Gr1kmTM: Greenland 1 kilometer Tide Model

Summary

The Greenland 1 kilometer Tide Model (Gr1kmTM) is a barotropic ocean tide model on a 1 km x 1 km polar stereographic grid. The model domain is shown in Figure 1. Development of the model is explained in the Methods section, below. Gr1kmTM consists of spatial grids of complex amplitude coefficients for sea surface height (relative to the seabed, i.e., "ocean tide") and depth-integrated currents ("volume transports") for 8 principal tidal constituents: 4 semidiurnal (M2, S2, K2, N2) and 4 diurnal (K1, O1, P1, Q1).

Model bathymetry is based on the 2014 30 arc-second General Bathymetric Chart of the Oceans GEBCO_2020 grid (GEBCO Compilation Group, 2020), with adjustments for major ice shelves (see Methods).

The Gr1kmTM gridded files are in binary and NetCDF format and are designed to be used with the following open-source software packages: the Matlab "Tide Model Driver" (TMD) toolbox, the Python "pyTMD" package, and the FORTRAN "OSU Tidal Prediction Software" (OTPS). These packages allow the user to browse the model for different constituents, and to make tidal predictions of sea surface heights, volume transports and currents for any time at any location within the model domain.

NOTE: Please also check the ESR Polar Tide Model webpage and our Arctic Data Center Portal for other Arctic-region barotropic tide models and more information on software packages.

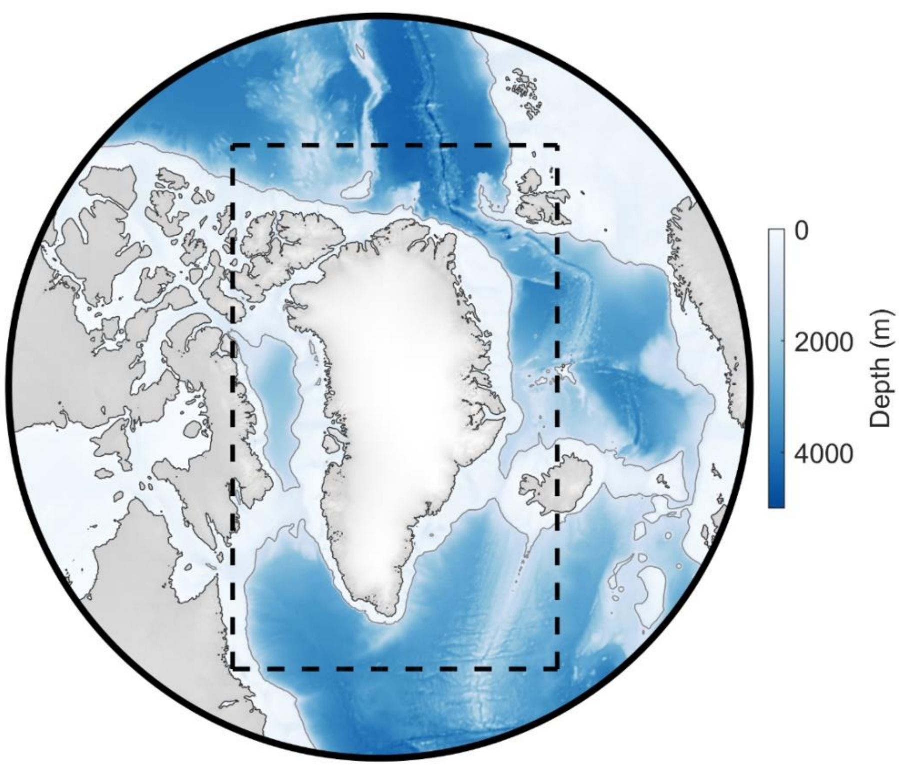

Figure 1: Domain for Gr1kmTM (dashed black line); grid is polar stereographic (standard latitude and longitude of 70°N and 45°W) with uniform spacing of 1 km. Color scale shows depth in meters.

