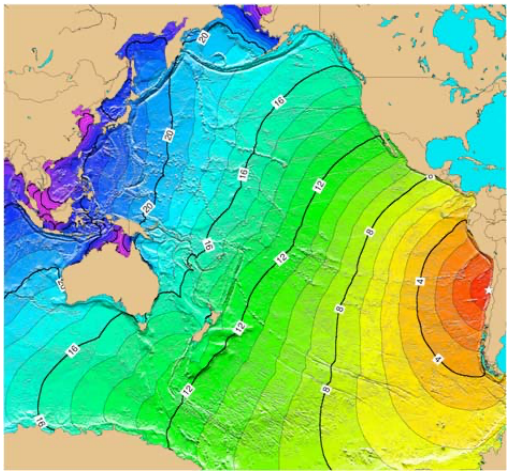
Tsunami Travel Time (TTT) Software Package
Version TTT SDK 4.0.1, Aug 2023

TTT_README.DOC

NOAA's National Centers for Environmental Research (NCEI, formerly National Geophysical Data Center), as the World Data Service for Geophysics (WDS-Geophysics), and the International Tsunami Information Center (ITIC), a NOAA-UNESCO/IOC Partnership, are collaborating to provide, free of charge, tsunami travel time calculation and display software to government organizations involved in providing tsunami warning and mitigation services. Other interested organizations and individuals are requested to obtain the software directly from the developer Geoware.

The Tsunami Travel Time software (TTT SDK v 4.0.1) was developed by Dr. Paul Wessel (Geoware, http://www.geoware-online.com), and is used by the NOAA Pacific Tsunami Warning Center. ITIC has purchased the TTT license to permit widespread free distribution. The public domain mapping software Generic Mapping Tools (GMT) was developed by Drs. Paul Wessel and Walter Smith (https://www.generic-mapping-tools.org/). For this PC-environment distribution, the ITIC and NCEI are also providing easy-to-use, sample scripts for running the software and producing maps such as shown to the right.



The software included in this distribution is for systems using a Microsoft Windows XP, Vista and 7/10 operating system. The software code available is not platform-specific, so ITIC/NCEI is able to provide other distributions, such as for Linux, Unix or Mac OSX, upon request.

Components included on this CD

1. TTT (Tsunami Travel Time) software, TTT SDK version 4.0.1. Copyright Paul Wessel, Geoware, 2018. http://www.geoware-online.com. Licensed to NOAA/ITIC for redistribution**.**
2. Global bathymetry grids derived from NCEI's ETOPO1 at varying resolutions (60, 30, 20, 15, 10, 5, 2 and 1 arc-minute, and 30 arc-sec grids) for the Pacific, Atlantic, and Indian Oceans.
3. Easy-to-use scripts for automatically calculating and making travel time maps.
4. Historical Earthquake and sea level station data sets. Historical Tsunamis TTT maps.
5. Hands-on exercises to illustrate how to make Indian Ocean, South China Sea, Pacific, and Caribbean region tsunami travel times maps.
6. GMT (Generic Mapping Tools), version 4.3.1. Released under the GNU General Public License (GPL). https://www.generic-mapping-tools.org/
7. Ghostscript, version 9.52. Released under the Aladdin Free Public License (AFPL). http://www.cs.wisc.edu/~ghost/
8. ImageMagick, version 7.1.1. Distributed under the Apache 2.0 license. http://www.imagemagick.org/script/license.php

For questions, please email Laura Kong (Laura.Kong@noaa.gov) at ITIC or Nicolas Arcos (nicolas.arcos@noaa.gov) at NCEI.

Technical Background

Background information on the calculation of tsunami travel times is provided in *TTTSDK4.0.1_Docs.pdf* (in C:\TTT Package\Software\TTT\doc), *Annex V: Methods for Tsunami Travel Time Calculation used by PTWC, WC/ATWC, and JMA* of the PTWS Operational Users Guide (draft, December 2007, and *Analysis of Observed and Predicted Tsunami Travel Times for the Pacific and Indian Oceans* (Wessel, 2009) in C:\TTT Package\TTT_GMT_otherdocs). Accuracy is most dependent on the accuracy of the bathymetry file used for the calculations, e.g., the finer grid size of the bathymetric file, the more accurate the estimate - at the same time, however, computation time increases significantly as finer grid size bathymetric files are used (e.g., calculation using 2-min (distance, ~2 mile grid interval) bathymetry grid takes 10 minutes (time) or more to complete). Inadequate characterization of the tsunami source (epicenter point source vs. finite fault rupture length) can also result in significant differences between the predicted and observed times. Together, these errors can cause large delays (up to hours).

