divx/com/divx/mac/download/. The organization of the entire atlas is somewhat atypical; all the animations and links are placed on the DVD while a separate booklet is devoted to five chapters providing explanatory and analytical information on air traffic control, flight mapping, and air traffic patterns. While anyone who has ever used a mouse will be tempted to bypass the booklet and start clicking on the interactive links on the computer screen, it may be helpful to read the booklet first in order to understand the overall picture on how North American air traffic is managed by the FAA and its Canadian counterpart as well as many of the industry's terminologies.

The DVD home page is a lead-in screen organized into 9 interactive linked pages: *All flights*, *Aircrafts*, *Airlines*, *Airports*, *Corridors*, *Regions*, *States*, *Links*, and *About*. Other than the *Links* and *About* pages, all of the linked pages contain animations; over 70 in total, created from more than 100,800 individual maps. Each animation utilizes 1440 frames (the number of minutes in a day) to display all of the flights that took place in a 24-hour period beginning at noon and ending at noon of the next day. The animation screen provides an option of selecting animations speeds at 0.5X, 1X, and 2X. In addition to the moving planes, an animated analog clock runs on the lower left corner to tie in the traffic pattern with the time of day. The data for these flights were from March 2003 to September 2005 and the animations were created with a 2002 program called FlyteTrax (FlyteTrax.com).

The *All Flights* page presents three animations: one over Canada, one over the continental U.S., and one over the Caribbean. From these animations, one can identify the spatial and temporal patterns of the heavy traffic corridors. It is easy to identify air traffic over northern Canada and distinguish those that are mere commuters between isolated northern Canadian communities from international flights that are taking advantage of the polar routes. The *Aircraft* page breaks down all the flights by the make and model of the aircraft (for example, Boeing 757s) that are in flight in that 24 hour period. It is a little unclear why this page was included; I doubt there are many who are interested in specific patterns based only on the make of aircrafts.

The *Airlines* page classifies all flights by airline and is perhaps the most useful page of the entire atlas. One can visualize the traffic patterns of the top ten passenger airlines plus three other airlines, the top 4 cargo airlines, and all foreign airline traffic in the US. Spatial comparisons can indicate where each airline has its major passenger markets; hubs for each airline can be clearly identified. It is also interesting to note the time frame when some of these airlines have the least amount of traffic, provoking thoughts of whether that airline can be more aggressive in promoting routes at these times (for instance, Southwest Airline does not have a single flight in the air from 2:15 am to 5 am Central Standard Time). Flight patterns generally begin each morning, for each airline, from the east coast first and end with west coast traffic at night. In contrast, the animation for Federal Express airplanes clearly reveals a different work schedule; at 2 pm, which is normally a busy air passenger traffic time, there are only two Fed Ex flights in the air. Beginning at 3 pm, large numbers of flights depart its headquarters at Memphis, TN and from 10 pm through 1:30 am, also large numbers of flights return to Memphis. It then remains quiet until 3:15 am when many Fed Ex planes leave Memphis for the morning delivery nationwide.

The *Airports* page can also provide useful spatial information. Animations are provided for twenty US and eight Canadian airports, basically showing all air traffic going in and out of each airport. The *Corridors*, *Regions*, and *States* pages are similar organizations of flights based on different spaces. In the *States* page, eight animations are presented for eleven states or pairs of states (states that were combined into one single animation include Colorado and Kansas, Montana and Idaho, Nevada and Utah). Also in the *States* page are two air traffic animations that show two different time frames for Hurricane Katrina along the Gulf Coast. It is interesting to see the pattern of air traffic being affected by the Hurricane.

The technical aspects of animation are very well achieved. The design of the animated maps was thoughtful and effective. Each animation this reviewer saw presented clear visualization of the spatial patterns of the air traffic. Analytical maps from the booklet presented generalized spatial patterns for the red-eye flights, the morning waves, the hub spokes, the hub pulse clusters, the hub commuters, the mail service traffic (and its unique work time schedules), as well as international arrivals. While the animations are effective in showing each spatial scene, it must be remembered that data for each animation were based on flight patterns that were mapped as a one-time (24 hour) instant that may vary from year to year as airline routes are changed by the FAA and/or the airlines themselves. Thus, the contribution of an atlas such as this one should be treated more as an example of good technical production or even a well designed collection of animations that may lead to meaningful visual analytical interpretations rather than the common expectation that an atlas provides complete reference information. Such an expectation may be next to impossible to achieve for an animated atlas. Other than the usefulness that was described above by the pages, there appears to be limited application value. It was also unclear to the reviewer who may be the intended audience. No information was provided to this reviewer regarding any commercial distribution of this atlas, its market price, or how to obtain a copy. Nevertheless, it was a joy to watch the animations, contemplate the spatial patterns that were presented, and learn more about the air traffic industry.

Wabanaki Homeland and the New State of Maine: The 1820 Journal and Plans of Survey of Joseph Treat

Edited with an Introduction by Micah A. Pawling
University of Massachusetts Press
Amherst, Massachusetts, 2007
300 pages, with reproductions of hand drawn maps throughout
$34.95 hardcover
ISBN 978-1-55849-578-4

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Wabanaki Homeland and the New State of Maine: The 1820 Journal and Plans of Survey of Joseph Treat begins with a detailed Introduction by Micah A. Pawling to the Joseph Treat journal and surveys. Pawling prepared this book while a Ph.D. candidate in history at the University of Maine. His Introduction provides important insight into the driving political and cultural forces that necessitated the Treat expedition in the first place. Pawling also explains the ongoing significance of Treat's documents in historical context.

The Joseph Treat journal itself was created in diary format during the course of a fifty-six-day exploration of northern Maine waterways undertaken in 1820. Treat's detailed surveys of the region are complemented by his journal entries to provide a unique overview of place and time. The original spelling, punctuation, capitalization, and sentence structure used by Treat have been retained in their entirety (as reflected in the passages quoted within this review) and include the Penobscot place names Treat learned along the way from his Wabanaki guide, John Neptune. Helpful footnotes have been added by Pawling as an adjunct to the original text to familiarize readers with the current place names and locations of the areas referenced in the Treat journal and to provide historical commentary or cite related textbooks that further illuminate the journal entries.

As a new state in 1820, Maine was eager to settle northeast boundary disputes with neighboring New Brunswick and other Canadian territories. The Saint Croix River had previously been established as the official boundary between eastern Maine and southwestern New Brunswick, but the northern boundary between Maine and Canada was much less certain. Major Joseph Treat was hired by Maine's Governor King and his executive council to explore and document the lands along the Penobscot and Saint John Rivers, which comprised much of the disputed area. In 1820, this land was largely the province of the Wabanaki people, and little was known about its geography outside the Native American community. (Micah

Pawling explains in his Introduction that for the purposes of this book the term "Wabanaki people" refers to the Mi'kmaqs, Maliseets, Passamaquoddies and Penobscots, along with other Abenaki Indian groups.) Both Maine and New Brunswick wanted control of the vast quantities of timber indigenous to the region, but no viable claim could be made by either side until a recognized boundary was established.

Since much of the Maine interior was still largely inhabited by Native Americans, and in particular the Wabanaki people, the Treat expedition required Native American knowledge and insight to facilitate its travels. John Neptune, a prominent Penobscot leader, guided the Treat expedition and greatly influenced the Treat journal.

Joseph Treat was born in Bangor, Maine, in 1775 to a prominent merchant family. He learned surveying through firsthand experience. In the early nineteenth century, Treat's familiarity with the local geography earned him a respected place in the Penobscot River Valley community. Many of his business dealings are described in Pawling's Introduction, since they played a small but important role in regional development and politics.

John Neptune was born in 1767. He previously worked with Joseph Treat on a survey of Mount Katahdin and the East Branch of the Penobscot River in 1804. In 1816, Neptune was named lieutenant governor, or second chief of his Penobscot tribe. He was considered a great religious leader among his people.

Prior to statehood in 1820, the District of Maine was part of Massachusetts. During the twenty-five years preceding the Treat expedition, the ownership and rights to lands in the Penobscot River Valley were hotly contested by the governing powers of Massachusetts and the Wabanaki people. For instance, a treaty had been established in 1796 involving islands within the Penobscot River to which both parties felt they were entitled,, depending on which way the treaty was interpreted. The Penobscots felt that all the river islands were interconnected; thus they believed that their defined ownership of even a portion of one of the islands entitled them to ownership of all the islands as well as to the waterways between them. The Massachusetts government felt equally entitled to single out certain of these islands for sale and development by white settlers, including Joseph Treat. The Penobscots became increasingly concerned about the development of mills on the river islands, since mills prevented the free movement of fish to Penobscot fishing grounds upstream and fish was the mainstay of the Penobscot diet at that time.

In July 1820, an alliance was formed by treaty between the new State of Maine and the Penobscot people. In return for recognizing the new state over their previous associations with Massachusetts, the Penobscots requested protection of their tribal rights, including defined fishing areas. Joseph Treat signed the treaty as a witness.

In September 1820, Treat began preparing for the fifty-six-day expedition that, as initially planned, would lead him along the Penobscot River to the Saint John River by way of Chesuncook Lake and a portion of the Allagash River. Joining him were John Neptune as guide and Captain Jacob Holyoake. They would be traveling by birchbark canoe and on foot, depending on conditions.

The expedition officially began on Tuesday, September 26, 1820. Treat's journal entries document the geographic landscape of the region seen along the way, as well as what Treat considered the important cultural and economic features of his time:

Marshes Island is seven miles long and contains 5,000 acres of land on which there are many excellent mill seats at Old Town and Stillwater in Orono. —Madamiscontis is a considerable stream, has 2 ponds on which are saw and grist mills.

The copies of the original survey sketches Treat made along the rivers and waterways alternate pages with the corresponding journal entries made at each location. The sketches are very well detailed, particularly considering the conditions under which they must have been made, and include the locations of homesteads along the river as well as the owners' names. The journal carefully describes the variety and size of the timber growth in each area, since one of the key goals of this expedition was to note whether and where this important resource may have been disturbed to benefit British/Canadian interests:

In this days journey up river we see many stumps of pine trees near the bank which have been cut from one to three years ago—We also see some mill logs and timber on the shore—and presume that timber is cut 30 to 40 miles above where we went which is 15 miles up the River from its junction with the St. John.—

By October 8, the expedition party had reached Mount Katahdin, the highest elevation in Maine. The journal estimated the height of the mountain to be "at least 6,000 feet," although Katahdin's highest point is actually closer to 5,267 feet. From Katahdin's peak, the party took bearings of the surrounding ponds and mountains until mid-afternoon and then returned to their camp at the base of the mountain. A partial listing of the actual bearings noted during the expedition, along with their Penobscot place names, is included in the journal.

By mid-October the expedition reached Chesuncook Lake despite some minor delays caused by bad weather and water levels too low in some areas of the river to make safe canoe passage possible. In fact, the low water levels were such a concern that Treat at this point had to change the original expedition route:

My intention was, and agreeably to my instructions, to have gone up the West branch to its source, but finding the water very low in the River, had yesterday concluded to go up the river as far as the Portage to Moose head, return to Cheesuncook, thence to St. Johns, but the season being late, the water so very low, and having lost considerable time by stormy windy weather, and from information of the Indians camped here that it will take 4 days to go and return from Moose Lake—also that the water is very low in the St. John and we cannot make much progress on our route—I this day concluded to go as fast as possible to Madawaska which the Indians say in the present state of the streams will take 10 to 12 days—I am however in hopes that the last rains will raise the streams through which we have to pass—

Once on the Saint John River, the expedition party encountered many French settlers along the shore. Treat used the opportunity to replenish his party's bread supply, which had gotten low due to the extra days of travel caused by bad weather and low water levels. The expedition party was also out of candles at this point, so many of the survey sketches and journal entries were being done by firelight. On October 23, Treat estimated 150 families were living along the Saint John River near what is now Madawaska, Maine. He described the farming practices among these families:

The Madaweskians raise good wheat, rye, oats, barley and peas and excellent potatoes—the land produces excellent grass—they keep many cows and oxen of a small hardy breed—very fat also and small Canadian or Pony horses—which are very serviceable—a small proportion of their cleared land is tilled compared with the quantity of grass or meadow land.—

On October 25, in snowy weather, Treat noted "spottings" on the trees along the river that he believed marked the eastern boundary line between Maine and New Brunswick. He felt it was particularly important to note the locations of houses and other settlement in that area in case a future war with England should break out.

With snow and cold increasingly an issue, Treat was forced on October 28 to alter his route once again. Rather than risking the ice-covered streams that Neptune anticipated by continuing up the Aroostook River to the east branch of the Penobscot River and thence homeward, the expedition party decided to return to the larger Saint John River after a brief exploration of the Aroostook:

It commenced snowing last evening at nine o'clock, and snowed a little during the night—very cold weather—Here we conclude to go one days journey up the Aroostick and return to the St. John and home by Madawamkeag—

By November 16, ice was making travel very treacherous. If the ice on the river was thin enough, the expedition party would break through with poles and continue slowly along the river by canoe. If the ice was thicker, the party had to carry the canoe or build sleds along the way to drag it across the ice. Travel was necessarily slow, and only enough rations remained for two more days. There had been no settlers along the shore for quite a distance, which meant there was no opportunity for Treat to replenish their supplies:

We have no provisions except two quarts of Indian meal and 1/3 a pound of Pork—a small quantity of ginger and some sugar—We make our meal into hasty pudding and eat half of that and the pork for supper—and hope to arrive tomorrow night at the Passadumkee where we can replenish our stock of Provisions—

The news was better two days later:

We resume our journey and travel on the ice to the foot of Ma,da,na,cook dead water, thence on land and ice to Mr. Nolen's near Passadunkee, where we procure refreshment, and remain this night having travelled this day about twenty miles—

On the evening of Monday, November 20, 1820, the Treat expedition finally returned to Bangor, where Treat would submit his report to Governor King. The journey and the journal end here.

Minutes of the 1820 treaty negotiations between the Penobscot Indian Nation and the State of Maine are provided as an Appendix to *Wabanaki Homeland and the New State of Maine: The 1820 Journal and Plans of Survey of Joseph Treat*. The text of the treaty itself is also included, followed by a detailed index that completes the volume.

I must admit that I have a lifelong fondness for the State of Maine, I have always appreciated good maps, I am an avid reader of biographical material, and I work in the civil engineering and survey industry, so I was predisposed to enjoy this book on a variety of levels. I found the similarities between the style of Treat's hand-drawn survey work and its modern computer-aided equivalent to be quite striking at times. Even with the state-of-the-art equipment currently available, I am sure that many of today's surveyors can relate to the hazards of surveying remote locations in order to document the critical points of reference needed by the population at large.

Although ongoing development has changed even the northernmost part of Maine, the area documented in Treat's journal will still be recognizable to anyone interested in Maine's geography or history. Pawling's extensive Introduction provides the perfect preamble to the journal itself. I came away with a greater appreciation of the Treat expedition by first understanding the circumstances surrounding it than I would have by simply reading the journal by itself.

