

# Open Source Tools for Coastal Dynamics Monitoring

Alexey Noskov

Heidelberg University, Im Neuenheimer Feld 348, Heidelberg, Germany;

## ABSTRACT

Coastal dynamics monitoring is an actual topic today. Hundreds of solutions are available. Advanced technologies (e.g., automatic terrestrial laser scanning) are applied for developed areas. At the same time, old-school approaches are still applicable, especially for distant coastal zones. More accessible methods including the use of total stations (instead of LIDAR scanners) or even regular theodolites and meteorological data based approaches for coastal dynamics modeling remains popular in research of distant Arctic areas. In this works, Open Source tools implemented for such research activities are described.

The first tool implements Popov-Sovershaev wave-wind energy calculation method. The second tool was designed for calculation, integration and visualization of shoreline profiles usually measured by a total station. The tool supports polar and Cartesian coordinate systems. Points can be projected onto either trend line or user defined line. The tool enables to compare different profiles and illustrate dynamics of coastal segments. The mentioned tools are integrated by an extendable application framework. Currently, it supports the two mentioned main tools and several service tools including programming console, map viewer and SQLite database management widget. Tools are integrated by the Tcl/Tk programming language allowing users to deploy light weight extremely portable application with graphic user interface.

Two more tools suitable to smaller scale research will be available soon. First, a tool for multi-temporal aerospace imagery visualization/interpretation is developed. Second, a tool for bathymetry data interpolation and visualization is developed to help researchers converting scanned bathymetric charts to elevation models.

**Keywords:** data visualization, coastal dynamics, shoreline profiles, free open source software

## 1. INTRODUCTION

Today, Arctic is an intensively developed region. Arctic coasts are very active in term of dynamics. The permafrost and sea ice make processes extremely active and unpredictable. Thus, careful systematic monitoring of coastal dynamics is required. Arctic is hardly accessible, hence, conventional approaches to coastal dynamics monitoring are inapplicable in many cases.

From the early 1980s, a network of coastal dynamics monitoring has been deployed in a number of key sites of Barents and Kara sea. The network is still supported and developed. The network allows obtaining concrete field coastal dynamics monitoring data.

In the frame of this work, open source tools for the monitoring network are developed. A tool for shoreline profile calculation allows processing of field data obtained mainly from total stations. The tool enables to compare profiles obtained in various years. This provides worth concrete data for coastal dynamics monitoring. Another tool is developed for wind-wave energy computation. It allows modeling of coastal dynamics monitoring and even preparing forecasts for tens of years.

The rest of the article is organized as follows. Section 2 provides background work. Section 3 introduces a common programming environment. The tool for shoreline profiles calculation is described in Section 4. The tool for wind-wave energy calculation is discussed in 5. Section 6 concludes the article.

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Further author information: (Send correspondence to Alexey Noskov)  
Alexey Noskov: E-mail: a@n-kov.com, Telephone:+49 6221 54-5506, a.n-kov.com

## 2. BACKGROUND

Geomorphological coastal zone research often utilize shoreline profiles.<sup>1</sup> Shoreline profiles can be easily obtained by relatively low-cost methods. It is popular to use such profiles for monitoring and modeling of coastal dynamics.

Complex morpholithodynamics monitoring was implemented in several key sites of Russian Arctic.<sup>2</sup> Morpho and lithodynamics research of the coasts and seabed of Gulf of Ob and Baydaratskaya Bay of Kara Sea and Varandey (Pechora Sea of Barents Sea) has been conducted. Results has been obtained by the working group on the basis of long term monitoring at the gas pipeline crossing design. Reliable values of coastal erosion and deformations of the coastal zone cross profile have been achieved.

In another work,<sup>3</sup> a methodology of coastal dynamics monitoring has been described. According to the article, the significant part of coastal investigations is carried out using total station. First, scheduled coordinates and heights of reference points of a network are defined. The received values are compared with last year's ones to control the changes in position of the profiles. The following stage of the work is construction of profiles by a method of trigonometric leveling.

A network for coastal dynamics monitoring covering several key sites in Russian Arctic (Barents and Kara seas) is supported from early 1980s.<sup>4</sup> Obtained data allow estimating the scale of morpholithodynamic processes. It is established that the most considerable factors for dynamics of coasts in the considered areas are cryogenic-lithological composition of coastal bluff sediments and wind-wave regime (probability of extreme storm surges, exceeding beach levels in its rear part along the whole coastline). Among them, the wind-wave factor plays an active role in coastal dynamics. When, the cryogenic-lithological composition of coastal bluff is a passive factor; it is activated by the former one (vise-versa is inapplicable). Average long-term rate of coastal erosion in the key sites is from 0.2 to 2.8 m per year on different parts of the coast.