Gr1kmTM: Model Summary

Build Date:	2021
Version Number:	1
Model type:	Forward (dynamics-based); barotropic (depth-integrated)
Grid:	1-km uniform polar stereographic (70°N, 45°W)
Constituents:	M_2, S_2, N_2, K_2, K_1, O_1, P_1, Q_1
Units:	*z* (sea surface height; meters); *U, V* (transports; m^2/s)
Coordinates:	Transports are in East (*U*) and North (*V*) components

Files

Binary Model files

Files for use with TMDv2.5, OTPS, and PyTMD

Model_Gr1kmTM_v1	Model control file, used by TMDv2.5 and OTPS to identify gridded bathymetry and constituent files
h_Gr1kmTM_v1	Complex amplitude coefficients for sea surface height
UV_Gr1kmTM_v1	Complex amplitude coefficients for volume transports
grid_Gr1kmTM_v1	Grid of bathymetry (water column thickness under ice shelves)
xy_ll_Gr1kmTM	File for converting between polar stereo native grid and lat, lon

NetCDF Model file

File for use with TMD3.0 and PyTMD

Gr1kmTM_v1.nc	Model file in NetCDF format

Documentation

Gr1kmTM_v1_README.pdf	(This file) Readme file for the Gr1kmTM model
Gr1kmTM_FileFormat_binary.pdf	Document describing format of files included in the binary model package
Gr1kmTM_FileFormat_NetCDF.pdf	Document describing format of NetCDF model file

Depth-averaged currents (*u*, *v*) can be obtained from transports as (*U*/*H*, *V*/*H*), where *H* is water column height. Open access software (see "File Formats" section) provides tools to extract the tidal information as either elevations, transports, or currents.

Contact Susan Howard (showard@esr.org) or Laurie Padman (padman@esr.org) for advice about the use of this model.

Methods

Gr1kmTM was developed using the Regional Ocean Modelling System (ROMS) version 3.7 (Haidvogel et al., 2000; Shchepetkin and McWilliams, 2005; Budgell, 2005), solving the depth-integrated shallow water equations on a 1 km x 1 km polar stereographic grid of the ocean surrounding Greenland (Figure 1). ROMS is a hydrostatic, 3-D primitive equation numerical model that uses a terrain-following (sigma-level) coordinate system. For producing tidal coefficients for a barotropic model, we are interested in the depth-integrated solution. The model was forced at the open boundaries with both depth-averaged tidal currents and elevation values from the TOPEX/Poseidon global barotropic tidal solution version 9.1 (TPXO9.1) for the semidiurnal constituents and from Arc2kmTM (Howard and Padman, 2021) for the diurnal constituents. We applied potential tides (equilibrium tides plus self-attraction and loading (SAL)) as forcing across the domain. The inclusion of the potential tide forcing significantly improves the accuracy of the tidal solutions. Although ROMS can be run as a purely barotropic 2-D model, the inclusion of potential tides in current versions requires that a baroclinic (depth-dependent) solution be calculated. Therefore, we ran our simulations with 5 levels and constant temperature and salinity (i.e., a homogeneous ocean), to mimic a barotropic model but to allow for inclusion of potential-tide forcing.

Model bathymetry is based on IceBridge BedMachine Greenland, Version 4 (Morlighem et al., 2021) merged with the global GEBCO_2020 grid (GEBCO Compilation Group, 2020) to fill in outer regions of domain.

A high resolution (100 m) coastline file from J. Mouginot (Rignot and Mouginot, 2012) was used to define the Greenland land mask but was extended inshore to the grounding lines of the largest remaining Greenland ice shelves (Petermann, Steensby, Ryder, 79 N, Zachariae Isstrøm, Storstrømmen, and Rink Isbræ) based on the Greenland Bedmachine Version 4. Several modifications to the ice shelves were made as follows:

- The frontal location of Petermann Glacier was modified to match its 2021 location based on satellite imagery. We used a MODIS image from 2021-08-03T00_00_00Z as our guide for defining the location of the new ice front.
- On the north side of 79 N Glacier, glacial ice in Dijmphna Sound that is represented as grounded in BedMachine Greenland Version 4 has since been identified as floating, and more recently has disappeared through calving. We interpolated values from fieldwork from Ardnt et al. (2015) as to estimate water depth in this region.
- Zachariae Isstrøm has also experienced significant mass loss events (An et al., 2021, Mouginot et al., 2015). Although the main ice shelf disappeared, a remaining detached section is still present. We used a MODIS image from 2021-08-03T00_00_00Z to redefine the land and ice shelf in this region.