What struck me most about the journal were the references Treat made to sharing a meal and spending a night with many of the settlers he met along the way. He uses words like "politely" and "very politely" to describe the treatment he and his party received from people who were essentially total strangers. It is hard to envision taking any kind of trip in today's society and relying solely on the kindness of strangers for occasional food and lodging. The dangers it would present to parties on both sides would simply be too great for such a journey to be feasible.

Pawling's Introduction includes details about the 1842 Webster-Ashburton Treaty that eventually determined Maine's northern boundary, but little information about the later lives of Joseph Treat, John Neptune, or Jacob Holyoake. I suppose this is in keeping with today's cruise ship mentality, where people travel closely together for a set length of time and may even form attachments, but ultimately go their separate ways and lose contact once their home port is reached. Even so, after vicariously joining the Treat expedition and traveling in harsh conditions with these men for nearly two months, I would like to have learned more about what happened to them, both personally and professionally, after the expedition was over. References are made in the footnotes, however, to other textbooks that might provide this information.

That being said, I would still highly recommend this book for anyone with an interest in surveying, biographies, American history, American geography, Native American culture, or Maine in particular. *Wabanaki Homeland and the New State of Maine: The 1820 Journal and Plans of Survey of Joseph Treat* provides a multi-faceted look at the complexities of human relations in the burgeoning United States and the important role that cartography played in both documenting and influencing historical events.

Cartographic Science: A Compendium of Map Projections, with Derivations

Donald Fenna
CRC Press, Boca Raton. 2007.
ISBN 0-8493-8169-X, hardbound, alkaline paper. 491 numbered pages; hundreds of diagrams, tables, and illustrations.

Reviewed by daan Strebe

Reviewer's Note: *The author used software (Geocart) I wrote to illustrate much of the text, cites Geocart and me in the acknowledgments, and illustrates three projections I developed. I did not edit, review, or contribute to the text in any way; nor did I know of Dr. Fenna or his enterprise until it was effectively finished. My contact with Dr. Fenna was largely in the form of Geocart technical support.*

The last quarter of the twentieth century saw publication of many English language encyclopedic works on small-scale map projections. D.H. Maling published the seminal *Coordinate Systems and Map Projections* in 1973, significantly revising and expanding it for a 1992 edition. The prolific John P. Snyder led out the 80s with *Map Projections Used by the US Geological Survey* in 1982 and expanded it into 1987's *Map Projections — A Working Manual*. His 1989 *An Album of Map Projections* presents a wide array of projections in a standardized format, along with generating formulæ in the appendix. He cemented his credentials as a historian of map projections with 1993's *Flattening the Earth —Two Thousand Years of Map Projections*, describing hundreds of projections, many with formulæ. Frederick Pearson II issued *Map Projection Methods* in 1984, polishing and expanding it in 1990's *Map Projections: Theory and Application*. Canters and Decleir systematically catalogued many dozens of world map projections in a highly regular format in their 1989 *The World in Perspective: A Directory of World Map Projections*.

Someone interested in map projections would have muddled through a very lonely hobby in 1972. Formulae for simply generating a wide variety of projections were not to be found consolidated in any source. While plenty of texts were published on the topic, they tended to be monotonous repetitions of the basics of cylindric, conic, and azimuthal themes. If you wanted to know how to construct a van der Grinten projection—long the mainstay of National Geographic's world maps—you might likely have needed to refer directly to van der Grinten's original patent. Yet less than twenty fecund years later, one could choose to drown oneself in projections both celebrated and obscure for the price of a text or two — and rather well-written ones at that. One might suppose the needs have been sated.

Against that history, Dr. Fenna sets an ambitious agenda. Yes, his *Compendium* is yet another catalogue of map projections; yet it is more. Most of the aforementioned encyclopædic works present mathematical derivations of the foundations of map projection theory and of the basic categories of projections. They also all present final formulæ for the profusion of projections that appear in passing. Derivations of those formulæ, however, are largely absent. Fenna aims to fill this void, specifically aspiring to be "a companion to [Snyder's] *Album* and a bridge to there from his [*Flattening the Earth*]." Audacious, perhaps, but not impossible. We shall see if he succeeds.

The book begins with a careful explanation of the text's purpose, scope, structure, nomenclature, idiosyncrasies, and sources. This same minute care is perpetuated throughout; the style is an antithesis to the breathtakingly terse texts of the early twentieth century. A mathematician already possessed of all the mathematical tools and insights might find the derivations tedious and the pedantry unwelcome, but Fenna anticipates this, stating that the needs of those without specialized knowledge are given priority. Given my later remarks on audience, his choice might have been wise.

He first describes the "curved world"; progresses into the "spherical world" (comprising the bulk of the book); devotes a few dozen pages to the "ellipsoidal world"; and finishes with a few pages about the "real world." This progression, of course, mirrors successively less abstract models of the earth while concentrating most heavily on the fittest abstraction for small-scale maps. Conveniently, it also parallels successively more complicated mathematics, a progression important to the book's purpose and design.

Each of these parts is divided into very focused chapters. Many chapters come with "tutorials" describing the mathematical concepts used thenceforth. Theoretically, no more than high school algebra is required to start the book, and, theoretically, one could learn what one needed from the text as one progresses. Practically, however, few of those who never took a calculus course have any business picking up this text. The earlier tutorials are far more likely to act as refreshers than as primers. Naturally, trigonometry appears immediately; differential and integral calculus follows by chapter 4; linear algebra appears in chapter 8; and complex analysis in chapter 13. One may stop anywhere along the way having learned important concepts about map projections.

After the requisite introduction of literal projections, the text moves into the pseudo- *thises* and *thats*, since these are generally mathematically simple projections, particularly the pseudocylindrics. The treatment of topics is commendably complete at each level of mathematics. By page 167, interruptions are dealt with, not just as a concept, but mathematically. Aspect (or case) comes next. Globular projections get their own chapter, showing how the early, geometrically motivated projections of Roger Bacon, Nicolosi, and others get developed algebraically. Fenna then goes on to describe some of the clever methods by which people have built on existing projections to achieve their own map projection designs without resorting to difficult mathematics. This is a novel treatment.

The text liberally intersperses formulæ, numbered according to Fenna's unusual scheme of using the page number followed by progressive alphabetic letters. There is no "it is obvious that" or "intermediate steps are left as an exercise for the reader" hand-waving; the formulæ are discussed as they are presented, and the author does not expect the reader to muster mathematical innovation just to follow a derivation.

If the roster of projection illustrations seems familiar, it is because Dr. Fenna chose, presumably in keeping with his stated agenda, to display at least the projections appearing in Snyder's Album, and in very similar format. A few others show up, including the only non-diagrammatic illustration: a reproduction of A.F. Spilhaus's 1942 polar aspect August epicycloidal oceanic map. The transverse Mercator on page 412 is not quite what it implies itself to be, since a whole world version on an ellipsoid is not rectangular. I would have gladly assisted in getting the correct map out of Geocart had I known he was trying, since I'm rather fond of the projection.

Moving decidedly into the later sections of the book, we find a thorough treatment of distortion and its optimization. This prepares the way for minimal-error conformal projections, an important and fairly advanced topic. Fenna finishes the spherical section with a chapter on novelty projections.

The author's treatment of ellipsoidal projections is comparatively brief, though he presents the entire mathematical foundation and then focuses on the ubiquitous Universal Transverse Mercator. The brevity is warranted. Ellipsoidal projections are the purview of geodesy, an enterprise very different from small-scale projections. The text ends with an even briefer description of the physics of the geoid and its mensuration. Several glossaries and indices complete the book.

As confirmed in private correspondence, Dr. Fenna not only wrote the book but also planned it, designed it, laid it out, digitally typeset it, and delivered it camera-ready to the publishers. They accepted this against their standard practice of typesetting the text themselves. It's probably a better book this way; Fenna was able to preserve illustration juxtapositions that he felt were important, and the chance of typographical errors in formulæ was reduced.

Still, a technical text like this is very hard to proofread, and this one suffers the occasional typo, though fewer than in Maling or Pearson. Table 6-15, describing the Robinson projection geometry, for example, shows the progression of the parallels along the y-axis as increments from the previous parallel and also as a resulting sum. Half of the table of increments shows the previous value incorrectly, simply repeating the same value over and over. Fortunately the resulting sums in the list, which are what one would use to realize the projection, are practically correct. (The x-value for the 55th parallel deviates from Pearson's 1990 amended formulation of Robinson by 7 in the fourth decimal place — a harmless discrepancy.)

The section on ellipsoidal geodesic lengths contains typographical errors in the final formula, 395b. One may detect and correct the errors by carefully following the derivation, yet that would be futile: they are obviated by a far more serious problem. Fenna follows Pearson's 1984 derivation, alluring in the simplicity and accessibility of the result. Sadly, Pearson makes a fundamental error early on in the derivation, and then unwittingly repeats it in his 1990 text. The result is a fiction. Correct computations require considerably more involved procedures. A generation of programmers following Pearson have banged their heads against their keyboards, unsure whether discrepancies between their programs' calculations and geodesic benchmarks arose from programming bugs or incorrect formulæ. It is truly regrettable to have the error repeated in a new text, particularly one so likely to be referred to. We may never be rid of the monster. I consider this particular error to be the most egregious of Fenna's work in its potential impact. (Dr. Fenna states in a private communication that he does not remember whether he used Pearson as a source. Fenna neither acknowledged nor disputed the error.)

Does Fenna's work succeed? Measured against his own agenda, it does, without a doubt. He recognized an important gap in the literature. His work fills that gap with a model of conscientious presentation. Yes, you could pore over hundreds of original journal papers for derivations if you needed them, but the purpose of an encyclopædic work is to relieve you of that chore. Fenna's predecessors packaged the formulæ for you; Fenna packages the derivations for you.

There is, however, the question of audience. Who actually needs this book? If, for example, you wished to write map projection software, what would the *Compendium* do for you that Snyder's books would not? Curiously, not a lot. Derivations are largely irrelevant to the enterprise of creating maps from map projections. That is not to say one can just hire a general programming serf, hand over *Snyder's Album*, and expect to end up with a professional-quality map projections package. The overwhelming bulk of a properly written map projection routine lies not in the literal expression of the mathematics as a computer program. That part is usually simple and sometimes trivial. The real work is in the infuriating, sometimes seemingly endless effort needed to make the program work for all inputs. That is because the pithy mathematics for many projections contain far-from-pithy traps and pitfalls. Computers aren't infinitely accurate; most numerical calculations of this sort carry sixteen digits. Stray too close to some special coordinate, and you will end up subtracting two numbers that are very close to each other, thereby losing most of those sixteen digits. Stray too close to another coordinate, and an intermediate calculation will balloon to infinity, destroying the remaining calculations for that coordinate. Naïvely programmed projections work across most of the map but fail in particular places or along particular paths.

As a case study, consider the transverse Mercator projection. We all know the standard Mercator: it shows regions away from the equator as increasingly large, ballooning to infinity at the poles. Therefore we cut off the map at some high latitude, typically below 80°. Whether you work with the sphere or ellipsoid, the normal aspect of the Mercator is infinite in extent. A sphere being completely symmetrical, it does not matter how you orient it; the result is the same infinite expanse, even if you tilt the developing cylinder over on its side so that it contacts the earth along the prime meridian instead of the equator. Developing the ellipsoid against that tilted cylinder results in the heavily used "UTM" (Universal Transverse Mercator) and the many Gauß-Krüger systems. However, surprisingly (and known only rarely), this transverse development is finite even applied to the entire ellipsoid. It is this map that page 412 illustrates incorrectly. While utterly unconventional, it's not a bad map as conformal world maps go.

Unfortunately, it is also fiendishly difficult to compute. I can express the mathematics in a single English paragraph, all the way down to the level of detail required to program the general case. Yet that modest expression belies the real complexity of programming for all inputs. My own computer implementation consists of a thousand lines of intricate program code, even excluding the usual named functions such as sine or logarithm. While the example is extreme, these regions of numeric treachery are common in map projections. If you seek a text to describe how to program each projection, Fenna's text is not that text. That text has not been written. On the other hand, derivations aside, Fenna's text presents formulæ for more map projections than any of the other works, effectively replacing them if that is all one needs.

As a reference for someone who researches map projections, I find the text convenient for finding, for example, which standard parallel Trystan Edwards advocated for the equal-area cylindric projection, or to follow the mathematical processes that motivated McBryde's and Thomas's pseudocylindric projections, or to refresh my memory of the mathematical development of Snyder's complex polynomials. While nothing replaces original sources, the consolidation is genuinely helpful.

I would choose this title for many reasons if I were to teach a course in map projections. For one, the pedantic text relieves a student's common frustration: what does the author mean by this term? Is it specialty nomenclature, and if so, what is its definition? Or is it meant in a more general sense? That same pedantry relieves the teacher of having to grant students leniency when they wheedle for credit based on an incorrect but (barely) plausible interpretation of the text. If the student did not get it, you can't blame the author. For another reason, the sequential development of the mathematics offers a natural curriculum for the course. For yet another, the tutorials sprinkled around the text assist the student in practical ways, ridding them of the need for a companion text on mathematics. And last, the book's execution is good on all counts: written well, designed intelligently, methodical, paced evenly, indexed and referenced well, and otherwise considerate of the reader's needs.

While one must be wary of treating any text uncritically — and the Compendium does not come without errors — I welcome Dr. Fenna's contribution to my library. I hope it wears my red annotations with honor.

The Natures of Maps: Cartographic Constructions of the Natural World

Denis Wood and John Fels
Chicago: University of Chicago Press, 2008.
Cloth: $49 ISBN: 13: 978-0-226-90604-1

Reviewed by Tom Koch
University of British Columbia

Reviewer's note: This review was based on page proofs received in August 2007 from ESRI Press. Minor changes that typically occur in the final preparation of the book make it likely any page assignments to quotes included in this review might change slightly. Precise attribution of quotes from the proofs have therefore not been included in this review.

Maps of Nature / The Natures of Maps

In 1986 Wood and Fels disassembled the map, describing ten codes through which its signs create meaning. Their argument was subsequently enfolded into Wood's *The Power of Maps*, one of the best selling books on mapping in recent decades. Twenty-one years later, Wood and Fels have put the map back together again "by replacing the whole idea of the map as a representation with that of the map as a system of propositions." In their new text, Wood and Fels insist that "The map is not a picture." Instead, they assert, "[i]t is an argument [; …] everything about a map, from top to bottom, is an argument."

The argument that maps are systems of propositions is made in two brief introductory chapters and then applied across nine subsequent chapters whose subject is nature and the natural world as constructed in more than fifty maps, typically a *National Geographic Magazine* supplement to a USGS map. Chapter titles, often echoing map titles, reflect the way the maps construct nature: "Threatened Nature," "Threatening Nature," "Nature as Cornucopia," "Possessable Nature," "Nature as Science," "Nature as Mystery," or "Nature as Park."

Each chapter proposes a view of nature that is instantiated in the maps. Because maps are *objects* in which the *subject* of nature is explored, the power of the argument is lodged in the maps whose unpacking reveals nature as "something drawn not from the world but from the minds of men and women; for maps are made not of wildlife, earthquakes, hurricanes, mountains, canyons, birds, but of signs–these themselves composed of marks and concepts. The map: a field of concepts." In that field two perspectives contend: Nature is not simply the maps' subject, but the maps are objects within which different conceptions of nature contend. This is elegant and subtle, a conjunction of subject and object that argues the nature of maps through maps of nature. Both the argument and its form are unique. Nothing like this has been attempted in cartography before.