The wind-wave factor of coastal dynamics can be modeled. Hence, a correct wind-wave model enriched by multi-temporal field data enables to prepare quite accurate coastal dynamics forecasts applicable for tens of years. Such method has been introduced by Popov and Sovershaev in Russian.<sup>5</sup> In 2001, Ogorodov proposed a refined and translated to English version of the method.<sup>6</sup> An application of the Popov-Sovershaev method was described for a storm surges use-case.<sup>7</sup>

According to Ogorodov et al., the main advantage of this method is the fact that it is cheaper than field observations. Another advantage is the possibility to determine parameters of sediment fluxes and evolution of the coastal zone for several years, that is usually impossible to do during one field season. An essential fault of the method is approximate and sometimes questionable results because of insufficiently developed theory of lithodynamic processes. Two equations are applied separately for deep and shallow water. In contrast to deep water, for shallow water cases, the H parameter representing length of wave "acceleration" is utilized.

The following source data are required to implement the method: wind data (usually delivered with standard meteorological data), sea ice data for cold seas and digital elevation model (DEM) of sea bottom (or bathymetry data).

## 3. IGIS.TK AS A COMMON ENVIRONMENT FOR COASTAL DYNAMICS MONITORING TOOLS

Integrated Geographic Information System Tool Kit (IGIS.TK)<sup>8</sup> is designed as programming environment and end-user oriented application for the coastal dynamics monitoring open source tools. The web site of the application is managed by the Fossil version control system.<sup>9</sup> Anyone can contribute to the project.

Tcl/Tk programming language<sup>10</sup> has been selected as a main programming language. The rationale for such decision is as follows. First, Tcl offers meta-programming facilities, i.e., programming code itself can be considered as data, and vice versa. It allows the developer to decrease the programming code and provide tricky solutions for programming tasks. As a result, Tcl is not sticked to any programming paradigm. In other words, it can be applied for writing programs in either procedural structural or procedural object-oriented manner. By default, users can write simple procedural applications; using functions (procedures) allows structural programming. TclOO is a standard package offers simple object-oriented Python-like engine. [Incr Tcl] is an extension which provides C++ like object-oriented option. In Tcl, all data types are represented as strings.

This makes the development extremely flexible and reduces amount of code. Tk is a library, which offers light-weight widgets for graphic user interface (GUI) programming. Most of the Python distribution contains a minimal Tcl/Tk environment, which enables GUI development offered by TKInter. Tcl/Tk is a cross-platform environment available for all major operational systems including Android (through AndroWish,<sup>11</sup> which allows to run desktop Tcl and Tk programs almost unaltered on the Android platform). Moreover, Tcl is usually described as "glue" programming language. It makes possible to bunch solutions written in various programming languages. Tcl offers libraries and facilities to access functions and objects written in Unix Sh/Bash, Python, C/C++, Java, Fortran, R etc. Hence, it is easy to write GUI applications for integration various programs written in different programming languages. From the above mentioned facts, one may conclude that Tcl/Tk is the suitable environment for the considered work.

For further development, a common environment for integrating the developing tools is required. It has been decided to use eZdit<sup>12</sup> application as such environment. eZdit is a cross-platform editor written in Tcl/Tk. eZdit runs on Mac, Linux and Microsoft Windows (prospectively, it can be run on Android as well). Features include syntax highlighting, auto-completion, code browsing, auto-indentation, etc. It also support plugins which extend the editor's functionality. eZdit is a light-weight application; it has a nice appearance and provides very flexible layout. The editor contains TKCon (Tcl GUI console for interactive programming). Tcl/Tk environment and eZdit are used for an implementation of the common environment for the developing tools.

IGIS.TK can be downloaded as a source code archive (in \*.zip or \*.tar.gz) or by cloning the whole project (fossil clone). The main application of IGIS.TK is delivered by a file `u/tk/main.tk`. It runs main GUI environment. In general, it is slightly modified eZdit editor. According to Google Code, the editor was under intensive development in period from December 2009 to December 2011. The latest version (0.9.3) was released 29th of December 2011; further development was discontinued. Despite this, the source code is mature, bug-free and very readable. It allows using eZdit as a framework for IGIS.TK GUI.

The command `File→Eval IGIS file` is provided by GUI; it evaluates Tcl files in the frame of IGIS.TK GUI and opens a next tab for evaluating scripts. The prepared user interface is utilized as editor of source code for interactive processing and as a container for executing tools prepared for IGIS.TK.

