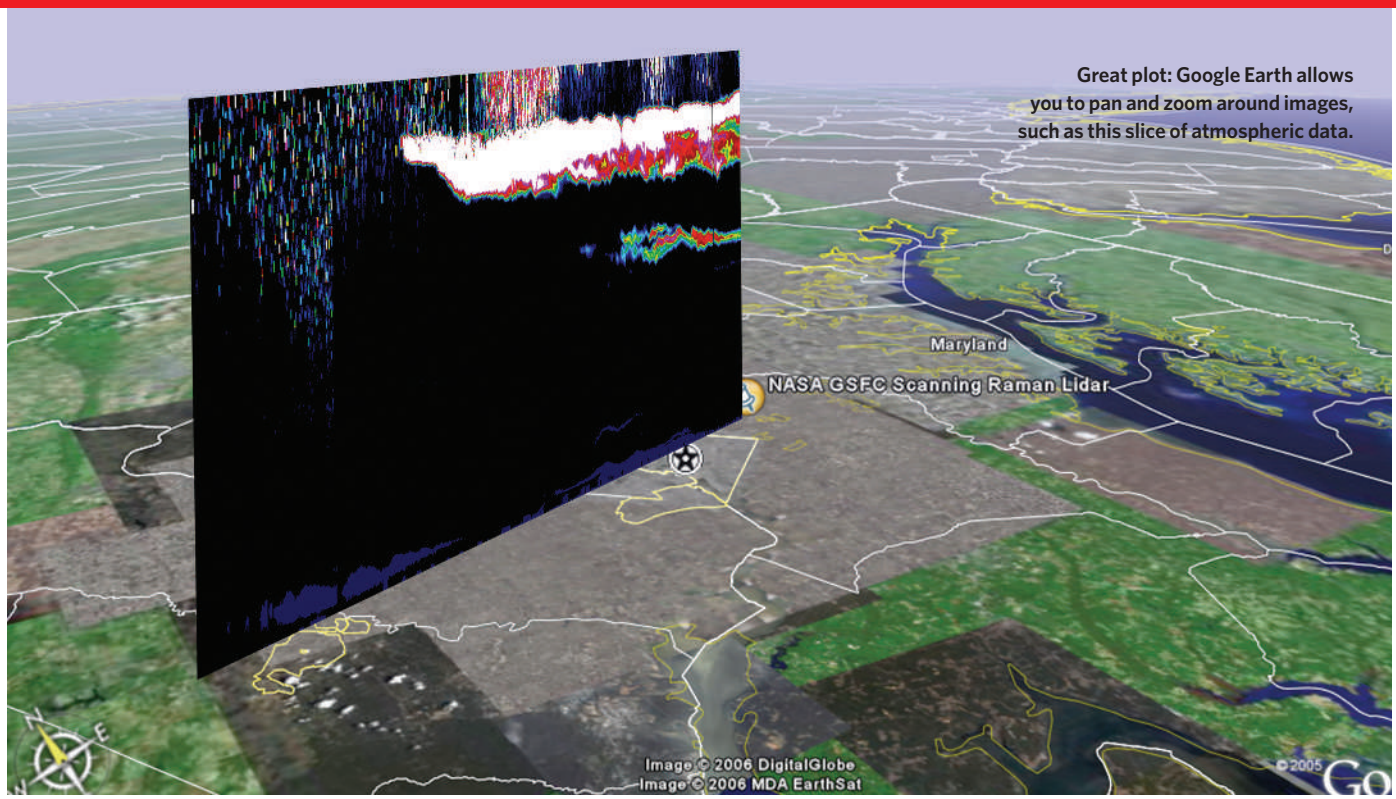


Great plot: Google Earth allows you to pan and zoom around images, such as this slice of atmospheric data.

ECOTRONICS/GOOGLE EARTH

The web-wide world

Life happens in three dimensions, so why doesn't science? **Declan Butler** discovers that online tools, led by the Google Earth virtual globe, are changing the way we interact with spatial data.

Next month, biologist Erik Born will be wielding a crossbow and firing satellite tags into the hides of walruses, having manoeuvred his rubber dinghy through the pack ice off western Greenland. By tagging the walruses, Born will be able to track the animals' movements and behaviour from afar over several years. He will keep an eye on them using the same free Internet tool that has opened the eyes of millions to the possibilities of digital geography (and the sight of their house from above) — the Google Earth virtual globe.