To say it is unique is not to suggest its ideas are new but that they have never been applied in this way before to maps. The authors bring to their study a perspective that has been well articulated in the sociology of scientific knowledge by scholars that include, in a partial list: Ian Hacking (*The Social Construction of What?*), Bruno Latour (*We Have Never Been Modern*), Andrew Pickering (*The Mangle of Practice: Time, Agency and Science*), John V. Pickstone (*Ways of Knowing: A New History of Science, Technology, and Medicine*), Hans-Jörg Rheinberger (*Toward a History of Epistemic Things*), and especially Steven Shapin and Simon Schaffer (*Leviathan and the Air-Pump*).

Wood and Fels' goal is not, as David N. Livingstone's book title had it, *Putting Science in its Place: Geographies of Scientific Knowledge*, but putting mapping *into* science as a tool not of illustration, but of substantive argument, a tool of what the history of science folks call "knowledge creation." The map becomes the workbench on which ideas about nature are hammered out, not a frame in which the inhuman world is displayed. Nature is human, Wood and Fels argue, and so are the maps that present its many faces.

The core idea of the book is an axiom asserting that maps are constituted of fundamental propositions that take the form, "this is there." Such propositions make the dual claim that some thing (person, Koala bear, ocean current, tree) or quality (disease, health, drought, rain) exists and, secondly, that it can be located on a map. This fundamental "posting" as Wood and Fels call it, gives the map its ability to establish relationships between things in the map: "To claim that *this is there* is to make a powerful claim precisely because it implies the ability to perform an existence test: *you can go there and check it out*." This "map logic" is unfolded in a "spatial/meaning calculus." The conclusion is that maps assert a reality that is observable, a reality that is testable, but a reality that, at the same time, remains a construct we self-consciously create.

In this fashion the authors transpose the map from a medium apart from science to one that is inherently scientific. Argument, proposition, and testing have been the principal procedure of science since the seventeenth century: the world is known through observations and tests. These observations and tests constitute arguments submitted to knowledgeable outsiders whose confirmation establishes them as facts. Insisting that this is also the *modus operandi* of maps transforms mapping into an active intellectual enterprise, into a science that creates knowledge.

Whether the map subject is endangered species in Australia or the fracture lines of the earth's tectonic plates, mapping establishes the subject as real: *this thing* (a Koala bear, the Pacific plate, a storm track) *is there* (in Australia, on the U.S. coast, moving across the Midwestern states).

The semiotic codes first described by Wood and Fells in their 1986 paper now serve to instantiate their postings ("a 'this' is 'there'"). The authors use, but do not dwell on, cognitive linguistics as an interpretive tool. They propose a "cognitive cartographics" in which "mental maps" are replaced by cognitive, mental spaces as a flexible frame within which meaning is constructed. That construction is played out in the layout of the map itself. As Wood and Fels argue, "The principles underlying the graphic design of maps, far from being essentially aesthetic, are wholly at the service of the map's construction of knowledge, a construction built in real time by the map readers and typically validated on the spot (as evidenced by its use)." Within this framework it is impossible to say, as generations of cartographers have, that, "A map is a graphic representation of spatial relations (or relationships in/across/through space)" (Vasiliev 2006). Instead, maps by Wood and Fels' definition present arguments in which relationships are proposed, creating a world that results from the mapmaker's decisions rather than merely reflecting one outside the mapmaker's control.

Finally, Wood and Fels argue that the map image itself cannot be understood except as embedded in a *paramap* "that surrounds and extends a map in order to present it." The paramap consists of the *peri*map (elements of which include ancillary maps, legends, scales, and so on) and a broadly conceived *epi*map including the article within which a map may be embedded. For example, John Snow's famous map of Broad Street cannot be understood outside the context not only of its design but also of the publication in which it was embedded. The map at once confirms the reality of the subject (cholera) as it draws authority from the text with which it is associated (Snow 1855). Again, Wood and Fels borrowed the idea, this time from the literary critic Gerard Genette (1997), but its use with maps is novel and powerful.

The Natures of Maps demands first-rate maps as exhibits because the argument about the nature of maps is made through close readings. As noted, most came from the National Geographic or the USGS, and they're spectacular. *The Natures of Maps* was developed under contract with ESRI Press, which, fortunately, was willing to present the maps in this oversize book in full color and glorious detail. ESRI also provided a talented designer, Savitri Brant, who is almost a third author. Her layout advantages the maps, and so the text as well. As a result, the book is intelligent *and* drop-dead gorgeous; turning the project into an art book as well as a theoretical study of maps and nature.

Last October, however, ESRI Press was reorganized and over a dozen books under contract were dropped. This occurred weeks before Wood and Fels' project was scheduled for production. Four different presses almost immediately expressed interest in picking up and publishing this volume, and the University of Chicago won the contest for its publication. *The Natures of Maps* fits nicely within its catalogue of works on the history of cartography and cartographic applications to different disciplines.

Many will be grateful for, though I regret, the failure to expand on the transposition of cognitive linguistics into the cognitive cartographics promised but never really developed. The idea, as presented in early chapters, is a way around the problem of "mental maps" filed in the brain and the limitations of the Piaget-based developmental psychology with which they have in the past been argued. The idea is so potentially useful that its promise needs exploration and could perhaps have been better expanded in an additional chapter.

I also wished for a chapter on some of the ramifications of this concept of maps as self-conscious constructs arguing elements of the world. Perhaps the most critical lesson for the professional mapmaker is the degree to which Wood and Fels' argument insists that mapmakers are responsible for the way in which their maps *build* worldview rather than simply "reflect" the world. *The Natures of Maps* underscores but does not discuss the disconnect between the map and the mapmaker's responsibility for it (Koch 2006). With the idea of maps as representation it was easy to disassociate the mapmaker from the map ("It's just the way the world is"). If maps are arguments, then mapmakers are more than illustrators and are, in fact, responsible for the conclusions their work promotes.

No one book can say everything. It may be a strength of this one that the ramifications are lightly sketched and the theoretical deftly articulated but not hammered in on every page. Wood and Fels let the maps make their argument, creating the reality they propose. It's a beautiful book and one whose propositions will be the source of ideas, articles, and books for years to come.

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Cartographic Collections

Cartographic Collections: 2008 and Beyond

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In 2006, Chris Thiry and an army of 46 co-editors from around the country edited the 3rd edition of *Guide to U.S. map resources* by the Map and Geography Round Table (MAGERT) of the American Library Association. In the *Guide* one learns that there are at least 566 map libraries in the United States. These range from small map collections such as Alaska's Ketchikan Public Library with 1,500 maps and 10 atlases to the grand New York Public Library with over 400,000 maps and 16,000 atlases or the Harvard Map Collection with 400,000 maps and 9,000 atlases.

In 2000, 714 map collections from 121 different countries (including 72 from the U.S.) were highlighted in the 4th Edition of the *World Directory of Map Collections*, published by the International Federation of Library Associations (IFLA), Section of Geography and Map Libraries and edited by Olivier Loiseaux.

The detailed descriptions in these two directories illustrate that map collections are as varied as the uses of maps themselves. Each map library has unique characteristics; all face similar challenges. There is the need to keep up with rapidly changing technology, adjust priorities based on shrinking budgets, understand and serve the changing information needs of clientele and find creative ways to deal with space limitations.

NACIS and *Cartographic Perspectives* have a long tradition of recognizing the uniqueness of map collections. From NACIS's foundation in 1980 its publications featured many articles about map libraries. In the spring of 1990, *Cartographic Perspectives* launched a column devoted entirely to map libraries and librarians entitled "Map Library Bulletin Board." It was described as a "forum offered to encourage communication among map librarians at a time of rapid technological transition. Questions, comments and announcements are invited."

The column enjoyed a great deal of success over the years. Articles appeared that described collections, unique projects and generally provided an opportunity for map librarians to share information. In the beginning, the general editors of *Cartographic Perspectives* coordinated the articles and submissions. Some years had no submissions while many years had 3-6 articles per year.

Between 1996 and 2003, Melissa Lamont edited the journal and oversaw the inclusion of nineteen articles about map libraries in the U.S., Canada and the United Kingdom.

In 2003, Chris Mixon took over the editorship. He was successful in soliciting many interesting and engaging articles and implementing a name change for the column. The new column name, "Cartographic Collections" more broadly defines the purpose of the column, which is to highlight collections of all types including paper, online and digital spatial data collections. In 2006 Chris's job changed and he had to step down as editor and handed the reigns over to Bob Kibbee and Angie Cope.

In this issue of *Cartographic Perspectives*, Bob and Angie happily announce their joint editorship of the ever vibrant "Cartographic Collections." As a kick off to this next phase, we felt that it would be helpful to know where the column is going by seeing were it's been. This issue features a bibliography of past articles from the "Map Library Bulletin Board" and "Cartographic Collections." The articles demonstrate the wealth of information that has been shared between NACIS members over *Cartographic Perspectives'* eighteen year history.

Bob and Angie have a number of articles lined up for future issues that promise to celebrate the variety and uniqueness of cartographic collections. The IFLA and MAGERT directories demonstrate the variety of collections in existence and "Cartographic Collections" will continue to provide the stories.

The format and content of articles is not limited to broad overviews, although those are certainly welcome. Your description of your collection may alert readers to unique content or new approaches to common problems. We encourage articles on special projects and unique partnerships. There is ongoing interest in all facets of how to bring a collection online, for example, or other issues of digitization. Other topics might include services, special formats, collection development, public relations, preservation — all the elements of managing cartographic collections.

In the past the most of the articles have been submitted from academic collections. We would like to see more submissions from public libraries, society libraries and the collections maintained by commercial vendors. International readers shouldn't be discouraged by the "North American" in NACIS. "Cartographic Collections" encourages submissions from the international community.

Please share your story by contacting Angie at acope@uwm.edu or Bob at rk14@cornell.edu

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Mapping: Methods & Tips

Matrix Projection
"A true equal area map of the world"

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A Brief History of Map Projections

Maps have been prepared by men since ancient times. Babylonians of 2500 BC. Romans of Jesus' time and feudals of the middle ages all prepared local maps showing natural features such as rivers, mountains, shorelines and forests; and man made features such as roads, bridges, property lines and structures. Since the real size and shape of the world was not commonly known until as late as the 16th century, all earlier world maps were incomplete and inaccurate. By the end of the 16th century real world maps were being produced in Europe.

The following is a brief history of world map design from the 16th century to the present. It will be followed by some examples of known world maps and series of new designs by Abbass Bazeghi in more detail.

Before Ferdinand Magellan's explorations, by 1520 AD, and Nicolaus Copernicus publishing his hypothesis of the heliocentric nature of the known universe in 1543 AD, the earth was assumed by most people to be flat; with the exception of very few, including Columbus, Magellan and Copernicus who had read about Eratosthenes of Greece, residing in Alexandria, Egypt around the third century BC.

Eratosthenes, by measuring heights and shadows of obelisks in Aswan, Egypt at the Tropic of Cancer, and Alexandria some 800 kilometers north of Aswan, geometrically proved that the earth is spherical and showed that the circumference of the Earth is 50 times longer than the 800 kilometer distance between Aswan and Alexandria. This is very close to the actual distance by current measurements. Eratosthenes' discovery remained unknown by most people for many centuries. But the myth of a spherical world continued.

By 1492 AD Christopher Columbus had convinced Queen Isabella of Spain to finance an exploratory voyage to find a route to the east and India by sailing west. If the earth is indeed round, then one will reach India by sailing west in addition to an eastern route involving difficult and often dangerous roads over many lands.

Columbus finally reached land further west in the Atlantic Ocean. He assumed that he had reached the shores of India and did not realize that he had found a new unknown land “America”. Consequently, he grossly miscalculated the size of the earth.

Ferdinand Magellan, the Portuguese explorer, was the first to circumnavigate the earth by 1520 AD. He provided more accurate data than ever before to prove the spherical shape and size of the earth.

By 1543 AD, Nicolaus Copernicus of Poland had correctly described the earth as a sphere rotating around its axis with one moon orbiting around it. The earth with its moon and all observable planets and even fixed stars were assumed to be orbiting the sun as the center of the universe. Copernicus' theory was perfected by Johannes Kepler of Germany about 50 years later.

By the 1560's the earth was accepted by most intellectuals, scholars and scientists to be spherical. However, the dispute over the heliocentric theory of Copernicus and earlier geocentric theory still continued even to the time when Galileo Galilei of Italy was experimenting with telescopes verifying Copernicus' theory by providing more proofs as late as 1616 AD. He was forced by the powerful governing church to stop teaching Copernicus' theory or roundness of the

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Abbas Bazeghi graduated from the University of California, Berkeley, class of 1968, with a 5 year professional degree in architecture. He has completed hundreds of architectural projects during the last 36 years. He is presently practicing in Santa Barbara, California as an architect/cartographer.

He worked as a cartographer in Iran from 1955 to 1962 and was trained by three master cartographers. He came to San Francisco in February 1962 and attended San Francisco State College for one year, then transferred to UC Berkeley in 1963 to study architecture.

He has continued his cartographic work and has spent a great amount of time during the last 15 years in pursuit of designing the ultimate "equal area projection". He has designed 6 original world maps, the best and the last one being "Matrix Projection".

earth. By 1623, with a new Pope in office, Galileo was left alone to do his work.

Nevertheless, by 1570 AD new world maps based on the spherical shape of the earth began to appear in Europe. By 1569 AD a new view of the earth was presented by a leading cartographer, the Flemish Gerhardus Mercator. This new map, known as the Mercator projection, is still the most familiar world map in use. The genius of Mercator's projection is the rectangular grid. Although the earlier versions were only partial maps of known places and shorelines, with lots of guess work on size and extent of land masses, nevertheless, the Mercator projection provided a grid to expand on and refine as more accurate surveys of shorelines and land masses were prepared in the following years. The basic design of the grid remained unchanged.

The Mercator projection was invented to provide a tool for navigation and charting routes for voyages on the high seas. This is achieved by assuming the meridians as straight, vertical and parallel lines, equally spaced along the equator. The parallels are presented as straight horizontal lines, parallel to the equator, spaced to provide the best geometric proportion and compensate for the distortions caused by parallel meridians. Although the Mercator projection has been a very useful tool for navigators, it has not been a good viewing map. It depicts the earth grossly distorted and not equal to the areas in comparison.

Other earlier attempts were made by 17th century cartographers to present the world, visually, more realistic than the Mercator projection. The most well known example was introduced around 1660 by Andreas Cellarius, where the world is shown as two perfect circles side by side. The map is an artistic presentation and is not based on scientific or mathematical rules. The earth map in this design is grossly distorted with a great deal of guess work and many missing or obscure parts of land and seas. This projection is now used as decoration, often seen in gold paper prints.

From the 16th century to the 20th century the world was well traveled and mapped. During the last 400 years almost all places have been accurately surveyed and most places aerial photographed. But the Mercator projection as the standard world map remained unchanged and supreme until very recently.

