National Aeronautics and Space Administration

Determining the Scientific Impact of a Geodesy Network at Enceladus

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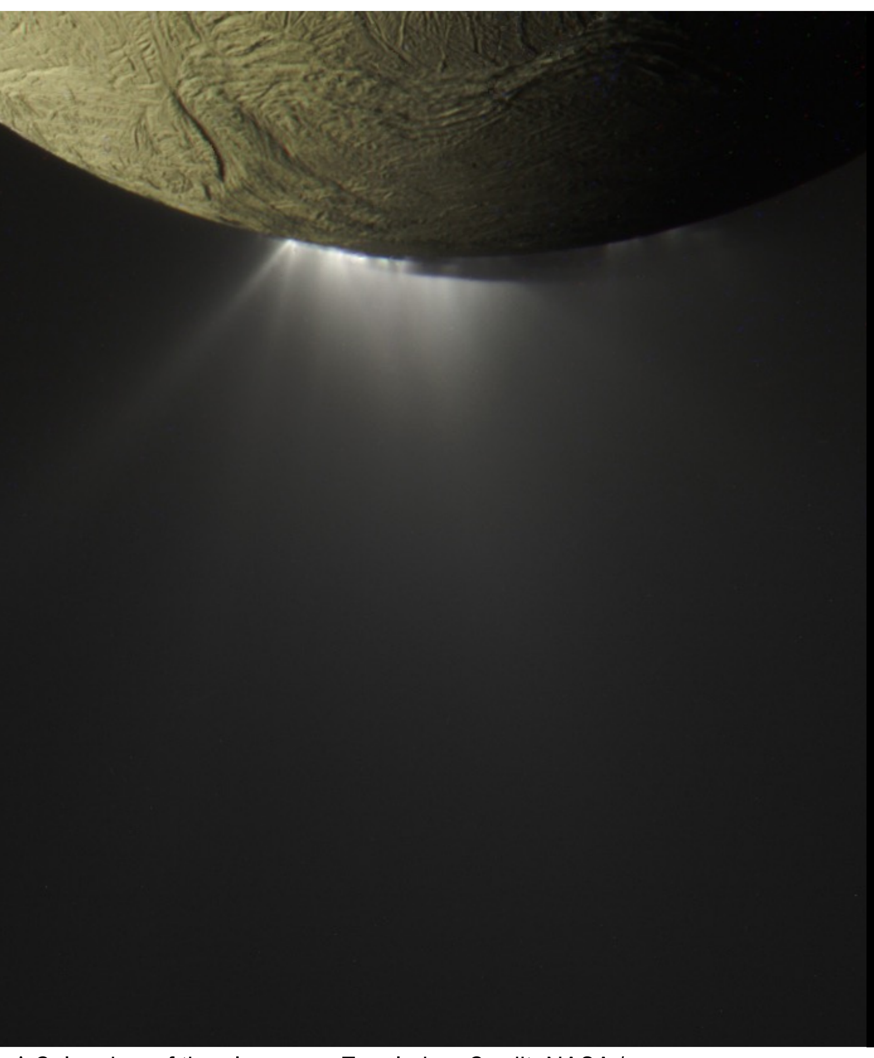
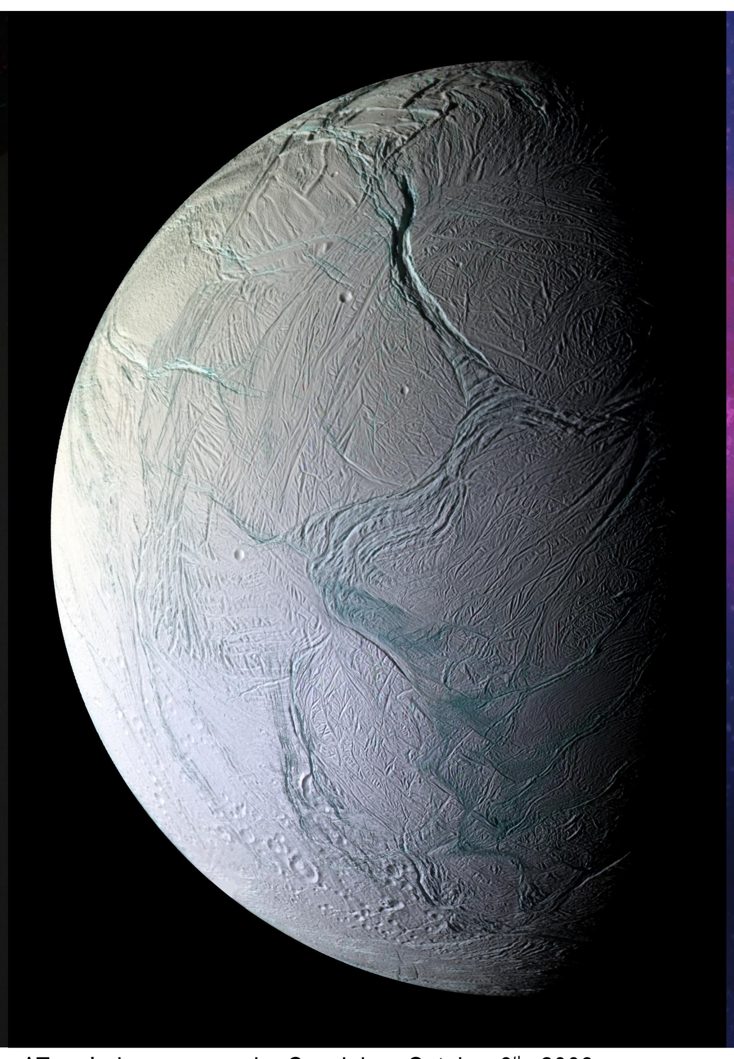
Program: FY22 R&TD Strategic Initiative

