NASA World Wind: Opensource GIS for Mission Operations

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Abstract—This paper describes NASA World Wind, its technical architecture and performance, and its emerging use for mission operations. World Wind is a geographic information system that provides graphical access to terabytes of imagery and elevation models for planets and other celestial objects including satellite and other data of the Earth, Moon, Mars, Venus, and Jupiter; as well as astronomical data made available through the Sloan Digital Sky Survey. World Wind is also a customizable system that can be integrated as part of other applications. World Wind is not only an application in which add-ons can be integrated, but is also being developed as a plugin that can be integrated with other applications.

This paper also describes the significant contributions of the international opensource community in making World Wind what it is today. Contributions have involved the following: 1) lead development of add-ons, several of which have been integrated as part of the core system available for direct download via sourceforge, 2) lead provider of high-resolution data sets, 3) lead help desk support through internet relay chat for end-users and developers, and 4) significant technical contributions to the core system including bug identification, tracking and resolution as well as ideas for new features and source code modifications. [1] [2]

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[1] 1-4244-0525-4/07/$20.00 ©2007 IEEE.
[2] IEEEAC paper #1048, Version 2, Updated October 20, 2006

1. INTRODUCTION

NASA World Wind is a three-dimensional geographic information system developed by the National Aeronautics & Space Administration (NASA), its partners, and the opensource community. World Wind is both a system for highly interactive geographic data browsing utilizing the Internet, as well as a stand alone computer application. The World Wind system uses a novel approach to rapidly serve terabytes of imagery and elevation models for planets and other celestial objects including satellite and other data of the Earth, Moon, Mars, Venus, and Jupiter; as well as astronomical data made available through the Sloan Digital Sky Survey. World Wind is both a geographic browser for public domain science data, as well as a platform for land, sea, air and space mission operations.

NASA and other organizations have a wealth of planetary science data, representing the main output from thousands of satellites in earth-orbit and from dozens of costly missions to other planets. Considering that the main output of most missions to other planets is the geographic data that gets returned to Earth, public benefits derived from use of the planetary data represent the most significant return on investment for the public.

The most important attribute of NASA World Wind as an open source project is its unique potential to aggregate a multitude of public and private geographic data sets, providing access not only to NASA data but also to data from other government agencies, industry, and the general public. The user interface of the World Wind browser is designed for the layperson, giving convenient access to all kinds of geographically referenced information, thereby hiding the technical details related to finding, accessing and retrieving geographic data.

The open source nature of World Wind client browser in conjunction with a modular expandable systems architecture allows developers to easily customize the client through plug-ins. A multitude of additions have been contributed from the open source community [4] which have significantly increased the capabilities of the World Wind browser as well as significantly increased the available data.

As a dynamic geographic browser, World Wind has widespread use for education using public domain data. As a platform for mission operations, World Wind has begun to be used for earth missions (e.g., response to natural disasters such as fires), and for planetary missions (e.g., lunar exploration).

2. GEOGRAPHIC INFORMATION BROWSING

World Wind is an information system that allows users to geographically browse terabytes of Earth, Moon and other planetary data through the internet.

Analogous to browsing text and imagery using a http browser, i.e. FireFox, Microsoft Internet Explorer and Apple's Safari, the geographic information system (GIS) consists of clients and a heterogeneous network of data servers, see Fig. 1.

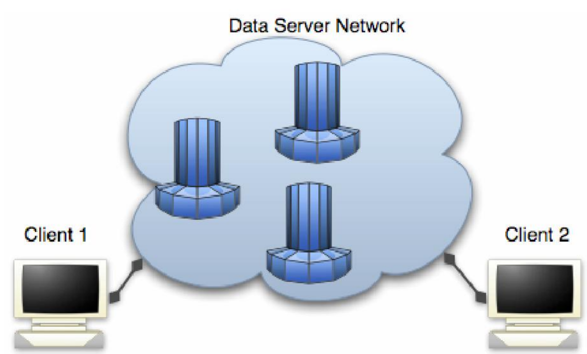

Figure 1 Users connect with their geobrowser client through the internet. Multiple data sources can be visualized "mashed up" on the client side at the same time.