The National Geographic Society, since 1922, had been using a revised version of the Mercator projection which was developed by an American engineer, Alphons Van der Grinten. This projection, much like the Mercator, was also grossly distorted visually, depicting Greenland 554% larger than it is. The ex-Soviet Union was depicted 223% larger and the USA 68% larger. The Robinson projection has been their official map since 1988.

Since there have been repeated complaints about visual distortions of the Mercator's design, despite its geometric and mathematical correctness, many attempts have been made to improve it visually.

By 1963, Arthur H. Robinson, professor emeritus of cartography and geography at the University of Wisconsin-Madison, introduced a new design in which he has reduced the visual distortions of the Mercator projection by bringing the meridians closer together as they approach the north and south poles. The distance from north pole to south pole is also made equal in length, at (0)° meridian, to actual length. Where in the Mercator projection, the (0)°, as well as all the meridians, are presented 2 times longer than they are.

The Robinson projection is less distorted visually than the Mercator projection. Never-the-less, it is not free of distortion and it is not an equal area map. Alaska, Russia and Greenland are skewed and bent out of shape. However, it is graphically well balanced and looks very attractive. It would have been a great projection if the earth really looked like that or was that size.

There are about 200 projections that have been designed, mostly in the 20th century, of which only very few have been widely used. Many of these projections are not known by most people.

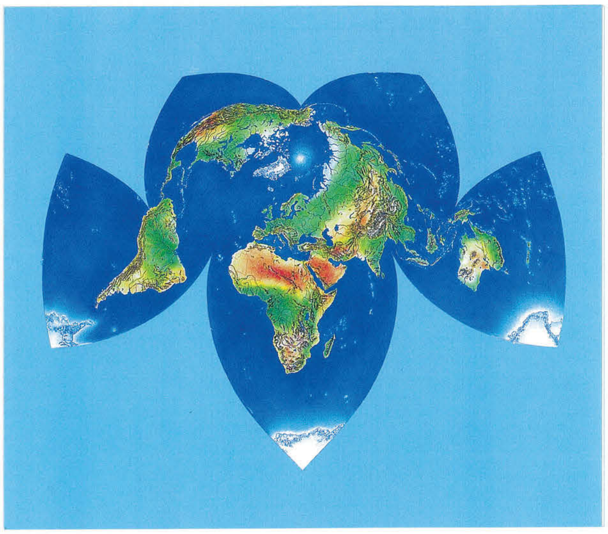
I have developed a new innovative method of designing original and geometrically precise equal area world maps. The method does not involve projecting the grid of meridians and parallels to a cylindrical or conical, two dimensional, planes. Rather, it involves sizing and designing each segment of the globe, formed by the cross sections of the meridians and parallels, individually.

The overall design of the world map is first conceived by carefully selecting the interruptions and creating a grid where the shapes of the segments and distortions are controlled by design to achieve the best relevant size and shape of each segment as close to the real size and shape on the globe as possible. Once the overall design is conceived, a hand drawn schematic line drawing is prepared, scanned and imported to AutoCad. (AutoCad is a software product developed by AutoDesk for architects and engineers for drafting and rapidly calculating geometric sizes and areas of surfaces among many other useful drafting tools).

On a 15 degree grid, the globe is covered by a total of 288 segments. There are only 6 typical segments. It takes 48 of each of the 6 segments to cover the entire surface area of the globe. These segments on a given world map design are then individually shaped and enclosed by geometrically definable arcs of circles. The main challenge is to keep the curves in alignment from segment to segment to maintain a visually smooth and attractive overall design. The process is really an effort in combining art and mathematically precise geometry; it is a marriage of art and science. The next step is to calculate the surface area of each enclosed segment. Fortunately, it is rather easy to calculate the exact surface area of any segment enclosed by arcs of circles using AutoCad. Each segment can be fine tuned by changing the radii of the arcs and recalculating until the exact required area is achieved. Without the right software, such as AutoCad, it would be impossible or extremely difficult to complete the work. Any change of shape or size of any segment has a domino effect and involves changing many neighboring segments. Even using AutoCad does not eliminate the tedious and time consuming process of fine tuning to achieve the final desired precision, but it is doable.

After completing a geometrically precise grid, coordinates of any point on the grid may be obtained instantly from the AutoCad file. These coordinates then can be used to formulate the map for interpolating inputs from satellites or compliance with other scientific methods of designing equal area world maps.

A few of these existing projections are shown with a series from the publication: Jon Able Light, Matrix Projection "A true equal area map of the world. Copyright 2006 by Abbass Bazeghi.



Jon Able Light

MATRIX PROJECTIONS

"True equal area world maps"

A mathematically precise direct equal area polar projection. Copyright©2006, Abbass Bazeghi. All rights reserved.

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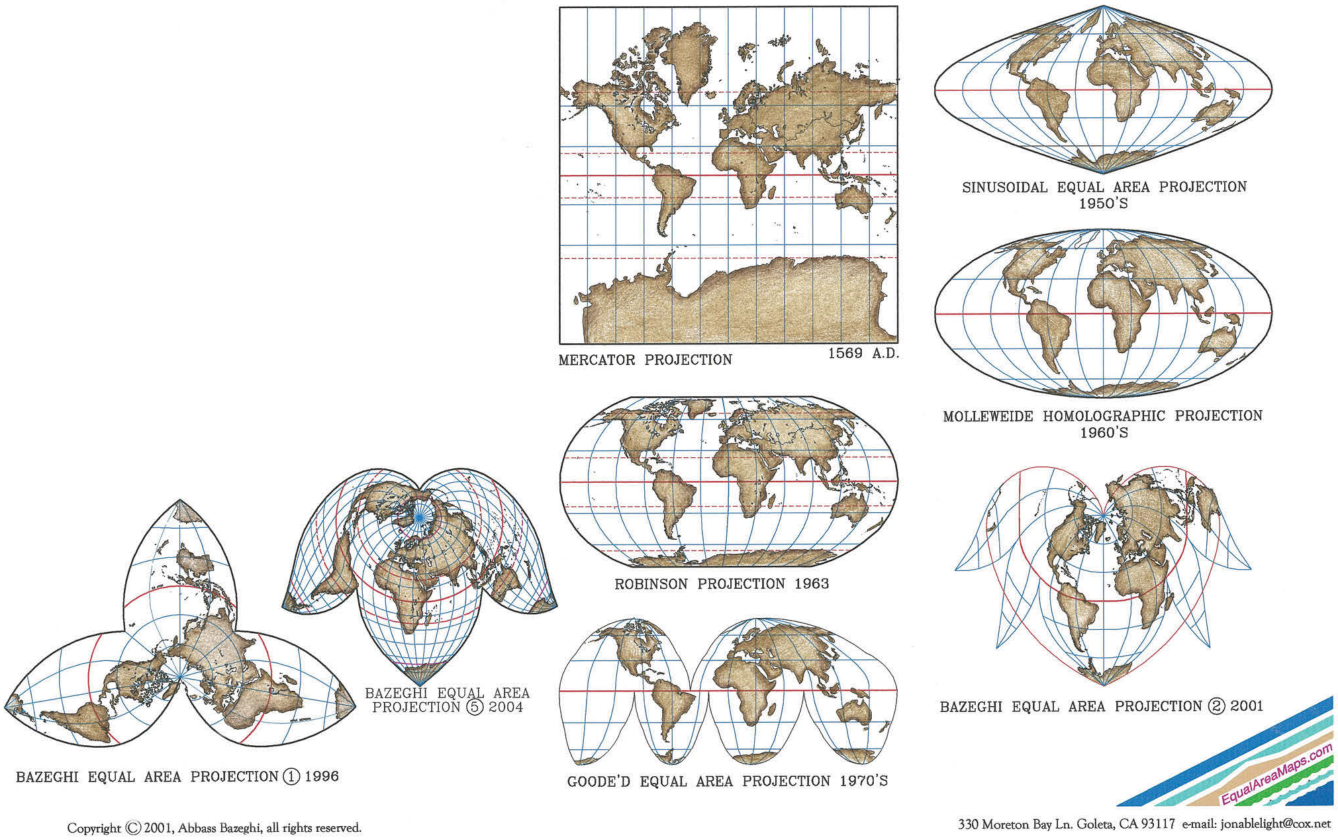
MERCATOR PROJECTION
1569 A.D.
SINUSOIDAL EQUAL AREA PROJECTION
1950'S
MOLLEWEIDE HOMOLOGRAPHIC PROJECTION
1960'S
ROBINSON PROJECTION 1963
BAZEGHI EQUAL AREA PROJECTION ⑤ 2004
BAZEGHI EQUAL AREA PROJECTION ② 2001
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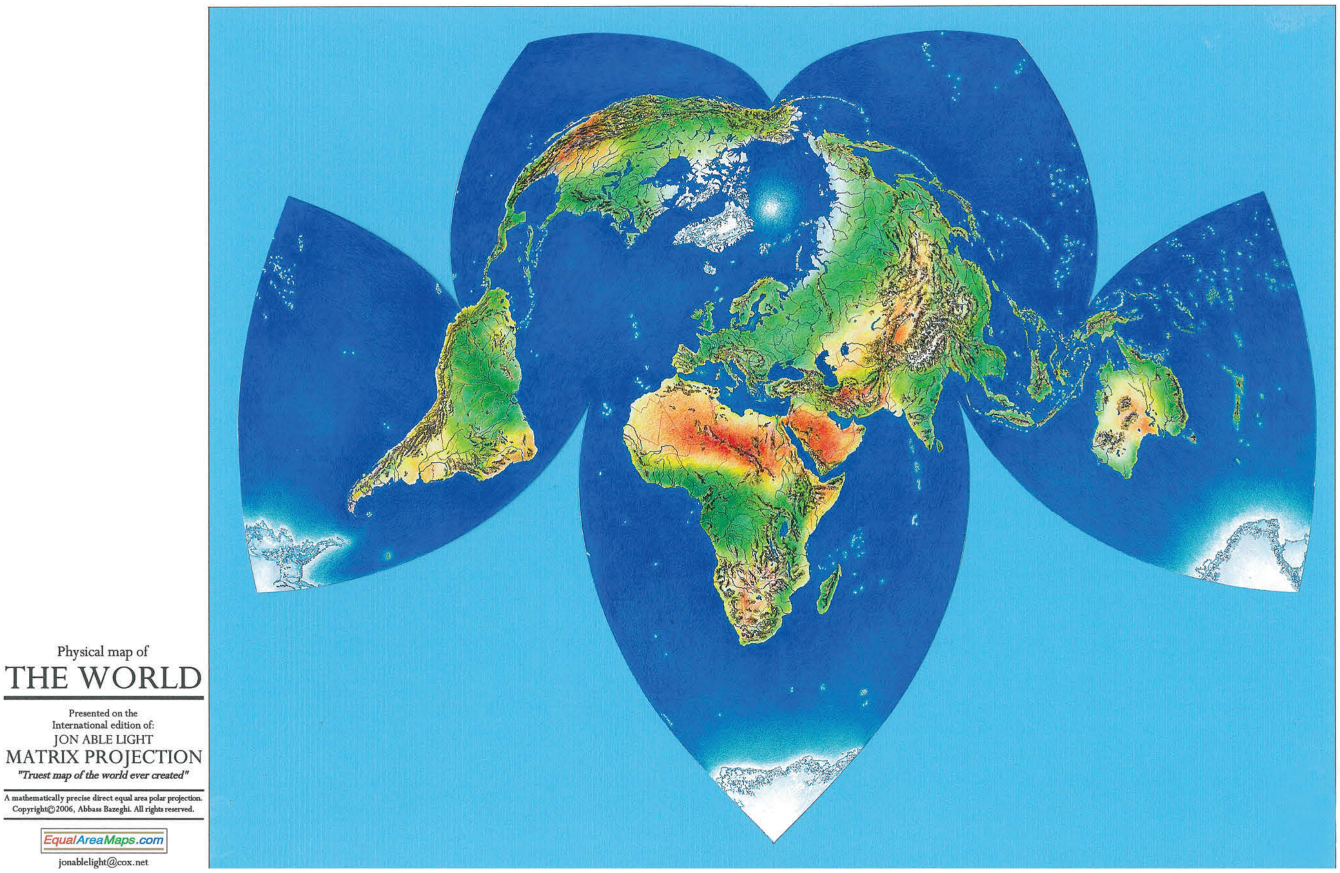
Physical map of
THE WORLD
Presented on the
International edition of:
JON ABLE LIGHT
MATRIX PROJECTION
"Truest map of the world ever created"
A mathematically precise direct equal area polar projection.
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JON ABLE LIGHT
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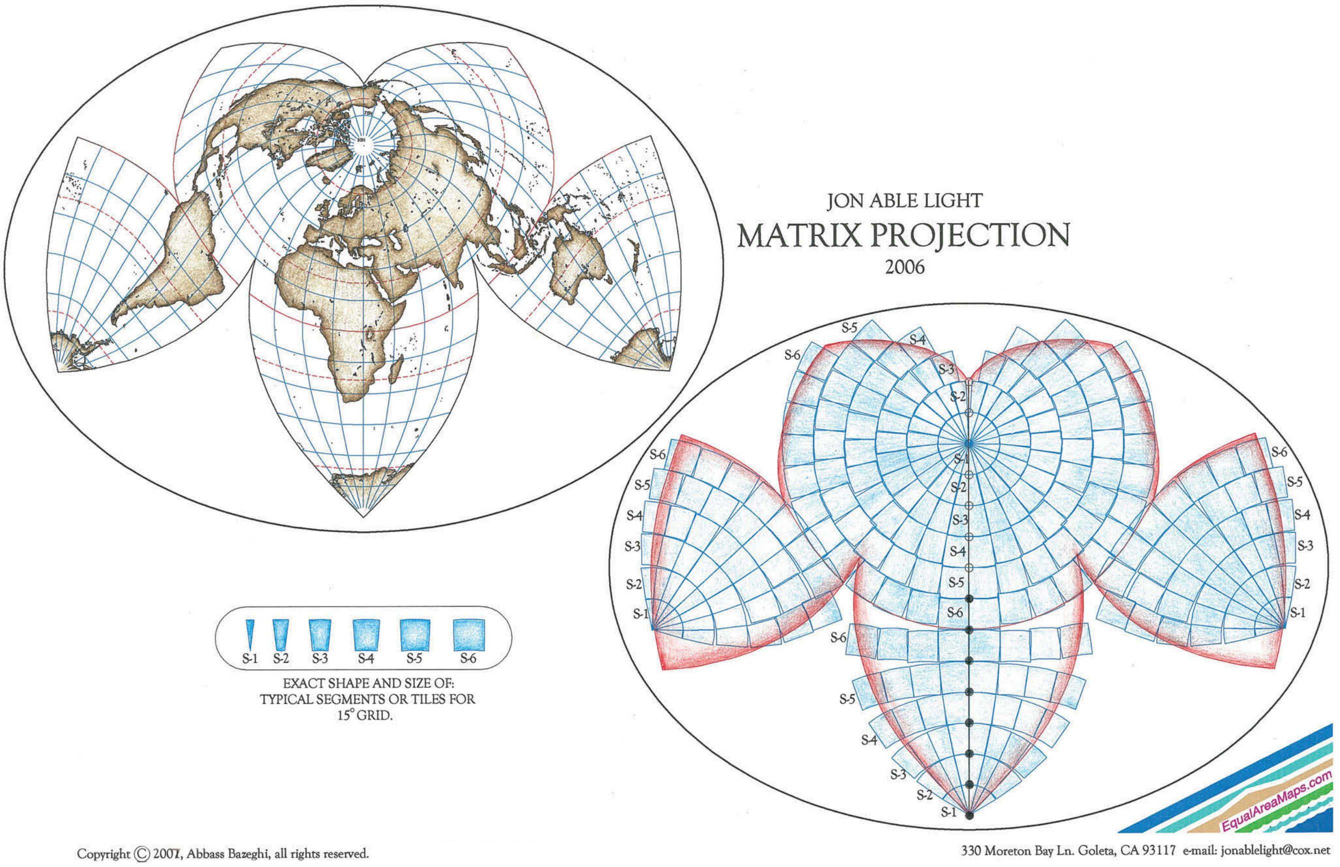