TTTSDK4.0.1 upgrades from TTTSDK4.0 by updating all 9 bathymetry grids using latest global grid sources.

Installation Instructions

If you have an older version of the TTT Software package, please uninstall first. This can be done through the Control Panel ->Add/Remove Programs.

It may be required to run the installer as a user with administrative privileges. Run Setup_TTT_vx.x_xxbit_YYYYMMDD.exe to install the TTT software, examples, GMT, Ghostscript and ImageMagick. All required software, except Ghostscript and ImageMagick, will be installed in the directory specified (i.e. 'C:\TTT Package'). If you already have Ghostscript or ImageMagick installed, you may choose not to install these packages at this time. The installer will ask if you would like to install Ghostscript, and will then launch a separate installer for Ghostscript (loaded in C:\Program Files\gs). Then it will ask to install ImageMagick, and will then launch a separate installer for ImageMagick (loaded in C:\Program Files\ImageMagick-versionNumber.

Computer Requirements

The software included in this distribution is for systems using a Microsoft Windows XP, Vista, 7 & 10 operating system. The software code available is not platform-specific, so NGDC/ ITIC is able to provide other distributions, such as for Linux, Unix or Mac OSX, upon request.

The recommended computer specifications/requirements are:

- PC running Windows (XP/Vista/7/10)
- At least 256 MB of RAM
- At least 900 MB of hard disk space
- No CPU speed requirements, but the software will run faster on faster CPUs.

Directory Structure for Software Usage

Files to be used for TTT calculation and plotting can be found in the following directories.

```
Directory:  C:\TTT Package\Software\TTT\bin

TTT calculation:  ttt_clientXX.exe
TTT mapmaking (using GMT):
      Fixed region:    ttt_fancy_atl/ind/pac/world.bat
      User-specified:  ttt_fancy.bat
Examples using above scripts:
C:\TTT Package\Examples\EXAMPLE_CARIBBEAN or IO_SCS/MAKRAN/PACIFIC
```

Main Scripts for ttt_calcXX
ttt_autoXX.bat
ttt_fancy_atl/ind/pac_auto.bat

Output files from running ttt_calcXX.exe will be placed in sub-directory:
C:\TTT Package\Examples\TTT_AUTO_xxxxxx,
where xxxxxx equals computer clock HRMNSC

Data files:
Historical earthquakes (USGS Centennial List):
   GMT-plot format: centennial6_ed.txt
   Reference files: centennial6.txt, centennial.xyzm
Sea level stations (as received by PTWC):
   Data files: stations.txt, stations_tidetool.txt (Feb 2022)
   Maps: PTWC_AtlanticMediterranean/Caribbean/IndianOcean/Pacific
                _SL_Stations_YYYYMMDD.pdf (Feb 2022)
Color pallets (as read by scripts): CPT\ttt1-30.cpt, centennial.cpt

Software Usage Instructions

The software included is to be run from the Windows command line, or by double-clicking on a .bat script in order to open a Window command window for running the software. Easy-to-use software (executable and scripts) for calculating travel times and making travel time maps are included in this distribution, and described in this section and the next (Easy TTT calculation and plotting). The executable ttt_client.exe and the plotting scripts are located in C:\TTT Package\Software\TTT\bin.

Examples and hands-on exercises which utilize ttt_client.exe (calculation) and ttt_fancy (plotting) can be found in the Examples section of this document and in C:\TTT Package\Examples (for Caribbean, Indian Ocean, Pacific, South China Sea).