The name geographic information describes a collection of data that can be referenced by latitude, longitude, altitude, and time. Most popular examples of geographic information are maps, satellite and aerial imagery, elevation models, country boundaries, and city place names. In a wider scope, all information that can be tagged with a location and time stamp can be considered geographic information. For example, newly emerging GeoRSS feeds [5,6] can relay news information with a geographic origin.

The daunting challenge for a geographic client browser is to seamlessly integrate and display vastly different geographic information modes. Nowadays, it is not enough to simply display a map of some region, additional dynamic information modes need to be displayed and put into context as well (e.g., weather sensor readings, and live aerial video feeds).

World Wind Geographic Browser

The World Wind client is an interactive 3D geographic visualization system. Earth and other planets can be explored from directly overhead as well as from a surface perspective. 3D visualization is most powerful when zooming in and out from an astronaut's perspective to a surface perspective, and when viewing terrain from a surface perspective, see Fig. 3. When viewing from directly overhead and from relatively close to the surface, 3D visualization in World Wind looks similar to a traditional 2D map viewer. In order to achieve rendering of large scale terrain data with refresh rates for interactive fly-overs, World Wind makes extensive use of caching and advanced 3D terrain rendering algorithms.

For each globe, there is a default digital elevation model (DEM) that is based on the nominal radius of the globe and augmented with elevation data from available sources. Figure 1 below illustrates how images are draped over an elevation model at a global scale, and Figure 2 illustrates how this is done at a local scale.

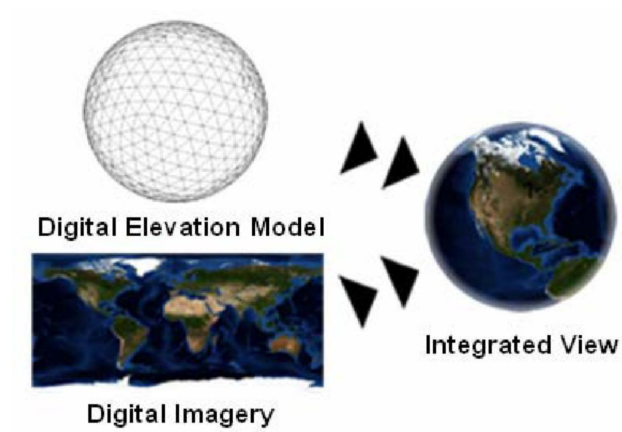

Figure 2 Texture mapping at global scale

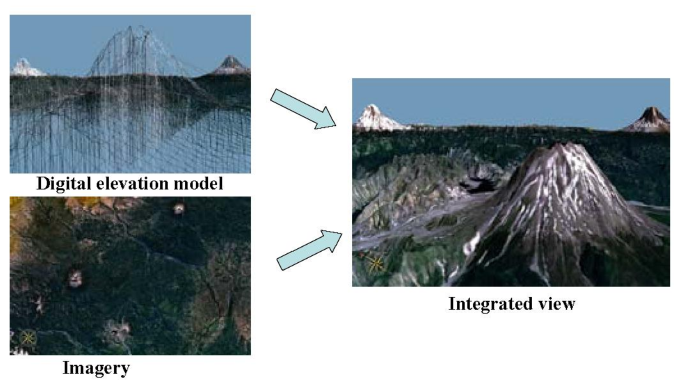

Figure 3: Texture mapping at local scale (Mt. St. Helens)

Digital Elevation Models (DEMs)

World Wind currently has detailed elevation models for the Earth, the Moon, and Mars. For Earth, the U.S. Geological Survey (USGS) National Elevation Dataset (NED) is used in conjunction with the Shuttle Radar Tomography Mission (SRTM) datasets [7]. NED merges the highest-resolution, best quality elevation data available for the United States into a seamless format. NED has a consistent projection (Geographic), resolution (1 arc second), and elevation units (meters). SRTM includes data for about 80% of all land on Earth, covering most of the land surfaces between 60 degrees north latitude and 54 degrees south latitude. SRTM data is 90 meter averaged from its original 30 meter data.

The digital elevation data for the Moon is of much lower resolution compared to Earth. World Wind's Moon DEM is a product from various data sources and Lunar missions. The global lunar DEM stems from the laser altimeter measurements between 75 degrees south to 75 degrees north from the Clementine mission. The Clementine laser altimeter collected an elevation value for every 514 km^2 on average. With interpolation, a 2km per pixel resolution map was derived. In addition a stereographically reconstructed DEM from the Apollo mission mapping camera as well as the region of the Tyco crater from Earth bound radar backscattering experiments [11] with 500m per pixel resolution is fused into the global map.