Strategic Focus Area: Next-Generation Ocean World Geodesy: Enceladus — Strategic Initiative Leader: Rosaly M. Lopes

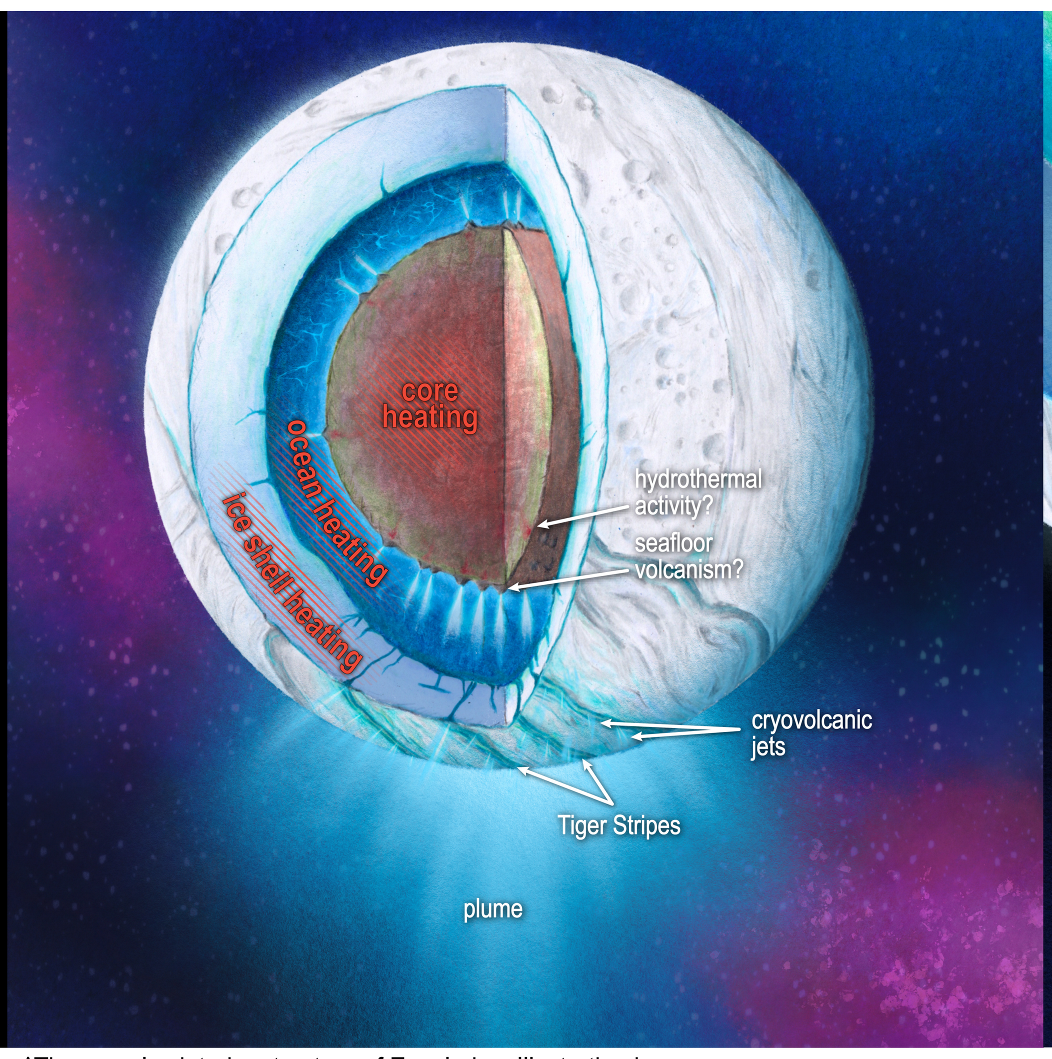
OBJECTIVES: The overarching goal of this R&TD is to develop the fundamental scientific tools that tie to science questions to capabilities that could be provided by next-generation ocean world geodesy, with a focus on Enceladus. At present, there are critical gaps in available geophysical models of Enceladus, inhibiting the community's ability to create testable hypotheses, with quantitative predictions for measurements, and ultimately answer science questions. The primary objective for this year was to develop a new global geophysical model of Enceladus capable of simulating crustal deformation which incorporates viscoelastic rheology, shell thickness variations, faulting, and other relevant processes at high spatial and temporal scale. Most state-of-the-art geophysical models of Enceladus are built on questionable simplifying assumptions, such as the treatment of faulting, assumed rheological models, the role of faulting on global deformation, and global symmetry. **Enceladus's faults are the conduits by which ocean material is ejected into space, yet we do not understand how they form or evolve, nor their role in Enceladus's past/present habitability.** We have developed a new finite element model of Enceladus using PyLith—a toolkit developed and rigorously tested for Earth applications.



