AN OPEN-SOURCE GUI FOR CALCULATING ICY MOON TIDAL STRESSES USING SATSTRESS.

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Introduction: We have modified the open-source program SatStress (http://code.google.com/p/satstress), developed at the University of Colorado-Boulder and JPL [1], used for calculating the tidal stresses on a satellite that is fully differentiated into a rocky core, a global subsurface ocean, and a decoupled, ice shell. Wahr et al. (2009) [1] used gravitational potential theory to determine the tidal stresses on a satellite. Like SatStress, SatStressGUI (currently in beta testing) is capable of calculating the combined effects of diurnal tides and nonsynchronous rotation (NSR) for both elastic and viscoelastic cases. We felt that the lack of simple learning-curve accessibility of the source code created a need for a user-friendly program that was capable of the same calculations, while maintaining the intent of the SatStress developers to provide an open-source program for planetary scientists. Accordingly, SatStressGUI will eventually be open-source.

About SatStressGUI: SatStressGUI is broken into five parts: Satellite, Stresses, Tensor, Grid, and Plot. The first part or tab (Satellite) is where the satellite is built (Fig. 1). As an example of what would be included in these parameters we have included a table that features the satellite built for Europa (Table 1) based on data in [1]. Each layer of the satellite is assumed to have a density ρ, two elastic moduli (shear modulus μ and Lamé parameter λ), a layer thickness, l, and a viscosity, η. There is also an option to enter the tensile strength of the upper ice layer. This is for determining where lineaments will form if the tensile strength of the ice is overcome.

The second tab (Stresses) is for selecting the stress components to be calculated. For now, diurnal and NSR are the only available stresses that are included. These can be done independently of each other if the user is only interested in diurnal stresses or NSR stresses. In this tab there is also a location to save the Love numbers for the satellite.

The third tab (Tensor) offers the user the option to calculate the stress tensor or principal stresses at any single point on the satellite (as opposed to a grid of points). The input parameters are latitude/longitude, orbital position (diurnal), and time for NSR stress build-up (if applicable). For single-point calculations, no further parts/tabs of the program are needed.

The fourth tab (Grid) allows the user define a grid of points anywhere on the satellite surface to calculate stresses (Fig. 2). This grid is used the final tab for projecting the data on a map. The Grid tab is also used for determining the amount of NSR and orbital location(s) where calculations will be performed. For calculating diurnal tides, the user specifies the orbital starting position, orbital termination position, and the number of increments during the orbit. For calculating the magnitude of the NSR stresses, the user enters a period of NSR rotation (one complete rotation of the ice shell), degrees of accumulation or time of accumulation, and the number of increments. The increment option allows the user to step through several calculations to see how the stress components change from the minimum input value to the maximum input value.

In the final tab (Plot) the user can preview the results on the defined grid and export the data into a geospatial analysis program (such as ArcGIS). It is possible to contour gradients in principal stresses, mean stresses, and differential stresses. Similar to [1], tick marks can also be used to represent the principal stresses (Figure 3). For plotting tick marks, the available options are the principal stresses, planes of maximum shear stresses, and both normal components of the stress tensor. Cauchy's equations have not yet been incorporated into the program for calculating normal and shear stresses for any plane, but may be added later. We have also included multiple map projections for displaying the data (cylindrical equidistant, Miller Cylindrical, Mercator, orthographic, and polar projection).

Table 1- Input values for building Europa in Satellite. Ice_u stands for the upper brittle layer of the ice shell, and Ice_l stands for the lower more ductile part of the ice shell.

Mass of Jupiter (kg)	M_{jup}	1.8986 x 10^{27}
Orbit Eccentricity	e	0.009
Orbit semimajor axis (m)	a	6.079 x 10^{8}
NSR Period (yr)	yr	12,000 - 120,000
Density [ice u] (kg m^{-3})	ρ_u	916.7
Shear Modulus [ice u] (GPa)	μ_u	3.487 x 10^9
Lamé Parameter [ice u] (GPa)	λ_u	6.79533
Thickness [ice u] (m)	l_u	2,000-22,000
Viscosity [ice u] (Pa s)	η_u	1x10^{22}
Density [ice l] (kg m^{-3})	ρ_l	916.7
Shear Modulus [ice l] (GPa)	μ_{λ}	3.487 x 10^9
Lamé Parameter [ice l] (GPa)	λ_l	6.79533
Thickness [ice l] (m)	l	0-8000
Viscosity [ice l] (Pa s)	η_l	1x10^{17}
Density [ice u] (kg m^{-3})	ρ_o	1,000
Shear Modulus [ocean] (GPa)	μ_o	0
Lamé Parameter [ocean] (GPa)	λ_o	2.9
Thickness [ocean] (m)	l_o	150,000
Viscosity [ocean] (Pa s)	η_o	0
Density [core] (kg m^{-3})	ρ_c	3,487.60
Shear Modulus [core] (GPa)	μ_{χ}	40
Lamé Parameter [core] (GPa)	λ_{χ}	40
Thickness [core] (m)	l_c	2,000-22,000
Viscosity [core] (Pa s)	η_c	1,391,000