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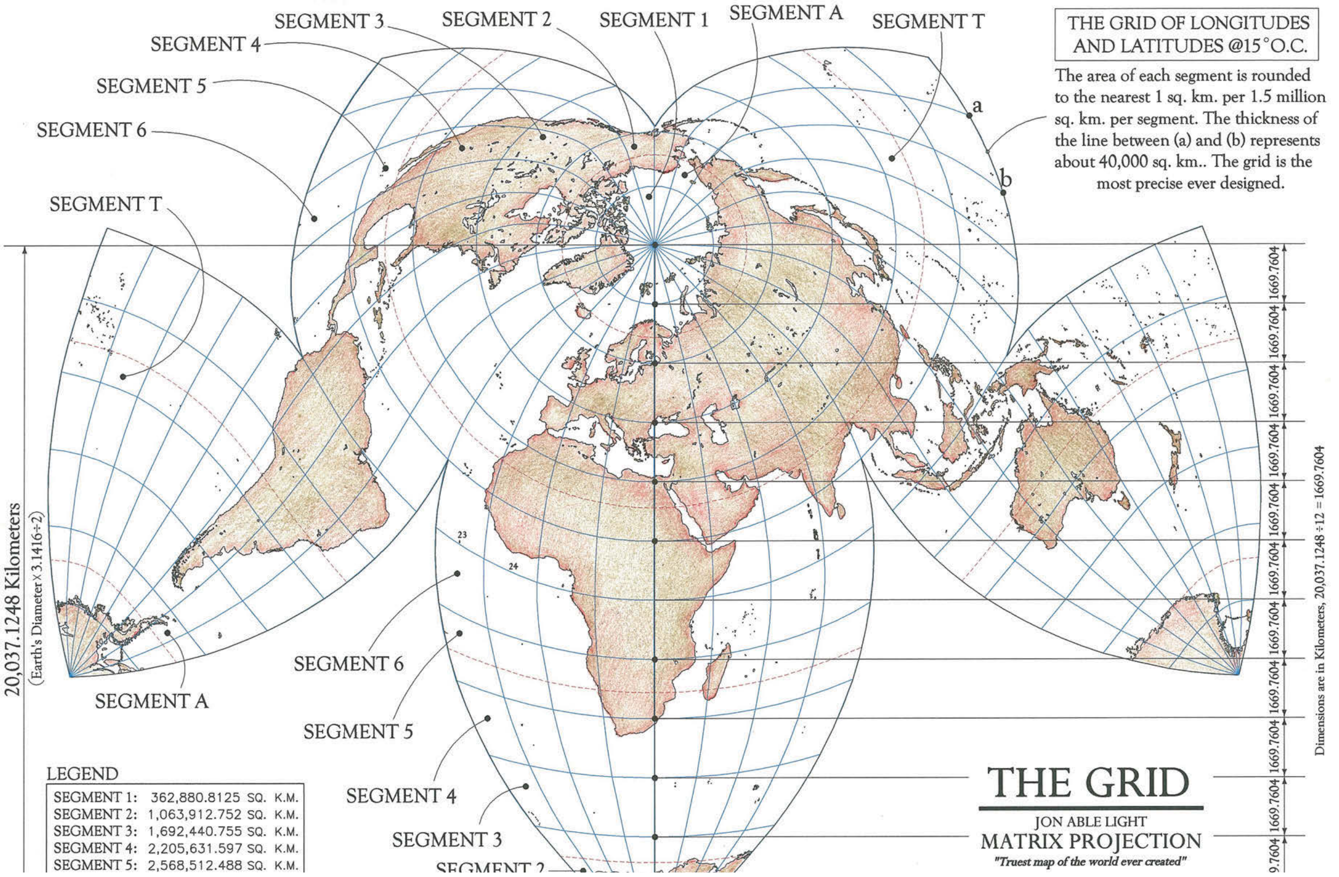

THE GRID OF LONGITUDES AND LATITUDES @15°O.C.

The area of each segment is rounded to the nearest 1 sq. km. per 1.5 million sq. km. per segment. The thickness of the line between (a) and (b) represents about 40,000 sq. km.. The grid is the most precise ever designed.

LEGEND

SEGMENT 1:	362,880.8125 SQ. K.M.
SEGMENT 2:	1,063,912.752 SQ. K.M.
SEGMENT 3:	1,692,440.755 SQ. K.M.
SEGMENT 4:	2,205,631.597 SQ. K.M.
SEGMENT 5:	2,568,512.488 SQ. K.M.

#	Location Lon. Lat.	X	Y
1	90°N	10,000.0000	20,037.1284
2	30°E, 75°N	10,000.0000	18,367.3680
3	30°E, 60°N	10,000.0000	16,697.6076
4	30°E, 45°N	10,000.0000	15,027.8472
5	30°E, 30°N	10,000.0000	13,358.0868
6	30°E, 15°N	10,000.0000	11,688.3264
7	30°E, 0°	10,000.0000	10,018.5660
8	30°E, 15°S	10,000.0000	8,348.8056
9	30°E, 30°S	10,000.0000	6,679.0452
10	30°E, 45°S	10,000.0000	5,009.2848
11	30°E, 60°S	10,000.0000	3,339.5244
12	30°E, 75°S	10,000.0000	1,669.7604
13	90°S	10,000.0000	0
14	45°E, 75°N	10,422.2973	18,422.6693
15	45°E, 60°N	10,825.5684	16,802.4935
16	45°E, 45°N	11,167.4960	15,170.2763
17	45°E, 30°N	11,423.2299	13,498.0619
18	45°E, 15°N	11,605.4312	11,818.3391
19	45°E, 0°	11,666.5011	10,135.7090
20	45°E, 15°S	11,605.3631	8,447.0219
21	45°E, 30°S	11,432.2134	6,732.9138
22	45°E, 45°S	11,187.9720	5,036.0984
23	45°E, 60°S	10,838.0470	3,357.3707
24	45°E, 75°S	10,427.2173	1,679.9536
25	60°E, 75°N	10,820.4869	18,580.9285
26	60°E, 60°N	11,609.5519	17,108.5945
27	60°E, 45°N	12,267.4195	15,567.6082
28	60°E, 30°N	12,780.3158	13,947.0298
29	60°E, 15°N	13,129.8845	12,260.3893
30	60°E, 0°	13,298.7206	10,525.3363
31	60°E, 15°S	13,177.5121	8,754.5401
32	60°E, 30°S	12,856.0300	6,938.1593
33	60°E, 45°S	12,362.7710	5,155.2028
34	60°E, 60°S	11,680.3348	3,416.6592
35	60°E, 75°S	10,860.5983	1,699.6433
36	75°E, 75°N	11,161.5762	18,839.9944
37	75°E, 60°N	12,277.4113	17,598.3855
38	75°E, 45°N	13,249.0668	16,228.1268
39	75°E, 30°N	14,002.4370	14,661.7721
40	75°E, 15°N	14,557.4068	13,006.4951
41	75°E, 0°	14,802.8828	11,198.3978
42	75°E, 15°S	14,689.5838	9,235.4790
43	75°E, 30°S	14,237.1634	7,282.9169
44	75°E, 45°S	13,518.4031	5,358.8351
45	75°E, 60°S	12,539.8690	3,518.2069
46	75°E, 75°S	11,300.2115	1,730.0192
47	90°E, 75°N	11,428.3745	19,175.0555
48	90°E, 60°N	12,813.7902	18,236.2107
49	90°E, 45°N	14,050.0215	17,086.0218
50	90°E, 30°N	15,038.1140	15,645.7833
51	90°E, 15°N	15,818.9239	14,006.9544
52	90°E, 0°	16,167.0765	12,088.3332
53	90°E, 15°S	16,083.9711	9,947.6035
54	90°E, 30°S	15,590.2310	7,774.8746
55	90°E, 45°S	14,672.8937	5,657.1886
56	90°E, 60°S	13,382.7863	3,662.7863
57	90°E, 75°S	11,744.0079	1,770.4359
58	90°E, 0°	16,711.4209	12,531.2090
59	90°E, 15°S	17,883.0264	11,204.4580
60	90°E, 30°S	19,308.0938	10,081.5243
61	90°E, 45°S	20,918.2142	9,186.2087
62	90°E, 60°S	22,656.8282	8,503.8385
63	90°E, 75°S	24,516.1995	8,065.6807
64	90°S	26,480.1839	7,877.0053
65	105°E, 75°N	11,600.4151	19,571.3467
66	105°E, 60°N	13,172.1552	18,987.1540
67	105°E, 45°N	14,631.0426	18,087.5662
68	105°E, 30°N	15,877.9492	16,818.7392
69	105°E, 15°N	16,882.7173	15,255.5548
70	105°E, 0°	17,807.2858	13,736.1130
71	105°E, 15°S	18,898.4228	12,337.9818
72	105°E, 30°S	20,171.7736	11,113.8409
73	105°E, 45°S	21,610.2511	10,028.9237
74	105°E, 60°S	23,158.8774	9,132.8147
75	105°E, 75°S	24,797.0069	8,405.7154
76	120°E, 75°N	11,662.6754	19,994.6861
77	120°E, 60°N	13,328.1460	19,805.6845
78	120°E, 45°N	14,939.1943	19,230.9978
79	120°E, 30°N	16,452.7140	18,035.9951
80	120°E, 15°N	17,735.9140	16,586.2886
81	120°E, 0°	18,814.5148	15,062.2809
82	120°E, 15°S	19,841.6783	13,579.5620
83	120°E, 30°S	21,006.3998	12,172.2951

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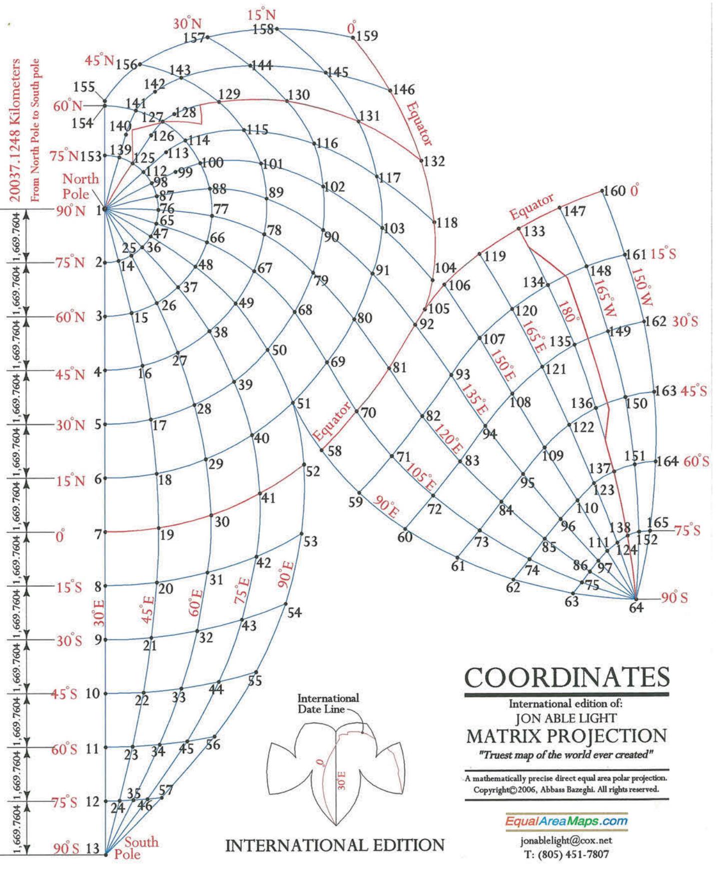
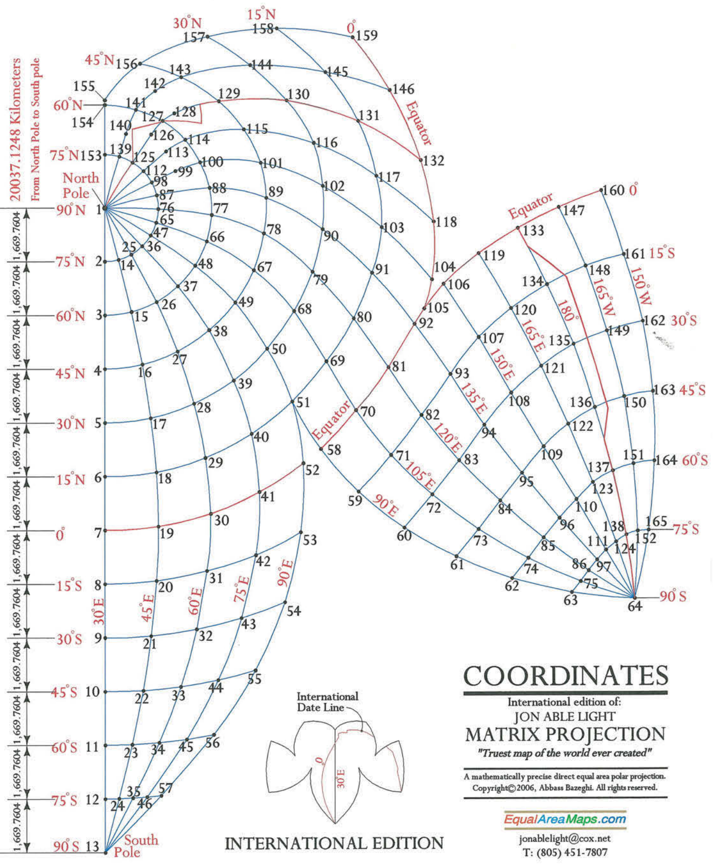
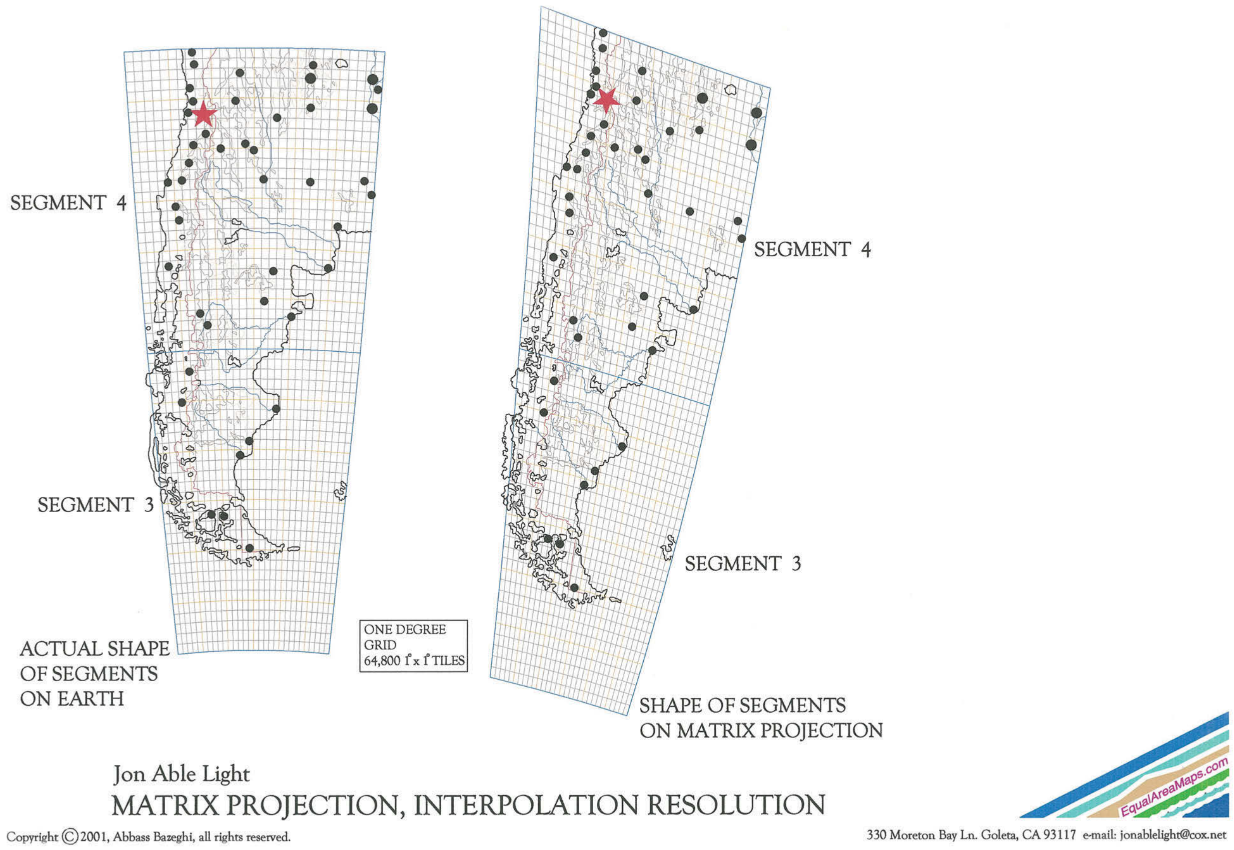