When the walruses migrate in the spring, Born and anyone else with a copy of the Google Earth software and a decent Internet connection, will be able to follow their westerly path to Baffin Island or the Canadian coast, and their return.

Born, who works at the Greenland Institute of Natural Resources in Nuuk, got the idea from his colleague Leif Toudal Pedersen, a remote-sensing researcher at the Technical University of Denmark in Lyngby. Last month, Pedersen began using Google Earth to visualize live data from satellites, recording the density and drift of Arctic ice, as well as the position of individual buoys and icebergs. Born's decision to follow suit means they can collaborate easily, with a tool that is free and convenient.

Combining Born's tracking data with Pedersen's maps should reveal how changes in ice affect the walruses' movements and behaviour. With traditional Geographic Information Systems (GIS) software — which was previously the only way to deal with spatial data like these — combining the two data streams would have been a headache. With Google Earth it will be effortless, says Pedersen: "It provides a very easy interface to a lot of different data."

Home page

To the casual user, of which it has attracted millions since its launch last June, the appeal of Google Earth is the ease with which you can zoom from space right down to street level, with images that in some places are sharp enough to show individual people. Its popularity with a growing number of scientists lies in the almost-equal ease with which it lets them lay data with a spatial component on top of background imagery — a trick they can repeat with multiple data sets. By offering researchers an easy way into GIS software, Google Earth and other virtual globes are set to go beyond representing the world, and start changing it.

Leaving aside its value as a tool for meshing data, Google Earth is simply an excellent visualization aid. It really comes into its own when you 'tilt' the browser away from the default vertical view, and fly along in three dimensions, swooping over mountains and through valleys, or along city streets with buildings looming up on all sides.

David Whiteman, an atmospheric scientist at NASA's Goddard Space Flight Center, is using this fly-by feature to understand local weather systems. Meteorological phenomena that occur over distances between 2 and 200 km are poorly predicted by current weather models, and scientists badly need real-time observations to refine their predictions.

So this summer, Whiteman will take part in a large field project, observing a three-dimensional column of the atmosphere centred on the Howard University campus in Beltsville, Maryland. Measurements will be made simultaneously by a battery of aircraft and satellite-borne instruments, including Whiteman's Raman Airborne Spectroscopic Lidar, which measures the properties of atmospheric water vapour, aerosol particles and cloud droplets.

This exercise will generate masses of data on the formation and behaviour of clouds, which the three-dimensional capabilities of virtual globes are ideally suited to viewing. "We are going to be able to display curtains of data of different atmospheric quantities, looking into them from above and flying along them," explains Whiteman. "We will have the topology of the terrain; you will be able to see uplift and cloud formation, and its interaction with precipitation." And like Born's work, these easily viewed data can be shared instantly with colleagues.

"I think it's just a short matter of time before

systems like Google Earth are an essential requirement for people in our field," says Whiteman. "As soon as one group shows that this is useful, everyone will adopt it."

Indeed, increasing amounts of scientific data are becoming available, often in real time, in formats that can be displayed by virtual globes. Millions of species distributions from the Global Biodiversity Information Facility, headquartered in Copenhagen, Denmark, are available for Google Earth, for example.

Digital watch

The eventual impact will be nothing less than the realization of a 'digital Earth', as described by former US vice-president Al Gore in 1998. "Digital Earth was always intended to allow us to 'fly' from space (virtually, of course) down through progressively higher resolution data sets to hover above any point on the Earth's surface — and then display information relevant to that location from an infinite number of sources," says Gore. "Its highest purpose was to use the Earth itself as an organizing metaphor for digital information." But the project died a death in 2001 after Gore lost the 2000 US presidential election.

Michael Goodchild, a GIS expert at the University of California, Santa Barbara, says that scientists' use of virtual globes is breathing fresh life into Gore's dream. There is renewed hope that every sort of information on the state of the planet, from levels of toxic chemicals to the incidence of diseases, will become available to all with a few moves of the mouse.

The GIS software is already an important tool for understanding spatial and temporal factors in a wide range of disciplines. But many scientists that could use GIS do not, and it has remained largely the preserve of specialists. Goodchild is convinced that tools like Google Earth will increase awareness of GIS's potential and encourage researchers to explore more powerful GIS techniques. "It's like the effect of the personal computer in the 1970s, where previously there was quite an élite population of computer users," Goodchild enthuses. "Just as the PC democratized computing, so systems like Google Earth will democratize GIS."

