# From Scientist and Sensor to Synthesis:
## Overview of the GCE Data Toolbox for MATLAB


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Georgia Coastal Ecosystems LTER

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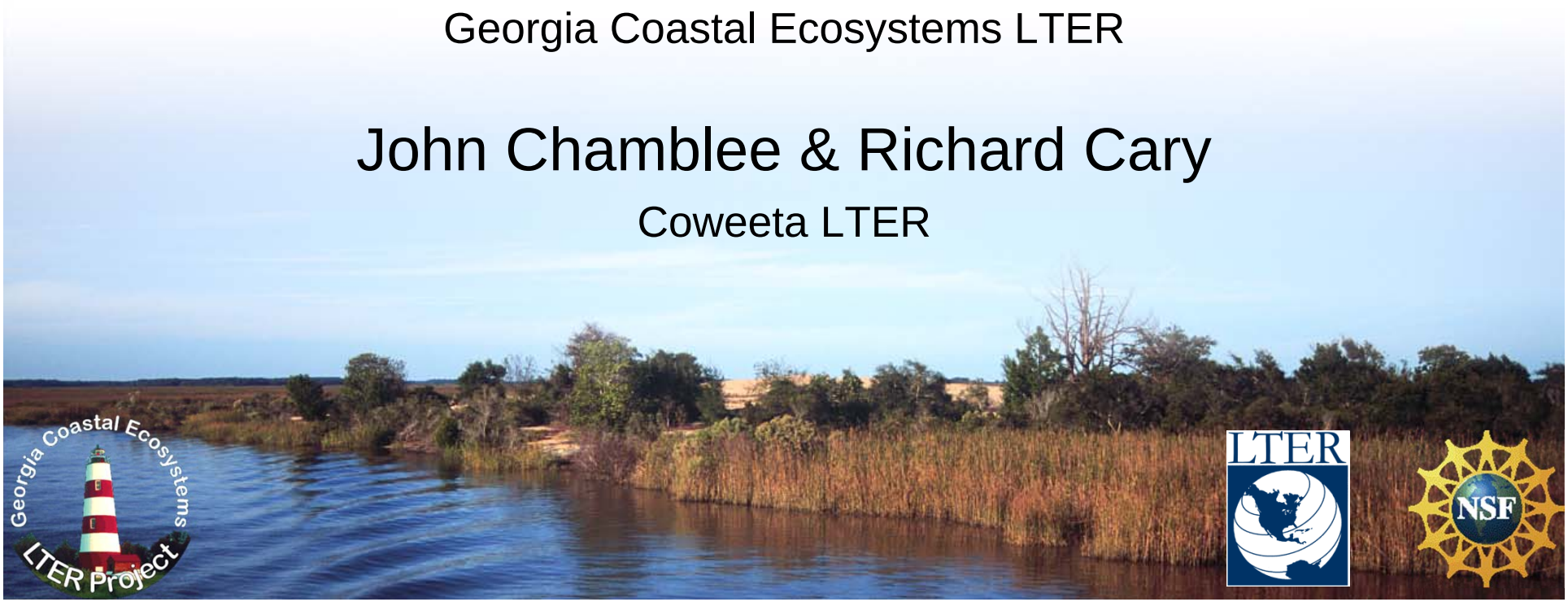


# Background & Motivation

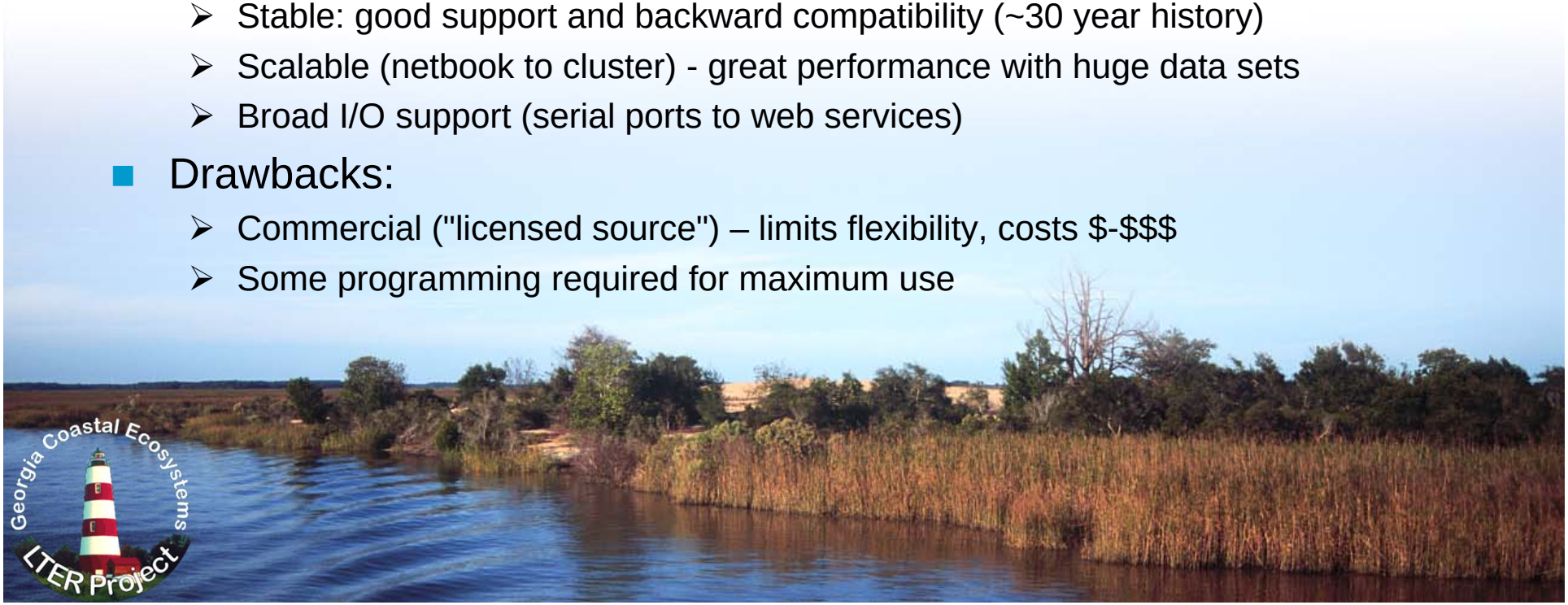
- Georgia Coastal Ecosystems LTER project started in Sept 2000
  - Large data collection effort (cruises, moorings, met stations, water quality, field surveys, ...)
  - NSF & LTER require data archiving and sharing
  - LTER requires detailed “metadata” for every data set
  - Needed to **standardize** data processing, quality control, documentation
- No ready-to-use software for LTER data management
  - Lots of great papers and reports, no tools to download
  - Most LTER sites were using “flat files” – limiting
  - A few sites using relational databases, client/server apps – proprietary, complex, unfamiliar, require constant network access
- Chose to develop custom data management software (MATLAB)
  - Experienced using MATLAB for automating data processing, GUIs
  - Better code-reuse potential than database/web solution
  - Best compromise: file-based but supports fully dynamic operations

# What is MATLAB?

- From Mathworks: (http://www.mathworks.com/products/matlab/)