For Mars, the global elevation map is the product of the MOLA experiment from the Mars Global Surveyor (MGS) mission resulting in a map resolution of 460m per pixel.

Earth	SRTM30Plus
	SRTM 3-arc/sec v2
	USGS NED 1-arc/sec
Mars	MOLA elevation model
Moon	Lunar elevation model (USGS)

Table 1 Digital Elevation Models (DEM) in World Wind

Digital imagery

Multiple terabytes of digital imagery are made available in World Wind from a variety of sources for Earth, Moon, Mars, Venus, Jupiter and Jupiter's moons Callisto, Europa, Ganymede and Io. The following list identifies the main datasets currently available in the default installation of World Wind.

Earth	Blue Marble Next Generation (500m/pixel)
	NLT Landsat 7 Visible Color (30m/pixel)
	NLT Landsat 7 Pseudo Color (30m/pixel)
	OnEarth Landsat 7 Visible Color (15m/pixel)
	OnEarth Landsat 7 Pseudo Color (15m/pixel)
	Geocover 1990 Landsat 7 Pseudo
	Geocover 2000 Landsat 7 Pseudo (15m/pixel)
	USGS Digital Ortho (1m/pixel)
	USGS Urban Area Ortho (15cm-1m/pixel)
	USGS Topographic Maps
Mars	MOC 256 (ASU)
	MOC 256 Colorized
	MOLA Color (ASU)
	MOLA Colored (JPL)
	Mars THEMIS (ASU)
	Mars THEMIS Color
	MDIM 2.1 (JPL-USGS)
Moon	Clementine 40xx
	Clementine 30xx
	Shaded Elevation Map
Jupiter	Jupiter Base Map
	Jupiter Moons: Callisto, Europa, Ganymede, Io
Venus	Magellan Imaging Radar (Color)
	Magellan Imaging Radar (Grey)
	Magellan Shaded Relief

Table 2 Digital Image data in World Wind

Web Map Service: Tiled imagery

World Wind uses a multi-resolution layering technique that shows progressively more detail as a user zooms in to various locations. To do this, World Wind stores multiple copies of the same map at successively higher resolutions. Using a map in WGS 84 projection of the Earth as an example, at Layer 0, World Wind breaks down the image into 50 tiles, each at 36° x 36° segments, see Fig. 4. Layer 1 increases this resolution by a factor of 4, meaning that the same image of Earth is now broken down into 18° x 18° segments, resulting in 200 tiles of information. At Layer 2, the resolution becomes 9° x 9° for 800 tiles, Layer 3 is 4.5° x 4.5° and 3200 tiles, etc.

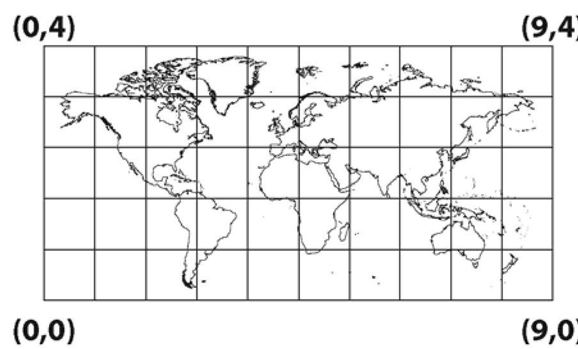

Figure 4. World Wind geographic tiling scheme, layer 0

As a user zooms in to various locations, World Wind requests the necessary data from servers across the internet, downloading only the information that is required to display the view requested by the user.

NASA custom and Open WMS protocol

In its simplest form, World Wind directly requests tiled imagery (images of size 512x512 in jpeg and other formats) from a server using a simple NASA custom HTTP request protocol. The client issues a simple request with the following parameters:

T=*dataset*&**X=***column*&**Y=***row*&**L=***resolution level.*

Here, the *column*, *row* and *level* parameters refer to the location and size of the geographically referenced region on the worldmap in a simple geographic projection, Fig 4.

Equally well supported is the Web Mapping Service (WMS) 1.3 protocol specification from the Open Geospatial Consortium [8]. WMS is a broadly adopted standard. World Wind easily operates with servers based on this standard.