Producing TTT plots is a 2-stage process. First, the TTT program is executed to calculate the tsunami travel times over the specified map boundaries (e.g., create a grid file of tsunami travel times). Second, the GMT software is used to make a postscript plot of the travel times, and to create raster images (such as in jpg or png formats). The GMT software is a general plotting software that can be customized to produce many types of plots. Further information and documentation on GMT can be found in C:\TTT Package\TTT_GMT_otherdocs\GMT_Manuals

1. The TTT program (ttt_client.exe) is executed to calculate the tsunami travel time to each point on a grid. This calculation is made using input files giving 1) the earthquake epicenter (or a series of point locations representing a long fault rupture) 2) the water depth, which is extracted from the bathymetric file. TTT is run with the following command (text in square brackets, i.e. [ ], should be replaced with the appropriate file name):

   ttt_client [bathymetry grid filename] -e[epicenter filename] -T[travel-time grid filename] -VL
   The travel-time grid is the output file. The bathymetric grid name is given without the .i2 extension, all other filenames should be given with the file extensions.

   Information on ttt_client.exe
   ttt_client is a command-line program that generates tsunami travel time grids (in GMT grdfile or GeoTIFF format) given an input bathymetry grid and a source location. It can also be used to report the travel times to a list of stations given an existing travel-time grid as input.

Usage:
ttt_client <input_bathymetry_file> [-A<stations_file>] [-R(w/e/s/n)]
[-E<lon/lat> or -e<file>] [-I] [-N<nodes>] [-O|o<yyyy/mm/dd/hh/mi/ss>]
[S[<radius>][/<depth>]] [-T<output_ttt_file>] [-G<output_geotiff_file>] [-V[L]] [-U]

ttt_client attempts to decode <input_bathymetry_file> using the following order:
1. If filename ends in ".b" it is read as bathymetry data [GMT binary float format].
2. If $TTT_DIR/<input_bathymetry_file>.i2 exists it will be used as bathymetry data [GMT binary short format].

OPTIONS:
-A Gives filename with multiple stations to which we will estimate the Estimated Tsunami Arrival time (ETA) if option –O is given ("tsunami origin time"). If –O is not given, ETA will output the tsunami travel time.
-b Do NOT normalize the travel times to avoid bias [Default will correct for bias]
-E Sets the location of the epicenter using the format <lon/lat>
-e Gives filename with multiple "epicenters" to mimic a non-point source.
-I Store travel times as 2 byte integers with units of 10 sec [Default is 4-byte float in hours]
-N Number of Huygens nodes to use (8, 16, 32, 48, 64) [64]
-O Sets "tsunami origin time" (UTC), which is assumed to be the earthquake origin time in the simplest case. Use lower case -o if local time is used
Note: this calculation will only work correctly for the years 1970 to 2038.
-R Specify a sub-region of the grid [Use entire grid].
-S Substitute nearest ocean node if epicenter is on land. Optionally, append search radius in degrees [5]. Furthermore, you may append the shallowest depth you want to place epicenter [0].
-T Names the output grdfile with travel times in hrs [ttt.b or ttt.i2 (see -I)].
-U Use UTC time when reporting ETAs (requires -A).
-V Run in verbose mode. Append L to get progress messages from within the tttAPI library.

2. The output is then plotted using GMT (Generic Mapping Tools), which is a general command line controlled graphics tool. To simplify the plotting stage, basic batch script files are provided. These are four hardwired scripts for plotting the individual and world oceans (ttt_fancy_atl.bat, ttt_fancy_ind,bat, ttt_fancy_pac.bat), and one interactive script (ttt_fancy.bat) to plot any desired region and to specify contour plotting interval and other simple customization. However, plots are entirely customizable if GMT is learned.

All the scripts have a similar run command format, e.g.,

ttt_fancy [travel-time grid filename] [bathymetry grid filename] [epicenter filename] [ps filename]

ttt_fancy_atl/ind/pac [travel-time grid filename] [bathymetry grid filename] [epicenter filename] [ps filename]

GMT batch script files:
ttt_fancy_atl.bat, ttt_fancy_ind.bat, ttt_fancy_pac.bat, ttt_fancy_world.bat, ttt_fancy.bat

Each of these batch files, run from the Windows command line, runs a series of GMT commands to generate colored contour maps (with shaded-relief bathymetry) of tsunami travel time grids generated by ttt_client.exe. Each batch file is customized for each ocean (Pacific, Indian, Atlantic/Caribbean), or can be interactively specified (ttt_fancy.bat).

ttt_fancy_atl/ind/pac.bat creates output files under the current directory.
ttt_fancy creates output files under a subdirectory (TTT_FANCY_timestamp) under C:\TTT Package\Examples, where timestamp is the current computer clock time (hr min sec).