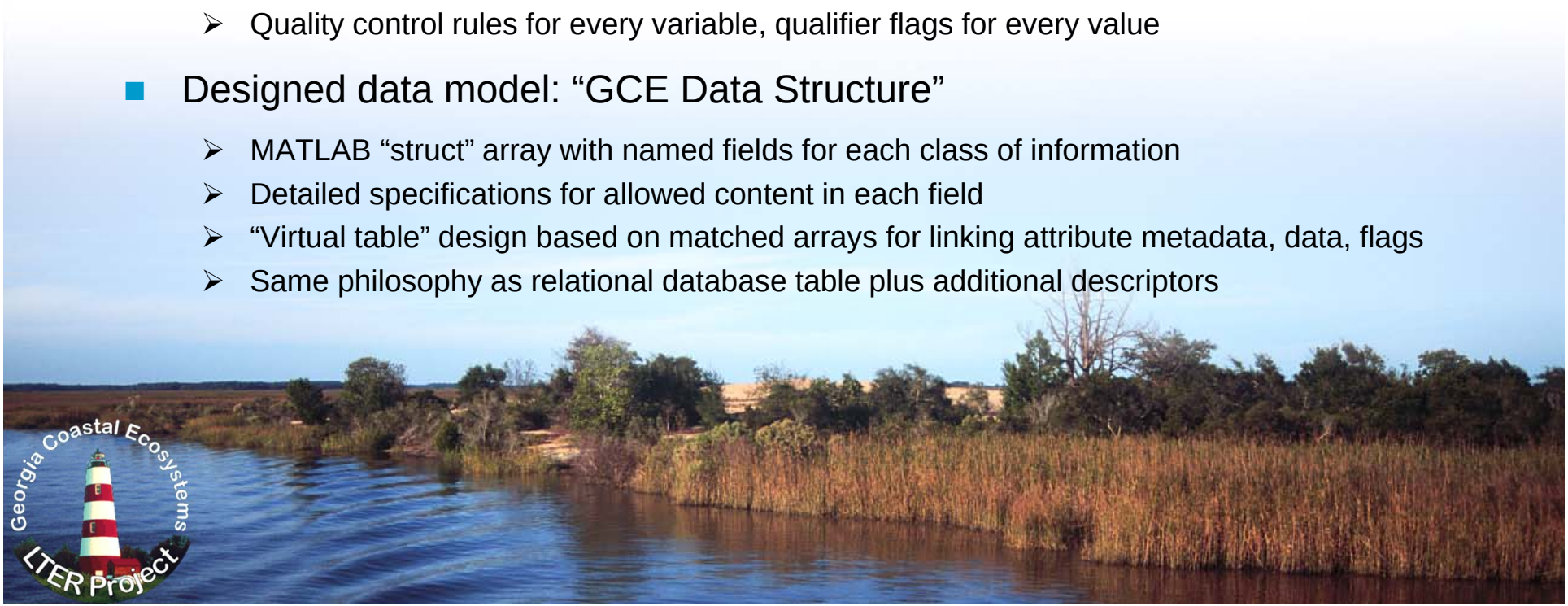
  "MATLAB is a programming environment for algorithm development, data analysis, visualization, and numerical computation. Using MATLAB, you can solve technical computing problems faster than with traditional programming languages, such as C, C++, and Fortran."

- Benefits:
  - Ubiquitous in engineering and many science branches
  - Rapid development with lots of pre-built functionality, Java integration
  - Cross-platform code, GUIs and data formats (Windows, *nix, Mac OS/x)
  - Stable: good support and backward compatibility (~30 year history)
  - Scalable (netbook to cluster) - great performance with huge data sets
  - Broad I/O support (serial ports to web services)
- Drawbacks:
  - Commercial ("licensed source") – limits flexibility, costs $-$$$
  - Some programming required for maximum use

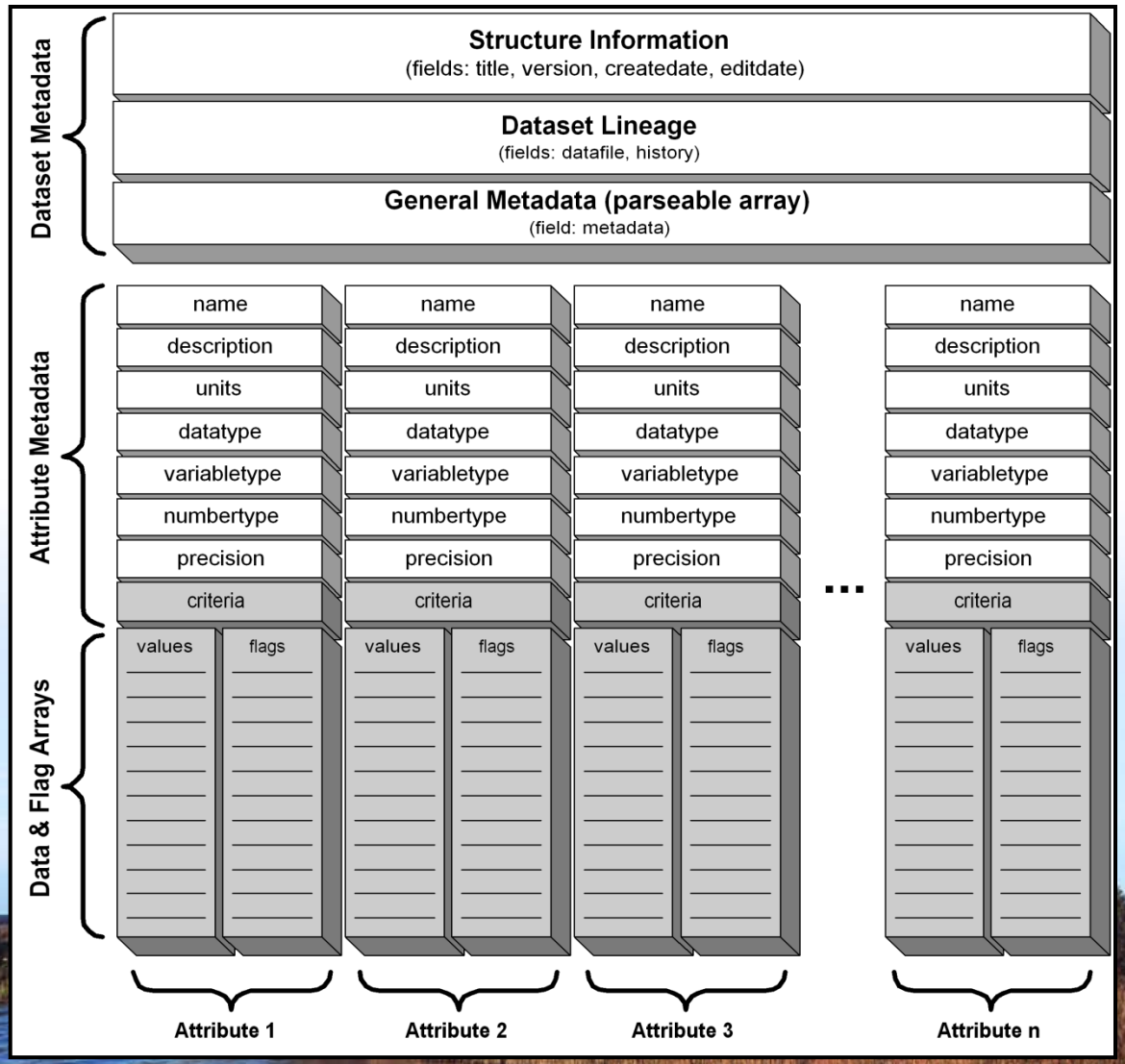


# Toolbox Development

- Started by reviewing ESA's "FLED" report
  - Gross, Katherine L. and Catherine E. Pake. 1995. Final report of the Ecological Society of America Committee on the Future of Long-term Ecological Data (FLED). Volume I: Text of the Report. The Ecological Society of America, Washington, D.C.
- Identified information storage requirements
  - Any number of numeric (integer, float, exponential) and text variables
  - Structured attribute metadata for each variable (name, units, desc., type, precision, ...)
  - Structured documentation (dataset metadata) for dynamic updating, formatting
  - Versioning and processing history info (lineage)
  - Quality control rules for every variable, qualifier flags for every value
- Designed data model: "GCE Data Structure"
  - MATLAB "struct" array with named fields for each class of information
  - Detailed specifications for allowed content in each field
  - "Virtual table" design based on matched arrays for linking attribute metadata, data, flags
  - Same philosophy as relational database table plus additional descriptors



