NPS AUV Workbench: Rehearsal, Reality, Replay for Unmanned Vehicle Operations

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Modeling, Virtual Environments & Simulation (MOVES) Institute

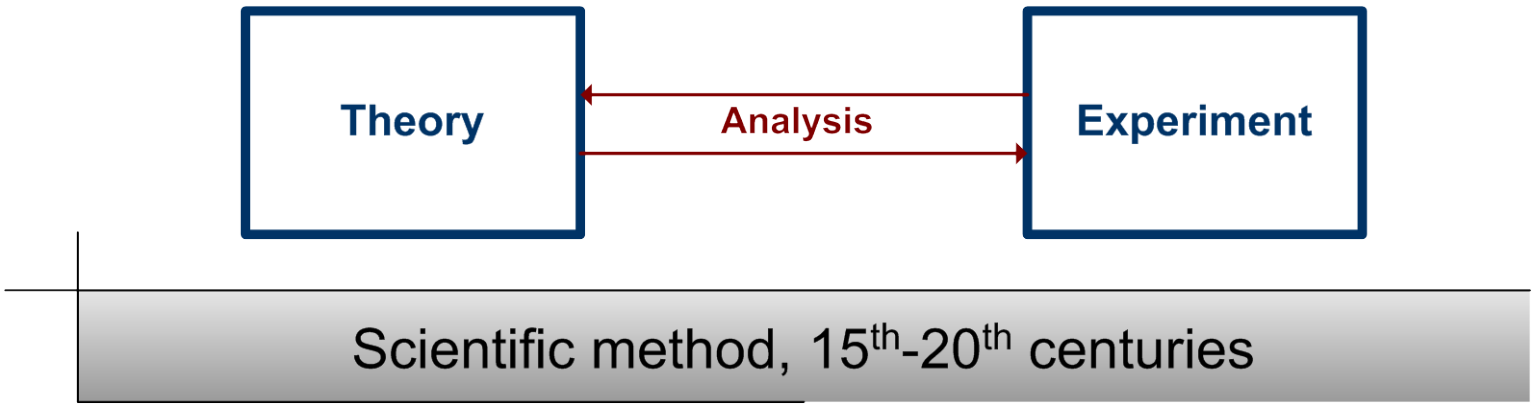
30 August 2010

Topics

- *Why* modeling & simulation?
- AUV Workbench Components
- Sonar Visualization
- Technologies: X3D, XML, XMSF
- Looking ahead
- Demonstrations

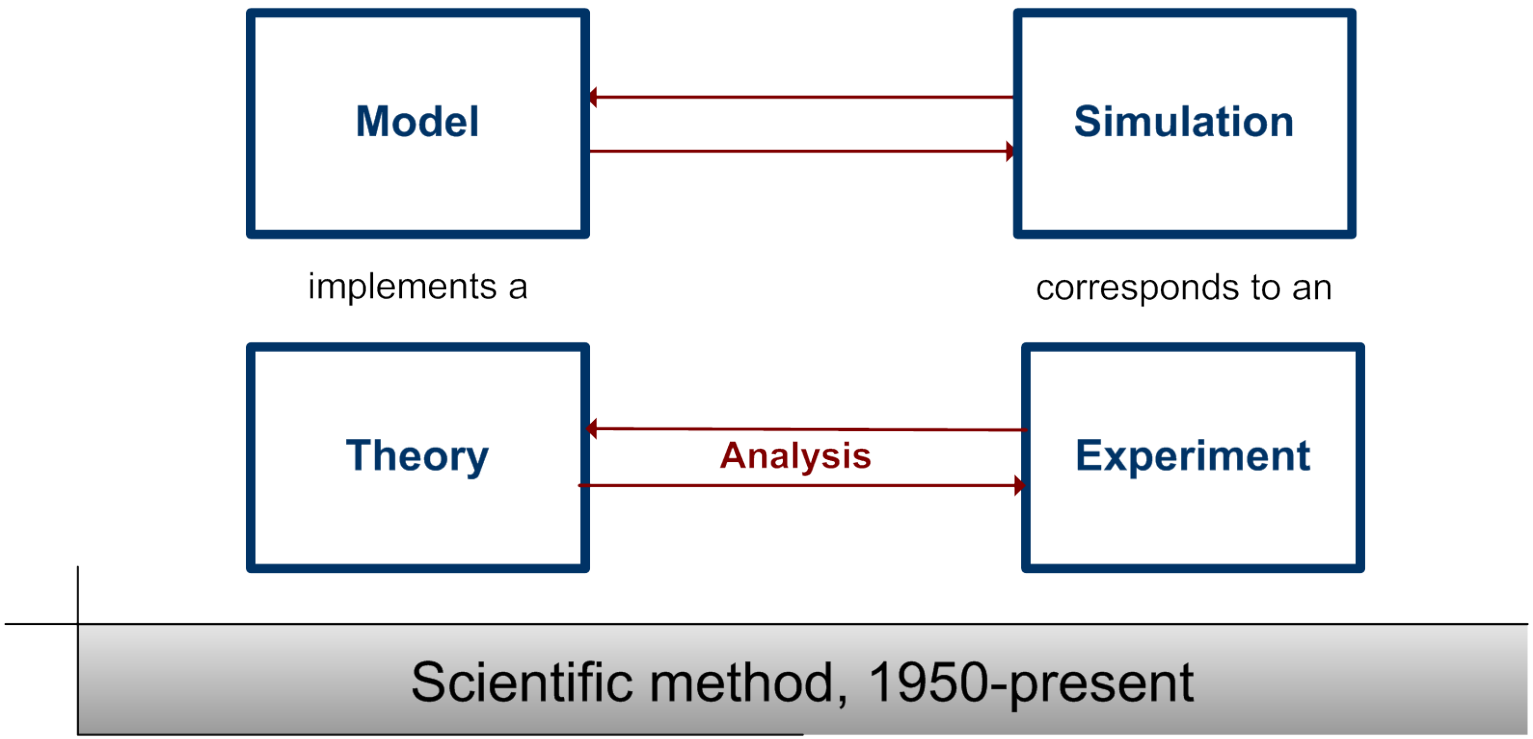
theory = conceptual description of reality

experiment = test theory in physical world



model = formal representation of reality

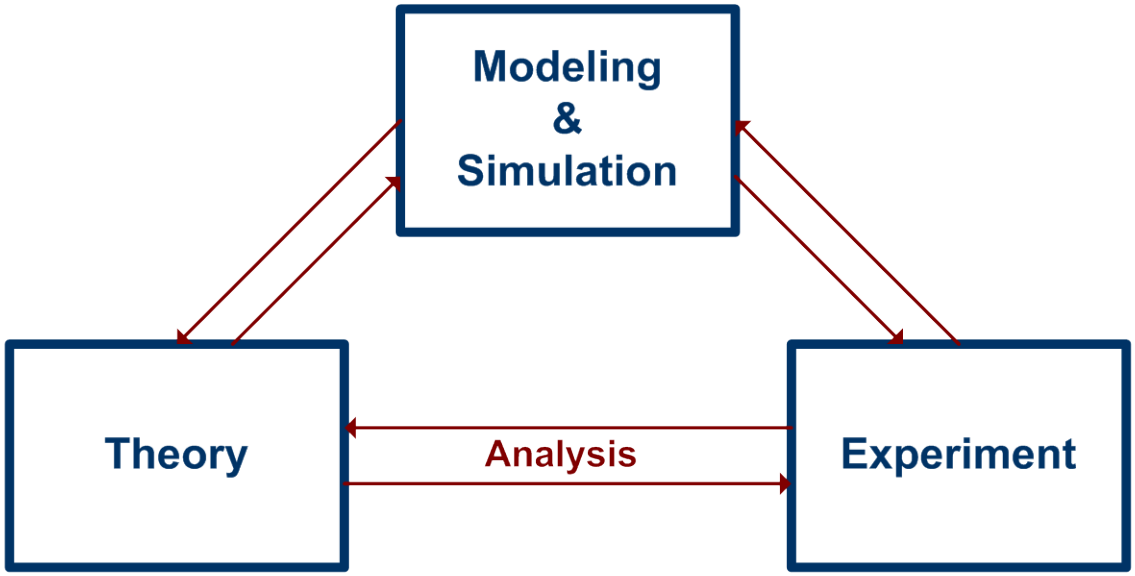
simulation = behavior of model over time



running together

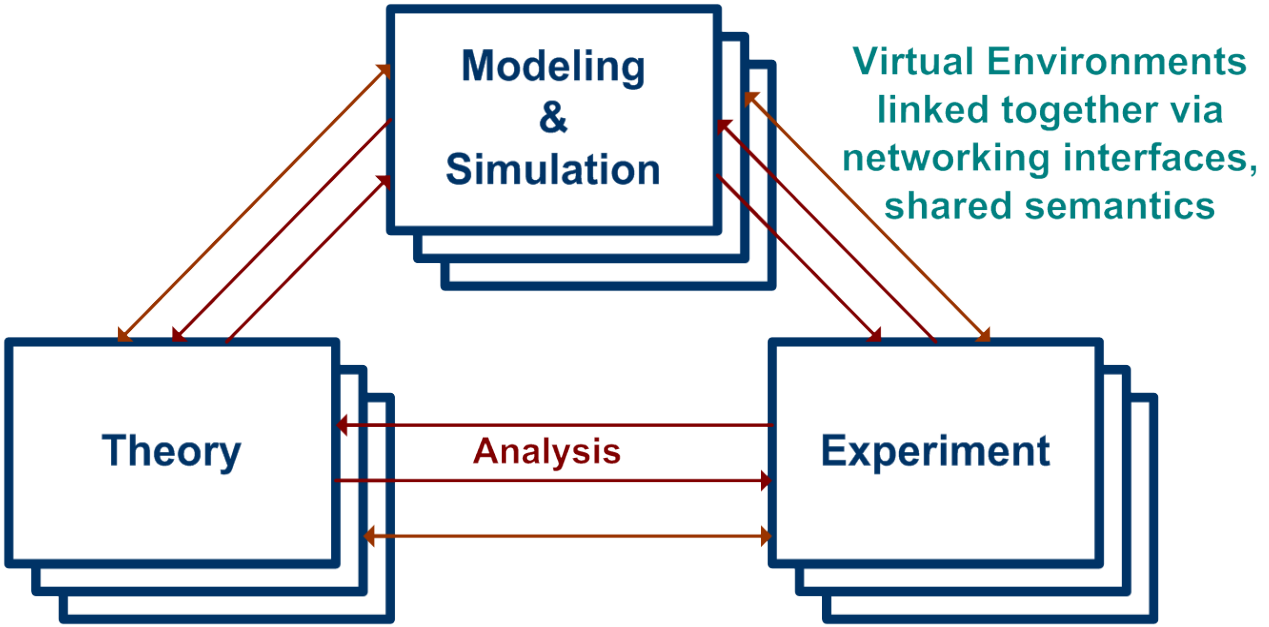
model = formal representation of reality

simulation = behavior of model over time



Scientific method, 1950-present

Virtual environments can connect all models and simulations together

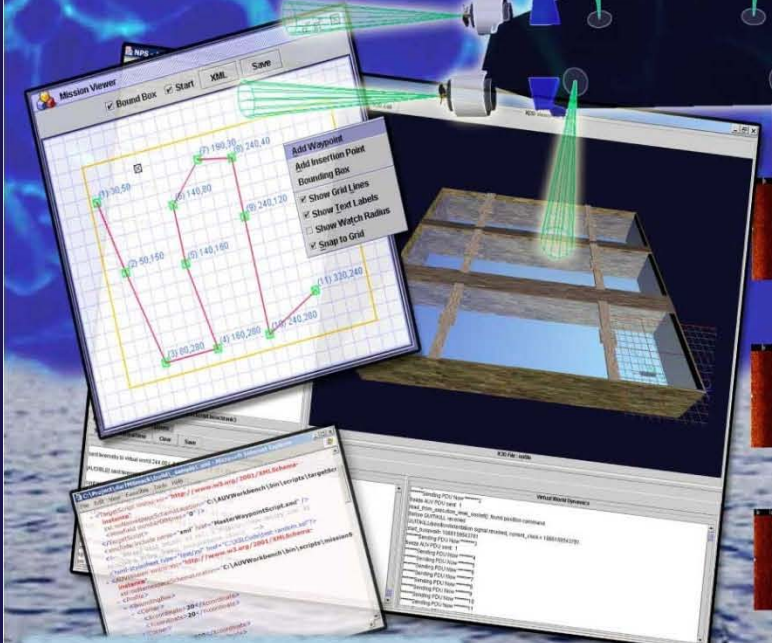


Scientific method, emerging 21st century

AUV Workbench Project Description

- Open source, Java, XML, X3D graphics
- Mission planning
- Robot mission execution
- Hydrodynamics response
- Sonar modeling
- 3D visualization
- Compressed radio frequency (RF) and acoustic communications

Robot Mission Planning and 3D Visualization



Autonomous Unmanned Vehicle Workbench

Rehearsal
Reality
Replay

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NAVAL POSTGRADUATE SCHOOL
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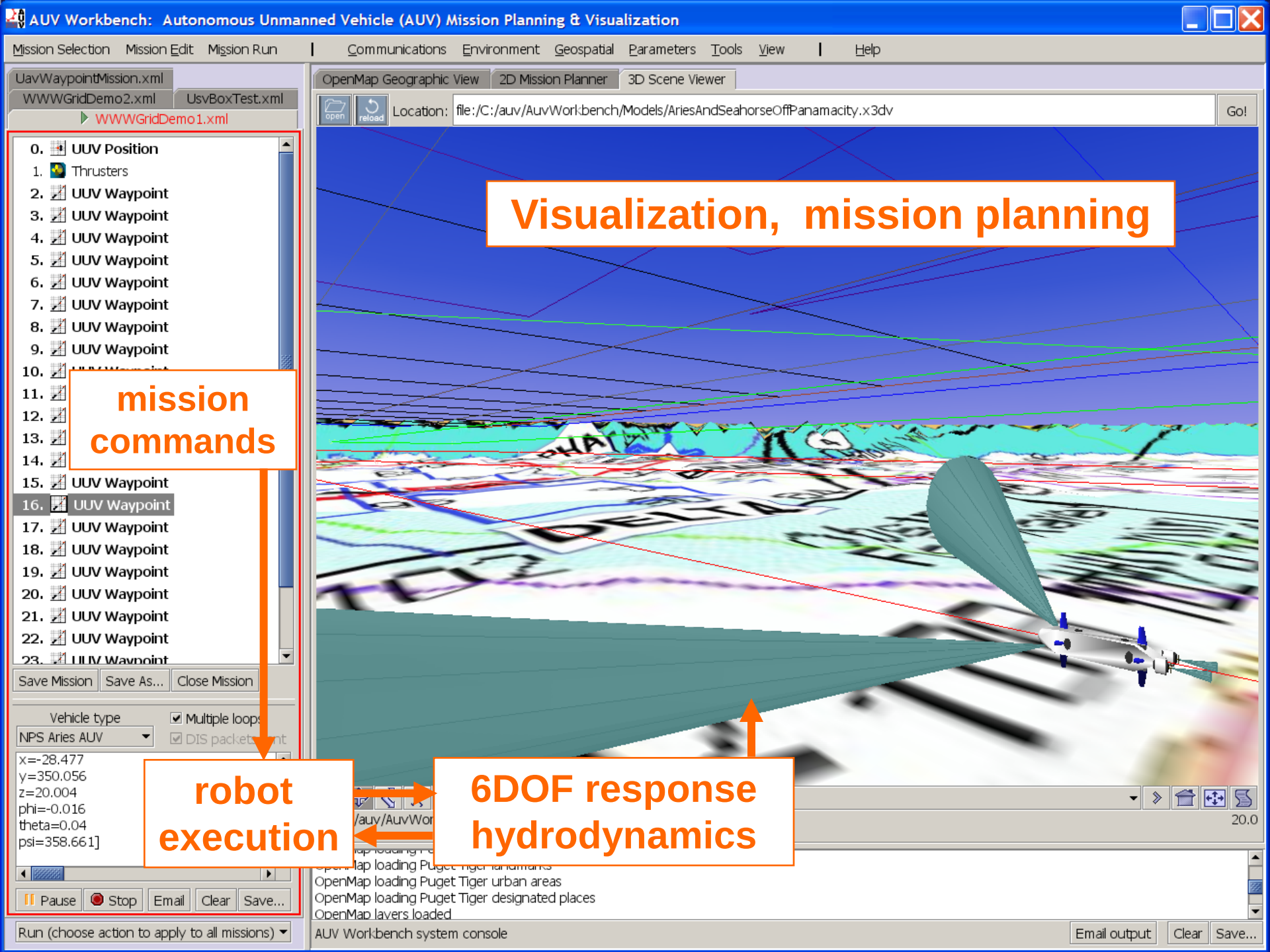
"Effects-Based Thinking"