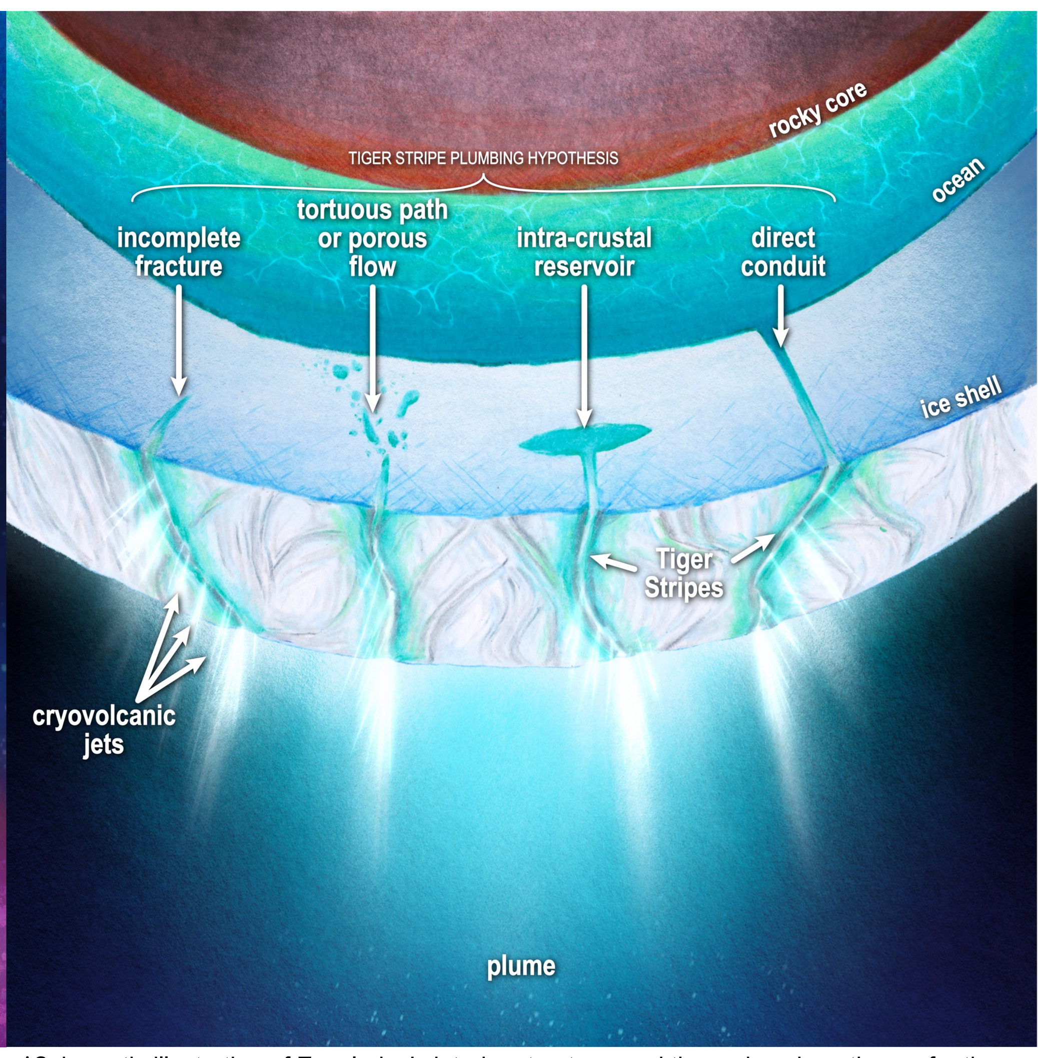
^ Color view of the plumes on Enceladus. Credit: NASA / JPL-Caltech / SSI / Kevin M. Gill.