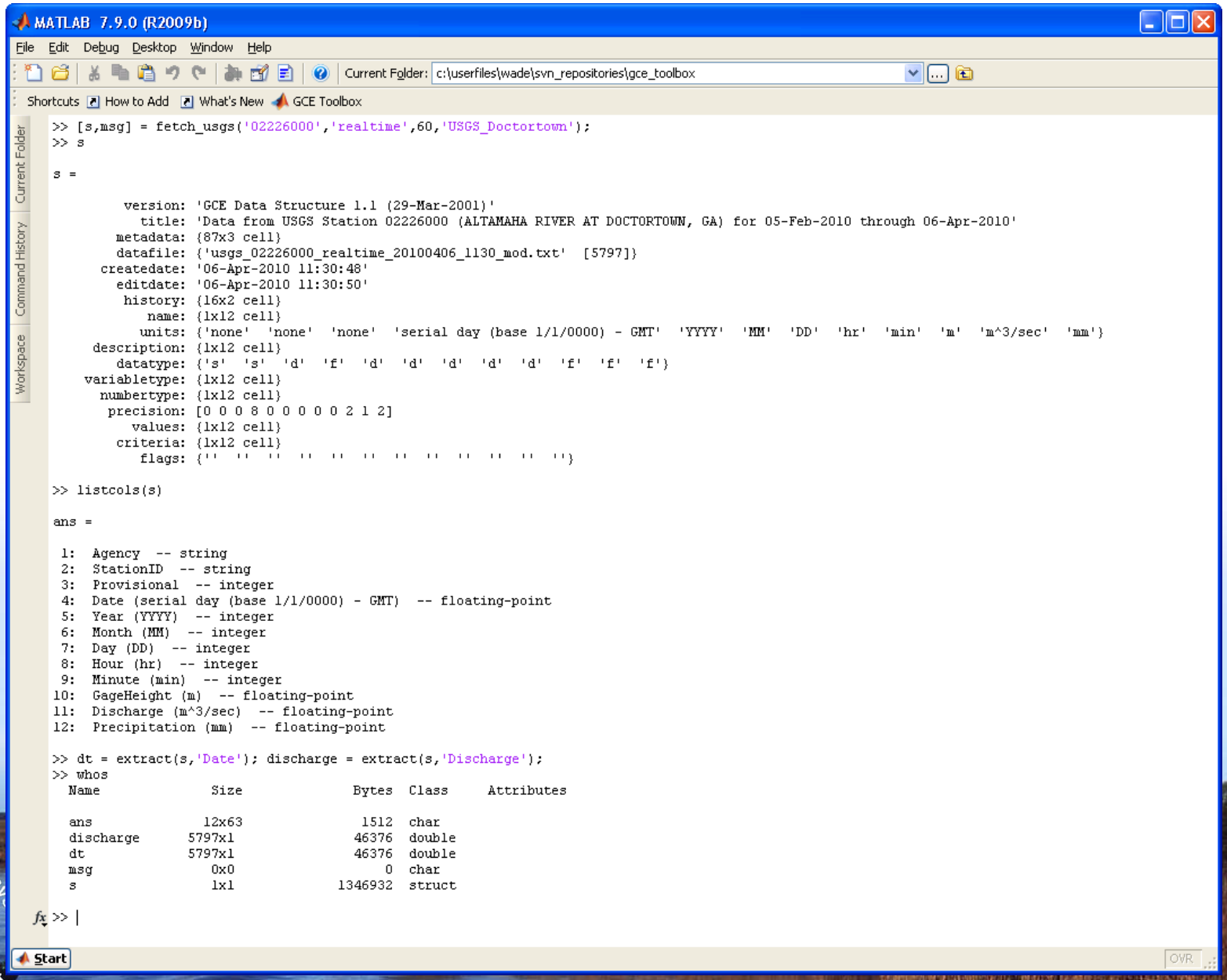
# Data Model (GCE Data Structure)



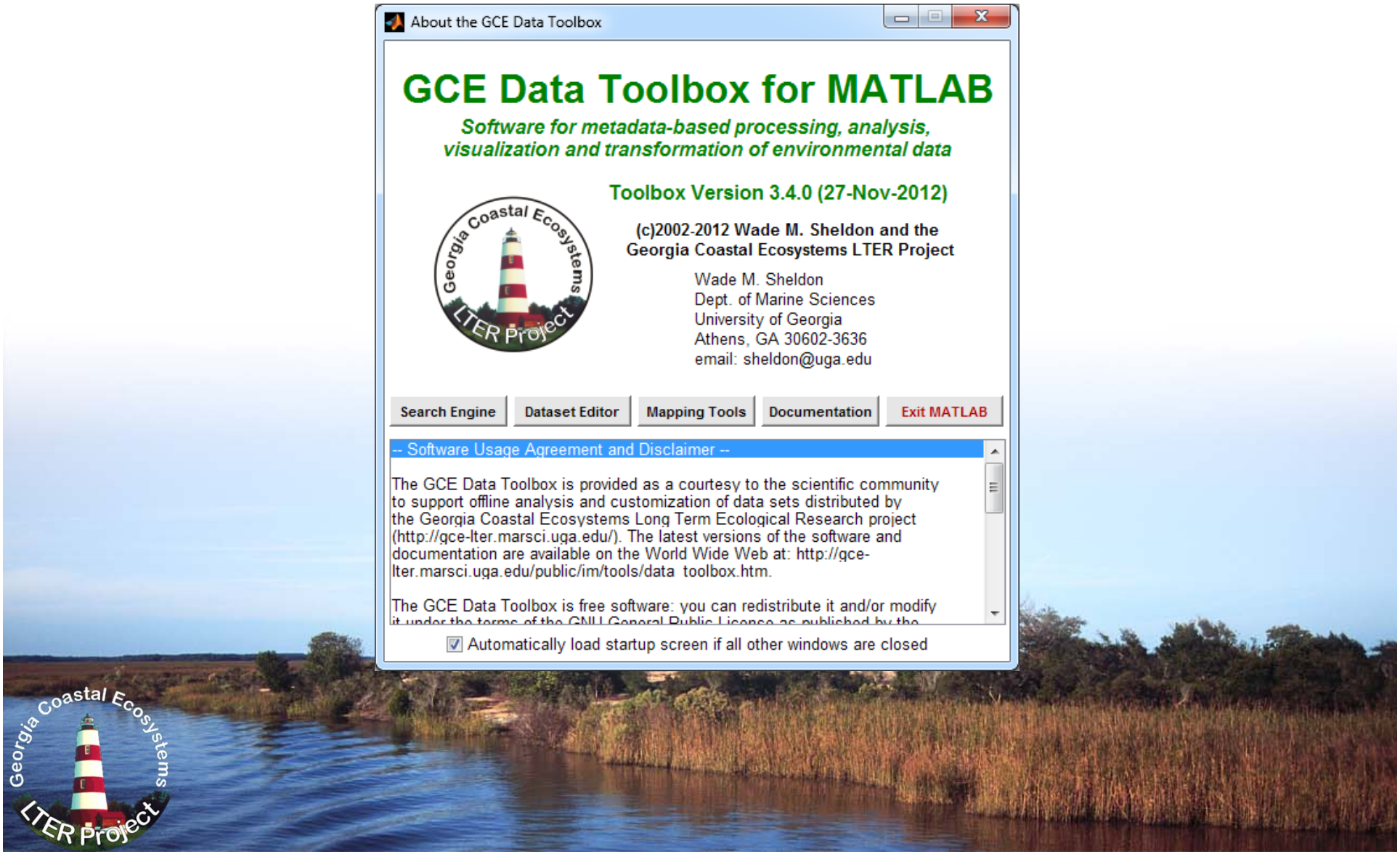
# Toolbox Development

- Developed MATLAB software library to work with data structures
  - Utility functions to abstract low-level operations (API)
    - Create structure, add/delete columns, copy/insert/delete rows
    - Extract, sort, query, update data, update flags
  - Analytical functions for high-level operations
    - Statistics, visualizations, geographic & date/time transformations
    - Unit inter-conversions, aggregation/re-sampling, joining data sets
  - GUI interface functions to simplify using the toolbox
  - All functions use metadata, data introspection to auto-parameterize and automate operations (semantic processing)
- Developed indexing and search support (and GUI search engine)