Proper elevation data and image coverage are requested for the specific resolution layer and view point. World Wind caches the requested data locally and therefore can seamlessly transition from one layer to the next, revealing successively more detail as the user navigates around the World.

World Wind controls and layer manager

Besides mouse and keyboard controls for interactive navigation, World Wind allows users via command line to select the world to view, and control various visualization parameters including the following:

- **world** <string>
- **lat** <decimal> *(in degrees)*
- **lon** <decimal> *(in degrees)*
- **alt** <decimal> *(in meters)*
- **view** <decimal> *(in degrees) – used as an alternate to altitude, specifies the camera's range of view in degrees*
- **dir** <decimal> *(in degrees) – compass heading*
- **tilt** <decimal> *(in degrees) – camera's tilt from 0-90 degrees where 0 degrees is perpendicular to the surface*
- **bank** <decimal> *(in degrees) – camera's tilt perpendicular to the ground surface*
- **layer** <string> *name of layer (case sensitive) to enable*

Web pages can link to geographic locations in World Wind with a simple *worldwind://goto/<parameters>* command.

3. High Performance Architecture

Rapidly deploying multiple terabytes of geographic information for distributed access requires a high performance server infrastructure. Large scale terrain data including aerial imagery or elevation data on a grid, is frequently divided into smaller files and practically delivered via multiple high capacity disk drives. Also, there are multiple file formats for geographic referenced data. Our server architecture currently supports all data formats that are in accordance with the Geospatial Data Abstraction Library (GDAL) [9]. Typically one large dataset divided into multiple files conforms to only one data standard. Our high performance server infrastructure is implemented in the Python programming language.

Request process flow

In the simplest case, data is requested via the NASA custom http protocol. The client issues an HTTP get request to the root server specifying the kind of data sets, the geographic location and expanse. This request can be routed to a load balanced server system taking also into account the geographic region and resolution level before dispatching the request to a proper processing server, see Fig 5.

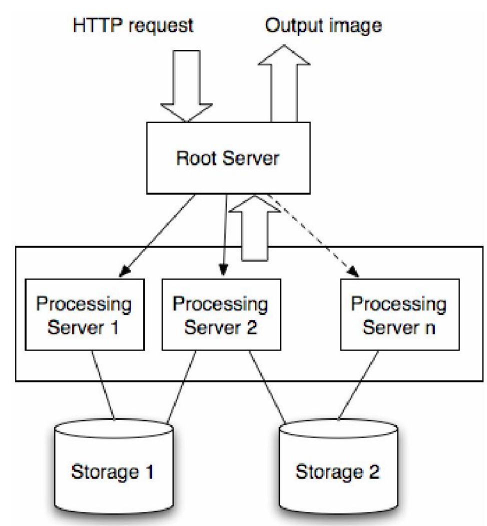

Figure 5. Load balanced geographic data processing server system. A dedicated root server dispatches incoming requests to the proper processing servers.

In order to provide the World Wind client user with the illusion of a virtual flight over a digital globe, it is paramount to receive data as quickly as possible. Caching, both on the client and the server side, is used to speed up the response time for requests of digital terrain data. Client-side caching also enables offline usage of the system.

Digital geographic data in native geographic data file formats is mostly not suitable for serving directly to the World Wind client for the following reasons.

- Data files are large, often exceeding 1 Gbyte.
- Terrain data projection is not simple equi-rectangular (geographic) as required
- Image data format is not in simple 24 bit RGB

In order to address these reasons described above, on-demand processing is utilized.

On demand processing

For a World Wind client request, geographically referenced image data needs to be in a specific format and geographic projection. We found that preprocessing the entire dataset is impractical for time and storage reasons. Preprocessing can easily double the data storage requirements and even may take weeks worth of computing time on modern server hardware.

Our experience with real data and tracking of millions of client requests led us to the conclusion that high resolution geographic data is only accessed for a small percentage of entire global datasets (<10%). Thus, on demand processing of data sets is a viable and successful strategy.

Firstly, the processing server checks whether cached results for the client request are available. Typically the response time for serving cached files is short, on the order of 0.015s. Only when data can not be retrieved from the cache is it necessary to process the native geographic data files. The time for handling native geographic data in preparation for the specific World Wind client request depends on the data format and whether an image resolution pyramid is available. In our experience, GeoTiff [10] files with internal tiling and a resolution pyramid can be processed rather quickly. Overall, processing time varies from 3s to about 20s on a modern fast server.