^Enceladus, as seen by Cassini on October 9th, 2008. Credit: NASA / JPL / SSI.

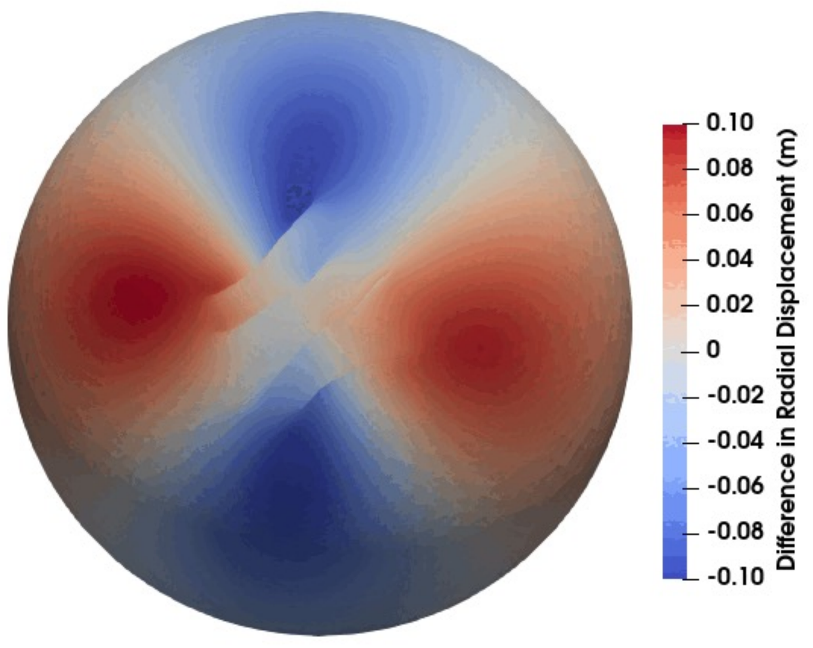


^The complex interior structure of Enceladus. Illustration by James Tuttle Keane and Aaron Rodriquez.