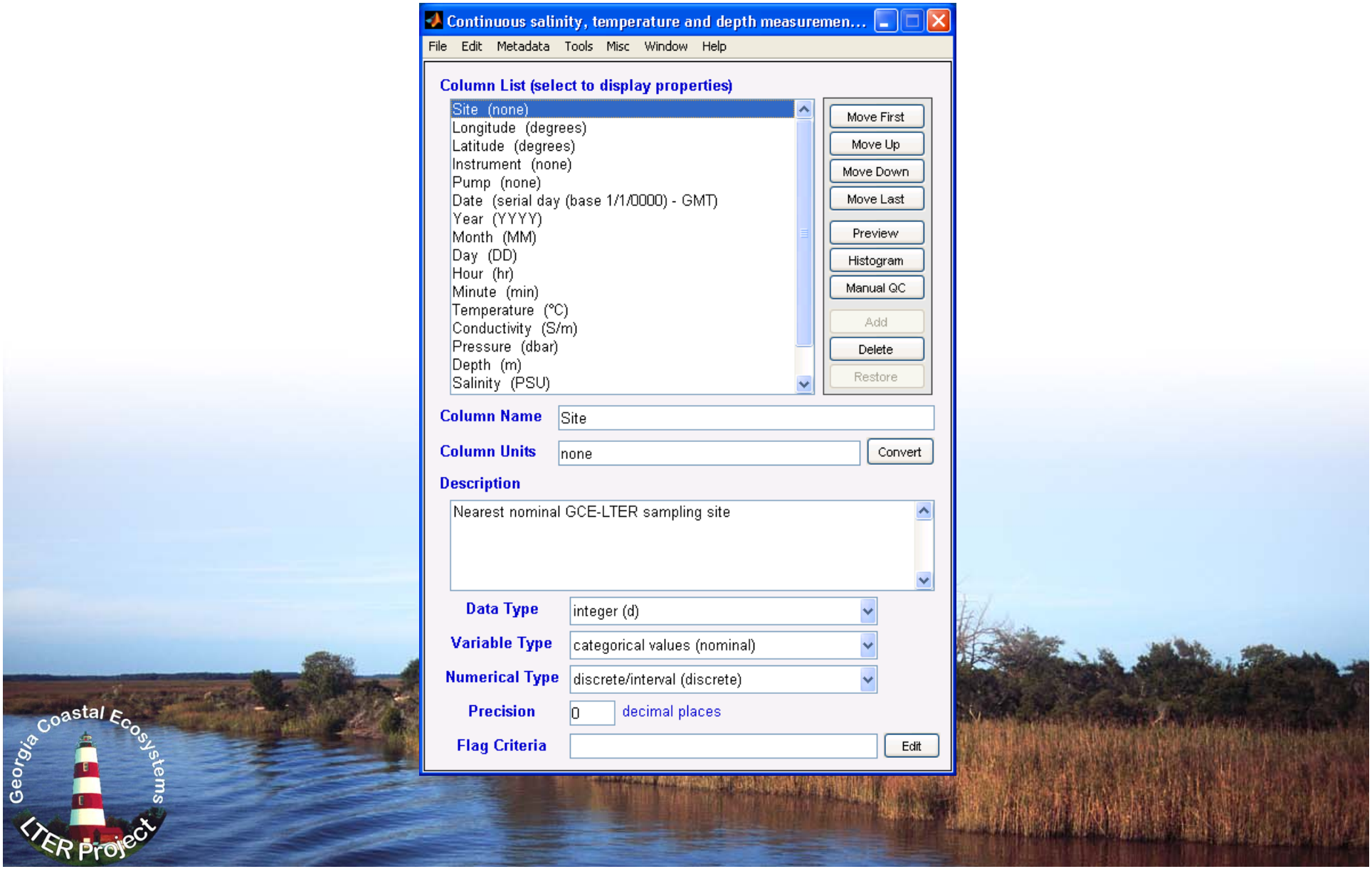
# Command Line



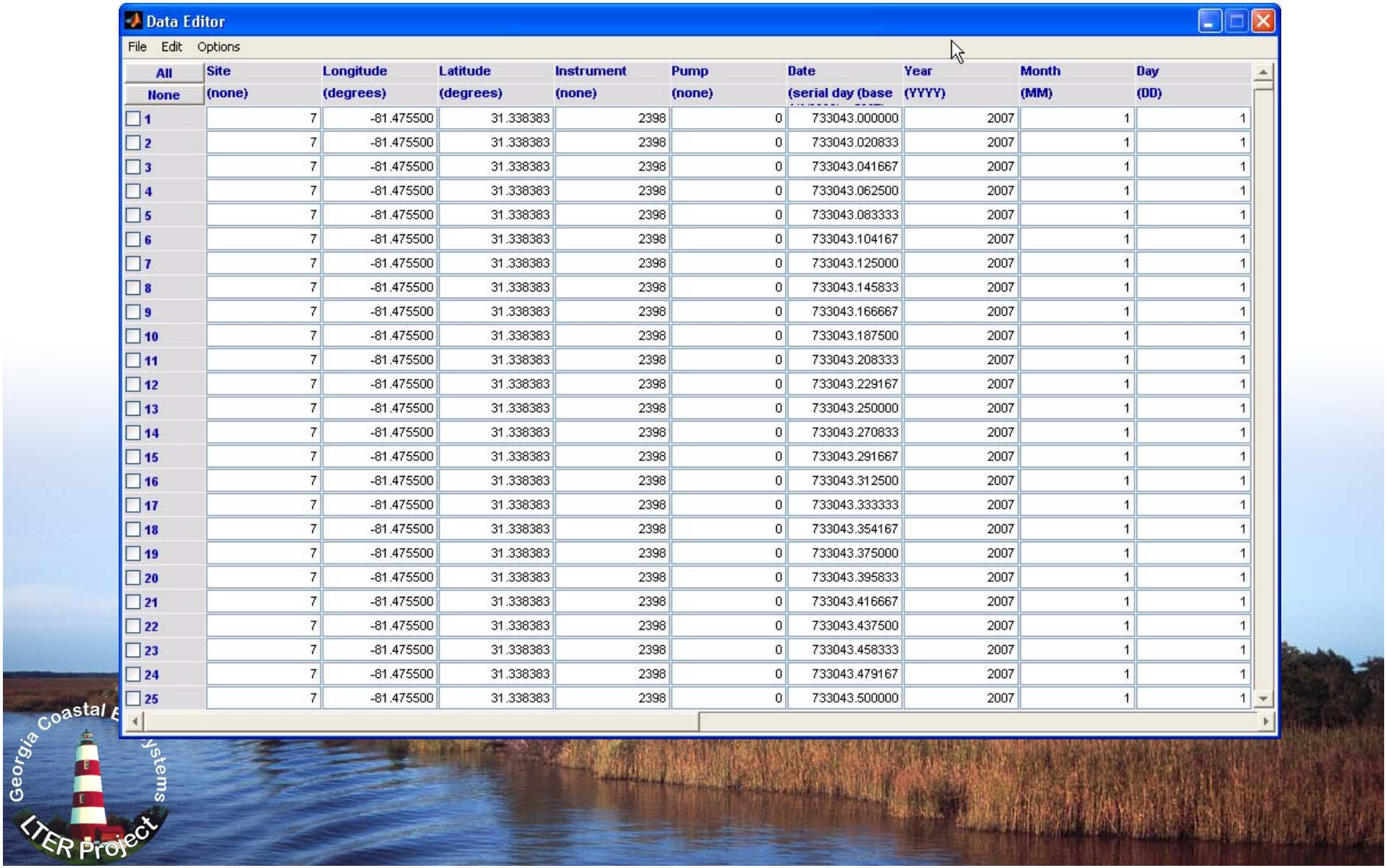
# Startup Dialog



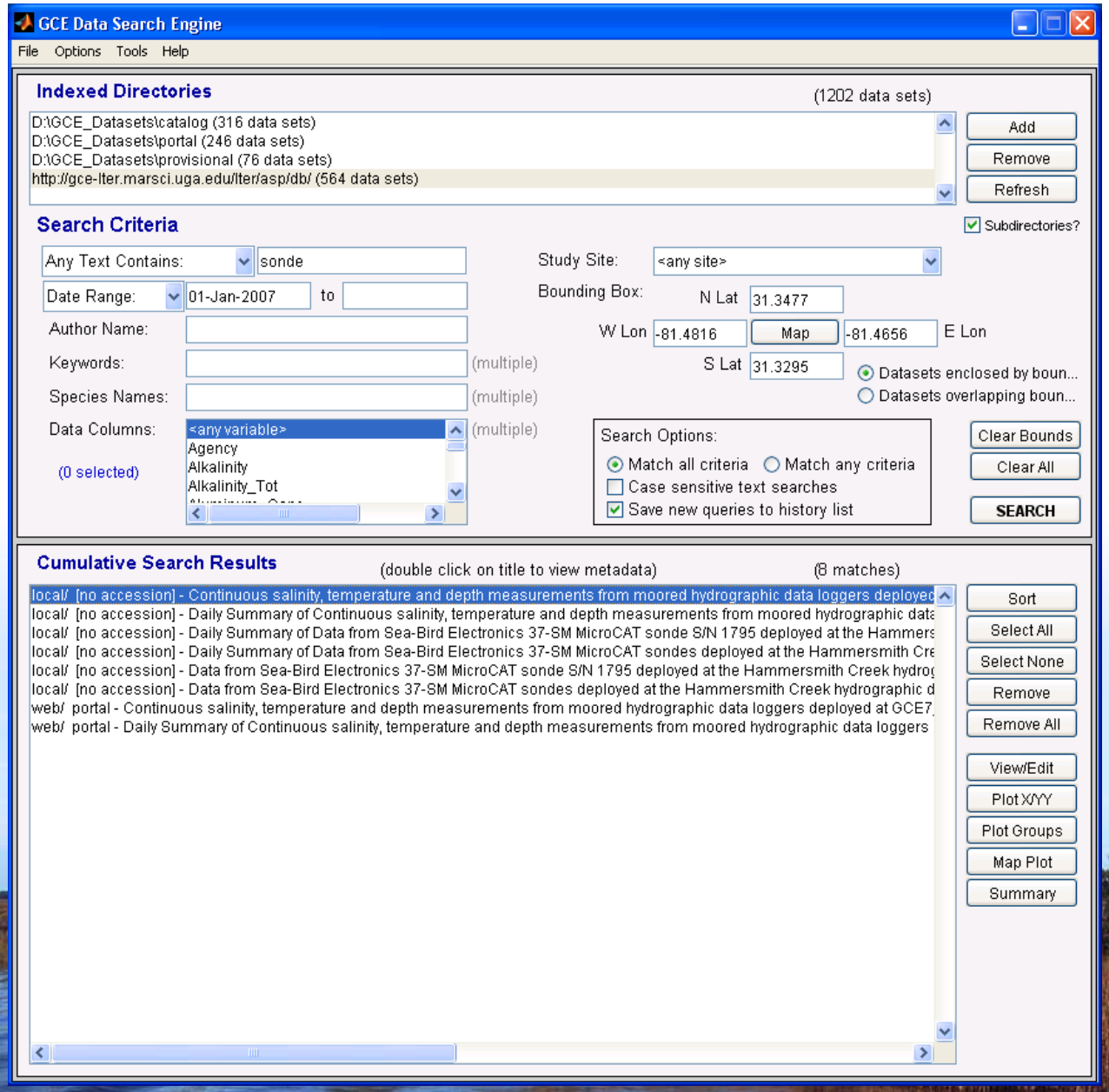
# Dataset Editor



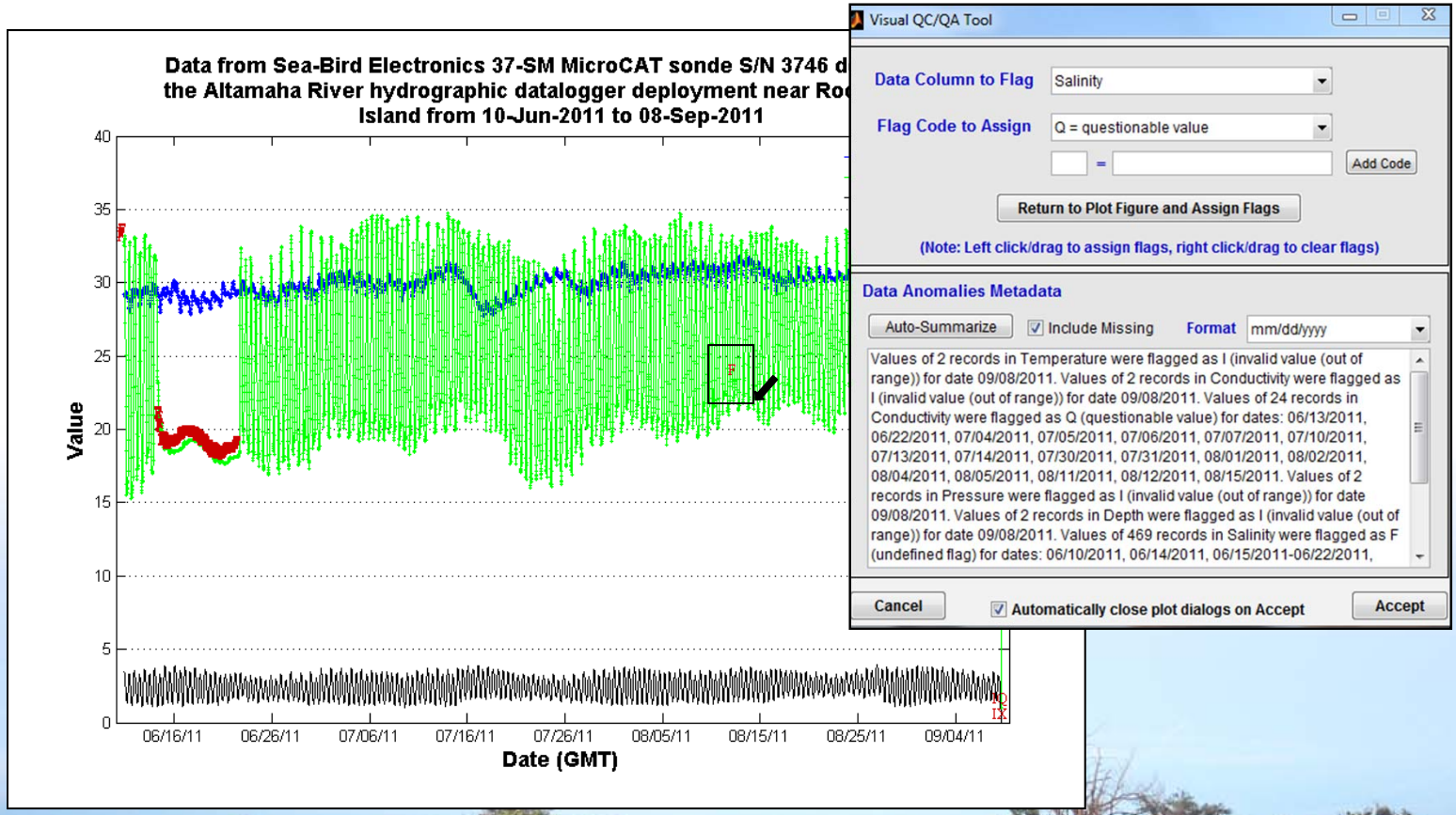
# Data Viewer/Editor



# Data Search Engine



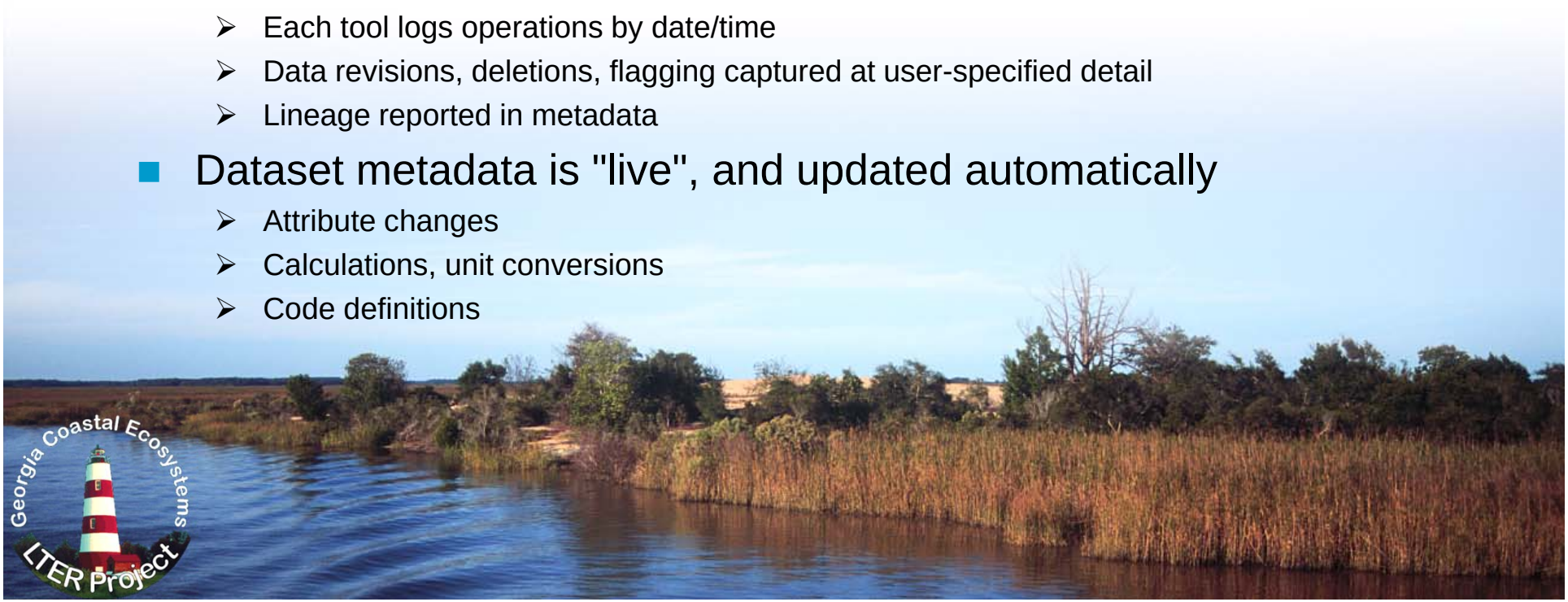
# Interactive Plotting & Q/C Tools




Georgia Coastal Ecosystems LTER Project