In order to test the solution, the two following common widget were implemented: map and database management widgets. The map widget (file `u/tk/osm.igis.tcl`) is based on `osm.tcl`,<sup>13</sup> which is a small GUI application (730 lines of code). The application was slightly modified to make it suitable for evaluation in the frame of IGIS.TK. The database management widget (file `u/tk/tksqlite.igis.tcl`) is based on `tksqlite.tcl`,<sup>14</sup> which is much bigger application (14800 lines of code). Despite this, it was quite easy to adopt the application for the framework. In order to modify the existing GUI application to make it suitable for IGIS.TK, a frame elements of the GUI framework is used instead of root GUI element. Screenshots demonstrated the developed graphic environment and the implemented widgets are provided by Fig.1.

In this article, version 0.0.2 Prototype of IGIS.TK is considered. The current version is described as "prototype", because many implemented features are still sticked to the conducted project.

#### 4. SHORELINE PROFILES CALCULATION

In Section 2, it was mentioned that calculating shoreline profiles and wind-wave energy are two key processes in the considered approaches to coastal dynamics monitoring. In this section, a tool for shoreline profile calculation is considered. The tool is resided in the following file of IGIS.TK: `e/coasts/profiles.igis.tcl`.

`profiles.igis.tcl` allows users to process row data from a total station or even old-school mechanical theodolite. Data can be presented in either angles or Cartesian coordinates. This enables to apply the tool for various data sources, e.g., echo-sounder data.

In Fig. 2, the working process is demonstrated. In the upper side of the frame, a user should define source data file and path to result files. By default, CSV text data format is used. This format is common for table data and supported by many applications (e.g., LibreOffice Calc, Microsoft Excel, QGIS, ArcMap, ect.). In order to demonstrate the prepared tool, data obtained for two profiles shot on the Varandey (Pechora Sea) key site; source data are resided in the `e/coasts/profile_sample_data.csv` file. Data were exported directly from a

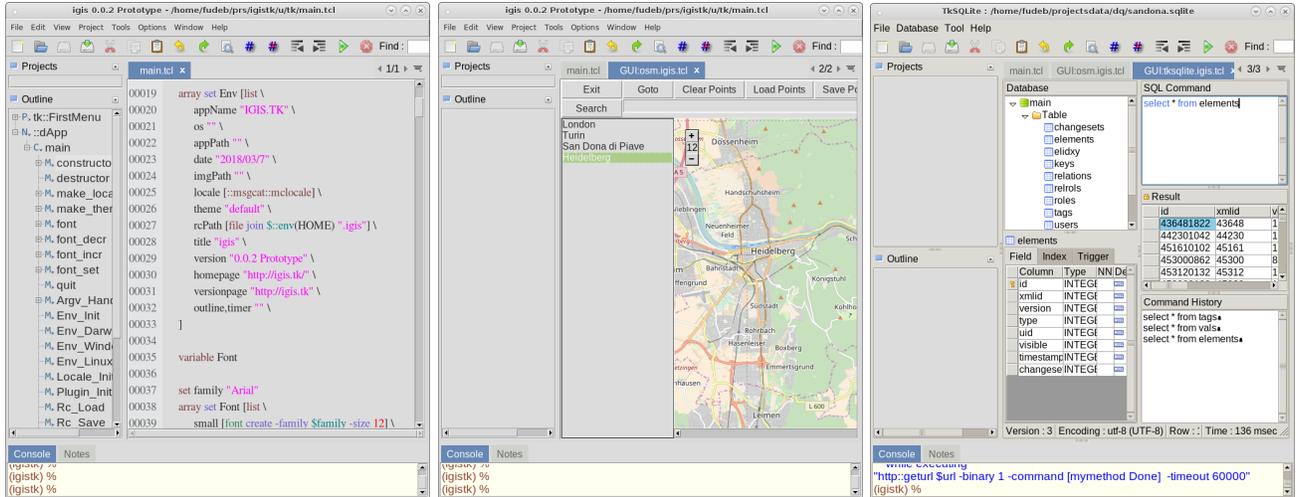


Figure 1. User Interface of IGIS.TK. From left to right: editor mode, map and database widgets

total station in a raw CSV format. Each point is represented by distance to a landmark, vertical and horizontal angles in decimal degrees.