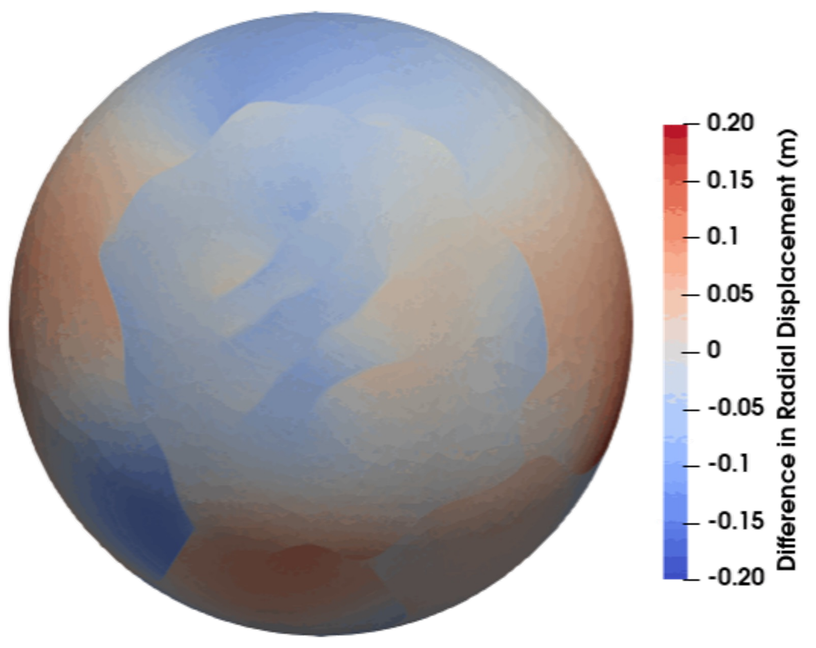


^Schematic illustration of Enceladus's interior structure, and the various hypotheses for the plumbing of the tiger stripes. Illustration by James Tuttle Keane & Aaron Rodriquez.

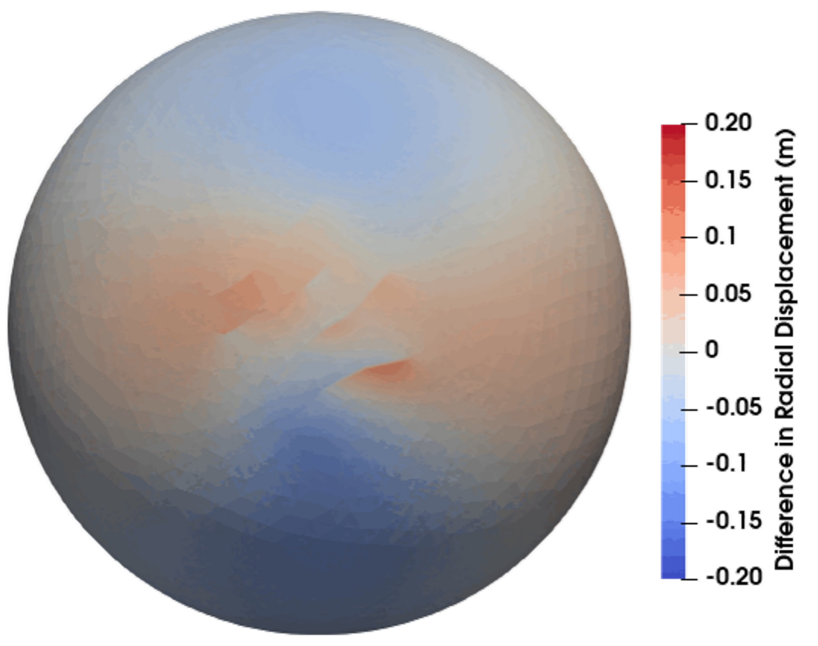
APPROACH & RESULTS: **We have developed a new global geophysical model of Enceladus**, capable of simulating realistic crustal deformation by incorporating ice shell thickness variations, faulting, viscoelastic rheology, and other relevant processes—all modeled at high spatial and temporal scale. This model, called SatDef, is based on the 3D viscoelasto-plastic finite element code, PyLith, which is well established tin the terrestrial geoscience community. We have benchmarked SatDef against analytical models (e.g., SatStressGUI) and previously published finite element models (e.g., Běhounková et al. 2017). We are continuing to add capabilities to SatDef, and are now entering the phase of the R&TD where we can explore the parameter space and craft testable hypotheses that are the necessary for future geodetic investigations of Enceladus.