#	Location Lon. Lat.	COORDINATES X	Y
84	120°E, 45°S	22,282.6175	10,914.6895
85	120°E, 60°S	23,637.4988	9,765.9042
86	120°E, 75°S	25,045.5263	8,739.7363
87	135°E, 75°N	11,616.4479	20,423.4905
88	135°E, 60°N	13,263.6539	20,651.2115
89	135°E, 45°N	15,013.7779	20,335.8222
90	135°E, 30°N	16,769.1553	19,355.1093
91	135°E, 15°N	18,306.3534	17,998.4539
92	135°E, 0°	19,627.4487	16,413.2061
93	135°E, 15°S	20,737.0269	14,853.0681
94	135°E, 30°S	21,789.7831	13,271.3980
95	135°E, 45°S	22,966.5310	11,776.3680
96	135°E, 60°S	24,136.6638	10,372.8335
97	135°E, 75°S	25,308.5346	9,075.8876
98	150°E, 75°N	11,459.2179	20,827.8142
99	150°E, 67.5°N	12,197.9167	21,173.9391
100	150°E, 60°N	12,966.5926	21,433.3269
101	150°E, 45°N	14,840.1279	21,426.6837
102	150°E, 30°N	16,771.2041	20,703.5389
103	150°E, 15°N	18,609.2537	19,418.9455
104	150°E, 0°	20,167.1463	17,791.8046
105	140.5°E, 0°	19,926.7016	16,888.1849
106	150°E, 0°	20,525.8235	17,653.6299
107	150°E, 15°S	21,620.0350	15,995.4311
108	150°E, 30°S	22,632.5633	14,268.8684
109	150°E, 45°S	23,638.7596	12,593.1392
110	150°E, 60°S	24,666.8225	10,952.8857
111	150°E, 75°S	25,594.9592	9,378.9407
112	165°E, 75°N	11,200.8177	21,177.9318
113	165°E, 66.5°N	11,907.0144	21,786.8825
114	165°E, 60°N	12,507.9060	22,150.9039
115	165°E, 45°N	14,314.4450	22,464.3096
116	165°E, 30°N	16,491.4763	22,040.3088
117	165°E, 15°N	18,439.7316	21,015.7466
118	165°E, 0°	20,221.6893	19,588.6155
119	165°E, 0°	21,615.9810	18,599.9481
120	165°E, 15°S	22,631.0258	16,889.5481
121	165°E, 30°S	23,566.2241	15,096.3079
122	165°E, 45°S	24,410.4480	13,296.5702
123	165°E, 60°S	25,181.0512	11,483.4929
124	165°E, 75°S	25,901.2933	9,636.7302
125	180°, 75°N	10,861.1650	21,442.7742
126	180°, 65.15°N	11,438.8196	22,313.1591
127	180°, 60°N	11,796.5561	22,736.5516
128	180°, 56.6°N	12,159.8824	22,969.4764
129	180°, 45°N	13,546.9681	23,343.5652
130	180°, 30°N	15,640.0969	23,366.2230
131	180°, 15°N	17,873.0437	22,723.1979
132	180°, 0°	19,823.0310	21,497.4450
133	180°, 0°	22,838.7876	19,382.9520
134	180°, 15°S	23,749.5909	17,628.9491
135	180°, 30°S	24,577.4061	15,777.5760
136	180°, 45°S	25,244.5863	13,808.1045
137	180°, 60°S	25,805.3811	11,839.9732
138	180°, 75°S	26,220.9946	9,854.6497
139	165°W, 75°N	10,445.5489	21,630.2972
140	165°W, 67.87°N	10,654.3061	22,335.5498
141	165°W, 60°N	10,964.3621	23,085.0413
142	165°W, 52.85°N	11,559.9138	23,668.6280
143	165°W, 45°N	12,374.7187	24,095.6071
144	165°W, 30°N	14,509.8755	24,465.6635
145	165°W, 15°N	16,852.8015	24,241.5944
146	165°W, 0°	18,854.3778	23,679.4662
147	165°W, 0°	24,112.1004	20,026.9619
148	165°W, 15°S	24,954.7431	18,203.1386
149	165°W, 30°S	25,627.1808	16,190.5036
150	165°W, 45°S	26,154.9594	14,147.7907
151	165°W, 60°S	26,443.1921	12,061.7411
152	165°W, 75°S	26,574.8056	9,970.7851
153	150°W, 75°N	9,995.2908	21,693.0090
154	150°W, 60°N	9,995.2908	23,235.1210
155	150°W, 61.25°N	9,995.2908	23,384.1416
156	150°W, 45°N	11,091.2060	24,521.6641
157	150°W, 30°N	13,191.0959	25,353.5731
158	150°W, 15°N	15,329.3600	25,609.5553
159	150°W, 0°	17,698.0466	25,320.9143
160	150°W, 0°	25,448.5270	20,544.7956
161	150°W, 15°S	26,144.8751	18,560.9383
162	150°W, 30°S	26,735.6012	16,489.4039
163	150°W, 45°S	27,046.2418	14,311.6657
164	150°W, 60°S	27,086.5346	12,150.3189
165	150°W, 75°S	26,910.0566	9,996.8175

Continuation





Jon Able Light

MATRIX PROJECTION, INTERPOLATION RESOLUTION

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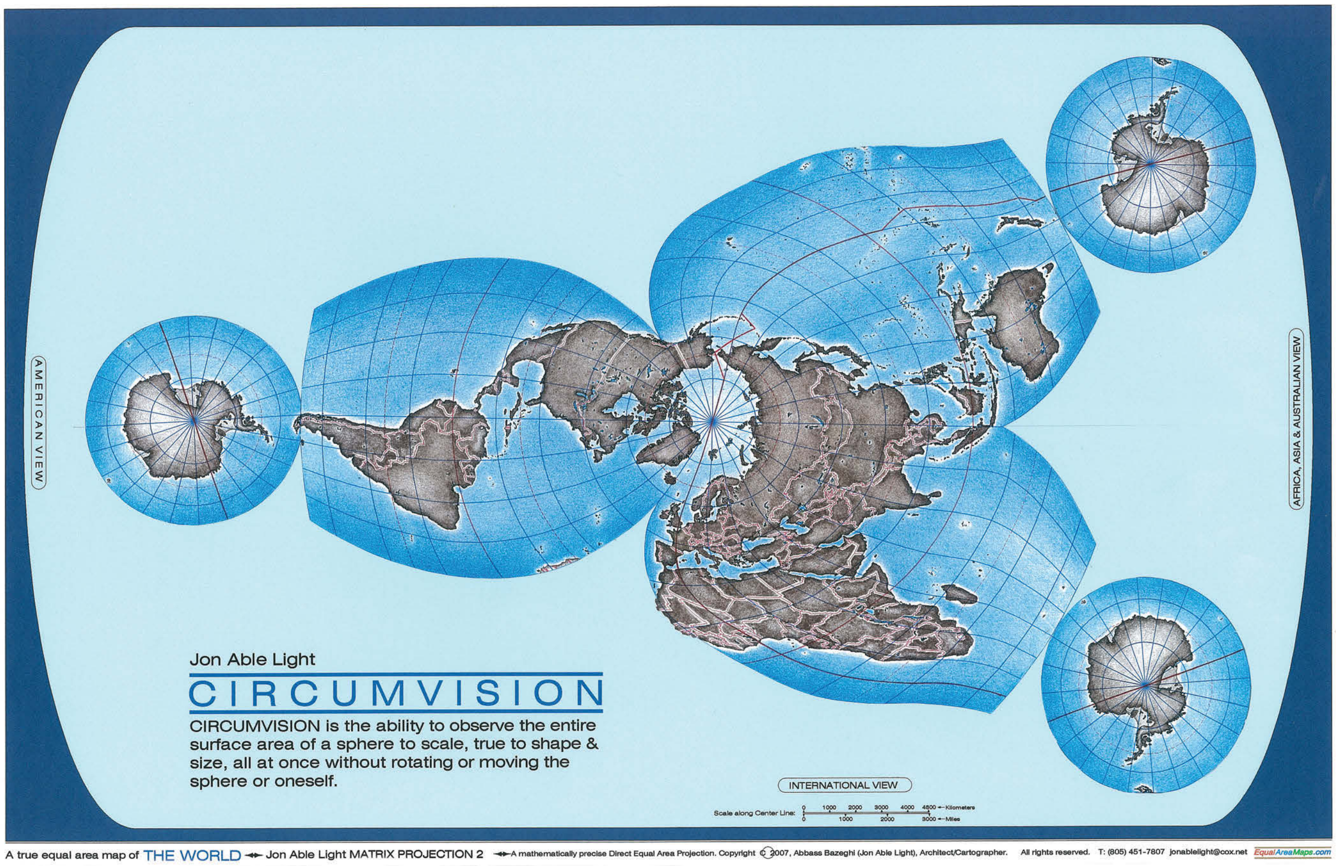

Jon Able Light

CIRCUMVISION

CIRCUMVISION is the ability to observe the entire surface area of a sphere to scale, true to shape & size, all at once without rotating or moving the sphere or oneself.

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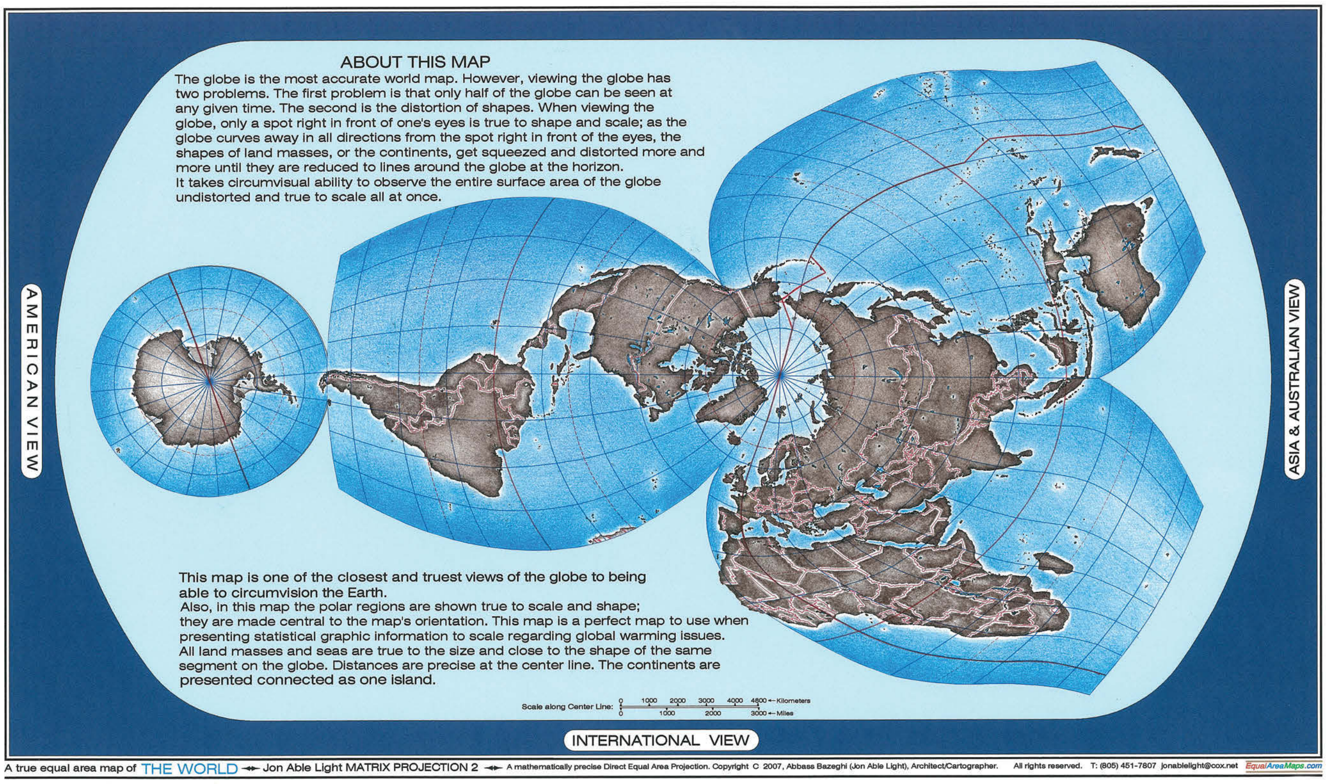