Our 3 R's: rehearsal, reality, replay

- Same needs and capabilities for each: mission, visualization, data support, etc.
- AUV workbench supports each
  - ongoing work, starting to mainstream
- 15 years of accumulated effort
  - integrating great variety of successful work
  - new work projects occurring regularly
- Collaboration is welcome

Rehearsal

Mission planning and preparation


AUV Workbench: Autonomous Unmanned Vehicle (AUV) Mission Planning & Visualization
Mission Selection
Mission Edit
Mission Run
Communications
Environment
Geospatial
Parameters
Tools
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UsvBoxTest.xml
WWWGridDemo1.xml
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2. UUV Waypoint
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Save...
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OpenMap Geographic View
2D Mission Planner
3D Scene Viewer
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Go!
Visualization, mission planning
mission commands
robot execution
6DOF response hydrodynamics
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AUV Workbench system console
Email output
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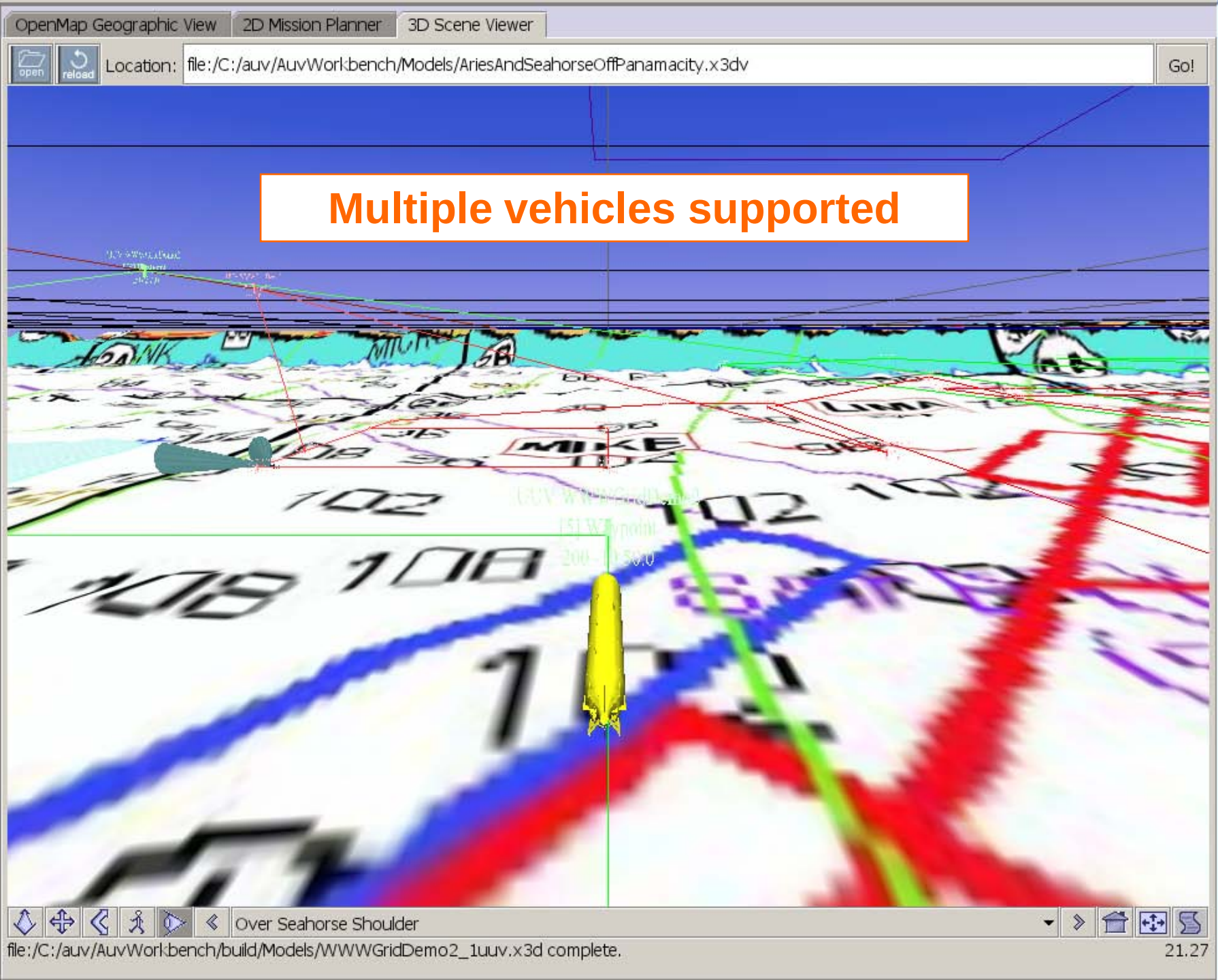
Save...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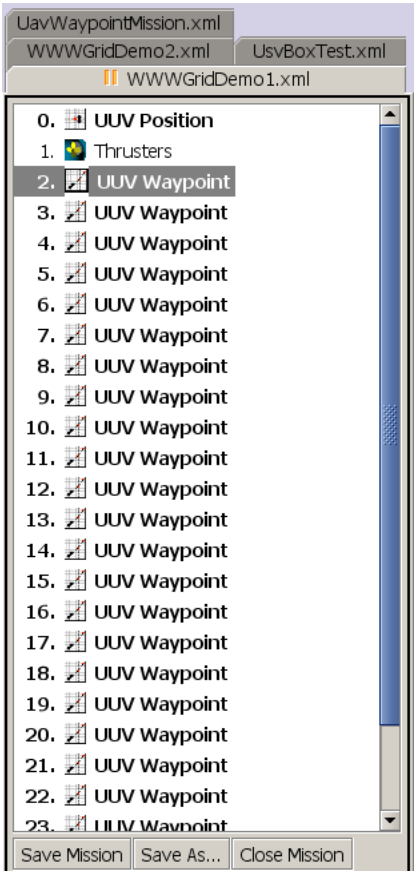
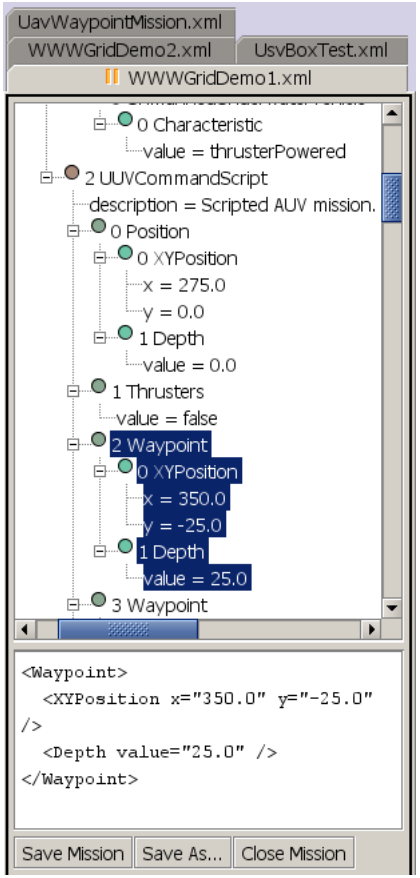
Multiple vehicles supported
Over Seahorse Shoulder
file:/C:/auv/AuvWorkbench/build/Models/WWWGridDemo2_1uuv.x3d complete.
21.27

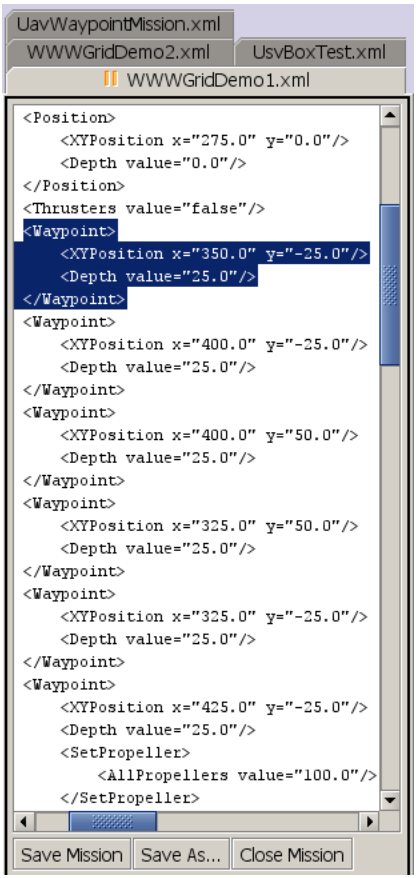
Rehearsal

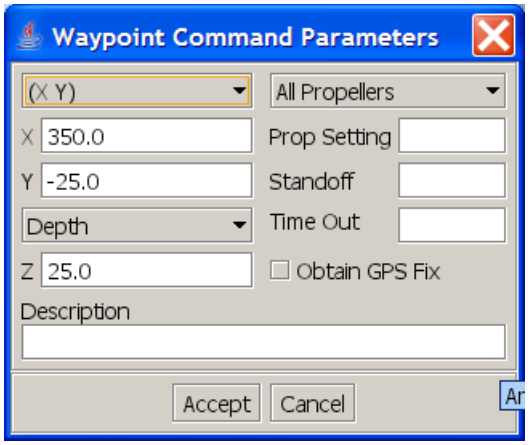
- Prepare missions, either manually or automatically via other software tools
- Test robot software's ability to perform commands
- Test again with physics "in the loop"
  - Hydrodynamics and control are critical, difficult
  - Sonar, environmental modeling
- Repeat until robust, with cautious respect
  - "Simulation is doomed to success" – G. Bekey