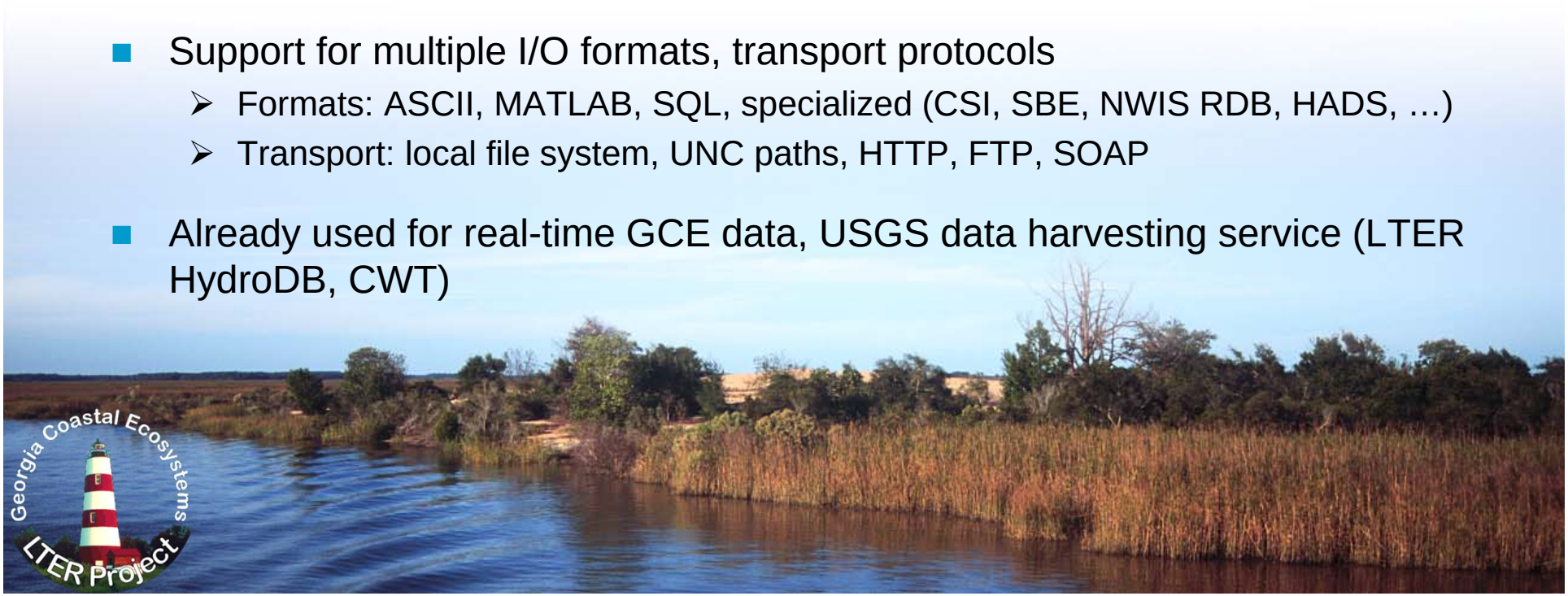
# Key Concepts

- Every operation is performed in context of a "dataset"
  - Passing data columns to a tool transports metadata as well
  - Dataset metadata used to guide transformation, plotting, analysis
  - Metadata used to auto-parameterize functions
- Data structure instances are independent
  - Each step along a workflow results in a complete data set with metadata
  - Intermediate datasets can be saved or overwritten in workflows
- Processing history ("lineage") information captured for all steps
  - Each tool logs operations by date/time
  - Data revisions, deletions, flagging captured at user-specified detail
  - Lineage reported in metadata
- Dataset metadata is "live", and updated automatically
  - Attribute changes
  - Calculations, unit conversions
  - Code definitions