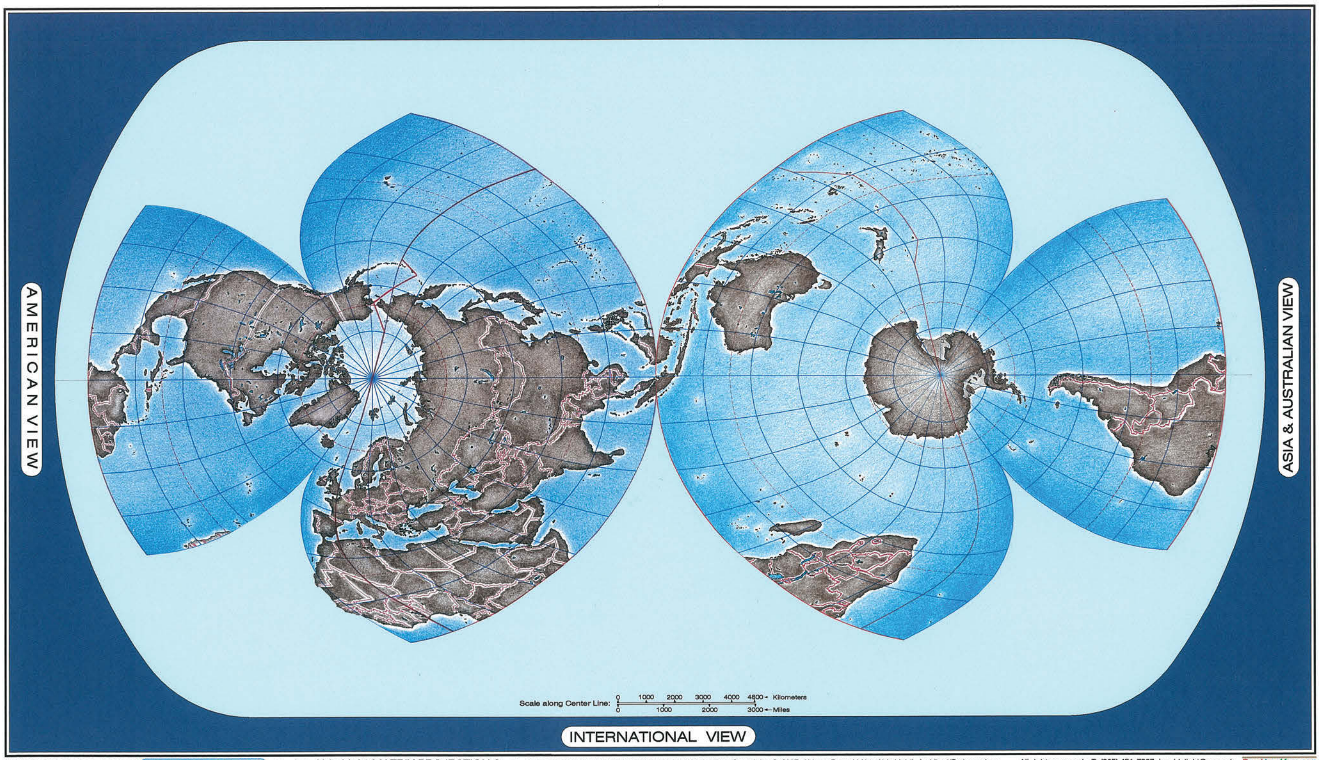
ABOUT THIS MAP

The globe is the most accurate world map. However, viewing the globe has two problems. The first problem is that only half of the globe can be seen at any given time. The second is the distortion of shapes. When viewing the globe, only a spot right in front of one's eyes is true to shape and scale; as the globe curves away in all directions from the spot right in front of the eyes, the shapes of land masses, or the continents, get squeezed and distorted more and more until they are reduced to lines around the globe at the horizon.
It takes circumvisual ability to observe the entire surface area of the globe undistorted and true to scale all at once.

This map is one of the closest and truest views of the globe to being able to circumvision the Earth.
Also, in this map the polar regions are shown true to scale and shape; they are made central to the map's orientation. This map is a perfect map to use when presenting statistical graphic information to scale regarding global warming issues.
All land masses and seas are true to the size and close to the shape of the same segment on the globe. Distances are precise at the center line. The continents are presented connected as one island.

A true equal area map of THE WORLD ↔ Jon Able Light MATRIX PROJECTION 2 ↔ A mathematically precise Direct Equal Area Projection. Copyright © 2007, Abbass Bazeghi (Jon Able Light), Architect/Cartographer. All rights reserved. T: (805) 451-7807 jonablelight@cox.net EqualAreaMaps.com

ABOUT THE EARTH Total surface area of the Earth: 197,370,457.1 Sq. Miles (511,187,127.9 Sq. Kilometers). Diameter at the equator: 7,926.2 Miles (12,756.0 Sq. Kilometers)
Total area of the oceans and seas is about 71%, and the land area is about 29% of the total surface area of the Earth. Distance from the Sun: 93 million Miles (149.6 million Kilometers)
World population is about 6.5 Billion by mid 2007, it is increasing at a rate of .14% per year. (about 90 million in 2007) . As much as USA population every 3 years. August 2007



A true equal area map of THE HEMISPHERES ↔ Jon Able Light MATRIX PROJECTION 3 ↔ A mathematically precise Direct Equal Area Projection. Copyright © 2007, Abbass Bazeghi (Jon Able Light), Architect/Cartographer. All rights reserved. T: (805) 451-7807 jonablelight@cox.net EqualAreaMaps.com

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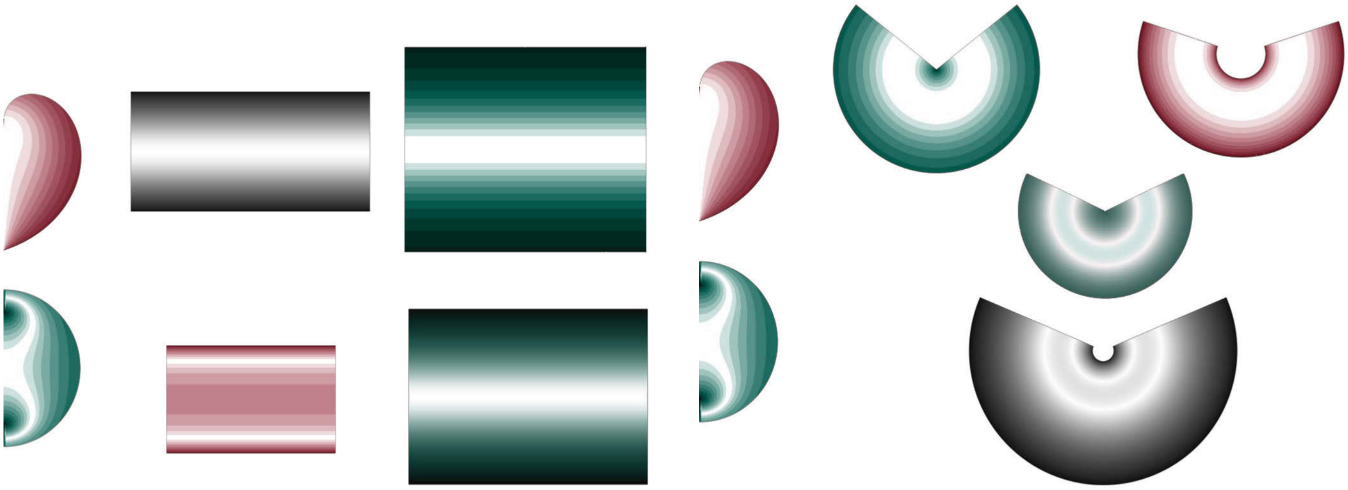
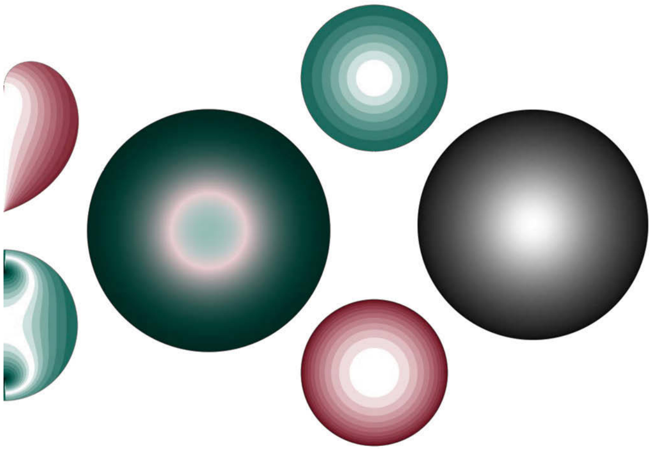
Visual Fields