Mission views: iconic, tree, XML, dialog box



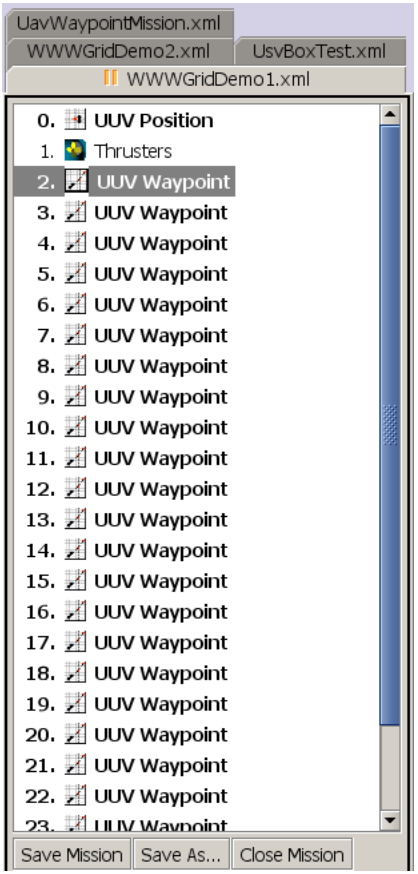


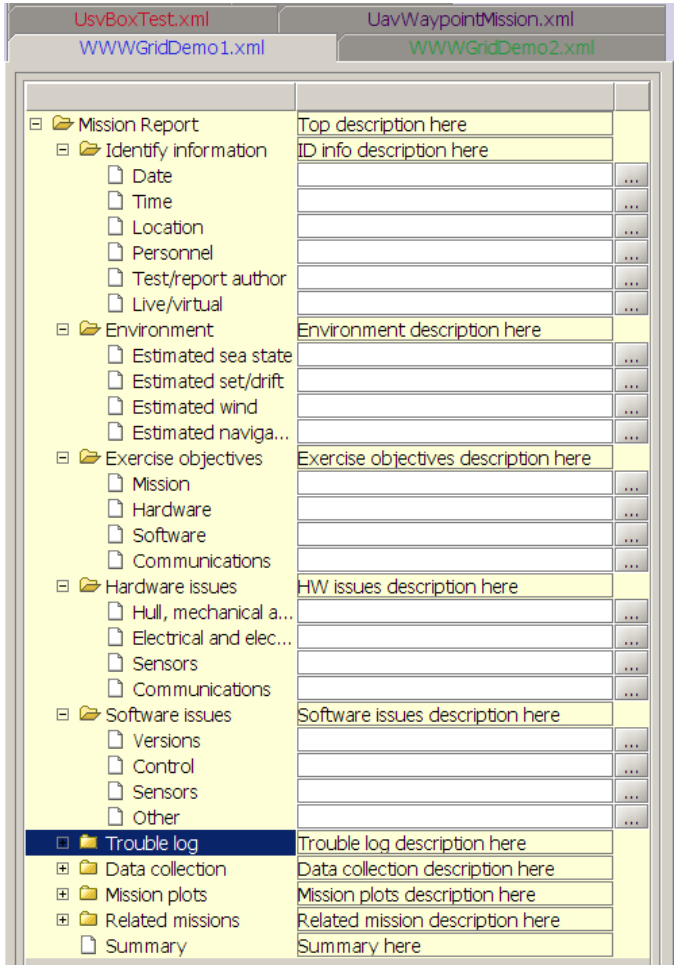


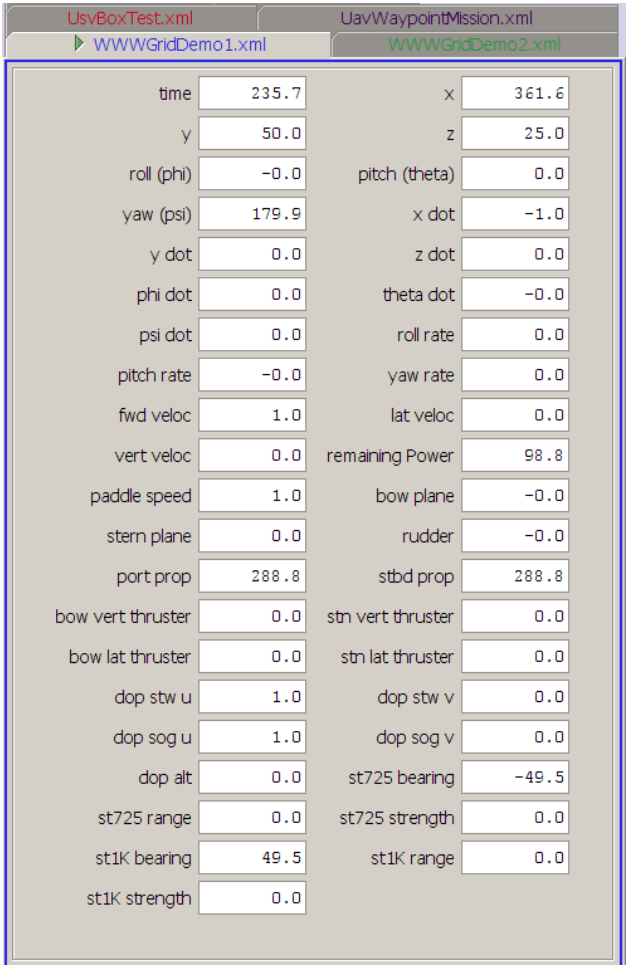


Each view is consistent with GIS, 2D, 3D views

Supporting views: mission metadata, state







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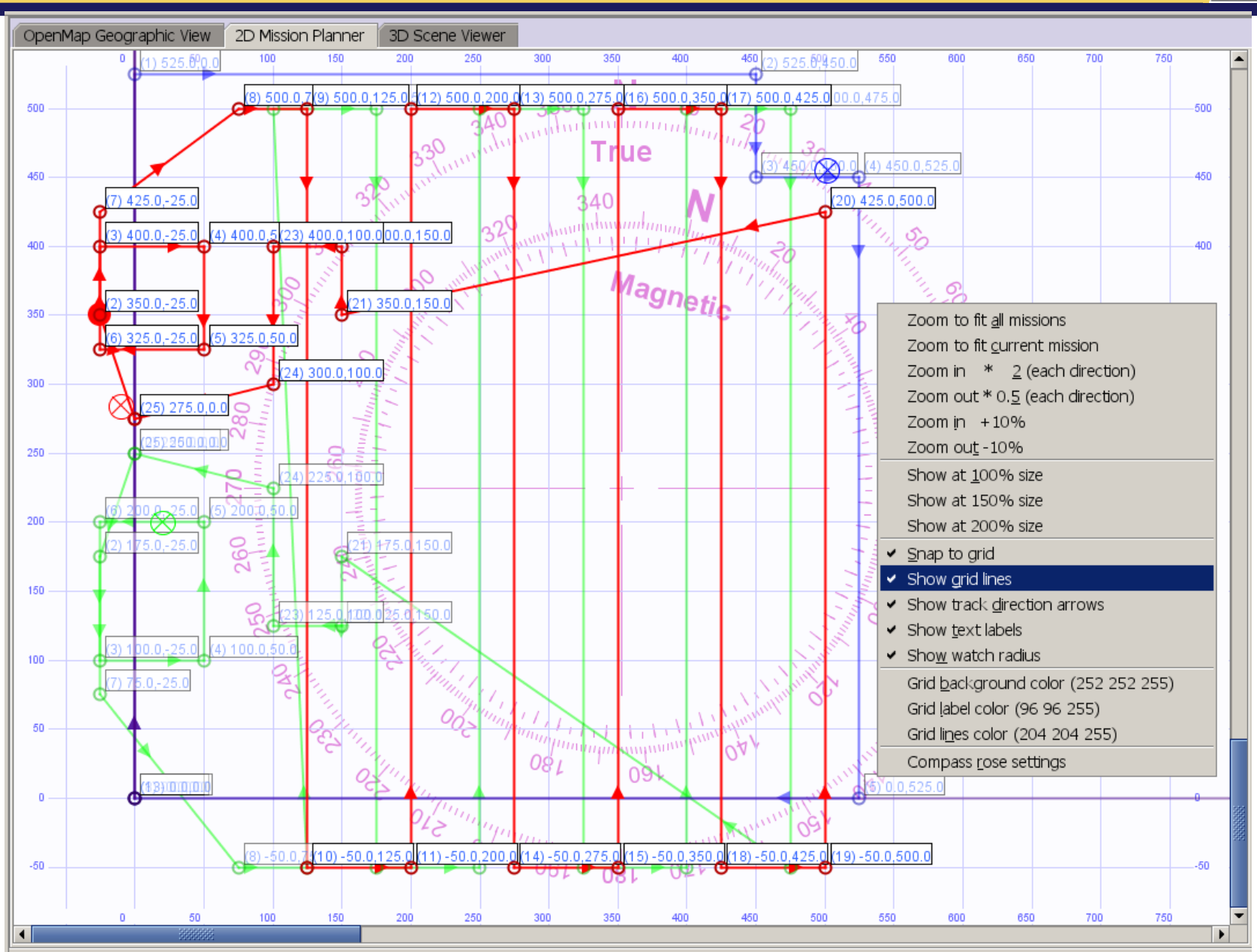
2D planner: script missions

XMSF



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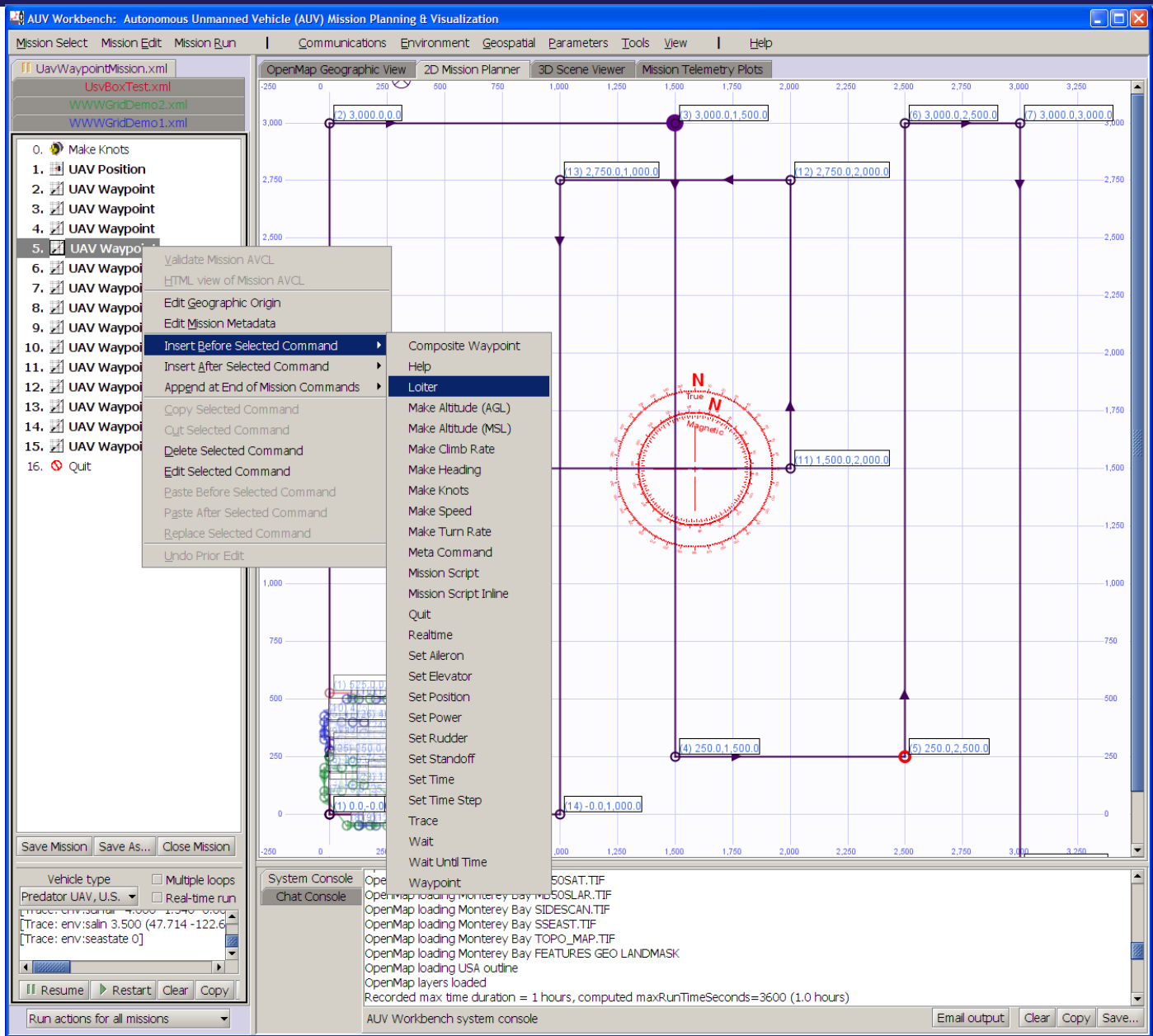
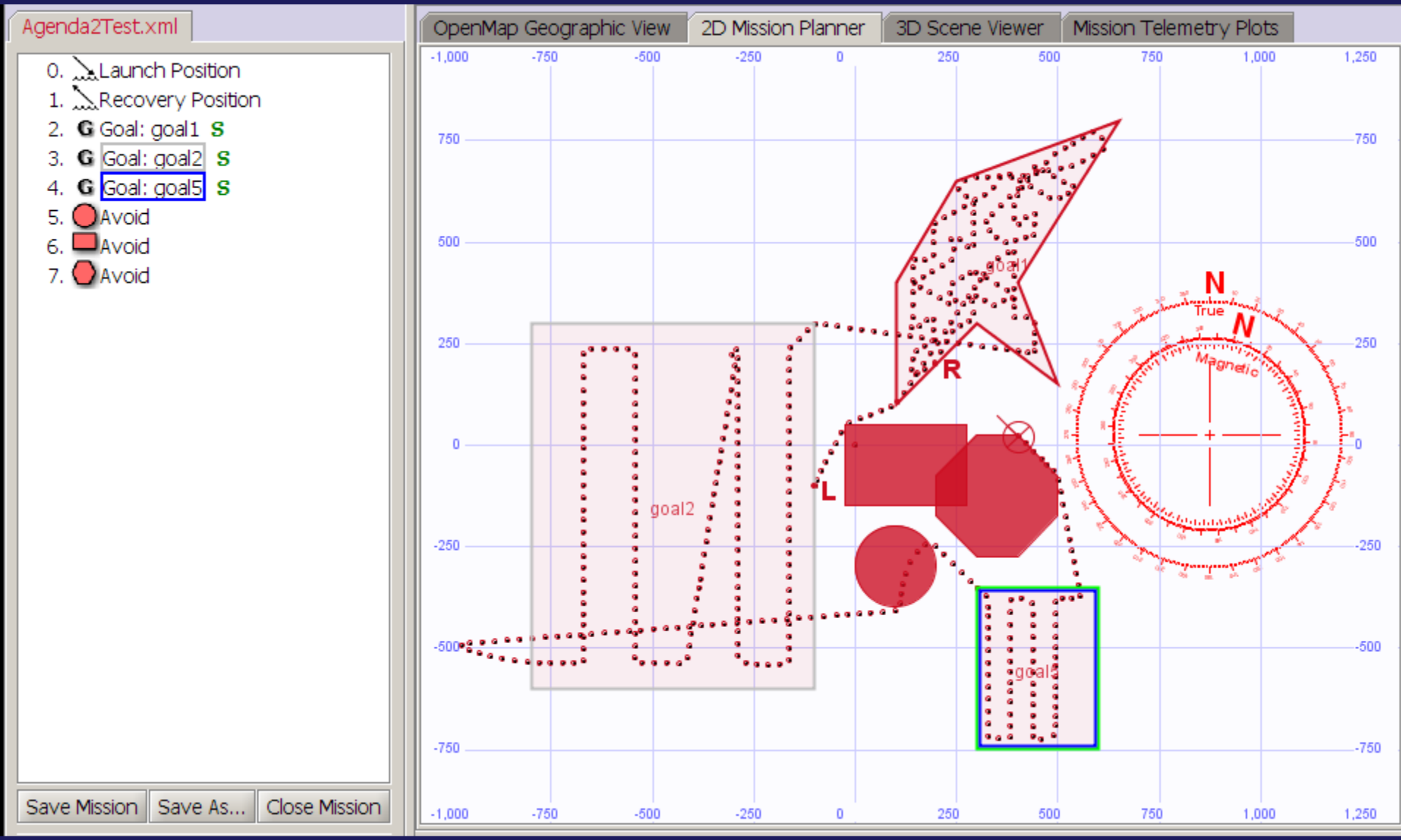
2D planner: script missions