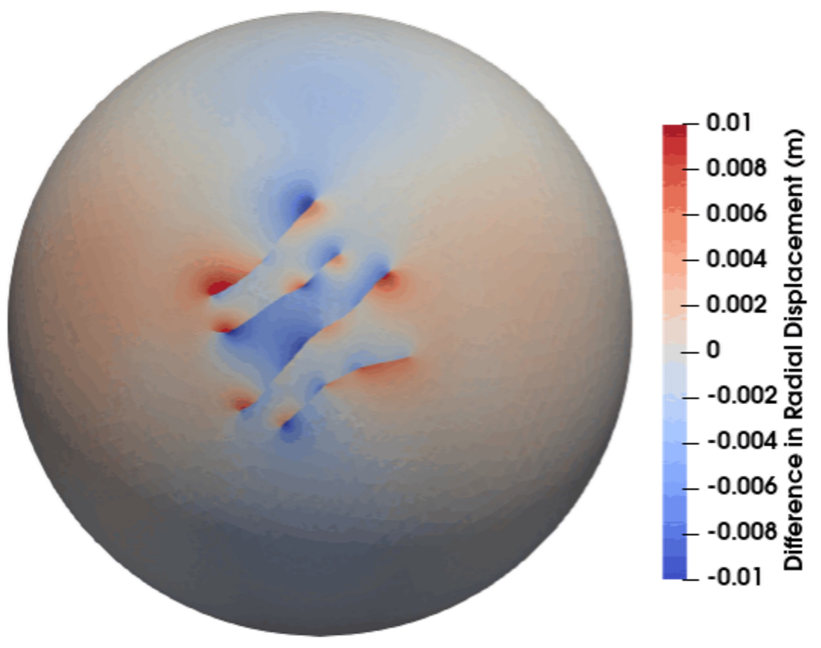
^SatDef model of Enceladus, including **crustal thickness variations and through-going vertical tiger stripe faults**. The model is referenced to an simple, spherically symmetric model of Enceladus. The view is centered on the south pole. This shows Enceladus at one time in its orbit (near periapse); the deformation is cyclical over Enceladus's orbit.



^SatDef model of Enceladus, including **crustal thickness variations and through-going vertical tiger stripe faults and zones of crustal weakness.** The model is referenced to an simple, spherically symmetric model of Enceladus. The view is centered on the south pole. This shows Enceladus at one time in its orbit (near periapse); the deformation is cyclical over Enceladus's orbit.



^SatDef model of Enceladus, including **crustal thickness variations and through-going dipping (35°) tiger stripe faults**. The model is referenced to an simple, spherically symmetric model of Enceladus. The view is centered on the south pole. This shows Enceladus at one time in its orbit (near periapse); the deformation is cyclical over Enceladus's orbit.



^SatDef model of Enceladus, including **crustal thickness variations and vertical tiger stripe faults that cut through 95% of the ice shell**. The model is referenced to an simple, spherically symmetric model of Enceladus. The view is centered on the south pole. This shows Enceladus at one time in its orbit (near periapse); the deformation is cyclical over Enceladus's orbit.

SIGNIFICANCE & BENEFITS TO JPL/NASA: This R&TD is directly relevant to JPL's strategic goals of exploring ocean worlds like Enceladus, and investigating their habitability. Geodesy provides one of the few ways to interrogate the hidden interiors of ocean worlds at a range of spatial and temporal scales—synergistic with seismology and electromagnetic methods. This R&TD is particularly timely, as it will enable JPL to propose competitive Discovery and New Frontiers missions that explore habitability with a multi-pronged, wholistic approach—**complementing and enhancing life-detection investigations**. This work can feed forward to the Enceladus Orbilander flagship in the future, and have applications for a variety of other worlds (e.g., Io, Europa, etc.). This work supports JPL's long-standing history of leadership in planetary geophysics.

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Publications: We have presented results at several conferences (e.g., LPSC 2022, OPAG 2022, AGU 2022), and are working on our first peer reviewed publications.

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