With knowledge of GMT commands (documentation at https://www.generic-mapping-tools.org/, and also in C:\TTT Package\TTT_GMT_otherdocs), these files can be modified to create other desired output. By default, a Postscript document and PNG image files are created, but other formats (.jpg, tif, etc) are available.

Usage:
ttt_fancy_atl <input_tttgrid> <input_bathygrid> <input_epicenter_file> <output_psfile>
ttt_fancy_ind <input_tttgrid> <input_bathygrid> <input_epicenter_file> <output_psfile>
ttt_fancy_pac <input_tttgrid> <input_bathygrid> <input_epicenter_file> <output_psfile>
ttt_fancy <input_tttgrid> <input_bathygrid> <input_epicenter_file> <output_psfile>

Easy TTT calculation and plotting

To provide for easier calculation and map-making, a user-friendly GUI named ttt_calc32.exe and ttt_calc64.exe (referred to as ttt_calcXX.exe) is provided which simplifies and automates the process. ttt_calcXX.exe uses the **ttt_autoXX.bat** scripts (Windows). **ttt_calcXX.exe** and its associated scripts creates a travel time data file and two maps (ocean-wide and zoomed-in) using user-input information on the tsunami source location (latitude and longitude), magnitude (assumed to be from an earthquake), bathymetry file grid size, source origin time, and map region. To run quickly, 15-arc min bathymetry is recommended; for greater accuracy, a finer resolution bathymetric grid should be used.

ttt_calcXX.exe runs specific regional ttt_fancy scripts (**ttt_fancy_atl/ind/pac_auto.bat**) to make the maps, Output files are created under C:\TTT Package\Examples\TTT_AUTO_xxxxxx), where is xxxxxx is the computer clock time (hr, min, sec) at the time the script is run.

Instructions for using ttt_caclXX.exe and information on parameters that can be changed to customize plots are included in the file C:\TTT Package\TTT_calc_ttt_auto_README_feb22.pdf

Troubleshooting: Required environment variables

If the software does not work correctly, please check that these environment variables are properly set:
TTT_DIR should be set to the TTT data directory
(i.e. C:\TTT Package\Software\TTT\share\data)
GMTHOME should be set to the GMT home directory
(i.e. C:\\TTT Package\Software\GMT)
GMT_SHAREDIR should be set to the GMT share directory
(i.e. C:\TTT Package\Software\GMT\share)

The system PATH should contain:

- the TTT bin directory (i.e. C:\TTT Package\Software\TTT\bin)
- the GMT bin directory (i.e. C:\TTT Package\Software\GMT\bin)
- the Ghostscript bin directory (i.e. C:\Program Files\gs\gs9.52\bin)

These variables can be modified by opening the Control Panel, clicking on System and Security, clicking on System, clicking on Advanced system settings, then clicking on Environment Variables, and editing the PATH.

Examples

Software Usage Examples (provided by NCEI)

The software is to be run from the Windows command line, or by double-clicking on a .bat script in order to open a Window command window for running the script containing the software.

You can run these examples from the "bin" directory (i.e. C:\TTT Package\Software\TTT\bin). Or, if using another directory, please copy the files 'epicenter_1960.txt', 'epicenters_2004.txt', and 'epicenter_1964.txt', and 'stations_pacific_ocean.txt' in "bin" to this new directory and run the scripts from there. In C:\TTT Package\TTT_Maps, you can also find some example TTT maps for historical events.

- Generate a new global travel-time grid with the 1960 Chile earthquake as the source, using 5' bathymetry, and report the travel times to multiple stations listed in 'stations_pacific_ocean.txt':

  ```
  ttt_client ttt_topo_5m -eepicenter_1960.txt -Tttt_chile_1960_5m.b -Astations_pacific_ocean.txt
  -VL
  ```

- Generate a colored contour map for the Pacific Ocean using the 'ttt_chile_1960_5m.b' global travel-time grid (this will create a Postscript file and a .PNG image as output):

  ```
  ttt_fancy_pac ttt_chile_1960_5m.b ttt_topo_5m epicenter_1960.txt ttt_chile_1960_5m.ps
  ```