XMSF

Can edit missions by adding or removing script commands

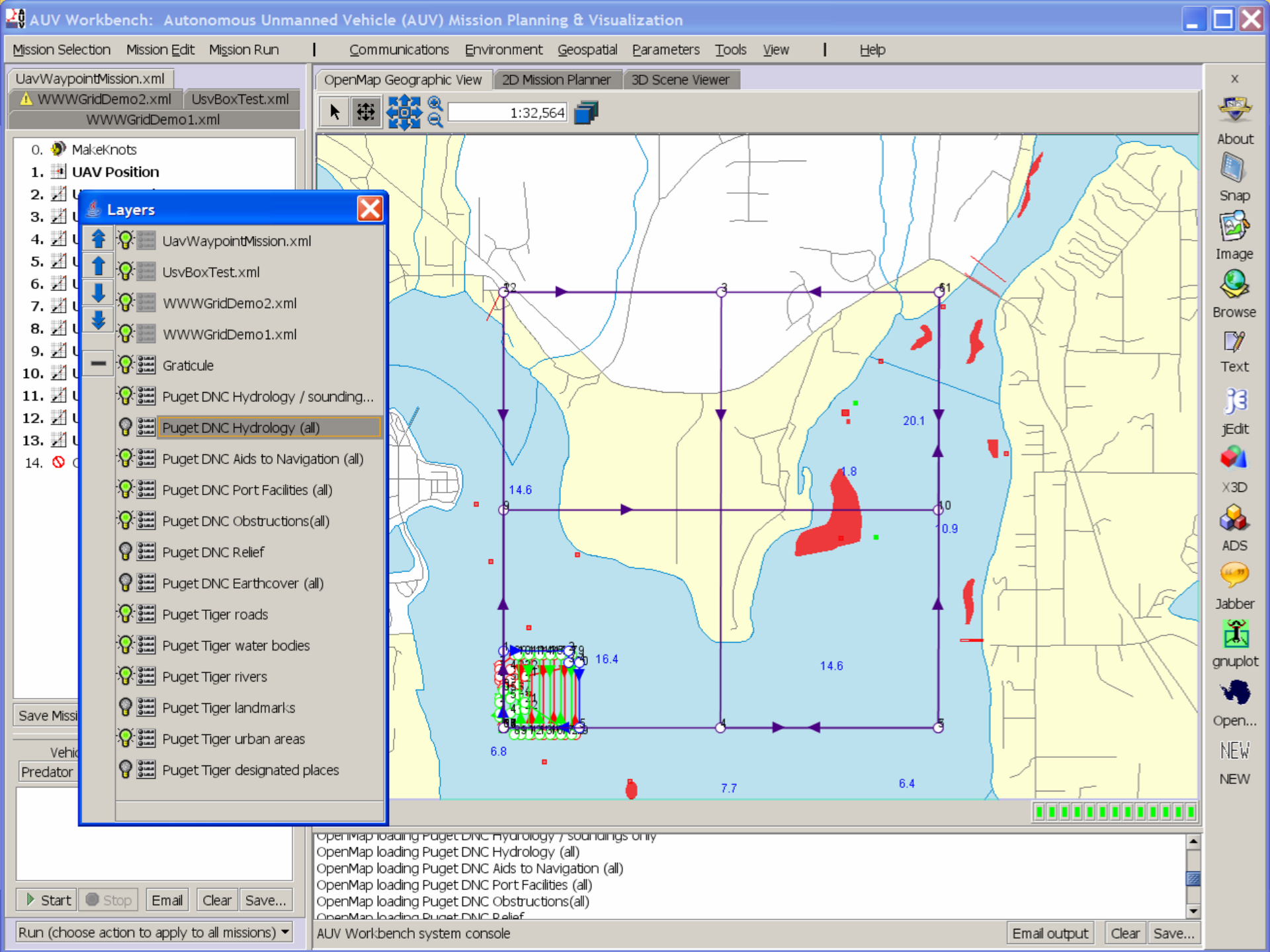


2D planner: agenda missions



OpenMap GIS display

- OpenMap http://www.openmap.org
  - Geographic Information System (GIS)
  - Open source Java, bundled
  - Building layers for areas of interest
  - Geographic coordinates throughout
  - Will synchronize with mission definitions, X3D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Puget DNC Port Facilities (all)
Puget DNC Obstructions(all)
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Puget Tiger rivers
Puget Tiger landmarks
Puget Tiger urban areas
Puget Tiger designated places
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1.8
14.6
10.9
16.4
14.6
6.8
7.7
6.4
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Text
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X3D
ADS
Jabber
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Open...
NEW
Predator
Start
Stop
Email
Clear
Save...
Run (choose action to apply to all missions)
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OpenMap loading Puget DNC Aids to Navigation (all)
OpenMap loading Puget DNC Port Facilities (all)
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AUV Workbench system console
Email output
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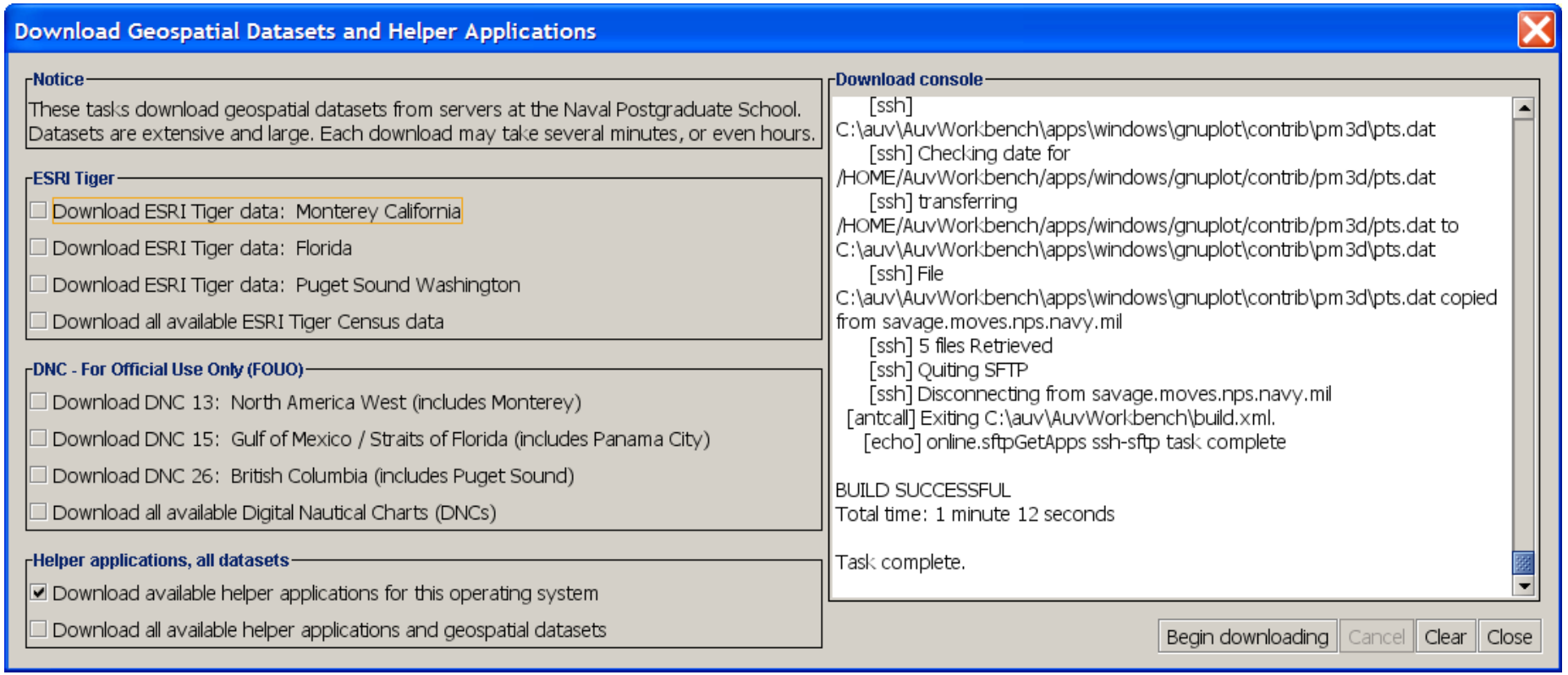
Save...

Secure sftp download of large GIS datasets



Reality: real-time mission support

- Monitor mission progress
- Task-level control using same mission vocabulary
- Visualize and supervise operations
  - caveat, again: work in progress
- Integrate acoustic and RF communications
- Chat for distributed collaboration among participants, both human and robotic

Real-time mission data import/export

- Export
  - Mission commands that are already rehearsed
  - Convert to specific dialect particular to that robot
- Import
  - Mission telemetry recording detailed track data
  - Data products: imagery, video, mission log, etc.

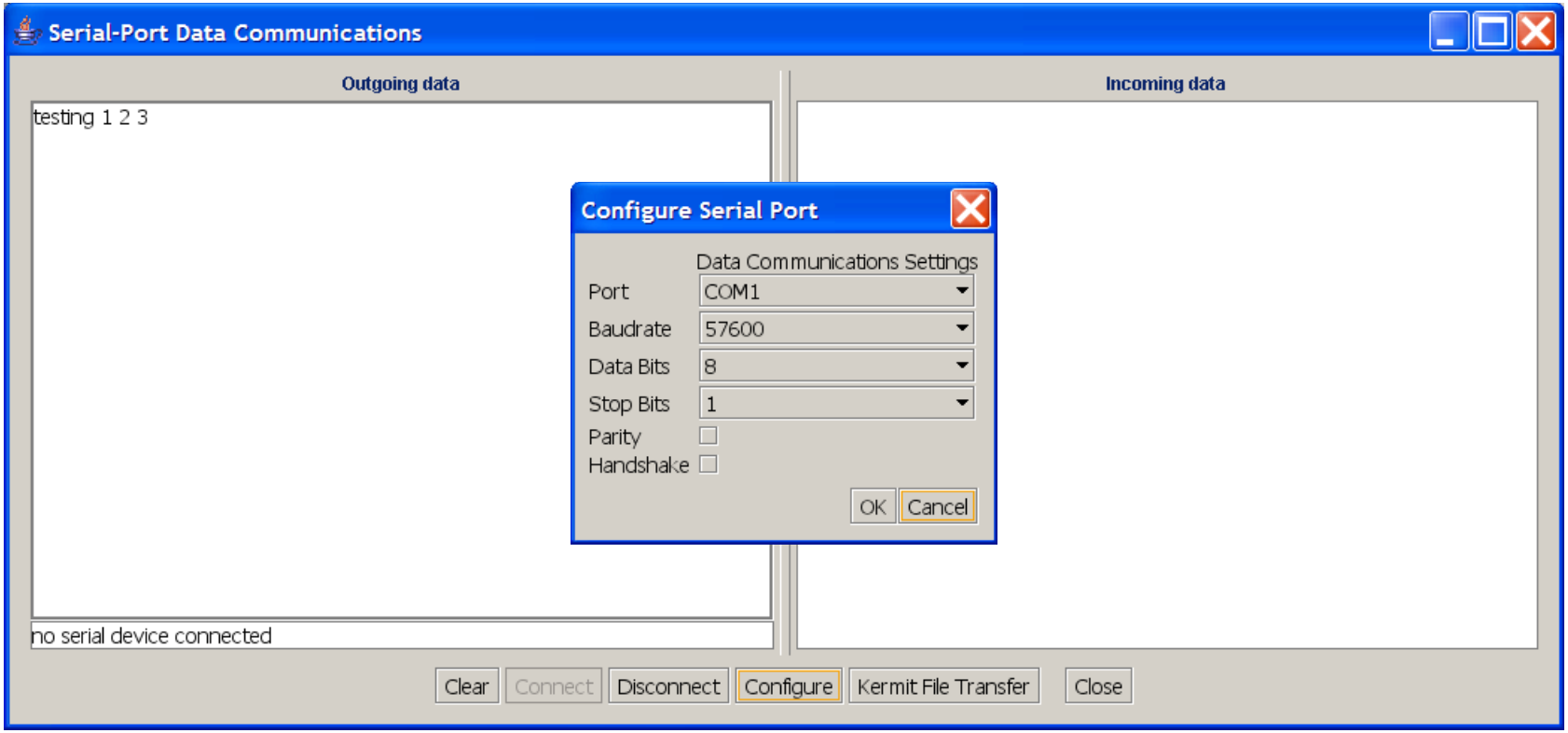
Record mission metadata for archives

- Support operator keeping detailed notes, kept in context when conducting mission
- Prompt for full details as appropriate
- Archive notes for later review and followup

- Future work
  - Automatic tests to confirm configuration, control
  - Automate pre-underway checklists

Serial port communications

- Configurable to different devices, ports



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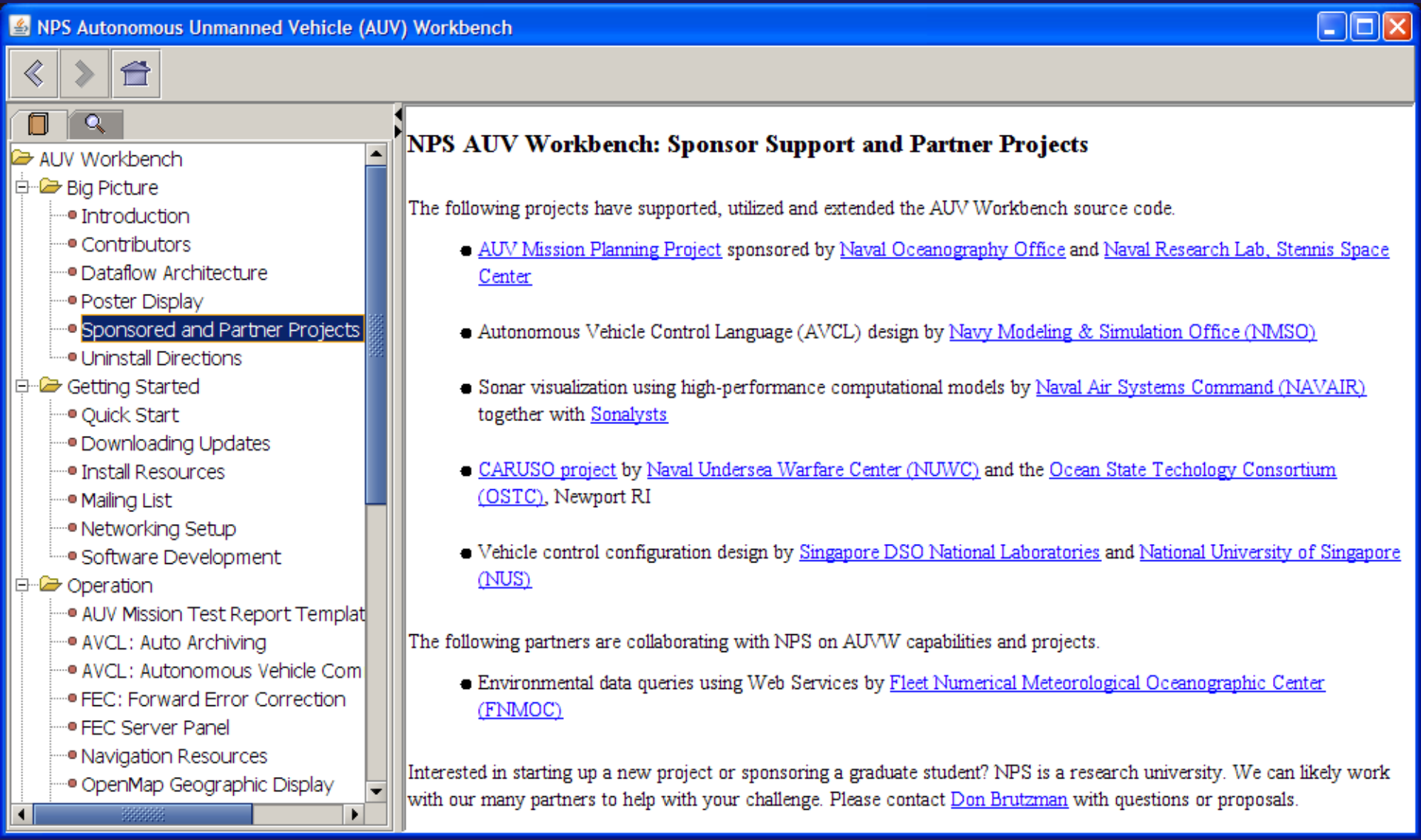
JavaHelp support