Further in this section, a workflow for profiles calculation is presented. Decimal degrees are converted to radian. Cartesian coordinates are calculated according the following trivial equations.

$$\begin{aligned}
 D &= d \cdot \sin(v) \\
 h &= d \cdot \cos(v) - h_s + h_l \\
 x &= d \cdot \cos(h) \\
 y &= d \cdot \sin(h)
 \end{aligned}$$

In order to draw profile correctly, each point needs to be projected to a line. A line can be set by a user or defined automatically. By default points are projected to a trend line. A trend line is calculated according to the linear regression function. The a and b parameters required for line specification are defined according to the following equations:

$$\begin{aligned}
 SumX &= \sum_0^{num} x \\
 SumY &= \sum_0^{num} y \\
 xm &= SumX/num \\
 ym &= SumY/num \\
 SX &= \sum_{i=0}^{num} SumX + (x - xm) \cdot (y - ym) \\
 SY &= \sum_{i=0}^{num} SumY + (x - xm)^2 \\
 b &= SX/SY
 \end{aligned}$$

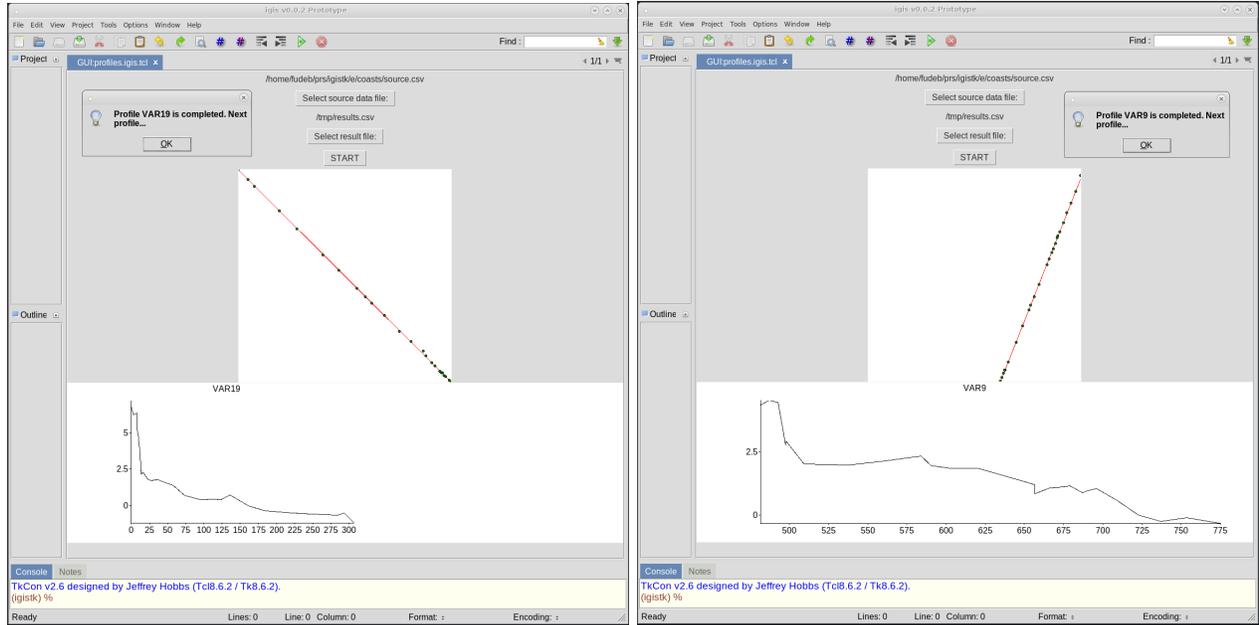


Figure 2. IGIS.TK evaluates e/coasts/profiles.igis.tcl

$$a = ym - b \cdot xm$$

Each point is projected to a defined line, i.e., an intersection of a trend line and a perpendicular line constructing from a considering point is defined. A threshold for the distance from a point to a trending line can be specified. By default it equals to 5 meters (i.e., points with distances from a trend line farther then 5 meters are not considered). In Fig. 2, results of calculation are presented in two graphs. The first upper graph shows 2D map visualizing a trend line and points. The second lower graph represents a profile.

## 5. COMPUTATION OF WIND-WAVE ENERGY

The wind-wave energy calculation is implemented in e/coasts/windenergy\_np.sh. The code is written mainly in Bash, some parts are written in Python. The implementation is specific for Novy Port settlement (Gulf of Ob, Kara Sea). Some parameters are hard coded. Thus, current implementation cannot be applied for other key sites. Sample data are delivered by e/coasts/meteodata\_novyport\_2011\_rp5ru.csv. A work in progress towards universal implementation of wind-wave energy computation is presented in the e/coasts/windenergycalc.sh file. Prospectively, the tools should be reimplemented in C programming language, the current version is a prototype.