We used water column thickness (wct) rather than seabed depth for ice shelf areas. We determined wct under ice shelves by first calculating the ice draft using gridded ice surface elevation (relative to the sea surface) minus the gridded ice thickness. We then calculated wct as the difference between the ice draft and gridded bed topography. All variables were taken from BedMachine Greenland Version 4.

Tests indicate that tidal height fields are reasonably well represented in ice shelf areas; however, tidal currents will depend on often large uncertainties in water column thickness, which can also change substantially over time as an ice shelf advances or retreats, thins or collapses.

Validation

The model was validated using tide height amplitude and phase coefficients from coastal and benthic tide gauge records within the model domain, extracted from the Kowalik and Proshutinsky (1994) dataset.

Important Notes

- For tide heights, this model provides ocean tide only; i.e., sea surface height change relative to the seabed. Some applications (e.g., correction of satellite altimetry) will require adjustment for seabed deformation ("ocean tide loading"). Users require a separate ocean load tide model for this calculation.
- Bathymetry in some areas is poorly constrained by data. For barotropic currents, we recommend that the user calculates depth-integrated volume transport, then divides by the latest depth/wct data to estimate depth-averaged currents.
- The tide model grid is polar stereographic. The binary files do not contain (lat,lon) grid information. To convert from (x,y) to (lat,lon) and vice versa, Matlab TMD 2.5 users must use the xy_ll_Gr1kmTM.m script provided in this download. For OTPS and pyTMD, use available code with standard latitude and longitude of 70°N, 45°W. The NetCDF model file provides both (x, y) and (lat, lon) coordinates, along with the projection information. TMD 3 includes the scripts needed to convert between coordinate systems.
- A new feature of the NetCDF model file is that U and V coefficients are now centered on the H nodes and provided in 1 file. The binary files remain in their original Arakawa C-grid structure, and provided as separate U/V, H, and grid files.

File Formats

Binary Model Files

The files are written as Fortran binary sequential files, formatted to match the Oregon State Tidal Inversion Software (OTIS) format. These files can be easily accessed using ESR's Matlab "Tide Model Driver" (TMD) v2.5 toolbox (https://github.com/EarthAndSpaceResearch/TMD_Matlab_Toolbox_v2.5), the community Python-based pyTMD software (https://github.com/tsutterley/pyTMD), and OSU's FORTRAN "OSU Tidal Prediction Software" (OTPS) (https://www.tpxo.net/otps). For full details of our file format, please refer to Gr1kmTM_FileFormat.pdf included in the model download.

NetCDF Model File

The NetCDF model file is in the consolidated NetCDF format for global and regional tide models, introduced in 2023. More information on this new format can be found at: https://github.com/chadagreene/Tide-Model-Driver/blob/main/doc/TMD_model_file_format.md. This file can be used with the TMD 3.0 toolbox (https://github.com/chadagreene/Tide-Model-Driver) and the community Python-based pyTMD software (https://github.com/tsutterley/pyTMD).

Related Links

Arctic Tides Portal at ADC: https://arcticdata.io/catalog/portals/ArcticTides/

ESR Polar Tide Models:	https://www.esr.org/research/polar-tide-models/
OSU Tidal Prediction Software (OTPS):	https://www.tpxo.net/otps
pyTMD package:	https://github.com/tsutterley/pyTMD
TMD Matlab Toolbox v2.5:	https://github.com/EarthAndSpaceResearch/TMD_Matlab_Toolbox_v2.5
TMD 3.0 Matlab Toolbox:	https://github.com/chadagreene/Tide-Model-Driver

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