XMSF



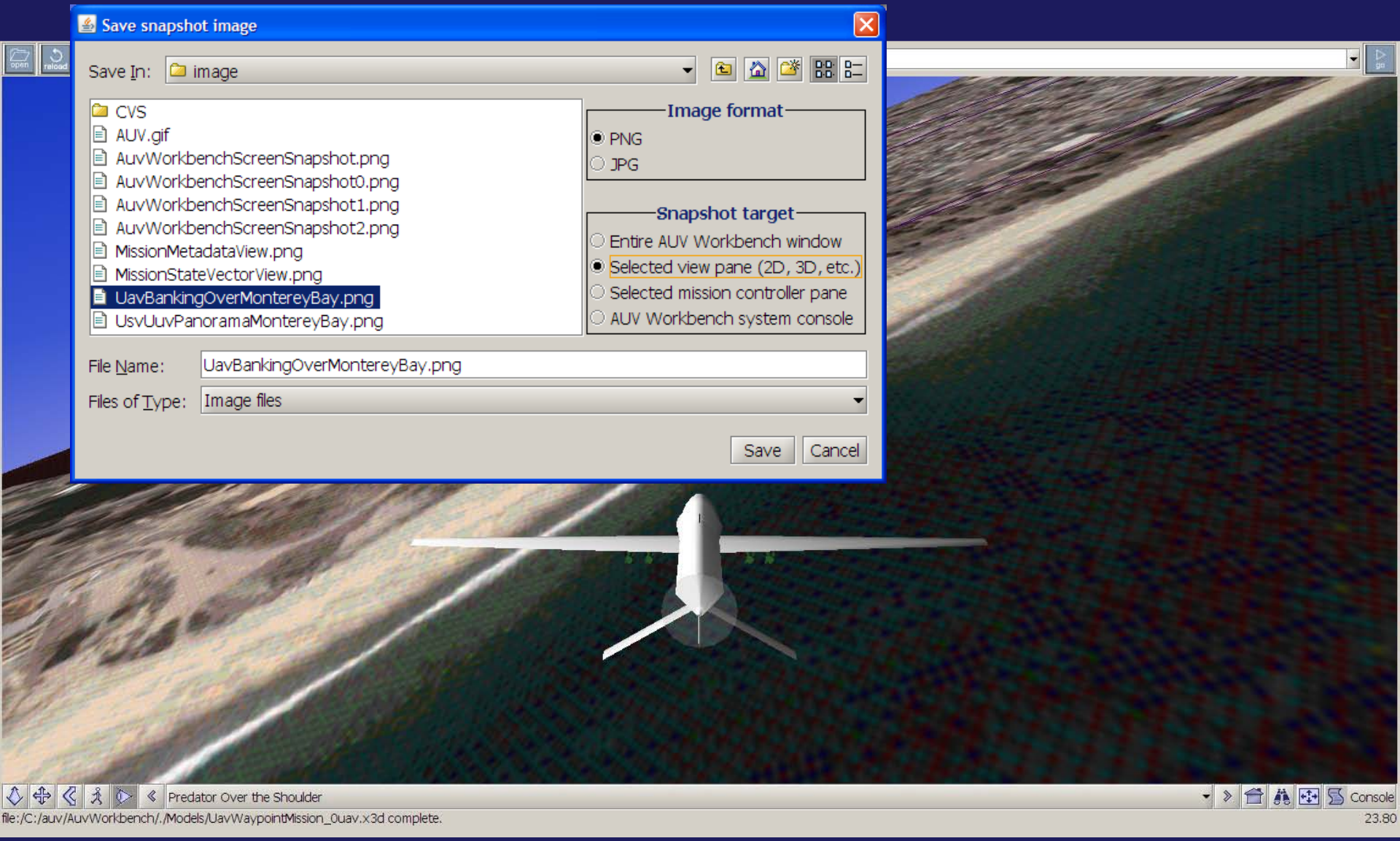
NPS AUV Workbench: Theses

All NPS theses and dissertations are searchable online via the Bosun search engine at the Dudley Knox Library.

The following theses are included in the NPS AUV Workbench documentation distribution.

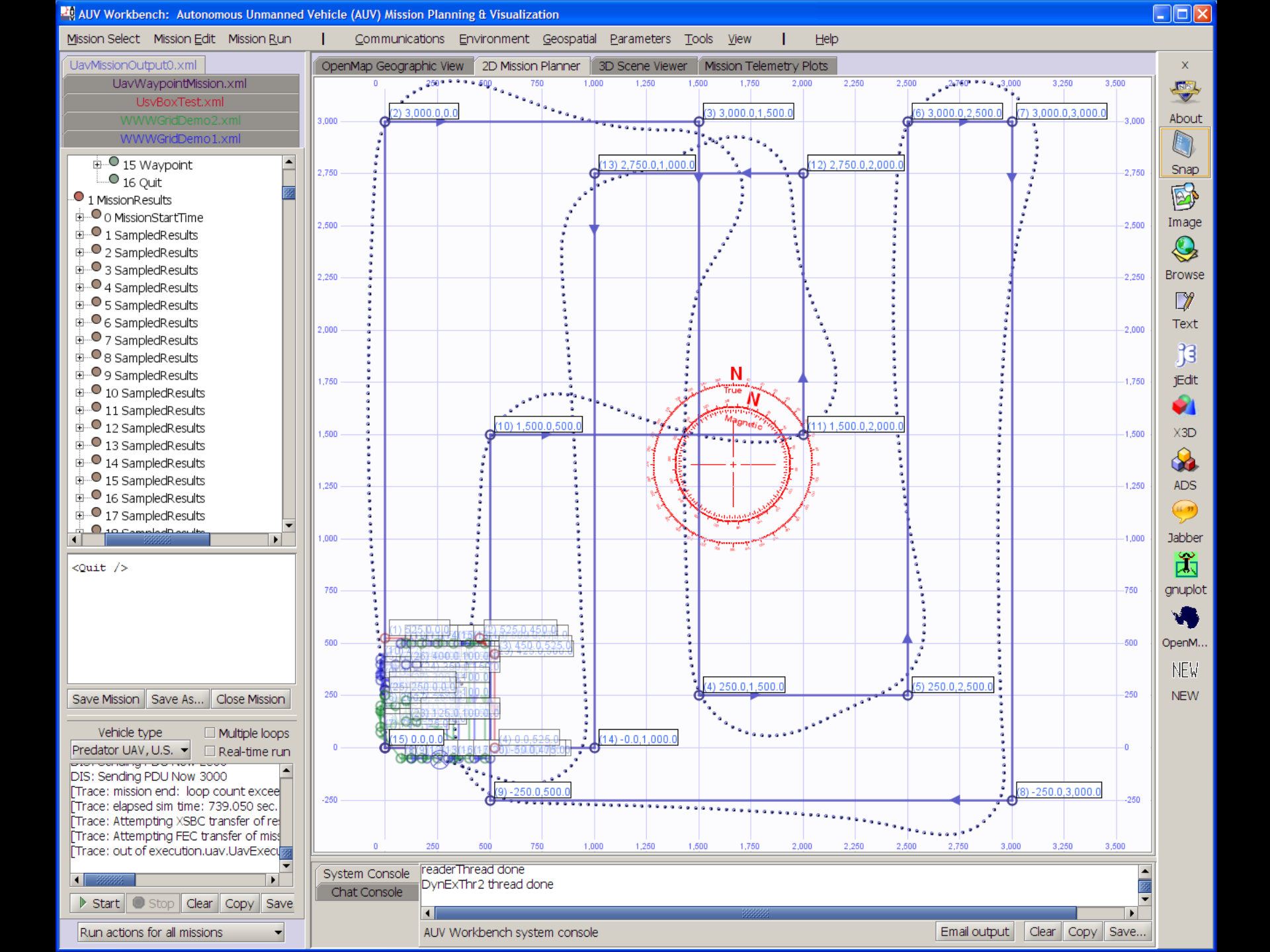
- Ayala, Miguel Arnaldo, *Execution-Level Java Software and Hardware for the NPS Autonomous Underwater Vehicle (AUV)*, Masters Thesis, Naval Postgraduate School, Monterey California, September 2002.
- Boncal, Richard J., *A Study of Model-based Maneuvering Controls for Autonomous Underwater Vehicles*, Masters Thesis, Naval Postgraduate School, Monterey California, December 1987.
- Burkley, Frederick Garvin, *An Acoustic Sensor History Server for a Submarine Combat Control System*, Masters Thesis, Northeastern University, Boston Massachusetts, August 2002.
- Burns, Michael L., *Merging Virtual and Real Execution-Level Control Software for the Phoenix Autonomous Underwater Vehicle (AUV)*, Masters Thesis, Naval Postgraduate School, Monterey California, September 1996.
- Byrne, Kevin Michael, *Real-Time Modeling of Cross-Body Flow for Torpedo Tube Recovery of the Phoenix Autonomous Underwater Vehicle (AUV)*, Masters Thesis, Naval Postgraduate School, Monterey California, March 1998. Also available: slideset.
- Davis, Duane T., *Precision Control and Maneuvering of the Phoenix Autonomous Underwater Vehicle (AUV) for Entering a Recovery Tube*, Masters Thesis, Naval Postgraduate School, Monterey California, September 1996.
- Fodrea, Lynn Renee, *Obstacle Avoidance Control for the Remus Autonomous Underwater Vehicle (AUV)*, Masters Thesis, Naval Postgraduate School, Monterey California, December 2002.
- Hawkins, Darrin L. and Van Leuvan, Barbara C., *An XML-based Mission Command Language for Autonomous Underwater Vehicles (AUVs)*, Masters Thesis, Naval Postgraduate School, Monterey California, June 2003.
- Holliday, Timothy M., *Real-Time 3D Sonar Modeling and Visualization*, Masters Thesis, Naval Postgraduate School, Monterey California, June 1998.
- Johnson, Jay, *AUV Steering Parameter Identification for Improved Control Design*, Masters Thesis, Naval Postgraduate School, Monterey California, June 2001. Also available: slideset.
- Kucik, Daniel P., *"Follow the Leader" Tracking by Autonomous Underwater Vehicles (AUVs) using Acoustic Communications and Ranging*, Masters Thesis, Naval Postgraduate School, Monterey California, September 2003.
- Leaver, R. Greg, *VRML Terrain Modeling for the Monterey Bay National Marine Sanctuary (MBNMS)*, Masters Thesis, Naval Postgraduate School, Monterey California, September 1998.
- Lee, Chin Siong, *NPS AUV Workbench: Collaborative Environment for Autonomous Underwater Vehicles (AUVs) Mission Planning and 3D Visualization*, Masters Thesis, Naval Postgraduate School, Monterey California, March 2004. Also available: thesis slideset, Jabber agents slideset, and XML Tactical Chat (XTC) slideset.
- Leonhardt, Bradley J., *Mission Planning and Mission Control for the Phoenix Autonomous Underwater Vehicle (AUV): Implementation and Experimental Study*, Masters Thesis, Naval Postgraduate School, Monterey California, March 1996.
- Neushul, James D., *Interoperability, Data Control and Battlespace Visualization using XML, XSLT and X3D*, Masters Thesis, Naval Postgraduate School, Monterey California, September 2003.
- Norbraten, Terry D., *Utilization of Forward Error Correction (FEC) Techniques with Extensible Markup Language (XML) Schema-based Binary Compression (XSBC) Technology*, Masters Thesis, Naval Postgraduate School, Monterey California, December 2004. Also available: thesis slideset.
- Rauch, Travis, *Tactical Savage Modeling Analysis Language (SMAL): Metadata for Tactical Simulations and Visualizations*, Masters Thesis, Naval Postgraduate School, Monterey California, March 2006.
  "http:RosettiSonarVisualizationThesis.September2004.pdf">*Tactical Web Services: Using XML and Java Web Services to Conduct Real-time, Net-centric Sonar Visualization*, Masters Thesis, Naval Postgraduate School, Monterey California, September 2004.
- Serin, Ekrem, *Design and Test of the Cross-Format Schema Protocol (XFSP) for Networked Virtual Environments*, Masters Thesis, Naval Postgraduate School, Monterey California, March 2003. Also available: slideset.
- Zeswitz, Steven*NPSNET: Integration of Distributed Interactive Simulation (DIS) Protocol for Communication Architecture and Information Interchange*, Masters Thesis, Naval Postgraduate School, Monterey California, September 1993.

Snapshot support



Replay: post-mission support

- Automatic archiving of mission to server
  - Being built into workbench – simplify user tasks
- Integration and compression of all relevant data into single compressed XML file
  - Metadata for mission
  - Many pieces: ordered mission, commands, telemetry, coefficients, contacts, etc. etc.
  - Autonomous Vehicle Control Language (AVCL) is Ph.D. work by CDR Duane Davis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3D Scene Viewer
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Image
Browse
Text
jEdit
X3D
ADS
Jabber
gnuplot
OpenM...
NEW
NEW

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Geographic track plot

XMSF

- AUVW Mission Telemetry
  - UsvMissionOutput0.xml/2007.04.22/15.05.03 PDT
    - Geographic chart
      - Geographic XY plot
    - Vehicle posture versus time
      - Position x y z
      - Orientations phi theta psi
      - Linear velocities u v w
      - Rotational velocities p q r
    - Vehicle effectors versus time
      - Plane surfaces forward aft
      - Rudder and heading (psi) values
      - Propeller values port starboard all
  - UavMissionOutput0.xml/2007.04.22/15.05.26 PDT
    - Geographic chart
      - Geographic XY plot
    - Vehicle posture versus time
      - Position x y z
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      - Propeller values port starboard all
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      - Rudder and heading (psi) values
      - Propeller values port starboard all
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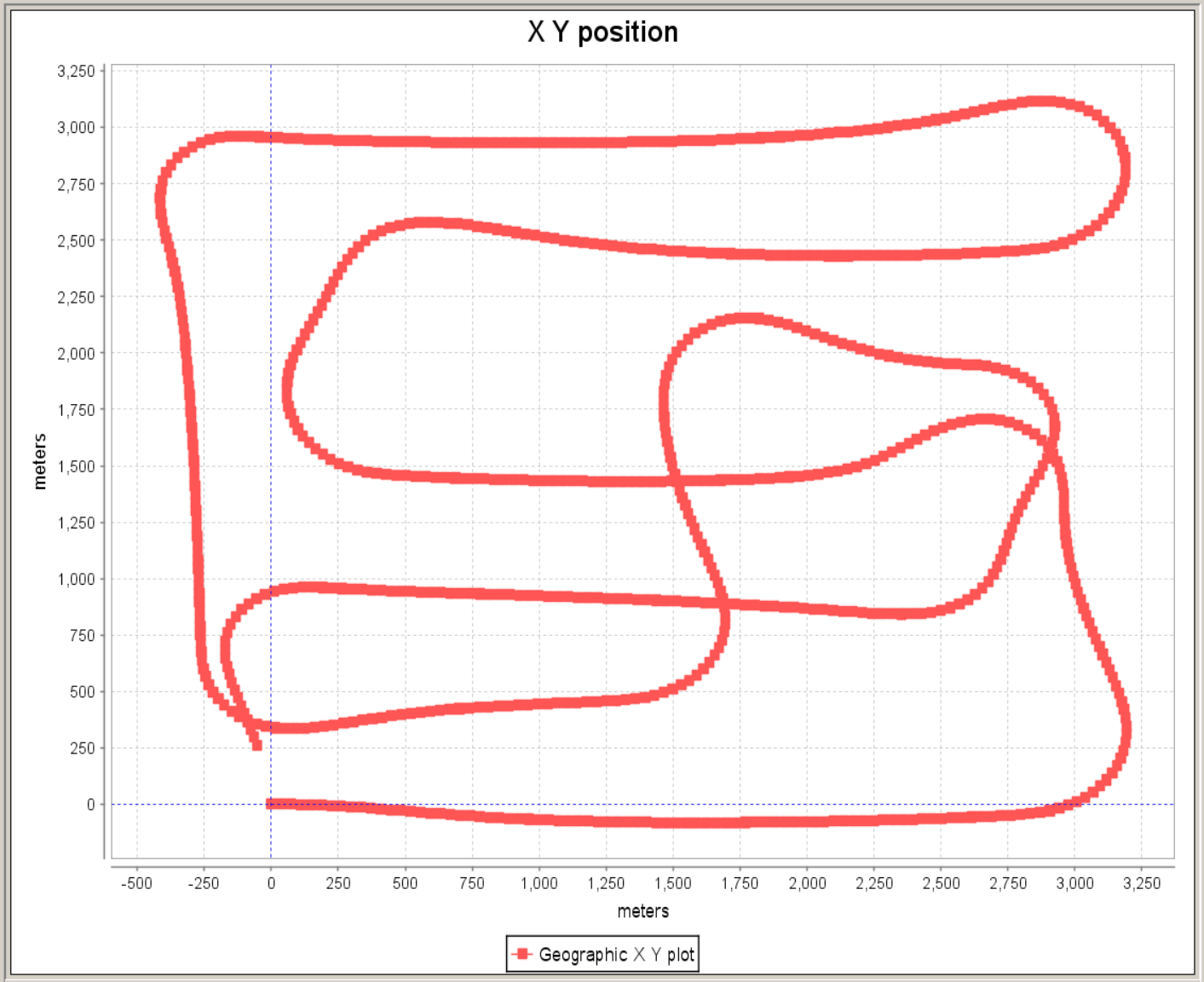
      - Plane surfaces forward aft
      - Rudder and heading (psi) values
      - Propeller values port starboard all



Geographic X Y plot. Robot coordinate system: world coordinates for vehicle position. +X (North) and +Y (East) data in meters.