Four input parameters have to be specified for calculation:  $w$  (speed of wind, in m/s),  $dur$  (duration of wind with considered speed),  $d$  (average depth of see, in meters) and  $h$  (length of wave "acceleration", in km). The wind-wave energy is calculated according to the following equations.

$$v_2 = w^2$$

$$v_3 = w^3$$

$$v_5 = w^2$$

$$x_h = d/h$$

$$hv_2 = h/v_2$$

$$fhv_2 = 2 \cdot 10^{-5} \cdot (10 \cdot hv_2)^2$$

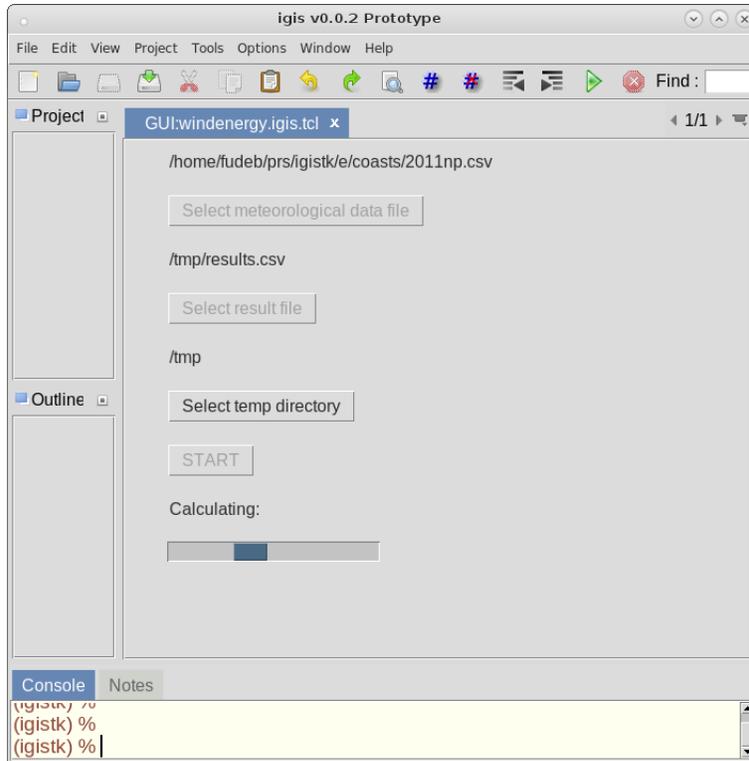


Figure 3. Wind-Wave energy calculation tool. Frontend.

$$We_{sw} = v_5 \cdot fhv_2 \cdot dur$$

$$We_{dw} = 3 \cdot 10^{-6} \cdot d \cdot v_3 \cdot dur$$

Where,  $We_{sw}$  is wave energy for deep water ( $x_h$  less then 9 meters);  $We_{dw}$  is wave energy for shallow water ( $x_h$  more then 9 meters). Wind energy is summarized according to rhumbs. The approach was described in detail by Ogorodov in 2001.<sup>6</sup>

GUI for the described tool is implemented in Tcl. It is provided by the `e/coasts/windenergy.igis.tcl` file. In Fig. 3, the tool's fronted is illustrated.

Three input parameters can be specified, an input file with meteorological data, path to result file and temp directory for storing some intermediate working files. Currently, the tool is configured to use meteorological data provided by the RP5.RU web site. The site allows obtaining archive data.

Progress bar is appeared during the execution. The current implementation is quite slow. Hence, the algorithm should be improved and the tool needs to be reimplemented in high-performance way (e.g., using C programming language).

## 6. CONCLUSIONS AND FUTURE WORK

IGIS.TK, the environment for spatial data processing tools, has been introduced. The environment allows users to easily implement their tools with simple GUI. It can be utilized either as an environment for programming code writing and evaluation or as a container for deployment and shipping of programming products. IGIS.TK has been originally developed for data conversion, quality assessment, data fusion and generalization. As was shown in this article, the environment can be easily utilized for other tasks.

Tools for calculating shoreline profiles and wave-wind energy implemented several years ago were integrated with IGIS.TK. Now, they are delivered as extensions of the environment. Included sample data allows users to verify the developed tools.

Currently, IGIS.TK and the developed tools for coastal dynamics monitoring are at the prototype level. IGIS.TK evaluates tools in the global scope. It leads to conflicts of tools. Further, tools should be evaluated in a separate interpreter. Moreover, a specification is required for writing tools with GUI.

As IGIS.TK, the tools for coastal dynamics monitoring are at the prototype level. Hard coded parameters have to be eliminated from the source code. In general, the tool for profile calculation can be applied for any data. GUI has to be implemented in a responsive stretched manner to be suitable for various screens. In order to improve performance and widen the usability, the tool for wind-wave energy calculation has to be reimplemented.

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