Discussion: SatStress was created as a tool for planetary scientists. SatStressGUI has been created with the same ideas in mind. There have been previous efforts to calculate the distribution of stresses across the surface [2-3], which can be used as a basis of comparison. Ultimately the program will be of use for interpretation of deformation features such as lineaments and how they relate to a calculated stress field [4-10]. We hope that this aids in future attempts to correlate a calculated stress field and lineament orientations.

References: [1] Wahr et al. (2009) *Icarus*, 200 188-206. [2] Greenberg et al. (1998) *Icarus* 135, 64-78. [3] Harada & Kurita (2007) *GRL* 34, L11204, doi:10.1029/2007GL029554. [4] Leith & McKinnon (1996) *Icarus* 120 387-398. [5] Hoppa et al. (1999) *Science* 285, 1899-1902. [6] Hoppa et al. (1999) *Icarus* 141, 287-298. [7] Hoppa et al. (2001) *Icarus* 153, 208-213. [8] Kattenhorn (2002) *Icarus* 157, 490-506. [9] Groenleer & Kattenhorn (2008) *Icarus* 193, 158-181. [10] Smith-Konter & Pappalardo (2008) *Icarus* 198, 435-451.

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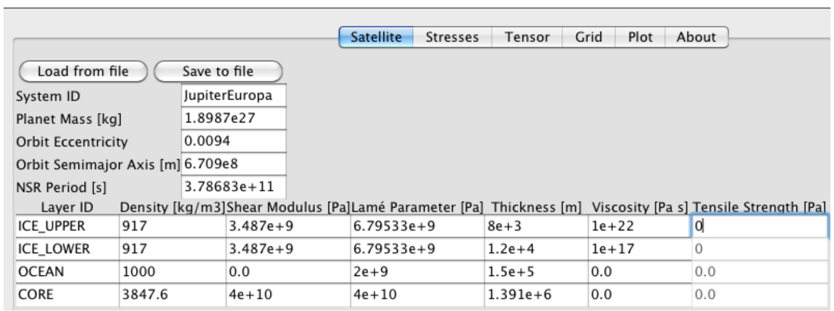

Figure 1- Tab one of the program (Satellite), where the satellite is built. Input parameters are in Table 1.

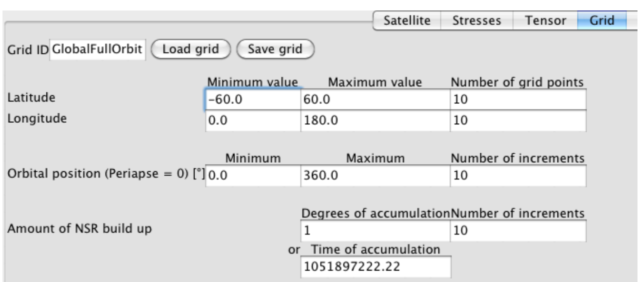

Figure 2- Example of input values for Grid tab. Calculation is performed for one degree of NSR and a full orbital cycle.

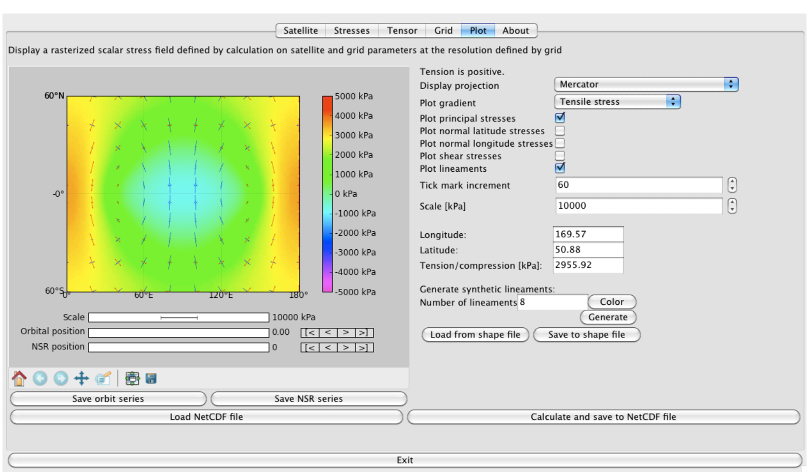

Figure 3- Stress results for one degree of NSR over a portion of Europa's surface. No diurnal stresses are present. The tick marks are principal stresses and are color-coded red (tension) or blue (compression).