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x y z versus t plot

XMSF

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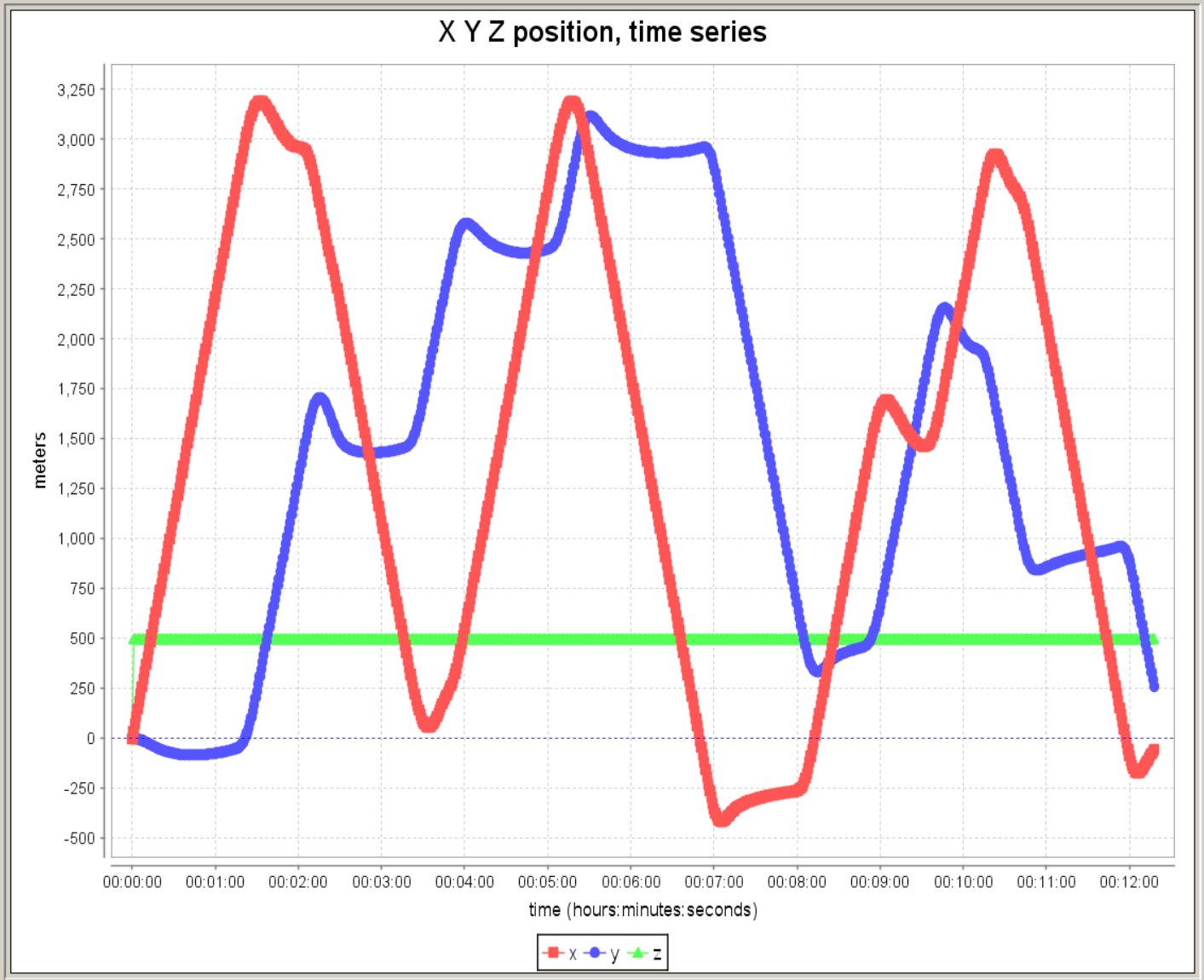
      - Propeller values port starboard all
  - UuvMissionOutput0.xml/2007.04.22/15.06.45 PDT
    - Geographic chart
      - Geographic XY plot
    - Vehicle posture versus time
      - Position x y z
      - Orientations phi theta psi
      - Linear velocities u v w
      - Rotational velocities p q r
    - Vehicle effectors versus time
      - Plane surfaces forward aft
      - Rudder and heading (psi) values
      - Propeller values port starboard all



X Y Z telemetry time-series plot. Robot coordinate system: world coordinates for vehicle position. +X (North), +Y (East) and +Z (down) data in meters versus mission time.

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phi theta psi versus t plot

XMSF

- AUVW Mission Telemetry
  - UsvMissionOutput0.xml/2007.04.22/15.05.03 PDT
    - Geographic chart
      - Geographic XY plot
    - Vehicle posture versus time
      - Position x y z
      - Orientations phi theta psi
      - Linear velocities u v w
      - Rotational velocities p q r
    - Vehicle effectors versus time
      - Plane surfaces forward aft
      - Rudder and heading (psi) values
      - Propeller values port starboard all
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      - Orientations phi theta psi
      - Linear velocities u v w
      - Rotational velocities p q r
    - Vehicle effectors versus time
      - Plane surfaces forward aft
      - Rudder and heading (psi) values
      - Propeller values port starboard all
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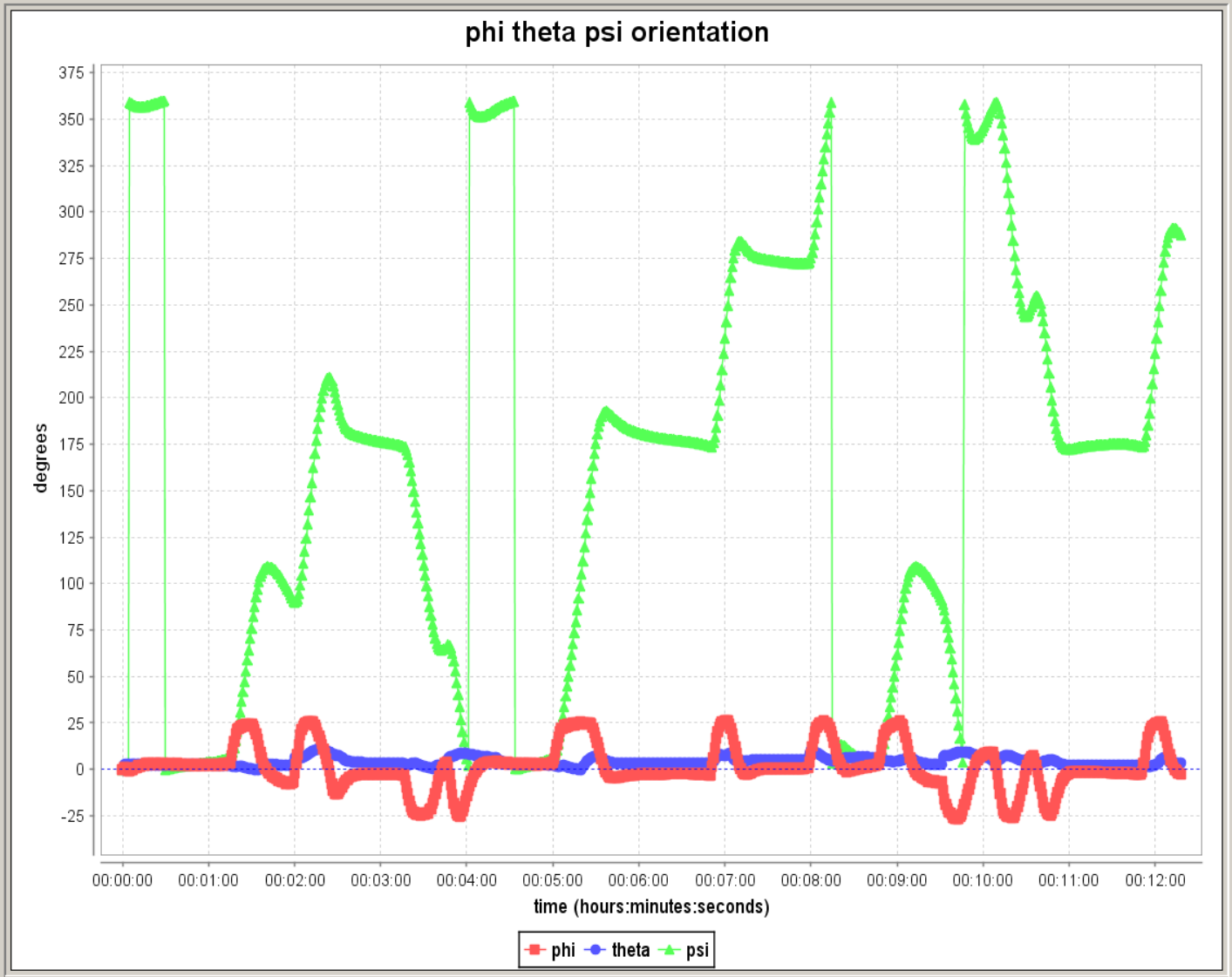
    - Vehicle posture versus time
      - Position x y z
      - Orientations phi theta psi
      - Linear velocities u v w
      - Rotational velocities p q r
    - Vehicle effectors versus time
      - Plane surfaces forward aft
      - Rudder and heading (psi) values
      - Propeller values port starboard all
  - UuvMissionOutput0.xml/2007.04.22/15.06.45 PDT
    - Geographic chart
      - Geographic XY plot
    - Vehicle posture versus time
      - Position x y z
      - Orientations phi theta psi
      - Linear velocities u v w
      - Rotational velocities p q r
    - Vehicle effectors versus time
      - Plane surfaces forward aft
      - Rudder and heading (psi) values
      - Propeller values port starboard all



Rotational angles (phi theta psi) time-series plot. Rotational angles (phi theta psi) measured about world-coordinate axes (+X +Y +Z) respectively. Units are degrees/second versus mission time. Positive values rotate according to the right-hand rule.

Physical modeling

- Control algorithms and 6 degree-of-freedom (6DOF) hydrodynamics response
- Sonar propagation, attenuation
- Collision detection
  - Direct vehicle contact and sensor contact
  - Separate use of same X3D graphics models
- Visualization greatly aids understanding
  - provides good “forcing function” for integration

Control algorithm coefficients

jEdit - C:\auv\AuvWorkbench\build\configuration\controlCoefficients\AriesControlConfiguration.xml

File Edit Search Markers Folding View Utilities Macr

Search for:

AriesControlConfiguration.xml (C:\auv\AuvWorkbench\build\configuration\controlCoefficients\)

```
<?xml version="1.0" encoding="UTF-8"?>.
<ExecutionDynamicsConfiguration vehicle="aries" date="02 February 2005" description="Sample combined configura
        <UUVControlConstants units="metric" description="Control coefficients applicable to control laws imple
                <PIDControl enabled="true" description="PD depth and waypoint coefficients are unstable and ne
                        <AngularConstants kTheta="15.0" kThrusterTheta="15.0" kPsi="5.0" kThrusterPsi="0.6" kP
                        <LinearConstants kV="0.0" kW="6.5876" kThrusterV="3.2938" kThrusterW="263.5046"/>.
                        <HoverConstants kPropellerHover="658.7615" kSurgeHover="19762.85" kThrusterHover="26.3
                        <DepthConstants kZ="10.0" kThrusterZ="30.0" kZIntegral="1.524"/>.
                        <CurrentConstants kPropellerCurrent="6600.0" kThrusterCurrent="40.0"/>.
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                        <LateralConstants kThrusterLateral="48.0"/>.
                        <RotationalConstants kThrusterRotate="1.5"/>.
                </OpenLoopControl>.
                <SlidingModeControl enabled="true" description="Sliding mode plane and rudder control for head
                        <HeadingConstants kSigmaR="-0.9499" kSigmaPsi="0.5103" kEtaSteering="1.0" kPhiSteering
                        <DepthConstants kSigmaQ="0.7693" kSigmaTheta="0.6385" kSigmaZ="0.0221" kEtaDive="1.0"
                </SlidingModeControl>.
                <LQRControl enabled="false" description="LQR (DSO Singapore developed) plane and rudder contro
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                        <DepthConstants kZ="0.6325" kTheta="3.5185" kQ="3.1305" kW="-0.1776"/>.
                </LQRControl>.
                <SonarControl targetDiscriminationDistance="5.0" st725ScanWidth="60.0" st1000ScanWidth="60.0"
                <ControlLimits maxRpm="700.0" minWaypointRpm="200.0" nominalWaypointRpm="400.0" maxThruster="2
                <Standoff distance="10"/>.
                <HoverPointTransition distance="7"/>.
        </UUVControlConstants>.
        <UUVExecutionParameters description="Miscellaneous defaults that may be overridden by command-line valu
                <InstalledHardware st1000="true" st725="true" displayScreen="true"/>.
                <RunOptions trace="false" realTime="false" tacticalLevel="false" textOutput="false" multipleLo
                <Dynamics host="localhost" port="3211"/>.
```

2,66 Top (xml,none,UTF-8) - - - - W 5/6Mb

6DOF dynamics coefficients

jEdit - C:\auv\AuvWorkbench\build\configuration\dynamicsCoefficients\AriesDynamicsConfiguration.xml

File Edit Search Markers Folding View Utilities Macr

Search for:

AriesDynamicsConfiguration.xml (C:\auv\AuvWorkbench\build\configuration\dynamicsCoefficients\)

```
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        <UUVDynamicsCoefficients units="british" description="ARIES mathematical model coefficients">.
                <Vehicle weight="435" buoyancy="435" length="10.0" diameter="0.79" height="0.79" mbtWeight="0",
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                <BuoyancyCenter x="0.0104" y="0" z="0"/>.
                <ControlConfiguration bodyThrusters="false" squareHull="true" xBowVertical="1.41" xSternVertic
                <OperationalCharacteristics maxSpeed="6.1" maxSurge="15" maxSway="15" maxHeave="15" maxRoll="1
                <InertiaMatrix Ixx="2.7" Iyy="210" Izz="225" Ixy="0" Ixz="0" Iyz="0"/>.
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                <SwayCoefficients YuDot="0" YvDot="-0.0343" YwDot="0" YpDot="0" YqDot="0" YrDot="-0.00178" Yuu
                <HeaveCoefficients ZuDot="0" ZvDot="0" ZwDot="-0.0934" ZpDot="0" ZqDot="-0.00253" ZrDot="0" Zv
                <RollCoefficients KuDot="0" KvDot="0" KwDot="0" KpDot="-0.00024" KqDot="0" KrDot="0" Kuu="0" K
                <PitchCoefficients MuDot="0" MvDot="0" MwDot="-0.00253" MpDot="0" MqDot="-0.00625" MrDot="0" M
                <YawCoefficients NuDot="0" NvDot="-0.00178" NwDot="0" NpDot="0" NqDot="0" NrDot="-0.00047" Nuu
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```
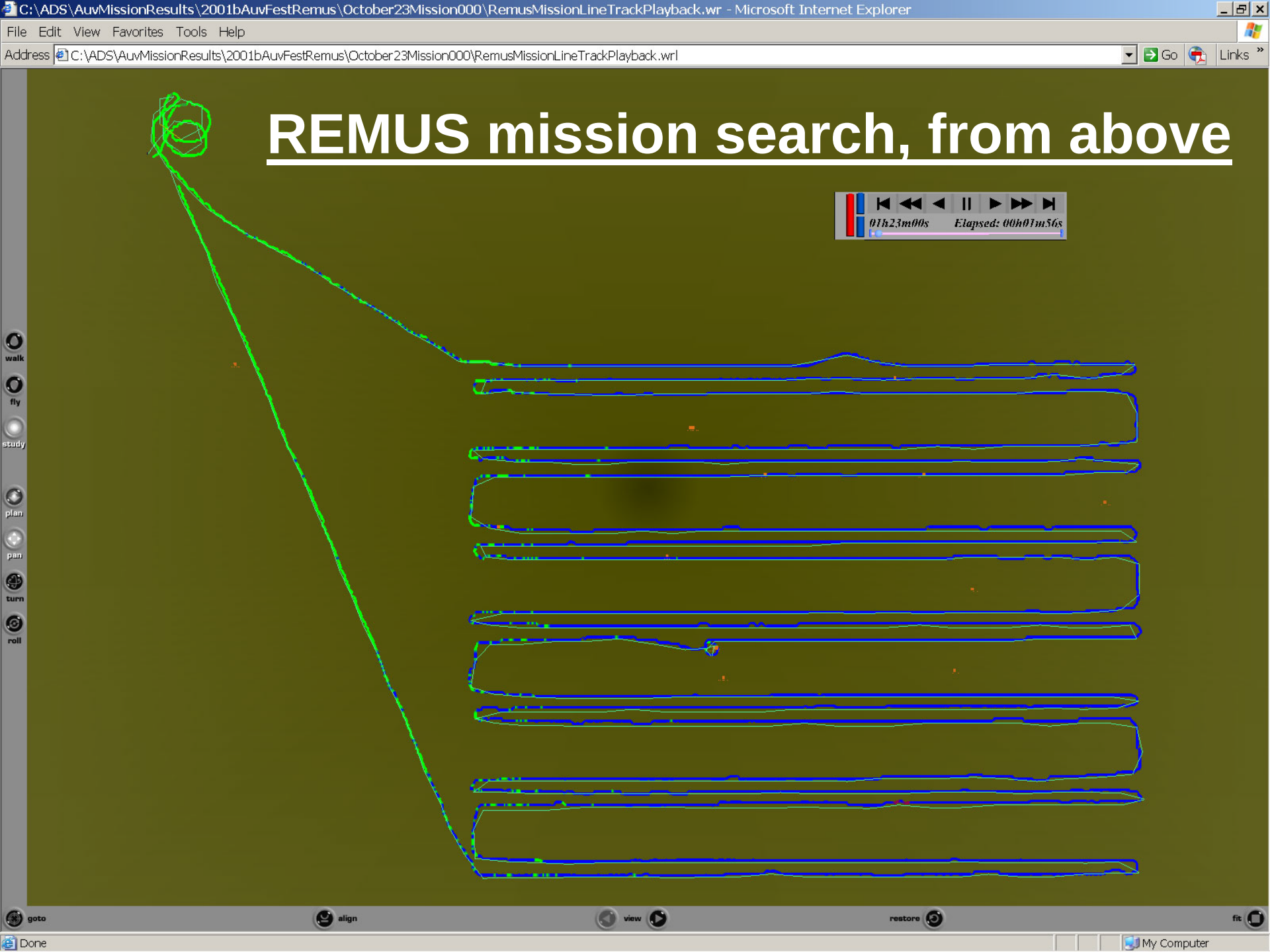

7,48-62 Top XML parsing complete, 2 error(s) (xml,none,UTF-8) - - - - W 4/7Mb

Wave modeling

- Triple sinusoid Pierson Moskowitz equations provide good emulation of variable sea state
  - Well understood example model
  - Many other variations exist, could substitute
- Real-time modeling of underwater vehicle response when broached
  - Split hull into sections
  - Compute each one as linear approximation
  - Buoyancy components add to overall response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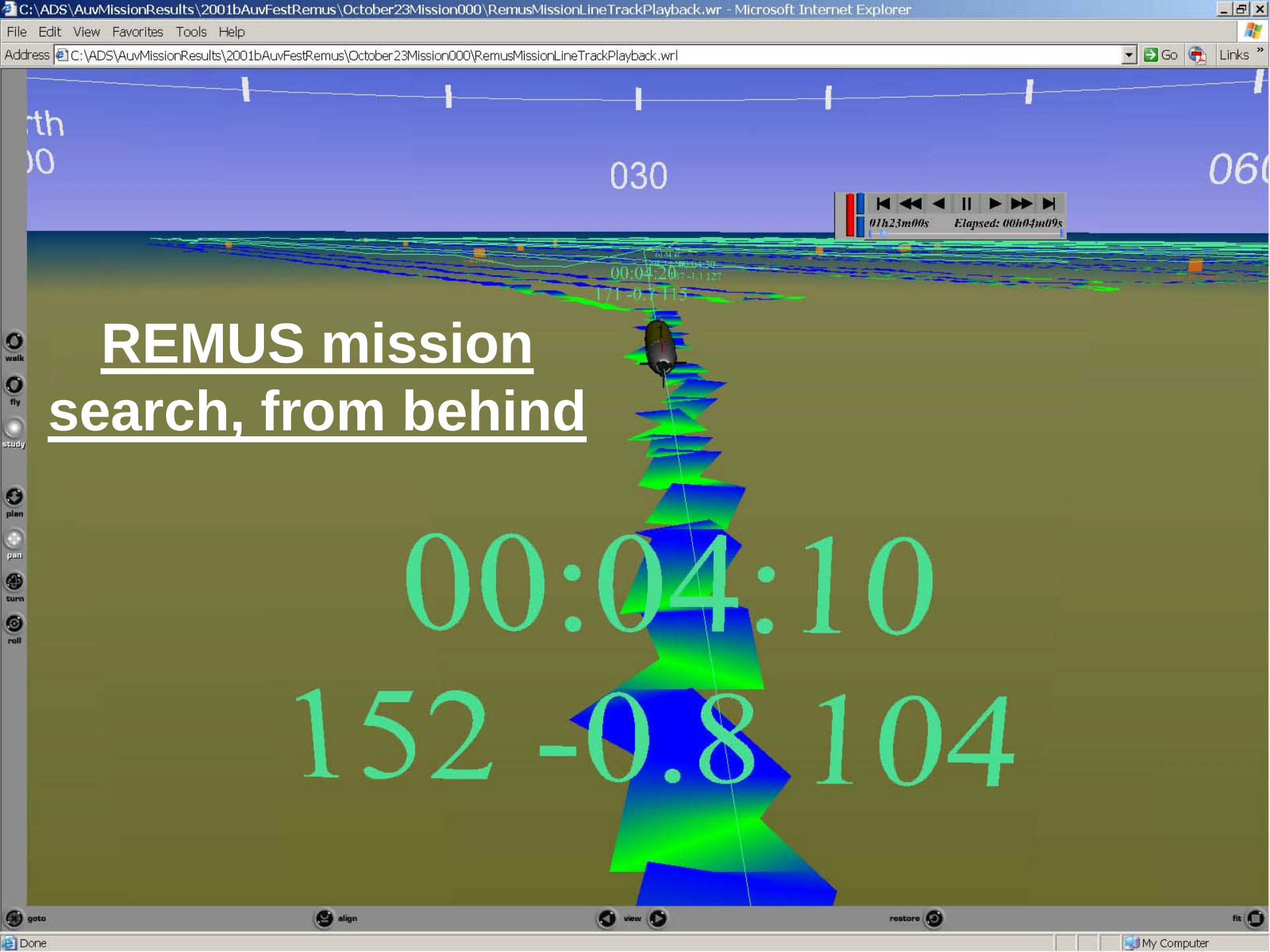
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fly
study
plan
pan
turn
roll
goto
align
view
restore
fit
Done
My Computer

Group development support

- Open standards throughout
- Open source Java for software
- All data structured as XML
- Website https://savage.nps.edu/AuvWorkbench
- XMSF Bugtracker
- Email list with hypermail archive
- Online autoinstallers

NPS Autonomous Unmanned Vehicle (AUV) Workbench

Information

- Flyer, poster, and latest slidesets
- Presentations, papers, theses, dissertations
- Autonomous Vehicle Command Language (AVCL)
- SAVAGE Modeling and Analysis Language (SMAL)

Tutorial (abstract and slides) presented at Unmanned Untethered Submersibles Technology (UUST) Symposium, 19-22 August 2007, Durham New Hampshire

Installation and open-source software development

- Autoinstall software
- Mailing list and mailing list archive
- XMSF Issue Tracker for bug reports and feature requests
- Version control: SVN source archive with SVN Web view of source files
- AUV Workbench AutoUpdate Control for manual control of automatic nightly server-side software updates (available to system administrators only)

Example missions

- AUV Workbench Robot Telemetry: Savage Archives
- AUV Workbench Robot Telemetry: SavageDefense Archives (password protected)

Example Auto Generated Post-mission Report

- Generic Auto Generated Post-mission Report

Related resources

- Extensible 3D (X3D) Graphics (also X3D Help, X3D-Edit, X3D examples, X3D Earth and X3dGraphics.com)
- Scenario Authoring and Visualization for Advanced Graphical Environments (Savage) and Savage Defense X3D model archives

XMSF Bugtracker

Actions

- Search existing bug reports
- Enter a new bug report
- Summary reports and charts

- Change password or user preferences
  Logout brutzman@nps.navy.mil
- Add to Sidebar (Requires Mozilla or Netscape 6)

Enter a bug # or some search terms:
Show [Help]

Supported projects

- NPS Autonomous Unmanned Vehicle (AUV) Workbench
- Extensible Modeling and Simulation Framework (XMSF)

Help references

- Bugzilla Guide
- Bugzilla documentation page
- Bugzilla version 2.18rc2
- Don McGregor's guides to Concurrent Version System (CVS), Using CVS with SSH Tunnels and Ant

Actions: New | Search | Find bug # | Reports | My Requests | My Votes | Sanity check | Log out brutzman@nps.navy.mil
Edit: Prefs | Parameters | Users | Products | Flags | Groups | Keywords
Saved Searches: My Bugs | Active bugs | All bugs | attachments | auvw | calendar | FOUO | license | new | P1 | savage | sonar | usw-xml | waterside-protection | xj3d

AuvWorkbench -- NPS AUV Workbench software development. Open, unmoderated, archived.

About AuvWorkbench

Mailing list support

English (USA)

The NPS Autonomous Unmanned Vehicle (AUV) Workbench is used for rehearsal, real-time control and replay of AUV/UAV missions. Physics-based hydronamics/aerodynamics and sensor propagation/interaction are used to test robot software in realistic ways. X3D graphics, DIS networking and XMSF web services are integral components. This software and associated models are open source, use open standards, and are available for shared use. Open, unmoderated, archived.

Further information regarding the NPS AUV Workbench is available at http://www.movesinstitute.org/xmsf/xmsf.html#Projects-AUV.

The large (80MB) autoinstaller is available at http://terra.cs.nps.navy.mil/AUV/workbench.

Bugs and improvements in the NPS AUV Workbench are viewable on the XMSF Bugtracker pages.

To see the collection of prior postings to this mailing list, visit the AuvWorkbench Archives.

Using AuvWorkbench

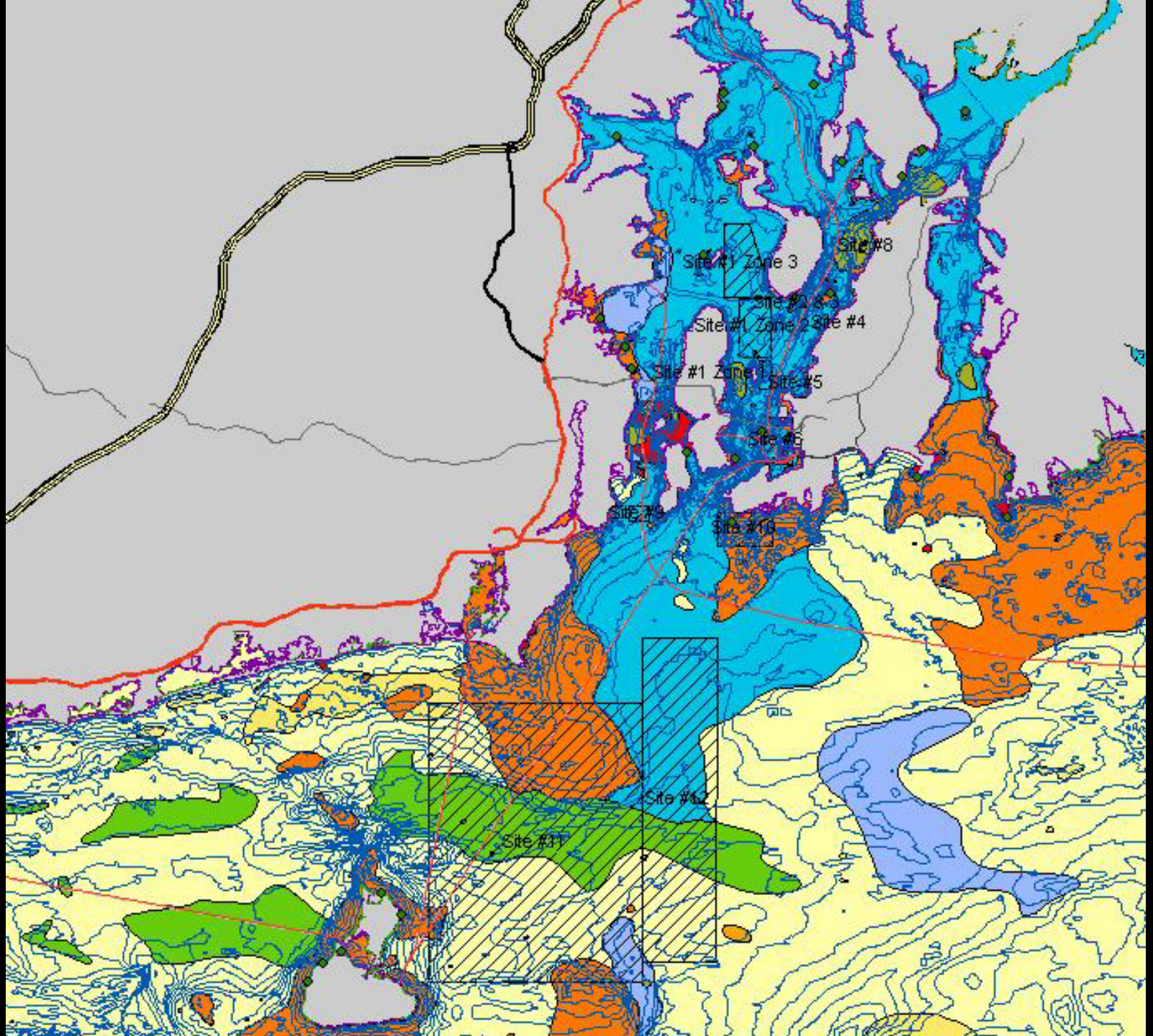
To post a message to all the list members, send email to auvworkbench@MovesInstitute.org.

You can subscribe to the list, or change your existing subscription, in the sections below.

Subscribing to AuvWorkbench

Environmental data inputs

- Constant vectors for ocean current, wind
- NetCDF environmental data developed by NAVO/NRL Stennis supercomputer models
- FNMOC web-services query to live/projected meteorological sources using Joint Metoc Brokering Language
  - Worked briefly but was a moving target…
- Other inputs welcome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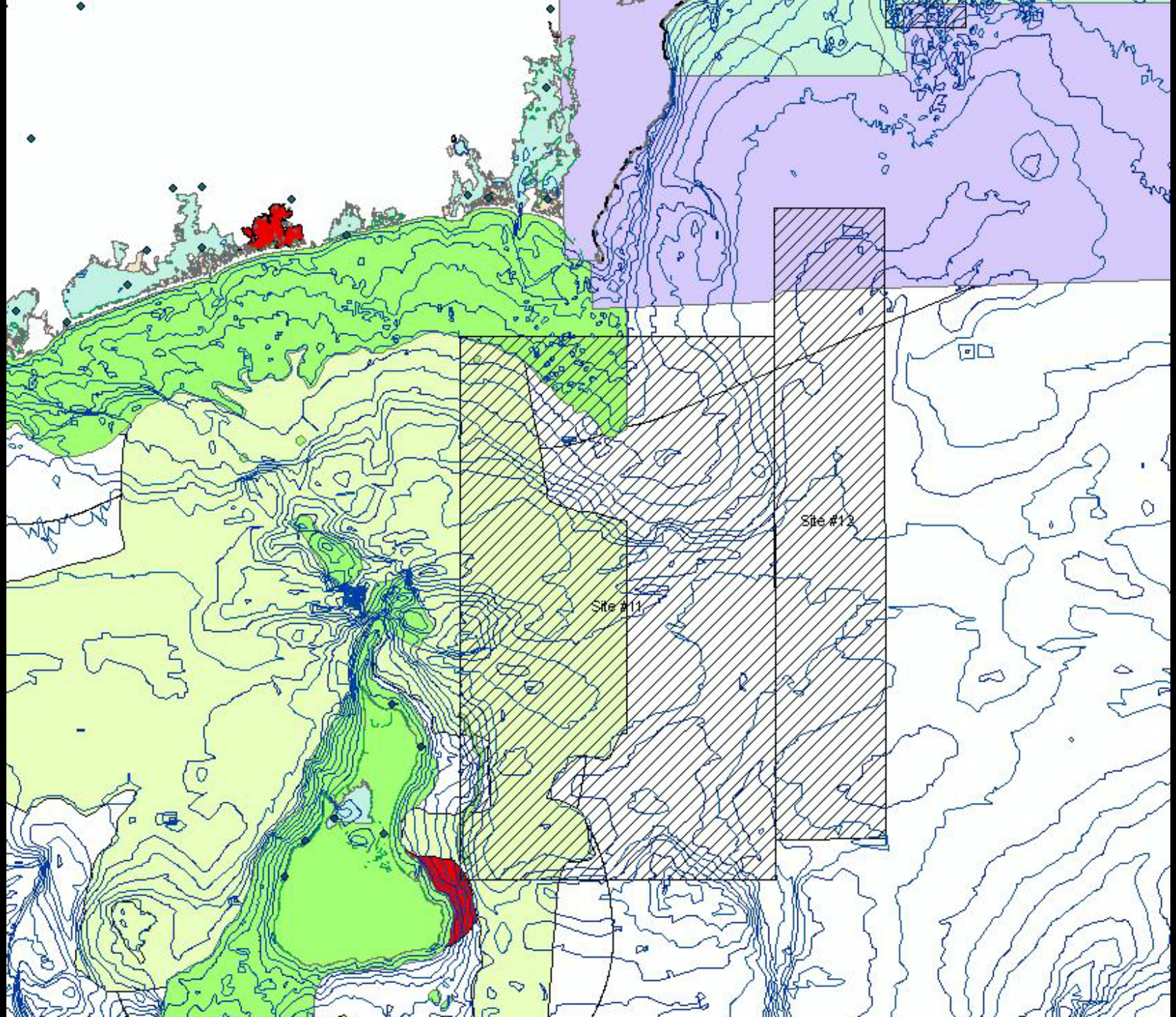
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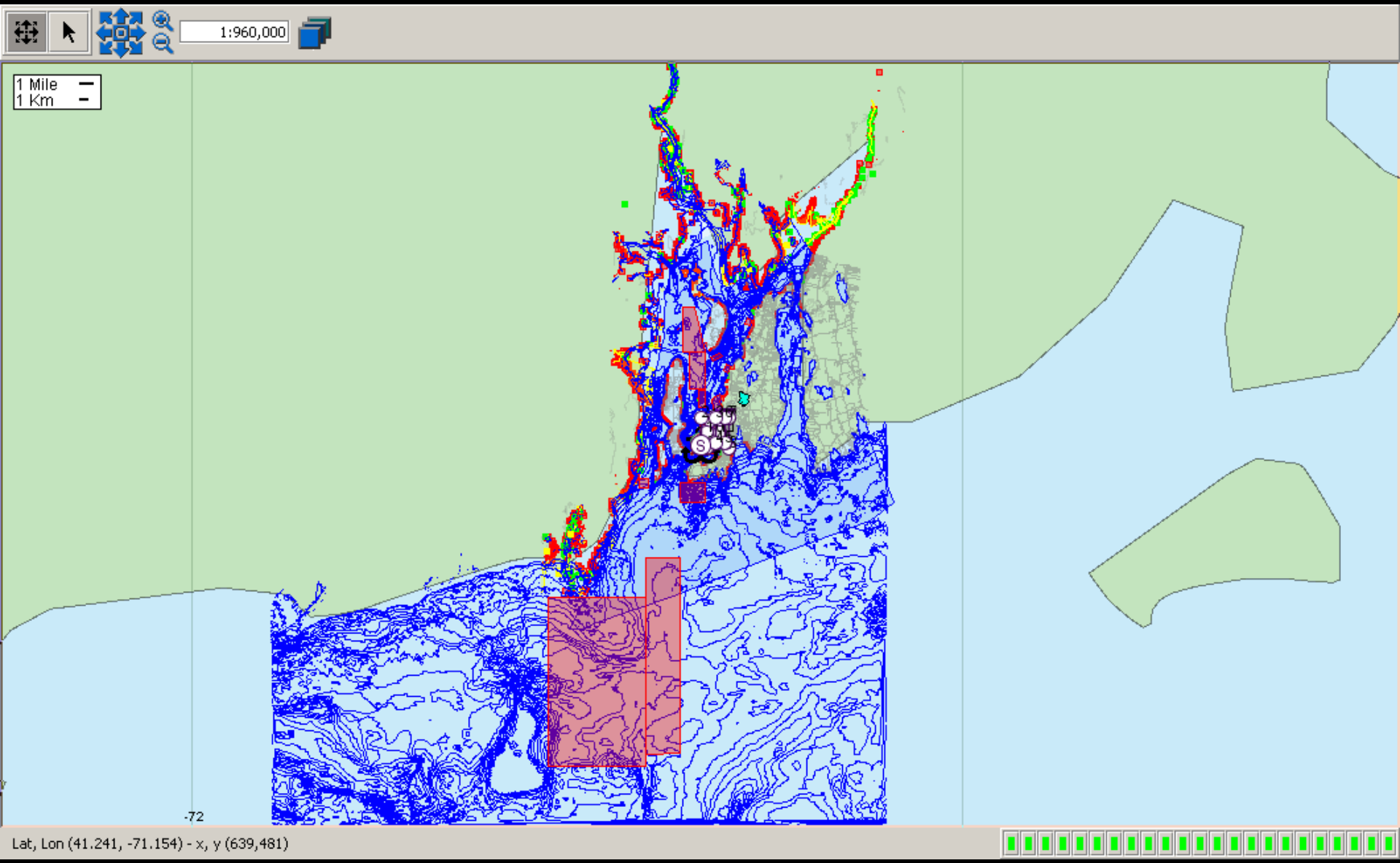
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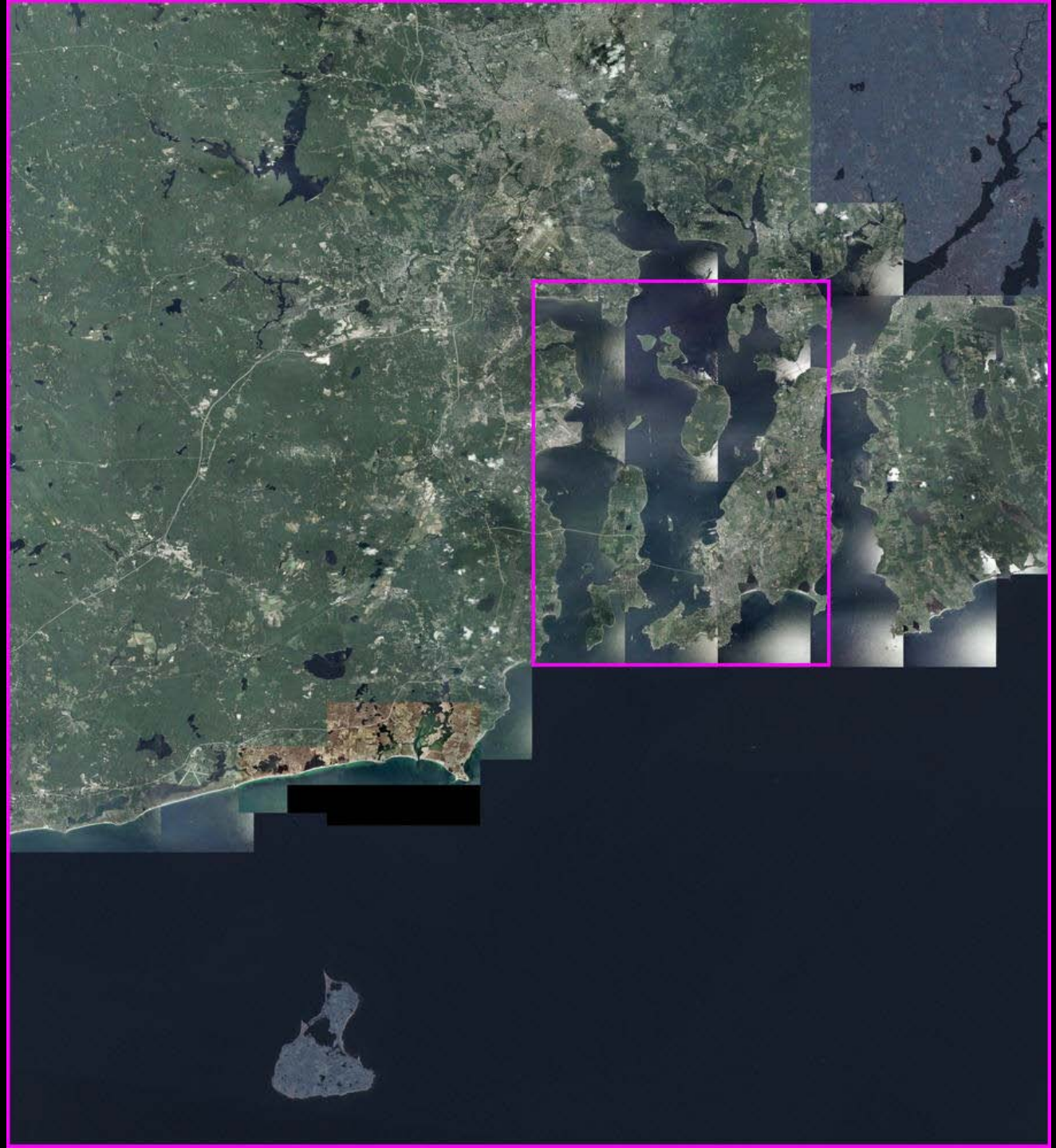


Site #6

Summary

- Significant collected AUV capabilities
  - Support rehearsal, reality, replay
- Integrated as tactical application
- Open standards: XMSF, X3D, chat, etc.
- Open source + commercial compatibility
- Improved messaging, net-centric exemplar
- We hope to add all possible vehicles!

Collaboration and questions welcome

Acronyms 1

- 3D: Three dimensional
- 6DOF: Six degrees of freedom (x y z, roll pitch yaw)
- AUV: Autonomous Underwater Vehicle
- AVCL: Autonomous Vehicle Control Language
- CD: Compact Disk
- CUP: Common Undersea Picture
- FEC: Forward Error Correction
- FNMOC: U.S. Navy Fleet Numerical Meteorological & Oceanographic Center
- HPCC: High-Performance Computing Center
- Java: programming language
- METOC: meteorological and oceanographic (data)
- NAVAIR: U.S. Naval Air Systems Command

Acronyms 2

- NPS: Naval Postgraduate School, Monterey California
- P_D: Probability of detection
- RF: radio frequency
- RRA: Recursive Ray Acoustics Sonar Propagation
- SBIR: Small Business Innovative Research
- TDA: Tactical Decision Aid
- USW: Undersea Warfare
- X3D: Extensible 3D Graphics Specification
- XML: Extensible Markup Language
- XMSF: Extensible Modeling and Simulation Framework
- XSBC: XML Schema-based Binary Compression
- XTC: XML Tactical Chat

Contact

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