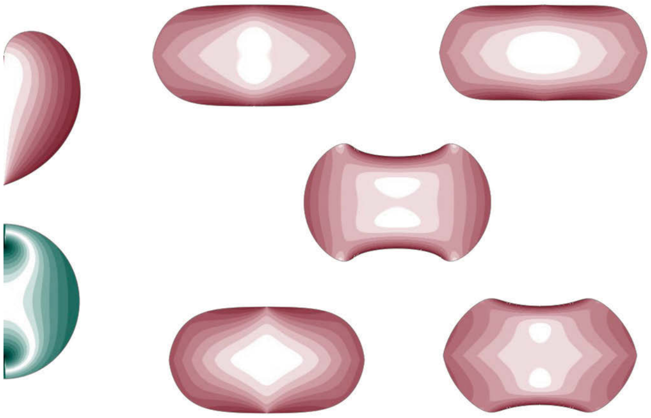
Beautiful Lies

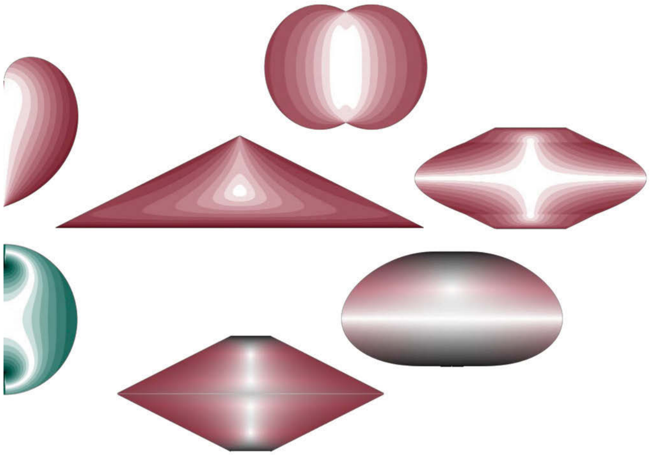
when distortion becomes art

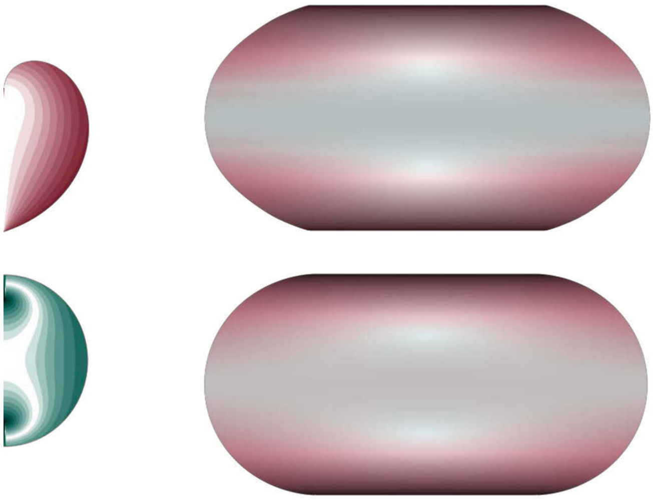
daan Strebe
NACIS 2007

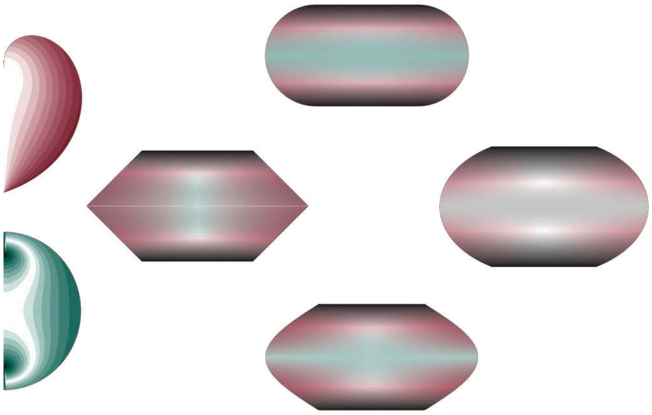


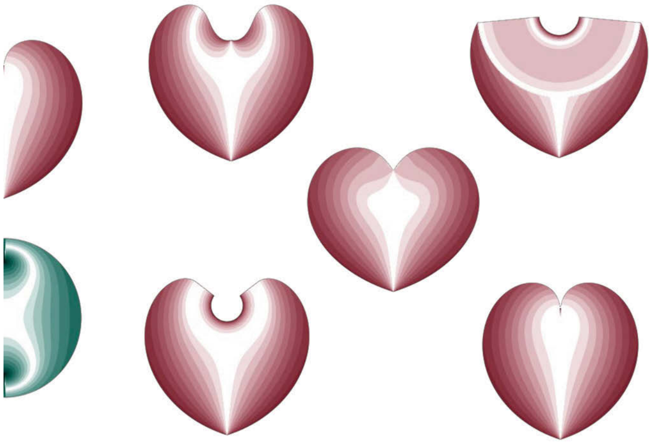


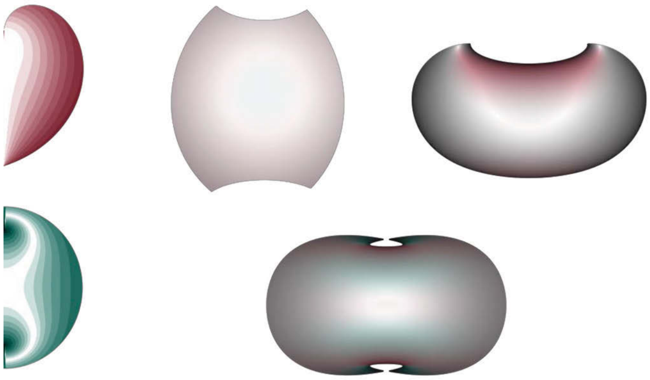


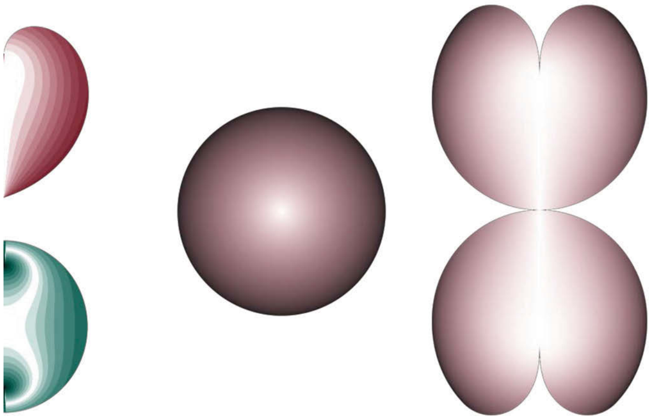


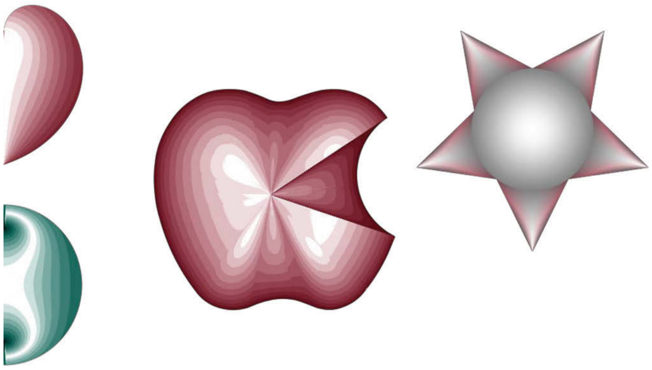


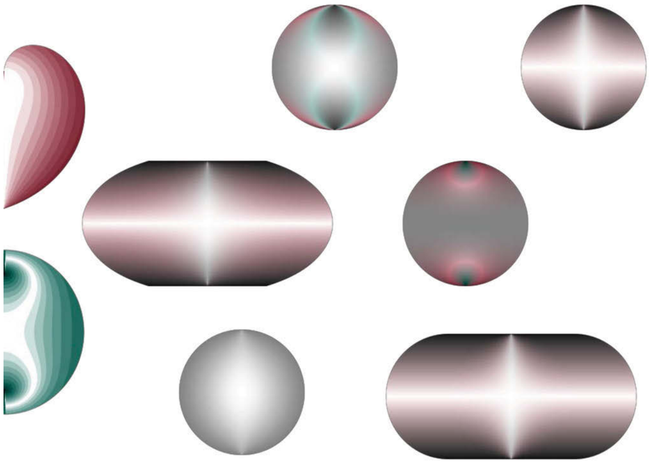


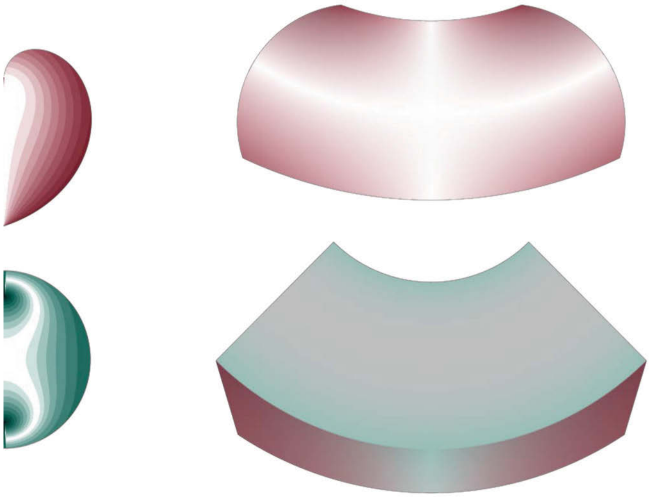


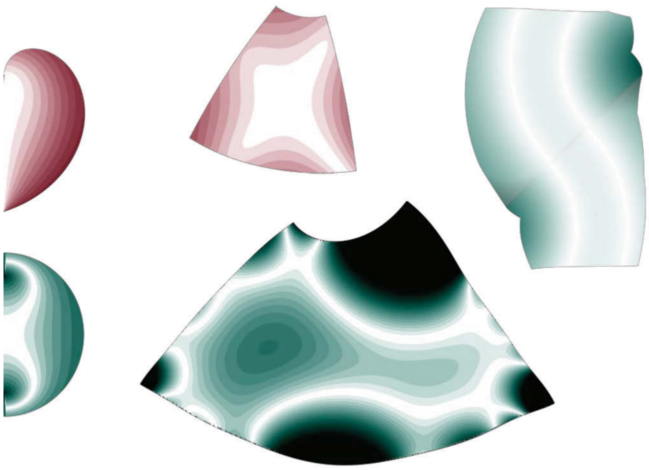


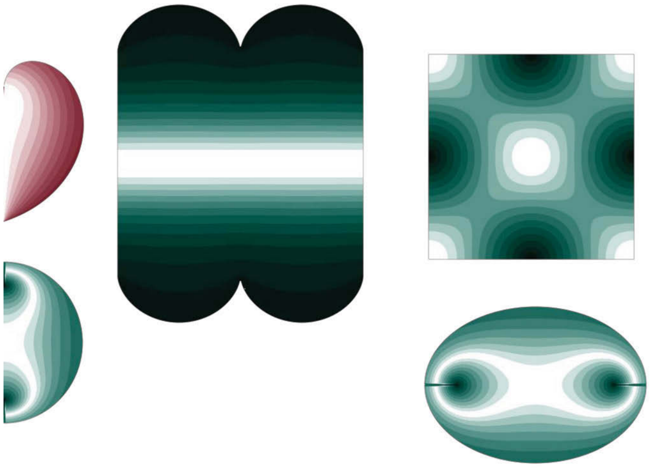


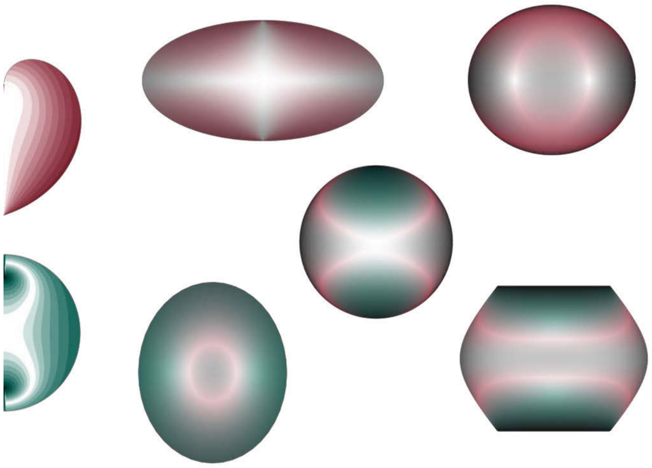


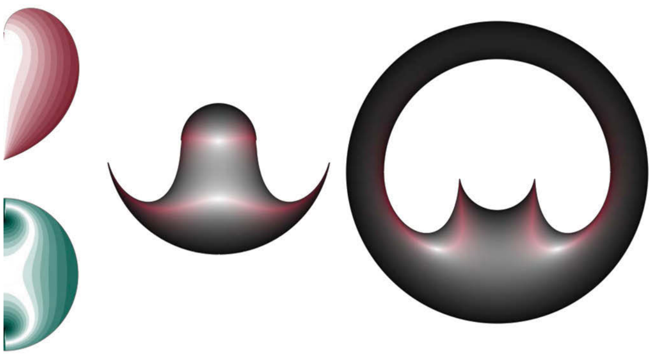


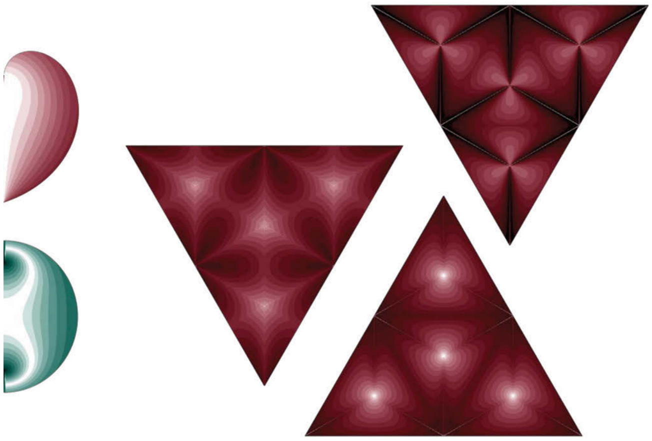


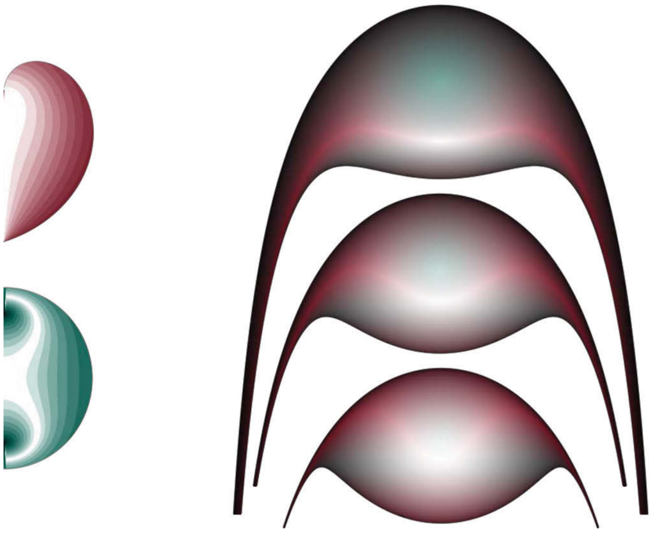












Color Figures

Maps and the Internet: What a Mess It Is and How to Fix It

Michael Peterson

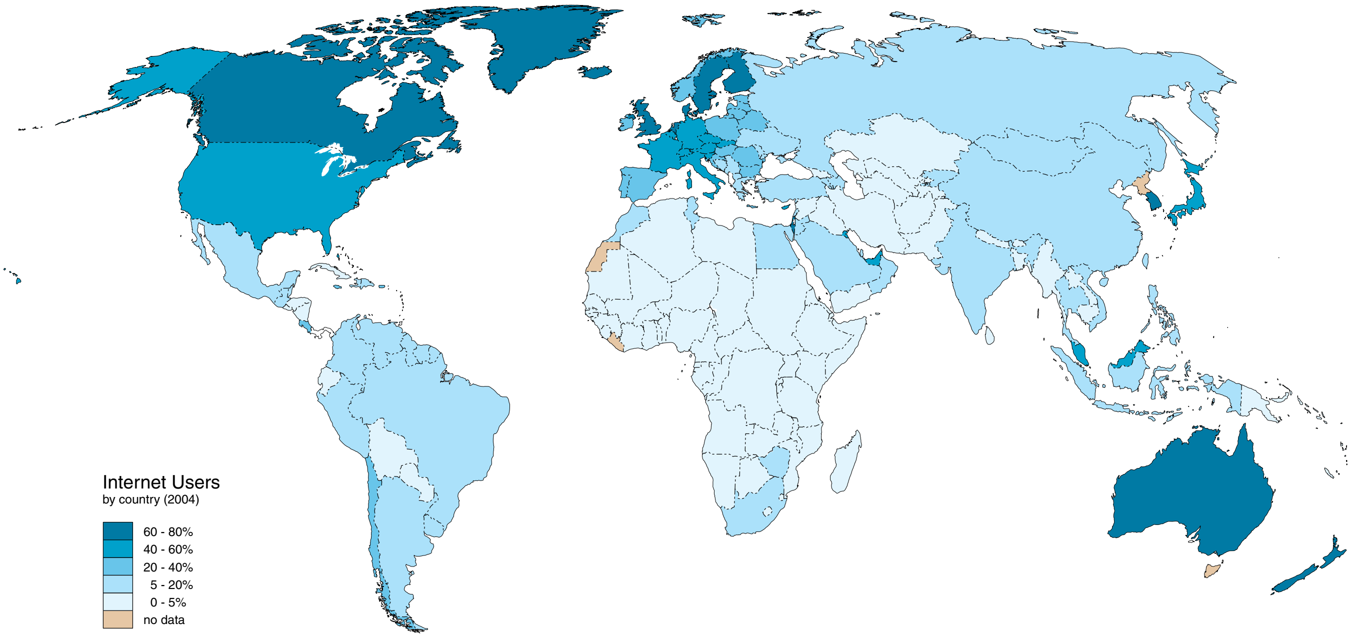


Figure 1. The percentage of Internet users by country.

Flex Projector–Interactive Software for Designing World Map Projections

Bernhard Jenny, Tom Patterson, and Lorenz Hurni

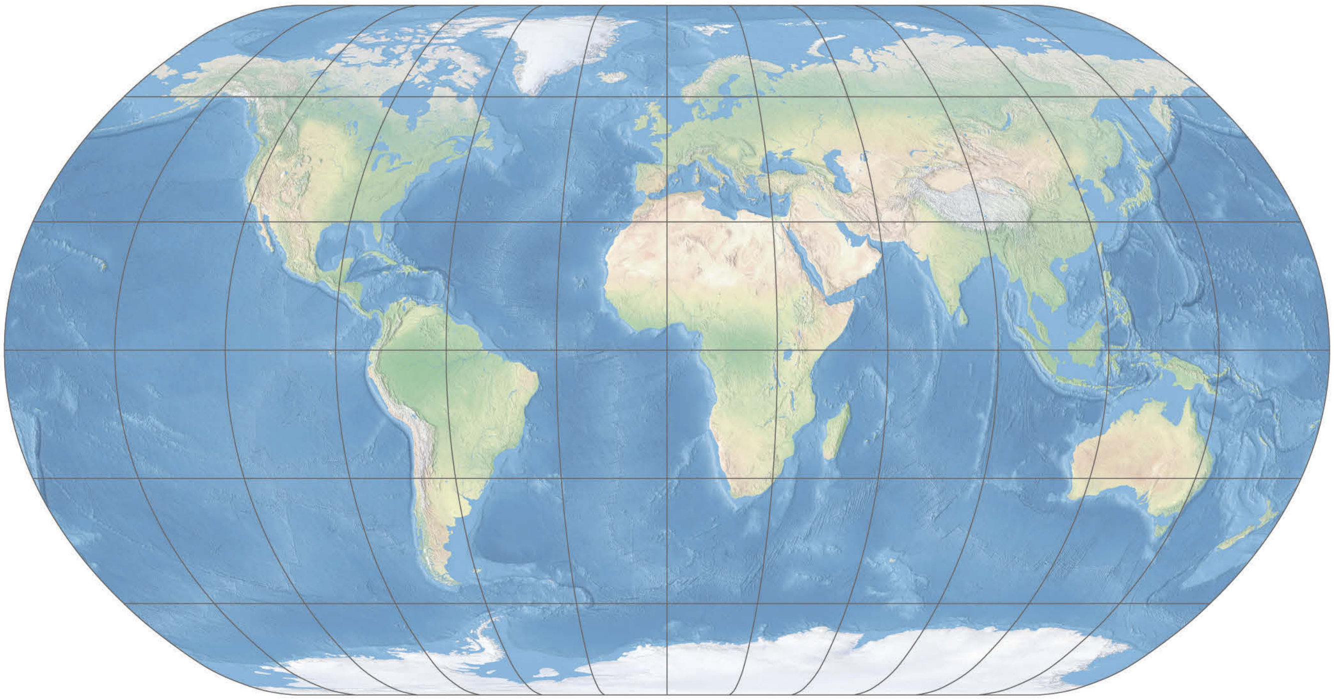


Figure 5. The Natural Earth projection applied to the Natural Earth II dataset.

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