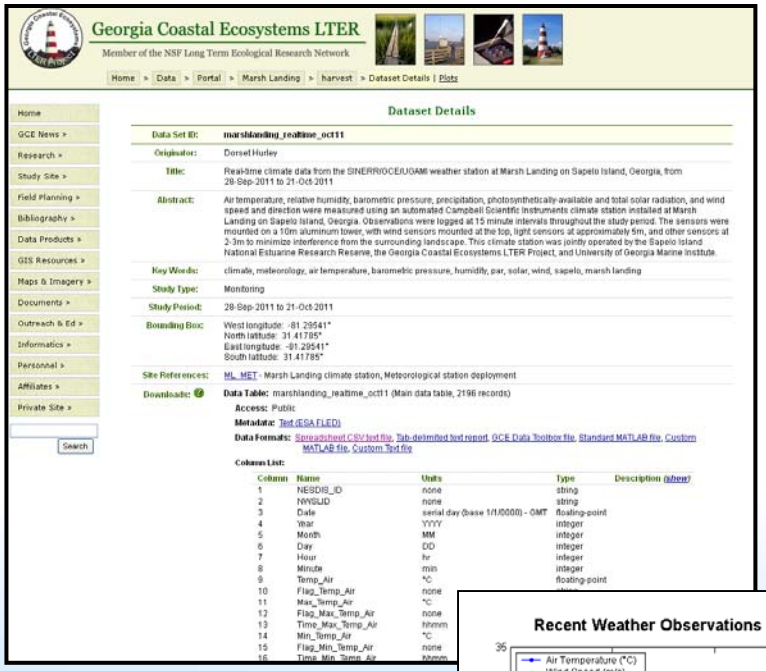


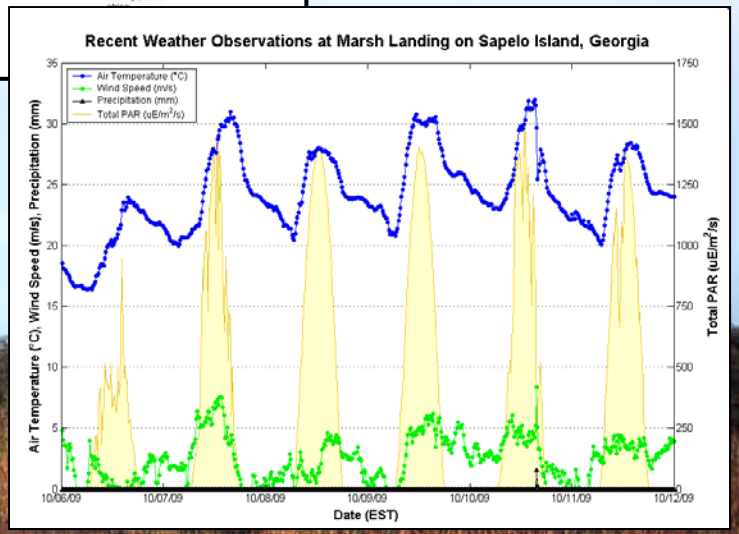
# Suitability for Real-Time Sensor Data

- Good Scalability
  - Data volumes only limited by computer memory (tested >2 GB data sets)
  - Multiple instances can be run on high-end, 64bit, clustered workstations
  - Good flag evaluation performance in use, testing with diverse rule sets
- Good scope for automation
  - Command-line API for unattended batch processing via workflow scripts
  - Timed and triggered workflow implementations easy to deploy
- Support for multiple I/O formats, transport protocols
  - Formats: ASCII, MATLAB, SQL, specialized (CSI, SBE, NWIS RDB, HADS, …)
  - Transport: local file system, UNC paths, HTTP, FTP, SOAP
- Already used for real-time GCE data, USGS data harvesting service (LTER HydroDB, CWT)



# Real-Time GCE Data Harvesting



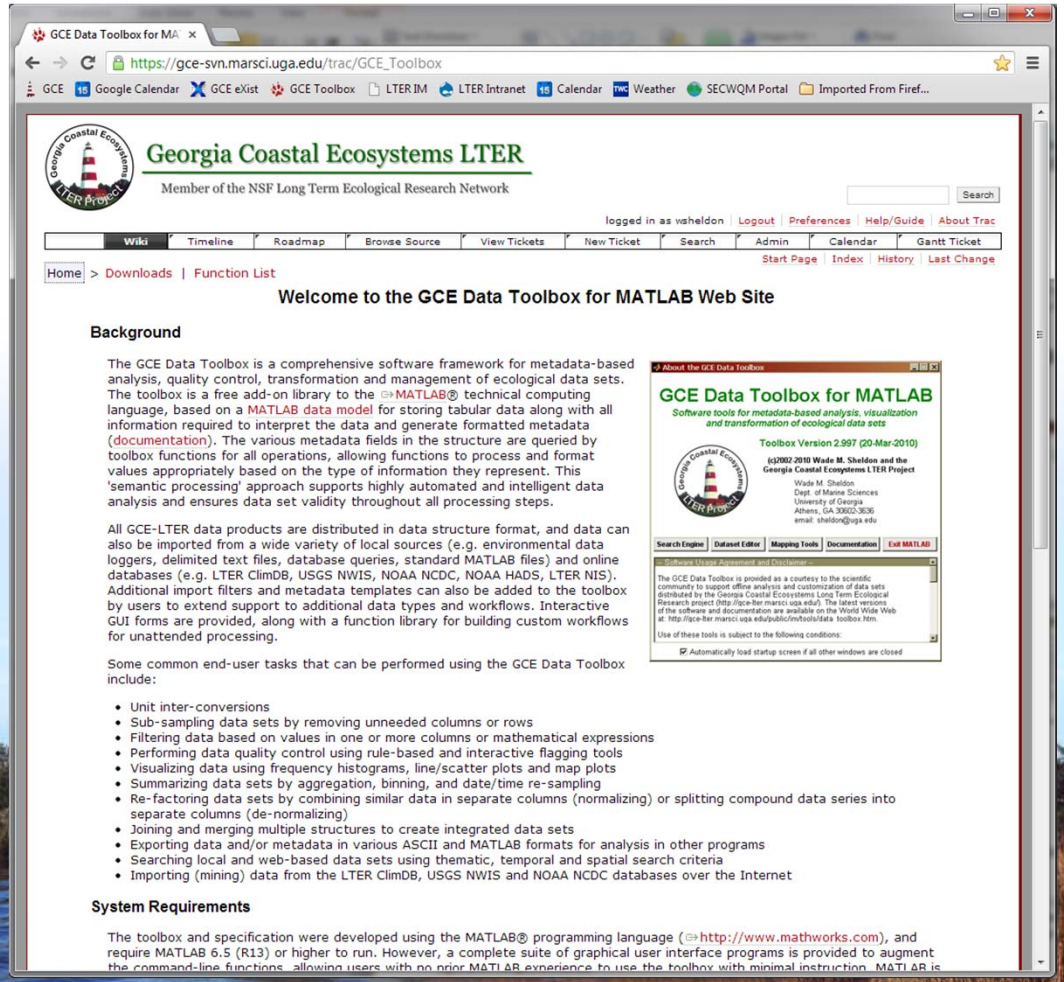



# Implementation Scenarios

- End-to-End Processing (logger-to-scientist)
  - Acquire raw data from logger, file system, network (CIFS,HTTP,FTP,SOAP)
  - Assign metadata from template or using forms to validate and flag data
  - Review data and fine-tune flag assignments
  - Generate distribution files & plots, archive data, index for searching
  - Scientists can use toolbox on their desktop
- Data Pre-processing
  - Acquire, validate and flag raw data (on demand or timed/triggered)
  - Upload processed data files (e.g. csv) or value & flag arrays to RDBMS (e.g HIS)
- Workflow Step
  - Call toolbox from other software as part of workflow (e.g. LoggerNet)
  - DataTurbine via MATLAB off-ramp or Java API
  - Kepler via MATLAB actor ???