Hence, for each processing server, World Wind uses a single threaded response pipeline for all requests that lead to retrieving cached data products. All other requests are thrown into a multi-threaded processing pool, see Fig 6. With this strategy, the server is responsive even when burdened with numerous requests and high processing loads.

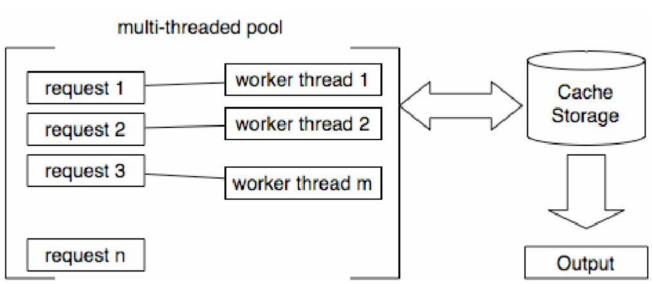

Figure 6. The processing server responds to a request in two ways. An immediate response is formed if requested data is found in the cache, otherwise the request is thrown into a multi-threaded processing pool. To prevent a server overload, only a small number of worker threads tackle a large pool of requests.

4. TECHNICAL PERFORMANCE

Since its release, the World Wind software has been downloaded more than 10 million times from sourceforge, with around 11,000 downloads per day at the time of this writing. There are estimated to be another several million downloads from other sites as well. Each download is currently about 60 Mbytes including default data.

Date (UTC)	Downloads
13 Oct 2006	10,390
12 Oct 2006	10,674
11 Oct 2006	10,635
10 Oct 2006	10,650
9 Oct 2006	11,432
8 Oct 2006	12,510
7 Oct 2006	15,598

Table 3 World Wind Downloads per day

Logs on the World Wind servers have registered an average of 6.5 million image requests per day, 155 gigabytes of imagery downloaded per day, for an average of 14,940 unique users per day over a recent eight-month period.

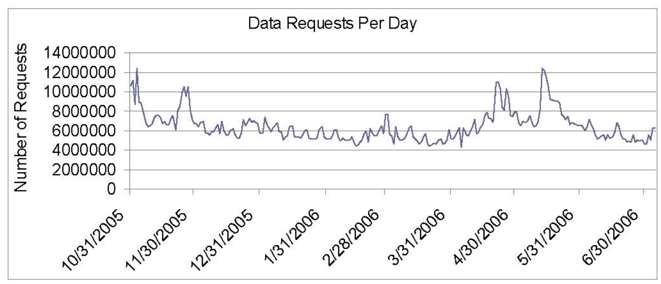

Figure 7: Data requests per day

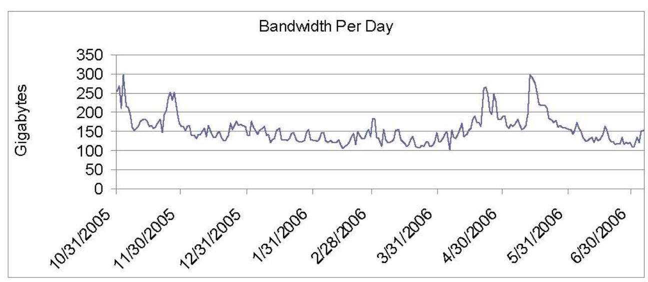

Figure 8: Downloads per day

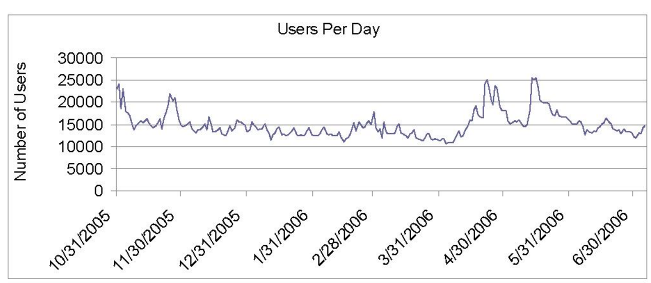

Figure 9: Users per day

5. APPLICATION TO MISSION OPERATIONS

World Wind has emerging application for use with mission operations on Earth (e.g., response to natural disasters such as fires), and mission operations for other planets and celestial objects (e.g., lunar exploration). Key to such mission operations is the integration of static data (e.g., base elevation data and imagery), as well as dynamic data (e.g., recent data from satellites and unmanned air vehicles (UAVs). An example application area is response to disasters such as forest fires using three primary sources of dynamic data: 1) MODIS Rapid Response Imagery, 2) UAV Imagery, and 3) Naval Research Laboratory Weather Data.