Goodchild illustrates the system's ease with an anecdote from his own teaching. "Typically, I used to spend an entire year taking senior undergraduates through courses in GIS. And at the end of the year, as a treat, I might let them generate a three-dimensional fly-by over a landscape," he says. "Now, using Google Earth, a ten-year old can do that." Goodchild thinks that once scientists experience this easy visualization, they will be drawn into deeper forms of analysis using the powerful techniques that GIS professionals have developed over decades.

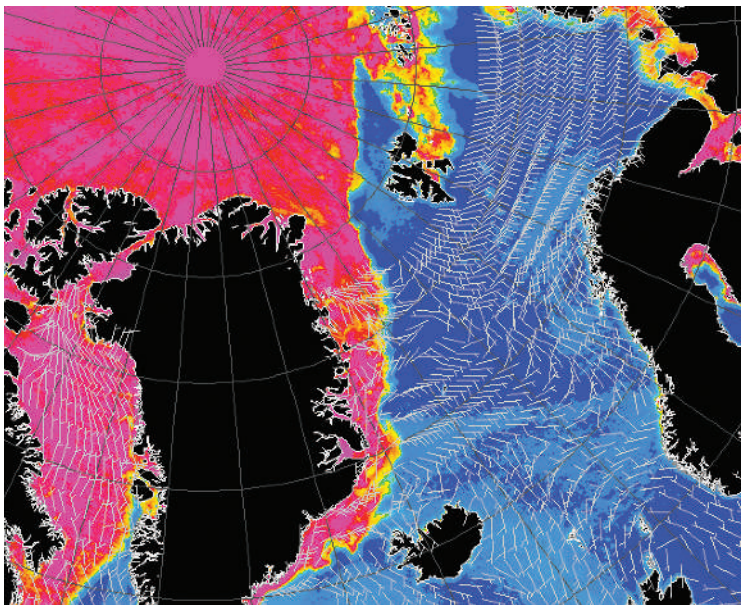
GIS techniques use statistics to predict or explain patterns, whether they be outbreaks of vector-borne disease or urban crime waves. Displaying such patterns on the current version of Google Earth requires gentle hacking. But Brian McClendon, director of engineering at Google Earth, says he wants as many people as possible to use the program — and will consider adding features that make it easier for them to get their data into it. McClendon is hoping to attract scientists who will generate interesting content for Google Earth's other customers.

Whiteman emphasizes, however, that three-dimensional visualization is about more than just creating images. He says it is critical for generating scientific hypotheses and the questions they go on to test. "What have I measured; what are the relationships I have here; what can I explore? It is part of getting an intuitive grasp of the problem, the measurements and the analytical challenge".

If one can simultaneously visualize the data and the predictions from models, areas where the data agree or disagree with the model jump out, he says. "This could dramatically improve the efficiency of exploring relationships among quantitative data."

E. W. BORN

The time has come: online tools will revolutionize the way walruses and other animals are tracked.



L. T. PEDERSEN/TECHNICAL UNIV. DENMARK

Pretty useful: virtual globes can display live data such as sea-ice distributions and wind directions on the same map.

Popular movement

Google Earth has no analytic functions and is not designed to replace professional GIS software; in fact, it should be a boon to the software makers. "Google Earth is just the most fantastic thing I have ever seen," says Jack Dangermond, founder and president of ESRI, the world's largest creator of GIS software. ESRI, which is based in Redlands, Virginia, and other GIS companies that were caught napping by Google Earth are now eager to capitalize on its success. They are creating a slew of products that combine its ease of use with their traditional analytic strengths. "It really is opening up our world," says Dangermond, "and business is booming."

Later this year, ESRI will release a huge upgrade of its flagship desktop GIS product, ArcGIS, which will let users publish virtual globes on the Internet and analyse their data in many ways. "We have taken several thousand functions and deployed them in an Internet environment," says Dangermond.

As part of the package, ESRI will also release a free visualization tool, ArcGis Explorer, which some GIS professionals are calling a Google-Earth killer. Data in Google Earth need to be in a specific format; ESRI's tool will allow users to view not only data from ESRI's

own products, but also information in formats that are being increasingly standardized through the Open Geospatial Consortium. This international body is working to ensure that computers can understand descriptions of the spatial features of anything from highways and postcodes to icebergs.