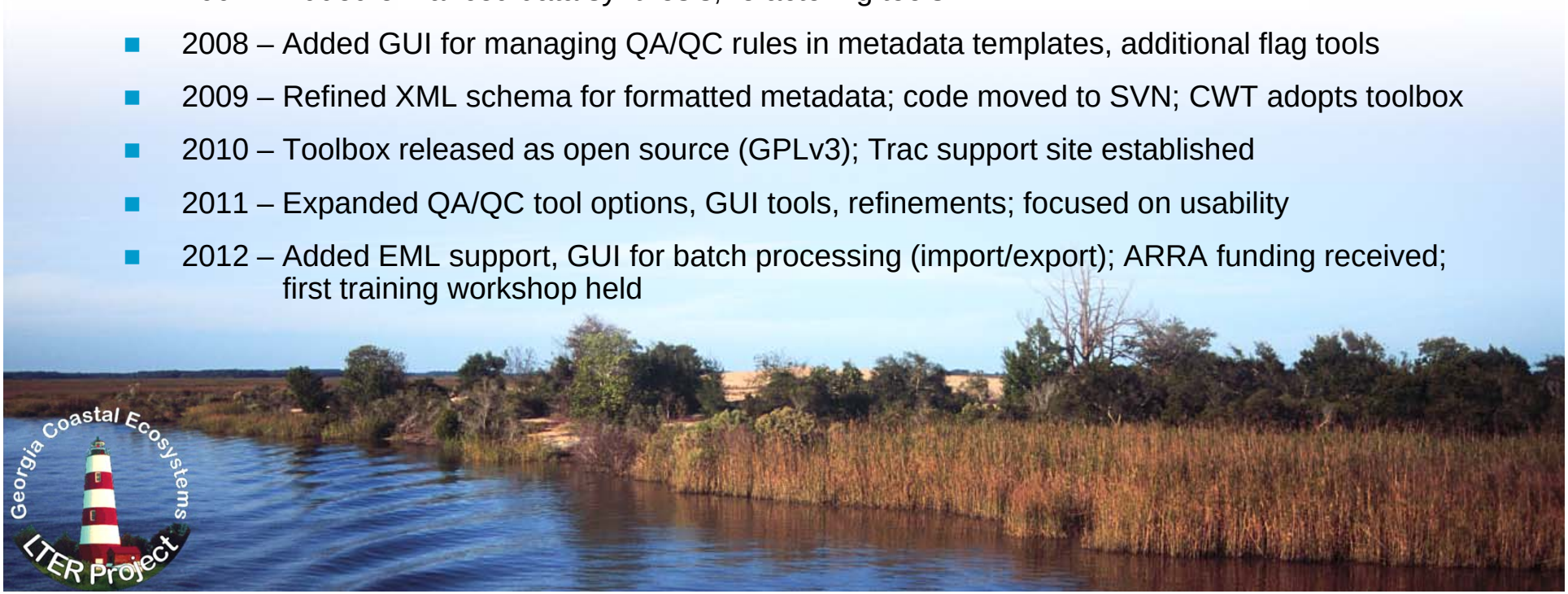
# Toolbox Code & Support

- Trac support web site: https://gce-svn.marsci.uga.edu/trac/GCE_Toolbox
- SVN address: https://gce-svn.marsci.uga.edu/svn/GCE_Toolbox/trunk *(login required)*



# Toolbox Timeline

- 2001 – Initial toolbox development completed in May 2001, Metabase MMS online Sep 2001
- 2002 – Added basic GUI interface, released code to GCE affiliates
- 2003 – Added dynamic data harvesting support (USGS, NOAA, CSI LoggerNet); automated USGS harvesting service for ClimDB/HydroDB
- 2004 – Added "search engine" tool for local search/integration of data
- 2005 – First public distribution of "compiled" code; source code on request to LTER sites
- 2006 – Added ClimDB data mining GUI
- 2007 – Added enhanced data synthesis, refactoring tools
- 2008 – Added GUI for managing QA/QC rules in metadata templates, additional flag tools
- 2009 – Refined XML schema for formatted metadata; code moved to SVN; CWT adopts toolbox
- 2010 – Toolbox released as open source (GPLv3); Trac support site established
- 2011 – Expanded QA/QC tool options, GUI tools, refinements; focused on usability
- 2012 – Added EML support, GUI for batch processing (import/export); ARRA funding received; first training workshop held

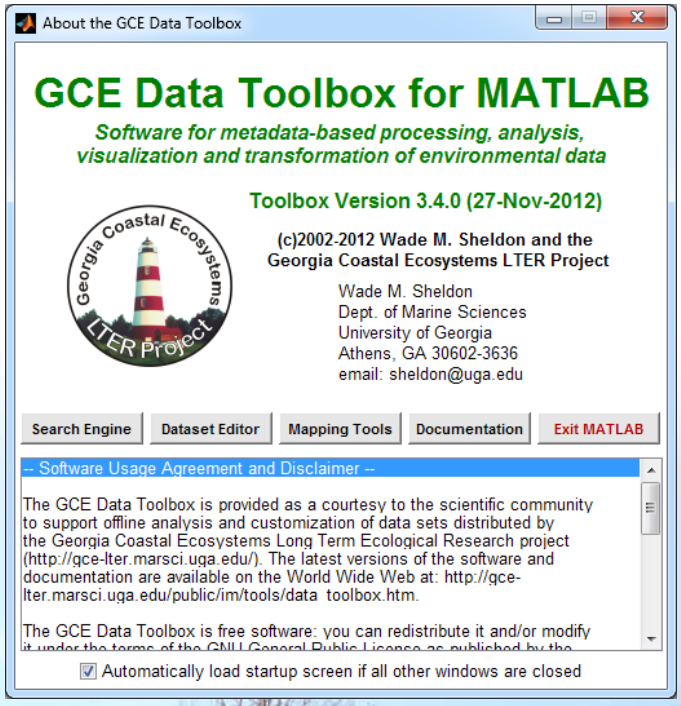


# What's Next?

- Shameless plug: help us decide!
- Metadata model enhancements
  - Add "schema" support for better EML, Metabase alignment
  - Add EML export, enhance EML import
  - Better Metabase integration (fully bidirectional push/pull)
- Improve harvest management
  - Add GUI tools for configuring harvest info, plot info
  - Add GUI for managing timers
  - Add data harvesting "dashboard" for monitoring activity
- Improve documentation and training materials

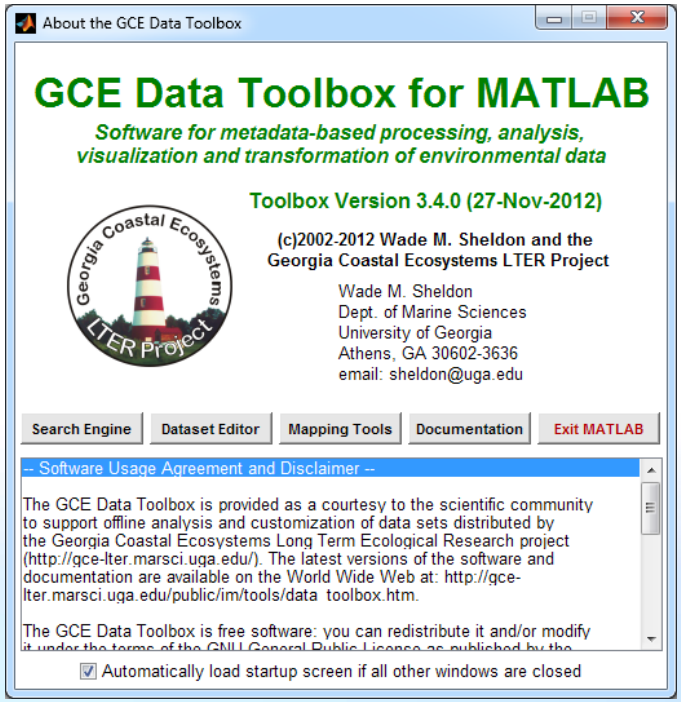
# Interactive Training – Day 1

- Installing and starting the GCE Data Toolbox
- Introduction to the Data Set Editor application
- Importing and exploring data
  - Generic ASCII
  - Specialized logger formats
- Metadata management
  - Defining attribute metadata
  - Documentation metadata
  - Metadata templates
- QA/QC framework
  - Defining flags
  - Creating “rules”
  - Visual QA/QC
  - Copying and locking/unlocking flags
- Creating and exporting products
  - Batch processing raw data
  - Integrating data (join, merge)
  - Exporting



# Interactive Training – Day 2

- Automating data processing
  - Intro to command line API
  - Scripted workflows
  - Data harvesting support
  - Harvest timers
- Working with your own data
  - Choosing an import filter
  - Defining metadata, templates
  - Post-processing, analysis
  - Harvesting scenarios
  - ...



# Interactive Training – Day 3

- Metabase MMS & GCE Toolbox
  - Intro to the Metabase MMS
  - Services and applications
  - EML & NIS support
  - Metabase-Toolbox integration
  - Future plans
- Open discussion
  - Training feedback
  - Next steps
  - “Missing links”
  - ...