MODIS Rapid Response Imagery

Moderate-Resolution Imaging Spectroradiometer (MODIS) Data is displayed in World Wind with data from the MODIS Rapid Response System made available by NASA's Goddard Space Flight Center, the University of Maryland, and the U.S. Forest Service. MODIS views the entire surface (land, oceans, clouds, aerosols, etc.) of the Earth every one to two days at a "moderate resolution" of 250 meters to 1 kilometer, and can provide access to satellite images within minutes of a satellite passing overhead. World Wind provides ready access to a range of MODIS imagery for Fires, Floods, Dust & Smoke, Storms, Volcanoes, and other phenomena. Figure 10 below shows an image from MODIS integrated in World Wind for fires and smoke in the Los Angeles area, Southern California on 9/17/2006 at 9:00pm.

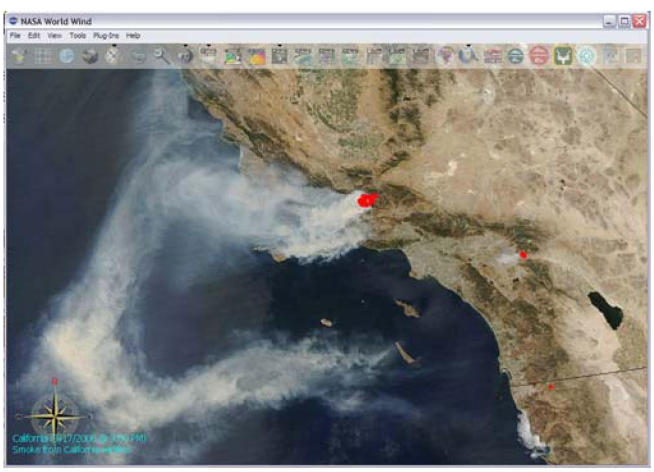

Figure 10: Rapid Fire MODIS imagery of a 9/2006 fire.

UAV Imagery

Complimentary research is exploring the use of unmanned air-vehicles (UAVs) such as the NASA Altair (See Figure 11) to support forest fire monitoring operations. UAVs can provide continuous monitoring of an active fire, with higher resolution and more frequent update than MODIS. World Wind has begun to support collaborative decision environments for UAV operations [12]. The goal of this work is to provide the U.S. Forest Service with near real-time high resolution imagery to compliment satellite imagery which only gets updated every one to two days. Use of World Wind is being explored for the planning and monitoring of UAV flight paths and operations (See Figure 12). UAV position during flight can be monitored relative to flight sector boundaries and no-fly zones, and UAV sensor data can be geocoded and made available to users through World Wind.

Figure 11: NASA Unmanned Air Vehicle (UAV) - Altair

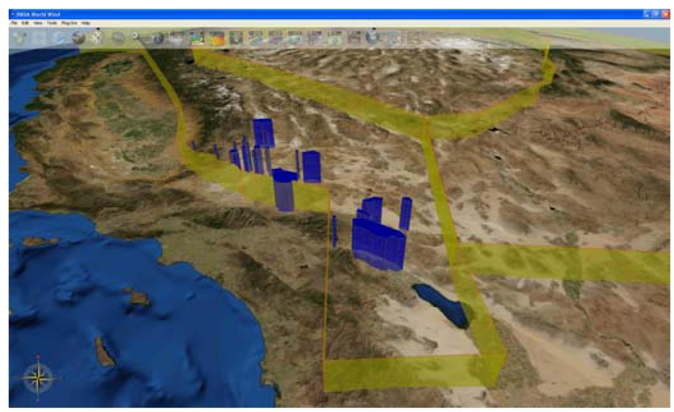

Figure 12: Supporting UAV Flight Operations. World Wind displays flight sector boundaries (yellow) with exclusion zones (blue) over California.