- Generate a new global travel-time grid in GMT grid format ('ttt_2004_1226.b') for the 2004 Indian Ocean tsunami, approximating the earthquake rupture with a list of multiple epicenters, then generate a global contour map (Postscript and .PNG image format) of the travel times:

  ```
  ttt_client ttt_topo_5m -eepicenters_2004.txt -Tttt_2004_1226.b –VL
  ttt_fancy_world ttt_2004_1226.b ttt_topo_5m epicenters_2004.txt ttt_2004_1226.ps
  ```

- Generate a new travel-time grid ('ttt_alaska_1964.b') for the 1964 Alaska earthquake, automatically moving the epicenter to the nearest water node of at least 100 meters depth, then generate a colored contour map for the Pacific (Postscript and .PNG image format) of the travel times:

  ```
  ttt_client ttt_topo_5m -eepicenter_1964.txt -Tttt_alaska_1964.b -S5/-100 –VL
  ttt_fancy_pac ttt_alaska_1964.b ttt_topo_5m epicenter_1964.txt ttt_alaska_1964.ps
  ```

Converting Tsunami Travel Time grid output to GeoTIFF (for importing into GIS software)
This series of commands will convert a tsunami travel time grid in GMT binary grid format ('example_ttt.b') into a GeoTIFF that can be imported into most GIS software (i.e. ArcGIS). The free software package GDAL/FWTools is required for this conversion (available at http://fwtools.maptools.org/)

```
grdreformat example_ttt.b=bf example_ttt.grd=cs
gdal_translate –a_ullr -180 90 180 -90 –a_srs epsg:4326 example_ttt.grd example_ttt.tif
```

Software Usage Examples (provided by ITIC)
Plots for Tsunami Warning Operations

These files, located in C:\TTT Package\Software\TTT\bin and in C:\TTT Package\Examples, create commonly-used images to support tsunami warning operations. The "Hands-on exercise" examples have been used in trainings by the ITIC and so are accompanied by instructions for installing and running the scripts.

EASY TTT CALCULATION AND PLOTTING (PRE-SET OPTIONS) – see previous section:
ttt_calcXX.exe: easy and quick creation of travel time contour maps using user-specified arc-min bathymetry files
ttt_calcXX.exe quickly outputs a map, one or two zoomed-in maps and a file of tsunami travel or arrival times to user-selected locations. Inputs are the earthquake epicenter, magnitude, region for the contour maps, and a location file where travel times (or arrival times if the origin time is specificd) are tabulated. Output files are placed in a directory that is automatically created under the "Examples" subdirectory using the computer clock time for each run.
ttt_calcXX.exe calls **ttt_autoXX.bat, ttt_client.exe** and **ttt_fancy_atl/ind/pac_auto.bat,** and automatically creates pre-named output files. To run quickly, 15-arc min topography is recommended; for greater accuracy, especially for near-shore maps, a finer resolution bathymetric grid should be used but the travel time computation will take longer.
ttt_calcXX.exe can be run from any directory, but all data files that are plotted should reside in C:\TTT Package\Software\TTT\bin. In other words, if epicenters, stations, and/or historical earthquakes will be plotted, these files should exist in C:\TTT Package\Software\TTT\bin. Alternatively, **ttt_autoXX.bat** can be edited to include the full path of the data files.

For more detailed instructions for its usage, see *TTT_calc_ttt_auto_README_feb22.pdf*

GENERAL PLOTTING
ttt_fancy.bat: Allows user-specified boundaries and several customization options, including option to color shade only some ttt contour intervals.
ttt_fancy.bat requires 30 files (ttt1.cpt to ttt30.cpt) that are in the sub-directory "CPT" The .cpt files are color palettes that differ by the number of hours contoured in colors versus non-colored (white). If this script is run in another directory, the "CPT" directory and **ttt_fancy.bat** should be copied to that new directory, and the .bat file should be edited to designate the correct directory to use for the scripts and other input files.

HANDS-ON TUTORIALS
These handouts are hands-on exercises providing step-by-step instructions for creating travel time contour maps using the TTT and GMT softwares.
Scenarios are from the Caribbean, Pacific Ocean, Indian Ocean, and South China Sea (C:\TTT Package\Examples\EXAMPLE_CARIBBEAN or IO_SCS / MAKRAN / PACIFIC)