Unlike Google Earth, the ESRI viewer comes equipped with a series of analytic tools. Scientists can run models on their servers, and simultaneously view them over the Internet in ArcGis Explorer by dragging and dropping data files. They can fuse multiple data sources on screen, and export them in whatever format they choose. Still, McClendon believes that both Google and ESRI will profit from a generally increased interest in GIS, and says he welcomes the competition. "I think that we want many more people to understand and care about GIS, and ESRI's tools are the best in the business for that," says McClendon.

Skyline Software Systems, based in Chantilly, Virginia, was one of the first companies to offer a virtual globe: TerraExplorer. Later this year it will release Skyline Online, a browser-based tool similar to ArcGis Explorer. "It will empower users at home as well as researchers with capabilities that have been available only to government agencies until now," says company president, Ronnie Yaron.

Globe trotters

Meanwhile, in the public sector, NASA has no intention of using its World Wind virtual globe to compete with Google, at least according to one scientist on the project, who did not wish to be identified. He points out that World Wind is explicitly designed for scientific information, and its code is open source so that scientists and software developers can tailor it to their needs. He admits that World Wind's performance lags behind that of Google Earth: it is slower and eats up much more memory and processor time. But NASA intends to remedy these performance issues — a major upgrade will be released in July, he says.

Joshua Been, GIS librarian at the University of Texas, Arlington, sees firsthand how Google Earth is promoting interest in a range of professional GIS systems. Researchers and students increasingly come to him wanting to use Google Earth or World Wind, but most of their queries need analyses beyond straightforward visualization, he says. "So I try my hardest to show them the super-cool capabilities of full-blown GIS."

Still, Been's library offers the same level of support for the two free systems as it does for professional software, and he encourages people to use them. "If they want GIS data to be viewable in a free and public three-dimensional viewer, Google Earth will continue to be the standard," he says. "I disagree entirely that ArcGIS Explorer will be a 'Google-Earth killer'."

ESRI

Free ride: creators of geospatial software such as Jack Dangermond say that "business is booming".

For Ming-Hsiang Tsou, a geographer at San Diego State University in California, "the year 2005 was a watershed for GIS on the Internet". He notes in particular how natural disasters, such as the tsunami and Hurricane Katrina, etched the power and utility of GIS and Google Earth into people's minds (see page 787). Before Google Earth appeared, Tsou himself created interactive two-dimensional Internet maps of the 2003 San Diego wildfires, featuring data on fire spread, hot spots and rescue operations.

> **"We are going to be able to display curtains of atmospheric data and look into them from above or fly alongside them."**
> — David Whiteman

The huge public interest in such visualizations means scientific information is being made much more accessible to users, he says. Meteorological radar data and satellite images have long been available online, but Google Earth is allowing the agencies that provide them, such as the US National Oceanic and Atmospheric Administration (NOAA), to make the data more useful and user friendly.

Real-time weather information can now be displayed in Google Earth alongside the landmarks and routes in which the general public is interested, says Valliappa Lakshmanan, a NOAA researcher at the University of Oklahoma, Norman. People can use Google Earth to ask: "How far is the rain core from the route that I will take this afternoon? Is it near grandma's house?" Such detail is possible because the resolution of forecast data is now as good as 1 km, updated every 120 seconds.

The value of scientific data increases the more you can link it to information that the user already considers important, says Lakshmanan. "Scientists should take this opportunity to use GIS to present their scientific results in a way that users can easily tie to other data sources."

Nowhere is this more true than in the environmental sciences. One of the traditional roles of GIS has been to provide data to support decision-making. And environmental groups that have discovered GIS are starting to use it to change the balance of power in public debates. As more citizens become concerned about their local environment, easy-to-use virtual globes will facilitate the communication of spatial information between stakeholders and government agencies.

Back in Greenland, Born and Pedersen hope to be able to record the effects of climate change on the spread of sea ice and on their tagged walruses. If the ice continues to recede in the Davis Strait, as it has for the past two decades, they will be able to monitor its immediate impact on walrus feeding grounds. Is it too much to hope that, in future, the same approach to sharing data will help us decide what to do about global climate change? ■

Declan Butler is a senior reporter for *Nature* based in Paris.

For more on Google Earth, see page 763 and www.nature.com/news.