Navel Research Laboratory (NRL) Weather Data

World Wind can seamlessly integrate a multitude of high resolution data sources that cover the entire globe. The Naval Research Laboratory located in Monterey, California provides real time weather information from GEOS and POES satellites. Data processing and modeling is done at the NRL super computer facilities, then the resulting data products are made available via World Wind. With a simple mouse click, World Wind instantly displays real time weather imagery and relevant barometric weather information, see Fig 13.

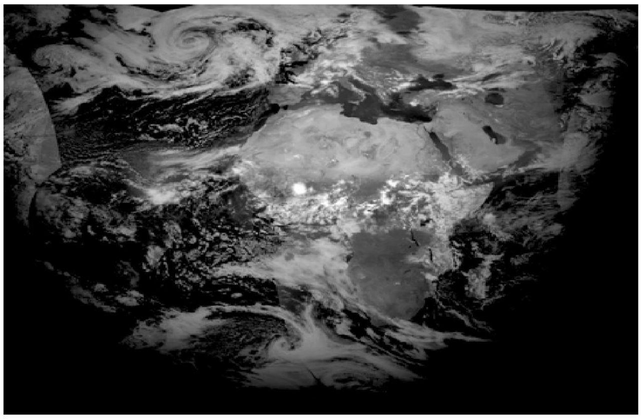

Figure 13. NRL weather GOES satellite imagery in visible spectrum with image resolution of about 4km per pixel. This image shows weather over the African continent.

6. Opensource Community Contributions

World Wind was released as open source in August 2004. Since then the opensource community has made significant contributions through a variety of means including: 1) Add-Ons, 2) High resolution data, 3) Help desk, and 4) Core system.

Add-Ons: One of the most powerful features of World Wind is its add-on architecture. This allows anyone to contribute data to World Wind, creating various local maps and overlays, making World Wind infinitely expandable. Some add-ons show historical or educational information, such as the routes of famous explorers, political maps, weather data or national parks. Some enable sophisticated dynamic tracking such as the GPS Tracker developed by Javier Santoro, and the Satellite Tracker developed by Mashiharu and Robert Newman. Others support localization to other languages such as the Installer Translations Add-on which converts the user interface text into a variety of languages including Bulgarian, Croatian, Czech, Danish, Dutch, Estonian, Finnish, French, Galician, German, Greek, Hungarian, Indonesian, Italiano, Japanese, Luxembourgish, Norwegian, Polish, Brazilian, Portuguese, Romanian, Russian, Serbian, Serbian, Latin, Slovak, Spanish, Swedish, Thai, and Turkish. There are literally hundreds of Add-ons made available by the opensource community [4]. Some of the popular ones based on page views are [4]:

- Katrina Data Add-On (270530 views)
- OnMars (113199 views)
- OneEarth (73026 views)
- 2005 Hurricane Imagery Add-On (47772 views)
- GPS Tracker (plugin) (41242 views)
- ZoomIt! (38397 views)
- Google Maps to Worldwind for Firefox (26328 views)

High resolution data: The opensource community provides high resolution datasets for use in World Wind, and the World Wind ZoomIt! Add-on is one in particular that makes available a large number of high resolution datasets for locations around the world. The following lists areas currently available via the World Wind ZoomIt! Add-on [4].

Australia
- West Australia - Topographic, geology, gravity (2004), and magnetic (2005) maps

New Zealand
- 2.5 meter natural-color and panchromatic mosaic from years 1994 to 2004

South Africa
- Robben Island - 0.5 meter natural-color mosaic

United States
- Florida State - 1 meter natural-color mosaic from year 2004
- Indiana State - 1 meter natural-color mosaic from year 2003 National Agriculture Imagery Program
- Massachusetts State - 0.5 meter natural-color mosaic from years 2001 and 2003
- New York State* - 0.3 meter natural-color mosaic from years 2002 and 2003 New York State Digital Orthoimagery Program
- Nassau County* - 0.15 meter natural-color mosaic from year 2004 New York State Digital Orthoimagery Program
- Montana State* - 0.3 meter natural-color mosaic from year 2004
- West Virginia - 0.6 meter natural-color mosaic from year 2003
- Birmingham, Alabama - from year 2002
- Anchorage, Alaska - from year 2002
- Boise, Idaho - from year 2003
- Baton Rouge, Louisiana - from year 2002
- Augusta, Maine - from year 2003
- Baltimore-Annapolis, Maryland - from years 2002 to 2003
- Augusta, Maine - from year 2003
- Nevada* - from year 2003
- New Mexico* - from years 2002 to 2004
- Greensboro-Winstonsalem, North Carolina - from year 2002
- Cincinnati, Ohio - from year 2002
- Allentown-Bethlehem, Pennsylvania - from year 2002
- Texas* - from year 2002

Help desk: The opensource community also provides significant resource for user and developer help, through the publishing and hosting of online documentation and participation in online forums including internet relay chat.

Documentation includes FAQs, user tutorials and documentation, developer road map and add-on guide, bug & issue tracking, and new features. The following list shows popular pages on the main opensource community's website with view counts [4]:

- *World Wind FAQ (957725 views)*
- *Video Card Compatibility (621924 views)*
- *World Wind Users Document (82032 views)*
- *World Wind Walkthrough Tutorial (75445 views)*
- *Road Map (53006 views)*
- *Keyboard actions (32454 views)*
- *Development (28671 views)*
- *Creating add-ons (25565 views)*
- *Guide to 1.3.3 (21589 views)*
- *Chat (20352 views)*
- *What's new in 1.3.4 (19210 views)*
- *World Wind 1.3alpha Bugs (18432 views)*
- *World Wind Issues (17534 views)*

Through online chat, the community often references users to particular documentation through URLs. During the previous 676 days, a total of 4471 users[3] participated in the World Wind internet chat, contributing 735383 lines of text-based chat. Less than 1% of the users based on nicknames (25 of 4471) contributed approximately 70% of the total lines of text (513831 of 735383). The following tables and figures shows recent statistics on the most referenced URLs in the chat and the reference counts (see Table 4); the top-ten most active contributors based on number of lines contributed (see Table 5), and the most active times of day the chat is used (See Figure 12). Of note is that the most referenced URLs are those of the most general interest (i.e., FAQ, Tour, and Main Page).

URL	Uses
http://www.worldwindcentral.com/wiki/World_Wind_FAQ	506
http://alteviltech.com/WorldWind/Tour/	194
http://www.worldwindcentral.com	102

Table 4: URLs referenced in World Wind internet chat

	Nick	Number of lines	When?	Number of Words	Words per line
1	Llynix	67433		439905	6.5
2	f0urtyfour	51781		376674	7.3
3	bull	45620		263459	5.8
4	TomServo	36189		244996	6.8
5	Nowak	35714		233579	6.5
6	TheBean	33529		247895	7.4
7	adamhill	28920		281687	9.7
8	ShockFire	25297		228263	9.0
9	T_Servo_Work	23793		183546	7.7
10	dumdumhead	23720		246538	10.4

Table 5: Top 10 contributors to World Wind internet chat [4]

Figure 14 shows the percentage of internet chat activity at various hours of the day, with the highest percentages of time at midnight.

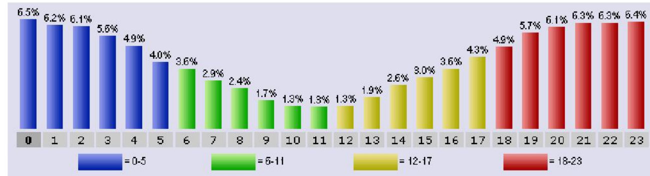

Figure 14: Most active times of use of World Wind internet chat [4]

Core System: Through various forums, the opensource community has made significant technical contributions improving the quality of the core system including bug identification, tracking and resolution as well as ideas for new features and source code modifications. Examples of additional functionality added to World Wind by the open-source community include a planimetric measurement tool, a near real-time Earthquake marker, a World Wind script maker, and a GPS tracking tool.

New or updated add-ons and plug-ins are being released on a regular basis, enhancing World Wind with new features, functionality and data sets. Most of these additions can be found online at www.worldwindcentral.com. This community-run web site features a growing library of World Wind materials, such as user and developer documentation, forums, and over 150 downloadable add-ons and plug-ins.

7. CONCLUSIONS

World Wind has proven to be a highly downloaded and used geographic information system, that has benefited greatly from being an opensource project. World Wind is continuing to evolve, with a cross-platform Java version of World Wind in the works. World Wind has evolved significantly based on requirements to support mission operations, and is also continuing to evolve based on the ideas and efforts of the opensource community.

8. ACKNOWLEDGEMENTS

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[3] User count is based on the count of unique nicknames.

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